The University of Kansas

Information and Telecommunication Technology Center

Technical Report

Earth Observation System Satellite Communication Characteristics

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Abstract

This document is a collection of Earth Observation System (EOS) satellites which have been studied for the Space Based Internet project at The University of Kansas. This document gives a brief view into each of the 24 satellites and their instruments studied under the SBI project.

The satellites in this document are Low Earth Orbit satellites and belong to the Earth Observing System of satellites. This document makes an attempt at providing information on a collection of satellites in one document.

Earth-observing systems (EOS) are used to study the clouds, water and energy cycles; oceans; chemistry of the atmosphere; land surface; water and ecosystem processes; glaciers and polar ice sheets; and the solid Earth. It consists of a series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans, which will expand our perspective of the global environment and climate.

Space Based Internet (SBI) aims at applying mobile wireless network technology to satellite systems using innovative topology and routing algorithms. SBI is based on designing a prototype based on this concept and proposes to implement an emulation system to test this prototype. The emulation system shall model satellites in an actual satellite system.

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1 Earth Observing System

The Earth Observing System (EOS)[25] is the centerpiece of NASA's Earth Science Enterprise (ESE). It consists of a science component and a data system supporting a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. By enabling improved understanding of the Earth as an integrated system, the EOS program has benefits for us all. The EOS Project Science Office (EOSPSO) is committed to helping bring program information and resources to program scientists and the general public alike.

Since its creation in 1958, NASA has been studying the Earth and its changing environment by observing the atmosphere, oceans, land, ice, and snow, and their influence on climate and weather. We now realize that the key to gaining a better understanding of the global environment is exploring how the Earth's systems of air, land, water, and life interact with each other. This approach - called Earth System Science - blends together fields like meteorology, oceanography, biology, and atmospheric science.

In 1991, NASA launched a more comprehensive program to study the Earth as an environmental system, now called the Earth Science Enterprise. By using satellites and other tools to intensively study the Earth, we hope to expand our understanding of how natural processes affect us, and how we might be affecting them. Such studies will yield improved weather forecasts, tools for managing agriculture and forests, information for fishermen and local planners, and, eventually, the ability to predict how the climate will change.

The Earth Science Enterprise[25.1] has three main components: a series of Earth-observing satellites, an advanced data system, and teams of scientists who will study the data. Key areas of study include clouds; water, energy cycles; oceans; chemistry of the atmosphere; land surface; water, ecosystem processes; glaciers, polar ice sheets; the solid Earth.

Phase I of the Earth Science Enterprise had been comprised of focused, free-flying satellites, Space Shuttle missions, and various airborne and ground-based studies. Phase II began in December of 1999 with the launch of the first Earth Observing System (EOS) satellite, Terra (formerly AM-1) and Landsat 7. EOS is the first observing system to offer integrated measurements of the Earth's processes. It consists of a science component and a data system supporting a coordinated series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. An era of unprecedented observational capability for understanding the planet has been initiated, which shall benefit all of us and the planet.

Just as the first weather and communications satellites fundamentally changed our way of thinking about those fields, so the elements of the Earth Science Enterprise will expand our perspective of the global environment and climate. Working together with our partners around the world, we are well on our way to improving our knowledge of the Earth and using that knowledge to the benefit of all humanity and hence to the planet.

Methods used for obtaining the satellite and its instrument details:

- Web resources

  Major web sites: http://www.eorc.nasda.go.jp/

  http://www.earth.nasa.gov/

- NASA satellite technical documents

Document organization:

- Each chapter contains description of an Earth Observation Satellite
- Each sub section in a chapter describes a satellite instrument
- Sources for the satellite and the instrument are available in the *References* section
- Orbit characteristics have been checked with NASA for satellites whose information is either not complete or is unavailable

2 Advanced Earth Observing Satellite (ADEOS)

Nominal orbital characteristics: [1]

Apogee Altitude : 804.6 km

Perigee Altitude : 789.0 km

Orbit Inclination : 98.625 deg.

Period : 100.8 min.

TOMS FOV at nadir: 42 km square

Space Craft and Orbit

Design Life: 3 years

Launch Vehicle: H-II(5m in diameter fairing)

Launch Site: Tanegashima Space Center, Kagoshima

Launch Date: 17 August 1996

Orbit Type: Sun Synchronous Subrecurrent

Altitude: 800 km

Inclination: 98.6 deg

Period: 101 min.

Recurrent Period: 41 days

Local time at descending node: 10:15 - 10:45 AM

Data Transmission: Direct Transmission and Inter-orbit Communication (Equipped with Mission Data Recorder)

Major Charcateristics of ADEOS

Purpose

1. To acquire data on global environmental changes, such as the greenhouse effect, ozone layer depletion, tropical deforestation and abnormal climatic conditions, using two NASDA-developed core sensors and six Announcement of Opportunity (AO) sensors supplied by NASA, CNES, the Ministry of International Trade and Industry and the Environment Agency of Japan.
2. To develop and verify the functions of the Ocean Color and Temperature Scanner (OCTS) and the Advanced Visible and Near- Infrared Radiometer (AVNIR)
3. To develop and verify the technology necessary for future large-scale earth observation satellites.
4. To verify the intersatellite data relay technology, by data relay experiments with COMETS

Orbit

Type : Sun Synchronous Subrecurrent (flight to the east)

(Recurrent: 14+11 per 41 revs. per day)

Local Time at Descending Node: 10:30±15 (AM)

Recurrent Period: 41 days

Altitude: 796.75 km

Inclination: 98.59 degrees

Period: 100.92 minutes

Orbits per Recurrent Period: 585

Minimum Interorbital Distance: 68.5 km (over the equator)

Other Characteristics:

Shape: Module Type with deployable solar paddle (one wing), NASA Scatterometer (NSCAT) and Ocean Color and Temperature Scanner (IOCS)

Body: Approx. 4 x 4 x 5 (m)

Mass: Approx. 3.56 tons (at lift-off)

Reliability Prediction: Probability of the satellite surviving for 3 years (excluding mission instruments, IOCS and DTL): more than 0.77

Power Consumption: Minimum: 4,500 W (EOL)

Designed Life Span: 3 years

Attitude Control: Three-axis strap-down attitude detection system and zero-momentum attitude control system

Note:

IOCS: Inter Orbit Communication Subsystem

DTL : Direct Transmission or Local Users

2.1 Ocean Color and Temperature Scanner (OCTS):

Ocean Color and Temperature Scanner (OCTS) [1.1] is an optical radiometer to achieve highly sensitive spectral measurement with 12 bands covering visible and thermal infrared region. In the visible and near-infrared bands, the ocean conditions are observed by taking advantage of spectral reflectance of the dissolved substances in the water and phytoplankton. On the other hand, the sea surface temperature is accurately measured in 4 thermal infrared bands. Advanced Visible and Near Infrared Radiometer (AVNIR) NASA Scatterometer (NSCAT).

OCTS is an optical radiometer devoted to the frequent global measurement of ocean color and sea surface temperature. OCTS will show the amount of chlorophyll and dissolved substances in the water, and temperature distribution. OCTS data will be used for determination of ocean primary production and carbon cycle, and be used for getting the information of ocean conditions for fishery and environment monitoring etc. OCTS is a successor to CZCS (Coastal Zone Color Scanner), the U.S. projects, which was the first real optical sensor for ocean observation onboard NIMBUS-7 launched in 1978.

OCTS has 8 bands in visible and near-infrared region and 4 bands in thermal region, and achieves highly sensitive spectral measurement with these bands. The observation bands are determined on the characteristics of spectral reflectance of the object substances, atmospheric windows and atmospheric correction. The spatial resolution is about 700m. This is applicable to the observation of coastal zone and land, the feature of these area barriers quickly compared to the open ocean. As the swath width is about 1400km on the ground, OCTS can observe the same area every 3 days and can monitor rapidly changing phenomena. OCTS has optical calibration function using solar light and halogen lamp as the calibration source. OCTS has two data transmission modes.

All raw pixel data are transmitted through X band with fine data transmission mode. One pixel data is sampled from every 6x6km area as typical data of the area and is transmitted at UHF band in coarse data transmission mode.

OCTS consists of scanning radiometer unit, which contains optical system and detector module, and-electrical unit. OCTS adopts catoptric optical system and mechanical rotating scanning method using mirror. this is because OCTS covers wide range of wavelength and wide scanning angles. OCTS can tilt its line of sight along the track to prevent the sunglitter at the sea surface from interrupting the observation. For high sensitivity, each band has 10pixels aligned to the track. The infrared detectors are cooled at 100k by a large radiant cooler facing the deep space.

Table 1. Characteristics of OCTS

Instantaneous Field Of View	0.85mrad(Ground Surface - 700m)
Scanning Range	- +-40deg.(ground level distance 1400km)
MTF	0.35
Polarization sensitivity	Band 1 : 5% or less Band 2-8 : 2% or less
Tilt Angle	-20deg. ,0deg., +20deg
Collaboration	VNIR :Solar, Internal Light Source
	IR : Deep Space, Black Body
Quantization	10bit/pixel
Course Data Transmission(DTL)	4Bands(443nm,565nm,665nm,11.0□m)

Developer of Sensor: NASDA

Mission Objectives: Measuring the quantity of chlorophyll and dissolved substances in the water, and ocean temperature distribution.

Data Application: To determine the oceans primary production and carbon cycles and for fishing and ocean condition.

Mass: Approx. 370 kg

Power Consumption: Approx 270 W

Spectral Bands: Visible-Near Infrared: 8 bands Infrared: 4 bands

Instantaneous Field of View (IFOV): 0.85 mrad (ground surface distance: approx. 700m)

Scanning Angle: ±40 degrees (ground surface distance: approx.1,400 km)

Data Rate: 3.0 Mbps and 23.4375 Kbps

2.2 Total Ozone Mapping Spectrometer (TOMS):

Total Ozone Mapping Spectrometer (TOMS) [1.2] is an optical sensor to measure the albedo of the earth's atmosphere at six narrow spectral bands. The total ozone content is interrelated with changes of solar radiation in the near ultraviolet wavelengths so that the spatial distribution of the total ozone can be inferred by observing several near UV bands. In addition, the TOMS observation data can be used to make quantitative estimates of sulfur dioxide gases in the near UV band.

Characteristics:

Provider of Sensor: NASA

Mission Objectives: The observation of total ozone and sulfur dioxide distribution

Data Application: To monitor the ozone hole in the South Pole and changes in the amount of ozone after the implementation of the CFC Protocol

Mass(IFOV): Approx. 32.1 kg

Power Consumption: Approx.14 W

Spectral Bands: 6 UV wavelengths

Method: The wavelengh is selected by the Chopper after the polarized light has been removed

IFOV: 3 x 3 degrees

Data Rate: 0.736 Kbps

2.3 Polarization and Directionality of the Earth's Reflectance (POLDER):

Polarization and Directionality of the Earth's Reflectances (POLDER) [1.3] is an optical sensor for observing the surface reflectance in visible and near infrared bands. The major differences are that POLDER can observe an area from various directions and the spectral characteristics of the reflected solar light. POLDER has a wide FOV lens with +/-43 degrees (along the track) x +/-51 degrees (cross track), and adopts pushbroom technique and an area can be observed from the maximum 14 different directions. This observation helps understand angular characteristics of the earth's reflectance. In addition, POLDER can observe multipolarization in multibands by rotating 16 types of interference filters and polarizers. Similar to Total Ozone Monitoring Spectrometer (TOMS), the wide FOV of POLDER enables the entire earth surface to be scanned four times for 5 days.

Characteristics:

Provider of Sensor: CNES

Mission Objectives: Observation of the polarization, directional and spectral characteristics of solar light reflected by aerosols, clouds, oceans and land surfaces

Data Application: To study the heat radiation balance and circulation of aerosols in the troposphere.

Mass(IFOV): Approx. 129.69 kg

Power Consumption: Approx.148.8W

Pixel Size: (274 pixels x 242 lines) 6 x 7 km

Spectral Bands: 8 Bands

Instantaneous Field of View (IFOV): ±42.6 x ±51.0 degrees

Data Rate: 0.882 Mbps(EA)

2.4 Improved Limb Atmospheric Spectrometer (ILAS):

Improved Limb Atmospheric Spectrometer (ILAS) [1.4] developed by the Environment Agency of Japan is a sensor to monitor the polar stratospheric ozone. The object of ILAS is to monitor and study changes in the stratosphere, which are triggered by emissions of Chloro Fluoro Carbons (CFC), and to check the effectiveness of world-wide emission controls of CFCs.

ILAS is a spectrometer that observes the atmospheric limb absorption spectrum from the upper troposphere to the stratosphere using sunlight (solar occultation technique). This covers the infrared region (850-1610cm-1) and the near visible region (753 to 781nm). ILAS is designed based on LAS (Limb Atmospheric infrared Spectrometer), which was aboard EXOS-C (Ohzora, ISAS). It was developed to improve observation accuracy and also to detect minor constituents related to ozone hole chemistry. ILAS's observations are focused on the high latitude regions because of the geometrical relation of the solar occultation events with the sun-synchronous orbit. From these spectral observations, ILAS can measure the vertical profile of ozone hole related components: ozone (O3), nitrogen dioxide (NO2), aerosols, water vapor (H2O), CFC11, methane (CH4), nitrous oxide (N2O), temperature, and pressure.

This dataset covers the key physical and chemical parameters which characterize ozone hold events: the cooling at the polar lower stratosphere, PSC formation, the removal of nitrogen reservoirs, and the ozone reduction by activated chemical chain reactions. ILAS will continue to contribute to research into stratospheric ozone changes into the late 1990's.

ILAS Main Characteristics

Spectral Coverage: IR (850-1610cm, 6.21-11.77um); Visible (753-784nm)

Spectrometer: Gratung Spectrometer with Lonear Linear Array Detector

Spectral Data Sampling Rate: 12MHz

IFOV: 2km Vertical x 13km Horizontal

Observation Parameters: O3, NO2, H2O), CFC11, CH4, N2O, aerosols, temperature, & pressure

Observation Region: N57-70 degree, S60-85 degree

Weight: 140kg

Power: <100W

Size: 800x1600x550mm

Provider of Sensor: Environment Agency (EA)

Mission Objectives: Observation of atmospheric trace elements(ozone, nitrous oxide, nitric acid, nitrogen dioxide, methane, water vapor, aerosols and CFC) as well as temperature and atmospheric pressures.

Data Application: To study the physical and chemical phenomena of the ozone layer depletion and to measure ozone levels in order to verify the effectiveness of action taken against CFCs

Mass: Approx. 130.2 kg

Power Consumption: 61.2 W (Operating mode on average)
78.3 W (Peak)

Spectral Bands: 2 channels (Infrared and Visible)

Instantaneous Field of View (IFOV): Transverse view (mainly sunset and sunrise)

Channel 1 (Infrared): 2 x 13 km

Channel 2 (Visible) : 2 x 2 km

Data Rate: 0.517 Mbps

ILAS measures the sequence of the limb atmospheric absorption spectrum which pass the various tangent heights, in 12Hz. The absorption (concentration) of each layer is derived from this spectral data stream. ILAS tracks the radiometric center of the solar disk. ILAS also has an IFOV position sensor which measues the angle between IFOV and the top edge of the sun.

2.5 Retroreflector in Space (RIS):

RIS Observation Concept [1.5]

RIS (Retroreflector In Space) is a retroreflector for an earth-satellite-earth laser used in long-path absorption experiments. RIS has a corner-cube structure with an effective diameter of 50 cm. Measurements of ozone, CFC12, CO2, CH4, etc. are carried out using infrared pulsed lasers.

RIS Main Charateristics

Effective Diameter: 50 cm

Reflectivity: &mt; 0.8

Wavelength region: 0.4-14um

Effective divergence of reflected beam: 60urad

Weight: 44kg

Provider of Sensor: Environment Agency (EA)

Mission Objectives: To observe the vertical distribution of ozone and methane, as well as the quantity of carbon dioxide, nitric acid, carbon monoxide, nitrous oxide and CFCs in the atmosphere

Data Application: To monitor the chemicals involved in ozone layer depletion and the greenhouse effect and study their dynamics

Mass: Approx. 44 kg

Wavelength Region (Reflected Spectrum): Ultraviolet to Infrared (350 nm-14 µm)

Instantaneous Field of View (IFOV): Approx. ±30 degrees

2.6 Interferometric Monitor for Greenhouse Gases (IMG):

The Interferometric Monitor for Greenhouse Gases (IMG) [1.6] is a sensor to monitor the earth's radiation balance, the temperature profile of the atmosphere, the temperature of the earth's surface, and physical properties of clouds. It was developed by the Japan Resources Observation System Organization (JAROS) for the Ministry of International Trade and Industry (MITI).

IMG will obtain detailed spectra of thermal infrared radiation from the earth's surface and atmosphere. The detailed spectra measured by the IMG will be used to infer atmospheric concentrations of water vapor and other greenhouse gases.

A global increase in tropospheric concentrations of trace gases, such as carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons (CFCs) has been noted. These increases have been brought about by human activities. Now however we have limited knowledge of the magnitude or distribution of the anthropogenic sources of these gases. Two sources whose magnitude must be investigated are deforestation and biomass burning. IMG will map the global and regional distribution of emission sources by measuring variations in the concentrations of trace gases.

Moreover, natural sources and sink strengths of trace gases may vary widely with different terrestrial and oceanic ecosystems.

IMG is a Michelson-type Fourier Transform Spectrometer (FTS) with two mirrors and a beam splitter. The incident radiation received from the earth is divided by the beam splitter into two paths. One mirror is moved so that the two paths produce an interference pattern when they are recombined. The signal measured by the detector, the interferogram, can be Fourier transformed to obtain the incident spectrum. The diameter of the entrance aperture for the optics is 10cm. The moving mirror is suspended on magnetic bearings and scans a 10 cm long path in 10 seconds.

IMG Main Characteristics

Spectral Range of Measurement: 714-303 cm (14 - 3.3um)

Wave number resolution: 0.1cm (apodized)

Absolute accuracy of measurement: < = 1k

Stability of measurement: <= 0.1k

Interferogram scan time: <= 10sec

Sampling per intergerogram: <= 100,000

Mass: < 115kg

Power consumption: < 150w

Approximate Size: within 1000x800x500mm

Provider of Sensor: Ministry of International Trade and Industry (MITI)

Mission Objectives: Observation of atmospheric trace elements(carbon dioxide, water vapor, methane, nitrous oxide and ozone)

Data Application: To monitor and study the distribution of gases involved in the greenhouse effect, the temperature profile of the atmosphere, the temperature of the earth's surface and the heat radiation balance

Mass(IFOV): Approx. 31 kg

Power Consumption: Approx. 55 W (Imaging mode) Approx. 21 W (Stand-by mode)

Spectral Range: 3.3-14 µm (3 bands)

Instantaneous Field of View (IFOV): 0.6 x 0.6 degrees (Spatial Resolution: Approx.8 x 8 km)

Data Rate: 0.882 Mbps(EA)

2.7 Advanced Visible and Near-Infrared Radiometer (AVNIR):

Advanced Visible and Near-Infrared Radiometer (AVNIR) [1.7] is an optical sensor for measuring surface reflectance in 3 visible bands and 1 near-infrared band. The three visible bands are indicated by blue, green and red while the near-infrared band is suitable to observe vegetation. AVNIR has 4 multispectral bands of 16m resolution and 1 panchromatic band of 8m resolution. AVNIR scans about 80km swath width along the cross track, using the large lineararray CCDs with 5,000 pixels (multispectral band) and 10,000 pixels (panchromatic band).

AVNIR is a high resolution optical sensor for the wide range of the Earth surface monitoring. The AVNIR data is used to understand vegetation and soil conditions in order to contribute to solving such phenomena as desertification and deforestation of tropical forests. In the land and urban utilization, the observation data of artificial structures and plant distribution profile contributes to creating better living environment. Other observation data such as surface reflectance and radiance plays a key role in evaluation of energy balance of the earth. Given the fact that all the environmental issues have been addressed at the local and regional levels, the AVNIR data with high resolution is valuable for the global environment observation community.

AVNIR is composed of two units, the Scanning Radiometer Unit (SRU) which mainly consists of optical components and the Electronic Unit (ELU) which mainly processes the image data.

The observation light is reflected by a pointing mirror with 0.5 degrees drive angles. Optics in SRU adopts a Catadioptric Schimidt optical system as a mirror while spectrum is splitted into 4 multispectral bands and 1 panchromatic band by combined effects of optical prism and interference filter.

After the optical signals are converted to electrical signals, Charged Coupled Devices (CCDs) scan those signals and output to the ELU. As CCDs have a capability of changing the integration time of the optical signals, sensitivity can be well maintained even in the dark area.

The electrical signals are amplified in the Process Amplifier, and then converted to the digital signals. The digital signals are processed in Image Processing Assembly and transmitted to bus module. The multispectral observation data is compressed by about 10% in order to reduce the transmission data rate.

Characteristics:

Developer of Sensor: NASDA

Mission Objectives: To examine the distribution of vegetation, soils, farmland, deforestation and urban areas

Data Application: To monitor such phenomena as desertification, destruction of tropical forests and pollution of coastal zones, and to study land use and resource exploration.

Mass: Approx. 233 kg

Power Consumption: Approx 300 W

Spectral Bands:

Multispectral Band : 4 bands

Panchromatic Band : 1 band

Instantaneous Field of View (IFOV):

Multi : 20 μrad (ground surface distance: approx.16m)

Pa : 10 μrad (ground surface distance: approx.8m)

Swath Width: 80 km (scanning angle: approx. 5.7(degrees)

Data Rate: 60 Mbps x 2 channels

2.8 NASA Scatterometer (NSCAT):

NASA Scattrometer (NSCAT) [1.8] is an active microwave radar to measure winds over the oceans by transmitting Ku band microwave pulse (13.995 GHz) and receiving backscatter powers from the ocean surface. The backscatter powers is subject to changes in direction of surface waves. Multidirectional measurements can thus be used to solve wind speed and direction simultaneously by using algorithm derived from the previous studies.

NSCAT makes simultaneous measurements of the backscatter powers with three different directions for each side along the track so that wind speed and direction of the sea surface are inferred. The antenna is with a fan beam of 28 degrees (along the direction of beam radiation). The frequency of backscatter powers in changed by Doppler shift.

Mission:

NSCAT was launched at 6:54 p.m. U.S. PDT, Friday, August 16, 1996, aboard the Advanced Earth Observing Satellite (ADEOS), a mission of the National Space Development Agency of Japan. ADEOS was launched into a near-polar Sun-synchronous orbit, by an H-II launch vehicle from Japan's Tanegashima Space Center. The largest satellite ever developed by Japan, ADEOS had a mass of approximately 3500 kilograms and a power-generation capability of approximately 4500 watts; its overall dimensions at launch were 4 x 4 x 5 meters. When the NSCAT antenna and the solar array paddle were deployed, the satellite was an impressive 11 meters in height and the solar array extends outward 29 meters.

Science Objectives:

Acquire all-weather high-resolution measurements of near-surface winds over the global oceans.

Determine atmospheric influences, ocean response and air-sea interactions on various spatial and temporal scales.

Develop improved methods of assimilating wind data into numerical weather and wave prediction models.

Combine wind data with measurements from various scientific disciplines to understand processes of global climatic change and weather.

Measurements:

The instrument was operated continuously at a frequency of 13.995 Giga Hertz.

Six dual-polarized, 3-meter long, stick-like antennas collected backscatter data with a resolution of 50 km for nine months before loss.

Backscatter data was combined and processed to yield 268,000 globally distributed wind vectors per day.

Planned Missions:

70% of the entire earth surface is covered with the ocean, which is the largest reservoir on the Earth and contains various thermal elements and greenhouse gases. It is likely that the ocean wind is deeply interrelated with the ocean changes on scales ranging from day to year, and the changes have great effects on climatic and environmental changes. Although the traditional measurements of ocean wind by ships and buoys are limited spatially and temporally, NSCAT has wide instantaneous field of views and makes frequent observation. This observation data will contribute to improvements of numerical weather forecast and ocean circulation model, and a better understanding of thermal balance in the upper ocean and environmental phenomena such as El Nino.

The Traveling Wave Tube Amplifier (TWTA) in the RF subsystem produces a radar pulse with 13.995 Ghz (frequency), 5m/sec (width), 62 Hz (repetition frequency). The pulse is fed to each antenna via switch matrix. After the received signals are converted to base band frequency level, they are transmitted to the digital subsystem.

The antenna subsystem consists of six independent fan beam antennas (two pairs of two antennas and two pairs of a single antenna). Each antenna configuration is two array antennas with wave guide slots (each for vertical and horizontal polarization). Two pairs of two antennas use one polarization while the other antennas do both polarization. The antennas will be deployed after launch. The backscatter powers, of which frequency is changed by Doppler shift, are processed by digital Doppler processor in the digital subsystem, and then transmitted to bus module.

Instrument Description:

Mass: 280 Kg

Power: 240 Watts

Data rate: 3.2 Kbps

Provider of Sensor: NASA

Mission Objectives: The measurement of wind speed and direction over the oceans

Data Application: To predict global weather

Mass(IFOV): Approx. 300 kg

Power Consumption: Approx.275 W

Wave Frequency: 13.995 GHz

Method: Resonant scattering (Bragg Scattering)

Swath Width: 600 km x 2 swaths

Data Rate: 2.94 Kbps

Every two days, under all weather and cloud conditions, NSCAT measured wind speeds and directions over at least 90% of the Earth's ice-free oceans. Since oceans cover approximately 70% of Earth's surface, NSCAT played a key role in scientists' efforts to understand and predict complex global weather patterns and climate systems. NSCAT used eight antenna beams to scan two wide bands of ocean, one on each side of the instrument's orbital path. NSCAT transmitted short pulses of microwave energy to probe ocean surfaces and then measured the reflected or backscattered power. Variations in the magnitude of this backscattered power are caused by changes in small (centimeter-sized), wind-driven waves. Using a method called Doppler processing (a change in the observed frequency of the radio waves due to relative motion of source and observer), the measured backscattered power was separated into cells at specific locations on Earth's surface; these were then transmitted to the ground for processing. During ground processing, wind direction and speed was determined from these variations. Within two weeks of receiving the raw data, the ground system processed wind measurements.

2.9 ADEOS Technical Data Acquisition Equipment (TEDA)

Bus module:

Component: Heavy Ion Telescope, Dose Monitor, Contamination Monitor, Single Event Upset Monitor, Potential Monitor

Date Rate: 144 bps

- *Communications & Data Handling Subsystem (C & DH)*

- *Telemetry/Low Rate Mission Data*

  Frequency : 2220 MHz

  Modulation : PCM (Bi ø-L) - PSK/PM

  Bit Rate : 4096 bps (Real-time) 32768 bps (Reproduce)

- *Command*

  Frequency : 2044.25 MHz

  Modulation : PCM (MRZ-L) - PSK/PM

  Bit Rate : 500 bps (Real-time)

- *Ranging*

  Ranging Signal : Major Tone 500 KHz

  Modulation : Tone/PM

  Automatic/Autonomous Operation

- *Inter Orbit Communication Subsystem (IOCS):*
    - *S band*

      ADEOS => COMETS: Telemetry/Ranging/Low Rate Mission Data

      COMETS => ADEOS : Command/Ranging
    - *Ka band*

      ADEOS => COMETS: Real-time/Reproducting of Mission Data

      (Maximum Transmission Rate : 120 Mbps)

- *Mission Data Processing Subsystem (MDP):*

  Transmitting Data Selection, Edition and Transmitting Route Selection

  Mission Data Recording/Reproduction

  Data Recorder : 3 units

  Recording Rate : 3/6/60 Mbps

  Reproducting Rate: 60 Mbps

- *Direct Transmission Subsystem (DT):*

  X band x 3 (8.15/8.25/8.35 GHz)

  X1 (40W): Real-time/Reproduce Mission Data

  (Maximum Transmission Rate : 60 Mbps)

  X2 (40W): Real-time/Reproduce Mission Data

  (Maximum Transmission Rate : 60 Mbps)

  X3 (8W) : Real-time Mission Data

  (Maximum Transmission Rate : 6 Mbps,

  Mission Instrument: OCTS, AVNIR, POLDER, IMG, ILAS, LMDR)

Regulation Method : 33.5 V - 52 V Floating Bus

Shunt System : Digital Sequential Shunt System

Battery : NiCd Battery 35 AH x 5 units

- *Solar Array Paddle Subsystem (PDL)*

  Type : Flexible Paddle

  Power Generation : Minimum 4,500 W (EOL)

  Solar Cell : Si/BSFR Solar Cell

- *Attitude and Orbit Control Subsystem (AOCS)*

  Control System : Zero-Momentum/3-axis Strap Down

  Sensors : Inertial Sensor, Earth Sensor, Fine SunSensor

  Actuator : 4 Skew Reaction Wheel, Magnetic Torquer

  Attitude Control Precision : 0.2 degrees per axis (Max.)

  Attitude Stability : 0.003 degrees/sec per axis (Max.)

- *Reaction Control Subsystem (RCS)*

  Propellant : Hydrazine Blow-Down (mono liquid propellant)

  Thruster : 20 N thruster x 4, 1 N thruster x 16

  Tank : 3 units, 550 mm (internal dia.), surface tensiontype

- *Direct Transmission for Local Users (DTL)*

  Main Function : Direct Transmission of OCTS coarse data to local users

  Frequency : 467.7 MHz

  Data Rate : 23.4375 Kbps (Max.)

- *Thermal Control Subsystem (TCS)*

  System : Independent Thermal Control (active/passive jointly use)

  Configuration : Thermal louver, Heat pipe, Heater, Multilayer Insulation

- *Structure Subsystem (STR)*

  Configuration :

  Bus Module (truss structure)

  Mission Module (frame structure using reinforced panels)

  Rigidity:

  Flight Axis : Minimum 30 Hz

  Perpendicular to Flight axis : Minimum 10 Hz

- *Integration Subsystem (INT)*

  Mechanical Integration : Bracket, Harness, etc.

  Electrical Integration : Wire harness, Coaxial cable, Power distributor, etc.

3 Advanced Earth Observing Satellite II (ADEOS II)

The Advanced Earth Observation Satellite-II (ADEOS-II) 0, the successor to ADEOS, has been developed to advance Earth observation technologies. It acquires data to help researchers understand the mechanism of the global environmental changes such as global warming and to support meteorology and fishery activities. It is equipped with two NASDA sensors: AMSR for quantitatively observing various geophysical data concerning the water cycle, and GLI for observing oceans, land and clouds with high accuracy. It also carries three sensors provided by international and domestic partners. ADEOS-II is expected to provide the data necessary for us to understand the circulation of water, energy, and carbon in order to contribute to studies on global environmental changes.

Table 2. ADEOS-II Orbit parameters

Altitude	802.9 km
Inclination	98.62 deg
Eccentricity	0.001
Desc. Node	10:30
Period	101 min
Repeat Cycle	4 days
Path/day	14 + 1/4

Table 3. Orbit Elements

Semi-major Axis	7189.2897km
Eccentricity	0.001
Inclination	98.62deg
Right Ascension of Ascending node	108.26deg
Argument of Perigee	90deg
Mean Anomaly	270deg

3.1 AMSR (Advanced Microwave Scanning Radiometer):

The Advanced Microwave Scanning Radiometer (AMSR)0 is a multi-frequency, dual-polarized microwave radiometer that detects microwave emissions from the Earth's surface and atmosphere. Various geophysical parameters, particularly those related to water (H2O), can be estimated from AMSR data. In addition to the proven parameters such as water vapor, precipitation, and sea surface wind speed, novel geophysical parameters, including sea surface temperature and soil moisture, are expected to be retrieved by using new frequency channels. The largest ever microwave radiometer antenna enables us to perform continuous global observation with high spatial resolution. Long-term record of AMSR measurements will play an important role in climate change monitoring as well as in providing indispensable information for understanding the Earth's climate system, including water and energy circulation. Near real-time products will be used for investigating satellite data assimilation into weather forecasting models and will contribute to improving forecast accuracy.

