Earth Observation Satellites

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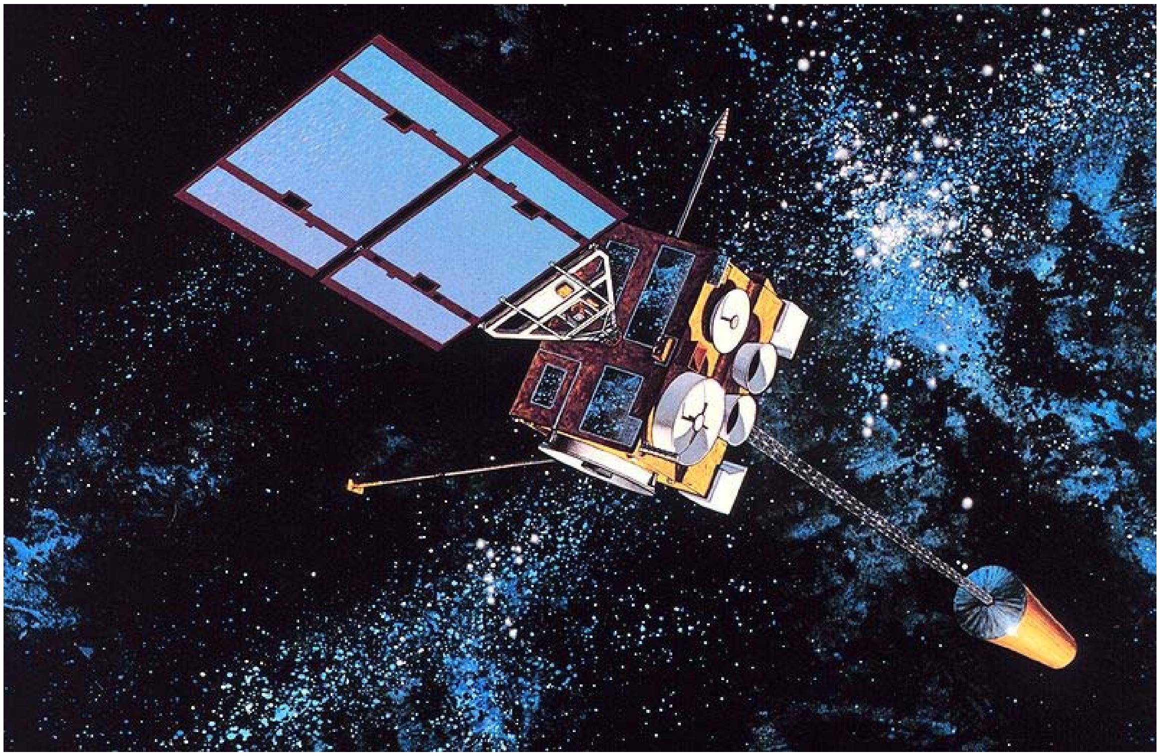
Earth Observation Satellite

An Earth observation satellite, ERS 2

Earth observation satellites are satellites specifically designed to observe Earth from orbit, similar to reconnaissance satellites but intended for non-military uses such as environmental monitoring, meteorology, map making etc. Geostationary satellites hover over the same spot, providing continuous monitoring to a portion of the Earth's surface. Polar orbiting satellites provide global coverage, but only twice per day at any given spot.

Weather



GOES-8, a United States weather satellite

A weather satellite is a type of satellite that is primarily used to monitor the weather and climate of the Earth. These meteorological satellites, however, see more than clouds and cloud systems. City lights, fires, effects of pollution, auroras, sand and dust storms, snow cover, ice mapping, boundaries of ocean currents, energy flows, etc., are other types of environmental information collected using weather satellites.

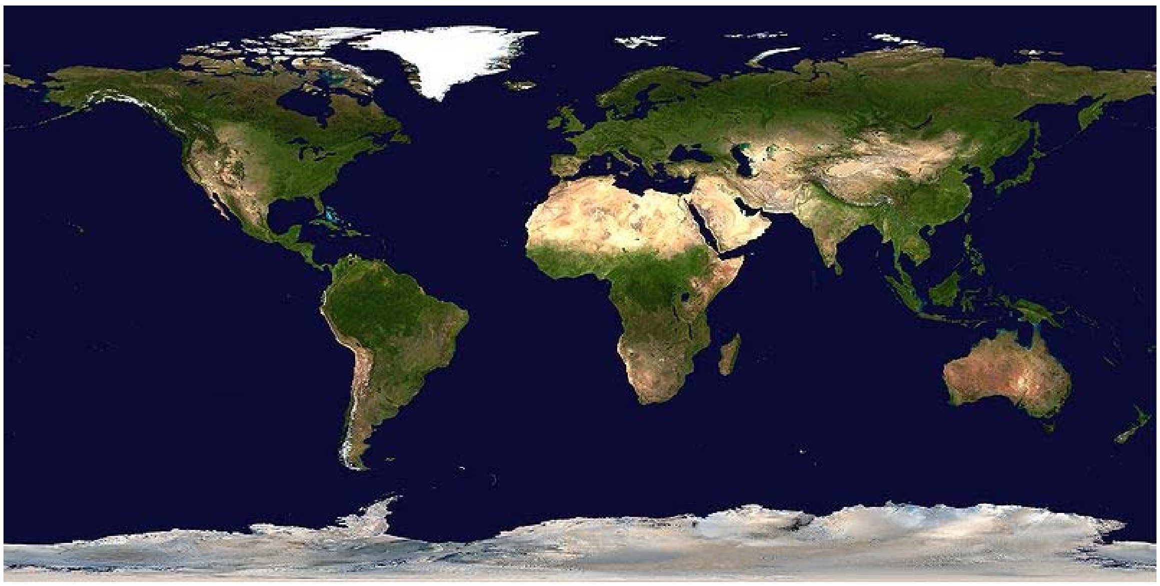
Weather satellite images helped in monitoring the volcanic ash cloud from Mount St. Helens and activity from other volcanoes such as Mount Etna. Smoke from fires in the western United States such as Colorado and Utah have also been monitored.

El Niño and its effects on weather are monitored daily from satellite images. The Antarctic ozone hole is mapped from weather satellite data. Collectively, weather satellites flown by the U.S., Europe, India, China, Russia, and Japan provide nearly continuous observations for a global weather watch. used via visible light and infrared rays of the electromagnetic spectrum.

Environmental monitoring

Other environmental satellites can assist environmental monitoring by detecting changes in the Earth's vegetation, sea state, ocean color, and ice fields. By monitoring vegetation changes over time, droughts can be monitored by comparing the current vegetation state to its long term average. For example, the 2002 oil spill off the northwest coast of Spain was watched carefully by the European ENVISAT, which, though not a weather satellite, flies an instrument (ASAR) which can see changes in the sea surface.

Mapping

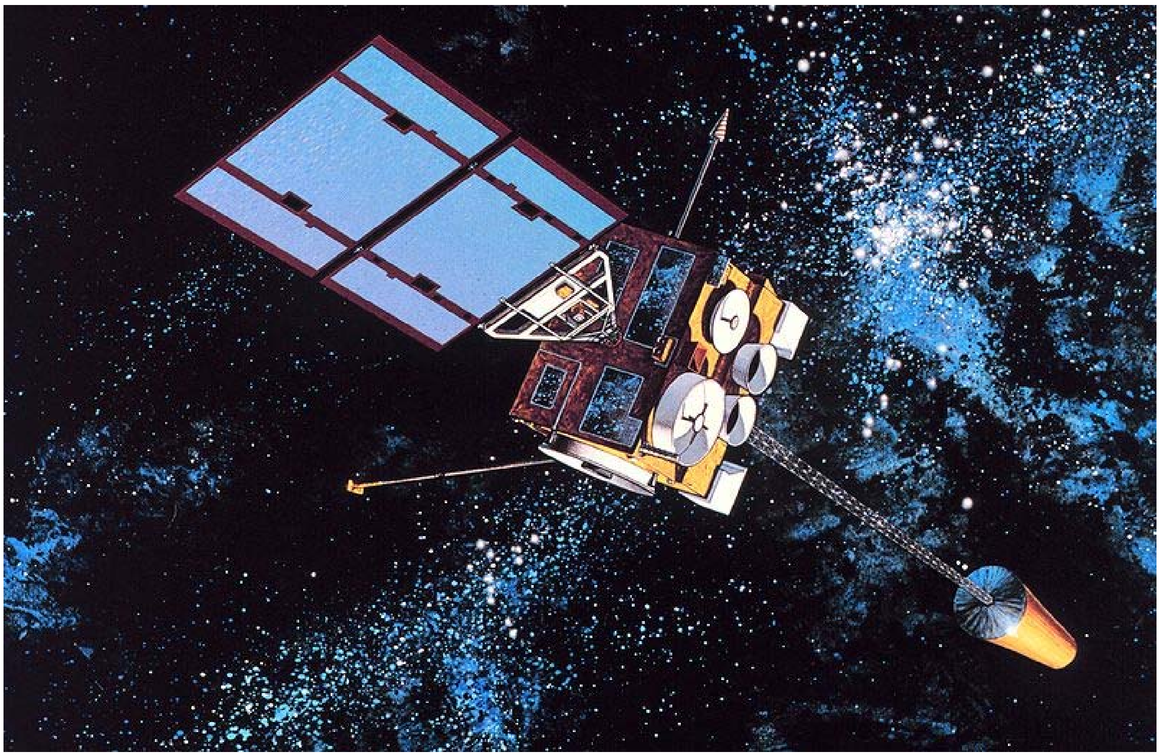


A composite satellite image of the earth, showing its entire surface, both land and ocean, in Plate carrée projection.

Terrain can be mapped from space with the use of satellites, such as RADARSAT-1 and TerraSAR-X.

Chapter- 2

Weather Satellite



GOES-8, a United States weather satellite

The **weather satellite** is a type of satellite that is primarily used to monitor the weather and climate of the Earth. Satellites can be either polar orbiting, seeing the same swath of the Earth every 12 hours, or geostationary, hovering over the same spot on Earth by orbiting over the equator while moving at the speed of the Earth's rotation. These meteorological satellites, however, see more than clouds and cloud systems. City lights, fires, effects of pollution, auroras, sand and dust storms, snow cover, ice mapping, boundaries of ocean currents, energy flows, etc., and other types of environmental information are collected using weather satellites. Weather satellite images helped in monitoring the volcanic ash cloud from Mount St. Helens and activity from other volcanoes such as Mount Etna. Smoke from fires in the western United States such as Colorado and Utah have also been monitored.

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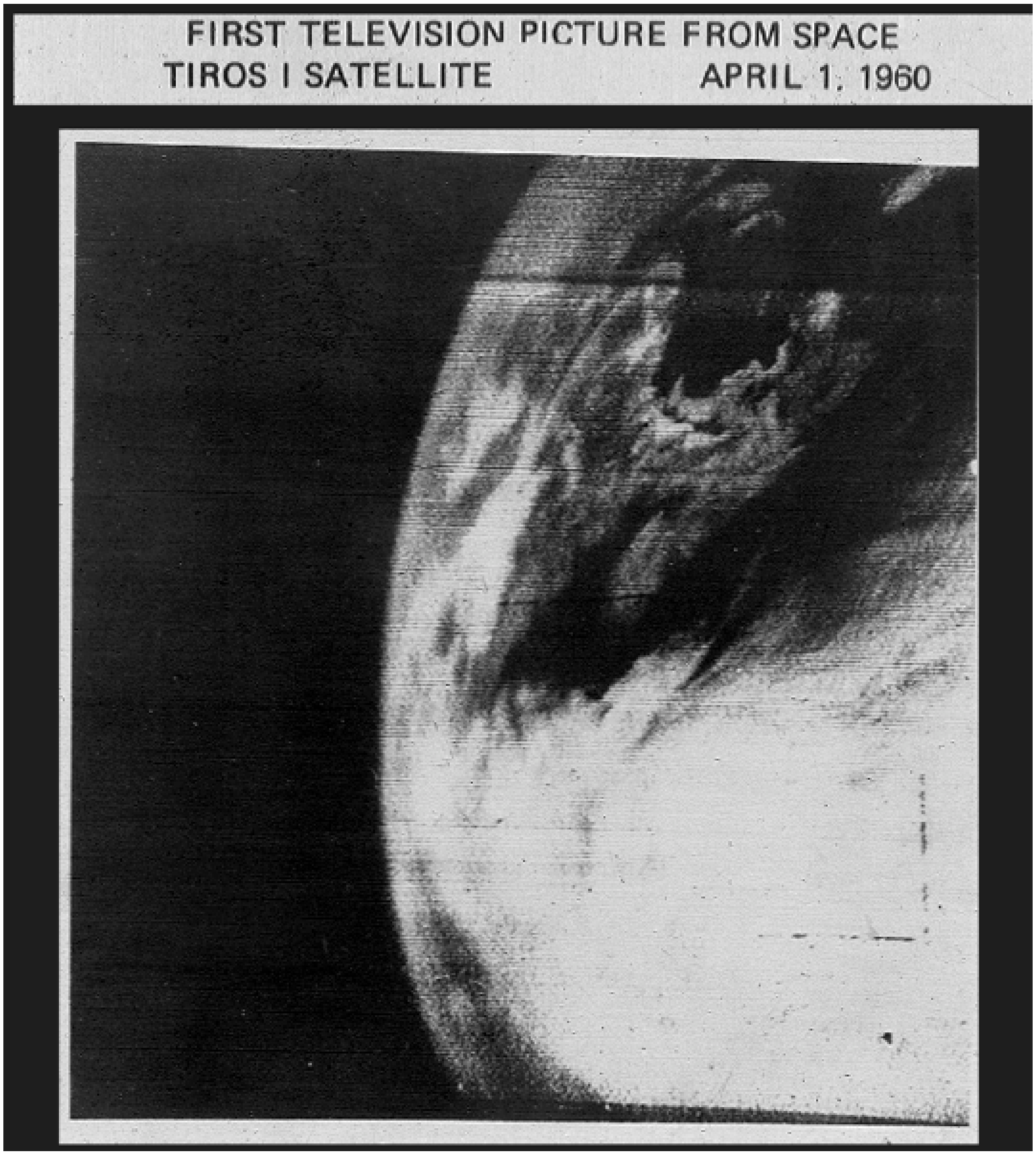
Observation

Observation is typically made via different 'channels' of the Electromagnetic spectrum, in particular, the Visible and Infrared portions.

Some of these channels include:

- *Visible and Near Infrared:* 0.6 µm - 1.6 µm - For recording cloud cover during the day
- *Infrared:* 3.9 µm - 7.3 µm (Water Vapour), 8.7 µm, - 13.4 µm (Thermal imaging)

History



The first television image of Earth from space from the TIROS-1 weather satellite

The first weather satellite, Vanguard 2, was launched on February 17, 1959. It was designed to measure cloud cover and resistance, but a poor axis of rotation kept it from collecting a notable amount of useful data.

The first weather satellite to be considered a success was TIROS-1, launched by NASA on 1 April 1960. TIROS operated for 78 days and proved to be much more successful than Vanguard 2. TIROS paved the way for the Nimbus program, whose technology and findings are the heritage of most of the Earth-observing satellites NASA and NOAA have launched since then.

Visible spectrum

Visible-light images from weather satellites during local daylight hours are easy to interpret even by the average person; clouds, cloud systems such as fronts and tropical storms, lakes, forests, mountains, snow ice, fires, and pollution such as smoke, smog, dust and haze are readily apparent. Even wind can be determined by cloud patterns, alignments and movement from successive photos.

Infrared spectrum

The thermal or infrared images recorded by sensors called scanning radiometers enable a trained analyst to determine cloud heights and types, to calculate land and surface water temperatures, and to locate ocean surface features. Infrared satellite imagery can be used effectively for tropical cyclones with a visible eye pattern, using the Dvorak technique, where the difference between the temperature of the warm eye and the surrounding cold cloud tops can be used to determine its intensity (colder cloud tops generally indicate a more intense storm). Infrared pictures depict ocean eddies or vortices and map currents such as the Gulf Stream which are valuable to the shipping industry. Fishermen and farmers are interested in knowing land and water temperatures to protect their crops against frost or increase their catch from the sea. Even El Niño phenomena can be spotted. Using color-digitized techniques, the gray shaded thermal images can be converted to color for easier identification of desired information.

Types

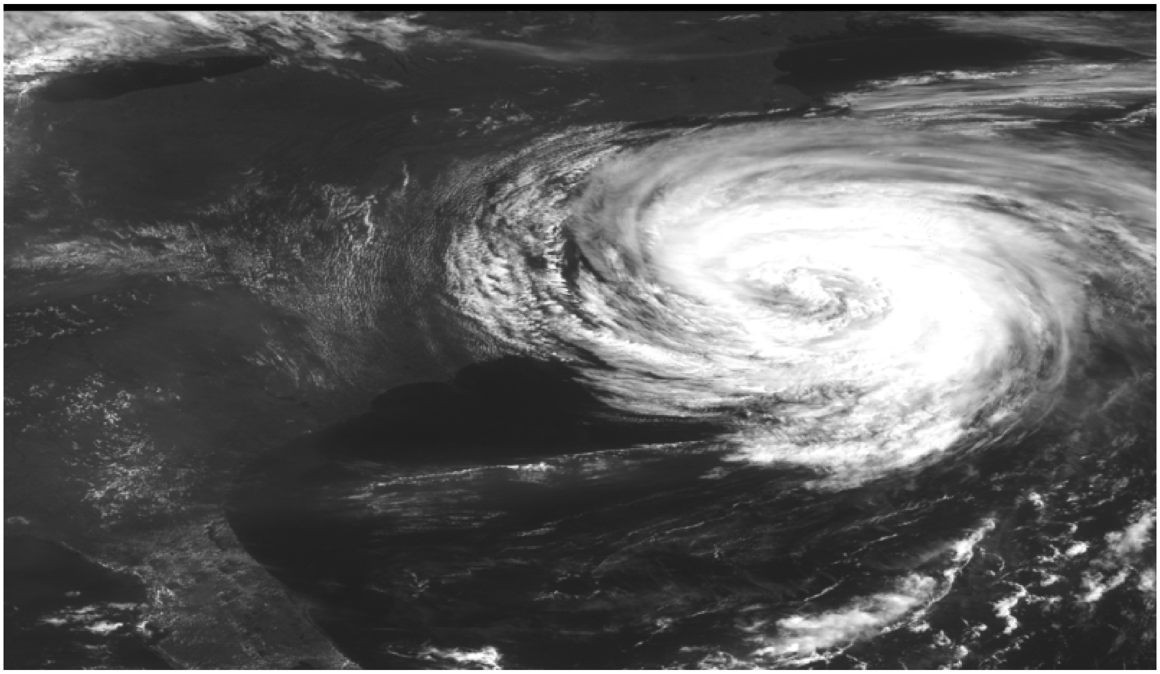


Image from the GOES-9 weather satellite of Hurricane Felix.

