JPL D-13400, Rev. A

Earth Observing System

MISR

Multi-angle Imaging Spectro-Radiometer

Level 1 Ancillary Geographic Product Algorithm Theoretical Basis

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Jet Propulsion Laboratory
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Multi-angle Imaging SpectroRadiometer (MISR)

Level 1
Ancillary Geographic Product
Algorithm Theoretical Basis

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The MISR web site should be consulted to determine the latest released version of this document (http://www-misr.jpl.nasa.gov). Approval signatures are on file with the MISR Project.

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Document Change Log

Revision	Date	Affected Portions and Description
Original	September, 1996	All
Revision A	November 26, 1999	Algorithm to compute the average surface normal zenith angle, average surface normal azimuth angle, as well as standard deviation of scene elevation to mean slope.

TBD List

Location	Description
3.4.2	Algorithm for projecting from Plate Carrée to Albers Equal Area will be determined during Verion 2 activities.
3.6.3	Algorithm for projecting from Albers Equal Area to SOM will be determined during Verion 2 activities.

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Acronym List

A

ADP..Algorithm Development Plan 3-18
AGP..Ancillary Geographic Product 3-1
AGPID ....AGP Intermediate Dataset 3-1
ATB..Algorithm Theoretical Basis 1-1

C

CAG ....Cartographic Applications Group 3-3, 4-1
CCD ....Charge-Coupled Device 2-1
CM ....Calibration Mode 2-1

D

DAAC ....Distributed Active Archive Center 2-2
DEM.......................................Digital Elevation Model 3-3
DID ....DTED Intermediate Dataset 3-1
DMA ....Defense Mapping Agency 3-1
DPD..Data Product Description 1-2
DSSR ....Data System Science Requirements 1-2
DTED.....................................Digital Terrain Elevation Dataset 3-1

E

EIP..Experiment Implementation Plan 1-2
EOS ....Earth Observing System 3-1
ESRI.......................................Environmental System Research Institute 3-8

G

GIS ....Geographic Information System 3-8
GM ....Global Mode 2-1

I

IFOV ....Instantaneous Field of View 2-1
ISR ....Instrument Science Requirements 1-2

J

JPL ....Jet Propulsion Laboratory 1-2, 3-3

L

LM..Local Mode 2-1

M

MISR......................................Multi-angle Imaging SpectroRadiometer 3-1

1.0 INTRODUCTION

1.1 PURPOSE

This Algorithm Theoretical Basis (ATB) document describes the algorithms used to derive the parameters which make up the Level 1 Ancillary Geographic Product (AGP). These parameters are summarized in Table 1. In particular, this document identifies the sources of input data, both MISR and non-MISR, required for parameter derivation, and provides the physical theory and mathematical background underlying derivation of the AGP.

Table 1: Level 1 Ancillary Geographic Product Description By Parameter

Parameter name	Units	Horizontal Sampling and (Coverage)	Comments
Geographic latitude	deg	1.1 km (Global)	• Relative to WGS84 ellipsoid
Geographic longitude	deg	1.1 km (Global)	• Relative to WGS84 ellipsoid
Average scene elevation	m	1.1 km (Global)	• Relative to WGS84 ellipsoid
Point elevation	m	1.1 km (Global)	• Relative to WGS84 ellipsoid
Standard deviation of scene elevation	m	1.1 km (Global)	• Calculated from sub-1.1 km data • If sub-1.1 km data not present, a flag will indicate source.
Regional average scene elevation	m	17.6 km (Global)	• Relative to WGS84 ellipsoid
Regional standard deviation of scene elevation	m	17.6 km (Global)	• Calculated from 1.1 km data
Average surface-normal zenith angle	deg	1.1 km (Global)	• Relative to WGS84 ellipsoid-normal at surface
Standard deviation of scene elevation relative to mean slope	m	1.1 km (Global)	• Calculated from values used to establish the surface and slope
Average surface-normal azimuth angle	deg	1.1 km (Global)	• Relative to local North at WGS84 ellipsoid
Land/water identifier	none	1.1 km (Global)	• Land/ocean/inland water/ephemeral water/coastline mask
Dark water algorithm suitability mask	none	1.1 km (Global)	• Corresponds to ocean or inland water areas which are ≥5 km from a shoreline and >50m deep

1.2 SCOPE

This document serves to identify sources of input data, provides a background to the algorithm selection, and gives a mathematical description of the processes to be used for creation of the AGP. It also describes the practical considerations which must be factored into the algorithm development. Chapter 1 defines the AGP, and lists MISR project and reference documents relevant to AGP production. Chapter 2 gives an overview of the instrument and MISR processing. Chapter 3 gives the theoretical basis of AGP processing. Chapter 4 lists assumptions and limitations.

1.3 APPLICABLE MISR DOCUMENTS

A listing of applicable MISR Project documents is provided below. The MISR web site (http://www-misr.jpl.nasa.gov) should be consulted to determine the latest released version of each of these documents.

1.3.1 Controlling Project Documents

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

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

1.3.2 Reference Project Documents

(1) Data Product Description (DPD), JPL D-11103.

(2) MISR Level 1 Georectification and Registration Algorithm Theoretical Basis, JPL D-11532.

(3) MISR Level 2 Cloud Detection and Classification Algorithm Theoretical Basis, JPL D-11399.

(4) MISR Level 2 Aerosol Retrieval Algorithm Theoretical Basis, JPL D-11400.

(5) MISR Level 2 Surface Retrieval Algorithm Theoretical Basis, JPL D-11401.

(6) MISR Mission Operations Planning and Requirements, JPL D-11594.

(7) MISR Instrument Science Requirements (ISR), JPL D-9090.

1.4 REVISIONS

Upon approval of this plan, it shall be placed under change control, with the original version being utilized as a baseline. Change control will commence after a formal review of the document, after which the authorized JPL personnel sign an agreement accepting the document as is.

