Replacement Sensor Model Tagged Record Extensions Specification for NITF 2.1

draft

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Prepared for the NGA

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ACRONYMS

API	Application Program Interface
EO	Electro-Optical
JITC	Joint Interoperability Test Command
NGA	National Geospatial-Intelligence Agency
NITF	National Imagery Transmission Format
RSM	Replacement Sensor Model
SAR	Synthetic Aperture Radar
TRE	Tagged Record Extension
US	United States

1.0 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.

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.

The white paper, “Replacement Sensor Models”, J Dolloff, 3/05/04, an invited submittal to the 2004 Manual of Photogrammetry, provides a detailed description of the RSM. The various components making up the RSM, their application, and their generation are described. RSM performance and a top level summary of RSM image support data are also presented. The white paper is included as appendix C of this specification.

1.1 Overview of the RSM TREs

The 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. The following table contains a summary of the eight RSM TREs.

RSM TRE #	Abbreviation	Name	Contents
1	RSMIDA	RSM Identification	Id's, 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	RSM Direct Error Covariance	RSM multi-image direct error covariance
5	RSMAPA	RSM Adjustable Parameters	RSM adjustable parameters
6	RSMECA	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

An RSMIDA TRE is always included in an image's RSM support data. An RSM ground-to-image function is also included, either in RSMPIA and RSMPCA TREs (polynomial), or RSMGIA and RSMGGA TREs (grid), or both. The RSMAPA TRE is only included when the RSM adjustable parameter values are non-zero, i.e., RSM adjusted support data. The RSM image support data error covariance is optional. If supplied, it is the direct form contained in the RSMDCA TRE and/or the indirect form contained in the RSMECA TRE.

For a given image, there may be more than one RSMPCA TRE and more than one RSMGGA TRE provided, corresponding to multiple image sections. If only one RSMPCA TRE is provided (one section), the RSMPIA TRE is optional. If only one RSMGGA TRE is provided (one section), the RSMGIA 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.)

2.0 RSM TRE placement in an 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 overflow area, if necessary. Alternatively, the entire set of RSM TREs may be placed directly into the overflow area. In addition, for this alternative, if the same set of RSM TREs is also applicable to more than one image segment in the NITF file, only one 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 RSMIDA 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 RSMIDA 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 RSMPIA and RSMGIA 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 can not 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, regardless the amount of space available in the 200k byte 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 RSMIDA, one RSMPCA, and either one relatively small RSMDCA or one RSMECA TRE. This RSM TRE Set is typically less than 10k bytes in size, and can usually be placed entirely in the image subheader, if so desired. 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 RSMAPA TRE. Typically, a direct error covariance is also generated and placed into an RSMDCA TRE.

The updated RSM TRE Set is identical to the initial RSM TRE Set with the following exceptions: (1) it includes the new RSMAPA and RSMDCA TREs, (2) if the initial RSM TRE Set contained a previous RSMDCA or RSMECA 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 follows. An image is 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. 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.

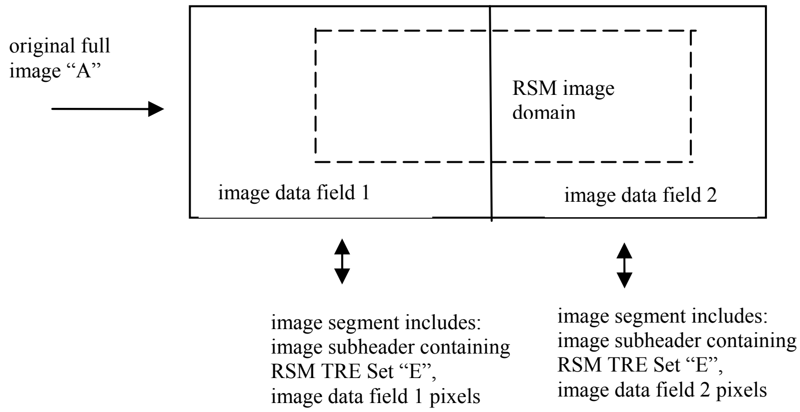
For the remainder of this specification, the term “associated image” is defined as that unique image containing a particular RSM TRE Set.

Note that there may exist multiple images associated with the same original full image, but 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.

(Note that 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.)

(Note that 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 RSMDCA, RSMAPA, and RSMECA TREs is used for identification.)

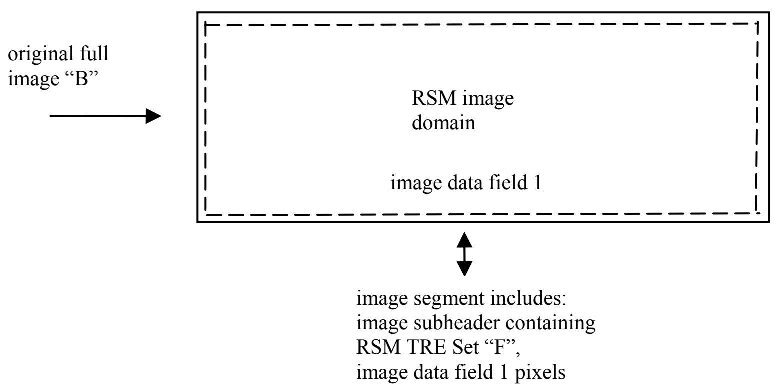
Figure 1 below illustrates many of the concepts discussed above associated with RSM TRE Sets and multiple images. For ease of illustration, an image data field is assumed to be a direct subset of the original full image.



RSM TRE Set “E” includes multiple TRE’s, all specifying: original full image “A”, edition “J”

RSM applicable over RSM image domain, specified in RSMIDA TRE

image “A/E” consists of image “A” pixels and image support data contained in RSM TRE Set “E”. (Note that no actual TRE field actually specifies the value “A/E”.)

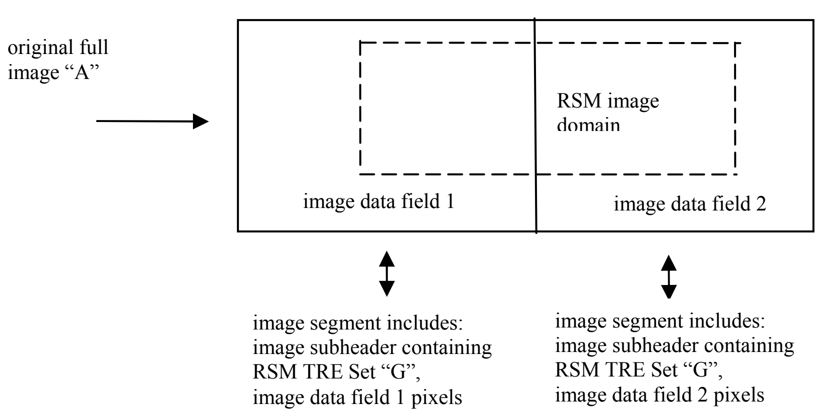


RSM TRE Set “F” includes multiple TRE’s all specifying: original full image “B”, edition “K”

RSM applicable over RSM image domain specified in RSMIDA TRE

image “B/F” consists of image “B” pixels and image support data contained in RSM TRE Set “F”

Original full image “A” RSM support data is then adjusted via a triangulation, resulting in:



RSM TRE Set “G” includes multiple TRE’s all specifying: original full image “A”, edition “L”

RSM applicable over RSM image domain specified in RSMIDA TRE

image “A/G” consists of image “A” pixels and image support data contained in RSM TRE Set “G”

Subsequent image exploitation allowed for image combinations: “A/E” or “B/F” or “A/G” or “A/E” and “B/F” or “B/F” and “A/G”, but not “A/E” and “A/G”.

Figure 1: RSM TRE Sets and multiple images

3.0 RSM TRE development status

All eight RSM TREs are reasonably mature, and have been explicitly generated and tested for multiple sensors, including various combinations of space-borne, air-borne, EO, SAR, scanning, and frame sensors.

4.0 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 (s/w) module. The RSM exploiter provides requested sensor model functionality through an input/output (i/o) interface. The requests are from an application program, which may 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 an 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.

