Replacement Sensor Model Tagged Record Extensions Specification for NITF 2.1

23 July 2004
Updated 14 January 2013

Prepared for the NGA

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Table of Contents

1 Introduction to the Replacement Sensor Model (RSM) 1
1.1 Overview of the RSM TREs 1
1.2 Version B TREs 3
1.3 RSM Generator and RSM Exploiter 3
1.4 Document Road Map 4
2 RSM TRE Placement in a NITF File 5
2.1 Definitions and Rules 5
2.1.1 Non-Standard Use of the Original Full Image ID 7
2.2 RSM TRE Set Size 8
2.3 RSM TRE Modification 9
2.4 Definition of an “Image” for RSM TRE Descriptions 10
3 Sensor Model Functionality Supported by the RSM TREs 12
3.1 RSM Exploiter Interface List 12
4 Overview of the RSM TRE Descriptions 18
4.1 Appendices 18
4.2 Format Tables 18
4.2.1 Value Range and Other Checks 18
4.3 TRE-Level Constraints 20
5 RSM Identification (RSMID) TRE 21
5.1 Overview 21
5.2 Time-of-Image Model 21
5.3 RSM Ground Coordinate System 22
5.4 RSM Image Coordinate System 23
5.5 RSM Image Domain 24
5.6 RSM Ground Domain 24
5.7 Illumination Model 26
5.8 Trajectory Model 28
5.9 RSMIDA Format 28
6 RSM Polynomial Identification (RSMPI) TRE 42
6.1 Overview 42
6.2 Low Order Polynomial 42
6.3 Sectioning 42
6.4 RSMPIA Format 44
7 RSM Polynomial Coefficients (RSMPC) TRE 48
7.1 Overview 48
7.2 Polynomials 48
7.3 TRE Size and Number of TREs 49
7.4 RSMPCA Format 49
8 RSM Direct Error Covariance (RSMDCA) TRE 56
8.1 Overview 56
8.2 Direct Error Covariance Form 56
8.3 Adjustable Parameter Definitions in Support of the Direct Error Covariance 57

8.3.1 Overview ... 57
8.3.2 Local Coordinate System Definition ... 58
8.3.3 Effect on RSM Ground-to-Image Function and Partial Derivatives ... 59
8.3.4 Local Coordinate System Details ... 62
8.4 Covariance Matrix Element Ordering and Matrix Size ... 62
8.5 Summary ... 62
8.6 RSMDCA Format ... 63
9 RSM Direct Error Covariance (RSMDCB) TRE ... 71
9.1 Overview ... 71
9.2 Direct Error Covariance Form ... 72
9.3 Adjustable Parameter Definitions in Support of the Direct Error Covariance and Error Propagation ... 73
9.3.1 Overview ... 73
9.3.2 Definitions and Identification of Adjustable Parameters ... 74
9.3.3 Basis Option ... 79
9.3.4 Local Rectangular Coordinate System Details ... 81
9.4 Cross-Covariance Matrix Element Ordering and Size ... 82
9.5 Summary ... 83
9.6 RSMDCB Format ... 84
10 RSM Adjustable Parameters (RSMAPA) TRE ... 94
10.1 Overview ... 94
10.2 Adjustable Parameters ... 94
10.2.1 Local Coordinate System Definition ... 94
10.2.2 Effect on RSM Ground-to-Image Function ... 95
10.2.3 Local Coordinate System Details ... 98
10.2.4 Two Possible Sets of RSM Active Adjustable Parameters ... 98
10.3 RSMAPA Format ... 100
11 RSM Adjustable Parameters (RSMAPB) TRE ... 107
11.1 Overview ... 107
11.2 Active Adjustable Parameter Values ... 107
11.3 Adjustable Parameter Definitions and Identification ... 107
11.3.1 Basis Option ... 112
11.3.2 Local Rectangular Coordinate System Details ... 112
11.4 RSMAPB Format ... 113
12 RSM Indirect Error Covariance (RSMECA) TRE ... 122
12.1 Overview ... 122
12.2 Groups of Error Covariance Information ... 122
12.3 Indirect Error Covariance Form ... 124
12.3.1 Additional Computations if Non-Stationary Stochastic Error Model ... 127
12.3.2 Comparison to Direct Error Covariance ... 129
12.3.3 Indirect Error Covariance in “Direct Error Covariance Form” ... 129
12.4 Adjustable Parameter Definitions in Support of the Indirect Error Covariance ... 130
12.4.1 Overview ... 130
12.4.2 Local Coordinate System Definition ... 130

12.4.3 Effect on RSM Ground-to-Image Function and Partial Derivatives ... 131
12.4.4 Local Coordinate System Details ... 134
12.5 Unmodeled Error Covariance ... 134
12.6 Covariance Matrix Element Ordering ... 136
12.7 RSMECA Format ... 136
13 RSM Indirect Error Covariance (RSMECB) TRE ... 149
13.1 Overview ... 149
13.2 Groups of Error Covariance Information ... 150
13.3 Indirect Error Covariance Form ... 151
13.3.1 Correlation Models ... 153
13.3.2 Additional Computations if Non-Stationary Stochastic Error Model ... 157
13.3.3 Comparison to Direct Error Covariance ... 159
13.3.4 Indirect Error Covariance in “Direct Error Covariance Form” ... 160
13.4 RSM Adjustable Parameter Identification and Definitions in Support of the Indirect Error Covariance ... 160
13.4.1 Overview ... 160
13.4.2 Basis Option ... 166
13.4.3 Local Rectangular Coordinate System Details ... 167
13.5 Unmodeled Error Covariance ... 167
13.6 Matrix Element Ordering ... 169
13.7 RSMECB Format ... 169
14 RSM Ground-to-Image Grid Identification (RSMGI) TRE ... 184
14.1 Overview ... 184
14.2 Low Order Polynomial ... 184
14.3 Sectioning ... 184
14.4 RSMGIA Format ... 186
15 RSM Ground-to-Image Grid (RSMGG) TRE ... 190
15.1 Overview ... 190
15.2 Ground Space – Image Space Correspondence Grid ... 190
15.2.1 Interpolation ... 192
15.2.2 Grid Point Values ... 192
15.3 TRE Size and Number of TREs ... 193
15.4 RSMGGA Format ... 193
16 Glossary ... 199

List of Appendices

Appendix A – Additional Resources ... A-1
Appendix B – The ABC’s of RSM: An Introduction to the Replacement Sensor Model ... B-1
Appendix C – RSM Extraction and Adjustment of Large Field of View Frame Imagery ... C-1
Appendix D – RSM Compliance Testing ... D-1

List of Tables

Table 1. Summary of the Eight RSM TREs 3
Table 2. RSMIDA TRE Format Table 41
Table 3: RSMPIA TRE Format Table 47
Table 4: RSMPCA TRE Format Table 55
Table 5: RSMDCA TRE Format Table 70
Table 6: RSMDCB TRE Format Table 93
Table 7: RSMAPA TRE Format Table 106
Table 8: RSMAPB TRE Format Table 121
Table 9: RSMECA TRE Format Table 148
Table 10: RSMECB TRE Format Table 183
Table 11: RSMGIA TRE Format Table 189
Table 12: RSMGGA TRE Format Table 198

List of Figures

Figure 1. RSM TRE Sets and Multiple Images 11
Figure 2: Example of RSM Primary Ground Coordinate System – Rectangular 23
Figure 3: RSM Image Domain 24
Figure 4: RSM Ground Domain 25
Figure 5: Illumination Angles 27
Figure 6: Sectioning of the RSM Image Domain for Polynomials 43
Figure 7: Example of RSM Local Coordinate System 59
Figure 8: RSM Adjustable Ground-to-Image Function 61
Figure 9: Example of RSM Local Rectangular Coordinate System 76
Figure 10: RSM Adjustable Ground-to-Image Function 78
Figure 11: Example of RSM Local Coordinate System 95
Figure 12: The RSM Adjustable Ground-to-Image Function 97
Figure 13: Example of RSM Local Rectangular Coordinate System 109
Figure 14: RSM Adjustable Ground-to-Image Function 111
Figure 15: Example of Piece-Wise Linear Correlation Function $\rho(\tau)$ 127
Figure 16: Example of RSM Local Coordinate System 131
Figure 17: The RSM Adjustable Ground-to-Image Function 133
Figure 18: Example of Piece-Wise Linear Correlation Function $\rho(\tau)$ 154
Figure 19: First Set of Examples of CSM Four-Parameter Correlation Function $\rho(\tau)$ 156
Figure 20: Second Set of Examples of CSM Four-Parameter Correlation Function $\rho(\tau)$ 157
Figure 21: Example of RSM Local Rectangular Coordinate System 162
Figure 22: RSM Adjustable Ground-to-Image Function 164
Figure 23: Sectioning of the RSM Image Domain for Grids 185
Figure 24: Grid Z-Planes 191
Figure 25: Grid Plane 1 191

ACRONYMS

API	Application Program Interface
ASPRS	American Society of Photogrammetry and Remote Sensing
CSM	Community Sensor Model
EO	Electro-Optical
IR	Infrared
JITC	Joint Interoperability Test Command
NGA	National Geospatial-Intelligence Agency
NITF	National Imagery Transmission Format
NITFS	National Imagery Transmission Format Standard
NTB	NITFS Technical Board
RSM	Replacement Sensor Model
SAR	Synthetic Aperture Radar
STDIDC	Standard ID version C
SVD	Singular Value Decomposition
TRE	Tagged Record Extension
US	United States

1 INTRODUCTION TO THE REPLACEMENT SENSOR MODEL (RSM)

The Replacement Sensor Model (RSM) is a general sensor model that is designed to replace the full functionality of virtually any imaging sensor model. It includes an adjustable ground-to-image function and an error covariance that provides for rigorous error propagation. Typically, the imaging sensor model that RSM replaces is a "physical" sensor model. RSM is also termed a "true replacement sensor model."

Those who are new to RSM in particular or sensor modeling in general are encouraged to read Appendix B: The ABCs of RSM. It is an easier-to-read introduction that will facilitate understanding of this specification.

RSM image support data for a specific sensor and specific image is generated by any suitably configured "up-stream" process. Inputs to this process are the original sensor model's image support data, and outputs are the RSM image support data. Internally, the process contains and utilizes both the original sensor model and the RSM.

Subsequently, the only resident sensor model required by "down-stream" users is the RSM. Furthermore, in order to exploit any image from any sensor, only the corresponding image and RSM image support data are required as inputs.

RSM and its image support data are designed to provide equivalent geospatial mensuration and triangulation capabilities as compared to original sensor models and their image support data. RSM-based exploitation by the down-stream user can include optimal multi-image geopositioning, or "target" extraction, and the optimal adjustment of image support data, or triangulation.

The above RSM characteristics and capabilities provide significant sensor model development cost savings and maintenance cost savings to the user. They also provide a potential image support data standard for all imaging sensors. Details of the original sensor model and its image support data are also hidden, potentially important to sensor model developers and others.

1.1 OVERVIEW OF THE RSM TRES

RSM image support data is contained in NITF 2.1 Tagged Record Extensions (TREs). This data supports any imaging sensor, including commercial and tactical sensors. There are eight RSM TREs, each identified by a five-character designator and appended with a one-character version (see Table 1). An RSMID TRE must always be included in an image's RSM support data, while the other seven are chosen as applicable or required for a given image.

Of the eight TREs, three of them have an A and a B version. The version B TREs extend the set of RSM adjustable parameters and must be used together. This means that selection is made from one of two sets of TREs: either the eight version A TREs (Set A) or the three version B TREs and remaining five version A-only TREs (Set AB).

An RSMID TRE must always be included in an image's RSM support data.

An RSM ground-to-image function must be included, either in RSMPI and RSMPC TREs (polynomial), RSMGI and RSMGG TREs (grid), or both.

The RSMAP TRE can be omitted when RSM adjustable parameter values are zero. However, it must be included when the RSM adjustable parameter values are non-zero, i.e., there is RSM adjusted support data.

RSM error covariance is optional. If supplied, it can be the direct form contained in the RSMDC TRE, the indirect form contained in the RSMEC TRE, or both.

For a given image, there may be more than one RSMPC TRE and more than one RSMGG TRE provided, corresponding to multiple image sections. If only one RSMPC TRE is provided (one section), the RSMPI TRE is optional. If only one RSMGG TRE is provided (one section), the RSMGI TRE is optional.

(Note that the term "image" is explicitly defined later in section 2.4 of this specification in the context of RSM TREs contained in an NITF file.)

RSM TRE #	TRE	Name	Contents
1	RSMIDA	RSM Identification	IDs, time-of-image model, optional illumination model, footprint information
2	RSMPIA	RSM Polynomial Identification	Image section definitions for polynomials
3	RSMPCA	RSM Polynomial Coefficients	Polynomial coefficients for a section
4	RSMDCA RSMDCB	RSM Direct Error Covariance	RSM multi-image direct error covariance
5	RSMAPA RSMAPB	RSM Adjustable Parameters	RSM adjustable parameters
6	RSMECA RSMECB	RSM Error Covariance	RSM indirect error covariance data
7	RSMGIA	RSM Ground-to-image Grid Identification	Image section definitions for grids

8	RSMGGA	RSM Ground-to-image Grid	Ground point-image point correspondences for a section

Table 1. Summary of the Eight RSM TREs

1.2 VERSION B TRES

Version B TREs extend the capabilities of the initial version A TREs. All three version B TREs reference an extended set of RSM adjustable parameters. The extended set improves RSM adjustability and error propagation performance for some sensors and applications. These sensors typically have a very large number of original adjustable parameters. The extended set of RSM adjustable parameters also includes a "basis" option capability. It allows for easy automatic selection of the appropriate set of RSM adjustable parameters during RSM generation for an arbitrary sensor/application.

The RSMDCB TRE allows the generation and exploitation of an arbitrarily large direct error covariance.

The RSMECB TRE allows for sets of active RSM adjustable parameters that vary from image to image (no TRE format change required).The RSMECB TRE also supports the choice between two different general functional forms or models for the representation of the temporal correlation of errors: (1) the previous piece-wise linear model, and (2) the CSM four-parameter model. This allows for greater flexibility and higher RSM-to-original sensor model fidelity. Many original (aka physical) sensor models are now representing temporal correlation using the CSM four-parameter model for convenience. (Note that CSM corresponds to the Community Sensor Model, an API for sensor models, and not a specific sensor model itself.) Finally, as specified in the RSMECB description, an SVD-based matrix square root is to be used during exploitation of this TRE instead of a Cholesky-based matrix square root for better performance.

1.3 RSM GENERATOR AND RSM EXPLOITER

There are two RSM software module concepts that are referred to in this specification. The first is an RSM generator, which populates appropriate RSM image support data for a given image (i.e, it generates RSM TREs). The second is an RSM exploiter, which provides sensor model functionality given RSM image support data.

Specific implementations of each module have been developed and are referred to in this document as the RSM Generator and RSM Exploiter. The RSM Generator has defaults that automatically select the most appropriate RSM TRE configuration for each image and also constructs the TREs. It is also highly configurable for advanced users. The RSM Exploiter implementation is a CSM plugin that creates sensor models from RSM image support data. Both modules have been thoroughly tested and are available to appropriate organizations. See Appendix A for contact information.

1.4 DOCUMENT ROAD MAP

The remainder of this document is essentially divided into three different areas: (1) Sections 2-4 supply background information; (2) Sections 5-15 describe the RSM TREs in detail, and (3) the appendices describe additional resources, such as references to documentation, contact information, compliance testing recommendations, and the ABCs of RSM.

2 RSM TRE PLACEMENT IN A NITF FILE

2.1 DEFINITIONS AND RULES

A set of RSM TREs is associated with the image data field in an image segment of an NITF file. The TREs are placed in the corresponding image subheader and continued in the general overflow area, if necessary. If the TREs are too large to fit in the image subheader the entire set of RSM TREs may be placed directly into the overflow area. Also, if a set of RSM TREs is applicable to more than one image segment in the NITF file, a single copy of the set is placed into the overflow area.

A set of RSM TREs in conjunction with the RSM is intended to provide equivalent support for geospatial mensuration and triangulation as would be provided by the corresponding original image support data in conjunction with the original sensor model. In some infrequent situations, an NITF image segment may contain multiple "scan blocks" which would require multiple sets of original image support data and possibly multiple original sensor models. RSM TREs are not intended for use with such images, and a single scan block will be assumed in the following. (Potential methods to account for multiple scan blocks are also discussed in section 2.1.1.)

An image data field may be identical to the entire original full image or may be a "mapped" portion of the original full image. In general, the image data field is simply a grid of pixel values whose row and column counts are a function of the row and column counts of the original full image. Because the RSM is relative to the original full image, this image mapping function can be rather general and can represent a warping of the original full image to the image data field. The image mapping function simply serves to map the RSM ground-to-"original full image" relationship provided in the RSM TREs to an equivalent RSM ground-to-"image data field" relationship, i.e., if $I_{data} = M(I_{orig})$, and $I_{orig} = h(X,R)$, then $I_{data} = M(h(X,R))$, where I_{orig} is the two-dimensional vector containing the original full image row and column count, I_{data} the two-dimensional vector containing the image data field row and column count, M the image mapping function, $h(X,R)$ the RSM adjustable ground-to-image function, X the three-dimensional ground point, and R the vector of non-zero RSM adjustable parameter values (if any).

(Note that if there are no adjustable parameter values ($R \equiv 0$), $h(X,R)$ simply reduces to the RSM ground-to-image function $g(X)$, either a polynomial, interpolated grid, or combination. Also, the image mapping function M is assumed invertible, hence, $X_{hor} = h^{-1}(M^{-1}(I_{data}), z, R)$, where z is the ground point height, X_{hor} its horizontal position, and $h^{-1}(I_{orig}, z, R)$ the RSM image (and height)-to-ground function.)

A set of RSM TREs does not specify the image data field - original full image mapping function (M). Other data in the NITF file does so if needed, such as an ICHIPB TRE in the same image subheader. The mapping represented by ICHIPB is the result of a linear interpolation between image corner points.

A set of RSM TREs is also termed an "RSM TRE Set". All TREs in an RSM TRE Set contain the image identification (ID) of the original full image. Therefore, different image data fields of the same original full image (which are in different image segments, possibly in different NITF files) will have the same image ID. But image data fields that belong to different original full images will have different image IDs.

An RSM TRE Set always includes an RSMID TRE, which contains the RSM image domain field that specifies the region of validity of the RSM support data (RSM TRE Set) within the original full image. The RSM image domain can be any rectangular subset of the original full image, independent of the image data field with which it is associated in the image segment. It is specified relative to the image coordinate system of the original full image. The RSM image domain may also be divided into multiple image sections, each containing its own RSM ground-to-image function. The RSM image domain is typically the entire original full image, assuming that the corresponding original sensor model and its image support data is valid over the entire original full image. (The RSM image domain's relationship to the original full image is detailed further in the description of the RSMID TRE provided later in this specification. The relationship between multiple image sections and the RSM image domain is detailed further in the description of the RSMPI and RSMGI TREs provided later in this specification.)

All TREs in an RSM TRE Set contain an RSM edition field, its value invariant over the TREs in this set. The value of the edition field in two RSM TRE Sets serves to identify whether the sets differ in substance, i.e., whether their non-edition field portions differ.

Only one RSM TRE Set per original full image is to be used for any image exploitation process. (Of course, for a particular original full image, all image data from multiple image data fields with identical RSM TRE Sets can be used if within the RSM image domain.) The edition field allows this rule to be conveniently enforced. For example, the edition field in the RSM TRE Set associated with an image data field and unadjusted support data will differ from the edition field in the RSM TRE Set associated with another image data field from the same original full image and adjusted support data. The difference in the value of their edition fields flags the difference in their adjustment status.

These two image data fields, along with their different support data (RSM TRE Sets), are not to be exploited simultaneously.

2.1.1 NON-STANDARD USE OF THE ORIGINAL FULL IMAGE ID

Possible non-standard situations involving the original full image identification are as follows. When an RSM TRE Set is generated, if the original full image identification is unavailable from the original sensor model and image support data, the image ID is set to all spaces in the corresponding field in all TREs in the RSM TRE Set. If two RSM TRE Sets both have spaces as their image IDs, they should be considered as corresponding to different (and unknown) original full images by an image exploitation process. If they actually correspond to the same original full image and both are used simultaneously in either a multi-image targeting or triangulation solution, results will not be optimal. However, this is far less a problem than if they were considered from the same original full image when they were not. If the latter, exploitation results could be totally divergent.

Regardless whether the original full image identification (image ID) is available or not, if the relationship between the image data field and the original full image is not provided in the NITF file, such as in an ICHIPB TRE, the image data field in the image segment associated with the RSM TRE Set is assumed to be identical to the original full image. Specifically, the image data field row count is identical to the original full image row count, and the image data field column count is identical to the original fill image column count.

In some cases, as part of its normal concept of operations, an "image provider" may divide an original full image into multiple image data fields and assign a different original full image ID to each as a matter of convenience for storage and future dissemination. (Operationally, an image provider may be part of the up-stream generation process or between the up-stream generation process and the down-stream user community.) As a word of caution, it is pointed out that this is not an optimal procedure regarding performance of potential down-stream multi-image geopositioning or triangulation solutions that simultaneously involve more than one of these image data fields. The fact that the support data (error) is highly correlated between the image data fields is lost. The optimal approach is for the image provider to assign the same original full image ID to all the image data fields, and to place each in its own image segment with a common RSM TRE Set.

Note also that nothing prevents the image provider from processing (e.g., resampling, rectifying, etc.) the original full image and re-defining the result as the original full image. The result may also be divided into multiple image data fields. This is a legitimate standard use of the original full image ID, consistent with the RSM TREs, assuming a valid original sensor model is available during RSM TRE Set generation and applicable to the re-defined original full image. However, again, if the image data fields are not assigned the same (re-defined) original full image ID, subsequent multi-image geopositioning and triangulation may not be optimal.

Recall that RSM TREs are not to be used if an NITF image segment contains multiple “scan blocks”, under the premise that the sensor operational parameters may change discontinuously between blocks in such a way that a single original sensor model and corresponding set of image support data would not be adequate for geospatial mensuration and triangulation. Alternatively, if each of these scan blocks is instead placed in a different image segment, an RSM representation is allowed. However, a different original full image should be used for each scan block, i.e., the RSM TRE Set for each of the corresponding image segments has a different image ID.

However, it is possible that some legacy NITF files may contain multiple scan blocks in the same image segment that also reference the same original full image ID. A future version of RSM TREs may be developed that augment each RSM TRE to include an additional field for the scan block ID. A unique RSM TRE Set would then be associated with each scan block, and all would be inserted into the same image segment.

2.2 RSM TRE SET SIZE

When an up-stream process generates an RSM TRE Set for an image data field, it typically adds it to a pre-existing NITF file that contains the image data field. This file also typically contains the image support data associated with the original sensor model, and is used by the up-stream process when generating the corresponding RSM TRE Set. Therefore, the RSM TRE Set contains information equivalent to some of the data already in the corresponding image segment. However, in general, the RSM TRE Set simply augments this data, i.e., the data is not removed. Regardless, some pre-existing data cannot be removed, such as data that defines the relationship between the image data field and the original full image, such as an ICHIPB TRE. This data is required by the user, in addition to the RSM TRE Set, for image exploitation.

Each RSM TRE in an RSM TRE Set is less than 100k bytes in length. For a given image segment, when the RSM TRE set, along with any other pre-existing TREs, total 200k bytes or greater in size, they extend from the corresponding image subheader into the overflow area. Note that the 200k byte area consists of two 100k byte areas, and each TRE must be in one area or the other. Also, as mentioned previously, the entire RSM TRE set may be placed into the overflow area. (Note that the 100k and 200k byte size constraints are approximations, actual size constraints are a few tens of pixels smaller.)

A typical RSM TRE Set corresponds to an unadjusted, (rational) polynomial, RSM ground-to-image function that is applicable to the entire RSM image domain via one image section, and either a direct error covariance or an indirect error covariance. If a direct error covariance, it typically references the associated original full image alone (more precisely, the RSM image domain within the original full image), or also references another original full image that together with the associated original full image make-up a stereo pair. Thus, the RSM TRE Set consists of one RSMID, one RSMPC, and either one relatively small RSMDC or one RSMEC TRE. This RSM TRE Set is typically less than 10k bytes in size, and is placed entirely in the image subheader. On the other hand, if a direct error covariance is included and applicable to many original full images, or if a multi-section polynomial and/or multi-section grid RSM ground-to-image function is included, the total size can exceed 200k bytes, in which case the RSM TRE Set would extend into the overflow area, or alternatively, reside entirely in the overflow area.

2.3 RSM TRE MODIFICATION

As mentioned earlier, when a set of RSM TREs is first generated for an image data field, it is generated by a suitably configured up-stream process. Once disseminated down-stream, the image data field and its RSM TRE Set are then exploited by one or more users. For suitably configured users, exploitation may also include modifying, or “updating”, the RSM and disseminating the corresponding updated RSM TRE Set to other users. The updated RSM TRE Set must have a unique value for the edition field, thus differentiating it from the initial RSM TRE Set. It is recommended that the resultant NITF file that contains the updated RSM TRE Set not contain the initial RSM TRE Set.

There are primarily two types of update. The first adjusts the RSM support data via a triangulation, which results in the generation of non-zero RSM adjustable parameters applicable to the RSM image domain of the associated original full image. The adjustable parameter values are placed into an RSMAP TRE. Typically, a direct error covariance is also generated and placed into an RSMDC TRE.

The updated RSM TRE Set is identical to the initial RSM TRE Set with the following exceptions: (1) it includes the new RSMAP and RSMDC TREs, (2) if the initial RSM TRE Set contained a previous RSMDC or RSMEC covariance TRE, it is removed, (3) the updated RSM TRE Set has a new, unique value for the edition field contained in all of its TREs. If there are multiple image data fields associated with the original full image, the identical updated RSM TRE Set is placed into each corresponding image segment.

The second type of update simply “re-maps” an image data field into one or more smaller image data fields. Or, more generally, the update simultaneously re-maps multiple image data fields associated with the original full image into different image data fields. This process is intended to support more efficient exploitation by intended downstream users. Regardless whether one or multiple data fields are re-mapped, the updated RSM TRE Set placed into a new image segment associated with a new image data field may remain identical to the original RSM TRE Set, with the exception of a new value for the edition field. The fact that the updated RSM TRE Set may now have a larger RSM image domain than may be required has no adverse affect on any subsequent image exploitation.

Note that the above re-mapping process need not be performed exclusively by down-stream users. An image provider may perform this task as well.

2.4 DEFINITION OF AN “IMAGE” FOR RSM TRE DESCRIPTIONS

For the remainder of this specification, the term “image” is defined as an original full image with corresponding image support data contained in a particular RSM TRE Set. An image is contained in one or more NITF image segments (though it is rarely more than one). Each image segment contains the (identical) RSM TRE Set in its image subheader, and an image data field of pixels related to the original full image.

For the remainder of this specification, the term “associated image” is defined as that unique image containing a particular RSM TRE Set.

There may exist multiple images associated with the same original full image. If so, their RSM TRE Sets differ, as indicated by different values in their edition fields. For example, one such image may correspond to unadjusted RSM support data, where the other corresponds to adjusted RSM support data via a triangulation process. In this case, it is up to the user (exploitation process) to decide which image is appropriate to exploit for their particular operational requirements. This decision may be made based on the size of their RSM image domains, whether an image is unadjusted or adjusted, the generation date of the NITF file as specified in the NITF file, or other criteria.

Multiple images associated with the same original full image are contained in different NITF image segments, assuming that an updated RSM TRE Set is not placed into the same image segment that contains the initial RSM TRE Set. This operational restriction is recommended, as discussed previously.

Images associated with different original full images but common support data processing (e.g., triangulation) do not have the same value for the edition field. Thus, when images associated with different original full images but the same triangulation are to be identified, a triangulation id provided in the RSMDC, RSMAP, and RSMEC TREs is used for identification.

Figure 1 below illustrates many of the concepts discussed above associated with RSM TRE Sets and multiple images. For ease of illustration, an image data field is assumed to be a direct subset of the original full image.

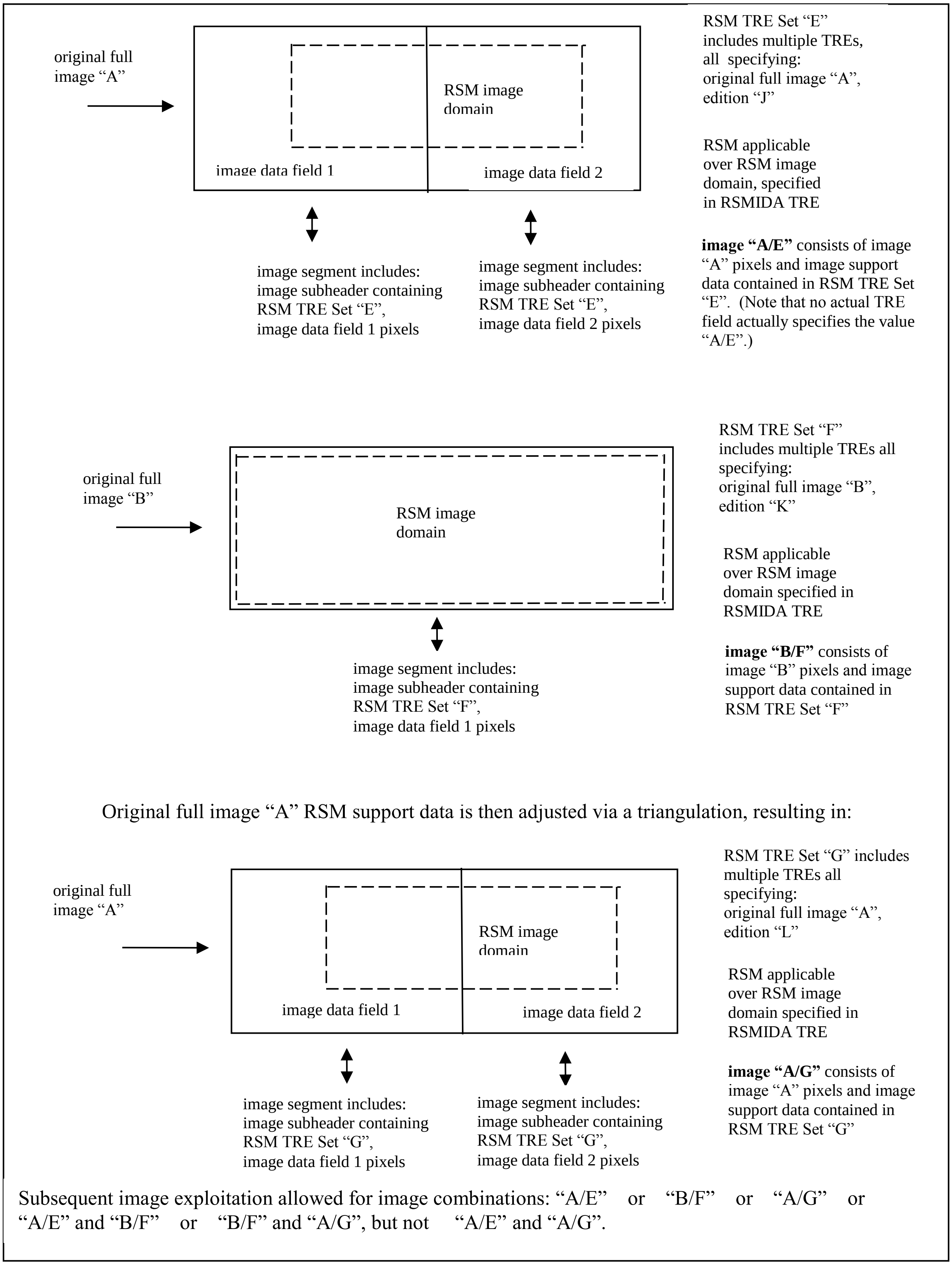

Figure 1. RSM TRE Sets and Multiple Images

3 SENSOR MODEL FUNCTIONALITY SUPPORTED BY THE RSM TRES

An RSM TRE Set provides for sensor model functionality. In particular, it is the basic input to an "RSM exploiter" software module. The RSM exploiter provides requested sensor model functionality through an application programmer's interface (API). The requests are from an application program that might be performing a geopositioning solution, triangulation solution, or other form of higher-level image exploitation.

Typically, the application program also parses out the RSM TRE Set from a NITF file and provides it to the RSM exploiter. When applicable, it also does this for multiple RSM TRE Sets, each associated with a different image (and different original full image ID), which may be in the same NITF file or different NITF files. For example, multiple RSM TRE Sets are required when exploitation is based on multiple images, e.g., stereo extraction (geopositioning). It is assumed that the application program also maps image data field row and column counts to and from original full image row and column counts. Thus, the RSM exploiter deals exclusively with original full image row and column counts.

Depending on the RSM exploiter design, multiple RSM TRE Sets can be provided to the exploiter simultaneously or sequentially. In addition, some data normally contained in an RSM TRE may also be passed into the RSM exploiter directly through a sensor model API.

3.1 RSM EXPLOITER CAPABILITY

Dependent on the specific types of RSM TREs contained in an RSM TRE Set, the appropriate subset of the following interface list (or an equivalent list) should be supported by an RSM exploiter. Unless specifically stated otherwise, the interface is applicable to the RSM TRE Set's associated image.

Required interface capability

1. Application program (AP) requests image row/column location corresponding to supplied ground point location. RSM exploiter (EXP) provides requested data.

   EXP utilizes an RSMPC and (optional) RSMPI TRE if the RSM ground-to-image function is a (rational) polynomial. EXP utilizes an RSMGG and (optional) RSMGI TRE if the RSM ground-to-image function is an interpolated grid. EXP utilizes all the above TREs if the RSM ground-to-image function is a (rational) polynomial with corrections from an interpolated grid.

   In addition, regardless the form of the RSM ground-to-image function, if the RSM image support data is adjusted, EXP also utilizes the RSMAP TRE in order to compute image row/column from an RSM adjusted ground-to-image function.

The RSMID TRE is also utilized in order to define the RSM primary ground coordinate system, the RSM image domain, and the approximate RSM ground domain.

EXP determines the type of RSM ground-to-image function (including adjusted or unadjusted) by which of the above TREs are present in the RSM TRE Set.

Let us term the appropriate set of TREs that supports the AP's request for an image row/column, the "basic ground-to-image set". It is a subset of the RSM TRE Set.

2. AP requests partial derivatives of image row/column with respect to ground point at supplied ground point location. EXP provides requested data.

   EXP utilizes the basic ground-to-image set.

3. AP requests partial derivatives of image row/column with respect to a supplied RSM adjustable parameter identification at supplied ground point location. EXP provides requested data.

   EXP utilizes the basic ground-to-image set. If the RSMAP TRE is not part of the basic ground-to-image set, either the RSMDC TRE or RSMEC TRE is also utilized in order to define the Local ground coordinate system.

4. AP requests the RSM direct error covariance. In addition, the corresponding original full image identification and number of active RSM "error model" adjustable parameters for each applicable image, and the (ordered) identification of these parameters for the associated image, are requested. EXP provides the requested data.

   EXP utilizes the RSMDC TRE.

5. AP requests the RSM indirect error covariance for a set of images from the same sensor. For each image, the original full image ID and a set of image row/column locations are also specified in the request. The corresponding number and (ordered) identification of all active RSM "error model" adjustable parameters for each image (and common across images) are also requested as output, along with the RSM indirect error covariance. EXP provides the requested data.

   EXP utilizes the RSMEC TRE for each of the requested images, i.e., more than one RSM TRE Set may be required.

6. AP requests the 2×2 unmodeled error covariance corresponding to a specified row/column location in the associated image. Also, AP can request the 2×2 unmodeled error cross-covariance corresponding to two specified row/column locations in the associated image (A ground point location(s) can be specified instead of a row/column location(s); the latter will be computed internally by the RSM exploiter.) EXP provides requested data if it is available.

   EXP utilizes optional data within the RSMEC TRE. EXP also utilizes the basic ground-to-image set if a ground point is specified in lieu of a row/column location.

7. AP requests illumination azimuth/elevation angles at specified image row/column location. (A ground point location can be specified instead of a row/column location; the latter will be computed internally by the RSM exploiter.) EXP provides requested data if it is available.

   EXP utilizes optional data within the RSMID TRE. EXP also utilizes the basic ground-to-image set if a ground point is specified in lieu of a row/column location.

8. AP request trajectory position/velocity at specified time. EXP provides requested data if it is available.

   EXP utilizes optional data within the RSMID TRE.

9. AP requests original full image ID. EXP provides requested data.

   EXP utilizes the RSMID TRE.

10. AP requests sensor id. EXP provides requested data if it is available.

    EXP utilizes optional data within the RSMID TRE.

11. AP requests sensor type. EXP provides requested data if it is available.

    EXP utilizes optional data within the RSMID TRE.

12. AP requests original full image size. EXP provides requested data if it is available.

    EXP utilizes optional data within the RSMID TRE.

13. AP requests RSM image domain. EXP provides requested data.

EXP utilizes RSMID TRE.

14. AP requests edition id. EXP provides requested data.

    EXP utilizes the RSMID TRE.

15. AP requests triangulation id. EXP provides requested data.

    EXP utilizes the RSMDC or RSMAP or RSMEC TREs, if available, and in that order of priority.

16. AP requests RSM ground domain's height range. EXP provides requested data.

    EXP utilizes RSMID TRE.

17. AP requests the time-of-image corresponding to supplied row/column location. (A ground point location can be specified instead of a row/column location; the latter will be computed internally by the RSM exploiter.) EXP provides requested data.

    EXP utilizes RSMID TRE. EXP also utilizes the basic ground-to-image set if a ground point is specified in lieu of a row/column location.

18. AP requests identity and definition of RSM primary ground coordinate system. EXP provides requested data.

    EXP utilizes the RSMID TRE.

19. AP requests the polynomial and/or grid ground-to-image function fit error for all sections applicable to polynomials and/or all sections applicable to grids. For grids, the recommended interpolation order is also requested for each section. EXP provides requested data if it is available.

    EXP utilizes the RSMPI and optional data in all RSMPC TREs, if available.

    EXP utilizes the RSMGI and optional data in all RSMGG TREs, if available.

<u>Optional interface capability</u>

20. AP requests ground point horizontal coordinates at supplied image row/column and ground point height coordinate. EXP provides requested data.

    EXP utilizes the basic ground-to-image set.

The successful output of the requested data is predicated on the inherent capability of the original sensor model to support this functionality for the image (geometry).

EXP supports this functionality independent of the RSM primary ground coordinate system.

This functionality is optional, in that it is based on an iterative inverse of the RSM adjustable ground-to-image function. Therefore, it can be performed within the AP instead of by EXP, with EXP supporting this AP functionality via (1).

21. AP requests the value corresponding to the specified identity of an RSM adjustable parameter. EXP provides requested data.

    EXP utilizes the RSMAP TRE, if present

    The value will be zero if the associated image's RSMAP TRE is not present, or if present, if the identified RSM adjustable parameter is not active, i.e., not an RSM "adjusted parameter".

22. AP requests the identity of all active RSM adjustable parameters for the associated image that correspond to the RSM image support data error covariance, i.e., active "error model" adjustable parameters. EXP provides the requested data.

    EXP utilizes the RSMDC TRE, and if not present, the RSMEC TRE.

23. AP requests an RSM image support data error covariance element corresponding to the associated image and the specified identification of two RSM "error model" adjustable parameters. EXP provides the requested data.

    EXP utilizes the RSMDC TRE, or if not present, the RSMEC TRE.

24. AP requests that portion of the RSM direct error covariance associated with applicable images. Applicable images are the associated image and each image referenced by the RSM direct error covariance and for which an RSM TRE Set is available. The corresponding original full image identification, number of active RSM "error model" adjustable parameters and their (ordered) identification, are also requested for each applicable image. EXP supplies the requested data.

    EXP utilizes the RSMDC TRE for each of the applicable images, i.e., more than one RSM TRE Set may be required.

25. AP requests the RSM indirect error covariance for a set of images from the same sensor in a "direct error covariance form", directly suitable for use in a triangulation solution process, as detailed in the RSMEC TRE description. For each image, the original full image ID is also specified in the request. The corresponding number and (ordered) identification of all active RSM "error model" adjustable parameters for each image (and common across images) are also requested as output, along with the RSM indirect error covariance. In the "direct error covariance form", the indirect error covariance is applicable to the images and independent of image row/column location(s). If there are k images and m adjustable parameter per image, the indirect error covariance is a $km \times km$ matrix. EXP provides the requested data.

    EXP utilizes the RSMEC TRE for each of the requested images, i.e., more than one RSM TRE Set may be required.

Comments

The information via the optional interface capability is also inherent via the (default) required interface capability – just not as convenient.

Depending on the RSM exploiter (EXP) design and its interface to the application program (AP), ground locations specified/received by the application program can be relative to one or more of the following coordinate systems: geodetic, WGS 84 rectangular, or the (variable) RSM primary ground coordinate system. If the RSM primary ground coordinate system is not utilized, the RSM exploiter performs any necessary coordinate system conversions.

4 OVERVIEW OF THE RSM TRE DESCRIPTIONS

The remainder of this specification presents detailed description of the various RSM TREs, followed by a glossary of abbreviations and definition of terms that are used throughout this specification.

As part of the RSM TRE descriptions, an introduction to each TRE is provided that describes overall TRE content and applications. Note that some introductory material is redundant across some of the TRE descriptions, since each TRE is to stand alone when applicable. For example, the RSMID TRE is always included in the RSM support data (RSM TRE Set) for an image, so its introductory material is not duplicated across the other TRE descriptions. On the other hand, any combination of RSMDC, RSMAP, and RSMEC TREs may be included in an image's RSM support data. Therefore, much of the introductory material defining RSM adjustable parameters is duplicated across these TRE descriptions. This material is required for the application of each of these TREs.

4.1 APPENDICES

Appendix A provides various references to supporting documentation and contact information.

Appendix B contains The ABCs of RSM, which is a conceptual overview of sensor modeling, error propagation, and RSM.

Appendix C details a study of RSMs from large field of view frame imagery.

Appendix D provides guidance for RSM compliance testing.

4.2 FORMAT TABLES

Each of the following RSM TRE descriptions includes a format table for the associated RSM TRE. In these RSM TRE format tables, the "Type" column has a value of "R" (required) or "C" (conditional). If a field (Table row) has a type "R", it is always included in the TRE. If it has a value of "C", it may be included, depending on documented conditions. Also, the addition of "<>" around "R" or "C" indicates that the corresponding field may contain spaces instead of the described data, due to the unavailability of the described data or its optional population.

4.2.1 VALUE RANGE AND OTHER CHECKS

All fields in an RSM TRE have a value range specified in the TRE's format table that should be checked for compliance by an RSM generator when generated, and by an RSM exploiter when utilized.

The possible value range for most fields is extremely large, which requires the use of Scientific Notation (see Glossary). The numeric fields in RSM TREs requiring Scientific Notation are 21 Bytes in BCS-A format. When all numeric values in these fields may be used, the value range is specified in Scientific Notation as

±9.99999999999999E±99,

which is equivalent to the range

-9.99999999999999E+99 to +9.99999999999999E+99

(note that the exponent covers the range of -99 to +99, and is negative for all values between, but not equal to, plus and minus one, which occurs in the middle of the above range as it passes through zero). For other value ranges in the fields requiring Scientific Notation the value ranges are first specified in the appropriate Scientific Notation format followed by the common numeric values. For example:

1) The range of a unit vector is represented as:

   -1.00000000000000E+00 to
   +1.00000000000000E+00
   (-1 to +1)

   (note that in this case the exponent can be either negative or zero).

2) The range of zero to pi (π) radians as:

   +0.00000000000000E+00 to
   +3.14159265358979E+00
   (0 to pi)

   (where again the exponent can be either negative or zero).

In some cases, further quantification of the possible value range may also include properties corresponding to a collection of fields in an RSM TRE. For example, a field may be within a loop and correspond to an element of a positive definite error covariance matrix (see the RSMEC TRE description). If so stated in the “Value Range” column, this is a further constraint on the field’s values. The assembled error covariance should be checked to ensure that it is a positive definite error covariance. Another example is the year, month, and day fields corresponding to a date (see the RSMID TRE description). They must be consistent. For example, February 29th is only allowed for a leap year.

As mentioned previously, range value constraints can involve a collection of fields as well as each individual field in an RSM TRE. In addition there are a few range value constraints involving fields in different TREs that are in the same RSM TRE Set. Specifically, the original full image ID field should have the same value for all TREs in the RSM TRE Set. The edition field should also have the same value for all TREs in the RSM TRE Set. The triangulation ID field should have the same value for any RSMDC, RSMAP, or RSMEC TREs in the RSM TRE Set.

4.3 TRE-LEVEL CONSTRAINTS

In addition to range value constraints associated with all TREs in an RSM TRE Set, there are TRE-level constraints that should be checked for compliance by an application program/RSM generator and an application program/RSM exploiter. These are:

1. One and only one RSMID TRE is included (in the RSM TRE Set)
2. At least one RSMPC TRE or at least one RSMGG is included
3. If more than one RSMPC TRE is included, an RSMPI TRE is also included
4. If more than one RSMGG TRE is included, an RSMGI TRE is also included
5. The number of RSMPC TREs included is in conformance with the number specified within the RSMPI TRE, if included
6. The number of RSMGG TREs is in conformance with the number specified within the RSMGI TRE, if included
7. No more than one RSMDC is included (A version only – there can be multiple RSMDCB TREs)
8. No more than one RSMAP is included
9. No more than one RSMEC is included

5 RSM IDENTIFICATION (RSMID) TRE

5.1 OVERVIEW

The Replacement Sensor Model (RSM) Identification TRE (RSMID) is always supplied in an image's RSM support data. It contains various identifiers, provides a time-of-image model, defines the RSM primary ground coordinate system, specifies the applicable RSM image domain relative to the original full image, provides an approximation of the corresponding RSM ground domain, provides an optional illumination direction model, and provides an optional sensor trajectory model.

The RSM image domain may correspond to any rectangle within the original full image. It is defined by the RSM TRE generation process and supported by the original sensor model and its support data. The RSM image domain specifies where the RSM support data is applicable within the original full image Further details of the RSM image domain and corresponding ground domain are provided later in this introduction.

The identification (ID) information provided by the TRE includes the image ID (character field IID) of the original full image, and an RSM edition (character field EDITION). Both of these fields are also included in all other RSM TREs. The value of IID is the same for all RSM TREs associated with the same image, i.e., in the same RSM TRE Set. The value of EDITION is the same for all of these RSM TREs as well, and provides both an abbreviated RSM generation history and a method to uniquely identify images, e.g., differentiate between images with the same original full image ID but different levels of support data (adjusted vs. unadjusted, etc.).

If the field IID has a value of all spaces, an original full image ID was unavailable from the original sensor model image support data or other sources, and hence, unavailable for the RSM image support data for the associated image.

5.2 TIME-OF-IMAGE MODEL

The time information that is provided by the RSMID TRE may be used to determine the approximate time that each pixel was collected. The acquisition time of an arbitrary imaged pixel position (r, c) anywhere within the original full image, whether part of the RSM image domain or not, is modeled according to the following formula (the symbol $\lfloor\ \rfloor$ indicates integer floor):

$$t = t_0 + \left\lfloor \frac{r}{NRG} \right\rfloor \cdot TRG + \left\lfloor \frac{c}{NCG} \right\rfloor \cdot TCG$$

t_0 = Time Zero. Time is provided by the combination of fields' year, month, day, hour, minute, second and corresponds to the $(r,c)=(0,0)$ pixel location of the original full image.
r = row desired
c = column desired
NRG = Number of rows acquired simultaneously
TRG = Time between adjacent row groups
NCG = Number of columns acquired simultaneously
TCG = Time between adjacent column groups

Note that for all RSM TREs, the image coordinate convention is that the center of the first pixel in the original full image is $(r,c)=(0.5,0.5)$. The RSM image coordinate system is defined in more detail later in this introduction.

A group of pixels, all with the same collection time, is defined as an "image element". For example, if the sensor associated with the image is a frame camera, all pixels within the image will have the same collection time. Thus, there is only one "image element", the entire image. (This is indicated when the fields TRG and TCG both have values of zero.) On the other hand, if the sensor is a scanning sensor, all pixels within the same line may be collected at the same time. For this case, there are m image elements, assuming an $m \times n$ image, where m is the number of rows (lines) and n is the number of columns (samples). (This is indicated when the field TCG has a value of zero.)

If fields NRG, TRG, NCG, and TCG have a value of all spaces, a time-of-image model was unavailable from the original sensor model, and hence, unavailable for the RSM for the associated image. If so, the RSM indirect error covariance (RSMEC TRE) cannot be used with this image in conjunction with other images from the same sensor, as the time interval between two of these images cannot be determined.

5.3 RSM GROUND COORDINATE SYSTEM

The RSMID TRE specifies the RSM primary ground coordinate system. Unless specifically noted otherwise in a TREs description, all other RSM TREs in the same RSM TRE Set use this same ground coordinate system. The ground coordinate system specified is either Geodetic (latitude, longitude, and height above the WGS 84 reference ellipsoid), or Rectangular. Regardless whether the coordinate system is specified as Geodetic or Rectangular, associated ground point locations are represented as a triple – x, y, and z. If Geodetic, x corresponds to longitude, y to latitude, and z to height. The Rectangular system is defined in this TRE by an offset and rotation about the WGS 84 Rectangular coordinate system:

$$X = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} XUXR & YUXR & ZUXR \\ XUYR & YUYR & ZUYR \\ XUZR & YUZR & ZUZR \end{bmatrix} \cdot \left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{WGS}-84} - \begin{bmatrix} XUOR \\ YUOR \\ ZUOR \end{bmatrix} \right).$$

Figure 2 illustrates the Rectangular system. Note that when the Rectangular system is specified, it typically corresponds to a local tangent plane coordinate system centered within the RSM image domain's ground footprint at a nominal height above the ellipsoid.

A Rectangular system should be specified when the image footprint is near the earth's North or South pole. Either a Rectangular or Geodetic system can be specified when the footprint is near 180 degrees East longitude. However, if Geodetic, the range for longitude is then specified in field GRNDD as (0,2pi) radians instead of the usual (-pi, +pi) radians.

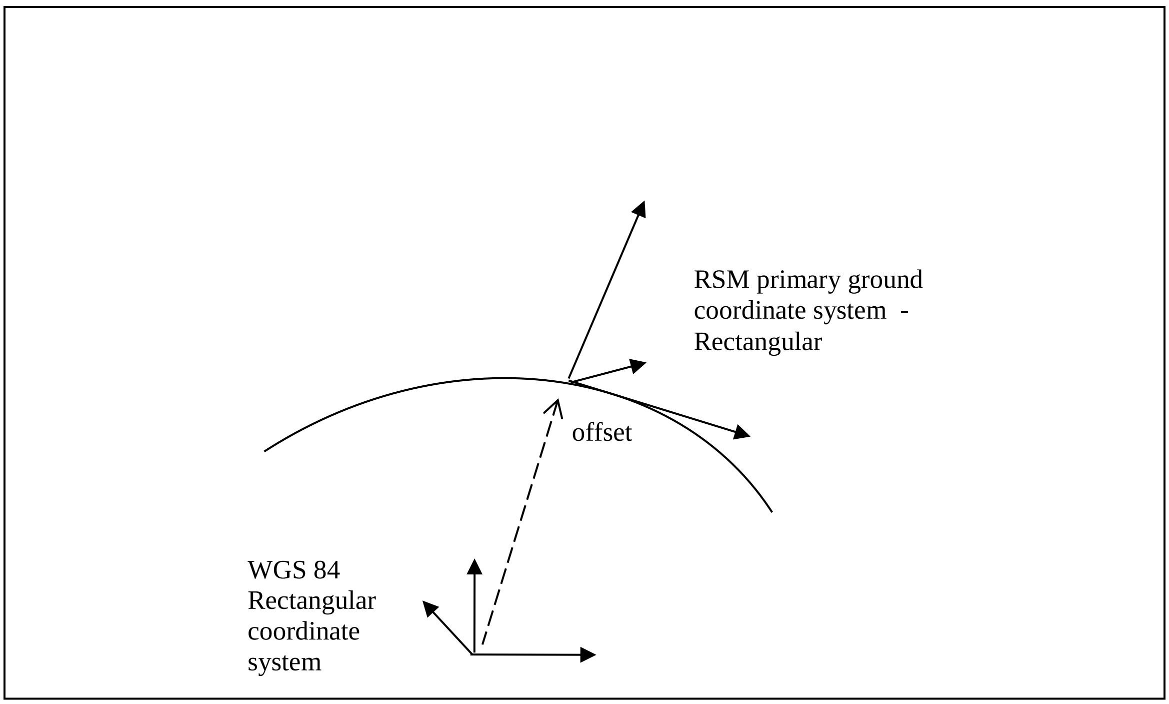

Figure 2: Example of RSM Primary Ground Coordinate System – Rectangular

5.4 RSM IMAGE COORDINATE SYSTEM

The RSM image coordinate system convention is defined as follows. The upper left corner of the upper left pixel of the original full image has continuous image coordinates (pixel position) $(r,c) = (0.0,0.0)$, and the center of the upper left pixel has continuous image coordinates $(r,c) = (0.5,0.5)$. The first row of the original full image has discrete image row coordinate $R = 0$, and corresponds to a range of continuous image row coordinates of $r = [0,1)$. The first column of the original full image has discrete image column coordinate $C = 0$, and corresponds to a range of continuous image column coordinates of $c = [0,1)$. Thus, for example, continuous image coordinates $(r,c) = (5.6,8.3)$ correspond to the sixth row and ninth column of the original full image, and discrete image coordinates $(R,C) = (5,8)$.

5.5 RSM IMAGE DOMAIN

The RSMID TRE includes the specification of the valid image domain where the RSM is expected to be applied. This RSM image domain is a rectangle defined by the minimum and maximum discrete row coordinate values, and the minimum and maximum discrete column coordinate values. These discrete coordinate values are with respect to the original full image and correspond to fields MINR, MAXR, MINC, and MAXC, respectively. The original full image is FULLR pixels $\times$ FULLC pixels in size. Figure 3 presents an example on an RSM image domain within the original full image.

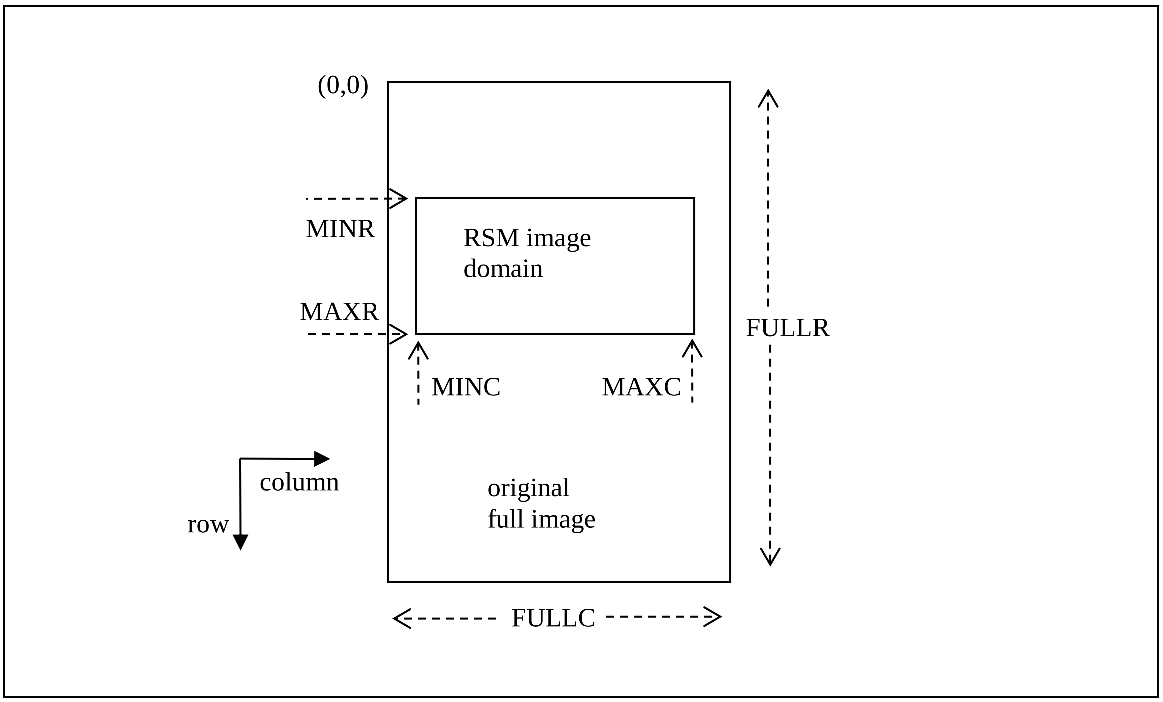

Figure 3: RSM Image Domain

5.6 RSM GROUND DOMAIN

The RSMID TRE includes an approximation of the corresponding ground domain where the RSM representation is valid. This approximation is termed the "RSM ground domain". The RSM ground domain (Figure 4) is a solid in three-dimensional space bounded by a hexahedron with quadrilateral faces specified using eight three-dimensional vertices contained in contiguous fields V1X through V8Z, where V1X corresponds to the x-component of V1 in the RSM primary ground coordinate system, etc.

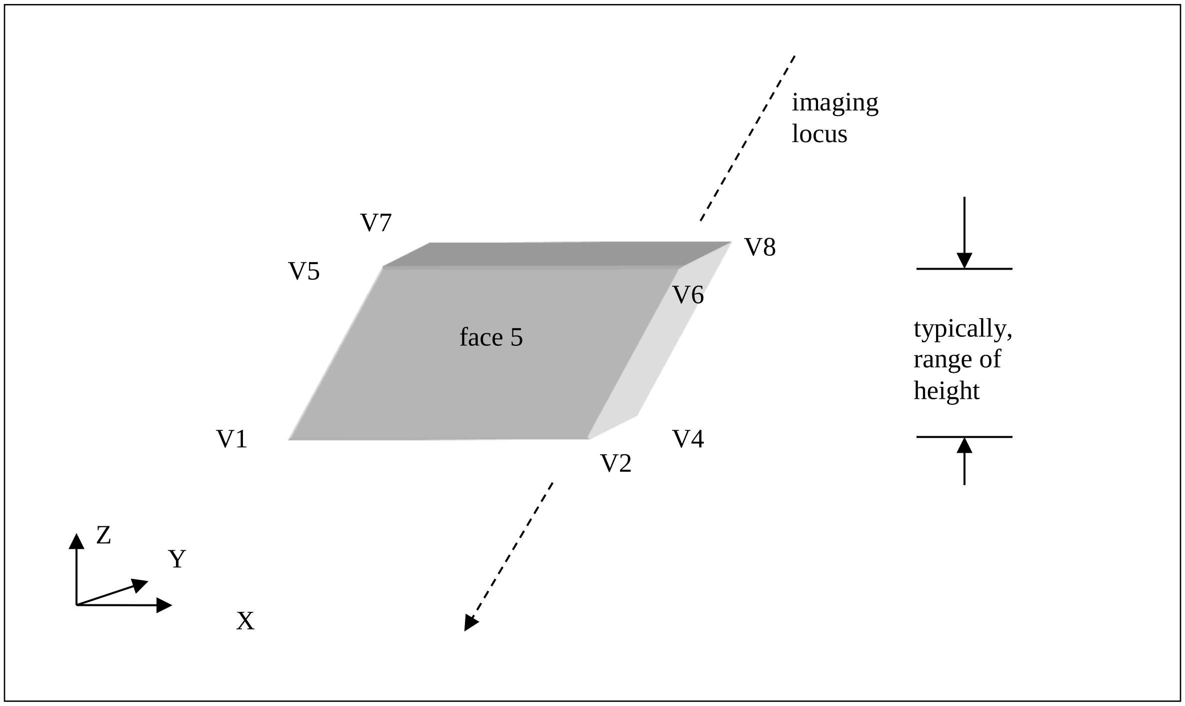

Figure 4: RSM Ground Domain

Each of the six faces is a plane quadrilateral defined by four vertices in counter-clockwise order as viewed from outside the solid and facing the plane in question: (1) face 1 - V1/V3/V4/V2, face 2 - V5/V6/V8/V7, face 3 - V1/V5/V7/V3, face 4 - V2/V4/V8/V6, face 5 - V1/V2/V6/V5, face 6 - V3/V7/V8/V4. In order to unambiguously define the order of the vertices in the support data, the following metric relationships are imposed: V1X<V2X, V1Y<V3Y, and V1Z<V5Z.

Typically, face 1 and face 2 are also generated such that they each correspond to a constant height value, with face 2 at the larger height. Thus, for example, if the RSM primary ground coordinate system is Geodetic, the z-coordinates of vertices V5/V6/V8/V7 are constant in value and correspond to the larger height. (Note that when Geodetic coordinates are specified as the RSM primary ground coordinate system, the faces are actually slightly curved.)

Regardless the relationship of the faces to height, the faces can also be used to assist in single or multi-image exploitation planning and/or post-analyses. In particular, if a face corresponds to a constant height, it represents the "image footprint" of the RSM image domain at that height. Interpolation between two faces, each at a constant height, can also provide an image footprint at a desired height anywhere within the RSM ground domain.

The primary purpose of the RSM ground domain is to define the region of validity of the RSM TRE Set representation in ground space. The RSM ground domain is generated such that if a ground point X is within the RSM ground domain, the RSM ground-to-image function is well-behaved at that point. In addition, if the corresponding ground-to-image function output I is also within the RSM image domain, it is accurate. In particular, all aspects of the RSM TRE Set are then valid, including the illumination model, image support data error covariance, etc., if present. (The added condition regarding the output I is required because the RSM ground domain is an approximation.)

The following conditions determine whether a ground point X is within the RSM ground domain (solid). Each condition corresponds to a particular face and ensures that X is on the side of the face that is inside the solid. The superscript "^{T}" represents the vector transpose and the symbol "$\times$" represents the vector cross-product.

1. $(X - V2)^T((V4 - V2) \times (V1 - V2)) \geq 0$ (face 1)
2. $(X - V6)^T((V5 - V6) \times (V8 - V6)) \geq 0$ (face 2)
3. $(X - V1)^T((V3 - V1) \times (V5 - V1)) \geq 0$ (face 3)
4. $(X - V2)^T((V6 - V2) \times (V4 - V2)) \geq 0$ (face 4)
5. $(X - V2)^T((V1 - V2) \times (V6 - V2)) \geq 0$ (face 5)
6. $(X - V4)^T((V8 - V4) \times (V3 - V4)) \geq 0$ (face 6)

If all six conditions are satisfied, the ground point X is within the RSM ground domain.

Typically, the check that X is within the RSM ground domain is seldomly needed during the exploitation process. One exception is when X corresponds to an image point within the RSM image domain, but the ground point estimate is known to be inaccurate.Another is when the corresponding image point is near the boundary of the RSM image domain. However, for all X , a check should be performed that the corresponding ground-to-image function's output I is within the RSM image domain.

5.7 ILLUMINATION MODEL

Optional illumination information is provided by the RSMID TRE. If this data is for an optical sensor, the information provided gives the direction of the sun's illumination. However, if this data is for a SAR sensor, the information provided gives the direction of incident, active radiation. Illumination direction is used in shadow-based mensuration and is approximated by two polynomials. Specifically, illumination elevation (φ) and azimuth (λ) angles are computed from quadratic functions of image position (r, c). The illumination angles for a particular image position are defined in a local rectangular coordinate system that is tangent to a geodetic surface corresponding to that image position. The geodetic surface is defined at the ground coordinate corresponding to the image position at the reference geodetic height for the image (see Figure 5). This coordinate system is a local tangent plane coordinate system, with axis aligned East, North, and Up. If there is a ground reference point for the image, then the reference geodetic height is that point's height, otherwise it is the mean of the geodetic heights of the eight corners (vertices) of the RSM ground domain. The azimuth angle is measured in radians clockwise from north in the tangent plane. The elevation angle is measured in radians upward from the tangent plane. The direction is from the ground toward the source, so that the elevation angle is generally positive. The image coordinates are with respect to the original full image, but the polynomials are only valid within the RSM image domain. The following defines the polynomials:

$$\varphi = IE0 + IER \cdot r + IEC \cdot c + IERR \cdot r^2 + IERC \cdot r \cdot c + IECC \cdot c^2$$
$$\lambda = IA0 + IAR \cdot r + IAC \cdot c + IARR \cdot r^2 + IARC \cdot r \cdot c + IACC \cdot c^2$$

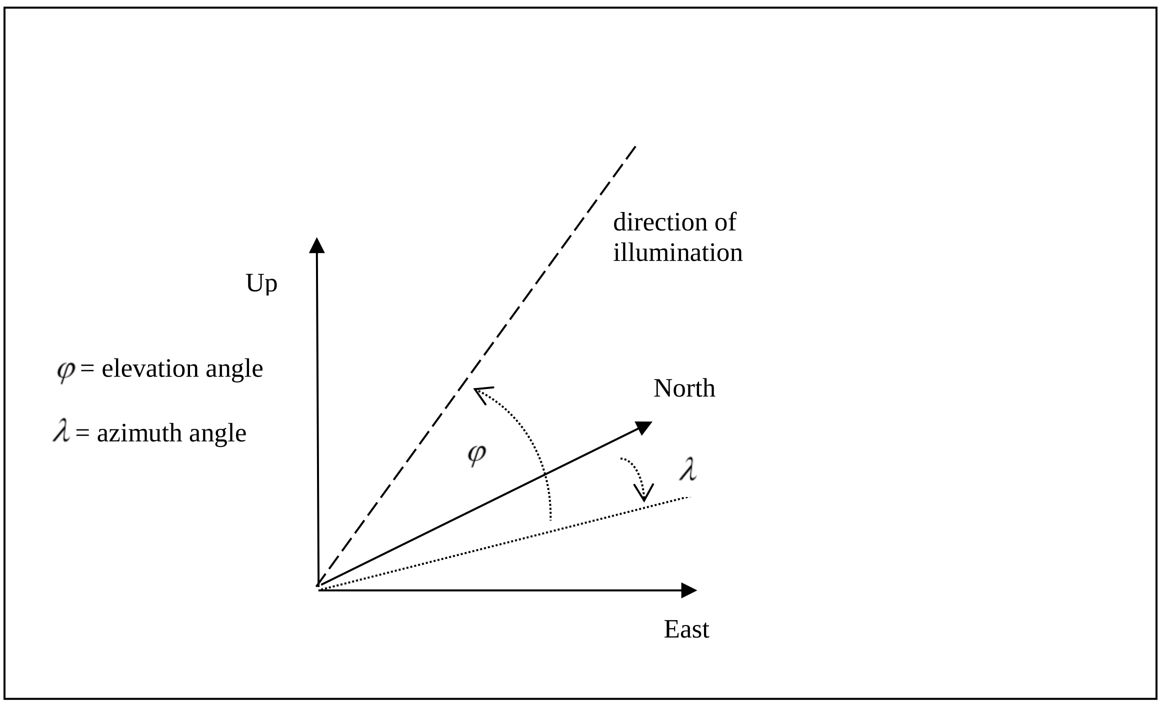

Figure 5: Illumination Angles

IA0 is typically chosen to fall in one of the standard ranges –pi to pi or 0 to 2pi. IE0 is typically chosen to fall in the range –pi/2 to pi/2. The range is chosen by the TRE creator to ensure continuity of all values φ and λ over the RSM image domain, and they can even be exceeded if necessary in order to obtain the best fit.

The computed values φ and λ can exceed standard ranges as well. If particular standard ranges are required, the computed values must be adjusted to fall within the standard ranges required. For instance, if φ exceeds pi/2 by (positive) delta, subtract 2*delta (and add pi to the corresponding λ to maintain consistency) to bring the elevation angle into the range –pi/2 to pi/2. Similarly, add or subtract 2pi to λ to bring it into the desired standard range (following any elevation angle-based correction).

5.8 TRAJECTORY MODEL

An optional sensor (platform) trajectory model is also provided by the RSMID TRE as ancillary information. Specifically, the sensor's three dimensional position, velocity, and acceleration are provided as a function of time from a reference. This reference time corresponds to t_0 (Time Zero), previously described in the time-of-image model. The coordinate system used to represent the trajectory is the RSM primary ground coordinate system, previously discussed and specified within this TRE. The following defines the sensor trajectory model:

$$pos\_x(t) = px + vx \cdot (t - t_0) + 0.5 \cdot ax \cdot (t - t_0)^2$$
$$vel\_x(t) = vx + ax \cdot (t - t_0)$$
$$pos\_y(t) = py + vy \cdot (t - t_0) + 0.5 \cdot ay \cdot (t - t_0)^2$$
$$vel\_y(t) = vy + ay \cdot (t - t_0)$$
$$pos\_z(t) = pz + vz \cdot (t - t_0) + 0.5 \cdot az \cdot (t - t_0)^2$$
$$vel\_z(t) = vz + az \cdot (t - t_0)$$

The above sensor trajectory model is applicable across the time span corresponding to the RSM image domain. The model parameters $px, vx, ax, py, vy, ay, pz, vz, az$ correspond to the contiguous fields SPX through SAZ contained in this TRE, respectively.

5.9 RSMIDA FORMAT

Table 2 specifies the detailed format for the Replacement Sensor Model Identification version A (RSMIDA) TRE.

