# Forecasting Precipitation Distributions Associated with Cool-Season 500-hPa Cutoff Cyclones in the Northeastern United States

Melissa Payer, Lance F. Bosart, Daniel Keyser
*Department of Atmospheric and Environmental Sciences*
*University at Albany, SUNY*

Neil A. Stuart and Thomas A. Wasula
*NOAA/NWS, Albany, NY*

**M.S. Thesis Presentation**
**8 July 2010**

NOAA/CSTAR Grant NA07NWS4680001

# Motivation

- Forecasting precipitation distributions associated with 500-hPa cool-season cutoff cyclones can be a challenge in the Northeast U.S. (NE)
- Forecast uncertainties often arise due to variation in cutoff cyclone speed/location and interaction with the complex topography in the NE
- Identifying signatures differentiating between precipitation distributions would help forecasters

# Objectives

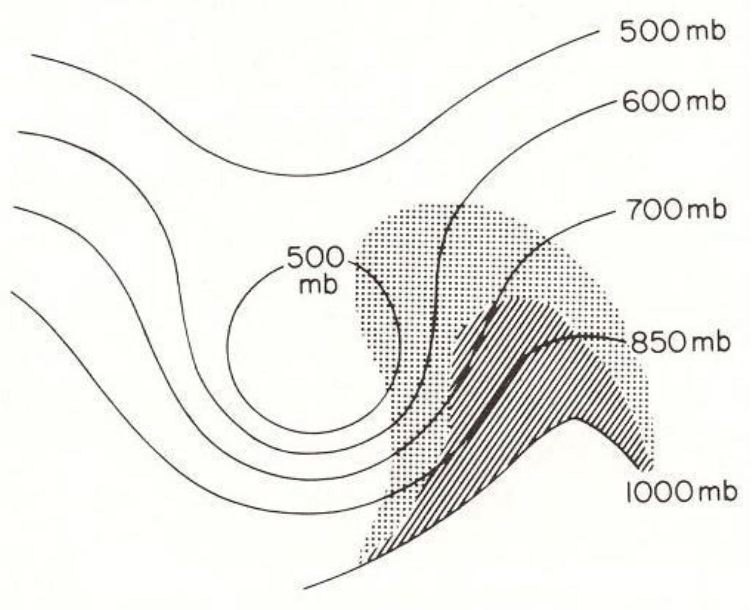
- Create composites of cutoff cyclones categorized by tilt, structure, and precipitation amount
- Perform case studies of difficult-to-forecast cutoff cyclones as well as cutoff cyclones associated with varying precipitation distributions
- Identify signatures differentiating between various precipitation distributions

# Outline

- Overview of cutoff cyclones and precipitation
  - Precipitation distribution
  - Influence of terrain
- Cyclone-relative composites
  - Average location of cutoff cyclones
  - Brief overview of three composite categories
- Case study
  - 1–4 January 2010 cutoff cyclone

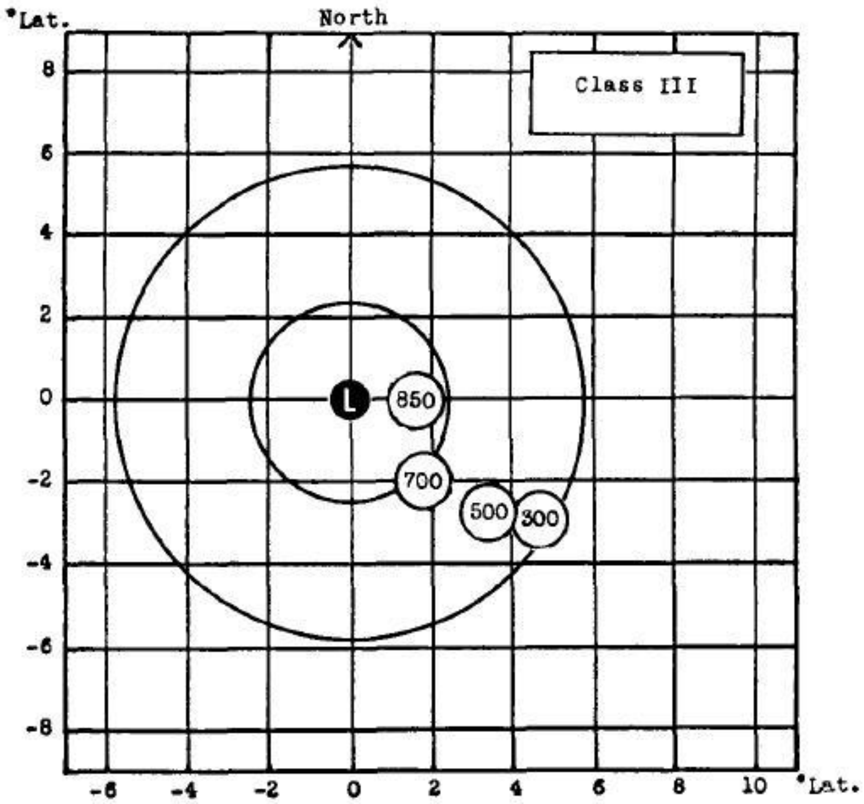
# Cutoff Cyclones and Precipitation

- Hsieh (1949) documented the precipitation distribution associated with a 500-hPa cutoff cyclone
  - Precipitation was distributed asymmetrically about the system
  - Light precipitation was located near the cyclone core while heavy precipitation was observed southeast of the cyclone center



# Cutoff Cyclones and Precipitation

- Klein et al. (1968) examined precipitation distributions associated with cutoff cyclones in the western U.S.
  - 300, 500, 700, 850 hPa
  - The most intense (Class III) cyclones were found to have precipitation occurring in the southeast quadrant
  - For weak systems the precipitation is generally located near the center of the cyclone in the southwest quadrant

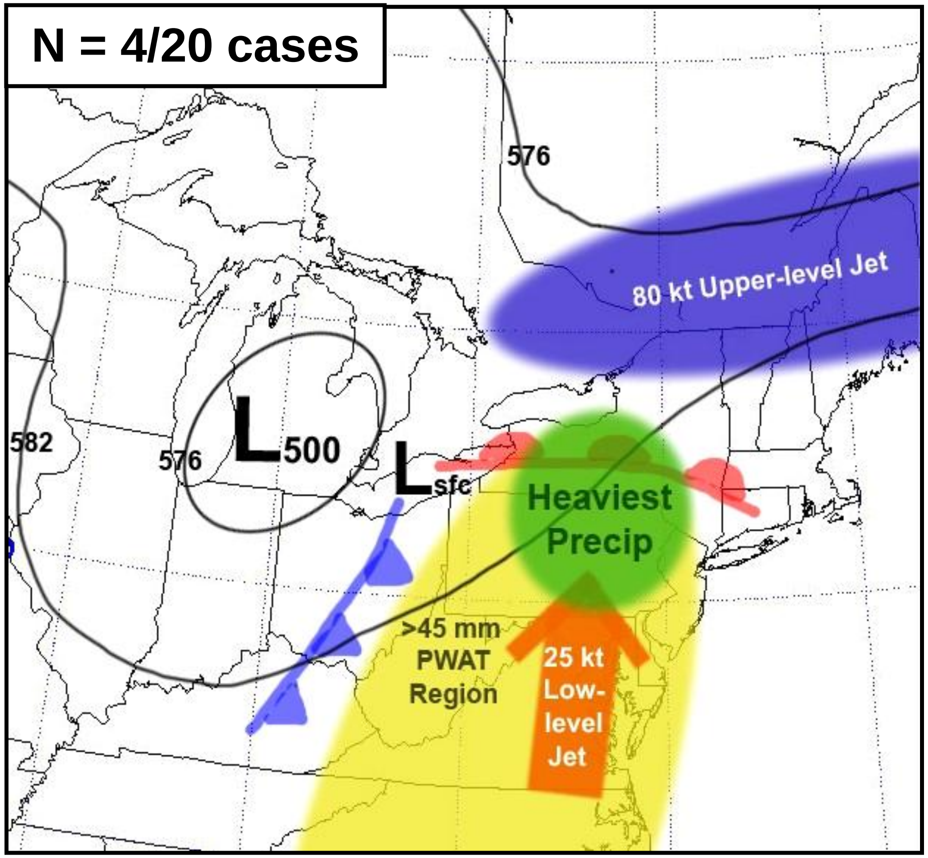


# Cutoff Cyclones and Precipitation

- Aiyyer and Atallah (2002) studied precipitation associated with 500-hPa cutoff cyclones in the NE
  - Approximately 30% of annual precipitation in the NE can be attributed to 500-hPa cutoff cyclones
  - The optimal location for cutoff cyclones producing heavy precipitation in the NE is to the west of the region
  - During the cool season the precipitation is strongly modified by upslope flow and lake-effect enhancement
- Fracasso (2004) completed a climatology of cool-season (Oct–May) 500-hPa cutoff cyclones in the NE
  - Observed enhanced precipitation amounts collocated with higher terrain

# Cutoff Cyclones and Precipitation

- Scalora (2009) examined warm-season (June–Sept) 500-hPa cutoff cyclones in the NE
  - Classified 20 cutoff cyclone cases into five categories based on tilt of 500-hPa cutoff cyclone
  - Developed conceptual models to identify where precipitation and severe weather will be most significant



# Data

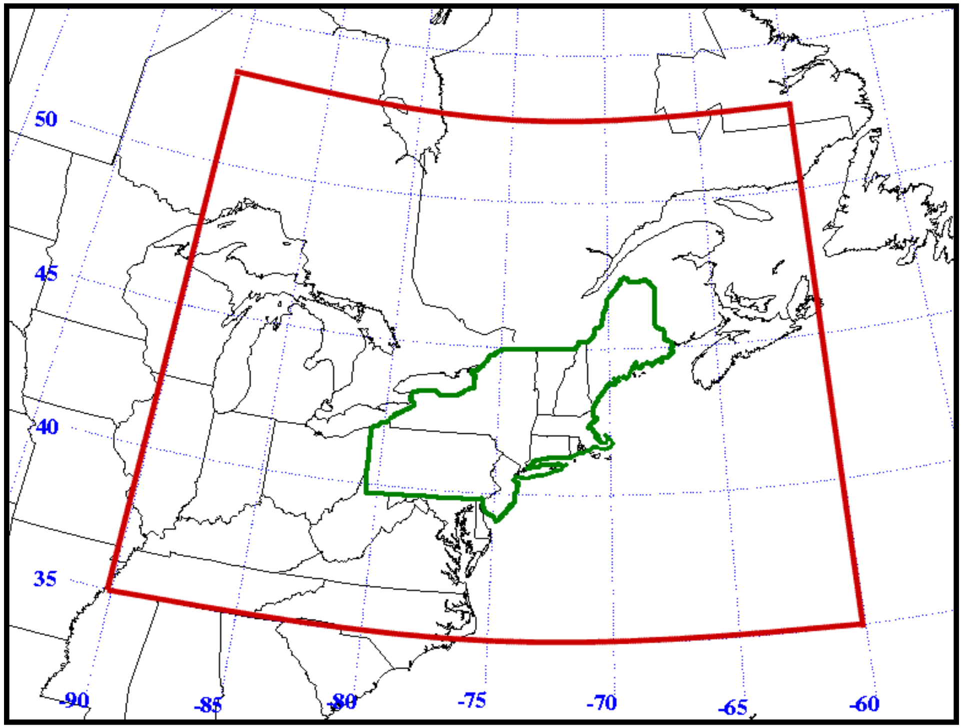
- Cyclone-relative Composites
  - 1.0° GFS analysis data
  - 2.5° NCEP–NCAR reanalysis data
- Case Study
  - 0.5° GFS analysis data
  - 2.5° NCEP–NCAR reanalysis data (climatologies created for 1979–2008)
  - Standardized anomalies fields were created from 1.0° GFS analyses with respect to climatology
  - 6-h National Precipitation Verification Unit (NPVU) QPE
  - NEXRAD base reflectivity
  - Hourly surface observation data

# Methodology

- Analysis period:
  - Cool season (1 Oct–30 Apr)
  - 2004/05–2008/09
- Cutoff cyclone domain:

  35–52.5 °N, 90–60 °W
- Cutoff cyclone criteria:
  - 30-m height rise in all directions
  - Duration ≥12 h
- Precipitation domain:

