INTRODUCTION to

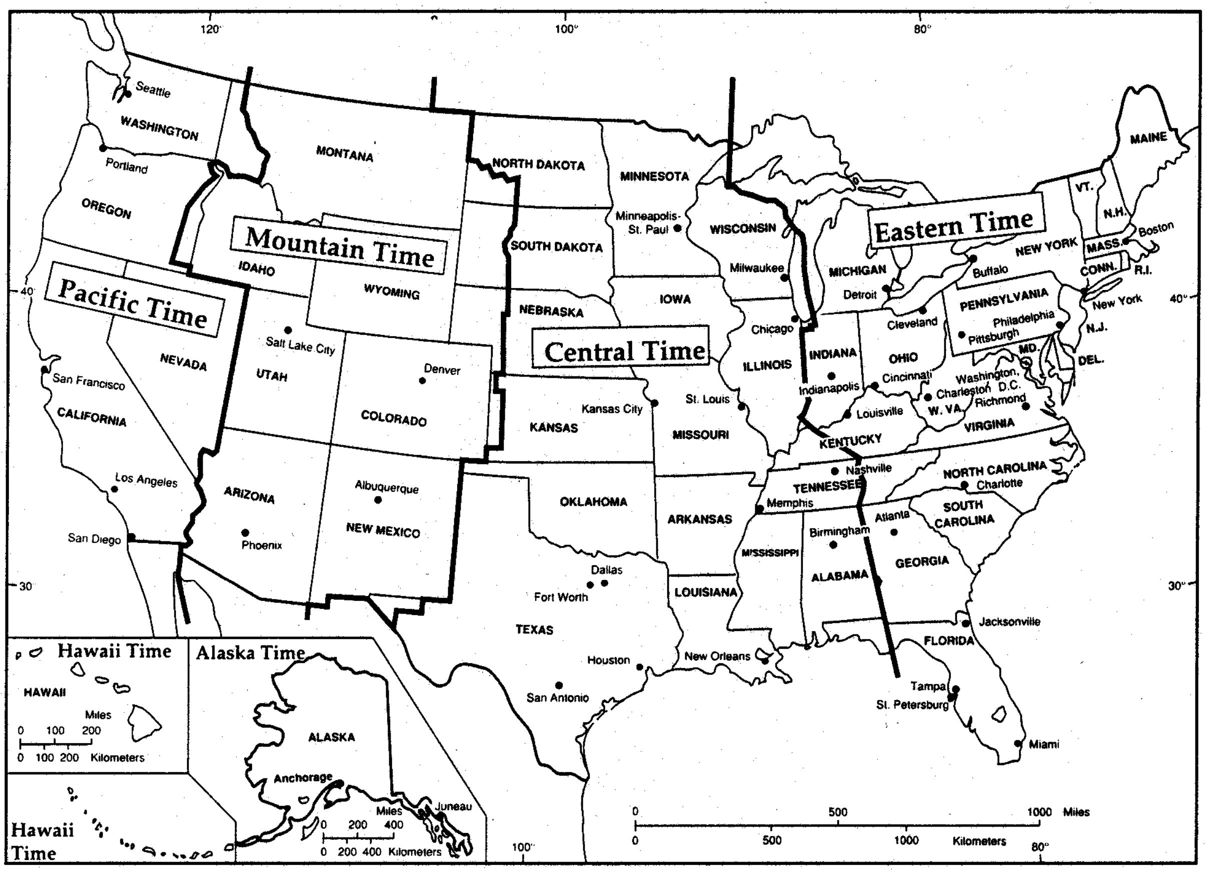
WEATHER DATA, WEATHER MAPS, and SATELLITE/RADAR IMAGES

Chapter 1. Meteorological Time, Map Projection, and US Topography

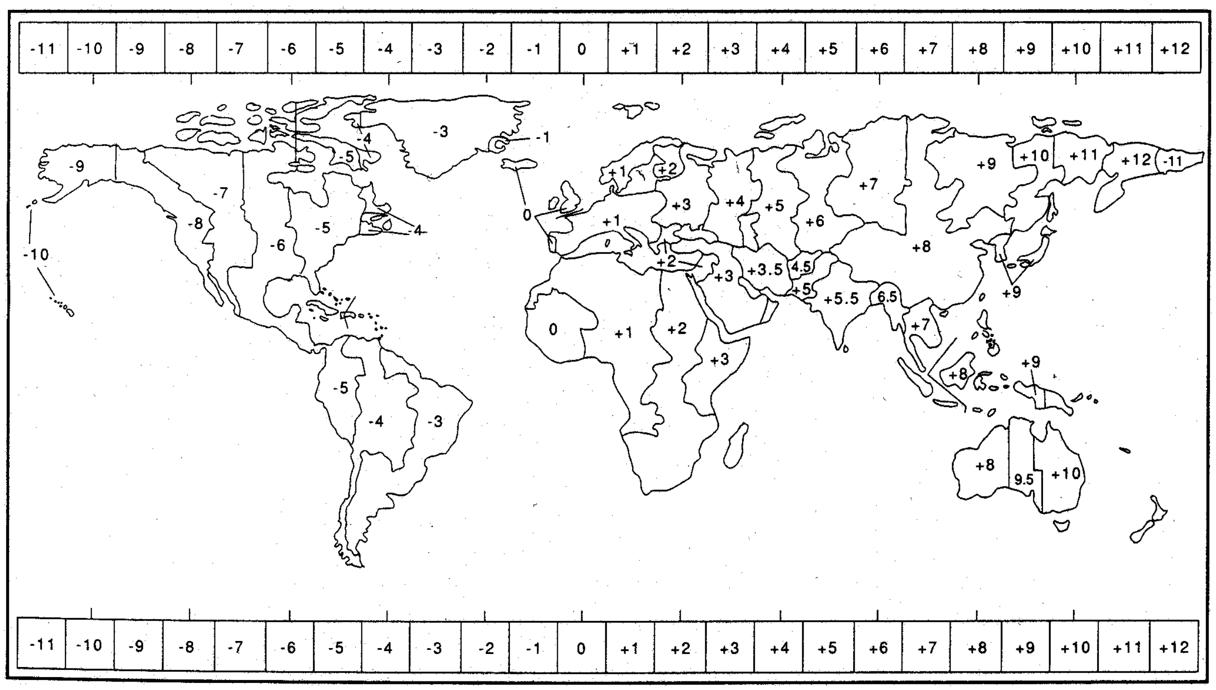
1. Meteorological time (UTC (Coordinated Universal Time), Z (Zulu) time, GMT (Greenwich Mean Time))

A map without time stamp is useless and the meteorological operations are of international concern. It is necessary to have a single, systematic time keeping scheme, so weather observations at the different countries are taken at the same meteorological time (but at different local times), and each weather map is labeled with a 24-hour meteorological time, namely, Coordinated Universal Time (UTC).

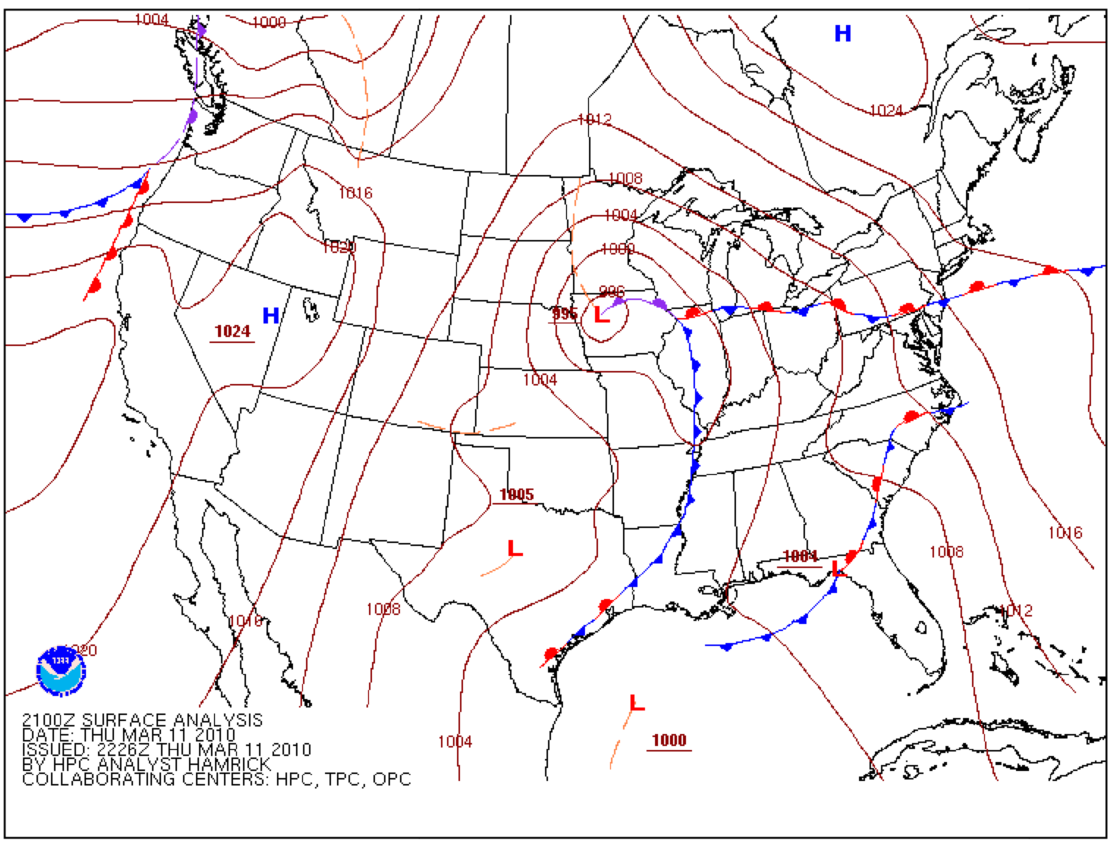
UTC is formally called Greenwich Mean Time (GMT), and it is also called Z time. UTC time indicates the local time zone on the Greenwich Prime Meridian (i.e., 0^{o} longitude over England). The Eastern Standard Time is 5 hours behind UTC, but 4 hours behind UTC when the daylight saving time is applied between March and November.



Standard time zones within the United States.



Standard world time zones in hours ahead (+) or behind (-) Coordinated Universal Time (UTC)



A surface map with isobars, pressure systems and fronts.

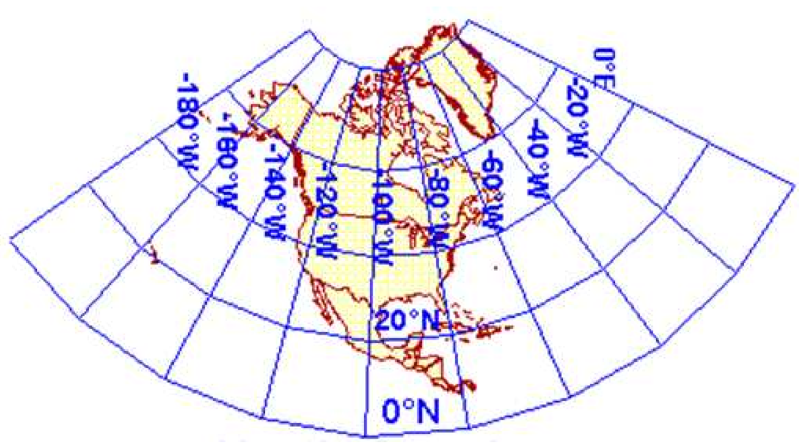
2. Map Projections

All meteorological variables, such as temperature, pressure, dew point, and wind are reported at the surface and upper air stations. These weather data are then plotted and analyzed on the maps of earth coordinates (longitude (x), latitude (y), and height (z)).

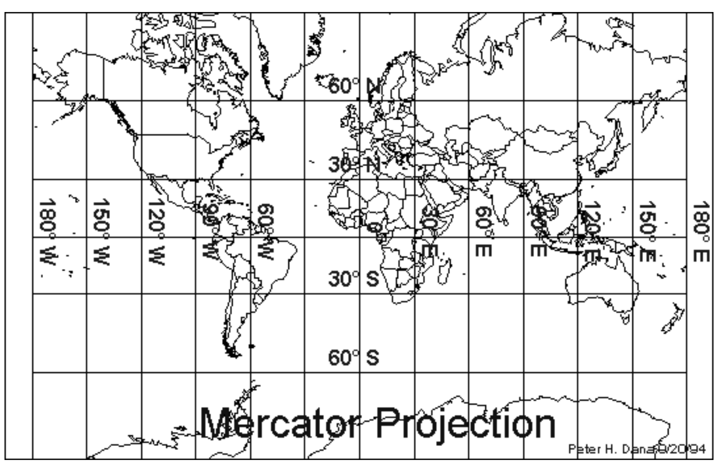
Longitude is defined as the angular distance in degrees of arc measured east or west of the starting line of longitude from the center of earth. Latitude is defined as the angular distance in degrees of arc measured north or south of the starting line of latitude (the Equator) from the center of earth.

The area between the 23.5^oN and 23.5^oS is called the tropics. The area between 15 and 35 degrees of latitudes is called the subtropics; the area between 30 and 65 degrees of latitudes is the midlatitudes (i.e., extratropics); and the area within the Arctic Circle (or Antarctic Circle) is the polar region.

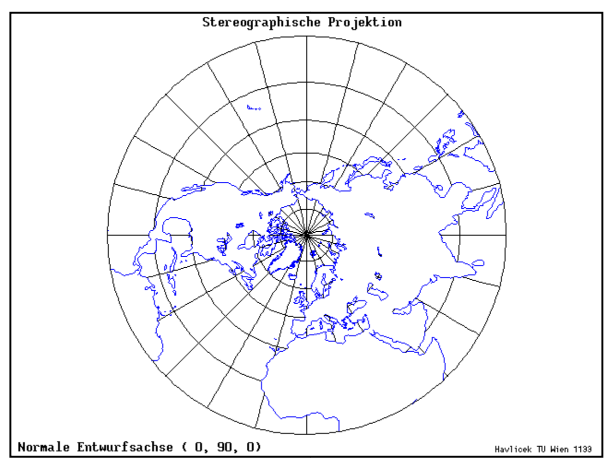
Since the earth is spherical and the horizontal map is two-dimensional, a map projection has to be chosen to adequately represent the shape and distance of the real earth. For the continental US, Lambert Conformal Conic projection is widely used. This projection provides realistic shape and distance on the map. For tropical regions, Mercator projection is used; while over the polar regions, polar stereographic projection works best.



North American in Lambert conformal conic projection.



The world in Mercator projection.

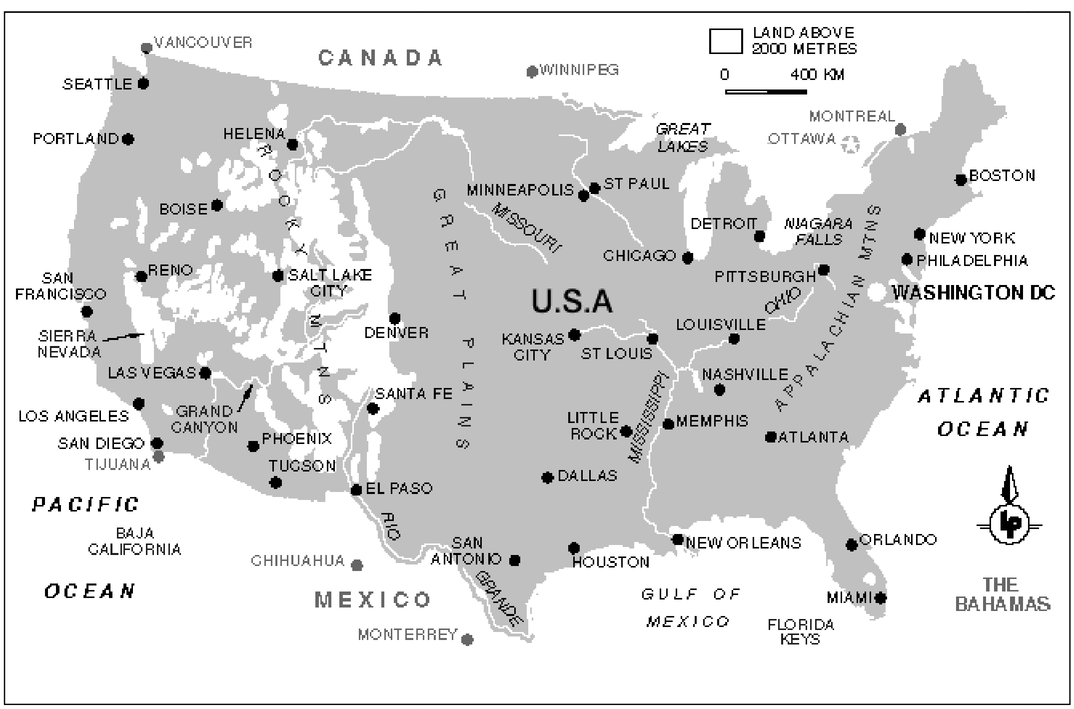


Northern Hemisphere in polar stereographic projection.

3. US Topography

Local weather and climate are greatly influenced by the topography, especially the mountains. Interactively, topography and geography produce local weather events and global weather patterns.

Geography of the North America.



US Geography.

United States of America.

NOAA National Weather Service Offices.

Chapter 2. Surface Observations

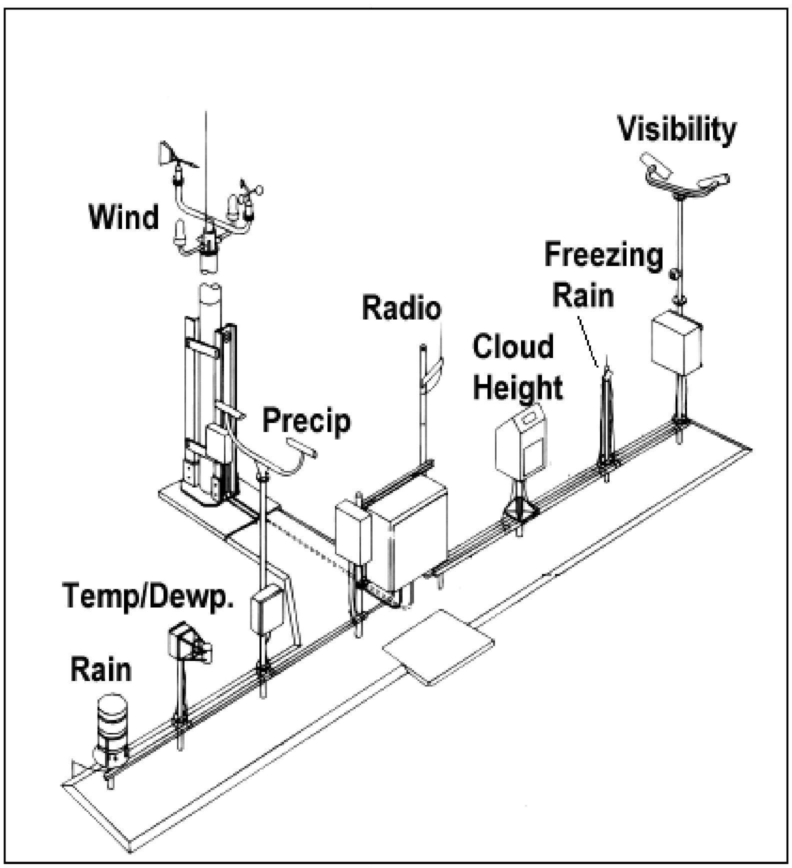
1. ASOS (Automated Surface Observing System) (See details at http://www.nws.noaa.gov/asos/)

The Automated Surface Observing System (ASOS) program is a joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). The ASOS systems serve as the nation's primary surface weather observing network. ASOS is designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities.