RSMIDA – Replacement Sensor Model Identification						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Value Range**	**Type**
			TAG Information			
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMIDA	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	Bytes	1628	R
			Image Information			
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R
ISID	Image Sequence Identifier. This field contains a character string that uniquely identifies an image sequence acquired by a single sensor. The associated image is a member of this image sequence.	40	BCS-A	N/A	N/A Population optional Default is all spaces	<R>
SID	Sensor Identifier. This field contains a character string that identifies the specific sensor used to acquire the associated image. Analagous to STDIDC mission. Must be unique among images of a given sensor type.	40	BCS-A	N/A	N/A Population optional Default is all spaces	<R>
STID	Sensor Type Identifier. This field contains a character string that uniquely identifies the capabilities of the sensor used to acquire the associated image, including make, model, processing chain, etc. Analagous to the CSM pedigree. The following conventions are strongly encouraged in order to support functionality that depends on their distinction: **a.** Inclusion of “EO”, “IR”, or “SAR” as applicable **b.** Inclusion of “_RSM” at end.	40	BCS-A	N/A	N/A Population optional but strongly encouraged Default is all spaces	<R>

YEAR	Year of Image Acquisition. This field identifies the UTC year the image was taken.	4	BCS-A	Year	0000 to 9999 All spaces if unavailable Value must be consistent with the values for MONTH and DAY	<R>
MONTH	Month of Image Acquisition. This field identifies the UTC month of the year that the image was taken.	2	BCS-A	Month	01 to 12 All spaces if unavailable Value must be consistent with the values for YEAR and DAY	<R>
DAY	Day of Image Acquisition. This field identifies the UTC day of the month that the image was taken.	2	BCS-A	Day	01 to 31 All spaces if unavailable Value must be consistent with the values for YEAR and MONTH	<R>
HOUR	Hour of Image Acquisition. This field identifies the UTC hour of the day that the image was taken.	2	BCS-A	Hour	00 to 23 All spaces if unavailable	<R>
MINUTE	Minute of Image Acquisition. This field identifies the UTC minute of the hour that the image was taken.	2	BCS-A	Minute	00 to 59 All spaces if unavailable	<R>
SECOND	Second of Image Acquisition. This field identifies the UTC number of seconds past the minute that image acquisition occurred for the row 0, column 0 in the original full image. *Note that the range exceeds 60 seconds due to a possible UTC leap second..	9	BCS-A	Second	00.000000 to 60.999999 * All spaces if unavailable	<R>
NRG	Number of Rows Acquired Simultaneously. This field contains the number of rows that are acquired simultaneously (in a single group).	8	BCS-A	pixels	00000001 to 99999999 All spaces if unavailable	<R>
NCG	Number of Columns Acquired Simultaneously. This field contains the number of columns that are acquired simultaneously (in a single group).	8	BCS-A	pixels	00000001 to 99999999 All spaces if unavailable	<R>
TRG	Time Between Adjacent Row Groups. This field contains the time period that elapses between a row group and the next higher group of rows. Allowed to have a negative value to accommodate an image inadvertently “inserted” in “backwards” time order.	21	BCS-A	seconds	±9.99999999999999E±99 All spaces if unavailable	<R>
TCG	Time Between Adjacent Column Groups. This field contains the time period that elapses between a column group and the next higher group of columns. Allowed to have a negative value to accommodate an image inadvertently “inserted” in “backwards” time order.	21	BCS-A	seconds	±9.99999999999999E±99 All spaces if unavailable	<R>

GRNDD	Ground Domain Form. An arbitrary ground point is specified with coordinates *X*, *Y*, and *Z*. This field specifies the corresponding coordinate system as either Geodetic (G or H) or Rectangular (R). If Geodetic, *X*, *Y*, and *Z*, correspond to longitude, latitude, and height above the ellipsoid, respectively. Longitude is specified east of the prime meridian, and latitude is specified north of the equator. Units for *X*, *Y*, and *Z*, are radians, radians, and meters, respectively. The range for *Y* is (-pi/2 to pi/2). The range for *X* is (-pi to pi) when GRNDD=G, and (0 to 2pi) when GRNDD=H. The latter is specified when the RSM ground domain contains a longitude value near pi radians. If Rectangular, *X*, *Y*, and *Z* correspond to a coordinate system that is defined as an offset from and rotation about the WGS 84 Rectangular coordinate system. The field GRNDD specifies the applicable coordinate system for all ground points referenced in all RSM TREs for this image, unless specifically stated otherwise for a particular TRE.	1	BCS-A	N/A	G,H, R	R
XUOR	Rectangular Coordinate Origin (XUOR). This field provides the WGS 84 *X* coordinate of the origin of the Rectangular coordinate system.	21	BCS-A	meters	±9.99999999999999E±99 All spaces if GRNDD=G or H	<R>
YUOR	Rectangular Coordinate Origin (YUOR). This field provides the WGS 84 *Y* coordinate of the origin of the Rectangular coordinate system.	21	BCS-A	meters	±9.99999999999999E±99 All spaces if GRNDD=G or H	<R>
ZUOR	Rectangular Coordinate Origin (ZUOR). This field provides the WGS 84 *Z* coordinate of the origin of the Rectangular coordinate system.	21	BCS-A	meters	±9.99999999999999E±99 All spaces if GRNDD=G or H	<R>
XUXR	Rectangular Coordinate Unit Vector (XUXR). This field provides the WGS 84 *X* component of the unit vector defining the *X*-axis of the Rectangular coordinate system.	21	BCS-A	N/A	0000000000000E+00 to +1.00000000000000E+00 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>

XUYR	Rectangular Coordinate Unit Vector (XUYR). This field provides the WGS 84 *X* component of the unit vector defining the *Y*-axis of the Rectangular coordinate system.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>
XUZR	Rectangular Coordinate Unit Vector (XUZR). This field provides the WGS 84 *X* component of the unit vector defining the *Z*-axis of the Rectangular coordinate system.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>
YUXR	Rectangular Coordinate Unit Vector (YUXR). This field provides the WGS 84 *Y* component of the unit vector defining the *X*-axis of the Rectangular coordinate system.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>
YUYR	Rectangular Coordinate Unit Vector (YUYR). This field provides the WGS 84 *Y* component of the unit vector defining the *Y*-axis of the Rectangular coordinate system.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>
YUZR	Rectangular Coordinate Unit Vector (YUZR). This field provides the WGS 84 *Y* component of the unit vector defining the *Z*-axis of the Rectangular coordinate system.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>
ZUXR	Rectangular Coordinate Unit Vector (ZUXR). This field provides the WGS 84 *Z* component of the unit vector defining the *X*-axis of the Rectangular coordinate system.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>

ZUYR	Rectangular Coordinate Unit Vector (ZUYR). This field provides the WGS 84 Z component of the unit vector defining the Y-axis of the Rectangular coordinate system.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>
ZUZR	Rectangular Coordinate Unit Vector (ZUZR). This field provides the WGS 84 Z component of the unit vector defining the Z-axis of the Rectangular coordinate system	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) All spaces if GRNDD=G or H Value consistent with fields XUXR through ZUZR forming an orthogonal matrix	<R>
V1X	Vertex 1 - X coordinate of the RSM ground domain. This field provides the value of the x coordinate of vertex V1 of the RSM ground domain.	21	BCS-A	Radians or meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99 Fields V1X and V2X values constrained such that V1X<V2X	R
V1Y	Vertex 1 - Y coordinate of the RSM ground domain. This field provides the value of the y coordinate of vertex V1 of the RSM ground domain.	21	BCS-A	Radians or meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99 Fields V1Y and V3Y values constrained such that V1Y<V3Y	R
V1Z	Vertex 1 - Z coordinate of the RSM ground domain. This field provides the value of the z coordinate of vertex V1 of the RSM ground domain.	21	BCS-A	Meters	±9.99999999999999E±99 Fields V1Z and V5Z values constrained such that V1Z<V5Z	R

V2X	Vertex 2 - X coordinate of the RSM ground domain. This field provides the value of the *x* coordinate of vertex V2 of the RSM ground domain.	21	BCS-A	Radians or meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99 Fields V1X and V2X values constrained such that V1X<V2X	R
V2Y	Vertex 2 - Y coordinate of the RSM ground domain. This field provides the value of the *y* coordinate of vertex V2 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99	R
V2Z	Vertex 2 - Z coordinate of the RSM ground domain. This field provides the value of the *z* coordinate of vertex V2 of the RSM ground domain.	21	BCS-A	Meters	±9.99999999999999E±99	R
V3X	Vertex 3 - X coordinate of the RSM ground domain. This field provides the value of the *x* coordinate of vertex V3 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99	R
V3Y	Vertex 3 - Y coordinate of the RSM ground domain. This field provides the value of the *y* coordinate of vertex V3 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99 Fields V1Y and V3Y values constrained such that V1Y<V3Y	R
V3Z	Vertex 3 - Z coordinate of the RSM ground domain. This field provides the value of the *y* coordinate of vertex V3 of the RSM ground domain.	21	BCS-A	Meters	±9.99999999999999E±99	R

V4X	Vertex 4 - X coordinate of the RSM ground domain. This field provides the value of the *x* coordinate of vertex V4 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99	R
V4Y	Vertex 4 - Y coordinate of the RSM ground domain. This field provides the value of the *y* coordinate of vertex V4 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 i/2 to pi/2) RNDD=R 9999999999999E±99	R
V4Z	Vertex 4 - Z coordinate of the RSM ground domain. This field provides the value of the *z* coordinate of vertex V4 of the RSM ground domain.	21	BCS-A	Meters	±9.99999999999999E±99	R
V5X	Vertex 5 - X coordinate of the RSM ground domain. This field provides the value of the *x* coordinate of vertex V5 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99	R
V5Y	Vertex 5 - Y coordinate of the RSM ground domain. This field provides the value of the *y* coordinate of vertex V5 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99	R
V5Z	Vertex 5 - Z coordinate of the RSM ground domain. This field provides the value of the *z* coordinate of vertex V5 of the RSM ground domain.	21	BCS-A	Meters	±9.99999999999999E±99 Fields V1Z and V5Z values constrained such that V1Z<V5Z	R

V6X	Vertex 6 - X coordinate of the RSM ground domain. This field provides the value of the *x* coordinate of vertex V6 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, +9.99999999999999E+99	R
V6Y	Vertex 6 - Y coordinate of the RSM ground domain. This field provides the value of the *y* coordinate of vertex V6 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99	R
V6Z	Vertex 6 - Z coordinate of the RSM ground domain. This field provides the value of the *z* coordinate of vertex V6 of the RSM ground domain.	21	BCS-A	Meters	±9.99999999999999E±99	R
V7X	Vertex 7 - X coordinate of the RSM ground domain. This field provides the value of the *x* coordinate of vertex V7 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99	R
V7Y	Vertex 7 - Y coordinate of the RSM ground domain. This field provides the value of the *y* coordinate of vertex V7 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99	R
V7Z	Vertex 7 - Z coordinate of the RSM ground domain. This field provides the value of the *z* coordinate of vertex V7 of the RSM ground domain.	21	BCS-A	Meters	±9.99999999999999E±99	R

V8X	Vertex 8 - X coordinate of the RSM ground domain. This field provides the value of the *x* coordinate of vertex V8 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99	R
V8Y	Vertex 8 - Y coordinate of the RSM ground domain. This field provides the value of the *y* coordinate of vertex V8 of the RSM ground domain.	21	BCS-A	Radians or Meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99	R
V8Z	Vertex 8 - Z coordinate of the RSM ground domain. This field provides the value of the *z* coordinate of vertex V8 of the RSM ground domain.	21	BCS-A	Meters	±9.99999999999999E±99	R
GRPX	Ground Reference Point X. This field provides the x-coordinate of the Ground Reference Point. The Ground Reference Point is optional. If not supplied, this field and the next two fields have values of all spaces.	21	BCS-A	Radians or meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99 Population optional Default is all spaces	<R>
GRPY	Ground Reference Point Y. This field provides the y-coordinate of the Ground Reference Point.	21	BCS-A	Radians or meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99 Population optional Default is all spaces	<R>
GRPZ	Ground Reference Point Z. This field provides the z-coordinate of the Ground Reference Point.	21	BCS-A	Meters	±9.99999999999999E±99 Population optional Default is all spaces	<R>
FULLR	Number of Rows in Full Image. This field contains the number of image rows covered by the original full image. This is ancillary information and not required for RSM implementation.	8	BCS-A	pixels	00000001 to 99999999 All spaces if unavailable	<R>

FULLC	Number of Columns in Full Image. This field contains the number of image columns covered by the original full image. This is ancillary information and not required for RSM implementation.	8	BCS-A	pixels	00000001 to 99999999 All spaces if unavailable	<R>
MINR	Minimum Row. This field provides the minimum row value of the RSM image domain relative to original full image.	8	BCS-N	pixels	00000000 to 99999999	R
MAXR	Maximum Row. This field provides the maximum row value of the RSM image domain relative to original full image.	8	BCS-N	pixels	00000000 to 99999999	R
MINC	Minimum Column. This field provides the minimum column value of the RSM image domain relative to original full image.	8	BCS-N	pixels	00000000 to 99999999	R
MAXC	Maximum Column. This field provides the maximum column value of the RSM image domain relative to original full image.	8	BCS-N	pixels	00000000 to 99999999	R
IE0	Illumination Elevation Angle Constant Coefficient. This field provides the approximate angle from the local tangent plane coordinate system's horizontal ground plane to the primary source of scene illumination for image position (0, 0). Typically between -pi/2 and pi/2, though this range can be exceeded in order to ensure continuity of all computed elevation angles in an image. See section 5.7. The illumination direction model is optional. If not supplied, this field and the next 11 fields have values of all spaces.	21	BCS-A	radians	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IER	Illumination Elevation Angle Coefficient Per Row. This field provides the approximate elevation angle change per image row.	21	BCS-A	radians per pixel	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IEC	Illumination Elevation Angle Coefficient Per Column. This field provides the approximate elevation angle change per image column.	21	BCS-A	radians per pixel	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IERR	Illumination Elevation Angle Coefficient Per Row Squared. This field provides the approximate elevation angle change per image row squared.	21	BCS-A	radians per pixel squared	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IERC	Illumination Elevation Angle Coefficient Per Row-Column. This field provides the approximate elevation angle change per image row-column.	21	BCS-A	radians per pixel squared	±9.99999999999999E±99 Population optional Default is all spaces	<R>

IECC	Illumination Elevation Angle Coefficient Per Column Squared. This field provides the approximate elevation angle change per image column squared.	21	BCS-A	radians per pixel squared	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IA0	Illumination Azimuth Angle Constant. This field provides the approximate angle clockwise from true north to the primary source of scene illumination (in the local tangent plane coordinate system's horizontal ground plane) for image position (0, 0). Typically between –pi and pi or 0 and 2pi, but can exceed both ranges. Range is chosen to ensure continuity of all computed azimuth angles in an image. See Section 5.7.	21	BCS-A	radians	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IAR	Illumination Azimuth Angle Coefficient Per Row. This field provides the approximate azimuth angle change per image row.	21	BCS-A	radians per pixel	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IAC	Illumination Azimuth Angle Coefficient Per Column. This field provides the approximate azimuth angle change per image column.	21	BCS-A	radians per pixel	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IARR	Illumination Azimuth Angle Coefficient Per Row Squared. This field provides the approximate azimuth angle change per image row squared.	21	BCS-A	radians per pixel squared	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IARC	Illumination Azimuth Angle Coefficient Per Row-Column. This field provides the approximate azimuth angle change per image row-column.	21	BCS-A	radians per pixel squared	±9.99999999999999E±99 Population optional Default is all spaces	<R>
IACC	Illumination Azimuth Angle Coefficient Per Column Squared. This field provides the approximate azimuth angle change per image column squared.	21	BCS-A	radians per pixel squared	±9.99999999999999E±99 Population optional Default is all spaces	<R>

SPX	Sensor x-position. This field provides the sensor position x-coordinate value at reference time t_0.	21	BCS-A	Radians or meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99 Population optional Default is all spaces	<R>
SVX	Sensor x-velocity. This field provides the sensor velocity x-coordinate value at reference time t_0.	21	BCS-A	Radians per second or meters per second	±9.99999999999999E±99 Population optional Default is all spaces	<R>
SAX	Sensor x-acceleration. This field provides the sensor acceleration x-coordinate value at reference time t_0.	21	BCS-A	Radians per second squared or meters per second squared	±9.99999999999999E+99 Population optional Default is all spaces	<R>
SPY	Sensor y-position. This field provides the sensor position y-coordinate value at reference time t_0.	21	BCS-A	Radians or meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99 Population optional Default is all spaces	<R>
SVY	Sensor y-velocity. This field provides the sensor velocity y-coordinate value at reference time t_0.	21	BCS-A	Radians per second or meters per second	±9.99999999999999E±99 Population optional Default is all spaces	<R>

SAY	Sensor y-acceleration. This field provides the sensor acceleration y-coordinate value at reference time t_0.	21	BCS-A	Radians per second squared or meters per second squared	±9.99999999999999E±99 Population optional Default is all spaces	<R>
SPZ	Sensor z-position. This field provides the sensor position z-coordinate value at reference time t_0.	21	BCS-A	Meters	±9.99999999999999E±99 Population optional Default is all spaces	<R>
SVZ	Sensor z-velocity. This field provides the sensor velocity z-coordinate value at reference time t_0.	21	BCS-A	Meters per second	±9.99999999999999E±99 Population optional Default is all spaces	<R>
SAZ	Sensor z-acceleration. This field provides the sensor acceleration z-coordinate value at reference time t_0.	21	BCS-A	Meters per second squared	±9.99999999999999E±99 Population optional Default is all spaces	<R>

Table 2. RSMIDA TRE Format Table

6 RSM POLYNOMIAL IDENTIFICATION (RSMPI) TRE

6.1 OVERVIEW

The Replacement Sensor Model Polynomial Identification TRE (RSMPI) associates a RSM (rational) polynomial ground-to-image function with an image. The TRE gives general information regarding the polynomial geometric image / ground relationship. In particular, it identifies which image section is applicable to an arbitrary ground point. The RSM image domain may consist of a single section or it may be divided into at most 256 sections. Each section has its own unique (rational) polynomial ground-to-image function, defined in its own RSM polynomial coefficient TRE (RSMPC). Most images require only one section.

6.2 LOW ORDER POLYNOMIAL

A low order numerator-only polynomial provided in this TRE (RSMPI) is used to generate coarse image row (r) and column (c) coordinates from given ground coordinates. This quadratic model is applied to an arbitrary ground position $X = [x \quad y \quad z]^T$ within the RSM ground domain as follows:

$$r = R0 + RX \cdot x + RY \cdot y + RZ \cdot z + RXX \cdot x^2 + RXY \cdot xy + RXZ \cdot xz + RYY \cdot y^2 + RYZ \cdot yz + RZZ \cdot z^2$$
$$c = C0 + CX \cdot x + CY \cdot y + CZ \cdot z + CXX \cdot x^2 + CXY \cdot xy + CXZ \cdot xz + CYY \cdot y^2 + CYZ \cdot yz + CZZ \cdot z^2$$

6.3 SECTIONING

The resultant image coordinates are within the RSM image domain for the associated image and are relative to the original full image. There are a specifiable number of evenly spaced, rectangular sections in the RSM image domain. The field RNIS specifies the number of sections in the row direction, the field CNIS specifies the number of sections in the column direction. The field RSSIZ specifies the number of rows per section, and the field CSSIZ specifies the number of columns per section. An arbitrary section is defined by the row section number (RSN) and column section number (CSN) that it corresponds to. The fields RSN and CSN are contained in the RSMPC TREs. The RSM image domain is defined by the fields MINR, MAXR, MINC, and MAXC that are provided in the RSMID TRE. (See Figure 6.)

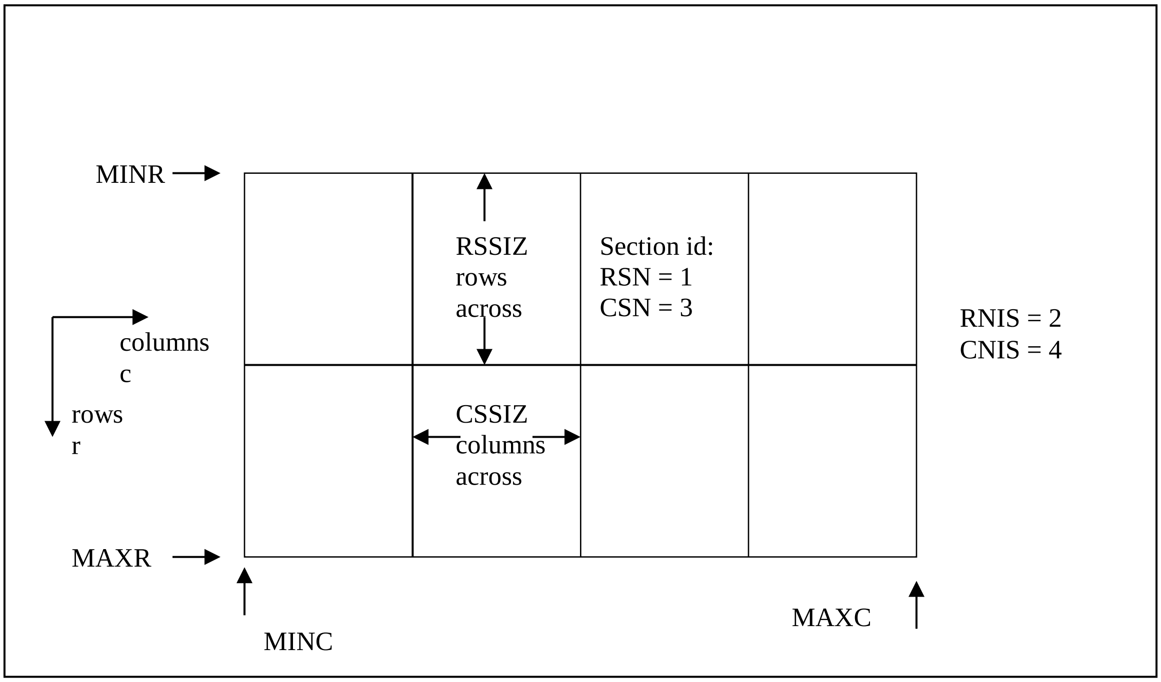

Figure 6: Sectioning of the RSM Image Domain for Polynomials

The following determines the row and column section numbers for an arbitrary row and column value output from the above quadratic model. (The first row section is numbered 1, and the first column section is numbered 1.) Thus, it determines which section is applicable to an arbitrary ground point within the RSM ground domain:

$$RSN = \left\lfloor \frac{r - MINR}{RSSIZ} \right\rfloor + 1$$

$$CSN = \left\lfloor \frac{c - MINC}{CSSIZ} \right\rfloor + 1$$

The symbol $\lfloor\ \rfloor$ indicates integer floor. If either RSN or CSN is less than 1, set it to 1. If RSN is greater than $RNIS$, set $RSN = RNIS$. If CSN is greater than $CNIS$, set $CNS = CNIS$.

Note that, although the RSM ground-to-image function may consist of multiple polynomials corresponding to multiple sections within the RSM image domain, the RSM adjustable parameters (see the RSMAP TRE format description) are with respect to the overall RSM ground-to-image function and the entire RSM image domain, i.e., there are not multiple sets of RSM adjustable parameters corresponding to multiple sections within the RSM image domain.

If there are multiple sections, this TRE (RSMPI) is always provided with the associated image. If there is only one section, the inclusion of this TRE is optional.

6.4 RSMPIA FORMAT

Table 3 specifies the detailed format for the Replacement Sensor Model Polynomial Identification version A (RSMPIA) TRE.

RSMPIA – Replacement Sensor Model Polynomial Identification						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMPIA	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	Bytes	591	R
Image Information						
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R
R0	Low Order Polynomial Constant Coefficient for Row. This field provides the constant term used in the approximate image row position low order polynomial.	21	BCS-A	pixels	±9.99999999999999E±99	R
RX	Low Order Polynomial Coefficient of X for Row. This field provides the coefficient of *x* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *x* units (radians or meters)	±9.99999999999999E±99	R
RY	Low Order Polynomial Coefficient of Y for Row. This field provides the coefficient of *y* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *y* units (radians or meters)	±9.99999999999999E±99	R

RZ	Low Order Polynomial Coefficient of Z for Row. This field provides the coefficient of *z* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *z* units (meters)	±9.99999999999999E±99	R
RXX	Low Order Polynomial Coefficient of XX for Row. This field provides the coefficient of *xx* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *xx* units (radians squared or meters squared)	±9.99999999999999E±99	R
RXY	Low Order Polynomial Coefficient of XY for Row. This field provides the coefficient of *xy* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *xy* units (radians squared or meters squared)	±9.99999999999999E±99	R
RXZ	Low Order Polynomial Coefficient of XZ for Row. This field provides the coefficient of *xz* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *xz* units ((radians)(meters) or meters squared)	±9.99999999999999E±99	R
RYY	Low Order Polynomial Coefficient of YY for Row. This field provides the coefficient of *yy* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *yy* units (radians squared or meters squared)	±9.99999999999999E±99	R
RYZ	Low Order Polynomial Coefficient of YZ for Row. This field provides the coefficient of *yz* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *yz* units ((radians)(meters) or meters squared)	±9.99999999999999E±99	R
RZZ	Low Order Polynomial Coefficient of ZZ for Row. This field provides the coefficient of *zz* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *zz* units (meters squared)	±9.99999999999999E±99	R
C0	Low Order Polynomial Constant Coefficient for Column. This field provides the constant term used in the approximate image column position low order polynomial.	21	BCS-A	pixels	±9.99999999999999E±99	R
CX	Low Order Polynomial Coefficient of X for Column. This field provides the coefficient of *x* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *x* units (radians or meters)	±9.99999999999999E±99	R
CY	Low Order Polynomial Coefficient of Y for Column. This field provides the coefficient of *y* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *y* units (radians or meters)	±9.99999999999999E±99	R
CZ	Low Order Polynomial Coefficient of Z for Column. This field provides the coefficient of *z* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *z* units (meters)	±9.99999999999999E±99	R

CXX	Low Order Polynomial Coefficient of XX for Column. This field provides the coefficient of *xx* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *xx* units (radians squared or meters squared)	±9.99999999999999E±99	R
CXY	Low Order Polynomial Coefficient of XY for Column. This field provides the coefficient of *xy* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *xy* units (radians squared or meters squared)	±9.99999999999999E±99	R
CXZ	Low Order Polynomial Coefficient of XZ for Column. This field provides the coefficient of *xz* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *xz* units ((radians)(meters) or meters squared)	±9.99999999999999E±99	R
CYY	Low Order Polynomial Coefficient of YY for Column. This field provides the coefficient of *yy* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *yy* units (radians squared or meters squared)	±9.99999999999999E±99	R
CYZ	Low Order Polynomial Coefficient of YZ for Column. This field provides the coefficient of *yz* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *yz* units ((radians)(meters) or meters squared)	±9.99999999999999E±99	R
CZZ	Low Order Polynomial Coefficient of ZZ for Column. This field provides the coefficient of *zz* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *zz* units (meters squared)	±9.99999999999999E±99	R
RNIS	Row Number of Image Sections. This field identifies the number of sections the RSM image domain is divided into along the row direction for representation of the ground-to-image relationship.	3	BCS-N	N/A	001 to 256	R
CNIS	Column Number of Image Sections. This field identifies the number of sections the RSM image domain is divided into along the column direction for representation of the ground-to-image relationship.	3	BCS-N	N/A	001 to 256	R
TNIS	Total Number of Image Sections. This field contains the total number of rectangular sections the RSM image domain is divided into for representation of the ground-to-image relationship. The value in this field is the product of the values in the RNIS and CNIS fields. Thus, the value of the field TNIS, with a maximum of 256, places constraints on the values of the fields RNIS and CNIS. This number represents the total number of RSMPC TREs.	3	BCS-N	N/A	001 to 256	R

RSSIZ	Section Size in Rows. This field contains the number of rows contained in a single section. Note that its value is represented as a positive non-integer because it equals the number of rows in the RSM image domain divided by the number of sections in the row direction, not necessarily an integer value.	21	BCS-A	pixels	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	R
CSSIZ	Section Size in Columns. This field contains the number of columns contained in a single section. Note that its value is represented as a positive non-integer. Note that its value is represented as a positive non-integer because it equals the number of columns in the RSM image domain divided by the number of sections in the column direction, not necessarily an integer value.	21	BCS-A	pixels	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	R

Table 3: RSMPIA TRE Format Table

7 RSM POLYNOMIAL COEFFICIENTS (RSMPC) TRE

7.1 OVERVIEW

The Replacement Sensor Model Polynomial Coefficients TRE (RSMPC) contains the polynomial coefficients and related data needed to define a RSM (rational) polynomial ground-to-image function. The polynomial takes a ground position within the RSM ground domain into a corresponding image position within the RSM image domain. In particular, within a specific section in the RSM image domain, as specified by the fields RSN and CSN. The coordinates of the polynomial's image position output are with respect to the original full image.

7.2 POLYNOMIALS

This TRE contains a ground-to-image rational polynomial for the image row coordinate. It consists of a numerator polynomial divided by a denominator polynomial. This TRE also contains a ground-to-image rational polynomial for the image column coordinate. It consists of a numerator polynomial divided by a denominator polynomial. Thus, this TRE contains a total of four polynomials. Coefficients for each polynomial are in order from smallest to largest power first among x, then y, and then among z.

For example, the rational polynomial for the image row coordinate (r) is represented as follows:

$$r = \frac{\sum_{k=0}^{umz}\sum_{j=0}^{umy}\sum_{i=0}^{umx} a_{ijk} x^i y^j z^k}{\sum_{k=0}^{unz}\sum_{j=0}^{uny}\sum_{i=0}^{unx} b_{ijk} x^i y^j z^k}.$$

The coefficients for the numerator polynomial are the a_{ijk} (field RNPCF), and the coefficients for the denominator polynomial are the b_{ijk} (field RDPCF). The maximum powers for the numerator polynomial (umx, umy, umz) correspond to fields RNPWRX, RNPWRY, and RNPWRZ. The maximum powers for the denominator polynomial (unx, uny, unz) correspond to fields RDPWRX, RDPWRY, RDPWRZ.

An offset and scale factor are provided in this TRE for each ground coordinate, the image row coordinate, and the image column coordinate (a total of five offsets and five scale factors). For a given coordinate, a, the corresponding offset and scale factor define the relationship between un-normalized and normalized coordinates as follows:

$$a_{normalized} = \frac{a - offset}{scalefactor}$$

where the above coordinate a is generic and represents any of the ground or image coordinates.

A rational polynomial's independent variables (x, y, z) are with respect to normalized ground coordinates, and its dependent variables (r, c) are with respect to normalized image coordinates. Thus, an arbitrary ground point's coordinates must first be normalized prior to rational polynomial evaluation. Following evaluation, the corresponding normalized image coordinates must then be un-normalized. As a reminder, all un-normalized image coordinates are with respect to the original full image.

Note that the offset and scale factor values are unique to the specific RSMPC TRE (image section within the RSM image domain). Their values are such that a normalized coordinate is within the approximate range of values $[-1, 1]$.

7.3 TRE SIZE AND NUMBER OF TRES

As detailed in the description for field CEL, the size of one RSMPCA TRE can be up to 18546 bytes (though it is typically 5778 bytes). However, if multiple RSMPCA TREs are required, corresponding to multiple image sections as specified in the RSMPI TRE, their total number of bytes may approach or exceed 200,000 bytes, requiring their (and possibly other RSM TREs') placement into the overflow area for the image.

7.4 RSMPCA FORMAT

Table 4 specifies the detailed format for the Replacement Sensor Model Polynomial Coefficients version A (RSMPCA) TRE.

RSMPCA – Replacement Sensor Model Polynomial Coefficients						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMPCA	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	bytes	486 to 18546 Typical value equals 5778, corresponding to a third-order rational polynomial	R
Image Information						

IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R
RSN	Row Section Number. This field contains the image row section number that the following polynomial coefficients apply to.	3	BCS-N	N/A	001 to 256	R
CSN	Column Section Number. This field contains the image column section number that the following polynomial coefficients apply to.	3	BCS-N	N/A	001 to 256	R
RFEP	Row Fitting Error. This field contains the rms fit error estimate applicable to the row rational polynomial relative to the original sensor model's ground-to-image function. The value of RFEP assumes that an RSM ground-to-image (correction) grid is not employed, if available. The value of RFEP is non-negative.	21	BCS-A	pixels	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative valuePopulation optional Default is all spaces	<R>
CFEP	Column Fitting Error. This field contains the rms fit error estimate applicable to the column rational polynomial relative to the original sensor model's ground-to-image function. The value of CFEP assumes that an RSM ground-to-image (correction) grid is not employed, if available. The value of CFEP is non-negative.	21	BCS-A	pixels	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative valuePopulation optional Default is all spaces	<R>
RNRMO	Row Normalization Offset. This field contains the offset used in the defining relationship between un-normalized and normalized image row coordinates r for the ground-to-image rational polynomial.	21	BCS-A	Pixels	±9.99999999999999E±99	R
CNRMO	Column Normalization Offset. This field contains the offset used in the defining relationship between un-normalized and normalized image column coordinates c for the ground-to-image rational polynomial.	21	BCS-A	Pixels	±9.99999999999999E±99	R

XNRMO	X Normalization Offset. This field contains the offset used in the defining relationship between un-normalized and normalized ground coordinates x for the ground-to-image rational polynomial.	21	BCS-A	Radians or meters	±9.99999999999999E±99	R
YNRMO	Y Normalization Offset. This field contains the offset used in the defining relationship between un-normalized and normalized ground coordinates y for the ground-to-image rational polynomial.	21	BCS-A	Radians or meters	±9.99999999999999E±99	R
ZNRMO	Z Normalization Offset. This field contains the offset used in the defining relationship between un-normalized and normalized ground coordinates z for the ground-to-image rational polynomial.	21	BCS-A	Meters	±9.99999999999999E±99	R
RNRMSF	Row Normalization Scale Factor. This field contains the scale factor used in the defining relationship between un-normalized and normalized image row coordinates r for the ground-to-image rational polynomial	21	BCS-A	Pixels	±9.99999999999999E±99, except for zero Must be non-zero value	R
CNRMSF	Column Normalization Scale Factor. This field contains the scale factor used in the defining relationship between un-normalized and normalized image column coordinates c for the ground-to-image rational polynomial	21	BCS-A	Pixels	±9.99999999999999E±99, except for zero Must be non-zero value	R
XNRMSF	X Normalization Scale Factor. This field contains the scale factor used in the defining relationship between un-normalized and normalized ground coordinates x for the ground-to-image rational polynomial.	21	BCS-A	Radians or meters	±9.99999999999999E±99, except for zero Must be non-zero value	R
YNRMSF	Y Normalization Scale Factor. This field contains the scale factor used in the defining relationship between un-normalized and normalized ground coordinates y for the ground-to-image rational polynomial	21	BCS-A	Radians or meters	±9.99999999999999E±99, except for zero Must be non-zero value	R
ZNRMSF	Z Normalization Scale Factor. This field contains the scale factor used in the defining relationship between un-normalized and normalized ground coordinates z for the ground-to-image rational polynomial	21	BCS-A	Meters	±9.99999999999999E±99, except for zero Must be non-zero value	R
RNPWRX	Row Numerator Polynomial Maximum Power of X. This field contains the maximum power of normalized x coordinate used in the image section's row numerator polynomial.	1	BCS-N	N/A	0 to 5	R
RNPWRY	Row Numerator Polynomial Maximum Power of Y. This field contains the maximum power of normalized y coordinate used in the image section's row numerator polynomial.	1	BCS-N	N/A	0 to 5	R
RNPWRZ	Row Numerator Polynomial Maximum Power of Z. This field contains the maximum power of normalized z coordinate used in the image section's row numerator polynomial.	1	BCS-N	N/A	0 to 5	R

RNTRMS	Row Numerator Polynomial Number of Polynomial Terms. This field contains the number of terms (coefficients) in the image section's row numerator polynomial. The value of this field is the same as: $(RNPWRX + 1) * (RNPWRY + 1) * (RNPWRZ + 1)$.	3	BCS-N	N/A	001 to 216	R
…Begin for each row numerator polynomial term (RNTRMS entries)						
RNPCF	Polynomial Coefficient. This field contains one coefficient of the image section's row numerator polynomial. The $(RNPWRX + 1)*(RNPWRY + 1)*(RNPWRZ + 1)$ total number of field entries are ordered in concert with the following polynomial form (or summation order): $\sum_{k=0}^{RNPWRZ}\sum_{j=0}^{RNPWRY}\sum_{i=0}^{RNPWRX} a_{ijk}x^i y^j z^k$ where x is the normalized x ground coordinate, y is the normalized y ground coordinate, and z is the normalized z ground coordinate. The first RNPCF field entry corresponds to a_{000}, the second to a_{100}, and so on.	21	BCS-A	N/A	±9.99999999999999E±99	R
…End for each row numerator polynomial term						
RDPWRX	Row Denominator Polynomial Maximum Power of X. This field contains the maximum power of normalized x coordinate used in the image section's row denominator polynomial.	1	BCS-N	N/A	0 to 5	R
RDPWRY	Row Denominator Polynomial Maximum Power of Y. This field contains the maximum power of normalized y coordinate used in the image section's row denominator polynomial.	1	BCS-N	N/A	0 to 5	R
RDPWRZ	Row Denominator Polynomial Maximum Power of Z. This field contains the maximum power of normalized z coordinate used in the image section's row denominator polynomial.	1	BCS-N	N/A	0 to 5	R
RDTRMS	Row Denominator Polynomial Number of Polynomial Terms. This field contains the number of terms (coefficients) in the image section's row denominator polynomial. The value of this field should be the same as $(RDPWRX + 1) * (RDPWRY + 1) * (RDPWRZ + 1)$.	3	BCS-N	N/A	001 to 216	R
…Begin for each row denominator polynomial term (RDTRMS entries)						

RDPCF	Polynomial Coefficient. This field contains one coefficient of the image section's row denominator polynomial. The $(RDPWRX + 1)*(RDPWRY + 1)*(RDPWRZ + 1)$. total number of field entries are ordered in concert with the following polynomial form (or summation order): $\sum_{k=0}^{RDPWRZ}\sum_{j=0}^{RDPWRY}\sum_{i=0}^{RDPWRX} b_{ijk}x^i y^j z^k$ where x is the normalized x ground coordinate, y is the normalized y ground coordinate, and z is the normalized z ground coordinate. The first RDPCF field entry corresponds to b_{000}, the second to b_{100}, and so on.	21	BCS-A	N/A	±9.99999999999999E±99	R
…End for each row denominator polynomial term						
CNPWRX	Column Numerator Polynomial Maximum Power of X. This field contains the maximum power of normalized x coordinate used in the image section's column numerator polynomial.	1	BCS-N	N/A	0 to 5	R
CNPWRY	Column Numerator Polynomial Maximum Power of Y. This field contains the maximum power of normalized y coordinate used in the image section's column numerator polynomial.	1	BCS-N	N/A	0 to 5	R
CNPWRZ	Column Numerator Polynomial Maximum Power of Z. This field contains the maximum power of normalized z coordinate used in the image section's column numerator polynomial.	1	BCS-N	N/A	0 to 5	R
CNTRMS	Column Numerator Polynomial Number of Polynomial Terms. This field contains the number of terms (coefficients) in the image section's column numerator polynomial. The value of this field should be the same as $(CNPWRX + 1) * (CNPWRY + 1) * (CNPWRZ + 1)$.	3	BCS-N	N/A	001 to 216	R
…Begin for each column numerator polynomial term (CNTRMS entries)						

CNPCF	Polynomial Coefficient. This field contains one coefficient of the image section's column numerator polynomial. The $(CNPWRX + 1)*(CNPWRY + 1)*(CNPWRZ + 1)$ total number of field entries are ordered in concert with the following polynomial form (or summation order): $$\sum_{k=0}^{CNPWRZ}\sum_{j=0}^{CNPWRY}\sum_{i=0}^{CNPWRX} c_{ijk} x^i y^j z^k$$ where x is the normalized x ground coordinate, y is the normalized y ground coordinate, and z is the normalized z ground coordinate. The first CNPCF field entry corresponds to c_{000}, the second to c_{100}, and so on.	21	BCS-A	N/A	±9.99999999999999E±99	R
…End for each column numerator polynomial term						
CDPWRX	Column Denominator Polynomial Maximum Power of X. This field contains the maximum power of normalized x coordinate used in the image section's column denominator polynomial.	1	BCS-N	N/A	0 to 5	R
CDPWRY	Column Denominator Polynomial Maximum Power of Y. This field contains the maximum power of normalized y coordinate used in the image section's column denominator polynomial.	1	BCS-N	N/A	0 to 5	R
CDPWRZ	Column Denominator Polynomial Maximum Power of Z. This field contains the maximum power of normalized z coordinate used in the image section's column denominator polynomial.	1	BCS-N	N/A	0 to 5	R
CDTRMS	Column Denominator Polynomial Number of Polynomial Terms. This field contains the number of terms (coefficients) in the image section's column denominator polynomial. The value of this field should be the same as $(CDPWRX + 1) * (CDPWRY + 1) * (CDPWRZ + 1)$.	3	BCS-N	N/A	001 to 216	R
…Begin for each column denominator polynomial term (CDTRMS entries)						

CDPCF	Polynomial Coefficient. This field contains one coefficient of the image section's column denominator polynomial. The ($CDPWRX$ + 1)∗($CDPWRY$ + 1)∗($CDPWRZ$ + 1) total number of field entries are ordered in concert with the following polynomial form (or summation order): $$\sum_{k=0}^{CDPWRZ}\sum_{j=0}^{CDPWRY}\sum_{i=0}^{CDPWRX} d_{ijk}x^i y^j z^k$$ where x is the normalized x ground coordinate, y is the normalized y ground coordinate, and z is the normalized z ground coordinate. The first CDPCF field entry corresponds to d_{000}, the second to d_{100}, and so on.	21	BCS-A	N/A	±9.99999999999999E±99	R
…End for each column denominator polynomial term						

Table 4: RSMPCA TRE Format Table

8 RSM DIRECT ERROR COVARIANCE (RSMDCA) TRE

8.1 OVERVIEW

The Replacement Sensor Model Direct Error Covariance version A TRE (RSMDCA) provides RSM direct error covariance. RSM direct error covariance is applicable to all of the active RSM adjustable parameters corresponding to multiple (typically correlated) images. The original full image IDs (field IIDI) and number of active RSM adjustable parameters per image (field NPARI) that correspond to each of these images are provided in this TRE. (All the images have different original full image IDs.) The number of images referenced can be one, i.e., just the associated image. If multiple images are applicable, they always include the associated image. Note that in general, the RSM direct error covariance provides a statistical description of image support data error.

Also included in this TRE are the identities of the specific RSM adjustable parameters that are active for the associated image. There are 36 contiguous fields (IRO through GZZ) corresponding to each potential adjustable parameter. This set of parameters is defined as the RSM Adjustable Parameter Choice Set. The first 20 contiguous fields (IRO through ICZZ) correspond to RSM image-space adjustable parameters and the remaining 16 contiguous fields (GXO through GZZ) correspond to RSM ground-space adjustable parameters. If a field value is all spaces, the adjustable parameter is inactive, i.e., its error is not relevant and not referenced by the direct error covariance. If it is not all spaces, its value is the index into the associated image's error covariance for the adjustable parameter. (Both the row and column dimensions of the associated image's error covariance equal the total number of active adjustable parameters for this image.) For example, an index value of 3 specifies that both the third row and third column of the associated image's error covariance reference the error in the value of this adjustable parameter. The adjustable parameter's value, used to actually modify the RSM ground-to-image function, is specified in the RSMAPA TRE. Note: If the RSMAPA TRE is not present, the value is assumed to equal zero.

Note that most sensors require between 5 to 12 active RSM adjustable parameters for an image, either all image-space or all ground-space adjustable parameters. Space-borne sensors typically utilize image-space adjustable parameters.

8.2 DIRECT ERROR COVARIANCE FORM

The direct error covariance contains the associated image's error covariance as well as the other images' error covariance and the error cross-covariance between all image pairs. Thus, for a given adjustable parameter for the associated image, its index into the direct error covariance is equal to its index into the associated image error covariance plus an offset. The offset equals the total number of active RSM adjustable parameters for the images that precede the associated image in the direct error covariance. The offset is determined by the values and order of the fields IIDI and NPARI in this TRE.

For example, assume that the direct error covariance (CR) is applicable to three correlated images. Assume that the first image has 12 active RSM adjustable parameters, and that both the second and third images have 6 active RSM adjustable parameters. Assume that the associated image is the second image. Thus, the symmetric 24×24 direct error covariance matrix (CR) contained in this TRE (the matrix elements are stored in upper triangular order in field DERCOV) has the following form:

$$CR = \begin{bmatrix} C_{R11} & C_{R12} & C_{R13} \\ . & C_{R22} & C_{R23} \\ . & . & C_{R33} \end{bmatrix} .$$

In general, C_{Rij} is the cross-covariance between the errors in image i's RSM adjustable parameters and image j's RSM adjustable parameters. Thus, for example, C_{R11} is the first image's 12×12 error covariance. C_{R22} is the second image's (associated image) 6×6 error covariance. C_{R12} is the 12×6 error cross-covariance between images 1 and 2. Also, for example, if an active adjustable parameter for the associated image has an index equal to 2, relative to the associated image error covariance (C_{R22}), it has an index equal to $12+2=14$, relative to the direct error covariance (CR).

Note that the errors in the values of the RSM adjustable parameters, statistically characterized by the direct error covariance (CR), are "image" errors. That is, the errors are assumed constant over all pixel locations within an image's RSM image domain. The values of the RSM adjustable parameters are constant over the RSM image domain as well. However, their effect on the RSM ground-to-image function varies as a function of image pixel location (actually corresponding ground location), as discussed later in this introduction. Correspondingly, the effect of RSM adjustable parameter errors on the RSM ground-to-image function's (output) error varies as a function of pixel location as well.

8.3 ADJUSTABLE PARAMETER DEFINITIONS IN SUPPORT OF THE DIRECT ERROR COVARIANCE

8.3.1 OVERVIEW

As mentioned previously, the active RSM adjustable parameters for the associated image are identified in this TRE. The associated image's error covariance is relative to the errors in the values of these adjustable parameters.

Thus, application of the associated image error covariance requires the complete definition of these adjustable parameters. In particular, their definition is required in order to compute the partial derivatives of image measurements with respect to the adjustable parameters. These partial derivatives support error propagation, and are utilized in both geopositioning and triangulation solutions. The following provides the remaining details required for their complete definition. (If the direct error covariance references other images, their RSMDCA TREs are also required in order to completely define their adjustable parameters, and hence, those portions of the direct error covariance applicable to them, i.e. both their image error covariance and their image error cross-covariance blocks.)

8.3.2 LOCAL COORDINATE SYSTEM DEFINITION

The RSM adjustable parameters for the associated image reference a secondary, rectangular coordinate system – termed the "Local coordinate system". That is, their application to adjust the RSM ground-to-image function for a given ground point, requires the representation of that ground point in the Local coordinate system. Typically, this coordinate system is a local tangent plane system centered within the RSM image domain's footprint at a nominal height above the ellipsoid and rotated to be aligned as follows: the z-axis is aligned with the imaging locus direction (line-of-sight vector for an electro-optical sensor), the x-axis is aligned with the image line ("sweep" or "scan") direction, and the y-axis completes a right-handed rectangular system. Figure 7 illustrates a typical RSM Local coordinate system. It is defined by an offset and rotation relative to the WGS 84 Rectangular coordinate system, as detailed later. If X represents the ground point in the RSM primary ground coordinate system, let $X*$ represent the ground point in the Local coordinate system. Note that the specific Local coordinate system varies from image to image.

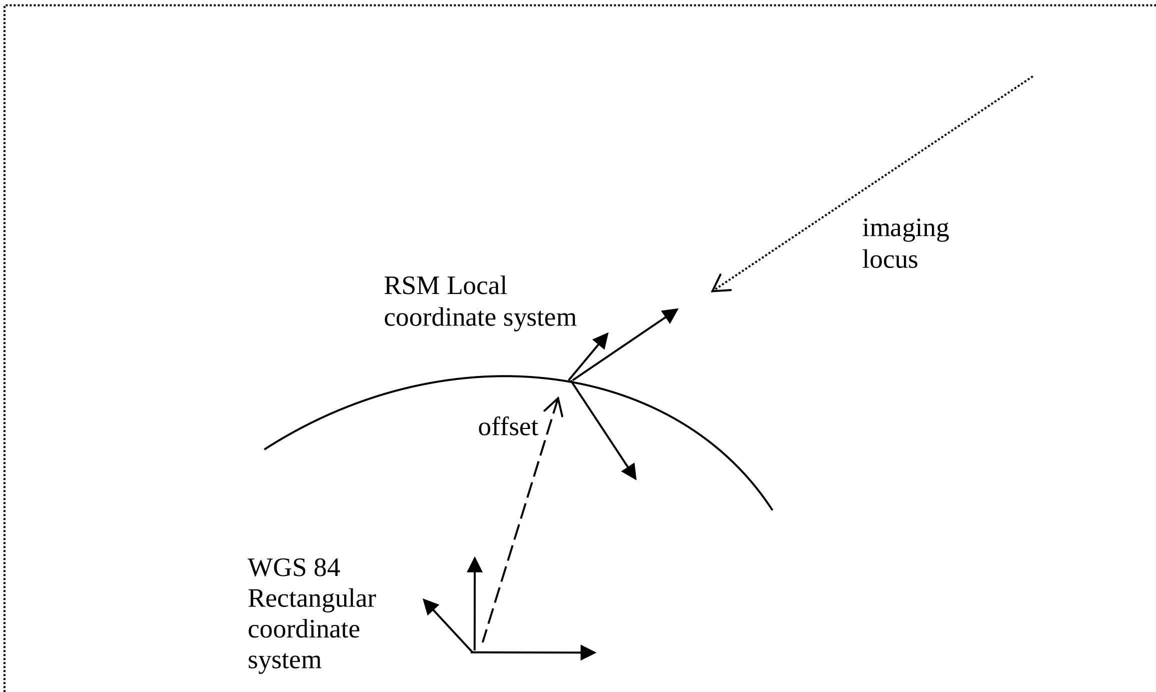

Figure 7: Example of RSM Local Coordinate System

8.3.3 EFFECT ON RSM GROUND-TO-IMAGE FUNCTION AND PARTIAL DERIVATIVES

The RSM ground-to-image function (e.g., rational polynomial) outputs a two dimensional image point $I = [r \quad c]^T$ corresponding to a three-dimensional ground point $X = [x \quad y \quad z]^T$ input. The summed effects $\Delta I = [\Delta r \quad \Delta c]^T$ of all active image-space adjustable parameters are used to modify the output of the RSM ground-to-image function (i.e., $I \rightarrow I + \Delta I$). Similarly, the summed effects $\Delta X = [\Delta x \quad \Delta y \quad \Delta z]^T$ of all active ground-space adjustable parameters are used to modify the input to the RSM ground-to-image function (i.e., $X \rightarrow X + \Delta X$) represented in the RSM primary ground coordinate system. The effect of each adjustable parameter, whether an image-space or ground-space adjustable parameter, is based on the value of the adjustable parameter and the value of the (unadjusted) ground point $X*$, as represented in the Local coordinate system. The actual relationship between an adjustable parameter's effect on either X or I (i.e., its contribution to ΔX or ΔI) is based on the value of the parameter, the value of (unadjusted) $X*$ in the Local coordinate system, and the definition of the adjustable parameter as provided in the descriptions for fields IRO through GZZ. For example, assume that the image-space adjustable parameter associated with field IRX is active and represented symbolically as δr_x. The adjustable parameter's contribution to the modification of the row coordinate of I is defined as $\Delta r = \delta r_x \cdot x$, where x is the *x*-coordinate value of the ground point $X*$, expressed in the Local coordinate system. Therefore, the partial derivative of the row image coordinate with respect to the adjustable parameter is $\partial r/\partial(\delta r_x) = x$. The following further details the RSM adjustable parameters, their detailed definitions required in order to compute the various partial derivatives.

In general, the image-space adjustable parameters that affect the image row coordinate do so as follows: $r \rightarrow r + \Delta r$, where $\Delta r = \delta r \cdot x^i \cdot y^j \cdot z^k$. δr represents the particular adjustable parameter, x, y, z are the coordinates of the ground point $X*$ as represented in the Local coordinate system, and the powers i, j, k each have a value within the set $\{0,1,2\}$ and $(i + j + k) \leq 2$. Each adjustable parameter corresponds to a unique combination of powers. The above general description is also applicable to the image-space adjustable parameters that have an effect on the image column coordinate.

In general, ground-space adjustable parameters have an effect on the three dimensional components of the ground point X summarized as follows: the ground point is transformed to a Local coordinate system representation, $X \rightarrow X*$, the adjustable parameter(s) modify the ground point in the Local coordinate system representation, $X* \rightarrow (X* + \Delta X*)$, the adjusted ground point is transformed back to an RSM primary ground coordinate system representation, $(X* + \Delta X*) \rightarrow X'$, and the result is equivalent to a modification of the original ground point, $X' \Leftrightarrow (X + \Delta X)$. Individual ground-space adjustable parameters have varied functional forms associated with their effects on the ground point. The first seven fields associated with these adjustable parameters (GXO to GS) correspond to a standard photogrammetric seven parameter (small angle) transformation of $X*$, the remaining nine fields (GXX to GZZ) correspond to coefficients of polynomial correction terms, similar in form to those for Δr discussed previously. In particular, the seven parameter adjustment is defined as follows, where X_a^* represents the adjusted ground point in the Local coordinate system, and the symbols $\{\delta x \quad \delta y \quad \delta z \quad \delta\alpha \quad \delta\beta \quad \delta\kappa \quad \delta s\}$ correspond to the contiguous fields GXO to GS:

$$X_a^* = X^* + \Delta X^* = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} 1+\delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & 1+\delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & 1+\delta s \end{bmatrix} X^*, \text{ or}$$

$$\Delta X^* = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} X^*$$

An example of a ground-space adjustable parameter's effect (contribution to ΔX^*) corresponding to field GXR, represented symbolically as $\delta\alpha$, is as follows: $\Delta y = \delta\alpha \cdot z$ and $\Delta z = -\delta\alpha \cdot y$, $y \rightarrow y + \Delta y$ and $z \rightarrow z + \Delta z$, or more generally, $X^* \rightarrow X^* + \Delta X^*$, where $\Delta X^{*T} = [0 \quad \Delta y \quad \Delta z]$. An example of the effect of the ground-space adjustable parameter corresponding to field GXY, represented as δx_y, is as follows: $\Delta x = \delta x_y \cdot y$, or more generally, $X^* \rightarrow X^* + \Delta X^*$, where $\Delta X^{*T} = [\Delta x \quad 0 \quad 0]$.

The RSM adjustable ground-to-image function $h(X,R)$ integrates the RSM ground-to-image function with the adjustments, as illustrated in Figure 8. The RSM ground-to-image function $g(X)$ can be either a rational polynomial ($poly$) or an interpolated ground point - image point correspondence grid ($grid$). Both are functions of the ground point location (X) as well as the RSM image support data, such as polynomial coefficients or grid values. (The RSMPC TRE and RSMGG TRE describe the appropriate image support data, respectively.) RSM image-space adjustable parameters are applied through one adjustment function (I_adj) and RSM ground-space adjustable parameters are applied through another (X_adj). These functions simply generate the ΔI and ΔX corrections per the definitions of the active RSM adjustable parameters. Both are functions of ground point location (X), internally converted to an X^* representation, as well as the active RSM adjustable parameters (values) R contained in the RSMAPA TRE for the associated image. Application of the RSM adjustable parameters is independent of which RSM ground-to-image function is provided in the RSM image support data.

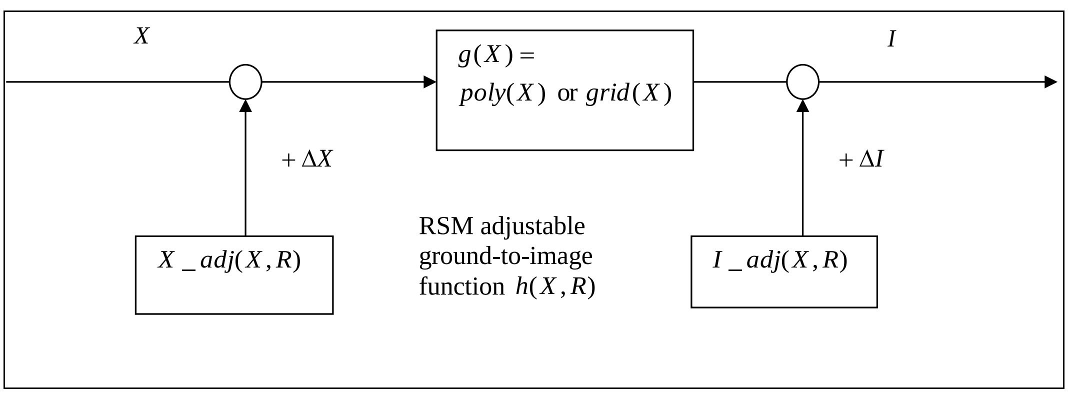

Figure 8: RSM Adjustable Ground-to-Image Function

The input X (and its correction ΔX) and output I (and its correction ΔI) of the RSM ground-to-image function are with respect to un-normalized coordinates. Evaluation of the RSM ground-to-image function is actually performed with respect to normalized coordinates. The RSM ground-to-image function handles all required normalization and un-normalization, as described in the RSMPC TRE and the RSMGG TRE.

In summary, the detailed definitions of the RSM adjustable parameters that were presented above are required in order to define the partial derivatives of the image measurement (I) with respect to the (active) adjustable parameters (R); in particular, in order to compute $\partial h / \partial R$. Assuming m adjustable parameters for the associated image, $\partial h / \partial R$ is a $2 \times m$ matrix.

8.3.4 LOCAL COORDINATE SYSTEM DETAILS

The following defines the Local coordinate system relative to the WGS 84 Rectangular coordinate system. The contiguous fields XUOL through ZUOL specify the origin (offset) of the Local coordinate system relative to the WGS 84 Rectangular coordinate system, and the contiguous fields XUXL through ZUZL the rotation. These fields are provided in this TRE.

$$X^* = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{LOCAL}} = \begin{bmatrix} XUXL & YUXL & ZUXL \\ XUYL & YUYL & ZUYL \\ XUZL & YUZL & ZUZL \end{bmatrix} \cdot \left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{WGS-84}} - \begin{bmatrix} XUOL \\ YUOL \\ ZUOL \end{bmatrix} \right).$$

Note that the definition of the Local (rectangular) coordinate system is also (redundantly) supplied in the associated image's RSMAPA TRE and RSMECA TRE, when available. Also, in order to convert a ground point X represented in the RSM primary ground coordinate system (e.g., Geodetic) to the Local coordinate system, it must first be converted from the RSM primary system to the WGS 84 Rectangular coordinate system.

8.4 COVARIANCE MATRIX ELEMENT ORDERING AND MATRIX SIZE

As mentioned previously, the values of the direct error covariance elements (field DERCOV) are provided in this TRE. Only the upper triangular portion of the error covariance is supplied. It is provided in row major order (the top row first, followed by the second row less the leftmost column, all the way to the rightmost element of the bottom row).

The direct error covariance is contained entirely in only one RSMDCA TRE. Thus, in order that it not exceed 99,999 bytes in size, the number of images it references is limited as detailed in the description of field NIMGE.

8.5 SUMMARY

The RSM direct error covariance can support a wide variety of exploitation activities. It can statistically represent unadjusted or adjusted RSM image support data errors. It can support either subsequent geopositioning or RSM triangulation. For the former, it provides the foundation for error propagation, i.e., the propagation of the support data error (covariance) to the target position error (covariance). For the later, it provides the a priori error covariance of the RSM adjustable parameters for solution (adjustment).

8.6 RSMDCA FORMAT

Table 5 specifies the detailed format for the Replacement Sensor Model Direct Error Covariance (RSMDCA) TRE.

RSMDCA – Replacement Sensor Model Direct Error Covariance						
Field	**Name/Description**	**Size**	**Form**	**Units**	**Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMDCA	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	bytes	597 to 99988	R
Image Information						
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R
TID	Triangulation ID. This field contains an identifier that is unique to the most recent process after RSM support data generation that led to the adjustments and/or error covariance in this RSM support data edition. The field value is all spaces if there has been no such process.	40	BCS-A	N/A	N/A Default is all spaces	<R>
NPAR	Number of Parameters. This field contains the number of (active) RSM adjustable parameters of the associated image. It is the row and the column dimensions of the image's error covariance.	2	BCS-N	N/A	01 to 36	R

NIMGE	Number of Images. This field contains the number of images corresponding to the RSM direct error covariance. The fields NIMGE and NPART are constrained such that (NIMGE)(82)+(0.5)(NPART+1)(NPART)(21) is less than 99495 bytes. Thus, for example, if there are 6 RSM adjustable parameters per image, there could be up to 16 images represented by the direct error covariance, i.e., NIMGE=16 and NPART=96.	3	BCS-N	N/A	001 to 999	R
NPART	Total Number of Parameters. This field contains the number of (active) RSM adjustable parameters associated with all of the images. It is both the row and column dimensions of the direct error covariance.	5	BCS-N	N/A	00001 to 35964	R
…Begin for each image (NIMGE entries)						
IIDI	Image Identifier. This field contains the original full image identification corresponding to an image associated with the RSM direct error covariance. Identifications are listed in order of their corresponding image's "placement" in the RSM direct error covariance.	80	BCS-A	N/A	N/A	R
NPARI	Number of Parameters. This field contains the number of active RSM adjustable parameters associated with the image.	2	BCS-N	N/A	01 to 36	R
…End for each image						
Local Coordinate System Definition for RSM Adjustable Parameters for image						
XUOL	Local Coordinate Origin (XUOR). This field provides the WGS 84 *X* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	R
YUOL	Local Coordinate Origin (YUOL). This field provides the WGS 84 *Y* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	R
ZUOL	Local Coordinate Origin (ZUOL). This field provides the WGS 84 *Z* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	R
XUXL	Local Coordinate Unit Vector (XUXL). This field provides the WGS 84 *X* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R

XUYL	Local Coordinate Unit Vector (XUYL). This field provides the WGS 84 *X* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
XUZL	Local Coordinate Unit Vector (XUZL). This field provides the WGS 84 *X* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUXL	Local Coordinate Unit Vector (YUXL). This field provides the WGS 84 *Y* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUYL	Local Coordinate Unit Vector (YUYL). This field provides the WGS 84 *Y* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUZL	Local Coordinate Unit Vector (YUZL). This field provides the WGS 84 *Y* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUXL	Local Coordinate Unit Vector (ZUXL). This field provides the WGS 84 *Z* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R

ZUYL	<u>Local Coordinate Unit Vector (ZUYL).</u> This field provides the WGS 84 Z component of the unit vector defining the Y-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUZL	<u>Local Coordinate Unit Vector (ZUZL).</u> This field provides the WGS 84 Z component of the unit vector defining the Z-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
RSM Adjustable Parameter-Error Covariance Correspondence						
Image-space Adjustable Parameters						
IRO	<u>Image Row Constant Index.</u> This field provides the value of the index into the associated image's error covariance for the RSM adjustable parameter: constant offset adjustment of the image row position. A value of all spaces for the field specifies that this adjustable parameter is not active (not used). For example, if the value of the field is 3, this particular adjustable parameter corresponds to row 3 and column 3 of the associated image's error covariance. In particular, the (3, 3) element of the error covariance corresponds to the adjustable parameter's variance of error. In general, the RSM direct error covariance corresponds to the RSM adjustable parameters associated with multiple images. If m images precede the associated image in the RSM direct error covariance, and if their total number of active adjustable parameters equals k, then the value of the field IRO plus k equals the index into the direct RSM error covariance for this particular adjustable parameter for the associated image. The fields IIDI and NPARI of this TRE provide the information required to determine image order and number of active adjustable parameters for all images associated with the RSM direct error covariance. The following 35 fields provide the same type of information as the IRO field, but each is associated with a different RSM adjustable parameter. All of the adjustable parameters reference Local (rectangular) ground coordinates x, y, and z. Note that the field IRO and following 19 fields are associated with RSM image-space adjustable parameters, and the next 16 fields are associated with RSM ground-space adjustable parameters. Together, they are the elements of the RSM Adjustable Parameter Choice Set.	2	BCS-A	N/A	01 to 36 All spaces if not used (adjustable parameter not active)	<R>

IRX	Image Row X Index. The image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRY	Image Row Y Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRZ	Image Row Z Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRXX	Image Row X^2 Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRXY	Image Row XY Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point xy position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRXZ	Image Row XZ Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point xz position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRYY	Image Row Y^2 Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRYZ	Image Row YZ Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point yz position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRZZ	Image Row Z^2 Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICO	Image Column Constant Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the constant offset adjustment of the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICX	Image Column X Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICY	Image Column Y Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>

ICZ	Image Column Z Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICXX	Image Column X^2 Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICXY	Image Column XY Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point xy position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICXZ	Image Column XZ Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point xz position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICYY	Image Column Y^2 Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICYZ	Image Column YZ Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point yz position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICZZ	Image Column Z^2 Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
Ground-space Adjustable Parameters						
GXO	Ground X Constant Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the constant offset adjustment of the ground x position.	2	BCS-A	N/A	01 to 36 All spaces if not used (adjustable parameter not active)	<R>
GYO	Ground Y Constant Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the constant offset adjustment of the ground y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZO	Ground Z Constant Index. The Image error covariance index associated with the following RSM Adjustable Parameter: the constant offset adjustment of the ground z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GXR	Ground Rotation X. The Image error covariance index associated with the following RSM Adjustable Parameter: the small angle ground point rotation about the x-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GYR	Ground Rotation Y. The Image error covariance index associated with the following RSM Adjustable Parameter: the small angle ground point rotation about the y-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>

GZR	Ground Rotation Z. The Image error covariance index associated with the following RSM Adjustable Parameter: the small angle ground point rotation about the *z*-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GS	Ground Scale. The Image error covariance index associated with the following RSM Adjustable Parameter: the multiplicative ground point scale factor.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GXX	Ground X Adjustment Proportional to X index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *x* position applied to the ground point *x* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GXY	Ground X Adjustment Proportional to Y index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *y* position applied to the ground point *x* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GXZ	Ground X Adjustment Proportional to Z index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *z* position applied to the ground point *x* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GYX	Ground Y Adjustment Proportional to X index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *x* position applied to the ground point *y* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GYY	Ground Y Adjustment Proportional to Y index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *y* position applied to the ground point *y* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GYZ	Ground Y Adjustment Proportional to Z index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *z* position applied to the ground point *y* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZX	Ground Z Adjustment Proportional to X index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *x* position applied to the ground point *z* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZY	Ground Z Adjustment Proportional to Y index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *y* position applied to the ground point *z* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZZ	Ground Z Adjustment Proportional to Z index. The Image error covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point *z* position applied to the ground point *z* position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>

Error Covariance Data						
…Begin for each Direct Error Covariance element (1/2(NPART+1)(NPART) entries)						
DERCOV	Direct Error Covariance Element. This field contains an element of the RSM Direct Error Covariance. The elements correspond to the upper triangular portion of the error covariance. They are in row major order.	21	BCS-A	N/A	±9.99999999999999E±99 Collectively, the DERCOV values must correspond to a positive semi-definite error covariance matrix	R
…End for each element						

Table 5: RSMDCA TRE Format Table

9 RSM DIRECT ERROR COVARIANCE (RSMDCB) TRE

9.1 OVERVIEW

RSM direct error covariance provides a statistical description of image support data error for one or more (multiple) images. It statistically references errors in the values of all active RSM adjustable parameters for these images. The Replacement Sensor Model Direct Error Covariance version B TRE (RSMDCB) provides blocks of the RSM direct error covariance applicable to the associated image.

When RSM direct error covariance is provided, the RSM TRE Set for the associated image contains at least one RSMDC TRE. This TRE contains the covariance block (sometimes termed the auto-covariance block or matrix) for the associated image and may contain cross-covariance blocks between it and other images referenced by the direct error covariance. If more cross-covariance blocks for the associated image are applicable than can be contained in one RSMDC TRE, one or more additional RSMDC TREs are included in its RSM TRE Set. These additional RSMDC TREs do not contain the covariance block. Also, a cross-covariance block is never duplicated within an RSMDC TRE or across multiple RSMDC TREs for the associated image. (See Section 9.2 for details on the RSM direct error covariance definition and form, including its constituent covariance and cross-covariance blocks.)

In order for an RSM exploiter to assemble and utilize an entire multi-image direct error covariance, it must access each image's RSM TRE Set and all RSMDC TREs contained therein.

The RSM TRE generation process insures that each relevant cross-covariance block in the RSM direct error covariance is placed in one of the RSMDC TREs contained within the collective RSM TRE Sets. In order to minimize support data bandwidth, it is recommended that RSMDC TREs be generated such that no cross-covariance block (or its matrix transpose) is duplicated across RSM TRE Sets. (Note that if the cross-covariance block for image pair i-j is not supplied and the covariance blocks i-i and j-j are supplied, then the cross-covariance block i-j is assumed identically equal to zero (uncorrelated images) by an RSM exploiter.)

The RSM TRE generation process insures a common value for field TID in all RSMDC TREs in all corresponding RSM TRE Sets. This positively identifies the RSMDC TREs as corresponding to the same RSM direct error covariance. The TID value is unique to the particular RSM direct error covariance.

The overall design approach described above allows for the specification of very large direct error covariance while still conforming to the size constraints of the RSMDC TRE. A very large direct error covariance is associated with a large number of correlated images and/or a large number of active RSM adjustable parameters. It typically corresponds to the *a posteriori* error covariance resulting from a simultaneous image support data adjustment (triangulation) involving many images.

The row dimension for each cross-covariance block contained in an RSMDCB TRE is common and specified in field NROWCB. It equals the number of active adjustable parameters for the associated image (field IID). In addition, at least one RSMDCB TRE for the associated image specifically identifies these active adjustable parameters. The column dimension for each cross-covariance block contained in an RSMDCB TRE is not necessarily common and is specified in field NCOLCB. It equals the number of active adjustable parameters for the corresponding image. This image is also identified by its original full image ID in field IIDI.

(Note that if an RSMDCB includes the identification of the active adjustable parameters for the associated image, their number is also contained in the field NPAR, i.e., NPAR=NROWCB.)

All cross-covariance blocks statistically reference errors in the values of active RSM adjustable parameters – those corresponding to the row dimension and those corresponding to the column dimension. The actual values of these adjustable parameters are zero unless specified otherwise by an RSMAPB TRE for the appropriate image.

