The Influence of Boundary Layer Mixing on the 26–28 January 2015 "Twitter" Snowstorm

Matthew Vaughan and Robert Fovell

18th Cyclone Workshop

5 October 2017

Motivating Question

- How do physics parameterizations affect extratropical cyclone (ET) development and evolution?

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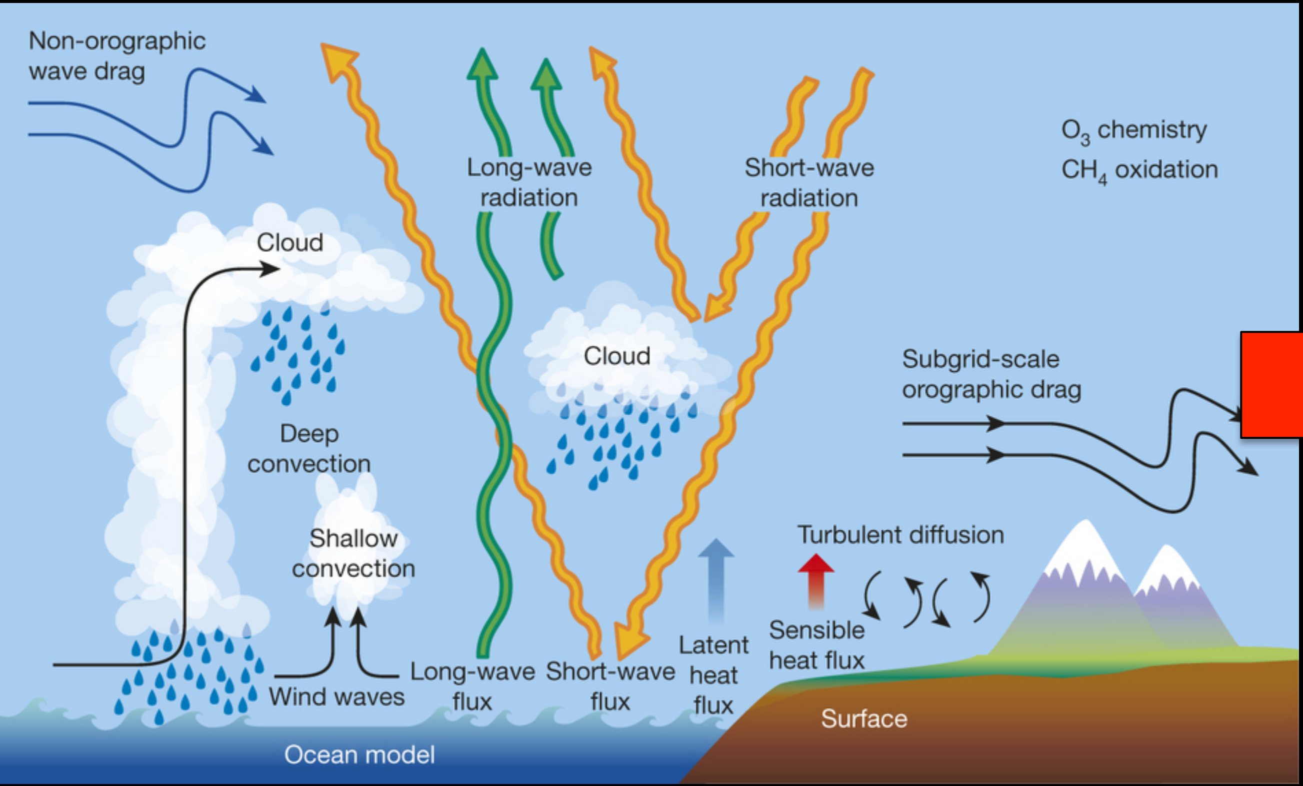
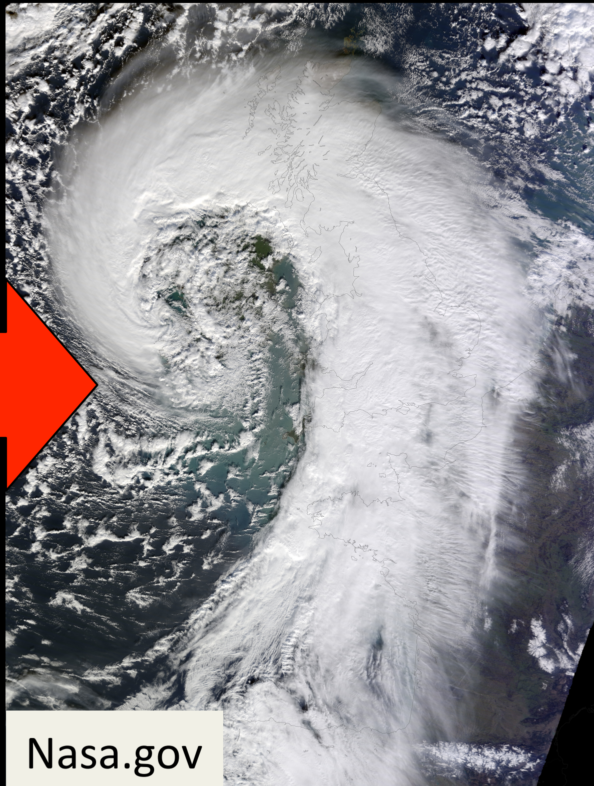
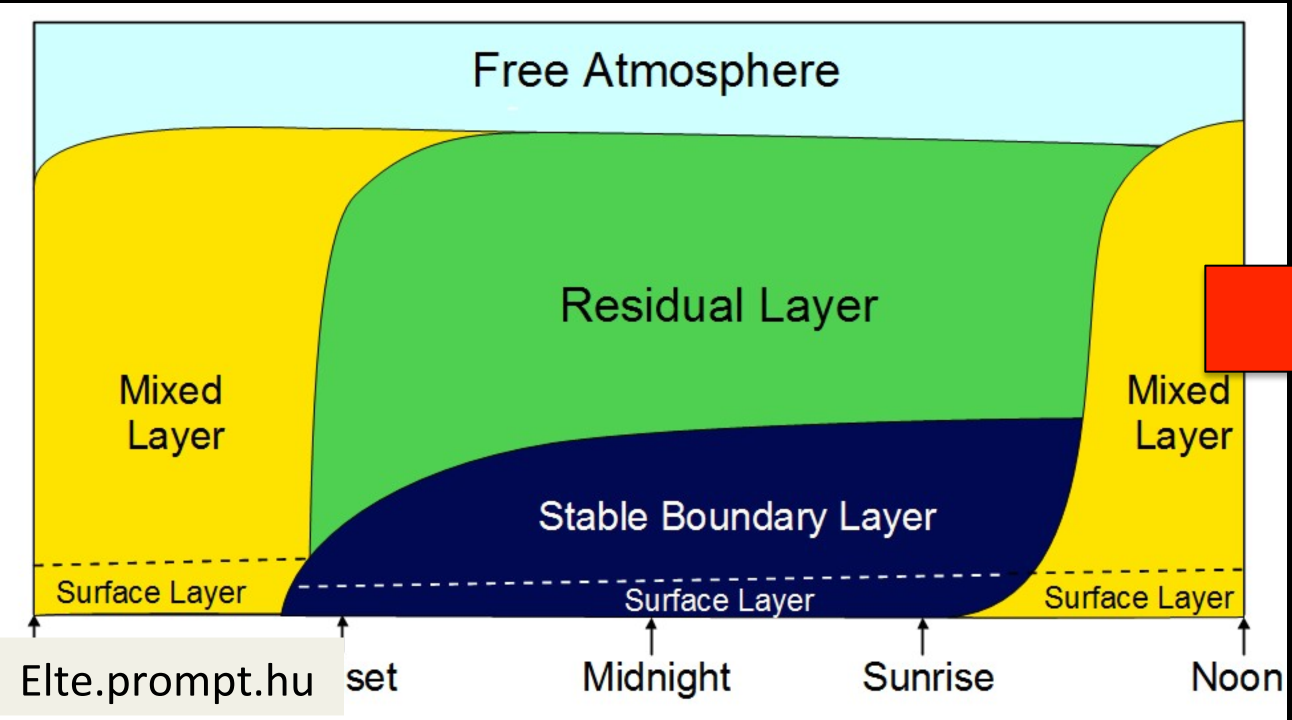


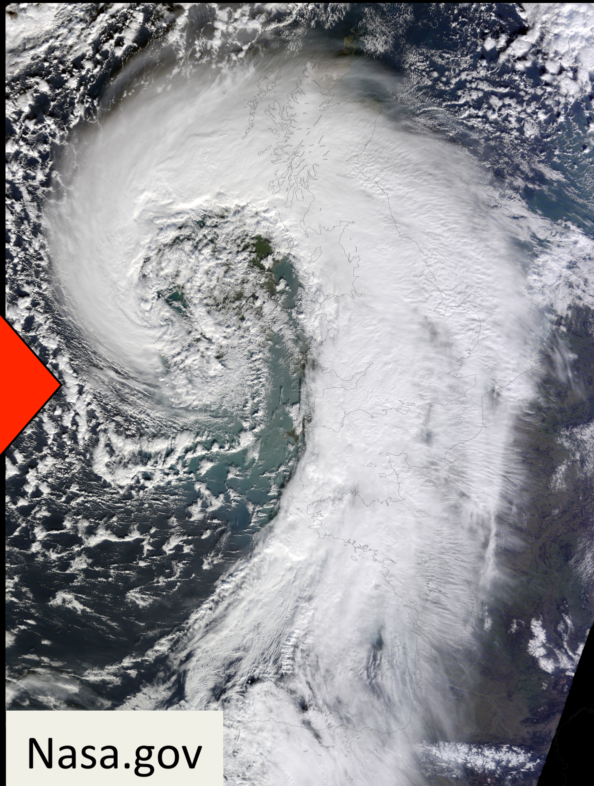


Motivating Question (more focused)

- How does boundary layer mixing strength effect ET development and evolution within WRF



Elte.prompt.hu



Nasa.gov

Background

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  - Adamson et al. (2005) highlighted PV generation (dry) through Ekman pumping and baroclinic processes
  - Stoelinga (1996) found PV generated from latent heating was crucial to cyclone evolution
    - ~70% of the low-level nondivergent circulation
    - PBL can influence thermal and moisture profiles

Background

- Beare (2007) found Ekman pumping, forced mostly by the cold conveyor-belt, important to cyclone evolution.

PBL Mixing Sensitivity

- Turning off PBL mixing in the unstable cold-sector boundary layer increased deepening by 22.5 hPa
- Turning off all mixing produced ~25hPa of deepening

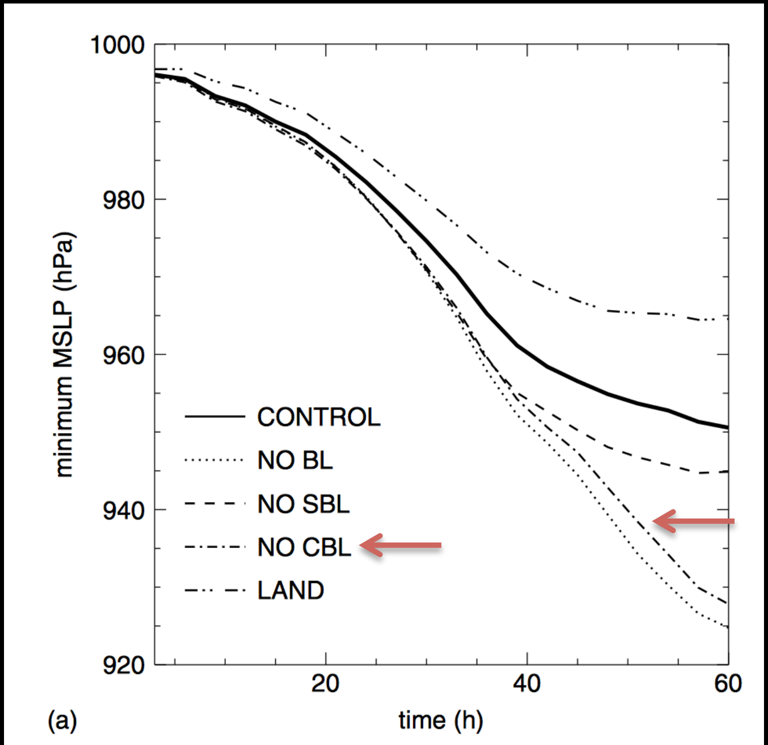

Figure 10. Time series of (a) the minimum mean-sea-level pressure over the cyclone for the coarse sensitivity experiment. (Beare 2007)

Background

- Motivated by these results, we use WRF to assess the impact of PBL mixing on extratropical cyclones.

PBL Processes in WRF

- Turbulent PBL processes are too small to resolve for km-scale models
  - Subgrid scale processes must be parameterized

- Goal is to describe the mean turbulent vertical transport of heat, momentum and moisture by eddies
  - One common approach is through a nonlocal (e.g., YSU), K-profile scheme

All about the eddies

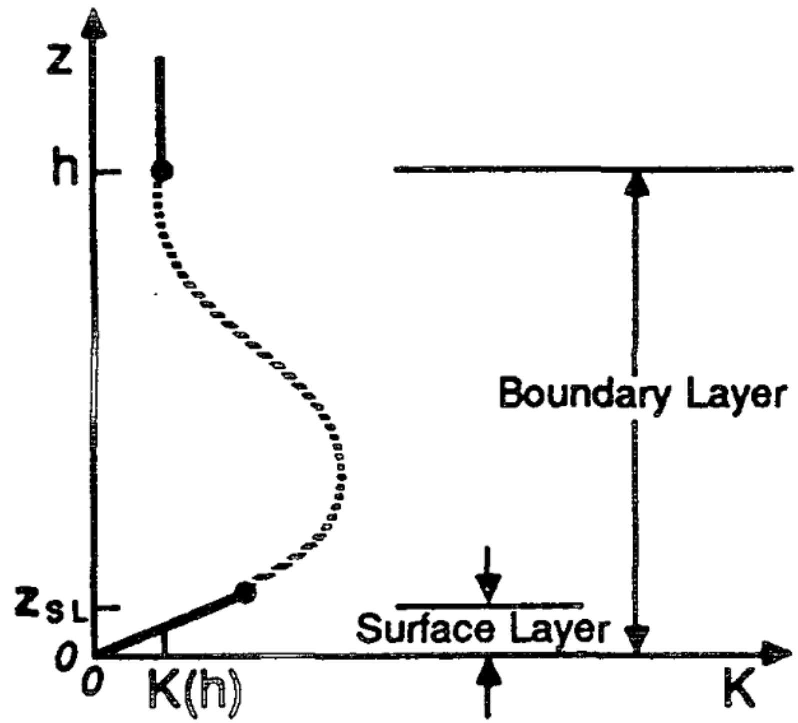

FIG. 1. Typical variation of eddy viscosity K with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

Hong and Pan (1996)

- How do you obtain an eddy diffusivity (K) profile?
  - Develop it (MYJ)
  - **Enforce it (YSU)**

$$-\overline{(w'\phi')} = K_{\phi}\frac{\partial\overline{\phi}}{\partial z},$$

Coniglio et al. (2013)

YSU Scheme

- YSU scheme estimates PBL height and imposes K-profile shape function
  - PBL height (h) is where the bulk Richardson number equals the critical Richardson number (BCR)

$$K_{zm} = \kappa w_s z(1 - \frac{z}{h})^2$$

$$\mathrm{Rib}(z) = \frac{g[\theta_v(z) - \theta_s]z}{\theta_{va} U(z)^2}$$

Hong (2006)

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Appropriate surface potential temp

Potential temp at lowest model level

Critical Richardson number varies with version (~0.75–0.0).

Hong (2006)

YSU Scheme

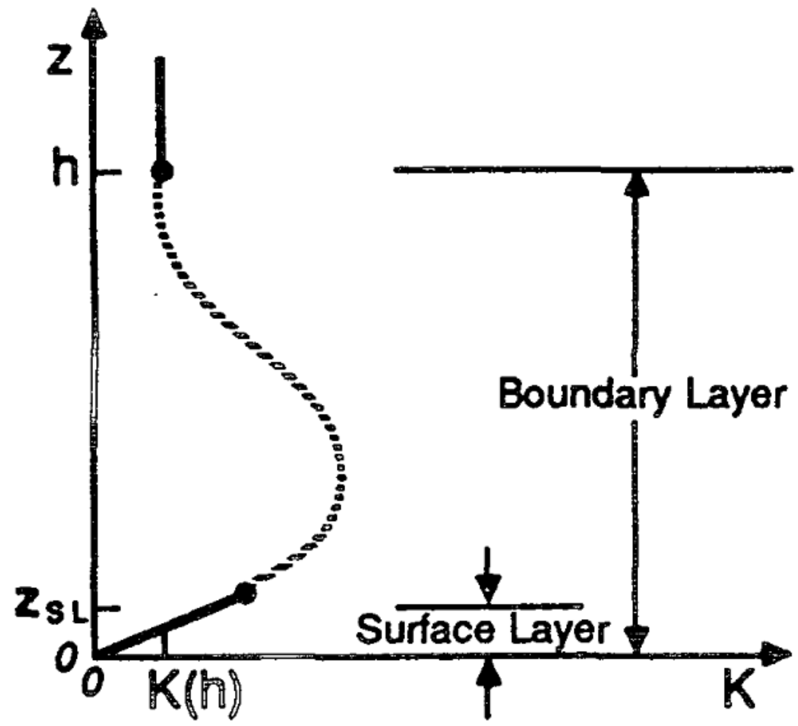


FIG. 1. Typical variation of eddy viscosity K with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

- Iterative process to find PBL height

Hong and Pan (1996)

