MET 3502 Synoptic Meteorology

Lecture 6:

Review of instrumentation and data sources

The National Weather Service (NWS)

U.S. federal agency charged with providing weather, water, and climate warnings and forecasts

•Started as part of the Army Signal Corps in 1870
•NWS successfully completed modernization and restructuring (1999)

• Recent achievements:

*** lead time for tornado warnings has more than doubled (11 minutes versus 4 minutes)**
*** lead time for flash flood warnings has increased by more than 500 percent (52 minutes versus 10 minutes)**

• Goal: NWS forecasts will be continuous, cumulative, consistent, relevant, and make the most effective use of data and computing power!

National Weather Service Mission Statement:

"*The National Weather Service (NWS) provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure which can be used by other governmental agencies, the private sector, the public, and the global community.*"

NOAA/National Weather Service/Associated Centers

http://www.weather.gov/organization_prv

– National Support Centers

NWS Headquarters

Headquarters (HQ)
Office of Hydrologic Development (OHD)
Office of Climate, Water, & Weather Services (OCWWS)
Office of Operational Systems (OOS)
Office of Science and Technology (OST)
Office of The Chief Financial Officer/ Chief Administrative Office (OCFO)
Office of Chief Information Officer (OCIO)
Strategic Planning and Policy Office (SPP)
Executive Affairs (Staff) Office (OEA)
Office Equal Opportunity & Diversity Management (OEODM)
International Activities Office (IA)
Communications Office (COM)

National Centers

National Centers for Environmental Prediction (NCEP)
Hydrologic Information Center (HIC)
National Data Buoy Center (NDBC)
National Operational Hydrologic Remote Sensing Center (NOHRSC)
Telecommunications Operations Center (TOC)
NOAA/NWS Training Center (W/TC)

National Centers for Environmental Prediction (NCEP)

Aviation Weather Center (AWC)
Climate Prediction Center (CPC)
Environmental Modeling Center (EMC)
Weather Prediction Center (WPC)
NCEP Central Operations (NCO)
National Hurricane Center (NHC)
Ocean Prediction Center (OPC)
Space Weather Prediction Center (SWPC)
Storm Prediction Center (SPC)

National Specialized Centers

Alaska Aviation Weather Unit (AAWU)
Central Pacific Hurricane Center (CPHC)
Climate Diagnostics Center (CDC)
Hydrology Laboratory (HL)
International Tsunami Information Center (ITIC)
National Climatic Data Center (NCDC)
National Operational Hydrologic Remote Sensing Center (NOHRSC)
National Severe Storms Laboratory (NSSL)
Pacific Tsunami Warning Center (PTWC)
Spaceflight Meteorology Group (SMG)
West Coast/Alaska Tsunami Warning Center (WC/ATWC)

National Centers for Environmental Prediction

NCEP Central Operations:
Mission: oversee the implementation and monitoring of NCEP's production suite

Environmental Modeling Center (EMC)
Mission: improve numerical weather, marine and climate predictions at the National Centers for Environmental Prediction (NCEP)

The Storm Prediction Center (SPC)

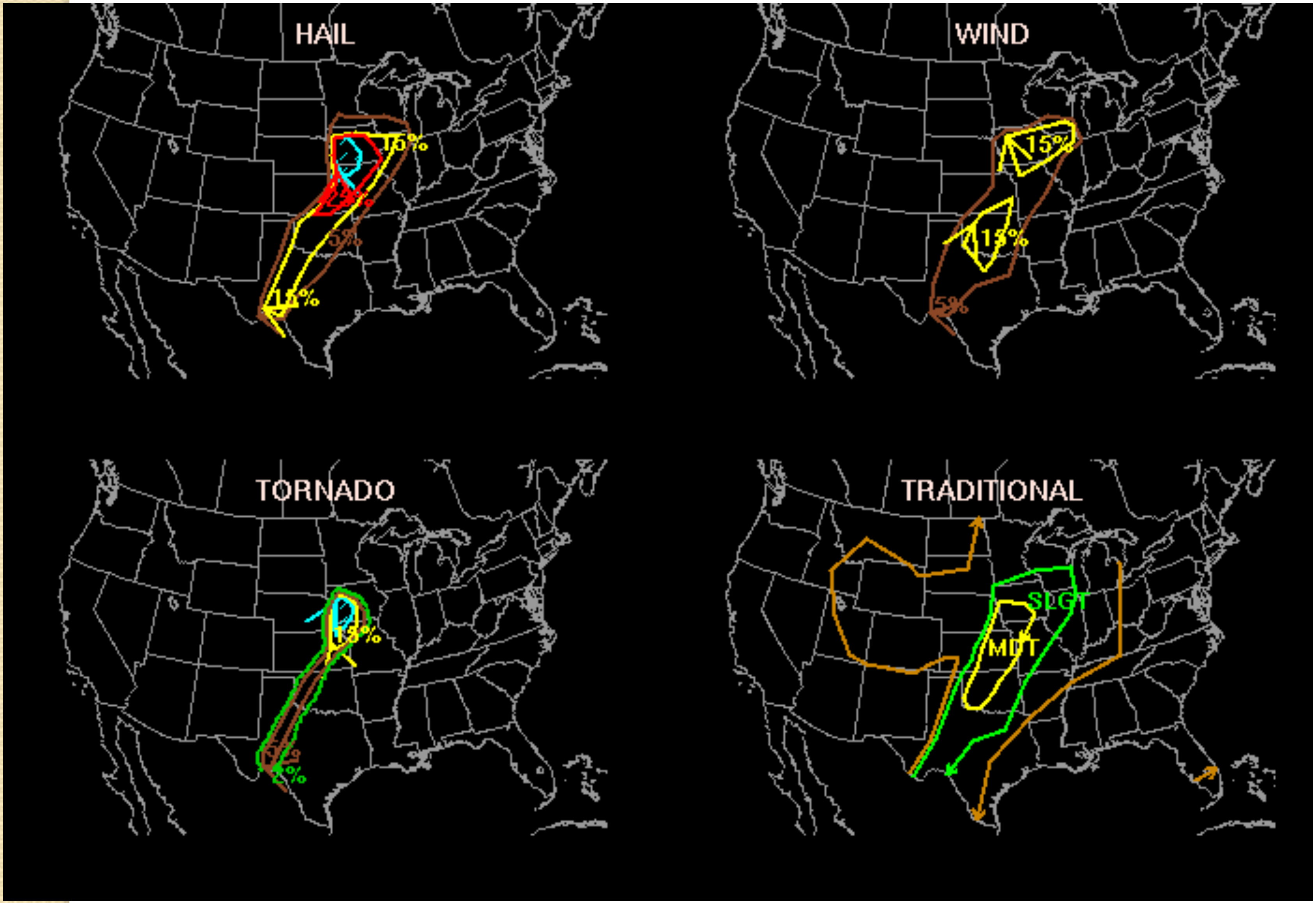
Mission: *provide timely and accurate forecasts and watches for severe thunderstorms and tornadoes over the contiguous United States.

* monitors heavy rain, heavy snow, and fire weather events across the U.S. and issues specific products for those hazards.

http://www.spc.noaa.gov/

Located in Norman, Oklahoma

Example of SPC Forecasts



The National Hurricane Center (NHC)

Mission:

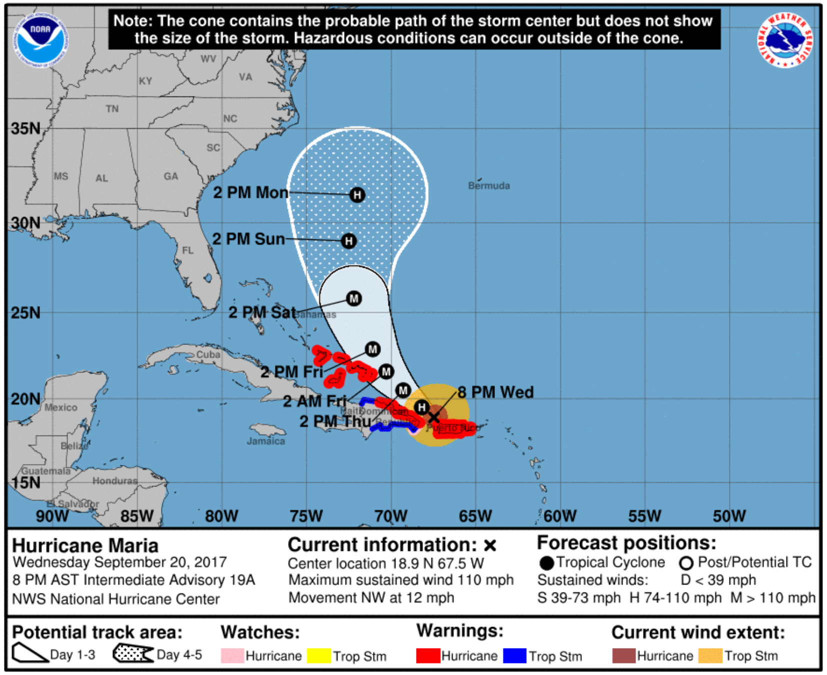
Save lives, mitigate property loss, and improve economic efficiency by issuing the best watches, warnings, forecasts and analyses of hazardous tropical weather (i.e. Hurricanes).

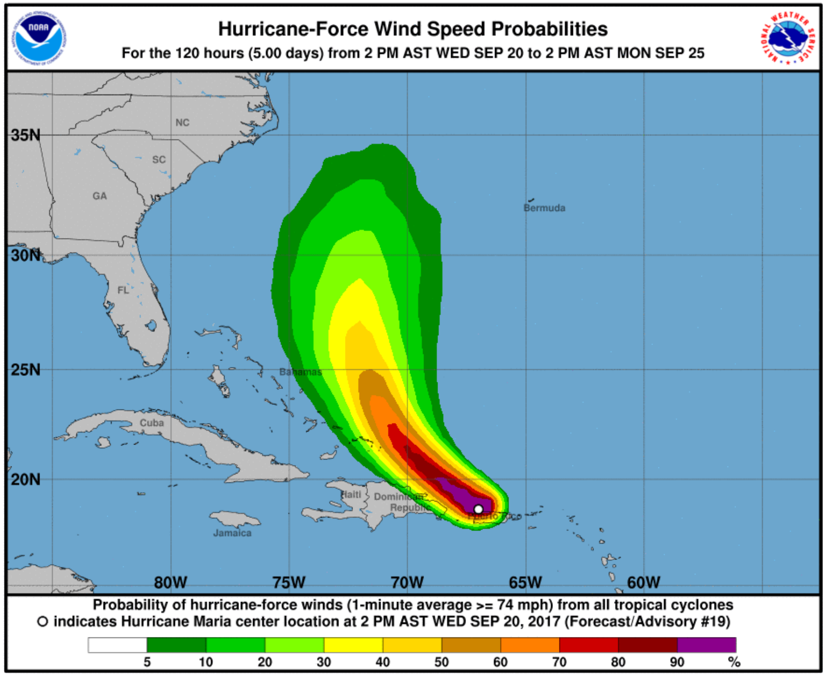
NHC generates forecasts for twenty-four countries in the Americas, Caribbean, and for the waters of the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and the eastern North Pacific Ocean

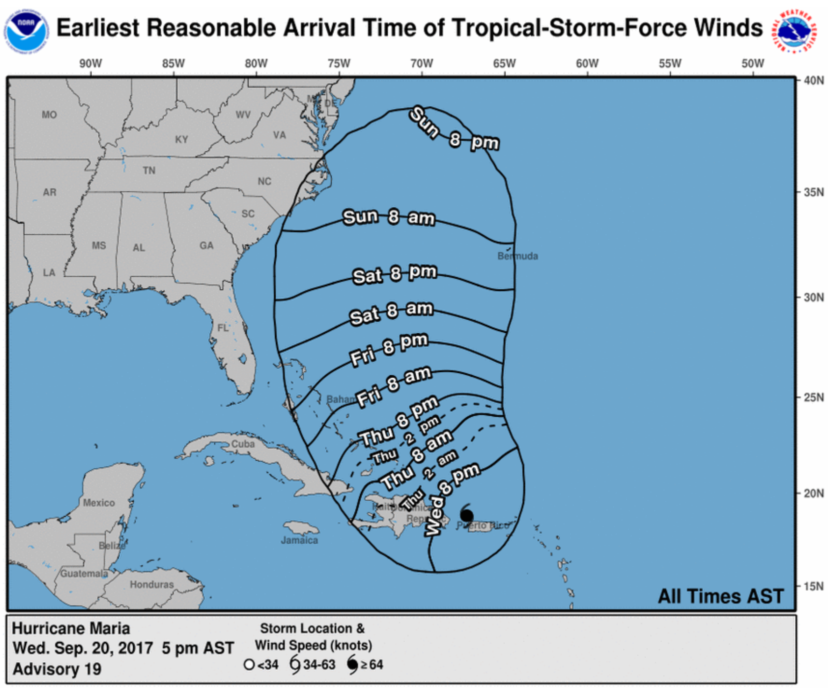
http://www.nhc.noaa.gov/

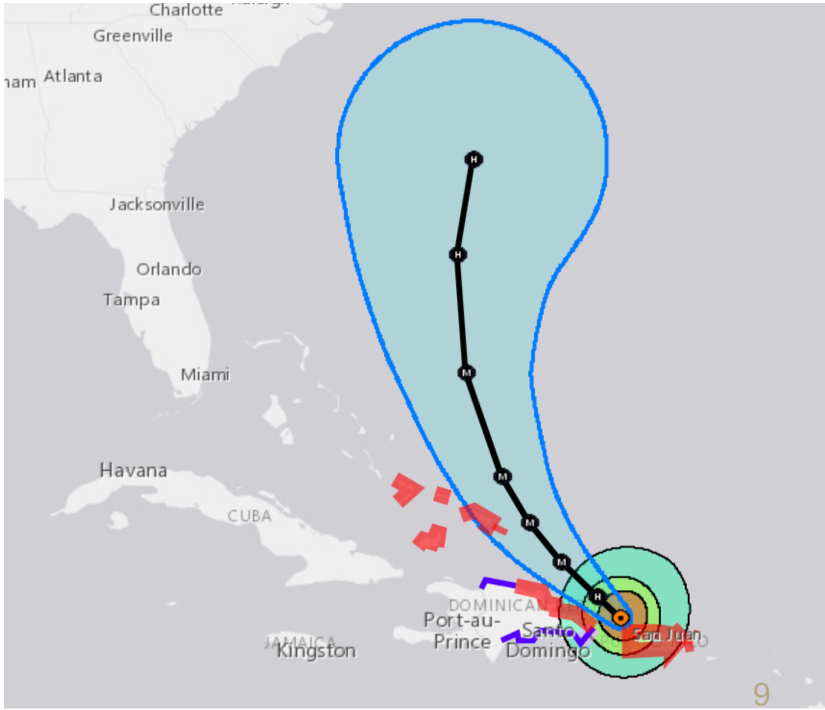
Located in Miami, Florida

NHC


Note: The cone contains the probable path of the storm center but does not show the size of the storm. Hazardous conditions can occur outside of the cone.
2 PM Mon
2 PM Sun
2 PM Sat
2 PM Fri
2 AM Fri
2 PM Thu
8 PM Wed
35N
30N
25N
20N
15N
90W
85W
80W
75W
70W
65W
60W
55W
50W
Hurricane Maria
Wednesday September 20, 2017
8 PM AST Intermediate Advisory 19A
NWS National Hurricane Center
Current information: ×
Center location 18.9 N 67.5 W
Maximum sustained wind 110 mph
Movement NW at 12 mph
Forecast positions:
Tropical Cyclone
Post/Potential TC
Sustained winds:
D < 39 mph
S 39-73 mph H 74-110 mph M > 110 mph
Potential track area:
Day 1-3
Day 4-5
Watches:
Hurricane
Trop Stm
Warnings:
Hurricane
Trop Stm
Current wind extent:
Hurricane
Trop Stm


Hurricane-Force Wind Speed Probabilities
For the 120 hours (5.00 days) from 2 PM AST WED SEP 20 to 2 PM AST MON SEP 25
35N
30N
25N
20N
80W
75W
70W
65W
60W
Probability of hurricane-force winds (1-minute average >= 74 mph) from all tropical cyclones
indicates Hurricane Maria center location at 2 PM AST WED SEP 20, 2017 (Forecast/Advisory #19)
5
10
20
30
40
50
60
70
80
90
%


Earliest Reasonable Arrival Time of Tropical-Storm-Force Winds
90W
85W
80W
75W
70W
65W
60W
55W
50W
40N
35N
30N
25N
20N
15N
Sun 8 pm
Sun 8 am
Sat 8 pm
Sat 8 am
Fri 8 pm
Fri 8 am
Thu 8 pm
Thu 2 pm
Thu 8 am
Thu 2 am
Wed 8 pm
All Times AST
Hurricane Maria
Wed. Sep. 20, 2017 5 pm AST
Advisory 19
Storm Location &
Wind Speed (knots)
<34
34-63
≥64

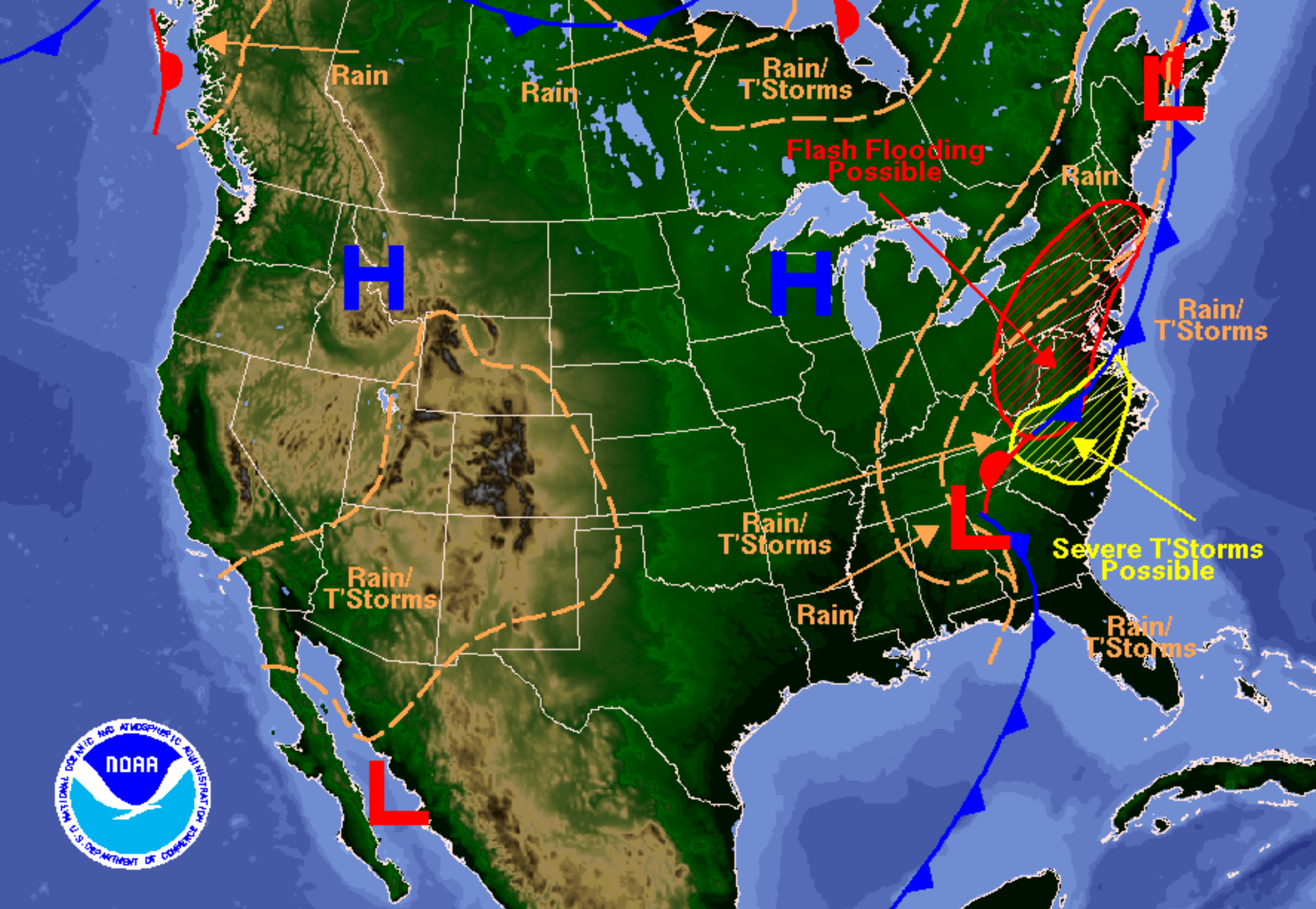

Charlotte
Greenville
Atlanta
Jacksonville
Orlando
Tampa
Miami
Havana
CUBA
Port-au-Prince
Santo Domingo
Kingston
San Juan

The Weather (formerly Hydrometeorological) Prediction Center

The primary functions of the WPC:

*Quantitative Precipitation Forecasts (QPF)
*Numerical Model Diagnostics and Interpretation concerning the current runs of the NCEP short range numerical models.
*Surface Analysis : manual analyses of surface fronts and pressure systems over North America and adjacent oceans at 3 hour intervals
* Medium-Range (days 3-7) Public Forecasts: The medium range forecasters are responsible for preparing forecasts for the 3 to 7 day period.

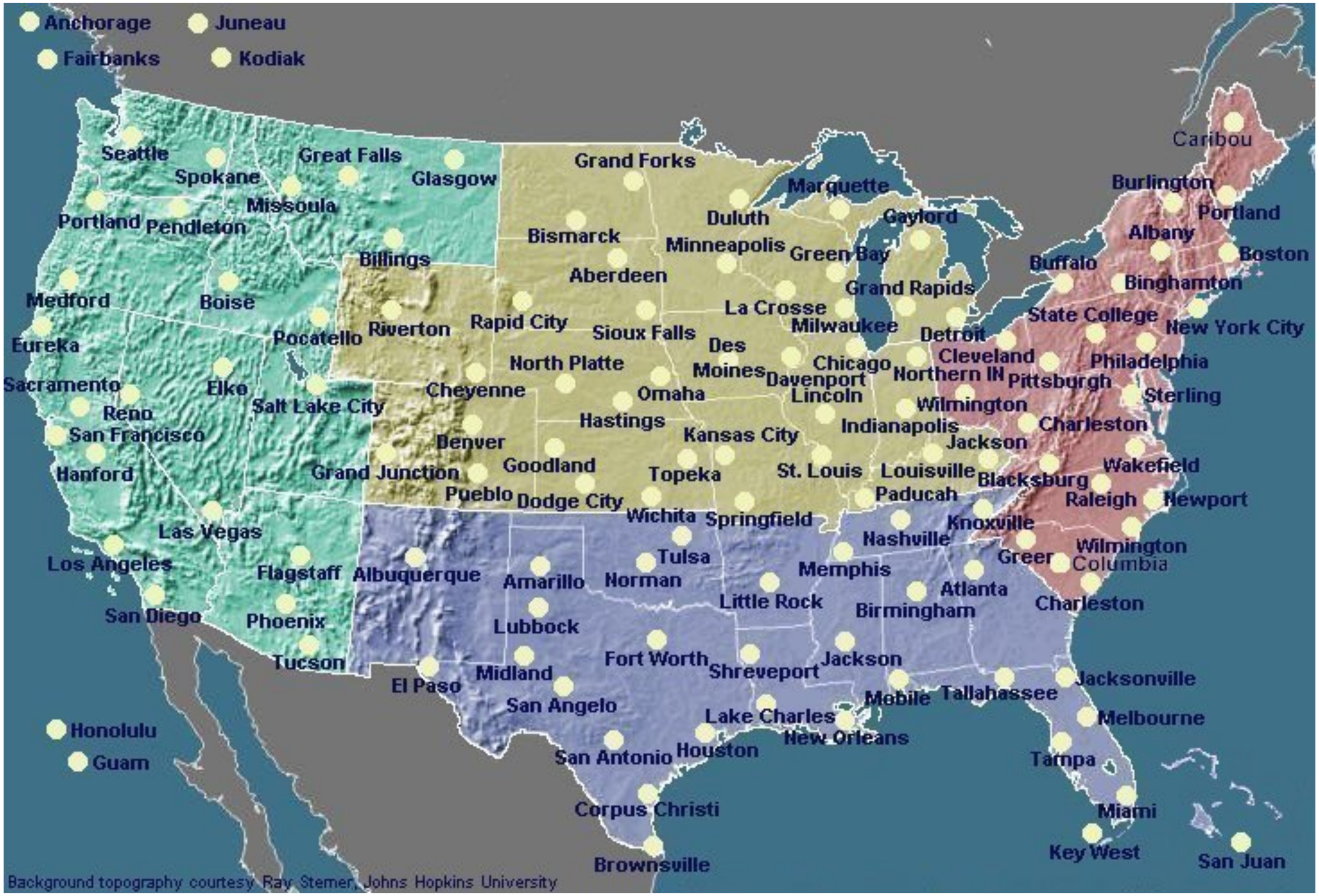
http://www.wpc.ncep.noaa.gov/index.shtml



Weather Forecast for Tue, Sep 06, 2011, issued 3:26 AM EDT
DOC/NOAA/NWS/NCEP/Hydrometeorological Prediction Center
Prepared by Mcreynolds based on HPC, SPC, and NHC forecasts

WPC FORECAST

National Weather Service Forecast Offices



Instrumentations operated by NWS:

Automated Surface Observing Systems (ASOS)

NEXRAD (Next-Generation Radar a network of 159 high-resolution S-band Doppler weather radar)

Wind profilers

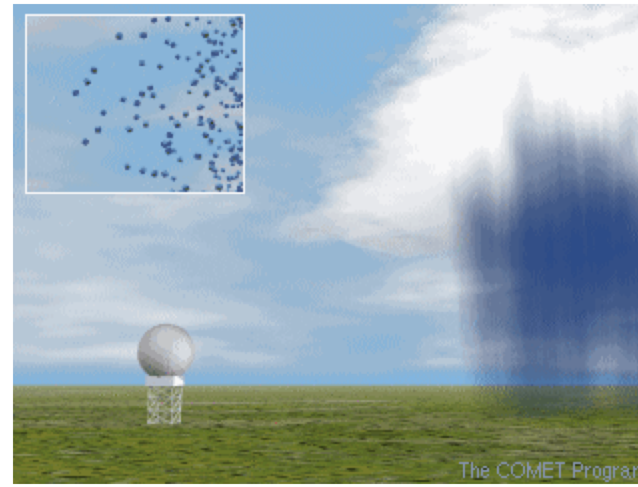
GOES satellite

Web Site:

http://www.weather.gov/

Active vs. Passive Remote Sensing

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



Examples: X-Ray, Radar, Lidar

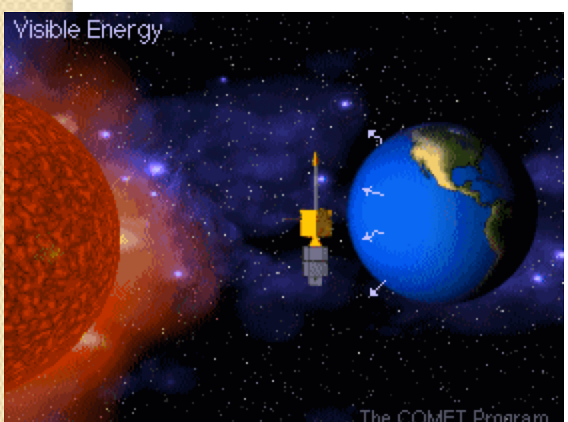
- How does radar work? Radar works by transmitting a pulse of electromagnetic energy. Objects (raindrops, ice, snow, birds, insects, terrain, and buildings) reflect that energy. Part of the reflected energy is received back at the radar. Once the radar receives the reflected signal, computer programs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

Active vs. Passive Remote Sensing (Cont.)

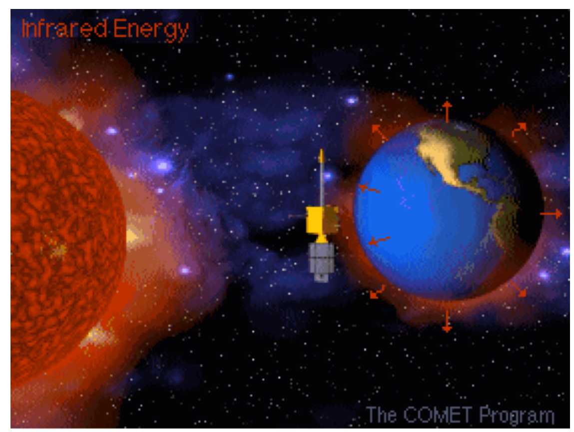
- Passive remote sensors observe electromagnetic waves emitted by objects.

Example: Camera;
Satellite infrared (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.

