Accuracy Analysis in Support of the Global Quality Assessment of MISR Georectified Radiance Product

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ABSTRACT

Instantaneously, the nine pushbroom cameras of the Multi-angle Image SpectroRadiometer (MISR) instrument view the Earth at nine discrete angles, ranging from forward 70°, 60°, 45°, 25°, nadir, to symmetric aftward angles in the along-track direction. Each MISR camera contains four spectral bands. All 36 channels of MISR imagery are routinely and automatically processed on the ground to build the Level 1 geo-rectified radiance products (GRP). In order to assess the quality of the MISR GRP with respect to the geo-registration and co-registration accuracy requirements, comprehensive and multi-level accuracy analysis were defined and implemented both pre-launch using simulated MISR data and post-launch applied to the actual MISR data. The extensive and interactive accuracy analysis provides not only estimates and verifications on the geo-registration accuracy of the MISR GRP, but also a foundation for an automatic and global quality assessment (QA) approach. Together, the extensive and interactive analysis, and the automatic QA will ensure each GRP has quantitative QA labels, either automatically created, or manually edited, according to the level of QA process, indicating whether the GRP is of nominal quality (within the requirements), or abnormal.

1. INTRODUCTION

The purpose of MISR instrument is to study the ecology and climate of the Earth through the acquisition of systematic, global multi-angle imagery in reflected sunlight (Diner, et. al, 1998). The remote sensing of dynamic Earth phenomena through multiple directions creates new photogrammetric challenges. One of the fundamental requirements is to have multi-angle imagery be precisely registered on the Earth and co-registered automatically during the Level 1B2 geo-rectification process. The stack of multi-angle and multi-band geo-registered radiance products will then be used by the subsequent Level 2 science processing for the extraction of geophysical parameters about the Earth's surface, aerosols, and clouds.

The MISR instrument has nine pushbroom cameras, each contains 1504 photo-active pixels per scan line. The imagery of the red band and all bands of the nadir camera are reported at the full 275m sampling resolution, whereas the imagery of the remaining channels are sub-sampled at 1100m resolution. Two types of GRP are created during the Level 1B2 standard processing for each MISR camera and band. One is called the terrain-registered GRP. The other one is called the ellipsoid-registered GRP. Terrain GRP is the ortho-rectified MISR imagery projected on the Earth terrain level. These products are primarily used for the geophysical study of the Earth surface and aerosols in the atmospheres. Ellipsoid GRP is the projection of MISR imagery onto the WGS84 ellipsoid. They are primarily used for stereo cloud retrievals and cloud albedo studies. All GRP are projected onto the Space-Oblique Mecator (SOM) map projection (Snyder, 1987). The geo-registration accuracy is required at the fine pixel level (275m) with 95% confidence. The mis-registration of the geo-rectification process comes mainly from three sources: (a) camera geometric pointing, (b) errors in the knowledge of spacecraft navigation, and (c) the geo-rectification algorithm itself. The camera geometric model (CGM) is calibrated in the MISR SCF and then used by the Level 1B2 standard processing. The geo-rectification algorithm employs a number of image registration transforms, namely: ellipsoid transform, band-to-band transform, and processing to nominal reference orbiting image (ROI) transform to bring the image down to the Earth. A special adaptive approach is applied to the processing of the terrain registration of the red-band imagery, where image matching between a processing image and the ROI is applied, to further correct for errors in the knowledge navigation data. The correction information is then carried on to the rest bands and the ellipsoid registration. Jovanovic, et. al, (1998) provides details on the registration algorithm.