YSU Scheme

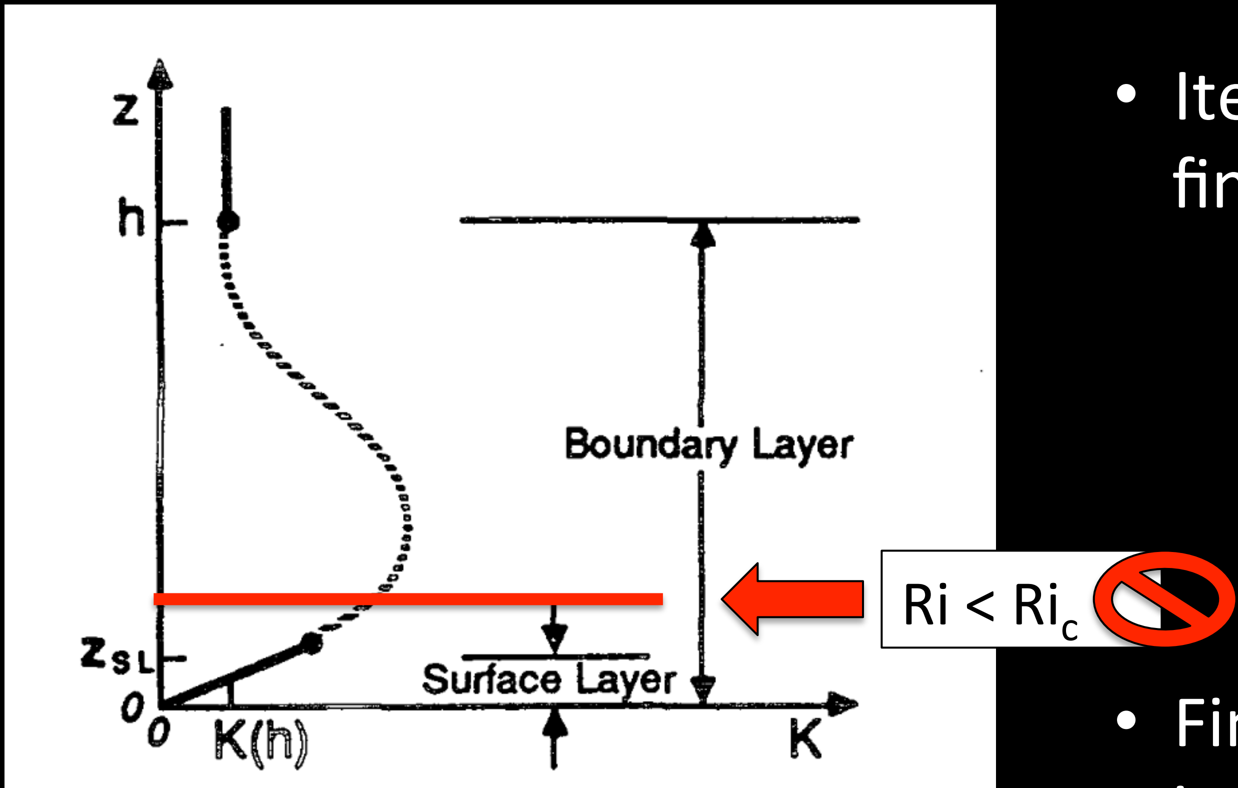
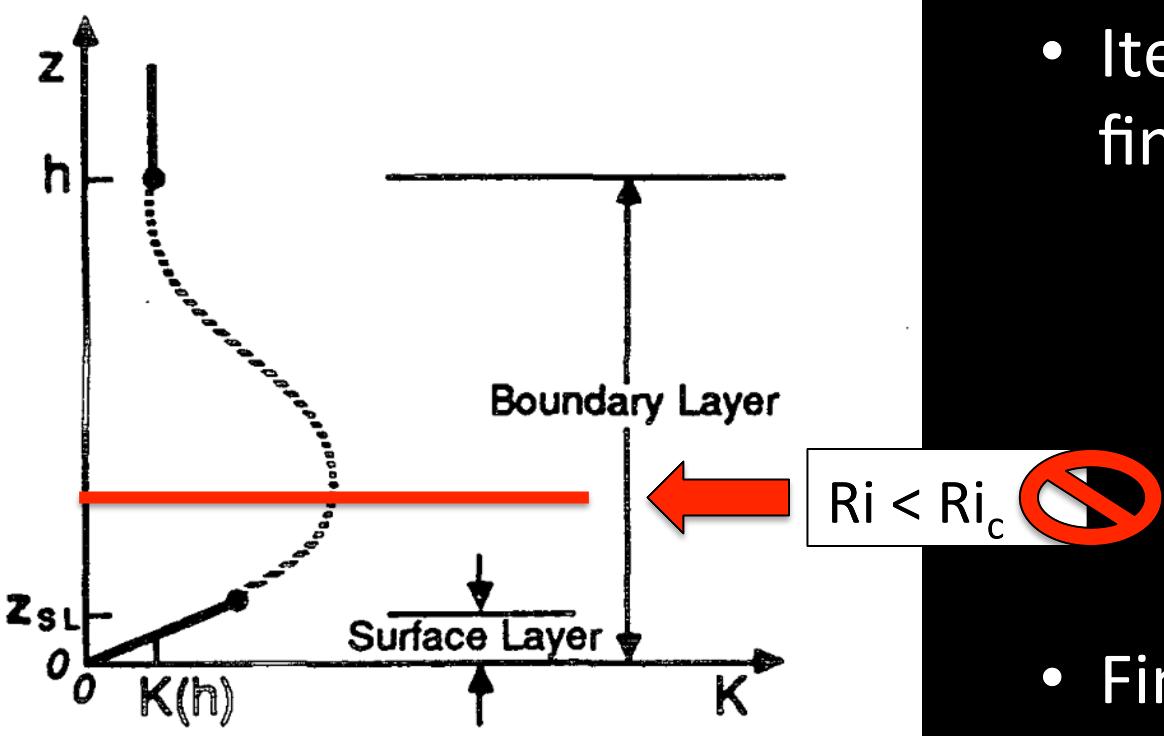


FIG. 1. Typical variation of eddy viscosity *K* with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

- Iterative process to find PBL height
- Find where bulk Ri is less than critical Ri

Hong and Pan (1996)

YSU Scheme



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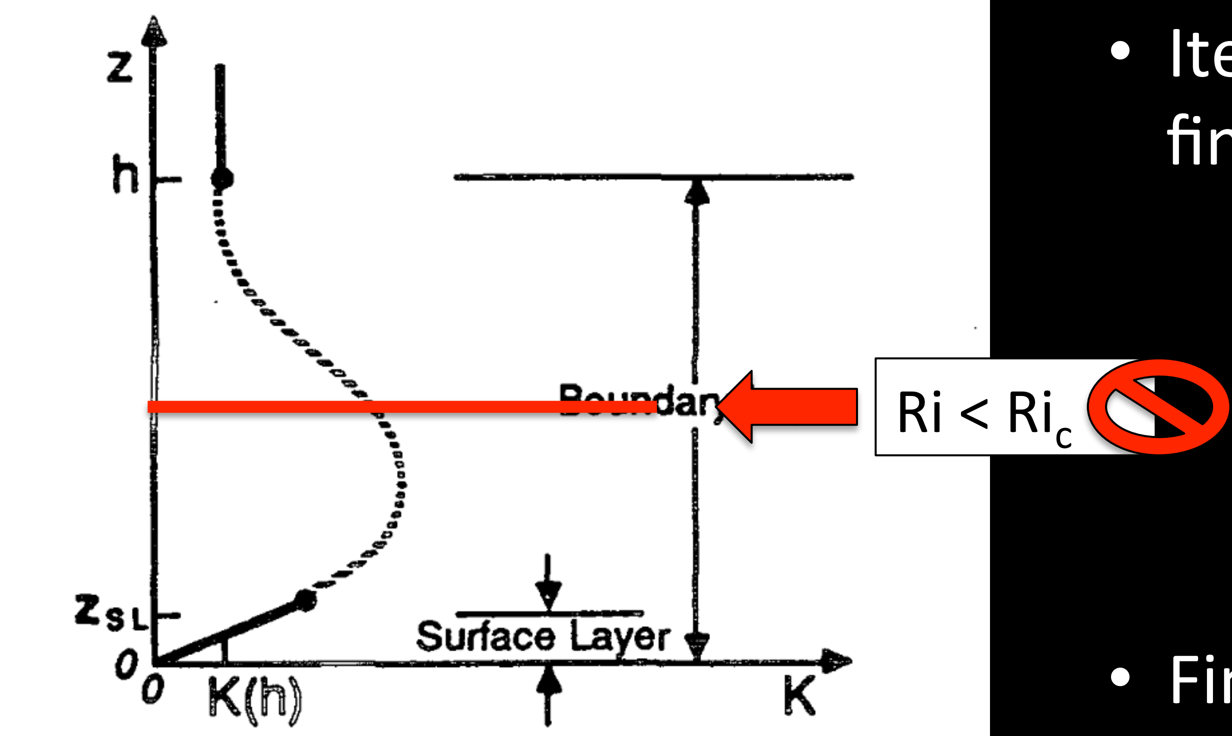

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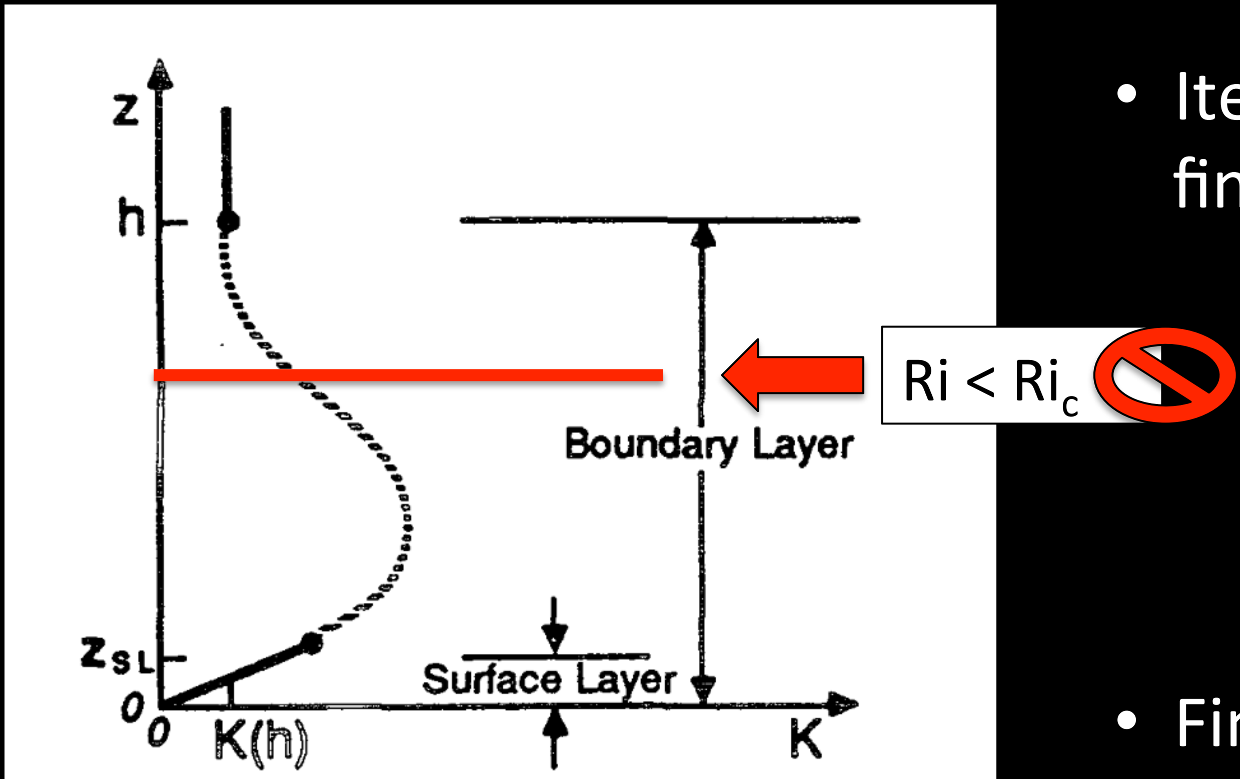

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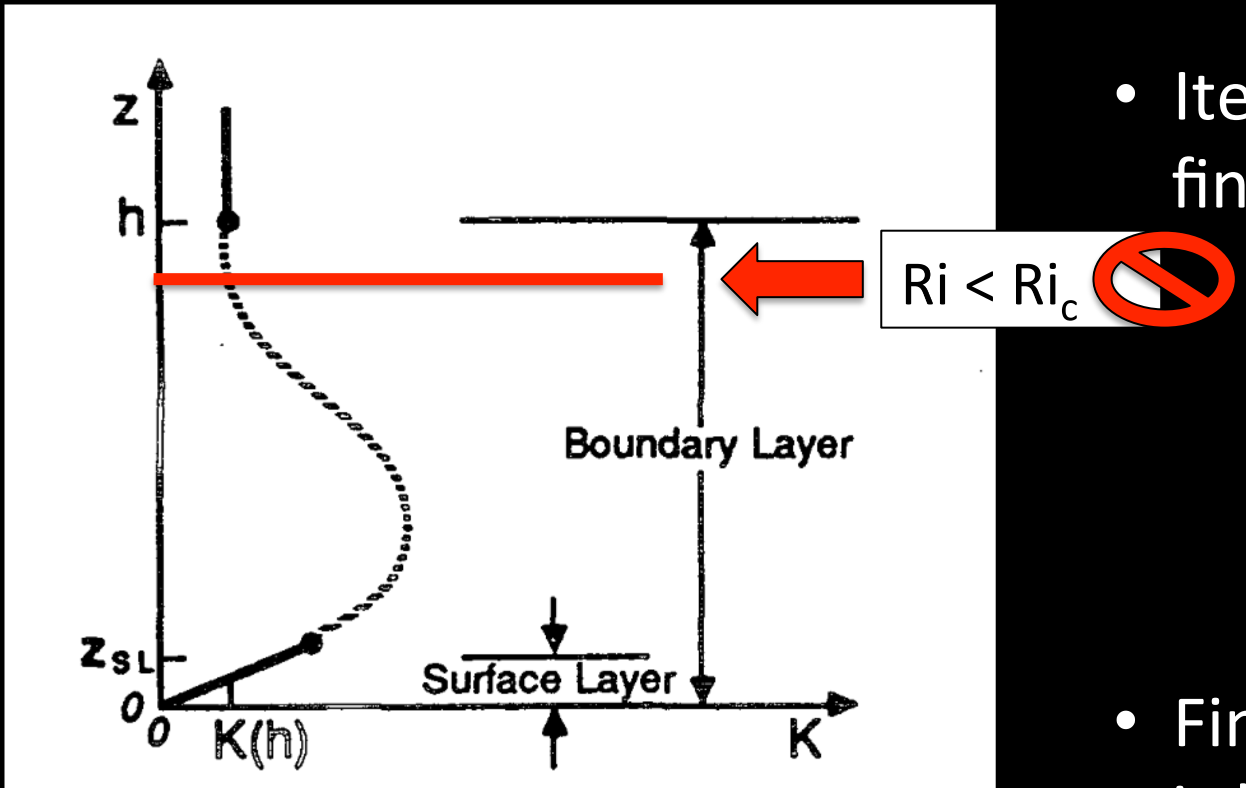

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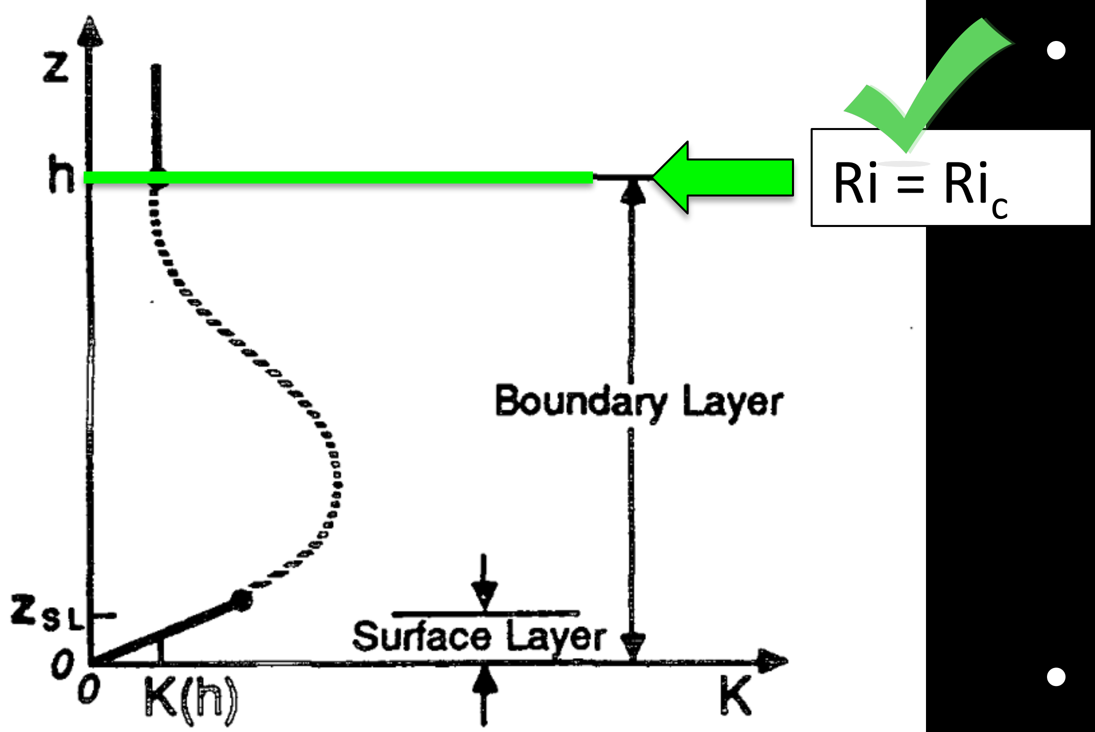
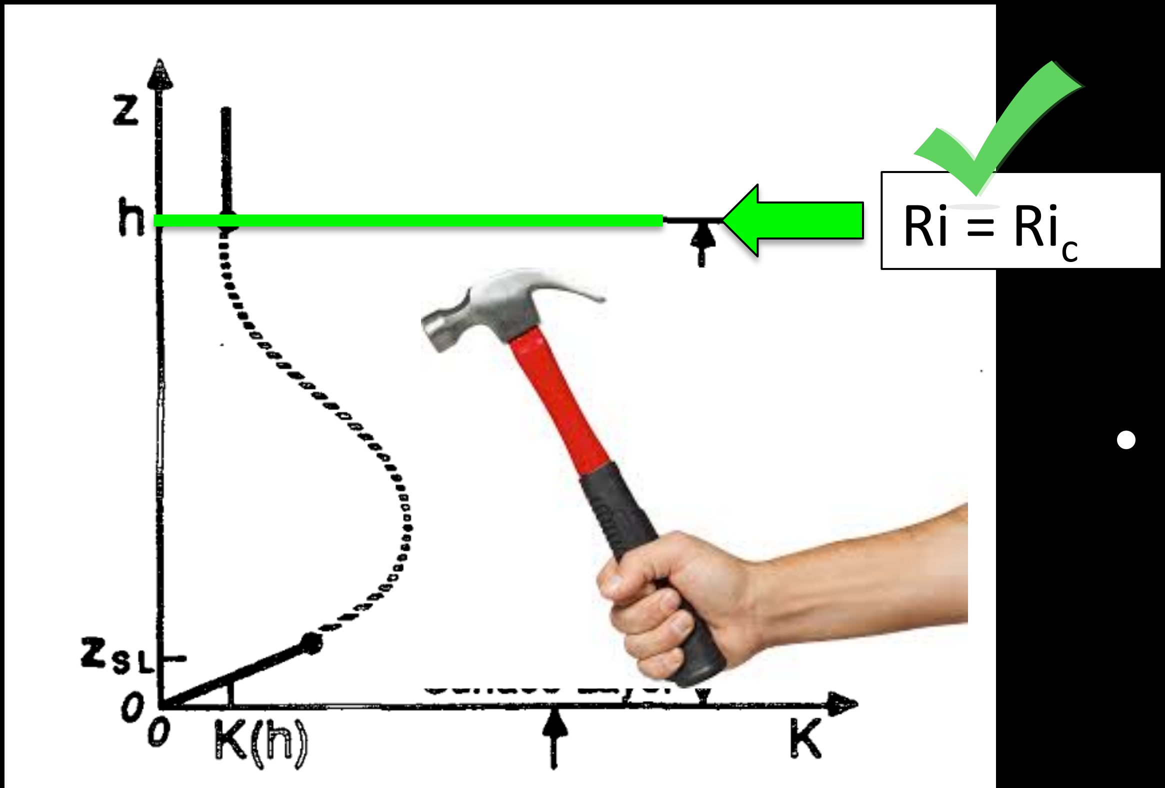


FIG. 1. Typical variation of eddy viscosity K with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

- Iterative process to find PBL height
- Once PBL height is found…

Hong and Pan (1996)

YSU Scheme



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- Prescribe mixing profile

Hong and Pan (1996)

Project Question

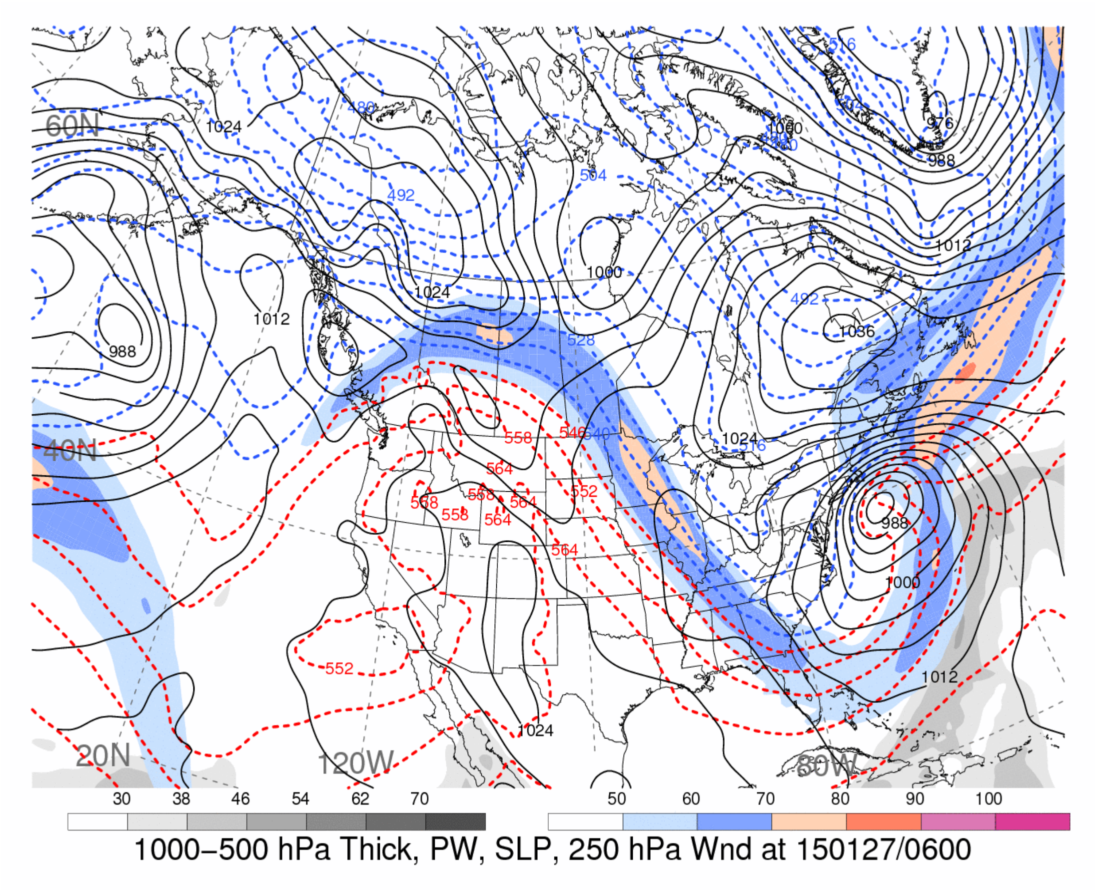
- What significance does critical bulk Richardson number have on winter cyclones?

