
Severe storm from Feb. 17-19, 2012 in Lebanon. Up to 2 m snow and 100 km/hr winds

MODIS Feb. 20, 2012

From February 17 to 19, a severe storm blasted the Lebanese coast with 100-kilometer (60-mile) winds and dropped as much as 2 meters (7 feet) of snow on parts of the country, news sources said. Temperatures dropped to near freezing along the coast, while snowplows struggled to clear the main roadway between Beirut and Damascus.

The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured this natural-color image on February 20, 2012. Snow covers much of Lebanon, and extends across the border with Syria. Another expanse of snow occurs just north of the Syria-Jordan border.

Snow in Lebanon is not uncommon, and the country is home to ski resorts. Still, this fierce storm may have been part of a larger pattern of cold weather in Europe and North Africa.

**References**

*The Daily Star.* (2012, February 18). Lebanon hit by extreme weather conditions. Accessed February 21, 2012.

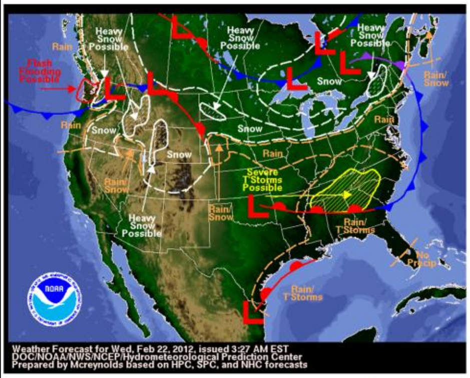
Naharnet. (2012, February 19). Storm subsides after coating Lebanon in snow. Accessed February 21, 2012.

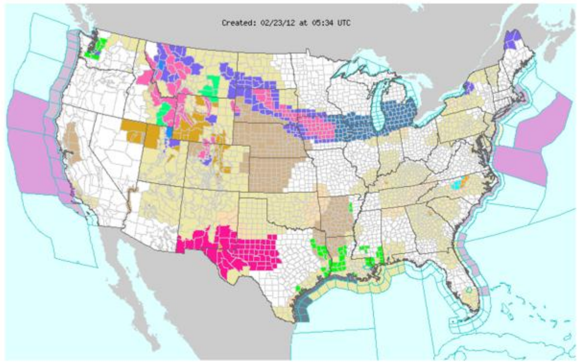
NASA image courtesy LANCE/EOSDIS MODIS Rapid Response Team at NASA GSFC. Caption by Michon Scott.

Instrument: Terra - MODIS

Severe Weather Monitoring Chapter 12

# NOAA Weather Storm Warnings for the US for Feb. 23, 2012




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

* Critical fire warning

## Floods: Most common natural hazard

Flooding is the most common of all natural hazards. Each year, more deaths are caused by flooding than any other thunderstorm related hazard. We think this is because people tend to underestimate the force and power of water. Six inches of fast-moving water can knock you off your feet. Water 24 inches deep can carry away most automobiles. Nearly half of all flash flood deaths occur in automobiles as they are swept downstream. Most of these deaths take place when people drive into flooded highway dips of low drainage areas. T

Flash Floods

Flash floods tend to be associated with many types of convection, all capable of producing excessive rainfall amounts over a particular area, so detection remains a challenge. Sometimes a flash flood threat is overshadowed by other severe weather events happening at the same time.

The key to detecting flash flood producing rainfall is determining the location, areal extent, and time duration of the most intense rainfall cores associated with MCS's. The main tools used to detect heavy rainfall signatures associated with flash floods are satellite, lightning observing systems, radar, and rain gauges.

**Satellite evidence**

Satellite imagery can indicate the presence of larger and smaller-scale systems associated with heavy rainfall. It clearly indicates the organization of larger features associated with Mesoscale Convective Systems, and also aids in estimating rainfall using IR-based cloud-top temperatures.

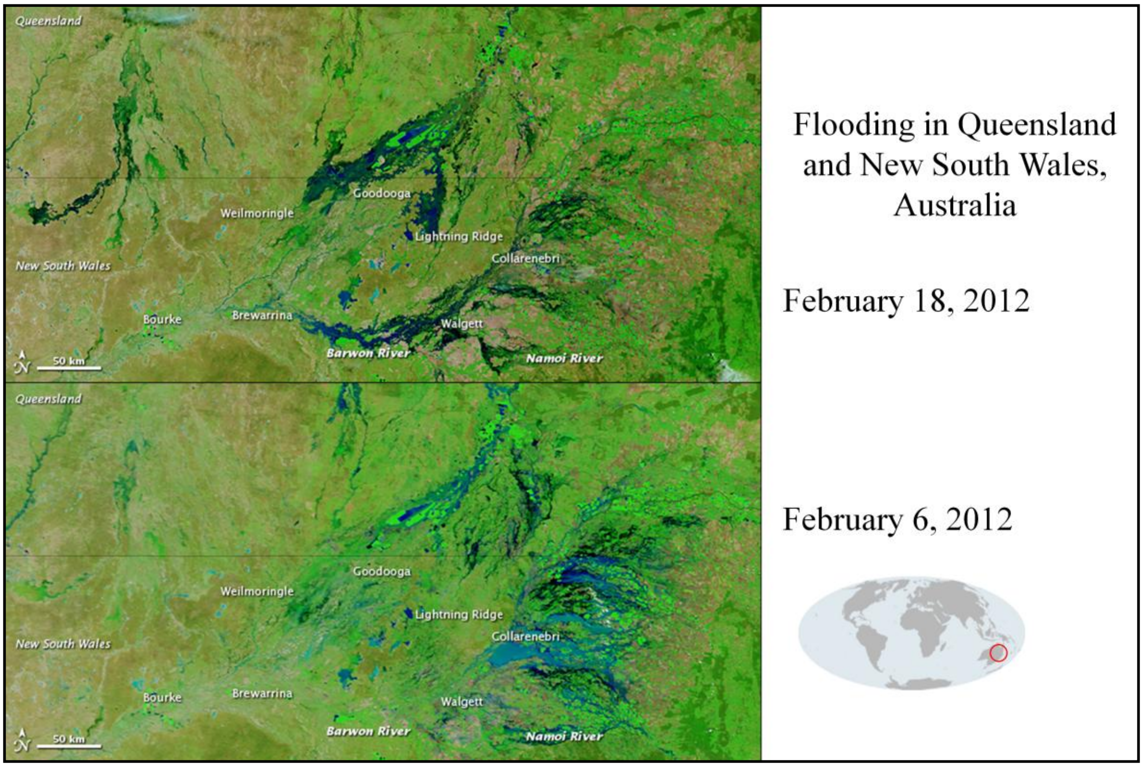
**Lightning detection evidence**

Lightning detection systems can indicate the presence of deep moist convection, which can help detect SOME potential flash flooding situations. The heaviest rainfall seems to occur where the lighting strikes are most intense.

**Radar evidence**

WSR-88D radars graphically display precipitation on a map. Radar can show the location of the intense rainfall cores associated with deep moist convection, and estimate the duration of rainfall. Radar can also track the evolution of convective systems over time. Forecasters are able to watch existing cells intensify, and see when new cells begin to develop aloft. Animation of radar provides specific information on the movement of convective systems and helps in the assessment of the flash flood threat.

Currently, the NWS uses products developed for WSR-88D radars to aid in issuing flash flood statements, watches, or warnings. One product estimates one-hour precipitation accumulation to assess rainfall intensities for flash flood warnings, urban flood statements and special weather statements. Another product estimates accumulated rainfall, continuously updated, since the last one-hour break in precipitation. This product is used to locate flood potential over urban or rural areas, estimate total basin runoff and provide rainfall accumulations for the duration of the event.




Along the border between the Australian states of Queensland and New South Wales, several communities were flooded in early February 2012. By mid-month, the flood waters had moved west. On February 19, online news source NineMSN reported that as many as 10,000 residents of northeastern New South Wales would likely be isolated from the outside world by high water.

The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite acquired these images on February 18, 2012 (top), and February 6, 2012 (bottom). Both images show flood conditions, but they also show the movement of water along the Barwon and Namoi Rivers and other waterways in the region.

These images use a combination of visible and infrared light to better distinguish between water and land. Water varies from electric blue to navy, with darker shades generally indicating deeper water. Vegetation is bright green. Bare ground is earth-toned.

On February 6, floods are largely confined to areas east of Walgett. By February 18, flooding has receded east of that town, but floods have traveled westward along tributaries of the Darling River. New flooding is especially apparent between Walgett and Brewarrina, and north of Lightning Ridge and Goodooga.

NineMSN reported that several thousand residents were already isolated in the communities of Walgett, Collarenebri, Weilmoringle, and Goodooga, and flooding in those areas could persist for weeks. Floods were also expected in Brewarrina and Bourke over the next month.

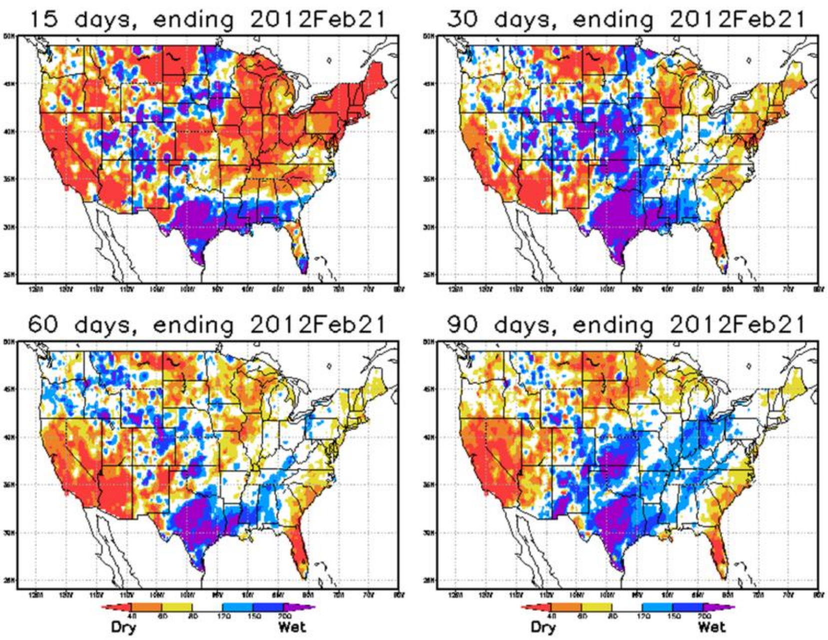
**References**

NineMSN. (2012, February 19). Warnings issued as NSW floods creep west. Accessed February 20, 2012.

NASA images courtesy LANCE/EOSDIS MODIS Rapid Response Team at NASA GSFC. Caption by Michon Scott.

Instrument: Terra - MODIS

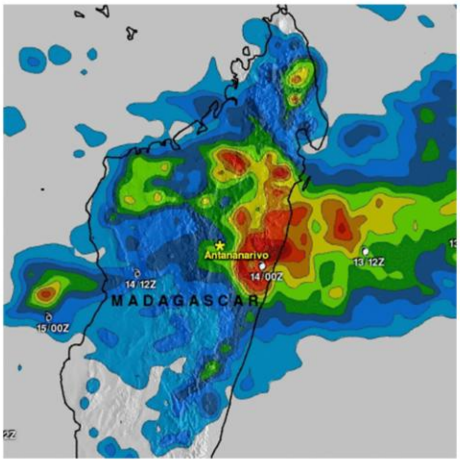
**Precipitation, Percent of Normal:**
**Last 15, 30, 60 and 90 Days**



February 8-15, 2012

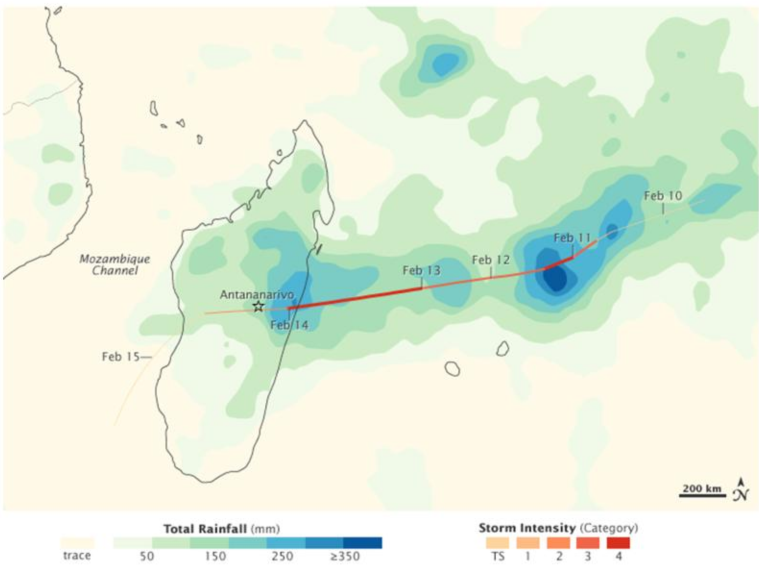
**Deadly Tropical Cyclone Giovanna Floods Madagascar**

Tropical Rainfall Mapping Mission (TRMM) UTC




This analysis indicates that the highest rainfall totals of over 250mm fell in the coastal area east of Madagascar's capitol of Antananarivo.

TRMM-based precipitation estimates (3B42)from a merger of all available satellite data. This Multi-satellite Precipitation Analysis (TMPA) done at the NASA Goddard Space Flight Center provides estimates of rainfall over the global Tropics.




Acquired Feb. 8-14, 2012

When Tropical Cyclone Giovanna came ashore in eastern Madagascar, the well-organized storm not only brought high winds, but also heavy rain. Flooding affected multiple neighborhoods in the capital city of Antananarivo and surrounding areas. As of February 15, 2012, the death toll stood at 16.

This map shows the rain associated with Giovanna from February 8 to 14, 2012. The heaviest rainfall—more than 350 millimeters, or nearly 14 inches—appears in dark blue. The lightest—less than 50 millimeters, or 2 inches—appears in light green. Trace amounts appear in pale yellow. The heaviest rainfall occurs east of Madagascar, but almost equally heavy rainfall occurs along the island's east coast.

