Chapter 2: Meteorological Measurements

- Surface Measurements
- Rawinsondes
- Radar
- Satellite

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Meteorologists understand and predict weather using two scientific approaches:

(1) Analysis of meteorological measurements

(2) Numerical modeling

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Synoptic Meteorology

- Observations of atmospheric properties are taken at different locations at the same time to construct weather maps for analysis.

- Meteorologists call these measurements ***synoptic*** and studies using these measurement ***synoptic meteorology***.

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Technology and Meteorology

1600	thermometer	
1640s	barometer	
1660s	anemometer	
1700s	hygrometer	
1854	telegraph	construction of first weather map
1930s	rawindsonde	routine upper-air information became available
1940s	radar	mapping precipitation
1950s	computer	numerical weather prediction
1960s	satellite	world-wide coverage of measurements
1990s	PC and internet	weather information to your desk

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Observation Time for Weather Map

- Weather organizations throughout the world use the **UTC** (Universal Coordinated Time) as the reference clock for weather observations.
- UTC is also denoted by the abbreviation **GMT** (Greenwich Meridian Time) or, often as the last two zeroes omitted, **Z** (Zulu).
- Observations of the upper atmosphere are coordinately internationally to be made at 0000 UTC (midnight at Greenwich; 0Z; 0GMT) and 1200 UTC (noon at Greenwich; 12Z; 12GMT).
- Synoptic observations have traditionally been done every 6 hours or every 3 hours, depending on the station.
- Local time should be 1 hour earlier for every (360/24)=15° of longitude west of Greenwich.

➔Local time in Los Angeles (118 ° W) and the rest of the Pacific Standard Time is 8 (= 118°/15°) hours earlier than Greenwich.

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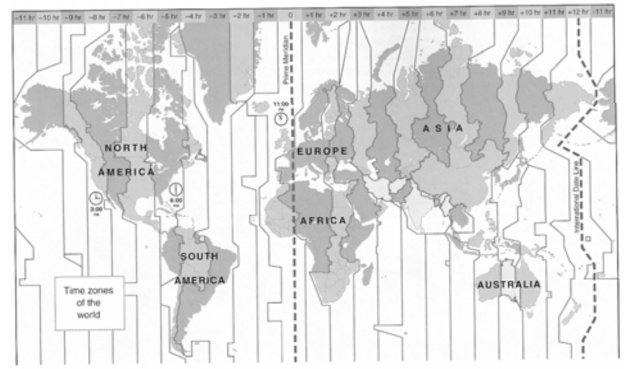
Time Zone



(from *Meteorology: Understanding the Atmosphere*)

7/7/2005 7/8/2005 7/7/2005

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UTC And US Standard Time

		Pacific	Mountain	Central	Eastern	Atlantic
1200 UTC	STANDARD	4 a.m.	5 a.m.	6 a.m.	7 a.m.	8 a.m.
	DAYLIGHT	5 a.m.	6 a.m.	7 a.m.	8 a.m.	9 a.m.
0000 UTC	STANDARD	4 p.m.	5 p.m.	6 p.m.	7 p.m.	8 p.m.
	DAYLIGHT	5 p.m.	6 p.m.	7 p.m.	8 p.m.	9 p.m.

Eastern Time Zone = UTC - 5 hrs

Pacific Time Zone = UTC – 8 hrs

Alaska Time Zone = UTC – 9 hrs

Hawaii Time Zone = UTC – 10 hrs

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Surface Measurements: ASOS/AWOS

Courtesy of NOAA

- Automated Surface (Weather) Observing Systems (ASOS or AWOS) are now used to make standard measurements of atmospheric properties at most location in North America.
- The measurements are reported hourly in North America and every three hours worldwide, at 0000, 0300, 0600, 0900, 1200, 1500, 1800, and 2100 UTC.