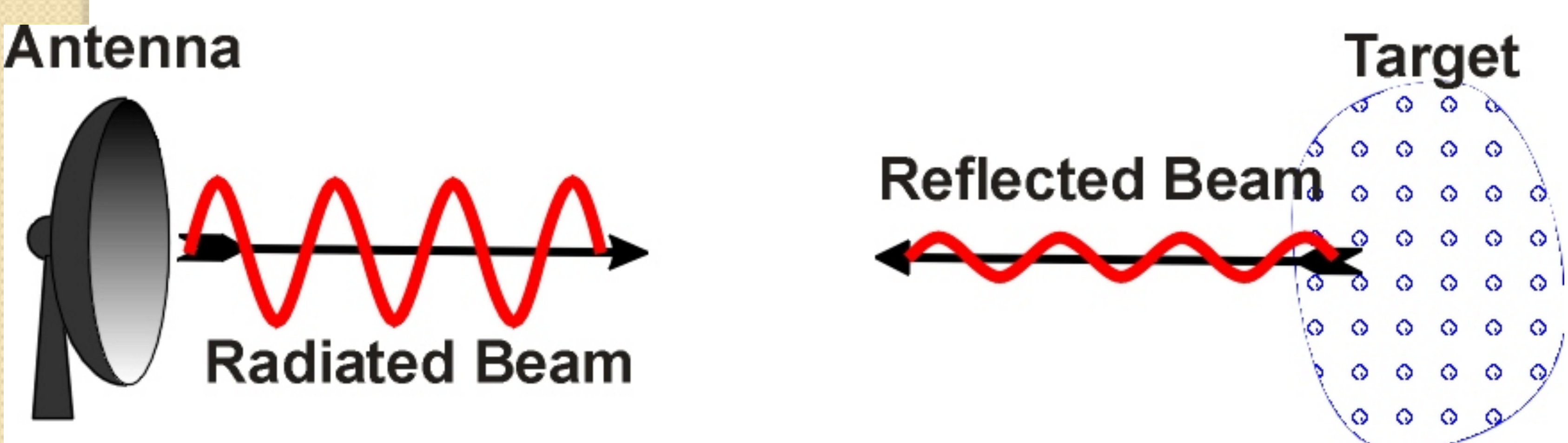


How does weather radar work?

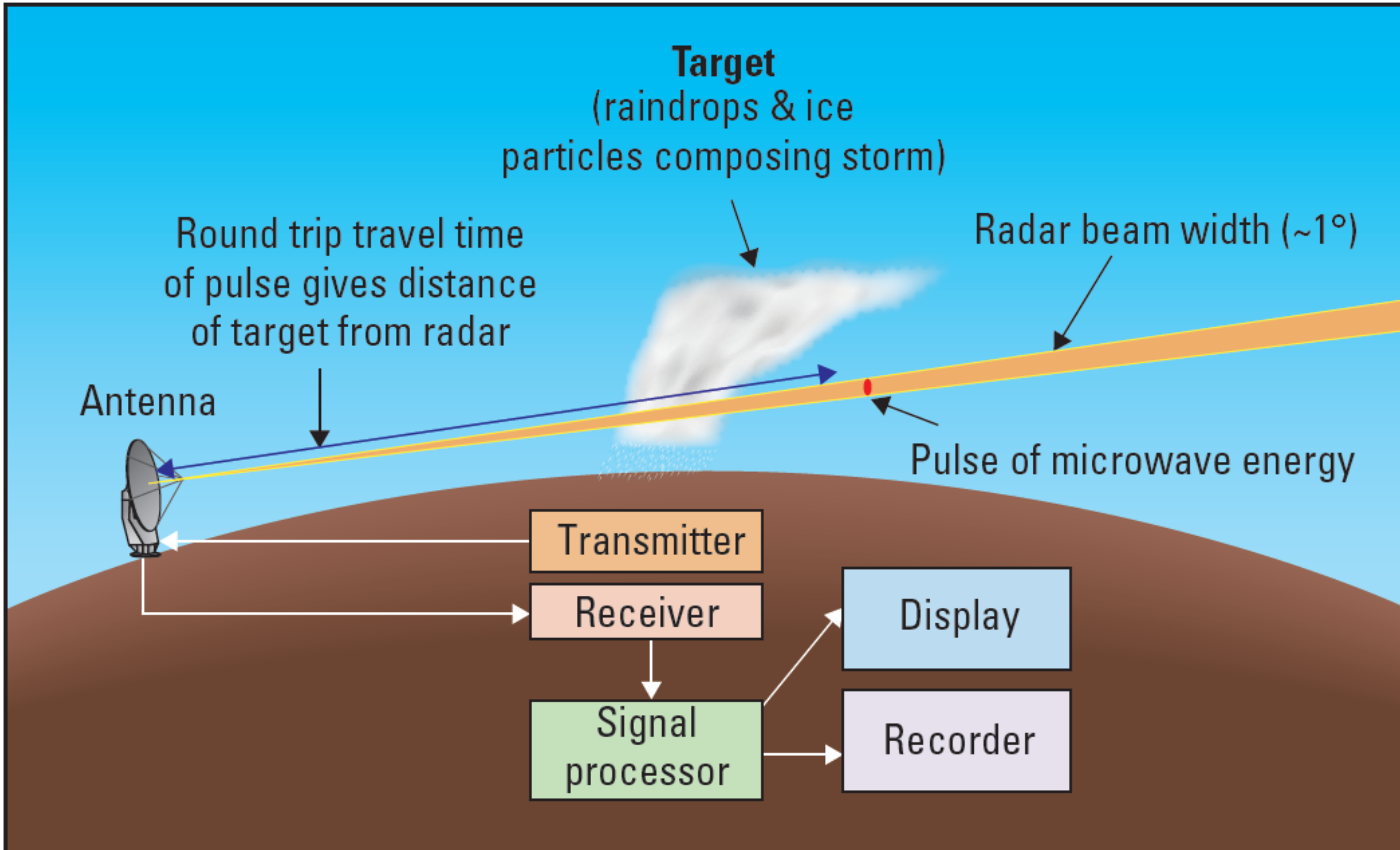
- **Radar is active remote sensor**, which emits electromagnetic (EW) waves that travel to an object and are reflected back toward the sensor.
- **A typical weather radar works by** transmitting **pulses** of EM waves (signals). Objects/targets (raindrops, ice, snow, birds, insects, terrain, and buildings) scatter that energy. Part of the backscattered energy is received back at the radar. Once the radar receives the reflected signal (echo), computer programs and meteorologists interpret the signal to determine where it is precipitating.
- Weather radar basically consists of 4 main components:
  - **a transmitter** to generate the high-frequency signal;
  - **an antenna** to send the signal out into space and receive the echo back from the target;
  - **a receiver** to detect and amplify the the signal so it is strong enough to be useful;
  - **a display system** to allow people to see what the radar has detected
- Modern weather radars use a single antenna for both transmitting and receiving. Weather radars send out short pulses of energy and then wait a while so the signal can travel out at the speed of light, hit a target, and return back to the antenna. After an appropriate wait, another pulse is sent out.

How Does Weather 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 and then is reflected back to antenna
- Time of travel tells distance
- Brightness of echo tells size and/or number of cloud/precipitation particles/scatterers



The principle components of a weather radar



Types of radar

- **Monostatic vs. bistatic radar**
  - Monostatic: use a single antenna for both receiving & transmitting (**most weather radars are monostatic**)
  - Bistatic: has two antennas (could be in different locations), one for transmitting, one for receiving
- **Continuous wave vs. pulsed radar**
  - Pulsed Radar: Radar transmits (sends out) a short pulse of EM wave and then waits for an echo from target (**weather radar are pulsed radar**)
  - Continuous wave radar: transmits and receives EM waves continuously (police radar)
- **Doppler radar:** most weather radars have Doppler function to detect wind. For example, WSR-88D/NEXRAD radars.
- **Dual-Polarization radar:** some weather radars have dual-polarization (dual-pol) function to detect particle shape. NWS is updating WSR-88D/NEXRAD radars to add this function.

What does a weather 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*;

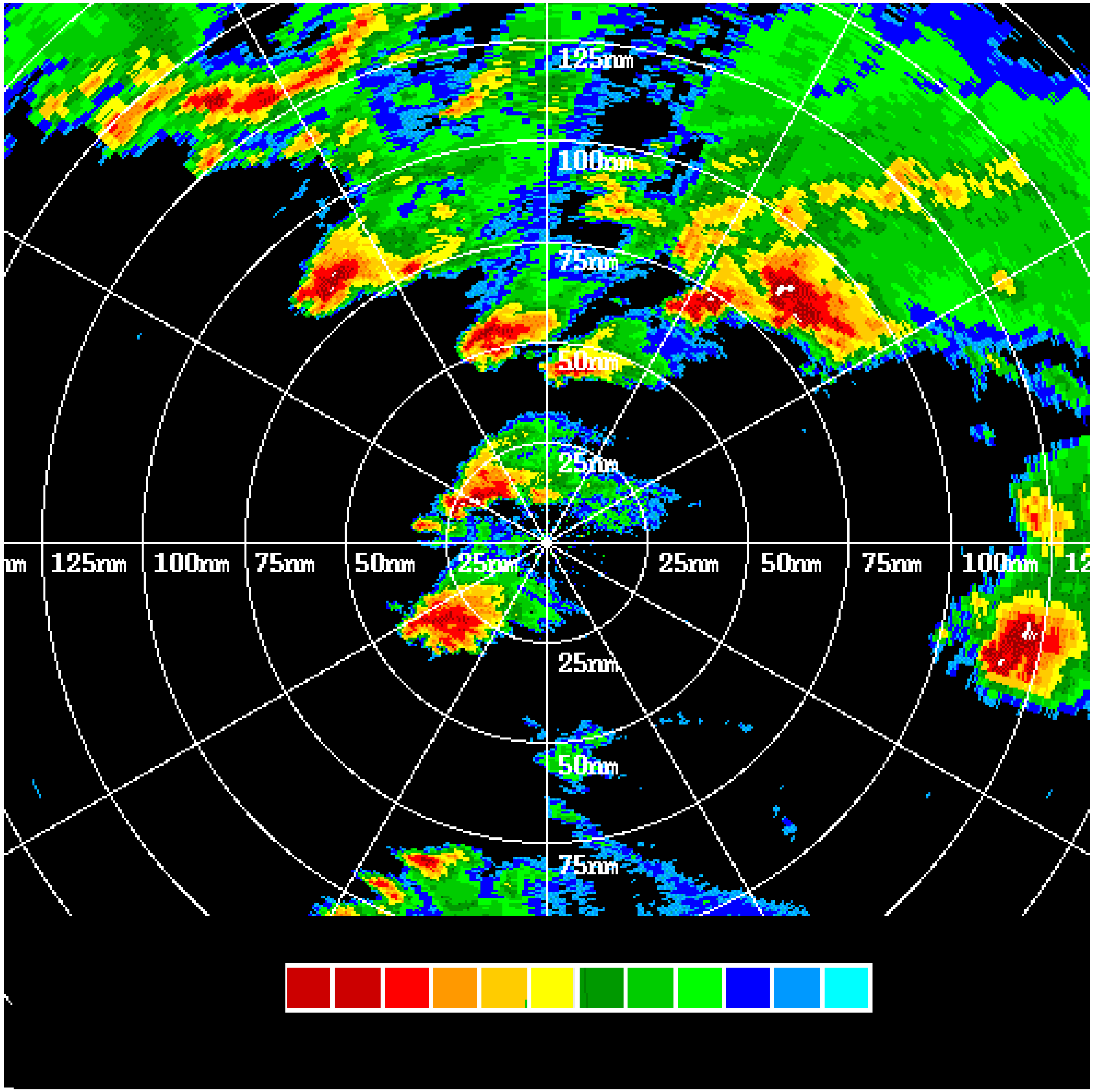
2. The pointing angles of the antenna, which determines ***the altitude of the precipitation and its geographic location***;

3. The amount of microwave energy transmitted and the amount 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.

5. (Specifically for Dual-Pol radar) **The differential radar reflectivity,** which can be used to discriminate ***the types of particles*** (hail, rain, snow, small ice crystals, etc.) within a storm.

Radar reflectivity: A measure of the power scattered back to the radar from objects in the path of a radar beam. 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.



Ground-Based Weather Radar Antenna Scanning Patterns

(airborne & spaceborne radars have different scanning patterns)

- **Horizontal Scan (PPI - Plan Position Indicator):** the antenna fixes at one elevation angle and rotates about a vertical axis, scanning the horizon or above the horizon in all azimuthal direction from 0-360 degree.
- **Vertical Scan (RHI - Range Height Indicator):** the antenna fixes at one azimuthal angle/direction and rotates vertically, scanning the vertical cross section of this azimuthal direction from 0-90 degree elevation angle.
- **Volume Scan:** The antenna will do a full circle at one elevation angle, then tilt up a degree or two and do another circle. The antenna will complete as many as 10 to 20 different elevation angles and then repeat the whole cycle in a period of about 4 to 6 minutes.

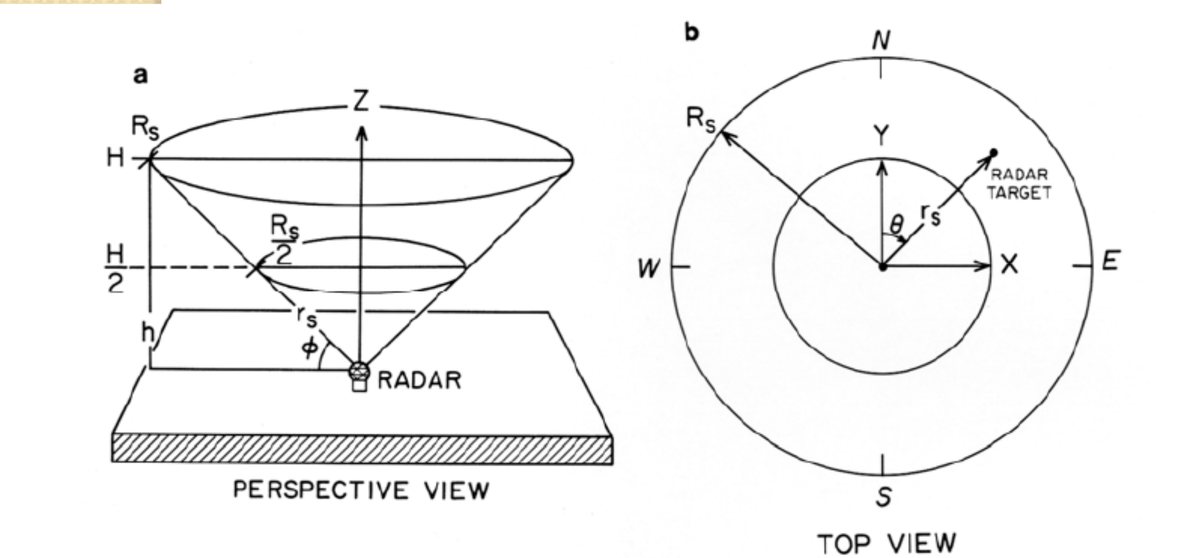
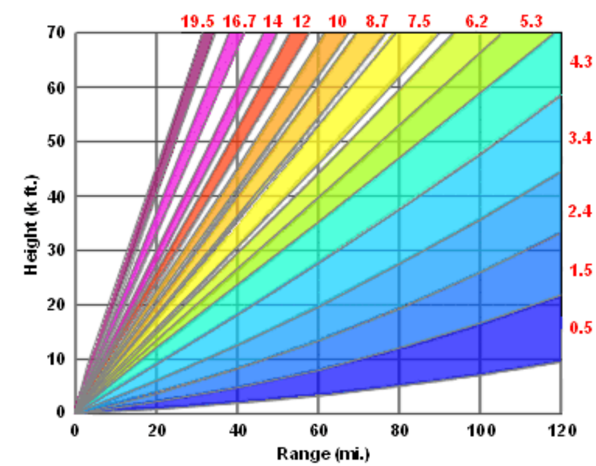


Fig. 2.1.1. Doppler radar viewing configuration. (a) Radar scanning around vertical axis, Z, at a constant elevation angle, ϕ; (b) view of (a) from the top, representing a PPI (plan position indicator) display. R_s is slant range (on conical surface) of the edge of the display corresponding to height 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 of A Series of Elevation Angles during One Volume Scan

Weather Radar Displays/Indicators: PPI

- Plan Position Indicator (PPI): displays the radar data in a map-like format, usually with the radar at the center. Distance is given by adding range marks (Range rings) around the rada
- PPI is displayed on compass coordinates (not polar coordinates): up- North; down-south; right-east, left-west.

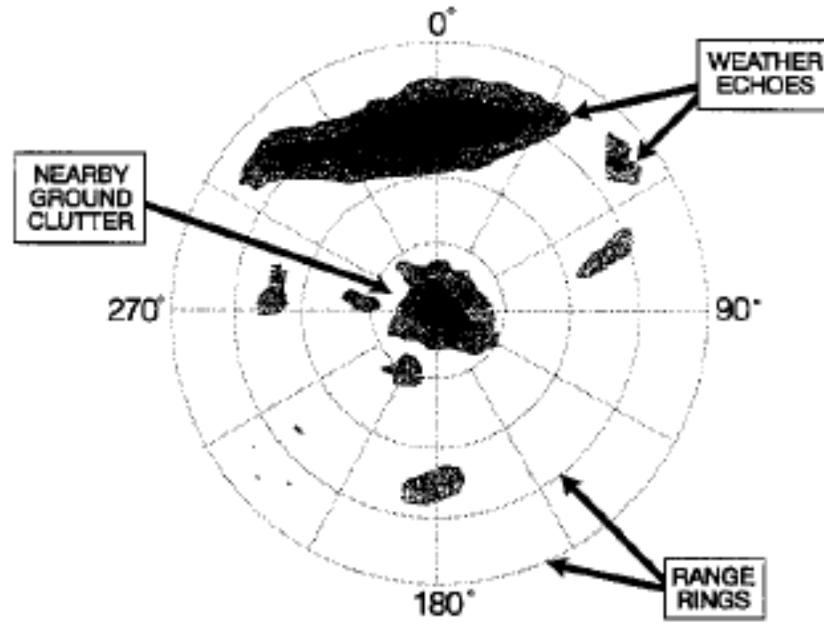
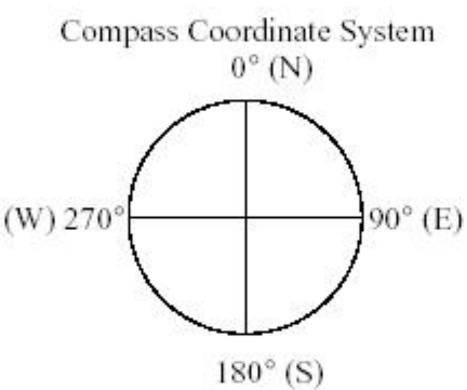
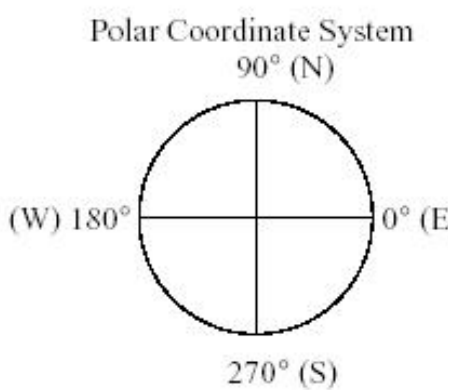
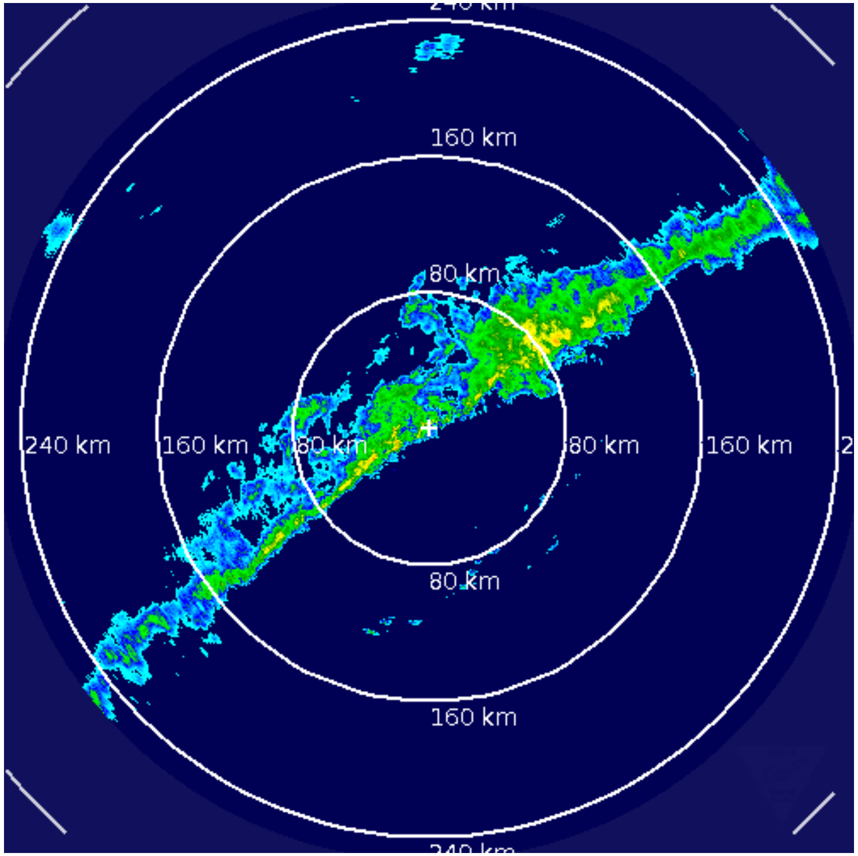


Figure 2.11 Schematic diagram of a PPI display showing nearby ground clutter and distant weather echoes. Echo intensity is indicated by shading, where the darker the shading, the stronger the echo.





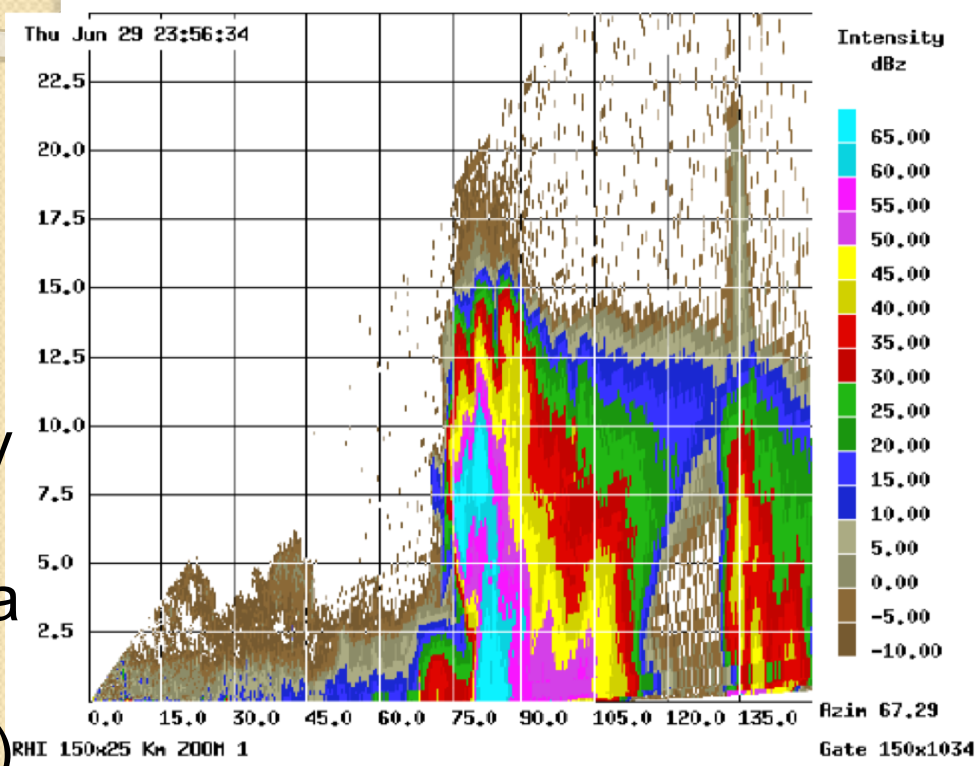
PPI: Cold Front



Bermuda Weather Service Radar image showing a band of rain associated with a cold front at 3:43pm local time December 31st 2013.

Weather Radar Displays/Indicators: RHI

RHI –Range Height Indicator

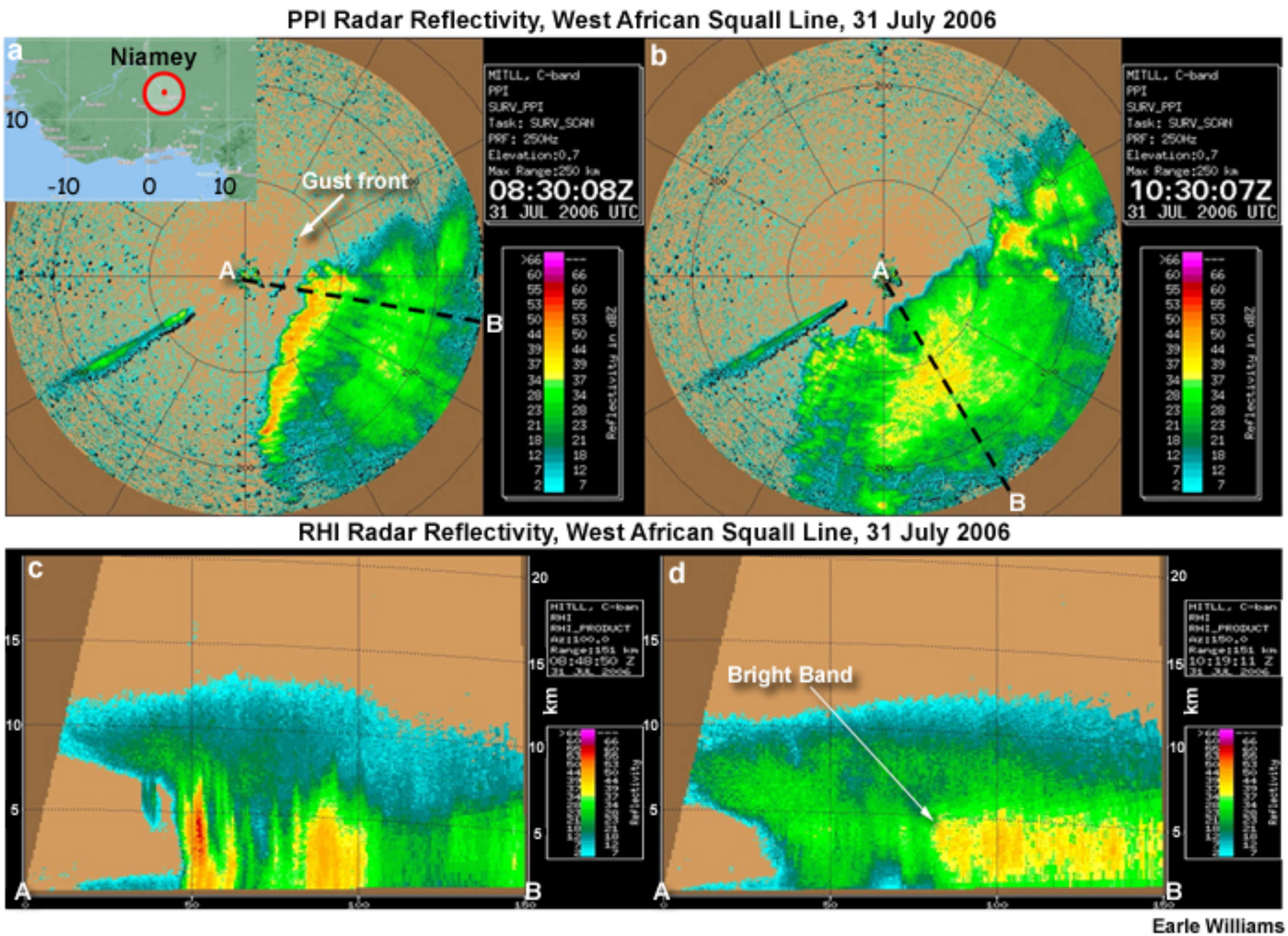


Height Above Radar (km)

Range/Horizontal Distance From Radar (km)

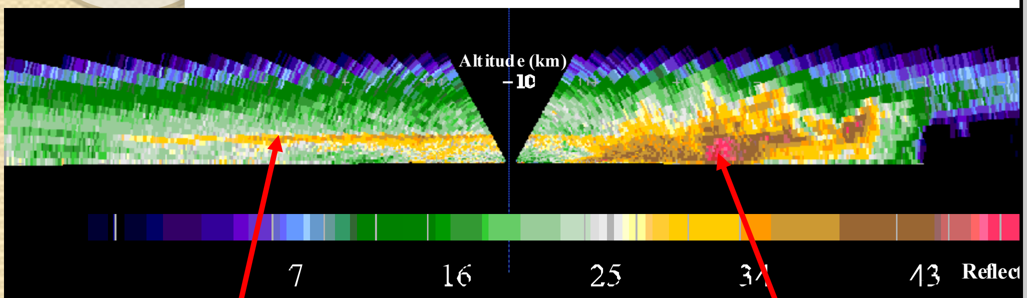
- Range Height Indicator (RHI): displays the radar data in a vertical cross-section format, usually with the radar at the left-bottom corner. RHI is very useful to show the vertical structure of storm.
- It's very helpful to have both the horizontal (PPI) & vertical (RHI) view of a storm.