There are about 886 ASOS stations across the nation taking surface observations automatically and continuously. Each ASOS station is identified with a 4-letter station id, for example, KAVL is for Asheville Regional Airport.

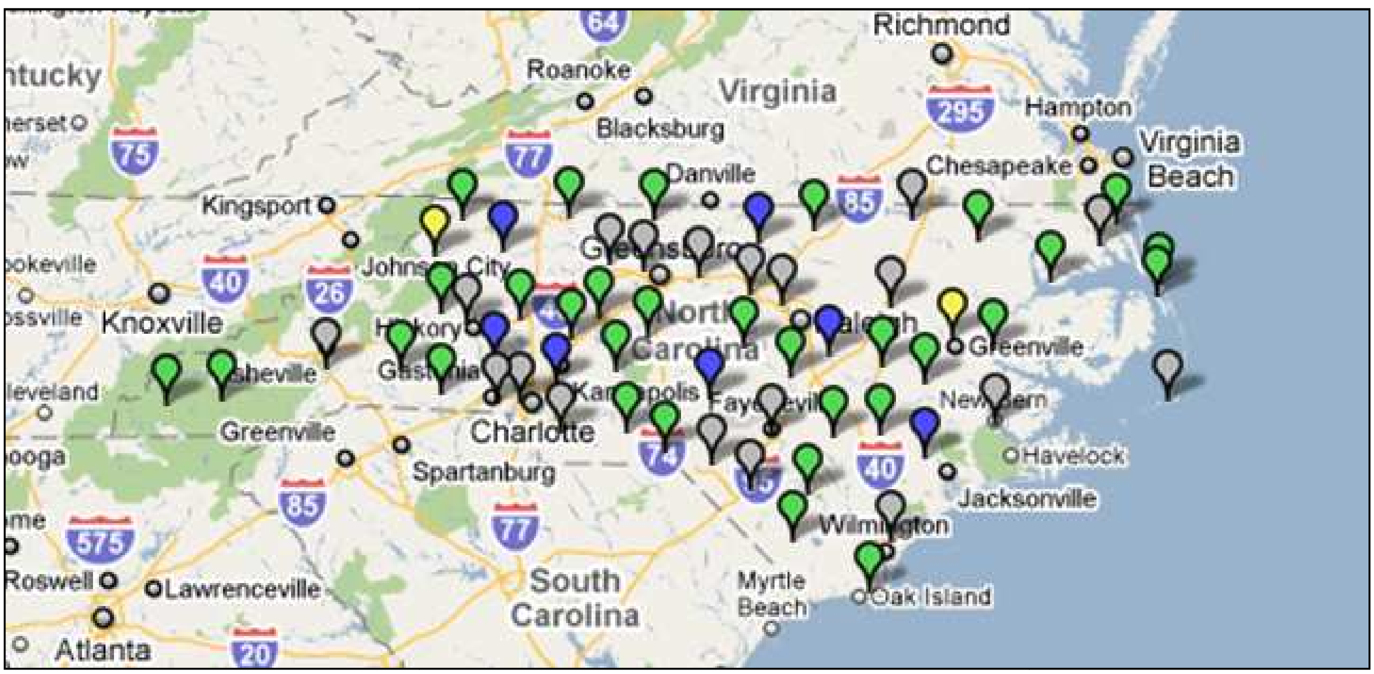
ASOS reports following basic weather elements:

- Sky condition: cloud height and amount (clear, scattered, broken, overcast) up to 12,000 feet.
- Visibility (to at least 10 statute miles).
- Basic present weather information: type and intensity for rain, snow, and freezing rain.
- Obstructions to vision: fog, haze.
- Pressure: sea-level pressure, altimeter setting.
- Ambient temperature, dew point temperature.
- Wind: direction, speed and character (gusts, squalls).
- Precipitation accumulation.
- Selected significant remarks including- variable cloud height, variable visibility, precipitation beginning/ending times, rapid pressure changes, pressure change tendency, wind shift, peak wind.



An illustration of ASOS station.

ASOS near the end of runway at Asheville Regional Airport.
(from http://weather.gladstonefamily.net/site/KAVL)



Weather Station Types					
AWOS A	AWOS A/V	AWOS I	AWOS II	AWOS III	AWOS IIIP
AWOS IIIT	AWOS IIIP/T	ASOS	AWSS	AWOS IV	Misc.

ASOS/AWOS stations in North Carolina.
(from http://www.faa.gov/air_traffic/weather/asos/?state=NC)

2. Surface Station (plotting) Model

The ASOS weather observations are encoded to METAR (METeorological Aviation Report) format for recording and data-transmission. Both raw and decoded METAR data are easily accessible on the Internet.

A sample of METAR report is listed below:

KAVL 111954Z 17007KT 3SM -RA BR BKN005 OVC008 11/11 A2980 RMK AO2 CIG 003V006 SLP082 P0004 T01110106

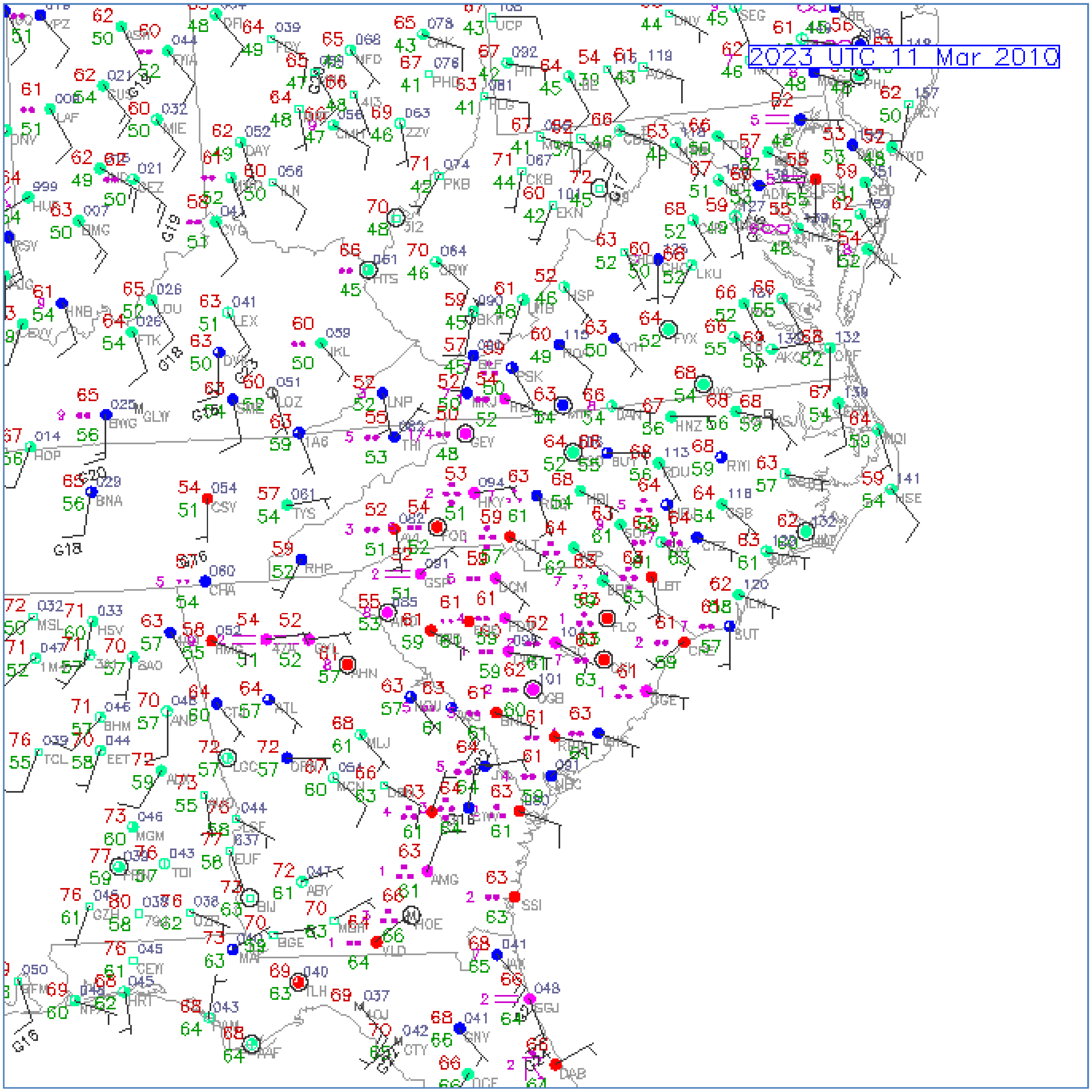
And the decoded weather data for this METAR report are:

Conditions at:	KAVL observed 11 March 2010 19:54 UTC
Temperature:	11.1°C (52°F)
Dewpoint:	10.6°C (51°F) [RH = 97%]
Pressure (altimeter):	29.80 inches Hg (1009.2 mb) [Sea-level pressure: 1008.2 mb]
Winds:	from the S (170 degrees) at 8 MPH (7 knots; 3.6 m/s)
Visibility:	3 miles (5 km)
Ceiling:	500 feet AGL
Clouds:	broken clouds at 500 feet AGL overcast cloud deck at 800 feet AGL
Present Weather:	-RA BR (light rain, mist)

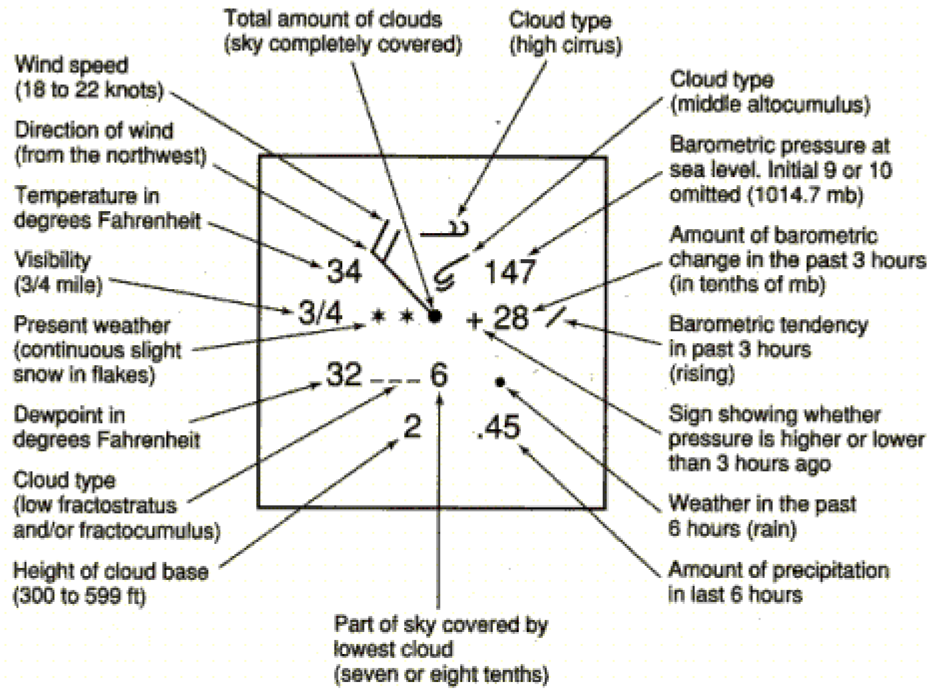
More detailed information about METAR can be found at
http://www.ncdc.noaa.gov/oa/wdc/metar/index.php

For current METAR data	**http://aviationweather.gov/adds/metars/**
	http://www.rap.ucar.edu/weather/surface/
	http://leonardo.met.tamu.edu/Weather_Interface/

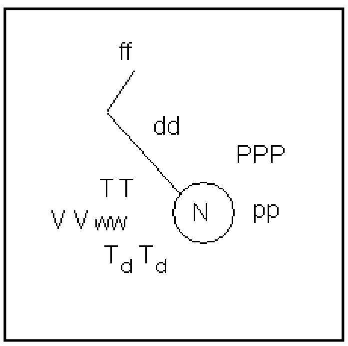
The ASOS observations are also plotted (according to surface station model) on a US map to depict the weather conditions in real time such as the map below.



Surface plots in the Southeastern States. (from http://www.rap.ucar.edu/weather/surface/)



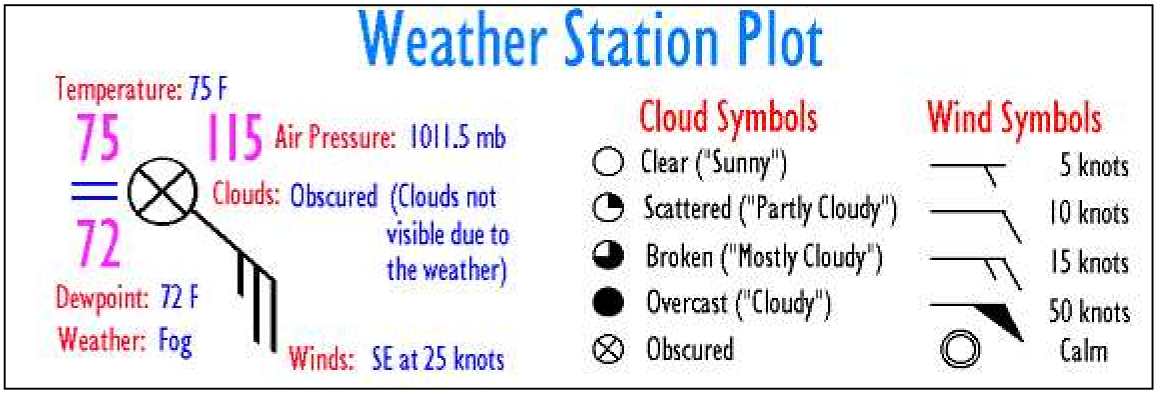
Surface Station Model.



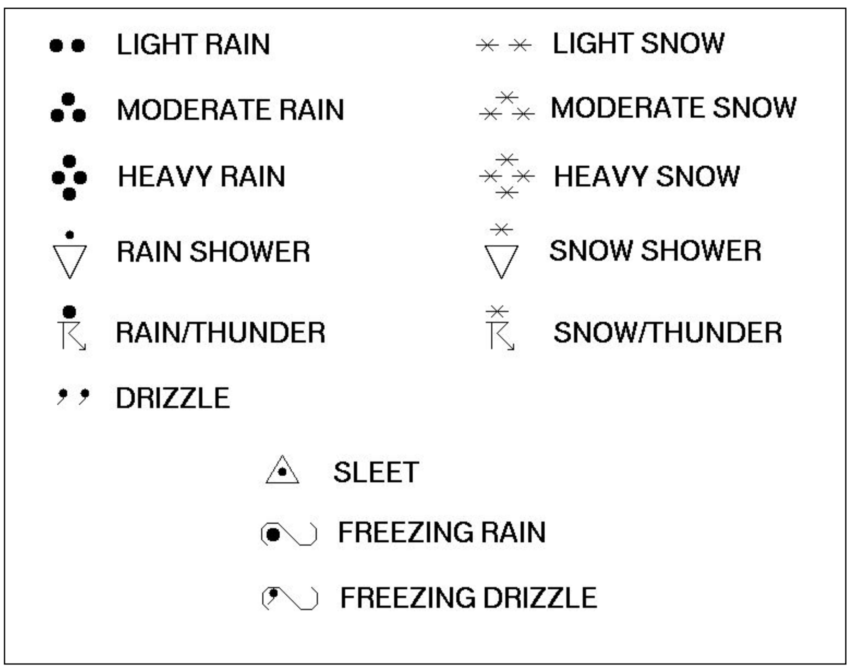
A simplified surface station model.

- **TT - Temperature**: In the United States surface temperature is expressed in units of degrees Fahrenheit. In most other countries of the world, it is expressed in degrees Celsius.

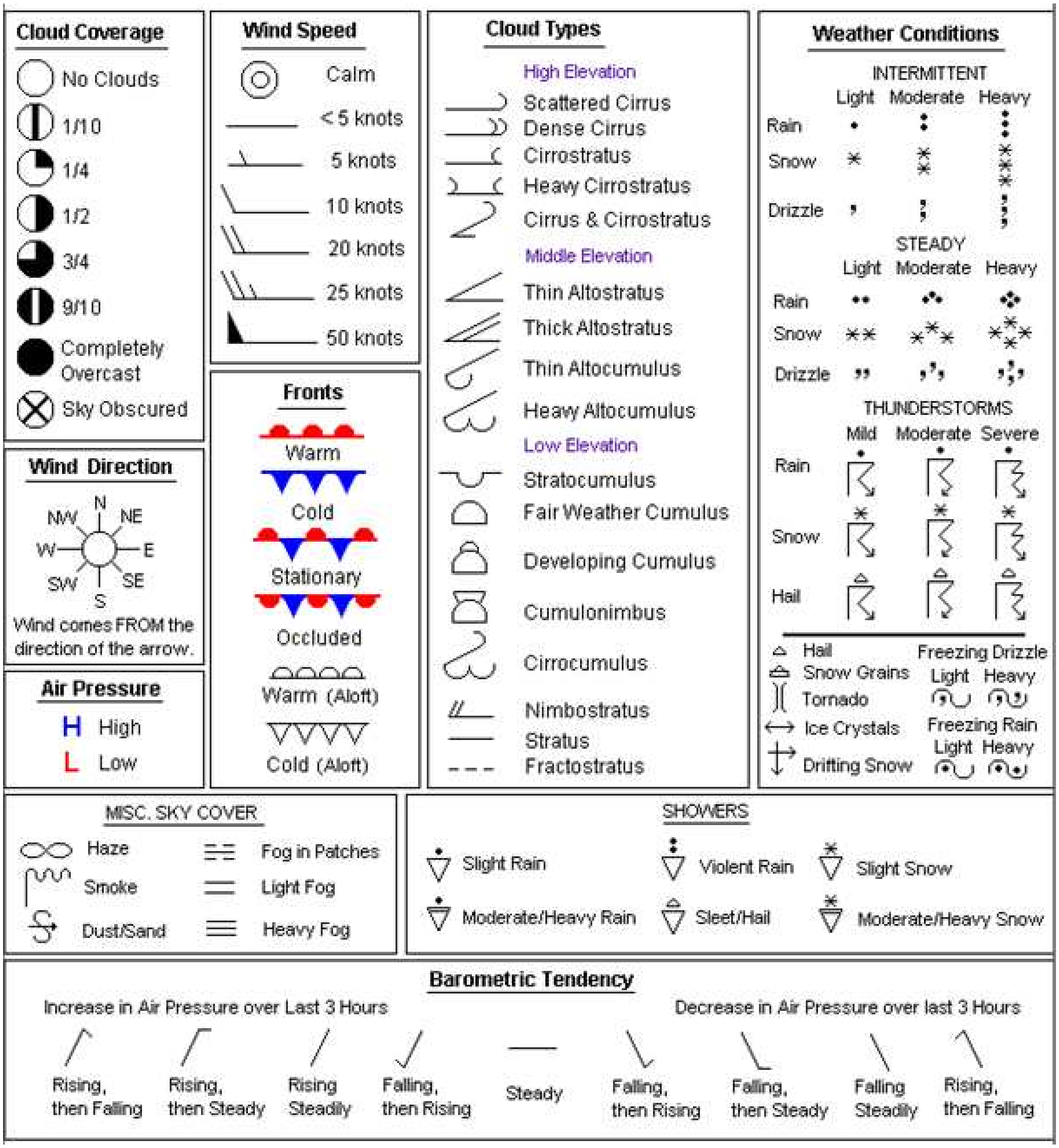
- **T_dT_d - Dew point temperature**: Expressed in the same units as temperature.
- **N - Cloud cover**: Total cloud amount represents the fraction of sky covered by cloud.
- **VV - Visibility**: How far we can see, expressed in units of miles.
- **dd - Wind direction**: The line (i.e., a bar) represents the direction **from** which the wind is blowing.
- **ff - Wind speed**: The barbs on the wind direction line representing the wind speed. Wind speed is measured in knots (1 knot =1.15 miles per hour). One long barb equals 10 knots, a short barb 5 knots and a solid triangle represents a wind speed of 50 knots. Calm condition has a circle around the station circle, and wind speed of 2 knots does not have any barbs on the wind direction line.
- **ww - present weather conditions**: Symbols are used to convey information on the type of weather that was observed when the observations were made.
- **PPP – Mean Sea Level Pressure**: The units are coded in mb. The leading 9 or 10 are dropped as is the decimal. So 234 represents a pressure of 1023.4 mb while 834 represents a pressure of 983.4 mb.
- **pp - Change in surface pressure over the last three hours**. The change in pressure is represented by a value and a line that tells us how the pressure was changing.