Superimposed on the rainfall is Giovanna's storm track, with darker shades of red corresponding with a greater storm intensity. Before making landfall, Giovanna strengthened to a Category 4 storm.

This image is based on data from the Multisatellite Precipitation Analysis produced at NASA's Goddard Space Flight Center, which estimates rainfall by combining measurements from many satellites and calibrating them using rainfall measurements from the Tropical Rainfall Measuring Mission (TRMM) satellite.

**References**

Associated Press (2012, February 15). Cyclone kills 16 in Madagascar. *Seattle Post Intelligencer.* Accessed February 15, 2012.

Joint Typhoon Warning Center. (2012, February 15). Tropical Cyclone 12S (Giovanna) Warning. Accessed February 15, 2012.

Unisys Weather. (2012, February 15). Giovanna Tracking Information. Accessed February 15, 2012.

NASA Earth Observatory image by Jesse Allen, using near-real-time data provided courtesy of TRMM Science Data and Information System at Goddard Space Flight Center. Caption by Michon Scott.

High Sediment Transport after Heavy Rains in Madagascar


Onibe River
February 19, 2012
ALI imager

In February 2012, Tropical Cyclone Giovanna made landfall in eastern Madagascar, packing winds of 125 knots (230 kilometers per hour) and heavy rains in excess of 250 millimeters (10 inches) along the coast. On February 20, the Integrated Regional Information Networks reported that Giovanna had damaged or destroyed thousands of homes in Madagascar and killed at least 23 people.

The Advanced Land Imager (ALI) on NASA's Earth Observing-1 (EO-1) satellite captured this natural-color image of the sediment-choked Onibe River on February 19, 2012. The river appears muddy brown throughout this landscape, and delivers a thick plume of sediment to the Indian Ocean.

The Onibe River arises in the highlands of Madagascar's interior and empties into the ocean just north of the coastal town of Mahavelona (also known as Foulpointe). The river lies along the track Giovanna followed when it came ashore. Giovanna's heavy rains spurred equally heavy runoff into the Onibe River.

In eastern Madagascar, rivers are typically short and fast-moving, thanks to the area's stark relief. Madagascar's highest mountain, for example, is 2,876 meters (9,436 feet) above sea level yet lies just 120 kilometers (75 miles) from the coast. The steep slopes lead to significant erosion, but even compared to the island's usual runoff rates, the Onibe carried a heavy load of mud and debris in the wake of Giovanna. An ALI image of the same area on February 6 showed virtually no sediment plume at the mouth of the river.

Cyclones rank among the most frequent natural hazards for Madagascar. After coming ashore in mid-February, Cyclone Giovanna blew westward over the island, traveled southward through the Mozambique Channel, then curved back to the east, skirting Madagascar's southern shore.

**References**

CIA World Factbook. (2012, February 8). Madagascar. Accessed February 21, 2012.

Cox, R., Bierman, P., Jungers, M.C., Rakotondrazafy, A.F.M. (2009). Erosion rates and sediment sources in Madagascar inferred from Be analysis of lavaka, slope, and river sediment. *The Journal of Geology,* 117(4), 363–376.

Integrated Regional Information Networks. (2012, February 20). Madagascar: Cyclone Giovanna struck with little warning. Accessed February 21, 2012.

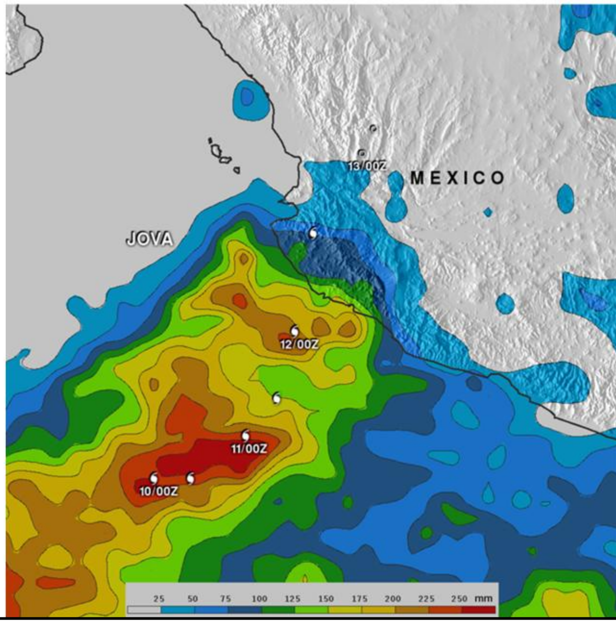
Tropical Rainfall Measuring Mission. (2012, February 12). Deadly Tropical Cyclone Giovanna floods Madagascar.Accessed February 21, 2012.

Unisys Weather. (2012, February 20). Giovanna Tracking Information. Accessed February 20, 2012.

NASA Earth Observatory image created by Jesse Allen and Robert Simmon, using EO-1 ALI data provided courtesy of the NASA EO-1 team. Caption by Michon Scott.

Instrument: EO-1 - ALI

The highest rainfall totals over the central coast of Mexico in association with Hurricane Jova are ~100 to 150 mm, shown in green and yellow, and rapidly fall off inland. October 6-11, 2011

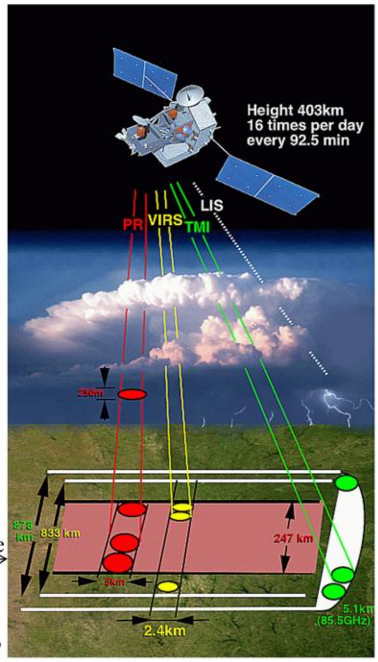


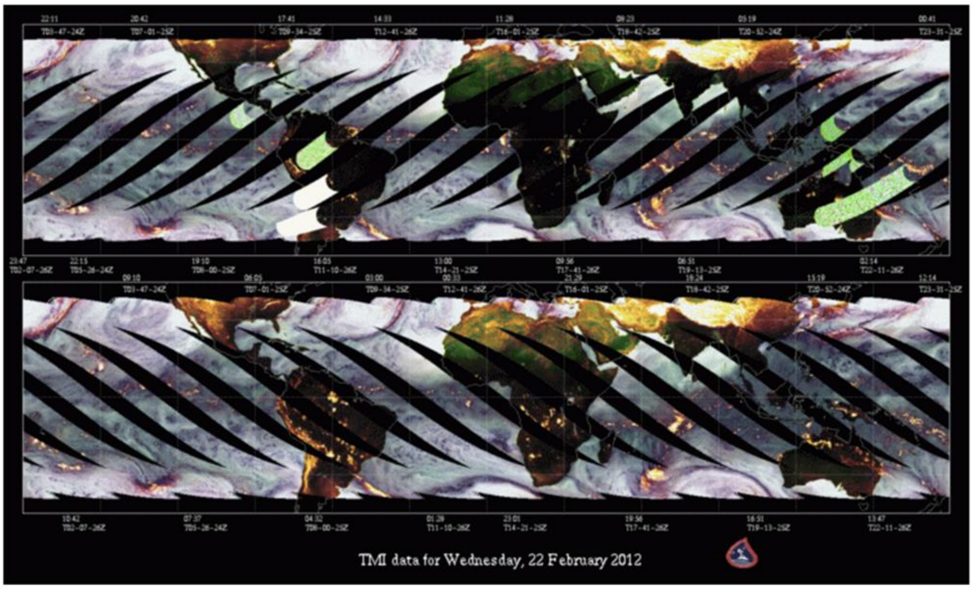
Tropical Rainfall Mapping Mission (TRMM)

A joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical rainfall, launched 1997

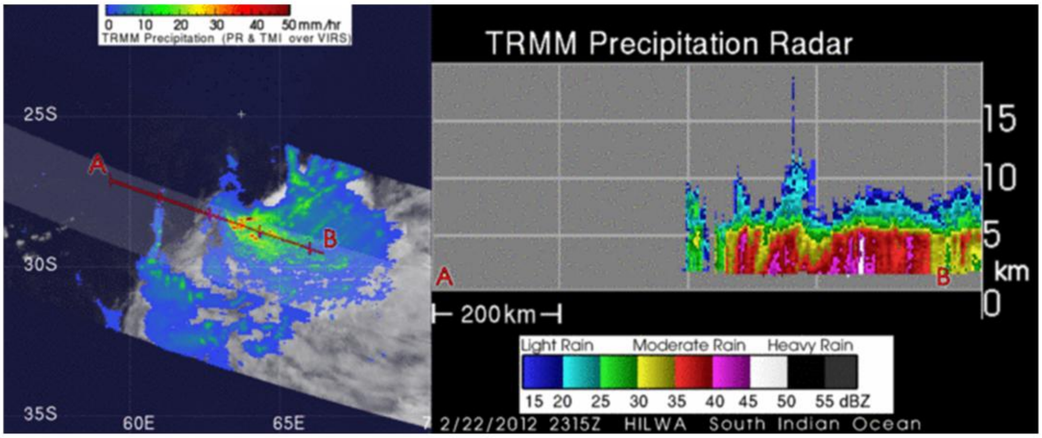
PR Precipitation Radar
TMI TRMM Microwave Imager
VIRS Visible and Infrared Scanner (5 bands, 0.63-12μm)
LIS Lightning Imaging Sensor
CERES Clouds and Earth's Radiant Energy System (3 bands: 0.3-100μm, 0.3-5μm, 8-12 μm)