Both PPI and RHI from a Squall Line: RHIs in the bottom row are vertical cross-sections along line AB on the PPIs on the top row

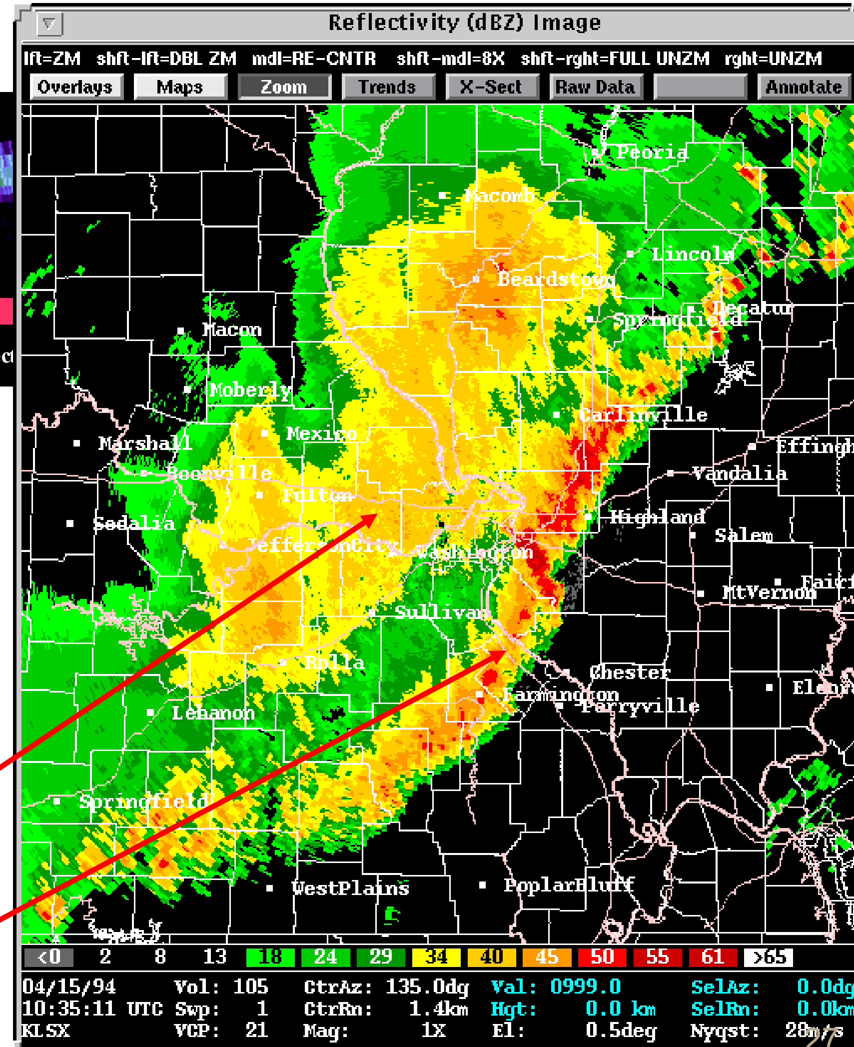


Bright Bands on Radar Vertical Image

Vertical cross section of radar reflectivity in a squall line



Horizontal radar reflectivity image of the same squall line



Bright band indicating stratiform precipitation regions

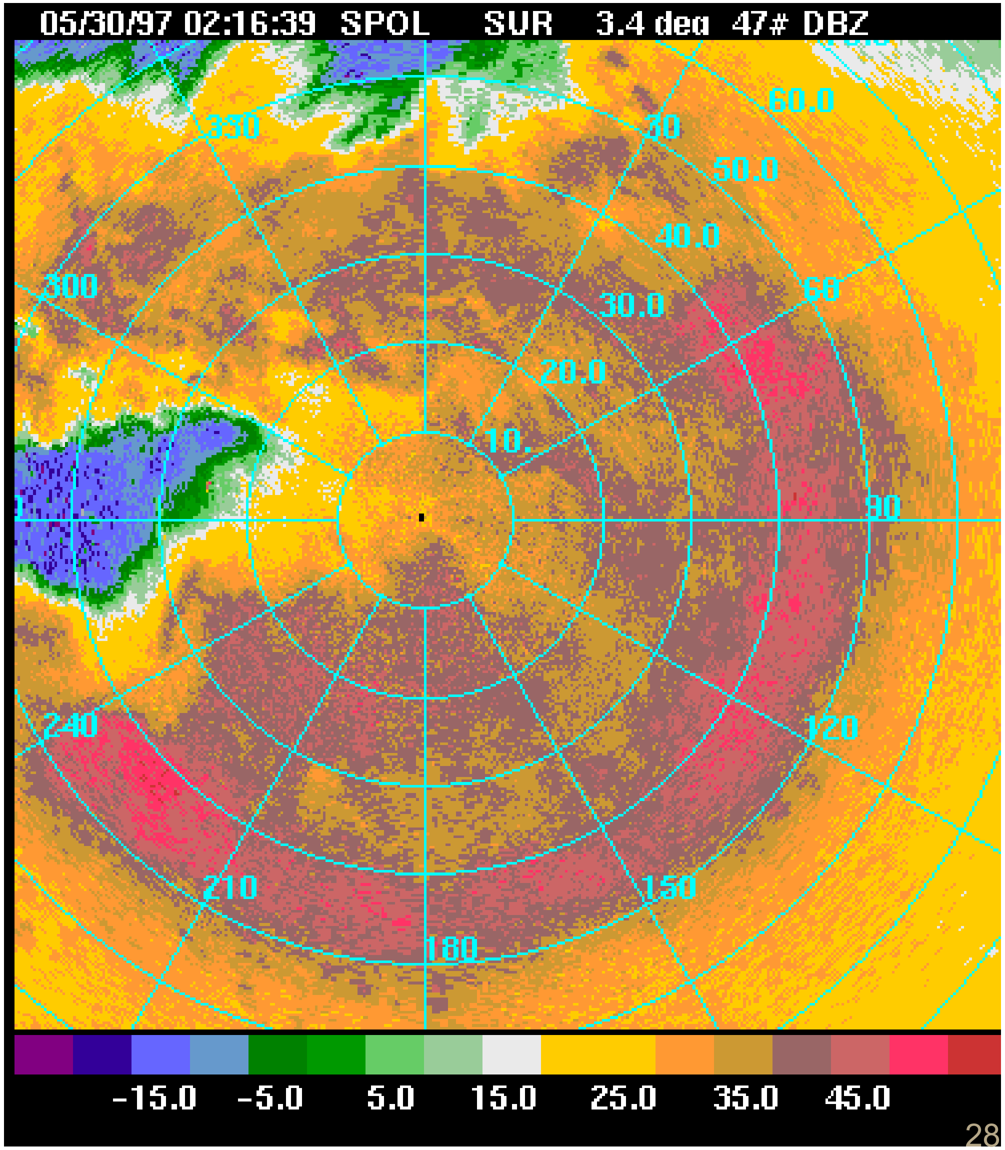
Convective Region without bright bands

Stratiform precipitation regions

Convective precipitation Region

Bright Band on Radar PPI Image

- The enhanced half-circle ring with 45-50 dBZ reflectivity is the bright band.
- Since the antenna elevation angle is 3.4 deg in this case, the echo height at 40-50 km distance is located at the melting level.
- Cases like this could cause overestimation of precipitation rate due to the bright band contamination when using Z-R relationship to estimate rain.



Hail

- Definition: Hail is defined as precipitation in the form of ice that has a diameter of at least 5 mm.
- Hail ranges from 5 mm to about 10 cm in diameter.
- Hail occurs almost always in thunderstorms, but can fall from rainstorms too.
- 85 % of all thunderstorms contain hail at least during part of their lives.

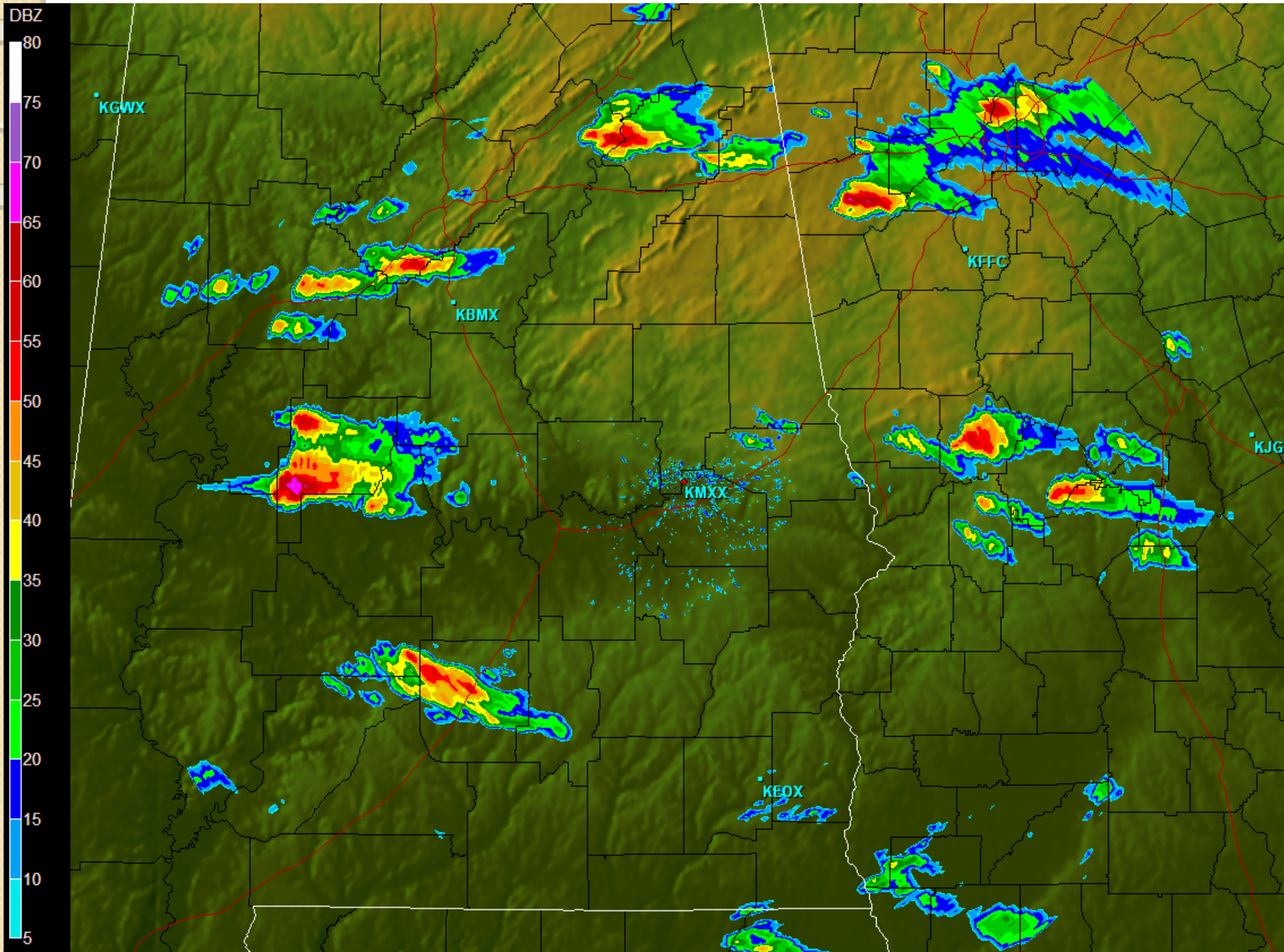
Detection of Hail by Conventional Radar

- **Reflectivity of Rain:** usually 20-50 dBZ (sometime could go up to 55 dBZ)
- **Reflectivity of Hail:** a general rule:
  - reflectivity>= 60 dBZ, definitely hail; 50-55 dBZ, possible hail; >=70 dBZ, large hail.
- **Uncertainties:**
  - Wet hails has greater reflectivity values than dry hails at the same size.
  - Almost all hailstones are in Mie region for 3-cm and 5-cm radars. For 10-cm radar, small hail is in Rayleigh region, but large hail is in Mie region
- **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.

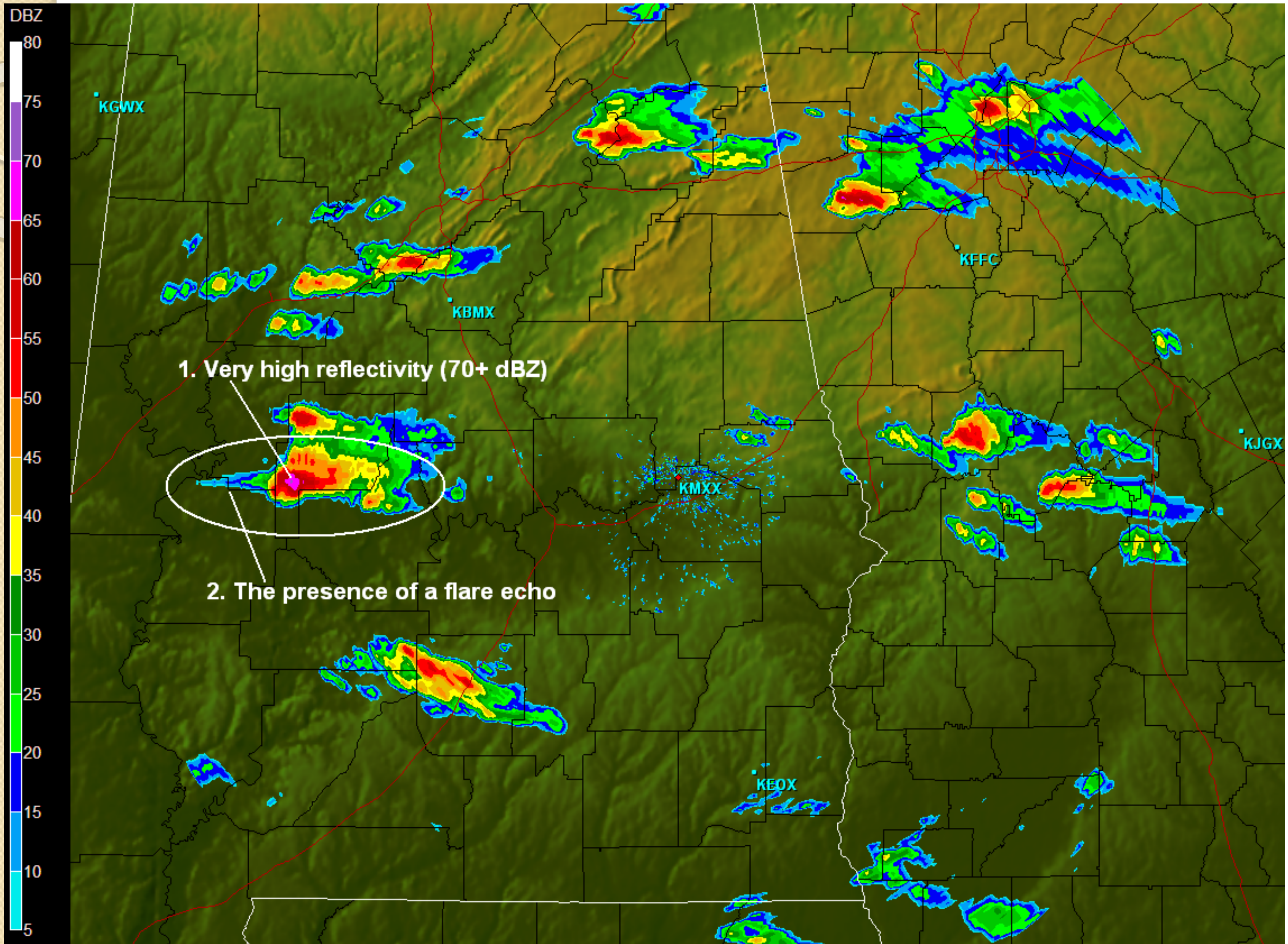
How does a Flare Echo occur?

- Radar transmitted microwave radiation is *strongly* scattered in all directions, by large hail.
- Some of the energy initially scattered by large hail hits the ground, and, in turn, is back-scattered. Some of the energy back-scattered by the ground strikes large hail within the storm.
- This back-scattered signal from the ground is still sufficiently strong that large hail back-scatters some of the energy to the radar.
- This weaker signal arrives a bit later than the initial strong signal of back-scattered energy, so the radar interprets this second signal as a weak, elongated echo (which meteorologists refer to as a flare echo).

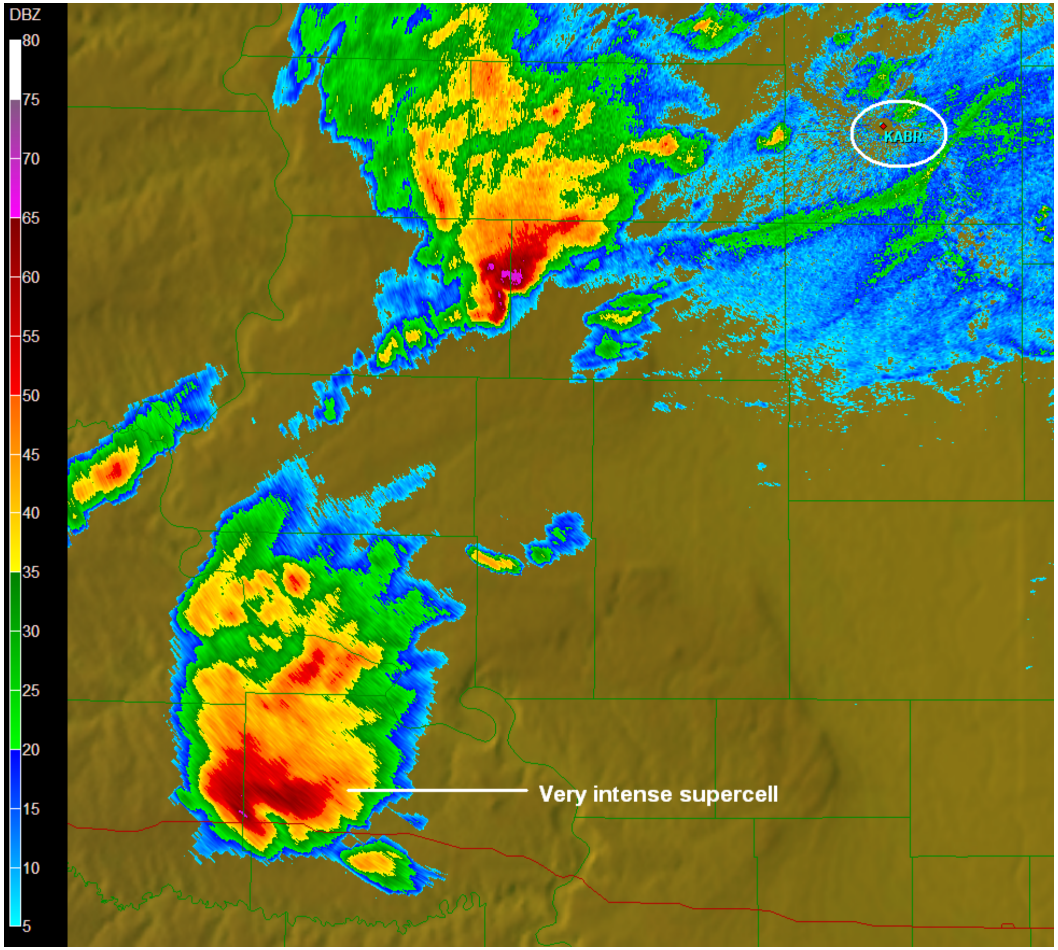
Which echo is likely to producing large hail?



Answer:


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

Severe thunderstorms over South Dakota, July 23, 2010

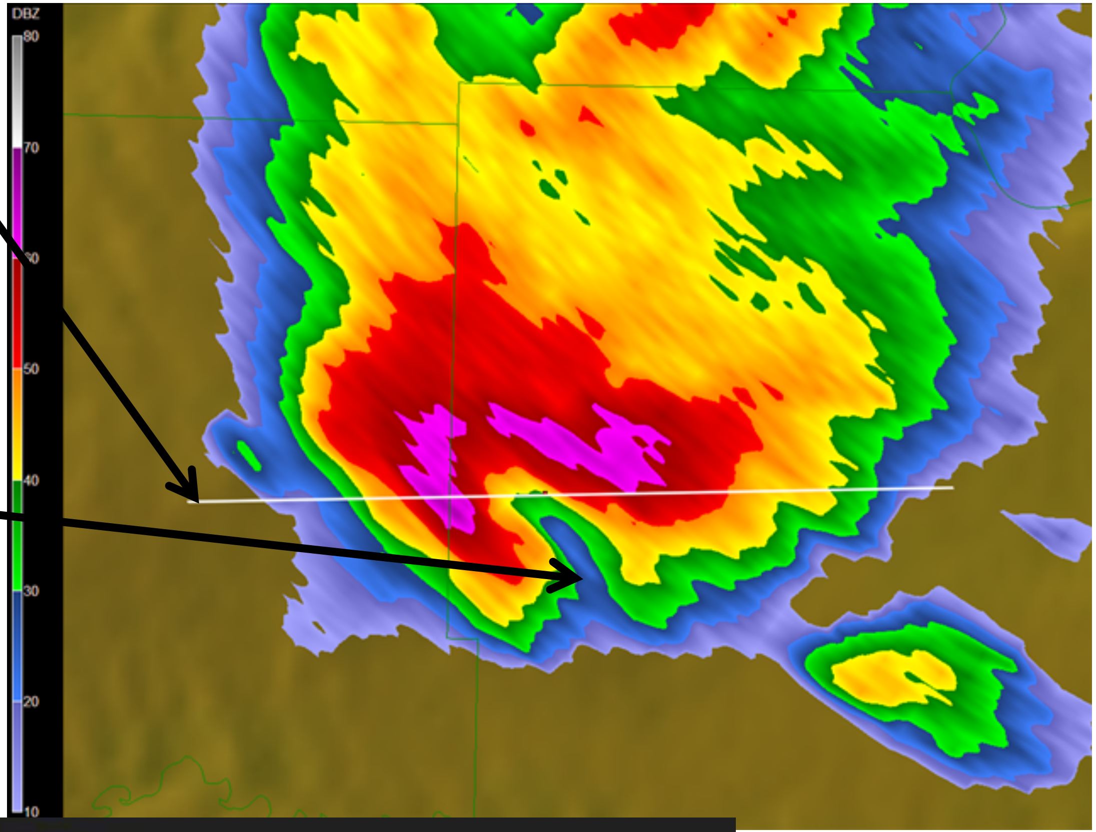


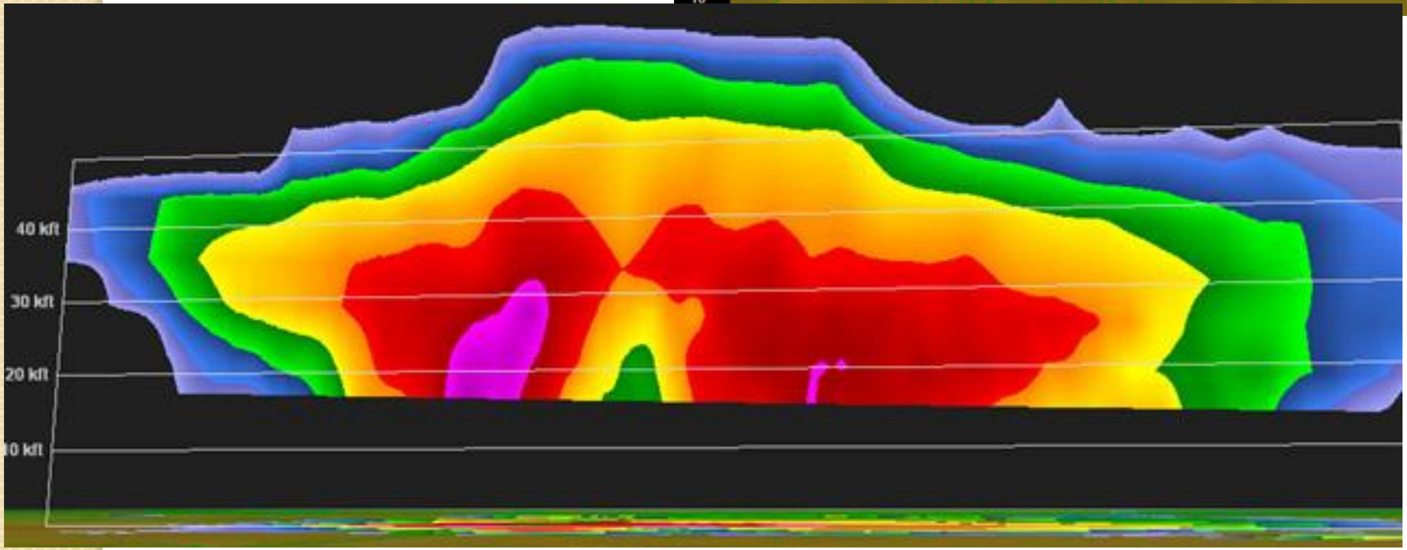
The giant hailstone that fell from a supercell at the town of Vivian, South Dakota, on July 23, 2010, had a record-breaking diameter of eight inches.

Cross section

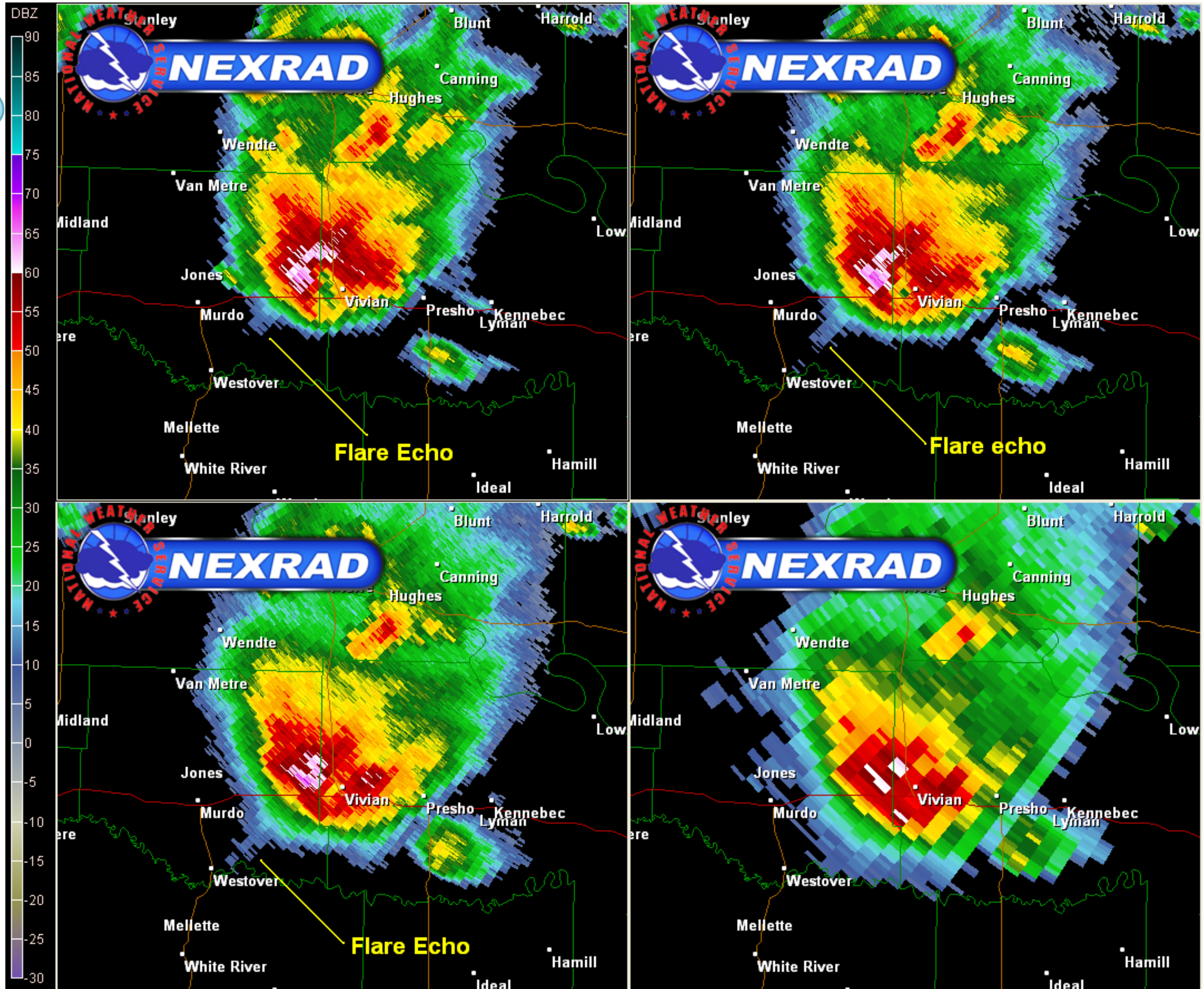
Cross-section along this line

Hook Echo





Radar images at Aberdeen SD around 23Z on July 23 (0.5, 0.9, 1.3, 1.8 degree elevation angles)



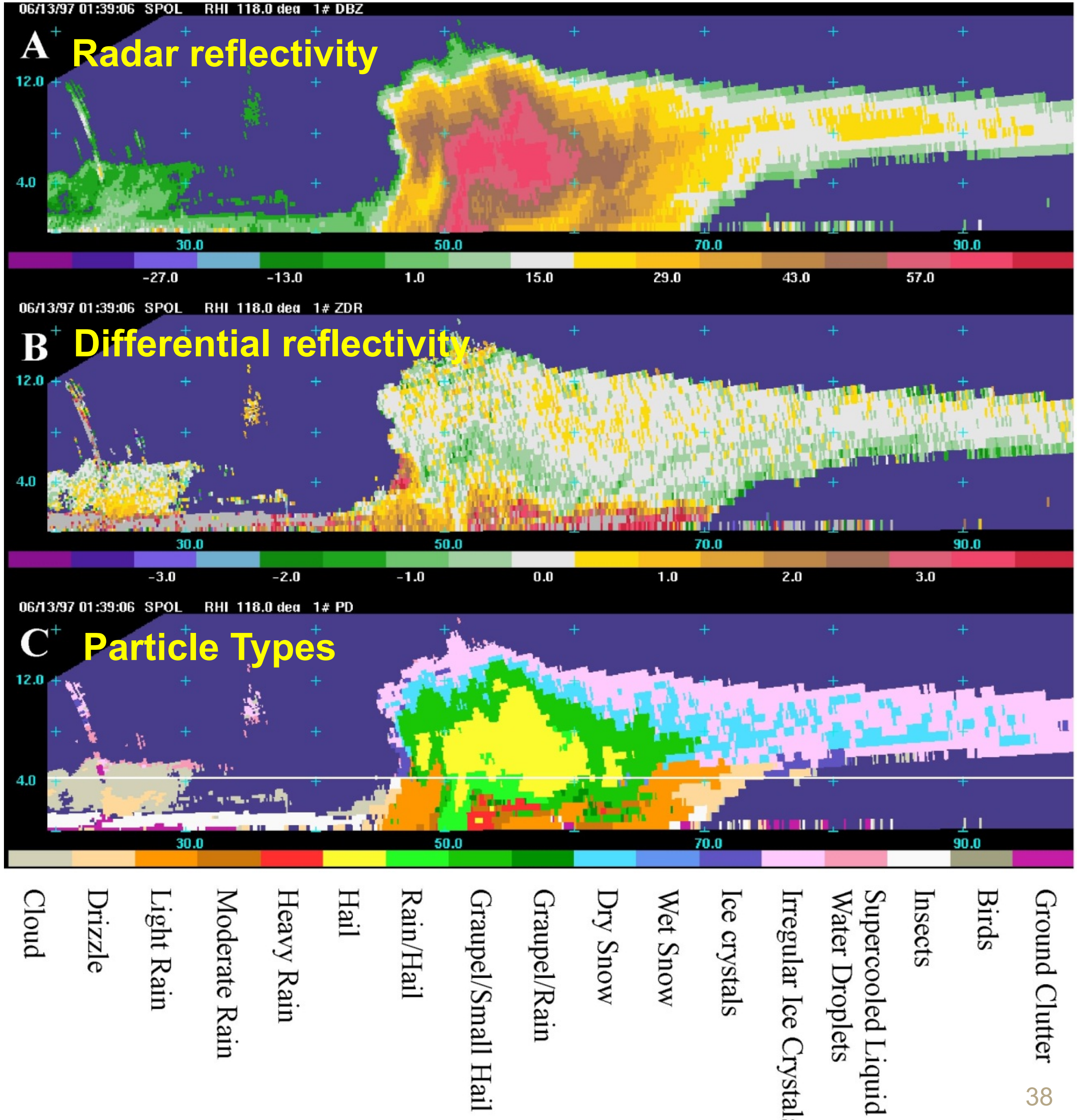
Dual-Polarization (Dual-Pol) Radar

- **Convectional radar** can not determine hail exactly
- **Dual-pol radar** will improve warnings for hail. Dual-pol radars are capable of distinguishing regions of hail from regions of heavy rain. They measure many parameters related to the polarization state of the transmitted and received radar energy. The set of measurable quantities that can be derived from polarization diversity radars together can be used to discriminate the types of particles (hail, rain, snow, small ice crystals, etc.) within a storm.
- **NWS is upgrading its Doppler radar network (WSR-88D)** to include dual-polarization function.

