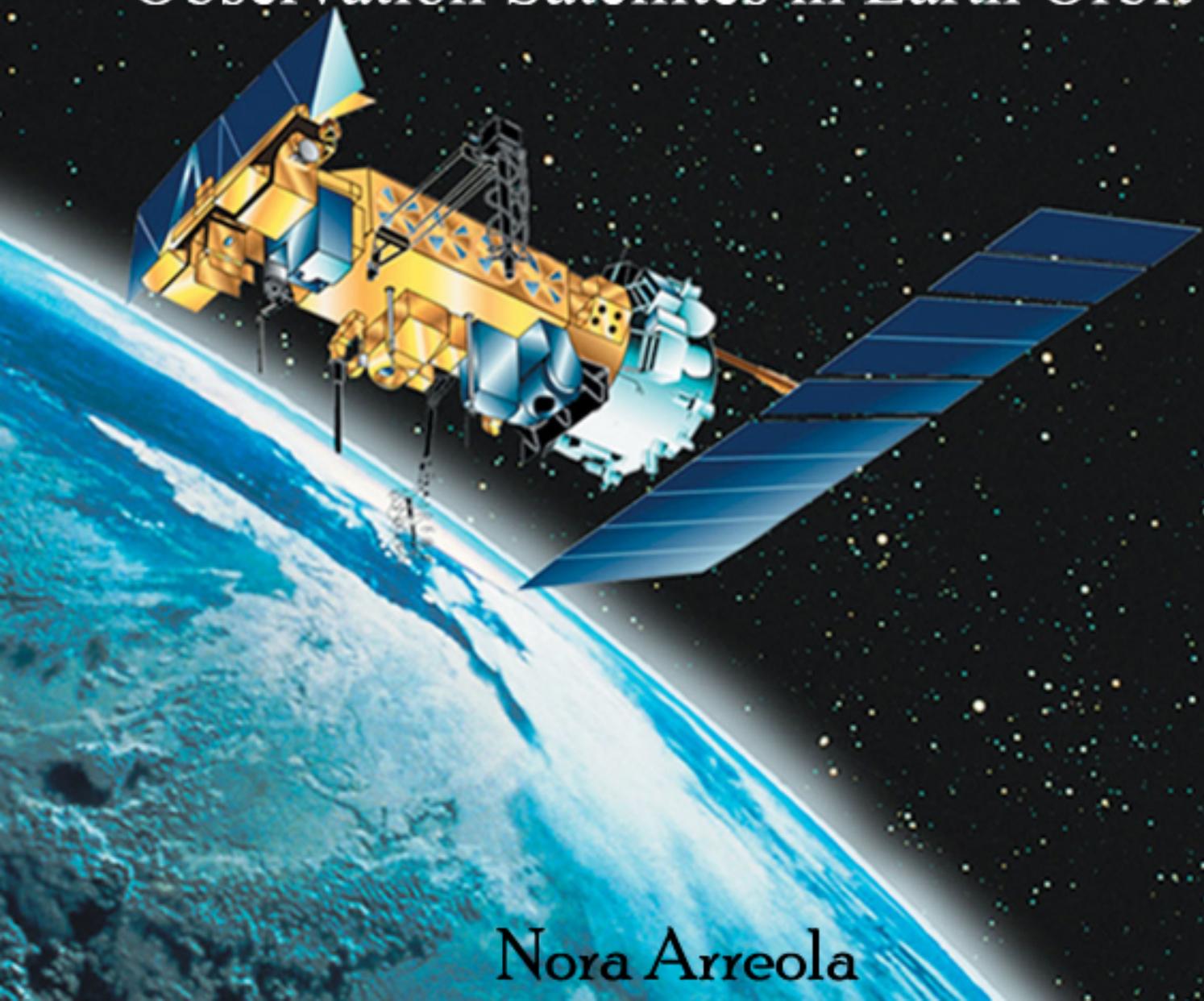


# Meteorological Remote Sensing Systems and Observation Satellites in Earth Orbit



Nora Arreola

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## Chapter- 1

# Landsat 7

**Landsat 7**

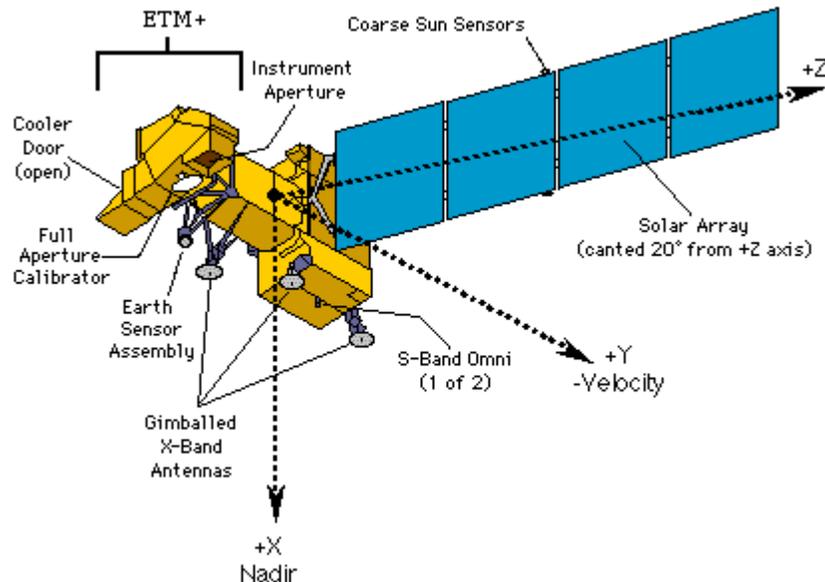


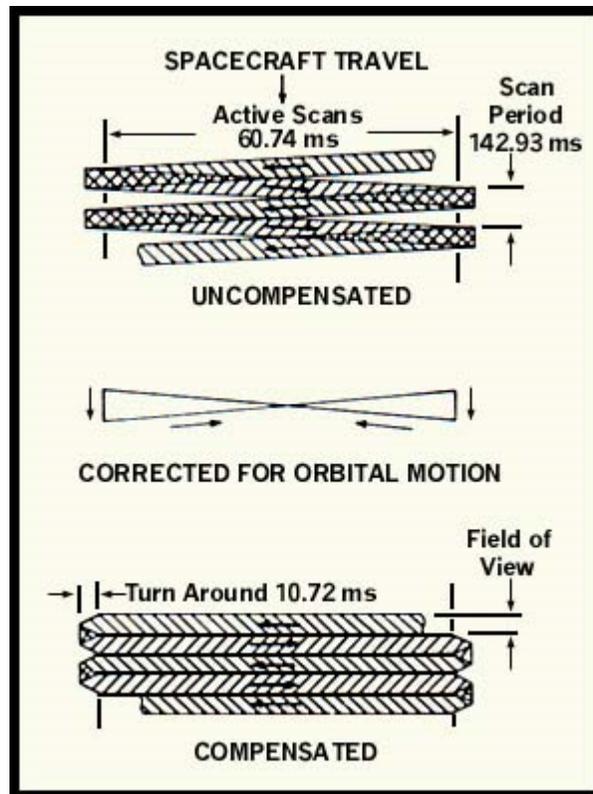
<b>Launch date</b>	1999-04-15 18:32:00 UTC
<b>Carrier rocket</b>	Delta II 7920
<b>Launch site</b>	Space Launch Complex 2W Vandenberg Air Force Base
<b>Mission duration</b>	elapsed: 11 years, 10 months, and 9 days
<b>COSPAR ID</b>	1999-020A
	<b>Orbital elements</b>
<b>Reference system</b>	WRS-2

<b>Regime</b>	Sun-synchronous, near-polar
<b>Inclination</b>	98.2°
<b>Altitude</b>	705 km (438 mi)
<b>Repeat interval</b>	16 days
<b>Swath width</b>	185 km (115 mi)
<b>Equatorial crossing time</b>	10:00 AM +/- 15 minutes

**Landsat 7**, launched on April 15, 1999, is the latest satellite of the Landsat program. Landsat 7's primary goal is to refresh the global archive of satellite photos, providing up-to-date and cloud-free images. Although the Landsat Program is managed by NASA, data from Landsat 7 is collected and distributed by the USGS. The NASA World Wind project allows 3D images from Landsat 7 and other sources to be freely navigated and viewed from any angle. The satellite's companion, Earth Observing-1, trails one minute following the exact orbital characteristics.

## Satellite specifications





The effect of the SLC on ETM+ scans.

Landsat 7 was designed to last for five years, and has the capacity to collect and transmit up to 532 images per day. It is in a polar, sun-synchronous orbit, meaning it scans across the entire earth's surface. With an altitude of 705 kilometres  $\pm$  5 kilometres, it takes 232 orbits, or 16 days, to do so. The satellite weighs 1973 kg, is 4.04 m long, and 2.74 m in diameter. Unlike its predecessors, Landsat 7 has a solid state memory of 378 gigabits (roughly 100 images). The main instrument on board Landsat 7 is the Enhanced Thematic Mapper Plus (ETM+).

## Main features

- A panchromatic band with 15 m (49 ft) spatial resolution (band 8)
- Visible (reflected light) bands in the spectrum of blue, green, red, near-infrared (NIR), and mid-infrared (MIR) with 30 m (98 ft) spatial resolution (bands 1-5, 7)
- A thermal infrared channel with 60 m spatial resolution (band 6)
- Full aperture, 5% absolute radiometric calibration

## Scan Line Corrector failure

On May 31, 2003 the Scan Line Corrector (SLC) in the ETM+ instrument failed. The SLC consists of a pair of small mirrors that rotate about an axis in tandem with the motion of the main ETM+ scan mirror. The purpose of the SLC is to compensate for the forward motion (along-track) of the spacecraft so that the resulting scans are aligned

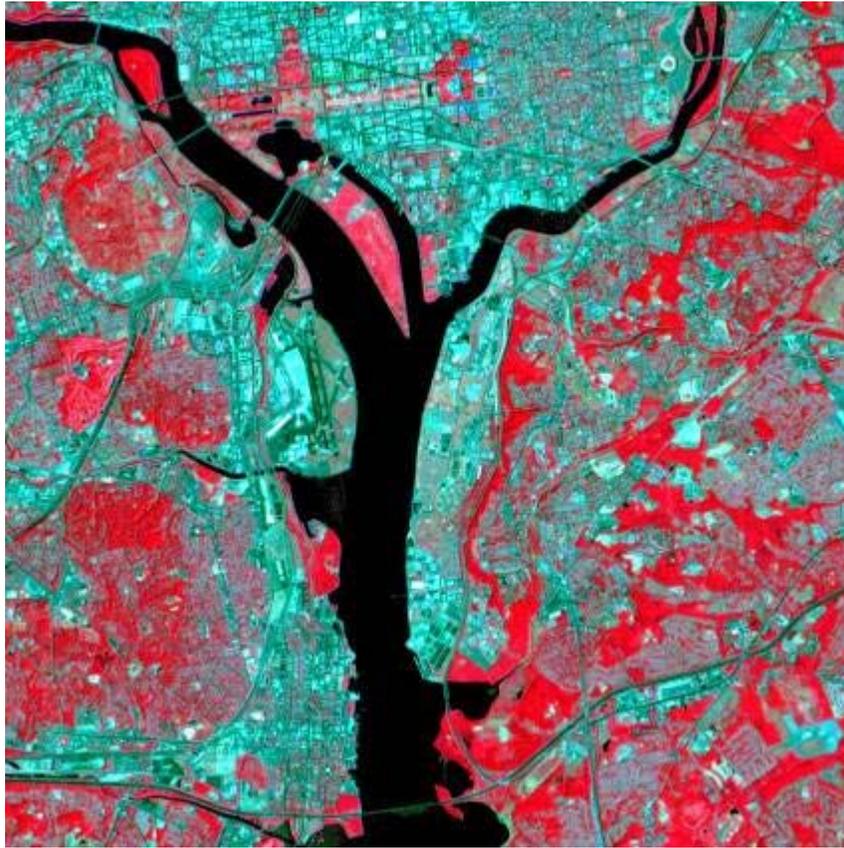
parallel to each other. Without the effects of the SLC, the instrument images the Earth in a "zig-zag" fashion, resulting in some areas that are imaged twice and others that are not imaged at all. The net effect is that approximately one-fourth of the data in a Landsat 7 scene is missing when acquired without a functional SLC.

Following the SLC failure, an Anomaly Response Team (ART) was assembled, consisting of representatives from the USGS, NASA, and Hughes Santa Barbara Remote Sensing (the manufacturer of the ETM+ instrument). The team assembled a list of possible failure scenarios, most of which pointed at a mechanical problem with the SLC itself. Since there is no backup SLC, a mechanical failure would indicate that the problem was permanent. However, the team was unable to rule out the possibility of an electrical failure, though such a possibility was deemed remote. Nevertheless, on September 3, 2003, USGS director Charles G. Groat authorized the Landsat project to reconfigure the ETM+ instrument and various other subsystems on board Landsat 7 to use the spacecraft's redundant ("Side-B") electrical harness.

With this authorization, the USGS flight operations team at the NASA Goddard Space Flight Center uploaded a series of commands to the spacecraft, instructing it to operate using the redundant electrical harness. This operation was successful, and on September 5, 2003, the ETM+ instrument was turned on and acquired data that was sent to the Landsat ground system at EROS outside of Sioux Falls, South Dakota. It was immediately apparent that the migration to the Side-B electrical harness had not fixed the problem with the SLC. Following this, the instrument was reconfigured to use its primary electrical harness. The subsequent conclusion of the ART was that the SLC problem was mechanical and permanent in nature.

Landsat 7 continues to acquire data in this mode. Data products are available with the missing data optionally filled in using other Landsat 7 data selected by the user. To continue the Landsat legacy, studies are underway to fly an equivalent scientific sensor on a new satellite.

## Satellite imagery



False color IR image of Washington DC, taken by Landsat 7.

In August 1998, NASA contracted EarthSat to produce Landsat GeoCover (*Geocover 2000* in NASA World Wind) — a positionally accurate orthorectified Landsat Thematic Mapper and Multispectral Scanner imagery covering the majority of the Earth's land mass. The contract was part of the NASA Scientific Data Purchase which was administrated through NASA's John C. Stennis Space Center. GeoCover was later enhanced to EarthSat NaturalVue, a simulated natural color Landsat 7 derived circa year 2000, orthorectified, mosaicked and color balanced digital image dataset. Other commercial simulated true color 15-meter global imagery products built from the NASA Landsat 7 imagery include TerraColor from Earthstar Geographics, TruEarth (found in Google Earth and Google Maps) from TerraMetrics, BrightEarth from ComputaMaps, simulated natural color from Atlogis and a product of i-cubed used in World Wind.

Largest parts of the earth surface displayed on web mapping services like Google Maps/Google Earth, MSN Maps or Yahoo Maps are based on enhanced and color balanced Landsat 7 imagery.

## Chapter- 2

# QuikSCAT

### QuikSCAT



Artist conception of QuikSCAT

<b>Organization</b>	JPL, NASA
<b>Mission Type</b>	Earth observation
<b>Contractor</b>	Ball Aerospace & Technologies Corp.
<b>Satellite of</b>	Earth
<b>Launch</b>	June 19, 1999 on a Titan 23G
<b>Launch site</b>	Vandenberg Air Force Base

<b>Mission duration</b>	2–3 years (used for 10 years)
<b>Mass</b>	971 kg (launch)
<b>Webpage</b>	<a href="http://winds.jpl.nasa.gov/missions/quikscat/">winds.jpl.nasa.gov/missions/quikscat/</a> <a href="http://NASA.gov">NASA.gov</a>

#### Orbital elements

<b>Semimajor Axis</b>	7180.8 km
<b>Eccentricity</b>	0.00014
<b>Inclination</b>	98.6 degrees
<b>Orbital Period</b>	100.93 minutes
<b>Right ascension of the ascending node</b>	178.47 degrees
<b>Argument of perigee</b>	47.4 degrees

#### Instruments

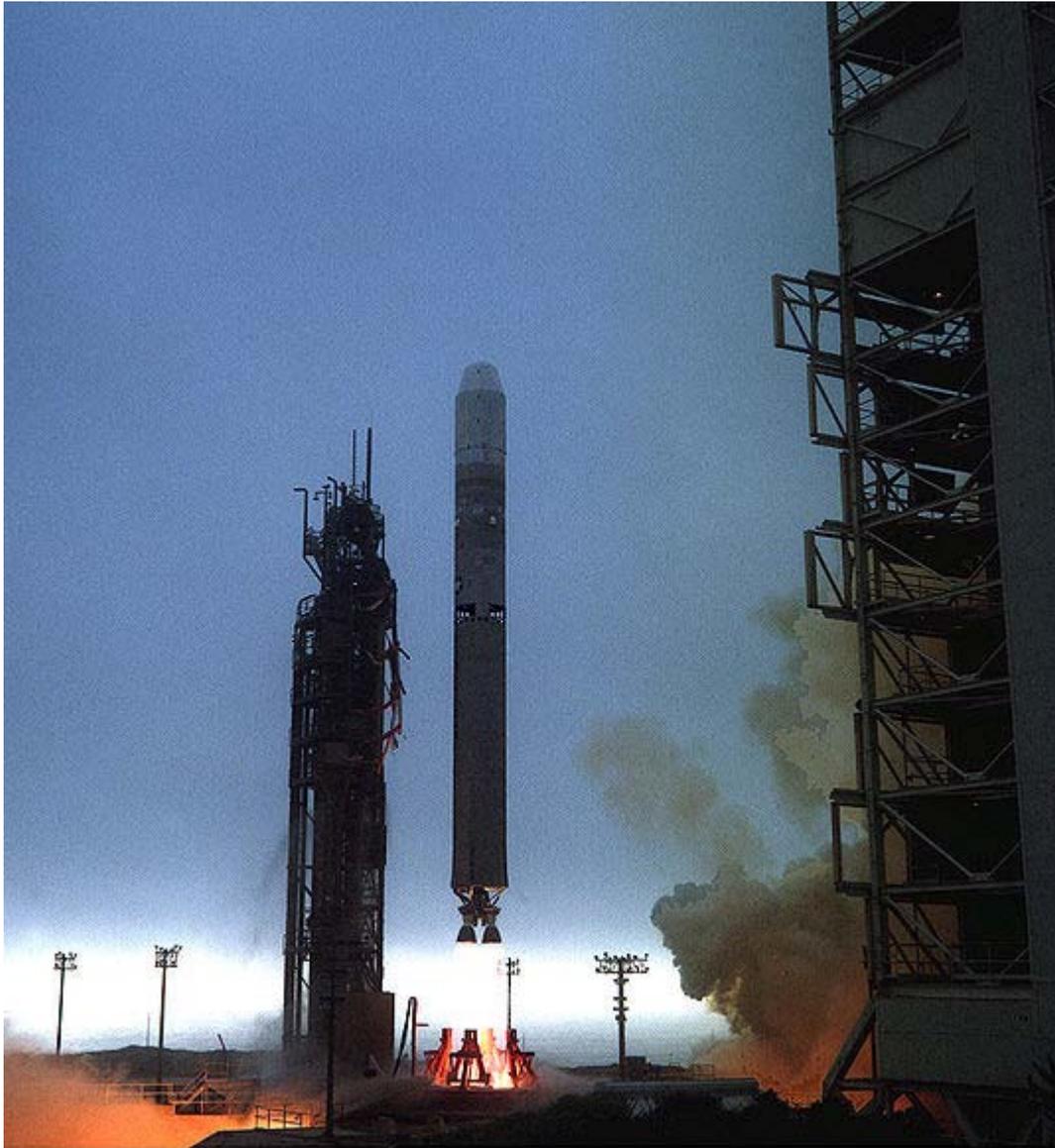
<b>SeaWinds</b>	microwave radar that measures near-surface wind speed and direction
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The **QuikSCAT** (Quick Scatterometer), an earth-observing satellite, provided estimates of wind speed and direction over the oceans to National Oceanic and Atmospheric Administration and others. This "quick recovery" mission intended to replace the NASA Scatterometer (NSCAT), which failed in June 1997. The satellite launched on 19 June 1999 with an intended mission of two or three years. QuickSCAT, however, continued to operate for a decade and stopped working circa 23 November 2009, when the bearings in the motor of the spinning antenna failed.

When QuikScat operated normally and the antenna rotated, the spacecraft collected information on winds in strips 1800 kilometers wide on a daily basis. The QuikScat scatterometer still continues to provide useful remote sensing data over specific regions and giving scientists a way to test the accuracy of other space-based scatterometers.

Quick-scat operates in a Sun-synchronous orbit (low-earth orbit).

## Construction and launch



**D061999a JPL PhotoLab**

Launch of the Titan II on June 19, 1999

In 1996, the NASA Scatterometer (NSCAT) was launched aboard the Japanese Advanced Earth Observing Satellite. This satellite was designed to record surface winds over water across the world for several years. However, an unexpected failure in 1997 led to an early termination of the NSCAT project. Following this briefly successful mission, NASA began constructing a new satellite to replace the failed one. They planned to build it and have it prepared for launch as soon as possible to limit the gap in data between the two satellites. In just 12 months, the Quick Scatterometer (QuikSCAT) satellite was constructed and ready to be launched, faster than any other NASA mission since the 1950s.

The QuikSCAT project was originally budgeted at \$93 million, including the physical satellite, the launch rocket, and ongoing support for its science mission. A series of rocket failures in November 1998 grounded the Titan (rocket family) launcher fleet, delayed the launch of QuickScat, and added \$5 million to this initial cost.

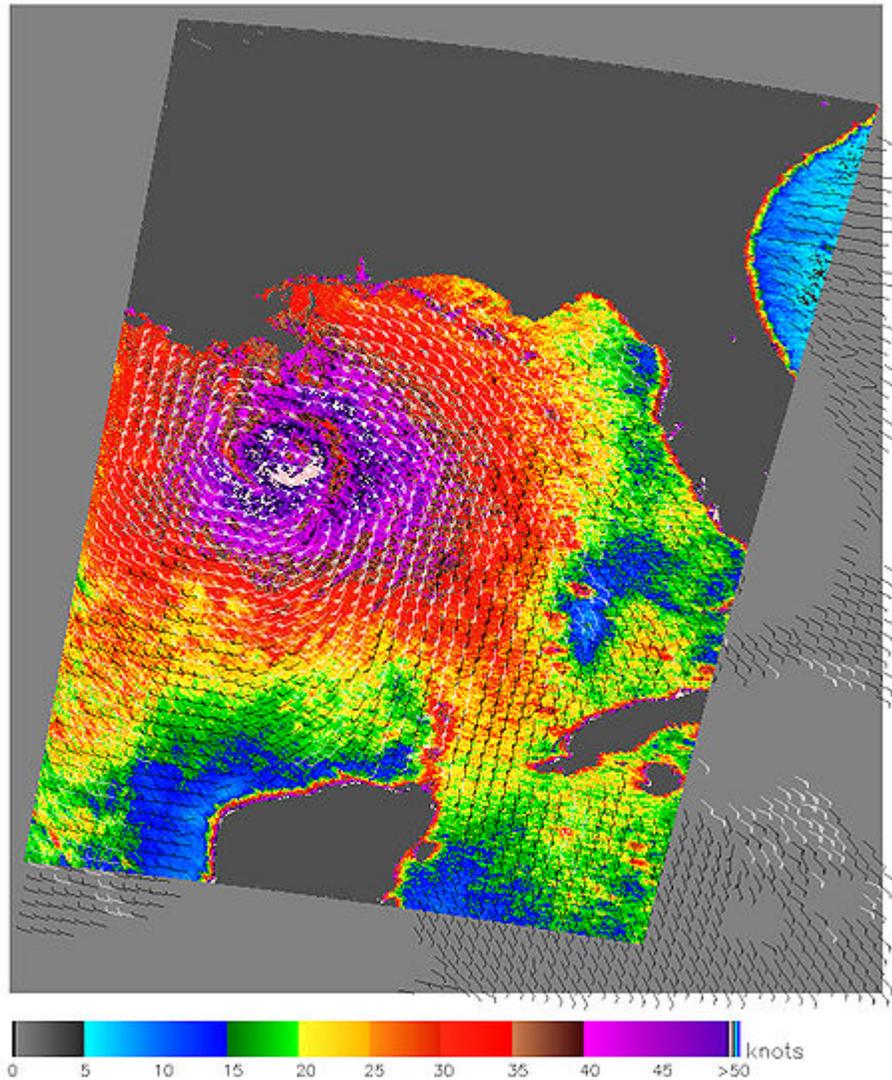
A new instrument, the SeaWinds scatterometer, was attached to the satellite. The SeaWinds instrument, a specialized microwave radar system, measured both the speed and direction of winds near the ocean surface. It used two radars and a spinning antenna to record data across nine-tenths of the oceans of the world in a single day. It recorded roughly four hundred thousand wind measurements daily, each covering an area 1800 kilometers (1,118 miles) in width. Jet Propulsion Laboratory and the NSCAT team jointly managed the project of construction of the satellite at the Goddard Space Flight Center. Ball Aerospace & Technologies Corp. supplied the materials to construct the satellite.

In light of the record-setting construction time, engineers who worked on the project were given the American Electronics Achievement Award. This was only achieved due to the new type of contract made specifically for this satellite. Instead of the usual year given to select a contract and initiate development, it was constrained to one month.