AMSR is scheduled to be launched on board the Advanced Earth Observing Satellite-II (ADEOS-II) in 2002. ADEOS-II is an integrated observing platform with multiple sensors covering the spectrum from visible to microwave frequencies. In addition to AMSR, a combination of these sensors will provide a means of examining the Earth's phenomena from various aspects.

An AMSR follow-on series is being studied for the Global Change Observation Mission (GCOM) as one of the core instruments to contribute to the long-term global monitoring. The GCOM series, including the ADEOS-II, will enable constructing a 15-year satellite climate record.

The AMSR project is an international activity with scientists and engineers collaborating worldwide in algorithm development and data validation.

AMSR is an eight-frequency, total-power microwave radiometer with dual polarization (except two vertical channels in the 50GHz band). Conical scanning is employed to observe the Earth's surface with a constant incidence angle. Multifrequency measurement is realized by an array of primary horns. Calibration counts are obtained every scan by using the hot load target (around 300K) and the cold-sky mirror to introduce the temperature of deep space (around 3K). The offset-parabolic antenna is the largest space-borne microwave radiometer antenna of its kind. A spatial resolution better than before enables us not only to resolve small-scale features, including clouds, precipitation, sea ice, and land, but also to improve retrieval accuracy of geophysical parameters.

In addition to the typical frequency channels, 6-GHz and 50-GHz channels have been added to obtain information on sea surface temperature through clouds, soil moisture, and atmospheric temperature.

Table 4. AMSR – Frequency and beam characteristics

Center Frequency (GHz)	6.925	10.65	18.7	23.8	36.5	50.3	52.8	89.0 A	89.0 B
Band Width (MHz)	350	100	200	400	1000	200	400	300	
Polarization	Vertical and Horizontal					Vertical		Vertical and Horizontal	
3dB Beam Width (°)	1.8	1.2	0.65	0.75	0.35	0.25	0.25	0.15	0.15
IFOV (km)	40x70	27x46	14x25	17x29	8x14	6x10	6x10	3x6	
Sampling Interval (km)	10x10							5x5	
Temperature Sensitivity (K)	0.34	0.7	0.7	0.6	0.7	1.8	1.6	1.2	
Incidence Angle (°)	55.0								54.5
Dynamic Range (K)	2.7 - 340								
Swath Width (km)	Approximately 1600								
Integration Time (msec)	2.5							1.2	
Quantization (bit)	12	10							
Scan Cycle (sec)	1.5								

3.2 GLI (Global Imager)

Global Imager (GLI)0 is an optical sensor aiming at observing globally and so frequently the reflected solar radiation from the earth's surface including land and ocean, and cloud or the infrared radiation for measuring the physical content such as chlorophyll, dissolved organic substance, surface temperature, vegetation distribution, vegetation biomass, distribution of snow and ice, and albedo of snow and ice, etc. These data may be used for grasping the global circulation of carbon, monitoring cloud, snow, ice, and sea surface temperature, and grasping the primary marine production.

GLI is an advanced type of the mission of Ocean Color and Temperature Scanner (OCTS) on-board ADEOS for further expansion of observation. GLI has 22 bands in visible and near-infrared region (VNIR), 5 bands in short-wave length infrared region (SWIR), and 7 bands in middle and thermal infrared region for its multispectral observation. Although the ground resolution is at the nadir of 1km, a part of the bands in VNIR and SWIR has a resolution of 250 m at the nadir which will be used for observing vegetation and cloud. The observation region by mechanically scanning is 12 picture elements (12 km) to the forward direction and 1600 km in the cross-track direction.

Table 5. GLI Characteristics

Spectral Range	0.375 - 12.5mm
# of Special Bands	36
Spectral Bandwidth	10nm(VNIR/1km)
Instantaneous Field of View(IFOV)	1.25mrad & 312.5mrad (1km & 250m nadir)
Scanning Angle	}45‹(Ground Surface 1600km)
S/N,NE∆T	800,0.1K(1.25mrad IFOV bands)
Quantization	12bits
MTF	0.35
Polarization Sensitivity	Under 2%
Tilting Angle	-20,0, +20
Coarse Data Transmission (Direct Transmission for Local user)	4Band (443nm,565nm,667nm,11.95mm)

3.3 ILAS-II (Improved Limb Atmospheric Spectrometer -II)

Improved Limb Atmospheric Spectrometer-II (ILAS-II)[2.3] is an atmospheric observation sensor developed by the Environment Agency to monitor and study the ozone layer in the high latitudinal stratosphere of both the southern and northern hemispheres.

ILAS-II, with the same systems configuration as that of ILAS (loaded on "Midori"), can measure the altitudinal distribution of atmospheric temperature and pressure very accurately thanks to its broader spectral coverage and improved altitude resolution.

Table 6. Main characteristics of ILAS-II

Spectral Coverage (wavenumber)		Ch.1: 6.21 - 11.76 µm (1,610 - 850 cm^{-1}) Ch.2: 3.0 - 5.7 µm (3,333 - 1,754 cm^{-1}) Ch.3: 12.78 - 12.85 µm (782 - 778 cm^{-1}) Ch.4: 753 - 784 nm (13,280 - 12,755 cm^{-1})
Observation parameters		O_3, HNO_3, CH_4, H_2O, N_2O, NO_2, CFC-11, CFC-12, $ClONO_2$, aerosol, temperature, pressure, CO_2 (for pressure measurement)
Altitude for measurement		10 - 60 km (continuous observation from the cloud top to 250 km)
Target accuracy	**Altitude resolution**	1 km
	Profile	1 % for ozone, 5 % for trace constituents other than $ClONO_2$, and under study for $ClONO_2$
Areas for measurement (latitude range)		Northern Hemisphere: 57 - 72 degrees Southern Hemisphere: 65 - 90 degrees
Spectrometers		Ch.1 - Ch.3: Grationg spectrograph with array detectors (Element number Ch.1: 44, Ch.2: 22, Ch.3: 22) Ch.4: Grating spectrograph (Element number: 1024)
Data rate		453.7 kbps (10 Hz sampling)
Weight		133 kg (max.)
Power consumption		120 W (max.)

3.4 SeaWinds

The SeaWinds[2.4] scatterometer is a specialized microwave radar that measures near-surface wind velocity (both speed and direction) under all weather and cloud conditions over Earth's oceans. The experiment is a follow-on mission and continues the data series initiated in 1996 by the NSCAT.

SeaWinds uses a rotating dish antenna with two beams. The antenna radiates microwave pulses at a frequency of 13.4 gigahertz across broad regions on Earth's surface. SeaWinds will collect data in a continuous 1,800-kilometer-wide band, making approximately 400,000 measurements per day.

Mission

SeaWinds is a part of the Earth Observing System (EOS) which is designed to address global environmental changes, and is a joint mission with the National Space Development Agency of Japan (NASDA). Winds are a critical factor in determining regional weather patterns and climate. Oceans cover 70 percent of Earth's surface, and as the only remote-sensing system to provide accurate, frequent, high-resolution measurements of ocean surface wind velocities, under all weather conditions, scatterometers play an increasingly important role in oceanographic, meteorological and climate studies.

As part of the SeaWinds Project, NASA sponsors a team of scientific investigators who advised the project during the development of the instrument and ground data processing system. The science team will conduct research with SeaWinds data; their studies are expected to lead to improved methods of global weather forecasting and modeling.

Science Objectives

- Acquire all-weather, high-resolution measurements of near-surface winds over the global oceans
- Determine atmospheric forcing, ocean response and air-sea interaction mechanisms on various spatial and temporal scales
- Combine wind data with measurements from scientific instruments in other disciplines to understand mechanisms of global climate change and weather patterns

Operational Objectives

- Improve weather forecasts near coastlines by using wind data in numerical weather- and wave-prediction models I
- Improve storm warning and monitoring

Table 7. Instrument Description

Radar	13.4 gigahertz; 110-watt pulse at 189-hertz PRF
Antenna	1-meter-diameter rotating dish producing 2 spot beams sweeping in a circular pattern
Mass	200 kilograms
Power	220 watts
Average Data Rate	40 kilobits per second

Measurements

- 1,800-kilometer swath during each orbit provides approximately 90-percent coverage of Earth's oceans every day
- Wind-speed measurements of 3 meters/ second to 20 meters/ second with 2 meters/ second accuracy; direction with 20 degrees accuracy
- Wind vector resolution of 50 kilometers

Winds over the ocean modulate air-sea changes in heat, moisture, gases and particulates, regulating the crucial bond between atmosphere and ocean that establishes and maintains global and regional climate. Measurements of surface wind velocity can be used in regional and global numerical weather models to improve our ability to predict weather.

As the only remote-sensing system to provide accurate, frequent, high-resolution measurements of ocean surface wind velocities, under all weather conditions, scatterometers play an increasingly important role in oceanographic, meteorological and climatic studies.

SeaWinds was scheduled to launch on board ADEOS-II from Tanegashima, Japan in February 2002, but NASA has been advised by the National Space Development Agency of Japan (NASDA) that the Japanese Space Activities Commission (SAC) want to have 3 successful H-IIA rocket launches prior to the ADEOS-II launch. This sets the ADEOS-II launch to take place no earlier than November 2002. The SeaWinds Project is managed for NASA's Earth Science Enterprise by the Jet Propulsion Laboratory, a division of the California Institute of Technology.

3.5 POLDER (Polarization and Directionality of the Earth's Reflectances)

POLDER[2.5] is the first space instrument to simultaneously observe the polarization and the multi-spectral and directional signatures of reflected radiation. Its observations will make it possible to reach certain physical-optical characteristics of distribution of short wave radiation as well as the water vapor content.

The regular increase in greenhouse gases due to anthropogenic emissions in the atmosphere may have a major impact on the Earth's climate in the forthcoming decades. In order to reduce the uncertainties in forecasting climatic changes, it is necessary to better understand the processes involved in interactions between aerosols, clouds, radiation and atmospheric circulation. Current numerical models poorly represent such interactions and there is a need to quantify their role in phenomena involved in the evolution of the climate system.

Table 8. Characteristics of POLDER

Mass	32 kg
Volume	0.8 x 0.5 x 0.25 m^3
Power Consumption	50 W (IMAGE MODE)
Encoding	12 BITS
Data Rate	883 kbps
Field of View	± 43° along track
	± 51° cross track
Swath	2400 KM
Pixel (at nadir)	6 KM x 7 KM
Mission Lifetime	3 YEARS

4 CloudSat

CloudSat[3] is a NASA Earth System Science Pathfinder (ESSP) Mission and is part of the Earth Science Enterprise (ESE). CloudSat is a satellite experiment designed to measure the vertical structure of clouds from space. CloudSat will fly millimeter-wave (94 GHz) radar that is capable of seeing practically all clouds and precipitation - from very thin cirrus clouds to thunderstorms producing heavy precipitation. The spacecraft will also carry a near-infrared spectrometer that will measure the altitude and optical properties of clouds and aerosols in the O2 A-band between 761.1 and 772.20nm.

CloudSat's primary goal is to furnish data needed to evaluate and improve the way clouds are represented in global models, thereby contributing to better predictions of clouds and thus to their poorly understood role in climate change and the cloud-climate feedback. CloudSat is a multi-satellite, multi-sensor experiment. CloudSat will fly in tight formation with the PICASSO-CENA satellite, which will carry a dual-wavelength (532 and 1064 nm) polarization-sensitive lidar that provides high resolution vertical profiles of aerosols and clouds. CloudSat and PICASSO-CENA will follow behind the Aqua (formerly EOS-PM) satellite in a somewhat looser formation. Aqua will carry a variety of passive microwave, infrared and optical instruments.

Orbit

The CloudSat mission was designed with a two-year lifetime to enable more than one seasonal cycle to be observed, although radar lifetime data indicates that the radar is expected to operate for 3 years with a 99% probability. The desired orbit is that of the EOS-PM satellite which is a sun-synchronous, 705-km altitude orbit. CloudSat is designed around the Ball Aerospace RS2000 spacecraft bus that is being used for both QuikScat and ICESat. Communications is accomplished via an S-band transceiver using a nearly Omni-directional patch antenna. The maximum mass of the commercial spacecraft will not exceed 700 kg and the spacecraft subsystems and payload will require a maximum power level of 1170 W.

The U. S. Air Force Space Test Program will provide ground operations and manage communications. It is expected that the data will be downlinked up to about 10 times per day providing a data latency of about 2-4 hours. The Cooperative Institute for Research in the Atmosphere (CIRA) at the Colorado State University (CSU) will handle data processing and archiving of the data. Some portion of the data will be processed and distributed to operational centers for use in near-real-time assimilation and cloud forecast evaluations.

The primary CloudSat payload consists of 94-GHz Cloud Profiling Radar (CPR) and a near-infrared Profiling A-Band Spectrometer/Visible Imager (PABSI). The secondary payload is the dual wavelength lidar system of PICASSO-CENA and the payload of EOS-PM, notably including CERES, AIRS, AMSR and MODIS.

4.1 Cloud Profiling Radar (CPR)

The CloudSat Cloud Profiling Radar (CPR)[3.1] provides calibrated radar reflectivity, (e.g., radar backscatter power), as a function of distance from the spacecraft. The CPR will be developed jointly by NASA/JPL and the Canadian Space Agency (CSA). The design has a strong heritage derived from existing ground-based and airborne cloud radars (Mead et. al, 1994; Sadowy et. al, 1997).

The requirements for CPR are dictated by the science objectives. Based on our current understanding of cloud reflection, the sensitivity of CPR must provide a nominal detectable reflectivity factor of approximately -29 dBZ, a 70 dB dynamic range, and a calibration accuracy of 1.5 dB. This will allow CPR to detect almost all radiatively and hydrologically significant clouds.

The radar footprint is 1.4 km, and will be averaged over 0.3 seconds to produce an effective footprint of 4-km (along-track) by 1.4 km (cross-track). It will operate in two modes, the normal mode will yield 500-m vertical resolution between the surface and 20 km and a pulse-compressed mode with a vertical resolution of 250m between 5 and 20 km. The radar footprint necessitates an antenna diameter of approximately 2 meters. The antenna pattern requires that the spacecraft be pointed with an accuracy of 0.5o to minimize direct surface reflections and contamination from sidelobes.

The choice of radar frequency, 94 GHz, is a trade-off between sensitivity, antenna gain, atmospheric transmission, and radar transmitter efficiency. Sensitivity and antenna gain increase with frequency while atmospheric transmission and transmitter efficiency decrease with frequency. Since a space-based platform sets strong constraints on antenna size, a frequency of 94 GHz provides an optimum compromise between the competing factors. An international frequency allocation at 94 GHz has recently been set-aside for spaceborne radar use. The choice of frequency means that a small percentage of the time when very thick clouds or heavy precipitation is present, CPR will not be able to penetrate to the cloud base. The mission objective dictates this choice.

CPR System Characteristics. Mode 1: 100% SP; Mode 2: 50% SP and 50% CP.

Table 9. CPR Characteristics

Parameter	Short pulse	Chirp pulse
Nominal frequency	94 GHz	94 GHz
pulse width	3.3μsec	33.3 μsec
PRF	4300 Hz	800 Hz
minimum detectable Z*	-30 dBZ	-36 dBZ
data window	0-25 km	5-25 km
antenna size	1.95 m	1.95 m
dynamic range	70 dB	70 dB
integration time	0.3 sec	0.3 sec
vertical resolution	500 m	500 m
cross-track resolution	1.2 km	1.2 km
along-track resolution	3.5 km	3.5 km
along-track sampling	2 km	2 km
data rate	15 kbps	15 kbps
*Equivalent radar reflectivity that gives a mean power equal to the standard deviation after integration and noise subtraction. Atmospheric attenuation is not included.		

4.2 Profiling Oxygen A-Band Spectrometer and Visible Imager (PABSI)

The Profiling A-Band Spectrometer/Visible Imager (PABSI)[3.2] instrument both measures the atmospheric radiance of the O_2 A-band rotational spectrum between 761.61 nm and 772.20 nm and records narrow-band images at 747.5 and 761.5 nm. The high-resolution spectrometer determines optical depth and altitude of thin clouds and aerosols by making high spectral resolution (0.5 cm-1) measurements at the Oxygen A-band. A "thicket" of closely spaced spectral lines characterizes the Oxygen A-band. Therefore, a small change in wavelength will vary the rate at which light is attenuated as it traverses the atmosphere.

With measurements made at a wide range of attenuation lengths, it is possible to determine optical depth, photon path length, characteristics of scattering particles, and cloud and aerosol layer altitude (Stephens and Heidinger, 1999). The imager allows researchers to identify mesoscale weather systems corresponding to the cloud and aerosol profiles. The imager will be able to associate profiles with cloud systems such as tropical storms, cumulus columns, or uniform stratus decks. PABSI will achieve a signal-to-noise of 100:1 that will enable measurement of optically thin cloud. The measurement technique is also sensitive to small changes in the optical depth of very deep clouds, a capability not presently possible with current systems. The measurement approach yields optical depths over the range from 0.03

Both the imager and spectrometer are sensitive to reflected sunlight and thus only generate science data on the day-side of the Earth.

Table 10. PABSI Spacecraft Resource Requirements-1

Mass—including 25% margin (3kg)	11 kg
Power—including 25% margin (3W)	
average	15 W
peak	15 W
Volume	43 x 42 x 16 cm
Pointing/knowledge	S/C sufficient
Data rate:	
imager	30 kb/s
spectrometer	95 kb/s

Table 11. PABSI Spacecraft Resource Requirements-2

Requirement	Imager	Spectrometer
Spectral region (nm)	747.5±5 761.5±1	761.6- 772.2
Spectral resolution	N/A	26,000
IFOV/pixel (km)		
crosstrack	0.5	1.0
alongtrack	0.25	0.042
FOV (km)		
crosstrack	15	1.0
alongtrack	0.25	0.9
Integration period (ms)	66	132
SNR		
r = 0.06 (ocean)	~2260	~330
r = 0.65 (cloud)	~7800	~1100
Absolute radiometry (%)		
goal	2	1
requirement	4	4
Relative radiometry (%)	2	1

5 EOS-Chem (Aura)

The Earth's climate is regulated in part by chemicals and particles in the atmosphere. The complex interactions of these constituents from both natural sources, such as biological activity and volcanoes, and man-made sources, such as biomass burning, are contributing to global change and effect the creation and depletion of ozone. The objective of the EOS Aura Mission[4] is to study the chemistry and dynamics of the Earth's atmosphere from the ground through the mesosphere. The mission will provide global surveys of several atmospheric constituents which can be classified into anthropogenic sources (CFC types), radicals (e.g., ClO, NO, OH), reservoirs (e.g., HNO, HCl), and tracers (e.g., N2O, CO2, H2O). Temperature, geopotential heights, and aerosol fields will also be mapped. This mission will provide the first global measurements of several important tropospheric chemicals. The Aura Mission was established in December 1991 and will be launched in June 2003 on a Delta 7920 rocket from the Western Test Range. The expected performance period is a minimum of five years. The Aura Mission is composed of four complementary instruments on the EOS Common Spacecraft.

The Aura (EOS Chem) mission, planned for a December 2002 launch, consists of four instruments on a common spacecraft that will be launched into a 705 km, 98.2° inclination, polar sun-synchronous orbit. The mission is designed for a 5-year life with a goal of 6 years of operation. The spacecraft will have an ascending-node equatorial crossing time of 1:45 p.m. The objective of the Aura (EOS Chem) mission is to study the chemistry and dynamics of the Earth's atmosphere, with emphasis on the upper troposphere and lower stratosphere (5-20 km). The mission will measure ozone, aerosols, and several key atmospheric constituents that play an important role in atmospheric chemistry, air quality, and climate. This mission will help in understanding the chemical and pollutant transport phenomena that are essential ingredients in evaluating the environmental policies and international agreements on chlorofluorocarbon (CFC) phase out.

The Aura (EOS Chem) satellite is based on the EOS Common Spacecraft, the same platform hosting the PM mission. The spacecraft total weight is 2967 kg, of which 1200 kg is the instrument weight. The spacecraft is modular in design and is easily adaptable to the mission-specific needs.

EOS Aura's Instruments, HIRDLS, MLS, OMI, and TES, contain advanced technologies that have been developed for use on environmental satellites. Each instrument provides unique and complementary capabilities that will enable daily global observations of Earth's atmospheric ozone layer, air quality, and key climate parameters.

5.1 HIRDLS — High Resolution Dynamics Limb Sounder

The HIRDLS [4.1] instrument has a long heritage extending back to Nimbus-4, and will obtain profiles over the entire globe, including the poles, both day and night. Complete Earth coverage (including polar night) can be obtained in 12 hours.

HIRDLS is an infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine: temperature; the concentrations of O3, H2O, CH4, N2O, NO2, HNO3, N2O5, CFC11, CFC12, ClONO2, and aerosols; and the locations of polar stratospheric clouds and cloud tops. The goals are to provide sounding observations with horizontal and vertical resolution superior to that previously obtained; to observe the lower stratosphere with improved sensitivity and accuracy; and to improve understanding of atmospheric processes through data analysis, diagnostics, and use of two- and three-dimensional models.

High horizontal resolution is obtained with a commandable azimuth scan which, in conjunction with a rapid elevation scan, provides profiles up to 3,000 km apart in an across-track swath. Vertical profiles are spaced every 5° in latitude and longitude. Observations of the lower stratosphere and upper troposphere are improved through the use of special narrow and more-transparent spectral channels. The instrument is programmable; thus, a variety of observation modes can be used, and may be adapted in flight to observe unpredicted geophysical events.

Table 12. HIRDLS parameters

Item	Parameter
Spectral Range:	6 to 18 mm
Standard profile spacing:	5° longitude x 5° latitude, and 1-km vertical resolution; programmable to other modes and resolutions
Swath:	Typically six profiles across 2,000-to-3,000-km-wide swath .
Spatial resolution:	Profile spacing 500 x 500 km horizontally (equivalent to 5° long x 5° lat) x 1 km vertically; averaging volume for each data sample 1 km vertical x 10 km across x 300 km along line-of-sight
Mass:	220 kg
Duty cycle:	100%
Power:	220 W (average), 239 W (peak)
Data rate:	65 kbps
Thermal control:	Stirling cycle cooler, heaters, sun baffle, radiator panel
Thermal operating range:	20-30° C
Scan range:	Elevation, 22.1° to 27.3° below horizontal, Azimuth, -21° (sun side) to +43° (anti-sun side)
Detector IFOV:	1 km vertical x 10 km horizontal

5.2 MLS — Microwave Limb Sounder

EOS MLS[4.2] objectives address three priority science areas of the U.S. Global Change Research Program:

1. Changes in ozone, UV radiation, and atmospheric chemistry;
2. decade-to-century climate change; and
3. seasonal-to-interannual climate variability.

EOS MLS continues the successful effort started on UARS MLS, and uses advanced technology to provide important new measurements. Particularly noteworthy in this regard are its capabilities for OH, HO2, and BrO; measurements of these species have never before been possible on a global scale, but are essential for a comprehensive understanding of stratospheric chemistry. The instrument observes in spectral bands centered near the following frequencies:

118 GHz, primarily for temperature and pressure;

190 GHz, primarily for H2O, HNO3, and continuity with UARS MLS measurements;

240 GHz, primarily for O3 and CO;

640 GHz, primarily for N2O, HCl, ClO, HOCl, BrO, HO2, and SO2; and

2.5 THz, primarily for OH.

Table 13. MLS Parameters

Name	Parameter
Spectral bands	At millimeter and submillimeter wavelengths.
Spatial resolution	Measurements are performed along the sub-orbital track, and resolution varies for different parameters; 5 km cross-track x 500 km along-track x 3 km vertical are typical values.
Mass	490 kg
Duty cycle	100%
Power	550 W full-on
Data rate	100 kbps
Thermal control	Via radiators and louvers to space as well as heaters
Thermal operating range	10-35° C
FOV	Boresight 60-70° relative to nadir
1.5 km vertical x 3 km cross-track x 300 km along-track at the limb tangent point (instantaneous field-of-view at 640 GHz)	

Some features of the MLS technique include

- Measurements that can be made reliably even in the presence of cirrus, polar stratospheric clouds, or volcanic aerosols
- Measurements made continuously at all times of day and night
- The ability to measure many atmospheric gases, temperature and pressure
- The ability to spectrally-resolve emission lines at all altitudes which allows measurements of very weak lines in the presence of nearby strong ones
- Composition measurements which are relatively insensitive to uncertainties in atmospheric temperature
- A very accurate spectroscopic data base
- Instrumentation with excellent calibration and stability that can be modularly designed for ease in accommodating changing measurement priorities, can provide good vertical resolution which is set by the size of the antenna, and with new array technology can provide good horizontal resolution including complete coverage between orbits.

5.3 OMI — Ozone Monitoring Instrument

OMI[4.3] is a contribution of the Netherlands's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI) to the EOS Aura mission. It will continue the TOMS record for total ozone and other atmospheric parameters related to ozone chemistry and climate. OMI measurements will be highly synergistic with the other instruments on the EOS Aura platform. The OMI instrument employs hyperspectral imaging in a push-broom mode to observe solar backscatter radiation in the visible and ultraviolet. The Earth will be viewed in 740 wavelength bands along the satellite track with a swath large enough to provide global coverage in 14 orbits (1 day). The nominal 13 x 24km spatial resolution can be zoomed to 13x13 km for detecting and tracking urban-scale pollution sources. The hyperspectral capabilities will improve the accuracy and precision of the total ozone amounts. The hyperspectral capabilities will also allow for accurate radiometric and wavelength self calibration over the long term.

Features:

- Continue global total ozone trends from satellite measurements beginning in 1970 with BUV on Nimbus-4.
- Map ozone profiles at 36 x 48 km, a spatial resolution never achieved before.
- Measure key air quality components such as NO2, SO2, BrO, OCLO, and aerosol characteristics.
- Distinguish between aerosol types, such as smoke, dust, and sulfates.
- Measure cloud pressure & coverage, providing data to derive tropospheric ozone.
- Map global distribution and trends in UV-B radiation.
- A combination of algorithms including TOMS version 7, Differential Optical Absorption Spectroscopy (DOAS), Hyperspectral BUV Retrievals and forward modeling will be used together to extract the various OMI data products.
- Near Real Time (NRT) production of ozone and other trace gases
- Works only in daylight.

OMI Parameters

The instrument observes Earth's backscattered radiation with a wide-field telescope feeding two imaging grating spectrometers. Each spectrometer employs a CCD detector. Onboard calibration includes a white light source, LEDs, and a multi-surface solar-calibration diffuser. A de-polarizer removes the polarization from the backscattered radiation.

Table 14. Wavelength Range of OMI

Visible	350 – 500 nm
UV	UV-1, 270 to 314 nm, UV-2 306 to 380 nm
Spectral resolution	1.0 - 0.45 nm FWHM
Spectral sampling	2-3 for FWHM
Telescope FOV	114° (2600 km on ground)
IFOV	3 km, binned to 13 x 24 km
Detector	CCD: 780 x 576 (spectral x spatial) pixels
Mass	65 kg
Duty cycle	60 minutes on daylight side
Power	66 watts
Data rate	0.8 Mbps (average)

5.4 TES — Tropospheric Emission Spectrometer

TES[4.4] is a high-resolution infrared-imaging Fourier transform spectrometer with spectral coverage of 3.2 to 15.4 µm at a spectral resolution of 0.025 cm -1, thus offering line-width-limited discrimination of essentially all radiatively active molecular species in the Earth's lower atmosphere. TES has the capability to make both limb and nadir observations. In the limb mode, TES has a height resolution of 2.3 km, with coverage from 0 to 34 km. In the downlooking modes, TES has a spatial resolution of 0.53 x 5.3 km with a swath of 5.3 x 8.5 km. TES is a pointable instrument and can access any target within 45° of the local vertical, or produce regional transects up to 885-km length without any gaps in coverage.

TES employs both the natural thermal emissions of the surface and atmosphere and reflected sunlight, thereby providing day-night coverage anywhere on the globe. Observations from TES will further understanding of long-term variations in the quantity, distribution, and mixing of minor gases in the troposphere, including sources, sinks, troposphere-stratosphere exchange, and the resulting effects on climate and the biosphere. TES will provide global maps of tropospheric ozone and its photochemical precursors. These observations will serve as primary inputs to a database of the three-dimensional distribution (on global, regional, and local scales) of gases important to tropospheric chemistry, troposphere-biosphere interactions, and troposphere-stratosphere exchange.

Other objectives include:

- Simultaneous measurements of NO_2 , CO, O_3 , and H_2O for use in the determination of the global distribution of OH, an oxidant of central importance in tropospheric chemistry;
- Measurements of SO_2 and NO_2 as precursors to the strong acids H_2SO_4 and HNO_3, which are the main contributors to acid deposition;
- Measurements of gradients of many tropospheric species in order to understand troposphere-stratosphere exchange;
- Determination of long-term trends in radiatively active minor constituents in the lower atmosphere to investigate effects on global radiative balance and atmospheric dynamics.

Table 15. TES Parameters

Maximum sampling time of 16 sec, with a signal-to-noise ratio of up to 600:1	
Nadir and limb viewing (fully targetable)	
Limb mode	Altitude coverage = 0-34 km
Spectral region	3.2 to 15.4 µm, with four single-line arrays optimized for different spectral regions
Swath	5.3 x 8.5 km
Spatial resolution	0.53 x 5.3 km
Mass	385 kg (allocation)
Duty cycle	Variable
Power	334 W (allocation)
Data rate	6.2 Mbps (peak); 4.9 MMbps (average)
Thermal control by	2 Stirling cycle coolers, heater, radiators
Thermal operating range	0-30° C FOV: +45° to -72° along-track, ±45° cross-track
Instrument IFOV	12 x 7.5 mrad

6 Earth Observing 1 (EO 1)

Earth Observing-1[5] is the first satellite in NASA's New Millennium Program Earth Observing series. The EO missions will develop and validate instruments and technologies for space-based Earth observations with unique spatial, spectral and temporal characteristics not previously available. EO-1's primary focus is to develop and test a set of advanced technology land imaging instruments. However, many other key instruments and technologies are part of the mission and will have wide ranging applications to future land imaging missions in particular and future satellites in general. EO-1 will be inserted into an orbit flying in formation with the Landsat 7 satellite taking a series of the same images. Comparison of these "paired scene" images will be one means to evaluate EO-1's land imaging instruments. EO-1's smaller, cheaper and more capable spacecraft, instruments and technologies will set the pace for future Earth Science missions in the New Millennium.

Three revolutionary land imaging instruments on EO-1 will collect multispectral and hyperspectral scenes over the course of its mission in coordination with the Enhanced Thematic Mapper (ETM+) on Landsat 7. Breakthrough technologies in lightweight materials, high performance integrated detector arrays and precision spectrometers will be demonstrated in these instruments. Detailed comparisons of the EO-1 and ETM+ images will be carried out to validate these instruments for follow-on missions.

Mission

The EO-1 mission has four overall objectives that are consistent with the major ESE NMP goal of reducing costs and expanding the capability of future land observation missions:

- Evaluate selected technologies in the context of meeting science needs in the twenty-first century for continuing Landsat-class observations at reduced cost and with enhanced capability
- NASA will evaluate space-based imaging spectrometers for potential future ESE scientific, applied, and commercial uses
- NASA will use EO-1 to evaluate new ways of conducting missions in the twenty-first century, which includes formation flying with other satellites, approaches to inter-satellite and lunar calibration, and autonomous navigation/instrument operation.
- Use the EO-1 mission to provide a technology infusion path for future NASA and other government agency satellite missions.

The EO-1 Validation Program will focus on the first three EO-1 mission objectives, in order of priority as listed above.

Mission Operations[5]

EO-1 will fly in a 705 km circular, sun-synchronous, 16 day ground track orbit at a 98.7 degree inclination. This orbit allows EO-1 to match within one minute the Landsat 7 ground track and collect identical images for later comparison on the ground. Once or twice a day, sometimes more, both Landsat 7 and EO-1 will image the same ground areas (scenes). All three of the EO-1 land imaging instruments will view all or sub-segments of the Landsat 7 swath. For each data acquisition, to be called a data collection event (DCE), over 20 Gbits of scene data from the ALI, Hyperion, and LAC will be collected simultaneously and stored in the on-board solid state data recorder at high rates. When the EO-1 spacecraft is in range of a ground station, the spacecraft will automatically transmit its recorded data to the ground station for temporary storage and shipment to the Goddard Space Flight Center (GSFC). The planned mission lifetime is 1 year.