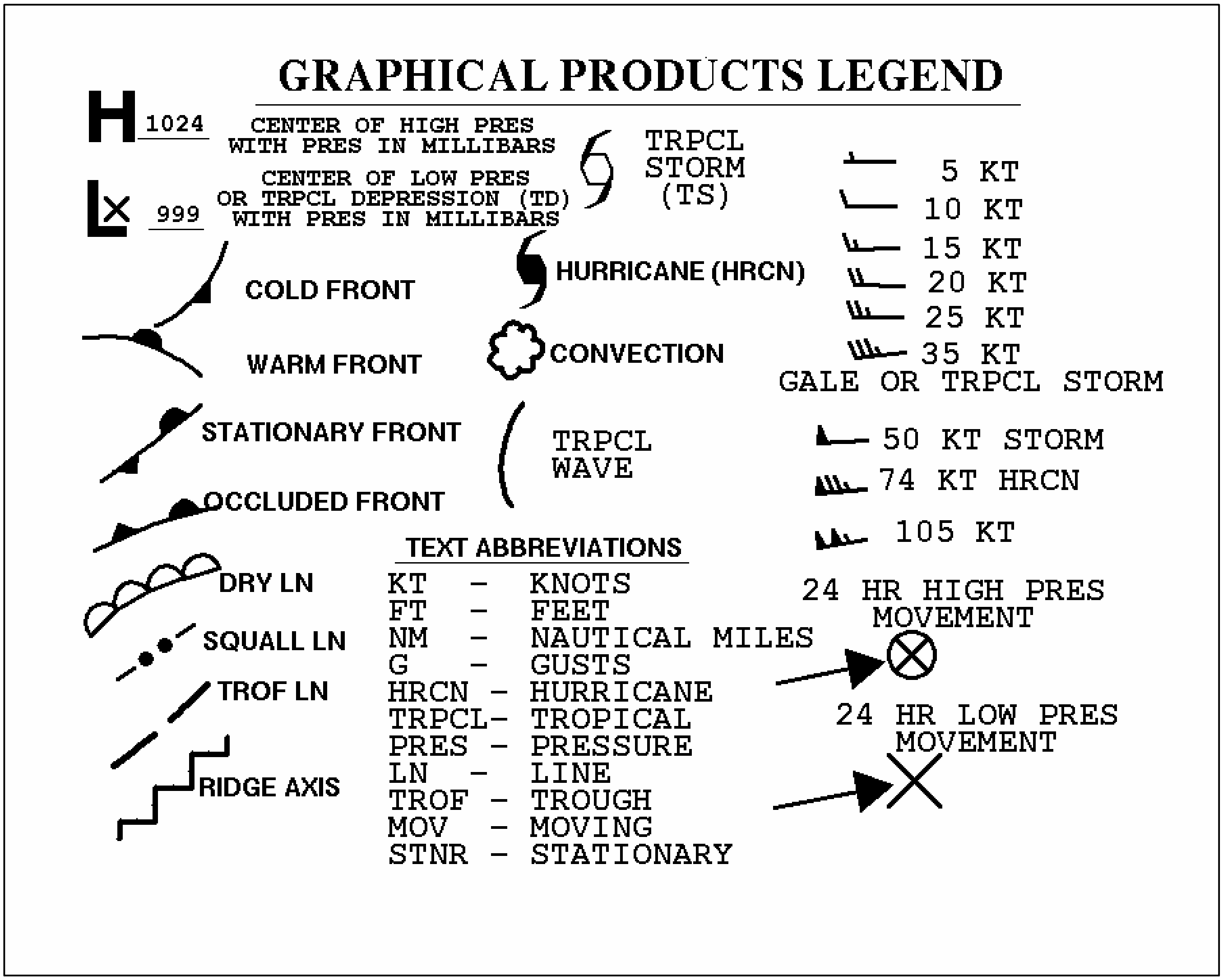
In this station plot above, the temperature is 75°F, the dew point 72°F, the wind direction is southeast (135°) at 25 knots. The pressure is 1011.5 mb (or hPa). The sky is obscured due to surface fog. The current weather is fog.



Selected weather symbols.



Weather Symbols. (from http://www.state.nj.us/dep/seeds/wssym.htm)



Marine weather graphical products legend.
(from http://www.opc.ncep.noaa.gov/product_description/PLBZ04.GIF)

For current print-quality plotted surface map	**http://w1.spc.woc.noaa.gov/exper/mesoanalysis/s4/sfcmap.pdf**
	http://ww2010.atmos.uiuc.edu/(Gh)/wx/surface.rxml
For current plotted surface map	**http://www.rap.ucar.edu/weather/surface/**

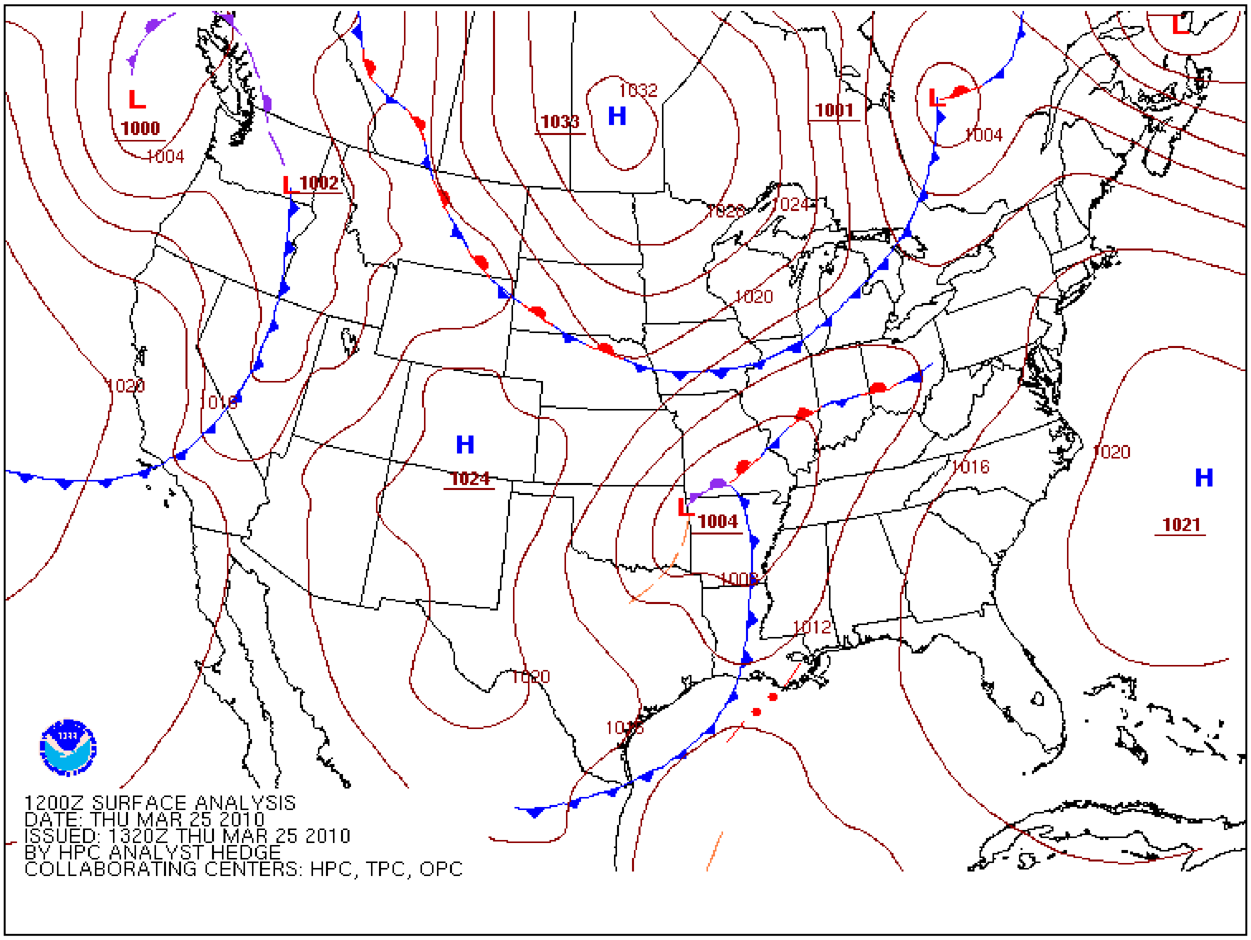
3. MSLP (Surface) Map

An isobaric analysis is performed on the plotted surface map to identify high and low pressure centers, ridges and troughs. An isobar is a line of constant (equal) pressure values.

Pressure patterns indicate general wind directions, namely, a clockwise circulation around a surface high pressure system, while a counterclockwise circulation around a surface low. The variations of pressure (i.e., gradients) provide the estimate of wind speed, namely, stronger winds over the tighter pressure gradient areas.

The analyzed surface map is also called Mean Sea Level Pressure (MSLP) map, because the pressures on the map are the pressures at the mean sea level (0 m), NOT the station pressures as observed at the ASOS stations.

Frontal analysis (to identify various fronts and instability lines) and weather pattern analysis (to depict areas of different types of precipitation, and fog/haze/mist) are also completed on the MSLP maps. The MSLP (surface) maps are available online every three hours.

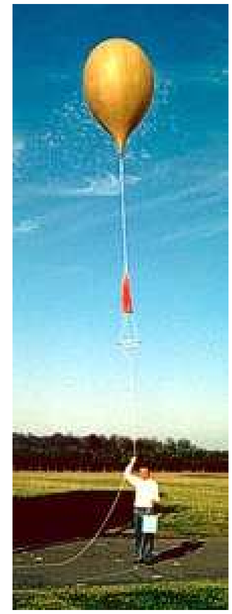


A typical MSLP map presents the isobaric analysis (to study pressure gradients and winds), weather patterns (including pressure centers, fronts, any instability lines), and areas of precipitation.

For current MSLP (surface) maps	**http://www.hpc.ncep.noaa.gov/html/sfctxt.html**
For archived MSLP (surface) maps	**http://www.hpc.ncep.noaa.gov/dailywxmap/**

Chapter 3. Upper Air (Rawinsonde) Observations

1. Introduction



The atmosphere is a three dimensional system, if the temporal variations of the atmosphere is also considered, the atmosphere is a four dimensional system (i.e., space and time). To describe the spatial variations of the atmosphere, we need to have the observations aloft. Upper air is observed regularly by a network of upper air stations, which are also called rawinsonde stations. The instrument we use to measure upper air weather elements is called “radiosonde” or “rawinsonde (radio wind sonde)”.

The U.S. Weather Bureau first used radiosondes in 1936. Currently, 132 National Weather Service (NWS) rawinsonde stations are distributed across the continental United States. Worldwide, there are nearly 900 upper-air observation stations. Radiosondes are launched from these stations twice daily (every 12 hours), 40 to 60 minutes prior to 0000 and 1200 UTC.

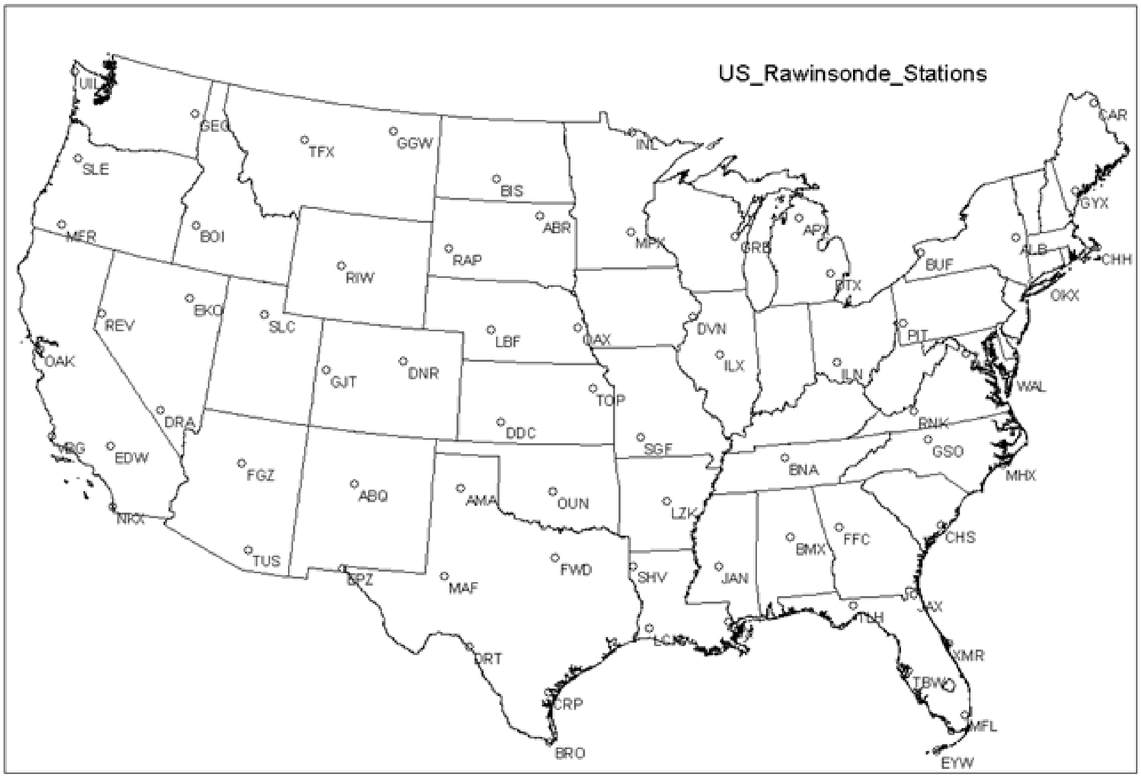
Radiosondes can be launched in almost any type of weather. While the radiosonde is reasonably durable, severe thunderstorms and heavy precipitation may cause instrument failure or radio interference. Other supplementary data are aircraft reports, lidar, profilers, radar, and satellite measurements.

The radiosonde is a small, expendable instrument package that is suspended below a six feet wide balloon filled with hydrogen or helium. As the radiosonde rises at about 1,000 feet/minute (300 meters/minute), sensors on the radiosonde measure profiles of pressure, temperature, and relative humidity.

These sensors are linked to a battery powered radio transmitter that sends the sensor measurements to a ground receiver. By tracking the position of the radiosonde in flight, information on wind speed and direction aloft is also obtained. Observations where winds aloft are also obtained are called "rawinsonde" observations.

The radiosonde flight can last in excess of two hours, and during this time the radiosonde can ascend to over 115,000 feet (35,000 m) and drift more than 125 miles (200 km) from the release point. During the flight, the radiosonde is exposed to temperatures as cold as -130℉ (-92℃) and an air pressure only few thousandt hs of what is found on the Earth's surface.

When the balloon has expanded beyond its elastic limit (about 20 feet in diameter) and bursts, a small parachute slows the descent of the radiosonde, minimizing the danger to lives and property.



US upper air stations.

The National Weather Service is in the process of replacing the current outdated radiosondes at upper air stations with new versions that use a Global Positioning System (GPS) to track the flight. The new rawinsonde system is called The Upper Air Radiosonde Replacement System (RRS). For details on RRS, please visit **http://www.nws.noaa.gov/rrs/index.htm.**

Improvements in these RRS observations will include:

- Requiring less operator interaction and maintenance,
- Providing complete high-resolution information to users,
- Providing consistent and accurate measurement of surface weather parameters at the point of balloon release, and
- Increase amount of data provided to users (at one second resolution or about every 20 feet through the atmosphere).

More information about rawinsonde observations, please visit

http://www.ua.nws.noaa.gov/factsheet.htm

http://www.ua.nws.noaa.gov/

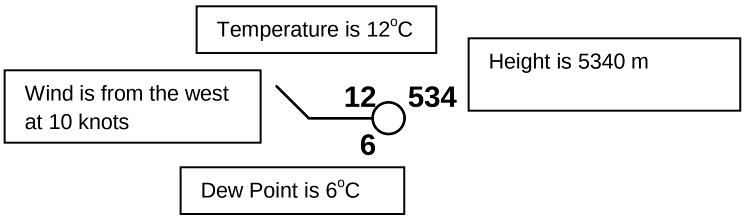
http://www.erh.noaa.gov/gyx/UA/introduction.php

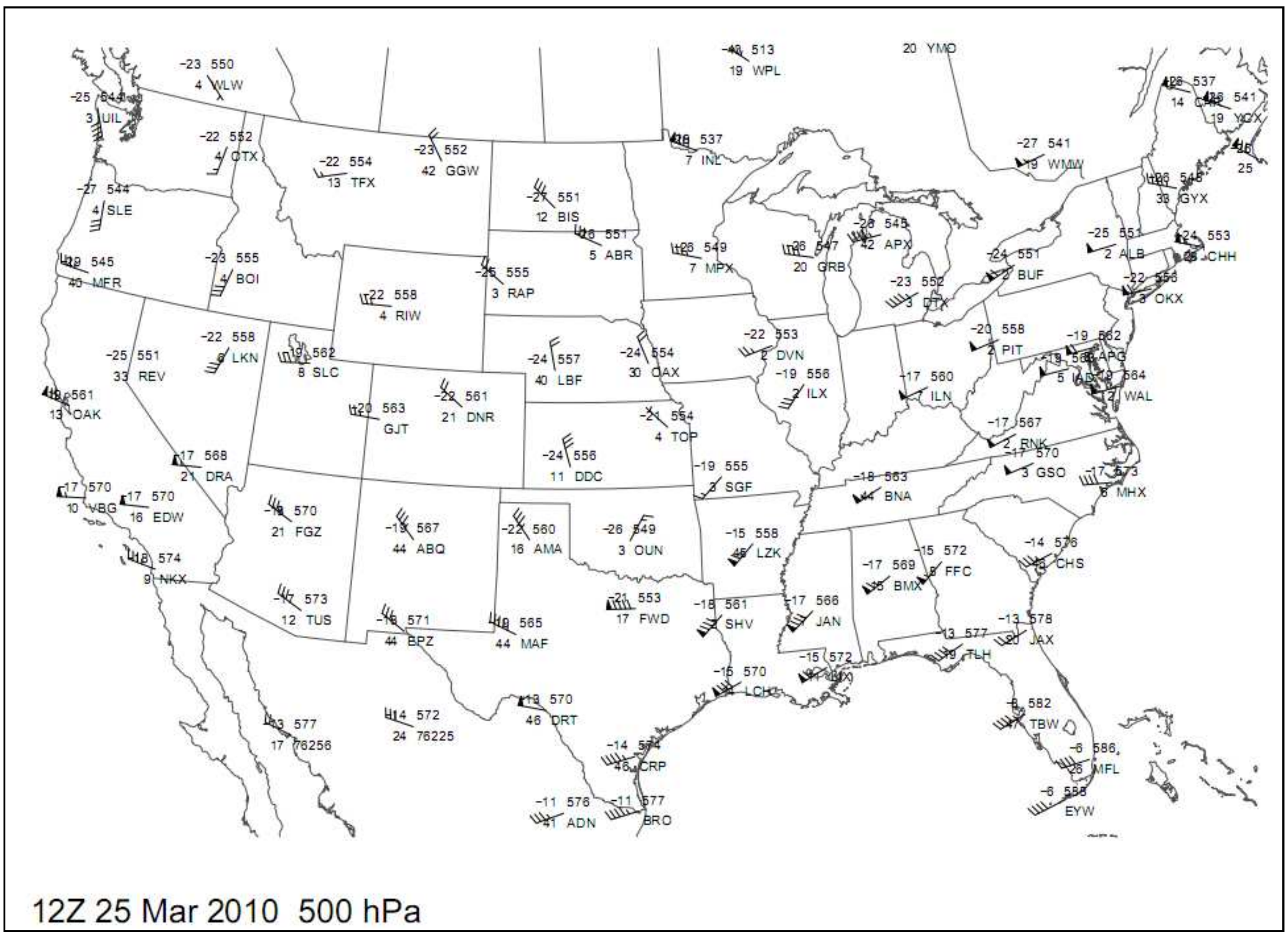
2. Upper Air Station Model

The observed upper air rawinsonde data (i.e., temperature, dew point, pressure, and wind) are routinely plotted on a constant pressure (i.e., isobaric) chart with a US background for analysis in order to understand and study upper air weather patterns including centers of high and low pressure, troughs and ridges, wind flow and wind direction changes.