Note pixel size

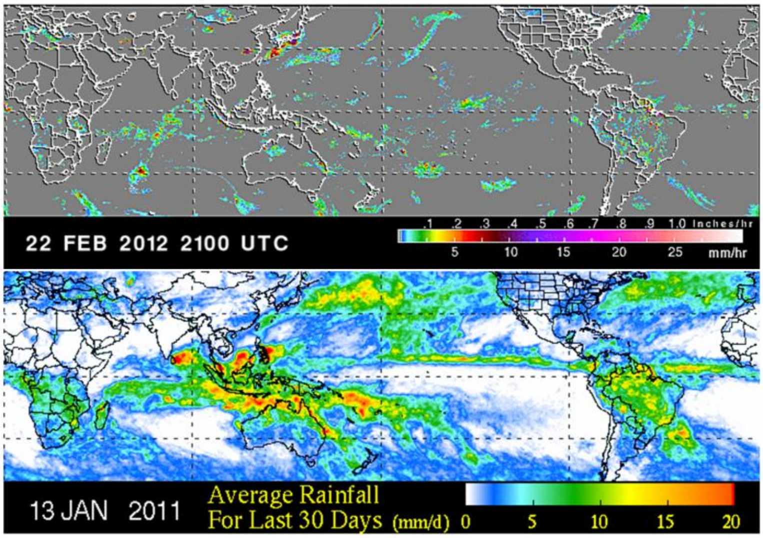



TMI data for Wednesday, 22 February 2012

Latest Tropical Cyclone



TRMM Precipitation Data

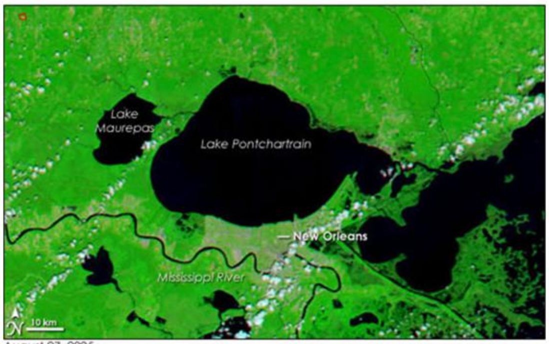


After Katrina


August 30, 2005

August 30, 2005

Before Katrina




August 27, 2005

August 27, 2005

September 15, 2005

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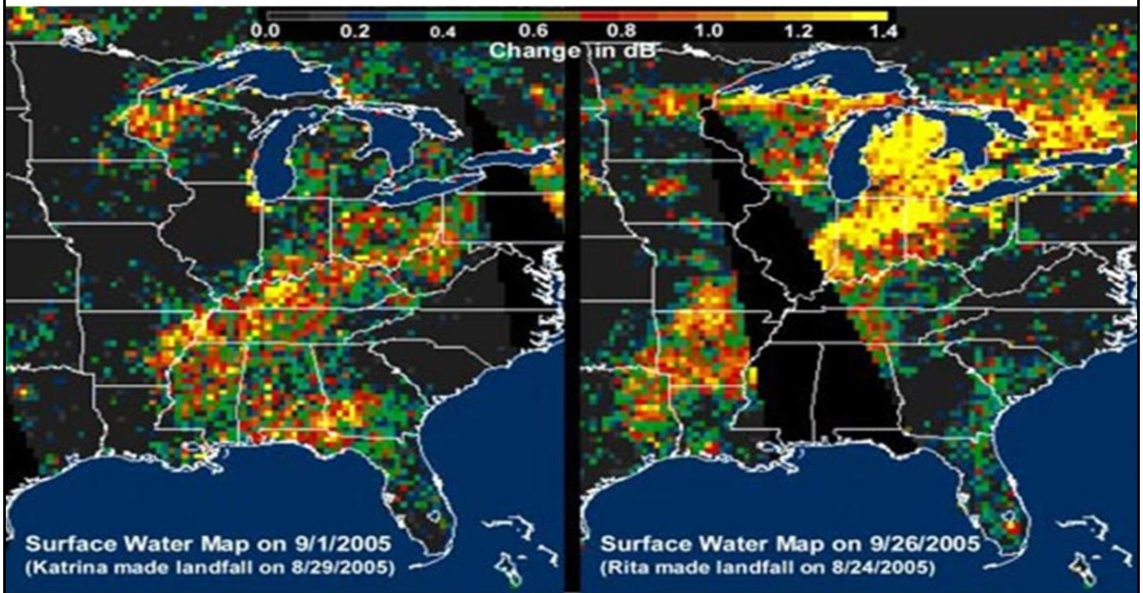
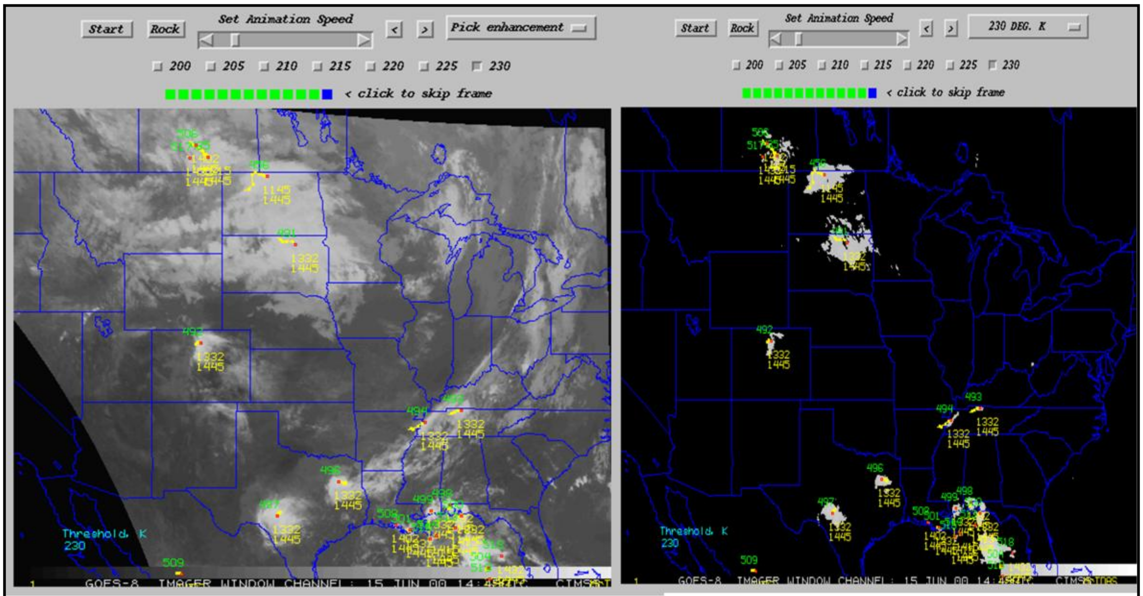
September 7, 2005


September 7, 2005

## QuikScat satellite data used to monitor changes in surface water




Data from NASA's QuikScat satellite are used to monitor changes in surface water resulting from Hurricanes Katrina and Rita in the Mississippi River basin. In these images, the colors represent an increase in surface soil moisture resulting from rainfall. Rainfall from the two hurricanes can take several weeks to manifest itself as increased river discharge in large rivers such as the Mississippi.




## Small Thunderstorm Tracking

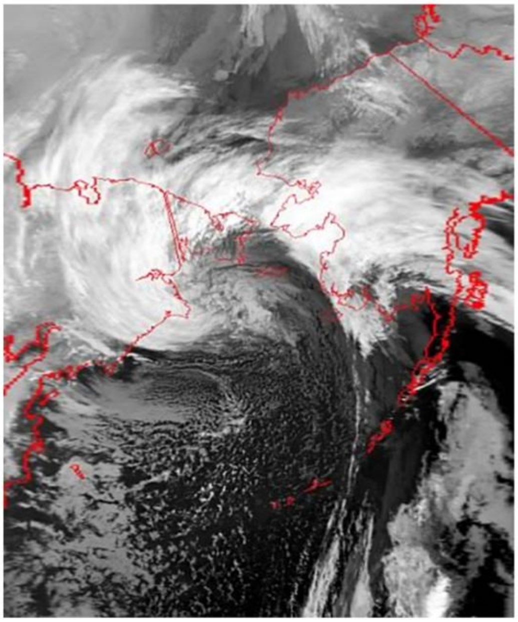
GOES Imager

Severe thunderstorms are thunderstorms that produce tornadoes, large hail or are accompanied by high winds. Lightning and floods are often of concern to a severe weather forecaster.

GOES Data used to track severe localized storms.

## Coastal Climatology and Extreme Weather Events in Alaska and the Arctic

Ice Storms
October 19, 2004



Satellite image - Storm of October 19, 2004

Coastal communities in Alaska are subjected to periodic weather events that can take on an "extreme" and dangerous nature. Water ran through the streets of Nome, AK on October 19, 2004, when a powerful winter storm moved in from the Aleutian Islands. Driven by heavy moisture from a typhoon east of Japan and cold air from Far East Russia, the storm lowered air pressure to 941 millibars (mb), well into hurricane strength, and pounded western Alaska with 50 to 80 mph winds. Nome, a coastal city of 3500 people, reported gusts up to 59 mph, comparable to another powerful storm in November of 1974. The storm surge height reached 10.45 feet, sending waves over the sea wall and into the city. Storm surge, water that is pushed toward shore by wind force, can combine with normal tide to create extremely high tidewater and represents the most destructive aspect of coastal storms. In comparison, the storm surge height of the 1974 storm was 10 feet. The Fairbanks National Weather Service (NWS) *Storm Data and Unusual Weather Phenomena* report for October, 2004 estimated overall storm damages at approximately $20 million, with Nome incurring the bulk of the damage.

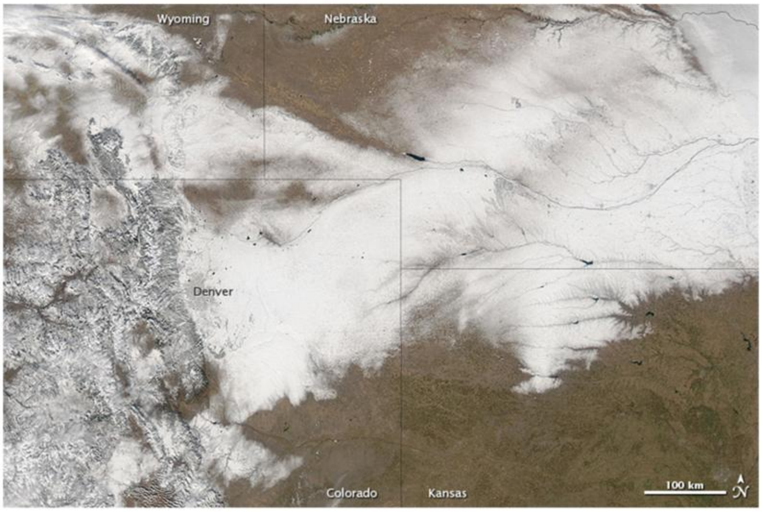
Satellite image - storm of October 19, 2004 (click on image for larger view)

When severe storms happen in populated areas there is significant impact on residents and infrastructure. During the October 2004 storm in Nome, forty-five people had to be evacuated and thirteen homes were damaged. Other homes near Front Street were vacated because of leaking propane tanks from nearby businesses. Many city buildings suffered structural damage, including the State building, the historic Cape Nome Road House, and the water treatment system. Power lines were downed, roofs blown off, and rocks and driftwood were scattered over the main street and against buildings. The seawall that protects the harbor was also damaged.

Atmospheric scientists categorize this type of weather as an "extreme event." In general, the term "extreme event" covers a variety of weather occurrences over a range of time frames, from single events to unusual changes in climate variability, lasting days or weeks. Examples include heavy rains, dry spells, strong storms and winds, and extreme temperatures. Normal air pressure at sea level is 1013.25 mb ("millibars", a unit of pressure measurement), but during severe storms and extreme events, air pressure can drop by 30 to 70 mb, as it did during the Nome storm (Fig. 1). Low pressure also brings strong winds, which is why meteorologists pay close attention to the "central pressure" range of storm systems of all types (Fig. 2).

Several factors can influence the intensity of northern storms, including temperature, sea ice and wind. Recent studies have shown a warming trend in the Arctic and decreasing summertime sea ice cover, leaving open water areas along many coastlines. Sea ice plays a major role in determining the extent of storm impacts on a coastline. Solid ice cover, and even floating ice, dampens wave activity, reducing its intensity. By contrast, in areas of open water, nothing limits the full development of wind-driven waves. The presence of "land-fast" sea-ice, which is sea-ice bonded to the coast, also limits the effects of coastal erosion by directly protecting the coastline from waves. Surface air temperature projections, derived from several climate models of the Arctic, predict that the warming trend will continue (Fig. 3). Such a trend could result in increasing the frequency of extreme weather events and the coastal flooding and erosion associated with these events.

## Record-breaking snowstorm struck Colorado; Snow cover forms a wide, uneven track over Wyoming, Kansas, and Nebraska




MODIS
Feb. 5, 2012

A record-breaking snowstorm struck Colorado in early February 2012, closing an interstate highway, grounding flights, and dropping more than a foot of snow on the Denver area. After moving out of northeastern Colorado, the storm left heavy snow across Nebraska.

The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this natural-color image on February 5, after skies had largely cleared over the region. Snow and mountain peaks create a mottled appearance in western Colorado. Elsewhere, the snow cover forms a wide, uneven track over Wyoming, Kansas, and Nebraska.

This snowfall did not break all-time records in Colorado, but it did break records for the month of February. The storm deposited 15.9 inches (40.4 centimeters) in Denver and 22.7 inches (57.7 centimeters) in Boulder. The National Weather Service also reported up to 18 inches (46 centimeters) of snow west of Omaha, Nebraska.

NWS meteorologists explained that northeastern Colorado generally experiences storms of this magnitude in March or April. This February storm showed some of the same characteristics of powerful spring storms, as a weather front from the Pacific Northwest converged with moisture from the Gulf of Mexico.

Colorado ski resorts welcomed the precipitation after suffering from below-normal snow cover for most of the 2011–2012 ski season. But the new snow raised the risk of avalanches. On February 6, the Colorado Avalanche Information Center reported "considerable" avalanche danger across much of the state.

**References**

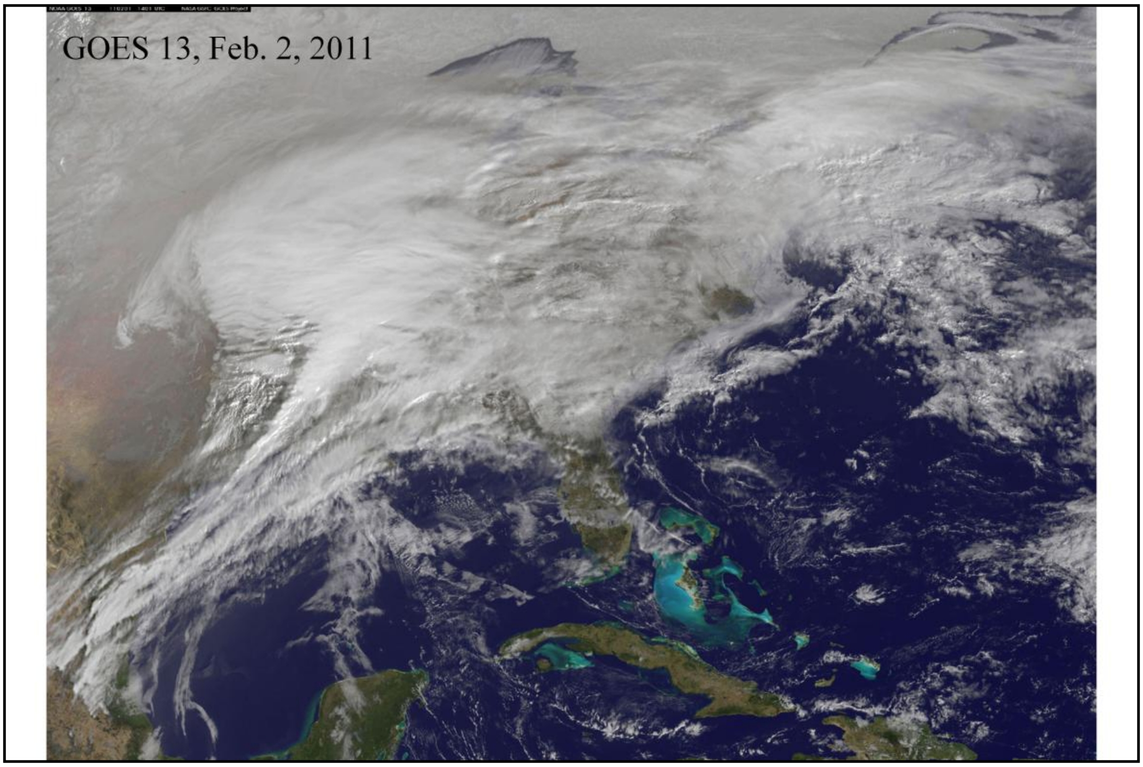
Associated Press. (2012, February 5). Storm blankets Nebraska after hitting Colorado. *USA Today.* Accessed February 6, 2012.

Colorado Avalanche Information Center. (2012, February 6). Forecast. Accessed February 6, 2012.

National Weather Service, Omaha/Valley, Nebraska. (2012, February 5). Storm Total Snowfall Feb 3–4. Accessed February 6, 2012.

