ASTER
User's Guide

Part I

General

(Ver.4.0)

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ERSDAC

Earth Remote Sensing Data
Analysis Center

ASTER User's Guide
Part I

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1. Introduction

1.1. Document purpose

This document provides the necessary information to user to utilize ASTER data and also introduces reference information such as ASTER instruments, ground systems, and data products.

1.2. EOS project

NASA is promoting the Earth Observation System (EOS) Project, a comprehensive space borne observation of the Earth, to understand global changes especially changes in climate.

EOS can be divided into Satellite Observation Systems, Data Processing and Data Information Systems, and Research Programs using the observation data. Satellite Observation Systems were originally planned to use large platforms with many sensors for comprehensive simultaneous observation. Due to budget cuts, however, the size of the project has been significantly reduced. A series of satellite launches is planned until the year 2008, and the observations to continue until the year 2012.

The EOS Project will handle a very large volume of data. Unlike traditional Earth observation projects, EOS allocates more than half of its total financial resources into the Ground Data Processing and Data Information Systems.

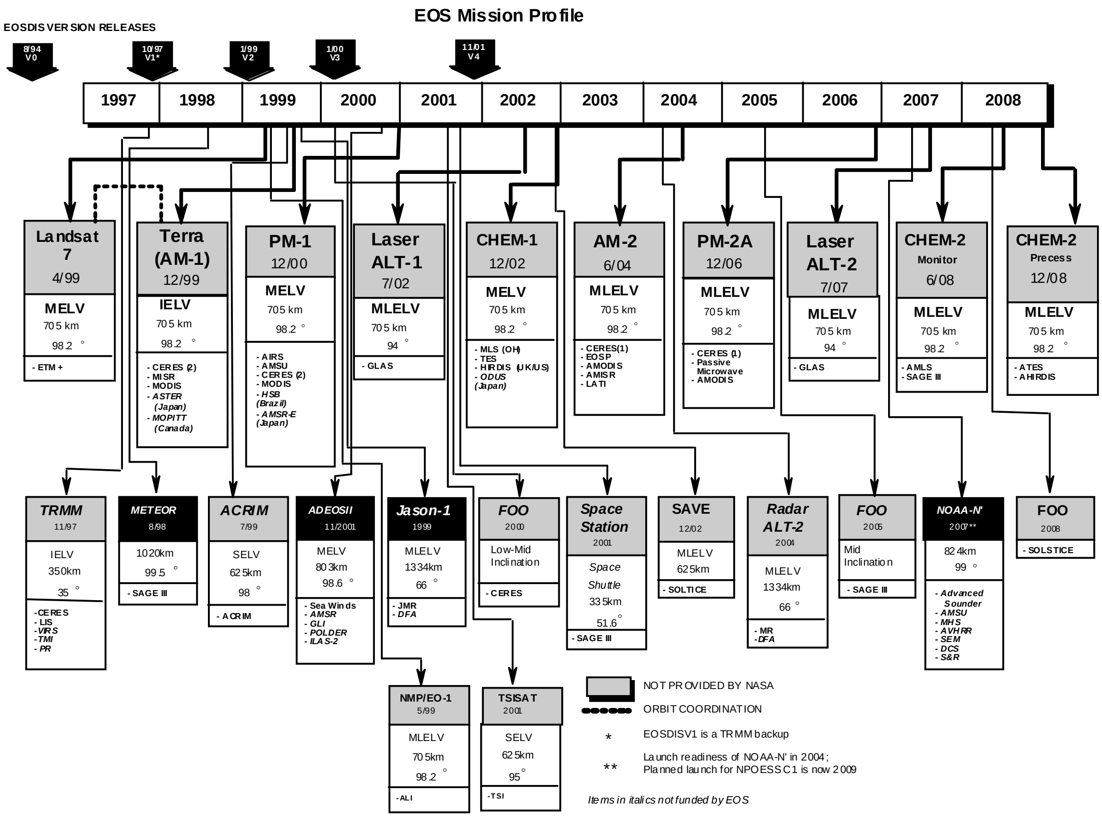


Figure 1-1 EOS Observation Plan

1.3. Background of ASTER

The Ministry of International Trading and Industry (MITI) launched a Japanese Earth Resource Satellite (JERS-1) in 1992, its primary purpose, to investigate Earth resources. JERS-1 users of geology and resource remote sensing have since then requested MITI to develop more advanced sensors than those of JERS-1 in order to obtain more detailed geological data and to understand phenomena such as volcanic activities which would significantly impact the global environment. Responding to their desire MITI developed ASTER (Advance Space-borne Thermal Emission and Reflection Radiometer). ASTER is on board of the first platform of EOS Project, Terra was launched in December, 1999. MITI designated Japan Resources Observation Systems (JAROS) for the sensor development and Earth Remote Sensing Data Analysis Center (ERSDAC) for development of the data applications and ground data processing systems.

The ASTER Project established the ASTER Science Team comprised of Japanese and American researchers in a wide spectrum of fields including geology, geological resources, meteorology, agriculture and forestry, and environmental science. ASTER Science Team takes initiative to define the purpose of ASTER Project and to coordinate its user requirements, which are the basis to define specifications for the sensors, the ground data processing systems, and sensor operations.

Since the ASTER Project is a part of the EOS Project, the ASTER Project is managed under close coordination of Japan and the United States. Japan shares the responsibility of ASTER sensor development, generation of the most optimal observation plans accommodating and implementing data acquisition requests from the ASTER users, and data processing of raw data to generate data in standard format (Level 1 processing), while the United States shares the responsibility of providing the platform, a launch vehicle and launch service, and up-link and down-link of commands and telemetry data.

1.4. Science objectives

The purpose of the ASTER Project is to make contributions to extend the understanding of local and regional phenomena on the Earth surface and its atmosphere. The goals are as follows.

1. To promote research of geological phenomena of tectonic surfaces and geological history through detailed mapping of the Earth topography and geological formation. (This goal includes contributions to applied researches of remote sensing.)
2. To understand distribution and changes of vegetation.
3. To further understand interactions between the Earth surface and atmosphere by surface temperature mapping.
4. To evaluate impact of volcanic gas emission to the atmosphere through monitoring of volcanic activities.
5. To contribute understanding of aerosol characteristics in the atmosphere and of cloud classification.
6. To contribute understanding of roles the coral reefs play in the carbon cycle through coral classification and global distribution mapping of corals.

1.5. Application of ASTER data

ASTER data has the following characteristics.

- High spatial resolution
- Wide spectral range of visible, near IR, short wave IR and thermal IR
- Stereo view in the same orbit

Researches taking advantages of these characteristics are planned. Terra also has other sensors namely MODIS, MISR, CERES, and MOPITT which have different features from

ASTER. Combination of ASTER data and data from other sensors can provide better atmospheric correction and vicarious calibration. The multiple payloads on Terra also enable observations that were not possible with only one sensor.

Sample proposed researches applying ASTER data are as follows.

1) Land area

- Monitoring of active volcanoes and observation of eruptions
- Monitoring of coastal erosion and sedimentation of the U. S. Atlantic and the Gulf coasts Geological study of African Graben, Southern Mexico, and the Andes
- Monitoring of vegetation in tropical rain forests
- Monitoring of swamps

- Estimation of energy flux on land surface
- Generation of digital elevation model (DEM) for topography of the South Eastern Asia

2) Sea and limnetic areas

- Mapping and establishing coral reef database of Western Pacific
- Monitoring of turbidity and aquatic vegetation
- Sea surface temperature analysis of coastal areas

3) Snow and ice

- Monitoring of glacier movement in Antarctic coast
- Analysis of paleoclimate by glacier observation in the Central Asia
- Analysis of sea ice distribution, albedo and temperature of iceberg

4) Atmosphere

- Cloud classification
- Monitoring of cloud and ice in polar regions

Figure 1-2 shows the applications of ASTER

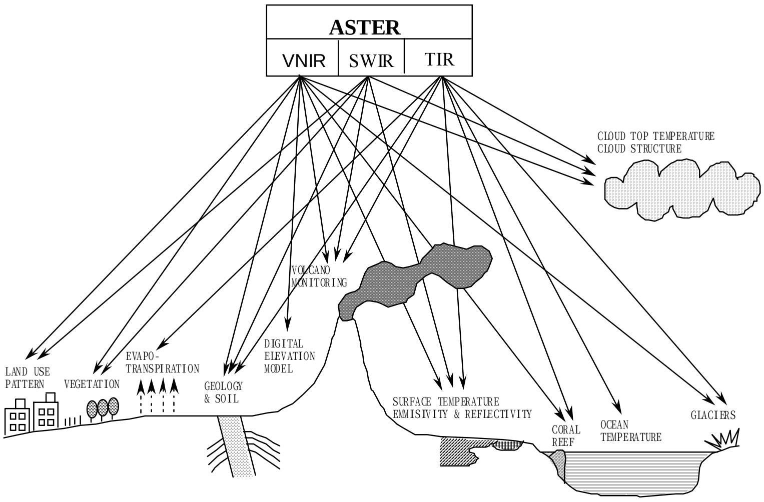


Figure 1-2 Applications of ASTER

2. ASTER Instrument

2.1. Terra Spacecraft and ASTER Instrument Overview

Terra: ASTER is an advanced multispectral imager which is to fly on Terra polar orbiting spacecraft with other 4 sensors in December 1999 under international cooperation. The instrument covers a wide spectral region from the visible to the thermal infrared by 14 spectral bands each with high spatial, spectral and radiometric resolutions. ASTER stands for the Advanced Spaceborne Thermal Emission and Reflection radiometer. The Terra spacecraft is operated in a circular, near polar orbit at an altitude of 705 km. The orbit is sun-synchronous with a local time of 10:30 a.m. The repeat cycle is 16 days. Thus, the orbit parameters are same as Landsat except for the local time as shown in Table 2-1. Figure 2-1 shows the Terra on-orbit configuration with ASTER which consists of six units.

Table 2-1 Orbit Parameters

Orbit	Sun synchronous Descending
Semi-major axis (Mean)	7078 km
Eccentricity	0.0012
Time of day	10:30 ± 15 min. am
Altitude range	700 - 737 km (705 km at equator)
Inclination	98.2° ± 0.15°
Repeat cycle	16 days (233 revolutions/16days)
Distance between adjacent orbits	172 km
Orbit period	98.9 min
Orbit position knowledge	±150 m/3 axes, 3□
Repetition accuracy	±20 km, 3□

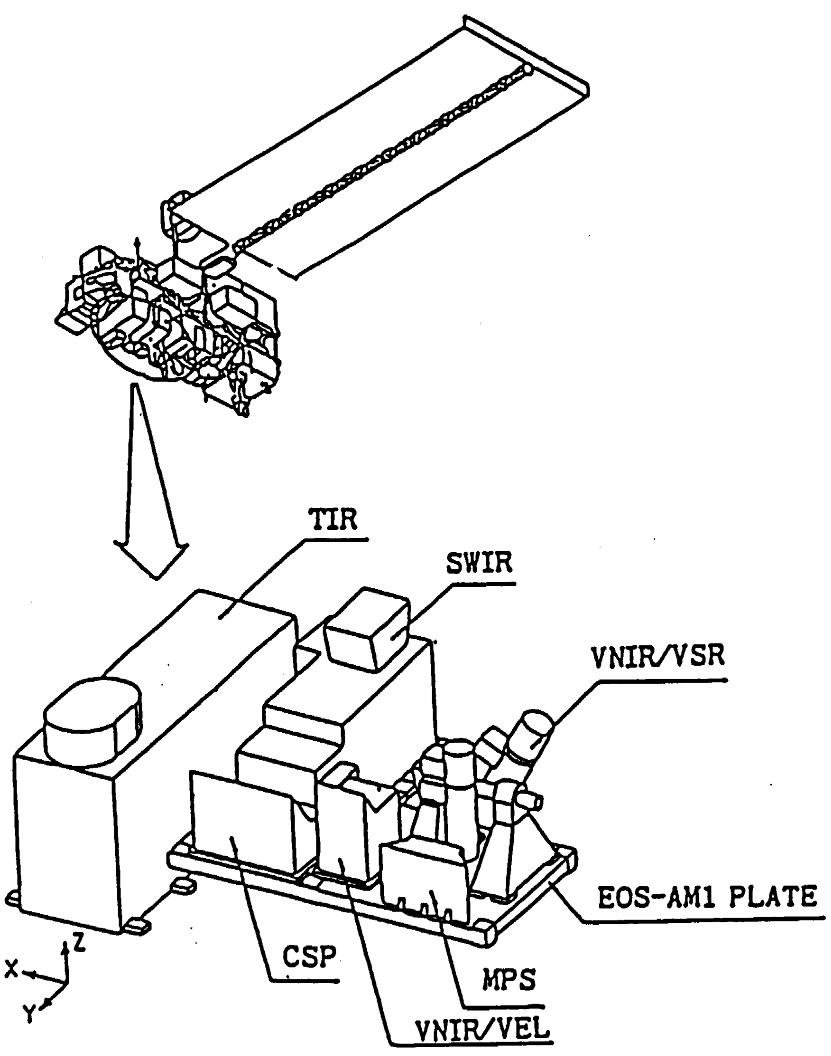


Figure 2-1 Terra on-orbit configuration with ASTER

General Purpose: The ASTER instrument will aid in the study of the interaction between the geosphere, hydrosphere, cryosphere, and atmosphere of the earth from a geophysical point of view respectively. More specific areas science investigations include (a) geology and soil , (b) volcano monitoring , (c) carbon cycling and marine ecosystem , (d) aerosol and cloud study , (e) evapotranspiration, (f) hydrology , (g) vegetation and ecosystem dynamics, and (h) land surface climatology

Basic Concept: The basic concept of the ASTER instrument is to acquire quantitative spectral data of reflected and emitted radiation from the earth's surface in the 0.5-2.5 and 8-12 μm atmospheric windows at spatial and spectral resolutions appropriate for various science objectives. Key features of ASTER compared to other optical imagers are; (1) spectral data acquisition with a high spatial resolution of 15 m in visible and near infrared regions, (2) stereoscopic capability in the along track direction, (3) high spectral resolution in short wave infrared region, and (4) high spectral and spatial resolutions in thermal infrared region.

Development Organization: The ASTER development is being undertaken by the Japan Resources Observation System Organization (JAROS) which is a nonprofit organization under the control of the Ministry of International Trade and Industry (MITI). The contracting companies of the ASTER instrument are NEC Corporation for system and VNIR subsystem, Mitsubishi Electric Corporation for SWIR subsystem, Fujitsu Limited for TIR subsystem, and Hitachi Limited for Master Power Supply.

2.2. Baseline Performance

Performance Requirements: The ASTER instrument is designed to meet the base line performance shown in Table 2-2 which was defined in accordance with scientific objectives of the mission. The last three parameters (peak data rate, mass, and peak power) are consequence of the instrument design and fabrication to meet these scientific requirements. Several improvements have been incorporated in order to exceed the performance of the existing optical sensor such as Landsat/TM, SPOT/HRV and JERS/OPS. These include an increase in the base-to-height ratio of stereo imaging from 0.3 to 0.6 for improved surface elevation. An increase in the number of bands in the SWIR region from 4 to 6 to enhance the surface lithologic mapping capability. The addition of 5 spectral bands in TIR spectral region to derive accurate surface temperatures and emissivities. Improved radiometric resolutions and accuracies are requested to enhance interpretation.

Table 2-2 ASTER baseline performance requirements

Subsystem	Band No.	Spectral Range (µm)	Radiometric Resolution	Absolute Accuracy (□	Spatial Resolution	Signal Quantization Levels
VNIR	1	0.52 - 0.60	NEΔ□≤ 0.5 %	≤ ±4 %	15 m	8 bits
	2	0.63 - 0.69				
	3N	0.78 - 0.86				
	3B	0.78 - 0.86				
SWIR	4	1.600 - 1.700	NEΔ□ ≤ 0.5 %	≤ ±4 %	30 m	8 bits
	5	2.145 - 2.185	NEΔ□ ≤ 1.3 %			
	6	2.185 - 2.225	NEΔ□ ≤ 1.3 %			
	7	2.235 - 2.285	NEΔ□ ≤ 1.3 %			
	8	2.295 - 2.365	NEΔ□ ≤ 1.0 %			
	9	2.360 - 2.430	NEΔ□ ≤ 1.3 %			
TIR	10	8.125 - 8.475	NEΔT ≤ 0.3 K		90 m	12 bits
	11	8.475 - 8.825		≤ 3K(200-240K)		
	12	8.925 - 9.275		≤ 2K(240-270K)		
	13	10.25 - 10.95		≤ 1K(270-340K)		
	14	10.95 - 11.65		≤ 2K(340-370K)		

Stereo Base-to-Height Ratio	0.6 (along-track)
Swath Width	60 km
Total Coverage in Cross-Track Direction by Pointing	232 km
Mission life	5 years
MTF at Nyquist Frequency	0.25 (cross-track) 0.20 (along-track)
Band-to-band registration	Intra-telescope: 0.2 pixels Inter-telescope: 0.3 pixels of coarser band
Peak data rate	89.2 Mbps
Mass	406 kg
Peak power	726 W

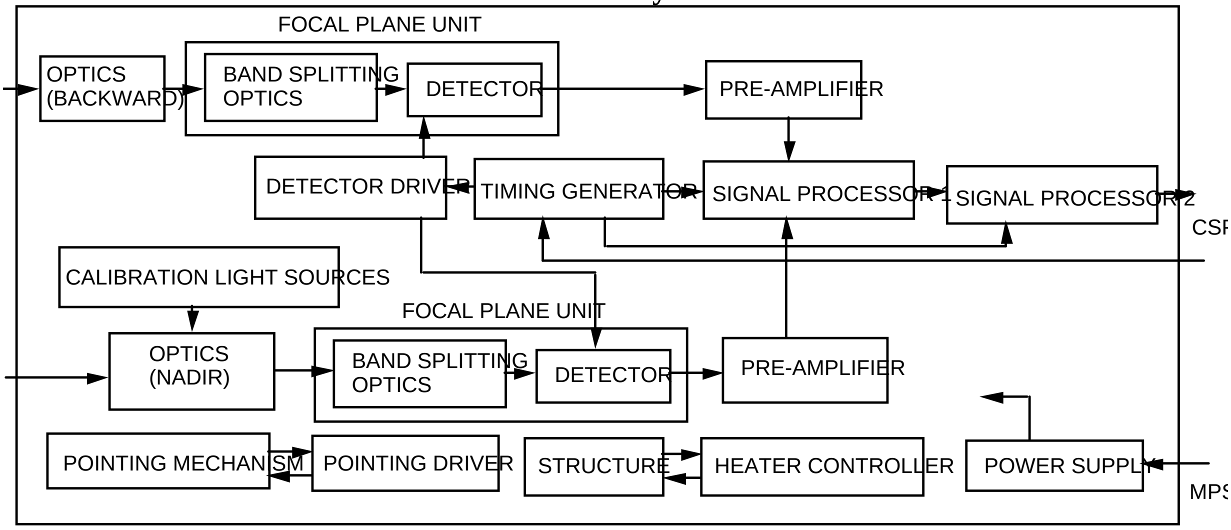
2.3. System Layout

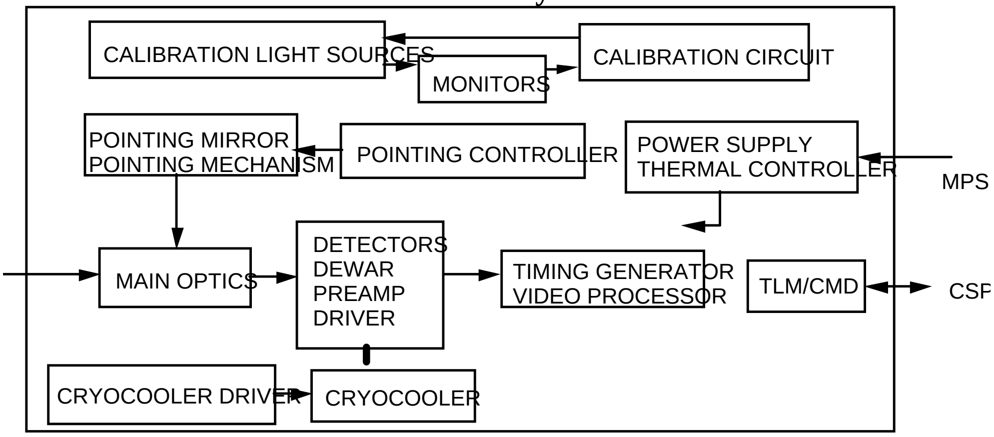
Telescopes: In order to cover the wide spectral range of the ASTER instrument, the components have been separated into three subsystems, visible and near infrared radiometer(VNIR) subsystem, short wave infrared radiometer (SWIR) subsystem and thermal infrared radiometer (TIR). The VNIR subsystem has two telescopes, a nadir looking telescope and a backward looking telescope. The two telescopes enable the stereoscopic a large base-to-height ratio of 0.6 in the along-track direction with the minimum mass resource. On JERS/OPS only one telescope was used which limited the base-to-height ratio. While three telescopes concept needs extra mass for one more telescope and extra data rate for transmitting the data, although it is ideal for a large base-to-height ratio. A combination of the nadir and backward telescopes is the consequence of the trade-off between the performance and the resources.

Pointing Function: The pointing function is provided for global coverage in the cross-track direction by changing the center of the swath, since the swath width of ASTER is 60 km and the distance between the neighboring orbit is 172 km. The optical axes of the VNIR and SWIR telescopes can be tilted in the cross-track direction to cover a wide range in that direction. For TIR telescope the scanning mirror has the tilt mechanism in addition to vibration function. The range is specified so as to cover 272 km from a spacecraft altitude of 705 km. The total coverage of 272 km is obtained by adding a spacecraft recurrent inaccuracy of ±20 km to the user's requirement (232 km). For VNIR band, the extra range is provided to observe a special target with a shorter period.

Integration on Terra: All components are integrated on the spacecraft as shown in Figure 2-1. The configuration can be divided into six blocks; (1) VSR block (two telescopes of VNIR), (2) VEL block (electronics of VNIR), (3) SWIR block, (4) TIR block, (5) CSP block and (6) MPS block. The thermal control of the SWIR and the TIR subsystems is carried out mainly by the cold plates with capillary pumps and partly by radiators. Other blocks employ independent thermal control by radiation.

Schematic Configuration: Figure 2-2 shows the more detailed functional block diagram.


VNIR Subsystem


SWIR Subsystem

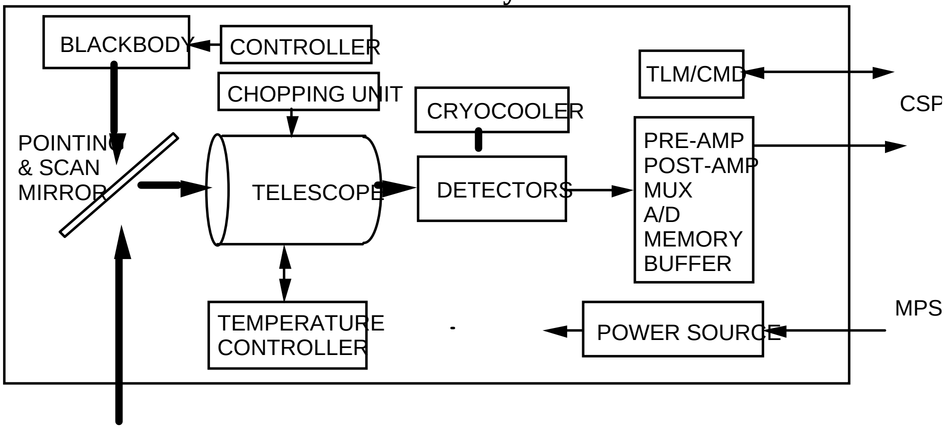

TIR Subsystem

Figure 2-2 Functional brock diagram

Figure 2-3 shows the more detailed schematic configuration of each subsystem.

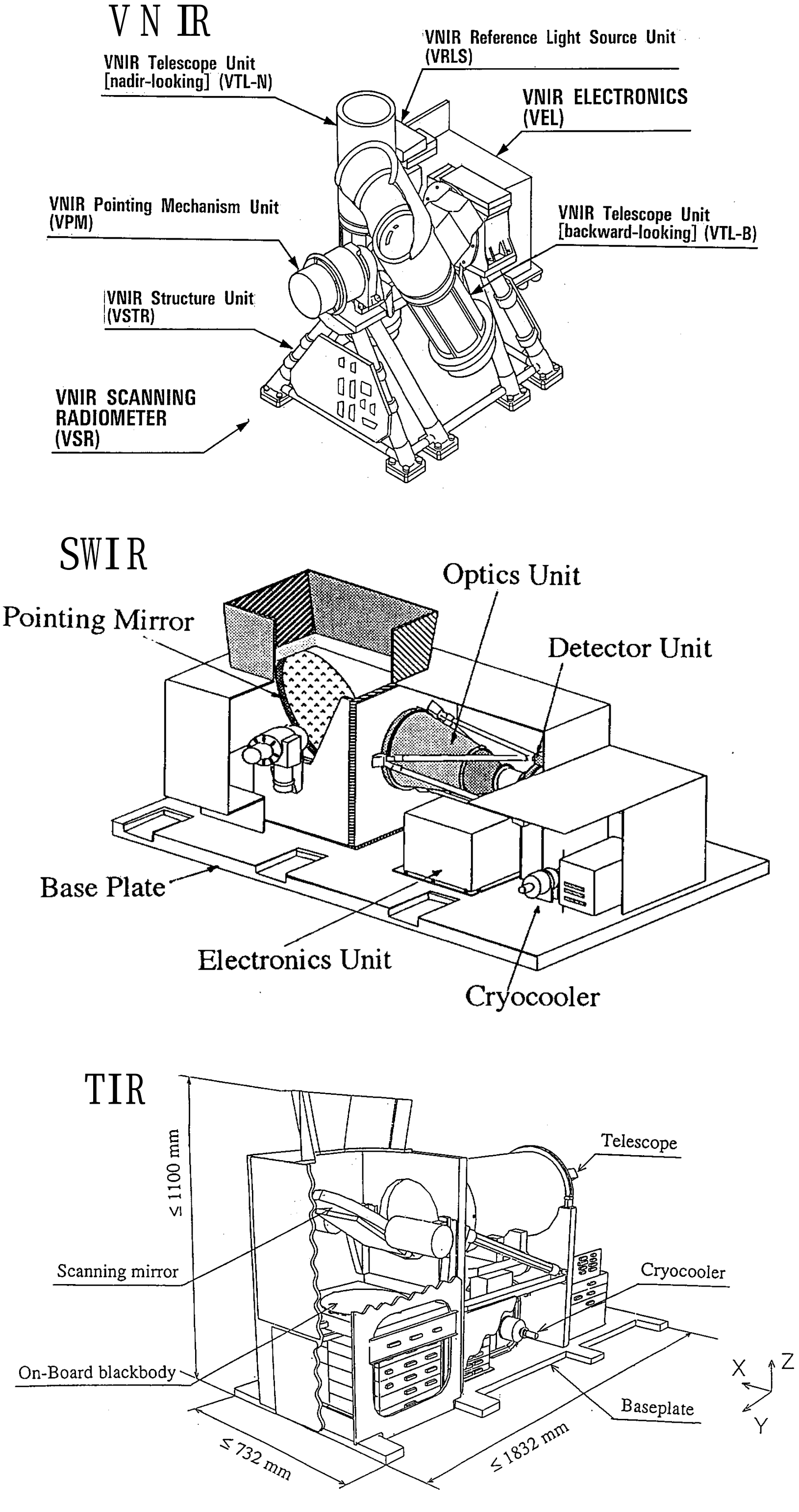


Figure 2-3 Schematic configuration of each subsystem

Stereo Configuration: Figure 2-4 shows the stereo configuration for which the backward telescope is adopted. The relation between B/H ratio and α is B/H = tan α, where α is the angle between the nadir and the backward direction at a observing point on the earth surface. The angle α which corresponds to B/H ratio of 0.6 is 30.96˚. By considering the curvature of the earth surface, the setting angle between the nadir and the backward telescope is designed to be 27.60˚.

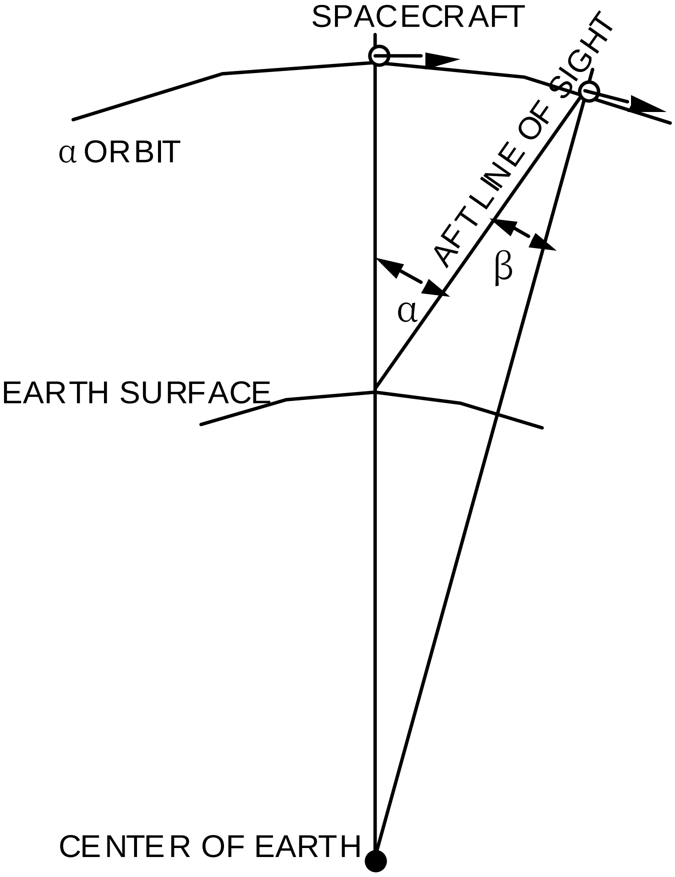


Figure 2-4 Stereo configuration

2.4. System Components

Primary Components: Table 2-3 summarizes the primary ASTER functions and components. A different type of telescope is employed for each optical sensing subsystem to meet its wavelength region and size of focal plane requirements. Exact spectral separation of all bands is carried out by band pass filters. Both VNIR and SWIR images are obtained by pushbroom scanning employing linear array detectors of Si-CCD and PtSi-CCD, respectively. TIR images are obtained by mechanical scanning with 10 HgCdTe PC type detectors per spectral band, giving a total of 50 detectors. ASTER has four uncooled and two cooled focal planes. The band pass filters of the SWIR and TIR subsystems are integrated together with detectors on the cooled focal planes to suppress thermal radiation from the filters. The SWIR and the TIR focal planes are cooled by separate mechanical Stirling cycle cryocoolers.