A comprehensive accuracy analysis plan in support of the global QA of GRP was made and implemented pre-launch, and applied since MISR was launched in December of 1999 on board the NASA satellite Terra, the flag ship of the Earth observation system (EOS). The plan has two objectives. First, it defines an automatic geo-rectification QA measurement to cope with the high-speed routine process and high-volume data products. Second, it defines tools and procedures that can be used to derive and validate the automatic measurement. In this plan, the geo-registration accuracy analysis and QA are defined through three levels. The first level is the routine evaluations of a set of QA parameters at the science computing facility (SCF) of the MISR instrument. In order to achieve this kind of automatic evaluation, QA parameters are extracted during the standard processing. The definition of the set of QA parameters and their normal behavior range are determined from both the second and third level QA, namely the interactive and extensive accuracy analysis, respectively. In practice, the operation of the global QA could be implemented hierarchically and combine all three levels. The time line of various analysis and QA activities is defined in Table 1. Before launch, accuracy analyses at all levels were repeated to estimate the geo-registration accuracy using simulated MISR data and to provide the tools for the global QA measurement. After launch, routine QA is run continuously, whereas interactive and extensive analyses are only run as needed by the in-flight geometric calibration, or triggered by lower level QA. In the next few sections, all three levels of accuracy analysis and QA activities will be described in detail. Examples of analyses will also be illustrated during the discussion. Section 5 presents the experimental results related to accuracy analysis and QA activities. Finally a summary is presented in section 6.

Table 1. QA Time line overview.

Time	Pre-launch	In-flight Calibration	Years followed
Routine	Initial Estimate	Continuously	→
Interactive	Initial Estimate	Heavily	1. Often triggered by routine QA. 2. Semi-annually.
Extensive	Initial Estimate	Heavily	1. Occasionally triggered by interactive. QA. 2. Annually.

2. EXTENSIVE ANALYSIS

Extensive accuracy analysis is for thorough validation of the geo-rectification process, with special software tools and external data sources. Because of resource restrictions, extensive analysis is applied only to a limited amount of data. The main objectives of the extensive analysis are to determine the geo-rectification and co-registration accuracy of the study regions, and to monitor the error allocations and the response of automatic QA measurements to geo-rectification accuracy.

2.1. Pre-launch Estimate

Before launch, extensive accuracy analysis using simulated MISR imagery was conducted at each baseline of the software implementation. The external source data employed to assess the absolute accuracy of the GRP include the registered Landsat TM imagery and the digital elevation model (DEM) of the test regions. First, MISR imagery was simulated using the registered Landsat imagery and DEM, according to a simulated nominal orbit navigation and a pre-launch CGM. The simulation details can be found in Lewicki, et. al. (1994). Next, a set of "truth" or "expected" data was also created by rigorous point-by-point backward projection from the Earth surface, either the terrain surface or the WGS84 ellipsoid, up to MISR imagery at each 275m or 1100m SOM grid point, depending on band resolution. The result of this is also called the *expected projection parameters*, which provides the expected mapping of the MISR image coordinates at the SOM grids.

Special test software tools were developed to estimate the systematic accuracy of the L1B2 geo-rectification algorithm and its response to errors in the knowledge navigation data. Particularly, when the standard processing software was running in the diagnostic mode, the following diagnostic datasets were created:

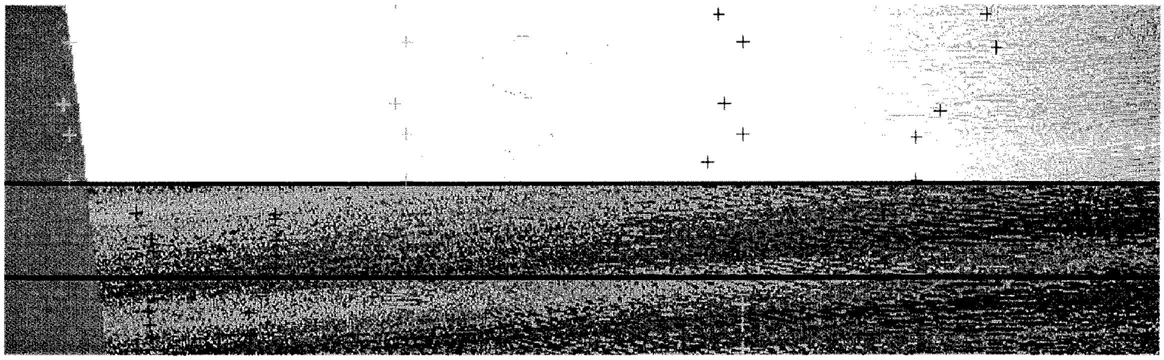
1. *Diagnostic projection parameters*: This contains the "actual mapping" of MISR image coordinate at every SOM grid as the results of Level 1B2 standard processing.
2. *Diagnostic grid point descriptions*: This contains a thematic image layer for each GRP, indicating how image registration is segmented. In the case of red band terrain processing, image registration is segmented adaptively. Each segment is called a processing grid. Sub-gridding is stopped when either image matching between a

processing MISR imagery and ROI meet the accuracy requirement or there is no improvement from image matching. Each type of tie point used for image registration is also displayed with a symbol of a designated color, to indicate the distribution of tie points, the point type as either a navigation point, an image transform point, an image matching point, or a detected blunder.