9.2 DIRECT ERROR COVARIANCE FORM

Assume that the direct error covariance is applicable to n images, identified as images 1 through n for simplicity. The direct error covariance matrix CR has the following form:

$$CR = \begin{bmatrix} CR_{11} & CR_{12} & .. & CR_{in} \\ CR_{21} & CR_{22} & .. & .. \\ .. & .. & .. & .. \\ CR_{n1} & .. & .. & CR_{nn} \end{bmatrix}, \text{ where } CR_{ji} = CR_{ij}^{T} .$$

In general, CR_{ij} is the cross-covariance between image i and image j (cross-covariance block i-j). It is a $m_i x m_j$ matrix, where m_i is the number of active RSM adjustable parameters for image i and m_j is the number of active RSM adjustable parameters for image j. If R_i corresponds to the vector of (ordered) active RSM adjustable parameters for image i, and εR_i the corresponding errors in its value, the cross-covariance matrix CR_{ij} is formally defined as $CR_{ij} = E\{\varepsilon R_i \varepsilon R_j^T\}$. (All errors are assumed to have a mean value of zero.)

An RSMDC TRE contained in the RSM TRE Set for associated image k ($1 \le k \le n$) contains up to n CR_{kj} cross-covariance blocks, where the values of j must satisfy $1 \le j \le n$. If $j = k$, this cross-covariance block is also called the (auto) covariance block. The covariance block C_{kk} is symmetric, while all other cross-covariance blocks CR_{kj} are in general rectangular, and even if square are (internally) non-symmetric.

9.3 ADJUSTABLE PARAMETER DEFINITIONS IN SUPPORT OF THE DIRECT ERROR COVARIANCE AND ERROR PROPAGATION

9.3.1 OVERVIEW

As mentioned previously, the active RSM adjustable parameters for the associated image are identified in the RSMDC TRE. The associated image's cross-covariance blocks are relative to errors in their values. Thus, application of the associated image's cross-covariance blocks requires the complete identification and definition of these adjustable parameters.

In particular, their definition is required in order to compute the partial derivatives of image measurements with respect to the adjustable parameters. These partial derivatives support error propagation, and are utilized in both geopositioning and triangulation solutions. The following sections provide remaining details required for their complete definition. (In general, a cross-covariance block is also relative to errors in the values of adjustable parameters from the other image. The identification and definition of these active RSM adjustable parameters are also required, as discussed below.)

Error propagation associated with the entire direct error covariance requires the identification and definition of each image's active RSM adjustable parameters, supplied in that image's RSMDC TREs. If we define CR as before, and define $I^* = \begin{bmatrix} .. & I_{p_i i}^T & .. \end{bmatrix}^Y$ as a vector of two-dimensional image measurements ($I^T = \begin{bmatrix} r & c \end{bmatrix}$) corresponding to multiple measurements (p_i) made in multiple images $i = 1,..,n$, statistical propagation of support data error to image space for all images is accomplished as follows:

$$CI = (\partial I^* / \partial R^*) CR (\partial I^* / \partial R^*)^T \text{, where } R^* = \begin{bmatrix} R_1^T & .. & R_n^T \end{bmatrix}^T .$$

If $I*$ is a $s \times 1$ vector ($s = \sum_{i=1}^{n} 2p_i$) and R^* a $t \times 1$ vector ($t = \sum_{i=1}^{n} m_i$, m_i the number of active RSM parameters for image i), CR is the txt direct error covariance, $(\partial I^* / \partial R^*)$ is the $s \times t$ partial derivative matrix, and CI the $s \times s$ error covariance corresponding to errors in the image measurements I^* due to support data errors εR^*. Note that all correlation of errors between all active RSM adjustable parameters and between all images is accounted for in CR, and their corresponding effect on all image measurement errors is statistically specified (including correlations) in CI .

The RSMDC TRE defines and identifies the active RSM adjustable parameters for the associated image as defined in the following sections 9.3.2 - 9.3.4. Note that the associated identification/definition TRE fields are conditional in the RSMDC TRE and are only included when the field INCAPD is set equal to "Y". If there are multiple RSMDC TREs for the associated image, INCAPD must equal "Y" for at least one. Use of the field INCAPD allows for the reduction of image support data bandwidth when multiple RSMDC TREsare required for the associated image.

9.3.2 DEFINITIONS AND IDENTIFICATION OF ADJUSTABLE PARAMETERS

Active RSM adjustable parameters for the associated image are either active RSM image-space adjustable parameters or active RSM ground-space adjustable parameters, as specified by field APTYP in the RSMDC TRE.

RSM image-space adjustable parameters correspond to adjustable parameters that adjust an image row coordinate value (r) and an image column coordinate value (c) corresponding to an arbitrary ground point location $X = [x \quad y \quad z]^T$. An individual adjustable parameter either adjusts an image row coordinate value or an image column coordinate value. The adjustments Δr and Δc corresponding to adjustable parameters ap_{rijk} and ap_{cijk} are computed as follows:

$$\Delta r = ap_{rijk} x^i y^j z^k$$

$$\Delta c = ap_{cijk} x^i y^j z^k$$

The adjustable parameters (ap_{rijk} and ap_{cijk}) are uniquely identified by their collective x, y, z powers (exponents) and whether they adjust image row or image column coordinates. The coordinates x, y, and z correspond to normalized ground point coordinates expressed in a Local coordinate system. Normalization is performed by an offset and scale factor for each coordinate. These normalization parameters are in contiguous fields (NSFX-NOFFZ), and allow for an approximate range of (-1,1) for each ground coordinate value. An example of their application for normalization of the y coordinate is as follows:

$$y \rightarrow (y - offset_y) / scale_y \, .$$

Because the ground coordinates are normalized, all image-space adjustable parameters have units of pixels, as do the corrections Δr and Δc. Normalization of the Local coordinates helps to insure overall stability since the value of $x^i y^j z^k$ that multiplies an adjustable parameter during an image row or column adjustment can become extremely large if coordinates are not normalized for large images and large exponents.

There are two possible choices for the Local coordinate system, either Local Rectangular or Local Non-Rectangular, as specified in field LOCTYP. For Local Non-Rectangular, x, y, and z correspond to the ground point's corresponding image row coordinate, image column coordinate, and geodetic height, respectively. The Local Rectangular coordinate system is defined as a rectangular system that is offset and rotated relative to the WGS-84 coordinate system. It is typically specified as a local tangent plane system centered within the RSM image domain's footprint at a nominal height above the ellipsoid and rotated to be aligned as follows: the z-axis is aligned with the imaging locus direction (line-of-sight vector for an electro-optical sensor), the x-axis is aligned with the image line ("sweep" or "scan") direction, and the y-axis completes a right-handed rectangular system. (When the Local Rectangular coordinate system is footprint centered, corresponding Local Rectangular coordinate normalization offsets, such as $offset_y$, typically have a value of zero.)

Figure 9 illustrates a typical Local Rectangular coordinate system. Specification of a Local Rectangular coordinate system is unique to the associated image and based on contiguous fields (XUOL-ZUZL) as detailed later in this introduction.

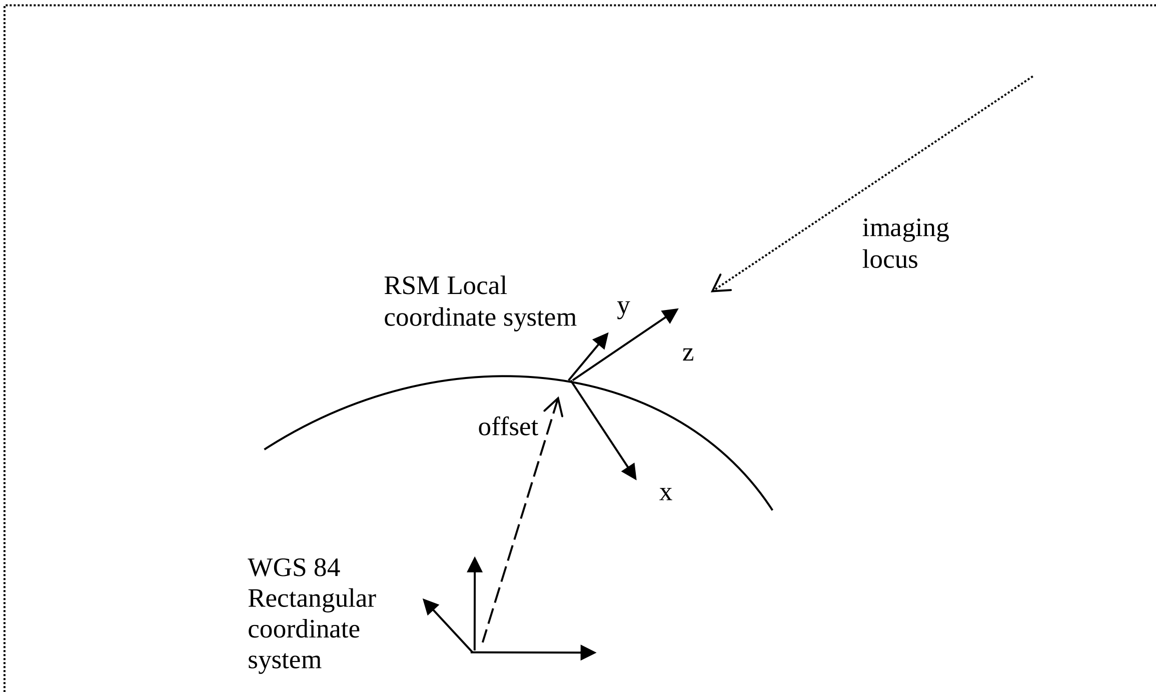

Figure 9: Example of RSM Local Rectangular Coordinate System

Note that the choice of Local Rectangular or Local Non-rectangular is provided for flexibility. The Local Rectangular coordinate system inherits general analytic advantages associated with rectangular (orthonormal) coordinates, and its absolute orientation is insensitive to any abrupt changes in imaging geometry across the imaging time interval. The Local Non-Rectangular coordinate system may provide advantages when very long images are (smoothly) scanned due to significant changes in instantaneous image geometry from one end of the image to the other. The coordinate system is continuously in alignment with these changes.

RSM ground-space adjustable parameters reference normalized Local Rectangular coordinates only. The coordinate system is typically specified as a local tangent plane system centered within the RSM image domain's footprint at a nominal height above the ellipsoid (z-axis vertical). An individual ground-space adjustable parameter is either a parameter associated with a "seven parameter" adjustment or a "rate" adjustment. The seven parameter adjustment is defined as follows, where the symbols $\{\delta x \quad \delta y \quad \delta z \quad \delta\alpha \quad \delta\beta \quad \delta\kappa \quad \delta s\}$ correspond to the adjustable parameters:

$$\begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

The vector on the left side of the above equation corresponds to adjustments in the un-normalized coordinates of the ground point expressed in Local Rectangular coordinates with units of meters. The vector on the far right side of the equation corresponds to normalized coordinates of the ground point expressed in Local Rectangular coordinates. Because these coordinates are unit-less, the adjustable parameters all have units of meters, as do the corrections $\Delta x, \Delta y, \Delta z$.

(If Local coordinate scale factors ($scale_x, scale_y, scale_z$) are set equal in value by the TRE generation process, Local coordinate values no longer necessarily range from -1.0 to 1.0. However, the above seven parameter adjustment is now equivalent to the standard photogrammetric seven parameter (small angle) transformation. It is recommended that the scale factors be set equal to a common value in a manner that yields ranges for the three local coordinates as close as possible to the interval -1.0 to 1.0.)

There are nine possible ground-space adjustable parameters corresponding to rate adjustments and denoted by the symbols $\{ap_{xx}, ap_{xy}, .., ap_{zz}\}$. They adjust the un-normalized coordinates of the ground point in Local Rectangular coordinates specifically as follows:

$$\Delta x = ap_{xx} x \text{ , } \Delta x = ap_{xy} y \text{ , } \Delta x = ap_{xz} z \text{ ,}$$

$$\Delta y = ap_{yx} x \text{ , } \Delta y = ap_{yy} y \text{ , } \Delta y = ap_{yz} z \text{ ,}$$

$$\Delta z = ap_{zx} x \text{ , } \Delta z = ap_{zy} y \text{ , } \Delta z = ap_{zz} z \text{ .}$$

Again, these adjustable parameters and the corrections have units of meters.

Each of the 16 possible ground-space adjustable parameters is identified by a unique four character identifier detailed in the TRE's specified format (Table 6).

Note that application of RSM adjustable parameters, whether image-space or ground-space adjustable parameters, first requires converting the corresponding ground point from representation in the RSM primary ground coordinate system to the appropriate Local system. And for the case of ground-space adjustable parameters, the adjusted ground point must also be converted back to the RSM primary coordinate system.

Figure 10 presents the RSM adjustable ground-to-image function $h(X,R)$, where X corresponds to the un-normalized three dimensional ground point in the RSM primary ground coordinate system. The functions $I\_adj(X,R)$ and $X\_adj(X,R)$ apply the previously documented adjustment equations for active image-space and ground-space adjustable parameters, respectively. (The functions also internally convert X from the primary system to the (normalized) Local system.)

$\Delta I = [\Delta r \quad \Delta c]^T$ denotes the summed effects at ground point location X of all active RSM image-space adjustable parameters. For example, if the active image-space adjustable parameters correspond to (combined) powers in x and y less than or equal to one: $\Delta r = ap_{r000} + ap_{r100} \cdot x + ap_{r010} \cdot y$, and $\Delta c = ap_{c000} + ap_{c100} \cdot x + ap_{c010} \cdot y$.

$\Delta X = [\Delta x \quad \Delta y \quad \Delta z]^T$ denotes the summed effects at ground point location X of all active RSM ground-space adjustable parameters.

The vector R represents the active RSM adjustable parameters in the order that they are specified in this populated TRE, e.g., vector element two corresponds to the second active adjustable parameter identified in the populated TRE (see Table 6).

Note that during RSM TRE generation, selection and subsequent specification of active RSM adjustable parameters is independent of selection and subsequent specification of the RSM ground-to-image function (polynomial and/or interpolated grid). In addition, the RSM ground-to-image function $g(X)$ is actually performed with respect to normalized coordinates. The RSM ground-to-image function handles all required normalization and un-normalization, as described in the RSMPC TRE and the RSMGG TRE.

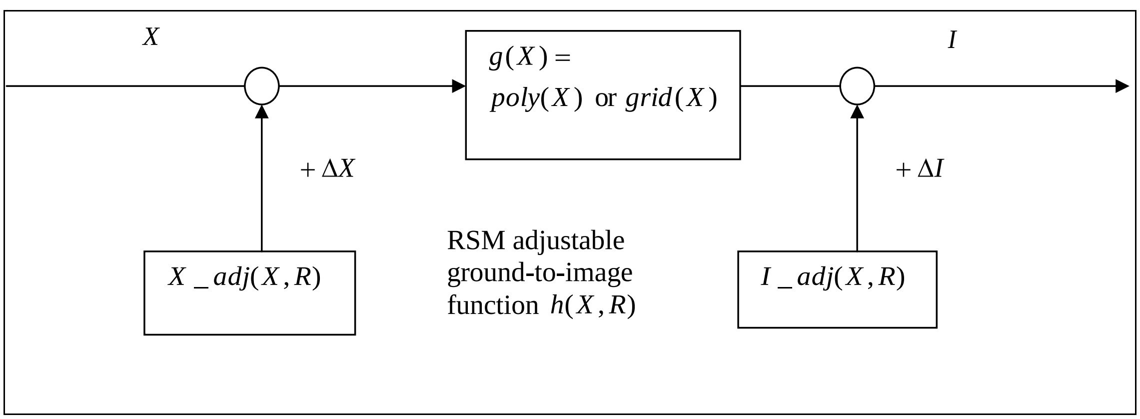

Figure 10: RSM Adjustable Ground-to-Image Function

The total number of active image-space adjustable parameters is specified in field (NISAP). Individual active adjustable parameters are identified in contiguous fields (XPWRR-ZPWRR) and contiguous fields (XPWRC-ZPWRC). The index of an active adjustable parameter into a cross-covariance block for the associated image corresponds to the order it is identified in the populated TRE.

The total number of active ground-space adjustable parameters is specified in field (NGSAP). Individual active adjustable parameters are identified in field (GSAPID). The index of an active parameter into a cross-covariance block for the associated image corresponds to the order it is identified in the populated TRE.

As mentioned earlier, active RSM adjustable parameters require definition and identification in order to support error propagation. In particular, to project the (RSM support data) image error covariance to image space via the partial derivatives of image coordinates with respect to the active adjustable parameters. These derivatives are computed for the various active adjustable parameters by taking the appropriate derivatives of the previous equations.

For example, the partial derivative of the image column coordinate with respect to an image-space adjustable parameter is computed as follows:

$$\partial c / \partial ap_{cijk} = \partial \Delta c / \partial ap_{cijk} = \partial (ap_{cijk} x^i y^j z^k) / \partial ap_{cijk} = x^i y^j z^k$$

(Recall that in the above the ground point's location (x, y, z) is represented as normalized coordinates in the Local system.)

Partial derivatives of image coordinates with respect to ground-space adjustable parameters are more involved because they adjust image coordinates indirectly. For example, the partial derivative of the image row coordinate with respect to the ground-space adjustable parameter ap_{xy} is computed as follows:

$$\partial r / \partial ap_{xy} = (\partial r / \partial X)(\partial X / \partial ap_{xy})$$

In this equation, X represents the ground point's location in the primary coordinate system, and $\partial r / \partial X$ (1×3) is readily computed from the RSM ground-to-image function for the row coordinate, i.e., $\partial r / \partial X = \partial g_r(X) / \partial X$.

The (3×1) $\partial X / \partial ap_{xy} = (\partial X / \partial X_L)(\partial X_L / \partial ap_{xy})$, where X_L represents the ground point location in the (un-normalized) Local Rectangular coordinate system. $\partial X / \partial X_L$ $(3x3)$ is readily computed from the Local Rectangular coordinate system and the primary coordinate system defining parameters. Also, from the definition of ap_{xy}, the (3×1) $\partial X_L / \partial ap_{xy} = [scale_x \cdot y \quad 0 \quad 0]^T$, where y is the second component of the ground point's location in normalized Local Rectangular coordinates.

9.3.3 BASIS OPTION

When this option is invoked (APBASE=Y), the set of RSM adjustable parameters specified in this TRE (as described previously) become a "basis" set of adjustable parameters. Symbolically, they are contained in the vector R, now assumed to have n elements. Another set of RSM adjustable parameters is defined as a linear combination of the elements of R. Symbolically, this new set is contained in the vector R', where $R' = AR$, and the matrix A is $m \times n$, $m \leq n$, with the rank of A equal to m. The vector R' has m elements (or more specifically, m_k elements for associated image k). The vector R' contains the (new) set of active adjustable parameters.

The image error covariance (and cross-covariance) contained in this TRE is now with respect to R'. The field NPAR now corresponds to the number of elements (m) in R'. The field NBASIS corresponds to the number of elements (n) in R.

Typically, the image error covariance and A are determined during generation of this TRE from an initial error covariance with respect to the basis set R using principal component analysis. R can also be written as a linear combination of R' based on the pseudo-inverse of A, designated as $A^{\#}$. Thus, $R = A^{\#}R'$, where $A^{\#} = A^T(AA^T)^{-1} = A^T$. The equality $A^{\#} = A^T$ follows because the rows of A are unit eigenvectors and members of an orthonormal basis of vectors.

Use of principal component analysis may allow for easier automatic selection of appropriate active RSM adjustable parameters during TRE generation with corresponding positive definite error covariance and a high fidelity relative to the associated image's original sensor model's adjustable parameters and support data error covariance.

For example, the entire collection of possible RSM adjustable parameters (RSM Adjustable Parameter Choice Set) contains over 200 candidates, most corresponding to possible high-order image-space adjustable parameters that reference combined powers of Local x, y, and z coordinates. A typical basis set (R) contains a much smaller subset, but still contains a "generous" number of RSM adjustable parameters, such as all image-space adjustable parameters that reference combined powers of Local x and y coordinates less than or equal to a (combined) maximum. In addition, if the Local x coordinate is aligned with the image line direction (time) for a pushbroom or "scanning" sensor, the maximum allowed power of the y coordinate may be further restricted less than a maximum allowed power for the x coordinate.

This generous set insures high fidelity of the RSM image error covariance with respect to the corresponding original sensor model image error covariance (projected to image space). However, the RSM image error covariance is either non-positive definite (non-invertible) or has an extremely large condition number, hence, nearly non-positive definite. Principal component analysis of the RSM image error covariance is then used to determine a smaller set (R') of active adjustable parameters as a linear combination of the basis set. This new set still maintains adequate fidelity, but now corresponds to a positive-definite error covariance with reasonable condition number. As an example of the number of adjustable parameters involved with this option, a space-born push-broom sensor may have a basis set (R) with 20 adjustable parameters and a final set (R') with 12 active adjustable parameters.

When the basis option is on (APBASE=Y), the RSMDCB TRE contains the identification of the elements of the basis (R), the matrix A that maps the basis (R) to the set of active adjustable parameters (R'), and the image error covariance (and cross-covariance) with respect to R' for the associated image. Corresponding exploiter functionality is invoked by specification of the appropriate partial derivatives of image coordinates with respect to R', and the update of the RSM ground-to-image function from values of R' solved for during an RSM adjustment (triangulation):

1. $\partial I / \partial R' = (\partial I / \partial R) A^T$, and
2. values of R' map to values of R via $R = A^T R'$, where the subsequent R affects the ground-to-image function.

The first of these equations supports the statistical propagation of RSM support data errors to image space, i.e., the projection of the associated image's error covariance (and cross-covariance) contained in this TRE to image space. (The computation of the partial derivatives $\partial I / \partial R$ was documented previously.) The second equation maps adjustments contained in R' to R for subsequent application in the RSM adjustable ground-to-image function for the associated image.

9.3.4 LOCAL RECTANGULAR COORDINATE SYSTEM DETAILS

The following defines the Local Rectangular coordinate system relative to the WGS 84 Rectangular coordinate system. The contiguous fields XUOL through ZUOL specify the origin (offset) of the Local coordinate system relative to the WGS 84 Rectangular coordinate system, and the contiguous fields XUXL through ZUZL elements of the rotation matrix. These fields are provided in this TRE.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{LOCAL}} = \begin{bmatrix} XUXL & YUXL & ZUXL \\ XUYL & YUYL & ZUYL \\ XUZL & YUZL & ZUZL \end{bmatrix} \cdot \left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{WGS-84}} - \begin{bmatrix} XUOL \\ YUOL \\ ZUOL \end{bmatrix} \right).$$

Note that the definition of the Local Rectangular coordinate system is also redundantly supplied in other TREs for the associated image. Also, in order to convert a ground point X represented in the RSM primary ground coordinate system (e.g., Geodetic) to the Local Rectangular coordinate system, it must first be converted from the RSM primary system to the WGS 84 Rectangular coordinate system.

9.4 CROSS-COVARIANCE MATRIX ELEMENT ORDERING AND SIZE

As mentioned previously, cross-covariance blocks (matrices) corresponding to the associated image are provided in this TRE. In particular, the values of the elements of matrices C_{kj} are supplied, where the index k corresponds to the associated image, and the index j corresponds to an image correlated with the associated image (possibly itself), where $1 \leq j \leq n$. There are a total of up to n image cross-covariance blocks. The dimension of a matrix C_{kj} is $m_k \times m_j$, where m_k is the number or active adjustable parameters for the associated image and m_j is the number of active adjustable parameters for image j. (Note that in order to simplify the TRE format, the symmetry of C_{kk} is not exploited since all the other C_{kj} are not necessarily (internally) symmetric.)

Field IID provides the identification of the associated image and field NROWCB the number of its active adjustable parameters (m_k). (The value of field NROWCB also equals the value of field NPAR, when the latter is present). Field NIMGE provides the total number of images involved, i.e., the total number of cross-covariance blocks contained in this TRE. Fields IIDI and NCOLCB provide the identification of each image and its corresponding number of active RSM adjustable parameters (m_j). The elements of a matrix C_{kj} are contained in field CRSCOV and are stored in row major order.

The size of an RSMDCB TRE cannot exceed 99,996 bytes. Therefore the number of cross-covariance blocks it may contain is limited, i.e., NROWCB*NCOLCB*(21 bytes/element), summed over all (NIMGE) images, must be less than approximately 99k bytes. Assuming 6 active RSM adjustable parameters per image, approximately 120 correlated images (cross-covariance blocks) can be accommodated in an individual RSMDCB TRE. Assuming 18 active RSM adjustable parameters per image, approximately 13 correlated images can be accommodated in an individual RSMDCB TRE.

For the 18 adjustable parameter case, let us further assume that there are a total of 15 images associated with the entire direct error covariance. Therefore, in order for an RSM exploiter to assemble the entire direct error covariance, it would require receipt of 15 RSM TRE Sets, one for each image, with each RSM TRE Set containing either one or two RSMDCB TREs.

For example: (1) the RSM TRE Set for image 1 contains two RSMDCB that collectively contain image i-j cross-covariance blocks 1-1, 1-2, ..,1-15, (2) the RSM TRE Set for image 2 contains two RSMDCB that collectively contain cross-covariance blocks 2-2, 2-3, ..,2-15, (3) the RSM TRE Set for image 3 contains one RSMDCB that contains cross-covariance blocks 3-3, 3-4, ..,3-15, (4) ... (14) the RSM TRE Set for image 14 contains one RSMDCB that contains cross-covariance blocks 14-14, 14-15, and (15) the RSM TRE Set for image 15 contains one RSMDCB that contains cross-covariance block 15-15. (Because i equals j, this block is actually a covariance (or auto-covariance) block.)

Another example that requires more RSM TRE bandwidth: (1) the RSM TRE Set for image 1 contains two RSMDCB that collectively contain image i-j cross-covariance blocks 1-1, 1-2, ..,1-15, (2) the RSM TRE Set for image 2 contains two RSMDCB that collectively contain cross-covariance blocks 2-1, 2-2, 2-3, ..,2-15, (3) ... (15) the RSM TRE Set for image 15 contains two RSMDCB that collectively contains cross-covariance blocks 15-1, 15-2, ..,15-15. Note that within the individual RSMDCB TREs contained in an image's RSM TRE Set, the cross-covariance blocks may be stored in any order. For example, the first RSMDCB for image 2 may contain (in order) cross-covariance blocks 2-2, 2-1, 2-3, .. ,2-14, and the second RSMDCB, cross-covariance block 2-15.

(The above sizing estimates assume that the definition and identification of the active RSM adjustable parameters requires little RSMDCB TRE bandwidth, as is typical, i.e., the "basis option" is not applicable or there are relatively few associated adjustable parameters , or that the definition and identification of the adjustable parameters are included (INCAPD=Y) in only one of the multiple RSMDCB TREs for the associated image. In addition, the above sizing estimates and restrictions were per TRE. There is also an approximate 1 Gbyte restriction for the sum of all TREs in an RSM TRE Set. This restriction corresponds to the allowed size of the NITF Data Extension Segment. This added restriction is not a factor since approximately 10000 RSMDCB, each approximately 100000 bytes in size, are allowed.)

9.5 SUMMARY

In summary, the RSM direct error covariance can support a wide variety of exploitation activities and is contained in (multiple) RSMDC TREs. It can statistically represent unadjusted or adjusted RSM image support data errors. It can support either subsequent geopositioning or RSM triangulation. For the former, it provides the foundation for error propagation, i.e., the propagation of the support data error (covariance) to the target position error (covariance). For the latter, it can provide either the *a priori* error covariance of the RSM adjustable parameters prior to their solution (adjustment), or their *a posteriori* error covariance after solution. Finally, use of the RSMDCB TRE allows for the representation of an arbitrarily large direct error covariance.

9.6 RSMDCB FORMAT

Table 6 specifies the detailed format for the Replacement Sensor Model Direct Error Covariance version B (RSMDCB) TRE.

RSMDCB – Replacement Sensor Model Direct Error Covariance						
Field	**Name/Description**	**Size**	**Form**	**Units**	**Estimated Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMDCB	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	bytes	00269 to 99985	R
Image Information						
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R
TID	Triangulation ID. This field contains an identifier that is unique to the most recent process after RSM support data generation that led to the adjustments and/or error covariance in this RSM support data edition.	40	BCS-A	N/A	N/A	R
Cross-covariance block information						
NROWCB	Number of rows per block. This field contains the number of rows in each cross-covariance block contained in this TRE. NROWCB is equal to the number of active adjustable parameters for the associated images, i.e., NROWCB=NPAR.	2	BCS-N	N/A	01 to 36	R
Number of images referenced by cross-covariance blocks (column dimension)						

NIMGE	Number of Images. This field contains the number of images corresponding to the cross-covariance blocks contained in this TRE. Each of these images corresponds to the column dimension of a cross-covariance block. NIMGE equals the number of cross-covariance blocks contained in this TRE.	3	BCS-N	N/A	001 to 999	R
…Begin for each image (NIMGE entries)						
IIDI	Image Identifier. This field contains the original full image identification corresponding to an image associated with the columns of a cross-covariance block contained in this TRE. Identifications are listed in the order their corresponding cross-covariance block are stored (see field CRSCOV)	80	BCS-A	N/A	N/A	R
NCOLCB	Number of columns per block. This field contains the number of columns in the cross-covariance block associated with image IIDI. NCOLCB is equal the number of active adjustable parameters for image IIDI. If IIDI=IID, the cross-covariance block is also a covariance (or auto-covariance) block and NCOLCB=NROWCB.	2	BCS-N	N/A	01 to 36	R
…End for each image						
INCAPD	Include Adjustable Parameter Definitions Flag. This field specifies whether the RSM adjustable parameters for the associated image are identified and defined in the following fields. At least one populated RSMDCB for the associated image must have INCAPD=Y.	1	BCS-A	N/A	Y or N	R
...if (INCAPD=Y)						
RSM Adjustable Parameter Identification for the associated image						
NPAR	Number of Active RSM Adjustable Parameters. This field contains the total number of active RSM adjustable parameters for the associated image. The value of this field is the row dimension of any cross-covariance (block) for the associated image that is contained in this TRE. NPAR's maximum value of 36 constrains the covariance block to be of reasonable size. (If the "basis" option is off (APBASE=N), NPAR=NISAP if APTYP=I, and NPAR=NGSAP if APTYP=G. If the basis option is on (APBASE=Y), NPAR corresponds to the number of (new) active adjustable parameters and the number of rows in the matrix A, as described for field APBASE.)	2	BCS-N	N/A	01 to 36	R

APTYP	Adjustable Parameter Type. This field identifies whether RSM adjustable parameters are image-space (APTYP=I) or ground-space (APTYP=G) adjustable parameters.	1	BCS-A	N/A	I or G	C
LOCTYP	Local Coordinate System Identifier. This field identifies whether the Local coordinate system references rectangular ground coordinates (LOCTYP=R) or non-rectangular (image row/image column/geodetic height) coordinates (LOCTYP=N). If RSM adjustable parameters are specified as ground-space (APTYP=G), the only valid value is LOCTYP=R.	1	BCS-A	N/A	R or N	C
Normalization Factors for the Local System						
NSFX	Normalization Scale Factor for X. This field contains the normalization scale factor for the x component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	C
NSFY	Normalization Scale Factor for Y. This field contains the normalization scale factor for the y component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	C
NSFZ	Normalization Scale Factor for Z. This field contains the normalization scale factor for the z component of the Local coordinate system	21	BCS-A	meters	±9.99999999999999E±99	C
NOFFX	Normalization Offset for X. This field contains the normalization offset for the x component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	C
NOFFY	Normalization Offset for Y. This field contains the normalization offset for the y component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	C
NOFFZ	Normalization Offset for Z. This field contains the normalization offset for the z component of the Local coordinate system.	21	BCS-A	meters	±9.99999999999999E±99	C
Local Rectangular Ground Coordinates Detailed Definition for Associated image						
...if (LOCTYP=R)						
XUOL	Local Coordinate Origin (XUOR). This field provides the WGS 84 X coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C
YUOL	Local Coordinate Origin (YUOL). This field provides the WGS 84 Y coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C

ZUOL	Local Coordinate Origin (ZUOL). This field provides the WGS 84 *Z* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C
XUXL	Local Coordinate Unit Vector (XUXL). This field provides the WGS 84 *X* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
XUYL	Local Coordinate Unit Vector (XUYL). This field provides the WGS 84 *X* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
XUZL	Local Coordinate Unit Vector (XUZL). This field provides the WGS 84 *X* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
YUXL	Local Coordinate Unit Vector (YUXL). This field provides the WGS 84 *Y* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
YUYL	Local Coordinate Unit Vector (YUYL). This field provides the WGS 84 *Y* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
YUZL	Local Coordinate Unit Vector (YUZL). This field provides the WGS 84 *Y* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
ZUXL	Local Coordinate Unit Vector (ZUXL). This field provides the WGS 84 *Z* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
ZUYL	Local Coordinate Unit Vector (ZUYL). This field provides the WGS 84 *Z* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C

ZUZL	Local Coordinate Unit Vector (ZUZL). This field provides the WGS 84 Z component of the unit vector defining the Z-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
...end if (LOCTYP=R)						
RSM Adjustable Parameters Basis Option						
APBASE	Basis Option. This field indicates whether the RSM adjustable parameters "basis" option is on (APBASE=Y). If this option is off (APBASE=N), the RSM adjustable parameters specified in the following fields are the active RSM adjustable parameters. The order (component number) of an active RSM adjustable parameter is the order in which it is specified. If this option is on, the RSM adjustable parameters specified in the following fields are the basis set of RSM adjustable parameters. The order (component number) of a basis RSM adjustable parameter is the order in which it is specified. If this option is on, the active RSM adjustable parameters are a linear combination of the basis set of RSM adjustable parameters. The matrix A (field AEL) maps the basis set to the active set of RSM adjustable parameters. In addition, the pseudo-inverse of the matrix A is equal to the matrix A transpose. It maps the active set to the basis set of RSM adjustable parameters. The matrix A is mxn, where $m \le n$ and the rank of A equals m. The number of adjustable parameters (n) in the basis set is specified in field NBASIS. The number of active adjustable parameters (m) is specified in the field NPAR. The RSM image error covariance is always with respect to the active RSM adjustable parameters. For example, the second active RSM adjustable parameter corresponds to row 2 and column 2 of the image (auto) covariance, and corresponds to row 2 and column k of the cross-covariance of the associated image with image k.	1	BCS-A	NA	Y or N	C
Image-Space Adjustable Parameters						
,,,if (APTYP = I)						

NISAP	Number of Image-Space Adjustable Parameters. This field contains the total number of image-space adjustable parameters. If the basis option is off (APBASE=N), specified image-space adjustable parameters are the active RSM adjustable parameters. The total number of image-space adjustable parameters is constrained as follows: (0<NPAR=NISAP=(NISAPR + NISAPC)<37). NISAPR is the number of image-space adjustable parameters that affect the image row-coordinate, and NISAPC the number that affect the image column-coordinate. If the basis option is on (APBASE=Y), specified image-space adjustable parameters are the basis RSM adjustable parameters. The total number of image-space adjustable parameters making up the basis set is constrained as follows: (0<NBASIS=NISAP=(NISAPR + NISAPC)<100).	2	BCS-A	N/A	1-36 (if APBASE=N) 1-99 (if APBASE=Y)	C
NISAPR	Number of Image-Space Adjustable Parameters for Image Row Coordinate. This field provides the total number of image-space adjustable parameters that adjust the image row coordinate. The general form for the row coordinate adjustment (Δr) corresponding to an adjustable parameter (ap) is as follows: $\Delta r = ap_{rijk} \cdot x^i \cdot y^j \cdot z^k$, where i,j,k are the corresponding powers of normalized Local coordinates x,y,z, respectively. Each adjustable parameter has units of pixels.	2	BCS-A	N/A	0-36 (if APBASE=N) 0-99 (if APBASE=Y)	C
…Begin for each image-space adjustable parameter for row adjustment (NISAPR entries)						
XPWRR	Row Parameter Power of X. The power (exponent) of x associated with this image-space adjustable parameter for image row adjustment. This power along with the following two powers (fields) uniquely specify the adjustable parameter. x is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image row coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C

YPWRR	Row Parameter Power of Y. The power (exponent) of y associated with this image-space adjustable parameter for image row adjustment. y is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image column coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
ZPWRR	Row Parameter Power of Z. The power (exponent) of z associated with this image-space adjustable parameter for image row adjustment. z is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized geodetic height coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
…End for each image-space adjustable parameter for row adjustment						
NISAPC	Number of Image-Space Adjustable Parameters for Image Column Coordinate. This field provides the total number of image-space adjustable parameters that adjust the image column coordinate. The general form for the column coordinate adjustment (Δc) corresponding to an adjustable parameter (ap) is as follows: $\Delta c = ap_{cijk} \cdot x^i \cdot y^j \cdot z^k$, where i,j,k are the corresponding powers of normalized Local coordinates x,y,z, respectively. Each adjustable parameter has units of pixels.	2	BCS-A	N/A	0-36 (if APBASE=N) 0-99 (if APBASE=Y)	C
…Begin for each image-space adjustable parameter for column adjustment (NISAPC entries)						
XPWRC	Column Parameter Power of X. The power (exponent) of x associated with this image-space adjustable parameter for image column adjustment. This power along with the following two powers (fields) uniquely specify the adjustable parameter. x is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image row coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
YPWRC	Column Parameter Power of Y. The power (exponent) of y associated with this image-space adjustable parameter for image column adjustment. y is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image column coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C

ZPWRC	Column Parameter Power of Z. The power (exponent) of z associated with this image-space adjustable parameter for image column adjustment. z is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized geodetic height coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
…End for each image-space adjustable parameter for column adjustment						
...end if (APTYP=I)						
Ground-Space Adjustable Parameters						
...if (APTYP=G)						

NGSAP	<u>Number of Ground-Space Adjustable Parameters</u> This field provides the total number of ground-space adjustable parameters. Each ground-space adjustable parameter is either associated with a "seven parameter" adjustment or is a first order "rate" term. The general form for the seven parameter adjustment is: $\begin{bmatrix} dx \\ dy \\ dz \end{bmatrix} = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$, where the vector on the left side of the equation is the ground-space adjustment in Local rectangular ground coordinates (meters), the vector on the far right side of the equation is the ground point location in normalized Local rectangular ground coordinates. The seven parameters $\delta x, \delta y, \delta z, \delta\alpha, \delta\beta, \delta\kappa, \delta s$, are termed x-offset, y-offset, z-offset, rotation angle alpha, rotation angle beta, rotation angle kappa, and scale. For identification purposes in the field below, these seven parameters are assigned 4 character identifications "OFFX", "OFFY" ,"OFFZ", "ROTX", "ROTY", "ROTZ", "SCAL", respectively. Each has units of meters. There a total of 9 possible rate terms $ap_{xx}, ap_{xy},.., ap_{zz}$, termed "XRTX", "XRTY", "XRTZ", "YRTX", "YRTY", "YRTZ", "ZRTZ", "ZRTY, "ZRTZ, respectively. Their effect is illustrated as follows for the adjustable parameter "XRTY" (ap_{xy}) and corresponding adjustment Δx : $\Delta x = ap_{xy} y$. If the basis option is off (APBASE=N), specified ground-space adjustable parameters are the active RSM adjustable parameters. If the basis option is on (APBASE=Y), specified ground-space adjustable parameters are the basis RSM adjustable parameters. The total number of ground-space adjustable parameters (NGSAP) is constrained to be between 1 and 16 regardless the value of APBASE, i.e., regardless if the basis option is on or off. If the basis option is off, NPAR=NGSAP. If the basis option is on, NBASIS=NGSAP.	2	BCS-A	N/A	1-16	C

…Begin for each ground-space adjustable parameter (NGSAP entries)						
GSAPID	Ground-space Adjustable Parameter ID. This field identifies a ground-space adjustable parameter.	4	BCS-A	N/A	OFFX,OFFY,OFFZ, ROTX,ROTY,ROTZ, SCAL, XRTX, XRTY,XRTZ, YRTZ,YRTY,YRTZ, ZRTX,ZRTY,ZRTZ	C
…End for each ground-space adjustable parameter						
…end if (APTYP=G)						
...if (APBASE=Y)						
NBASIS	Number of Basis Adjustable Parameters. This field contains the number of RSM adjustable parameters in the basis set. It is equal to the number of columns in the matrix A. NBASIS=NISAP or NGSAP, depending on whether the previously identified adjustable parameters were image-space or ground-space adjustable parameters. The number of columns must be no less than the number of rows in the matrix A, i.e., NBASIS $\geq$ NPAR. The size of the matrix A is also constrained such that NPAR*NBASIS ≤ 1296 .	2	BCS-N	N/A	1-99	C
...Begin for each A element (NPAR*NBASIS entries)						
AEL	Matrix A Element. This field contains an element of the matrix A. The elements are stored in row major order.	21	BCS-A	N/A	±9.99999999999999E±99	C
...End loop over elements of matrix A						
...end if (APBASE=Y)						
...end if (INCAPD=Y)						
Direct Error Covariance (Cross-covariance blocks for the associated image with each image listed (in order) in field IIDI)						
....Begin for each image (NIMGE entries)						
…Begin for each cross-covariance matrix element (NROWCB*NCOLCB) entries)						
CRSCOV	Cross-covariance Element. This field contains an element of the cross-covariance matrix (block) for the associated image and the image. The matrix dimension is NROWCBxNCOLCB. Elements are stored in row major order.	21	BCS-A	N/A	±9.99999999999999E±99 Element values must correspond to a symmetric (auto) covariance matrix but not necessarily a symmetric cross-covariance matrix. Element values must be consistent with an assembled positive (semi) definite direct error covariance.	R
…End for each element						
...End for each image						

Table 6: RSMDCB TRE Format Table

10 RSM ADJUSTABLE PARAMETERS (RSMAPA) TRE

10.1 OVERVIEW

The Replacement Sensor Model Adjustable Parameters version A TRE (RSMAPA) identifies RSM adjustment parameters for the associated image, and in particular, which RSM adjustable parameters are active and their current value. If an RSMAP TRE is not provided, all RSM adjustable parameters for the associated image are assumed to have a value of zero. When an RSMAP TRE is provided, the corresponding values of the active adjustable parameters typically reflect the output of an RSM adjustment process (e.g., triangulation).

10.2 ADJUSTABLE PARAMETERS

There are 36 contiguous fields (IRO through GZZ) corresponding to each potential adjustable parameter. This set of parameters is defined as the RSM Adjustable Parameter Choice Set. The first 20 contiguous fields (IRO through ICZZ) correspond to RSM image-space adjustable parameters and the remaining 16 contiguous fields (GXO through GZZ) correspond to RSM ground-space adjustable parameters. A value of all spaces indicates that the adjustable parameter is inactive (not used); otherwise the value specifies its index into the RSM Adjustment Vector. The TRE also includes the contiguous values of the RSM Adjustment Vector components (field PARVAL), and hence, the values of the active RSM adjustable parameters. The dimension of the RSM Adjustment Vector equals the number of active adjustable parameters, and of course, all inactive RSM adjustable parameters have a value of zero by definition.

Note that most sensors require between 5 to 12 active RSM adjustable parameters for an image, either all image-space or all ground-space adjustable parameters. Space-borne sensors typically utilize image-space adjustable parameters.

10.2.1 LOCAL COORDINATE SYSTEM DEFINITION

The adjustable parameters for the associated image reference a secondary, rectangular coordinate system – termed the “Local coordinate system." That is, their application to adjust the RSM ground-to-image function for a given ground point, requires the representation of that ground point in the Local coordinate system. Typically, this coordinate system is a local tangent plane system centered within the RSM image domain’s footprint at a nominal height above the ellipsoid and rotated to be aligned as follows: the z-axis is aligned with the imaging locus direction (line-of-sight vector for an electro-optical sensor), the x-axis is aligned with the image line (“sweep”) direction, and the y-axis completes a right-handed rectangular system. Figure 11 illustrates a typical RSM Local coordinate system. It is defined by an offset and rotation relative to the WGS 84 Rectangular coordinate system, as detailed later. If X represents the ground point in the RSM primary ground coordinate system, let $X*$ represent the ground point in the Local coordinate system.

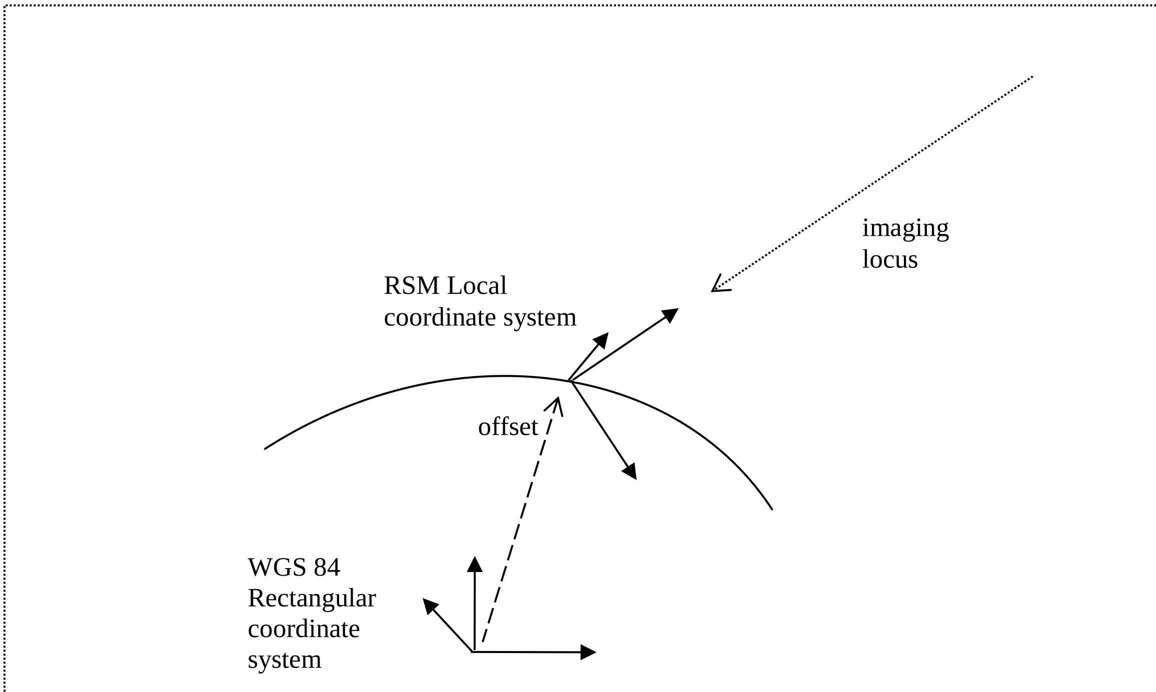

Figure 11: Example of RSM Local Coordinate System

10.2.2 EFFECT ON RSM GROUND-TO-IMAGE FUNCTION

The RSM ground-to-image function (e.g., rational polynomial) outputs a two-dimensional image point $I = [r \quad c]^T$ corresponding to a three-dimensional ground point $X = [x \quad y \quad z]^T$ input. The summed effects $\Delta I = [\Delta r \quad \Delta c]^T$ of all active image-space adjustable parameters are used to modify the output of the RSM ground-to-image function, i.e. $I \to I + \Delta I$. Similarly, the summed effects $\Delta X = [\Delta x \quad \Delta y \quad \Delta z]^T$ of all active ground-space adjustable parameters are used to modify the input to the RSM ground-to-image function, i.e., $X \to X + \Delta X$, represented in the RSM primary ground coordinate system. The effect of each adjustable parameter, whether an image-space or ground-space adjustable parameter, is based on the value of the parameter and the value of the (unadjusted) ground point $X*$, as represented in the Local coordinate system. The actual relationship between an adjustable parameter's effect on either X or I, i.e. its contribution to ΔX or ΔI, is based on the value of the parameter, the value of (unadjusted) $X*$ in the Local coordinate system, and the definition of the adjustable parameter as provided in the descriptions for fields IRO through GZZ. For example, assume that the image-space adjustable parameter associated with the field IRX is active and has a value represented by δr_x. (Actually, the value of the field IRX contains the index into the RSM Adjustment

Vector (field PARVAL) which contains the value of the adjustable parameter.) Then its contribution to the modification of the row coordinate of I is as follows: $\Delta r = \delta r_x \cdot x$, where x is the x-coordinate value of the ground point $X*$, expressed in the Local coordinate system.

In general, the image-space adjustable parameters that affect the image row coordinate do so as follows: $r \to r + \Delta r$, where $\Delta r = \delta r \cdot x^i \cdot y^j \cdot z^k$. δr represents the particular adjustable parameter, x, y, z are the coordinates of the ground point $X*$ as represented in the Local coordinate system, and the powers i, j, k each have a value within the set $\{0,1,2\}$ and $(i + j + k) \le 2$. Each adjustable parameter corresponds to a unique combination of powers. The above general description is also applicable to the image-space adjustable parameters that have an effect on the image column coordinate.

In general, ground-space adjustable parameters have an effect on the three dimensional components of the ground point X summarized as follows: the ground point is transformed to a Local coordinate system representation, $X \to X*$, the adjustable parameter(s) modify the ground point in the Local coordinate system representation, $X* \to (X* + \Delta X*)$, the adjusted ground point is transformed back to an RSM primary ground coordinate system representation, $(X* + \Delta X*) \to X'$, and the result is equivalent to a modification of the original ground point, $X' \Leftrightarrow (X + \Delta X)$. Individual ground-space adjustable parameters have varied functional forms associated with their effects on the ground point. The first seven fields associated with these adjustable parameters (GXO to GS) correspond to a standard photogrammetric seven parameter (small angle) transformation of $X*$, the remaining nine fields (GXX to GZZ) correspond to coefficients of polynomial correction terms, similar in form to those for Δr discussed previously. In particular, the seven parameter adjustment is defined as follows, where X_a^* represents the adjusted ground point in the Local coordinate system, and the symbols $\{\delta x \quad \delta y \quad \delta z \quad \delta\alpha \quad \delta\beta \quad \delta\kappa \quad \delta s\}$ correspond to the contiguous fields GXO to GS:

$$X_a^* = X^* + \Delta X^* = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} 1+\delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & 1+\delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & 1+\delta s \end{bmatrix} X^*, \text{ or}$$

$$\Delta X^* = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} X^*$$

An example of a ground-space adjustable parameter's effect (contribution to $\Delta X*$) corresponding to field GXR, represented symbolically as $\delta\alpha$, is as follows:

$\Delta y = \delta\alpha \cdot z$ and $\Delta z = -\delta\alpha \cdot y$, $y \to y + \Delta y$ and $z \to z + \Delta z$, or more generally, $X^* \to X^* + \Delta X^*$, where $\Delta X^{*T} = [0 \quad \Delta y \quad \Delta z]$. An example of the effect of the ground-space adjustable parameter corresponding to field GXY, represented as δx_y, is as follows: $\Delta x = \delta x_y \cdot y$, or more generally, $X^* \to X^* + \Delta X^*$, where $\Delta X^{*T} = [\Delta x \quad 0 \quad 0]$.

The RSM adjustable ground-to-image function $h(X, R)$ integrates the RSM ground-to-image function with the adjustments, as illustrated in Figure 12. The RSM ground-to-image function $g(X)$ can be either a rational polynomial ($poly$) or an interpolated ground point - image point correspondence grid ($grid$). Both are functions of the ground point location (X) as well as the RSM image support data, such as polynomial coefficients or grid values. (The RSMPC TRE and RSMGG TRE describe the appropriate image support data, respectively.) RSM image-space adjustable parameters are applied through one adjustment function (I_adj) and RSM ground-space adjustable parameters are applied through another (X_adj). These functions simply generate the ΔI and ΔX corrections per the definitions of the active RSM adjustable parameters. Both are functions of ground point location (X), internally converted to an X^* representation, as well as the active RSM adjustable parameters (values) R contained in the RSMAPA TRE for the associated image. Application of the RSM adjustable parameters is independent of which RSM ground-to-image function is provided in the RSM image support data.

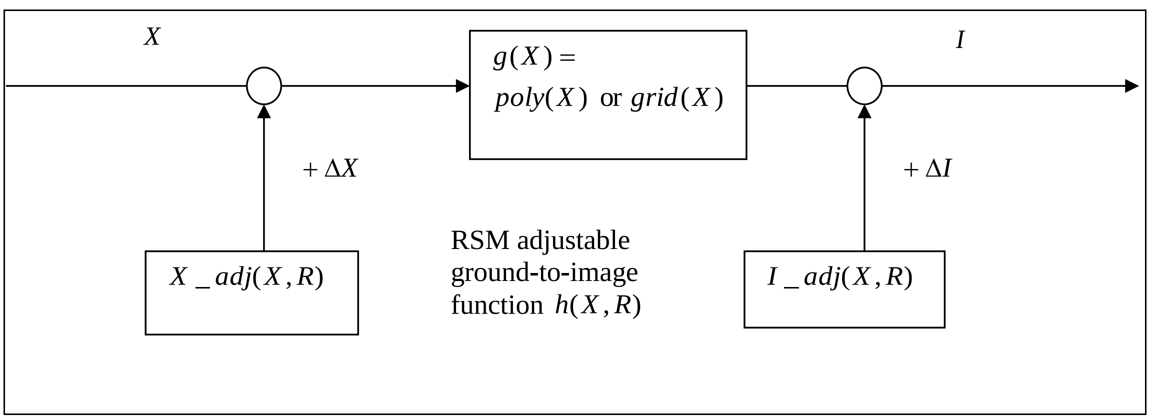

Figure 12: The RSM Adjustable Ground-to-Image Function

Note that the values of the RSM adjustable parameters are applicable to all pixel locations within the associated image's RSM image domain. That is, an RSM adjustable parameter's value is constant over the entire RSM image domain. However, its effect on the RSM ground-to-image function does vary with pixel (actually corresponding ground) location, as described previously. In addition, for ground points near the RSM ground domain boundary, application of non-zero RSM adjustable parameters to the RSM ground-to-image function may push the resultant image coordinate somewhat outside the RSM image domain (and the corresponding ground point somewhat outside the RSM ground domain). This is not a problem for reasonable adjustment magnitudes, because the RSM ground-to-image function is actually generated from the original sensor model's ground-to-image correspondence over a larger domain than specified by the RSM image and ground domains. (Of course, this assumes that the original sensor model supports the larger domain.)

The above input X (and its correction ΔX) and output I (and its correction ΔI) of the RSM ground-to-image function are with respect to un-normalized coordinates. Evaluation of the RSM ground-to-image function is actually performed with respect to normalized coordinates. The RSM ground-to-image function handles all required normalization and un-normalization, as described in RSMPC TRE and RSMGG TRE.

10.2.3 LOCAL COORDINATE SYSTEM DETAILS

The following defines the Local coordinate system relative to the WGS 84 Rectangular coordinate system. The contiguous fields XUOL through ZUOL specify the origin (offset) of the Local coordinate system relative to the WGS 84 Rectangular coordinate system, and the contiguous fields XUXL through ZUZL the rotation. These fields are provided in this TRE.

$$X^* = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{LOCAL}} = \begin{bmatrix} XUXL & YUXL & ZUXL \\ XUYL & YUYL & ZUYL \\ XUZL & YUZL & ZUZL \end{bmatrix} \cdot \left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{WGS-84}} - \begin{bmatrix} XUOL \\ YUOL \\ ZUOL \end{bmatrix} \right).$$

Note that the definition of the Local (rectangular) coordinate system is also (redundantly) supplied in the error covariance TREs (RSMDCA and RSMECA) for the associated image, when available. Also, in order to convert a ground point X represented in the RSM primary ground coordinate system (e.g., Geodetic) to the Local coordinate system, it must first be converted from the RSM primary system to the WGS 84 Rectangular coordinate system.

10.2.4 TWO POSSIBLE SETS OF RSM ACTIVE ADJUSTABLE PARAMETERS

Note that, for complete flexibility, there can actually be two different sets of "active" RSM adjustable parameters for the associated image. (However, both sets will reference the same Local coordinate system.) One set corresponds to the error model and is applicable to the RSM adjustable parameter error covariance, either the RSM direct error covariance or the RSM indirect error covariance, whichever is applicable. This active set is also termed the set of RSM "error model" adjustable parameters. It identifies which adjustable parameters (errors) the RSM error covariance refers to. Their identity is essential in support of error propagation; in particular, the projection of the RSM error covariance to image space via the partial derivative of image measurements with respect to the appropriate RSM adjustable parameters. The set of RSM error model adjustable parameters is identified as the active RSM adjustable parameters in the appropriate RSM error covariance TRE, either RSMECA or RSMDCA.

The other set of active RSM adjustable parameters contains the current set of adjusted parameters, i.e., those adjustable parameters with non-zero values that modify the RSM ground-to-image function. They are typically the result of an RSM triangulation, i.e., a triangulation directly involving the adjustment of previously generated RSM image support data. This set of active RSM adjustable parameters is also termed the set of RSM “adjusted” parameters. The set of RSM adjusted parameters, along with their values, is identified as the active RSM adjustable parameters in this TRE (RSMAPA).

For many RSM applications, there is only one set of active RSM adjustable parameters by definition - the RSM error model adjustable parameters. This occurs when RSM support data is generated directly from either adjusted or unadjusted original sensor model support data. A subsequent RSM triangulation has not taken place, and there are no RSM adjusted parameters.

When a subsequent RSM triangulation does take place, there will be two sets of active RSM adjustable parameters, RSM adjusted parameters and RSM error model adjustable parameters. The former corresponds to the adjustments generated by the triangulation, and the latter corresponds to the corresponding RSM direct error covariance also generated by the triangulation. Following the triangulation, these two sets of RSM adjustable parameters are identical, including the parameter order within the sets. In most cases, the RSM support data is then generated referencing both of these identical sets using the RSMAPA and RSMDCA TREs. However, in some cases, prior to actual TRE generation, these two sets can change.

For example, assume that the RSM triangulation is performed for the associated image as well as a number of other same-pass images from the same sensor. The triangulation solves for the adjustable parameters for these images and their (non-zero) values are saved as RSM adjusted parameters for the appropriate images. However, in order to minimize support data bandwidth, the corresponding multi-image RSM direct error covariance which references these same adjustable parameters is not placed in the RSM image support data. It is approximated by the RSM generating application as an RSM indirect error covariance for the same pass images. As part of the approximation, the RSM indirect error covariance also references a different set of RSM error model adjustable parameters. In this case, the RSM error model adjustable parameters will differ from the RSM adjusted parameters, as specified by the RSMAPA and RSMECA TREs.

10.3 RSMAPA FORMAT

Table 7 specifies the detailed format for the Replacement Sensor Model Adjustable Parameters (RSMAPA) TRE.

RSMAPA – Replacement Sensor Model Adjustable Parameters						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier	6	BCS-A	N/A	RSMAPA	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	bytes	507 to 1243	R
Image information						
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R
TID	Triangulation ID. This field contains an identifier that is unique to the most recent process after RSM support data generation that led to the adjustments and/or error covariance in this RSM support data edition. The field value is all spaces if there has been no such process.	40	BCS-A	N/A	N/A Default is all spaces	<R>
NPAR	Number of Parameters. This field contains the number of (active) RSM adjustable parameters (dimension of RSM Adjustment Vector) of the associated image	2	BCS-N	N/A	01 to 36	R
Local Coordinate System Definition for RSM Adjustable Parameters for the image						
XUOL	Local Coordinate Origin (XUOR). This field provides the WGS 84 X coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	R

YUOL	Local Coordinate Origin (YUOL). This field provides the WGS 84 *Y* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	R
ZUOL	Local Coordinate Origin (ZUOL). This field provides the WGS 84 *Z* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	R
XUXL	Local Coordinate Unit Vector (XUXL). This field provides the WGS 84 *X* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
XUYL	Local Coordinate Unit Vector (XUYL). This field provides the WGS 84 *X* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
XUZL	Local Coordinate Unit Vector (XUZL). This field provides the WGS 84 *X* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUXL	Local Coordinate Unit Vector (YUXL). This field provides the WGS 84 *Y* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUYL	Local Coordinate Unit Vector (YUYL). This field provides the WGS 84 *Y* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R

YUZL	Local Coordinate Unit Vector (YUZL). This field provides the WGS 84 *Y* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUXL	Local Coordinate Unit Vector (ZUXL). This field provides the WGS 84 *Z* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUYL	Local Coordinate Unit Vector (ZUYL). This field provides the WGS 84 *Z* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUZL	Local Coordinate Unit Vector (ZUZL). This field provides the WGS 84 *Z* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
“Active” RSM Adjustable Parameters						
Adjustable Parameter- RSM Adjustable Parameter Vector correspondence						
Image-space Adjustable Parameters						

IRO	Image Row Constant Index. This field provides the value of the index into the associated image's RSM Adjustment Vector for the RSM adjustable parameter: the constant offset adjustment of the image row position. A value of all spaces for the field specifies that this adjustable parameter is not active (not used). For example, if IRO=3, the third element of the associated image's RSM Adjustment Vector corresponds to the adjustable parameter: constant offset adjustment of the image row position. The following 35 fields provide the same type of information as the IRO field, but each is associated with a different RSM adjustable parameter. All of the adjustable parameters reference Local (rectangular) ground coordinates x, y, and z. Note that the field IRO and following 19 fields are associated with RSM image-space adjustable parameters, and the next 16 fields are associated with RSM ground-space adjustable parameters. Together, they are the elements of the RSM Adjustable Parameter Choice Set.	2	BCS-A	N/A	01 to 36 All spaces if not used (adjustable parameter not active)	<R>
IRX	Image Row X Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point x position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRY	Image Row Y Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point y position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRZ	Image Row Z Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point z position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRXX	Image Row X^2 Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point x^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRXY	Image Row XY Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point xy position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRXZ	Image Row XZ Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point xz position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>

IRYY	Image Row Y^2 Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point y^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRYZ	Image Row YZ Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point yz position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
IRZZ	Image Row Z^2 Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point z^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICO	Image Column Constant Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the constant offset adjustment of the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICX	Image Column X Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point x position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICY	Image Column Y Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point y position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICZ	Image Column Z Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point z position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICXX	Image Column X^2 Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point x^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICXY	Image Column XY Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point xy position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICXZ	Image Column XZ Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point xz position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICYY	Image Column Y^2 Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point y^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>

ICYZ	Image Column YZ Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point yz position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
ICZZ	Image Column Z^2 Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point z^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
Ground-space Adjustable Parameters						
GXO	Ground X Constant Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the constant offset adjustment of the ground x position.	2	BCS-A	N/A	01 to 36 All spaces if not used (adjustable parameter not active)	<R>
GYO	Ground Y Constant Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the constant offset adjustment of the ground y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZO	Ground Z Constant Index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the constant offset adjustment of the ground z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GXR	Ground Rotation X. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the small angle ground point rotation about the x-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GYR	Ground Rotation Y. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the small angle ground point rotation about the y-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZR	Ground Rotation Z. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the small angle ground point rotation about the z-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GS	Ground Scale. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the multiplicative ground point scale factor.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GXX	Ground X Adjustment Proportional to X index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point x position applied to the ground point x position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GXY	Ground X Adjustment Proportional to Y index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point y position applied to the ground point x position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>

GXZ	Ground X Adjustment Proportional to Z index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point z position applied to the ground point x position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GYX	Ground Y Adjustment Proportional to X index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point x position applied to the ground point y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GYY	Ground Y Adjustment Proportional to Y index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point y position applied to the ground point y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GYZ	Ground Y Adjustment Proportional to Z index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point z position applied to the ground point y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZX	Ground Z Adjustment Proportional to X index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point x position applied to the ground point z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZY	Ground Z Adjustment Proportional to Y index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point y position applied to the ground point z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
GZZ	Ground Z Adjustment Proportional to Z index. The RSM Adjustment Vector index associated with the following RSM adjustable parameter: the coefficient for ground point z position applied to the ground point z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<R>
Adjustable Parameters Data						
…Begin for each RSM Adjustment Vector component (active adjustable parameter) for the associated image (NPAR entries)						
PARVAL	Component Value. This field contains the value contained in the next component of the RSM Adjustable Parameter Vector.	21	BCS-A	N/A	$\pm$9.99999999999999E$\pm$99	R
…End for each component						

Table 7: RSMAPA TRE Format Table

11 RSM ADJUSTABLE PARAMETERS (RSMAPB) TRE

11.1 OVERVIEW

The Replacement Sensor Model Adjustable Parameters version B (RSMAPB) TRE identifies the current values of active RSM adjustable parameters for the associated image. If an RSMAP TRE is not provided, all RSM adjustable parameters for the associated image are assumed to have a value of zero. When an RSMAP TRE is provided, corresponding values typically reflect the output of an RSM adjustment process (e.g., triangulation).

11.2 ACTIVE ADJUSTABLE PARAMETER VALUES

This TRE identifies the active RSM adjustable parameters for the associated image, as detailed in section 11.3. Their corresponding values are also stored in the RSM Adjustment Vector (R) contained in this TRE (field PARVAL). The order of the elements in the RSM Adjustment Vector correspond to the exact order the active adjustable parameters are identified in this populated TRE (see Table 8). The dimension of the RSM Adjustment Vector equals the number of active adjustable parameters (field NPAR). The RSM Adjustment Vector is used to adjust the RSM ground-to-image function, as detailed in section 11.3.

11.3 ADJUSTABLE PARAMETER DEFINITIONS AND IDENTIFICATION

Active RSM adjustable parameters for the associated image are either active RSM image-space adjustable parameters or active RSM ground-space adjustable parameters, as specified by field APTYP in the RSMAPB TRE.

RSM image-space adjustable parameters correspond to adjustable parameters that adjust an image row coordinate value (r) and an image column coordinate value (c) corresponding to an arbitrary ground point location $X = \begin{bmatrix} x & y & z \end{bmatrix}^T$. An individual adjustable parameter either adjusts an image row coordinate value or an image column coordinate value. The adjustments Δr and Δc corresponding to adjustable parameters ap_{rijk} and ap_{cijk} are computed as follows:

$$\Delta r = ap_{rijk} x^i y^j z^k$$

$$\Delta c = ap_{cijk} x^i y^j z^k$$

The adjustable parameters (ap_{rijk} and ap_{cijk}) are uniquely identified by their collective x, y, z powers (exponents) and whether they adjust image row or image column coordinates. The coordinates x, y, and z correspond to normalized ground point coordinates expressed in a Local coordinate system. Normalization is performed by an offset and scale factor for each coordinate. These normalization parameters are in contiguous fields (NSFX-NOFFZ), and allow for an approximate range of (-1,1) for each ground coordinate value. An example of their application for normalization of the y coordinate is as follows:

$$y \rightarrow (y - offset_y) / scale_y \; .$$

Because the ground coordinates are normalized, all image-space adjustable parameters have units of pixels, as do the corrections Δr and Δc. Normalization of the Local coordinates helps to insure overall stability since the value of $x^i y^j z^k$ that multiplies an adjustable parameter during an image row or column adjustment can become extremely large if coordinates are not normalized for large images and large exponents.

There are two possible choices for the Local coordinate system, either Local Rectangular or Local Non-Rectangular, as specified in field LOCTYP. For Local Non-Rectangular, x, y, and z correspond to the ground point's corresponding image row coordinate, image column coordinate, and geodetic height, respectively. The Local Rectangular coordinate system is defined as a rectangular system that is offset and rotated relative to the WGS-84 coordinate system. It is typically specified as a local tangent plane system centered within the RSM image domain's footprint at a nominal height above the ellipsoid and rotated to be aligned as follows: the z-axis is aligned with the imaging locus direction (line-of-sight vector for an electro-optical sensor), the x-axis is aligned with the image line ("sweep" or "scan") direction, and the y-axis completes a right-handed rectangular system. (When the Local Rectangular coordinate system is footprint centered, corresponding Local Rectangular coordinate normalization offsets, such as $offset_y$, typically have a value of zero.)

Figure 13 illustrates a typical Local Rectangular coordinate system. Specification of a Local Rectangular coordinate system is unique to the associated image and based on contiguous fields (XUOL-ZUZL) as detailed later in this introduction.

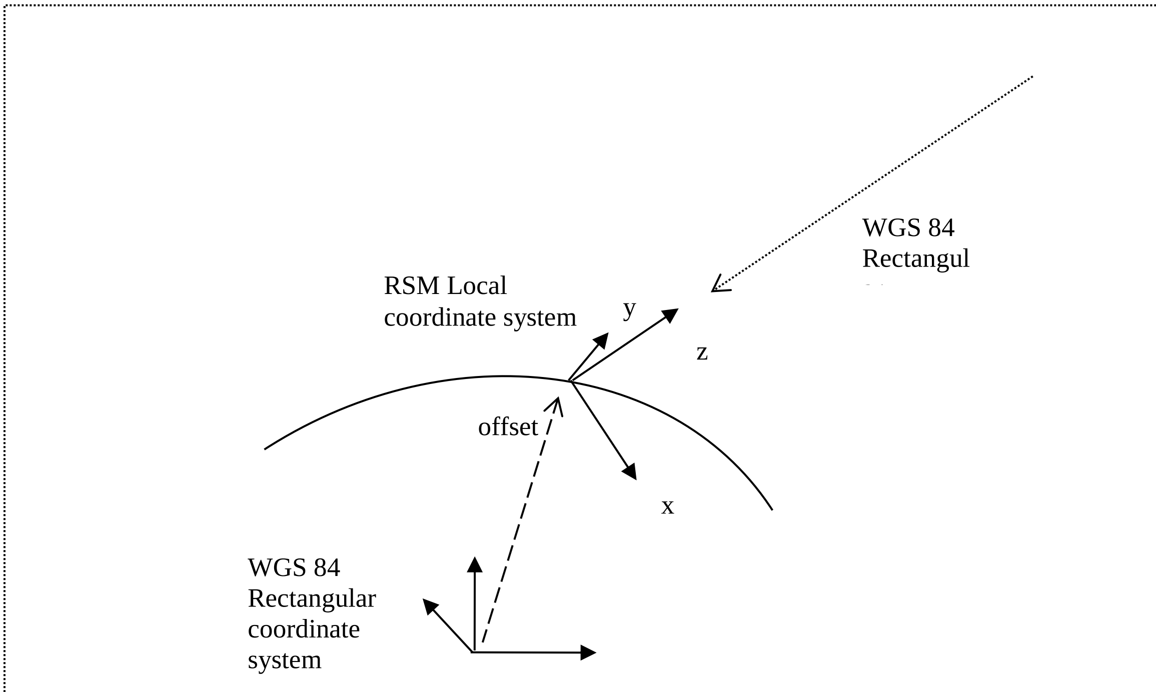

Figure 13: Example of RSM Local Rectangular Coordinate System

Note that the choice of Local Rectangular or Local Non-rectangular is provided for flexibility. The Local Rectangular coordinate system inherits general analytic advantages associated with rectangular (orthonormal) coordinates, and its absolute orientation is insensitive to any abrupt changes in imaging geometry across the imaging time interval. The Local Non-Rectangular coordinate system may provide advantages when very long images are (smoothly) scanned due to significant changes in instantaneous image geometry from one end of the image to the other. The coordinate system is continuously in alignment with these changes.