4.1 RSM exploiter i/o list

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

RSM exploiter i/o list

Required i/o 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 RSMPCA and (optional) RSMPIA TRE if the RSM ground-to-image function is a (rational) polynomial. EXP utilizes an RSMGGA and (optional) RSMGIA 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 RSMAPA TRE in order to compute image row/column from an RSM adjusted ground-to-image function.

The RSMIDA 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 RSMAPA TRE is not part of the basic ground-to-image set, either the RSMDCA TRE or RSMECA 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 RSMDCA 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 RSMECA 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 RSMECA 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 RSMIDA 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 RSMIDA TRE.

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

EXP utilizes the RSMIDA TRE.

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

EXP utilizes optional data within the RSMIDA TRE.

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

EXP utilizes optional data within the RSMIDA TRE.

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

EXP utilizes optional data within the RSMIDA TRE.

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

EXP utilizes RSMIDA TRE.

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

EXP utilizes the RSMIDA TRE.

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

EXP utilizes the RSMDCA or RSMAPA or RSMECA TREs, if available, and in that order of priority.

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

EXP utilizes RSMIDA 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 RSMIDA 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 RSMIDA 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 RSMPIA and optional data in all RSMPCA TREs, if available.

EXP utilizes the RSMGIA and optional data in all RSMGGA TREs, if available.

<u>Optional i/o 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 RSMAPA TRE, if present

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

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(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 RSMDCA TRE, and if not present, the RSMECA 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 RSMDCA TRE, or if not present, the RSMECA 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 RSMDCA 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 RSMECA 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 RSMECA TRE for each of the requested images, i.e., more than one RSM TRE Set may be required.

Comments

Note that information via the optional i/o capability is also inherent via the (default) required i/o capability – just not as convenient.

Note that 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.

5.0 RSM compliance testing

5.1 RSM exploiter

The RSM was originally developed at BAE Systems, Mission Solutions, San Diego, California. In particular, a specific RSM exploiter, termed the "RSM Exploiter", has been developed by BAE Systems for the NGA. Under NGA's supervision, the s/w 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 i/o list (section 4.1), including all options, are supported by the RSM Exploiter.

The RSM exploiter i/o 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 i/o correspondence table (file) for each set. A table entry consists of a specific i/o request and the corresponding correct response and acceptance tolerance. Every applicable i/o request, corresponding to both required and optional i/o capabilities, is in the RSM Gold Standard for a particular RSM TRE Set. (However, compliance testing of an optional i/o capability is not performed/required when an RSM exploiter's design does not support the optional i/o capability.) Also, all possible ground coordinate system representations (geodetic, WGS 84 rectangular, and RSM primary ground coordinate system) are included in the i/o 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) RSMIDA is always included and not listed.
(2) RSMPCA or RSMGGA must be included.
(3) If RSMPIA is included then so must RSMPCA.
(4) If RSMGIA is included then so must RSMGGA.

For example:

(1) If an RSMPCA compliance level is specified, an unadjustable, single section, polynomial ground-to-image function is supported;
(2) If an RSMPCA/RSMDCA compliance level is specified, an unadjustable, single section, polynomial ground-to-image function with direct error covariance is supported;
(3) If an RSMPIA/RSMPCA/RSMECA compliance level is specified, an unadjustable, multi-section, polynomial ground-to-image function with indirect error covariance is supported;
(4) If RSMAPA/RSMPIA/RSMPCA/RSMGIA/RSMGGA/RSMDCA is specified, an adjustable, multi-section, polynomial and/or grid ground-to-image function with direct error covariance is supported;
(5) If RSMAPA/RSMPIA/RSMPCA/RSMGIA/RSMGGA/RSMDCA/RSMECA 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 i/o capability) in that TRE is assumed supported as well. If it is known a priori 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 RSMIDA TRE), specification of support can be caveat 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 an NITF image segment in an 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.

5.2 RSM generator

An RSM TRE Set is built by an "RSM generator" s/w module using the appropriate original sensor models and corresponding image support data. An RSM generator is typically controlled by an application program that supplies the appropriate original sensor model functionality and support data to the generator, and places the generated RSM TRE Set into an NITF file. This process or a higher-level process then disseminates the NITF file to the intended user community.

A specific RSM generator, termed the “RSM Generator”, has been developed by BAE Systems for the NGA. Under NGA’s supervision, the s/w 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 automatically generates an applicable RSM TRE Set using the original sensor models and their image support data. This is done for any and all sensors (sensor models) 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 caveat 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 program with a properly integrated RSM exploiter, in addition to the imagery and generated RSM TRE Sets provided in the NITF file(s).

Regardless 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 6.2.1 of this specification discusses verification checks in more detail. In addition, the appropriate placement of an RSM TRE Set by the application program (with integrated RSM generator) 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.

6.0 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 which 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 RSMIDA 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 RSMDCA, RSMAPA, and RSMECA 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.

6.1 Appendices

This specification’s introduction and the following RSM TRE descriptions contain all the information required in order to exercise all associated sensor model functionality. However, appendices are also included in order to facilitate “mapping” that information to actual equations and algorithms. In particular:

Appendix A details recommended methods to interpolate an RSM ground point-image point correspondence grid contained in the RSMGGA TRE. An algorithm to compute the corresponding derivative of the interpolated image point with respect to the ground point is also included.

Appendix B details the computation of all relevant partial derivatives. Both the partial derivatives of image measurements with respect to the RSM adjustable parameters and the partial derivatives of image measurements with respect to ground position are presented. Both are required in support of optimal geopositioning and triangulation solutions, including reliable error propagation or solution accuracy predictions. In addition, detailed descriptions of all RSM adjustable parameters and ground coordinate system transformations are provided.

Appendix C contains the white paper “Replacement Sensor Models”. Definitions of all major RSM components are included. For example:

(1) ground-to-image function (polynomial and/or grid),
(2) image (and height)-to-ground function, an iterative inverse of the ground-to-image function,
(3) adjustable parameters,
(3) adjustable ground-to-image function,
(4) adjustable image (and height)-to-ground function,
(5) support data error covariance (direct, indirect, unmodeled).

Detailed algorithms for the generation of RSM image support data, as well as detailed algorithms for optimal exploitation of same, are included. For example, generation of a ground-to-image polynomial, a direct error covariance, and an indirect error covariance are detailed. Optimal multi-target, multi-image geopositioning solutions and triangulation solutions using RSM are also detailed.

6.2 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.

In addition, the entry “± 9.99999999999999E+99” in the “Estimated Value Range” column specifies a scientific notation representation for the field’s value in BCS-A. Thus, for example, the value -100.1 would be represented as “-1.00100000000000E+02”, and .00023 would be represented as “+2.30000000000000E-04”.

6.2.1 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 using scientific notation is extremely large; hence, in most cases, quantification of the range is not provided other than it is a scientific representation. When it is provided, it is listed immediately under the “± 9.99999999999999E+99” entry. This additional information typically specifies whether the value is positive or non-negative, less than or equal to one, etc.

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 RSMECA TRE description). If so stated in the “Estimate 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 RSMIDA 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 RSMDCA, RSMAPA, or RSMECA TREs in the RSM TRE Set.

Finally, 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 RSMIDA TRE is included (in the RSM TRE Set)
(2) at least one RSMPCA TRE or at least one RSMGGA is included
(3) if more that one RSMPCA TRE is included, an RSMPIA TRE is also included
(4) if more that one RSMGGA TRE is included, an RSMGIA TRE is also included
(5) the number of RSMPCA TREs included is in conformance with the number specified within the RSMPIA TRE, if included
(6) the number of RSMGGA TREs is in conformance with the number specified within the RSMGIA TRE, if included
(7) no more than one RSMDCA is included
(8) no more than one RSMAPA is included
(9) no more than one RSMECA is included

7.0 RSM Identification (RSMIDA) TRE

7.1 Overview

The Replacement Sensor Model (RSM) Identification TRE (RSMIDA) 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.

7.2 Time-of-image model

The time information that is provided by the RSMIDA 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 (RSMECA TRE) can not be used with this image in conjunction with other images from the same sensor, as the time interval between two of these images can not be determined.

7.3 RSM ground coordinate system

The RSMIDA 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.