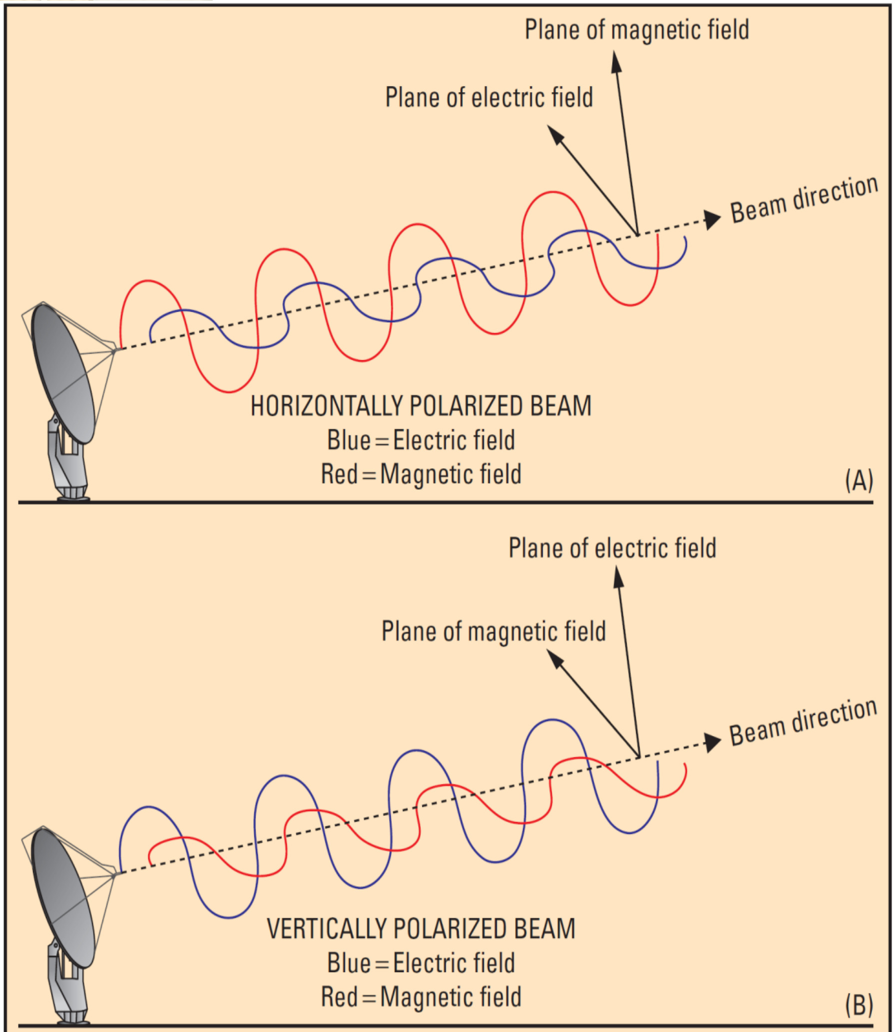
Dual-Pol radar can discriminate different particle shapes & precipitation types

Differential reflectivity: a measure of the shape of the particles within the beam.

Panel (c): **hail has high dBZ and low differential dBZ values.** Most hail is above 4 km (freezing level). But the downward pointing finger of hail is most likely to reach the ground.

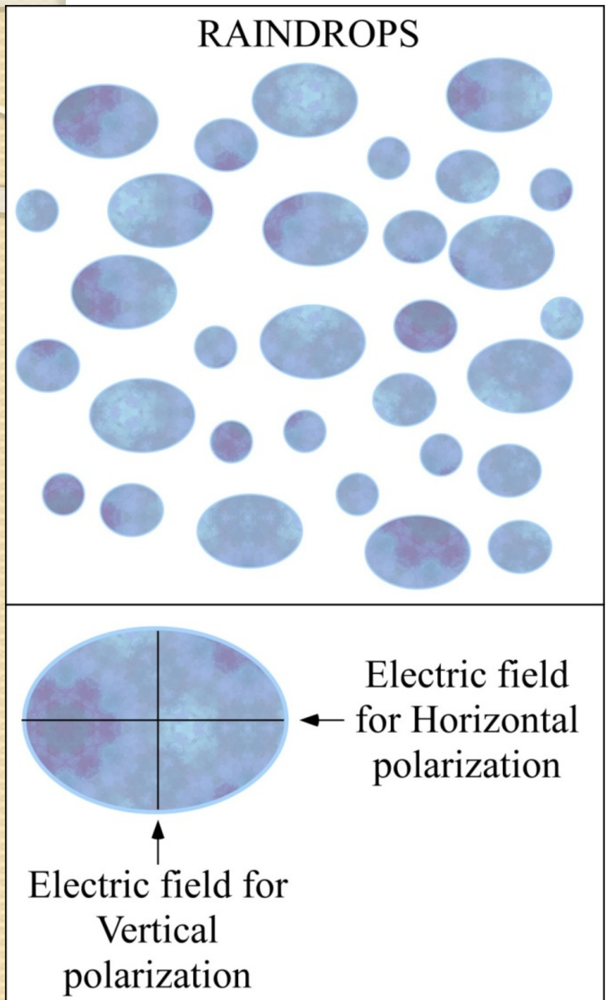


Radar Polarization



- **Radar transmit EM waves** with oscillating electronic and magnetic fields. **E and M fields are perpendicular** to each other and to the direction of radar beam.
- **Convectional radar**: E field oscillates in a plane horizontally (parallel to Earth surface)—Horizontally Polarized (A). Some radars could be Vertically Polarized (B).
- **Dual-Pol Radar**: The orientation of the electric field (polarization) is switched back & forth between horizontal & vertical orientation.
- **Differential reflectivity** is the ratio of the reflectivity measured at horizontal polarization to that at vertical polarization.

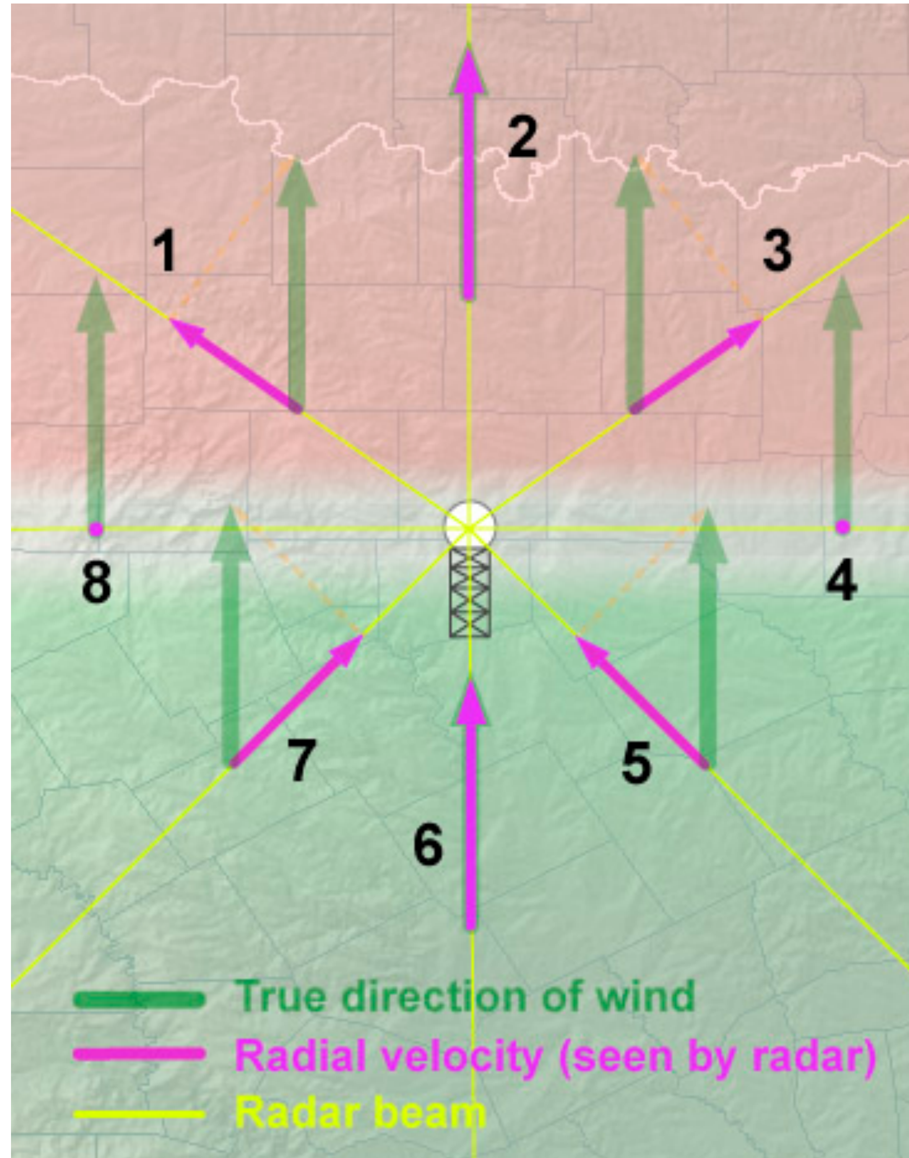
Differential Reflectivity of Rain & Hail



- **Raindrops:** oval shape. Horizontally polarized reflectivity is larger than vertically polarized reflectivity. Therefore, differential reflectivity is 1-2 dB for moderate rain & 3-4 dB for heavy rain.
- **Hailstones:** some are spherical, others have different shapes. But overall, hailstones fall randomly with no preferred orientation. Therefore, when radar views a large number of hailstones, the differential reflectivity is about 0 dB.

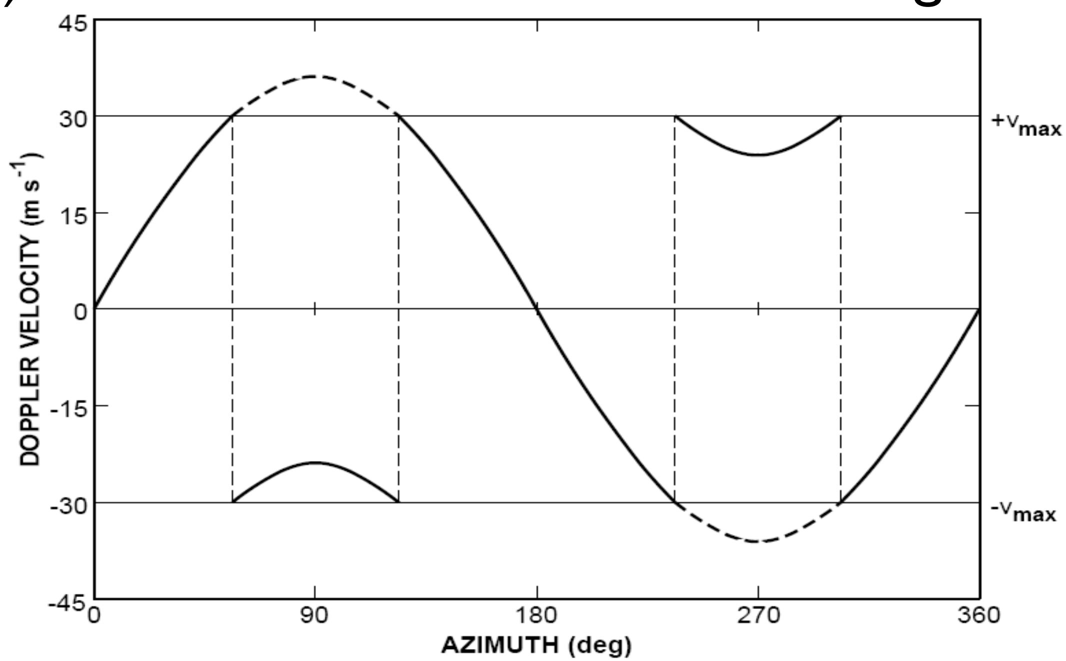
Doppler Radial Velocity

- A Doppler radar can measure winds besides reflectivity. However, it only measures the **Doppler Radial Velocity Vr**, which is the component of the real wind V along the direction of the radar beam.
- **V=Vr*cosα,** where α is the angle between the radar beam and the true direction of wind.
- **Two special cases:** When the radar beam direction is the same as the true direction of wind, V=Vr; when they are perpendicular, Vr=0



Velocity Folding/Aliasing

The figure below shows the measured Doppler radial velocity Vr as a function of the azimuth angle of radar beam relative to the north (0 deg at north) for an environmental wind blowing from the west at 36 m/s.

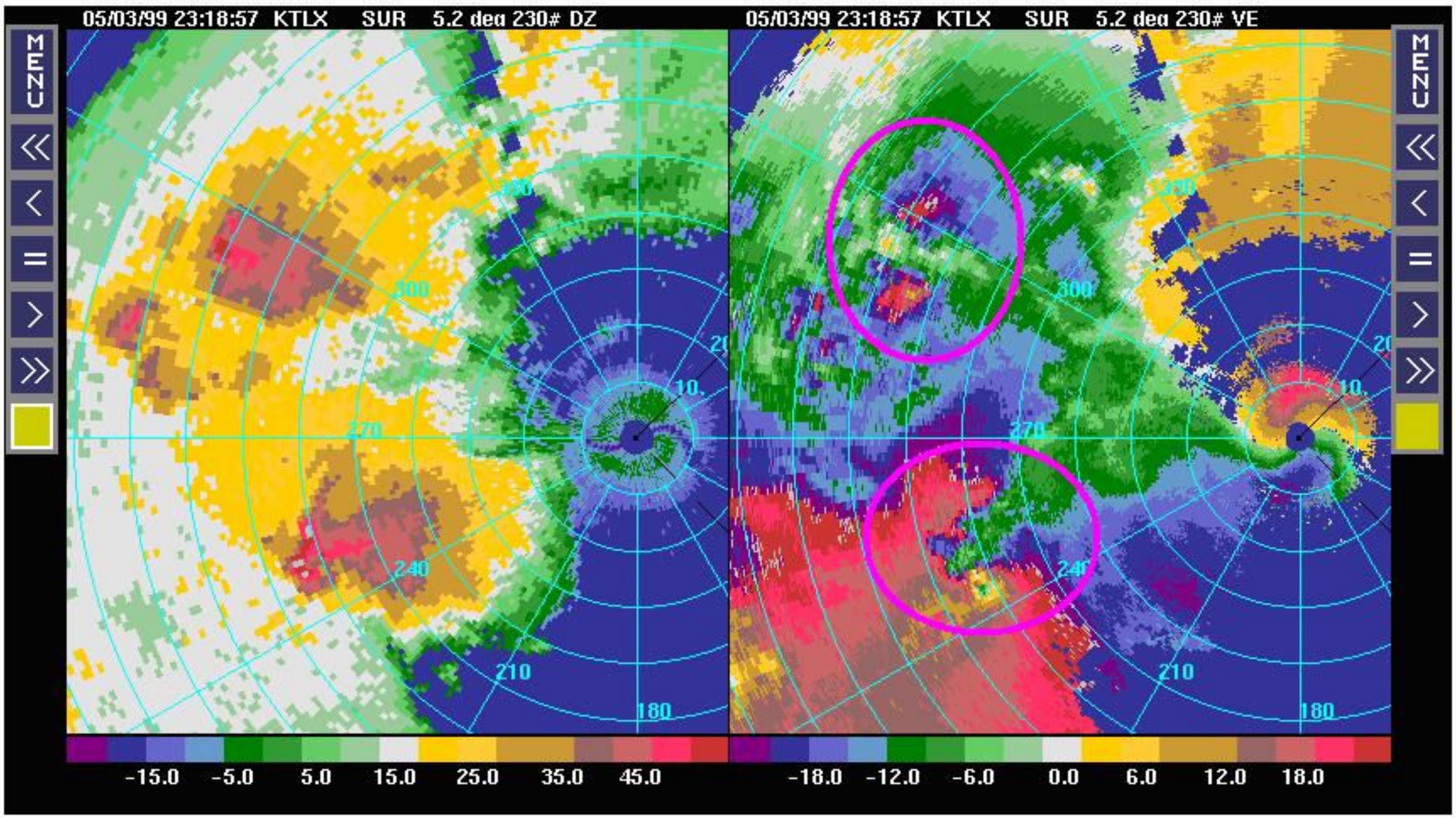


- The aliasing process causes the Doppler velocity values offset by 2 V_{max} (here V_{max} =30 m/s)until they fall within +/- V_{max}. Thus, +36 m/s is aliased to: ***36 m/s -2*30 m/s=-24 m/s***

So $V_r = V_{real} - 2\,V_{max}$ ***or*** $V_{real} = V_r + 2\,V_{max}$

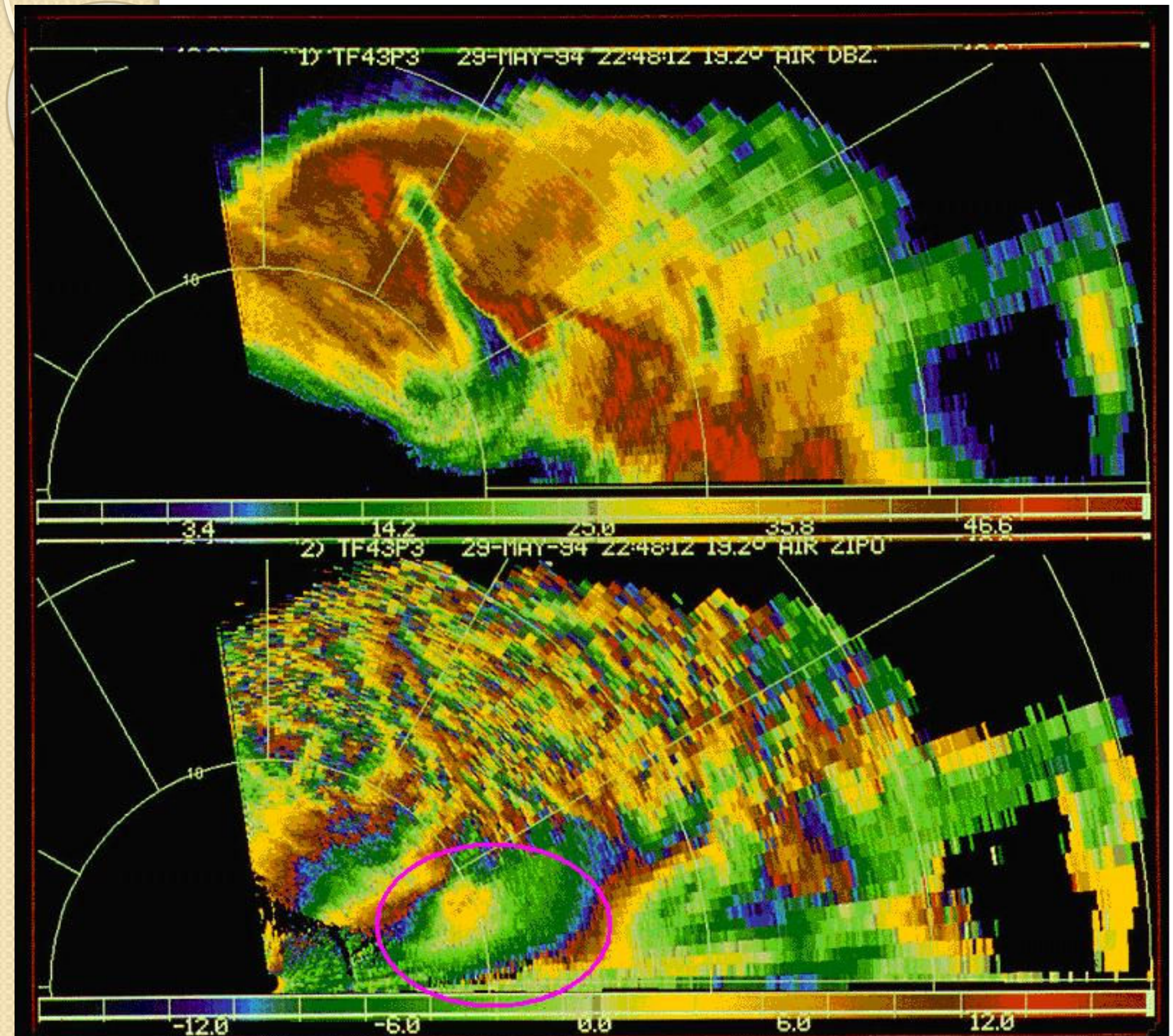
Recognizing Velocity Aliasing/Folding

- Velocity folding is at velocity discontinuity regions(usually in strong reflectivity regions) where Doppler velocity changes from maximum negative values to maximum positive values, or vice versa.



Radar Reflectivity in dBZ **Doppler radial velocity in m/s**

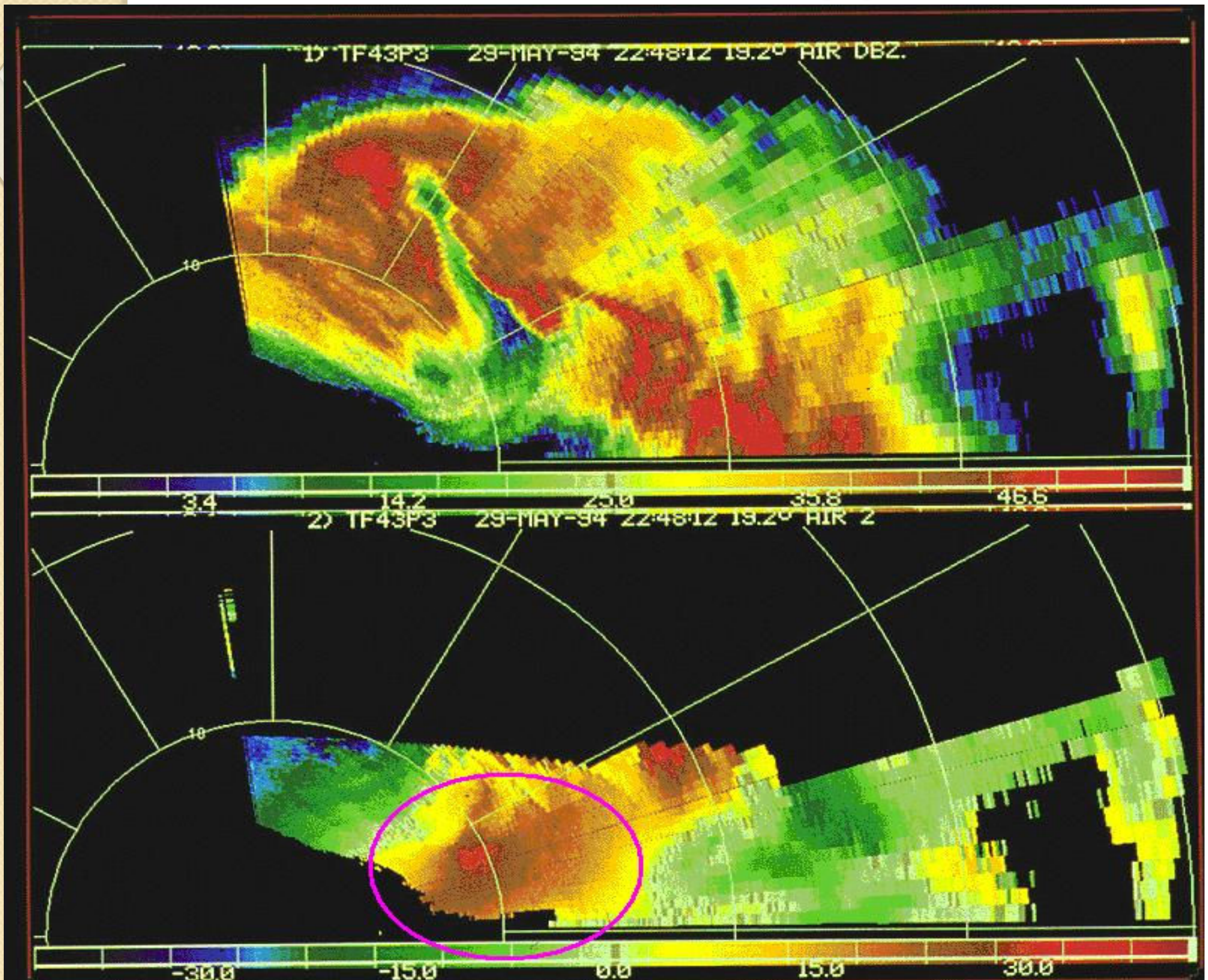
Another Doppler velocity folding case



Reflectivity in dBZ

Doppler radial velocity in m/s

Corrected/Unfolded Doppler Radial Velocity



Reflectivity in dBZ

Unfolded Doppler radial velocity in m/s

Interpretation of Doppler Velocity

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

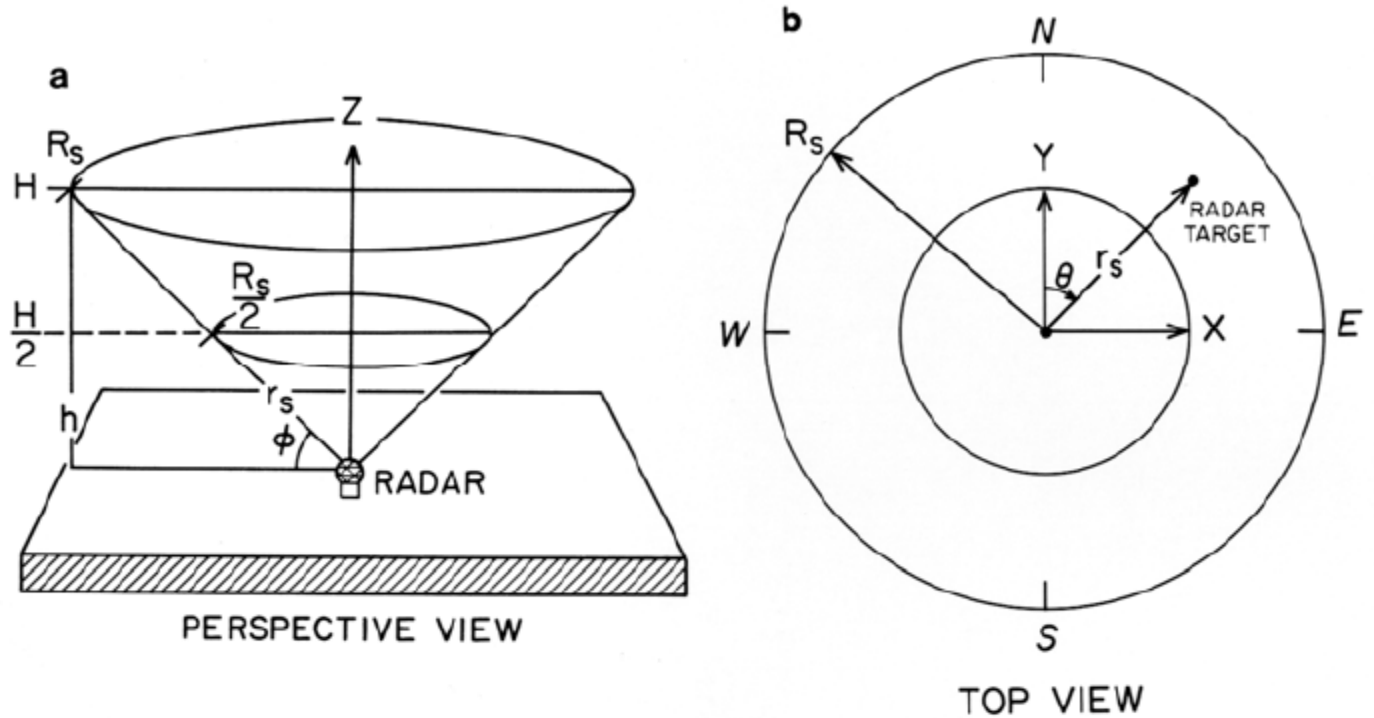


***Fig. 2.1.1**. Doppler radar viewing configuration. (a) Radar scanning around vertical axis, Z, at a constant elevation angle, ϕ; (b) view of (a) from the top, representing a PPI (plan position indicator) display. R_s is slant range (on conical surface) of the edge of the display corresponding to height 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 VAD display
- 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.
- Wind speed at a given height is the maximum value around a constant slant range circle. Wind direction at a given height is determined from the zero value curve.