There are two basic types of meteorological satellites: geostationary and polar orbiting.

Geostationary

Geostationary weather satellites orbit the Earth above the equator at altitudes of 35,880 km (22,300 miles). Because of this orbit, they remain stationary with respect to the rotating Earth and thus can record or transmit images of the entire hemisphere below continuously with their visible-light and infrared sensors. The news media use the geostationary photos in their daily weather presentation as single images or made into movie loops. These are also available on the city forecast pages of noaa.gov (example Dallas, TX).

Several geostationary meteorological spacecraft are in operation. The United States has two in operation; GOES-11 and GOES-12. GOES-12, designated GOES-East, is located over the Amazon River and provides most of the U.S. weather information. GOES-11 is GOES-West over the eastern Pacific Ocean. Russia's new-generation weather satellite Elektro-L 1 operates at 76°E over the Indian Ocean. The Japanese have one in operation; MTSAT-1R over the mid Pacific at 140°E. The Europeans have Meteosat-8 (3.5°W) and Meteosat-9 (0°) over the Atlantic Ocean and have Meteosat-6 (63°E) and Meteosat-7 (57.5°E) over the Indian Ocean. India also operates geostationary satellites called INSAT which carry instruments for meteorological purposes. China operated the Feng-Yun（風雲) geostationary satellites FY-2D at 86.5°E and FY-2E at 123.5°E, which are no longer in use anymore.

Polar orbiting

Computer controlled motorized parabolic dish antenna for tracking LEO weather satellites.

Polar orbiting weather satellites circle the Earth at a typical altitude of 850 km (530 miles) in a north to south (or vice versa) path, passing over the poles in their continuous flight. Polar satellites are in sun-synchronous orbits, which means they are able to observe any place on Earth and will view every location twice each day with the same general lighting conditions due to the near-constant local solar time. Polar orbiting weather satellites offer a much better resolution than their geostationary counterparts due their closeness to the Earth.

The United States has the NOAA series of polar orbiting meteorological satellites, presently NOAA 17 and NOAA 18 as primary spacecraft, NOAA 15 and NOAA 16 as secondary spacecraft, NOAA 14 in standby, and NOAA 12. Europe has the Metop-A satellite. Russia has the Meteor and RESURS series of satellites. China has FY-1D and FY-3A. India has polar orbiting satellites as well.

DMSP

Turnstile antenna for reception of 137 MHz LEO weather satellite transmissions

The United States Department of Defense's Meteorological Satellite (DMSP) can "see" the best of all weather vehicles with its ability to detect objects almost as 'small' as a huge oil tanker. In addition, of all the weather satellites in orbit, only DMSP can "see" at night in the visual. Some of the most spectacular photos have been recorded by the night visual sensor; city lights, volcanoes, fires, lightning, meteors, oil field burn-offs, as well as the Aurora Borealis and Aurora Australis have been captured by this 450-mile-high space vehicle's low moonlight sensor.

At the same time, energy monitoring as well as city growth can be accomplished since both major and even minor cities, as well as highway lights, are conspicuous. This informs astronomers of light pollution. The New York City Blackout of 1977 was captured by one of the night orbiter DMSP space vehicles.

In addition to monitoring city lights, these photos are a life saving asset in the detection and monitoring of fires. Not only do the satellites see the fires visually day and night, but the thermal and infrared scanners on board these weather satellites detect potential fire sources below the surface of the Earth where smoldering occurs. Once the fire is detected, the same weather satellites provide vital information about wind that could fan or spread the fires. These same cloud photos from space tell the firefighter when it will rain.

Dramatic photos are provided by all the weather satellites, but even more definitive were the DMSP night visible-light pictures of the 700 oil well fires that Iraq started on 23 February 1991 as they fled Kuwait. These fires were vividly illustrated as huge flashes in the night photos, far outstripping the glow of large populated areas. The fires consumed millions of gallons of oil; the last was doused on November 6.

Uses

Snowfield monitoring, especially in the Sierra Nevada, can be helpful to the hydrologist keeping track of how much snow is available for runoff vital to the water sheds of the western United States. This information is gleaned from existing satellites of all agencies of the U.S. government (in addition to local, on-the-ground measurements). Ice floes, packs and bergs can also be located and tracked from weather space craft.

Even pollution whether it's nature-made or man-made can be pinpointed. The visual and infrared photos show effects of pollution from their respective areas over the entire earth. Aircraft and rocket pollution, as well as condensation trails, can also be spotted. The ocean current and low level wind information gleaned from the space photos can help predict oceanic oil spill coverage and movement. Almost every summer, sand and dust from the Sahara Desert in Africa drifts across the equatorial regions of the Atlantic Ocean. GOES-EAST photos enable meteorologists to observe, track and forecast this sand cloud. In addition to reducing visibilities and causing respiratory problems, sand clouds suppress hurricane formation by modifying the solar radiation balance of the tropics. Other dust storms in Asia and mainland China are common and easy to spot and monitor, with recent examples of dust moving across the Pacific ocean and reaching North America.

In remote areas of the world with few local observers, fires could rage out of control for days or even weeks and consume millions of acres before authorities are alerted. Weather satellites can be a tremendous asset in such situations. Nighttime photos also clearly show the burn-off in the gas and oil fields of the Middle East and African countries. This burn-off throws large amounts of carbon dioxide into the atmosphere.

Chapter- 3

Commercial Earth Observation Satellites

EROS (satellite)

Earth Resources Observation Satellite (EROS) is a series of Israeli commercial Earth observation satellites, designed and manufactured by Israel Aircraft Industries (IAI), with optical payload supplied by El-Op. The satellites are owned and operated by ImageSat International, another Israeli company, with some 35 full-time employees (of IntelSat's total of 50). EROS A was launched, on December 5, 2000 and EROS B on April 25, 2006.

EROS A

EROS A was launched on the Russian Start-1 launcher on December 5, 2000, from the Svobodny Launch Complex in eastern Siberia, to a Low Earth orbit (LEO) altitude of 480 km. The satellite provides commercial images with an optical resolution of 1.8 meters. The satellite orbits earth in a sun synchronous orbit, so that its imaged target is always in daylight. It always crosses the equator at 9:45am local time.

Its dimensions: height: 2.3 m, diameter: 1.2 m, head: 0.7 m. It weighed 250 kg at launch. It was built based on the military reconnaissance satellite Ofeq 3, which was previously built, also by IAI and El-Op, for Israeli government use.

EROS B

ImageSat initially planned to launch a similar satellite every 6 months after EROS A.

EROS B was finally launched on April 25, 2006 aboard a Russian Start-1 rocket from the Svobodny Launch Complex in eastern Siberia. The satellite offers an optical resolution of 70 cm (about two feet), and as of launch date plans were to use it to monitor Iran's developing nuclear program for potential threats to Israeli security.

Plans

EROS C is planned for launch in 2010, and its optical resolution has still not been decided.

ImageSat announced plans to launch a total of three more satellites in later dates, in order to provide full coverage of the entire planet surface with six functional satellites.

Ikonos

IKONOS	
Organization	GeoEye
Mission Type	Earth observation
Contractor	Lockheed Martin Space Systems
Satellite of	Earth
Launch	September 24, 1999 on an Athena 2
Launch site	Vandenberg Air Force Base
Mission duration	Ongoing
Mass	726 kg (launch)
Orbital elements	
Semimajor Axis	7056.97 km
Eccentricity	0.00013
Inclination	98.10 degrees
Orbital Period	98.33 minutes
Right ascension of the ascending node	68.015 degrees
Argument of perigee	93.06 degrees
Instruments	
Visible Sensors	1-meter panchromatic and 4-meter multispectral

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 µm	0.445-0.516 µm
2 (Green)	*	0.506-0.595 µm
3 (Red)	*	0.632-0.698 µm
4 (Near IR)	*	0.757-0.853 µm

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)

QuickBird

QuickBird	
Organization	DigitalGlobe
Mission Type	Earth observation
Contractor	Ball Aerospace & Technologies
Satellite of	Earth
Launch	October 18, 2001 on a Delta II
Launch site	Vandenberg Air Force Base
Mission duration	5 years
Mass	1018 kg (launch)
Orbital elements	
Semimajor Axis	6828 km
Inclination	98 degrees
Orbital Period	93.4 minutes
Instruments	
Visible cameras	60 cm panchromatic 2.4 meter multispectral

QuickBird is a high-resolution commercial earth observation satellite, owned by DigitalGlobe and launched in 2001 as the first satellite in a constellation of three scheduled to be in orbit by 2008. QuickBird uses Ball Aerospace's Global Imaging System 2000 (BGIS 2000) that collects the fourth highest resolution commercial imagery of Earth after WorldView-1, WorldView-2 and GeoEye-1 and boasts the largest image size and the greatest on-board storage capacity of any satellite. The satellite collects panchromatic (black & white) imagery at 60-70 centimeter resolution and multispectral imagery at 2.4- and 2.8-meter resolutions.

At this resolution, detail such as buildings and other infrastructure are easily visible. However, this resolution is insufficient for working with smaller objects such as a license plate on a car. The imagery can be imported into remote sensing image processing software, as well as into GIS packages for analysis. The imagery can also be used as a backdrop for mapping applications, such as Google Earth and Google Maps.

- Launch Date: October 18, 2001
- Launch Window: 1851-1906 GMT (1451-1506 EDT)
- Launch Vehicle: Delta II
- Launch Site: SLC-2W, Vandenberg Air Force Base, California
- USAF Designation: Quickbird 2

Contractors include Ball Aerospace & Technologies, Kodak and Fokker Space.

QuickBird I

The first QuickBird was launched in November 2000, by EarthWatch from the Plesetsk Cosmodrome in Russia. QB-1 failed to reach planned orbit and was declared a failure.

Specifications

Sensors

- 60 cm (24 in) (1.37 μrad) panchromatic at nadir
- 2.4 m (7 ft 10 in) (5.47 μrad) multispectral at nadir
    - MS Channels: blue (450-520 nm), green (520-600 nm), red (630-690 nm), near-IR (760-900 nm)

Swath width and area size

- Nominal swath width: 16.5 km at nadir
- Accessible ground swath: 544 km centered on the satellite ground track (to 30° off nadir)
- Area of interest
    - Single area: 16.5 km by 16.5 km
    - Strip: 16.5 km by 165 km

Orbit

- Altitude: 450 km – 98 degree sun synchronous inclination
- Revisit frequency: 1 to 3.5 days depending on latitude at 60 cm resolution
- Viewing angle: Agile spacecraft, in-track and cross-track pointing
- Period 93.4 minutes

Onboard storage

- 128 Gigabit capacity (approximately 57 single area images)

Spacecraft

- Fueled for 7 years
- 2100 lb (950 kg), 3.04 m (10 ft) in length

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°, and completing 14 + 5/26 revolutions per day.

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^2 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 µm). 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 μm)
- Blue (450 – 525 μm)
- Green (530 – 590 μm)
- Red (625 – 695 μm)
- Near-infrared (760 – 890 μm)

- Footprint: 60 km x 60 km
- Responsive satellite tasking, with 6 tasking plans per day, per satellite
- Capacity to acquire up to 3 million km^2. daily
- Launches scheduled in 2012 and 2013

Disaster Monitoring Constellation

The **Disaster Monitoring Constellation** (**DMC**) consists of a number of remote sensing satellites constructed by Surrey Satellite Technology Ltd (SSTL) and operated for the Algerian, Nigerian, Turkish, British and Chinese governments by DMC International Imaging. The DMC provides emergency Earth imaging for disaster relief under the International Charter for Space and Major Disasters, which the DMC formally joined in November 2005. Other DMC Earth imagery is used for a variety of civil applications by a variety of governments. Spare available imaging capacity is sold under contract.

The DMC provides far larger areas of imagery than, but at comparable resolution to, established government imaging satellites such as Landsat. DMC imagery was deliberately designed to be comparable to Landsat imagery, in order to leverage the expertise and software of the large established remote sensing community used to working with Landsat images. Imagery can be provided far more rapidly from the DMC than from Landsat, thanks to having multiple similar satellites in orbit ready to cross over a point of interest, and the larger images produced. This brings the responsiveness that is needed for emergencies and for disaster support, with images provided across the Internet from the responsive satellite and a member country's ground station within a day or less of a request being made.

The DMC has monitored the effects and aftermath of the Indian Ocean Tsunami (December 2004), Hurricane Katrina (August 2005), and many other floods, fires and disasters.

The individual DMC satellites are:

First Generation

- AlSAT-1 (Algeria), launched November 2002, which completed its mission in August 2010.
- BilSAT (Turkey), launched September 2003, which completed its mission in August 2006 due to failed battery cells
- NigeriaSAT-1 (Nigeria), launched September 2003.
- UK-DMC (United Kingdom), launched September 2003.

Second Generation

- Beijing-1 (China), launched October 2005.
- UK-DMC 2 (United Kingdom), launched July 2009.
- Deimos-1 (Spanish commercial), launched July 2009.
- NigeriaSAT-2 and NigeriaSAT-X (NX), planned to launch in late 2010.

The sun-synchronous orbits of these satellites are coordinated so that the satellites follow each other around an orbital plane, ascending north over the Equator at 10:15 am local time (and 10:30 am local time for Beijing-1).

Some of these satellites also include other imaging payloads and experimental payloads: onboard hardware-based image compression (on BilSAT), a GPS reflectometry experiment and onboard Internet router (on the UK-DMC satellite). The DMC satellites are notable for communicating with their ground stations using the Internet Protocol for payload data transfer and command and control, so extending the Internet into space, and allowing experiments with the Interplanetary Internet to be carried out. Many of the technologies used in the design of the DMC satellites, including Internet Protocol use, were tested in space beforehand on SSTL's earlier UoSAT-12 satellite.

SSTL is building more DMC satellites for Nigeria.

Chapter- 4

Other Earth Observation Satellites

TerraSAR-X

TerraSAR-X, a German Earth observation satellite, is a joint venture being carried out under a public-private-partnership between the German Aerospace Center DLR and EADS Astrium GmbH; the exclusive commercial exploitation rights are held by the geo-information service provider Infoterra GmbH. TerraSAR-X was launched on June 15, 2007 and has been in operational service since January 2008. Following the launch of a second sister satellite, TanDEM-X in early 2010, the two satellites act as a pair.

Satellite and Mission

Launch date	June 15, 2007
Carrier rocket	Dnepr rocket
Launch site	Baikonur Cosmodrome, Kazakhstan
Satellite mass	1230 kg
Satellite size	5m height by 2,4 m diameter
Type	Low Earth Orbit
Altitude	514 km (319 mi)
Inclination	97,44°
Radar Frequency	9,65 GHz
Repeat cycle	94,92 minutes

With its active phased array X-band SAR antenna (wavelength 31 mm, frequency 9.6 GHz), TerraSAR-X acquires new high-quality radar images of the entire planet whilst circling Earth in a polar orbit at 514 km altitude. The orbit is selected such that the satellite flies in a sun-synchronous dusk-dawn orbit, which means that it moves along the day-night boundary of the Earth and always presents the same face to the sun, ensuring an optimum energy supply via the solar cells. TerraSAR-X is designed to carry out its task for five years, independent of weather conditions and illumination, and reliably provides radar images with a resolution of up to 1m.

Features of TerraSAR-X:

- resolution of up to 1m,
- excellent radiometric accuracy,
- geometric accuracy unrivalled by any other commercial spaceborne sensor,
- quick site access time of 2.5 days max. (2 days at 95% probability) to any point on Earth,
- unique agility (rapid switches between imaging modes and polarisations)

TerraSAR-X Imaging Modes

TerraSAR-X acquires radar data in the following three main imaging modes:
SpotLight: up to 1m resolution, scene size 10 km (width) x 5 km (length)
StripMap: up to 3m resolution, scene size 30 km (width) x 50 km (length*)
ScanSAR: up to 18 m resolution, scene size 100 km (width) x 150 km (length*)
(*StripMap & ScanSAR: acquisition length extendable to up to 1,650 km.)

In addition, the unique design of TerraSAR-X's SAR antenna allows a variety of **polarimetric combinations**: single or dual polarization and even full polarimetric data takes, are possible.

Depending on the desired application, one of **four different product types** (processing levels) can be selected

- Single Look Slant Range Complex (SSC)
- Multi Look Ground Range Detected (MGD)
- Geocoded Ellipsoid Corrected (GEC)
- Enhanced Ellipsoid Corrected (EEC)

Advantages of radar technology

RADAR stands for *Radio Detection and Ranging* and contains traditionally:

- Range finding (EDM) by means of the time a reflected signal needs to return;
- Direction measurement over the adjustment of the antenna, and recently;
- also different analysis such as SAR, polarization, Interferometry etc.

Satellites with radar technology are still relatively new compared to optical camera systems. The resolution (detail sharpness) is in principle lower, but radar has other advantages: radar is independent of illumination and weather conditions, so that acquisitions can be made at any time of the day or night and independent of cloud coverage. This contributes significantly to the reliability of the system a property that is required by many applications and users.

Early radar satellite techniques were e.g. the Altimetrie (leveling over the sea), NASA's SEASAT (launched in 1978), regulation of waves/wind or soil data. Nowadays we can measure for instance the speed of other satellites to mm/sec exactly (GRACE), and the slow deformation of volcanos. The military has used radar since the late 1930s and RADAR satellites at least since since 1978.

Innovations with TerraSAR X

TerraSAR X will exhibit some technical-industrial novelties. One of these innovations is a kind of zoom shot, with the resolution and scanning field vice versa changeable in a 1:10 relationship, either a larger area to grasp or a small area with the highest possible resolution.

Furthermore the antenna can be aligned by electronics within an angle range so that the point of view is adjustable. Earlier radar satellites could radiate the antenna only in one direction.