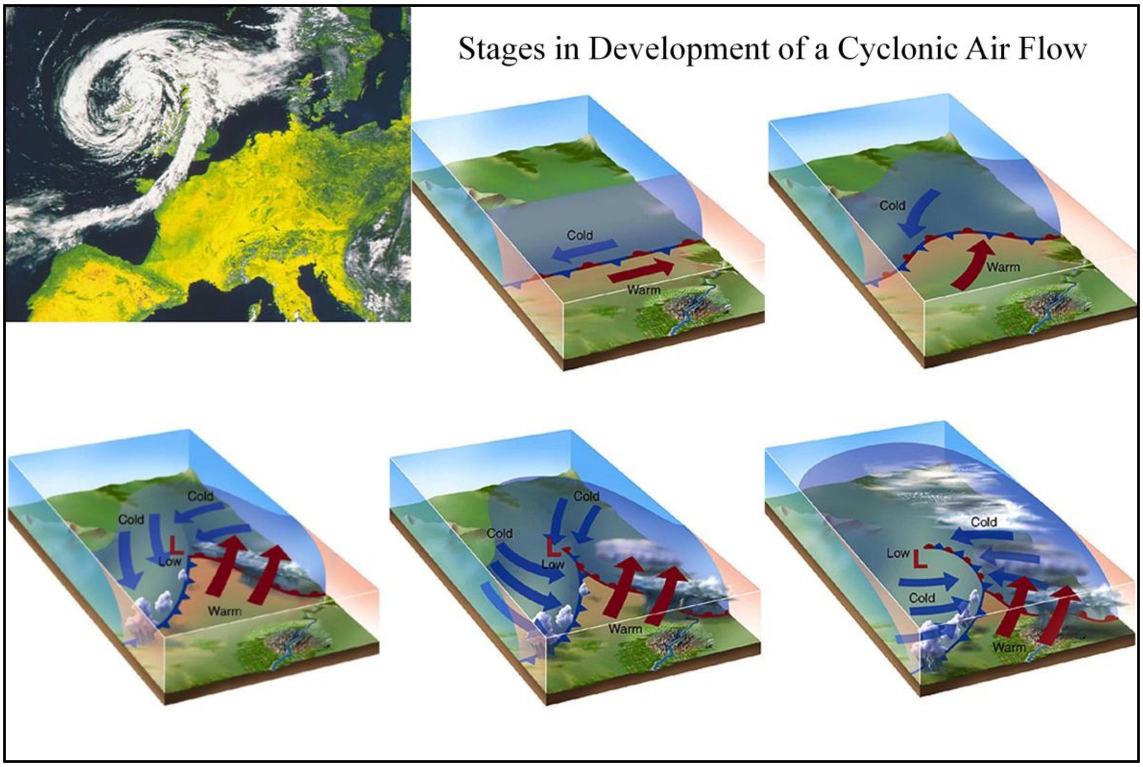
National Weather Service, Denver/Boulder, Colorado. (2012, February 5). Post-Storm Summary of the February 2–4, 2012 Record Breaking Storm. Accessed February 6, 2012.

NASA image courtesy Jeff Schmaltz, LANCE/EOSDIS MODIS Rapid Response Team at NASA GSFC. Caption by Michon Scott.



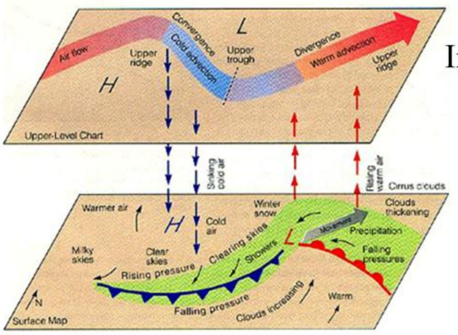

Visible and infrared images and animations of the storm's clouds and movement are created every 15 minutes by the NASA GOES Project at NASA's Goddard Space Flight Center, Greenbelt, Md. using data from GOES-11 and GOES-13, the Geostationary Operational Environmental Satellites. The GOES-13 and GOES-11 satellites that cover the eastern and western U.S., respectively, are operated by NOAA.

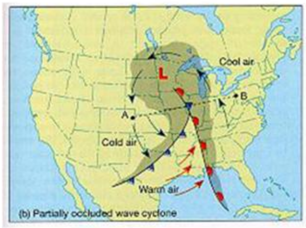
# Cyclonic Storms: Hurricanes and Typhoons

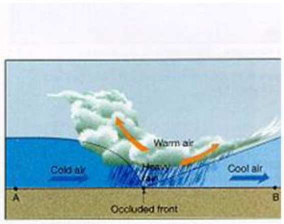


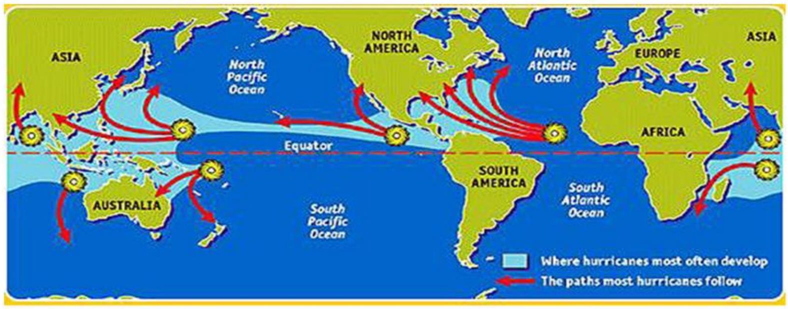

The development of the cyclone follows a general sequence of stages beginning with the advance of an Arctic Cold Front into cooler air (to the south in the northern hemisphere) and often ending with an occluded phase.

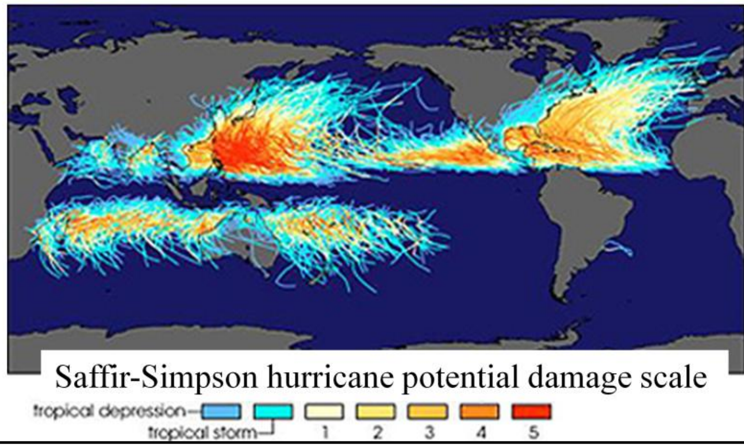
Initiation of a Cyclonic Circulation Pattern



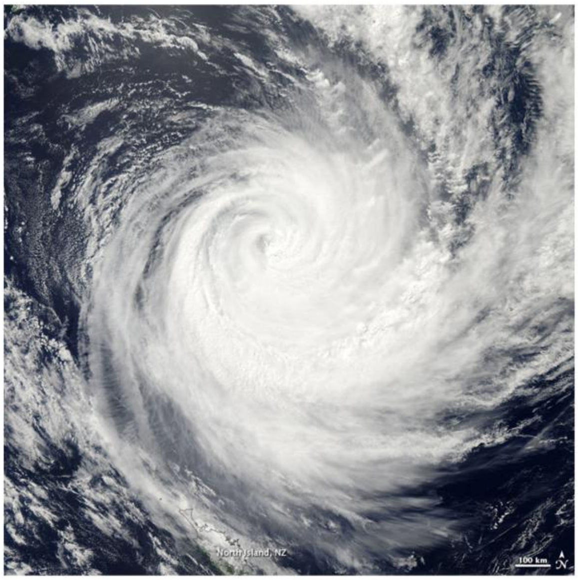



Driven by westward flowing upper level trade winds, and powered by their extreme internal energy derived from hot air condensation, hurricanes move across the Atlantic toward North and South America. Depending on interactions with air masses on the continents or the open ocean, hurricanes will frequently be blocked or deflected northward and may or may not make landfall.

The map (below) plots the worldwide distribution of the paths of major cyclones (hurricanes) during the last 150 years.

## Cyclone Atu, Feb. 21, 2011 approaching New Zealand

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Tropical Cyclone Atu approached the North Island of New Zealand on February 23, 2011. The U.S. Navy's Joint Typhoon Warning Center (JTWC) reported that, as of 10:00 p.m. Auckland time on February 23, Atu was located roughly 505 nautical miles (935 kilometers) north-northeast of the city. The storm had maximum sustained winds of 70 knots (130 kilometers per hour) and gusts up to 85 knots (155 kilometers per hour).

The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this natural-color image around 3:10 p.m. local time on February 23, 2011. One of Atu's spiral arms extends over New Zealand's North Island.

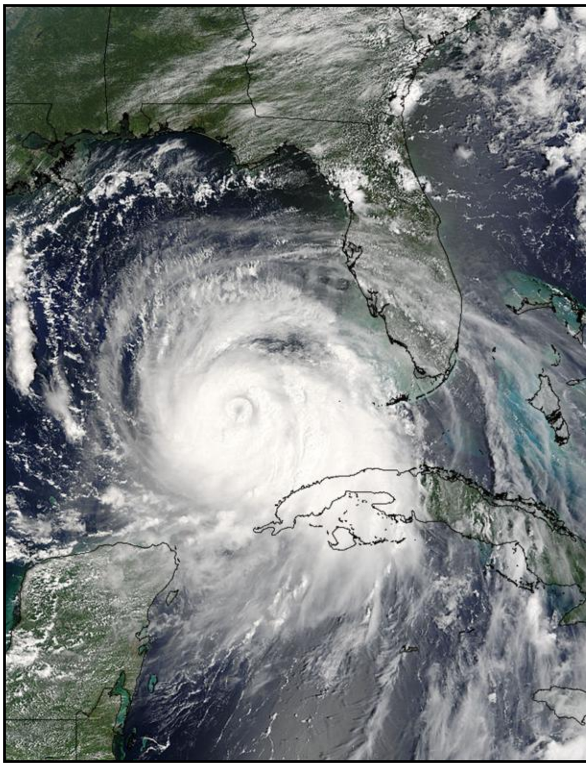
The JTWC reported that Atu was currently transitioning to an extra-tropical storm, and forecast that the storm would weaken thanks to reduced sea surface temperatures and increased vertical wind shear. Atu was nevertheless expected to remain strong as it became an extra-tropical low.

**References**

Joint Typhoon Warning Center. (2011, February 23). Tropical Cyclone 17P (Atu) Warning. Accessed February 23, 2011.

NASA image courtesy Jeff Schmaltz, MODIS Rapid Response Team at NASA GSFC. Caption by Michon Scott.

Instrument: Aqua - MODIS



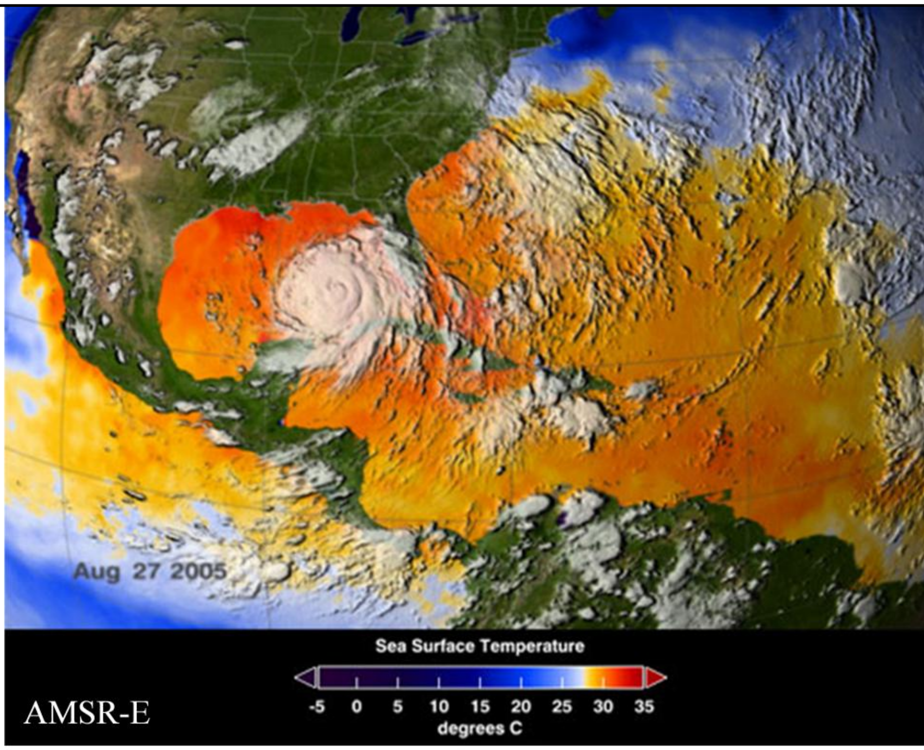
**August 27, 2005, marked the first day that an eye became apparent At Category 3 Hurricane**

**Katrina roils over the Gulf of Mexico, August 2005**

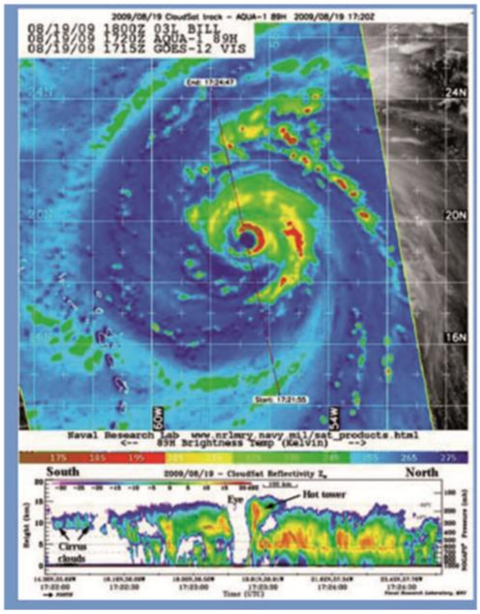

*MODIS Image Courtesy NASA Earth Observatory*

August 27, 2005, marked the first day that an eye became apparent in satellite imagery of Hurricane Katrina. In the morning of August 27, Katrina's winds reached 185 kilometers per hour, making the storm a Category 3 hurricane. When the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured this image at 11:20 a.m. U.S. Central time, the inner eyewall had begun to deteriorate and an outer eyewall was forming. The two eyewalls are clearly visible as two concentric circles at the center of the storm. Katrina was also expanding, and by the end of the day, had doubled in size.

The next day, Katrina exploded into a Category 5 hurricane with winds of 257 kilometers per hour. When Katrina came ashore on August 29, it was one of the deadliest and costliest storms to hit the United States.