The particular scenes that EO-1 will acquire for ALI, Hyperion, and LAC will be selected based on the needs of successful proposers, the NASA EO-1 Program and Project Offices, USGS, and other partners in satellite hyperspectral data validation. It is anticipated that the integrated mission acquisition requirements will allow for an acquisition strategy that includes: 1) sufficient scenes to ensure the availability of at least 200 scenes for MS/Pan comparisons against Landsat 7 ETM+ and 200 scenes for Hyperion validation for an appropriate variety of ground target, atmospheric, and instrument conditions; 2) scenes over well characterized test sites (e.g. EOS or other hyperspectral sensor calibration and validation sites); 3) acquisition of some long (i.e. >400 km) transects of data; and 4) acquisition of scenes in areas of active regional field studies.

Three instruments will be flown on the EO-1 spacecraft. Each instrument incorporates revolutionary land imaging technologies that will enable future Landsat and Earth observing missions to more accurately classify and map land utilization globally.

6.1 Advanced Land Imager (ALI)

The Earth Observing-1 (EO-1) Advanced Land Imager (ALI)[5.1] is the first Earth-Observing instrument to be flown under NASA's New Millennium Program (NMP). The ALI employs novel wide-angle optics and a highly integrated multi spectral and panchromatic spectrometer.

The Advanced Land Imager (ALI) instrument is intended to provide a development path for future Landsat-type instrument technology. The EO-1 implementation of ALI consists of a 15_ Wide Field Telescope (WFT) and partially populated focal plane occupying one fifth of the field-of-view (37 km ground swath). It has nine multi spectral (MS) bands with 30 m spatial resolution and one 10 m panchromatic (Pan) band. A full-up version of this instrument is projected to have one quarter the mass, one fifth the power consumption, and one seventh the instrument volume of the Landsat 7 ETM+ instrument while providing improved performance. The ALI does not, however, include a thermal infrared band. The overall objective of the ALI validation is to assess the capability of ALI to produce calibrated, multispectral images of the land area of the Earth.

The Earth Observing-1 (EO-1) Advanced Land Imager (ALI) is a technology verification instrument under the New Millennium Program (NMP). The focal plane for this instrument is partially populated with four sensor chip assemblies (SCA) and covers 3° by 1.625°. Operating in a pushbroom fashion at an orbit of 705 km, the ALI will provide Landsat type panchromatic and multispectral bands. These bands have been designed to mimic six Landsat bands with three additional bands covering 0.433-0.453, 0.845-0.890, and 1.20-1.30 µm. The ALI also contains wide-angle optics designed to provide a continuous 15° x 1.625° field of view for a fully populated focal plane with 30-meter resolution for the multispectral pixels and 10 meter resolution for the panchromatic pixels. Data Rate of the instrument is 300 Mbps

Wideband Advanced Data Recorder Processor (WARP)[5.2]: 44 Gbit capacity, receives smples at 102.4 Mbps from RS-422 output channel. ALI ControlElectronics (ALICE) provides 960 bps of house keeping data for tracking ALI operational status and state. It will be in an orbit that covers the same ground track as LandSAT 7 approx., one minute later.

The panchromatic detectors subtend 10 m square pixels on the ground and are sampled every 10 m as the Earth image moves across the array.

6.2 The Atmospheric Corrector (AC)

An ability to accurately correct images for atmospheric conditions is required to exploit fully the better-calibrated, higher signal-to-noise, and greater spatial resolution surface measurements of future space-borne instruments. A wedge spectral imaging system is included in the EO-1 manifest to provide atmospheric water vapor and thin cirrus extinction correction to the imaging data collected by both the ALI and the co-orbiting Landsat 7 ETM+ instrument. This Linear Etalon Imaging Spectral Array (LEISA) Atmospheric Corrector (LAC)[5] is a high-spectral resolution system with variable resolution (e.g., 35 cm-1 or 3.5 nm at 1000 nm wavelength) and a spectral range of 890-1600 nm. LAC has 250-m spatial resolution and a full 185-km Landsat swath width.

The Atmospheric Corrector[5.3] provides the following capabilities via a compact and simple bolt on design for future Earth Science, land-imaging missions:

- High spectral, moderate spatial resolution hyperspectral imager using a wedge filter technology.
- Spectral coverage of .85-1.5 um, bands are selected for optimal correction of high spatial resolution images.
- Correction of surface imagery for atmospheric variability (primarily water vapor).

Characteristics[5.4]

Mass: 8 Kg

Power: 40W (on); 0 (off) (10min warm-up period before data is valid)

Sun Avoidance: can be exposed to the sun for only a few minutes.

Glint Avoidance: TBD

Communication & Data Handling:

A data rate of ~95 Mbps will allow for sampling in the in-track direction (16bits/pixel). A data rate of ~190 Mbps will allow for double sampling in the in-track direction and enhance the atmospheric correction capability.

Communication:

Increased data transmission requirements set by volume of data acquired at rates given above.

6.3 Hyperion Instrument

The Hyperion hyperspectral imager[5] is a pathfinder to benchmark the potential of space-based imaging spectrometers for Earth observation applications, both for direct hyperspectral data analysis and as a flexible means for creating Landsat-equivalent multispectral data sets. The instrument is a 220-channel imager with 10 nm wide contiguous bands and a swath width of 7.5 km. Its spatial resolution of 30 m matches that of Landsat. Its spectral coverage from 400-2500 nm will allow investigators to address a broad range of Earth science research and applied uses. Relatively detailed atmospheric analysis using Hyperion will allow cross calibration with LAC. Synthesis of Landsat bands using data from an imaging spectrometer may provide increased flexibility for future missions, enabling both hyperspectral science and applications as well as Landsat-class data continuity. Hyperion will allow us to explore software approaches to Landsat band synthesis.

The Hyperion provides a high resolution hyperspectral imager capable of resolving 220 spectral bands (from 0.4 to 2.5 μm) with a 30 meter resolution. The instrument can image a 7.5 km by 100 km land area per image and provide detailed spectral mapping across all 220 channels with high radiometric accuracy. The instrument originally conceived a drop in to the ALI instrument and is now baselined to be a standalone instrument on EO-1.

The major components of the instrument include the following:

- System fore-optics design based on the KOMPSAT EOC mission. The telescope provides for two separate grating image spectrometers to improve signal-to-noise ratio (SNR).
- A focal plane array which provides separate short wave (SWIR) and visible spectral (VNIR) detectors based on spare hardware from the LEWIS HSI program.
- A cryocooler identical to that fabricated for the LEWIS HIS mission for cooling of the SWIR focal plane.

7 EOS PM (Aqua)

EOS PM Mission[6]

The Focus for the Aqua Project is the multi-disciplinary study of the Earth's Interrelated Processes (atmosphere, oceans, and land surface) and their relationship to earth system changes. The global change research emphasized with the Aqua instrument data sets include: atmospheric temperature and humidity profiles, clouds, precipitation and radiative balance; terrestrial snow and sea ice; sea surface temperature and ocean productivity; soil moisture; and the improvement of numerical weather prediction.

Aqua is one of a series of space-based platforms that are central to NASA's Earth Science Enterprise (ESE), a long-term study of the scope, dynamics and implications of global change. The Aqua program is composed of Aqua and other spacecraft (including Terra and EOS Chemistry) and a data distribution system (ESDIS, and Mission Operations Center Implementation Team). Multidisciplinary teams of scientists and researchers from North and South America, Asia, Australia and Europe will put the data to work.

Launching date: December/2000
Launching vehicle: Delta
Lifetime: Six years

Orbital Parameters

Sun - synchronous, polar
Altitude - 705 km nominal
Inclination - 98.2 +/- 0.1 degrees
Ascending node - 1:30 p.m. +/- 15 minutes
Period - 98.8 minutes

7.1 AMSR/E- Advanced Microwave Scanning Radiometer-EOS:

The EOS AQUA AMSR[6.1] will measure geophysical parameters supporting several global change sciences and monitoring efforts. Of particular importance to its success is an external calibration design, which has proved suitable in other satellite microwave instrumentation for long-term monitoring of subtle changes in temperature and other variables.

The PM-1 AMSR is a twelve channel, six frequency total power passive microwave radiometer system. It measures brightness temperatures at 6.925, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz. Vertically and horizontally polarized measurements are taken at all channels.

The AMSR rotates continuously about an axis parallel to the local spacecraft vertical at 40 rpm. At an altitude of 705 km, it measures the upwelling scene brightness temperatures over an angular sector of ± 61 degrees about the sub-satellite track, resulting in a swath width of 1445 km. During a period of 1.5 seconds the spacecraft sub-satellite point travels 10 km. Even though the instantaneous field-of-view for each channel is different, active scene measurements are recorded at equal intervals of 10 km (5 km for the 89 GHz channels) along the scan. The half cone angle at which the reflector is fixed is 47.4 degrees which results in an Earth incidence angle of 55.0 degrees.

AMSR is an instrument for measuring the following:

- **Sea Ice**

  Monitoring of sea ice parameters, such as ice type and extent, is necessary to understand how this frozen blanket over the ocean acts to change climate through its ability to insulate the water against heat loss to the frigid atmosphere above it, and through its ability to reflect sunlight that would otherwise warm the ocean.

- **Precipitation**

  Precipitation has extremely important roles, through provision of water to the biosphere and as an air conditioning agent that removes excess heat from the surface (through evaporation) and making Earth habitable**.** The AMSR will measure rain rates over both land and ocean. Over the ocean, the AMSR microwave frequencies can probe through smaller cloud particles to measure the microwave emission from the larger raindrops. The AMSR will provide sensitivity to oceanic rain rates as high as 50 mm/hr (about 2 inches per hour). Over land, the AMSR can measure the scattering effects of large ice particles that later melt to form raindrops. These measurements, though less direct a measure of rainfall intensity, are converted to a rain rate with the help of cloud models.

- **Sea Surface Temperature**

  Over the ocean, AMSR will provide sea surface temperatures (SST) through most types of cloud cover, supplementing infrared-based measurements of SST that are restricted to cloud-free areas. SST fluctuations are known to have a profound impact on weather patterns across the globe, and the AMSR's all-weather capability could provide a significant improvement in our ability to monitor SST's and the processes controlling them.

- **Total Integrated Water Vapor**

  The total integrated water vapor of the atmosphere will be measured over the ocean, which is important for the understanding of how water is cycled through the atmosphere. Since water vapor is the Earth's primary greenhouse gas, and it contributes the most to future projections of global warming, it is critical to understand how it varies naturally in the Earth system.

- **Wind Speed**

  Ocean surface roughness is also measured by AMSR, which will be converted into a near-surface wind speed. These winds are one important component of how much water is evaporated from the surface of the ocean. The winds help to maintain the water vapor content of the atmosphere while precipitation continually removes it.

- **Cloud Liquid Water**

  AMSR cloud water estimates over the ocean will help studies of whether clouds, and their ability to reflect sunlight, increase or decrease under various conditions. This could be an important feedback mechanism that either enhances or mitigates global warming, depending on whether clouds increase or decrease with warming.

- **Snow Cover**

  In much the same way as the AMSR can see large ice particles in the upper reaches of rain systems, it also measures the scattering effects of snow cover. These measurements are empirically related to snow cover depth and water content based upon field measurements. Like sea ice, snow cover has a large influence on how much sunlight is reflected from the Earth. It also acts as a blanket, keeping heat from escaping from the underlying soil, and allowing deep cold air masses to develop during the winter. It further provides an important storage mechanism for water during the winter months, which then affects how much surface wetness is available for vegetation and crops in the spring. AMSR monitoring of snow cover will allow studies and monitoring of how snow cover variations interplay with other climate fluctuations.

- **Soil Moisture**

  Wet soil can be identified in the AMSR observations if not too much vegetation is present. The AMSR will provide the most useful satellite data yet for determination of how well low frequency (6.9 GHz) microwave observations can be used to monitor surface wetness. Surface Wetness is important for maintaining crop and vegetation health, and its monitoring on a global basis would allow drought-prone areas to be monitored for signs of drought.

Table 16. AMSR Performances-1

Center frequencies (GHz)	6.925	10.65	18.7	23.8	36.5	89.0	50.3 / 52.8
Bandwidth (MHz)	350	100	200	400	1000	3000	200 / 400
Polarization	V/H	V/H	V/H	V/H	V/H	V/H	V
Sensitivity (K, target)	0.3	0.6	0.6	0.6	0.6	1.1	1.8 / 1.3
IFOV (km*km)	71*41	46*26	25*15	23*14	14*8	6*4	12*6
Sampling Rate (km*km)	10*10	10*10	10*10	10*10	10*10	5*5	10*10
Integration time (msec)	2.6	2.6	2.6	2.6	2.6	1.3	2.6

Table 17. AMSR Performances-2

Accuracy (K)	< 1
Dynamic Range (K)	3 to 340
Incidence angle (deg.)	55
Swath Width (km)	approx. 1,600
Receiver	Total power

AMSR features[5]:

The 2m-diameter antenna can measure SST and soil moisture at 6 and 10 GHz. With its higher spatial resolution, retrieval accuracy will be improved for geophysical parameters such as total water vapor content, total liquid water content, and precipitation. AMSR data will be transmitted to the EOC via a data relay satellite every orbit, so they can be used by meteorological agencies as initial conditions for weather forecast models. GLI and SeaWinds data are available, and a combined use of AMSR, GLI and SeaWinds data will improve retrieval accuracy.

Specifications[6.2]

- Accuracy: 1 K or better
- Swath: 1445 km
- Spatial resolution: 6 x 4 km (89.0 GHz), 14 x 8 km (36.5 GHz), 32 x 18 km (23.8 GHz), 27 x 16 km (18.7 GHz), 51 x 29 km (10.65 GHz), 75 x 43 km (6.925 GHz)
- Incidence angle: 55 degrees
- Sampling interval: 10 km for 6-36 GHz channels, 5 km for the 89 GHz channel
- Mass: 324±15 kg
- Duty cycle: 100 %
- Power: 350±35 W
- Data rate: 87.4 kbps avg, 125 kbps peak
- Thermal control by: Passive radiator, thermostatically controlled heaters
- Thermal operating range: -5 to 40°C
- FOV: Forward-looking conical scan
- Pointing requirements, design value (instrument only, 3 sigma):
- Accuracy: 600 arcsec/axis for roll and pitch;
- NA for yaw
- Stability: 80 arcsec/sec/axis for roll and pitch;
- NA for yaw
- Knowledge: 300 arcsec/axis for roll and pitch;
- NA for yaw
- Physical size:
- Sensor Unit: 1.95 x 1.5 x 2.2 m (stowed);
- 1.95 x 1.7 x 2.4 m (deployed)
- Control Unit: 0.8 x 1.0 x 0.6 m

7.2 MODIS-Moderate Resolution Imaging Spectroradiometer

MODIS[6.3] is an EOS facility instrument designed to measure biological and physical processes on a global basis every 1-to-2 days. Slated for both the Terra and EOS PM satellites, the instrument will provide long-term observations from which an enhanced knowledge of global dynamics and processes occurring on the surface of the Earth and in the lower atmosphere can be derived. This multidisciplinary instrument will yield simultaneous, congruent observations of high-priority atmospheric (aerosol and cloud properties, water vapor and temperature profiles), oceanic (sea-surface temperature and chlorophyll), and land-surface features (land-cover changes, land-surface temperature, snow cover, and vegetation properties). The instrument is expected to make major contributions to understanding the global Earth system, including interactions among land, ocean, and atmospheric processes.

The MODIS instrument employs a conventional imaging spectroradiometer concept, consisting of a cross-track scan mirror and collecting optics, and a set of linear arrays with spectral interference filters located in four focal planes. The optical arrangement will provide imagery in 36 discrete bands between 0.4 and 14.5 μm selected for diagnostic significance in Earth science. The spectral bands will have spatial resolutions of 250, 500, or 1,000 m at nadir. Signal-to-noise ratios are greater than 500 at 1-km resolution (at a solar zenith angle of 70°), and absolute irradiance accuracies are $< \pm 5\%$ from 0.4 to 3 μm (2% relative to the sun) and 1 percent or better in the thermal infrared (3.7 to 14.5 μm). MODIS instruments will provide daylight reflection and day/night emission spectral imaging of any point on the Earth at least every 2 days, operating continuously.

MODIS will provide specific global data products, which include the following:

- Surface temperature with 1-km resolution, day and night, with absolute accuracy of 0.3 K-0.5 K for oceans and 1 K for land;
- water-leaving radiance to within 0.2 percent from 415 to 653 nm;
- chlorophyll fluorescence within 50 percent at surface concentrations of 0.5 mg m -3 ;
- concentration of chlorophyll-a within 35 percent, net ocean primary productivity, other optical properties;
- vegetation/land-surface cover, conditions, and productivity:
    - Net primary productivity, leaf area index, and intercepted photosynthetically active radiation
    - land cover type, with change detection and identification;
    - vegetation indices corrected for atmosphere, soil, and directional effects; and
    - snow cover and reflectance;
- cloud mask containing confidence of clear sky (or, alternatively, the probability of cloud), shadow, fire, and heavy aerosol at 1-km resolution;
- cloud properties characterized by cloud phase, optical thickness, droplet size, cloud-top pressure, and temperature;
- aerosol properties defined as optical thickness, particle size, and mass loading;
- fire occurrence, temperature, and burn scars;
- global distribution of total precipitable water; and
- cirrus cloud cover

MODIS will fly on both the Terra and EOS PM satellites to maximize cloud-free remote sensing of the Earth's surface and to exploit synergism with other EOS sensors.

Parameters

- 36 spectral bandsÐ21 within 0.4-3.0 µm; 15 within 3-14.5 µm
- Continuous global coverage every 1 to 2 days
- Polarization sensitivity: 2% from 0.43 µm to 2.2 µm and ±45° scan
- Signal-to-noise ratios from 900 to 1300 for 1-km ocean color bands at 70° solar zenith angle
- NEDT's typically <0.05 K at 300 K
- Absolute irradiance accuracy of 5% for <3 µm and 1% for >3 µm
- Daylight reflection and day/night emission spectral imaging
- Swath: 2,300 km at 110° (±55°) from 705-km altitude
- Mass: 229 kg
- Duty cycle: 100%
- Power: 162.5 W (average), 225 W (peak)
- Data rate: 6.2 Mbps (average), 10.5 Mbps (day), 3.2 Mbps (night)
- Thermal control by: Radiators
- Thermal operating range: 268 K ± 5 K
- Instrument IFOV: 250 m (2 bands), 500 m (5 bands), 1,000 m (29 bands)
- Pointing requirements (platform + instrument, 3 sigma):

  Control: 3,600 arcsec

  Knowledge: 141 arcsec

  Stability: 28 arcsec/sec

  Jitter: 1,031 arcsec/sec (yaw and roll), 47 arcsec/sec (pitch)
- Physical size: 1.044 x 1.184 x 1.638 m

7.3 AMSU-Advanced Microwave Sounding Unit

The AMSU instrument[6.4] consists of two sensors, AMSU-A1 and -A2

Measurements: Atmospheric temperature and humidity

Properties: Senses in 15 discrete channels in the range of 50 to 89 GHz

Sponsor: NASA GSFC

Developer: Aerojet

The AMSU[6.5] has 15 channels and spatial resolution of about 50 km near nadir. There are 30 footprints per scanline and about 10800 scanlines per day. There are 14 orbits per day. Each orbit is about 3 Mbytes. The data can be ordered from Goddard DAAC. Measurements are continuous.

7.4 AIRS- Atmospheric Infrared Sounder

AIRS[6.6] obtains temperature and moisture profiles by observing the "signature" of carbon dioxide near the wavelengths of 4.2 μm and 15 μm and water vapor near 6.3 μm. Atmospheric gases such as carbon dioxide, water vapor, ozone, methane, and carbon dioxide strongly absorb around certain wavelengths of infrared energy. Absorption increases in strength and in band coverage with increasing amounts of atmospheric gas and, therefore, increasing thickness or depth into the atmosphere. By observing at very high spectral resolution (very narrow bands) at several wavelengths near the central absorption feature (4.2, 15, or 6.3 μm, for example), one "sees" to different levels in the atmosphere. The strength of the signal at a specific band is also dependent on temperature.

To determine the temperature or humidity at a specific altitude (or pressure), AIRS takes the signals from many different spectrally narrow bands, assigns pre-determined weighting functions to each band based on previous observations, and uses them to derive a vertical profile that fits the signals.

An AIR has been selected by NASA to fly on the EOS AQUA satellite, scheduled for launch in late 2000. AIRS consists of an array grating spectrometer that provides coverage in the infrared (IR) with a spectral resolution of 1200 (lambda/delta lambda) and a photometer that measures the visible (VIS) and near-infrared (NIR) range. The high spectral resolution enables the separation of the contribution of unwanted spectral emissions and, in particular provides spectrally clean "super windows," which are ideal for surface observations.

All channels will be downlinked on a routine operational basis. AIRS takes only 22.41 ms to obtain nearly 2400 IR measurements for each AIRS "footprint," 1.1° in diameter. This diameter is the equivalent of 13.5 km in diameter directly below the spacecraft at the Earth's surface. Each IR scan produces 90 footprints across the flight track and takes 8/3 (2.67) seconds. The VIS/NIR portion of AIRS has a footprint of 0.185°, or about 2.3 km on the ground; the VIS/NIR photometer is boresighted to the spectrometer to allow simultaneous visible and infrared observations. About nine AIRS footprints are contained within each about 40-km at the Earth's surface.

The VIS/NIR photometer uses optical filters to define four spectral bands in the 400 nm to1000 nm region. It operates in ambient ranges of 293 to 300K (20°C to 27°C). Signals from both the spectrometer and the photometer pass through onboard signal and data processing electronics. Data from AIRS are finally transmitted to the spacecraft at an average rate of 1.27 Mbps.

7.5 HSB- Humidity Sounder for Brazil

The HSB instrument[6.7] will be supplied by INPE to fly in the year 2000 on PM-1 spacecraft, together with the Atmospheric Infrared Sounder (AIRS) and Advanced Microwave Sounding Unit (AMSU-A), constituting so an advanced sounding system.

The microwave humidity sounder is part of a sounding system that acts in a synergic way, and will provide humidity and temperature profiles much more accurately than that of sounders currently in the market. It will also have the capacity of detecting precipitation under the clouds. The horizontal resolution will be 50km for temperature and 15km for humidity, both in the subsatellite point. The temperature error will be around 1 K to 1.5 K and 5 to 15 percent for humidity.

The HSB instrument is a passive 4-channel radiometer that receives and measures radiation from the atmosphere in order to obtain data on humidity profiles for weather forecasting.

Characteristics[6.8]

Weight: 60 kg

Power: 80W

Spatial resolution: 13.5 km at nadir

Field of View: 1.1º

Data Rate: 4.2 Kbps

Swath: 1650 km

Dimensions: 526mm X 700mm X 650 mm

Temperature

Sensitivity: 1.0 K to 1.2 K

Scan: angle: ± 48.95º

Period: 8/3 s

The complete list of AIRS/AMSU/HSB standard products follows[6.6]

Atmosphere

- Atmospheric Temperature Profiles
- Humidity Profile
- Total Precipitable Water
- Fractional Cloud Cover
- Cloud Top Height
- Cloud Top Temperature

Surface

- Skin Surface Temperature
- Day/Night Surface Temperature Difference
- Outgoing Day/Night Longwave Surface Flux
- Sea Surface Temperature

AIRS/AMSU/HSB will additionally provide the following research products that will require post-launch verification

Atmosphere

- Precipitation Estimate
- Tropopause and Stratopause Height
- Outgoing Longwave Spectral Radiation
- Cloud Optical Thickness

Surface

- Surface Spectral Emissivity
- Surface Albedo
- Net Shortwave Flux

The data retrieved from the AIRS/AMSU/HSB instrument complement will improve global modeling efforts, numerical weather prediction, study of the global energy and water cycles, detection of the effects of greenhouse gases, investigation of atmosphere-surface interactions, and monitoring of climate variations and trends. These objectives will be met through improvements in the accuracy of several weather and climate parameters, including atmospheric temperature and water vapor, land and ocean surface temperature, cloud distribution and spectral properties, and outgoing longwave radiation.

Simultaneous observations of the atmosphere and clouds from AIRS will allow characterization of the spectral properties of clouds for enhanced understanding of their role in modulating the greenhouse effect, and the increased resolution and number of infrared sounding channels (an increase of two orders of magnitude beyond current operational sounders) will improve the accuracy of weather forecasting.

7.6 CERES- Clouds and the Earth's Radiant Energy System

The Clouds and the Earth s Radiant Energy System (CERES)[6.9] experiment is one of the highest priority scientific satellite instruments developed for EOS. CERES products include both solar-reflected and Earth-emitted radiation from the top of the atmosphere to the Earth's surface. Cloud properties are determined using simultaneous measurements by other EOS instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS). Analyses of the CERES data, which build upon the foundation laid by previous missions such as the Earth Radiation Budget Experiment (ERBE), will lead to a better understanding of the role of clouds and the energy cycle in global climate change.

CERES instruments were launched aboard the Tropical Rainfall Measuring Mission (TRMM) in November 1997 and on the EOS Terra satellite in December 1999. Two additional instruments will fly on the EOS Aqua spacecraft in 2002. Multiple satellites are needed to provide adequate temporal sampling since clouds and radiative fluxes vary throughout the day. The first 24 months of CERES data collected on both TRMM and Terra demonstrate that the CERES instruments are substantially improved over the ERBE instruments. The CERES data show lower noise, improved ties to the ground calibration in absolute terms, and smaller fields of view. CERES instrument calibration stability on TRMM and Terra is typically better than 0.2%, and calibration consistency from ground to space is better than 0.25%. Onboard calibration sources provide traceability of the measurements to the International Temperature Scale of 1990 at the 0.2% level. Such levels of accuracy have never before been achieved for radiation budget instruments.

Measurements: Radiative energy flux

Properties: Two sensor, one scanning cross track, the other scanning azimuthally view in three channels per scanner: shortwave (0.3 to 5 µm), longwave (8 to 12 µm), and "total" (0.3 to > 50 µm)

Sponsor: NASA LaRC

Developer: TRW Space & Electronics Group

CERES Objectives

The scientific justification for the CERES measurements can be summarized by three assertions:

- Changes in the radiative energy balance of the Earth-atmosphere system can cause long-term climate changes (e.g., carbon dioxide inducing global warming)
- Besides the systematic diurnal and seasonal cycles of incoming solar energy, changes in cloud properties (amount, height, optical thickness) cause the largest changes of the Earth's radiative energy balance
- Cloud physics is one of the weakest components of current climate models used to predict potential global climate change.

CERES has four main objectives:

- For climate change analysis, provide a continuation of the ERBE record of radiative fluxes at the top of the atmosphere (TOA), analyzed using the same algorithms that produced the ERBE data.
- Double the accuracy of estimates of radiative fluxes at TOA and the Earth's surface.
- Provide the first long-term global estimates of the radiative fluxes within the Earth's atmosphere.
- Provide cloud property estimates that are consistent with the radiative fluxes from surface to TOA.

Table 18. Technical Specifications of CERES

Orbits	705 km altitude, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (PM-1), sun-synchronous, near-polar; 350 km altitude, 35° inclination (TRMM)
Spectral Channels	Solar Reflected Radiation (Shortwave): 0.3 - 5.0 μm Window: 8 - 12 μm, Total: 0.3 to > 100 μm
Swath Dimensions	Limb to limb
Angular Sampling	Cross-track scan and 360° azimuth biaxial scan
Spatial Resolution	20 km at nadir (10 km for TRMM)
Mass	45 kg
Duty Cycle	100%
Power	45 W
Data Rate	10 kbps
Size	60 x 60 x 70 cm (deployed)
Design Life	6 years

8 Ice, Cloud, and land Elevation Satellite (ICESat)

The ICESat Mission[7] begins with a launch on a Delta II (Model 7320) Expendable Launch Vehicle (ELV) in July 2001, into a near polar Low Earth Orbit (LEO) at an altitude of 600 km with an inclination of 94 degrees. The spacecraft accommodates the GLAS instrument which is currently estimated at a mass not to exceed 300kg and power of 330 W (each including 20% contingency), to fully achieve the EOS requirements. The predicted total mission launch mass is 970kg, including fuel and an allocated mass contingency based on design maturity. This launch mass is well within the capability of the Delta II with its calculated maximum allowable payload launch mass to our mission orbit equal to 1080kg.

Instrument

The Geoscience Laser Altimeter System (GLAS) is the sole instrument on the ICESat flight. GLAS, an integral part of the EOS program, is a satellite laser altimeter designed to measure ice-sheet topography and associated temporal changes, as well as cloud and atmospheric properties. Operation of GLAS over land and water will provide along-track topography. The Geoscience Laser Altimeter System (GLAS) includes a laser system to measure distance, a receiver of signals from the Global Positioning System (GPS) of satellites, and a star-tracker attitude-determination system. The laser will transmit short pulses (4 nano-seconds) of infrared light (1064 nanometers wavelength) and visible-green light (532 nanometers). Photons reflected back to the spacecraft from the surface of the Earth and from the atmosphere, including the inside of clouds will be collected in a 1-Meter diameter telescope. Laser pulses at 40 times per second will illuminate spots (footprints) 70 meters in diameter, spaced at 175-meter intervals along Earth's surface.

Measurement Approach

- Uses Nd:YAG laser with 1064 and 532 nm output
- Height measurements are determined from the round-trip pulse time of the infrared pulse flight
- Cloud and aerosol data are extracted from the green pulse
- Swath: Nadir viewing
- At 40 pulses per second, the centers of 70 m spots are separated in the along track direction by 170 m for a 600 km altitude orbit; cross track resolution is determined by the 183 day ground track repeat cycle which yields 15 km track spacing at the equator and 2.5 km at 80 degrees latitude

Accommodation Issues

Mass: 300 kg

Duty cycle: 100%

Power: 330 W average

Data rate: ~450bps

Thermal control by: radiators supplemented by heaters, heat pipes

Thermal operating range: 20 deg +/- 5 deg C

Telescope field of view: nadir only, 375 microradians

Instrument field of view: ~70 m laser footprint at nadir at 1064 nm

Pointing requirements (platform+instrument):

Control (3 sigma): 30 arcsec roll, 60 arcsec pitch, 1 degr yaw

Post-processed pointing knowledge (1-sigma): 1.5 arcsec (roll and pitch axes, to be provided by instrument-mounted star trackers laser reference sensor gyroscope)

Post-processed position requirements: radial orbit for ice sheet to < 5 cm and along-track/cross-track position to < 20 cm (to be provided by spacecraft-mounted GPS receiver and SLR array)

Physical size: telescope is 100 cm in diameter, height is ~175 cm

The laser altimeter measures the time required for a laser pulse of 5 nanosecond duration to complete the round trip from the instrument to the Earth's surface and back to the instrument. This time interval can be converted into a distance by multiplying with the speed of light, and the one-way distance can be obtained as half the round trip distance. With the position of the instrument in space determined from a high accuracy Global Positioning System (GPS) receiver and from star camera and gyroscopes carried on the instrument/ spacecraft, the laser direction in space will be determined. From the GPS-determined position, the altimeter measurement and the laser pointing direction, the location on the surface of Earth illuminated by the laser pulse can be determined. The series of such laser spot, or footprint, locations provides a profile of the surface. Analysis of the sequence of laser spots over time enables the determination of temporal change in topography.

A diode pumped Q-switched Nd:YAG laser operating in the near infrared (1064 nanometers) is used for the measurement of surface topography. Back-scattered light in the green (532 nanometers) is used for measurement of aerosols and other atmospheric characteristics. The return photons will be collected in a 1 meter diameter telescope and the laser will transmit 40 pulses per second to the surface. The spots produced on the Earth's surface will have a 70 meter diameter and the spacing between spots will be 175 meters, caused by the orbital motion of the spacecraft.

