

An Overview of NASA's Terra Spacecraft and Mission

K. Jon Ranson Yoram Kaufman David Herring

NASA/GSFC, Greenbelt, MD 20771 USA,
TEL: 301-614-6650, FAX: 301-614-6695, e-mail: jon.ranson@gssc.nasa.gov

ABSTRACT NASA is poised to launch the first major platform for the Earth Observing System, Terra, (formerly AM-1). The platform, scheduled for launch in late 1999, will have five instruments and acquire global data for a wide variety of scientific studies of the Earth's land, oceans, and atmosphere. The mission will initiate a process of long-term measurements designed to assess and monitor the health of the Earth. This paper discusses the mission and the key Earth System Science observations. In addition, plans for science outreach activities are described.

1. Terra Spacecraft

The EOS Terra platform will fly in a near-polar, sun-synchronous orbit so that it descends across the equator at 10:30 a.m. when daily cloud cover over the land tends to be minimal. EOS PM, to be launched in 2000 will fly in an ascending orbit with a 1:30 p.m. equatorial crossing time to enable study of diurnal variability. Table 1 lists the details of the Terra spacecraft.

Table 1. Characteristics of the Terra Satellite

Dimensions (primary structure)	5.9 m x 1.7 m x 2.0 m
Payload mounting area	9.7 m ²
Total mass	5190 kg
Payload mass	1172 kg
Total power	2.5 kW avg., 3.0 kW peak
Payload power	1.2 kW avg., 1.7 kW peak
Data transmission	2 Ku-band channels, 75 Mbps each X-band channel, 12.5 Mbps
Orbit position knowledge	150 m
Pointing performance	90 arcsec knowledge, 150 arcsec accuracy

To support the heat dissipation requirements of the instruments, the spacecraft provides an advanced technology capillary pumped heat transport system that transports heat from the instrument to passive radiators mounted on the spacecraft. This system was tested on the Space Shuttle and is expected to have significant benefits to future spacecraft.

The guidance, navigation, and control subsystem will maintain the orientation of the spacecraft in orbit. This subsystem uses star trackers to maintain spacecraft pointing within the specifications shown in Table 1. In addition, this subsystem provides safe-hold control in the event of a spacecraft anomaly.

Electrical power for all subsystems and instruments is generated by a solar array using gallium arsenide solar cells. Power is stored in

nickel hydrogen batteries to enable the spacecraft to operate during the dark portion of the orbit. The platform uses a 128-V system, unique to civilian Earth observing satellites.

2. Instruments

Terra has five complementary scientific instruments that will extend the measurements of their heritage sensors (e.g., Advanced Very High Resolution Radiometer (AVHRR), Coastal Zone Color Scanner (CZCS), and the Earth Radiation Budget Experiment (ERBE), but with a higher degree of calibration and characterization. Fig. 1 depicts the spacecraft and the five instruments. Table 2 summarizes the main characteristics of the instruments.

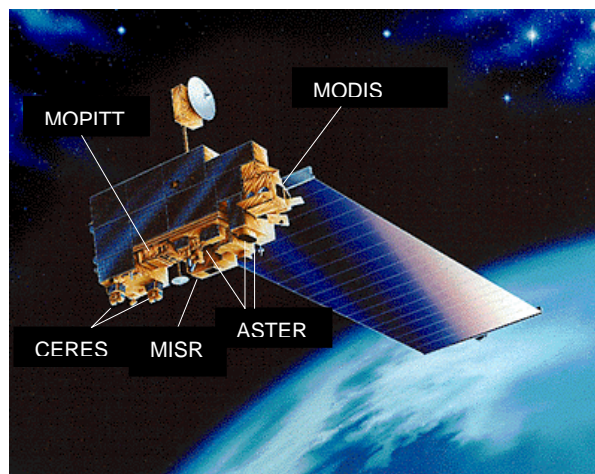


Fig. 1. The EOS Terra spacecraft with the five science instruments.

