MET 4300/5355

Lecture 4:

Radar and Satellite (CH2)

In-situ vs. Remote Sensing

- Sensing : Using instruments/devices to measure parameters

  Thermometers measure temperature, radar guns measure the speed of passing cars

- Two categories of sensing devices: in-situ sensing and remote sensing

- In-situ sensing:

  In-situ sensing/measuring devices are in contact with the medium or object they are sensing.

  Examples: ASOS, Rawinsonde, buoys, reconnaissance plane, staff stream gauge

What is Remote Sensing?

- Remote Sensing :

  Remote sensing measurement devices are *not* in direct contact with the objects they sense.

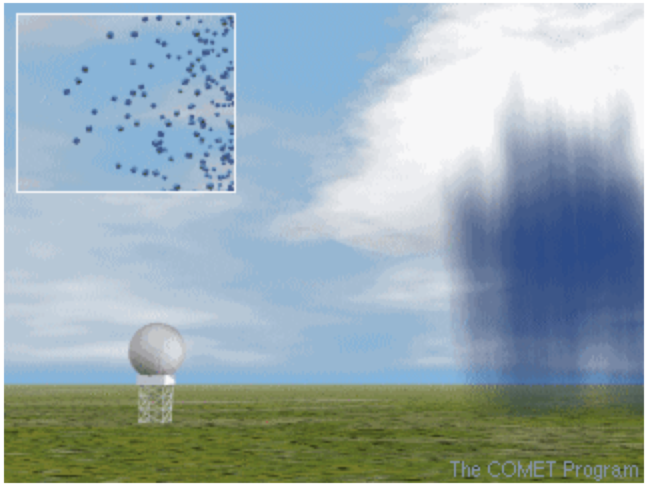
- Which of the following are In-situ sensors, and which are Remote Sensors?

  1. Camera
  2. Satellite
  3. Hand in water
  4. Metal detector
  5. X-ray
  6. Barometer

Active vs. Passive Remote Sensing

- Active remote sensors emit electromagnetic (EM) waves that travel to an object and are reflected back toward the sensor.

  Example: X-Ray, Radar, Lidar, Wind profiler



- Radar works by transmitting a pulse of EM energy. Objects (raindrops, ice, snow, birds, insects, terrain, and buildings) reflect that energy. Part of the reflected energy is received back at the radar. Once the radar receives the reflected signal, computer programs and meteorologists interpret the signal to determine where it is precipitating.

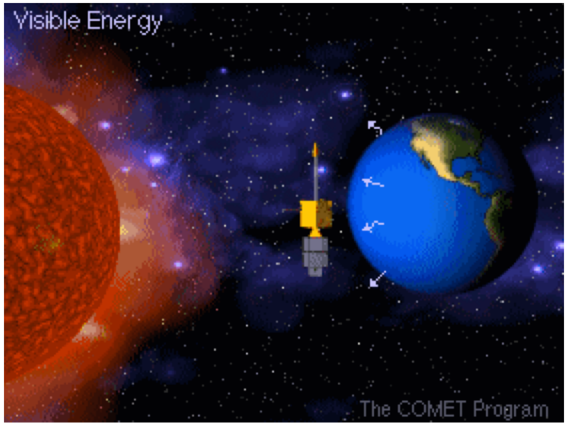
Active vs. Passive Remote Sensing (Cont.)

- Passive remote sensors observe EM waves emitted by objects.

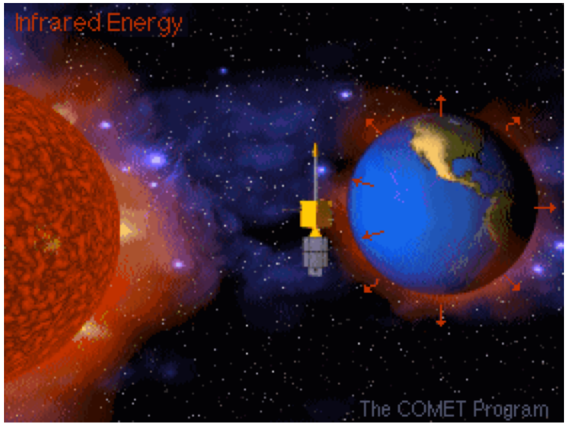
  Example: Camera;

  Satellite IR, Visible, Passive Microwave sensors

- Satellite visible sensors: visible imagery is available only during daylight hours since sunlight is reflected only during that period.

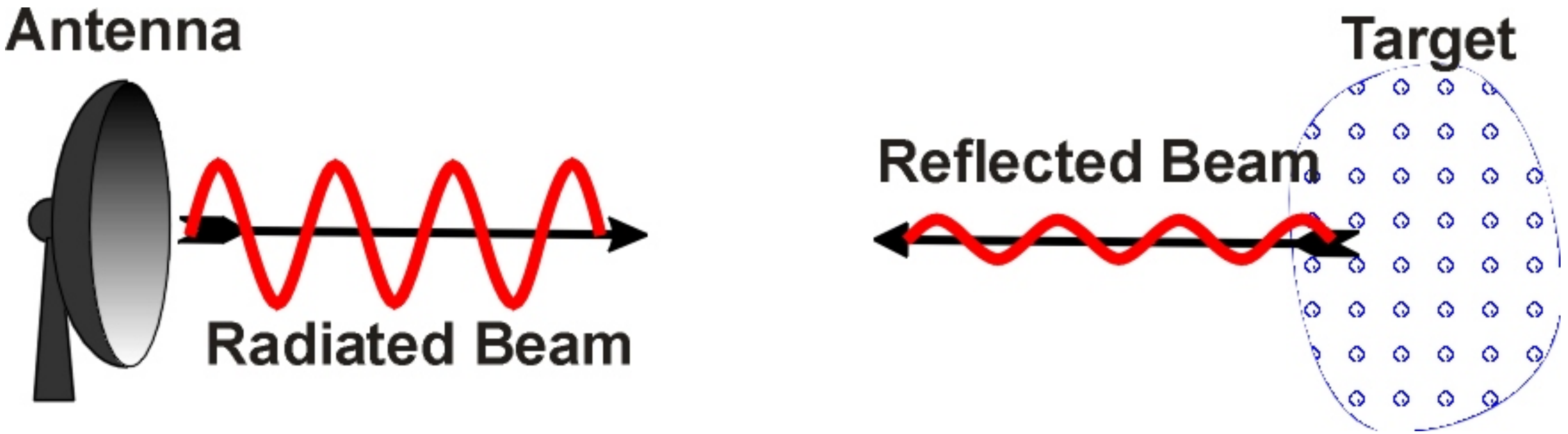


- Satellite IR sensors: Infrared energy is emitted 24 hours a day from the earth's surface and the atmosphere and is sensed by satellites continuously.

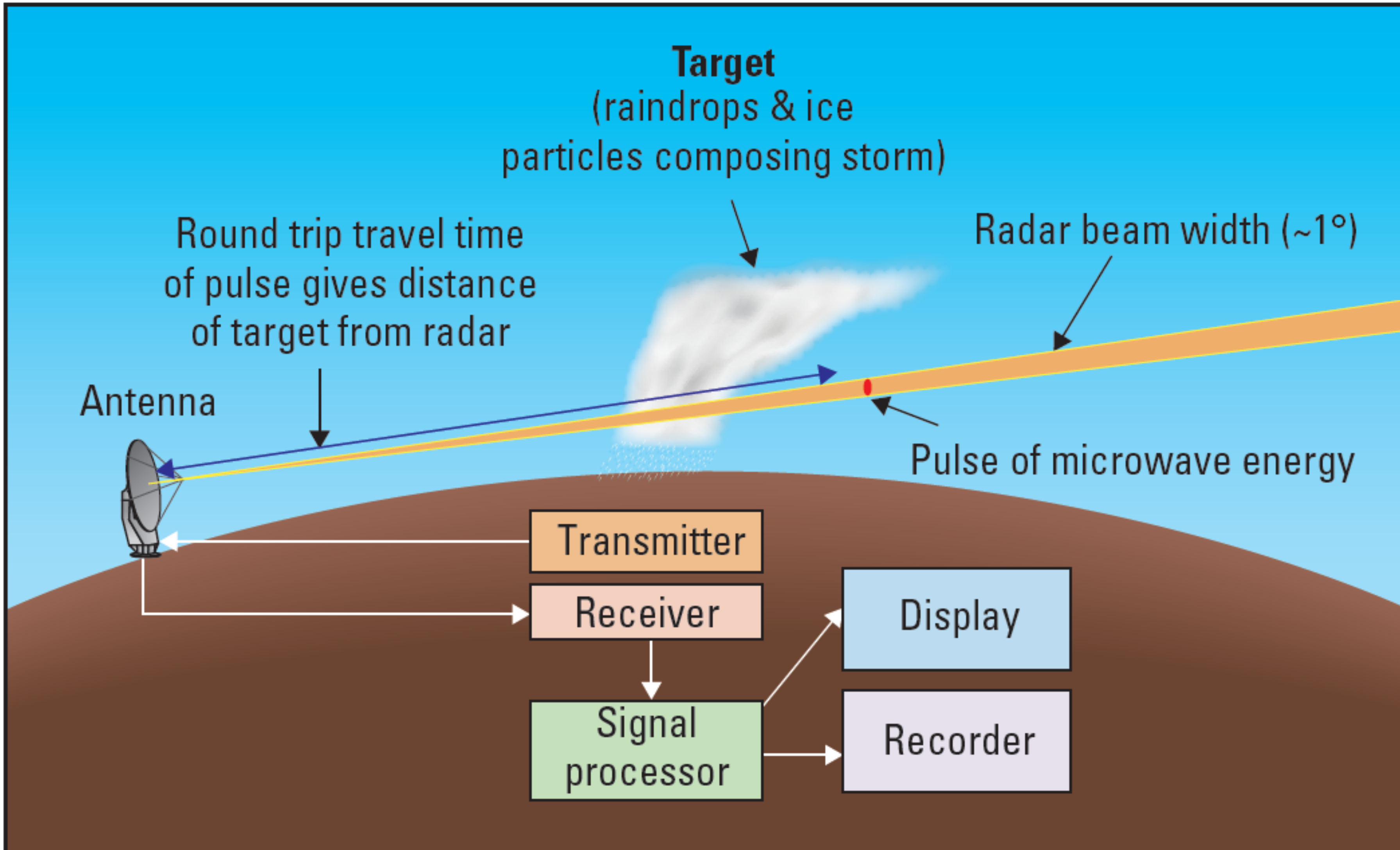


How Does Radar Work?

- Radar emits pulses of microwave energy (between two pulses, there is a waiting/listening time)
- The energy (radar beam) travels until it reaches a target
- Reflected back to antenna
- Time of travel tells distance
- Brightness of echo tells size and/or number of scatterers



The principle components of a weather radar



Transmitter & Antenna

- Transmitter is an electronic component of the radar that creates microwaves that are focused into a narrow beam by an antenna.
- Antenna is the device that sends the radar’s signal into the atmosphere.

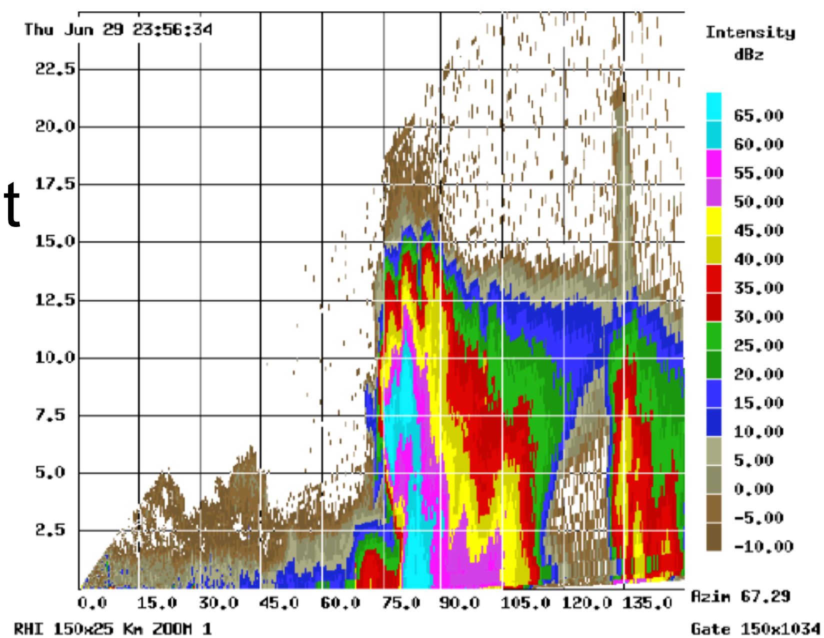
Receiver

- To detect and amplify the very weak signals received by the antenna.
- Very sensitive, some with dynamic range of 80 or 90 dB
- Logarithmic receiver, digital receiver

Common Weather Radar Computer Displays/Indicators

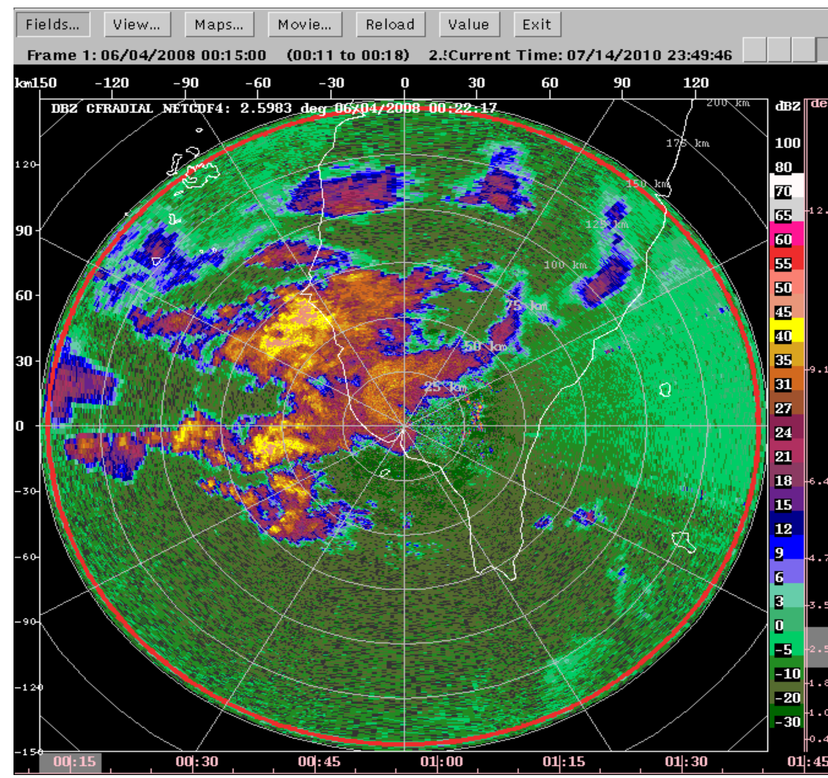
RHI –Range Height Indicator

Height (km)



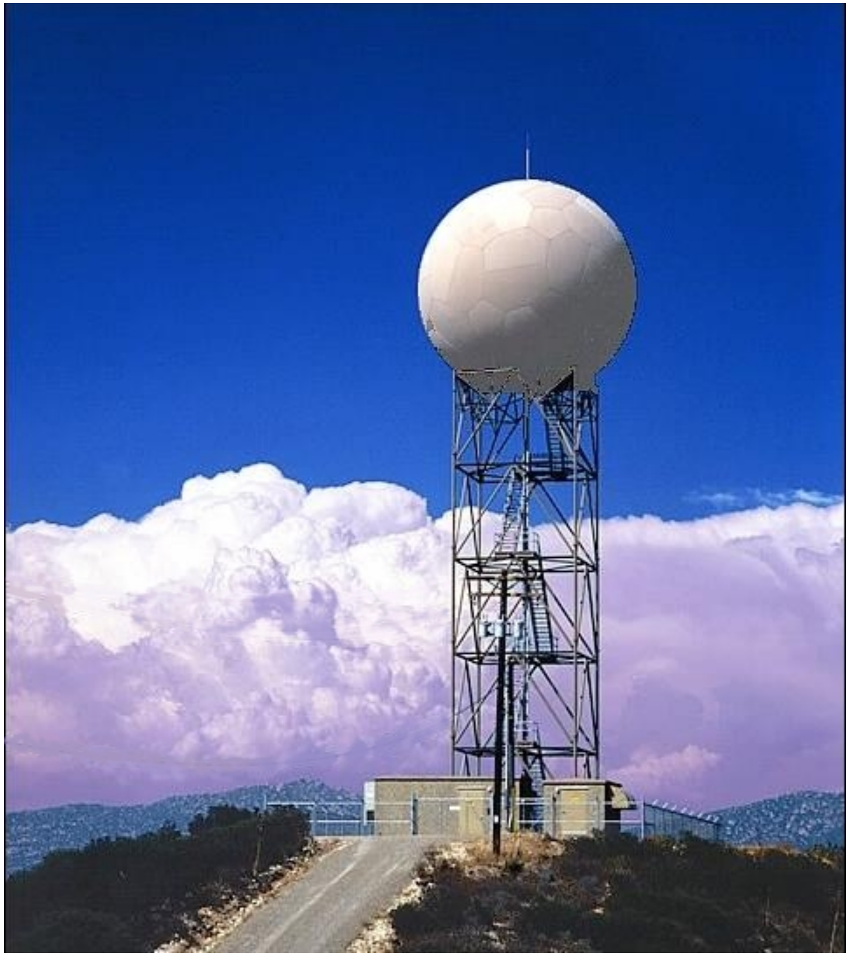
Range (km)