  New England, NY, PA, NJ



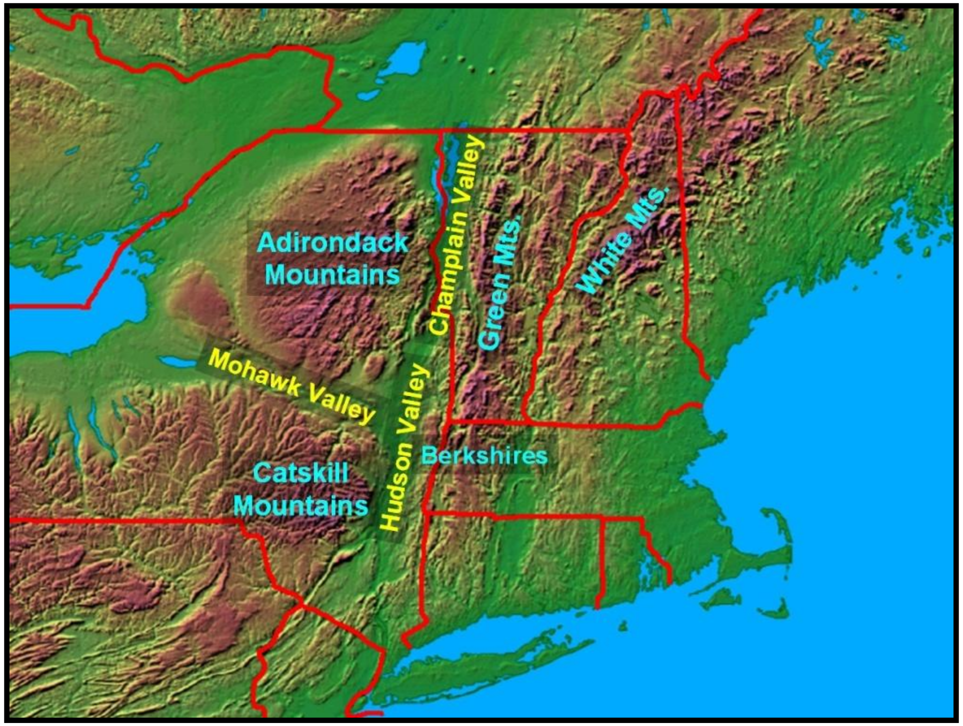

- Cutoff cyclone days were defined as a 24-h period from 1200 to 1200 UTC in which a cutoff cyclone was present in domain

# Methodology

- Analysis period:
  - Cool season (1 Oct–30 Apr)
  - 2004/05–2008/09
- Cutoff cyclone domain:

  35–52.5 °N, 90–60 °W
- Cutoff cyclone criteria:
  - 30-m height rise in all directions
  - Duration ≥12 h
- Precipitation domain:

  New England, NY, PA, NJ




- Cutoff cyclone days were defined as a 24-h period from 1200 to 1200 UTC in which a cutoff cyclone was present in domain

# Cyclone-relative Composites

# Composite Methodology

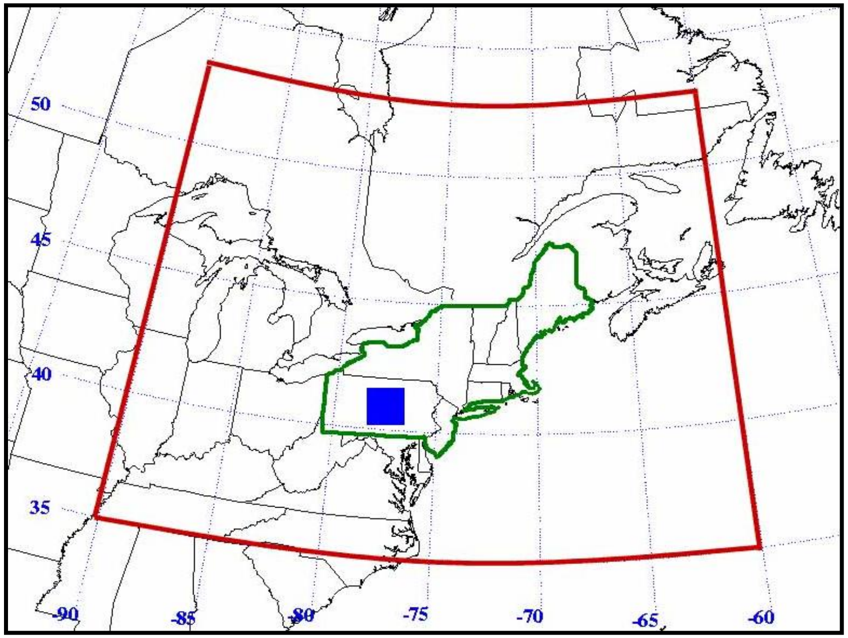
Each cutoff cyclone day (n=384) was categorized by…

1) Precipitation amount observed: heavy precipitation (HP), light precipitation (LP), or no precipitation (NP)

   – HP: $\geq$5% of precipitation domain received 25 mm (n=100)

   – LP: <5% of precipitation domain received 25 mm (n=250)

   – NP: no precipitation observed in the domain (n=34)

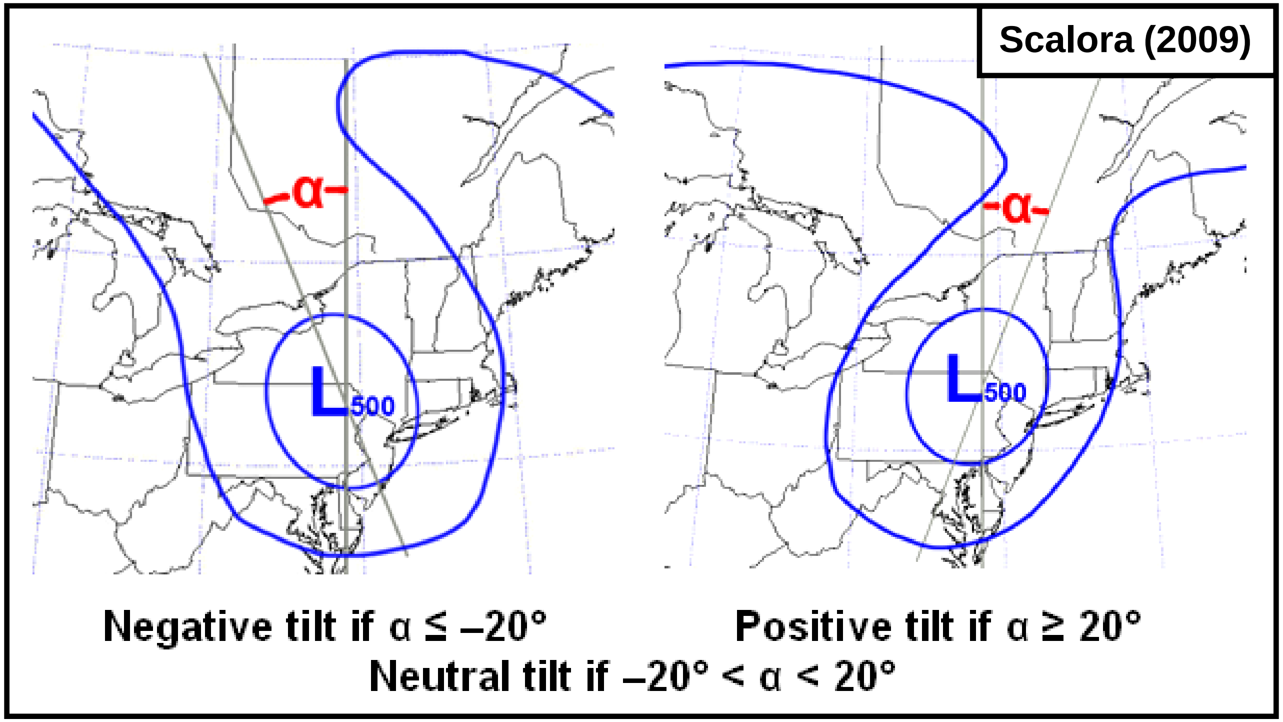


# Composite Methodology

Each cutoff cyclone day (N=384) was categorized by…

1) Precipitation amount observed

2) Tilt: negative, neutral, or positive



# Composite Methodology

Each cutoff cyclone day (N=384) was categorized by…

1) Precipitation amount observed

2) Tilt

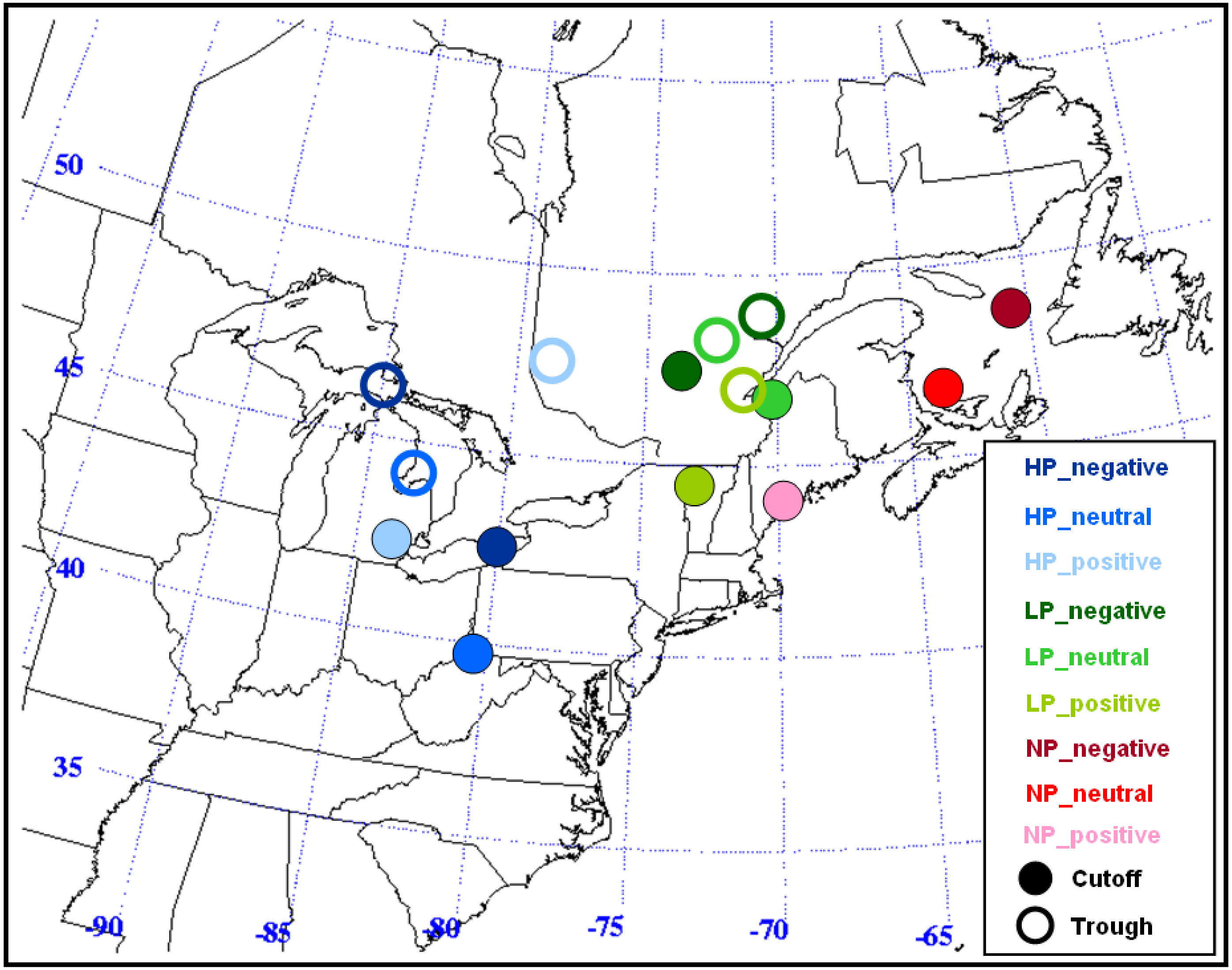
3) Structure: cutoff or trough

**cutoff:** presence of 250-hPa zonal wind standardized anomaly of −2.0 σ or below on the poleward side of the cyclone (i.e., purely separated from the background westerly flow)

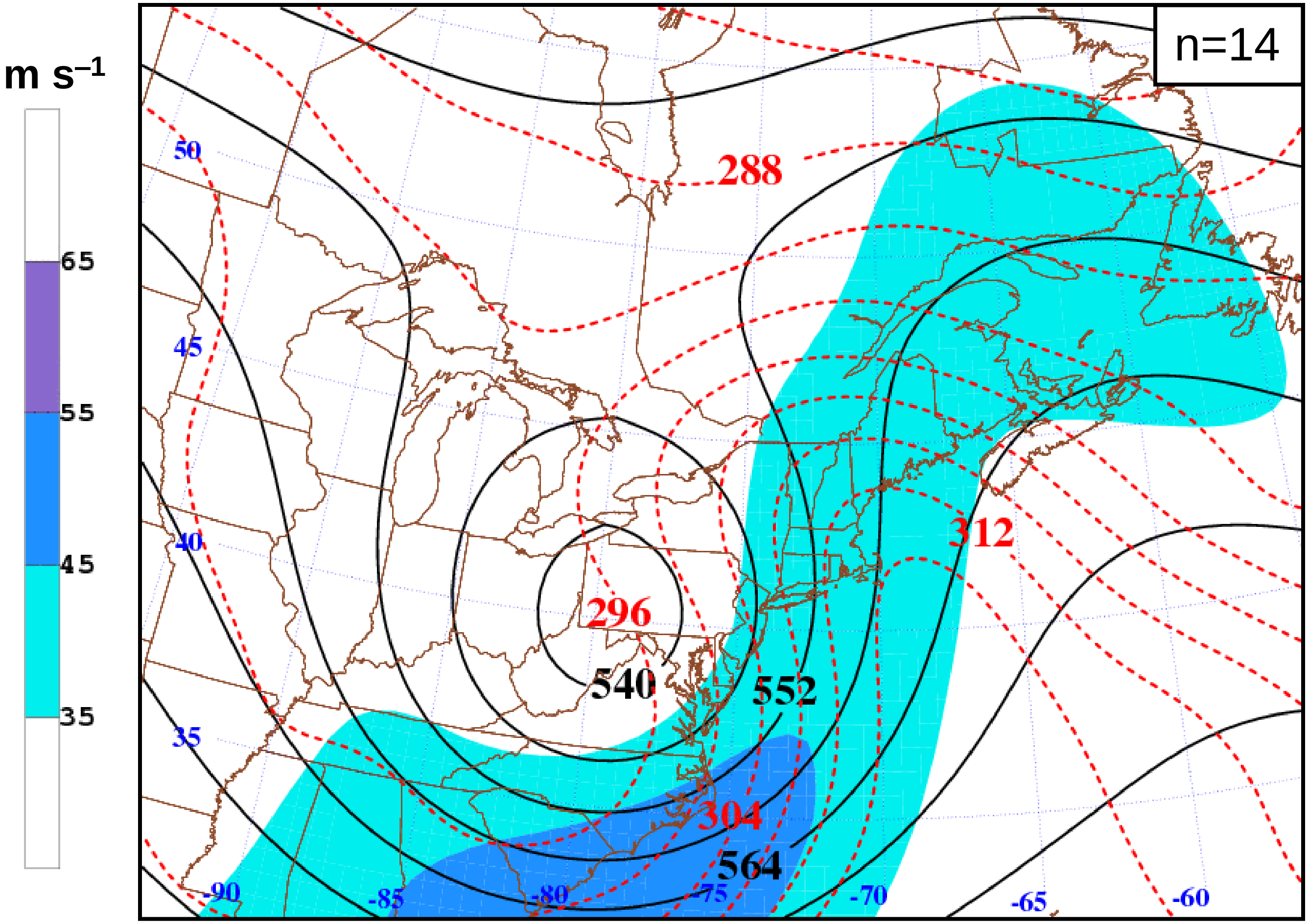
**trough**: does not meet the cutoff criteria (essentially a closed low embedded within a large-scale trough)