Table 2-3 Significant ASTER function and components

Item	VNIR	SWIR	TIR
Scan	Pushbroom	Pushbroom	Whiskbroom
Telescope optics	Reflective (Schmidt) D=82.25 mm (Nadir) D=94.28 mm (Backward)	Refractive D=190 mm	Reflective (Newtonian) D=240 mm
Spectrum separation	Dichroic and band pass filter	Band pass filter	Band pass filter
Focal plane (Detector)	Si-CCD 5000 x 4	PtSi-CCD 2048 x 6	HgCdTe (PC) 10 x 5
Cryocooler (Temperature)	not cooled	Stirling cycle, 77 K	Stirling cycle, 80 K
Cross-track pointing	Telescope rotation ±24˚	Pointing mirror rotation ±8.55˚	Scan mirror rotation ±8.55˚
Thermal control	Radiator	Cold plate and Radiator	Cold plate and Radiator
Calibration method	2 sets of Halogen lamps and monitor diodes	2 sets of Halogen lamps and monitor diodes	Blackbody 270 - 340 K

2.5. Spectral Performance

Definition: The central wavelength is defined by the center of the band width, and the band width is defined at a half value of the peak responsivity

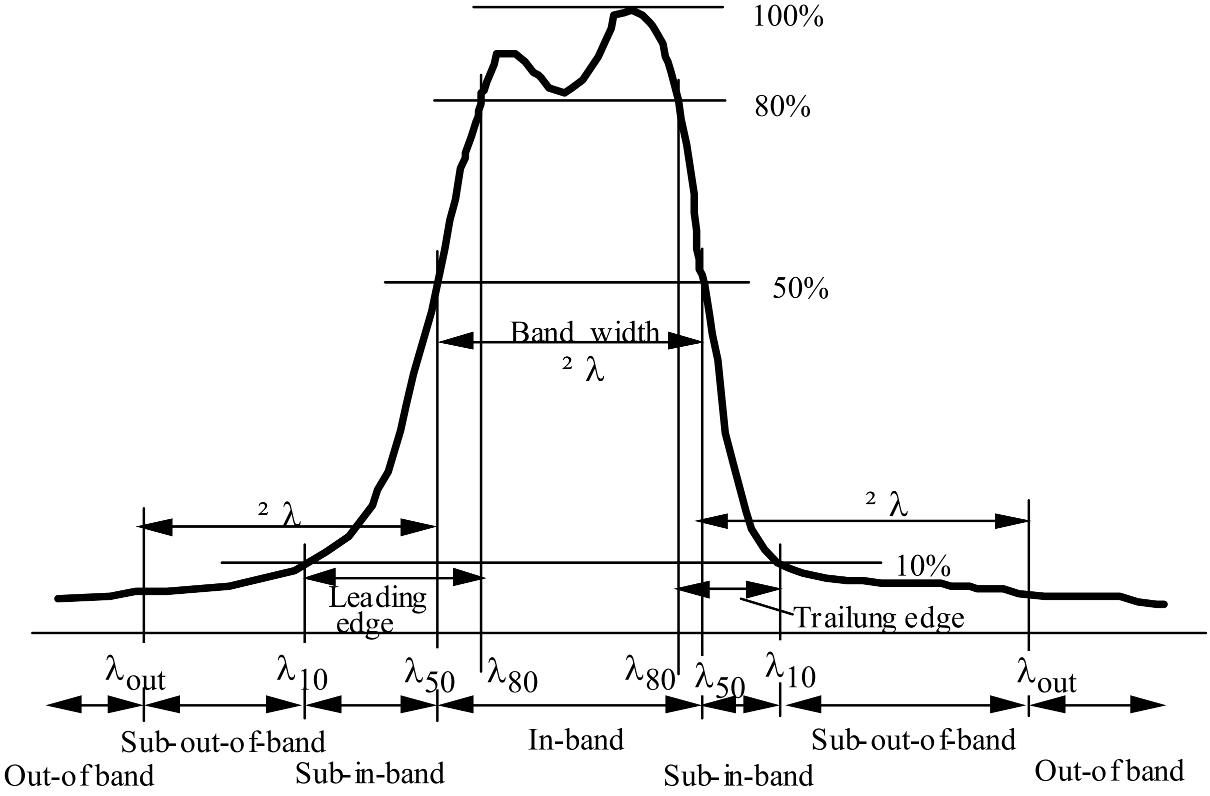


Figure 2-5 Definition of spectral characteristics

General Spectral Performance: Spectral separation capability is one of the most important features of ASTER instrument. The central wavelength and width of each band was carefully selected to meet the scientific requirements, especially for SWIR and TIR bands. Table 2-4 shows the measured values of the central wavelength, the momentum center and the band width together with the specification. It should be noted that the difference between the central wavelength and the momentum centers is very small.

Table 2-4 Spectral performance

Bands	Central wavelength (μm)		Momentum center (μm)	Band width (μm)	
	Specified value	Measured value	Measured value	Specified value	Measured value
1	0.56 ± 0.01	0.556	0.556	0.08 ± 0.02	0.09
2	0.66 ± 0.01	0.659	0.661	0.06 ± 0.02	0.06
3N	0.81 ± 0.01	0.807	0.807	0.10 ± 0.02	0.10
3B	0.81 ± 0.01	0.804	0.804	0.10 ± 0.02	0.11
4	1.650 ± 0.010	1.657	1.656	0.10 ± 0.020	0.092
5	2.165 ± 0.007	2.169	2.167	0.04 ± 0.010	0.035
6	2.205 ± 0.007	2.209	2.208	0.04 ± 0.010	0.040
7	2.260 ± 0.007	2.263	2.266	0.05 ± 0.010	0.047
8	2.330 ± 0.010	2.334	2.336	0.07 ± 0.015	0.070
9	2.395 ± 0.010	2.400	2.400	0.07 ± 0.015	0.068
10	8.30 ± 0.08	8.274	8.291	0.35 ± 0.08	0.344
11	8.65 ± 0.08	8.626	8.634	0.35 ± 0.08	0.347
12	9.10 ± 0.08	9.072	9.075	0.35 ± 0.08	0.361
13	10.60 ± 0.10	10.654	10.657	0.70 ± 0.12	0.667
14	11.30 ± 0.10	11.303	11.318	0.70 ± 0.12	0.593

Spectral Profile:

Figure 2-6 shows the spectral response profiles of all bands as a function of the wavelength.

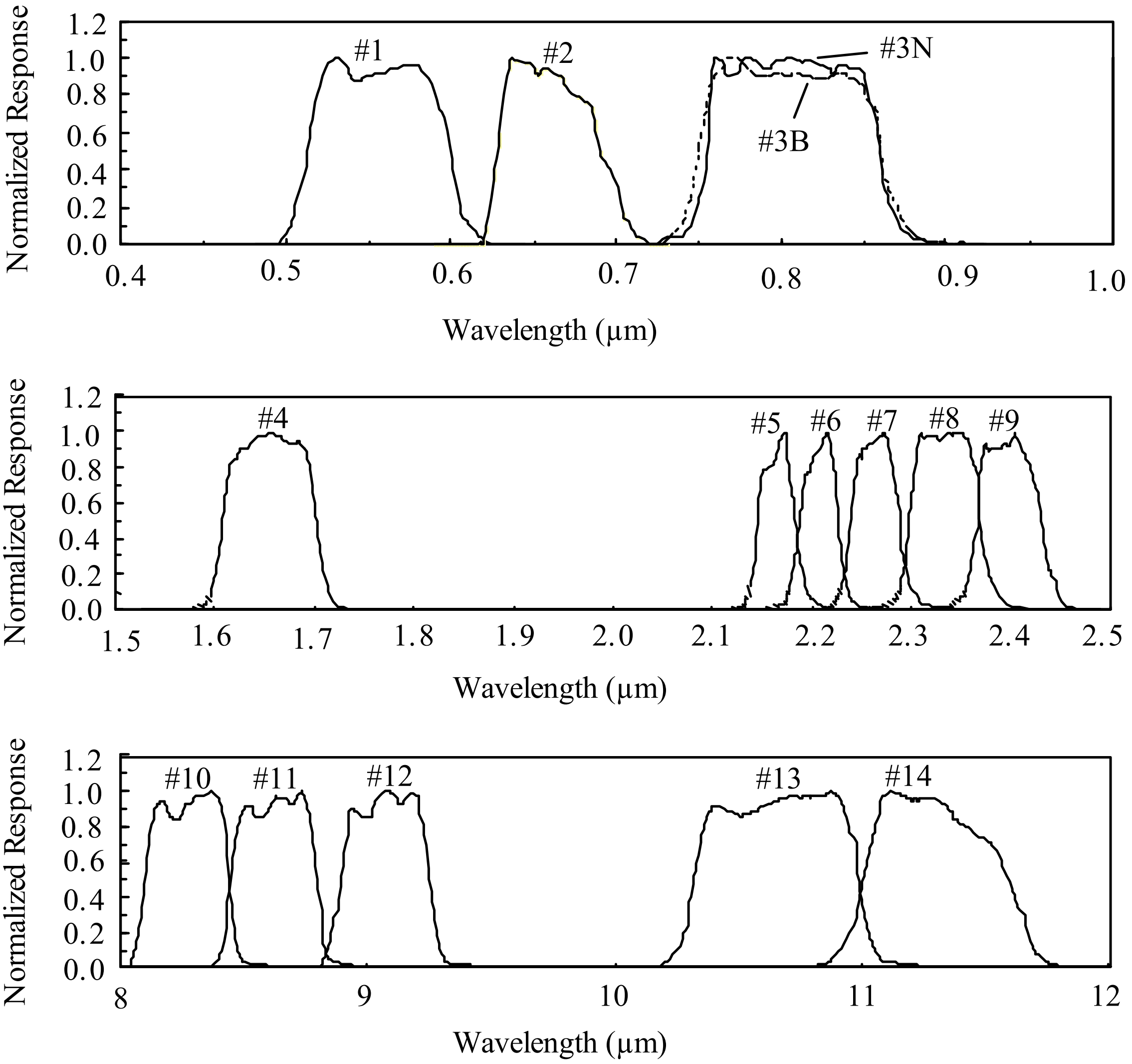


Figure 2-6 Spectral response

Detailed Band Edge Response: A sharp band edge response is also required to satisfy the high spectral resolution. Table 2-5 shows the measured band edge response with the specification. The band edge response is defined by the wavelength difference between 10 % and 80 % of the peak responsibility. Band pass filters are mainly responsible for these spectral performance. The spectral performance of PFM meets these specifications with high accuracy.

Table 2-5 Band edge response

Bands	Lower band edge (nm)		Upper band edge (nm)	
	Specified	Measured	Specified	Measured
1	≤ 35	16.6	≤ 35	19.9
2	≤ 35	9.7	≤ 35	32.4
3N	≤ 35	18.1	≤ 60	27.4
3B	≤ 35	14.9	≤ 60	22.2
4	≤ 40	21	≤ 40	19
5	≤ 33	20	≤ 33	19
6	≤ 33	19	≤ 33	15
7	≤ 33	17	≤ 33	21
8	≤ 33	17	≤ 33	23
9	≤ 33	17	≤ 33	23
10	≤ 140	67	≤ 150	64
11	≤ 140	76	≤ 150	66
12	≤ 140	71	≤ 150	68
13	≤ 280	111	≤ 300	105
14	≤ 280	141	≤ 300	273

2.6. Radiometric Performance

Radiometirc Signal Flow: Figure 2-7 shows the radiometric signal flow of the ASTER instrument. Reflected or emitted radiation from the earth surface reaches detectors through the optics and is converted into the electric signal. Incident radiation may include stray light from the large earth disk which is one of radiometric error sources. For the VNIR and SWIR the electric current is integrated in the detector during a sampling period to convert to the electric charge. The electric current or the electric charge is then converted into the voltage, followed by amplification with variable gain and then digitization by the AD converters. Detectors of TIR receive the radiation not only from the target but also from the optics and the structure of TIR itself. The initial stage of the TIR electronic circuit is in AC operation to avoid the effect of a large offset. A DC signal is restored prior to main part of the electronic processing.

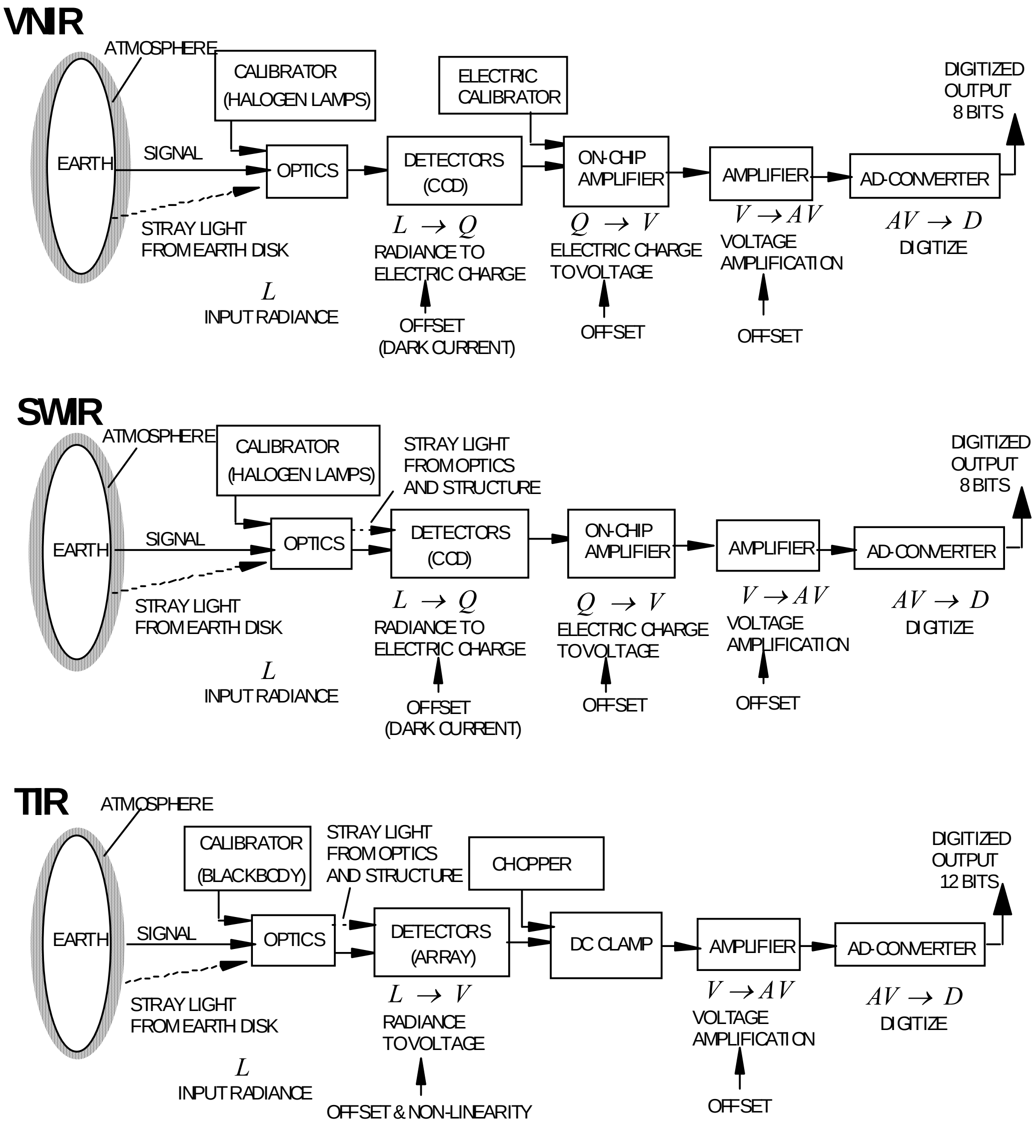


Figure 2-7 Radiometric signal flow

Input Radiance: The input radiance is one of the most important parameters for the instrument design. The properly constrained values are essential for the effective use of DN (Digital Number) values and to avoid radiometric signal saturation over bright targets. The input radiance was carefully calculated with the method outlined below by the ASTER science team and used by the instrument design and fabrication team.

Table 2-6 shows the maximum, the high level and the low level radiances defined by the target radiance in front of each radiometer. The specification on radiometric accuracy is applied to the high level radiance. For the wavelength region of VNIR and SWIR subsystems, the radiances above the atmosphere were estimated with two kinds of calculation codes; LOWTRAN-7 and Meteorological Research Institute (MRI) code. Calculation conditions which are used to determine the input radiance employed here are shown below. The condition which gives the largest radiance was employed for each code. The assumed spacecraft orbit parameters are a local time of 10:30 am at the equator, sun synchronous descending
node and an orbit inclination of 98.2 deg.

MRI code (for VNIR bands 1-3)
(i) Atmosphere divided into 5 layers (0-2 km, 2-5 km, 5-13 km, 13-25 km, 25-100 km).
(ii) No aerosol
(iii) Rayleigh scattering calculated by using LOWTRAN-6 for mid latitude in summer.
(iv) Complete diffuse target with a reflectance of 70 %.
(v) A solar zenith angle of 24.5 deg correspond to that on a latitude of 45 deg N at the summer solstice.

LOWTRAN-7 (for SWIR bands 4-9)
(i) Atmosphere model for 1976 US standard.
(ii) Aerosol model for desert.
(iii) Complete diffuse target with a reflectance of 70 %.
(iv) A solar zenith angle of 20.7 deg correspond to that on the equator at the vernal equinox.

For VNIR bands 1-3, MRI code gives a larger radiance than LOWTRAN-7. The difference was attributed to multi-scattering between atmosphere and earth surface, which is not included in the calculation by LOWTRAN-7. Therefore, the radiance calculated by MRI code under the above conditions is employed as the high level input radiance of VNIR bands.

For SWIR bands 4-9, LOWTRAN-7 gives a slightly larger radiance than MRI code. The small difference was attributed to atmospheric scattering. The radiance calculated by LOWTRAN-7 under the above conditions is employed as the high level input radiance of SWIR bands.

A concept of the maximum input radiance which is specified as 20% larger than the high level input radiance is employed not only to avoid the saturation for targets with very high reflectance such as clouds but also to compensate any ambiguity of the calculation model. A low level input radiance was also defined which was 20% of the high level input radiance. The low level input radiance is necessary to specify the radiometric performance for targets with low reflectance and for a large solar zenith angle.

For the TIR bands 10-14, the input radiance is specified by a blackbody temperature, since it is not only simple but also convenient for the instrument performance test which use blackbody as a source of radiation.

Table 2-6 Input radiance (W/m^2/sr/μm)

Band No.	Maximum input radiance	High level input radiance	Low level input radiance
1	427	356	71.2
2	358	298	59.6
3N	218	182	36.4
3B	218	182	36.4
4	55.0	45.8	9.16
5	17.6	14.7	2.94
6	15.8	13.2	2.64
7	15.1	12.6	2.52
8	10.55	8.79	1.76
9	8.04	6.70	1.34
10-14	Radiance of 370 K blackbody	Radiance of 300 K blackbody	Radiance of 200 K blackbody

Gain Setting: The VNIR and SWIR subsystems have independent gain switching function. The gain setting accuracy is specified as ±1% or less. Each subsystem will not be saturated for its electronics including detector element up to the input radiance divided by the maximum radiance by the multiplication factors.

The high gain setting is necessary to allocate a large DN output for a low reflectance target input. The low gain-1 is prepared to give a redundancy for unexpected high reflectance targets, though almost all targets are expected to be observed by normal gain setting.

Specially prepared low gain-2 of SWIR bands is for the observation of high temperature targets such as lava. The highest observable temperature of targets is about 650K corresponding to a saturation input radiance of 130 W/(m^2•sr•μm) of the CCD linear array.

Table 2-7 shows the measured values of the gains of the VNIR and SWIR spectral bands. The gains of some bands have slightly different values for odd and even pixels, since the outputs of the odd and even pixels are processed by different electronic circuits. The TIR subsystem does not have a gain setting function because it is a 12-bit system.

Table 2-7 Gain setting

Subsystem	Ban No.	Hight/Normal			Low-1/Normal			Low-2/Normal		
		Spec.	Measured value		Spec.	Measured value		Spec.	Measured value	
			Odd	Even		Odd	Even		Odd	Even
VNIR	1	2.5	2.475	2.469	0.75	0.749	0.752	N/A		
	2	2.0	1.989	1.998	0.75	0.758	0.752			
	3N	2.0	2.055	2.028	0.75	0.759	0.754			
	3B	2.0	1.987	2.012	0.75	0.758	0.760			
SWIR	4	2.0	1.993	1.993	0.75	0.751	0.751	0.75	0.751	0.751
	5	2.0	1.988	1.988	0.75	0.748	0.748	0.17	0.167	0.167
	6	2.0	1.988	1.988	0.75	0.748	0.748	0.16	0.157	0.157
	7	2.0	1.989	1.989	0.75	0.748	0.748	0.18	0.171	0.171
	8	2.0	1.988	1.988	0.75	0.748	0.748	0.17	0.162	0.162
	9	2.0	1.989	1.989	0.75	0.748	0.748	0.12	0.116	0.116

Radiometric Sensitivity: The instrument parameter for the radiometric resolution is signal-to-noise ratio (S/N) rather than NEΔρ described in Table 2-2. Therefore, NEΔρ is translated into S/N by using the relation, S/N = (target reflectance)/ NEΔρ. User's requirement is applied to the high level input radiance. Therefore, 70 % target reflectance which is employed to estimate the high level input radiance is used for the conversion between NEΔρ and S/N. For TIR bands, the radiometric resolution is specified directly by user required parameter NEΔT which is convenient for the instrument performance test.

The radiometric resolution for the low level input radiance is specified, though it is not included in the user requirements. A decrease in photon noise for the low level input radiance is taken into account. The total noise is expected to decrease down to 70% for VNIR bands and 80% for SWIR bands compared to the noise of the high input radiance in this specification. For TIR bands, NEΔT for the low input radiance is specified as 2.5K or 1.5K depending on bands by considering that the required accuracy is 3K and the input radiance for bands 10-12 is very low for 200K blackbody target.

Table 2-8 shows the measured radiometric sensitivities with the specified values for the high and low level input radiances which are defined by signal to noise ratio (S/N) for VNIR and SWIR subsystems and noise equivalent temperature difference (NEΔT) for TIR subsystem. The excellent radiometric performance of ASTER can be expected based on the preflight evaluation of PFM on the ground.

Table 2-8 Radiometric sensitivity

Subsystem	Band No.	S/N or NEΔT for high level radiance		S/N or NEΔT for low level radiance	
		Specified value	Measured value	Specified value	Measured value
VNIR	1	≥ 140	370 - 278	≥ 40	170 - 78
	2	≥ 140	306 - 256	≥ 40	122 - 74
	3N	≥ 140	202 - 173	≥ 40	70 - 58
	3B	≥ 140	183 - 150	≥ 40	72 - 56
SWIR	4	≥ 140	466 - 292	≥ 35	368 -63
	5	≥ 54	254 -163	≥ 13.5	77 - 45
	6	≥ 54	229 -150	≥ 13.5	73 - 36
	7	≥ 54	234 - 151	≥ 13.5	72 - 35
	8	≥ 70	258- 165	≥ 17.5	81 - 34
	9	≥ 54	231 - 156	≥ 13.5	73 - 44
TIR	10	≤ 0.3 K	0.17 - 0.07 K	≤ 2.5 K	1.34 - 0.68 K
	11	≤ 0.3 K	0.14 - 0.09 K	≤ 2.5 K	1.27 - 0.63 K
	12	≤ 0.3 K	0.13 - 0.07 K	≤ 2.5 K	1.05 - 0.42 K
	13	≤ 0.3 K	0.09 - 0.05 K	≤ 1.5 K	0.49 - 0.26 K
	14	≤ 0.3 K	0.13 - 0.09 K	≤ 1.5 K	0.65 - 0.33 K

Radiometric Calibration : The absolute radiometric calibration of the PFM VNIR and SWIR radiometers was performed by using large integrating spheres which were lit at the High Level Input Radiance for each band. The integrating spheres were calibrated against fixed-point blackbodies of copper (1084.62 C), zinc (419.527 C), and tin (231.928 C) through variable temperature blackbodies. The calibration uncertainty was evaluated at better than 3% for VNIR and 6% for SWIR, considering the cross calibration results among NASA GSFC, NIST, University of Arizona and NRLM in 1995 and 1996. The nonlinearity of both radiometers was measured and was less than 1% of the High Level Input Radiance.

The two on-board calibration lamps for VNIR and SWIR were calibrated through the radiometer itself against the integrating sphere. After launch the on-board calibration will be done once every 17 days and will be used to correct for change with time of the radiometers. Inflight calibrations are planned to ensure and correct, if necessary, the performance of the on-board calibrators.

PFM TIR was calibrated against a standard blackbody in a thermal vacuum chamber. The temperature of the standard blackbody was varied at ten points from 200 K to 370 K both in the hot and cold cases which correspond to the cold plate temperature of 25 C and 20 C, respectively. From these cases three calibration coefficients, constant, linear and second order term, were determined. After launch TIR see the on-board blackbody at 270 K before each observation. The constant term will be corrected by this blackbody observation (this is called short term calibration). The temperature of the on-board blackbody will be changed from 270 K to 340 K once every 17 days for long term calibration, and the linear term will be corrected.

2.7. Geometric Performance

Focal Plane Configuration: Figure 2-8 shows the focal plane configuration. The detector layout is expressed by the foot print on the ground in relation to the spacecraft flight direction and the boresight of each telescope. The sizes on the focal planes are shown with the configuration, because the sizes on the ground depend on the spacecraft altitude. These sizes are designed so as to meet the base line requirement for the spatial resolution within the fabrication accuracy of the focal length when the spacecraft altitude is 705 km.

The SWIR and the TIR subsystems employ the stagger detector alignment for the cross-track and the along-track directions, respectively, to enhance the radiometric sensitivity, since the stagger alignment makes it possible to have a larger detector size than the pixel-to-pixel spacing (center-to-center dimension) which defines the Nyquist spatial resolution. However, it should be noted that the larger detector size sacrifices the MTF. The SWIR detector sizes are 20 um in the cross-track direction and 17 micro m in the along-track direction, while the pixel-to-pixel spacing is 16.5 µm in the cross-track direction and 33 µm in the along-track direction. The TIR detector size is 50 µm x 50 µm which equal to the pixel-to-pixel spacing in the along-track direction.

For VNIR and SWIR subsystems, one line of image data of all bands in the cross-track direction are acquired simultaneously because of data sampling function of CCD detector arrays. For TIR subsystem, they are acquired time-sequentially in accordance to the scanning speed of the mirror because of the whiskbroom scanning method. A tilt angle of 0.3 degrees is set for the compensation of the earth rotation during the scan period so as to align the swath line at the right angle to the spacecraft flight direction. All scan direction in the cross-track direction is designed to be at the right angle to the spacecraft flight direction.

The focal plane configuration was carefully designed to meet the accuracy and stability requirements which were necessary to meet the scientific requirements on geometric performance such as the band-to-band registration.