3. *Diagnostic image matching log*: This is an ASCII file, with information about matching attempted on every tie point, such as: success or failure flag, type of matcher, image matching correction, uncertainty, and reliability etc.
4. *Diagnostic image transform log*: This is also an ASCII file, with details on image transform coefficients, number of tie points, types of tie points, and residuals, etc.

Extensive analysis is usually applied to a segment of 10 to 20 blocks (or 5120 to 10240 image lines) long. The standard processing is usually run using a simulated orbit navigation data with known errors. The difference between the *expected projection parameters* and the *diagnostic projection parameters* can be derived at each SOM grid (275m or 1100m resolution). Statistics are computed based upon this high-resolution difference file. To understand the behavior of the differences at various test cases, such as: (a) high orbit perturbation, (b) orbit attitude with large dynamic errors, (c) rough terrain, (d) image covered or partially covered with clouds, the *diagnostic grid description* is displayed and superimposed over either the radiance imagery or the difference imagery of the "projection parameters" for visual examination. As an example, Figure 1 shows a difference-image between the "projection parameters" from a pre-launch extensive analysis with a segment of simulated MISR data over the Mexico mountain region. Only the east side of the swath segment is displayed in the figure where north is towards the top of the image. The image values represent the along-track geo-registration errors at the SOM locations. The brightest value of this difference image is about 0.5 pixels and the darkest value is about –0.2 pixels. The smooth values on the left edge of the image are areas with no image data acquired. The red-band grid point description image is superimposed over the difference image. The red lines are the grid lines that separate the processing grids. The light green cross symbols represent navigation tie points, the orange symbols represent image transform tie points, and the dark blue symbols are least-square image matching points. This example shows the geo-registration accuracy is closely related to how the image swath is segmented and a discontinuity may occur along the boundary between processing grids. It also shows that when orbit data contains large dynamic errors, missing matching points at the side of a swath could cause a localized lower geo-registration accuracy, but missing matching points in the middle of the swath may cause little problem. This example indicated that geo-registration QA measurements must include image sub-gridding and image matching as key factors.

Figure 1. Red-band grid point description image superimposed over a difference image between the *diagnostic projection parameters* and the *expected projection parameters* from an extensive simulation analysis.



To verify the geo-rectification accuracy, interactive analysis is usually employed so an analyst can visually examine and manually measure the geo-registration accuracy. An extensive analysis including the production and examination of diagnostic outputs plus interactive studies was very time consuming, but it led to a first cut on the accuracy estimate of the GRP and the definition of a preliminary set of QA parameters. Table 2 contains a list of critical QA parameters defined from the pre-launch extensive analysis. These parameters are produced by the Level 1B2 standard processing and stored in a companion QA product. Some grid level parameters are only valid for the red-band terrain processing where image matching is applied. Among all of these parameters, the most significant one is the geometric data quality indicator (GDQI). GDQI is derived based on the summation of the rest of the critical QA parameters of the red-band geo-registration processing and therefore provides the overall geo-registration quality for the current camera. A positive GDQI indicates nominal accuracy, whereas a negative GDQI indicates poor geo-registration accuracy.

Table 2. MISR GRP critical QA parameters.