EVENT HISTORY & EXPERIMENTAL DESIGN

26–28 January Snowstorm

- Coastal extratropical cyclone impacting New England and parts of the Mid-Atlantic

0600 UTC 27 January 2015 "Twitter" snowstorm

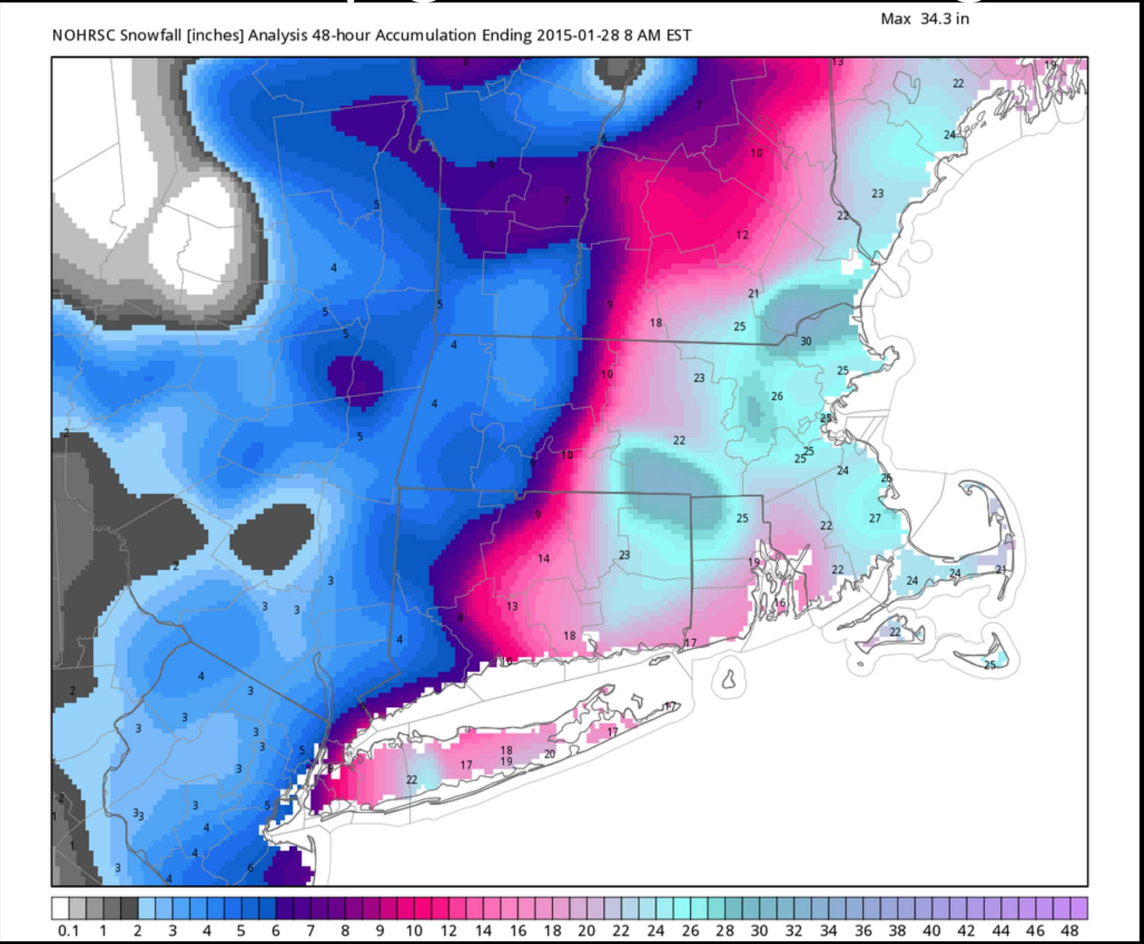


"My deepest apologies to many key decision makers and so many members of the general public," said Gary Szatkowski, meteorologist-in-charge at the National Weather Service in Mount Holly (NJ.com)

Courtesy: H. Archambault

26–28 January Snowstorm

- Crippling snowfall over much of the Northeast. Sharp gradient on Long Island

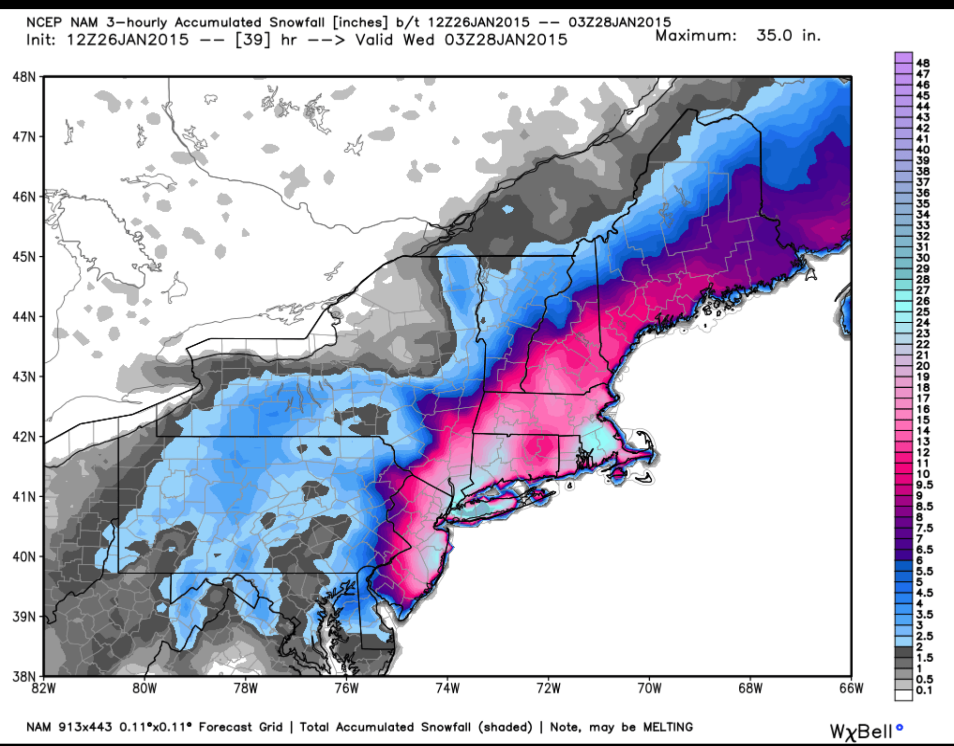


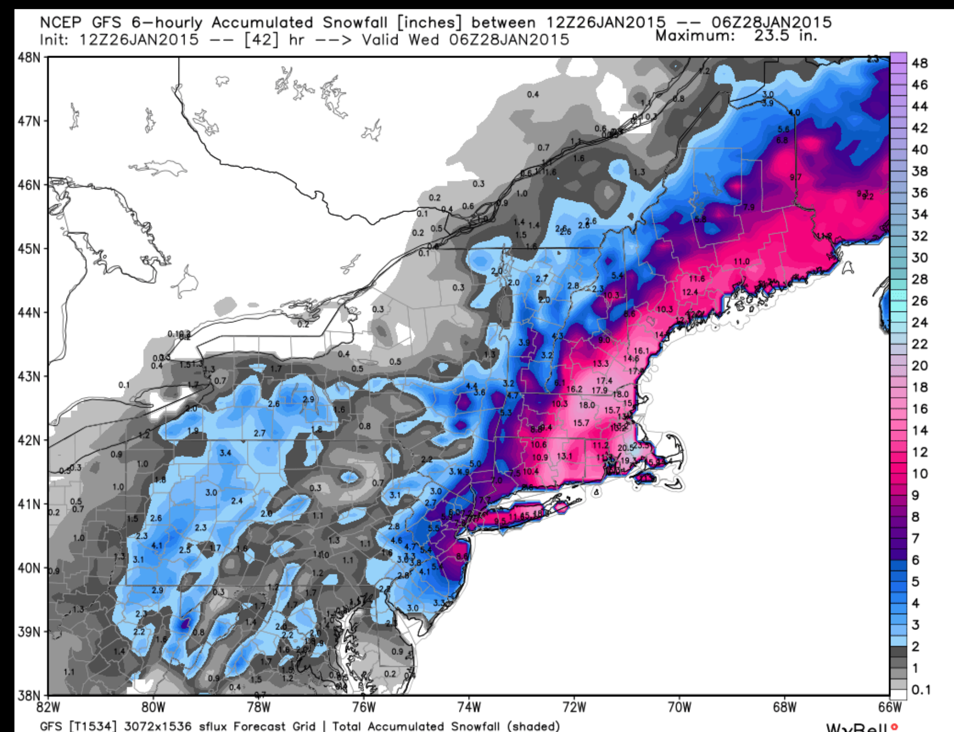
WeatherBell

26–28 January Snowstorm

- Substantial spread within the models

NAM WeatherBell GFS



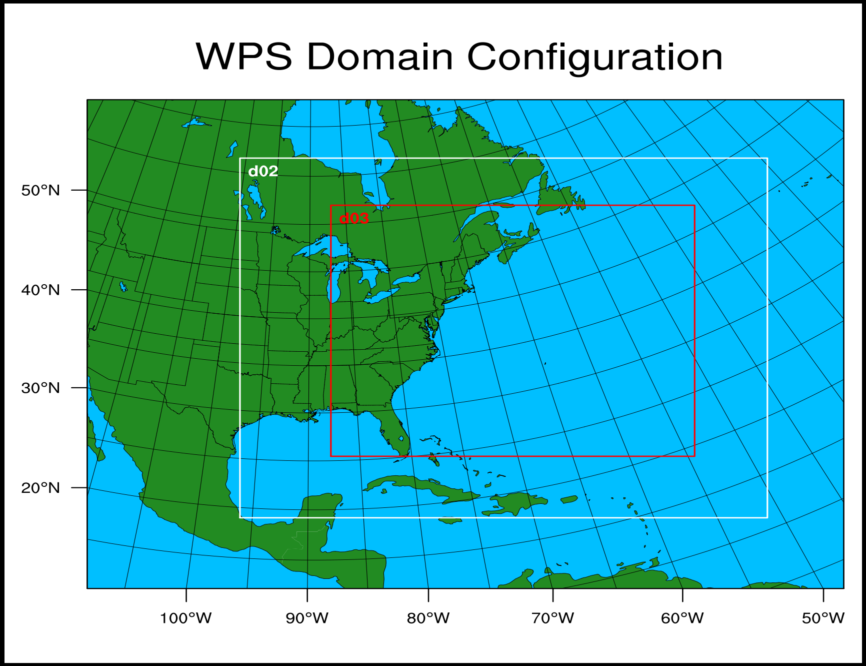


Experimental Design

- Vary the critical bulk Richardson number in a WRF simulation of the 27 January 2015 snowstorm
  - 0000 UTC 26 to 0000 UTC 29 January 2015
- Recall iterative process used by YSU scheme
  - Altering critical Richardson number effectively changes the strength and depth of PBL mixing

Experimental Design

- Initial and boundary conditions: ERA-I
- **Triple Nest**
  - **4-km inner domain,**
- Similar physics to RAP
  - Benjamin et al. (2016)
- Use YSU PBL scheme
- Set critical Richardson number to 0.0 or 0.25



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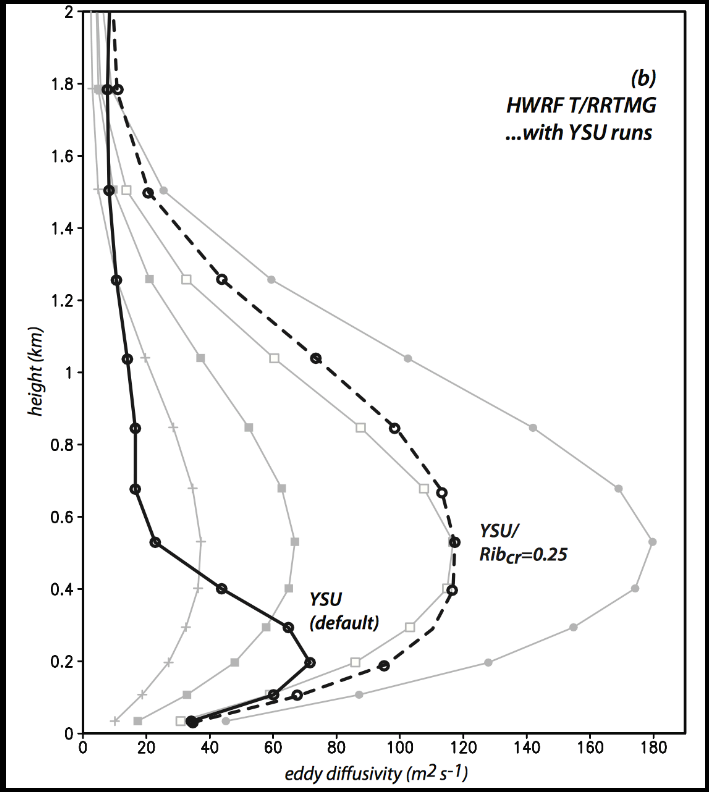
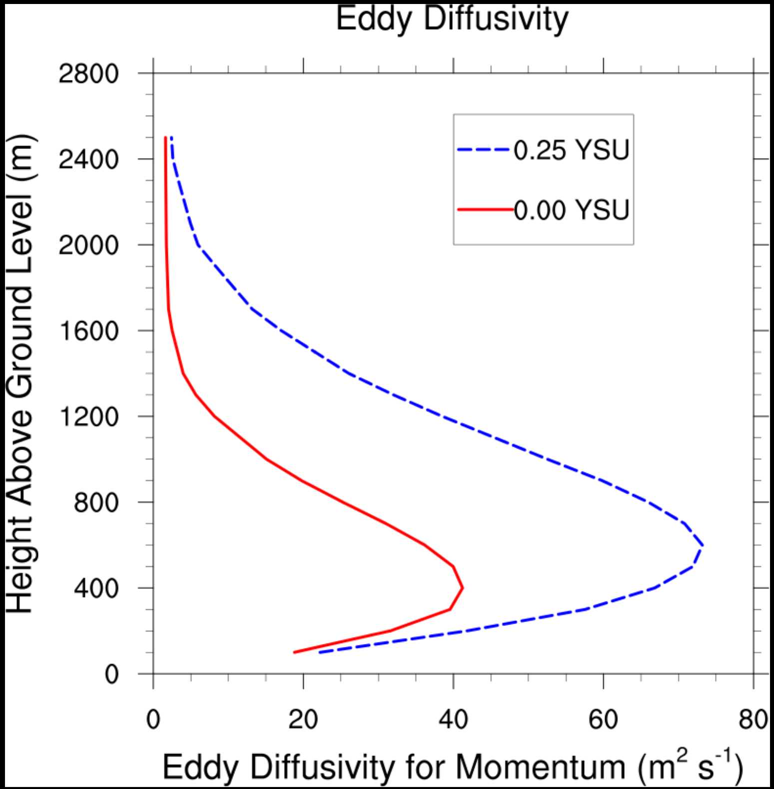
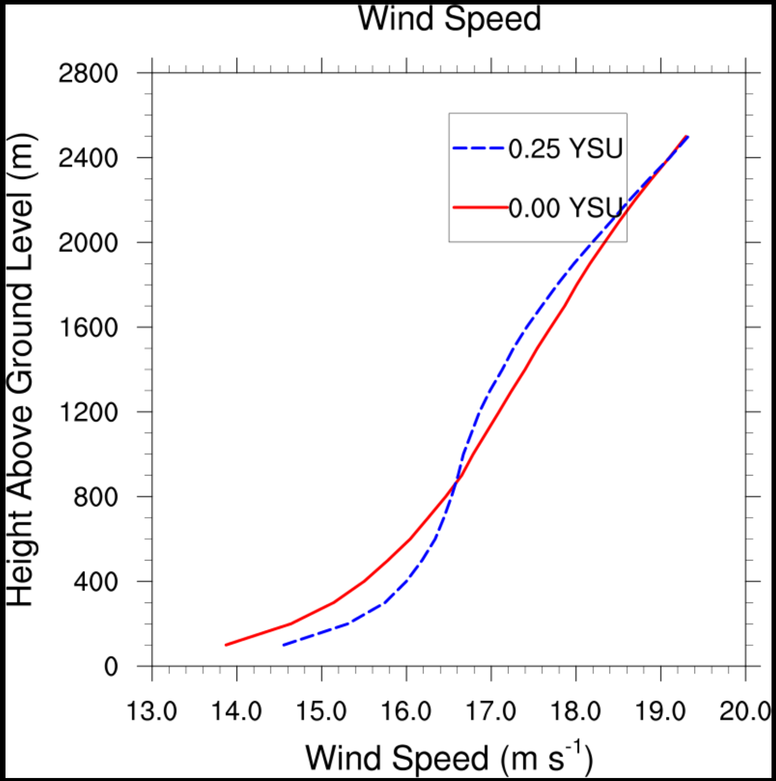


Radius vs. height cross-sections showing the temporally-averaged symmetric components of water vapor (shaded) and eddy diffusivity applied to vapor (*Kh*; 10 m2 s−1 contours) using YSU with (a) Rib*cr*=0.25, and (b) the default setup. (Bu et al. 2017)

Vertical Profiles in the Warm Sector

– Results for eddy diffusivity, wind speed, and mixing ratio all are consistent with prior PBL studies