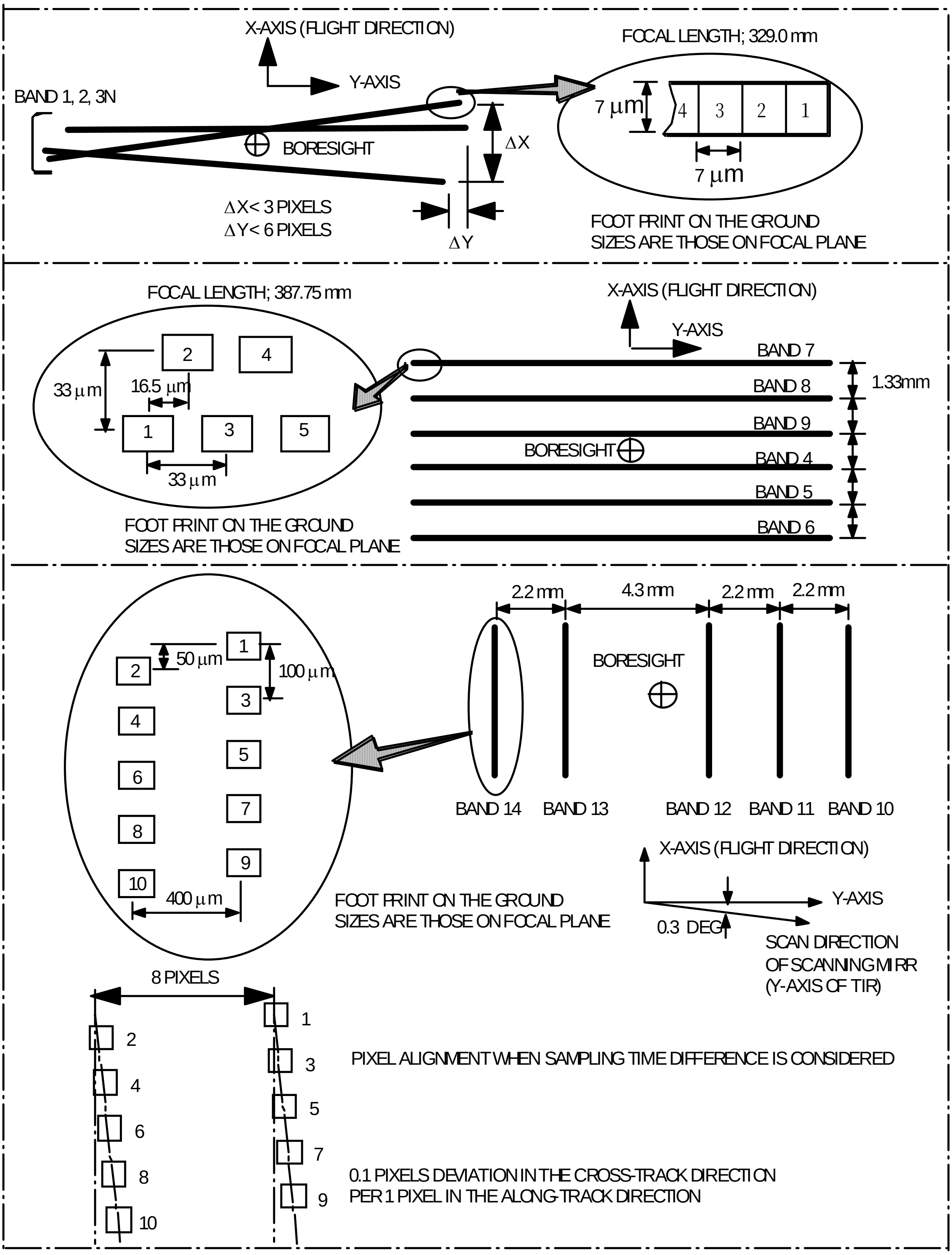


Figure 2-8 Focal plane configuration

Accuracy of configuration: Electronically scanned linear detector arrays for VNIR and SWIR subsystems are arranged one linear array for each band to obtain one line data in the cross-track direction for each scan period. For TIR subsystem ten detectors for each are arranged to obtain ten lines in the cross-track direction for each scan period. The deviation and the stability among detectors on the focal plane is specified as shown in Table 2-9. For TIR subsystem, only, the deviation is defined as deviation from integer times of the nominal pixel size

The bias is the fixed deviation from the exact band-to-band registration and specified by considering the current state of the art. Except for TIR subsystem, the resampling is necessary for precise band-to-band registration even in the same telescope. The stability is specified so as to be kept within 0.2 pixels of each band during the life of instrument in order to assure a registration accuracy of 0.2 pixels in the same telescope by using only preflight parameters on the focal plane configuration.

For VNIR subsystem the bias deviation in the along-track direction is specified as greater than that in the cross-track direction to maintain a registration accuracy of around 0.2 pixels without compensating the earth rotation.

Table 2-9 Accuracy of Detector cofiguration

Subsystem	Bias		Stability (3σ)
	Along-track	Cross-track	
VNIR	≤ 3 pixels	≤ 6 pixels	≤ ±0.2 pixels
SWIR	≤ 420 pixels	≤ 0.2 pixels	≤ ±0.2 pixels
TIR	≤ 0.05 pixels	≤ 0.05 pixesl	N/A

Spatial Resolution: The spatial resolution or the pixel size is defined on the basis of the Nyquist sampling theorem. Therefore, the pixel size means the spacing between the nearest data sampled for both the cross-track and the along-track directions.

The instrument parameters on the spatial resolution in the cross-track direction are the pixel spacing (center-to-center dimension) of linear array detectors for the VNIR and the SWIR subsystems, and the data sampling distance for the TIR subsystem described with the angle as shown in Table 2-10. Therefore, the spatial resolution on the ground depends not only on the spacecraft altitude but also on the pointing angle. The spatial resolution angles are specified and then designed so as to meet the requirement, which is described with the spatial resolution on the ground, for the nadir direction from a nominal spacecraft altitude of 705 km.

The instrument parameters on the spatial resolution in the along-track direction is the scan period defined by data sampling period every swath line as shown in Table 2-10. Therefore, the spatial resolution on the ground directly depends on the spacecraft velocity which slightly depends on the altitude and the latitude of the nadir direction. The scan periods are specified and then designed so as to meet the requirement, when the spacecraft is crossing over the equator with an altitude of 705 km.

Table 2-10 Geometric parameters

Subsystem		IFOV angle in cross-track (μrad)	Scan period in along-track (ms)
VNIR	Nadir	21.3 ± 0.4	2.199 ± 0.02
	Backward	18.6 ± 0.3	2.199 ± 0.02
SWIR		42.6 ± 0.8	4.398 ± 0.044
TIR		127.5 ± 2.5	131.94 ± 0.13*

Poinging Function: The pointing range in the cross-track direction is defined as the angle from the nadir direction of spacecraft. Other pointing parameters are defined for the installed plane of each subsystem, and applied only for the pointing range of ±8.55 degrees. These pointing function are specified by Ttable 2-11. The specifications except for VNIR range are applied only for the range of ±8.55 degree.

The pointing function is provided for global coverage in the cross-track direction by changing the center of the swath. The range is specified so as to cover 272km from a platform altitude of 705km. The total coverage of 272km is obtained by adding a platform recurrent inaccuracy of ±20km to the user's requirement (232km). For VNIR band, the extra range is provided to observe a special target with a shorter period.

The pointing repeatability and accuracy are important parameter for band-to-band registration among different telescopes and specified by considering the current state of the art. The accuracy and the repeatability specified correspond to 41 and 6.1 pixels of a VNIR resolution of 15m, respectively. Therefore, new parameters for band-to-band registration among different telescopes must be searched by ground processing such as correlation when the pointing mode is changed, though the searching range can be reduced by the accuracy or the repeatability.

When the pointing is kept in the same mode, band-to-band registration accuracy among different telescope is decided by the stability. The stability is specified so as to be kept within 0.1 pixels of each band during 8 minutes correspond to the maximum data acquisition time for each orbit.

Table 2-11 Pinting Functions (Requirement)

Items		VNIR	SWIR	TIR
Range		≥ ±24°	≥ 8.55°	
Accuracy of pointing axis		≤ ±360 arcsec from X axis		
Setting resolution		≤ ±45 arcsec		
Repeatability (3σ)		≤ ±180 arcsec		
Detecting resolution		≤ ±20 arcsec		
Detection accuracy (3σ		≤ ±27 arcsec		
Variable frequency		≥ 20,000		≥200,000
Pointing time		60 sec		
Stability	Roll	≤ ±0.44 arcsec	≤ ±0.88 arcsec	≤ ±2.6 arcsec
(3σvalues in	Pitch	≤ ±0.44 arcsec	≤ ±0.88 arcsec	≤ ±2.6 arcsec
8 minutes)	Yaw	≤ ±2.2 arcsec	≤ ±4.5 arcsec	≤ ±13.4 arcsec

Relative Pointing Knowledge: Table 2-12 shows the relative pointing knowledge among the different telescopes which is important for the band-to-band registration. Although the static error can be removed using the image matching data acquired during the initial checkout period, it is clear from Table 9 that the knowledge is not accurate enough for carrying out the inter-telescope registration only by the system correction in the ground processing. Therefore, the image matching techniques will have to be carried out regularly for a good inter-telescope registration.

Table 12 Relative pointing knowledge among different telescopes (Prediction)

	Unit	Dynamic Error			Static Error		
		Roll	Pitch	Yaw	Roll	Pitch	Yaw
VNIR - SWIR	arcsec, 3□	±31	±24	±16	±44	±45	±334
	m, 3□	±106	±82	±11	±150	±154	±220
VNIR - TIR	arcsec, 3□	±17	±19	±17	±57	±50	±49
	m, 3□	±58	±65	±11	±194	±170	±32
SWIR - TIR	arcsec, 3□	±30	±26	±16	±56	±53	±305
	m, 3□	±102	±89	±11	±190	±181	±221

Geolocation Knowledge: Table 2-13 shows the pixel geolocation knowledge which can be predicted from the spacecraft position knowledge, the spacecraft pointing knowledge and the ASTER pointing knowledge. Only the dynamic error is important for the geolocation accuracy, because the static error can be removed using GCP (Ground Control Point) observation data during the initial checkout period. A geolocation accuracy of about fifty meters can be anticipated for the targets without the terrain error (targets of the nadir direction, for example).

Table 2-13 Pixel geolocation knowledge (Prediction)

		Specification	Dynamic error (3□)	Static error (3□)
Along-track (m)	Spacecraft *[1]	±342	±28	±111
	ASTER/VNIR	±205	±38	±99
	Total	±431 *[2]	±47	±149
Cross-track (m)	Spacecraft *[1]	±342	±25	±148
	ASTER/VNIR	±205	±48	±103
	Total	±437 *[2]	±54	±180

*1: No skipped orbit, two 10 minutes contact per orbit with arbitrary TDRS, moderate to high solar and geomagnetic activety, 150 meter TDRS ephemeris errors.

*2: Slightly larger than RSS of two values (Spacecraft and ASTER instrument), because of some unallocated margin.

2.8. Modulation Transfer Function

Table 2-14 shows the measured values of the modulation transfer function (MTF) at the Nyquist and the 1/2 Nyquist spatial frequencies for the along-track and the cross-track directions with the specified values. The square wave response is employed to specify the MTF. The signal integration effect in the along-track direction was included for the VNIR and the SWIR subsystems which employ the pushbroom scanning method. A moving target was used to measure the MTF in order to consider the integration effect for VNIR. While for SWIR the integration effect was evaluated by calculation to correct the measured values using a fixed target. This situation is not applied to the TIR subsystem which is employs the whiskbroom (mechanical) scanning method.

The lower MTF in the along-track direction for VNIR subsystem is a consequence of the deterioration due to the signal integration effect. For SWIR subsystem the MTF in the cross-track direction has the almost same values as those in the along-track direction. This is due to the larger detector size than the pixel spacing which is employed to enhance the radiometric sensitivity as described in previous section (Focal Plane Configuration section).

Table 2-14 MTF (Measured values, square wave response)

Subsystem	Band No.	Along-track		Cross-track	
		Nyquist	1/2 Nyqusit	Nyquist	1/2 Nyquist
VNIR	1	0.23 - 0.28	0.72 - 0.77	0.40 - 0.51	0.82 - 0.84
	2	0.22 - 0.28	0.71 - 0.75	0.48 - 0.58	0.84 - 0.87
	3N	0.26 - 0.29	0.74 - 0.75	0.50 - 0.55	0.81 - 0.84
	3B	0.26 - 0.30	0.78 - 0.81	0.30 - 0.64	0.78 - 0.89
SWIR	4	0.34 - 0.36	0.79 - 0.83	0.40 - 0.43	0.79 - 0.92
	5	0.32 - 0.36	0.80 - 0.85	0.39 - 0.44	0.73 - 0.86
	6	0.34 - 0.36	0.79 - 0.84	0.37 - 0.45	0.74 - 0.84
	7	0.31 - 0.34	0.75 - 0.84	0.35 - 0.40	0.74 - 0.85
	8	0.33 - 0.36	0.81 - 0.84	0.32 - 0.44	0.71 - 0.86
	9	0.35 - 0.39	0.83 - 0.89	0.33 - 0.43	0.70 - 0.85
TIR	10	0.36 - 0.41	0.79 - 0.83	0.34 - 0.38	0.79 - 0.83
	11	0.37 - 0.42	0.78 - 0.81	0.34 - 0.36	0.77 - 0.81
	12	0.37 - 0.39	0.78 - 0.81	0.34 - 0.37	0.79 - 0.82
	13	0.34 - 0.37	0.74 - 0.78	0.35- 0.37	0.79 - 0.83
	14	0.31 - 0.37	0.69 - 0.76	0.34 - 0.39	0.78 - 0.83
Specification		≥ 0.20	≥ 0.50	≥ 0.25	≥ 0.50

2.9. Polarization Performance

Table 2-15 shows the measured polarization sensitivity for VNIR and SWIR bands. Very small polarization sensitivity was obtained from the current design of optics.

Table 2-15 Polarization sensitivity (Measured values %)

Specification	VNIR bands				SWIR bands						TIR bands				
	1	2	3N	3B	4	5	6	7	8	9	10	11	12	13	14
≤ ±3	0.6	0.3	0.5	0.4	1.4	0.6	0.4	0.8	0.9	0.9	N/A				

2.10. ASTER World Reference System (WRS)

Major Features: The World Reference System (WRS) is used to define a scene position on the earth surface with a combination of path and row numbers. Major features of ASTER WRS is shown below.

(1) Path/Row positions are defined for the nominal orbit.

(2) Distance between adjacent scene centers is less than 60 km.

(3) The orbit inclination angle is 98.2˚.

(4) Each scene center position is defined to make the scene spacing angle from the Earth center identical. This means that the spacecraft flight time for each scene is constant.

(5) The most northern position (N81.8˚) and the most southern position (S81.8˚) correspond to the scene borders.

(6) Each crossing node at equator always corresponds to the scene center.

(7) The row number starts at the first scene of the descending path and ends at the final scene of the ascending path.

(8) The path number increases along the direction from the east to the west starting at W64.6˚ which corresponds to the first path crossing the North America.

(9) WGS-84 is used to describe the Earth ellipsoid.

(10) Row numbers of major points are shown in Figure 2-9.

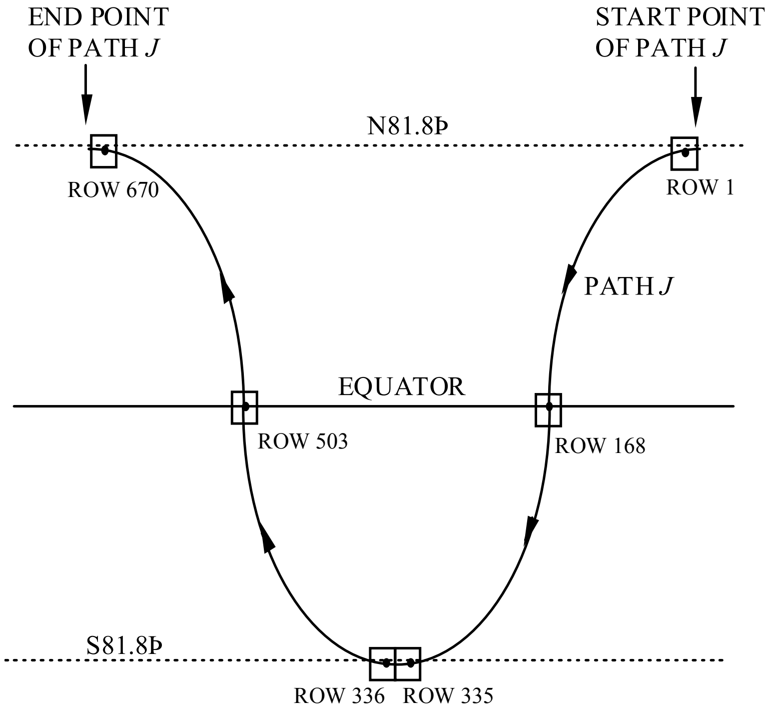


Figure 2-9 Row numbers of major points

Calculation of Scene Position :

Scene number for one path

- From item (5) of major features, the scene number on a quarter of Earth surface is N+0.5 (N:integer). Therefore, total scene number on one path is 4N+2.

- From items (2) and (4) of major features, the scene number must be larger than $2\pi a/60=667.9$, where a is the Earth radius at the equator and 6378.137 km.

- The minimum scene number which satisfies above two conditions is 670.

- One path is divided into 670 scenes.

Latitude for Each Row Number

The geocentric latitude □ for the row number k can be calculated as follows.

$$\square\,\square\sin^{-1}[\cos\{360(K - 0.5)/K_{max}\}\sin\square] , \qquad (2.10\text{-}1)$$

where $K_{max} = 670$ and □ is the complementary angle of the orbit inclination, that is, 81.8°.

The geocentric latitude □ can be converted into the geodetic latitude □ using the following relation.

$$\square = \tan^{-1} (C \tan\square \qquad .\,\square 1\square$$

where C =1.0067396 (a ratio of the Earth radius at the equator to that at the pole)

Longitude at the Equator for Each Path Number

The longitude $\square_{k=168,J}$ of the descending node at the equator for the path J can be expressed as follows.

$$\square_{k=168,J} = -64.60 - 360(J - 1)/233 \qquad (\text{for } J = 1\text{-}75) \qquad (2.10\text{-}3)$$
$$\square_{k=168,J} = 295.40 - 360(J - 1)/233 \qquad (\text{for } J = 76 – 233) \qquad (2.10\text{-}3)'$$

Longitude for Row K and Path J

Then the longitude $\square_{k,J}$ of row K and path J can be expressed as follows.

For the descending path (K=1 - 335)

$$\square_{k,J} - \square_{\square=168,J} = \tan^{-1}[\tan\{360(168 - K)/K_{max}\}\cos\square] + (168 - K)\,(T\square_e /K_{max}) + 360N , \qquad (2.10\text{-}4)$$

For the ascending path (K=336 - 670)

$$\square_{k,J} - \square_{k=168,J} = \tan^{-1}[\tan\{360(503 - K)/K_{max}\}\cos\square] +180 + (168 - K)\,(T\square_e /K_{max})360N, \qquad (2.10\text{-}4)'$$

where T and $\square_e$ are the orbit period of the spacecraft and the angular velocity of the earth rotation, respectively. The integer number N is selected to satisfy $-180<\square_{k,J}\leq 180$.

The values T and $\square_e$ can be calculated as follows.

$$T = 16 \text{ x } 24 \text{ x } 60/233 = 98.884 \quad \text{minutes,} \qquad (2.10\text{-}5)$$

$$\square_e = 360 /86400=4.1666667 \text{ x } 10^{-3} \quad \text{degree/sec.} \qquad (2.10\text{-}6)$$

Table 2-16 Latitude and Longitude values for center of each scene
Longitude values are difference from ROW 168.

ROW No.	Latitude(degree)		Longitude	ROW No.	Latitude(degree)		Longitude	ROW No.	Latitude(degree)		Longitude
	(geocentric)	(geodetic)	(degree)		(geocentric)	(geodetic)	(degree)		(geocentric)	(geodetic)	(degree)
1	81.796	81.850	94.279	51	61.744	61.904	19.869	101	35.576	35.758	8.388
2	81.761	81.815	90.492	52	61.231	61.393	19.496	102	35.047	35.228	8.236
3	81.691	81.746	86.752	53	60.718	60.882	19.134	103	34.517	34.697	8.086
4	81.589	81.644	83.087	54	60.203	60.369	18.781	104	33.988	34.167	7.937
5	81.453	81.510	79.523	55	59.688	59.856	18.439	105	33.459	33.636	7.789
6	81.287	81.345	76.080	56	59.173	59.342	18.106	106	32.929	33.105	7.643
7	81.092	81.151	72.774	57	58.656	58.827	17.781	107	32.400	32.574	7.498
8	80.869	80.929	69.617	58	58.139	58.311	17.465	108	31.870	32.043	7.354
9	80.621	80.683	66.615	59	57.621	57.795	17.157	109	31.340	31.512	7.211
10	80.350	80.414	63.771	60	57.103	57.279	16.857	110	30.811	30.980	7.070
11	80.058	80.123	61.086	61	56.585	56.761	16.564	111	30.281	30.449	6.930
12	79.745	79.812	58.555	62	56.065	56.243	16.278	112	29.751	29.917	6.791
13	79.415	79.484	56.174	63	55.546	55.725	15.998	113	29.221	29.385	6.653
14	79.069	79.140	53.936	64	55.025	55.206	15.725	114	28.691	28.853	6.516
15	78.707	78.781	51.835	65	54.505	54.687	15.458	115	28.160	28.321	6.380
16	78.333	78.409	49.863	66	53.984	54.167	15.196	116	27.630	27.788	6.245
17	77.946	78.024	48.011	67	53.462	53.646	14.941	117	27.100	27.256	6.111
18	77.548	77.629	46.272	68	52.940	53.125	14.690	118	26.569	26.724	5.977
19	77.140	77.224	44.638	69	52.418	52.604	14.445	119	26.039	26.191	5.845
20	76.723	76.809	43.102	70	51.896	52.082	14.204	120	25.508	25.658	5.714
21	76.298	76.387	41.656	71	51.373	51.560	13.968	121	24.978	25.125	5.583
22	75.866	75.957	40.294	72	50.849	51.038	13.737	122	24.447	24.592	5.453
23	75.426	75.520	39.010	73	50.326	50.515	13.510	123	23.916	24.059	5.324
24	74.981	75.077	37.797	74	49.802	49.992	13.287	124	23.386	23.526	5.196
25	74.529	74.628	36.652	75	49.278	49.468	13.068	125	22.855	22.993	5.069
26	74.073	74.174	35.568	76	48.753	48.944	12.853	126	22.324	22.459	4.942
27	73.611	73.715	34.541	77	48.229	48.420	12.642	127	21.793	21.926	4.816
28	73.145	73.252	33.568	78	47.704	47.895	12.434	128	21.262	21.392	4.690
29	72.676	72.785	32.643	79	47.178	47.370	12.230	129	20.731	20.859	4.566
30	72.202	72.314	31.764	80	46.653	46.845	12.028	130	20.200	20.325	4.441
31	71.725	71.840	30.928	81	46.127	46.319	11.830	131	19.669	19.791	4.318
32	71.245	71.362	30.131	82	45.601	45.794	11.635	132	19.138	19.257	4.195
33	70.762	70.882	29.370	83	45.075	45.268	11.443	133	18.607	18.723	4.072
34	70.277	70.399	28.644	84	44.549	44.741	11.254	134	18.075	18.189	3.950
35	69.788	69.913	27.950	85	44.022	44.215	11.068	135	17.544	17.655	3.829
36	69.298	69.425	27.285	86	43.496	43.688	10.884	136	17.013	17.121	3.708
37	68.805	68.935	26.649	87	42.969	43.161	10.703	137	16.482	16.587	3.587
38	68.311	68.442	26.039	88	42.442	42.633	10.524	138	15.950	16.052	3.467
39	67.814	67.948	25.452	89	41.914	42.106	10.347	139	15.419	15.518	3.348
40	67.316	67.452	24.889	90	41.387	41.578	10.173	140	14.887	14.983	3.229
41	66.816	66.954	24.348	91	40.859	41.050	10.001	141	14.356	14.449	3.110
42	66.314	66.455	23.826	92	40.331	40.521	9.832	142	13.824	13.914	2.991
43	65.811	65.954	23.324	93	39.804	39.993	9.664	143	13.293	13.379	2.873
44	65.307	65.452	22.839	94	39.276	39.464	9.498	144	12.761	12.845	2.756
45	64.801	64.949	22.371	95	38.747	38.935	9.334	145	12.230	12.310	2.639
46	64.294	64.444	21.920	96	38.219	38.406	9.172	146	11.698	11.775	2.522
47	63.786	63.938	21.483	97	37.691	37.877	9.012	147	11.167	11.240	2.405
48	63.277	63.431	21.060	98	37.162	37.347	8.854	148	10.635	10.705	2.289
49	62.767	62.923	20.651	99	36.633	36.818	8.697	149	10.103	10.170	2.172
50	62.256	62.414	20.254	100	36.104	36.288	8.542	150	9.572	9.635	2.057

ROW No.	Latitude(degree)		Longitude	ROW No.	Latitude(degree)		Longitude	ROW No.	Latitude(degree)		Longitude
	(geocentric)	(geodetic)	（degree)		(geocentric)	(geodetic)	（degree)		(geocentric)	(geodetic)	（degree)
151	9.040	9.100	1.941	201	-17.544	-17.655	-3.829	251	-44.022	-44.215	-11.068
152	8.508	8.565	1.826	202	-18.075	-18.189	-3.950	252	-44.549	-44.741	-11.254
153	7.977	8.030	1.710	203	-18.607	-18.723	-4.072	253	-45.075	-45.268	-11.443
154	7.445	7.495	1.596	204	-19.138	-19.257	-4.195	254	-45.601	-45.794	-11.635
155	6.913	6.959	1.481	205	-19.669	-19.791	-4.318	255	-46.127	-46.319	-11.830
156	6.382	6.424	1.366	206	-20.200	-20.325	-4.441	256	-46.653	-46.845	-12.028
157	5.850	5.889	1.252	207	-20.731	-20.859	-4.566	257	-47.178	-47.370	-12.230
158	5.318	5.354	1.138	208	-21.262	-21.392	-4.690	258	-47.704	-47.895	-12.434
159	4.786	4.818	1.023	209	-21.793	-21.926	-4.816	259	-48.229	-48.420	-12.642
160	4.254	4.283	0.909	210	-22.324	-22.459	-4.942	260	-48.753	-48.944	-12.853
161	3.723	3.748	0.795	211	-22.855	-22.993	-5.069	261	-49.278	-49.468	-13.068
162	3.191	3.212	0.682	212	-23.386	-23.526	-5.196	262	-49.802	-49.992	-13.287
163	2.659	2.677	0.568	213	-23.916	-24.059	-5.324	263	-50.326	-50.515	-13.510
164	2.127	2.142	0.454	214	-24.447	-24.592	-5.453	264	-50.849	-51.038	-13.737
165	1.595	1.606	0.341	215	-24.978	-25.125	-5.583	265	-51.373	-51.560	-13.968
166	1.064	1.071	0.227	216	-25.508	-25.658	-5.714	266	-51.896	-52.082	-14.204
167	0.532	0.535	0.114	217	-26.039	-26.191	-5.845	267	-52.418	-52.604	-14.445
168	0.000	0.000	0.000	218	-26.569	-26.724	-5.977	268	-52.940	-53.125	-14.690
169	-0.532	-0.535	-0.114	219	-27.100	-27.256	-6.111	269	-53.462	-53.646	-14.941
170	-1.064	-1.071	-0.227	220	-27.630	-27.788	-6.245	270	-53.984	-54.167	-15.196
171	-1.595	-1.606	-0.341	221	-28.160	-28.321	-6.380	271	-54.505	-54.687	-15.458
172	-2.127	-2.142	-0.454	222	-28.691	-28.853	-6.516	272	-55.025	-55.206	-15.725
173	-2.659	-2.677	-0.568	223	-29.221	-29.385	-6.653	273	-55.546	-55.725	-15.998
174	-3.191	-3.212	-0.682	224	-29.751	-29.917	-6.791	274	-56.065	-56.243	-16.278
175	-3.723	-3.748	-0.795	225	-30.281	-30.449	-6.930	275	-56.585	-56.761	-16.564
176	-4.254	-4.283	-0.909	226	-30.811	-30.980	-7.070	276	-57.103	-57.279	-16.857
177	-4.786	-4.818	-1.023	227	-31.340	-31.512	-7.211	277	-57.621	-57.795	-17.157
178	-5.318	-5.354	-1.138	228	-31.870	-32.043	-7.354	278	-58.139	-58.311	-17.465
179	-5.850	-5.889	-1.252	229	-32.400	-32.574	-7.498	279	-58.656	-58.827	-17.781
180	-6.382	-6.424	-1.366	230	-32.929	-33.105	-7.643	280	-59.173	-59.342	-18.106
181	-6.913	-6.959	-1.481	231	-33.459	-33.636	-7.789	281	-59.688	-59.856	-18.439
182	-7.445	-7.495	-1.596	232	-33.988	-34.167	-7.937	282	-60.203	-60.369	-18.781
183	-7.977	-8.030	-1.710	233	-34.517	-34.697	-8.086	283	-60.718	-60.882	-19.134
184	-8.508	-8.565	-1.826	234	-35.047	-35.228	-8.236	284	-61.231	-61.393	-19.496
185	-9.040	-9.100	-1.941	235	-35.576	-35.758	-8.388	285	-61.744	-61.904	-19.869
186	-9.572	-9.635	-2.057	236	-36.104	-36.288	-8.542	286	-62.256	-62.414	-20.254
187	-10.103	-10.170	-2.172	237	-36.633	-36.818	-8.697	287	-62.767	-62.923	-20.651
188	-10.635	-10.705	-2.289	238	-37.162	-37.347	-8.854	288	-63.277	-63.431	-21.060
189	-11.167	-11.240	-2.405	239	-37.691	-37.877	-9.012	289	-63.786	-63.938	-21.483
190	-11.698	-11.775	-2.522	240	-38.219	-38.406	-9.172	290	-64.294	-64.444	-21.920
191	-12.230	-12.310	-2.639	241	-38.747	-38.935	-9.334	291	-64.801	-64.949	-22.371
192	-12.761	-12.845	-2.756	242	-39.276	-39.464	-9.498	292	-65.307	-65.452	-22.839
193	-13.293	-13.379	-2.873	243	-39.804	-39.993	-9.664	293	-65.811	-65.954	-23.324
194	-13.824	-13.914	-2.991	244	-40.331	-40.521	-9.832	294	-66.314	-66.455	-23.826
195	-14.356	-14.449	-3.110	245	-40.859	-41.050	-10.001	295	-66.816	-66.954	-24.348
196	-14.887	-14.983	-3.229	246	-41.387	-41.578	-10.173	296	-67.316	-67.452	-24.889
197	-15.419	-15.518	-3.348	247	-41.914	-42.106	-10.347	297	-67.814	-67.948	-25.452
198	-15.950	-16.052	-3.467	248	-42.442	-42.633	-10.524	298	-68.311	-68.442	-26.039
199	-16.482	-16.587	-3.587	249	-42.969	-43.161	-10.703	299	-68.805	-68.935	-26.649
200	-17.013	-17.121	-3.708	250	-43.496	-43.688	-10.884	300	-69.298	-69.425	-27.285

