

February 21

Weather monitoring

Chapter 12

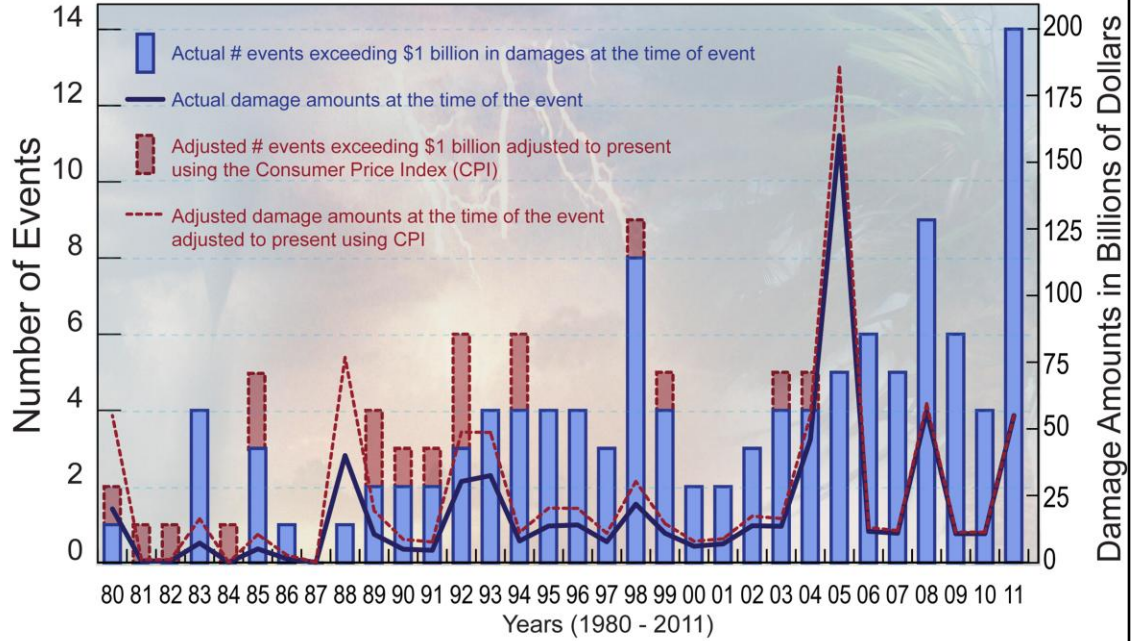
POES, Polar orbits
GOES, Geostationary orbits
Scattering and absorption in atmosphere
Radiation and energy budget
Clouds and Aerosols

In 2011, the US exceeded 12 \$1 Billion weather-related disasters
the most recorded for any year, although other years have higher total damage.

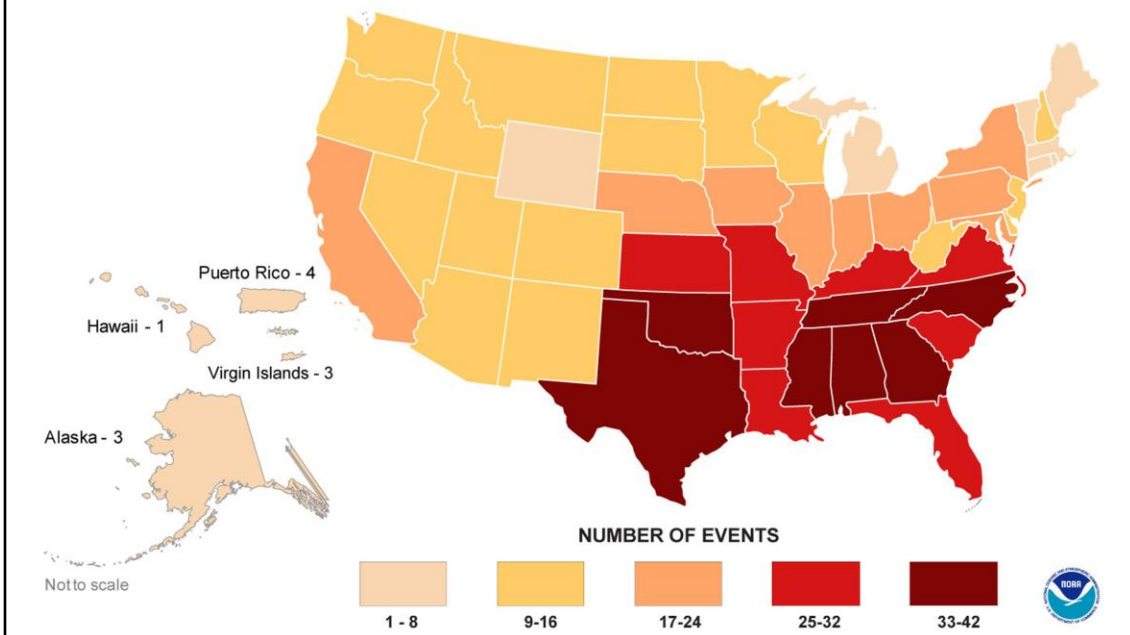


Billion Dollar Weather/Climate Disasters

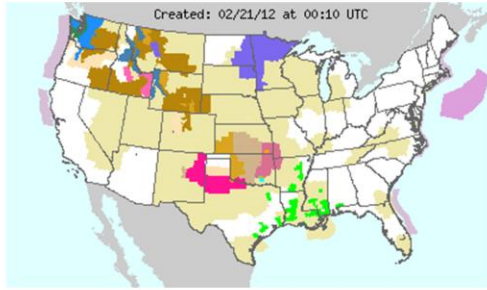
1980 - 2011
NOAA/NESDIS/NCDC



Billion Dollar Weather/Climate Disasters 1980 - 2011



NOAA Weather Storm Warnings for the US for Feb. 21, 2012



Severe Thunderstorm Warning	Gale Warning	Flood Watch
Winter Storm Warning	Red Flag Warning	High Wind Watch
High Wind Warning	Winter Weather Advisory	Gale Watch
Storm Warning	High Surf Advisory	Fire Weather Watch
Avalanche Warning	Small Craft Advisory	Special Weather Statement
Severe Thunderstorm Watch	Brisk Wind Advisory	Hazardous Weather Outlook
Severe Weather Statement	Wind Advisory	Hydrologic Outlook
Flood Warning	Winter Storm Watch	

3 Sets of US Polar Orbiting Weather Observing Satellites

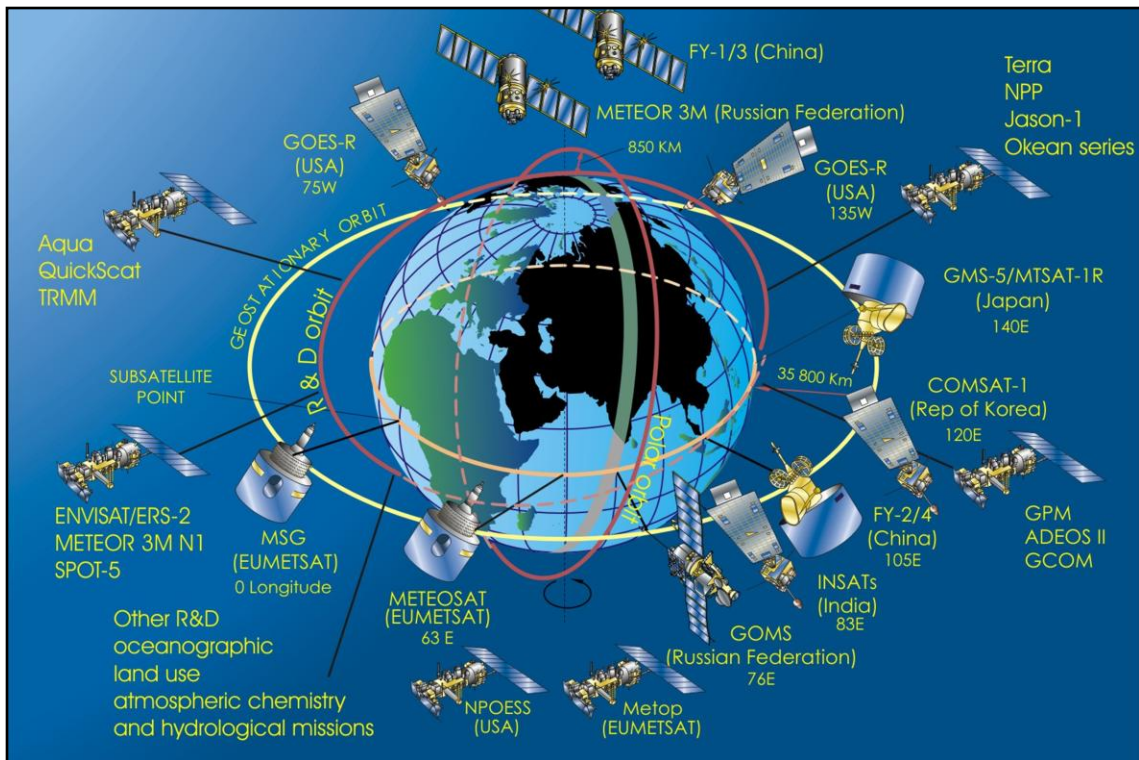
1. NOAA POES operational satellite system
2. DoD DMSP Operational Weather Satellite Series
3. NASA Research Earth Observing Satellites (Terra, Aqua, Aura)

Start of the Next Generation Joint Polar Satellite System (JPSS) NOAA, NASA and DoD Weather Satellite System

1. Suomi National Polar orbiting Partnership Satellite (NPP) 11/28/2011
2. First JPSS scheduled ~ 2016

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NOAA Polar-orbiting Operational Environmental Satellite (POES) continually monitor the power flux carried by the protons and electrons that produce aurora in the atmosphere. Measures the power flux observations obtained during a single pass of the satellite over a polar region (which takes about 25 minutes). Your chance of seeing an aurora depends on chance of seeing an aurora, you need to know the level of geomagnetic activity at the time you are viewing.



International Coordinated Weather Satellite Programs

The Environmental Observation Satellite network includes five operational near-polar-orbiting satellites and six operational geostationary environmental observation satellites as well as several Research and Development satellites (See WMO's [Space Programme](#) for current information). Polar orbiting and geostationary satellites are normally equipped with visible and infra-red imagers and sounders, from which many meteorological parameters are derived. Several of the polar-orbiting satellites are equipped with sounders instruments that can provide vertical profiles of temperature and humidity in cloud free areas. Geostationary satellites are used to measure wind velocity in the tropics by tracking clouds and water vapor.

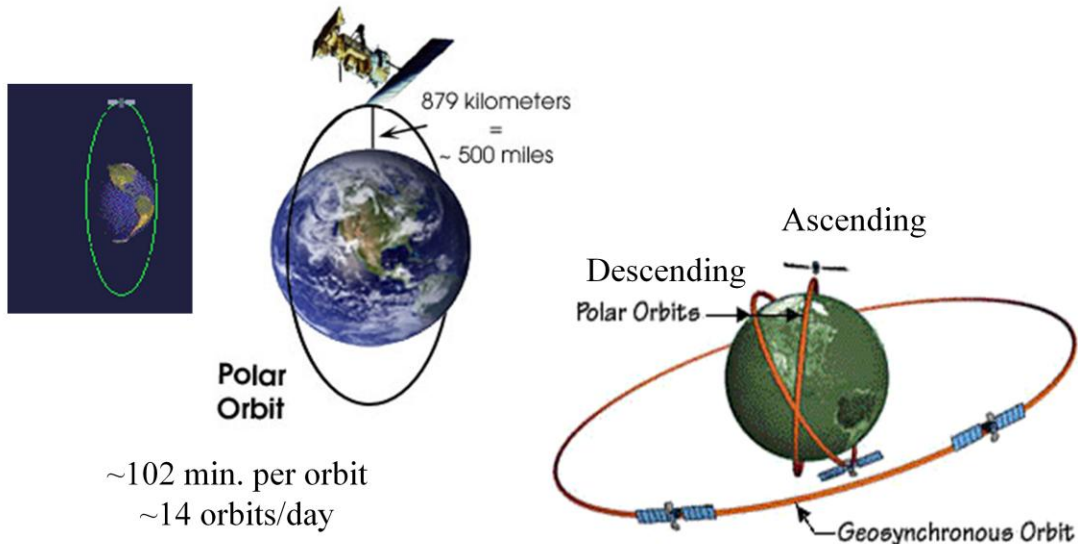
Satellite sensors, communications and data assimilation techniques are evolving steadily so that better use is being made of the vast amount of satellite data. Improvements in numerical modeling in particular, have made it possible to develop increasingly sophisticated methods of deriving the temperature and humidity information directly from the satellite radiances. Research and Development (R&D) satellites comprise the newest constellation in the space-based component of the Global Observational System (GOS). R&D missions provide valuable data for operational use as well as for many WMO supported programmes. Instruments on R&D missions either provide data not normally observed from operational meteorological satellites or improvements to current operational systems.

International Program Cooperation

In the 1980s, NOAA needed to balance the high cost of space systems and the growing need to provide a complete and accurate description of the atmosphere at regular intervals as inputs to numerical weather prediction and climate monitoring support systems. This led NOAA to enter into discussions and agreements at the international level with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). The goal of this cooperation is to provide continuity of measurements from polar orbits, cost sharing, and improved forecast and monitoring capabilities through the introduction of new technologies.

Building upon the POES program, an agreement is in place between NOAA and EUMETSAT on the Initial Joint Polar-orbiting Operational Satellite System (IJPS). This program will include two series of independent but fully coordinated NOAA and EUMETSAT satellites, exchange of instruments and global data, cooperation in algorithm development, and plans for real-time direct broadcast. Under terms of the IJPS agreement, NOAA will provide NOAA-N and NOAA-N' satellites for flights in the afternoon orbit while EUMETSAT makes available METOP-1 and METOP-2 satellites for flights in the mid-morning orbit. The first METOP satellite is was launched Oct. 19, 2006.

Satellite Orbits: POES and GOES



Polar-orbiting Operational Environmental Satellites (POES)

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Polar orbiting satellites travel in a circular orbit moving from pole to pole. These satellites collect data in a swath beneath them as the earth rotates on its axis. In this way, a polar orbiting satellite can “see” the entire planet twice in a 24 hour period. The basic weather service operational mode deploys two polar orbiting satellites continuously, one passing north to south (descending) and the other passing south to north (ascending), circling the earth every 12 hours. Polar Orbiting Satellites are inserted into sun-synchronous orbits which place the spacecraft in a relatively constant relationship to the sun so that the ascending node will remain at a constant solar time on each descending orbit, permitting images and data to be received by direct broadcast at the same time each day. **Polar Orbiting Earth Satellites (POES)** are significantly closer to Earth than **Geostationary Operational Environmental Satellites (GOES)**, orbiting at an altitude of only 879 kilometers, (approximately 500 miles) so it only takes one hour and 42 minutes (102 min.) to complete a full orbit. This orbit (called low earth orbit or LEO) results in high resolution images and atmospheric profiles.

Geosynchronous orbits are located at about 36000 km above the surface in an equatorial orbit and travel at a speed equal to the rotation of the earth. This keeps them continuously over the same geographic location all the time. While pixel sizes are larger (generally), five of these satellites measure continuously the entire earth, minus the polar regions.

World's First Meteorological Satellite: Launched April 1, 1960

Not in
Polar
orbit



After 1st 8,
all are in
polar orbits



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Since 1960 38 satellites in the TIROS series have been launched.

The world's first meteorological satellite, was launched from Cape Canaveral on April 1, 1960. Named TIROS for **Television Infrared Observation Satellite**, it demonstrated the advantage of mapping the earth's cloud cover from satellite altitudes. TIROS showed clouds banded and clustered in unexpected ways. Sightings from the surface had not prepared meteorologists for the interpretation of the cloud patterns that the view from an orbiting satellite would show.

From April 1, 1960 to July 2, 1965 ten TIROS satellites were launched. The satellites ensured continuity of data throughout the early years. The first four TIROS satellites had an inclination of 48 degrees and the next four had an inclination of 58 degrees, thus they were not polar-orbiting. The last two TIROS were the first polar-orbiting meteorological satellites. The next series of satellites, named ESSA, for Environmental Science Services Administration, were launched from February 3, 1966 to Feb. 26, 1969. Nine satellites in the ESSA series were launched during this time. These satellites were also polar-orbiting satellites.

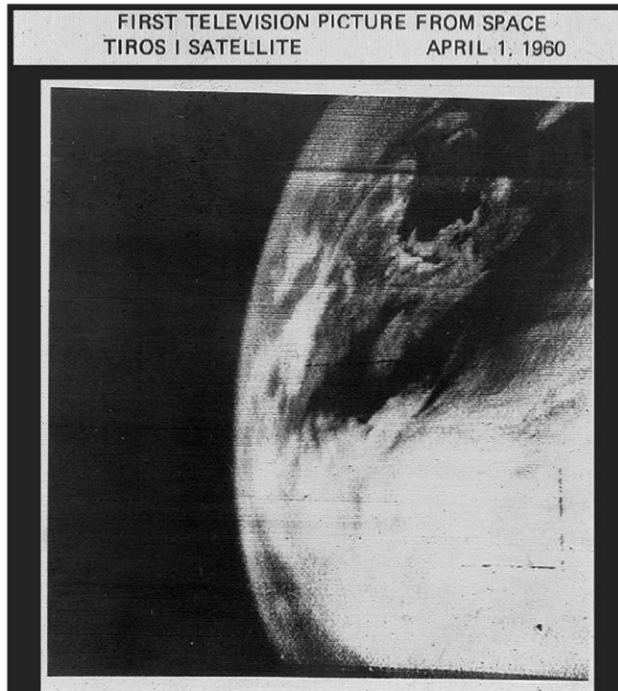
On Jan. 23, 1970, the first of the improved satellites was launched. This satellite was named **ITOS 1**, for Improved TIROS Operational Satellite. Between December 11, 1970 and July 29, 1976. Five ITOS satellites designated NOAA-1 through 5 were launched. **NOAA-1** was the first satellite to bear the NOAA name and the first to be launched after the establishment of NOAA in October 1970.

From October 13, 1978 to July 23, 1981, satellites in the TIROS-N series were launched. The N represented the next generation of operational satellites. NOAA-6 and NOAA-7 were launched during this time frame. **The AVHRR (Advanced Very High Resolution Radiometer) and TIROS Operational Vertical Sounder suite started on TIROS-N.**

On March 28, 1983, the first of the **Advanced TIROS-N (or ATN)** satellites designated NOAA-8 was launched. These satellites are physically larger and have more power, than their predecessors, to accommodate more equipment. NOAA continues to operate the ATN series of satellites today with improved instruments. The current configuration is NOAA-14, launched Dec. 12, 1994, and NOAA-15, launched May 13, 1998. NOAA-15 is the first in a series of five satellites with improved imaging and sounding capabilities that will operate over the next decade. (This series is NOAA-K (15), -L, -M, -N, and N'.) NOAA-N was launched May 20, 2005, which became NOAA 18. **NOAA-N is the first in a series of polar-orbiting satellites to be part of a joint cooperation project with the European Organisation for the Exploitation of Meteorological Satellites (EUMESTAT).**

GOES 13 is currently operating (GOES N launched May 24, 2006) over the western North America and GOES 12 over eastern North America.

53 Years Ago:
Photo of TIROS 1



Advanced Very High Resolution Radiometer (AVHRR), since 1978

Fifty-three years ago, on April 1, 1960, the world's first weather satellite lifted off from Cape Canaveral, Fla., opening a new and exciting dimension in weather forecasting. Leaders from NASA and the National Oceanic and Atmospheric Administration, or NOAA, hailed the milestone as an example of a strong agency partnership and commitment to flying the best Earth observation satellites today and in the future.

The first image from the Television Infrared Observation Satellite, known as TIROS-1, was a fuzzy picture of thick bands and clusters of clouds over America. An image captured a few days later revealed a typhoon approximately 1,000 miles east of Australia. TIROS-1, a polar-orbiting satellite, weighed 270 pounds and carried two cameras and two video recorders.