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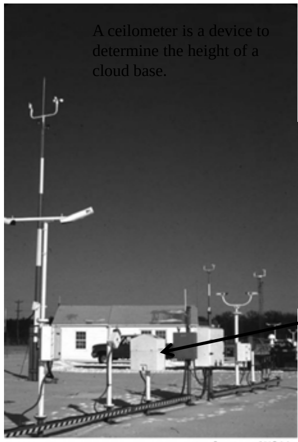
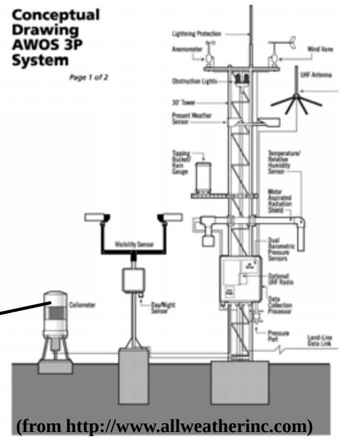
AWOS



Courtesy of NOAA



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What Instruments does ASOS/AWOS Have?

- Rain sensor
- Temperature sensor
- Dewpoint temperature sensor
- Pressure sensor
- Device to detect precipitation
- Wind vane for wind direction
- Anemometer for wind speed
- Devices to measure sky conditions

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What does ASOS/AWOS Report?

- Cloud height and amount
- Visibility
- Precipitation type, intensity, and accumulation (bgn/ending time)
- Obstruction to vision (such as fog or haze) (maybe visibility)
- Sea-level pressure (may also report pressure tendency)
- Altimeter setting
- Temperature
- Dewpoint temperature
- Wind direction, speed, and character (gusts, squalls)

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Surface Weather Stations

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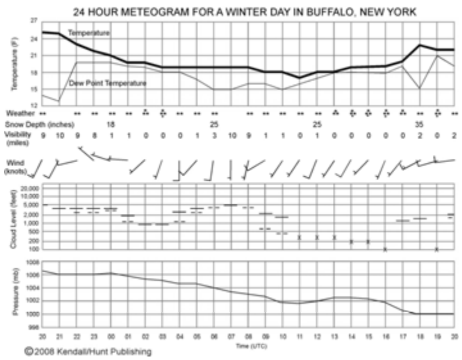
Meteogram



- Surface data from ASOC/AWOS stations are plotted on ***meteograms***; graphs that show how several atmospheric properties change with time.

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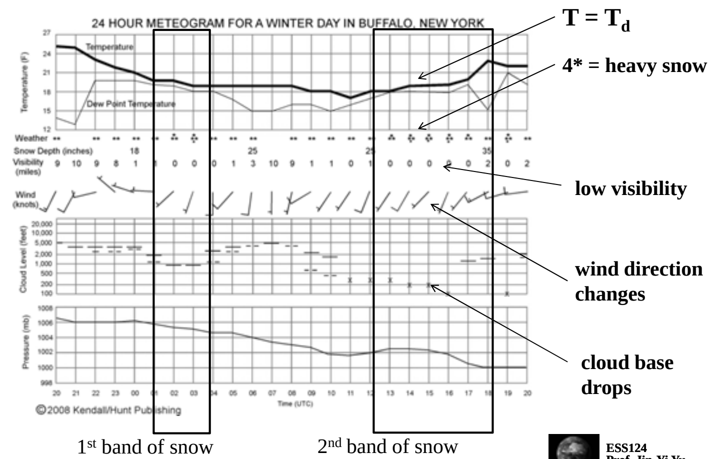
A Winter Day in Buffalo, NY



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Rawinsondes

- To understand weather systems, measurements are required through the depth of the troposphere and well into the stratosphere.
- Raiwinsondes are designed for this purpose.
- A rawinsonde is a balloon-borne instruments system that measure pressure, temperature, dewpoint temperature, wind direction, and speed.

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Rawinsonde Stations

- Rawinsondes are lunched worldwide twice a day at 0000 UTC and 1200 UTC.
- Rawindonses are normally launched 50 minutes prior to the standard time (1200, 0000 UTC), so that they sample the jetstream level around 250mb close to 1200 and 0000 UTC.
- The balloons typically rise about 20km (~60mb) before they burst.
- It usually takes about an hour before it bursts.