ROW	Latitude(degree)		Longitude	ROW	Latitude(degree)		Longitude	ROW	Latitude(degree)		Longitude
No.	(geocentric)	(geodetic)	(degree)	No.	(geocentric)	(geodetic)	(degree)	No.	(geocentric)	(geodetic)	(degree)
301	-69.788	-69.913	-27.950	351	-78.333	-78.409	-142.498	401	-53.984	-54.167	-177.164
302	-70.277	-70.399	-28.644	352	-77.946	-78.024	-144.349	402	-53.462	-53.646	-177.420
303	-70.762	-70.882	-29.370	353	-77.548	-77.629	-146.089	403	-52.940	-53.125	-177.670
304	-71.245	-71.362	-30.131	354	-77.140	-77.224	-147.723	404	-52.418	-52.604	-177.916
305	-71.725	-71.840	-30.928	355	-76.723	-76.809	-149.259	405	-51.896	-52.082	-178.156
306	-72.202	-72.314	-31.764	356	-76.298	-76.387	-150.705	406	-51.373	-51.560	-178.392
307	-72.676	-72.785	-32.643	357	-75.866	-75.957	-152.067	407	-50.849	-51.038	-178.623
308	-73.145	-73.252	-33.568	358	-75.426	-75.520	-153.351	408	-50.326	-50.515	-178.850
309	-73.611	-73.715	-34.541	359	-74.981	-75.077	-154.563	409	-49.802	-49.992	-179.073
310	-74.073	-74.174	-35.568	360	-74.529	-74.628	-155.709	410	-49.278	-49.468	-179.292
311	-74.529	-74.628	-36.652	361	-74.073	-74.174	-156.793	411	-48.753	-48.944	-179.507
312	-74.981	-75.077	-37.797	362	-73.611	-73.715	-157.819	412	-48.229	-48.420	-179.719
313	-75.426	-75.520	-39.010	363	-73.145	-73.252	-158.793	413	-47.704	-47.895	-179.927
314	-75.866	-75.957	-40.294	364	-72.676	-72.785	-159.718	414	-47.178	-47.370	-180.131
315	-76.298	-76.387	-41.656	365	-72.202	-72.314	-160.596	415	-46.653	-46.845	-180.332
316	-76.723	-76.809	-43.102	366	-71.725	-71.840	-161.433	416	-46.127	-46.319	-180.530
317	-77.140	-77.224	-44.638	367	-71.245	-71.362	-162.230	417	-45.601	-45.794	-180.725
318	-77.548	-77.629	-46.272	368	-70.762	-70.882	-162.990	418	-45.075	-45.268	-180.917
319	-77.946	-78.024	-48.011	369	-70.277	-70.399	-163.716	419	-44.549	-44.741	-181.106
320	-78.333	-78.409	-49.863	370	-69.788	-69.913	-164.411	420	-44.022	-44.215	-181.293
321	-78.707	-78.781	-51.835	371	-69.298	-69.425	-165.075	421	-43.496	-43.688	-181.476
322	-79.069	-79.140	-53.936	372	-68.805	-68.935	-165.712	422	-42.969	-43.161	-181.658
323	-79.415	-79.484	-56.174	373	-68.311	-68.442	-166.322	423	-42.442	-42.633	-181.837
324	-79.745	-79.812	-58.555	374	-67.814	-67.948	-166.908	424	-41.914	-42.106	-182.013
325	-80.058	-80.123	-61.086	375	-67.316	-67.452	-167.471	425	-41.387	-41.578	-182.187
326	-80.350	-80.414	-63.771	376	-66.816	-66.954	-168.013	426	-40.859	-41.050	-182.359
327	-80.621	-80.683	-66.615	377	-66.314	-66.455	-168.534	427	-40.331	-40.521	-182.529
328	-80.869	-80.929	-69.617	378	-65.811	-65.954	-169.037	428	-39.804	-39.993	-182.697
329	-81.092	-81.151	-72.774	379	-65.307	-65.452	-169.521	429	-39.276	-39.464	-182.862
330	-81.287	-81.345	-76.080	380	-64.801	-64.949	-169.989	430	-38.747	-38.935	-183.026
331	-81.453	-81.510	-79.523	381	-64.294	-64.444	-170.441	431	-38.219	-38.406	-183.188
332	-81.589	-81.644	-83.087	382	-63.786	-63.938	-170.878	432	-37.691	-37.877	-183.348
333	-81.691	-81.746	-86.752	383	-63.277	-63.431	-171.301	433	-37.162	-37.347	-183.507
334	-81.761	-81.815	-90.492	384	-62.767	-62.923	-171.710	434	-36.633	-36.818	-183.664
335	-81.796	-81.850	-94.279	385	-62.256	-62.414	-172.106	435	-36.104	-36.288	-183.819
336	-81.796	-81.850	-98.082	386	-61.744	-61.904	-172.491	436	-35.576	-35.758	-183.972
337	-81.761	-81.815	-101.869	387	-61.231	-61.393	-172.864	437	-35.047	-35.228	-184.124
338	-81.691	-81.746	-105.609	388	-60.718	-60.882	-173.227	438	-34.517	-34.697	-184.275
339	-81.589	-81.644	-109.274	389	-60.203	-60.369	-173.579	439	-33.988	-34.167	-184.424
340	-81.453	-81.510	-112.838	390	-59.688	-59.856	-173.922	440	-33.459	-33.636	-184.571
341	-81.287	-81.345	-116.281	391	-59.173	-59.342	-174.255	441	-32.929	-33.105	-184.718
342	-81.092	-81.151	-119.586	392	-58.656	-58.827	-174.579	442	-32.400	-32.574	-184.863
343	-80.869	-80.929	-122.744	393	-58.139	-58.311	-174.895	443	-31.870	-32.043	-185.007
344	-80.621	-80.683	-125.745	394	-57.621	-57.795	-175.203	444	-31.340	-31.512	-185.149
345	-80.350	-80.414	-128.589	395	-57.103	-57.279	-175.503	445	-30.811	-30.980	-185.290
346	-80.058	-80.123	-131.275	396	-56.585	-56.761	-175.797	446	-30.281	-30.449	-185.431
347	-79.745	-79.812	-133.806	397	-56.065	-56.243	-176.083	447	-29.751	-29.917	-185.570
348	-79.415	-79.484	-136.187	398	-55.546	-55.725	-176.362	448	-29.221	-29.385	-185.708
349	-79.069	-79.140	-138.424	399	-55.025	-55.206	-176.636	449	-28.691	-28.853	-185.845
350	-78.707	-78.781	-140.525	400	-54.505	-54.687	-176.903	450	-28.160	-28.321	-185.981

ROW	Latitude(degree)		Longitude	ROW	Latitude(degree)		Longitude	ROW	Latitude(degree)		Longitude
No.	(geocentric)	(geodetic)	(degree)	No.	(geocentric)	(geodetic)	(degree)	No.	(geocentric)	(geodetic)	(degree)
451	-27.630	-27.788	-186.116	501	-1.064	-1.071	-192.133	551	25.508	25.658	-198.074
452	-27.100	-27.256	-186.250	502	-0.532	-0.535	-192.247	552	26.039	26.191	-198.206
453	-26.569	-26.724	-186.383	503	0.000	0.000	-192.361	553	26.569	26.724	-198.338
454	-26.039	-26.191	-186.515	504	0.532	0.535	-192.474	554	27.100	27.256	-198.471
455	-25.508	-25.658	-186.647	505	1.064	1.071	-192.588	555	27.630	27.788	-198.605
456	-24.978	-25.125	-186.777	506	1.595	1.606	-192.701	556	28.160	28.321	-198.740
457	-24.447	-24.592	-186.907	507	2.127	2.142	-192.815	557	28.691	28.853	-198.876
458	-23.916	-24.059	-187.036	508	2.659	2.677	-192.928	558	29.221	29.385	-199.013
459	-23.386	-23.526	-187.164	509	3.191	3.212	-193.042	559	29.751	29.917	-199.151
460	-22.855	-22.993	-187.292	510	3.723	3.748	-193.156	560	30.281	30.449	-199.290
461	-22.324	-22.459	-187.419	511	4.254	4.283	-193.270	561	30.811	30.980	-199.431
462	-21.793	-21.926	-187.545	512	4.786	4.818	-193.384	562	31.340	31.512	-199.572
463	-21.262	-21.392	-187.670	513	5.318	5.354	-193.498	563	31.870	32.043	-199.714
464	-20.731	-20.859	-187.795	514	5.850	5.889	-193.612	564	32.400	32.574	-199.858
465	-20.200	-20.325	-187.919	515	6.382	6.424	-193.727	565	32.929	33.105	-200.003
466	-19.669	-19.791	-188.043	516	6.913	6.959	-193.841	566	33.459	33.636	-200.150
467	-19.138	-19.257	-188.166	517	7.445	7.495	-193.956	567	33.988	34.167	-200.297
468	-18.607	-18.723	-188.288	518	7.977	8.030	-194.071	568	34.517	34.697	-200.446
469	-18.075	-18.189	-188.410	519	8.508	8.565	-194.186	569	35.047	35.228	-200.597
470	-17.544	-17.655	-188.532	520	9.040	9.100	-194.301	570	35.576	35.758	-200.749
471	-17.013	-17.121	-188.653	521	9.572	9.635	-194.417	571	36.104	36.288	-200.902
472	-16.482	-16.587	-188.773	522	10.103	10.170	-194.533	572	36.633	36.818	-201.057
473	-15.950	-16.052	-188.893	523	10.635	10.705	-194.649	573	37.162	37.347	-201.214
474	-15.419	-15.518	-189.013	524	11.167	11.240	-194.765	574	37.691	37.877	-201.373
475	-14.887	-14.983	-189.132	525	11.698	11.775	-194.882	575	38.219	38.406	-201.533
476	-14.356	-14.449	-189.251	526	12.230	12.310	-194.999	576	38.747	38.935	-201.695
477	-13.824	-13.914	-189.369	527	12.761	12.845	-195.116	577	39.276	39.464	-201.859
478	-13.293	-13.379	-189.487	528	13.293	13.379	-195.234	578	39.804	39.993	-202.024
479	-12.761	-12.845	-189.605	529	13.824	13.914	-195.352	579	40.331	40.521	-202.192
480	-12.230	-12.310	-189.722	530	14.356	14.449	-195.470	580	40.859	41.050	-202.362
481	-11.698	-11.775	-189.839	531	14.887	14.983	-195.589	581	41.387	41.578	-202.534
482	-11.167	-11.240	-189.956	532	15.419	15.518	-195.708	582	41.914	42.106	-202.708
483	-10.635	-10.705	-190.072	533	15.950	16.052	-195.828	583	42.442	42.633	-202.884
484	-10.103	-10.170	-190.188	534	16.482	16.587	-195.948	584	42.969	43.161	-203.063
485	-9.572	-9.635	-190.304	535	17.013	17.121	-196.068	585	43.496	43.688	-203.245
486	-9.040	-9.100	-190.420	536	17.544	17.655	-196.189	586	44.022	44.215	-203.428
487	-8.508	-8.565	-190.535	537	18.075	18.189	-196.311	587	44.549	44.741	-203.615
488	-7.977	-8.030	-190.650	538	18.607	18.723	-196.433	588	45.075	45.268	-203.804
489	-7.445	-7.495	-190.765	539	19.138	19.257	-196.555	589	45.601	45.794	-203.996
490	-6.913	-6.959	-190.880	540	19.669	19.791	-196.678	590	46.127	46.319	-204.191
491	-6.382	-6.424	-190.994	541	20.200	20.325	-196.802	591	46.653	46.845	-204.389
492	-5.850	-5.889	-191.109	542	20.731	20.859	-196.926	592	47.178	47.370	-204.590
493	-5.318	-5.354	-191.223	543	21.262	21.392	-197.051	593	47.704	47.895	-204.794
494	-4.786	-4.818	-191.337	544	21.793	21.926	-197.176	594	48.229	48.420	-205.002
495	-4.254	-4.283	-191.451	545	22.324	22.459	-197.302	595	48.753	48.944	-205.214
496	-3.723	-3.748	-191.565	546	22.855	22.993	-197.429	596	49.278	49.468	-205.429
497	-3.191	-3.212	-191.679	547	23.386	23.526	-197.557	597	49.802	49.992	-205.648
498	-2.659	-2.677	-191.793	548	23.916	24.059	-197.685	598	50.326	50.515	-205.871
499	-2.127	-2.142	-191.906	549	24.447	24.592	-197.814	599	50.849	51.038	-206.098
500	-1.595	-1.606	-192.020	550	24.978	25.125	-197.944	600	51.373	51.560	-206.329

ROW	Latitude(degree)		Longitude
No.	(geocentric)	(geodetic)	（degree)
601	51.896	52.082	-206.565
602	52.418	52.604	-206.805
603	52.940	53.125	-207.051
604	53.462	53.646	-207.301
605	53.984	54.167	-207.557
606	54.505	54.687	-207.818
607	55.025	55.206	-208.085
608	55.546	55.725	-208.359
609	56.065	56.243	-208.638
610	56.585	56.761	-208.924
611	57.103	57.279	-209.218
612	57.621	57.795	-209.518
613	58.139	58.311	-209.826
614	58.656	58.827	-210.142
615	59.173	59.342	-210.466
616	59.688	59.856	-210.799
617	60.203	60.369	-211.142
618	60.718	60.882	-211.494
619	61.231	61.393	-211.857
620	61.744	61.904	-212.230
621	62.256	62.414	-212.615
622	62.767	62.923	-213.011
623	63.277	63.431	-213.420
624	63.786	63.938	-213.843
625	64.294	64.444	-214.280
626	64.801	64.949	-214.732
627	65.307	65.452	-215.200
628	65.811	65.954	-215.684
629	66.314	66.455	-216.187
630	66.816	66.954	-216.708
631	67.316	67.452	-217.250
632	67.814	67.948	-217.813
633	68.311	68.442	-218.399
634	68.805	68.935	-219.009
635	69.298	69.425	-219.646
636	69.788	69.913	-220.310
637	70.277	70.399	-221.005
638	70.762	70.882	-221.731
639	71.245	71.362	-222.491
640	71.725	71.840	-223.288
641	72.202	72.314	-224.125
642	72.676	72.785	-225.003
643	73.145	73.252	-225.928
644	73.611	73.715	-226.902
645	74.073	74.174	-227.928
646	74.529	74.628	-229.012
647	74.981	75.077	-230.158
648	75.426	75.520	-231.370
649	75.866	75.957	-232.654
650	76.298	76.387	-234.016
ROW No.	(geocentric)	(geodetic)	（degree)
651	76.723	76.809	-235.462
652	77.140	77.224	-236.998
653	77.548	77.629	-238.632
654	77.946	78.024	-240.372
655	78.333	78.409	-242.223
656	78.707	78.781	-244.196
657	79.069	79.140	-246.297
658	79.415	79.484	-248.534
659	79.745	79.812	-250.915
660	80.058	80.123	-253.446
661	80.350	80.414	-256.132
662	80.621	80.683	-258.976
663	80.869	80.929	-261.977
664	81.092	81.151	-265.135
665	81.287	81.345	-268.440
666	81.453	81.510	-271.883
667	81.589	81.644	-275.447
668	81.691	81.746	-279.112
669	81.761	81.815	-282.852
670	81.796	81.850	-286.639

Table 2-17 Longitude values for descending crossing node at Equator

ASTER World Reference System (WRS) -II

PATH NO	Longitude (degree)	PATH NO	Longitude (degree)	PATH NO	Longitude (degree)	PATH NO	Longitude (degree)	PATH NO	Longitude (degree)
1	-64.600	51	-141.853	101	140.894	151	63.640	201	-13.613
2	-66.145	52	-143.398	102	139.348	152	62.095	202	-15.158
3	-67.690	53	-144.943	103	137.803	153	60.550	203	-16.703
4	-69.235	54	-146.488	104	136.258	154	59.005	204	-18.248
5	-70.780	55	-148.033	105	134.713	155	57.460	205	-19.793
6	-72.325	56	-149.579	106	133.168	156	55.915	206	-21.338
7	-73.870	57	-151.124	107	131.623	157	54.370	207	-22.883
8	-75.415	58	-152.669	108	130.078	158	52.825	208	-24.428
9	-76.961	59	-154.214	109	128.533	159	51.280	209	-25.973
10	-78.506	60	-155.759	110	126.988	160	49.735	210	-27.518
11	-80.051	61	-157.304	111	125.443	161	48.190	211	-29.064
12	-81.596	62	-158.849	112	123.898	162	46.645	212	-30.609
13	-83.141	63	-160.394	113	122.353	163	45.100	213	-32.154
14	-84.686	64	-161.939	114	120.808	164	43.555	214	-33.699
15	-86.231	65	-163.484	115	119.263	165	42.009	215	-35.244
16	-87.776	66	-165.029	116	117.718	166	40.464	216	-36.789
17	-89.321	67	-166.574	117	116.173	167	38.919	217	-38.334
18	-90.866	68	-168.119	118	114.627	168	37.374	218	-39.879
19	-92.411	69	-169.664	119	113.082	169	35.829	219	-41.424
20	-93.956	70	-171.209	120	111.537	170	34.284	220	-42.969
21	-95.501	71	-172.755	121	109.992	171	32.739	221	-44.514
22	-97.046	72	-174.300	122	108.447	172	31.194	222	-46.059
23	-98.591	73	-175.845	123	106.902	173	29.649	223	-47.604
24	-100.136	74	-177.390	124	105.357	174	28.104	224	-49.149
25	-101.682	75	-178.935	125	103.812	175	26.559	225	-50.694
26	-103.227	76	179.520	126	102.267	176	25.014	226	-52.239
27	-104.772	77	177.975	127	100.722	177	23.469	227	-53.785
28	-106.317	78	176.430	128	99.177	178	21.924	228	-55.330
29	-107.862	79	174.885	129	97.632	179	20.379	229	-56.875
30	-109.407	80	173.340	130	96.087	180	18.833	230	-58.420
31	-110.952	81	171.795	131	94.542	181	17.288	231	-59.965
32	-112.497	82	170.250	132	92.997	182	15.743	232	-61.510
33	-114.042	83	168.705	133	91.452	183	14.198	233	-63.055
34	-115.587	84	167.160	134	89.906	184	12.653		
35	-117.132	85	165.615	135	88.361	185	11.108		
36	-118.677	86	164.070	136	86.816	186	9.563		
37	-120.222	87	162.524	137	85.271	187	8.018		
38	-121.767	88	160.979	138	83.726	188	6.473		
39	-123.312	89	159.434	139	82.181	189	4.928		
40	-124.858	90	157.889	140	80.636	190	3.383		
41	-126.403	91	156.344	141	79.091	191	1.838		
42	-127.948	92	154.799	142	77.546	192	0.293		
43	-129.493	93	153.254	143	76.001	193	-1.252		
44	-131.038	94	151.709	144	74.456	194	-2.797		
45	-132.583	95	150.164	145	72.911	195	-4.342		
46	-134.128	96	148.619	146	71.366	196	-5.888		
47	-135.673	97	147.074	147	69.821	197	-7.433		
48	-137.218	98	145.529	148	68.276	198	-8.978		
49	-138.763	99	143.984	149	66.730	199	-10.523		
50	-140.308	100	142.439	150	65.185	200	-12.068		

2.11. Orbit Characteristics

Local Time: The Terra spacecraft is operated in a circular, near polar orbit at an altitude of 705 km. The orbit is sun-synchronous with equatorial crossing at a local time of 10:30 a.m. The local time depends on both latitude and off-nadir angle of an observation point. Table 2-18 and Figure 2-10 show the relation between latitude and local time for the nadir position of the spacecraft.

Table 2-18 Relation between Latitude and Local time of nadir position

Inclination: 98.2 degrees
Equator crossing time: 10:30 am for descending orbit

Latitude (degree)		Local Time
(Geodetic)	(Geocentric)	(h:m:s)
81.854155	81.799999	16:05:11
80	79.933978	13:43:58
70	69.875992	11:42:58
60	59.833074	11:10:42
50	49.810387	10:55:25
40	39.810608	10:46:31
30	29.833633	10:40:40
20	19.876628	10:36:26
10	9.934393	10:33:02
0	0.000000	10:30:00
-10	-9.934393	10:26:58
-20	-19.876628	10:23:34
-30	-29.833633	10:19:20
-40	-39.810608	10:13:29
-50	-49.810387	10:04:35
-60	-59.833074	9:49:18
-70	-69.875992	9:17:02
-80	-79.933978	7:16:02
-81.854155	-81.799999	4:54:49

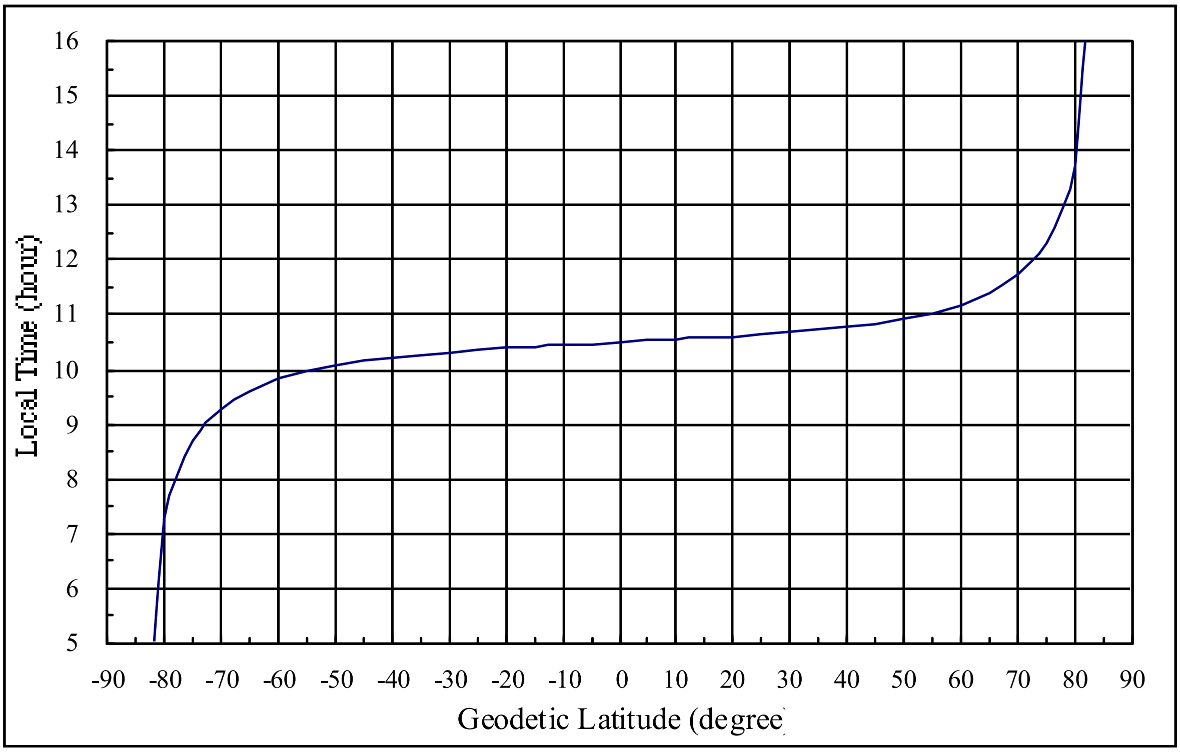


Figure 2-10 Relation between Latitude and Local time of nadir position

Path Sequence: The Terra spacecraft is operated sequentially for the orbit numbers from 1 to 233 and jump over at intervals of 16 for the path number. Table 2-19 shows the relation between the orbit and path numbers.

Table 2-19 Relation between orbit and path numbers

Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.
1	1	16	8	31	15	46	22	61	29	76	36
2	17	17	24	32	31	47	38	62	45	77	52
3	33	18	40	33	47	48	54	63	61	78	68
4	49	19	56	34	63	49	70	64	77	79	84
5	65	20	72	35	79	50	86	65	93	80	100
6	81	21	88	36	95	51	102	66	109	81	116
7	97	22	104	37	111	52	118	67	125	82	132
8	113	23	120	38	127	53	134	68	141	83	148
9	129	24	136	39	143	54	150	69	157	84	164
10	145	25	152	40	159	55	166	70	173	85	180
11	161	26	168	41	175	56	182	71	189	86	196
12	177	27	184	42	191	57	198	72	205	87	212
13	193	28	200	43	207	58	214	73	221	88	228
14	209	29	216	44	223	59	230	74	4	89	11
15	225	30	232	45	6	60	13	75	20	90	27

Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.
91	43	106	50	121	57	136	64	151	71	166	78
92	59	107	66	122	73	137	80	152	87	167	94
93	75	108	82	123	89	138	96	153	103	168	110
94	91	109	98	124	105	139	112	154	119	169	126
95	107	110	114	125	121	140	128	155	135	170	142
96	123	111	130	126	137	141	144	156	151	171	158
97	139	112	146	127	153	142	160	157	167	172	174
98	155	113	162	128	169	143	176	158	183	173	190
99	171	114	178	129	185	144	192	159	199	174	206
100	187	115	194	130	201	145	208	160	215	175	222
101	203	116	210	131	217	146	224	161	231	176	5
102	219	117	226	132	233	147	7	162	14	177	21
103	2	118	9	133	16	148	23	163	30	178	37
104	18	119	25	134	32	149	39	164	46	179	53
105	34	120	41	135	48	150	55	165	62	180	69

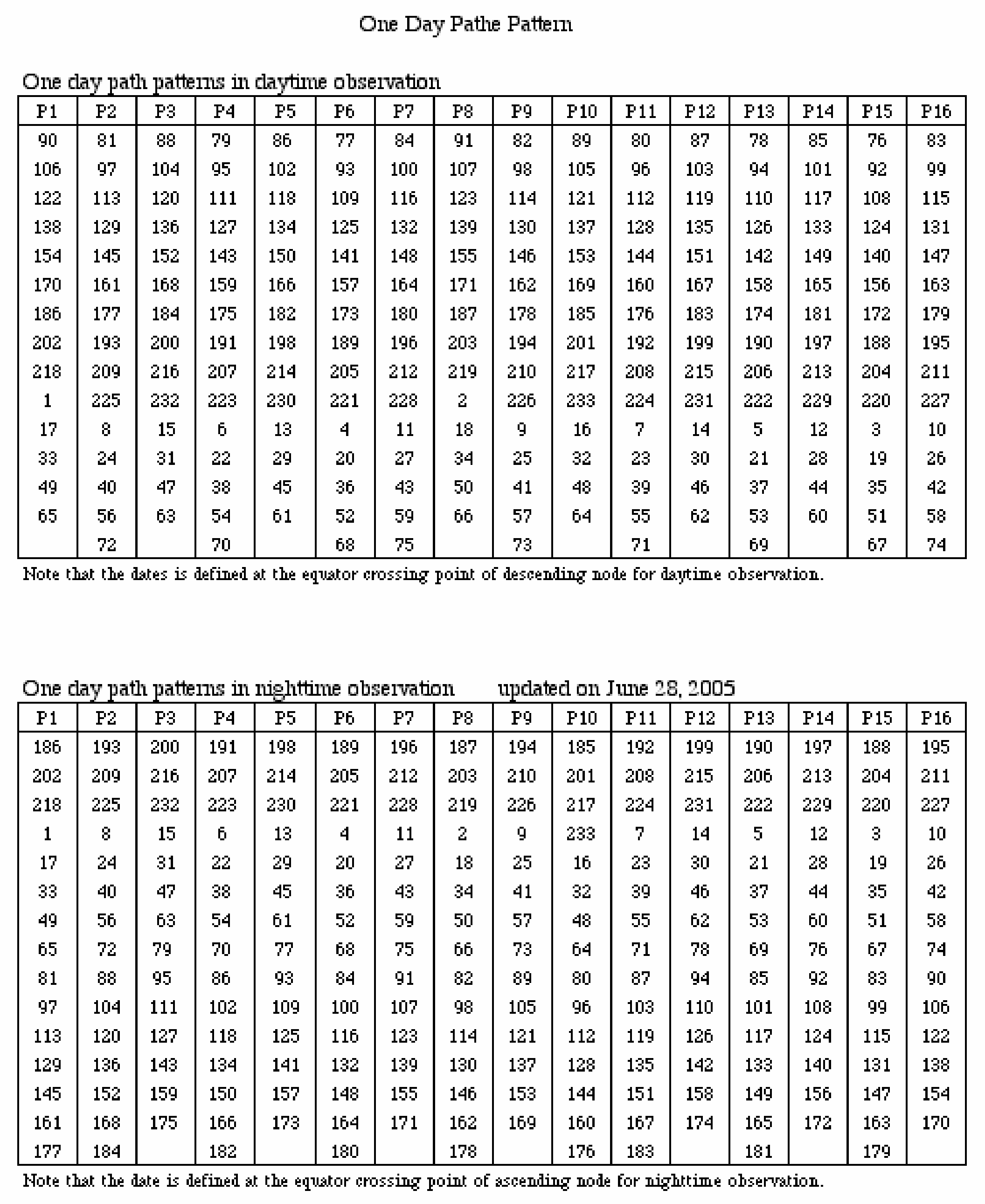
Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.	Orbit No.	Path No.
181	85	196	92	211	99	226	106	8	113
182	101	197	108	212	115	227	122	9	129
183	117	198	124	213	131	228	138	10	145
184	133	199	140	214	147	229	154	11	161
185	149	200	156	215	163	230	170	12	177
186	165	201	172	216	179	231	186	13	193
187	181	202	188	217	195	232	202	14	209
188	197	203	204	218	211	233	218	15	225
189	213	204	220	219	227	1	1	16	8
190	229	205	3	220	10	2	17	17	24
191	12	206	19	221	26	3	33	18	40
192	28	207	35	222	42	4	49	19	56
193	44	208	51	223	58	5	65	20	72
194	60	209	67	224	74	6	81	21	88
195	76	210	83	225	90	7	97	22	104

2.12 Path Calendar

Terra spacecraft have the same orbit as Landsat 7 with a different local time of 30 minutes. Therefore, we have the same path as Landsat 7. Since Terra recurrent cycle is 16 days, there are 16 one day path patterns, respectively, for both the daytime and the nighttime observations. Table 20 shows the 16 path patterns for the daytime and the nighttime observations.. The date is defined at the equator crossing point. Note that real date is different by one day when the path cross the date change line.