"TIROS-1 started the satellite observations and interagency collaborations that produced vast improvements in weather forecasts, which have strengthened the nation," said NASA Administrator Charles Bolden. "It also laid the foundation for our current global view of Earth that underlies all of climate research and the field of Earth system science."

TIROS-1 was NASA's first attempt in using satellites to help scientists study weather systems on Earth. NASA managed the program with help from the U.S. Army Signal Research and Development Lab, RCA, the U.S. Weather Bureau (now the National Weather Service) and the U.S. Naval Photographic Interpretation

Center.

"This satellite forever changed weather forecasting," said Jane Lubchenco, undersecretary of commerce for oceans and atmosphere and NOAA administrator. "Since TIROS-1, meteorologists have far greater information about severe weather and can issue more accurate forecasts and warnings that save lives and protect property."

NASA launched all 10 of the TIROS satellites. Throughout the 1960s, each satellite carried increasingly advanced instruments and technology. By 1965, meteorologists combined 450 TIROS images into the first global view of the world's weather, picking up a line of clouds over the Pacific Ocean barreling toward the United States.

In 1975, NASA launched the first Geostationary Operational Environmental Satellite, or GOES, 22,300 miles into space. Its ability to orbit in sync with Earth's rotation, combined with polar-orbiting satellites, gave U.S. meteorological forecasters a powerful tool.

"We could not provide skillful hurricane forecasts without the crucial imagery and data from geostationary and polar-orbiting satellites," said Chris Landsea, the science operations officer at NOAA's National Hurricane Center in Miami. "Before satellites, tropical storms and hurricanes were often missed if they stayed out over the open ocean. Now we know tropical storms and hurricanes have swings in numbers from decade to decade."

With continued technological improvements, the satellites gave scientists the ability to track changes in climate, from the subtle onset of drought and its impact on vegetation to monitoring global sea-surface temperatures that signal atmospheric phenomena, such as El Nino and La Nina.

On Feb. 6, 2009, NASA launched the last of the TIROS satellites, NOAA N-Prime, from Vandenberg Air Force Base in California. Now called NOAA-19, the satellite provides coverage for the afternoon orbit, while the morning orbit is handled by a European satellite through a partnership with NOAA and the European Organisation for the Exploitation of Meteorological Satellites.

On Feb. 1, 2010, the White House restructured the National Polar-orbiting Operational Environmental Satellite System, or NPOESS, tri-agency effort among NOAA, NASA and the Department of Defense. Through the NOAA-NASA partnership, another polar-orbiting satellite called the NPOESS Preparatory Project is scheduled to launch in late 2011. It will demonstrate the capabilities of next-generation sensors and provide continuity with NASA's Earth Observing System satellites. The NOAA-NASA team also will build, launch and operate two more polar satellites under the Joint Polar Satellite System. The satellites are planned to be ready for launch in 2015 and 2018.

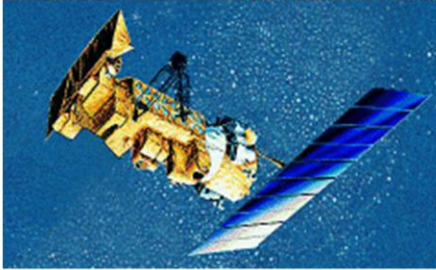
NOAA and NASA also are working to launch the next generation GOES-R series of satellites, beginning in 2015. These spacecraft will have twice the clarity of today's GOES and provide

more than 20 times the information.

POES satellites include: [Defense Meteorological Satellite Program \(DMSP\)](#), Landsat, SPOT and [NOAA Polar-orbiting Operational Environmental Satellites \(NPOES\)](#). The [DMSP](#) and [NPOES](#) satellites are operational meteorological satellites. Imagery from successive orbits overlay each other, providing global daily coverage from each satellite. Commercial polar orbiters like Landsat and SPOT, on the other hand, are intended for geophysical remote sensing, with an emphasis on high-resolution and multispectral imagery, at the cost of daily global coverage.

NOAA Polar-orbiting Operational Environmental Satellites (POES) are three-axis-stabilized spacecrafts that are launched into an orbit 830-870 kilometers high, constantly circling the Earth in an almost north-south orbit, passing close to both poles. POES satellites from NOAA-6 offer 4 or 5 channel multispectral daily repetitive global coverage. Image provided by: National Climatic Data Center. The NOAA-12 -14 belong to the TIROS series known as the advanced Television Infrared Observing System satellite (The first meteorological satellite was one of the TIROS family).

What is Advantage of Polar Orbit?



POES Planning Launch Schedule



NOAA 19

Feb. 2, 2009

METOP - B (am)

May 23, 2012

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The POES orbit (above) relative to the Earth's surface is sun-synchronous. Its track is due to a combination of the orbital plane of the satellite coupled with the rotation of the Earth beneath the satellite. The orbit is slightly tilted towards the northwest and does not actually go over the poles. The red path follows the earth track of the satellite, the transparent overlay indicates the coverage area for the Advanced Very High Resolution Radiometer (AVHRR) imaging instrument carried by NOAA/POES satellites. This instrument scans a swath roughly 3000 kilometers wide.

The POES satellite system offers the advantage of daily global coverage, by making nearly polar orbits roughly 14.1 times daily. Since the number of orbits per day is not an integer the sub orbital tracks do not repeat on a daily basis, although the local solar time of each satellite's passage is essentially unchanged for any latitude. Currently in orbit we have a morning and afternoon satellite, which provide global coverage four times daily. The POES system includes the Advanced Very High Resolution Radiometer (AVHRR) and the Tiros Operational Vertical Sounder (TOVS).

Because of the polar orbiting nature of the POES series satellites, these satellites are able to collect global data on a daily basis for a variety of land, ocean, and atmospheric applications. Data from the POES series supports a broad range of environmental monitoring applications including weather analysis and forecasting,

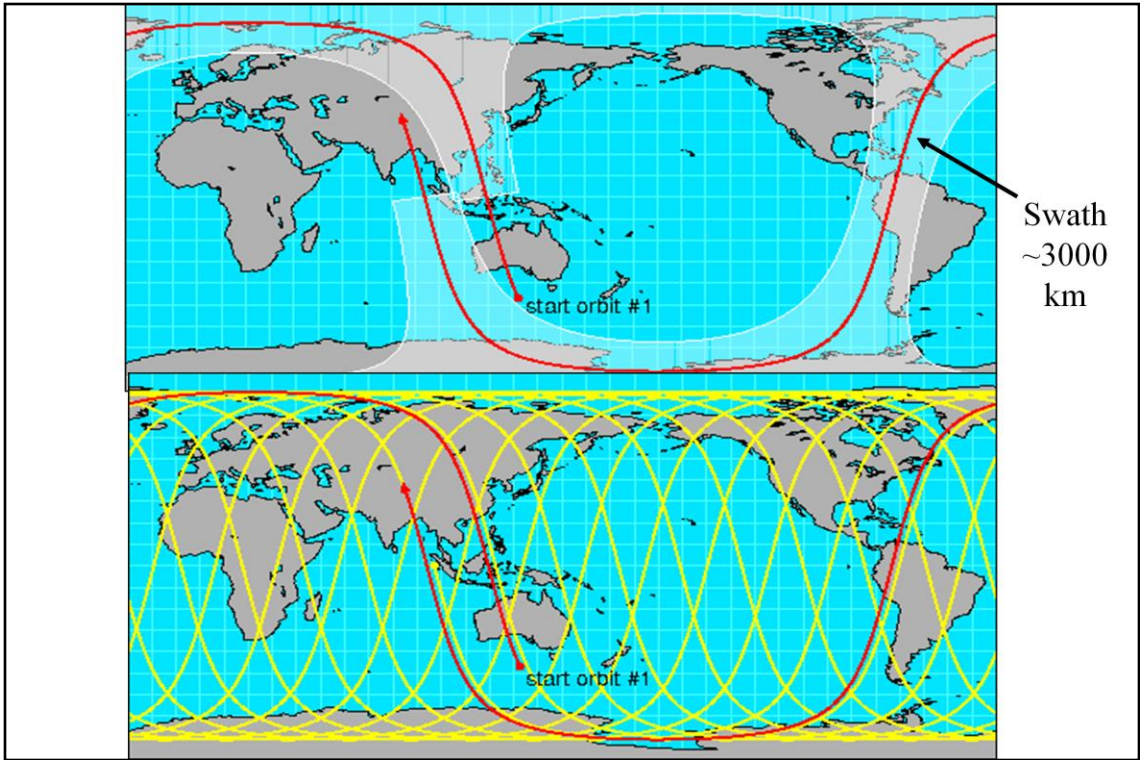
climate research and prediction, global sea surface temperature measurements, atmospheric soundings of temperature and humidity, ocean dynamics research, volcanic eruption monitoring, forest fire detection, global vegetation analysis, search and rescue, and many other applications.

Initial Joint Polar-Orbiting Operational Satellite System (IJPS)

The IJPS series of missions constitute a joint European/United States polar orbiting satellite system that, from the ocean remote sensing perspective, will supplement and continue the SST/Aerosol time series from the POES AVHRR. The IJPS data will provide enhanced resolution SST products. IJPS will also include the Advanced Scatterometer (ASCAT) which will provide, for the first time, an operational scatterometer for measuring ocean surface winds. As operational missions, continuous efforts are required to maintain the operational vicarious in-situ calibrations, as well as inter-calibrate with the existing POES AVHRR instruments.

The POES system includes the Advanced Very High Resolution Radiometer (AVHRR) and the Tiros Operational Vertical Sounder (TOVS).

NOAA-N Prime is the last in the K, L, M, N and N Prime series of satellites (it became NOAA 19 after it was launched). These satellites have served the nation well since 1960, when the world's first weather satellite was launched by the National Aeronautics and Space Administration (NASA). In 1978, TIROS-N was launched, revolutionizing weather satellite capabilities. NOAA has worked with NASA to continuously improve the TIROS satellites, and in 1983 began the Advanced TIROS-N (ATN) program. NOAA-N Prime carries a suite of instruments that provides critical global data for weather and climate predictions. Like its predecessors, NOAA-N Prime will provide 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. NOAA-N Prime is part of the international satellite-aided search and rescue missions which have been credited with saving over 22,000 lives since 1982. NOAA is dedicated to enhancing economic security and national safety through research and prediction of weather and climate-related events and by providing environmental stewardship of the nation's coastal and marine resources.



1st light (image) AVHRR from N-19 (formally N') over Atlantic Coast, Feb. 6, 2009 at 1814 UTM

Channels 1, 2



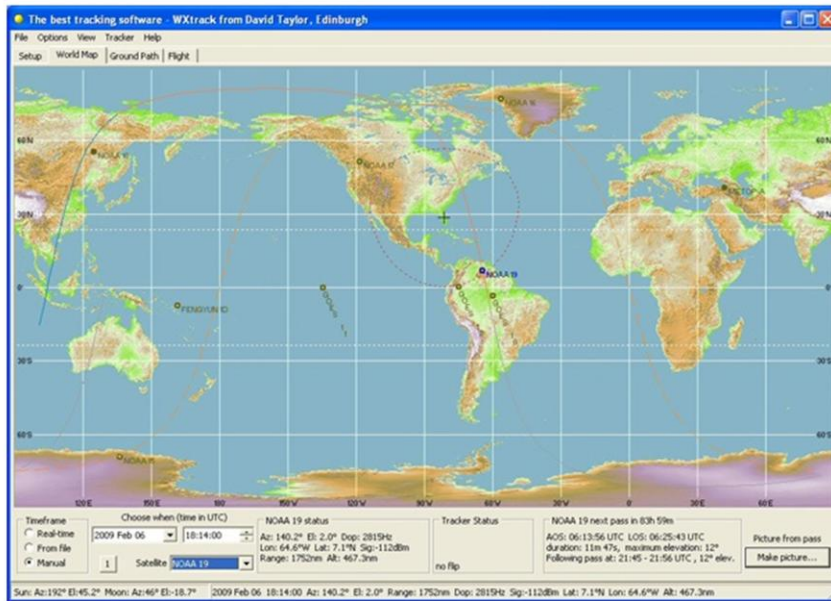
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This NOAA-19 Advanced Very High Resolution Radiometer (AVHRR/3) Automatic Picture Transmission (APT) image was taken in by Fred E. Piering from orbit 4 on February 6, 2009 at 1814 Zulu Time (1:14 p.m. EST). APT imagery has nearly equal geometric resolution of 4 km (2.4 mile) along the scan line.

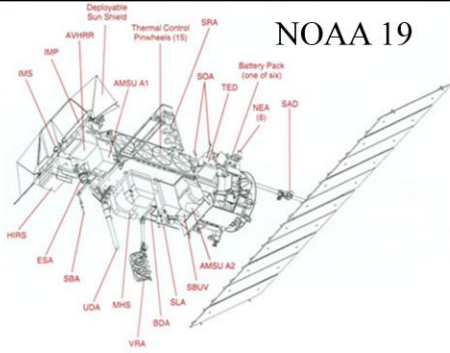
Piering used a home built antenna and receiver. He describes himself as weather satellite hobbyist and has been active in APT data capture since 1971. Among the areas recognized in this image are the northern tip of South America, Cuba, the eastern Gulf of Mexico, Florida, the Chesapeake Bay, the Great Lakes, the east coast of the United States and Canada.

The dual images are from Channels 1 and 2 of the AVHRR/3. The National Oceanic and Atmospheric Administration NOAA-N Prime spacecraft lifted off at 2:22 a.m. PST on February 6, 2009 onboard a NASA Delta II 7320-10 Space Launch Vehicle. NOAA-N Prime was renamed NOAA-19 after achieving orbit.

Location of NOAA 19 at time of First Light Image



NOAA 19



Advanced Very High Resolution Radiometer (AVHRR/3)



Advanced Microwave Sounding Unit (AMSU)



Solar Backscatter Ultraviolet Radiometer (SBUV/2)



High Resolution Infrared Sounder (HIRS)



Space Environment Monitor (SEM-2)



Microwave Humidity Sounder (MHS)

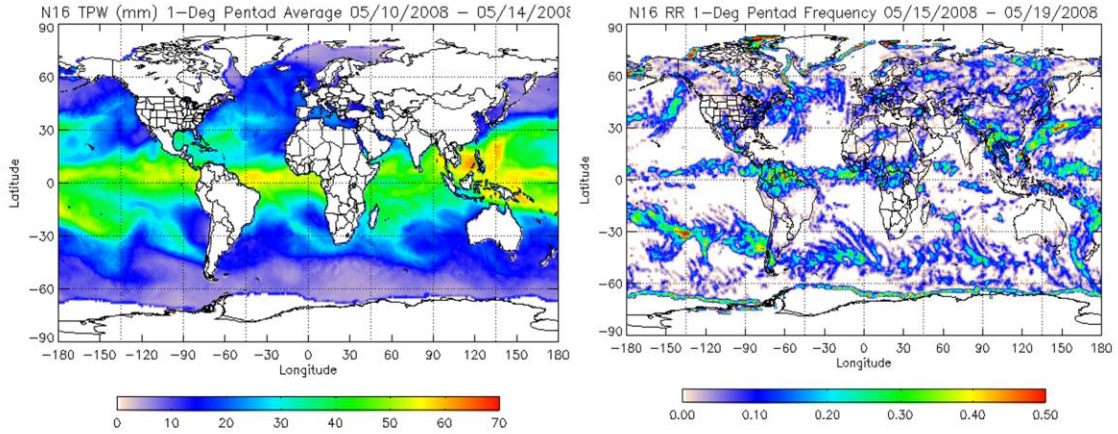


Search and Rescue Repeater and Processor (SARR and SARP)



Solid State Recorder (SSR) and Digital Tape Recorder (DTR)

NOAA-16 AMSU Climate Products



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AMSU is dedicated to the retrieval of near-real-time operational surface and precipitation products using antenna temperatures from the AMSU-A and AMSU-B/MHS instruments on board of NOAA's KLMNN series and the EUMETSAT Polar Systems (EPS) MetOp series polar-orbiting satellites. This project has advanced from 5 products at its Day-1 phase to 9 products at the Day-2 phase. The current Day-2 MSPPs products include: **rain rate and falling snow, total precipitable water, cloud liquid water, snow cover, snow water equivalent, sea ice concentration, ice water path, emissivity (23.8 GHz, 51.4 GHz, and 20.3 GHz), and land surface temperature**. NOAA-15 (or NOAA-K), which was launched on May 13, 1998, is the first in the series to support microwave instruments, AMSU-A and AMSU-B, for the generation of hydrological products in cloudy regions where visible and infrared instruments have decreased capability. NOAA-16 (or NOAA-L) was launched on September 21, 2000, NOAA-17 (or NOAA-M) on June 24, 2002, NOAA-18 (or NOAA-N) on May 20, 2005, and EUMETSAT's MetOp-A (or MetOp-2) on October 19, 2006.

AMSU-A is a 15-channel cross-track, stepped-line scanning, total power microwave radiometer. The instrument has an instantaneous field-of-view of 3.3o at the half-power points providing a nominal spatial resolution at nadir of 48 km (29.8 mi). The antenna provides a cross-track scan, scanning +48.5o(-48.5o) from nadir with a total of 30 Earth fields-of-view per scan line. This instrument completes one scan every 8/3 seconds.

AMSU-B is a 2-channel cross-track, continuous line scanning, total power microwave radiometer. The instrument has an instantaneous field-of-view of 1.1o. Spatial resolution at nadir is nominally 16 km (9.94 mi). The antenna provides a cross-track scan, scanning +48.95o(-48.95o) from nadir with a total of 90 Earth fields-of-view per scan line. This instrument completes one scan every 8/3 seconds.

MHS is a 2-channel cross-track, continuous line scanning, total power microwave radiometer. The instrument has an instantaneous field-of-view of 1.1o. Spatial resolution at nadir is nominally 17 km (10.56 mi). The antenna provides a cross-track scan, scanning +50o(-50o) from nadir with a total of 90 Earth fields-of-view per scan line. This instrument completes one scan every 8/3 seconds.

These are ocean algorithms for TPW (FV1, not expected to know this information).

$$L = a_0 \ln(T_s - TB_2) - a_1 \ln(T_s - TB_1) - a_2$$

$$V = b_0 \ln(T_s - TB_1) - b_1 \ln(T_s - TB_2) - b_2$$

where L is vertically integrated cloud liquid water ($L = \int_0^{\tau} \rho_w dz$), V is vertically integrated water vapor ($V = \int_0^{\tau} \rho_w dz$), and

$$a_0 = 0.5k_{22} / (k_{22}k_{21} - k_{21}k_{22})$$

$$a_1 = k_{21} / k_{22}$$

$$a_2 = 2.0k_{22} + a_1k_{21} / m + (1.0 - a_1) \ln(T_s) + \ln(1.0 - \epsilon_{s1}) - a_0 \ln(1.0 - \epsilon_{s2})$$

$$b_0 = k_{22} / (k_{22}k_{21} - k_{21}k_{22})$$

$$b_1 = k_{21} / k_{22}$$

$$b_2 = -2.0k_{21} + b_1k_{21} / m + (1.0 - b_1) \ln(T_s) + \ln(1.0 - \epsilon_{s1}) - b_0 \ln(1.0 - \epsilon_{s2})$$

where ϵ is sea surface emissivity, k_1 is water vapor mass absorption coefficient, and k_2 is cloud liquid water mass absorption coefficient. Coefficient k_2 can be derived from the following relationship

$$\tau_2 = k_2 V$$

There is a similar relationship for coefficient k_1 :

$$\tau_1 = k_1 L$$

Using Rayleigh's approximation, one can express k_1 in terms of cloud layer temperature, T_c , as

$$k_1 = a_3 + b_3 T_c + c_3 T_c^2$$

Oxygen optical thickness is parameterized as a function of sea surface temperature through

$$\tau_2 = a_4 + b_4 T_s$$

Rain rate is computed based on an IWP and rain rate relation derived from the **MMS cloud model data**.

$$RR = a_5 + a_6 IWP + a_7 IWP^2$$

where the coefficients a_5 to a_7 are given in the table below.