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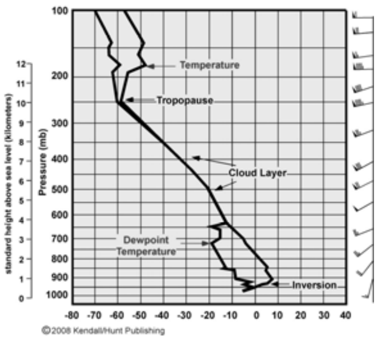
Sounding and Stuve Diagram



- The vertical structure of the atmosphere above a location on the Earth measured by a rawinsonde is called a ***sounding***.
- The sounding is usually plotted on a ***Stuve Diagram*** which uses pressure (mb; in <u>log</u> form) as its vertical axis and temperature (°C) as the horizontal axis.

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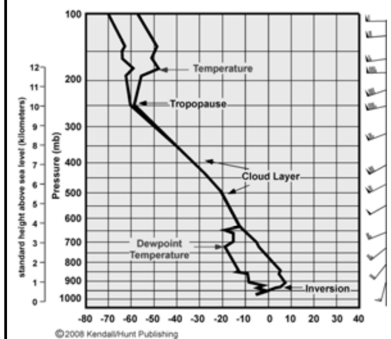
A Sounding over Minneapolis, Minnesota



- An inversion layer, where the temperature increases with height, is located between the surface and 905mb.
- A cloud layer is present between 640mb and 250mb.
- In the cloud layer, the temperature and dewpoint temperature are equal.
- The tropopause is located at 250mb.
- The jetstream is between 250mb and 180mb.

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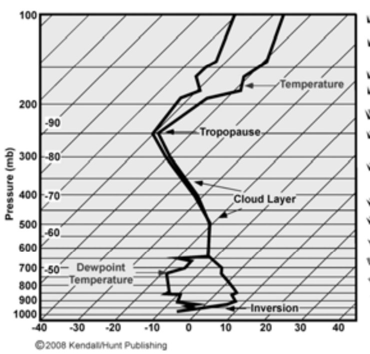
Skew-T/Log P Diagram



- Another way to display the vertical structure from sounding is the Skew-T/Log P Diagram.
- Lines of constant temperature are not vertical but skewed on this diagram.
- The is the most common diagram used in meteorology to plot soundings.

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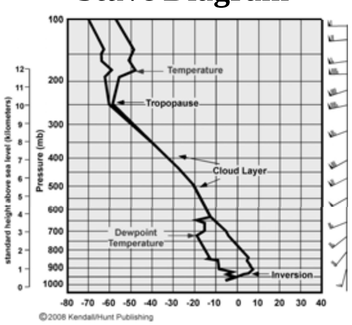
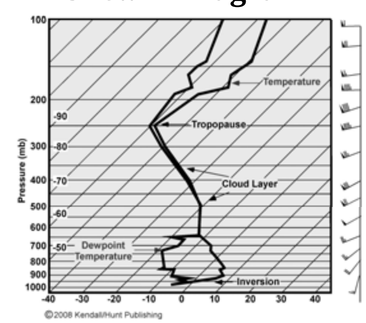
Stuve and Skew-T Diagrams