When the document has been placed under change control, subsequent versions will require a MISR Science System Change Request authorized by the MISR Principal Investigator and approved by the relevant JPL representatives.Major additions and deletions will be indicated by a change log; minor corrections by change bars. Wherever possible, existing section numbers will be retained so that section numbers are stable references. Text in the deleted sections will be replaced by the word “[DELETED]”.

2.0 EXPERIMENT OVERVIEW

2.1 MISR INSTRUMENT

The purpose of the MISR experiment is to acquire systematic multi-angle imagery for global monitoring of top-of-atmosphere and surface albedos and to characterize the radiative properties of aerosols, clouds, and surface scenes.

The MISR instrument consists of nine pushbroom cameras. It is capable of global coverage every nine days, and flies in a 705-km descending polar orbit. The cameras are arranged with one camera pointing toward the nadir (designated An), one bank of four cameras pointing in the forward direction (designated Af, Bf, Cf, and Df in order of increasing off-nadir angle), and one bank of four cameras pointing in the aftward direction (using the same convention but designated Aa, Ba, Ca, and Da). Images are acquired with nominal view angles, relative to the surface reference ellipsoid, of 0°, 26.1°, 45.6°, 60.0°, and 70.5° for An, Af/Aa, Bf/Ba, Cf/Ca, and Df/Da, respectively. Each camera uses four Charge-Coupled Device (CCD) line arrays in a single focal plane. The line arrays consist of 1504 photoactive pixels plus a set of light-shielded pixels per array, each 21 μm x 18 μm. Each line array is filtered to provide one of four MISR spectral bands. The spectral band shapes will nominally be gaussian, and centered at 446, 558, 672, and 866 nm.

MISR contains 36 parallel signal chains corresponding to the four spectral bands in each of the nine cameras. Each signal chain contains the output from the 1520 pixels (1504 photo-active plus 8 light-shielded and 8 CCD serial register "overclock" pixels) in each detector array. The zonal 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 9 days at the equator, and 2 days near the poles. The cross-track 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 214 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. The instrument is capable of buffering the data to provide 2 sample x 2 line, 4 sample x 4 line, or 1 sample x 4 line averages, in addition to the mode in which pixels are sent with no averaging. The averaging capability is individually selectable within each of the 36 channels.

There are several observational modes of the MISR instrument. Global Mode (GM) refers to continuous operation with no limitation on swath length. Global coverage in a particular spectral band of one camera is provided by operating the corresponding signal chain continuously in a selected resolution mode. Any choice of averaging modes among the nine cameras that is consistent with the instrument power and data rate allocation is suitable for Global Mode. Additionally, Local Mode (LM) provides high resolution images in all 4 bands of all 9 cameras for selected Earth targets. This is accomplished by inhibiting pixel averaging in all bands of each of the cameras in sequence, one at a time, beginning with the first camera to acquire the target and ending with the last camera to view the target. The instrument geometry limits the along-track length of Local Mode targets to about 300 km. Finally, in Calibration Mode (CM) the on-board calibration hardware is deployed and calibration data are acquired for the cameras. Calibration data will be obtained for each spatial sampling mode (see above) by cycling each channel through the various modes during the calibration period. Calibration Mode will be used on a monthly basis during routine mission operations, although early in the mission it will be used more frequently.

2.2 MISR SCIENCE DATA PROCESSING

MISR Science Data Processing (SDP) generates science data products from MISR instrument data. The MISR Science Computing Facility (SCF) and Distributed Active Archive Center (DAAC) represent the primary entities in which the functions of MISR science data processing will be deployed. The MISR SCF will support the development of MISR science algorithms, as well as provide quality control and data validation services with respect to MISR science data processing. This will include production of data and coefficients used to augment and improve the performance of the science algorithms that operate at the DAAC. The MISR DAAC, which is shared with several other EOS instruments, is the facility at which MISR science algorithms will operate in a high volume, real-time mode to produce standard science data products.

The generation of standard science data products at the DAAC can be divided into five production steps. Each step has at least one primary output product, but may have other secondary output products. It is convenient to think of these five steps as occurring in sequence, with the predecessor producing at least one complete product, a portion of which is the primary input for the successor. The five steps are 1) Level 1A Instrument Data Reformatting and Annotation, 2) Level 1B1 Radiometric Scaling and Conditioning, 3) Level 1B2 Geometric Rectification and Registration, 4) Level 2 Science Retrievals, and 5) Level 3 Global Gridding. Each of these steps correspond to processing levels of a product generation flow, as shown in Figure 1. These levels conform generally to the EOS scheme from Level 1 to Level 3.

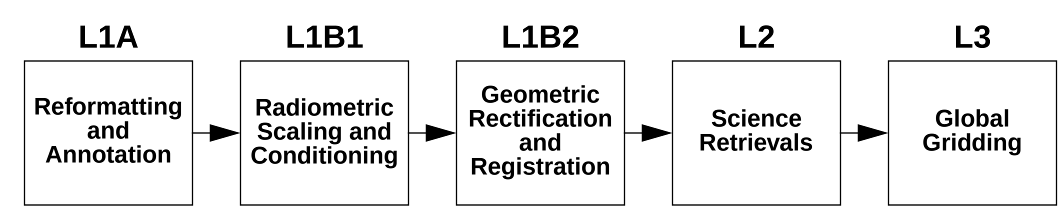


Figure 1: MISR Product Generation Flow

Production of standard products at the DAAC cannot operate independently of the rest of the MISR SDP. For example, it has critical dependence on calibration parameters and lookup data which must be produced at the SCF, such as threshold datasets, climatologies, model datasets or the like. These functions are separated from DAAC activities because they require much closer scrutiny by the MISR science team than the MISR DAAC could provide. Updates to these data structures occur infrequently compared to the rate of standard product generation, and therefore fit into the more limited processing capabilities of the SCF. Other essential functions of the SDP that have activities at the SCF include quality assessment, algorithm validation, software development, and instrument operations.