Note: Since there were so few NP cutoff cyclone days they were not separated into cutoff/trough

# Average Location of Cutoff Cyclones

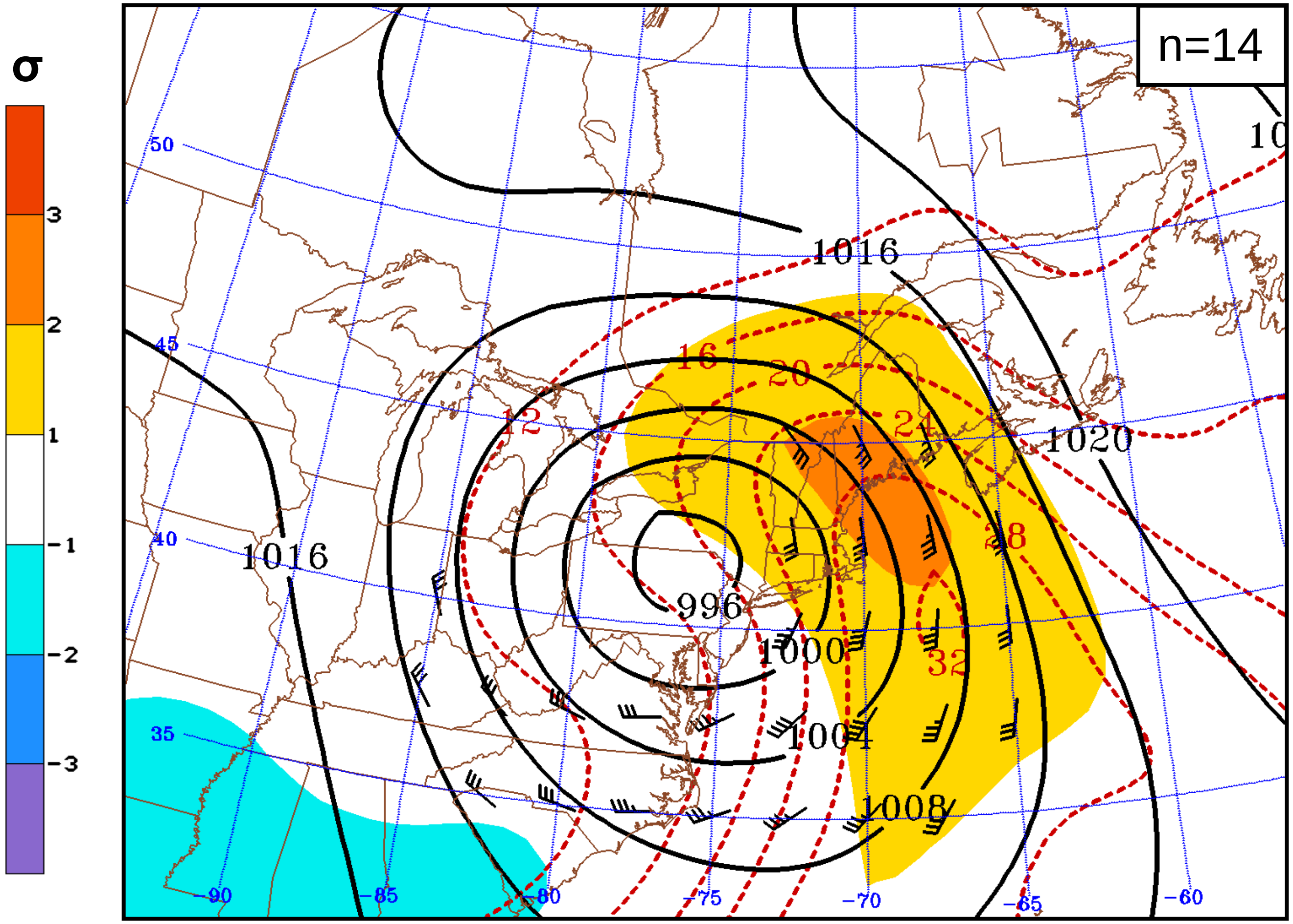


# Composite: HP_neutral_cutoff



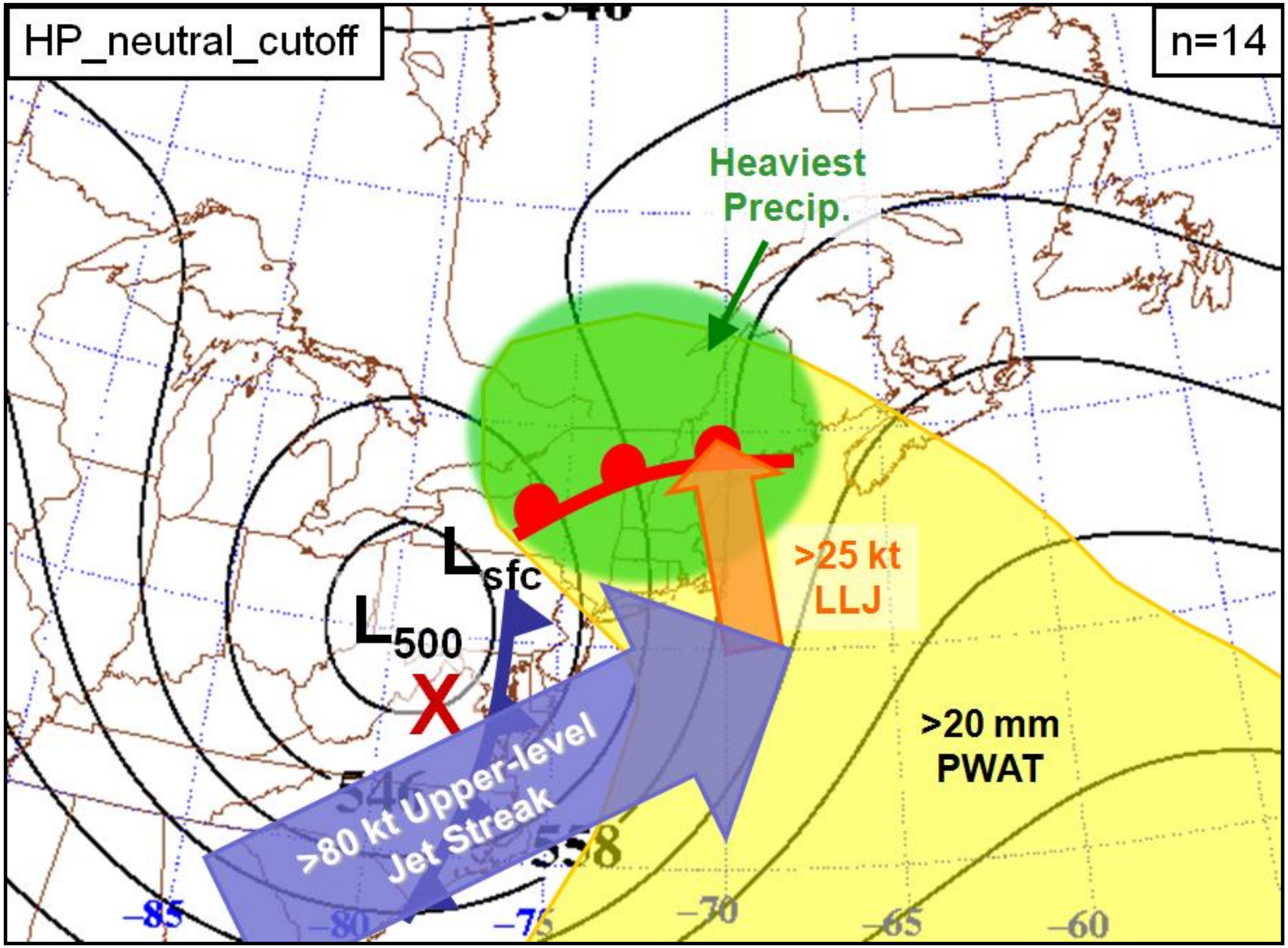

250-hPa wind (m s$^{-1}$, shaded), 500-hPa geo. height (dam, solid contours), and 850-hPa potential temperature (K, dashed contours)

# Composite: HP_neutral_cutoff

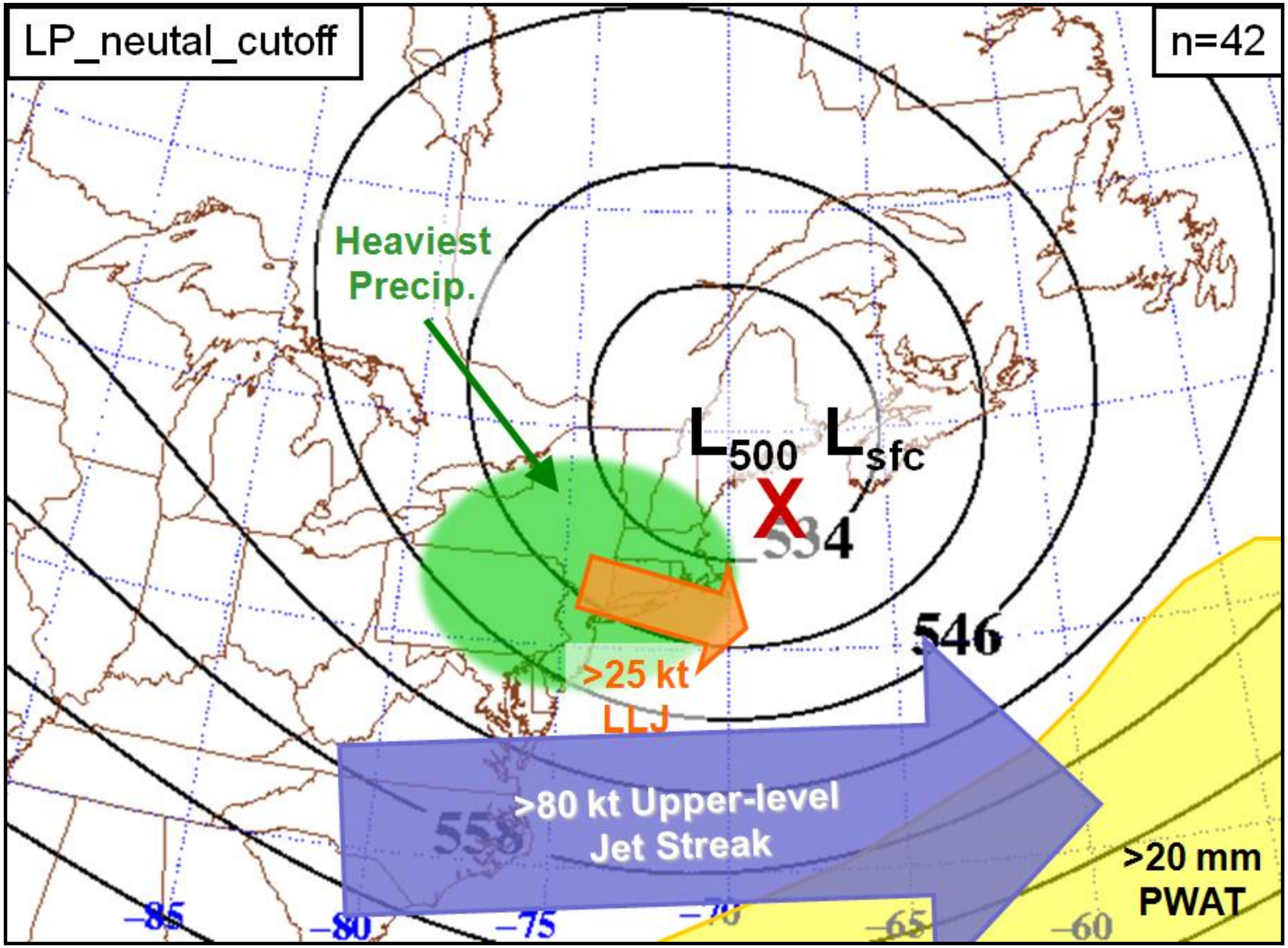



Stand. anom. of precipitable water (σ, shaded), MSLP (hPa, solid contours), 850-hPa wind ($\geq$30 kt, barbs), and precipitable water (mm, dashed contours)