Key Facts

- NASA Earth Observing System Facility Instrument : Geoscience Laser Altimeter System (GLAS)
- Nadir-pointed laser altimeter; spacecraft enables off-nadir pointing capability
- Measures polar ice-sheet topography and temporal changes in topography; cloud heights, planetary boundary heights, and aerosol vertical structure; and land and water topography
- NASA/Goddard Space Flight Center in-house development of GLAS
- Laser is diode pumped, Q-switched Nd:YAG laser with 40 Hz pulse repetition; 75 mJ at 1064 nm and 35 mJ at 532 nm
- Receiver telescope is 1 meter diameter
- Heritage: airborne and spaceborne laser altimetry and lidar systems; satellite laser ranging systems
- GLAS completed Preliminary Design Review; Critical Design Review completed in March 1999
- GLAS will be carried on ICESat (Ice, Cloud and land Elevation Satellite)
- ICESat spacecraft delivery order signed February 1998, with Ball Aerospace, Boulder, CO; ICESat completed Mission Design Review in December, 1998
- Orbit altitude is 600 km, near circular (frozen), 94 degree inclination
- Verification orbit uses 8 day repeat pattern during first 120 days after launch
- Mission orbit (post-verification) uses 183 day repeat pattern
- Global Positioning System receiver provides 5 cm (radial) orbit position; ground-based laser ranging provides validation and backup
- On-board star cameras and gyros provide spacecraft orientation and laser pointing direction
- Launch in July 2001
- 3 year lifetime with 5 year goal

Orbit Characteristics

The near circular, near polar orbit has an altitude of approximately 600 km.

Two primary orbits will be used:

- Verification/validation orbit: this orbit has a ground track repeat cycle of 8 days to enable overflights of specific locations on the Earth which will be instrumented to support measurement verification or data product validation
- Mission orbit: this orbit has a ground track repeat cycle of 183 days to enable uniform sampling of the surface with high resolution. At the equator, the separation between ascending tracks will be about 15 km after 183 days

The orbit planned for use is known as a "frozen orbit", meaning that in spite of the Earth's oblateness, the perigee will remain fixed (in an average sense) at the northernmost latitude (essentially at the North pole). Accounting for the fact that the Earth is an oblate spheroid, the following range of altitudes (with respect to mean sea level) will exist for both orbits:

- Near the North pole 605km
- Near the South pole 623km
- Near the equator 593 km

Since the orbit is frozen, perigee does not circulate and the altitude will be a function of latitude. The orbit inclination was chosen to be 94 degrees. This inclination provides coverage to 86 deg latitude, thereby ensuring coverage of the fast-flowing Antarctic ice streams that flow onto the Ross Ice Shelf. The retrograde inclination was chosen for the geometry of crossovers, the intersections between the ascending and descending ground tracks. Crossover points are a key analysis technique to meet the science requirements.

Specific orbit characteristics

Verification orbit (mean values)

8 day repeat in 119 orbital revolutions

Semimajor axis: 6971 km

Eccentricity: 0.0013

Inclination: 94 degr

Argument of perigee: 90 degr

Mission orbit (mean values)

183 day repeat in 2723 orbital revolutions

Semimajor axis: 6970 km

Eccentricity: 0.0013

Inclination: 94 degr

Argument of perigee: 90 degr

The node location will be selected to meet other requirements, such as the overflight of verification sites.

GLAS (the Geoscience Laser Altimeter System)[7.1] will be launched aboard the Ice, Cloud and Land Elevation Satellite (ICESat) into a near-polar orbit (inclination 94 degrees) in early 2002. GLAS is part of NASA's Earth Science Enterprise (ESE) which includes a series of satellites beginning in 1999 to measure Earth's atmosphere, oceans, land, ice, and biosphere for a period of 10 to 15 years. The main goal of ESE is to measure changes in the earth-atmosphere system, which are indicative of climate and environmental change. GLAS will be the first atmospheric backscatter lidar to make continuous measurements of the Earth's atmosphere from space. The lidar will provide unprecedented views of atmospheric cloud and aerosol structure and give us information on the height and thickness of radiatively important cloud layers which is needed for accurate short term climate and weather prediction.

Use of GLAS atmospheric measurementsl:

GLAS, the first laser-ranging (lidar) instrument for continuous global observations of Earth, will make unique atmospheric observations as an important component of the ESE climate change program. In the figure below, laser measurements of clouds obtained from an aircraft have been adjusted to simulate measurements to be made with the spaceborne GLAS, demonstrating its capability to observe the vertical distribution of clouds and aerosols. The strongest backscatter signals are white, changing to blue for low backscatter signal. High cirrus clouds, typically found between heights of 11 and 15 km, generally exhibit lower scattering. The data simulation shows that even tenuous, thin cloud layers will be detected by GLAS. Such sub-visible cirrus clouds (which are difficult or impossible to detect using passive techniques) may be very important in determining the atmospheric radiative balance. Aerosols in lower levels of the atmosphere will also be detected.

GLAS will provide lidar observations of cloud heights, bases, cloud optical properties, planetary boundary layer (PBL) heights, lifting condensation levels (LCL), troposphere and stratospheric aerosols, and polar stratospheric clouds. When combined with passive radiometric observations, important meteorlogical parameters such as the optical thickness of cirrus clouds and the moisture content of the PBL will be inferred. In addition, the lidar data will be valuable for supplementing and validating EOS passive sensors for cloud and aerosol detection.

Effect of polar clouds and haze on climate:

Polar clouds are very important for understanding weather in polar regions and have a definite influence on regional climate. The very low temperatures and long periods of darkness in the polar regions limit standard satellite techniques, which are based on passive sensing. However, for the same reasons, polar clouds are very important for understanding weather in polar regions and the relation to Earth's climate. The GLAS instrument will be uniquely sensitive to observing cloud cover and important processes of the polar atmosphere. These include polar stratospheric clouds, which effect the ozone hole, and a phenomenon known as clear-air, ice-crystal precipitation, which is thought to be a major factor in the mass balance of the Antarctic ice sheet. The atmospheric channel of GLAS will also help researchers interpret laser signals obtained from the ice sheet surface in the presence of low clouds, fog, or blowing snow.

Table 19. GLAS Parameters

	532nm	1064nm
Laser Pulse Energy	36 mJ	74 mJ
Laser PRF	40 Hz	40 Hz
Telescope Diameter	1.0 m	1.0 m
Reciever FOV	0.15 mrad	0.475 mrad
Optical Bandwidth	< 25 pm	< 1.4 nm
Detector Quantum Efficiency	0.6	0.3
Detection Scheme	Photon Counting	Analog
Surface Ranging Accuracy		10 cm
Pointing Knowledge		3 arsec

9 Jason 1

Jason[8] is an oceanography mission to monitor global ocean circulation, discover the tie between the oceans and atmosphere, improve global climate predictions, and monitor events such as El Niño conditions and ocean eddies. The Jason-1 satellite carries a radar altimeter and it is a follow-on mission to the highly successful TOPEX/Poseidon mission. It is joint mission between France and USA. The satellite will be launched in late 2000. The specification of "1" attests to the expectation that "Jason-1" is one of a series of TOPEX/Poseidon follow-on missions.

Table 20. Jason-1 Parameters[8.1]

Sponsor	NASA & CNES
Expected Life	5 years
Primary Applications	Oceanography & climate change
Primary SLR Application(s)	calibrate satellite altimeter
COSPAR ID	0105501
SIC Code	4378
NORAD SSC Code	26997
Launch Date	2001
RRA Diameter	16 cm
RRA Shape	Hemispherical
Reflectors	9 corner cubes
Orbit	Circular
Inclination	66 degrees
Eccentricity	0.000
Perigee	1336 km
Period	112 minutes
Weight	500 kg (fueled)

Sea-level measurement accuracy < 4.2 cm required, < 2.5 cm goal

Data turn-around 3-hour data product within one hour of data reception

Data coverage global between 66 deg N and 66 deg S

Data availability through (NASA/JPL) and CNES

The Jason satellite uses the standard multi-purpose PROTEUS bus. A dedicated Payload Instrument Module (PIM) has been built for this mission to accommodate the instruments. The payload module has the same structural definition as the platform. The design is such that the payload is thermally decoupled from the platform. The Jason satellite is a protoflight model. The Platform has already been successfully qualified on a structural mock-up (static, sine, acoustic vibration, shock and solar vacuum tests).

The Jason satellite has a design lifetime of three years but the components are built to withstand the expected radiation environment for five years (1336-km orbit). Consumables are also sized for a five-year mission. The maximum power consumption is about 435 W. The overall satellite mass is less than 500 kg with full loading of hydrazine (28 kg) and the satellite is about 3.4 meters high. Due to the high orbit nodal rate (2° per day), the satellite performs yaw-steering attitude control maneuvers to provide the solar array with proper solar illumination. The payload science data rate of 25 kbps is continuously stored in the onboard mass memory and is downloaded each time a terminal is within view at 613 kbits/s.

Storage capacity: 2 Gbits (EOL)[8.2]
Downlink capacity: 650 kbps.
Uplink capacity: 4 kbps.

Jason will orbit the Earth 4,700 times per year surveying ocean currents[8.3] with radar altimeters and mapping the topography of the ocean. It will also measure the temperature of the water surface and the amount of moisture in the air. By doing these things Jason-1 will provide a 5-year view of global ocean topography, increase our understanding of ocean circulation and seasonal changes, improve the forecasting of weather, measure global sea level change and improve ocean tide models.

Sensors and primary functions:

Altimeter - Measures sea level (CNES)

Radiometer - Measures water vapor (NASA)

DORIS - Satellite tracking (CNES)

TRSR - Global Positioning System receiver (NASA)

Laser retroflector array - Satellite positioning (NASA)

Satellite and orbit features

Satellite mass 500kg

Satellite altitude 1336 km

Orbit type circular

Jason-1's orbit[8.4] is identical to that of TOPEX/POSEIDON. It is optimized to study large-scale ocean variability and to provide coverage of 90% of the world's oceans over a ten-day cycle.

Choice of orbit

Jason-1's high altitude (1,336 kilometers) reduces interactions with the Earth's atmosphere and gravity field to a minimum, thus making orbit determination easier and more precise. The orbit inclination of 66 degrees north and south enables the satellite to cover most of the globe's unfrozen oceans. The orbit's repeat cycle is just under 10 days (9.9156 days to be precise, i.e., 10 days minus two hours)—in other words, the satellite passes over the same point on the Earth's surface (to within one kilometer) every ten days. This cycle is a trade-off between spatial and temporal resolution designed for the study of large-scale ocean variability. The fact that the orbit is prograde and not Sun-synchronous also avoids aliasing of different tide components at the same frequency.

Further, using the same orbit as TOPEX/POSEIDON will ensure better inter-calibration and data continuity. The orbit is also designed to pass over two dedicated ground calibration sites: Cap Senetosa in Corsica and the Harvest oil rig platform in California, USA.

Maneuvers

A satellite's orbit parameters tend to change over time as a result of atmospheric drag. In the long term, more or less periodic variations also occur due to instabilities in the Earth's gravity field, solar radiation pressure, and other forces of smaller magnitude.

Orbit maneuvers are performed every 40 to 200 days. Intervals between maneuvers depend chiefly on solar flux and each maneuver lasts 20 to 60 minutes. Where possible, they are performed at the end of the orbit cycle, and above solid earth, so that lost data acquisition time is reduced to a minimum.

Orbit parameters

Main characteristics

Semi-major axis: 7714.4278 km

Eccentricity: 0.000095

Inclination (non-heliosynchronous): 66.039°

Auxiliary data

Reference altitude (equatorial): 1,336 km

Nodal period (duration of half-revolution or pass): 6,745.72 seconds (112'42" or 1h52')

Repeat cycle: 9.9156 days

Number of passes per cycle: 254

Ground track separation at Equator: 315 km

Acute angle at Equator crossings: 39.5°

Longitude at Equator of pass 1: 99.9242°

Orbital velocity: 7.2 km/s

Ground scanning velocity: 5.8 km /s

Instrumentation[8.5]

Jason-1 will have the following instrumentation onboard:

- Jason Microwave radiometer
- DORIS dual frequency system receiver
- Dual-frequency solid-state altimeter
- GPS receiver
- Retroreflector array

9.1 Laser RetroReflector Array (RRA)

The laser retroreflector array[8.6] has mirrors that reflect laser beams aimed at the satellite from lasers on the ground. The reflected laser light is used to measure the position of the satellite so that scientists on Earth can know where Jason is above the Earth and how high it is.

Characteristics

The corner cubes are made of research grade radiation resistant suprasil quartz. Their performance is optimized at the green wavelength, 532 nanometers. The corner cubes are symmetrically mounted on a hemispherical surface with one nadir-looking corner cube in the center, surrounded by an angled ring of eight corner cubes. This will allow laser ranging in the field of view angles of 360 degrees in azimuth and 60 degrees elevation around the perpendicular to the satellite's -Zs earth panel. The design is identical to the array to be used on ADEOS-2 and GFO-1.

The LRA is an array of mirrors that provide a target for laser tracking measurements from the ground. By analyzing the round-trip time of the laser beam, we can locate very precisely where the satellite is on its orbit.

Function

The LRA is used to calibrate the other location systems on the satellite (DORIS, TRSR) with a very high degree of precision.

Principle

The LRA is a passive instrument that acts as a reference target for laser tracking measurements performed by ground stations. Laser tracking data are analyzed to calculate the satellite's altitude to within a few millimeters. However, the small number of ground stations and the sensitivity of laser beams to weather conditions make it impossible to track the satellite continuously. That is why other onboard location systems are needed.

Technical data

The retroflectors are placed on the nadir face of the satellite. The totally passive unit consists of nine quartz corner cubes arrayed as a truncated cone, with one cube in the center and the others arranged azimuthally around the cone. This arrangement will allow laser ranging at field-of-view angles of 360 degrees in azimuth and 60 degrees elevation around the perpendicular. The retroreflectors are optimized for a wavelength of 532 nanometers (green), offering a field of view of about 100 degrees. Jason-1's LRA was built by ITE Inc. under contract to NASA's Goddard Space Flight Center.

Location systems

The location systems onboard Jason-1 complement each other to measure the satellite's position on orbit to within two centimeters on the radial component. The LRA is highly accurate but it requires ground stations that are complex to operate, and its use can be restricted by adverse weather conditions. It is used to calibrate the other two location systems so that the satellite orbit can be determined as accurately as possible. The TRSR (GPS) acquires data that complement DORIS measurements to determine the orbit in real time and to support precise orbit determination.

9.2 Altimeter

The Poseidon-2 Altimeter[8.7] is a two-frequency altimeter which measures the height of the satellite above the sea surface. It does this by sending out radar pulses at two frequencies and listening for their echoes from the sea surface. It carefully measures the time for the radio signal to go down and back. When we divide the time by two and multiply by the speed of light we get the distance from the satellite to the ocean surface.

POSEIDON-2 is the mission's main instrument, derived from the experimental POSEIDON-1 altimeter on TOPEX/POSEIDON. It is a compact, low-power, low-mass instrument offering a high degree of reliability. POSEIDON-2 is a radar altimeter that emits pulses at two frequencies (13.6 and 5.3 GHz, the second frequency is used to determine electron content in the atmosphere) and analyzes the return signal reflected by the surface. The signal round-trip time is estimated very precisely to calculate the range, after applying corrections. (Instrument supplied by CNES)

From Poseidon-1 to Poseidon-2

The design of Poseidon-2 has been enhanced in several areas. In particular, a second frequency has been added in the C-band for ionosphere corrections, sampling has been improved, and digital components have replaced analog circuits wherever possible.

Design life: 5 years (operating permanently)

Mass: 2x25 kg (backup)

Antenna mass: 8 kg

Power consumption: 70 W (C-band and Ku-band)

Telemetry rate (all waveforms): 22 kbits/s

9.3 Microwave Radiometer

The Jason Microwave Radiometer[8.8] listens to the radio waves produced by the ocean surface, by clouds, and by water vapor in the atmosphere. It uses these signals to calculate the amount of water vapor in the atmosphere. Water vapor slows the signal from the altimeter. This causes the altimeter to calculate that the ocean surface is further away than it really is by about 10 cm. This is a small error but we need to remove it. The JMR acquires measurements via three separate frequency channels to determine the path delay of the altimeter's radar signal due to atmospheric water vapor.

Function

The JMR measures water vapor content in the atmosphere so that we can determine how it impacts radar signal propagation. Its measurements also can be used directly for studying other atmospheric phenomena, particularly rain.

Principle

The JMR is a passive receiver that collects radiation reflected by the oceans at frequencies of 18.7, 23.8, and 34 GHz. Radiation measured by the radiometer depends on surface winds, ocean temperature, salinity, foam, absorption by water vapor and clouds, and various other factors. To determine atmospheric water vapor content accurately, we need to eliminate sea surface and cloud contributions from the signal received by the radiometer. That is why the JMR uses different frequencies, each of which is more sensitive than the others to one of these contributions. The main 23.8-GHz frequency is used to measure water vapor; the 34-GHz channel provides the correction for non-rain-bearing clouds; and the 18.7-GHz channel is highly sensitive to wind-driven variations in the sea surface. By combining measurements acquired at each of these frequencies, we can extract the water vapor signal.

9.4 DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite)

DORIS[8.9] is used to determine the velocity (how fast something is moving) of the satellite. DORIS stands for Doppler Orbitography and Radiopositioning Integrated by Satellite. DORIS measures the Doppler shifts of two radio frequencies transmitted to DORIS from beacons on Earth.

The DORIS instrument onboard Jason-1 provides real-time location and precise orbit determination. DORIS measurements are also used for geophysical studies, in particular through the International DORIS Service (IDS). DORIS is a dual-frequency instrument able to determine atmospheric electron content.

Function

Real-time location: DIODE

The DIODE onboard navigator locates the satellite on orbit in real time. This information is essential for providing altimetry data in real time or near-real time.

Every 10 seconds, DIODE runs a program that:

- Acknowledges commands
- Predicts the satellite's position using a model of its motion
- Corrects the predicted position on the basis of DORIS measurements (when the satellite is within view of a ground beacon)
- Delivers the calculated position to users

By measuring and comparing the path delay of signals transmitted at two separate frequencies, DORIS is able to calculate the electron content in the atmosphere. This information is then used to determine perturbations on the altimeter's radar signal. This function complements the dual-frequency altimeter function.

Principle

DORIS orbitography beacons transmit signals at two separate frequencies (2036.25 MHz and 401.25 MHz) to the satellite. The receiver onboard the satellite analyzes the received signal frequencies to calculate its velocity relative to earth. This velocity is fed into orbit determination models to derive the satellite's position on orbit to within two centimeters on the radial component.

9.5 The Turbo Rogue Space Receiver TRSR

It is a global positioning system (GPS) receiver. TRSR[8.10] measures the position of the satellite by tracking the signals from GPS satellites and ground systems simultaneously. It can listen to 16 GPS signals at once. Using the signals it can measure its position with an accuracy of about 10 cm.

The TRSR (Turbo Rogue Space Receiver) is a tracking system that uses the GPS constellation of satellites to determine the exact position of a transmitter.

Function

The TRSR supports precise orbit determination by the DORIS system. It also helps to improve gravity field models and provides data for satellite positioning accurate to about 50 meters and 50 nanoseconds.

Principle

The TRSR receives dual-frequency navigation signals continuously and simultaneously from 16 GPS satellites. It uses these signals to acquire phase measurements accurate to about one millimeter and pseudo-range measurements accurate to about 10 centimeters.

Technical data

The onboard system consists of two independent receivers operating in cold redundancy, each with an omnidirectional antenna, low-noise amplifier, quartz oscillator, sampling converter, and a baseband digital processor communicating via the bus interface.

10 Lightweight Synthetic Aperture Radar (**LightSAR)**

LightSAR[9] is a low mass, low cost Synthetic Aperture radar that would be launched on a EOS satellite, to perform high resolution radar mapping of land cover, and generate topographic maps to study natural hazards such as earthquakes, floods, and volcanoes. The scientific data collected has commercial applications such as remote sensing, and energy management applications, crop monitoring, mapping, and mineral exploration.

LightSAR System[9.1]

The LightSAR System comprises space and ground segments.

General Requirements:

- Meet as many user requirements as possible at the lowest achievable cost.
- Provide users rapid and low-cost access to radar data products.
- Demonstrate advanced radar technologies' ability to reduce costs and enhance performance.
- >=5 year lifetime (LightSAR Workshop recommendation).

- Orbit Altitude: 600 km, with 97.6 minute period
- Orbit Geometry: Circular, 97.8° inclination, sun-synchronous, 6 A.M. ascending node, 23 minutes maximum eclipse
- Coverage: Global, 10 day repeat cycle
- Launch: Year 2000 (goal)
- Launch Vehicle: Taurus XL, with Star 37 upper stage and 92" dia fairing (rated to deliver 960 kg to the LightSAR orbit), or equivalent.

LightSAR Radar

- High-performance synthetic aperture radar, featuring:
  - Selected component miniaturization and lightweight structures
  - Planar array antenna, with electronic beam steerin
  - Deployable antenna, attached to bus by outrigger structure
  - RF and Digital electronics housed in spacecraft bus
  - Six Modes of Operation
- Frequency: 1.2575 GHz (L-band)
- Aspect: Right or left looking, achieved by spacecraft roll maneuver
- On-Time/Orbit: 10 min. (Spotlight) to 30 min. (ScanSAR) [data rate-limited]
- Pulse width (μsec): 15, 3
- PRF (Hz): 1,600 Nominal; 1,200 Min, 1,750 Max
- Sample size: 8,4 bits/sample (BFPQ), and 4 bits/sample (no BFPQ)
- Power: 1.24 kW max; 1.15 kW antenna, 90W electronics (10 min./Spotlight)
- Mass: <250 kg (225 kg antenna, 25 kg electronics)
- Antenna: 10.8 m (az.) x 2.9 m (elev.) deployed; fan-folds in two 4-segment wings that straddle the spacecraft bus when stowed
- Electronics: 10 x 16 x 30cm (approx. 4,800 cm3) packaging volume
- Interface, Command/ Telemetry Data: VME bus or 1.0 kbps, fixed format, standard RS422, or equivalent, with command encryption
- Interface, Radar Data: 150Mbps, fixed format, standard CCSDS data stream, or equivalent, with satellite ephemeris data embedded in header.

Table 21. LightSAR Point Design Radar Capabilities

Mode of Operation	High Resolution Spotlight	High Resolution Strip Map	Quad Polarization	Dual Polarization	Repeat Pass Interferometer	ScanSAR
Resolution (m)	3	6-10	50	25	25	100
Ground Swath (km)	15x20	22	50	50	100	250
Number of Looks	3	3	10	4	4	8
Field of View From Nadir	20-52	20-52	20-40	25-52	25-44	20-52
Polarizations	HH or VV	HH or VV	HH, HV, VV, VH	HH + HV, or VV + VH	HH or VV	HH + HV, or VV + VH
Noise Equiv Sigma (dB)	-20	-20	-30	-25	-25	-25
Bandwidth (MHz)	80	80	10, 15	10, 15	15	2.5
Data Rate (Mbps)	150	150	120	60	60	40

LightSAR Spacecraft Bus

- Autonomy: Operate w/o commands 24 hr (typical), 7-day max
- Mass: <710 kg (flight weight, without 250 kg radar)
- Power: 50 Amp-Hr batteries; 1-axis gimbaled solar array
- Attitude Control:
- Pointing Accuracy: elevation 0.5°, azimuth 0.1°; knowledge: 0.01°
- Perform 70-degree roll maneuver in 10 min. (for right and left looking)
- [Assumed design includes hot gas thrusters, reaction wheels, inertial reference unit(s), star tracker(s), sun sensors, magnetometer, and onboard Global Positioning System (GPS)]
- Propulsion: Maintain 250 m dia tube about velocity vector [Drag makeup; upper stage de-spin]
- Data Storage: Radar data recording
- for ~ 1 orbit (Spotlight mode), 3 orbits (ScanSAR mode)
- 90 G bit solid state memory
- Data Link, Radar: X-band transmitter, at 150 Mbps, Command \ Telemetry: S-band receiver/ transmitter, with command encryption

LightSAR Ground Segment

- Ground Segment Point Design connects end users to radar satellite.
- Response Time, for data product request and processing turn-around:
- Quick-Look: 1-6 hr, with electronic delivery
- Nominal: 8 days
- Ground Segment functional elements, may be implemented in various ways at widely dispersed locations.
- Actual design implementation will be tailored to the needs of a business enterprise.

11 MicroLab 1 - Optical Transient Detector (ML1 – OTD)

The Optical Transient Detector[10] was carried as a secondary payload on a Pegasus, an orbital Sciences Corporation air-launched rocket. The Pegasus launch on April 3, 1995 delivered the OTD into an Earth orbit of approximately 710 kilometers (446 miles) altitude, with an inclination of 70 degrees. With that orbit, and OTD's wide 100-degree field of view, it surveys virtually all areas of the globe where lightning normally occurs. The combination of the wide field-of-view lens and the altitude of the orbit allow OTD to observe an area of the earth equivalent to 1300x1300 sq km (about 1/300 of the total surface area of the earth) as it orbits the globe.

Between September 1, 1995 and August 31, 1996, the OTD observed nearly 1 million lightning flashes worldwide. The lightning flash densities (flashes per square kilometer per year) for some are calculated statistically using OTD data from more than 400 separate 3 minute observations of each location on the earth. From this information, it is now estimated that over 1.2 billion lightning flashes (intracloud plus cloud-to-ground) occur around the world every year. Most of the lightning is in the InterTropical Convergence Zone (ITCZ) over the continents, and there is far more lightning over the landmasses than over the oceans. This results from the stronger vertical motions in continental clouds than in oceanic clouds.

Each day of OTD data has been totaled into a single image. Using these images, it is easy to tell from a glance on which days there was a particularly high or low amount of lightning activity over a given area. At the end of each month, OTD Browse Data is quality checked and archived. The most current OTD browse data is kept in a Non-Quality Controlled area for those who need the data as soon as possible. This data may contain inaccuracies.

Orbit Characteristics[10.2]

The OTD was sent into a near polar orbit with an inclination of 70 degrees at an altitude of 740 km. In this orbit, with its 100 degree field-of-view, it is able to survey almost all areas of Earth where lightning occurs. Its wide field-of-view and altitude of orbit lets it see around 1/300th of the Earth's total surface as it orbits the globe (which it does every 100 minutes).

If the OTD's near polar orbit were changed to a sun synchronous orbit, it would not be able to survey lightning flashes for both the daytime and nightime. This would leave out a large percentage of lightning flashes around the world. If it were placed in an orbit in which it was always in the sunlight, it's efficiency rate (which is a shaky 40-65%) would be reduced due to glint and radiation.

If the OTD were place in a Low Earth Orbit, its range of coverage would be limited by its inclination, so less of the globe would be surveyed. And if it were moved out to a geosynchronous orbit, only part of the Earth could be surveyed which would not make sense since the goal of the OTD was to get a global survey of lightning flashes; plus the satellite's resolution probably is not good enough to get accurate results from that kind of altitude.

Instrument

The Optical Transient Detector (OTD)[10.1] is a highly compact combination of optical and electronic elements. It was developed as an in-house project at NASA's Marshall Space Flight Center in Huntsville, Alabama. The name, Optical Transient Detector, refers to its capability to detect the momentary changes in an optical scene that indicate the occurrence of lightning. The OTD instrument is a major advance over previous technology in that it can gather lightning data under daytime conditions as well as at night. In addition, it provides much higher detection efficiency and spatial resolution than has been attained by earlier lightning sensors.

The sensor system (camera) is approximately 8 inches in diameter and 15 inches high, while the supporting electronics package is about the size of a standard typewriter. Together, the two modules weigh approximately 18 kilograms (40 pounds). The total weight of the satellite placed on orbit is 75 kilograms (165 pounds).

The Optical Transient Detector (OTD), the world's first space-based sensor capable of detecting and locating lightning events in the daytime as well as during the nighttime with high detection efficiency was designed and built at Marshall Space Flight Center (MSFC). The concept for this instrument was developed at NASA's Marshall Space Flight Center in the 1980's, and was selected for development as part of NASA's Earth Observing System (EOS). The purpose of the sensor is to detect the full spectrum of lightning flashes, including cloud to ground, cloud to cloud, and intra-cloud (within cloud) lightning events. Ground-based techniques detect only cloud-to-ground lightning events which are believed to comprise 25% of the total lightning activity. In addition, these techniques generally detect lightning activity near land masses; very little information is provided regarding lightning events over the Earth's oceans. OTD is designed to aid scientists in determining the global distribution of lightning activity and thunderstorms and the characteristics of the Earth's electric circuit.

OTD is designed to detect, locate and measure the intensity of lightning for scientific investigation of the distribution and variability of total lightning over the Earth and to increase our understanding of the Earth's atmosphere system. Lightning is closely coupled to storm convection dynamics, and can be correlated to the global rates, amounts and distribution of convective precipitation.

The Optical Transient Detector contributes to studies of Earth's water cycle, sea-surface temperature variations, electrical coupling of thunderstorms with the ionosphere and magnetosphere, and modeling of the global distribution of electrical fields and currents in the Earth's atmosphere. In addition, it begins the development of a global lightning climatological database for use in NASA's Mission to Planet Earth Global Climate Change Program.

OTD technological innovations include a narrowband, very stable, refractory oxide interference filter; a high-speed (f/1.6) telecentric telescope assembly; a high-speed focal plane which processes 500 images per second; and a real time event processor which processes 10 million pixels per second to extract lightning signals from a bright daytime background.

12 PICASSO-CENA

PICASSO-CENA[11] will provide key measurements of aerosol & cloud properties needed to improve climate predictions. PICASSO-CENA will fly a 3 channel lidar with a suite of passive instruments in formation with EOS PM to obtain coincident observations of radiative fluxes and atmospheric state. This comprehensive set of measurements is essential for accurate quantification of global aerosol and cloud radiative effects.

The PICASSO-CENA[11.1] satellite will be developed over a 3 year period and launched in early 2003 using a small (SELV-II B class) launch vehicle. The satellite consists of a science payload of four instruments integrated to an Alcatel PROTEUS spacecraft bus. PICASSO-CENA will fly in a sun-synchronous 705 km circular orbit in formation with the EOS PM satellite. PICASSO-CENA will be monitored and commanded from CNES facilities in France. The payload operations center will be located at NASA LaRC.

Data will be downlinked 3 times daily and transferred to NASA LaRC where it will be processed and archived.

PICASSO-CENA spacecraft configuration

Payload Power (avg): 232 W

Payload Mass/Spacecraft Bus Capability: 178 kg

Satellite Mass/Launch Vehicle Capability: 478 kg

Propellant: 16 kg

Data storage: 24 Gbits

The science payload consists of four co-aligned nadir viewing instruments:

A 2-wavelength (532 nm and 1064 nm) polarization-sensitive lidar that provides high resolution vertical profiles of aerosols and clouds. Examples of this measurement capability can be found at the LITE homepage. A high spectral resolution (0.5 cm-1) A-band spectrometer (ABS) that provides calibrated measurements of reflected sunlight over the oxygen absorption band centered at 765 nm. Information on aerosol and cloud scattering and absorption properties is embedded in these spectra. The high spectral resolution of the ABS measurements is a key feature of the ABS and provides new retrieval capabilities beyond those of lower spectral resolution instruments. An imaging infrared radiometer (IIR) that provides calibrated infrared radiances at 10.5 microns and 12.0 microns. These wavelengths are optimized for combined IIR/lidar retrievals of cirrus particle size. A high-resolution wide field camera (WFC) that acquires high spatial resolution imagery for meteorological context.

12.1 Lidar

Specifications

- Lidar type: Nd:YAG, diode-pumped, Q-switched, frequency-doubled
- Wavelength: 532 nm and 1064 nm
- Repetition rate: 27 Hz
- Telescope aperture: 1.0 m
- Horizontal/vertical resolution: 250 m/ 30 m
- Data rate: 279 kbps

Lidar offers unique capabilities for atmospheric sensing[11.2]. Lidar is ideally suited for detecting and profiling aerosol layers and tenuous clouds, even at night or over in homogeneous terrain.