PPI –Plan Position Indicator

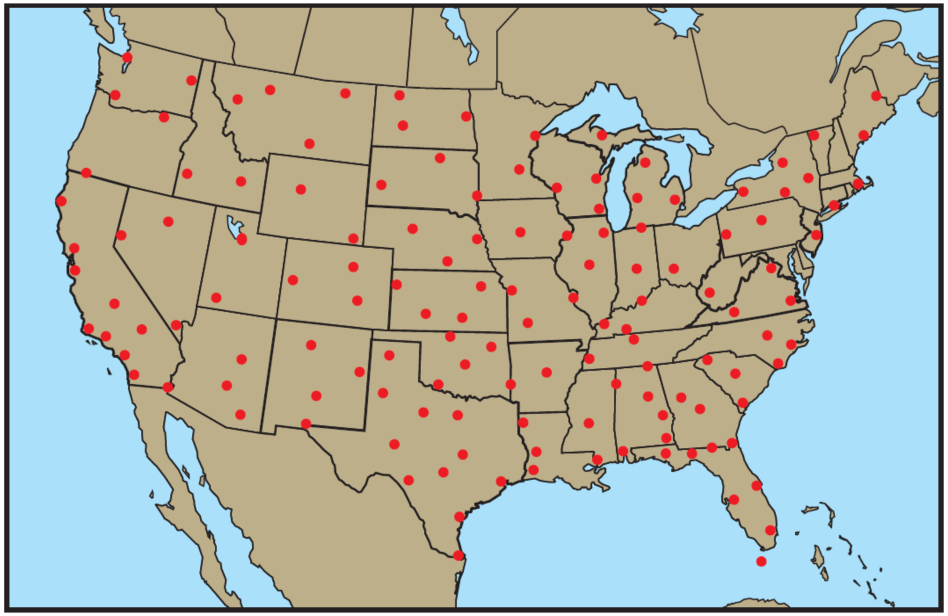


WSR-88D

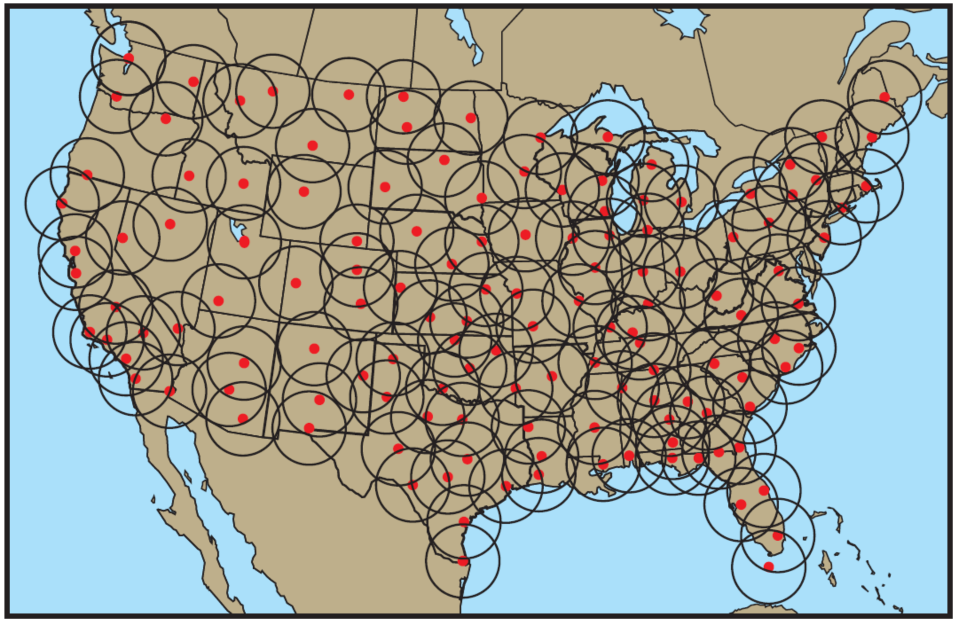
- Deployed at ~165 sites, US & worldwide
- S-Band (~10.7 cm)
- Power
  - 750 kW peak
  - 1.56 kW average
- Antenna diameter 8.5 m, or 28 ft
- Beam width 0.95^{o}
- Rotates $36^{o}\ s^{-1}$
- Pulse length 1.57-4.7 microseconds
- PRF 318-1304 pulses/sec
- Range:
  - 460 km for reflectivity
  - 230 km for Doppler wind



(A) WSR-88D radar locations



(B) Area of coverage by each radar at 10,000 feet above ground level.



What does a Doppler radar measure?

1. the time it takes for the microwave energy to travel from the transmitter to the target and back to the receiver, which determines *the distance to the precipitation*;

2. the pointing angles of the antenna, which determines ***the altitude of the precipitation and its geographic location***;

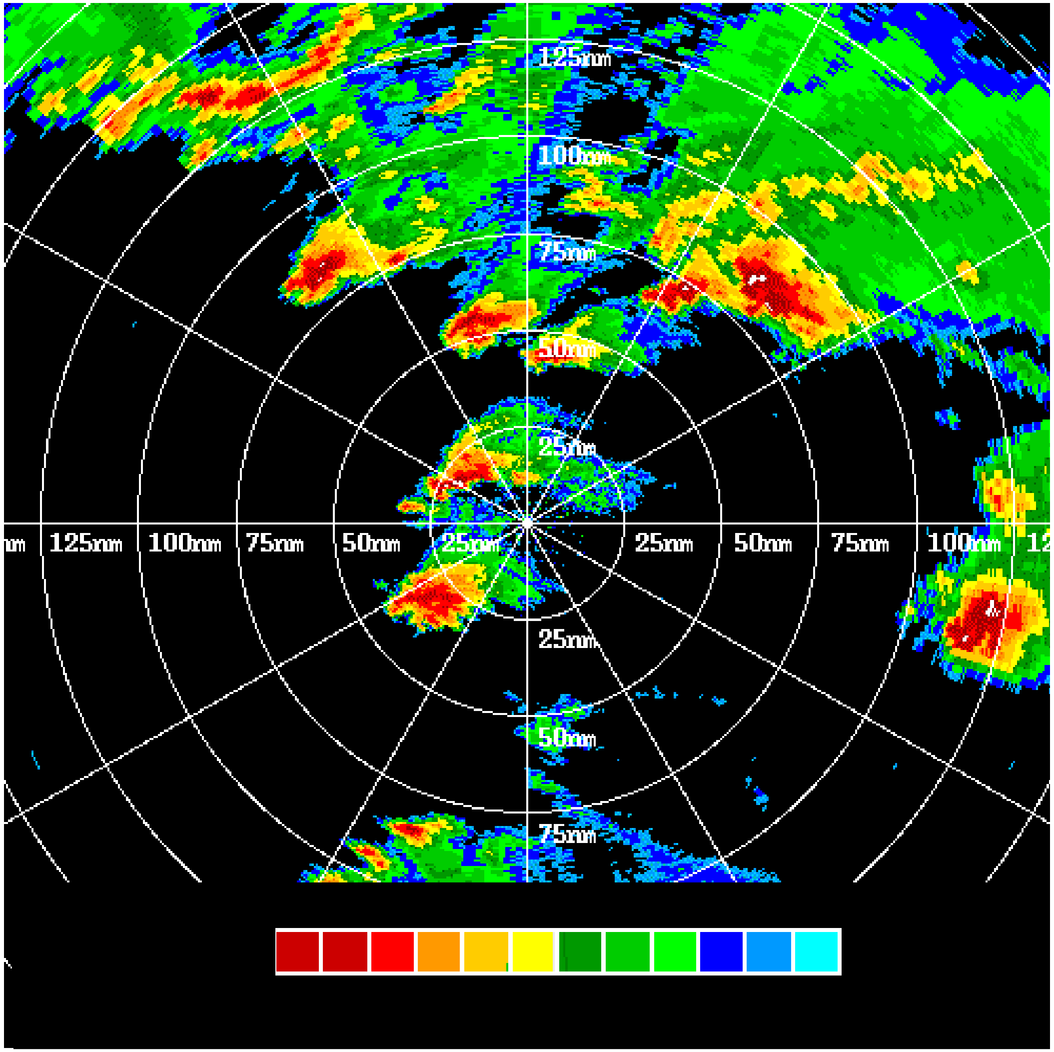
3. the amount of microwave energy returned to the radar (scattered back by the target), which determines ***the radar reflectivity,*** *then* ***intensity of the precipitation****, and when integrated over time, the total precipitation*;

4. (Specifically for Doppler radar) **the frequency shift** between the transmitted signal and the signal received from the target, which determines **the *speed of the wind toward or away from the radar***. The latter can be used to detect strong winds, wind shifts, and rotation in the flow.

Radar reflectivity Z (dBZ=10 log Z): is a measure of the power scattered back to the radar from objects in the path of a radar beam

Z depends on 3 parameters**:** the **size** of the precipitation particles, the **type** of particles (ice crystals, hail, or rain), and the **number** of particles in the sample volume.

Z is proportional to **the sum of the sixth power of the diameter of all the particles** illuminated by a pulse provided the particles are much smaller than the radar wavelength**.**



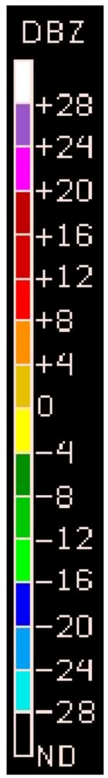
“Precipitation” mode

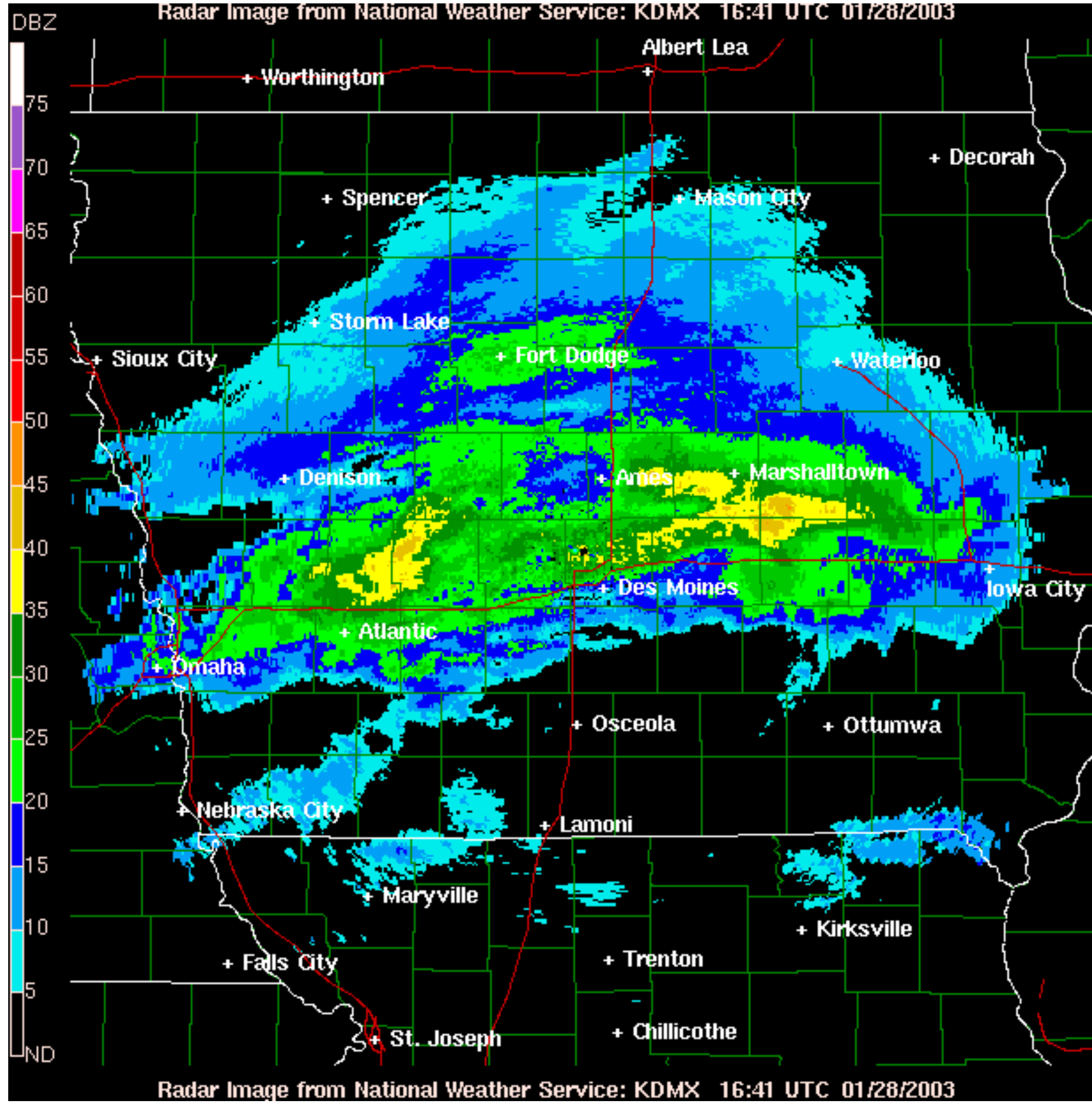
Approximate conversion of radar reflectivity to rainfall rate

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

Precipitation Mode

Clear Air Mode





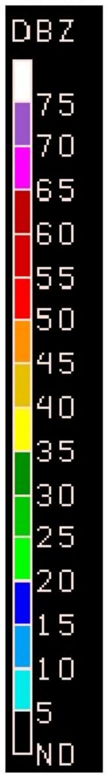
“Clear air” mode (often used for snow)

Radar parameters set to increase sensitivity

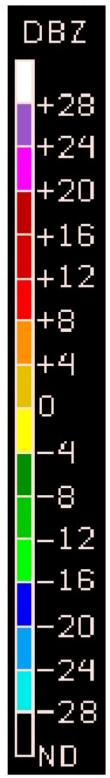
Approximate conversion of radar reflectivity to rainfall rate

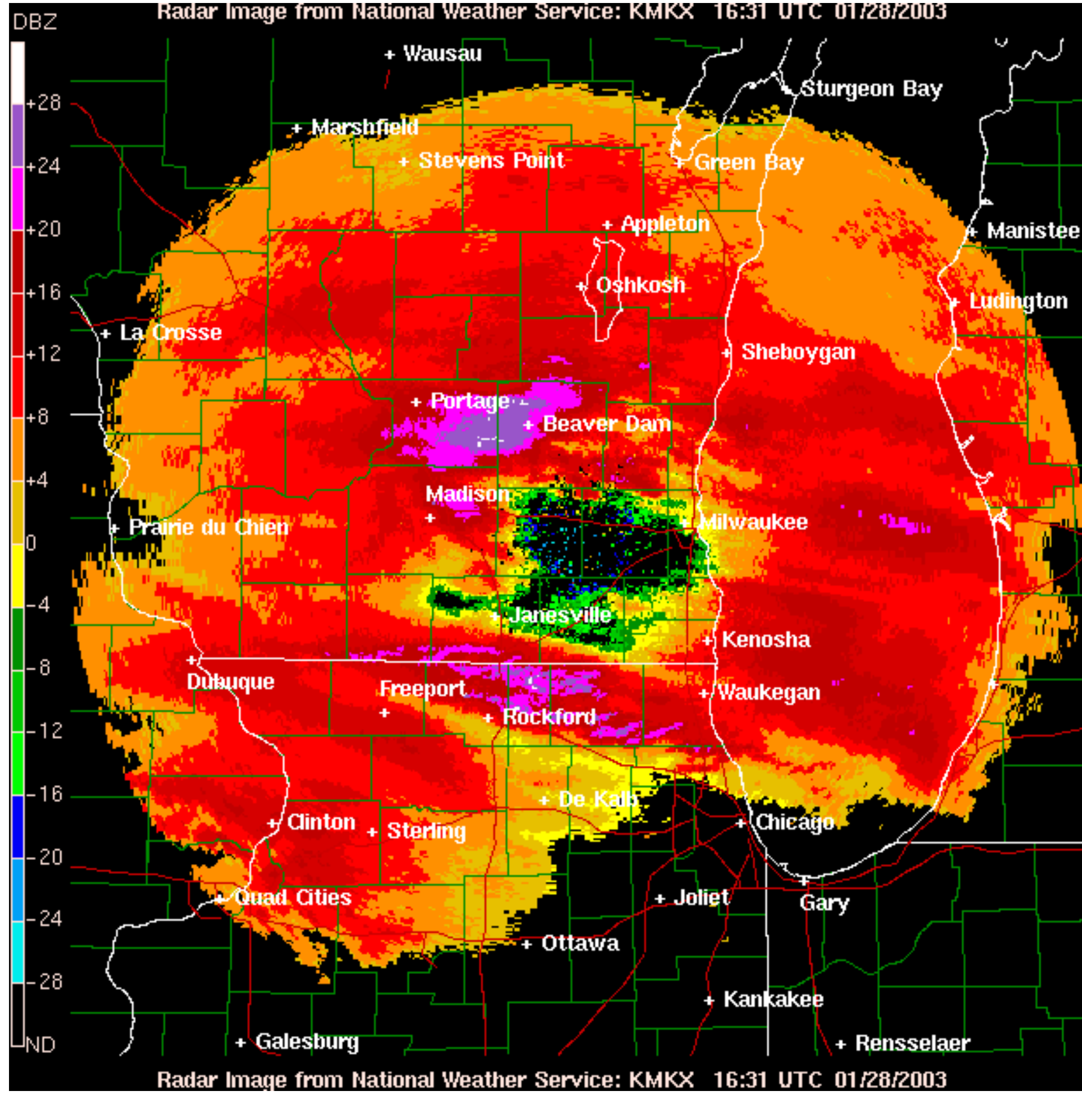
Radar Reflectivity (dBZ)	Rainfall Rate (inches/hr)
65	16+
60	8.0
55	4.0
52	2.5
47	1.3
41	0.5
36	0.3
30	0.1
20	trace