# Composite Summary: HP_neutral_cutoff



# Composite Summary: LP_neutral_cutoff



# Composite Summary

- Location of 500-hPa cutoff cyclone center largely determines precipitation amount
  - HP cutoff cyclones located over eastern Great Lakes
  - LP cutoff cyclones located over the precipitation domain
  - NP cutoff cyclones located to the northeast of the precipitation domain
- Location of heaviest precipitation varies
  - Eastern quadrant for HP cutoff cyclones
  - Western quadrants for LP cutoff cyclones
- HP cutoff cyclone composites indicate favorable forcing for ascent in the exit region of the upper-level jet streak and moisture transport at low levels over the precipitation domain

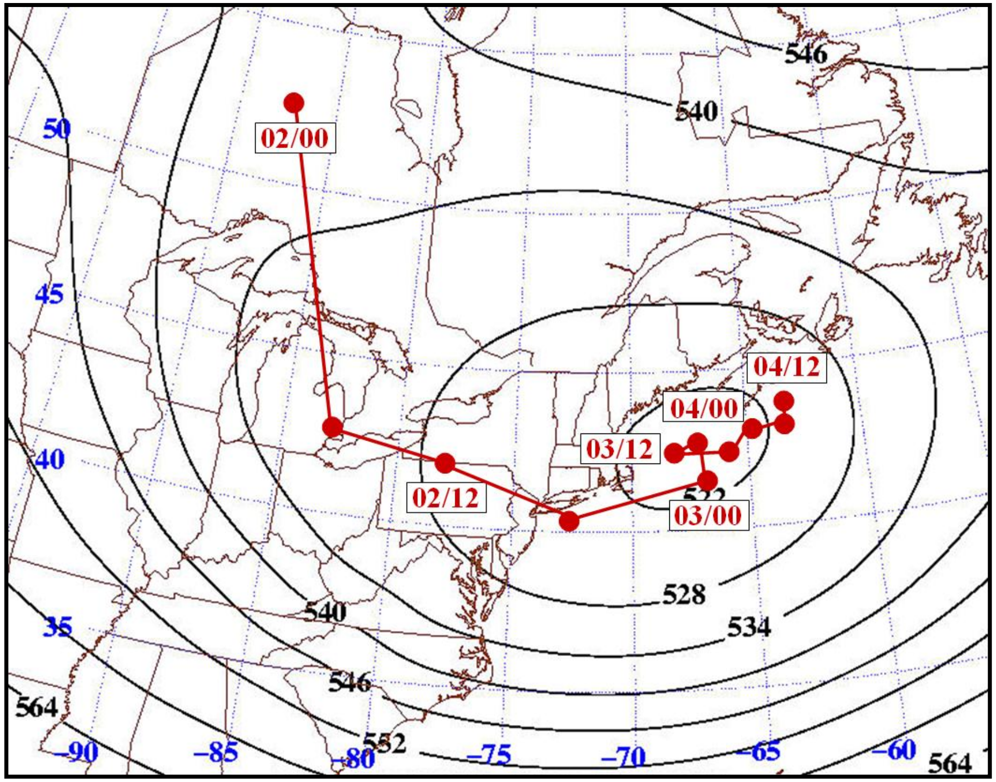
# Case Study

## 1–4 January 2010 Cutoff Cyclone

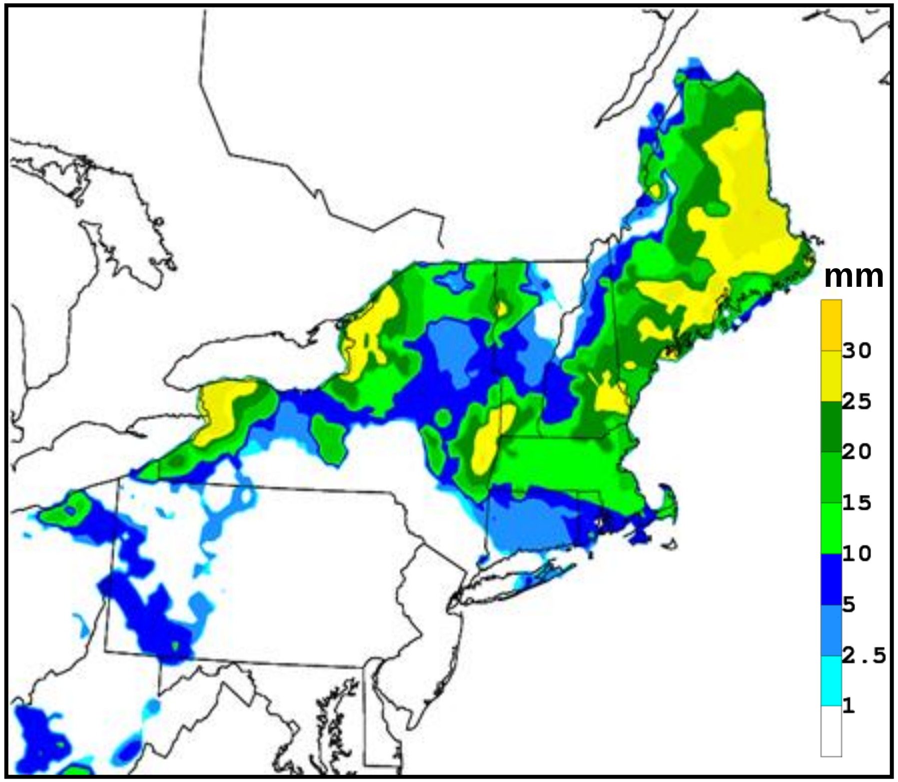
# Overview

- Long duration event (cutoff cyclone in domain for ~60 h)
- Cutoff cyclone stalled over the Atlantic and retrograded into the Gulf of Maine
- Record-breaking snowfall was observed at Burlington, VT with an event total of 37.6 in.
- Numerical models showed considerable variability leading up to the event
- Just prior to the event, the NAM seemed to capture the terrain enhancement well but QPF amounts were too high

# Track and Precipitation Distribution

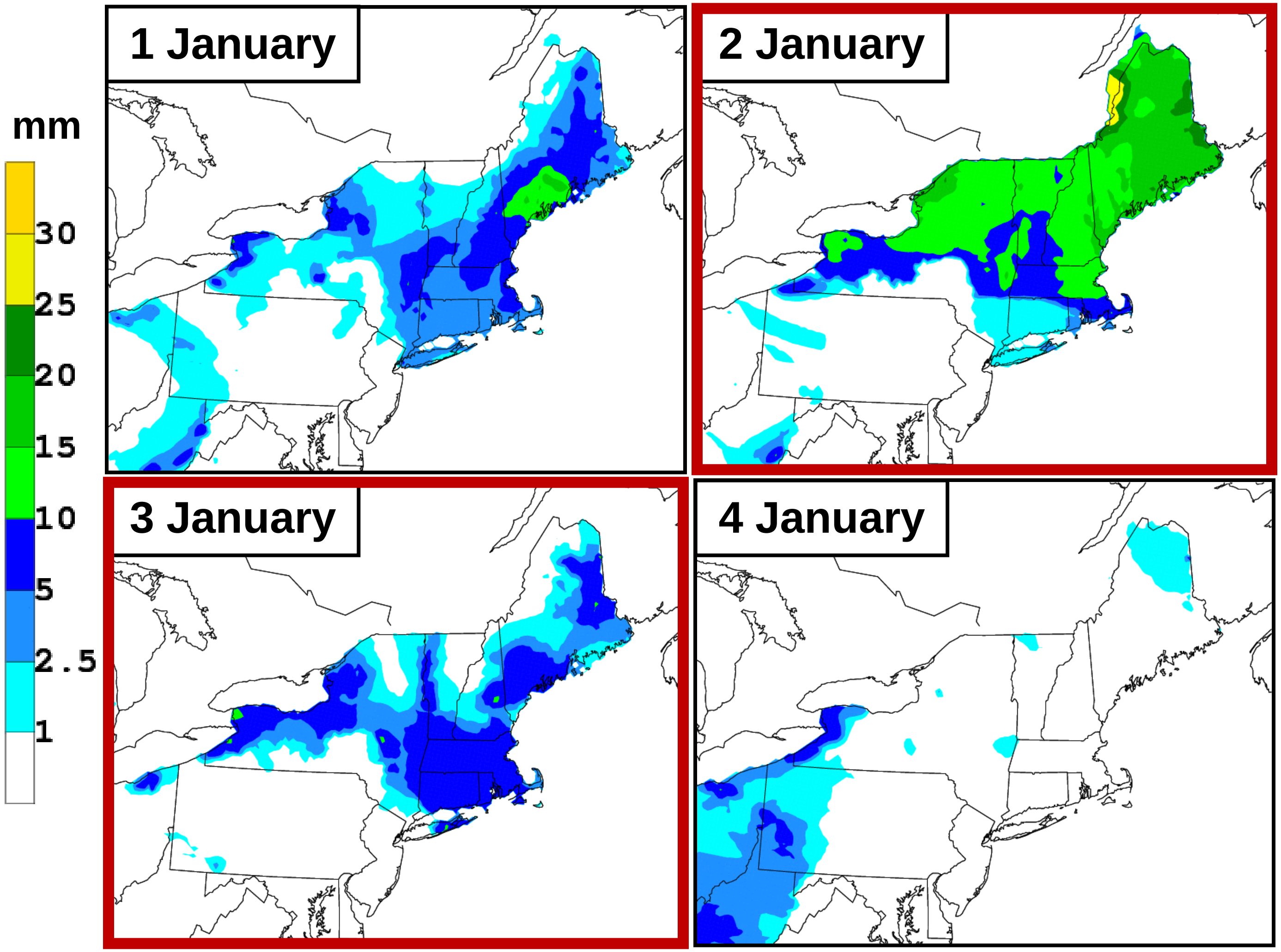



1–4 January 2010
500-hPa mean geo. heights (dam)
and track of cutoff cyclone every 6 h



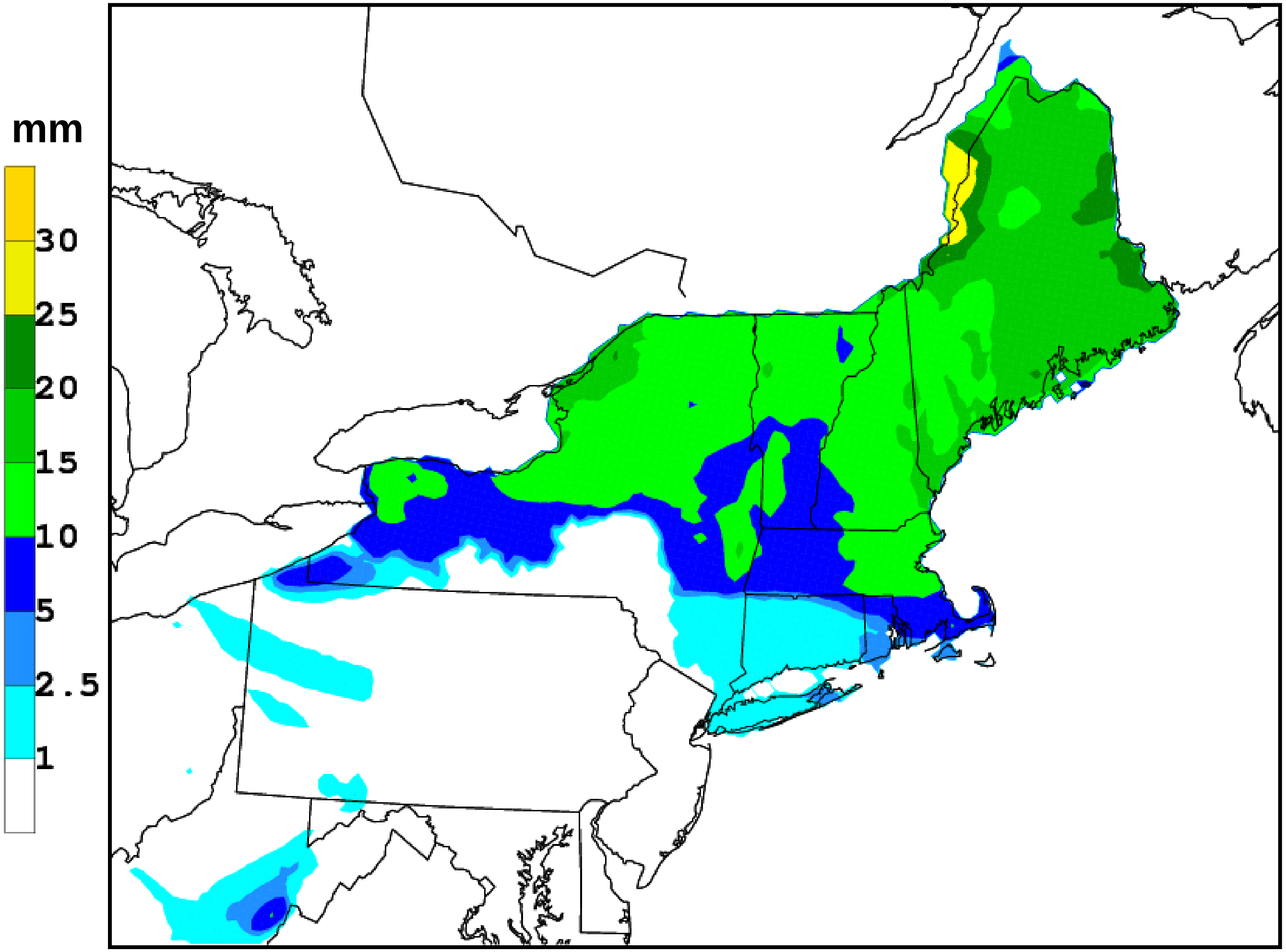

1–4 January 2010
4-day NPVU QPE (mm)