3.0 ALGORITHM DESCRIPTION

3.1 PROCESSING CONTEXT

The Ancillary Geographic Product (AGP) is essentially a global database of geographic properties, tailored to the needs of the MISR mission. The AGP is utilized in the creation of all MISR Level 1B2 and Level 2 products throughout the mission and is required for the interpretation of those products.

The parameters in this product are reported in a Space-Oblique Mercator (SOM) map projection. The map resolution of the projection is 1.1 km; this defines the horizontal sampling for most of the parameters. The horizontal datum, or surface-basis, for the projection is the WGS84 ellipsoid. This map projection and surface-basis is identical to what will be used for all the Level 1B2 and Level 2 parameters.

The AGP shall consist of 233 parts (of one or more files), corresponding to the 233 repeat orbits of the EOS AM-1 spacecraft. The length and width covered by the AGP needs to be large enough to contain the maximum overlap width of the swath seen by all nine MISR camera views. This width varies per latitude to a minimum near the poles and a maximum of 378 km near the equator. The length of the AGP covers the maximal starting and ending points of the MISR instrument mapping of the surface. Since a mapping swath runs from terminator to terminator for every orbit, the AGP must run from the terminator of the summer solstice at the north end of the orbit and the terminator of the winter solstice at the south end.

3.2 PROCESSING OUTLINE

The first step in the creation of the AGP is the construction of the DTED Intermediate Dataset (DID). The DID is the basic input dataset required for the creation of the MISR Ancillary Geographic Product (AGP). The DID is essentially an elevation database for the entire Earth stored in a Plate Carrée (simple cylindrical) projection at 3 arc second resolution. The elevation values come primarily from the Defense Mapping Agency (DMA) Digital Terrain Elevation Dataset (DTED) which has been adjusted from Mean Sea Level (MSL) to the WGS84 ellipsoid and normalized between 1° cells by using a block adjustment technique [3]. Additional data sources, such as the DMA Digital Chart of the World (DCW) Hypsography (i.e., vector elevation contours) and ETOPO5 datasets, have also been used to fill in gaps in the DTED. In addition to elevation, the DID also currently supplies a land/ocean mask derived from the DMA World Vector Shoreline (WVS) and metadata giving a quality measure and source for each 1° by 1° cell.

After the DID was built, the next step was to project the DID region by region into an equal-area projection. Currently, the Albers Equal-Area projection has been chosen. All of the remaining parameters of the AGP are then calculated on the equal-area projection. Also needed at this stage are bathymetry data from ETOPO5 to determine the Dark Water Algorithm Suitability mask. The result is the pre-launch AGP Intermediate Dataset (AGPID).

Finally, the parameters are projected to predetermined blocks in a Space Oblique Mercator projection. The after launch EOS orbit parameters are needed for the SOM projection.