Thorough validation of the Day-2 rain rate algorithm revealed a strong positive bias over oceans and a weaker negative bias over land. In addition, a non-uniform distribution of rain rates existed due to the problems noted in the IWP algorithm (see above). Finally, the maximum allowed rain rate of 20 mm/hr was not realistic and was attributed to the relationship used to convert IWP to rain rate. The improved algorithm has incorporated the following changes:

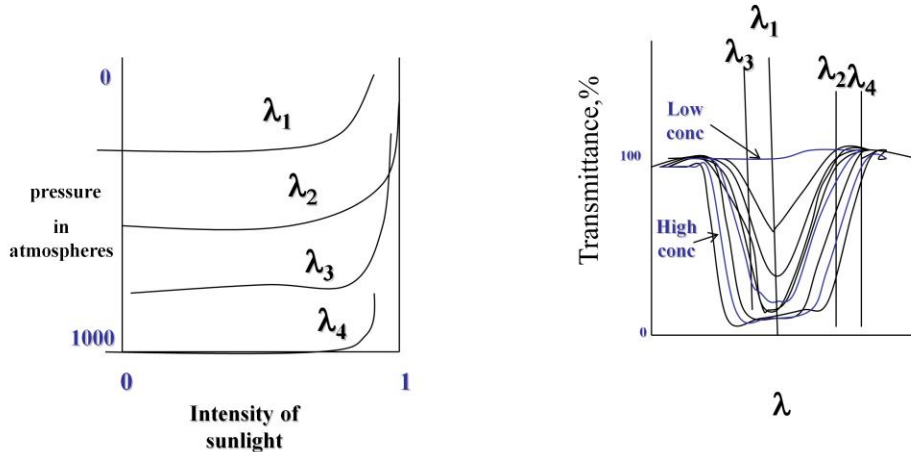
A "convective index" (CI) (e.g., weak, moderate and strong) is computed by using the three 183 GHz channels by examining differences between them; the larger the depressions are at 183+1, the deeper the convection.

Depending upon the convective index, rain rate is computed using different coefficients (note table below).

The maximum allowed rain rate is 30 mm/hr.

Remote Sensing Sounding Basics

Variation in direct beam sunlight in and near an absorption band of a trace gas



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Absorption increases with concentration of water vapor and the volume of the gas layer which determines the transmittance of energy through the atmospheric profile. The atmosphere is not homogenous through its profile and differences in the concentration of water vapor occurs, thus the transmittance will change faster in some regions of the profile as compared to others. This is quantified by the derivative of transmittance with respect to atmospheric pressure (height) for different wavelengths. Thus for each wavelength, the radiation received at the sensor is predominantly comes from a different altitude. Moreover, if the temperature at each level is known and the pressure is known, than it is possible to estimate the concentration of the water vapor (or other gases). If the bands are placed with respect to other gasses, such as CO₂, than their concentrations can be estimated.

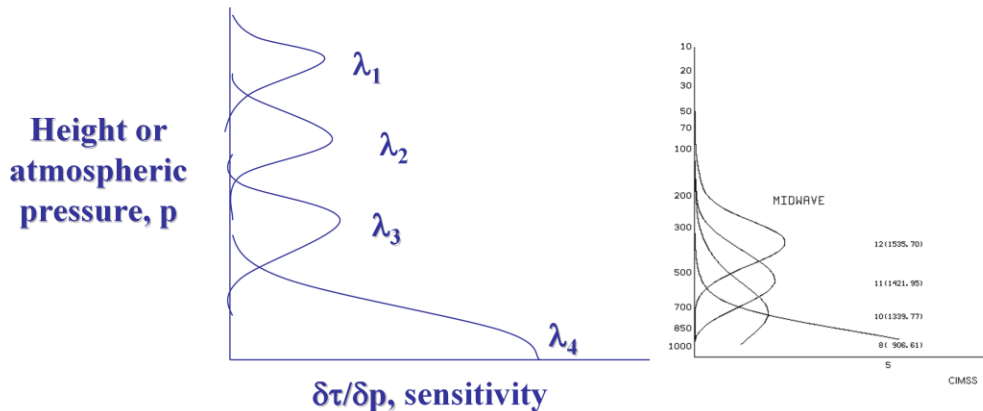
The real meaning of this function is to show from where *most* of the radiation is coming from and it's therefore called *weighting function*. As the absorption has a bell shape it follows that, for each wavelength, the radiation received is coming from a different altitude. This is exactly the purpose of sounding. As the wavelength employed gets closer to a window region, the atmosphere becomes more and more transparent and it's possible to obtain information from lower layers.

Provided the temperature at each level is known, it is then possible to retrieve the

concentration of a gas of interest for various heights. There are, however, some constraints. To begin with, the absorption band must be selected very carefully to avoid interference from other gases; this may limit the choice to regions that are less than optimal for many reasons. Second, the number of observable layers is limited by the number of wavelength used, as well as the precision with which the temperature profile is known. Finally, as the weighting function moves closer to the surface, emissions from the latter cannot be considered negligible any more.

Water Vapor

The basics behind sounding



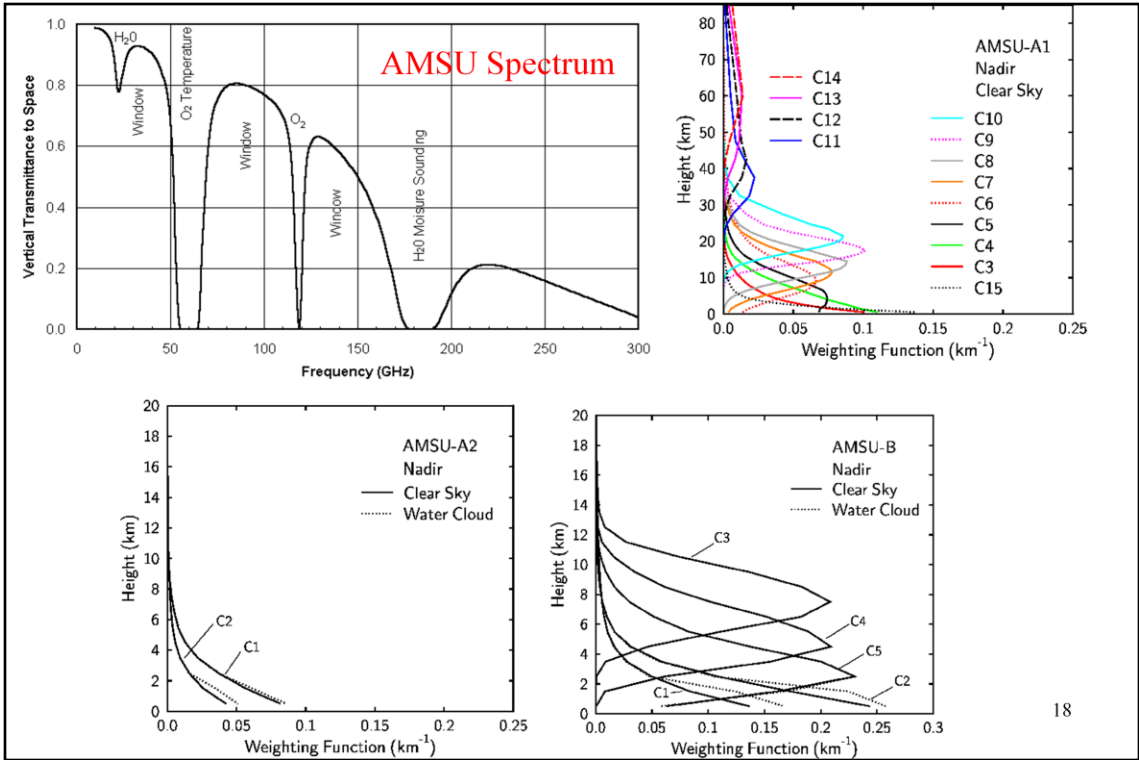
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Sounding is a method used in remote sensing as opposed to *surface observation*. The focus of the remote observer is shifted from the (earth) surface to the medium that is in between, the atmosphere. Without entering in mathematical detail, the radiation measured at some receiver (e.g. satellite) results from the contribution of both the radiation emitted from the surface and that emitted from the atmosphere itself as a result of its above-zero temperature.

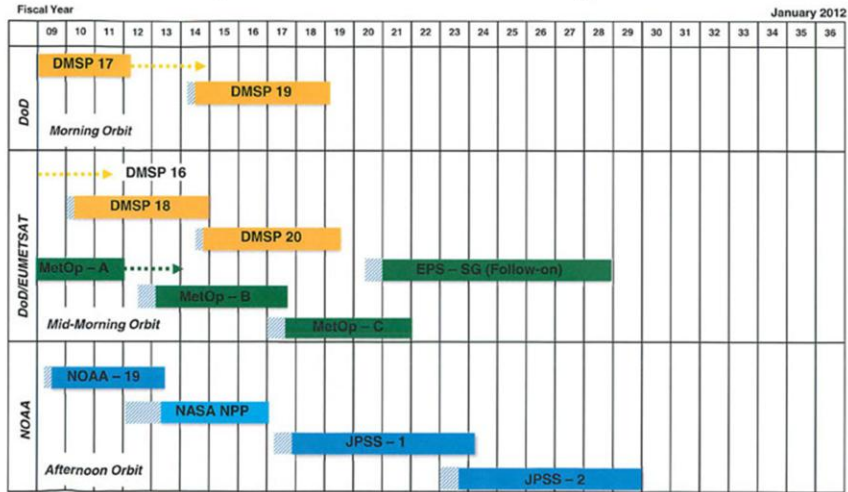
Each of the gases that comprise the atmosphere has a different ability to absorb the radiation, or let it through, which varies with the radiation wavelength. Wavelength regions where absorption for the whole atmosphere is very low are called *window regions* and are obviously suitable for earth-surface observation. Regions where a significant absorption occurs for some gas are called *absorption bands* for that particular gas and may be used to get information about it.

It is easy to understand that absorption increases with the concentration of the gas and the thickness of the gas layer. This two variables determine a parameter called *transmittance*. As the thickness of the gas layer keeps increasing, going from the top of the atmosphere to the surface, increases, the transmittance is expected to decrease accordingly. It will, however, decrease more steeply in some regions than others, depending on the wavelength. This concept of *steepness* is expressed mathematically with the use of a derivative. The figure below shows the derivative of the transmittance for several wavelengths, where the vertical axis represents atmospheric pressure as a useful substitute for height (1000 is ground level).

Absorption increases with concentration of water vapor and the thickness of the gas layer. These variables determine the transmittance of thermal IR through the atmospheric profile. If the wavelength is located in an atmospheric window and little absorption is occurring then the energy will penetrate further down towards the surface. If the wavelength is located at a strong water absorption feature, then the transmittance is low and the energy will not penetrate very far. Thus for each wavelength, the radiation received at the sensor comes from a different altitude. If the temperature and the pressure at each level are known, it is possible to estimate the concentration of the water vapor (or other gas).



Continuity of NOAA's Polar (Primary) Operational Satellite Programs



Approved: *[Signature]*
 Assistant Administrator for
 Satellite and Information Services

Signed on: 2-07-2012

.....▶ Satellite is operational beyond design life [Hatched Box] Post Launch Test
 [Blue Box] Operational

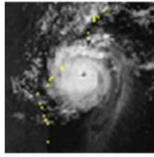


Office of Satellite Operations

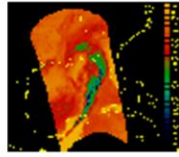
NOAA 17 Spacecraft Status Summary Subsystem Status:
 Click on the subsystem name to get detailed status for that subsystem.

Subsystem	Description	Status	Status Color	Meaning
ADACS	Attitude Determination and Control System	Green		
AMSU-A1	Advanced Microwave Sounding Unit -A1	Red		
AMSU-A2	Advanced Microwave Sounding Unit -A2	Green		
AMSU-B	Advanced Microwave Sounding Unit -B	Orange		
AVHRR	Advanced Very High Resolution Radiometer	Orange		
CCS	Command and Control System	Green		
COMM	Communications	Yellow		
DCS	Data Collection System	Green		
DHS	Data Handling System	Green		
DPLY	Deployment Subsystem			
EPS	Electrical Power System	Green	GREEN	= Operational (or capable of)
FSW	Flight Software			
GROUND	Polar Acquisition and Command System (PACS)			
HIRS	High Resolution Infrared Radiation Sounder	Green	YELLOW	= Operational with limitations (or Standby)
RCS	Reaction Control Subsystem			
SARP	Search and Rescue Processor	Green	ORANGE	= Operational with Degraded Performance
SARR	Search and Rescue Repeater	Green	RED	= Not Operational
SBUV	Solar Backscatter ultraviolet Radiometer	Green	BLUE	= Functional but Turned Off
SEM	Space Environment Monitor	Green		
THERM	Thermal Control System	Green	BLANK	= No Status Reported

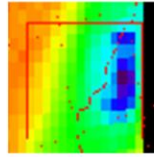
Defense Meteorological Satellite Program (DMSP)



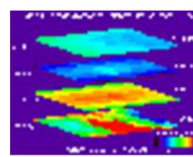
OLS:
Operational Line
Scanner



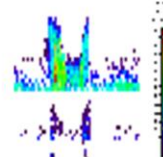
SSM/I
microwave
imager



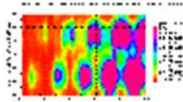
SSMT/2-
Atmospheric
Water Vapor
Profiler



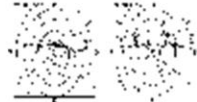
SSM/T
Atmospheric
Temperature
Profiler



SSMJ/4
Precipitation
electron and
ion
spectrometer



SSES Ion
Scintillation
Monitor



SSM
Magnetomer

21

The DMSP program is operated by the [Air Force Space and Missile Systems Center \(SMC\)](#).

DMSP monitors the meteorological, oceanographic, and solar-terrestrial physics environments.

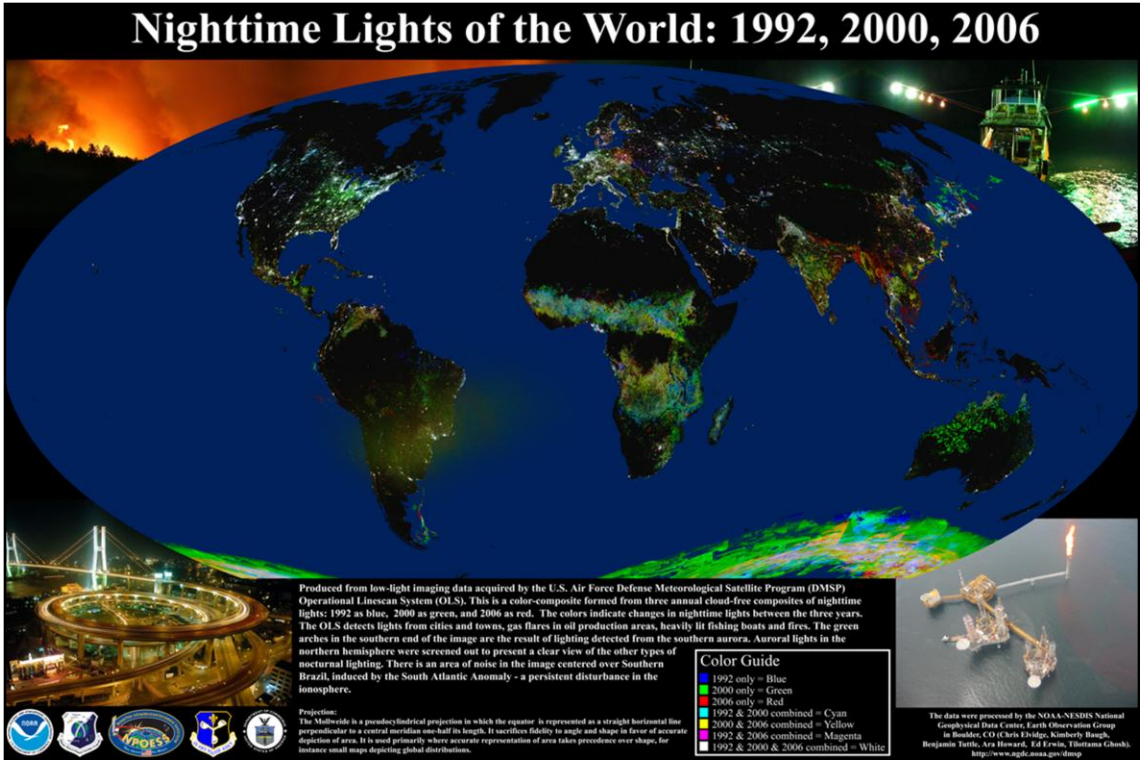
Each DMSP satellite has a 101 minute, sun-synchronous near-polar orbit at an altitude of 830km above the surface of the earth. The visible and infrared sensors (OLS) collect images across a 3000km swath, providing global coverage twice per day. The combination of day/night and dawn/dusk satellites allows monitoring of global information such as clouds every 6 hours. The microwave imager (MI) and sounders (T1, T2) cover one half the width of the visible and infrared swath. These instruments cover polar regions at least twice and the equatorial region once per day. The space environment sensors (J4, M, IES) record along-track plasma densities, velocities, composition and drifts.

The data from the DMSP satellites are received and used at operational centers continuously. The data are sent to the [National Geophysical Data Center's Solar Terrestrial Physics Division](#) Earth Observation Group ([NGDC/STP/EOG](#)) by the [Air Force Weather Agency \(AFWA\)](#) for creation of an archive.

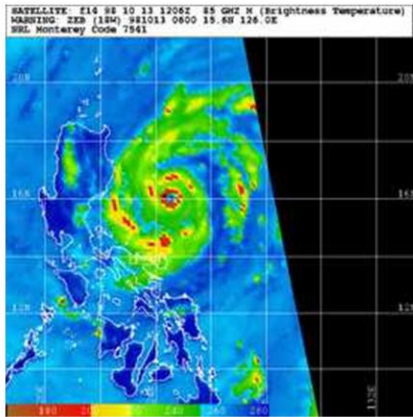
Currently, data from 4 satellites (3 day/night, 1 dawn/dusk) are added to the archive each day.

OLS: Operational Line Scanner





The Changing Nighttime Lights of the World poster depicts the lights from cities, gas flares, fishing boats, the southern aurora, and fires. The data includes the years 1992, 2000, and 2006.

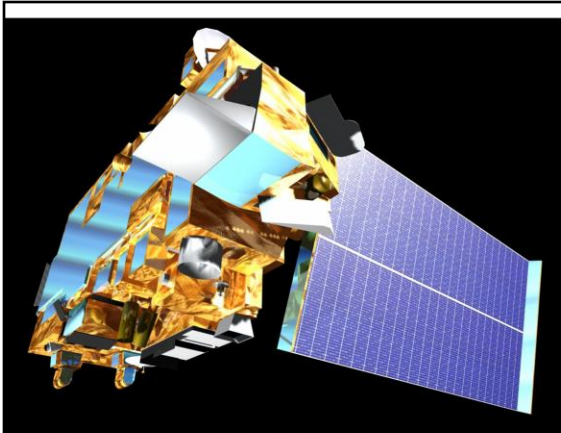


Graphic Image Maps for SSM/I

Each daily, 3-day, weekly and monthly graphic image map displays one geophysical parameter, 10 meter Surface Wind Speed (W), Columnar Water Vapor (V), Cloud Liquid Water (L), or Rain Rate (R).

The daily maps display the local morning or evening satellite passes separately. The date of the data displayed is the date at Greenwich Mean time the data were collected.