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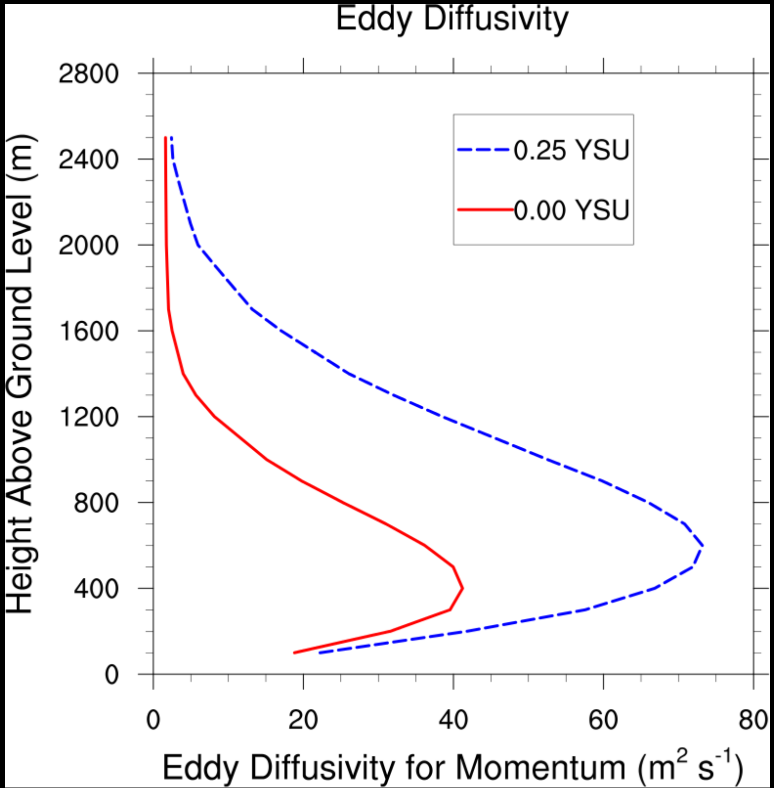
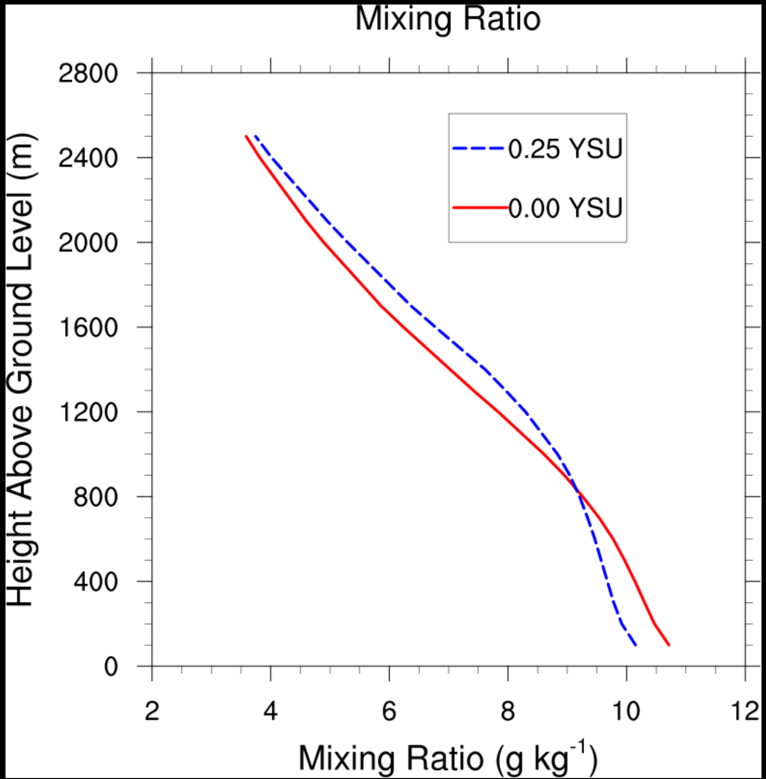
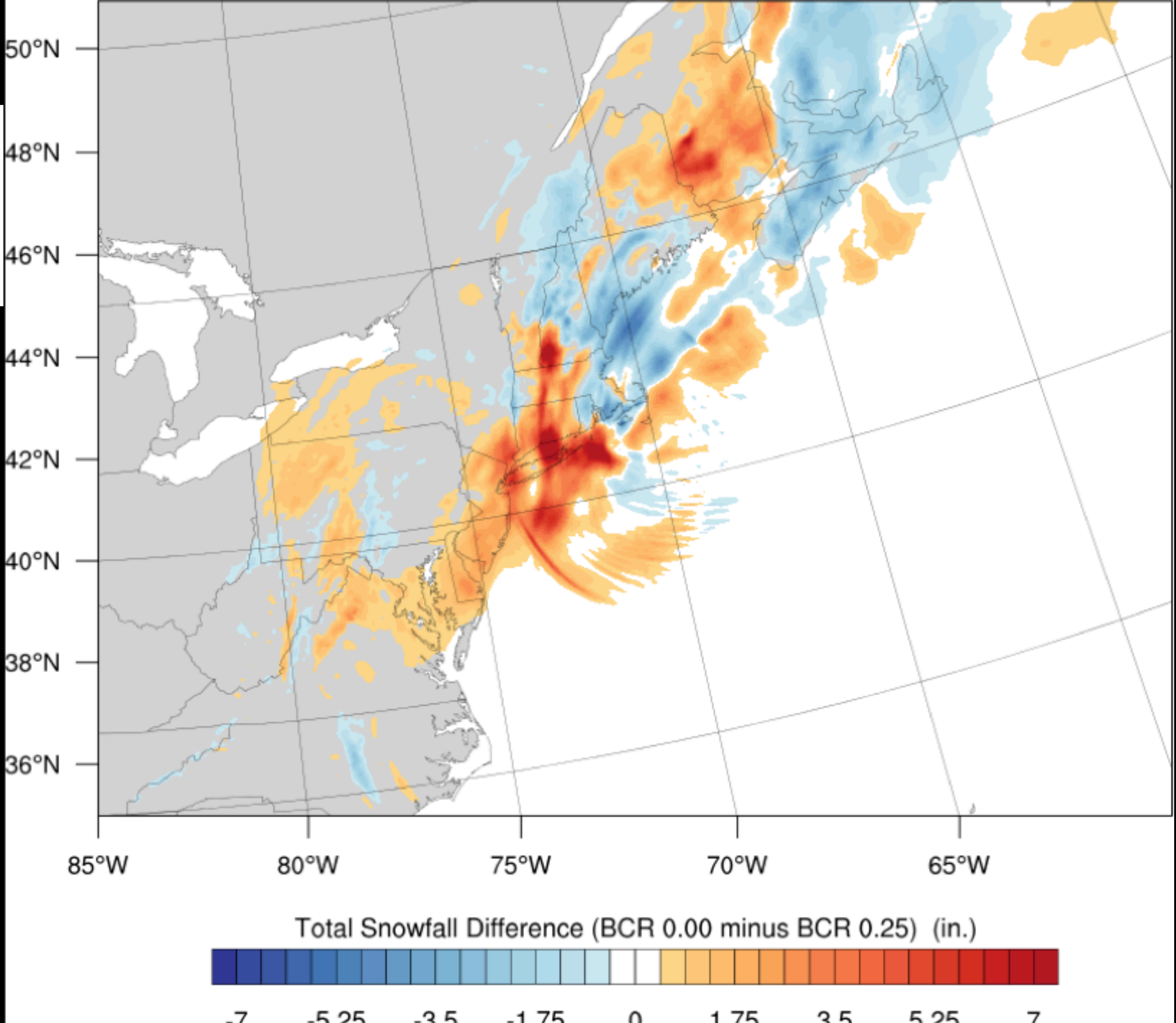




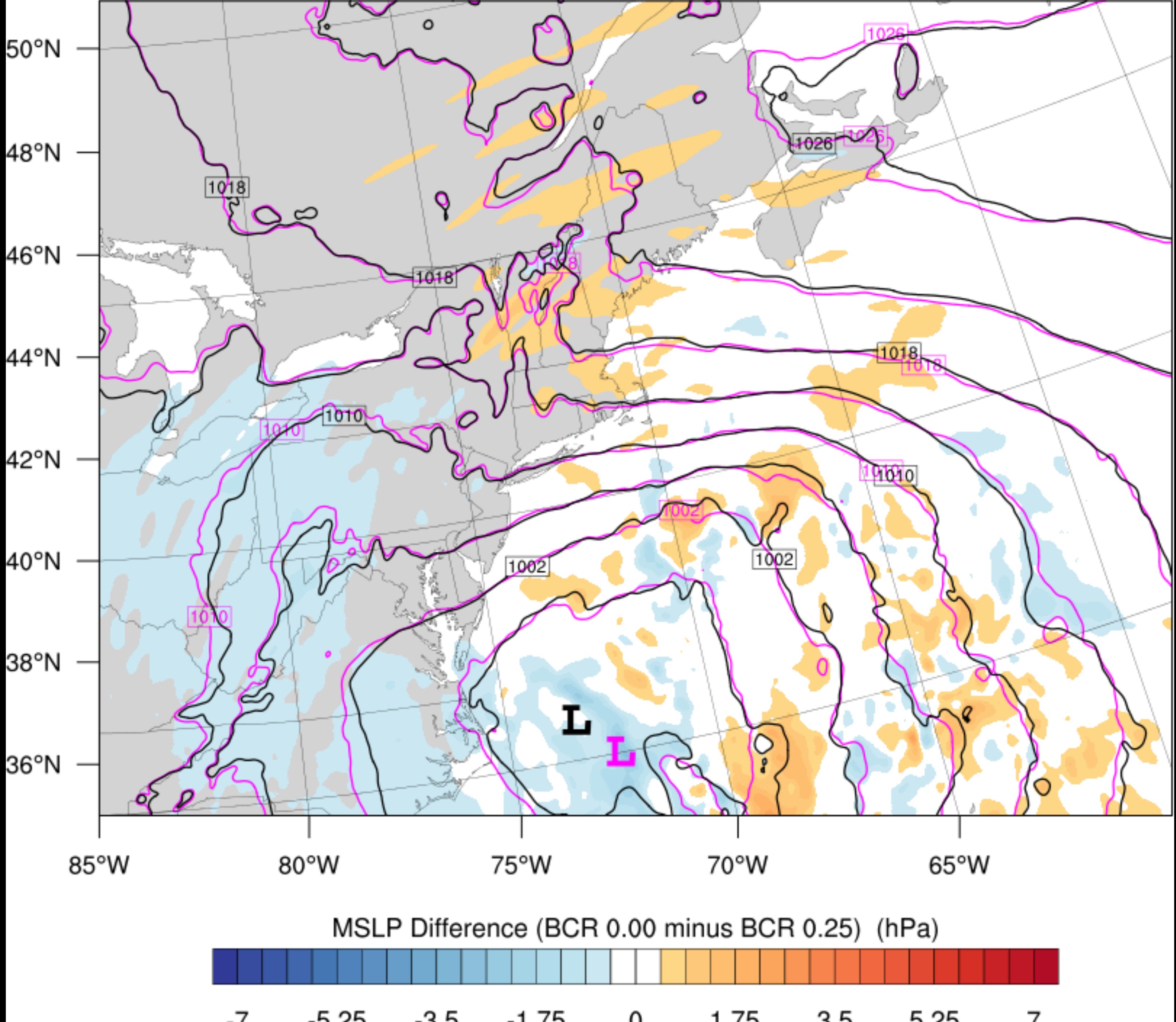
RESULTS

Total Snowfall Difference
(less mixing–more mixing)



MSLP Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0000 UTC 27 January



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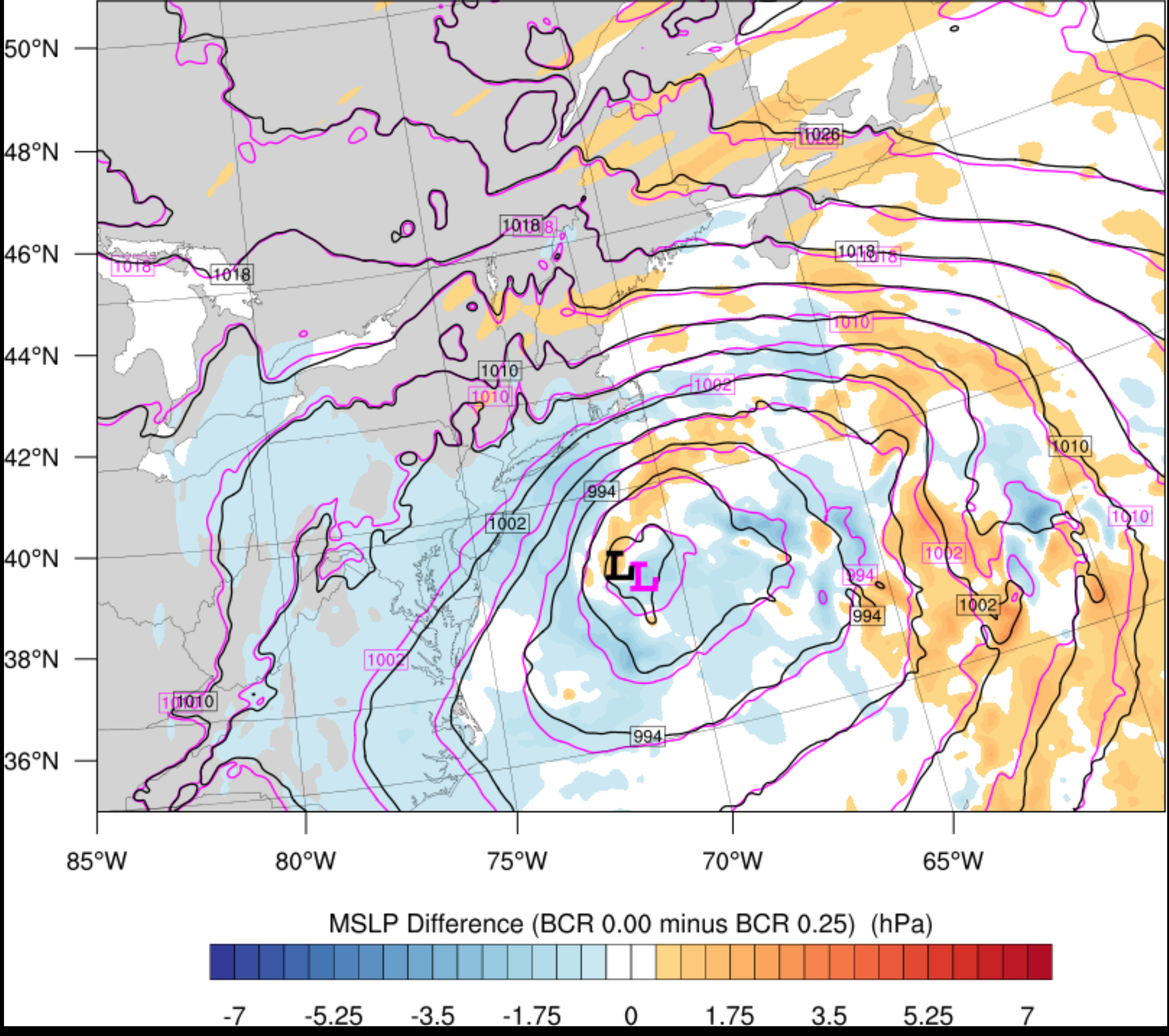
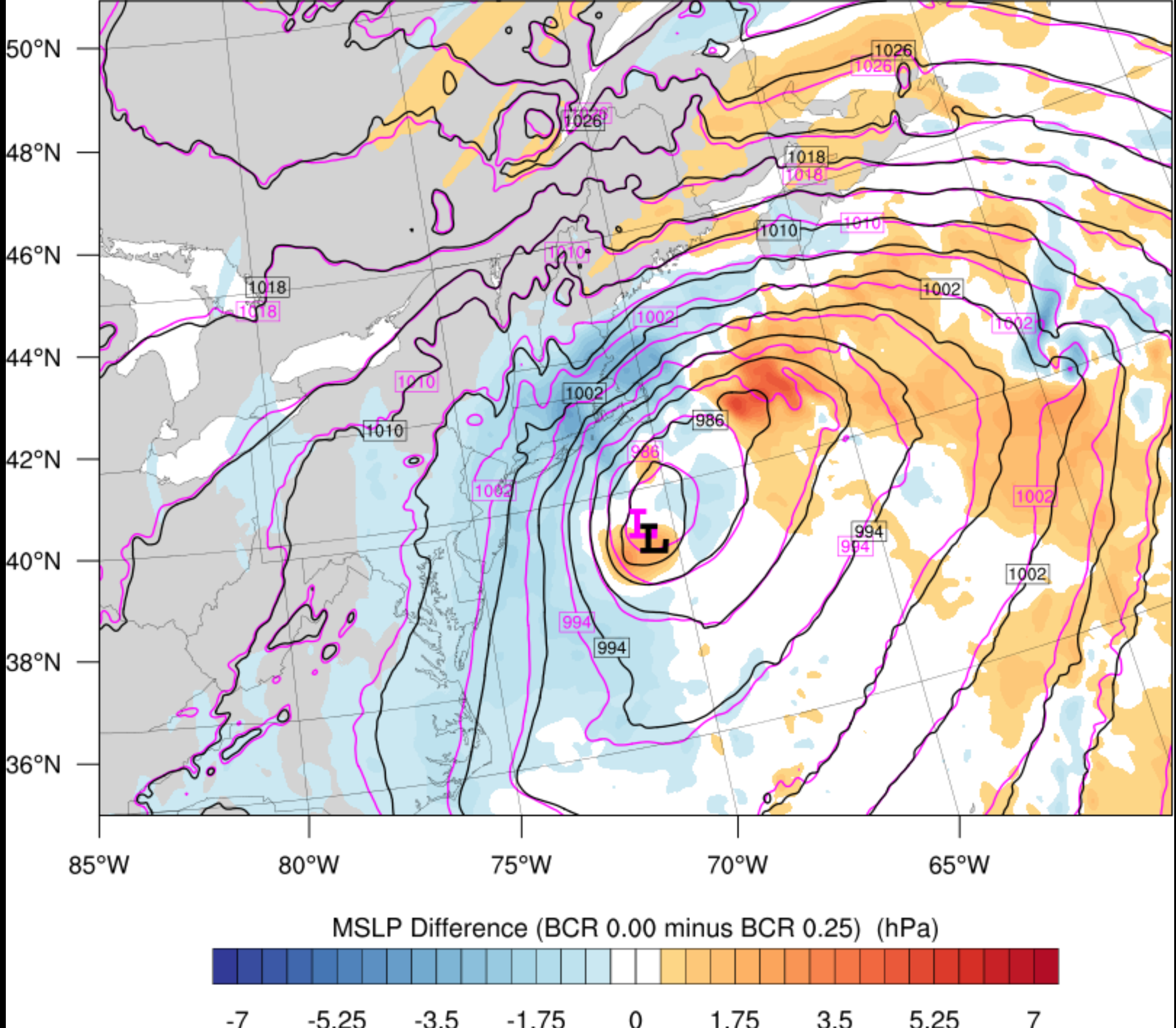


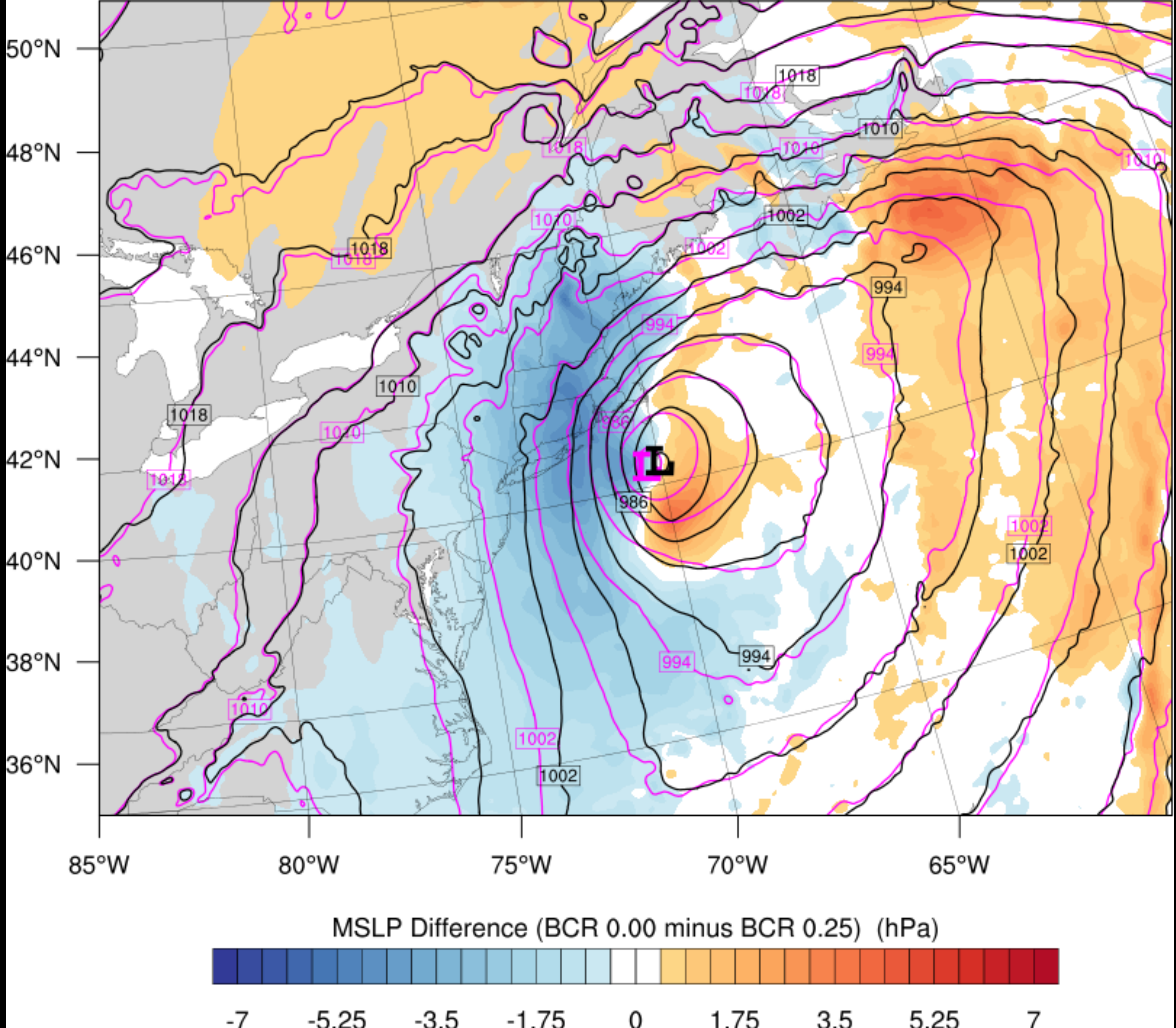
MSLP Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

