JPL D-13228

Earth Observing System

MISR

Multi-angle
Imaging
Spectro-
Radiometer

In-flight Geometric Calibration Plan

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Multi-angle Imaging SpectroRadiometer (MISR)

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To determine the latest released version of this document, consult the MISR web site (http://www-misr.jpl.nasa.gov)

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1.0 INTRODUCTION

1.1 IDENTIFICATION AND PURPOSE

This MISR In-flight Geometric Calibration (IGC) Plan describes the concept, development strategy and operational design to be used for geometric calibration of the instrument and for producing the Geometric Calibration Dataset (GCD) which is required as an input to the L1B2 standard processing. In particular, this document describes characteristics of the required input data; outlines the algorithm underlying the usage of ground control data in order to calibrate the MISR cameras and image data; describes the development activities related to the algorithm, input data, software and documentation; outlines test and validation approaches; and defines calibration related mission operations and operational procedures.

1.2 SCOPE

This document focuses on the following MISR geometric calibration issues:

- Geometric Calibration Dataset description and use
- Ground Control Points and use of the DTED Intermediate Dataset
- Test of the calibration S/W and algorithm performance during the development phase
- Validation of the GCD and L1B2 Georectified Radiance Product (GRP) during flight
- Development strategy and phasing
- Mission operations and procedures
- SCF Hardware and Software requirements

The mathematical description and theoretical basis underlying production of the GCD is given in the L1 Geometric Calibration ATB (JPL D-13399) document. The mathematical description and theoretical basis underlying usage of GCD during L1B2 standard processing is given in the L1B2 Georectification and Registration ATB document(JPL D-11532 Rev. B).

This document covers only the MISR in-flight geometric calibration. The preflight geometric camera calibration is described only at a high level (i.e., overview). A more detailed description of those activities is given in the MISR Preflight Calibration Plan (JPL D-11392).

This document is divided into seven sections. Section 1 provides the identification, purpose, and scope for the document and lists MISR project documents and other EOS reference documents which are relevant to the Geometric Calibration. Section 2 gives a conceptual overview of the MISR geometric processing with emphasis on the In-flight Geometric Calibration (IGC) segment of that processing. Section 3 describes, in general, the calibration algorithm and use of the Geometric Calibration Dataset (GCD). Section 4 presents geometric calibration development strategy. Section 5 describes the testing of the calibration algorithm and software during its development phase. Section 6 defines specific mission operations and operational procedures to be taken during in-flight calibration, including validation activities. Section 7 describes required SCF hardware and software capabilities needed for full support of the in-flight geometric calibration process.

1.3 APPLICABLE MISR DOCUMENTS

1.3.1 Controlling Project Documents

1) MISR Experiment Implementation Plan (EIP), vols. 1 and 2 (Instrument), JPL D-8796

2) MISR Experiment Implementation Plan (EIP), vols. 3 and 4 (Science, Data Processing, and Instrument Operations), JPL D-11520

3) MISR Instrument Science Requirements (ISR), JPL D-9090, Rev. B

4) MISR Instrument Functional and Design Requirements (IFDR), JPL D-9988, Rev. A

5) MISR Data System Science Requirements (DSSR), JPL D-11398

1.3.2 Reference Project Documents

1) Level 1 Georectification and Registration ATB, JPL D-11532, Rev. B
2) MISR Algorithm Development and Validation Management Plan, JPL D-11220
3) MISR Preflight Calibration Plan, JPL D-11392

1.3.3 Other Reference Documents

1) General Instrument Interface Specification (GIIS), GSFC 420-03-02, 1 Dec. 1992, Rev. A
2) Unique Instrument Interface Document (UIID), MISR Instrument, EOS-AM Project, GSFC 421-12-13-02
3) PGS Toolkit Users Guide for the ECS Project, EOSDIS Core System Project, 194-809-SD4-001, 4 February, 1994, Draft
4) Requirements Document for the EOS-AM Spacecraft, GSFC 421-10-01
5) MISR Science Data Processing Sizing Estimates, (SDPSE), JPL D-12569

2.0 MISR GEOMETRIC PROCESSING

2.1 INTRODUCTION

The Multi-Angle Imaging Spectro-Radiometer (MISR) instrument is part of the Earth Observing System (EOS) payload to be launched in 1998. The purpose of MISR is to study the ecology and climate of the Earth through the acquisition of systematic, global multi-angle imagery in reflected sunlight. The instrument flies in a sun-synchronous 705-km descending polar orbit, and is capable of global coverage every nine days. MISR will acquire multi-spectral images at nine discrete angles relative to the local vertical. Four of the nine pushbroom cameras are pointed forward of the spacecraft position, one pointed at nadir, and four pointed in the aftward direction. Each camera acquires images in four spectral bands: blue, green, red, and near-IR. The overlap swath width of the MISR imaging data (that is, the swath seen in common by all nine cameras) is 360 km, which provides global multi-angle coverage of the entire Earth in nine days at the equator, and two days at the poles.The cross-track instantaneous field of view (IFOV) and sample spacing of each pixel is 275 m for all of the off-nadir cameras, and 250 m for the nadir camera. Along-track IFOV’s depend on view angle, ranging from 250 m in the nadir to 707 m at the most oblique angle. Sample spacing in the along-track direction is 275 m in all cameras.

In order to derive geophysical parameters such as aerosol optical depth, bidirectional reflectance factors, and hemispheric reflectance, measured incident radiances from all nine cameras must be coregistered. Furthermore, the coregistered image data must be geolocated in order to meet experiment objectives such as: a) produce a data set of value to long-term monitoring programs and allow intercomparassions of data on time scales exceeding that of an individual satellite, and b) provide EOS synergism and allow data exchange between spacecraft instruments. Ultimately, the Georectified Radiance Product (GRP) resulting from the L1B2 standard processing of radiometrically corrected MISR imagery must satisfy coregistration and geolocation requirements imposed by the science algorithms.

2.2 ELEMENTS OF THE SYSTEM

Major challenges in designing the approach to be used for geometric processing of MISR imagery include:

1) Removal of the errors introduced by inaccurate navigation and attitude data, and inaccurate Camera Geometric Model (CGM) parameters
2) Removal of the distortions introduced by surface topography
3) Achieving a balance between limited hardware resources, huge data volume and processing requirements
4) Autonomous and non-stop aspects of the production system

Given the limitations of L1B2 standard processing (i.e., hardware, human resources, and processing time) a need for the supporting activities occurring at the Science Computing Facilities (SCF)

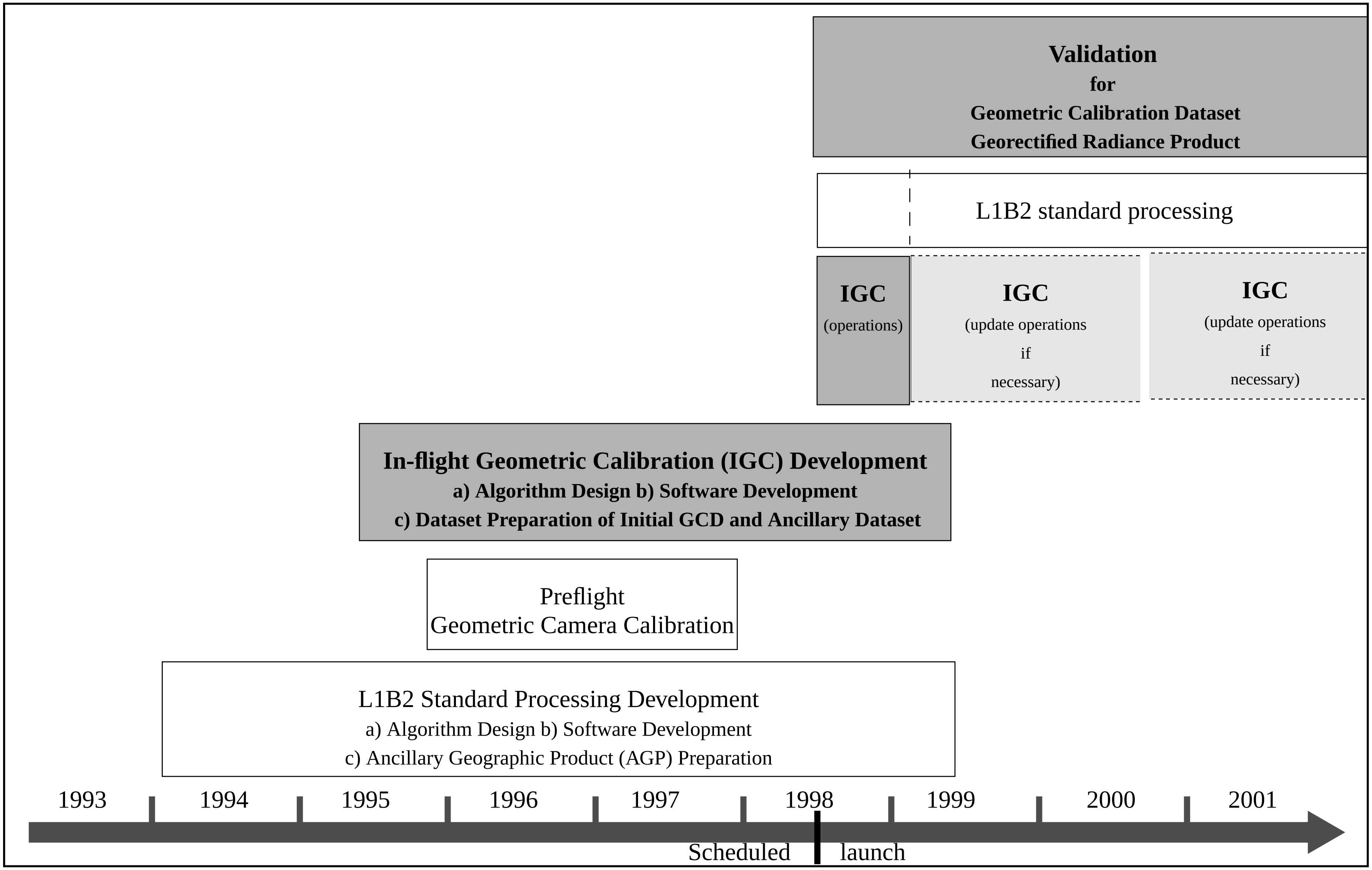

Figure 1: Elements of the MISR geometric processing system.

(the activities belonging to the shadowed boxes represent In-flight Geometric Calibration and are covered in this plan) and dealing with the issues listed above is recognized. All of the operations related to the MISR geometric processing and their relation to the lifetime of the MISR mission are given in Figure 1. This document covers only a subset of those operations and issues corresponding in particular to:

1) Design of the geometric calibration algorithms
2) Software development for the geometric calibration
3) Preparation of the initial Geometric Calibration Dataset (GCD) and ancillary dataset for the In-flight Geometric Calibration (IGC) operations
4) IGC operations and production of the in-flight GCD
5) Validation of the GCD and the L1B2 Georectified Radiance Product (GRP)

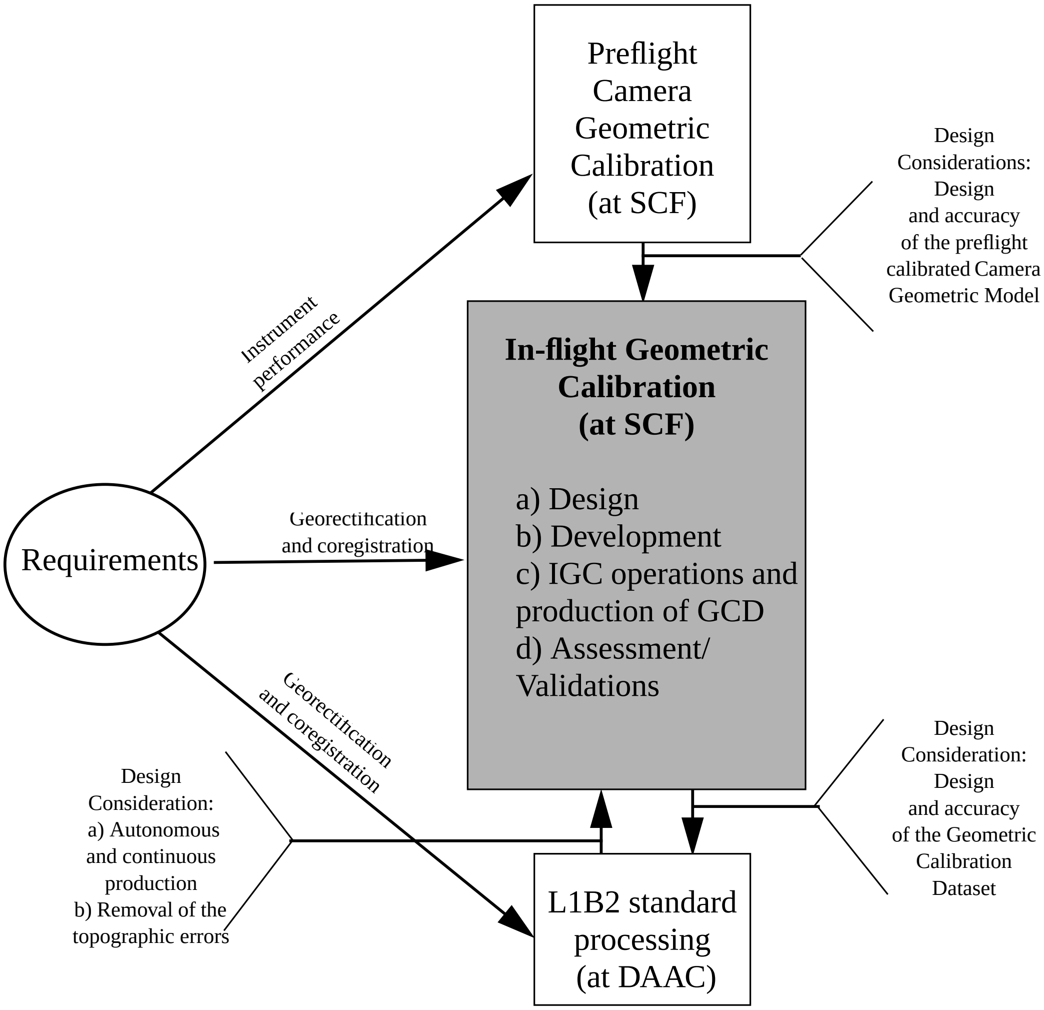

Figure 1: MISR geometric processing
(interrelationships and design considerations)

The items listed above represent the In-flight Geometric Calibration which is a prerequisite for the successful production of the Georectified Radiance Product (GRP) during L1B2 standard processing.