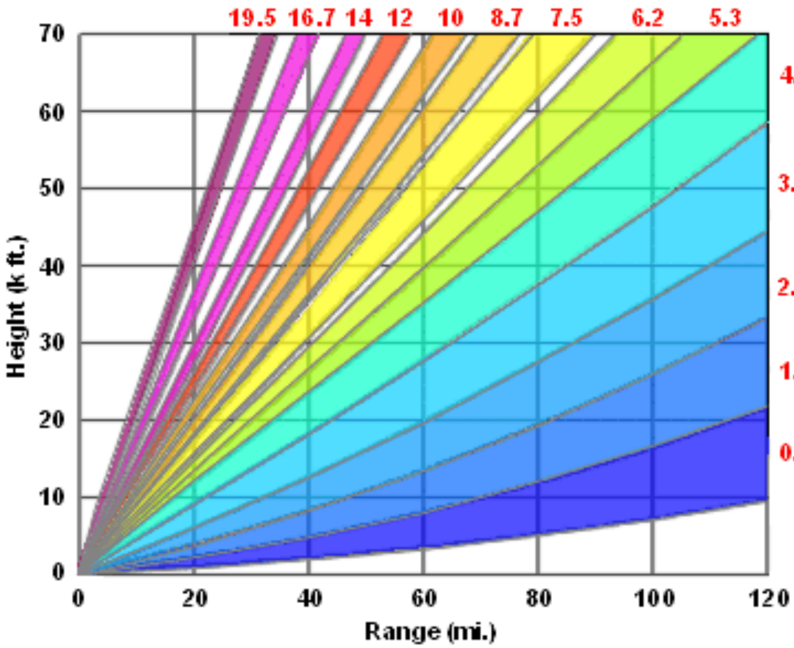
Precipitation Mode

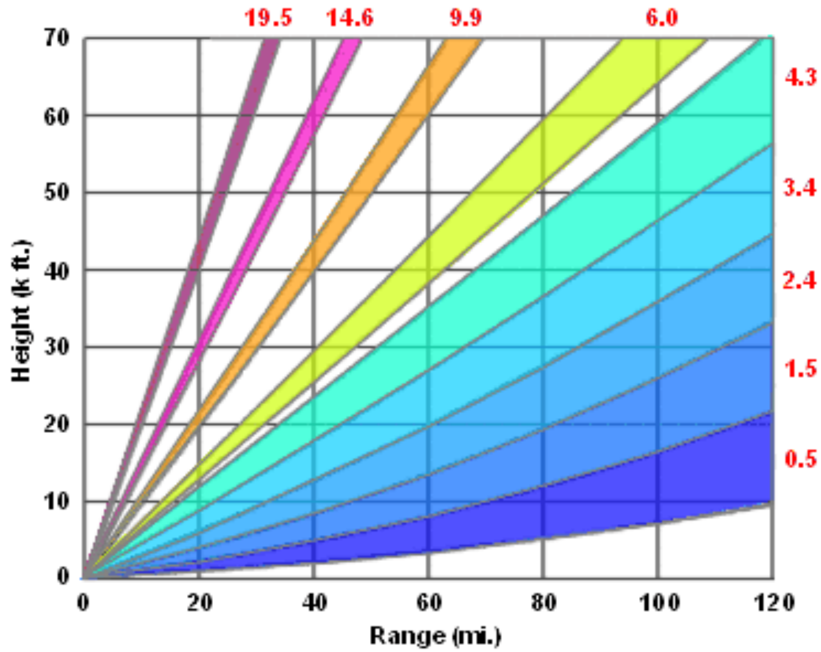


Clear Air Mode







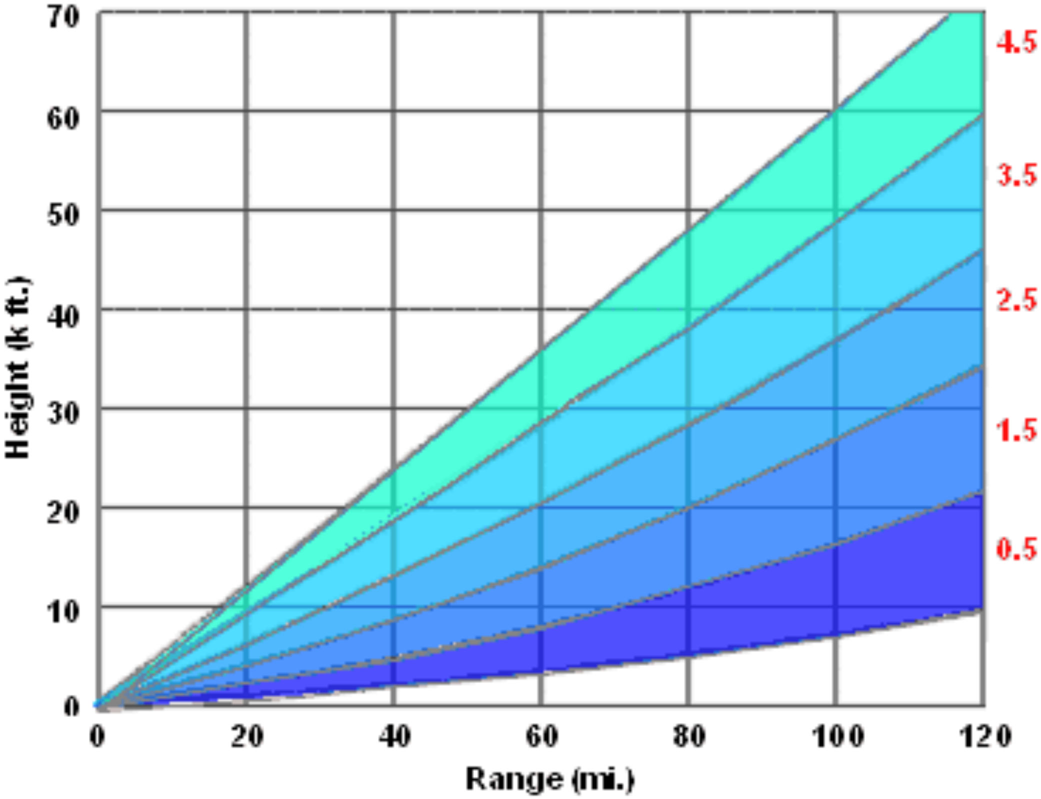


Precipitation mode scan geometry

Severe weather scan geometry

Saves time…fewer elevations

Clear air mode: Fewer elevations, slower antenna rotation to achieve greater sensitivity for sensing clear air turbulence, insects and clouds, light drizzle or light snowfall.



Z-R (Reflectivity-Rain) Relationships

Empirical power-law Z-R relationship:

$$z = AR^b$$

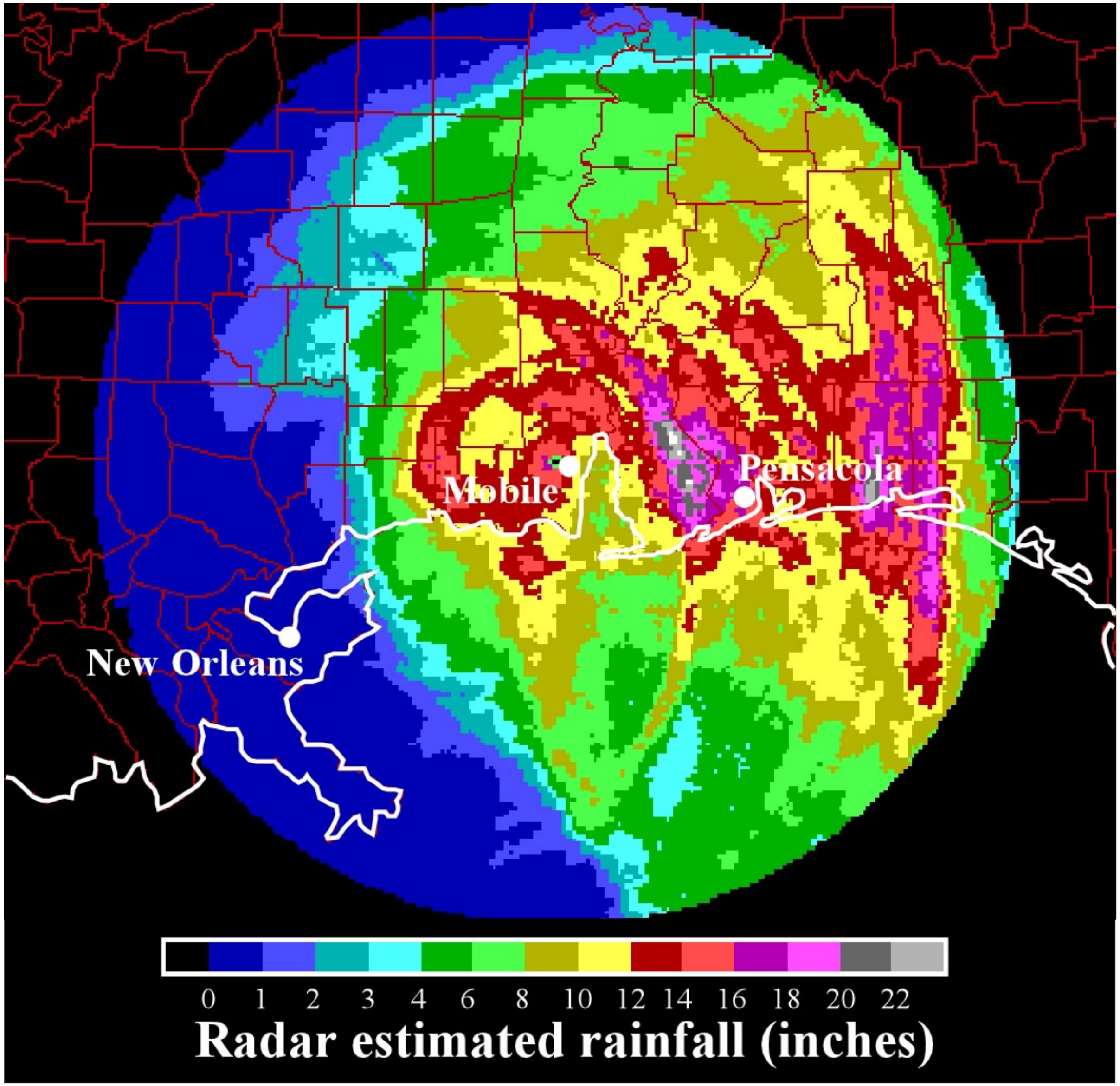
where z is the radar reflectivity factor (mm^6/m^3), R is rain rate (mm/h), and A and b are empirical constants.

Marshall-Palmer Z-R relationship:

$$z = 200R^{1.6}$$

Z-R relationships are different for different meteorological conditions.

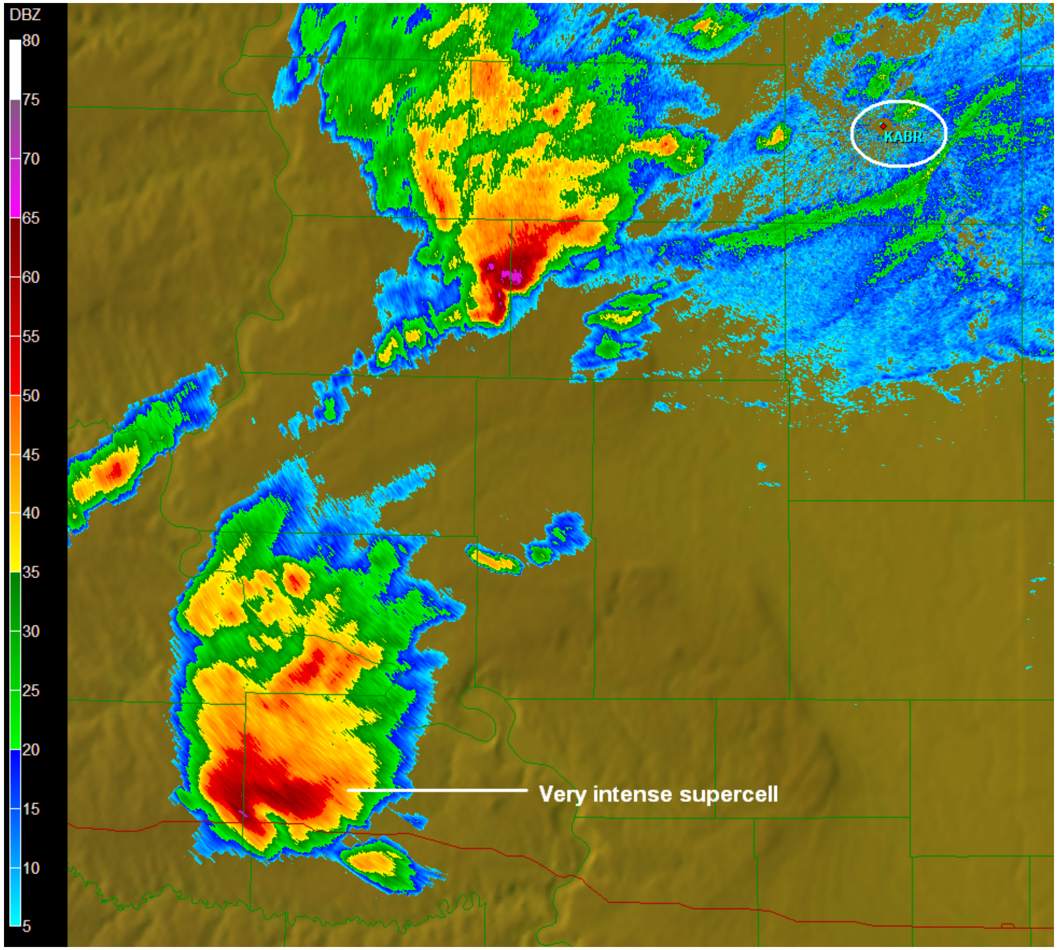
Accumulated rainfall in Hurricane Georges of 1999



Reflectivity for hail

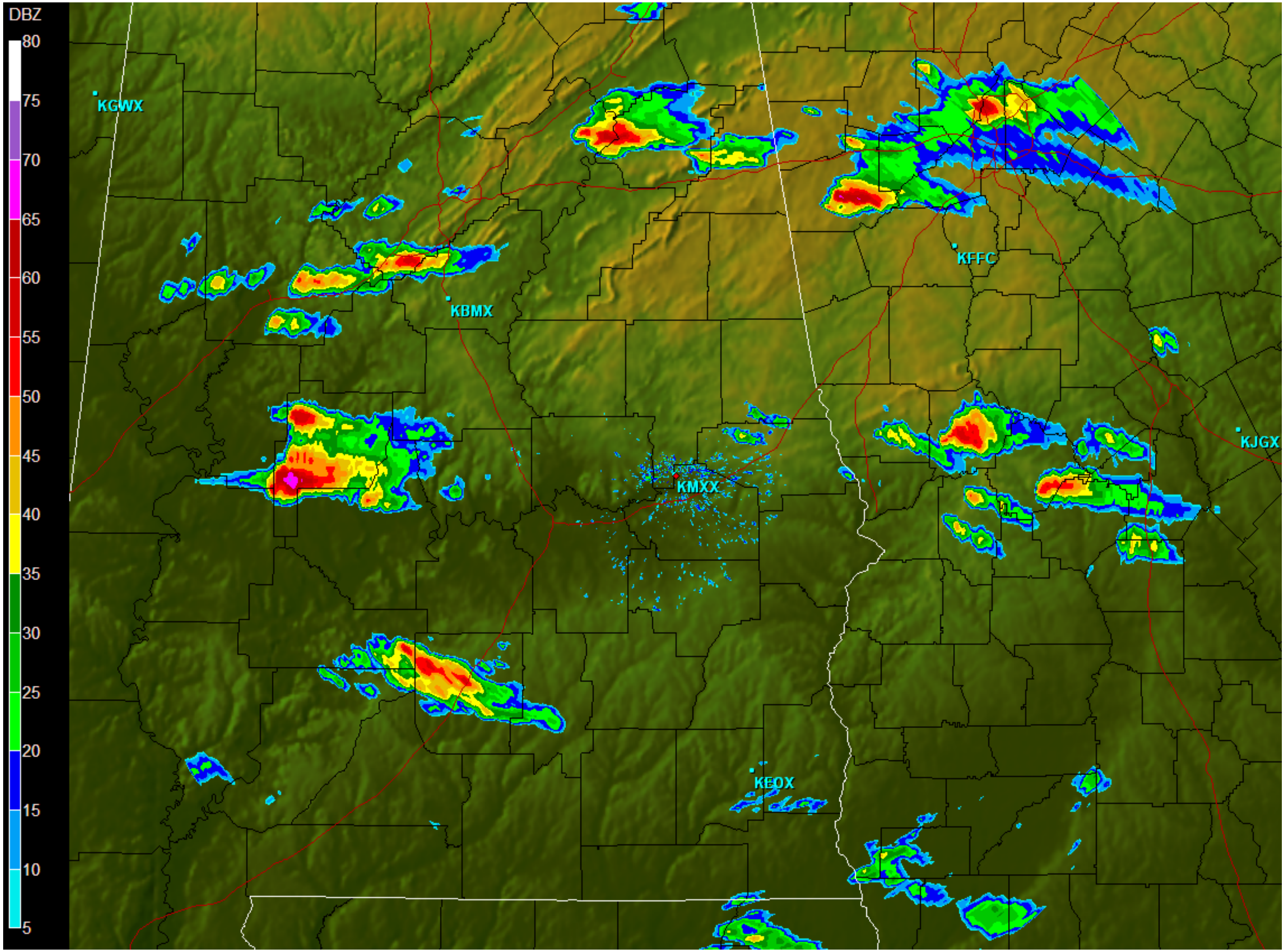
- Rain: usually 20-50 dBZ (sometime could go up to 55 dBZ)
- Hail: a general rule: reflectivity>= 60 dBZ, definitely hail; 50-55 dBZ, possible hail
- **A flare echo** (sometimes called a "hail spike") is an artifact that sometimes appears on images of radar reflectivity when large hail is present in severe thunderstorms. It is due to the EM energy reflection to the earth surface then reflected back to the hail stone, then backscattered to the radar. So its distance from the radar is a bit longer than the hail echo itself.