1200 UTC 27 January



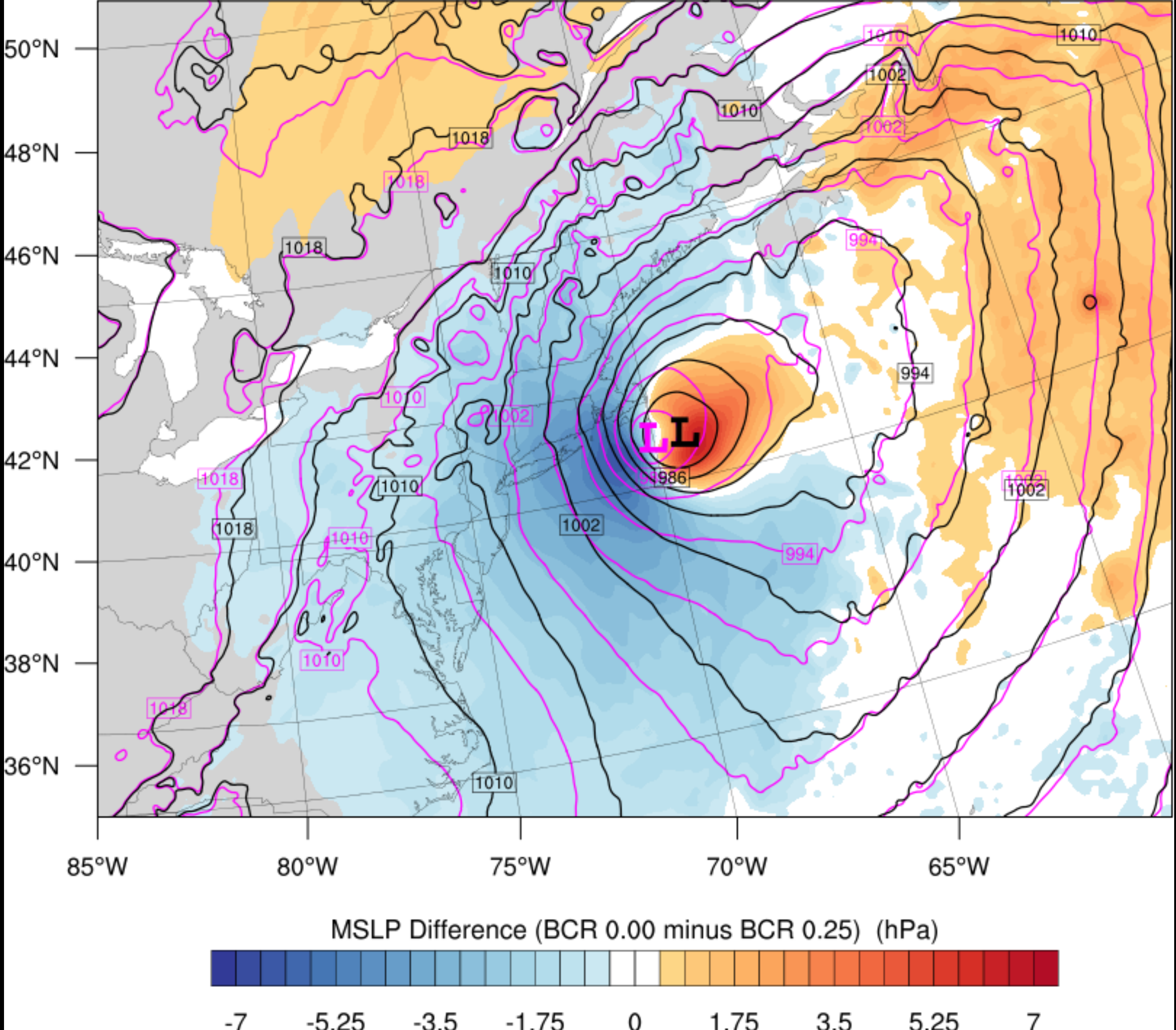
MSLP
Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

1800 UTC 27 January



MSLP Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0000 UTC 28 January



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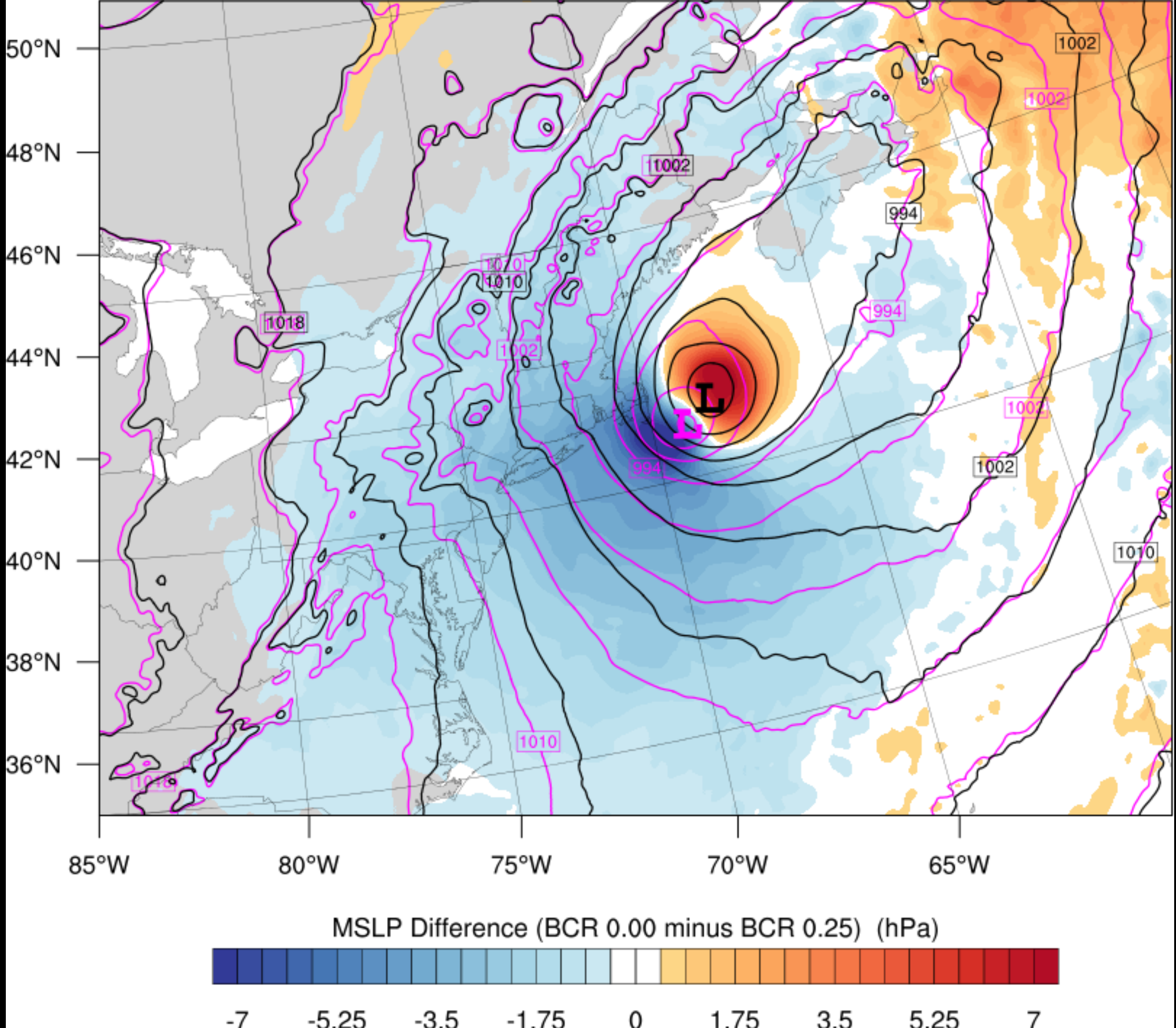
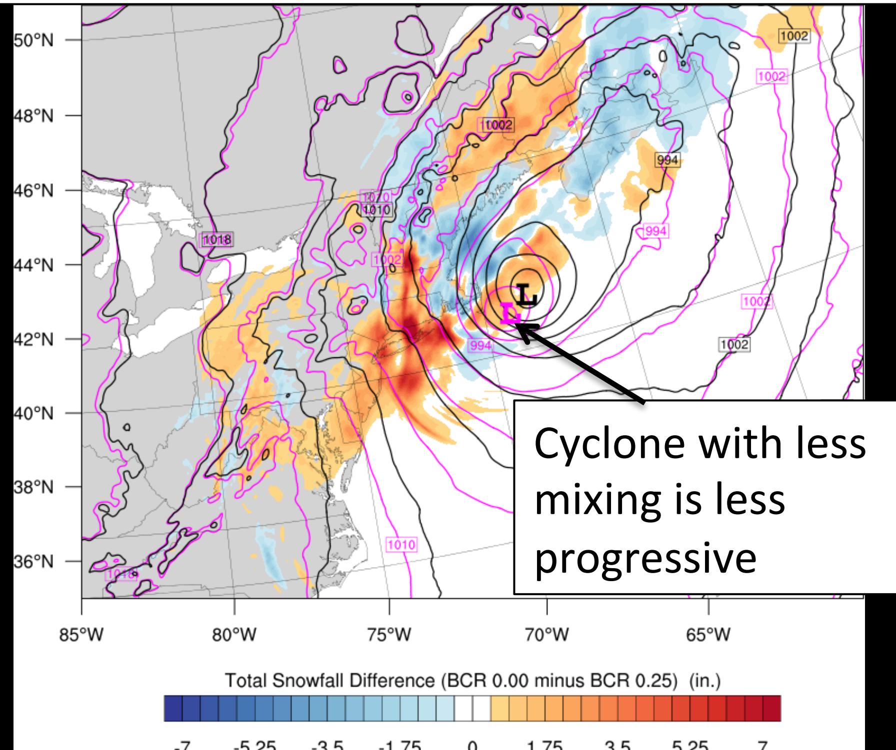


Remarks

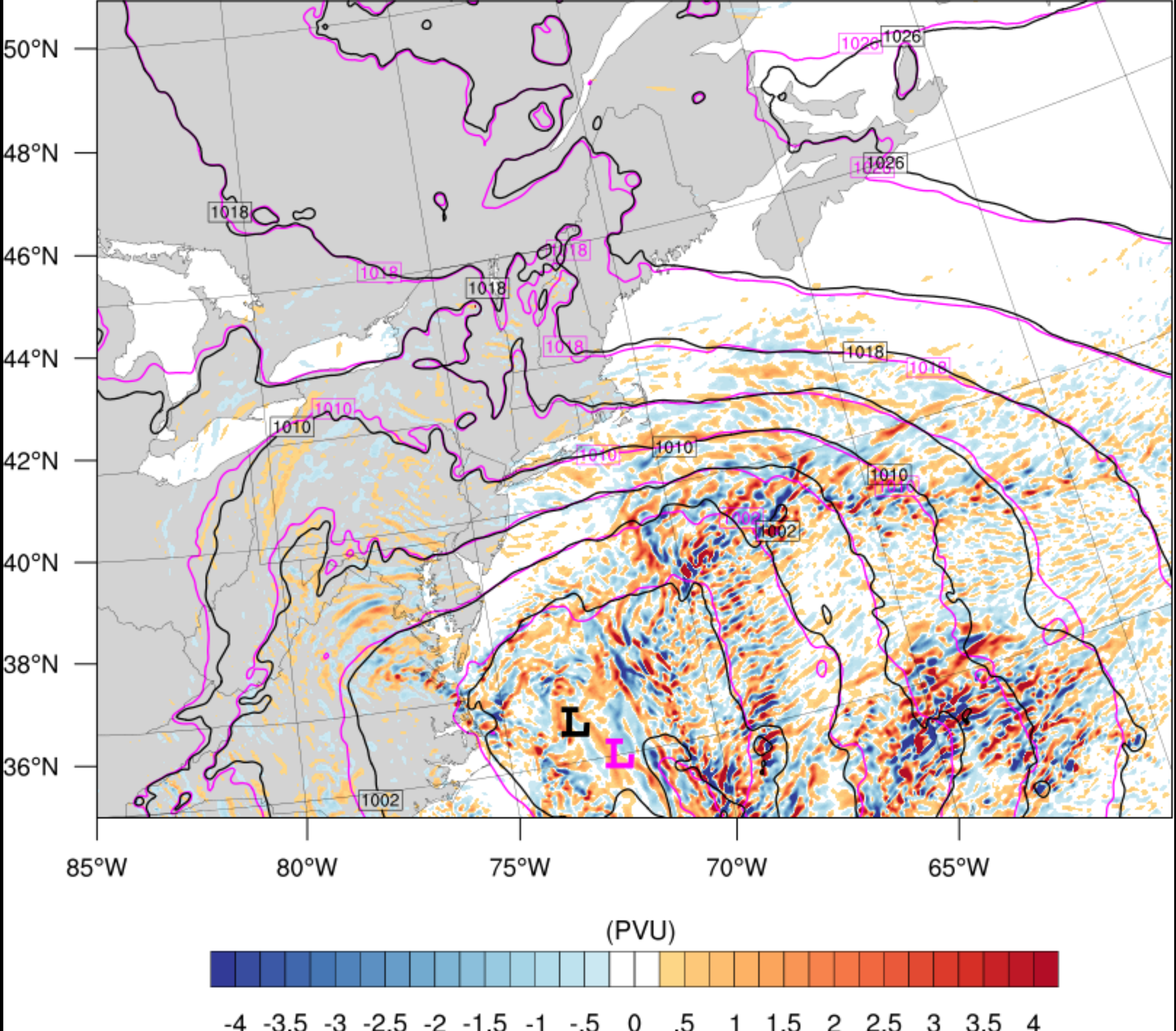
- Less mixing storm has generally higher precipitation totals and lags behind more mixing case
  - What does the mixing do to the lower-tropospheric PV field?

Total Snowfall Difference (less mixing–more mixing) and MSLP (Magenta contours = less mixing) at 0600 UTC 28 January 2015



950–700-hPa PV Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0000 UTC 27 January



950–700-hPa PV Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

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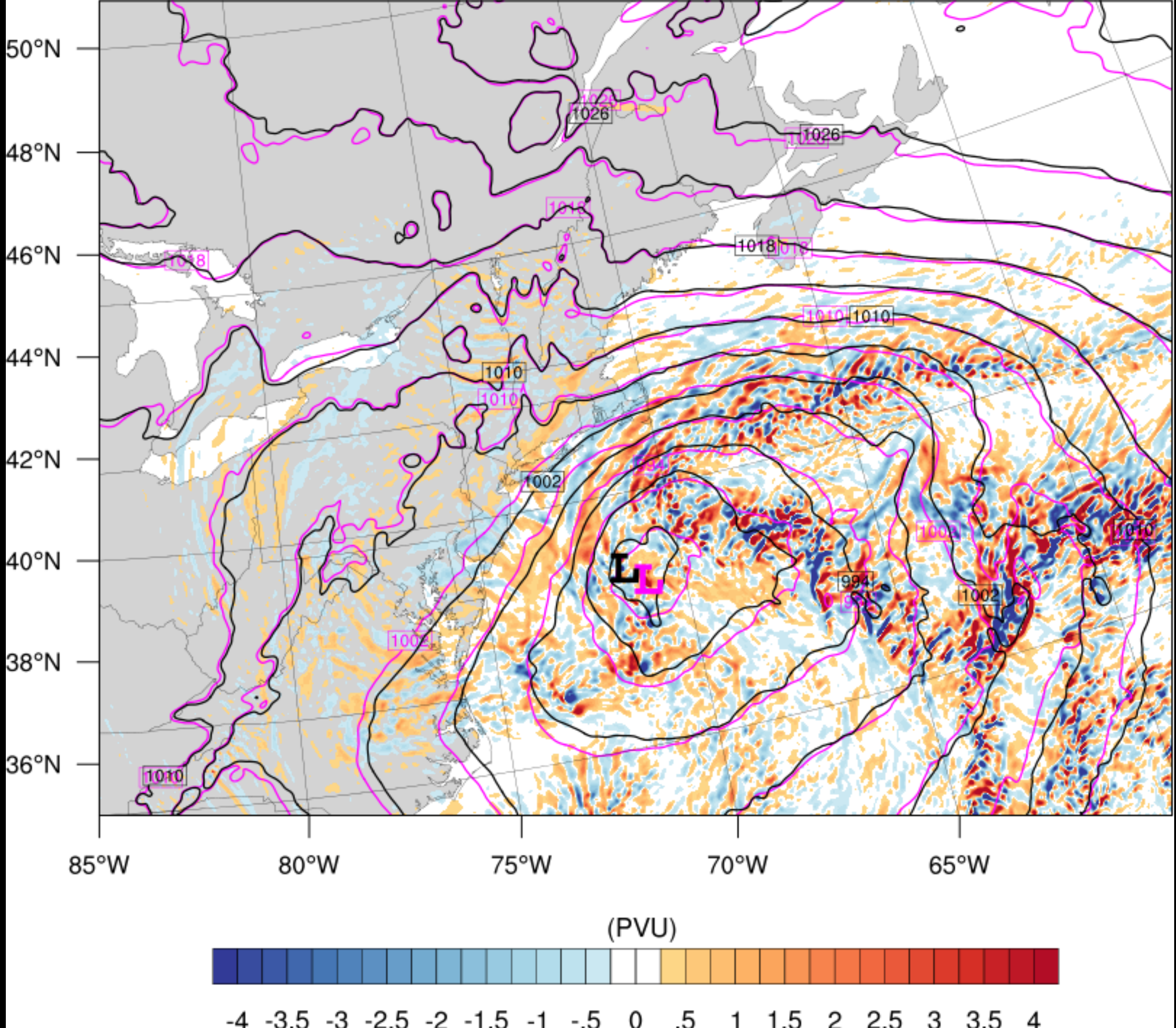
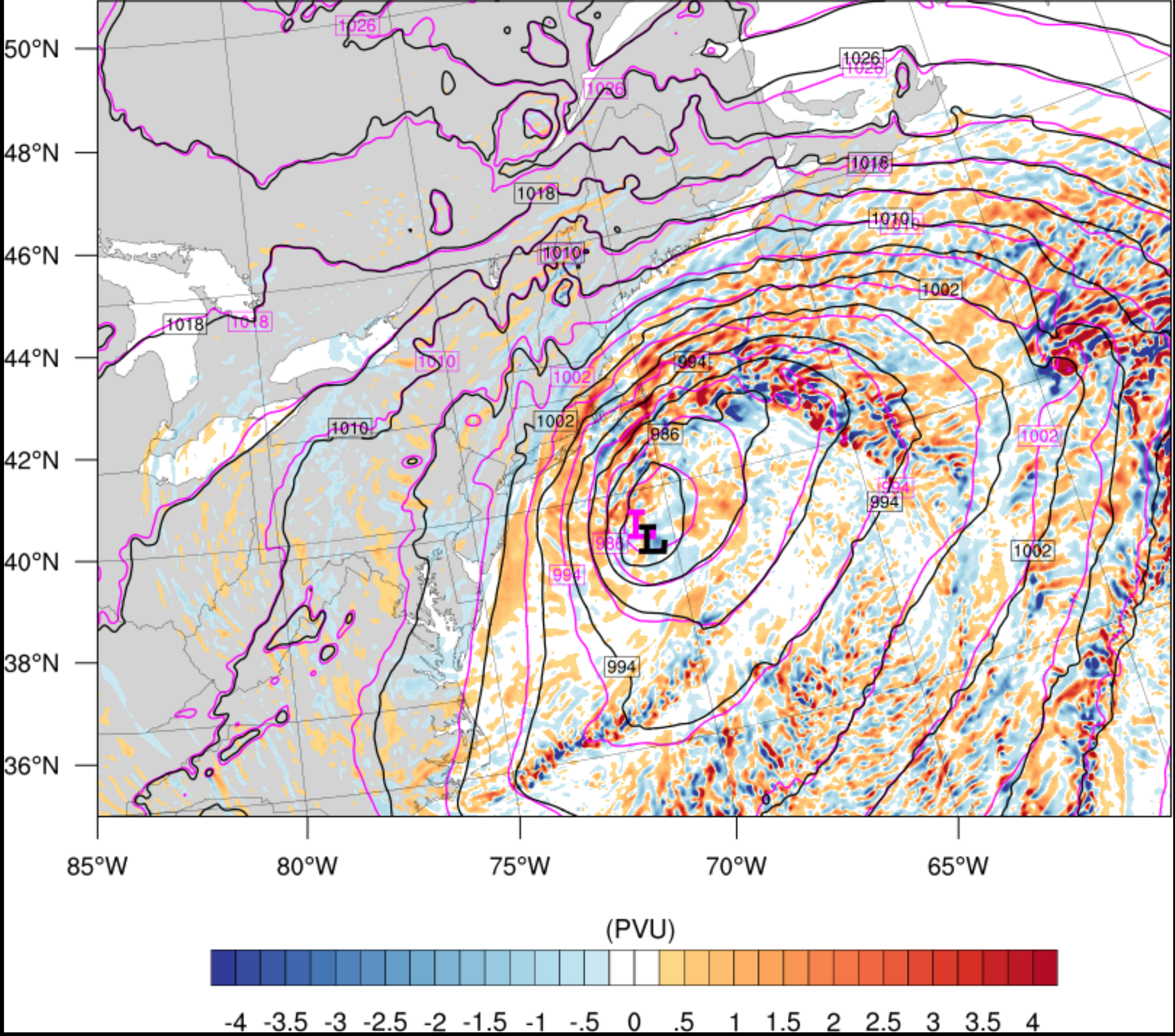