•Aster

the Advanced Spaceborne Thermal Emission and Reflection Radiometer (Fujisada et al., 1998), will collect [high spatial resolution (15-90m), multi-spectral visible through thermal, infrared data for local and regional process studies. ASTER is a cooperative effort between NASA and Japan's Ministry of International Trade and Industry (MITI),

with the collaboration of scientific and industrial organizations in both countries. ASTER consists of three distinct telescope subsystems: VNIR, SWIR, and TIR. It is a high spatial, spectral, and radiometric resolution, 14-band imaging radiometer. Spectral separation is accomplished through discrete bandpass filters and dichroics. Each subsystem operates in a different spectral region.

Unlike the other instruments aboard Terra, ASTER will not collect data continuously; rather, it will collect an average of 8 minutes of data per orbit. All three ASTER telescopes are pointable in the cross-track direction. The pixel resolution is fixed within each telescope, but varies between the telescopes. ASTER will acquire multi-spectral data of surface temperature and surface reflectance, and will enable mapping of soils, geology, land use and land cover change (Yamaguchi et al. 1998). In addition, ASTER will produce stereoscopic images and terrain elevations.

•Ceres

the Clouds and the Earth's Radiant Energy Systems a broadband scanning thermistor bolometer package with extremely high radiometric measurement precision and accuracy (Wielicki et al. 1998). CERES will measure the Earth's radiation budget and provide cloud property estimates to assess clouds' roles in radiative fluxes from the surface to the top of the atmosphere.

CERES is a broadband scanning thermistor bolometer package with extremely high radiometric measurement precision and accuracy. The Terra spacecraft will carry two identical instruments: one will operate in a cross-track scan mode and the other in a biaxial scan mode. The cross-track mode will essentially continue the measurements of the Earth Radiation Budget Experiment (ERBE) mission as well as the Tropical Rainfall Measuring Mission (TRMM). The biaxial scan mode will provide new angular flux information that will improve the accuracy of angular models used to derive the Earth's radiation balance.

•MISR

or Multi-angle Imaging SpectroRadiometer, will provide imagery at moderate resolution (275 m -1.1 km) at different viewing angles. MISR is a new type of instrument designed to view the Earth with cameras pointed at nine different angles. One camera points toward nadir, and the others provide forward (along track) and aftward view angles, at the Earth's surface, of 26.1, 45.6, 60.0, and 70.5 degrees. As the instrument flies overhead, each region of the Earth's surface is successively imaged

by all nine cameras in each of four wavelengths (blue, green, red, and near-infrared) ,viz. Figure 2.

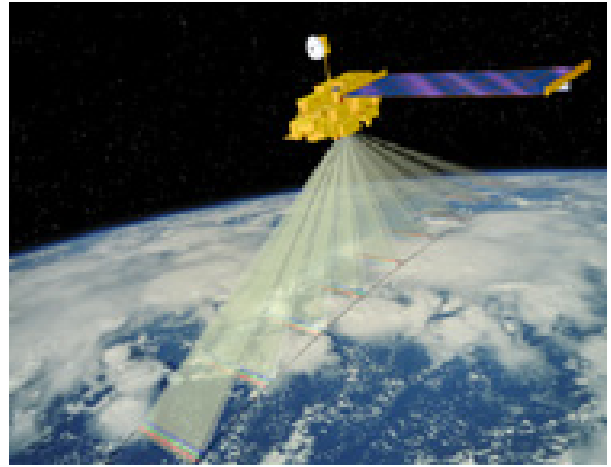


Fig.2. Illustration of data acquisition by the nine cameras of MISR.

The multi-angular data of MISR will enable the study of the angular properties of scattering of sunlight by surface cover, aerosol and clouds, as well as retrieval of aerosol plume and cloud heights stereoscopically (Diner et al. 1998). MISR will monitor the monthly, seasonal, and long-term trends in: the amount and type of atmospheric aerosol particles, including those formed by natural sources and by human activities; the amount, types, and heights of clouds; and the distribution of land surface cover, including vegetation canopy structure.