	Daily	3-Day	Weekly	Monthly	Units
Surface Wind Speed:	15	15	15	12	meters/second
Atmospheric Water Vapor:	60	60	60	60	millimeters
Cloud Liquid Water:	0.3	0.3	0.3	0.24	millimeters
Rain Rate:	20	10	5.0	2.0	millimeters/hour



The NASA Terra Satellite

ASTER: <http://asterweb.jpl.nasa.gov/>

CERES: [\[www.larc.nasa.gov/ceres/\]\(http://www.larc.nasa.gov/ceres/\)](http://asd-</p></div><div data-bbox=)

MISR: <http://mISR.jpl.nasa.gov/>

MODIS: <http://modis.gsfc.nasa.gov/>

MOPITT:

<http://www.acd.ucar.edu/mopitt/>

The NASA Aqua Satellite

<http://aqua.nasa.gov/about/>

AIRS /instrument_airs.php

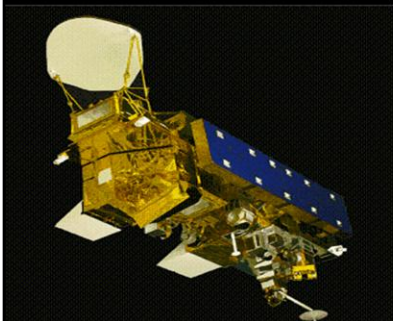
SMSU-A /instrument_amsu.php

HSB /instrument_hsb.php

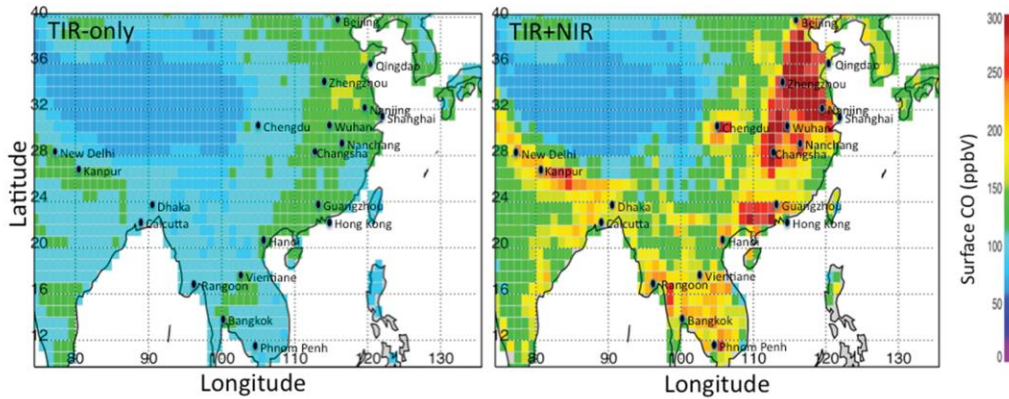
AMSR-E /instrument_amsr.php

MODIS /instrument_modis.php

CERES /instrument_ceres.php



MOPITT Surface CO averages for September–November, 2005–2008 in central/east Asia.

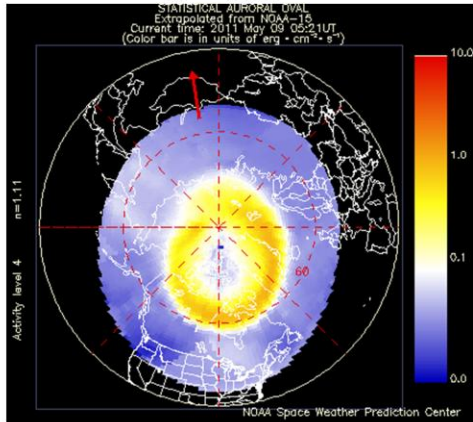


MOPITT developed the first multispectral retrievals (exploiting coincident thermal-infrared and nearinfrared observations) of CO from space

Distribution of Aurora over the Poles

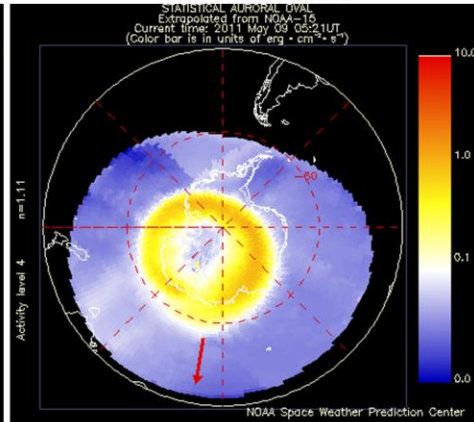
Center time of most recent polar pass
measurement: 2011 May 9 0413 UT

$n = 1.11$



Center time of most recent polar pass
measurement: 2011 May 9 0313 UT

$n = 1.11$



The current extent and position of the auroral oval in the Northern & Southern Hemisphere, extrapolated from measurements taken during the most recent polar pass of the NOAA POES satellite. 27

The current extent and position of the auroral oval at each pole, extrapolated from measurements taken during the most recent polar pass of the NOAA POES satellite.

The red arrow in the plot, that looks like a clock hand, points toward the noon meridian.

NOAA continually monitors the power flux carried by the protons and electrons that produce aurora in the atmosphere. SWPC has developed a technique that uses the power flux observations obtained during a single pass of the satellite over a polar region (which takes about 25 minutes) to estimate the total power deposited in an entire polar region by these auroral particles. The power input estimate is converted to an auroral activity index that ranges from 1 to 10.

This presentation provides an estimate of the location, extent, and intensity of aurora on a global basis. For example, the presentation gives a guide to the possibility that the aurora is located near a given location in the northern hemisphere under the conditions that existed at the time of the most recent polar satellite pass.

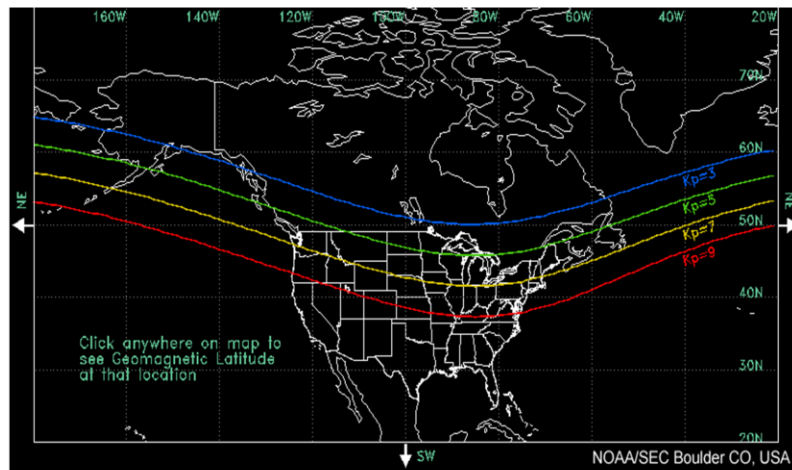
Normalization factor (n)

A normalization factor of less than 2.0 indicates a reasonable level of confidence in the estimate of power. The more the value of n exceeds 2.0, the less confidence should be placed in the estimate of hemispheric power and the activity level.

The process to estimate the hemispheric power, and the level of auroral activity, involves using this normalization factor which takes into account how effective the satellite was in sampling the aurora during its transit over the polar region. A large (> 2.0) normalization factor indicates that the transit through the aurora was not very effective and the resulting

estimate of auroral activity has a lower confidence.

Geomagnetic Latitude to See Aurora's of Different Intensity



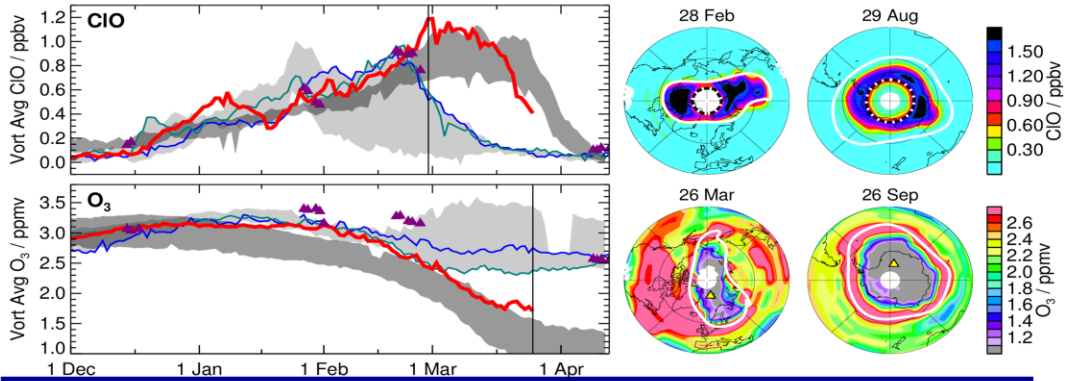
To Reach Central California Requires a KP of 10+

28

NOAA Polar-orbiting Operational Environmental Satellite (POES) continually monitor the power flux carried by the protons and electrons that produce aurora in the atmosphere. Measures the power flux observations obtained during a single pass of the satellite over a polar region (which takes about 25 minutes). Your chance of seeing an aurora depends on chance of seeing an aurora, you need to know the level of geomagnetic activity at the time you are viewing.

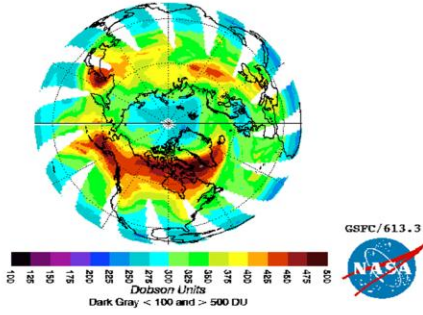
Aura Satellite observations of unprecedented 2011 Arctic ozone loss

Unusually prolonged cold conditions in Spring 2011-- Arctic stratosphere promoted levels of chlorine activation and chemical ozone loss never before observed in the Arctic comparable to those in the Antarctic in some winters

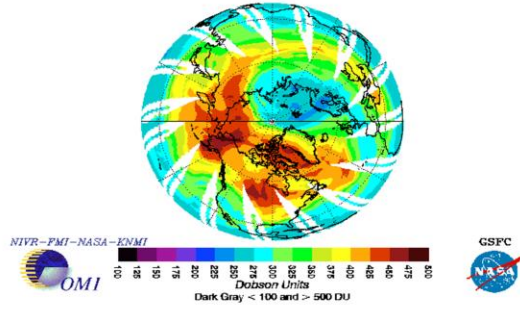


Aura Microwave Limb Sounder (MLS) observations of Arctic vortex average ClO and Ozone at 485 K (~18km) in 2010/2011 (red) compared to 2004/2005 (blue), 2007/2008 (green), the 2004–2010 envelope (pale grey) and UARS MLS for 1996/1997 (purple triangles). Darker grey shading shows the comparable record for the Antarctic (shifted by six months). Maps show selected 2011 days in the Arctic (left) compared to equivalent 2010 days in Antarctic (right)

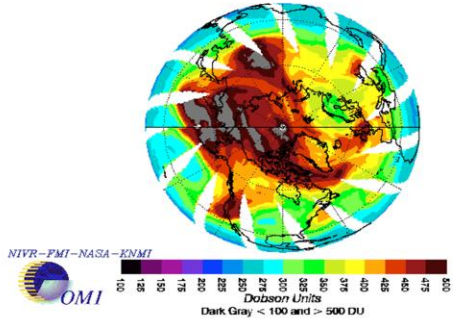
EP/TOMS Corrected Total Ozone for Mar 31, 1997



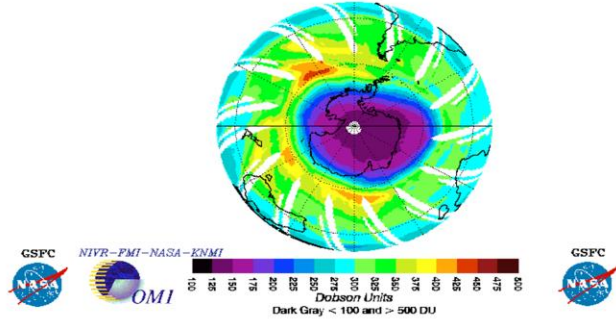
OMI Total Ozone for Mar 31, 2011



OMI Total Ozone for Mar 31, 2010



OMI Total Ozone for Sep 30, 2010



Joint Polar Satellite System (JPSS) Instruments

CrIS: The Cross-track Infrared Sounder, with ATMS, collects atmospheric data to calculate temperature and moisture profiles at high (~ daily) temporal resolution.

OMPS: The Ozone Mapping and Profiler Suite monitors ozone from space.

ATMS: The Advanced Technology Microwave Sounder with CrIS, will profile atmospheric temperature and moisture.



VIIRS: The Visible/Infrared Imager/Radiometer Suite collects visible/infrared imagery and radiometric data.

CERES: space and time distribution of the Earth's Radiation Budget components

TSIS: Total [solar] Irradiance Monitor (TIM) and the solar Spectral Irradiance Monitor (SIM), over 0.2 to 2.7 μm .

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CrIS

Cross-track Infrared Sounder (CrIS) is the first in a series of advanced operational sounders that will provide more accurate, detailed atmospheric temperature and moisture observations for weather and climate applications. This high-spectral resolution infrared instrument will take 3-D pictures of atmospheric temperatures, water vapor and trace gases. It will provide over 1,000 infrared spectral channels at an improved horizontal spatial resolution and measure temperature profiles with improved vertical resolution to an accuracy approaching 1 Kelvin (the absolute temperature scale). This information will help significantly improve climate prediction and both short-term weather "nowcasting" and longer-term forecasting. It will also provide a vital tool for National Oceanic and Atmospheric Administration (NOAA) to take the pulse of the planet continuously and assist in understanding major climate shifts. The CrIS instrument is developed by the [ITT Corporation](#), Ft Wayne, Indiana.

OMPS

Ozone in the atmosphere keeps the Sun's ultraviolet radiation from striking the Earth. The Ozone Mapping and Profiler Suite (OMPS) will measure the concentration of ozone in the atmosphere, providing information on how ozone concentration varies with altitude. Data from OMPS will continue three decades of climate measurements of this important parameter used in global climate models. The OMPS measurements also fulfill the U.S. treaty obligation to monitor global ozone concentrations with no gaps in coverage. OMPS is comprised of two sensors, a nadir sensor and limb sensor. Measurements from the nadir sensor are used to generate total column ozone measurements, while measurements from the limb sensor generate ozone profiles of the along-track limb scattered solar radiance. The OMPS instrument is developed by the [Ball Aerospace & Technologies Corporation](#), Boulder, Colorado.

VIIRS

Visible/Infrared Imager Radiometer Suite(VIIRS) will combine the radiometric accuracy of the Advanced Very High Resolution Radiometer (AVHRR) currently being flown on the NOAA polar orbiters with the high spatial resolution (0.56 km) of the Operational Linescan System (OLS) flown on DMSP. The VIIRS will provide imagery of clouds under sunlit conditions in about a dozen bands, and will also provide coverage in a number of infrared bands for night and day cloud imaging applications. VIIRS will have multi-band imaging capabilities to support the acquisition of high-resolution atmospheric imagery and generation of a variety of applied products including visible and infrared imaging of hurricanes and detection of fires, smoke, and atmospheric aerosols. VIIRS will also provide capabilities to produce higher-resolution and more accurate measurements of sea surface temperature than currently available from the heritage AVHRR instrument on POES, as well as provide an operational capability for ocean-color observations and a variety of derived ocean-color products. The VIIRS instrument is developed by the [Raytheon Company](#), El Segundo, California.

ATMS

The Advanced Technology Microwave Sounder (ATMS) will operate in conjunction with the CrIS to profile atmospheric temperature and moisture. The ATMS is the next generation cross-track microwave sounder that will combine the capabilities of current generation microwave temperature sounders (Advanced Microwave Sounding Unit – AMSU-A) and microwave humidity sounders (AMSU-B) that are flying on NOAA's POES. The ATMS draws its heritage directly from AMSU-A/B, but with reduced volume, mass and power. The ATMS has 22 microwave channels to provide temperature and moisture sounding capabilities. Sounding data from CrIS and ATMS will be combined to construct atmospheric temperature profiles at 1 degree Kelvin accuracy for 1 km layers in the troposphere and moisture profiles accurate to 15 percent for 2 km layers. Higher (spatial, temporal and spectral) resolution and more accurate sounding data from CrIS and ATMS will support continuing advances in data assimilation systems and NWP models to improve short- to medium-range weather forecasts. The ATMS instrument is developed by the [Northrop Grumman Corporation](#), Azusa, California.

CERES

The CERES measurements seek to develop and improve weather forecast and climate models prediction, to provide measurements of the space and time distribution of the Earth's Radiation Budget (ERB) components, and to develop a quantitative understanding of the links between the ERB and the properties of the atmosphere and surface that define that budget. The observations from CERES are essential to understanding the effect of clouds on the energy balance (energy coming in from the sun and radiating out from the earth), which is one of the largest sources of uncertainty in our modeling of the climate.

TSIS

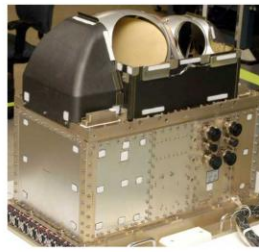
TSIS measures the variability in the Sun's total output using two sensors. The Total Irradiance Monitor (TIM) is a broadband measurement while Spectral Irradiance Monitor (SIM) measures the spectral distribution of the solar irradiance between 0.2 & 2.7 μm . There is no operational heritage, but this instrument suite will continue the capabilities from the research measurements of TSIS on NASA's SORCE mission.

Joint Polar Satellite System: **Suomi National Polar-orbiting Partnership
(Suomi NPP)**

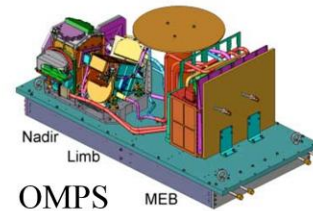
Core Suite of Weather and Climate Instruments



CrIS



ATMS



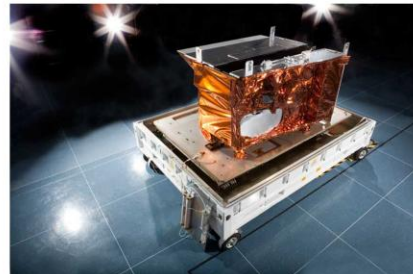
OMPS MEB



NASA Suomi NPP
Preparatory
Program Mission
October 28, 2011



CERES



VIIRS

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On Feb. 1, 2010, the White House restructured the National Polar-orbiting Operational Environmental Satellite System, or NPOESS, tri-agency effort among NOAA, NASA and the Department of Defense. Through the NOAA-NASA partnership, a polar-orbiting satellite called the NPOESS Preparatory Project (NPP) was launched in late 2011. It will demonstrate the capabilities of next-generation sensors and provide continuity with NASA's Earth Observing System satellites. The NOAA-NASA team also will build, launch and operate two more polar satellites under the **Joint Polar Satellite System**. The satellites are planned to be ready for launch in 2015 and 2018.

The **Cross-track Infrared Sounder (CrIS)** and the Advanced Technology Microwave Sounder (ATMS) will collect atmospheric data to permit the calculation of temperature and moisture profiles at high (~ daily) temporal resolution.

Clouds and Earth's Radiant Energy System, or CERES: monitors the amount of energy entering and exiting the top of the atmosphere.

The **Ozone Mapping and Profiler Suite (OMPS)** monitors ozone from space. OMPS will collect total column and vertical profile ozone data and continue the daily global data produced by the current ozone monitoring systems, the Solar Backscatter Ultraviolet radiometer (SBUV)/2 and Total Ozone Mapping Spectrometer (TOMS), but with higher fidelity. The collection of this data contributes to fulfilling the U.S. treaty obligation to monitor the ozone depletion for the Montreal Protocol to ensure no gaps on ozone coverage.

The **Visible/Infrared Imager/Radiometer Suite (VIIRS)** visible/infrared imagery and radiometric data. Data types include atmospheric, clouds, earth radiation budget, clear-air land/water surfaces, sea surface temperature, ocean color, and low light visible imagery. VIIRS contributes to 23 Environmental Data Records (EDRs) and is the primary instrument for 18 EDRs.

The **Visible Infrared Imager / Radiometer Suite (VIIRS)** will combine the radiometric accuracy

of the Advanced Very High Resolution Radiometer (AVHRR) currently flown on the NOAA polar orbiters with the high (0.65 kilometer) spatial resolution of the Operational Linescan System (OLS) flown on DMSP. The VIIRS will provide imagery of clouds under sunlit conditions in about a dozen visible channels (or frequency bands), as well as provide coverage in a number of infrared channels for night and day cloud imaging applications. VIIRS will have multichannel imaging capabilities to support the acquisition of high resolution atmospheric imagery and generation of a variety of applied products including: visible and infrared imaging of hurricanes and detection of fires, smoke, and atmospheric aerosols. VIIRS will also provide capabilities to produce higher resolution and more accurate measurements of sea surface temperature than currently available from the heritage AVHRR instrument on POES, as well as an operational capability for ocean color observations and a variety of derived ocean color products.