The newly constructed satellite was set to launch on a Titan II rocket from Vandenberg Air Force Base in California. The rocket lifted off at 7:15 pm PDT on 19 June 1999. Roughly two minutes and thirty seconds after launch, the first engine was shut down and the second was engaged as it moved over the Baja California Peninsula. A minute later, the nose cone, at the top of the rocket, separated into two parts. Sixteen seconds later, the rocket was re-oriented to protect the satellite from the sun. For the next 48 minutes, the two crafts flew over Antarctica and later over Madagascar, where the rocket reached its desired altitude of 500 mi (800 km).

At 59 minutes after launch, the satellite separated from the rocket and was pushed into its circular orbit around Earth. Shortly after, the solar arrays were deployed and connection was established with the satellite at 8:32 pm PDT with a tracking station in Norway. For the next two weeks, the shuttle used bursts from its engine to fine-tune its location and correct its course to the desired motion. Eighteen days after take-off, the scatterometer was turned on and a team of 12 personnel made detailed reviews of function of QuikSCAT. A month after entering orbit, the team completed the checks, and QuikSCAT began circling the globe constantly. NASA planned for the satellite to operate for two years.

## Uses



JPL/BYU P1B20052402316q.KATRINA\_050829\_12L.WRove3

QuikSCAT image of Hurricane Katrina on August 28, 2005 over the Gulf of Mexico

Not long after being activated, the data collected by the satellite proved to be very useful in forecasting tropical cyclones. The scatterometer's ability to record wind speeds at the surface allows meteorologists to determine whether a low pressure area is forming and enhance the ability to predict sudden changes in structure and strength. QuikSCAT continuously provided data from across the globe without error, "The data are looking great, better even than we expected." The first tropical cyclone captured by the SeaWinds instrument was Typhoon Olga in the western Pacific basin. The system was constantly monitored by the satellite from its generation on July 28 to its demise in early August.

Members of the QuikSCAT project believed that the satellite would eventually have a major role in climatological studies, weather prediction and oceanographic research.

During 2000, a public statement about the improvement of weather forecasting was attributed to the data provided by QuikSCAT. During the year, the satellite began recording wind directions, allowing forecasters to better predict when a storm could develop. Data was also provided in real-time for areas previously without recording devices, filling the information gaps across the world.

Other uses of the data include resource assessment for the emerging offshore wind energy industry. WindScan has taken advantage of satellite data specifically for this purpose.

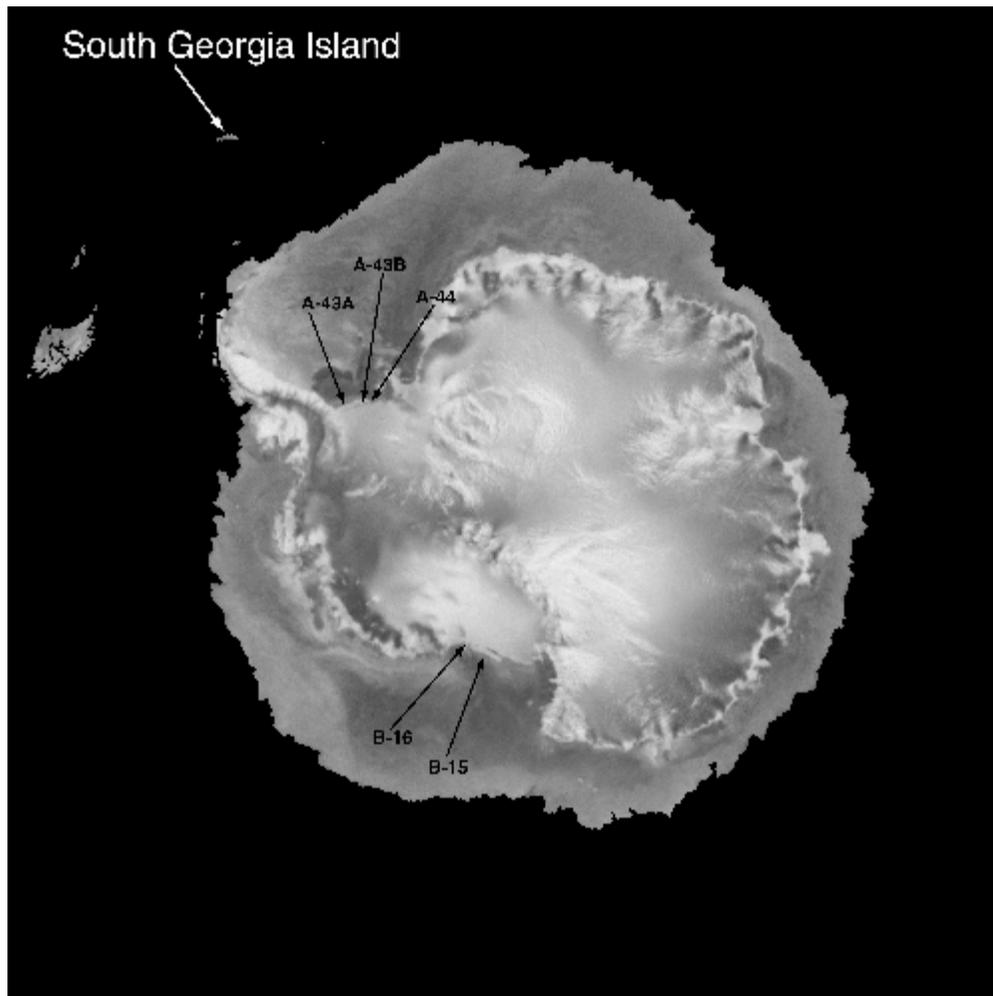


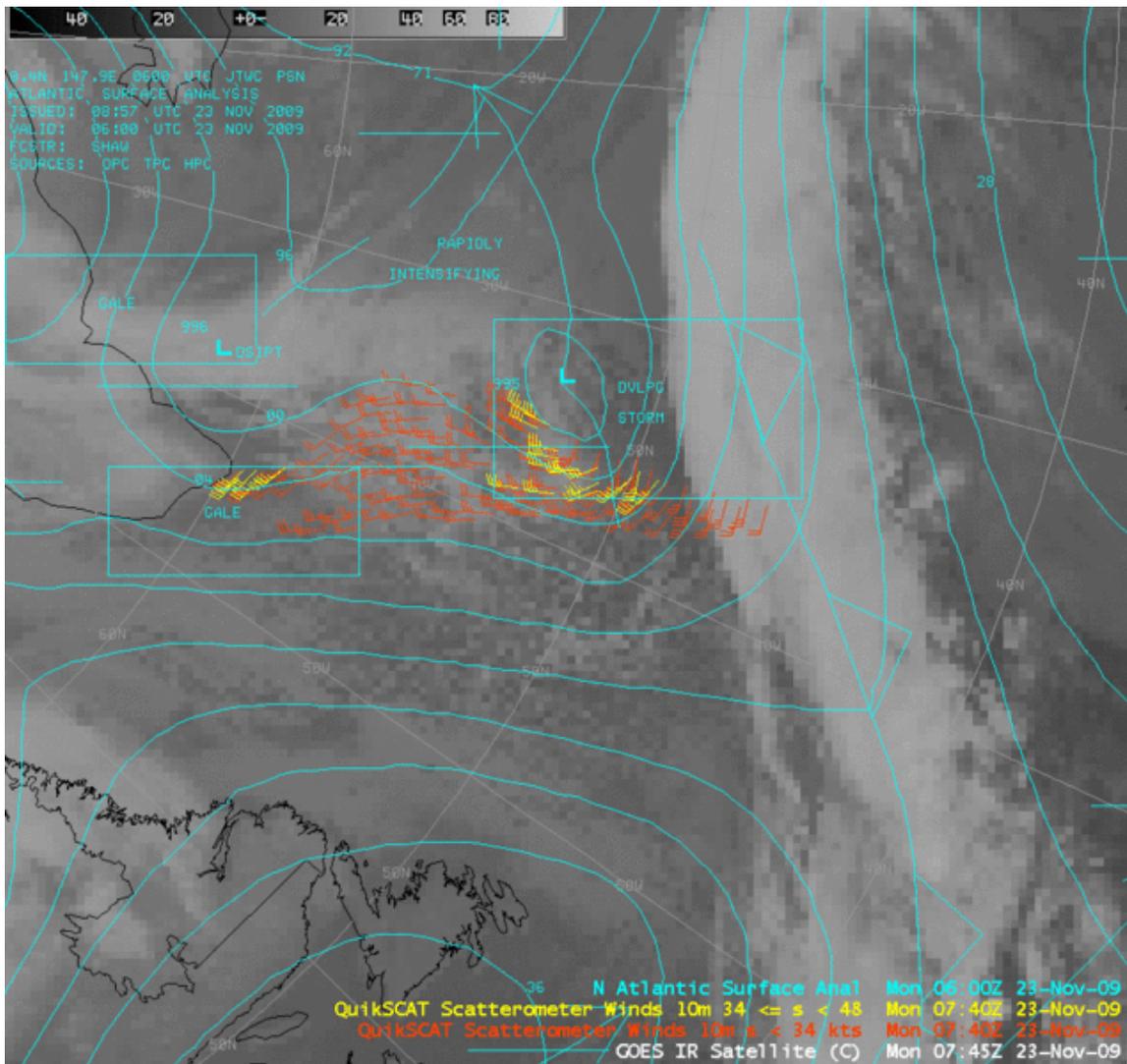
Image of Antarctica produced by the SeaWinds instrument on May 24, 2000

## **2007 Bill Proenza controversy**

In 2007, Bill Proenza, the head of the National Hurricane Center at the time, stated in a public message that the loss of the QuikSCAT satellite would greatly harm the quality of

hurricane forecasts. This followed the loss of the main power source, leading to the satellite running on a backup generator. He claimed that three-day forecasts would be roughly 16% less accurate following the loss of QuikSCAT. However, this was found to be an exaggeration, during his controversial time at the center, which eventually led to him being removed from his position. Although the satellite aids in hurricane intensity, it does not do so exclusively and other satellites in orbit, with similar equipment, record the same information.

## 2009 sensor loss



The last image produced from QuikSCAT data (placed on top of two GOES images) shortly before the antenna stopped spinning. Note the small area where wind data is present in comparison the area covered by the image.

During mid-2009, the QuikSCAT project began noticing a gradual deterioration in the bearings that allow the antenna that provides real-time data. The bearings produced more friction than in the past nine years the satellite was in orbit. This friction slowed the rate the antenna spun, leading to gaps in data recorded by QuikSCAT across the world. This culminated in the antenna's failure on November 23, 2009. Upon failing, it was announced that the satellite was likely at the end of its mission and would no longer be used. The sensor on the satellite was confirmed to have failed around 0700 UTC. The loss only affected the real-time scanning equipment; the long-term data collection remained intact and operational. According to NASA, the failure resulted from the age of the satellite. The mechanism that seized was designed to last only five years; however, it remained operational for roughly ten years, twice its expected use. On November 24, NASA managers began to assess how extensively affected the satellite was and if it was possible to restart the spinning antenna. Contingency plans for what to do in the event of QuikSCAT's failure were also reviewed.

## **Replacement**

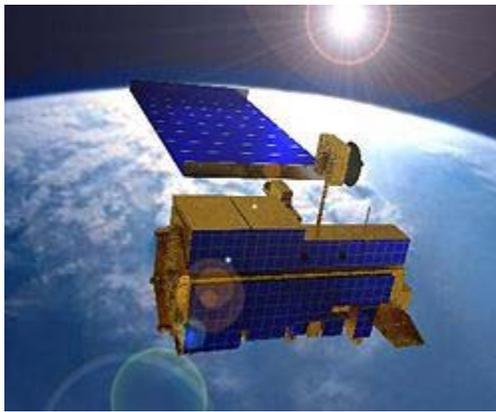
Replacement of this satellite remains a topic of debate. Although NHC forecasters occasionally cite the data provided by QuikSCAT, some do not feel that the value of the data warrants the expenditure that would be necessary for replacement of the satellite with a similar instrument, but rather advocate development of a more advanced satellite.

A joint project for creating a new satellite with the next generation of equipment has been announced by NASA and the NHC. The new satellite is scheduled to be operational in 2015, at which time it will be put in orbit around Earth.

## Chapter- 3

# Terra (Satellite)

### Terra (EOS AM-1)



Terra (EOS AM-1)

<b>Operator</b>	NASA
<b>Satellite of</b>	<b>Earth</b>
<b>Launch date</b>	December 18, 1999
<b>Launch vehicle</b>	Atlas II AS
<b>Launch site</b>	Vandenberg AFB
<b>COSPAR ID</b>	1999-068A
<b>Homepage</b>	<a href="http://terra.nasa.gov/">http://terra.nasa.gov/</a>
<b>Mass</b>	4,864 kg (10,723 lb)

#### Orbital elements

<b>Eccentricity</b>	0
<b>Inclination</b>	98.2°

<b>Apoapsis</b>	685 km (426 mi)
<b>Periapsis</b>	654 km (406 mi)
<b>Orbital period</b>	98.1 minutes

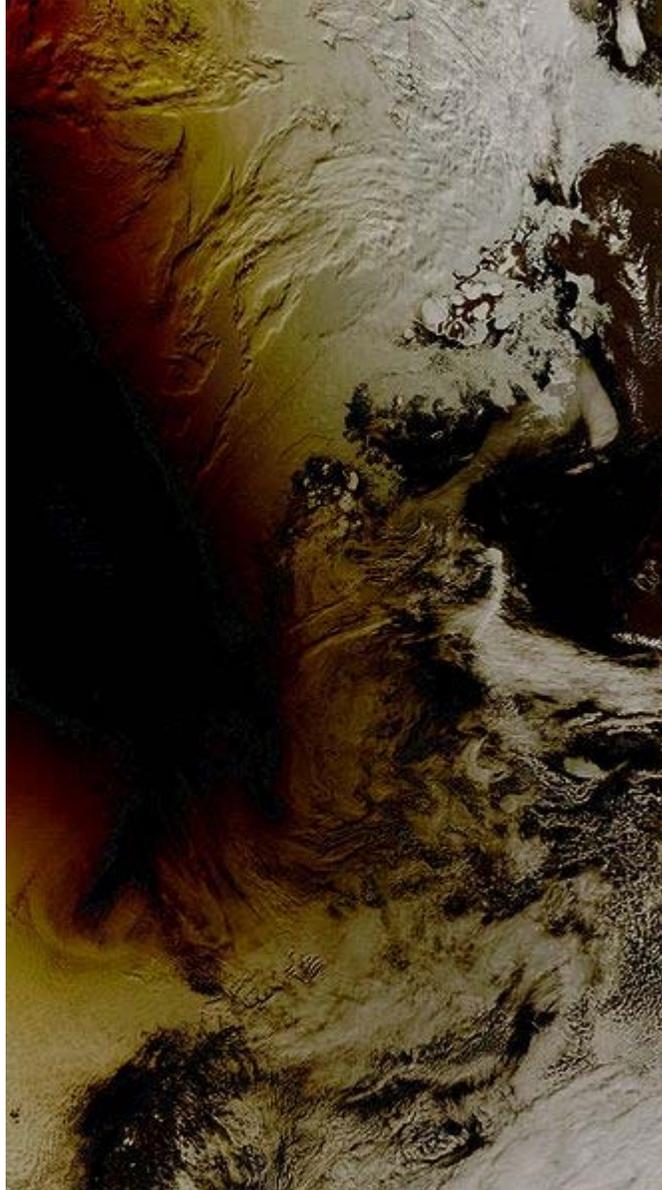
**Terra (EOS AM-1)** is a multi-national NASA scientific research satellite in a sun-synchronous orbit around the Earth. It is the flagship of the Earth Observing System (EOS). The name "Terra" comes from the Latin word for Earth.

## Launch

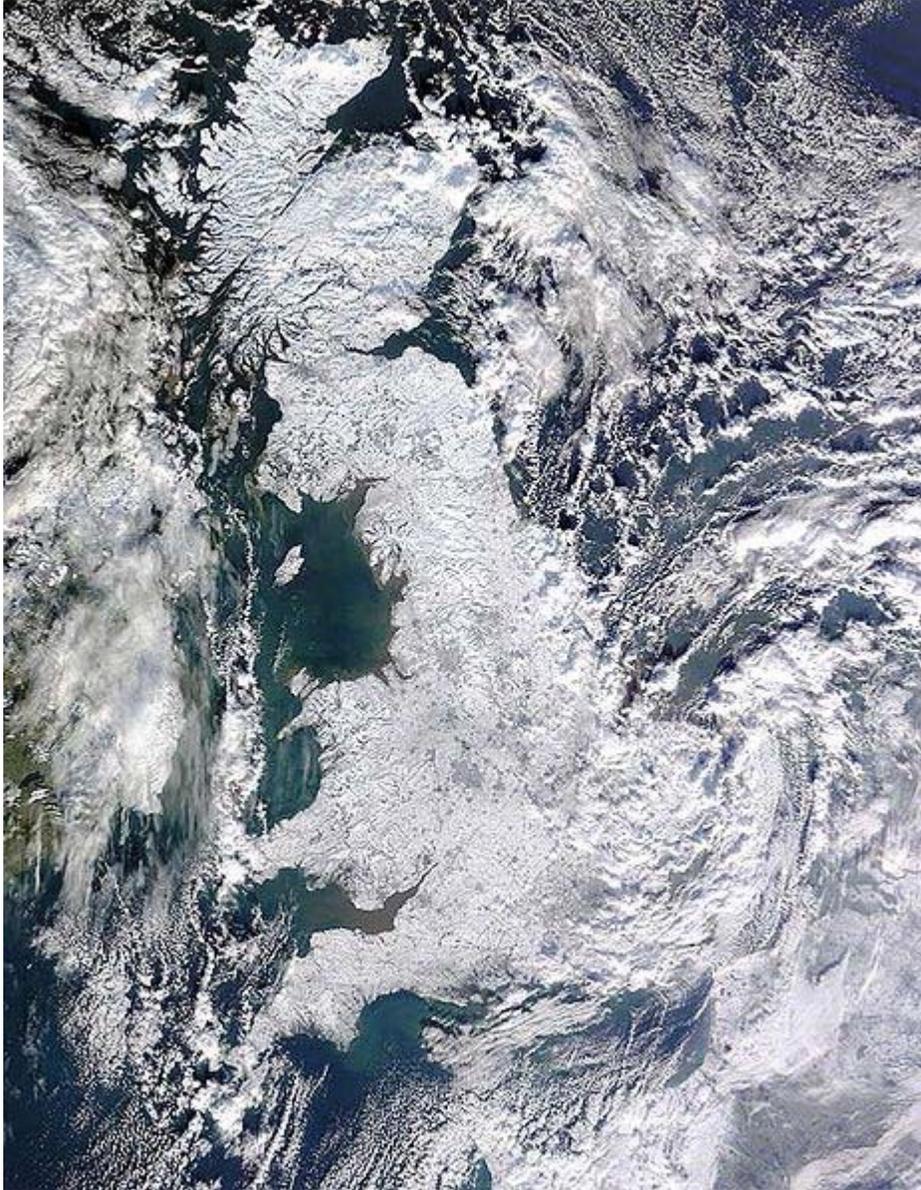
The satellite was launched from Vandenberg Air Force Base on December 18, 1999, aboard an Atlas IIAS vehicle and began collecting data on February 24, 2000.



The BP slick just off the Louisiana coast on April 30, 2010, visible from space.



The Solar eclipse of August 1, 2008 over Russia, Norway, and the Arctic Ocean as seen from NASA's Terra satellite.



The effects of the European winter storms of 2009–2010 on Great Britain, seen from Terra.



The Deepwater Horizon oil spill oil slick as seen from space by NASA's Terra satellite on May 1, 2010.

## **Mission**

Terra carries a payload of five remote sensors designed to monitor the state of Earth's environment and ongoing changes in its climate system:

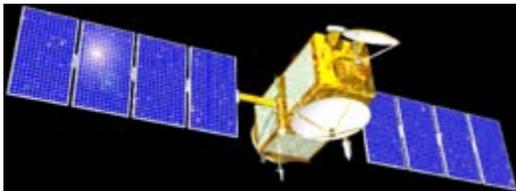
- ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)
- CERES (Clouds and the Earth's Radiant Energy System)
- MISR (Multi-angle Imaging SpectroRadiometer)
- MODIS (Moderate-resolution Imaging Spectroradiometer)
- MOPITT (Measurements of Pollution in the Troposphere)

Data from the satellite helps scientists better understand the spread of pollution around the globe. Studies have used instruments on Terra to examine trends in global carbon monoxide and aerosol pollution. The data collected by Terra will ultimately become a new, 15-year global data set.

## Chapter- 4

# Jason-1

### Jason-1



Artist's interpretation of the Jason-1 satellite

<b>Operator</b>	NASA, CNES
<b>Mission type</b>	Earth orbiter
<b>Launch date</b>	2001
<b>Launch vehicle</b>	Delta II
<b>Mission duration</b>	three years, now on extended mission
<b>Homepage</b>	<a href="#">Ocean Surface Topography from Space</a>

#### **Orbital elements**

<b>Orbital period</b>	6754.0s
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**Jason-1** is a satellite oceanography mission to monitor global ocean circulation, study the ties between the ocean and the atmosphere, improve global climate forecasts and predictions, and monitor events such as El Niño and ocean eddies.

It is the successor to the TOPEX/Poseidon mission, which measured ocean surface topography from 1992 through 2005. Like its predecessor, Jason-1 is a joint project between the NASA (United States) and CNES (France) space agencies. Jason-1's successor, the Ocean Surface Topography Mission on the Jason-2 satellite, was launched in June 2008. These satellites provide a unique global view of the oceans that is impossible to acquire using traditional ship-based sampling.

Jason-1 was built by Thales Alenia Space using a Proteus platform, under a contract from CNES, as well as the main Jason-1 instrument, the Poseidon-2 altimeter (successor to the Poseidon altimeter on-board TOPEX/Poseidon)

Jason-1 was designed to measure climate change through very precise millimeter-per-year measurements of global sea level changes. As did TOPEX/Poseidon, Jason-1 uses an altimeter to measure the hills and valleys of the ocean's surface. These measurements of sea surface topography allow scientists to calculate the speed and direction of ocean currents and monitor global ocean circulation. The global ocean is Earth's primary storehouse of solar energy. Jason-1's measurements of sea surface height reveal where this heat is stored, how it moves around Earth by ocean currents, and how these processes affect weather and climate.

Jason-1 was launched on December 7, 2001 from California's Vandenberg Air Force Base aboard a Delta II rocket. During the first months Jason-1 shared an almost identical orbit to TOPEX/Poseidon, which allowed for cross calibration. At the end of this period, the older satellite was moved to a new orbit midway between each Jason ground track. Jason has a repeat cycle of 10 days.

Recent orbit maneuvers in 2009 put the Jason-1 satellite on the opposite side of Earth from the Jason-2 satellite, which is operated by the U.S. and French weather agencies. Jason-1 now flies over the same region of the ocean that Jason-2 flew over five days earlier. Its ground tracks fall mid-way between those of Jason-2, which are about 315 kilometers (195 miles) apart at the equator.

This interleaved tandem mission provides twice the number of measurements of the ocean's surface, bringing smaller features such as ocean eddies into view. The tandem mission also helps pave the way for a future ocean altimeter mission that would collect much more detailed data with its single instrument than the two Jason satellites now do together.

The program is named after the Greek mythological hero Jason.

## **Satellite instruments**

Jason-1 has five 5 instruments:

- Poseidon 2 - Nadir pointing Radar Altimeter using C band and Ku band for measuring height above sea surface.
- Jason Microwave Radiometer (JMR) - measures water vapor along altimeter path to correct for pulse delay
- DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) for orbit determination to within 10 cm or less and ionospheric correction data for Poseidon 2.
- BlackJack Global Positioning System receiver provides precise orbit ephemeris data

- Laser retroreflector array works with ground stations to track the satellite and calibrate and verify altimeter measurements.

The Jason-1 satellite, its altimeter instrument and a position-tracking antenna were built in France. The radiometer, Global Positioning System receiver and laser retroreflector array were built in the United States.