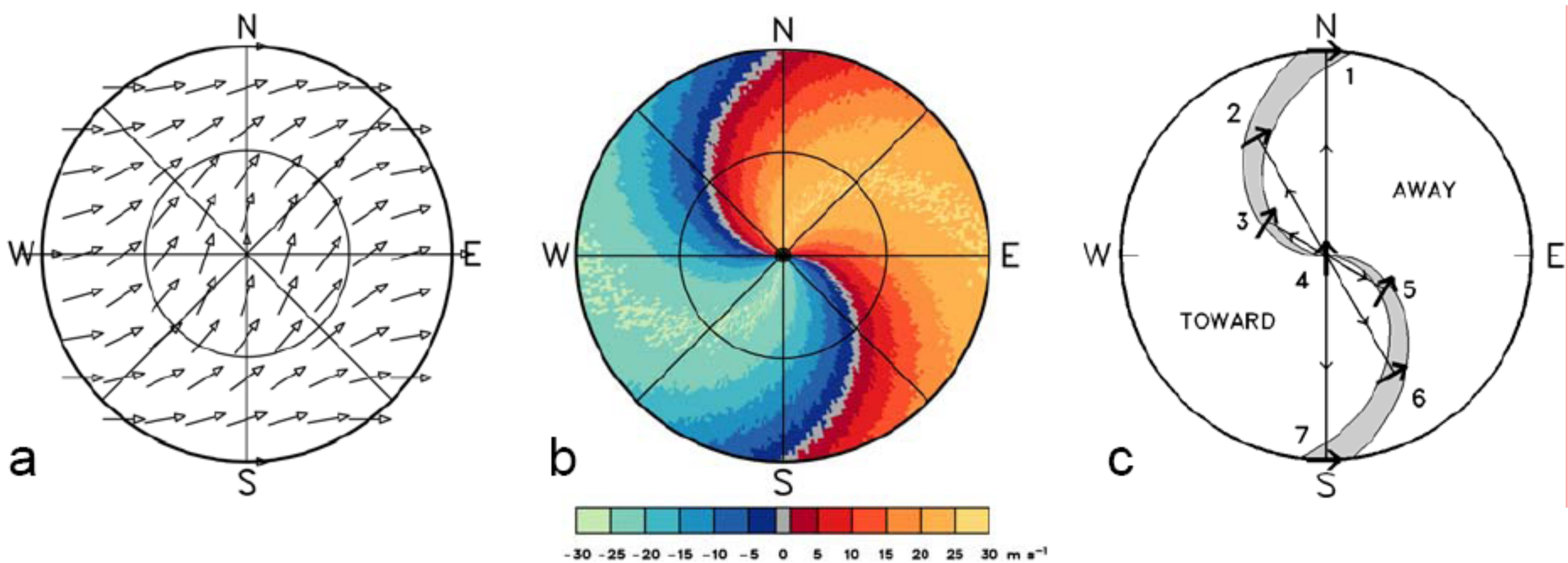


Fig. 2.1.2. Plan view of (a) environmental wind field and (b) corresponding single Doppler velocity pattern for wind with constant speed (26 m s^{-1} or 50 kt) and with direction changing uniformly from southerly at the ground (center of display) through southwesterly to westerly at the edge of the display. 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 vertical profiles having constant wind directions

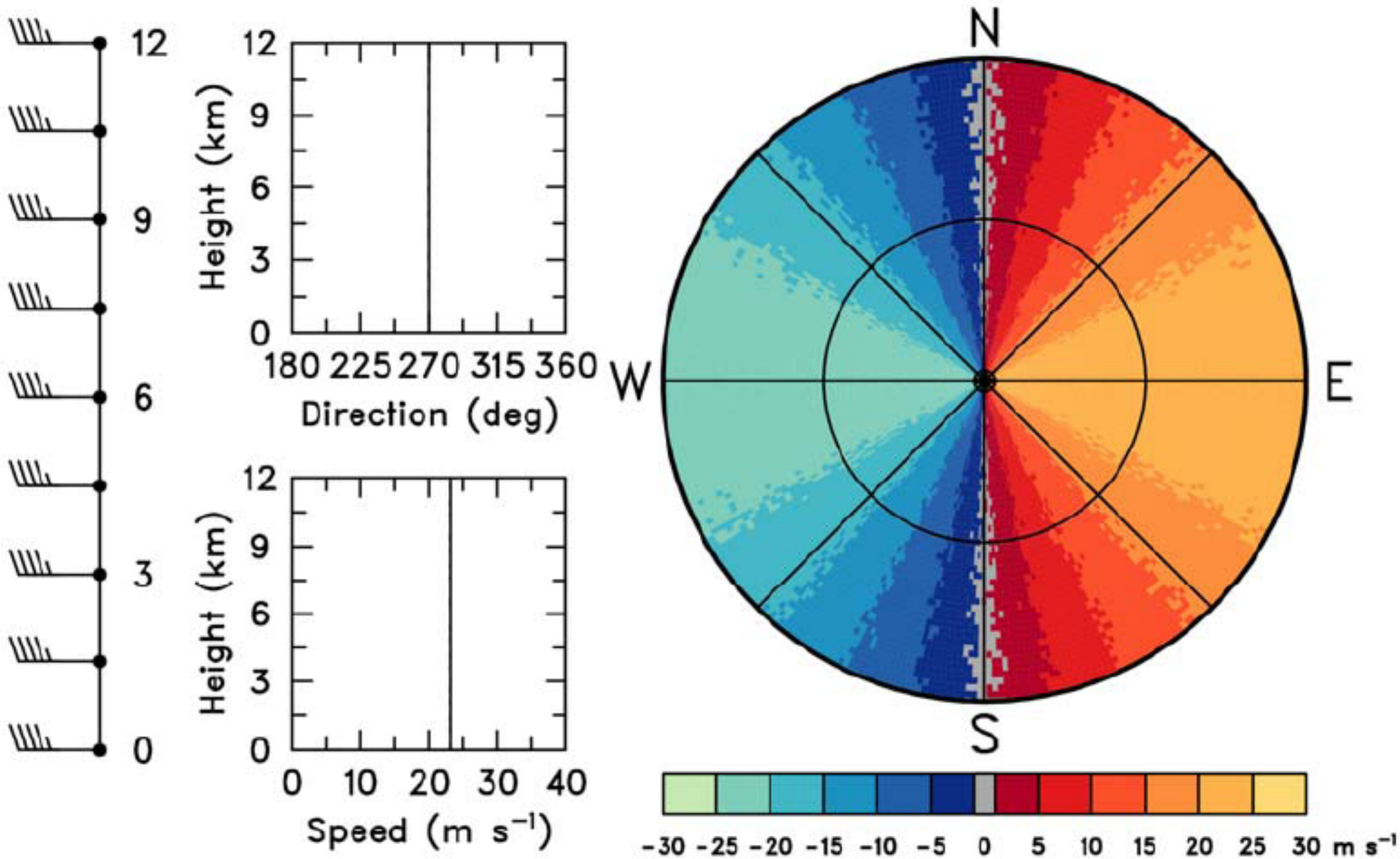


***Fig. 2.2.1**. Doppler velocity pattern (right) corresponding to a vertical wind profile (left) where both speed (23 m s^{-1} or 45 kt) and direction (270°) are constant with height. Negative (positive) Doppler velocities represent flow toward (away from) radar. Radar is at the center of the display.*

Patterns associated with vertical profiles having constant wind directions

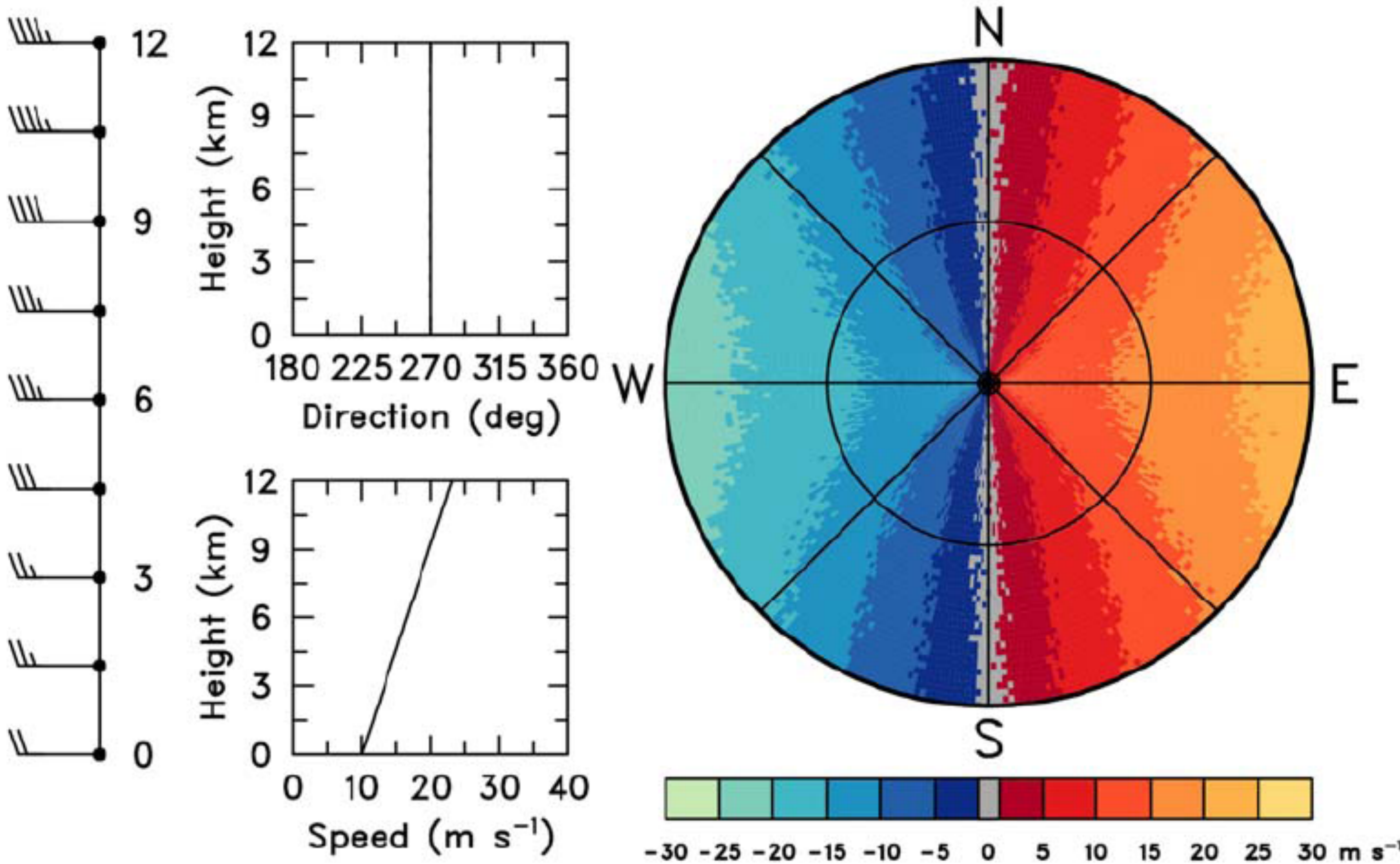


***Fig. 2.2.2**. Same as Fig. 2.2.1, except that the wind speed increases from 10 m s^{-1} (19 kt) at the ground to 23 m s^{-1} (45 kt) at the edge of the display.*

Patterns associated with vertical profiles having constant wind directions

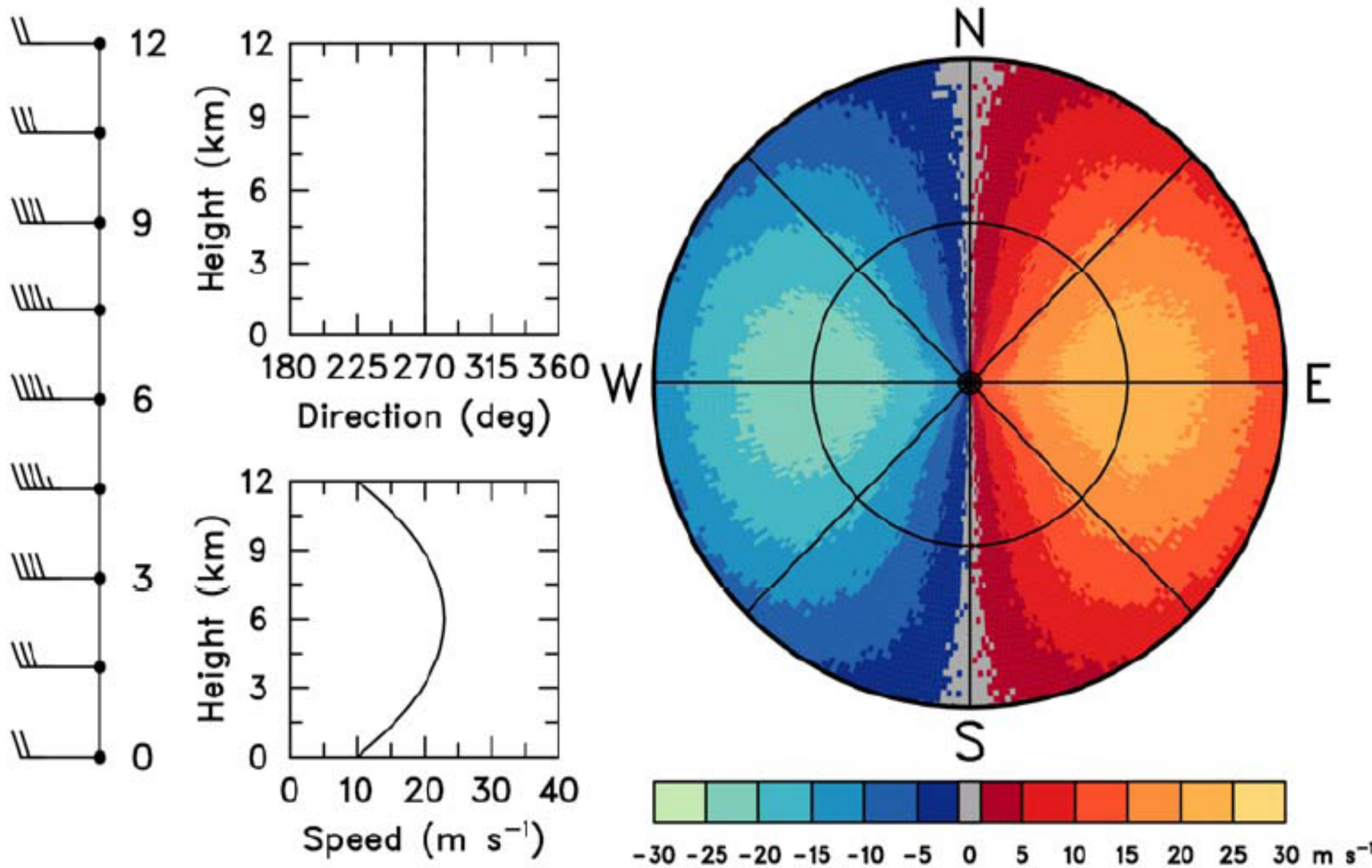


Fig. 2.2.3. *Same as Fig. 2.2.1, except that the wind speed is a maximum of 23 m s^{-1} (45 kt) midway between the ground and the height corresponding to the edge of the display. Speed is 10 m s^{-1} (19 kt) at the surface and at the edge of the display.*

Patterns associated with nonuniform horizontal wind fields (difluent)

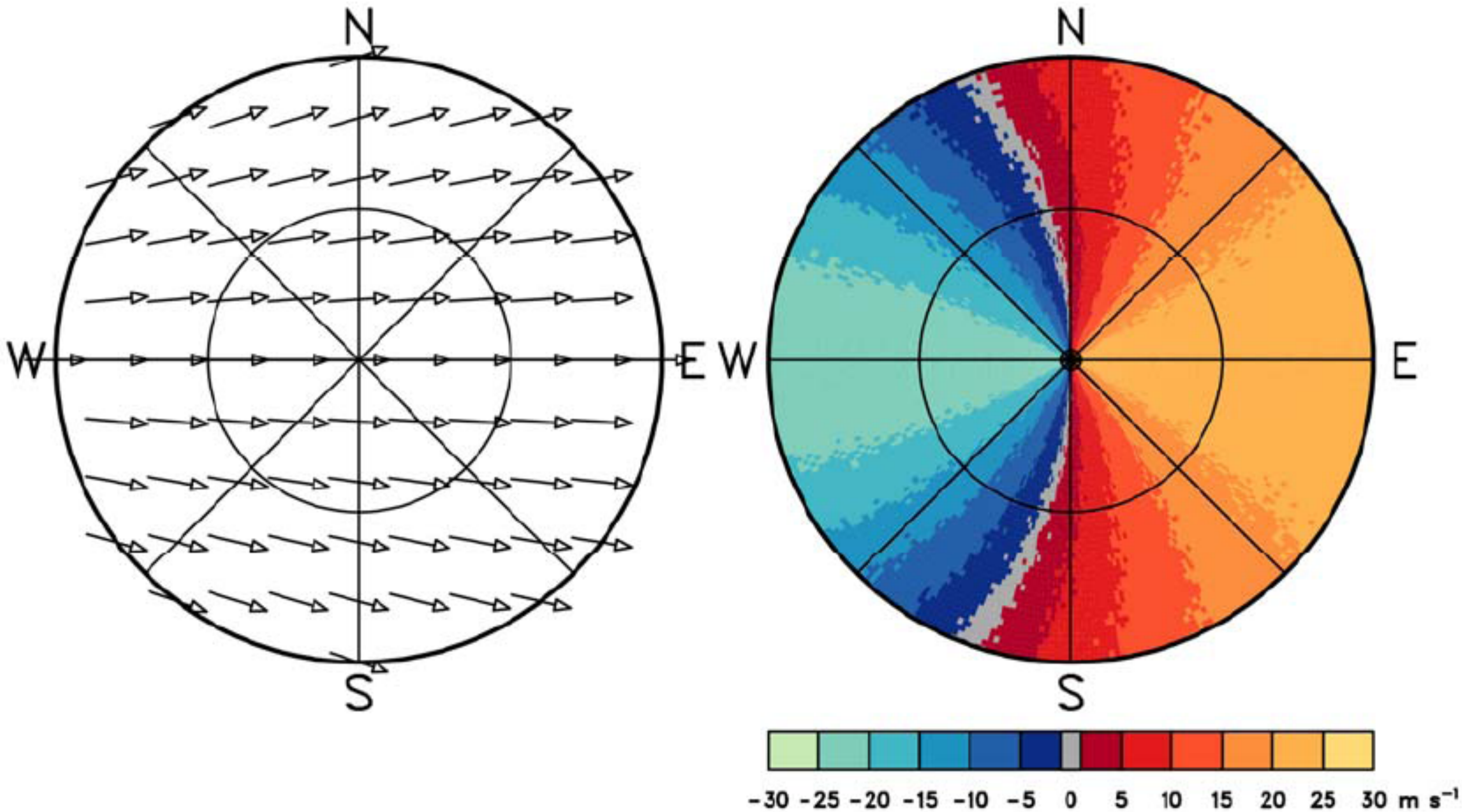


***Fig. 2.3.1**. Doppler velocity pattern (right) corresponding to a horizontal flow field that is difluent with the same speed (23 m s^{-1} or 45 kt) at all heights (left). Negative (positive) Doppler velocities represent flow toward (away from) the radar. Radar location is at the center of the display.*

Patterns associated with nonuniform horizontal wind fields (confluent)

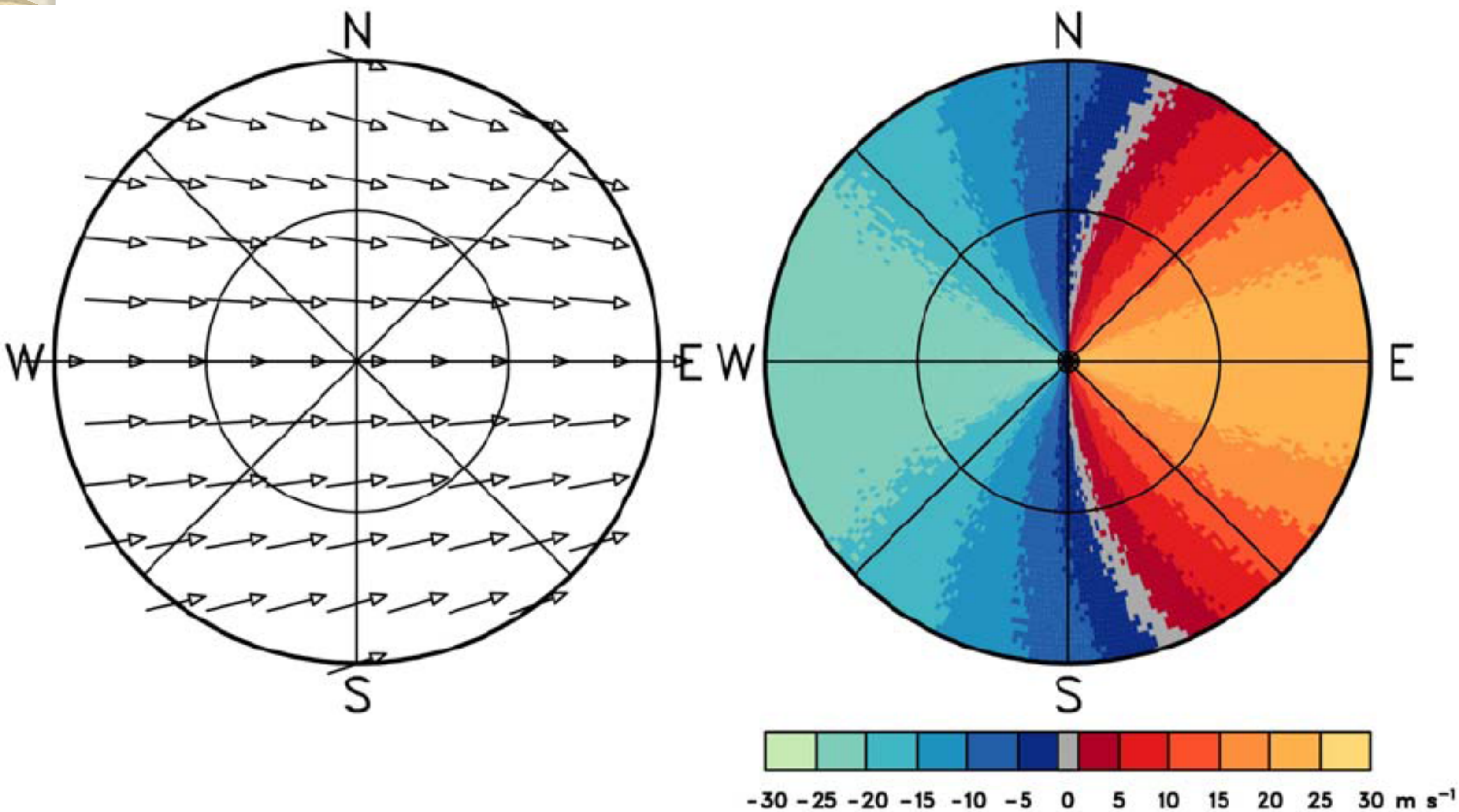


***Fig. 2.3.2**. Same as Fig. 2.3.1, except that the horizontal flow field is confluent with the same speed (23 m s^{-1} or 45 kt) at all heights.*

Patterns associated with vertical profiles having constant wind speed

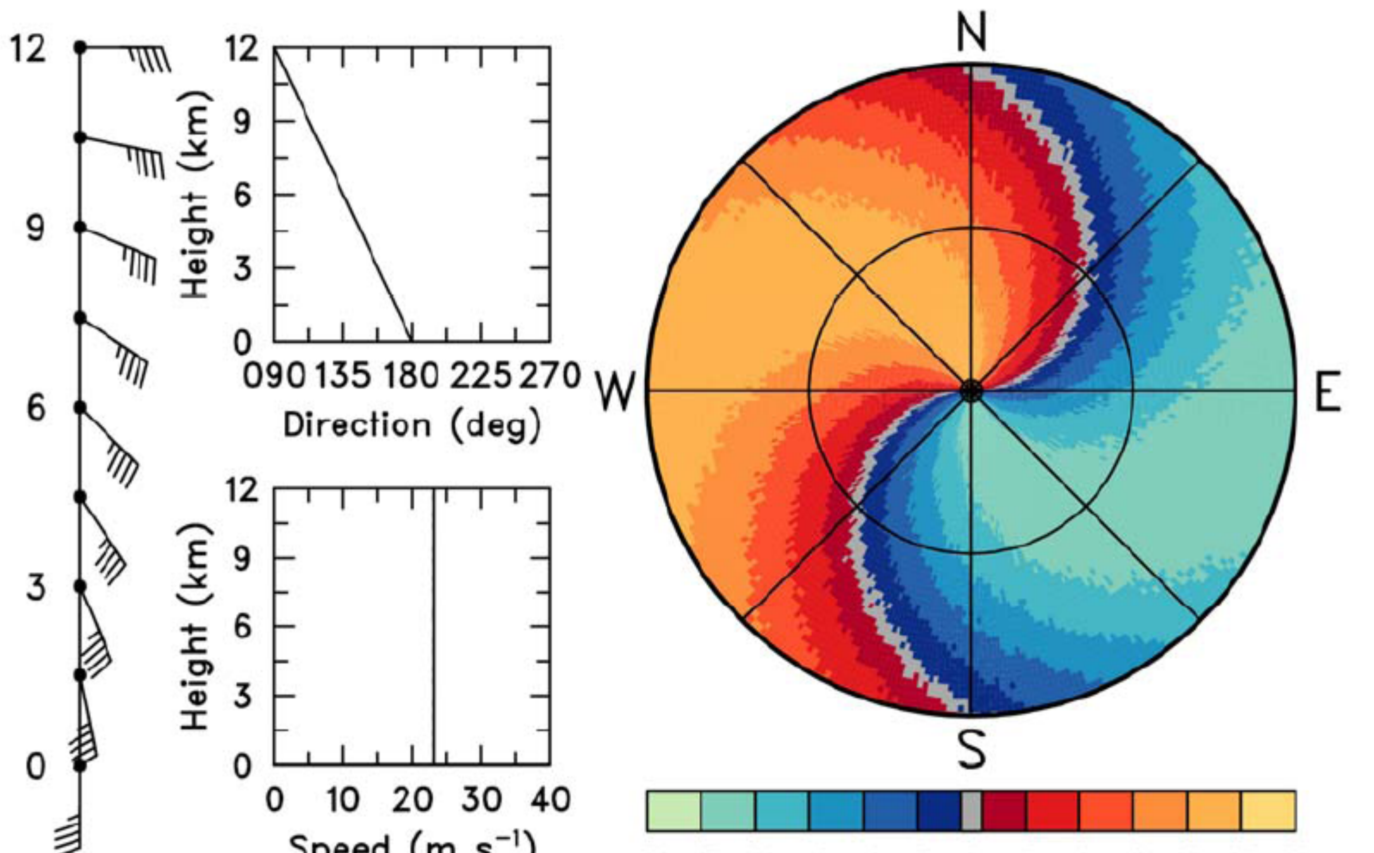
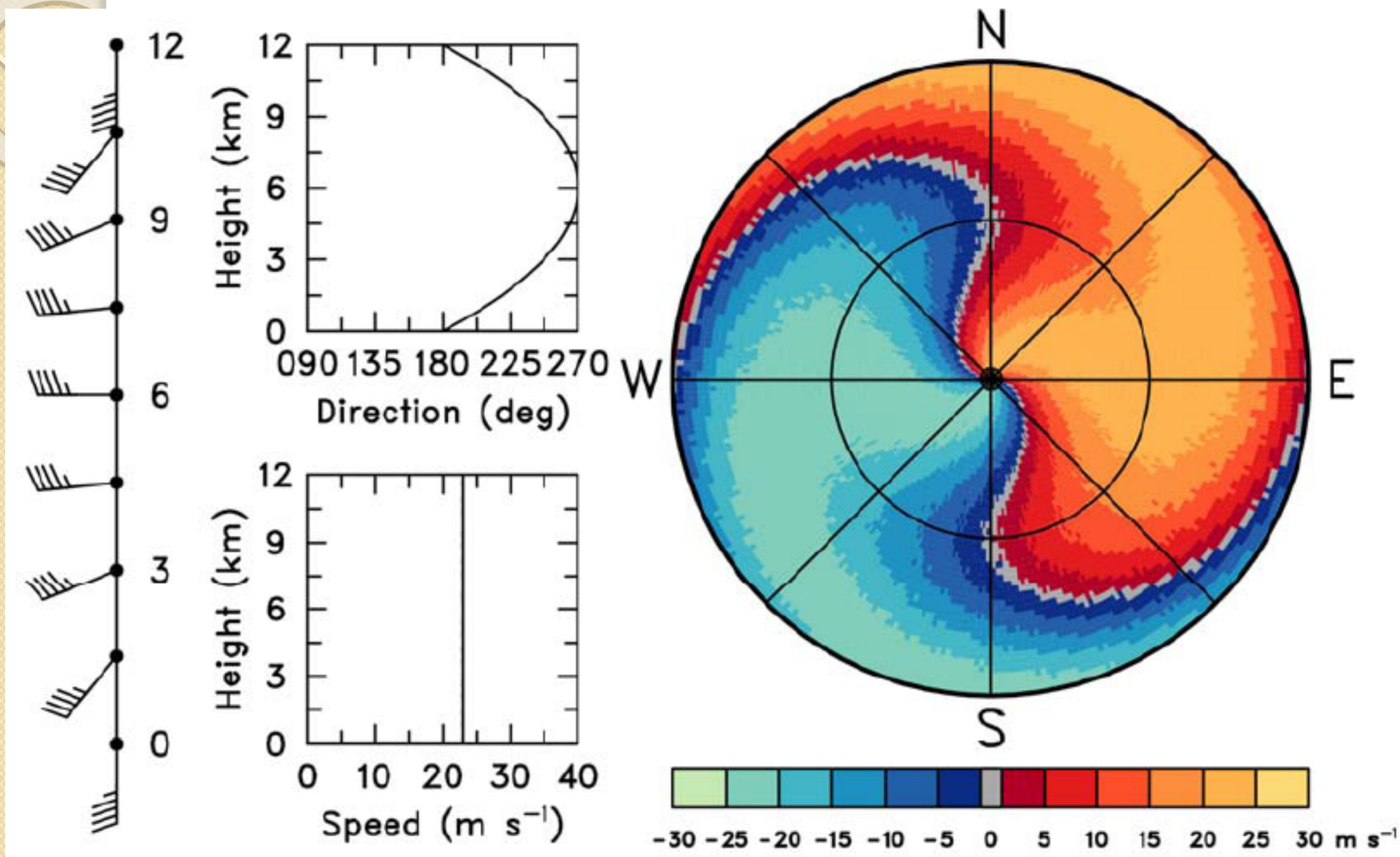
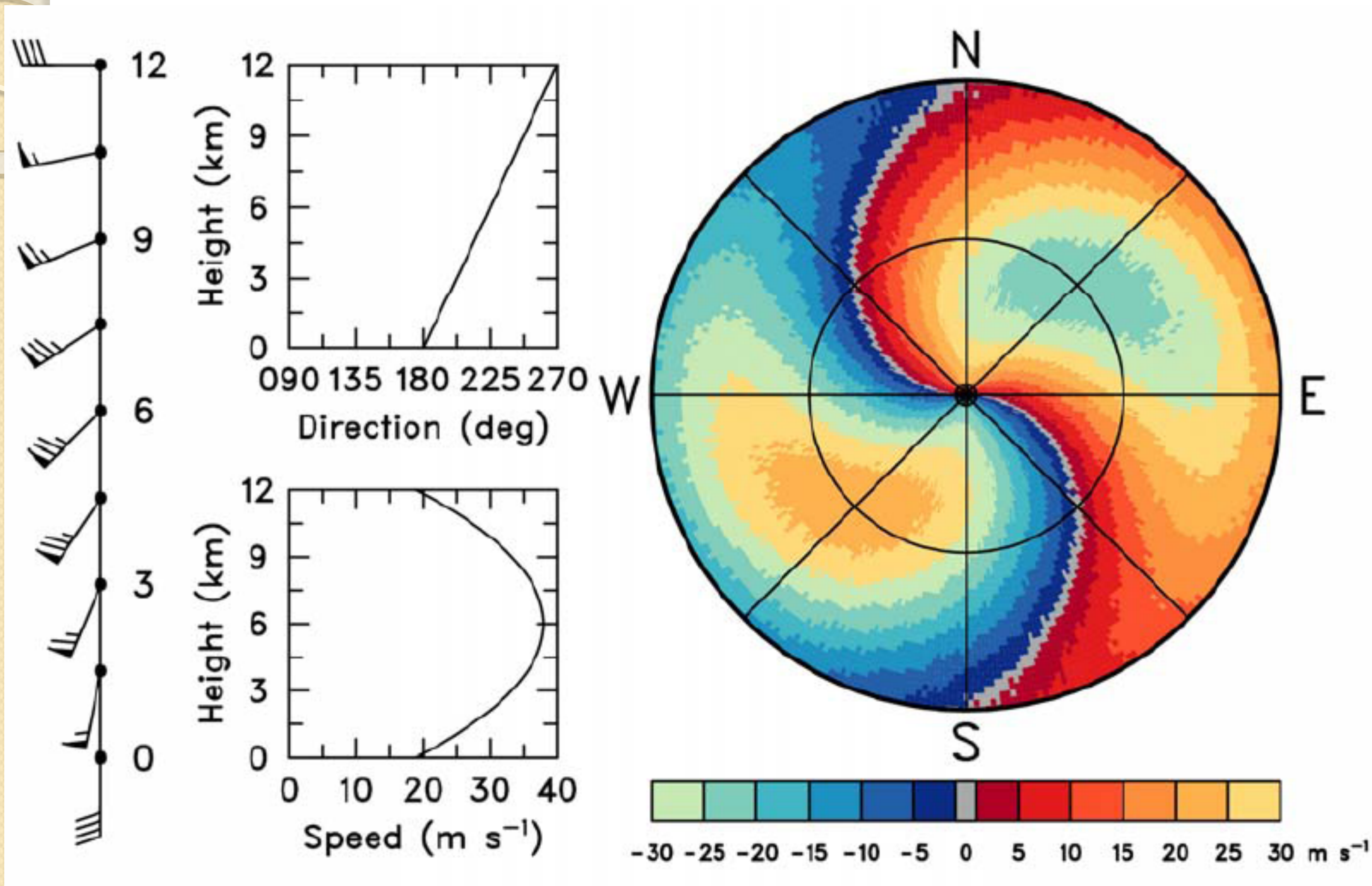