Aug 27 2005
Sea Surface Temperature
-5 0 5 10 15 20 25 30 35
degrees C
AMSR-E

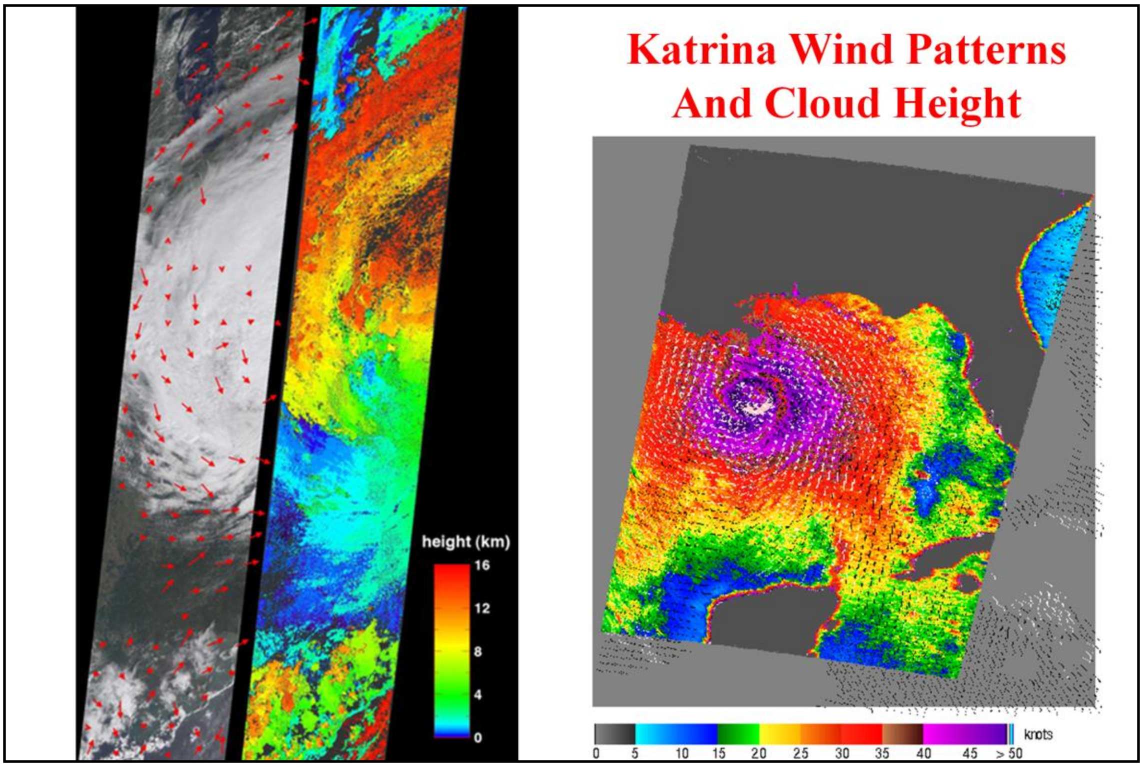
The U.S. National Hurricane Center and U.S. Naval Research Laboratory (NRL) Synergistically use AMSR-E and CloudSat Radar data for weather applications.




AMSR-E 89 GHz (top) and CloudSat Radar (bottom) Results for Hurricane Bill (Atlantic) on 8/19/09.

135 MPH winds,
460 mile diameter

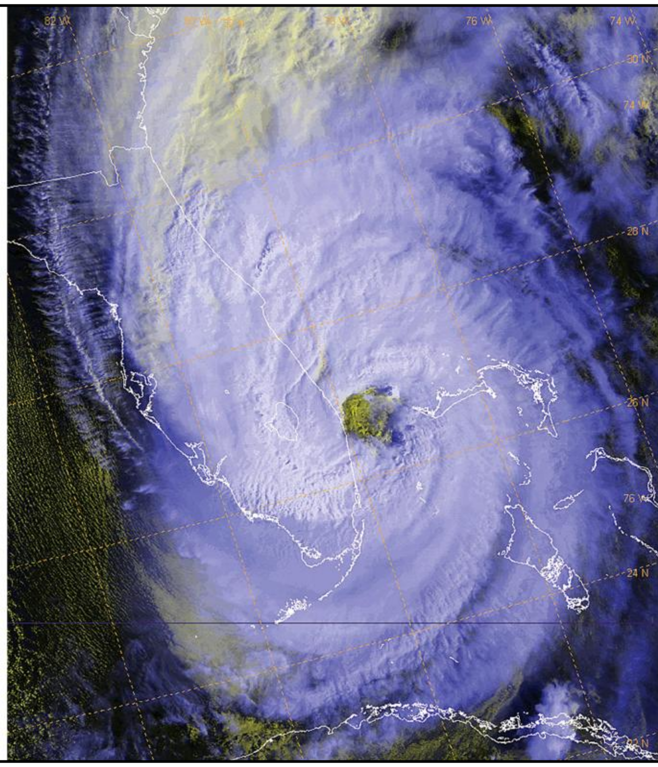
**Hurricane Bill** was a relatively large Atlantic tropical cyclone, attaining a maximum gale-diameter of 460 mi (740 km). A Cape Verde type hurricane, Bill originated from a tropical wave that emerged from the western coast of Africa on August 12, and organized into a tropical depression near the Cape Verde islands on August 15. The depression was quickly upgraded to a tropical storm, earning the name *Bill*. Tracking generally west-northwestward, the tropical system attained hurricane status on August 17 and major hurricane status on August 18. The following day, Bill attained peak intensity with winds of 135 mph (217 km/h) and a minimum central pressure of 943 mbar (27.8 inHg). It weakened as it veered north, passing Bermuda with little impact, and Bill lost tropical characteristics as it passed over Nova Scotia and Newfoundland. However, waves up the East Coast killed two people, and the hurricane passed close enough to warrant tropical cyclone watches and warnings in both the United States and Canada.


Katrina Wind Patterns
And Cloud Height
height (km)
16
12
8
4
0
knots
0 5 10 15 20 25 30 35 40 45 > 50

# Hurricane Wilma

## 2005 10/24

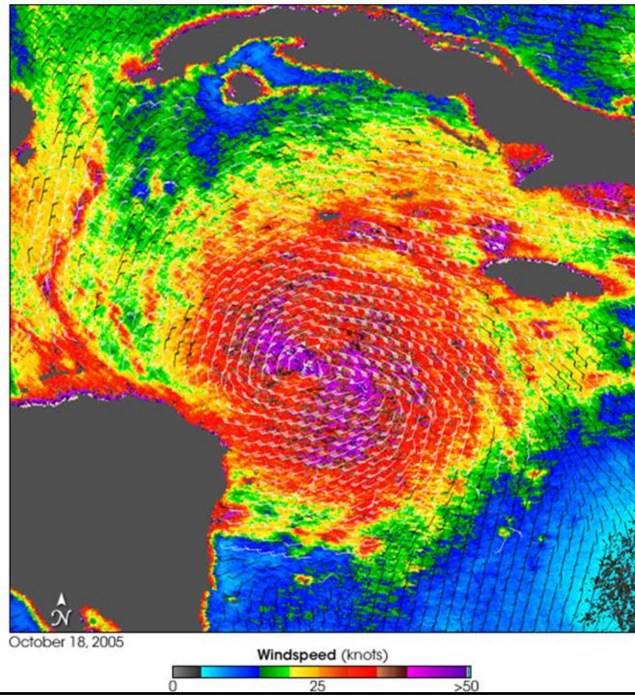
DMSP OLS Image



OFFUTT AIR FORCE BASE, Neb. -- This satellite photo, provided by the Air Force Weather Agency here, shows the status of Hurricane Wilma as of 8:25 a.m. EST, today. The image captures the Category 2 storm off the coast of Florida. The center of the storm's eye about 75 miles northeast from Miami. A Defense Meteorological Satellite Program satellite took the image, and is actually a composite of two satellite images. (U.S. Air Force photo)

Hurricane Wilma, NASA's QuikSCAT satellite on October 18, 2005

Ku band microwave




Early radar measurements over oceans were corrupted by noise. It was not known that the clutter was the radar response to winds until 1960s. Early scatterometers successfully estimated ocean wind speed and direction, and were applied to a wide variety of problems, including weather forecasting and estimation of tropical rain forest reduction. The Ku-band scatterometer instrument, The Quick Scatterometer "QuikSCAT" microwave radar measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans. (**http://winds.jpl.nasa.gov/missions/quikscat/index.cfm**) It was launched in June 1999.

**Hurricane Wilma**

Hurricane Wilma observed by NASA's QuikSCAT satellite on October 18, 2005, at 23:31 UTC (7:31 p.m. Eastern Daylight Time) when the hurricane had sustained winds of 130 kilometers per hour. Within twelve hours of this observation, Wilma dramatically increased powe, to Category 5 with sustained winds of 280 km/hr! At that point, Wilma became **the most powerful storm** in terms of both wind speed and air pressure ever measured in an Atlantic hurricane.

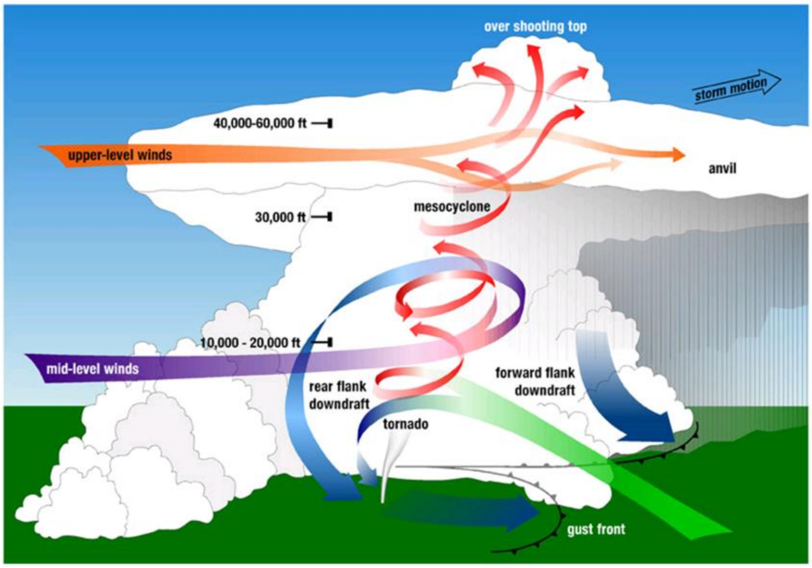
The image depicts wind speed in color and wind direction with small barbs. White barbs show areas of heavy rain. The highest wind speeds, shown in purple, surround the center of the storm.

Ground measurements of the wind strength of Hurricane Wilma show sustained winds somewhat higher than QuikSCAT observations. This is because the power of the storm makes accurate measurements difficult. The scatterometer sends pulses of microwave energy through the atmosphere to the ocean surface, and measures the energy that bounces back from the wind-roughened surface. The energy of the microwave pulses changes depending on wind speed and direction, giving scientists a way to monitor wind around the world.

Tropical cyclones (the generic term for hurricanes and typhoons), are difficult to measure. To relate the radar energy return to actual wind speed, scientists compare measurements taken from buoys and other ground stations to data the satellite acquired at the same time and place. Because the high wind speeds generated by cyclones are rare, scientists do not have corresponding ground information to know how to translate data from the satellite for wind speeds above about 93 km/hr. Also, the unusually heavy rain found in a cyclone distorts the microwave pulses in a number of ways, making a conversion to accurate wind speed difficult. The scatterometer provides a picture of the relative wind speeds within the storm and shows wind direction.

NASA image courtesy of David Long, Brigham Young University, on the QuikSCAT Science Team, and the Jet Propulsion Laboratory.

# Tornadoes are the most violent of all atmospheric storms




Tornadoes are the most violent of all atmospheric storms.

There are two types of tornadoes: those that come from a supercell thunderstorm, and those that do not.

Tornadoes that form from a supercell thunderstorm are the most common, and often the most dangerous. A supercell is a long-lived (greater than 1 hour) and highly organized storm feeding off an updraft (a rising current of air) that is tilted and rotating. This rotating updraft - as large as 10 miles in diameter and up to 50,000 feet tall - can be present as much as 20 to 60 minutes before a tornado forms. Scientists call this rotation a mesocyclone when it is detected by Doppler radar. The tornado is a very small extension of this larger rotation. Most large and violent tornadoes come from supercells.

April 28, 2011; Tornadoes: Nature's Most Violent Storms


35

Outside Griffin, Georgia across lightly populated farmland.

Among the more than 150 tornadoes reported on April 27 and 28, 2011, was a rare EF-5 storm. Such a storm has the capacity to collapse a concrete building. The tornado hit Smithville, Mississippi, where it killed at least 14 people, and moved northeast nearly 3 miles toward the Alabama border. It is the first EF5 tornado to occur in Mississippi since 1966, according to the National Weather Service.

Thunderstorms develop in warm, moist air in advance of eastward-moving cold fronts. These thunderstorms often produce large hail, strong winds, and tornadoes. Tornadoes in the winter and early spring are often associated with strong, frontal systems that form in the Central States and move east. Occasionally, large outbreaks of tornadoes occur with this type of weather pattern. Several states may be affected by numerous severe thunderstorms and tornadoes.

During spring in the Central Plains, thunderstorms frequently develop along a "dryline," which separates very warm, moist air to the east from hot, dry air to the west. Tornado-producing thunderstorms may form as the dryline moves east during the afternoon hours.

Along the front range of the Rocky Mountains, in the Texas panhandle, and in the southern High Plains, thunderstorms frequently form as air near the ground flows "upslope" toward higher terrain. If other favorable conditions exist, these thunderstorms can produce tornadoes.

Tornadoes occasionally accompany tropical storms and hurricanes that move over land. Tornadoes are most common to the right and ahead of the path of the storm center as it comes onshore.

On April 27, 2011, a devastating tornado tore through Tuscaloosa, Alabama. The storm packed winds of 190 miles (310 kilometers per hour) and left a path of debris running southwest to northeast. On May 2, 2011, the Advanced Land Imager (ALI) on NASA's Earth Observing-1 (EO-1) satellite captured this natural-color image of the tornado track through Tuscaloosa.

The tan-toned, debris-filled path passes through the center of town, affecting both commercial and residential properties. The track passes south of Bryant Denny Stadium and just north of University Mall. The mayor of Tuscaloosa estimated the cost of clearing the debris to be between $70 and $100 million.

Running roughly parallel to the tornado track is a contrail from a plane.