RSM ground-space adjustable parameters reference normalized Local Rectangular coordinates only. The coordinate system is typically specified as a local tangent plane system centered within the RSM image domain's footprint at a nominal height above the ellipsoid (z-axis vertical). An individual ground-space adjustable parameter is either a parameter associated with a "seven parameter" adjustment or a "rate" adjustment. The seven parameter adjustment is defined as follows, where the symbols $\{\delta x \quad \delta y \quad \delta z \quad \delta\alpha \quad \delta\beta \quad \delta\kappa \quad \delta s\}$ correspond to the adjustable parameters:

$$\begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

The vector on the left side of the above equation corresponds to adjustments in the un-normalized coordinates of the ground point expressed in Local Rectangular coordinates with units of meters. The vector on the far right side of the equation corresponds to normalized coordinates of the ground point expressed in Local Rectangular coordinates. Because these coordinates are unit-less, the adjustable parameters all have units of meters, as do the corrections $\Delta x, \Delta y, \Delta z$.

(If Local coordinate scale factors ($scale_x, scale_y, scale_z$) are set equal in value by the TRE generation process, Local coordinate values no longer necessarily range from -1.0 to 1.0. However, the above seven parameter adjustment is now equivalent to the standard photogrammetric seven parameter (small angle) transformation. It is recommended that the scale factors be set equal to a common value in a manner that yields ranges for the three local coordinates as close as possible to interval -1.0 to 1.0.)

There are nine possible ground-space adjustable parameters corresponding to rate adjustments and denoted by the symbols $\{ap_{xx}, ap_{xy}, .., ap_{zz}\}$. They adjust the un-normalized coordinates of the ground point in Local Rectangular coordinates specifically as follows:

$$\Delta x = ap_{xx}x \,,\ \Delta x = ap_{xy}y \,,\ \Delta x = ap_{xz}z \,,$$

$$\Delta y = ap_{yx}x \,,\ \Delta y = ap_{yy}y \,,\ \Delta y = ap_{yz}z \,,$$

$$\Delta z = ap_{zx}x \,,\ \Delta z = ap_{zy}y \,,\ \Delta z = ap_{zz}z \,.$$

Again, these adjustable parameters and the corrections have units of meters.

Each of the 16 possible ground-space adjustable parameters is identified by a unique four character identifier detailed in the TRE's specified format (Table 8).

Note that application of RSM adjustable parameters, whether image-space or ground-space adjustable parameters, first requires converting the corresponding ground point from representation in the RSM primary ground coordinate system to the appropriate Local system. And for the case of ground-space adjustable parameters, the adjusted ground point must also be converted back to the RSM primary coordinate system.

Figure 14 presents the RSM adjustable ground-to-image function $h(X,R)$, where X corresponds to the un-normalized three dimensional ground point in the RSM primary ground coordinate system. The functions $I\_adj(X,R)$ and $X\_adj(X,R)$ apply the previously documented adjustment equations for active image-space and ground-space adjustable parameters, respectively. (The functions also internally convert X from the primary system to the (normalized) Local system.)

$\Delta I = [\Delta r \quad \Delta c]^T$ denotes the summed effects at ground point location X of all active RSM image-space adjustable parameters. For example, if the active image-space adjustable parameters correspond to (combined) powers in x and y less than or equal to one: $\Delta r = ap_{r000} + ap_{r100} \cdot x + ap_{r010} \cdot y$, and $\Delta c = ap_{c000} + ap_{c100} \cdot x + ap_{c010} \cdot y$.

$\Delta X = [\Delta x \quad \Delta y \quad \Delta z]^T$ denotes the summed effects at ground point location X of all active RSM ground-space adjustable parameters.

The vector R represents the active RSM adjustable parameters (values) in the order that they are specified in this populated TRE, e.g., vector element two corresponds to the second active adjustable parameter identified in the populated TRE (see Table 8). (Internally, the RSM ground-to-image function $g(X)$ is actually performed with respect to normalized coordinates. The RSM ground-to-image function handles all required normalization and un-normalization, as described in the RSMPC TRE and the RSMGG TRE.)

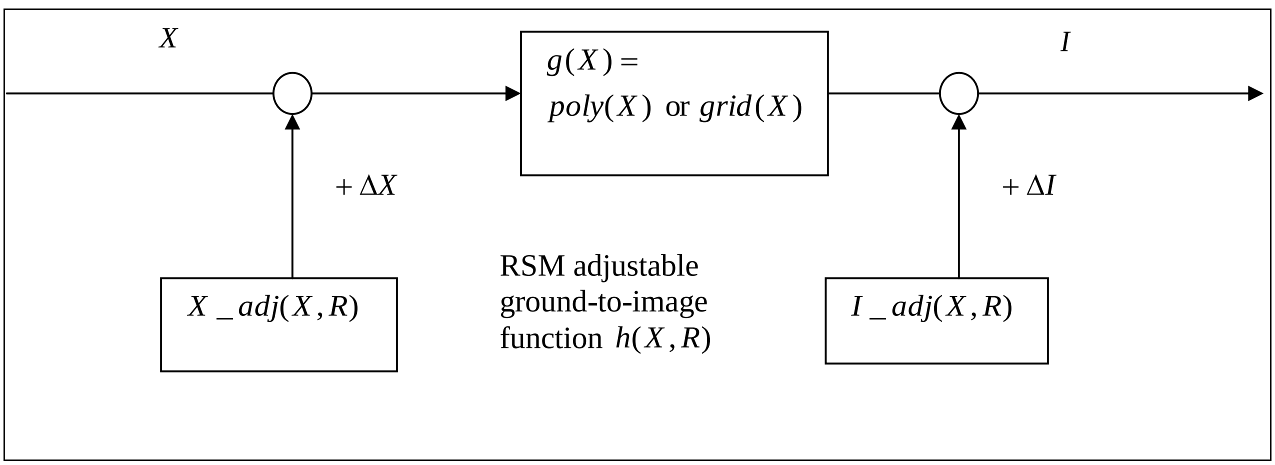

Figure 14: RSM Adjustable Ground-to-Image Function

The total number of active image-space adjustable parameters is specified in field (NISAP). Individual active adjustable parameters are identified in contiguous fields (XPWRR-ZPWRR) and contiguous fields (XPWRC-ZPWRC).

The total number of active ground-space adjustable parameters is specified in field (NGSAP). Individual active parameters are identified in field (GSAPID).

11.3.1 BASIS OPTION

When this option is invoked (APBASE=Y), the set of RSM adjustable parameters specified in this TRE (as described previously) become a "basis" set of adjustable parameters. Symbolically, they are contained in the vector R, assumed to have n elements. Another set of RSM adjustable parameters is defined as a linear combination of the elements of R. Symbolically, this new set is contained in the vector R', where $R' = AR$, and the matrix A is $m \times n$, $m \leq n$, with the rank of A equal to m. The vector R' contains the (new) set of active adjustable parameters.

The RSM Adjustment Vector contained in this TRE is now defined as R'. The field NPAR now corresponds to the number of elements (m) in R'. The field NBASIS corresponds to the number of elements (n) in R.

Typically, the matrix A is determined during initial generation of this TRE along with a corresponding error covariance using principal component analysis (see RSMDCB for an overview of the process and its potential benefits). R is also a linear combination of R' based on the pseudo-inverse of A, designated as $A^{\#}$. Thus, $R = A^{\#}R'$, where $A^{\#} = A^T(AA^T)^{-1} = A^T$.

When this option is on, the RSMAPB TRE contains the identification of the adjustable parameters that make up the elements of the basis (R), the matrix A that maps the basis (R) to the set of active adjustable parameters (R'), and the values of the active adjustable parameters, i.e., the (new) RSM Adjustment Vector (R'). In order to adjust the RSM ground-to-image function, an RSM exploiter maps the current values of R' contained in this TRE to current values of R via $R = A^T R'$. It then applies R to the ground-to-image function as illustrated in Figure 14.

11.3.2 LOCAL RECTANGULAR COORDINATE SYSTEM DETAILS

The following defines the Local Rectangular coordinate system relative to the WGS 84 Rectangular coordinate system. The contiguous fields XUOL through ZUOL specify the origin (offset) of the Local coordinate system relative to the WGS 84 Rectangular coordinate system, and the contiguous fields XUXL through ZUZL elements of the rotation matrix. These fields are provided in this TRE.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{LOCAL}} = \begin{bmatrix} XUXL & YUXL & ZUXL \\ XUYL & YUYL & ZUYL \\ XUZL & YUZL & ZUZL \end{bmatrix} \cdot \left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{WGS-84}} - \begin{bmatrix} XUOL \\ YUOL \\ ZUOL \end{bmatrix} \right).$$

Note that the definition of the Local Rectangular coordinate system is also redundantly supplied in other TREs for the associated image. Also, in order to convert a ground point X represented in the RSM primary ground coordinate system (e.g., Geodetic) to the Local Rectangular coordinate system, it must first be converted from the RSM primary system to the WGS 84 Rectangular coordinate system.

11.4 RSMAPB FORMAT

Table 8 specifies the detailed format for the Replacement Sensor Model Adjustable Parameters version B (RSMAPB) TRE.

RSMAPB – Replacement Sensor Model Adjustable Parameters						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Estimated Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier	6	BCS-A	N/A	RSMAPB	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	bytes	00321 to 28411	R
Image information						
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R
TID	Triangulation ID. This field contains an identifier that is unique to the most recent process after RSM support data generation that led to the adjustments and/or error covariance in this RSM support data edition.	40	BCS-A	N/A	N/A	R
RSM Adjustable Parameter Identification for the associated image						

NPAR	Number of Active RSM Adjustable Parameters. This field contains the total number of (active) RSM adjustable parameters for the associated image. It is the number of elements (components) in the RSM Adjustment Vector (field PARVAL). The value is constrained to less than 37 to insure an RSM Adjustment Vector (and associated error covariance) of practical size. (If the "basis" option is off (APBASE=N), NPAR=NISAP if APTYP=I, and NPAR=NGSAP if APTYP=G. If the basis option is on (APBASE=Y), NPAR corresponds to the number of (new) active adjustable parameters and the number of rows in the Matrix A, as described for field APBASE.)	2	BCS-N	N/A	01 to 36	R
APTYP	Adjustable Parameter Type. This field identifies whether RSM adjustable parameters are image-space (APTYP=I) or ground-space (APTYP=G) adjustable parameters.	1	BCS-A	N/A	I or G	R
LOCTYP	Local Coordinate System Identifier. The field identifies whether the Local coordinate system references rectangular ground coordinates (LOCTYP=R) or non-rectangular (image row/image column/geodetic height) coordinates (LOCTYP=N). If RSM adjustable parameters are specified as ground-space (APTYP=G), the only valid value is LOCTYP=R.	1	BCS-A	N/A	R or N	R
Normalization Factors for the Local System						
NSFX	Normalization Scale Factor for X. This field contains the normalization scale factor for the x component of the Local coordinate system Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	R
NSFY	Normalization Scale Factor for Y. This field contains the normalization scale factor for the y component of the Local coordinate system Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	R
NSFZ	Normalization Scale Factor for Z. This field contains the normalization scale factor for the z component of the Local coordinate system	21	BCS-A	meters	±9.99999999999999E±99	R
NOFFX	Normalization Offset for X. This field contains the normalization offset for the x component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	R
NOFFY	Normalization Offset for Y. This field contains the normalization offset for the y component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	R
NOFFZ	Normalization Offset for Z. This field contains the normalization offset for the z component of the Local coordinate system.	21	BCS-A	meters	±9.99999999999999E±99	R

Local Rectangular Ground Coordinates Detailed Definition for Associated Image						
...if (LOCTYP=R)						
XUOL	Local Coordinate Origin (XUOR). This field provides the WGS 84 X coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E+99	R
YUOL	Local Coordinate Origin (YUOL). This field provides the WGS 84 Y coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E+99	R
ZUOL	Local Coordinate Origin (ZUOL). This field provides the WGS 84 Z coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E+99	R
XUXL	Local Coordinate Unit Vector (XUXL). This field provides the WGS 84 X component of the unit vector defining the X-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
XUYL	Local Coordinate Unit Vector (XUYL). This field provides the WGS 84 X component of the unit vector defining the Y-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
XUZL	Local Coordinate Unit Vector (XUZL). This field provides the WGS 84 X component of the unit vector defining the Z-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUXL	Local Coordinate Unit Vector (YUXL). This field provides the WGS 84 Y component of the unit vector defining the X-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUYL	Local Coordinate Unit Vector (YUYL). This field provides the WGS 84 Y component of the unit vector defining the Y-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R

YUZL	Local Coordinate Unit Vector (YUZL). This field provides the WGS 84 *Y* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUXL	Local Coordinate Unit Vector (ZUXL). This field provides the WGS 84 *Z* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUYL	Local Coordinate Unit Vector (ZUYL). This field provides the WGS 84 *Z* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUZL	Local Coordinate Unit Vector (ZUZL). This field provides the WGS 84 *Z* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
...end if (LOCTYP=R)						
RSM Adjustable Parameter Basis Option						

APBASE	<u>Basis Option.</u> This field indicates whether the RSM adjustable parameters "basis" option is on (APBASE=Y). If this option is off (APBASE=N), the RSM adjustable parameters specified in the following fields are the active RSM adjustable parameters. The order (component number) of an active RSM adjustable parameter is the order in which it is specified. If this option is on, the RSM adjustable parameters specified in the following fields are the basis set of RSM adjustable parameters. The order (component number) of a basis RSM adjustable parameter is the order in which it is specified. If this option is on, the active RSM adjustable parameters are a linear combination of the basis set of RSM adjustable parameters. The matrix A (field AEL) maps the basis set to the active set of RSM adjustable parameters. In addition, the pseudo-inverse of the matrix A is equal to the matrix A transpose. It maps the active set to the basis set of RSM adjustable parameters. The matrix A is mxn, where $m \le n$ and the rank of A equals m. The number of adjustable parameters (n) in the basis set is specified in field NBASIS. The number of active adjustable parameters (m) is specified in the field NPAR. The RSM image error covariance is always with respect to the active RSM adjustable parameters. For example, the second active RSM adjustable parameter corresponds to row 2 and column 2 of the image (auto) covariance, and corresponds to row 2 and column k of the cross-covariance of the associated image with image k.	1	BCS-A	NA	<u>Y or N</u>	C
Image-Space Adjustable Parameters						
...if (APTYP=I)						

NISAP	<u>Number of Image-Space Adjustable Parameters.</u> This field contains the total number of image-space adjustable parameters. If the basis option is off (APBASE=N), specified image-space adjustable parameters are the active RSM adjustable parameters. The total number of image-space adjustable parameters is constrained as follows: (0<NPAR=NISAP=(NISAPR + NISAPC)<37). NISAPR is the number of image-space adjustable parameters that affect the image row-coordinate, and NISAPC the number that affect the image column-coordinate. If the basis option is on (APBASE=Y), specified image-space adjustable parameters are the basis RSM adjustable parameters. The total number of image-space adjustable parameters making up the basis set is constrained as follows: (0<NBASIS=NISAP=(NISAPR + NISAPC)<100).	2	BCS-A	N/A	1-36 (if APBASE=N) 1-99 (if APBASE=Y)	C
NISAPR	<u>Number of Image-Space Adjustable Parameters for Image Row Coordinate</u>. This field provides the total number of image-space adjustable parameters that adjust the image row coordinate The general form for the row coordinate adjustment (Δr) corresponding to an adjustable parameter (ap) is as follows: $\Delta r = ap_{rijk} \cdot x^{i} \cdot y^{j} \cdot z^{k}$, where i,j,k are the corresponding powers of normalized Local coordinates x,y,z, respectively. Each adjustable parameter has units of pixels.	2	BCS-A	N/A	0-36 (if APBASE=N) 0-99 (if APBASE=Y)	C
…Begin for each image-space adjustable parameter for row adjustment (NISAPR entries)						
XPWRR	<u>Row Parameter Power of X</u>. The power (exponent) of x associated with this image-space adjustable parameter for image row adjustment. This power along with the following two powers (fields) uniquely specify the adjustable parameter. x is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image row coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
YPWRR	<u>Row Parameter Power of Y</u>. The power (exponent) of y associated with this image-space adjustable parameter for image row adjustment. y is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image column coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C

ZPWRR	Row Parameter Power of Z. The power (exponent) of z associated with this image-space adjustable parameter for image row adjustment. z is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized geodetic height coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
...End for each active image-space adjustable parameter for row adjustment						
NISAPC	Number of Image-Space Adjustable Parameters for Image Column Coordinate. This field provides the total number of image-space adjustable parameters that adjust the image column coordinate. The general form for the column coordinate adjustment (Δc) corresponding to an adjustable parameter (ap) is as follows: $\Delta c = ap_{cijk} \cdot x^i \cdot y^j \cdot z^k$, where i,j,k are the corresponding powers of normalized Local coordinates x,y,z, respectively. Each adjustable parameter has units of pixels.	2	BCS-A	N/A	0-36 (if APBASE=F) 0-99 (if APBASE=T)	C
…Begin for each image-space adjustable parameter for column adjustment (NISAPC entries)						
XPWRC	Column Parameter Power of X. The power (exponent) of x associated with this image-space adjustable parameter for image column adjustment. This power along with the following two powers (fields) uniquely specify the adjustable parameter. x is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image row coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
YPWRC	Column Parameter Power of Y. The power (exponent) of y associated with this image-space adjustable parameter for image column adjustment. y is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image column coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
ZPWRC	Column Parameter Power of Z. The power (exponent) of z associated with this image-space adjustable parameter for image column adjustment. z is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized geodetic height coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
...End for each image-space adjustable parameter for column adjustment						
...end if (APTYP=I)						
Ground-Space Adjustable Parameters						
...if(APTYP=G)						

NGSAP	<u>Number of Ground-Space Adjustable Parameters</u> This field provides the total number of ground-space adjustable parameters. Each ground-space adjustable parameter is either associated with a "seven parameter" adjustment or is a first order "rate" term. The general form for the seven parameter adjustment is: $\begin{bmatrix} dx \\ dy \\ dz \end{bmatrix} = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix},$ where the vector on the left side of the equation is the ground-space adjustment in Local rectangular ground coordinates (meters), the vector on the far right side of the equation is the ground point location in normalized Local rectangular ground coordinates. The seven parameters $\delta x, \delta y, \delta z, \delta\alpha, \delta\beta, \delta\kappa, \delta s$, are termed x-offset, y-offset, z-offset, rotation angle alpha, rotation angle beta, rotation angle kappa, and scale. For identification purposes in the field below, these seven parameters are assigned 4 character identifications "OFFX", "OFFY" ,"OFFZ", "ROTX", "ROTY", "ROTZ", "SCAL", respectively. Each has units of meters. There a total of 9 possible rate terms $ap_{xx}, ap_{xy},.., ap_{zz}$, termed "XRTX", "XRTY", "XRTZ", "YRTX", "YRTY", "YRTZ", "ZRTZ", "ZRTY, "ZRTZ, respectively. Their effect is illustrated as follows for the adjustable parameter "XRTY" (ap_{xy}) and corresponding adjustment Δx: $\Delta x = ap_{xy} y$. If the basis option is off (APBASE=N), specified ground-space adjustable parameters are the active RSM adjustable parameters. If the basis option is on (APBASE=Y), specified ground-space adjustable parameters are the basis RSM adjustable parameters. The total number of ground-space adjustable parameters (NGSAP) is constrained to be between 1 and 16 regardless the value of APBASE, i.e., regardless if the basis option is on or off. If the basis option is off, NPAR=NGSAP. If the basis option is on, NBASIS=NGSAP.	2	BCS-A	N/A	1-16	C
…Begin for each ground-space adjustable parameter (NGSAP entries)						

GSAPID	Ground-space Adjustable Parameter ID. This field identifies a ground-space adjustable parameter.	4	BCS-A	N/A	OFFX,OFFY,OFFZ, ROTX,ROTY,ROTZ, SCAL, XRTX, XRTY,XRTZ, YRTZ,YRTY,YRTZ, ZRTX,ZRTY,ZRTZ	C
...End for each ground-space adjustable parameter						
...end if (APTYP=G)						
...if (APBASE=Y)						
NBASIS	Number of Basis Adjustable Parameters. This field contains the number of RSM adjustable parameters in the basis set. It is equal to the number of columns in the matrix A. NBASIS=NISAP or NGSAP, depending on whether the previously identified adjustable parameters were image-space or ground-space adjustable parameters. The number of columns must be no less than the number of rows in the matrix A, i.e., NBASIS$\geq$NPAR. The size of the matrix A is also constrained such that NPAR*NBASIS≤ 1296 .		BCS-N	N/A	1-99	C
...Begin for each A element (NPAR*NBASIS entries)						
AEL	Matrix A Element. This field contains an element of the matrix A. The elements are stored in row major order.	21	BCS-A	N/A	$\pm$9.99999999999999E$\pm$99	C
...End loop over elements of matrix A						
...end if (APBASE=Y)						
RSM Adjustment Vector values						
…Begin for each RSM Adjustment Vector component for the associated image (NPAR entries)						
PARVAL	Component Value. This field contains the value contained in the next component of the RSM Adjustable Parameter Vector.	21	BCS-A	N/A	$\pm$9.99999999999999E$\pm$99	R
…End for each component						

Table 8: RSMAPB TRE Format Table

12 RSM INDIRECT ERROR COVARIANCE (RSMECA) TRE

12.1 OVERVIEW

The Replacement Sensor Model Error Covariance version A TRE (RSMECA) contains general error covariance information. The corresponding error covariance generated from this information is termed the RSM indirect error covariance. Errors correspond to a specified set of (active) RSM adjustable parameters. Note that in general, the RSM indirect error covariance provides a statistical description of image support data error.

The indirect error covariance can correspond to an arbitrary number of pixel locations from an arbitrary number of images from the same sensor. (All the images have different original full image IDs.) Each of these images has the same set of (active) RSM adjustable parameters. In order to generate an indirect error covariance associated with multiple images, an RSMEC TRE from each image must be used.

More specifically, the information contained in the RSMECA TRE allows for generation of an error covariance for the RSM adjustable parameter group at multiple times (or equivalently, multiple pixel locations) within one or more correlated images (actually, within their RSM image domains) from the same sensor. If there are a total of n pixel locations of interest and m specified RSM adjustable parameters per image, the indirect error covariance generated will be an $nm \times nm$ matrix.

The RSM indirect error covariance is relative to errors in the RSM adjustable parameter values. The actual values of the RSM adjustable parameters are provided in the RSMAPA TRE for each image involved. For a given image, if the corresponding RSMAPA TRE is not provided, the corresponding RSM adjustable parameter values are assumed equal to zero, corresponding to unadjusted RSM image support data.

The indirect error covariance is typically applicable when the RSM image support data is unadjusted, i.e., not the result of an RSM triangulation. Also, it is typically used in the support of subsequent geopositioning, or “target” extraction. In general, an arbitrary number of images containing an arbitrary number of targets can be utilized simultaneously by the geopositioning solution process. The corresponding target image measurements, their mensuration error covariance, and indirect error covariance can then be combined by the solution process to provide an optimal estimate of target positions and their associated error covariance.

12.2 GROUPS OF ERROR COVARIANCE INFORMATION

The RSMECA TRE contains the following specific groups of information required to construct the indirect error covariance. If the indirect error covariance is applicable to other images in addition to the associated image, the RSMECA TRE from each of these images is also required. The groups of information are:

1. Error covariance of the original sensor model adjustable parameters applicable at an arbitrary time (pixel location) in the associated image's RSM image domain. An error covariance is actually supplied for each independent subset of original adjustable parameters. These error covariances are block diagonals within the full error covariance (with block zero's elsewhere). The field NUMOPG specifies the number of original adjustable parameters and the field ERRCVG specifies the actual error covariance element values for an independent subset. Note that this data does not actually describe (or rely on a description of) the original sensor model adjustable parameters. Thus, no knowledge of the original sensor model is provided or needed for successful RSMECA TRE implementation. (Of course, knowledge of the original sensor model is required for RSMECA TRE generation prior to its dissemination via the RSM image support data.) The membership of the (unknown) adjustable parameters within each independent subgroup is assumed invariant across the correlated images.
2. A time correlation model for the above errors that allows for generation of the cross-covariance of original sensor model adjustable parameter errors at two different times. There are multiple time correlation models, each associated with a different, independent subset of original sensor model adjustable parameters. All of these models have a common form – a piece-wise linear, non-negative, convex function. The function has a "starting" correlation value of one at tau equal to zero, and has a correlation "floor" value of zero for large values of tau. Tau (τ) is the correlation function's independent variable, a time difference for this particular application. The fields TCDF, NCSEG, CORSEG, and TAUSEG define the correlation function for an independent subset of original adjustable parameters. For a given independent subset, the corresponding value of TCDF is assumed invariant across the correlated images.
3. Identification of the applicable (active) RSM adjustable parameters and their index into the RSM error cross-covariance. There are a total of 36 potential RSM adjustable parameters – 20 RSM image-space adjustable parameters (contiguous fields IRO through ICZZ), and 16 RSM ground-space adjustable parameters (contiguous fields GXO through GZZ). A value of all spaces in a field indicates that the corresponding adjustable parameter is not "active". Otherwise, its value equals the index of the active adjustable parameter into the RSM error cross-covariance matrix. The RSM error cross-covariance is applicable to errors in the values of the active adjustable parameters at two (possibly the same) times or pixel locations, and is described in more detail below. Also, the definition of the

ground coordinate system referenced by the RSM adjustable parameters is provided.

4. A mapping matrix for the associated image that relates the error covariance associated with the original sensor model adjustable parameters to an error covariance associated with the RSM adjustable parameters. Field MAP contains the value of the mapping matrix elements. Note that the mapping matrix is different in value (not dimension) for each correlated image.

Note that most sensors require between 5 to 12 active RSM adjustable parameters for an image, either all image-space or all ground-space adjustable parameters. Space-borne sensors typically utilize image-space adjustable parameters

12.3 INDIRECT ERROR COVARIANCE FORM

The following further describes and integrates the above groups (1-4) of indirect error covariance information. Define CR as the indirect error covariance corresponding to a total of n pixel locations within the same or different images (RSM image domains). Assume m active RSM adjustable parameters per image. Define $p = n \cdot m$. CR is a $p \times p$ symmetric matrix:

$$CR = \begin{bmatrix} C_{R11} & C_{R12} & . & . & C_{R1n} \\ . & C_{R22} & . & . & . \\ . & . & . & C_{Rij} & . \\ . & . & . & . & . \\ . & . & . & . & C_{Rnn} \end{bmatrix}.$$

C_{Rij} is the cross-covariance between the errors in the active RSM adjustable parameters at the time of pixel i and at the time of pixel j. It has dimension $m \times m$, and is computed as follows:

$$C_{Rij} = \Phi_{i*} C_{Sij} \Phi_{j*}^T,$$

where Φ_{i*} is the mapping matrix corresponding to the image $i*$ that contains pixel i, and Φ_{j*} is the mapping matrix corresponding to the image $j*$ that contains pixel j. C_{Sij} is the cross-covariance between the errors in the original sensor model adjustable parameters at the time of pixel i and at the time of pixel j. (Note that when $i = j$, the RSM error cross-covariance C_{Rij} becomes the RSM error covariance C_{Rii} for the active RSM adjustable parameters at the time of pixel i.)

As mentioned previously, C_{Rij} is applicable to the active RSM adjustable parameters, their identities invariant across the correlated images. For a given active adjustable parameter, it's field (e.g. IRO) contained in the RSMECA TRE for any of the correlated images has a value equal to the index into C_{Rij}. For example, if the field value is 3, row 3 of C_{Rij} corresponds to the error in the value of this active adjustable parameter applicable at the time of pixel i, and column 3 of C_{Rij} corresponds to the error in the value of this active adjustable parameter applicable at the time of pixel j.

C_{Sij}, used in the computation of C_{Rij}, is computed from the original sensor model adjustable parameter error covariance C_{Si*} associated with image $i*$, the corresponding time correlation function $\rho_{Si*}(\tau)$ associated with image $i*$, and the (absolute) time difference τ between pixels i and j:

$$C_{Sij} = \rho_{Si*}(\tau)C_{Si*} = \begin{bmatrix} \rho_{Si*1}(\tau)C_{Si*1} & 0 & . & . & 0 \\ . & . & . & . & . \\ . & . & \rho_{Si*k}(\tau)C_{Si*k} & . & . \\ . & . & . & . & 0 \\ . & . & . & . & \rho_{Si*w}(\tau)C_{Si*w} \end{bmatrix}.$$

The symmetric C_{Sij} is in block diagonal form. The individual C_{Si*k} and $\rho_{Si*k}(\tau)$ correspond to the error covariance and scalar time correlation function for the independent subgroup k of original adjustable parameters. Since $\rho_{Si*k}(\tau)$ is a scalar function of τ, if C_{Si*k} is $m_k \times m_k$, then $\rho_{Si*k}(\tau)C_{Si*k}$ is an $m_k \times m_k$ diagonal block of C_{Sij}. A total of w subgroups is assumed.

The above formulation for C_{Sij}, and hence C_{Rij}, assumes that C_{Si*k} and $\rho_{Si*k}(\tau)$ are invariant across images ($i*$) when multiple images are involved. This corresponds to a wide-sense stationary stochastic error model and is applicable to most applications involving the use of the RSMECA TRE. If instead, a higher fidelity non-stationary stochastic error model is applicable as indicated by variable values of C_{Si*k} and/or $\rho_{Si*k}(\tau)$ across the images, additional processing is required in order to ensure a valid (positive semi-definite) indirect error covariance CR. The additional processing is detailed later in this RSMECA TRE description.

Note that, in general, all errors (ε) referenced in the various RSM TRE descriptions are assumed unbiased, i.e., $E\{\varepsilon\} = 0$. In addition, the term "independent subgroups" of adjustable parameters actually refers to uncorrelated errors associated with adjustable parameters from the different subgroups (i.e., $E\{\varepsilon 1 \cdot \varepsilon 2\} = 0$, where $\varepsilon 1$ represents the error in an adjustable parameter from independent subgroup 1, and $\varepsilon 2$ represents the error in an adjustable parameter from independent subgroup 2.)

As mentioned previously, the fields TCDF, NCSEG, CORSEG, and TAUSEG define the correlation function for an independent subset (subgroup) of original adjustable parameters. There are multiple linear segments i ($i = 1,..N$) associated with a correlation function, as specified by the value of N (NCSEG). Each of these segments has a corresponding correlation value ρ_i (CORSEG) and correlation time value τ_i (TAUSEG) applicable at the beginning of the segment. Thus, the value of a correlation function $\rho(\tau)$ (e.g. $\rho_{Si*k}(\tau)$) for a given value of τ is as follows (see Figure 15):

$$\rho(\tau) = \begin{cases} \rho_i + \dfrac{(\rho_{i+1} - \rho_i)(\tau - \tau_i)}{(\tau_{i+1} - \tau_i)} & , \tau_i \le \tau < \tau_{i+1} \\ 0 & , \tau_N \le \tau \end{cases} .$$

Note that τ_N is also termed the "cut-off" time, or τc.

The above equation is applicable to original adjustable parameter errors modeled as "image element" errors, as specified by a value of 0 in the field TCDF. (An "image element" is that portion of an image that has a unique time of imaging assigned to it, per the time model contained in the RSMID TRE for that image.) If the value of TCDF is 2, errors are modeled as "restricted image element" errors, and the above equation is only applicable when τ represents the time difference between two pixels in the same image. If the two pixels are from different images, then $\rho(\tau) = 0$ for all values of τ.

If the value of TCDF is 1, errors are modeled as "image" errors, and the above equation is applicable regardless the images associated with the two pixels; however, the definition of τ is changed from the time between two pixels, to the time between the two images that the two pixels are from. (The "image element", in this case, "becomes" the entire RSM image domain.) The time of an image is defined as the time of its center pixel within the RSM image domain. Thus, if the two images are the same image, τ has a value of zero. And, in particular, two pixels from the same image have a correlation value of 1.0. Note that, regardless the value of the field TCDF, if the two pixels associated with the time difference τ are the same pixel, or actually within the same image element, $\tau = 0$ and $\rho(\tau) = 1.0$.

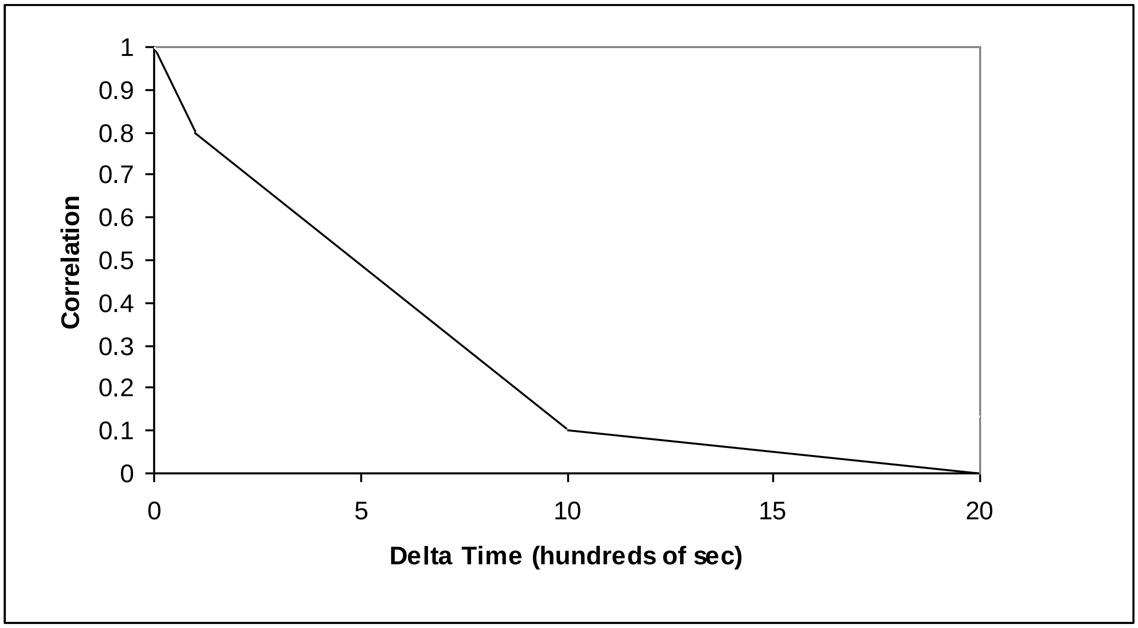

Figure 15: Example of Piece-Wise Linear Correlation Function $\rho(\tau)$

12.3.1 ADDITIONAL COMPUTATIONS IF NON-STATIONARY STOCHASTIC ERROR MODEL

As mentioned previously, when the values of C_{Si^*k} and/or $\rho_{Si^*k}(\tau)$ vary across the images i^*, original adjustable parameter errors associated with independent subgroup k are modeled as non-stationary stochastic errors. The error model is an approximation based on the combination of q wide-sense stationary error models, each associated with an image referenced by the indirect error covariance ($1 \le i^* \le q$). Each wide-sense stationary error model is based on the original sensor model error covariance and time correlation data contained in the corresponding image's RSMECA TRE.

(Note that although the values of C_{Si^*k} and/or $\rho_{Si^*k}(\tau)$ vary across the images i^* in the non-stationary case, the associated original adjustable parameters (identities) and their type of error remain invariant across the images i^* for each subgroup k. In particular, the values of fields ERRCVG, NCSEG, CORSEG, and TAUSEG may vary, but the values of fields IGN, NUMOPG, and TCDF do not.)

Computation of the RSM indirect error covariance in support of a non-stationary stochastic error model is identical to that specified previously for an assumed wide-sense stationary stochastic error model, with exceptions detailed below.

The block entry of C_{Sij} corresponding to independent subgroup k and images i^* and j^* is modified as follows: $\rho_{Si^*k}(\tau)C_{Si^*k} \rightarrow \bar{\rho}_{Si^*j^*k}(\tau)C_{Si^*k}^{1/2}C_{Sj^*k}^{T/2}$. The matrix superscripts correspond to a matrix square root based on a Cholesky factorization (decomposition) of the corresponding error covariance matrix, i.e., for a general positive definite error covariance C, $C = C^{1/2}C^{T/2}$, where $C^{1/2}$ is in lower triangular form and its transpose $C^{T/2}$ is in upper triangular form.

The scalar correlation function $\bar{\rho}_{Si^*j^*k}(\tau)$ is an "ensemble" correlation function, and consists of an average of correlation functions, each correlation function associated with an image that is correlated with both image i^* and image j^*, i.e., $\bar{\rho}_{Si^*j^*k}(\tau) = (1/n_{r^*})\sum_{r^*}\rho_{Sr^*k}(\tau)$, where each image r^* is correlated with both images i^* and j^*. There are a total of $n_{r^*} \le q$ such images. (The independent subgroup k is also applicable, but no longer mentioned for ease of description.)

In general, two images are correlated either directly or indirectly. If the (piece-wise linear decay) correlation function for image i^* decays to zero at the "cut-off" time τc_{i^*}, and the correlation function for image j^* decays to zero at the "cut-off" time τc_{j^*}, images i^* and j^* and directly correlated when $\tau b_{i^*j^*} \le \max(\tau c_{i^*}, \tau c_{j^*})$, where $\tau b_{i^*j^*}$ is defined as the smallest time interval possible between an arbitrary pixel location in image i^* and an arbitrary pixel location in image j^*.

Two images i^* and j^* are indirectly correlated if there is a "chain" of directly correlated images that "connects" them. For example, if image i^* is directly correlated with image a^*, and image a^* is directly correlated with image b^* , and image b^* is directly correlated with image j^*.

The following are examples of groups of correlated images, where t_{i^*} designates image i^*'s time of first pixel (seconds), and dt_{i^*} designates its image "scan" duration (seconds):

(1) images 1^* , 2^*, 3^*; $t_{1^*} = 0$, $t_{2^*} = 100$, $t_{3^*} = 300$; $dt_{1^*} = dt_{2^*} = dt_{3^*} = 10$; $\tau c_{1^*} = \tau c_{2^*} = \tau c_{3^*} = 3000$; all possible image pairs are directly correlated, thus the ensemble correlation function applicable to any image pair (i^*, j^*) within the set of three images is the same function, $\bar{\rho}_{Si^*j^*k}(\tau) = (1/3)[\rho_{S1^*k}(\tau) + \rho_{S2^*k}(\tau) + \rho_{S3^*k}(\tau)]$.

(2) images 1^* , 2^*, 3^*, 4^*, 5^*; $t_{1^*} = 0$, $t_{2^*} = 100$, $t_{3^*} = 4000$, $t_{4^*} = 6000$, $t_{5^*} = 8000$; $dt_{1^*} = dt_{2^*} = dt_{3^*} = dt_{4^*} = dt_{5^*} = 10$; $\tau c_{1^*} = \tau c_{2^*} = 1000$, $\tau c_3 = \tau c_4 = \tau c_5 = 3000$; there are two different sets of correlated images $\{1^*, 2^*\}$, via direct correlation, and $\{3^*, 4^*, 5^*\}$, via direct and indirect correlation; when image pair (i^*, j^*) is from the first set, $\bar{\rho}_{Si^*j^*k}(\tau) = (1/2)[\rho_{S1^*k}(\tau) + \rho_{S2^*k}(\tau)]$, when

from the second set, $\bar{\rho}_{Si^*j^*k}(\tau) = (1/3)[\rho_{S3^*k}(\tau) + \rho_{S4^*k}(\tau) + \rho_{S5^*k}(\tau)]$, and when i^* is in one set and j^* in the other, $\bar{\rho}_{Si^*j^*k}(\tau) = 0$.

The remainder of this RSMECA TRE description is independent of whether errors are modeled as wide-sense stationary or non-stationary stochastic errors.

12.3.2 COMPARISON TO DIRECT ERROR COVARIANCE

Note that an RSM indirect error covariance, assembled with TCDF=1 (“image” errors) for all original adjustable parameters and corresponding to one pixel in each of n images from the same sensor, has a correspondence to the RSM direct error covariance (RSMDCA TRE). It has the same external form as the direct error covariance - both the indirect error covariance and the direct error covariance reference n sets of RSM adjustable parameter “image” errors across the n images. (Each set in the n sets of corresponding RSM adjustable parameters reference the same active RSM adjustable parameter definitions.) In particular, assuming all n images were known prior to TRE generation, a direct error covariance could be built identical to the assembled indirect error covariance.

However, in general, the direct error covariance can be more general internally than the indirect error covariance. That is, the correlation between RSM adjustable parameters (errors) between images does not have to conform to an a priori model (piece-wise linear decay for associated original adjustable parameter errors) inherent with the indirect error covariance. The direct error covariance can also be more general externally – it can correspond to images from different sensors with different sets of active RSM adjustable parameters. On the other hand, if the number of images (n) is reasonably large and from the same sensor, the direct error covariance’s RSMDCA TRE requires more image support data bandwidth than does the indirect error covariance’s RSMECA TRE. Also, all images referenced by the direct error covariance must be specifically identified prior to its generation, and all RSM adjustable parameter errors can be modeled as “image” errors (TCDF=1) only. Neither of these restrictions apply to the indirect error covariance.

12.3.3 INDIRECT ERROR COVARIANCE IN “DIRECT ERROR COVARIANCE FORM”

The RSM indirect error covariance can be built in a “direct error covariance form”, directly suitable for use in a triangulation solution process, if so desired. In the “direct error covariance form”, the indirect error covariance is applicable to the specified images, but independent of image row/column location(s). If there are k images and m adjustable parameter per image, the indirect error covariance is a $km \times km$ matrix. All errors in each independent subgroup are assumed “image” errors, as opposed to “image element” or “restricted image element” errors, regardless the value of the TCDF field in the RSMECA TRE. (This is an approximation when the TCDF value specifies either "image element" or "restricted image element" errors. It is not an approximation when the TCDF value specifies "image" errors, as they are 100% positively correlated across all pixel locations in the image, by definition.) In addition, if the TCDF field for a particular independent subgroup specifies "image element" errors, the corresponding time correlation function is assumed applicable to the time between images. If the TCDF field specifies "restricted image element" errors, the correlation between images is assumed zero.

The remainder of this RSMECA description assumes that the RSM indirect error covariance is not in "direct error covariance form", i.e., it is generally applicable to multiple pixel locations per image and multiple images, as described earlier.

12.4 ADJUSTABLE PARAMETER DEFINITIONS IN SUPPORT OF THE INDIRECT ERROR COVARIANCE

12.4.1 OVERVIEW

As mentioned previously, the active RSM adjustable parameters for the associated image (and for all other correlated images) are identified in this TRE (RSMECA). The RSM error cross-covariance C_{Rij} is relative to the errors in the values of these adjustable parameters at the time associated with pixel i and the errors in the values of these adjustable parameters at the time associated with pixel j. Thus, application of C_{Rij} (and the entire indirect error covariance CR, as well) requires the complete definition of these adjustable parameters. In particular, the definition is required in order to compute the partial derivatives of image measurements with respect to the set of adjustable parameters referenced by the RSM error cross-covariance, in support of error propagation. The following provides remaining details.

12.4.2 LOCAL COORDINATE SYSTEM DEFINITION

The adjustable parameters for the associated image reference a secondary, rectangular coordinate system – termed the "Local coordinate system." That is, their application to adjust the RSM ground-to-image function for a given ground point, requires the representation of that ground point in the Local coordinate system. Typically, this system is a local tangent plane system centered within the RSM image domain's footprint at a nominal height above the ellipsoid and rotated to be aligned as follows: the z-axis is aligned with the imaging locus direction (line-of-sight vector for an electro-optical sensor), the x-axis is aligned with the image line ("sweep") direction, and the y-axis completes a right-handed rectangular system. Figure 16 illustrates a typical RSM Local coordinate system. It is defined by an offset and rotation relative to the WGS 84 Rectangular coordinate system, as detailed later. If X represents the ground point in the RSM primary ground coordinate system, let $X*$ represent the ground point in the

Local coordinate system. Note that the specific Local coordinate system varies from image to image.

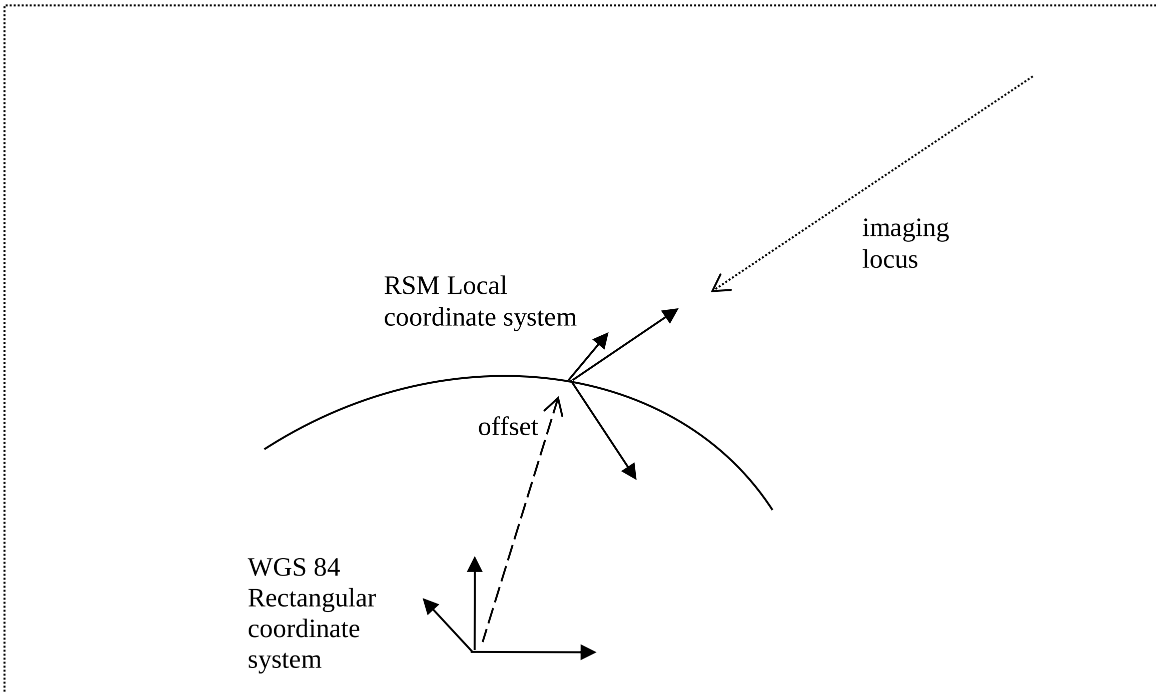

Figure 16: Example of RSM Local Coordinate System

12.4.3 EFFECT ON RSM GROUND-TO-IMAGE FUNCTION AND PARTIAL DERIVATIVES

The RSM ground-to-image function (e.g., rational polynomial) outputs a two dimensional image point $I = [r \quad c]^T$ corresponding to a three-dimensional ground point $X = [x \quad y \quad z]^T$ input. The summed effects $\Delta I = [\Delta r \quad \Delta c]^T$ of all active image-space adjustable parameters are used to modify the output of the RSM ground-to-image function, i.e. $I \rightarrow I + \Delta I$. Similarly, the summed effects $\Delta X = [\Delta x \quad \Delta y \quad \Delta z]^T$ of all active ground-space adjustable parameters are used to modify the input to the RSM ground-to-image function, i.e., $X \rightarrow X + \Delta X$, represented in the RSM primary ground coordinate system. The effect of each adjustable parameter, whether an image-space or ground-space adjustable parameter, is based on the value of the adjustable parameter and the value of the (unadjusted) ground point $X*$, as represented in the Local coordinate system. The actual relationship between an adjustable parameter's effect on either X or I, i.e. its contribution to ΔX or ΔI, is based on the value of the parameter, the value of (unadjusted) $X*$ in the Local coordinate system, and the definition of the adjustable parameter as provided in the descriptions for fields IRO through GZZ. For example, assume that the image-space adjustable parameter associated with field IRX is active and represented symbolically as

δr_x. The adjustable parameter's contribution to the modification of the row coordinate of I is defined as $\Delta r = \delta r_x \cdot x$, where x is the x-coordinate value of the ground point $X*$, expressed in the Local coordinate system. Therefore, the partial derivative of the row image coordinate with respect to the adjustable parameter is $\partial r / \partial(\delta r_x) = x$. The following further details the RSM adjustable parameters, their detailed definitions required in order to compute the various partial derivatives.

In general, the image-space adjustable parameters that affect the image row coordinate do so as follows: $r \to r + \Delta r$, where $\Delta r = \delta r \cdot x^i \cdot y^j \cdot z^k$. δr represents the particular adjustable parameter, x, y, z are the coordinates of the ground point $X*$ as represented in the Local coordinate system, and the powers i, j, k each have a value within the set $\{0,1,2\}$ and $(i + j + k) \leq 2$. Each adjustable parameter corresponds to a unique combination of powers. The above general description is also applicable to the image-space adjustable parameters that have an effect on the image column coordinate.

In general, ground-space adjustable parameters have an effect on the three dimensional components of the ground point X summarized as follows: the ground point is transformed to a Local coordinate system representation, $X \to X*$, the adjustable parameter(s) modify the ground point in the Local coordinate system representation, $X* \to (X* + \Delta X*)$, the adjusted ground point is transformed back to an RSM primary ground coordinate system representation, $(X* + \Delta X*) \to X'$, and the result is equivalent to a modification of the original ground point, $X' \Leftrightarrow (X + \Delta X)$. Individual ground-space adjustable parameters have varied functional forms associated with their effects on the ground point. The first seven fields associated with these adjustable parameters (GXO to GS) correspond to a standard photogrammetric seven parameter (small angle) transformation of $X*$, the remaining nine fields (GXX to GZZ) correspond to coefficients of polynomial correction terms, similar in form to those for Δr discussed previously. In particular, the seven parameter adjustment is defined as follows, where X_a^* represents the adjusted ground point in the Local coordinate system, and the symbols $\{\delta x \quad \delta y \quad \delta z \quad \delta\alpha \quad \delta\beta \quad \delta\kappa \quad \delta s\}$ correspond to the contiguous fields GXO to GS:

$$X_a^* = X^* + \Delta X^* = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} 1+\delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & 1+\delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & 1+\delta s \end{bmatrix} X^*, \text{ or}$$

$$\Delta X^* = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} X^*$$

An example of a ground-space adjustable parameter's effect (contribution to $\Delta X *$) corresponding to field GXR, represented symbolically as $\delta\alpha$, is as follows: $\Delta y = \delta\alpha \cdot z$ and $\Delta z = -\delta\alpha \cdot y$, $y \rightarrow y + \Delta y$ and $z \rightarrow z + \Delta z$, or more generally, $X* \rightarrow X * + \Delta X *$, where $\Delta X *^T = [0 \quad \Delta y \quad \Delta z]$. An example of the effect of the ground-space adjustable parameter corresponding to field GXY, represented as δx_y, is as follows: $\Delta x = \delta x_y \cdot y$, or more generally, $X* \rightarrow X * + \Delta X *$, where $\Delta X *^T = [\Delta x \quad 0 \quad 0]$.

The RSM adjustable ground-to-image function $h(X, R)$ integrates the RSM ground-to-image function with the adjustments, as illustrated in Figure 17. The RSM ground-to-image function $g(X)$ can be either a rational polynomial ($poly$) or an interpolated ground point - image point correspondence grid ($grid$). Both are functions of the ground point location (X) as well as the RSM image support data, such as polynomial coefficients or grid values. (The RSMPC TRE and RSMGG TRE describe the appropriate image support data, respectively.) RSM image-space adjustable parameters are applied through one adjustment function (I_adj) and RSM ground-space adjustable parameters are applied through another (X_adj). These functions simply generate the ΔI and ΔX corrections per the definitions of the active RSM adjustable parameters. Both are functions of ground point location (X), internally converted to an $X*$ representation, as well as the active RSM adjustable parameters (values) R contained in the RSMAPA TRE for the associated image. Application of the RSM adjustable parameters is independent of which RSM ground-to-image function is provided in the RSM image support data.

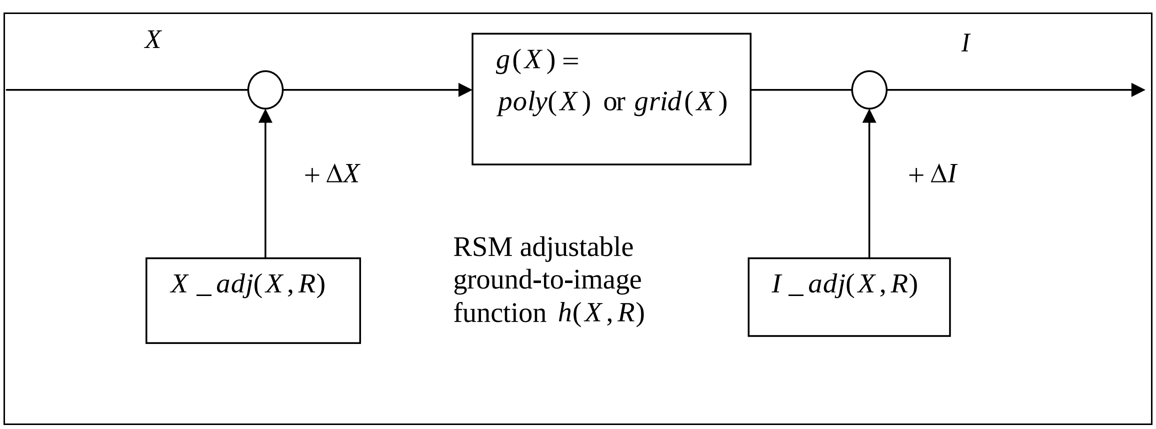

Figure 17: The RSM Adjustable Ground-to-Image Function

Note that the values of the RSM adjustable parameters are applicable to all pixel locations within the associated image's RSM image domain. That is, an RSM adjustable parameter's value is constant over the entire RSM image domain. However, its effect on the RSM ground-to-image function does vary with pixel (actually corresponding ground) location, as described above.

The above input X (and its correction ΔX) and output I (and its correction ΔI) of the RSM ground-to-image function are with respect to un-normalized coordinates. Evaluation of the RSM ground-to-image function is actually performed with respect to normalized coordinates. The RSM ground-to-image function handles all required normalization and un-normalization, as described in RSMPC TRE and RSMGG TRE.

In summary, the detailed definitions of the RSM adjustable parameters that were presented above are required in order to define the partial derivatives of the image measurement (I) with respect to the (active) adjustable parameters (R); in particular, in order to compute $\partial h / \partial R$. Assuming m adjustable parameters for the associated image, $\partial h / \partial R$ is a $2 \times m$ matrix.

12.4.4 LOCAL COORDINATE SYSTEM DETAILS

The following defines the Local coordinate system relative to the WGS 84 Rectangular coordinate system. The contiguous fields XUOL through ZUOL specify the origin (offset) of the Local coordinate system relative to the WGS 84 Rectangular coordinate system, and the contiguous fields XUXL through ZUZL the rotation. These fields are provided in this TRE.

$$X^* = \begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{LOCAL}} = \begin{bmatrix} XUXL & YUXL & ZUXL \\ XUYL & YUYL & ZUYL \\ XUZL & YUZL & ZUZL \end{bmatrix} \cdot \left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{WGS-84}} - \begin{bmatrix} XUOL \\ YUOL \\ ZUOL \end{bmatrix} \right).$$

Note that the definition of the Local (rectangular) coordinate system is also (redundantly) supplied in the TREs RSMAPA and RSMDCA for the associated image, when available. Also, in order to convert a ground point X represented in the RSM primary ground coordinate system (e.g., Geodetic) to the Local coordinate system, it must first be converted from the RSM primary system to the WGS 84 Rectangular coordinate system.

12.5 UNMODELED ERROR COVARIANCE

The RSMECA TRE may also contain information specifying an unmodeled error covariance corresponding to multiple pixel locations within the associated image's RSM image domain. Unmodeled errors represent the summed effects of all errors that cannot be represented as RSM adjustable parameter errors. If present, they are typically relatively non-systematic, "high frequency" errors.

Representation of unmodeled errors is done directly in image space. The corresponding unmodeled error covariance is applicable to errors at an arbitrary time (pixel location) in the associated image's RSM image domain. These unmodeled errors are also assumed correlated between pixel locations, as represented by a correlation model as a function of number of rows between pixel locations and a correlation model as a function of number of columns between pixel locations. The unmodeled errors are assumed uncorrelated between images. Specifically, the unmodeled error covariance (CU) for the associated image is defined as follows:

$$CU = \begin{bmatrix} C_{U11} & C_{U12} & . & . & C_{U1q} \\ . & C_{U22} & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & C_{Uqq} \end{bmatrix},$$

where there are an assumed q pixel locations of interest within the RSM image domain, and C_{Uij} is the 2×2 error cross-covariance between pixels i and j given by:

$$C_{Uij} = \rho_U(\Delta u_{ij})\rho_V(\Delta v_{ij})C_U \ .$$

The upper triangular portion of the symmetric 2×2 error covariance C_U is specified in the fields URR, URC, and UCC. The correlation function $\rho_U(\Delta u_{ij})$ is specified in the fields UNCSR, UCORSR, and UTAUSR. The correlation function $\rho_V(\Delta v_{ij})$ is specified in the fields UNCSC, UCORSC, and UTAUSC. The row and column distances between pixels i and j are defined as Δu_{ij} and Δv_{ij}, respectively. Both the scalar correlation functions $\rho_U(\Delta u_{ij})$ and $\rho_V(\Delta v_{ij})$ are of the same form as the correlation function used for the indirect error covariance. However, τ is redefined from being the time between pixels to the distance (number of rows or columns) between pixels. Also, there is no explicit counterpart to the field TCDF for these functions. Unmodeled errors are assumed "restricted image element errors", where the image element is the pixel.

Note that unmodeled errors are typically not applicable. Also, if unmodeled errors are applicable, modeled errors can be represented by either the indirect error covariance (RSMECA) or the direct error covariance (RSMDCA). For both of these reasons, the unmodeled error covariance information is conditional within this (RSMECA) TRE, as defined by fields INCLIC and INCLUC. If the RSM support data for the associated image contains both the RSMECA TRE and the RSMDCA TRE, the latter takes precedence for modeled errors, and the former specifies unmodeled error if INCLUC=Y.

12.6 COVARIANCE MATRIX ELEMENT ORDERING

Finally, regarding the ordering of matrix elements in this TRE, the error covariance associated with the original sensor model adjustable parameters for a particular independent subgroup is in an upper triangular form. The upper triangular matrix is provided in row major order (the top row first, followed by the second row less the leftmost column, all the way to the rightmost element of the bottom row).

The mapping matrix is in row major order with one row per RSM adjustable parameter and one column per original adjustable parameter. Note that it is not in upper triangular form.

12.7 RSMECA FORMAT

Table 9 specifies the detailed format for the Replacement Sensor Model Error Covariance (RSMECA) TRE.

RSMECA – Replacement Sensor Model Error Covariance						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Value Range**	**Type**
			TAG Information			
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMECA	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	bytes	354 to 43045 Typical value equals 2060	R
			Image Information			
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R

TID	Triangulation ID. This field contains an identifier that is unique to the most recent process after RSM support data generation that led to the adjustments and/or error covariance in this RSM support data edition. The field value is all spaces if there has been no such process.	40	BCS-A	N/A	N/A Default is all spaces	<R>
INCLIC	Include Indirect Error Covariance Flag. If the value of this field is Y, the indirect error covariance information is included in this TRE.	1	BCS-A	N/A	Y or N	R
INCLUC	Include Unmodeled Error Covariance Flag. If the value of this field is Y, the unmodeled error covariance information is included in this TRE.	1	BCS-A	N/A	Y or N	R
…if (INCLIC = Y) then include the following fields:						
NPAR	Number of RSM Adjustable Parameters. This field contains the number of (active) RSM adjustable parameters of the associated image. It is the dimension of both the row and the column dimensions of the (mapped) RSM image error covariance. The maximum allowed number of RSM adjustable parameters is 36.	2	BCS-N	N/A	01 t0 36	C
NPARO	Number of Original Adjustable Parameters. This field contains the number of original adjustable parameters of the associated image. It is both the row and column dimensions of the (unmapped) original image error covariance. The maximum allowed number of original adjustable parameters is 36.	2	BCS-N	N/A	01 to 36	C
IGN	Number of Independent Subgroups. This field contains the number of independent adjustable parameter (error) subgroups associated with the original adjustable parameters of the associated image.	2	BCS-N	N/A	01 to 36	C
CVDATE	Version Date of the Original Image Error Covariance. Date representing the version of the error model applicable to the original image error covariance. If populated, and two images are from the same sequence of images from the same sensor, and if the values of CVDATE are different in the two RSMECA TREs, all original adjustable parameter (errors) are assumed uncorrelated between the images.	8	BCS-A	N/A	YYYYMMDD (YYYY=four digit year, MM=two digit month; DD=two digit day) Population optional Default is all spaces Value must correspond to a valid date	<C>
Local Coordinate System Definition for RSM Adjustable Parameters for the associated image						

XUOL	Local Coordinate Origin (XUOL). This field provides the WGS 84 X coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C
YUOL	Local Coordinate Origin (YUOL). This field provides the WGS 84 Y coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C
ZUOL	Local Coordinate Origin (ZUOL). This field provides the WGS 84 Z coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C
XUXL	Local Coordinate Unit Vector (XUXL). This field provides the WGS 84 X component of the unit vector defining the X-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
XUYL	Local Coordinate Unit Vector (XUYL). This field provides the WGS 84 X component of the unit vector defining the Y-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
XUZL	Local Coordinate Unit Vector (XUZL). This field provides the WGS 84 X component of the unit vector defining the Z-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
YUXL	Local Coordinate Unit Vector (YUXL). This field provides the WGS 84 Y component of the unit vector defining the X-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C

YUYL	Local Coordinate Unit Vector (YUYL). This field provides the WGS 84 *Y* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
YUZL	Local Coordinate Unit Vector (YUZL). This field provides the WGS 84 *Y* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
ZUXL	Local Coordinate Unit Vector (ZUXL). This field provides the WGS 84 *Z* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
ZUYL	Local Coordinate Unit Vector (ZUYL). This field provides the WGS 84 *Z* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
ZUZL	Local Coordinate Unit Vector (ZUZL). This field provides the WGS 84 *Z* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
RSM Adjustable Parameter-Error Covariance correspondence						
Image-space Adjustable Parameters						

IRO	Image Row Constant Index. This field provides the value of the index into the RSM error cross-covariance for the RSM adjustable parameter: constant offset adjustment of the image row position. A value of all spaces for the field specifies that this adjustable parameter is not active (not used). The RSM error cross-covariance C_{Rij} is applicable to the errors in the active RSM adjustable parameters at the time of pixel i and the errors in the active RSM adjustable parameters at the time of pixel j. For example, if the value of the field is 3, this particular adjustable parameter corresponds to row 3 and column 3 of the RSM error cross- covariance. In particular, when the two pixels (times) are the same, the (3, 3) element corresponds to the adjustable parameter's variance of error at the time of pixel i. The following 35 fields provide the same type of information as the IRO field, but each is associated with a different RSM adjustable parameter. All of the adjustable parameters reference Local (rectangular) ground coordinates x, y, and z. Note that the field IRO and following 19 fields are associated with image-space adjustable parameters, and the next 16 fields are associated with ground-space adjustable parameters. Together, they are the elements of the RSM Adjustable Parameter Choice Set.	2	BCS-A	N/A	01 to 36 All spaces if not used (adjustable parameter not active)	<C>
IRX	Image Row X Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
IRY	Image Row Y Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
IRZ	Image Row Z Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>

IRXX	Image Row X^2 Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
IRXY	Image Row XY Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point xy position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
IRXZ	Image Row XZ Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point xz position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
IRYY	Image Row Y^2 Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
IRYZ	Image Row YZ Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point yz position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
IRZZ	Image Row Z^2 Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z^2 position applied to the image row position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICO	Image Column Constant Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the constant offset adjustment of the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICX	Image Column X Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICY	Image Column Y Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>

ICZ	Image Column Z Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICXX	Image Column X^2 Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICXY	Image Column XY Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point xy position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICXZ	Image Column XZ Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point xz position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICYY	Image Column Y^2 Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICYZ	Image Column YZ Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point yz position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
ICZZ	Image Column Z^2 Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z^2 position applied to the image column position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
Ground-space Adjustable Parameters						
GXO	Ground X Constant Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the constant offset adjustment of the ground x position.	2	BCS-A	N/A	01 to 36 All spaces if not used (adjustable parameter not active)	<C>
GYO	Ground Y Constant Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the constant offset adjustment of the ground y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>

GZO	Ground Z Constant Index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the constant offset adjustment of the ground z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GXR	Ground Rotation X. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the small angle ground point rotation about the x-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GYR	Ground Rotation Y. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the small angle ground point rotation about the y-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GZR	Ground Rotation Z. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the small angle ground point rotation about the z-axis.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GS	Ground Scale. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the multiplicative ground point scale factor.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GXX	Ground X Adjustment Proportional to X index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x position applied to the ground point x position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GXY	Ground X Adjustment Proportional to Y index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y position applied to the ground point x position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GXZ	Ground X Adjustment Proportional to Z index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z position applied to the ground point x position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GYX	Ground Y Adjustment Proportional to X index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x position applied to the ground point y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GYY	Ground Y Adjustment Proportional to Y index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y position applied to the ground point y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>

GYZ	Ground Y Adjustment Proportional to Z index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z position applied to the ground point y position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GZX	Ground Z Adjustment Proportional to X index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point x position applied to the ground point z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GZY	Ground Z Adjustment Proportional to Y index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point y position applied to the ground point z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
GZZ	Ground Z Adjustment Proportional to Z index. The RSM error cross-covariance index associated with the following RSM Adjustable Parameter: the coefficient for ground point z position applied to the ground point z position.	2	BCS-A	N/A	01 to 36 All spaces if not used	<C>
Error Covariance Data						
…Begin for each original Adjustable Parameter independent error subgroup (IGN entries)						
NUMOPG	Number of Original Adjustable Parameters in Subgroup. This field contains the number of contiguous original adjustable parameters in this independent error subgroup. (Independent error subgroups are contiguous as well.)	2	BCS-N	N/A	01 to 36 Sum of IGN entries of NUMOPG must equal NPARO	C
…Begin for each element of the original image error covariance for this independent error subgroup (1/2(NUMOPG+1)(NUMOPG) entries)						
ERRCVG	Original Error Covariance Element. This field contains an original adjustable parameter error covariance element corresponding to the independent error subgroup. The elements correspond to the upper triangular portion of the error covariance. They are in row major order.	21	BCS-A	N/A	±9.99999999999999E±99 Collectively, the ERRCVG values for the subgroup must correspond to a positive definite error covariance matrix	C
…End for each element of the original image error covariance for the independent error subgroup						

TCDF	Time Correlation Domain Flag. This field defines the type of original adjustable parameter error, and hence, the corresponding correlation function domain, for this independent error subgroup. If this field is 0, the time correlation applies to all time intervals, both within and between images. The associated errors in the original adjustable parameters are "image element errors". If this field is 1, the time correlation applies to time intervals between images only. Time correlation for time intervals within an image is defined 100% positively correlated. The associated errors in the original adjustable parameters are "image errors". If this field is 2, the time correlation applies to time intervals within an image only. Time correlation for time intervals between images is defined as zero. The associated errors in the original adjustable parameters are "restricted image element errors".	1	BCS-N	N/A	0, 1, 2	C
NCSEG	Number of Correlation Segments. This field contains the number of piece-wise linear correlation segments that make up the correlation function for this independent error subgroup.	1	BCS-N	N/A	2 through 9	C
…Begin for each correlation segment (NCSEG entries)						
CORSEG	Segment Correlation Value. This field contains the correlation value applicable at the beginning of the segment. Note that the value is defined as one for the first segment (correlation segment=1), and defined as zero for the last segment (correlation segment=NCSEG). It is a nonnegative number for all segments, decreasing in value from one segment to the next.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.00000000000000E+00 (0 to +1) Value consistent with a non-negative, convex, piece-wise linear correlation function defined by NCSEG entries of CORSEG and TAUSEG	C

TAUSEG	Segment Tau Value. This field contains the correlation time (tau) applicable at the beginning of the segment. Note that the value is defined as zero for the first segment (correlation segment=1). It is a positive number for all other segments, increasing in value from one segment to the next. Note that the values of the fields CORSEG and TAUSEG for all the segments are further constrained such that the corresponding piece-wise linear correlation function is convex (non-positive and non-decreasing slope from one segment to the next). Also, the last segment is defined equal to zero for all tau greater than the last segment's TAUSEG value.	21	BCS-A	seconds	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value Value consistent with a non-negative, convex, piece-wise linear correlation function defined by NCSEG entries of CORSEG and TAUSEG	C
…End for each correlation segment						
…End for each independent error subgroup						
…Loop over mapping matrix elements ((NPAR)(NPARO) entries)						
MAP	Mapping Matrix Element. This field contains the value of the next mapping matrix element, stored in row major order. The mapping matrix is used to map the associated image's original error covariance to RSM error covariance. The mapping matrix has NPAR rows and NPARO columns.	21	BCS-A	N/A	±9.99999999999999E±99	C
…End loop over mapping matrix elements						
…End if (INCLIC = Y)						
…if (INCLUC = Y) then include the following fields:						
Unmodeled Error Covariance data						
URR	Unmodeled Row Variance. This field provides the variance of unmodeled error represented as an image row error.	21	BCS-A	pixels^2	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value	C
URC	Unmodeled Row-Column Covariance. This field provides the covariance between the unmodeled error represented as an image row error and unmodeled error represented as an image column error.	21	BCS-A	pixels^2	±9.99999999999999E±99 Collectively, URR, URC, and UCC values must correspond to a positive semi-definite (2x2) error covariance matrix	C
UCC	Unmodeled Column Variance. This field provides the variance of unmodeled error represented as an image column error.	21	BCS-A	pixels^2	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value	C
UNCSR	Number of Correlation Segments for independent variable ROW distance. This field contains the number of piece-wise linear correlation segments that make up the correlation function for unmodeled error with independent variable image row distance.	1	BCS-N	N/A	2 through 9	C
…Begin for each correlation segment (UNCSR entries)						

UCORSR	Segment Correlation Value. This field contains the correlation value applicable at the beginning of the segment. Note that the value is defined as one for the first segment (correlation segment=1), and defined as zero for the last segment (correlation segment=UNCSR). It is a nonnegative number for all segments, decreasing in value from one segment to the next.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.00000000000000E+00 (0 to +1) Value consistent with a non-negative, convex, piece-wise linear correlation function defined by UNCSR entries of field UCORSR and field UTAUSR	R
UTAUSR	Segment Tau Value. This field contains the correlation row distance (tau) applicable at the beginning of the segment. Note that the value is defined as zero for the first segment (correlation segment=1). It is a positive number for all other segments, increasing in value from one segment to the next. Note that the values of the fields UCORSR and UTAUSR for all the segments are further constrained such that the corresponding piece-wise linear correlation function is convex (non-negative and non-decreasing slope from one segment to the next). Also, the last segment is defined equal to zero for all tau greater than the last segment's UTAUSR value.	21	BCS-A	pixels	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value Value consistent with a non-negative, convex, piece-wise linear correlation function defined by UNCSR entries of field UCORSR and field UTAUSR	C
…End for each correlation segment						
UNCSC	Number of Correlation Segments for independent variable Column distance. This field contains the number of piece-wise linear correlation segments that make up the correlation function for unmodeled error with independent variable image column distance.	1	BCS-N	N/A	2 through 9	C
…Begin for each correlation segment (UNCSC entries)						
UCORSC	Segment Correlation Value. This field contains the correlation value applicable at the beginning of the segment. Note that the value is defined as one for the first segment (correlation segment=1), and defined as zero for the last segment (correlation segment=UNCSC). It is a nonnegative number for all segments, decreasing in value from one segment to the next.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.00000000000000E+00 (0 to +1) Value consistent with a non-negative, convex, piece-wise linear correlation function defined by UNCSC entries of field UCORSC and field UTAUSC	C

UTAUSC	Segment Tau Value. This field contains the correlation column distance (tau) applicable at the beginning of the segment. Note that the value is defined as zero for the first segment (correlation segment=1). It is a positive number for all other segments, increasing in value from one segment to the next. Note that the values of the fields UCORSC and UTAUSC for all the segments are further constrained such that the corresponding piece-wise linear correlation function is convex (non-negative and non-decreasing slope from one segment to the next). Also, the last segment correlation is defined equal to zero for all tau greater than the last segment's UTAUSC value.	21	BCS-A	pixels	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value Value consistent with a non-negative, convex, piece-wise linear correlation function defined by UNCSC entries of field UCORSC and field UTAUSC	C
…End for each correlation segment						
…End if (INCLUC = Y)						

Table 9: RSMECA TRE Format Table

13 RSM INDIRECT ERROR COVARIANCE (RSMECB) TRE

13.1 OVERVIEW

The Replacement Sensor Model Error Covariance version B TRE (RSMECB) contains general error covariance information applicable to correlated images from the same sensor. This information includes the error (auto) covariance for the associated image and a temporal correlation model used to build the error cross-covariance between images. The corresponding multi-image error covariance generated from this information is termed the RSM indirect error covariance. Errors correspond to a specified set(s) of active RSM adjustable parameters. Note that in general, the RSM indirect error covariance provides a statistical description of image support data error for one or more images.