Stuve Diagram



Skew-T Diagram



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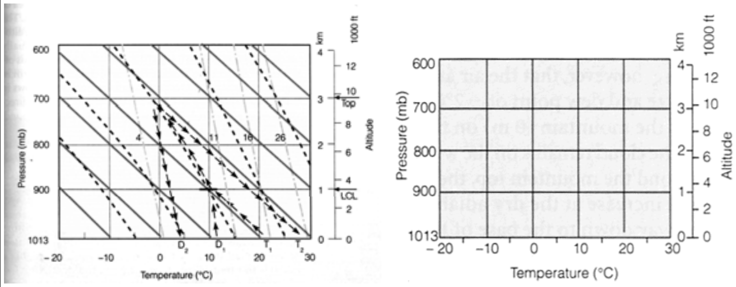
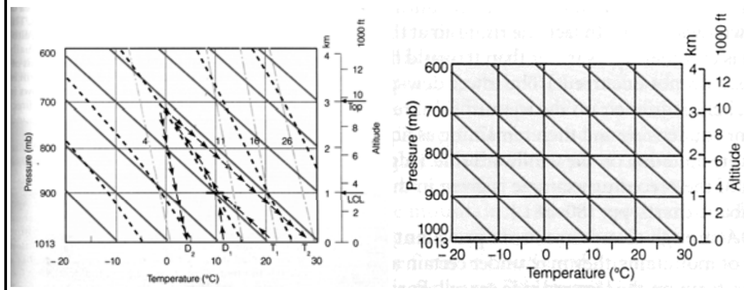
Adiabatic Chart: *P* and *T*



(from *Meteorology Today*)

Adiabatic Chart: *Dry Adiabatic* / θ



(from *Meteorology Today*)

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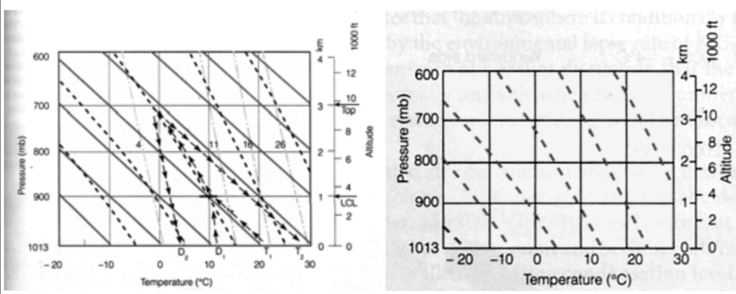
Adiabatic Chart: *Moist Adiabatic*



(from *Meteorology Today*)

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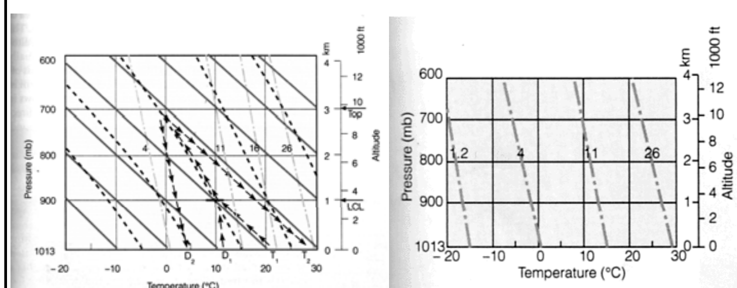
Adiabatic Chart: *Mixing Ratio*



(from *Meteorology Today*)

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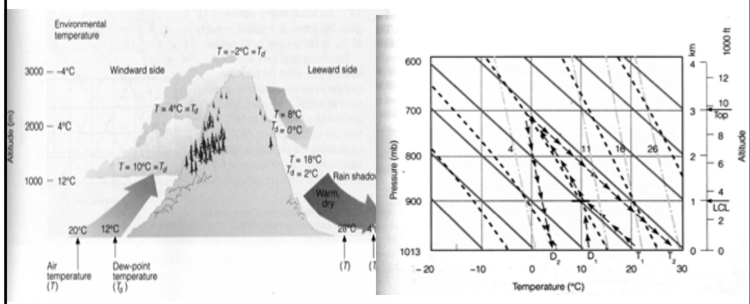
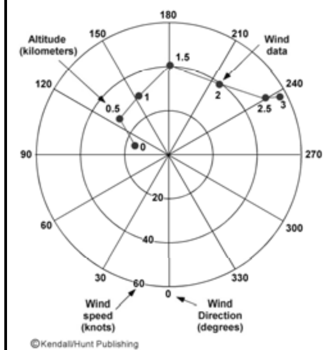
An Example

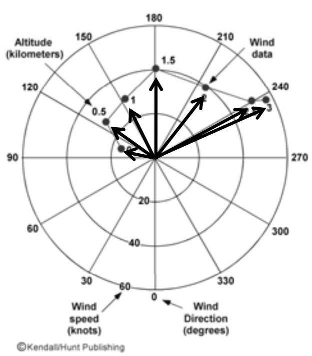


Hodographs



- Meteorologists use ***hodographs*** to display the vertical wind shear information collected from rawinsondes.
- The change of wind direction and speed between two altitudes is called ***vertical wind shear***.
- Hodographs show wind sped and direction at evenly spaced altitudes, for example at 0.5, 1.0, 1.5, and 2.0 kilometers.