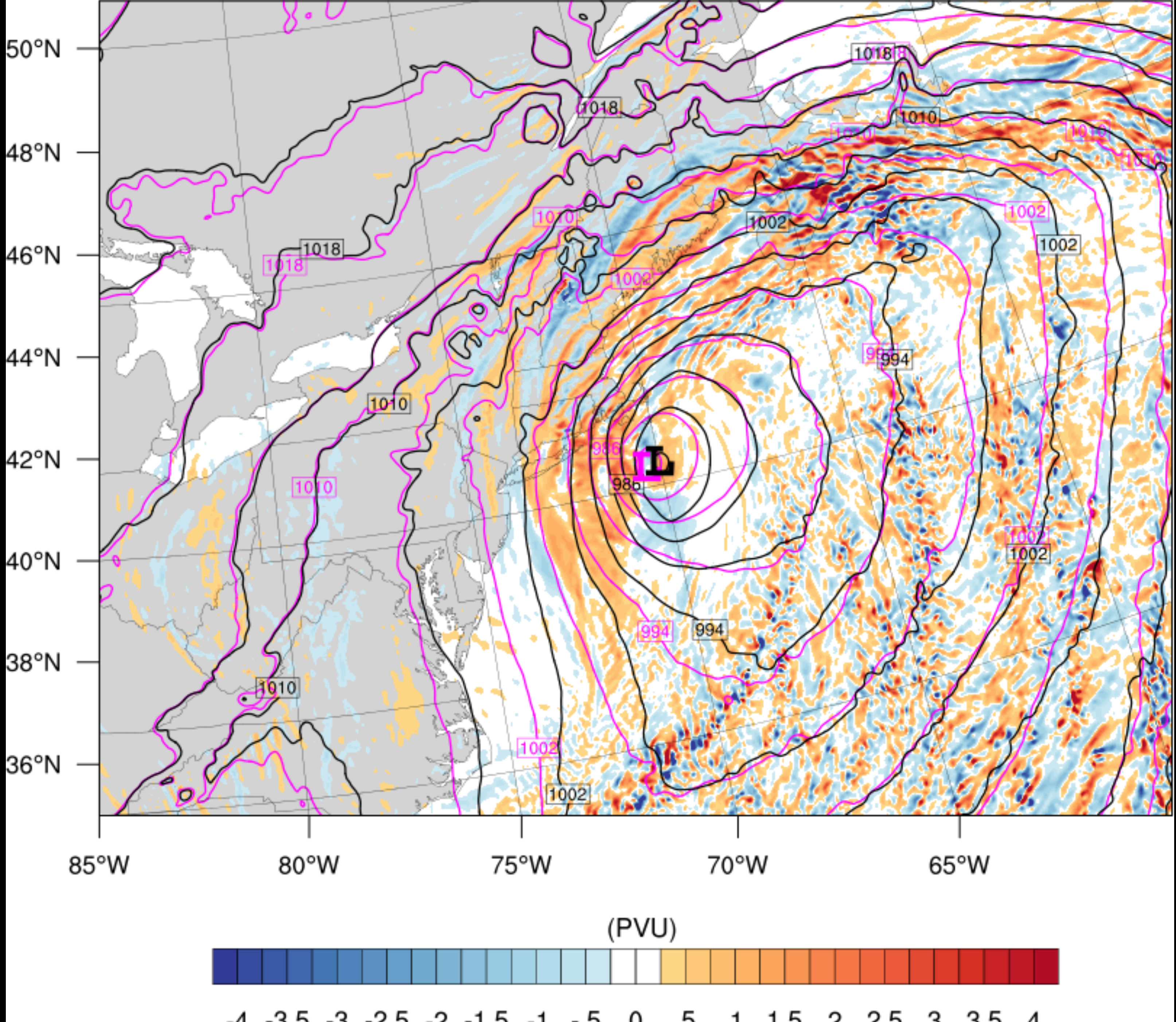
950–700-hPa PV Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

1200 UTC 27 January



950–700-hPa PV Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

1800 UTC 27 January



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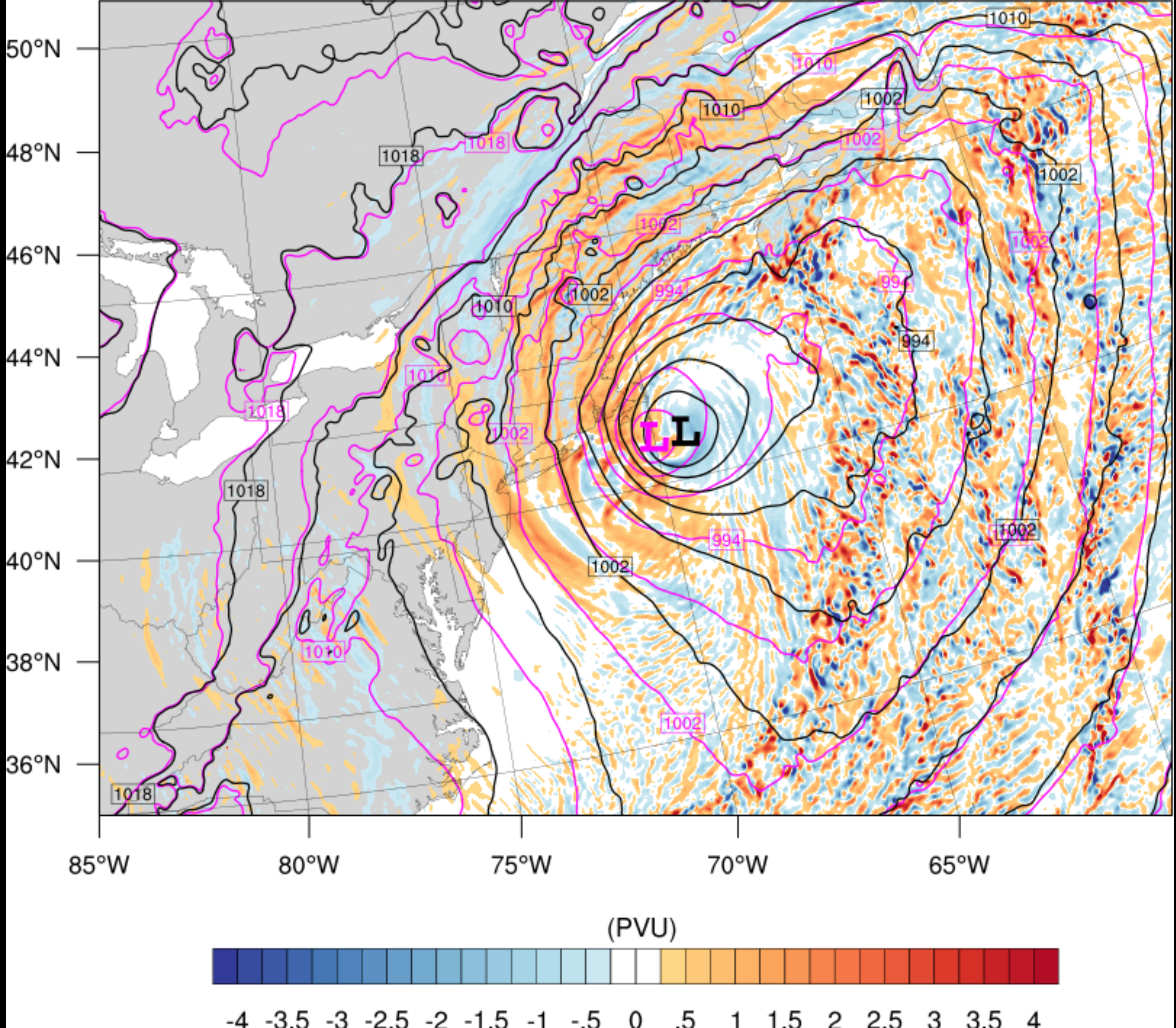

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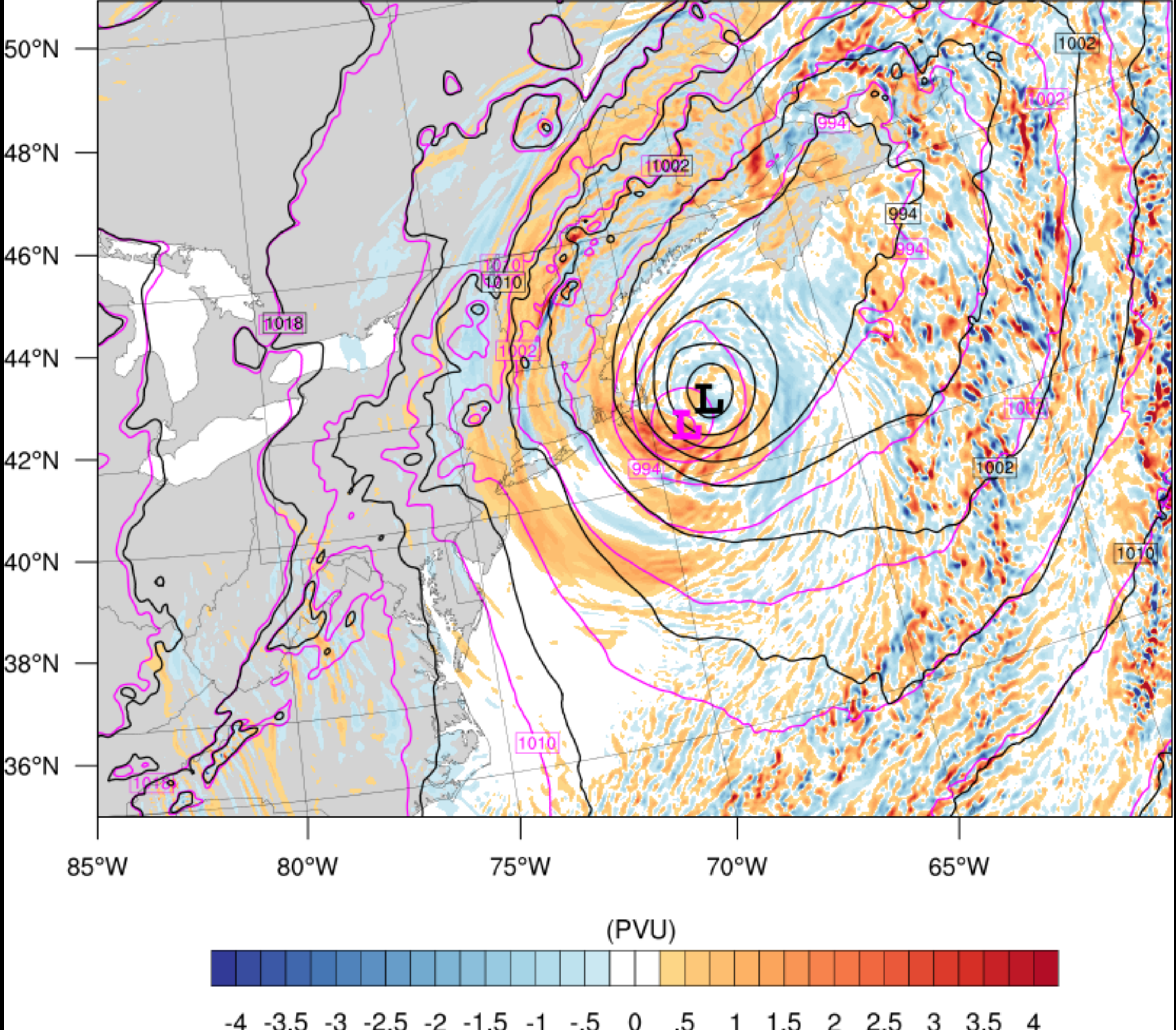
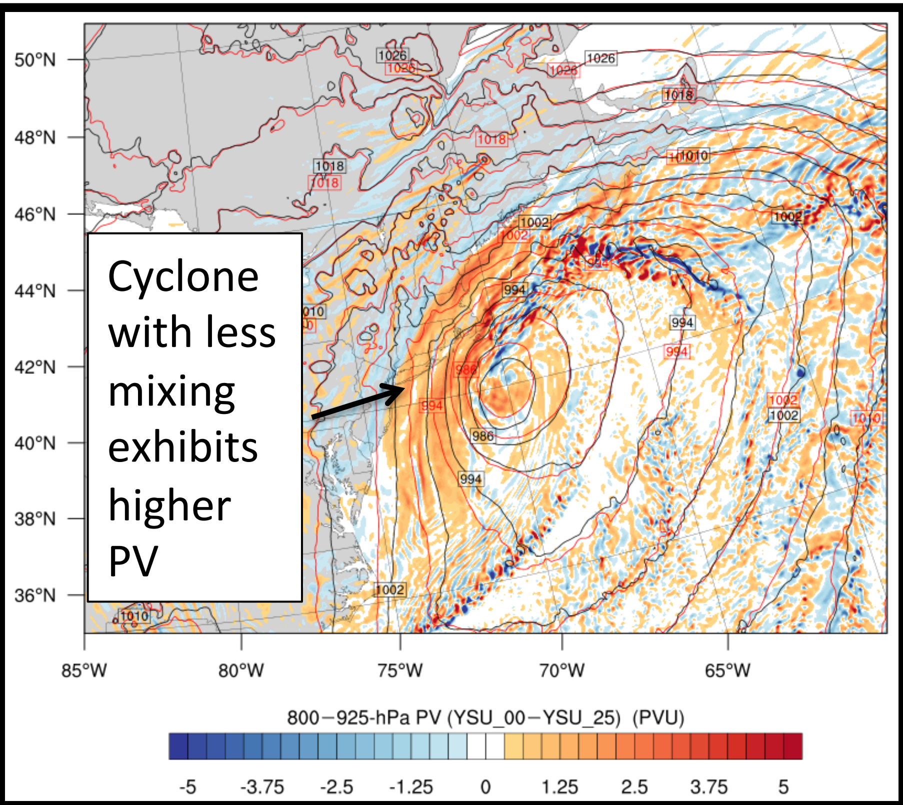


Remarks

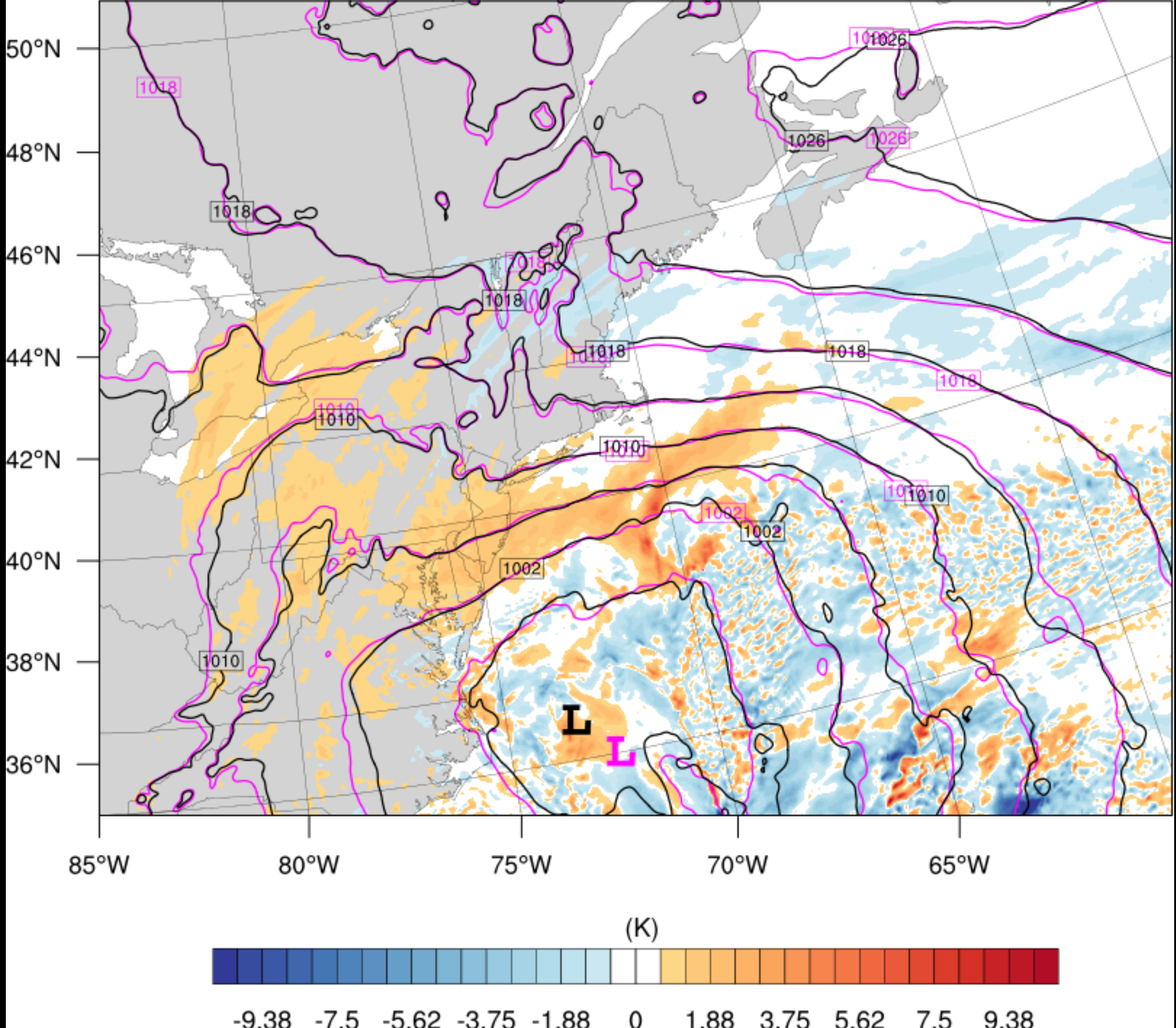
- Less mixing storm has higher low-level PV to the north and west
  - Likely influences low-level circulation
  - What may cause the additional PV?