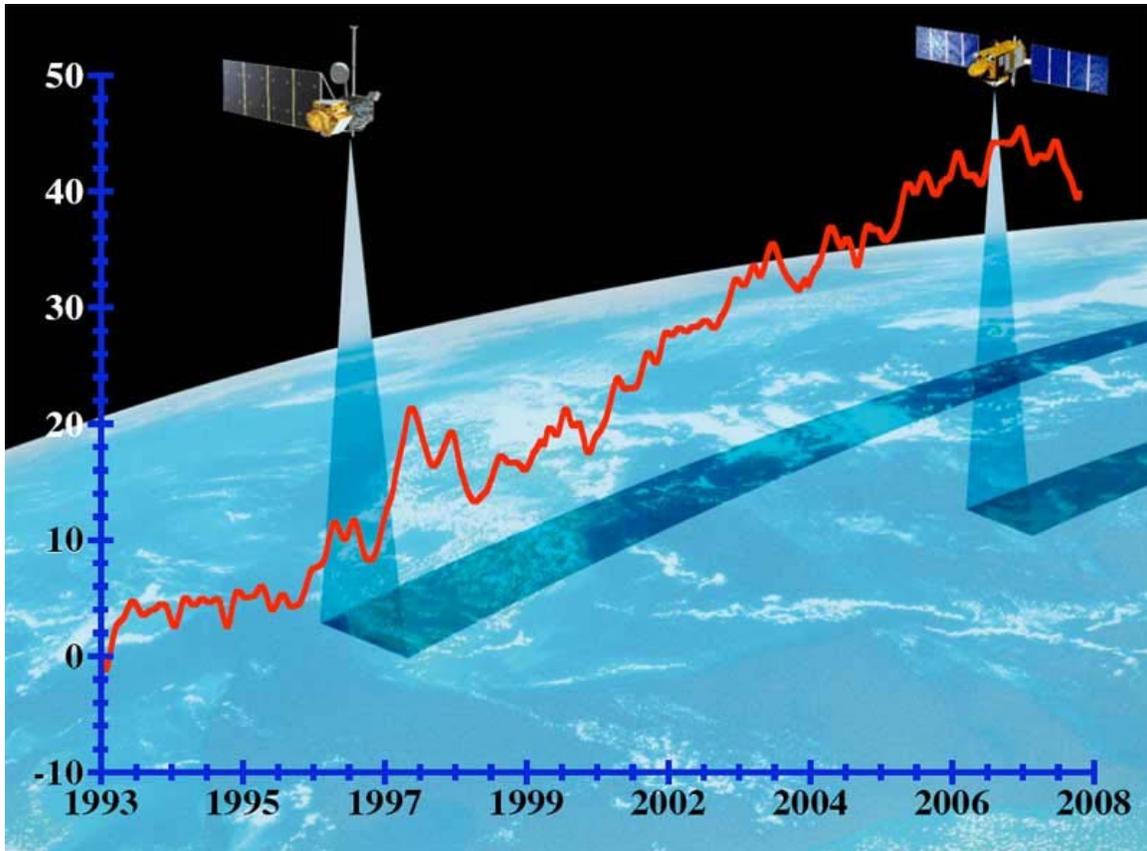
## **Use of information**

TOPEX/Poseidon and Jason-1 have led to major advances in the science of physical oceanography and in climate studies. Their 15-year data record of ocean surface topography has provided the first opportunity to observe and understand the global change of ocean circulation and sea level. The results have improved the understanding of the role of the ocean in climate change and improved weather and climate predictions. Data from these missions are used to improve ocean models, forecast hurricane intensity, and identify and track large ocean/atmosphere phenomena such as El Niño and La Niña. The data are also used every day in applications as diverse as routing ships, improving the safety and efficiency of offshore industry operations, managing fisheries, and tracking marine mammals.

TOPEX/Poseidon and Jason 1-have made major contributions to the understanding of:

- Ocean Variability

The missions revealed the surprising variability of the ocean, how much it changes from season to season, year to year, decade to decade and on even longer time scales. They ended the traditional notion of a quasi-steady, large-scale pattern of global ocean circulation by proving that the ocean is changing rapidly on all scales, from huge features such as El Nino and La Nina, which can cover the entire equatorial Pacific, to tiny eddies swirling off the large Gulf Stream in the Atlantic.



Global sea level has risen about 3 millimeters (0.1 inch) a year since Topex/Poseidon (on the left) began its precise measurement of sea surface height in 1993 and was followed by Jason-1 in 2001. In this graph, the vertical scale represents globally averaged sea level. Seasonal variations in sea level have been removed to show the underlying trend. Image credit: University of Colorado

- Sea Level Change

Measurements by TOPEX/Poseidon and Jason-1 show that mean sea level has been rising by about three millimeters (.12 inches) a year since 1993. This is about twice the estimates from tide gauges for the previous century, indicating a possible recent acceleration in the rate of sea level rise.

The data record from these altimetry missions has given scientists important insights into how global sea level is affected by natural climate variability, as well as by human activities.

- Planetary Waves

TOPEX/Poseidon and Jason-1 made clear the importance of planetary-scale waves, such as Rossby and Kelvin waves. No one had realized how widespread these waves are. Thousands of kilometers wide, these waves are driven by wind under the influence of

Earth's rotation and are important mechanisms for transmitting climate signals across the large ocean basins. At high latitudes, they travel twice as fast as scientists believed previously, showing the ocean responds much more quickly to climate changes than was known before these missions.

- Ocean Tides

The precise measurements of TOPEX/Poseidon's and Jason-1 have brought knowledge of ocean tides to an unprecedented level. The change of water level due to tidal motion in the deep ocean is known everywhere on the globe to within 2.5 centimeters (one inch). This new knowledge has revised notions about how tides dissipate. Instead of losing all their energy over shallow seas near the coasts, as previously believed, about one third of tidal energy is actually lost to the deep ocean. There, the energy is consumed by mixing water of different properties, a fundamental mechanism in the physics governing the general circulation of the ocean.

- Ocean Models

TOPEX/Poseidon and Jason-1 observations provided the first global data for improving the performance of the numerical ocean models that are a key component of climate prediction models.

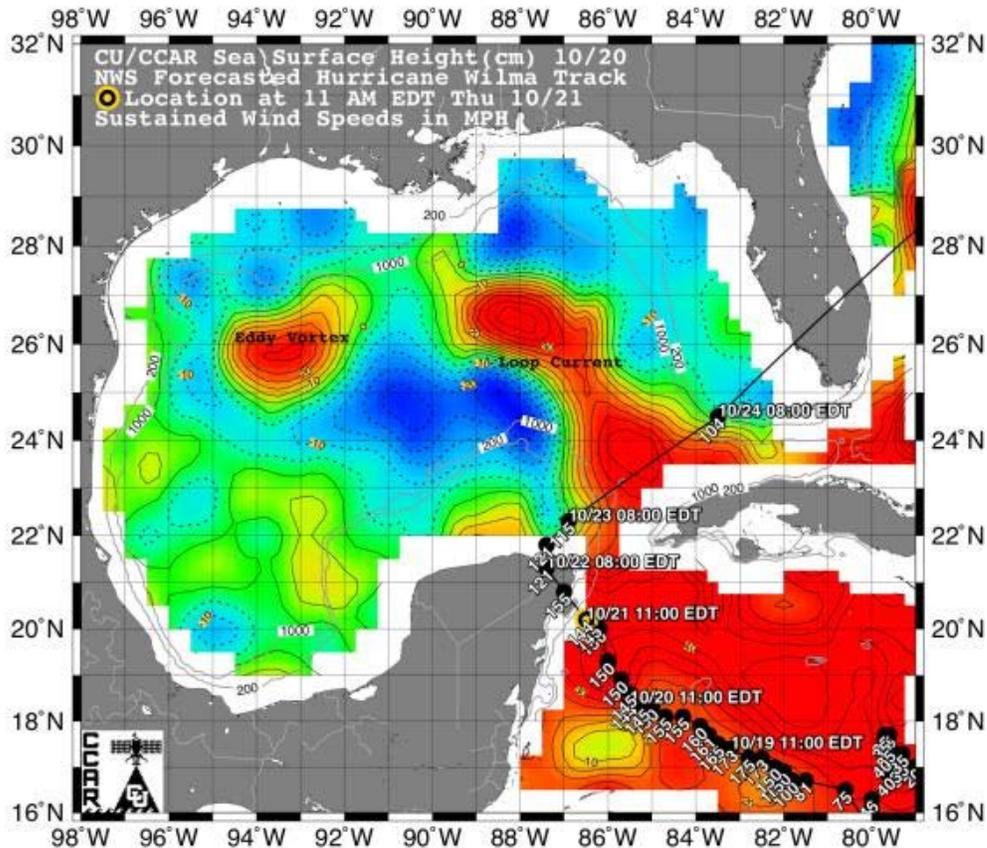
TOPEX/Poseidon and Jason-1 data are available at the University of Colorado Center for Astrodynamics Research, NASA's Physical Oceanography Distributed Active Archive Center, and the French data archive center AVISO.

## **Benefits to society**

Altimetry data have a wide variety of uses from basic scientific research on climate to ship routing. Applications include:

Climate Research: Altimetry data are incorporated into computer models to understand and predict changes in the distribution of heat in the ocean, a key element of climate.

El Niño & La Niña Forecasting: Understanding the pattern and effects of climate cycles such as El Niño helps predict and mitigate the disastrous effects of floods and drought.



Altimetry reveals the ocean heat that can fuel hurricanes.

Hurricane Forecasting: Altimeter data and satellite ocean wind data are incorporated into atmospheric models for hurricane season forecasting and individual storm severity.

Ship Routing: Maps of ocean currents, eddies, and vector winds are used in commercial shipping and recreational yachting to optimize routes.

Offshore Industries: Cable-laying vessels and offshore oil operations require accurate knowledge of ocean circulation patterns to minimize impacts from strong currents.

Marine Mammal Research: Sperm whales, fur seals, and other marine mammals can be tracked, and therefore studied, around ocean eddies where nutrients and plankton are abundant.

Fisheries Management: Satellite data identify ocean eddies which bring an increase in organisms that comprise the marine food web, attracting fish and fishermen.

Coral Reef Research: Remotely sensed data are used to monitor and assess coral reef ecosystems, which are sensitive to changes in ocean temperature.

Marine Debris Tracking: The amount of floating and partially submerged material, including nets, timber and ship debris, is increasing with human population. Altimetry can help locate these hazardous materials.

## Chapter- 5

# Ocean Surface Topography Mission

### OSTM/Jason-2



Artist's interpretation of the Jason-2 satellite

<b>Operator</b>	NASA, CNES, NOAA, EUMETSAT
<b>Mission type</b>	Earth orbiter
<b>Launch date</b>	June 20, 2008
<b>Launch vehicle</b>	Delta II
<b>Mission duration</b>	Three years with provision for two-year extended mission
<b>Homepage</b>	Ocean Surface Topography from Space

#### Orbital elements

**Orbital period** 6754.0s



The launch of OSTM



Jason-2 after separation from its carrier rocket

The **Ocean Surface Topography Mission (OSTM)** on the **Jason-2** satellite is an international Earth observation satellite mission that continues the sea surface height measurements begun in 1992 by the joint NASA/CNES TOPEX/Poseidon mission and followed by the NASA/CNES Jason-1 mission launched in 2001.

Like its two predecessors, OSTM/Jason-2 uses high-precision ocean altimetry to measure the distance between the satellite and the ocean surface to within a few centimeters. These very accurate observations of variations in sea surface height—also known as ocean topography—provide information about global sea level, the speed and direction of ocean currents, and heat stored in the ocean.

Jason-2 was built by Thales Alenia Space using a Proteus platform, under a contract from CNES, as well as the main Jason-2 instrument, the Poseidon-3 altimeter (successor to the Poseidon and Poseidon 2 altimeter on-board TOPEX/Poseidon and Jason-1)

Scientists consider the 15-plus-year climate data record that this mission will extend critical understanding how ocean circulation is linked to global climate change.

OSTM/Jason-2 was launched at 07:46 UTC on June 20, 2008, from Space Launch Complex 2W at the Vandenberg Air Force Base in California, USA, by a Delta II 7320 rocket. The spacecraft separated from the rocket 55 minutes later.

It is now in a 1,336 km (830 mi) circular, non-sun-synchronous orbit at an inclination of 66 degrees to Earth's equator, allowing it to monitor 95 percent of Earth's ice-free ocean every 10 days. Jason-1 has been moved to the opposite side of Earth and now flies over the same region of the ocean that Jason-2 flew over five days earlier. Jason-1's ground tracks fall mid-way between those of Jason-2, which are about 315 kilometers (195 miles) apart at the equator. This interleaved tandem mission provides twice the number of measurements of the ocean's surface, bringing smaller features such as ocean eddies into view. The tandem mission also helps pave the way for a future ocean altimeter mission that would collect much more detailed data with its single instrument than the two Jason satellites now do together.

With OSTM/Jason-2, ocean altimetry makes the transition from research into operational mode. Responsibility for collecting these measurements moves from the space agencies to the world's weather and climate forecasting agencies, which use them for short-range, seasonal, and long-range weather and climate forecasting.

## **Science objectives**

- Extend the time series of ocean surface topography measurements beyond TOPEX/Poseidon and Jason-1 to accomplish two decades of observations
- Provide a minimum of three years of global ocean surface topography measurement
- Determine the variability of ocean circulation at decadal time scales from combined data record of TOPEX/Poseidon and Jason-1
- Improve the measure of the time-averaged ocean circulation
- Improve the measure of global sea-level change
- Improve open ocean tide models

## **Ocean altimetry**

Spaceborne radar altimeters have proven to be superb tools for mapping ocean-surface topography, the hills and valleys of the sea surface. These instruments send a microwave pulse to the ocean's surface and time how long it takes to return. A microwave radiometer corrects any delay that may be caused by water vapor in the atmosphere. Other corrections are also required to account for the influence of electrons in the ionosphere and the dry air mass of the atmosphere. Combining these data with the precise location of the spacecraft makes it possible to determine sea-surface height to within a few centimetres (about one inch). The strength and shape of the returning signal also provides information on wind speed and the height of ocean waves. These data are used in ocean models to calculate the speed and direction of ocean currents and the amount and location of heat stored in the ocean, which, in turn, reveals global climate variations.

## **Atomic clock synchronization**

Another payload aboard Jason-2 is the T2L2 (Time Transfer by Laser Link) instrument. T2L2 is used to synchronize atomic clocks at ground stations, and to calibrate the on-board clock of the Jason-2 DORIS instrument. On 6 November 2008 CNES reported the T2L2 instrument was working well.

## **Joint effort**

OSTM/Jason-2 is a joint effort by four organizations. The mission participants are:

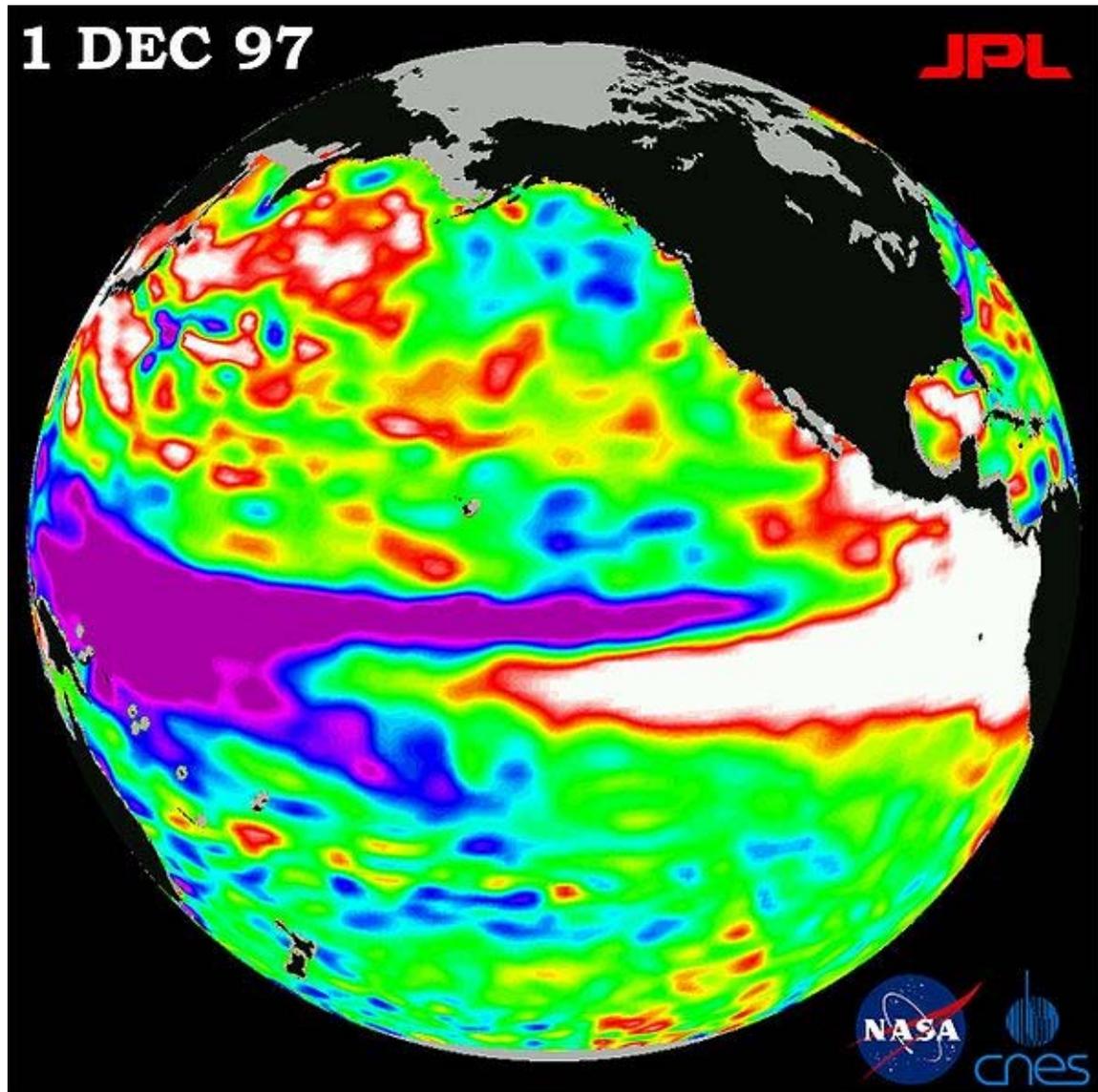
- National Oceanic and Atmospheric Administration (NOAA)
- National Aeronautics and Space Administration (NASA)
- France's Centre National d'Études Spatiales (CNES)
- European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)

CNES provided the spacecraft, NASA and CNES jointly provided the payload instruments and NASA's Launch Services Program at the Kennedy Space Center was responsible for the launch management and countdown operations. After completing the on-orbit commissioning of the spacecraft, CNES handed over operation and control of the spacecraft to NOAA in October 2008.

CNES will process, distribute and archive the research-quality data products that will become available in 2009. EUMETSAT will process and distribute operational data received by its ground station to users in Europe and will archive the data. NOAA will process and distribute operational data received by its ground stations to non-European users and archive that data along with the CNES data products. NOAA and EUMETSAT will generate the near-real-time products and distribute them to users.

NASA will evaluate the performance of its instruments: the advanced microwave radiometer, the Global Positioning System payload, and the laser retroreflector assembly. In addition, NASA and CNES will validate scientific data products. NASA's Jet Propulsion Laboratory in Pasadena, California, manages the mission for NASA's Science Mission Directorate in Washington.

## Prior similar missions



OSTM/Jason-2's predecessor TOPEX/Poseidon caught the largest El Niño in a century seen in this image from Dec. 1, 1997.

The two previous altimetry missions TOPEX/Poseidon and Jason-1 have led to major advances in the science of physical oceanography and in climate studies. Their 15-year data record of ocean surface topography has provided the first opportunity to observe and understand the global change of ocean circulation and sea level. The results have improved the understanding of the role of the ocean in climate change and improved weather and climate predictions. Data from these missions are used to improve ocean models, forecast hurricane intensity, and identify and track large ocean/atmosphere phenomena such as El Niño and La Niña. The data are also used every day in applications as diverse as routing ships, improving the safety and efficiency of offshore industry operations, managing fisheries and tracking marine mammals.

Some of the areas in which TOPEX/Poseidon and Jason 1-have made major contributions, and to which OSTM/Jason-2 will continue to add, are:

- Ocean Variability

The missions revealed the surprising variability of the ocean, how much it changes from season to season, year to year, decade to decade and on even longer time scales. They ended the traditional notion of a quasi-steady, large-scale pattern of global ocean circulation by proving that the ocean is changing rapidly on all scales, from huge features such as El Nino and La Nina, which can cover the entire equatorial Pacific, to tiny eddies swirling off the large Gulf Stream in the Atlantic.

- Sea Level Change

Measurements by TOPEX/Poseidon and Jason-1 show that mean sea level has been rising by about three millimeters (.12 inches) a year since 1993. This is about twice the estimates from tide gauges for the previous century, indicating a possible recent acceleration in the rate of sea level rise.

The data record from these altimetry missions has given scientists important insights into how global sea level is affected by natural climate variability, as well as by human activities.

- Planetary Waves

TOPEX/Poseidon and Jason-1 made clear the importance of planetary-scale waves, such as Rossby and Kelvin waves. No one had realized how widespread these waves are. Thousands of kilometers wide, these waves are driven by wind under the influence of Earth's rotation and are important mechanisms for transmitting climate signals across the large ocean basins. At high latitudes, they travel twice as fast as scientists believed previously, showing the ocean responds much more quickly to climate changes than was known before these missions.

- Ocean Tides

The precise measurements of TOPEX/Poseidon's and Jason-1 have brought knowledge of ocean tides to an unprecedented level. The change of water level due to tidal motion in the deep ocean is known everywhere on the globe to within 2.5 centimeters (one inch). This new knowledge has revised notions about how tides dissipate. Instead of losing all their energy over shallow seas near the coasts, as previously believed, about one third of tidal energy is actually lost to the deep ocean. There, the energy is consumed by mixing water of different properties, a fundamental mechanism in the physics governing the general circulation of the ocean.

- Ocean Models

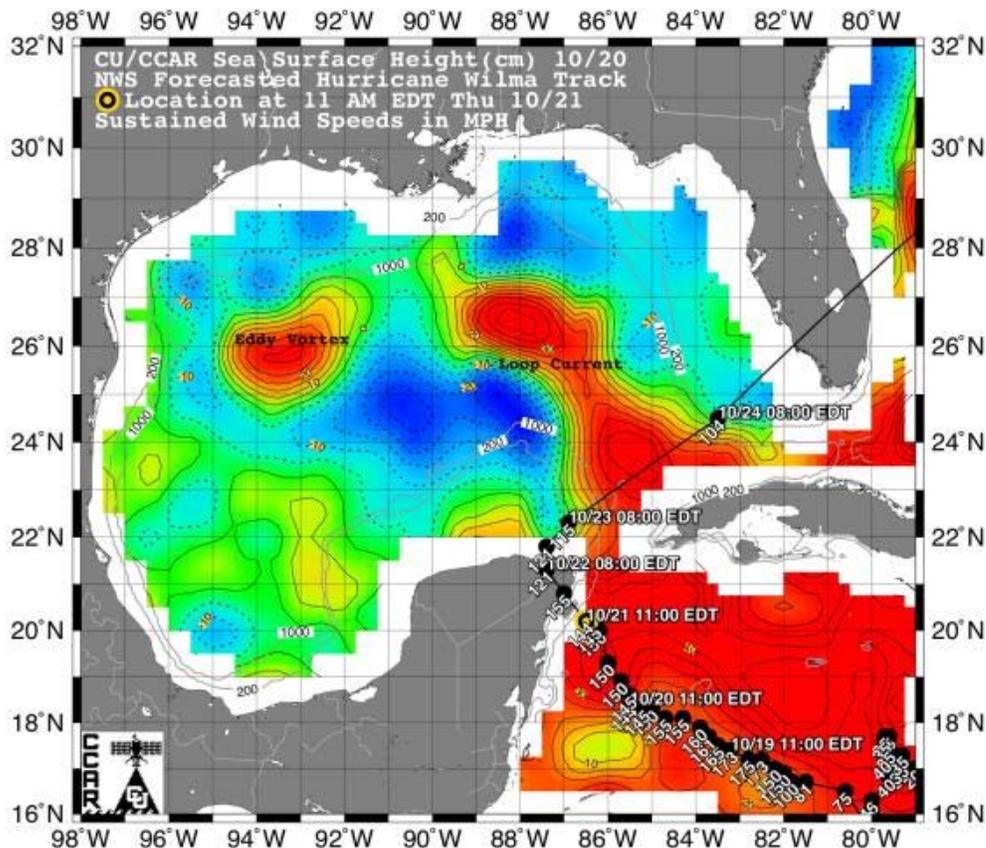
TOPEX/Poseidon and Jason-1 observations provided the first global data for improving the performance of the numerical ocean models that are a key component of climate prediction models.

## Data use and benefits

The mission's first validated data products in support of improved weather, climate and ocean forecasts are now being distributed to the public within a few hours of observation. Beginning in 2009, other data products for climate research will be available a few days to a few weeks after observations are taken by the satellite.

Altimetry data have a wide variety of uses from basic scientific research on climate to ship routing. Applications include:

- Climate research: Altimetry data are incorporated into computer models to understand and predict changes in the distribution of heat in ocean, a key element of climate.
- El Niño and La Niña forecasting: Understanding the pattern and effects of climate cycles such as El Niño helps predict and mitigate the disastrous effects of floods and drought.



Altimetry reveals the ocean heat that can fuel hurricanes.

- Tropical cyclone forecasting: Altimeter data and satellite ocean wind data are incorporated into atmospheric models for hurricane season forecasting and individual storm severity.
- Ship routing: Maps of currents, eddies, and vector winds are used in commercial shipping and recreational yachting to optimize routes.
- Offshore industries: Cable-laying vessels and offshore oil operations require accurate knowledge of ocean circulation patterns, to minimize impacts from strong currents.
- Marine mammal research: Sperm whales, fur seals, and other marine mammals can be tracked, and therefore studied, around ocean eddies where nutrients and plankton are abundant.
- Fisheries management: Satellite data identify ocean eddies which bring an increase in organisms that comprise the marine food web, attracting fish and fishermen.
- Coral reef research: Remotely sensed data are used to monitor and assess coral reef ecosystems, which are sensitive to changes in ocean temperature.
- Marine debris tracking: Altimetry can help locate hazardous materials such as floating and partially submerged fishing nets, timber, and ship debris.