The indirect error covariance can correspond to an arbitrary number of pixel locations (times) from an arbitrary number of images from the same sensor. (All the images have different original full image IDs.) In order to generate an indirect error covariance associated with multiple images, an RSMEC TRE from each image must be used.

If there are p_i pixel locations of interest and m_i active RSM adjustable parameters for image i, $i=1,..,n$, the indirect error covariance generated will be an $\sum_{i=1}^{n} p_i \cdot m_i \times \sum_{i=1}^{n} p_i \cdot m_i$ matrix. All images must correspond to the same sensor, but the set (identity) of active RSM adjustable parameters can vary from image to image in order to best represent the original sensor model's adjustability and error covariance across different imaging geometries. The set (identity) of adjustable parameters for the original sensor model is assumed invariant across the images.

The RSM indirect error covariance is relative to errors in the active RSM adjustable parameter values. The actual values of the RSM adjustable parameters are provided in the RSMAPB TRE for each image involved. For a given image, if the corresponding RSMAPB TRE is not provided, the corresponding RSM adjustable parameter values are assumed equal to zero, corresponding to unadjusted RSM image support data.

The indirect error covariance is typically applicable when image support data (original or RSM) is unadjusted, i.e., not the result of a triangulation. If a triangulation was performed, the direct error covariance (RSMDCB) is typically used to represent the error covariance. If both an indirect error covariance (RSMECB) and a direct error covariance (RSMDCB) are in the RSM TRE set for the associated image, the direct error covariance takes precedence. If in addition, an RSM adjustment has been performed as indicated by the presence of RSMAPB, the direct error covariance pertains to the adjusted RSM image support data and the indirect error covariance pertains to the unadjusted (*a priori*) RSM image support data.

13.2 GROUPS OF ERROR COVARIANCE INFORMATION

The RSMECB TRE contains the following specific groups of information required to construct the indirect error covariance. If the indirect error covariance is applicable to other images in addition to the associated image, the RSMECB TRE from each of these images is also required. The groups of information are:

1. Error (auto) covariance relative to the original sensor model adjustable parameters applicable at an arbitrary time (pixel location) in the associated image's RSM image domain. An error covariance is actually supplied for each independent subset of original adjustable parameters. These error covariances are block diagonals within the full error covariance (with block zero's elsewhere). The field NUMOPG specifies the number of original adjustable parameters and the field ERRCVG specifies the actual error covariance element values for an independent subset. Note that this data does not actually describe (or rely on a description of) the original sensor model adjustable parameters. Thus, no knowledge of the original sensor model is provided or needed for successful RSMECB TRE implementation. (Of course, knowledge of the original sensor model is required for RSMECB TRE generation prior to its dissemination via the RSM image support data.) The membership of the (unknown) adjustable parameters within each independent subgroup is assumed invariant across the correlated images. There are a total of NPARO original adjustable parameters for the associated image.
2. A time (temporal) correlation model for the above errors that allows for generation of the cross-covariance of original sensor model adjustable parameter errors at two different times. There are multiple time correlation models, each associated with a different, independent subset of original sensor model adjustable parameters. All of these models have a common form – either a piece-wise linear, non-negative, convex function, or a CSM four-parameter function as indicated by the field ACSMC. The piece-wise linear function has a "starting" correlation value of one at tau equal to zero, and has a correlation "floor" value of zero for large values of tau. Tau (τ) is the correlation function's independent variable, a time difference for this particular application. The fields TCDF, NCSEG, CORSEG, and TAUSEG define the correlation function for an independent subset of original adjustable parameters. For a given independent subset, the corresponding value of TCDF is assumed invariant across the correlated images. The CSM four-parameter function is defined similarly. It too is a function of tau. The fields TCDF, AC, ALPC, BETC, and TC define the correlation function; the latter four fields correspond to the specific "four parameters" of the four-parameter correlation function. This correlation

functional form allows for more general correlation starting values and floor values than does the piece-wise linear functional form.

3. Identification of the applicable (active) RSM adjustable parameters and their index into the RSM error cross-covariance for the associated image. There are a total of NPAR active RSM adjustable parameters for the associated image. The RSM error cross-covariance is applicable to errors in the values of the active adjustable parameters, and is described in more detail below. Also, the definition of the ground coordinate system referenced by the RSM adjustable parameters is provided. Note that the identity of the applicable active RSM adjustable parameters can vary from image to image from the same sensor. If they do, they typically vary +/- 2 elements from a common set of (sensor dependent) adjustable parameters.

4. A mapping matrix for the associated image that relates the error covariance associated with the original sensor model adjustable parameters to an error covariance associated with the active RSM adjustable parameters. Field MAP contains the value of the mapping matrix elements. Note that the mapping matrix is different in value (and possibly row dimension) for each correlated image. The mapping matrix has NPAR rows and NPARO columns.

13.3 INDIRECT ERROR COVARIANCE FORM

The following further describes and integrates the above groups (1-4) of indirect error covariance information. Assume a total of n correlated images from the same sensor. Assume p_i pixel locations (times) of interest and m_i active RSM adjustable parameters for image i, $i = 1,..,n$. Define $q_i = p_i \cdot m_i$, and $q = \sum_{i=1}^{n} q_i$.

The indirect error covariance CR is the following $q \times q$ symmetric matrix:

$$CR = \begin{bmatrix} C_{R11} & C_{R12} & . & . & C_{R1q} \\ . & C_{R22} & . & . & . \\ . & . & . & C_{Rij} & . \\ . & . & . & . & . \\ . & . & . & . & C_{Rqq} \end{bmatrix}.$$

C_{Rij} is the cross-covariance (block) between the errors in the active RSM adjustable parameters at the time of pixel i $(i = 1,..,q)$ and at the time of pixel j ($j = 1,..,q)$. It has dimension $m_{i*} \times m_{j*}$, where $i*$ is the image that contains pixel i, and $j*$ is the image that contains pixel j. C_{Rij} is computed by an RSM exploiter as follows:

$$C_{Rij} = \Phi_{i*} C_{Sij} \Phi_{j*}^T,$$

where Φ_{i*} is the mapping matrix corresponding to image $i*$. C_{Sij} is the cross-covariance between the errors in the original sensor model adjustable parameters at the time of pixel i and at the time of pixel j. If there are s original adjustable parameters per image, C_{Sij} is an sxs cross-covariance matrix, and Φ_{i*} is an $m_{i*} \times s$ mapping matrix. (Note that when $i = j$, the RSM error cross-covariance C_{Rij} becomes the RSM error (auto) covariance C_{Rii} for the active RSM adjustable parameters at the time of pixel i.)

As mentioned previously, C_{Rij} is applicable to both the active RSM adjustable parameters for image $i*$ and the active RSM adjustable parameters for image $j*$ The row index into C_{Rij} corresponds to the order in which the active adjustable parameters are identified in image $i*$'s populated RSMECB TRE (see Table 10). For example, if an RSM adjustable parameter is the third active adjustable parameter identified in the TRE, row 3 of C_{Rij} corresponds to the error in the value of that active adjustable parameter applicable at the time of pixel i. Similarly, the column index into C_{Rij} corresponds to the order in which the active adjustable parameters are identified in image $j*$'s populated RSMECB TRE.

C_{Sij}, used in the computation of C_{Rij}, is computed from the original sensor model adjustable parameter error covariance C_{Si*} associated with image $i*$, the corresponding time correlation function $\rho_{Si*}(\tau)$ associated with image $i*$, and the (absolute) time difference τ between pixels i and j:

$$C_{Sij} = \rho_{Si*}(\tau) C_{Si*} = \begin{bmatrix} \rho_{Si*1}(\tau)C_{Si*1} & 0 & . & . & 0 \\ . & . & . & . & . \\ . & . & \rho_{Si*k}(\tau)C_{Si*k} & . & . \\ . & . & . & . & 0 \\ . & . & . & . & \rho_{Si*w}(\tau)C_{Si*w} \end{bmatrix}.$$

The symmetric C_{Sij} is in block diagonal form. The individual C_{Si*k} and $\rho_{Si*k}(\tau)$ correspond to the error covariance and scalar time correlation function for the independent subgroup k of original adjustable parameters. Since $\rho_{Si*k}(\tau)$ is a scalar function of τ, if C_{Si*k} is $s_k \times s_k$, then $\rho_{Si*k}(\tau)C_{Si*k}$ is an $s_k \times s_k$ diagonal block of C_{Sij}. A total of w subgroups is assumed, thus $s = \sum_{k=1}^{w} s_k$.

The above formulation for C_{Sij}, and hence C_{Rij}, assumes that C_{Si^*k} and $\rho_{Si^*k}(\tau)$ are invariant across images (i^*) when multiple images are involved. This corresponds to a wide-sense stationary stochastic error model and is applicable to most applications involving the use of the RSMECB TRE. If instead, a higher fidelity non-stationary stochastic error model is applicable as indicated by variable values of C_{Si^*k} and/or $\rho_{Si^*k}(\tau)$ across the images, additional processing is required in order to ensure a valid (positive semi-definite) indirect error covariance CR. The additional processing is detailed later in this RSMECB TRE description.

(Note that, in general, all errors (ε) referenced in the various RSM TRE descriptions are assumed unbiased, i.e. $E\{\varepsilon\}=0$. In addition, the term "independent subgroups" of adjustable parameters actually refers to uncorrelated errors associated with adjustable parameters from the different subgroups, i.e. $E\{\varepsilon 1\cdot\varepsilon 2\}=0$, where $\varepsilon 1$ represents the error in an adjustable parameter from independent subgroup 1, and $\varepsilon 2$ represents the error in an adjustable parameter from independent subgroup 2.)

13.3.1 CORRELATION MODELS

Correlation models for all independent groups either correspond to a piece-wise linear correlation functional form or the CSM (Community Sensor Model) four-parameter functional form. Both of these forms represent strictly positive definite correlation functions (spdcf). The choice between the two functional forms allows for greater flexibility in the modeling of correlation.

13.3.1.1 PIECE-WISE LINEAR CORRELATION FUNCTIONAL FORM

As mentioned previously, the fields TCDF, NCSEG, CORSEG, and TAUSEG define the correlation function for an independent subset (subgroup) of original adjustable parameters. There are multiple linear segments i ($i=1,..N$) associated with a correlation function, as specified by the value of N (NCSEG). Each of these segments has a corresponding correlation value ρ_i (CORSEG) and correlation time value τ_i (TAUSEG) applicable at the beginning of the segment. Thus, the value of a correlation function $\rho(\tau)$ (e.g. $\rho_{Si^*k}(\tau)$) for a given value of τ is as follows (see Figure 18):

$$\rho(\tau)=\begin{cases}\rho_i+\dfrac{(\rho_{i+1}-\rho_i)(\tau-\tau_i)}{(\tau_{i+1}-\tau_i)} & ,\tau_i\le\tau<\tau_{i+1}\\ 0 & ,\tau_N\le\tau\end{cases}.$$

Note that τ_N is also termed the "cut-off" time, or τc.

The above equation is applicable to original adjustable parameter errors modeled as “image element” errors, as specified by a value of 0 in the field TCDF. (An “image element” is that portion of an image that has a unique time of imaging assigned to it, per the time model contained in the RSMID TRE for that image.) If the value of TCDF is 2, errors are modeled as “restricted image element” errors, and the above equation is only applicable when τ represents the time difference between two pixels in the same image. If the two pixels are from different images, then $\rho(\tau) = 0$ for all values of τ.

If the value of TCDF is 1, errors are modeled as “image” errors, and the above equation is applicable regardless the images associated with the two pixels; however, the definition of τ is changed from the time between two pixels, to the time between the two images that the two pixels are from. (The “image element”, in this case, “becomes” the entire RSM image domain.) The time of an image is defined as the time of its center pixel within the RSM image domain. Thus, if the two images are the same image, τ has a value of zero. And, in particular, two pixels from the same image have a correlation value of 1.0. (Note that, regardless the value of the field TCDF, if the two pixels associated with the time difference τ are the same pixel, or actually within the same image element, $\tau = 0$ and $\rho(\tau) = 1.0$.)

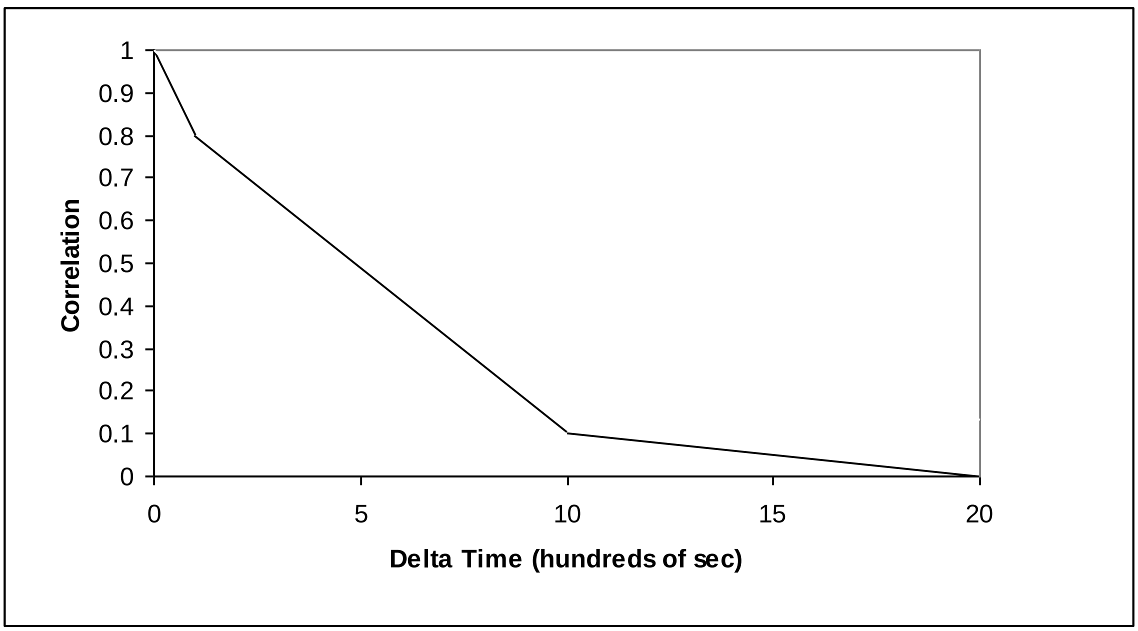

Figure 18: Example of Piece-Wise Linear Correlation Function $\rho(\tau)$

13.3.1.2 CSM FOUR-PARAMETER CORRELATION FUNCTIONAL FORM

As mentioned previously, the fields TCDF, AC, ALPC, BETC, and TC define the CSM four-parameter correlation function for an independent subset (subgroup) of original adjustable parameters. The field TCDF defines the type of errors that are being modeled, and the exact definition of the independent variable tau (τ), exactly as described previously in section 13.3.1.1. The remaining four fields correspond to the four parameters A, alpha, beta, and T, respectively. The correlation function is defined as:

$$\rho(\tau) = A[\alpha + \frac{(1-\alpha)(1+\beta)}{\beta + e^{\tau/T}}]$$

$$0 < A \le 1; 0 \le \alpha(\text{"}alpha\text{"}) < 1; 0 < T; 0 \le \beta(\text{"}beta\text{"}) \le 10$$

$$\rho(\tau = 0) \equiv 1$$

$$\rho(\tau = +epsilon) = A$$

$$\rho(\tau \to +\infty) = A\alpha$$

Where “epsilon” is a very small positive value which approaches 0. Figure 19 presents three examples which correspond to the more typical case of A=1 and alpha=0. Three different values of the parameter beta are used. The larger the value of beta, the larger the value of correlation for a specified value of tau (absolute value of delta time). Figure 20 presents a second set of three examples corresponding to a case when A is less than 1 and alpha is greater than 0. The values of these parameters yield a correlation value less than 1 at a small positive value for tau, and a non-zero value for correlation at large values of tau. Note that, even when A is less than 1, correlation at tau equal to zero is still defined as equal to 1.

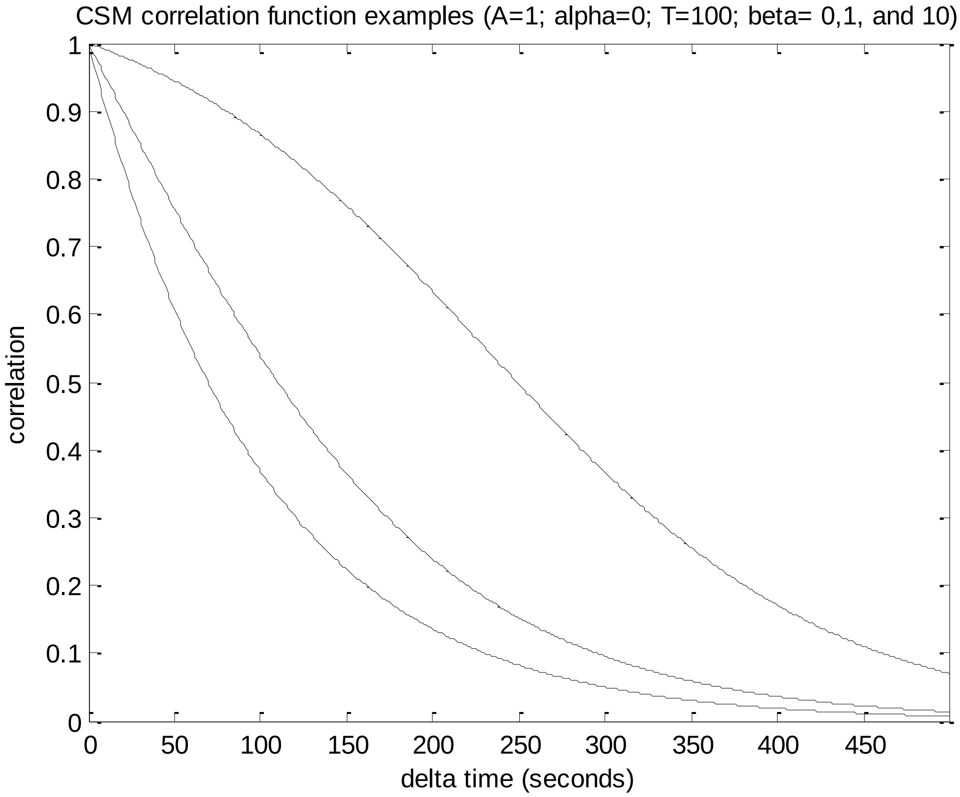

Figure 19: First Set of Examples of CSM Four-Parameter Correlation Function $\rho(\tau)$

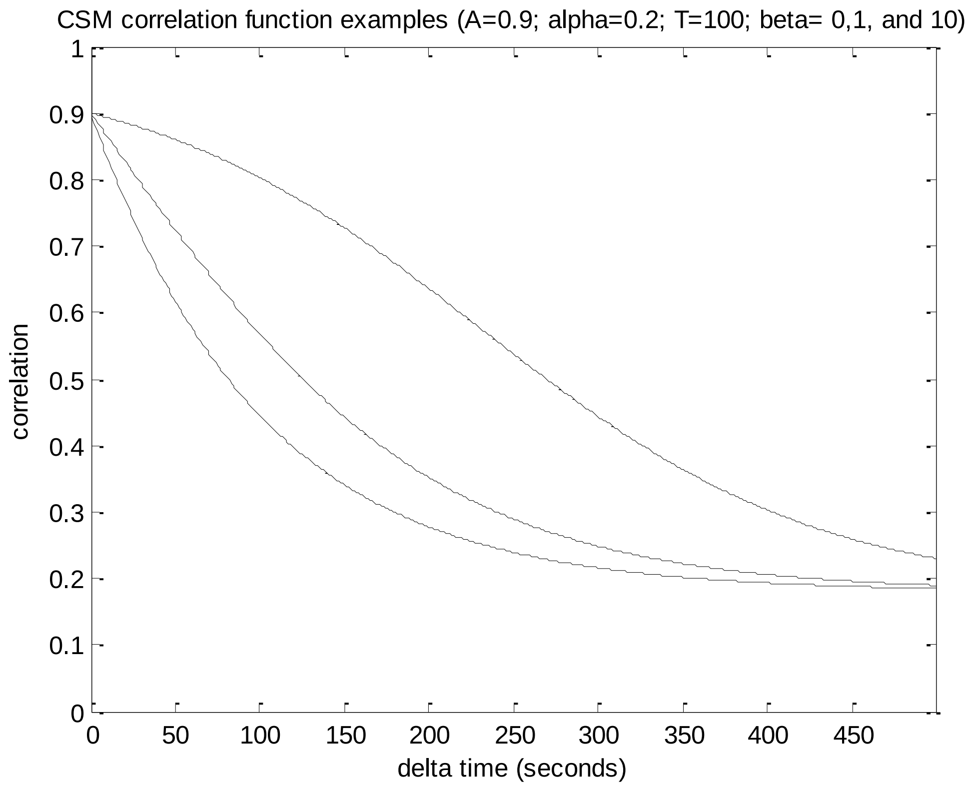

Figure 20: Second Set of Examples of CSM Four-Parameter Correlation Function $\rho(\tau)$

13.3.2 ADDITIONAL COMPUTATIONS IF NON-STATIONARY STOCHASTIC ERROR MODEL

As mentioned previously, when the values of C_{Si^*k} and/or $\rho_{Si^*k}(\tau)$ vary across the images i^*, original adjustable parameter errors associated with independent subgroup k are modeled as non-stationary stochastic errors. The error model is an approximation based on the combination of n wide-sense stationary error models, each associated with an image referenced by the indirect error covariance $(1 \leq i^* \leq n)$. Each wide-sense stationary error model is based on the original sensor model error (auto) covariance and time correlation data contained in the corresponding image's RSMECB TRE.

Note that although the values of C_{Si^*k} and/or $\rho_{Si^*k}(\tau)$ vary across the images i^* in the non-stationary case, the associated original adjustable parameters (identities) and their type of error remain invariant across the images i^* for each subgroup k. For example, if the piece-wise linear correlation functional form is specified, the values of fields ERRCVG, NCSEG, CORSEG, and TAUSEG may vary, but the values of fields IGN, NUMOPG, and TCDF do not.

Computation of the RSM indirect error covariance in support of a non-stationary stochastic error model is identical to that specified previously for an assumed wide-sense stationary stochastic error model, with exceptions detailed below.

The block entry of C_{Sij} corresponding to independent subgroup k and images $i*$ and $j*$ is modified as follows: $\rho_{Si*k}(\tau)C_{Si*k} \rightarrow \bar{\rho}_{Si*j*k}(\tau)C_{Si*k}^{1/2}C_{Sj*k}^{T/2}$. The matrix superscript "1/2" corresponds to the matrix principal square root of the corresponding error covariance matrix. The matrix superscript "T/2" corresponds to the transpose of the matrix principal square root. The matrix principal square root is based on Singular Value Decomposition, and for a covariance matrix C, $C = C^{1/2}C^{T/2}$.

The scalar correlation function $\bar{\rho}_{Si*j*k}(\tau)$ is an "ensemble" correlation function, and consists of an average of correlation functions, each correlation function associated with an image that is correlated with both image $i*$ and image $j*$, i.e.,

$\bar{\rho}_{Si*j*k}(\tau) = (1/n_{r*})\sum_{r*}\rho_{Sr*k}(\tau)$, where each image $r*$ is correlated with both images $i*$ and $j*$. There are a total of $n_{r*} \leq n$ such images. (The independent subgroup k is also applicable, but no longer mentioned for ease of description.)

In general, two images are correlated either directly or indirectly. If the (piece-wise linear decay) correlation function for image $i*$ decays to zero at the "cut-off" time τc_{i*}, and the correlation function for image $j*$ decays to zero at the "cut-off" time τc_{j*}, images $i*$ and $j*$ and directly correlated when $\tau b_{i*j*} \leq \max(\tau c_{i*}, \tau c_{j*})$, where τb_{i*j*} is defined as the smallest time interval possible between an arbitrary pixel location in image $i*$ and an arbitrary pixel location in image $j*$.

Two images $i*$ and $j*$ are indirectly correlated if there is a "chain" of directly correlated images that "connects" them. For example, if image $i*$ is directly correlated with image $a*$, and image $a*$ is directly correlated with image $b*$, and image $b*$ is directly correlated with image $j*$.

Note that if CSM four-parameter correlation functions are applicable, all image pairs are correlated by definition; hence, the ensemble correlation function is simply the average over all images. However, if piece-wise linear functions are applicable, the determination of direct and indirect correlations between image pairs is required, as illustrated in the following examples.

The following are examples of groups of correlated images, where t_{i*} designates image $i*$'s time of first pixel (seconds), and dt_{i*} designates its image "scan" duration (seconds):

(1) images $1*$, $2*$, $3*$; $t_{1*}=0$, $t_{2*}=100$, $t_{3*}=300$; $dt_{1*}=dt_{2*}=dt_{3*}=10$; $\tau c_{1*}=\tau c_{2*}=\tau c_{3*}=3000$; all possible image pairs are directly correlated, thus the ensemble correlation function applicable to any image pair $(i*, j*)$ within the set of three images is the same function:
, $\bar{\rho}_{Si*j*k}(\tau)=(1/3)[\rho_{S1*k}(\tau)+\rho_{S2*k}(\tau)+\rho_{S3*k}(\tau)]$.

(2) images $1*$, $2*$, $3*$, $4*$, $5*$; $t_{1*}=0$, $t_{2*}=100$, $t_{3*}=4000$, $t_{4*}=6000$, $t_{5*}=8000$; $dt_{1*}=dt_{2*}=dt_{3*}=dt_{4*}=dt_{5*}=10$; $\tau c_{1*}=\tau c_{2*}=1000$, $\tau c_{3}=\tau c_{4}=\tau c_{5}=3000$; there are two different sets of correlated images $\{1*,2*\}$, via direct correlation, and $\{3*,4*,5*\}$, via direct and indirect correlation; when image pair $(i*, j*)$ is from the first set, $\bar{\rho}_{Si*j*k}(\tau)=(1/2)[\rho_{S1*k}(\tau)+\rho_{S2*k}(\tau)]$, when from the second set, $\bar{\rho}_{Si*j*k}(\tau)=(1/3)[\rho_{S3*k}(\tau)+\rho_{S4*k}(\tau)+\rho_{S5*k}(\tau)]$, and when $i*$ is in one set and $j*$ in the other, $\bar{\rho}_{Si*j*k}(\tau)=0$.

The remainder of this RSMECB TRE description is independent of whether errors are modeled as wide-sense stationary or non-stationary stochastic errors.

13.3.3 COMPARISON TO DIRECT ERROR COVARIANCE

Note that an RSM indirect error covariance, assembled with TCDF=1 ("image" errors) for all original adjustable parameters and corresponding to one (arbitrary) pixel in each of n images from the same sensor, has a correspondence to the RSM direct error covariance (see RSMDCB TRE). It has the same external form as the direct error covariance - both the indirect error covariance and the direct error covariance reference n sets of RSM adjustable parameter "image" errors across the n images. In particular, assuming all n images were known prior to TRE generation, a direct error covariance could be built identical to the assembled indirect error covariance.

However, in general, the direct error covariance can be more general internally than the indirect error covariance. That is, the correlation between RSM adjustable parameters (errors) between images does not have to conform to an *a priori* model (piece-wise linear decay for associated original adjustable parameter errors) inherent with the indirect error covariance. The direct error covariance can also be more general externally—it can correspond to images from different sensors with different sets of active RSM adjustable parameters. On the other hand, if the number of images (n) is reasonably large and from the same sensor, the direct error covariance's RSMDCB TRE requires more image support data bandwidth than does the indirect error covariance's RSMECB TRE. Also, all images referenced by the direct error covariance must be specifically identified prior to its generation, and all RSM adjustable parameter errors can be modeled as "image" errors (TCDF=1) only. Neither of these restrictions apply to the indirect error covariance.

13.3.4 INDIRECT ERROR COVARIANCE IN "DIRECT ERROR COVARIANCE FORM"

The RSM indirect error covariance can be built in a "direct error covariance form", directly suitable for use in a triangulation solution process, if so desired. In the "direct error covariance form", the indirect error covariance is applicable to the specified images, but independent of image row/column (pixel) location(s). If there are n images, m_i adjustable parameter for image $i = 1,..,n$, the indirect error covariance is an $\sum_{i=1}^{n} m_i \times \sum_{i=1}^{n} m_i$ matrix. All errors in each independent subgroup are assumed "image" errors, as opposed to "image element" or "restricted image element" errors, regardless the value of the TCDF field in the RSMECB TRE. (This is an approximation when the TCDF value specifies either "image element" or "restricted image element" errors. It is not an approximation when the TCDF value specifies "image" errors, as they are 100% positively correlated across all pixel locations in the image, by definition.) In addition, if the TCDF field for a particular independent subgroup specifies "image element" errors, the corresponding time correlation function is assumed applicable to the time between images. If the TCDF field specifies "restricted image element" errors, the correlation between images is assumed zero.

The remainder of this RSMECB description assumes that the RSM indirect error covariance is not in "direct error covariance form", i.e., it is generally applicable to multiple pixel locations per image and multiple images, as described earlier.

13.4 RSM ADJUSTABLE PARAMETER IDENTIFICATION AND DEFINITIONS IN SUPPORT OF THE INDIRECT ERROR COVARIANCE

13.4.1 OVERVIEW

As mentioned previously, the active RSM adjustable parameters for the associated image are identified in this TRE (RSMECB). Application of corresponding C_{Rij} blocks contained in the indirect error covariance CR requires the complete definition of these active adjustable parameters. In particular, their definition is required in order to compute the partial derivatives of image measurements with respect to the adjustable parameters that are referenced by C_{Rij}, in support of error propagation. The following provides remaining details.

Active RSM adjustable parameters for the associated image are either active RSM image-space adjustable parameters or active RSM ground-space adjustable parameters, as specified by field APTYP in the RSMECB TRE.

RSM image-space adjustable parameters correspond to adjustable parameters that adjust an image row coordinate value (r) and an image column coordinate value (c) corresponding to an arbitrary ground point location $X = [x \quad y \quad z]^T$. An individual adjustable parameter either adjusts an image row coordinate value or an image column coordinate value. The adjustments Δr and Δc corresponding to adjustable parameters ap_{rijk} and ap_{cijk} are computed as follows:

$$\Delta r = ap_{rijk} x^i y^j z^k$$

$$\Delta c = ap_{cijk} x^i y^j z^k$$

The adjustable parameters (ap_{rijk} and ap_{cijk}) are uniquely identified by their collective x, y, z powers (exponents) and whether they adjust image row or image column coordinates. The coordinates x, y, and z correspond to normalized ground point coordinates expressed in a Local coordinate system. Normalization is performed by an offset and scale factor for each coordinate. These normalization parameters are in contiguous fields (NSFX-NOFFZ), and allow for an approximate range of (-1,1) for each ground coordinate value. An example of their application for normalizing the y coordinate is as follows:

$$y \rightarrow (y - offset_y) / scale_y \, .$$

Because the ground coordinates are normalized, all image-space adjustable parameters have units of pixels, as do the corrections Δr and Δc. Normalization of the Local coordinates helps to insure overall stability since the value of $x^i y^j z^k$ that multiplies an adjustable parameter during an image row or column adjustment can become extremely large if coordinates were not normalized for large images and large exponents.

There are two possible choices for the Local coordinate system, either Local Rectangular or Local Non-Rectangular, as specified in field LOCTYP. For Local Non-Rectangular, x, y, and z correspond to the ground point's corresponding image row coordinate, image column coordinate, and geodetic height, respectively. The Local Rectangular coordinate system is defined as a rectangular system that is offset and rotated relative to the WGS-84 coordinate system. It is typically specified as a local tangent plane system centered within the RSM image domain’s footprint at a nominal height above the ellipsoid and rotated to be aligned as follows: the z-axis is aligned with the imaging locus direction (line-of-sight vector for an electro-optical sensor), the x-axis is aligned with the image line (“sweep” or "scan") direction, and the y-axis completes a right-handed rectangular system. (When the Local Rectangular coordinate system is footprint centered, corresponding Local Rectangular coordinate normalization offsets, such as $offset_y$, typically have a value of zero.)

Figure 21 illustrates a typical Local Rectangular coordinate system. Specification of a Local Rectangular coordinate system is unique to the associated image and based on contiguous fields (XUOL-ZUZL) as detailed later in this introduction.

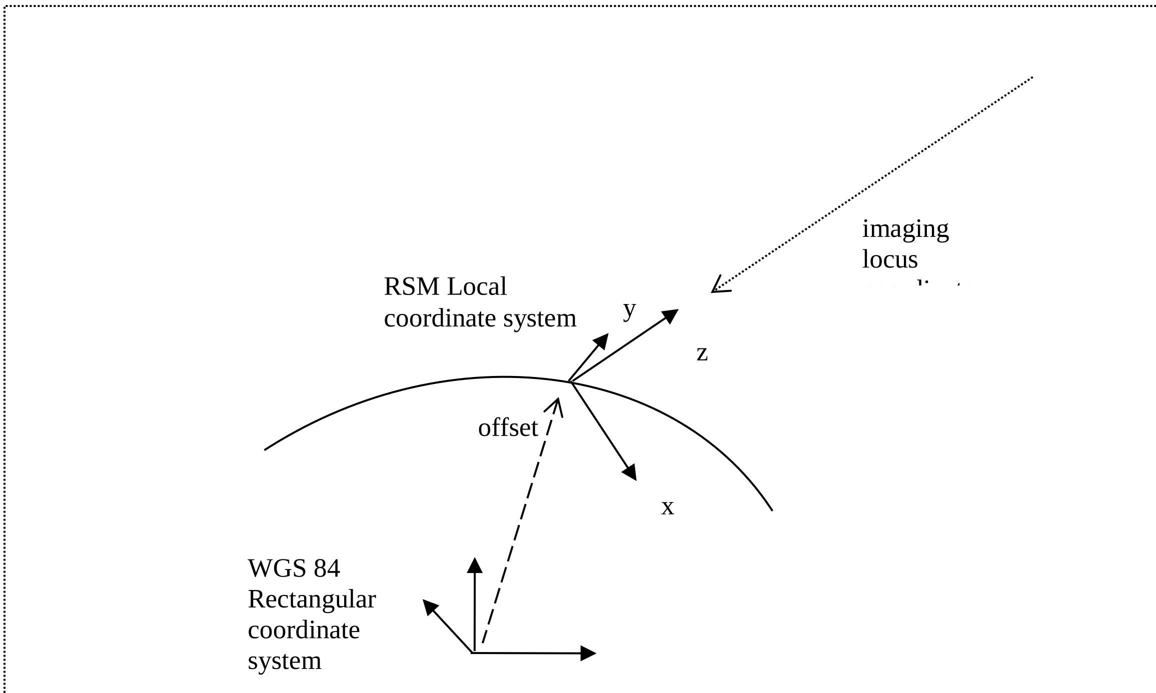

Figure 21: Example of RSM Local Rectangular Coordinate System

Note that the choice of Local Rectangular or Local Non-rectangular is provided for flexibility. The Local Rectangular coordinate system inherits general analytic advantages associated with rectangular (orthonormal) coordinates, and its absolute orientation is insensitive to any abrupt changes in imaging geometry across the imaging time interval. The Local Non-Rectangular coordinate system may provide advantages when very long images are (smoothly) scanned due to significant changes in instantaneous image geometry from one end of the image to the other. The coordinate system is continuously in alignment with these changes.

RSM ground-space adjustable parameters reference normalized Local Rectangular coordinates only. The coordinate system is typically specified as a local tangent plane system centered within the RSM image domain's footprint at a nominal height above the ellipsoid (z-axis vertical). An individual ground-space adjustable parameter is either a parameter associated with a "seven parameter" adjustment or a "rate" adjustment. The seven parameter adjustment is defined as follows, where the symbols $\{\delta x \quad \delta y \quad \delta z \quad \delta\alpha \quad \delta\beta \quad \delta\kappa \quad \delta s\}$ correspond to the adjustable parameters:

$$\begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

The vector on the left side of the above equation corresponds to adjustments in the un-normalized coordinates of the ground point expressed in Local Rectangular coordinates with units of meters. The vector on the far right side of the equation corresponds to normalized coordinates of the ground point expressed in Local Rectangular coordinates. Because these coordinates are unit-less, the adjustable parameters all have units of meters, as do the corrections $\Delta x, \Delta y, \Delta z$.

(If Local coordinate scale factors ($scale_x, scale_y, scale_z$) are set equal in value by the TRE generation process, Local coordinate values no longer necessarily range from -1.0 to 1.0. However, the above seven parameter adjustment is now equivalent to the standard photogrammetric seven parameter (small angle) transformation. It is recommended that the scale factors be set equal to a common value in a manner that yields ranges for the three local coordinates as close as possible to interval -1.0 to 1.0.)

There are nine possible ground-space adjustable parameters corresponding to rate adjustments and denoted by the symbols $\{ap_{xx}, ap_{xy}, .., ap_{zz}\}$. They adjust the un-normalized coordinates of the ground point in Local Rectangular coordinates specifically as follows:

$\Delta x = ap_{xx} x$, $\Delta x = ap_{xy} y$, $\Delta x = ap_{xz} z$,

$\Delta y = ap_{yx} x$, $\Delta y = ap_{yy} y$, $\Delta y = ap_{yz} z$,

$\Delta z = ap_{zx} x$, $\Delta z = ap_{zy} y$, $\Delta z = ap_{zz} z$.

Again, these adjustable parameters and the corrections have units of meters.

Each of the 16 possible ground-space adjustable parameters is identified by a unique four character identifier detailed in the TRE's specified format (Table 10).

Note that application of RSM adjustable parameters, whether image-space or ground-space adjustable parameters, first requires converting the corresponding ground point from representation in the RSM primary ground coordinate system to the appropriate Local system. And for the case of ground-space adjustable parameters, the adjusted ground point must also be converted back to the RSM primary coordinate system.

Figure 22 presents the RSM adjustable ground-to-image function $h(X,R)$, where X corresponds to the un-normalized three dimensional ground point in the RSM primary ground coordinate system. The functions $I\_adj(X,R)$ and $X\_adj(X,R)$ apply the previously documented adjustment equations for active image-space and ground-space adjustable parameters, respectively. (The functions also internally convert X from the primary system to the (normalized) Local system.)

$\Delta I = [\Delta r \quad \Delta c]^T$ denotes the summed effects at ground point location X of all active RSM image-space adjustable parameters. For example, if the active image-space adjustable parameters correspond to (combined) powers in x and y less than or equal to one: $\Delta r = ap_{r000} + ap_{r100} \cdot x + ap_{r010} \cdot y$, and $\Delta c = ap_{c000} + ap_{c100} \cdot x + ap_{c010} \cdot y$.

$\Delta X = [\Delta x \quad \Delta y \quad \Delta z]^T$ denotes the summed effects at ground point location X of all active RSM ground-space adjustable parameters.

The vector R represents the active RSM adjustable parameters in the order that they are specified in this populated TRE, e.g., vector element two corresponds to the second active adjustable parameter identified in the populated TRE (see Table 10). (Internally, the RSM ground-to-image function $g(X)$ is actually performed with respect to normalized coordinates. The RSM ground-to-image function handles all required normalization and un-normalization, as described in the RSMPC TRE and the RSMGG TRE.)

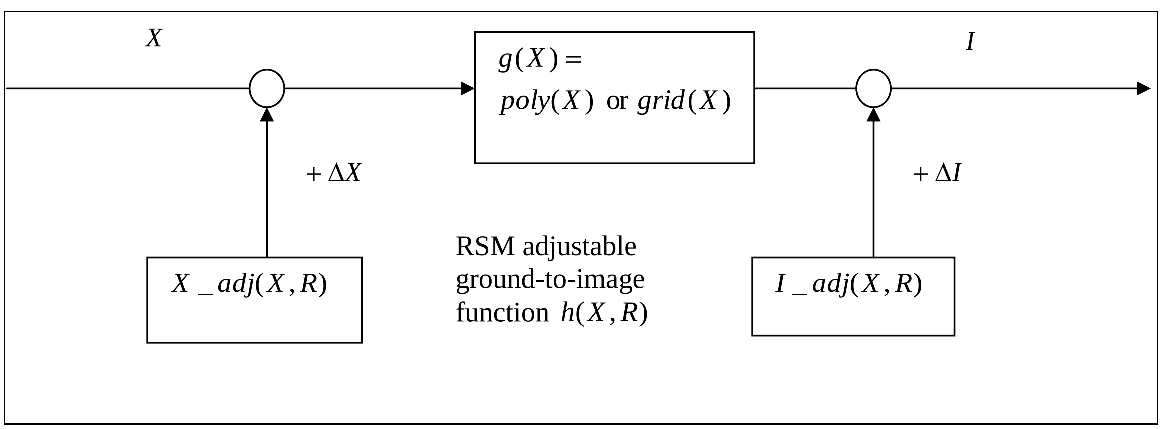

Figure 22: RSM Adjustable Ground-to-Image Function

The total number of active image-space adjustable parameters is specified in field (NISAP). Individual active adjustable parameters are identified in contiguous fields (XPWRR-ZPWRR) and contiguous fields (XPWRC-ZPWRC).

The index of an active adjustable parameter into a cross-covariance block for the associated image (or, equivalently, the row of the corresponding mapping matrix) corresponds to the order it is identified in the populated TRE.

The total number of active ground-space adjustable parameters is specified in field (NGSAP). Individual active parameters are identified in field (GSAPID). The index of an active parameter into a cross-covariance block for the associated image (or, equivalently, the row of the corresponding mapping matrix) corresponds to the order it is identified in the populated TRE

As mentioned earlier, active RSM adjustable parameters require definition and identification in order to support error propagation. In particular, to project the (RSM support data) image error covariance (more generally, C_{Rij}) to image space via the partial derivatives of image coordinates with respect to the active adjustable parameters. These derivatives are computed for the various active adjustable parameters by taking the appropriate derivatives of the previous equations.

For example, the partial derivative of the image column coordinate with respect to an image-space adjustable parameter is computed as follows:

$$\partial c / \partial ap_{cijk} = \partial \Delta c / \partial ap_{cijk} = \partial (ap_{cijk} x^i y^j z^k) / \partial ap_{cijk} = x^i y^j z^k$$

(Recall that in the above the ground point's location (x, y, z) is represented as normalized coordinates in the Local system.)

Partial derivatives of image coordinates with respect to ground-space adjustable parameters are more involved because they adjust image coordinates indirectly. For example, the partial derivative of the image row coordinate with respect to the ground-space adjustable parameter ap_{xy} is computed as follows:

$$\partial r / \partial ap_{xy} = (\partial r / \partial X)(\partial X / \partial ap_{xy})$$

In this equation, X represents the ground point's location in the primary coordinate system, and $\partial r / \partial X$ (1×3) is readily computed from the RSM ground-to-image function for the row coordinate, i.e., $\partial r / \partial X = \partial g_r(X) / \partial X$.

The (3×1) $\partial X / \partial ap_{xy} = (\partial X / \partial X_L)(\partial X_L / \partial ap_{xy})$, where X_L represents the ground point location in the (un-normalized) Local Rectangular coordinate system. $\partial X / \partial X_L$ $(3x3)$ is readily computed from the Local Rectangular coordinate system and the primary coordinate system defining parameters. Also, from the definition of ap_{xy}, the (3×1) $\partial X_L / \partial ap_{xy} = \begin{bmatrix} scale_x \cdot y & 0 & 0 \end{bmatrix}^T$, where y is the second component of the ground point's location in normalized Local Rectangular coordinates.

13.4.2 BASIS OPTION

When this option is invoked (APBASE=Y), the set of RSM adjustable parameters specified in this TRE (as described previously) become a "basis" set of adjustable parameters. Symbolically, they are contained in the vector R, assumed to have n elements. Another set of RSM adjustable parameters is defined as a linear combination of the elements of R. Symbolically, this new set is contained in the vector R', where $R' = AR$, and the matrix A is $m \times n$, $m \leq n$, with the rank of A equal to m. The vector R' contains the (new) set of active adjustable parameters.

The RSM image error covariance (more generally, C_{Rij}) assembled from data in this TRE is now with respect to R'. Equivalently, the mapping matrix contained in this TRE is also now with respect to R'. The field NPAR now corresponds to the number of elements (m) in R'. The field NBASIS corresponds to the number of elements (n) in R.

Typically, the mapping matrix and A are determined during generation of this TRE from an initial error covariance with respect to the basis set R using principal components analysis (see RSMDCB for an overview of the process and its potential benefits). R is also a linear combination of R' based on the pseudo-inverse of A, designated as $A^{\#}$. Thus, $R = A^{\#}R'$, where $A^{\#} = A^T(AA^T)^{-1} = A^T$.

When this option is on, the RSMECB TRE contains the identification of the adjustable parameters that make up the elements of the basis (R), the matrix A that maps the basis (R) to the set of active adjustable parameters (R'), and the mapping matrix (Φ) with respect to the set of active RSM adjustable parameters R'. Corresponding exploiter functionality is invoked by specification of the appropriate partial derivatives of image coordinates with respect to R', and the update of the RSM ground-to-image function from values of R' solved for during an RSM adjustment (triangulation):

1. $\partial I / \partial R' = (\partial I / \partial R)A^T$, and

2. Values of R' map to values of R via $R = A^T R'$ where the subsequent R affects the ground-to-image function.

The first of these equations supports the statistical propagation of RSM support data errors to image space, i.e., the projection of the associated image's error covariance (more generally, C_{Rij}) assembled from data in this TRE to image space. (The computation of the partial derivatives $\partial I / \partial R$ was discussed previously). The second equation maps adjustments contained in R' to R for subsequent application in the RSM adjustable ground-to-image function for the associated image.

13.4.3 LOCAL RECTANGULAR COORDINATE SYSTEM DETAILS

The following defines the Local Rectangular coordinate system relative to the WGS 84 Rectangular coordinate system. The contiguous fields XUOL through ZUOL specify the origin (offset) of the Local coordinate system relative to the WGS 84 Rectangular coordinate system, and the contiguous fields XUXL through ZUZL elements of the rotation matrix. These fields are provided in this TRE.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{LOCAL}} = \begin{bmatrix} XUXL & YUXL & ZUXL \\ XUYL & YUYL & ZUYL \\ XUZL & YUZL & ZUZL \end{bmatrix} \cdot \left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}_{\text{WGS-84}} - \begin{bmatrix} XUOL \\ YUOL \\ ZUOL \end{bmatrix} \right).$$

Note that the definition of the Local Rectangular coordinate system is also redundantly supplied in other TREs for the associated image. Also, in order to convert a ground point X represented in the RSM primary ground coordinate system (e.g., Geodetic) to the Local Rectangular coordinate system, it must first be converted from the RSM primary system to the WGS 84 Rectangular coordinate system.

13.5 UNMODELED ERROR COVARIANCE

The RSMECB TRE may also contain information specifying an unmodeled error covariance corresponding to multiple pixel locations within the associated image's RSM image domain. Unmodeled errors represent the summed effects of all errors that cannot be represented as RSM adjustable parameter errors. If present, they are typically relatively non-systematic, "high frequency" errors. Representation of unmodeled errors is done directly in image space. The corresponding unmodeled error covariance is applicable to errors at an arbitrary time (pixel location) in the associated image's RSM image domain. These unmodeled errors are also assumed correlated between pixel locations, as represented by a correlation model as a function of number of rows between pixel locations and a correlation model as a function of number of columns between pixel locations. The unmodeled errors are assumed uncorrelated between images. Specifically, the unmodeled error covariance (CU) for the associated image is defined as follows:

$$CU = \begin{bmatrix} C_{U11} & C_{U12} & . & . & C_{U1q} \\ . & C_{U22} & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & C_{Uqq} \end{bmatrix},$$

where there are an assumed q pixel locations of interest within the RSM image domain, and C_{Uij} is the 2×2 error cross-covariance between pixels i and j given by:

$$C_{Uij} = \rho_U(\Delta u_{ij})\rho_V(\Delta v_{ij})C_U .$$

The upper triangular portion of the symmetric 2×2 error covariance C_U is specified in the fields URR, URC, and UCC.

The correlation functions $\rho_U(\Delta u_{ij})$ and $\rho_V(\Delta v_{ij})$ both correspond to either a piece-wise linear functional form or a CSM four parameter functional form, as specified in the field UACSMC. If a piece-wise linear functional form, $\rho_U(\Delta u_{ij})$ is specified in the fields UNCSR, UCORSR, and UTAUSR. The correlation function $\rho_V(\Delta v_{ij})$ is specified in the fields UNCSC, UCORSC, and UTAUSC. If a CSM four-parameter functional form, $\rho_U(\Delta u_{ij})$ is specified in the fields UACR, UALPCR, UBETCR, and UTCR. The correlation function $\rho_V(\Delta v_{ij})$ is specified in the fields UACC, UALPCC, UBETCC, and UTCC.

Independent of functional form, the row and column distances between pixels i and j are defined as Δu_{ij} and Δv_{ij}, respectively. Also, although the scalar correlation functions $\rho_U(\Delta u_{ij})$ and $\rho_V(\Delta v_{ij})$ are of the same general form as the correlation functions used for the indirect error covariance, τ is redefined from being the time between pixels to the distance (number of rows or columns) between pixels. Also, there is no explicit counterpart to the field TCDF for these functions. Unmodeled errors are assumed “restricted image element errors”, where the image element is the pixel.

Note that unmodeled errors are not always applicable. However, if applicable, modeled (as opposed to unmodeled) errors can be represented by either the indirect error covariance RSMECB or the direct error covariance RSMDCB. For both of these reasons, the unmodeled error covariance information is conditional within this RSMECB TRE, as defined by fields INCLIC and INCLUC. If the RSM support data for the associated image contains both the RSMECB TRE and the RSMDCB TRE, the latter takes precedence for modeled errors, and the former specifies unmodeled error if INCLUC=Y.

13.6 MATRIX ELEMENT ORDERING

Finally, regarding the ordering of matrix elements in this TRE, the error covariance associated with the original sensor model adjustable parameters for a particular independent subgroup is in an upper triangular form with matrix elements in field ERRCVG. The upper triangular matrix is provided in row major order (the top row first, followed by the second row less the leftmost column, all the way to the rightmost element of the bottom row). The associated image's mapping matrix is a full matrix in row major order with elements in field MAP. If the basis option is on, the A matrix is a full matrix in row major order with elements in field AEL.

The mapping matrix is in row major order with one row per RSM adjustable parameter and one column per original adjustable parameter. Note that it is not in upper triangular form.

13.7 RSMECB FORMAT

Table 10 specifies the detailed format for the Replacement Sensor Model Error Covariance version B (RSMECB) TRE.

RSMECB – Replacement Sensor Model Error Covariance						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Estimated Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMECB	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	bytes	00371 to 98487	R
Image Information						
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R

TID	Triangulation ID. This field contains an identifier that is unique to the most recent process after RSM support data generation that led to the adjustments and/or error covariance in this RSM support data edition.	40	BCS-A	N/A	N/A	R
TRE Covariance Options						
INCLIC	Include Indirect Error Covariance Flag. If the value of this field is Y, the indirect error covariance information is included in this TRE.	1	BCS-A	N/A	Y or N	R
INCLUC	Include Unmodeled Error Covariance Flag. If the value of this field is Y, the unmodeled error covariance information is included in this TRE.	1	BCS-A	N/A	Y or N	R
…if (INCLIC = Y) then include the following fields:						
NPARO	Number of Original Adjustable Parameters. This field contains the number of original adjustable parameters of the associated image. It is both the row and column dimensions of the (unmapped) original image error covariance and the original image error cross-covariance. The maximum allowed number of original adjustable parameters is 53.	2	BCS-N	N/A	01 to 53	C
IGN	Number of Independent Subgroups. This field contains the number of independent adjustable parameter (error) subgroups associated with the original adjustable parameters of the associated image.	2	BCS-N	N/A	01 to 36	C
CVDATE	Version Date of the Original Image Error Covariance. Date representing the version of the error model applicable to the original image error covariance. If populated, and two images are from the same sequence of images from the same sensor, and if the values of CVDATE are different in the two RSMECB TREs, all original adjustable parameter (errors) are assumed uncorrelated between the images.	8	BCS-A	N/A	YYYYMMDD (YYYY=four digit year, MM=two digit month; DD=two digit day) Population optional Default is all spaces Value must correspond to a valid date	<C>
RSM Adjustable Parameter Identification for the associated image						

NPAR	Number of Active RSM Adjustable Parameters. This field contains the total number of active RSM adjustable parameters for the associated image. The value of this field is the row dimension of any RSM cross-covariance (block) for the associated image, as well as the row dimension of the associated image's mapping matrix (field MAP). It is also both the row and the column dimension of any RSM (auto) covariance (block) for the associated image. NPAR's maximum value of 36 constrains an RSM covariance block to be reasonable size. (If the "basis" option is off (APBASE=N), NPAR=NISAP if APTYP=I, and NPAR=NGSAP if APTYP=G. If the basis option is on (APBASE=Y), NPAR corresponds to the number of (new) active adjustable parameters and the number of row in the matrix A, as described for field APBASE.)	2	BCS-N	N/A	01 to 36	R
APTYP	Adjustable Parameter Type. This field identifies whether RSM adjustable parameters are image-space (APTYP=I) or ground-space (APTYP=G) adjustable parameters.	1	BCS-A	N/A	I or G	C
LOCTYP	Local Coordinate System Identifier. The field identifies whether the Local coordinate system references rectangular ground coordinates (LOCTYP=R) or non-rectangular (image row/image column/geodetic height) coordinates (LOCTYP=N). If RSM adjustable parameters are specified as ground-space (APTYP=G), the only valid value is LOCTYP=R.	1	BCS-A	N/A	R or N	C
Normalization Factors for the Local System						
NSFX	Normalization Scale Factor for X. This field contains the normalization scale factor for the x component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	C
NSFY	Normalization Scale Factor for Y. This field contains the normalization scale factor for the y component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	C
NSFZ	Normalization Scale Factor for Z. This field contains the normalization scale factor for the z component of the Local coordinate system	21	BCS-A	meters	±9.99999999999999E±99	C
NOFFX	Normalization Offset for X. This field contains the normalization offset for the x component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	C

NOFFY	Normalization Offset for Y. This field contains the normalization offset for the y component of the Local coordinate system. Units are meters if field LOCTYP=R or pixels if LOCTYP=N.	21	BCS-A	meters or pixels	±9.99999999999999E±99	C
NOFFZ	Normalization Offset for Z. This field contains the normalization offset for the z component of the Local coordinate system.	21	BCS-A	meters	±9.99999999999999E±99	C
Local Rectangular Ground Coordinates Detailed Definition for Associated image						
...if (LOCTYP=R)						
XUOL	Local Coordinate Origin (XUOL). This field provides the WGS 84 *X* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C
YUOL	Local Coordinate Origin (YUOL). This field provides the WGS 84 *Y* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C
ZUOL	Local Coordinate Origin (ZUOL). This field provides the WGS 84 *Z* coordinate of the origin of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	meters	±9.99999999999999E±99	C
XUXL	Local Coordinate Unit Vector (XUXL). This field provides the WGS 84 *X* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
XUYL	Local Coordinate Unit Vector (XUYL). This field provides the WGS 84 *X* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
XUZL	Local Coordinate Unit Vector (XUZL). This field provides the WGS 84 *X* component of the unit vector defining the *Z*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
YUXL	Local Coordinate Unit Vector (YUXL). This field provides the WGS 84 *Y* component of the unit vector defining the *X*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
YUYL	Local Coordinate Unit Vector (YUYL). This field provides the WGS 84 *Y* component of the unit vector defining the *Y*-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C

YUZL	Local Coordinate Unit Vector (YUZL). This field provides the WGS 84 Y component of the unit vector defining the Z-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
ZUXL	Local Coordinate Unit Vector (ZUXL). This field provides the WGS 84 Z component of the unit vector defining the X-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
ZUYL	Local Coordinate Unit Vector (ZUYL). This field provides the WGS 84 Z component of the unit vector defining the Y-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
ZUZL	Local Coordinate Unit Vector (ZUZL). This field provides the WGS 84 Z component of the unit vector defining the Z-axis of the Local (rectangular) coordinate system. This coordinate system is part of the RSM adjustable parameters definition for the image.	21	BCS-A	N/A	-1.00000000000000E+00 to +1.00000000000000E+00 (-1 to +1) Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	C
...end if (LOCTYP=R)						
RSM Adjustable Parameter Basis Option						

APBASE	Basis Option. This field indicates whether the RSM adjustable parameters "basis" option is on (APBASE=Y). If this option is off (APBASE=N), the RSM adjustable parameters specified in the following fields are the active RSM adjustable parameters. The order (component number) of an active RSM adjustable parameter is the order in which it is specified. If this option is on, the RSM adjustable parameters specified in the following fields are the basis set of RSM adjustable parameters. The order (component number) of a basis RSM adjustable parameter is the order in which it is specified. If this option is on, the active RSM adjustable parameters are a linear combination of the basis set of RSM adjustable parameters. The matrix A (field AEL) maps the basis set to the active set of RSM adjustable parameters. In addition, the pseudo-inverse of the matrix A is equal to the matrix A transpose. It maps the active set to the basis set of RSM adjustable parameters. The matrix A is mxn, where $m \leq n$ and the rank of A equals m. The number of adjustable parameters (n) in the basis set is specified in field NBASIS. The number of active adjustable parameters (m) is specified in the field NPAR. The RSM image error covariance is always with respect to the active RSM adjustable parameters. For example, the second active RSM adjustable parameter corresponds to row 2 and column 2 of the image (auto) covariance, and corresponds to row 2 and column k of the cross-covariance of the associated image with image k.	1	BCS-A	NA	Y or N	C
Image-space Adjustable Parameters						
...if (APTYP=I)						

NISAP	Number of Image-Space Adjustable Parameters. This field contains the total number of image-space adjustable parameters. If the basis option is off (APBASE=N), specified image-space adjustable parameters are the active RSM adjustable parameters. The total number of image-space adjustable parameters is constrained as follows: (0<NPAR=NISAP=(NISAPR + NISAPC)<37). NISAPR is the number of image-space adjustable parameters that affect the image row-coordinate, and NISAPC the number that affect the image column-coordinate. If the basis option is on (APBASE=Y), specified image-space adjustable parameters are the basis RSM adjustable parameters. The total number of image-space adjustable parameters making up the basis set is constrained as follows: (0<NBASIS=NISAP=(NISAPR + NISAPC)<100).	2	BCS-A	N/A	1-36 (if APBASE=N) 1-99 (if APBASE=Y)	C
NISAPR	Number of Image-Space Adjustable Parameters for Image Row Coordinate. This field provides the total number of image-space adjustable parameters that adjust the image row coordinate. The general form for the row coordinate adjustment (Δr) corresponding to an adjustable parameter (ap) is as follows: $\Delta r = ap_{rijk} \cdot x^i \cdot y^j \cdot z^k$, where i,j,k are the corresponding powers of normalized Local coordinates x,y,z, respectively. Each adjustable parameter has units of pixels.	2	BCS-A	N/A	0-36 (if APBASE=N) 0-99 (if APBASE=Y)	C
...Begin for each image-space adjustable parameter for row adjustment (NISAPR entries)						
XPWRR	Row Parameter Power of X. The power (exponent) of x associated with this image-space adjustable parameter for image row adjustment. This power along with the following two powers (fields) uniquely specify the adjustable parameter. x is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image row coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C

YPWRR	Row Parameter Power of Y. The power (exponent) of y associated with this image-space adjustable parameter for image row adjustment. y is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image column coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
ZPWRR	Row Parameter Power of Z. The power (exponent) of z associated with this image-space adjustable parameter for image row adjustment. z is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized geodetic height coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
...End for each image-space adjustable parameter for row adjustment						
NISAPC	Number of Image-Space Adjustable Parameters for Image Column Coordinate. This field provides the total number of image-space adjustable parameters that adjust the image column coordinate. The general form for the column coordinate adjustment (Δc) corresponding to an adjustable parameter (ap) is as follows: $\Delta c = ap_{cijk} \cdot x^i \cdot y^j \cdot z^k$, where i,j,k are the corresponding powers of normalized Local coordinates x,y,z, respectively. Each adjustable parameter has units of pixels.	2	BCS-A	N/A	0-36 (if APBASE=N) 0-99 (if APBASE=Y)	C
...Begin for each image-space adjustable parameter for column adjustment (NISAPC entries)						
XPWRC	Column Parameter Power of X. The power (exponent) of x associated with this image-space adjustable parameter for image column adjustment. This power along with the following two powers (fields) uniquely specify the adjustable parameter. x is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image row coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
YPWRC	Column Parameter Power of Y. The power (exponent) of y associated with this image-space adjustable parameter for image column adjustment. y is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized image column coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C

ZPWRC	Column Parameter Power of Z. The power (exponent) of z associated with this image-space adjustable parameter for image column adjustment. z is a normalized Local rectangular ground coordinate (LOCTYP=R) or a normalized geodetic height coordinate (LOCTYP=N)	1	BCS-A	N/A	0-5	C
...End for each image-space adjustable parameter for column adjustment						
...end if (APTYP=I)						
Ground-Space Adjustable Parameters						
...if(APTYP=G)						

NGSAP	Number of Ground-Space Adjustable Parameters This field provides the total number of ground-space adjustable parameters. Each ground-space adjustable parameter is either associated with a "seven parameter" adjustment or is a first order "rate" term. The general form for the seven parameter adjustment is: $\begin{bmatrix} dx \\ dy \\ dz \end{bmatrix} = \begin{bmatrix} \delta x \\ \delta y \\ \delta z \end{bmatrix} + \begin{bmatrix} \delta s & \delta\kappa & -\delta\beta \\ -\delta\kappa & \delta s & \delta\alpha \\ \delta\beta & -\delta\alpha & \delta s \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$, where the vector on the left side of the equation is the ground-space adjustment in Local rectangular ground coordinates (meters), the vector on the far right side of the equation is the ground point location in normalized Local rectangular ground coordinates. The seven parameters $\delta x, \delta y, \delta z, \delta\alpha, \delta\beta, \delta\kappa, \delta s$, are termed x-offset, y-offset, z-offset, rotation angle alpha, rotation angle beta, rotation angle kappa, and scale. For identification purposes in the field below, these seven parameters are assigned 4 character identifications "OFFX", "OFFY" ,"OFFZ", "ROTX", "ROTY", "ROTZ", "SCAL", respectively. Each has units of meters. There a total of 9 possible rate terms $ap_{xx}, ap_{xy}, .., ap_{zz}$, termed "XRTX", "XRTY", "XRTZ", "YRTX", "YRTY", "YRTZ", "ZRTZ", "ZRTY, "ZRTZ, respectively. Their effect is illustrated as follows for the adjustable parameter "XRTY" (ap_{xy}) and corresponding adjustment Δx: $\Delta x = ap_{xy} y$. If the basis option is off (APBASE=N), specified ground-space adjustable parameters are the active RSM adjustable parameters. If the basis option is on (APBASE=Y), specified ground-space adjustable parameters are the basis RSM adjustable parameters. The total number of ground-space adjustable parameters (NGSAP) is constrained to be between 1 and 16 regardless the value of APBASE, i.e., regardless if the basis option is on or off. If the basis option if off, NPAR=NGSAP. If the basis option if on, NBASE=NGSAP.	2	BCS-A	N/A	1-16	C

...Begin for each ground-space adjustable parameter (NGSAP entries)						
GSAPID	Ground-space Adjustable Parameter ID. This field identifies a ground-space adjustable parameter.	4	BCS-A	N/A	OFFX,OFFY,OFFZ, ROTX,ROTY,ROTZ, SCAL, XRTX, XRTY,XRTZ, YRTZ,YRTY,YRTZ, ZRTX,ZRTY,ZRTZ	C
...End for each ground-space adjustable parameter						
...end if (APTYP=G)						
...if (APBASE=Y)						
NBASIS	Number of Basis Adjustable Parameters. This field contains the number of RSM adjustable parameters in the basis set. It is equal to the number of columns in the matrix A. NBASIS=NISAP or NGSAP, depending on whether the previously identified active adjustable parameters were image-space or ground-space active adjustable parameters. The number of columns must be no less than the number of rows in the matrix A, i.e., $NBASIS \geq NPAR$. The size of the matrix A is also constrained such that $NPAR*NBASIS \leq 1296$.	2	BCS-N	N/A	1-99	C
...Begin for each A element (NPAR*NBASIS entries)						
AEL	Matrix A Element. This field contains an element of the matrix A. The elements are stored in row major order.	21	BCS-A	N/A	±9.99999999999999E±99	C
...End loop over elements of matrix A						
...end if (APBASE=Y)						
Error Covariance Data						
…Begin for each original Adjustable Parameter independent error subgroup (IGN entries)						
NUMOPG	Number of Original Adjustable Parameters in Subgroup. This field contains the number of contiguous original adjustable parameters in this independent error subgroup. (Independent error subgroups are contiguous as well.)	2	BCS-N	N/A	01 to 53 Sum of IGN entries of NUMOPG must equal NPARO	C
…Begin for each element of the original image error covariance for this independent error subgroup (1/2(NUMOPG+1)(NUMOPG) entries)						
ERRCVG	Original Error Covariance Element. This field contains an original adjustable parameter error covariance element corresponding to the independent error subgroup. The elements correspond to the upper triangular portion of the error covariance. They are in row major order.	21	BCS-A	N/A	±9.99999999999999E±99 Collectively, the ERRCVG values for the subgroup must correspond to a positive definite error covariance matrix	C
…End for each element of the original image error covariance for the independent error subgroup						

TCDF	Time Correlation Domain Flag. This field defines the type of original adjustable parameter error, and hence, the corresponding correlation function domain, for this independent error subgroup. If this field is 0, the time correlation applies to all time intervals, both within and between images. The associated errors in the original adjustable parameters are "image element errors". If this field is 1, the time correlation applies to time intervals between images only. Time correlation for time intervals within an image is defined 100% positively correlated. The associated errors in the original adjustable parameters are "image errors". If this field is 2, the time correlation applies to time intervals within an image only. Time correlation for time intervals between images is defined as zero. The associated errors in the original adjustable parameters are "restricted image element errors".	1	BCS-N	N/A	0, 1, 2	C
ACSMC	CSM Correlation Option. This field indicates whether a CSM correlation functional form is to be used (ACSMC=Y). instead of the baseline piece-wise linear correlation functional form (ACSMC=N) in order to represent the correlation of adjustable parameter error.	1	BCS-A	N/A	Y or N	C
…if (ACSMC=N)						
NCSEG	Number of Correlation Segments. This field contains the number of piece-wise linear correlation segments that make up the correlation function for this independent error subgroup.	1	BCS-N	N/A	2 through 9	C
…Begin for each correlation segment (NCSEG entries)						
CORSEG	Segment Correlation Value. This field contains the correlation value applicable at the beginning of the segment. Note that the value is defined as one for the first segment (correlation segment=1), and defined as zero for the last segment (correlation segment=NCSEG). It is a nonnegative number for all segments, decreasing in value from one segment to the next.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.00000000000000E+00 (0 to +1) Value consistent with a non-negative, convex, piece-wise linear correlation function defined by NCSEG entries of CORSEG and TAUSEG	C
TAUSEG	Segment Tau Value. This field contains the correlation time (tau) applicable at the beginning of the segment. Note that the value is defined as zero for the first segment (correlation segment=1). It is a positive number for all other segments, increasing in value from one segment to the next. Note that the values of the fields CORSEG and TAUSEG for all the segments are further constrained such that the corresponding piece-wise linear correlation function is convex (non-positive and increasing slope from one segment to the next). Also, the last segment is defined equal to zero for all tau greater than the last segment's TAUSEG value.	21	BCS-A	seconds	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value Value consistent with a non-negative, convex, piece-wise linear correlation function defined by NCSEG entries of CORSEG and TAUSEG	C
…End for each correlation segment						

…end if (ACSMC=N)						
…if (ACSMC=Y)						
AC	This field provides the CSM correlation function A parameter.	21	BCS-A	N/A	+0.00000000000001E-99 to +1.00000000000000E+00 (greater than 0 and less than or equal to +1)	C
ALPC	This field provides the CSM correlation function alpha parameter.	21	BCS-A	N/A	+0.00000000000000E+00 to +9.99999999999999E-01 (greater than or equal to 0 and less than +1)	C
BETC	This field provides the CSM correlation function beta parameter.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.000000000000000E+01 (0 to +10)	C
TC	This field provides the CSM correlation function T parameter.	21	BCS-A	seconds	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	C
…end if (ACSMC=Y)						
…End for each independent error subgroup						
…Loop over mapping matrix elements ((NPAR)(NPARO) entries)						
MAP	Mapping Matrix Element. This field contains the value of the next mapping matrix element, stored in row major order. The mapping matrix is used to map the associated image's original error covariance to RSM error covariance. The mapping matrix has NPAR rows and NPARO columns.	21	BCS-A	N/A	±9.99999999999999E±99	C
…End loop over mapping matrix elements						
…end if (INCLIC = Y)						
…if (INCLUC = Y) then include the following fields:						
Unmodeled Error Covariance data						
URR	Unmodeled Row Variance. This field provides the variance of unmodeled error represented as an image row error.	21	BCS-A	pixels^2	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value	C
URC	Unmodeled Row-Column Covariance. This field provides the covariance between the unmodeled error represented as an image row error and unmodeled error represented as an image column error.	21	BCS-A	pixels^2	±9.99999999999999E+99 Collectively, URR, URC, and UCC values must correspond to a positive semi-definite (2x2) error covariance matrix	C
UCC	Unmodeled Column Variance. This field provides the variance of unmodeled error represented as an image column error.	21	BCS-A	pixels^2	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value	C
UACSMC	Unmodeled CSM Correlation Option. This field indicates whether a CSM correlation functional form is to be used (UACSMC=Y). instead of the baseline piece-wise linear correlation functional form (UACSMC=N) in order to represent the correlation of unmodeled error.	1	BCS-A	N/A	Y or N	C
…if(UACSMC=N)						
UNCSR	Number of Correlation Segments for independent variable ROW distance. This field contains the number of piece-wise linear correlation segments that make up the correlation function for unmodeled error with independent variable image row distance.	1	BCS-N	N/A	2 through 9	C

…Begin for each correlation segment (UNCSR entries)						
UCORSR	Segment Correlation Value. This field contains the correlation value applicable at the beginning of the segment. Note that the value is defined as one for the first segment (correlation segment=1), and defined as zero for the last segment (correlation segment=UNCSR). It is a nonnegative number for all segments, decreasing in value from one segment to the next.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.00000000000000E+00 (0 to +1) Value consistent with a non-negative, convex, piece-wise linear correlation function defined by UNCSR entries of field UCORSR and field UTAUSR	C
UTAUSR	Segment Tau Value. This field contains the correlation row distance (tau) applicable at the beginning of the segment. Note that the value is defined as zero for the first segment (correlation segment=1). It is a positive number for all other segments, increasing in value from one segment to the next. Note that the values of the fields UCORSR and UTAUSR for all the segments are further constrained such that the corresponding piece-wise linear correlation function is convex (non-negative and increasing slope from one segment to the next). Also, the last segment is defined equal to zero for all tau greater than the last segment's UTAUSR value.	21	BCS-A	pixels	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value Value consistent with a non-negative, convex, piece-wise linear correlation function defined by UNCSR entries of field UCORSR and field UTAUSR	C
…End for each correlation segment						
UNCSC	Number of Correlation Segments for independent variable Column distance. This field contains the number of piece-wise linear correlation segments that make up the correlation function for unmodeled error with independent variable image column distance.	1	BCS-N	N/A	2 through 9	C
…Begin for each correlation segment (UNCSC entries)						
UCORSC	Segment Correlation Value. This field contains the correlation value applicable at the beginning of the segment. Note that the value is defined as one for the first segment (correlation segment=1), and defined as zero for the last segment (correlation segment=UNCSC). It is a nonnegative number for all segments, decreasing in value from one segment to the next.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.00000000000000E+00 (0 to +1) Value consistent with a non-negative, convex, piece-wise linear correlation function defined by UNCSC entries of field UCORSC and field UTAUSC	C

UTAUSC	Segment Tau Value. This field contains the correlation column distance (tau) applicable at the beginning of the segment. Note that the value is defined as zero for the first segment (correlation segment=1). It is a positive number for all other segments, increasing in value from one segment to the next. Note that the values of the fields UCORSC and UTAUSC for all the segments are further constrained such that the corresponding piece-wise linear correlation function is convex (non-negative and increasing slope from one segment to the next). Also, the last segment correlation is defined equal to zero for all tau greater than the last segment's UTAUSC value.	21	BCS-A	pixels	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value Value consistent with a non-negative, convex, piece-wise linear correlation function defined by UNCSC entries of field UCORSC and field UTAUSC	C
…End for each correlation segment						
…end if (UACSMC=N)						
…if (UACSMC=Y)						
UACR	This field provides the CSM correlation function A parameter for unmodeled error with independent variable row distance.	21	BCS-A	N/A	+0.00000000000001E-99 to +1.00000000000000E+00 (greater than 0 and less than or equal to +1)	C
UALPCR	This field provides the CSM correlation function alpha parameter for unmodeled error with independent variable row distance.	21	BCS-A	N/A	+0.00000000000000E+00 to +9.99999999999999E-01 (greater than or equal to 0 and less than +1)	C
UBETCR	This field provides the CSM correlation function beta parameter for unmodeled error with independent variable row distance.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.000000000000000E+01 (0 to +10)	C
UTCR	This field provides the CSM correlation function T parameter for unmodeled error with independent variable row distance.	21	BCS-A	seconds	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	C
UACC	This field provides the CSM correlation function A parameter for unmodeled error with independent variable column distance.	21	BCS-A	N/A	+0.00000000000001E-99 to +1.00000000000000E+00 (greater than 0 and less than or equal to +1)	C
UALPCC	This field provides the CSM correlation function alpha parameter for unmodeled error with independent variable column distance.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.00000000000000E+00 (greater than or equal to 0 and less than +1)	C
UBETCC	This field provides the CSM correlation function beta parameter for unmodeled error with independent variable column distance.	21	BCS-A	N/A	+0.00000000000000E+00 to +1.000000000000000E+01 (0 to +10)	C
UTCC	This field provides the CSM correlation function T parameter for unmodeled error with independent variable column distance.	21	BCS-A	seconds	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	C
…end if (UACSMC=Y)						
…end if (INCLUC = Y)						

Table 10: RSMECB TRE Format Table

14 RSM GROUND-TO-IMAGE GRID IDENTIFICATION (RSMGI) TRE

14.1 OVERVIEW

The Replacement Sensor Model Ground-to-image Grid Identification TRE (RSMGI) associates a ground-to-image grid with an image. The (interpolated) ground-to-image grid makes up the RSM ground-to-image function. The RSMGI TRE provides general information regarding the ground-to-image grid's geometric image / ground relationship. In particular, it identifies which image section is applicable to an arbitrary ground point. The RSM image domain may consist of a single section or it may be divided into at most 256 sections. Each section has its own unique ground-to-image grid, defined in its own RSM Ground-to-image Grid TRE (RSMGG). Most images require only one section.

