An investigation of simulated low-level jets produced by different PBL schemes in the WRF-ARW as verified against tower data

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Presentation Overview

- Mixing length modifications in the MYNN PBL scheme.
- LLJ case study
  - PBL scheme comparison and verification with wind tower data.
  - Vertical resolution tests

TKE Formulation

Both PBL schemes use an equation for TKE is expressed as:

$$\frac{d\left(q^2/2\right)}{dt} - \frac{\partial}{\partial z}\left[l_m q S_q \frac{\partial}{\partial z}\left(\frac{q^2}{2}\right)\right] = P_s + P_b + \varepsilon$$

$$P_s = -u'w'\frac{\partial u}{\partial z} - v'w'\frac{\partial v}{\partial z}$$

$$P_b = \beta g\left(\overline{w'\theta_v'}\right)$$

$$\varepsilon = \frac{q^3}{B_1 l_m}$$

Where $S_q = 0.2$, $\beta = 1/273$ and B_1 is determined from experimental data.

MYNN Mixing Length Formulation

The mixing length is designed such that the shortest length scale among, l_s, l_t, and l_b will dominate:

$$\frac{1}{l_m} = \frac{1}{l_s} + \frac{1}{l_t} + \frac{1}{l_b}$$

where the surface layer length scale l_s is a function of the dimensionless height ($\zeta = z/L$; where L in the M-O length):

$$l_s = \begin{cases} kz/3.7 & \text{if } \zeta \geq 1 \\ kz(1 + 2.7\zeta)^{-1} & \text{if } 0 \leq \zeta < 1 \\ kz(1 - 100\zeta)^{0.2} & \text{if } \zeta < 0 \end{cases}$$

and the turbulent length scale l_t is:

$$l_t = 0.23 \frac{\int_{z=0}^{\infty} zq\,dz}{\int_{z=0}^{\infty} q\,dz}$$

Modification #1:
Only integrate to z=PBLH + 1 km.

For stable conditions, the buoyancy length scale l_b is:

$$l_b = \left[1 + 5\left(\frac{q_c}{l_t N}\right)^{1/2}\right]\frac{q}{N}$$

or $l_b = \infty$ if $N < 0$.

Modification #2:
Add BouLac-type buoyancy length scale

To reduce chance of excessively large mixing length, $l_m = \min(l_m, c^* q/N)$, where c<1.0.

BouLac Mixing Length Formulation

Taken from Bougeault and LaCarrere (1989), at each level in the atmosphere the mixing length, l_m, is related to the distance that a parcel can be displaced vertically with a given amount of TKE:

$$l_{\mathrm{up}} = \int_{z}^{z+l_{up}} \beta[\theta(z) - \theta(z')]dz' = TKE(z)$$

$$l_{\mathrm{down}} = \int_{z-l_{down}}^{z} \beta[\theta(z') - \theta(z)]dz' = TKE(z)$$

and l_{down} is constrained to $l_{down} < z$.

The resultant l_m is then taken as the minimum of l_{down} *and* l_{up}.

Method of Implementation

Goal: To maintain original MYNN PBL physics in the PBL, but employ BouLac PBL mixing length in the free atmosphere.

$$l_{\mathrm{b}} = l_{b(MYNN)}(1 - W) + l_{BL}W$$

Where W is a hyperbolic tangent weighting function dependent on z:

$$W = 0.5\tanh\left(\frac{z - (z_i + \Delta z)}{\Delta z}\right) + 0.5$$

Where z_i is the PBL height and Δz is the half-distance of the transition region between the PBL, where $l_{b(MYNN)}$ dominates and the free atmosphere, where l_{BL} dominates.

The PBL height is determined to be the level at which $\theta_v = \theta_{vsfc} + 1$ and $\Delta z = 1000$ m.