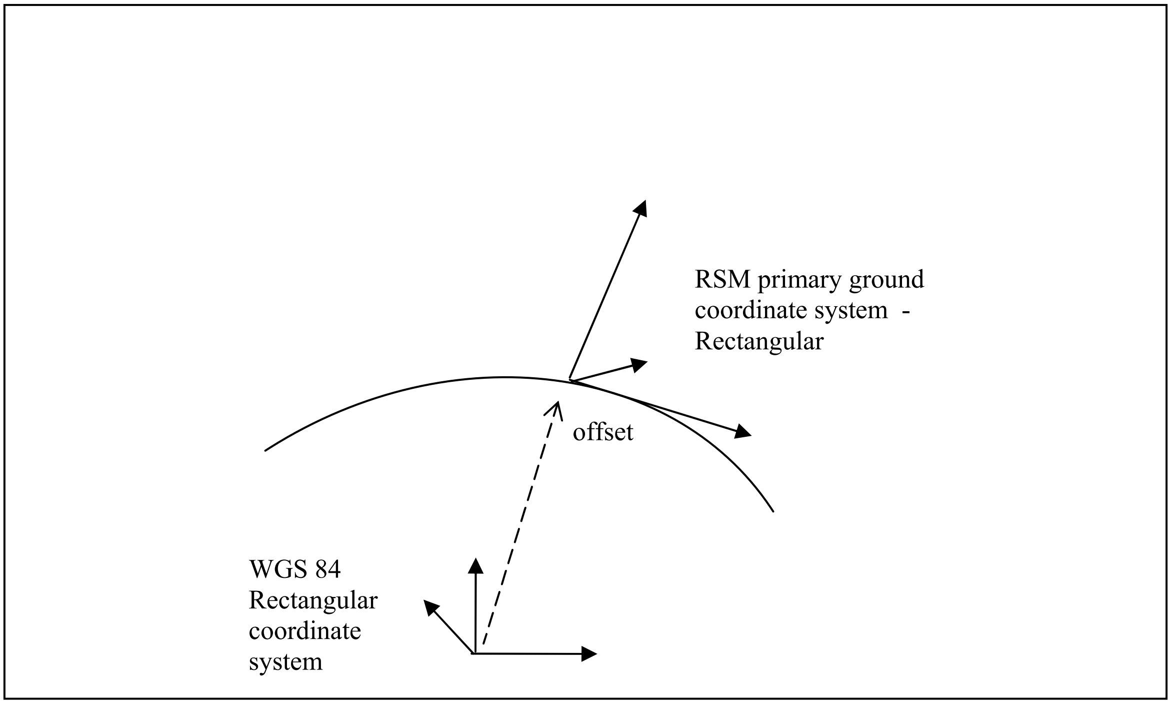

Figure 2: Example of RSM primary ground coordinate system - Rectangular

7.4 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 $(R,C)=(5,8)$.

7.5 RSM image domain

The RSMIDA 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.

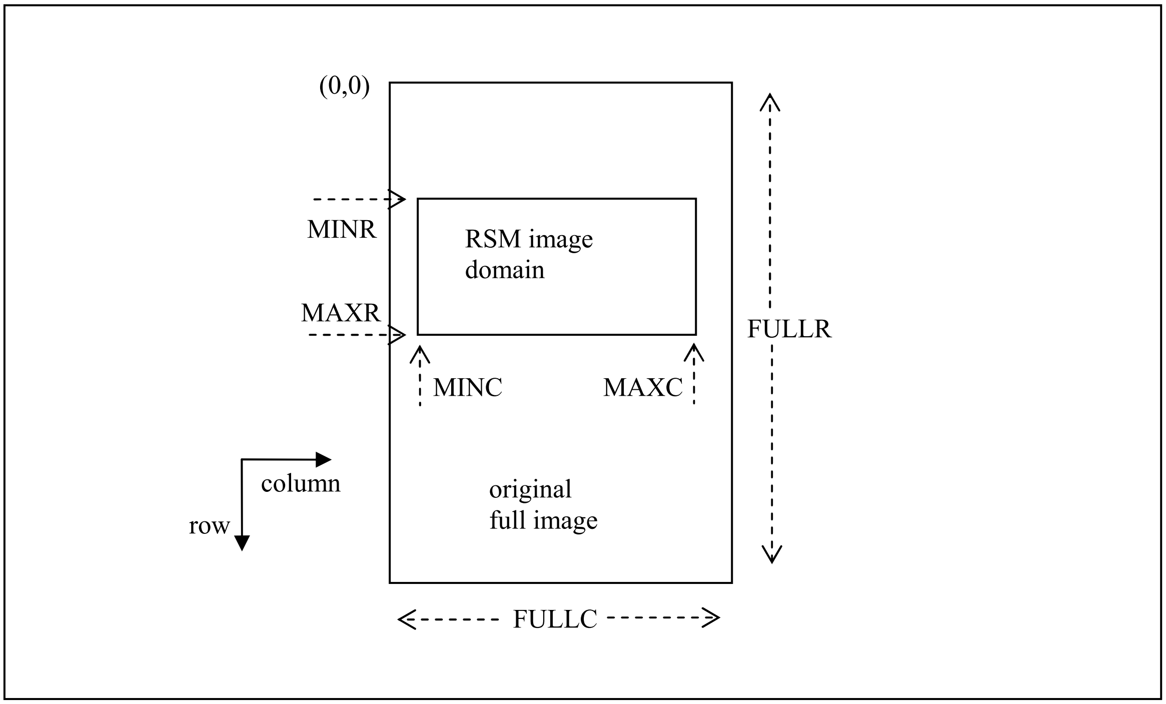

Figure 3: RSM image domain

7.6 RSM Ground domain

The RSMIDA 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.

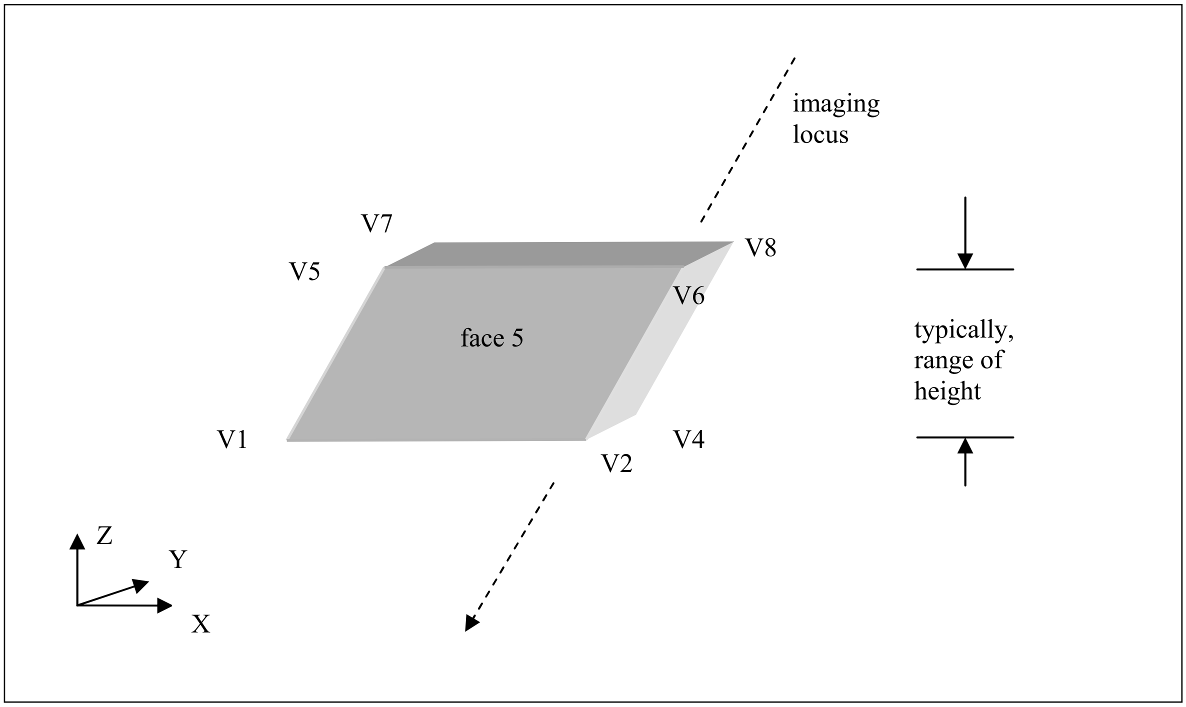

Figure 4: RSM ground domain

Each of the six faces is a plane quadrilateral defined by four vertices in counter-clockwise order as viewed from outside the solid: (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 needs to be performed only infrequently during an exploitation process, either when X corresponds to an inaccurate a priori estimate of a ground point that is to correspond to an image point within the RSM image domain, or 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.