The Lidar In-space Technology Experiment (LITE) instrument was designed with the capability to make measurements of clouds, aerosols in the stratosphere and troposphere, the height of the planetary boundary layer (PBL), and atmospheric temperature and density in the stratosphere between 25 km and 40 km altitude. Additionally, limited measurements of the surface return strength over both land and ocean were collected to explore retrievals of surface properties. Most surface return data were collected at near-nadir angles, but several Landmark Track maneuvers were performed by Discovery to measure the angular dependence of the sea surface return. The primary geophysical parameters measured by LITE are listed below, followed by the scientific rationale behind some of the measurement objectives.

Commanding of the LITE instrument was accomplished primarily from Mission Control in Houston. All commands go to the Instrument Controller, which parses the commands and relays them to the Aft Optics or Boresight Assembly subsystems, if required. Instrument level commands are executed by the Instrument Controller. The LITE instrument command set is very versatile, including over 200 commands to control every facet of the instrument operation.

There are five predefined operating modes:

- Standby
- Day Datatake
- Night Datatake
- Autonomous
- BITS

In Standby mode the high voltage to the detectors is off and the receiver aperture is closed. The instrument defaults to Standby mode at power-up and reverts to Standby when each of the other modes terminates. The BITS (Built In Test System) mode is used for instrument diagnostics. The detectors are powered on, the aperture is closed, and light emitting diodes are used to illuminate the detectors with a signal of known time dependence, simulating a backscatter signal, for the purpose of assessing the performance of the detectors and electronics. In Standby and BITS modes the laser is not fired. For Night Datatake mode the interference filters are moved out of the optical path and the aperture is moved to the 3.5 mrad position. In Day Datatake mode the interference filters are moved into the optical path and the aperture is moved to the 1.1 mrad position. In Autonomous mode the instrument automatically cycles between the Day Datatake mode and the Night Datatake mode as the orbiter crosses the terminator. The instrument monitors the background light level and decides when to change between Day and Night modes.

The optical lidar return signal covers a dynamic range of 5 to 6 orders of magnitude from an altitude of 40 km to the surface return pulse. Peak signal returns from clouds vary by more than 2 orders of magnitude. The instantaneous linear dynamic range of the system is much less than this. By varying the PMT gain and by adding attenuation to the amplifier chain the system was able to cover this entire dynamic range, although not on a single profile. Observing time during the mission was split between aerosols, clouds, and the surface, which generally required separate gain and attenuation settings. The three channels can be configured independently. For example, the instrument can be set up so that surface returns are measured at 532 nm, while the 355 nm channel is used for stratospheric aerosol studies.

The instrument activation procedure was begun soon after the payload bay doors were opened, about 3 hours after launch, with the instrument ready to operate for the first scheduled lidar operations at 5.5 hours after launch. During the mission there were ten datatakes ranging from about 3.5 hours to 5 hours in length and 32 short snapshots of 15 minutes to 40 minutes each. When not lasing, the system was put into Standby mode. Each datatake covered roughly three orbits and was located in the time line to accommodate a mix of correlative measurement activities and studies of regional phenomena. The snapshots were focused on specific regional phenomena or correlative sites.

The instrument was powered continuously for over 220 hours during the mission, with 53 hours of lasing. There were no performance anomalies, which threatened mission success. However, tests conducted on the first day of the mission indicated a problem with the High Data Rate Recorder (HDRR). In spite of this, the operations team was able to downlink and archive in real time about 80% of the high rate data, which was generated. Because the low-rate data stream was backed up on a different Shuttle recorder during TDRSS loss-of-signal, 100% of the instrument status data and quick-look science data were obtained. A total of 43.5 hours of high rate profiles and 53 hours of quick-look profiles were acquired. The ground tracks for the low-rate data provided good coverage between 57 N and 57 S. There was a gap in the high-rate coverage between 60 E and 85 E due to the `zone of exclusion', where neither TDRSS satellite was in view.

12.2 A-band spectrometer (ABS)

Specifications

- Wavelength range: 763 to 769 nm
- Spectral resolution: 0.5 cm-1
- Field of view: 900 m
- Data rate: 43.7 kbps

12.3 Imaging infrared radiometer (IIR)

Specifications

Wavelength range: 10.5 and 12.0 micron

Spectral resolution: 0.8 micron

Data rate: 20.5 kbps

12.4 Wide field camera (WFC)

Specifications

Wavelength range: 620 to 670 nm

Field of view: 125 m/ 25 km

Data rate: 28.3 kbps

13 Poseidon 1 & 2

Launched into Earth orbit in August 1992, TOPEX/POSEIDON[12] enables early warnings of El Niño and La Niña weather patterns that have caused devastating floods in some areas and drier than normal periods in other places. A partnership between the U.S and France to monitor global ocean circulation, discover the tie between the oceans and atmosphere, and improve global climate predictions, the TOPEX/Poseidon satellite measures global sea level with unparalleled accuracy. Other areas of applications include ship routing, commercial fishing, sport sailing, hurricanes, ocean circulation, marine mammals, shipboard research, climate forecasting, lobster larvae studies, and work on marine debris and coral reef health.

The National Aeronautics and Space Administration (NASA) provided the satellite bus and five instruments with their associated ground elements[12.1]. NASA's Jet Propulsion Laboratory is responsible for project management, and operates the satellite through NASA's Tracking and Data Relay Satellite System. The French Space Agency, Centre National d'Etudes Spatiales (CNES), furnished two instruments with their associated ground elements and a dedicated launch on a Ariane 42P rocket. Both CNES and NASA provide precision orbit determination and process and distribute data to 38 science investigators from nine nations, as well as other interested scientists.

In August 1992, TOPEX/Poseidon was launched into Earth's orbit by an Ariane 42P rocket from the European Space Agency's Space Center located in Kourou, French Guiana -- the first launch of a NASA payload from this site. From its orbit 1,336 kilometers (830 miles) above the Earth's surface, TOPEX/Poseidon measures sea level along the same path every 10 days using the dual frequency altimeter developed by NASA and the CNES single frequency solid-state altimeter. This information is used to relate changes in ocean currents with atmospheric and climate patterns.

Measurements from NASA's Microwave Radiometer provide estimates of the total water-vapor content in the atmosphere, which is used to correct errors in the altimeter measurements. These combined measurements allow scientists to chart the height of the seas across ocean basins with an accuracy of less than 10 centimeters (4 inches)

TOPEX/Poseidon is considerably more complicated than a car[12.2], and having been in space, which is a harsh environment, for over 7 years it needs careful monitoring. Seven years is a very long time by satellite standards and the fact that it is still flying is a tribute to the people who built TOPEX/Poseidon and the mission control teams. SinceTOPEX/Poseidon was designed to operate for 3 to 5 years, maintaining successful operations for over 7 years is a significant accomplishment and a tribute to the mission design and operations teams.

The reason that the extraordinary TOPEX/POSEIDON mission was designed and implemented was to gather information about the world's oceans, and especially about ocean currents, over an extended period of time. To do this, the instruments on the satellite take extremely precise measurements of the height of the ocean surface above the center of the Earth - commonly called sea level - on a 10-day repeat cycle. This information has significant practical applications in such areas as the study of worldwide weather patterns, the monitoring of shoreline evolution, and the protection of our great ocean fisheries.

Several things are communicated. The aim of the mission, of course, is to gather altimeter measurements of the topography of the ocean surface. Thus, one of the altimeters is taking observations at all times (the NASA altimeter 90 percent of the time, the CNES altimeter 10 percent). This constitutes a massive amount of data, with almost the entire globe's oceans being measured every ten days.

Objectives[12.3]

- Three-year global view of Earth's oceans
- Improved understanding of ocean currents
- Improved forecasting of global climate

Mission

- Joint NASA-CNES program
- Launched August 10, 1992
- Launch Vehicle: Arianespace's Ariane 42P
- Launch Site: Centre Spatial Guyanais, Kourou, French Guiana
- Operations for 3-year prime mission, 6-year extended: JPL
- Orbit: 1336-km, circular, 66° inclination
- 10-day repeat of ground track (±1-km accuracy)
- Covers 95% of ice-free oceans every 10-days

Spacecraft

- Based on Fairchild's Multi-Mission Spacecraft bus
- Total mass: 2402 kg (5296 lbs)
- Single solar panel provides 3.4 kW of power
- 1.2 m (4 foot) high-gain antenna communicates through TDRSS
- Reaction wheels and torque rods maintain 3-axis stabilization and nadir pointing
- Hydrazine propellant system provides orbital maintenance

Payload/Sensors

- NASA dual-frequency (C- and Ku-band) altimeter and CNES single-frequency (Ku-band) solid-state altimeter measures height above sea
- NASA microwave radiometer measures water vapor along altimeter path to correct for pulse delay
- NASA Global Positioning System demonstration receiver provides precise orbit ephemeris data
- NASA laser retroreflector array works with ground stations to track satellite and calibrate and verify altimeter measurements.
- CNES DORIS Doppler tracking antenna receives ground signals for precise orbit determination, satellite tracking, and ionospheric correction data for CNES altimeter

Data

- Sea-level measurement accuracy 4.2 cm (1.7 inch)
- Data coverage global between 66°N and 66°S latitude
- Data availability through NASA/JPL and CNES

14 Quick Scatterometer **(QuikSCAT)**

NASA's Quick Scatterometer (QuikSCAT) was lofted into space at 7:15 p.m. Pacific Daylight Time on Saturday (6/19/99) atop a U.S. Air Force Titan II launch vehicle from Space Launch Complex 4 West at California's Vandenberg Air Force Base. The satellite was launched in a south-southwesterly direction, soaring over the Pacific Ocean at sunset as it ascended into space to achieve an initial elliptical orbit with a maximum altitude of about 800 kilometers (500 miles) above Earth's surface.

The SeaWinds instrument on the QuikSCAT satellite is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans.

SeaWinds uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 gigahertz across broad regions on Earth's surface. The instrument will collect data over ocean, land, and ice in a continuous, 1,800-kilometer-wide band, making approximately 400,000 measurements and covering 90% of Earth's surface in one day.

Mission Description

Launch Vehicle: Titan II

Mission Life: 2 years (3 years consumables)

Orbit: Sun-synchronous, 803 km, 98.6° inclination orbit

Spacecraft

ADCS approach: 3-axis stabilized, Star Tracker/IRU/Reaction Wheels, C/A Code GPS

Pointing Acc.: < 0.1° absolute per axis

Pointing Knowl.: < 0.05° per axis

Telecom: (Science) 2 Mbps S-band P/L (Hskp) 5, 16, 256 Kbps S-Band, 2 Kbps S-Band uplink

Propulsion: N2H4 Blowdown

Mass: 970 Kg

Orbital Avg Power: 874 W

Data Capacity: 8 Gbits

Instrument Description

Radar: 13.4 gigahertz; 110-watt pulse at 189-hertz pulse repetition frequency (PRF)

Antenna: 1-meter-diameter rotating dish that produces two spot beams, sweeping in a circular pattern

Mass: 200 kilograms

Power: 220 watts

Average Data Rate: 40 kbps

Measurements

- 1,800-kilometer swath during each orbit provides approximately 90-percent coverage of Earth's oceans every day.
- Wind-speed measurements of 3 to 20 meters/second, with an accuracy of 2 meters/second; direction, with an accuracy of 20 degrees.
- Wind vector resolution of 25 kilometers.

15 Stratospheric Aerosol and Gas Experiment II (SAGE II)

The SAGE II sensor[14] was launched into a 57-degree inclination orbit aboard the Earth Radiation Budget Satellite (ERBS) in October 1984. During each sunrise and sunset encountered by the orbiting spacecraft, the instrument uses the solar occultation technique to measure attenuated solar radiation through the Earth's limb in seven channels centered at wavelengths ranging from 0.385 to 1.02 micrometers. The exo-atmospheric solar irradiance is also measured in each channel during each event for use as a reference in determining limb transmittances.

SAGE II measures gas and aerosol extinction profiles at the Earth's limb during each solar occultation (sunrise or sunset) experienced by ERBS[14.1]. Each day, 15 sunrise and 15 sunset profiles are measured with equal spacing in longitude. Because the ERBS orbit has an inclination angle of 57 degree (i.e., it is non sun-synchronous), the sampling latitude progresses northward and southward as the orbital nodes move westward with respect to the Earth-Sun line, acquiring global coverage (except for the polar regions) in about 40 days.

The transmittance measurements are inverted using the "onion-peeling" approach to yield 1-km vertical resolution profiles of aerosol extinction (at 0.385, 0.453, 0.525, and 1.02 micrometers), ozone, nitrogen dioxide, and water vapor. The focus of the measurements is on the lower and middle stratosphere, although retrieved aerosol, water vapor, and ozone profiles often extend well into the troposphere under non-volcanic and cloud-free conditions. SAGE II was preceded into orbit by sister instruments SAM II (Stratospheric Aerosol Measurement II), which has been measuring 1.0-micrometer aerosol extinction in the polar regions since 1978, and SAGE I, which provided near global measurements of aerosol extinction (at 0.45 and 1.0 micrometers), ozone, and nitrogen dioxide from 1979-1981.

Since the solar occultation technique is inherently self-calibrating, accurate estimates can be made of long-term trends in the retrieved atmospheric constituents to aid in assessing their role in global change. This is a summary of major results which have emanated from the SAGE II (augmented by SAM II and SAGE I) measurements.

The spaceborne SAGE II instrument provides self-calibrating, near global measurements of atmospheric aerosols, ozone, NO_2, and water vapor. These data, in conjunction with data from sister instruments SAM II and SAGE I, can be used to estimate long-term constituent trends and identify responses to episodic events such as volcanic eruptions. Major results of these programs include illustration of the stratospheric impact of the 1991 Mount Pinatubo eruption, identification of a negative global trend in lower stratospheric ozone during the 1980s, and quantitative verification of the positive water vapor feedback in current climate models. The constituent record provided by SAGE II will be continued and improved by its successor SAGE III, currently planned for multiple launches beginning in the year 2000 as part of the Earth Observing System.

The platform for SAGE II is the Earth Radiation Budget Satellite[14.2]:
(ERBS). Nominal orbit parameters for ERBS are:
Launch Date: October 5, 1984
Planned Duration: 2 years
Actual Duration: ongoing
Orbit: non-sun synchronous, circular at 650 km
Inclination: 57 degrees
Nodal Period: 96.8 minutes

SAGE II instrument

The SAGE II instrument is a seven-channel Sun photometer using a Cassegrainian-configured telescope, holographic grating, and seven silicon photodiodes, some with interference filters, to define the seven spectral channel bandpasses. Solar radiation is reflected off a pitch mirror into the telescope with an image of the Sun formed at the focal plane. The instrument's instantaneous field-of-view, defined by an aperture in the focal plane, is a 0.5-by-2.5 arc-minute slit that produces a vertical resolution at the tangent point on the Earth's horizon of about 0.5 kilometers.

Radiation passing through the aperture is transferred to the spectrometer section of the instrument containing the holographic grating and seven separate detector systems. The holographic grating disperses the incoming radiation into the various spectral regions centered at the 1020, 940, 600, 525, 453, 448, and 385 nanometer wavelengths. Slits on the Rowland circle of the grating define the spectral bandpass of the seven spectral channels. The spectrometer system is inside the azimuth gimbal to allow the instrument to be pointed at the Sun without image rotation. The azimuth gimbal can be rotated over 370 degrees so that measurements can be made at any azimuth angle.

The operation of the instrument during each sunrise and sunset measurement is totally automatic. Prior to each sunrise or sunset encounter, the instrument is rotated in azimuth to its predicted solar acquisition position. When the Sun's intensity reaches a level of one percent of maximum in the Sun sensor, the instrument adjusts its azimuth position to lock onto the radiometric center of the Sun to within +/-45 arc-seconds and then begins acquisition of the Sun by rotating its pitch mirror in a predetermined direction depending on whether it is a sunrise or a sunset.

When the Sun is acquired, the pitch mirror rotates back and forth across the Sun at a rate of about 15 arc-minutes per second. The radiometric channel data are sampled at a rate of 64 samples per second per channel, digitized to 12-bit resolution, and recorded for later transmission back to Earth.

16 Stratospheric Aerosol & Gas Experiment III (SAGE III)

Three flights of the SAGE III[15] instrument are currently planned including a flight aboard a Russian Meteor-3M platform in early 2001 and the International Space Station in 2004. The launch of the third SAGE III mission has not been identified.

Typically the spacecraft orbits the Earth approximately once every 90 minutes or sixteen times per day, depending on orbital parameters. Each orbit provides two measurement opportunities, one for each sunset and one for each sunrise. Therefore SAGE can acquire 32 separate measurements during each 24-hour period, and measurement occurs at different geographical locations over the Earth depending on the spacecraft orbit. The number of measurement opportunities and the geographical coverage can be increased when measurements are made during both lunar and solar occultation events.

Occultation Technique

The solar occultation measurement technique[15.1] is a very simple method of measuring vertical profiles of atmospheric optical depth profiles from Earth orbit using the sun as a light source. As the spacecraft orbits the Earth, the SAGE instrument points toward the sun and measures its intensity. It observes sunsets when the spacecraft moves from the sunlit toward the dark side of the Earth. Before each sunset starts, the line-of-sight (LOS) between the spacecraft and the sun is unobstructed by the atmosphere so that the sun's intensity as measured by the SAGE instrument is unattenuated. But, when the spacecraft starts to dip below the horizon so that the LOS passes through a portion of the atmosphere, the sun's intensity will be attenuated due to aerosols and gases in the atmosphere that scatter and absorb sunlight.

During sunrise events, when the spacecraft moves from the dark towards the sunlit side of Earth, the sun is first viewed through the atmosphere, and then along an unobstructed path when the spacecraft rises above the horizon. Thus, the measurement sequence during sunrise is just the reverse of that during sunset. In both instances the SAGE instrument acquires a measure of attenuation caused by aerosols and gases in the atmosphere, thereby making it possible to quantify these species as a function of altitude.

Typically the spacecraft orbits the Earth approximately once every 90 minutes or sixteen times per day, depending on orbital parameters. Each orbit provides two measurement opportunities, one for each sunset and one for each sunrise. Therefore SAGE can acquire 32 separate measurements during each 24-hour period, and measurement occurs at different geographical locations over the Earth depending on the spacecraft orbit. The number of measurement opportunities and the geographical coverage can be increased when measurements are made during both lunar and solar occultation events.

Instrument

SAGE III incorporates two new design elements: a CCD linear array of detectors and a 16-bit A/D converter. Combined, these allow wavelength calibration, self-consistent determination of the viewing geometry, lunar occultation measurements, and expanded wavelength coverage. The spectrometer provides wavelength coverage between 280 nm and 1550 nm. The CCD linear array provides continuous coverage between 280 nm and 1030 nm at approximately 1-nm resolution. A discrete photodiode is used to make aerosol measurements at 1550 nm. This configuration enables SAGE III to make multiple measurements of the absorption features of each target gaseous species and multi-wavelength measurements of broadband extinction by aerosols.

Description[15.2]

The Stratospheric Aerosol and Gas Experiment III (SAGE III) is an Earth Observing System (EOS) - joint mission between the U.S. National Aeronautics and Space Administration (NASA) and the Russian Space Agency (RSA). SAGE III is one of nine experiments on the Russian Meteor-3M(1) spacecraft.

SAGE III is designed to monitor globally the vertical distribution of stratospheric aerosols, ozone, water vapor, nitrogen dioxide and trioxide, chlorine dioxide and temperature from Earth orbit. SAGE III is a spectrometer that measures extinction of solar and lunar radiation through the Earth's atmosphere during occultation events.

Launch

Launch vehicle is a Zenit-2 Launch site is Baikonur Cosmodrome Planned launch date is May 5, 2001

Orbit

- Sun-synchronous orbit
- Altitude: 1,020 +/- 20 km
- Inclination: 99.64 degrees
- Ascending node: 9:15 a.m. (+/- 15 minutes tolerance)

Vital Statistics

- Weight: 76 kg
- Size: 73 cm x 45 cm x 93 cm
- Power: 80 watts
- Design life: 5 years (Meteor-3M spacecraft design life is 3 years)

Instrument Characteristics

- Wavelength Range: 282 - 1,550 nm
- Spectral Channels: 9 Spectral Bands
- Vertical Resolution: 1 - 2 km
- FOV (Field of View): -24.81 to -31.02 deg. El, +/- 185 deg.
- Az Instantaneous FOV: +/- .5 km
- Vertical Data system: 14 bits A/D
- Data rate: 115 Kbps during event

16.1 Meteor-3M Mission

Meteor-3M[15.3] will be placed in a sun synchronous orbit that yields solar measurement opportunities between 50° and 80° North and 30° and 50° South. The high northern latitude coverage will provide insight into the processes leading to ozone depletion during boreal winter and provide coverage that complements the mid and low latitude coverage provided by SAGE II and other SAGE III missions. SAGE III/ISS (International Space Station), on the other hand, will be in an inclined orbit that provides near global coverage over the course of about a month.

The return link for the Meteor-3M mission is similar to the scheme used during the Meteor 3/ TOMS mission. For the Meteor-3M / SAGE III mission, identical sets of instrument data will be relayed two times daily to ground stations located in Obnisk, Russia and Wallops Island, Virginia. The GSFC Wallops Flight Facility (WFF) is responsible for data reception, archival of raw data for at least two weeks, data quality monitoring, and will support data transfer to LaRC.

Upon receipt at WFF, the raw SAGE data will be automatically transferred to SAGE III operations center for Level 0 conversion. Level 0 data will be distributed to the SAGE III Scientific Computer Facility (SCF) and to the EOSDIS LaRC DAAC.

Lunar occultation data should be obtained whenever the solar zenith angle for the tangent location is greater than 95 degrees and the phase of the moon is between 90 degrees and 270 degrees (0 degrees = new moon, 180 degrees = full moon). During the operational phase of the Meteor-3M/SAGE III mission, solar occultation data should be obtained every spacecraft sunset event and spacecraft sunrise event.

16.2 International Space Station (ISS) Mission

SAGE III is scheduled to be a part of the International Space Station (ISS)[15.4] payload beginning in 2004. ISS will be placed in a 51°-inclined orbit that yields SAGE III solar measurement opportunities from 70° South to 70° North over the course of one month. This orbit is similar to that of SAGE II (a 57°-inclined orbit) and is well suited to SAGE III's primary mission to provide long-term global monitoring of ozone and aerosol variations.

Similar to the ISS forward link, the return link consists primarily of TDRSS and the EHOSC at MSFC. It is anticipated that SAGE III science data will be relayed through TDRSS to the EHOSC at least every third orbit. Data will be available on EHOSC computers for automatic transfer to SAGE III operations center computers. Level 0 processing will be performed by the SAGE III operations center. The EHOSC will archive raw data for at least two weeks. Like Meteor 3M operations, the SAGE III operations center will perform health, safety, and performance monitoring and will ensure that. Level 0 data is transferred to the SAGE SCF and to the EOSDIS LaRC DAAC.

16.3 Flight of Opportunity (FOO) Mission

The third SAGE III mission has not formally been selected.

17 SEASTAR/ Sea-viewing Wide Field-of-view Sensor Project (SeaWiFS)

The purpose of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project[16] is to provide quantitative data on global ocean bio-optical properties to the Earth science community. Subtle changes in ocean color signify various types and quantities of marine phytoplankton (microscopic marine plants), the knowledge of which has both scientific and practical applications. The SeaWiFS Project will develop and operate a research data system that will process, calibrate, validate, archive and distribute data received from an Earth-orbiting ocean color sensor.

Since an orbiting sensor can view every square kilometer of cloud-free ocean every 48 hours, satellite-acquired ocean color data constitute a valuable tool for determining the abundance of ocean biota on a global scale and can be used to assess the ocean's role in the global carbon cycle and the exchange of other critical elements and gases between the atmosphere and the ocean. SeaWiFS will operate as a follow-on sensor to the Coastal Zone Color Scanner (CZCS), which ceased operations in 1986.

The SeaStar satellite carries the SeaWiFS instrument[16.1] which is designed to monitor the color of the world's oceans. Various ocean colors indicate the presence of different types and quantities of marine phytoplankton, which play a role in the exchange of critical elements and gases between the atmosphere and oceans. The satellite will monitor subtle changes in the ocean's color to assess changes in marine phytoplankton levels, and will provide data to better understand how these changes affect the global environmental and the oceans' role in the global carbon cycle and other biogeochemical cycles. Complete coverage of the Earth's oceans will occur every two days.

The NASA sponsored mission was contracted as a "data buy" from a Orbital Sciences Corporation, who will build, launch, and operate the satellite, and then sell data from the satellite to NASA. NASA will retain all rights to data for research purposes, while will OSC retain all rights for commercial and operational purposes. The mission is a follow on to the Coastal Zone Color Scanner (CZCS).

Spacecraft

Nadir pointing. 3-axis stabilized to 0.5 deg with 0.08 deg knowledge using 2 momentum wheels, torque rods. Attitude determination via redundant sun sensors, horizon sensors, and magnetometers. Hydrazine propulsion using four 1-lbf thrusters is used for orbit raising and orbit maintenance. Nitrogen propulsion system provides satbilization during launch. Downlink using L-Band at 665.4 kbps, and S-Band at 2 Mbps. Uplink using S-Band at 19.2 kbps. Redundant GPS receivers for orbit determination. Four deployed solar panels with zenith-facing cells and two body-mounted side-facing solar panels produce 165 watts orbit-average after 5 years. 160 MBytes solid state recorder.

Payload

Only one instrument is carried: the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). Consisting of an optical scanning telescope and an electronics module, SeaWiFS will image the Earth's oceans in 8 frequency bands. The scanning telescope rotates at six revolutions per second in the cross-track direction to provide scan coverage with a spatial resolution of 1.13 km.

Data Collection[16.2]

SeaWiFS will produce scientific data of two spatial resolutions: LAC will be broadcast continuously and recorded selectively, while GAC will be recorded onboard the spacecraft. GSFC will receive LAC direct broadcasts routinely for the East Coast of the U.S., and various HRPT stations around the world will receive other real-time LAC broadcasts. The NASA WFF will receive recorded LAC data, for limited pre selected areas, and all GAC data, which it will forward to the SDPS at GSFC.

In order to meet the science goals, the SPO objectives are to obtain full GAC data every two days, which requires nearly complete use of onboard recording capability and transmission time to GSFC. The limited space for LAC recording will be allocated, in priority order, to 1) monitoring essential sensor functions; 2) covering key optical calibration and validation activities; and 3) science studies, which require full-resolution data.

Currently, the Pegasus[16.4] is flown aloft under the body of a modified Lockheed L-1011 aircraft and released at an altitude of about 39,000 ft, whereupon the launch vehicle engages and lifts the spacecraft to a low Earth, circular, parking orbit of 278 km with an inclination of 98 degree 20 minute. The solar panels are deployed at this time which along with the batteries, are the sensor's power sources.

The SeaStar spacecraft has an onboard hydrazine propulsion system that is then used to raise the satellite to its final 705-km circular, noon, sun-synchronous orbit. The final orbit is reached approximately 20 days following launch. The launch is presently planned to occur from the U.S. West Coast during daylight hours, although launch from the East Coast is under consideration. At 25 days after launch, the SeaWiFS instrument is powered up and checked out. At launch plus 30 days, data collection operations commence.

Two telemetry streams are transmitted. The first is real-time LAC data merged with spacecraft health and instrument telemetry at 665.4 kbps. This is transmitted at L-band with a frequency of 1702.56 MHz. The other telemetry stream consists of stored GAC and selected LAC, along with spacecraft health and instrument telemetry, at 2.0 Mbps. This is transmitted at S-band with a frequency of 2272.5 MHz. The command system uses S-band with an uplink of 19.2 kbaud at 2092.59MHz.

Mission Characteristics:

Orbit Type: Sun Synchronous at 705 km

Equator Crossing: Noon +20 min, descending

Swath Width: 2,801 km LAC/HRPT (58.3 degrees)

Swath Width: 1,502 km GAC (45 degrees)

Spatial Resolution: 1.1 km LAC, 4.5 km GAC

Real-Time Data Rate: 665 kbps

Revisit Time: 1 day

Digitization: 10 bits

The lunar observation can, therefore, be accomplished under nearly full moon conditions through the identical SeaWiFS optical path as that for Earth scenes. The detected and amplified signals are routed from the scanner to the electronics module where they are further amplified and then filtered to limit the noise bandwidth. The filtered signals are digitized by a 12 bit analog-to-digital converter and the digitized signals directed to a commandable processor where the TDI operation is performed in real time as data are generated. The resultant summed signals are divided by four and rounded to 10 bit numbers, and then sent from the processor to the spacecraft data system at 1.885 Mbps during the data acquisition period of each scan line.

The instrument angular momentum will be compensated by the angular momentum wheel. This is necessary to avoid nutation coupling when the instrument is tilted. Implementation will consist of a brushless DC motor driven synchronously at approximately 2,000 rpm. The accurately controlled frequency derived from the instrument clock will ensure compliance to the 1 oz-in-sec uncompensated angular momentum requirement for the spacecraft attitude control system.

SeaWiFS possesses the capability of recording 8-10 minutes of 1 km resolution[16.4] LAC data daily, in addition to the daily compilation of 4.5 km resolution global GAC data. The recorded LAC data and the global GAC data are downlinked to NASA/GSFC each day. Recorded LAC data is obtained for Calibration and Validation (Cal/Val) of SeaWiFS data, and for regions of special interest. Regions of special interest may include areas where research cruises are underway, locations where oceanographic buoys are deployed, or areas where special experiments are being performed. Designation of these regions is made by the SeaWiFS Project. Researchers who require 1 km resolution data for a particular region of interest must contact the SeaWiFS Project for scheduling arrangements.

17.1 Sea-viewing Wide Field-of-view Sensor (SeaWiFS)

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS)[16.5] is an eight-channel visible light radiometer dedicated to global ocean color measurements which are used to detect and analyze patterns of biological activity in the marine environment. The mission parameters of SeaWiFS allow coverage of more than 90% of the ocean surface every two days. SeaWiFS will map global ocean color at a resolution of 4.5 kilometers, and it also provides regional data at a resolution of 1 kilometer. SeaWiFS is the follow-on mission to the Coastal Zone Color Scanner (CZCS), and the predecessor to several ocean color satellite sensors scheduled for deployment in the years 1998-2002.

Ocean color remote sensing is based on the principle that particulate and dissolved substances suspended in water will interact with incident light. Where concentrations of particulate matter and dissolved substances are low, conditions typical for the open ocean, water molecules scatter light similar to the way that the atmosphere scatters light, producing a characteristic deep blue color. The scattering of light by particulates and the absorption of light by dissolved substances will alter this color.

Chlorophyll, the photosynthetic pigment found in phytoplankton, absorbs strongly in the red and blue regions of the visible light spectrum and reflects in the green. As the concentration of phytoplankton increases, the color of the water will therefore appear increasingly green. The absorption of light by chlorophyll can be quantified to determine the concentration of chlorophyll in water, allowing estimation of phytoplankton abundance in a given area.

The relationship between light absorption and chlorophyll concentration may be complicated by the presence of light-scattering inorganic particulate matter in the water. Particulate matter concentrations generally increase in coastal regions, such that the water color near the coast trends from green to brown or reddish-brown. Even though chlorophyll may be present in higher concentrations near the coast, the presence of particulate matter makes it more difficult to extract the amount of light absorption due solley to chlorophyll. In addition, certain classes of phytoplankton form hard mineral shells that scatter light very effectively, such that the water color can appear shade of aquamarine or milky white.

SeaWiFS measures light intensity in several bands. The measurements allow quantification of light absorption and subsequent estimation of chlorophyll and suspended matter concentrations. SeaWiFS improves on the CZCS mission by having better bands for atmospheric correction (i.e., removing the effect of light scattering by the Earth's atmosphere), which will particularly aid the estimation of chlorophyll and suspended matter in coastal regions.