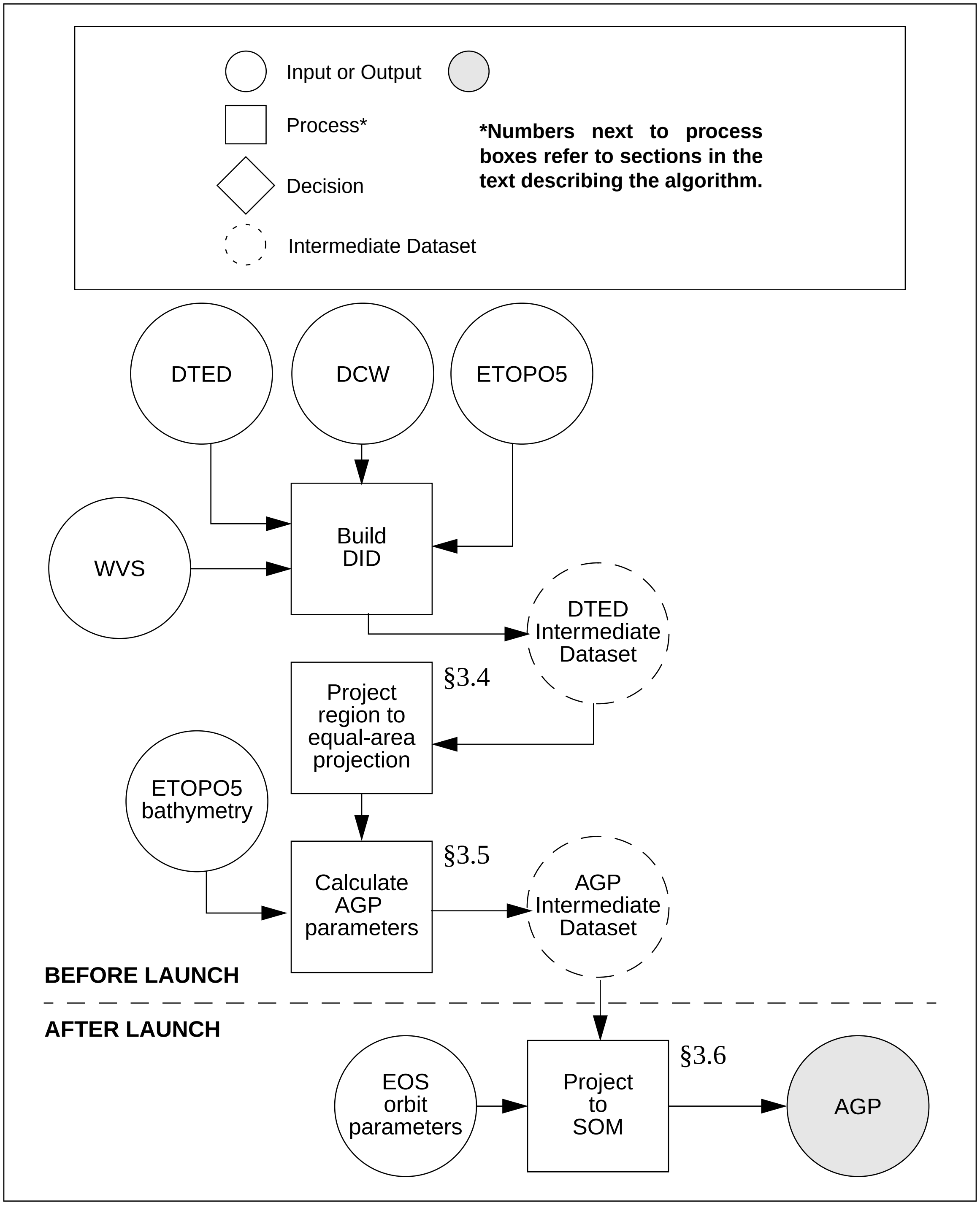


Figure 2: AGP Generation Activities Before and After Launch

3.3 ALGORITHM INPUT

The datasets required as input for the creation of the AGP are listed below.

Table 2: Ancillary Geographic Product inputs

Input data	Source of data
DTED	DMA
WVS (land/water mask)	DMA
DCW (hypsography)	DMA
ETOPO5 (elevation and bathymetry)	NGDC
EOS orbit parameters	SDP Toolkit

3.3.1 DTED

The Defense Mapping Agency (DMA) Digital Terrain Elevation Data (DTED) Level 1 is a global DEM dataset supplied on CD-ROM. The data are in a Plate Carrée (simple cyclindrical) map projection. The Level 1 post spacing is 3 arc seconds (approximately 100 meters). The horizontal datum is the World Geodetic System 1984 reference ellipsoid. Initially, the vertical datum is Mean Sea Level (MSL). During the construction of the AGP, the elevations are adjusted to the WGS84 ellipsoid.

Accuracy statements are individually calculated for every product and provided in the Accuracy Header Record. Accuracy objectives are: Absolute Horizontal: 50 meters at 90 percent circular error and Absolute Vertical: ±30 meters at 90 percent linear error.

3.3.2 WVS (land/water mask)

The DMA World Vector Shoreline (WVS) product was used to separate land from ocean/sea areas. The product was derived from digitizing 1:250,000 map sources where available, and 1:389,000 navigation charts when higher resolution products were not available. The vector data have been converted by the Cartographic Applications Group (CAG) at JPL to a raster mask of 1.1 km cells.

3.3.3 DCW (hypsography)

The DMA had the Digital Chart of the World (DCW) prepared from its global inventory of 1:1,000,000 scale map products. These maps contain elevation contours for every 1000 foot elevation and a file of spot height elevations. Conformity of the elevation model to drainage basin terrain is accomplished by using the DCW hydrographic file of rivers/streams [2]. The resultant elevation model is converted from feet and MSL to meters above the WGS84 ellipsoid.

3.3.4 ETOPO5 (elevation and bathymetry)

The ETOPO5 is a global dataset originally developed by the DMA, and later converted to WGS84 by the National Geophysical Data Center (NGDC). ETOPO5 is grid raster providing elevation above sea level and depth below sea level at 5 arc minute postings (approximately 10 km). The data sources were the 1:1,000,000 series over land (Operational Navigation Chart), and the Nautical Charts available over the ocean.

3.3.5 EOS orbit parameters

The SOM map projection requires parameters that describe the EOS spacecraft orbit. These include the angle of inclination, the orbit time required for the revolution of the spacecraft, and the geodetic longitude of the ascending node for each of the 233 repeat orbits.

3.4 THEORETICAL DESCRIPTION - PROJECT REGION TO EQUAL-AREA

3.4.1 Albers Conical Equal-Area Map Projection

For the calculation of certain parameters of the AGP, such as slope gradient and slope aspect, the algorithm requires the underlying grid to be equal-area. The map projection of the DID, Plate Carrée, is therefore not sufficient. The data in the DID must be projected to an equal-area map projection.

The Albers Conical Equal-Area map projection has been chosen for the intermediate AGP parameter calculation. The projection is mathematically based on a cone that is conceptually secant on two parallels. Like other conics, Albers Conical Equal Area has concentric arcs for parallels and equally spaced radii for meridians. Parallels are not equally spaced, but are farthest apart between the standard parallels, and closer together on north and south edges. This projection possesses the property of equal area and the standard parallels are correct in scale and correct in every direction. Thus, there is no angular distortion (i.e., meridians intersect parallels at right angles) and conformality exists along the standard parallels. The North or South Pole (which the MISR instrument does not see) is represented by an arc.

3.4.2 Projection algorithm

The projection algorithm is currently being prototyped. A final decision for which algorithm to use will be made during Version 2 activities.

3.5 THEORETICAL DESCRIPTION - CALCULATE AGP PARAMETERS

3.5.1 Average scene elevation

3.5.1.1 Definition

This is the orthometric height averaged over the SOM grid location measured relative to the WGS84 ellipsoid. It is calculated by taking the mean of all elevation values within the 1.1 km grid on the equal area projection. If sub-1.1 km elevation values are not available, the nearest elevation value in a lower resolution dataset is used.

Since the DID has elevation values recorded relative to Mean Sea Level, geoid undulations are also accounted for, in order to calculate height relative to the ellipsoid.

3.5.1.2 Units

Meters relative to WGS84 ellipsoid.

3.5.1.3 Resolution

Reported every 1.1 km grid center.

3.5.1.4 Accuracy/Precision

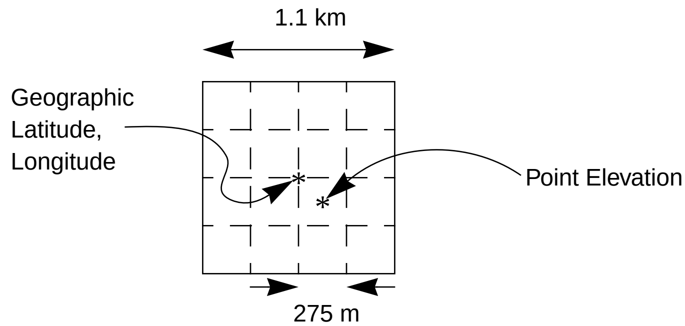
Accuracy depends on input data.