The upper air data are plotted according to the upper air station (plotting) model as displayed below:

Upper Air Station Model at 500 hPa



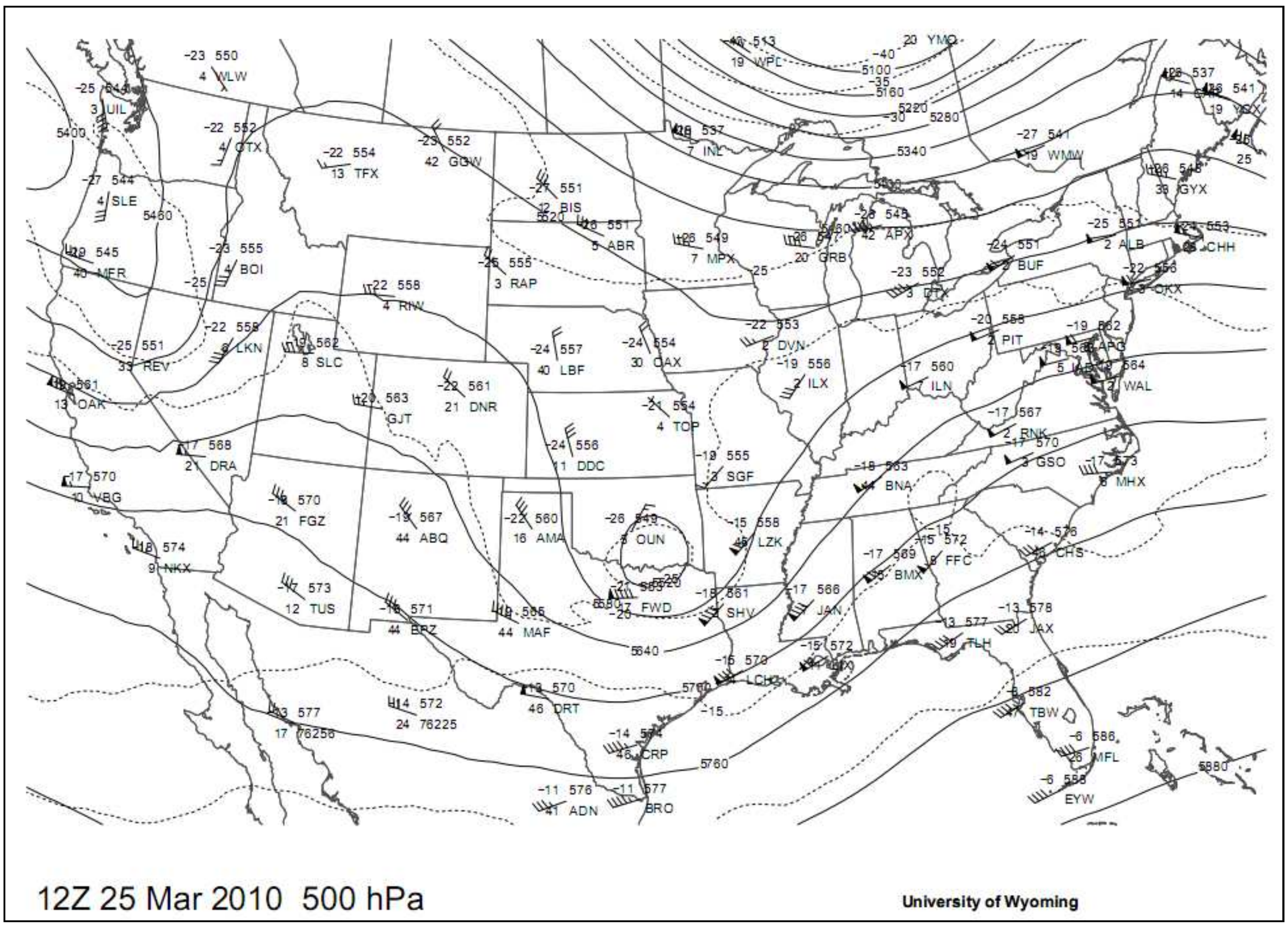


A plotted 500 hPa map. (from http://weather.uwyo.edu/upperair/uamap.html)

3. Upper Air Maps

The mandatory constant pressure levels (i.e., isobaric surfaces) for analysis are 1000, 925, 850, 700, 500, 400, 300, 250, 200, 150, 100, 50, 30, 20, 10, 7, 5, 2, and 1 hPa. The heights and temperatures on potted upper air maps are routinely analyzed by drawing contours (i.e., isoheights) and isotherms to depict pressure and thermal patterns. High values of contours on an isobaric chart correspond to high-pressure systems or ridges. Low values of contours (i.e., lines of constant/equal heights) correspond to low-pressure systems or troughs.

Wind speeds near the jet stream level (about 300 hPa) are also analyzed with the isotach (line of constant wind speed) analysis. The winds on the isobaric charts are called upper-level winds, and they are very close to the gradient winds, which are parallel to curved contours and do not cross the contours. The upper-level winds tend to flow from the west toward the east with high-pressure regions on the right and low-pressure regions on the left of winds in the Northern Hemisphere.



An analyzed 500 hPa map. (from http://weather.uwyo.edu/upperair/uamap.html)

For current/archived upper air maps	**http://weather.uwyo.edu/upperair/uamap.html**
	http://www.spc.noaa.gov/obswx/maps/
Official NWS DIFAX maps	**http://weather.noaa.gov/fax/nwsfax.html**
Current upper air maps	**http://www.rap.ucar.edu/weather/upper/**
	http://weather.unisys.com/upper_air/index.html

4. Sounding

The upper air (rawinsonde) data are also plotted vertically with height (i.e., pressure) at the rawinsonde stations on a thermodynamic diagram to depict the vertical changes of weather variables. The plotting of temperature and dew point on a thermodynamic diagram is called a sounding. Sounding data can provide numerous instability indices and variables that would help us understand and predict severe weather as well as winter weather.

1. Introduction

Upper air data are acquired routinely twice a day (00 and 12 UTC) by releasing and monitoring rawinsondes at upper air stations. Upper air data including temperature, relative humidity (dew point), pressure (height), and wind direction and speed are used to construct upper air constant pressure charts, and soundings in thermodynamic diagrams.

A hodograph is also produced based on the plot of vertical wind vectors at mandatory levels on a polar coordinate (azimuth and range) diagram. The common origin (0 degrees, 0 knots) is considered “calm” and the location of the station. The local north is to the top of the diagram. The degrees of azimuth increase clockwise, i.e., local east is 90^o, local south is 180^o, and local west is 270^o. Winds at mandatory levels are plotted at the tip of vectors extending from the origin, and these points are connected and labeled. The trace of upper level winds on the hodograph can help identify vertical wind shear in wind direction and speed, it also instrumental in determining what type of thunderstorms will develop and what the potential is for rotating updrafts and tornadic activity.

Depending on the strength of the winds aloft, the upper air data collected are **not** always representative right over the launch site, because strong winds aloft blow the balloon quite a distance away downstream.

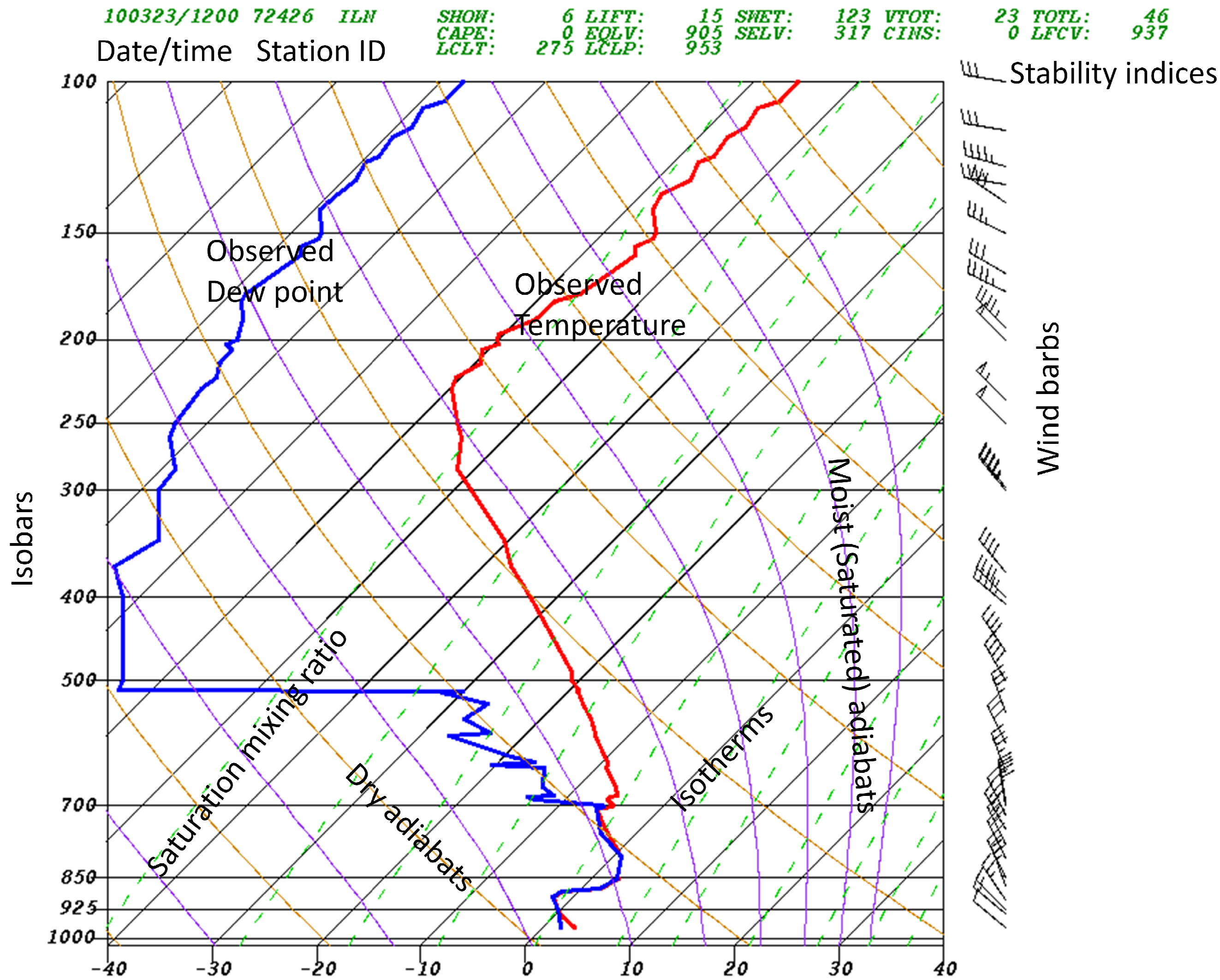
2. Thermodynamic Diagram

Meteorologists use thermodynamic diagrams and graphical techniques to determine atmospheric temperature and humidity variables, and stability indices. Lengthy calculations are avoided since the mathematical relationships have been accounted for in designing thermodynamic diagrams. In other words, meteorologists utilize thermodynamic diagrams to understand vertical variations of weather elements; to investigate the atmospheric instability; to study the effects of moisture; to determine inversion layers; and to predict severe weather.

3. Coordinates on the Thermodynamic Diagram

Any thermodynamic diagram should contain following five sets of lines or curves:

- Pressure (isobars);
- Temperature (isotherms);
- Dry adiabat (isentropes);
- Saturation (or "moist") adiabat (iso-equivalent potential temperature); and
- Saturation mixing ratio (isohumes).



A sounding plot on the skew T-log p diagram.

3.1. Isobars and Isotherms

Pressure and temperature uniquely define the thermodynamic state of an air parcel of unit mass at any time. In a Skew T-log p diagram, the isobars are horizontal lines, and isotherms are slanted from lower left to upper right, with warmer temperatures to the right. In a Stuve diagram, isobars and isotherms are horizontal and vertical lines, respectively. The altitude of the parcel is of secondary consideration, because its pressure and any subsequent changes in pressure are more important for determining the changes in the state of the parcel. However, an additional scale is provided along the side to approximate the geometric altitude of various pressure levels, using a typical reference (standard) atmosphere.

You can locate a parcel's position on the chart with respect to the temperature and pressure lines. A point (p, T) on the chart does not necessarily have to fall on the reference lines. You can interpolate, or draw in all these lines through that point as long as you keep them parallel to the reference lines. You should note that the values of pressure decrease from bottom to top and that the non-uniform spacing reflects the manner in which the pressure changes with height in the real atmosphere. Dewpoint temperature of the air parcel (T_d) is also plotted upon the diagram at the same pressure level of air temperature to display the moisture content of upper air.

3.2. Dry Adiabats

The sloping straight lines on the thermodynamic diagram are called "dry adiabats" and represent the dry adiabatic process lapse rate. The lapse rate represented by a dry adiabat is $9.8^oC/km$. If you would lift an air parcel from a known initial point to a final point, you could trace the amount of cooling on the nearest dry adiabat.

Because that the potential temperature is conserved in the dry adiabatic process, each adiabat represents the value of potential temperature (θ) in Kelvin (K). The potential temperature is defined as that temperature that an air parcel would have if taken dry adiabatically to a pressure of 1000 mb. For example, a parcel with a pressure of 700 mb and an air temperature of 0^oC lies along an adiabat marked 303 K. This parcel, along with all other parcels lying along this adiabat, would have a potential temperature of 303 K. If these parcels were brought dry adiabatically to 1000 mb, the final parcel temperature would be 30^oC or 303 K.

3.3. Moist (Saturated) Adiabats

Moist adiabats appear on the thermodynamic diagram as a set of curves with slopes ranging from $2^oC/km$ in warm air near the surface to that approaching the dry adiabats ($9.8^oC/km$) in cold air aloft. These curves portray the temperature changes that occur upon a saturated air parcel when lifted.

3.4. Isohumes (lines of constant saturation mixing ratio)

These saturation mixing ratio lines uniquely define the saturation mixing ratio, w_s, for each combination of temperature and pressure. The mixing ratio is defined as the mass of water vapor per mass of dry air, expressed as grams of water vapor per kilogram of dry air. If the temperature and the pressure of an air parcel are known, the parcel's saturation mixing ratio can be read directly from the chart using the set of saturation mixing ratio lines. Suppose we had an air parcel with a temperature equal to 26^oC and a pressure of 1000 mb, then w_s = 20 g of water / 1 kg of dry air, or $20*10^{-3}$.

The actual mixing ratio of the air parcel, w, can also be determined similarly from the dewpoint temperature and these saturation mixing ratio lines. For example, an air parcel with $T = 26^oC$ and $T_d = 15^oC$ at p = 1000 mb, then w_s = 20 g/kg and w = 10 g/kg as estimated from the lines of saturation mixing ratio. Relative humidity can then be determined by computing the ratio of w to w_s.

4. Interpretation of the Soundings

The thermodynamic diagrams help meteorologist quickly interpret the vertical temperature, humidity and wind structure of the atmosphere above a given location. In the troposphere, the temperature usually decreases with altitude, as indicated by the plot of the standard atmosphere, an average vertical structure of the atmosphere. However, on any particular day, the temperature profile obtained from the radiosonde could depart significantly from this reference, especially in the lower troposphere.

If the environmental temperature increases as the height increases, then that layer of air is called an "inversion" layer. If the temperature remains constant as the height increases, then that layer is called an "isothermal" layer.

The height of the tropopause, a seasonally and latitudinally variable boundary between the troposphere and stratosphere, can be determined from the plotted sounding. Usually this height is defined as the lowest point where the temperature profile becomes isothermal or develops an inversion over an extended layer. Typically this level occurs somewhere between 6 km in polar regions and 16 km in the tropics.

The typical dewpoint profile also decreases in the lower atmosphere, as one moves away from the surface where water is usually more available. A region of the dewpoint profile that is within several degrees of the air temperature profile would indicate a possible cloud or a low level fog, since the layer would be close to saturation with respect to water vapor. If a radiosonde ascends through a cloud, the dewpoint could increase.

The vertical wind profile plotted along the side of the diagram often shows that the wind speed increases from the surface upward through the lower atmosphere. The increase in wind speed in the lowest 100 mb of the earth's surface typically results from the diminishing effects of surface friction that retards the surface wind speed. Strong winds near the upper part of the chart would indicate the upper tropospheric jet stream.

The wind direction may also change with height. In the lowest 100 mb of the atmosphere, the winds tend to "veer", or turn in a clockwise direction with height, because of the decreased effects of friction. Above this level, changes in the wind direction are related to horizontal differences in air temperature. If the winds veer with height (i.e., winds turning in a clockwise direction with height), warm air would be expected to move into the region (i.e., warm advection). However, if the winds "backed" with height (i.e., winds turning in a counterclockwise direction with height), cold air would be anticipated (i.e., cold advection).

4.1. Atmospheric Stability

Several atmospheric stability indices are routinely computed from rawinsonde data. Normally there are displayed on the right side of the Skew T-log p (or Stuve) diagram. Meteorologists use these indices to investigate the potential for severe thunderstorms. The vertical wind shear can also be studied from the hodograph to define the types of thunderstorms.

4.2. Effects of Moisture

Skew T-log p (or Stuve) diagram allows for the moisture levels to be tracked through the column of the atmosphere measured and are used in forecasting cloud formation, precipitation types and amounts, and severe thunderstorms.