Overall, MISR geometric processing is driven by specific requirements (i.e., geometric, georectification, and coregistration) which are stated in the MISR Instrument Science Requirements (ISR) and Data System Science Requirements (DSSR) documents. However, the concept underlying In-flight Geometric Calibration is also driven by the specific design of the L1B2 standard processing. The L1B2 standard processing algorithm, described in the Level 1B2 Algorithm Theoretical Basis: Georectified Radiance Product document, is based on the use of the Geometric Calibration Dataset. Figure 1 represents the interrelationships among the requirements and various parts of the geometric processing. The arrows between boxes represent design considerations. Also shown are the locations of the computing facilities (DAAC and SCF) used for the various activities.

2.3 IN-FLIGHT GEOMETRIC CALIBRATION: AN OVERVIEW

In the previous section a breakdown of the overall MISR geometric processing was given, including the elements relevant to the IGC. In this section a more detailed overview of those operations related to the IGC is presented.

There are two principal goals of the IGC: 1) to provide the GCD as input to the L1B2 standard processing, and 2) to validate the quality of the L1B2 Georectified Radiance Product (GRP) and update the GCD if necessary. The creation and use of the GCD and its subsets, the Camera Geometric Model (CGM), Projection Parameters (PP) file and Reference Orbit Imagery (ROI) files, are explained in more detail in Section 3.0. The validation of the GRP will occur throughout the mission and its results may trigger updates in all or part of the GCD.

In order to meet these two goals various activities must be undertaken before launch and throughout the mission. Their relationship is presented as a flow diagram in Figure 2. Each of the activities may be classified into four major phases: 1) Design, 2) Development, 3) IGC Operations and Production of GCD, and 4) Quality Assessment/Validation.

Design: The primary objective of this phase is to define the theory underlying the calibration algorithm, including identification and description of the ancillary dataset, e.g., Ground Control Points (GCPs). This is the initial phase of the overall IGC work and will provide input to most of the subsequent development activities. However, some of the design decisions may evolve over time, based on results and experience obtained from testing during development.

Development: The primary objectives of this phase are: a) development of software that implements the geometric calibration algorithm, b) preparation of the ancillary datasets including GCPs and Digital Terrain Elevation Dataset (DTED) Intermediate Dataset (DID), c) creation of the initial GCD based on preflight measurement of the cameras and predicted navigation and attitude data, and d) creation of the initial MISR Geometric Calibration Data Acquisition Plan. This phase includes work that must be completed before launch and will provide input and necessary software tools to the IGC operations and production, as well as validation.

IGC Operations and Production of GCD: These operations will start after in-flight radiometric calibration is concluded, the final goal being production of a valid GCD. The operations include acquisition of MISR calibration data (imagery, spacecraft navigation and attitude); creation of the GCD including in-flight calibrated CGM; PP and ROI files; and validation of the created GCD. A period of six or more months will be allocated for this work before the first in-flight GCD is delivered and staged at the DAAC. Due to seasonal changes on the Earth's surface there may be a need for additional PP and ROI datasets corresponding to certain latitudes of the globe. The specific requirement related to this issue will be established during development. Updating of the GCD will either depend on the results from validation activities or may be triggered by reports from the

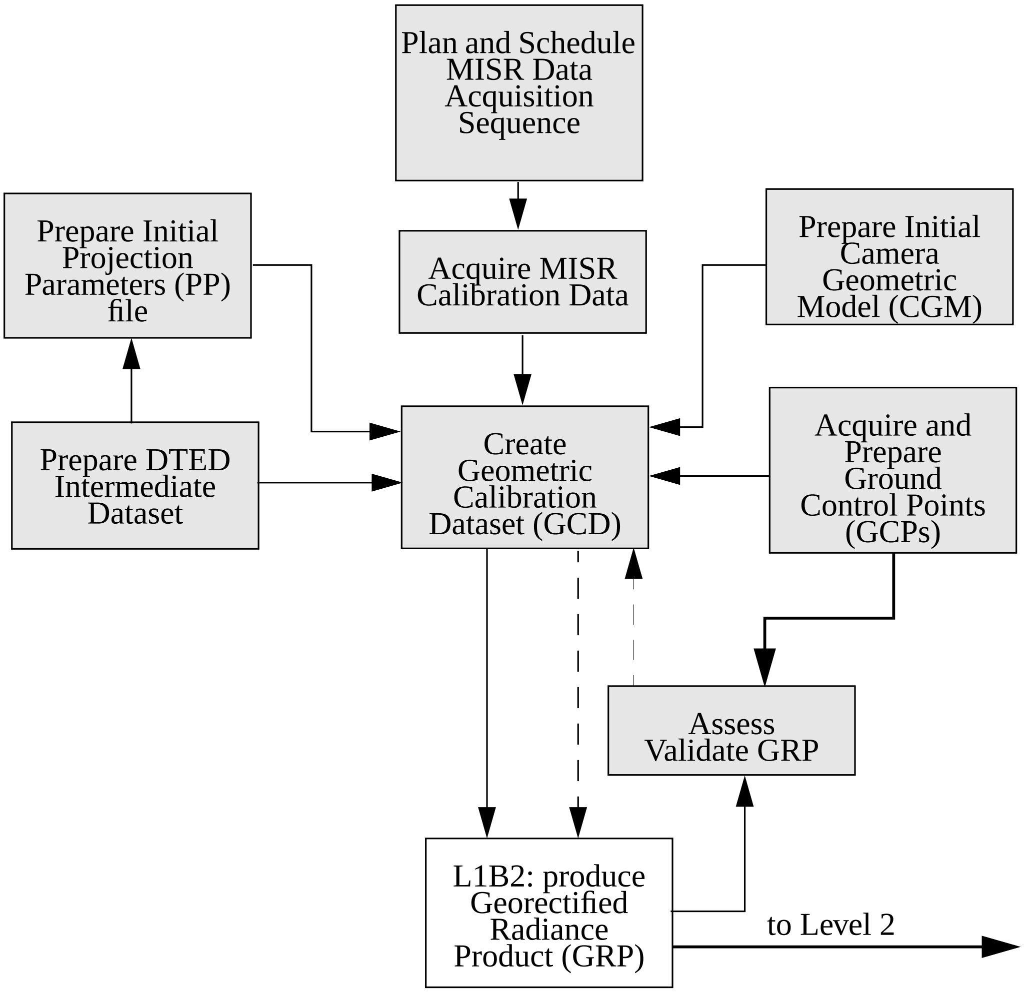

Figure 2: In-flight Geometric Calibration: An Overview of Activities.
(Dashed lines represent path which will be executed only in the case of negative validation results)

EOS Operation Center indicating possible spacecraft events which may result in the change of MISR pointing.

Quality Assessment/Validation: The objective of this phase is to continuously monitor the quality of the L1B2 Georectified Radiance Product. The focus is on geometric accuracy of the derived image dataset. Based on the amount of work involved and the number of times they will be repeated, the validation activities are divided into: a) routine, b) interactive and c) extensive. Ultimately, validation results will determine if there is a need to update the GCD.

3.0 CALIBRATION ALGORITHM OVERVIEW

3.1 OBJECTIVES

One of the unique challenges of MISR L1B2 data processing subsystem is to routinely and autonomously georectify and coregister imagery from 36 spectral bands with widely varying view angles. Routine L1B2 processing (described in the L1B2 ATB document) relies on the GCD as an input. Therefore, a geometric calibration effort must be completed in order to meet georectification and coregistration accuracy requirements continuously during standard processing.

The calibration process is divided into two segments. The first segment, Camera Geometric Model Calibration, focuses on the calibration of the camera physical and derived parameters which are used to define a pixel's pointing direction relative to the EOS AM-1 spacecraft reference point. The second segment, called Creation of the Projection Parameters and Reference Orbit Imagery, focuses on the correction of errors embodied in the navigation data (EOS AM-1 ephemeris and attitude) which are used to define position and pointing of the spacecraft relative to the Geocentric Inertial Coordinate System (GCI).

The Camera Geometric Model Calibration will be conducted preflight (i.e., in the MISR calibration laboratory) and in-flight, during the first few months after launch. During the mission, in-flight camera calibration will be repeated occasionally, in particular: 1) at a selected date, once a year, 2) after lunar maneuver, 3) after a report from the EOS Operation Center which indicate possible changes of MISR pointing, and 4) after standard processing performance indicators, resulting from the validation, which suggest possible deviation from the previously calibrated CGM. In the case of a lunar maneuver happening once a year, 1) and 2) may be combined into one instance. The preflight measurements, described in Reference [4], will not include effects of the launch and gravity release deformations of the mechanical connections between the optical bench and the satellite platform, etc. Therefore, the objective of the In-flight Camera Geometric Model Calibration is to recalibrate parameters of the camera which are significantly sensitive to those effects.

The Creation of the Projection Parameters and Reference Orbit Imagery will generate input for the L1B2 standard processing with three major objectives: 1) to provide routine elimination of the errors in the navigation data, 2) to provide routine elimination of the topographic effects on the georectified imagery, and 3) to significantly simplify the standard processing algorithm and reduce its processing load.

The final result of the overall geometric calibration is the Geometric Calibration Dataset which consists of the calibrated Camera Geometric Model (CGM), the Projection Parameters (PP), and the Reference Orbit Imagery (ROI). This dataset is needed for successful L1B2 standard processing.

3.2 ALGORITHM OUTLINE

The concepts of the MISR geometric calibration algorithm can be viewed in two ways. The first view is with respect to time, resulting in two processes called: 1) Preflight Geometric Calibration, and 2) In-flight Geometric Calibration. The second view is with respect to the objectives of calibration, and results in two parts called: 1) Camera Geometric Model (CGM) Calibration, and 2) Creation of Projection Parameters and Reference Orbit Imagery. However, these two views intersect each other. An illustration of the breakdown of the calibration algorithm is given in Table 1. This table does not include preparation of the ancillary dataset (e.g., ground control points). That kind of work is included in the calibration development activities and is separate from the calibration algorithm.

Table 1: Geometric Calibration Algorithm Breakdown

OBJECTIVES *TIME*	Characterize Elements of Camera Geometric Model (e.g., boresight angle)	**1)** Elimination of the errors in navigation data. **2)** Elimination of topographic effects **3)** Simplification of standard L1B2 processing
Before Launch	PREFLIGHT CAMERA GEOMETRIC MODEL CALIBRATION	N/A
After Launch	IN-FLIGHT CAMERA GEOMETRIC MODEL CALIBRATION	CREATION OF PP AND ROI

The completion of the creation of PP and ROI depends on the completion of the in-flight CGM calibration. However, a number of tasks can be completed simultaneously. An overview of the individual tasks is given in the following sections.

3.2.1 Preflight Camera Geometric Model Calibration

The MISR preflight calibration activity includes a group of measurements which are called preflight camera geometric model calibration. The camera model is a mathematical expression that gives an arbitrary pixel's viewing direction, in an appropriate coordinate system, as a function of several variables (the camera model is explained in more detail in the Level 1 In-flight Geometric Calibration ATB document (JPL D-13399). The objectives of the preflight camera geometric model calibration is to characterize those variables (i.e., parameters) in order to: 1) verify that instrument science requirements (geometric) are satisfied before launch, and 2) provide input to the in-flight geometric calibration. The various parameters require different types of calibration, given their sensitivities and expected changes during the life of the instrument. Some of the parameters can be measured simply by inspection or set at specified values during assembly. Other parameters, particularly those sensitive to temperature changes, require more complicated calibration approaches.

For example, the effective focal length will depend on a number of variables, one of those being temperature. The Code V lens model will be used to predict distortion of effective focal length (see Reference[5]). The Code V prediction will be verified during the preflight field-of-view test. This test is also called “pixel-θ measurement”, and is used to determine the focal length as a function of the temperature and field position. If the test results agree with the model we will be able to reliably predict in-flight focal length based on the temperature telemetry. The test will be done in the MISR thermal vacuum chamber (optical characterization chamber (OCC), and is the responsibility of the optical engineering team. More about this test can be found in Reference[1] .

The other preflight calibration task is to define the orientation of a given camera to the optical bench. The measurements of these parameters is the primary motivation behind development of the Collimator Array Tool (CAT) which is described in Reference [9]. The objectives of the CAT measurements are: 1) to verify that camera pointing angles are within the required tolerances of their nominal values, 2) to determine the degree to which pointing varies with temperature, 3) to determine if pointing varies in a repeatable fashion with temperature and verify related requirements, and 4) to verify pointing stability requirements. The CAT boresight algorithm, which will translate CAT measurements into the camera boresight error, is described in a number of design file memoranda (see References[3] and[4]).

An extensive calibration phase for the MISR instrument will be pursued immediately following the assembly of the protoflight cameras. In addition, the camera pointing will be verified at various times between instrument assembly and launch.

3.2.2 In-flight Geometric Calibration

3.2.2.1 Introduction

Due to the deformations of the mechanical connections between the optical bench and the spacecraft platform, caused by launch and gravity release on the camera system, certain parameters of the camera model must be recalibrated during flight. The in-flight Camera Geometric Model calibration is designed to accomplish this task. In addition, a goal of the in-flight geometric calibration is to provide the means to automatically remove the effects of navigation errors and surface topography on the Georectified Radiance Product during standard processing using a simplified approach. The in-flight creation of the Projection Parameters (PP) and Reference Orbit Imagery (ROI) is designed to accomplish these goals.