Scanning and trajectory

With the adjustable angle radar sensor - along with other course refinements (precession by the earth flattening) - any place on earth can be observed preferentially within 1–3 days.

For a specific point on the Earth's equator, TerraSAR X has a revisit cycle of 11 days. The revisit time decreases towards the poles, e.g. northern Europe has a revisit time of typically 3–4 days.

Ground segment

The ground operating mechanism and controls for the TerraSAR X is developed by the DLR in Oberpfaffenhofen. It consists of Mission Operating Equipment, the Payload Ground Segment and the Instrument Operation and Calibration Segment. At the base of the ground segment lies the German Space Operation Center (GSOC), the German Remote Sensing Datum Center (DFD) as well as Institutes for Methodology of Remote Sensing (MF) and the Institute for High-Frequency Engineering and Radar Systems (HR) which are all part of the DLR.

Applications

Applications of the high-resolution TerraSAR-X radar imagery include:

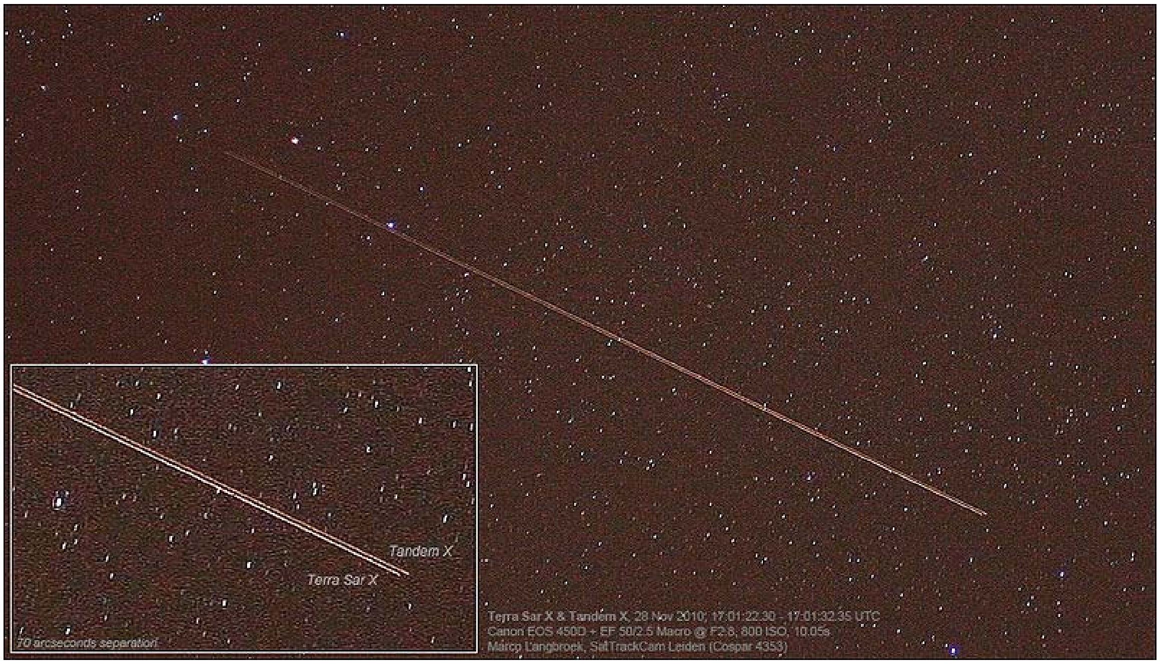
- **Topographic Mapping:** 2D and 3D, in scales down to 1:25,000, map updates
- **Surface Movement:** Based on timeseries acquired by TerraSAR-X over the same area surface displacements caused by subsurface mining, oil-/gas extraction, infrastructure construction, excavations, or underground engineering can be visualised.
- **Change Detection:** for the monitoring of large-scale construction projects, infrastructure networks, monitoring and documentation of changes and developments
- **Land Cover and Land Use Mapping:** accurate and up-to-date land cover / land use informations, also from places, where it is difficult to get informations with using other technologies because of permanent cloud cover
- **Defence and Security Applications:** Applications include effective mission planning, the quick assessment of natural or manmade disasters or border control through detection of paths (changes), fences and moving objects
- **Rapid Emergency Response:** due to its rapid revisit time TerraSAR-X is a reliable source of information in case of natural or man-made disasters (e.g. earth quakes, floods, military conflicts etc.) providing reliable information for disaster management and response allowing the recognition and assessment of damages to populated areas and traffic infrastructure, the identification of focus areas, and an efficient coordination of rescue actions.
- **Environmental applications:** e.g. forest monitoring, flood monitoring, water quality applications
- **Further applications** currently under evaluation: Traffic Monitoring, Maritime applications, vegetation monitoring

Scientific use of TerraSAR-X data

The scientific use of the TerraSAR-X data will be coordinated through the TerraSAR-X Science Service System by the DLR. The new-quality data records, as provided by TerraSAR-X, will offer a vast amount of new research incentives, for instance in ecology, geology, hydrology and oceanography. The smallest movements of the Earth's surface (plate tectonics, volcanism, earthquake) are further scientific fields of application.

Commercial use of TerraSAR-X data

In order to ensure the commercial success of the mission, Astrium GmbH founded its 100% subsidiary Infoterra GmbH in 2001; the company being responsible for establishing a commercial market for TerraSAR-X data as well as TerraSAR-X-based geo-information products and services.



The radar remote sensing satellites TanDEM X and Terra SAR X photographed while flying in close formation (photo by Marco Langbroek, Leiden, the Netherlands). Movement is from lower right to upper left in this 10 second exposure.

The future

TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurements) is a second, very similar spacecraft launched successfully on June 21, 2010 from Baikonur Cosmodrome in Kazakhstan. Since October of 2010, TerraSAR-X and TanDEM-X fly in a close formation at distances of only a few hundred metres and record data synchronously. This unique twin satellite constellation will allow the generation of global digital elevation models (DEMs) of an unprecedented accuracy, coverage and quality –a consistent DEM of the Earth's land surface is envisaged to be acquired and generated within three years after launch. This DEM is to feature a vertical accuracy of 2m (relative) and 10m (absolute), within a horizontal raster of approximately 12x12 square meters, slightly varying depending on the geographic latitude.

COSMO-SkyMed

COSMO-SkyMed (**CO**nstellation of small **S**atellites for the **M**editerranean basin **O**bservation) is an Earth observation satellite system funded by the Italian Ministry of Research and Ministry of Defence and conducted by the Italian Space Agency (ASI), intended for both military and civilian use.

The space segment of the system will include four medium-sized satellites equipped with synthetic aperture radar (SAR) sensors with global coverage of the planet. Observations of an area of interest will be repeated several times a day in all-weather conditions. The imagery will be applied to defense and security assurance in Italy and other countries, seismic hazard analysis, environmental disaster monitoring, and agricultural mapping.

Space segment

The four satellites are planned for sun-synchronous polar orbits, phased at 90° and at an altitude of 619 km with an orbit of 97 minutes. The expected operating life of each satellite is estimate in 5 years.

The satellites main components are:

- Two solar array for 3.8 kW at 42 V DC
- Stabilization, navigation and GPS systems
- Synthetic aperture radar working in X band
- 300 Gbit on-board memory and 310 Mbit/s data-link with ground segments

Launch

United Launch Alliance is providing launch services for the first three satellites. Satellite processing for the first two satellites was handled by the Astrotech Space Operations subsidiary of SPACEHAB. The first satellite was launched at 22:34 GMT, on 8 June 2007, aboard a Delta II 7420-10 rocket from Vandenberg AFB. An identical rocket launched COSMO-2 at 02:31:42 GMT on 9 December 2007, the launch having been delayed from 6 December due to bad weather, and problems with the rocket's cork insulation. COSMO-3 launched at 02:38 GMT on 25 October 2008, also aboard a Delta II 7420-10. A Delta II flying in the 7420-10 configuration will also be used to launch COSMO-4. Launched from Vandenberg Air Force Base on November 5, 2010 at 1920L.

Ground segment

The ground segment of the system is composed by:

- Command Center:
  - Italian Centro Controllo e Pianificazione Missione del Fucino
- Tracking and data stations:

    - Argentinian Cordoba station
    - Sweden Kiruna station
- User Ground Segments:
    - Italian Matera Civil User Ground Segment
    - Italian Pratica di Mare Defence User Ground Segment
    - France Defence User Ground Segment

The Argentinian and the France government are involved respectively in the civil and in the military segment of the system.

Flares

The COSMO-SkyMed satellites are lesser-known deliverers of satellite flares, sometimes approaching magnitude -2. Although overshadowed by the Iridium satellites, the flares are often long-lasting, with the satellites traversing much of the sky at brighter-than-average magnitudes.

WorldView-1

	WorldView-1
Organization	DigitalGlobe
Mission Type	Earth observation
Contractor	Ball Aerospace & Technologies
Satellite of	Earth
Launch	September 18, 2007 on a Delta II
Launch site	Vandenberg Air Force Base
Mission duration	7.25 years
Mass	2,500 kg (launch)
Orbital elements	
Semimajor Axis	0000 km
Inclination	97.2 degrees
Orbital Period	94.6 minutes
Instruments	
Visible camera	50 cm panchromatic

WorldView-1 is a commercial earth observation satellite owned by DigitalGlobe. It was launched September 18, 2007, and DigitalGlobe plans to launch another, similar satellite after its construction is finished in late 2008. First imagery from WorldView-1 is expected to be available prior to October 18, the six-year anniversary of the launch of QuickBird, DigitalGlobe's current satellite.

WorldView-1, was built by Ball Aerospace & Technologies. Ball Aerospace built the spacecraft bus and the camera (instrument) using the off-axis camera design identical to QuickBird with the instrument's focal plane being supplied by ITT Corporation. The camera is a panchromatic imaging system featuring half-meter resolution imagery. With an average revisit time of 1.7 days, WorldView-1 is capable of collecting up to 750,000 square kilometers (290,000 square miles) per day of half-meter imagery.

WorldView-1 was partially financed through an agreement with the National Geospatial-Intelligence Agency (NGA). Some of the imagery captured by WorldView-1 for the NGA will not be available to the general public. However, WorldView-1 will free capacity on DigitalGlobe's QuickBird satellite to meet the growing commercial demand for multi-spectral geospatial imagery.

- Launch Date: September 18, 2007
- Launch Time: 1835 GMT (2:35 p.m. EDT)
- Launch Vehicle: Delta II
- Launch Site: Vandenberg Air Force Base, California

WorldView-2

	WorldView-2
Organization	DigitalGlobe
Mission Type	Earth observation
Contractor	Ball Aerospace & Technologies
Satellite of	Earth
Launch	October 8, 2009 on a Delta II
Launch site	Vandenberg Air Force Base
Mission duration	7.25 years
Mass	2,800 kg (6,200 lb)
Orbital elements	
Altitude	770 kilometers
Inclination	97.2 degrees
Orbital Period	100 minutes
Instruments	

WorldView-2 is a commercial Earth observation satellite owned by DigitalGlobe. WorldView-2 provides commercially available panchromatic imagery of .5 m resolution, and eight-band multispectral imagery with 1.8 m (5 ft 11 in) resolution. It was launched October 8, 2009 to become DigitalGlobe's third satellite in orbit, joining WorldView-1 which was launched in 2007 and QuickBird which was launched in 2001.

Design and construction

Ball Aerospace built the spacecraft, which includes an optical telescope that can image objects 18 in (460 mm) in diameter.

Launch

WorldView-2 was launched October 8, 2009 from Vandenberg Air Force Base on a Delta II flying in the 7920 configuration. The launch vehicle was provided by the United Launch Alliance and launch services were administered by Boeing.

Use

DigitalGlobe expects commercial imagery will be available about 90 days after launch.

GeoEye-1

GeoEye-1 is a high-resolution earth observation satellite owned by GeoEye, which was launched in September 2008.

History

On December 1, 2004, General Dynamics C4 Systems announced it had been awarded a contract worth approximately $209 million to build the OrbView-5 satellite. Its sensor is designed by the ITT Corporation.

The satellite, now known as GeoEye-1, was originally scheduled for April 2008 but lost its 30-day launch slot to a U.S. government mission which had been delayed. It was rescheduled for launch August 22, 2008 from Vandenberg Air Force Base aboard a Delta II launch vehicle. The launch was postponed to September 4, 2008, due to unavailability of the Big Crow telemetry-relay aircraft. It was delayed again to September 6 because Hurricane Hanna interfered with its launch crews.

The launch took place successfully on September 6, 2008 at 11:50:57 a.m. PDT (1850:57 UTC). The GeoEye-1 satellite separated successfully from its Delta II launch vehicle at 12:49 p.m. PDT (1949 UTC), 58 minutes and 56 seconds after launch.

Specifications and operation

Specifications	
Mass at launch	1,955 kg (4,310 lb)
Bus mass	1,260 kg (2,800 lb)
Solar panels	GaAs, 3862W at the end of the life.
Data Downlink	150 or 740 Mbps, X-Band.
Aperture	1.1 m (3.6 ft)
Focal length	13.3 m (44 ft)
Field of View	more than 1.28°
Design lifetime	7 years in orbit, fully redundant.

GeoEye-1 provides 41 cm (16 in) panchromatic and 1.65 m (5.4 ft) multispectral imagery in 15.2 km (9.4 mi) swaths. The spacecraft is intended for a sun-synchronous orbit at an altitude of 684 km (425 mi) and an inclination of 98 degrees, with a 10:30 a.m. equator crossing time. GeoEye-1 can image up to 60 degrees off nadir. It is operated out of Dulles, Virginia.

At the time of its launch, GeoEye-1 was the world's highest resolution commercial earth-imaging satellite. GeoEye-1 was manufactured in Gilbert, Arizona by General Dynamics and launched from Vandenberg Air Force Base in California. The first image was returned on October 7, of Kutztown University in Pennsylvania.

Google, which has its logo on the side of the rocket, has exclusive online mapping use of its data. While GeoEye-1 is capable of imagery with details the size of 41 cm (16 in), that resolution will only be available to the US government. Google will have access to details of 50 cm (20 in). Prior maximum commercial imagery was 60 centimetres (24 in).

The National Geospatial-Intelligence Agency and Google both paid $502 million for the satellite and upgrades to GeoEye's four ground stations.

2009 Anomaly

In December 2009 GeoEye announced it had suspended imagery collections by GeoEye-1 for a few days, citing an irregularity in the downlink antenna. "The irregularity appears to limit the range of movement of GeoEye-1's downlink antenna, which may in turn affect GeoEye-1's ability to image and downlink simultaneously," GeoEye said.

Chapter- 5

Earth Observing System

The **Earth Observing System** (**EOS**) is a program of NASA comprising a series of artificial satellite missions and scientific instruments in Earth orbit designed for long-term global observations of the land surface, biosphere, atmosphere, and oceans of the Earth. The satellite component of the program was launched in 1997. The program is centerpiece of NASA's Earth Science Enterprise (ESE).

Aqua (satellite)

Aqua

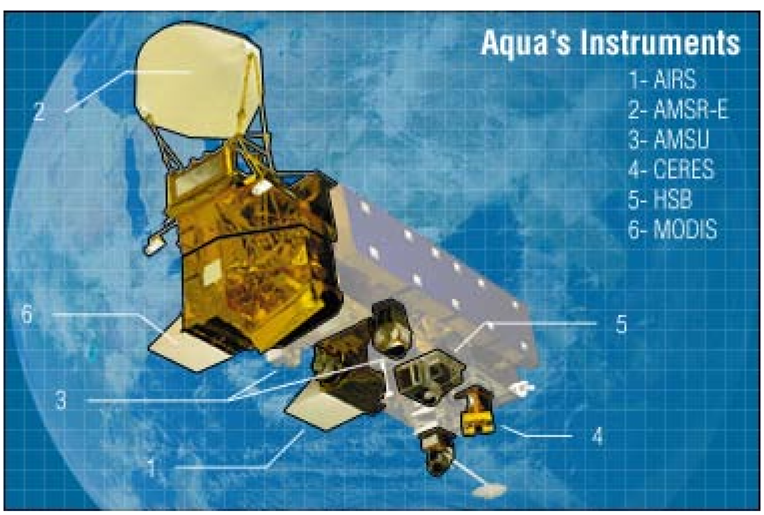
Aqua (EOS PM-1)

Operator	NASA
Satellite of	**Earth**
Launch date	May 4, 2002
Launch vehicle	Delta II
Launch site	Vandenberg AFB
Mission duration	Planned 6 Year Mission
COSPAR ID	2002-022A
Mass	3,117 kg (6,872 lb)

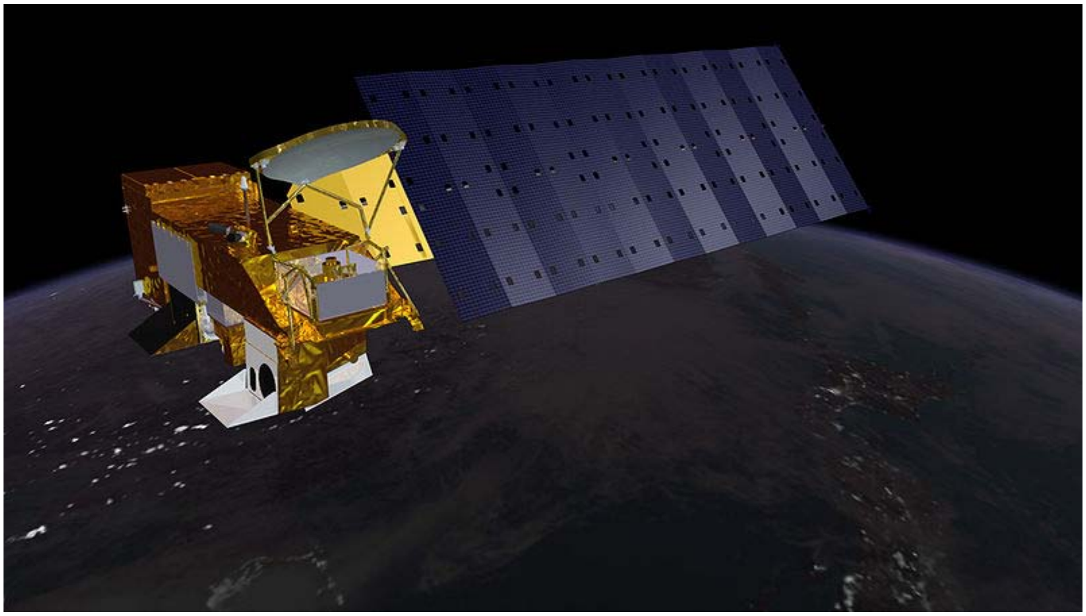
Power	4444 W
	Orbital elements
Regime	LEO
Semimajor axis	7077.75 km
Eccentricity	0.001203
Inclination	98.14°
Apoapsis	708 km (440 mi)
Periapsis	691 km (429 mi)
Orbital period	98.4 minutes
Longitude	N/A
Orbits per day	14.5625

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).