The NPOESS Preparatory Project (NPP) is a joint mission to extend key measurements in support of long-term monitoring of climate trends and of global biological productivity. It extends the measurement series being initiated with EOS Terra and AQUA by providing a bridge between NASA's EOS missions and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) of the Integrated Program Office (IPO). The NPP mission will provide operational agencies early access to the next generation of operational sensors, thereby greatly reducing the risks incurred during the transition. This will permit testing of the advanced ground operations facilities and validation of sensors and algorithms while the current operational systems are still in place. This new system will provide nearly an order of magnitude more data than the current operational system.

NPOESS will provide long-term systematic measurements of key environmental variables beginning about 2009. In preparation for this system, NPP will provide risk reduction for this future operational system and it will maintain continuity of certain environmental data sets that were initiated with NASA's Terra and Aqua satellites. These measurements will be taken by three different sensors; Visible Infrared Imaging spectroRadiometer Suite (VIIRS), Crosstrack Infrared Sounder (CrIS), and Advanced Technology Microwave Sounder (ATMS). These sensors will collect data on atmospheric and sea surface temperatures, humidity soundings, land and ocean biological productivity, and cloud and aerosol properties. This data will be used for long-term climate and global change studies.

NPP Instruments

Visible Infrared Imaging Radiometer Suite, or VIIRS: will survey broad swaths of the land, oceans and air, enabling scientists to monitor everything from phytoplankton and other organisms in the sea, to vegetation and forest cover to the amount of sea ice at the poles.

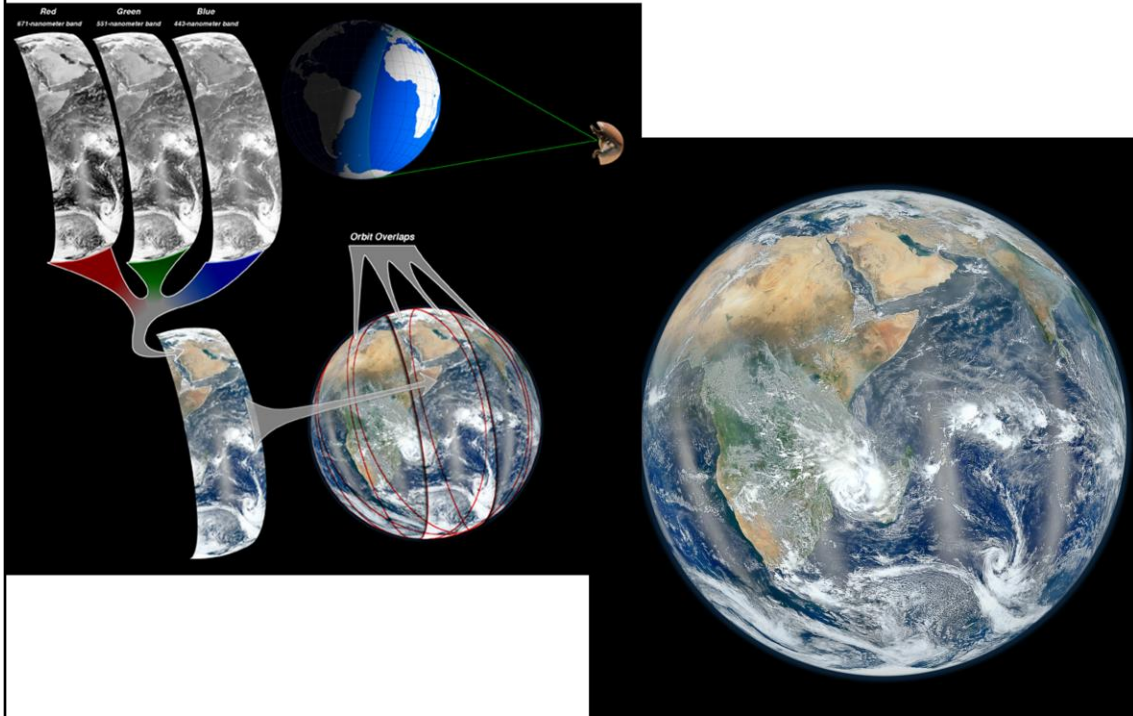
Ozone Mapper Profiler Suite, or OMPS: maps and profiles ozone throughout the atmosphere.

Clouds and Earth's Radiant Energy System, or CERES: monitors the amount of energy entering and exiting the top of the atmosphere.

Cross-track Infrared Sounder, or CrIS: measures temperature profiles with greater resolution, improving climate prediction and both short-and long-term weather forecasting, and scientists' understanding of major climate shifts.

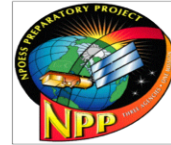
Advanced Technology Microwave Sounder, or ATMS: works in conjunction with CrIS to make detailed vertical profiles of atmospheric pressure, heat and moisture.

VIIRS Eastern Hemisphere Image 02/02/2012

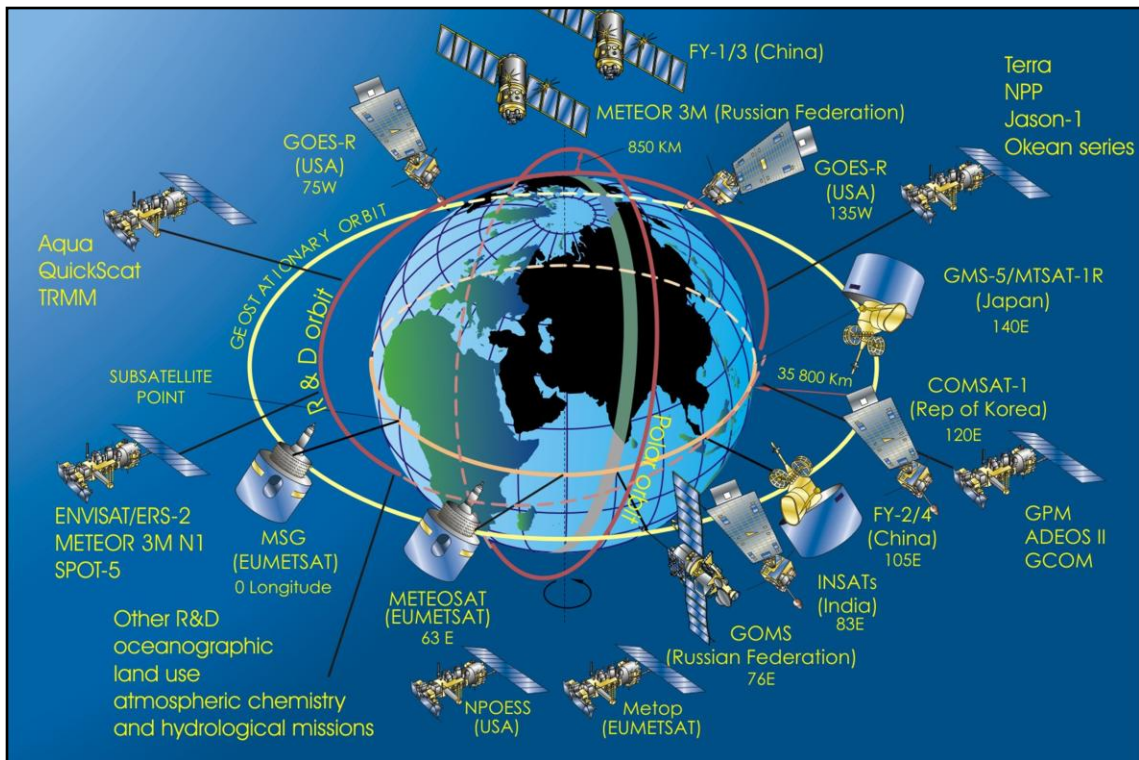


The Suomi NPP satellite is in a polar orbit around Earth at an altitude of 512 miles (about 824 kilometers), but the perspective of the new Eastern hemisphere 'Blue Marble' is from 7,918 miles (about 12,743 kilometers). NASA scientist Norman Kuring managed to 'step back' from Earth to get the big picture by combining data from six different orbits of the Suomi NPP satellite. Or putting it a different way, the satellite flew above this area of Earth six times over an eight hour time period. Norman took those six sets of data and combined them into one image.

Transition of Systematic Measurements (EOS → NPP → NPOESS)



	EOS Era	NPP Era	NPOESS Era
Measurements	24/24 EOS Measurements	14/24 EOS Measurements	14+ EOS Measurements
Instruments:	MODIS, AIRS, AMSU, HSB, CERES, TOMS, OMI, ACRIM, TSIM, SOLSTICE, HIRDLS, MLS, AMSR, EOSP, SeaWiFS, ASTER, ETM+	VIIRS, CrIS, ATMS, OMPS, CERES	VIIRS, CrIS, ATMS, OMPS, ERBS, TSIM, CMIS, GPSOS, SESS, Radar Altimeter, DCS, SARSAT, APS
Algorithms:	NASA funded, PI led teams	EDRs IPO funded; Instrument/SSPR contractor teams with OAT oversight	EDRs IPO funded; Instrument/SSPR contractor teams with OAT oversight
Processing:	EOSDIS / PI Processing (NASA)	<u>Level 1, selected CDRs</u> NASA funded (via AO process)	<u>Level 1, selected CDRs</u> TBD
Archive & Distribution:	Mid Term: EOSIDS Long Term: NOAA (TBR)	EDRs IDPS (IPO) CDRs SDS (NASA) Mid Term: NOAA Long Term: NOAA	EDRs IDPS (IPO) CDRs TBD Mid Term: NOAA Long Term: NOAA
Standards:	NASA led	IPO/NASA/NOAA led	IPO/NOAA led



International Coordinated Weather Satellite Programs

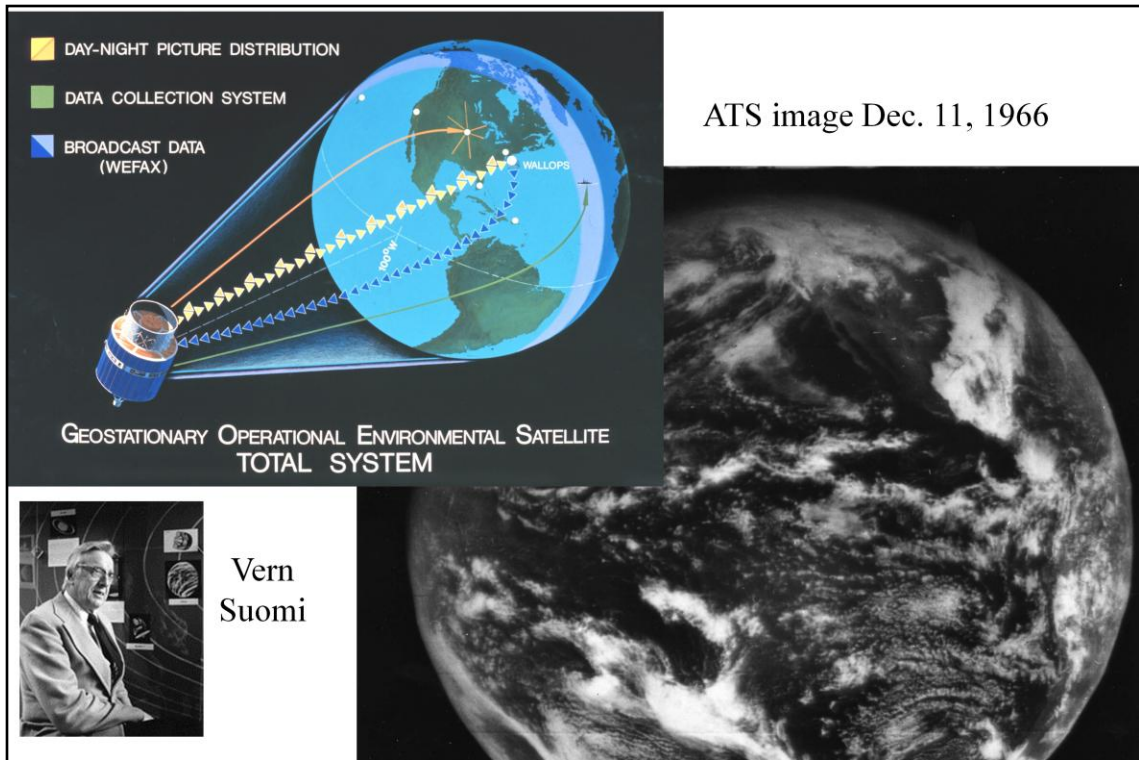
The Environmental Observation Satellite network includes five operational near-polar-orbiting satellites and six operational geostationary environmental observation satellites as well as several Research and Development satellites (See WMO's [Space Programme](#) for current information). Polar orbiting and geostationary satellites are normally equipped with visible and infra-red imagers and sounders, from which many meteorological parameters are derived. Several of the polar-orbiting satellites are equipped with sounders instruments that can provide vertical profiles of temperature and humidity in cloud free areas. Geostationary satellites are used to measure wind velocity in the tropics by tracking clouds and water vapor.

Satellite sensors, communications and data assimilation techniques are evolving steadily so that better use is being made of the vast amount of satellite data. Improvements in numerical modeling in particular, have made it possible to develop increasingly sophisticated methods of deriving the temperature and humidity information directly from the satellite radiances. Research and Development (R&D) satellites comprise the newest constellation in the space-based component of the Global Observational System (GOS). R&D missions provide valuable data for operational use as well as for many WMO supported programmes. Instruments on R&D missions either provide data not normally observed from operational meteorological satellites or improvements to current operational systems.

International Program Cooperation

In the 1980s, NOAA needed to balance the high cost of space systems and the growing need to provide a complete and accurate description of the atmosphere at regular intervals as inputs to numerical weather prediction and climate monitoring support systems. This led NOAA to enter into discussions and agreements at the international level with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). The goal of this cooperation is to provide continuity of measurements from polar orbits, cost sharing, and improved forecast and monitoring capabilities through the introduction of new technologies.

Building upon the POES program, an agreement is in place between NOAA and EUMETSAT on the Initial Joint Polar-orbiting Operational Satellite System (IJPS). This program will include two series of independent but fully coordinated NOAA and EUMETSAT satellites, exchange of instruments and global data, cooperation in algorithm development, and plans for real-time direct broadcast. Under terms of the IJPS agreement, NOAA will provide NOAA-N and NOAA-N' satellites for flights in the afternoon orbit while EUMETSAT makes available METOP-1 and METOP-2 satellites for flights in the mid-morning orbit. The first METOP satellite is was launched Oct. 19, 2006.



ATS image Dec. 11, 1966

The Applications Technology Satellite series was a set of six NASA spacecraft launched from Dec. 7, 1966, to May 30, 1974, created to explore and flight-test new technologies and techniques for communications, meteorological and navigation satellites. ATS was a multi-purpose engineering satellite series, testing technology in communications and meteorology from geosynchronous orbit. The major objective of the early ATS satellites was to test whether gravity would anchor the satellite in a synchronous orbit (22,300 statute miles above the Earth), allowing it to move at the same rate the Earth is turning, thus seeming to remain stationary. Although the ATS satellites were intended mainly as test beds, they also collected and transmitted meteorological data and functioned at times as communications satellites. ATS provided the first color images from space as well as regular cloud cover images for meteorological studies.

ATS spin scan camera (1966) was developed by Verner Suomi, father of modern satellite meteorology at U. Wisconsin (Ph.D. U. Chicago in 1953).

The Spin-Scan Cloud Camera, introduced by Verner Suomi in 1963, represented a revolutionary milestone in satellite instrumentation. This brilliant technical idea formed the scientific foundation for geosynchronous satellite imaging for the world's operational weather services. The Spin-Scan Cloud Camera in geosynchronous orbit made it possible to observe weather systems at intervals as small as a few minutes and hence to measure the dynamics of many phenomena, for example, air motion, cloud height and growth rates, rainfall location and amounts,

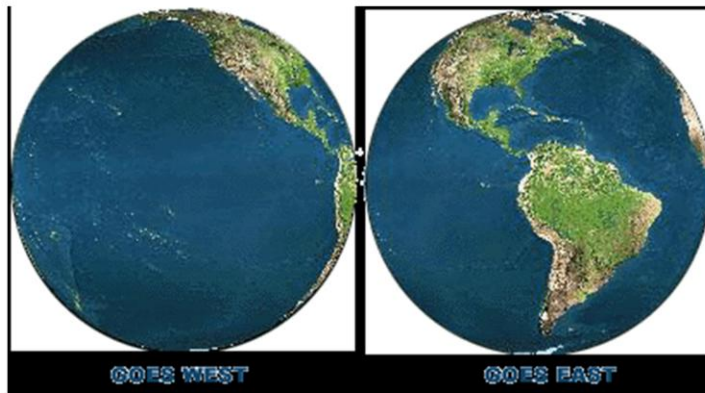
and the extent of atmospheric pollution. Other satellite systems produced interesting aperiodic pictures, but the geostationary Spin-Scan Cloud Camera data enabled evolutionary time sequence studies that described weather accurately and permitted the research necessary for operational applications. Satellite sensing thus moved from qualitative viewing to quantitative measurement, from a research curiosity to an operational necessity. The idea for the camera was first conceived while Suomi was serving as the first Chief Scientist for the National Weather Service. He sought to develop a system that could take frequent observations of a single weather phenomenon and provide time-rate-of-change information about the weather. To achieve the necessary geostationary orbit, 22,000 miles away from Earth, profound design problems had to be overcome. Suomi and Robert Parent solved these by using a spinning satellite to provide inertial stability and a small scanning reflective telescope that scanned swaths of the Earth progressively to create whole Earth images. These cameras were first flown on the Applications Technology Satellite series (ATS I and III) in the 1960s and they provided eight years of high quality, accurate images of the Earth's surface and atmosphere.

GOES satellites provide the kind of continuous monitoring necessary for intensive data analysis. They circle the Earth in a geosynchronous orbit, which means they orbit the equatorial plane of the Earth at a speed matching the Earth's rotation. This allows them to hover continuously over one position on the surface. The geosynchronous plane is about 35,800 km (22,300 miles) above the Earth, high enough to allow the satellites a full-disc view of the Earth. Because they stay above a fixed spot on the surface, they provide a constant vigil for the atmospheric "triggers" for severe weather conditions such as tornadoes, flash floods, hail storms, and hurricanes. When these conditions develop the GOES satellites are able to monitor storm development and track their movements.

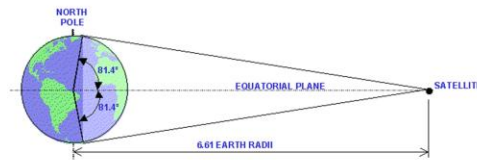
Data is transmitted in various "modes" but at between 15 minutes and about 30 minute intervals.

GOES satellite imagery is used to estimate rainfall during the thunderstorms and hurricanes for flash flood warnings, as well as estimates snowfall accumulations and overall extent of snow cover. Such data help meteorologists issue winter storm warnings and spring snow melt advisories. Satellite sensors also detect ice fields and map the movements of sea and lake ice.

U.S. GOES East and GOES West



GOES N (GOES-13) launched from Cape Canaveral on a Delta IV rocket May 24, 2006



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Geostationary Operational Environmental Satellites

"The first GOES was launched on Oct. 16, 1975. The early GOES satellites were spin stabilized and viewed the earth only about ten percent of the time. These satellites were in operation from 1975 until 1994. From April 13, 1994, to the present, a new generation of three-axis stabilized spacecraft (GOES I-M) has been in operation. GOES-8, the first of the new generation, was launched April 13, 1994. Since then, GOES-9, GOES-10, and GOES-11 have been launched. This generation of satellites view the earth 100 percent of the time, taking continuous images and soundings. GOES satellites provide data for severe storm evaluation, information on cloud cover, winds, ocean currents, fog distribution, storm circulation and snow melt, using visual and infrared imagery. The satellites also receive transmissions from free-floating balloons, buoys and remote automatic data collection stations around the world.

GOES satellites are a mainstay of weather forecasting in the United States. They are the backbone of short-term forecasting or nowcasting. The real-time weather data gathered by GOES satellites, combined with data from Doppler radars and automated surface observing systems, greatly aids weather forecasters in providing warnings of thunderstorms, winter storms, flash floods, hurricanes, and other severe weather. These warnings help to save lives and preserve property.