Since the creation of the PP and ROI will deal with the geometric errors of the complete system, including the spacecraft, MISR optical bench, and individual MISR cameras, the in-flight CGM calibration will focus on each of the cameras independently. The output of the in-flight CGM calibration is required as an input to the creation of the PP and ROI.

3.2.2.2 In-flight Camera Geometric Model (CGM) Calibration

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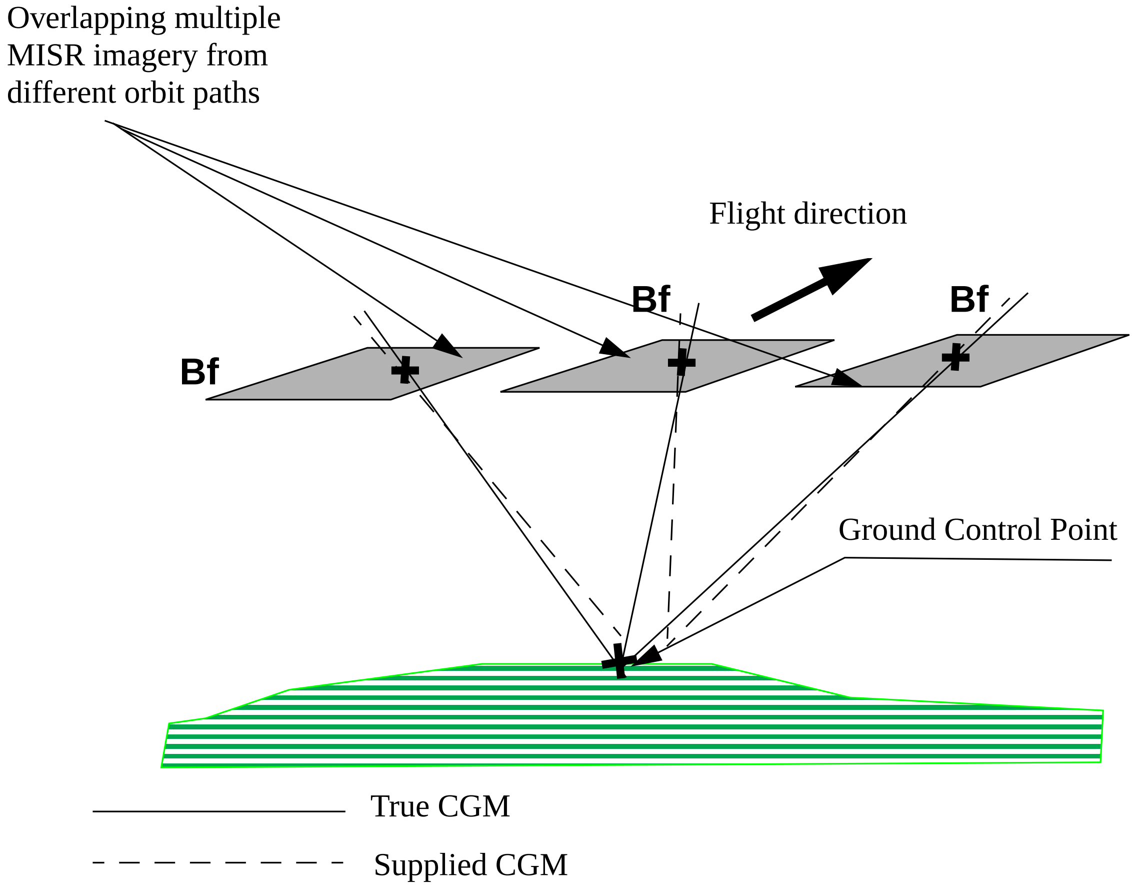

Figure 3: In-flight CGM Calibration

Some of the parameters of the camera model previously characterized during preflight calibration must be verified on orbit. The exact set of parameters to be recalibrated is given in the “Level 1 In-flight Geometric Calibration ATB (JPL D-13399)”. The recalibrated values must stay inside an a priori assigned range. Otherwise, in-flight calibration data and procedures must be reexamined by the members of the Georectification Algorithm Team. Some findings may have to be referred to upper management (see Figure 5). The calibration algorithm will make use of Ground Control Points (GCPs) and it will focus on the recalibration of each camera individually in order to isolate static and systematic (e.g., temperature dependent) errors of the individual cameras from the errors reported in the navigation data. This is possible by having a large number of observations by a single camera of well-defined and well-distributed ground targets or GCPs.

A mathematical expression used to describe the ray between a ground point and the image of that point, as seen by a MISR camera, is used as the model for the least-squares estimation of certain camera model parameters. A large number of observations and good distributions of GCPs is needed so that effects of the errors in the navigation data on the estimation of the camera model parameters can be fully minimized. A single GCP will be seen multiple times from a single camera during a 16-day period, and this significantly increases the number of observations and at the same time provides a good distribution of ground control points across a camera field of view.

The mathematical description of the algorithm along with the error budget analysis is given in the Level 1 In-flight Geometric Calibration ATB document (JPL D-13399).

3.2.2.3 In-flight creation of Projection Parameters (PP) and Reference Orbit Imagery (ROI)

The Level 1B2 Georectified Radiance Product must satisfy the geometric science requirements as stated in the Data System Science Requirements (DSSR) document. The calibrated Camera Geometric Model, even when it meets the geometric instrument science requirements, may not be sufficient to provide a georectified radiance product of the desired accuracy. After applying the calibrated camera model two types of errors remain significant: 1) errors in the navigation data, and 2) displacements due to the surface topography. The following approach is adopted and will be conducted at the SCF in order to remove the effects of those errors. The final result are PP and ROI files.

1) Adjustment.
   A “simultaneous bundle adjustment” (a least square data estimation technique) constrained by a relatively high resolution Digital Elevation Model (DEM) is used to improve the accuracy of the navigation data later used to produce PP and ROI.

   The “simultaneous bundle adjustment” takes advantage of the following MISR characteristics: 1) at a single instant of time MISR “sees” nine different, widely separated, targets on the ground, and 2) a single location on the ground is seen at nine different instants of time. If the errors in the navigation data are modeled as time dependent then it is possible to write a mathematical model which will utilize known MISR characteristics and improve the accuracy of the navigation data.

This model is certainly good for improving relative accuracy (during a time period) of the navigation data. In order to obtain absolute accuracy (i.e., relative to a fixed ground coordinate system) additional ground control information is needed. For that purpose, in addition to already available GCPs, a high resolution DEM can be included as a good constraint to the adjustment.

Also, an algorithm which will accurately identify conjugate (e.g. tie, common) points in the nine images is used as a supplement to the bundle adjustment. This algorithm uses feature extraction and feature matching techniques in order to do identification of conjugate points without human intervention. A supporting method, using a human operator, will also be in place.

2) Forward Projection (Projection Parameters).
Using the improved navigation data, the displacements of the ground points seen by MISR cameras due to the surface topography combined with MISR cameras viewing angle are computed. These displacements are computed using a high accuracy (i.e., subpixeling) forward projection method. Additional information given by this method is that ground points obscured from MISR cameras are recorded. The results of this computation are called projection parameters and they are stored in a file which will be delivered to the DAAC.

3) Reference Orbit Imagery.
The operations described in 1 and 2 will be done a very limited number of times. The PP will provide data which are effectively free of errors in the navigation data and errors due to the topography. In order to take advantage of such information during standard processing, imagery corresponding to the PP must be created. This imagery is called Reference Orbit Imagery (ROI) and is used during image matching of continuously incoming imagery. The creation of the ROI involves a type of image mosaicking in order to obtain maximum cloud-free regions.

3.3 SUPPORTING DATA SETS

The methods proposed for the in-flight geometric calibration require certain data sets to be prepared and tested before launch. The purpose of these data sets is to either provide initial pointing of MISR cameras or to provide additional ground (non-spacecraft) information so that pointing can be improved. The three separate data sets are:

1) Camera Geometric Model dataset (preflight)
This dataset is the result of the preflight camera geometric calibration. It consists of a set of parameters which are used to define the pointing direction of an arbitrary pixel, in the instrument (i.e., optical bench) coordinate system. These parameters reflect distortions (including temperature dependencies) from the ideal optical system. Some of these parameters will be recalibrated in-flight.

2) Ground Control Points (GCPs)
   A single ground control point is a geolocated image patch of a well-defined and easily identifiable ground feature. This ground feature must be found and precisely located in the MISR image, primary via an automated image matching technique or by visual stereo measurement as the second choice. The optimum size (e.g., about 30x30 MISR pixels) of the image patch is driven by the image matching algorithm requirement. The image patch must be produced from the digital imagery with ground resolution much higher than that of MISR. In addition, a corresponding DEM with the appropriate accuracy is needed in order to produce an image patch which is adequate with respect to the geometry and sampling characteristics of MISR cameras.

   Ground control points are used to detect errors in the pointing of a MISR camera, at two occasions during in-flight calibration. First, they are used in order to separate navigation errors from the errors in the camera geometric model, so that parameters of this model can be updated. Later, ground control points will be used as an excellent constraint while correcting navigation data errors. In both cases, the geolocation accuracy, number, and distribution of the GCPs is very important. For example, a pole-to-pole distribution of GCPs is needed in order to remove errors in temperature dependent camera parameters. Also, GCPs should be uniformly distributed across the FOV of a single camera. While searching for and preparing GCP image chips the goal is to obtain accuracy of 1/10 of a MISR nadir pixel for the ground location of the features representing the GCP. More accurate GCPs would not be useful since the 1/10 of a pixel is the accuracy limit of the image matching algorithm. However, depending on the nature and the size of the errors in the camera model somewhat less accurate (no worse than 1/2 of a pixel) GCPs will still be useful during calibration. An optimum required number and distribution of the GCPs will be established during calibration development time. The current estimate is 40 points. However, the calibration software will not be limited to a fixed number of GCPs.

3) Digital Elevation Model (DEM)
   A global digital elevation map will be prepared from DMA DTED-1 data. Gaps in the existing DTED-1 land coverage will be filled with other sources of DEM data (i.e., DCW, ETOP-5). This global elevation map is also called DTED Intermediate Dataset (DID), and it will be prepared for MISR by the Cartographic Application Group (CAG) at JPL. The DID is basically a single DEM dataset consisting of multiple subgrids (physical files), where each subgrid is divided into many identically formatted tiles using the TIFF-6 file format. The elevation postings are on a 3 arcsec grid regardless of the original data source. However, information necessary to determine the source of each posting, elevation accuracy, and possible artifacts will be a part of the DID.

   The DID is used: a) to compute effects of the topography on the geometry of the images taken from nine different viewing angles, and b) as the ground control surface (not point) information used while detecting errors in the navigation data.

3.4 DELIVERABLE

The final product of the in-flight geometric calibration is the Geometric Calibration Dataset (GCD) which will be delivered to the DAAC, and used as an input to L1B2 standard processing. The GCD consist of three major parts:

1) Camera Geometric Model dataset. In particular. there will be nine sets of parameters corresponding to the nine MISR cameras. This is basically the same set of parameters as the one created preflight. The only differences between the in-flight and preflight camera models may be in the values of those parameters which are in-flight calibrated.

2) Projection Parameters (PP) file. The PP file provides geolocation information for as-acquired MISR imagery on a pixel-by-pixel basis. The final result of the L1B2 standard processing is MISR imagery orthorectified (i.e., corrected for terrain displacement) and projected to the Space Oblique Mercator (SOM) map grid, which is also used to define the PP file. The separation between grid points is 275 m which is the nominal ground spacing of the pixels in the MISR images. The ground location of a grid point is given by the definition of the SOM map. The image location of a grid point is given by the pair of coordinates, called the projection parameters. A set of projection parameters covering the SOM map grid as seen by a single camera and corresponding to the red band image data is called the Projection Parameters file.

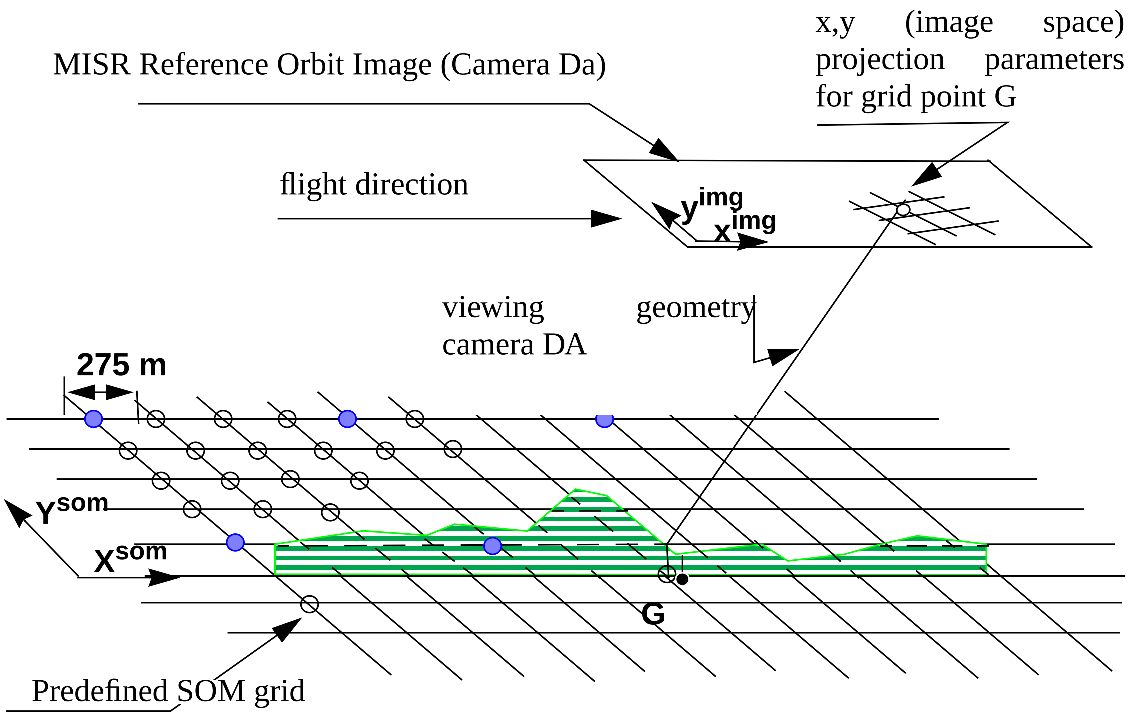

Figure 4: Projection Parameters and Reference Orbit Imagery

There will be nine PP files for each of 233 MISR orbit paths corresponding to 233 orbits of the EOS-AM1 spacecraft 16-day repeat cycle.