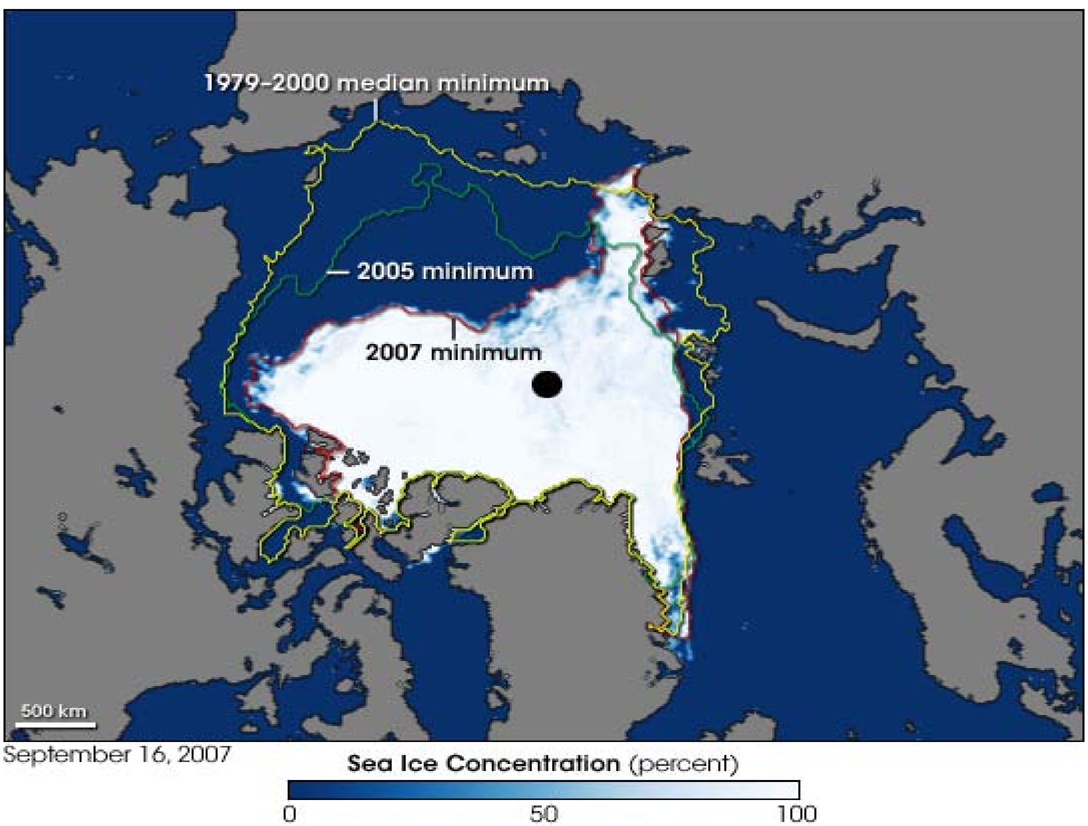
The name "Aqua" comes from the Latin word for water. The satellite was launched from Vandenberg Air Force Base on May 4, 2002, aboard a Delta II rocket. Aqua is on a Sun-synchronous orbit. It flies leading the satellite formation called the "A Train" with several other satellites (Aura, CALIPSO, CloudSat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



Aqua (EOS PM-1)



The Aqua satellite



An image of Arctic shrinkage from Aqua observations

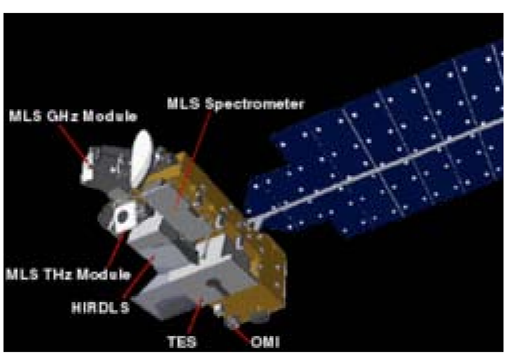
Aqua carries six instruments for studies of water on the Earth's surface and in the atmosphere:

- 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.

Aura (satellite)

Aura



Aura (EOS CH-1)

Operator	NASA

Mission type	Earth Observation
Satellite of	**Earth**
Launch date	July 15, 2004 10:02:00 UTC
Launch vehicle	Delta II
Launch site	Vandenberg AFB
COSPAR ID	2004-026A
Mass	2,970 kg (6,550 lb)
Power	4.6 kW
	Orbital elements
Eccentricity	0.00028312
Inclination	98.2°
Apoapsis	688 km (428 mi)
Periapsis	684 km (425 mi)
Orbital period	98.5 minutes

Aura (EOS CH-1) is a multi-national NASA scientific research satellite in orbit around the Earth, studying the Earth's ozone layer, air quality and climate. It is the third major component of the Earth Observing System (EOS) following on Terra (launched 1999) and Aqua (launched 2002). Aura follows on from the Upper Atmosphere Research Satellite (UARS).

The name " Aura" comes from the Latin word for air. The satellite was launched from Vandenberg Air Force Base on July 15, 2004 aboard a Delta II 7920-10L rocket. Aura flies in formation with the "A Train", a collection of several other satellites (Aqua, CALIPSO, CloudSat and the French PARASOL), in a sun-synchronous orbit, the satellites having an equatorial crossing time in the afternoon.

Aura carries four instruments for studies of atmospheric chemistry:

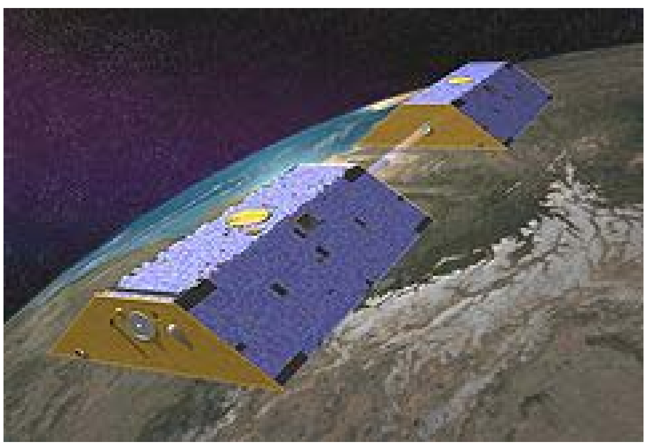
- HIRDLS — High Resolution Dynamics Limb Sounder — measures infrared radiation from ozone, water vapor, CFCs, methane and nitrogen compounds. Developed jointly with the United Kingdom Natural Environment Research Council. The HIRDLS chopper shutdown on March 17, 2008 and has not produced science since.
- MLS — Microwave Limb Sounder — measures emissions from ozone, chlorine and other trace gases, and clarifies the role of water vapor in global warming.

- OMI — Ozone Monitoring Instrument — uses ultraviolet and visible radiation to produce daily high-resolution maps. Developed by the Finnish Meteorological Institute and the Netherlands Agency for Aerospace Programmes.
- TES — Tropospheric Emission Spectrometer — measures tropospheric ozone in infrared wavelengths, also carbon monoxide, methane and nitrogen oxides.

The Aura spacecraft has a mass of about 1,765 kg. The body is 6.9 m long with the extended single solar panel about 15 m.

Gravity Recovery and Climate Experiment

Gravity Recovery and Climate Experiment (GRACE)



Artist's concept of the twin GRACE satellites

Operator	NASA and German Aerospace Center (DLR)
Major contractors	Space Systems/Loral and Astrium GmbH
Mission type	Earth Orbiter
Launch date	March 17, 2002
Launch vehicle	Three-stage Rockot from Plesetsk Cosmodrome, Russia
Mission duration	Five-year primary mission extended

COSPAR ID	2002-012A
Homepage	GRACE
Mass	487 kilograms (1,074 lb) each
Power	Solar

The **Gravity Recovery And Climate Experiment** (GRACE), a joint mission of NASA and the German Space Agency, has been making detailed measurements of Earth's gravity field since its launch in March 2002.

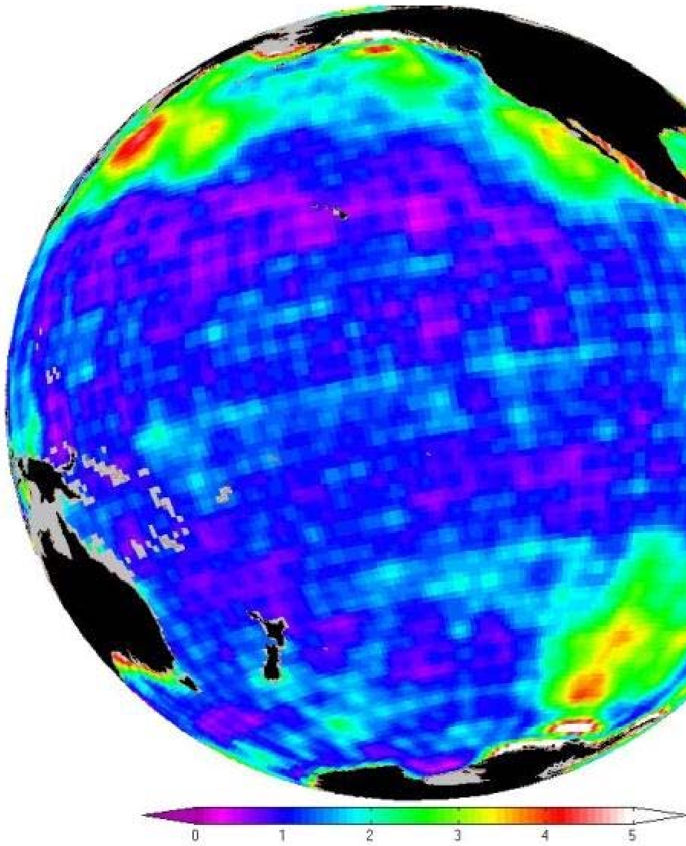
Gravity is determined by mass. By measuring gravity, GRACE shows how mass is distributed around the planet and how it varies over time. GRACE data are important tools for studying Earth's ocean, geology, and climate.

GRACE is a collaborative endeavor involving the Center for Space Research at the University of Texas, Austin; NASA's Jet Propulsion Laboratory, Pasadena, Calif.; the German Space Agency and Germany's National Research Center for Geosciences, Potsdam. The Jet Propulsion Laboratory is responsible for the overall mission management under the NASA ESSP program.

The principal investigator is Dr. Byron Tapley of the University of Texas Center for Space Research, and the co-principal investigator is Dr. Christoph Reigber of the GeoForschungsZentrum (GFZ) Potsdam.

The GRACE satellites were launched from Plesetsk Cosmodrome, Russia on a Rockot (SS-19 + Breeze upper stage) launch vehicle, on March 17, 2002.

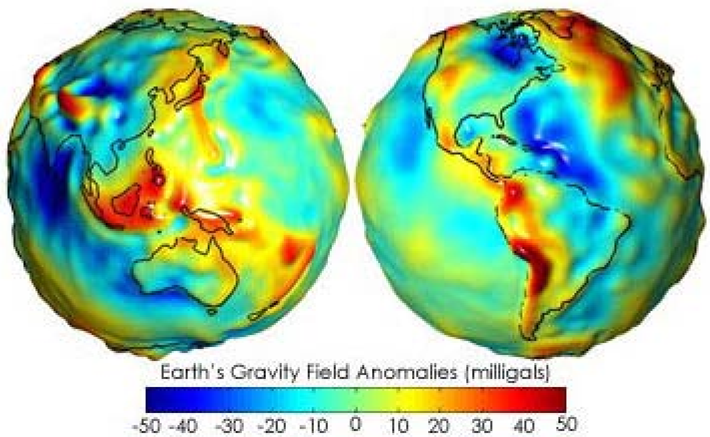
Discoveries and applications



Variations in ocean bottom pressure measured by GRACE

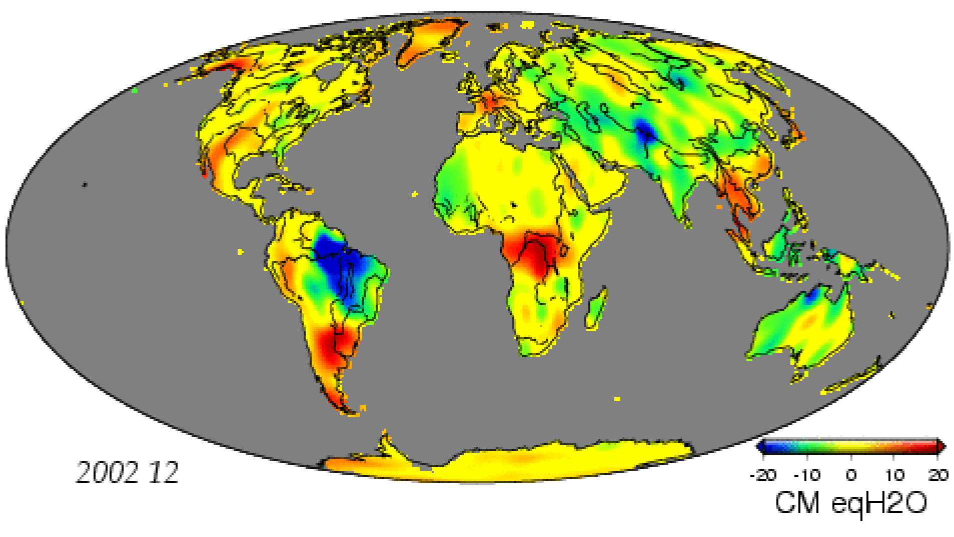
The monthly gravity maps generated by Grace are up to 1,000 times more accurate than previous maps, substantially improving the accuracy of many techniques used by oceanographers, hydrologists, glaciologists, geologists and other scientists to study phenomena that influence climate.

From the thinning of ice sheets to the flow of water through aquifers and the slow currents of magma inside Earth, measurements of the amount of mass involved provided by GRACE help scientists better understand these important natural processes.

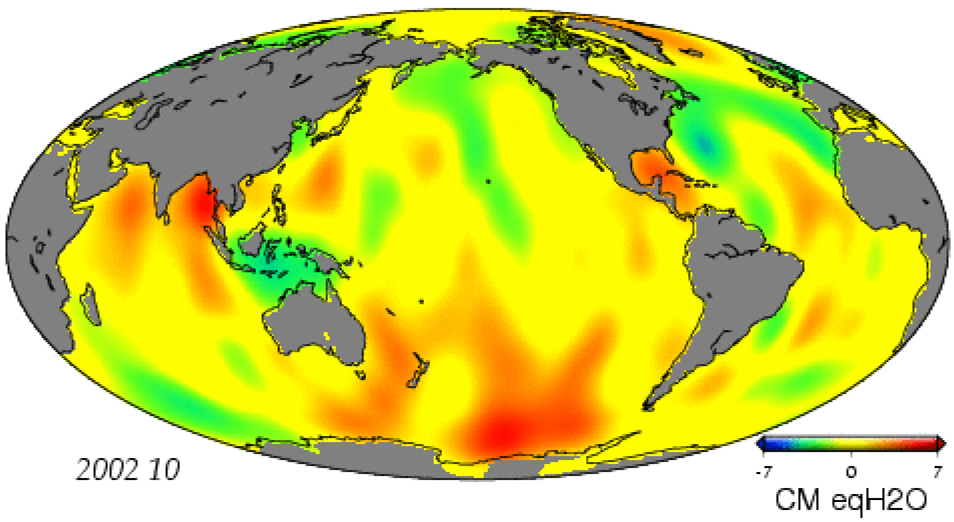


Gravity anomaly map from GRACE

Among the first important applications for GRACE data was to improve the understanding of global ocean circulation. The hills and valleys in the ocean's surface are due to currents and variations in Earth's gravity field. GRACE enables separation of those two effects to better measure ocean currents and their effect on climate. GRACE data are also critical in helping to determine the cause of sea level rise, whether it is the result of mass being added to the ocean, from melting glaciers, for example, or from thermal expansion of warming water or changes in salinity.



Global Gravity Anomaly



Global Gravity Anomaly

The data so far obtained by GRACE are the most precise gravimetric data yet recorded: they have been used to re-analyse data obtained from the LAGEOS experiment to try to measure the relativistic frame-dragging effect. In 2006, a team of researchers led by Ralph von Frese and Laramie Potts used GRACE data to discover the 480-kilometer (300-mile) wide Wilkes Land crater in Antarctica, which probably formed about 250 million years ago. GRACE has been used to map the hydrologic cycle in the Amazon River basin and the location and magnitude of post-glacial rebound from changes in the free air gravity anomaly. GRACE data have also been used to analyze the shifts in the Earth's crust caused by the earthquake that created the 2004 Indian Ocean tsunami. Scientists have recently developed a new way to calculate ocean bottom pressure—as important to oceanographers as atmospheric pressure is to meteorologists—using GRACE data.

How GRACE works

GRACE is the first Earth-monitoring mission in the history of space flight whose key measurement is not derived from electromagnetic waves either reflected off, emitted by, or transmitted through Earth's surface and/or atmosphere. Instead, the mission uses a microwave ranging system to accurately measure changes in the speed and distance between two identical spacecraft flying in a polar orbit about 220 kilometers (137 miles) apart, 500 kilometers (311 miles) above Earth. The ranging system is so sensitive it can detect separation changes as small as 10 micrometres (about one-tenth the width of a human hair) over a distance of 220 kilometers.

As the twin GRACE satellites circle the globe 16 times a day, they sense minute variations in Earth's gravitational pull. When the first satellite passes over a region of slightly stronger gravity, a gravity anomaly, it is pulled slightly ahead of the trailing satellite. This causes the distance between the satellites to increase. The first spacecraft then passes the anomaly, and slows down again; meanwhile the following spacecraft accelerates, then decelerates over the same point.