Information on a Hodograph



- ***Wind Speed***: distance from the center of the hodograph denotes wind speed.
- ***Wind Direction***: each dot on the hodograph can be regarded as the head of an arrow pointing from the diagram center in the direction the air is moving.
- ***Vertical Wind Shear***: The length of a line between two points denotes wind speed shear.

- This is a hodograph of a severe thunderstorm that usually forms in an environment with a strong wind shear.

Thermal Wind Balance

(1) Geostrophic Balance

$$v_g = \frac{1}{f}\frac{\partial \Phi}{\partial x} \quad \text{and} \quad u_g = -\frac{1}{f}\frac{\partial \Phi}{\partial y}$$

(2) Hydrostratic Balance

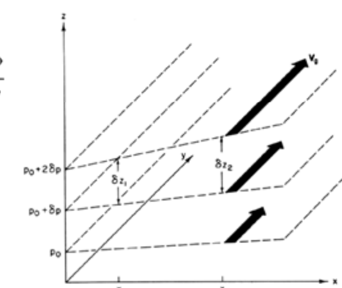
$$\frac{\partial \Phi}{\partial p} = -\alpha = -\frac{RT}{p}$$

Combine (1) and (2) ➔

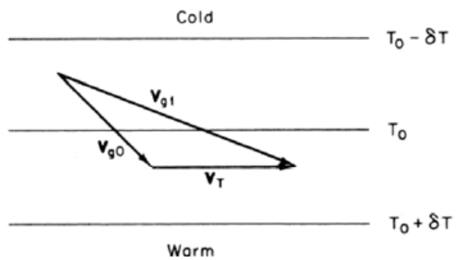
$$p\frac{\partial v_g}{\partial p} \equiv \frac{\partial v_g}{\partial \ln p} = -\frac{R}{f}\left(\frac{\partial T}{\partial x}\right)_p$$

$$p\frac{\partial u_g}{\partial p} \equiv \frac{\partial u_g}{\partial \ln p} = \frac{R}{f}\left(\frac{\partial T}{\partial y}\right)_p$$

➡ $$\boxed{\frac{\partial \mathbf{V}_g}{\partial \ln p} = -\frac{R}{f}\mathbf{k} \times \nabla_p T}$$



Physical Meanings



- The thermal wind is a vertical shear in the geostrophic wind caused by a horizontal temperature gradient. Its name is a misnomer, because the thermal wind is not actually a wind, but rather a wind gradient.
- The vertical shear (including direction and speed) of geostrophic wind is related to the horizontal variation of temperature.

➔ The thermal wind equation is an extremely useful diagnostic tool, which is often used to check analyses of the observed wind and temperature fields for consistency.

➔ It can also be used to estimate the mean horizontal temperature advection in a layer.

➔ **Thermal wind blows parallel to the isotherms with the warm air to the right facing downstream in the Northern Hemisphere.**

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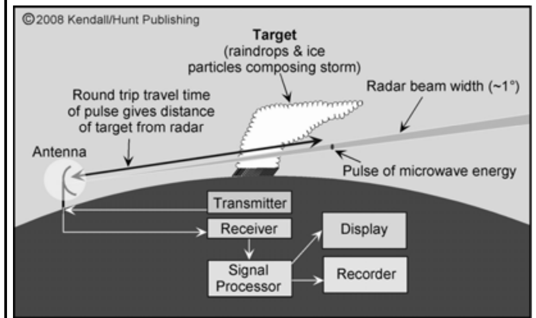
Radar