3) A specific MISR image related to the PP file is called Reference Orbit Imagery. Even though the PP file and ROI correspond to a single orbit path they may be created from several different orbit passes in order to minimize cloud cover. The red band is used to create ROI for two reasons: a) global imagery at the highest resolution is (275 m) will be obtained in the red band, and b) the red band is the best in regards to the image matching characteristics.

Both of these files, in addition to the pairs of coordinates (PP) and radiance value (ROI), will have some flag data in order to identify conditions like cloudy/clear, or land/ocean, for example.

3.4.1 Geometric Calibration Dataset as input to L1B2

3.4.1.1 Introduction

The L1B2 standard processing algorithm and the Geometric Calibration Dataset were designed concurrently in order to make the standard processing algorithm more robust and less computationally intensive. In particular, PP and ROI data concepts were created due to the specific MISR geometric characteristics and demanding L1B2 standard processing requirements. Having PP and ROI as input will make the routine and autonomous nature of the L1B2 processing much more feasible. In order to have the standard processing working before in-flight calibration is completed, a crude GCD will be initially delivered to the DAAC. During this time the L1B2 standard product will be produced but the geolocation and coregistration accuracy will depend directly on the preflight camera calibration and supplied navigation data only.

3.4.1.2 Use of the calibrated Camera Geometric Model

The CGM approach is a fairly common way of defining the pointing direction of an individual pixel relative to the instrument coordinate system. It has been used in a number of remote sensing mapping missions. Of course, the number and type of parameters depend on the individual sensor characteristics. If translated to photogrammetric terminology the CGM consist of “interior orientation parameters”. Using the same language, the supplied navigation data will define what is called “exterior orientation parameters”. So, CGM in conjuction with the supplied navigation data will provide the pointing vector of an arbitrary pixel, relative to the Earth fixed (i.e., Conventional Terrestrial Reference) coordinate system. This pointing vector is the fundamental information, relative to the geolocation issues, used during L1B2 standard processing, for both the terrain-projected and ellipsoid-projected radiance product (see MISR Level 1 Georectification and Registration ATB, JPL D-11532, Rev. B).

3.4.1.3 Use of the PP and ROI

The PP and ROI are used as a supplement to the projection vector obtained from the CGM and supplied navigation data, while producing the terrain-projected radiance product. In particular, the PP is used to establish an intersection of that pointing vector with the terrain other than a water body; ROI is used via image matching with the new imagery, to provide the pointing correction needed due to the errors in the supplied navigation data. For the ellipsoid-projected radiance product, pointing corrections obtained through the image matching are extrapolated so they can be applied to the mathematically defined ellipsoid surface. Similarly, in areas such as large deserts and cloud covered regions, use of ROI is not attainable so that geolocation and coregistration accuracy is limited by the accuracy of the calibrated CGM, supplied navigation data, and the extrapolated pointing corrections.

4.0 CALIBRATION DEVELOPMENT STRATEGY

4.1 INTRODUCTION

The calibration development represents a large number of tasks which must be accomplished before the launch of MISR. These must meet a number of objectives. The primary goal of the calibration development is to provide the necessary means so that MISR in-flight geometric calibration can start from the first day that newly acquired MISR data ia available, given that other conditions (e.g., radiometric calibration) are adequate. In addition, development requirements for calibration development is planned so that internal deliveries of the calibration dataset are synchronized with the L1B2 standard processing software. Another important factor influencing the calibration development plan is human resource availability.

4.2 ACTIVITIES

The major activities that must be accomplished during calibration development are:

1) Calibration Algorithm development.

2) Dataset development: Ground Control Points (GCPs), DTED Intermediate Dataset (DID), Camera Geometric Model (preflight measurements) Initial PP file.

3) Software development: Calibration Software, DID access software, COTS tools.

4) Documentation: MISR Calibration Data Acquisition Plan, MISR Calibration Mission Operation Plan, Calibration Procedures User Guide.

4.2.1 Calibration Algorithm

The calibration algorithm itself must be the focus of the activities during the early stages. The design and development of the software implementing the algorithm and the related datasets depend on having a well defined and stable algorithm theory. The following algorithm development activities will take place.

1) Test overall feasibility of the calibration algorithm

2) Test and improve algorithm practicability in regard to a limited number and accuracy of ground control data

3) Establish lower bounds in regard to the number and accuracy of ground control data

4) Provide error analysis and error propagation (i.e., quality information) method.

4.2.2 Datasets

The integrity of the in-flight calibration will depend on the quantity and quality of ground control data. Although availability and accessibility of the sources used to generate ground control data (i.e., GCPs and DID) will eventually be greatly expanded, an adequate DID and set of GCPs must be available during development in order to test calibration software and procedures. The possibility of updating these datasets as new sources become available will be a design consideration. The major objectives are:

1) Generate a sufficient number of well distributed GCPs.

2) Produce the DID with the maximum available DTED data included.

3) Perform Quality Assessment (QA) of the DID, comparing it with available DEMs of higher resolution.

In addition to the ground control dataset, the Camera Geometric Model based on the preflight measurements and the initial PP file based on predicted navigation and attitude data must be prepared before launch. These datasets will be used until in-flight calibration is completed, and therefore must be of the same form as the final GCD.

4.2.3 Software

There will be three types of software used during in-flight calibration: 1) software developed by the MISR Georectification Algorithm Team (GAT), 2) software developed by other groups at JPL, and 3) COTS software tools. The MISR DST will develop software implementing the calibration algorithm. The Cartographic Application Group (CAG) at JPL is responsible for software to access the DID dataset. The COTS software will primarily be image processing and GIS packages including specific stereo measurements capability such as those implemented on the modern Digital Photogrammetric Workstation (DPW). Major guidelines related to the software activities are:

1) All of the software shall be controlled by MISR Configuration Management.

2) The calibration software shall be developed and tested according to the MISR software development standards (see Reference [6]).

3) The JPL produced software shall have associated documentation defined by the JPL D-4000 standards (e.g., SRD, Software Test Plan).

4) If appropriate, user guides should be written for certain parts of JPL developed software.

4.2.4 Documentation

This document, In-flight Geometric Calibration Plan, is part of the calibration development effort. Some of the sections in the document will need to be updated during the development period. It is conceivable that one or two sections of this plan will develop into separate documents. For example, a MISR Geometric Calibration Mission Operations Plan may emerge from Section 6.0. Similarly, there may be a separate Calibration Procedures User Guide and L1B2 Validation Plan. It has yet to be determined what and how much of the required information can be placed in a single document as opposed to a number of separate ones. Nevertheless, it is certain that a MISR Calibration Data Acquisition Plan will be required as a separate document. Most of the documentation can be finalized during the later stages of development. Furthermore, the documents which include information based on the specific orbit parameters may require a major update during the first few months of the mission. A separate document already published is the L1 Geometric Calibration ATB (JPL D-13399).

4.3 MILESTONES

The calibration development is synchronized with the development of the L1B2 standard processing software. Thus, major deliveries of the standard processing software are also milestones for the calibration development. The Geometric Calibration Dataset will also be delivered. However, at each of those deliveries an entirely different set of calibration development objectives is met. High level calibration objectives corresponding to the standard processing software deliveries are shown in Table 2, beginning with the algorithm tests and then proceeding to the development of the software in accordance with MISR software standards. However, effort in regard to algorithm improvement and testing will continue with a decreasing intensity as the launch approaches. Similarly, development of the input dataset will go on continuously and will depend on the results from the algorithm testing. The experience from the algorithm and software testing must propagate to the relevant documentation via regular updates. For example, it is expected that there will be four updates of the In-flight Geometric Calibration Plan. Topics such as the Mission Plan and Procedural Plan are ones which are expected to be finalized after algorithm and software tests are concluded.

Table 2: Calibration Development Milestones in relation to the standard processing software delivery schedule (version completion dates are given in the top row)**.**

Version β (03/96)	Version 1 (01/97)	Version 2 (10/97)	Version 2.1 (04/98)
Algorithm 1) Test In-flight Camera Geometric Model 2) Projection Param.File and Reference Orbit Imagery (forward projection only, no mosaicking)	**Algorithm** 1) Test creation of PP and ROI .2) Test the number of control points needed 3) Test the accuracy of DID	**Algorithm** 1) Test the number of control points versus accuracy of DID. 2) Test bundle adjustment and mosaicking.	**Algorithm** 1) Update of bundle adjustment and mosaicking.
Input Dataset 1) Camera Geometric Model (nominal) 2) Ground Control Points (partial) 3) Digital Elevation Model (partial)	**Input Dataset** 1)Camera Geometric Model (realistic) 2) Ground Control Points (well defined) 3) Digital Elevation Model (access software)	**Input Dataset** 1) Ground Control Points (data format) 3) Digital Elevation Model (updated)	**Input Dataset** 1) Dataset in final format. 2) Compression, optimization.
Software 1) Prototype In-flight Camera Geometric Model	**Software** 1)Creation of the Projection Parameters file and Reference Orbit Imagery.	**Software** 1) Additional validation software 2) Formal version of s/w and documentation (SRD, Software Test Plan) 3) Unit test 4) COTS	**Software** 1) Update unit test 2) Test operational procedures 3) Additional validation software
Documentation 1) In-flight Geometric Calibration Plan (first version) 2) ATB	**Documentation** 1) In-flight Geometric Calibration Plan (update) 2) ATB (update)	**Documentation** 1) In-flight Geometric Calibration Plan (update), MISR Calibration Mission Operation Plan, Validation Plan	**Documentation** 1) Plan and Schedule of MISR Data Acquisition Sequence 2) Operational Procedures Test Plan 3) Others as necessary

4.4 PERSONNEL ORGANIZATION

The personnel responsible for work encompassed in this document are in general responsible for the entire algorithm underlying production of the Georectified Radiance Product, and are therefore, called the Georectification Algorithm Team (GAT). The members of this team can be divided into the following groups: a) the photogrammetrists, b) software developers, and c) data analysts. The primary responsibilities of the photogrammetrists are: 1) overall algorithm design, 2) prototype of certain parts of the algorithms, 3) design of test cases, 4) definition of the geometric calibration operations and procedures, 5) participation in the software development, and 6) lead geometric calibration operations, overseeing preparation of the input data (e.g., ground control points), 7) approval of the calibration data. The primary responsibilities of the software developers are: 1) design and coding of the calibration software, 2) software testing, 3) software documentation and 4) participation in geometric calibration operations and analysis of the calibration data. The primary responsibilities of the data analysts are: 1) collection and preparation of the data required as input to the geometric calibration operations, 2) collection and preparation of the test data, 3) acquisition and preparation of the MISR data required for the geometric calibration 4) data analysis during testing, and 5) data analysis during geometric calibration operations.

The Georectification Algorithm Team is lead by the Georectification Engineer (equivalent to a Cognizant Development Engineer or CDE in other MISR subsystems) who reports to the Science Data System Engineer. The MISR Principal Investigator has overall algorithm responsibility and the MISR Science Data System Manager has Project responsibility

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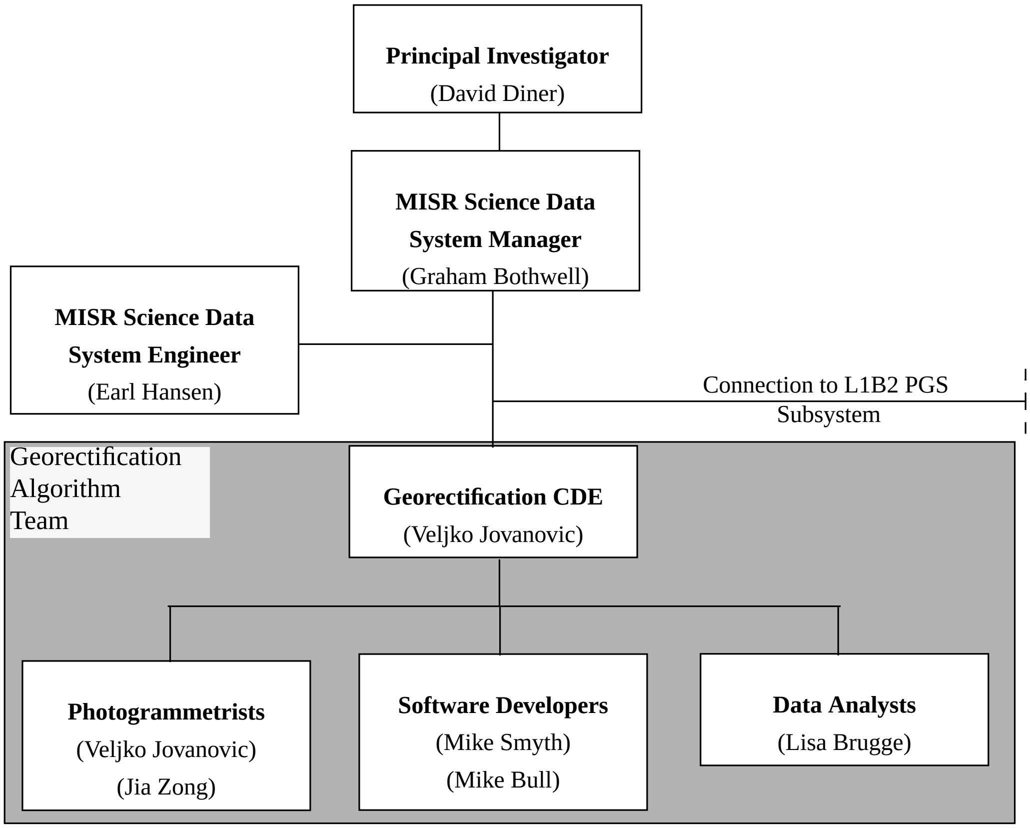

Figure 5: Organization of the Georectification Algorithm Team showing flowdown of responsibility

While Figure 5 presents the nominal organization, in practice there is considerable sharing of the responsibilities, e.g., software developers have been chosen who have certain photogrammetrist capabilities and vice versa.