Acquisition Equipment

Sensor/Instrument Description

The primary optics of SeaWiFS consist of an off-axis folded telescope and a rotating half-angle mirror. Radiation backscattered by the Earth's surface and atmosphere is collected by the telescope and reflected onto the mirror, and the beam path is then directed through beam splitters (dichroics, which transmit some wavelengths and reflect the rest) to separate the radiation into four wavelength regions.

Spectral bandpass filters are used to narrow these regions to the 20 nm requirements of the eight SeaWiFS spectral bands, and the radiation then falls on silicon detector elements. The electronics module amplifies the detector signal, performs analog-to-digital conversion and time delay and integration for data transmission. Instrument calibration utilizes an on-board solar radiation diffuser and lunar observation. The instrument may be tilted forward or backward 20 degrees along the spacecraft orbital trajectory to minimize the effects of sun glint.

Source/Platform

The OrbView-2 satellite (formerly called "SeaStar") orbits in a sun-synchronous, descending node orbit at an altitude of 705 km. The orbital period is 98.9 minutes, with an inclination of 98.217 degrees. Local time of descending node is 12:05 PM + 15 minutes. The satellite was launched on August 1, 1997 into a 305 km orbit, and 32 orbit-raising burns performed over the next month raised the orbit to its final altitude.

The satellite has a three-axis stabilized system consisting of orthogonal magnetic torque rods for roll and yaw control and two momentum wheels for pitch stabilization. The satellite is equipped with sun sensors, horizon sensors, and magnetometers.

The propulsion system consists of two subsystems, a reaction control system and a hydrazine propulsion system. The reaction control system uses nitrogen and provides third stage stabilization during the launch. The hydrazine propulsion system is used for raising the orbit from the nominal 278 km parking orbit to the 705 km sun-synchronous operational orbit. In addition, it is used for orbit trim requirements over the life of the mission. The spacecraft employs four Hamilton Standard one pound thrusters.

Redundant global positioning system (GPS) receivers are used for orbit determination, an essential component of satellite and data navigation (Earth location). The orbit state derived from GPS is included in the spacecraft health telemetry.

Two telemetry streams are transmitted. The first is real-time LAC data merged with spacecraft health and instrument telemetry at 665.4 kbps. This is transmitted at L-band with a frequency of 1702.56 MHz. The other telemetry stream consists of stored GAC and selected LAC, along with spacecraft health and instrument telemetry, at 2.0 Mbps. This is transmitted at S-band with a frequency of 2272.5 MHz. The command system uses S-band with an uplink of 19.2 kbaud at 2092.59 MHz.

Source/Platform Mission Objectives

The primary mission objective of SeaWiFS and the Orbview-2 satellite is to obtain a continuous five-year record of ocean radiance observations.

Nominal operating parameters for SeaWiFS

Scan Width: 58.3 deg (LAC); 45.0 deg (GAC)

Scan Coverage: 2,800 km (LAC); 1,500 km (GAC)

Pixels along Scan: 1,285 (LAC); 248 (GAC)

Nadir Resolution: 13 km (LAC); 4.5 km (GAC)

Scan Period: 0.167 seconds

Tilt: -20, 0, +20 deg

Digitization: 10 bits

Principles of Operation

Remote sensing instruments measure electromagnetic energy that is either reflected or emitted from objects and surfaces. This measurement technique can be termed either radiometry or photometry, depending on the wavelength range of the energy being measured. Radiometry refers to measurement of electromagnetic radiation, ranging from X-rays to radio waves. Photometry refers specifically to measurement of energy in the human optical wavelength range. The terms "spectral radiometry" or "spectral photometry" refer to measurements of energy defined per unit of wavelength.

Data Acquisition Methods

Telemetry from the instrument is either transmitted directly to ground High Resolution Picture Transmission (HRPT) stations or recorded on the instrument for later transmission during downlink sessions to GSFC. Direct broadcast data is 1 km resolution LAC data. Recorded data is either 1 km resolution LAC data (primarily for calibration and validation) and 4.5 km resolution GAC data. The GAC data is used for the production of the global data set. Data is placed on disk and then processed to Level 1A, Level 2, and Level 3 products by the SeaWiFS Project. The data are then transmitted to the Goddard DAAC for archive and distribution. (HRPT data are processed to Level 1A by the receiving station, then sent to the SeaWiFS Project and subsequently to the DAAC.)

Temporal Coverage

Full-time operation of SeaWiFS began on September 18, 1997, such that the first complete daily Level 3 product is on September 19, 1997. Daily Level 3 products prior to September 18 have partial global coverage. Full-time operation of SeaWiFS obtains approximately 14.5 orbital swaths of data per day.

18 Seawinds 1A

The SeaWinds scatterometer[17] is a specialized microwave radar that measures near-surface wind velocity (both speed and direction) under all weather and cloud conditions over Earth's oceans. The experiment is a follow-on mission and continues the data series initiated in 1996 by the NSCAT. SeaWinds uses a rotating dish antenna with two beams. The antenna radiates microwave pulses at a frequency of 13.4 gigahertz across broad regions on Earth's surface. SeaWinds will collect data in a continuous 1,800-kilometer-wide band, making approximately 400,000 measurements per day.

SeaWinds is a part of the Earth Observing System (EOS) which is designed to address global environmental changes, and is a joint mission with the National Space Development Agency of Japan (NASDA).

Instrument

18.1 SeaWind

Radar: 13.4 gigahertz; 110-watt pulse at 189-hertz PRF

Antenna: 1-meter-diameter rotating dish producing 2 spot beams sweeping in a circular pattern

Mass: 200 kilograms

Power: 220 watts

Average Data Rate: 40 kilobits per second

SeaWinds is scheduled for launch in November 2001, aboard Japan's Advanced Earth Observing Satellite (ADEOS-II). The SeaWinds Project is managed for NASA's Earth Science Enterprise by the Jet Propulsion Laboratory, a division of the California Institute of Technology.

The SeaWinds[17.1] on QuikSCAT mission is a "quick recovery" mission to fill the gap created by the loss of data from the NASA Scatterometer (NSCAT), when the satellite it was flying on lost power in June 1997. QuikSCAT is scheduled to launch from California's Vandenberg Air Force Base aboard a Titan II vehicle in early summer 1999, and will continue to collect important ocean wind data that was begun by NSCAT in September 1996. The SeaWinds instrument on the QuikSCAT satellite is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans.

SeaWinds uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 gigahertz across broad regions on Earth's surface. The instrument will collect data over ocean, land, and ice in a continuous, 1,800-kilometer-wide band, making approximately 400,000 measurements and covering 90% of Earth's surface in one day.

Science Objectives

- Acquire all-weather, high-resolution measurements of near-surface winds over global oceans.
- Determine atmospheric forcing, ocean response, and air-sea interaction mechanisms on various spatial and temporal scales.
- Combine wind data with measurements from scientific instruments in other disciplines to help us better understand the mechanisms of global climate change and weather patterns.
- Study both annual and semi-annual rain forest vegetation changes.
- Study daily/seasonal sea ice edge movement and Arctic/Antarctic ice pack changes.

Operational Objectives

- Improve weather forecasts near coastlines by using wind data in numerical weather- and wave-prediction models.
- Improve storm warning and monitoring.

Mission Description

- Launch Vehicle: Titan II
- Mission Life: 2 years (3 years consumables)

Orbit: Sun-synchronous, 803 km, 98.6° inclination orbit

Spacecraft

- ADCS approach: 3-axis stabilized, Star Tracker/IRU/Reaction Wheels, C/A Code GPS
- Pointing Acc.: < 0.1° absolute per axis
- Pointing Knowl.: < 0.05° per axis
- Telecom: (Science) 2 Mbps S-band P/L
  (Hskp) 5, 16, 256 Kbps S-Band, 2 Kbps S-Band uplink
- Propulsion: N2H4 Blowdown
- Mass: 970 Kg
- Orbital Avg Power: 874 W
- Data Capacity: 8 Gbits

Ground Systems

- Tracking by Earth Polar Ground stations Svalbard, Norway; Poker Flats, Alaska; Wallops Island, Virginia; and McMurdo, Antarctica; Hatoyama, Japan (contingency station).
- High-quality research data products produced at JPL and distributed to science community within 2 weeks of receipt.
- Scatterometer science data products are distributed through the JPL Physical Oceanography Distributed Active Archive Center (PO.DAAC), a scientific data distribution site: http://podaac.jpl.nasa.gov.
- Operational data products produced at National Oceanic & Atmospheric Administration (NOAA) for international meteorological community within 3 hours of data collection.

Instrument Description

- Radar: 13.4 gigahertz; 110-watt pulse at 189-hertz pulse repetition frequency (PRF)
- Antenna: 1-meter-diameter rotating dish that produces two spot beams, sweeping in a circular pattern
- Mass: 200 kilograms
- Power: 220 watts

Average Data Rate: 40 kilobits per second

Measurements

- 1,800-kilometer swath during each orbit provides approximately 90-percent coverage of Earth's oceans every day.
- Wind-speed measurements of 3 to 20 meters/second, with an accuracy of 2 meters/second; direction, with an accuracy of 20 degrees.
- Wind vector resolution of 25 kilometers.

19 SPAce Readiness Coherent Lidar Experiment (SPARCLE)

Direct measurements of the tropospheric winds have been cited as a major missing element in NASA's Mission to Planet Earth program[18]. More accurate and precise measurements would provide a greater impact on numerical weather prediction models than any other space-based observation. To measure the winds in clear air, NASA's Marshall Space Flight Center and the Global Hydrology and Climate Center (GHCC) have been selected to develop the Space Readiness Coherent Lidar Experiment (SPARCLE), a test model of a large-scale laser that could measure winds across the planet where there are no instruments.

- Validate coherent lidar wind measurement performance prediction models to confirm scalability to follow-on missions.
- Measure Line Of Sight (LOS) wind component at several fixed azimuths to demonstrate single shot accuracy, system backscatter sensitivity, and to obtain data sets for validation/calibration of Doppler wind lidar performance models that will be used in the design of follow-on missions.
- Obtain data sets using several scanning paterns for evaluation of sampling/signal processing strategies (including shot accumulation) for employment in follow-on missions.
- Demonstrate ability to deliver multi-perspective LOS wind measurement that are of sufficient quality and quantity to meet Mission To Planet Earth (MTPE) goals and improve the performance of weather and climate models as is currently being assessed through NCEP data assimilation experiments using simulated Doppler wind lidar data.

Attributes of SPARCLE

- Pulsed, Eyesafe, Coherent Detection Doppler Wind Lidar
- 100 mJ, 6 Hz., 0.25 m, 30 degree from nadir
- 300 km, 51 degrees or greater orbit
- MSFC/LaRC/JPL/GSFC/UAH/CTI/SWA Collaboration
- Science Products: LOS & Vector winds, Cloud Heights & Properties, and Aerosol Backscatter Distribution

The "readiness" part means that SPARCLE[18.1] will be limited in capabilities and time; only about 50 hours of observations on its Shuttle mission. However, scientists expect that it will light the way for more ambitious instruments aboard large satellites dedicated to monitoring the environment.

SPARCLE will aim pulses of eye-safe laser light into the atmosphere and measure the light, which is reflected back to it by dust and aerosols in the atmosphere. The time between pulse and echo will (like radar) determine the distance to an object. The shift in the color of the light will tell how fast the particles are moving along the laser's line of sight. By analyzing a series of pulse echoes, scientists using SPARCLE will be able to build a model that shows the movement of clear air.

The heart of SPARCLE will be a compact optical system in a GAS can with an opening lid (the second GAS can will hold the electronics). A transmitter laser will send a pulse of low-intensity infrared light through a telescope to the Earth below. A rotating glass wedge will allow some pointing control since the GAS cans are firmly bolted to the sill of the Shuttle payload bay.

20 Shuttle Radar Topography Mission (SRTM)

On February 11, 2000, the Shuttle Radar Topography Mission (SRTM)[19] payload onboard the Space Shuttle Endeavour launched into space. With its radars sweeping most of the land surfaces of the Earth, SRTM acquired enough data during its ten days of operation to obtain the most complete near-global high-resolution database of the Earth's topography. To acquire topographic (elevation) data, the SRTM payload was outfitted with two radar antennas. One antenna was located in the Shuttle's payload bay, the other on the end of a 60 meter (200 foot) mast that extended from the payload pay once the Shuttle was in space. The Shuttle Radar Topography Mission (SRTM) is an international project spearheaded by the National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA).

The space shuttle orbit Earth 16 times each day[19.1]. During the 11-day mission, Space Shuttle Endeavour, carrying the SRTM payload, will complete 176 orbits of Earth, flying tail forward at 7.5 km/sec (17,000 mph).

Instrument

The SRTM instrument consisted of three sections. The main antenna was located in the payload bay of Shuttle Endeavour, the mast was connected to the main antenna truss, and an outboard antenna was connected to the end of the mast.

The heart of the SRTM radar is the SIR-C/X-SAR radar, which flew twice on the Space Shuttle in 1994. Several modifications have been made, which give the SRTM system new capabilities compared with SIR-C/X-SAR. The major change is the addition of C-band and X-band antennas at the end of the 60-meter (200-foot) mast. These secondary, or "outboard" antennas, allow the radar to use a technique called interferometry to map the elevation of the terrain in a single pass, which was not possible with SIR-C/X-SAR.

Interferometry can be likened to a person dropping two pebbles into a puddle of water and watching the ripples, or concentric circles of water emanating outward from the splash, meet and interfere with each other. Those interference patterns caused by the rippling water from the two pebbles will be measured by the radar systems onboard the Shuttle to acquire topographic data. The main antenna on the Shuttle and the outboard antenna on the tip of the mast will bounce radar off Earth simultaneously, and will retrieve "backscattered" radar data as the signals from both antennas are scattered and begin to interfere with each other.

The design of the SRTM mission is also different from SIR-C/X-SAR. Instead of focusing on a limited number of "supersite" targets for repeated viewing, as was done with SIR-C/X-SAR, SRTM is designed to map as much of the land surface as possible. SRTM will cover all of the land surface between 60 degrees north and 56 degrees south latitudes. SIR-C/X-SAR covered less than 30% of the Earth's land area.

The C-band and X-band can operate simultaneously or independently. For the most part, they will operate together. The only disadvantage to that is that joint operations will consume more power, but since the coverage of sites with both frequencies is desirable, the basic plan takes this power usage into account.

The radar systems will be collecting data during 159 orbits. The systems will be turned on and off as the data plan dictates. The SRTM will map over all land surfaces between 60 degrees North latitude and 54 degrees South latitude. This is a topography mission, so the oceans won't be included. The instrument will be turned on over the ocean from time to time near the coasts, but only for reference purposes.

Data will be stored on board the shuttle. However, we will send a small amount of data to the ground during the flight to allow monitoring of the end-to-end system. We'll release some of this data to the public during the flight.

All data will be recorded onboard the Shuttle. Appropriate communications links are available about once per day to downlink the data. This once-a-day opportunity will be shared by both the X-band and C-band, and data will be played back in real time if it is being collected at that time, or tape-recorded data will be played back. The C-band and X-band will share the link time according to mutually agreed on priorities established during mission planning. The downlinked data will be used to verify the performance of the sensor.

It takes four times as long to play back C-band data as it takes to record it. X-band data will be played back at half the rate it is recorded. The Shuttle is able to transmit at 50 million bits per second through NASA's Tracking and Data Relay Satellites (TDRS) to the White Sands, New Mexico station. The radars produce data six times faster. The Shuttle data link will be through TDRS. Relay link time is scheduled and limited by satellite position and the priorities of other customers.

The data products from SRTM will be in the form of mosaics of image strips rather than individual image frames. The US Geological Survey Eros Data Center will be distributing the data, but we haven't decided yet how to segment the mosaics for distribution. Probably it will be something like 5 deg lat x 5 deg lon. The current plan is to produce a publicly available DEM at 3 arc sec (about 90 m) resolution and 2 image mosaics, possibly at the full 30 m resolution. The image mosaics would represent ascending passes and descending passes and would therefore have illumination from opposite sides. We are not planning on rigorously calibrating the image data, but we will try to characterize it during processing. In addition, the individual strip image data may be made available, but we have not decided how to do that.

21 Terra

Introduction

Terra will circle around the Earth, very nearly from pole to pole, in an orbit that descends across the equator at 10:30 a.m[20]. local time when cloud cover over land is minimal and its view of the surface is least obstructed. The satellite's orbit will be roughly perpendicular to the direction of Earth's spin, so that the viewing swaths from each overpass can be compiled into whole global images. Over time, these global images will enable scientists to show and tell the stories of the causes and effects of global climate change.

The sensors on Terra will not actively scan the surface (such as with laser beams or microwave pulses). Rather, the sensors work much like a digital camera. Sunlight that is reflected by Earth, and heat that is emitted from Earth, will pass through the apertures of Terra's sensors. This radiant energy will then be focused onto specially designed detectors that are sensitive to selected regions of the electromagnetic spectrum, ranging from visible light to heat. The information produced by these detectors will then be transmitted back to Earth and processed by computers into images that can be interpreted.

Table 22. Continuous Measurement Sites[20.1]

2000 Overpass Calendar

Tahoe	Thangoo	Amburla	Uardry
California	Broome	Alice Springs	Hay
USA	Australia	Australia	Australia
(p7)	(p13)	(p12)	(p6)
(43,33)	(110,73)	(103,76)	(93,84)
Feb 25	Feb 15	Feb 14	Feb 8
Mar 12	Mar 2	Mar 1	Feb 24
Mar 28	Mar 18	Mar 17	Mar 11
Apr 13	Apr 3	Apr 2	Mar 27
Apr 29	Apr 19	Apr 18	Apr 12
May 15	May 5	May 4	Apr 28
May 31	May 21	May 20	May 14
Jun 16	Jun 6	Jun 5	May 30
Jul 2	Jun 22	Jun 21	Jun 15
Jul 18	Jul 8	Jul 7	Jul 1
Aug 3	Jul 24	Jul 23	Jul 17
Aug 19	Aug 9	Aug 8	Aug 2
Sep 4	Aug 25	Aug 24	Aug 18
Sep 20	Sep 10	Sep 9	Sep 3
Oct 6	Sep 26	Sep 25	Sep 19
Oct 22	Oct 12	Oct 11	Oct 5
Nov 7	Oct 28	Oct 27	Oct 21
Nov 23	Nov 13	Nov 12	Nov 6
Dec 9	Nov 29	Nov 28	Nov 22
Dec 25	Dec 15	Dec 14	Dec 8
Â 8			
Â	Dec 31	Dec 30	Dec 24

Table 23. Specifications of the Terra Spacecraft

Orbit inclination:	98.3 degrees from the Equator
Orbit period:	98.88 minutes
Equator crossing:	10.30 a.m. (north to south)
Ground track repeat cycle:	16 days, i.e. every 16 days (or 233 orbits) the pattern of orbits repeats itself
Builder:	Lockheed Martin

21.1 ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer

Scientists use ASTER data to create detailed maps of land surface temperature, emissivity, reflectance, and elevation[20.2]. 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 (VNIR/Visible & Near InfraRed, SWIR/ Short Wave InfraRed and TIR / Thermal InfraRed) are pointable in the crosstrack direction. Given its high resolution and its ability to change viewing angles, ASTER will produce stereoscopic images and detailed terrain height models.

Table 24. **ASTER Instrument Characteristics**

Characteristic	VNIR	SWIR	TIR
Spectral Range	Band 1: 0.52 - 0.60 µm Nadir looking	Band 4: 1.600 - 1.700 µm	Band 10: 8.125 - 8.475 µm
	Band 2: 0.63 - 0.69 µm Nadir looking	Band 5: 2.145 - 2.185 µm	Band 11: 8.475 - 8.825 µm
	Band 3: 0.76 - 0.86 µm Nadir looking	Band 6: 2.185 - 2.225 µm	Band 12: 8.925 - 9.275 µm
	Band 3: 0.76 - 0.86 µm Backward looking	Band 7: 2.235 - 2.285 µm	Band 13: 10.25 - 10.95 µm
		Band 8: 2.295 - 2.365 µm	Band 14: 10.95 - 11.65 µm
		Band 9: 2.360 - 2.430 µm	
Ground Resolution	15 m	30m	90m
Data Rate (Mbits/sec)	62	23	4.2
Cross-track Pointing (deg.)	±24	±8.55	±8.55
Cross-track Pointing (km)	±318	±116	±116
Swath Width (km)	60	60	60
Detector Type	Si	PtSi-Si	HgCdTe
Quantization (bits)	8	8	12

ASTER is an on-demand instrument. This means that data will only be acquired over a location if a request has been submitted to observe that area. Any data that ASTER has already acquired are available to all by ordering those data from the Earth Observing System Data Gateway (EDG). To request that ASTER acquire new data see instructions below. Higher level data products are only produced on demand; instructions for requesting these products are described below. Processing of level 1A data to level 1B is provided through the Japanese ASTER Ground Data System (see below).

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.

Sample proposed researches applying ASTER data are as follows.

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

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

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

Atmosphere

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

Table 25. ASTER Observing Modes

Observing mode	TIR	SWIR	VNIR		Typical Observing Targets
			V1/2	V3N/B	
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 ASTERÕs VNIR or SWIR bands.
- Some targets may require repetitive observations on short time scales. The VNIR telescope has a +/-24¡ cross-track pointing capability (TIR and SWIR have only +/-8.55¡), 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.

Instrument activities

The ASTER Scheduler will generate sequences of Òinstrument activities.Ó 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 timestep.

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 EarthÕs dark side. Long-term calibrations of TIR are observations of a variable-temperature on-board blackbody.

21.1.1 VNIR:

The VNIR subsystem[20.4] consists of two independent telescope assemblies to minimize image distortion in the forward and nadir looking telescopes. The detectors for each of the bands listed in Table II consists of 5000 element silicon charge coupled detectors (CCD's). Only 4000 of these detectors are used at any one time. A time lag occurs between the acquisition of the forward image and the nadir image. During this time earth rotation displaces the image center. The VNIR subsystem automatically extracts the correct 4000 pixels based on orbit position information supplied by the EOS platform.

The VNIR optical system is a reflecting-refracting improved Schmidt design. The forward looking telescope focal plane contains only a single detector array (Band 3 of Table II) and uses an interference filter for wavelength discrimination. The focal plane of the nadir telescope contains 3 line arrays (Bands 1-3 of Table II) and uses a dichroic prism and interference filters for spectral separation allowing all three bands to view the same area simultaneously. The telescope and detectors are maintained at 296 + 3K using thermal control and cooling from a platform provided cold plate. On-board calibration of the two VNIR telescopes is accomplished with either of two independent calibration devices for each telescope.

The radiation source is a halogen lamp. A diverging beam from the lamp filament is input to the first optical element (Schmidt corrector) of the telescope subsystem filling part of the aperture. The detector elements are uniformly irradiated by this beam. In each calibration device, two silicon photo-diodes are used to monitor the radiance of the lamp. One photo-diode monitors the filament directly and the second monitors the calibration beam just in front of the first optical element of the telescope. The temperature of the lamp base and the photo-diodes is also monitored. Provision for electrical calibration of the electronic components is also provided.

The system signal-to-noise is controlled by specifying the NE delta rho to be < 0.5% referenced to a diffuse target with a 70% albedo at the equator during equinox. The absolute radiometric accuracy is to be + 4% or better.

The VNIR subsystem produces by far the highest data rate of the three ASTER imaging subsystems. With all four bands operating (3 nadir and 1 forward) the data rate including image data, supplemental information and subsystem engineering data is 62 Mbps.

21.1.2 SWIR

The SWIR subsystem[20.5] uses a single aspheric refracting telescope. The detector in each of the six bands is a Platinum Silicide-Silicon (PtSi-Si) Schottky barrier linear array cooled to 80K. Cooling is provided by a split Stirling cycle cryocooler with opposed compressors and an active balancer to compensate for the expander displacer. The on-orbit design life of this cooler is to be 50,000 hours. Although ASTER will operate with a low duty cycle (8% average data collection time) the cryocooler will operate continuously because the cool-down and stabilization time is long. No cyrocooler has yet demonstrated this length of performance and the development of this long-life cooler is one of several major technical challenges facing the ASTER team.

The cryocooler is a major source of heat. Because the cooler is attached to the SWIR telescope, which must be free to move to provide cross-track pointing, this heat cannot be removed using a platform provided cold plate. This heat is transferred to a local radiator attached to the cooler compressor and radiated to space.

Six optical bandpass filters are used to provide spectral separation. No prisms or dichroic elements are used for this purpose. A calibration device similar to that used for the VNIR subsystem is used for inflight calibration. The exception is that the SWIR subsystem has only one such device.

The NE delta rho will vary from 0.5 to 1.3% across the bands from short to long wavelength. Since bands 5-9 are narrower than those used in developing the conceptual design. The absolute radiometric accuracy is to be +4% or better. The combined data rate for all six SWIR bands, including supplementary telemetry and engineering telemetry, is 23 Mbps.

Components

- Cryocooler- The platinum Silicide-Silicon Schottky barrier linear detector array in each of the six SWIR channels are cooled to 80 K using a mechanical split Stirling cycle cooler of long life and low vibration design.
- Pointing Module - The pointing mirror can point +/- 8.54 degrees from the nadir direction to allow coverage of any point on the earth over the spacecraft's 16 day mapping cycle. This mirror is also periodically used to direct light from either of two calibration lamps into the subsystem's telescope.
- Telescope- The SWIR subsystem uses a single fixed aspheric refracting telescope.

21.1.3 TIR

The TIR subsystem uses a Newtonian catadioptric system with an aspheric primary mirror and lenses for aberration correction. Unlike the VNIR and SWIR telescopes, the telescope of the TIR subsystem is fixed with pointing and scanning done by a mirror. Each band uses 10 Mercury-Cadmium-Telluride (HgCdTe) detectors in a staggered array with optical band-pass filters over each detector element. Each detector has its own pre-and post-amplifier for a total of 50. Performance of the system will be improved if photovoltaic detectors can be used. Development of such detectors is a technical challenge.

As with the SWIR subsystem, the TIR subsystem will use a mechanical split Stirling cycle cooler for maintaining the detectors at 80K. In this case, since the cooler is fixed, the waste heat it generates will be removed using a platform supplied cold plate.

The scanning mirror functions both for scanning and pointing. In the scanning mode the mirror oscillates at about 7 Hz. For calibration, the scanning mirror rotates 180 degrees from the nadir position to view an internal black body, which can be heated or cooled. The scanning/pointing mirror design precludes a view of cold space, so at any one time only a one-point temperature calibration can be effected. The system does contain a temperature controlled and monitored chopper to remove low frequency drift. In flight, a single point calibration can be done frequently (e.g., every observation) if necessary. On a less frequent interval, the black body may be cooled or heated (to a maximum temperature of 340K) to provide a multi-point thermal calibration. Facility for electrical calibration of the post-amplifiers is also provided. Another major technical challenge facing the ASTER team is to establish before flight that the elements of the in-flight calibration and subsystem design will permit high quality accurate thermal radiometry.

For the TIR subsystem, the signal-to-noise can be expressed in terms of an NE delta T. The requirement is that the NE delta T be less than 0.3K for all bands with a design goal of less than 0.2K. The signal reference for NE delta T is a blackbody emitter at 300K. The accuracy requirements on the TIR subsystem are given for each of several brightness temperature ranges as follows: 200 - 240K, 3K; 240 - 270K, 2K; 270 - 340K, 1K; and 340 - 370K, 2K.

The total data rate for the TIR subsystem, including supplementary telemetry and engineering telemetry, is 4.2 Mbps. Because the TIR subsystem can return useful data both day and night, the duty cycle for this subsystem has been set at 16%. The cryocooler, like that of the SWIR subsystem, will operate with a 100% duty cycle.

21.2 CERES Clouds and the Earth's Radiant Energy System

There are two identical CERES instruments aboard Terra that measure the Earth's total radiation budget and provide cloud property estimates that enable scientists to assess clouds' roles in radiative fluxes from the surface to the top of the atmosphere. One CERES instrument 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), while 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.

CERES has four main objectives:

- Provide a continuation of the ERBE record of radiative fluxes at the top of the atmosphere (TOA), analyzed using the same algorithms that produced the ERBE data.
- Double the accuracy of estimates of radiative fluxes at TOA and the Earth's surface.
- Provide the first long-term global estimates of the radiative fluxes within the Earth's atmosphere.
- Provide cloud property estimates that are consistent with the radiative fluxes from surface to TOA.

Technical Specifications

Sun-synchronous Orbits: 705 km altitude, 10:30 a.m. descending node (Terra) or 1:30 p.m.ascending node (PM-1), near-polar; 350 km altitude, 35° inclination (TRMM)

Spectral Channels: Solar Reflected Radiation (Shortwave): 0.3 - 5.0 µm

Window: 8 - 12 µm

Total: 0.3 to > 100 µm

Swath Dimensions: Limb to limb

Angular Sampling: Cross-track scan and 360° azimuth biaxial scan

Spatial Resolution: 20 km at nadir (10 km for TRMM)

Mass: 45 kg

Duty Cycle: 100%

Power: 45 W

Data Rate: 10 kbps

Size: 60 x 60 x 70 cm (deployed)

Design Life: 6 years

CERES is a scanning broadband radiometer[20.6] that measures reflected sunlight and emitted thermal energy from the surface of the Earth and the atmosphere. The radiometer is made up of three sensors, each with its own telescope mounted on a gimbaled platform that continuously scans across the Earth in a 6.6-second cycle.

21.3 Multi-angle Imaging Spectro-Radiometer (MISR)

MISR[20.7] measures top-of-atmosphere, cloud and surface angular reflectance functions, and measures surface BRDF, aerosol, and vegetation properties using four spectral bands in each of nine pushbroom imaging cameras oriented at different angles along-track. The detectors are CCDS, the filters are interference qw.

The details of how sunlight is scattered by forests, deserts, snow- and ice-covered surfaces, cumulus, stratus, and cirrus clouds, and smoke from forest fires, soot, and other by-products of industry -- all affect our climate.

Most satellite instruments look only straight down, or toward the edge of the planet. To fully understand Earth's climate, and to determine how it may be changing, we need to know the amount of sunlight that is scattered in different directions under natural conditions. MISR is a new type of instrument designed to address this need — it will view the Earth with cameras pointed at nine different angles. One camera points toward nadir, and the others provide forward and aftward view angles, at the Earth's surface, of 26.1°, 45.6°, 60.0°, and 70.5°. 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).

To accomplish its objective it will measure earth's brightness in 4 spectral bands, at each of 9 look angles spread out in forward and aft directions along the flight path. Spatial samples are acquired every 275 meters. Over a period of 7 mins a 360km wide swath of earth comes into view at all 9 angles. Global coverage with the satellite MISR will be acquired once every 9 days at the equator, the nominal mission lifetime is 6 years. The Jet Propulsion Laboratory in Pasadena, California is building MISR for NASA. MISR is one of five instruments scheduled to be launched into polar orbit aboard NASA's Terra spacecraft in August 1999. The spacecraft will fly in a "sun-synchronous" orbit, designed so that it crosses the equator every 98 minutes, always at 10:30 a.m. local time, as Earth rotates below.

Table 26. Specifications of the MISR Instrument

Mission life	6 years
Instrument mass	148 kg
Instrument powe	Approximately 117 W peak, 75 W average
Data rate	3.3 Megabits/second average, 9.0 Megabits/second peak
Global coverage time	Every 9 days, with repeat coverage between 2 and 9 days
	depending on latitude
Crosstrack swath width	360 km common overlap of all 9 cameras
	Fore, nadir, and aft viewing cameras have names ending
Nine pushbroom cameras	with letters f, n, a respectively and four camera designs
	with increasing viewing angle
View angles	0, 26.1, 45.6, 60.0, and 70.5 degrees
Spectral coverage	4 bands (blue, green, red, and near-infrared)
Detectors	Charge Coupled Devices (CCDs), each camera with 4
	independent line arrays (one per filter)
Radiometric accuracy	3% at maximum signal
Detector (focal plane)	-5 ±0.1 degrees C (cooled by thermo-electric cooler)
temperature	
Temperature of main structure	+5 degrees C
Builder	Jet Propulsion Laboratory, Pasadena, California, U.S.A.