4.3. Inversions and Lapse Rates

Inversions play an important role in determining cloud forms, precipitation, and visibility. An inversion acts as a lid on the vertical movement of air in the layers below. As a consequence, convection produced by heating the air from below is limited to levels beneath the inversion. Diffusion of dust, smoke, and other air pollutants is likewise limited. In regions where a pronounced inversion is present at a low level, convective clouds cannot grow high enough to result in showers and, at the same time, visibility may be greatly reduced below the inversion, even in the absence of clouds, by the accumulation of dust and smoke particles. Because the air near the base of the inversion is cool, fog is frequently present there.

Another important influence of inversions is reflected in the diurnal range in temperature. The principal heating of the air during the day is produced by contact with the ground, the temperature of which is raised by the solar radiation to which the air is transparent. The solar radiation is absorbed by the ground, and the heat is then transferred to the air by conduction and convection. Since the inversion base represents the upper limit to which heat is carried by convection, only a shallow layer of air will be heated if the inversion is low and large, and the rise in temperature will be great.

The lapse rate is defined as the rate of decrease of temperature with increasing height. It is positive when the temperature decreases with elevation (i.e., in most conditions), zero when the temperature is constant with elevation (i.e., an isothermal condition), and negative when the temperature increases with elevation (i.e., an inversion condition). The standard tropospheric lapse rate is 6.5°C/km. The actually observed lapse rates are highly variable from one layer to other layers, also from one location to others, and from time to time.

The dry adiabatic lapse rate is computed from the specific heat of air at constant pressure (c_p) and the gravitational acceleration (g). The dry adiabatic lapse rate is equal to 9.8°C/km; thus, the temperature of an air parcel that ascends or descends 5 km would fall or rise 49°C, respectively.

When an air parcel that is saturated with water vapor rises, some of its moisture will condense, releasing heat and causing the parcel to cool more slowly than it would if it were not saturated. This moist adiabatic lapse rate varies considerably from 2°C/km to 9.8 °C/km. The greater the amount of moisture contained in the air, the smaller the adiabatic lapse rate; as the air parcel rises, cools, and loses its moisture through condensation, its lapse rate increases and approaches the dry adiabatic lapse rate.

The comparison between the observed lapse rate in the atmosphere and the dry and moist adiabatic lapse rates can help determine the vertical stability of the atmosphere, i.e., the tendency of an air particle to return to its original position (i.e., a stable condition) or to accelerate away from its original position (i.e., an unstable condition) after being given a slight vertical displacement. For this reason, the lapse rate is important to meteorologists in forecasting certain types of cloud formations, the incidence of thunderstorms, and the intensity of atmospheric turbulence.

An introduction to interpret sounding data can be found at http://www.atmos.millersville.edu/~lead/SkewT_Home.html

An excellent PowerPoint presentation about severe weather analysis from sounding perspective can be found at http://moe.met.fsu.edu/~acevans/cases/svrwx.ppt

For current and archived print-quality sounding plots and data	**http://weather.uwyo.edu/upperair/uamap.html**
For current sounding plots and data	**http://www.rap.ucar.edu/weather/upper/**
	http://weather.unisys.com/upper_air/skew/index.html
	http://www.spc.noaa.gov/exper/soundings/
	http://asp1.sbs.ohio-state.edu/main.php?pageloc=upperair

Chapter 4. Remote Sensing: Weather Satellites and Satellite Images

(from http://www.srh.noaa.gov/jetstream/remote/remote_intro.htm)

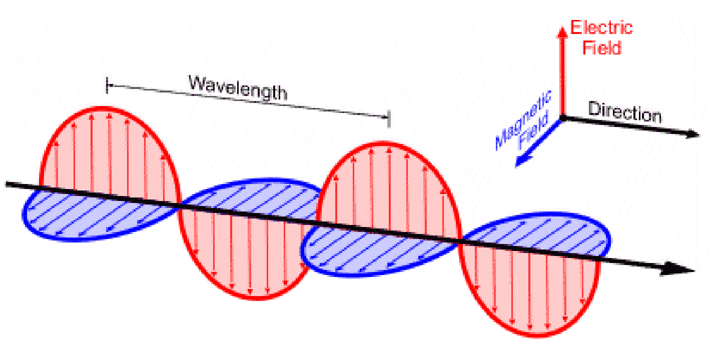
1. Introduction

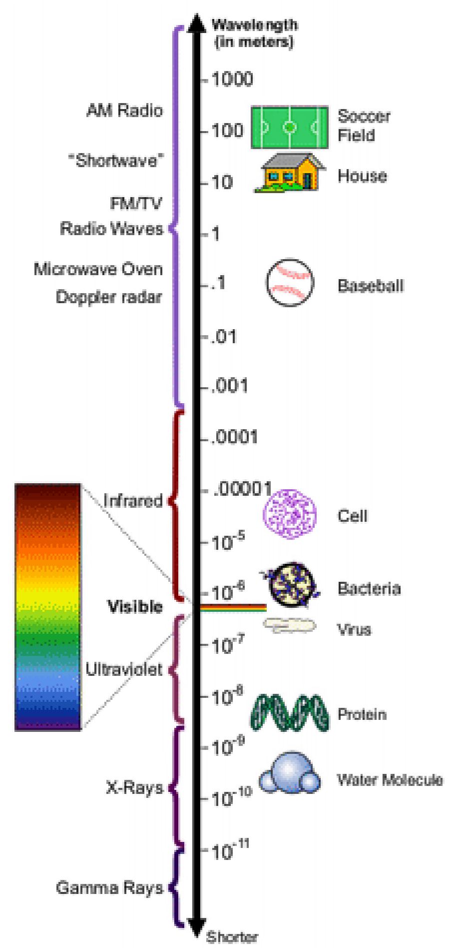
Remote sensing is the science of obtaining information about a subject or object without actually being in contact with that subject or object. In the National Weather Service remote sensing equipment is used in the detection and measurement of weather phenomena with devices sensitive to electromagnetic energy such as...

- Light (satellite)
- Heat (infrared scanners on satellites)
- Radio Waves (Doppler radar)

Remote sensing provides a unique perspective from which to observe large regions. These sensors can measure energy at wavelengths which are beyond the range of human vision. In this section we will discover the various methods the National Weather Service uses to help us derive forecasts, weather watches, and warnings.

Electromagnetic waves





Electromagnetic Spectrum

Electromagnetic waves are invisible forms of energy that travel though the universe. However, you can "see" some of the results of this energy. The light that our eyes can see is actually part of the electromagnetic spectrum. This visible part of the electromagnetic spectrum consists of the colors that we see in a rainbow - from reds and oranges, through blues and purples. Each of these colors actually corresponds to a different wavelength of light.

The sound we hear is a result of waves which we cannot see. Sound waves need something to travel through in order for it to move from one place to the next. Sound can travel through air because air is made of molecules. These molecules carry the sound waves by bumping into each other, like dominoes knocking each other over. Sound can travel through anything made of molecules - even water! There is no sound in space because there are no molecules there to transmit the sound waves.

Electromagnetic waves are not like sound waves because they do not need molecules to travel. This means that electromagnetic waves can travel through air, solid objects and even space. This is how astronauts on spacewalks use radios to communicate. Radio waves are a type of electromagnetic wave.

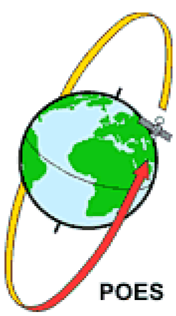
Electricity can be static, like what holds a balloon to the wall or makes your hair stand on end. Magnetism can also be static like a refrigerator magnet. But when they change or move together, they make waves - electromagnetic waves.

Electromagnetic waves are formed when an electric field (which is shown in red arrows) couples with a magnetic field (which is shown in blue arrows). Magnetic and electric fields of an electromagnetic wave are perpendicular to each other and to the direction of the wave.

When you listen to the radio, watch TV, or cook dinner in a microwave oven, you are using electromagnetic waves. Radio waves, television waves, and microwaves are all types of electromagnetic waves. They only differ from each other in wavelength. Wavelength is the distance between one wave crest to the next.

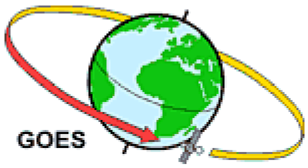
Waves in the electromagnetic spectrum vary in size from very long radio waves the size of buildings, to very short gamma-rays smaller than the size of the nucleus of an atom.

2. Satellites



The world's first meteorological satellite, was launched from Cape Canaveral on April 1, 1960. Named TIROS for **T**elevision **I**nf**r**ared **O**bservation **S**atellite, 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.

TIROS was a polar orbiting satellite. Polar orbiting satellites (POES) continued to be used today and offer 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 orbital tracks do not repeat on a daily basis. Currently in orbit we have morning and afternoon satellites, which provide global coverage four times daily.

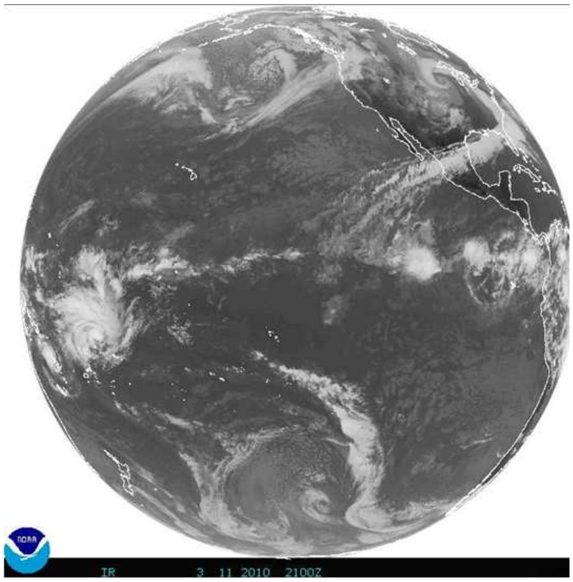


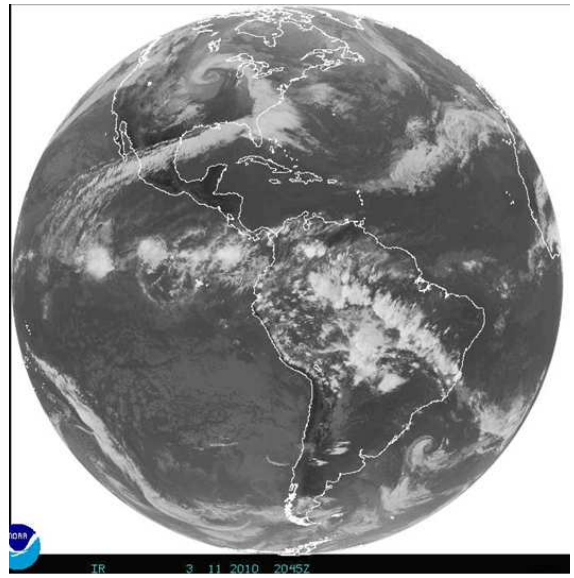
The geostationary (GOES) satellites were placed in orbit beginning in 1966. Unlike POES satellite, GOES satellites orbit at an altitude of 22,236 miles (35,786 km). At this distance the satellite completes one orbit of the earth in 24 hours. The net result is the satellite appears stationary, relative to the earth. This allows them to hover continuously over one position on the surface. 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.

There are advantages and disadvantages to each kind of orbit.

	Advantages	**Disadvantages**
Polar Orbits	• Closer to the earth with an orbit of about 520 miles (833 km) above the surface. • Much more detailed images. • Excellent views of the polar regions.	• Cannot see the whole earth's surface at any one time. • The path of each orbit changes due to the earth's rotation so no two images are from the same location. • Limited to about six or seven images a day since most of the time the satellite is below the earth's horizon and out of range of listening equipment.
Geostationary orbits	• Always located in the same spot of the sky relative to the earth. • Can view the entire earth at all times. • Can record images as fast as once every minute. • View is always from same perspective so motion of clouds over the earth's surface can be computed. • Also receives transmissions from free-floating balloons, buoys and remote automatic data collection stations around the world.	• Located about 22,000 miles (35,000 km) in space, providing less detail views of the earth. • Views of the polar regions are limited due to the earth's curvature.

3. GOES Images

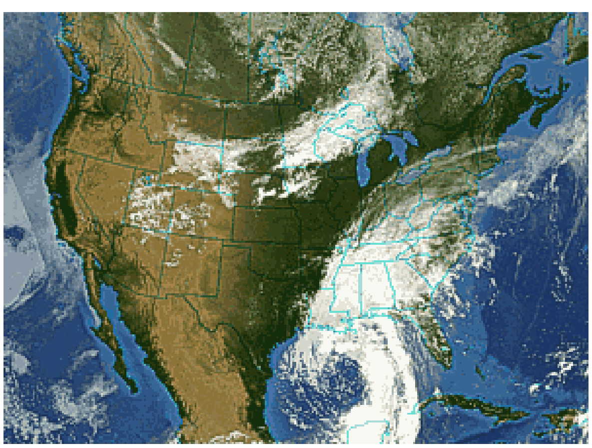




Geostationary Operational Environmental Satellites (GOES) satellites are a mainstay of weather forecasting for the National Weather Service. Satellite images you see on the nightly TV weathercast are from GOES satellites.

The United States operates two meteorological satellites in geostationary orbit, one over the equator at 75°W with a view of the East Coast and the other over the equator at 135°W for the West Coast view. At right, ar e the views from each satellite.

Since the satellites are positioned over the equator, they are viewing 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.



However, computer enhancements of these images are common. Probably the most common enhancement is combining both GOES West and East into one image of the continental U.S. and changing the perspective (right). This view (the same time frame as the two above full disk views) has been enhanced to color the surface of the earth as well change the perspective to make it *appear* the satellite is directly over the center of the U.S.

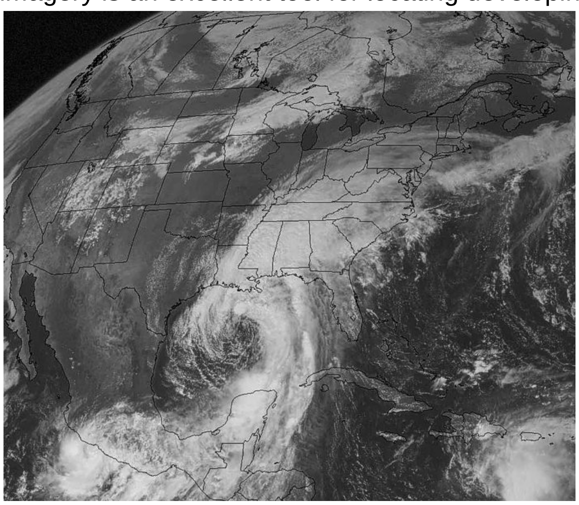
4. Basic Images

Three types of satellite images are readily available to the public to study the cloud coverage, cloud type, pressure patterns, low level clouds, sea surface temperatures, temperatures of cloud tops and surfaces, moisture concentrations in the upper and middle troposphere. The looping of satellite images is especially useful in recognizing wind flow and evolutions of a pressure system. Some satellite images are (color) enhanced to differentiate the temperatures or grayness. These satellites are capable of providing information on clouds and moisture in three primary forms - **visible**, **infrared** (IR), and **water vapor** imagery.

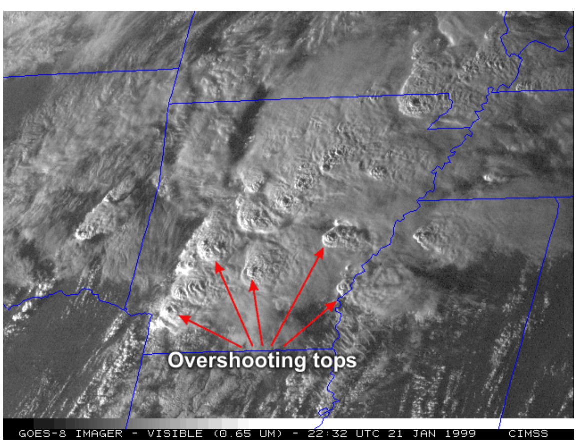
Visible imagery

Visible imagery is just like the name suggests; an image of the earth in visible light. This is a similar manner to that of a person taking a picture with a camera. The satellite detects sunlight reflected from objects within the viewfinder. In the case of the satellite, the objects are the upper surfaces of clouds. Thick clouds do a much better job of reflecting light and therefore appear brighter in visible photos.

With the satellites 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.



This visible view of North America was taken on September 25, 2002 at 12:45 p.m. CDT.



This is a late afternoon visible image of the tops of strong thunderstorms over Arkansas January 21, 1999 and shows the level of detail available.

The strong updrafts are poking through the tops of the thunderstorms (overshooting tops) casting shadows to the to the northeast of each updraft.

This view is created as the strong updraft rises into the stratosphere. When it does the updraft collapses giving this bubbly appearance.

However, if the sun elevation was high overhead, the depth perception would have been lost which make it difficult to determine the cloud type and height.

Advantage:

- You can see where clouds are developing, long often long before showers and thunderstorms are visible on radar.
- Since all clouds are visible, you can see different motions in the winds in the atmosphere.

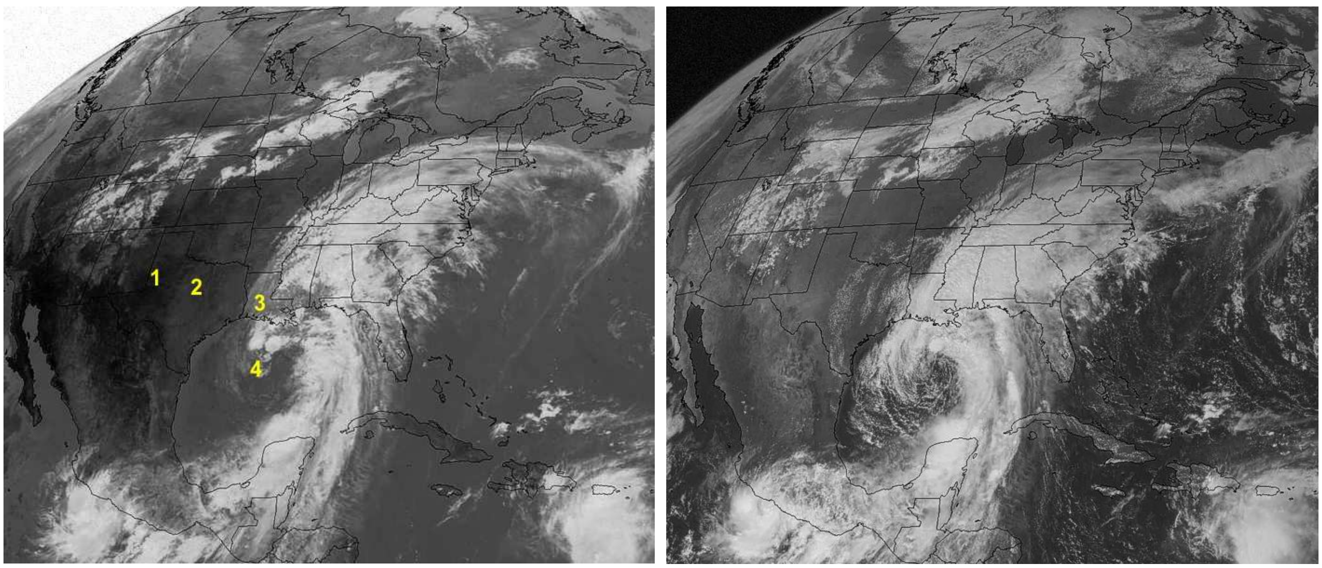
Disadvantage:

- Obviously, only useful during daylight hours.
- All clouds, whether low to the ground or high in the atmosphere appear the same so you cannot determine heights.
- Also, in winter, it is often difficult to tell the difference between snow cover and clouds with the visible image.