•Modis

or MODERate resolution Imaging Spectroradiometer, will enable a comprehensive daily evaluation of Earth's lands, oceans and atmosphere with its 36 spectral bands at 250 m to 1 km spatial resolution (Barnes et al., 1998). Some specific goals of MODIS are regional and global land cover characteristics and landcover change, ocean productivity, aerosol properties over land and ocean, precipitable water vapor, atmospheric temperature profiles, cloud droplet size, cloud height and cloud top temperature.

MODIS is a whisk broom scanning imaging radiometer consisting of a cross-track scan mirror, collecting optics, and a set of linear arrays with spectral interference filters located in four focal planes. MODIS has a viewing swath width of 2330 km (the field of view sweeps ± 55 degrees cross-track) and will provide high-radiometric resolution images of daylight-reflected solar radiation and day/night thermal emissions over all regions of the globe. The broad spectral coverage of the

instrument (0.4 - 14.4 μm) is divided into 36 bands of various bandwidths optimized for imaging specific surface and atmospheric features. The observational requirements also lead to a need for very high radiometric sensitivity, precise spectral band and geometric registration, and high calibration accuracy and precision.

•Mopitt

Measurements Of Pollution In The Troposphere, will provide global maps of tropospheric carbon monoxide maps in three altitude layers and global tropospheric methane maps (Drummond et al., 1998). MOPITT is an instrument designed to enhance our knowledge of the lower atmosphere and to particularly observe how it interacts with the land and ocean biospheres. Its specific focus is on the distribution, transport, sources, and sinks of carbon monoxide and methane in the troposphere. MOPITT is a scanning radiometer employing gas correlation spectroscopy to measure upwelling and reflected infrared radiance in three absorption bands of carbon monoxide and methane. The instrument modulates sample gas density by changing the length or the pressure of the gas sample in the optical path of the instrument. MOPITT has a spatial resolution of 22 km at nadir and a swath width of 640 km.

Each Terra instrument was developed under the supervision of a science team that also provides algorithms for analysis of the data and derivation of Earth system measurements. The science teams also will validate these products and use them in scientific investigations.

The science data generated by each instrument will be sent to the spacecraft over high bandwidth communication lines. These data are multiplexed and written to a solid state recorder, then sent to the communication subsystem for transmission to the ground. The solid state recorder is designed to hold approximately two orbits of data, and stores about 140 Gb of data using advanced technology solid state memory devices.

3. Ground Segment

For transmission of data to the ground, two communications capabilities are available. First, data can be transmitted via the Tracking and Data Relay Satellite System (TDRSS) on Ku-band to the TDRSS Ground Station in White Sands, New Mexico. Second, data can be transmitted directly to the ground on X-band. In both cases transmission is scheduled to occur at specific times, based on the availability of the TDRSS or on the proximity of a ground station. In addition, continuous direct broadcast of MODIS data is available on X-band

and can be acquired by anyone with the appropriate hardware and software.

Data from the EOS Terra spacecraft will flow via the TDRSS to the ground station in White Sands, New Mexico, where the data will be captured, corrected to eliminate transmission errors and artifacts, separated by instrument of origin, and stored. This initial processing is known as Level 0 processing and is performed by the EOS Data and Operations System (EDOS). Level 0 data for each instrument will then be transferred (over the EOS networks) to the appropriate Distributed Active Archive Center (DAAC) for further processing.

4. Calibration

To achieve consistent and accurate measurements that can be used to detect climatic and environmental change, the signals recorded by the detectors in each instrument must be calibrated. Calibration of the EOS instruments requires that the ongoing performance of each be carefully characterized. Unprecedented attention is being paid to instrument calibration on Terra, including:

- Pre-flight comparison among the instruments;
- Installation of calibration devices on the instruments for on-orbit calibration and characterization;
- On-orbit maneuvers of the Terra platform for additional calibration and characterization including moon-viewing maneuvers;

- Validation of the calibration by comparing satellite observations to simultaneous aircraft observations and to targets on the Earth's surface and in the atmosphere that have known, stable, or measured physical properties;

- Analysis of the multiple calibration information, resolution of conflicting information, and formulation of the calibration used in the data analysis; and
- Planned comparison with future EOS platforms.