Fig. 2.4.1. *Doppler velocity pattern (right) corresponding to a vertical wind profile (left) with constant wind speed (23 m s^{-1} or 45 kt) and wind direction backing from southerly to easterly with height. Negative (positive) Doppler velocities represent flow toward (away from) the radar. Radar location is at the center of the display.*

Patterns associated with vertical profiles having constant wind speed



Patterns associated with vertical profiles of varying wind speed and direction



Patterns associated with horizontal discontinuities in the wind field

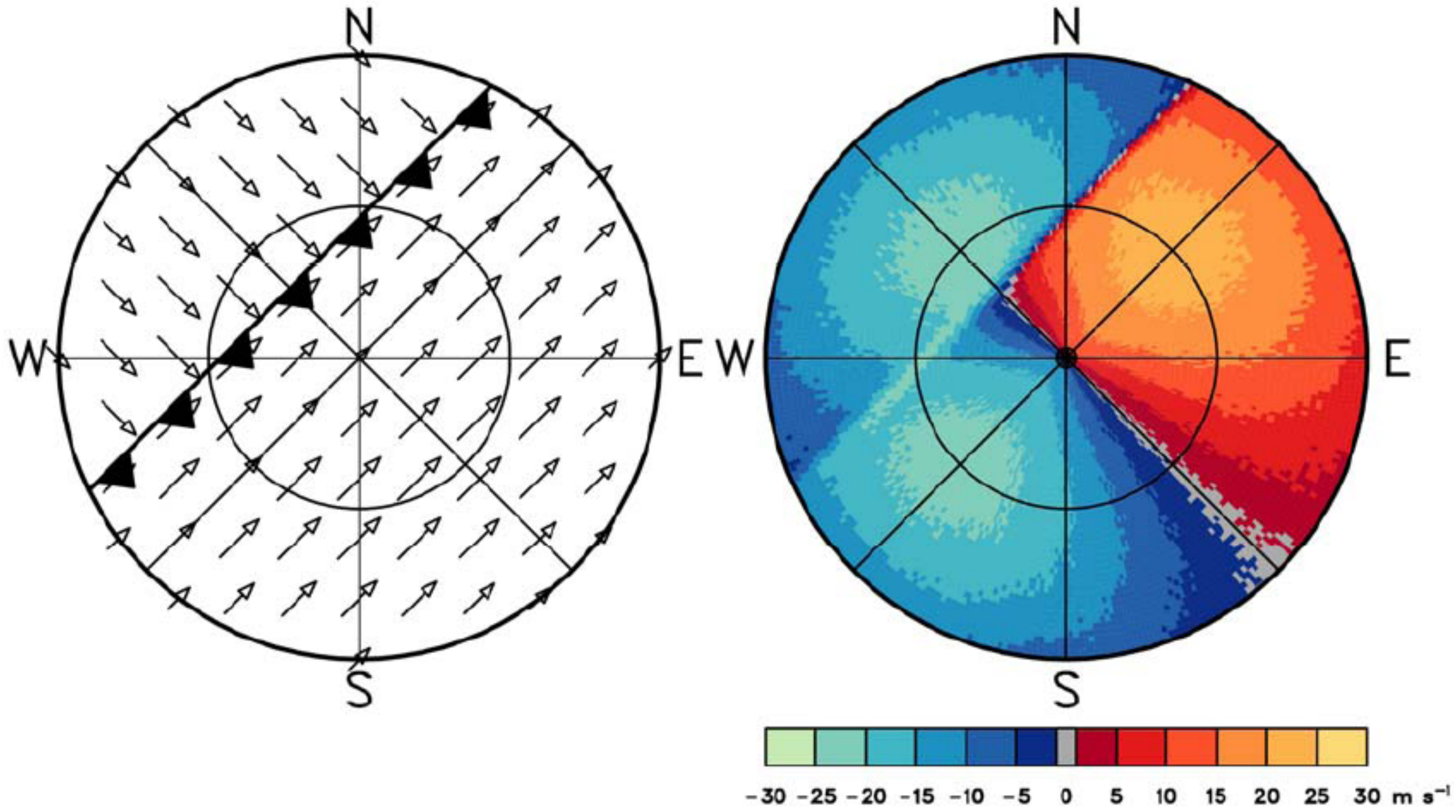
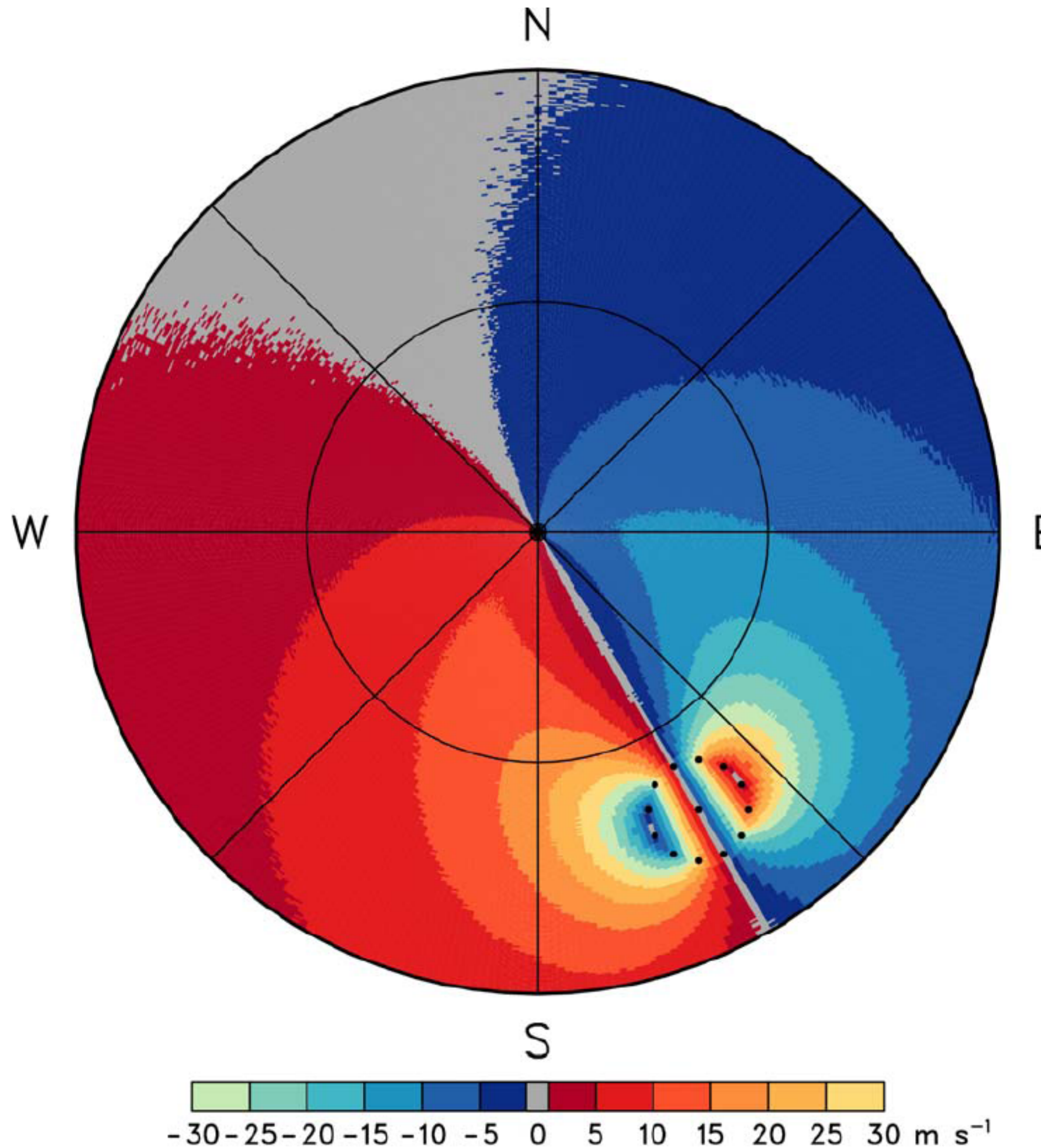


Fig. 2.7.1. *Doppler velocity pattern (right) corresponding to the approach of a wind field discontinuity from the northwest (left). There is a southwesterly low-altitude velocity maximum of 22 m s^{-1} (43 kt) ahead of the discontinuity and a northwesterly velocity maximum of 22 m s^{-1} (43 kt) behind it. Wind speed at the ground is 11 m s^{-1} (21 kt). Arrow length is proportional to wind speed. Negative (positive) Doppler velocities represent flow toward (away from) the radar. Radar location is at the center of the display.*

Patterns associated with a tropical cyclone

- Velocity folding occurred in this image.
- Doppler Vmax=30m/s
- After unfolding, the maximum real wind speed=60m/s



Patterns associated with a mesocyclone

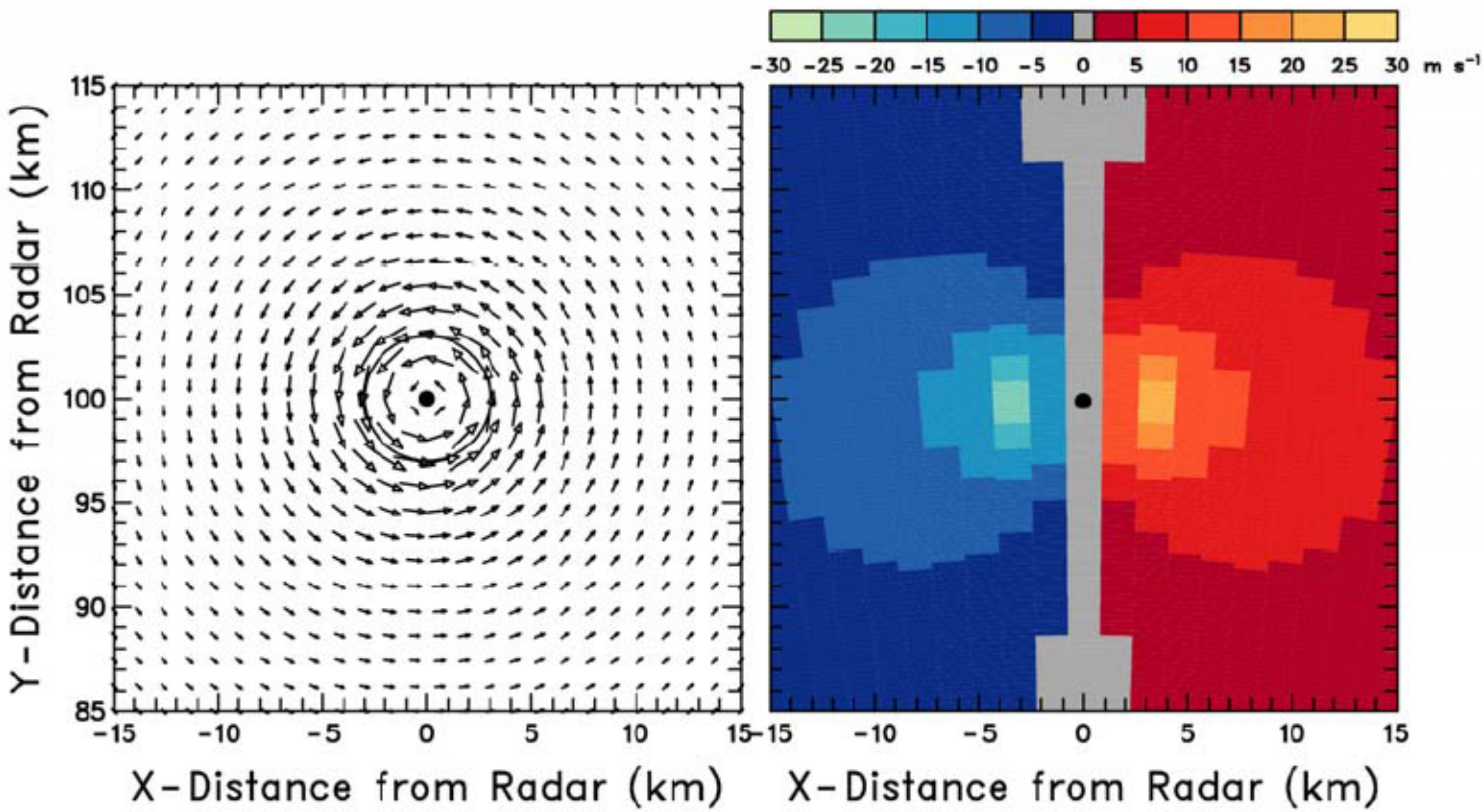
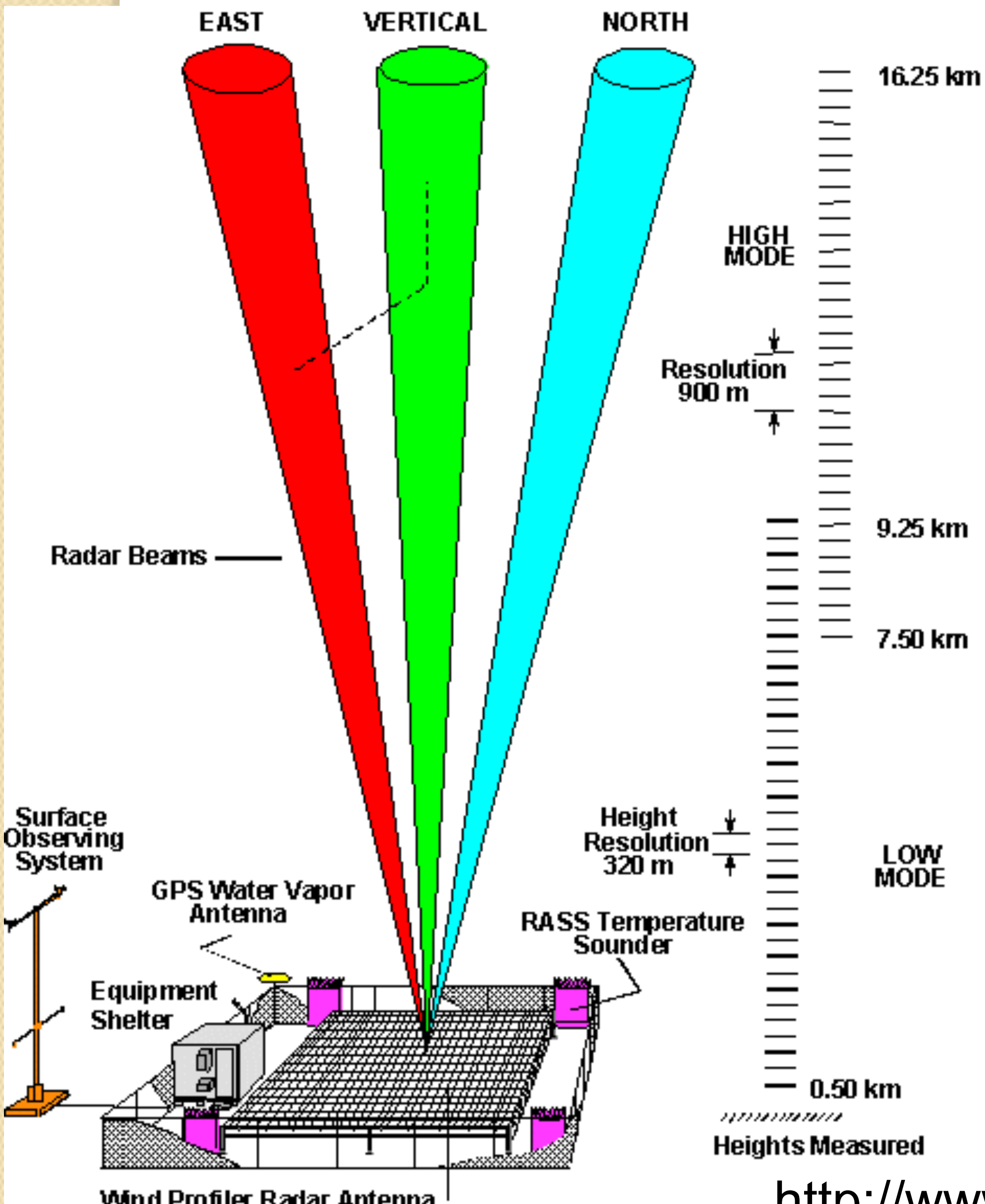
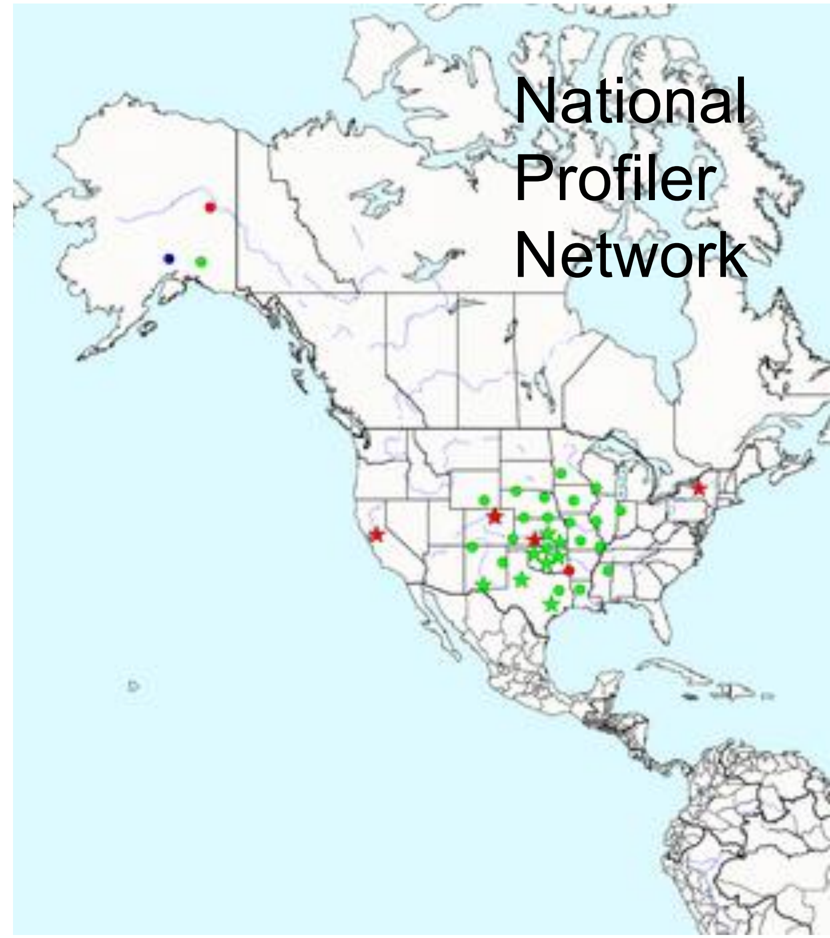


***Fig. 4.3.2**. Same as Fig. 4.3.1, except that the Doppler velocity pattern (right) corresponds to a mesocyclonic (left) that has peak tangential velocities of 25 m s^{-1} (49 kt) at a radius of 3 km (1.6 n mi) from the circulation center (black dot).*

Wind Profiler

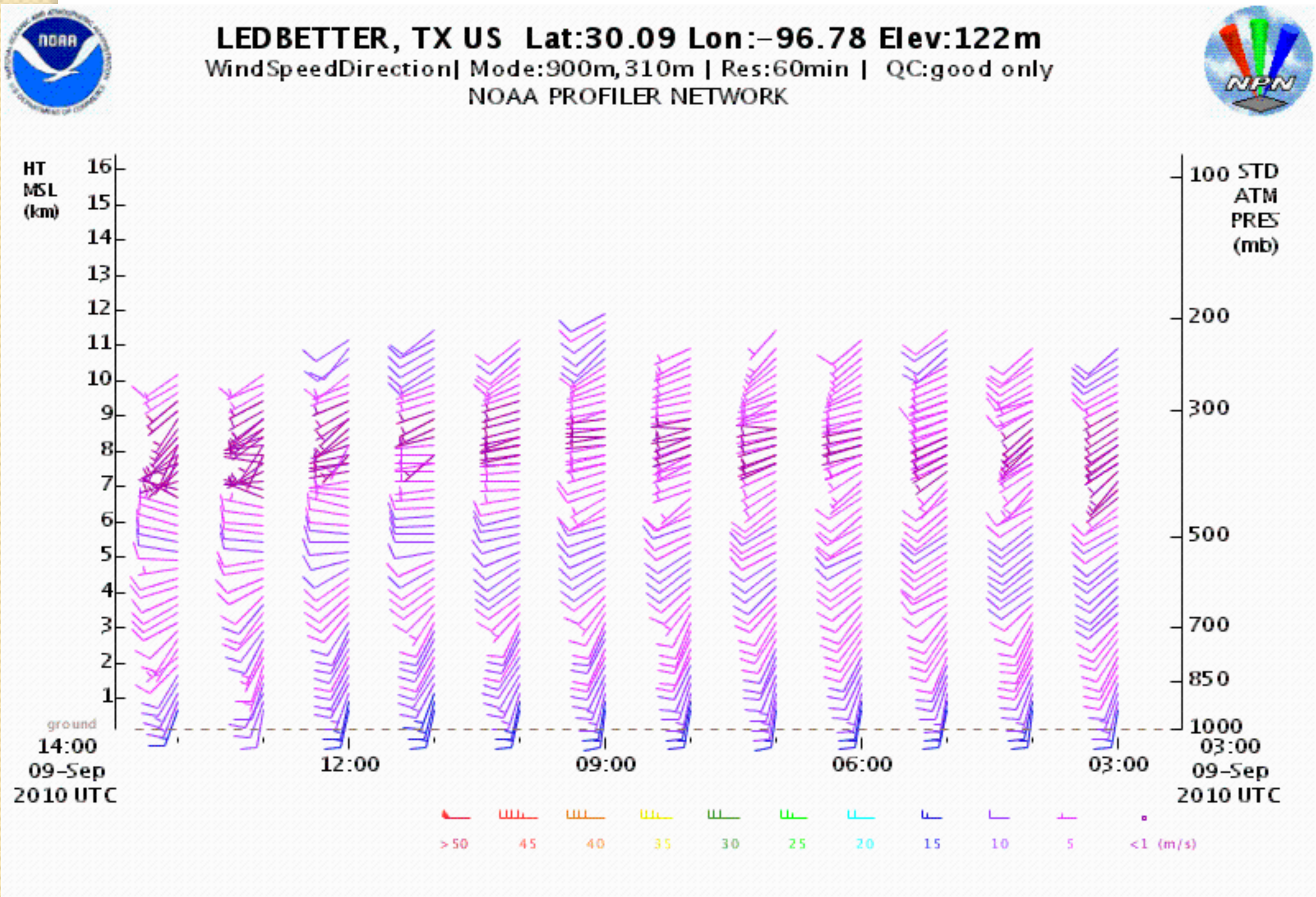
Wind Profilers use a three beam system





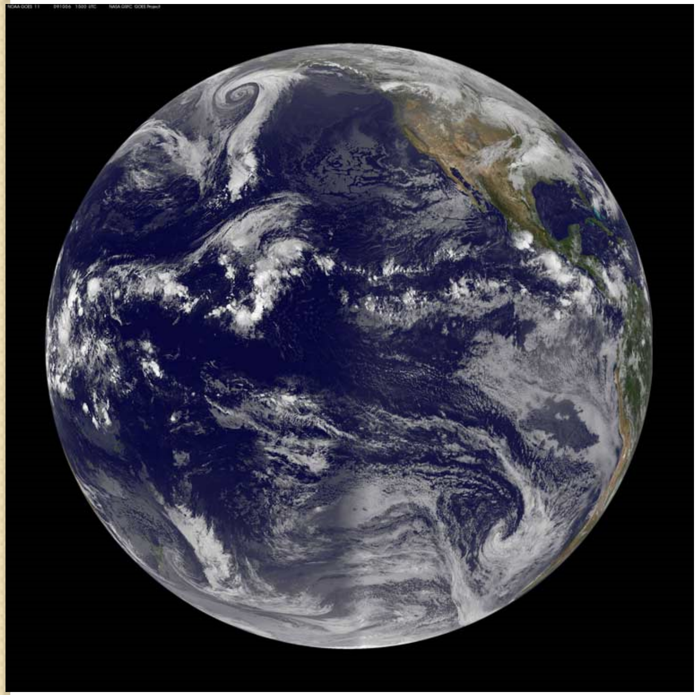
http://www.profiler.noaa.gov/npn/profiler.jsp

Example of profiler data from Led Better, TX

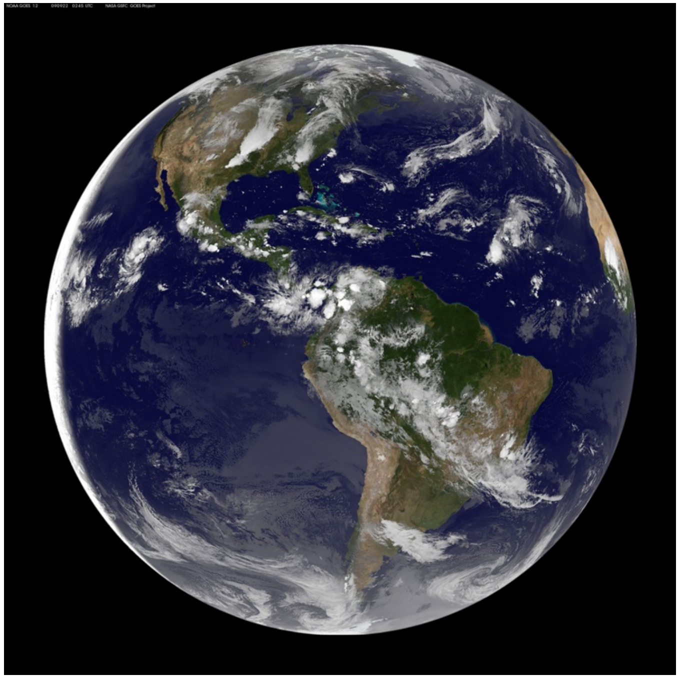


US GOES Satellites

- GOES (geostationary operational environmental satellites) East: over the US east coast.
- GOES West: one over the US west coast.
- Between them they can provide images for the whole U.S.
- Future GOES-R (2015): higher spatial and temporal resolution.