The National Oceanic and Atmospheric Administration (NOAA) reported that the tornado was spawned by a supercell thunderstorm that lasted more than seven hours. The supercell started in Newton County, Mississippi, at 2:54 p.m. Central Daylight Time (CDT), and finally ended in Macon County, North Carolina, at 10:18 p.m. CDT. The trail of damage stretched 80.3 miles (129.2 kilometers) long and as much as 1.5 miles (2.4 kilometers) wide.

Between 7:00 a.m. CDT on April 25 and 7:00 a.m. on April 28, a total of 305 tornadoes struck the southeastern and central United States, according to a preliminary estimate from NOAA released May 4. The tornado that passed through Tuscaloosa caused more than 1,000 injuries and at least 65 deaths across several towns and cities, the highest number of fatalities from a single tornado in the United States since May 25, 1955.

**References**

NOAA National Weather Service. (2011, May 3). Public Information Statement. Accessed May 3, 2011.

NOAA. (2011, May 4). April 2011 tornado information. Accessed May 5, 2011.

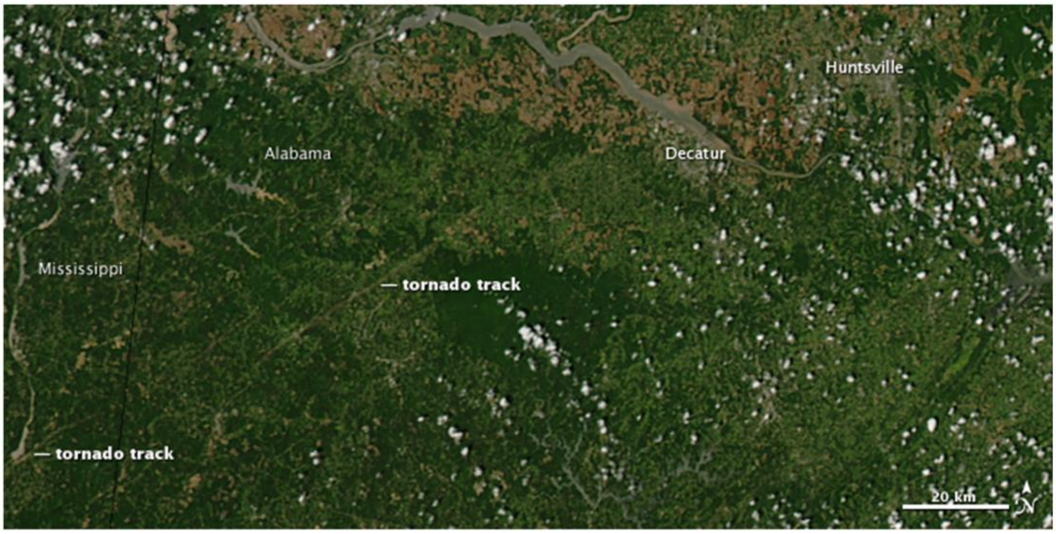
Sides, M. (2011, May 2). Latest update on Tuscaloosa from Mayor Maddox. WBRC. Accessed May 3, 2011.

**More images of this event in Natural Hazards**

NASA Earth Observatory image created by Jesse Allen and Robert Simmon, using EO-1 ALI data provided courtesy of the NASA EO-1 team. Caption by Michon Scott.

Instrument: EO-1 - ALI

April 28, 2011; Tornadoes: Nature's Most Violent Storms. Weather Service rated this tornado at EF4, with winds around 175 mph. The track was about 12 miles long and caused more than 20 deaths.




Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite

April 27, 2011
before/after tornado

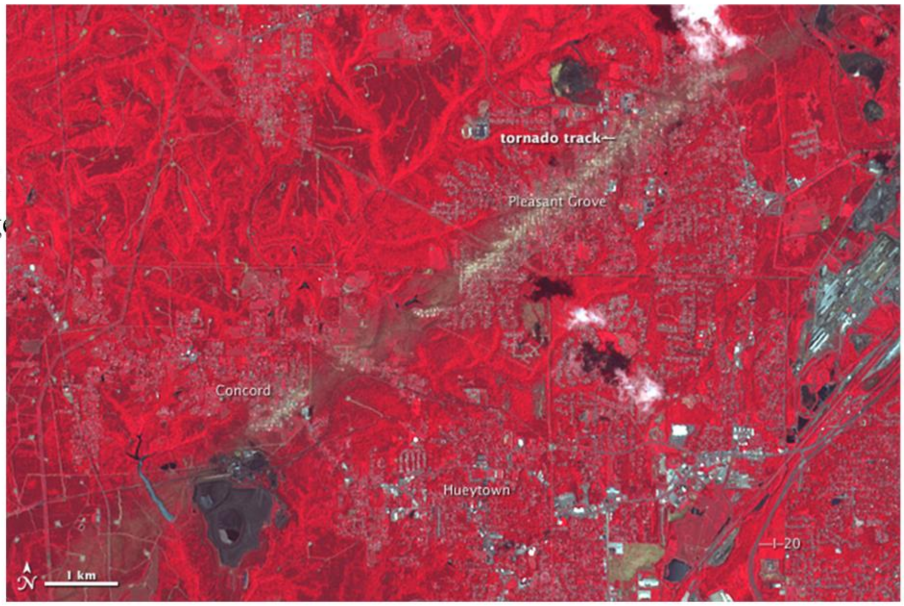
Severe Convective Storms

37

So far, there have been an estimated 1042 (as of May 1) tornadoes in 2011, NOAA said. The annual tornado record is 1,817, set in 2004. May is historically the most active month for tornadoes.

## Hueytown tornado, near Birmingham, AL On April 28, 2011

May 4, 2011
ASTER image




38

A tornado damage inflicted on Tuscaloosa on April 27, 2011, was just one part of a tornado track roughly 80.3 miles (129.2 kilometers) long and up to 1.5 miles (2.4 kilometers) wide. On May 4, 2011, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on NASA's Terra satellite observed another segment of the tornado track, closer to Birmingham, Alabama.

ASTER combines infrared, red, and green wavelengths of light to make false-color images that distinguish between water and land. Water is blue. Buildings and paved surfaces are blue-gray. Vegetation is red. The tornado track appears as a beige stripe running diagonally through this image.

On May 5, the National Oceanic and Atmospheric Administration (NOAA) National Weather Service issued updated information on the violent storms in the Birmingham area. Along the length of its 80-mile path, the tornado that passed through Tuscaloosa and Birmingham caused more than 1,000 injuries and at least 65 deaths. With winds of 190 miles (310 kilometers per hour), the tornado resulted from a supercell thunderstorm that lasted almost seven and a half hours, and traveled from Mississippi to North Carolina, spawning several violent tornadoes.

Between 7:00 a.m. CDT on April 25 and 7:00 a.m. on April 28, a total of 305 tornadoes struck the southeastern and central United States, according to NOAA's updated survey released May 4. The high-resolution version of this image shows two more tornado tracks, one to the north and one to the south, both running parallel to the tornado track through Tuscaloosa and Birmingham.

**References**

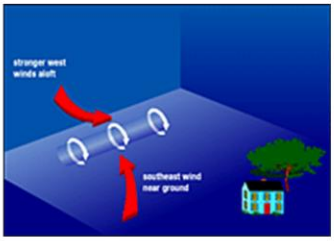
NOAA National Weather Service. (2011, May 5). Weather Forecast Office, Birmingham, Alabama. Accessed May 5, 2011.

NOAA. (2011, May 4). April 2011 tornado information. Accessed May 5, 2011.

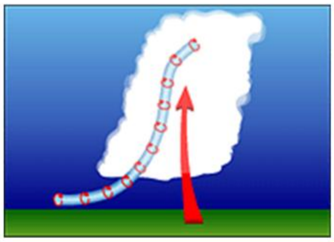
NASA Earth Observatory image created by Jesse Allen, using data provided courtesy of NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team. Caption by Michon Scott.

Instrument: Terra - ASTER

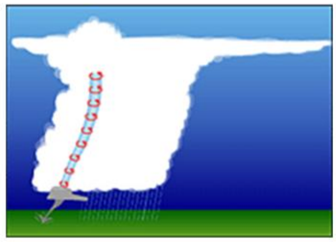
# Development of a Tornado




Before thunderstorms develop, change in wind direction and increase in wind speed with increasing height creates an invisible, horizontal spinning effect in the lower atmosphere.

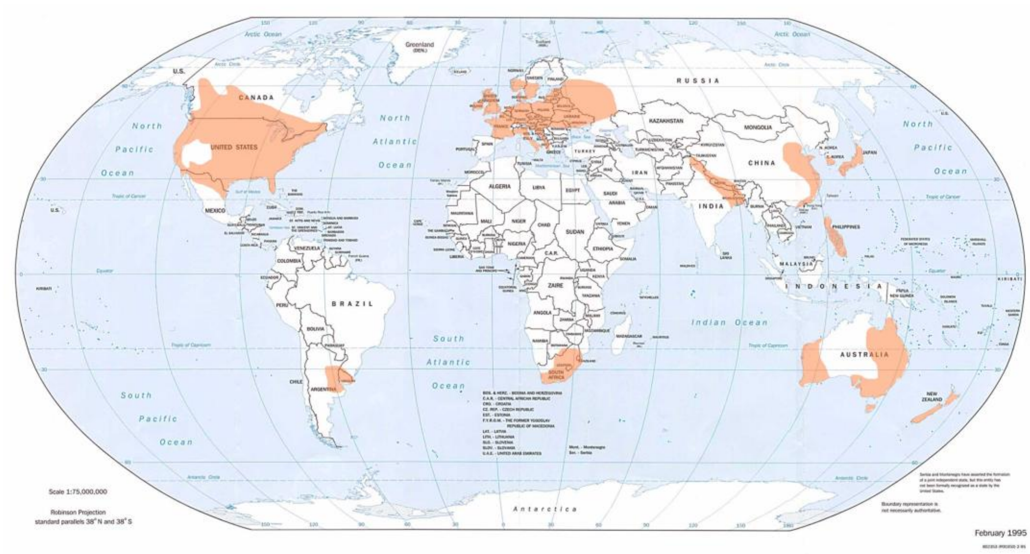


Rising air within the thunderstorm updraft tilts the rotating air from horizontal to vertical.



An area of rotation, 2-6 miles wide, now extends through much of the storm. Most strong and violent tornadoes form within this area of strong rotation.

**Regions of the world with increased likelihood of experiencing tornadoes**

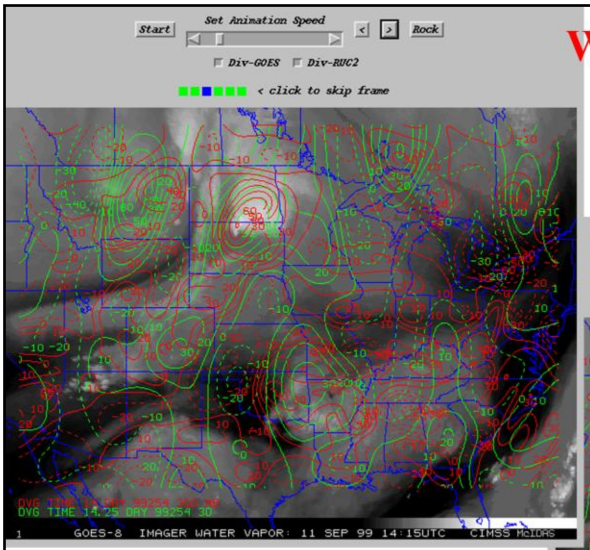


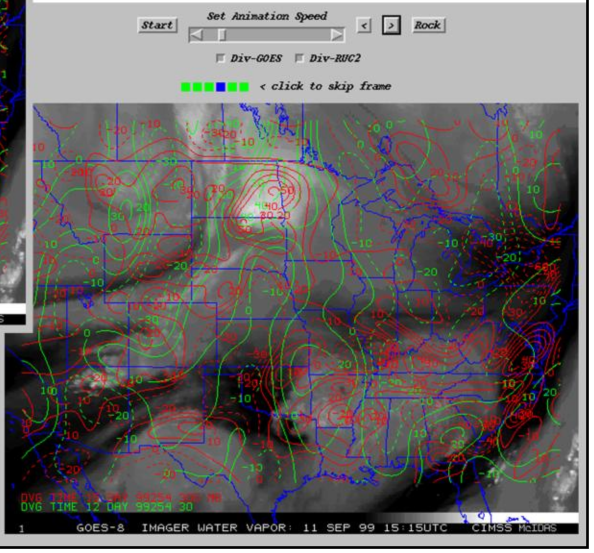

40

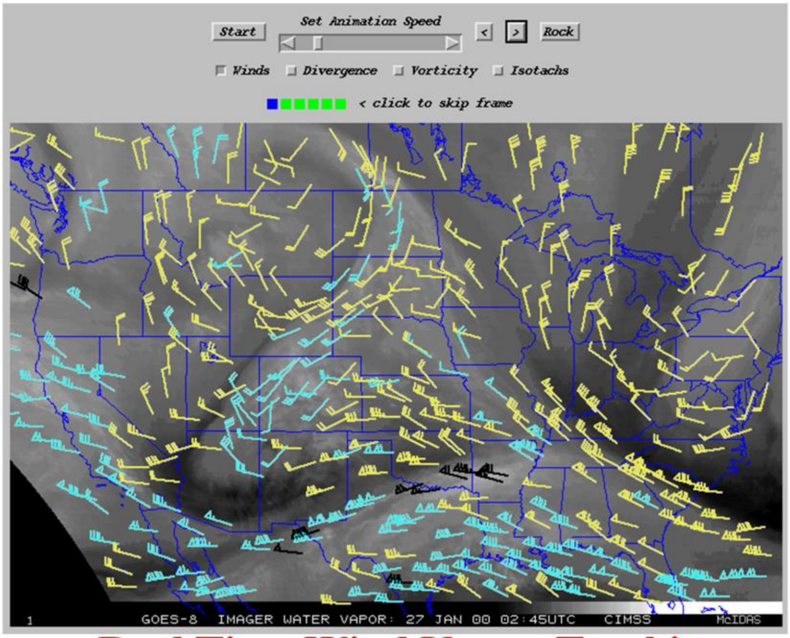
In terms of absolute tornado counts, the United States leads the list, with an average of over 1,000 tornadoes recorded each year. A distant second is Canada, with around 100 per year.