The current development strategy is partly driven by available human resources, particularly in specialized areas. Specifically, only one person could be assigned 100% during the first development. Another 100% employee is planned early in 1996. Other people will work on the task part time. For instance, in the first part of the development people with the more specific skills and interests (e.g., photogrammetric, ray casting, image matching, image processing) are needed. Later, people with more general software development background will be appropriate. Table 3 provides a summary of the required workforce, relative to the schedule for major software deliveries of the standard processing software.

Table 3: Required work force for the Geometric Calibration Development.

Version B (06/95 - 01/96)	Version 1 (01/96 - 01/97)	Version 2 (01/97 - 10/97)	Version 2.1 (10/97 - 04/98)
Required	**Required**	**Required**	**Required**
1 photogr. 100%	1 photogr 100% 1 photogr 50% 1 s/w devel. 100% 1 s/w devel. 50% 1 data anal. 50%	1 photogr 100% 1 photogr 100% 1 s/w devel. 100% 1 s/w devel. 100% 1 data anal. 50%	Will be defined in the beginning of ‘97.

5.0 DEVELOPMENT TESTING

5.1 INTRODUCTION

During the development phase, before the launch of the EOS-AM1 spacecraft, a number of tests must be conducted so that a reliable set of calibration software, and operational procedures, along with the complete set of ancillary ground control data are ready at the time of launch. All of the tests can be divided into three levels:

- Test of the algorithm and input dataset performance.The first level of testing activities will be used to verify that the calibration algorithm theory provides a proper basis for the production of the required GCD. These tests will happen in the first phase of development. During this phase, versions of the software implementing the calibration algorithm will not be tested thoroughly, e.g., there will be no unit test included for some portions of the algorithm.
- Test of the software. The more extensive software testing will occur in the second development phase. At that time, a more formal version of the software should be developed along with the proper documentation. One of the documents which will be required at that time is the Software Test Plan.
- Test of the operational procedures. In the final phase of the development the operational procedures, which encompasses use of the developed software, COTS software, and required hardware.

Test procedures used for the higher level testing will include extended forms of test procedures used for the lower level testing, as shown in Figure 6.

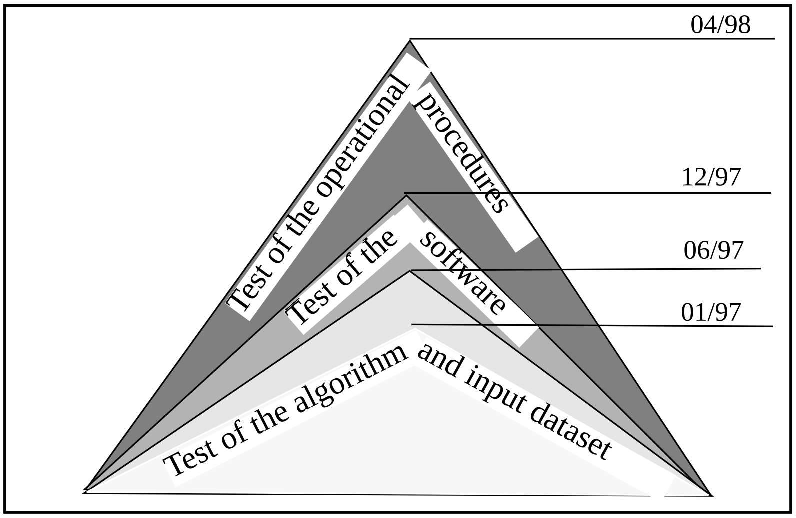

Figure 6: Three levels of development testing

For example, the software-oriented testing requires a larger number of input data cases (software related potential errors in input) and more granularity of the software tested (unit tests) than algorithm-oriented testing. However, underlying procedures and expected results (e.g., two image points being matched) may be the same at each level of testing.

5.2 TEST OF THE CALIBRATION ALGORITHM AND INPUT DATASET

5.2.1 Test Procedures

During the development period before January, 1997, testing activity objectives will be related to the soundness and feasibility of the calibration algorithm. Theoretically, the specific design of the calibration algorithm must provide production of the GCD to meet certain accuracy requirements. For that purpose, the overall calibration algorithm is broken into a number of separate elements which will be independently tested focusing on the accuracy-related capabilities. At the same time this testing will examine the initial version of the software implementing the calibration algorithm. However, extensive software testing is not an objective during this development period. The following is a list of test procedures associated with the various algorithm elements

5.2.1.1 Test of GCP production

In producing an individual GCP image chip, an orthorectified and georeferenced Landsat TM image with associated DEM is used as the input. The centroid of a feature on this image will be selected to be the center of the produced image. While producing the image chip, the Landsat image must be reformatted in order to comply with the geometry and resolution of the MISR cameras.

Objective 1 of the test is to verify that the centroid selected on the orthorectified image is still in the center of the newly reformatted image chip. One additional copy of the Landsat image will be prepared. This copy will contain an artificially placed white-cross target over the centroid of the feature. The location of this white-cross target can be easily measured even after the Landsat image is reformatted. If the location of the target is exactly on the center of the produced image chip then the same software and procedures may be used to reformat the Landsat image without the white-cross target. Otherwise, the software and procedure must be adjusted until the desired result is achieved.
Objective 2 is to test the potential of producing GCPs from images originating from sources other than Landsat TM. The test procedures will be the same, the only difference will be the source of the images used.

5.2.1.2 Test of DID product

The DID will be produced using mostly DTED data (65% of the land surface) and other available global elevation data in areas where DTED is not available.

Objective 1 is to test the accuracy of the elevations obtained using DID products and the corresponding access software. This will be accomplished by comparing DID obtained elevations with the available DEM products of higher resolution and accuracy. The test will be limited to the availability and distribution of the DEM with the higher resolution. This test should verify accuracy of the elevation data used to generate the product. In addition, this test will examine reliability and performances of the DID access software.

5.2.1.3 Test of Ground Point Identification

The Ground Point Identification entails use of area-based image matching software applied on the GCP image chips.

Objective 1 is to test the performance of the image matching algorithm. Two or more images (i.e., Landsat, SPOT) of the same ground location obtained at different times must be available. One of these images will be used to produce a GCP image chip and the other will be used to simulate MISR imagery. The test consists of matching the MISR images with the GCP.

Objective 2 is to establish a quantitative measure of the matching suitability of all GCPs prepared for use during IGC. The matching software will output statistics indicating matching suitability.

Objective 3 is to establish if multiple GCPs are needed at one latitude due to the Sun-angle and seasonal changes. This testing will require several images corresponding to the same ground location obtained at different times of the year. The results of this testing can be related to the needs of multiple ROI (see Section 5.2.1.8, Objective 4).

5.2.1.4 Test of the Least-Square Space Resection

This algorithm element is used to estimate the values of certain parameters of the CGM.

Objective 1 of the test is to verify that parameters of the CGM, which are subject to change relative to the preflight measurements, can be recalibrated during flight. The CGM will be modified by adding errors to those parameters that will be used to produce simulated MISR imagery. At the same time, the nominal CGM will be used while measuring the location of the GCP. The measurement will be used as input to the least-square estimation of preselected parameters. The test includes analysis of the detected errors and associated variance-covariance matrix.

Objective 2 is determination of the optimal number and distribution of the GCPs. The test procedure is very similar to that of Objective 1. The major difference is that errors to be introduced to the CGM must be more realistically predicted by the preflight camera calibration team. A number of cases (number and distribution of GCP versus errors) must be examined.

5.2.1.5 Test of Tie Point Collection

This algorithm element is used to identify and locate tie (i.e., conjugate) points in nine different MISR images.

Objective 1 of this test is to assess the required capability of feature-based matching for tie point collection. The test includes: a) simulation of MISR imagery for nine cameras, b) feature extraction and feature matching c) qualitative and quantitative measurement of the difference between locations obtained through the matching and the correct a priori location known due to the fact that data are simulated.

5.2.1.6 Test of Simultaneous Bundle Adjustment

This adjustment is used to model and estimate errors in the supplied navigation and attitude data.

Objective 1 of this test is to assess the capability of adjusting the estimated piecewise cubic spline polynomial used to account for errors in navigation and attitude data. For that purpose, two sets of navigation and attitude data are generated. The first set, treated as one without errors, is used to obtain image coordinates of the tie points in multiple MISR imagery. The second set, which will contain errors in the navigation and attitude, will be used as input to the adjustment, along with the tie points image coordinates. The estimated piecewise cubic spline should reflect differences between the two sets of navigation and attitude data. This will be assessed by plotting the spline function against the errors introduced so that qualitative and quantitative measures can be made.

Objective 2 is assessment of the function used to interpolate the surface represented by the DID. The procedures described above will be repeated by using different functions for the continuous interpolated surface. The best method will be chosen during this test.

Objective 3 is to estimate the optimum number of tie points and location of the spline’s knots in relation to the tie points. Relevance of this test will depend on the soundness of the predicted navigation and attitude data.

Objective 4 is to determine needs for the GCPs especially in regions where there is no DTED data available.

5.2.1.7 Test of Projection Parameters

The Projection Parameters represent image coordinates of the SOM grid centers as they are seen in multiple MISR imagery. They will be generated using the in-flight calibrated CGM and navigation and attitude data including correction for errors.

Objective 1 is to test the accuracy of the obtained projection parameters. This test will include placement of white-cross targets on the location of the grid points representing the SOM map grid. Then, simulated MISR imagery containing these targets is produced. A corresponding set of projection parameters will be produced via a selected algorithm. The location of the white-cross target should be at the same location as the corresponding projection parameter.

Objective 2 is to test the capability of the algorithm to produce an accurate obscuration mask. This test will be conducted by simulating changes in the ground elevation and deriving the obscuration mask which must reflect those changes.

5.2.1.8 Test of Reference Orbit Imagery

The Reference Orbit Imagery consists of multiple MISR imagery exactly associated with the Projection Parameters. It will be produced as a composite of the MISR images corresponding to one or more orbit passes.

Objective 1 is to assess smoothness and continuity of the ROI, which is a composite of two or more MISR images taken at different times. This objective includes qualitative estimates of the smoothness and continuity using ERDAS “Imagine” image processing software. The quantitative measure must be defined during prototype of the mosaicking algorithm.

Objective 2 is to assess correspondence between the composite ROI and the associated composite PP file.This includes addition of a flag to the composite PP and ROI data. This flag (used only for testing purposes) will indicate the source of the elements in the composite. Overlay of the maps containing these flags will indicate whether the data from the respective sources correspond to each other.

Objective 3 is to estimate the time required to produce cloud-free ROIs. For this purpose a global dynamic data set of at least one-year is needed (e.g., AVHRR).

Objective 4 is to estimate needs for multiple sets of ROI over the same region to account for the effect of seasonal variations on the image matching success rate. So, multiple data over the same region should be used as input to the image matching software with a representative dataset.

5.2.2 Test Data

The data to be used as input during development testing can be classified into the following groups:

1) Simulated MISR imagery
2) Ground Control Points
3) Digital Elevation Models.
4) Simulated navigation and attitude data
5) Camera Geometric Model with the simulated errors
6) Global Dynamic dataset (e.g., AVHRR)
7) Airborne MISR data

The required type and quantity of test data varies depending on the test procedures and specific objectives being investigated. Table 4 provides a summary of the test data associated with the testing of various calibration algorithm elements. Distinction is made between test data required to test general algorithm performance and test data required for investigating optimum quantity and quality of data used as input to the algorithm (e.g., GCP DID, MISR images). The table is read as follows:

- As an example, consider the Least-Square Resection part of the calibration algorithm in the middle column.
- In the second column from the left test objective related to general algorithm performance is stated.
- The test data required by this test objective are given in the left column.
- The test objective related to the input dataset associated with this algorithm element are given in the second column from the right.
- Required test data are given in the right column.

Table 4: Summary of prelaunch tests and required test data

Test data required by Group 1 Objectives	Group 1 (Algorithm performances related objectives)	Corresponding algorithm element	Group 2 (Input dataset related objectives)	Test data required by Group 2 Objectives
10 Landsat TM images representing various image textures adequate for GCP. Associated DEMs must be included.	Test the accuracy of the GCP coordinates after resampling input image source.	GCP production	Test the potential of producing GCP from image sources other than Landsat TM	Geo-registered images other than Landsat TM
A number (?) of high resolution DEMs corresponding to the regions of DID with various sources data.	Test the accuracy of the elevation postings.	DID production	N/A	N/A
10 GCP representing various image textures.	Test the performance of the area-based image matching	GCP identification	Test for the optimum number of GCPs in regards to the Sun-angle and seasonal changes.	10 sets of GCPs distributed at various latitudes. Each set consist of 2-4 seasonal image chips of the same GCP.