The United States operates two meteorological satellites in geostationary orbit, one over the East Coast and one over the West Coast with overlapping coverage over the United States. The GOES satellites are a critical component of the ongoing National Weather Service modernization program, aiding forecasters in providing more precise and timely forecasts.

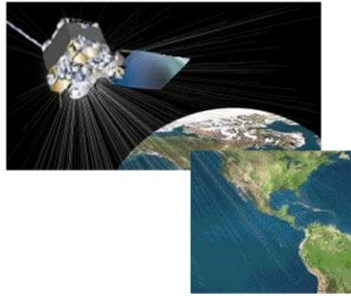
Four US GOES satellites are currently available for operational use:

[GOES-12](#) is designated GOES-South, currently located at 60°W .

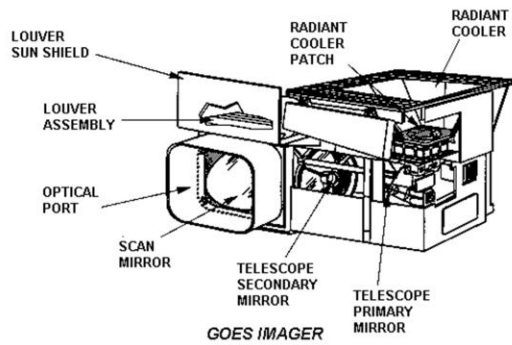
GOES-13 is designated GOES-East, currently located at 75°W. It provides most of the U.S. weather information.

GOES 14 was placed in orbit on 7 July 2009, underwent Post-Launch Testing until December 2009 and then was placed in on-orbit storage at 105° W..

GOES 15 is designated GOES-West, currently located at 135°W over the Pacific Ocean.



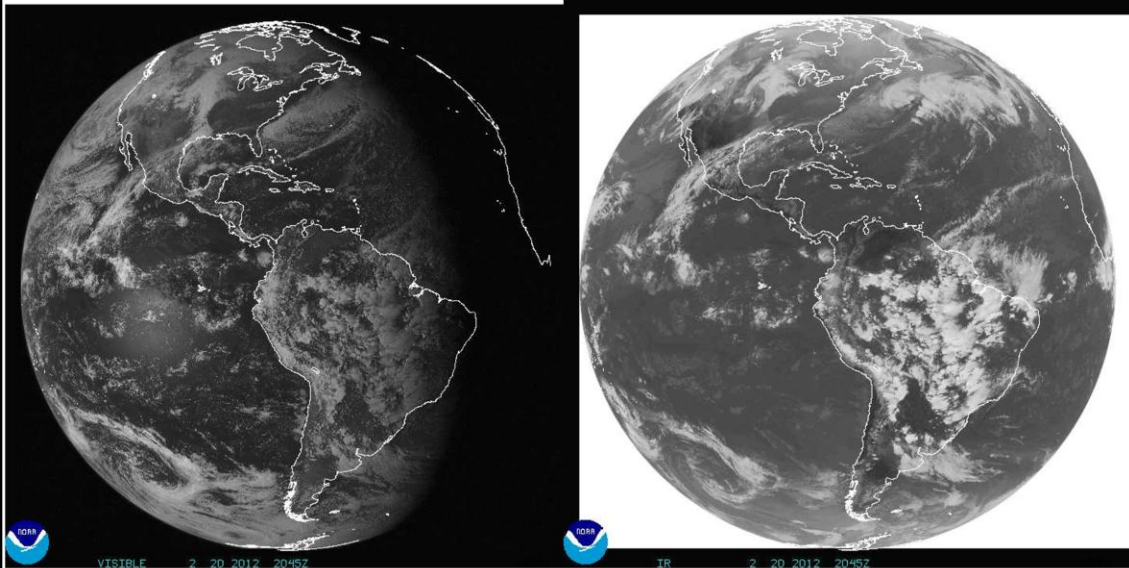
GOES: Imager



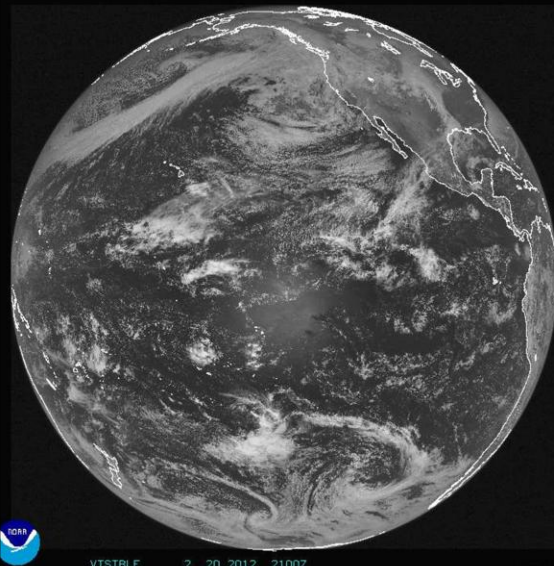
Imager Instrument Characteristics (GOES I-M)

Channel number:	1 (Visible)	2 (Short-wave)	3 (Moisture)	4 (IR 1)	5 (IR 2)
Wavelength range (μm)	0.55 - 0.75	3.80 - 4.00	6.50 - 7.00	10.20 - 11.20	11.50 - 12.50
Instantaneous Geographic Field of View (IGFOV) at nadir	1 km	4 km	8 km	4 km	4 km
Radiometric calibration	Space and 290 K infrared internal backbody				
Calibration frequency	Space: 2.2 sec (full disc), 9.2 or 36.6 sec (sector/area) Infrared: 30 minutes typical				
System absolute accuracy	IR channels: less than or equal to 1 K Visible channel: 5% of maximum scene irradiance				
Imaging rate	Full earth disc, less than or equal to 26 minutes				

GOES East on 2/20/2012 Visible and TIR bands

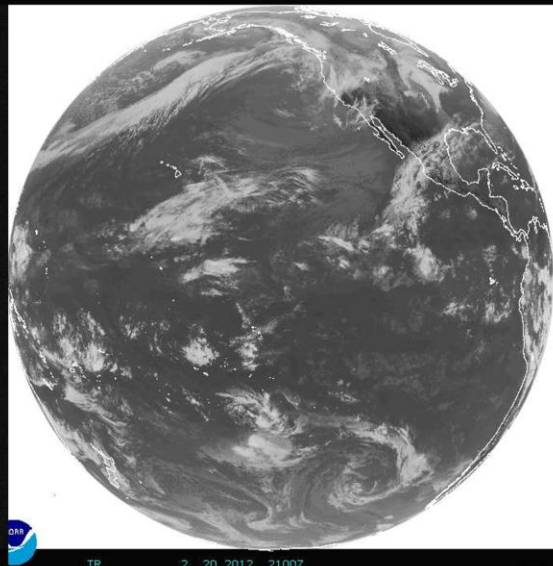


GOES West 9 on Feb. 20, 2012



VISIBLE 2 20 2012 2100Z

VIS 2/20/2012 2100Z



IR 2 20 2012 2100Z

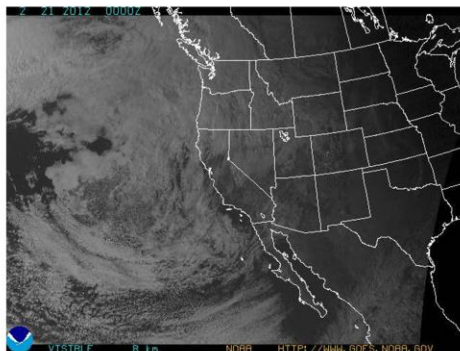
IR 2/20/2012 2100Z

GOES WEST
February 21, 2012
0000Z



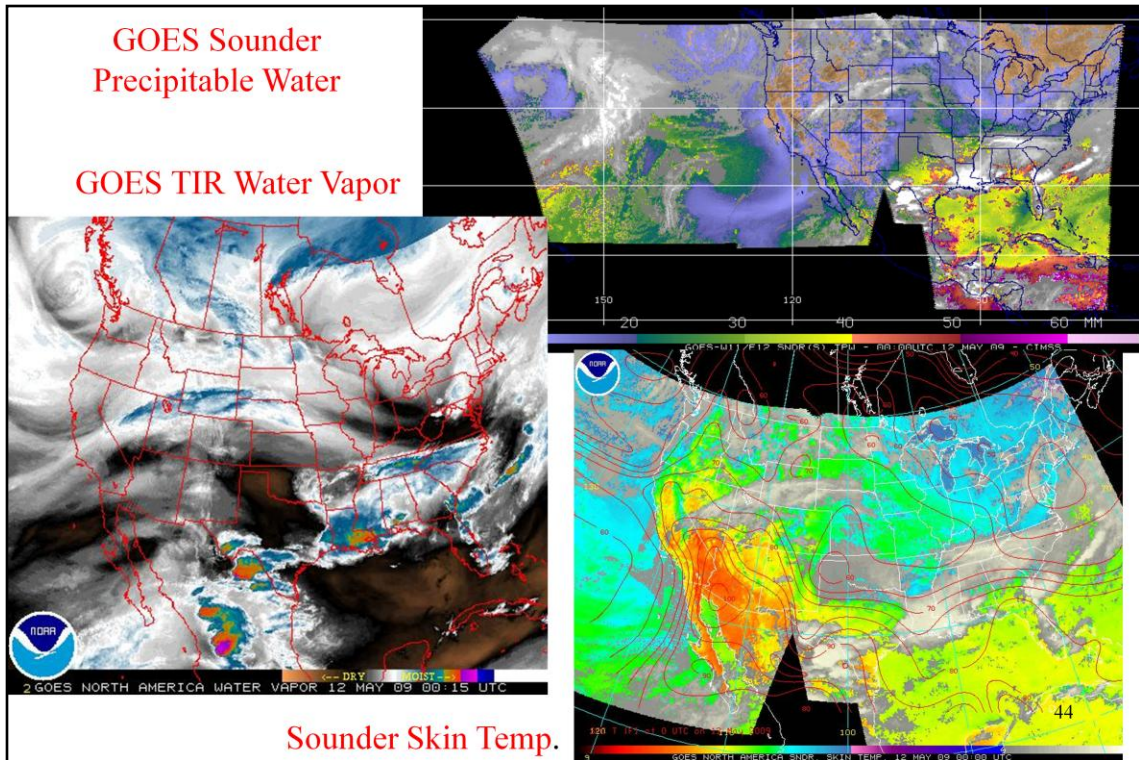
TIR Image Band 4

Water Vapor 2/20/2012 2330Z



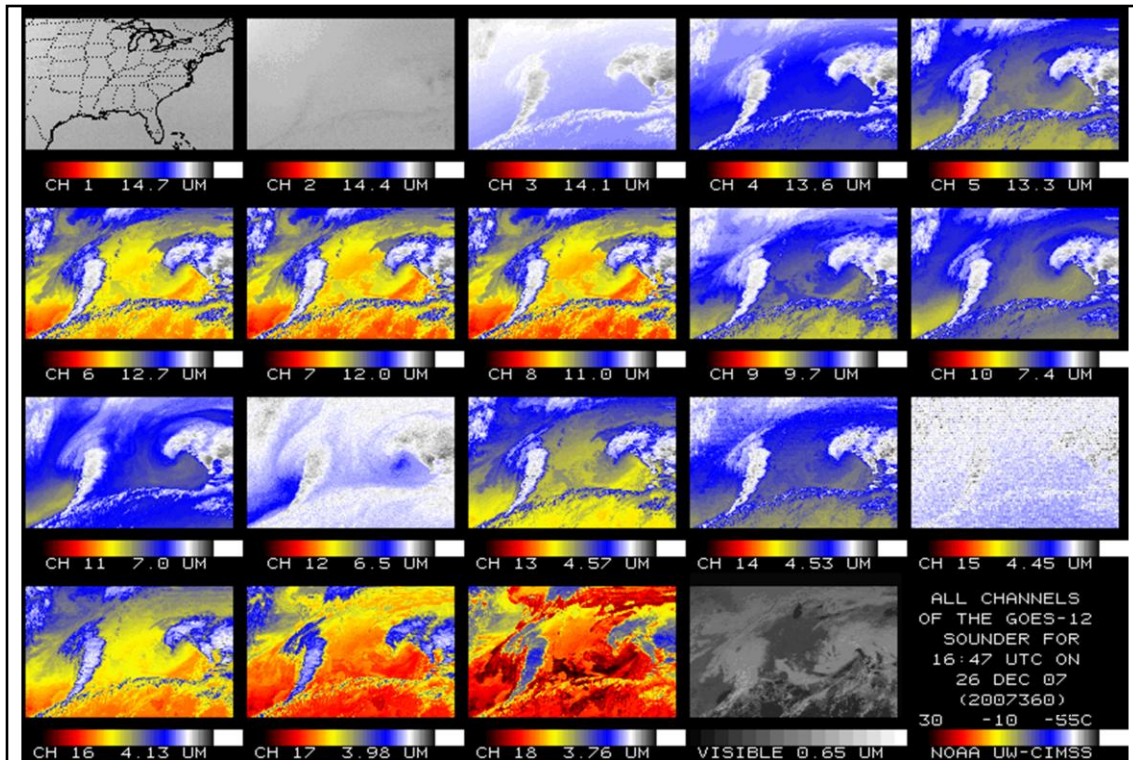
Visible band

8 km



Sounder Skin Temp.

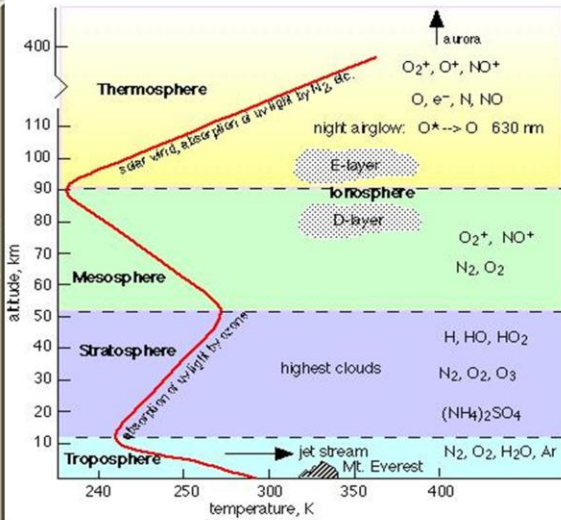
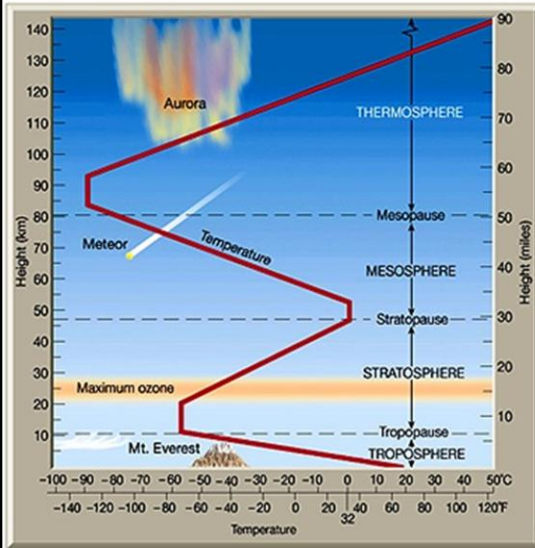
The GOES [imager](#) has one water vapor channel ([channel 3](#)),

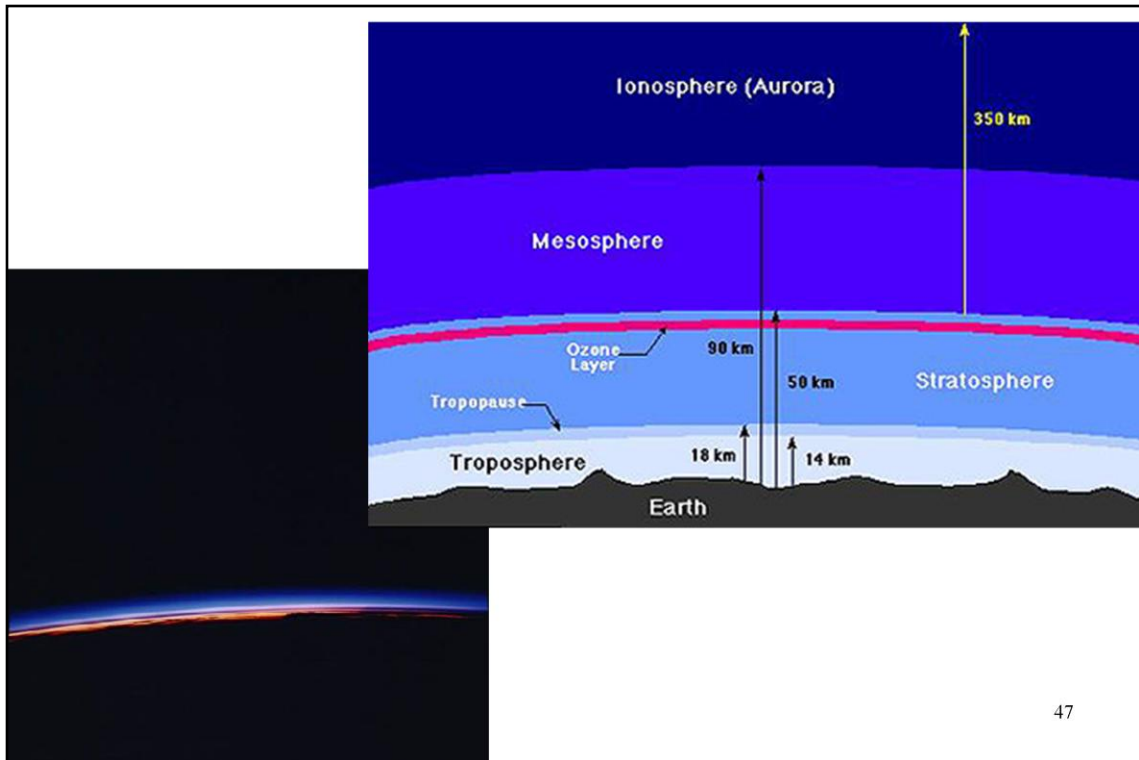


The GOES sounder has three water vapor bands (bands 10, 11 and 12) at various wavelength intervals within the 6.5-7.4 micron range. On a water vapor image, each pixel is assigned a *gray scale* based on the measured brightness temperature. Typically, *white* indicates a very *cold* brightness temperature (radiation from a *moist layer* or cloud in the upper troposphere), and *black* indicates a *warm* brightness temperature (radiation from the Earth or a *dry layer* in the middle troposphere).

The "moist" and "dry" features seen on water vapor imagery result from various combinations of *vertical motion*, *horizontal deformation* and *moisture advection* within the middle and upper troposphere (generally the 4-12 km altitude range). Such features exhibit spatial and temporal continuities which are evident using image animation loops. Water vapor is therefore a "passive tracer" which can be used to represent three-dimensional atmospheric motions on the meso and synoptic scale.