# Water vapor Images used to Track Winds

1 hour interval



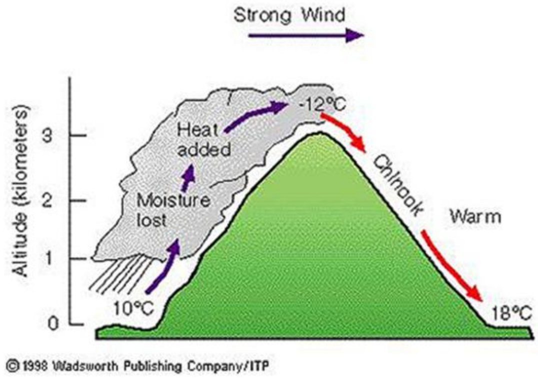



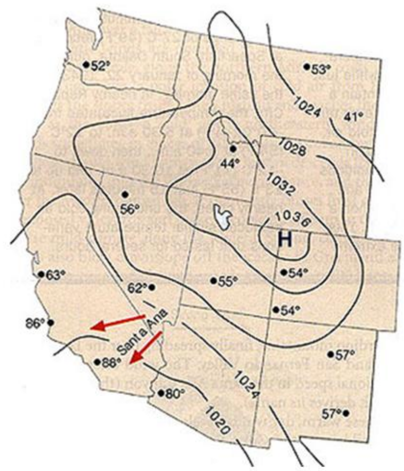



# Real Time Wind Vector Tracking

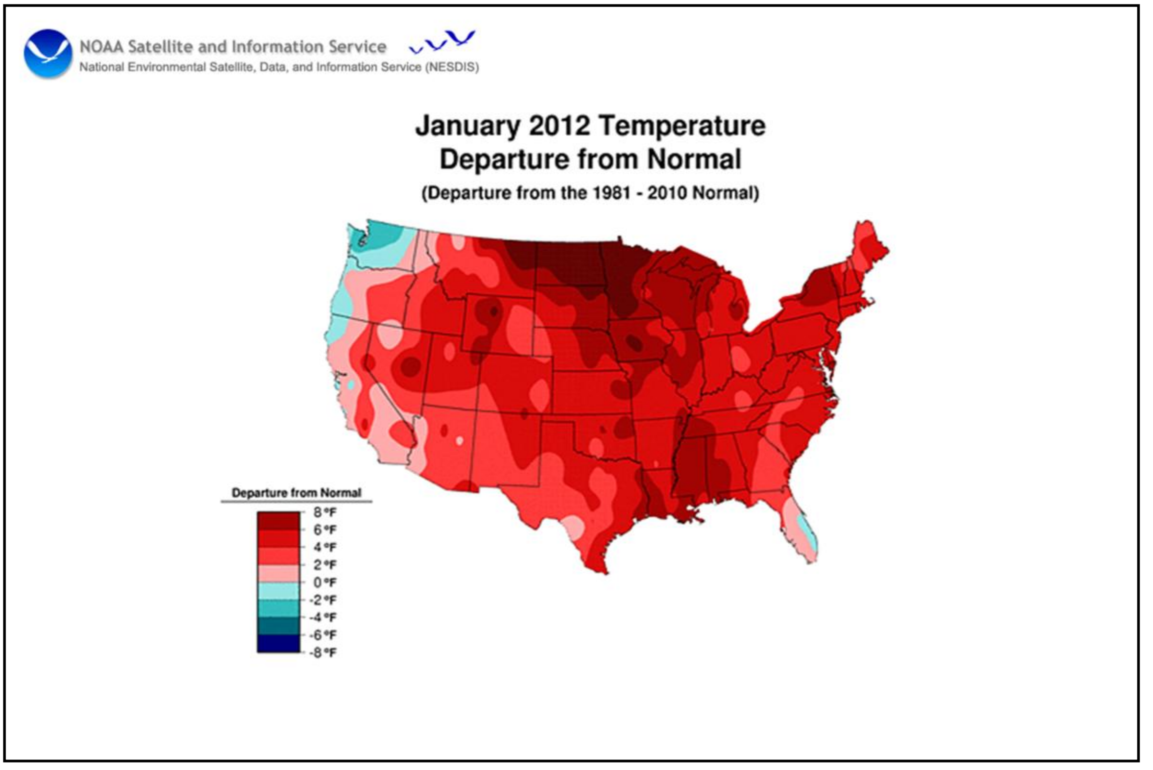
GOES Water Vapor

## Wind Storms

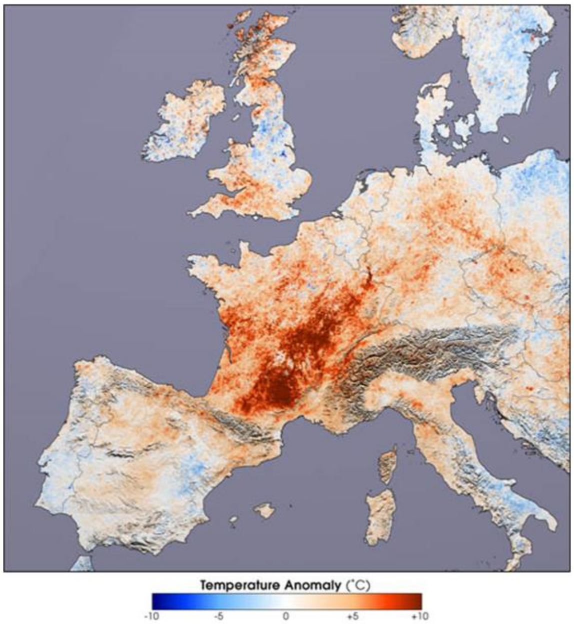



On a grander scale, warm air that forms beyond a mountain range cools as it rises to make a high and can then be driven over those mountains, cool more and descend to low lands beyond. In Southern California, these are called Santa Ana winds, which involve heating in the Mojave Desert to the north, passage of that warm air over the Transverse Ranges, and rapid descent (high winds) into the Los Angeles Basin. This was the main factor in the disastrous fires during October 2003 and since.


NOAA Satellite and Information Service
National Environmental Satellite, Data, and Information Service (NESDIS)
January 2012 Temperature
Departure from Normal
(Departure from the 1981 - 2010 Normal)
Departure from Normal
8 °F
6 °F
4 °F
2 °F
0 °F
-2 °F
-4 °F
-6 °F
-8 °F

## Extreme Temperature Storms



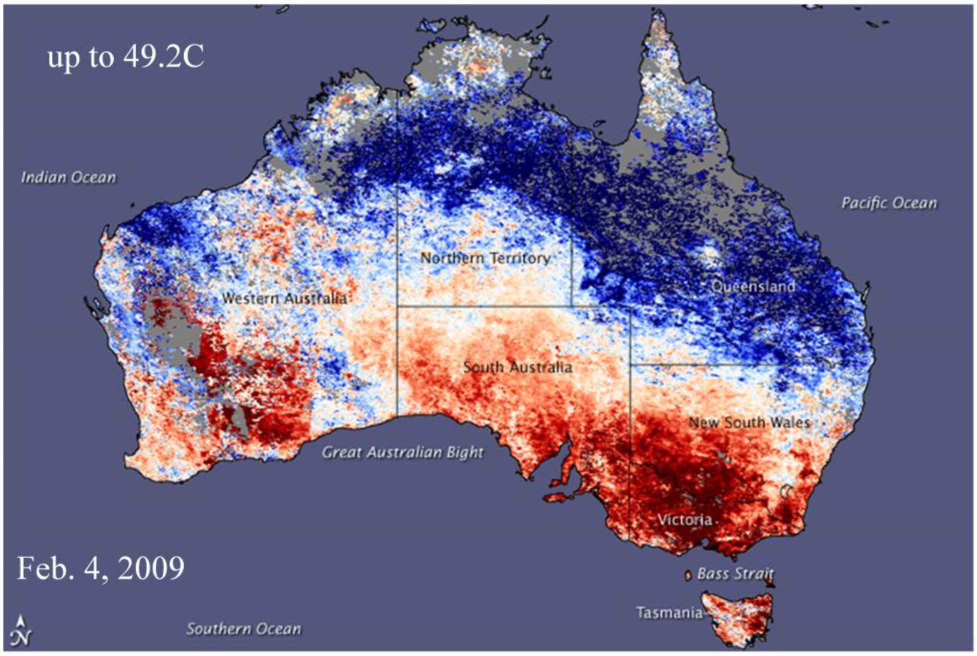

**European Heat Wave August 16, 2003**

Europe was experiencing a historic heat wave that had been responsible for at least 3,000 deaths in France alone in the summer of 2003. Compared to July 2001, temperatures in July 2003 were sizzling. This image shows the differences in day time land surface temperatures collected in the two years by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. A blanket of deep red across southern and eastern France (left of image center) shows where temperatures were 10 degrees Celsius (18 degrees Fahrenheit) hotter in 2003 than in 2001. White areas show where temperatures were similar, and blue shows where temperatures were cooler in 2003 than 2001.

Even the Alps, which arc across southeastern France, Switzerland, Austria, and northern Italy (just below image center), were very warm. Glaciers were melting rapidly and swelling rivers and lakes to dangerously high levels. Climbers had to be evacuated from Switzerland's famous Matterhorn after melting triggered the collapse of a rock face. The popular climbing destination was closed while geologists assessed the possibility of further collapses.

The heat wave stretched northward all the way to the United Kingdom, particularly southern England (bottom of island) and Scotland (top of island). In London, trains were shut down over fears that tracks would buckle in the heat, while in Scotland the high temperatures combined with falling water levels in rivers and streams threatened the spawning and survival of salmon. Throughout France, Spain, Portugal, and Italy, the intense heat and dry conditions sparked devastating forest fires that killed at least 15 people.

Image courtesy Reto Stockli and Robert Simmon, based upon data provided by the MODIS Land Science Team.




**Exceptional Australian Heat Wave**

For those who track their local temperatures using the Celsius scale, 40 degrees is a daunting number. In early February 2009, residents of southeastern Australia were cringing at their weather forecasts, as predictions of temperatures above 40 degrees Celsius (104 degrees Fahrenheit) meant that a blistering heat wave was continuing.

This map of Australia shows how the land surface temperature from January 25 to February 1 compared to the average mid-summer temperatures the continent experienced between 2000-2008. Places where temperatures were warmer than average are red, places experiencing near-normal temperatures are white, and places where temperatures were cooler than average are blue. The data were collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. While southern Australia was scorching, a similarly large area of northern and central Australia was several degrees cooler than it was in the previous nine years. The cool anomaly across that region is probably linked to the above-average rainfall the area has received during this year's wet season.

Land surface temperature is how hot the surface of the Earth would feel to the touch in a particular location. From a satellite's point of view, the "surface" is whatever it sees when it looks through the atmosphere to the ground. That could be the sand on a beach, the grass on a lawn, the roof of a building, or a paved road. Thus, daytime land surface temperature is often much higher than the air temperature that is included in the daily weather report—a fact that anyone who has walked barefoot across a parking lot on a summer afternoon could verify.

The Australian Bureau of Meteorology (BOM) called this heat wave "exceptional," not only for the high temperatures but for their duration. One-day records were broken in multiple cities, with temperatures in the mid-40s. In Kyancutta, South Australia, the temperature reached 48.2 degrees Celsius (118.8 degrees Fahrenheit). Many places also set records for the number of consecutive days with record-breaking heat.

Nighttime temperatures broke records, too. In their special statement on the heat wave, the BOM wrote, "On the morning of 29 January, an exceptional event also occurred in the northern suburbs of Adelaide around 3 a.m., when strong north-westerly winds mixed hot air aloft to the surface. At RAAF Edinburgh [a regional airport], the temperature rose to 41.7°C at 3:04 a.m. Such an event appears to be without known precedent in southern Australia."

**References**

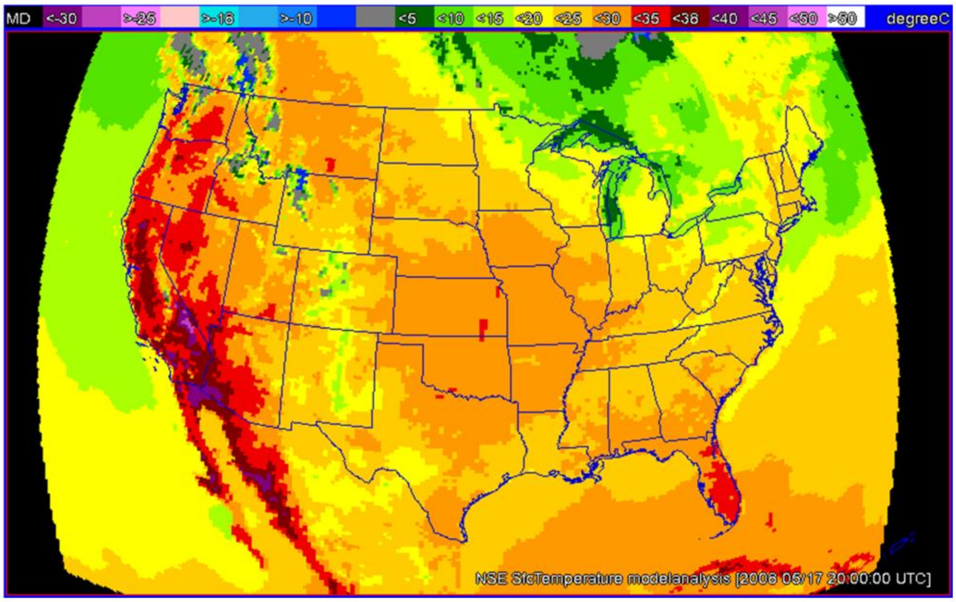
Grant, D. (2009, February 4). Heatwave sets records across southeast Australia. Australian Bureau of Meteorology Website. Accessed February 4, 2009.

Australian National Climate Centre. (2009). The exceptional January-February 2009 heatwave in south-eastern Australia, Bureau of Meteorology, Special Climate Statement 17. (pdf) Australian Bureau of Meteorology Website. Accessed February 4, 2009.