# Daily Precipitation Distributions



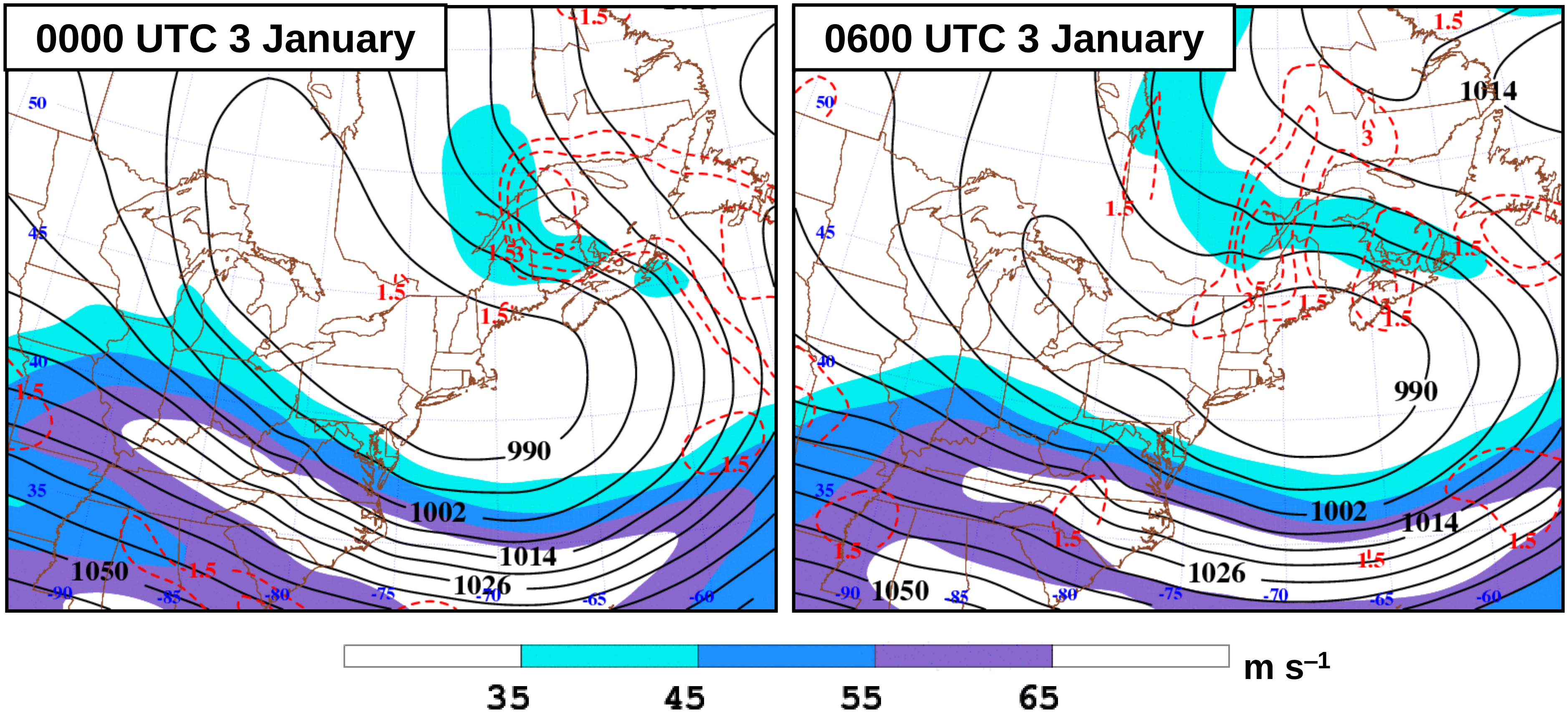

24-h NPVU QPE (mm)

# 2 January 2010



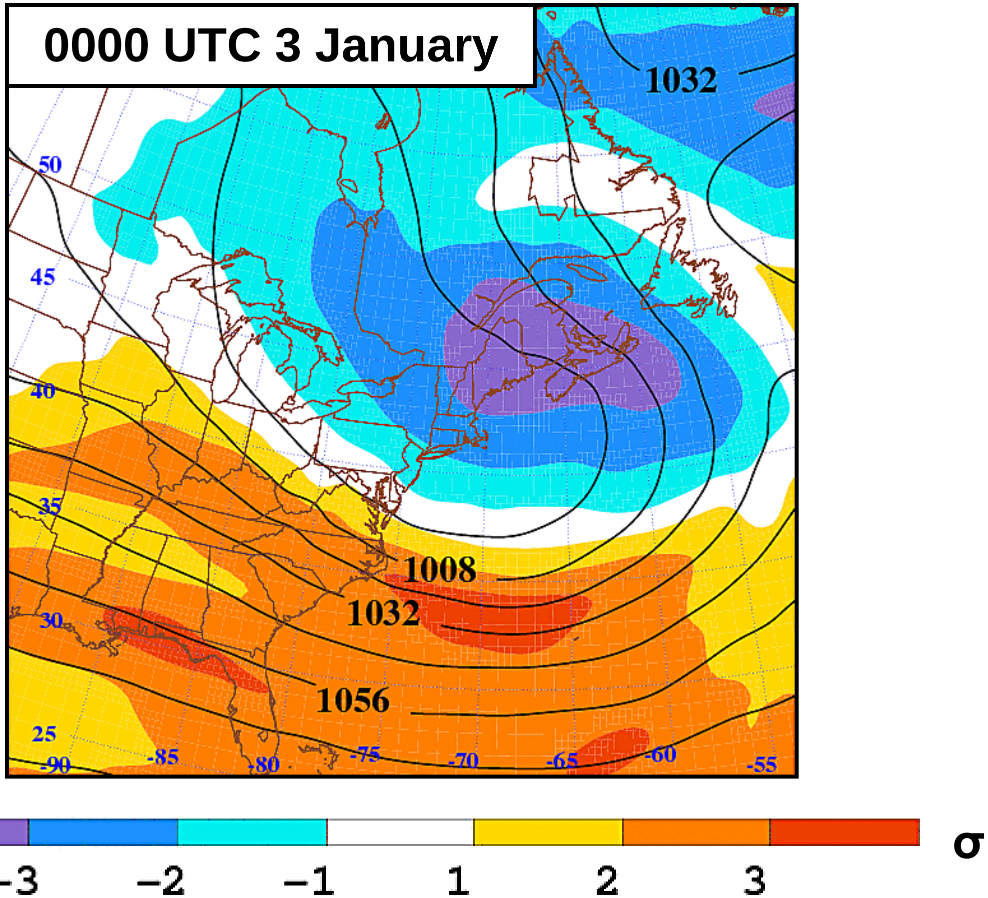

24-h NPVU QPE (mm) ending 1200 UTC 3 January 2010

# 2 January 2010: 250 hPa



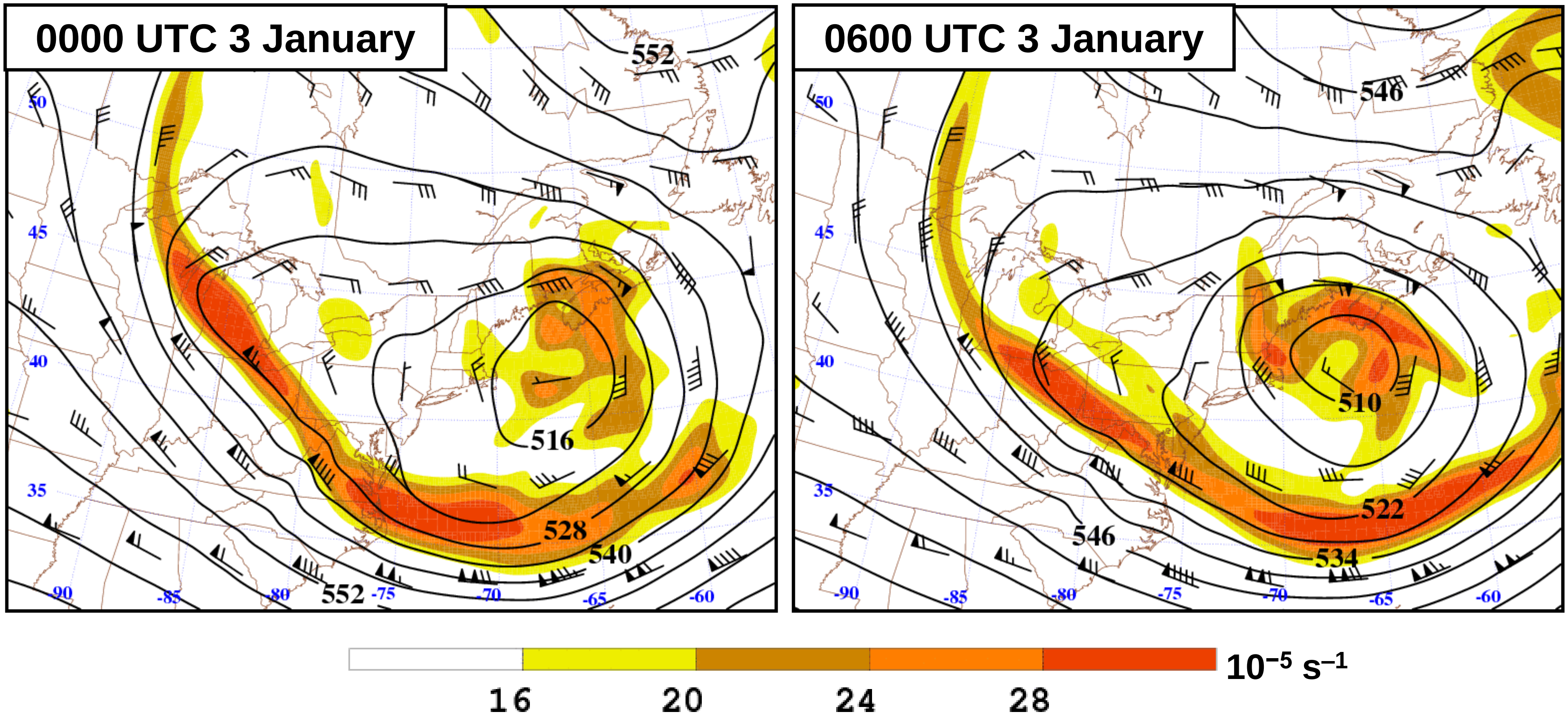

250-hPa geo. height (dam, solid contours), wind (m $s^{-1}$, shaded), and divergence ($10^{-5}$ $s^{-1}$, dashed contours)