Note that the RSMGI TRE is completely analogous to the RSMPI TRE that is used when a (rational) polynomial makes up the RSM ground-to-image function. If both TREs are present for the associated image, the output of the RSM ground-to-image grid is defined as an image space correction to the output of the RSM (rational) polynomial. (Because the RSMGI TRE is optional when there is only one image section, the actual condition is that at least one RSMGG TRE and at least one RSMPC TRE are present.) However, the image sections defined in the RSMGI TRE are completely independent of the image sections defined in the RSMPI TRE.

14.2 LOW ORDER POLYNOMIAL

A low order numerator-only polynomial provided in this TRE (RSMGI) is used to generate coarse image row (r) and column (c) coordinates from given ground coordinates. This quadratic model is applied to an arbitrary ground position $X = [x \quad y \quad z]^T$ within the RSM ground domain as follows:

$$r = GR0 + GRX \cdot x + GRY \cdot y + GRZ \cdot z + GRXX \cdot x^2 + GRXY \cdot xy + GRXZ \cdot xz + GRYY \cdot y^2 + GRYZ \cdot yz + GRZZ \cdot z^2$$
$$c = GC0 + GCX \cdot x + GCY \cdot y + GCZ \cdot z + GCXX \cdot x^2 + GCXY \cdot xy + GCXZ \cdot xz + GCYY \cdot y^2 + GCYZ \cdot yz + GCZZ \cdot z^2$$

14.3 SECTIONING

The resultant image coordinates are within the RSM image domain for the associated image and are relative to the original full image. There are a specifiable number of evenly spaced, rectangular sections in the RSM image domain. The field GRNIS specifies the number of sections in the row direction, the field GCNIS specifies the number of sections in the column direction. The field GRSSIZ specifies the number of rows per section, and the field GCSSIZ specifies the number of columns per section. An arbitrary section is defined by the row section number (GGRSN) and column section number (GGCSN) that it corresponds to. The fields GGRSN and GGCSN are contained in the RSMGG

TREs. The RSM image domain is defined by the fields MINR, MAXR, MINC, and MAXC that are provided in the RSMID TRE. (See Figure 23.)

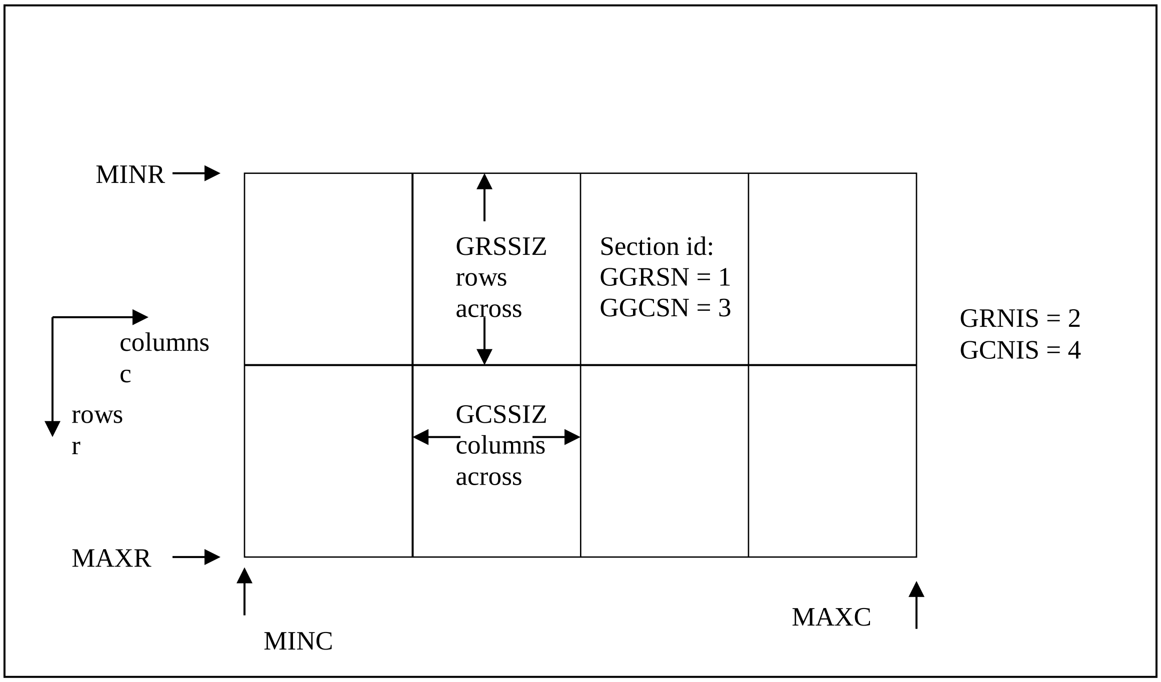

Figure 23: Sectioning of the RSM Image Domain for Grids

The following determines the row and column section numbers for an arbitrary row and column value output from the above quadratic model. Thus, it determines which section is applicable to an arbitrary ground point within the RSM ground domain:

$$GGRSN = \left\lfloor \frac{r - MINR}{GRSSIZ} \right\rfloor + 1$$

$$GGCSN = \left\lfloor \frac{c - MINC}{GCSSIZ} \right\rfloor + 1$$

The symbol $\lfloor \ \rfloor$ indicates integer floor. If either $GGRSN$ or $GGCSN$ is less than 1, set it to 1. If $GGRSN$ is greater than $GRNIS$, set $GGRSN = GRNIS$. If $GGCSN$ is greater than $GCNIS$, set $GGCNS = GCNIS$.

Note that, although the RSM ground-to-image function may consist of multiple ground-to-image grids corresponding to multiple sections within the RSM image domain, the RSM adjustable parameters (see the RSMAPA TRE description) are with respect to the overall RSM ground-to-image function and the entire RSM image domain, i.e., there are not multiple sets of RSM adjustable parameters corresponding to multiple sections within the RSM image domain.

If there are multiple sections, this TRE (RSMGI) is always provided with the associated image. If there is only one section, the inclusion of this TRE is optional.

Also, when multiple sections, grid spacing and alignment may differ between adjacent grids, each grid contained in its own RSMGG TRE. Therefore, grids corresponding to adjacent sections typically overlap to ensure "continuity". Thus, for example, if a grid is evaluated at a ground point near its section's boundary, there will be enough surrounding grid points to ensure interpolation of the proper order.

14.4 RSMGIA FORMAT

Table 11 specifies the detailed format for the Replacement Sensor Model Grid Identification version A (RSMGIA) TRE.

RSMGIA – Replacement Sensor Model Grid Identification						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMGIA	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	Bytes	591	R
Image Information						
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R

GR0	Low Order Polynomial Constant Coefficient for Row. This field provides the constant term used in the approximate image row position low order polynomial.	21	BCS-A	pixels	±9.99999999999999E±99	R
GRX	Low Order Polynomial Coefficient of X for Row. This field provides the coefficient of *x* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *x* units (radians or meters)	±9.99999999999999E±99	R
GRY	Low Order Polynomial Coefficient of Y for Row. This field provides the coefficient of *y* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *y* units (radians or meters)	±9.99999999999999E±99	R
GRZ	Low Order Polynomial Coefficient of Z for Row. This field provides the coefficient of *z* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *z* units (meters)	±9.99999999999999E±99	R
GRXX	Low Order Polynomial Coefficient of XX for Row. This field provides the coefficient of *xx* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *xx* units (radians squared or meters squared)	±9.99999999999999E±99	R
GRXY	Low Order Polynomial Coefficient of XY for Row. This field provides the coefficient of *xy* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *xy* units (radians squared or meters squared)	±9.99999999999999E±99	R
GRXZ	Low Order Polynomial Coefficient of XZ for Row. This field provides the coefficient of *xz* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *xz* units ((radians)(meters) or meters squared)	±9.99999999999999E±99	R
GRYY	Low Order Polynomial Coefficient of YY for Row. This field provides the coefficient of *yy* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *yy* units (radians squared or meters squared)	±9.99999999999999E±99	R
GRYZ	Low Order Polynomial Coefficient of YZ for Row. This field provides the coefficient of *yz* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *yz* units ((radians)(meters) or meters squared)	±9.99999999999999E±99	R
GRZZ	Low Order Polynomial Coefficient of ZZ for Row. This field provides the coefficient of *zz* used in the approximate image row position low order polynomial.	21	BCS-A	pixels per *zz* units (meters squared)	±9.99999999999999E±99	R
GC0	Low Order Polynomial Constant Coefficient for Column. This field provides the constant term used in the approximate image column position low order polynomial.	21	BCS-A	pixels	±9.99999999999999E±99	R
GCX	Low Order Polynomial Coefficient of X for Column. This field provides the coefficient of *x* used in the approximate image column position low order polynomial.	21	BCS-A	pixels per *x* units (radians or meters)	±9.99999999999999E±99	R

GCY	Low Order Polynomial Coefficient of Y for Column. This field provides the coefficient of y used in the approximate image column position low order polynomial.	21	BCS-A	pixels per y units (radians or meters)	±9.99999999999999E±99	R
GCZ	Low Order Polynomial Coefficient of Z for Column. This field provides the coefficient of z used in the approximate image column position low order polynomial.	21	BCS-A	pixels per z units (meters)	±9.99999999999999E±99	R
GCXX	Low Order Polynomial Coefficient of XX for Column. This field provides the coefficient of xx used in the approximate image column position low order polynomial.	21	BCS-A	pixels per xx units (radians squared or meters squared)	±9.99999999999999E±99	R
GCXY	Low Order Polynomial Coefficient of XY for Column. This field provides the coefficient of xy used in the approximate image column position low order polynomial.	21	BCS-A	pixels per xy units (radians squared or meters squared)	±9.99999999999999E±99	R
GCXZ	Low Order Polynomial Coefficient of XZ for Column. This field provides the coefficient of xz used in the approximate image column position low order polynomial.	21	BCS-A	pixels per xz units ((radians)(meters) or meters squared)	±9.99999999999999E±99	R
GCYY	Low Order Polynomial Coefficient of YY for Column. This field provides the coefficient of yy used in the approximate image column position low order polynomial.	21	BCS-A	pixels per yy units (radians squared or meters squared)	±9.99999999999999E±99	R
GCYZ	Low Order Polynomial Coefficient of YZ for Column. This field provides the coefficient of yz used in the approximate image column position low order polynomial.	21	BCS-A	pixels per yz units ((radians)(meters) or meters squared)	±9.99999999999999E±99	R
GCZZ	Low Order Polynomial Coefficient of ZZ for Column. This field provides the coefficient of zz used in the approximate image column position low order polynomial.	21	BCS-A	pixels per zz units (meters squared)	±9.99999999999999E±99	R
GRNIS	Row Number of Image Sections. This field identifies the number of sections the RSM image domain is divided into along the row direction for representation of the ground-to-image relationship.	3	BCS-N	N/A	001 to 256	R
GCNIS	Column Number of Image Sections. This field identifies the number of sections the RSM image domain is divided into along the column direction for representation of the ground-to-image relationship.	3	BCS-N	N/A	001 to 256	R

GTNIS	Total Number of Image Sections. This field contains the total number of rectangular sections the RSM image domain is divided into for representation of the ground-to-image relationship. The value in this field is the product of the values in the GRNIS and GCNIS fields. Thus, the value of the field GTNIS, with a maximum of 256, places constraints on the values of the fields GRNIS and GCNIS. This number represents the total number of RSMGG TREs.	3	BCS-N	N/A	001 to 256	R
GRSSIZ	Section Size in Rows. This field contains the number of rows contained in a single section. Note that its value is represented as a positive non-integer because it equals the number of rows in the RSM image domain divided by the number of sections in the row direction, not necessarily and integer value.	21	BCS-A	pixels	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	R
GCSSIZ	Section Size in Columns. This field contains the number of columns contained in a single section. Note that its value is represented as a positive non-integer because it equals the number of columns in the RSM image domain divided by the number of sections in the column direction, not necessarily and integer value.	21	BCS-A	pixels	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	R

Table 11: RSMGIA TRE Format Table

15 RSM GROUND-TO-IMAGE GRID (RSMGG) TRE

15.1 OVERVIEW

The Replacement Sensor Model Ground-to-image Grid TRE (RSMGG) contains the ground point - image point correspondences that make up the RSM ground-to-image grid. The interpolated grid takes a ground position within the RSM ground domain into a corresponding image position within the RSM image domain. The coordinates of the resultant image position are with respect to the original full image. They are also within a specific section of the RSM image domain, as specified by the fields GGRSN and GGCSN. That is, a particular RSMGG TRE corresponds to a specific image section, as discussed in the RSMGI TRE format description.

15.2 GROUND SPACE – IMAGE SPACE CORRESPONDENCE GRID

An image section's RSM ground-to-image grid consists of an image location $I_j = [r \quad c]^T$ associated with each three dimensional ground point $X_j = [x \quad y \quad z]^T$ located within a grid spanning the image section's footprint over a range of z-coordinate values. The actual X_j values are not included, but are defined in the RSM support data by the following parameters: the (constant) z-coordinate value of the first grid-plane (field ZPLN1), the number of grid-planes (NPLN), and the (constant) z-coordinate spacing interval between grid-planes (DELTAZ); the (constant) x-coordinate spacing interval (DELTAX) and (constant) y-coordinate spacing interval (DELTAY) between grid points within a grid-plane and common across grid-planes; the value of the initial grid point's (x,y)-coordinates in the first grid-plane (XIPLN1 and YIPLN1), and for the remainder of the grid-planes, their (unique) initial grid point's (x,y)-coordinates, specified as an integer number of x-coordinate spacing intervals (IXO) and integer number of y-coordinate spacing intervals (IYO) from the first grid-plane's initial grid point location; finally, for each grid-plane, the (unique) integer number of grid points in the x-direction (NXPTS) and the (unique) integer number of grid points in the y-direction (NYPTS).

Figure 24 illustrates an RSM ground grid with four z-planes, and Figure 25 its first z-plane. Ground point locations occur at the intersection of the x-grid lines with the y-grid lines in each z-plane.

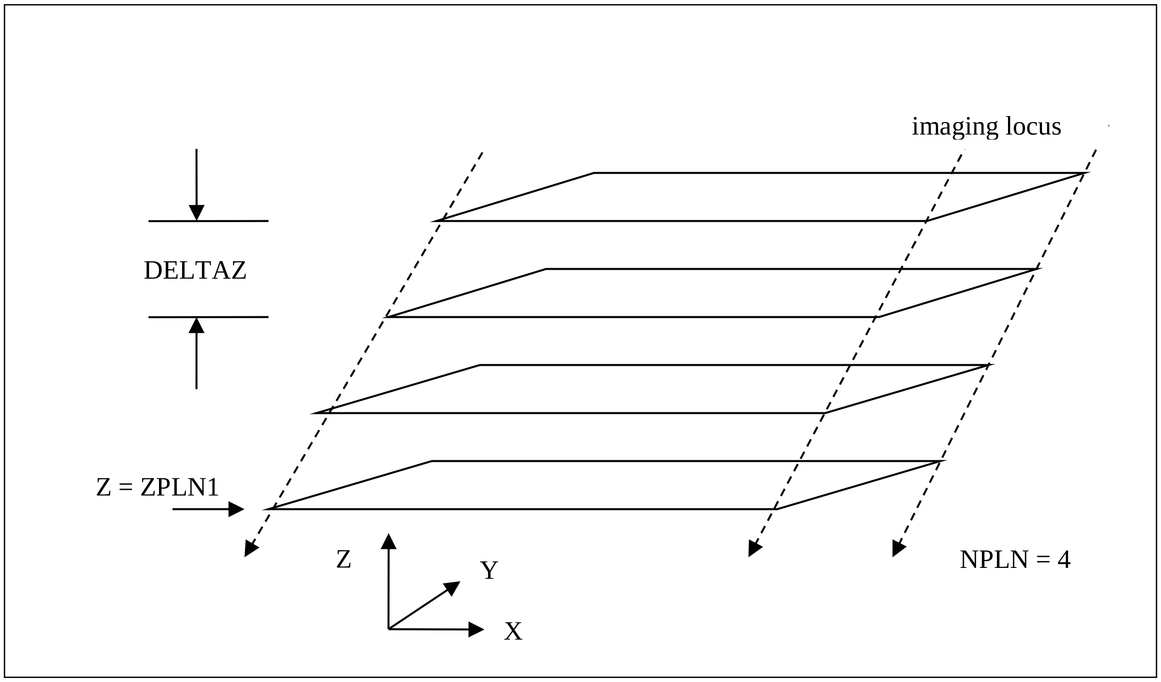

Figure 24: Grid Z-Planes

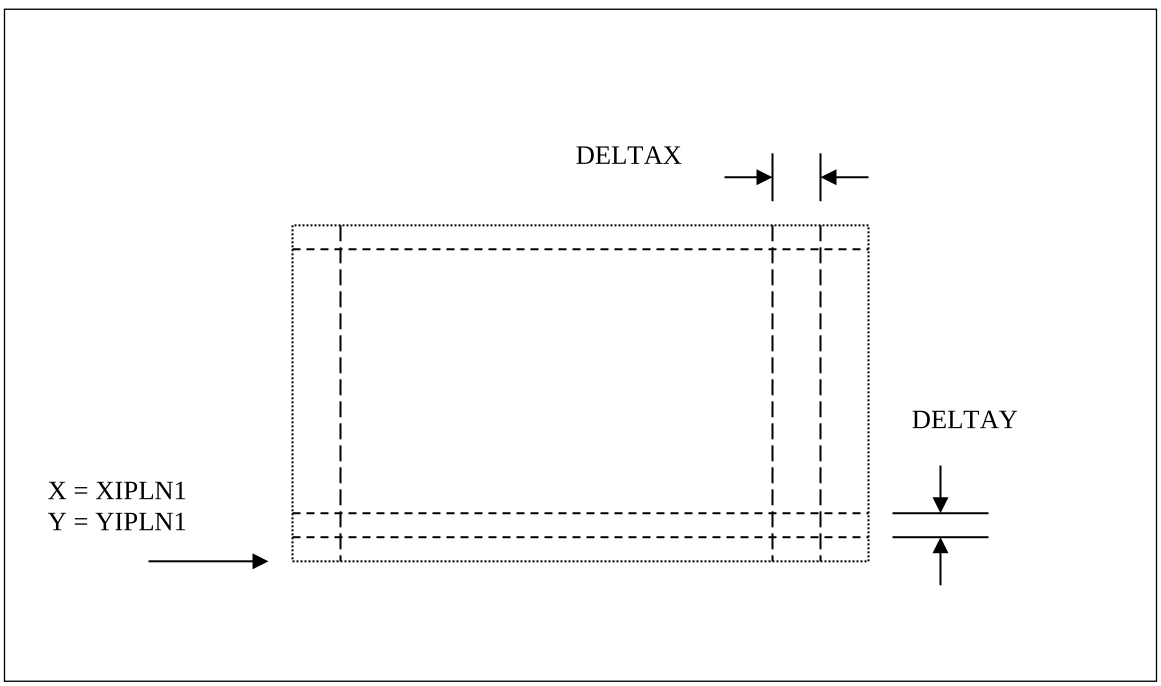

Figure 25: Grid Plane 1

The three-dimensional grid described above corresponds to a constant rectangular x-y grid in each z-plane, but allows for an irregular "terrace" pattern as the planes increase in z-value. This relatively general grid specification is more efficient than simply a grid corresponding to a cuboid ("box") in the applicable coordinate system. The latter can contain numerous "extraneous" grid points that do not correspond to valid image coordinates.

For example, assume that the RSM primary ground coordinate system is Geodetic. If the (optical) sensor imaging geometry is nadir and if the image section's ground footprint is oriented east-west and north-south, there are virtually no extraneous grid points. If, however, either of these conditions is not true, there are extraneous grid points.

The “terrace” pattern compensates for a non-nadir effect. If the RSM primary ground coordinate system is also Rectangular, more efficiency is possible. If the Rectangular system is defined as a local tangent plane ground coordinate system centered within the image section footprint at a nominal elevation, and also rotated in approximate horizontal alignment with the footprint, there will be few extraneous grid points. The fewer the extraneous grid points, the less the RSM support data bandwidth.

15.2.1 INTERPOLATION

The RSM ground-to-image function, based on the ground-to-image grid, outputs an image coordinate I associated with an arbitrary ground point X. The function interpolates the I_j in a set of X_j surrounding X. A recommended interpolation method is (separable) tri-quadratic Lagrange interpolation, which uses the nearest 3×3×3 grid of X_j surrounding X. When X is outside the grid boundary or a 3×3×3 grid is not available, linear interpolation/extrapolation is recommended. Another recommended interpolation method is (separable) tri-cubic Lagrange interpolation, which uses the nearest 4×4×4 grid of X_j surrounding X. It can provide higher fit accuracy in some imaging circumstances. The recommended interpolation method (order) is optionally specified in the field INTORD, along with statistics of corresponding “fit” error relative to the original sensor model's ground-to-image relationship (fields GGRFEP and GGCFEP).

15.2.2 GRID POINT VALUES

The grid of actual image row and column coordinate values are contained in fields RCOORD and CCOORD. The corresponding total number of digits (characters) contained in these fields are specified in fields TNUMRD and TNUMCD. The total number of digits can range from 3 to 11. The corresponding number of digits to the right of the decimal point (fractional digits) are specified in fields FNUMRD and FNUMCD. The number of fractional digits can range from 1 to 3.

For example, if TNUMRD equals 6 and FNUMRD equals 2, image row coordinate values contained in RCOORD are represented as xxxx.xx pixels. RCOORD contains six decimal digit characters. The decimal point character is not included. Another equivalent interpretation is that RCOORD contains a six digit integer, with units of 1/100th of a pixel.

The non-negative coordinate values specified in RCOORD and CCOORD are actually relative to signed grid reference values as specified in fields REFROW and REFCOL; hence, absolute coordinate values may be negative. This could occur if the section was the first or last in the original full image, and the grid was to extend beyond the image for continuity purposes, However, this could only occur if the original sensor model supported a ground-to-image relationship outside the original full image.

If for a given grid point, the fields RCOORD and CCOORD contain the value all spaces, a valid image coordinate is unavailable. However, a non-all spaces value does not necessarily correspond to a pixel location within the image section. The ground-to-image grid associated with a particular image section typically overlaps adjacent grids for continuity purposes associated with interpolations and numerical partial derivative calculations near grid (section) boundaries, and with effects of non-zero RSM adjustable parameter values.

15.3 TRE SIZE AND NUMBER OF TRES

As detailed in the description for field CEL, the size of one RSMPC TRE can approach the maximum TRE size of 99988 bytes. This value depends primarily on the total number of grid points and number of digits per image coordinate. In addition, if multiple RSMPC TREs are required, corresponding to multiple image sections as specified in the RSMGI TRE, their total number of bytes may exceed 200,000 bytes, requiring their (and possibly other RSM TREs) placement into the overflow area for the image.

Note, however, the number of grid points per image section, the number of image coordinate digits (range and precision), the number of image sections, and even the simultaneous use of a ground-to-image polynomial, can all be "selected" in an integrated manner by the RSM TRE generation process in order to limit the number of bytes per RSMGG TRE. In addition, the total number of bytes corresponding to multiple RSMPC TREs can be limited to a reasonable value. This value is required to be less than approximately 25,600,000 bytes, which corresponds to the maximum number of possible image segments (256) and the maximum number of bytes per individual RSMPC TRE.

15.4 RSMGGA FORMAT

Table 12 specifies the detailed format for the Replacement Sensor Model Ground-to-image Grid version A (RSMGGA) TRE.

RSMGGA – Replacement Sensor Model Ground-to-image Grid						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Value Range**	**Type**
TAG Information						
CETAG	Unique Extension Type Identifier Unique TRE identifier.	6	BCS-A	N/A	RSMGGA	R
CEL	Length of User-Defined Data Length in bytes of data contained in subsequent fields. (TREs length is 11 plus the value given in the CEL field)	5	BCS-N	bytes	390 to 99988	R
Image Information						
IID	Image Identifier. This field contains a character string that uniquely identifies the original full image that corresponds to the associated image. This is not to be confused with the identification of an image derived by filtering, chipping, re-sampling, or other such image-to-image transformations. The image identifier is left justified with trailing spaces.	80	BCS-A	N/A	N/A All spaces if unavailable	<R>
EDITION	RSM Image Support Data Edition. This field contains a character string that uniquely identifies the RSM support data for the associated original full image. It is to consist of an identifier of up to 20 characters for the processor that generated the RSM support data, to which is appended up to 20 characters that are unique among RSM TRE sets that are generated by that processor.	40	BCS-A	N/A	N/A	R
GGRSN	Ground-to-image Grid Row Section Number. This field contains the image row section number that the following ground-to-image grid applies to	3	BCS-N	N/A	001 to 256	R
GGCSN	Ground-to-image Grid Column Section Number. This field contains the image column section number that the following ground-to-image grid applies to	3	BCS-N	N/A	001 to 256	R
GGRFEP	Ground-to-image Grid Row Fitting Error. This field contains the rms fit error estimate applicable to the row ground-to-image grid relative to the original sensor model's ground-to-image function. The value of GGRFEP assumes that an RSM ground-to-image polynomial is also employed, if available. When a ground-to-image polynomial is available, the ground-to-image grid represents corrections to the polynomial, and field GGRFEP represents the rms error of the combined polynomial and grid evaluation.	21	BCS-A	pixels	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value Population optional Default is all spaces	<R>

GGCFEP	Ground-to-image Grid Column Fitting Error. This field contains the rms fit error estimate applicable to the column ground-to-image grid relative to the original sensor model's ground-to-image function. The value of GGCFEP assumes that an RSM ground-to-image polynomial is also employed, if available. When a ground-to-image polynomial is available, the ground-to-image grid represents corrections to the polynomial, and field GGCFEP represents the rms error of the combined polynomial and grid evaluation.	21	BCS-A	pixels	+0.00000000000000E+00 to +9.99999999999999E+99 Non-negative value Population optional Default is all spaces	<R>
INTORD	Ground-to-image Grid Interpolation Order. This field specifies the recommended interpolation order to be used in determining row and column image coordinates from the ground-to-image grid. The fitting error statistics provided in fields GGRFEP and GGCFEP above are based on assumed use of the recommended interpolation order. Field GGRFEP and GGCFEP should only be populated if field INTORD is populated. The recommended order specified in INTORD is either 0, 1, 2, or 3. These values correspond to nearest neighbor, separable tri-linear Lagrange, separable tri-quadratic Lagrange, and separable tri-cubic Lagrange interpolations, respectively.	1	BCS-A	N/A	0,1,2,3 Population optional Default is all spaces	<R>
Grid plane and grid point position data						
NPLN	Number of Grid Planes. This field contains the total number of grid planes.	3	BCS-N	N/A	002-999	R
DELTAZ	Delta Z Between Grid Planes. This field contains the constant delta Z between grid planes.	21	BCS-A	meters	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	R
DELTAX	Delta X Between Grid Points. This field contains the constant delta x between points in a grid plane. This value is the same for all grid planes.	21	BCS-A	Radians or meters	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	R
DELTAY	Delta Y Between Grid Points. This field contains the constant delta y between points in a grid plane. This value is the same for all grid planes.	21	BCS-A	Radians or meters	+0.00000000000001E-99 to +9.99999999999999E+99 Positive value	R
ZPLN1	Z Value of Plane 1. This field contains the constant Z value of the first plane. All other planes have greater Z values. Within a given grid plane, all points have a common Z-coordinate value.	21	BCS-A	meters	±9.99999999999999E±99	R

XIPLN1	X Value of Initial Point in Plane 1. This field contains the value of the x -coordinate of the first grid point in the first grid plane.	21	BCS-A	Radians or meters	If GRNDD=G, -3.14159265358979E+00 to +3.14159265358979E+00 (-pi to pi) If GRNDD=H, +0.00000000000000E+00 to +6.28318530717958E+00 (0 to 2pi), If GRNDD=R, ±9.99999999999999E±99	R
YIPLN1	Y Value of Initial Point in Plane 1. This field contains the value of the y -coordinate of the first grid point in the first grid plane.	21	BCS-A	Radians or meters	If GRNDD=G or H, -1.57079632679489E+00 to +1.57079632679489E+00 (-pi/2 to pi/2) If GRNDD=R ±9.99999999999999E±99	R
REFROW	Reference Image Row Coordinate Value. This field contains the reference image row coordinate value across all grid points across all grid planes. This value is within the RSM image domain and with respect to the original full image.	9	BCS-N	pixels	-99999999 to +99999999	R
REFCOL	Reference Image Column Coordinate Value. This field contains the reference image column coordinate value across all grid points across all grid planes. This value is within the RSM image domain and with respect to the original full image.	9	BCS-N	pixels	-99999999 to +99999999	R
TNUMRD	Total Number of Image Row Coordinate Digits. The value of this field specifies the total number of digits used in field RCOORD to specify the image row coordinate value relative to the value of REFROW.	2	BCS-N	N/A	3 - 11	R
TNUMCD	Total Number of Image Column Coordinate Digits. The value of this field specifies the total number of digits used in field CCOORD to specify the image column coordinate value relative to the value of REFCOL.	2	BCS-N	N/A	3 - 11	R
FNUMRD	Number of Image Row Coordinate Fractional Digits. The value of this field specifies the number of fractional digits used in field RCOORD to specify the image row coordinate value relative to the value of REFROW.	1	BCS-N	N/A	1-3	R
FNUMCD	Number of Image Column Coordinate Fractional Digits. The value of this field specifies the number of fractional digits used in field CCOORD to specify the image row coordinate value relative to the value of REFCOL.	1	BCS-N	N/A	1-3	R
…Begin for grid plane 2 through the total number of grid planes (NPLN-1 entries)						

IXO	Initial Grid Points X Offset. This field contains the offset of this grid plane's initial grid point's x-coordinate value relative to the first grid plane's initial grid point's x-coordinate value, expressed as a signed integer multiple of delta x.	4	BCS-N	N/A	±999	R
IYO	Initial Grid Points Y Offset. . This field contains the offset of this grid plane's initial grid point's y-coordinate value relative to the first grid plane's initial grid point's y-coordinate value, expressed as a signed integer multiple of delta y.	4	BCS-N	N/A	±999	R
…End for each non-initial grid plane						
…Begin for each grid plane (NPLN entries)						
NXPTS	Number of Grid Points in the X Direction. This field contains the total number of grid points in the x direction in this grid plane. For this grid plane, the x-coordinate of each grid point is equal to the initial grid point's x-coordinate plus a non-negative multiple of delta x.	3	BCS-N	N/A	002 to 999	R
NYPTS	Number of Grid Points in the Y Direction. This field contains the total number of grid points in the y direction in this grid plane. For this grid plane, the y-coordinate of each grid point is equal to the initial grid point's y-coordinate plus a non-negative multiple of delta y.	3	BCS-N	N/A	002-999	R
…For each grid point ((NXPTS)(NYPTS) entries)						
RCOORD	Grid Point's Row Coordinate. This field contains the value of the image row coordinate for the current grid point, expressed as a non-negative offset from field REFROW. Grid points are stored in matrix row major order. The first matrix element corresponds to this grid's initial grid point. A matrix row corresponds to a constant x –coordinate value. A matrix column corresponds to a constant y –coordinate value.	3 – 11, per field TNUMRD	BCS-A	0.1, 0.01, or 0.001 pixels, per field FNUMRD	000 - 999 to 00000000000 – 99999999999, per field TNUMRD. If a valid row coordinate value is unavailable, the field contains all spaces (3-11 spaces per field TNUMRD).	<R>
CCOORD	Grid Point's Column Coordinate. This field contains the value of the image column coordinate for the current grid point, expressed as a non-negative offset from field REFCOL. Grid points are stored in matrix row major order. The first matrix element corresponds to this grid's initial grid point. A matrix row corresponds to a constant x –coordinate value. A matrix column corresponds to a constant y –coordinate value.	3 - 11, per field TNUMCD	BCS-A	0.1, 0.01, or 0.001 pixels, per field FNUMCD	000 - 999 to 00000000000 – 99999999999, per field TNUMCD. If a valid column coordinate value is unavailable, the field contains all spaces (3-11 spaces per field TNUMCD).	<R>

…End for each grid point
…End for each grid plane

Table 12: RSMGGA TRE Format Table

16 GLOSSARY

Adjustable parameters – A set of adjustments to parameters that affect a ground-to-image function. Their values are typically zero corresponding to unadjusted image support data, and non-zero following the adjustment ("triangulation") of a collection of image support data.

Associated image – The original full image associated with a particular RSM TRE Set (see "image").

Down-stream user– A user (e.g., exploitation work station or electronic light table) that receives an RSM TRE Set(s) in an NITF files(s) for subsequent RSM-based image exploitation. The RSM TRE Set was generated by an upstream-process prior to user's receipt.

Ground-to-image function – Maps a three-dimensional ground point to a two-dimensional image point.

Ground space – the three-dimensional mathematical space in which physical objects are defined.

Image – An image is an original full image with corresponding image support data contained in an RSM TRE Set. An image is contained in one or more NITF image segments. Each image segment contains the (identical) RSM TRE Set in its image subheader, and an image data field of pixels related to the original full image.

Image data field– See MIL-STD-2500B, section 5.4.3.

Imaging locus – For a given image point, the imaging locus is defined as all possible corresponding ground (three-dimensional object space) points. For example, for an optical sensor, the imaging locus corresponds to all points along an image ray, its direction approximated by the line-of-sight vector between a ground point and sensor.

Image mapping function – A function or relationship (M) that maps original full image row and column coordinates (counts) to image data field row and column coordinates (counts).

Image section – A rectangular portion of the RSM image domain applicable to a particular RSM ground-to-image function (polynomial or grid).

Image segment – See MIL-STD-2500B section 5.1.3.

Image space – the two-dimensional mathematical space in which image coordinates are defined.

Image support data – The metadata that enables a sensor model for a particular image.

Line/sample – Image coordinates equivalent to (original full) image row/column coordinates.

Original sensor model – A physical, or "rigorous", sensor model applicable to a specific sensor. It typically includes a ground-to-image function (or its inverse), adjustable parameters, and an error covariance applicable to the errors in the adjustable parameter values that represents the image support data uncertainty.

Original sensor model image support data– The image support data that enables an original sensor model for a particular image. This image support data typically consists of a time history of the sensor position, velocity, attitude, interior orientation parameters, etc.

Overflow area – More precisely "TRE_OVERFLOW DES", see MIL-STD_2500B, section 5.8.1.3.

Replacement Sensor Model (RSM) – A general sensor model that provides for equivalent geospatial mensuration and triangulation (adjustment) capabilities as the original sensor model for virtually any imaging sensor. The RSM includes an RSM ground-to-image function, RSM adjustable parameters and an error covariance applicable to the errors in the adjustable parameter values that represents the RSM image support data uncertainty, and equivalently, the original sensor model image support data uncertainty.

Row and column counts– Equivalent to image row and column coordinate values.

RSM adjustable ground-to-image function – An RSM ground-to-image function adjusted by non-zero RSM adjustable parameter values.

RSM Adjustable Parameter Choice Set – There are 36 defined RSM adjustable parameters: 20 image-space adjustable parameters and 16 ground-space adjustable parameters. A subset of these adjustable parameters are identified in the RSMDC, RSMEC, and RSMAP TREs as being applicable, or active, for the associated image.

RSM edition – A character string that uniquely identifies RSM support data for the associated original full image. It differentiates between two RSM TRE Sets associated with the same original full image. For example, one set may correspond to unadjusted RSM image support data and the other to adjusted RSM image support data.

RSM exploiter – A software module that provides the appropriate sensor model functionality associated with an RSM TRE Set. For example, it provides the image point corresponding to a supplied ground point.

RSM Exploiter – A specific API-driven RSM exploiter built by BAE Systems for the NGA.

RSM generator – A software module that generates RSM image support data (RSM TRE Set) from an original sensor model and its image support data.

RSM Generator – A specific API-driven RSM generator built by BAE Systems for the NGA.

RSM ground domain – The approximate ground domain associated with the RSM image domain, a function of imaging geometry and range of height above the WGS 84 ellipsoid.

RSM ground-to-image function – A ground-to-image function that consists of either a collection of ground-to-image (rational) polynomials (one per image section), collection of interpolated ground-to-image grids (one per image section), or both. If the latter, the interpolated grid provides corrections to the polynomial's output.

RSM image domain – The rectangular region within the original full image where the RSM and its image support data (RSM TRE Set) is applicable.

RSM image support data – The image support data (RSM TRE Set) that enables the RSM for a particular image.

RSM image support data error covariance – An error covariance applicable to errors in the RSM adjustable parameter values associated with one or more images. It represents the uncertainty in the image support data, and is in the form of either the RSM direct error covariance or RSM indirect error covariance.

RSM Local coordinate system – The coordinate system referenced by RSM adjustable parameters, typically a ground coordinate system with the z-axis aligned along the direction of the imaging locus at the center of the RSM image domain.

RSM primary ground coordinate system – The specifiable ground coordinate system referenced by the RSM ground-to-image function, either geodetic or Rectangular.

Replacement Sensor Model (RSM) Tagged Record Extensions (TREs)

RSM Adjustable Parameters TRE (RSMAP) – Contains the RSM adjustable parameter values resulting from the adjustment of RSM image support data from an adjustment process, such as triangulation. The particular adjustable parameters associated with the values are also termed active adjusted parameters.

RSM Direct Error Covariance TRE (RSMDC) – Contains the (direct) error covariance applicable to the RSM adjustable parameters for one or more images. Images may be from any combination of sensors. The particular adjustable parameters referenced by the error covariance are also termed active error model adjustable parameters.

RSM Error Covariance TRE (RSMEC) – Contains the error covariance information defining an error covariance applicable to the RSM adjustable parameters for one or more images. Images must correspond to the same sensor, but other than the associated image, the images are not explicitly identified as part of the information contained in the RSMEC TRE for the associated image. The particular adjustable parameters referenced by the error covariance are also termed active error model adjustable parameters.

RSM Grid Identification TRE (RSMGI) – Defines the location of multiple sections within the RSM image domain, each of which is associated with a unique (interpolated) ground-to-image grid as represented in its own RSMGG TRE.

RSM Grid TRE (RSMGG) – Contains a ground-to-image grid representing the RSM ground-to-image function for a particular image section.

RSM Identification TRE (RSMID) – Contains various image and optional sensor identifications, coordinate system definitions, and regions of RSM applicability. Also contains a time-of-image model, an optional illumination model, and an optional trajectory model.

RSM Polynomial Identification (RSMPI) TRE – Defines the location of multiple sections within the RSM image domain, each of which is associated with a unique (rational) polynomial ground-to-image function as represented in its own RSMPC TRE.

RSM Polynomial Coefficients (RSMPC) TRE – Contains a (rational) polynomial representing the RSM ground-to-image function for a particular image section. The polynomial is specified by the provided polynomial order, coefficients, and various scale factors.

RSM TRE Set – A set of Replacement Sensor Model tagged record extensions applicable to a particular image.

Scientific Notation – Scientific Notation (also called power-of-10 notation) is a method for expressing a given quantity as a number having the significant digits necessary for the specified degree of precision. It can be expressed as a coefficient followed by an exponent (where the coefficient is multiplied by 10 raised to the power of the exponent). For example, using the coefficient 3.140, the numeric value in Scientific Notation can be represented as 3.140E+nn, where "E" indicates the exponent portion and "+nn" specifies the power of 10 that the coefficient is multiplied by for the numeric values. In this example, 3.140E-01 = 0.314, 3.140E+00 = 3.140, and 3.140E+02 = 314.0, where the exponent portion determines how many places to move the decimal point to the right or left for positive and negative values, respectively (note that by convention, when the exponent is zero, it is always represented as a positive exponent). For a Scientific Notation format designed to handle the maximum precision possible, standard practice is to fill the non-significant digits with zeros. The precision of the data collected can usually be determined by the non-zero digits in multiple entries for the same types of fields (when no other information is available to determine it).

Sensor model – A mathematical model which includes the relationships between the ground coordinates of objects , the image coordinates at which data pertaining to the objects can be found, and the time of data acquisition. In addition, the sensor model includes adjustable parameters that affect the ground-to-image relationship, and error covariance data applicable to the errors in the adjustable parameter values. The error covariance can characterize the uncertainty in sensor model parameters and data, which in turn, can be used to characterize the uncertainty in the ground-to-image relationship.

Up-stream process – A process which first generates an RSM TRE Set from original image support data using both the RSM and original sensor model. It then inserts the RSM TRE Set into an NITF file and disseminates it down-stream to either an intended user community for exploitation or to an intermediary image-provider. An upstream-process could be a ground station that first receives imagery and original image support via a sensor down-link.

Appendix A

Additional Resources

There are a number of resources available for further understanding of RSM.

The following are published by the American Society of Photogrammetry and Remote Sensing (ASPRS). The first is a general overview and status (as of 2008) of RSM, the second is an overview of its performance, and the third contains detailed RSM equations and algorithms.

Dolloff, J., M. Iiyama, and C. Taylor (2008). The Replacement Sensor Model (RSM): Overview, Status, and Performance Summary. ASPRS 2008 Annual Conference, April 28-May 2, 2008.

Taylor, C., J. Dolloff, and M. Iiyama (2008). Replacement Sensor Model (RSM) Performance For Triangulation and Geopositioning. ASPRS 2008 Annual Conference, April 28-May 2, 2008.

Dolloff, J. (2004). Replacement Sensor Models, Chapter 11.3, *Manual of Photogrammetry*, 5th Edition. J. C. McGlone editor. ASPRS, pp. 887-943.

There are three additional appendices that accompany this specification:

Appendix B, "The ABCs of RSM: An Introduction to the Replacement Sensor Model," is a good starting point for users who have not had previous experience with RSM. Note that the B TRE versions are referred to as "X" versions and that some of the references in the text are outdated, but the reference section has been updated.

Appendix C, "RSM Extraction and Adjustment of Large Field of View Frame Imagery", is a performance study of RSM that successfully handles a very difficult scenario.

Appendix D provides guidelines for compliance testing of RSM generators and RSM exploiters.

Further assistance regarding RSM can be obtained by contacting the NGA MSP program office:

Cheryl Herbaugh	NGA MSP PM	571.557.9893	cheryl.j.herbaugh@nga.mil
Catherine Orner	NGA MSP COR	571.557.8392	catherine.f.orner@nga.mil
MSP Help Desk		858.592.5677	msphelp@baesystems.com

Note that assistance includes inquiries regarding the availability of the RSM Generator and RSM Exploiter (CSM sensor model plug-in) that are referred to in some of the resources mentioned above as well as in the main body of this specification.

Appendix B

The ABC's of RSM: An Introduction to the Replacement Sensor Model

September 30, 2006

Michelle Iiyama
John Dolloff
Charles Taylor

BAE SYSTEMS

Table of Contents

1.0 Introduction B-4
2.0 Prelude B-4
3.0 What's a Physical Sensor Model? B-6
3.1 Parts Is Parts B-10
3.2 What Can You Do With It? B-15
3.3 How Does It All Work? B-21
3.4 If It's Not Broke, Why Fix It? B-21
4.0 What Is RSM? B-22
4.1 Parts…We Have Them All B-24
4.2 One Size Fits All B-31
4.3 Advantage…RSM B-32
5.0 Evolution B-33
5.1 The Journey B-33
5.2 Seeing Is Believing B-34
6.0 Cooking With RSM B-37
6.1 Cooking From Scratch B-37
6.2 Just Add Water… B-38
7.0 Tributes B-42
8.0 Coda B-42
9.0 References B-44

Table of Tables

Table B1: RSM TREs B-31
Table B2: Original Sensor Model vs. RSM B-36

Table of Figures

Figure B1: Sample Optical Image B-5
Figure B2: Sample Sensors and Their Images B-6
Figure B3: Image Point / Ground Point Relationship B-7
Figure B4: Image-To-Ground Height Dependence B-9
Figure B5: Effects of Sensor Position Errors B-12
Figure B6: Effects of Attitude Errors B-13
Figure B7: Effects of Focal Length Errors B-14
Figure B8: Mono Extraction and Accuracy Prediction B-17
Figure B9: Multi-Image Extraction and Accuracy Prediction B-18
Figure B10: Sensor Parameter Adjustments B-20
Figure B11: RSM Flow B-23
Figure B12: RSM Ground-To-Image B-25
Figure B13: RSM Ground-To-Image Function B-26
Figure B14: Application of RSM Adjustable Ground-to-Image Function B-28
Figure B15: RSM Sample Geo-positioning Tests B-35
Figure B16: Integration of RSM Generator B-40
Figure B17: Integration of RSM Exploiter B-41

1.0 Introduction

This document provides a light introduction to the Replacement Sensor Model referred to by the acronym, RSM. No prior knowledge of sensor models, or advanced math is required; and in fact, we will avoid the use of equations. The following will describe RSM, its benefits, its development history, and in the end, discuss how to obtain it. For those intrigued to know more, they are invited to follow the references to more detailed documentation.

> Note 1.0-1: Throughout this document there will be "little blue boxes" containing notes that offer additional insight and depth. They are not deemed necessary to the basic description.

Advisory: Parts of this document are intended to be somewhat whimsical in nature in order to prevent drowsiness.

2.0 Prelude

Before we can begin talking about a replacement sensor model, we need to understand not only what a sensor model is, but what a sensor is. A sensor, according to the Merriam-Webster dictionary is:

> *A device that responds to a physical stimulus ([such] as heat, light, sound, pressure, magnetism, or a particular motion) and transmits a resulting impulse (as for measurement or operating a control)*

In our case, a sensor is quite simply a fancy camera mounted upon a moving vehicle (platform), and takes pretty pictures (images). Imagine being in an airplane, taking a picture of the ground below (**Figure B1**).

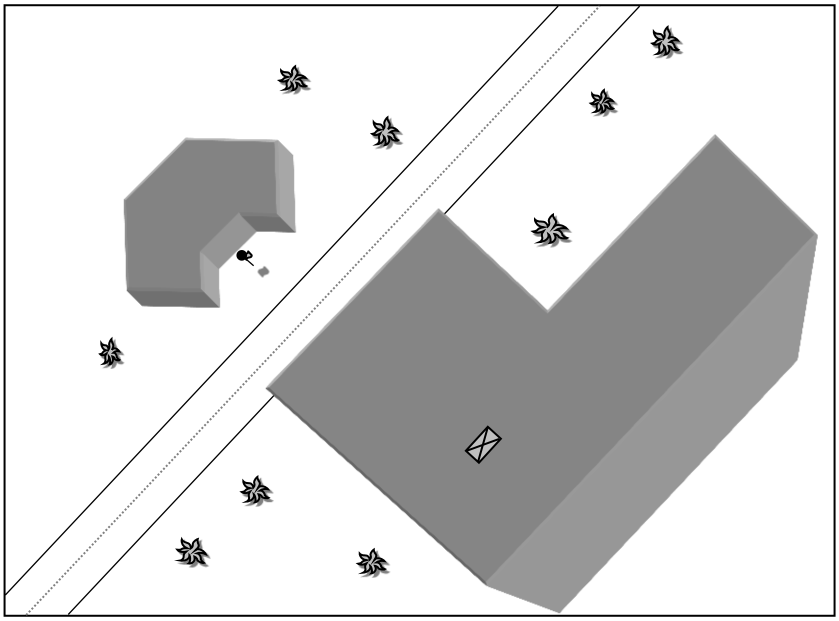

Figure B1: Sample Optical Image

So, in our context a sensor takes pictures. Looking at the picture above, we can see identifiable objects: buildings, a street, a flag pole. But it's just a picture. Suppose we wanted more information from that picture, like the ground coordinates (i.e. ground position or geo-location) of the vent (marked with an 'X') on the rooftop of the larger building. What processes are involved and what do they rely on?

In general, the process of deriving and using information from an image is termed "image exploitation". Furthermore, when the information includes the geo-location of features or objects in an image, the processes involved are more specifically termed "geo-positioning" processes. Targeting with reliable accuracy predictions is an important example of a geo-positioning process. Other examples include: Digital Elevation Model (DEM) generation, site model generation, and change detection. And what do these processes have in common? They as well as all other geo-positioning processes rely upon the physical sensor model as their basic building block.

Before proceeding further, we must first back up a little and note that there are different types of sensors with different resulting images (**Figure B2**). Not only are there the optical sensors that produce images we recognize as pictures, but there are sensors that produce images with geo-positioning information that are difficult to visually interpret, like Synthetic Aperture Radar (SAR). And still, there are other sensors that measure quantities such as radiometric data. For this discourse, we are concerned with geo-positioning aspects; thus, for introductory ease, we will (in general) limit our discussion to optical sensors producing easily recognizable images. However, we note that although we are discussing optical sensors and images primarily, the Replacement Sensor Model also works for SAR and other types of images, which is discussed later.

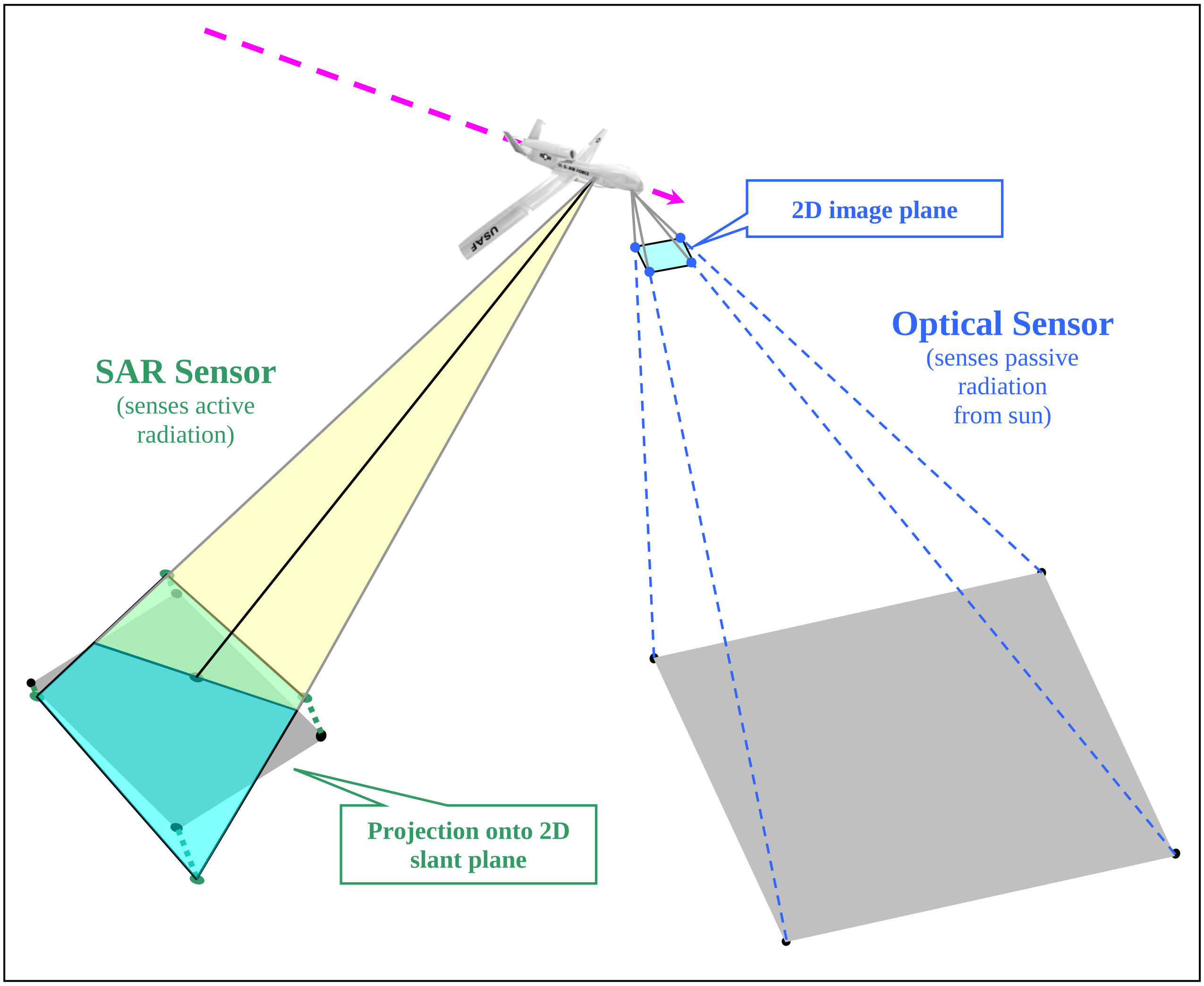

Figure B2: Sample Sensors and Their Images

Now, before we go on to discuss the physical sensor model, let's first present a few preliminary definitions that will be used throughout the remainder of this exploration. The term "image point" will be used to represent a specific pixel location on the image. It is specified by two coordinates: (line, sample) or alternatively (row, column). Furthermore, the term "ground point" will be used to represent a specific location on or near the earth's surface. It is specified by three coordinates: (x, y, z) or alternatively (latitude, longitude, height or elevation). Now, on with the adventure…

3.0 What's a Physical Sensor Model?

A sensor's physical sensor model is a mathematically rigorous description of the relationship between the pixel coordinates of the image and the physical ground coordinates they represent. **Figure B3** presents a conceptual representation of this relationship.

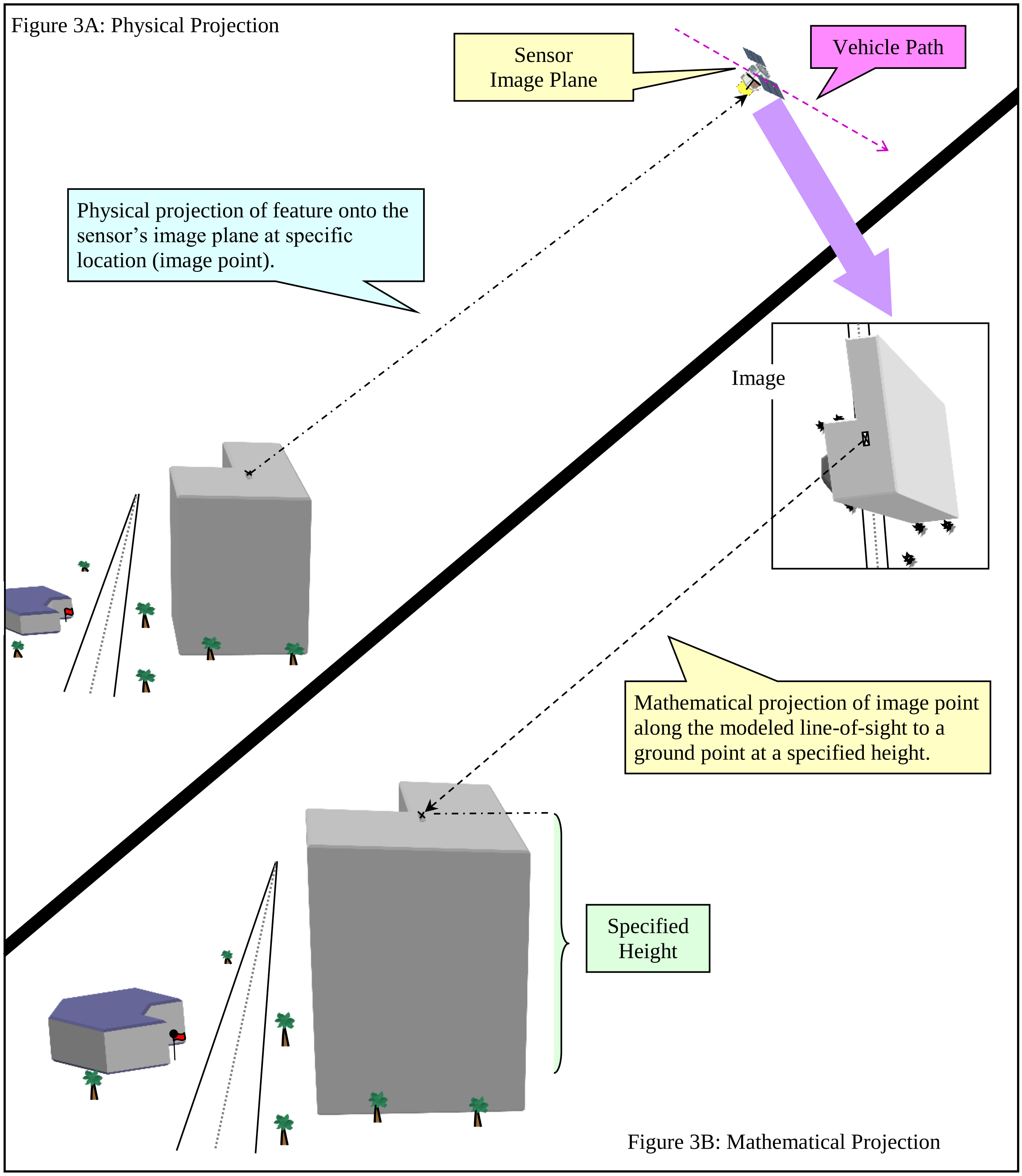

Figure B3: Image Point / Ground Point Relationship

For an optical sensor, the incident radiation from the sun (a.k.a. sunlight) reflects off of objects and features in the scene onto the sensor's image plane. Let's term this process a "physical projection"—see **Figure B3-A**, the top portion of **Figure B3**. An image is then formed, either in (near) real-time or later at a ground processing station. The physical sensor model is then used to relate an image point to corresponding ground points along the line-of-sight. Let's term this process a "mathematical projection"—see **Figure B3-B**, the bottom portion of **Figure B3**. A unique ground point is then identified by the specification of an external (user supplied) height, which is typically obtained from a Digital Elevation Model (DEM).

Each sensor has a sensor model that is a physically-based mathematical algorithm that models the line-of-sight (LOS). That means, the algorithm captures and interprets the mechanics of the sensor's physical construction, as well as the physics and relationships of additional information about how the image was taken, and uses this information in a mathematical algorithm to determine (model) the LOS. It is important to note that the physical sensor model can vary greatly from one sensor to the next.

The additional information needed for the physical sensor model is collected and reported as part of the image support data for each image, and includes physical parameters such as: where the sensor was when the image was taken (i.e. the geo-location of the sensor, or sensor position, or ephemeris), the direction the sensor was pointing (i.e. the attitude), focal length (for optical sensors, the distance from the imaging plane to the optical lens), and vehicle velocity (for SAR sensors).

The image support data is usually contained in a file that accompanies the image; whereas the image itself can be thought of as simply a file of "gray-shade" or "gray-count" values per pixel location.

The physical sensor model's image-to-ground function projects an image point along the LOS to a specified height, resulting in the reported ground point. Thus, if we change the specified height, we will get a different ground point. Notice, that in **Figure B4**, using height 1 would return the "correct" geo-location (ground point) of the vent. However, as an example, specifying an incorrect height 2, the same projection returns the geo-location not of the intended vent, but of the "Embassy" across the street.

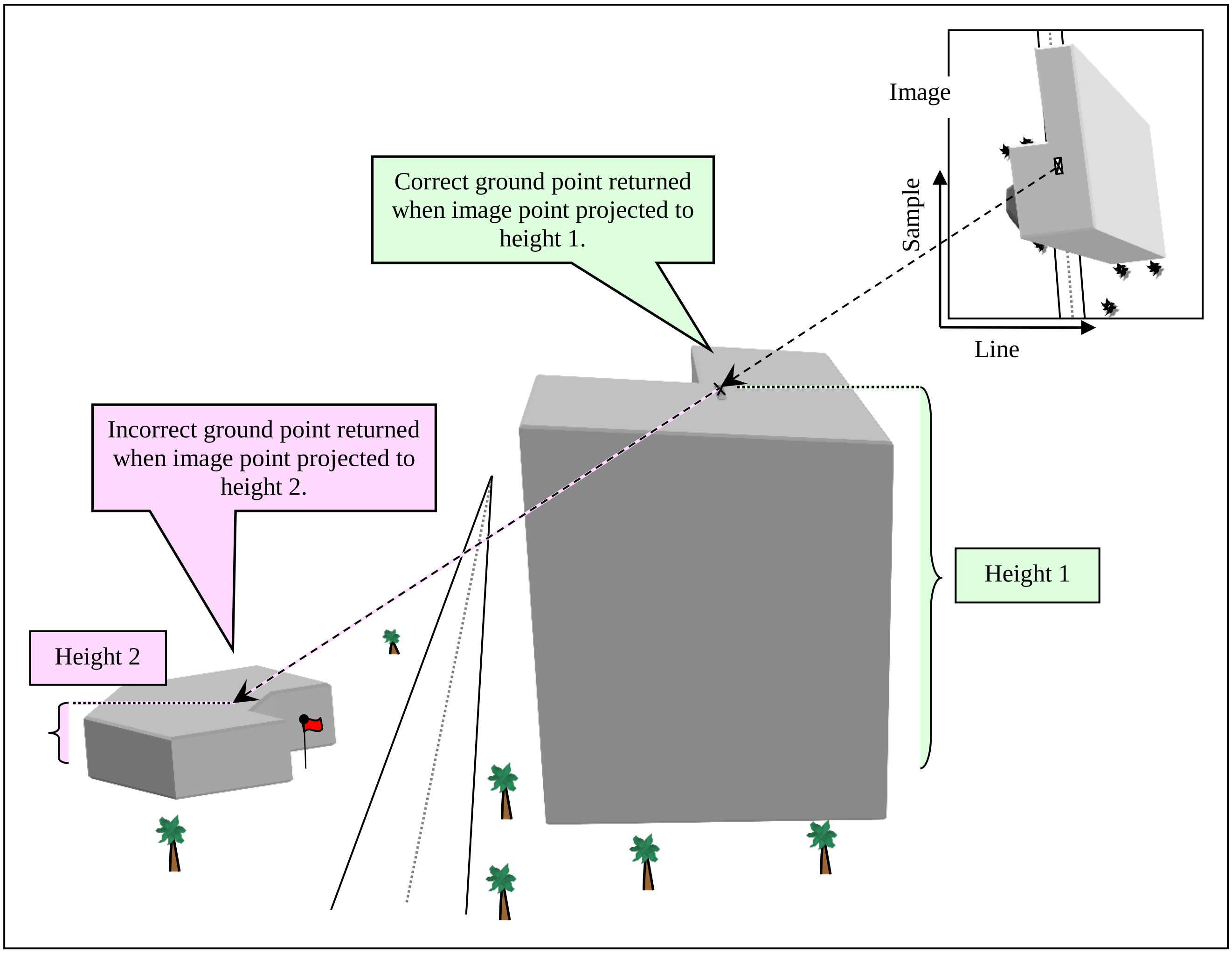

Figure B4: Image-To-Ground Height Dependence

In the example above, an incorrect ground point was obtained when the wrong height was specified. However, errors in the reported ground point will always happen operationally because of unavoidable errors in a DEM, unavoidable image measurement errors, and unavoidable errors in the image support data (examples to be given in the following sections). Given all of this, it is undeniable that for most applications, a ground point is not enough information. In addition to the geo-location, users (especially those responsible for launching weapons) need a reliable prediction of how accurate that ground point is. Thus, a complete physical sensor model will provide not only the capability of identifying an image/ground relationship, but also be able to tell us how accurate that image/ground relationship is.