## Chapter- 6

# Soil Moisture Active and Passive mission

### Soil Moisture Active and Passive Mission (SMAP)



Artist's Concept of SMAP

<b>Operator</b>	NASA
<b>Mission type</b>	Orbiter
<b>Launch date</b>	2014
<b>Mission duration</b>	3 years
<b>Homepage</b>	<a href="#">NASA's SMAP home page</a>
<b>Power</b>	Solar panels

The **Soil Moisture Active and Passive mission** (SMAP) is in the first tier of missions recommended for NASA by the Earth Science Decadal Survey. It has been selected for launch in November 2014.

### Mission overview

SMAP will provide measurements of the land surface soil moisture and freeze-thaw state with near-global revisit coverage in 2–3 days. SMAP surface measurements will be

coupled with hydrologic models to infer soil moisture conditions in the root zone. These measurements will enable science applications users to:

1) Understand processes that link the terrestrial water, energy and carbon cycles; 2) Estimate global water and energy fluxes at the land surface; 3) Quantify net carbon flux in boreal landscapes; 4) Enhance weather and climate forecast skill; 5) Develop improved flood prediction and drought monitoring capability.

SMAP observations will be acquired for a period of at least three years after launch. A comprehensive validation, science, and applications program will be implemented, and all data will be made available publicly through the NASA archive centers.

## **Measurement concept**

The SMAP observatory includes a dedicated spacecraft and instrument suite that will be launched into a near-polar, sun-synchronous orbit on an expendable launch vehicle.

The SMAP measurement system consists of a radiometer (passive) instrument and a synthetic aperture radar (active) instrument operating with multiple polarizations in the L-band range (1.20-1.41 GHz).

The active and passive sensors provide coincident measurements of the surface emission and backscatter. The instruments sense conditions in the top 5 cm of soil through moderate vegetation cover to yield globally mapped estimates of soil moisture and its freeze-thaw state. The combined active and passive measurement approach takes advantage of the spatial resolution of the radar and the sensing accuracy of the radiometer.

## **System characteristics**

The radar and radiometer share a single feed and deployable mesh reflector antenna system (diameter 6 m) that rotates around the nadir axis making conical scans of the surface. The wide swath provides near-global revisit 2–3 days.

### SMAP System Characteristics

	RADAR	RADIOMETER
Frequency	1.2 GHz	1.41 GHz
Polarizations	VV, HH, HV	V, H, U
Resolution	1-3 km*	40 km
Antenna diam	6 m	
Rotation rate	14.6 rpm	
Incidence angle	40 degrees	
Swath width	1000 km	
Orbit	Polar, Sun-Synchronous	
Local Time asc node	6 am	
Altitude	670 km	

\* Over outer 70% of swath

## Program description

SMAP is a directed mission of the National Aeronautics and Space Administration NASA with a target launch date in November 2014. The SMAP project is managed for NASA by the Jet Propulsion Laboratory JPL, with participation by the Goddard Space Flight Center GSFC. SMAP builds on the heritage and risk reduction activities of NASA's ESSP Hydros Mission.

## Science and applications

SMAP observations will be used to characterize hydrologic and ecosystem processes including land-atmosphere exchanges of water, energy, and carbon. SMAP soil moisture and freeze-thaw information will directly benefit several societal applications areas, including:

### Weather and climate forecasting

Initialization of numerical weather prediction models and seasonal climate models with accurate soil moisture information will extend forecast lead times and enhance prediction skill.

### Drought

SMAP soil moisture information will improve the monitoring and forecasting of drought conditions, enabling new capabilities for mitigating drought impacts.

## **Floods and landslides**

Hydrologic forecast systems calibrated and initialized with high-resolution soil moisture fields will lead to improved flood forecasts and will provide essential information on the potential for landslides.

## **Agricultural productivity**

Soil moisture observations from SMAP will lead to improvements in crop yield forecasts and will enhance the capabilities of crop water stress decision support systems for agricultural productivity.

## **Human health**

Improved seasonal soil moisture forecasts will directly benefit famine early warning systems. Benefits will also be realized through improved predictions of heat stress and virus spread rates, and improved disaster preparation and response.

## Chapter- 7

# Aqua (Satellite)

### Aqua



Aqua (EOS PM-1)

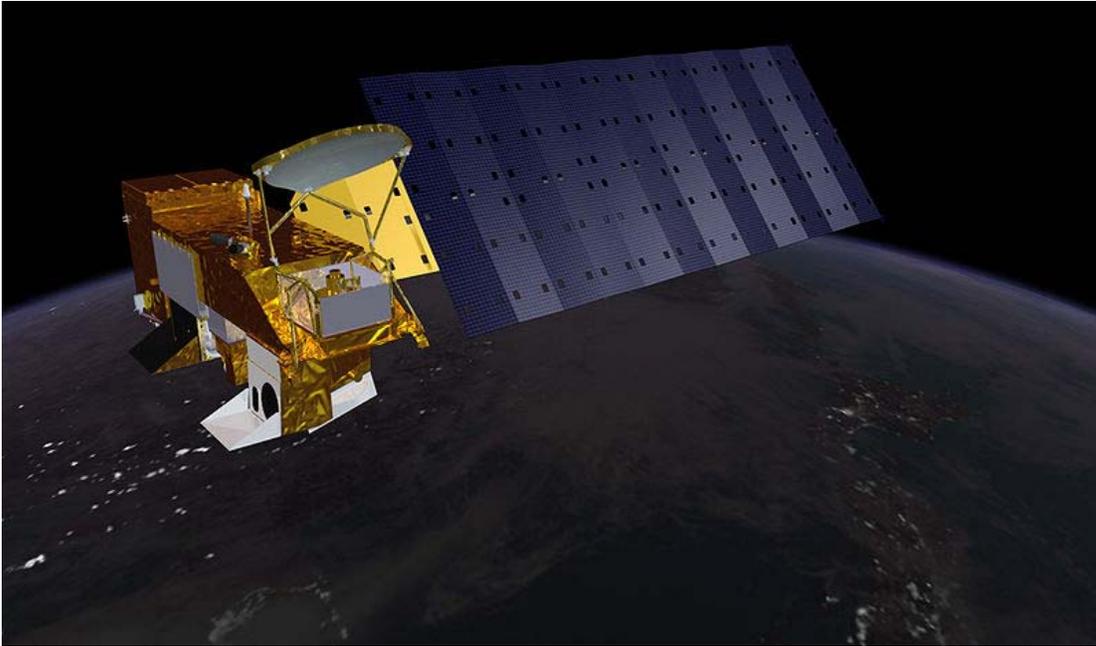
<b>Operator</b>	NASA
<b>Satellite of</b>	<b>Earth</b>
<b>Launch date</b>	May 4, 2002
<b>Launch vehicle</b>	Delta II
<b>Launch site</b>	Vandenberg AFB
<b>Mission duration</b>	Planned 6 Year Mission
<b>COSPAR ID</b>	2002-022A
<b>Mass</b>	3,117 kg (6,872 lb)
<b>Power</b>	4444 W
	<b>Orbital elements</b>
<b>Regime</b>	LEO
<b>Semimajor axis</b>	7077.75 km

<b>Eccentricity</b>	0.001203
<b>Inclination</b>	98.14°
<b>Apoapsis</b>	708 km (440 mi)
<b>Periapsis</b>	691 km (429 mi)
<b>Orbital period</b>	98.4 minutes
<b>Longitude</b>	N/A
<b>Orbits per day</b>	14.5625

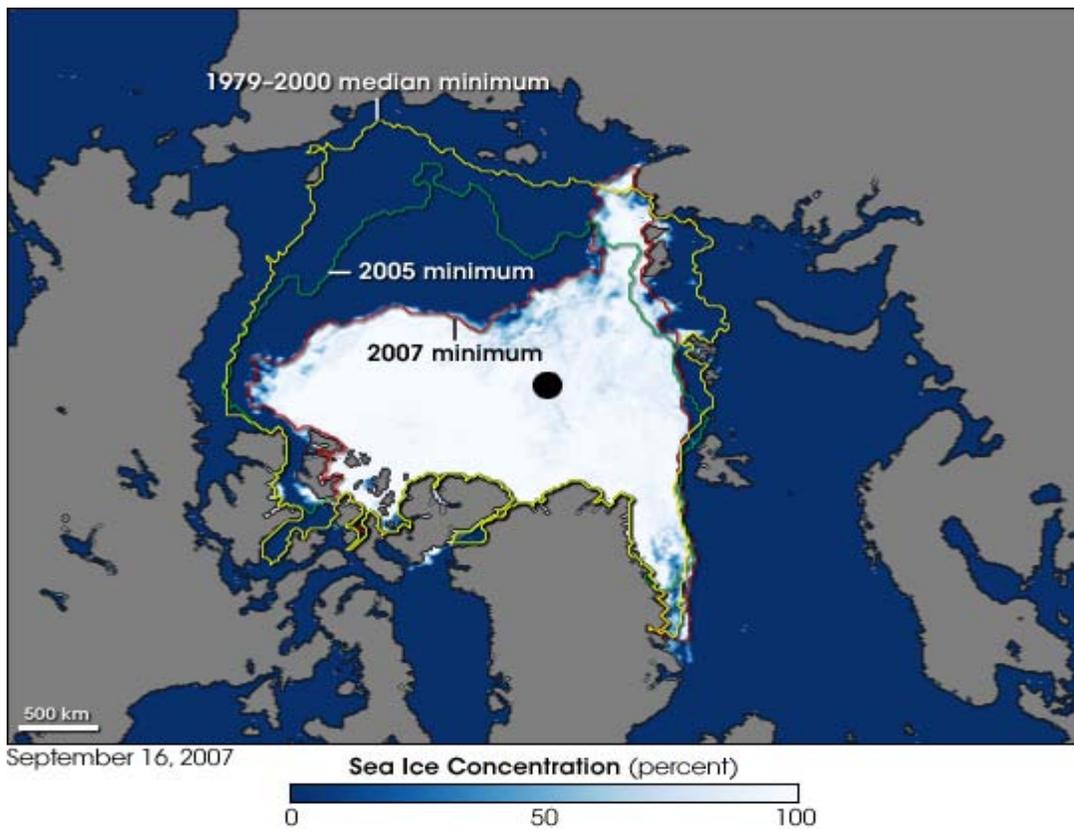
**Aqua (EOS PM-1)** is a multi-national NASA scientific research satellite in orbit around the Earth, studying the precipitation, evaporation, and cycling of water. It is the second major component of the Earth Observing System (EOS) preceded by Terra (launched 1999) and followed by Aura (launched 2004).



Aqua (EOS PM-1)



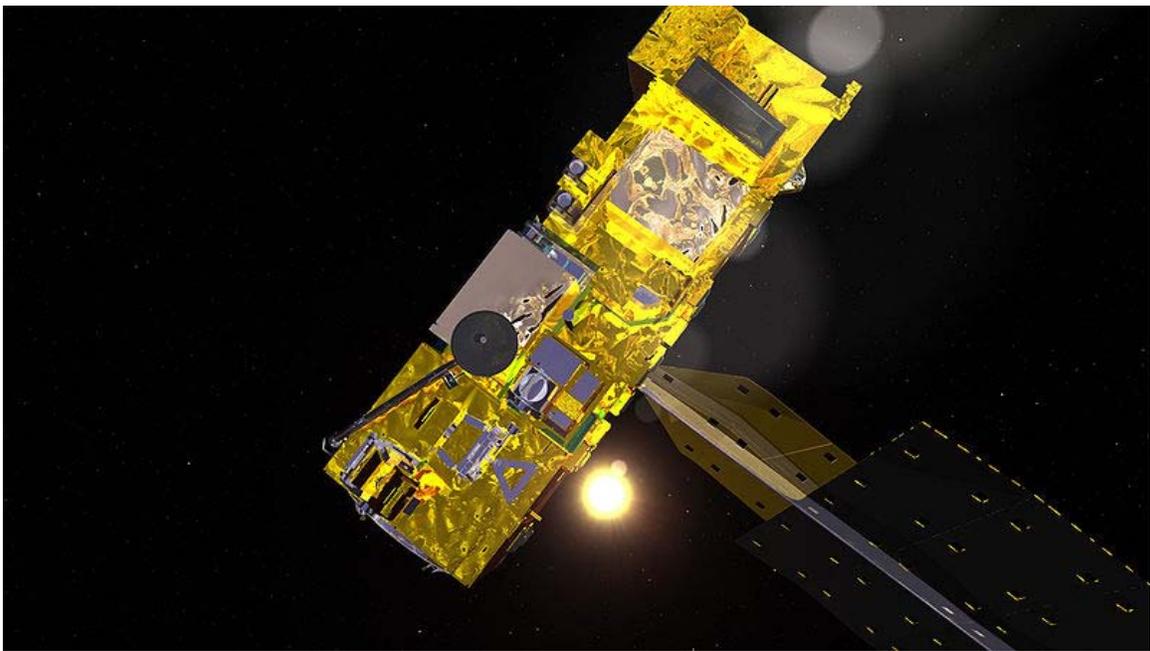
The Aqua satellite.



An image of Arctic shrinkage from Aqua observations



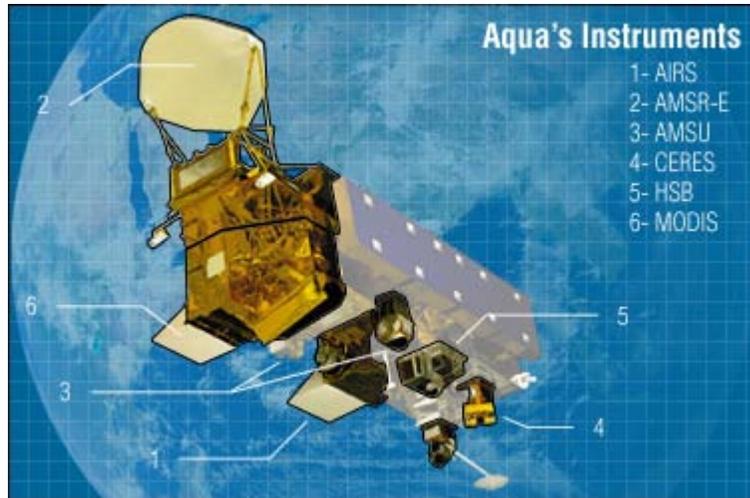
Amsr006



Aqua NASA satellite



Aqua assembly



Aqua instruments

The name "Aqua" comes from the Latin word for water. The satellite was launched from Vandenberg Air Force Base on May 4, 2002, aboard a Delta II rocket. Aqua is on a Sun-synchronous orbit. It flies leading the satellite formation called the "A Train" with several other satellites (Aura, CALIPSO, CloudSat and the French PARASOL).

Aqua carries six instruments for studies of water on the Earth's surface and in the atmosphere:

- AMSR-E — Advanced Microwave Scanning Radiometer-EOS — measures cloud properties, sea surface temperature, near-surface wind speed, radiative energy flux, surface water, ice and snow. Furnished by the National Space Development Agency of Japan.
- MODIS — Moderate Resolution Imaging Spectroradiometer, also measures cloud properties and radiative energy flux, also aerosol properties; land cover and land use change, fires and volcanos. This instrument is also aboard Terra.
- AMSU-A — Advanced Microwave Sounding Unit — measures atmospheric temperature and humidity.
- AIRS — Atmospheric Infrared Sounder — measures atmospheric temperature and humidity, land and sea surface temperatures.
- HSB — Humidity Sounder for Brazil — VHF band equipment measuring atmospheric humidity. Furnished by Instituto Nacional de Pesquisas Espaciais of Brazil. The HSB instrument has been in survival mode since 2/5/2003.
- CERES — Clouds and the Earth's Radiant Energy System, Flying Models 3 and 4, measure broadband radiative energy flux.

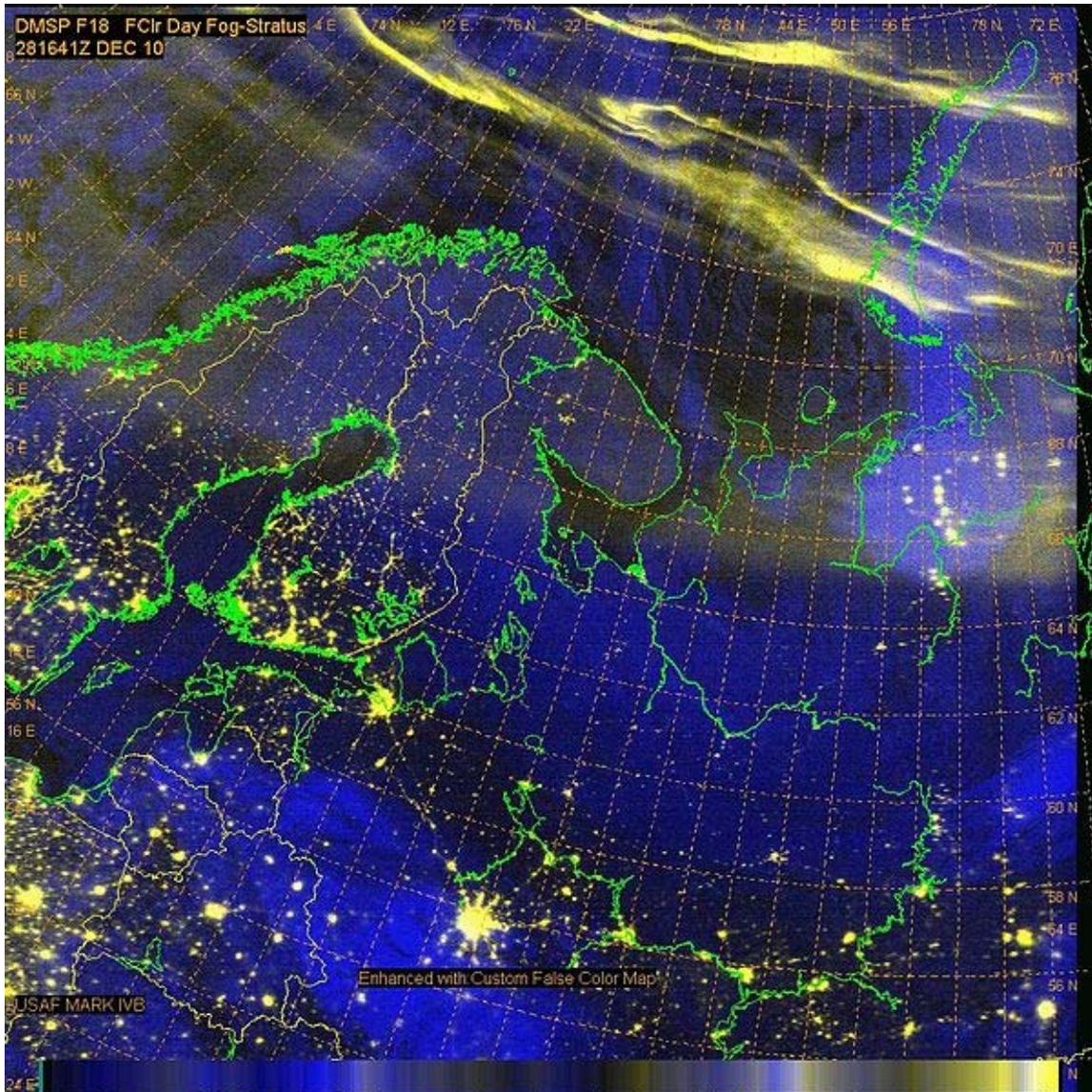
The Aqua spacecraft has a mass of about 2,850 kilograms (6,300 lb), plus propellant of about 230 kilograms (510 lb) (at launch). Stowed, the satellite is 2.68 m x 2.49 m x 6.49 m. Deployed, Aqua is 4.81 m x 16.70 m x 8.04 m.

## Chapter- 8

# Defense Meteorological Satellite Program



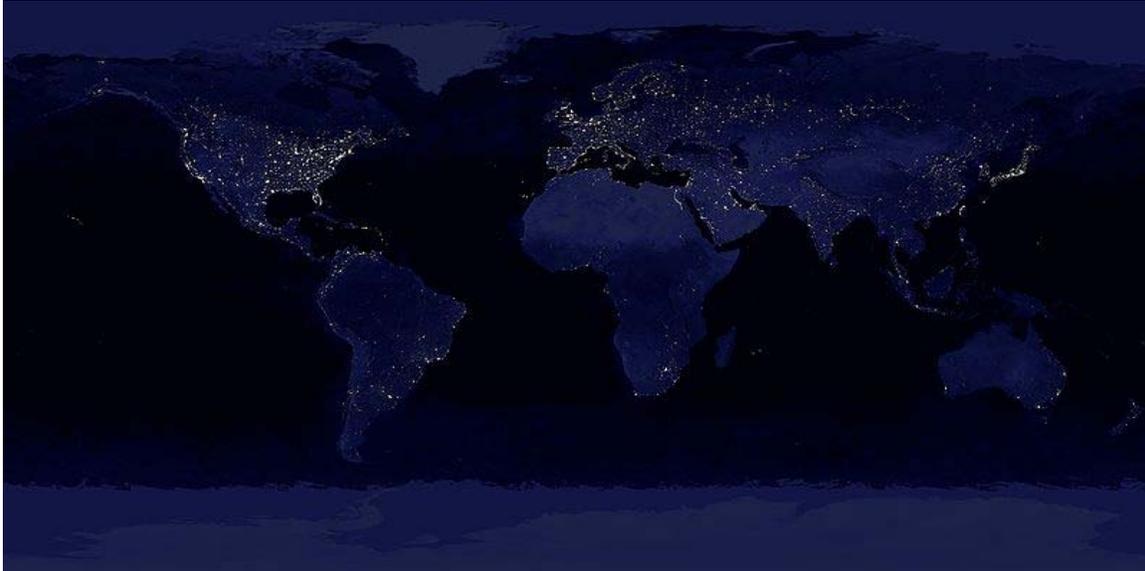
An artist's impression showing one of the Block 5D-3 spacecraft in orbit.



DMSP images of Auroral bands circling north of Scandinavia

The **Defense Meteorological Satellite Program (DMSP)** monitors meteorological, oceanographic, and solar-terrestrial physics for the United States Department of Defense. The program is now run by the National Oceanic and Atmospheric Administration. The (originally classified) mission of the satellites was revealed in March 1973. They provide cloud cover imagery from polar orbits that are sun-synchronous at nominal altitude of 450 nautical miles (830 km).

## History



Rendering of lights on Earth's surface created using DMSP observations

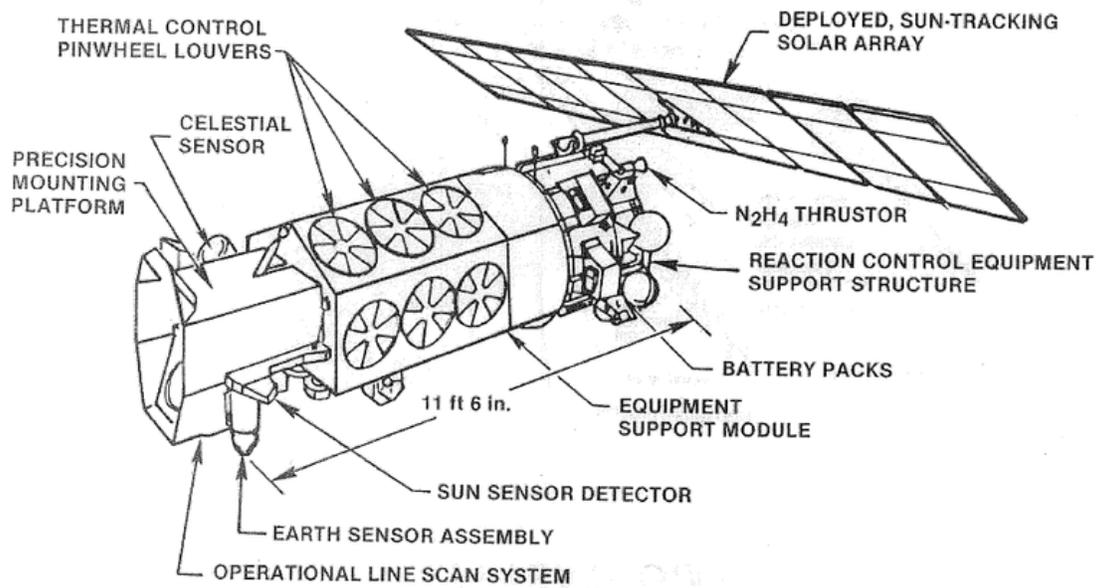
During the 1960s, one of most important projects the United States civil space program was involved in and dealt with meteorology and weather forecasting. Unbeknownst to many, the U.S. military services were also starting up a weather satellite program. This program, the DMSP, would relay important weather and climate data to the warfighter for more effective military operations. From the onset of the DMSP program, knowledge of its existence was limited to 'need-to-know' personnel. The United States Congress had assigned a substantial budget towards the civil weather satellite program; if knowledge of a second military program came out, it would have been hard for the military to justify it.

Initial operations of early DMSP systems provided radio return of cloud-cover imagery for planning of US high-resolution photographic reconnaissance and surveillance missions, which utilized film-return systems. DMSP satellites operated in a sun-synchronous orbit; passing over the north and south poles, the satellite would 'see' different strips of the Earth at the same local time each day. The DMSP satellites had periods of roughly 101 minutes, so they would orbit the Earth 14.3 times in 24 hours. This period combined with the sun-synchronous orbit would have the satellite pass over the whole surface of the planet twice a day.