Table 21 shows the path calendar indicated by the one day path pattern from 2000 to 2008.

Table 2-20 One Day Path Pattern



One Day Pathe Pattern

One day path patterns in daytime observation

P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
90	81	88	79	86	77	84	91	82	89	80	87	78	85	76	83
106	97	104	95	102	93	100	107	98	105	96	103	94	101	92	99
122	113	120	111	118	109	116	123	114	121	112	119	110	117	108	115
138	129	136	127	134	125	132	139	130	137	128	135	126	133	124	131
154	145	152	143	150	141	148	155	146	153	144	151	142	149	140	147
170	161	168	159	166	157	164	171	162	169	160	167	158	165	156	163
186	177	184	175	182	173	180	187	178	185	176	183	174	181	172	179
202	193	200	191	198	189	196	203	194	201	192	199	190	197	188	195
218	209	216	207	214	205	212	219	210	217	208	215	206	213	204	211
1	225	232	223	230	221	228	2	226	233	224	231	222	229	220	227
17	8	15	6	13	4	11	18	9	16	7	14	5	12	3	10
33	24	31	22	29	20	27	34	25	32	23	30	21	28	19	26
49	40	47	38	45	36	43	50	41	48	39	46	37	44	35	42
65	56	63	54	61	52	59	66	57	64	55	62	53	60	51	58
	72		70		68	75		73		71		69		67	74

Note that the dates is defined at the equator crossing point of descending node for daytime observation.

One day path patterns in nighttime observation updated on June 28, 2005

P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
186	193	200	191	198	189	196	187	194	185	192	199	190	197	188	195
202	209	216	207	214	205	212	203	210	201	208	215	206	213	204	211
218	225	232	223	230	221	228	219	226	217	224	231	222	229	220	227
1	8	15	6	13	4	11	2	9	233	7	14	5	12	3	10
17	24	31	22	29	20	27	18	25	16	23	30	21	28	19	26
33	40	47	38	45	36	43	34	41	32	39	46	37	44	35	42
49	56	63	54	61	52	59	50	57	48	55	62	53	60	51	58
65	72	79	70	77	68	75	66	73	64	71	78	69	76	67	74
81	88	95	86	93	84	91	82	89	80	87	94	85	92	83	90
97	104	111	102	109	100	107	98	105	96	103	110	101	108	99	106
113	120	127	118	125	116	123	114	121	112	119	126	117	124	115	122
129	136	143	134	141	132	139	130	137	128	135	142	133	140	131	138
145	152	159	150	157	148	155	146	153	144	151	158	149	156	147	154
161	168	175	166	173	164	171	162	169	160	167	174	165	172	163	170
177	184		182		180		178		176	183		181		179	

Note that the date is defined at the equator crossing point of ascending node for nighttime observation.

Table 2-21 Path Calendar

Path Calendar in 2000

Upper : Date
Lower: One day path pattern

January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
												P12	P13	P14	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14

February

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	
16	17	18	19	20	21	22	23	24	25	26	27	28	29		
P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11		

March

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10

April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	

May

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7

June

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	

July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4

August

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3

September

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	

October

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16

November

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	

December

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

Table 2-21 Path Calendar

Path Calendar in 2001

Upper : Date
Lower: One day path pattern

January

1 P14	2 P15	3 P16	4 P1	5 P2	6 P3	7 P4	8 P5	9 P6	10 P7	11 P8	12 P9	13 P10	14 P11	15 P12	
16 P13	17 P14	18 P15	19 P16	20 P1	21 P2	22 P3	23 P4	24 P5	25 P6	26 P7	27 P8	28 P9	29 P10	30 P11	31 P12

February

1 P13	2 P14	3 P15	4 P16	5 P1	6 P2	7 P3	8 P4	9 P5	10 P6	11 P7	12 P8	13 P9	14 P10	15 P11	
16 P12	17 P13	18 P14	19 P15	20 P16	21 P1	22 P2	23 P3	24 P4	25 P5	26 P6	27 P7	28 P8			

March

1 P9	2 P10	3 P11	4 P12	5 P13	6 P14	7 P15	8 P16	9 P1	10 P2	11 P3	12 P4	13 P5	14 P6	15 P7	
16 P8	17 P9	18 P10	19 P11	20 P12	21 P13	22 P14	23 P15	24 P16	25 P1	26 P2	27 P3	28 P4	29 P5	30 P6	31 P7

April

1 P8	2 P9	3 P10	4 P11	5 P12	6 P13	7 P14	8 P15	9 P16	10 P1	11 P2	12 P3	13 P4	14 P5	15 P6	
16 P7	17 P8	18 P9	19 P10	20 P11	21 P12	22 P13	23 P14	24 P15	25 P16	26 P1	27 P2	28 P3	29 P4	30 P5	

May

1 P6	2 P7	3 P8	4 P9	5 P10	6 P11	7 P12	8 P13	9 P14	10 P15	11 P16	12 P1	13 P2	14 P3	15 P4	
16 P5	17 P6	18 P7	19 P8	20 P9	21 P10	22 P11	23 P12	24 P13	25 P14	26 P15	27 P16	28 P1	29 P2	30 P3	31 P4

June

1 P5	2 P6	3 P7	4 P8	5 P9	6 P10	7 P11	8 P12	9 P13	10 P14	11 P15	12 P16	13 P1	14 P2	15 P3	
16 P4	17 P5	18 P6	19 P7	20 P8	21 P9	22 P10	23 P11	24 P12	25 P13	26 P14	27 P15	28 P16	29 P1	30 P2	

July

1 P3	2 P4	3 P5	4 P6	5 P7	6 P8	7 P9	8 P10	9 P11	10 P12	11 P13	12 P14	13 P15	14 P16	15 P1	
16 P2	17 P3	18 P4	19 P5	20 P6	21 P7	22 P8	23 P9	24 P10	25 P11	26 P12	27 P13	28 P14	29 P15	30 P16	31 P1

August

1 P2	2 P3	3 P4	4 P5	5 P6	6 P7	7 P8	8 P9	9 P10	10 P11	11 P12	12 P13	13 P14	14 P15	15 P16	
16 P1	17 P2	18 P3	19 P4	20 P5	21 P6	22 P7	23 P8	24 P9	25 P10	26 P11	27 P12	28 P13	29 P14	30 P15	31 P16

September

1 P1	2 P2	3 P3	4 P4	5 P5	6 P6	7 P7	8 P8	9 P9	10 P10	11 P11	12 P12	13 P13	14 P14	15 P15	
16 P16	17 P1	18 P2	19 P3	20 P4	21 P5	22 P6	23 P7	24 P8	25 P9	26 P10	27 P11	28 P12	29 P13	30 P14	

October

1 P15	2 P16	3 P1	4 P2	5 P3	6 P4	7 P5	8 P6	9 P7	10 P8	11 P9	12 P10	13 P11	14 P12	15 P13	
16 P14	17 P15	18 P16	19 P1	20 P2	21 P3	22 P4	23 P5	24 P6	25 P7	26 P8	27 P9	28 P10	29 P11	30 P12	31 P13

November

1 P14	2 P15	3 P16	4 P1	5 P2	6 P3	7 P4	8 P5	9 P6	10 P7	11 P8	12 P9	13 P10	14 P11	15 P12	
16 P13	17 P14	18 P15	19 P16	20 P1	21 P2	22 P3	23 P4	24 P5	25 P6	26 P7	27 P8	28 P9	29 P10	30 P11	

December

1 P12	2 P13	3 P14	4 P15	5 P16	6 P1	7 P2	8 P3	9 P4	10 P5	11 P6	12 P7	13 P8	14 P9	15 P10	
16 P11	17 P12	18 P13	19 P14	20 P15	21 P16	22 P1	23 P2	24 P3	25 P4	26 P5	27 P6	28 P7	29 P8	30 P9	31 P10

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

Table 2-21 Path Calendar

Path Calendar in 2002

Upper : Date
Lower: One day path pattern

January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9

February

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	
16	17	18	19	20	21	22	23	24	25	26	27	28			
P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5			

March

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4

April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	

May

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1

June

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	

July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14

August

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13

September

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	

October

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10

November

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	

December

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

Table 2-21 Path Calendar

Path Calendar in 2003

Upper : Date
Lower: One day path pattern

January

1 P8	2 P9	3 P10	4 P11	5 P12	6 P13	7 P14	8 P15	9 P16	10 P1	11 P2	12 P3	13 P4	14 P5	15 P6	
16 P7	17 P8	18 P9	19 P10	20 P11	21 P12	22 P13	23 P14	24 P15	25 P16	26 P1	27 P2	28 P3	29 P4	30 P5	31 P6

February

1 P7	2 P8	3 P9	4 P10	5 P11	6 P12	7 P13	8 P14	9 P15	10 P16	11 P1	12 P2	13 P3	14 P4	15 P5	
16 P6	17 P7	18 P8	19 P9	20 P10	21 P11	22 P12	23 P13	24 P14	25 P15	26 P16	27 P1	28 P2			

March

1 P3	2 P4	3 P5	4 P6	5 P7	6 P8	7 P9	8 P10	9 P11	10 P12	11 P13	12 P14	13 P15	14 P16	15 P1	
16 P2	17 P3	18 P4	19 P5	20 P6	21 P7	22 P8	23 P9	24 P10	25 P11	26 P12	27 P13	28 P14	29 P15	30 P16	31 P1

April

1 P2	2 P3	3 P4	4 P5	5 P6	6 P7	7 P8	8 P9	9 P10	10 P11	11 P12	12 P13	13 P14	14 P15	15 P16	
16 P1	17 P2	18 P3	19 P4	20 P5	21 P6	22 P7	23 P8	24 P9	25 P10	26 P11	27 P12	28 P13	29 P14	30 P15	

May

1 P16	2 P1	3 P2	4 P3	5 P4	6 P5	7 P6	8 P7	9 P8	10 P9	11 P10	12 P11	13 P12	14 P13	15 P14	
16 P15	17 P16	18 P1	19 P2	20 P3	21 P4	22 P5	23 P6	24 P7	25 P8	26 P9	27 P10	28 P11	29 P12	30 P13	31 P14

June

1 P15	2 P16	3 P1	4 P2	5 P3	6 P4	7 P5	8 P6	9 P7	10 P8	11 P9	12 P10	13 P11	14 P12	15 P13	
16 P14	17 P15	18 P16	19 P1	20 P2	21 P3	22 P4	23 P5	24 P6	25 P7	26 P8	27 P9	28 P10	29 P11	30 P12	

July

1 P13	2 P14	3 P15	4 P16	5 P1	6 P2	7 P3	8 P4	9 P5	10 P6	11 P7	12 P8	13 P9	14 P10	15 P11	
16 P12	17 P13	18 P14	19 P15	20 P16	21 P1	22 P2	23 P3	24 P4	25 P5	26 P6	27 P7	28 P8	29 P9	30 P10	31 P11

August

1 P12	2 P13	3 P14	4 P15	5 P16	6 P1	7 P2	8 P3	9 P4	10 P5	11 P6	12 P7	13 P8	14 P9	15 P10	
16 P11	17 P12	18 P13	19 P14	20 P15	21 P16	22 P1	23 P2	24 P3	25 P4	26 P5	27 P6	28 P7	29 P8	30 P9	31 P10

September

1 P11	2 P12	3 P13	4 P14	5 P15	6 P16	7 P1	8 P2	9 P3	10 P4	11 P5	12 P6	13 P7	14 P8	15 P9	
16 P10	17 P11	18 P12	19 P13	20 P14	21 P15	22 P16	23 P1	24 P2	25 P3	26 P4	27 P5	28 P6	29 P7	30 P8	

October

1 P9	2 P10	3 P11	4 P12	5 P13	6 P14	7 P15	8 P16	9 P1	10 P2	11 P3	12 P4	13 P5	14 P6	15 P7	
16 P8	17 P9	18 P10	19 P11	20 P12	21 P13	22 P14	23 P15	24 P16	25 P1	26 P2	27 P3	28 P4	29 P5	30 P6	31 P7

November

1 P8	2 P9	3 P10	4 P11	5 P12	6 P13	7 P14	8 P15	9 P16	10 P1	11 P2	12 P3	13 P4	14 P5	15 P6	
16 P7	17 P8	18 P9	19 P10	20 P11	21 P12	22 P13	23 P14	24 P15	25 P16	26 P1	27 P2	28 P3	29 P4	30 P5	

December

1 P6	2 P7	3 P8	4 P9	5 P10	6 P11	7 P12	8 P13	9 P14	10 P15	11 P16	12 P1	13 P2	14 P3	15 P4	
16 P5	17 P6	18 P7	19 P8	20 P9	21 P10	22 P11	23 P12	24 P13	25 P14	26 P15	27 P16	28 P1	29 P2	30 P3	31 P4

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

Table 2-21 Path Calendar

Path Calendar in 2004

Upper : Date
Lower: One day path pattern

January

1 P5	2 P6	3 P7	4 P8	5 P9	6 P10	7 P11	8 P12	9 P13	10 P14	11 P15	12 P16	13 P1	14 P2	15 P3	
16 P4	17 P5	18 P6	19 P7	20 P8	21 P9	22 P10	23 P11	24 P12	25 P13	26 P14	27 P15	28 P16	29 P1	30 P2	31 P3

February

1 P4	2 P5	3 P6	4 P7	5 P8	6 P9	7 P10	8 P11	9 P12	10 P13	11 P14	12 P15	13 P16	14 P1	15 P2	
16 P3	17 P4	18 P5	19 P6	20 P7	21 P8	22 P9	23 P10	24 P11	25 P12	26 P13	27 P14	28 P15	29 P16		

March

1 P1	2 P2	3 P3	4 P4	5 P5	6 P6	7 P7	8 P8	9 P9	10 P10	11 P11	12 P12	13 P13	14 P14	15 P15	
16 P16	17 P1	18 P2	19 P3	20 P4	21 P5	22 P6	23 P7	24 P8	25 P9	26 P10	27 P11	28 P12	29 P13	30 P14	31 P15

April

1 P16	2 P1	3 P2	4 P3	5 P4	6 P5	7 P6	8 P7	9 P8	10 P9	11 P10	12 P11	13 P12	14 P13	15 P14	
16 P15	17 P16	18 P1	19 P2	20 P3	21 P4	22 P5	23 P6	24 P7	25 P8	26 P9	27 P10	28 P11	29 P12	30 P13	

May

1 P14	2 P15	3 P16	4 P1	5 P2	6 P3	7 P4	8 P5	9 P6	10 P7	11 P8	12 P9	13 P10	14 P11	15 P12	
16 P13	17 P14	18 P15	19 P16	20 P1	21 P2	22 P3	23 P4	24 P5	25 P6	26 P7	27 P8	28 P9	29 P10	30 P11	31 P12

June

1 P13	2 P14	3 P15	4 P16	5 P1	6 P2	7 P3	8 P4	9 P5	10 P6	11 P7	12 P8	13 P9	14 P10	15 P11	
16 P12	17 P13	18 P14	19 P15	20 P16	21 P1	22 P2	23 P3	24 P4	25 P5	26 P6	27 P7	28 P8	29 P9	30 P10	

July

1 P11	2 P12	3 P13	4 P14	5 P15	6 P16	7 P1	8 P2	9 P3	10 P4	11 P5	12 P6	13 P7	14 P8	15 P9	
16 P10	17 P11	18 P12	19 P13	20 P14	21 P15	22 P16	23 P1	24 P2	25 P3	26 P4	27 P5	28 P6	29 P7	30 P8	31 P9

August

1 P10	2 P11	3 P12	4 P13	5 P14	6 P15	7 P16	8 P1	9 P2	10 P3	11 P4	12 P5	13 P6	14 P7	15 P8	
16 P9	17 P10	18 P11	19 P12	20 P13	21 P14	22 P15	23 P16	24 P1	25 P2	26 P3	27 P4	28 P5	29 P6	30 P7	31 P8

September

1 P9	2 P10	3 P11	4 P12	5 P13	6 P14	7 P15	8 P16	9 P1	10 P2	11 P3	12 P4	13 P5	14 P6	15 P7	
16 P8	17 P9	18 P10	19 P11	20 P12	21 P13	22 P14	23 P15	24 P16	25 P1	26 P2	27 P3	28 P4	29 P5	30 P6	

October

1 P7	2 P8	3 P9	4 P10	5 P11	6 P12	7 P13	8 P14	9 P15	10 P16	11 P1	12 P2	13 P3	14 P4	15 P5	
16 P6	17 P7	18 P8	19 P9	20 P10	21 P11	22 P12	23 P13	24 P14	25 P15	26 P16	27 P1	28 P2	29 P3	30 P4	31 P5

November

1 P6	2 P7	3 P8	4 P9	5 P10	6 P11	7 P12	8 P13	9 P14	10 P15	11 P16	12 P1	13 P2	14 P3	15 P4	
16 P5	17 P6	18 P7	19 P8	20 P9	21 P10	22 P11	23 P12	24 P13	25 P14	26 P15	27 P16	28 P1	29 P2	30 P3	

December

1 P4	2 P5	3 P6	4 P7	5 P8	6 P9	7 P10	8 P11	9 P12	10 P13	11 P14	12 P15	13 P16	14 P1	15 P2	
16 P3	17 P4	18 P5	19 P6	20 P7	21 P8	22 P9	23 P10	24 P11	25 P12	26 P13	27 P14	28 P15	29 P16	30 P1	31 P2

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

Table 2-21 Path Calendar

Path Calendar in 2005

Upper : Date
Lower: One day path pattern

January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1

February

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	
16	17	18	19	20	21	22	23	24	25	26	27	28			
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13			

March

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12

April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	

May

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9

June

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	

July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6

August

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5

September

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	

October

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2

November

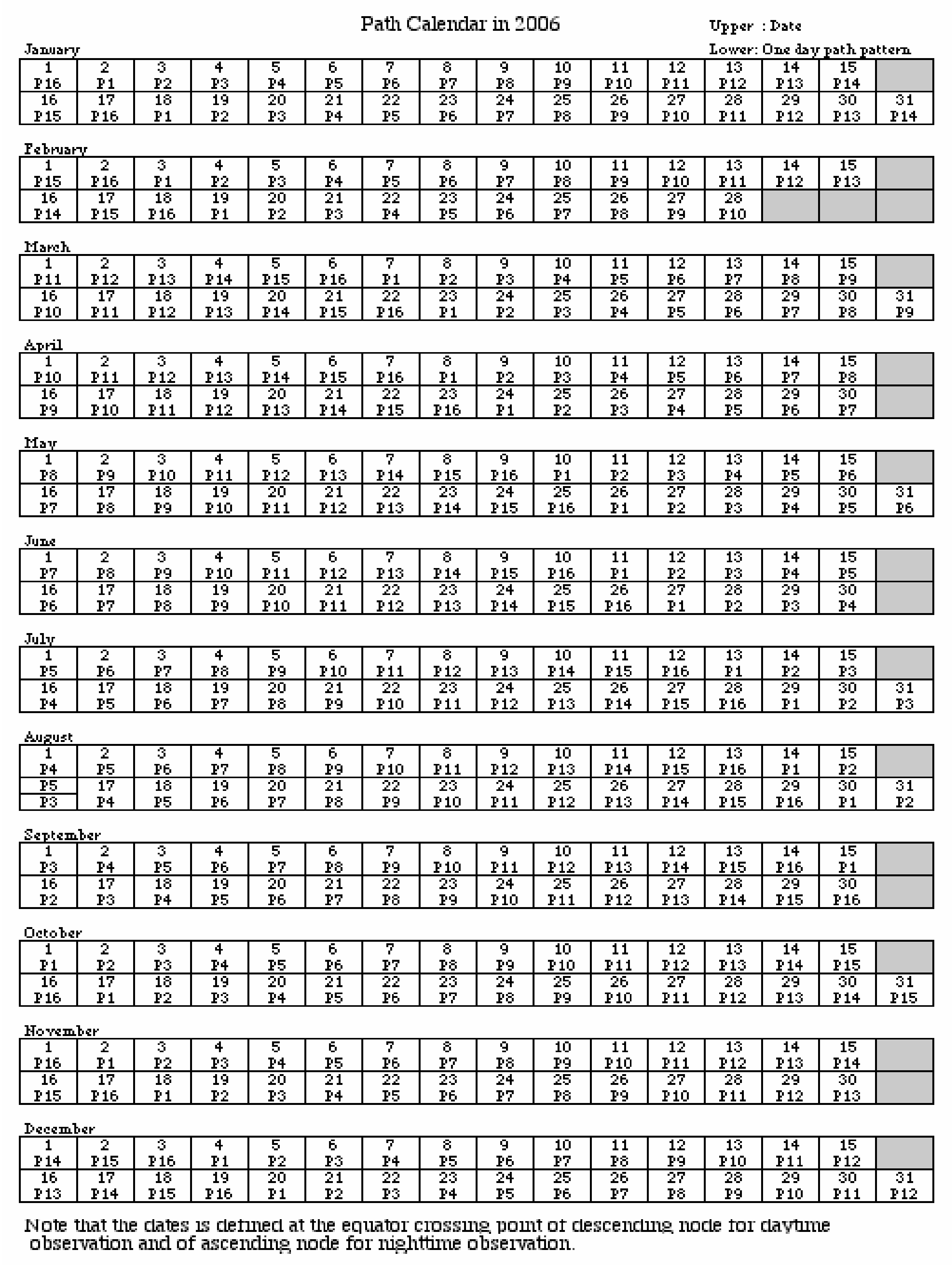
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	

December

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

Table 2-21 Path Calendar



Path Calendar in 2006

Upper : Date
Lower: One day path pattern

January

1 P16	2 P1	3 P2	4 P3	5 P4	6 P5	7 P6	8 P7	9 P8	10 P9	11 P10	12 P11	13 P12	14 P13	15 P14	
16 P15	17 P16	18 P1	19 P2	20 P3	21 P4	22 P5	23 P6	24 P7	25 P8	26 P9	27 P10	28 P11	29 P12	30 P13	31 P14

February

1 P15	2 P16	3 P1	4 P2	5 P3	6 P4	7 P5	8 P6	9 P7	10 P8	11 P9	12 P10	13 P11	14 P12	15 P13	
16 P14	17 P15	18 P16	19 P1	20 P2	21 P3	22 P4	23 P5	24 P6	25 P7	26 P8	27 P9	28 P10			

March

1 P11	2 P12	3 P13	4 P14	5 P15	6 P16	7 P1	8 P2	9 P3	10 P4	11 P5	12 P6	13 P7	14 P8	15 P9	
16 P10	17 P11	18 P12	19 P13	20 P14	21 P15	22 P16	23 P1	24 P2	25 P3	26 P4	27 P5	28 P6	29 P7	30 P8	31 P9

April

1 P10	2 P11	3 P12	4 P13	5 P14	6 P15	7 P16	8 P1	9 P2	10 P3	11 P4	12 P5	13 P6	14 P7	15 P8	
16 P9	17 P10	18 P11	19 P12	20 P13	21 P14	22 P15	23 P16	24 P1	25 P2	26 P3	27 P4	28 P5	29 P6	30 P7	

May

1 P8	2 P9	3 P10	4 P11	5 P12	6 P13	7 P14	8 P15	9 P16	10 P1	11 P2	12 P3	13 P4	14 P5	15 P6	
16 P7	17 P8	18 P9	19 P10	20 P11	21 P12	22 P13	23 P14	24 P15	25 P16	26 P1	27 P2	28 P3	29 P4	30 P5	31 P6

June

1 P7	2 P8	3 P9	4 P10	5 P11	6 P12	7 P13	8 P14	9 P15	10 P16	11 P1	12 P2	13 P3	14 P4	15 P5	
16 P6	17 P7	18 P8	19 P9	20 P10	21 P11	22 P12	23 P13	24 P14	25 P15	26 P16	27 P1	28 P2	29 P3	30 P4	

July

1 P5	2 P6	3 P7	4 P8	5 P9	6 P10	7 P11	8 P12	9 P13	10 P14	11 P15	12 P16	13 P1	14 P2	15 P3	
16 P4	17 P5	18 P6	19 P7	20 P8	21 P9	22 P10	23 P11	24 P12	25 P13	26 P14	27 P15	28 P16	29 P1	30 P2	31 P3

August

1 P4	2 P5	3 P6	4 P7	5 P8	6 P9	7 P10	8 P11	9 P12	10 P13	11 P14	12 P15	13 P16	14 P1	15 P2	
P5 P3	17 P4	18 P5	19 P6	20 P7	21 P8	22 P9	23 P10	24 P11	25 P12	26 P13	27 P14	28 P15	29 P16	30 P1	31 P2

September

1 P3	2 P4	3 P5	4 P6	5 P7	6 P8	7 P9	8 P10	9 P11	10 P12	11 P13	12 P14	13 P15	14 P16	15 P1	
16 P2	17 P3	18 P4	19 P5	20 P6	21 P7	22 P8	23 P9	24 P10	25 P11	26 P12	27 P13	28 P14	29 P15	30 P16	

October

1 P1	2 P2	3 P3	4 P4	5 P5	6 P6	7 P7	8 P8	9 P9	10 P10	11 P11	12 P12	13 P13	14 P14	15 P15	
16 P16	17 P1	18 P2	19 P3	20 P4	21 P5	22 P6	23 P7	24 P8	25 P9	26 P10	27 P11	28 P12	29 P13	30 P14	31 P15

November

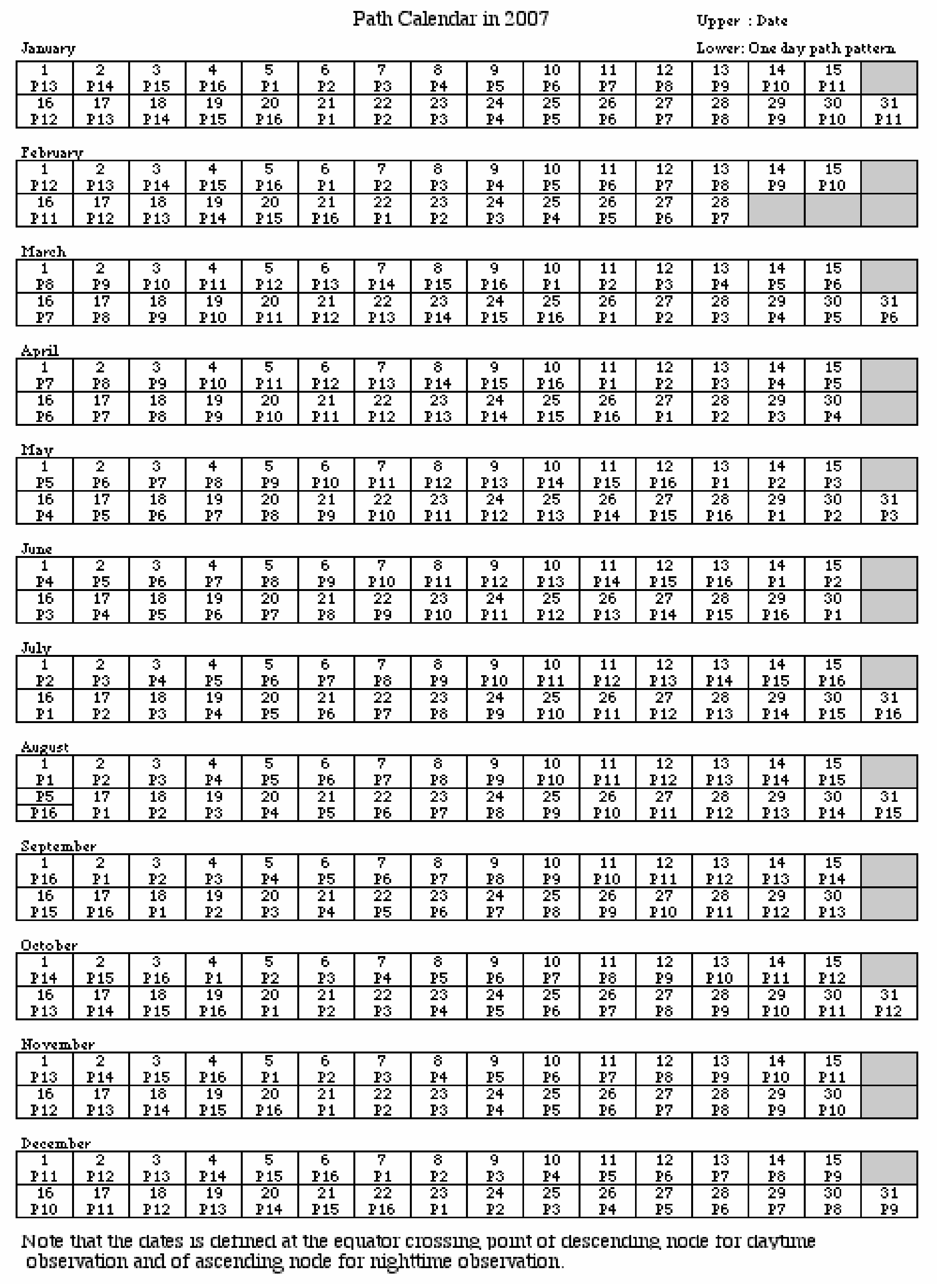
1 P16	2 P1	3 P2	4 P3	5 P4	6 P5	7 P6	8 P7	9 P8	10 P9	11 P10	12 P11	13 P12	14 P13	15 P14	
16 P15	17 P16	18 P1	19 P2	20 P3	21 P4	22 P5	23 P6	24 P7	25 P8	26 P9	27 P10	28 P11	29 P12	30 P13	