7.7 Illumination model

Optional illumination information is provided by the RSMIDA 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 are defined in a local rectangular coordinate system that is tangent to the geodetic surface of constant height at the ground coordinate that corresponds to the image coordinates and 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:

$$\varphi = IE0 + IER \cdot r + IEC \cdot c + IERR \cdot r^2 + IERC \cdot r \cdot c + IECC \cdot c^2$$

$$\lambda = IA0 + IAR \cdot r + IAC \cdot c + IARR \cdot r^2 + IARC \cdot r \cdot c + IACC \cdot c^2$$

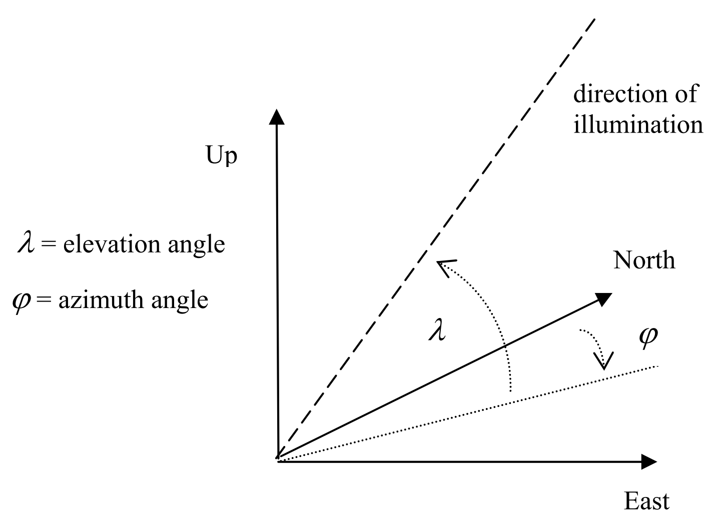

Figure 5: Illumination angles

7.8 Trajectory model

An optional sensor (platform) trajectory model is also provided by the RSMIDA 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.

7.9 RSMIDA format

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

RSMIDA – Replacement Sensor Model Identification						
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	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 to 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 uniquely identifies the sensor used to acquire the associated image.	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 sensor capabilities available in the sensor used to acquire the associated image. The sensor type identifier includes identification of sensor make and model. Any two sensors that have the same features and capabilities will have the same sensor type.	40	BCS-A	N/A	N/A Population optional 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99	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	±9.99999999999999E+99	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	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	±9.99999999999999E+99	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	±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	±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	±9.99999999999999E+99	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	±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	±9.99999999999999E+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	±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	±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	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	±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	±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	±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	±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	+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	+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	+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	+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). The elevation angle is defined to be in the range (-pi/2 to pi/2) radians. 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/Grazing 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). The azimuth angle is typically in the range (0 to 2pi) radians. However, it can exceed this range to ensure continuity of the azimuth angle over the RSM image domain when the azimuth is near 2pi radians. The user should check the azimuth value (polynomial output) and add +/- 2pi if necessary to place into the range (0 to 2pi).	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	±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 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 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	±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 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 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

8.0 RSM Polynomial Identification (RSMPIA) TRE

8.1 Overview

The Replacement Sensor Model Polynomial Identification TRE (RSMPIA) 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 (RSMPCA). Most images require only one section.

8.2 Low order polynomial

A low order numerator-only polynomial provided in this TRE (RSMPIA) 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 $X = \begin{bmatrix} x & y & z \end{bmatrix}^T$ within the RSM ground domain as follows:

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

8.3 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 RSMPCA TREs. The RSM image domain is defined by the fields MINR, MAXR, MINC, and MAXC that are provided in the RSMIDA TRE. (See Figure 6.)

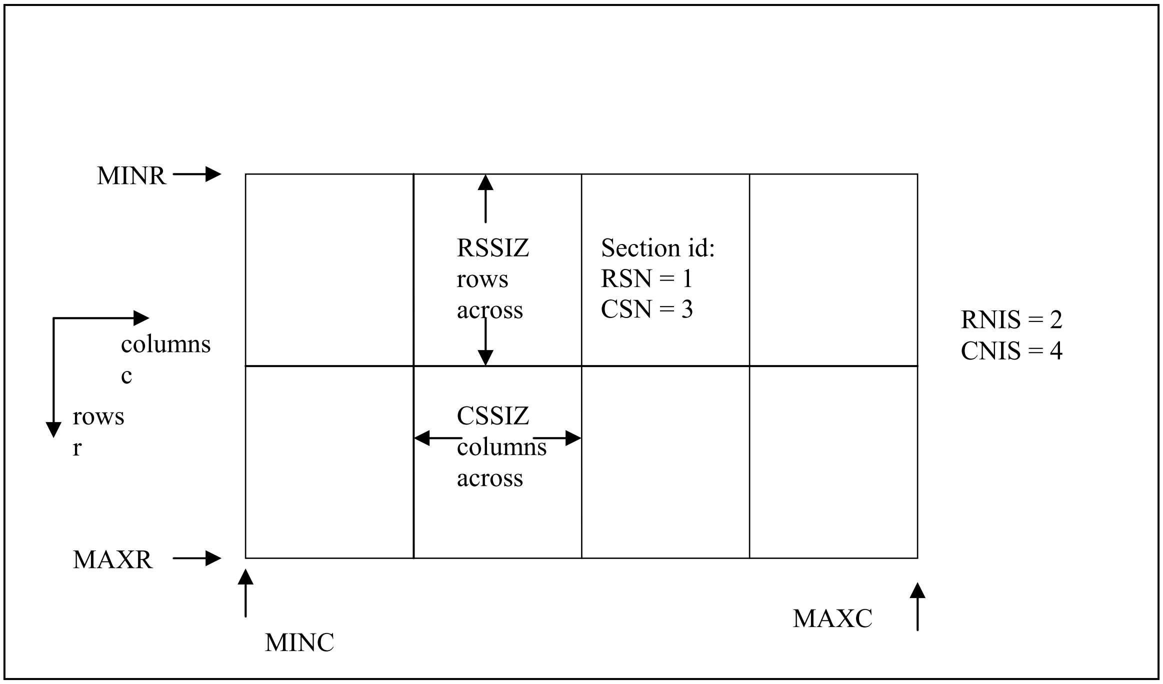

Figure 6: Sectioning of the RSM image domain for polynomials

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 RSMAPA 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 (RSMPIA) is always provided with the associated image. If there is only one section, the inclusion of this TRE is optional.

8.4 RSMPIA format

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

RSMPIA – Replacement Sensor Model Polynomial Identification						
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	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 to 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 RSMPCA 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	±9.9999999999999E+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	±9.9999999999999E+99 Positive value	R

Table 3: RSMPIA TRE format table

9.0 RSM Polynomial Coefficients (RSMPCA) TRE

9.1 Overview

The Replacement Sensor Model Polynomial Coefficients TRE (RSMPCA) 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.

9.2 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 RSMPCA TRE (image section within the RSM image domain). Their values are such that a normalized coordinate is within the approximate range of values $[-1, 1]$.

9.3 TRE size and number of TREs

As detailed in the description for field CEL, the size of one RSMPCA TRE is less than or equal to 18546 bytes, and typically 5778 bytes in size. However, if multiple RSMPCA TREs are required, corresponding to multiple image sections as specified in the RSMPIA 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.

9.4 RSMPCA format

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

RSMPCA – Replacement Sensor Model Polynomial Coefficients						
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	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 to 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	±9.99999999999999E+99 Non-negative value Population 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	+9.99999999999999E+99 Non-negative value Population 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	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	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	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	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	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	±9.9999999999999E+99	R
…End for each column denominator polynomial term						

Table 4: RSMPCA TRE format table

10.0 RSM Direct Error Covariance (RSMDCA) TRE

10.1 Overview

The Replacement Sensor Model Direct Error Covariance TRE (RSMDCA) provides the RSM direct error covariance. The 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. (The 36 potential adjustable parameters correspond to the RSM Adjustable Parameter Choice Set.) The 20 contiguous fields (IRO through ICZZ) correspond to RSM "image space" adjustable parameters, and the 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

10.2 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.