DMSP - Block 5D3

### DMSP 5 D-2 SATELLITE



DMSP - Block 5D2

# BLOCK 5D SATELLITE ILLUSTRATED

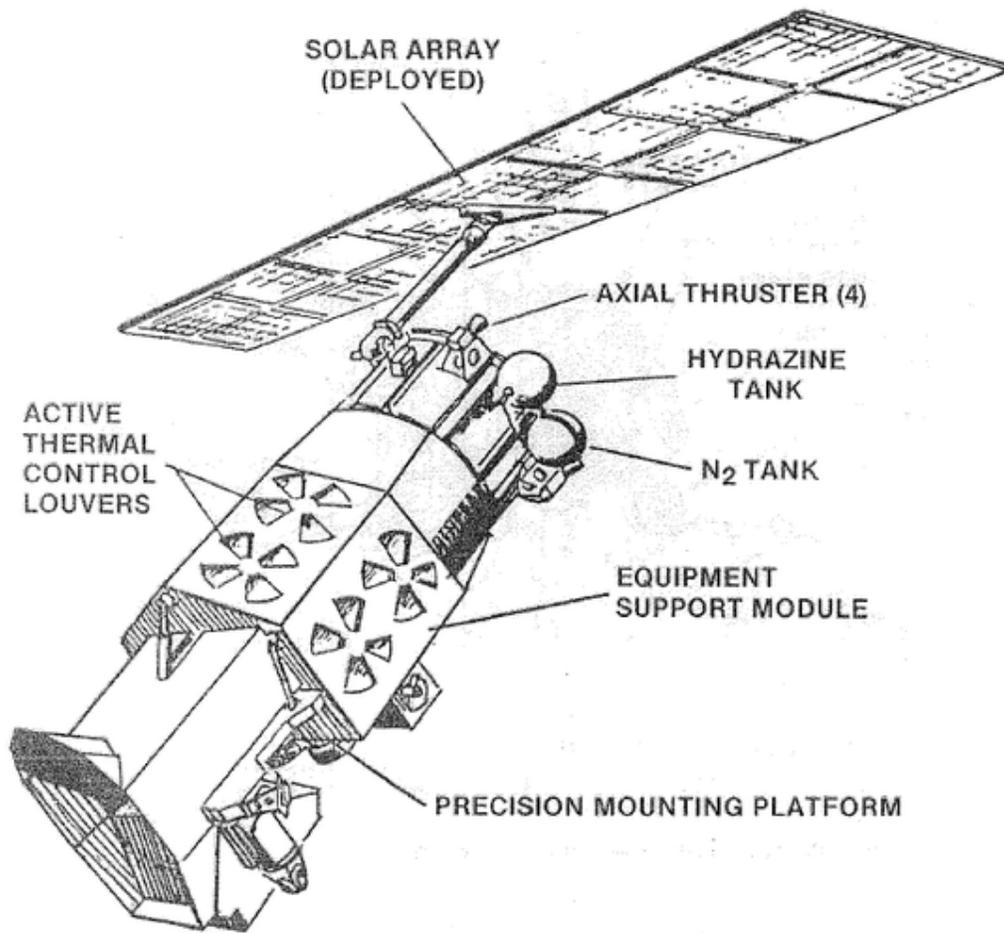


DIAGRAM OF DMSP's BLOCK 5D-1 SATELLITE.

DMSP - Block 5D1



DMSP Shroud at SLC-10

The images acquired were relayed to the Earth and received by two command and readout stations established at retired Nike missile sites located near Fairchild Air Force Base, Washington and Loring Air Force Base, Maine. From these sites, the images were then sent to Air Force Global Weather Central (AFGWC) located at Offutt Air Force Base, Nebraska. Images would then be processed, forming a mosaic representing the cloud patterns that were observed from the orbiting satellites. Meteorologists could then provide flight crews and other commanders with up-to-date observations for their particular missions. Further advancements enabled data to be collected in the visual spectrum down to a half-moonlit scene. Infrared processing enabled night viewing. Other enhancements increased onboard processing, this includes multiple onboard computers and expanded power requirements.

Now in its fifth decade of service, the DMSP has proven itself to be a valuable tool in scheduling and protecting military operations on land, at sea, and in the air. In December 1972, DMSP data was declassified and made available to the civil/scientific community. On June 1, 1998 the control and maintenance of the satellites were transferred to NOAA in order to reduce costs.

## Launch history

DSMP was initially known as **Program 35**. The first successful launch of a Program 35 spacecraft used a Scout X-2 rocket lifting off from Point Arguello near Vandenberg Air

Force Base (VAFB) on 1962-08-23. This was P35-2; the earlier P35-1 launch on 1962-05-24 had failed to reach orbit. All five Program 35 launch attempts using Scout rockets, including the two successes, were made from VAFB SLC-5. Other early launches were conducted using Thor launch vehicles, with Altair or Burner II upper stages. Program 35 had by this time been renamed the Data Acquisition and Processing Program, and the **DAPP** acronym is sometimes used for these satellites. Eight satellites were launched using Atlas E launch vehicles between 1982 and 1995. Three were launched aboard Titan II vehicles between 1997 and 2003. One has been launched on a Delta IV rocket.

The next DMSP launch will be of the F18 satellite, scheduled for launch from Vandenberg aboard an Atlas V on October 18, 2009. United Launch Alliance plans to use the DMSP-18 mission to flight-test centrifugal propellant settling as a cryogenic fuel management technique that might be used in future propellant depots.

### Block 1

Block 1										
Name	ID	Launch date	Launch vehicle	Mass (kg)	Period (min)	Perigee (km)	Apogee (km)	Inclination (deg)	Status	Alt. name
DMSP 1 F1		23 May 1962	Scout						Failed to orbit; 2nd stage exploded	Program 35 F-1
DMSP 1 F2		23 Aug 1962	Scout						Success; EOM 11 Jun 1963	Program 35 F-2
DMSP 1 F3		19 Feb 1963	Scout						Improper orbit; first DMSP with infrared system	Program 35 F-3
DMSP 1 F4		26 Apr 1963	Scout						Failed to orbit; 3rd stage exploded	Program 35 F-4
DMSP 1 F5		27 Sep 1963	Scout						Failed to orbit; 3rd stage failure	Program 35 F-5
DMSP 1 F6		19 Jan 1964	Thor-Agena						EOM 10 Jul 1964	Program 35 F-6

			D							
DMSP 1 F7		19 Jan 1964	Thor- Agena D						EOM 17 Mar 1965	Program 35 F-7
DMSP 1 F8		17 Jun 1964	Thor- Agena D						EOM 16 Feb 1966	Program 35 F-8
DMSP 1 F9		17 Jun 1964	Thor- Agena D						15 Oct 1965	Program 35 F-9

## Chapter- 9

# Envisat

### Envisat



Model of Envisat

<b>Operator</b>	European Space Agency
<b>Mission type</b>	Earth observation
<b>Launch date</b>	1 March 2002 at 01:07 UTC
<b>Carrier rocket</b>	Ariane 5
<b>COSPAR ID</b>	2002-009A
<b>Homepage</b>	<a href="http://envisat.esa.int/">http://envisat.esa.int/</a> <a href="http://envisat.esa.int">envisat.esa.int</a>
<b>Mass</b>	8,211 kg (18,100 lb)
	<b>Orbital elements</b>
<b>Regime</b>	Polar orbit

<b>Inclination</b>	98.6°
<b>Apoapsis</b>	791 km (492 mi)
<b>Periapsis</b>	785 km (488 mi)
<b>Orbital period</b>	100.6 min
<b>Repeat interval</b>	35 days

#### **Instruments**

ASAR

RA-2

MWR

MIPAS

MERIS

AATSR

**Main instruments** DORIS

GOMOS

SCIAMACHY

**Envisat** ("Environmental Satellite") is an Earth-observing satellite. It was launched on 1 March 2002 aboard an Ariane 5 from the Guyana Space Centre in Kourou, French Guyana into a Sun synchronous polar orbit at an altitude of 790 km (490 mi) ( $\pm$  10 km (6.2 mi)). It orbits the Earth in about 101 minutes with a repeat cycle of 35 days.

This €2.3 billion European Space Agency (ESA) programme launched the largest earth observation satellite put into space (as of late 2006), being 26 m (85 ft)  $\times$  10 m (33 ft)  $\times$  5 m (16 ft) and having a mass of 8.5 t (8.4 LT; 9.4 ST).

## **Mission**

Envisat is an Earth observation satellite. Its objective is to service the continuity of European Remote-Sensing Satellite missions, providing additional observational parameters to improve environmental studies.

In working towards the global and regional objectives of the mission, numerous scientific disciplines use the data acquired from the different sensors on the satellite, to study such things as atmospheric chemistry, ozone depletion, biological oceanography, ocean temperature and colour, wind waves, hydrology (humidity, floods), agriculture and arboriculture, natural hazards, digital elevation modelling (using interferometry), monitoring of maritime traffic, atmospheric dispersion modelling (pollution), cartography and study of snow and ice.

## **Instruments**

Envisat carries an array of nine Earth-observation instruments that gather information about the earth (land, water, ice, and atmosphere) using a variety of measurement principles. A tenth instrument, DORIS, provides guidance and control.

Several of the instruments are advanced versions of instruments that were flown on the earlier ERS 1 and ERS 2 missions and other satellites.

### **MERIS**

MERIS (MEdium Resolution Imaging Spectrometer) measures the reflectance of the Earth (surface and atmosphere) in the solar spectral range (390 to 1040 nm) and transmits 15 spectral bands back to the ground segment.

MERIS was built at the Cannes Mandelieu Space Center.

### **AATSR**

AATSR (Advanced Along Track Scanning Radiometer) can measure the temperature of the sea surface.

It is a passive radiometer which aims to measure the tempemissions from the surface of the earth in the visible and infrared spectra. Because of its wide angle lens it is possible to make very precise measurements of atmospheric effects on how emissions from the Earth's surface propagate.

AATSR is the successor of ATSR1 and ATSR2, payloads of ERS 1 and ERS 2. AATSR can measure Earth's surface temperature to a precision of 0.3 K (0.54 °F), for climate research.

Among the secondary objectives of AATSAR is the observation of environmental parameters such as water content, biomass, and vegetal health and growth.

### **GOMOS**

GOMOS (Global Ozone Monitoring by Occultation of Stars) uses the principle of occultation. Its sensors detect light from a star traversing the Earth's atmosphere and measures the depletion of that light by trace gases nitrogen dioxide (NO<sub>2</sub>), nitrogen trioxide, (NO<sub>3</sub>), OCIO), ozone (O<sub>3</sub>) and aerosols present between about 20 to 80 km (12 to 50 mi) altitude. It has a resolution of 3 km (1.9 mi).

## **SCIAMACHY**

SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY) compares light coming from the sun to light reflected by the Earth, which provides information on the atmosphere through which the earth-reflected light has passed.

SCIAMACHY is an image spectrometer with the principal objective of mapping the concentration of trace gases and aerosols in the troposphere and stratosphere. Rays of sunlight that are reflected transmitted, backscattered and reflected by the atmosphere are captured at a high spectral resolution (0.2 to 0.5 nm) for wavelengths between 240 to 1,700 nm, and in certain spectra between 2,000 and 2,400 nm.

Its high spectral resolution over a wide range of wavelengths can detect many trace gases even in tiny concentrations. The wavelengths captured also allow effective detection of aerosols and clouds.

SCIAMACHY uses 3 different targeting modes: to the nadir (against the sun), to the limb (through the atmospheric corona), and during solar or lunar eclipses.

## **RA-2**

RA-2 (Radar Altimeter 2) is a dual-frequency Nadir pointing Radar operating in the  $K_u$  band and S bands, it is used to define ocean topography, map/monitor sea ice and measure land heights.

## **MWR**

MWR (Microwave Radiometer) for measuring water vapour in the atmosphere and estimate the tropospheric delay for the Altimeter

## **DORIS**

DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) determines the satellite's orbit to within 10 centimetres (4 in).

## **GOMOS**

GOMOS (Global Ozone Monitoring by Occultation of Stars) looks to stars as they descend through the Earth's atmosphere and change color, which also tells a lot about the presence of gases such as ozone ( $O_3$ ), and allows for the first time a space-based measurement of the vertical distribution of these trace gases.

## MIPAS

MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) is a Fourier transforming infrared spectrometer which provides pressure and temperature profiles, and profiles of trace gases nitrogen dioxide (NO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), ammonia (CH<sub>4</sub>), nitric acid (HNO<sub>3</sub>), ozone (O<sub>3</sub>), and water (H<sub>2</sub>O) in the stratosphere. The instrument functions with high spectral resolution in an extended spectral band, which allows coverage across the globe in all seasons and at equal quality night and day. MIPAS has a vertical resolution of 3 to 5 kilometres (2 to 3 mi) depending on altitude (the larger at the level of the upper stratosphere).

## ASAR

ASAR (Advanced Synthetic Aperture Radar) operates in the C band in a wide variety of modes. It can detect changes in surface heights with sub-millimeter precision. It serves as a data link for ERS 1 and ERS 2, providing numerous functions such as observations of different polarities of light or combining different polarities, angles of incidence and spatial resolutions.

Mode	Id	Polarisation	Incidence	Resolution	Swath
Alternating polarisation	AP	HH/VV, HH/HV, VV/VH	15 – 45°	30 – 150 m	58 – 110 km
Image	IM	HH, VV	15 – 45°	30 – 150 m	58 – 110 km
Wave	WV	HH, VV		400 m	5 × 5 km
Suivi global (ScanSAR)	GM	HH, VV		1 km	405 km
Wavescan (ScanSAR)	WS	HH, VV		150 m	405 km

These different types of raw data can be given several levels of treatment (suffixed to the ID of the acquisition mode: IMP, APS, and so on):

- RAW (raw data, or "Level 0"), which contains all the information necessary to create images.
- S (complex data, "Single Look Complex"), images in complex numeric form, the real and imaginary parts of the output of the compression algorithm
- P (precision image), amplified image with constant pixel width (12.5 m for IMP)
- M (medium precision image), amplified radiometry image with a resolution greater than P
- G (geocoded image), amplified image to which simple geographical transforms have been applied to show relief.

Data capture in WV mode is unusual in that they constitute a series of 5 km × 5 km spaced at 100 km.

## **Cost**

Envisat cost 2.3 BEuro (including 300 MEuro for 5 years operations) to develop and launch

## Chapter- 10

# Geostationary Operational Environmental Satellite

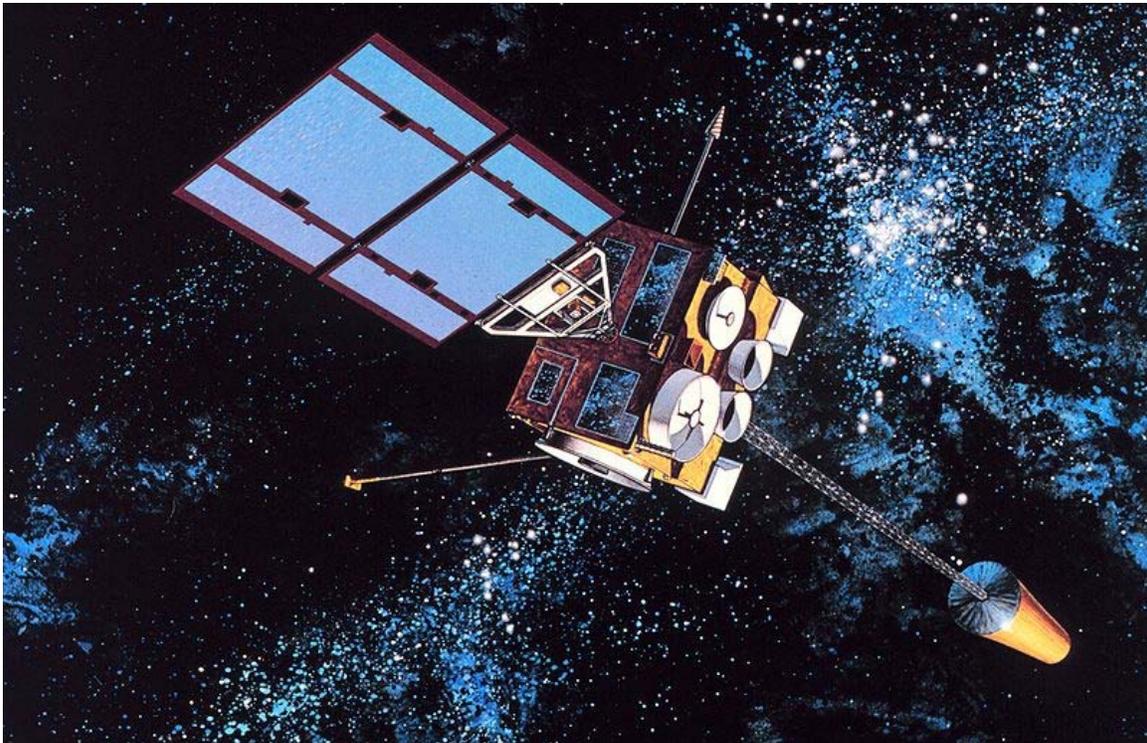


The GOES N satellite was launched on a Delta IV rocket from SLC-37B, Cape Canaveral Air Force Station, Florida

The **Geostationary Operational Environmental Satellite** (or **GOES**) system, operated by the United States National Environmental Satellite, Data, and Information Service (NESDIS), supports weather forecasting, severe storm tracking, and meteorology research. Spacecraft and ground-based elements of the system work together to provide a continuous stream of environmental data. The National Weather Service (NWS) uses the GOES system for its United States weather monitoring and forecasting operations, and scientific researchers use the data to better understand land, atmosphere, ocean, and climate interactions.

The GOES system uses geosynchronous satellites which—since the launch of SMS-1 in 1974—have been a basic element of U.S. weather monitoring and forecasting.

## Satellites



**GOES-8**, a decommissioned United States weather satellite.

Four GOES satellites are currently available for operational use:

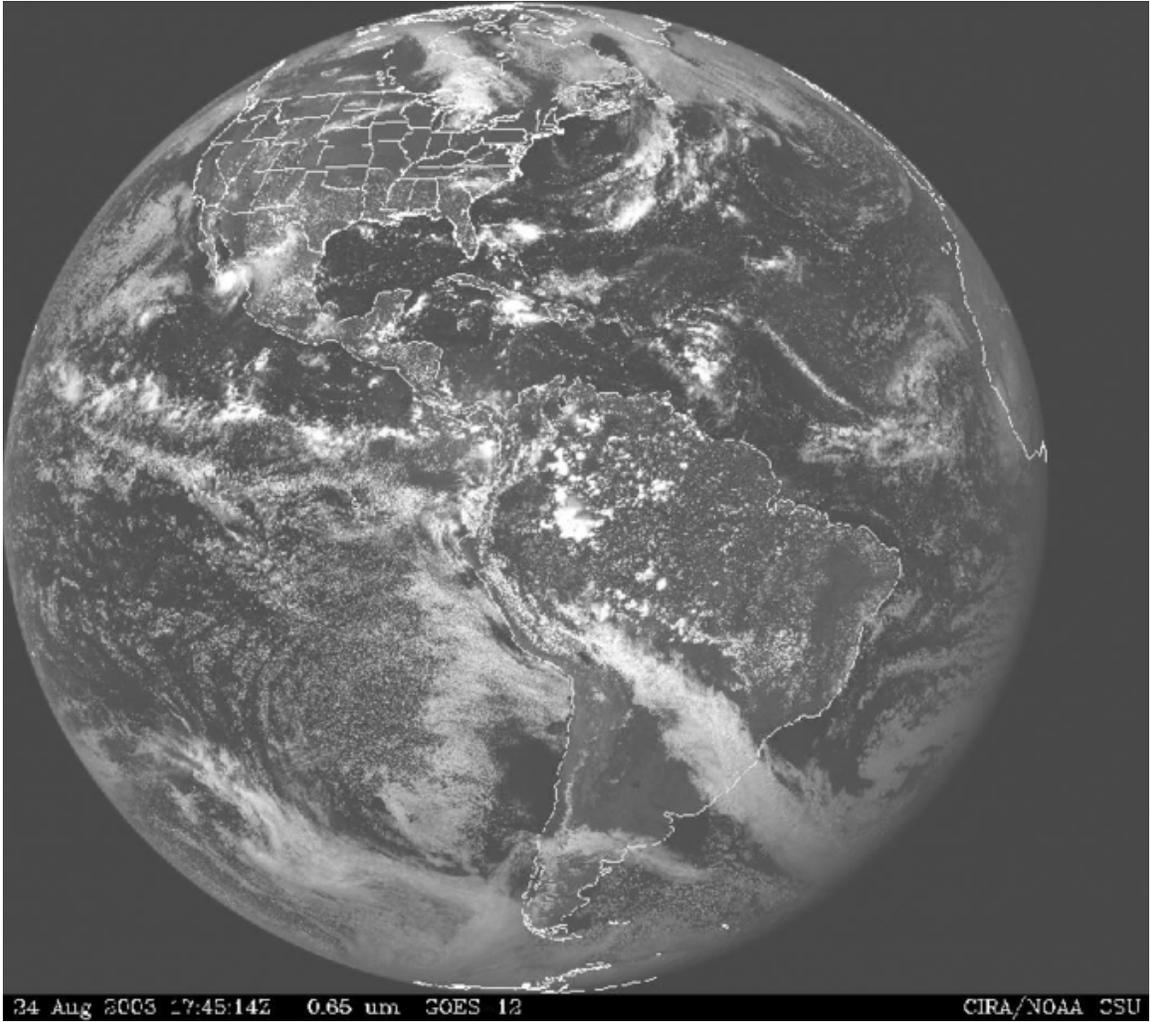
- GOES-11 is designated GOES-West, currently located at 135°W over the Pacific Ocean.
- GOES-12 is designated GOES-South, currently located at 75°W over the Amazon River.
- GOES-13 is designated GOES-East, currently located at 105°W. It provides most of the U.S. weather information.
- GOES 14 was placed in orbit on 7 July 2009, underwent Post-Launch Testing until December 2009 and then was placed in on-orbit storage.

Several GOES satellites are still in orbit, either inactive or re-purposed. GOES-3 is no longer used for weather operations, but is a critical part of the communication links between the United States and Amundsen-Scott South Pole Station. Geostationary satellites cannot ordinarily be seen at all from the poles, but they require station keeping fuel to keep them stationary over the equator. When station keeping fuel runs out, solar and lunar perturbations increase the satellite's inclination so that its ground track begins to describe a figure-8 in the north-south direction. This usually ends the satellite's primary mission. But when the inclination is high enough, the satellite may begin to rise above the polar horizons at the extremes of the figure-8, as is the case for GOES-3. A nine-meter dish was constructed at the station, and communication with the satellite is currently possible for about five hours per day. Data rates are around 2.048 Mbit/s bi-directional under optimum conditions.

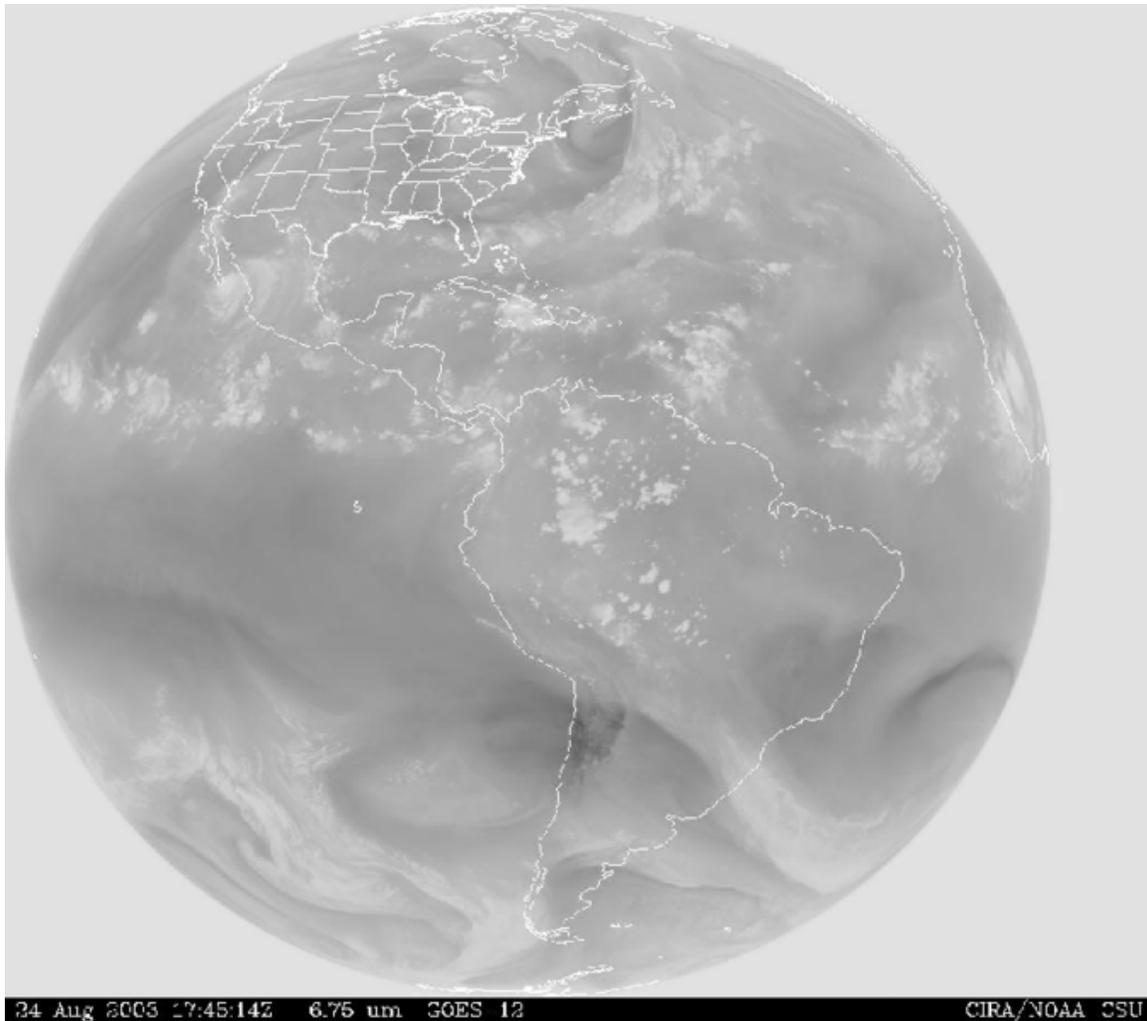
GOES-8 (GOES-East when it was in operation) is in a parking orbit, currently drifting about 4°W daily. It was decommissioned on April 1, 2003, and deactivated on May 5, 2004, after the failure of its propulsion system.