Recorded to the nearest meter.

3.5.2 Point elevation

3.5.2.1 Definition

This is the ellipsoidal (geodetic) height relative to the WGS84 ellipsoid. It corresponds to the points with geographic locations defined to be 137.5 m south and 137.5 m east of the points representing 1.1 km grid centers (see diagram below). In order to obtain the most accurate point elevation given the accuracy of the original source (e.g. DTED) the computation should consist of the following steps: 1) Define the geographic location of the point selected to have point elevation (add offsets of 137.5 m to the SOM grid centers). 2) Compute the latitude and longitude of these points in order to relate them to the coordinate system of the input DID. 3) use bilinear interpolation to compute the elevation which corresponds to the point defined in 1). This point will be surrounded with 4 elevation postings at 3 arcsec in the DID. These 4 postings are used as input to the bilinear interpolation. 4) From the elevation obtained in 3) subtract the amount of geoid undulation corresponding to this geographic location.



3.5.2.2 Units

Meters relative to WGS84 ellipsoid.

3.5.2.3 Resolution

Reported every 1.1 km grid.

3.5.2.4 Accuracy/Precision

Accuracy depends on input data.

Recorded to the nearest meter.

3.5.3 Standard deviation of scene elevation

3.5.3.1 Definition

This parameter has two possible definitions:

1) If sub-1.1 km spatial resolution data are used to determine the average scene elevation for the grid location, then this is the standard deviation of those data values. The sample standard deviation (σ_E) for a set of k sub-1.1 km elevation values E is computed as follows:

$$\sigma_E = \sqrt{\frac{\sum_{i=1}^{k}(E_i - \mu_E)^2}{k-1}} \qquad (1)$$

where μ_E is the average scene elevation for a 1.1-km subregion described above.

2) In regions where sub-1.1 km data are not available or when less than three values are available to calculate the average scene elevation, a flag will be entered which specifies the data source.

3.5.3.2 Units

Meters.

3.5.3.3 Resolution

Reported every 1.1 km grid center.

3.5.3.4 Accuracy/Precision

Recorded to the nearest meter.

3.5.4 Regional average scene elevation

3.5.4.1 Definition

This is the orthometric height averaged over a 16×16 SOM grid locations measured relative to the WGS84 ellipsoid. It is calculated by taking the mean of all average scene elevation values within the 17.6 km region.

3.5.4.2 Units

Meters relative to WGS84 ellipsoid.

3.5.4.3 Resolution

Reported every 17.6 km grid center.

3.5.4.4 Accuracy/Precision

Accuracy depends on input data.

Recorded to the nearest meter.

3.5.5 Regional standard deviation of scene elevation

3.5.5.1 Definition

This is the standard deviation of the 16×16 array of 1.1 km data that make up the 17.6 km region.

The sample standard deviation (σ_E) for a set of k 1.1 km average scene elevation values μ_E is computed as follows:

$$\sigma_{\mu_E} = \sqrt{\frac{\sum_{i=1}^{k} (\mu_{E,i} - \bar{\mu}_E)^2}{k-1}} \tag{2}$$

where μ_E is the regional average scene elevation described above.

3.5.5.2 Units

Meters.

3.5.5.3 Resolution

Reported every 17.6 km grid center.

3.5.5.4 Accuracy/Precision

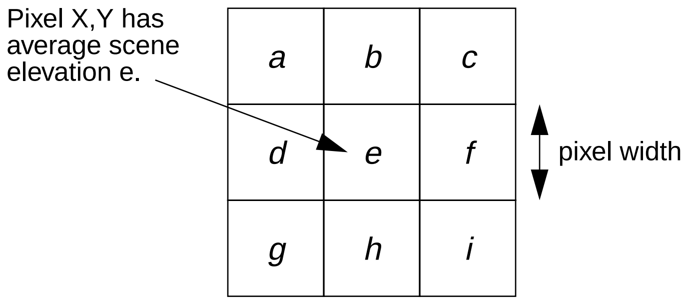
Recorded to the nearest meter.

3.5.6 Average surface-normal zenith angle

3.5.6.1 Definition

The average surface-normal zenith angle represents the average slope gradient angle at the grid location. It is the angle between the vector normal to the best-fit surface using the data input to the average scene elevation calculation and the vector normal to the WGS84 ellipsoid. The algorithm chosen has been determined by the U.S. Army Topographic Engineering Center (TEC) to have the best performance [4]. This algorithm is also the one used by the ESRI ARC/INFO GIS utility [1].

A 3×3 pixel window is used to calculate the slope gradient at each pixel. For a pixel at location X,Y, the average scene elevations around it are used to calculate the slope gradient as shown below:



where *a, b, c, d, f, g, h,* and *i* are the average scene elevations of the pixels around it in a 3 × 3 window.

First, the average elevation changes per unit of distance in the x and y direction (Δx and Δy) are calculated as:

$$\begin{aligned} \Delta x &= [(a + 2d + g) - (c + 2f + i)] / (8 \times w) \\ \Delta y &= [(a + 2b + c) - (g + 2h + i)] / (8 \times w) \end{aligned} \quad (3)$$

where *w* is the pixel width, which is equal to either:

1) $\frac{1.1}{3}$ km, if sub-1.1 km data is available, or

2) 1.1 km, otherwise.

The average surface-normal zenith angle (slope gradient) in degrees at pixel x,y is then calculated as:

$$s = \operatorname{atan}\left(\sqrt{(\Delta x)^2 + (\Delta y)^2}\right) \quad (4)$$

3.5.6.2 Units

Scaled degrees.

3.5.6.3 Resolution

Reported every 1.1 km grid.