# 2 January 2010: 250 hPa



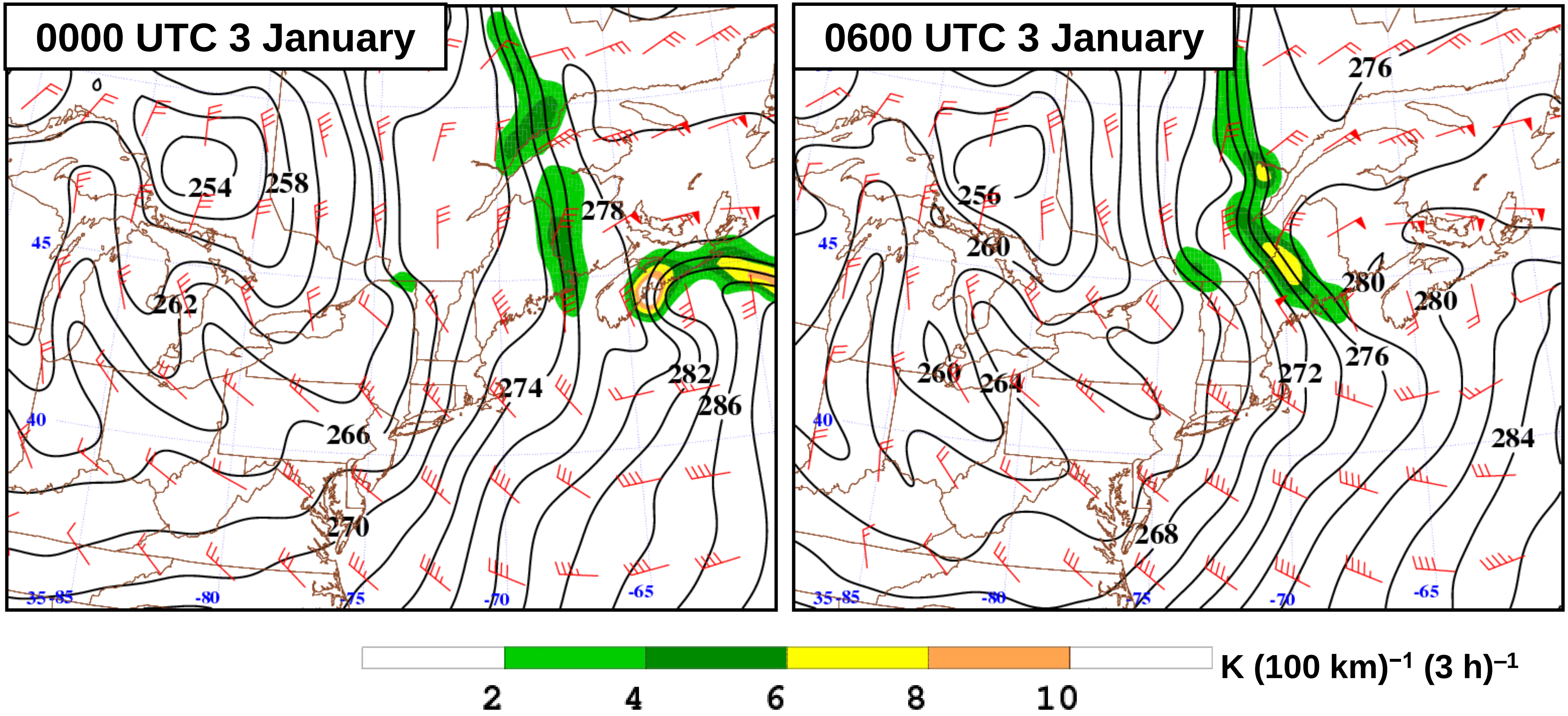

Standardized anomalies of 250-hPa zonal wind (σ, shaded), and 250-hPa geo. height (dam, solid contours)

# 2 January 2010: 500 hPa



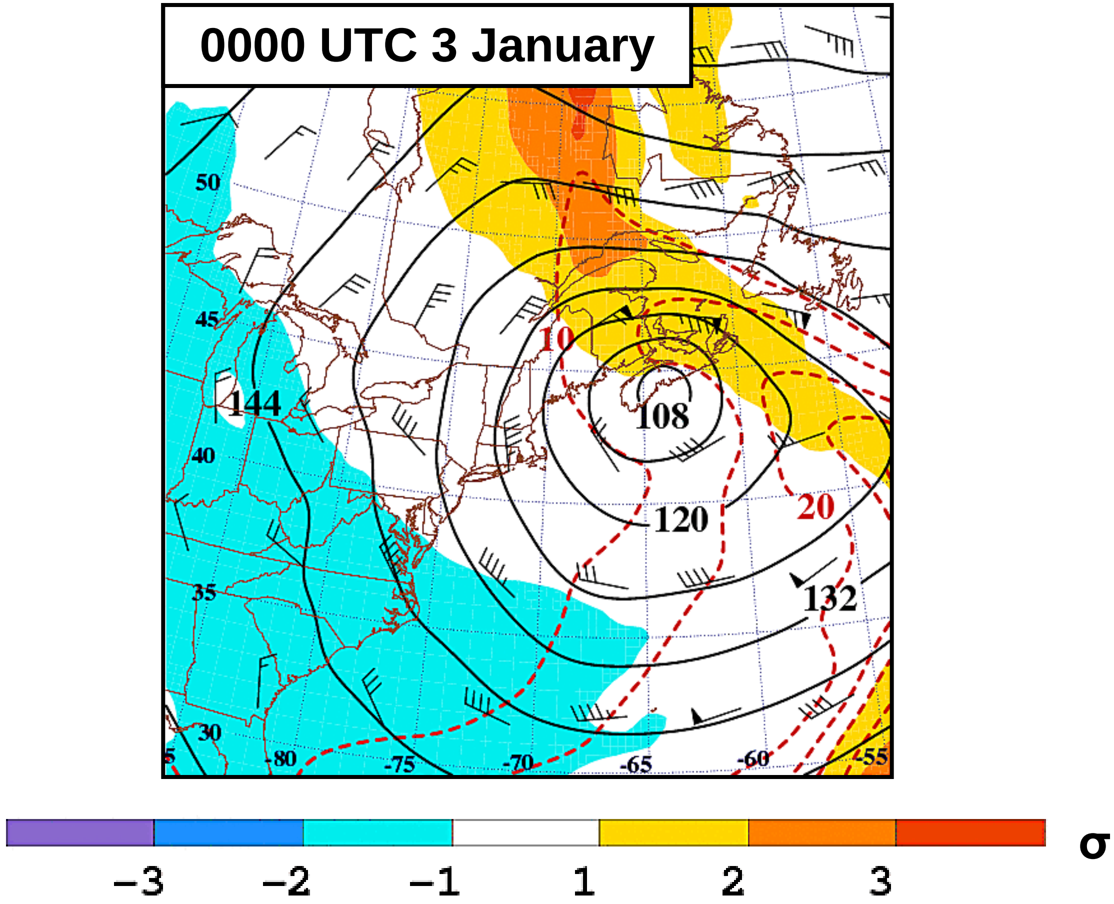

500-hPa geo. height (dam, solid contours), absolute vorticity ($10^{-5}$ $s^{-1}$, shaded), and wind (kt, barbs)

# 2 January 2010: 925 hPa



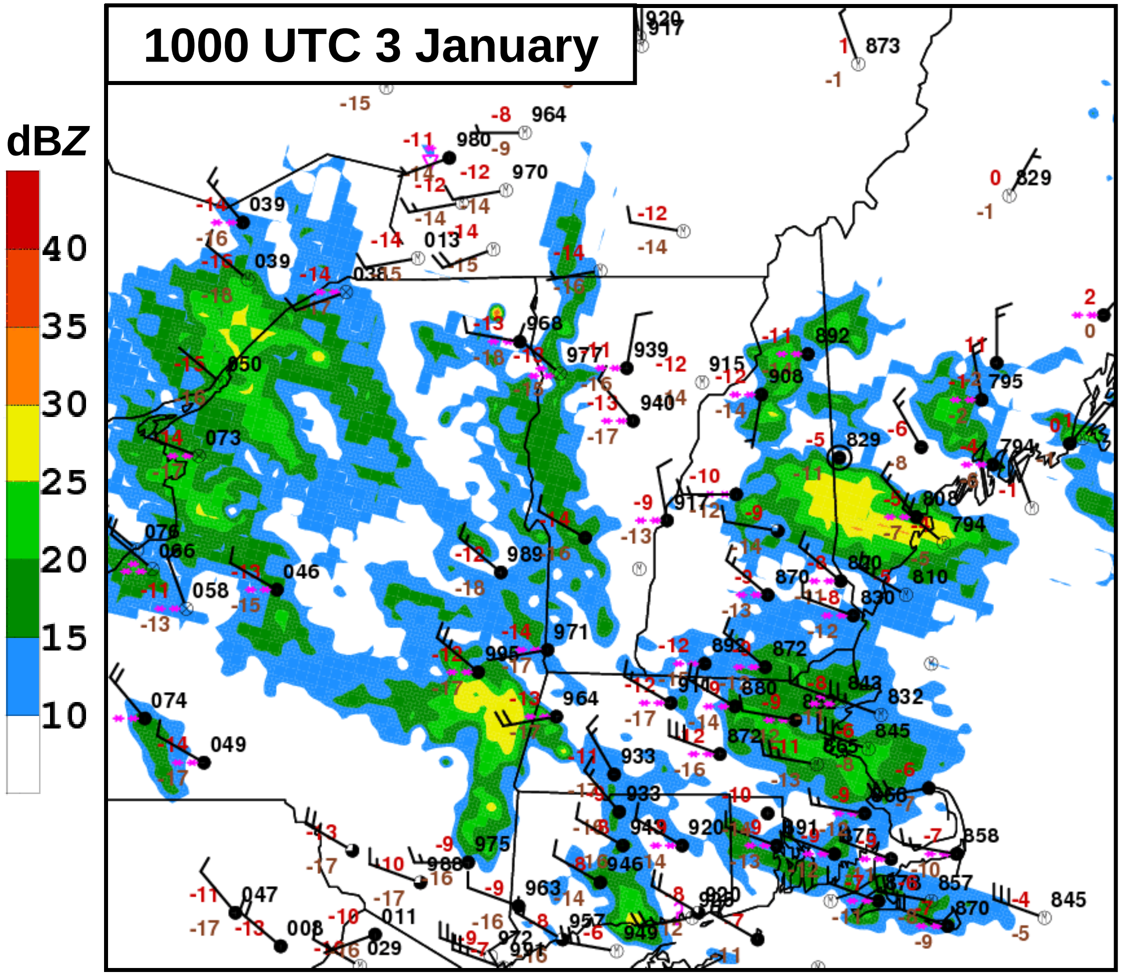

925-hPa frontogenesis [K (100 km)$^{-1}$ (3 h)$^{-1}$, shaded], potential temperature (K, solid contours), and wind (kt, barbs)

# 2 January 2010: 850 hPa




Standardized anomalies of precipitable water (σ, shaded), 850-hPa geo. height (dam, solid contours), wind (kt, barbs), and precipitable water (mm, dashed contours)

# 2 January 2010: Radar




Base reflectivity (dB*Z*) and surface observations

# 2 January 2010 Summary (1 of 2)

- Two primary regions of moderate precipitation (10–20 mm)

  1) Precipitation throughout Maine was enhanced by…

     – favorable forcing for ascent in the exit region of an easterly jet streak poleward of the cutoff cyclone

     – northeasterly low-level flow advecting anomalous (+1 to +3σ) moisture into the region

     – frontogenesis along a southwestward-moving warm front

# 2 January 2010 Summary (2 of 2)

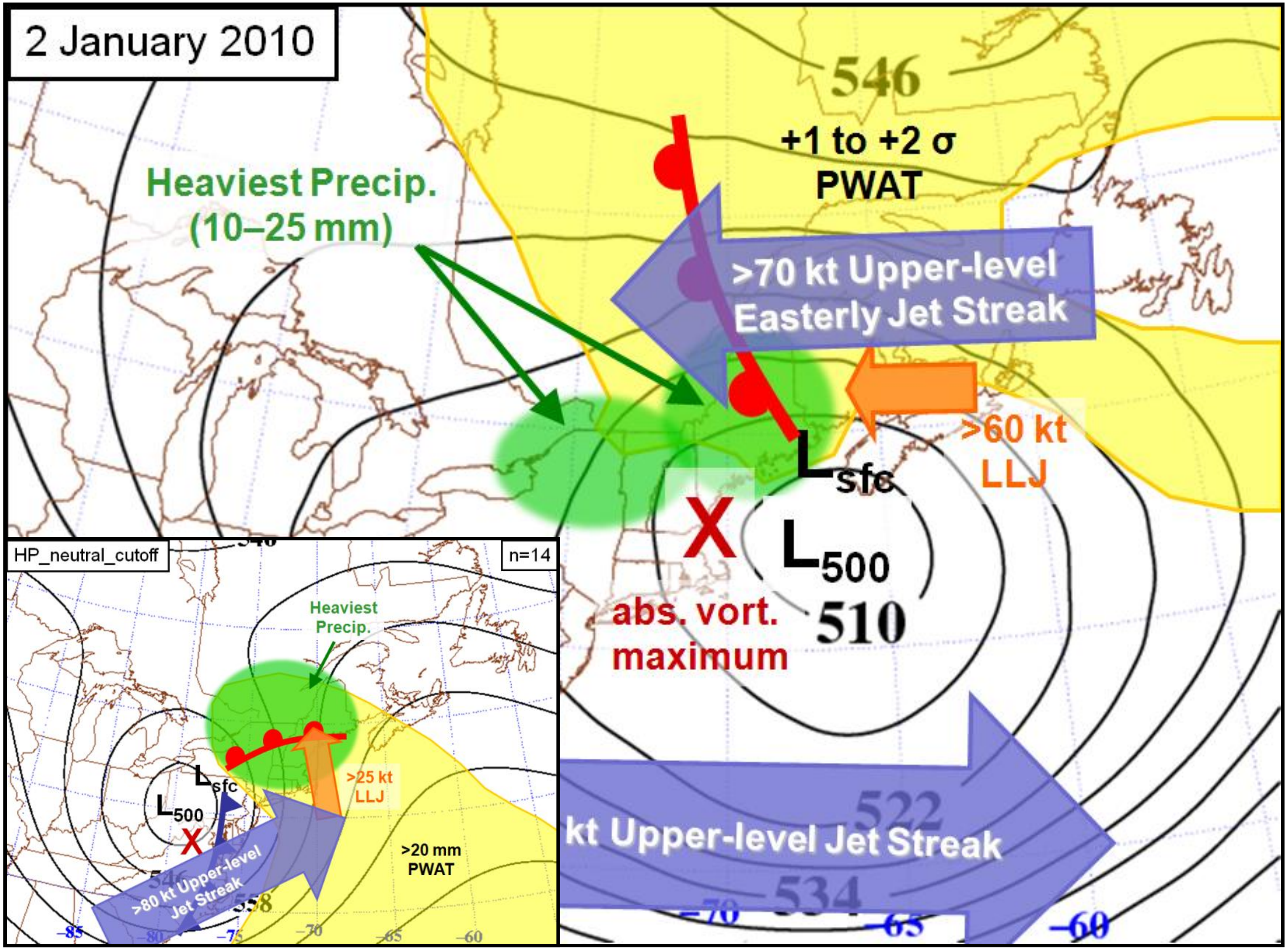
- Two primary regions of moderate precipitation (10–20 mm)