Full-disc view from GOES west.



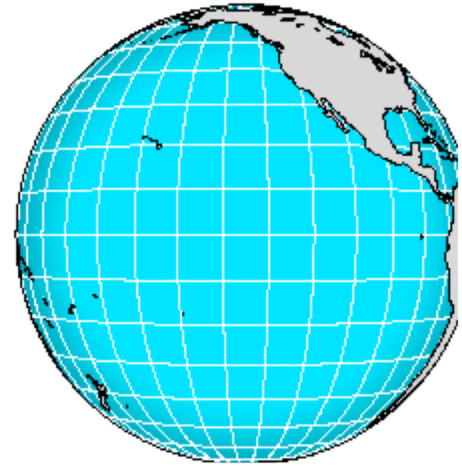
Full-disc view from GOES East.

Facts for Geostationary Orbits

1. **Continuous observation and high temporal resolution**: Since the field of view of a satellite in geostationary orbit is fixed, it always views the same geographical area, day or night. This is ideal for making regular sequential observations of cloud patterns over a region with visible and infrared radiometers. **High temporal resolution and constant viewing angles** are the defining features of geostationary imagery. Good for diurnal variation studies.

2. **Spatial resolution**: Geostationary satellites sensors are most useful for tracking atmospheric features over great distances because of their high temporal resolution (15 – 30 minute intervals) and hemispheric field of view . However, the orbital distance of the satellites means that **their spatial resolution is less than optimal for the identification of features smaller than 1km.**

Current Geostationary satellite coverage (2015)

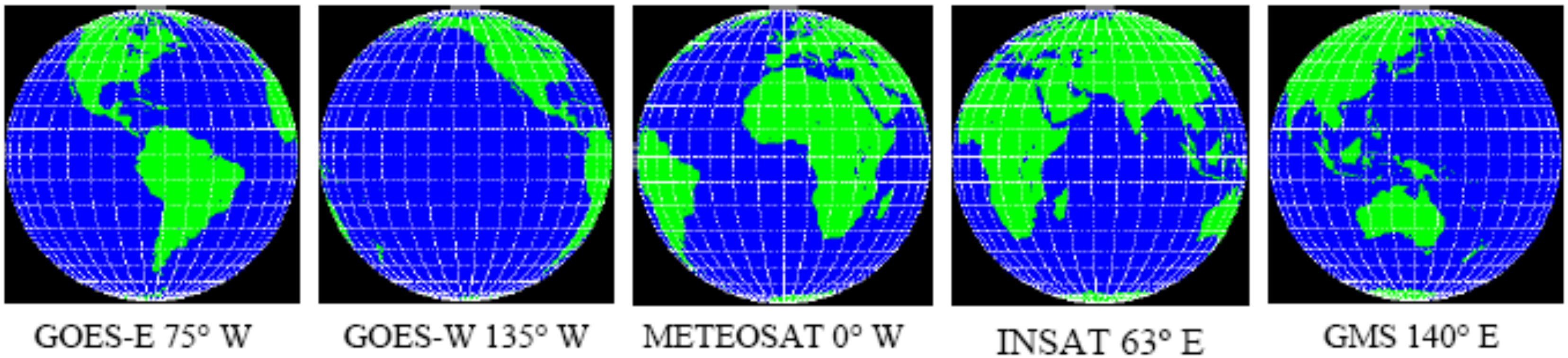


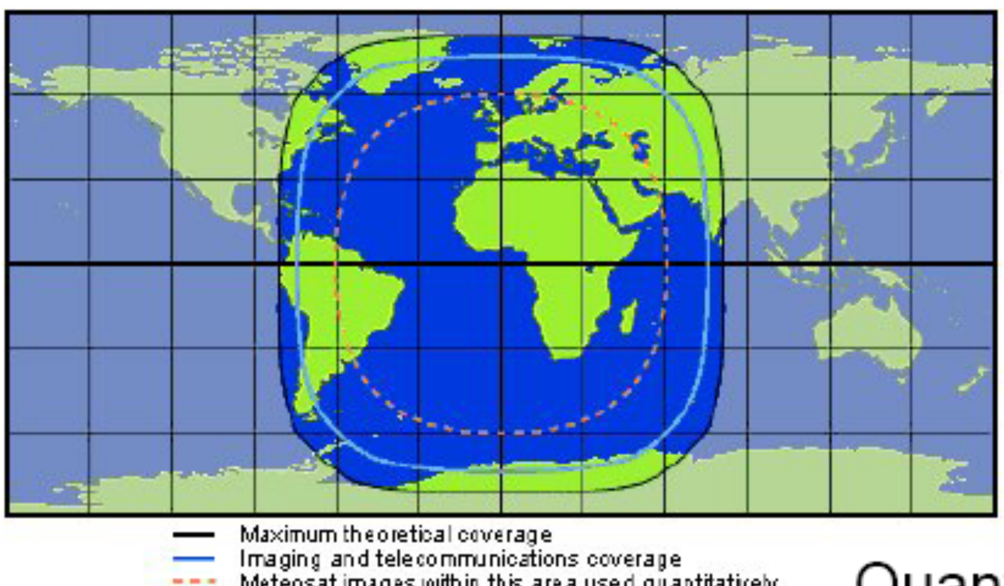
GOES-EAST: U.S. satellite, GOES-13 now at 75 deg west (launched in 2010)

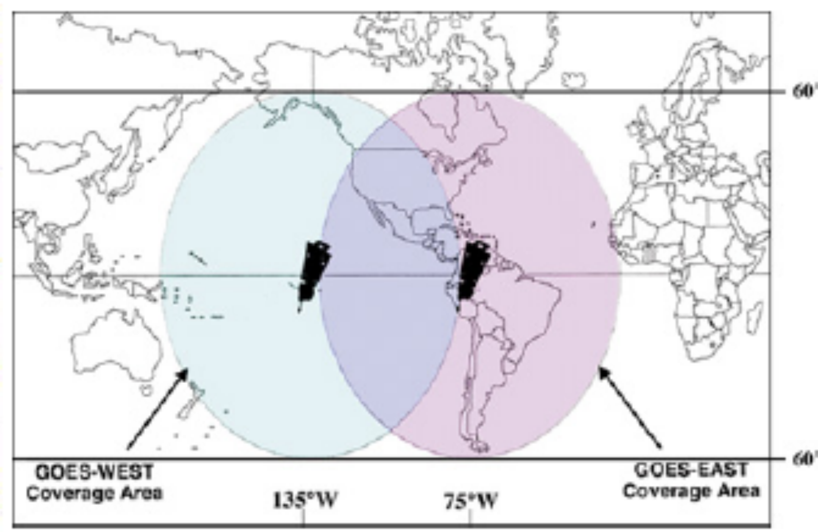
GOES-WEST: U.S. satellite, GOES-15 (launched in 2011) now at 135 degrees west

- Russia's new-generation weather satellite Elektro-L 1 operates at 76° E over the Indian Ocean.
- The Japanese have the MTSAT-2 located over the mid Pacific at 145° E and the Himawari 8 at 140° E.
- The Europeans have Meteosat-8 (3.5° W) and Meteosat-9 (0°) over the Atlantic Ocean and have Meteosat-6 (63° E) and Meteosat-7 (57.5° E) over the Indian Ocean.
- India also operates geostationary satellites called INSAT which carry instruments for meteorological purposes.
- China operated the Fengyun (风云) geostationary satellites FY-2D at 86.5° E and FY-2E at 123.5° E, which are no longer in use.

Views of Operational Geostationary Satellites

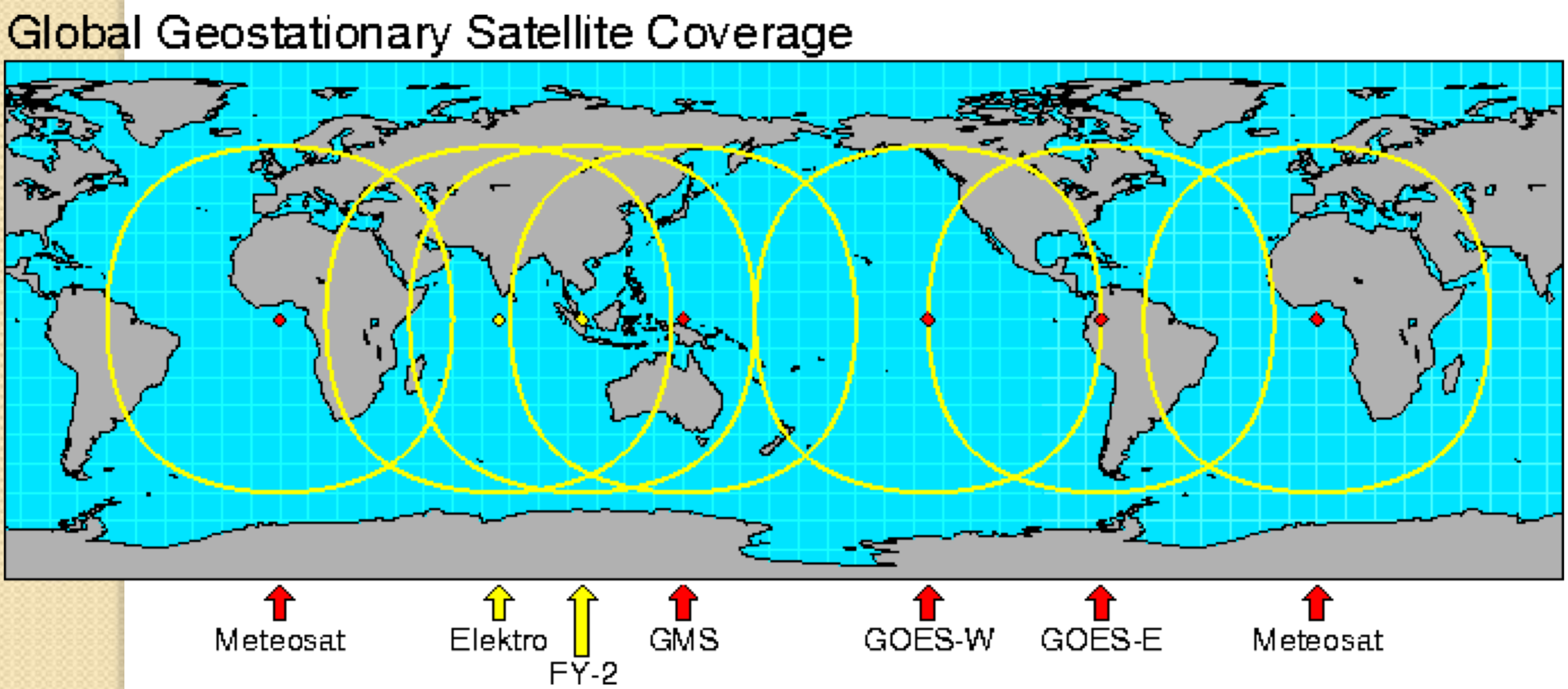






Quantitative coverage ~ 60N to 60S

Geostationary Satellite Coverages



Satellite Visible Channels

Spectrum: wavelengths around 0.5 μm

Rain or cloud droplets are geometric or Mie scatters ($r>>\lambda$), so we use reflection/refraction to replace scattering. A cloud only a few of tens meters thick is sufficient to scatter all of the visible radiation incident on it.

Absorption is negligible.

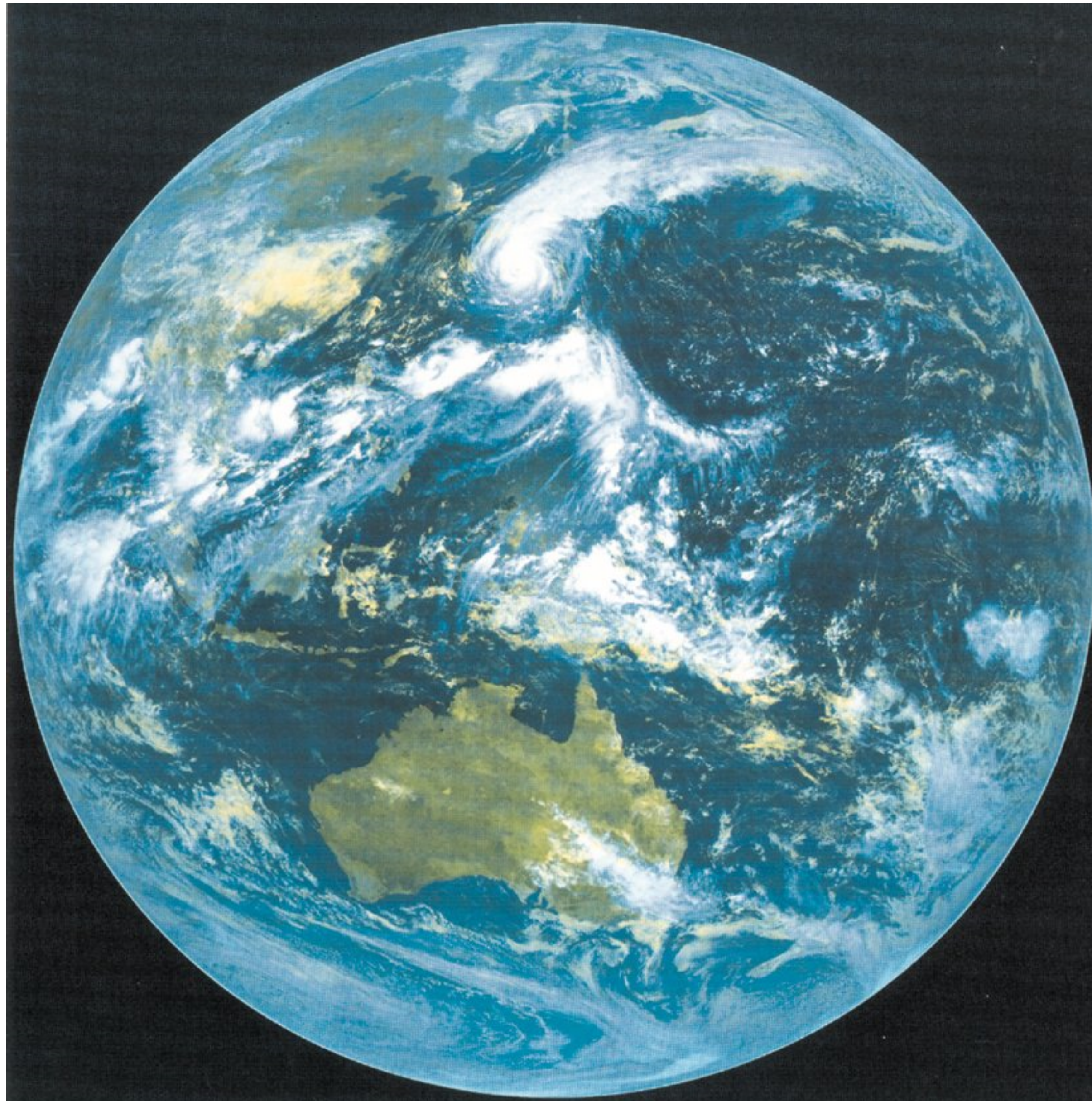
So visible channels detect sunlight reflected by clouds and the earth's surface -- *REFLECTANCE***.**

Visible Image Interpretation

Thick clouds (White) are bright in the visible imagery because thicker clouds generally have higher reflectance.

High clouds (White) are often semi-transparent and low clouds (Yellow) can be seen through them.

The land surface (Yellow) reflects sunlight less than clouds but more than the sea surface (Blue).



Satellite Infrared (IR) Channels

Spectrum: usually referred as the 10-12.5 μm window, in which the atmosphere is relatively transparent to the long-wave radiation from the Earth.

IR sensors from space measure the thermal IR emission (radiation) from the Earth surface & clouds.

The measured radiation can be converted to brightness temperature (T_B) using Planck's function. In IR channel, both clouds and Earth surface act as blackbody. So T_B is equal to actual physical temperature.

The higher the temperature of clouds or earth surface is, the stronger the measured infrared radiation. High clouds are very cold, while low clouds are much warmer. Thus, both the temperature and the height of the cloud top can be derived from the intensity of the infrared radiation.

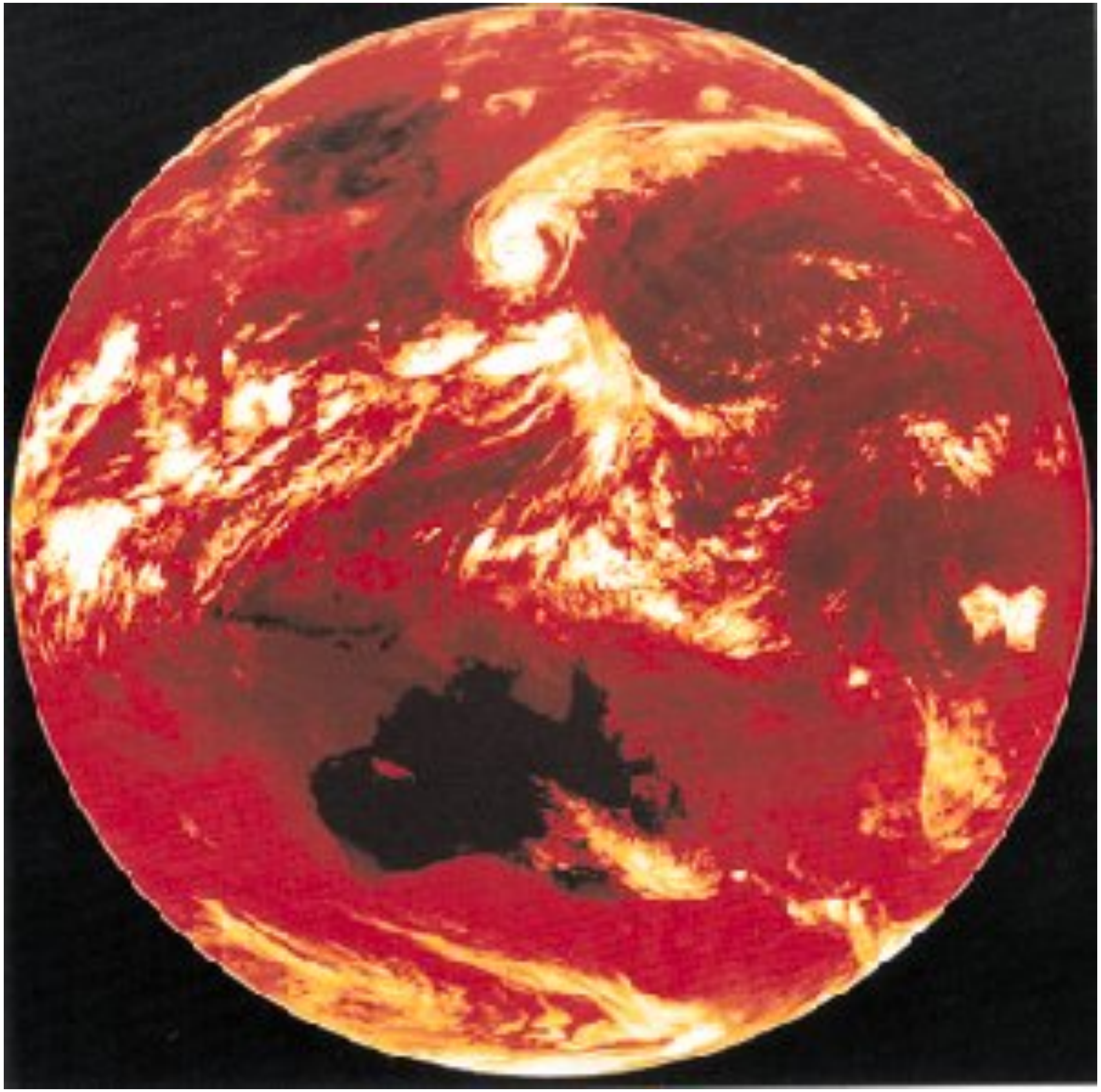
IR Image Interpretation

Thick clouds, such as those associated with the typhoon, look **white** (lowest temperature).

High clouds, which look semi-transparent in the visible imagery, are also shown **white or yellow**.

Low clouds are displayed as **red**. They may have temperatures close to that of the underlying ocean and are more difficult to identify in the infrared than in the visible imagery.

The desert in Australia is much hotter (**black**) than any cloud and shows up clearly.



IR Water Vapor Channels

- Spectrum: water vapor absorption band around 6.7 μm.

- As absorption by water vapor is strong in this band, radiation from the low clouds and the earth's surface do not normally reach the satellite.

- ***The intensity of the radiation received at these channels depends on the amount of water vapor in the upper and mid-troposphere as well as the temperature of the radiation source. Water vapor image does not only represent moisture, it is proportional to the mean temperature where roughly the top 3 mm of precipitable water exists. Both moisture and temperature are important factors.***

- The temporal changes of the humidity patterns can identify air movement and vortices even in the absence of clouds.

Water Vapor Image Interpretation

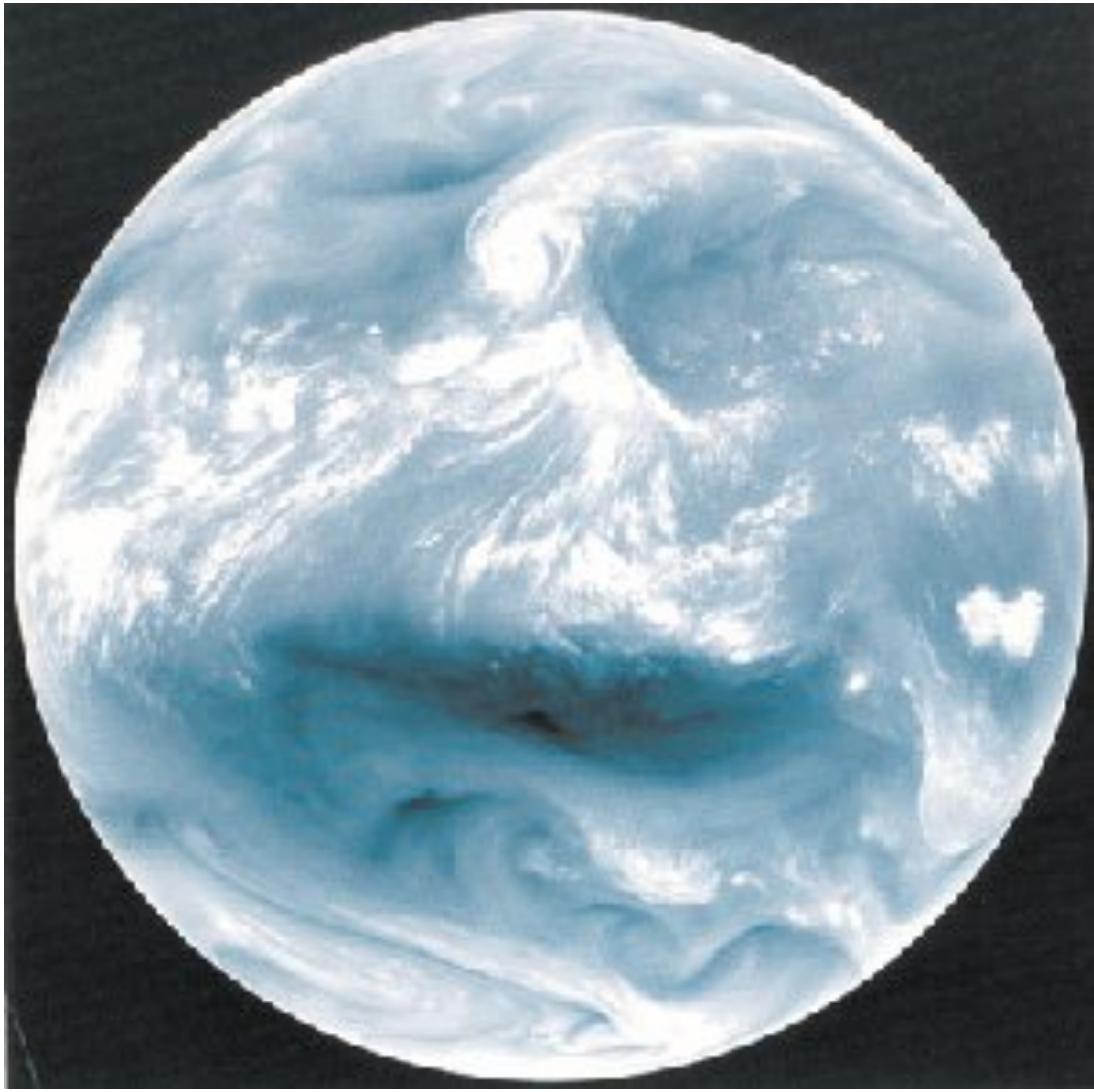
The brighter parts show the moister parts of the upper and mid-troposphere.

Thick clouds and high clouds are seen **white** (similar to IR and visible images). The earth's surface and low clouds are undetectable .

Grey shades corresponding to water vapor amounts are seen where there are no high and middle clouds.

In the southern hemisphere, **dark areas** can be seen, associated with dry upper air.

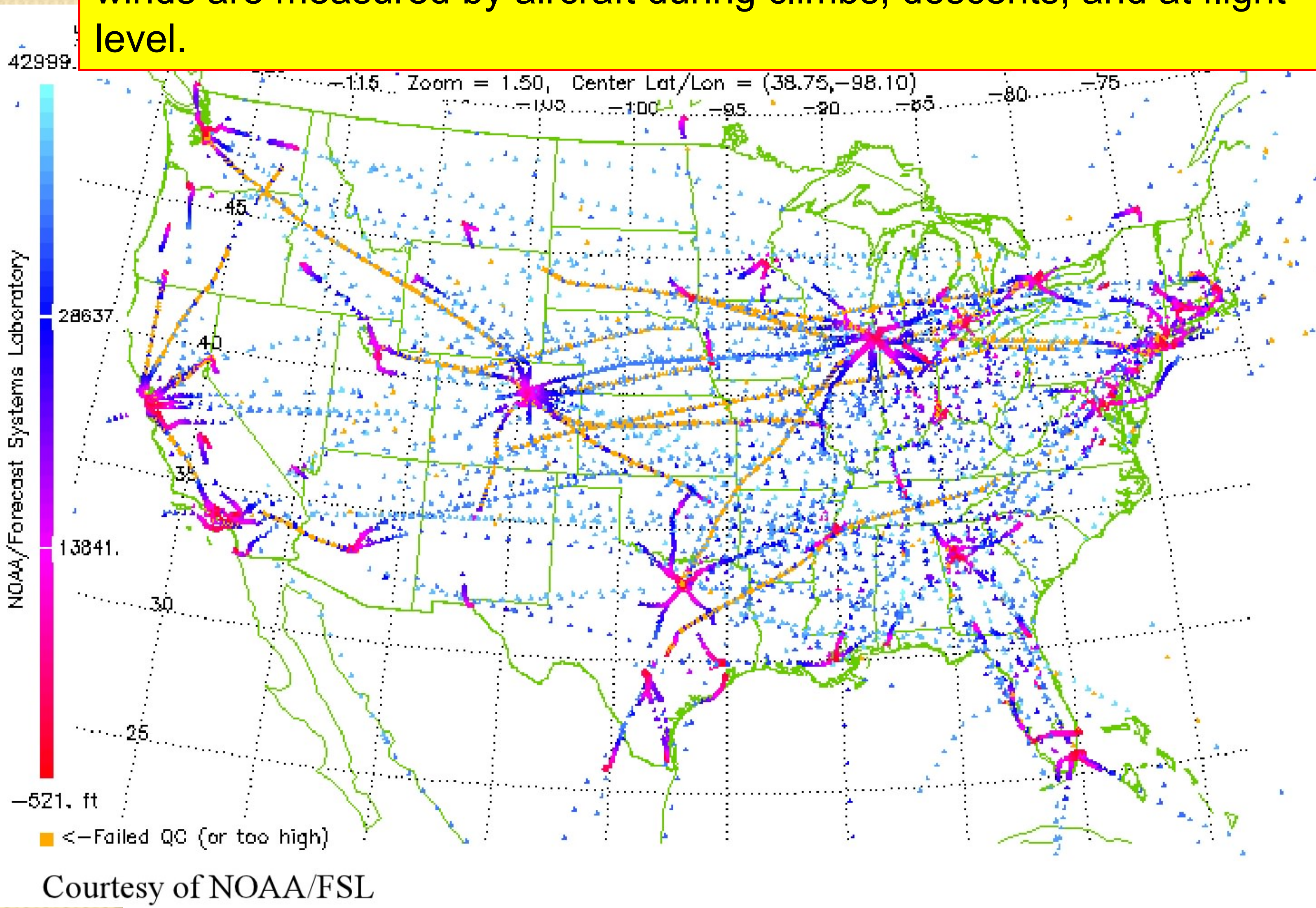
Many vortices of grey shades are also seen, associated with upper tropospheric lows.