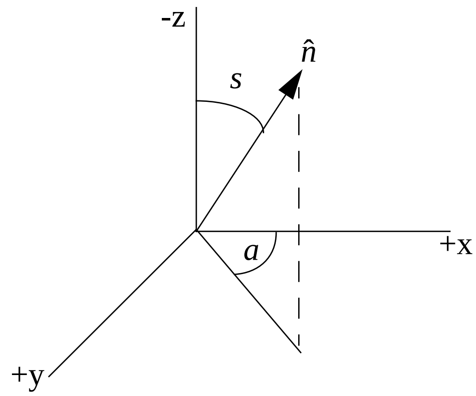
3.5.6.4 Accuracy/Precision

Recorded as the nearest integer calculated by $\text{degrees} \times \left(\frac{256}{90}\right)$.

3.5.7 Standard deviation of scene elevation relative to mean slope

3.5.7.1 Definition

Consider a right-hand local Cartesian coordinate system in which +x points to North, +y points East, and the z-axis is the local ellipsoid normal with +z pointing into the Earth, and -z pointing upward.



The normal vector to the plane describing the mean surface slope, $\hat{n}$, is given by:

$$\hat{n} = \begin{bmatrix} \sin s \cdot \cos a \\ \sin s \cdot \sin a \\ -\cos s \end{bmatrix} \qquad (5)$$

If the plane parallel to the mean surface slope goes through an altitude h_0 at the origin (x = y =0), then, for an arbitrary x, y the height on this plane is

$$h(x, y) = h_0 - \tan s \cdot (x \cos a + y \sin a) \qquad (6)$$

where s is the average surface-normal zenith angle described in §3.5.6 and a is the average surface-normal azimuth angle described in §3.5.8.

In order to calculate the standard deviation of the heights relative to the heights on the mean slope surface, after we have solved for h_0, s, and a, calculate

$$\sigma = \sqrt{\frac{\sum_{i=1}^{k} [h_{meas,\,i}(x, y) - h_i(x, y)]^2}{k-1}} \qquad (7)$$

where h_i is calculated using (6).

3.5.7.2 Units

Meters.

3.5.7.3 Resolution

Reported every 1.1 km grid.

3.5.7.4 Accuracy/Precision

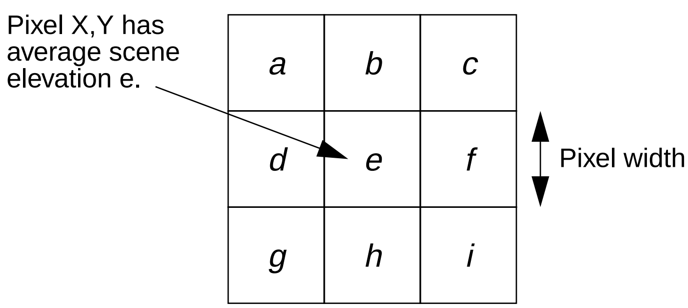
Recorded to the nearest meter.

3.5.8 Average surface-normal azimuth angle

3.5.8.1 Definition

The average surface-normal azimuth angle represents the average aspect of the slope at the grid location. It is the clock-wise oriented angle between the horizontal vector to local North and the horizontal projection of the surface-normal vector, evaluated in the horizontal plane tangent to the WGS84 ellipsoid.

A 3 × 3 pixel window is used to calculate the slope aspect at each pixel. For a pixel at location X,Y, the average scene elevations around it are used to calculate the slope aspect as shown below:



where *a, b, c, d, f, g, h,* and *i* are the average scene elevations of the pixels around it in a 3 × 3 window and the pixel width is equal to either:

1) $\frac{1.1}{3}$ km, if sub-1.1 km data is available, or

2) 1.1 km, otherwise.

First, the average elevation changes per unit of distance in the x and y direction (Δx and Δy) are calculated as:

$$\Delta x = [(a + 2d + g) - (c + 2f + i)] / (8 \times w)$$
$$\Delta y = [(a + 2b + c) - (g + 2h + i)] / (8 \times w) \qquad (8)$$

where w is the pixel width, which is equal to either:

1) $\frac{1.1}{3}$ km, if sub-1.1 km data is available, or

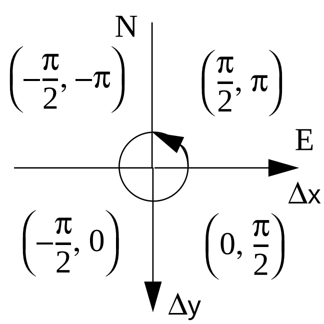
2) 1.1 km, otherwise.

The average surface-normal azimuth angle (slope aspect) in degrees at pixel x,y is then calculated as:

$$a = \pi - \mathrm{atan2}\left(\frac{\Delta x}{\Delta y}\right) \qquad (9)$$

Note that the arc tangent function atan2 is defined ranging from $-\pi$ to π.

$$\mathrm{atan2}\left(\frac{\Delta x}{\Delta y}\right) \Rightarrow$$



3.5.8.2 Units

Scaled degrees.

3.5.8.3 Resolution

Reported every 1.1 km grid.

3.5.8.4 Accuracy/Precision

Recorded as the nearest integer calculated by $\mathrm{degrees} \times \left(\frac{256}{360}\right)$.

3.5.9 Land/water identifiers

3.5.9.1 Definition

The land/water identifiers are classification masks labelling grid locations with values signifying land, ocean, inland water, ephemeral water, and coastline.

3.5.9.2 Units

None.

3.5.9.3 Resolution

Reported every 1.1 km grid.

3.5.9.4 Accuracy/Precision

Varies based on input.

3.5.9.5 Land identifier

Grid is identified as containing all land.

3.5.9.6 Ocean identifier

Grid is identified as containing all ocean.

3.5.9.7 Inland water identifier

Grid is identified as containing all inland water.

