Case Study: October 2011 Nor’easter

FIU MET 3502 Synoptic
Hurricane Forecasts

• Genesis: on large scale weather maps or satellite images, look for tropical waves (Africa easterly waves)

• Tropical storm or hurricane development:
  – Environmental conditions (CIMSS TC website):
    • High SST: >= 26 degree C
    • Low vertical wind shear: <= 5-10 m/s is favorable
    • High moisture: total precipitable water >= 50mm, SAL
  – Internal conditions:
    • Organized convection on IR image; deep convection (85 GHz) near center; ring formed in 37 GHz color image indicating RI (NRL TC website)
    • Upper level (200mb or 300 mb) outflow: anti-cyclonic (CIMSS TC website)
37 GHz Ring and TC Rapid Intensification (RI)

- RI is defined as 30 kt intensity increases during 24 hours (Kaplan and DeMaria 2003)

- Danielle was at 40 kt intensity; increased 33 kt in the next 24 hours
A Mid-latitude Cyclone: Snowfall totals

- Forecasters knew this was coming!!!!
“Top-down” model analysis

• 300 mb: Jet stream
• 500 mb: Vorticity
• 700 mb: Vertical Motion
• 850 mb: Temperature
• Surface: Pressure, Precipitation

• Note: this example only considers one time period at the height of the storm, the evolution of these features through time is important also
What to look for at 300 mb

• **Jet stream pattern** (zonal, split flow, blocking)
  – Note: Use 200 mb for subtropical jet, especially in summer
• **Ridges and troughs**: location and tilting (+ or -)
• Location of upper level highs and lows
• **Jet streaks**
  (a) Trough will amplify (deepen) if jet streak is on the left side of the trough axis
  (b) 4-quadrant model for rising/sinking motion
• **Upper-level divergence** = rising motion (especially if there is low-level WAA also)
Negatively Tilted Trough

- A negatively tilted trough:
  1. Indicates a low pressure has reached maturity,
  2. Indicates strong differential advection (middle and upper level cool air advecting over low level warm air advection). This increases thermodynamic instability.
  3. Indicates good vertical wind shear.

A deep low pressure, a negatively tilted trough, and a warm and moist warm sector combination east of the Rockies often produces a severe weather outbreak.
4-Quadrant Jet Model

- Rising motion: Right Entrance and Left Exit
- Sinking motion: Left Entrance and Right Exit
- Rising motion for a curved jet stream: north of jet axis if jet is in a highly curved flow
- Overall flow pattern? Tilted?
- Will troughs amplify?
- 4-quadrant model
- Any obvious areas of divergence?
What to look for at 500 mb

• **Vorticity**: location and type
  – Shear, Curvature, Earth (Coriolis)

• **Longwave and shortwave troughs**
  – Both associated with positive vorticity

• **Positive Vorticity Advection** (PVA or CVA)
  – High areas of vorticity being advected by strong winds (i.e. wind blows across vorticity contours)
  – Causes vertical motion (QG Omega equation)
- Location and type of vorticity
- Longwave and shortwave troughs
- Positive vorticity advection (PVA)
What to look for at 700 mb

• **Vertical Motion**
  – Should match up fairly well with our diagnostics from the other levels
  – Precipitation is likely in areas of upward motion, but moisture is necessary also

• **Location of fronts** (at 700 mb)
  – Look for a “kink” in height contours at the bottom of a trough, usually only works for strong cold fronts

• Note: Vertical motion is not always synoptically forced
  – Mountains can create “couplets” of upward/downward motion
  – Unusually high upward motion is common in convection
- Areas of rising/sinking motion
- Location of fronts
- Based on other maps, what is causing the vertical motion?
What to look for at 850 mb

- **Warm/cold airmasses**: location and strength
- **High/low pressure systems**: location and strength
  - Look for magnitude of height gradient
- **Strong thermal gradient = possible front**
- **Temperature advection** (associated with fronts and cyclones):
  - WAA = wind blowing from warm to cold
    - WAA = rising motion (2\textsuperscript{nd} term in QG omega equation)
  - CAA = wind blowing from cold to warm
    - CAA = sinking motion
- **Temperature advection is strongest with**:  
  1. Closely spaced isotherms  
  2. Closely spaced height contours (stronger winds)  
  3. Isotherms nearly perpendicular to height contours
- **Note**: 850 mb is essentially a surface map at high elevations
- Strength of Highs and Lows
- Warm and cold air masses
- Location of fronts
- Areas of strongest WAA and CAA
What to look for at the surface

• Surface **Highs, Lows, Fronts**
• **Model forecast precipitation**
  – Not necessarily accurate, especially for mesoscale features!!!
• **1000-500 mb thickness**: 540 dm contour often approximates the rain/snow line
• **Regions of divergence, convergence, confluence, diffluence**
  – Convergence = upward vertical motion
Surface

- Surface Highs and Lows
- Model forecast precipitation
- Location of 540 thickness contour
If you interpret the 300, 500, 700, and 850 mb maps properly, you already have a mental picture of this map before you look at it.