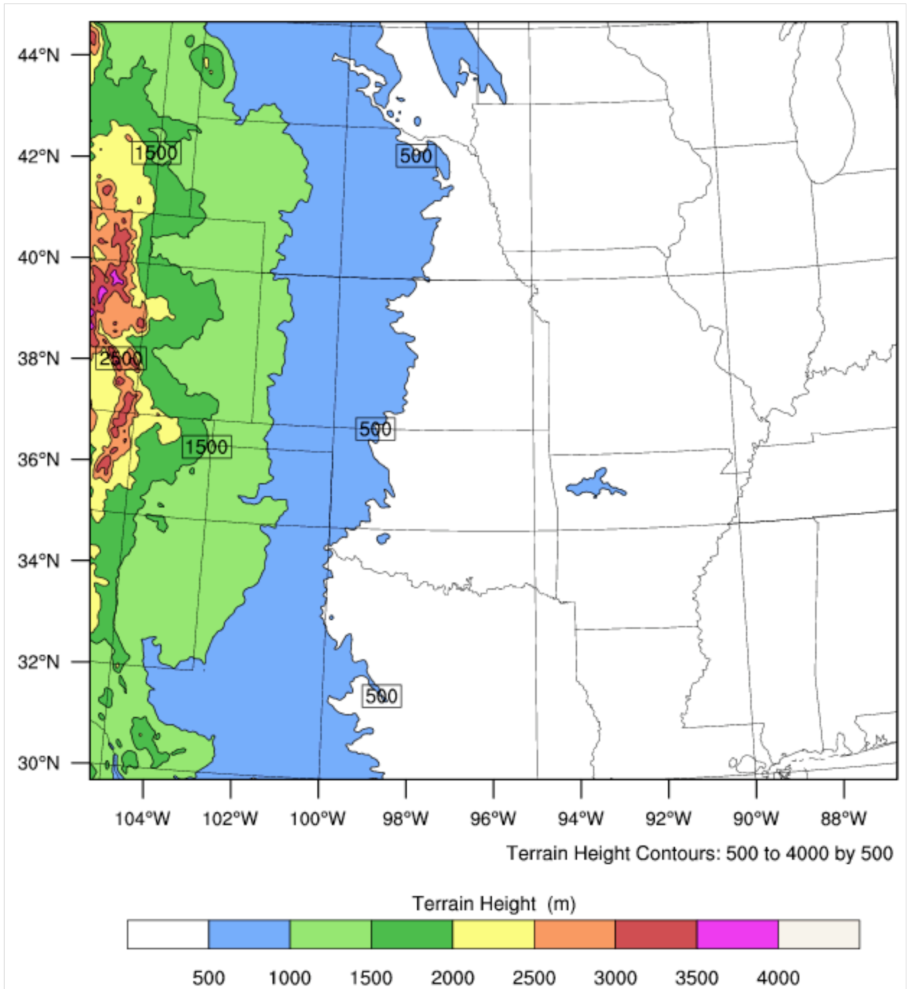
Summary Part I

- MYNN PBL scheme with BouLac mixing length aloft preserves the characteristics of the MYNN in the PBL while eliminating the erroneous TKE aloft.
- Upper-level mixing lengths and TKE are both reduced by ~80% and compare well with the BouLac PBL (as expected).

PBL Scheme Testing/Comparison

Given recent interest in the Rapid Refresh (RR) and High-Resolution RR (HRRR) for wind energy applications, low-level jets (LLJs) cases are good tests for the new PBL schemes.

LLJ case of 19 Aug 2007



WRF-ARW Configuration (v3.2):