- Weather radars are used to monitor precipitation.
- Radars send out microwave signals in a narrow beam from it transmitter in a very short time (about 1 millionth of a second).
- When microwaves encounter raindrops and hailstones, some of the energy is scattered back to the radar, whose the microwave echo is received.
- Based on the time between the microwave is transmitted and received, speed of light, antenna angle, radars can find the locations of rain in space

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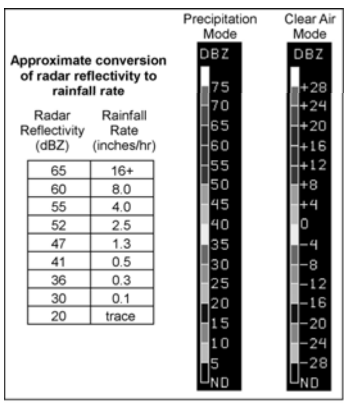
Radar Echo and Precipitation



Radar Reflectivity (dBZ)	Rainfall Rate (inches/hr)
65	16+
60	8.0
55	4.0
52	2.5
47	1.3
41	0.5
36	0.3
30	0.1
20	trace

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- The amount of the microwave energy returned to radars depends on three parameters: (1) <u>the size of precipitation particles</u>, (2) <u>the type of precipitation</u> (ice crystal, hail, rain), and (3) <u>the number of particle</u> in the radar beam.
- The greater the size and number of particles the beam intercepts, the larger the returned signal will be.
- Therefore, larger values of radar reflectivity are associated with heavy rain or hail and small values with non-precipitation clouds.

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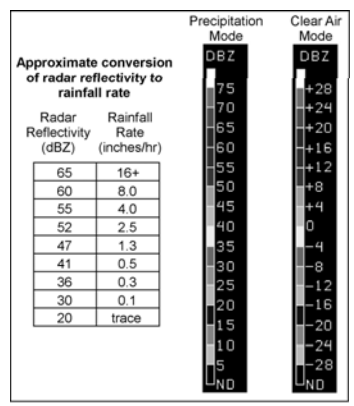
Processing of Radar Signals



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<u>Precipitation Mode</u>

Red, pink, purple, white

➔ intense precipitation

Yellow

➔ moderate rain

Green, blue

➔ light rain

<u>Clear Air Mode</u>

Radars receive energy scattered back from insets, birds, turbulence, and ground objects.

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Doppler Radar

- Doppler radars can provide not only precipitation information but also wind information (along the direction of radar beams).
- Doppler radars send out microwave signals in a specific frequency, which may be slightly shifted when the signals are scattered back due to the motion of precipitation. (similar to the higher and lower pitching sounds we hear with an approaching or leaving train).
- The larger the precipitation motion (which is due to wind blowing), the larger the shift.
- Therefore, Doppler radars can use the frequency shift information to derive the motion of the precipitation (and wind information).

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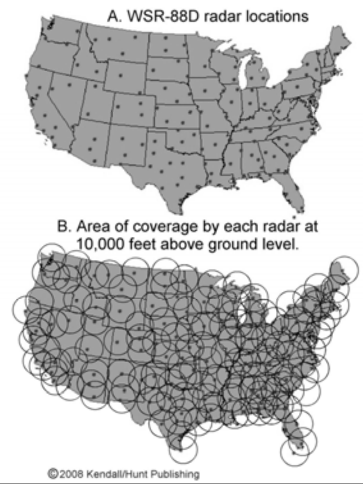
US Network of Doppler Radars



- The Doppler radar network was installed in the early and middle 1990s.
- Each radar can monitor the atmosphere a distance of approximately 250km (155 miles) from the radar location.
- Doppler radars are important to the studies of severe storm structure and dynamics.