NASA map by Jesse Allen, based on MODIS land surface temperature data. Caption by Rebecca Lindsey.

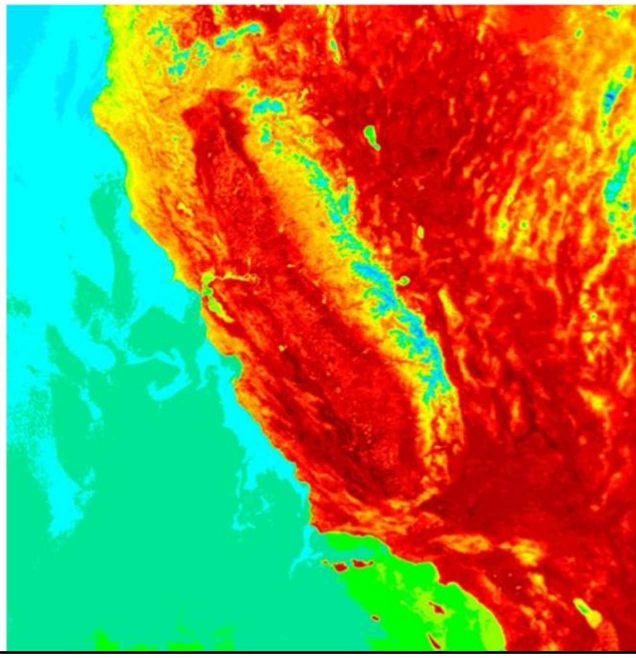
Instrument: Terra - MODIS

Saturday May 17, 2008 Temperatures

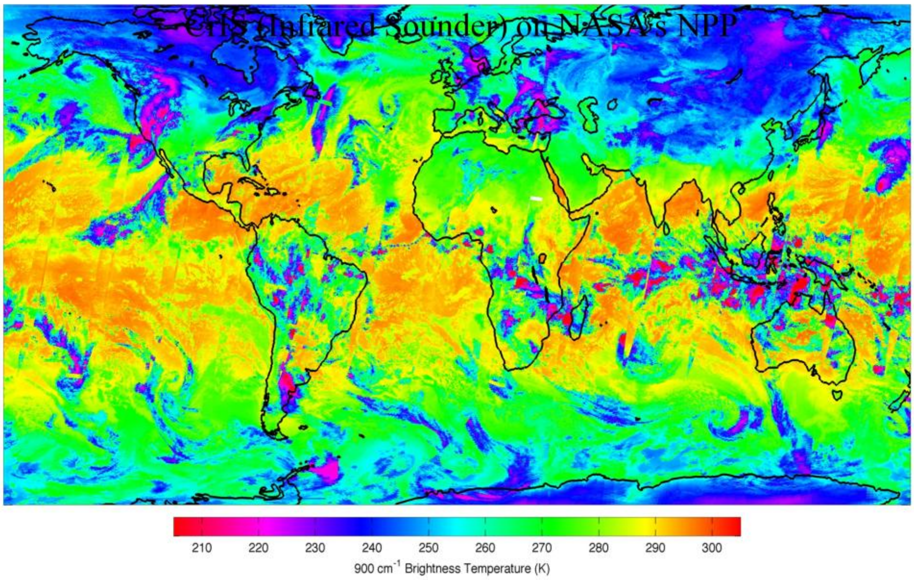


California Heat Wave September 3, 2007

up to 110F



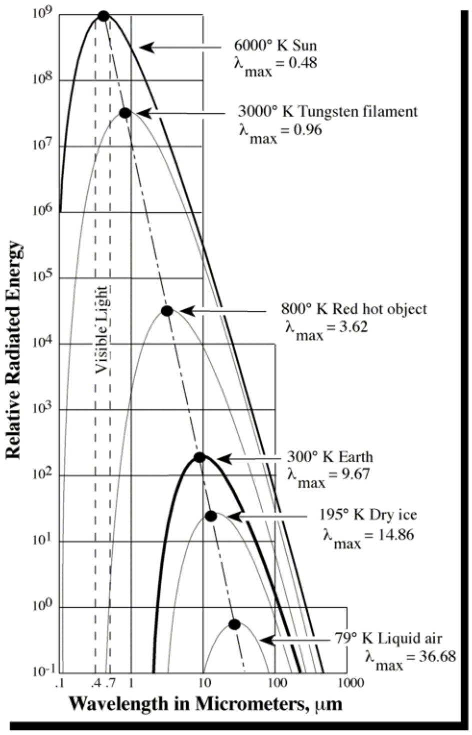
A major blast of hot air is backing into California which will send temperatures soaring into the 90's and 100's. Today is the seventh day that the heat wave has contributed to blackouts and no AC. All eyes are on energy companies as they run into supply issues over the next week. Temperatures hit 108 in the Hollywood Hills and in the 110's in the desert. Typically we see cool Pacific air dominate much of the coastal communities. However, as high pressure builds over the south west, there won't be any onshore flow. Warming winds from the west will cut off any marine layer that tends to build on the coast. Temperatures are the inland areas of southern California should reach around 100, that includes San Diego. Photo Credit: Nasa




apparent temperature of the surface assuming an emissivity of 1.0

Composited from January 21, 23, 25, 2012

CrIS, an advanced spectrometer with 1,305 infrared spectral channels, is designed to provide high vertical resolution information on the atmosphere's three-dimensional structure of temperature and water vapor. The Atmospheric Infrared Sounder (AIRS) on the EOS Aqua mission, launched in 2002, demonstrated how useful this type of data could be for understanding the atmosphere. CrIS will continue this data record and provide data for use in NOAA's numerical weather prediction models to forecast severe weather days in advance.




## Blackbody Radiation Curves for Several Objects including the Sun and Earth

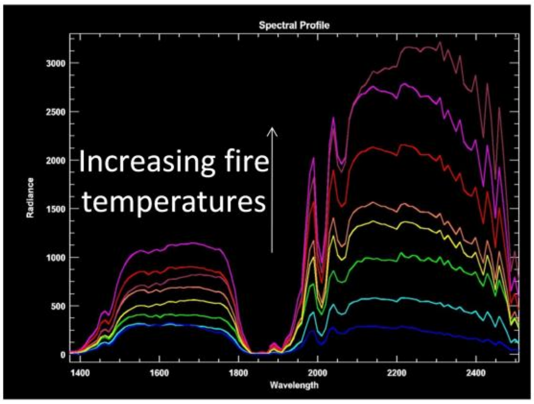
Note intensity and wavelength of maximum energy shifts to shorter wavelengths as the system gets hotter.

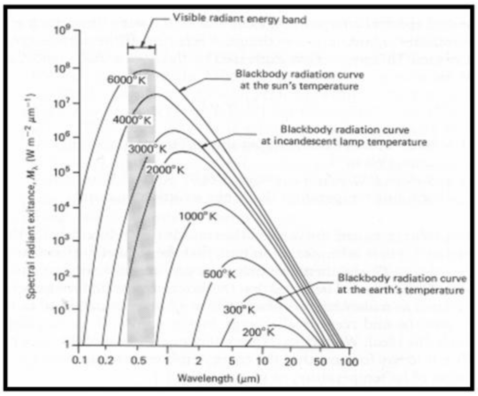
The blackbody temperature is the "external" temperature that a body radiates energy at that is proportional to its kinetic temperature (the internal temperature).

1 Watt = 1 Joule/sec/cm$^2$

# Mapping fire temperatures

Both quantity of radiance emitted and the wavelength of peak emission vary with T, making it possible to estimate fire temperature.

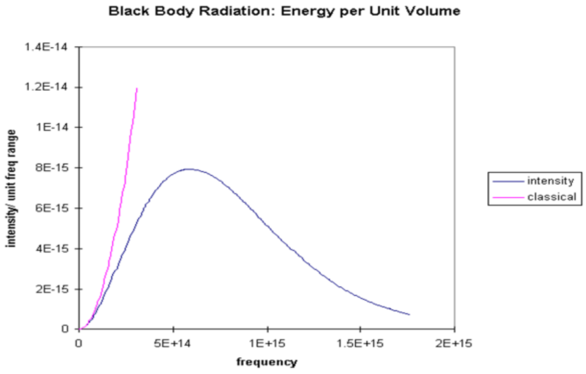


# Kirchhoff's Law:

A theorem (based on lab observations) that states that at a given temperature, energy is absorbed and radiated at the maximum possible rate per unit area, for each wavelength.

Gustav Kirchhof




Fails at very high frequencies (short wavelengths)

## Planck's Law (derived from E = hν = hc/λ)
## Energy is transferred from a warm body to a colder body

$$I'(\lambda,T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}}-1}.$$

Max Planck

I(λ, T)= Intensity = energy per unit surface area per unit time per unit solid angle as a function of wavelength

h = Planck's constant ($6.626 \times 10^{-34}$ J s)
c = speed light
k = Boltzmann's constant

The spectral radiance of EM radiation at all wavelengths from a black body at temperature *T*.

As a function of wavelength λ, Planck's law written (for unit solid angle) as:

This function peaks for $hc = 4.97\lambda kT$, a factor of 1.76 shorter in wavelength (higher in frequency) than the frequency peak (can be calculated as frequency instead of wavelength).

I' is the spectral radiance or energy per unit time per unit surface area per unit solid angle per unit wavelength (or frequency)

## Stefan-Boltzmann Law (for ideal blackbodies)

**$M_b$ is derived from Planck's equation as $M_{b,\lambda} = \sigma T^4$**

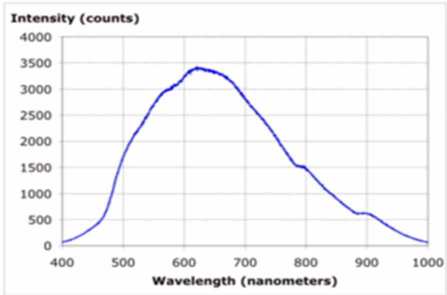
Total radiated energy (j or watts/m$^2$) by a black-body = ($\sigma$) * $T^4$

**$\sigma = 5.6697 \times 10^{-8}$ W m$^{-2}$ K$^{-4}$ µm K**

Josef Stefan

Ludwid Boltzmann

The Sun produces more spectral radiant exitance (*Mb*) at 6,000 K than the Earth at 300 K. As the temperature increases, the total amount of radiant energy measured in watts per m2 (the area under the curve) increases and the radiant energy peak shifts to shorter wavelengths.




The spectrum of an incandescent bulb in a typical flashlight. Here, the filament temperature appears to be about 4600 K due to a peak emittance around 630 nm. The shape shows that the filament is not a true black body.

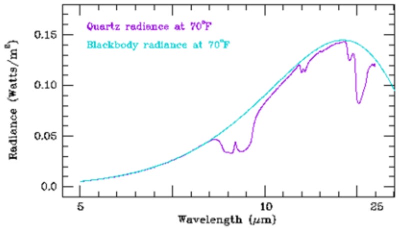
**For Gray Bodies S-B Expressed As:** $M_{\lambda} = \varepsilon\sigma T^4$

**Incorporating Emissivity (ε) allows calculation of Radiant flux of non-blackbody materials**

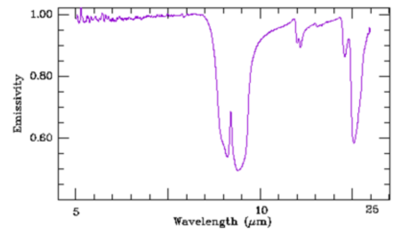
# Emissivity

Emissivity ($\varepsilon$) is the ratio between the true radiant flux from an object ($M_r$) and the blackbody emission at the same temperature ($M_b$).

$$\varepsilon_\lambda = M_r/M_b = (T_{rad}/T_{kin})^4$$



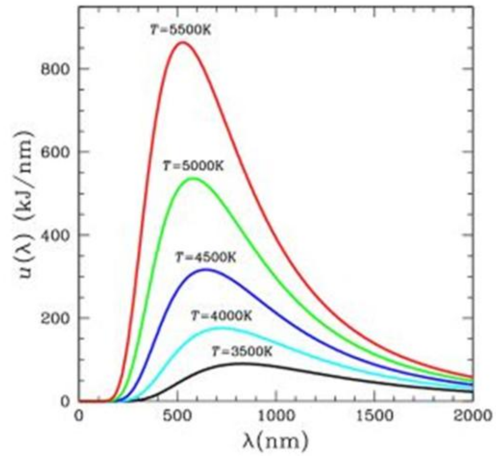

Quartz radiance spectrum along with a blackbody radiance spectrum at the same temperature.




Quartz emissivity spectrum: the result of dividing quartz radiance by blackbody radiance at the same temperature.

Emissivity can be estimated by measuring both the radiant temperature and the kinetic temperature at the same time.

# Relationship between Temperature and Wavelength: Wein's Displacement Law




Wilhelm Wein

## Wein's Displacement Law

**The relationship between the true temperature of a blackbody ($T$) in degrees Kelvin and its peak spectral exitance or dominant wavelength ($\lambda_{max}$) is described by Wein's displacement law:**

$$\lambda_{\max} = \frac{k}{T} \approx \frac{2898\ \mu\text{m K}}{\text{T}}$$

**where $k$ is a constant equaling 2898 µm °K**

Equal signs should be approximately equal≈

What you should know from this lecture

1. What types of severe storms can be monitored with remote sensing data? Extreme events of precipitation, snow, ice; heat, winds,
2. VNIR Imagers are commonly used; often before/after comparisons
3. Cloud cover often obscures the ground during many storms. Radar can penetrate clouds to observe ground (“all weather radar”)
4. Some instruments make vertical profiles of the atmosphere to provide more information about storms. Examples are from TRMM, AMSR-E (I will explain how these work in the lecture on lidar/radar)
5. How are the data analyzed? Often just visually by choosing bands and color displays. Often use before/after change detection. Simple methods like ratios are also used a lot. Why? Need for rapid analysis and release of the information. Changes are sufficiently large to be seen without complex analysis.
6. Know general properties of POES (AVHRR) and GOES (imager). MODIS on Terra and Aqua NASA platforms.
7. Stephane-Boltzman law relating energy and temperature for blackbodies and with emissivity for gray bodies
8. Weins displacement law for determining wavelength at maximum emission