Communication was lost for 13 days to GOES-12 on December 4, 2007 when it performed a standard station-keeping maneuver. GOES-11 initially took "full disk" images to cover the lost data until a contingency plan could be implemented. On December 5, 2007, GOES-10 was moved from South America operations to temporarily replace GOES-12 as the GOES-EAST operational satellite. On 9 December, communication with GOES-10 was also temporarily lost, but communication was resumed via a backup antenna. GOES-12 was successfully reactivated and moved back to normal operation following a thrust maneuver on 17 December. The trouble was traced to a leaking thruster valve, which pushed the satellite incorrectly. Emergency procedures were executed to cut off the valve, and a redundant thruster was activated to restore the location of the satellite.

GOES-10 was decommissioned on December 2, 2009 and was boosted to a graveyard orbit. It no longer had the fuel for required maneuvers to keep it on station. It joins GOES 8 and 9 which are already in graveyard orbits. With the cessation of GOES-10's duties, GOES-13 has replaced GOES-12 as "GOES-East". GOES-12 was then moved to 60W and resume South American duties for GOES-10.



GOES-12 visible light image.



GOES-12 water vapor image.

## **Purpose**

Designed to operate in geostationary orbit, 35,790 km (22,240 statute miles) above the earth, thereby remaining stationary with respect to a point on the ground, the advanced GOES I–M spacecraft continuously view the continental United States, neighboring environs of the Pacific and Atlantic Oceans, and Central, South America and southern Canada. The three-axis, body-stabilized spacecraft design enables the sensors to "stare" at the earth and thus more frequently image clouds, monitor earth's surface temperature and water vapour fields, and sound the atmosphere for its vertical thermal and vapor structures. Thus the evolution of atmospheric phenomena can be followed, ensuring real-time coverage of short-lived dynamic events, especially severe local storms and tropical cyclones—two meteorological events that directly affect public safety, protection of property, and ultimately, economic health and development. The importance of this capability has been exemplified during hurricanes Hugo (1989) and Andrew (1992).

The GOES I–M series of spacecraft are the principal observational platforms for covering such dynamic weather events and the near-earth space environment for the 1990s and into the 21st century. These advanced spacecraft enhance the capability of the GOES system to continuously observe and measure meteorological phenomena in real time, providing the meteorological community and atmospheric scientists greatly improved observational and measurement data of the Western Hemisphere. In addition to short-term weather forecasting and space environmental monitoring, these enhanced operational services also improve support for atmospheric science research, numerical weather prediction models, and environmental sensor design and development. Data is received via the NOAA Command and Data Acquisition ground station at Wallops Island, Virginia. The GOES satellites are controlled from the Satellite Operations Control Center (SOCC) located in Suitland, Maryland. During significant weather or other events the normal schedules can be altered to provide coverage requested by the National Weather Service and other agencies.

## **Payload**

The main mission is carried out by the primary payload instruments, the Imager and the Sounder. The Imager is a multichannel instrument that senses infrared radiant energy and visible reflected solar energy from the Earth's surface and atmosphere. The Sounder provides data for vertical atmospheric temperature and moisture profiles, surface and cloud top temperature, and ozone distribution.

Other instruments on board the spacecraft are the ground-based meteorological platform data collection and relay, and the space environment monitor. The latter consists of a magnetometer, an X-ray sensor, a high energy proton and alpha detector, and an energetic particles sensor, all used for in-situ surveying of the near-earth space environment. Satellites numbered 12 and greater also carry a solar imager, although none of these imagers are currently active.



Invertible GOES logo designed for Space Systems/Loral by Scott Kim

In addition, the GOES satellites carry Emergency Position-Indicating Radio Beacon (EPIRB) and Emergency Locator Transmitter (ELT) receivers, which are used for search-and-rescue purposes by the U.S. Air Force Rescue Coordination Center.

## **Satellite designations**

Before being launched, GOES satellites are designated by letters (-A, -B, -C...). Once a GOES satellite is launched successfully, it is redesignated with a number (-1, -2, -3...). So, GOES-A to GOES-F became GOES-1 to GOES-6. Because GOES-G was a launch failure, it never received a number. Since then, GOES-H to GOES-N became GOES-7 to GOES-13.

The procurement, design and manufacturing of GOES is overseen by NASA, while all operations of the satellites once in orbit are done by NOAA. GOES spacecraft have been manufactured by Boeing (GOES D-H and N-P) and Space Systems/Loral (A-C and I-M). The two current GOES series (I-M and N-P) are documented in the "GOES I-M Databook" and "GOES N Databook".

GOES-13 (which was designated GOES-N prior to orbiting) was launched by a Delta IV rocket from Space Launch Complex 37B at Cape Canaveral Air Force Station in Florida at 22:11 GMT May 24, 2006. The launch of GOES-O was delayed several times due to various issues. GOES-O was launched Saturday, June 27, 2009 at 6:51 p.m. EDT from Florida's Cape Canaveral Air Force Station at Space Launch Complex 37 piggybacking on a Delta IV rocket. The GOES-O satellite is a part of the GOES N Series, and was renamed as GOES-14 once it successfully arrived on orbit. GOES-14 will be stored and will be able to be activated for duty if another GOES satellite is decommissioned. GOES-P launched successfully on March 4, 2010 at 18:57 EST. Boeing will build and launch a GOES-Q only if either GOES-O or GOES-P fails to be delivered on-orbit in good working order.

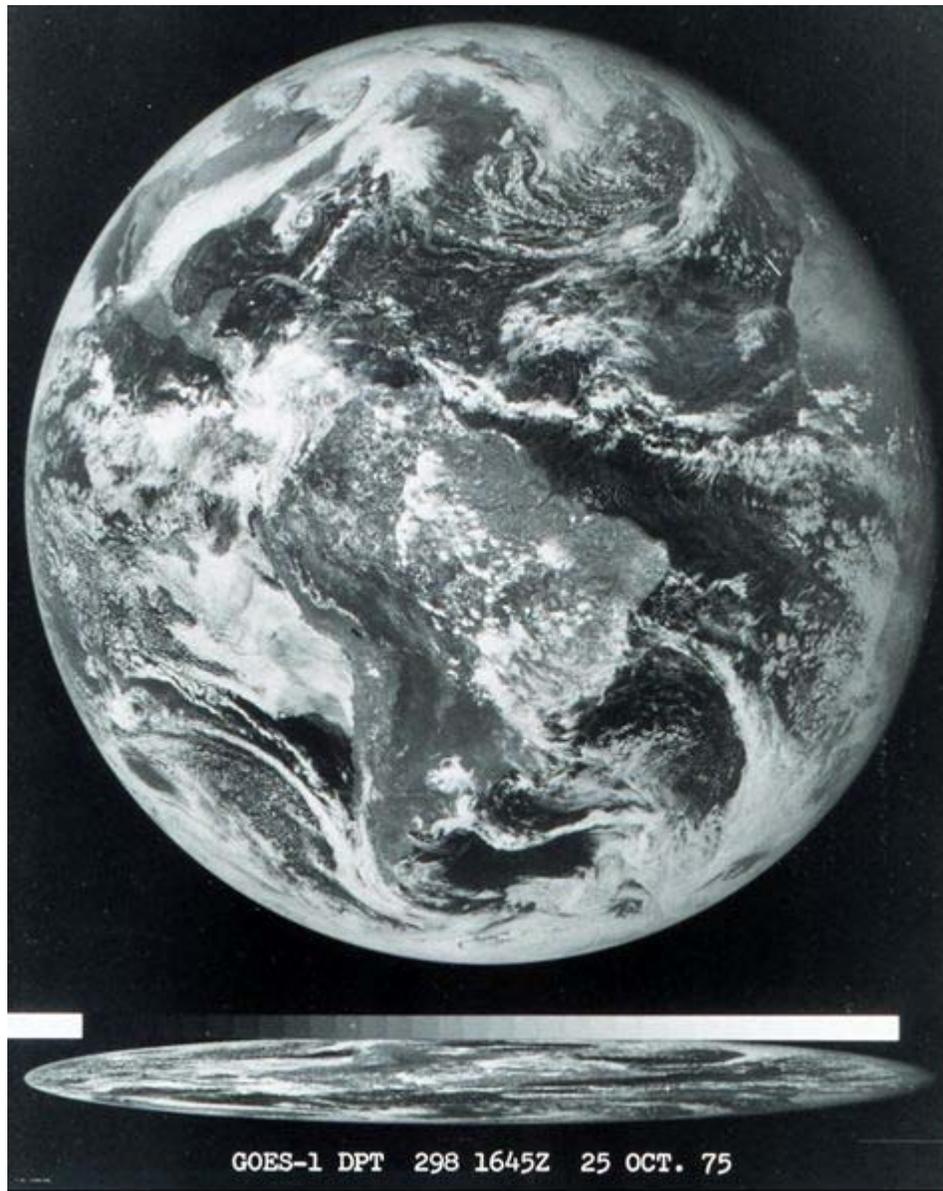
In October 2006, NOAA repositioned GOES-10 (originally GOES-K) over the Amazon region, to provide full time coverage for South American countries. Although NOAA currently sends images to South America, the frequency drops from 30-minutes to 3 hours whenever a storm occurs in North America, which is roughly 40% of the time during the hurricane season.

## **Future**

The GOES-R series of spacecraft is in the development phase. The first GOES-R series satellite is scheduled for launch in fiscal year 2015 and is expected to remain operational through December 2027. The proposed instrument package for the series initially included: the Advanced Baseline Imager (ABI); the Hyperspectral Environmental Suite (HES); the Space Environment In-Situ Suite (SEISS), which includes two Magnetospheric Particle Sensors (MPS-HI and MPS-LO), an Energetic Heavy Ion Sensor (EHIS), and a Solar and Galactic Proton Sensor (SGPS); the Solar Imaging Suite (SIS), which includes the Solar Ultraviolet Imager (SUVI), the Solar X-Ray Sensor (XRS), and the Extreme Ultraviolet Sensor (EUVS); the Geostationary Lightning Mapper (GLM); and the Magnetometer.

In September 2006 the Hyperspectral Environmental Suite (HES) was cancelled and the planned number of satellites was reduced from 4 to 2 by NOAA due to concerns about cost overruns. The planned delivery schedule was also slowed down in order to reduce costs. Contracts are planned to be awarded sometime in mid-2009. The expected cost is \$7.69 billion—a \$670 million increase from the prior \$7 billion estimate.

## History/status of GOES satellites



The first image obtained from the GOES 1 satellite, 1975 October 25, 1645 GMT.

- GOES 1, launched on October 16, 1975, *decommissioned*
- GOES 2, launched on June 16, 1977, *decommissioned*

- GOES 3, launched on June 16, 1978, *used as a communications relay for the South Pole research station.*
- GOES 4, launched on September 9, 1980, *decommissioned*
- GOES 5, launched on May 22, 1981, *deactivated on July 18, 1990*
- GOES 6, launched on April 28, 1983, *decommissioned*
- GOES-G, launched on May 3, 1986, *failed to orbit*
- GOES 7, launched April 28, 1987, *used as a communications satellite by Peacesat*
- GOES 8, launched on April 13, 1994, *decommissioned*
- GOES 9, launched on May 23, 1995, *decommissioned on June 15, 2007*
- GOES 10, launched on April 25, 1997, *decommissioned on December 2, 2009*
- GOES 11, launched on May 3, 2000, *in operation as GOES West*
- GOES 12, launched on July 23, 2001, *standby, providing coverage for South America*
- GOES 13, launched on May 24, 2006, *in operation as GOES East*
- GOES 14, launched on June 27, 2009, *on orbit - in storage*
- GOES 15, launched on March 4, 2010 *on orbit - testing*

## Chapter- 11

# Ikonos

### IKONOS

IKONOS 2

<b>Organization</b>	GeoEye
<b>Mission Type</b>	Earth observation
<b>Contractor</b>	Lockheed Martin Space Systems
<b>Satellite of</b>	Earth
<b>Launch</b>	September 24, 1999 on an Athena 2
<b>Launch site</b>	Vandenberg Air Force Base
<b>Mission duration</b>	Ongoing
<b>Mass</b>	726 kg (launch)
<b>Webpage</b>	<a href="http://www.geoeye.com/CorpSite/products/imagery-sources/Default.aspx#ikonos">http://www.geoeye.com/CorpSite/products/imagery-sources/Default.aspx#ikonos</a>

#### Orbital elements

<b>Semimajor Axis</b>	7056.97 km
<b>Eccentricity</b>	0.00013
<b>Inclination</b>	98.10 degrees
<b>Orbital Period</b>	98.33 minutes
<b>Right ascension of the ascending node</b>	68.015 degrees
<b>Argument of perigee</b>	93.06 degrees

#### Instruments

<b>Visible Sensors</b>	1-meter panchromatic and 4-meter multispectral
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**IKONOS** is a commercial earth observation satellite, and was the first to collect publicly available high-resolution imagery at 1- and 4-meter resolution. It offers multispectral (MS) and panchromatic (PAN) imagery. The IKONOS launch was called by John E. Pike “one of the most significant developments in the history of the space age”. IKONOS imagery began being sold on January 1, 2000.

It derived its name from the Greek term *eikōn* for image.

## **History**

IKONOS was originated under the Lockheed Martin Corporation as the Commercial Remote Sensing System (CRSS) satellite. On April 1994 Lockheed was granted one of the first licenses from the U.S. Department of Commerce for commercial satellite high-resolution imagery. On October 25, 1995 partner company Space Imaging received a license from the Federal Communications Commission (FCC) to transmit telemetry from the satellite in the eight-gigahertz Earth Exploration Satellite Services band. Prior to launch, Space Imaging changed the name of the satellite to IKONOS. IKONOS comes from the Greek word for "image".

Two satellites were originally planned for operation. The launch of *IKONOS-1* in 1999 failed when the payload fairing of the Athena rocket failed to separate, preventing the satellite from reaching orbit. *IKONOS-2* was planned for launch in 2000, but was renamed *IKONOS* and was launched on September 24, 1999 from Space Launch Complex 6 (SLC-6) at Vandenberg Air Force Base in California. The imaging sensors are panchromatic and multispectral. This satellite has a polar, circular, sun-synchronous 681-km orbit and both sensors have a swath width of 11 km. Its weight is 1600 pounds (720 kg).

In November 2000 Lockheed Martin received the "Best of What's New" Grand Award in the Aviation & Space category from Popular Science magazine. Space Imaging was acquired by ORBIMAGE in September 2005. The company was later renamed to GeoEye.

## **Specifications**

### **Spacecraft**

IKONOS is a 3-axis stabilized spacecraft designed by Lockheed Martin. The design later became known as the LM900 satellite bus system. The satellite's altitude is measured by two star trackers and a sun sensor and controlled by four reaction wheels; location knowledge is provided by a GPS receiver. The design life is 7 years; S/C body size=1.83 m x 1.57 m (hexagonal configuration); S/C mass = 817 kg; power = 1.5 kW provided by 3 solar panels.

The LM900 spacecraft is a three-axis stabilized bus that is designed to carry scientific payloads in LEOs. It provides precision pointing on an ultra stable highly agile platform. Payloads for a variety of scientific and remote sensing applications may be accommodated including laser sensors, imagers, radar sensors, electro-optical and astronomical sensors, as well as planetary sensors. The LM900 bus shares a hardware heritage with Iridium, which is the basis for the LM700 bus.

## Communications

IKONOS conducts telemetry, tracking and control in the 8345.968-8346.032 MHz band (downlink) and 2025-2110 MHz band (uplink). Downlink data carrier operates in the 8025-8345 MHz band.

## Optics & Detectors

IKONOS has a primary mirror aperture of 0.7 m (2.3 feet), and a folded optical focal length of 10 m (about 33 feet) using 5 mirrors. The main mirror features a honeycomb design to reduce mass. The detectors at the focal plane include a pan-chromatic and a multi-spectral sensor, with 13500 pixels and 3375 pixels respectively (cross-track). Total instrument mass is 171 kg (377 pounds) and it uses 350 watts.

## Imaging capabilities

### Spatial resolution

- 0.8 m panchromatic (1-m PAN)
- 4-meter multispectral (4-m MS)
- 1-meter pan-sharpened (1-m PS)

### Spectral Resolution

Band	1-m PAN	4-m MS & 1-m PS
1 (Blue)	0.45-0.90 $\mu\text{m}$	0.445-0.516 $\mu\text{m}$
2 (Green)	*	0.506-0.595 $\mu\text{m}$
3 (Red)	*	0.632-0.698 $\mu\text{m}$
4 (Near IR)	*	0.757-0.853 $\mu\text{m}$

### Temporal resolution

The revisit rate for IKONOS is 3 to 5 days off-nadir and 144 days for true-nadir.

### Radiometric resolution

The sensor collects data with a 11-bit (0-2047) sensitivity and are delivered in an unsigned 16-bit (0-65535) data format. From time-to-time the data are rescaled down to

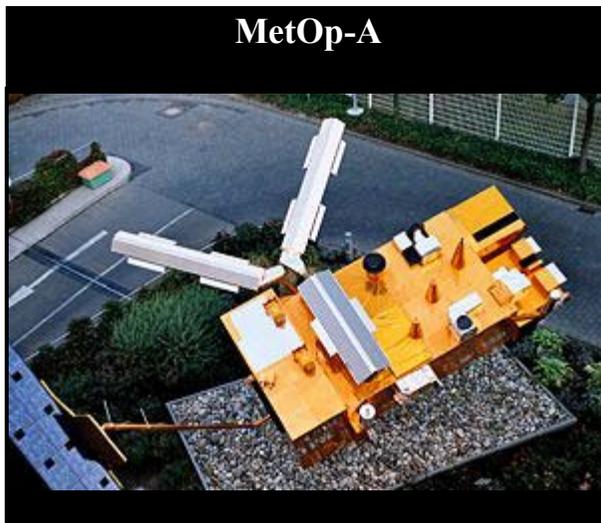
8-bit (0 - 255) to decrease file size. When this occurs much of the sensitivity of the data needed by Remote Sensing scientists is lost.

### **Swath**

11 km x 11 km (Single Scene)

## Chapter- 12

# MetOp



<b>Organization:</b>	EUMETSAT
<b>Mission type:</b>	Earth Science
<b>Satellite of:</b>	Earth
<b>Launch:</b>	October 19, 2006 at 16:28:00 UTC
<b>Launch vehicle:</b>	Soyuz ST Fregat
<b>Mission duration:</b>	October 25, 2006 - planned 5 years
<b>Mass:</b>	4093 kg

<b>Payload Mass:</b>	812 kg
<b>Webpage:</b>	European Space Agency
<b>Orbital elements</b>	
<b>Dimensions:</b>	6.2 × 3.4 × 3.4 metres (under the launcher fairing) 17.6 × 6.5 × 5.2 metres (deployed in orbit)
<b>Orbit:</b>	Sun-synchronous orbit
<b>Inclination:</b>	98.7° to the Equator
<b>Orbital period:</b>	101 minutes

**MetOp** is a series of polar orbiting meteorological satellites operated by the European Organisation for the Exploitation of Meteorological Satellites. The satellites are all part of the EUMETSAT Polar System. It is intended to replace the soon to be retired TIROS network. The satellites, the first of which was launched on October 19, 2006, are equipped with the same equipment as the TIROS satellites, plus extra atmospheric measuring instruments.

## Background

The Television Infrared Observation Satellite (TIROS) series of polar-orbiting satellites was launched in 1960. Operated by the National Oceanic and Atmospheric Administration (NOAA), TIROS proved extremely successful, providing accurate and detailed satellite imagery which helped provide accurate weather forecasts based on the data gathered from space. Since then, the United States have been providing meteorological data from this evolving series of polar satellites free of charge. However, in the early 1990s, NOAA unfolded plans to discontinue the monitoring service (the current TIROS K, L and M series) of the Polar Operational Environmental Satellites (POES). Europe consequently decided to balance the long-standing service provided by the United States with what was finally to become MetOp.

It has been developed as a joint undertaking between the European Space Agency (ESA) and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). MetOp is part of the European contribution to a co-operative venture with the NOAA through the Initial Joint Polar Satellite System (IJPS).

## Launch and deployment

MetOp-A, the first ever European polar-orbiting meteorological satellite, was successfully launched on 19 October 2006 from Baikonur\_Cosmodrome, Kazakhstan using a Soyuz-ST Fregat launcher, after six attempts. At just over 4,000 kg and measuring  $17.6 \times 6.5 \times 5.2$  m when in orbit, MetOp is Europe's second largest Earth-observation satellite, after ENVISAT which was launched in 2002.



MetOp model from above



MetOp model from below



Meteosat model



MSG model

The first signal from the satellite was received at 1835 BST on 20 October 2006, and it was confirmed that the satellite was in its nominally correct orbit with the solar panel deployed. Control of the satellite was with the European Space Operations Centre (ESOC — part of ESA) which had the responsibility of achieving the final positioning of the satellite, deployment of all the antennas and final reconfiguration of the satellite following necessary orbit control maneuvers. The satellite was handed over to EUMETSAT operations on 22 October 2006. The first image was received at 0800 UTC on 25 October—a visible light image of Scandinavia and Eastern Europe—but there was a six-month period of verification and calibration of the satellite and its instrument payload before it was declared operational. Before that point, the Met Office received data and started to test and then use it as input to the operational numerical weather prediction runs.

MetOp-A was declared fully operational in mid-May 2007 and the full data of its 11 scientific instruments are available to its users on operational basis

## Instruments

The following instruments are flown onboard the MetOp-A satellite:

- IASI - Infrared Atmospheric Sounding Interferometer
- MHS - Microwave Humidity Sounder

- GRAS - Global Navigation Satellite System Receiver for Atmospheric Sounding
- ASCAT - Advanced Scatterometer
- GOME-2 - Global Ozone Monitoring Experiment-2
- AMSU-A1/AMSU-A2 - Advanced Microwave Sounding Units
- HIRS/4 - High-resolution Infrared Radiation Sounder
- AVHRR/3 - Advanced Very High Resolution Radiometer
- A-DCS - Advanced Data Collection System
- SEM-2 - Space Environment Monitor
- SARP-3 - Search And Rescue Processor
- SARR - Search And Rescue Repeater

## **GOME-2**

The first atmospheric contributions by MetOp-A were made by the Global Ozone Monitoring Experiment-2 (GOME-2), a scanning spectrometer on board the satellite. GOME-2, developed by DLR (the German Aerospace Centre) as the successor of ERS-2's GOME (1995), provided coverage of most areas of planet Earth measuring the atmospheric ozone, the distribution of surface ultraviolet radiation, and the amount of nitrogen dioxide (NO<sub>2</sub>). The GOME-2 instrument provides a second source of ozone observations that supplement data from the SBUV/2 ozone instruments on the NOAA-18 and NOAA-19 satellites, which are part of the IJPS.

## **Infrared Atmospheric Sounding Interferometer (IASI)**

One of the most important instruments carried onboard MetOp is IASI, the most accurate infrared sounding interferometer currently in orbit. IASI observes the atmosphere in the infra-red (3.7 - 15.5  $\mu\text{m}$ ) in 8461 channels, allowing to measure the atmosphere temperature within 1°C and relative humidity within 10% for each slice of 1 km height. Earth surface is revisited twice a day. IASI by itself produces half of all MetOp data.

## **Future plans**

It is planned that subsequent MetOp satellites will be launched at approximately five year intervals, maintaining the service until at least 2020. The second in the series, MetOp-B, is due to be launched in mid 2012 from the Baikonur Cosmodrome. MetOp-C, the third satellite is to be launched in the 2016/2017 timeframe, from the Guiana Space Centre.

## Chapter- 13

# Meteor (Satellite)

The **Meteor** craft are weather observation satellites launched by the USSR. The Meteor satellites were designed to monitor atmospheric and sea-surface temperatures, humidity, radiation, sea ice conditions, snow-cover, and clouds.

## Meteor 2-21

**Meteor 2-21/Fizeau** is the twenty-first and last in the Meteor-2 series of Russian meteorological satellites launched in 1993.