By measuring the constantly changing distance between the two satellites and combining that data with precise positioning measurements from Global Positioning System (GPS) instruments, scientists can construct a detailed map of Earth's gravity.

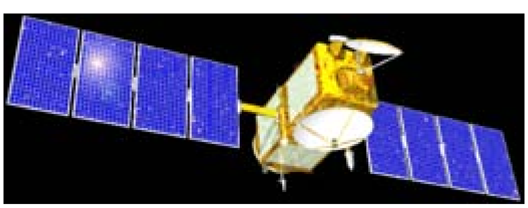
The two satellites (nicknamed "Tom" and "Jerry") constantly maintain a two-way microwave-ranging link between them. Fine distance measurements are made by comparing frequency shifts of the link. As a cross-check, the vehicles measure their own movements using accelerometers. All of this information is then downloaded to ground stations. To establish baseline positions and fulfill housekeeping functions, the satellites also use star cameras, magnetometers, and GPS receivers. The GRACE vehicles also have optical corner reflectors to enable laser ranging from ground stations, bridging the range between spacecraft positions and Doppler ranges.

Spacecraft

The spacecraft were manufactured by Astrium of Germany, using its "Flexbus" platform. The microwave RF systems, and attitude determination and control system algorithms were provided by Space Systems/Loral. The star cameras used to measure the spacecraft attitude were provided by Technical University of Denmark. The instrument computer along with a highly precise BlackJack GPS receiver and digital signal processing system has been provided by JPL in Pasadena. The highly precise accelerometer that is needed to separate atmospheric and solar wind effects from the gravitation data was manufactured by ONERA.

Jason-1

Jason-1



Artist's interpretation of the Jason-1 satellite

Operator	NASA, CNES

Mission type	Earth orbiter
Launch date	2001
Launch vehicle	Delta II
Mission duration	three years, now on extended mission
Homepage	Ocean Surface Topography from Space
	Orbital elements
Orbital period	6754.0s

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.

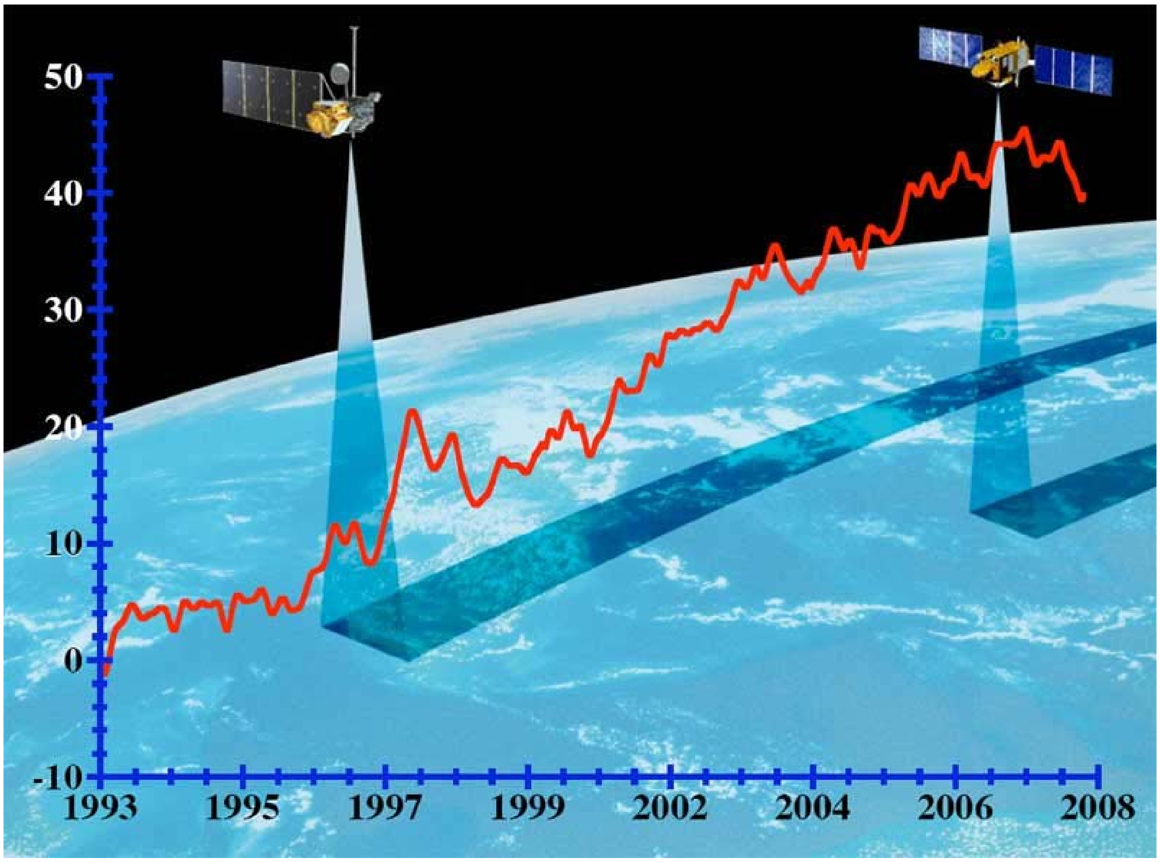
Use of information

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 knowl¬edge 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.

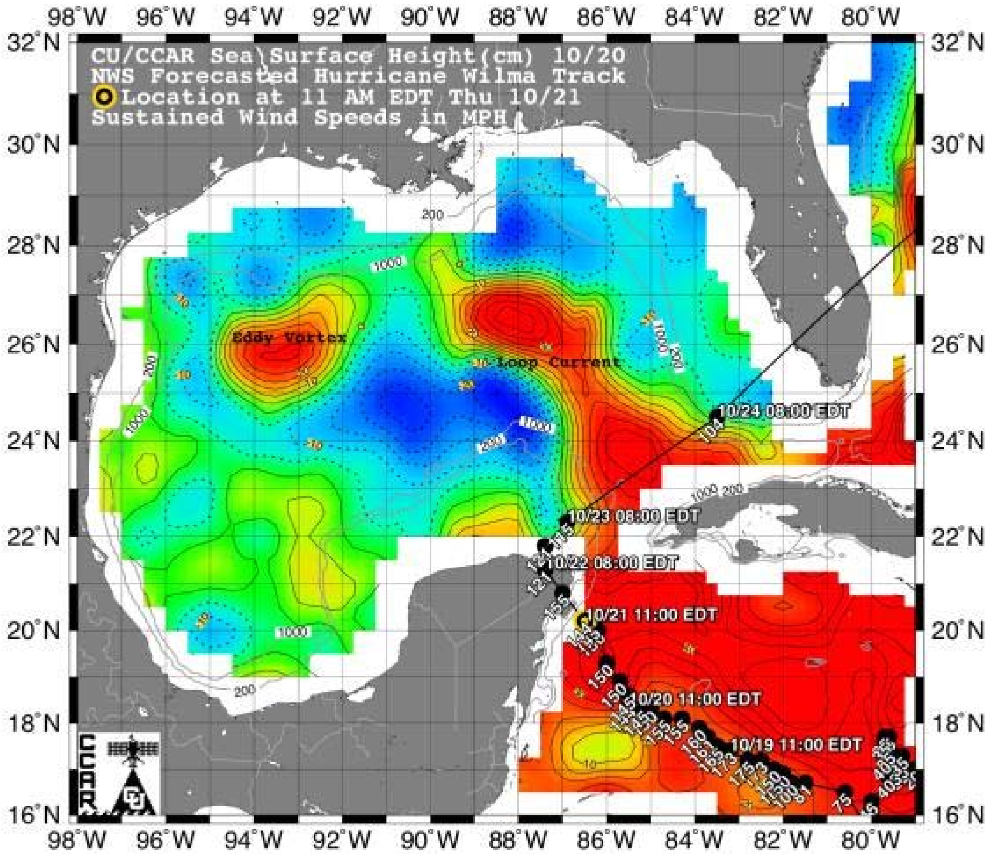
TOPEX/Poseidon and Jason-1 data are available at the University of Colorado Center for Astrodynamics Research, NASA's Physical Oceanography Distributed Active Archive Center, and the French data archive center AVISO.

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.

Orbiting Carbon Observatory

Orbiting Carbon Observatory

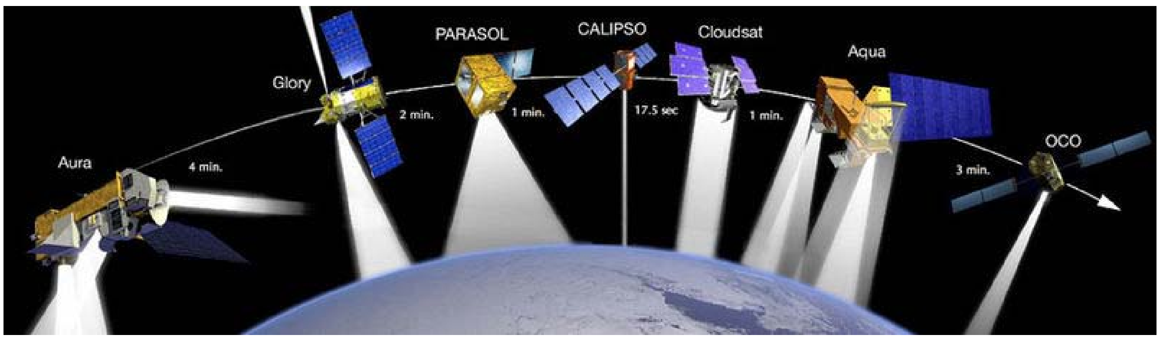
Artist rendition of the OCO satellite as it would have looked in orbit

Mission type	Climatology
Launch date	2009-02-24, 09:20 GMT
Carrier rocket	Taurus-XL 3110
Launch site	Vandenberg LC-576E
Mission duration	Launch failure Planned: 2 years
Orbital elements	
Regime	Sun-synchronous (planned)

The **Orbiting Carbon Observatory (OCO)** is a NASA satellite mission intended to provide global space-based observations of atmospheric carbon dioxide (CO_2). The original spacecraft was lost in a launch failure on February 24, 2009, when the payload fairing of the Taurus rocket which was carrying it failed to separate during ascent. The added mass of the fairing prevented the satellite from reaching orbit. It subsequently re-entered the atmosphere and crashed into the Indian Ocean near Antarctica. The FY 2010 NASA budget request includes US$170 million for NASA to develop and fly a replacement for the Orbiting Carbon Observatory.

Mission description

OCO's measurements would have been accurate enough to show for the first time the geographic distribution of carbon dioxide sources and sinks on a regional scale. The data would have improved the understanding of the global carbon cycle, the natural processes and human activities that influence the abundance and distribution of the greenhouse gas. This improved understanding was expected to enable more reliable forecasts of future changes in the abundance and distribution of carbon dioxide in the atmosphere and the effect that these changes may have on Earth's climate.



The A-Train satellite constellation

The OCO spacecraft was provided by Orbital Sciences Corporation. It was launched from Vandenberg Air Force Base in California on a dedicated Taurus XL rocket. However, the payload fairing — a clam shell-shaped covering that protects the satellite during launch — apparently failed to separate from the spacecraft. "We have not had a successful launch tonight and will not be able to have a successful OCO mission," NASA commentator George Diller said.

During its two-year mission, OCO would have flown in a near polar orbit which would have enabled the instrument to observe most of Earth's surface at least once every sixteen days. It would have flown in loose formation with a series of other Earth-orbiting satellites known as the Earth Observing System Afternoon Constellation, or the A-train. This coordinated flight formation was intended to enable researchers to correlate OCO data with data acquired by other instruments on other spacecraft. In particular, Earth scientists could have compared OCO data with nearly simultaneous measurements acquired by the Atmospheric Infrared Sounder (AIRS) instrument, flying on NASA's Aqua satellite.

The cost of the mission was US$280 million. It was sponsored by NASA's Earth System Science Pathfinder Program. NASA's Jet Propulsion Laboratory in Pasadena, California, manages OCO for NASA's Science Mission Directorate.

Technology

The satellite carried a single instrument that would have taken the most precise measurements of atmospheric carbon dioxide ever made from space. The instrument consisted of three parallel, high-resolution spectrometers, integrated into a common structure and fed by a common telescope. The spectrometers would have made simultaneous measurements of the carbon dioxide and molecular oxygen absorption of sunlight reflected off the same location on Earth's surface when viewed in the near-infrared part of the electromagnetic spectrum, invisible to the human eye.

As sunlight passes through Earth's atmosphere and is reflected from Earth's surface, molecules of atmospheric gases absorb very specific colors of light. If the light is divided into a rainbow of colors, called a spectrum, the specific colors absorbed by each gas appear as dark lines. Different gases absorb different colors, so the pattern of absorption lines provides a telltale spectral "fingerprint" for that molecule. OCO's spectrometers were designed to detect these molecular fingerprints.

Each of the three spectrometers was tuned to measure the absorption in a specific range of colors. Each of these ranges includes dozens of dark absorption lines produced by either carbon dioxide or molecular oxygen. The amount of light absorbed in each spectral line increases with the number of molecules along the optical path. OCO's spectrometers would have measured the fraction of the light absorbed in each of these lines with very high precision. This information was then to be analyzed to determine the number of molecules along the path between the top of the atmosphere and the surface.

If the amount of carbon dioxide varies from place to place, the amount of absorption will also vary. To resolve these variations, the observatory's instrument was to record an image of the spectrum produced by each spectrometer three times every second as the satellite flies over the surface at more than four miles per second. This information would then have been transmitted to the ground, where carbon dioxide concentrations would have been retrieved in four separate footprints for each image collected. These spatially varying carbon dioxide concentration estimates would then have been analyzed using global transport models, like those used for weather prediction, to infer the locations of carbon dioxide sources and sinks.

The OCO instrument was developed by Hamilton Sundstrand Sensor Systems in Pomona, California, and the Jet Propulsion Laboratory.

Launch data

Launch of OCO's Taurus XL rocket

- Date: February 24, 2009, 1:55 a.m. PST
- Launch Vehicle: Orbital Sciences Taurus XL
- Launch Site: Vandenberg Air Force Base – Launch Pad SLC 576-E

The OCO launch failed because the Taurus-XL launcher payload fairing failed to separate. A payload fairing is a clamshell-shaped cover that encloses and protects a payload on the pad and during early flight. Fairings are a standard component of expendable launch vehicles, and they are always jettisoned as soon as possible after a rocket has climbed high enough for heating from air friction to no longer risk damaging the payload. On this flight, the fairing should have been jettisoned several seconds after Stage 2 ignition. The extra mass of the fairing was not a significant factor during the flight of the larger lower stages, but it kept the relatively small Stage 3 from adding enough velocity to reach orbit, so the resulting sub-orbital ballistic path took the payload into the ocean near Antarctica, 17 minutes after liftoff.

The Orbital Taurus program manager John Brunschwyler said, "We could not make orbit. ... Initial indications are the vehicle did not have enough [force] to reach orbit and landed just short of Antarctica in the ocean. ... Certainly for the science community, it's a huge disappointment."

On July 17, 2009 NASA released a summary of its Mishap Investigation Board report. In the report the board provided recommendations to prevent any future problems associated with the four hardware components that could have caused the failure.

Proposed reflight

Three days after the failed February 2009 launch, the OCO science team sent NASA headquarters a proposal to build and launch an OCO "carbon copy", which planned to have the replacement satellite launched by late 2011. On February 1, 2010, the FY 2010 NASA budget request did include US$170 million for NASA to develop and fly a replacement for the Orbiting Carbon Observatory.

On June 23, 2010 NASA selected Orbital Sciences for OCO 2 to launch in February 2013 on a Taurus XL 3110 from Vandenberg Air Force Base in California.