QA Parameters	Level	Description	Valid Range
GDQI	Block	Overall geometric quality.	(-1, 1)
Number of processing grid cells	Block	Excessive sub-gridding means large dynamic orbit error.	(2, 32)
Standard deviation of image transform	Grid	This is the variance of the unit weight for image transform.	(0, 10)
Average image matching correction	Grid	This defines the average pointing error.	(-10, 10)
Standard deviation of image matching	Grid	Diverse matching corrections indicate dynamic orbit errors.	(-10, 10)
Ratio of matched to candidate tie points	Grid	Failure of matching could results in low geometric accuracy.	(0, 1)
Ratio of blunder to matching tie points	Grid	This provides a reliability measurement.	(0, 1)

2.2. Post Launch Validation

There have been two major campaigns happened in the MISR SCF in the effort of improving MISR geo-registration accuracy since launch. One was the in-flight calibration of the CGM. The analysis and QA for the CGM calibration is performed independently. The second campaign was the creation of ROI, which would provide the standard processing a set of nominal and cloud free MISR imagery for image matching in the effort of removing dynamic errors in the navigation data. The post-launch extensive analysis, with additional test procedures and tools, was employed heavily in the second campaign to validate the GRP geo-registration accuracy.

Again, geo-registered Landsat imagery was used for interactive measurements to provide the external reference. Samples of actual MISR orbits were run under the diagnostic mode, but no *expected projection parameters* were produced. A large amount of interactive measurements were made and diagnostic outputs were examined to verify the quality and error allocation of each piece of the algorithm from image sub-gridding, image transform, image point intersection based on navigation data, image point matching with ROI, blunder detection, to the overall accuracy. Examples of such analysis are given in Section 5. In addition, we added a comparison of the Level 2 stereo height retrieval with the known surface elevations at cloud free locations. The MISR Level 2 stereo height product is based on the image matching of the nadir and near-nadir (camera An, Aa, and Af) Ellipsoid GRP and reported at the 1100m SOM grids (Diner, et. al, 1999). On clear regions, it is expected that stereo retrieved heights should represent the Earth surface elevations. Therefore this comparison test could be made at every clear 1100m SOM grid to accumulate the systematic accuracy from a large amount of measurements

The results of the post-launch extensive analysis will be reported in Section 5. In addition to the validation of the geo-registration accuracy, the post-launch extensive analysis also updated the definition of the automatic QA: (a) the list of critical QA parameters is expanded with the percentage of the image area that passed image matching accuracy test and (b) GDQI is weighted with the quality description of the orbit navigation data.

3. INTERACTIVE ANALYSIS

Interactive analysis has always been included as part of the extensive analysis. Unlike extensive analysis, where quantitative accuracy numbers can be derived, interactive analysis mainly requires an analyst to visually examine imagery and manually measure sample points. Such interactive activities have been critical in the extensive analysis to identify problems and verify the result. They are also handy for a quick approval during the post launch studies when sample orbits were found abnormal by either automatic geo-registration QA or subsequent Level 2 science retrievals. In such cases, no diagnostic standard processing and analysis are required, but merely an operator to load the questioned GRP into Erdas Imagine, geographically link to a reference imagery, and measure either the relative or the absolute accuracy of the GRP, depending on the case.

Relative accuracy measurements are usually for the verification of the co-registration among multi-angle or multi-band imagery. Absolute accuracy measurement would require the reference of an independent geo-registered imagery, such as the Landsat imagery. The geo-registration accuracy of the geographically linked test imagery and reference imagery could be measured to sub-pixels. Examples of interactive accuracy measurements will be given in Section 5. For Terrain GRP, an operator may measure the miss-registration at difference surface types. For Ellipsoid GRP, an operator may measure the mis-registration along the coastlines when zero-disparity is expected. When two imagery of different angles are displayed in anaglyph, the Terrain GRP are expected to show no color disparities, whereas Ellipsoid GRP are expected to display the surface and cloud with true stereo effect. When an interactive QA is applied to a particular orbit, it may either trigger an extensive QA or cause an operator to manually edit the GDQI of the orbit.

4. AUTOMATIC QA

The main objective of automatic QA is to attach each GRP with a geo-registration QA measurement for the end users. It is also desired to provide the automatic monitoring capability in the SCF.

Following the design of the geometric QA plan, the creation of critical QA parameters was implemented as part of Level 1B2 geo-registration processing software. The definition and the nominal range of these QA parameters are based on extensive and interactive accuracy analysis in support of the global automatic QA. Each parameter represents a critical aspect of the geo-rectification algorithm. The end product users, however, may only need to understand that GDQI represents the summation of the geo-registration QA. Each GRP is associated with a separate QA product, created by the Level 1B2 standard processing. All QA products that contain critical QA parameters are automatically screened in the MISR SCF. The screening results are stored in a database in the SCF. Any exception discovered during the screening would be presented to a cognizant engineer automatically, which could trigger an interactive analysis.