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. The warmest objects appear the darkest, then as the temperature of the object decreases, the appearance is lighter and lighter until the lowest temperatures measured appear white.



This infrared view (above left) of North America was taken on September 25, 2002 at 12:45 p.m. CDT. Infrared images are constructed in such a way that they measure temperatures of objects, usually clouds.

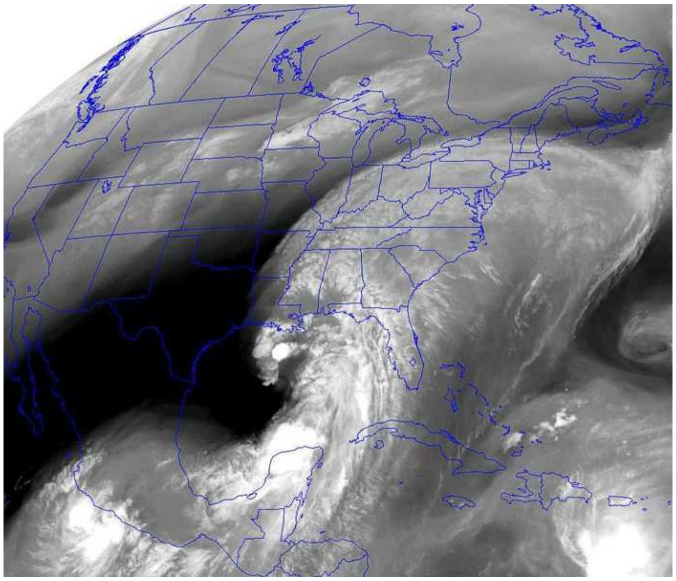
The corresponding visible image (above right) indicates
1. This area is cloud free. The satellite IR sensor therefore measures the ground temperature which is very warm.
2. This is a region of cumulus clouds with cloud top height below 10,000 ft. (3000 m).
3. Mid level clouds.
4. The white features just to the north of the number four are tops of thunderstorms just north of the center of Tropical Storm Isidore.

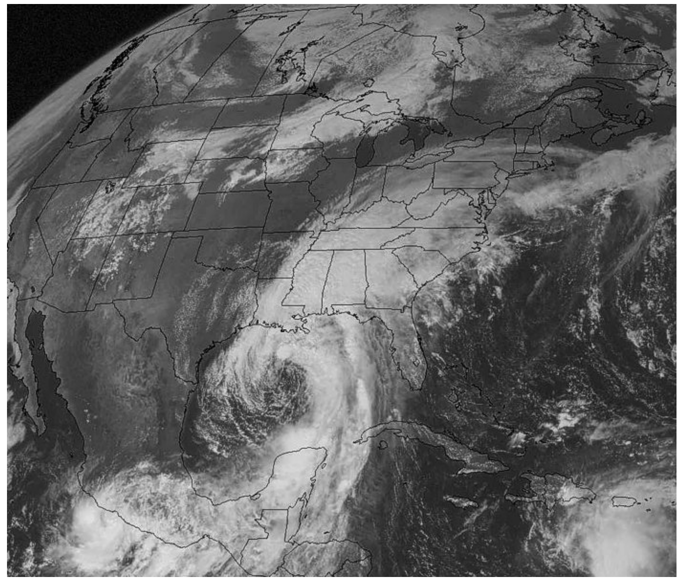
Advantage:
- We can see cloud patterns at night.
- You can determine the differences in cloud elevations.
- Developing thunder- storms are fairly easy to spot due to the very tall cumulonimbus clouds.

Disadvantage:
- The ability of seeing low clouds at night is greatly hampered since the temperature difference between the ground and the low clouds is usually very small.

<u>Water vapor imagery</u>

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" the top third of the troposphere. While the low level moisture is hidden from the satellite sensor, the upper level moist/dry areas is plainly observable. Moist areas show up as white and dry areas as black.





Since it cannot rain without moisture, this view helps show where the moisture is located in the atmosphere.

This moisture, while not seen in either the visible or IR image, will be readily observed in the water vapor imagery (above left). In this image, you will see moisture extending from southern California and Arizona northeast into southern Canada. On the corresponding visible image (above right) the actual cloud cover is limited over southern California but the supply of moisture helps fuel the showers and thunderstorms in Minnesota.

Advantage:

- Dark areas shows the moisture level in the atmosphere is low.
- You can see areas of rising and sinking air in the atmosphere. Sinking air (dark areas) indicates ridging and does not support the development of precipitation. The moisture, indicated by the gray and white areas also shows rising air which can lead to the formation of precipitation.

Disadvantage:

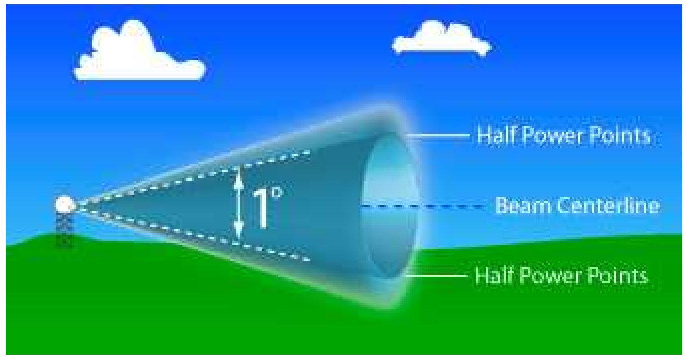
- This image cannot "see" below about 10,000 ft. (3000 m) elevation due to the absorption of the heat energy by the atmosphere.

For current satellite images	**http://www.srh.noaa.gov/srh/tropicalwx/satellite.php**
	http://wwwghcc.msfc.nasa.gov/GOES/
	http://www.goes.noaa.gov/
	http://www.rap.ucar.edu/weather/satellite/
	http://www.nhc.noaa.gov/satellite.shtml
	http://ww2010.atmos.uiuc.edu/(Gh)/wx/satellite.rxml
	http://www.ssec.wisc.edu/data/
Interactive composite maps	**http://www.spc.ncep.noaa.gov/exper/compmap/**

Chapter 5. Remote Sensing: Doppler Radar and Radar Images

(from http://www.srh.noaa.gov/jetstream/doppler/doppler_intro.htm)

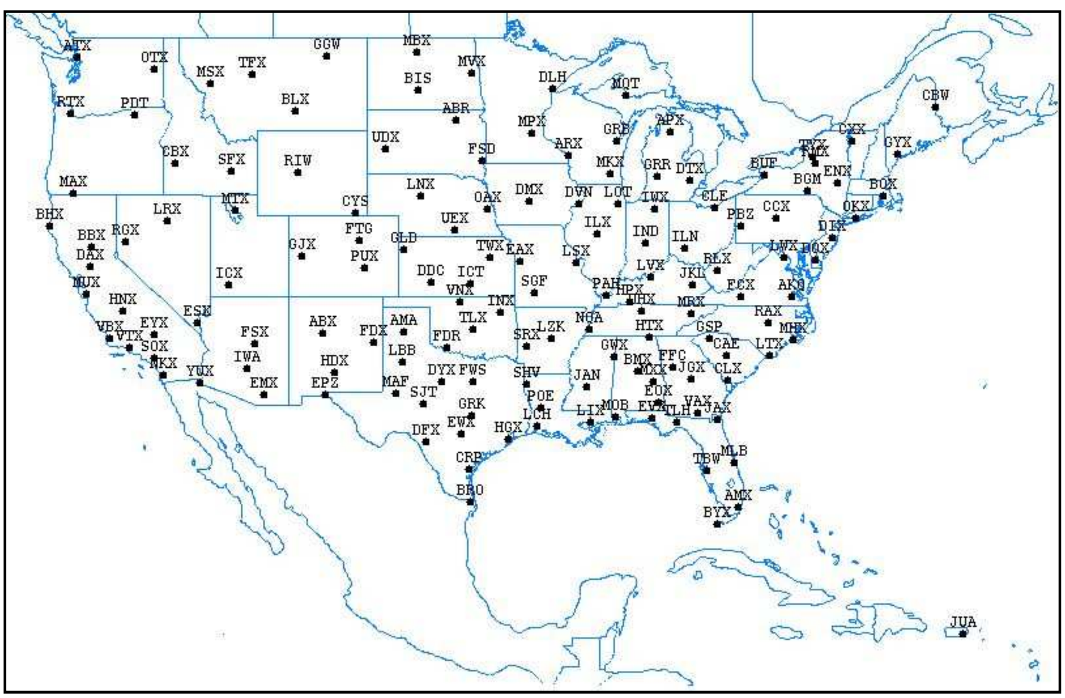
1. Introduction



The most effective tool to detect precipitation is radar. Radar, which stands for **RA**dio **D**etection **A**nd **R**anging, has been utilized to detect precipitation, and especially thunderstorms, since the 1940's. Radar enhancements have enabled NWS forecasters to examine storms with more precision.

The radar used by the National Weather Service is called the WSR-88D, which stands for Weather Surveillance Radar - 1988 Doppler (the prototype radar was built in 1988). As its name suggests, the WSR-88D is a Doppler radar, meaning it can detect motions toward or away from the radar as well as the location of precipitation areas. This ability to detect motion has greatly improved the meteorologist's ability to peer inside thunderstorms and determine if there is rotation in the cloud, often a precursor to the development of tornadoes.

There are 158 WSR-88D Doppler radar in the nation, including the U.S. Territory of Guam and the Commonwealth of Puerto Rico, operated by the National Weather Service and the Department of Defense.



US Doppler radar network.

NWS forecasters detect the severe weather events that threaten life and property using Doppler Weather Surveillance Radar (Model WSR-88D). The WSR-88D (also known as NEXRAD) observes the presence and calculates the speed and direction of severe weather elements such as tornadoes, downburst, flash floods, and violent thunderstorms. NEXRAD also provides quantitative area precipitation measurements, important in hydrologic forecasting of potential flooding. The severe weather and motion detection capabilities offered by NEXRAD increase the accuracy and timeliness of NWS warning services. In a cooperative effort with the Department of Defense (DOD) and the Federal Aviation Administration (FAA), the NWS deployed a total of 158 WSR-88D radars including 120 NWS, 12 FAA, and 26 DOD radars. Through an integrated network spanning the entire United States and its island territories, from Guam to Puerto Rico, WSR-88D dramatically enhances our ability to safeguard life, property and commerce.

The WSR-88D uses Doppler radar technology to:

- Substantially increase tornado warning lead time.
- Improve the detection and measurement of damaging winds, severe turbulence, wind shear and hail storms.
- Improve the forecast of the location and severity of thunderstorms.
- Increase the accuracy of identifying areas that are threatened.
- Substantially reduce the number of incorrect forecasts and false alarms.
- Increase the accuracy of rainfall estimates for flash flood warnings.
- Improve water resource management and river flood forecasts.

The following WSR-88D products are available to meteorologists and public:

Reflectivity Composite	Reflectivity Layer	Composite Reflectivity
Mean Radial Velocity	Echo Tops	Wind Profile
Velocity Azimuth Display	One-Hour Rainfall Accumulation	Three-Hour Rainfall Accumulation
Storm Total Rainfall Accumulation	Hourly Digital Rainfall Array	Vertically Integrated Liquid Water

Exactly how does radar work?

As the radar antenna turns, it emits extremely short bursts of radio waves, called pulses. Each pulse lasts about 0.00000157 seconds (1.57×10^{-6}), with a 0.00099843-second (998.43×10^{-6}) "listening period" in between. The transmitted radio waves move through the atmosphere at about the speed of light.

By recording the direction in which the antenna was pointed, the direction of the target is known as well. Generally, the better the target is at reflecting radio waves (i.e., more raindrops, larger hailstones, etc.), the stronger the reflected radio waves, or echo, will be.

This information is observed within the approximately 0.001-second listening period with the process repeated up to 1,300 times per second. By keeping track of the time it takes the radio waves to leave the antenna, hit the target, and return to the antenna, the radar can calculate the distance to the target.

The WSR-88D's pulses have an average transmitted power of about 450,000 watts. By comparison, a typical home microwave oven will generate about 1000 watts of energy. However, because of the very short period the radar is actually transmitting, when the time of all pulses *each hour* are totaled (the time the radar is actually transmitting), the radar is "on" for a little over 7 seconds each hour. The remaining 59 minutes and 53 seconds are spent listening for any returned signals.

The Doppler Advantage

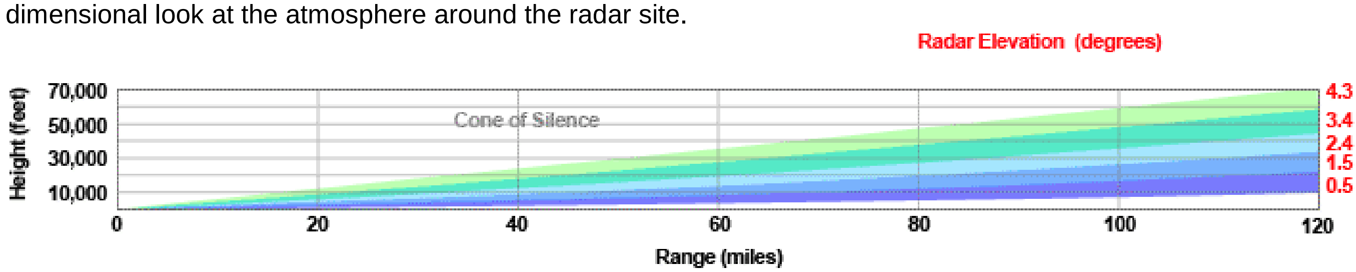
By their design, Doppler radar systems can provide information regarding the *movement* of targets as well their position. When the WSR-88D transmits a pulse of radio waves, the system keeps track of the **phase** (shape, position, and form) of the transmitted radio waves.

By measuring the *shift in phase* between a transmitted pulse and a received echo, the target's radial velocity (the movement of the target directly toward or away from the radar) can be calculated. A positive phase shift implies motion toward the radar and a negative shift suggests motion away from the radar.

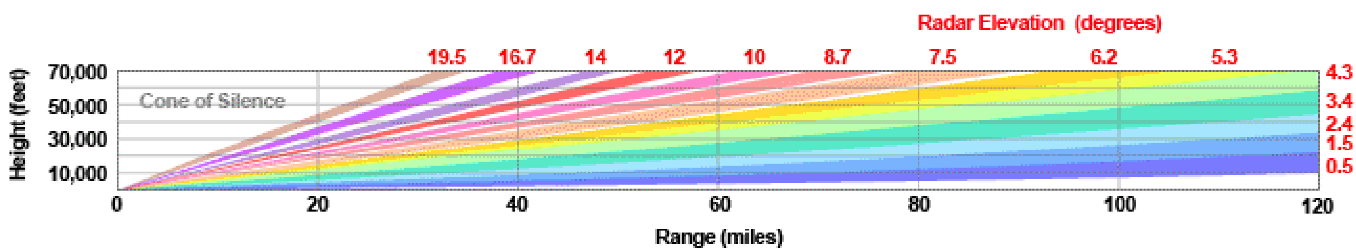
The larger the phase shift, the greater the target's radial velocity. The phase shift effect is similar to the "Doppler shift" observed with sound waves. An object emitting sound waves will transmit those waves in a *higher* frequency when it is approaching your location (inbound velocity = positive shift) as the sound waves are compressed. As the object moves away from a location, the sound waves will be stretched and have a lower frequency (outbound velocity = negative shift). You have probably heard this effect when an emergency vehicle drove past you with its siren blaring. As the vehicle passed your location, the pitch of the siren lowered.

Scanning the horizon

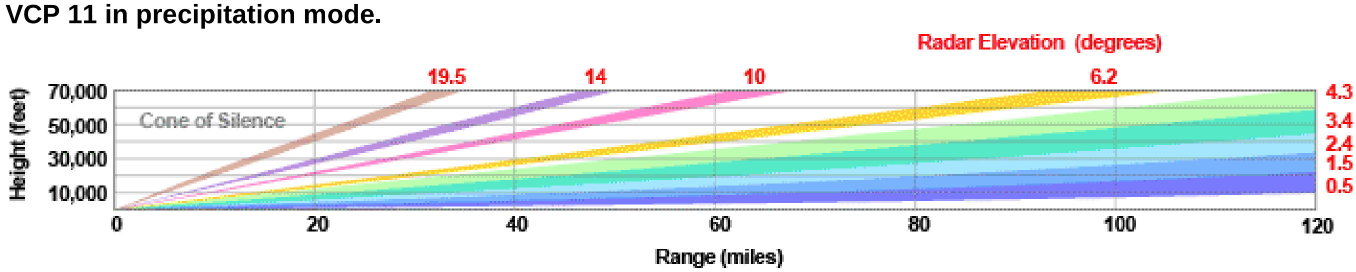
The WSR-88D employs scanning strategies in which the antenna automatically raises to higher and higher preset angles, or elevation slices, as it rotates. These elevation slices comprise a **volume coverage pattern** or VCP. Once the radar sweeps through all elevation slices a volume scan is complete. In precipitation mode, the WSR-88D completes a volume scan every 4-6 minutes depending upon which VCP is in effect, providing an updated 3-dimensional look at the atmosphere around the radar site.



VCP 31 and 32 in clear air mode.



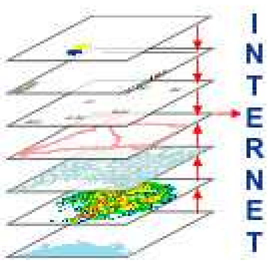
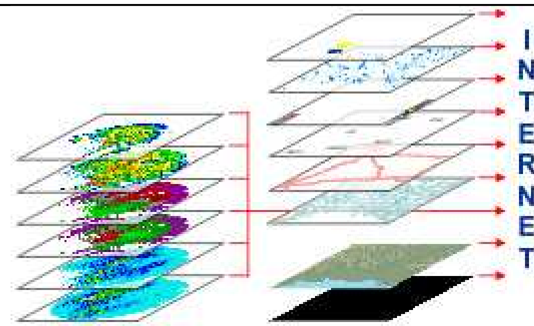
VCP 11 in precipitation mode.



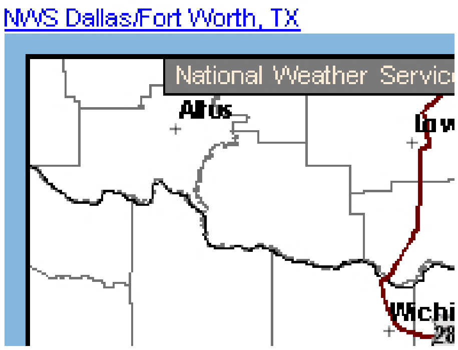
VCP 21 in precipitation mode.

NWS Radar on the Web

The National Weather Service has presents Doppler radar images on the web in two manners; a **Standard version** (an all-in-one image) and an **Enhanced version** by individual interactive layers. Follow are the differences and strengths/weakness of each.