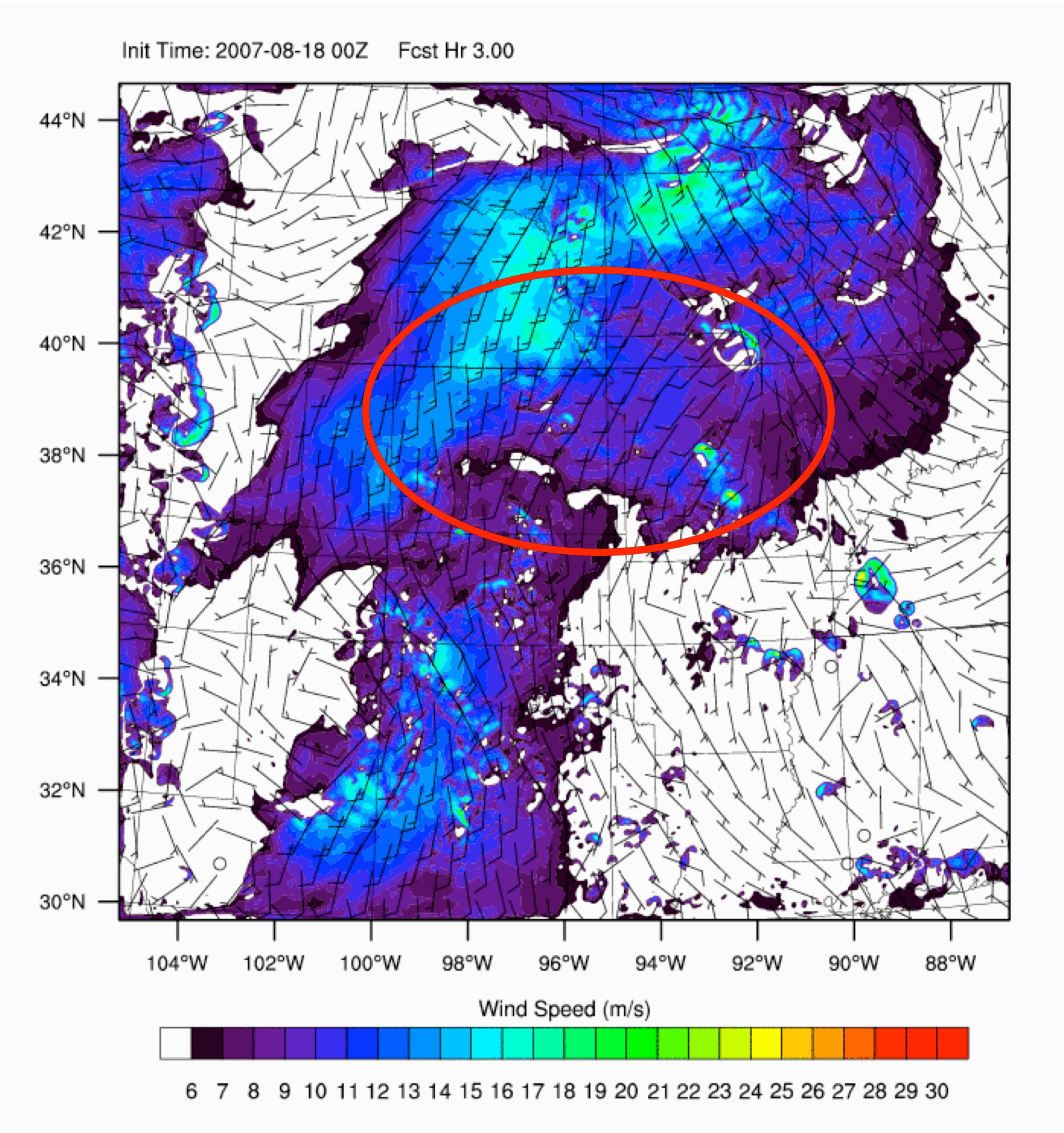
3.3 km grid spacing
51 and 58 vertical levels (6 and 12 below 400 m, respectively)
RUC LSM
No Convective Scheme
Thompson Microphysics
RRTM LW Radiation
Goddard SW radiation
MYJ/MYNN/QNSE PBL

Initial Conditions:

RUC 3-hourly analyses

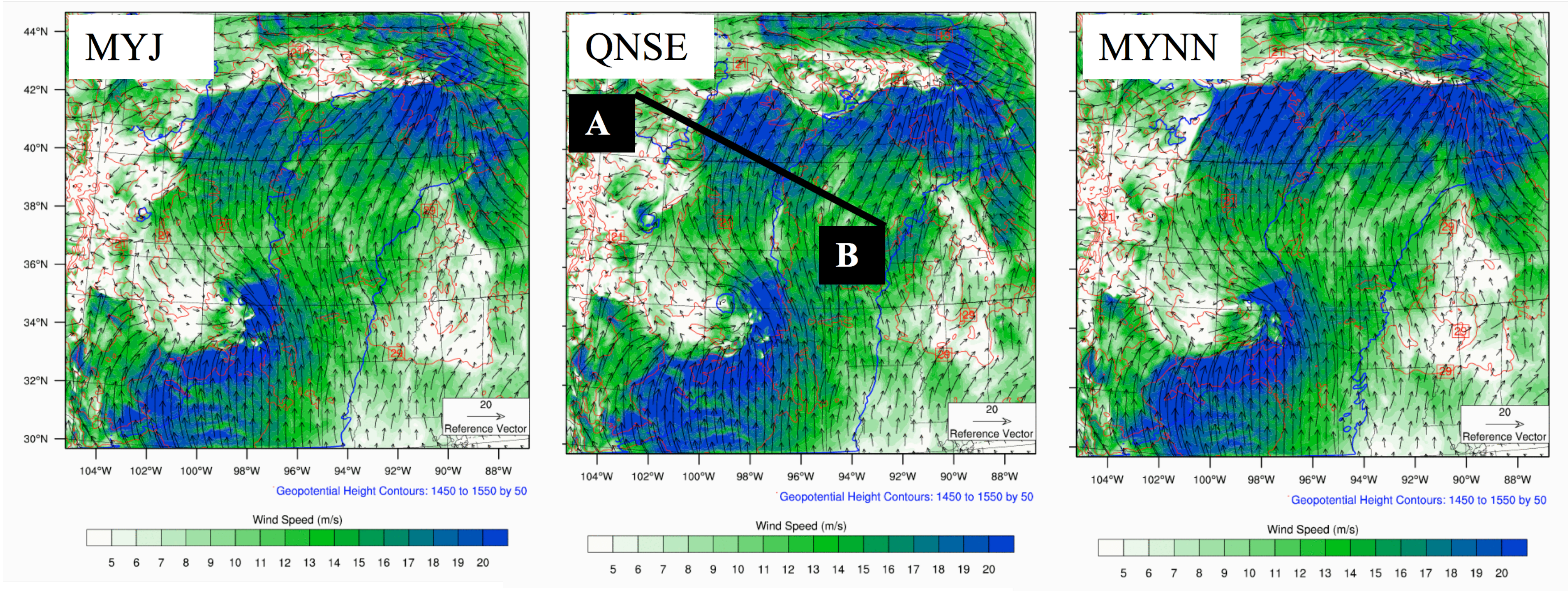
(Actual HRRR configuration covers all of CONUS)