10.3 Adjustable parameter definitions in support of the direct error covariance

10.3.1 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.)

10.3.2 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.

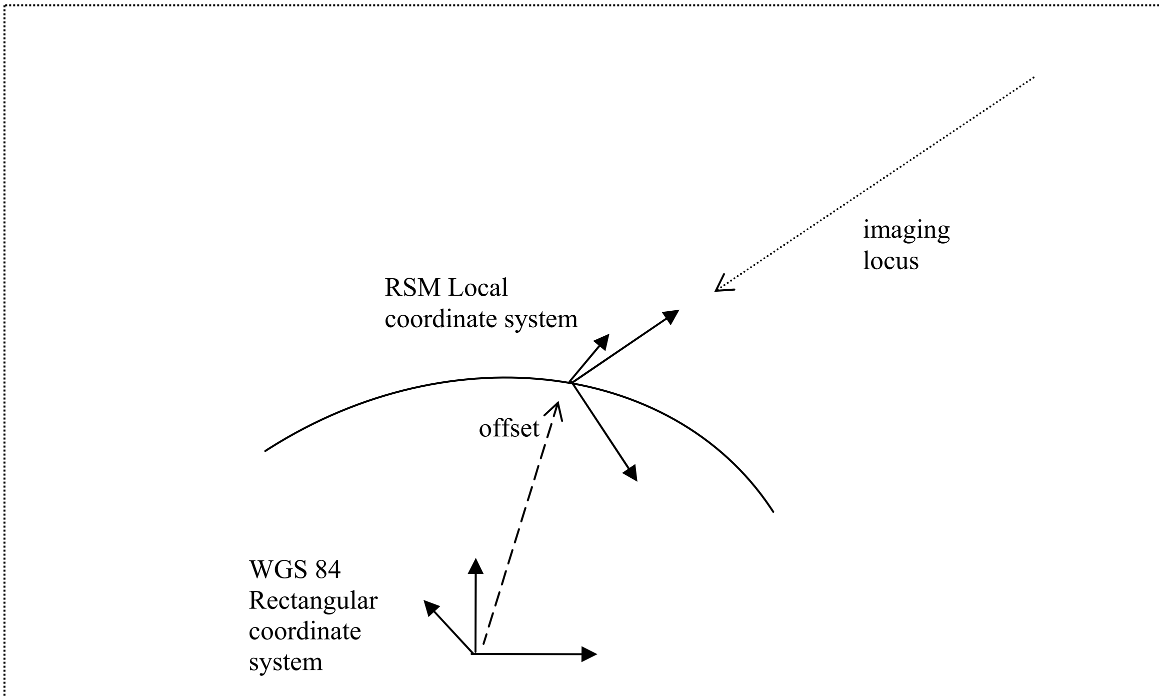

Figure 7: Example of RSM Local coordinate system

10.3.3 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 $I = \begin{bmatrix} r & c \end{bmatrix}^T$ corresponding to a three-dimensional ground point $X = \begin{bmatrix} x & y & z \end{bmatrix}^T$ input. The summed effects $\Delta I = \begin{bmatrix} \Delta r & \Delta c \end{bmatrix}^T$ 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 $\Delta X = \begin{bmatrix} \Delta x & \Delta y & \Delta z \end{bmatrix}^T$ 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 $(i + j + k) \le 2$. 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 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 RSMPCA TRE and RSMGGA 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.

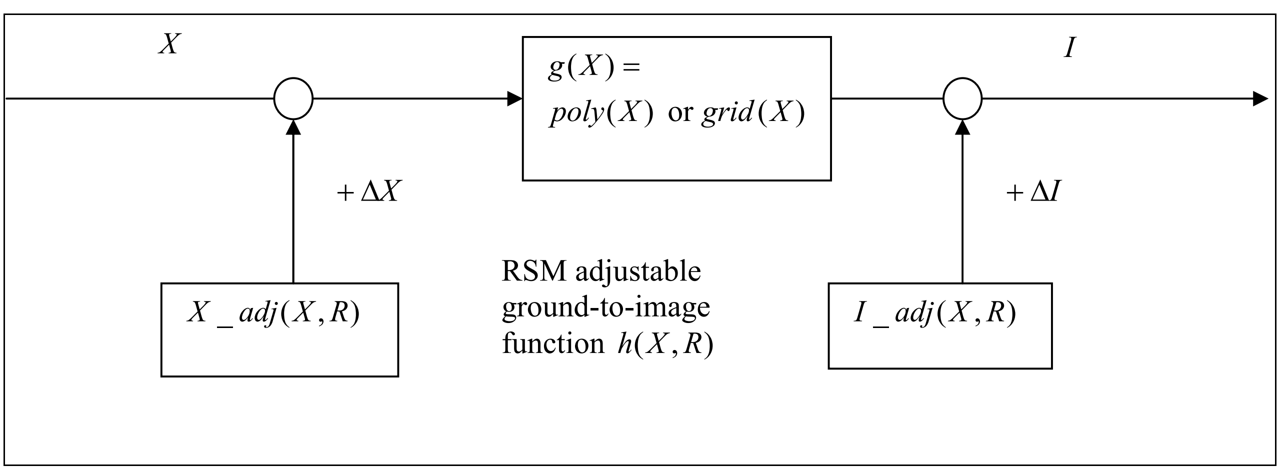

Figure 8: RSM adjustable ground-to-image function

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 RSMPCA TRE and the RSMGGA 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.

10.3.4 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.

10.4 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.

10.5 Summary

In 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).

10.6 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**	**Estimated 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 to 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 99999	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	±9.99999999999999E±99 Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R

XUYL	<u>Local Coordinate Unit Vector (XUYL).</u> 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	±9.99999999999999E±99 Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
XUZL	<u>Local Coordinate Unit Vector (XUZL).</u> 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	±9.99999999999999E±99 Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUXL	<u>Local Coordinate Unit Vector (YUXL).</u> 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	±9.99999999999999E±99 Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUYL	<u>Local Coordinate Unit Vector (YUYL).</u> 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	±9.99999999999999E±99 Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
YUZL	<u>Local Coordinate Unit Vector (YUZL).</u> 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	±9.99999999999999E±99 Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
ZUXL	<u>Local Coordinate Unit Vector (ZUXL).</u> 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	±9.99999999999999E±99 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	±9.99999999999999E±99 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	±9.99999999999999E±99 Value consistent with fields XUXL through ZUZL forming an orthogonal matrix	R
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 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>
IC0	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

11.0 RSM Adjustable Parameters (RSMAPA) TRE

11.1 Overview

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

11.2 Adjustable parameters

There are a total of 36 potentially active RSM adjustable parameters, 20 “image space” adjustable parameters and 16 “ground space” adjustable parameters. (The 36 potential adjustable parameters correspond to the RSM Adjustable Parameter Choice Set.) The contiguous fields IRO through GZZ correspond to these 36 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

11.2.1 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 9 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.