Terra (satellite)

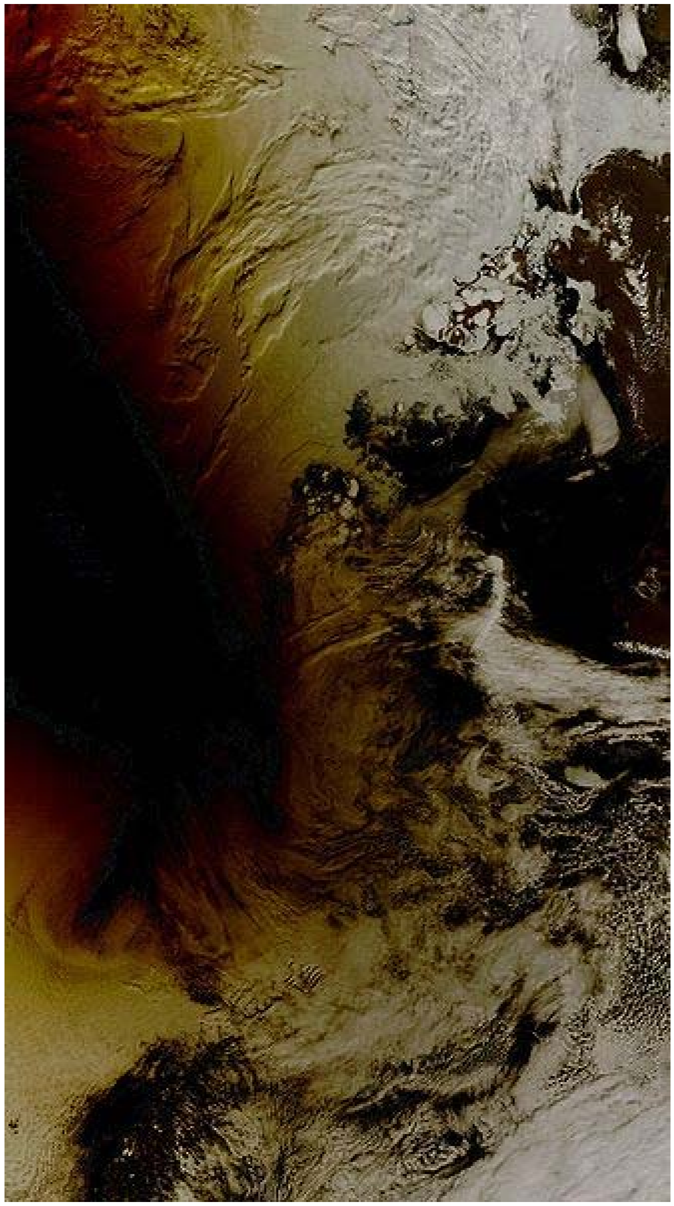
Terra (EOS AM-1)

Terra (EOS AM-1)	
Operator	NASA
Satellite of	**Earth**
Launch date	December 18, 1999
Launch vehicle	Atlas II AS
Launch site	Vandenberg AFB
COSPAR ID	1999-068A
Mass	4,864 kg (10,723 lb)
Orbital elements	
Eccentricity	0
Inclination	98.2°
Apoapsis	685 km (426 mi)
Periapsis	654 km (406 mi)
Orbital period	98.1 minutes

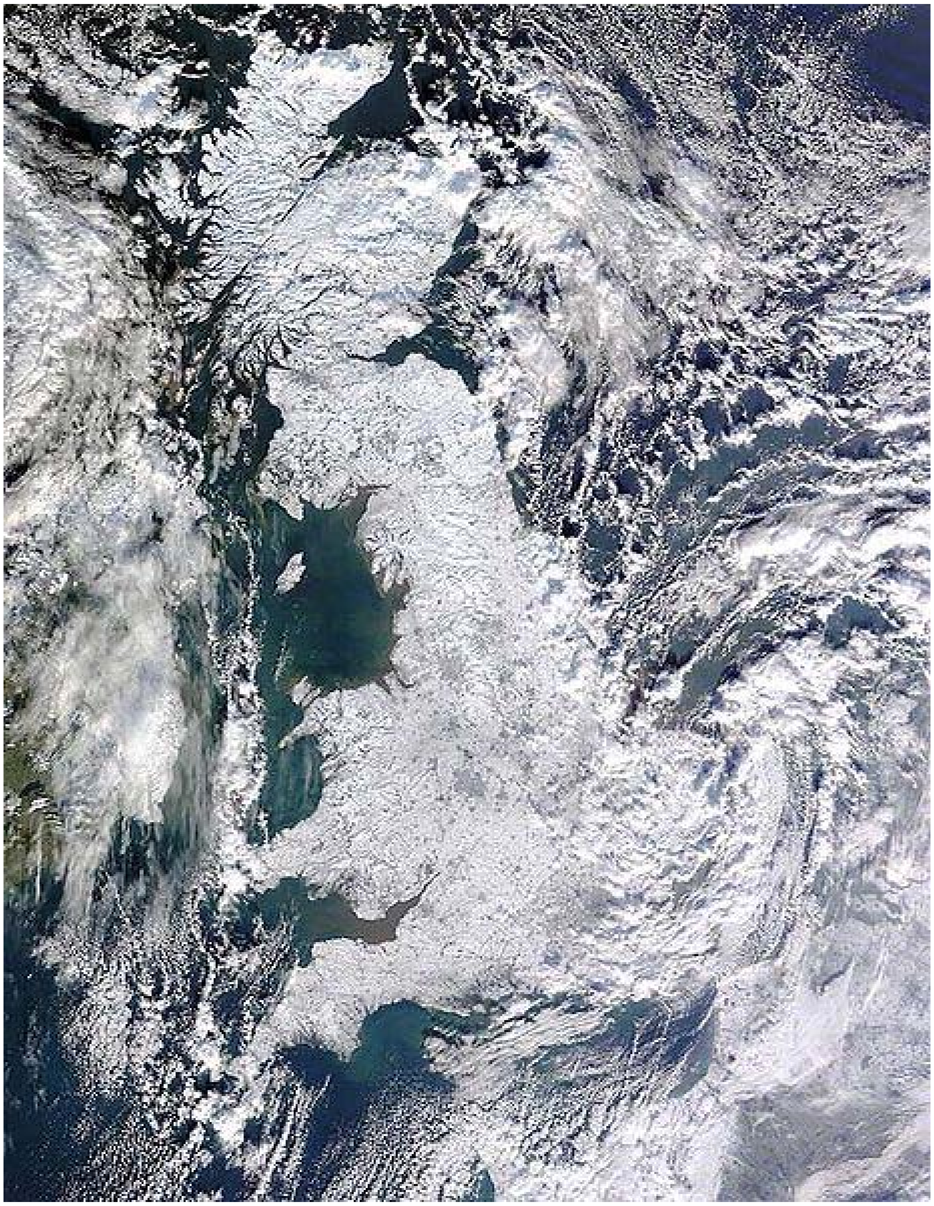
Terra (**EOS AM-1**) is a multi-national NASA scientific research satellite in a sun-synchronous orbit around the Earth. It is the flagship of the Earth Observing System (EOS). The name "Terra" comes from the Latin word for Earth.

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 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.

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

Mission

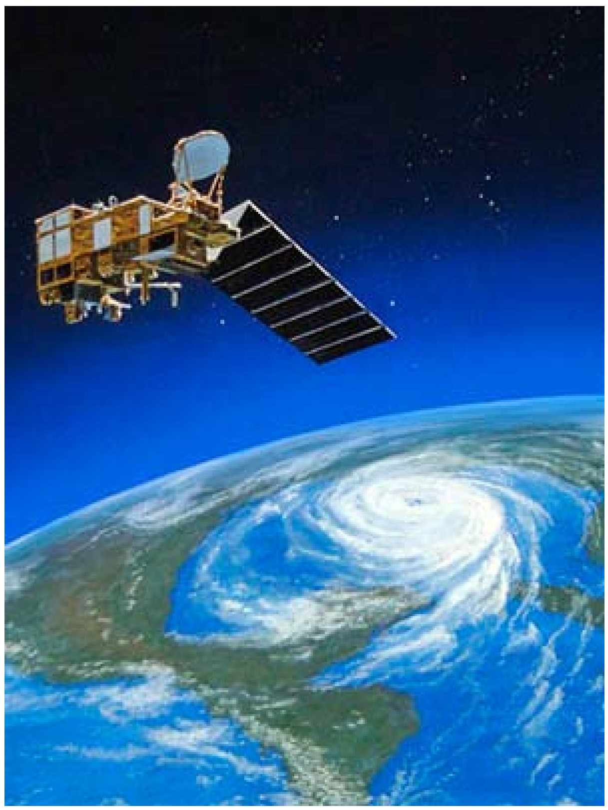
Terra carries a payload of five remote sensors designed to monitor the state of Earth's environment and ongoing changes in its climate system:

- 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- 6

National Polar-orbiting Operational Environmental Satellite System (NPOESS)



Illustration

The **National Polar-orbiting Operational Environmental Satellite System** (**NPOESS**) was to be the United States' next-generation satellite system that would monitor the Earth's weather, atmosphere, oceans, land and near-space environment. NPOESS satellites were to host proven technologies and operational versions of sensors that are currently under operational-prototyping by NASA. The estimated launch date for the first NPOESS satellite, "C1" or "Charlie 1" was around 2013. Issues with sensor developments were the primary cited reason for delays and cost-overruns.

NPOESS was to be operated by the NOAA / NESDIS / NPOESS Program Executive Office Flight Operations at the NOAA Satellite Operations Facility (NSOF) in Suitland, MD. Northrop Grumman Aerospace Systems (NGAS) was the primary system integrator for the NPOESS project. Raytheon, Ball Aerospace & Technologies Corp. and Boeing are developing the sensors.

NPOESS was a replacement for both the United States Department of Defense DMSP and the NOAA Polar Operational Environmental Satellites (POES) series.

The **NPOESS Preparatory Project (NPP)** program aimed to bridge the gap between old and new systems by flying new instruments on a satellite originally to be launched in 2005. The five instruments include the *Advanced Technology Microwave Sounder (ATMS)*, the *Cross-track Infrared Sounder (CrIS)*, the *Clouds and the Earth's Radiant Energy System (CERES)*, the *Visible Infrared Imager Radiometer Suite (VIIRS)* and the *Ozone Mapping and Profiler Suite (OMPS)*. The troubled NPP project was under review and the launch date had been postponed until September 2011.

The White House announced on February 1, 2010 that the NPOESS satellite partnership was to be dissolved, and that two separate lines of polar-orbiting satellites to serve military and civilian users would be pursued instead:

- The NOAA/NASA portion is called JPSS (Joint Polar Satellite System). The JPSS-1 spacecraft will be constructed by Ball Aerospace & Technologies Corp. under a fixed price contract of $248 million with a performance period through Feb. 1, 2015.

- The Defense department's portion is called DWSS (Defense Weather Satellite System.)

NOAA-15

NOAA-15 (designated NOAA-K before launch) is one of the NASA-provided TIROS series of weather forecasting satellite run by NOAA. It was launched on 13 May 1998, and is currently operational, in a sun-synchronous orbit, 807 km above the Earth, orbiting every 101 minutes. It hosts the AMSU-A and AMSU-B instruments, the AVHRR and High Resolution Infrared Radiation Sounder (HIRS/3) instruments, as well as a Space Environment Monitor (SEM/2).

APT transmission frequency is 137.62 MHz. Due to problems with the S-band transmitter high-gain antennas, NOAA-15 has been configured for High Resolution Picture Transmission using the S-Band Transmitter #2 (1702.5MHz) omnidirectional antenna.

NOAA-16

NOAA-16 (designated NOAA-L before launch) is one of the NASA-provided TIROS series of weather forecasting satellite run by NOAA. It was launched on 21 September 2000, and is currently operational, in a sun-synchronous orbit, 849 km above the Earth, orbiting every 102 minutes. It hosts the AMSU, AVHRR and High Resolution Infrared Radiation Sounder (HIRS) instruments APT transmitter. NOAA-16 has the same suite of instruments as carried by NOAA-15 plus an SBUV/2 instrument as well.

NOAA-16 APT is inoperable since November 15, 2000 and High Resolution Picture Transmission is via STX-1 (1698 MHz) since November 9, 2010.

NOAA-17

NOAA-17 is a weather forecasting satellite run by NOAA. It was launched on 24 June 2002, and is currently operational, in a sun-synchronous orbit, 810 km above the Earth, orbiting every 101 minutes. It hosts the AMSU, AVHRR and High Resolution Infrared Radiation Sounder (HIRS) instruments.

APT transmission frequency is 137.62 MHz

NOAA-18

NOAA-18 is a weather forecasting satellite run by NOAA. NOAA-N (18) was launched on May 20, 2005, into a sun-synchronous orbit at an altitude of 854 km above the Earth, with an orbital period of 102 minutes. It hosts the AMSU-A, MHS, AVHRR and High Resolution Infrared Radiation Sounder (HIRS) instruments, as well as the SBUV/2 ozone-monitoring instrument. It is the first NOAA POES satellite to use MHS in place of AMSU-B.

APT transmission frequency is 137.9125 MHz (NOAA-18 changed frequencies with NOAA-19 on June 23, 2009)

NOAA-19

NOAA-19, designated **NOAA-N'** (NOAA-N Prime) prior to launch, is the last of the United States National Oceanic and Atmospheric Administration's POES series of weather satellites (which is scheduled to be replaced by the next-generation NPOESS series). NOAA-19 was launched on 6 February 2009.

Launch

On 4 November 2008, NASA announced that the satellite had arrived at Vandenberg aboard a C-5 Galaxy military transport aircraft. Installation of the payload fairing took place 27 January 2009; second stage propellant was loaded on 31 January.

Several attempts were made to conduct the launch. The first attempt was scrubbed after a failure was detected in a launch pad gaseous nitrogen pressurization system. The second attempt was scrubbed after the failure of a payload fairing air conditioning compressor, which is also part of the ground support equipment at the launch pad.

The satellite was successfully launched aboard a Delta II flying in the 7320 configuration from Vandenberg Air Force Base at 2:22AM PST (5:22AM EST, 10:22 GMT) on 6 February 2009.

Instruments

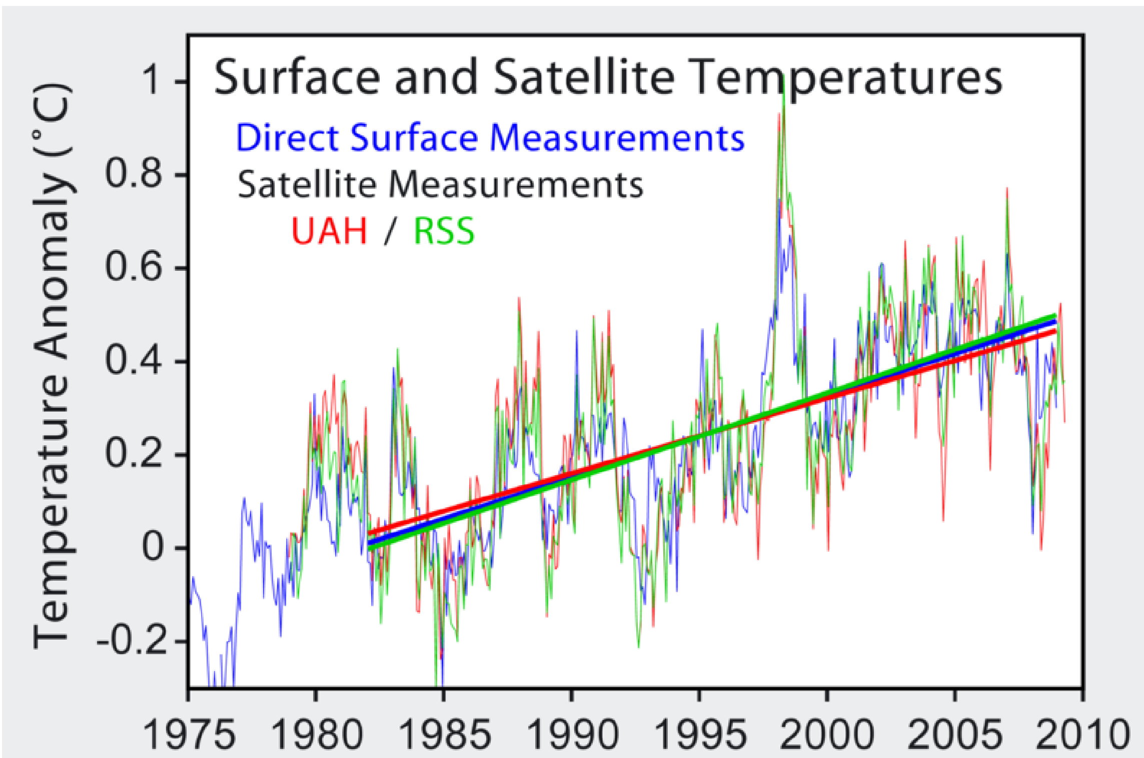
NOAA-N Prime carries a suite of instruments that provides data for weather and climate predictions. Like its predecessors, NOAA-N Prime provides global images of clouds and surface features and vertical profiles of atmospheric temperature and humidity for use in numerical weather and ocean forecast models, as well as data on ozone distribution in the upper part of the atmosphere, and near-Earth space environments—information important for the marine, aviation, power generation, agriculture, and other communities. The NOAA-N Prime primary instruments —the Advanced Very High Resolution Radiometer (AVHRR/3), High Resolution Infrared Radiation Sounder (HIRS/4), and the Advanced Microwave Sounding Unit (AMSU-A)—were all designed for a three-year mission. The Solar Backscatter Ultraviolet Spectral Radiometer (SBUV/2) was designed for a two-year mission, and the Microwave Humidity Sounder (MHS) was designed for a five-year mission.

Damage during manufacture

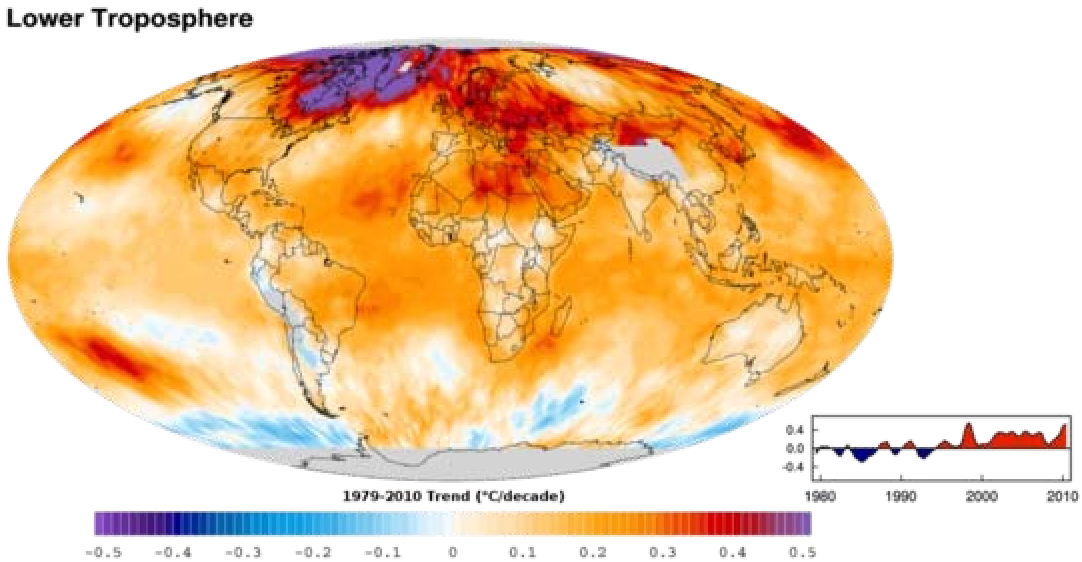
On September 6, 2003, the satellite was badly damaged while being worked on at the Lockheed Martin Space Systems factory in Sunnyvale, California. The satellite fell to the floor as a team was turning it into a horizontal position. A NASA inquiry into the mishap determined that it was caused by a lack of procedural discipline throughout the facility. While the turn-over cart used during the procedure was in storage, a technician removed twenty-four bolts securing an adapter plate to it without documenting the action. The team subsequently using the cart to turn the satellite failed to check the bolts before attempting to move the satellite. Lockheed Martin agreed to pay for repairs to the satellite out of profits it was to earn on the program.

