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

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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
Background

• How can the boundary layer affect ET development and evolution?
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• How can the boundary layer affect ET development and evolution?
  – 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

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

\[ -(w' \phi') = K \frac{\partial \phi}{\partial z}, \]

Coniglio et al. (2013)

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)
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)

\[
K_{zm} = \kappa w_s z \left(1 - \frac{z}{h}\right)^2
\]

\[
\text{Rib}(z) = \frac{g[\theta_v(z) - \theta_s]z}{\theta_{ua} U(z)^2}
\]

Hong (2006)
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- Critical Richardson number varies with version (~0.75–0.0).
- Appropriate surface potential temp
- Potential temp at lowest model level

Hong (2006)
YSU Scheme

• Iterative process to find PBL height

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YSU Scheme

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

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YSU Scheme

- Iterative process to find PBL height

\[ \text{Ri} = \text{Ri}_c \]

- Once PBL height is found...

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Hong and Pan (1996)
YSU Scheme

• Prescribe mixing profile

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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

“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)
26–28 January Snowstorm

- Crippling snowfall over much of the Northeast. Sharp gradient on Long Island
26–28 January Snowstorm

- Substantial spread within the models
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 ($K_h$; 10 m$^2$ s$^{-1}$ contours) using YSU with (a) Ribcr=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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MSLP
Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0000 UTC
27 January
MSLP Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0600 UTC 27 January
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)
MSLP Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0000 UTC 28 January
MSLP Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)  

0600 UTC 28 January
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?
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)

0600 UTC 27 January
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
950–700-hPa PV Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0000 UTC 28 January
950–700-hPa PV Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0600 UTC 28 January
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 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)

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

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

1800 UTC
27 January
925–800-hPa Theta-e Difference (fill; less mixing–more mixing) and MSLP (contoured; Magenta = less mixing, Black = more mixing)

0000 UTC 28 January
RECAP
Total Snowfall Difference (less mixing–more mixing) and MSLP (Magenta contours = less mixing) at 0600 UTC 28 January 2015

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

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

Cyclone with less mixing exhibits higher theta-e
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*

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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)