MISR is capable of taking image in two different resolution modes[20.8]. In Local Mode, selected targets 300km long are observed at the max resolution of 275m (pixel to pixel) in all cameras (250 meters across track for the nadir camera.)

However the data transmission rate would be excessive if the instrument worked continuously at this max resolution. Therefore away from these selected targets (there will typically be only 6 of these each day) the instrument operates in Global Mode, where the earth is observed continuously at lower resolutions. This is achieved by averaging the adjacent samples (in both cross-track & along-track directions on the ground). This averaging can be 4 by 4, 1 by 4 or 2 by 2 pixels, and can be individually selected for each camera and spectral band.

MISR will collect multi-angle as well as multi-spectral data never before obtained by satellite instruments. The additional information contained in these data will make it possible to set limits on particle size and composition, as well as aerosol amount, measured over ocean. The new data will also be used to derive aerosol properties in the atmosphere over heterogeneous land and dense dark vegetation.

With just two cameras, MISR can also measure distances by the same principle. Using all nine cameras, it will be possible to get even more information about cloud structure. MISR will retrieve cloud heights routinely, and for special case studies, will derive details about cloud shape, cloud thickness, and the roughness of cloud tops

Natural land surfaces display a wide range of albedo values. In the climatologically important polar regions, albedos of the ice-and-snow-covered areas (known as the cryosphere) are continuously modified by natural processes and by human sources of pollution. This affects the amount of solar energy reflected by the surface. A "feedback mechanism" between the atmosphere and the cryosphere results -- if a snow-covered surface is partly blackened by soot particles, for example, the surface will absorb more solar energy, which may melt the snow, and darken the surface further. Conversely, if a surface is whitened by a deposit of fresh snow, it will reflect more sunlight than before, helping to preserve the snow cover.

For vegetated terrain, knowing the albedo more accurately may lead to improved estimates of photosynthesis, transpiration rates, and the amount of absorbed photosynthetically active radiation (PAR). These parameters play an important role in models of the way surface vegetation and the atmosphere interact.

Most satellite instruments look at Earth only in a single direction, usually vertically downward. But, except for movie-screen material, common surfaces reflect different amounts of radiation in different directions. So to make good measurements of the total reflected flux, Earth's surface must be viewed from many directions. This is one way the multiple view angles of MISR will improve the our knowledge of Earth's albedo.

In addition to telling about biophysical fluxes, the albedos of vegetation canopies may contain some information about the structural state of the vegetation, such as: the amount of leaf area, leaf orientation statistics, the percentage of stems, branches, trunks, etc. Researchers have argued, on the basis of field measurements and 3-dimensional canopy modeling, that the directional reflectance characteristics (i.e., how much solar radiation is scattered from the canopy in a particular direction), is diagnostic of such canopy structure variables.

MISR will provide data sets of these angular reflectance "signatures" for many classes of surface cover. These angular "signatures" have the potential for improving the process of classifying and monitoring various "biome types" on a global basis.

The concentrations of chlorophyll "a" and phaeophytin "a" pigments in phytoplankton have been used to estimate the rate of biological productivity in ocean waters. The determination of phytoplankton pigment concentration is based on water-leaving radiances, known as ocean color, in several spectral bands in the visible and near-infrared. The primary instrument for assessing ocean productivity on the EOS spacecraft is MODIS. However, due to sun glint over a portion of the MODIS swath as the satellite passes over the equator, some imagery will be lost. This gap in the ocean color data will be partially filled by MISR.

MISR collects data only on the daylit side of the Earth. During each orbit of Earth, MISR obtains a swath of imagery that is 360 km wide and about 20,000 km long. Changes in the reflectance of Earth's surface during the vegetation growing season are observable on weekly time scales. In accordance with this, the selected MISR viewing swath width of 360 km allows viewing the entire Earth's surface in a period of 9 days, -- very close to one week.

The time between acquisition of successive lines of MISR data (the line repeat time) is the same for all cameras, with an average of 275 meters of downtrack displacement. For the 705 km orbit, this requires a repeat time of 40.8 milliseconds. MISR is capable of taking image data in two different spatial resolution modes. In Local Mode, selected targets 300 km long are observed at the maximum resolution of 275 meters (pixel to pixel) in all cameras (250 meters across track for the nadir camera.)

21.4 Moderate-resolution Imaging Spectroradiometer (MODIS)

MODIS Technical Specifications[20.9]

Orbit: 705 km, 10:30 a.m. descending node (AM-1) or 1:30 p.m. ascending node (PM-1), sun-synchronous, near-polar, circular

Scan Rate: 20.3 rpm, cross track

Swath Dimensions: 2330 km (cross track) by 10 km (along track at nadir)

Telescope: 17.78-cm diam. off-axis, afocal (collimated), with intermediate field stop

Size: 1.0 x 1.6 x 1.0 m

Weight: 228.7 kg

Power: 162.5 W (single orbit average)

Data Rate: 10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)

Quantization: 12 bits

Spatial Resolution: 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36)

Design Life: 6 years

With its sweeping 2,330-km-wide viewing swath, MODIS sees every point on our world every 1-2 days in 36 discrete spectral bands. Consequently, MODIS greatly improves upon the heritage of the NOAA Advanced Very High Resolution Radiometer (AVHRR) and tracks a wider array of the earth's vital signs than any other Terra sensor. For instance, the sensor measures the percent of the planet's surface that is covered by clouds almost every day. This wide spatial coverage will enable MODIS, together with MISR and CERES, to determine the impact of clouds and aerosols on the Earth's energy budget. The sensor has an unprecedented channel (centered at 1.375 microns) for detection of wispy cirrus clouds—believed to contribute to global warming by trapping heat emitted from the surface. Conversely, cumulus clouds and aerosols are thought to have a cooling effect on the Earth's surface by reflecting and absorbing incoming sunlight.

Almost every day over the entire globe, the sensor monitors changes on the land surface, thereby building upon and extending the heritage begun by Landsat. MODIS maps the areal extent of snow and ice brought by winter storms and frigid temperatures. The sensor observes the "green wave" that sweeps across continents as winter gives way to spring and vegetation blooms in response. It sees where and when disasters strike—such as volcanic eruptions, floods, severe storms, droughts, and wildfires—and will hopefully help people get out of harm's way. MODIS' bands are particularly sensitive to fires; they can distinguish flaming from smoldering burns and provide better estimates of the amounts of aerosols and gases fires release into the atmosphere.

MODIS sees changes in the Pacific phytoplankton populations that may signal the onset of the famous El Niño/La Nina climatic siblings well ahead of their arrival. In turn, by coupling its sea surface temperature and ocean color measurements, MODIS will observe the impacts El Niño and La Nina have on the microscopic marine plant. MODIS also has a unique new channel for measuring chlorophyll fluorescence. All plants bombarded with light begin to glow, or fluoresce, but in wavelengths that our eyes cannot see. The more plants fluoresce, the less energy they are using for photosynthesis. Thus, MODIS not only maps the distribution of phytoplankton, it also helps us gauge its health.

Data will also be available at the Distributed Active Archive Centers (DAAC's) approximately 90 to 120 days after first light[20.10]. These data will improve our understanding of global dynamics and processes occurring on the land, in the ocean, and in the lower atmosphere. For information about data availability, products, and sources, see the Data section.

The data from MODIS will improve our understanding of global dynamics and processes occurring on the land, in the oceans, and in the lower atmosphere. MODIS will play a vital role in the development of validated, global, interactive Earth system models able to predict global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment.

MODIS Instrument Status

The direct broadcast of MODIS data commences in a near-continuous mode at 4:00pm EDT today (April 28th). Direct broadcast service will be provided continuously around the globe, except when Terra is within view of one of the three deep-space network stations. Operating in this mode, results in the direct broadcast service being turned-off for approximately 90 minutes a day.

Tests are presently being planned to radiate the Goldstone DSN site, to demonstrate that Terra's direct broadcast service does not interfere with DSN command and control. Following the successful completion of that test, direct broadcast service will remain on 24 hours a day.

In June of 1998 NASA will launch the EOS-AM spacecraft[20.11], one of a series of spacecraft intended to collect information about the current state of the Earth's environment. The MODerate resolution Imaging Spectroradiometer (MODIS), the flagship instrument aboard EOS-AM, images the earth's atmosphere and surface in visual and infrared wavelengths with 12-bit precision. Data is collected for 36 spectral bands at three resolutions: 1000, 500, and 250 meters/pixel. MODIS peak data production rate is 11Mbits/sec.

EOS-AM telemetry systems can link to earth via TDRSS or by direct transmission to ground stations. The incoming data stream is processed by the EOS Data and Operations System (EDOS) and sent by network to Distributed Active Archive Centers, or DAACs, where it is stored, processed, and made available to the user community by the EOS Core System (ECS). ECS processing consists of many steps, each resulting in a data product designed for a specific purpose. A data product may be distributed directly to the user community used as input for later processing steps, or both.

21.5 Measurements of Pollution in the Troposphere (MOPITT)

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. Methane is a greenhouse gas with nearly 30 times the heat-trapping capacity of carbon dioxide; it is known to leak from swamps, livestock herds, and biomass burning, but the total output from these individual sources is unknown.

Carbon monoxide, which is expelled from factories, cars, and forest fires, hinders the atmosphere's natural ability to rid itself of harmful pollutants. MOPITT is the first satellite sensor to use gas correlation spectroscopy. The sensor measures emitted and reflected radiance from the Earth in three spectral bands. As this light enters the sensor, it passes along two different paths through onboard containers of carbon monoxide and methane. The different paths absorb different amounts of energy, leading to small differences in the resulting signals that correlate with the presence of these gases in the atmosphere. MOPITT's spatial resolution is 22 km at nadir and it 'sees' the Earth in swaths that are 640 km wide. Moreover, it can measure the concentrations of carbon monoxide in 5-km layers down a vertical column of atmosphere, to help scientists track the gas back to its sources.

The MOPITT instrument

- prime contractor COM DEV
- one of five instruments aboard Terra; one Japanese, three American, one Canadian
- opportunity for a second flight: pportunity around 2003
- 8-channel correlation spectrometer; 8 IR detectors cooled to 100 Kelvin; on-board calibration sources and cold space view calibration; cross-track scanning
- size: 103 x 73 x 44 cm; mass 182 kg; power 250 watts average; date rate 25 kbps average; horizontal resolution 22 x 22 km; vertical resolution surface to 15 km in 5 km layers

During the five-year mission, MOPITT[20.12] will continuously scan the atmosphere below it to provide the world with the first long-term, global measurements of carbon monoxide and methane gas levels in the lower atmosphere. Together with other EOS measurements, the data will help form the first long-term integrated measurements of the Earth's land, air, water and life processes. The database will be used by scientists to predict long-term effects of pollution, understand the increase of ozone in the lower atmosphere, and guide the evaluation and application of shorter-term pollution controls.

We all live in the troposphere-the region of the atmosphere from the ground to about 15 km – but measurements of carbon monoxide and methane in this region have so far been quite limited and localized. MOPITT - a very precise, high performance instrument-will be the first probe to make detailed measurements of both gases around the entire globe over an extended period of time, covering every location around the globe every four days over the course of its five-year lifetime.

Measurements of these gases are made by intercepting the infra-red radiation coming from the planet and then isolating the required signals[20.13]. MOPITT is a nadir sounding instrument since this gives the maximal chance of avoiding cloud features, but this implies that it can "see" the surface of the planet and the desired signals must be seen against the background of the surface radiation. The field-of-view of MOPITT is 22 x 22km and it views four fields simultaneously by the use of a 4 x 1 array of detector elements. The field of view is also continuously scanned through a swath about 600km[20.14] wide as the instrument moves along the orbit increasing both the spatial coverage of the instrument and the chance of finding gaps in the cloud coverage.

22 Tropical Rainfall Measuring Mission (TRMM)

TRMM Science Objectives[21]

- Obtain and study multi-year science data sets of tropical and subtropical rainfall measurements
- Understand how interactions between the sea, air and land masses produce changes in global rainfall and climate
- Improve modeling of tropical rainfall processes and their influence on global circulation in order to predict rainfall and variability at various periods of time
- Test, evaluate and improve satellite rainfall measurement techniques.

Tropical rainfall comprises more than two thirds of global rainfall. It is the primary distributor of heat through the circulation of the atmosphere. Understanding rainfall and its variability is crucial to understanding and predicting global climate change. Our current knowledge of rainfall is poor, especially over the oceans. By use of a low-altitude orbit of 217 miles (350 kilometers), TRMM's complement of state-of-the-art instruments will provide more accurate measurements. These new measurements will increase our knowledge of how rainfall releases heat energy to drive atmospheric circulation.

TRMM's orbit will range between 35 degrees north and 35 degrees south of the equator, allowing TRMM to fly over each position on the Earth's surface at a different local time each day. Scientists can use data from this kind of orbit to calculate rain variations over a 24-hour period; the result will be a data set vastly more informative than any now available.

TRMM is a joint project between the United States and Japan. The National Space Development Agency of Japan (NASDA) will provide the Precipitation Radar (PR) and an H-II rocket to launch the TRMM observatory in Fall 1997 for a three year mission. NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Md., will provide the observatory, four instruments, integration and test of the observatory and will operate the TRMM satellite via the Tracking and Data Relay Satellite System (TDRSS).

A gallium arsenide solar array/nickel cadmium battery power subsystem will provide 1,100 watts of load power to the satellite. A three-axis attitude control subsystem will stabilize the observatory and keep the instruments pointing toward Earth to within 0.2 degrees. A command and data handling subsystem will provide onboard commanding, data collection, processing and storage. This subsystem will use state-of-the-art technology employing a fiber optic data bus and solid state recorders. Data for each orbit will be stored on board and transmitted to the ground by the communication subsystem through TDRSS once per orbit.

The TRMM orbit[21.1] is circular, non-sun-synchronous, at an altitude of 350 km and an inclination of 35 degrees to the Equator. This orbit provides extensive coverage in the tropics and allows each location to be covered at a different local time each day. This kind of sampling will enable the analysis of the diurnal cycle of precipitation.

22.1 Precipitation Radar (PR)

The PR[21.2] will determine the vertical distribution of precipitation by measuring the "radar reflectivity" of the cloud systems and the weakening of a signal as it passes through the precipitation. A unique feature of the PR is the measurement of rain over land, where passive microwave channels have more difficulty.

The Precipitation Radar will be the first spaceborne instrument designed to provide three-dimensional maps of storm structure. The measurements should yield invaluable information on the intensity and distribution of the rain, on the rain type, on the storm depth and on the height at which the snow melts into rain. The estimates of the heat released into the atmosphere at different heights based on these measurements can be used to improve models of the global atmospheric circulation.

The Precipitation Radar has a horizontal resolution at the ground of about 2.5 miles (four kilometers) and a swath width of 137 miles (220 kilometers). One of its most important features will be its ability to provide vertical profiles of the rain and snow from the surface up to a height of about 12 miles (20 kilometers). The Precipitation Radar will be able to detect fairly light rain rates down to about .027 inches (0.7 millimeters) per hour.

At intense rain rates, where the attenuation effects can be strong, new methods of data processing have been developed that help correct for this effect. The Precipitation Radar is able to separate out rain echoes for vertical sample sizes of about 820 feet (250 meters) when looking straight down. It will carry out all these measurements while using only 224 watts of electric power—the power of just a few household light bulbs. The Precipitation Radar was built by the National Space Development Agency (NASDA) of Japan as part of its contribution to the joint US/Japan Tropical Rainfall Measuring Mission (TRMM).

Power

A fundamental requirement is ensuring that the spaceborne radar has enough power to detect the weak return echo from the raindrops when seen from TRMM's orbital height of 215 miles (350 kilometers) above the Earth.

22.2 TRMM Microwave Imager (TMI)

The TRMM Microwave Imager (TMI)[21.3] is a multi-channel radiometer, whose signals in combination can measure rainfall quite accurately over oceans and somewhat less accurately over the land. The TMI and PR data will yield the primary precipitation data sets.

The Tropical Rainfall Measuring Mission's (TRMM) Microwave Imager (TMI) is a passive microwave sensor designed to provide quantitative rainfall information over a wide swath under the TRMM satellite. By carefully measuring the minute amounts of microwave energy emitted by the Earth and its atmosphere, TMI will be able to quantify the water vapor, the cloud water, and the rainfall intensity in the atmosphere. It is a relatively small instrument that consumes little power. This, combined with the wide swath and the good, quantitative information regarding rainfall make TMI the "workhorse" of the rain-measuring package on Tropical Rainfall Measuring Mission.

22.3 Visible/infrared Radiometer (VIRS)

The Visible and Infrared Scanner (VIRS)[21.4] is one of the primary instruments to be flown aboard the Tropical Rainfall Measuring Mission (TRMM) observatory. VIRS is one of the three instruments in the rain-measuring package and will serve as a very indirect indicator of rainfall. It will also tie in TRMM measurements with other measurements that are made routinely using the meteorological Polar Orbiting Environmental Satellites POES) and those that are made using the Geostationary Operational Environmental Satellites (GOES) operated by the United States.

VIRS, as its name implies, senses radiation coming up from the Earth in five spectral regions, ranging from visible to infrared, or 0.63 to 12 micrometers. VIRS is included in the primary instrument package for two reasons. First is its ability to deliniate rainfall. The second, and even more important reason, is to serve as a transfer standard to other measurements that are made routinely using POES and GOES satellites. The intensity of the radiation in the various spectral regions (or bands) can be used to determine the brightness (visible and near infrared) or temperature (infrared) of the source.

If the sky is clear, the temperature will correspond to that of the surface of the Earth, and if there are clouds, the temperature will tend to be that of the cloud tops. Colder temperatures will produce greater intensities in the shorter wavelength bands, and warmer temperatures will produce greater intensities in the longer wavelength bands. Since colder clouds occur at higher altitudes the measured temperatures are useful as indicators of cloud heights, and the highest clouds can be associated with the presence of rain.

A variety of techniques use the Infrared (IR) images to estimate precipitation. Higher cloud tops are positively correlated with precipitation for convective clouds (generally thunderstorms) which dominate tropical (and therefore global) precipitation accumulations. One notable exception to this rule of thumb are the high cirrus clouds that generally flow out of thunderstorms. These cirrus clouds are high and therefore "cold" in the infrared observations but they do not rain. To differentiate these cirrus clouds from water clouds (cumulonimbus), a technique which involves comparing the two infrared channels at 10.8 and 12.0 micrometers can be employed. Nonetheless, IR techniques usually have significant errors for instantaneous rainfall estimates.

The strength of the IR observations lies in the ability to monitor the clouds continuously from geostationary altitude. By comparing the visible and infrared observations on the Tropical Rainfall Measuring Mission with the rainfall estimates of the TRMM Microwave Imager and Precipitation Radar, it is hoped that much more can be learned about the relationship of the cloud tops as seen from geostationary orbit.

VIRS uses a rotating mirror to scan across the track of the TRMM observatory, thus sweeping out a region 720 kilometers wide as the observatory proceeds along its orbit. Looking straight down (nadir), VIRS can pick out individual cloud features as small as two kilometers.

22.4 Lightning Imaging Sensor (LIS)

The Lightning Imaging Sensor[21.5] is a small, highly sophisticated instrument that will detect and locate lightning over the tropical region of the globe. Looking down from a vantage point aboard the Tropical Rainfall Measuring Mission (TRMM) observatory, 218 miles (350 kilometers) above the Earth, the sensor will provide information that could lead to future advanced lightning sensors capable of significantly improving weather "nowcasting."

Using a vantage point in space, the Lightning Imaging Sensor promises to expand scientists' capabilities for surveying lightning and thunderstorm activity on a global scale. It will help pave the way for future geostationary lightning mappers. From their stationary position in orbit, these future lightning sensors would provide continuous coverage of the continental United States, nearby oceans and parts of Central America. Researchers hope that future sensors will deliver day and night lightning information to a forecaster's work-station within 30 seconds of occurrence providing an invaluable tool for storm "nowcasting" as well as for issuing severe storm warnings.

The lightning detector is a compact combination of optical and electronic elements including a staring imager capable of locating and detecting lightning within individual storms. The imager's field of view allows the sensor to observe a point on the Earth or a cloud for 80 seconds, a sufficient time to estimate the flashing rate, which tells researchers whether a storm is growing or decaying.

The sensor was developed by the Global Hydrology Center at NASA's Marshall Space Flight Center in Huntsville, Ala., in conjunction with Lockheed Martin, Palo Alto, Calif., and Kaiser Electro Optics, Carlsbad, Calif. The sensor will provide information on cloud characteristics, storm dynamics, and seasonal as well as yearly variability of thunderstorms.

The Lightning Imaging Sensor will be three times more sensitive than a predecessor instrument known as the Optical Transient Detector, a lightning detector already orbiting the Earth. The sensor will study both day and night cloud-to-ground, cloud-to-cloud and intra-cloud lightning and its distribution around the globe.

The staring imager is made of an expanded optics lens system which provides a wide field of view and a narrow-band filter which minimizes background light. A highspeed, charge-coupled device detection array behaves similarly to the retina of the human eye by creating an image of the lightning event and the background scene. A real-time event processor then extracts the signal, thus determining when a lightning flash occurs.

The optics lens system allows lightning detection even in the presence of bright, sunlit clouds. Weak lightning signals that occur during the day are hard to detect because of background illumination. This system will remove the background signal, enabling the detection of 90 percent of all lightning strikes. Data recorded includes the time of a lightning event, its radiant energy, how bright the lightning flash is and an estimate of the lightning location.

The Lightning Imaging Sensor is approximately eight inches in diameter and 14 inches high, while the supporting electronics package is about the size of a standard typewriter. Together, the two modules weigh approximately 46 pounds and use about 25 watts of power.

LIS Characteristics[21.6]:

- Swath: 600 x 600 km
- Spatial resolution: 5 km
- Mass: 20 kg
- Duty cycle: 100%
- Power: 33 W
- Data rate: 6 kbps
- Thermal control by: Heater, radiator
- FOV: 80° x 80°
- Instrument IFOV: 0.7°
- Pointing requirements (platform+instrument, 3 s)
  Control: None
  Knowledge: 1 km on ground
  Stability: & Jitter TBD
- Physical size: Sensor head assembly (cylindrical): 20 x 30 cm
  Electronics assembly: 30 x 20 x 30 cm

22.5 Clouds and the Earth's Radiant Energy System (CERES)

The CERES instrument[21.7] is based on NASA Langley's highly successful Earth Radiation Budget Experiment, which used three satellites to provide global energy budget measurements from 1984 to 1993.

CERES will measure the energy at the top of the atmosphere, as well as estimate energy levels within the atmosphere and at the Earth's surface. Using information from very high resolution cloud imaging instruments on the same spacecraft, CERES also will determine cloud properties, including cloud-amount, altitude, thickness, and the size of the cloud particles. All of these measurements are critical for advancing our understanding of the Earth's total climate system and further improving climate prediction models.

Five CERES instruments will be flown on multiple satellites starting with TRMM, followed by a launch on the Earth Observing System (EOS)-AM satellite in 1998 and the EOS-PM satellite in 2000. Follow-up CERES satellite missions are planned to create a continuous 15-year history of highly accurate energy budget and cloud data for enhanced climate analyses.

23 Upper Atmosphere Research Satellite (UARS)

Spacecraft Mission Parameters[22]

Payload Complement = 10 science instruments

Initial Altitude = 600 km (324 nm)

Inclination = 57 deg

Attitude Control = 0.01 deg precision (1 sigma)

Size = 32 ft long, 15 ft diameter (launch configuration)

Weight = Observatory 15000 lbs

Total in STS 17000 lbs

Power = 16 kW orbital average

Data Rate = 32 kbps

Tape Recorders = NASA-Standard (2), 500 megabits each

Communications = 512 kbps, recorder playback 32 kbps, real-time science 1 kbps, engineering 0.125, 1, 2 kbps, command

Launch Vehicle = Space Transport System (STS)

Mission Life = 18 months covering 2 Northern Hemisphere winters (36-month design life).

UARS[22.9] operates 585 km above the Earth in a near circular orbit inclined 57 degrees to the equator. This orbit permits UARS sensors to view up to the 80 degree latitude bands providing essentially global coverage of the stratosphere and mesosphere. This also permits the UARS instrument to make measurements over the full range of local times at all geographic locations approximately every 36 days.

23.1 Solar Ultraviolet Spectral Irradiance Monitor (SUSIM)

The Solar Ultraviolet Spectral Irradiance Monitor (SUSIM)[22.1] is a dual dispersion spectrometer instrument which measures from near-Earth orbit the absolute irradiance of the sun in the ultraviolet (UV) wavelength range of 115 nm to 410 nm.

Solar Measurements

For centuries, the number of sunspots has been observed to vary on an 11-year cycle.Measurements during the last two solar cycles have shown that sunspot numbers and the magnitude of solar UV light are roughly correlated. Solar UV light can only be accurately measured from outside the Earth's atmosphere because this is where most of it is absorbed. The most practical way to observe the sun in the UV over an entire 11-year solar cycle is through a satellite-based instrument.

SUSIM UARS makes measurements over its 115-410 nm wavelength range daily at 1 and 5 nm resolutions and weekly at 0.15 nm resolution. It is hoped through careful and accurate calibrations made both before and during flight that the calibration of the instrument can be maintained to an absolute accuracy of 6% and a relative accuracy of 2% for the duration of a solar cycle.

Atmospheric Measurements

SUSIM UARS also observes occultations of the sun by the Earth's atmosphere. Through comparison of the amount of UV light of selected wavelengths that penetrate the atmosphere as a function of altitude, densities of upper atmosphere UV light absorbers molecular oxygen and ozone are measured.

Data rate: 2.0 kbps.

23.2 SOLar STellar Irradiance Comparison Experiment (SOLSTICE)

Purpose[22.2]

- The SOLar STellar Irradiance Comparison Experiment (SOLSTICE) is to determine solar variability on three basic time scales:
- Short-term variations spanning time periods of minutes to hours (exemplified by solar flares)
- Intermediate-term variations lasting days to weeks (characterized by the solar rotation and the development of active regions)
- Long-term variations (associated with the 11-year sunspot cycle or the 22-year magnetic field cycle).

The instrument will have a high relative accuracy and precision and will follow the short and intermediate-term solar variations at and below the one-percent level.

It is difficult to infer long-term solar variability directly from the SOLSTICE measurements because of the limited lifetime of UARS relative to the solar cycle. However, the unique feature of the SOLSTICE is its ability to compare accurately (to within 1%) the solar irradiance with the ultraviolet flux of bright blue stars. These stars then become the standard against which the solar irradiance is meqasured. Other instruments can remeasure these solar/stellar ratios at all future times. The direct comparison of the future ratios to those obtained by UARS can then be used to infer accurately the long-term variability of our Sun.

The SOLSTICE has a similar objective to the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) instrument but takes a different approach to calibrating the instrument, using a set of bright ultra-violet stars for reference calibration.

Functional Description

The SOLSTICE measures the magnitude of solar spectral irradiance of the total solar disk in the wavelength range 115 to 430 nm. During the daylight portion of each orbit, the Solar Stellar Pointing Platform (SSPP) points the instrument to Sun center and the SOLSTICE performs full wavelength scans. During the nighttime portion of most orbits, the SOLSTICE is reconfigured to use the stellar entrance and exit slits, and the SSPP is pointed to one of the selected calibration stars. The instrument will be in a fixed-wavelength mode and accumulate stellar data for approximately 15 minutes.

To compare accurately the irradiance of the Sun to that of a star, SOLSTICE uses the same optical system for both solar and stellar observations: the same mirrors, the same gratings, and the same detectors. The SOLATICE accomodates the seven to eight orders of magnitude difference between the solar and stellar flux by varying measurement time, spectral bandpass, and the instrument aperture.

Instrument Description

The SOLSTICE consists of a single instrument mounted to the Solar Stellar Pointing Platform (SSPP). The spectrometer includes three separate spectral channels, each with a separate grating and photomultiplier tube detector, to cover the full spectral range 115 to 430 nm. These three channels are stacked so that they share a common wavelength drive and common entrance and exit slit interchange mechanism.

The SSPP platform sun sensor is aligned to the SOLSTICE optic axis and is used to control the attitude of the SSPP for solar pointing. Stellar pointing is open loop using the onboard computer with attitude reference from the spacecraft attitude control subsystem and platform position encoders.

In both solar and stellar configurations, the optical flat is used only to fold the incoming beam. In the solar configuration, the f/100 solar beam is incident through a small entrance aperature (slit), diffracted by the grating, and focused on a small exit slit by the off-axis elliptical mirror. In the stellar configuration, the collimated stellar beam is incident through a large aperature, diffracted by the grating, and focused at a large exit slit at the off-axis ellipse focus. The optical layout is designed to maintain a similar illumination between solar and stellar configurations.

SOLSTICE uses three photomultiplier tubes. Each tube is capactively coupled to its individual Phase Amplifier Discriminator (PAD) unit. The shaped output pulses are available to the counting electronics. The phototubes are of the EMR 510 series. The first is a G-type (cesium iodide photocathode) with a magnesium fluoride window; the second is F-type (cesium telluride photocathode) with a fused-silica window; and the third is an N-type (high temperature bi-alkali photocathode) with a glass window. The G-type is sensitive from 115 to 200 nm, the F-type from 165 to 330 nm, and the N-type from 300 to 650 nm.

The SOLSTICE electronics consists of the three phototubes and pulse counting systems plus the grating control system, command-telemetry interface and synchronization, and motor interface and control. There is also a microprocessor in a bus architecture for executive control and decision making. The microprocessor controls the mose formatting and sequencing of the instrument based on commands presented to it. The data system consists of the photomultiplier tubes and 16-bit pure binary counters. The data are multiplexed into the telemetry stream along with instrument status and bit sync. The grating control logic is a closed-loop motor control system capable of articulating the grating from microprocessor control inputs. The microprocessor has executive control, integration, and data start logic, and has access to the data channels for storage or manipulation.

Instrument Parameters

- Type of Measurement: Full disk solar spectral irradiance.
- Type of Instrument: Three-channel grating spectrometer.
- Geophysical Parameters Determined: Solar electromagnetic energy incident on atmosphere.
- Wavelength Coverage: 115 to 440 newton meters (nm).
- Comments: Uses comparison with set of UV stars for determination of long-term stability.
- Spectral resolution: Solar: 0.12 and 0.25 nm.
- Stellar: 5.0 and 10 nm.
- Instrument weight: 41 lb.
- Average power: 8 watts.
- Data rate: 0.250 kbps.

23.3 Active Cavity Radiometer Irradiance Monitor (ACRIM II)

Purpose[22.3]

The objective of the Active Cavity Radiometer Irradiance Monitor (ACRIM II) is to conduct precise solar total irradiamce monitoring during a period of expected increasing solar activity, approaching the maximum for Solar Cycle 22. The ACRIM II measurements will aid both climatology and solar physics investigations.

The ACRIM II instrument, located on the UARS Solar Stellar Pointing Platform (SSPP), is an important component of the long-term solar irradiance monitoring by the National Climate Program. This program is studying solar irradiance variability and its effect on weather and climate over at least one solar magnetic cycle (about 22 years).

Functional Description

ACRIM II is designed for the continuous measurement of solar total irradiance with uniform sensitivity from the far-ultraviolet to the far-infrared wavelength range with an absolute uncertainty in the International System of Units of 1%, a single sample resolution of 0.012%, and a multiyear internal precision of 5 ppm.

Instrument Description

The ACRIM II instrument uses three Active Cavity Radiometer (ACR) pyrheliometers of the advanced Type V design. The modular design allows for the electronics and sensor module to be mounted separately. Electrical interface to the UARS is made through a Remote Interface Unit (RIU) on the SSPP. Command to, and all data from, the ACRIM II instrument are transmitted via the RIU.