  2) Precipitation across northern portions of New York, Vermont, and New Hampshire was primarily associated with…

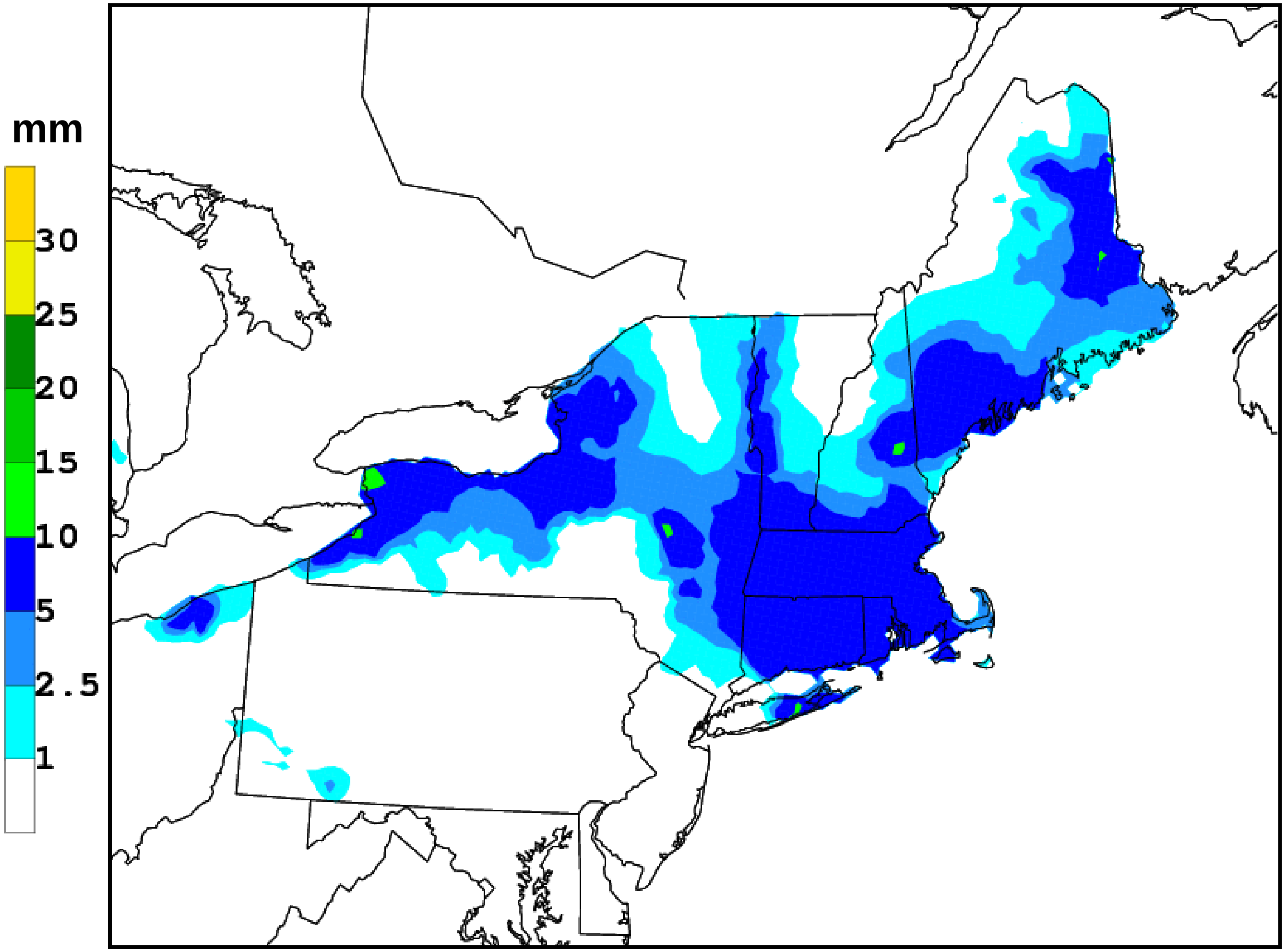
     – a westward-moving lobe of cyclonic absolute vorticity advection

     – upslope flow along the western slopes of the Berkshires and Green Mountains

# 2 January 2010 Conceptual Summary

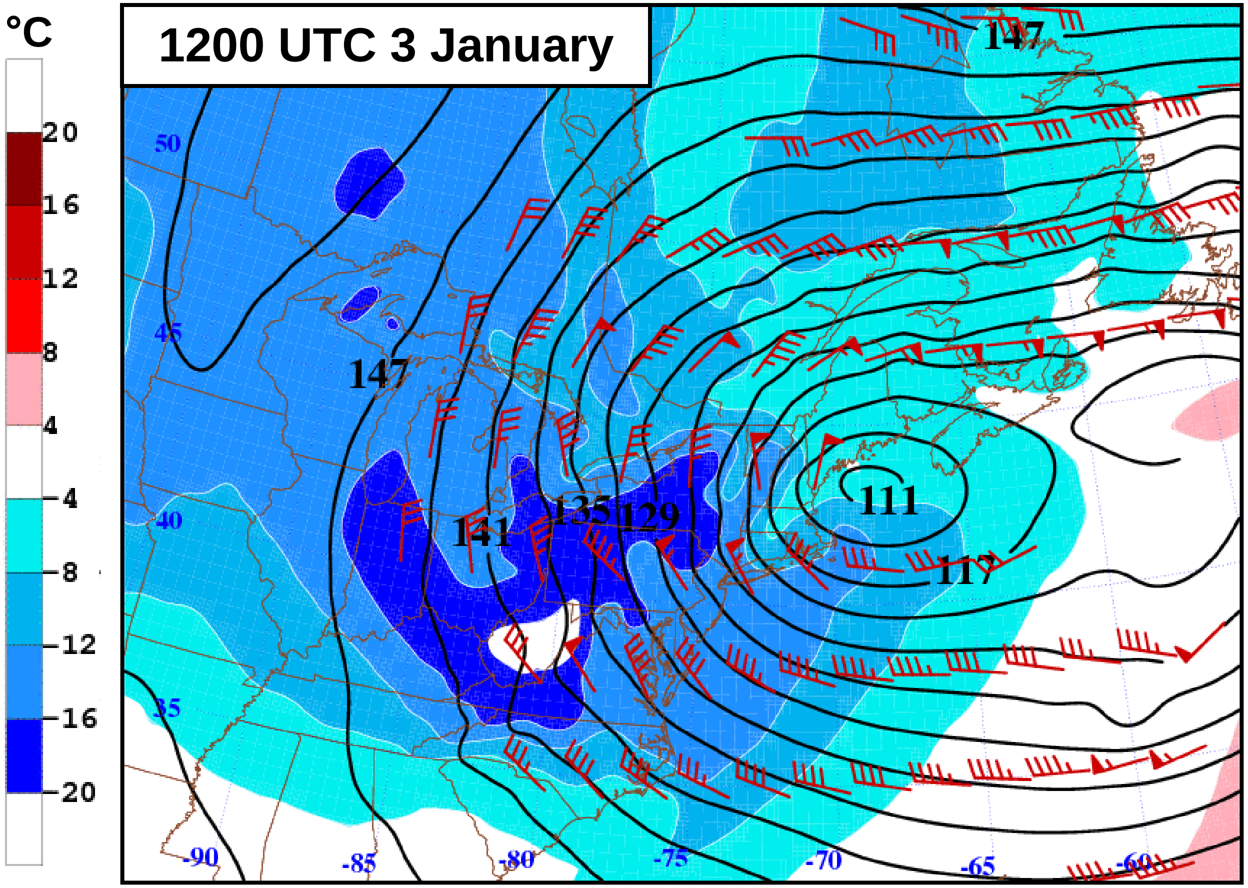


# 3 January 2010



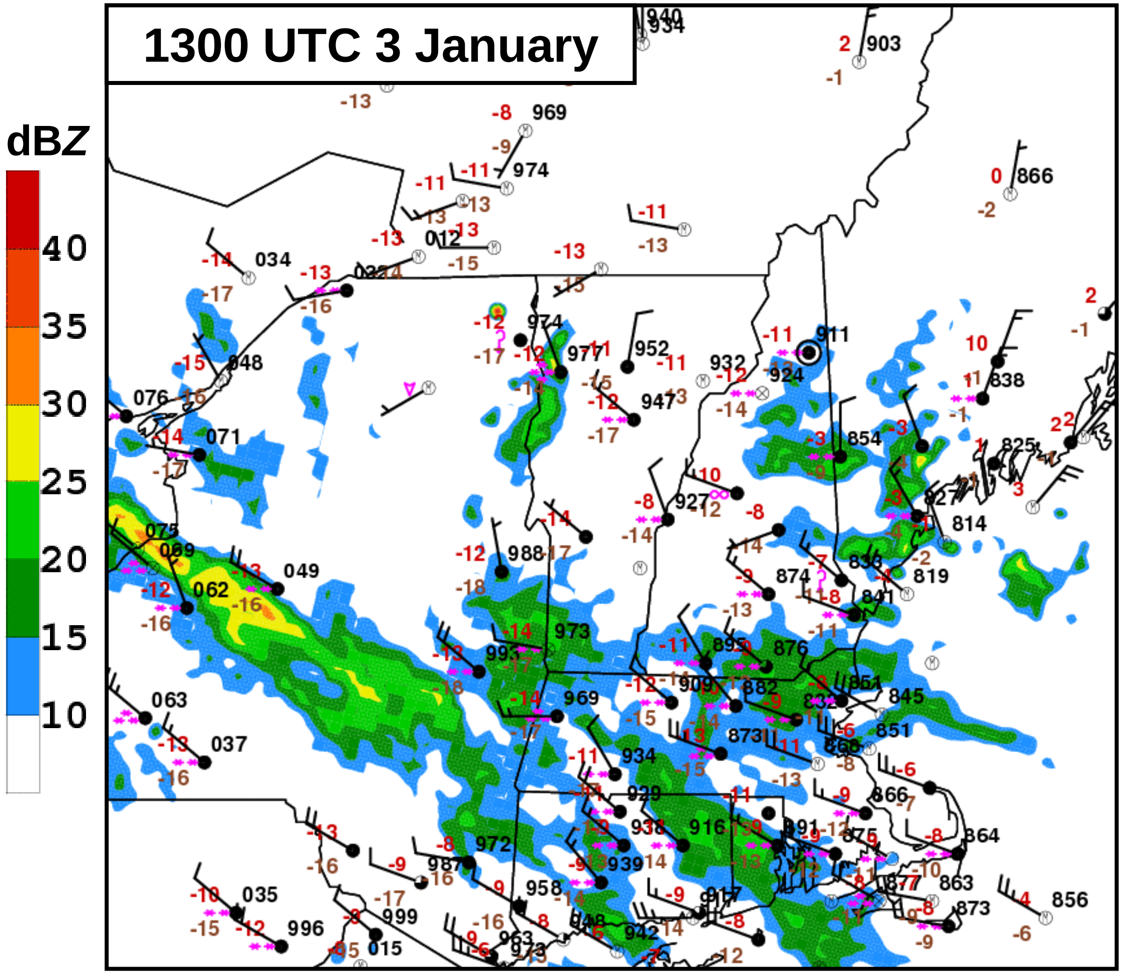

24-h NPVU QPE (mm) ending 1200 UTC 4 January 2010

# 3 January 2010: 850 hPa




850-hPa geo. height (dam, solid contours), temperature (°C, shaded), and wind ($\geq$30 kt, barbs)

# 3 January 2010: Radar




Base reflectivity (dB$Z$) and surface observations

# 3 January 2010 Summary

- Synoptic-scale forcing persisted, contributing to light precipitation amounts in southern New England
- Low-level flow was modified by the terrain effects and lake-effect enhancement
  - Precipitation in western New York was primarily due to northwesterly low-level flow, resulting in lake-effect snow bands off of Lakes Erie and Ontario
  - Precipitation along the New York/Vermont border was associated with…
    - low-level channeling flow through the Champlain Valley providing favorable conditions for a lake-effect snow band
    - ongoing enhanced precipitation along the western slopes of the Green Mountains

# Conclusions

- Use of conceptual models may increase situational awareness in forecasting precipitation distributions associated with cool-season 500-hPa cutoff cyclones

- Key factors influencing precipitation:
  - Location of 500-hPa cutoff cyclone center
  - Support for ascent provided by an upper-level jet streak
  - Onshore low-level flow contributing to moisture transport
  - Surface boundaries acting to locally enhance precipitation

- Low-level flow can be modified by the topography of the NE resulting in enhancement or suppression of precipitation in the vicinity of higher terrain

Acknowledgements

- Lance Bosart and Dan Keyser
- NWS Focal Points Tom Wasula and Neil Stuart
- Matt Scalora
- My fellow graduate students
  - Jonas, Jay, Tom, Ben, Heather, Nick, Alan, Tim, and Scott
- My professors
  - Paul, Mathias, Vince, Ryan, Chris
- Kevin Tyle
- Patti Seguin, Maria Moon, and Barbara Zampella
- My family and Steve

# References

Aiyyer, A.R., and E.H. Atallah, 2002: Precipitation associated with 500 hPa closed cyclones. *4th Northeast Operational Regional Workshop,* 5–6 November 2002, Albany, NY.