Severe thunderstorms over South Dakota, July 23, 2010

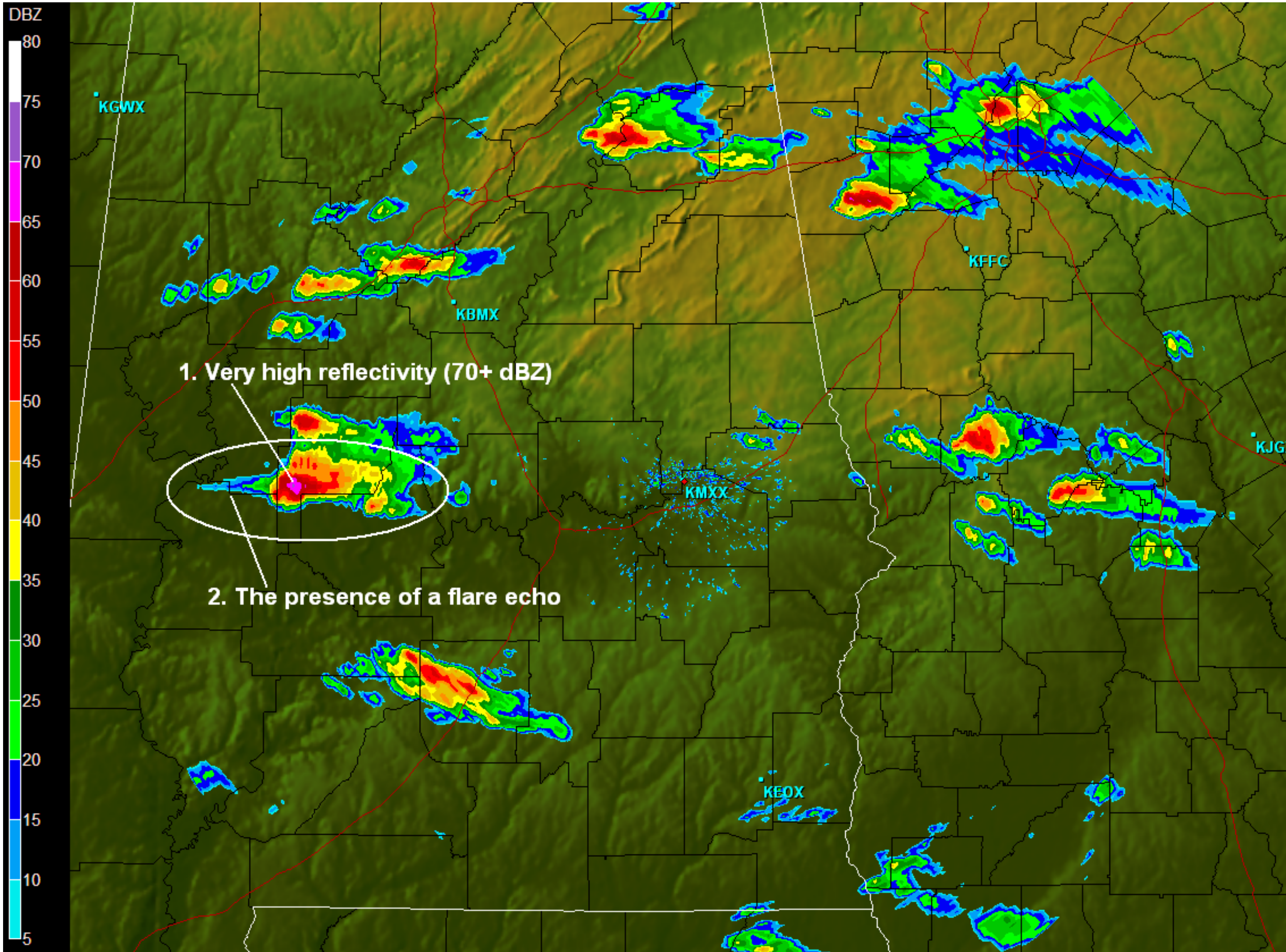


The giant hailstone that fell from a supercell at the town of Vivian, South Dakota, on July 23, 2010, had a record-breaking diameter of eight inches.

Which echo is likely to producing large hail?

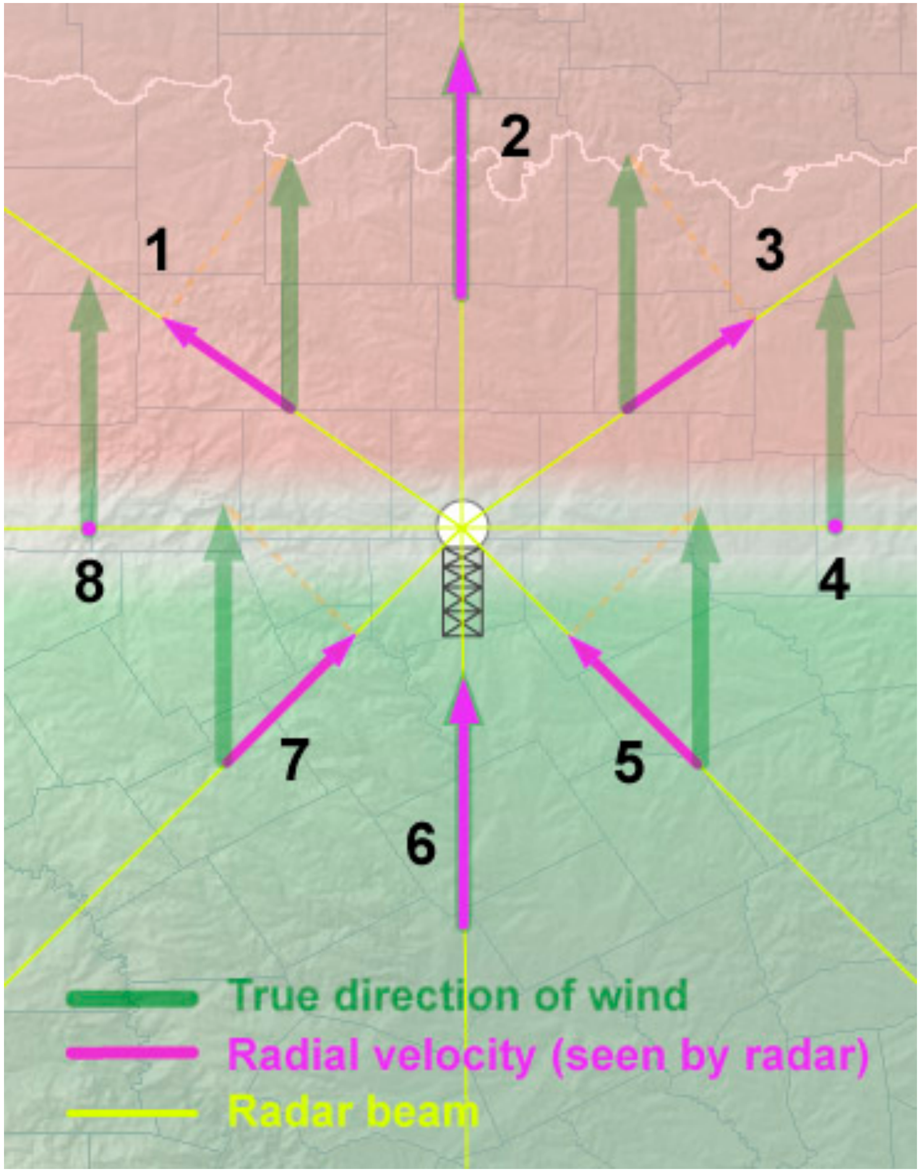


Answer:


DBZ
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
KGWX
KBMX
KFFC
KMXX
KJGX
KEOX
1. Very high reflectivity (70+ dBZ)
2. The presence of a flare echo

Doppler Radial Velocity

A measure of the component of the wind along the direction of the radar beam



Interpretation of Doppler Velocity

Doppler radar viewing configuration (scanning 360 degree at a given elevation angle).

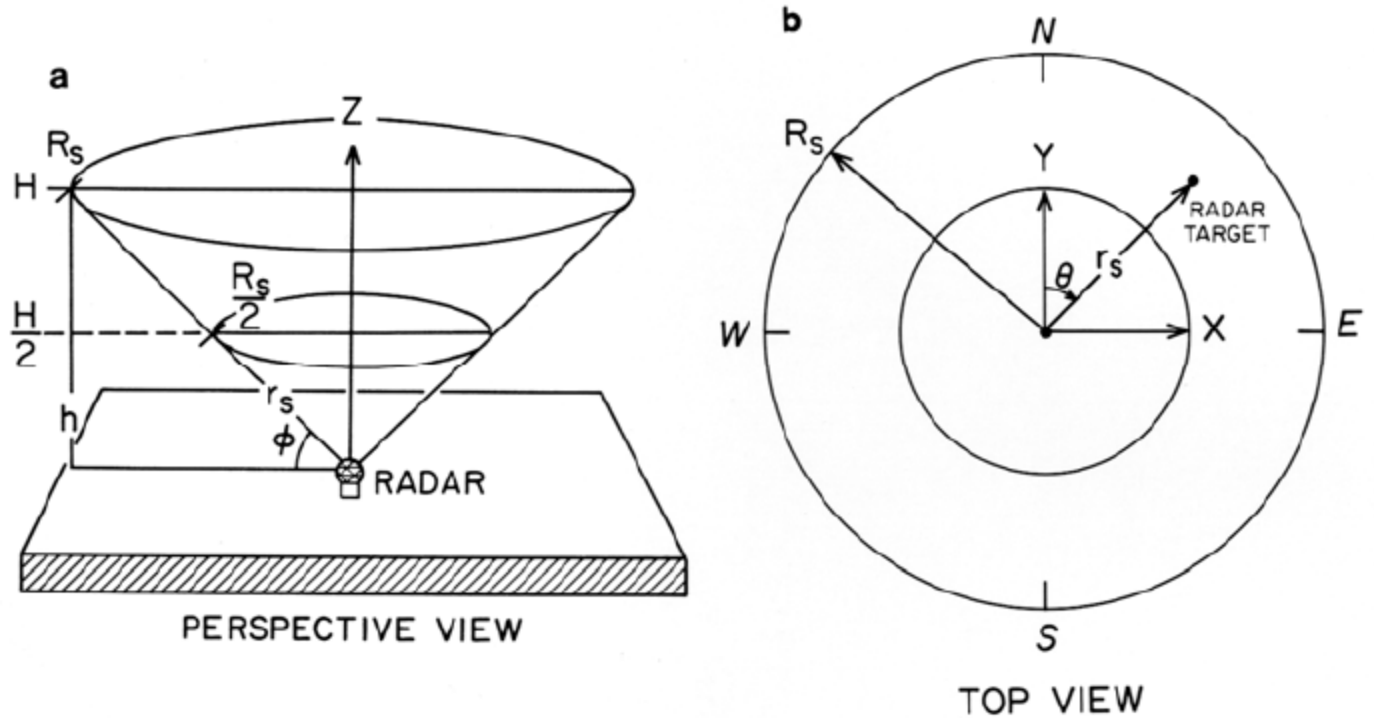


Fig. 2.1.1. *Doppler radar viewing configuration. (a) Radar scanning around vertical axis, Z, at a constant elevation angle, ϕ; (b) view of (a) from the top, representing a PPI (plan position indicator) display. R_s is slant range (on conical surface) of the edge of the display corresponding to height H above the ground. The three-dimensional position (x, y, h) of a radar scattering volume ("target") is computed from radar azimuth angle θ, elevation angle ϕ, and slant range r_s.*

An Example

- Get wind profile from Doppler radar PPI display (next a few slides)
- Doppler velocity is negative for toward radar, positive for away from radar
- Zero value zone means that the wind direction is perpendicular to the radar beam.
- The wind speed at a given height is the maximum value around a constant slant range circle.

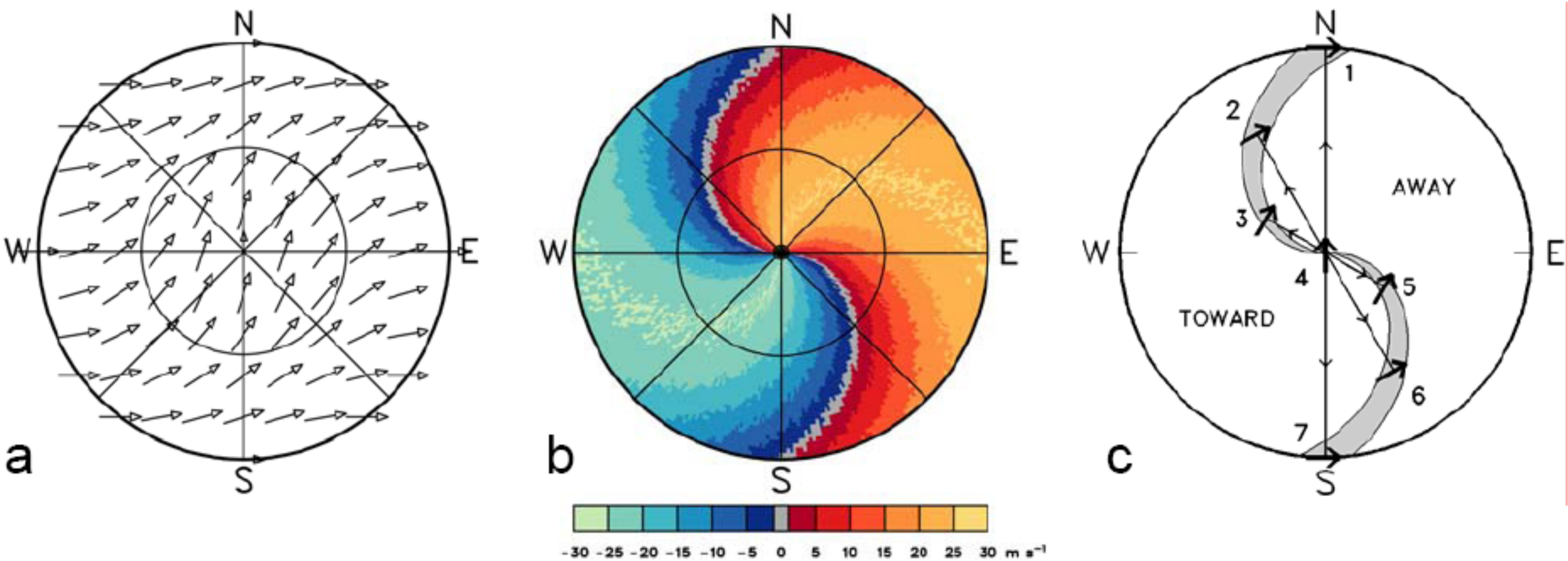


Fig. 2.1.2. Plan view of (a) environmental wind field and (b) corresponding single Doppler velocity pattern for wind with constant speed (26 m s^{-1} or 50 kt) and with direction changing uniformly from southerly at the ground (center of display) through southwesterly to westerly at the edge of the display. Part (c) illustrates how wind direction in a horizontally homogenous flow field can be interpreted using the zero Doppler velocity band. Uniform arrow length in (a)