December

1 P14	2 P15	3 P16	4 P1	5 P2	6 P3	7 P4	8 P5	9 P6	10 P7	11 P8	12 P9	13 P10	14 P11	15 P12	
16 P13	17 P14	18 P15	19 P16	20 P1	21 P2	22 P3	23 P4	24 P5	25 P6	26 P7	27 P8	28 P9	29 P10	30 P11	31 P12

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

Table 2-21 Path Calendar



Path Calendar in 2007

Upper : Date
Lower: One day path pattern

January

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11

February

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
16	17	18	19	20	21	22	23	24	25	26	27	28			
P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7			

March

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6

April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	

May

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	P3

June

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	P2	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P1	

July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16

August

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	
P5	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15

September

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	

October

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12

November

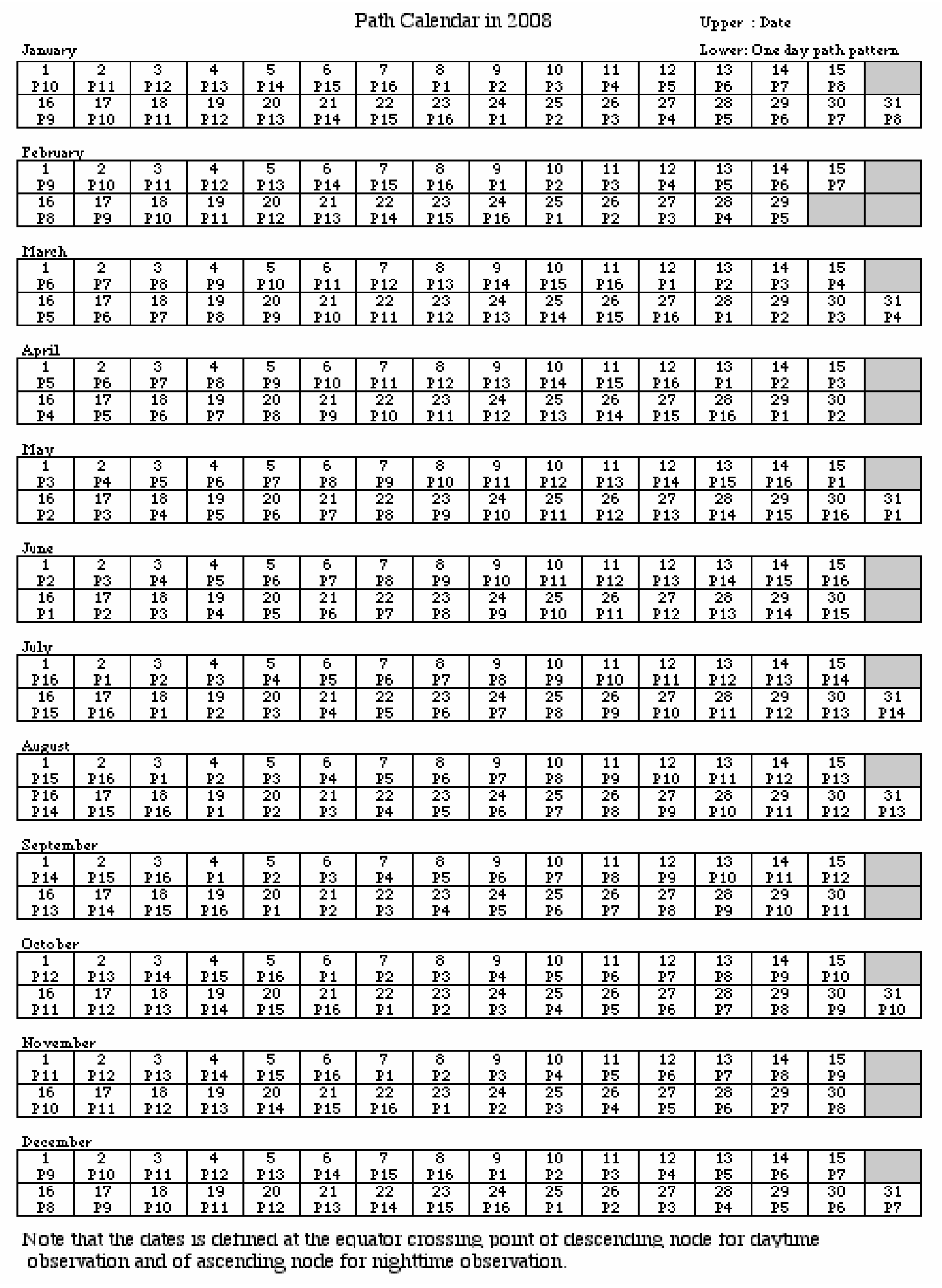
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	

December

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9	
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
P10	P11	P12	P13	P14	P15	P16	P1	P2	P3	P4	P5	P6	P7	P8	P9

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

Table 2-21 Path Calendar



Path Calendar in 2008

Upper : Date
Lower: One day path pattern

January

1 P10	2 P11	3 P12	4 P13	5 P14	6 P15	7 P16	8 P1	9 P2	10 P3	11 P4	12 P5	13 P6	14 P7	15 P8	
16 P9	17 P10	18 P11	19 P12	20 P13	21 P14	22 P15	23 P16	24 P1	25 P2	26 P3	27 P4	28 P5	29 P6	30 P7	31 P8

February

1 P9	2 P10	3 P11	4 P12	5 P13	6 P14	7 P15	8 P16	9 P1	10 P2	11 P3	12 P4	13 P5	14 P6	15 P7	
16 P8	17 P9	18 P10	19 P11	20 P12	21 P13	22 P14	23 P15	24 P16	25 P1	26 P2	27 P3	28 P4	29 P5		

March

1 P6	2 P7	3 P8	4 P9	5 P10	6 P11	7 P12	8 P13	9 P14	10 P15	11 P16	12 P1	13 P2	14 P3	15 P4	
16 P5	17 P6	18 P7	19 P8	20 P9	21 P10	22 P11	23 P12	24 P13	25 P14	26 P15	27 P16	28 P1	29 P2	30 P3	31 P4

April

1 P5	2 P6	3 P7	4 P8	5 P9	6 P10	7 P11	8 P12	9 P13	10 P14	11 P15	12 P16	13 P1	14 P2	15 P3	
16 P4	17 P5	18 P6	19 P7	20 P8	21 P9	22 P10	23 P11	24 P12	25 P13	26 P14	27 P15	28 P16	29 P1	30 P2	

May

1 P3	2 P4	3 P5	4 P6	5 P7	6 P8	7 P9	8 P10	9 P11	10 P12	11 P13	12 P14	13 P15	14 P16	15 P1	
16 P2	17 P3	18 P4	19 P5	20 P6	21 P7	22 P8	23 P9	24 P10	25 P11	26 P12	27 P13	28 P14	29 P15	30 P16	31 P1

June

1 P2	2 P3	3 P4	4 P5	5 P6	6 P7	7 P8	8 P9	9 P10	10 P11	11 P12	12 P13	13 P14	14 P15	15 P16	
16 P1	17 P2	18 P3	19 P4	20 P5	21 P6	22 P7	23 P8	24 P9	25 P10	26 P11	27 P12	28 P13	29 P14	30 P15	

July

1 P16	2 P1	3 P2	4 P3	5 P4	6 P5	7 P6	8 P7	9 P8	10 P9	11 P10	12 P11	13 P12	14 P13	15 P14	
16 P15	17 P16	18 P1	19 P2	20 P3	21 P4	22 P5	23 P6	24 P7	25 P8	26 P9	27 P10	28 P11	29 P12	30 P13	31 P14

August

1 P15	2 P16	3 P1	4 P2	5 P3	6 P4	7 P5	8 P6	9 P7	10 P8	11 P9	12 P10	13 P11	14 P12	15 P13	
P16 P14	17 P15	18 P16	19 P1	20 P2	21 P3	22 P4	23 P5	24 P6	25 P7	26 P8	27 P9	28 P10	29 P11	30 P12	31 P13

September

1 P14	2 P15	3 P16	4 P1	5 P2	6 P3	7 P4	8 P5	9 P6	10 P7	11 P8	12 P9	13 P10	14 P11	15 P12	
16 P13	17 P14	18 P15	19 P16	20 P1	21 P2	22 P3	23 P4	24 P5	25 P6	26 P7	27 P8	28 P9	29 P10	30 P11	

October

1 P12	2 P13	3 P14	4 P15	5 P16	6 P1	7 P2	8 P3	9 P4	10 P5	11 P6	12 P7	13 P8	14 P9	15 P10	
16 P11	17 P12	18 P13	19 P14	20 P15	21 P16	22 P1	23 P2	24 P3	25 P4	26 P5	27 P6	28 P7	29 P8	30 P9	31 P10

November

1 P11	2 P12	3 P13	4 P14	5 P15	6 P16	7 P1	8 P2	9 P3	10 P4	11 P5	12 P6	13 P7	14 P8	15 P9	
16 P10	17 P11	18 P12	19 P13	20 P14	21 P15	22 P16	23 P1	24 P2	25 P3	26 P4	27 P5	28 P6	29 P7	30 P8	

December

1 P9	2 P10	3 P11	4 P12	5 P13	6 P14	7 P15	8 P16	9 P1	10 P2	11 P3	12 P4	13 P5	14 P6	15 P7	
16 P8	17 P9	18 P10	19 P11	20 P12	21 P13	22 P14	23 P15	24 P16	25 P1	26 P2	27 P3	28 P4	29 P5	30 P6	31 P7

Note that the dates is defined at the equator crossing point of descending node for daytime observation and of ascending node for nighttime observation.

3. ASTER GROUND DATA SYSTEMS (ASTER GDS)

3.1 Overview

ASTER Ground Data Systems (ASTER GDS) is the ground system for ASTER operation, data processing, data archiving and distribution. ASTER has unique technical challenges and providing solutions to these challenges is the key function of ASTER GDS.

Intra- and inter-telescope misregistration needs to be corrected in the ground system.

Sensor's operational constraints of 8% duty cycle and 60km observational swath require that cross-track pointing is steerable.

For these two needs, the ASTER GDS plays an important role in the sensor operation and data processing and requires close coordination with NASA. ASTER GDS also receives data acquisition requests from users.

ASTER GDS, located in Japan, has important interfaces with the users as well as with the United States. ASTER GDS is a ground system to handle remote sensing data and its development employs the user's point of view rather than system developer's point of view.

3.2 Features of ASTER Ground Data Systems

Unlike traditional ground systems for remote sensing data receiving and processing, ASTER GDS has the following features.

User-friendliness; It employs Graphical User Interface (GUI) based man-machine interface and is capable to receive complex user requests including Data Acquisition Requests (DARs) and Data Product Requests (DPRs).

Open; It is a general purpose UNIX based open architecture system. Its design is independent of hardware platform.

Interoperability; It maintains interoperability with NASA EOSDIS.

Algorithm; It uses algorithms provided by science users.

Distributed; It is a distributed system in which each segment and subsystem has high independence and autonomy. The segments and subsystems are however effectively networked.

Scalability and enhancement; It can be upgraded to accommodate advancement in software and hardware technologies.

Reliability; It has high reliability and robustness.

Network; The backbone is a high-speed LAN for image data transmission. Users and the U. S. entities use external connection LAN to access ASTER GDS.

Parallel processing; Data volume transmit from NASA EOSDIS is very large, approximately 780 scenes per day. ASTER GDS is a high performance computer with parallel processing capability to continuously process such large volume of data.

Data compression; Data compression technology will be applied for efficient data storage. Automated storage systems will be used for large volume of data archive.

Data distribution media; Multiple media will be available for data distribution to accommodate diversity of user needs.

3.3 Configuration of ASTER GDS

The design of ASTER GDS is comprised with 3 segments, each of which has its own subsystems.

(1) ASTER Operation Segment (AOS)

AOS is for the ASTER sensor operation, and comprised with the following 2 subsystems.

1) Instrument Control Center (ICC)

ICC receives ASTER sensor data (i. e. telemetry data) from the EOS Data Operation Segment (EDOS) in the United States and provides periodic instrument analysis and support. It also generates ASTER sensor operation plans, schedules and commands to send to EOS Operation Center (EOC) in the United States.

2) Instrument Support Terminal (IST)

IST is mainly for the Science Team Leader and SSSG (Science Scheduling Support Group) who coordinate the data aquisition schedule of ASTER. They monitor and analyse the status of data acquisition and resolve the scheduling conflict if any arises.

(2) Science Data Processing Segment (SDPS)

This segment is responsible for data administration such as receiving data acquisition and generation requests and for ASTER data processing, distribution, archiving and algorithm development. SDPS is comprised with the following 4 segments.

1) Data Archive and Distribution Subsystem (DADS)

It receives Level 0 data from the United States, maintains and manages Level 1 to 4 data, Standard, Semi-standard and Special Data Products. It provides the data product to its requester on the requester specified physical medium. A portion of data is planned to be electronically transferred between Japan and the United States.

2) Product Generation Subsystem (PGS)

It generates Level 1 to 4 Standard Data Products and their corresponding browse meta-data to provide to DADS. Its high volume data processing includes mis-registration correction. The current baseline is that Level 0 processing is reversible, Level 1A processing is 780 scenes per day, 40% of which can be processed to Level 1B data with bulk correction.

3) Software Implementation Support Subsystem (SISS)

It supports algorithm and application program development, their calibration and validation by the scientists. It also generates Special Data Products. Databases including GCP library and the spectral database will reside in SISS and AO researchers can use these resources.

4) Information and Management Subsystem (IMS)

IMS is the interface through which the users can access the science data and the operational schedule. It is also the interface to input complex data acquisition and generation requests from users to ASTER GDS.

(3) Communication and System Management Segment (CSMS)

CSMS is to network and manage entire ASTER GDS and is comprised with the following 2 subsystems.

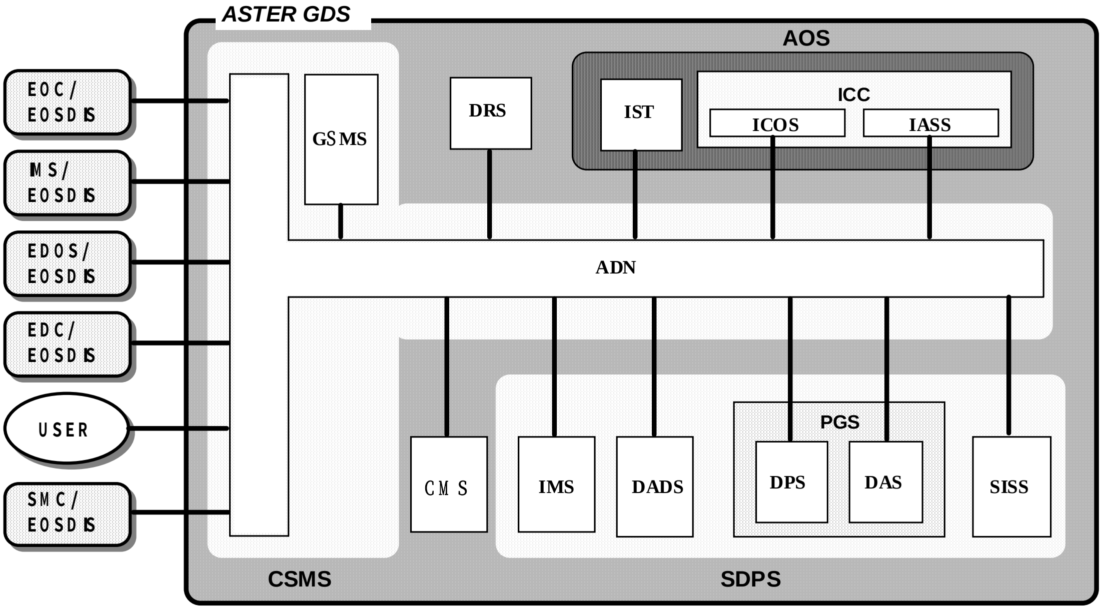
1) Ground System Management Subsystem (GSMS)

It coordinates with external entities, manages the ASTER GDS overall schedule, coordinates the schedules among segments, executes and manages the segment schedules, manages the whole system by monitoring loads to each segment, and manages system security.

2) ASTER Data Network (ADN)

It provides and manages data communication network capability between ASTER GDS and external entities and among ASTER GDS internal subsystems.

Functional configuration of ASTER GDS is as follows ;



4. Data products

4.1 Definition of data products

4.1.1 Standard data products

(1) Level 1A (Reconstracted, Unprocessed Instrument Data)

Product Description

The ASTER Level 1A raw data are reconstructed, unprocessed instrument digital counts with ground resolution of 15 m, 30 m, and 90 m for 3 VNIR (0.52-0.86 mm), 6 SWIR (1.60-2.43 mm), and 5 TIR (8.13-11.65 mm) channels. This product contains depacketized, demultiplexed, and realigned instrument image data with geometric correction coefficients and radiometric calibration coefficients appended but not applied. This includes correcting for SWIR parallax as well registration within and between telescopes. The spacecraft ancillary and instrument engineering data are also included. This product is the responsibility of Japan. The radiometric calibration coefficients consisting of offset and sensitivity information is generated from a database for all detectors. The geometric correction is the coordinate transformation for band-to-band coregistration.

Products Summary
Resolution : 15, 30, 90 m (VNIR, SWIR, TIR, respectively)
Input Band : VNIR, SWIR, TIR
Production : 780 scenes per day
Science Team Contact : H. Fujisada

(2) Level 1B (Registered Radiance at Sensor)

Product Description

This Level 1B product contains radiometrically calibrated and geometrically coregistered data for all ASTER channels. This product is created by applying the radiometric and geometric coefficients to the Level 1A data. The bands have been coregistered both between and within telescopes, and the data have been resampled to apply the geometric corrections. As for the Level 1A product, these Level 1B radiances are generated at 15m, 30m, and 90m resolutions corresponding to the VNIR, SWIR, and TIR channels. Calibrated, at-sensor radiances are given in W/(m 2 ¥ mm ¥ sr). This product serves as input to derived geophysical products.

Products Summary
Resolution : 15, 30, 90 m (VNIR, SWIR, TIR, respectively)
Input Band: VNIR, SWIR, TIR
Production : 310 scenes per day
Science Team Contact : H. Fujisada

(3) Level 2A02 (Relative Emissivity : D-Stretch)

Product Description

This parameter contains a decorrelation stretched image of ASTER TIR radiance data, color-enhanced by decorrelation of the color domain. This image is produced at a pixel resolution of 90m. Decorrelation-stretched images provide an overview that enhances reflectance and emissivity variations and subdues variations due to topography and temperature, respectively. The 8.3, 9.1, and 11.3 micrometer channels are routinely used, though the user may request as an on-demand product a decorrelation stretched image generated from any three TIR channels.

These images are used as a visual aid in reviewing the ASTER scene data and making the selection of suitable scenes for further analysis and research. In particular, a decorrelation-stretched image would show the potential user which scenes have spectral variations large enough to be useful for subsequent spectral analysis. In scenes with negligible spectral variation, the decorrelation stretch will produce images that appear noisy.

Research & Applications

The decorrelation stretch is a process that is used to enhance the spectral differences found in a multispectral image dataset. These images are used as a visual aid in browsing the ASTER scene data and making the selection of suitable scenes for further analysis and research. In particular, a decorrelation stretched image would show the potential user which scenes have spectral variations large enough to be useful for subsequent spectral analysis.

Suggested Reading

Gillaspie, A.R., A.B. Kahle, and R.E. Walker, 1986: Color enhancement of highly correlated images. I. Decorrelation and HSI contrast stretches. Rem. Sens. Environ., 20, 209-235.

Loeve, M., 1955: Probability Theory, D. van Nostrand Co., Princeton, N.J.

Rothery, D.A., 1987: Decorrelation stretching as an aid to image interpretation. Internat. J. Remote Sensing, 8, 1253-1254..

Taylor, M.M., 1973: Principal components color display of ERTS imagery. Third Earth Resources Technology Satellite-1 Symposium, 10-14 December, NASA SP-351, Vol. 1,
Section B, 150-160.

Products Summary
Resolution : 90 m
Input Band : TIR
Production : 50 scenes per day
Science Team Contact : R. Alley

(4) Level 2A03 (Relative Reflectance : D-Stretch)

Product Description

This parameter is a decorrelation stretched image of ASTER VNIR and SWIR radiance data, color-enhanced by decorrelation of the color domain. The image is produced at pixel resolutions of 15 m for VNIR and 30m for SWIR. Decorrelation-stretched images provide an overview that enhances reflectance and emissivity variations and subdues variations due to topography and temperature, respectively.

These images are used as a visual aid in reviewing the ASTER scene data and making the selection of suitable scenes for further analysis and research. In particular, a decorrelation-stretched image would show the potential user which scenes have spectral variations large enough to be useful for subsequent spectral analysis. In scenes with negligible spectral variation, the decorrelation stretch will produce images that appear noisy.

Research & Applications

The decorrelation stretch is a process that is used to enhance the spectral differences found in a multispectral image dataset. These images are used as a visual aid in browsing the ASTER scene data and making the selection of suitable scenes for further analysis and research. In particular, a decorrelation stretched image would show the potential user which scenes have spectral variations large enough to be useful for subsequent spectral analysis.

Suggested Reading

Gillaspie, A.R., A.B. Kahle, and R.E. Walker, 1986: Color enhancement of highly correlated images. I. Decorrelation and HSI contrast stretches. Rem. Sens. Environ., 20, 209-235.

Loeve, M., 1955: Probability Theory, D. van Nostrand Co., Princeton, N.J.

Rothery, D.A., 1987: Decorrelation stretching as an aid to image interpretation. Internat. J. Remote Sensing, 8, 1253-1254..

Taylor, M.M., 1973: Principal components color display of ERTS imagery. Third Earth Resources Technology Satellite-1 Symposium, 10-14 December, NASA SP-351, Vol. 1,
Section B, 150-160.

Products Summary
Resolution : 15 m (VNIR), 30 m (SWIR)
Input Band : VNIR, SWIR
Production : 50 scenes per day
Science Team Contact : R. Alley

(5) Level 2B01 (Surface Radiance)

Product Description

This parameter contains surface radiance, in W/m2/sr/um, for VNIR, SWIR and TIR channels at 15, 30m and 90m resolutions, respectively. Atmospheric corrections have been applied to these radiances, and surface radiances are calculated for clear sky scenes. The surface radiance is only of known accuracy for cloud-free pixels since primary inputs (temperature and water vapor profiles) are only available for the cloud-free case. Accurate atmospheric correction removes effects of changes in satellite-sun geometry and atmospheric conditions and improves surface type classification and estimates of the Earth's radiation budget, and use of ASTER data for applications such as agricultural management requires atmospheric correction. These atmospheric corrections, along with the corrections to other Terra instruments, mark the first implementation of operational atmospheric correction in environmental satellites.

The VNIR data are available in the daytime only, SWIR data are collected in daytime, and in the cases of high temperature sources (e.g., volcanoes, fires) may be collected at night..
Surface radiance from TIR data are available for both daytime and nighttime .

Research & Applications

The objective of this ASTER products is to provide estimates of the surface. The thermal infrared radiance includes both surface emitted and surface reflected components. After accurate atmospheric correction, seasonal and annual surface changes can be studied and surface kinetic temperature and emissivity can be extracted. Surface radiances can also be used for surface classification, desertification studies, and surface energy balance work.

Suggested Reading

Deschamps, P. and T. Phulpin, 1980: Atmospheric correction of infrared measurements of sea surface temperature using channels at 3.7, 11, and 12mm. Boundary Layer Met. , 18,
131-143.

Hilland, J.E., et al. , 1985: Production of global sea surface temperature fields for the Jet Propulsion Laboratory Workshop Comparisons. Geophys. Res., 90 (C6): 11,642-11,650.

McMillin, L.M., 1975: Estimation of sea surface temperature from two infrared window measurements with different absorption. J. Geophys. Res., 90, 11,587-11,600.

Prabhakara, C., et al., 1975: Estimation of sea surface temperature from remote sensing in the 11 and 13mm window region. J. Geophys. Res., 79, 5039-5044.

Price, J.C., 1984: Land surface temperature measurements from the split window channels of the NOAA 7 Advanced Very High Resolution Radiometer. J. Geophys. Res., 89,
7231-7237.

Products Summary
Resolution : 15, 30, 90 m (VNIR, SWIR, TIR, respectively)
Input Band : VNIR, SWIR, TIR
Production : 10 scenes per day
Science Team Contact : K. Thome (VNIR, SWIR), F. Palluconi (TIR)

(6) Level 2B03 (Surface Temperature)

Product Description

Land surface temperatures are determined from Planck's Law, using the emissivities from Level 2B04 to scale the measuredradiances after correction for atmospheric effects. Pixels classified as "cloud" will have no atmospheric correction due to a lack of knowledge of cloud height, and the cloud temperature will be given as the brightness temperature at sensor.

The five thermal infrared channels of the ASTER instrument enable direct surface emissivity estimates. Mapping of thermal features from optical sensors such as Landsat and AVHRR has been used for many developmental studies. These instruments, however, lack the spectral coverage, resolution and radiometric accuracy that will be provided by the ASTER instrument.

Research & Applications

The derived land surface temperature has applications in studies of surface energy and water balance. Temperature data will be used in the monitoring and analysis of volcanic processes, day and night temperature data will be used to estimate thermal inertia, and thermal data will be used for high-resolution mapping of fires as a complement to MODIS global fire data.

Current sensors provided only limited information useful for deriving surface emissivity and researchers currently are required to use emissivity surrogates such as land-cover type or vegetation index in making rough estimates of emissivity and hence land surface temperatures.

Suggested Reading

Dozier, J., and Z. Wan, 1994: Development of practical multiband algorithms for estimating land-surface temperature from EOS-MODIS data. Adv. Space Res., 13 (3), 81-90

Hook, S.J., A.R. Gabell, A.A. Green, and P.S. Kealy, 1992: A comparison of techniques for extracting emissivity information from thermal infrared data for geological studies.
Remote Sens. Environ., 42, 123-135.

Kahle, A.B., 1986: Surface emittance, temperature, and thermal inertia derived from Thermal Infrared Multispectral Scanner (TIMS) data for Death Valley, California. Geophysicas,
52(7), 858-874.

Products Summary
Resolution : 90 m
Input Band: TIR
Production : 10 scenes per day
Science Team Contact : A. Gillespie

Radiometric accuracy that will be provided by the ASTER instrument.

(7) Level 2B04 (Surface Emissivity)

Product Description

The land surface emissivity product contains surface emissivity at 90 m resolution generated only over the land from ASTER's five thermal infrared channels. Surface emissivity is required to derive land surface temperature (Level 2B03) data, also at a resolution of 90 meters.

The five thermal infrared channels of the ASTER instrument enable direct surface emissivity estimates. Mapping of thermal features from optical sensors such as Landsat and AVHRR has been used for many developmental studies. These instruments, however, lack the spectral coverage, resolution and radiometric accuracy that will be provided by the ASTER instrument.

Research & Applications

The emissivity product is critical for deriving land surface temperatures. It is therefore important in studies of surface energy and water balance. The emissivity product is also useful for mapping geologic and land-cover features.

Current sensors provided only limited information useful for deriving surface emissivity and researchers currently are required to use emissivity surrogates such as land-cover type or vegetation index in making rough estimates of emissivity and hence land surface temperatures.

Suggested Reading

Dozier, J., and Z. Wan, 1994: Development of practical multiband algorithms for estimating land-surface temperature from EOS-MODIS data. Adv. Space Res., 13 (3), 81-90

Hook, S.J., A.R. Gabell, A.A. Green, and P.S. Kealy, 1992: A comparison of techniques for extracting emissivity information from thermal infrared data for geological studies.
Remote Sens. Environ., 42, 123-135.

Kahle, A.B., 1986: Surface emittance, temperature, and thermal inertia derived from Thermal Infrared Multispectral Scanner (TIMS) data for Death Valley, California. Geophysicas,
52(7), 858-874.

Products Summary
Resolution : 90 m
Input Band : TIR
Production : 10 scenes per day
Science Team Contact : A. Gillespie

Radiometric accuracy that will be provided by the ASTER instrument.