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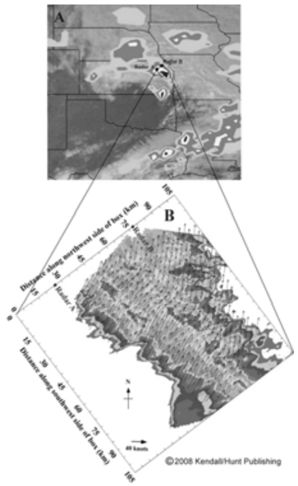
Storms over Northeastern Kansas



- The storms were observed both by infrared satellite image and two Doppler radars.
- The Doppler radars show showers occurred along a line where the wind shifted from southerly to southwesterly.

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Doppler Radar Measurements

MEASUREMENT	DERIVED QUANTITY
Time it takes for the microwave energy to travel from the transmitter to the target (precipitation) and back to the receiver	*Distance to the precipitation*
Pointing angles of the antenna	*Altitude of the precipitation and its geographic location*
The fraction of transmitted microwave energy that is scattered back to the antenna by the target	*The intensity of the precipitation, and when added over time, the total precipitation*
The frequency of the transmitted signal and the signal received from the target	*Speed of the wind toward or away from the radar*

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Wind Profiler

Courtesy of NOAA

- The wind profiler is another type of Doppler radar that operates in very high frequency (VHF) or ultra high frequency (UHF).
- The profiler has a "phased array antenna" that is different from the typical dish antenna.
- The phased array transmits signals with a light time delay from one side to the other across the creates a beam of radiation pointing in a specific direction.
- By using several beams, the profiler can measure the vertical profile of the wind (speed and direction).

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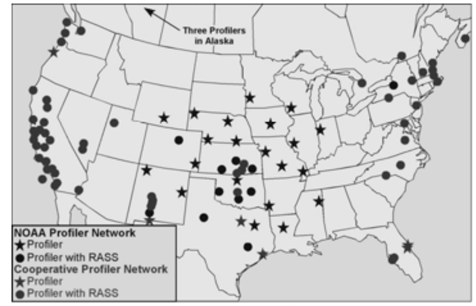
Wind Profiler Network



- Wind profiles work best in clear air.
- Wind profilers can measure wind profile up to 16.5 km.
- Wind profilers provide information of vertical wind structure similar to that provided by soundings but at a higher measurement frequency.

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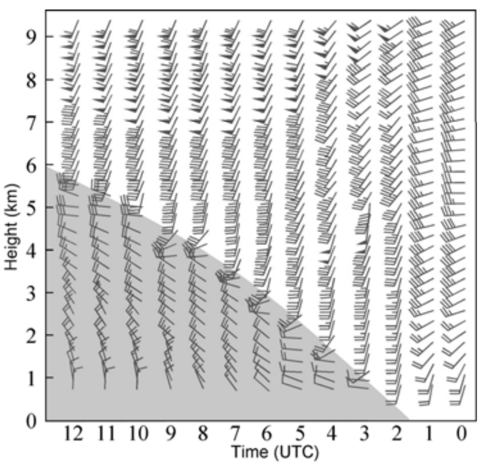
The Passage of a Cold Front Measured by a Wind Profiler



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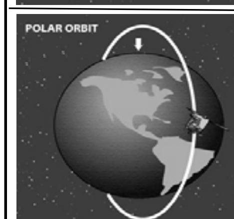
Satellites

- Satellites are found in two types of orbits: geostationary orbits and low Earth orbits.

- A satellite in a "Geo Synchronous" orbit hovers over one spot and follows the Earths spin along the equator.
- The satellite must be 35,800km above the Earth's surface.
- The satellite has a good view of the entire Earth's disk except for the polar regions.



- Low orbit satellites are normally several hundred to thousand kilometers above the Earth's surface.
- They are often placed in a near-polar orbit that is sun-synchronous, meaning the orbit cross the equator at the same local time every day.
- They only view a small part of the Earth at any one time and pass any point twice a day.