Interpreting Satellite Imagery

	Visible	Infrared	Water Vapor
Satellite measures	reflected solar radiation	emitted infrared (temperature)	infrared radiation emitted by water vapor only
Brightest regions	thick clouds, snow	coldest clouds or surfaces	moist air
Darkest regions	ocean, forests	warmest clouds or surfaces	dry air

Aeronautical Radio, Inc. Communications Addressing and Reporting System (commonly called ACARS) is a system that commercial aircraft use to transmit airline operational information as well as meteorological information from air to ground. Pressure, temperature, moisture and winds are measured by aircraft during climbs, descents, and at flight level.



Courtesy of NOAA/FSL

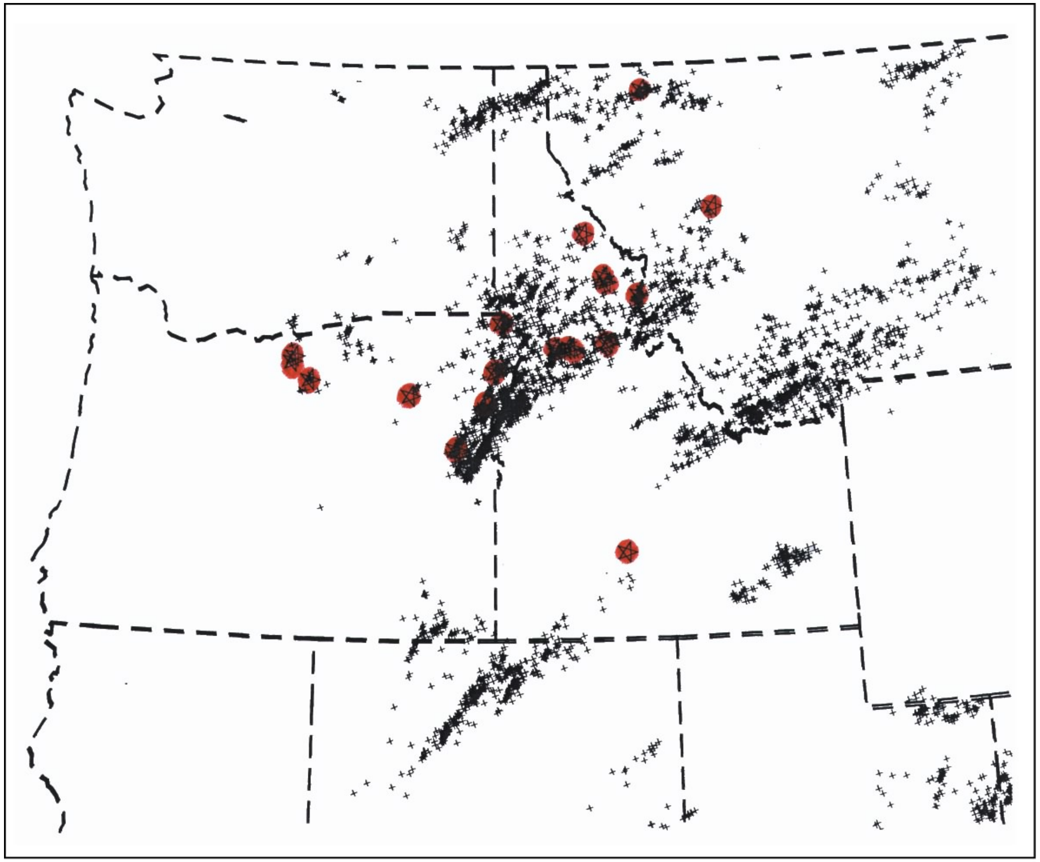
National lightning detection network

(operated by Vaisala Inc.)

Maps the location, polarity, “multiplicity”, and peak current of all cloud-to-ground lightning strikes in the United States in real time.

Courtesy of NOAA

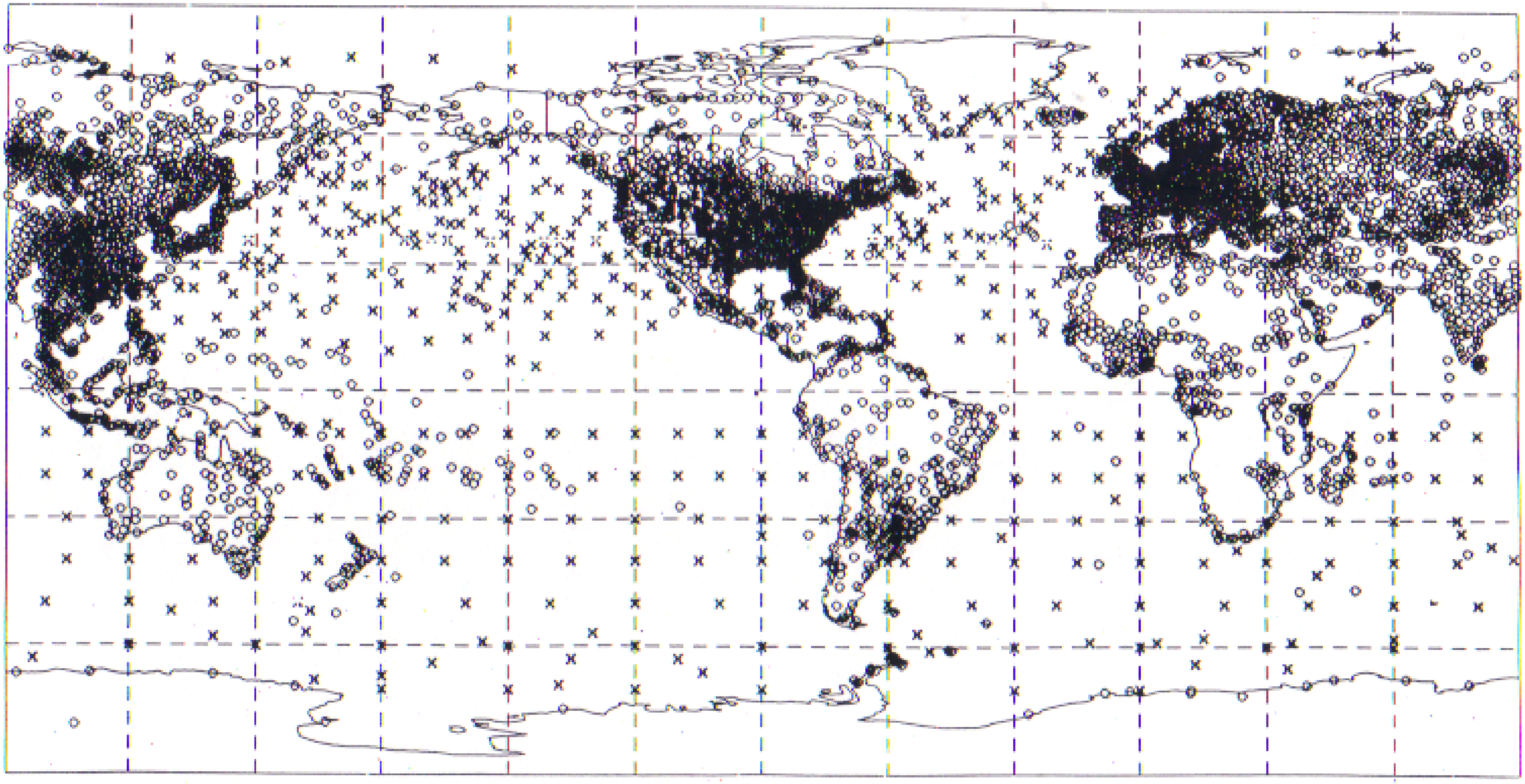
Photo: John McColgan, Courtesy of Alaskan Type 1 Incident Management Team, Bureau of Land Management, Alaska Fire Service.



Courtesy of Miriam Rorig, USDA Forest Service

Used for storm tracking, nowcasting potential utility disruptions, and for early fire detection.

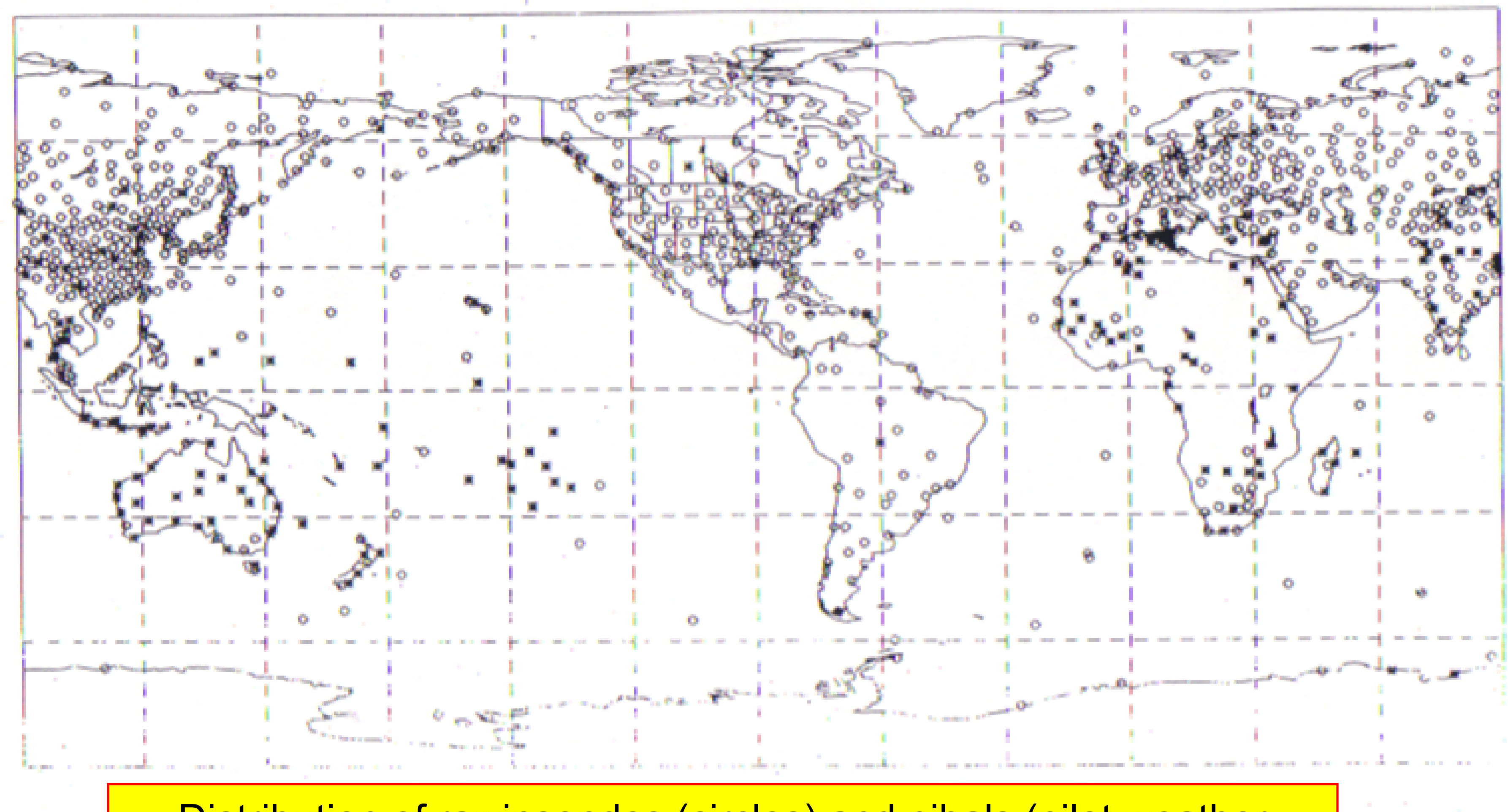
Global datasets used to initialize numerical weather prediction models



Distribution of land surface stations (circles) and sea level bogus observations (x) at 1200 UTC,

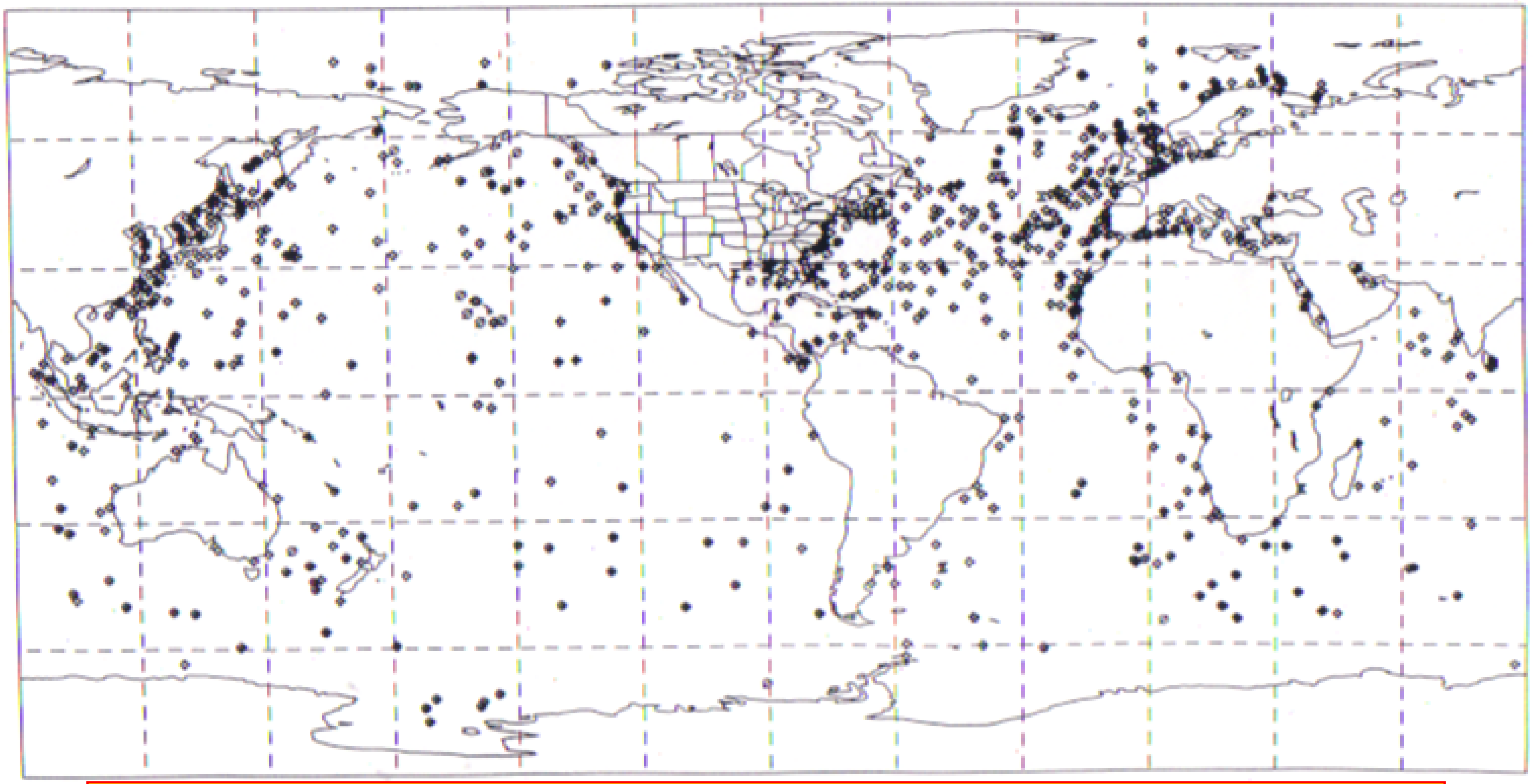
The bogus procedure usually adopts an idealized or composited data set representing an area, and then combines it with other data from observation and NWP model for final data analysis.

Global datasets used to initialize numerical weather prediction models



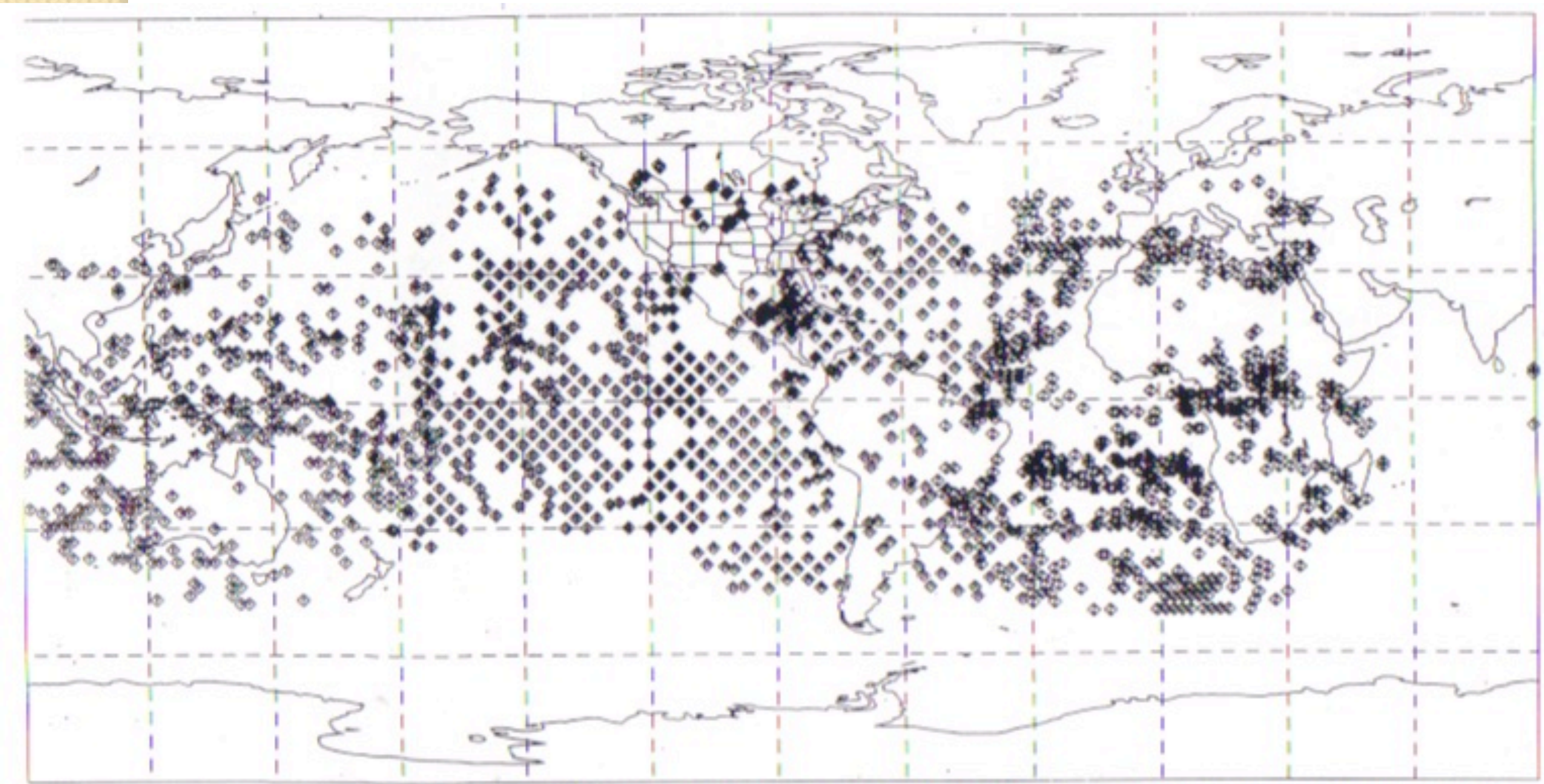
Distribution of rawinsondes (circles) and pibals (pilot weather balloon *) at 1200 UTC,

Global datasets used to initialize numerical weather prediction models



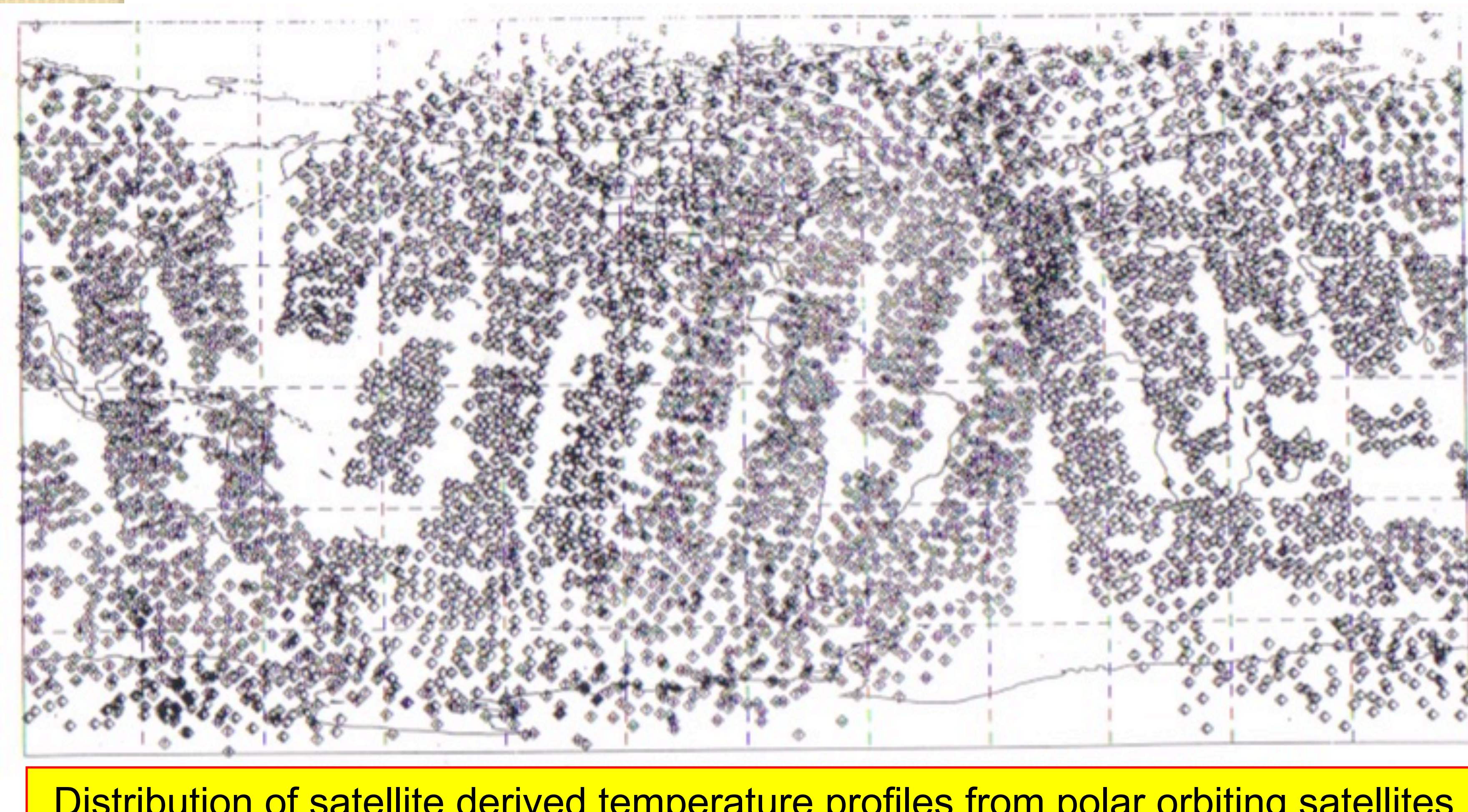
Distribution of marine observations from mobile ships, fixed ships, drifting buoys and fixed buoys at 1200 UTC

Global datasets used to initialize numerical weather prediction models



Distribution of cloud tracked wind observations from GOES 10, 12, 9, and the Japanese and European Satellites at 1200 UTC

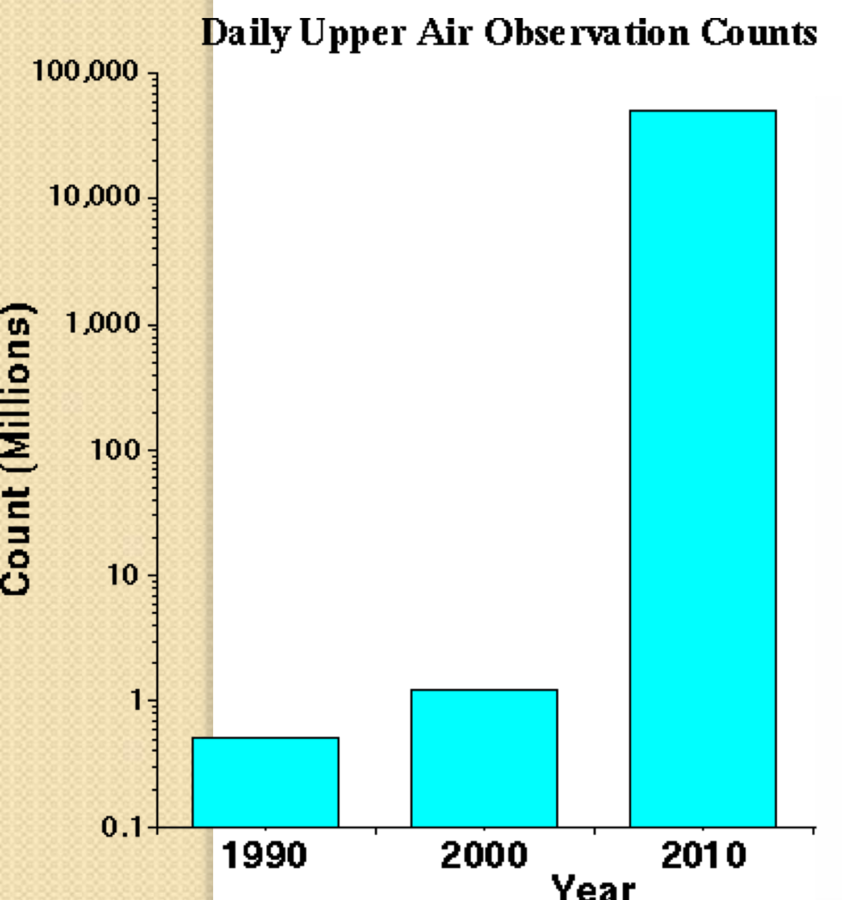
Global datasets used to initialize numerical weather prediction models

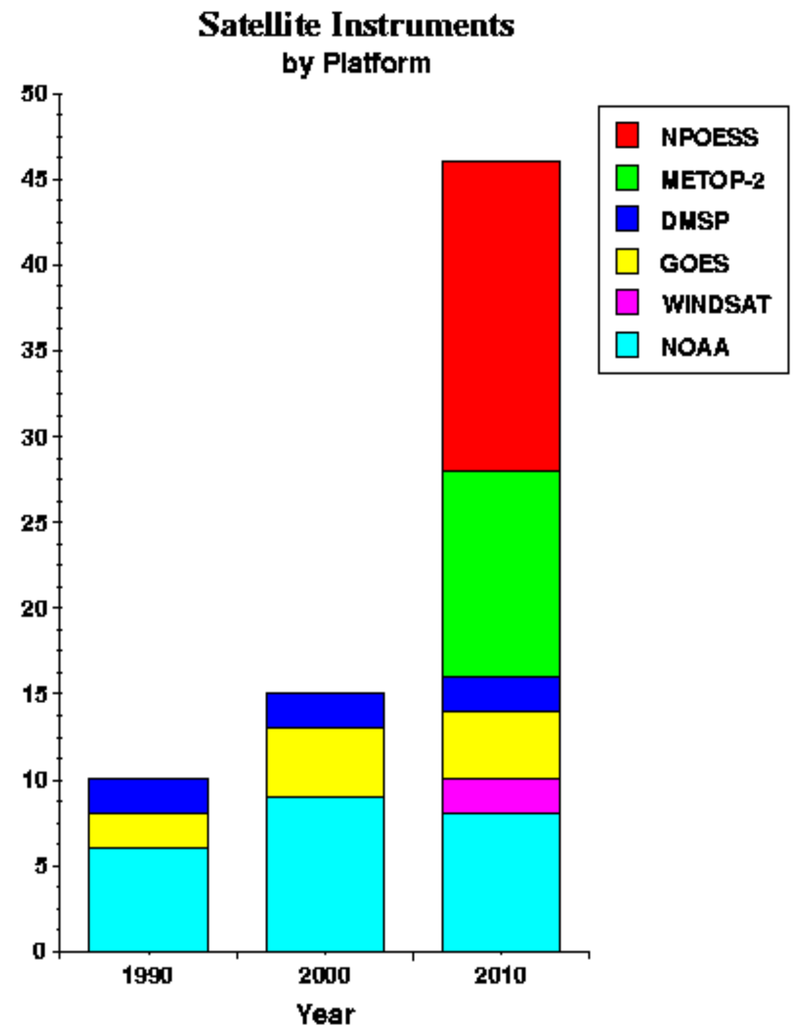


Distribution of satellite derived temperature profiles from polar orbiting satellites NOAA-10 and NOAA-11 at 1200 UTC

Over the US, Doppler radar observations are also used

GPS Integrated moisture, ocean scatterometer winds


Daily Upper Air Observation Counts
100,000
10,000
1,000
100
10
1
0.1
Count (Millions)
1990
2000
2010
Year


Satellite Instruments
by Platform
50
45
40
35
30
25
20
15
10
5
0
1990
2000
2010
Year
NPOESS
METOP-2
DMSP
GOES
WINDSAT
NOAA

The result is better forecasts!