Instrument Parameters

- Type of Measurement: Precise solar total irradiance.
- Type of Instrument: Three Type V Active Cavity Radiometers, one Sun position sensor.
- Parameters Determined: Measures solar total irradiance, 0 to 2000 watts per square meter. Measures instrument solar alignment with 0.1 degrees resolution.
- Wavelength Coverage: 0.001 to 1000 microns.
- Accuracy: 99.9% at solar total irradiance level.
- Precision: 0.012% of full scale for single samples. Phased operation of sensors for stand-alone calibration of degradation yields precision better than 0.005%, over 1-year periods.
- Field of view: 5 degrees with 1-degree tolerance for solar pointing.
- Instrument weight: 52 lb.
- Average power: 5 watts.
- Data rate: 0.5 kbps.

23.4 Cryogenic Limb Array Etalon Spectrometer (CLAES)

- Data rate: 3 kbps.
- Time required to perform measurement: 65 sec nominal
- Distance along spacecraft track: 495 km nominal

CLAES make measurements by looking at infrared emission from cloud particles and trace gases[22.4]

Key to understanding the chlorine chemistry in the polar stratosphere is the measurement of polar stratospheric clouds, chlorine monoxide, and the reservoir gas chlorine nitrate[22.5]. Chlorine nitrate has been measured by the Cryogen Limb Array Etalon Spectrometer, CLAES. CLAES makes measurements by looking at infrared emission from cloud particles and trace gases. CLAES measurements help to show that the polar stratospheric clouds which form in the cold Arctic stratosphere have converted most of the chlorine nitrate into the radical chlorine monoxide. In 1992, UARS measurements showed conclusively that an Arctic ozone hole is beginning to form.

The Cryogenic Limb Array Etalon Spectrometer (CLAES) measured vertical profiles of temperature and concentrations of ozone, methane, water vapor, nitrogen oxides, and other important species, including CFCs, in the stratosphere. CLAES also maps the horizontal and vertical distributions of aerosols in the stratosphere. These measurements are analyzed to better understand the photochemical, radiative, and dynamical processes taking place in the ozone layer.

CLAES was built by an instrument team based at Lockheed Palo Alto and launched on the Upper Atmosphere Research Satellite (UARS) on 12th September 1991. CLAES had a design lifetime of 18 months, beginning on 1st October 1991 and ceasing operations on 5th May 1993. The Principal Investigator is Dr Aidan E. Roche.

CLAES makes measurements of thermal emission from the Earth's limb in a number of spectral regions which are then used to derive stratospheric altitude profiles of temperature, pressure, ozone (O_3), water vapour (H_2O), methane (CH_4), nitrous oxide (N_2O), nitrogen oxide (NO), nitrogen dioxide (NO_2), dinitrogen pentoxide (N_2O_5), nitric acid (HNO_3), chlorine nitrate ($ClONO_2$), $CFCl_3$, CF_2Cl_2. Aerosol extinction coefficients are also calculated for each spectral region. The data coverage extends from 80°S to 80°N, but at any one time this is restricted to 34°S to 80°N or 34°N to 80°S. The vertical coverage of the measurements is from the tropopause to the lower mesosphere (10-60km).

Instrument Description

CLAES is a cryogenically cooled infrared spectrometer which measures thermal emission from the Earth's limb. Characteristic vibration-rotation spectral line radiances are obtained between 3.5 and 13 microns and these are then fed into retrieval algorithms to obtain pressures, temperatures and species mixing ratios.

The instrument observes the Earth's limb in a direction normal to the orbital track on the anti-sun side of the spacecraft.The tangent point is a great circle distance of approximately 23° (2500km) away from the sub-satellite track, and is swept horizontally along the limb by the motion of the spacecraft. The field of view of the instrument is centred on a point at approximately 35km altitude at the limb tangent point. The optical design allows observations to be performed over an altitude range of 10 to 60 km with a spacing of 2.5km.

The instrument observes radiation through a 6-inch aperture Mersene telescope. The altitude range of the observations is adjusted by means of a motorised limb acquisition and adjustment mirror (LAAM). The CLAES spectrometer consists of one of four tilt-scanned Fabry-Perot etalons which are used in conjunction with one or more of nine interference filters which define the spectral channels. Radiation emerging from the spectrometer is focussed onto the focal plane assembly (FPA) consisting of two linear arrays of SiGa detectors. The main array has 20 elements and provides 2.5 km spacing at the limb. A separate three-element array is used with the 3.5 mm HCL channel, which sacrifices vertical resolution to increase signal-to-noise for the weak atmospheric thermal emissions at this short wavelength.

CLAES carries a full aperture black body calibration source on the inside of the telescope aperture door, which is passively heated by radiation from the Earth when the door is open during data acquisition. When the door is closed the black body slowly cools allowing an end-to-end absolute radiometric calibration over a large part of the instrument's dynamic range.

The Cryogens which slowly evaporated as they cooled the instrument, were designed to last about 18 months in orbit, allowing CLAES to make scientific measurements from 1st October 1991 through 5th May 1993, when the cryogens finally evaporated and the instrument warmed up.

Measurement Techniques

Spectroscopy of the incoming radiation is performed by tilt-scanning one of the four Fabry-Perot etalons between 0 and 23° in conjunction with blocking filters to define the spectral channel. The spectrometer can operate in one of two modes :

- **Spectral Survey Mode** in which each of the nine spectral intervals is spectrally scanned in 0.02 cm^{-1} steps over the etalon's free spectral range. Each scan takes 65.5 seconds making a total of 590 seconds for all channels.

- **Primary Science Mode** this is the usual CLAES operating mode, in which all parameters required to retrieve geophysical parameters must be acquired in a single 65.5 second period - the time taken for the spacecraft to move 500 km along track. This is achieved by targetting a limited number of spectral positions in each of the nine intervals.

Data Processing Techniques

The UARS data processing is carried out at the Central Data Handling Facility at the Goddard Space Flight Center using software supplied by the instrument's Principal Investigator group. The data processing for UARS instruments consists of a progression through a sequence of `levels' from the raw telemetry at level 0 to geophysical quantities interpolated onto standard grids at level 3. The processing steps for CLAES are outlined below :

- **Level 1 processing**: In the first processing step, the level 0 data (the raw telemetry) is processed to remove instrument-specific effects and a set of calibrated data is derived in physical units (eg. voltages and radiances) tagged with their locations which are written to a level 1 product.

- **Level 2 processing** : The level 1 data are then processed further to produce the level 2 product which contains vertical profiles of temperature, pressure and mixing ratios of chemical constituents at the measurement positions. This step involves a complex retrieval algorithm which consists of two principal stages : In the first step the pressure and temperature are retrieved as a function of the instrument's altitude grid, using features of the CO_2 spectrum in the spectral channel at 789-793 cm^{-1}. This region also contains a significant contribution from ozone, which must be retrieved similtaneously. The temperatures and pressures are then fed into the retrievals of mixing ratios from the radiances measured in other spectral channels. The algorithm used in the routine retrievals of geophysical parameters from CLAES data is an optimal mix of two different processes, one involving a relaxation technique to obtain a similtaneous retrieval over the whole altitude range and the second using an onion-peeling process. Both algorithms use some a priori information.

- **Level 3A processing** : The level 2 data are profiles located at the measurement positions which are determined by the scan pattern and by the track of the tangent point. The level 2-3A processing step takes these data and interpolates them onto a standard set of vertical levels, evenly spaced in log pressure, and onto standard times (level 3AT) and standard latitudes (level 3AL).

Data

The public CLAES data held at the BADC is at level 3A version 8. Some files from earlier processing version (v0007) are also held where there are gaps in the version 8 data. The version number refers to the processing algorithm which is used to create the level 3A files. The data is stored in UARS binary format. Software is available to convert the files into ASCII data.

Spatial Coverage

Each spacecraft yaw manoeuvre changes the coverage from high latitudes in one hemisphere to high latitudes in the other. Thus, when the spacecraft files "forwards", the coverage is 80°S to 34°N, and when it flies "backwards" the coverage is 80°N to 34°S.

23.5 Improved Stratospheric and Mesospheric Sounder (ISAMS)

Instrument Description

ISAMS is an infrared radiometer[22.6], which measures thermal emission from the Earth's limb. Measurements are made in eight channels in the 4-17 microns range using pressure modulation and wideband radiometric techniques to select regions of the spectrum appropriate to the species to be measured.

The instrument observes the earth's limb in a direction normal to the orbital track (with a small offset to correct for the Doppler shift due to the Earth's rotation). The tangent point is a great circle distance of approximately 23° (approx. 2500km) away from the sub-satellite track.

A switching mirror is included in the optical path to allow the instrument to view the limb on either side of the spacecraft velocity vector, but in practice viewing on the "Sun-side" of the spacecraft is limited to periods when the Sun is behind the Earth so that solar radiation cannont enter the instrument.

The primary optics of the instrument focus the radiation onto a chopper which modulates between the Earth's limb and cold space at a frequency of 1kHz, giving a zero-radiance reference signal. The gain is measured relative to an internal black body calibration source at 290K.

The incoming beam is divided into 8 separate pressure modulator channels, each of which contains a sample of the gas to be measured. ISAMS uses pressure-modulator cells for each of the following gases : CO_2 (times 2), CO, CH_4, NO, N_2O, NO_2 and H_2O. The two CO_2 channels can be operated at different pressures which ensures that temperature measurements may be made over a extended range.

Each of the two CO_2 channels also contains a filter wheel to allow wideband measurements of three key chemical species - ozone (O_2), nitric acid (HNO_3) and dinitrogen pentoxide (N_2O_5) - none of which can be isolated in a gas cell. There is also a `window' channel at 12.1 microns which is relatively free of molecular absorption and can be used in the retrieval of aerosol opacities.

Measurement Techniques

The measurement technique used by ISAMS is known as Pressure Modulation Radiometry. The incoming radiation in each channel passes through a cell containing a sample of the gas to be measured, in which the pressure is modulated at a frequency of about 30Hz. A multi-layer interference filter in front of the detector restricts the radiation reaching the detector to a narrow part of the vibration-rotation band of the relevant species.

The signal processing electonics demodulates the signal from the detector at the chopper frequency to give a wideband signal for the spectral band defined by the interference filter. This "wideband" signal is then further demodulated at the pressure modulation frequency. This pressure modulated signal originates in or near the spectral lines of the species in the gas cell and is therefore very selective for radiation originating from that species in the atmosphere.

Data Processing Techniques

The UARS data processing is carried out at the Central Data Handling Facility at the Goddard Space Flight Center using software supplied by the Instrument's Principal Investigator group.

The data processing for UARS instruments consists of a progression through a sequence of `levels' from the raw telemetry at level 0 to geophysical quantities interpolated onto standard grids at level 3. The processing steps for ISAMS are outlined below :

Level 1 processing

At the level 0-1 processing step, instrument-specific effects are removed and a set of calibrated data are derived in physical units (eg. voltages and radiances) tagged with their locations.

Level 2 processing

The level 1 data are then processed further to produce the level 2 product which contains vertical profiles of temperature, pressure and mixing ratios of chemical constituents at the measurement positions. This step involves a complex inversion algorithm which consists of two principal stages :

Firstly the temperature and pressure are retrieved using the radiances from the CO2 channels, using a sequential estimation scheme, or Kalman filter, similar to that described by Rodgers et al (1984) for SAMS data. This method combines the radiance data with retrievals from neighbouring profiles and with climatology to produce a statistically optimal result.

The temperatures and pressures are then combined with the data from the constituent channels to retrieve vertical profiles of the constituents using a maximum likelihood estimator.

Level 3A processing

The level 2 data are profiles located at the measurement positions which are determined by the scan pattern and by the track of the tangent point. The level 2-3A processing step takes these data and interpolates them onto a standard set of vertical levels -- evenly spaced in log pressure, and onto standard times (level 3AT) and standard latitudes (level 3AL).

Horizontal Range

Views of the limb from the UARS orbit extend to approximately 10° of the pole. To achieve maximum latitude coverage, the instrument views at right angles to the orbit track.

A switching mirror allows the instrument to observe on either side of the orbital track, so that in principle the coverage could extend from 80°N to 80°S, every day. In practice, viewing is only possible from the Sun-viewing side of the spacecraft when the Sun is behind the Earth, so that solar radiation cannot enter the instrument. Generally, therefore the coverage is restricted to the anti-Sun side of the spacecraft between 34° in one hemisphere and 80° in the other. The spacecraft performs a 180° yaw approximately every 36 days so that the spacecraft orientation relative to the velocity vector is reversed. (eg. the spacecraft flies `backwards' rather than `forwards'). Each spacecraft yaw manoeuvre changes the coverage from high latitudes in one hemisphere to high latitudes in the other. Thus, when the spacecraft files `forwards', the coverage is 80°S to 34°N, and when it flies `backwards' the coverage is 80°N to 34°S.

Vertical Range

The vertical range depends on measured parameters.

Data rate: 1.250 kbps.

23.6 Microwave Limb Sounder (MLS)

Some features of the MLS technique include[22.7]:

- measurements which can be made reliably, even in the presence of cirrus, polar stratospheric clouds, or volcanic aerosols
- measurements made continuously at all times of day and night
- the ability to measure many atmospheric gases, temperature and pressure
- the ability to spectrally-resolve emission lines at all altitudes which allows measurements of very weak lines in the presence of nearby strong ones
- composition measurements which are relatively insensitive to uncertainties in atmospheric temperature
- a very accurate spectroscopic data base
- instrumentation with excellent calibration and stability that can be modularly designed for ease in accommodating changing measurement priorities, can provide good vertical resolution which is set by the size of the antenna, and with new array technology can provide good horizontal resolution including complete coverage between orbits.

Data rate: 1.250 kbps

23.7 Halogen Occulutation Experiment (HALOE)

Data rate: 4.0 kbps

23.8 High Resolution Doppler Imager (HRDI)

The High Resolution Doppler Imager (HRDI)[22.8] is one of the instruments onboard the Upper Atmospheric Research Satellite (UARS). The satellite waslaunched on 12 September 1991 as a part of NASA's effort to study the Earth'satmosphere. HRDI observes the emission and absorption lines of molecularoxygen (and other atmospheric components) in small volumes (4 km in heightby 50 km in width) above the limb of the Earth. From the Doppler shift ofthe lines, the horizontal winds can be determined, while the line shapesand strengths yield information about the temperature and atmospheric speciesmake-up.

Data rate: 4.750 kbps

23.9 WIND Imaging Interferometer (WINDII)

Data rate: 2.0 kbps

23.10 Particle Environment Monitor (PEM)

Data rate: 3.5 kbps

24 Vegetation Canopy Lidar (VCL)

The principal goal of the VCL mission is the characterization of the three-dimensional structure of the Earth[23].

Mission Overview

- Spacecraft: Orbital Sciences Corp. S/C Bus
- Instrument: MBLA from GSFC, based on SLA and MOLA instruments
- Design Lifetime: 2 years
- Mass/Orbital Average: S/C 260 kg
- Power: 168 W
- Instrument: Weight:133 kg
- Power: 220 W
- Orbit: 390 - 410 km, 67° inclination
- Orbit Adjustment: Monthly reboost to 410 km using monopropellant hydrazine
- Communications: S-band command and telemetry, X-band 28 Mbps science downlink
- Uplinks/Downlinks: 2 to 3 command loads per week, 4 data downlinks per day
- Data Volume: 2.2 Gbyte/day compressed
- 5.0 Gbyte/day depacketized
- Attitude: 0.1 deg. (3s) control arcsec (3s) knowledge
- Data Storage: 32 Gbits total memory = 36 hrs of data
- C & DH: 80C186 based computer
- S-band transponder, X-band transmitter
- Structure: Aluminum honeycomb plates with stringers, modular payload interface
- Power: 3.8 m2 GaAs arrays, 30 Ah NiH2 battery
- Thermal: Passive radiation with backup heaters
- Propulsion: 45 kg hydrazine propellant tank capacity feeding four 4.5 N thrusters

Instrument

- Lasers: 3 - 5 Nd:YAG diode-pumped pulsed lasers, operating at 1064 nm wavelength
- Laser Pulses: 242 pps (land), 10 mJ per pulse
- Telescope: 0.9 m f/1 parabolic mirror with 20 mrad total FOV and 0.3 mrad IFOV
- Detectors: Si avalanche photodiodes
- Waveform Digitization: 250 Megasamples/sec
- Swath Width: 8 km
- Resolution: 25 m (60 μrad) footprint diameter of 400 km altitude
- Track Spacing: 2 km
- Elevation Accuracy: < 1 m in low slope terrain
- Vegetation: < 1 m limited by 100:1 pulse detection dynamic
- Height: range and cal/val
- Orbit (elliptical) altitude is 400 km, and at 67 degree inclination[23.1]

25 Tracking & Data Relay Satellite System

The Tracking and Data Relay Satellite system[24] will consist of two Tracking and Data Relay satellites in geosynchronous orbit (130 degrees apart in longitude), an on-orbit spare, and a ground terminal facility (located at White Sands). The TDRS can transmit and receive data and track a user spacecraft in a low Earth orbit for a minimum of 85 percent of its orbit. TDRSS telecommunication services to and from the user's control and data processing facilities operate in a real-time, bent-pipe mode.

When fully operational, the TDRSS will provide continuous global coverage of Earth-orbiting satellites at altitudes from 750 miles to about 3,100 miles. At lower altitudes, there will be brief periods when satellites or spacecraft over the Indian Ocean near the equator are out of view. The TDRSS will be able to handle up to 300 million bits of information per second. Because eight bits of information make one word, this capability is equivalent to processing 300 14-volume sets of encyclopedias every minute.

The fully operational TDRSS network will consist of three satellites in geosynchronous orbits. The first, positioned at 41 degrees west longitude, is TDRS-East (TDRS-A). The next satellite, TDRS-West, will be carried into Earth orbit aboard the space shuttle and deployed and positioned at 171 degrees west longitude. The remaining TDRS will be positioned above a central station just west of South America at 62 degrees west longitude as a backup.

The satellites are positioned in geosynchronous orbits above the equator at an altitude of 22,300 statute miles. At this altitude, because the speed of the satellite is the same as the rotational speed of Earth, it remains fixed in orbit over one location. The eventual positioning of two TDRSs will be 130 degrees apart instead of the usual 180-degree spacing. This 130-degree spacing will reduce the ground station requirements to one station instead of the two stations required for 180-degree spacing.

The TDRS system serves as a radio data relay, carrying voice, television, and analog and digital data signals. It offers three frequency band services: S-band, C-band and high-capacity Ku-band. The C-band transponders operate at 4 to 6 GHz and the Ku-band transponders operate at 12 to 14 GHz.

The highly automated TDRSS network ground station, located at the White Sands Ground Terminal, is owned and managed by Contel. TDRSS also provides communication and tracking services for low Earth-orbiting satellites. It measures two-way range and Doppler for up to nine user satellites and one-way and Doppler for up to 10 user satellites simultaneously. These measurements are relayed to the Flight Dynamics Facility at GSFC from the WSGT.

Six TDRSs will be built by TRW's Defense and Space Systems Group, Redondo Beach, Calif. Contel owns and operates the satellites and the White Sands Ground Terminal, which was built jointly by the team of TRW, Harris Corporation and Spacecom. Electronic hardware was jointly supplied by TRW and Harris's Government Communications Division, Melbourne, Fla. TRW integrated and tested the ground station, developed software for the TDRS system and integrated the hardware with the ground station and satellites.

The ground station is located at a longitude with a clear line of sight to the TDRSs and very little rain, because rain can interfere with the Ku-band uplink and downlink channels. It is one of the largest and most complex communication terminals ever built.

The most prominent features of the ground station are three 60-foot Ku-band dish antennas used to transmit and receive user traffic. Several other antennas are used for S-band and Ku-band communications. NASA developed sophisticated operational control facilities at GSFC and next to the WSGT to schedule TDRSS support of each user and to distribute the user's data from White Sands to the user.

Automatic data processing equipment at the WSGT aids in satellite tracking measurements, control and communications. Equipment in the TDRS and the ground station collects system status data for transmission, along with user spacecraft data, to NASA. The ground station software and computer component, with more than 900,000 machine language instructions, will eventually control three geosynchronous TDRSs and the 300 racks of ground station electronic equipment.

Many command and control functions ordinarily found in the space segment of a system are performed by the ground station, such as the formation and control of the receive beam of the TDRS multiple-access phased-array antenna and the control and tracking functions of the TDRS single-access antennas.

Data acquired by the satellites are relayed to the ground terminal facilities at White Sands. White Sands sends the raw data directly by domestic communications satellite to NASA control centers at JSC (for space shuttle operations) and GSFC, which schedules TDRSS operations and controls a large number of satellites. To increase system reliability and availability, no signal processing is done aboard the TDRSs; instead, they act as repeaters, relaying signals to and from the ground station or to and from satellites or spacecraft. No user signal processing is done aboard the TDRSs.

A second TDRS ground terminal is being built at White Sands approximately 3 miles north of the initial ground station. The $18.5-million facility will back up the existing facility and meet the growing communication needs of the 1990s.

When the TDRSS is fully operational, ground stations of the worldwide STDN will be closed or consolidated, resulting in savings in personnel and operating and maintenance costs. However, the Merritt Island, Fla.; Ponce de Leon, Fla.; and Bermuda ground stations will remain open to support the launch of the space transportation system and the landing of the space shuttle at the Kennedy Space Center in Florida.

Deep-space probes and Earth-orbiting satellites above approximately 3,100 miles will use the three ground stations of the deep-space network, operated for NASA by the Jet Propulsion Laboratory, Pasadena, Calif. The deep-space network stations are in Goldstone, Calif.; Madrid, Spain; and Canberra, Australia.

During the lift-off and ascent phase of a space shuttle mission launched from the Kennedy Space Center. the space shuttle S-band system is used in a high-data-rate mode to transmit and receive through the Merritt Island, Ponce de Leon and Bermuda STDN tracking stations. When the shuttle leaves the line-of-sight tracking station at Bermuda, its S-band system transmits and receives through the TDRSS. (There are two communication systems used in communicating between the space shuttle and the ground. One is referred to as the S-band system; the other, the Ku-band, or K-band, system.)

To date, the TDRSs are the largest privately owned telecommunication satellites ever built. Each satellite weighs nearly 5,000 pounds in orbit. The TDRSs will be deployed from the space shuttle at an altitude of approximately 160 nautical miles, and inertial upper stage boosters will propel them to geosynchronous orbit.

The TDRS single-access parabolic antennas deploy after the satellite separates from the IUS. After the TDRS acquires the sun and Earth, its sensors provide attitude and velocity control to achieve the final geostationary position. Three-axis stabilization aboard the TDRS maintains attitude control. Body-fixed momentum wheels in a vee configuration combine with body-fixed antennas pointing constantly at Earth, while the satellite's solar arrays track the sun. Monopropellant hydrazine thrusters are used for TDRS positioning and north-south, east-west stationkeeping.

The antenna module houses four antennas. For single-access services, each TDRS has two dual-feed S-band / Ku-band deployable parabolic antennas. They are 16 feet in diameter, unfurl like a giant umbrella when deployed, and are attached on two axes that can move horizontally or vertically (gimbal) to focus the beam on satellites or spacecraft below. Their primary function is to relay communications to and from user satellites or spacecraft.

The high-bit-rate service made possible by these antennas is available to users on a time-shared basis. Each antenna simultaneously supports two user satellites or spacecraft (one on S-band and one on Ku-band) if both users are within the antenna's bandwidth.

The antenna's primary reflector surface is a gold-clad molybdenum wire mesh, woven like cloth on the same type of machine used to make material for women's hosiery. When deployed, the antenna's 203 square feet of mesh are stretched tautly on 16 sup porting tubular ribs by fine threadlike quartz cords. The antenna looks like a glittering metallic spiderweb. The entire antenna structure, including the ribs, reflector surface, a dual-frequency antenna feed and the deployment mechanisms needed to fold and unfold the structure like a parasol, weighs approximately 50 pounds.

For multiple-access service, the multielement S-band phased array of 30 helix antennas on each satellite is mounted on the satellite's body. The multiple-access forward link (between the TDRS and the user satellite or spacecraft) transmits command data to the user satellite or spacecraft, and the return link sends the signal outputs separately from the array elements to the WSGT's parallel processors. Signals from each helix antenna are received at the same frequency, frequency-division-multiplexed into a single composite signal and transmitted to the ground. In the ground equipment, the signal is demultiplexed and distributed to 20 sets of beam-forming equipment that discriminates among the 30 signals to select the signals of individual users. The multiple-access system uses 12 of the 30 helix antennas on each TDRS to form a transmit beam.

A 6.6-foot parabolic reflector is the space-to-ground-link antenna that communicates all data and tracking information to and from the ground terminal on Ku-band. The omni telemetry, tracking and communication antenna is used to control TDRS while it is in transfer orbit to geosynchronous altitude.

The solar arrays on each satellite, when deployed, span more than 57 feet from tip to tip. The two single-access, high-gain parabolic antennas, when deployed, measure 16 feet in diameter and span 42 feet from tip to tip.

Each TDRS is composed of three distinct modules: the equipment module, the communication payload module and the antenna module. The modular structure reduces the cost of individual design and construction.

The equipment module housing the subsystems that operate the satellite and the communication service is located in the lower hexagon of the satellite. The attitude control subsystem stabilizes the satellite so that the antennas are properly oriented toward the Earth and the solar panels are facing toward the sun. The electrical power subsystem consists of two solar panels that provide approximately 1,850 watts of power for 10 years. Nickel-cadmium rechargeable batteries supply full power when the satellite is in the shadow of the Earth. The thermal control subsystem consists of surface coatings and controlled electric heaters. The solar sail compensates for the effects of solar winds against the asymmetrical body of the TDRS.

The communication payload module on each satellite contains electronic equipment and associated antennas required for linking the user spacecraft or satellite with the ground terminal. The receivers and transmitters are mounted in compartments on the back of the single-access antennas to reduce complexity and possible circuit losses.

TDRS-A and its IUS were carried aboard the space shuttle Challenger on the April 1983 STS-6 mission. After it was deployed on April 4, 1983, and first-stage boost of the IUS solid rocket motor was completed, the second-stage IUS motor malfunctioned and TDRS-A was left in an egg-shaped orbit 13,579 by 21,980 statute miles-far short of the planned 22,300-mile geosynchronous altitude. Also, TDRS-A was spinning out of control at a rate of 30 revolutions per minute until the Contel/TRW flight control team recovered control and stabilized it.

Later Contel, TRW and NASA TDRS program officials devised a procedure for using the small (1-pound) hydrazine-fueled reaction control system thrusters on TDRS-A to raise its orbit. The thrusting, which began on June 6, 1983, required 39 maneuvers to raise TDRS-A to geosynchronous orbit. The maneuvers consumed approximately 900 pounds of the satellite's propellant, leaving approximately 500 pounds of hydrazine for the 10-year on-orbit operations.

During the maneuvers, overheating caused the loss of one of the redundant banks of 12 thrusters and one thruster in the other bank. The flight control team developed procedures to control TDRS-A properly in spite of the thruster failures.

TDRS-A was turned on for testing on July 6, 1983. Tests proceeded without incident until October 1983, when one of the Ku-band single-access-link diplexers failed. Shortly afterward, one of the Ku-band traveling-wave-tube amplifiers on the same single-access antenna failed, and the forward link service was lost. On November 19, 1983, one of the Ku-band TWT amplifiers serving the other single-access antenna failed. TDRS-A testing was completed in December 1984. Although the satellite can provide only one Ku-band single-access forward link, it is still functioning.

TDRS-B, C and D are identical to TDRS-A except for modifications to correct the malfunctions that occurred in TDRS -A and a modification of the C-band antenna feeds. The C-band minor modification was made to improve coverage for providing government point-to-point communications. TDRS -B was lost on the 51-L mission. The mission plan for TDRS-C is similar to that originally planned for TDRS-A. Backup project operations control centers have been added at TRW and at the TDRS Launch/Deployment Control Center in White Sands. These facilities will improve the reliability of control operations and the simultaneous control of TDRS-A in mission support and of TDRS-C during launch and deployment operations.

TDRS-C and its IUS are to be deployed from the space shuttle orbiter. Approximately 60 minutes later, the IUS first-stage solid rocket motor is scheduled to ignite. This will be followed by five maneuvers to allow monitoring of TDRS-C telemetry.

After the IUS second-stage thrusting is completed, the TDRSS mission team at White Sands will command deployment of the TDRS-C solar arrays, the space-ground link antenna and the C-band antenna while the TDRS is still attached to theIUS. Upon separation of the IUS from TDRS-C, the 16-foot-diameter single-access antennas will be deployed, unfurled and oriented toward Earth. Nominal deployment will place TDRS-C at 178 degrees west longitude.

Testing of TDRS-C will be initiated; and after initial checkout, TDRS-C will drift westward to its operational location at 171 degrees west longitude, southwest of Hawaii, where it will be referred to as TDRS-West. Operational testing will continue to verify the full-system capability with two operating satellites. On completion of this testing, about three to five months after the launch of TDRS-C, the TDRSS, for the first time, will provide its full-coverage capability in support of NASA space missions.

TDRS-D, identical to TDRS-C, will take the place of TDRS-A at 41 degrees west longitude above the equator, over the northeast corner of Brazil, and will be referred to as TDRS-East. TDRS-A will then be relocated, probably 79 degrees west longitude above the equator, over central South America, and will be maintained as an on-orbit spare.

These three satellites will make up the space segment of the TDRS system. The on-orbit spare, available for use if one of the operational satellites malfunctions, will augment system capabilities during peak periods. The two remaining satellites will be available as flight-ready spares.

The failure of TDRS-A's Ku-band forward link prohibits the operation of the text and graphics system that it is desired be placed on board all space shuttle orbiters. TAGS is a high-resolution facsimile system that scans text or graphic material and converts the analog scan data into serial digital data. It provides on-orbit capability to transmit text material, maps, schematics and photographs to the spacecraft through a two-way Ku-band link through the TDRSS. This is basically a hard-copy machine that operates by telemetry.

Until there is a dual TDRS capability, a teleprinter must be used on orbit to receive and reproduce text only (such as procedures, weather data and crew activity plan updates or changes) from the Mission Control Center. The teleprinter uses S-band and is not dependent on the TDRSS Ku-band. When the space shuttle orbiter is on orbit and its payload bay doors are opened, the space shuttle orbiter Ku-band antenna, stowed on the right side of the forward portion of the payload bay, is deployed. One drawback of the Ku-band system is its narrow pencil beam, which makes it difficult for the TDRS antennas to lock on to the signal. Because the S-band system has a larger beamwidth, the orbiter uses it first to lock the Ku-band antenna into position. Once this has occurred, the Ku-band signal is turned on.

The Ku-band system provides a much higher gain signal with a smaller antenna than the S-band system. The orbiter's Ku-band antenna is gimbaled so that it can acquire the TDRS. Upon communication acquisition, if the TDRS is not detected within the first 8 degrees of spiral conical scan, the search is automatically expanded to 20 degrees. The entire TDRS search requires approximately three minutes. The scanning stops when an increase in the received signal is sensed. The orbiter Ku-band system and antenna then transmits and receives through the TDRS in view.

At times, the orbiter may block its Ku-band antenna's view to the TDRS because of attitude requirements or certain payloads that cannot withstand Ku-band radiation from the main beam of the orbiter's antenna. The main beam of the Ku-band antenna produces 340 volts per meter, which decreases in distance from the antenna-e.g., 200 volts per meter 65 feet away from the antenna. A program can be instituted in the orbiter's Ku-band antenna control system to limit the azimuth and elevation angle, which inhibits direction of the beam toward areas of certain onboard payloads. This area is referred to as an obscuration zone. In other cases, such as deployment of a satellite from the orbiter payload bay, the Ku-band system is turned off temporarily.

When the orbital mission is completed, the orbiter's payload bay doors must be closed for entry; therefore, its Ku-band antenna must be stowed. If the antenna cannot be stowed, provisions are incorporated to jettison the assembly from the spacecraft so that the payload bay doors can be closed for entry. The orbiter can then transmit and receive through the S-band system, the TDRS in view and the TDRS system. After the communications blackout during entry, the space shuttle again operates in S-band through the TDRS system in the low- or high-data-rate mode as long as it can view the TDRS until it reaches the S-band landing site ground station.

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