925–800-hPa PV Difference (Fill, PVU, less mixing–more mixing) and MSLP (Red contours = less mixing) at 1800 UTC 27 January 2015



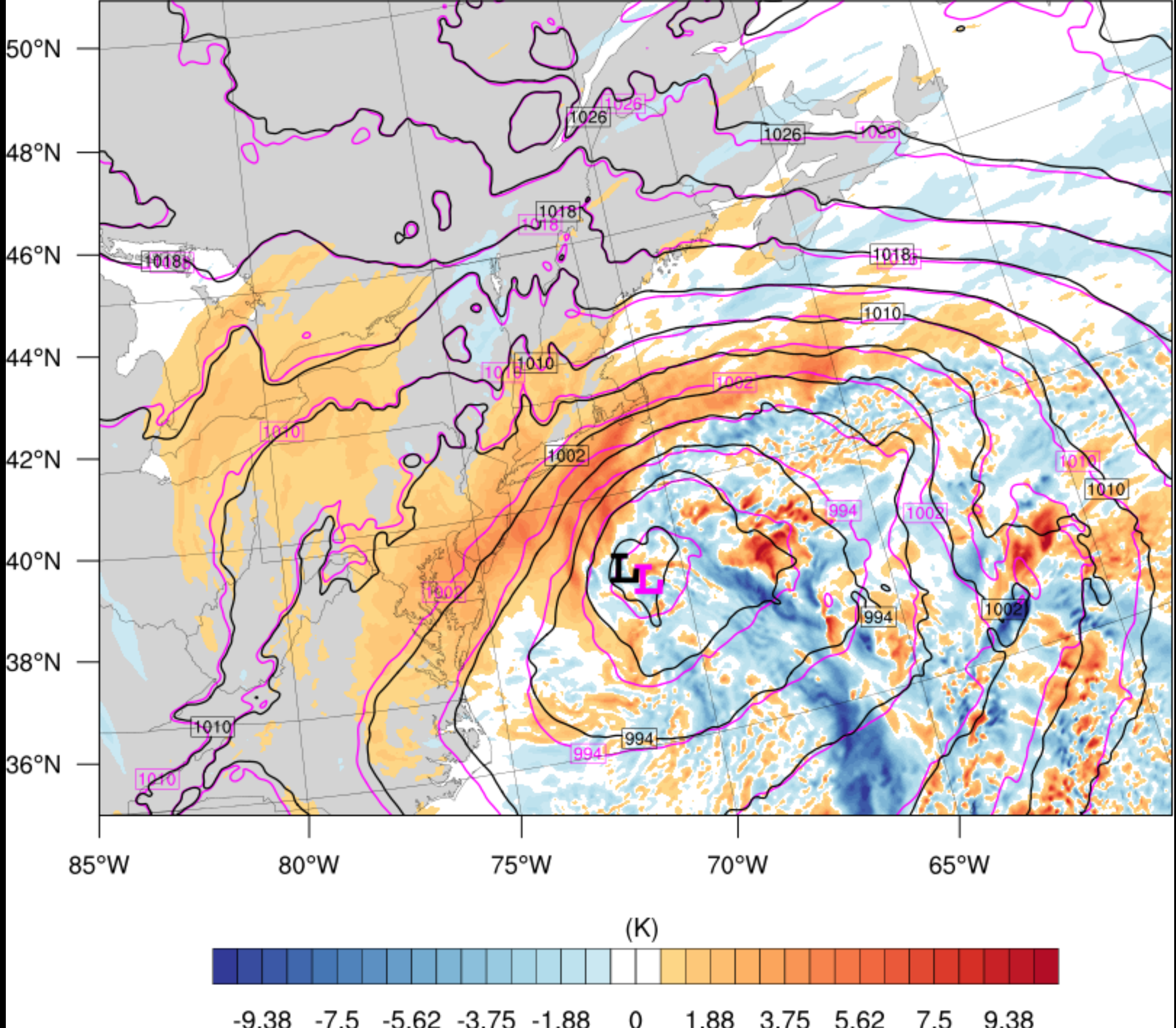
925–800-hPa Theta-e Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0000 UTC 27 January



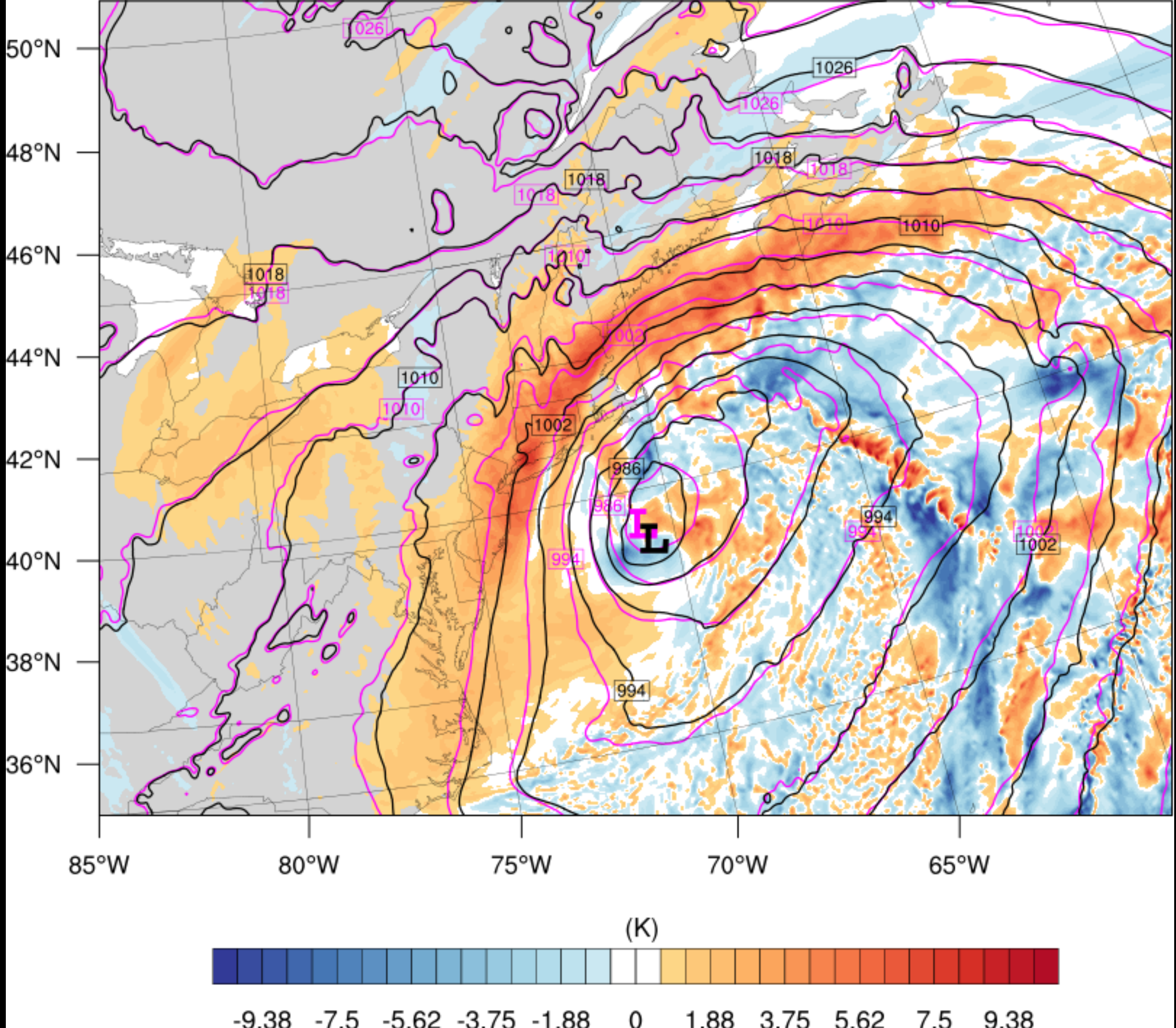
925–800-hPa Theta-e Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0600 UTC 27 January



925–800-hPa Theta-e Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

1200 UTC 27 January



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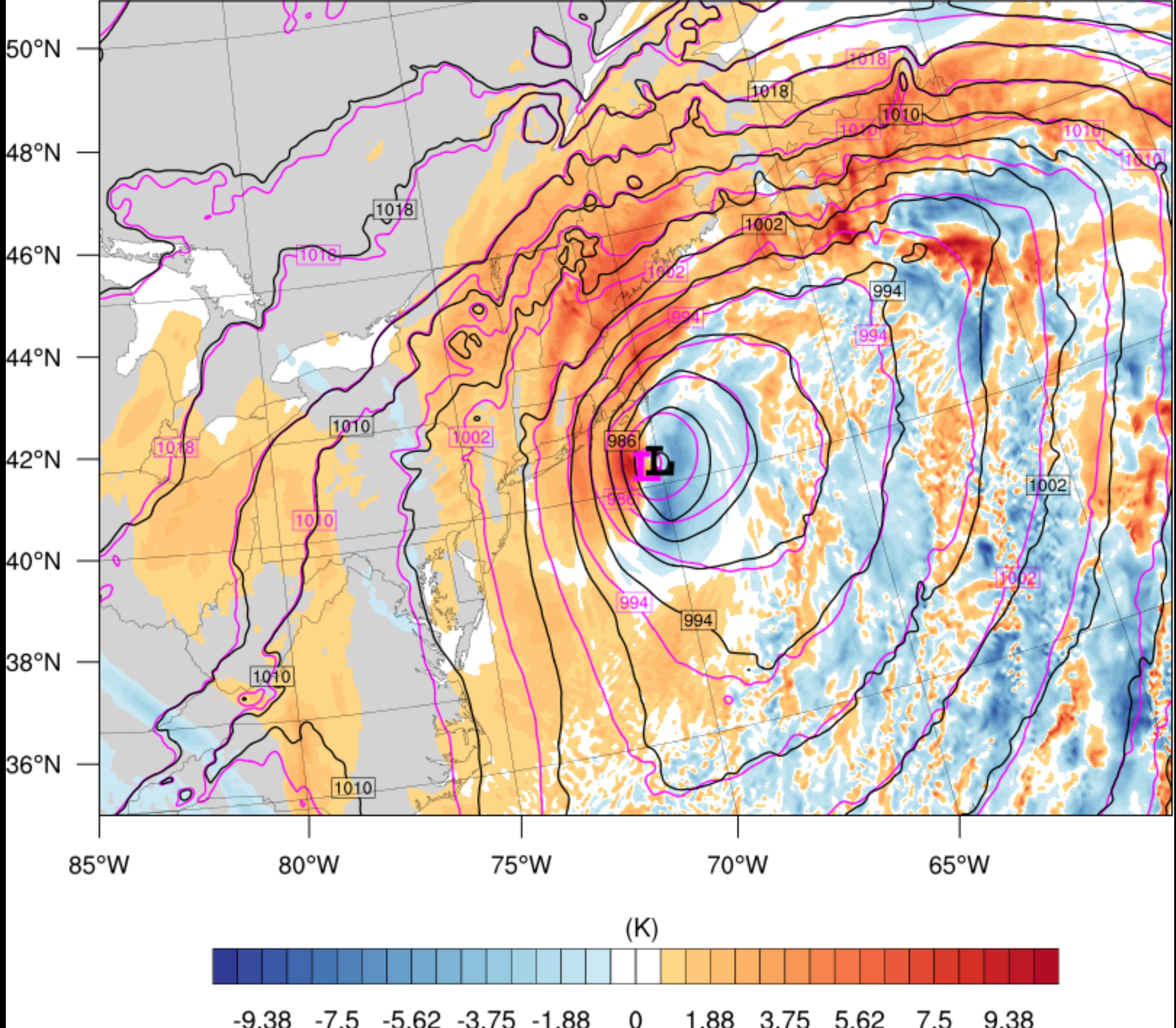

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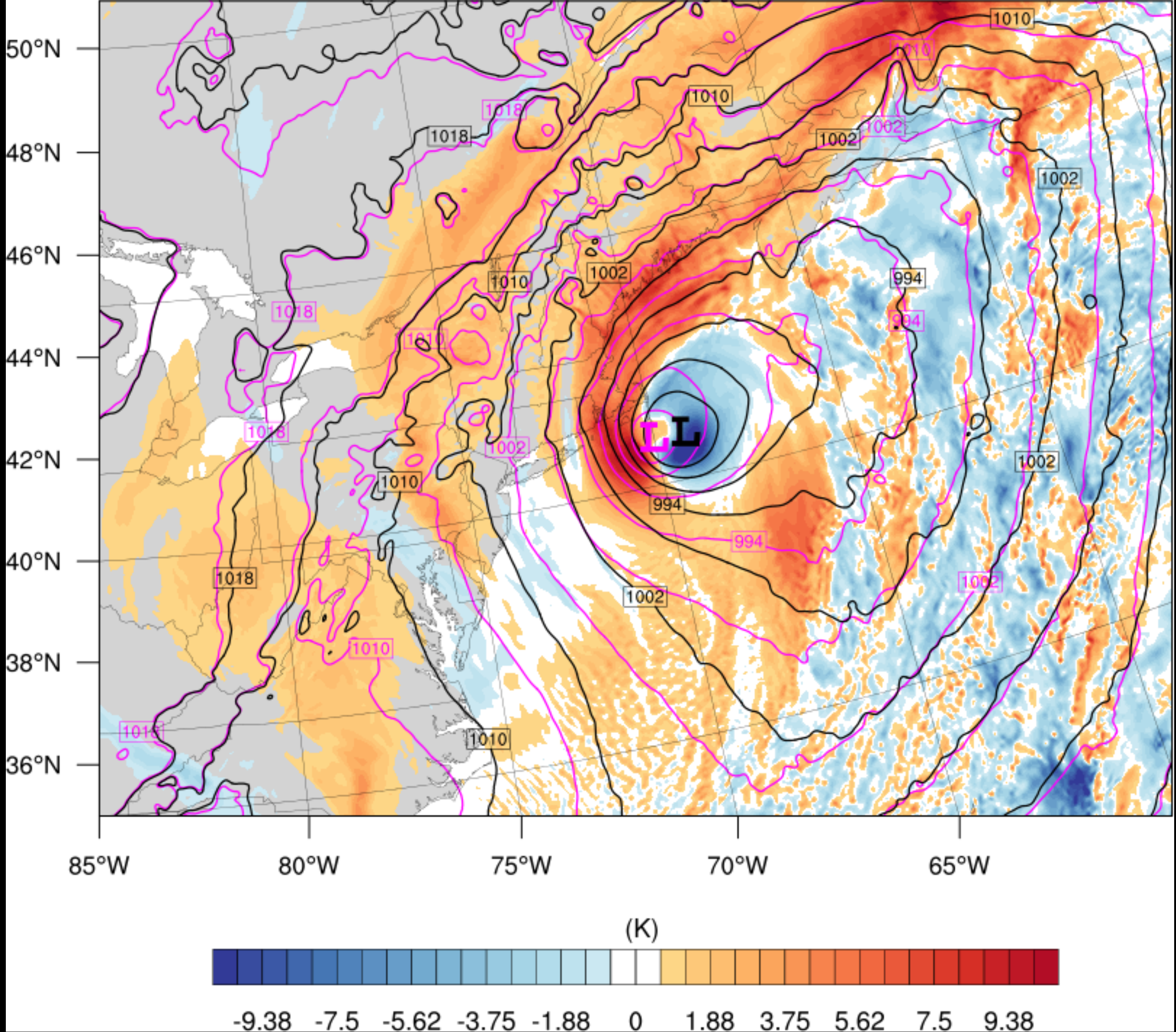