3.5.9.8 Ephemeral water identifier

Grid is identified as containing any ephemeral water based on 2 km resolution threshold from the DCW Water Bodies file.

3.5.9.9 Coastline identifier

Grid is identified as containing a mixture of land and ocean or land and inland water.

3.5.10 Dark Water Algorithm Suitability mask

3.5.10.1 Definition

Grid is identified as either ocean or inland water and is at least 5 km distance from a land grid in any direction and has a water depth of greater than 50 meters as recorded in ETOPO5 bathymetry data.

3.5.10.2 Units

None.

3.5.10.3 Resolution

Reported every 1.1 km grid.

3.5.10.4 Accuracy/Precision

Depends on input data.

3.6 THEORETICAL DESCRIPTION - PROJECT TO SOM

3.6.1 Space Oblique Mercator Map Projection

The Space Oblique Mercator (SOM) system is a space-based map projection, based on the Oblique Mercator projection, where the reference meridian nominally follows the spacecraft ground track. It provides a mapping from latitude/longitude to a coordinate system that is approximately aligned with the MISR swath.

The SOM projection is nearly conformal and has little scale distortion within the sensing range of an orbiting mapping satellite. It is the first projection to incorporate the Earth's rotation with respect to the orbiting satellite and is the standard format for Landsat data. The method of projection used is the modified cylindrical, for which the central line is curved and defined by the groundtrack of the orbit of the satellite. Plots for adjacent paths do not match without transformation.

For the algorithm description of the transformation to the SOM map projection, which is quite complex, the reader is referred to reference [5].

EOS orbit parameters are needed by the SOM projection. These include the angle of inclination, the orbit time required for the revolution of the spacecraft, and the geodetic longitude of the ascending node for each of the 233 repeat orbits.

3.6.2 Calculation of AGP block locations

A conceptual schematic for the calculation to determine the AGP block locations is shown in Fig-

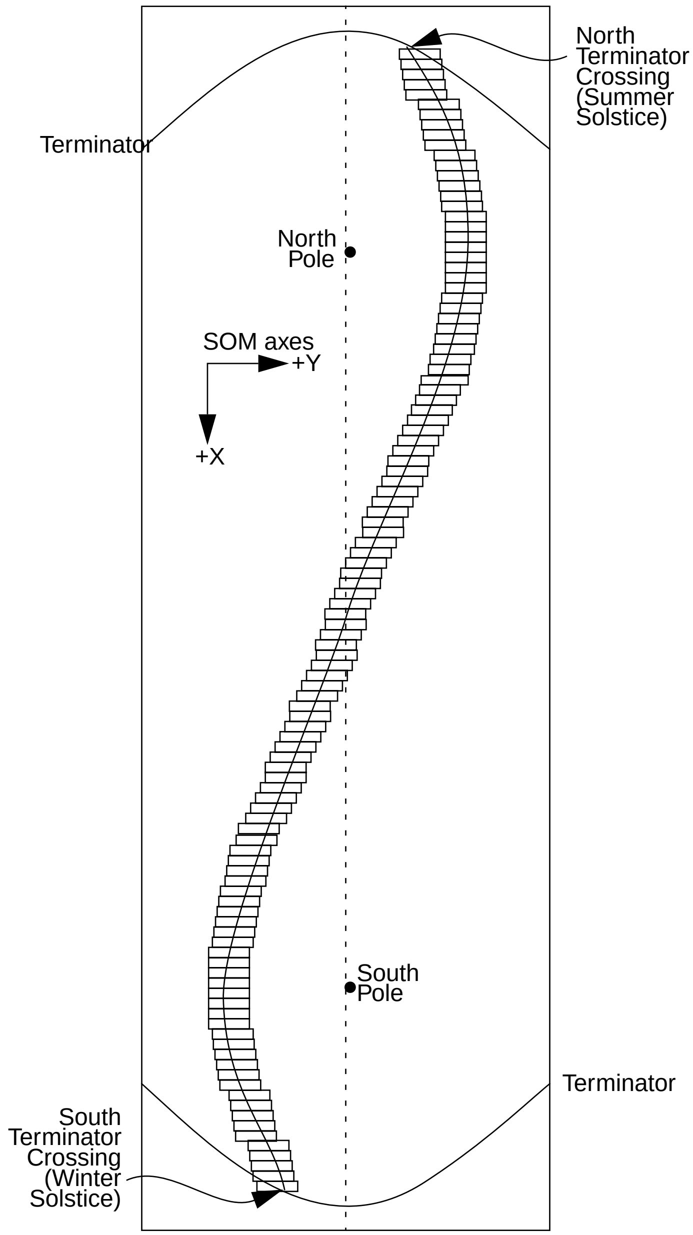


Figure 3: AGP blocks along an SOM projection

ure 3.

Since the MISR instrument acquires data from terminator to terminator during any one orbit, in order for the AGP to cover all possible orbits during a year, the AGP blocks must run from the summer solstice terminator crossing in the north to winter solstice terminator crossing in the south.

In addition, individual blocks are positioned according to several requirements, shown in Figure 4.