ILRS Mission Support Status: Satellite Laser Ranging (SLR) tracking support of this satellite was discontinued in October 1998. What makes Meteor 2-21 distinctive from the other meteorological satellites is its unique retroreflector array. Fizeau is named after a French physicist, Armand Fizeau, who in 1851 conducted an experiment which tested for the aether convection coefficient. SLR tracking of this satellite was used for precise orbit determination and the Experiment of Fizeau. The Experiment of Fizeau tests the theory of special relativity-that distance events that are simultaneous for one observer will not be simultaneous for an observer in motion relative to the first.

RetroReflector Array (RRA) Characteristics: The retro-reflector array consists of three corner cubes in a linear array with the two outer corner cubes pointing at 45 degree angles relative to the central cube. The central cube is made of fused silica and has a two-lobe Far Field Diffraction Pattern (FFDP) providing nearly equal intensities for compensated and uncompensated velocity aberration. Both outer reflectors have aluminum coating on the reflecting surfaces and near-diffraction-limited FFDPs. One of the end reflectors is made of fused silica with an index of refraction of 1.46 and should provide partial compensation of the velocity aberration. The other end reflector is made of fused glass with an index of refraction of 1.62 and should provide a perfect compensation of the velocity aberration.

SLR full-rate data from MOBLAS 4, MOBLAS 7, and Maidanak seem to confirm the presence of the compensating influence of the Fizeau effect. Resur-1, another Russian satellite launched in 1994, has 2 corner cubes reflectors with near diffraction-limited FFDPs, which were specifically designed for the continuation of this experiment.

WESTPAC, a future SLR satellite, will verify indisputably the existence or otherwise of the Fizeau effect.

Instrumentation: Meteor-2-21/Fizeau had the following instrumentation on board:

1. Scanning telephotometer
2. Scanning infrared radiometers
3. Radiation measurement complex
4. Retroreflector array

## Meteor 3



Launch of Meteor-3 on a Tsyklon-3 rocket

In the last days of the Cold War, **Meteor-3** carried the second **Total Ozone Mapping Spectrometer (TOMS)** aloft as the first and the last American-built instrument to fly on a Soviet spacecraft. Launched from the Plesetsk, Russia, facility near the White Sea, on August 15, 1991, Meteor-3 TOMS had a unique orbit that presents special problems for processing data. Meteor-3 TOMS began returning data in August 1991 and stopped in December 1994.

## **Meteor 3-5**

**Meteor 3-5**, launched in 1991, is in a slightly higher orbit than Meteor 2-21. It transmits on 137.300 MHz. Mechanically, it is similar to Meteor 2-21. Which satellite is in operation depends on the sun angles and consequently the seasons. Meteor 3-5 is usually the (Northern Hemisphere) "summer" satellite while 2-21 is in operation for approximately the half-year centered on winter.

## **Meteor 3-6/PRARE**

The METEOR 3-6/PRARE satellite is the sixth in the Russian METEOR-3 series of meteorological satellites launched in 1994. These satellites provide weather information including data on clouds, ice and snow cover, atmospheric radiation and humidity. The Meteor-3 class of satellites orbit in a higher altitude than the Meteor-2 class of satellites thus providing more complete coverage of the Earth's surface. The Meteor-3 has the same payload as the Meteor-2 but also includes an advanced scanning radiometer with better spectral and spatial resolution and a spectrometer for determining total ozone content. Meteorological data is transmitted to four primary sites in the former Soviet Union in conjunction with about 80 other smaller sites.

ILRS Mission Support Status: Satellite laser ranging and PRARE data was used for precision orbit determination and intercomparison of the two techniques. ILRS tracking support of this satellite was discontinued on November 11, 1995.

Instrumentation: METEOR-3-6 has the following instrumentation on board:

1) Scanning TV-sensor 2) Visible light and infrared radiometers 3) Scanning infrared radiometer 4) Ozone Mapper 5) Precise Range and Range-Rate Equipment (PRARE) 6) Retroreflector array

RetroReflector Array (RRA) Characteristics: The retro-reflector array is a box wing annulus with a diameter of 28 cm and has 24 corner cube reflectors.

## Meteor-3M



Meteor-3M satellite



Meteor-3M satellite atop its Zenit-2 launcher

The **Meteor-3M** series of satellites is to be an advanced series of polar orbiters with one 1.4 km resolution visible channel and a ten-channel radiometer with 3 km resolution.

The first of these, Meteor 3M-N1, was launched on December 10, 2001 at 17:18:57 UTC from the Baikonur Cosmodrome in Kazakhstan. The satellite is in a sun-synchronous orbit with an ascending node time of about 9 AM. An APT transmission was planned to only have a reduced resolution (2 km) visible channel data. The status of any APT capability on this satellite is unclear, but it is thought not to have an APT transmitter. No

APT transmissions have been received from this satellite. SLR mission support began on May 1, 2002.

METEOR-3M includes the SAGE III (Stratospheric Aerosol and Gas Experiment) payload and other instruments designed to measure temperature and humidity profiles, clouds, surface properties, and high energy particles in the upper atmosphere. SAGE III is a gyrating spectrometer that measures ultraviolet/visible energy that will be used to enhance our understanding of natural and human-derived atmospheric processes by providing accurate long-term measurements of the vertical structure of aerosols, ozone, water vapor, and other important trace gases in the upper troposphere and stratosphere.

Secondary mission objective is the flight testing of the novel-type spherical retroreflector for precise laser ranging.

ILRS Mission Support Status: SLR will be used for precise orbit determination and retroreflector research.

Instrumentation: 1. SAGE III 2. Spherical retroreflector 3. Other weather monitoring instruments

RetroReflector Array (RRA) Characteristics: The retroreflector is a glass ball 60 mm in diameter, fastened in a holder providing observation from Earth at elevations more than 30° (the retroreflector field of view is centered in the Nadir direction). The spherical retroreflector with its holder is fixed to the METEOR-3M spacecraft. The expected return signal strength level is between LAGEOS and ETALON.

## Chapter- 14

# SPOT (Satellite)



Spot-5 Satellite



Athens as seen by the Spot-5 satellite in 2002

**SPOT** (Satellite Pour l'Observation de la Terre) is a high-resolution, optical imaging Earth observation satellite system operating from space. It is run by Spot Image based in Toulouse, France. It was initiated by the CNES (Centre national d'études spatiales — the French space agency) in the 1970s and was developed in association with the SSTC (Belgian scientific, technical and cultural services) and the Swedish National Space Board (SNSB). It has been designed to improve the knowledge and management of the Earth by exploring the Earth's resources, detecting and forecasting phenomena involving climatology and oceanography, and monitoring human activities and natural phenomena. The SPOT system includes a series of satellites and ground control resources for satellite control and programming, image production, and distribution. The satellites were launched with the ESA rocket launcher Ariane 2, 3, and 4.

The company SPOT Image is marketing the high-resolution images, which SPOT can take from every corner of the Earth.

- SPOT 1 launched February 22, 1986 with 10 panchromatic and 20 meter multispectral picture resolution capability. Withdrawn December 31, 1990.

- SPOT 2 launched January 22, 1990 and deorbited in July 2009.
- SPOT 3 launched September 26, 1993. Stopped functioning November 14, 1997
- SPOT 4 launched March 24, 1998
- SPOT 5 launched May 4, 2002 with 2.5 m, 5 m and 10 m capability

## The SPOT orbit

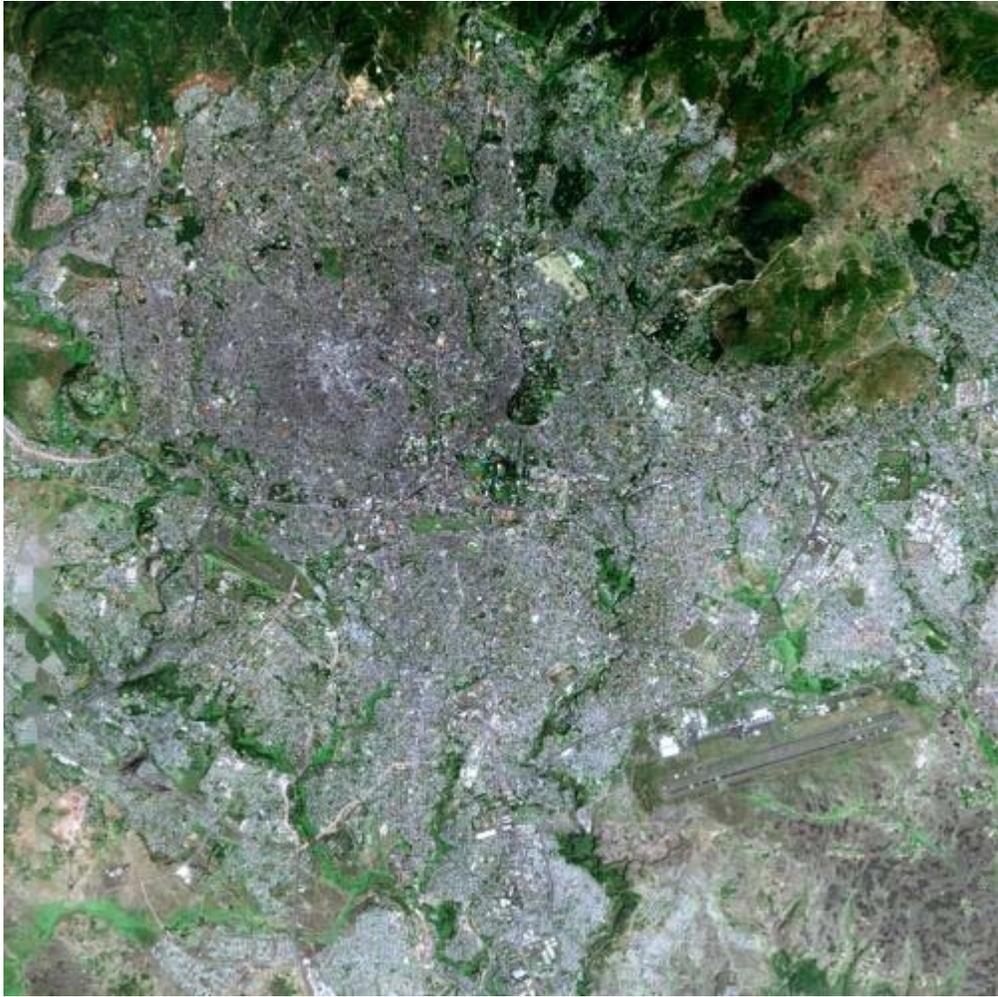
The SPOT orbit is polar, circular, sun-synchronous, and phased. The inclination of the orbital plane combined with the rotation of the Earth around the polar axis allows the satellite to fly over any point on Earth within 26 days. The orbit has an altitude of 832 kilometers, an inclination of  $98.7^\circ$ , and completing  $14 + 5/26$  revolutions per day.



Étang de Berre SPOT...



Abu Dhabi SPOT 1034



Addis Ababa SPOT



Agadir SPOT 1209

## **SPOT 1, 2, and 3**

Since 1986 the SPOT family of satellites has been orbiting the Earth and has already taken more than 10 million high quality images. SPOT 1 was launched with Ariane 2 on February 22, 1986. Two days later, the 1800 kg SPOT 1 transmitted its first image with a spatial resolution of 10 or 20 meters. SPOT 2 joined SPOT 1 in orbit on January 22, 1990 and SPOT 3 followed on September 26, 1993.

The satellite loads were identical, each including two identical HRV (High Resolution Visible) imaging instruments that were able to operate in two modes, either simultaneously or individually. The two spectral modes are panchromatic and multispectral. The panchromatic band has a resolution of 10 meters, and the three multispectral bands (G,R,NIR) have resolutions of 20 metres. They have a scene size of 3600 km<sup>2</sup> and a revisit interval of one to four days, depending on the latitude.

Because the orbit of SPOT 1 was lowered in 2003, it will gradually lose altitude and break up naturally in the atmosphere. Deorbitation of Spot 2 – in accordance with IADC

(Inter-Agency Space Debris Coordination Committee)- commenced in mid-July 2009 for a period of two weeks, with a final burn on 29 July 2009. SPOT 3 is not working anymore either, due to problems with its stabilization system.

## **SPOT 4**

SPOT 4 was launched on March 24, 1998 and features major improvements over SPOT 1, 2, and 3. The principal feature was the modification of the HRV, becoming a high-resolution visible and infrared (HRVIR) instrument. It has an additional band at mid-infrared wavelengths (1.58-1.75 micrometres), intended to provide capabilities for geological reconnaissance, vegetation surveys, and survey of snow cover.

## **SPOT 5**

SPOT 5 was launched on May 4, 2002 and has the goal to ensure continuity of services for customers and to improve the quality of data and images by anticipating changes in market requirements.

SPOT 5 has two high resolution geometrical (HRG) instruments that were deduced from the HRVIR of SPOT 4. They offer a higher resolution of 2.5 to 5 meters in panchromatic mode and 10 meters in multispectral mode (20 metre on short wave infrared 1.58 - 1.75  $\mu\text{m}$ ). SPOT 5 also features an HRS imaging instrument operating in panchromatic mode. HRS points forward and backward of the satellite. Thus, it is able to take stereopair images almost simultaneously to map relief.

## **SPOT 6 and SPOT 7**

SPOT 6 and SPOT 7 form a constellation of Earth-imaging satellites designed to provide continuity of high-resolution, wide-swath data up to 2023. EADS Astrium took the decision to build this constellation in 2009 on the basis of a perceived government need for this kind of data. Spot Image, a subsidiary of Astrium, is funding the satellites alone and owns the system (satellites and ground segments).

- The architecture is similar to that of the Pleiades satellites, with a centrally mounted optical instrument, a three-axis star tracker, a fibre-optic gyro (FOG) and four control moment gyros (CMGs).
- SPOT 6 and SPOT 7 will be phased in the same orbit as Pléiades 1 and Pléiades 2 at an altitude of 694 km.
- Image product resolution:
  - Panchromatic: 1.5 m
  - Colour merge: 1.5 m
  - Multispectral: 8 m
- Spectral bands, with simultaneous panchromatic and multispectral acquisitions:
  - Panchromatic (450 – 745  $\mu\text{m}$ )
  - Blue (450 – 525  $\mu\text{m}$ )

- Green (530 – 590  $\mu\text{m}$ )
  - Red (625 – 695  $\mu\text{m}$ )
  - Near-infrared (760 – 890  $\mu\text{m}$ )
- Footprint: 60 km x 60 km
- Responsive satellite tasking, with 6 tasking plans per day, per satellite
- Capacity to acquire up to 3 million  $\text{km}^2$ . daily
- Launches scheduled in 2012 and 2013

## Chapter- 15

# TOPEX/Poseidon



TOPEX/Poseidon made precise measurements of the ocean surface from 1992 to 2006.

Launched in 1992, **TOPEX/Poseidon** was a joint satellite mission between NASA, the U.S. space agency, and CNES, the French space agency, to map ocean surface topography. The first major oceanographic research vessel to sail into space, TOPEX/Poseidon helped revolutionize oceanography by proving the value of satellite ocean observations. The distinguished oceanographer Walter Munk described TOPEX/Poseidon as "the most successful ocean experiment of all times."

## Description

Before TOPEX/Poseidon, scientists had only a brief glimpse of Earth's ocean as a whole from the pioneering, but short-lived Seasat satellite. TOPEX/Poseidon's radar altimeter provided the first continuous global coverage of the surface topography of the oceans. From orbit 1,330 kilometers above Earth, TOPEX/Poseidon provided measurements of the surface height of 95 percent of the ice-free ocean to an accuracy of 3.3 centimeters. The satellite's measurements of the hills and valleys of the sea surface led to a fundamental new understanding of ocean circulation and its effect on climate.

The mission's most important achievement was to determine the patterns of ocean circulation - how heat stored in the ocean moves from one place to another. Since the ocean holds most of the Earth's heat from the Sun, ocean circulation is a driving force of climate. TOPEX/Poseidon made it possible for the first time to compare computer models of ocean circulation with actual global observations and use the data to improve climate predictions.

While a three-year prime mission was planned, TOPEX/Poseidon delivered more than 10 years of data from orbit. In those years, the mission:

- Measured sea level with an unprecedented accuracy
- Mapped global tides for the first time
- Monitored effects of currents on global climate change and produced the first global views of seasonal changes of currents
- Monitored large-scale ocean features like Rossby and Kelvin waves and studied such phenomena as El Niño, La Niña, and the Pacific Decadal Oscillation
- Mapped basin-wide current variations and provided global data to validate models of ocean circulation
- Mapped year-to-year changes in heat stored in the upper ocean
- Improved our knowledge of Earth's gravity field

In October 2005 after more than 62,000 orbits, TOPEX/Poseidon stopped providing science data after a momentum wheel malfunctioned, and the satellite was turned off on January 18, 2006.

TOPEX/Poseidon was launched using an Ariane 42P expendable launch vehicle. Lift-off from Kourou in French Guiana took place on 1992-08-10. At lift-off the mass of the satellite was 2,402 kilograms (5,300 lb). The mission was named after the ocean TOPography EXperiment and the Greek god of the ocean Poseidon.

## Measurements Continue



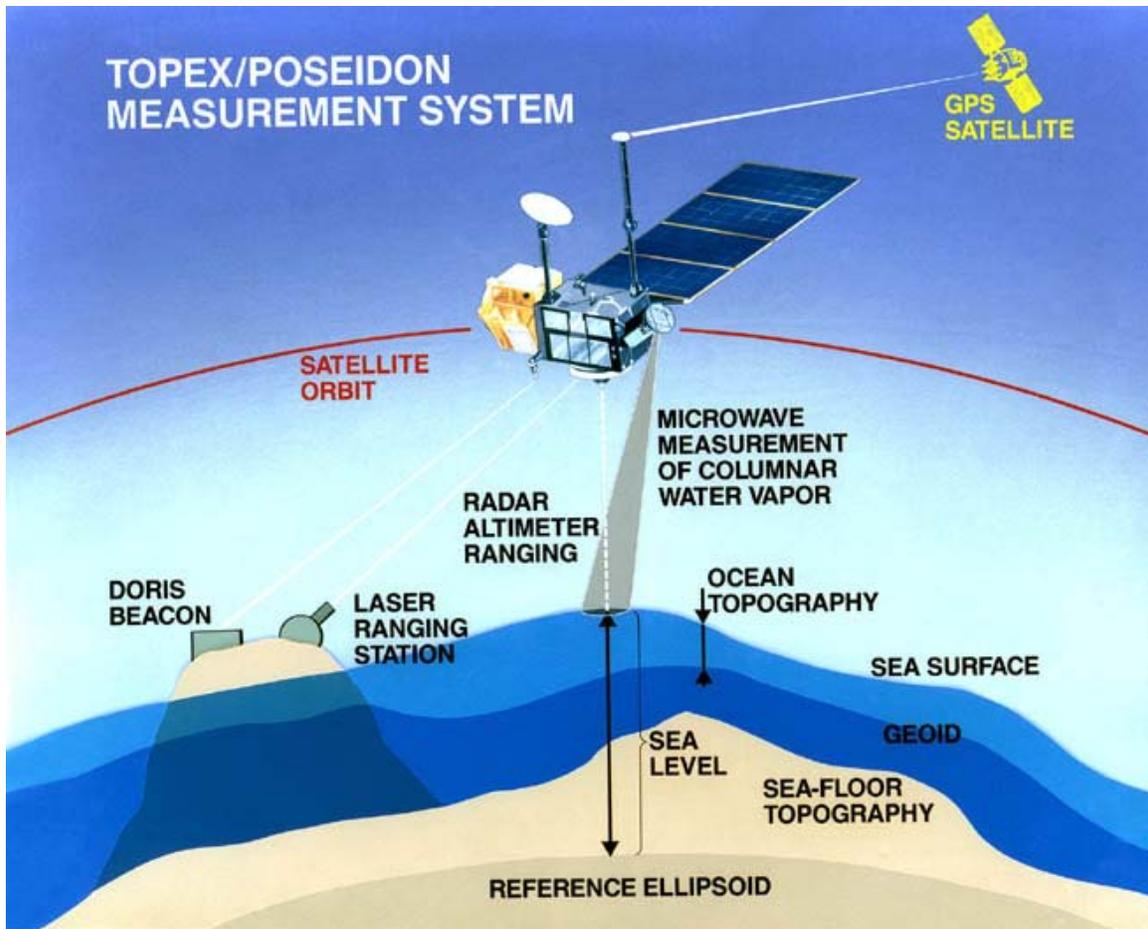
TOPEX/Poseidon's follow-on mission, Jason-1, was launched in 2001 to continue the ongoing measurements of sea surface topography. The two satellites, TOPEX/Poseidon and Jason-1, flew in a tandem mission for three years providing twice the coverage of the sea surface and allowing scientists to study smaller features than could be seen by one satellite.

The record of global sea surface height begun by TOPEX/Poseidon and Jason-1 continues into the future with the Ocean Surface Topography Mission on the Jason-2 satellite, which launched in June 2008. Planning for a Jason-3 mission is now underway.

## Instruments

TOPEX/Poseidon flew two onboard altimeters sharing the same antenna, but only one altimeter was operated at any time, with TOPEX given preference (on average 9 in 10 cycles during the first 10 years of the mission).

- TOPEX: The NASA-built Nadir pointing Radar Altimeter using C band (5.3 GHz) and Ku band (13.6 GHz) for measuring height above sea surface.
- Poseidon: The CNES-built solid state Nadir pointing Radar Altimeter using Ku band (13.65 GHz).



In addition to the altimeters, the TOPEX Microwave Radiometer (TMR) operating at 18, 21, and 37 GHz was used to correct for atmospheric wet path delay.

The satellite was also equipped with instruments to accurately pinpoint its location. Precise orbit determination is crucial because errors in locating the spacecraft would distort the sea level measurement calculated from the altimeter readings.

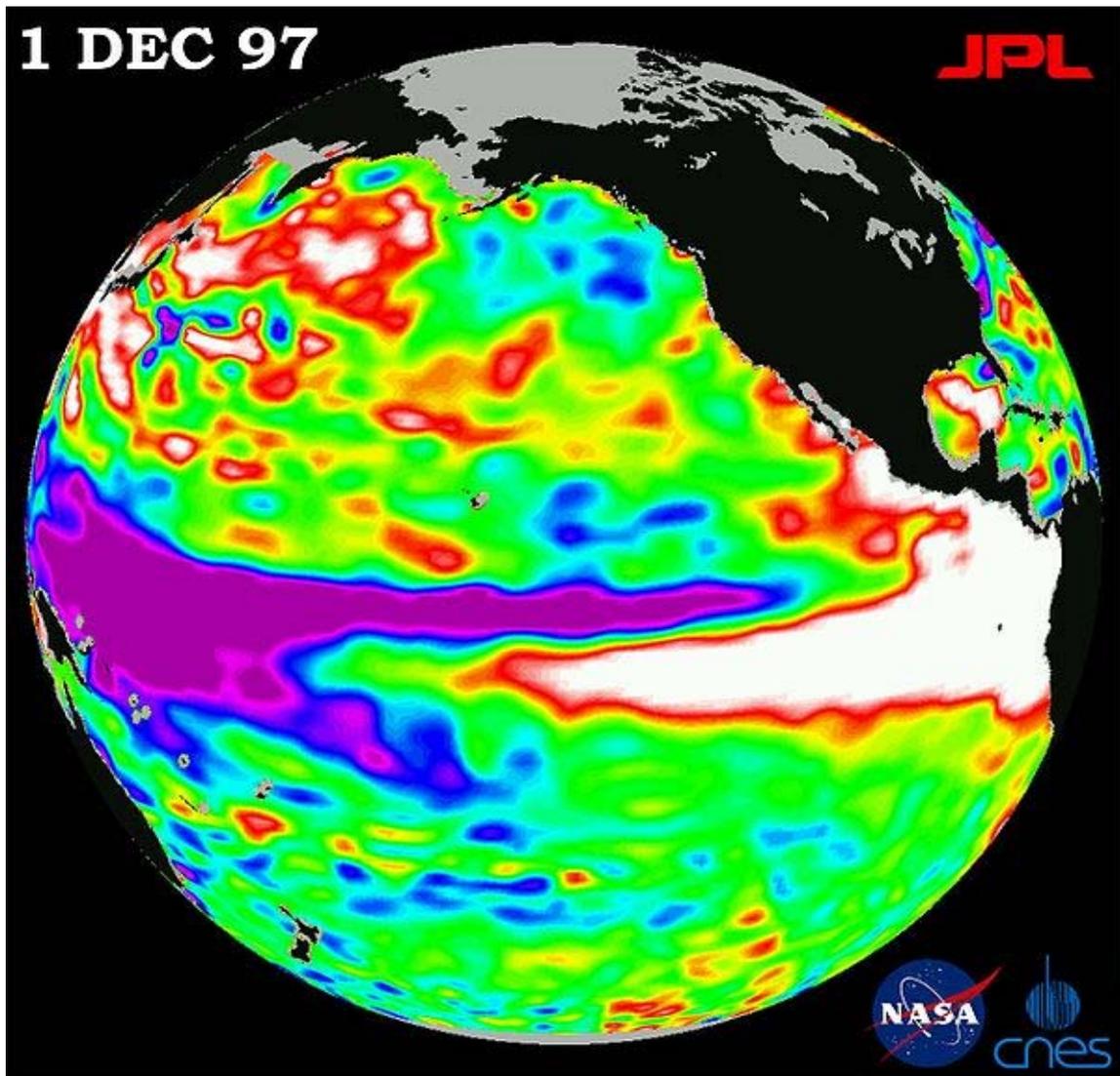
Three independent tracking systems determined the position of the spacecraft. The first, the NASA laser retroreflector array (LRA) reflected laser beams from a network of 10 to 15 ground-based laser ranging stations under clear skies. The second, for all-weather, global tracking, was provided by the CNES Doppler Orbitography and Radiopositioning Integrated by Satellite tracking system receiver (DORIS). This device uses microwave doppler techniques (changes in radio frequency corresponding to relative velocity) to track the spacecraft. DORIS consists of an on-board receiver and a global network of 40 to 50 ground-based transmitting stations.