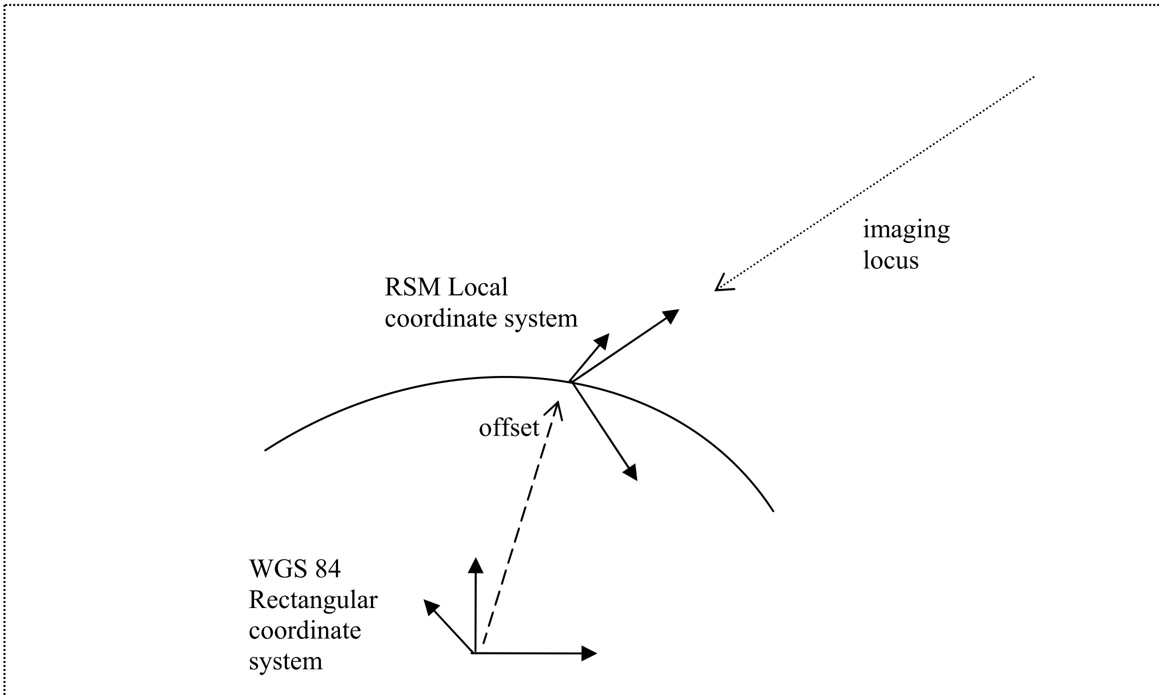

Figure 9: Example of RSM Local coordinate system

11.2.2 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. $I \rightarrow I + \Delta I$. 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 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: $r \rightarrow r + \Delta r$, 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 10. 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 RSMPCA TRE and RSMGGA 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.

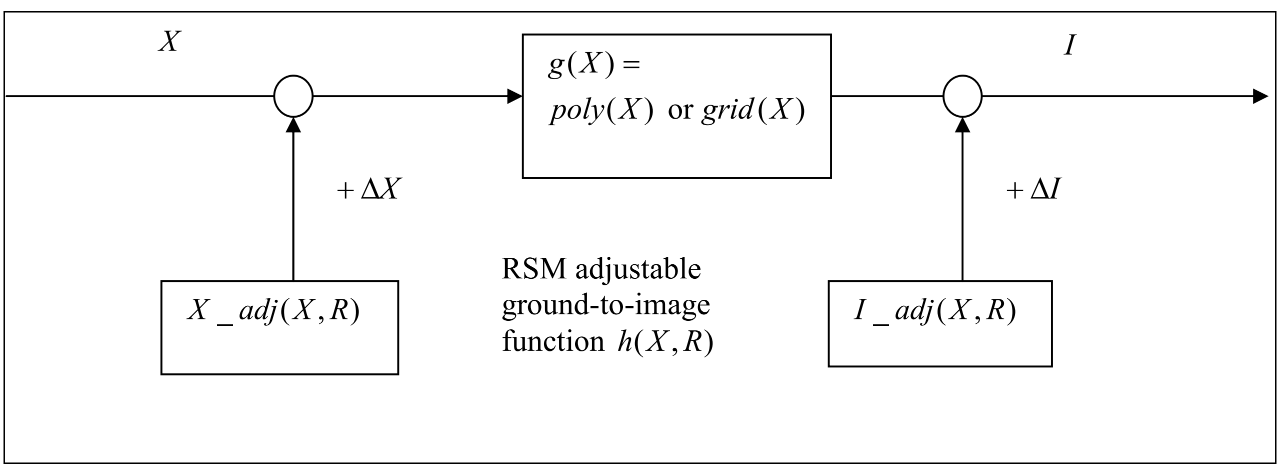

Figure 10: The RSM adjustable ground-to-image function

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 RSMPCA TRE and RSMGGA TRE.

11.2.3 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.

11.2.4 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, which ever 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.

11.3 RSMAPA format

Table 6 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**	**Estimated 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 to 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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>
IC0	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	±9.9999999999999E+99	R
…End for each component						

Table 6: RSMAPA TRE format table

12.0 RSM Indirect Error Covariance (RSMECA) TRE

12.1 Overview

The Replacement Sensor Model Error Covariance 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 RSMECA 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 11):

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

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 RSMIDA 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 $\rho(\tau) = 1.0$.)

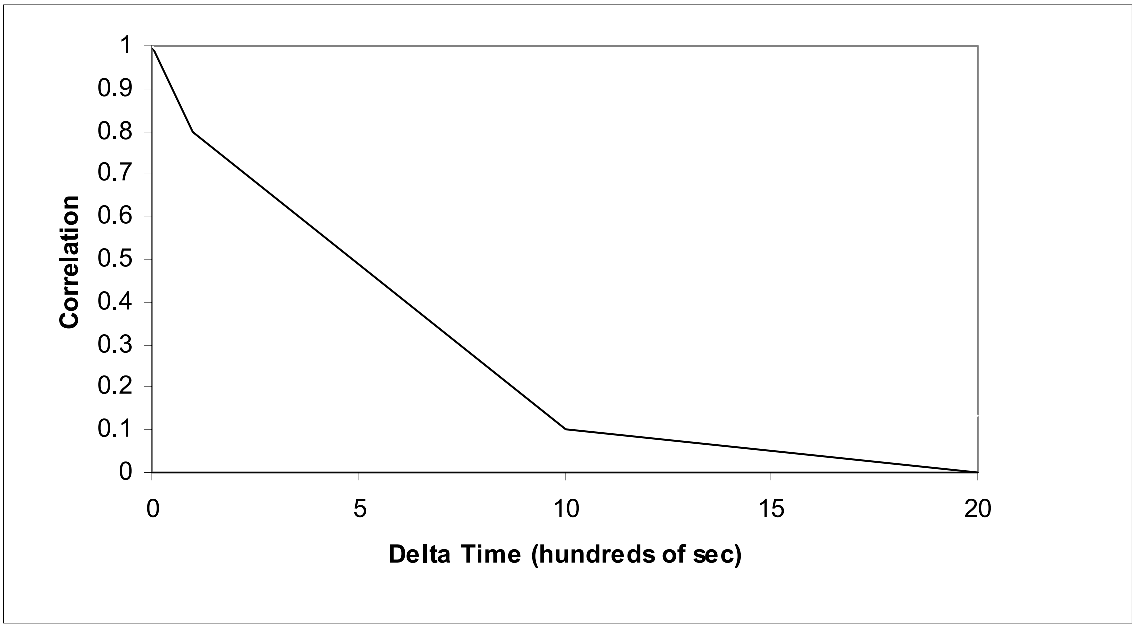

Figure 11: Example of piece-wise linear correlation function $\rho(\tau)$

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: $\rho_{Si*k}(\tau)C_{Si*k} \to \overline{\rho}_{Si*j*k}(\tau)C^{1/2}_{Si*k}C^{T/2}_{Sj*k}$. 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 $\overline{\rho}_{Si*j*k}(\tau)$ 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.,

$\overline{\rho}_{Si*j*k}(\tau) = (1/n_{r*})\sum_{r*}\rho_{Sr*k}(\tau)$, 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 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 $j*$.

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.

12.3.4 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 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 12 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.