(8) Level 2B05 (Surface Reflectance)

Product Description

The Level 2 surface reflectance data set contains surface reflectance for VNIR and SWIR channels at 15 m and 30 m resolutions, respectively, after applying the atmospheric corrections to observed radiances. Data are recorded as percent reflectance. Accurate atmospheric correction removes effects of changes in satellite-sun geometry and atmospheric conditions and improves surface type classification and estimates of the Earth's radiation budget, and use of ASTER data for applications such as agricultural management requires atmospheric correction. Surface reflectance is calculated for clear sky scenes only. These atmospheric corrections, along with the corrections to other Terra instruments, mark the first implementation of operational atmospheric correction in environmental satellites.

Research and Applications

The objective of these ASTER products is to provide estimates of the surface reflectance. After accurate atmospheric correction, seasonal and annual surface changes can be. Surface reflectances can also be used for surface classification, desertification studies, and surface energy balance work.

Suggested Reading

Deschamps, P. and T. Phulpin, 1980: Atmospheric correction of infrared measurements of sea surface temperature using channels at 3.7, 11, and 12mm. Boundary Layer Met. , 18,
131-143.

Hilland, J.E., et al. , 1985: Production of global sea surface temperature fields for the Jet Propulsion Laboratory Workshop Comparisons. Geophys. Res., 90 (C6): 11,642-11,650.

McMillin, L.M., 1975: Estimation of sea surface temperature from two infrared window measurements with different absorption. J. Geophys. Res., 90, 11,587-11,600.

Prabhakara, C., et al., 1975: Estimation of sea surface temperature from remote sensing in the 11 and 13mm window region. J. Geophys. Res., 79, 5039-5044.

Price, J.C., 1984: Land surface temperature measurements from the split window channels of the NOAA 7 Advanced Very High Resolution Radiometer. J. Geophys. Res., 89,
7231-7237.

Products Summary
Resolution : 15, 30 m (VNIR, SWIR respectively)
Input Band : VNIR, SWIR
Production : 5 scenes per day
Science Team Contact : K. Thome

4.1.2 Semi-Standard data products

(1) Level 3A01 (Radiance registered at sensor with ortho-photocorrection)

(2) Level 4A01 (Digital elevation model (Relative))

5. Data product request and data distribution

5.1 Process form data acquisition request to receipt product

T.B.D

5.2 Method of data acquisition request

T.B.D

5.3 Method of data search

T.B.D

5.4 Method of data processing request

T.B.D

5.5 Media of distributed data

T.B.D

5.6 Method of data distribution

T.B.D

5.7 Other

T.B.D

6. Calibration/Validation activity

6.1. Introduction

The objectives for this section is

1. to clarify the ASTER validation plan among the ASTER Science Team Members,
2. and to encourage validation activities among the ASTER Science Team Members

as well as other mission instrument team members.

The following documents are closely related to this document,

1. Algorithm theoretical basis document for ASTER Level-1 Data Processing (ver.2.0), ERSDAC LEL/7-10, Oct., 24, 1995.
2. ASTER Calibration Requirement(ver.3), Sep., 20, 1994.
3. Requirements on Prelaunch Geometric Calibration for ASTER, Oct., 15, 1994.
4. End-to-End Data System Concept, JPL D-11199, Oct., 13, 1994.
5. ASTER Calibration Management Plan(ver.3.0), Nov., 1994.
6. ASTER Calibration Plan, Japanese and US Science Team, ver.1.0, June 1996.

The EOS Validation Office has requested that viewgraphs and documents addressing the following topics be made available to summarize vicarious validation activities.

- Products to be validated
- Relevant instrument characteristics
- Approach for establishing scientific validity
- Confirmation of accuracy and precision
- EOS and non-EOS experimental activities
- Required operational activities
- Archival plans for validation information

to the extent these topics are relevant to on-board calibrator data, which do not represent a data product per se.

6.2. Calibration data to be validated and the procedures to be used

The on-board calibrator(OBC) data are to be validated periodically in three VNIR, six SWIR and five TIR bands of ASTER. Measurements of flat, homogeneous surface sites, and the atmopsheres above them, will be used in conjunction with radiative transfer codes to predict the top-of-atmosphere(TOA) spectral radiances in the bands of interest. These meausrements will be made at the time ASTER acquires images of the sites.

The procedures used constitute what is often referred to as vicarious calibration(VC). VC can be performed by reflectance based, radiance based methods, and sensor-to-sensor cross-comparison method. Presently, error budgets predict uncertainties in the range of 3 to 5 % depending on the approach used. It is expected these uncertainties will be decreased as field instruments and methodologies becomes more refined.

6.3. Validation and calibration

The VC methods mentioned above have been used for several years by researchers and national space agencies in Australia, Europe, Japan and the USA for the calibration of sensors with inadequate absolute calibration OBC systems. VC methods are equally appropriate for validation of OBC results and sensor calibration. In fact, in most case, they will be merged with OBC data to optimize the final calibration coefficients used the Level 1-B product.

6.4. Confirmation of precision and accuracy

The following steps are being considered to confirm precision and accuracy:

- Peer reviews of VC error budgets,
- Cross-comparisons of VC predictions of TOA spectral radiances from joint field campaigns
- Cross comparisons of reflectance based, radiance based and sensor-to-sensor comparison results
- Comparison with validated Level 2 products having high sensivity to calibration error

6.5. Required EOS and non-EOS experimental activities

We recommend the development of international collaborative VC programs for EOS and non-EOS sensors. These should be considered by the EOS calibration Scientists througth CEOS and/or by direct contact with other space agencies. We also recommend the establishement of an EOS calibration panel sub-group to coordinate and oversee all the Eos related VC activities.

6.6. Required operational measurements

6.6.1. Space-based measurements

The only spectral requirement is to ensure ASTER acquires data, i.e., is activated and corrected pointed when over selected calibration sites at the time VC campaigns are planned.

6.6.2. Ground-based measurements

The requirements for the reflectance-based and radiance-based methods and sensor-to-sensor aomparison methods aredesired fully in the references.

6.7. Archival plans for validation information

Plans presently call for vicarious calibration/validation field measurement data to be archived at the Oak Ridge National Laboratory, which is the designed DAAC and ERSDAC for field data and, in some cases, related sircraft data.

As a first step in this direction, the field data collected during the first VC joint field campaign in June 1996 as well as the second campaign in June 1997 and the third campaign in Dec.1997, are to be archived at the Oak Ridge DAAC as well as ERSDAC.

We presently await recommendations from Richard J.Olson at the Oak Ridge and ERSDAC people regarding formatting and the other details.

6.8. Inflight Validation Activities

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) consisting of a visible to near infrared (VNIR) radiometer, a shortwave infrared (SWIR) radiometer and thermal infrared (TIR) radiometer will be onboard the Earth Observing System's (EOS) Terra platform. The characteristics of ASTER have been published in several papers (1,2,3). In particular, the calibration plan for ASTER has been described in detail (4). One of the important issues for the calibration plan of ASTER is the determination of a set of calibration coefficients using preflight calibration, onboard calibration, cross-calibration (5) and vicarious calibration data.

In order to establish a method for determination of a set of calibration coefficients, a preliminary field campaign was conducted at Lunar Lake and Railroad Valley Playas in central Nevada in the USA in June 1996. The procedures and methods used and the data collected during the field campaign are briefly described here together with the current plans for ASTER calibration activities and a method for determining a set of calibration coefficients.

6.8.1. The generation of radiometric calibration coefficients

In this approach, the on-board calibrator (OBC) results alone are used to generate the Level-1B product. As vicarious calibration (VC) results, including sensor cross-comparisons are obtained, they are merged with the OBC results to provide the best estimate of the ASTER calibration coefficients.

The quality of the OBC and VC results are reviewed by a panel of radiometric scientists associated with the ASTER sensor. This panel determines the weightings used in the merging of the OBC and VC results. The best estimates of the ASTER calibration coefficients are publicized quarterly through newsletters, an Internet server, and/or other means.

The user can then modify results obtained using the Level-1B product according to how large the difference is between the OBC results and the OBC-merged-with-VC results.

The first panel meeting will be held the late Initial Checkout Period to determine the weights for OBC and VC as well as version 1.0 of the radiometric calibration coefficients.

6.8.2. The trend-equation approach to the production of a single set of calibration coefficients

This approach also uses a panel of radiometric scientists which reviews the OBC and VC results after the three-month sensor activation and evaluation (A and E) phase.(During the A and E phase, the OBC results alone are used to generate the Level-1B product.)

The panel determines a set of trend equations used until the next calibration panel review. At this time, deriving a new set of equations for the period from the start of A and E to the next review may be necessary. Most satellite sensors have shown a smooth asymptotic decay in their response with time. If this is the case with ASTER, it is likely that the extrapolated results from the trend equations will converge to match the actual results, probably after about a year.

The advantage of this second approach is that it provides only one set of calibration coefficients after convergence has been reached.

The advantage of the first approach is that incorporating it in the Level-1B algorithm is relatively easy.

Its disadvantage is that it may cause confusion if data users are not careful to state which set of coefficients they have used in arriving at their conclusions.

A final decision on the approach to be adopted has not yet been made.

6.8.3. The current baseline method for determining calibration coefficients

In addition to calibration information from the onboard calibration systems, there will also be cross-calibration, preflight, and other inflight data which can be used to determine the calibration of each of the three systems.

In order to determine the most reliable calibration coefficients, the following method is currently being considered. To summarize, the approach is to

1. check for consistency between the halogen lamp system A and B. (System A and B are to be switched every 17 days),
2. check for inter-channel dependency (do all bands within a telescope show similar tendencies),
3. if both (1) and (2) are satisfied, the onboard calibration data will be used to calculate calibration coefficients,
4. if (1) and (2) are not satisfied and if cross-calibration coefficients exist, the system's calibration coefficients will be calculated using the cross calibration data,
5. if (1) and (2) are not satisfied and no cross-calibration coefficients exist, the system's calibration coefficients are calculated using vicarious calibration data.

We expect vicarious calibration data to be taken approximately twice a year and a current plan is to use these data to check the calibration coefficients derived from the onboard calibration assembly and the cross-calibration data which is described in the following section.

6.8.4. Cross calibration

Terra carries several sensors in addition to ASTER.

These are the Moderate Resolution Imaging Spectroradiometer (MODIS), the Multi-angle Imaging Spectroradiometer (MISR), the Clouds and Earth's Radiant Energy System (CERES) and the Measurements of Pollution in the Troposphere (MOPITT) instrument.

The wavelength coverage of ASTER is overlapped with that of MODIS and MISR.

Because all three, ASTER, MODIS, and MISR, are on the same platform, they observe the same surface through the same atmosphere at the same time.

The data from the three sensors have some registration error, each has slightly different IFOVs, and the spectral bands are slightly different.

Even so, it should still be possible to cross-calibrate the instruments with reference to each other.

As an example, we could calibrate ASTER (referred to as instrument A) with using either MODIS or MISR (referred to instrument as B) (7,8,9).

In this cross-calibration, the following items should be taken into account,

1. Different atmospheric influences due to differences in the spectral coverage of the bands of each the instrument,
2. Different spectral reflectance and or spectral emissivity due to difference in the spectral coverage of the bands of each instrument,
3. Mis-registration between instrument data,
4. Different IFOV.

Taking these factors into account, we can simulate instrument A data from instrument B data.

A set of calibration coefficient is calculated by comparing the simulated instrument A data to the actual instrument A data collected of the target.

6.8.5. Calibration plans for an initial checkout period

During the initial checkout period, which occurs during the period shortly after launch, the methods described above will be reviewed using frequently acquired onboard calibration

data as well as vicarious calibration and cross-calibration data.

The current plans for the data acquisition of the onboard, vicarious and cross calibration data.

40 days are required for platform and instrument checkouts and we need to determine calibration coefficients within 90 days after launch.

This will allow us to have three repetition cycles, or 48 days (based upon the 16-day repeat cycle of ASTER), for onboard, cross-and vicarious calibration data acquisition.

We need frequent acquisition of the onboard calibrators for VNIR, SWIR and TIR in the early stages after launch so that we can determine the calibration data acquisition plan.

Once this is determined, we can check the consistency of the system using the onboard calibrators and we can also check the inter-band dependency.

6.8.6. Other Issues

Using homogeneous fields, stripe noise will be confirmed during the initial checkout period.

Other than that, Stray Light Effect will be checked together with MTF characteristics.

The aforementioned activities will be take place with the ERSDAC/GDS/SISS as well as the computing facilities of the ASTER Calibration Scientists.

REFERENCES

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2. P.Slater, K.Thome, A.Ono, F.Sakuma, K.Arai, et al., Radiometeric Calibration of ASTER, Journal of Remote Sensing Soiety of Japan, Vol.15, No.2, pp.16-23, June 1995.
3. K.Arai, An Assessment of Height Estimation Accuracy with EOS-a/ASTER, Proceedings of the Spatial Data 2000, pp.73-75, Sep.1991.
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5. ASTER Level 1 WG, ATBD:Analytical Theoretical Basis Document for Level 1 Products, Sep.1995.
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8. K.Arai, Post Launch Calibration of ASTER with MODIS data, Proceedings of the 3rd Annual IR Calibration Symposium in Utah State University, Sep.1992.
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10. S.Tsuchida, I Satoh, Y.Yamaguchi, K.Arai, T.Takashima, Algorithm of vicarious calibration using radiative transfer code based on boubling-adding method, Minutes of the ASTER Science Team Meeting, June 1996.

7. Instrument Operation

7.1 Instrument modes and activities

7.1.1 ASTER observing modes

For each ASTER observing mode, a different combination of telescopes will be turned on and different data will be recorded. Data from different ASTER telescopes are separately transmitted to the Terra memory and recorded. VNIR data from the 560-nm (V1) and 660-nm (V2) channels can be turned off while recording data from both 810-nm channels [nadir-looking (V3N) and backward-looking (V3B)]. The telescopes (and data channels) which are turned on, in each observing mode, are described in the following table.

Observing mode	TIR	SWIR	VNIR		Typical Observing
			V1/2	V3N/B	Targets
Full	On	On	On	On	Daytime land targets; Coastal waters
S+T	On	On	Off	Off	Volcanoes; fires
TIR	On	Off	Off	Off	Ocean; Night-time targets
VNIR	Off	Off	On	On	Vegetation
Stereo	Off	Off	Off	On	Glaciers; Ice sheets

ASTER will acquire stereo images (at 810 nm) when operating in Full, VNIR, or Stereo mode, by recording V3N and V3B data for an extra 60 seconds after a target has left the field of view of all 14 nadir-looking channels.

Although many ASTER science observations will be conducted in Full mode, the following exceptions have been identified:

- The Earth's night hemisphere will usually be observed in TIR mode, or S+T mode for hot targets (e.g. active volcanoes, forest fires).
- The open ocean will usually be observed in TIR mode. Most ocean surface targets will not have interesting signatures in ASTER's VNIR or SWIR bands.
- Some targets may require repetitive observations on short time scales. The VNIR telescope has +/-24 degrees cross-track pointing capability (TIR and SWIR have only +/-8.55 degrees), allowing such targets to be observed more often in VNIR mode.
- To decrease the data volume, periodic monitoring of the surface topography (and size) of glaciers and ice sheets may occur in Stereo mode.

7.1.2 Instrument activities

The ASTER Scheduler will generate sequences of “instrument activities”. Each activity is a sequence of instrument commands designed to accomplish some specific higher-level function. For each observation, an ASTER activity will consist of all commands necessary to change from one operating mode into another. The Scheduler first determines which mode ASTER should be in at each point in time, and then schedules the mode transition activities that will place the instrument in the right mode at each time-step.

7.1.3 On-board calibration activities

Short-term calibrations of TIR will be performed before each TIR observation. A long-term calibration of each system will be done approximately every 17 days. Long-term calibrations of SWIR and VNIR consist of observations of the on-board calibration lamps and the Earth’s dark side. Long-term calibrations of TIR are observations of a variable-temperature on-board blackbody.

7.2 Constraints on sensor operation

Limitations on data acquisition derive from a variety of sources, including limits on:

ASTER hardware,

- Number of telescope pointing changes during mission
- Dissipation of heat

Terra hardware,

- Available power for ASTER
- Volume of data that can be stored in the Terra solid state recorder,

Communications between Terra and ground

- Bandwidth of downlink
- Length of each downlink window
- Frequency of downlink windows

The ability to schedule ASTER instrument activities.

In order to manage Terra power, ASTER will not be allowed to exceed certain limits in its peak and orbital-average power.

To limit the number of times ASTER changes pointing directions during the mission, observations that would cause pointing changes will receive lower priorities than those that would not cause them.

The primary limitations on ASTER data collection are the data volume allocated to the instrument in Terra's memory (solid state recorder) and in the communications link with TDRSS (and various ground stations). To manage the solid state recorder and spacecraft-to-ground data traffic, ASTER has been allocated a maximum two-orbit-average data rate of 8.3 Mbps.

Thus, 16 minutes (about 108 scenes) of Full Mode data can be collected in any two-orbit period (3 hours and 18 minutes). Given that the instrument is scheduled to operate for six years, ASTER could collect approximately 1.7 million scenes of Full mode data. In practice, there will be factors that will decrease this amount, such as scheduling inefficiencies.

7.3 User categories

Anyone can request copies of existing ASTER data. However, only authorized users can request that ASTER acquire new data, by submitting data acquisition requests (see Chapter 5). Authorized ASTER users can be divided into several different categories. The science user categories are:

ASTER Science Team Leader
US ASTER Science Team Leader
ASTER Science Team Working Groups • Scientific discipline working groups, who will request new data on behalf of the Science Team, for local observations andfor large projects, including Regional Monitoring and Global Mapping.
ASTER Science Team Member • In this document, Associate Team Members are treated as Team Members.
EOS member • User from an EOS Instrument Team or Interdisciplinary Science (IDS) team.
Special-Priority Japan User • Equivalent to an EOS member from the US. Sub-category of AO User.
AO User • Non-EOS user selected by process described in LTIP Section 2.2.

The programmatic user categories are:

MITI/NASA • Program-level user.
IEOS agencies • User authorized by one of the international partners' agencies.
EOS Science Project Office
ASTER Science Project • Refers to Science Projects in Japan and the US • Generally the SSSG, as described in LTIP Section 6.2.
ASTER GDS/ESDIS Project
ASTER Instrument Team

To choose between conflicting observation alternatives, the ASTER Scheduler will use a prioritization algorithm described in LTIP Section 6.

One of the parameters used by this algorithm is the category of the ASTER users requesting an observation.

7.4 ASTER Data Categories

7.4.1 ASTER data types

Science data is only one of three major types of ASTER data. These three types, in order of priority for data acquisition, are:

Engineering data	Data required to monitor and maintain spacecraft and instrument health and safety
Calibration data	Data obtained as part of on-board calibration of the instrument
Science data	Data collected to meet the science objectives of the mission

7.4.2 Science data collection categories

To better manage the allocation of ASTER observing resources, three data collection categories for the science data have been defined. These categories are based on data-set size and science objectives. They are:

1) Local Observations	Images of limited areas, as requested byauthorized ASTER users
2) Regional Monitoring data	Multi-temporal images and/or images of large areas, in support of EOS science objectives
3) Global Map	Images in all ASTER wavelengths (and stereo) of the Earth's entire land surface and a portion of the oceans, acquired once during the Terra mission

1) Local Observations

Local Observations will be made in response to data acquisition requests from authorized ASTER users. Local Observations might include, for example, scenes for analyzing land use, surface energy balance, or local geologic features.

A subset of Local Observations are images of such ephemeral events as volcanoes, floods, or fires. Requests for "urgent observations" of such phenomena must be fulfilled in short time periods (of a few days). These requests receive special handling (described in LTIP Section 4.4).

2) Regional Monitoring Data

Regional data sets contain the data necessary for analysis of a large region or a region requiring multi-temporal analysis. One example might be imaging the advance and retreat of all mountain glaciers in the Himalayas as a function of season, for the six-year life of the mission. Another example might be analyzing changes in forest cover and resulting changes in air-surface moisture fluxes for the state of Rondonia (in the Brazilian Amazon) over six years. Some Regional data sets may require only single-time images of a large region.

A "Local Observation" data set and a "Regional Monitoring" data set are distinguished by the amount of viewing resources required to satisfy the request, where smaller requirements are defined as Local Observations and larger requirements are defined as Regional Monitoring. The cutoff between the two will be set by the Science Team and will be subject to change as the mission proceeds.

3) Global Map

The Global data set will be used by investigators of every discipline to support their research. The high spatial resolution of the ASTER Global Map will complement the lower resolution data acquired more frequently by other EOS instruments. This data set will include images of the entire Earth's land surface, using all ASTER spectral bands and stereo. This Global data set will be composed of those images which best meet the Global Map quality criteria, and will be identified in a TBD fashion. Each ASTER observation (regardless of whether it was originally scheduled for a local observation, regional monitoring, or the global map) will be assessed in Japan for its probability of significantly increasing the quality of the Global data set.

Each region of the Earth has been prioritized by the ASTER Science Team for observation as part of the Global Map. See Fig 7-1. This prioritization is reflected in the prioritization algorithm described in LTIP Section 6.

Currently the following characteristics have been identified for images in the Global Map data set:

- One-time coverage,
- High sun angle,
- Optimum gain for the local land surface,
- Minimum snow and ice cover,
- Minimum vegetation cover, and No more than 20% cloud cover (perhaps more for special sub-regions).

Fig 7-1 Different regions of the Earth have been assigned different priorities for acquiring Global Map data (Red shows highest priority regions, green middle priority, and blue lowest priority)

7.5 Requesting Data

To acquire ASTER data, a user will need to specify, in some detail, what data is needed. In particular, to request new ASTER data, the user will need to specify the geographic region and the time (e.g. season) for which data is required.

7.5.1 Existing data vs. new data

Access to existing ASTER data is guaranteed to any user. EOSDIS will provide user-interface software (the Java Earth Science Tool - JEST) to give users access to the US EOS data archives. ASTER GDS data archives will be accessible via the Information Management System (IMS) or the World Wide Web. Anyone using these tools can determine what ASTER data already exist for the geographic region and time interval under investigation, and can order copies of these data.

If a user finds appropriate Level 1 ASTER data in the archives, he can order them, using a Data Product Request (DPR). If the user desires higher-level standard or semi-standard data products, he can submit the appropriate request to EOSDIS or GDS. [Semi-standard data products will be provided only by the ASTER GDS.] If these data products do not exist, EOSDIS or GDS will generate and send them to the user.

After browsing the archives, an investigator may discover that no useful ASTER data exists for his investigation. An investigator who is already an authorized ASTER user can then request that ASTER be scheduled to acquire the new data. Other investigators may propose to MITI or NASA to become authorized.

7.5.2 Categories of data acquisition request

Three categories of requests for ASTER to acquire new data have been defined, as described in the following table.

Data Acquisition Request (DAR)	• Request for data acquisition from an individual investigator. • Limited spatial and temporal coverage : Local Observation.
Science Team Acquisition Request (STAR)	• Request for data acquisitionfrom the ASTER Science Team. • Large spatial and/or temporalcoverage : Regional Monitoringdata set, or Part of the GlobalMap. • Limited spatial and temporalcoverage : Local Observation.
Engineering Team Request (ETR)	• Request for ASTER data acquisition or other instrument activities from the ASTER Instrument Team. • Used for calibration or to ensure instrument health and safety.

The generic term "xAR" is used to refer to a DAR, STAR, or ETR.

7.5.3 ASTER Data Acquisition Requests (DARs)

Any request submitted by a single user, including an ASTER Science Team member, is considered a DAR. If it is determined that a DAR will require more than a specified amount of resources, the DAR will be rejected. In this case, the submittor may ask the ASTER Science Team to consider a DAR for possible acceptance as a STAR. If it is accepted, the ASTER Science Team will submit the STAR.

Generally, one DAR will be submitted to acquire each Local observation data set. Urgent data requests are a special sub-class of DAR.

7.5.4 ASTER Science Team Acquisition Requests (STARs)

The ASTER Science Team will determine which large-scale observing projects (from EOS investigators and the general science community) will be implemented. It is likely there will be many proposals originating from outside the team, for large observing projects (and associated STARs). These proposals will be evaluated in the same fashion as proposals originating from within the team.

1) Global Map STARs

Each of the AST's science working groups has prioritized the entire Earth, by region, for ASTER imaging. The resulting prioritized maps were combined into a single map of the Earth, indicating the classification of each region (with boundaries defined by the AST) into high-priority, medium-priority, and low-priority for ASTER Global Mapping.

2) Regional Monitoring STARs

Several large ASTER observing projects have already been identified which will require resources greater than will be available for Local Observations (or their DARs). If these projects are accepted by the AST, Regional Monitoring STARs will be entered for each one.

Examples of Regional Monitoring projects that have been suggested include volcano monitoring, cloud climatology, glacier monitoring, and monitoring of ecological research sites.

3) Local Observation STARs

Like other STARs, Local Observation STARs will be submitted by the Science Team. These STARs will generally request smaller amounts of data than the other categories of STARs. They may be submitted by the Science Team in response to requests from NASA, MITI, ASTER Science Working

Groups, the EOS Science Project office, the ASTER GDS or ESDIS Projects, etc. As for all other STARs, resource allocations for Local STARs will be determined by the Science Team. Urgent data requests will form a special sub-class of Local Observation STARs, just as they will for DARs.

7.5.5 Engineering Team Requests (ETRs)

Engineering activities of the ASTER instrument include long-term calibrations to track the radiometric performance of the instrument. The instrument team will be responsible for requesting these activities.

On-board calibrations are expected to take place approximately once every 17 days. Observations of the Moon, during lunar pitch maneuvers, for calibration, should be acquired once during the early part of the mission and once or twice per year thereafter.

7.5.6 XAR parameters

STARs and DARs will be stored in the xAR database. When submitting a xAR, a user needs to specify the requirements of his observations in some detail. These requirements are specified by the xAR parameters, which are described in Appendix B. Most of these parameters have default values, all of which will be supplied by the ASTER Science Team.

Although the user will enter most xAR parameters, some parameters will be specified by the ASTER GDS. The user will specify the geographic area of interest (AOI) for a xAR by entering the latitude and longitude for each corner of a polygon surrounding the area (on a map of the Earth). Details of how ASTER should observe this region will be specified by more xAR parameters.

ASTER observations can be requested for periodic intervals during the lifetime of a xAR. The user must specify the earliest and latest acceptable observations, as well as the duration and the period for data "acquisition windows."

Each user is expected to define the maximum extent of cloud cover he will accept in his observations.

Users can also define which wavelength regions (i.e. which ASTER telescopes) they require, and whether daytime and/or nighttime observations are required. They can also request specific viewing angles or sun-illumination angles for their observations.

A user can request that his observations be classified as urgent and, finally, he can request that the resulting ASTER data be processed as expedited data.

7.6 ASTER Scheduling

7.6.1 Scheduling Algorithm

Although ASTER could collect as many as 1.7 million scenes of Full mode data during the mission, there will be factors that will decrease this amount, such as scheduling inefficiencies. The purpose of the scheduling process and the Scheduler software is to maximize the scientific content of each schedule.

The Scheduler will be able to generate an ASTER activity schedule of any length by specifying the start and end times of a schedule as input parameters. For any length schedule, the Scheduler will determine ASTER activities one day at a time. The Scheduler divides each day into a series of short timesteps (between 1 s and 4.5 s long), for the purpose of prioritization.

Prioritization is the process of ranking possible observations, so that the observation opportunities with higher scientific or programmatic value are given higher probabilities of being scheduled. The Scheduler uses the prioritization function to calculate a priority for each potential observation.

The weighting factors in this function are prescribed by the Science Team in this document, and may be modified as the mission progresses. The prioritization function uses information from all xARs requesting a possible observation, along with some time-dependent and instrument information, as input variables.

An ASTER instrument configuration is a unique combination of observing mode, telescope gain settings, and cross-track viewing angle.

For each timestep, the Scheduler calculates the priority of observations in each instrument configuration. A time sequence of priorities, for a single instrument configuration, is called a “priority curve.” This is described further in LTIP Section 6.4.

After calculating all the priority curves, the Scheduler divides each curve into all reasonable time segments for requested ASTER observations (i.e. into reasonable times to begin and end these observations). It calculates the priority integrated over each time segment and then searches among all priority curves for the time segment which has the maximum integrated priority in the entire day. The instrument is scheduled to observe in the instrument configuration corresponding to that priority curve during this maximum-priority time segment. The Scheduler then searches for the next highest priority segment, and it schedules ASTER to observe in the instrument configuration for that priority curve, during that time segment.

This continues until the entire day has been scheduled. At each point in this process, the Scheduler checks to make sure that no operating constraints are being violated.