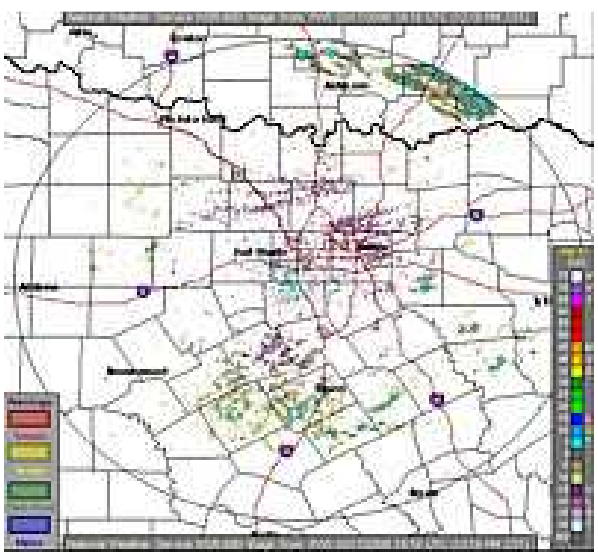
Standard Version	**Enhanced Version** **(Ridge Radar)**
	
In the **Standard** version, each radar image is combined with a legend, highways, and county/state outline overlays into one graphic which is made available via the web.	In the **Enhanced** version, individual radar images are transmitted as well as individual overlay maps for highways, rivers, cities, county boundaries and severe weather warnings.
Advantages: • Smallest file size to download for both loop and non-looping images. • Toggle loop on/off just by clicking on image. • No Java/Javascript needed. • Can save any image by right clicking on the image then select "Save As". • Printer friendly "white" background. **Disadvantage:** • Each radar image is on a separate webpage that must be downloaded. • Overlays are fixed and always visible. • Unable to stop looping on any image. Stopping the loop always takes you to the most recent image page.	**Advantages:** • Radar data available for GIS programs. • Individual non-changing overlays, such as topography, can be cached on the local computer eliminating retransmission for each update. • Individual images that change often (radar image itself, watches/warnings, etc.) are much smaller in file size (compared to the standard version image). • Overlays can be toggled on/off and settings are preserved when bookmarked or moving between adjacent radar locations. • Can measure distance and direction between points. • Can determine latitude and longitude of objects. **Disadvantage:** • Initial download size of files are much larger (compared with the standard version). • Extensive use of Java/Javascript.

How can you quickly tell which version of the radar you are viewing? The two obvious differences are in the border color around the radar image and background image. The standard version have a light blue border with a white background. The Enhanced version will have a dark blue border with a map background showing topography. (Samples below)

Standard Version	Enhanced Version (Ridge Radar)
	

For current local and national radar, click on http://www.srh.noaa.gov/ridge/Conus/.

Radar Map Projections

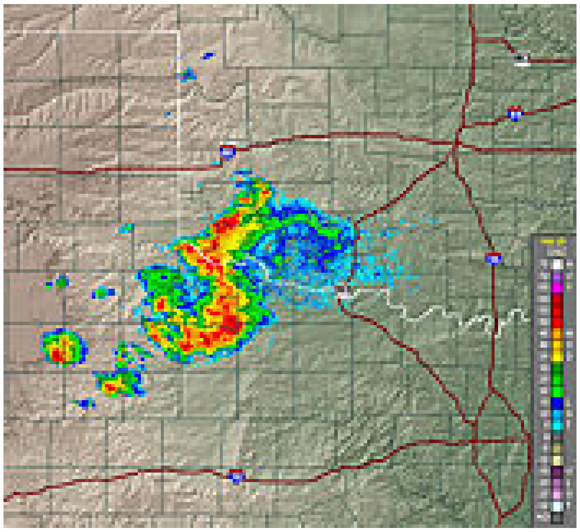


Except for the state of Alaska, the radar images provided by the National Weather Service are in an unprojected latitude/longitude format. This allows geographic information system (GIS) software to ingest NWS radar data for display with other information such as population density, etc. Because of this unprojected format, the radar images appear "squashed" or oval shaped. The squashing of the radar image increases with increasing distance north (and south) of the equator. The oval ring in the image (above) is the 124 nautical mile range ring, which is the distance "seen" in a "short range" Doppler radar image.

NWS Radar Images

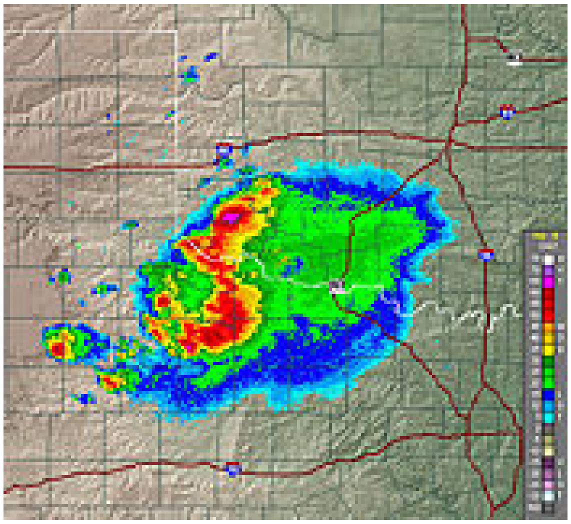
Whether looking at the standard or enhanced version of the NWS Doppler radar display the following examples of the different images applies to both varieties. In this section, the enhanced view will be used.
The National Weather Service provides several different images from the network of Doppler radars http://www.srh.weather.gov/ridge/). These images include reflectivity, velocity and rainfall information.

Reflectivity Images



These images are just as they sound as they paint a picture of the weather from the energy *reflected* back to the radar. There are two types available on the web; **Base** (or ½° elevation) reflectivity and **Composite** reflectivity.

Base Reflectivity is the default image. Taken from the lowest (½° el evation) slice, it is the primary image used to "see what's out there". There are two versions of Base Reflectivity image; the *short range* version which extends out to 124 nm (about 143 miles) and the *long range* version which extends out to 248 nm (about 286 miles). This image is available upon completion of the ½° elevat ion scan during each volume scan.



Composite Reflectivity images utilize all elevation scans during each volume scan to create the image. It is composed of the greatest echo intensity (reflectivity) from any elevation angle seen from the radar. It is used to reveal the highest reflectivity in all echoes.

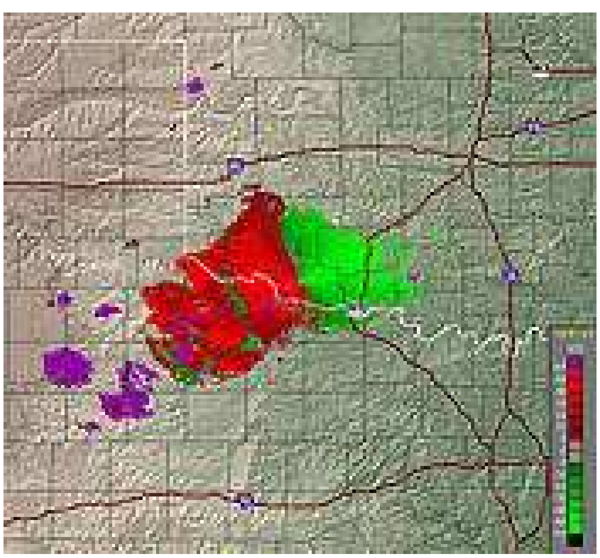
Another advantage of **Composite Reflectivity** is in mountainous regions. Often, the Base Reflectivity ½° elevation scan is not high enough to see over mountains. With the addition of higher elevations scans, weather information over mountain peaks can be seen.

Velocity Images

One of the best features on the 88d Doppler radar is its ability to detect motion. However, the only motion it can "see" is either directly *toward* or *away* from the radar. This is called radial velocity as it is the component of the target's motion that is along the direction of the radar beam.

In all velocity images, red colors indicate wind moving away from the radar with green colors representing wind moving toward the radar. It is very important to know where the radar is located as that is your reference point for proper interpolation of the wind's motion.

Base Velocity images provides a picture of the basic wind field from the ½° elevation scan. It is useful for determining areas of strong wind from downbursts or detecting the speed of cold fronts. However, since the radar only measures radial velocity, the strength of the wind will always be less than what is actually occurring unless the wind is moving directly toward or away from the radar.

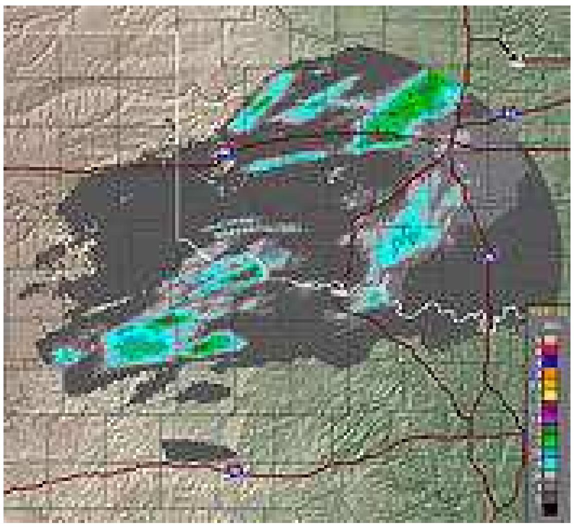


Also, the surface winds are only for areas near the radar. As distance increases from the radar, the reported value will be for increasing heights above the earth's surface.

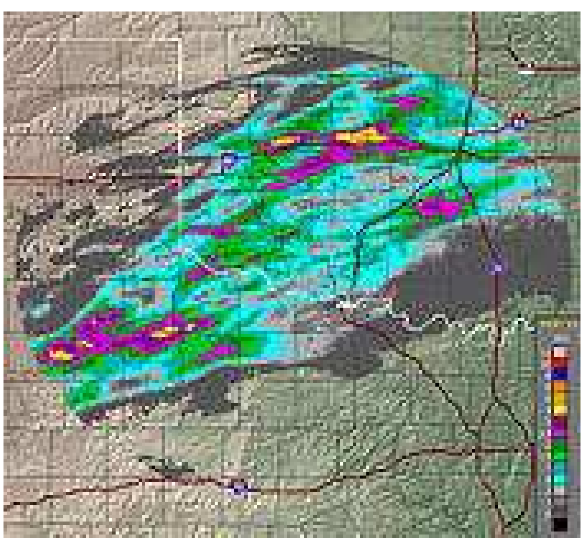
Storm Relative Motion images are very useful images to look for small scale circulations (called mesocyclones) in thunderstorms. Often, these small scale circulations are areas where tornadoes form.

What separates storm relative motion from base velocity is the motion of storms are "subtracted" from the overall flow of the wind. As storms move, their own motion can mask circulations within themselves. This motion is removed to make the view of the wind relative to the storm. In effect, what is seen is the wind's motion as if the storms were stationary.

Precipitation Images



There are two precipitation images made available via the web: One-hour Precipitation and Storm Total Precipitation. The maximum range of these two images is 124 nm (about 143 miles) from the radar location. They will not display accumulated precipitation more distant than 124 nm, even though precipitation may be occurring at greater distances. To determine accumulated precipitation at greater distances you should link to an adjacent radar.

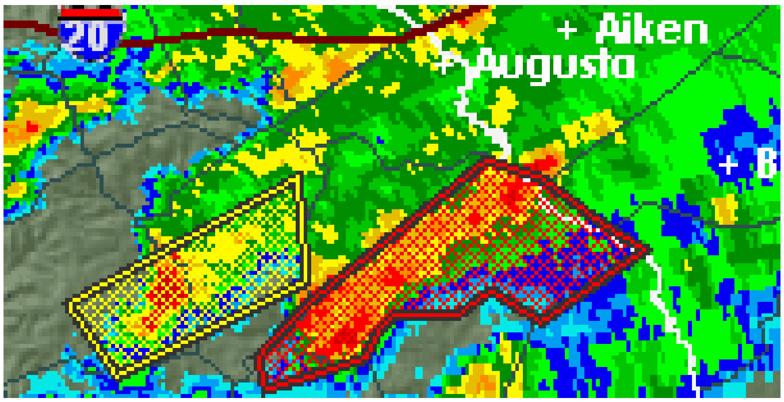


One-hour Precipitation is an image of estimated one-hour precipitation accumulation. It is used to assess rainfall intensities for flash flood warnings, urban flood statements and special weather statements.

Storm Total Precipitation image is of estimated 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.

Always check the time frame from which this image is created. There must be one hour without precipitation anywhere on the radar before the accumulation period begins again and, depending upon the weather patterns, that may be up to several days.

Weather Warnings



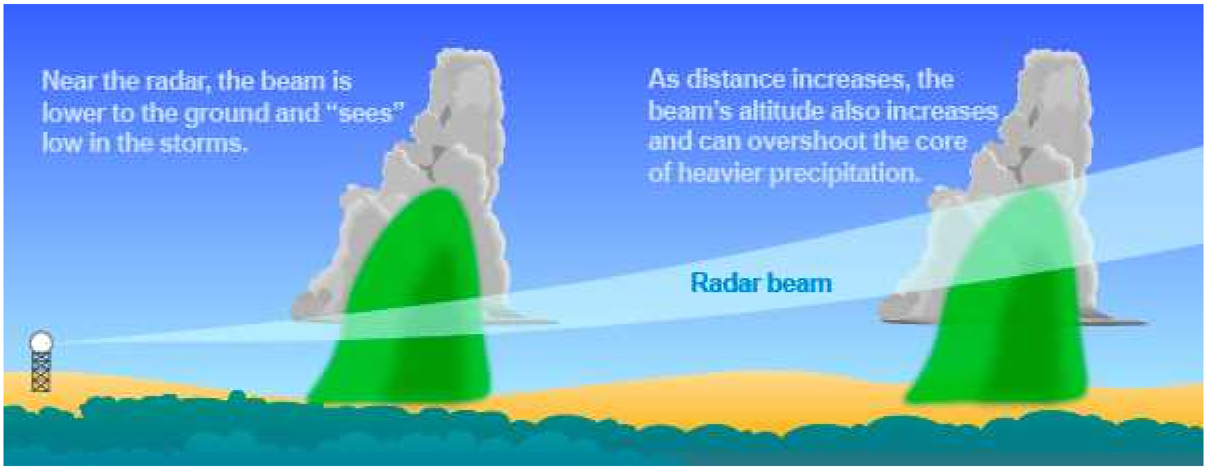
If any portion of a county is affected by severe weather, the NWS issues a weather warning for the *entire* county. However, we actually refine the region affected by drawing the warnings in polygons to indicate the exact region we believe severe weather may occur.

Included with the radar images are graphics of severe weather warnings. (These images can be hidden on the enhanced views of the Doppler radar by toggling off the warnings.) The colors, red, yellow, green and blue represent the four types of warnings that will appear on NWS Doppler radar images.

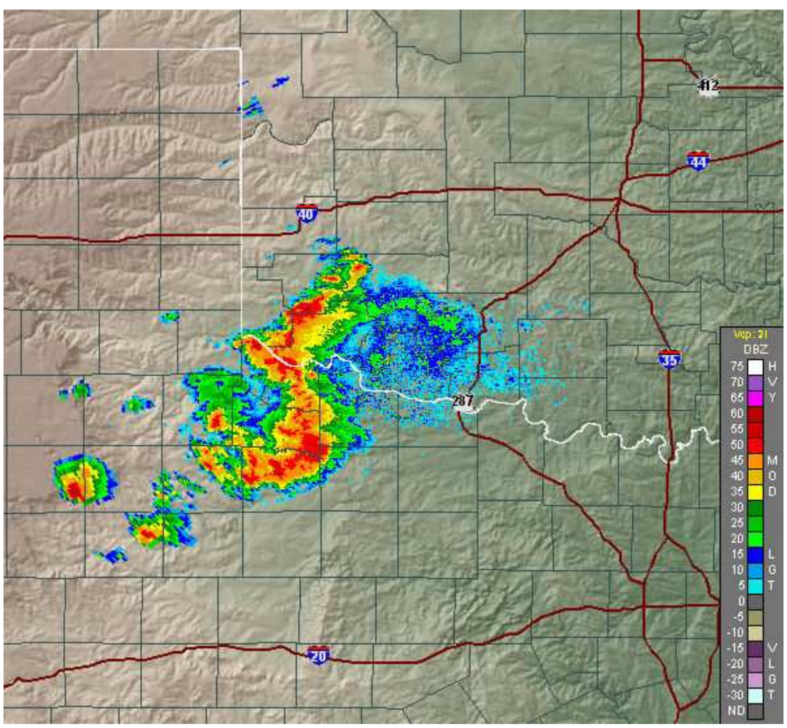
- **Red** - Tornado Warning. Issued when a tornado is imminent or occurring. A Tornado Warning implies an immediate threat to life and property.
- **Yellow** - Severe Thunderstorm Warning. Issued when a severe thunderstorm is imminent or occurring. A severe thunderstorm is defined as hail 1" or greater and/or a wind speed of 58 mph (50 kts / 93 km/h) or greater.
- **Green** - Flash Flood Warning. Issued with flash flooding is imminent or occurring.
- **Marine** - Special Marine Warning. Issued for hazardous weather conditions (thunderstorms over water, thunderstorms that will move over water, cold air funnels over water, or waterspouts) usually of short duration (2 hours or less) and producing sustained winds or frequent gusts of 34 knots or more that is not covered by existing marine warnings.

2. Doppler Radar Images

A. Base Reflectivity



Taken from the lowest (½°) elevation scan, base ref lectivity is excellent for surveying the region around the radar to look for precipitation. However, remember the radar beam increases in elevation as distance increases from the radar. This is due, in part, to the elevation angle itself but is more because the earth's surface curves away from the beam. This can lead to underestimating the strength and intensity of distant storms. For this reason, it is wise to always check the radar images from different locations to help provide the overall picture of the weather in any particular area.



This image (above) is a sample base reflectivity image from the Doppler radar in Frederick, OK. The radar is located in the center of the image. *The colors represent the strength of returned energy to the radar* expressed in values of decibels (dBZ). The color scale is located at the lower right of each image.

dBZ	Rain Rate (in/hr)
65	16+
60	8.00
55	4.00
52	2.50
47	1.25
41	0.50
36	0.25
30	0.10
20	Trace
< 20	No rain

These dBZ values equate to approximate rainfall rates indicated in the table above.

These are *hourly rainfall rates only* and are not the actual amounts of rain a location receives. The total amount of rain received varies with intensity changes in a storm as well as the storm's motion over the ground.
Also, thunderstorms can contain hail which is often a good reflector of energy. Typically, a hailstone is coated with a thin layer of water as it travels through the thunderstorm cloud. This thin layer of water on the hailstone will cause a storm's reflectivity to be greater, leading to a higher dBZ and an over estimate the amount of rain received.

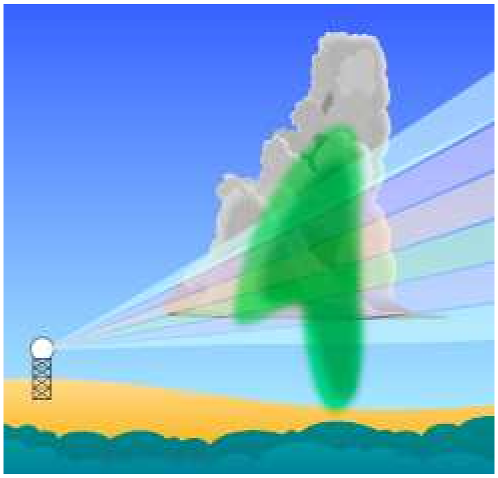
Value of 20 dBZ is typically the point at which light rain begins. The values of 60 to 65 dBZ are about the level where ¾" hail can occur. However, a value of 60 to 65 dBZ *does not* mean that severe weather is occurring at that location.

