Lecture 7-8:
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."
## 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 (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)
  - Aviation Weather Center (AWC)
  - Climate Prediction Center (CPC)
  - Environmental Modeling Center (EMC)
- 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)
Regional Support Centers

Regional Headquarters
- Alaskan Region
- Central Region
- Eastern Region
- Pacific Region
- Southern Region
- Western Region

Center Weather Service Units
- Albuquerque
- Anchorage
- Atlanta
- Boston
- Chicago
- Cleveland
- Denver
- Fort Worth
- Houston
- Indianapolis
- Jacksonville
- Kansas City
- Los Angeles
- Memphis
- Miami
- Minneapolis
- New York
- Oakland
- Salt Lake City
- Seattle
- Washington

River Forecast Centers (RFC)
- Alaska/Pacific
- Arkansas-Red Basin
- California-Nevada
- Colorado Basin
- Lower Mississippi
- Middle Atlantic
- Missouri River Basin
- Northcentral
- Northeast
- Northwest
- Ohio
- Southeast
- South Gulf

Regional Climate Centers (Non-Federal Sites)
- High Plains
- Midwestern
- Northeast
- Southeast
- Southern
- Western

Administrative Support Centers
- Workforce Management Office (WFO)
- Regional Client Service Offices
  - Benefits and Retirement Client Services
  - Time & Attendance Client Services

Additional links:
- Http://www.weather.gov/organization_prv
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
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
NWS Modernization (late ‘90’s early ‘00s):

**Advanced Weather Interactive Processing System (AWIPS)**
Advanced computer system to help forecasters integrate weather data at field offices, assist in analyzing storms and prepare warnings and forecasts.

**NOAAPORT**
Provides the broadcast link between national guidance centers and NWS field offices, and is also the source of data for private users.
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/
How does radar work?

- Active remote sensors emit electromagnetic (EM) waves that travel to an object and are reflected back toward the sensor.
  Example: X-Ray, Radar, Lidar

- 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 (backscattered) 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.
Simplified block diagram of a pulsed weather radar

Figure 2.1 Block diagram of a simple radar

Rinehart (5th edition 2010)
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** 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.
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.
“Precipitation” mode

Approximate conversion of radar reflectivity to rainfall rate

<table>
<thead>
<tr>
<th>Radar Reflectivity (dBZ)</th>
<th>Rainfall Rate (inches/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>16+</td>
</tr>
<tr>
<td>60</td>
<td>8.0</td>
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<td>0.3</td>
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<td>30</td>
<td>0.1</td>
</tr>
</tbody>
</table>
| 20                       | trace                     

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“Clear air” mode
(often used for snow)
Radar parameters set to increase sensitivity

Approximate conversion of radar reflectivity to rainfall rate

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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.
The bright band: an enhancement of radar reflectivity at the melting level when snowflakes falling from above aggregate and develop wet surfaces.

Note convective and stratiform regions of squall line. Precipitation estimates in stratiform region must be carefully examined because of bright band effects.
Aircraft radar measurements in Hurricane Dennis (2005)

Doppler velocity (m/s)  Reflectivity (dBZ)
The bright band
An extreme example of bright band contamination of precipitation estimation.
Reflectivity for hail

- Rain: usually 20-50 dBZ (sometime could go up to 55 dBZ)
- Hail: a general rule: reflectivity $\geq 60$ 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?
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, $\phi$; (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 $\theta$, elevation angle $\phi$, 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 ($26 \text{ m s}^{-1}$ 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.
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 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).
Patterns associated with a tropical cyclone (Max. real wind speed=60m/s; Doppler Vmax=30m/s. Velocity Folding!)
Tornado

Radar reflectivity

Radial Velocity

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Courtesy of NOAA/NSSL Photo Library
NEXRAD PRODUCTS:

**LEVEL 2 DATA**: Radar reflectivity and radial velocity at original sampling resolution. 
(Available from NCDC or Internet in real time)

**LEVEL 3 DATA**: NEXRAD Information and Dissemination System (NIDS) Products

- Individual radars
- Base reflectivity, Composite reflectivity
- Storm total precipitation, Vertically integrated liquid
- Radial velocity, Storm relative radial velocity

National or regional reflectivity composites
Available from NWS and other sources on line
Composite reflectivity: Maximum echo intensity at any scan level measured in dBZ
Storm Total Precipitation: Measured in inches fallen after an NWS selected start time.
Vertically integrated liquid (VIL): VIL is the integration of reflectivity within a column of air. Once thought to be related to potential hail size, but not really a good predictor.
Radial velocity: Velocity component along the radar beam direction (knots)
**Storm relative radial velocity**: Radial velocity with the component of storm motion along the beam subtracted. Best display to see mesoscyclones, tornado vortex signatures and microburst signatures.
Wind Profiler

Platteville, CO - August 23, 1989
Wind Profilers use a three beam system

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

National Profiler Network
Example of profiler data from Led Better, TX
Visible Satellite Imagery

0.4-.7 micrometer - B/W image from space (<1 km resolution)

Visible channels detect sunlight reflected by clouds and the earth's surface -- \textit{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).
11 micrometer - “Atmospheric Window” - Brightness temperatures are physical temperatures to a good approximation (8 km resolution).

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.
Water Vapor Satellite Imagery

6.7 micrometer - Water Vapor Absorption (depends on an integrated amount of water vapor in a vertically oriented atmospheric column, especially weighted toward the mid to upper troposphere, 3 to 7 miles altitude.) ~16-km resolution.
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.
Satellite imagery can be a very important tool in identifying airmass boundaries, which are often key to determining where an outbreak of severe convection will occur.

Home reading: http://www.meteor.wisc.edu/~hopkins/100hold/wxsatimg.htm

### Interpreting Satellite Imagery

<table>
<thead>
<tr>
<th>Satellite measures</th>
<th>Visible</th>
<th>Infrared</th>
<th>Water Vapor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightest regions</td>
<td>reflected solar radiation</td>
<td>emitted infrared (temperature)</td>
<td>infrared radiation emitted by water vapor only</td>
</tr>
<tr>
<td></td>
<td>thick clouds, snow</td>
<td>coldest clouds or surfaces</td>
<td>moist air</td>
</tr>
<tr>
<td>Darkest regions</td>
<td>ocean, forests</td>
<td>warmest clouds or surfaces</td>
<td>dry air</td>
</tr>
</tbody>
</table>

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Satellite Images for Mid-latitude Cyclones: Leaf Cloud
Open Comma Stage
Occluded Stage
Shearing Stage
Comma Cloud: Wide cloud shield often present north of front
Occluded Stage
Previous Geostationary satellite coverage (2004)

GOES 12

GOES 10

GOES 9

0000 UTC
3 JANUARY 2004

INDSAT

METEOSAT
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.
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.
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.

Used for storm tracking, nowcasting potential utility disruptions, and for early fire detection.
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
The result is better forecasts!