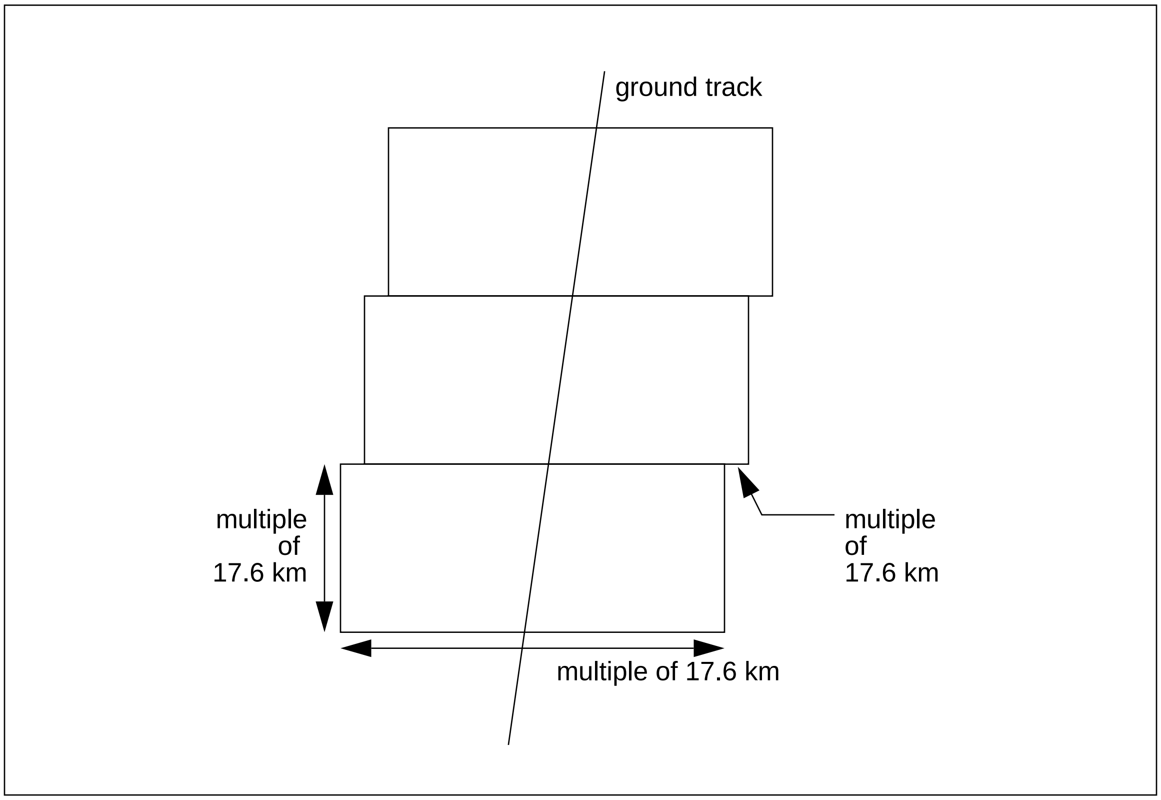


Figure 4: Positioning of individual AGP blocks

Each equal-sized block has a width and a length which is a multiple of 17.6 km. Each consecutive block is centered as closely as possible to the spacecraft ground track, with the rule that any cross-track shift can only be made in multiples of 17.6 km.

3.6.3 Projection algorithm

The projection algorithm is currently being prototyped. A final decision for which algorithm to use will be made during Version 2 activities.

3.6.4 Geographic latitude

3.6.4.1 Definition

The geographic latitude is the geodetic latitude coordinate of the center of the SOM grid location. This is calculated and stored in the AGP, so that the SOM calculation does not need to be repeated during standard processing of data.

3.6.4.2 Units

Degrees.

3.6.4.3 Resolution

Reported every 1.1 km grid center.

3.6.4.4 Accuracy/Precision

Must be accurate to 6 places past the decimal point to insure sub-meter precision.

3.6.5 Geographic longitude

3.6.5.1 Definition

The geographic longitude is the geodetic longitude coordinate of the center of the SOM grid location. This is calculated and stored in the AGP, so that the SOM calculation does not need to be repeated during standard processing of data.

3.6.5.2 Units

Degrees.

3.6.5.3 Resolution

Reported every 1.1 km grid center.

3.6.5.4 Accuracy/Precision

Must be accurate to 6 places past the decimal point to insure sub-meter precision.

3.7 PRACTICAL CONSIDERATIONS

3.7.1 Numerical computation considerations

Preparing the AGP Intermediate Dataset (AGPID) is computationally straightforward. However, conversion of the AGPID to the final AGP cannot be done until the spacecraft orbit is precisely known, i.e., after launch. This is a major computational task. The exact requirements are presently being clarified, though, it is expected that the SGI Power Challenge at the MISR SCF will meet the computational requirements.

3.7.2 Programming and procedural considerations

Software guidelines to be followed during algorithm development are described in the MISR Algorithm Development Plan (ADP).

3.7.3 Quality assessment and diagnostics

As the AGPID is built, its content will be continually monitored.

4.0 ASSUMPTIONS AND LIMITATIONS

4.1 ASSUMPTIONS

1) The Cartographic Applications Group (CAG) at JPL shall produce the DTED Intermediate Dataset (DID).

2) The CAG shall supply routines for accessing the DID.

3) The CAG shall produce an equal-area projection dataset containing the AGP parameters.

4) The CAG shall supply routines for accessing the equal-area projection dataset.

5) The CAG shall supply routines projecting the data from equal-area to Space Oblique Mercator (SOM) for predefined blocks.

4.2 LIMITATIONS

1) Spatial resolution of the standard parameters 1.1 km. Use of the AGP to geolocate MISR data of higher resolution will require interpolation, e.g. to 275 m.

5.0 REFERENCES

[1] Environmental Systems Research Institute. Help documentation for ARC/INFO 7.0.2, Redlands, CA., 1994.

[2] Hutchinson, M.F., "A new procedure for gridding elevation and stream line data with automatic removal of spurious pits." Journal of Hydrology 106, 1989, pp. 211-232.

[3] Ritter, N.D., and N.A. Bryant, "An Optimal Reference Plane Correction Algorithm for Mult-Source Digital Elevation Models." Proceedings, Eleventh Thematic Conference and Workshops on Applied Geologic Remote Sensing, Las Vegas, Nevada, 27-29 February, 1996.

[4] Ryder, W.H., and D.E. Voyadgis, "Measuring the Performance of Algorithms for Generating Ground Slope." Digital Topographic Data Technical Exchange Meeting, 9-11 April, 1996.

[5] Snyder, J.P., Map Projection - A Working Manual, United States Geological Survey Professional Paper 1395, U.S. Government Printing Office, Washington, 1987.