MODIS' detailed internal calibrations will be used, through simultaneous geolocated measurements, to help in the calibration of ASTER and MISR. The MODIS and ASTER high-resolution multi-channel observations of clouds will be used by CERES' low-resolution radiative flux measurements, and by MISR and MOPITT to determine the location of clouds as well as their distribution and properties. MISR's multi-angle measurements will determine the angular reflectance of land surface features, ocean glint, and clouds, all of which will be used by the MODIS, ASTER, and CERES Teams in their data analyses.

5. Science Themes and Products

The science priorities of NASA's Earth Science Enterprise (formerly Mission to Planet Earth) and

Table 2. Summary of the main characteristics of the EOS Terra Instruments

Instrument	ASTER	MODIS	MISR	CERES	MOPITT
Spatial Resolution (Nadir)	15m in visible 30m mid-IR 90m in TIR	250 m (2 bands) 500 m (5 bands) 100m (29 bands)	275 m to 1 km	22 km	22 km
Bands Spectral Range	14 bands 0.5-12 μm	36 bands 0.4-14 μm	4 bands 0.443, 0.555, 0.670, 0.865 μm	3 bands Solar 0.3-5.0 μm Thermal: 8-12 μm Total: 0.3 to >200 μm	3 bands 2.3 μm (CH ₄) 2.4 μm (CO) 4.7 μm (CO)
Spatial Coverage (Swath)	60 km	2330 km	360 km	2330 km	640 km
Temporal coverage	Images acquired by order	daily except near equator	6-9 days	daily	3-4 days
Stereo Capability	Yes	No	Yes	No	No
Main products	Temperature and emissivities. Digital elevation maps, Surface composition and vegetation maps. Clouds, ice at high resolution. Natural hazards - volcanoes, fires	Temperature (land and ocean), Ocean color (sediment, phytoplankton), Global vegetation/change. Clouds and Aerosol. Atmospheric. temperature and moisture profiles Snow cover. Ocean currents	Cloud angular reflectance. Aerosol and effect on radiation budget. Angular properties of surface reflectance	Cloud radiative forcing and feedbacks. Observational baseline of clear-sky radiative fluxes	CO profiles with 3 km vertical resolution. CH ₄ column in troposphere

the Earth Observing System (EOS) are to provide global observations and scientific understanding of:

Land Cover Change and Global Productivity: Analyze trends and patterns of change in regional land cover and in global primary production;

Seasonal To Interannual Climate Prediction: Improve forecasts of the timing and geographical extent of transient climate anomalies;

Natural Hazards: Characterize the extent, impacts and possible and risk reduction from earthquakes, wildfires, volcanoes, floods, and droughts;

Long-Term Climate Variability: Identify the mechanisms and factors that determine the long-term climate variation and trends, including human impacts;

Atmospheric Ozone: Detect changes in atmospheric ozone and the causes and consequences of those changes.

EOS Terra will provide the first global picture or set of "initial condition" measurements to begin nearly two decades of monitoring of the Earth's lands, oceans and atmosphere. The schedule for release of data products has been described by Kaufman et al., (1999). Terra, along with Landsat 7, will acquire a majority of the 24 measurements identified by NASA as required to advance

understanding the Earth system and identified in Table 3.

Within a year after launch, these measurements will enable scientists to begin monitoring global bio-productivity (land and oceans); land use and land cover; snow and ice distribution; global surface temperature (day and night); the distribution of clouds, as well as their structure (including macrophysics, microphysics, and radiative properties); radiative energy fluxes; the distribution of aerosols, as well as their properties, and water vapor; fire occurrence; and trace gases. This will improve our ability to detect human impacts on climate, identify "fingerprints" of human activity on climate, and predict climate change through the use of sophisticated computer models

After one year of Terra data, scientists will also begin to merge data from both Terra and Landsat 7 into regional process studies and models that will enable the detection of annual changes in land use and deforestation. Two to six years after launch, additional global "snapshots" will be taken that combine Terra data with other platforms such as Jason-1 and EOS PM-1.