For automatic monitoring purposes, statistics derived from the QA screening in the SCF would be evaluated periodically. Such statistics would indicate the overall GRP performance and potential error development.

5. EXPERIMENTAL RESULTS

5.1. Pre-launch Accuracy Analysis and Results

Extensive accuracy analyses using simulated MISR data were repeated several times to estimate the algorithm performance under the specification of the pre-launch CGM and the worst predicted orbit performance. Table 3 illustrates the estimated GRP geo-registration and co-registration uncertainty in along-track direction at the 95% confidence under such conditions through these repeated extensive accuracy analysis. The uncertainties in the cross-track direction are usually smaller.

Table 3. Pre-launch estimated GRP accuracy.

GRP	Camera	Uncertainty at 95% confidence (pixels)
Terrain Red-band	An	0.3
	Df	0.6
Terrain other bands	An	0.3
	Df	0.7
Ellipsoid all bands	An	0.2
	Df	0.6

5.2. Post Launch Validation and Results

The MISR instrument started Earth observation in February of 2000. Immediate post-launch analysis indicated the Terra orbit navigation data was very stable and met the prediction under nominal conditions. The MISR CGM, as expected, needed improvement. After a series of in-flight geometric calibrations, a final CGM was produced and delivered to be used during standard processing. The current quality estimates (Jovanovic, et. al, 2002) show that the stability of the CGM and the magnitude of the geo-rectification uncertainties are as expected for eight out of nine cameras. The standard deviations of these eight cameras are within the ranges of 100 m up to 300 m depending on the camera view angle. However, the geo-rectification performance of the Da camera is still beyond the expectation. Significant bias of about 300 m in cross-track direction and 100 m in along-track direction has been observed. The behavior of the CGM model for that camera is still under investigation.

5.3. Post Launch Extensive Analysis and QA Update

Under special occasions, the Terra satellite may lose its attitude accuracy around the time of maneuvers or due to interpolation intervals between attitude measurements being extended by other interruptions. Such occasions are very rare (<1%), but they could happen while observing a scientifically interesting region. The use of ROI in the production of GRP is specifically designed to reduce the effects of dynamic attitude changes in addition to any potential change in the CGM for the remaining mission. However, standard processing with ROI has not been officially started yet, pending a global test of Level 1B2 standard processing matching with ROI over a month long period. In this month long global test, which is still on going during the writing of this paper, statistics on the GRP geo-registration accuracy are accumulated from the automatic monitoring of: (a) matching the GRP with ground control points already collected for the camera geometric calibration, and (b) comparison of stereo height retrievals with the known surface elevation on clear scenes, and (c) extensive analysis. Figure 2 and 3 provide two examples of extensive and interactive analyses.

Figure 2 shows the red-band radiance image from an early MISR orbit, orbit 3603 and camera Ca, superimposed with the red-band grid point description image. In this example, one blunder, with symbol color of cyan, is shown on the top. Blunder plays a critical role in the geo-registration as it could potentially cause worse registration than critical role in the geo-registration as it could potentially cause worse registration than purely navigation tie points. By zooming into the local region in the image, we could see the area around the blunder was too featureless to match. The tools developed pre-launch helped essentially in the analysis and verification of the image matching and blunder detection. In fact, both image matching and blunder detection algorithm are modified along the course of the post-launch analysis. As results, these algorithms are more conservative to ensure the reliability of the image matching and the quality of the GRP.

Figure 2. Red-band grid point description image superimposed over the terrain registered radiance image of MISR orbit 3603.