7.6.2 Prioritization function

For each xAR, the Scheduler determines which geographic regions in the AOI have not yet been successfully observed in the current acquisition window. Only those regions which still need to be observed are considered when calculating priority curves. The priority for a single timestep on a priority curve is the sum of the priorities of each xAR whose AOI can be observed in that configuration at that timestep. This is expressed as follows:

$$P(timestep_j) = \sum_{j=1}^{n} p(xAR_j)$$

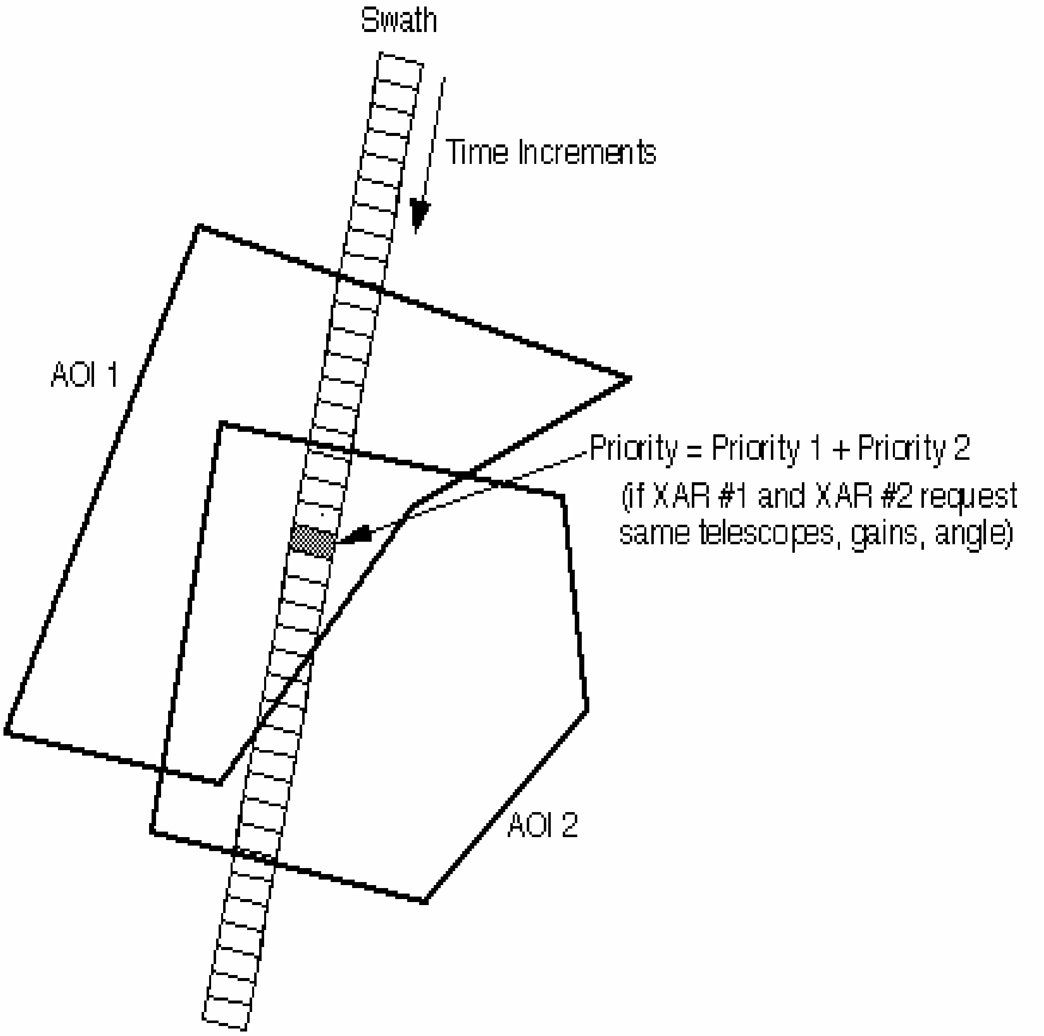

Fig 7-2 Total priority for a timestep is sum of the priorities of all relevant xARs

The prioritization function, p(xARj), is composed of several sub-functions. By changing, for example, the weights and inputs in the priority sub-function for data collection category, the SSSG can determine the allocation of ASTER data to the different categories. The priority sub-function for cloud cover is designed to grant a high priority to a xAR if it has a maximum allowed cloud cover that is greater than the predicted cloud cover for that timestep, and a low priority if the maximum allowed cloud cover is less than what is predicted.

7.6.3 Scheduling timeline

ASTER scheduling will be based on an “operations day,” beginning at 20:00 UTC (3:00 p.m. Eastern Standard Time, or 5:00 a.m. Japan Standard Time the following calendar day). See Fig 7-3, for a graphical representation of ASTER's scheduling timeline.

Every 24 hours, seven hours before the beginning of the operations day (8:00 a.m. EST or 10:00 p.m. JST), the EOS Operations Center (EOC) at GSFC will begin generating an ASTER command upload. This command sequence will be based upon a 27-hour schedule of ASTER activities (the One Day Schedule - ODS), generated in the ASTER ICC at ERSDAC.

The first command in this sequence will be executed by the ASTER instrument at the beginning of the operations day.

There are two One Day Schedules of ASTER activities. They are the:

- One Day Schedule ("Final ODS" in Fig 7-3)
  - Transmitted to GSFC 27 hours before beginning of the operations day.
  - Uses older global cloud prediction (for operations day).
- Updated One Day Schedule ("ODS Update" in Fig 7-3)
  - Transmitted to GSFC 7 hours before beginning of the operations day.
  - Uses latest possible global cloud prediction (for operations day).

1) The One Day Schedule ("ODS")

Each day, 27 hours before the beginning of an operations day (and 20 hours before the EOC begins to generate a command load), the ICC will transmit the ODS to the EOC. The cloud-cover forecast used for the ODS will be at least 20 hours older (and less accurate) than the one used for the ODS Update (see the next section). Because this would cause ASTER to acquire fewer images that meet user cloud-cover requirements, the ODSwill be used only as a backup during most of the mission, in case the ODS Update cannot be generated and transmitted in time.

By analyzing the ODS and generating simulated alternative ODSs on the Scheduler (before 7:00 p.m. JST), the SSSG can simplify the process of reviewing and modifying the ODS Update.

If NOAA cloud forecast data is not available to generate the ODS or the ODS Update, cloud climatology will be used.

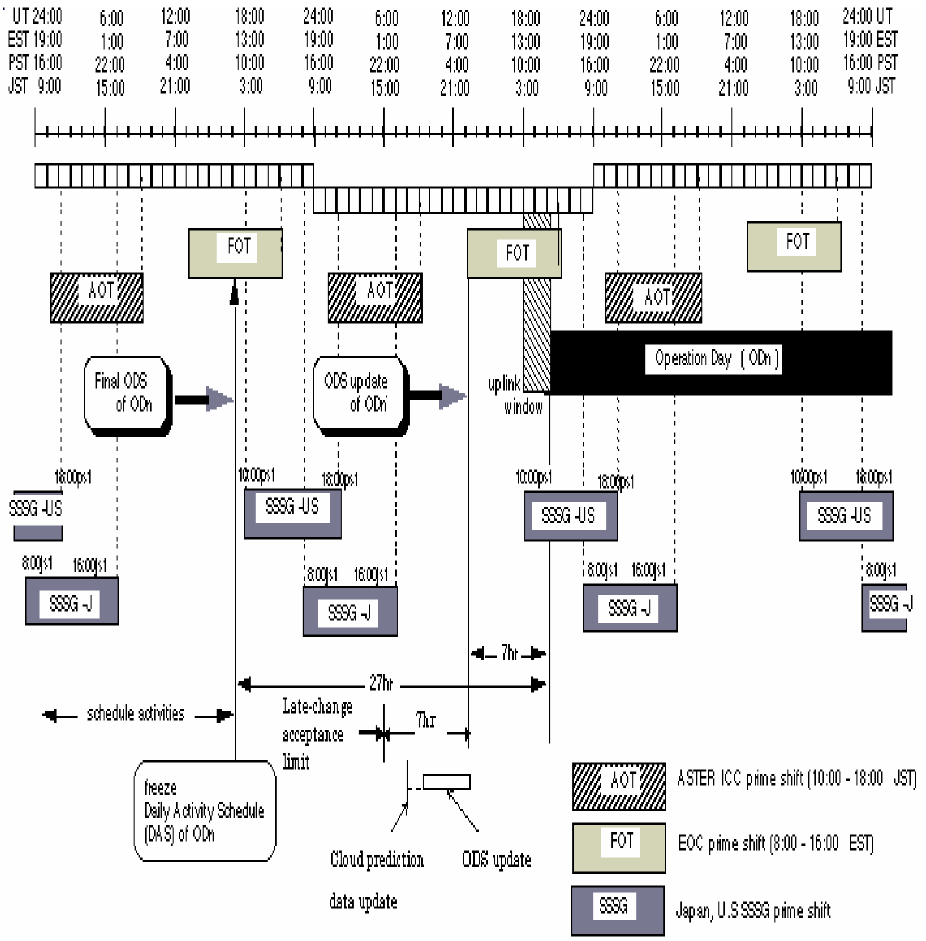

Fig 7-4 Timeline for generating the ASTER One Day Schedule

2) Updated One Day Schedule ("ODS Update")

To increase the fraction of ASTER images which are sufficiently free of clouds to meet the requirements of ASTER users, the Scheduler will input the latest cloud-cover forecast from NOAA, when it generates an ODS.

The predicted cloud cover will be used in the Prioritization function, as described in Appendix E. Cloud forecasts are accurate only for a short time into the future. Therefore, ASTER command loads will generally be based on the "ODS Update", which uses the latest NOAA forecast and is transmitted to the EOC at the last possible time (just before 8:00 a.m. EST).

Every six hours, NOAA (in Suitland, MD) generates a 72-hour global weather forecast, including predictions of cloud cover. This “Aviation” (AVN) forecast uses all the weather data from around the world which is available up to the time the forecast is generated, as model input. It takes about four hours to generate each forecast, so the 0600Z (06:00 a.m. UTC or 3:00 p.m. JST) forecast is available slightly after 7:00 p.m. JST.

Therefore, the following steps are taken to generate the ODS Update each day:

1) Retrieve NOAA's 0600Z AVN forecast, from server at GSFC

> 7:00 p.m. JST (5:00 a.m. EST)

2) Generate ODS Update at ICC, including review by SSSG

7:00 p.m. - 10:00 p.m. JST

3) Transmit ODS Update to EOC

< 10:00 p.m. JST (8:00 a.m. EST)

About three hours are available to receive the cloud forecast at the ICC, generate the ODS Update, review and possibly modify the ODS Update, and transmit the ASTER schedule to the EOC.

3) The Short Term Schedule

Each week the ASTER Scheduler will generate a Short Term Schedule (STS), which will be used (at the EOC) to help plan a week of spacecraft activities and TDRSS contacts. The initial version of the STS will be sent to the EOC, 21 days prior to the beginning of the operations week. Seven days later, the final version of the STS will be sent to the EOC. The Scheduler will use cloud climatology to generate the STS.

4) ASTER Long Term Schedules

On an ad hoc basis, the Scheduler will generate an ASTER Long Term Schedule (LTS), covering between three months and six years of ASTER operations. Analysis of an LTS will allow the SSSG to determine the effect of changing a STAR or the prioritization function, and will help the Science Team to better plan ASTER observations. There is no plan to transmit any LTS to the EOC.

7.6.4 Schedule modification

If necessary, a schedule may be modified by changing the priority of an observation.

The SSSG can adjust the priority for a specific xAR over a specific period of time. This is done by writing the appropriate "priority adjustment factor" in an input file, before running the Scheduler.
This technique provides a quick and convenient way of modifying the ODS or STS, without making the sort of long-term changes (i.e. modifying priority parameters or STARs) that require lengthy AST review.

To modify a Long Term Schedule, the SSSG will generally change STAR parameters and/or prioritization parameters (i.e. priority weighting factors in the prioritization function).

7.6.5 Schedule review and approval

The SSSG will have the opportunity to review the ODS. If necessary, they can enter priority adjustments for observations during the next operations day.

The SSSG can begin to inspect the ODS Update by 8:30 p.m. JST (assuming that the Scheduler can generate an ODS in one hour). If necessary, the SSSG could recommend some priority adjustments to the ASTER Science Team Leader, so that an improved ODS Update could be generated in time for transfer to GSFC before 10:00 p.m. JST.
The AST Leader is responsible for approving all ASTER schedules. If he is not available, the SSSG recommendations will be followed by the ICC operators. If the SSSG is not available, the first version of the ODS Update will be transmitted to GSFC.

There will be a similar review and approval process for the STS.

8. Related URL

ERSDAC Home Page	http://www.ersdac.or.jp/
ASTER Home Page	http://asterweb.jpl.nasa.gov/
ASTER GDS Home Page	http://www.gds.aster.ersdac.or.jp/
ASTER Science Home Page	http://www.science.aster.ersdac.or.jp/
Terra Home Page	http://terra.nasa.gov/
EOSDIS Home Page	http://eospso.gsfc.nasa.gov/eos_homepage/eosdis.html
ASTER Standard Products Algorithm Theoretical Basis Documents	http://eospso.gsfc.nasa.gov/atbd/astertables.html
Earth Observing System Home Page	http://eos.nasa.gov/
EOS Project Science Office	http://eospso.gsfc.nasa.gov/
Mission to Planet Earth Flight and Ground System Program	http://mtpe.gsfc.nasa.gov/
ECS Data Handling System (EDHS)	http://edhs1.gsfc.nasa.gov/
NASA HQ-Mission to Planet Earth	http://www.hq.nasa.gov/office/mtpe/
Global Land Information System	http://edcwww.cr.usgs.gov/glis/glis.html
JPL Home Page	http://www.jpl.nasa.gov/
NASA Home Page	http://www.nasa.gov/
NASA GSFC Home Page	http://www.gsfc.nasa.gov/
HDF Information Page	http://hdf.ncsa.uiuc.edu/about.html

9. Glossaries

Affiliated Data Center (ADC)

A facility not funded by NASA that processes, archives, and distributes Earth science data useful for Global Change research with which a working agreement has been negotiated by the EOS program.

The agreement provides for the establishment of the degree of connectivity and interoperability between EOSDIS and the ADC needed consistent and compatible with EOSDIS services. Such data-related services to be provided to EOSDIS by the ADC can vary considerably for each specific case.

Algorithm

Software delivered to the SDPS by a science investigator (PI, TL, or II) to be used as the primary tool in the generation of science products. The term includes executable code, source code, jog control scripts, as well as documentation.

Ancillary Data

Data other than instrument data required to perform an instrument's data processing.

They include orbit data, attitude data, time information, spacecraft or platform engineering data, calibration data, data quality information, and data form other instruments.

Attitude Data

Data that represent spacecraft orientation and onboard pointing information. Attitude data includes:

Attitude sensor data used to determine the pointing of the spacecraft axes, calibration and alignment data, Euler angles or quatermions, rates and biases, and associated parameters. Attitude generated on board i quaternion or Euler angles form. Refined and routine production data related to the accuracy or knowledge of the attitude.

Browse Data Product

Subsets of a larger data set, other than the directory and guide, generated for the purpose of allowing rapid interrogation (i.e.,browse) of the larger data set by a potential user. For example, the browse product for an image data set with multiple spectral bands and moderate spatial revolution might be and image in two spectral channels, at a degraded spatial resolution. The form of browse data is generally unique for each type of data set and depends on the nature of the data and the criteria used for data selection within the relevant scientific disciplines.

Calibration Data

The collection of data required to perform calibration of the instrument science data, instrument engineering data. and the spacecraft of platform engineering data. It includes pre-flight calibration measurements, in-flight calibrator measurements, calibration equation coefficients derived from calibration software routines, and ground truth data that are to be used in the data calibration processing routine.

Catalog Interoperability

Refers to the capability of the user interface soft ware of one data set directory or catalog to interact with the user interface at another data set directory or catalog. Three levels of Catalog Interoperability are recognized:

Level 1 Interoperability Simple network interconnectivity among systems.
Level 2 Interoperability catalog systems can exchange limited search and user information .
Level 3 Interoperability catalog systems exchange standard search protocols. This provides "virtual" similarity between different systems.

EDOS Production Data Sets

Data sets generated by EDOS using raw instrument or spacecraft packets with space-to-ground transmission artifacts removed, in time order, with duplicate data removed, and with quality/accounting (Q/A) metadata appended. Time span, number of packets, or number of orbits encompassed in a single data set are specified by the recipient of the data. These data sets are equivalent to level zero data formatted with Q/A metadata. For EOS, the data sets are composed of :

- instrument science packets,
- instrument engineering packets,
- observatory housekeeping packets, or
- onboard ancillary packets

with quality and accounting information form each individual packet and the data set itself and with essential formatting information for unambiguous identification and subsequent processing.

EDOS Quick Look Production Data Sets

Data sets generated by EDOS using raw instrument or spacecraft packets from a single TDRSS acquisition session and delivered to a user within minutes of receipt of the last packet in the session.

Transmission artifacts are removed, but time ordering and duplicat packet removal is limited to packets received during the TDRS contact period.

Command and Data Handling (C&DH)

The platform Command and Data Handling subsystem which conveys commands to the platform and research instruments, collects and formats observatory data, generates time and frequency references for subsystems and instruments, and collects and distributes ancillary data.

Command Group

A logical set of one more commands which are not stored onboard the observatory for delayed execution, but are executed immediately upon reaching their destination on board. For the U.S. platforms, from the perspective of the EOC, a preplanned command group is preprocessed by, and stored at, the EOC in preparation for later uplink. A real-time command group is unplanned in the sense that it is not preprocessed and stored by the EOC.

Commercial Off- The-Shelf (COTS)

"Commercial off-the -shelf" means a product, such as an item, material, software, component, subsystem, or system, sold or traded to the general public in the course of normal business operations at prices based on established catalog or market prices.

Comprehensive an Incremental Scheduling

Two modes of scheduling. Comprehensive scheduling is the automatic scheduling of a full set of events. Incremental scheduling is interactive scheduling of selected events.
For example, the initial generation of a schedule might user comprehensive scheduling, while the addition of a single event with the desire to avoid perturbing previously scheduled events might user incremental scheduling.

Conflict Free Schedule (CFS)

The schedule for and observatory which covers a 7-day period and is generated/updated daily based on the Instrument Activity Specifications for each of the instruments on the respective spacecraft. For an observatory schedule the platform subsystem activity specifications needed for routine platform maintenance and/or for supporting instruments activities are incorporated in the CFS.

Core-stored Commands and Tables

Commands and tables which are stored in the memory of the central onboard computer on the platform. The execution of these commands or the result of loading these operational tables occurs sometime following their storage. The term "core-stoed" applies only to the location where the items are sored on the observatory; core-stored commands or tables could be associated with the platform or any of the instruments

Correlative Data

Scientific data from other sources used in the interpretation or validation of instrument data products, e.g., ground truth data and/or data products of other instruments. These data are not utilized for processing instrument data.

Data Acquisition Request (DAR) Data Center

A request for future data acquisition by and instrument(s) that the user constructs and submits through the IMS. A facility storing, maintaining, and making available data sets for expected use in ongoing and /or future activities. Data centers provide selection and replication of data and needed documentation and, often, the generation of user tailored data products.

Data Product Levels

Data levels 1 through 4 as defined in the EOS Data Panel Report. Consistent with the CODMAC and ESADS definitions.

Raw Data-Data in their original packets, as received from the observatory, unprocessed by EDOS.

Level 0 : Raw instrument data at original resolution, time ordered, with duplicate packets removed.

Level 1A : Level 0 data, which may have been reformatted of transformed reversibly, located to a coordinate system, and packaged with needed ancillary and engineering data.

Level 1B : Radiometrically corrected and calibrated data in physical units at full instrument resolution as acquired.

Level 2 : Retrieved environmental variables (e.g., ocean wave height, soil moisture, ice concentration) at the same location and similar resolution as the Level 1 source data.

Level 3 : Data or retrieved environmental variables that have been spatially and/or temporally resampled (i.e., derived from Level 1 or Level 2 data products). Such resampling may include averaging and compositing.

Level 4 : Model output and/or variables derived from lower level data which are not directly measured by the instruments. For example, new variables based upon a time series of Level 2 or Level 3 data.

Data Set

A logically meaningful grouping or collection of similar or related data.

Data Set Documentation

Information describing the characteristics of a data set and its component granules, including format, source instrumentation, calibration, processing, algorithms, etc.

Direct Broadcast

Continuous down-link transmission of selected real-time data over a broad are (non-specific users).

Directory

A collection of uniform descriptions that summarize the contents of a large number of data sets. It provides information suitable for making an initial determination of the existence and contents of each data set. Each directory entry contains brief data set information (e.g., type of data, data set name, time and location bounds).

Distributed Active Archive Center (DAAC)

An EOSDIS facility which generates, archives and distributes EOS Standard Products and related information for the duration of the EOS mission. An EOSDIS DAAC is managed by an institution such as a NASA field center or a university, per agreement with NASA. Each DAAC contains functional elements for processing data (the PGS), for archiving and disseminating data (the DADS), and for user services and information management (elements of the IMS).

Earth Observation International Coordination Working Group (EO-ICWG) Engineering Data

A high-level group of international scientists which establishes and coordinates the EOS science program policy within the framework of international polar platformactivity.

All data available on-board about health, safety, environment, or status of the platform and instruments.

Platform Engineering Data : The subset of engineering data from platform sensor measurements and on-board computations.
Instrument Engineering Data : All non-science data provided by the instrument.
Housekeeping Data : The subset of engineering data required for mission and science operations.
These include health and safety, ephemeris, and other required environmental parameters.

Ephemeris Data

See Orbit Data

Facility Instrument

An instrument defined by NASA as having broad significance to the EOS Program and provided by a designated NASA center or foreign agency.

Granule

The smallest aggregation of data that is independently managed (i,e., described, inventoried, retrievable). Granules may be managed as logical granules and/or physical granules.

Ground Truth

Geophysical parameter data, measured or collected by other means than by the instrument itself, used as correlative or calibration data for that instrument data. includes data taken on the ground or in the atmosphere. Ground truth data are another measurement of the phenomenon of interest; they are not necessarily more "true" or more accurate than the instrument data.

Housekeeping Data

See Engineering Data

Immediate Command

Command issued to an instrument or subsystem that is transmitted with minimum delay for immediate execution. Delay would be due only to non-availability of uplink and/or the actual time to transmit the command.

Incremental Scheduling

See Comprehensive and Incremental Scheduling

In Situ Data

See Ground Truth

Institutional Facilities or Elements

Facilities established by an institution that take on some responsibility in support of EOSDIS, or elements of the EOSDIS that function as part of an institution, and represent both EOSDIS and the programs, goals and purpose of the institution.

Instrument Data

Data specifically associated with the instrument, either because they were generated by the instrument or included I data packets identified with that instrument.

These data consist of instrument science and engineering data, and possible ancillary data.

Instrument Engineering Data

See Engineering Data

Instrument Housekeeping Data

See Engineering Data

Instrument Micro-processor Memory Loads

Storage of data into the contents of the memory of an insturment's microprocessor, if applicable, These loads could include micro-processor-stored tables, microprocessor-stored commands, or updates to microprocessor software.

Instrument Science Data

Data produced by the science sensor(s) of an instrument, usually constituting the mission of that instrument.

Interdisciplinary Investigator Computing Facilities (IICF)

Project-provided facilities at interdisciplinary investigator locations used to pursue EOS-approved investigations and produce higher- level data sets.

Investigator Working Group   (IWG)

A group made up of the Principal Investigators and research instrument Team Leaders associated with the instruments on a single platform. The IWG defines the specific observing programs and data collection priorities for a single platform based on the guidelines from the IIWG.

Long-Term Instrument Plan (LTIP)

The plan generated by the instrument representative to the platform's IWG with instrument-specific information to complement the LTSP. The Project Scientist provides the LTIPs for each instrument to the ECS. LTIPs are distributed through the ECS SMC to the EOC and ICCs. It is generated or updated approximately ever six months and covers a period of up to approximately 5 years.

Long-Term Science Plan (LTSP)

The plan generated by the platform's IWG containing guidelines, policy, and priorities for its observatory. The Project Scientist provides the LTSP to the ECS ; the LTSP is distributed through the ECS SMC to the EOC and ICCs. The LTSP is generated or updated approximately every six months and covers a period of up to approximately 5 years.

Metadata

Information about data sets which is provided to the ECS by the data supplier or the generating algorithm and which provides a description of the content, format, and utility of the data set. Metadata may be used to select data for a particular scientific investigation.

Observatory

Integrated EOS flight element, consisting of the platform and the instruments.

Off-Line

Access to information by mail. telephone, facsimile, or other non-direct interface.

On-Line

Access to information by direct interface to an information data base via electronic networking.

Operational Data Orbit Data

Data created by an operational instrument (i.e., NOAA AMRIR). Data that represent spacecraft locations. Orbit (or ephemeris) data include: Geodetic latitude, longitude and height above an adopted reference ellipsoid (or distance from the center of mass of the Earth); a corresponding statement about the accuracy of the position and the corresponding time of the position (including the time system); some accuracy requirements may be hundreds of meters while other may be a few centimeters.

Payload Platform

Complement of instruments for a mission on a spacecraft or platform. The EOS spacecraft and its subsystems without the instruments.

Platform Test and Training System (PITS)

The system responsible for EOS observatory flight software maintenance and flight element simulation. The PTTS houses the EOS command and data handling flight subsystem simulator and the Mission and Simulation Software. These are used for testing flight software loads and data bases, verifying command sequences, supporting training of EOS observatory operators, supporting anomaly resolution activities, and supporting ground system testing.

Playback Data

Data that have been stored on-board the platform for delayed transmission to the ground.

Preplanned Command Group

See Command Group

Preplanned (Stored) Command

A command issued to an instrument or subsystem to be executed at some later time. These commands will be collected and forwarded during and available uplink prior to execution.

Principal Investigator (PI)

An individual who is contracted to conduct a specific scientific investigation. (An Instrument PI is the person designated by the EOS program as ultimately responsible for the delivery and performance of Standard Products derived from an EOS Instrument Investigation.)

Principal Investigator Computing Facility (PICF)

Project-provided facilities at Pi locations used to develop and maintain algorithms, produce data sets, and validate data.

Principal Investigator Instrument Prototype Product

An instrument selected pursuant to the EOS Announcement of Opportunity and provided by a PI and his home institution. Data product generated as part of a research investigation, of wide research utility, requiring too much data or computer power for generation at the investigator SCF, and accepted as candidate Standard Product by the IWG. Prototype Products will be generated at DAACs, but their routine generation is no guaranteed and will not interfere with other Standard Product generation.

Real-Time Command Group

See Command Group

Real-Time Data

Data that are acquired and transmitted immediately to the ground (as opposed to playback data). Delay is limited to the actual time required to transmit the data.

Special Data Products

Data products which are considered part of a research investigation and are produced for a limited region or time period, or data products which are not accepted as standard products.

Standard Products

(1) Data products generated as part of a research investigation, of wide research utility, accepted by the IWG and the EOS Program Office, routinely produced, and in general spatially and/or temporally extensive. Standard Level 1 products will be generated for all EOS instruments; standard Level 2 products will be generated for most EOS instruments.

(2) All data products which have been accepted for production at a PGS, including (1) above as well as prototype products.

Team Member Computing Facilities (TMCF)

Project-provided facilities at research instrument team member locations used to develop and test algorithms and assess data quality.

10. Acronyms

ADN	ASTER Data Network
AOS	ASTER Operation Segment
API	Applications Program Interfaces
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATBD	Algorithm Theoretical Basis Document
CCB	Change Control Board
CEOS	Committee on Earth Observations Satellites
CINTEX	CEOS Catalog Interoperability Experiment
CM	Configuration Management
COFUR	Cost of Fulfilling User Request
COTS	Commercial Off-the-Shelf
CSMS	Communications and System Management Segment
DAAC	Distributed Active Archive Center
DADS	Data Archive and Distribution System
DAR	Data Acquisition Request
DAS	Data Access System, Data Analysis Subsystem, Direct Access System
DB	Direct Broadcast
DCE	Distributed Computing Environment
DDL	Direct Down Link
DP	Direct Playback
DPS	Data Processing Subsystem
DRS	Direct Receiving Subsystem

DSN	Deep Space Network
EBnet	EOSDIS Backbone Network
Ecom	EOS Communications Network
ECS	EOS Core System
EDS	Expedited Data Set
EDOS	EOS Data and Operations System
EGS	EOS Ground System
EOC	EOS Operations Center
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
ERSDAC	Earth Remote Sensing Data Analysis Center
ESDIS	Earth Science Data and Information System
ETR	Engineering Team Request
FOS	Flight Operations Segment
GDS	Ground Data System
GSFC	Goddard Space Flight Center
GSMS	Ground System Management Subsystem
ICC	Instrument Control Center
IGS	Integrated Ground System
IMS	Information Management System
IOT	Instrument Operations Team
IST	Instrument Support Terminal
IWG	Investigator Working Group
JAROS	Japan Resources Observation System Organization

JPL	Jet Propulsion Laboratory
MITI	Ministry of International Trade and Industry
MODIS	Moderate Resolution Imaging Spectroradiometer
MOU	Memorandum of Understanding
MTPE	Mission to Planet Earth
MTTRS	Mean Time to Restore Service
MUX	Multiplexer
NASA	National Aeronautics and Space Administration
NCC	Network Control Center
NSI	NASA Science Internet
ODCs	Other Data Centers
OICD	Operations Interface Control Drawing
PGS	Product Generation System
PIP	Project Implementation Plan
POSIX	Portable Operating System Interface
PSO	Project Science Office
SCF	Scientific Computing Facilities
SDPS	Science Data Processing Segment
SID	Space Industry Division
SISS	Software Implementation Support Subsystem
SMC	System Monitoring and Coordination
SSSG	Software Implementation Support Subsystem
STAR	Science Team Acquisition Request
SWIR	Short Wave Infrared Radiometer

TDRSS	Tracking and Data Relay Satellite System
TIR	Thermal Infrared Radiometer
TOO	Target of Opportunity
U.S.	United States
VNIR	Visible and Near Infrared Radiometer
xAR	ASTER Instrument Activity Requests