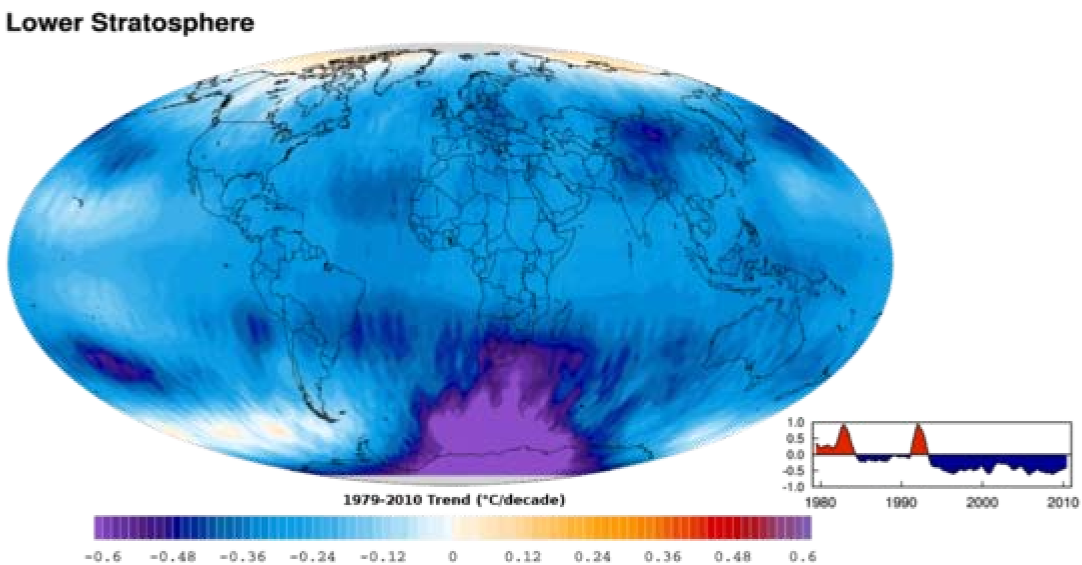
Chapter- 7

Satellite Temperature Measurements



Comparison of ground based measurements of surface temperature (blue) and satellite based records of mid-tropospheric temperature (red: UAH; green: RSS) since 1979. Trends plotted since January 1982.





Atmospheric temperature trends from 1979-2010 based on satellite measurements.

Satellite temperature measurements have been obtained from the sea surface since 1967 and from the troposphere since late 1978. By comparison, the usable balloon (radiosonde) record begins in 1958 but has less geographic coverage and is less uniform. Weather satellites measure radiances in various wavelength bands, which are then mathematically inverted to obtain indirect inferences of temperature. Surface measurements are derived from skin temperature, determined by thermal infrared imagery of weather satellites. These measurements can be used to locate weather fronts, monitor the El Niño-Southern Oscillation, determine the strength of tropical cyclones, and study urban heat islands. Wildfires, volcanos, and industrial hot spots can also be found via thermal imaging from weather satellites. Microwave sounding units (MSUs) on National Oceanic and Atmospheric Administration polar orbiting satellites have measured the intensity of upwelling microwave radiation from atmospheric oxygen, which is proportional to the temperature of broad vertical layers of the atmosphere. Satellite datasets show there has been warming in the troposphere over the past few decades, and cooling within the stratosphere, both of which are supported by global warming research.

Determination

Satellites do not measure temperature. They measure radiances in various wavelength bands, which must then be mathematically inverted to obtain indirect inferences of temperature. The resulting temperature profiles depend on details of the methods that are used to obtain temperatures from radiances. As a result, different groups that have analyzed the satellite data have obtained different temperature trends. Among these groups are Remote Sensing Systems (RSS) and the University of Alabama in Huntsville (UAH). Furthermore the satellite series is not fully homogeneous - it is constructed from a series of satellites with similar but not identical instrumentation. The sensors deteriorate over time, and corrections are necessary for satellite drift in orbit. Particularly large differences between reconstructed temperature series occur at the few times when there is little temporal overlap between successive satellites, making intercalibration difficult.

Surface measurements

Satellites may also be used to retrieve surface temperatures in cloud-free conditions, generally via measurement of thermal infrared from AVHRR. Weather satellites have been available to infer sea surface temperature (SST) information since 1967, with the first global composites occurring during 1970. Since 1982, satellites have been increasingly utilized to measure SST and have allowed its spatial and temporal variation to be viewed more fully. For example, changes in SST monitored via satellite have been used to document the progression of the El Niño-Southern Oscillation since the 1970s. Over the land the retrieval of temperature from radiances is harder, because of the inhomogeneities in the surface. Studies have been conducted on the urban heat island effect via satellite imagery. Use of advanced very high resolution infrared satellite imagery can be used, in the absence of cloudiness, to detect density discontinuities (weather fronts) such as cold fronts at ground level. Using the Dvorak technique, infrared satellite imagery can used to determine the temperature difference between the eye and the cloud top temperature of the central dense overcast of mature tropical cyclones to estimate their maximum sustained winds and their minimum central pressures. Along Track Scanning Radiometers aboard weather satellites are able to detect wildfires, which show up at night as pixels with a greater temperature than 308 K (95 °F). The Moderate-Resolution Imaging Spectroradiometer aboard the Terra satellite can detect thermal hot spots associated with wildfires, volcanos, and industrial hot spots.

Tropospheric and stratospheric measurements

Since 1979, microwave sounding units (MSUs) on NOAA polar orbiting satellites have measured the intensity of upwelling microwave radiation from atmospheric oxygen. The intensity is proportional to the temperature of broad vertical layers of the atmosphere, as demonstrated by theory and direct comparisons with atmospheric temperatures from radiosonde (balloon) profiles. Upwelling radiance is measured at different frequencies; these different frequency bands sample a different weighted range of the atmosphere. Channel 2 is broadly representative of the troposphere, albeit with a significant overlap with the lower stratosphere (the weighting function has its maximum at 350 hPa and half-power at about 40 and 800 hPa). In an attempt to remove the stratospheric influence, Spencer and Christy developed the synthetic "2LT" product by subtracting signals at different view angles; this has a maximum at about 650 hPa. However this amplifies noise, increases inter-satellite calibration biases and enhances surface contamination. The 2LT product has gone through numerous versions as various corrections have been applied.

Trends from the record

Year	UAH Trend
1991	0.087
1992	0.024
1993	-0.013
1994	-0.003
1995	0.033
1996	0.036
1997	0.040
1998	0.112
1999	0.105
2000	0.095
2001	0.103
2002	0.121
2003	0.129
2004	0.130
2005	0.139
2006	0.140
2007	0.143

Records have been created by merging data from nine different MSUs, each with peculiarities (e.g., time drift of the spacecraft relative to the local solar time) that must be calculated and removed because they can have substantial impacts on the resulting trend. The satellite record is short, which means adding a few years on to the record or picking a particular time frame can change the trends considerably. The problems with the length of the MSU record is shown by the table to the right, which shows the UAH TLT (lower tropospheric) global trend (°C/decade) beginning with Dec 1978 and ending with December of the year shown.

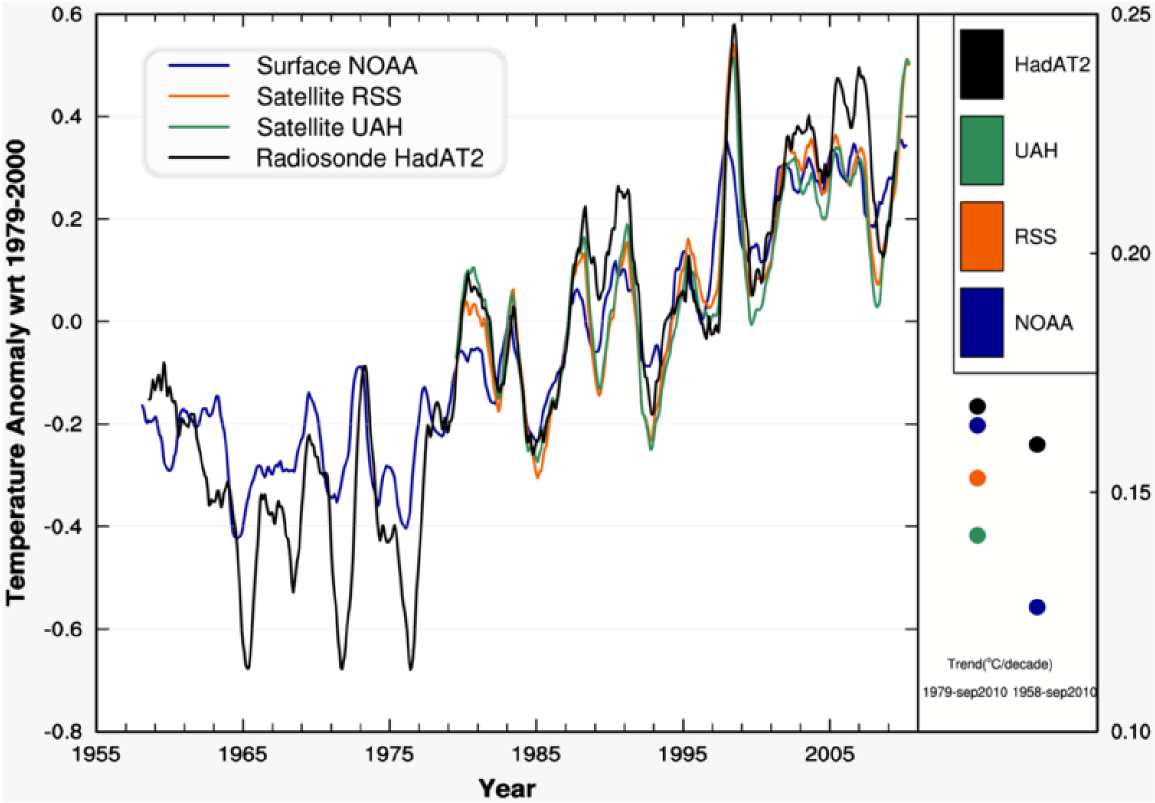
The process of constructing a temperature record from a radiance record is difficult. The satellite temperature record comes from a succession of different satellites and problems with inter-calibration between the satellites are important, especially NOAA-9, which accounts for most of the difference between various analyses. NOAA-11 played a significant role in a 2005 study by Mears *et al.* identifying an error in the diurnal correction that leads to the 40% jump in Spencer and Christy's trend from version 5.1 to 5.2. There are ongoing efforts to resolve differences in satellite temperature datasets.

Christy *et al.* (2007) find that the tropical temperature trends from radiosondes matches closest with his v5.2 UAH dataset. Furthermore, they assert there is a growing discrepancy between RSS and sonde trends beginning in 1992, when the NOAA-12 satellite was launched. This research found that the tropics were warming, from the balloon data, +0.09 (corrected to UAH) or +0.12 (corrected to RSS) or 0.05 K (from UAH MSU; ±0.07 K room for error) a decade.

Using the T2 channel (which include significant contributions from the stratosphere, which has cooled), Mears et al. of Remote Sensing Systems (RSS) find (through December 2010) a trend of +0.099 °C/decade. Spencer and Christy of the University of Alabama in Huntsville (UAH), find a smaller trend of +0.053 °C/decade. A less regularly updated analysis is that of Vinnikov and Grody with +0.20°C per decade (1978–2005). Another satellite temperature analysis is provided by NOAA/NESDIS STAR Center for Satellite Application and Research and use simultaneous nadir overpasses (SNO) to remove satellite intercalibration biases yielding more accurate temperature trends. The SNO analysis finds a 1979-2010 trend of +0.140°C/decade for T2 channel.

Lower stratospheric cooling is mainly caused by the effects of ozone depletion with a possible contribution from increased stratospheric water vapor and greenhouse gases increase. There is a decline in stratospheric temperatures, interspersed by warmings related to volcanic eruptions. Global Warming theory suggests that the stratosphere should cool while the troposphere warms The long term cooling in the lower stratosphere occurred in two downward steps in temperature both after the transient warming related to explosive volcanic eruptions of El Chichón and Mount Pinatubo, this behavior of the global stratospheric temperature has been attributed to global ozone concentration variation in the two years following volcanic eruptions. Since 1996 the trend is slightly positive due to ozone recover juxtaposed to a cooling trend of 0.1K/decade that is consistent with the predicted impact of increased greenhouse gases.

Comparison to instrumental record



1958-2009 radiosonde, satellite and surface temperature record

The satellite records have the advantage of global coverage, whereas the radiosonde record is longer. There have been complaints of data problems with both records.

To compare to the trend from the surface temperature record (approximately +0.07 °C/decade over the past century and +0.17 °C/decade since 1979) it is most appropriate to derive trends for the part of the atmosphere nearest the surface, i.e., the lower troposphere. Doing this, through December 2010:

- RSS v3.2 finds a trend of +0.163 °C/decade.
- UAH v5.4 finds a trend of +0.142°C/decade.

An alternative adjustment introduced by Fu *et al.* (2004) finds trends (1979–2001) of +0.19 °C/decade when applied to the RSS data set.

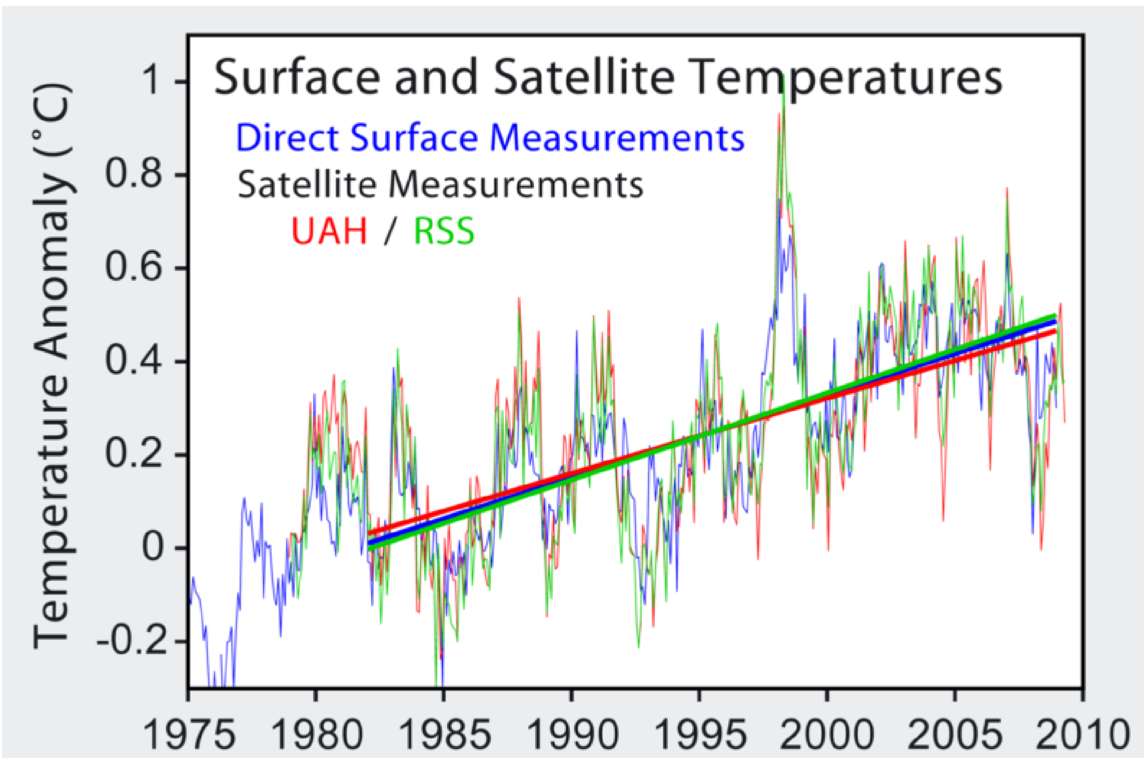
Reconciliation with climate models

Climate models predict that as the surface warms, so should the global troposphere. Globally, the troposphere should warm about 1.2 times more than the surface; in the tropics, the troposphere should warm about 1.5 times more than the surface. For some time the only available satellite record was the UAH version, which (with early versions of the processing algorithm) showed a global cooling trend for its first decade. Since then, a longer record and a number of corrections to the processing have revised this picture: the UAH dataset has shown an overall warming trend since 1998, though less than the RSS version. In 2001, an extensive comparison and discussion of trends from different data sources and periods was given in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (section 2.2.4).

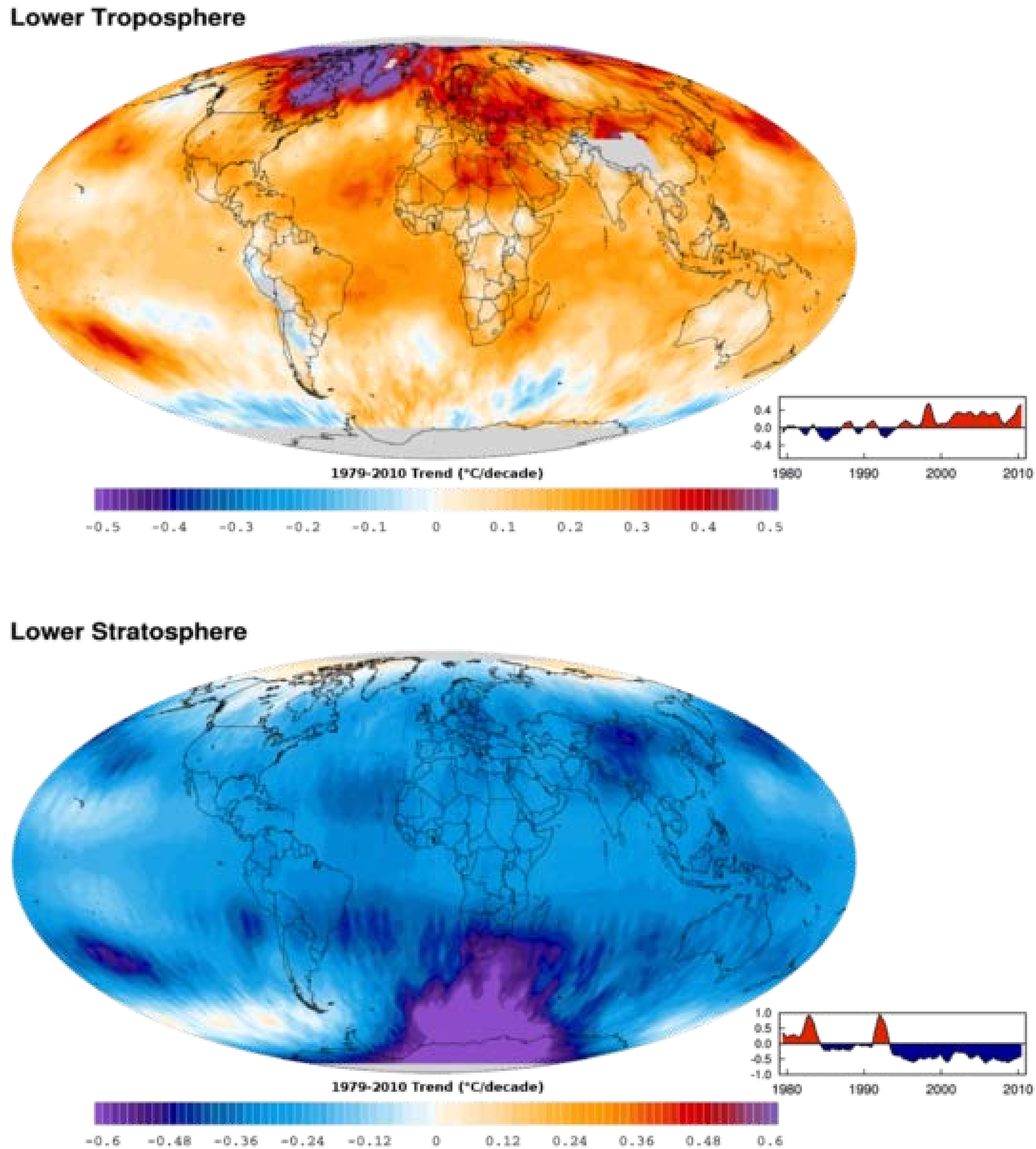
A detailed analysis produced by dozens of scientists as part of the US Climate Change Science Program (CCSP) identified and corrected errors in a variety of temperature observations, including the satellite data. Neither regression models nor other related techniques were reconcilable with observed data. The use of fingerprinting techniques on data yielded that "Volcanic and human-caused fingerprints were not consistently identifiable in observed patterns of lapse rate change." As such, issues with reconciling data and models remain. A potentially serious inconsistency has been identified in the tropics, the area in which tropospheric amplification should be seen. Over multi-decadal time scales, while almost all model simulations show greater warming aloft, most observations show greater warming at the surface. The lower troposphere trend derived from UAH satellites (+0.128 °C/decade) is currently lower than both the GISS and Hadley Centre surface station network trends (+0.161 and +0.160 °C/decade respectively), while the RSS trend (+0.158 °C/decade) is similar. However, the expected trend in the lower troposphere, given the surface data, would be around 0.194 °C/decade, making the UAH and RSS trends 66% and 81% of the expected value respectively.