The third system used an on-board experimental Global Positioning System (GPS) demonstration receiver to precisely determine the satellite's position continuously by analyzing the signals received from the U.S Air Force's GPS constellation of Earth orbiting satellites. TOPEX/Poseidon was the first mission to demonstrate that the Global

Positioning System could be used to determine a spacecraft's exact location and track it in orbit. Knowing the satellite's precise position to within 2 centimeters (less than 1 inch) in altitude was a key component in making accurate ocean height measurements possible.

A number of satellites use exotic dual-band radar altimeters to measure height from a spacecraft. That measurement, coupled with orbital elements (possibly from GPS), enables determination of the topography. The two lengths of radio waves permit the altimeter to automatically correct for varying delays in the ionosphere.

## Use of information



The 1997 El Nino

TOPEX/Poseidon's data have been the subject of more than 2,100 research publications. Some of the areas in which the data are used include:

- Climate Research
- Hurricane Forecasting
- El Niño & La Niña Forecasting
- Ship Routing
- Offshore Industries
- Fisheries Management
- Marine Mammal Research
- Coral Reef Research

## Chapter- 16

# Other Meteorological Remote Sensing Systems

## Tropical Rainfall Measuring Mission



Artist conception of the TRMM satellite.

The **Tropical Rainfall Measuring Mission (TRMM)** is a joint space mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall. The term refers to both the mission itself and the satellite that the mission uses to collect data. TRMM is part of NASA's Mission to Planet Earth, a long-term, coordinated research effort to study the Earth as a global system. The satellite was launched on November 27, 1997 from the Tanegashima Space Center in Tanegashima, Japan.

# **Instruments aboard the TRMM**

## **Precipitation Radar (PR)**

The Precipitation Radar is the first spaceborne instrument designed to provide three-dimensional maps of storm structure. The measurements yield 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.

## **TRMM Microwave Imager (TMI)**

The 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 quantitative information regarding rainfall make TMI the "workhorse" of the rain-measuring package on Tropical Rainfall Measuring Mission.

## **Visible and Infrared Scanner (VIRS)**

The Visible and Infrared Scanner is one of the three instruments in the rain-measuring package and serves as a very indirect indicator of rainfall. 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 delineate 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.

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

CERES measures the energy at the top of the atmosphere, as well as estimates 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 understanding the Earth's total climate system and improving climate prediction models.

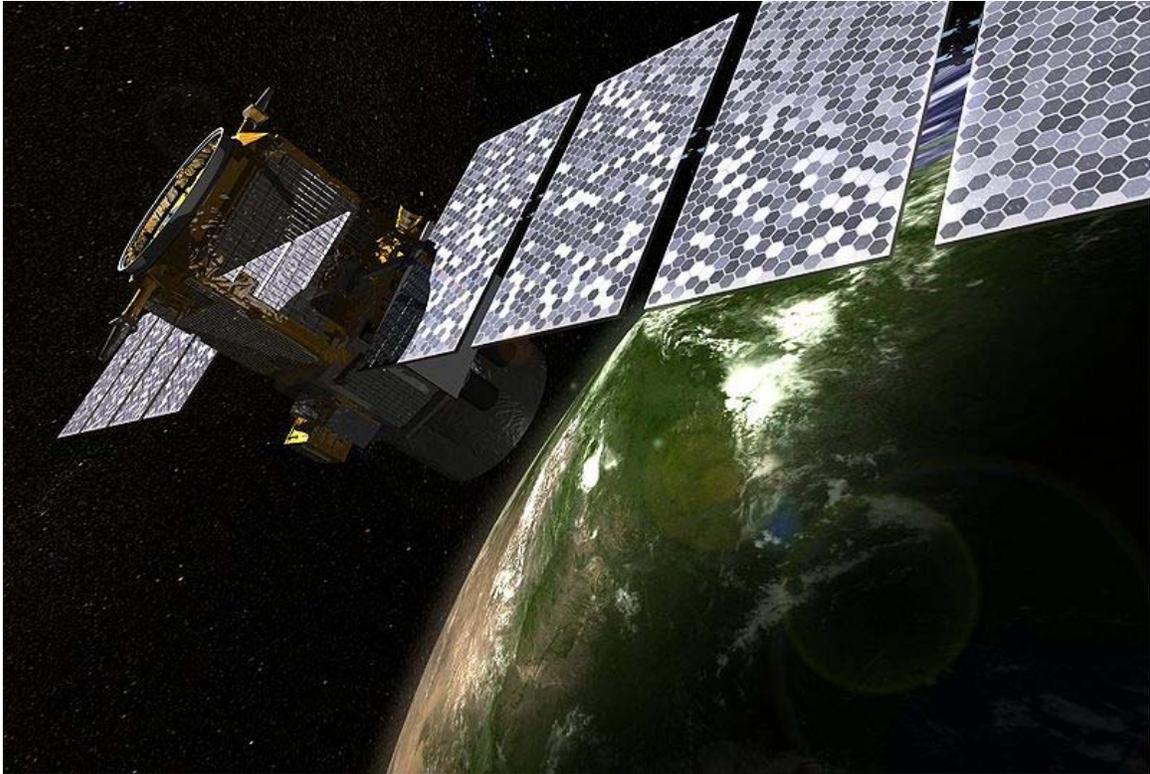
## **Lightning Imaging Sensor (LIS)**

The Lightning Imaging Sensor is a small, highly sophisticated instrument that detects and locates lightning over the tropical region of the globe. 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.

# CALIPSO



The Delta II rocket with CALIPSO and CloudSat on Launch Pad SLC-2W, VAFB.



CALIPSO

**CALIPSO** is a joint NASA (USA) and CNES (France) environmental satellite, built in the Cannes Mandelieu Space Center, which was launched atop a Delta II rocket on April 28, 2006. Its name stands for "Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations." Passive and active remote sensing Instruments onboard the CALIPSO satellite will monitor aerosols and clouds 24 hours a day. CALIPSO will fly in formation in the "A Train" with several other satellites (Aqua, Aura, CloudSat and the French PARASOL).

## Instruments

- **Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)** - a lidar that provides high-resolution vertical profiles of aerosols and clouds.
- **Wide Field Camera (WFC)** - a modified version of the commercial off-the-shelf Ball Aerospace CT-633 star tracker camera. It was selected to match band 1 of the MODIS instrument on the Aqua satellite.
- **Imaging Infrared Radiometer (IIR)** - used to detect cirrus cloud emissivity and particle size. The CALIOP laser beam is aligned with the center of the IIR image to optimize joint CALIOP/IIR observations.

In February 2009, CALIPSO switched over to the redundant laser as scheduled. The primary laser achieved its mission goal of three years of successful operation. The redundant laser has been performing beyond expectations. The CALIPSO mission was granted extended mission status in June 2009.

# CloudSat

CloudSat



Artist's Concept of CloudSat

<b>Operator</b>	NASA
<b>Major contractors</b>	Ball Aerospace and Technologies Corp.
<b>Mission type</b>	Earth orbiter
<b>Launch date</b>	April 28, 2006
<b>Launch vehicle</b>	Delta II
<b>Mission duration</b>	22 months primary mission
<b>Homepage</b>	<a href="#">CloudSat home page</a>
<b>Power</b>	Solar panels



The Delta II rocket with CloudSat and CALIPSO on Launch Pad SLC-2W, VAFB.

**CloudSat** is a NASA Earth observation satellite, which was launched on a Delta II rocket on 28 April 2006. It uses radar to measure the altitude and properties of clouds, adding to information on the relationship between clouds and climate in order to help resolve questions about global warming. CloudSat flies in formation in the "A Train", with several other satellites (Aqua, Aura, CALIPSO and the French PARASOL).

The mission was selected under NASA's Earth System Science Pathfinder program in 1999. Ball Aerospace & Technologies Corp. in Boulder, Colorado, designed and built the spacecraft.

The main instrument on CloudSat is the Cloud Profiling Radar (CPR), a 94-GHz nadir-looking radar that measures the power backscattered by clouds as a function of distance from the radar. The radar instrument was developed at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, with hardware contributions from the Canadian Space Agency. The overall design of the CPR is simple, well understood, and has a strong heritage from the many cloud radars already in operation in ground-based and airborne applications. Most of the design parameters and subsystem configurations are nearly identical to those for the Airborne Cloud Radar, which has been flying on the NASA DC-8 aircraft since 1998.

The CPR capitalizes on existing radar expertise and experience at JPL. Other radars already flown successfully or being developed by JPL include the Seasat SAR, SIR-A, SIR-B, SIR-C, the Shuttle Radar Topography Mission, Cassini Radar, NSCAT, QuickScat, and SeaWinds.

CloudSat's primary mission was scheduled to continue for 22 months in order to allow more than one seasonal cycle to be observed. Based on radar lifetime data, NASA expects the radar to operate for three years with a 99 % probability.

CloudSat is managed by the Jet Propulsion Laboratory. Colorado State University provides scientific leadership and science data processing and distribution. The cost of this project is approximately 200 million dollars.

## Glory (satellite)

### Glory



Artistic impression of *Glory* orbiting Earth.

<b>Operator</b>	NASA / GSFC
<b>Mission type</b>	Orbiter
<b>Satellite of</b>	Earth
<b>Launch date</b>	2011-02-25 ( <i>pending</i> )
<b>Launch vehicle</b>	Taurus XL

<b>Launch site</b>	Launch Complex 576 Vandenberg Air Force Base
<b>Mission duration</b>	<i>(launch pending)</i> (3 years expected)
<b>Homepage</b>	GSFC Glory website
<b>Mass</b>	545 kg (1,202 lb)
<b>Power</b>	400 W (solar array)



A few hours before the launch, NASA Deputy Administrator Lori B. Garver (left) visited the mission's launch site.

The **Glory satellite** is a planned NASA satellite mission that will collect data on the chemical, micro-physical and optical properties—and the spatial and temporal distributions—of aerosols, and will collect solar irradiance data for the long-term climate record.

The science focus areas served by Glory will include: atmospheric composition; carbon cycle, ecosystems, and biogeochemistry; climate variability and change; and water and energy cycles.

## Launch

Launch from Vandenberg Air Force Base aboard a Taurus XL rocket was planned for February 23, 2011 , but was delayed for technical reasons.

## Scientific instruments

### Aerosol Polarimetry Sensor (APS)



The Aerosol Polarimetry Sensor (APS) is a continuous scanning sensor that has the capability to collect visible, near infrared, and short-wave infrared data scattered from aerosols and clouds. It is designed to make multi-angle observations of Earth and atmospheric scene spectral polarization and radiance.

- **Instrument scientist:** Brian Cairns / GSFC (website)

### Cloud Camera



The cloud camera is a high-spatial-resolution two-band radiometer intended to facilitate the identification of cloudcontaminated APS pixels and to determine the fraction of the pixel area occupied by clouds. Over ocean, the cloud camera will be used to determine aerosol load and fine mode fraction based on the aerosol microphysical model determined from APS measurements. The Cloud Camera is not a separate instrument, but rather is used to identify clouds in the APS nadir pixel.

### Total Irradiance Monitor (TIM)



The Total Irradiance Monitor (TIM) is an active cavity radiometer that records total solar irradiance. It has four identical radiometers to provide redundancy and to help detect changes in the instrument from exposure to solar radiation. TIM is mounted on a platform that moves the instrument independent of the spacecraft.

- **Instrument scientist:** Greg Kopp / GSFC / University of Colorado (website / UoC website)

# Nimbus program



Artist's drawing of the general design of the Nimbus series of satellites. The solar-panel "wings" move throughout the day to track the Sun during the daylight part of the satellite's orbit. The 10-foot-tall satellite has the attitude control system on top, separated from a 5-foot-diameter "sensory ring" (center) with scaffolding. The sensory ring holds the batteries and electronics for each of the sensors that are mounted underneath the ring (bottom).

The **Nimbus** satellites were second-generation U.S. robotic spacecraft used for meteorological research and development. The spacecraft were designed to serve as stabilized, Earth-oriented platforms for the testing of advanced systems to sense and collect atmospheric science data. Seven Nimbus spacecraft have been launched into near-polar, sun-synchronous orbits beginning with Nimbus 1 on August 28, 1964. On board the Nimbus satellites are various instrumentation for imaging, sounding, and other studies in different spectral regions. The Nimbus satellites were launched aboard Thor-Agena rockets (Nimbus 1-4) and Delta rockets (Nimbus 5-7).

Over a 20-year period from the launch of the first satellite, the Nimbus series of missions was the United States' primary research and development platform for satellite remote-sensing of the Earth. The seven Nimbus satellites, launched over a fourteen-year period, shared their space-based observations of the planet for thirty years. NASA transferred the technology tested and refined by the Nimbus missions to the National Oceanic and Atmospheric Administration (NOAA) for its operational satellite instruments. The technology and lessons learned from the Nimbus missions are the heritage of most of the Earth-observing satellites NASA and NOAA have launched over the past three decades.

## **Contributions**

### **Weather forecasting**

At the time of its launch, the idea that intangible properties such as air pressure could be observed using a satellite orbiting hundreds of miles above the Earth was revolutionary. With each Nimbus mission, scientists broadened their ability to collect atmospheric characteristics that improved weather forecasting, including ocean and air temperatures, air pressure, and cloudiness. The global coverage provided by Nimbus satellites made accurate 3-5 day forecasts possible for the first time.

The ability of the Nimbus satellites to detect electromagnetic energy in multiple wavelengths (multi-spectral data), in particular the microwave region of the electromagnetic spectrum, made it possible for scientists to look into the atmosphere and tell the difference between water vapor and liquid water in clouds. In addition, they were able to measure atmospheric temperature even in the presence of clouds, a capability that allowed scientists to take the temperature in the "warm core" of hurricanes.

### **Radiation budget**

One of the most important scientific contributions of the Nimbus missions was their measurements of the Earth's radiation budget. For the first time, scientists had global, direct observations of the amount of solar radiation entering and exiting the Earth system. The observations helped to verify and refine the earliest climate models, and are still making important contributions to the study of climate change. As scientists consider the causes and effects of global warming, Nimbus radiation budget data provide a base for long-term analyses and make change-detection studies possible. The Nimbus technology gave rise to current radiation-budget sensors, such as the CERES instruments on NASA's Terra and Aqua satellites.

### **Ozone layer**

Even before the Nimbus satellites began collecting their observations of Earth's ozone layer, scientists had some understanding of the processes that maintained or destroyed it. They were pretty sure they understood how the layer formed, and they knew from laboratory experiments that halogens could destroy ozone. Finally, weather balloons had revealed that the concentration of ozone in the atmosphere changed over time, and

scientists suspected weather phenomena or seasonal change were responsible. But how all of these pieces of information worked together on a global scale was still unclear.

Scientists conducted experiments from NASA experimental aircraft and proved that atmospheric chemicals such as the chlorofluorocarbons (CFCs) released from refrigerants and aerosol sprays did destroy ozone. As Nimbus 7 satellite observations accumulated between 1978 and 1994, it became increasingly clear that CFCs were creating an ozone hole each winter season over Antarctica. Not only that, but despite some year-to-year variations, it appeared the hole was becoming larger. The Nimbus measurements made clear how severe the ozone hole problem was.

## **Sea ice**

When the Nimbus 5 spacecraft launched in 1972, scientists planned for its Electrically Scanning Microwave Radiometer to collect global observations of where and how much it rained across the world. However, a new priority for the sensor evolved in the months following its launch: mapping global sea ice concentrations. When Nimbus 7 launched in 1978, technology had improved enough for scientists to distinguish newly formed (i.e., "first year") sea ice from older ice, with the Scanning Multichannel Microwave Radiometer (SMMR) sensor. The data it collected during its 9-year lifespan provide a significant chunk of the long-term record of Earth's sea ice concentration that today's scientists use for studies of climate change.

Among the most serendipitous discoveries that the Nimbus missions made possible was that of a gaping hole in the sea ice around Antarctica in the Southern Hemisphere winters of 1974-76. In a phenomenon that has not been observed since, an enormous, ice-free patch of water, called a polynya, developed three years in a row in the seasonal ice that encases Antarctica each winter. Located in the Weddell Sea, each year the polynya vanished with the summer melt, but returned the following year. The open patch of water may have influenced ocean temperatures as far down as 2,500 meters and influenced ocean circulation over a wide area. The Weddell Sea Polynya has not been observed since the event witnessed by the Nimbus satellites in the mid-70s.

## **Global positioning system**

Nimbus satellites (beginning with Nimbus 3 in 1969) blazed the trail into the modern GPS era with operational search and rescue and data collection systems. The satellites tested the first technology that allowed satellites to locate weather-observation stations set up in remote locations and to command the stations to transmit their data back to the satellite. The most famous demonstration of the new technology was through the record-breaking flight of British aviator Sheila Scott, who tested the Nimbus navigation and locator communication system when she made the first-ever solo flight over the North Pole in 1971.

The Nimbus ground-to-satellite-to-ground communication system demonstrated the first satellite-based search and rescue system. Among the earliest successes were the rescue of

two hot air balloonists who went down in the North Atlantic in 1977 and, later that year, tracking a Japanese adventurer on his first attempt to be the first person to dogsled solo to the North Pole through Greenland. Tens of thousands of people over the past three decades have been rescued through the Search and Rescue Satellite-aided Tracking (SARSAT) operational system on NOAA satellites.

## Operation history of the Nimbus satellites

Satellite	Launch Date	Decay Date
Nimbus 1	August 28, 1964	May 16, 1974
Nimbus 2	May 15, 1966	January 17, 1969
Nimbus 3	April 14, 1969	January 22, 1972
Nimbus 4	April 8, 1970	September 30, 1980
Nimbus 5	December 11, 1972	
Nimbus 6	June 12, 1975	
Nimbus 7	October 24, 1978	

## Multi-Functional Transport Satellite

**Multifunctional Transport Satellites (MTSAT)** are a series of weather and aviation control satellites. They are geostationary satellites owned and operated by the Japanese Ministry of Land, Infrastructure and Transport and the Japan Meteorological Agency (JMA), and provide coverage for the hemisphere centred on 140° East; this includes Japan and Australia who are the principal users of the satellite imagery that MTSAT provides. They replace the GMS-5 satellite, also known as *Himawari 5* (“himawari” or “ひまわり” meaning “sunflower”). They can provide imagery in five wavelength bands — visible and four infrared, including the water vapour channel. The visible light camera has a resolution of 1 km; the infrared cameras have 4 km (resolution is lower away from the equator at 140° East). The spacecraft have a planned lifespan of five years. MTSAT-1 and 1R were built by Space Systems/Loral. MTSAT-2 was built by Mitsubishi.

### MTSAT-1 and GOES-9

#### Launch failure

The launch of MTSAT-1, on a Japanese H-II rocket, failed on November 15, 1999 and the spacecraft was destroyed. GMS-5, the satellite MTSAT-1 was intended to replace, was decommissioned on April 1, 2003 leaving Japan without weather satellite imagery.

## **NOAA loan**

To fill in the void, The United States National Oceanic and Atmospheric Administration (NOAA) loaned the GOES-9 satellite to the JMA and repositioned it over 145° East on May 22, 2003.

## **MTSAT-1R**

MTSAT-1R (also known as *Himawari 6*) was successfully launched on a H-IIA on February 26, 2005 and became partially operational on June 28, 2005 — the aviation payload was not functional as two MTSATs are required for air traffic control. GOES-9 was decommissioned when MTSAT-1R came online in June 2005.

## **MTSAT-2**

MTSAT-2 (also known as *Himawari 7*) successfully launched on February 18, 2006 and is positioned at 145° East. The weather functions of MTSAT-2 were put into hibernation until the end of MTSAT-1R's life (5 years from launch). The transportation and communication functions of MTSAT-2 will be utilized prior to that time.

### **Attitude control malfunction**

On November 5, 2007 JMA announced a malfunction in the attitude control of MTSAT-2. Attitude control was restored November 7, 2007. The presumed cause of the malfunction was improper functioning of an attitude control thruster. A spare thruster was used to return the spacecraft to normal operation.

## **Ground segment**

Ground stations for both satellites are located in Kobe and Hitachiota, Japan.

## **Meteosat**

The **Meteosat** series of satellites are geostationary meteorological satellites operated by EUMETSAT under the Meteosat Transition Programme (MTP) and the Meteosat Second Generation (MSG) program.

The MTP program was established to ensure the operational continuity between the end of the successful Meteosat Operational Programme in 1995 and Meteosat Second Generation (MSG), which came into operation at the start of 2004 using improved satellites. The MTP provides an overlap with MSG by continuing the current Meteosat system until at least the end of the year 2005. The MSG program will provide service until the MTG (Meteosat Third Generation) program takes over.

## **First generation**



A photograph of a Meteosat First Generation satellite prior to launch

The first generation of Meteosat satellites, Meteosat-1 to Meteosat-7, provide continuous and reliable meteorological observations from space to a large user community. In addition to the provision of images of the Earth and its atmosphere every half-hour in three spectral channels (Visible, Infrared) and Water Vapour, via the Meteosat Visible and Infrared Imager (MVIRI) instrument, a range of processed meteorological products is produced. Meteosat also supports the retransmission of data from data collection platforms in remote locations, at sea and on board aircraft, as well as the dissemination of meteorological information in graphical and text formats.

The satellites were manufactured by a consortium COSMOS, with Aerospatiale in its Cannes Mandelieu Space Center, as Prime, and included Matra, MBB, Selenia Spazio, Marconi Company.

They are 2.1 metres in diameter and 3.195 metres long. Its initial mass in orbit is 282 kg, and in orbit, the satellite spins at 100 rpm around its main axis

## **Meteosat Second Generation**

The contract for the second generation was awarded to Aerospatiale in its Cannes Mandelieu Space Center (now Thales Alenia Space), with main subcontractors as Matra, Messerschmitt, Alenia.

Meteosat Second Generation was designed in response to user requirements to serve the needs of Nowcasting applications and Numerical Weather Prediction. In addition the GERB instrument provides important data for climate monitoring and research.

The new satellites are spin-stabilised like the previous generation, but with many design improvements. The more frequent and comprehensive data collected by MSG also aids the weather forecaster in the swift recognition and prediction of dangerous weather phenomena such as thunderstorms, fog and explosive development of small but intense depressions which can lead to devastating wind storms.

The MSG satellites are 3.2 m in diameter and 2.4 m high and spins anti-clockwise at 100 RPM at an altitude of 36,000 km .

On January 29, 2004 the first Meteosat Second Generation satellite MSG-1, renamed to Meteosat-8, commenced routine operations. In addition to the main optical payload SEVIRI (Spinning Enhanced Visible and Infrared Imager), Meteosat-8 also carries the secondary payload GERB (Geostationary Earth Radiation Budget) instrument.

The launch of MSG-2 (renamed to Meteosat-9) took place on December 21, 2005.



The MSG control center in Darmstadt

In 2010 Meteosat-6, -7, -8 and -9 are all operational. Meteosat-6 and -7 are stationed over the Indian Ocean. Meteosat-8, and -9 are both located over Africa with various differences in operational configuration. Meteosat-6 provides a DCP service and is a backup to Meteosat-7, where Meteosat-7 provides the primary imagery coverage over the Indian Ocean (with images every 30-minutes). Meteosat-8 is a backup to Meteosat-9 (and Meteosat-8 also provides an operational European 'rapid scan' mode service, which commenced in the second quarter of 2008 (with images of Europe every 5 minutes)).

Meteosat-9 provides the main full earth imagery service over Europe and Africa (with images every 15-minutes).

The launch of MSG-3 is tentatively planned for 2012 and MSG-4 tentatively planned for 2014. Like MSG-1 and MSG-2, MSG-3 and MSG-4 are planned for launch by Arianespace.

### **Secondary Payloads**

Both MSG-1 and MSG-2 carry a Search and Rescue signal Processor (SARP) that detects 406 MHz distress signals from distress radiobeacons.

## **Meteosat Third Generation**

Considering the long development cycle for a new observational space system, EUMETSAT has been working on the definition and the planning for a Meteosat Third Generation (MTG) system since the year 2000. MTG components providing continuity of MSG services need to be available around 2015, before the end of the nominal lifetime of MSG. MTG preparatory activities started end of 2000 in cooperation with the European Space Agency (ESA), following the decision of the EUMETSAT Council to proceed with a Post-MSG User Consultation Process. The process is aimed at capturing the foreseeable needs of users of EUMETSAT's satellite data in the 2015-2025 timeframe. .

On March 19, 2010, ESA choose Thales Alenia Space for a final negotiation leading to a contract to be signed during June.

On June 22, 2010, Eumetsat confirm the choice of Thales Alenia Space