Between one and two years after launch, EOS scientists plan to correlate land use patterns and

Table 3. Contribution of EOS-Terra to the 24 Prioritized Global Environmental Variables.

Discipline	Measure	EOS Terra Instruments	Fulfillment of the Measure
ATMOSPHERE	Cloud Properties	MODIS, CERES, MISR, ASTER, Landsat	full
	Radiative Energy Fluxes	CERES	full
	Precipitation	---	---
	Tropospheric Chemistry	MOPITT	partial
	Stratospheric Chemistry	MOPITT	partial
	Aerosol Properties	MISR, MODIS	full
	Atmospheric Temperature	MODIS	partial
	Atmospheric Humidity	MODIS	partial
	Lightning	---	---
	LAND	Land Cover And Land Use Change	MODIS, MISR, ASTER/Landsat
Vegetation Dynamics		MODIS, MISR, ASTER/Landsat	full
Surface Temp.		MODIS, ASTER	full
Fire Occurrence		MODIS, ASTER/Landsat	full
Volcanic Effects		MODIS, ASTER/Landsat	full
Surface Wetness		MODIS	partial
OCEAN		Surface Temp.	MODIS, ASTER
	Phytoplankton & DOM	MODIS, MISR	full
	Surface Wind Fields	---	---
	Ocean surface Topography	---	---
CRYOSPHERE	Ice Sheet Topography & Ice Volume Change	---	---
	Sea Ice	MODIS, MISR, ASTER/Landsat	full
	Snow Cover	MODIS, MISR, ASTER/Landsat	full
SOLAR RADIATION	Total Solar Irradiance.	---	---
	UV Spectral Irradiance	---	---

land surface change with the observed global distributions of aerosol, water vapor, clouds, radiation, trace gases, and oceanic productivity. These measurements will all feed into EOS' regional and global climate models. Later (2 to 6 years), these comparisons will be repeated again together with Jason-1 and EOS PM-1 data.

Also within the first two years Terra will provide observations that will improve forecasts of the timing and geographical extent of transient climatic anomalies. The correlation between the regional and annual variations of clouds, aerosol, water vapor, biota in land and oceans, fires and trace gases, the radiation field, and major climatic events such as El Nino, volcanic activity, etc. can be investigated.

In addition, the new data sets from Terra will enable the development of improved methods for disaster prediction, characterization, and risk reduction from wildfires, volcanoes, floods, and drought.

These measurements begin a long-term monitoring of the changes in global climate and the environment expected to continue for nearly 20 years.

Since Terra is a research facility, some of the geophysical products will be derived using more than one instrument. For example, aerosol properties will be measured by MODIS using its wide spectral range and 1-2 day single view

coverage, and also independently by MISR using its multi-angle data, narrower spectral range, and 6-9 day global coverage. Vegetation properties will be derived from both MODIS and MISR data. Water vapor will be derived independently from MODIS—from near-infrared reflectance or based on the attenuation and emission of terrestrial infrared radiation. The simultaneous, geolocated products will allow scientists to develop broad science approaches to specific problems. For example, in the case of forest fires, the active fire area will be observed by MODIS and ASTER, and the emitted smoke particles will be observed by MISR and MODIS. Resulting deforestation and burn scars will be observed by ASTER and MODIS and the emitted trace gases--carbon monoxide and methane--will be observed by MOPITT. The resulting radiative forcing of climate will be observed by CERES.

6. Education and Outreach

While the major goal of NASA's Earth Science Enterprise is to increase scientific understanding of our planet, the ultimate product of the program is education in its broadest forms. One of the four goals of the Program is to "foster the development of an informed and environmentally aware public." Formal education initiatives are being designed for elementary through graduate levels. They include programs designed to enhance teacher/faculty

knowledge and research skills and provide curriculum support with instructional products. They will also present research experiences for students at NASA and related sites; produce programs and products that use advanced technologies for education; and promote activities involving collaborative efforts with a range of partners seeking to enhance multiple aspects of the educational process.