Chapter- 8

MSU Temperature Measurements



Comparison of ground based measurements of surface temperature (blue) and satellite based records of mid-tropospheric temperature (red: UAH; green: RSS) since 1979. Trends plotted since January 1982.



Atmospheric temperature trends from 1979-2010 based on satellite measurements.

Microwave sounding unit temperature measurements have been obtained from the troposphere since 1979, when they were included within NOAA weather satellites. By comparison, the usable balloon (radiosonde) record begins in 1958 but has less geographic coverage and is less uniform. Satellites do not measure temperature. They measure radiances in various wavelength bands, which must then be mathematically inverted to obtain indirect inferences of temperature. The resulting temperature profiles depend on details of the methods that are used to obtain temperatures from radiances. As a result, different groups that have analyzed the satellite data have obtained different temperature trends. Among these groups are Remote Sensing Systems (RSS) and the University of Alabama in Huntsville (UAH). Furthermore the satellite series is not fully homogeneous - it is constructed from a series of satellites with similar but not identical instrumentation. The sensors deteriorate over time, and corrections are necessary for satellite drift in orbit. Particularly large differences between reconstructed temperature series occur at the few times when there is little temporal overlap between successive satellites, making intercalibration difficult.

To compare to the trend from the surface temperature record (approximately +0.07 °C/decade over the past century and +0.17 °C/decade since 1979) it is most appropriate to derive trends for the part of the atmosphere nearest the surface, i.e., the lower troposphere. Doing this, through December 2010:

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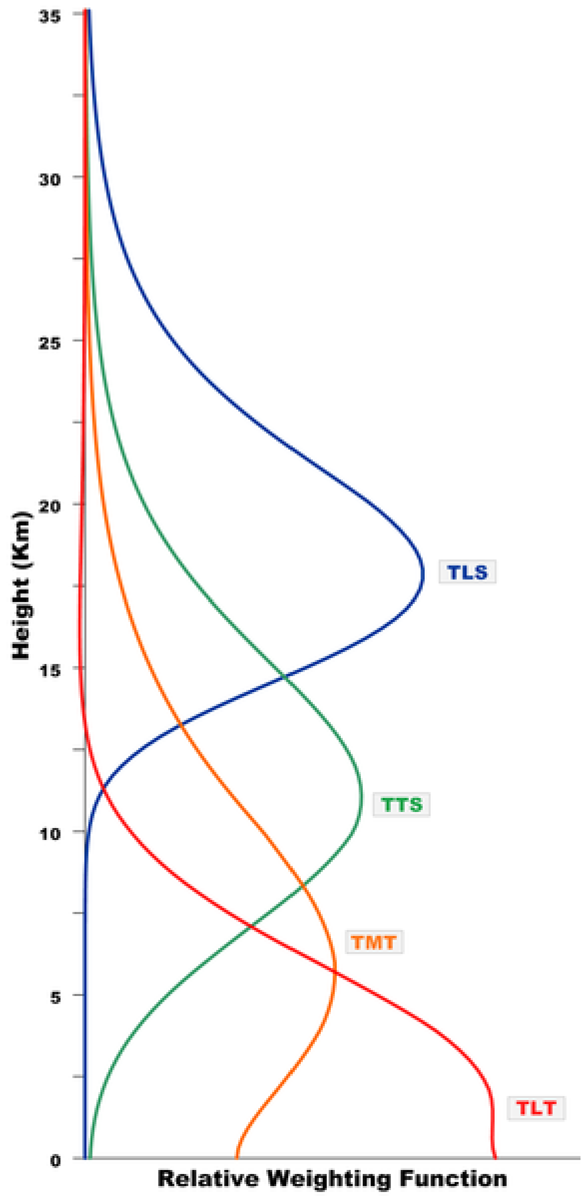
Using the TMT (or T2) channel (which include significant contributions from the stratosphere, which has cooled), Mears et al. of Remote Sensing Systems (RSS) find (through December 2010) a trend of +0.099 °C/decade. Spencer and Christy of the University of Alabama in Huntsville (UAH), find a smaller trend of +0.053 °C/decade. A less regularly updated analysis is that of Vinnikov and Grody with +0.20°C per decade (1978–2005). Another satellite temperature analysis is provided by NOAA/NESDIS STAR Center for Satellite Application and Research and use simultaneous nadir overpasses (SNO) to remove satellite intercalibration biases yielding more accurate temperature trends. The SNO analysis finds a 1979-2010 trend of +0.140°C/decade for TMT channel.

The satellite records have the advantage of global coverage, whereas the radiosonde record is longer. There have been complaints of data problems with both records, and difficulty reconciling climate model predictions with the observed data.

Creation of the satellite temperature record



MSU weighting function

Since 1979, microwave sounding units (MSUs) on NOAA polar orbiting satellites have measured the intensity of upwelling microwave radiation from atmospheric oxygen. The intensity is proportional to the temperature of broad vertical layers of the atmosphere, as demonstrated by theory and direct comparisons with atmospheric temperatures from radiosonde (balloon) profiles. Upwelling radiance is measured at different frequencies; these different frequency bands sample a different weighted range of the atmosphere. Channel 2 is broadly representative of the troposphere, albeit with a significant overlap with the lower stratosphere (the weighting function has its maximum at 350 hPa and half-power at about 40 and 800 hPa). In an attempt to remove the stratospheric influence, Spencer and Christy developed the synthetic "2LT" product by subtracting signals at different view angles; this has a maximum at about 650 hPa. However this amplifies noise, increases inter-satellite calibration biases and enhances surface contamination. The 2LT product has gone through numerous versions as various corrections have been applied.

Records have been created by merging data from nine different MSUs and AMSU data, each with peculiarities that must be calculated and removed because they can have substantial impacts on the resulting trend. The process of constructing a temperature record from a radiance record is difficult and some of the required corrections are as large as the trend itself:

Diurnal sampling

All the MSU instruments and to a lesser extent AMSU drift slowly from the sun-synchronous equatorial crossing time changing the local time observed by the instrument, therefore the natural diurnal cycle may be aliased into the long term trend. The diurnal sampling correction is in the order of a few hundredths °C/decade for TLT and TMT.

Orbit decay

All Polar orbiting satellite lose height after launch, the orbital decay is stronger during period of elevated solar activity when the enhanced ultraviolet radiation warm the upper atmosphere and increase the frictional drag over the spacecraft.

The orbital decay change the instrument view angle relative to the surface and thus the observed microwave emissivity, furthermore the long term time-series is constructed by sequential merging of the inter-calibrated satellite data so that the error is summed up over time, the required correction is in the order of 0.1°C/decade for TLT.

Calibration changes

Once every earth scan MSU instrument use the deep space (2.7K) and on-board warm targets to make calibration measures, however as the spacecraft drifts through the diurnal cycle the calibration target temperature may change due to varying solar shadowing effect, the correction is in the order of 0.1°C/decade for TLT and TMT.

One widely reported satellite temperature record, developed by Roy Spencer and John Christy at the University of Alabama in Huntsville (UAH), is current version corrects previous errors in their analysis for orbital drift and other factors. The record comes from a succession of different satellites and problems with inter-calibration between the satellites are important, especially NOAA-9, which accounts for most of the difference between the RSS and UAH analyses. NOAA-11 played a significant role in a 2005 study by Mears *et al.* identifying an error in the diurnal correction that leads to the 40% jump in Spencer and Christy's trend from version 5.1 to 5.2.

History of satellite temperature data interpretation

In the late 1990s the disagreement between the surface temperature record and the satellite records was a subject of research and debate. The lack of warming then seen in the records was noted. A report by the National Research Council that reviewed upper air temperature trends stated:

> "Data collected by satellites and balloon-borne instruments since 1979 indicate little if any warming of the low- to mid-troposphere—the atmospheric layer extending up to about 5 miles from the Earth's surface. Climate models generally predict that temperatures should increase in the upper air as well as at the surface if increased concentrations of greenhouse gases are causing the warming."

The same panel then concluded that

> "the warming trend in global-mean surface temperature observations during the past 20 years is undoubtedly real and is substantially greater than the average rate of warming during the twentieth century. The disparity between surface and upper air trends in no way invalidates the conclusion that surface temperature has been rising."

In 1998 the UAH data showed a *cooling* of 0.05K per decade (at 3.5 km - mid to low troposphere). Wentz & Schabel at RSS in their 1998 paper showed this (along with other discrepancies) was due to the orbital decay of the NOAA satellites. Once the orbital changes had been allowed for the data showed a 0.07K per decade *increase* in temperature at this level of the atmosphere.

In April 2002, for example, an analysis of the satellite temperature data showed warming of only 0.04 °C per decade, compared with surface measurements showing 0.17 ± 0.06 °C per decade.

Doubts had been raised as early as 2000 about the UAH analysis by the work of Prabhakara et al., which minimised errors due to satellite drift. They found a trend of 0.13 °C/decade, in reasonable agreement with surface trends.

Christy *et al.* (2007) find that the tropical temperature trends from radiosondes matches closest with his v5.2 UAH dataset. Furthermore, they assert there is a growing discrepancy between RSS and sonde trends beginning in 1992, when the NOAA-12 satellite was launched. This research found that the tropics were warming, from the balloon data, +0.09 (corrected to UAH) or +0.12 (corrected to RSS) or 0.05 K (from UAH MSU; ±0.07 K room for error) a decade.

The table below summarize the adjustments that have been applied to the UAH TLT dataset.

UAH version	Main adjustment	Trend correction	Year
A	Simple bias correction		1992
B	Linear diurnal drift correction	-0.03	1994
C	Removal of residual annual cycle related to hot target variation	0.03	1997
D	Orbital decay	0.10	1998
D	Removal of dependence of time variations of hot target temperature	-0.07	1998
5.0	Non-linear diurnal correction	0.008	2003
5.1	Tightened criteria for data acceptance	-0.004	2004
5.2	Correction of diurnal drift adjustment	0.035	2005
5.3	Annual cycle correction	0	2009
5.4	New annual cycle	0	2010

Another important critique of the satellite record is its shortness—adding a few years on to the record or picking a particular time frame can change the trends considerably.

Likewise, even though they began with the same data, each of the major research groups has interpreted it with different results. Most notably, Mears et al. at RSS find 0.193 °C/decade for lower troposphere up to July 2005, compared to +0.123 °C/decade found by UAH for the same period.

There are ongoing efforts to resolve these differences. Some believe that much of the disparity may have been resolved by the three papers in Science, 11 August 2005, which pointed out errors in the UAH 5.1 record and the radiosonde record in the tropics.

Stratospheric temperature trends

The satellites also measure the lower stratospheric temperature and show a decline in stratospheric temperatures, interspersed by warmings related to volcanic eruptions. Global Warming theory suggests that the stratosphere should cool while the troposphere warms However, the lower stratospheric cooling is mainly caused by the effects of ozone depletion with a possible contribution from increased stratospheric water vapor and greenhouse gases increase. The long term cooling in the lower stratosphere occurred in two downward steps in temperature both after the transient warming related to explosive volcanic eruptions of El Chichón and Mount Pinatubo, this behavior of the global stratospheric temperature has been attributed to global ozone concentration variation in the two years following volcanic eruptions. Since 1996 the trend is slightly positive due to ozone recover juxtaposed to a cooling trend of 0.1K/decade that is consistent with the predicted impact of increased greenhouse gases.

Reconciliation of data with climate models

Climate models predict that as the surface warms, so should the global troposphere. Globally, the troposphere should warm about 1.2 times more than the surface; in the tropics, the troposphere should warm about 1.5 times more than the surface. For some time the only available satellite record was the UAH version, which (with early versions of the processing algorithm) showed a global cooling trend for its first decade. Since then, a longer record and a number of corrections to the processing have revised this picture: the UAH dataset has shown an overall warming trend since 1998, though less than the RSS version. In 2001, an extensive comparison and discussion of trends from different data sources and periods was given in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (section 2.2.4).

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The CCSP SAP 1.1 Executive Summary states:

> "Previously reported discrepancies between the amount of warming near the surface and higher in the atmosphere have been used to challenge the reliability of climate models and the reality of human induced global warming. Specifically, surface data showed substantial global-average warming, while early versions of satellite and radiosonde data showed little or no warming above the surface. This significant discrepancy no longer exists because errors in the satellite and radiosonde data have been identified and corrected. New data sets have also been developed that do not show such discrepancies."

The IPCC Fourth Assessment Report Summary for Policymakers states:

> "New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates that are similar to those of the surface temperature record and are consistent within their respective uncertainties, largely reconciling a discrepancy noted in the TAR."

However, as detailed in CCSP SAP 5.1 Understanding and Reconciling Differences, neither Regression models or other related techniques were reconcilable with observed data. The use of fingerprinting techniques on data yielded that "Volcanic and human-caused fingerprints were not consistently identifiable in observed patterns of lapse rate change." As such, issues with reconciling data and models remain.

A potentially serious inconsistency has been identified in the tropics, the area in which tropospheric amplification should be seen. Section 1.1 of the CCSP report says:

> "In the tropics, the agreement between models and observations depends on the time scale considered. For month-to-month and year-to-year variations, models

> and observations both show amplification (i.e., the month-to-month and year-to-year variations are larger aloft than at the surface). This is a consequence of relatively simple physics, the effects of the release of latent heat as air rises and condenses in clouds. The magnitude of this amplification is very similar in models and observations. On decadal and longer time scales, however, while almost all model simulations show greater warming aloft (reflecting the same physical processes that operate on the monthly and annual time scales), most observations show greater warming at the surface.
> "These results could arise either because “real world” amplification effects on short and long time scales are controlled by different physical mechanisms, and models fail to capture such behavior; or because non-climatic influences remaining in some or all of the observed tropospheric data sets lead to biased long-term trends; or a combination of these factors. The new evidence in this Report favors the second explanation."

The lower troposphere trend derived from UAH satellites (+0.128 °C/decade) is currently lower than both the GISS and Hadley Centre surface station network trends (+0.161 and +0.160 °C/decade respectively), while the RSS trend (+0.158 °C/decade) is similar. However, the expected trend in the lower troposphere, given the surface data, would be around 0.194 °C/decade, making the UAH and RSS trends 66% and 81% of the expected value respectively.

Chapter- 9

UAH Satellite Temperature Dataset

The **UAH satellite temperature dataset**, developed at the University of Alabama in Huntsville, has been used within the global warming community as a tool for research since the 1990's. It was one of the first global temperature datasets developed from satellite information. Early on, there were inconsistencies in the dataset, which were mainly addressed by 2007, when comparing to the dataset to radiosonde measurements.

Satellite temperature measurements

Satellites do not measure temperature. They measure radiances in various wavelength bands, which must then be mathematically inverted to obtain indirect inferences of temperature. The resulting temperature profiles depend on details of the methods that are used to obtain temperatures from radiances. As a result, different groups that have analyzed the satellite data have obtained different temperature trends. Among these groups are Remote Sensing Systems (RSS) and the University of Alabama in Huntsville (UAH). Furthermore the satellite series is not fully homogeneous - it is constructed from a series of satellites with similar but not identical instrumentation. The sensors deteriorate over time, and corrections are necessary for satellite drift in orbit. Particularly large differences between reconstructed temperature series occur at the few times when there is little temporal overlap between successive satellites, making intercalibration difficult.

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Data inconsistencies

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For some time, the UAH satellite data's chief significance was that they appeared to contradict a wide range of surface temperature data measurements and analyses showing warming. In 1998 the UAH data showed a *cooling* of 0.05K per decade (at 3.5km - mid to low troposphere). Wentz & Schabel at RSS in their 1998 paper showed this (along with other discrepancies) was due to the orbital decay of the NOAA satellites. Once the orbital changes had been allowed for the data showed a 0.07K per decade *increase* in temperature at this level of the atmosphere.

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Corrections made

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As noted earlier, these temperature data, misinterpreted from the satellite data, are now known to have been too low.

Likewise, even though they began with the same data, each of the major research groups has interpreted it with different results. Most notably, Mears et al. at RSS find 0.193 °C/decade for lower troposphere up to July 2005, compared to +0.123 °C/decade found by UAH for the same period.

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