Table 4: Summary of prelaunch tests and required test data

Test data required by Group 1 Objectives	Group 1 (Algorithm performances related objectives)	Corresponding algorithm element	Group 2 (Input dataset related objectives)	Test data required by Group 2 Objectives
Simulated error in the CGM.	Test the capability of the algorithm to recalibrate certain elements of the CGM.	Least-Square Resection	Test for the optimum number and distribution of the GCP.	Predicted and suggested errors in the CGM, including worst cases.
About 20 images representing various surface condition and associated DEMs.	Test the accuracy of feature selection and feature matching	Tie points identification	N/A	N/A
Simulated errors in navigation and attitude data. Complete descending part of a orbit.	Test capability of algorithm to model errors and set the appropriate number of time knots at various splines.	Simultaneous Bundle Adjustment	Investigate what is the optimum number of tie points, GCPs, DID cover, and time knots, and interdependencies between these requirements.	Realistically estimated errors in the navigation and attitude data, including possible failures and worst cases.
* (No additional data to the ones listed above are needed).	Test accuracy of the projection parameters and capability of the algorithm to detect obscured pixels.	Forward Projection	Test for the number of ROI, over same ground region, required to allow for the effect of seasonal variations on the image matching success rate	A set of large image files distributed at various latitude with 2-4 images taken at the different times of year corresponding to the same region on the ground.
* (No additional data to the ones listed above are needed).	Test the accuracy and continuity on the boundaries.	Mosaicking PPF and ROI.	Investigate and estimate time required to produce cloud free ROI.	A global dynamic (year around) data set. Resolution may be lower than MISR.
$\sum TestData1$	$\sum Group1$	In-flight geometric calibration	$\sum Group2$	$\sum TestData2$

5.3 TEST OF THE CALIBRATION SOFTWARE

These testing activities, which focus on software related issues, will occur in the period between 07/97 and 12/97. They will be described in detail in the “Calibration Software Test Plan”.

5.4 TEST OF OPERATIONAL PROCEDURES

These testing activities, which focus on operational procedures representing integration of the calibration software and hardware, will occur in the period between 10/97 and launch. These activities will be described later in the “Operational Procedures Test Plan”.

6.0 MISSION OPERATIONS

6.1 INTRODUCTION

This section describes all of the activities related to the MISR geometric calibration which require human involvement. Calibration software development is not discussed as it is not a calibration operation per se. It is merely assumed that the software is ready at the time of launch.

Mission operations required for MISR geometric calibration can be divided into three high level categories:

1) Preliminary operations, which include preparation of the input datasets as well as planning and scheduling data acquisition sequences for the calibration and validation operations

2) Calibration operations, which include actual production of the GCD during the first six months of the mission, and later whenever the conditions under which the GCD produced has been significantly changed. These conditions are status of orbit parameters and parameters of the CGM.

3) Assessment/Validation operations, which include assessment of the: a) statistics generated during L1B2 standard processing b) accuracy of the Georectified Radiance Product and c) accuracy of the Geometric Calibration Dataset. Based on these assessments a need for repetition of the calibration operations and update of the GCD will be determined.

These categories are based upon the objectives and type of output produced by the respective grouping of the operations. However, the goal of this section is to go one step further and precisely identify a set of operations in each group, so that an independent set of procedures can be defined and assigned to each single operation. In that way, an operation can be treated as an independent and easily manageable calibration element with a reasonable size in regards to work force. The connection between individual mission operations is maintained through the input/output datasets.

Figure 7 is an activities diagram showing required mission operations and the connections between them. The flow can be considered as several loops through the activity labelled “Plan and Schedule MISR Data Acquisition”. There are two main flow loops.

The first one is via flows A and B (see Figure 7), returning through D. This deals with the production of the Geometric Calibration Dataset (GCD). This production must be designed as a loop since availability of the MISR data required for the calibration is not known ahead of time. In particular, cloudy MISR images would have the biggest influence on completeness of the GCD. Situations like missing navigation data or MISR radiance data may also occur and cause incompleteness of the GCD after the first run through the loop. Therefore, during configuration and management of the dataset, information about completeness of the GCD is extracted and used

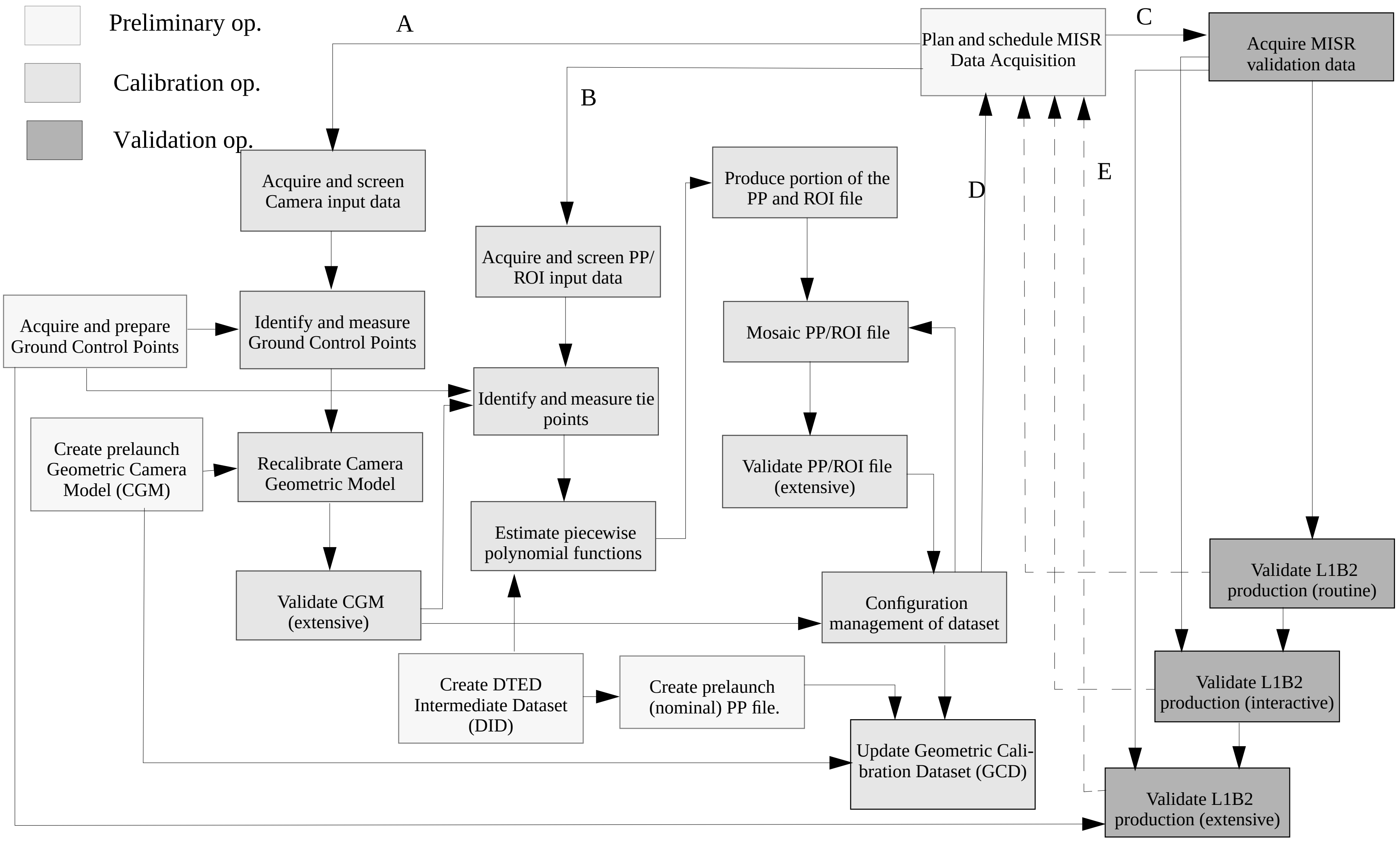

Figure 7: Mission operation related to the In-flight Geometric Calibration

to update the data acquisition plan.

The second main flow path is via C and the three dashed lines E (Figure 7). This deals with validation issues, and may also be a loop depending on the validation results. The dashed lines on the diagram indicate where changes in the data acquisition sequence are needed as a result of negative validation results. Details of each operation are given in the following sections.

6.2 PRELIMINARY OPERATIONS

The goals of preliminary operations are to prepare all the datasets necessary for input to calibration operations and to define “Plan and Schedule of MISR Data Acquisition”. The datasets required as input are: 1) Ground Control Points, 2) DTED Intermediate Dataset, 3) Preflight defined Camera Geometric Model, and 4) Initial (i.e., nominal) Projection Parameters file. The planning and scheduling of MISR data acquisition includes determination of the time intervals for transfer of MISR data from the DAAC to the SCF. The datasets to be transferred are: a) L1B1 radiometrically corrected product, b) navigation and attitude data, and c) engineering data.

6.2.1 Operational Procedures

6.2.1.1 Acquire and prepare Ground Control Points

The procedures included in this operations (for a single GCP) are:

1. Acquire images of the Earth’s surface containing texture suitable for image matching. The resolution must be higher than the nominal MISR resolution. A spectral band close to the wavelength of MISR red band is required. An example would be Landsat TM, Landsat MSS or SPOT images recently acquired.
2. Acquire a DEM corresponding to the same region as the image acquired in step 1. The resolution should be 100 m or higher, preferably at least 30 m.
3. Register image to the DEM using GIS tool.
4. Use image and DEM from the previous step to produce MISR-like image of the Earth surface. Apply nominal MISR viewing geometry and dynamic range of L1B1 radiometrically corrected product.
5. Extract an image chip of appropriate size (about 30 x 30 MISR pixels of 275 m resolution) with the feature of interest as the center of the image chip.
6. Test the matching suitability of the generated GCP image chip.
7. Edit the header of the GCP file and store the file to the GCP’s data base.

6.2.1.2 Create DTED Intermediate Dataset (DID)

The DID and access software will be produced by the Cartographic Application Group at JPL. The same group will produce associated documentation which will consist of a Data Description Document, Programmers’s Guide, and Software Description. The MISR group will test the DID by comparing it with available DEMs of higher resolution.

6.2.1.3 Create prelaunch Camera Geometric Model (CGM)

The goal of this operation is to create an initial CGM. Ground measurements of the camera geometric parameters will be used. The data structure of the initial CGM will be the same as the one from the In-flight Geometric Calibration. The steps are:

1. Collect the results of all of the ground measurements, focusing on the geometric performance of MISR cameras. In particular, those measurements are: a) effective focal length, b) boresight (crosstrack and downtrack), c) distortion (pixel-theta mapping), and d) orientation of the camera relative to the optical bench (CAT measurements).
2. Examine the results of the ground calibration, and make necessary format changes in order to create a data base which will be used to define the orientation of any pixel's viewing direction.
3. Create software to access the data base and create pointing vectors. This software along with the data base constitute the CGM.

6.2.1.4 Create prelaunch (nominal) Projection Parameters (PP) file

The goal of this operation is to create a nominal PP file so that L1B2 standard processing can be conducted even before In-flight Geometric Calibration is completed. However, reliability of this PP file is questionable due to the fact that predicted orbit parameters, navigation and attitude data may significantly differ from the real data during flight. Nevertheless, this file is useful for demonstrating L1B2 processing issues before a more reliable PP file is ready. The steps are:

1. Generate simulated navigation and attitude data using specifications and predicted orbit parameters.
2. Generate a predefined SOM grid based on the predicted orbit parameters.
3. Run a combination of backward and forward projections in order to produce PPs for the SOM grid centers.

6.2.1.5 Plan and Schedule MISR Data Acquisition

The goal of this operation is to define time intervals corresponding to the data segments which must be acquired from the MISR instrument and then transferred from the DAAC to the SCF. In particular, the datasets are: a) L1B1 radiometrically corrected product, b) navigation and attitude data, and c) engineering data.The time intervals will indicate when and how much data should be transferred, i.e., the starting point and duration of each piece of MISR data required for geometric calibration activities. They are primarily defined by the position of MISR footprints relative to the land surface at GCP locations. The following is a list of steps required to create time tables containing these time intervals. One of these tables controls the order of MISR data associated with the GCPs. Another table controls the order of MISR data corresponding to a large part of the orbit, if not the entire orbit. A third table will be related to the MISR data required by the assessment/validation activities. Most of these steps will be done using the ERDAS "Imagine" GIS package:

1. Select a map of the entire Earth to be used as a base map.
2. On the base map indicate the locations of all available GCPs.
3. Once the AM-1 spacecraft is in a stable orbit, overlay 233 orbit paths (i.e., footprints) across the base map.
4. Due to possible changes in the predicted orbit parameters (e.g., longitude of ascending node) the pre-defined SOM grid to be used for PPs may not be acceptable. Therefore, once the AM-1 spacecraft is in a stable orbit re-define the SOM grid, if necessary.
5. For each of the GCPs, predict time intervals which can be used to order MISR data corresponding to the GCP of interest. The overlays of the orbit paths and indicated locations of the GCP should be used to give initial input to the Image Point Intersection (IPI) routine to predict the time intervals. The output of this operation should be a time table with the GCP identification numbers and camera types as the row and column headings. This table will be called the “GCPs time table”.
6. Partition 233 orbit paths with emphasis on segregating the segments without land surface from those that contain land surface. The goal is to avoid transfer of unnecessary data (i.e., water only) to the SCF. An index number should be given to each segment. Also, as in the previous procedure, the ordering time intervals associated with the segments must be predicted so that a time table, called “Reference Orbit (RO) data time table” can be created.

Time tables corresponding to the assessment/validation and possible re-calibration activities, which may occur later, will be created separately from the time tables corresponding to the first cycle of IGC activities.

6.3 CALIBRATION OPERATIONS

The calibration operations are ones which are directly responsible for the production of the Geometric Calibration Dataset. In addition to the conclusions of the preliminary operations, the calibration operations require that the in-flight MISR radiometric calibration is completed, since only radiometrically corrected L1B1 data is appropriate input to the geometric calibration. There are two basic flow paths associated with the calibration operations. One deals with the in-flight calibration of the CGM, while the other deals with the production of the PP and ROI files. However, the results of the calibration of the CGM are required as input to the production of PP and ROI files. The production of the GCD can not be finished in only one pass through the data, due to the expected percentage of cloudy and missing data contained in the input. Therefore, several iterations should be anticipated.

6.3.1 Operational procedures related to the In-flight Calibration of CGM

This follows flow A in Figure 7.

6.3.1.1 Acquire and screen camera input data

The objectives of this operation are: a) to ensure transfer of all necessary data from the DAAC to the SCF, b) to provide cloud-free data, and c) to periodically verify accuracy of timetables.

1. Using the “GCPs timetable”, order MISR data associated with a set of available GCPs.
2. Visually verify the quality of the data: a) verify that image data are cloud-free, and b) verify that image data contain expected features.