Use the observations to determine exact locations and compare to model initialization.
**Multi-level analysis**

- **Is the low pressure system** _vertically stacked_?
  - Compare trough location at 500/300 mb to 850/700 mb
  - Developing low: vertical tilt to NW with height
  - Occluded low: vertically stacked

- **Tilting of fronts with height**
  - Important for determining location of frontal precip
  - Use surface, 850, and 700 mb

- **Forecasting thunderstorms/convection**
  - Use synoptic overview combined with vertical sounding
How do upper-level conditions help surface cyclone develop?

At perturbation stage, in the center of this circulation, there is mass convergence. When all that air hits the center, we have rising motion because it has nowhere else to go. If the upper levels are favorable for cyclone development, then there is a region of divergence aloft above the developing Low-pressure center. This will help pull the air that is converging at the surface upward and continue to develop the surface cyclone. The upper levels also steer the system and make it progress east.
Summary: Contributing factors to vertical motion over Northeast

- Upper level divergence due to region being located in right entrance + left exit region of two jet streaks
- 500 mb Positive Vorticity Advection (PVA)
- 850 mb Warm Air Advection (WAA)
- Surface low pressure system continuing to deepen due to NW tilting creating divergence over surface low
Other factors to consider for predicting exact snowfall totals:

- **Warm Soil temperature**
  - May limit snowfall accumulation due to melting
- **Warm ocean temperature**
  - Limiting factor if flow is onshore
- **Rising motion in “Dendritic Growth Zone”**
  - Snowflakes grow fastest in -12 to -18°C range
- **If snow falls during daytime, the high sun angle**
  - may melt snow off dark surfaces
- **Note: in a borderline rain/snow case, heavy snowfall rates**
  - will cancel out limiting factors due to high rates of adiabatic cooling (from intense rising motion) and latent heat of fusion (from flakes melting as they fall into warmer air)
Sources/Notes

• Information on interpreting weather maps can be found at: http://www.theweatherprediction.com

--reading assignment: http://www.theweatherprediction.com/charts/

• Mathematical derivations and interpretations are in Martin (2006)

• Weather maps like this can be found at:
  • http://aos.wisc.edu/weather/wx_models/Models.htm or http://sol.aos.wisc.edu

• Disclaimer: All vertical motion diagnostics are filled with assumptions. The omega terms can also cancel each other out in some cases. It is usually easy to diagnose a strong system, it is the weaker cases that are more challenging.
Jet stream analysis
Identifying the jet stream on water vapor imagery

• The 6.7 μm water vapor channel is sensitive to moisture in the upper atmosphere (above 500 mb), which makes it especially useful in identifying the jet stream

• Jet streams are often found:
  – Where water vapor features are moving rapidly (streaky features)
  – Near moisture gradients
  – In the vicinity of developing fronts or cyclones
Where is the jet stream?
Common types of jet stream patterns

• Zonal Flow
• Meridional Flow
• Split Flow
• Cutoff Low
• Blocking High
• Omega Block
• Rex Block
• Pineapple Express
Zonal Flow

- Dominant west to east flow pattern
- Low pressure systems are generally weak and move quickly
- Weather is generally quiet with few extremes
Split Flow

- Similar to zonal flow except with distinctly separate polar and subtropical jets
- Quiet weather between jets
- Fast moving, active weather elsewhere
Meridional Flow

- Dominant north-south flow pattern
- Low pressure systems are stronger and move slower than zonal flow
- Associated with temperature extremes
Cutoff low

- Starts as a normal trough, persists when trough continues to “dig” while rest of jet stream resumes ridging or zonal flow
- Associated with persistent cold, cloudy weather
Blocking High

- Forms from a ridge when warm advection wraps around to the poleward and west sides of the high
- Associated with summer heat waves in eastern US
- Example: The Bermuda High is a semi-permanent blocking high
Omega Block

- Jet stream takes shape of omega: $\Omega$ (low-high-low)
- Largest and least common blocking pattern, usually seen in summer
- Associated with most persistent/extreme droughts
Rex Block

- Blocking high on top of cutoff low
- Associated with persistent ridging (dry/warm weather) over most of US

Idealized Rex Block (500mb)
Dissipating a blocking pattern

• Deformation zone upstream (west) of block is the key to maintaining the blocking feature
  – Flow travels around block, either to the north or south
  – Deformation zone appears as a strong moisture gradient in water vapor imagery

• Numerical models tend to break down blocking patterns too quickly
Pineapple Express

• Strong jet stream from Hawaii to Pacific coast creates persistent moist flow to US Pacific coast
• Associated with very heavy rainfall
• More common in El Nino years