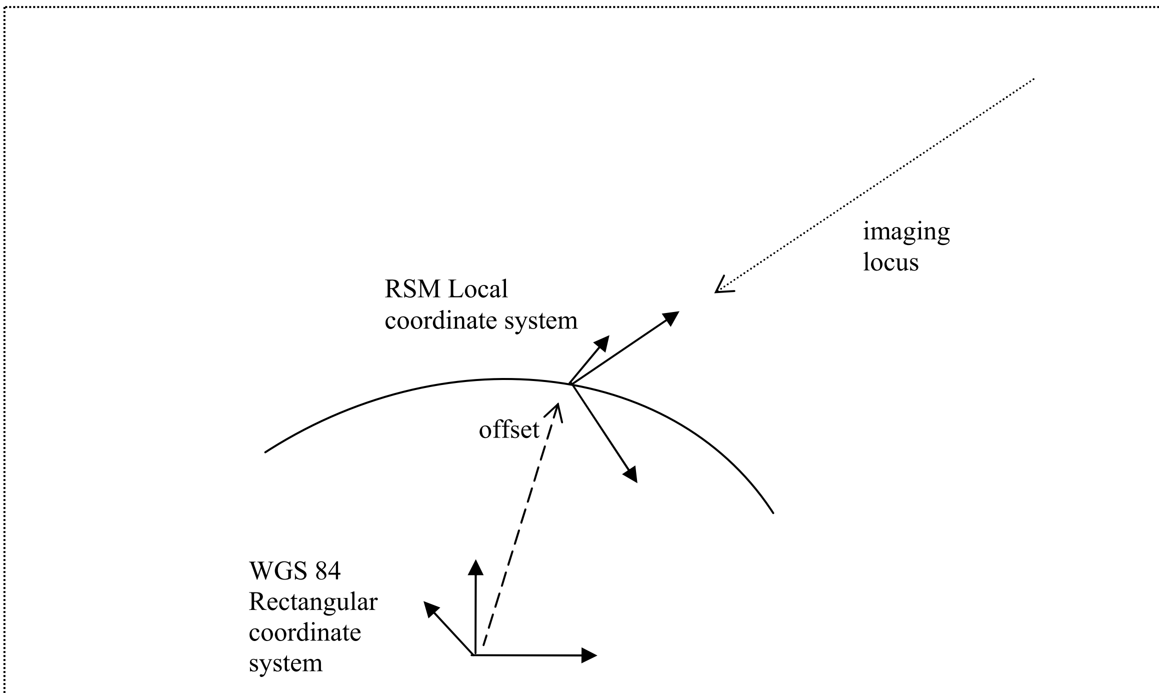

Figure 12: Example of RSM Local coordinate system

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. $I \to I + \Delta I$. 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 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 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 13. 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 RSMPCA TRE and RSMGGA 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.

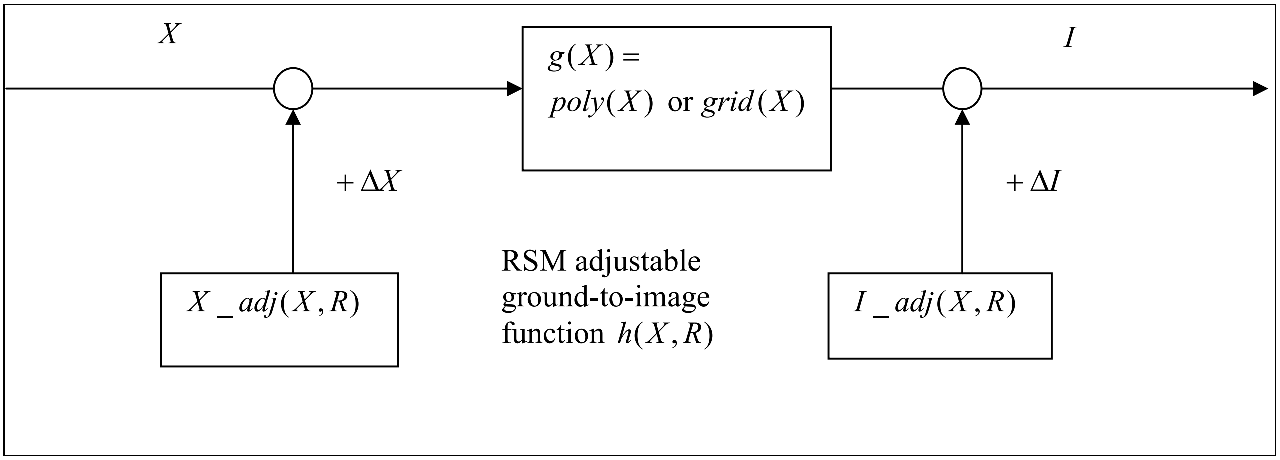

Figure 13: The RSM adjustable ground-to-image function

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 RSMPCA TRE and RSMGGA 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 can not 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 7 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**	**Estimated Value Range**	**Type**
TAG Information						
CETAG	<u>Unique Extension Type Identifier</u> 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 42864 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 to 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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	±9.99999999999999E+99 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>
IC0	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 NPAR	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	±9.99999999999999E+99 Greater than or equal to zero and less than or equal to one 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	±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	±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	±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	±9.99999999999999E+99 Greater than or equal to zero and less than or equal to one 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 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	±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	±9.99999999999999E+99 Greater than or equal to zero and less than or equal to one 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	±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 7: RSMECA TRE format table

13.0 RSM Ground-to-image Grid Identification (RSMGIA) TRE

13.1 Overview

The Replacement Sensor Model Ground-to-image Grid Identification TRE (RSMGIA) associates a ground-to-image grid with an image. The (interpolated) ground-to-image grid makes up the RSM ground-to-image function. The RSMGIA 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 (RSMGGA). Most images require only one section.

Note that the RSMGIA TRE is completely analogous to the RSMPIA 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 RSMGIA TRE is optional when there is only one image section, the actual condition is that at least one RSMGGA TRE and at least one RSMPCA TRE are present.) However, the image sections defined in the RSMGIA TRE are completely independent of the image sections defined in the RSMPIA TRE.

13.2 Low order polynomial

A low order numerator-only polynomial provided in this TRE (RSMGIA) 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:

$$r = GR0 + GRX \cdot x + GRY \cdot y + GRZ \cdot z + GRXX \cdot x^2 + GRXY \cdot xy + GRXZ \cdot xz + GRYY \cdot y^2 + GRYZ \cdot yz + GRZZ \cdot z^2$$

$$c = GC0 + GCX \cdot x + GCY \cdot y + GCZ \cdot z + GCXX \cdot x^2 + GCXY \cdot xy + GCXZ \cdot xz + GCYY \cdot y^2 + GCYZ \cdot yz + GCZZ \cdot z^2$$

13.3 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 RSMGGA TREs. The RSM image domain is defined by the fields MINR, MAXR, MINC, and MAXC that are provided in the RSMIDA TRE. (See Figure 14.)

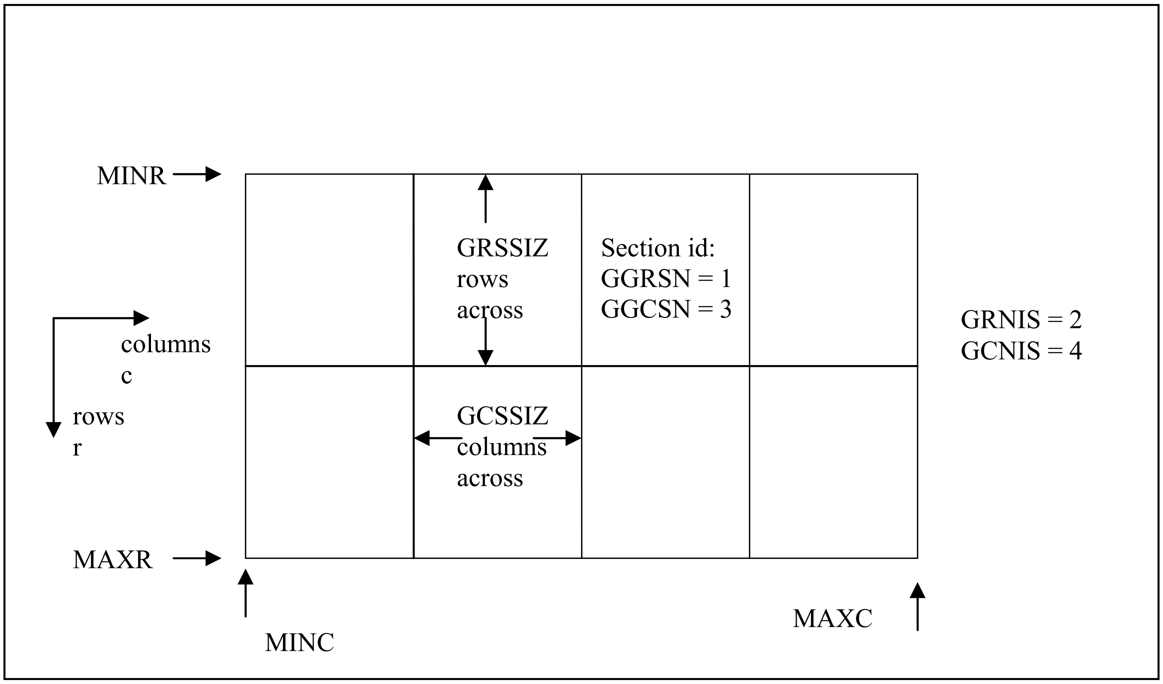

Figure 14: Sectioning of the RSM image domain for grids

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 (RSMGIA) 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 RSMGGA 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

13.4 RSMGIA format

Table 8 specifies the detailed format for the Replacement Sensor Model Grid Identification (RSMGIA) TRE.