Patterns associated with a mesocyclone

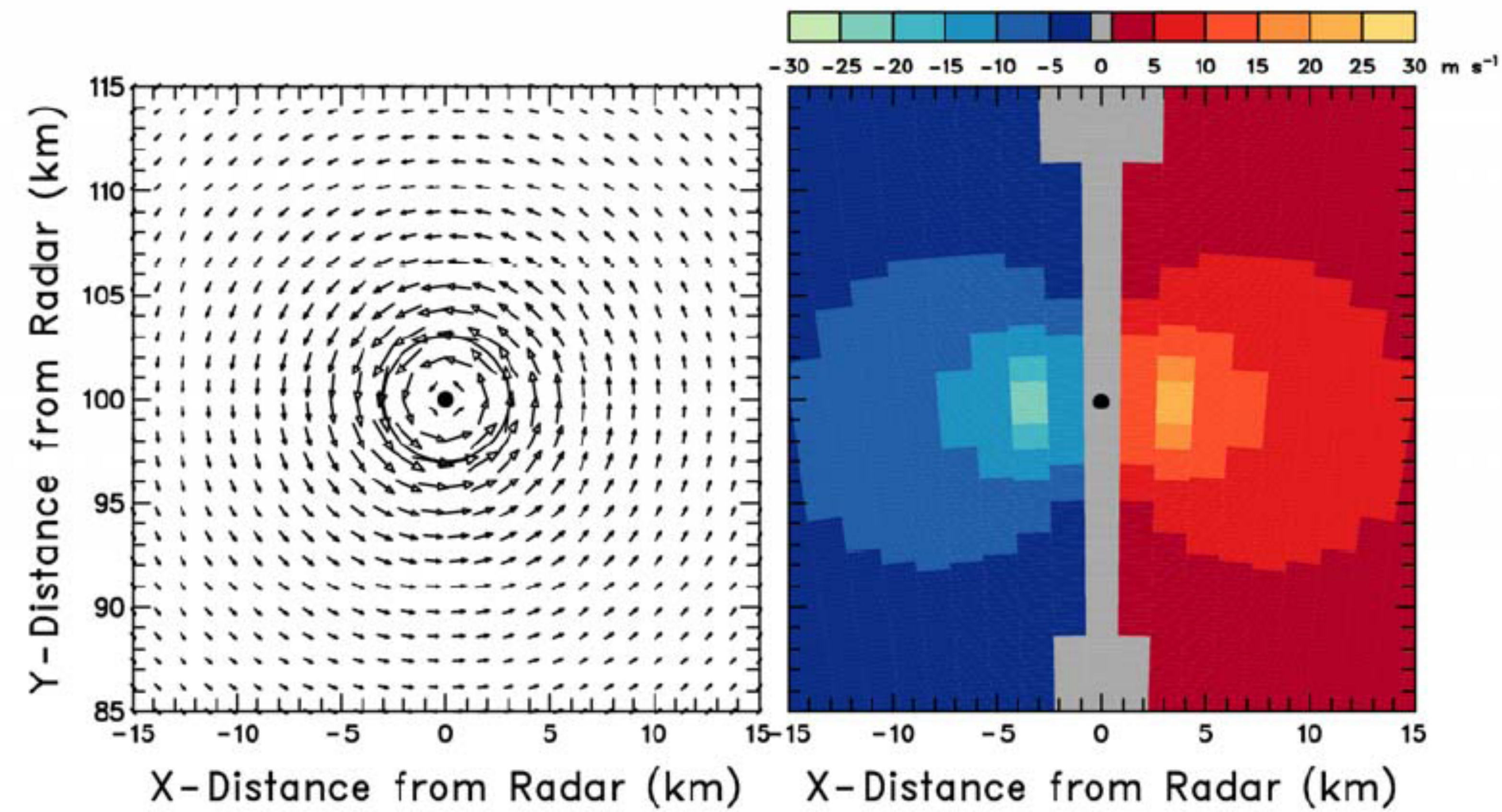
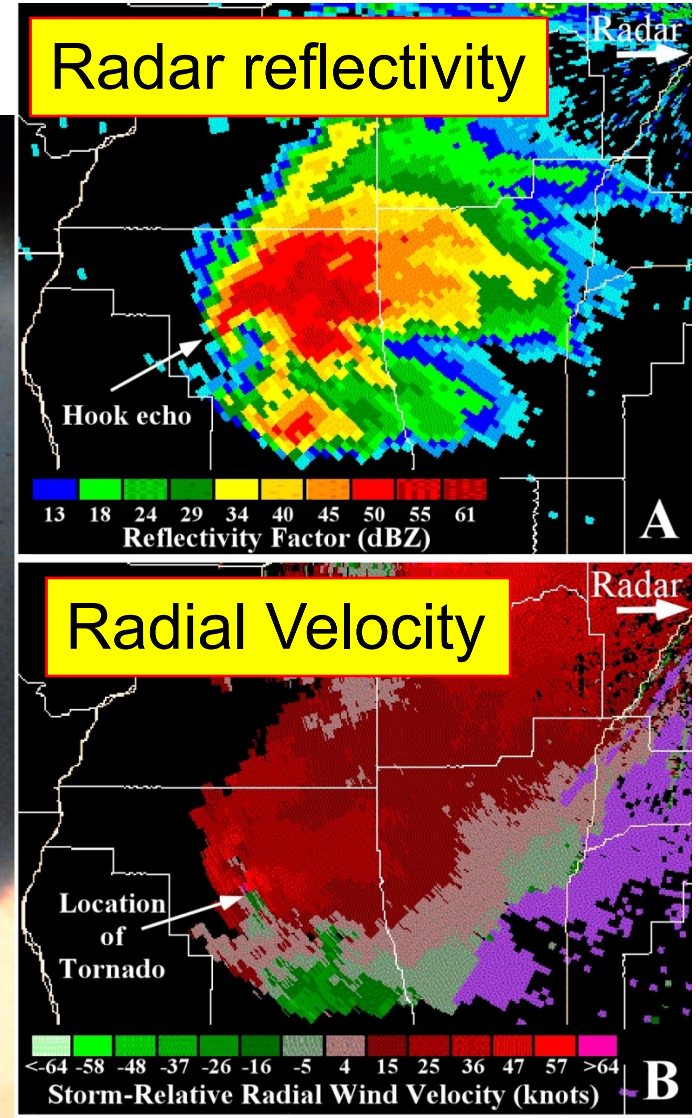


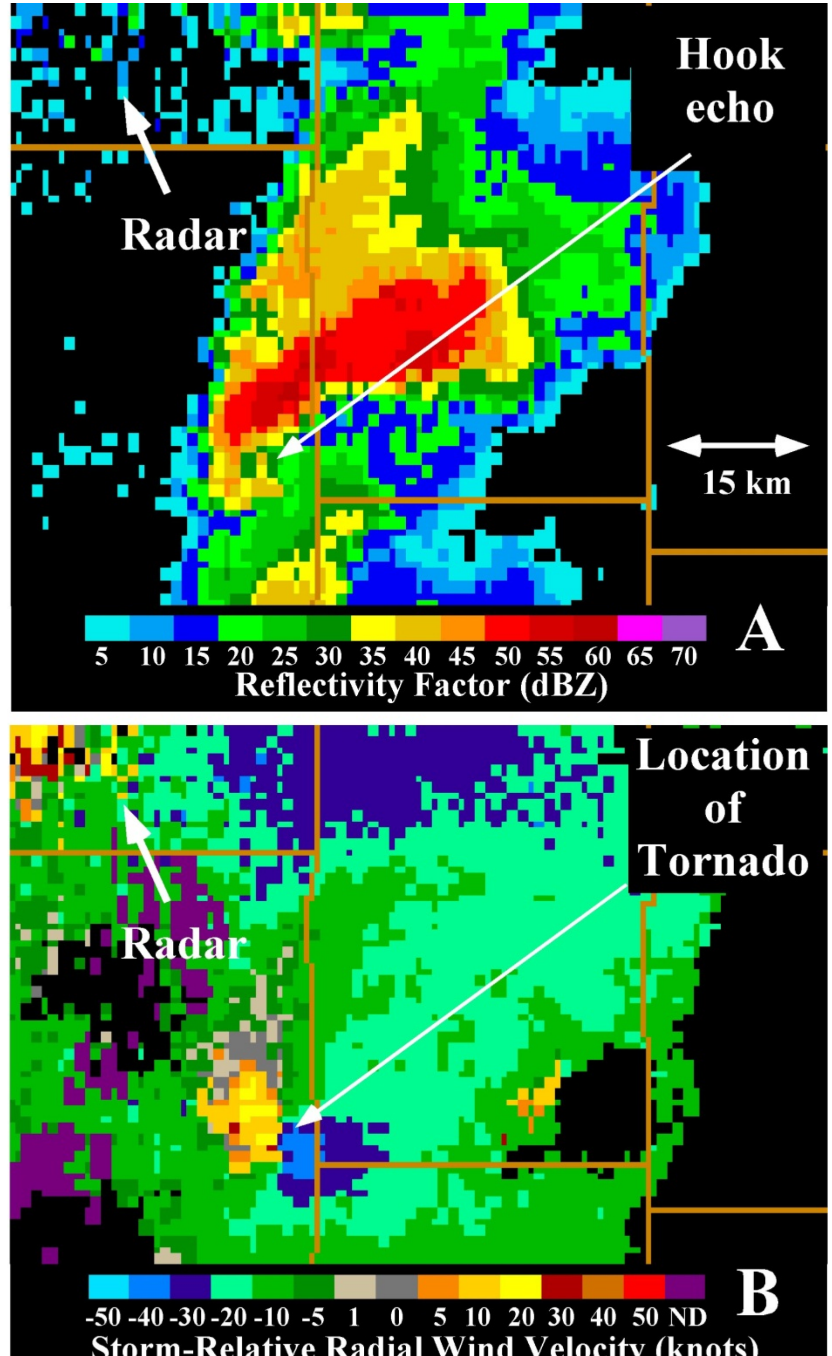
Fig. 4.3.2. *Same as Fig. 4.3.1, except that the Doppler velocity pattern (right) corresponds to a mesocyclonic (left) that has peak tangential velocities of 25 m s^{-1} (49 kt) at a radius of 3 km (1.6 n mi) from the circulation center (black dot).*

Tornado



Courtesy of NOAA/NSSL Photo Library

WSR-88D Images of a Tornado

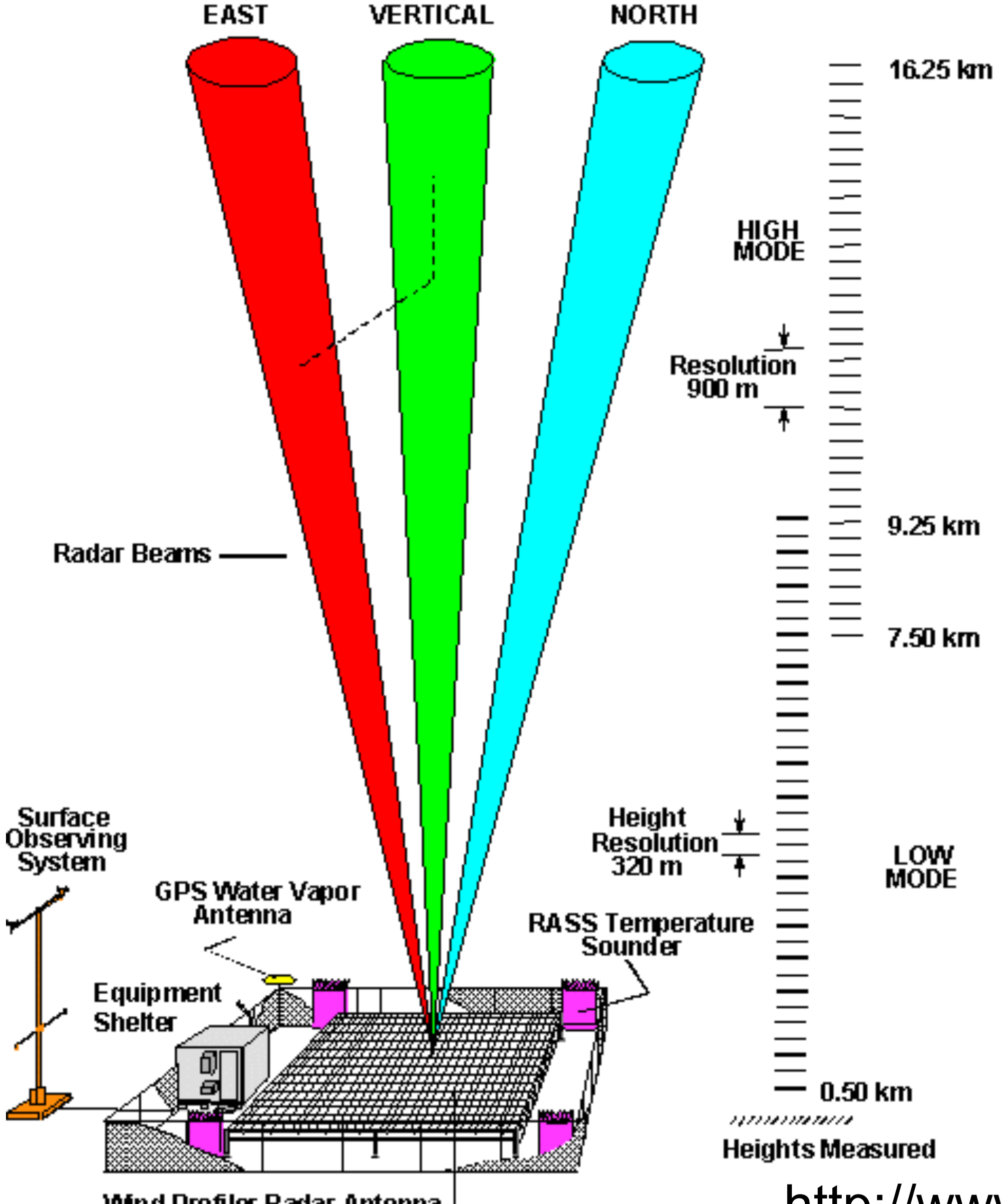


Wind Profiler Site with RASS (temperature profiler)

Wind Profiling

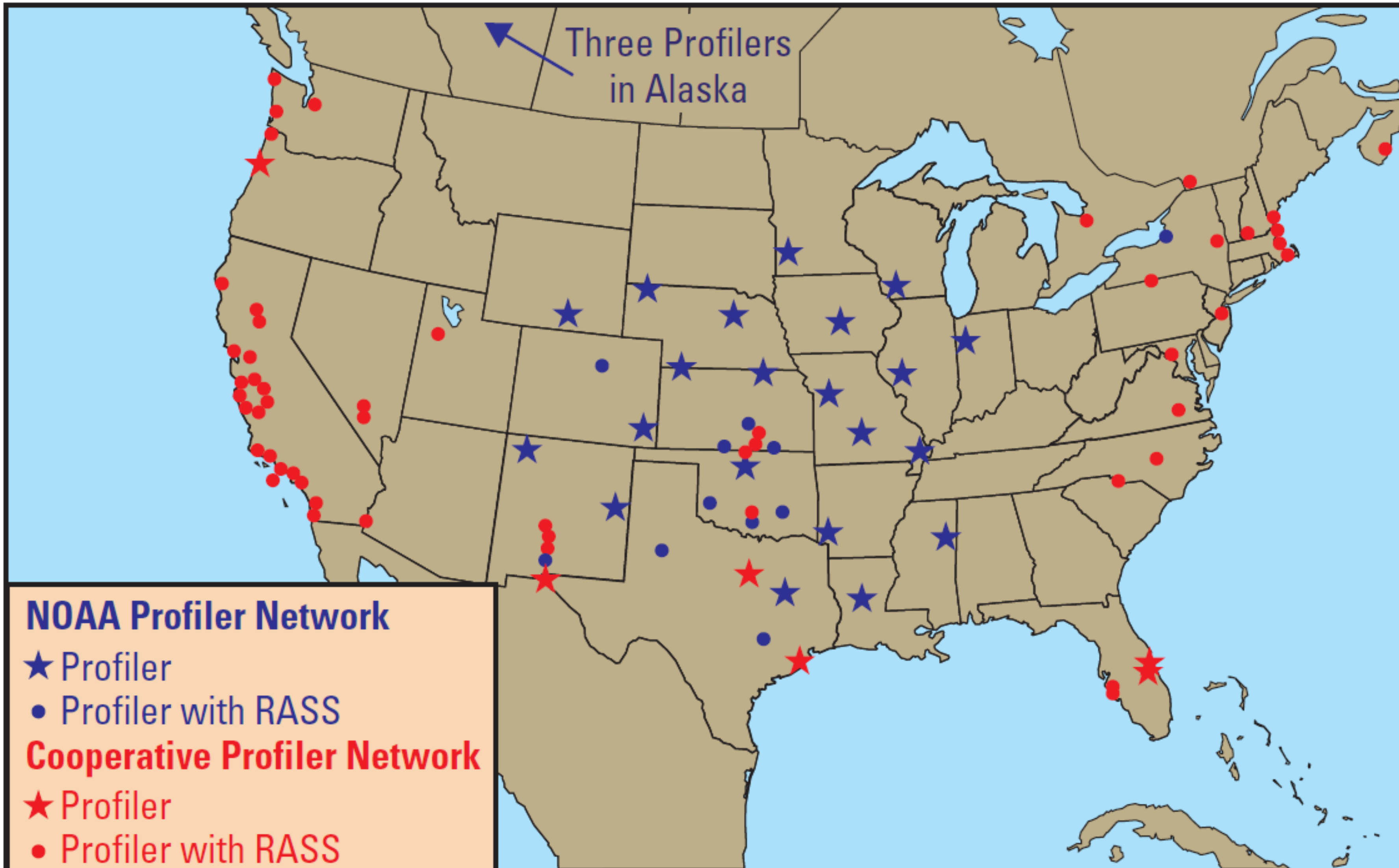
- A wind profiler is another type of Doppler radar that operates in very high frequency (VHF) and altra high frequency (UHF) radio bands.
- The antenna is an array of cables, called a phased array antenna.
- Energy is scattered by small variations in the atmospheric density associated with turbulence.