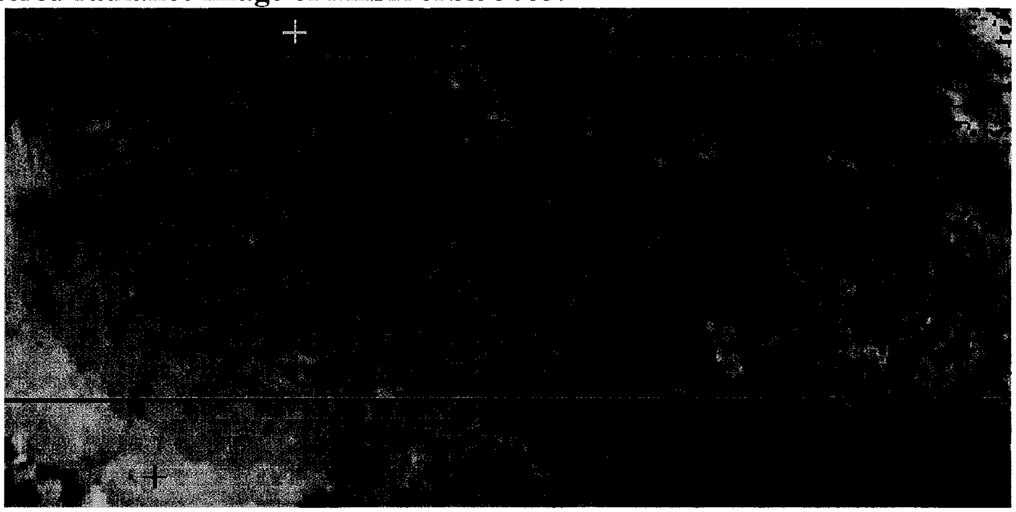
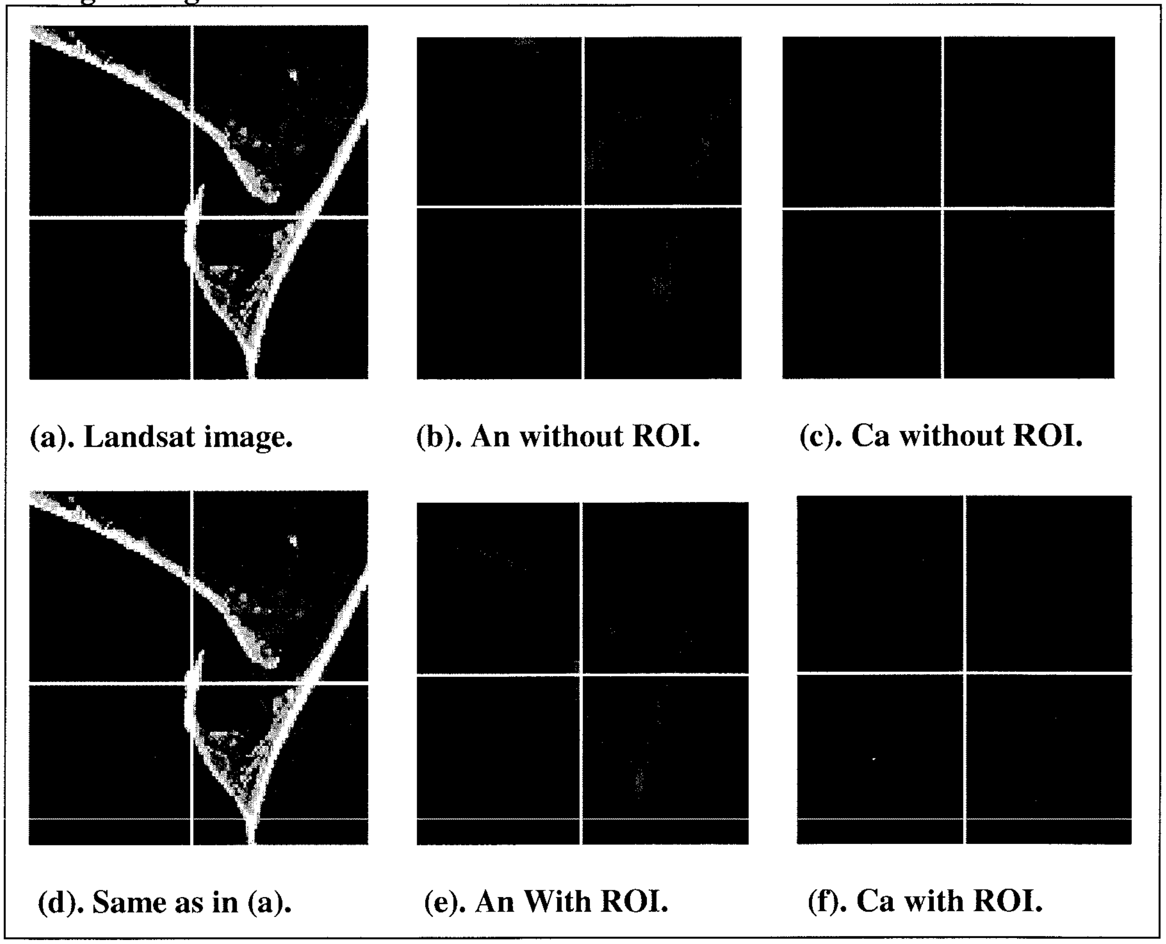