RSMGIA – Replacement Sensor Model Grid Identification						
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	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 to 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 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 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 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 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 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 (radians or 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 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 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 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 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 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 (radians or 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 RSMGGA 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	±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	±9.99999999999999E+99 Positive value	R

Table 8: RSMGIA TRE format table

14.0 RSM Ground-to-image Grid (RSMGGA) TRE

14.1 Overview

The Replacement Sensor Model Ground-to-image Grid TRE (RSMGGA) 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 RSMGGA TRE corresponds to a specific image section, as discussed in the RSMGIA TRE format description.

14.2 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 15 illustrates an RSM ground grid with four z-planes, and Figure 16 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.

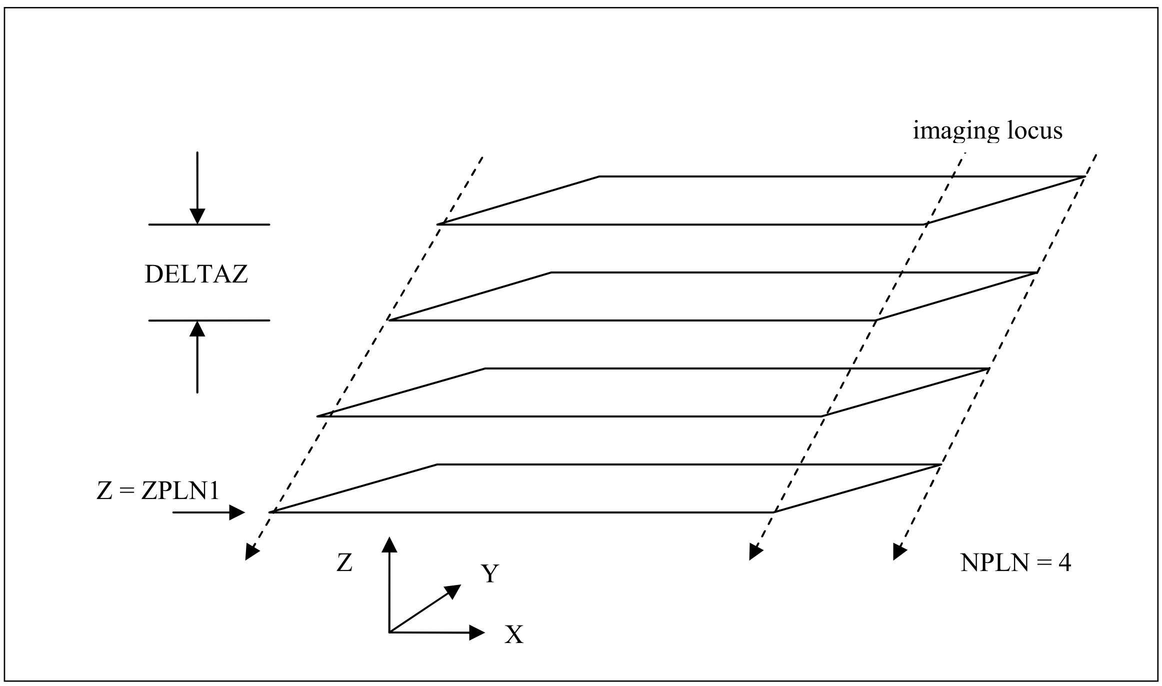

Figure 15: Grid z-planes

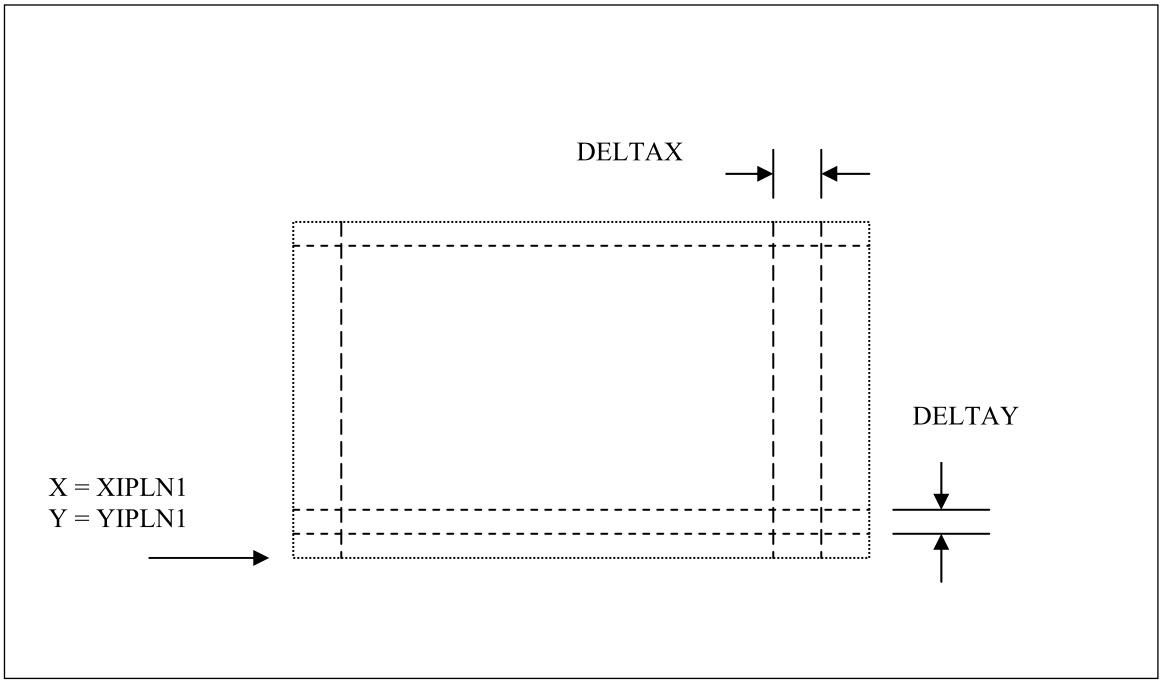

Figure 16: Grid plane 1

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.

14.2.1 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).

14.2.1 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 1/100 th 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.

14.3 TRE size and number of TREs

As detailed in the description for field CEL, the size of one RSMPCA 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 RSMPCA TREs are required, corresponding to multiple image sections as specified in the RSMGIA 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 RSMGGA TRE. In addition, the total number of bytes corresponding to multiple RSMPCA 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 RSMPCA TRE.

14.4 RSMGGA format

Table 9 specifies the detailed format for the Replacement Sensor Model Ground-to-image Grid (RSMGGA) TRE.

RSMGGA – Replacement Sensor Model Ground-to-image Grid						
Field	**Name/Description**	**Size**	**Format**	**Units**	**Expected Value Range**	**Type**
TAG Information						
CETAG	<u>Unique Extension Type Identifier</u> Unique TRE identifier.	6	BCS-A	N/A	RSMGGA	R
CEL	<u>Length of User-Defined Data</u> 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	<u>Image Identifier.</u> 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 to 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	±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	±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	±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	±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	±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	±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	±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 9: RSMGGA TRE format table

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").

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

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 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 parameters - 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 RSMDCA, RSMECA, and RSMAPA 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 s/w 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 s/w 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 (RSMAPA) - 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 (RSMDCA) - 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 (RSMECA) - 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 RSMECA 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 (RSMGIA) - 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 RSMGGA TRE.

RSM Grid TRE (RSMGGA) - contains a ground-to-image grid representing the RSM ground-to-image function for a particular image section.

RSM Identification TRE (RSMIDA) - 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 (RSMPIA) 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 RSMPCA TRE.

RSM Polynomial Coefficients (RSMPIA) 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.

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.