Wind Profilers use a three beam system, and measures wind profil

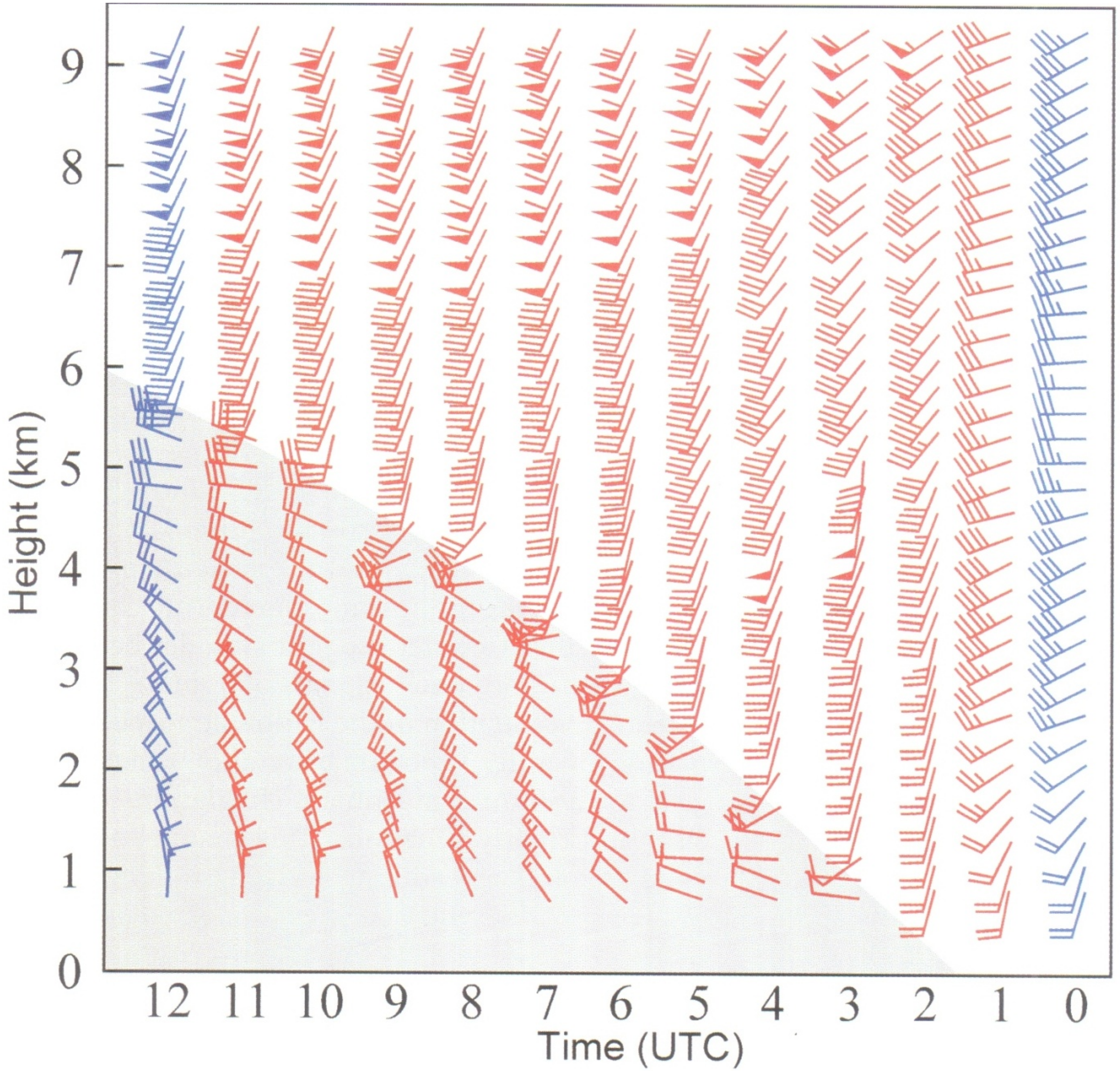


http://www.profiler.noaa.gov/npn/profiler.jsp

Locations of Profilers

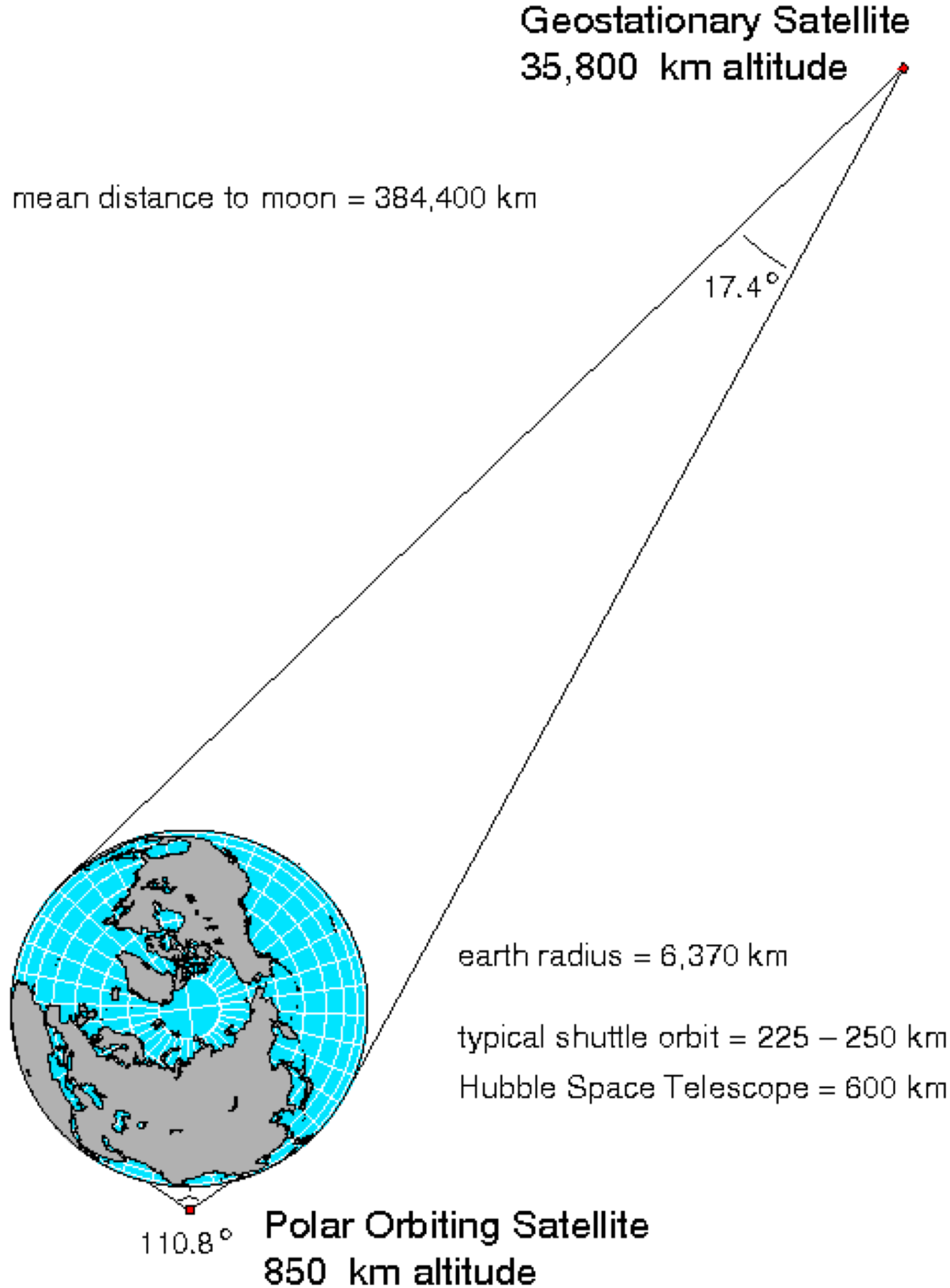


Wind Profiler Data in a Cold Front



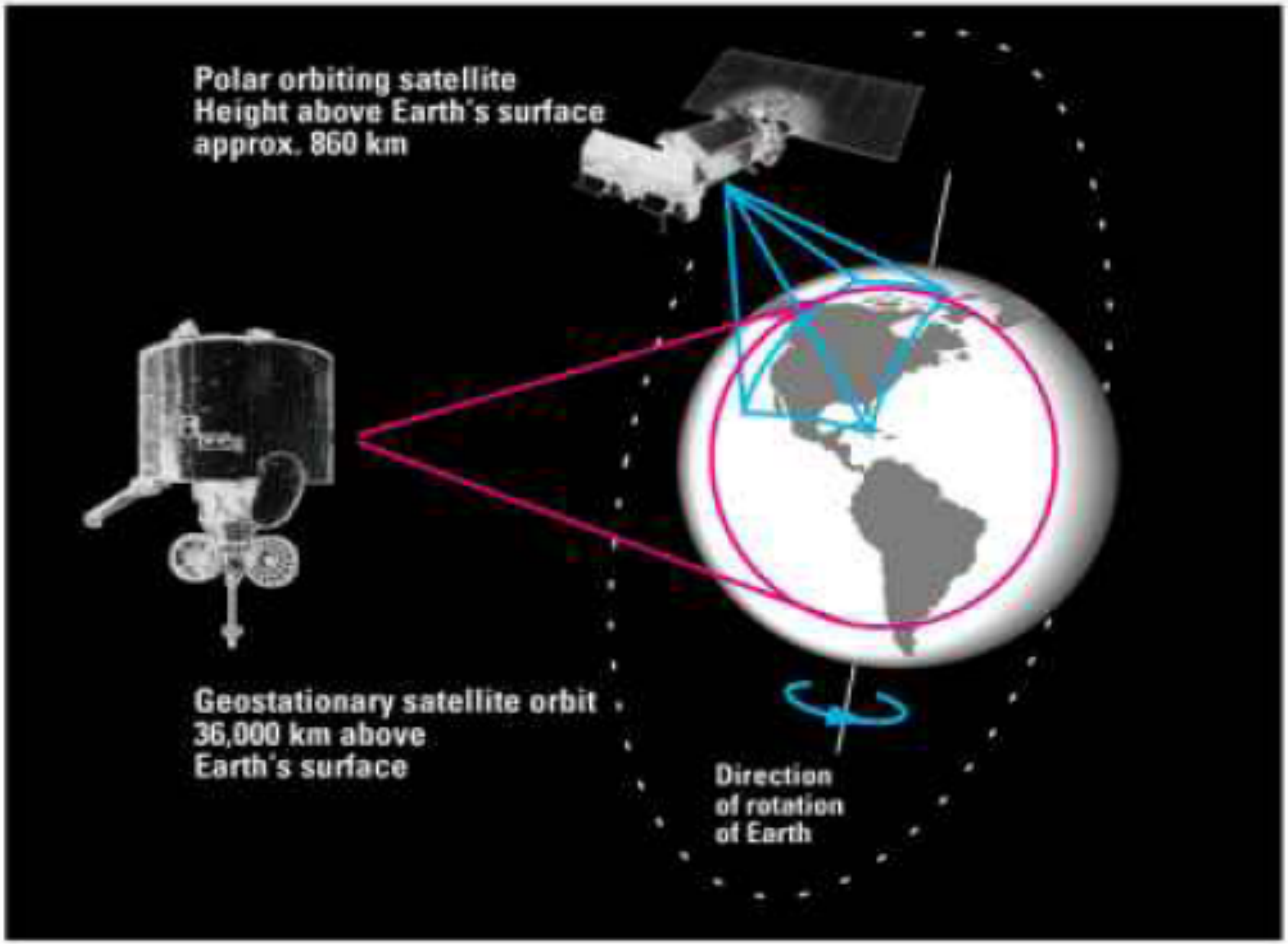
Orbits Used in Meteorological Satellites

- **A Geostationary Orbit (GEO):** is a circular orbit lying in Earth's equatorial plane. So the GEO satellites are synchronized with the Earth, having the same rotational velocity as Earth. A GEO satellite remains motionless relative to a point on the Earth's equator. It must be 35,800 km above the Earth's surface. High altitude-> a very good view of the Earth's disk except the polar regions. Images of the Earth are available every 15 mins.
- **Low Earth Orbit (LEO):** the orbit that is 200 to 1200 km above the Earth's surface (to distinguish from GEO*).* LEO satellites only view a small part of the Earth at any one time.
  - **Sunsynchronous Orbit:** LEO satellites often are placed in a near-polar orbit that is **sunsynchronous,** meaning that the orbit is synchronized with the sun. The satellite crosses the equator at the same local time every day.
  - **Polar Orbit** (or near-polar orbit): Any LEO that reaches high latitude.
  - **Equatorial Orbits:** Low inclination angle, thus orbits near the equator.
  - Usually, most LEO satellites are polar & sunsychronous, therefore called **Polar Orbiting Satellites**



Geostationary Satellite
35,800 km altitude
mean distance to moon = 384,400 km
17.4°
earth radius = 6,370 km
typical shuttle orbit = 225 – 250 km
Hubble Space Telescope = 600 km
110.8°
Polar Orbiting Satellite
850 km altitude

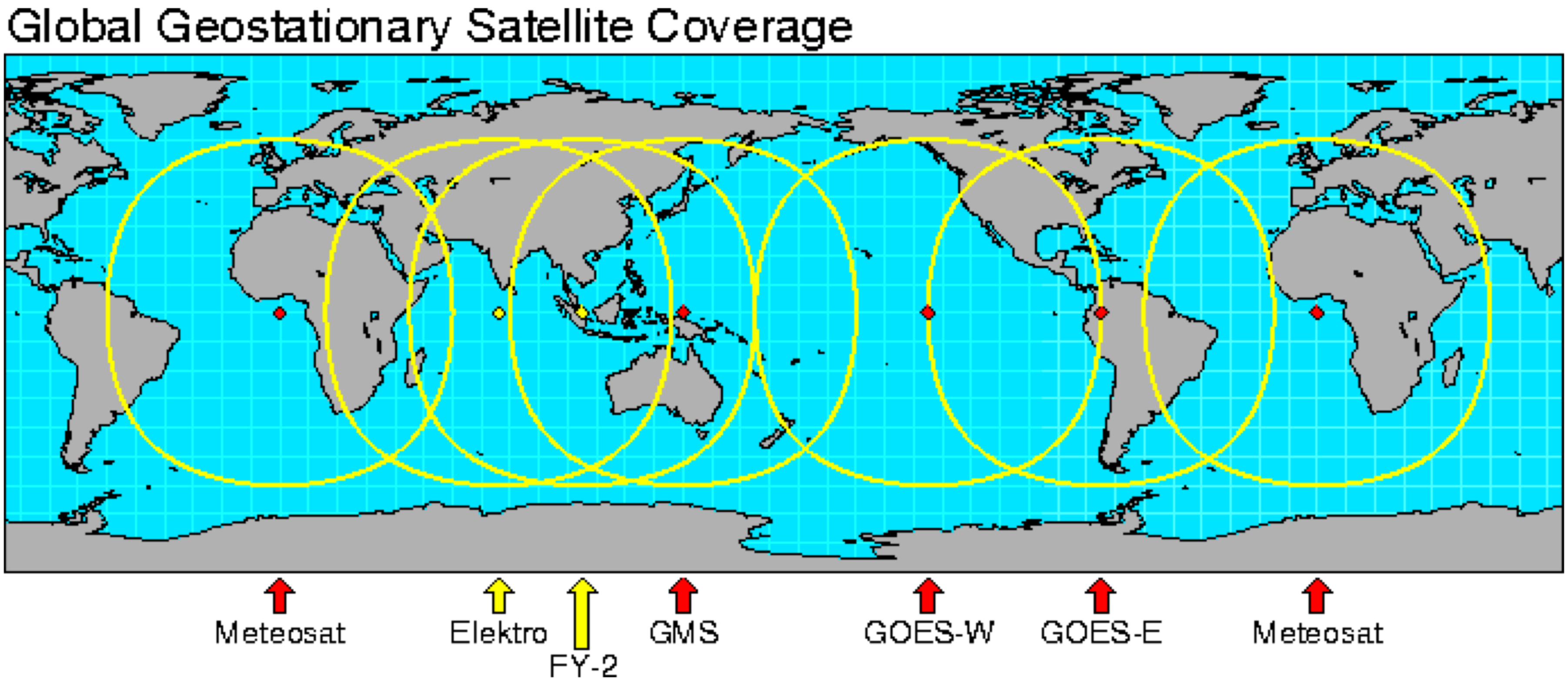
Polar vs Geostationary View



General comparison between Geostationary & Polar Orbiting Satellites

- Polar Orbiting Satellites —examples: DMSP, POES & NPOES
  - Relatively low (~850 km)
  - Earth rotates under satellite
  - Satellite passes overhead once during the day once at night
  - Or sunrise and sunset
  - Mainly for research purposes.
- Geostationary Satellites– examples: GOES (geostationary operational environmental satellites) East, GOES West, Meteosat, FY-2, etc.
  - High (34,000km)
  - Earth Rotates with satellite
  - Satellite remains above a fixed point on the surface
  - Mainly for operational purposes, such as GOES East, GOES West.

Geostationary Satellite Coverages (prior to 2011)



Geostationary Satellite Coverages (since 2011)

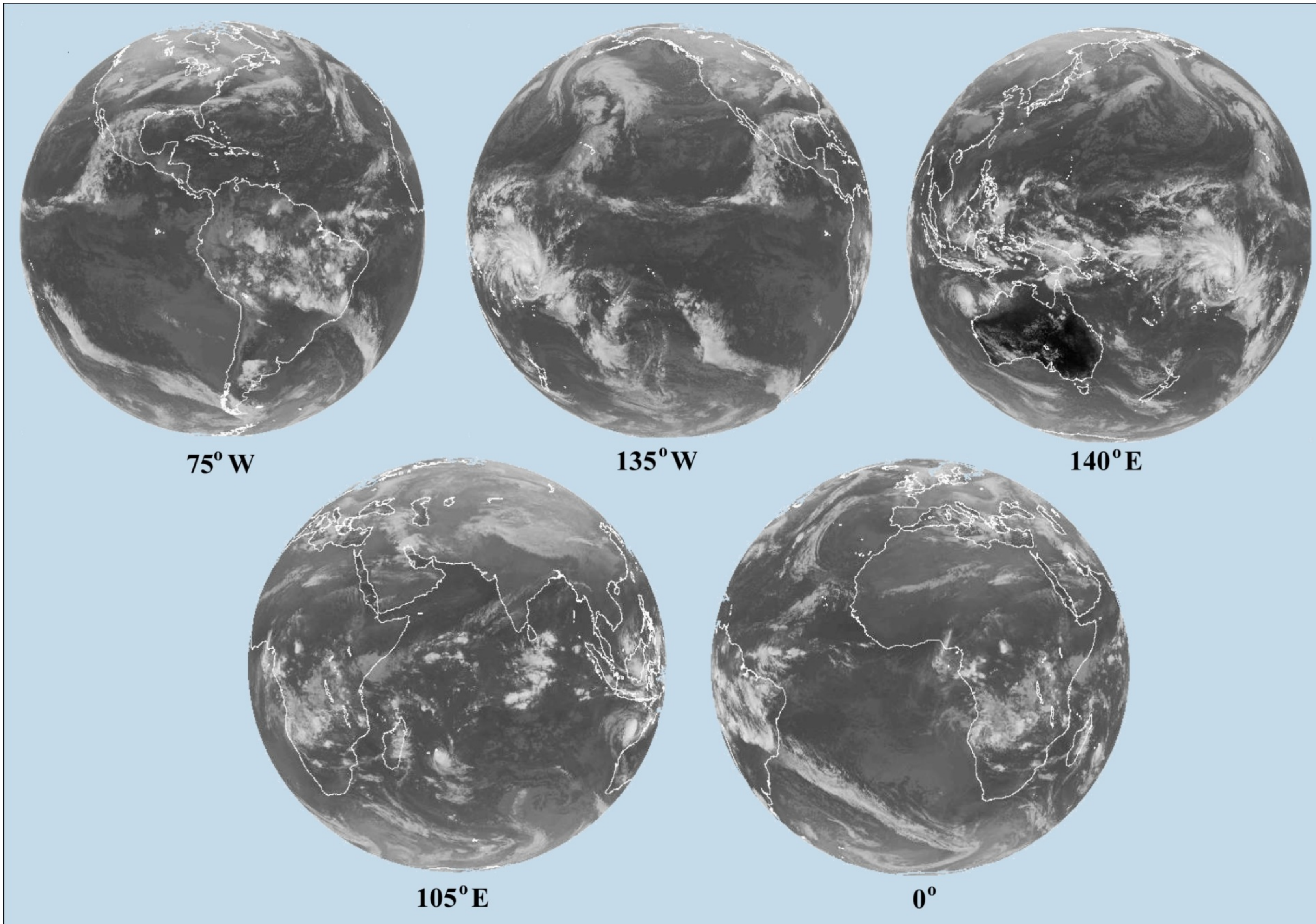


Fig. 2. Map of the ground path of one revolution of a typical near-polar orbiting satellite.