Figure 3 shows the interactive accuracy measurement on an extreme example of while the reported navigation attitude for the orbit was of reduced accuracy. In this figure, geographical links are made among a reference geo-registered Landsat scene (path 14 row 36), the red-band radiance imagery from MISR orbit 4242, cameras An and Ca. The first row shows measurements of the GRP run without ROI and the second row shows the GRP run with ROI. Without ROI, the GRP of the An and Ca cameras contain about 5 and 13 pixel shifts in the along-track direction, respectively. With ROI, the uncertainty is about 0.5~1 pixels for both cameras in this example. These interactive measurements agreed with the diagnostic outputs from the extensive tests.

Mean while, GDQI is found to be too simple to represent these special geo-registration conditions. Two additional factors are proposed to be included. They are (a) the orbit quality index associated with the navigation data and (b) the accuracy test resulted from the adaptive ROI matching. These updates on QA will be implemented in the standard processing software and be applied to the new and the reprocessed MISR imagery when ROI matching is officially kicked out.

Figure 3. Interactive accuracy measurements of MISR orbit 4242. The left image is a geo-registered Landsat scene, the middle image is radiance of the An camera, and the right image is from the Ca camera.



6. SUMMARY

A hierarchical and comprehensive accuracy analysis approach has been implemented and tested to support the automatic and global QA of the MISR GRP. A large amount of work has been done through extensive analysis to derive the geo-registration and co-registration accuracy of the MISR Level 1B2 geometric process and to link the accuracy allocation to the automatic QA measurements. Pre-launch accuracy analysis estimated that the GRP geo-registration accuracy is within the pixel level (275m) at the 95% confidence level. Post-launch analysis improved pieces of critical algorithms and the definition of automatic QA. Interactive QA has been employed regularly in examining and verifying the geo-registration quality since launch. Automatic QA and tools for automatic QA screening and analysis have been implemented, but need further update and work together with the upgrade of the Level 1B2 standard processing software when ROI is used in production. Once such update is implemented, all incoming and the existing MISR imagery will be run with the new software version to ensure each GRP with a meaningful GDQI to indicate its geo-registration quality.

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REFERENCE

Diner D. J., R. Davies, L. Di Girolamo, A. Horvath, C. Moroney, J Muller, S. R. Paradise, D. Wenkert, J. Zong, 1999, Level Cloud Detection and Classification Algorithm Theoretical Basis, *JPL internal document D-11399, Rev. D.* Jet Propulsion Laboratory, Pasadena CA.

Diner, D. J., J. C. Beckert, T. H. Reilly, T. P. Ackerman, C. J. Bruegge, J. E. Conel, R. Davies, S. A. W. Gerstl, H. R. Gordon, R. A. Kahn, J. V. Martonchik, J-P. Muller, R. Myneni, B. Pinty, P. J. Sellers, and M. M. Verstraete, 1998, Multi-angle Imagine SpectroRadiometer (MISR): Instrument description and experiment overview, *IEEE Trans. Geosci. Rem. Sens.*, 36(4), pp. 1072-1087.

Jovanovic V. M., M. M. Smyth, J. Zong, R. Ando, and G. W. Bothwell, 1998, MISR Photogrammetric data reduction for geophysical retrievals, *IEEE Trans. Geosci. Rem. Sens.*, 36(4), pp. 1290-1301.

Jovanovic, V. M., M. M. Smyth, and J. Zong, 2002, Personal communications (submitted to IEEE Trans. Geosci. Rem. Sens. pending review).

Snyder, J. 1987, Map Projections – A Working Manual, *U.S. Geological Survey Professional paper 1395*, pp. 214.