6.3.1.2 Identify and measure Ground Control Points

It is assumed that a set (the optimum number has to be established) of the GCPs and required MISR imagery corresponding approximately to these GCP is available on-line. The objective of this operation is to identify and measure the location of the GCPs in the respective MISR images so that corresponding navigation, attitude and camera data can be prepared as input to the next operation. This operation incorporates the following steps:

1. Establish a link between available GCPs and corresponding MISR imagery.
2. Run the image matching algorithm using GCPs and MISR imagery linked to those points.
3. Analyze results of the image matching. Based on the statistical data, identify the points which are not matched or have high probability of being matched erroneously.
4. Manually visit and measure, if possible, the points identified in the previous step.
5. Prepare input data for the next operation.

6.3.1.3 Recalibrate Camera Geometric Model (CGM)

It is assumed that the previous operation is fully completed for a set of GCPs. The objective of this operation is, via a least-square adjustment method, to estimate certain parameters of the CGM. This operation incorporates the following steps:

1. Run the least-square adjustment software.
2. Using the results from the previous step run blunder detection software.
3. Manually visit potential blunder locations and delete them from the adjustment, if necessary.
4. Analyze results of the adjustment.

6.3.1.4 Validate CGM (extensive)

The validation of the CGM is described in Section 6.4.2.

6.3.2 Operational procedures related to the creation of the PP and ROI

This follows flow B in Figure 7.

These operations may start only if the operations described in the Section 6.3.1 are fully completed for the entire set of GCPs. The following is a list of the independent operational elements and associated procedures which constitute in-flight creation of the PP and ROI:

6.3.2.1 Acquire and screen PP/ROI input data

The objectives of this operation are: a) to ensure transfer of all necessary data from DAAC to the SCF, b) to obtain cloud-free data, and c) to periodically verify accuracy of time tables.

1. Using the “RO data timetable” look at the browse data and then, if appropriate, order MISR data associated with the selected set of orbit segments.
2. Mask cloudy regions and define regions useful for production of PP and ROI. First, use conservative cloud screening algorithm and then finish up with visual inspection of ambiguous regions.
3. Periodically verify positional accuracy of image data.

6.3.2.2 Identify and measure tie points

The assumption is that MISR imagery (usable data, i.e., land and surrounding water) from all nine cameras corresponding to a single orbit is available on-line at the SCF. The objective of this operation is to identify and measure the locations of the conjugate features on the maximum number of cameras so that input to the Simultaneous Bundle Adjustment can be prepared. This operation incorporates the following steps:

1. Extract the features in all nine cameras.
2. Run the feature-based image matching algorithm.
3. Analyze results of the image matching and run a blunder detection algorithm.
4. Display locations of the matched features and, based on the number and distribution, assess necessity to manually measure tie points.
5. Manually measure tie points using stereo workstation.
6. Prepare input data for the next operation.

6.3.2.3 Estimate piecewise polynomial functions

The objective of this operation is to estimate the errors contained in the navigation and attitude data. This operation incorporates the following steps:

1. Estimate initial piecewise cubic spline polynomial. The tie point measurements from the previous operation will be used here. The objective is to define knots of the spline depending on the distribution of the tie points.
2. Run the simultaneous bundle adjustment software.
3. Run a blunder detection algorithm.
4. Visually investigate suspected blunder locations and remove confirmed blunders from the adjustment.
5. Analyze statistics associated with the estimated piecewise splines.
6. If necessary change the position of the spline’s knots and rerun the adjustment.
7. Check the accuracy of the estimated piecewise splines using previously selected check points.

8. Prepare input to the production of the PP.

6.3.2.4 Produce portion of the PP and ROI files

This operation requires input from previous operations. The objective is to produced PP and ROI files which will be used as input to the mosaicking of the final PP file. The extent of the PP file is defined during screening of the input data.This operation incorporates the following steps:

1. Run a combination of backward and forward projections in order to produce PPs. This output will be used later during mosaicking.
2. Extract portion of the MISR imagery. The extent of the extracted region must be the same as in the previous step. This ROI will be used later during mosaicking.
3. Investigate correspondence between portions of the PP and ROI files and make any necessary corrections.

6.3.2.5 Mosaic PP and ROI file

The creation of the PP and ROI corresponding to a single orbit path will require data from more than one orbit pass. The objective of this operation is to combine data from various orbit passes and mosaic them into a seamless continuous file. The precise set of procedures is yet to be defined.

6.3.2.6 Validate PP/ROI files (extensive)

The validation of the PP/ROI is described in Section 6.4.3.

6.3.3 Operational procedures related to the entire GCD

6.3.3.1 Configuration management of GCD

The objective of this operation is to maintain version control and obtain information about completeness of the current GCD. The MISR configuration management tool (i.e., ClearCase) is to be used for this operation. The steps are:

1. Based on the validation results, accept or reject portion of the GCD.
2. Assess completeness of the GCD and prepare information to be used for additional planning and scheduling of MISR data acquisition.
3. Prepare data to be sent back to the calibration loop.
4. Prepare data to be sent to the DAAC.

6.3.3.2 Update GCD

This operation entails transfer of the GCD from the SCF to the DAAC. The procedures to be conducted at the DAAC to replace the old GCD with the latest one will be defined later.

6.4 VALIDATION OPERATIONS

6.4.1 InteractiveInteractiveIntroduction

Validation operations will occur immediately after calibration operations are over and then periodically throughout the mission. The objectives of these operations are to assess accuracy of the GCD and to verify that the L1B2 Georetified Radiance Product continuously meets the geolocation and registration accuracy requirements. Based on the result of these operations the need for repetition of the calibration operations and updating of the GCD will be determined.

In this section, the concepts underlying assessment/validation tasks during in-flight geometric calibration and throughout the mission will be described. The assessment/validation procedures will be mostly derivations of the test procedures described earlier in Section 5.0. Nevertheless, we separate these tests due to important differences characterizing validations: a) real MISR and spacecraft data, b) acceptance criterion must be precisely established, c) limited amount of time available, and d) the goal is to validate data not to test and improve the algorithm. In this section, only a high level description of the assessment/validation operations and procedures is given. A more detail validation plan will be produced later.

The assessment/validation operation is divided into three groups based on the amount of required resources and level of completeness:

1) **Routine:** Routine assessment operation is an automatic process running with very little involvement of an analyst. It is based on the analysis of the statistical data obtained during L1B2 standard processing. The objective of this group of assessment procedures is to continuously monitor the quality of the L1B2 Georectified Radiance Product (GRP) with a inexpensive technique. The main disadvantages are related to the limitations and confidence level of the statistics used. However, the expectation is that this assessment will indicate some of the more obvious problems with the product. In those cases more demanding and more complete assessment/validation operations will be triggered.
2) **Interactive:** Interactive assessment operation is a process controlled by an analyst. It is based on the visual inspection of image or graph data. The objective is to recognize bad quality data without the need for more extensive validation processing. The main limitations is that only data anomalies visible to the human eye can be detected. However, the expectation is that this assessment is used as a filter before more demanding validation is attempted. In some cases the interactive assessment is the initial part of the extensive validation.The interactive assessment activity is either scheduled or triggered by a routine assessment.

Table 5: High level assessment/validation activities

	CGM	ROI & PP	L1B2 Georectified Radiance Product	
ROUTINE ASSESSMENT.	▨	▨	YES, after In-flight Geometric Calibration is concluded	Throughout the mission
INTERACTIVE ASSESSMENT	▨	▨	YES	During In-flight Geometric Calibration
	▨	YES, if required by the interactive assessment of L1B2 product	YES	Two times a year
	▨	YES, if required by the interactive assessment of L1B2 product	YES	After Lunar maneuvers
	▨	YES, if required by the interactive assessment of L1B2 product	YES, if required by the routine assessment	Occasional
EXTENSIVE VALIDATION	YES	YES		During In-flight Geometric Calibration
	YES	YES, if required	YES	Once every year
	YES	YES, if required	YES	After Lunar maneuvers
	YES, if required	YES, if required	YES, if required by the routine assessment	Occasional

3) **Extensive:** Extensive validation operation is a process which requires elements such as: a) analyst, b) special software and hardware, and c) external data. The objective is to fully investigate certain aspects of the data and make a quantitative assessment. The main restriction is that only limited amounts of data can be extensively validated due to the availability of external data and the resources required by the process. The extensive validation operation is either scheduled or triggered by a routine or interactive assessment.

The assessment/validation operations will be described in more detail later in this section. Table 5 shows when certain types of assessment/validation activities will be conducted in relation to a dataset. This table can be used as a high level assessment/validation plan.

6.4.2 Validation operation related to the Camera Geometric Model

There are no routine or interactive assessments focused on the CGM only.

The extensive validation of the CGM will occur primarily during in-flight geometric calibration. There are two basic parts of this validation:

Part I focuses on the rationality of the individual parameters of the CGM which are calibrated in-flight. Results obtained during in-flight calibration are compared with the preflight measurements. The differences shall be less than the thresholds determined through the preflight analysis. If not, a possible blunder exists in either in-flight or preflight measurements. Therefore, these actions should follow: a) investigate in-flight calibration measurements in order to find possible blunders, b) if found, repeat comparison with the preflight measurements, c) if not, report the finding to the higher organizational level.

Part II focuses on the absolute accuracy of the entire in-flight calibrated CGM. For this validation about 10 GCPs are set aside as check points (i.e., not used during calibration). The image coordinates of those GCPs on MISR images are measured manually and used as the reference. Then, using a mathematical model which includes CGM, the image coordinates of the GCPs are computed. There will be two sets of computed image coordinates. One set is obtained using preflight CGM while another set is obtained using in-flight calibrated CGM. The differences between computed and manually measured image coordinates will provide the answer about the accuracy of the in-flight calibrated CGM.

It should be pointed out that Part II validation may also occur sometime during the mission if triggered by the results of validation of the L1B2 product, ROI and PP. The results of this validation may motivate a repeat of the in-flight geometric calibration of CGM.

6.4.3 Validation operation related to the Projection Parameters (PP) and Reference Orbit Imagery(ROI)

There are no routine assessments of the PP and ROI.

The interactive assessment of PP and ROI will be conducted as a separate procedure only if motivated by the result of L1B2 GRP validation. During in-flight geometric calibration this assessment is part of an extensive validation. The activities include display of the PP and ROI files as raster images using ERDAS image processing software. The display can be in independent windows or overlays in a single window. The assessment focuses on visual investigation of the displayed images. Anomalies such as: a) unusual patterns in either of the files, b) unexpected cloudy data, or c) bad correspondence between the two files when displayed as overlays, will directly motivate new in-flight calibration efforts. So, the extensive quantitative validation can be avoided in this kind of situation.

The extensive validation of PP and ROI will occur on two occasions. First, during in-flight geometric calibration and second if motivated by the result of L1B2 GRP validation and interactive assessment of PP and ROI. The extensive validation focuses on the geometric accuracy of the PP in regards to the corresponding ROI. These validations are divided into two parts. Part I requires external data sources (i.e., GCPs) and will provide validation of the absolute accuracy of the PP and associated ROI on a limited number of locations. Part II uses nadir ROI and PP as the reference so that validation of relative accuracy (i.e., coregistration) between the nine cameras can be obtained on a global scale. In both cases the differences between measured image coordinates and those obtained through the PP are used as the quantitative measure. This validation may trigger recreation of the PP and ROI.

6.4.4 Validation operation related to the L1B2 Georectified Radiance Product

The routine assessment of the L1B2 product consists of automatic analysis of certain statistics obtained during L1B2 standard processing. These statistics are: a) percentage of image matching points used for the registration of one grid cell, b) standard deviation of the mapping function between new and reference imagery, and c) average difference (per grid cell) between predicted location of the grid point and one obtained after image location. These statistics will be analyzed at the SCF, and the results may trigger more demanding validations of the L1B2 product which are not scheduled originally.

The interactive assessment may be either scheduled or triggered by routine assessment of the L1B2 product. It includes a display of the georectified radiance product and visual inspection in search of possible anomalies. Images corresponding to the nine cameras may be displayed independently or as overlays using ERDAS image processing software. Anomalies such as: a) missing data, b) unusual patterns, and c) significant differences between cameras will indicate problems with the data and either avoid or trigger further extensive validations depending on the nature of the problem.

The extensive validation may be either scheduled or triggered by the routine and interactive assessment of the L1B2 georectified radiance product. It includes radiometric and geometric accuracy assessment. For assessment of the absolute geometric accuracy, external data, such as registered Landsat TM imagery, may be sufficient. However, for a reasonable assessment of radiometric accuracy, registered data obtained with an instrument with similar viewing characteristics (e.g., airborne MISR) must be available. In cases where there is no external data available only geometric consistency of the L1B2 standard processing may be validated. The validation consist of computing and analyzing differences between MISR data and “true data” (external or MISR data selected for reference).

7.0 HARDWARE AND SOFTWARE REQUIREMENTS

7.1 INTRODUCTION

In general, the MISR SCF at JPL is designed to: a) provide support to the science team research activities, b) provide an environment for developing, maintaining and updating algorithms and production software used by the DAAC, c) provide support for instrument integration and calibration activities, and d) provide an interface with the DAAC for data validation and quality assessment. The SCF is a network of computer workstations, peripherals, operating systems and application software.

In regards to the In-flight Geometric Calibration (IGC), the SCF shall: a) provide an environment for developing, maintaining, and updating in-flight geometric calibration algorithms and software, b) provide support for the collection, analysis, reduction, storage and access, to ground control information (i.e., GCPs and DID), c) provide connectivity and data transfer between the DAAC and SCF, and d) provide support for in-flight geometric calibration and validation, during the mission.

The following sections represent estimates affecting the system resources associated with the IGC activities. Also, data interchange scenarios and SCF hardware and software requirements are presented. The estimates and the requirements related to the preflight development period may differ significantly from those related to the in-flight calibration period.

7.2 IGC DATASET VOLUMES

7.2.1 Introduction

Volume estimates for the datasets have been made with respect to three major activities of the IGC: 1) collection of GCPs image chips and test data, 2) calibration of the CGM, 3) creation of the PP and ROI. In the last two components, the period of development will be delimited from the time during flight period.