Severe weather may be occurring with values less (or greater) than 60 to 65 dBZ due to...

- Hail that is totally frozen (without a thin layer of water in the surface). "Dry hail" is a very poor reflector of energy and can lead to an *underestimate* of a storm's intensity.
- Atmospheric conditions such a ducting. When ducting occurs, the radar beam is refracted into the ground (indicating stronger storms than what are actually occurring). However a worse case is when subrefraction is occurring and the beam is overshooting the most intense regions of storms (indicating weaker storms than what are actually occurring).
- Doppler radars that get out of calibration. The radar can become "hot" (indicating stronger storms than what are actually occurring) or "cold" (indicating weaker storms than what are actually occurring).

These are just some of the reasons to look at the weather using the adjacent radars.

B. Composite Reflectivity

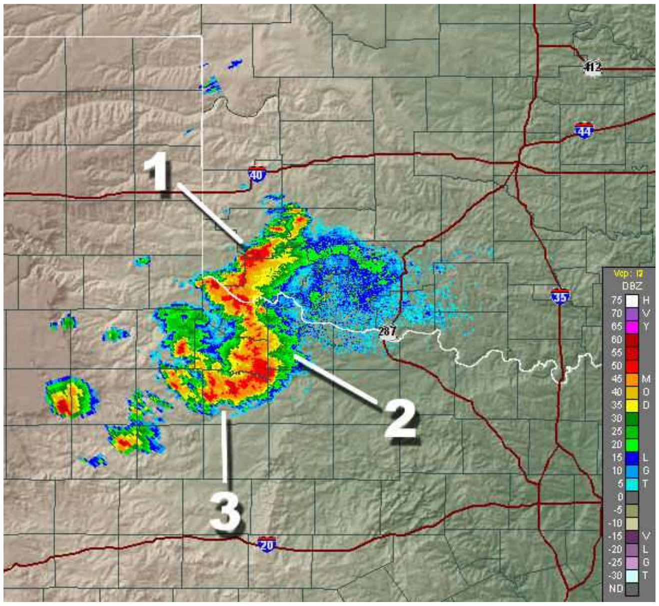


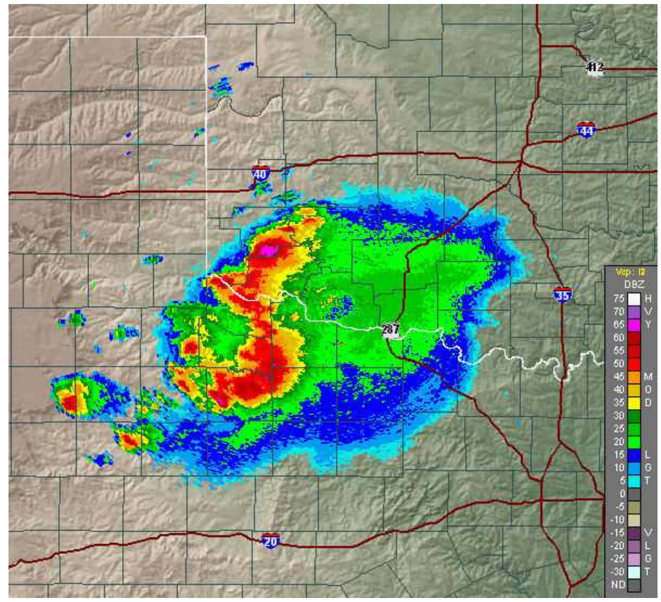
The strongest returned energy for each elevation angle in a volume scan is compiled into one image called, simply, composite reflectivity. Whereas the base reflectivity image is the first image available during a volume scan, the composite reflectivity image is one of the last views necessitated by the need for all elevation scans to be completed before this image can be produced.

Therein lies an important point when viewing composite reflectivity images; *always check the time of the image*. Often, the base reflectivity image and composite reflectivity image *will not have the same time* with the base reflectivity image being the most recent.

When compared with Base Reflectivity, the Composite Reflectivity can reveal important storm structure features and intensity trends of storms. This is important because often during the development of strong to severe thunderstorms, rain-free areas (or areas with light rain) develop as a result of strong updrafts.

The composite image (lower right) is much more "green" color near the radar (located at the center) than the base reflectivity image (lower left).





When higher elevation scan information is included in the composite reflectivity, it appears to indicate more widespread rain. However, the base reflectivity images does not show that rain so it is probably not reaching the ground but evaporating as it falls from very high in the atmosphere.

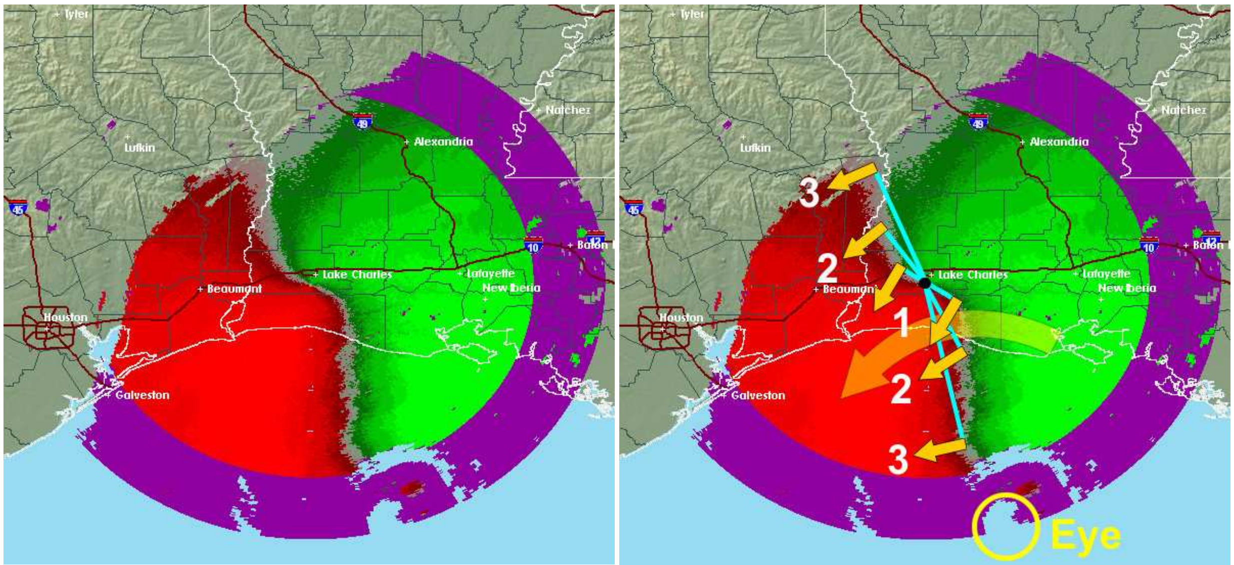
Evidence of very strong updrafts (leading to the possibility of severe weather) can be seen when comparing the two images. At #1, the fuschia colored region, visible on the composite image, is all but missing on the base reflectivity.

Using the color scale, this area is at 65 dBZ on the composite image. This is an area of concern as this is probably hail that has yet to fall. Remember the old adage "What goes up, must come down". Some or most of the hail may melt before reaching the ground but at the very least, intense, blinding rain may be about to occur near this location.

The notches, at #2 and #3, show more rain supported by strong updrafts. Those locations require additional interrogation to determine what is taking place at these locations which will come from the velocity products.
Note: Use caution when interpreting *any* radar image. No single image (or combination of images) from the NWS Doppler radar will provide the whole picture of the weather occurring in your area. Also, these images are a picture of what *HAS* happened and *not* what *IS* happening, as there will be a delay in the time the image was created and the time it is made available on the Internet. **Always check the time of each image.**

C. Base Velocity Image

This base velocity image is from the NWS Doppler radar in Lake Charles, LA during Hurricane Rita, September 2005. In velocity images, red colors indicated wind moving away from the radar with green colors indicating motion toward the radar. The transition zone between incoming and outgoing winds are indicated the gray-ish colors between the two. Purple indicated "range folded" areas (areas where the radar is unable to determine the radial velocity).



The direction of the wind can be estimated using this transition zone. From the radar, draw a line to any portion of the gray-ish area. The approximate wind direction is perpendicular to that line extending from the radar (yellow arrows in the image on the above right).

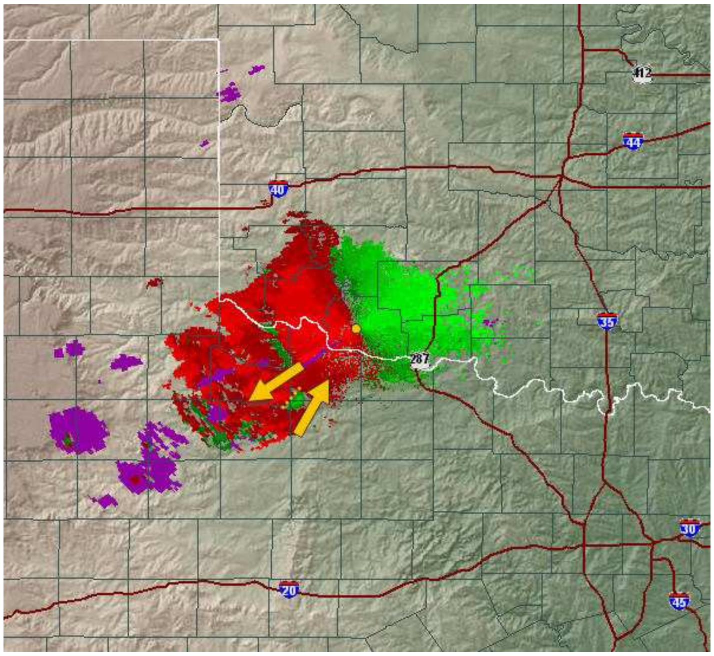
The radar's location is indicated by a black dot. The light blue lines are *radial lines* extending from the radar. The arrows at the end of each line are perpendicular to these radial lines and indicate the approximate direction of the wind at the end point of the lines.

Notice the change in direction of the wind as distance from the radar increases. Why the difference? At **#1**, the radar beam is near the earth's surface displaying wind low to the ground. The wind speed is reduced slightly due to friction with the earth's surface. As a result, the direction is angled *toward* the area of lowest pressure, the eye of the storm.

Farther up in the atmosphere, above this frictional layer, the wind direction is more what one would expect (indicated by the large curved yellow arrow). Yet at **#3**, the wind direction begins to diverge. This divergence is clockwise outflow at the top of the storm.

We see these different wind directions through the height of the storm due to the radar beam increasing in elevation as the distance from the radar increases.

D. Storm Relative Motion

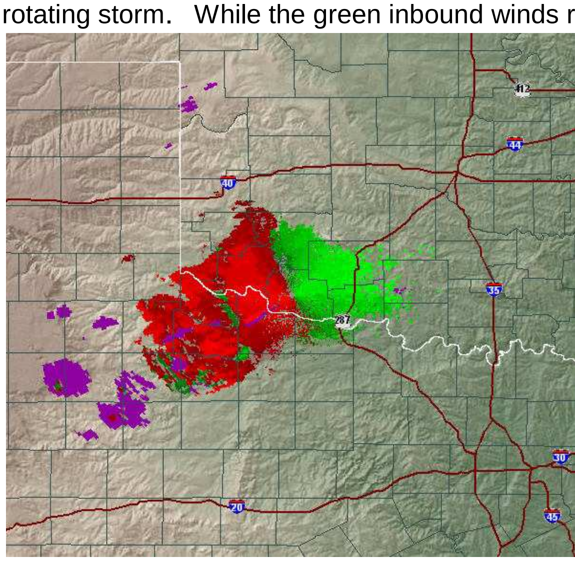


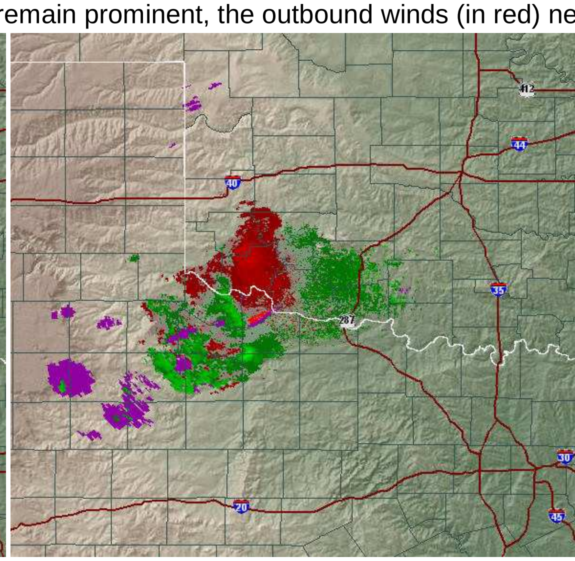
When the motion of storms are subtracted from the wind field, the result is a picture of the wind as if the storms were stationary. As in the case of all velocity images, red color indicates wind moving away from the radar with green color indicates motion toward the radar. (The radar is located in the center of the image.)

Small scale circulations, from which tornadoes often form, will typically be indicated by *strong inbound wind located beside strong outbound wind* relative to the radar.

The yellow dot in the center of the image is the radar's location. Notice the bright green region is beside the bright red region with the dividing line along a radial to the radar (yellow dashed line). This is one indicator that the storm appears to be rotating, called a supercell, and will be closely monitored by the NWS forecasters for possible tornado development.

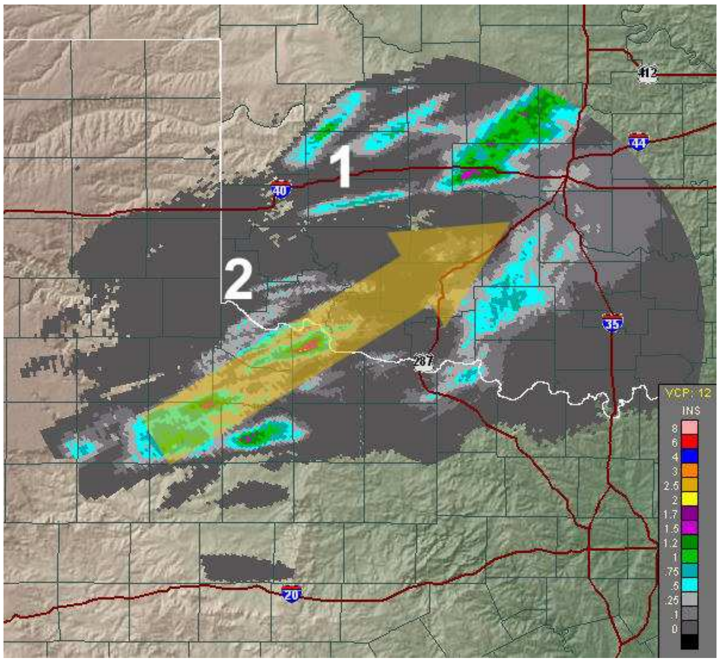
Comparing the storm relative motion image (below left) with base velocity image (below right) helps identify the rotating storm. While the green inbound winds remain prominent, the outbound winds (in red) nearly disappear.





In fact, just judging from the base velocity image, it might appear that there is only a strong inbound motion of gusty wind produced by the thunderstorm. However, when the storm relative motion image is teamed with the base velocity there is a clearer picture of the weather situation indicating a rotating thunderstorm.

E. One Hour Precipitation



Just as the name implies, this is an image (right) of the estimated precipitation during the previous hour. But also as in the case of other Doppler radar images, there needs to be some caution in viewing this image as there are two main factors to consider.

First, while the radar does a great job at correcting itself, there are times when the radar will be out of calibration. If the radar is "hot" (reporting echoes too strong) then the rainfall estimates will be an *over*estimate. Conversely, a "cool" radar will *under*estimate the precipitation. Always check nearby radars to see if they are reporting similar information to what is viewed by your local radar.

Second, hail makes an excellent reflector of energy. Thunderstorms with hail will *over*estimate the amount of precipitation and the larger the hailstones, the greater the *over*estimate.

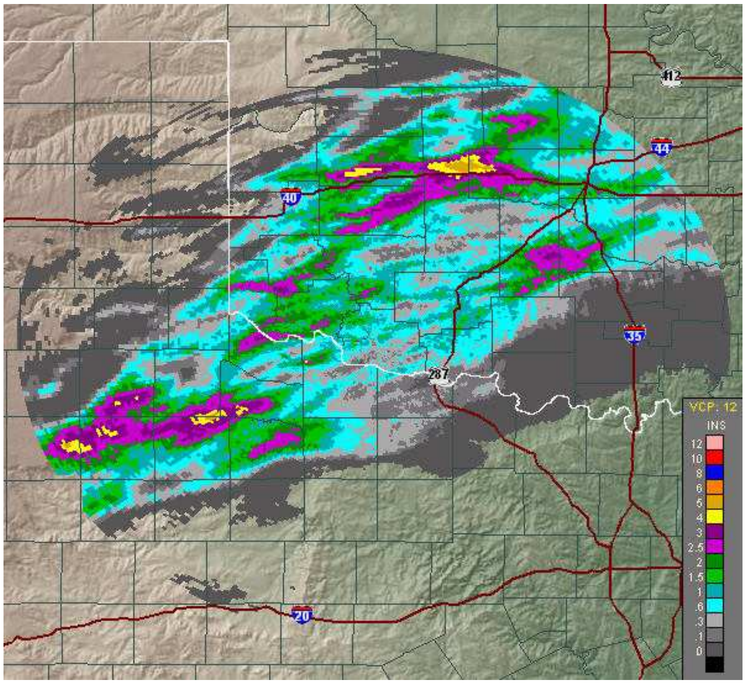
Besides estimating rainfall, both the static and looping One-hour Precipitation images can provide other useful information. This image is a good way to track individual storms located at #1 and #2.

The overall motion of the storms is indicated by the large yellow arrow. However at #1 there are storms moving in three directions. The first thing to notice is storms **DO NOT** always move parallel to the upper level winds. Some storms can move left, or right, of the upper level flow.

Thunderstorms also do not always move in straight lines. Sometimes they curve as in the case of the two small storms to the right of #2. This is valuable information as storms that tend to move right of the main airflow, either in a straight line or curved path, are often capable of producing severe weather.

These "right movers" may be difficult to see on looping reflectivity images but the rainfall pattern they leave behind can be invaluable in knowing which storms require extra attention.

6. Storm Total Precipitation



Just as the name implies, this is an image (above) of the estimated accumulation since the precipitation began. The accumulation continues until there is no precipitation for one hour anywhere within the range of the radar.

Often, in prolonged rainy periods, this accumulation can exceed five days or more. On the radar page, the accumulation time period for this image is located on the right side, just above the image.

As in the case of the one-hour precipitation image the radar does a great job at correcting itself, there are times when the radar will be out of calibration. If the radar is "hot" (reporting echoes too strong) then the rainfall estimates will be an *over*estimate.

Conversely, a "cool" radar will *under*estimate the precipitation. Always check nearby radars to see if they are reporting similar information to what is viewed by your local radar.

Also, hail makes an excellent reflector of energy. Thunderstorms with hail will *over*estimate the amount of precipitation and the larger the hailstones, the greater the *over*estimate.

For current radar images:

National interactive radar mosaic, both standard and enhanced (ridge) versions)	**http://radar.weather.gov/index_lite.htm**
National interactive radar mosaic	**http://www.nws.noaa.gov/radar_tab.php**
National radar images and loops	**http://weather.unisys.com/radar/rad_us.html**
	http://radar.weather.gov/radar.php?rid=gsp&product=N0R&overlay=11101111&loop=no