Vertical Structure of the Atmosphere



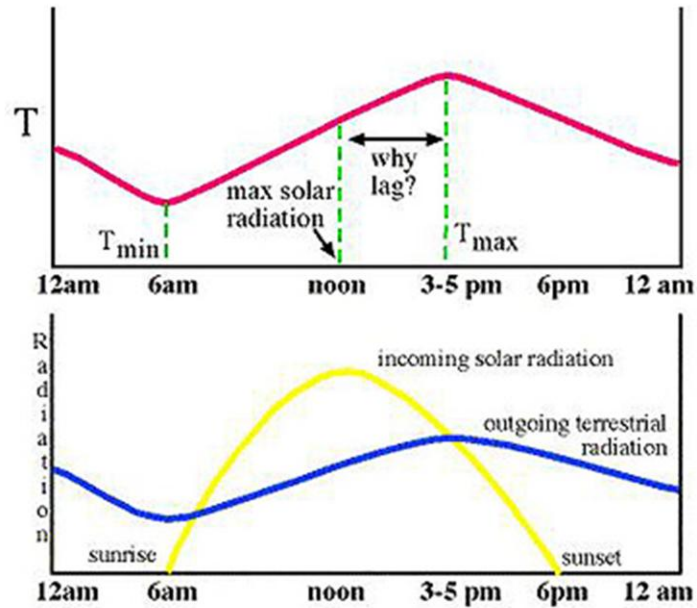


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Compared to the size of the Earth , the atmosphere is a thin shell. The part of the atmosphere we know best - the troposphere - is an even thinner shell, only 12 kilometers (7.5 miles) thick. It is in the troposphere that all weather occurs; it is only here that life exists. < **Space Shuttle Photograph of the Earth's limb. The thin atmosphere lighted by the setting Sun.**

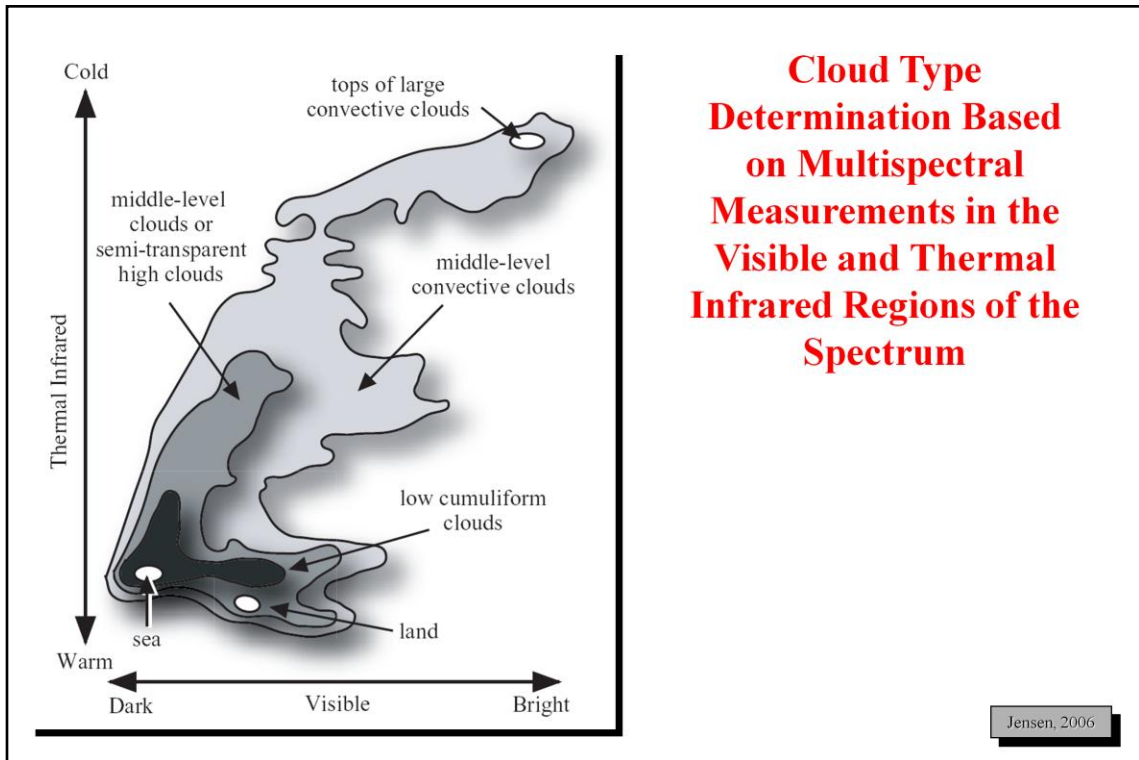
NASA Image STS006-46-147 from [NASA Image Exchange](#)

Diurnal Patterns in Incoming Solar Radiation



48

This chart shows incoming solar radiation peaks around high noon. Outgoing radiation reaches its minimum around dawn. But, it also attains its maximum about 3 to 4 hours after noon, thus, not coincident with the radiation peak. This lag is the result of several factors, chief of which is the effects of thermal uplifting and winds that carry heat upwards and slow down the surface temperature rise until mixing in mid-afternoon produces the hottest time of the day.



**Cloud Type
Determination Based
on Multispectral
Measurements in the
Visible and Thermal
Infrared Regions of the
Spectrum**

Jensen, 2006

Clouds

In the Visible and NIR region of the spectrum:

- **Cloud drops are non-selective scatterers**
- **Scattering efficiency is large**
- **Liquid water does not absorb in the visible thus minimal absorption in the visible.**
- **NIR absorption increases due to liquid water and water vapor absorption**
- **Averaged over the solar spectrum, clouds scatter roughly 74%, absorb 10%, and transmit 16%**

In the Thermal IR region (8.5-12.5 μm):

- **Cloud droplets are Mie scatterers**
- **Clouds absorb nearly all of the TIR radiation**
- **They are essentially blackbodies**

Cloud Characteristics Derived from Passive Remote Sensing

- cloud detection
- cloud type
- cloud reflectance
- cloud emissivity
- liquid water content
- optical depth
- cloud phase (water or ice)
- particle size distribution
- cloud top height



Super Typhoon Jangmi: Strongest Storm 2008

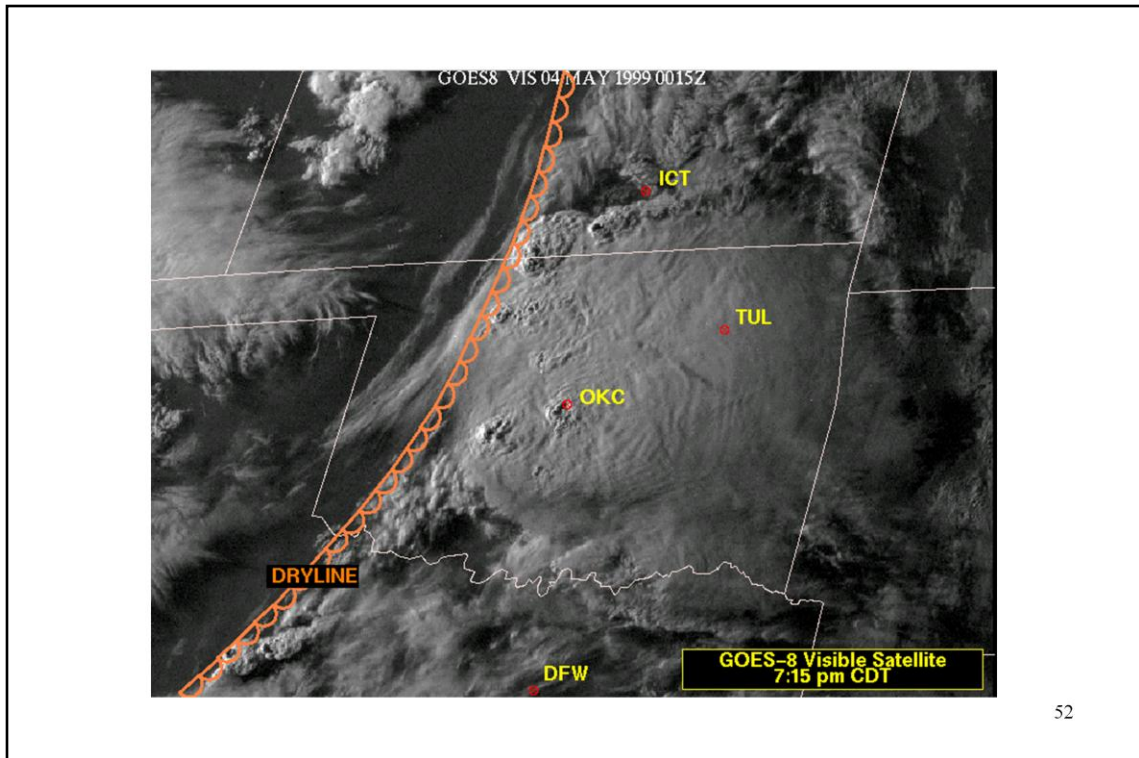
MODIS on Aqua Satellite 2008-09-27

Eye = 50km diameter

Cyclone Nargis, which killed tens of thousands of people when it struck Burma (Myanmar) in May, was more devastating, but the title of "strongest storm of 2008" goes to Super Typhoon Jangmi, shown in this image from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite from September 27, 2008. The image comes from the Earth Observatory's new World of Change: Severe Storms feature, a collection of images of the strongest storm each year from the past decade.

Seen from space, even a super typhoon seems more beautiful than dangerous. The 50-kilometer-wide eye of Jangmi is encircled by a smooth disk of clouds. Bands of clouds swirl gracefully into the low-pressure heart of the storm. The smooth cloud band north of the eye is studded with thunderstorms. The eye is tightly formed. The tighter the eye in a circular storm, the stronger the winds underneath.

On the ground, Jangmi was less lovely. It came ashore on northeastern Taiwan (pictured at upper left of the image) as a Category 4 typhoon, and torrential rains led to floods and landslides. With maximum sustained winds of 260 kilometers per hour (162 mph), Jangmi was not only the strongest storm in any ocean basin in 2008, it was also the only storm to reach Category 5 strength anywhere in the world that year.



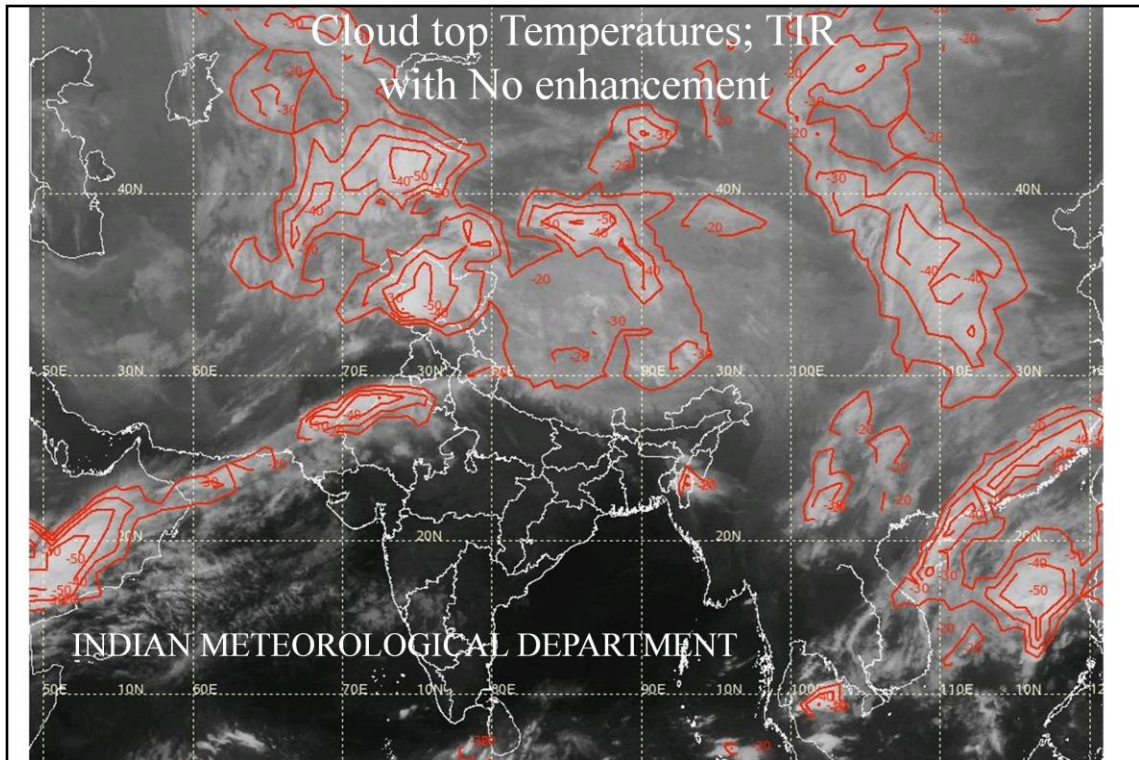
Thick clouds do a much better job of reflecting light and therefore appear brighter in visible photos. When GOES satellites are positioned over the equator, they view the northern hemisphere at an angle so you can get a sense of the vertical development of the clouds. Also taller clouds will cast shadows onto lower ones so visible imagery is an excellent tool for locating developing thunderstorms.

Infrared imagery

The obvious problem with visible imagery is that it is only available during the day. To combat this problem, the infrared (IR) sensor was devised. It senses radiant (heat) energy given off by the clouds. Warmer (lower in the atmosphere) clouds give off more energy than cold (higher) clouds. The IR sensor measures the heat and produces several images based upon different wavelengths in the IR range of the electromagnetic spectrum. Often these images are color enhanced to help better distinguish the taller (coldest, usually from thunderstorms) cloud tops.

Water vapor imagery

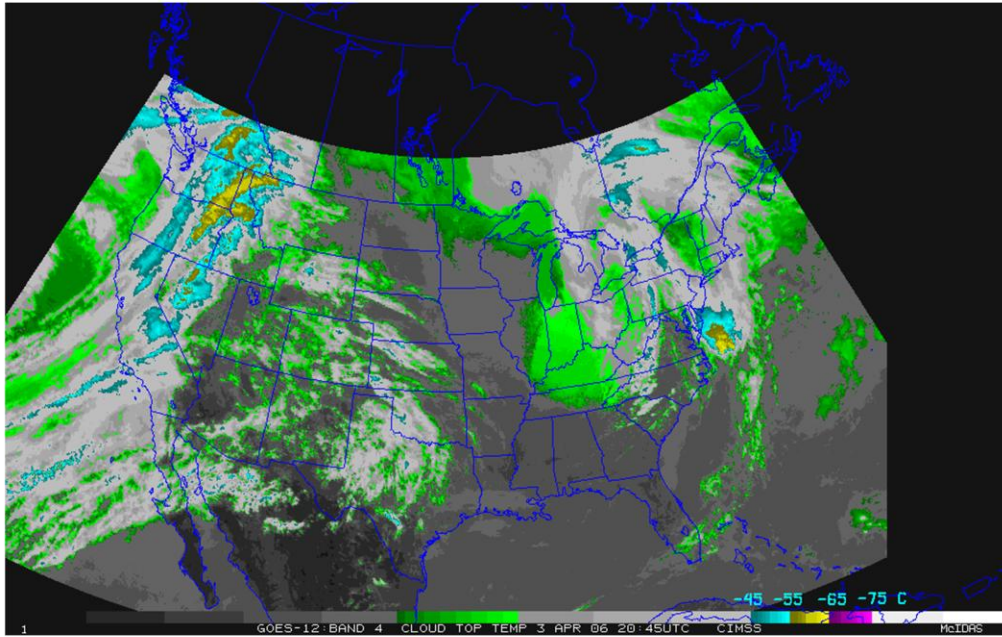
Water vapor imagery is unique in that it can detect water vapor (water in a gas state) in addition to clouds. However, due to absorption of energy by the atmosphere this view only "sees" of the top third of the troposphere. While the low level moisture is hidden from the satellite sensor, the upper level moist/dry areas are plainly observable. Moist areas show up as white, dry areas as black.



2009-April 02 at 00:00:03

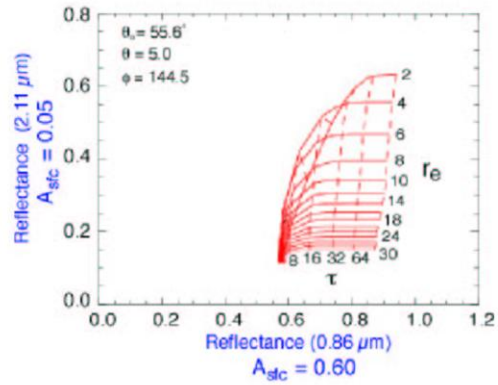
Cloud top Temperatures; TIR with No enhancement

Cloud Top Temperature

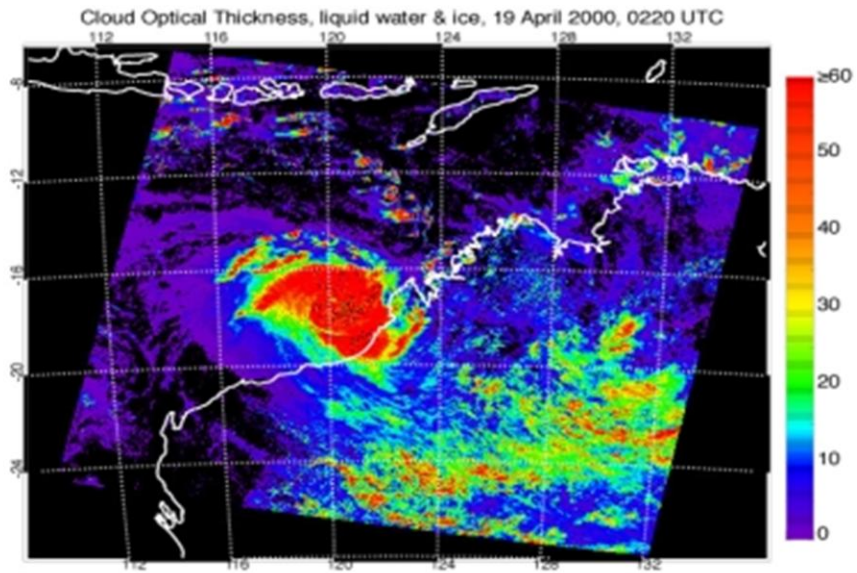


Cloud Optical Thickness

Reflection function of a non-absorbing band is primarily a function of optical depth while the reflection function of an NIR absorbing band is function of effective radius.

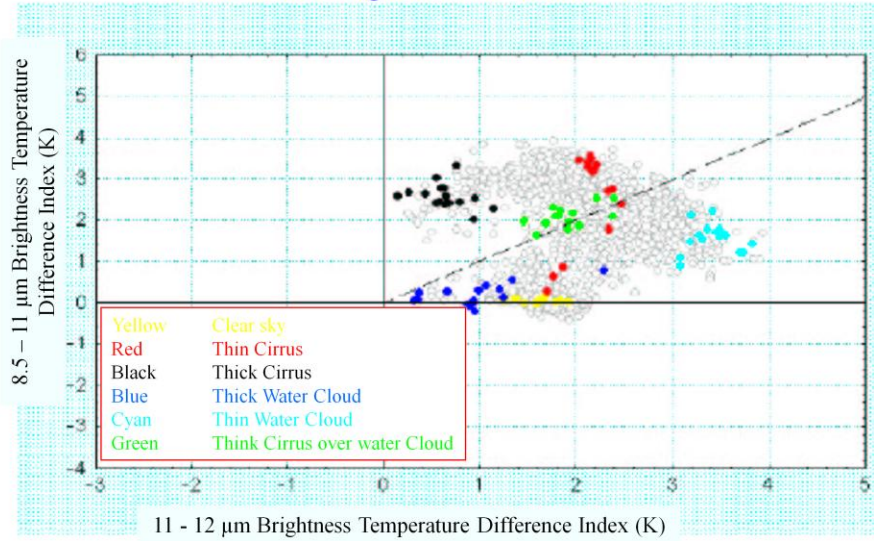


Cloud Optical Thickness



Thermodynamic Phase Detection

Differences in emissivity of water and ice at $8.5 \mu\text{m}$.
 $8.5 - 11 \mu\text{m}$ index is large and positive for ice clouds,
small and negative for water clouds.