Informal education initiatives are directed toward educating the scientific community and the general public concerning Earth Science. Brochures, NASA Fact Sheets, handbooks, newsletters, videos, and Internet sites are being made available. For example, the Terra home page (<http://terra.nasa.gov>) gives more details on the Terra mission, while the Earth Observatory (<http://earthobservatory.nasa.gov>) enables lay visitors to explore in-depth the causes and effects of climate and environmental change through the use of remote sensing data from a variety of EOS satellites. Since its public debut in April 1999, more than 2×10^6 visitors from over 100 different countries accessed the Earth Observatory, downloading in excess of 1×10^5 data sets.

Exhibits are currently being installed or planned for several museums. Where possible, the latest multimedia technologies for interactivity and data visualization are being used. The idea is to encourage a "hands on" approach that is educational, entertaining and inspiring. Other outreach activities include a "Writer's Workshop" conducted in July 1999 to acquaint the science press with the goals of EOS. The spacecraft name, Terra, was selected by a "Name the Platform Contest" that involved middle and high school students. Additional educational materials can be obtained through the EOS Project Science Web site at:

<http://www.hq.nasa.gov/office/mtpe/education.html>;
or at the NASA education internet site at:
http://eospo.gsfc.nasa.gov/eos_homepage/education.html;
or the Earth Observatory web site mentioned above.

7. Conclusion

The EOS Terra mission, with its five instruments and careful attention to calibration, will begin a long term process of quantifying the health of the Earth. Rapid population expansion, urbanization and industrialization may be stressing the planet. Analogous to modern day diagnostics of three-dimensional imaging of the body in various

electromagnetic wavelengths, EOS Terra and other international satellites will spectrally image the three-dimensional structure of the planet. Advances in theory and in-situ observations will enable us to convert these images into environmental parameters, including: the distribution of pollution in the air, land and ocean; the fraction of natural undisturbed biota and the fraction that is influenced by humans; the interactions between atmosphere, land and oceans. The resulting data, when integrated with ongoing in-situ measurements over the oceans, cryosphere, land and atmosphere, will help us to predict how our planet is expected to change, what we need to do to mitigate some of the negative changes and how to adapt to others

References

- Barnes W.L. *et al.*, 1998. "Pre-launch characteristics of the moderate resolution imaging spectroradiometer (MODIS) on EOS AM-1," *IEEE Trans. Geosci. Remote Sensing*, 36(4): 1088-1100.
- Diner, D. *et al.*, 1998. "Multi-angle Imaging SpectroRadiometer (MISR) instrument description and experiment overview," *IEEE Trans. Geosci. Remote Sensing*, 36(4):1072-1087.
- Drummond, J.R. and G.S. Mand, 1996 "The measurements of pollution in the troposphere (MOPITT) instrument: Overall performance and calibration requirements," *Journal of Atmospheric and Oceanic Technology*, vol. 13, pp. 314-320. *Geosci. Remote Sensing*, 36(4):1062-1071.
- Fujisada, H., F. Sakuma, A. Ono, and M. Kudoh. 1998. Design and preflight performance of ASTER instrument protoflight model. *IEEE Trans. Geosci. Remote Sensing*, 36(4):1152-1160
- Kaufman, Y.A., *et al.*, 1999. The Earth Observer, 11(01), NASA GSFC, Code 900, Greenbelt, MD 20771 USA. <http://eospo.gsfc.nasa.gov/>
- Wielicki, B.A. *et al.*, 1998. "Clouds and the Earth's Radiant Energy System (CERES): Algorithm Overview," *IEEE Trans. Geosci. Remote Sensing*, 36(4):1127-1141.
- Yamaguchi, *et al.*, 1998. "Overview of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)," *IEEE Trans. Geosci. Remote Sensing*, 36(4): 1062-1071