> Note 3.0-1: For optical sensors, the modeled line-of-sight (LOS) is also called the image ray. For all types of imaging sensors, the image/ground correspondence model equivalent to the optical LOS is called the imaging locus. For example, the imaging locus for a SAR sensor corresponds to the range-doppler circle.

> Note 3.0-2: For appropriate vehicles (e.g., space-borne) the modeled LOS includes corrections for physical phenomena such as atmospheric refraction (i.e., the physical bending of the light as it travels through the atmosphere).

3.1 Parts Is Parts

Every sensor model has, at the least, an image/ground relationship needed for extraction of a target's ground point. However, complete sensor models have three components or "parts": 1) an image/ground relationship, 2) adjustable parameters that affect the image/ground relationship, and 3) an error covariance that corresponds to errors in the adjustable parameters.

> Note 3.1-1: It is the adjustable parameters and their error covariances that allow us to generate accuracy predictions necessary for all reliable targeting applications.

3.1.1 Image/Ground Function

The image/ground relationship is needed for extraction of a target's ground coordinates. In order to support all geo-positioning applications, both an image-to-ground function and a ground-to-image function are needed.

The image-to-ground function has already been introduced–see **Figure B3** and **Figure B4**. It is a projection of an image point (pixel location) to the corresponding ground point at a specified height. The ground-to-image function goes the other direction. That is, it's a projection of a ground point to the corresponding image point. Both functions require 3 independent coordinates as input and provide 2 independent coordinates as output. More specifically, the image-to-ground function requires a 2-dimensional image point, e.g. (line, sample), and a specified height as input, and returns the 3-dimensional ground point, e.g. (latitude, longitude, height), whose 3rd dimension is really the height given as an input; while the ground-to-image function requires a 3-dimensional ground point as input, and returns the 2-dimensional image point.

Physical sensor models usually have a direct (explicit) image-to-ground function. Whereas in most cases the inverse function (ground-to-image) is not direct, but can be computed as an iterative process that repeatedly calls the image-to-ground function (typically 3 times). However, for some sensor models, the direct relationship is the ground-to-image function, in which case the image-to-ground function can be computed by an iterative process that repeatedly calls the ground-to-image function. Thus, for every sensor model, there is always both an image-to-ground and a ground-to-image function, one of which is usually an iterative inverse of the other.

3.1.2 Adjustable Parameters

Now, complete sensor models also have parameters that not only affect the image/ground relationship but are adjustable as well. In a typical optical sensor, these adjustable parameters include the sensor position when the image was taken, its attitude (what direction it was pointing), and its focal length.

Adjustments to these parameters consist of corrections to the initial (*a priori*) parameter values contained in the image support data. If the image support data contains adjustments/corrections to the *a priori* parameters, then we know that the image support data has gone through an “external” adjustment process such as “triangulation” or “image registration”. The use of the adjusted image support data in subsequent target extractions makes the resulting geo-location estimates more accurate.

In addition, adjustable parameters also serve as a mechanism for the statistical description of image support data (adjusted or unadjusted) uncertainty. In particular, an error covariance is defined relative to errors in the adjustable parameter values. It is the use of this error covariance in conjunction with the appropriate partial derivatives that allows various exploitation processes to correctly account for image support data uncertainty (see Sections 3.1.3 and 3.2.1 for more information).

So, how do errors in these adjustable parameters affect the image/ground relationship?

The sensor position affects the image/ground relationship such that if the sensor position is different from where you thought it was, the basic geometry will be off, resulting in a translation error in the image/ground projection. Thus, as depicted in **Figure B5**, using an incorrect sensor position returns the geo-location not of the "warehouse" (marked with an 'X'), but of the "hospital" across the street.

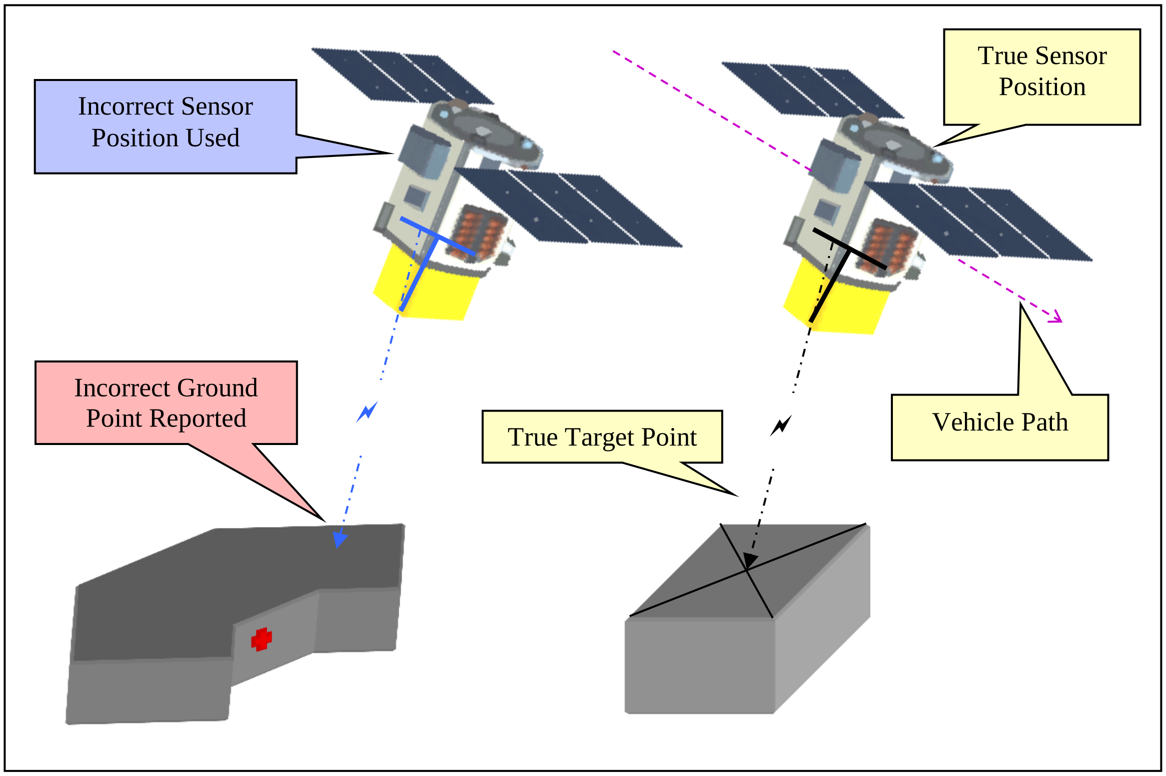

Figure B5: Effects of Sensor Position Errors

> Note 3.1.2-1: The sensor position is a three-dimensional position, so keep in mind that the position error can be in any or all three directions.

The attitude is the direction the camera was pointing at the time the image was taken. Thus, if the attitude values reported are in error, the sensor was actually pointing in a different direction than where we thought it was, and instead of returning the desired geo-location of the “factory”, we inadvertently get the geo-location of the “day-care center”. These errors are the rotation errors/adjustments commonly referred to as (roll, pitch, and yaw).

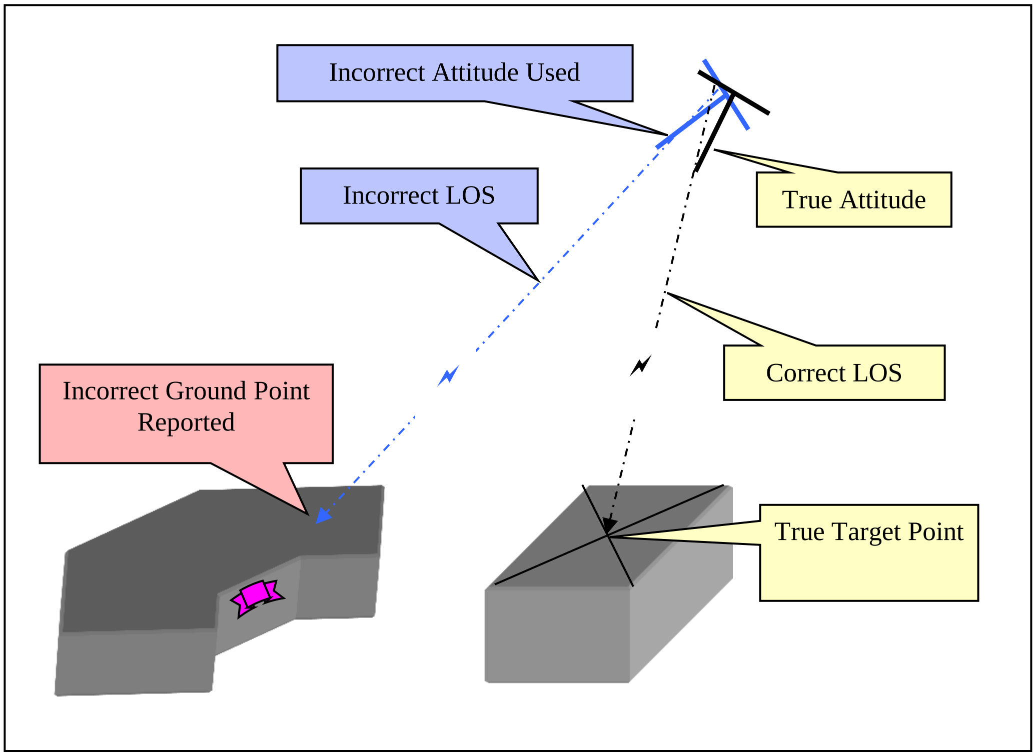

Figure B6: Effects of Attitude Errors

> Note 3.1.2-2: The effect of the attitude errors increases as the distance from the sensor to the target increases.

Finally, if the focal length is in error (from heat expansion, contraction, or calibration error) we end up with an incorrect LOS, which is again ultimately realized as an incorrect ground point.

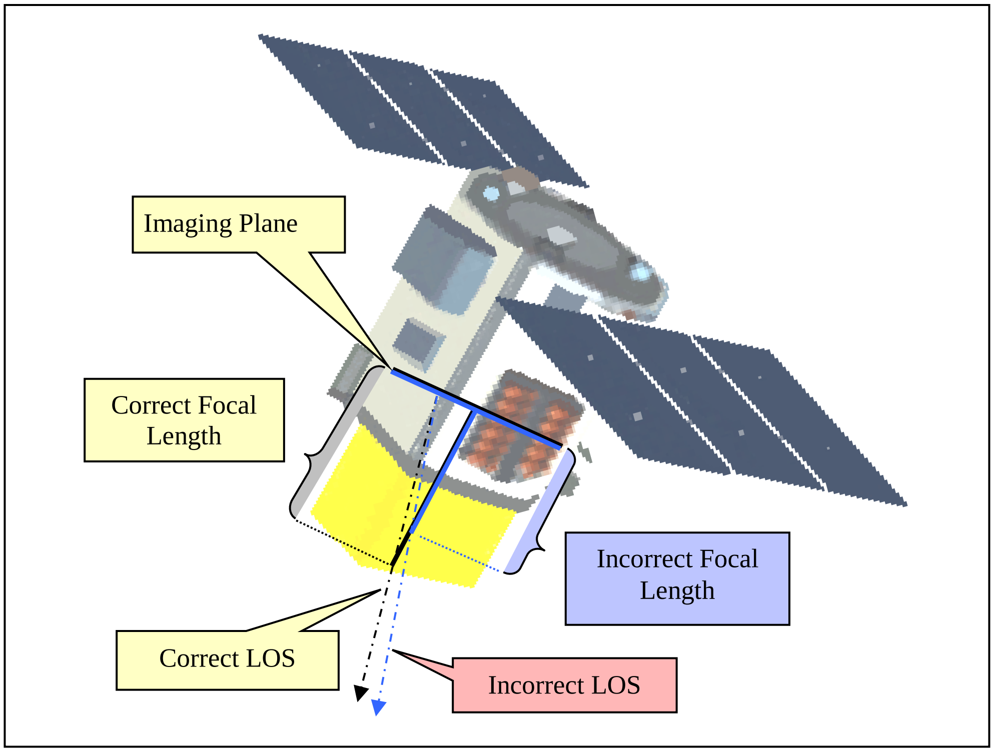

Figure B7: Effects of Focal Length Errors

> Note 3.1.2-3: The effect of the focal length error increases as the distance from the sensor to the target increases.

Thus, given that we need to know values for the adjustable parameters (sensor position, attitude, and focal length) in order to determine the ground point, we have demonstrated that if any of those values are in error, the resulting ground point will be in error as well.

But, we know that nothing is ever perfect. Adjustable parameter values are always in error since they correspond to previous measurements, estimates, and predictions, all of which are imperfect by their very nature. In fact, for sensor model applications, these errors are far from insignificant and must be accounted for. Specifically, we need to know how much uncertainty is in each parameter's value. That is, for a complete sensor model we also need an error covariance that corresponds to the adjustable parameters.

3.1.3 Error Covariance

An error covariance is simply a statistical description or representation of both the error (uncertainty) in each parameter of interest, and the correlation of errors between these parameters.

> Note 3.1.3-1: If there are n parameters of interest, the corresponding error covariance is represented by an $n \times n$ matrix.

A simple, non-sensor model, scalar (one-dimensional) example: If we measure a distance x to be 5 meters, and the measurement has a standard deviation of error of ±10 cm then, assuming the underlying error is normally distributed (sorry, a statistical definition necessity), there is a 68% probability that the true distance is somewhere between 4.9 and 5.1 meters. In this simple example, the covariance matrix is a 1×1 matrix (scalar) with a value equal to the variance (i.e. the square of the standard deviation).

As discussed earlier, a complete sensor model includes an error covariance corresponding to the adjustable parameters; which captures the uncertainty in the image support data.

> Note 3.1.3-2: In our optical frame sensor example, there are 7 adjustable parameters (3 that define sensor position, 3 that define attitude, and 1 for focal length). Thus, for one image the error covariance is a 7×7 matrix.

3.2 What Can You Do With It?

Very simply put, with a complete sensor model, we can do extractions, adjustments, and accuracy predictions.

Extract, adjust, and predict…what?

The extraction processes are methods for obtaining a geo-location, while the adjustment processes are methods used to refine the image support data used in the extraction process (to get a better ground point estimate). Thus, the extraction and adjustment processes both deal with methods of obtaining a geo-location. However as we pointed out earlier, for most users, knowing a “where” is not sufficient information to make a decision to take action on—users also need to know the accuracy of that ground point estimate. Thus, the following sections will discuss the extraction processes in conjunction with an appropriate accuracy prediction method.

3.2.1 Monoscopic Extraction and Accuracy Prediction

An extraction of ground point information using only one image is termed a mono (monoscopic) extraction. The mono extraction solution corresponds to the intersection of the modeled LOS with a height estimate, which is just the application of the sensor model's image-to-ground function (see **Figure B3** above).

More specifically, the mono extraction (image-to-ground function) inputs the image point specified as image coordinates (line, sample), or equivalently (row, column), where the target/object is seen in the image. It then projects the image point along the modeled LOS and intersects it with a specified height provided by an external source, such as a Digital Elevation Model (DEM). This projection results in a ground point, usually specified in geodetic ground coordinates (latitude, longitude, and height or elevation), but on occasion in rectangular ground coordinates, (x, y, z), depending upon the user's implementation.

The (mono extraction) solution's error covariance is computed by the extraction process using the image support data (adjustable parameter) error covariance projected along the modeled LOS, and the height error covariance obtained from the external source. The resultant solution error covariance, a 3×3 matrix, can be represented graphically as an error ellipsoid; which in turn, can be approximated by two numbers, the 90% horizontal circular error (CE), and the 90% vertical error (LE), (see **Figure B8**). These two numbers, CE and LE form the basis for accuracy prediction.

> Note 3.2.1-1: The extraction process also accounts for the uncertainty in the actual identification and measurement of the object's location in the image. However, the effect of this error is typically much less than the effects of the image support data errors.

Example: Suppose CE is 10 meters and LE is 30 meters. Then, we can say that it is 90% probable that the target's true location is horizontally within 10 meters of the computed solution; and similarly, it is 90% probable that the target's true location is vertically within 30 meters of the computed solution.

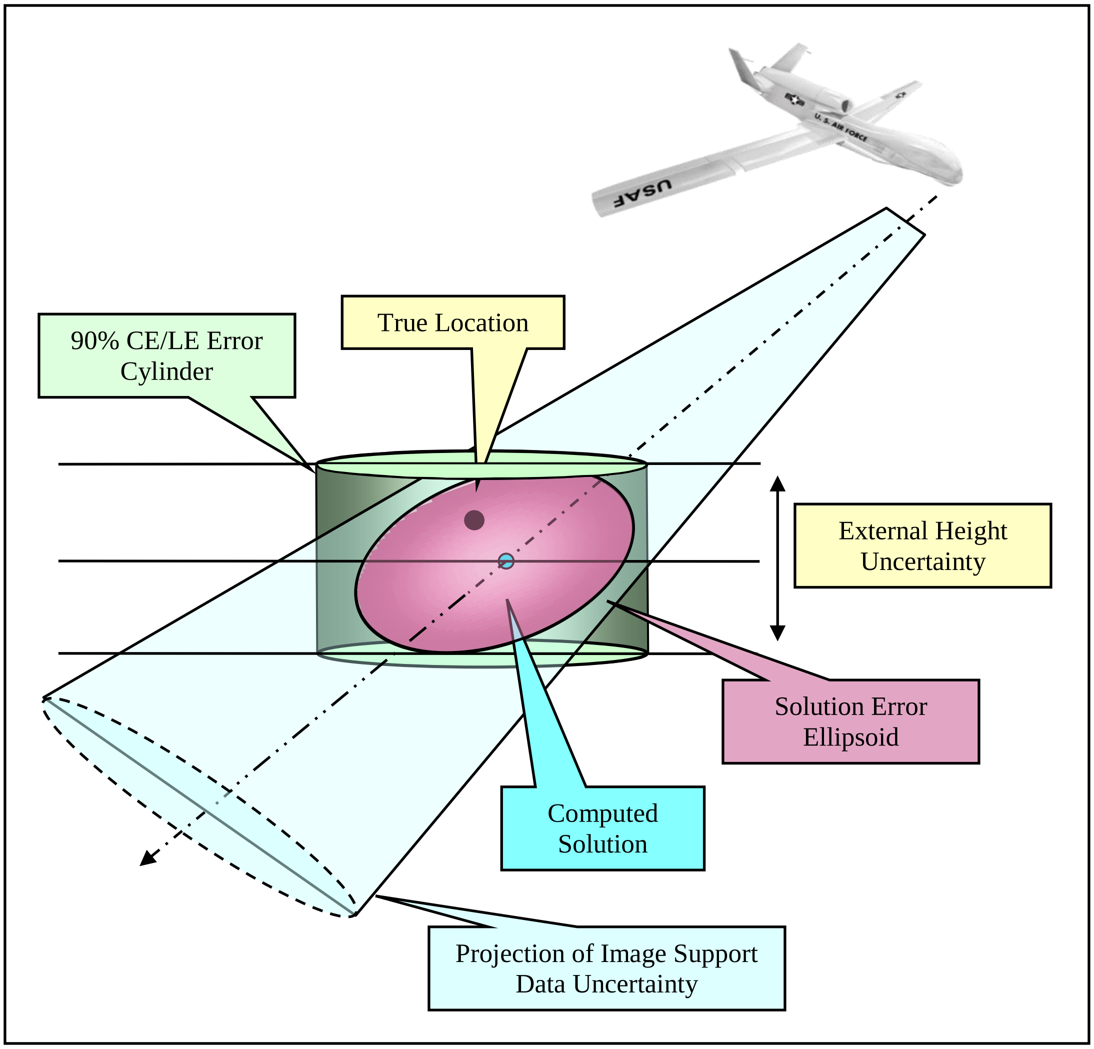

Figure B8: Mono Extraction and Accuracy Prediction

Note 3.2.1-2: The projection of the adjustable parameter error covariance is achieved via partial derivatives. In order to support extraction and accuracy prediction, a complete physical sensor model must support the computation of both partial derivatives of image coordinates (line and sample) with respect to the sensor's adjustable parameters, and the partial derivatives of image coordinates with respect to the target's ground coordinates.

Note 3.2.1-3: The extraction process is also applicable to the mensuration of objects—e.g. we can extract two ends of a runway for a measure of its length. In this case, the applicable accuracy predictions are then relative circular error (RCE) and relative linear error (RLE).

3.2.2 Multi-Image Extraction and Accuracy Prediction

When an object is viewed in multiple images (two or more), the multi-image extraction process is able to not only produce a more accurate solution, but is able to do it without external height information.

In this process, the modeled LOS, or image ray, from each image is generated using the image-to-ground function, and each ray's contribution to the solution is then weighted according to its corresponding image support data uncertainty (error covariance); such that, the smaller the uncertainty, the larger the weight is.

In this case, both the solution ground coordinates and its accuracy prediction are dependent on the error covariance (image support data uncertainty).

The following **Figure B9** graphically represents a three image solution and its resultant CE/LE error cylinder or accuracy prediction (underlying solution error ellipsoid not shown).

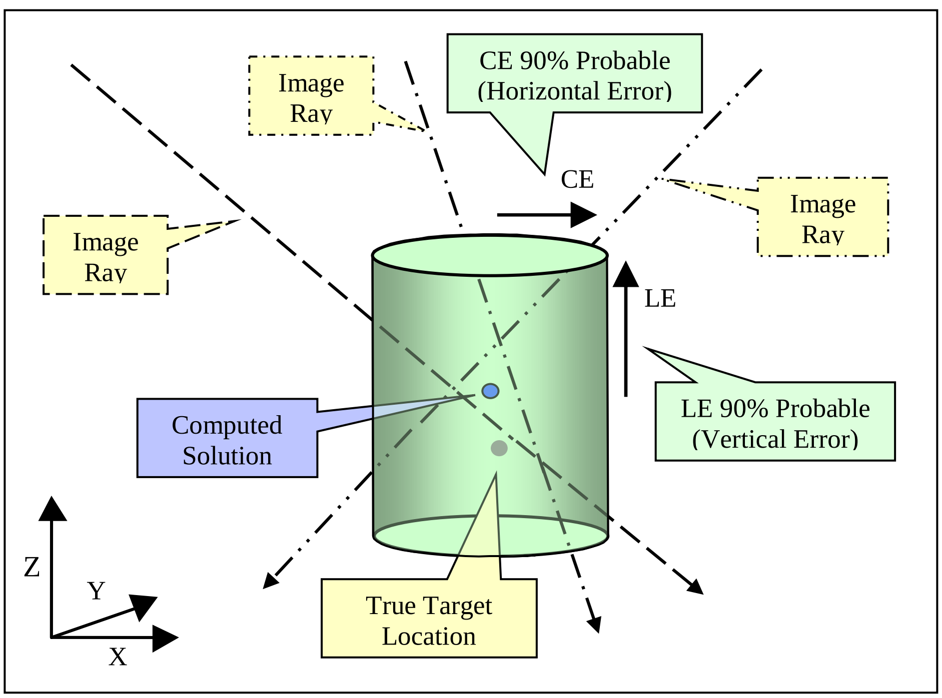

Figure B9: Multi-Image Extraction and Accuracy Prediction

> Note: 3.2.2-1: An optimal multi-image extraction solution (algorithm) is presented in the 2004 Manual of Photogrammetry (see reference [1]).

3.2.3 Support Data Adjustment

In an adjustment process such as triangulation, we simultaneously solve for corrections to sensor model adjustable parameters in one or more images—which requires the use of all three components of a complete physical sensor model(s).

The image-to-ground function and image support data (sensor model adjustable parameter) error covariance are used in a manner similar to their use in multi-image extractions. However, where the multi-image extraction process only solves for ground point locations, the adjustment process also solves for corrections to the adjustable parameters for each image and their corresponding (improved) error covariance. These corrections and improved error covariance are then saved in the image support data so that subsequent target (mono and multi-image) extractions can utilize the corrections for more accurate geo-locations, and the improved error covariances for reliable accuracy predictions.

> Note 3.2.3-1: If n images are involved in the adjustment process, with m adjustable parameters per image, the *a posteriori* (post solution) error covariance is an $nm \times nm$ matrix and reflects less uncertainty (is smaller) for each individual image, but also contains non-negligible correlations between images.

Figure B10 presents an overview of the adjustment process for the simplest scenario possible: one image (not shown explicitly in figure) using ground control points. Ground control points are photo-identifiable points with pre-determined ground locations and accuracy. The difference between the estimated ground control point locations using the pre-adjusted image support data with their known location (within the supplied accuracy) drives the adjustment process. The resulting accuracy of a post-adjustment extraction is far better than for a pre-adjustment extraction. In the following **Figure B10**, the resulting accuracy is idealized, as small residual errors always remain.

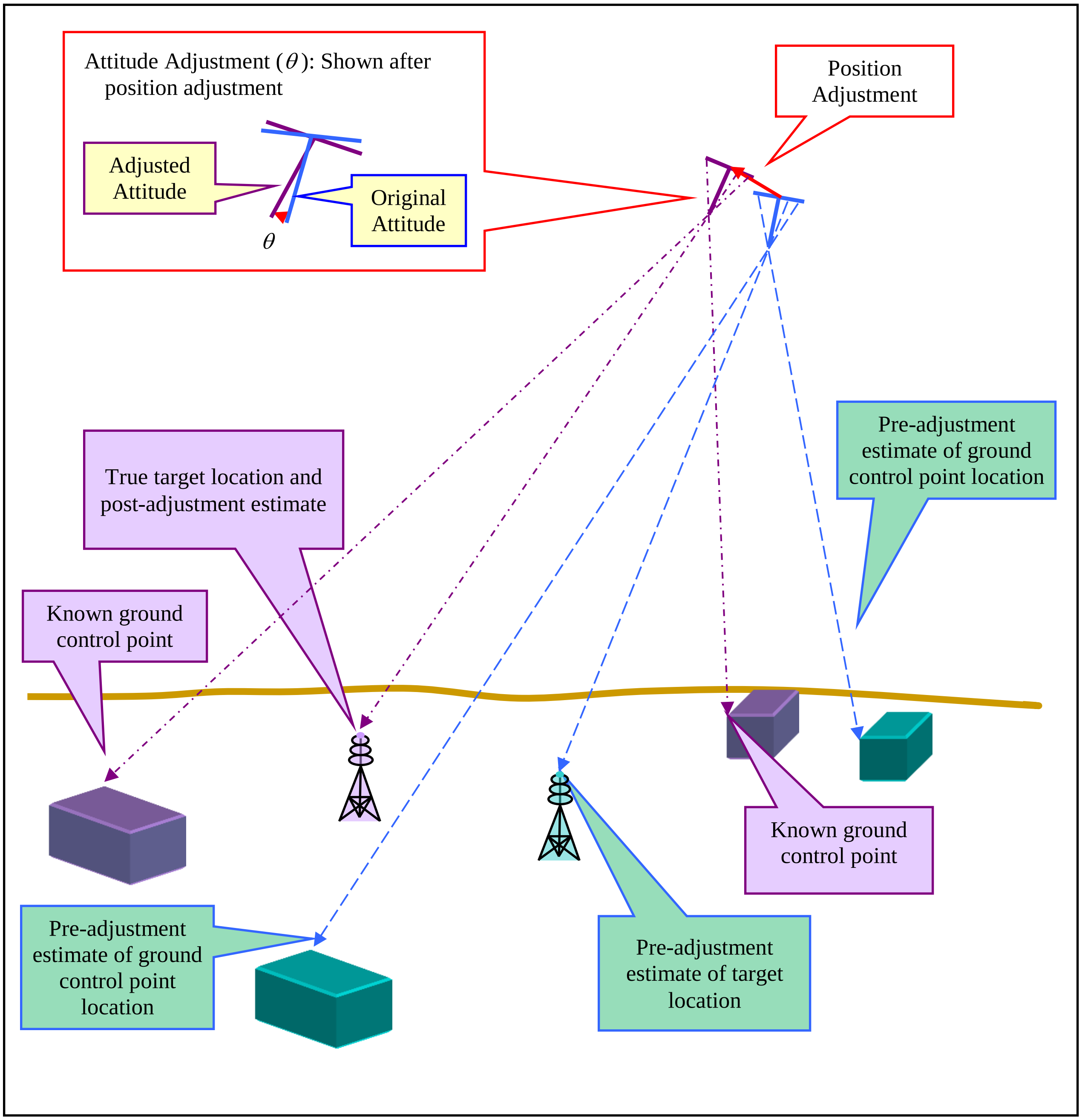

Figure B10: Sensor Parameter Adjustments

Note 3.2.3-2: In addition to the optimal geo-positioning (multi-image extraction) algorithm, the 2004 Manual of Photogrammetry discusses an optimal adjustment algorithm as well.

This concludes our "guided tour" of the three major components of a complete physical sensor model, and their critical roles in geo-positioning: extraction, adjustment, and accuracy prediction.

> Note 3.2.3-3: We need to emphasize that a complete physical sensor model doesn't actually perform these geo-positioning processes (extraction, adjustment, and accuracy prediction), higher level applications perform them. However, the applications require the complete physical sensor model in order to do so.

We now discuss the practical issues associated with development, maintenance, and operational readiness of sensor models, and following that, we discuss RSM itself.

3.3 How Does It All Work?

In today's world, a sensor model user (exploitation system) must work with imagery from many different sensors. There are different sensors for different capabilities, most with their own unique image support data format. Of the potentially hundreds of different sensors/image support data formats that exist now and in the near future, a given exploitation system may be interested in tens of them.

When a sensor is designed and put into operation, its sensor model and support data are defined (published), and made available to the user community. Each potential user must then implement and integrate the new sensor model and its typically unique image support data format in their system.

However, even once a sensor is in "full operation", it is not uncommon for the physical sensor model to change due to unexpected (or even expected but poorly planned) events. These events range from oversights in the initial development of the physical sensor model, to modifications to the sensor itself. Resultant changes to either the physical sensor model or the sensor-unique image support data formats result in an on-going development and maintenance effort on each user's part.

3.4 If It's Not Broke, Why Fix It?

For a user community to effectively develop, test, and maintain current and new sensor models, they must continually allocate a significant amount of money and manpower. Furthermore, during the implementation of any modifications to an operational sensor model or its sensor-unique image support data format, there is an operational readiness issue at hand. That is, until the user's system is modified, tested, and fielded (which could take months) the imagery produced from that sensor may result in wrong and inaccurate information—unusable for anything but possibly pretty pictures.

To help alleviate this on-going financial burden, and address the operational readiness issue, there have been several previous attempts made to develop a general sensor model that is capable of replacing physical sensor models in the user community. However, they were tailored to certain classes of sensors (e.g. space-borne electro-optical sensors), and they were not complete sensor models in that they were missing the adjustability and/or reliable accuracy prediction capabilities.

There is one exception. The Replacement Sensor Model (RSM) is a complete sensor model that combines all three characteristics, and is flexible enough that it can be used to replace virtually all sensor models in the user community.

4.0 What Is RSM?

The Replacement Sensor Model, RSM, is an adjustable non-physical based mathematical model. Its image support data has one format, and is initially populated using the original physical sensor model and its image support data. Once generated, only the RSM sensor model and its image support data is needed for all geo-positioning processes, i.e. extraction, adjustment (triangulation), and accuracy assessment. If the RSM image support data is generated “up-stream” (i.e. the image libraries, or at the ground processing stations), “down-stream” exploitation systems need only implement one sensor model, RSM.

An up-stream process containing an RSM (image support data) “generator” can process either adjusted or un-adjusted original (physical sensor model) image support data, and then make the RSM image support data (RSMSD) available to the down-stream user community (see **Figure B11**). Thus, down-stream users will be able to use RSM in their applications to support their image exploitation (geo-positioning) processes such as optimal target extraction. An RSM “exploiter” uses the RSM sensor model and the RSM image support data to provide all sensor model functionality to a user’s application (geo-positioning process).

The RSM support data received by the down-stream users faithfully reflects the accuracy of the physical sensor model’s image support data from which it was generated. However, if this accuracy is not adequate, adjustments to the RSM image support data can also be performed by the users if they have access to additional control information.

Note 4.0-1: Keep in mind that the RSM generation process is intended for "up-stream" image providers like ground stations, and image libraries who disseminate imagery. Most users are "down-stream" receivers of imagery that need an RSM exploiter, but not a RSM generator. However, if a "down-stream" user makes adjustments to the RSM image support data, and if properly equipped, they can also disseminate the adjusted RSMSD to other users.

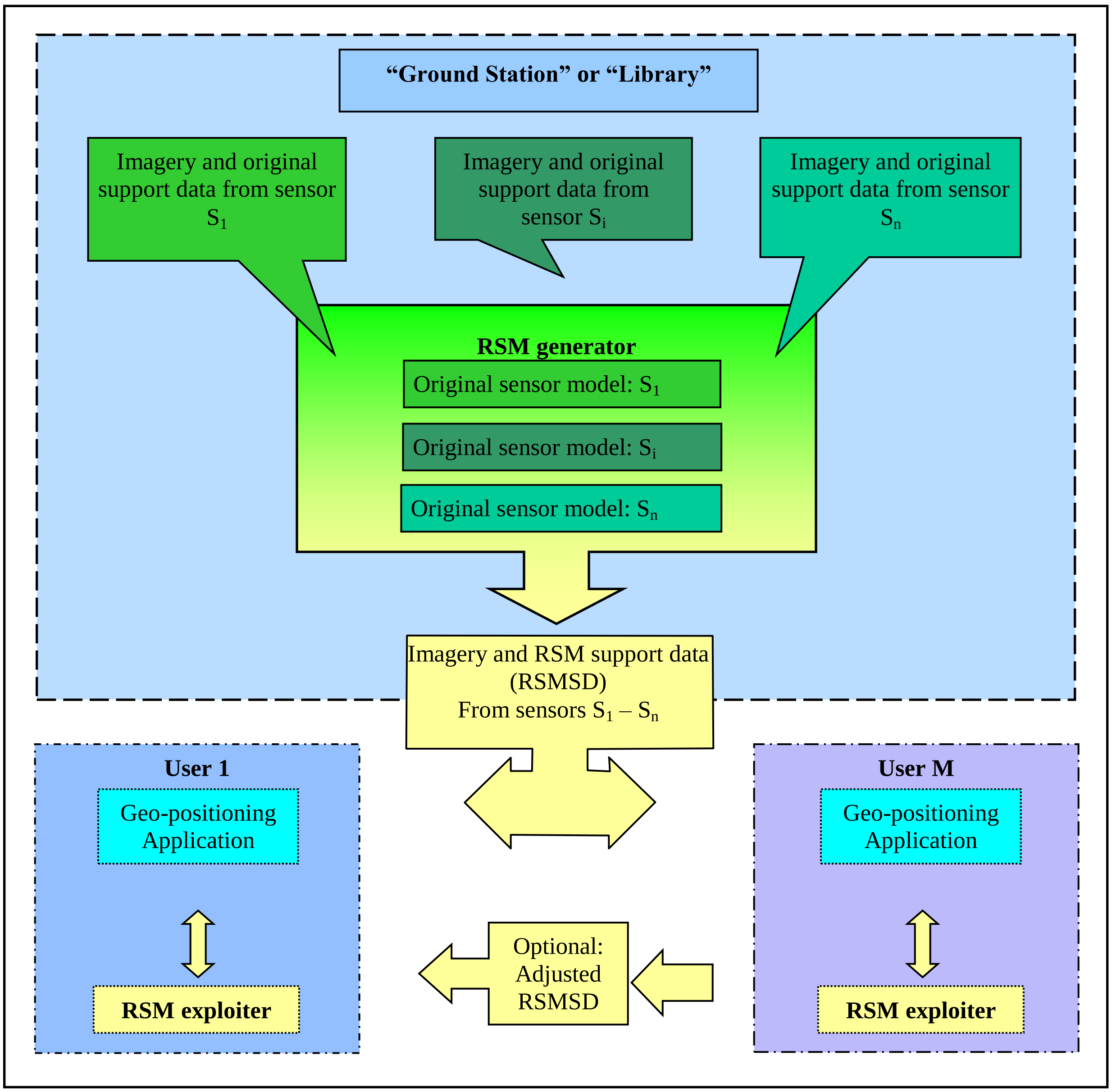

Figure B11: RSM Flow

As will be discussed in more detail, RSM is capable of:

1) Replacing a complete physical sensor model ("original" sensor model) for virtually any imaging sensor including: optical (electro-optical) sensors, such as frame and push-broom, SAR sensors, airborne and space-borne sensors (platforms)
2) Capturing all of the original sensor model error covariance information in an equivalent form, resulting in virtually identical accuracy predictions
3) Providing equivalent mensuration, extraction, and triangulation (support data adjustment) capabilities relative to the original sensor model it is replacing. For example, RSM is able to provide virtually identical multi-image targeting solutions—more about this a little later

Also, since RSM is flexible enough to work for virtually any imaging sensor the RSM support data (RSMSD) format is an excellent candidate to become the universal support data format standard for geo-positioning applications.

4.1 Parts…We Have Them All

RSM is a complete sensor model, and has all of the parts we expect a complete original physical sensor model to have. That is, RSM consists of three major components: 1) a ground-to-image function, whose image-to-ground relationship is computed by an iterative inverse, 2) adjustable parameters that affect the ground-to-image function, and 3) an error covariance relative to those adjustable parameters.

4.1.1 Ground-To-Image Function

The RSM uses a flexible non-physical based ground-to-image function. That is, as a mathematical function, it takes in a ground point and returns the corresponding image point. (Recall that an image-to-ground function is also available as an iterative inverse of the ground-to-image function.)

The following **Figure B12** is different from the previous figures, such as **Figure B3**, in that the ground point is directly mapped (functionally) to an image point (ground-to-image), and that there is no physical connection to the sensor as is depicted in **Figure B3**.

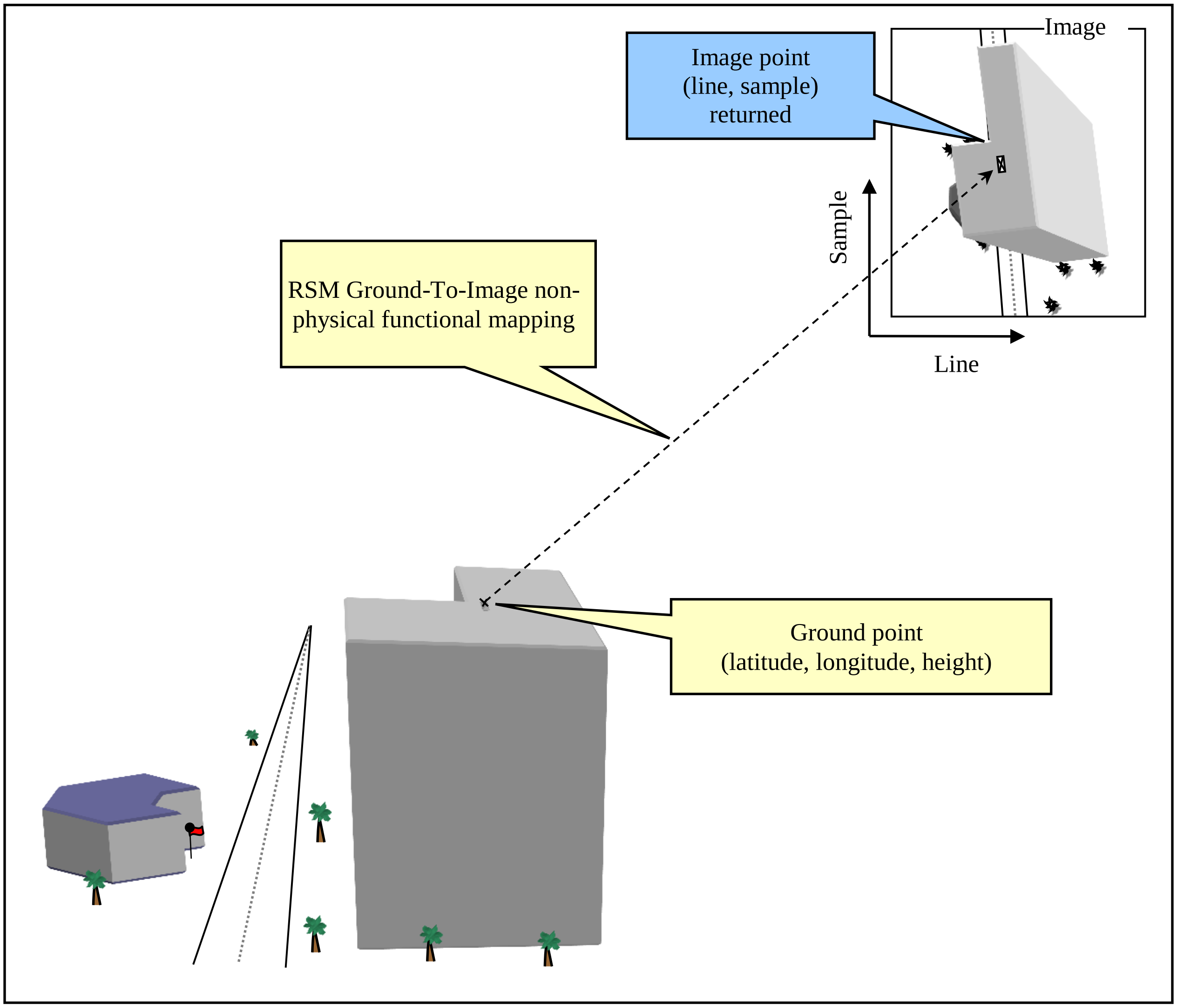

Figure B12: RSM Ground-To-Image

To accomplish this for any sensor, the elements defining the RSM ground-to-image function are generated using the original sensor model's image-to-ground correspondences in an "up-stream" RSM generating process. The RSM generation process then outputs the RSM ground-to-image function (elements) as part of the RSMSD. The RSM ground-to-image function is designed to be either a ground-to-image rational polynomial or a set of grids of ground point-image point correspondences, from which we can interpolate a specific image point for a given ground point, see **Figure B13**. If the RSM generator builds a polynomial, the RSM ground-to-image function elements are polynomial coefficients, if the RSM generator builds a grid, the function elements are correspondence values.

Warning: sufferers of acute math anxiety should skip the top portion of **Figure B13**'s RSM ground-to-image function depiction, or view it as a piece of squiggly-lined modern art, either way, we apologize for the equational slip.

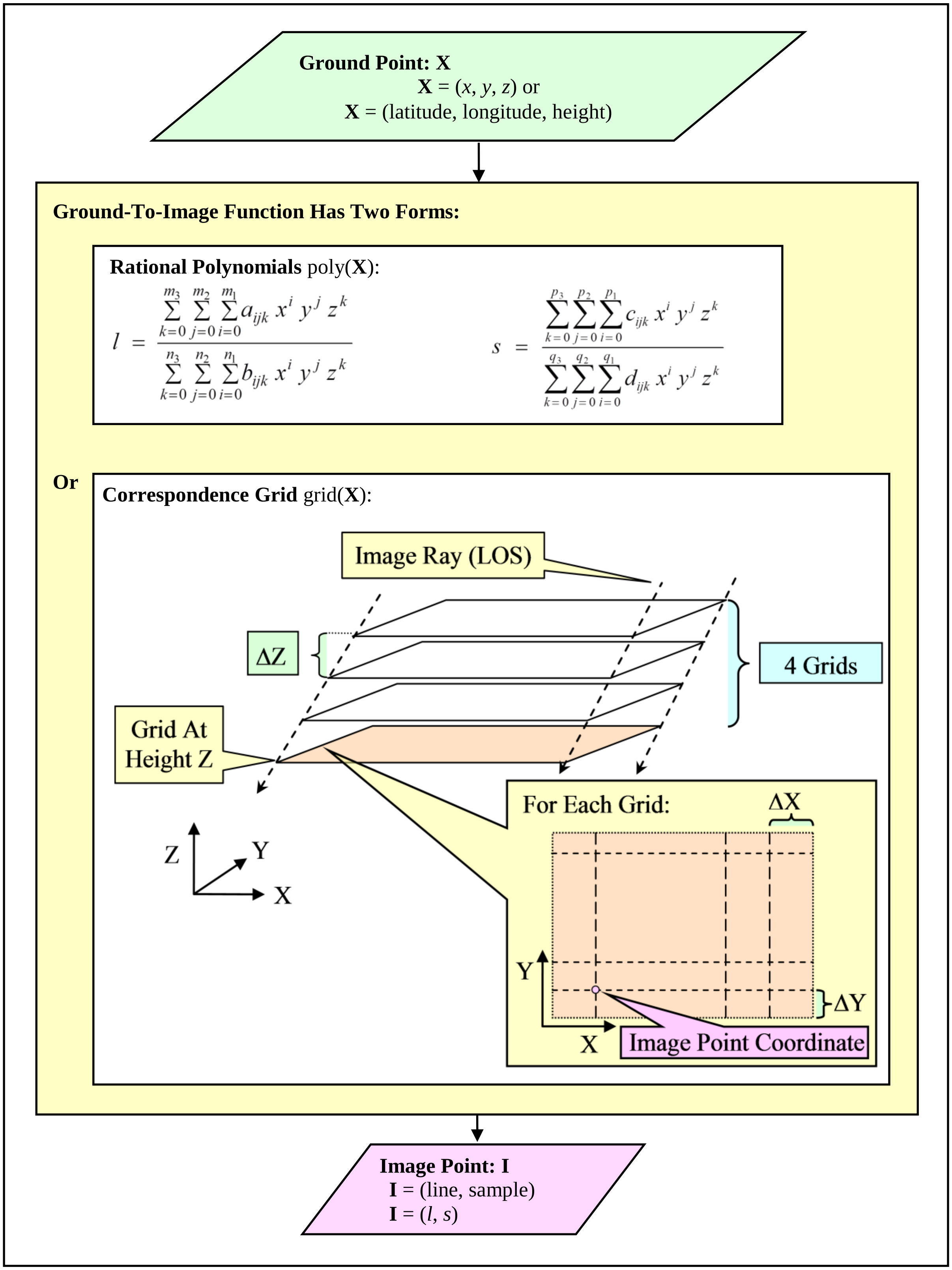

Figure B13: RSM Ground-To-Image Function

The RSM rational polynomial function is a robust model able to accommodate a diverse range of polynomial forms independently for both the numerator and denominator of each image coordinate (line and sample), and whose orders are not fixed (for example, at the 3rd degree). For additional fidelity, the RSM rational polynomial function also supports image partitioning, by using multiple polynomials, each of which covers a different section of the overall image.

> Note 4.1.1-1: Typically, the rational polynomial's coefficients are generated by a weighted least squares fit to a redundant set of image/ground point correspondences from the original sensor model. These correspondences are generated by calling the original sensor model's image-to-ground function over a grid of (line, sample) locations in the image and at various heights. The corresponding ground locations complete the correspondences.

The other option for the RSM ground-to-image function is a set of correspondence grids from which ground point/image points mappings can be interpolated. This option provides the flexibility needed for accurately matching sensor models when the polynomial fidelity is insufficient, which occurs with some wide field-of-view and some tactical sensors, i.e., imaging geometries that are not nicely modeled by the rational polynomial.

> Note 4.1.1-2: Images for which the correspondence grid is needed are determined during RSM generation on a case-by-case basis. For example, even at low altitude (600 m) with a wide field of view (90˚) a (large format) frame camera sensor can be modeled well using the RSM polynomial as demonstrated in a study done in conjunction with Purdue University—see reference [4]. This study included nadir (looking straight down) and oblique imaging geometries, with the latter using images that include the horizon.

> Note 4.1.1-3: Ok, we lied, there is actually a third RSM ground-to-image function option: using both the polynomials and correspondence grids in a synergistic fashion. That is, the correspondence grids can be used to provide corrections to the RSM polynomial output, and ultimately reduce the RSM image support data bandwidth.

4.1.2 Adjustable Parameters

The RSM adjustable parameters are either generic parameters ($\mathbf{A_G}$) directly affecting the ground-to-image function's input (ground point **X**), or generic parameters ($\mathbf{A_I}$) directly affecting the ground-to-image function's output (image point **I**), as depicted in **Figure B14**. The adjustable parameters transform the ground-to-image function into an "adjustable" ground-to-image function.

The applicable adjustable parameters are selected by the RSM generator from a fixed set in order to replicate the effects of the physical sensor model's adjustable parameters and their error covariance.

The identities of the RSM adjustable parameters selected by the RSM generator are included in the RSMSD. In addition, if an RSM adjustment has taken place, the adjusted (non-zero) values of these adjustable parameters are also included in the RSMSD.

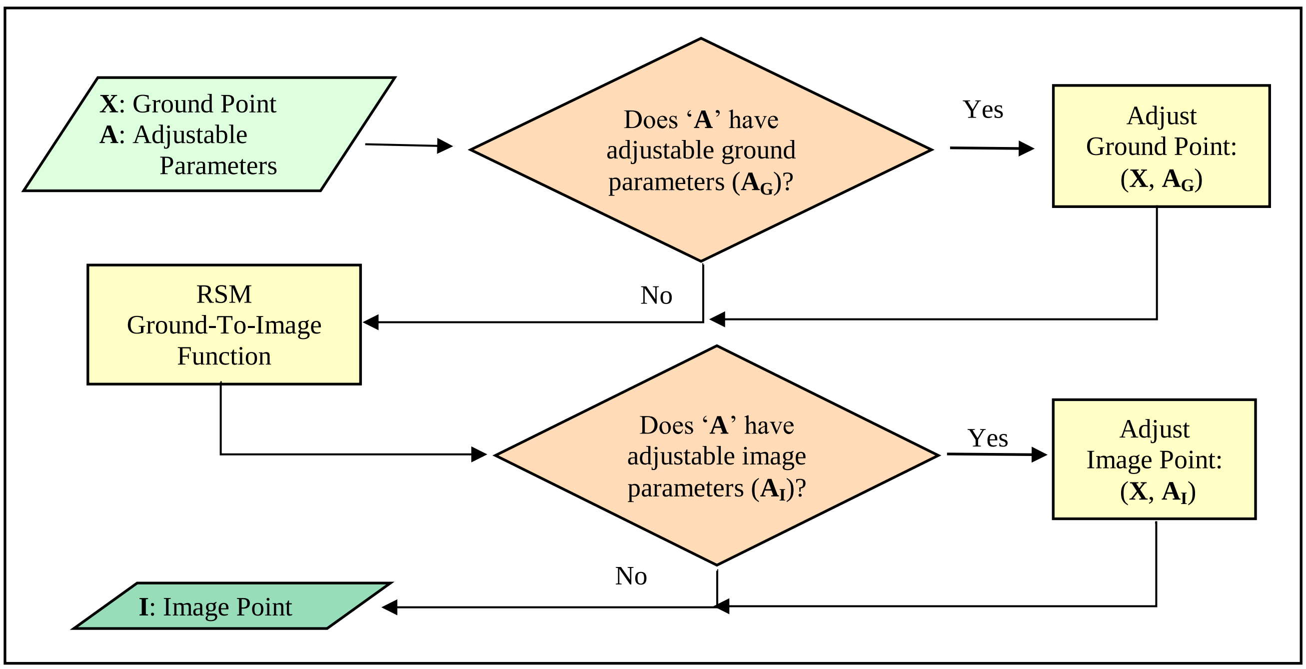

Figure B14: Application of RSM Adjustable Ground-to-Image Function

The number of RSM adjustable parameters selected by the RSM generator (generation algorithm) is usually a few less than the number of corresponding physical sensor model adjustable parameters. For example, the number of RSM adjustable parameters for the optical frame sensor we've been discussing is typically six, but can vary between five and seven depending on the particular sensor and imaging geometry. An electro-optical push-broom sensor might have 15 adjustable parameters in the physical sensor model and 12 for RSM.

Note 4.1.2-1: $\mathbf{A_I}$ contains coefficients of a polynomial-based correction; while $\mathbf{A_G}$ typically contains elements of an affine transformation (translation and small angle rotation). Both their selection and subsequent application are independent of the functional form (polynomial and/or grid) of the RSM ground-to-image function.

4.1.3 Error Covariance

The RSM is designed such that multi-image (also referred to as multi-ray), multi-ground point targeting solutions using RSM are equivalent to multi-image, multi-ground point solutions using the corresponding complete physical sensor models.

Note 4.1.3-1: The term "multi" is general in that there can be anywhere from 1 to *n* images and 1 to *m* ground points.

This is possible only because the RSM error covariance is generated in such a way by the RSM generator as to embody the equivalent information contained in the physical sensor model error covariance. This is true whether the error covariance is applicable to one image or a correlated set of images.

Note: 4.1.3-2: If there are a total of n physical sensor model adjustable parameters associated with the image or images, and m RSM adjustable parameters ($m \leq n$), the physical sensor model error covariance is an $n \times n$ matrix and the RSM error covariance is $m \times m$.

This error covariance is utilized to optimally weight multiple measurements from the same image as well as from different, possibly time correlated images; which then yields an optimal solution and provides for reliable solution accuracy predictions.

Note 4.1.3-3: Since RSM is a complete sensor model, the optimal multi-image extraction and adjustment algorithms presented in the 2004 Manual of Photogrammetry (mentioned in Note 3.2.2-1 and Note 3.2.3-2) are applicable for RSM as well.

4.1.4 I Can Do That Too!

Since the RSM is able to provide virtually identical multi-image targeting solutions, including reliable accuracy predictions, it's almost enough to say that the extraction and adjustment processes, and accuracy assessment for RSM are equivalent to the original sensor model's capabilities (see Section 5.2 for more details).

But not quite…

In addition to the extraction and adjustment capabilities previously described for sensor models, the original physical based sensor models can also provide other related capabilities such as: time of image, illumination direction, and the specification of platform position and velocity. Thus, in addition to its three major components, the RSM and its image support data also include an optional time model, illumination model, and platform trajectory model, which completes all of the original physical sensor model functionality.

> Note 4.1.4-1: The time model specifies the time a particular image pixel (i.e. image location (line, sample)) was imaged.

> Note 4.1.4-2: The illumination model specifies the illumination direction as a function of pixel location within the image. For an electro-optical sensor, the illumination direction corresponds to the direction of the sun; whereas, for a SAR sensor, the direction of radar energy. These illumination directions are needed to support shadow-based mensuration techniques, (i.e., using measurements of shadows to determine an object's height and length, but it's a shady practice).

> Note 4.1.4-3: The platform trajectory model supplies the platform trajectory (direction and velocity) as a function of time, useful for various ancillary operational and assessment activities.

…Now we can say the RSM is equivalent to the original physical sensor models in all aspects related to geo-positioning, i.e. extraction, adjustment, error propagation, and mensuration.

4.2 One Size Fits All

The RSM image support data (RSMSD) is contained in the RSM Tagged-Record Extensions (TREs) for the National Imagery Transmission Format (NITF) 2.1, detailed in the reference [2]. Eight TREs have been defined, as shown in **Table B1**.

Table B1: RSM TREs

CATEGORY: (When included in the RSM TRE Set for an image)		
Description	TRE(s)	Additional Comments
IDENTIFICATION (Always included)		
ID data	RSMIDA	Image identification, coordinate system definitions, etc.
GROUND-TO-IMAGE (Almost always included) One polynomial for entire image is typical (one RSMPCA only) Multiple sections/polynomials and/or multiple sections/grids possible		
Polynomial section ID	RSMPIA	Section identifications in image. Typically one section for entire image. RSMPCI only required if more than one (polynomial) section.
Polynomial coefficients	RSMPCA	Coefficients for ground-to-image polynomial. One RSMPCA per section.
Grid section ID	RSMGIA	Section identifications in image. Typically one section for entire (small) image. RSMGIA only required if more than one (grid) section.
Grid	RSMGGA	Grid of ground point – image point correspondences. One RSMGGA per section.
IMAGE SUPPORT DATA ERROR COVARIANCE (Usually included) One error covariance is typical Both types (one direct and one indirect) error covariance is possible		
Direct covariance	RSMDCA or RSMDCX	Explicit multi-image error covariance. Corresponding image and adjustable parameter identifications.
Indirect covariance	RSMECA or RSMECX	Data to build multi-image error covariance. A priori correlation model used for images from same sensor. Un-modeled error covariance may also be included.
IMAGE SUPPORT DATA CORRECTIONS (Typically not included) Included if RSM image support data has been adjusted		
Adjustable parameter corrections	RSMAPA or RSMAPX	Values of adjustable parameter corrections. Corresponding adjustable parameter identifications. If TRE not included, corrections assumed to equal zero.

Typically, the TRE set for an image consists of three TREs—one each of RSMIDA, RSMPCA, and RSMDCA. The total number of bytes (ASCII characters) for this TRE set is approximately 10k.

> Note 4.2-1: The baseline or "A" set of RSM TREs are currently available on the public side of the NTB Web Pages—see reference [2].

> Note 4.2-2: The baseline set of RSM TREs have undergone validation by the NITFS Technical Board (NTB) and the Joint Interoperability Test Command (JITC).

> Note 4.2-3: As a result of on-going development over the last few years, there is currently an updated set of TREs with improved capabilities that are waiting for adoption. The updated "X" TREs are RSMAPX, RSMDCX, and RSMECX. These latest RSM improvements are documented in the introduction to each updated TRE—see reference [3]. Upon adoption, the "X" TREs will either replace their "A" counterparts or become "B" TREs.

4.3 Advantage…RSM

Now that we've discussed RSM details for a while, let's step back from the trees and look at the forest—where we can discuss some top-level characteristics.

RSM is not just different, it's revolutionary. Just think how much simpler and more cost effective systems would be if you could just implement one sensor model into an exploitation system, and then only plan on minimal maintenance—if any at all. When new sensors, or modifications to operational sensors, need to be implemented into an exploitation system, there is zero implementation cost—IF the sensor provider or library or anywhere upstream has generated a set of RSM TREs for the new or modified sensor. Furthermore, given the RSM TREs, the new or modified sensor data (for geo-positioning functions) is immediately available, instead of months as it takes now. With RSM, we can now realize no development/integration time or cost associated with the implementation of a new or modified sensor (or sensor data format) into an existing exploitation system.

RSM is also very flexible in that not all of its components (capabilities) need to be utilized for every sensor; however, all components are available in order to support the highest levels of optimal image exploitation. In addition, the RSM also supports proprietary original sensor model development, in that, developers need not provide their detailed original sensor models and image support data to the user community, only the generated RSM image support data.

Thus, the National Geospatial-Intelligence Agency (NGA) is working to have RSM generators in place for government and commercial imaging systems, so that RSM will be universally available—RSM is already available in some U.S. government systems. Furthermore, the NITFS Technical Board (NTB) is working to insure that RSM image support data is an adopted NATO standard and an ISO-compliant international standard, which would complete the revolution. Viva la RSM!

5.0 Evolution

5.1 The Journey

Caution: the art of allegory is about to be abused.

…It was another dull and dreary day in 1997 when John Dolloff entered the BAE System's (sensor model) cafeteria. The sign read, "Special Du Jour—replacement sensor model". Can you believe it? It was the same at all cafeterias that day…it was Thursday. Hmm, I guess I'll try it, he thought. It looked good, real good. Taking a huge bite, he gagged. This is like cardboard! Picking up the recipe card entitled "Enjoy Yours At Home," he noticed the recipe was incomplete. 2/3 of the ingredients seemed to be missing. Forever a perfectionist in the kitchen, John went to work. A little here, a little there, adding the missing ingredients, he rebuilt the recipe. Finally, wiping the sweat from his brow…Ah, this is what it's supposed to taste like. Now, to get this recipe into every kitchen…

…all right, a bit of a stretch, but still metaphorically true. In particular:

Prior to RSM, the only replacement sensor models available were tailored to specific types of sensors and were not complete sensor models. However, they served as an important first step, and building upon them, RSM was created. RSM is the only known replacement sensor model that is complete and applicable to virtually all imaging sensors/platforms.

Following its inception, an RSM prototype was developed at BAE Systems. But there was still room for improvements, and RSM needed to be standardized and made available to image developers, distributors, and general users as well.

Enter the NGA.

Over the last six years (2001-2006), with the help (and significant contributions) of Dr. Charles Taylor, RSM has been fully developed under NGA sponsorship. With refinements and verification tests made from the suggestions of Professor Ed Mikhail of

Purdue University and additional support received from the NITFS Technical Board (NTB) regarding the specification of RSM image support data, RSM has been brought to fruition.

This development effort has resulted in a mature RSM, documented in the 2004 Manual of Photogrammetry, and in the RSM image support data specification for the NITF 2.1 Tagged Record Extensions (TREs).

5.2 Seeing Is Believing

The claims that the RSM gives virtually identical results in extraction, triangulation, and accuracies, are not lightly made. There have been numerous NGA sponsored studies and validation requirements levied upon RSM and its image support data.

So, what does it mean when we say virtually identical results?

In a series of tests over the last six years, we compared geo-positioning results using the original physical sensor model and its image support data against geo-positioning results using RSM and its image support data (RSMSD). The RSMSD was generated from the original sensor model and original image support data, and all other test conditions were identical. Some of the tests compared results after extraction, some after triangulation (adjustment), and still others after triangulation and extraction (see **Figure B15**). Both extraction and adjustment tests involved both single images and multiple images.

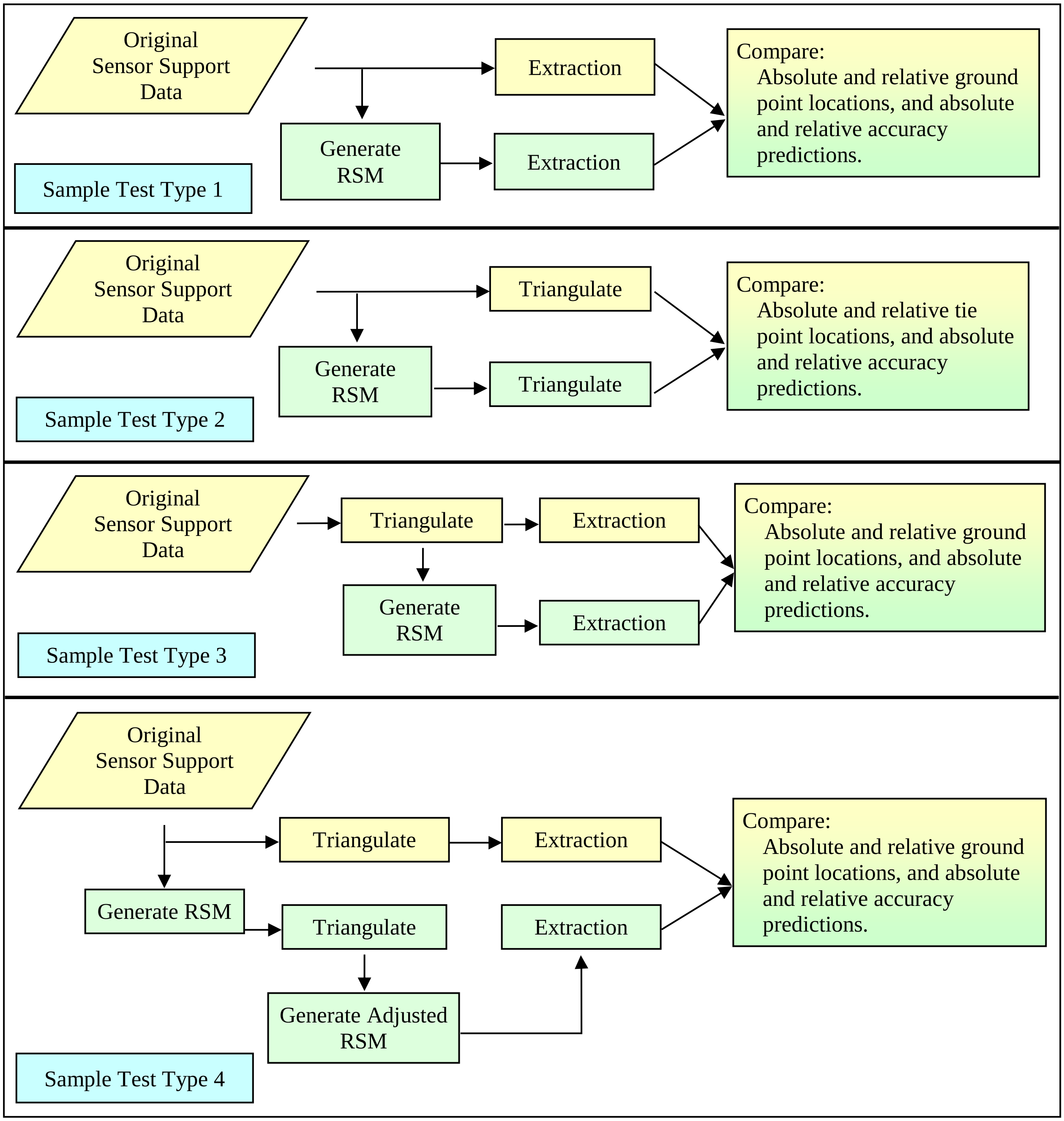

Figure B15: RSM Sample Geo-positioning Tests

From these studies, we have shown that the typical difference in the ground-to-image relationship between the original physical sensor model and its RSM counterpart is less than 1/20 pixel; the difference in (multi-image) target solution coordinates is less than 1/10 meter, and the difference in target absolute and relative accuracy predictions (CE/LE and RCE/RLE) is also less than 1/10 meter (see **Table B2**).

Similar results are also applicable after support data adjustments of the RSM image support data versus adjustment of the physical sensor model image support data. These adjustment comparisons correspond to Sample Test Types 2 and 4 in **Figure B15** and their results are characterized by “adjustability” in **Table B2**.

Table B2: Original Sensor Model vs. RSM

Original Sensor Model & Support Data vs. RSM & RSMSD	Difference (typical)	Units
Ground-to-Image	< 0.05	pixel
Image-to-Ground (pixel equivalent)	< 0.05	pixel
Multi-Image Target Solution	< 0.1	meter
Accuracy Prediction (CE/LE and RCE/RLE)	< 0.1	meter
Adjustability	< 0.1	meter

Furthermore, included in these geo-positioning studies, RSM and its support data have been successfully tested and validated for a number of diverse sensors (on both space-borne and air-borne platforms) including: commercial sensors, tactical sensors, EO (optical), SAR (Synthetic Aperture Radar), frame sensors, and push-broom sensors.

> Note 5.2-1: little disclaimer:
> Through these studies, we have also verified that the original image support data uncertainty can not be excessive in order for any RSM adjustment (triangulation) of the generated RSM image support data to yield virtually the same results as a (hypothetical) original adjustment of the original image support data. (See sample test types 2 and 4, in **Figure B15**). For example, the position of a space-borne sensor should be known, initially, to within 1000 meters in order to get virtually the same results.

> Note 5.2-2: If the original support data uncertainty is excessive, a resection of the original image support data using the original sensor model and external control should first be performed prior to generating RSM image support data, in which case the above disclaimer (Note 5.2-1) is no longer applicable.

> Note 5.2-3: This qualifier (Note 5.2-1) regarding original image support data uncertainty is not necessary for RSM-based extraction, only RSM-based adjustment.

6.0 Cooking With RSM

Now that it's clear that you need RSM, the question remains as to how to incorporate it into your system. There are two possibilities. One is to develop your own capability from scratch, which is discussed in the following Section 6.1, and the second is to take advantage of "software modules" that have already been developed and tested, which is discussed in Section 6.2.

However, we'd like to take this moment to reiterate: It has already been pointed out that the RSM model is a general and very flexible sensor model—it had to be in order for it to be applicable to virtually all sensors. But, with this flexibility came complexity. The RSM is not a simple algorithm to develop and implement, at least for RSM generation. Although one can argue that implementing the RSM sensor model from scratch will allow the user to uniquely tailor the deployment of RSM, this must be weighed against the potential development costs, which can be mitigated with the use of the available, fully developed and tested "software modules".

6.1 Cooking From Scratch

For those who wish to implement RSM capabilities from scratch, you will need to follow the references for more detailed descriptions, as the specific implementation details exceed the scope of this "light" introduction to RSM.

RSM is fully described and documented in the 2004 Manual of Photogrammetry (reference [1]). This treatise includes the algorithms and equations needed to generate RSM support data, such as polynomial coefficients, and the error covariance; as well as, the algorithms and equations needed to exploit the resulting RSM image support data.

> Note 6.1-1: Most users are considered down-stream receivers of imagery; in this case, you would only be concerned with implementing the RSM exploitation processes.

Furthermore, there is additional RSM documentation, giving more insight to algorithms, descriptions, and equations specific to the standardized formatting of the RSMSD, contained in the NITF 2.1 RSM TRE definitions currently available on the public side of the NTB Web Pages (reference [2]).