Cloud Types

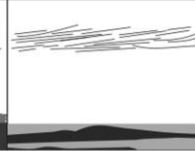
High Clouds



Cirrus (Ci)



Cirrocumulus (Cc)



Cirrostratus (Cs)

Middle Clouds



Altocumulus (Ac)



Altostratus (As)

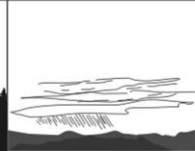
Low Clouds



Stratocumulus (Sc)



Stratus (St)



Nimbostratus (Ns)

clouds of Vertical Development



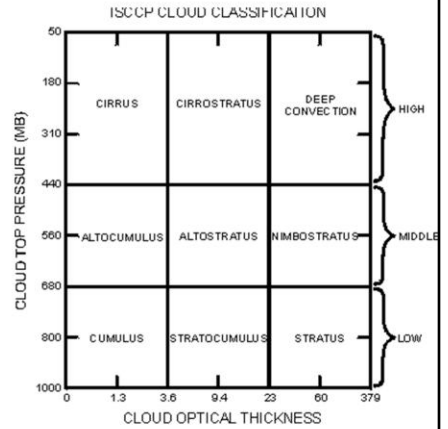
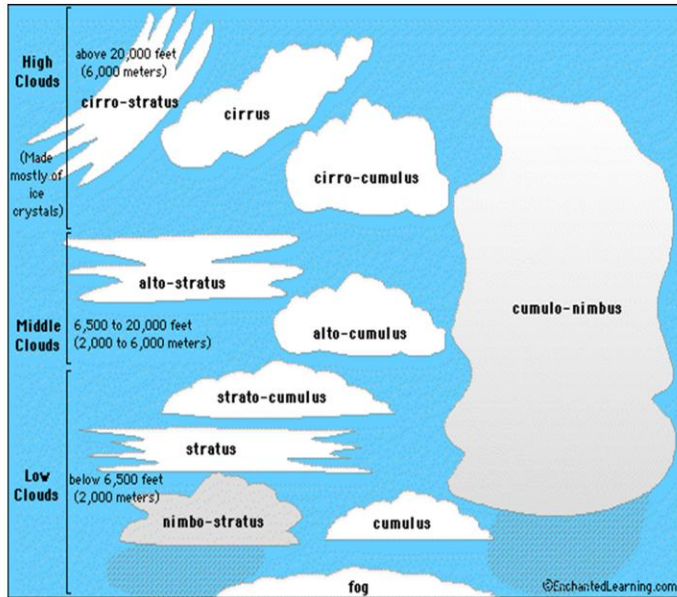
Cumulus (Cu)



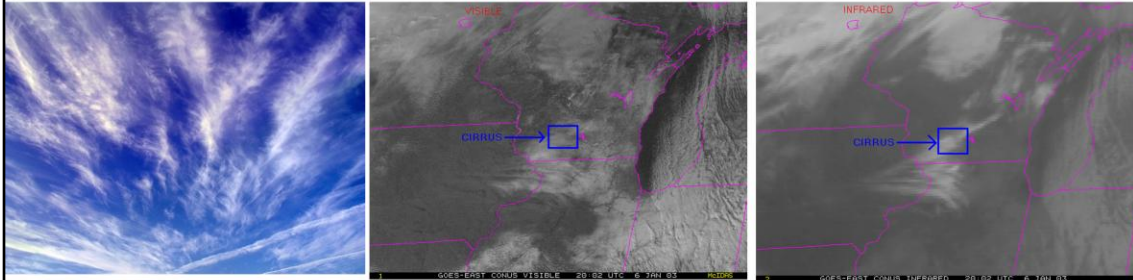
Cumulonimbus (Cb)



Cloud Types



The two most common high clouds are cirrus and cirrostratus



Cirrus clouds from below

Visible satellite image

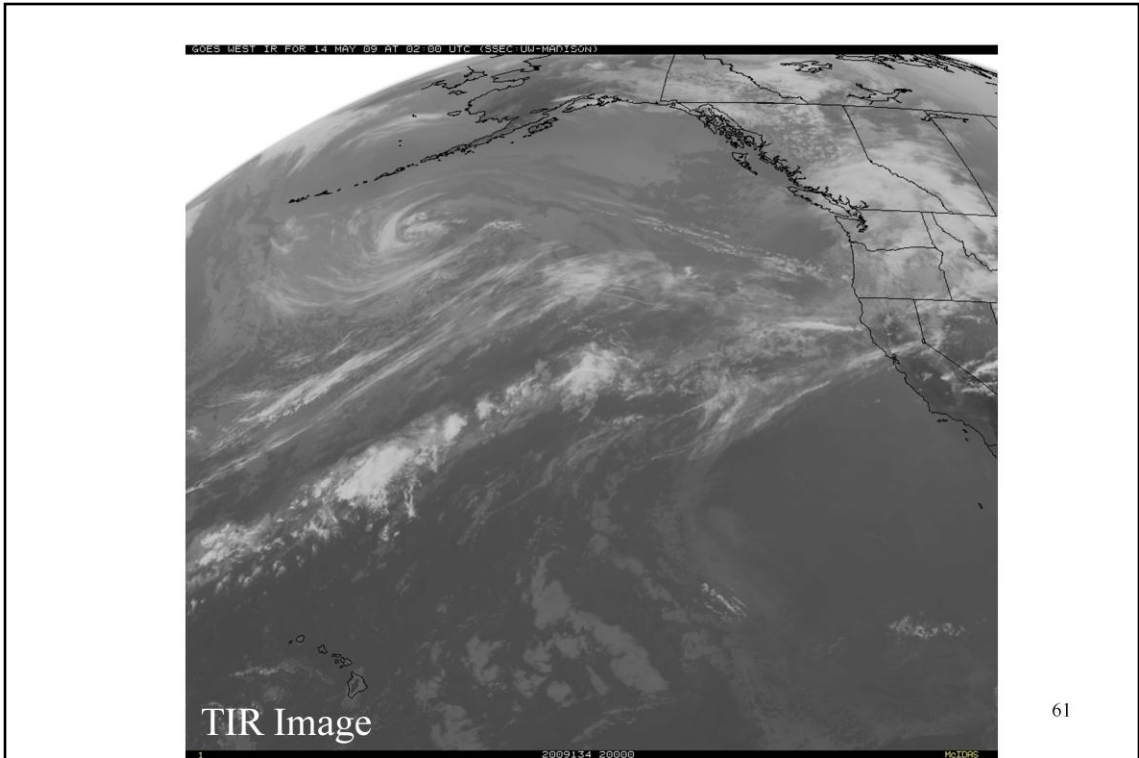
TIR satellite image

The most common form of high-level clouds are thin and wispy cirrus clouds. Typically found at heights > 6,000 meters, cirrus clouds are composed of ice crystals that originate from the freezing of super-cooled water droplets. Cirrus generally occur in fair weather and point in the direction of air movement at their elevation.

60

The biggest distinction between high clouds and other levels is the fact that they are made up of ice crystals and not water droplets. The two most common high clouds are **cirrus** and **cirrostratus**. Cirrus are thin and wispy as can be seen in the following photos and satellite images. They are a common cloud type that occurs in vertical motions ahead of large scale weather patterns. Cirrus clouds are associated with all weather systems. They can also be generated by flow over mountains or in regions with strong winds, such as the jet stream. They often occur as wisps aligned in the same direction and generally do not completely cover the sky.

Cirrus clouds contribute both to the atmosphere's greenhouse effect and to the Earth's albedo (the amount of sunlight the earth reflects); consequently it is not certain whether the net effect of cirrus clouds is to warm or cool the earth.



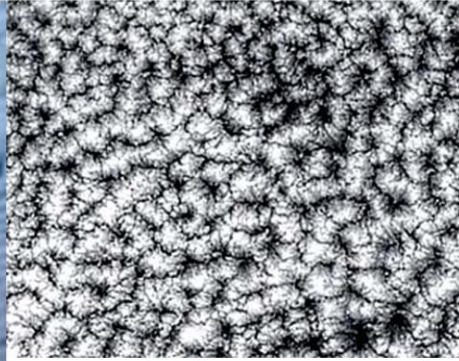
The coldest clouds are generally cirrus clouds which flow along the jet stream and mark the location of weather fronts. The first image is the latest GOES 10 Infrared View of the Pacific + West Coast.



A **cumulus cloud** has dense individual elements in the form of puffs, mounds or towers, with flat bases and tops. They are formed in the troposphere at a lower altitude than altocumulus, usually below 2,400 m. Though most common in warm summer weather, they can be formed at any time of year. The cumulus cloud can form a [cumulonimbus](#) cloud, which brings storms. Cumulus clouds often form in anti-cyclonic weather

62

anticyclone (i.e. opposite to a [cyclone](#)) is a weather phenomenon in which there is a descending movement of the air and a relative increase in barometric pressure over that part of the earth's surface



Landsat image, stratocumulus cloud cells, each about 10-15 km over the Pacific Ocean

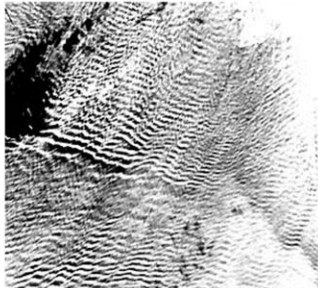
Alto**cumulus** clouds are characterized by globular masses or rolls in layers or patches, where the individual elements are larger and darker than those of cirrocumulus and smaller than those of stratocumulus. These clouds are found at medium altitudes, about 2400-6100 m. A middle cloud, usually white or gray, often occurs in layers or patches with wavy, rounded masses or rolls.

63

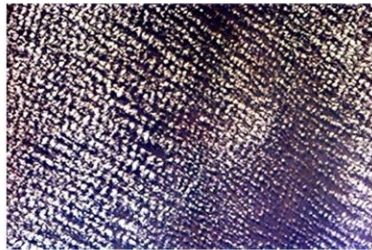
The scale of Landsat images, covering 180 km on a side, is especially suited to showing clouds in some detail but over an area in which their context is well displayed.

This Landsat image shows a pattern of stratocumulus cloud cells, each about 7-10 miles (10-15 km) over the Pacific Ocean. As warmer moist air rises in convection cells over the ocean and cools, condensing the water vapor into cloud droplets (which usually coalesce to form clouds), cold air then sinks around the sides of the cells. The dark space between cloud cells is not the ocean itself but a thin mass of water vapor, with low reflectance, associated with the sinking air.

Stratocumulus waves



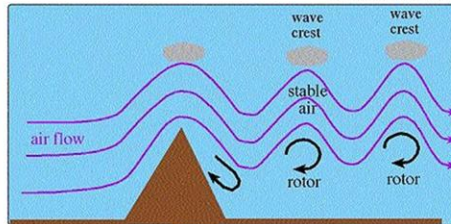
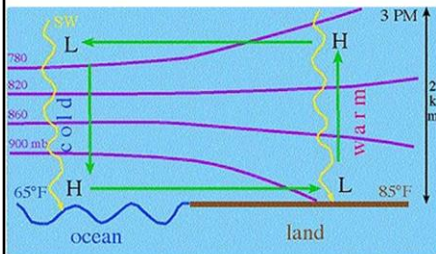
Landsat image over Barents Sea, near the Kola Peninsula



Cloud Streets, Kenya
radiative heating over land;
Aligned by wind shear



Cloud streets,
Hudson's Bay, Canada



Cloud Formation by Gravity Waves

64

On a larger scale, long period gravity waves can form in the upper atmosphere. This satellite image shows these regularly spaced linear clouds that represent the condensed moisture in a gravity wave train.

UPPER LEFT Stratocumulus clouds can often arrange themselves in waves, much like ripple marks on sand dunes, as evidenced in this Landsat image taken over the Barents Sea, near the Kola Peninsula.

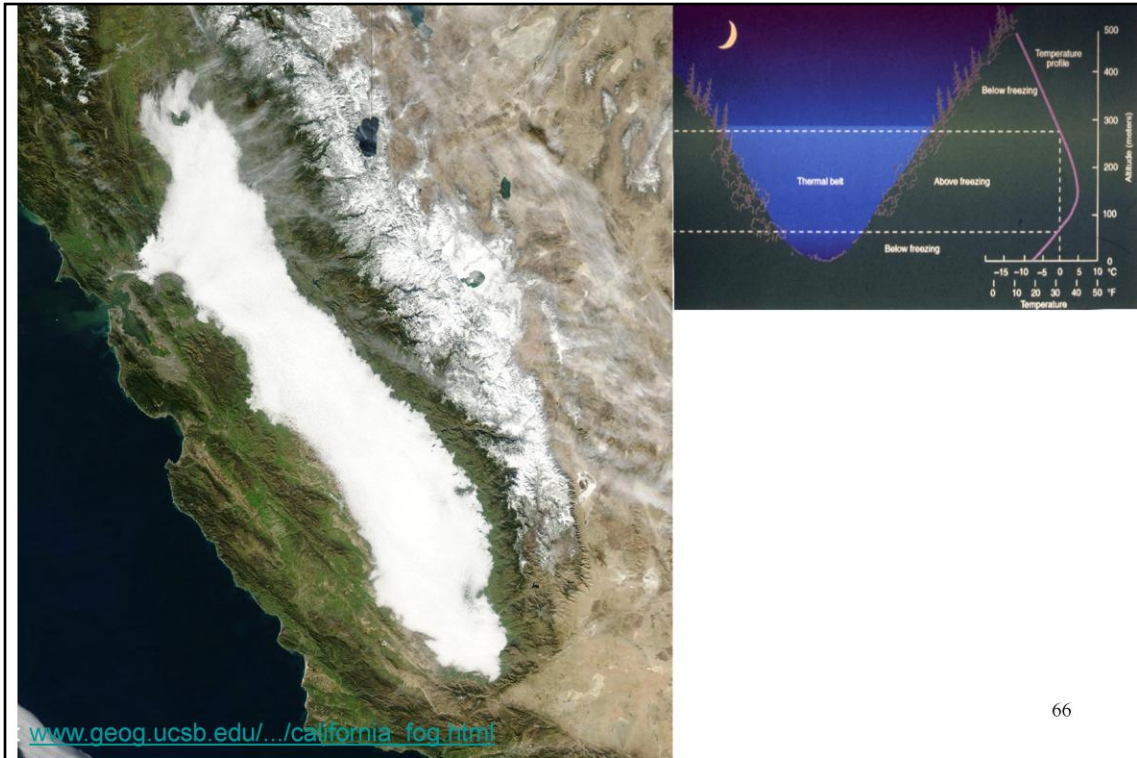
(MIDDLE) The next visible image, taken on an afternoon over Kenya, shows a series of cumulus clouds aligned in cloud streets. The cumulus clouds result from radiative heating over land, which forces buoyant bubbles (thermals) up. The cumuli are the visible tops of these thermals. They are aligned by wind shear. Cumulus clouds result from radiative heating over land, which forces buoyant bubbles (thermals) up. The cumuli are the visible tops of these thermals.

(Right) Cloud streets can be seen in in this satellite image of western Hudson's Bay in Canada. The winds are blowing eastward off the winter snow and ice on land over the open ocean.



Stratocumulus over Pacific Ocean and fog along coast

Stratocumulus clouds are common above the oceans, as seen here in MODIS image of the west coast of the United States. Of special interest is the crosslink between these clouds and low fog along the coast and especially in Puget Sound (Washington) and the San Francisco Bay (California).



What kind of data is this? Landsat VIS bands.

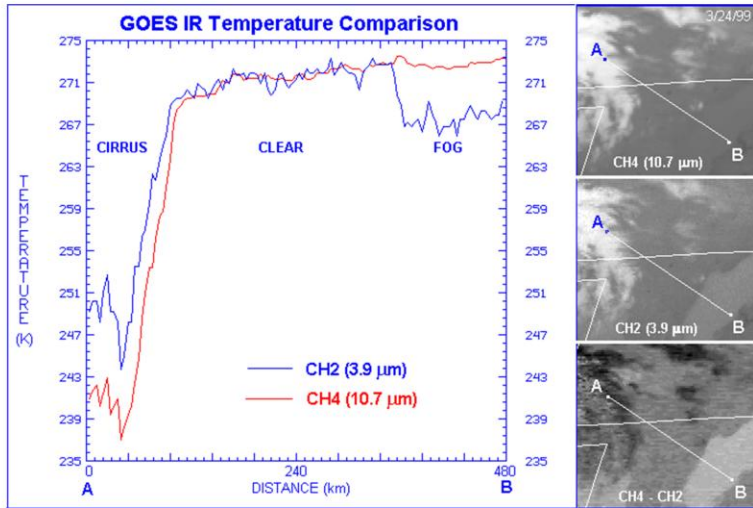
Central Valley fog, Sierra Nevada snowpack, and cirrus clouds in Nevada.

Radiation Fog produced by rapid surface cooling at night due to radiation loss. Associated with radiation inversion

Primarily occurs on winter nights. Most common on clear, calm nights associated with high pressure. Surface heating by sunlight penetrating fog often sufficient to evaporate fog in morning.

Commonly forms on floors of interior valleys. Thickest in low spots and builds upward from ground. Reduces frost hazard by trapping outgoing longwave.

Tule fog in Central Valley can persist for weeks. Fog layer builds to several hundred feet thick, effectively blocks out incoming sunlight. Very stable, won't dissipate until passing storm system stirs up atmosphere. High pressure that produces fog also causes offshore flow and clear, balmy weather in Southern California.



Brightness temperature trace for GOES Channel 2 (blue, 3.9 mm) and Channel 4 (red, 10.7mm) along the path A-B in the three images at right on 24 March 1999.



Cyclonic cloud banks off the coast of Iceland



Incoming Pacific storm approaching the coast of California; image was made by the SeaWiFS

Among the most striking cloud formations, and most common cloud pattern is the so-called cyclone, in the northern hemisphere a counterclockwise (ccw) spiral swirl, often associated with a major low, that delivers rain and even stronger storms, such as hurricanes. Wide field views can encompass the full systems of clouds comprising such lows. Here are two cyclonic cloud banks off the coast of Iceland:



MISR image of von Karman vortices formed from **stratocumulus clouds** on the leeward side of the Beersburg volcano (about 2.2 km high) on Jan Mayen Island (Norway), 600 km east of Iceland.

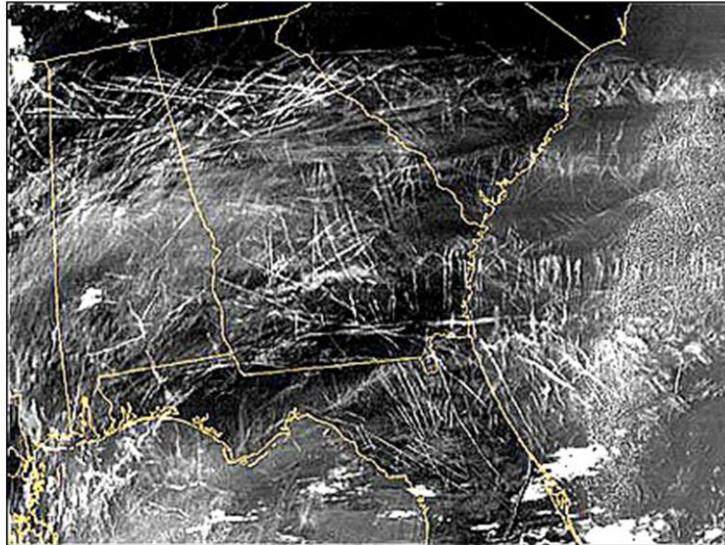
Stratocumulus cloud field over the ocean off the West African coast as winds blow around Canary Islands



This image, taken by the MISR sensor on Terra. A chain of swirls, known as **von Karman vortices**, has formed from **stratocumulus clouds** on the leeward side of the Beersburg volcano (about 2.2 km high) rising on the Jan Mayen island (Norwegian) 600 km east of Iceland. Winds streaming past this local obstruction induce the rotational perturbations that are expressed downwind as the vortices.

Similar gyres have formed in the **stratocumulus** cloud field over the ocean off the West African coast, as the northerly prevailing winds blow around the Canary Islands.

Contrails are believed to affect weather by raising short and long-term temperatures (about 1/3 degree per decade). MODIS image over the southeast U.S. 29 January 2004, showing a large number of contrails. At times more than 2000 planes are flying over the North American continent.



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One unique type of cloud is manmade. Contrails occur when exhaust from jet engines condenses. A narrow line of moisture makes up the contrail. Winds eventually dissipate it; in some instances conditions permit the contrail to survive for many minutes until their straight line distort and drift apart. Contrails are thought to affect weather by raising both short and long-term temperatures (estimated about a third of a degree per decade). Here is a MODIS image taken over the southeast U.S. on January 29, 2004 showing a large number of contrails.

Lecture 13: Weather Satellite data, What you should know:

- Importance of weather satellites to predict weather conditions
- Polar orbiting and geostationary satellites: characteristics of orbits and most common types
- PJSS plans; including NPP mission
- Solar radiation and seasonal variation
- Vertical profiles through atmosphere
- Scattering properties of particles
- Measurement of cloud properties
- Examples of cloud formations and cloud properties