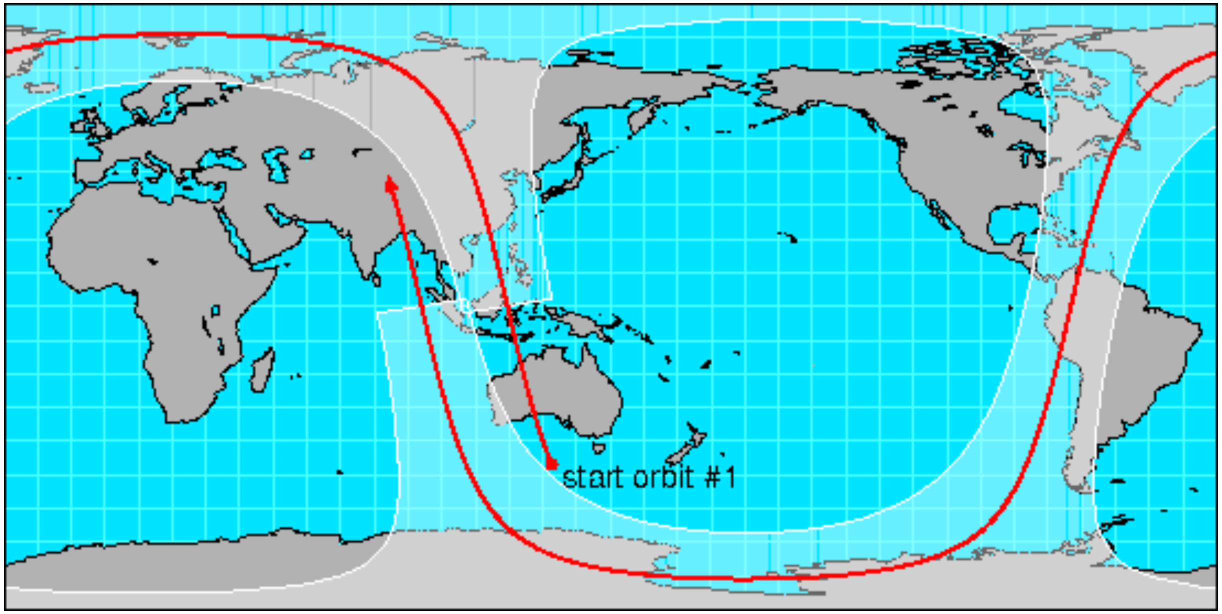


Fig. 3. The orbit of a near polar satellite as viewed from a point rotating with the Earth.

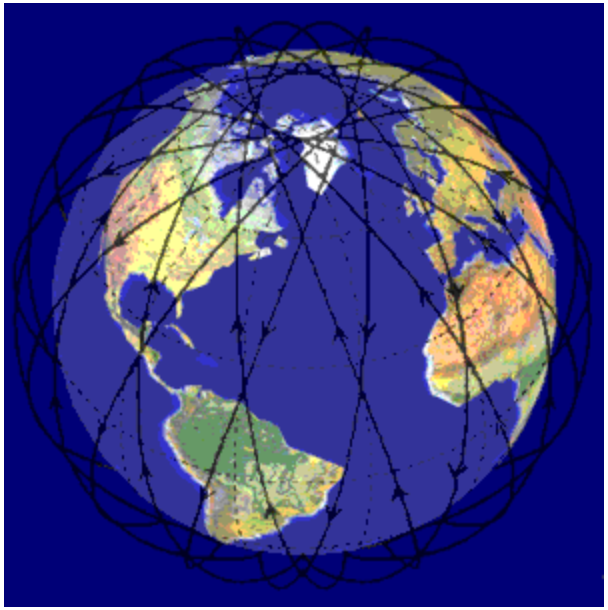
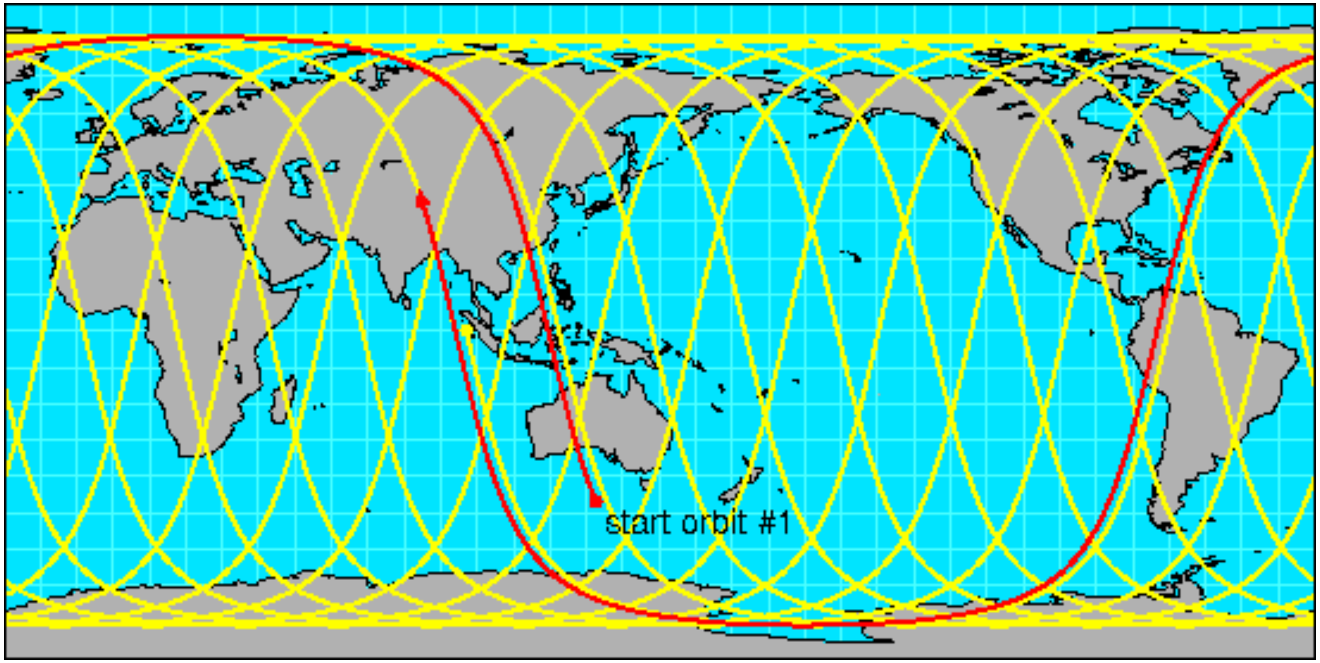


Fig. 4. The ground paths of the multiple orbital revolutions during one day for a near-polar orbiting satellite.



Depending on the ground swath of the satellite, it is possible to adjust the period (by varying the altitude), and thus the longitudinal displacement, in such a way as to ensure the observation of any point on the Earth within a certain time period. **Most of the near polar meteorological satellites ensure complete global coverage of the Earth during one day**, thanks to a ground swath of about 3300 km.

Meteorological Sensors on Geostationary Satellites

- Three electromagnetic frequency bands or channels:
  - Visible
  - Infrared (IR)
  - Water vapor

Table 2.2 Interpreting Satellite Imagery

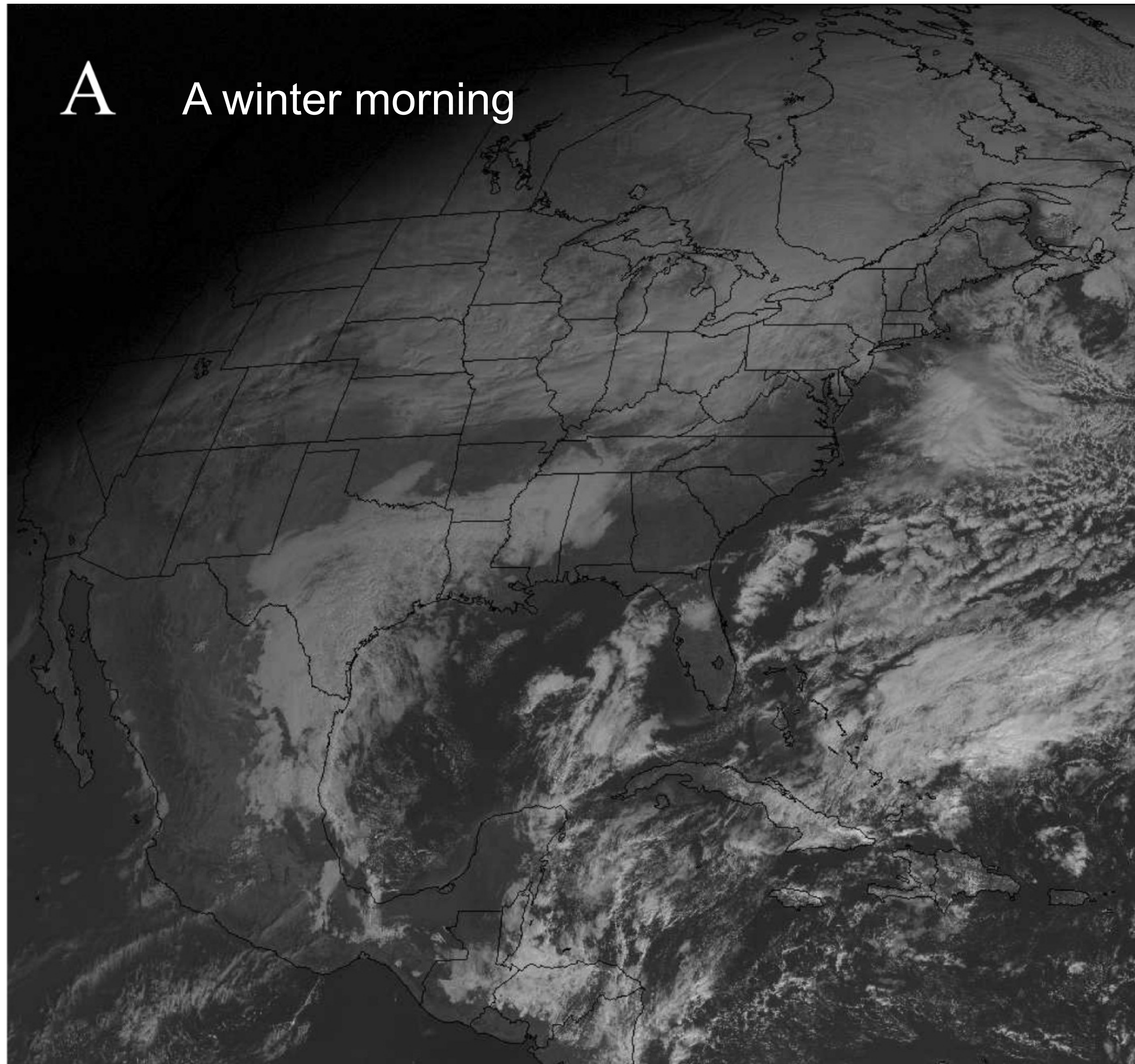
	Visible	Infrared	Water Vapor
Satellite Measures	reflected solar radiation	emitted infrared radiation (temperature)	infrared radiation emitted by water vapor only
Brightest Regions	thick clouds, snow	cold cloud tops (high clouds)	moist air
Darkest Regions	oceans, forests, unfrozen rivers in winter	warm cloud tops (low clouds) warm regions of the Earth's surface	dry air

Visible Image (black & white) Interpretation

Brightest regions:
clouds or snow.

Dark gray regions: surfaces that absorb most incoming solar radiation. For example, **oceans & forests. Land** is a little bit brighter than oceans.

Dark indicated no reflected radiation -- **night.**

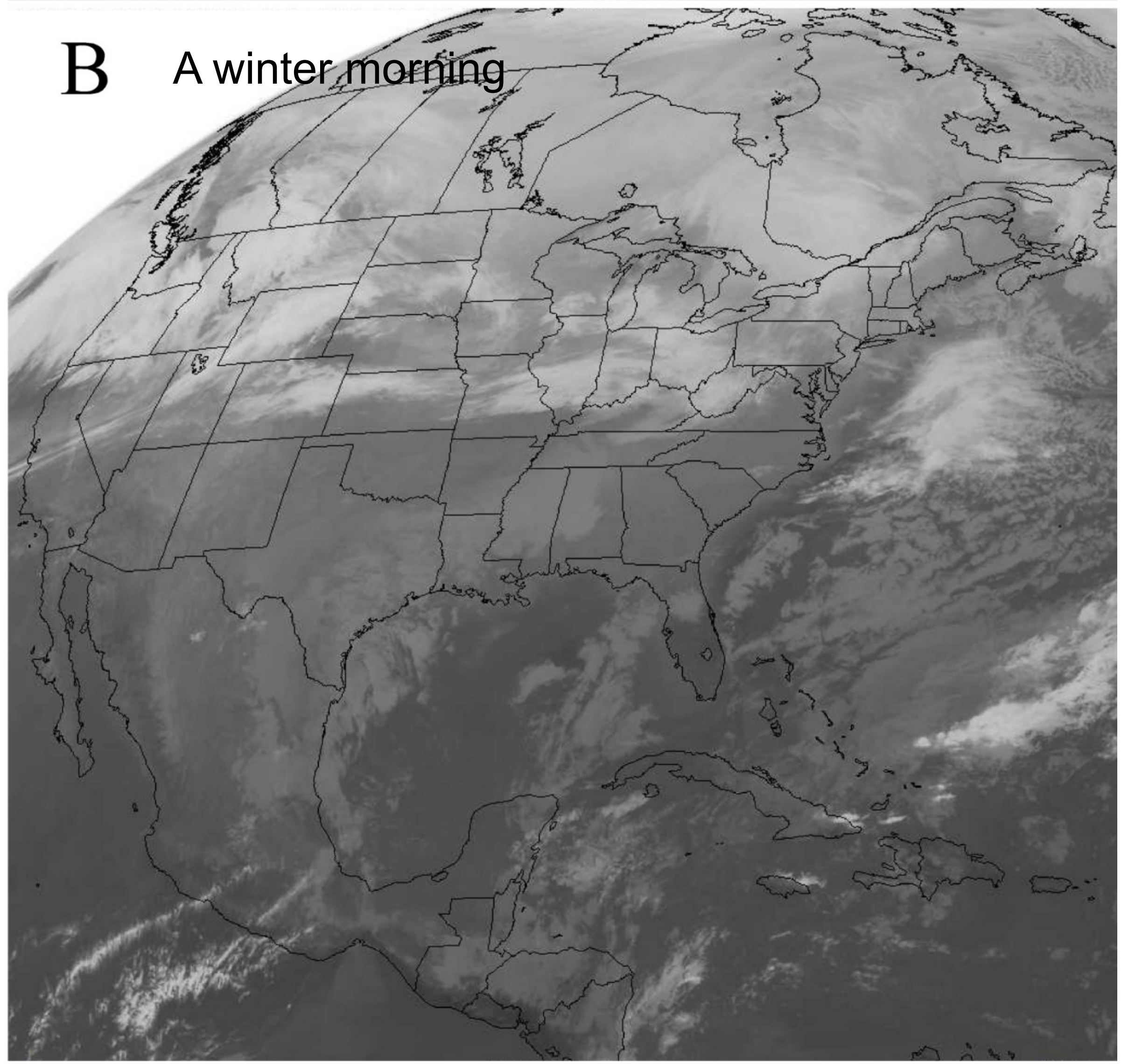


IR Image (black & white) Interpretation

Darkest shading indicates the warmest surfaces, such as **lower clouds and ground**. The clouds over Texas are bright in visible but dark gray in IR – warm-topped (low altitude) clouds or ground fog.

Brighter regions indicate colder surfaces (**higher clouds or snow**) – over Canada.