Note 6.1-2: (Recall Note 4.2-3) As a result of recent development, there is also an updated subset of RSM TREs that are waiting for adoption. The latest RSM improvements are documented in the introduction to each new TRE (reference [3]).

Note 6.1-3: Nothing about RSM is proprietary. BAE Systems has published a "Free License Agreement" to (1) assure 3rd parties that they will not infringe BAE Systems' intellectual property if they build their own RSM exploiter or generator, and (2) gives 3rd parties the right to build their own products which would emulate the standards of RSM.

6.2 Just Add Water…

The RSM has been implemented by BAE Systems for the NGA as two application programming interface (API)-driven software modules: the "RSM Generator", and the "RSM Exploiter". The initial release of the "RSM Generator" and "RSM Exploiter", were delivered to NGA at the end of 2004, and a second release in September of 2006.

Included with both the RSM Generator and RSM Exploiter software packages are an installation package, User's Manual, and the API description (see references [5] and [6]).

Currently, the RSM Generator and Exploiter are being maintained by BAE Systems, under the NGA's Mensuration Services Program (MSP). Thus, to inquire about obtaining the RSM Generator and/or the RSM Exploiter, contact reference [7]:

Additional information about the RSM Generator and RSM Exploiter can also be found in reference [8].

So, now that we know how to get RSM, which module(s) do I need?

Recall that the RSM generation processes are intended for "up-stream" image disseminators like ground processing stations or image libraries. Thus, if you are disseminating imagery, you are likely in need of the RSM Generator module. However, most users are "down-stream" imagery receivers, and thus only need the RSM Exploiter module.

Note 6.2-1: For users who are also adjusting RSM image support data (see **Figure B15**, Sample Test Type 4), an RSM Generator "lite" module is also needed if those adjustments are to be disseminated to others in the user community.

6.2.1 RSM Generator

RSM provides "one-stop" shopping for all your sensor model needs. However, in-order for the store to be fully stocked, the RSM Generator (factory) must have access to the original sensor model for each sensor of interest and corresponding image support data for each image of interest.

For a given image, the corresponding original sensor model and image support data are held by a "sensor model object", which is basically just a software "container" that supplies sensor model functionality initialized by the appropriate (and accompanying) image support data. The RSM Generator utilizes original sensor model objects in order to generate corresponding RSM image support data as depicted in **Figure B16**.

The RSM Generator uses the standardized Community Sensor Model (CSM) interface, which supports "plug-in" architecture (see reference [9] for more CSM details) to "communicate" with the sensor model objects provided by the higher-level application. If the higher-level application that hosts the RSM Generator uses an interface other than CSM, a translator must be provided or developed.

Thus, with access to the original sensor model objects, the RSM Generator is able to generate RSM image support data and populate the RSM TREs for incorporation into an NITF image by the upper-level application, thereby allowing the down-stream user community to use the RSM sensor model for all their geo-positioning needs.

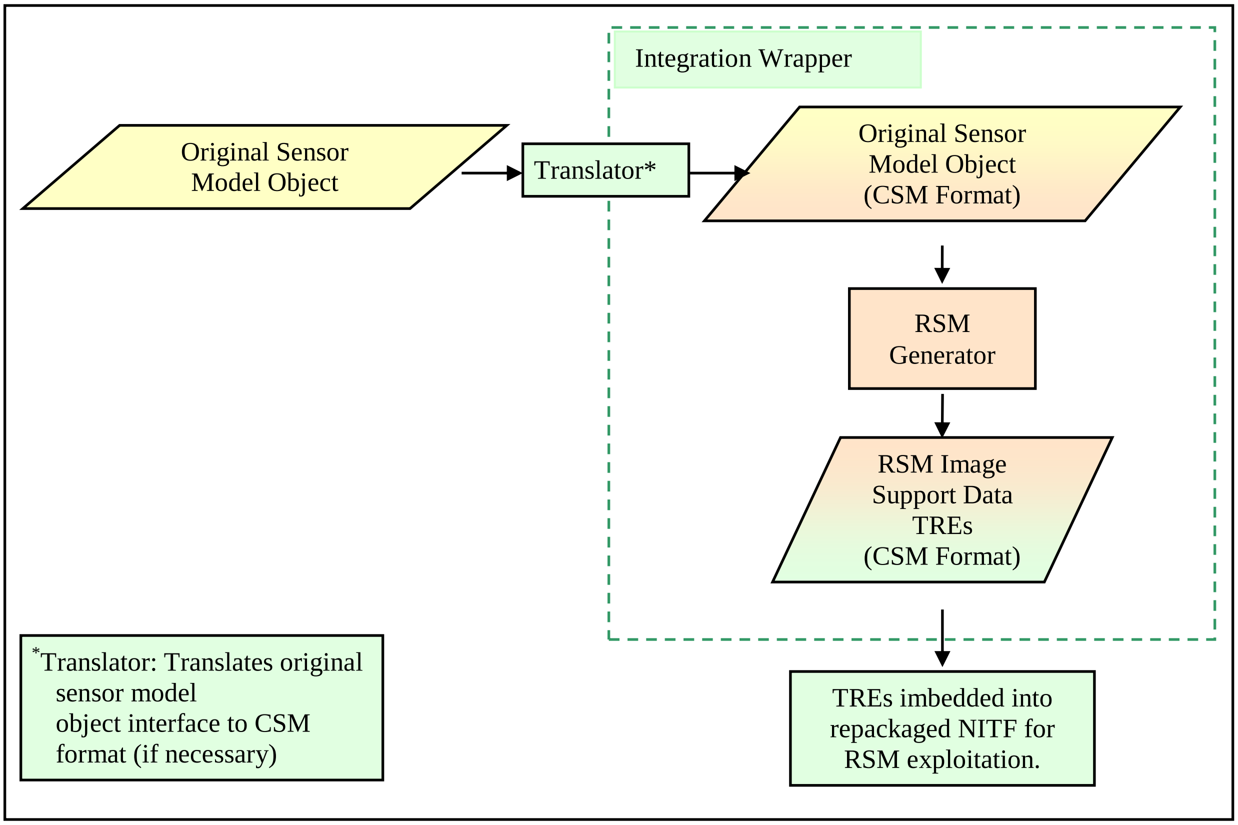

Figure B16: Integration of RSM Generator

The RSM Generator works automatically, and is designed to select and populate the best combination of TREs for many types of sensors/images.

More specifically, the RSM Generator automatically selects the appropriate form for the RSM ground-to-image function, and the appropriate set of RSM adjustable parameters and corresponding error covariance applicable for a specific physical sensor model(s) and its image support data. The RSM Generator then automatically produces the corresponding RSM image support data in standardized NITF 2.1 RSM TRE format.

The RSM Generator produces the appropriate subset of the 8 available TREs (see Section 4.2). Of course, the TREs produced must be compatible with the original sensor model and its image support data. For example, if the original sensor model has a ground/image relationship but not adjustable parameters or error covariance, only RSM TREs associated with the ground/image relationship will be produced.

The resultant RSM TREs are then typically repackaged with the original NITF tags in the NITF image by the upper-level application. By imbedding the new RSM TREs into the original set of NITF tags, there is never a loss of data (e.g., data not directly related to geo-positioning); and down-stream users also have the choice of using the original image support data (if they have the original physical sensor model implemented), or the RSM image support data.

> Note 6.2.1-1: **Figure B16** is a notional representation for integrating the RSM Generator into an upper-level application host. For details on integration, see references [5], [6] and [9].

6.2.2 RSM Exploiter

As described above, the RSM Exploiter is integrated by down-stream users, and does not need access to the original sensor model or its support data, all it needs are the RSM TREs.

Thus, given any set of RSM TREs retrieved from the NITF image by the upper-level application, the RSM Exploiter automatically provides all corresponding sensor model functionality to an exploitation application through the use of RSM sensor model objects (see **Figure B17**). The Exploiter also uses the standardized CSM interface to communicate with the sensor model object; thus, if necessary, a translator to and/or from CSM must be provided or developed.

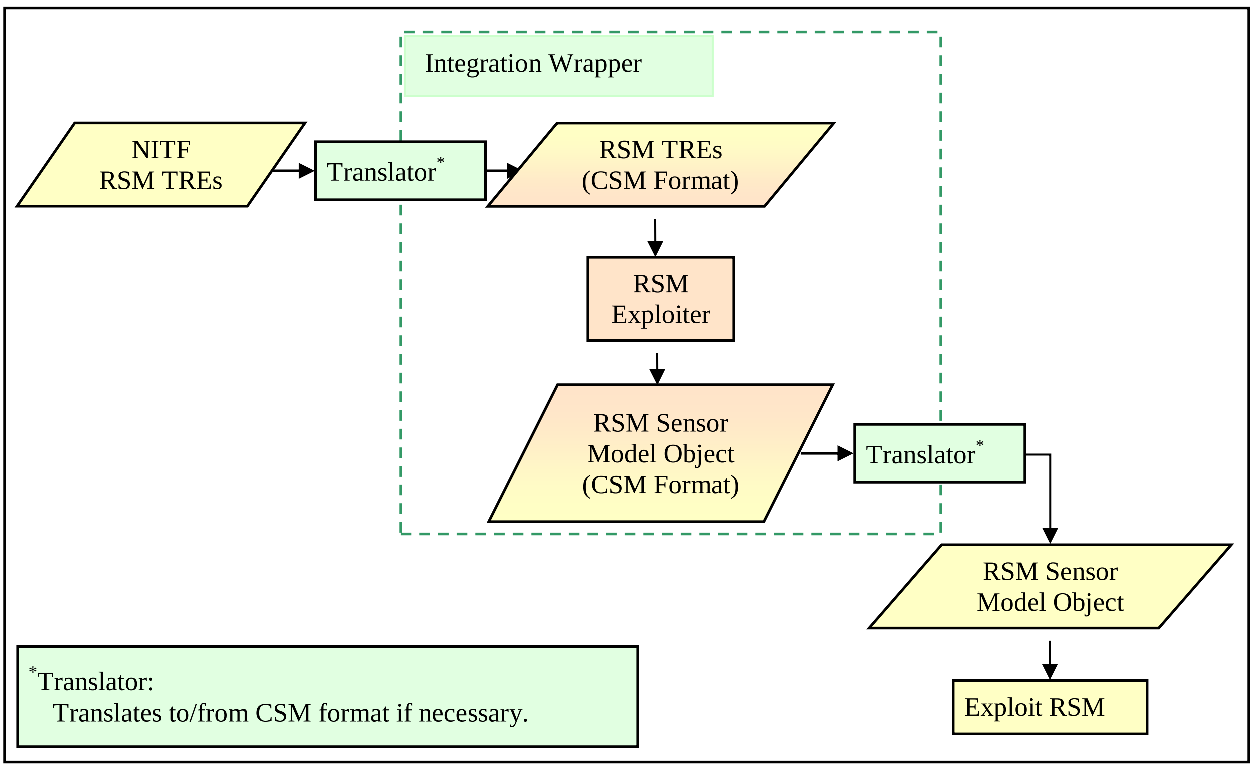

Figure B17: Integration of RSM Exploiter

But, what exactly do we mean by the RSM Exploiter "provides all sensor model functionality"?

It means, that when a user (application program) …

… asks for an image point, and provides a ground point,
the RSM Exploiter returns the corresponding image point.

… asks for a ground point, and provides an image point and specific height,
the RSM Exploiter returns the corresponding ground point.

… asks for the partial derivatives of image coordinates with respect to adjustable parameters and provides a ground point,
the RSM Exploiter returns the corresponding partial derivatives.

… asks for the multi-image support data error covariance for this image and another image,
the RSM Exploiter returns the corresponding multi-image error covariance.

… and so on,

… everything needed for optimal extraction, mensuration, adjustment, and accuracy prediction.

> Note 6.2.2-1: **Figure B17** is a notional representation for integrating the RSM Exploiter into an upper-level application host. For details on integration, see references [5], [6] and [9].

7.0 Tributes

We would like to take this opportunity to thank the National Geospatial-Intelligence Agency (NGA) for this document's overall charter and for their support during its preparation as a part of JTW contract # NMA201-01-C-0028.*

*Any mistakes in the use and possible abuse of attempted humor are solely the responsibility of the authors.

8.0 Coda

It's a small world after all…and RSM will help make our world smaller, and more accessible.

Well, on that note, we hope you've found this "introduction to RSM" helpful, insightful, and dare we say mildly entertaining? If you're intrigued about RSM, and want to learn more, then we've succeeded, and invite you to continue on to the references.

Thank you for sharing your time with us, and we hope to hear from you soon. In the immortal words of Dale Evans…

"Happy trails to you…"

9.0 References

Updates as of November 1, 2012:
References 2 and 3 have been superceded by the 2012 update to the RSM TRE specification.
References 5 and 6 have been replaced with the MSP Generator Service and RSM CSM sensor model plugin.
References 7 and 8 have been updated.

[1] Dolloff, John "Replacement Sensor Models", Chapter 11.3 in *Manual of Photogrammetry*, Fifth edition, Chris McGlone, editor, ASPRS, 2004.

[2] RSM Support Data (RSMSD) definitions are currently available on the public side of the NTB Web Pages: http://www.gwg.nga.mil/ntb/index.html, in particular:

Dolloff, John, and C. Taylor, *RSM Tagged Record Extensions Spec for NITF 2.1*, 2004, http://www.gwg.nga.mil/ntb/coordinationitems/RSM__NITF_TRE%27s_delivery_July_23_04.pdf.

[3] Dolloff, John, and C. Taylor, *Proposed Updates to RSM TREs: Extension to the RSM Tagged Record Extensions Spec for NITF 2.1*, September 30, 2006.*

[4] Taylor, Charles, J. Dolloff, M. Iiyama, and E. Mikhail, *RSM Extraction and Adjustment of Large Field of View Frame Imagery*, NGA September 30, 2006.*[†]

[5] BAE Systems, *JTW RSM Generator/Exploiter 2.1 User's Manual*, 2006.*

[6] BAE Systems, *JTW RSM Generator/Exploiter 2.1 Application Program Interface (API)*, 2006.*

[7] NGA's Mensuration Services Program (MSP) contact for RSM requests: MSP Help Desk (msphelp@baesystems.com).

[8] BAE Systems Geospatial eXploitation (Special) Products: http://www.socetgxp.com/content/products/special-products/replacement-sensor-model-rsm[†]

[9] *Community Sensor Model (CSM) Technical Requirements Document (TRD)*, Version 2.0, 2005. *

* References [3] through [6] and [9] are available via reference [7].
[†] Reference [4] and this appendix are available for download via reference [8].

Appendix C

RSM Extraction and Adjustment of Large Field of View Frame Imagery

September 30, 2006

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BAE SYSTEMS

Table of Contents

1.0 Preface C-3
2.0 Introduction C-3
3.0 RSM Performance Tests C-4
3.1 General Comparison Scenarios C-5
3.2 Nadir Geometry Test Case C-7
3.2.1 Results Using Baseline *A Priori* Support Data C-11
3.2.2 Results Using Modified *A Priori* Support Data C-15
3.3 Oblique Geometry Test Case and Results C-16
4.0 Conclusions C-20
5.0 Acknowledgements C-20
6.0 References C-21
Annex A C-22
A.1 Nadir Test Results Using Baseline *A Priori* Support Data C-22
A.2 Nadir Triangulation Results Using Modified *A Priori* Support Data C-22
A.3 Oblique Triangulation Results Using Simulated Support Data C-23

Table of Figures

Figure C1: Replace/Extract Scenario C-5
Figure C2: Triangulate/Replace/Extract Scenario C-6
Figure C3: Replace/Triangulate Scenario C-6
Figure C4: Replace/Triangulate/Extract Scenario C-7
Figure C5: Image Footprints and Ground Points C-9
Figure C6: Nadir vs Oblique Imaging Geometry. C-17

Table of Tables

Table C1: Aerial Frame Camera Specifications C-9
Table C2: Nadir Absolute Geopositioning Comparison C-11
Table C3: Nadir Relative Geopositioning Comparison Statistics C-12
Table C4: Nadir Replace/Triangulate/Extract Check Point Absolute Geopositioning Comparisons C-14
Table C5: Nadir Replace/Triangulate/Extract Check Point Relative Geopositioning Comparisons C-15
Table C6: Perturbed Absolute Geopositioning Comparison Statistics C-15
Table C7: Perturbed Relative Geopositioning Comparison Statistics C-16
Table C8: Oblique Absolute Geopositioning Comparison Statistics C-18
Table C9: Oblique Relative Geopositioning Comparison Statistics C-18
Table C10: Nadir Imaging Geometry Detail C-22
Table C11: Oblique Imaging Geometry Detail C-23

1.0 Preface

Replacement Sensor Model (RSM) performance has been successfully verified for a number of tactical sensors and commercial satellite sensors. The tactical sensor performance reports are classified and therefore their audience is strictly limited. The following assesses RSM performance for an unclassified low-altitude airborne sensor. In terms of imaging geometry (platform position), it is similar to many tactical sensors. However, this sensor is also challenging in that it has a large field-of-view. Both nadir and oblique imaging geometries are also addressed, where the latter includes imaging the horizon.

2.0 Introduction

A study was conducted of RSM target extraction and triangulation (adjustability) performances for large field-of-view (FOV) frame images. The goal of the study is to show that the RSM performance meets its charter for these images. The RSM charter is to provide image projective functionality (ground-to-image and image-to-ground), error propagation (accuracy prediction), and adjustability that are virtually equivalent to that of the original physically-based sensor model within the RSM operational assumptions.

There are two operational assumptions for RSM. The first is that the original sensor model is available at the point in the processing chain at which the RSM (image) support data are generated. That is, there is no provision for "resecting" the RSM support data from a few ground control point measurements.

The second operational assumption is that high-fidelity adjustability is realized only where the change in the model's operating point due to adjustment doesn't have too large of an effect on the sensor model partial derivatives, typically at the 1% level. This assumption means that if the original sensor model support data are of very low fidelity, it is advisable to "resect" or triangulate the original sensor model prior to generating RSM support data.

In terms of partial derivates, fidelity is relative to the particular imaging geometry. For example, the *a priori* position contained in the support data for a space-borne sensor can be in error on the order of 1000 meters and not cause a fidelity problem regarding RSM adjustability. On the other hand, this tolerance may reduce to tens of meters for low-altitude airborne sensors.

In summary, and stating the RSM charter in a slightly different way, target extraction (including accuracy prediction) based on RSM is to be virtually identical to target extraction based on the original sensor model. Furthermore, RSM triangulation is also to be virtually identical to the corresponding original sensor model triangulation assuming that the original sensor model's *a priori* support data are reasonably accurate.

The study is based on 12 aerial frame images over the Purdue University campus provided by Professor Ed Mikhail. The images are a challenging test case for RSM because their fields of view approach ninety degrees. With such a large field of view, the imaging geometry changes substantially from one part of the image to another. It is within the RSM charter to have high fidelity even under these conditions, and demonstrating that it does is a major goal of this performance test.

The study is in three main parts. The first part uses the original nadir imaging geometry in four test scenarios. The second part focuses on RSM triangulation performance, in order to see whether or not the performance for these images is limited by the accuracy of the original frame sensor model support data (according to the second operating assumption). In the third part, the image support data and measurements are modified to simulate highly oblique imaging geometry, and once again, RSM triangulation performance is assessed.

The organization of the report is as follows. First, the test scenarios are defined. Next, the results of the three main parts of the study are presented. The report concludes with general RSM references, followed by an annex containing two tables of detailed imaging geometry. A more extensive annex containing RSM performance on a per ground point basis can also be found in reference [4].

3.0 RSM Performance Tests

The geopositioning operation of "target extraction" consists of estimating the three-dimensional positions, and their uncertainties, of points (targets) based on their measurements in images. The sources of error that enter into the estimation of the uncertainties (accuracy prediction) are the image support data uncertainties and the uncertainties in the image measurements. The image support data uncertainties are expressed in terms of the uncertainties of adjustable parameters, but the parameters are not actually adjusted in the operation of target extraction.

The geopositioning operation of triangulation consists of simultaneously estimating the three-dimensional positions of points and adjusting image support data parameters. Triangulation also includes estimating the uncertainties of the positions and the support data adjustments.

In general, the uncertainties of positions and adjustable parameters are quantified by error covariance matrices. For this performance study, the metrics of absolute and relative horizontal circular error (CE90) and vertical linear error (LE90) are distilled from the covariance matrices estimated in target extraction and triangulation.

3.1 General Comparison Scenarios

Within its operational assumptions, RSM is designed to support the same estimation of point positions and their uncertainties, and allow sensor model parameter adjustment, and provide virtually the same results as the original sensor model it replaces. In this performance study, the RSM performance was analyzed in four scenarios of increasing complexity, as described below.

The simplest scenario is the Replace/Extract scenario. In this scenario, illustrated in Figure C1, the original sensor models are used for target extraction with a set of image measurements. Next, the original sensor models are provided to the RSM Generator and RSM support data are generated. Then, another target extraction operation is performed, with the same image measurements as the previous target extraction, but with the RSM support data rather than the original support data. Finally, the absolute and relative point positions and uncertainties are compared to determine how well the goals of RSM performance are met.

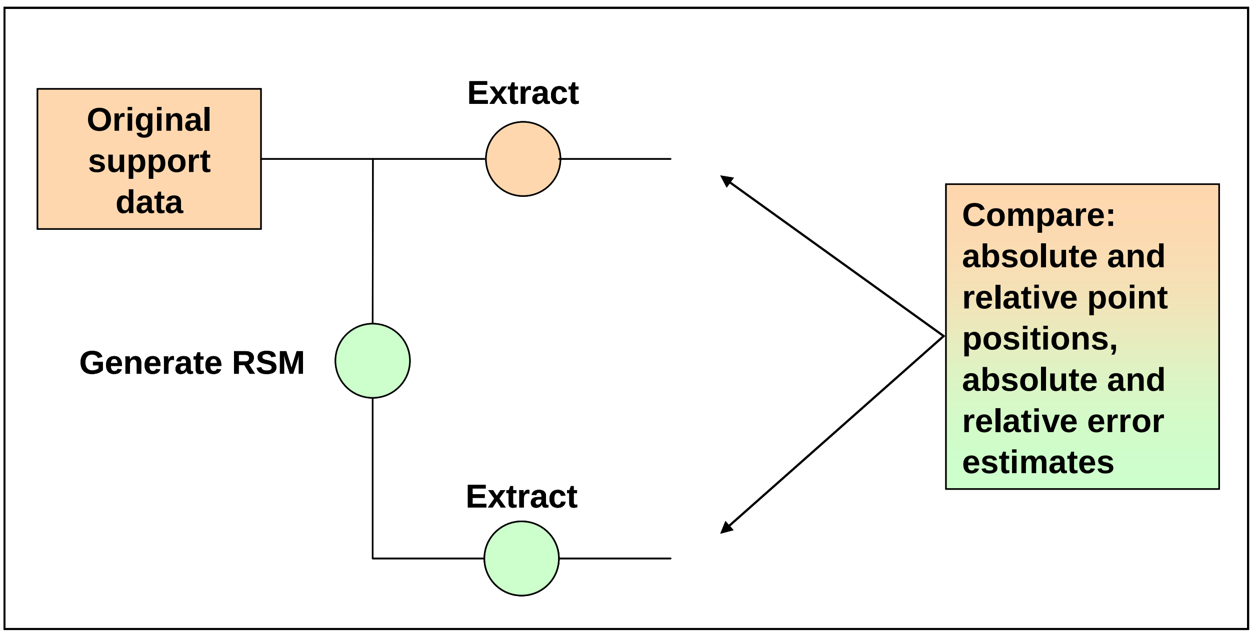

Figure C1: Replace/Extract Scenario

The Replace/Extract scenario described above uses the original support data, assumed not to have been previously triangulated. RSM is also designed to work with triangulated original sensor models. In the Triangulate/Replace/Extract scenario illustrated in Figure C2, a triangulation operation has been inserted ahead of the RSM Generation and extraction operations. The triangulation may include any combination of tie points and ground control points. The RSM Generator takes in both the triangulated original sensor models and the joint covariance matrix from the triangulation, and otherwise the operations are as in the Replace/Extract scenario.

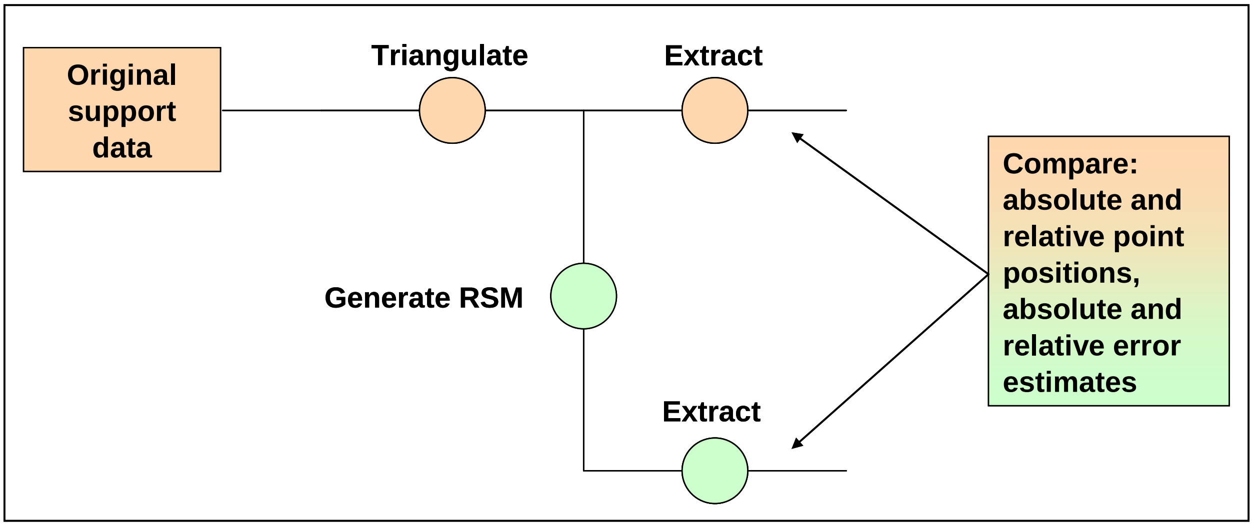

Figure C2: Triangulate/Replace/Extract Scenario

The Replace/Triangulate scenario, like the Triangulate/Replace/Extract scenario, begins with triangulation of the original sensor models, using tie points and/or ground control points. But after that it differs as shown in Figure C3, because in the Replace/Triangulate scenario the RSM Generator is given the un-triangulated original sensor models. Then, the RSM support data are used in a triangulation using the same tie and/or ground control points as the original sensor model triangulation. The performance is analyzed based on the tie points used in both triangulations—if the RSM goals are met then their positions and error estimates will be virtually the same.

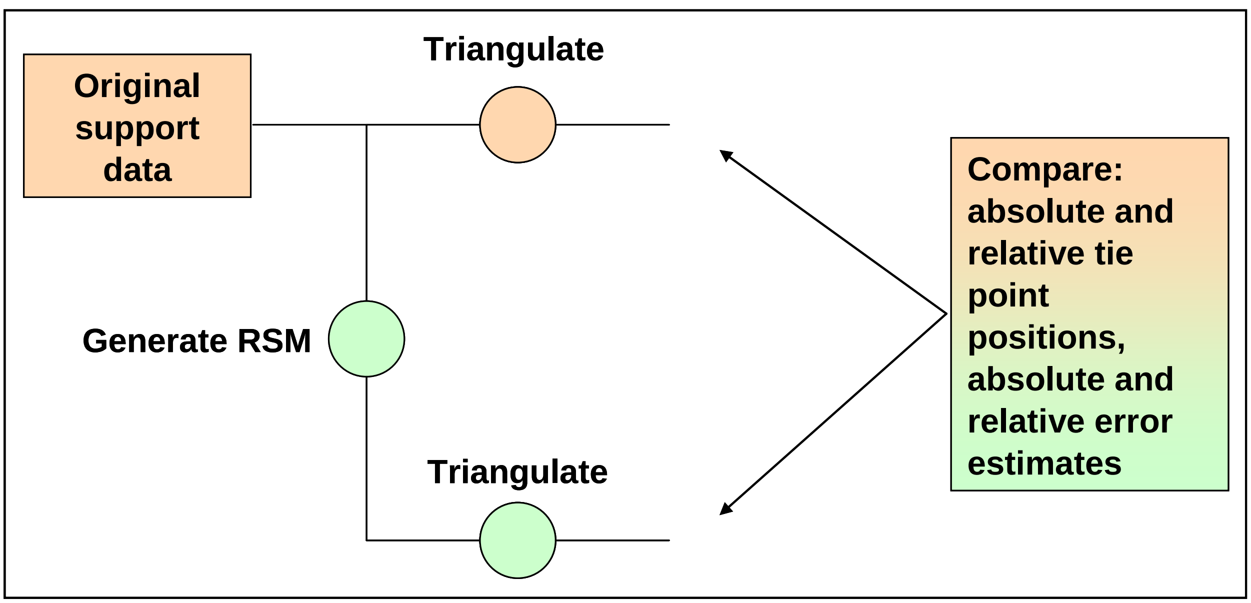

Figure C3: Replace/Triangulate Scenario

The RSM support data format is designed to retain the parameter adjustments and the *a posteriori* joint error covariance from triangulation, and this capability is used in the

Replace/Triangulate/Extract scenario, shown in Figure C4. It begins with the same operations as in the Replace/Triangulate scenario, and then a target extraction is performed with the triangulated original sensor models. A target extraction with the same image measurements is performed with the triangulated RSM sensor models, and the absolute and relative target positions and uncertainties are compared. The performance is expected to be about the same as for the Triangulate/Replace scenario, since no additional support data improvement happens in the target extraction operation, but the scenario is more complex operationally, because the adjustments and joint *a posteriori* error covariance need to be passed from triangulation to target extraction.

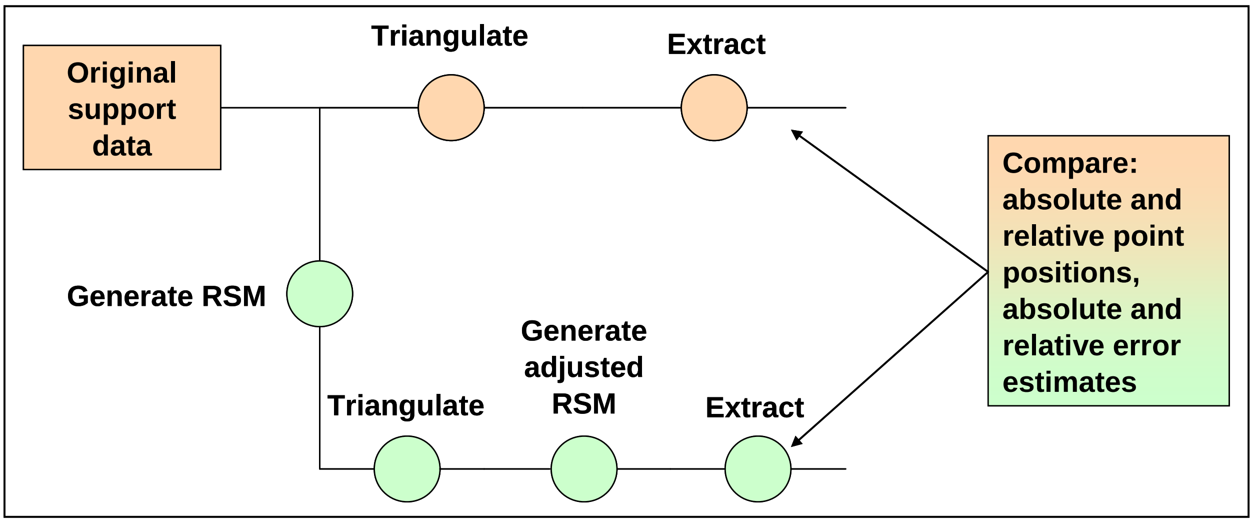

Figure C4: Replace/Triangulate/Extract Scenario

3.2 Nadir Geometry Test Case

The 12 test images were obtained with the aerial frame camera whose specifications are given in

Table C1. The camera was nadir-looking, and the platform was flown in a north-south direction. The platform height is around 800 m and the terrain height is around 200 m, so the platform is about 600 m above the ground. The full field of view is about 88 degrees in both directions (row and column, or line and sample). The image sizes are about 7700 pixels in each direction, and the ground sample distances (GSDs) are around 0.11 m. A more complete table of image geometry data is in the annex in Table C10.

Table C1: Aerial Frame Camera Specifications

Category	Specifications
Camera	Wild RC-10
Calibrated Focal Length	153.077 mm
Format	230 mm x 230 mm (9"x9")
Average Scale	1:4000
Scanned at pixel size	30 microns
Date	October 1999
Forward Overlap	80 %
Sidelap	60 %

The footprints of the test images are plotted in Figure C5. The figure also shows the locations of the ground control points, tie points, and check points that are described in the following paragraphs.

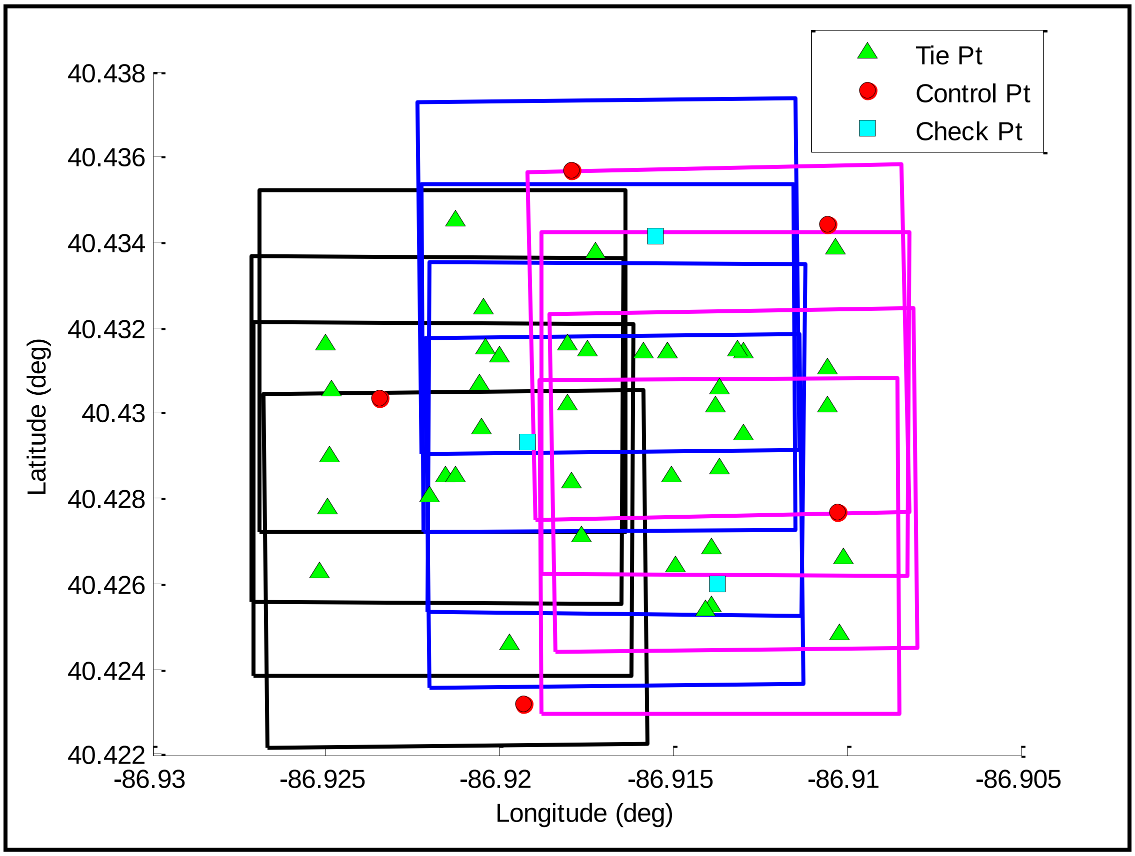

Figure C5: Image Footprints and Ground Points

When triangulation is included in a scenario, the images are triangulated with 5 surveyed ground control points, whose point identifiers are HISC (measured in 1 image), PH11 (3 images), LILY (1 image), BBLL (4 images), and STNE (2 images). Thus there are a total of 11 control point measurements. The control point error estimate is 0.1 m (1 standard deviation) in each horizontal component and 0.3 m in the vertical component. The control point uncertainties are modeled as uncorrelated between pairs of control points.

In addition to the control points, the triangulations use 40 tie points. The tie points are measured in two to ten images each, for a total of 186 tie point measurements.

Three surveyed check points are used in the target extraction operations, and these points are not included in the triangulations. Their point identifiers are PH12 (measured in 7 images), CHEM (3 images), and MACK (3 images). The check point error estimates are the same as the control point error estimates, except for MACK, which has error estimates of 0.3 m (1 standard deviation) in each horizontal component and 0.5 m in the vertical component. The surveyed coordinates of the check points are available for "ground truth" comparisons, but the main emphasis of the study is the comparison of RSM and original sensor model performance.

Image measurement errors are all taken to be 0.5 pixel one-standard-deviation in the line and sample directions for all measurements. This was done in the absence of any measurement error estimates in the data provided for the study. Metrics internal to triangulation indicate these error estimates are reasonable.

The first operational assumption for RSM is that an original physically-based sensor model must be available in the processing sequence when the RSM support data are generated. In this study, this requirement was met through the use of a rigorous frame sensor model with six adjustable parameters, along with its *a priori* image support data. The adjustable parameters are east-north-up (ENU) sensor position corrections and omega, phi, kappa euler angle corrections for the camera attitude. The baseline *a priori* uncertainties are set to 30 m (one standard deviation) for position corrections and 0.05 rad (one standard deviation) for angle corrections. The errors are assumed to be uncorrelated between images.

The frame sensor model adjustable parameter error estimates were obtained by engineering judgment when it was found that the error estimates originally provided were too large (too conservative). The error estimates originally provided were sensor model defaults not applicable to the specific scenario. They were 1225 m for each component of the sensor position and 1.53 rad for each attitude angle. An initial triangulation was performed with these error estimates, and the ratios of the sensor parameter adjustments to the *a priori* error estimates were found to be so small that the error estimates were statistically unreasonable. Thus, the *a priori* adjustable parameter error estimates were overly conservative. The same metric (ratio of sensor parameter adjustments to error estimates) showed that the revised error estimates in the preceding paragraph were reasonable.

The second operational assumption for RSM, which relates to RSM adjustment, is that the change in the model's operating point due to adjustment affects the sensor model partial derivatives below about the 1% level. The original sensor model error estimates suggest this will be exceeded by about a factor of five, as it will be shown, and therefore it is anticipated that some differences between original and RSM performance will be seen in RSM triangulations.

RSM support data were generated independently for the 12 images. The projective model selected and fit by the RSM Generator was a linear rational polynomial in rectangular coordinates. Root-mean-square (RMS) and maximum fitting errors (as compared with the original frame sensor model) were well under 0.001 pixels, both on the grid of fit points and with a random sampling of 1000 evaluation points per image.

The RSM adjustable parameters selected by the RSM Generator were ground-space adjustable parameters: translation (in three dimensions) and small-angle rotations about three orthogonal axes as defined in the RSM TRE specification. Thus there were a total of six RSM adjustable parameters per image.

The RSM generation, triangulation, target extraction, and original frame sensor modeling were done within BAE Systems' Real-Time Automated Geopositioning Environment (RAGE) rapid prototyping baseline (Socet Set and the Joint Targeting Workstation (JTW) were not used). In addition, the BAE/NGA RSM Generator and BAE/NGA RSM Exploiter modules were used.

3.2.1 Results Using Baseline *A Priori* Support Data

The first set of results uses the baseline *a priori* image support data as described above (30m and 0.05 rad one-standard-deviation frame sensor model adjustable parameter error estimates). The absolute and relative geopositioning comparison statistics between original sensor model and RSM tests are given in Table C2 and Table C3 for the four scenarios and additional details are contained in the annex.

In the following tables, the reference (Ref) columns apply to the original sensor model and the comparison (Comp) columns apply to RSM. The horizontal difference (Horiz diff) is the distance from the target's horizontal position as determined in original sensor model operations to the target's horizontal position as determined in RSM operations, and should be viewed in the context of the horizontal circular error estimate (CE). The vertical difference (Vert diff) is the offset of the height obtained in RSM operations with respect to the height obtained in original sensor model operations, and should be viewed in the context of the vertical linear error estimate (LE).

Table C2: Nadir Absolute Geopositioning Comparison

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Extract	RMS	75.178	75.154	145.935	146.003	0.074	0.137
	max	97.118	97.096	183.982	184.117	0.114	0.220
Triangulate/Replace	RMS	0.213	0.213	0.444	0.441	0.000	0.001

/Extract	max	0.241	0.241	0.517	0.513	0.000	0.001
Replace/Triangulate	RMS	0.256	0.255	0.498	0.496	0.235	0.298
	max	0.539	0.537	0.852	0.843	0.999	1.268
Replace/Triangulate /Extract	RMS	0.213	0.213	0.444	0.441	0.110	0.252
	max	0.241	0.241	0.517	0.517	0.155	0.419

Table C3: Nadir Relative Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Extract	RMS	103.666	103.628	209.951	210.068	0.121	0.191
	max	123.962	123.931	245.089	245.220	0.158	0.270
Triangulate/Replace /Extract	RMS	0.246	0.246	0.532	0.531	0.000	0.002
	max	0.299	0.299	0.661	0.660	0.000	0.003
Replace/Triangulate	RMS	0.302	0.302	0.570	0.566	0.326	0.415
	max	0.725	0.725	1.264	1.238	1.370	1.851
Replace/Triangulate /Extract	RMS	0.246	0.246	0.532	0.522	0.167	0.403
	max	0.299	0.299	0.661	0.646	0.235	0.542

The Replace/Extract scenario comparison statistics are in the first two lines of Table C2 and Table C3. For this scenario, the statistics are with respect to the three check points. The RMS absolute CE of about 75 m and absolute LE of about 146 m in Table C2 are large, due to the large *a priori* support data uncertainty, as there is no triangulation in this scenario. The RSM support data generation and extraction reproduces these figures to within much less than one meter. Also, the horizontal and vertical absolute target position differences are much less than one meter, and far less than the absolute CE and LE. Likewise, the RMS relative CE of about 104 m and relative LE of about 210 m in Table C3 are reproduced very well by the RSM extraction, and the relative solution differences are much less than one meter. As expected, the maximum statistics for the three check points are a little larger than the RMS statistics.

The Replace/Extract scenario discussed above is a challenging test case for several reasons. The target extraction is done with optimal weighting according to the support data uncertainty for each image and the uncertainty of each measurement, and not with simplifying assumptions such as equal weighting for each image. All twelve images are involved when the three points are extracted simultaneously, and there are at least three measurements for each check point. Therefore this case requires more than just high fidelity of the RSM ground-to-image projective function to the original projective function; it also requires high fidelity of the RSM adjustable parameter error covariance to the original sensor model error covariance for every image. The RSM performance is in close agreement with the original in this challenging case.

The second scenario, Triangulate/Replace/Extract, is considered next. In this scenario, the five control points, together with the tie points between the images, result in very accurate adjusted original support data. In Table C2 this is seen in the RMS CE of about 0.2 m and RMS LE of about 0.4 m. Also, Table C3 shows that the relative CE is about 0.2 m and the relative LE is about 0.5 m. The RSM tests show that the original sensor model geopositioning is reproduced with extraordinarily high fidelity in this scenario. All differences between original (reference) and RSM (comparison) positions and error estimates are well under 0.01 m.

The Triangulate/Replace/Extract performance is in line with other studies that show this to be a very favorable scenario for RSM. Note also that the original sensor multi-image (adjustable parameter) support data error covariance reflects a highly correlation between images following triangulation (as it should) and that the corresponding RSM multi-image error covariance successfully represented this error covariance with high fidelity.

For the Replace/Triangulate scenario, the statistics are evaluated over the 40 tie points (rather than the three check points used in the other three scenarios). Thus, the RMS statistics are more significant and representative than for the other three scenarios, and the maximum statistics lie further from the RMS than in the other three scenarios. In this scenario, Table C2 shows that the RMS absolute CE and LE are about 0.25 m and 0.5 m, respectively, and that the RSM computations of CE and LE are in excellent agreement with those obtained from the original sensor models. The RMS difference in absolute horizontal positions between original and RSM computations is about 0.2 m in this scenario, and the RMS difference in absolute vertical positions is about 0.3 m. The largest difference in absolute horizontal positions for the 40 tie points is about 1.0 m, and the largest difference in absolute vertical positions is about 1.3 m. Table C3 shows that the RSM relative CE and LE are about 0.3 m and 0.6 m, which are also in excellent agreement between original and RSM calculations. The RMS relative horizontal and vertical solution differences are about 0.3 m and 0.4 m, respectively. The largest relative horizontal and vertical solution differences for any of the 990 pairs of tie points are about 1.4 m and 1.9 m, respectively.

The RSM performance in the Replace/Triangulate scenario is an example of RSM performing well even outside of the envelope for which it was designed. RSM is designed to provide adjustability virtually equivalent to the adjustability of the original sensor model as long as the change in the model's operating point doesn't have too large of an effect on the sensor model partial derivatives, typically at the 1% level. In this study, adjustments on the order of the 30 m sensor position uncertainty and 0.05 rad attitude uncertainty at a range of 600 m affect the sensor model partial derivatives at about the 5% level. The second part of this study, presented below, examines the improvement in RSM adjustability performance when its second operating assumption is met.

As expected, the results for the final scenario, Replace/Triangulate/Extract, are comparable to the results of the Replace/Triangulate scenario. When the last two lines of and Table C3 (Replace/Triangulate/Extract scenario) are compared with the two lines just above them (Replace/Triangulate scenario), the main difference noted is that the maximum statistics are larger in the Replace/Triangulate scenario, because there are more points in the sample from which the maxima are taken.

Table C4 and Table C5 show the detailed "ground truth" check point comparisons for the Replace/Triangulate/Extract scenario. For each of the three check points and for both the original and RSM processes, the absolute and relative differences between the surveyed positions and the results of the target extraction are well within their 90 % error estimates. Note that the relevant error estimates in this case are the square roots of the sums of the squares (RSS) of the survey error estimates and the extraction error estimates. In most cases the RSM differences from the surveyed coordinates are a little larger than the original sensor model differences from the surveyed coordinates. The three cases in which the reverse is true are simply a result of good fortune, since the RSM support data are fit to the original sensor model and the RSM extraction is intended to match the original sensor model extraction, and no survey information is made available to the RSM Generator.

In the following Table C4, the reference (Ref) is the surveyed check point. No equality is expected between the comparison CE or LE (obtained from target extraction) and the reference CE or LE (obtained from the ground survey). The horizontal and vertical differences are with respect to the surveyed check points, and are not differences between original sensor model and RSM extractions. The horizontal differences should be considered in the context of the square root of the sum of the squares (RSS) of the reference and comparison CEs, and similarly the vertical differences should be considered in the context of the RSS of the reference and comparison LEs.

Table C4: Nadir Replace/Triangulate/Extract Check Point Absolute Geopositioning Comparisons

POINT ID	Comparison	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
PH12	Original	0.215	0.231	0.493	0.517	0.051	-0.112
	RSM		0.231		0.517	0.156	-0.104
CHEM	Original	0.215	0.158	0.493	0.337	0.020	-0.198
	RSM		0.158		0.334	0.082	-0.075
MACK	Original	0.644	0.241	0.822	0.459	0.076	-0.044
	RSM		0.241		0.453	0.134	-0.462
RMS	Original	0.411	0.213	0.623	0.444	0.054	0.134
	RSM		0.213		0.441	0.128	0.277

In the absence of any information about the relative uncertainties of the check points, Table C5 shows that the reference relative CE and LE have been taken to be zero, as if there were perfect positive correlation of ground survey errors between the points.

Table C5: Nadir Replace/Triangulate/Extract Check Point Relative Geopositioning Comparisons

POINT ID	POINT ID	Comparison	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
PH12	CHEM	Original	0.000	0.197	0.000	0.458	0.071	-0.086
		RSM		0.197		0.457	0.136	0.029
PH12	MACK	Original	0.000	0.299	0.000	0.661	0.050	0.068
		RSM		0.299		0.646	0.285	-0.358
MACK	MACK	Original	0.000	0.229	0.000	0.450	0.092	0.154
		RSM		0.230		0.439	0.203	-0.387
RMS (check point pair)		Original	0.000	0.246	0.000	0.532	0.073	0.109
		RSM		0.246		0.522	0.217	0.305

3.2.2 Results Using Modified *A Priori* Support Data

In order to verify that the accuracy of the RSM performance for triangulation in the study results above is limited primarily by the large change in the sensor model operating point in the triangulation, an experiment was performed as an excursion. The Replace/Triangulate and the Replace/Triangulate/Extract experiments were repeated using modified original *a priori* image support data. First, the original frame sensor models are triangulated with all of the control and tie points. Then, perturbations of the sensor positions and attitudes are randomly generated independently for all 12 images. The perturbations are consistent with support data errors of 8 m (one standard deviation) for position and 0.01 rad (one standard deviation) for attitude euler angles. With error estimates of this size, the changes in the sensor model partial derivatives in adjustment are expected to be around the 1% level, near the edge but not outside of the expected triangulation optimal performance envelope for RSM.

With the triangulated/perturbed *a priori* support data, the last two scenarios were repeated. The statistics of the comparisons of the original sensor model and RSM performance are shown in Table C6 and Table C7. As expected, the absolute and relative horizontal and vertical differences between original and RSM tie point positions have become smaller in this excursion study than with the baseline *a priori* support data. The table shows that the RMS differences are now well under 0.1 m. Recall that the GSDs of the images are about 0.11 m. The RSM solution differences, and even the maximum differences, are well below the 90% error estimates, confirming that the RSM performance is virtually the same in the adjustment as for the original sensor model.

Table C6: Perturbed Absolute Geopositioning Comparison Statistics

Scenario	Statistic	Ref	Comp	Ref	Comp	Horiz	Vert

		CE (m)	CE (m)	LE (m)	LE (m)	diff (m)	diff (m)
Replace/Triangulate	RMS	0.255	0.255	0.496	0.496	0.047	0.059
	max	0.539	0.540	0.850	0.850	0.127	0.175
Replace/Triangulate /Extract	RMS	0.213	0.213	0.442	0.440	0.035	0.050
	max	0.241	0.240	0.514	0.510	0.049	0.065

Table C7: Perturbed Relative Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Triangulate	RMS	0.302	0.302	0.567	0.567	0.058	0.083
	max	0.724	0.722	1.257	1.263	0.219	0.301
Replace/Triangulate /Extract	RMS	0.246	0.245	0.527	0.523	0.031	0.086
	max	0.299	0.299	0.655	0.648	0.043	0.110

3.3 Oblique Geometry Test Case and Results

The large-FOV frame test case is already challenging for RSM because of the large change in imaging geometry across the field of view. The test images are nadir-looking, but because of the wide field-of-view some of the imaging rays are inclined at forty degrees or more from nadir. A second excursion study was done to make the imaging geometry even more challenging. In the excursion, the study images were used as a basis for the simulation of more highly oblique images, while still keeping large fields of view. The obliquity was increased to the point where every image includes the horizon.

The simulation of the oblique test case begins with the triangulation of the nadir-looking original frame sensor models. The ground coordinates of all of the points after this initial triangulation are used as "truth" in the oblique case.

Next, a nominal azimuth angle and a nominal elevation angle are chosen for the oblique images. The same two angles are used for all twelve images. For this experiment, the azimuth angle was chosen to be 90 degrees, so that the sensor positions are moved eastward from their nadir-looking positions, and the elevation angle was chosen to be 30 degrees, so that the imaging geometry is highly oblique as shown in Figure C6. For each image, a new sensor position and attitude are found such the range for the oblique image is the same as for the corresponding nadir image, and so that the oblique image is centered on the same ground coordinates as the corresponding nadir image. The new sensor position and attitude are considered the "true" oblique image support data. The details of the simulated oblique imaging geometry are given in the Annex in Table C11.

With the simulated oblique sensor geometry for the 12 images, the "true" ground coordinates (obtained from triangulation of the nadir images as described above) are used to compute the corresponding "true" image coordinates for every image/ground point combination that had a measurement in the nadir case. The "true" image coordinates are then perturbed by randomly generated errors, normally distributed with a 1-standard-deviation error of 0.5 pixels. The perturbed measurements are stored for use in the oblique case for both the original sensor model and the RSM tests.

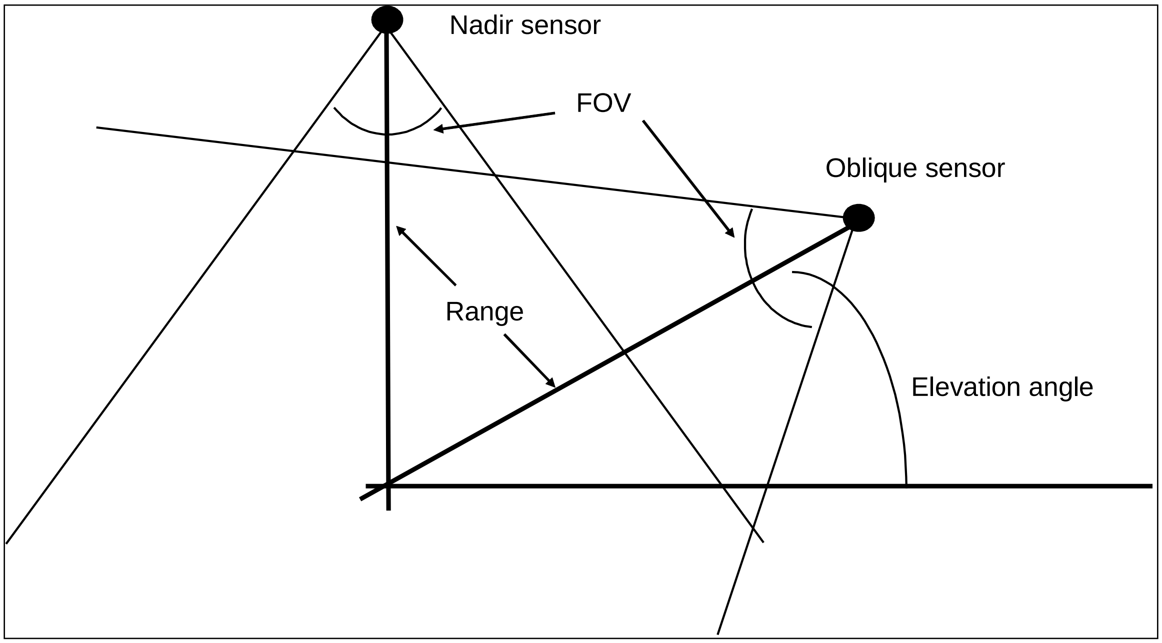

Figure C6: Nadir vs Oblique Imaging Geometry.

Once the "true" ground coordinates and "true" oblique support data have been used to compute the "true" image coordinates, and the latter have been perturbed for the purposes of experimentation, additional perturbations are generated for the experiments. First, perturbations are generated for the ground points. The amounts of the perturbations are consistent with a normal distribution with a 1-standard-deviation error of 0.1 m in each horizontal component and 0.3 m in the vertical component. Even though the coordinates of all of the ground points are perturbed, it is only for the three points used as ground control that the ground point perturbations affect the experiments.

Finally, perturbations are generated for the sensor position and attitude. The sensor position perturbations are consistent with a normal distribution with a 1-standard-deviation error of 8 m, and the attitude perturbations are consistent with a normal distribution with a 1-standard-deviation error of 0.01 rad (0.57 deg). The attitude errors correspond to about 8 m at the nominal range. The perturbed oblique image support data are used for the original sensor model experiments, and are used for generating the RSM support data. As with the excursion test for the nadir case above, the support data uncertainties are near the edge, but not outside, the expected triangulation optimal performance envelope for RSM.

The RSM projective model generation proceeds as in the nadir case, with the RSM Generator automatically selecting a linear rational polynomial in a local east-north-up rectangular coordinate system specific to each image. With the combination of large FOV and highly oblique image geometry, some of the image rows are directed above the horizon. In these cases, the RSM Generator automatically detects the failure of the original image-to-ground function and narrows the RSM image domain to a region in which there are no original sensor model errors. This is true when the top of the image is above the horizon (in which case the RSM Generator eliminates rows at the top of the image), and when the image is rotated so that the bottom of the image is above the horizon (in which case the RSM Generator eliminates rows at the bottom of the image); both types of cases arose in the study. As with the nadir images, the projective model fitting errors are well below 0.001 pixels.

As with the nadir images, the RSM Generator automatically selects ground-space translation (in three dimensions) and small-angle rotations about three orthogonal axes as the adjustable parameters, for a total of six RSM adjustable parameters, and finds a good mapping of the original to RSM error covariance.

When the simulated oblique sensor models are triangulated, an inspection of the triangulation log for the original sensor model shows that the adjustments are comparable with the simulated adjustable parameter uncertainties as expected (8 m one-standard deviation for sensor position, 0.01 rad one-standard deviation for attitude). This gives confidence that the simulation was developed correctly.

The absolute and relative geopositioning statistics for the simulated oblique images are shown in Table C8 and Table C9 below. Both the Replace/Triangulate and the Replace/Triangulate/Extract results are shown, and they are similar to each other. The CE and LE estimates differ by less than two percent between original sensor model and RSM operations. The RMS horizontal and vertical solution differences are around 0.1 m or less.

Table C8: Oblique Absolute Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Triangulate	RMS	0.446	0.447	0.405	0.406	0.099	0.042
	max	1.150	1.152	0.657	0.660	0.230	0.077
Replace/Triangulate /Extract	RMS	0.382	0.383	0.377	0.378	0.100	0.046
	max	0.534	0.535	0.409	0.410	0.112	0.057

Table C9: Oblique Relative Geopositioning Comparison Statistics

Scenario	Statistic	Ref CE (m)	Comp CE (m)	Ref LE (m)	Comp LE (m)	Horiz diff (m)	Vert diff (m)
Replace/Triangulate	RMS	0.556	0.557	0.444	0.445	0.108	0.033

	max	1.455	1.457	0.971	0.983	0.421	0.128
Replace/Triangulate /Extract	RMS	0.469	0.470	0.449	0.451	0.061	0.016
	max	0.556	0.557	0.552	0.555	0.084	0.022

4.0 Conclusions

All aspects of RSM performance were successfully verified for a large format frame camera using real imagery and image support data. The test scenario was challenging in that the sensor platform altitude was low and the sensor field-of-view large.

In particular, RSM extraction, accuracy prediction, and adjustments all matched their original sensor model counterparts to within approximately 0.001 pixels, 0.1 meters, and 0.1 meters, respectively.

The above adjustability results (only) required that the RSM operational constraint regarding support data uncertainty was satisfied. In particular, that pre-adjustment sensor model uncertainty was compatible with a 1% change or less to appropriate partial derivatives due to sensor model adjustment. Changes at the 5% level still provided reasonable comparisons between RSM triangulation and its original sensor model counterpart, but not virtually identical comparisons.

In addition, the overall test was expanded to address high oblique images that include the horizon. The baseline image support data was modified in order to simulate the high oblique images. RSM performance was successfully verified for this scenario as well.

5.0 Acknowledgements

We would like to take this opportunity to thank the National Geospatial-Intelligence Agency (NGA) for this performance sub-study of the RSM Tactical Imagery Study Phase 4 charter and for their support during the preparation of this paper as a part of JTW contract # NMA201-01-C-0028.

6.0 References

The following reference is a version of this report with an expanded appendix.

Taylor, Charles, J. Dolloff, M. Iiyama, and E. Mikhail. "RSM Extraction and Adjustment of Large Field of View Frame Imagery (with Expanded Appendix)", September 30, 2006. Available by request via :
BAE Systems Geospatial eXploitation (Special) Products:
http://www.socetgxp.com/content/products/special-products/replacement-sensor-model-rsm

Annex A

A.1 Nadir Test Results Using Baseline *A Priori* Support Data

Table C10: Nadir Imaging Geometry Detail

Image	Image ID	Number of rows	Number of columns	Ground reference height (m)	Image azimuth angle of north (rad)	Image azimuth angle of up (rad)	Row GSD (LOS-normal) (m)	Column GSD (LOS-normal) (m)	Azimuth angle of imaging locus (rad)	Elevation angle of imaging locus (rad)	Nominal sensor height (m)	Nominal range (m)	Row IFOV (per pixel) (mrad)	Column IFOV (per pixel) (mrad)	Row FOV (full image) (rad)	Column FOV (full image) (rad)
1	'1_6'	7776	7712	214	-3.068	0.073	0.115	0.115	-1.932	1.57	800	586	0.196	0.196	1.525	1.512
2	'1_7'	7840	7776	211	-3.075	0.067	0.115	0.115	-2.35	1.568	800	589	0.196	0.196	1.537	1.524
3	'1_8'	7904	7840	204	-3.075	0.067	0.116	0.116	-2.349	1.568	800	596	0.196	0.196	1.55	1.537
4	'1_9'	7840	7776	196	-3.061	0.081	0.118	0.118	-2.329	1.567	800	604	0.196	0.196	1.537	1.524
5	'2_4'	7840	7776	198	-3.06	0.082	0.118	0.118	-2.344	1.568	800	602	0.196	0.196	1.537	1.524
6	'2_5'	7776	7712	204	-3.068	0.074	0.116	0.116	-2.12	1.57	800	596	0.196	0.196	1.525	1.512
7	'2_6'	7872	7808	205	-3.081	0.061	0.116	0.116	-2.11	1.57	800	595	0.196	0.196	1.543	1.531
8	'2_7'	7840	7776	205	-3.059	0.083	0.116	0.116	-2.345	1.569	800	595	0.196	0.196	1.537	1.524
9	'3_5'	7776	7712	226	-3.068	0.073	0.112	0.112	-2.252	1.57	800	574	0.196	0.196	1.524	1.512
10	'3_6'	7840	7776	222	-3.059	0.083	0.113	0.113	-2.345	1.569	800	578	0.196	0.196	1.537	1.525
11	'3_7'	7840	7776	217	-3.074	0.067	0.114	0.114	-2.307	1.567	800	583	0.196	0.196	1.537	1.525
12	'3_8'	7936	7872	213	-3.048	0.093	0.115	0.115	-2.346	1.567	800	587	0.196	0.196	1.556	1.543

More extensive details for RSM performance on a per ground point basis can also be found in reference [4].

A.2 Nadir Triangulation Results Using Modified *A Priori* Support Data

Extensive details for RSM performance on a per ground point basis can also be found in reference [4].

A.3 Oblique Triangulation Results Using Simulated Support Data

Table C11: Oblique Imaging Geometry Detail

Image	Image ID	Number of rows	Number of columns	Ground reference height (m)	Image azimuth angle of north (rad)	Image azimuth angle of up (rad)	Row GSD (LOS-normal) (m)	Column GSD (LOS-normal) (m)	Azimuth angle of imaging locus (rad)	Elevation angle of imaging locus (rad)	Nominal sensor height (m)	Nominal range (m)	Row IFOV (per pixel) (mrad)	Column IFOV (per pixel) (mrad)	Row FOV (full image) (rad)	Column FOV (full image) (rad)
1	'1_6'	7776	7712	214	0.126	-3.015	0.115	0.115	1.565	0.531	511	588	0.196	0.196	1.523	1.512
2	'1_7'	7840	7776	211	0.138	-3.003	0.119	0.119	1.563	0.528	517	609	0.196	0.196	1.535	1.524
3	'1_8'	7904	7840	204	0.144	-2.998	0.126	0.127	1.567	0.513	520	646	0.196	0.196	1.548	1.537
4	'1_9'	7840	7776	196	0.159	-2.982	0.125	0.125	1.569	0.501	502	637	0.196	0.196	1.535	1.524
5	'2_4'	7840	7776	198	0.162	-2.979	0.115	0.115	1.569	0.533	496	586	0.196	0.196	1.535	1.524
6	'2_5'	7776	7712	204	0.136	-3.005	0.112	0.112	1.573	0.532	493	572	0.196	0.196	1.523	1.512
7	'2_6'	7872	7808	205	0.112	-3.029	0.111	0.111	1.575	0.519	487	568	0.196	0.196	1.541	1.531
8	'2_7'	7840	7776	205	0.163	-2.979	0.112	0.112	1.568	0.528	492	569	0.196	0.196	1.535	1.524
9	'3_5'	7776	7712	226	-2.998	0.148	0.107	0.107	1.573	0.534	503	546	0.196	0.196	1.523	1.512
10	'3_6'	7840	7776	222	-2.988	0.153	0.114	0.114	1.576	0.534	518	581	0.196	0.196	1.535	1.525
11	'3_7'	7840	7776	217	-3.001	0.14	0.114	0.114	1.582	0.529	510	581	0.196	0.196	1.535	1.525
12	'3_8'	7936	7872	213	-2.992	0.15	0.117	0.118	1.576	0.524	513	600	0.196	0.196	1.554	1.543

More extensive details for RSM performance on a per ground point basis can also be found in reference [4].

Appendix D

RSM Compliance Testing

RSM EXPLOITER

The RSM was originally developed at BAE Systems, Mission Solutions, San Diego, California. In particular, a specific RSM exploiter, referred to as the RSM Exploiter, has been developed by BAE Systems for the NGA. Under NGA's supervision, the software module's executables and API documentation are to be provided with no license fee to US government agencies and their contractors for Government Use Only. All sensor model functionality associated with the RSM exploiter interface list (section 3.1), including all options, are supported by the RSM Exploiter.

The RSM exploiter interface list also forms a basis for the compliance testing of an RSM exploiter, such as a program's integration of the RSM Exploiter.

Compliance testing of an RSM exploiter is performed by the JITC and based on an RSM Gold Standard. The standard contains a number of RSM TRE Sets, and an interface correspondence table (file) for each set. A table entry consists of a specific interface request and the corresponding correct response and acceptance tolerance. Every applicable interface request, corresponding to both required and optional interface capabilities, is in the RSM Gold Standard for a particular RSM TRE Set. (However, compliance testing of an optional interface capability is not performed/required when an RSM exploiter's design does not support the optional interface capability.) Also, all possible ground coordinate system representations (geodetic, WGS 84 rectangular, and RSM primary ground coordinate system) are included in the interface correspondence table.

Note that compliance testing is applicable to different compliance levels, defined by which RSM TREs, including associated functionality, are supported by an RSM exploiter. Any combination of TREs can be used to specify a particular compliance level with the following qualifications:

1. RSMID is always included and not listed.
2. RSMPC or RSMGG must be included.
3. If RSMPI is included then so must RSMPC.
4. If RSMGI is included then so must RSMGG.

For example:

1. If an RSMPC compliance level is specified, an unadjustable, single section, polynomial ground-to-image function is supported;

2. If an RSMPC/RSMDC compliance level is specified, an unadjustable, single section, polynomial ground-to-image function with direct error covariance is supported;
3. If an RSMPI/RSMPC/RSMEC compliance level is specified, an unadjustable, multi-section, polynomial ground-to-image function with indirect error covariance is supported;
4. If RSMAP/RSMPI/RSMPC/RSMGI/RSMGG/RSMDC is specified, an adjustable, multi-section, polynomial and/or grid ground-to-image function with direct error covariance is supported;
5. If RSMAP/RSMPI/RSMPC/RSMGI/RSMGG/RSMDC/RSMEC is specified, all RSM functionality is supported.

Note that when an RSM exploiter is specified as supporting a particular RSM TRE, all optional data (and corresponding required interface capability) in that TRE is assumed supported as well. If it is known that the RSM exploiter is not required to support some of the optional data in that TRE (e.g., the optional trajectory model data in the RSMID TRE), specification of support can be made accordingly. The RSM Exploiter supports all RSM TREs, including optional data.

Compliance testing also includes testing of the corresponding application program's ability to correctly parse (and utilize) an RSM TRE Set from a NITF image segment in a NITF file. (Of course, the application program utilizes the integrated RSM exploiter as well.) Depending on the compliance level under test, parsing may include multiple image segments, multiple RSM TRE Sets, and multiple NITF files.

RSM GENERATOR

An RSM TRE Set is built by an RSM generator software module using the appropriate original sensor models and corresponding image support data. An RSM generator is typically controlled by an application that supplies the appropriate original sensor model functionality and support data to the generator and places the generated RSM TRE Set into a NITF file. This process, or a higher-level process, then disseminates the NITF file to the intended user community.

A specific RSM generator, referred to as the RSM Generator, has been developed by BAE Systems for the NGA. Under NGA's supervision, the software module's executables and API documentation are to be provided with no license fee to US government agencies and their contractors for Government Use Only. The RSM Generator generates an applicable RSM TRE Set using the original sensor models and their image support data. This can be done for any sensor model supported through the API by an application program.

Similar to compliance testing of an RSM exploiter, compliance testing of an RSM generator is performed by the JITC and is applicable to a designated compliance level corresponding to which particular RSM TREs an RSM generator can generate. If need be, the designated level can be further specified to a particular set of sensors.

Compliance testing of an RSM generator is more difficult than for an RSM exploiter. Ideally, compliance testing ensures that generated RSM TRE Sets support all appropriate levels of image exploitation in a manner virtually equivalent to that support provided by the corresponding original sensor models and image support data. In particular, at the highest levels of compliance, multi-target and multi-image optimal geopositioning solutions and triangulation solutions based on RSM TRE Sets are virtually identical to corresponding (hypothetical) solutions based on the original sensor models and support data from which the RSM TRE Sets were generated. Solutions consist of target (or tie point) locations, their relative locations, and their predicted absolute and relative accuracies (error propagation). Solutions based on RSM require an application with a properly integrated RSM exploiter in addition to the imagery and generated RSM TRE Sets provided in the NITF file(s).

Regardless of the fidelity of RSM generator compliance testing , as a minimum it must always include verification that all generated RSM TREs are consistent with their specified structure, size, field data types and value ranges as specified in this specification. Section 4.2.1 of this specification discusses verification checks in more detail. In addition, the appropriate placement of an RSM TRE Set by the application within the image segment(s) of an NITF file must also be verified.

Note that a properly integrated RSM Generator is at the highest level of compliance.