7.2.2 Collection of Ground Control Points and test data

The first table gives volume estimates of the elements of the datasets used during development phase while creating GCPs and test data. These volumes correspond to the smallest element (i.e., unit) of a dataset. The 1% expansion is given to each unit to account for header and ancillary information.

Table 6: Data volume estimates of the datasets used for creation of GCP image chips test data (reported size/unit)

Dataset	Estimates	Mbytes
Landsat Image (including DEM)	given	150

The following table represents volume estimates for the data to be used during collection and creation of GCPs and test data. In particular, the required number of units, introduced in the previous table, is estimated and multiplied by the unit volume. Two scenarios are pertinent: 1) the total volume of the data to be in storage, and 2) the volume of the data required to be on-line. The volumes for the data to be in storage are expanded by 100% to account for backup and overhead space. The most probable input for GCP collection and generation of test data will be Landsat images with associated DEMs. A minimum of three copies of an image must be on-line: 1) acquired version, 2) reformatted for input in ERDAS Imagine tool, and 3) prepared as the input to the program which produces the GCP image chip. The maximum amount of disk space to be available on-line is calculated based on the expectation of working on five GCPs at the same time.

Table 7: Development period: Volume estimates of the datasets to be used for the collection of GCPs and test data: A) total required to store, B) required to be on-line

Input data	A) Total		B) On-line			
			Min		Max	
	Number of units	Mbytes (add 100%)	Number of units	Mbytes	Number of units	Mbytes
CGM	50	15000	3(formats)	450	5(GCP) x 3(formats) = 15	2250

7.2.3 Calibration of the CGM

The first table gives volume estimates of the elements of the datasets used during in-flight geometric calibration of the CGM. These volumes correspond to the smallest element (i.e., unit) of a dataset. The 1% expansion is given to each unit to account for header and ancillary information.

Table 8: Data volume estimates of the datasets used for in-flight geometric calibration of the CGM (reported size/unit)

Dataset	Estimates	kbytes
CGM (single camera)	73 (parameters) x 4(byte/parametrs) = 292 add 1%	0.3
GCP (one image chip)	40(lines) x 40(pixel/lines) x 2(byte/pixel) = 3200 add 1%	3.2
MISR images (single segment, during development)	100(lines) x 1504(pixel/lines) x 2(byte/pixel) = 300800 add 1%	303.8
Navigation data (per orbit)	see MISR Science Data Processing Estimate (SDPE D-12569)	268
Engineering data (per orbit)	see MISR SDPE	213
Camera engineering data (per orbit)	see MISR SDPE	548

The following table represents volume estimates for the data to be used during in-flight geometric calibration of the CGM. In particular, the required number of units, introduced in the previous table, is estimated and multiplied by the unit volume. Two scenarios are of particular interest: 1) the total volume of the data to be in storage, and 2) the volume of the data required to be on-line. The volumes for the data to be in storage are expanded by 100% to account for backup and overhead space.

This table refers to the development period, before launch. The dataset volumes for the period after launch may be different and they are NOT DEFINED at this time.

Table 9: Development period: Volume estimates of the datasets to be used for the development of the software for in-flight geometric calibration of the CGM: A) total required to store, B) required to be on-line

Input data	A) Total		B) On-line			
			Min		Max	
	Number of units	Mbytes (add 100%)	Number of units	Mbytes	Number of units	Mbytes
CGM	9	0.0054	1	0.0003	1	0.0003
GCP	40 x 9(cameras) = 360	6.5232	1	0.0032	40	0.2416
MISR images (during development)	40(points) x 9(camera/point) 3(image/camera) = 1080	589.020	1	0.303	120	36.490
Navigation data	30	9.2	1	0.268	30	9.2
Engineering data	30	12.4	1	0.213	30	12.4
Camera engineering data	30	33	1	0.548	30	33
TOTAL		650.148		1.335		91.332

7.2.4 Creation of the PP and ROI

The first table gives volume estimates of the elements of the datasets used during creation of the PP and ROI. These volumes correspond to the smallest element (i.e., unit) of a dataset. The 1% expansion is given to the each unit to account for header and ancillary information.

Table 10: Volume estimates of the datasets used for in-flight creation of PP and ROI (reported size/unit)

Dataset	Estimates	kbytes
CGM (single camera	73 (parameters) x 4 (byte/parameters) = 292 add 1%	0.3
DID (single file 10 x 10 degree, 3 sec. pixel resolution)	12000 x 12000 (pixel) x 2 (byte/pixel) = 288000000 add 1%	290880
MISR imagery during development (segment of 1000 lines)	1000(lines) x 1504(pixel/lines) x 2(byte/pixel) = 3008000 add 1%	3038.0
PP file (segment of 1000 lines)	1000 (lines) x 2100(pixel/line) x 5(byte/pixel) = 13536000 add 1%	13671.4
Navigation data (per orbit)	see MISR Science Data Processing Estimate (SDPE D-12569)	268
Engineering data (per orbit)	see MISR SDPE	213
Camera engineering data (per orbit)	see MISR SDPE	548

The following table represents volume estimates for the data to be used during in-flight creation of the PP and ROI. In particular, the required number of units, introduced in the previous table, is estimated and multiplied by the unit volume. Two scenarios of particular interest are: 1) the total volume of data to be in storage, and 2) volume of data required to be on-line. The volumes for the data to be in storage are expended by 100% to account for backup and overhead space.

This table refers to the development period, before launch. The dataset volumes for the period after launch may be different and they are NOT DEFINED at this time.

Table 11: Development period: Volume estimates of the datasets to be used for in-flight creation of PP and ROI: A) total required to store, B) required to be on-line

Input data	Total		On-line			
	Number of units	Mbytes (add 100%)	Min		Max	
			Number of units	Mbytes	Number of units	Mbytes
CGM	9	0.0054	9	0.0054	9	0.0054
GCP	40(GCP) x 9(cameras) = 360	6.2532	9	0.1563	90	1.563
DID	612	35603	1	58.174	17 x 3 = 51	2966.9
MISR images (during development)	72(units) x 9 (cameras) = 648	3995.6	2(units) x 9 (camera) = 18	110.988	648	3995.6
PP file	72(units) x 9 (cameras) = 648	17717.6	9	246.078	72	1968.5
Navigation data	30	9.2	1	0.306	1	0.306
Engineering data	30	12.4	1	0.413	1	0.413
Camera engineering data	30	33	1	1.1	1	1.1
SUM		57377.1		361.7		8934.4

7.3 TRANSFER DAAC-SCF-DAAC

The data transfer rate required by the in-flight calibration activity influences the design of the SCF-DAAC connection. Figure 8 shows IGC related data to be exchanged between these two facilities.

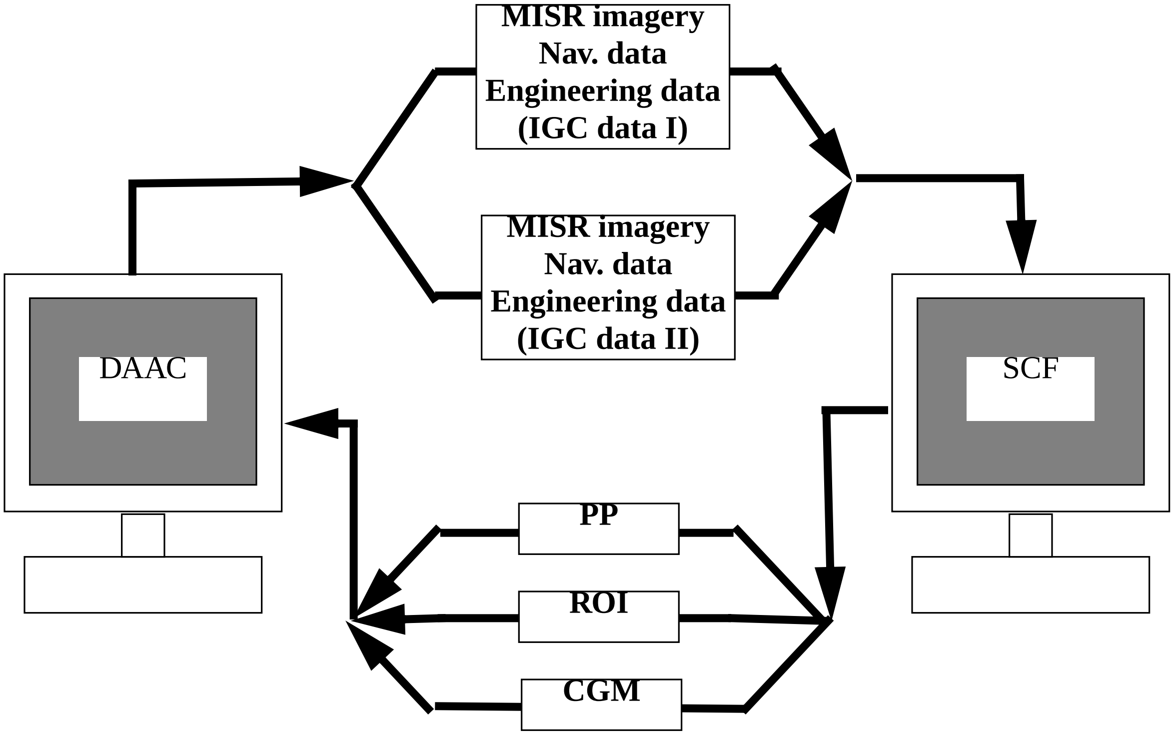

Figure 8: Transfer of data related to the IGC. “IGC data I” are related to the In-flight geometric calibration of CGM and “IGC data II” are related to the creation of PP and ROI

The transfer of “IGC data I” will start after in-flight radiometric calibration is concluded. It should last for about 30 days. These data are required only when MISR passes over a ground control point. In order to compute the data transfer rate the following assumptions are made:

1) There will be 60 GCPs.
2) During the period of 30 days each GCP will be seen four times.
3) Each time a GCP is observed 60 seconds worth of data per camera will be requested.
4) The average time of a orbit is set to be 5933 sec.
5) The amount of navigation and engineering data is insignificant when compared with the amount of MISR imagery, so it is excluded from estimates.

The data exchange rate estimates are given in the following table:

Table 12: Estimate of “IGC data I” exchange rate.

GCP	MISR imagery	Nav. data	Engineering data	Rate
60 GCP x 4 request/GCP = 240 request	60 seconds/camera / 0.0408 seconds/line = 1470 lines x 1504 pixel/line x 2 byte/pixel = 4.4 Mbyte/camera x 9 cameras = 39.6 Mbyte			
240 x	(39.6 +	insignificant	insignificant)	= 9504 Mbyte / 30 days = **316 Mbyte/day**

The transfer of “IGC data II” will start after in-flight radiometric calibration is concluded. It should last about 150 days. In order to compute the data transfer rate the following assumptions are made:

1) The data transfer would be required for 233 orbit paths.
2) For each orbit path four sets of data (on average) would be required in order to be able to maximize cloud-free region.
3) It is expected that only 50% of total data volume would be of interest for creation of PP and ROI. This 50% is obtained by assuming that land represents 30% of total land surface and another 20% is allocated for surrounding water.

The data exchange rate estimates are given in the following table.

The Geometric Calibration Dataset (GCD) consisting of CGM, PP, and ROI will be transferred from the SCF to the DAAC. A first transfer of the full datasets should be completed in the 180 days during in-flight geometric calibration activity, which will start after in-flight radiometric calibration is concluded. In order to estimate the data transfer rate the following assumptions are made:

1) The data volume corresponding to the CGM is insignificant when compared with the data volumes of PP and ROI. Therefore, CGM is not included in these estimates.
2) The data transfer is required for 50% of the total data corresponding to 233 orbits. The assumption is that PP and ROI are required only for the land portion of Earth surface (30%) and surrounding water (20%).

The data exchange rate estimates are given in the following table:

Table 13: Estimate of "IGC data II" exchange rate.

Orbit paths	MISR imagery	Nav. data	Engineering data	Rate
233 orbit paths x 4 request/path = 932 request x 50% (land+water)	72727 line/orbit x 1504 pixel/line x 2 byte/pixel = 218.8 Mbyte x 9 cameras = 1968.8 Mbyte			
466 x	(1968.8 Mbyte +	insignificant	insignificant)	= 917.5 Gbyte / 150 days = **6.1 Gbyte/day**

Table 14: Estimate of GCD (PP, ROI, CGM) exchange rate.

PP	ROI	CGM	Rate
233 orbit paths x 72727 line/orbit x 1504 pixel/line x 4 byte/pixel = 102 Gbyte x 9 cameras = 1835.1 Gbyte x 50% (land+ water) = 459 Gbyte	233 orbit paths x 72727 line/orbit x 1504 pixel/line x 2 byte/pixel = 51 Gbyte x 9 cameras = 458 Gbyte x 50% (land+ water) = 229.3 Gbyte		
459 +	229.0 +	insignificant	= 688 Gbyte / 180 days = **3.8 Gbyte/day**

7.4 IGC PROCESSING LOAD ESTIMATES

This will be estimated at the beginning of 1997 once version 1 of the IGC software is completed.

7.5 SPECIFIC CAPABILITIES

During development of IGC software and, in particular, during in-flight geometric calibration the SCF must provide specific operational capabilities. In particular:

1) Continuous display (monoscopic) of multiple MISR imagery
2) Continuous roaming through entire orbit of MISR image
3) High accuracy, i.e., better than 1/10 of a MISR pixel, 2D image coordinate measurement
4) Continuous display (stereoscopic) of pairs of MISR imagery
5) High accuracy (i.e., better than 1/10 of a MISR pixel when translated to the image) 3D ground point measurements
6) Image processing application
7) A limited scope of Geographic Information System (GIS) applications
8) Composing GUI on top of available image processing and GIS application software
9) Simultaneous display of multiple imagery and GUI forms requiring screen space larger than usual
10) High quality image printing

The listed operations require specific hardware and software to be part of the SCF.

8.0 REFERENCES

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