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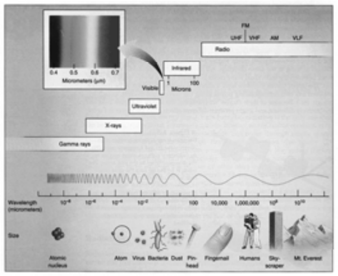
Spectrum of Radiation



Type of Energy	Wavelength (micrometers)
Gamma	<0.0001
X ray	0.0001 to 0.01
Ultraviolet	0.01 to 0.4
Visible	0.4 to 0.7
Near Infrared (NIR)	0.7 to 4.0
Thermal Infrared	4 to 100
Microwave	100 to 1,000,000 (1 meter)
Radio	>1,000,000 (1 meter)

Table 2–1 Wavelength Categorizations

(from *Understanding Weather & Climate*)

- Radiation energy comes in an infinite number of wavelengths.
- We can divide these wavelengths into a few bands.

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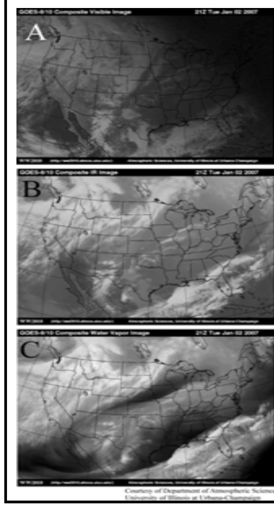
Geostationary Satellites



Visible Channel
- Measure the reflected visible light.
- Only available in daytime.
- Bright colors ➔ clouds or snow
- Dark colors ➔ oceans or forest…

Infrared Channel
- Measure the infrared radiation emitted by Earth and atmosphere.
- Work both day and night.
- Bright colors ➔ colder surface
- Dark colors ➔ warmer surface

Water Vapor Channel
- Provides water vapor information.
- Works day and night.
- Can identify jetstream locations.
- Bright colors ➔ moist airs.
- Dark colors ➔ dry airs.

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Interpreting Satellite Imagery

	VISIBLE	INFRARED	WATER VAPOR
SATELLITE MEASURES	reflected solar radiation	Emitted infrared radiation (temperature)	Infrared radiation emitted by water vapor only
BRIGHTEST REGIONS	thick clouds, snow	Cold cloud tops (high clouds)	Moist air
DARKEST REGIONS	Oceans, forests, unfrozen rivers in winter	Warm cloud tops (low clouds) warm regions of the earth's surface	Dry air

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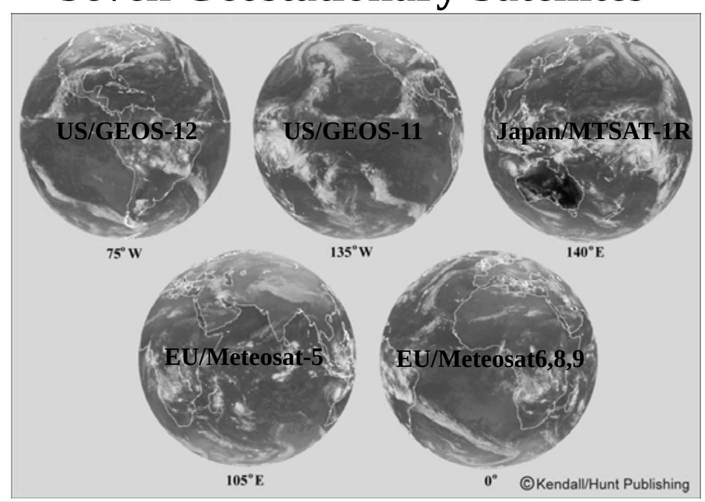
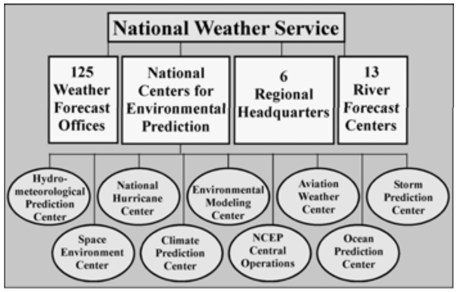
Seven Geostationary Satellites



National Weather Service



- NWS has six major operational national centers, including NCEP.
- NCEP has itself has nine specialized centers.
- The 125 Forecast Offices issue forecasts and severe thunderstorm and tornado warnings.

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