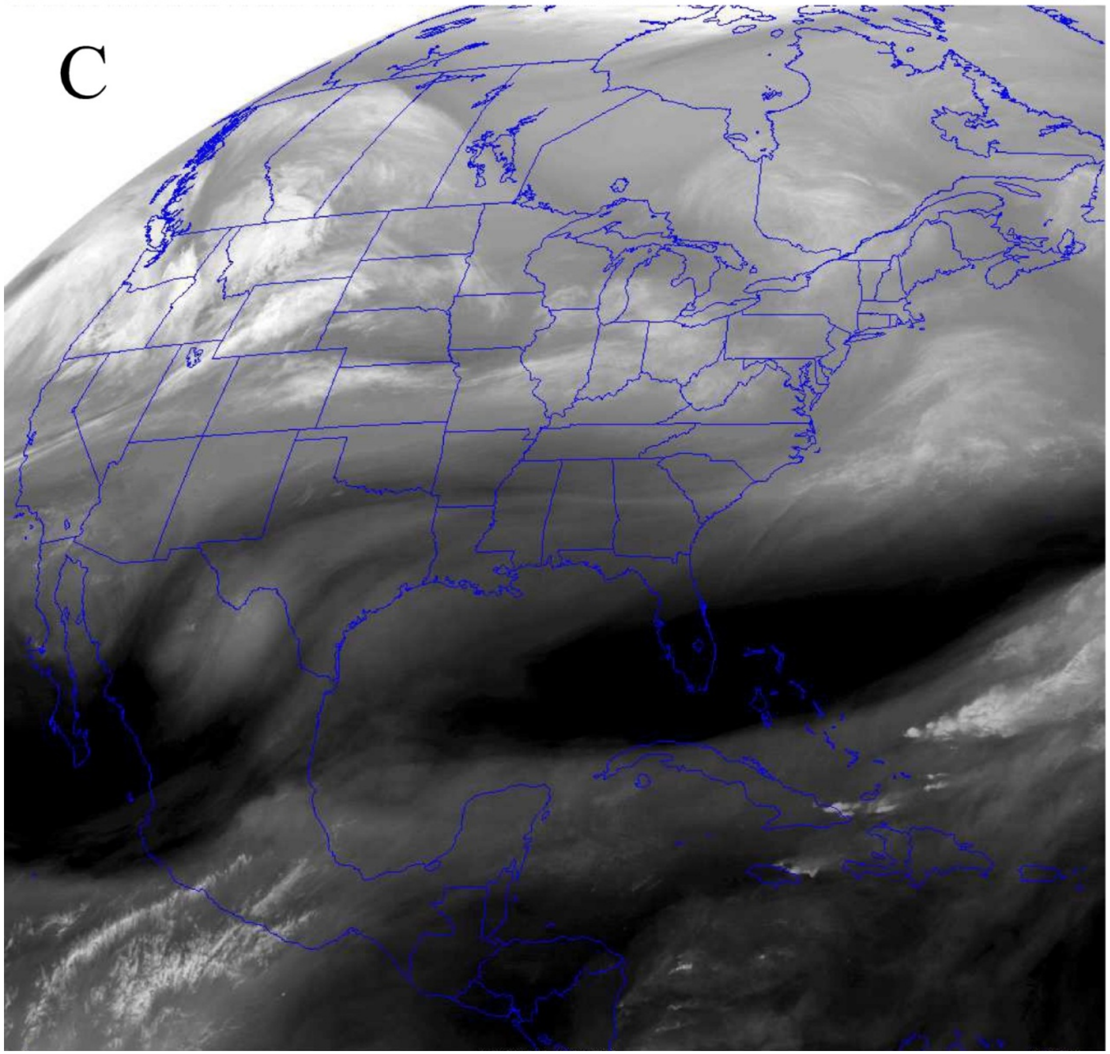
How about desert? -- black



Water Vapor Image (black & white) Interpretation

The brightest regions are moist air and cloud, while the darkest regions correspond to very dry air.

The bright/dark boundary indicates the location of upper troposphere jetstream. For example, subtropical jet from central Mexico, across the Caribbean Sea to the northern tip of Cuba, and eastward over the Atlantic.



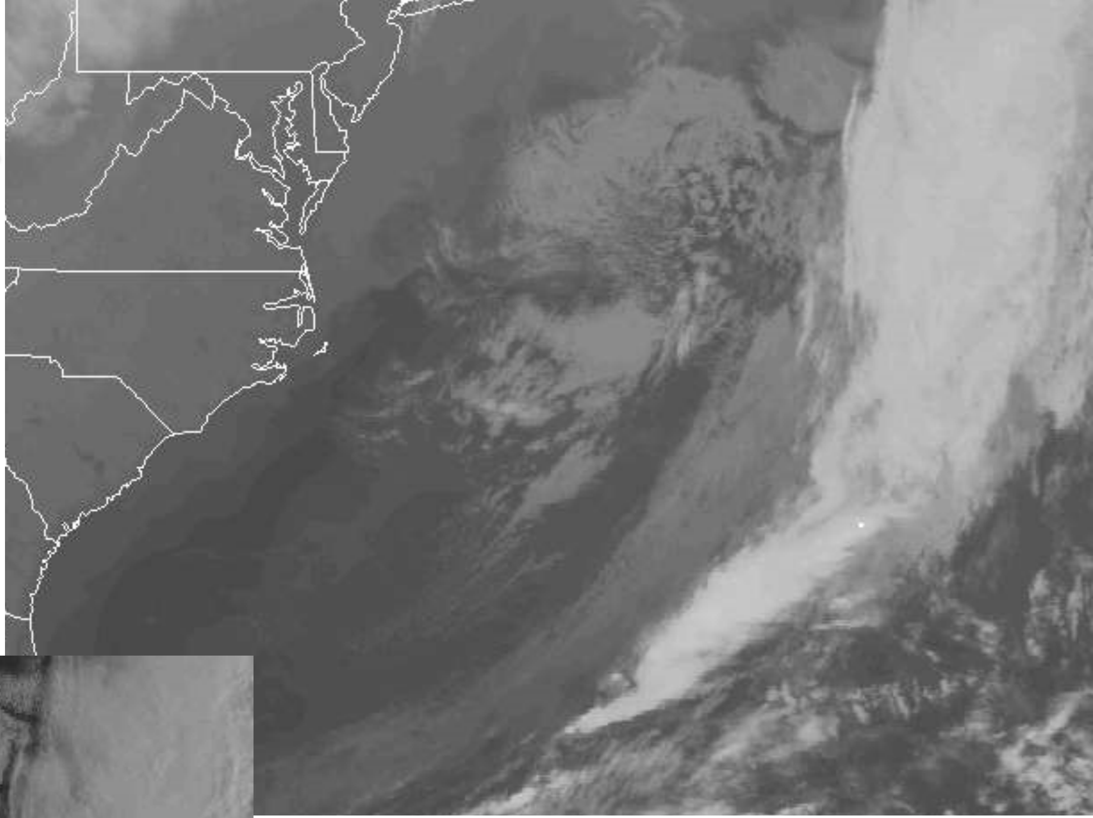
Distinguishing Different Image Types

Visible vs. IR

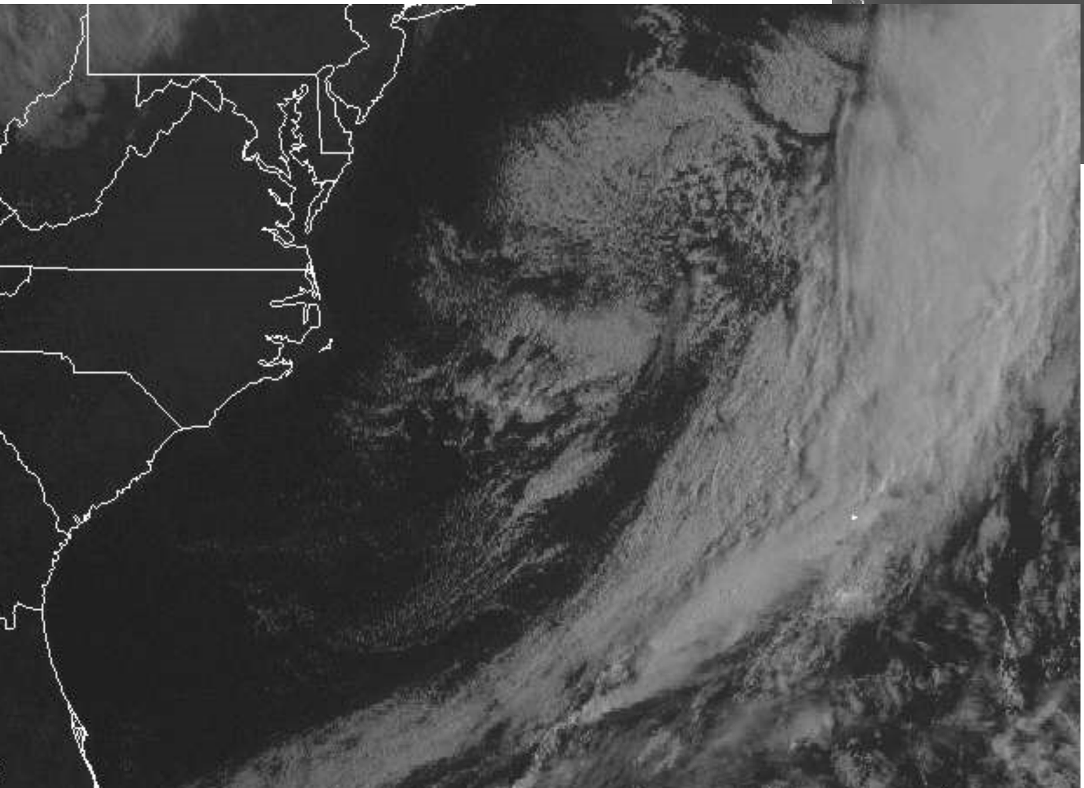
- Visible:
  - More clouds
  - More texture
  - Gray shades (usually)
- IR
  - Nighttime coverage*
  - Often color or BW enhanced

*DMSP exception

IR



Visible



US East Coast, 12:15 UTC (7:15 local time), Apr. 6, 2011

The US National Lightning Detection Network (NLDN) Detects Locations of Cloud-to-Ground Strokes

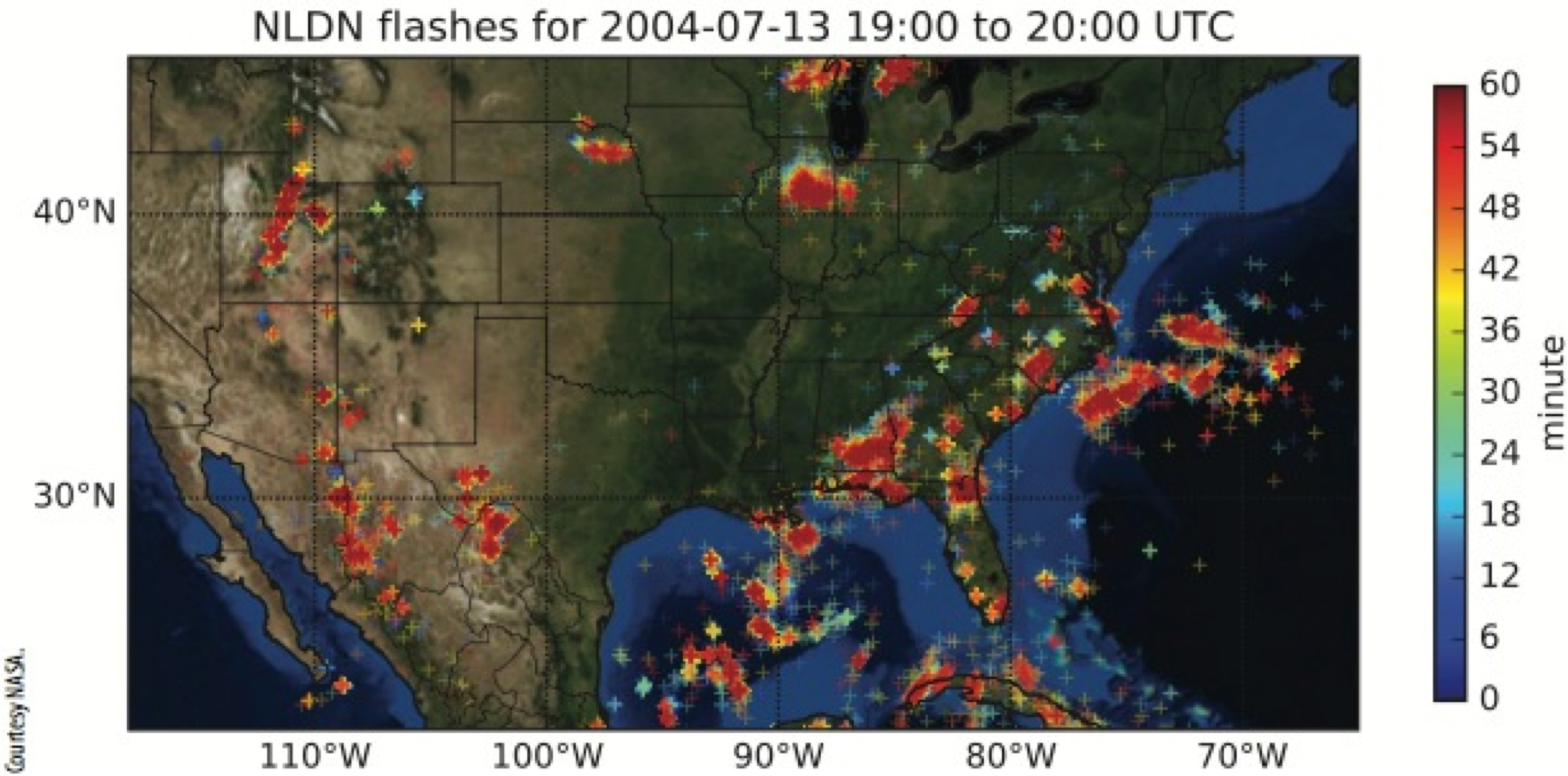
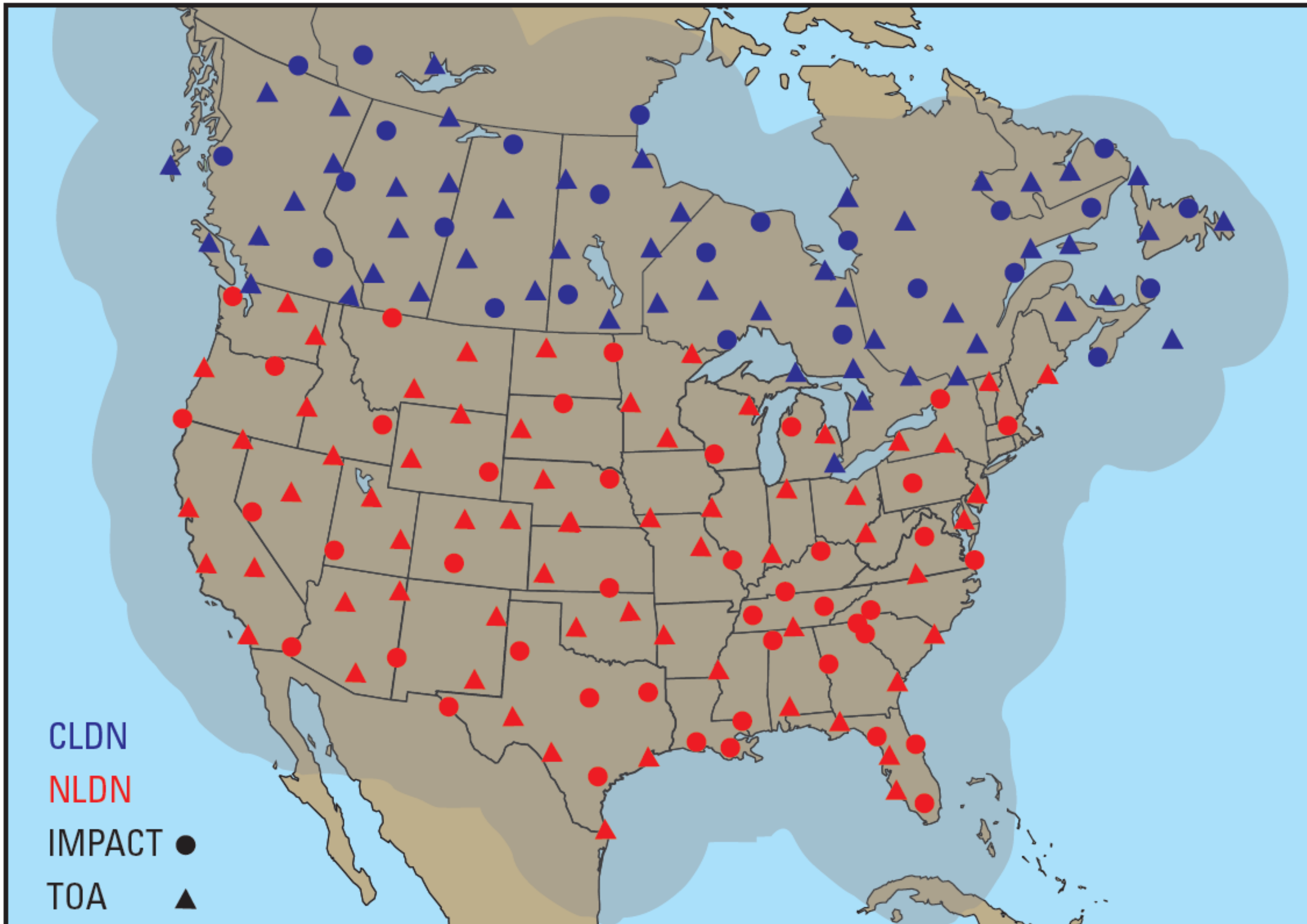


Figure 2.15 Lightning flashes for a one-hour period across the United States.

The US and Canadian National Lightning Detection Networks



Summary

- Radar---Microwave reflection from rain
  - Z-R relationship converts reflectivity to rainfall rate
  - Doppler radar uses frequency shift to compute wind component toward or away from the radar
- Satellites
  - Geostationary---over a fixed spot on the equator
  - Polar Orbiter---Two looks a day
  - Visible Light, Infra Red, and Water Vapor Imagery
- Profilers: Special Doppler radars that take hourly wind soundings
- AMDAR: Automated observations from commercial aircraft
- Lightning location network triangulates cloud-to-ground strokes