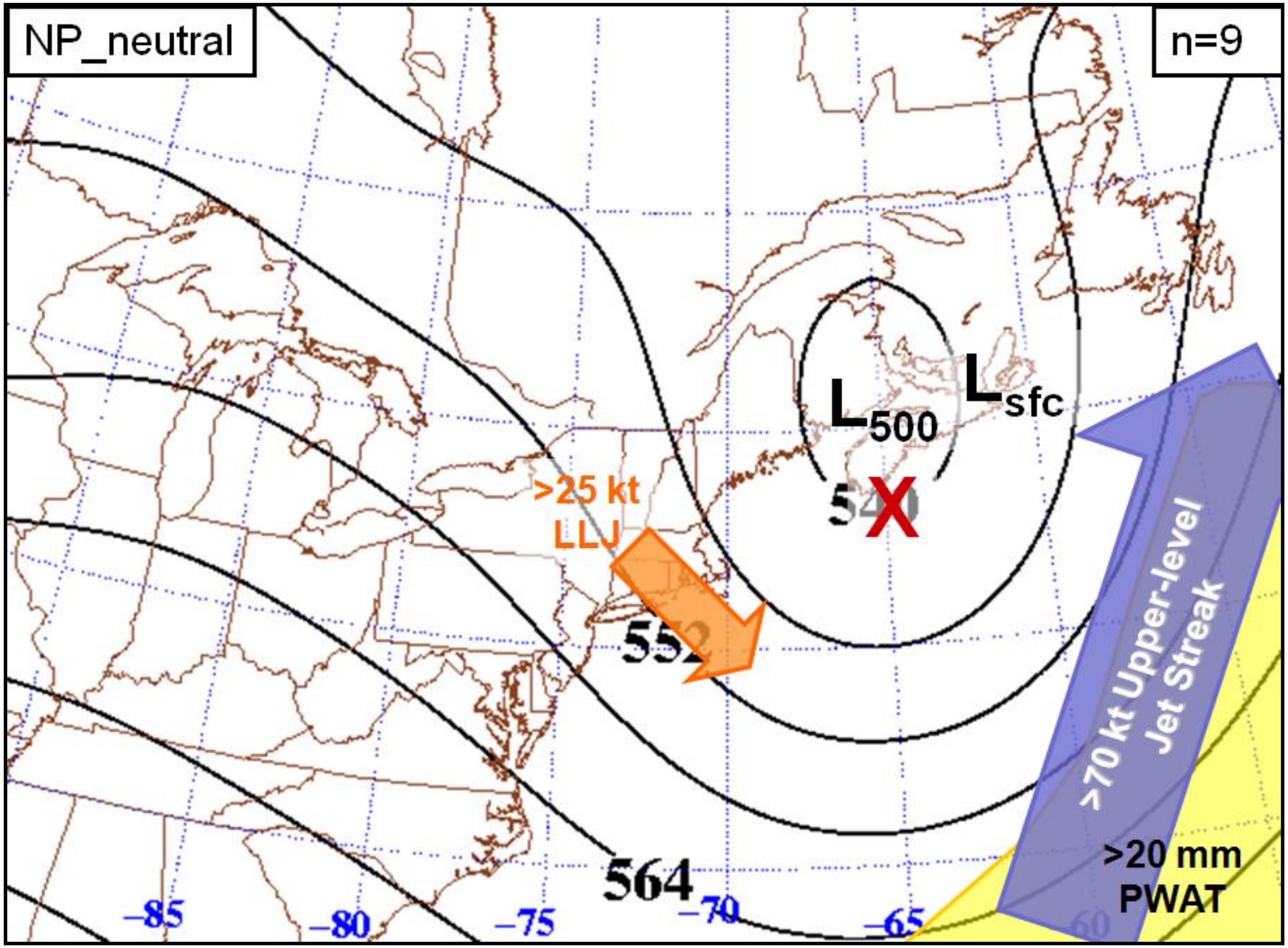
Fracasso, A.R., 2004: Case studies of cool season 500 hPa cutoff cyclone precipitation distribution. Masters of Science Thesis, Department of Earth and Atmospheric Sciences, University at Albany/SUNY, Albany, NY, 121 pp.

Hsieh, Y.P., 1949: An investigation of a selected cold vortex over North America. *J. Meteor.*, **6**, 401–410.

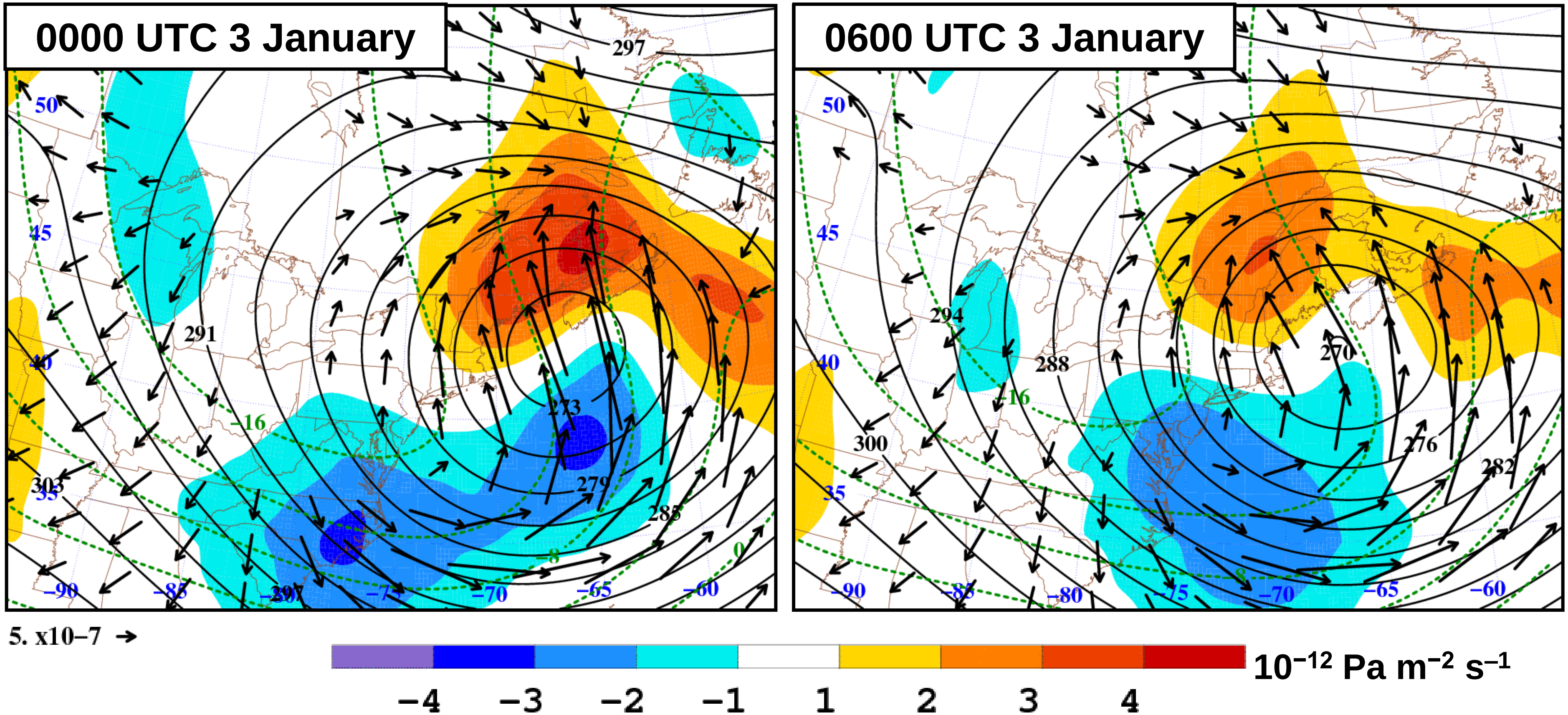
Klein, W.H., D.L. Jorgensen, and A.F. Korte, 1968: Relation between upper air lows and winter precipitation in the western plateau states. *Mon. Wea. Rev.*, **96**, 162–168.

Scalora, M., 2009: Forecasting distributions of warm-season precipitation associated with 500-hPa cutoff cyclones. Masters of Science Thesis, Department of Atmospheric and Environmental Sciences, University at Albany/SUNY, Albany, NY, 146 pp.

# Composite Summary: NP_neutral

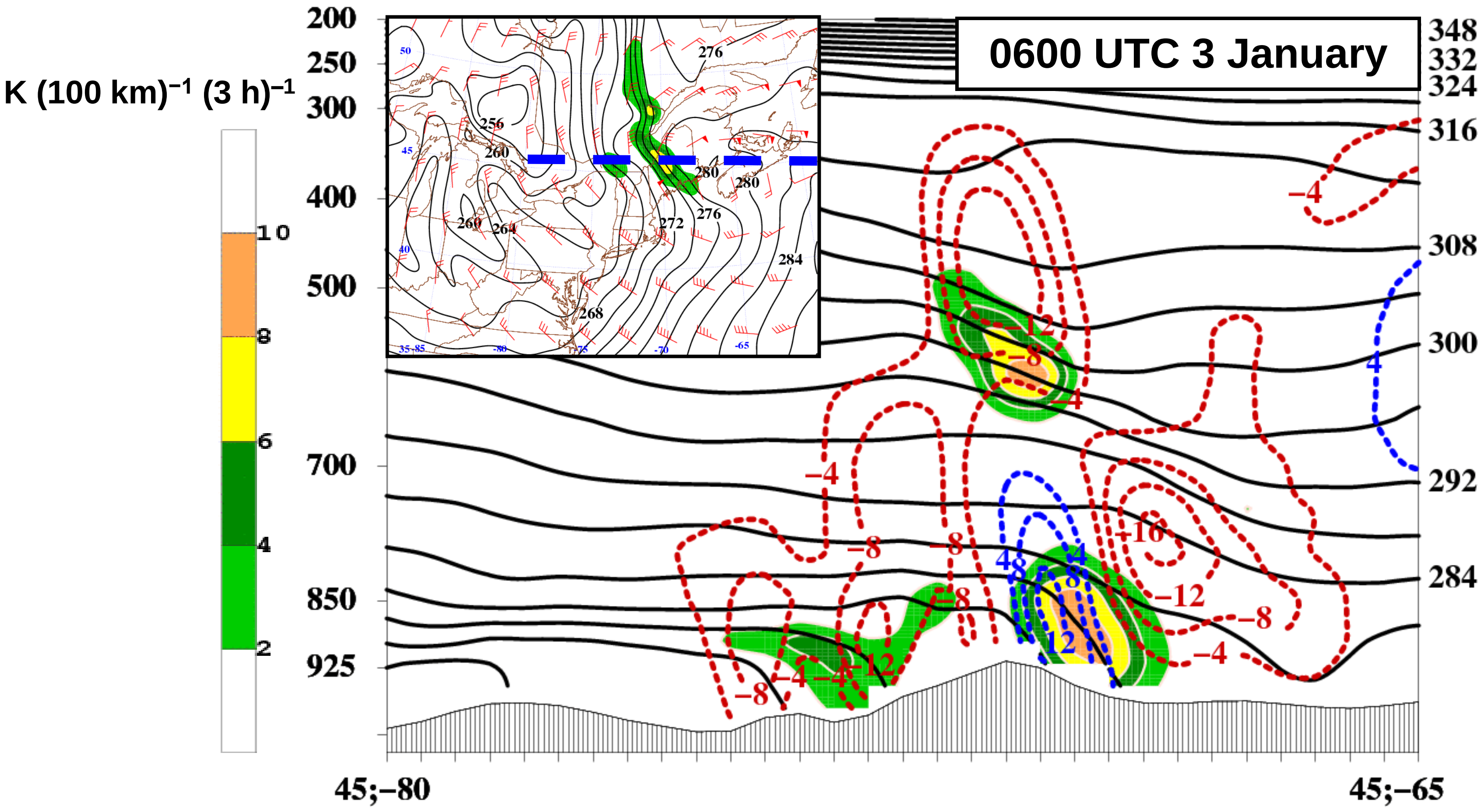


# 2 January 2010: 700 hPa




700-hPa geo. height (dam, solid contours), temperature (°C, dashed contours), Q vectors ($\geq$5 x $10^{-7}$ Pa $m^{-1}$ $s^{-1}$, arrows), and Q-vector convergence/divergence ($10^{-12}$ Pa $m^{-2}$ $s^{-1}$, shaded)

# 2 January 2010: Cross-section




Frontogenesis [K (100 km)$^{-1}$ (3 h)$^{-1}$, shaded], potential temperature (K, solid contours), and omega (μb s$^{-1}$, dashed contours; red-upward, blue-downward)