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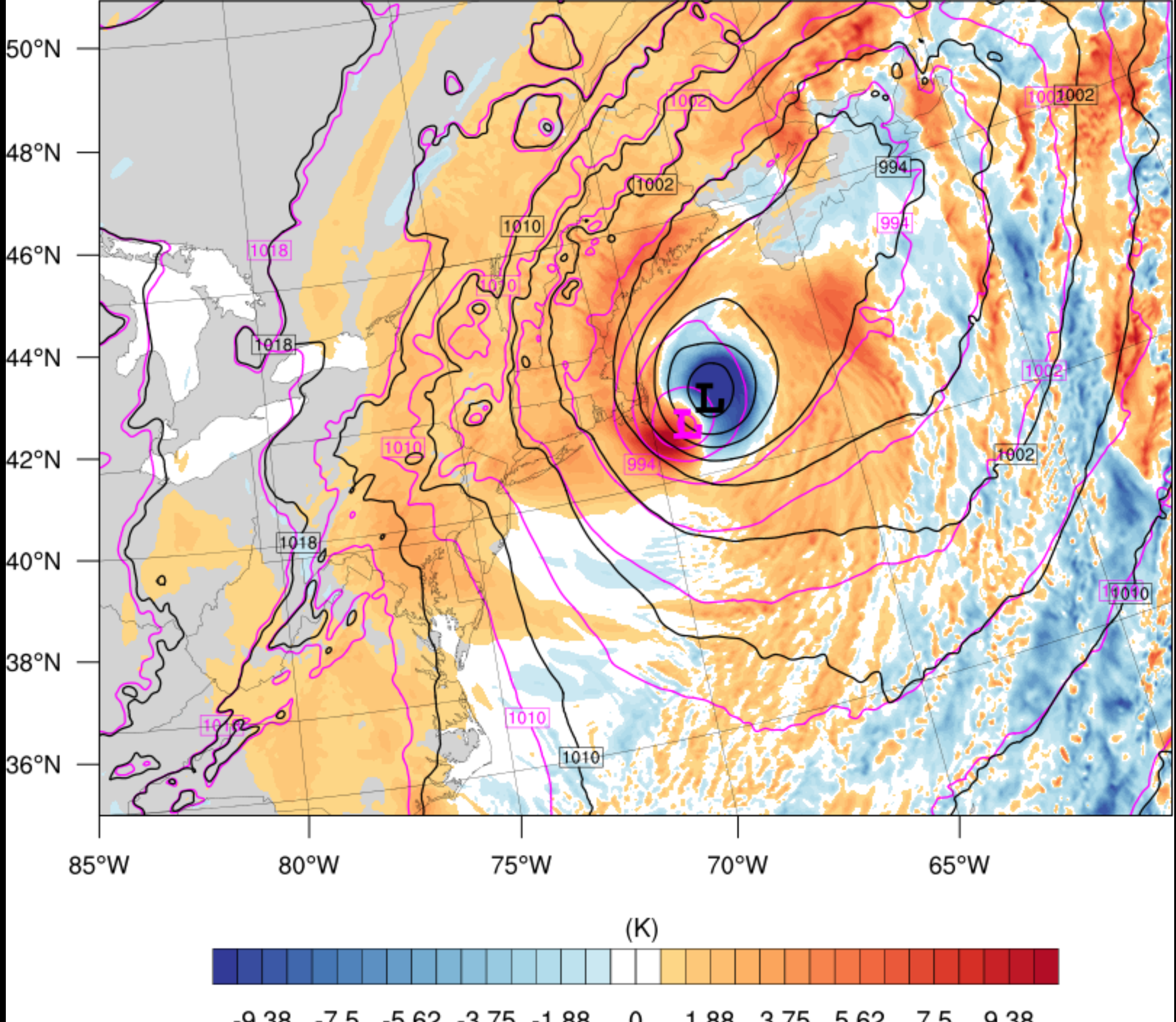
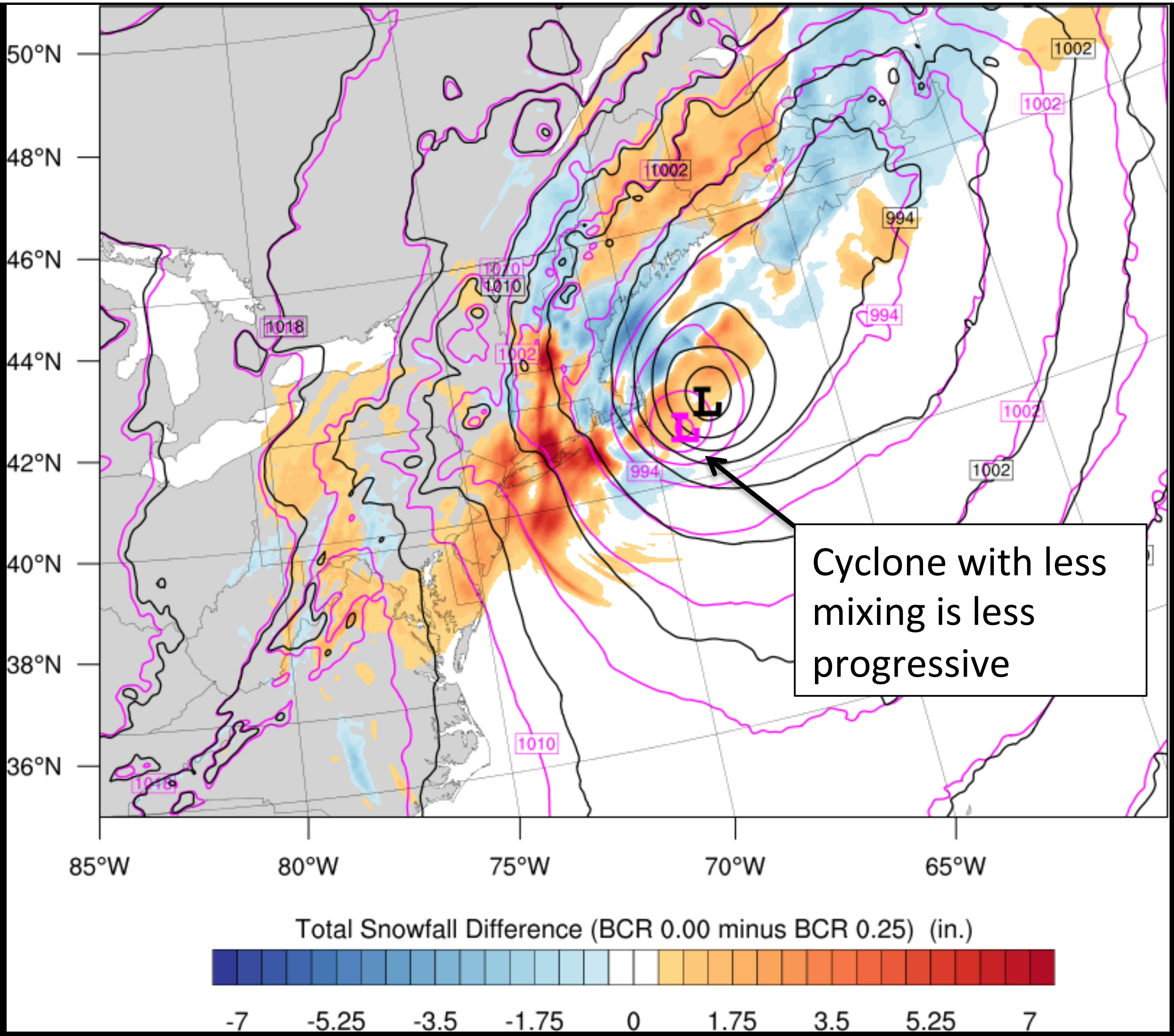
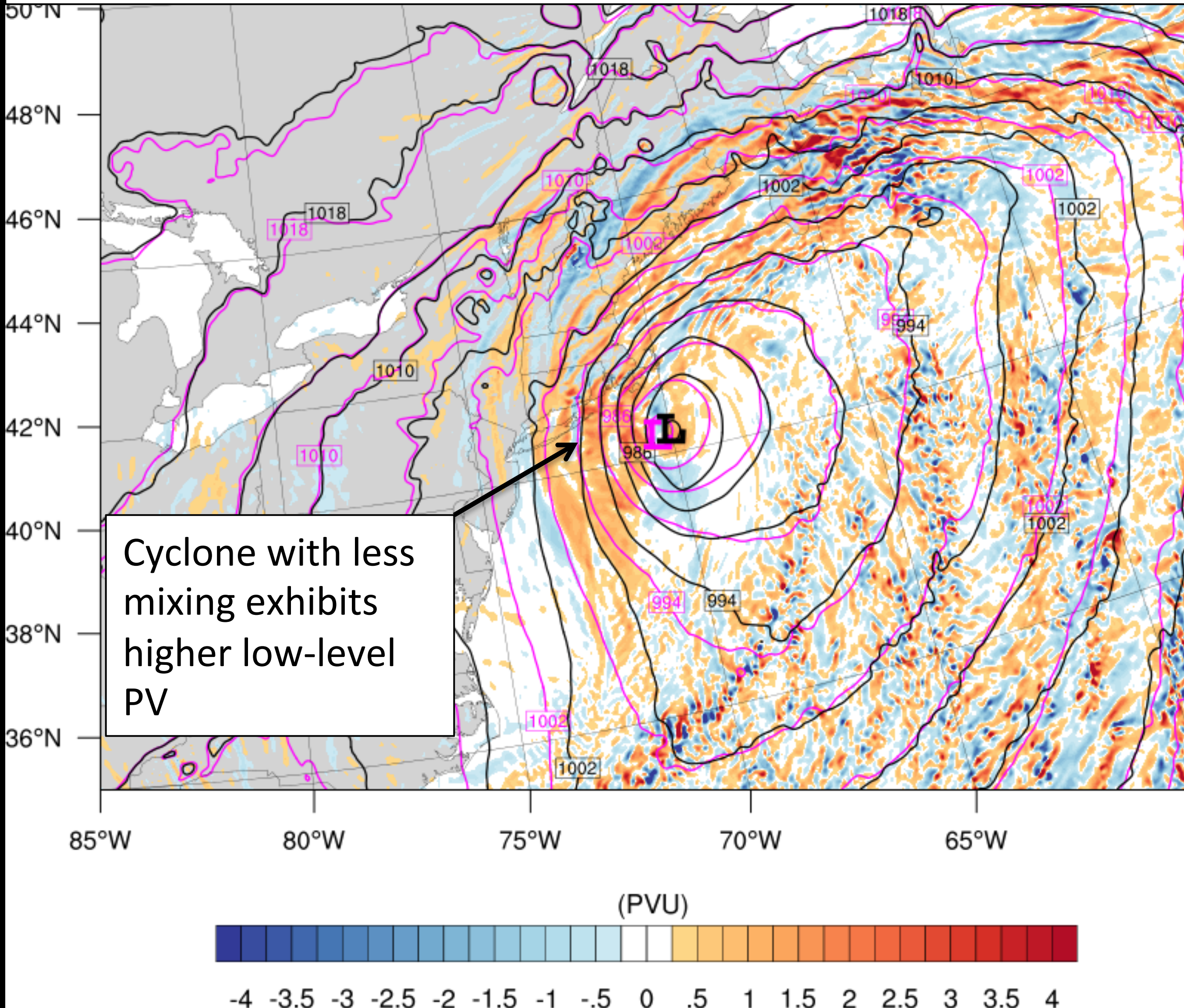


RECAP

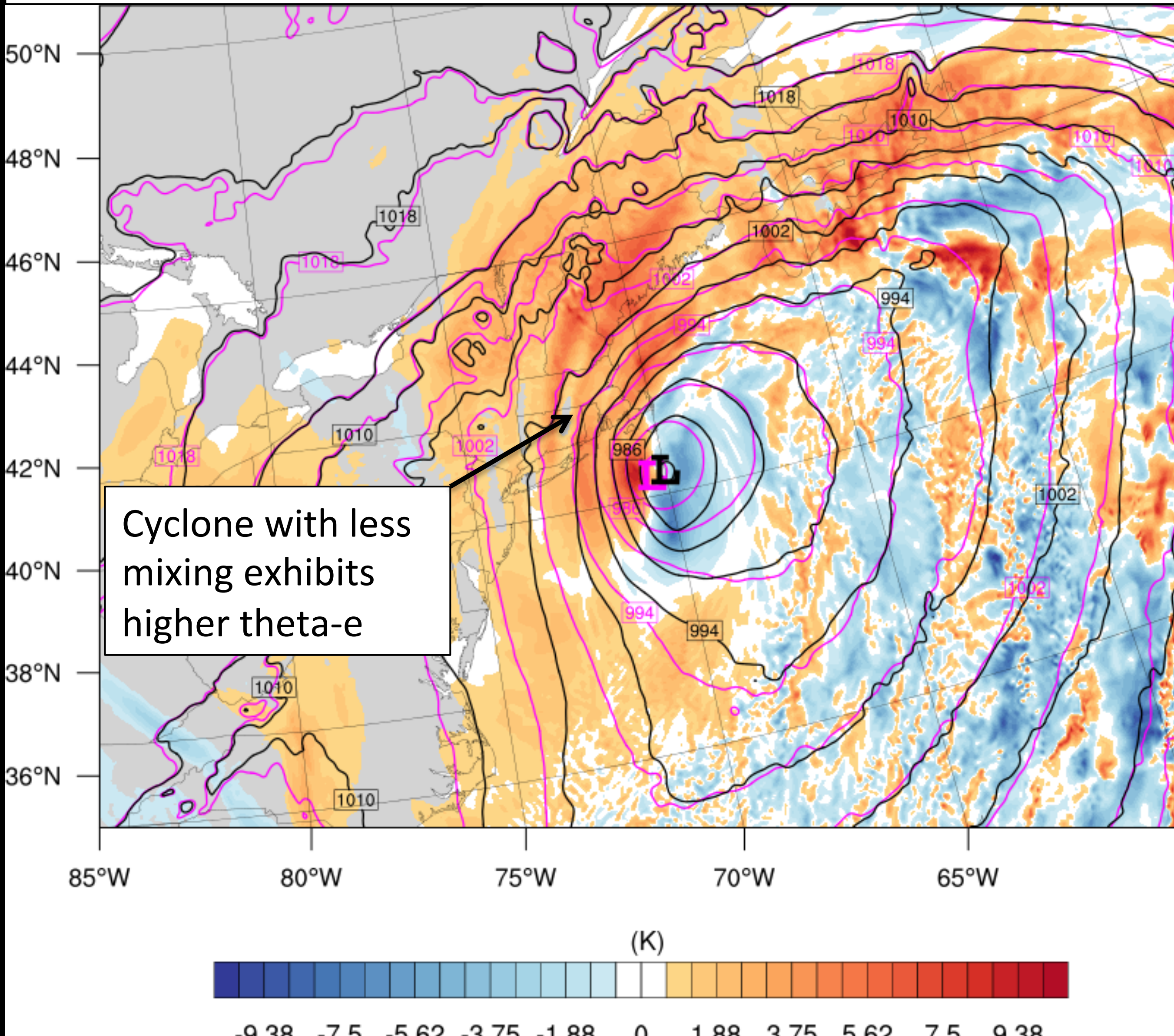
Total Snowfall Difference (less mixing–more mixing) and MSLP (Magenta contours = less mixing) at 0600 UTC 28 January 2015



925–800-hPa Theta-e Difference (Fill, PVU, less mixing–more mixing) and MSLP (Red contours = less mixing) at 1800 UTC 27 January 2015



950–700-hPa PV Difference (Fill, PVU, less mixing–more mixing) and MSLP (Red contours = less mixing) at 1800 UTC 27 January 2015



Concluding Remarks

- Less mixing leads to more precipitation and a less progressive storm
- Stronger PV evident on the north and west side of the cyclone in the less-mixing case
- Preservation of PBL theta-e within the less-mixing case may lead to more PV generation upon release of instability.
- Storm may be less progressive due to influence of PV on storm low-level circulation (Stoelinga 1996) and/or enhanced divergent outflow via latent heating

Future Work

– Trajectory analysis and PV inversion (Stoelinga 1996)

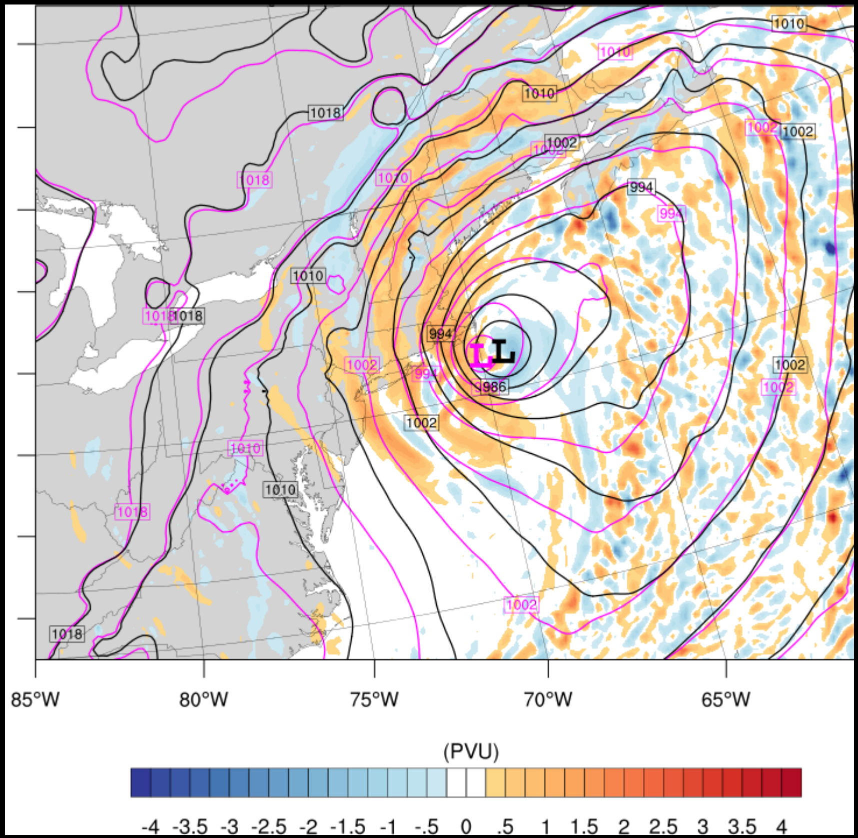
– Test additional cases (varying PWAT)

Swing by the poster: ***The Influence of Boundary Layer Mixing on the 27–28 January 2015 "Twitter" Snowstorm: Sensitivity Experiments***

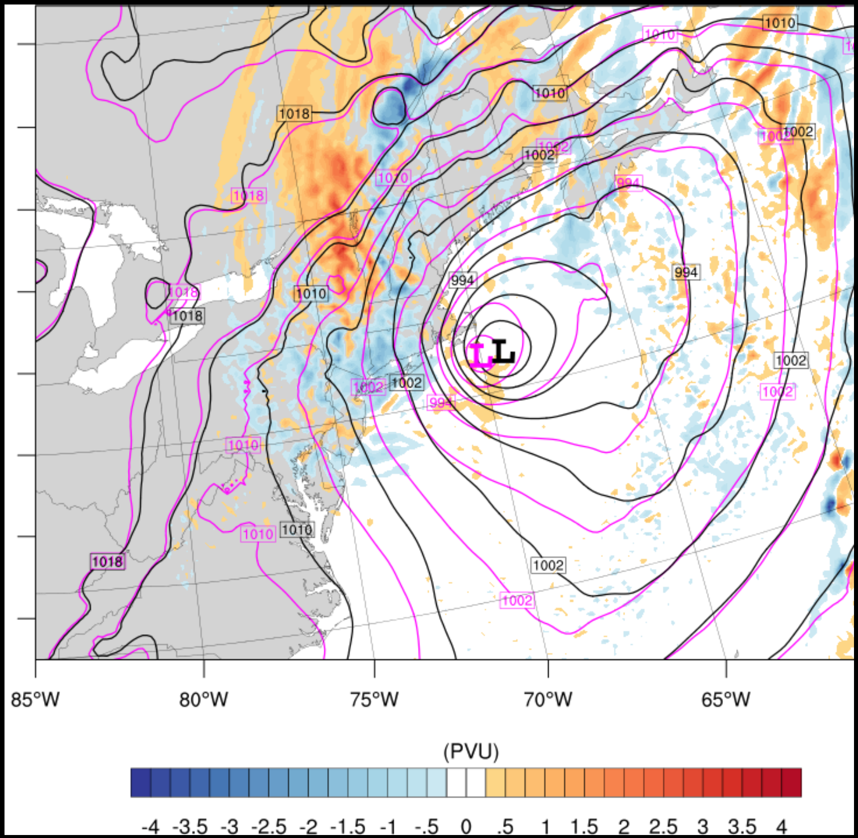
I was supported by the Department of Defense (DoD) through the National Defense Science & Engineering Graduate Fellowship (NDSEG) Program.

Extra Slides

950–700-hPa PV (00Z 28 Jan)

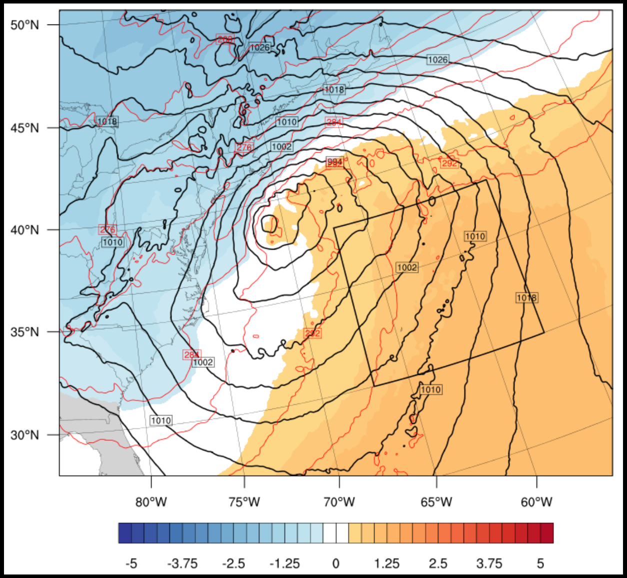


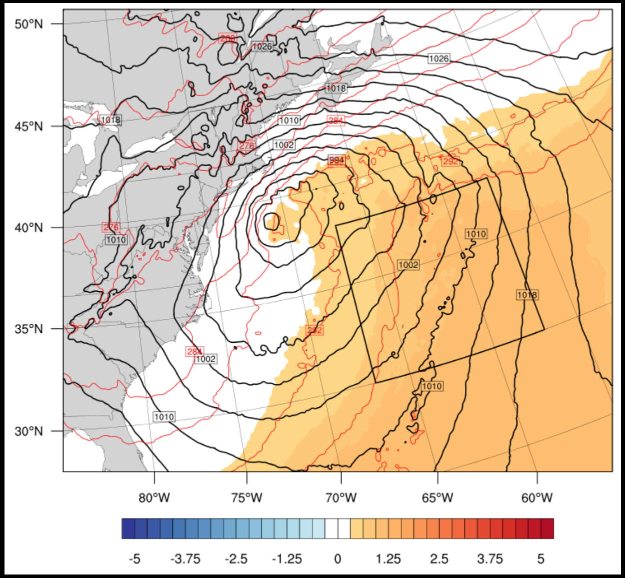
300–200-hPa PV (00Z 28 Jan)



Poor Man's Warm Sector

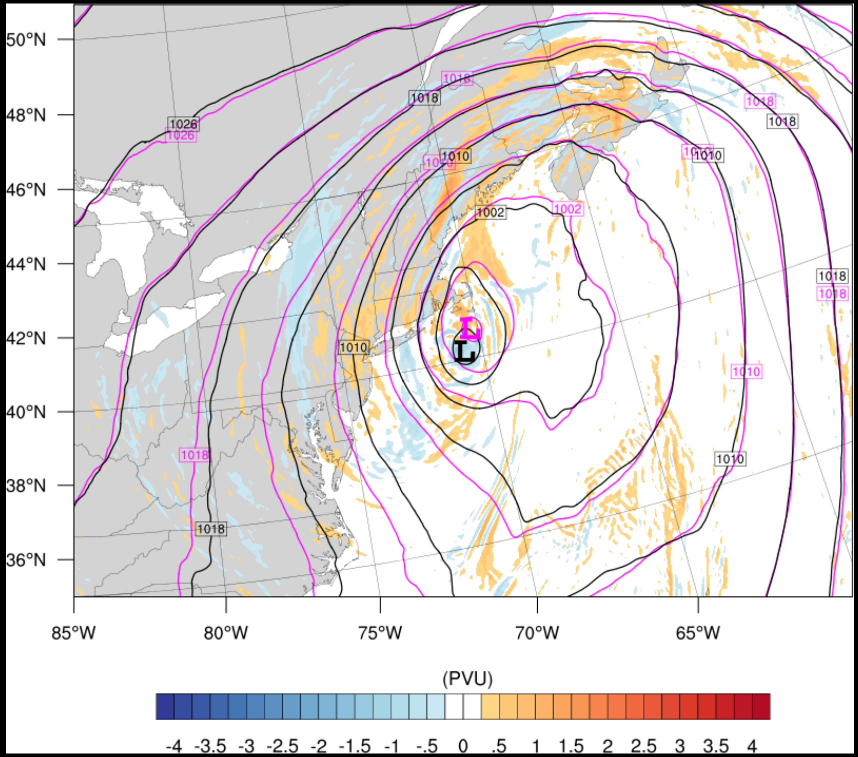
- Used layer-averaged 950–800-hPa theta to compute anomalies for each time-step within the domain
- Used positive anomalies for designating the warm sector





NOLH & Control

950–700-hPa PV (00Z 28 Jan)



950–700-hPa PV (00Z 28 Jan)