MYJ 100-m Wind Speed Evolution



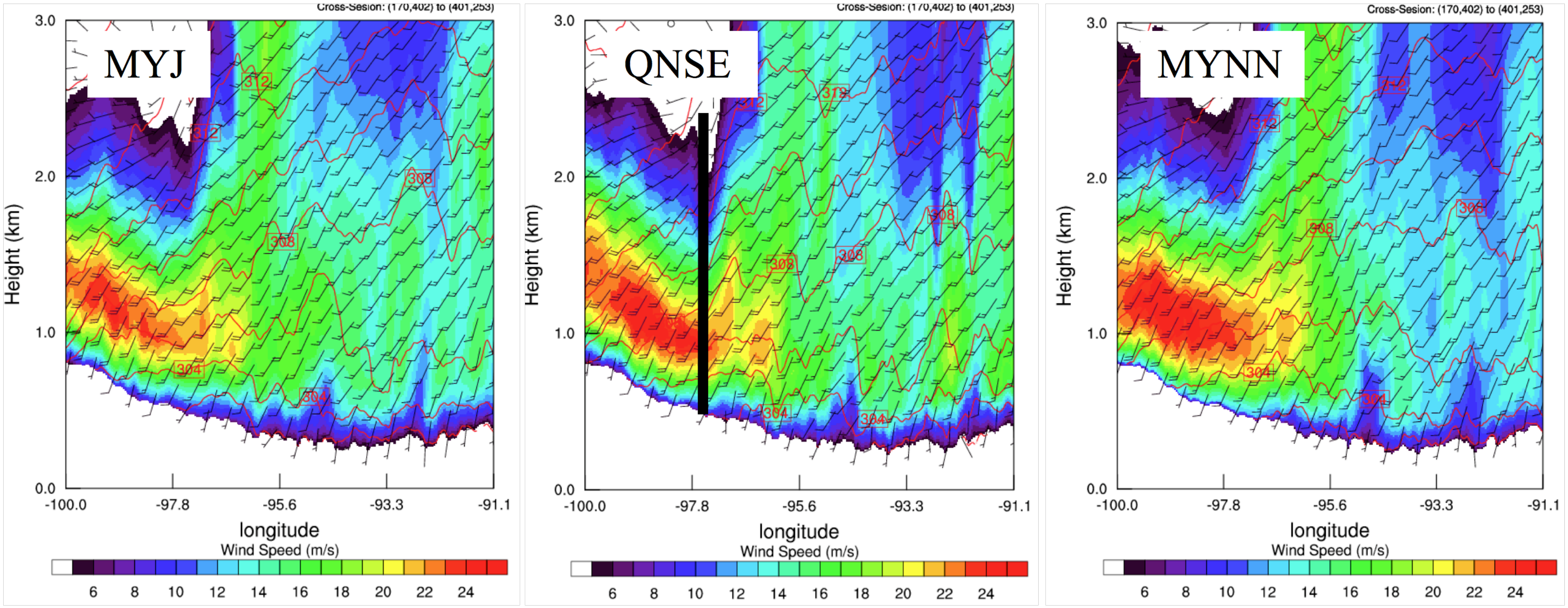
- Frames are produced from 10-min model output intervals.
- Tropical Depression Erin (W. OK) has strong surface wind speeds throughout the simulation.
- Nocturnal LLJ in NE, KS, IA, & MO reaches speeds > 15 m s^{-1}.

100-m wind speed @ 06Z 20070819



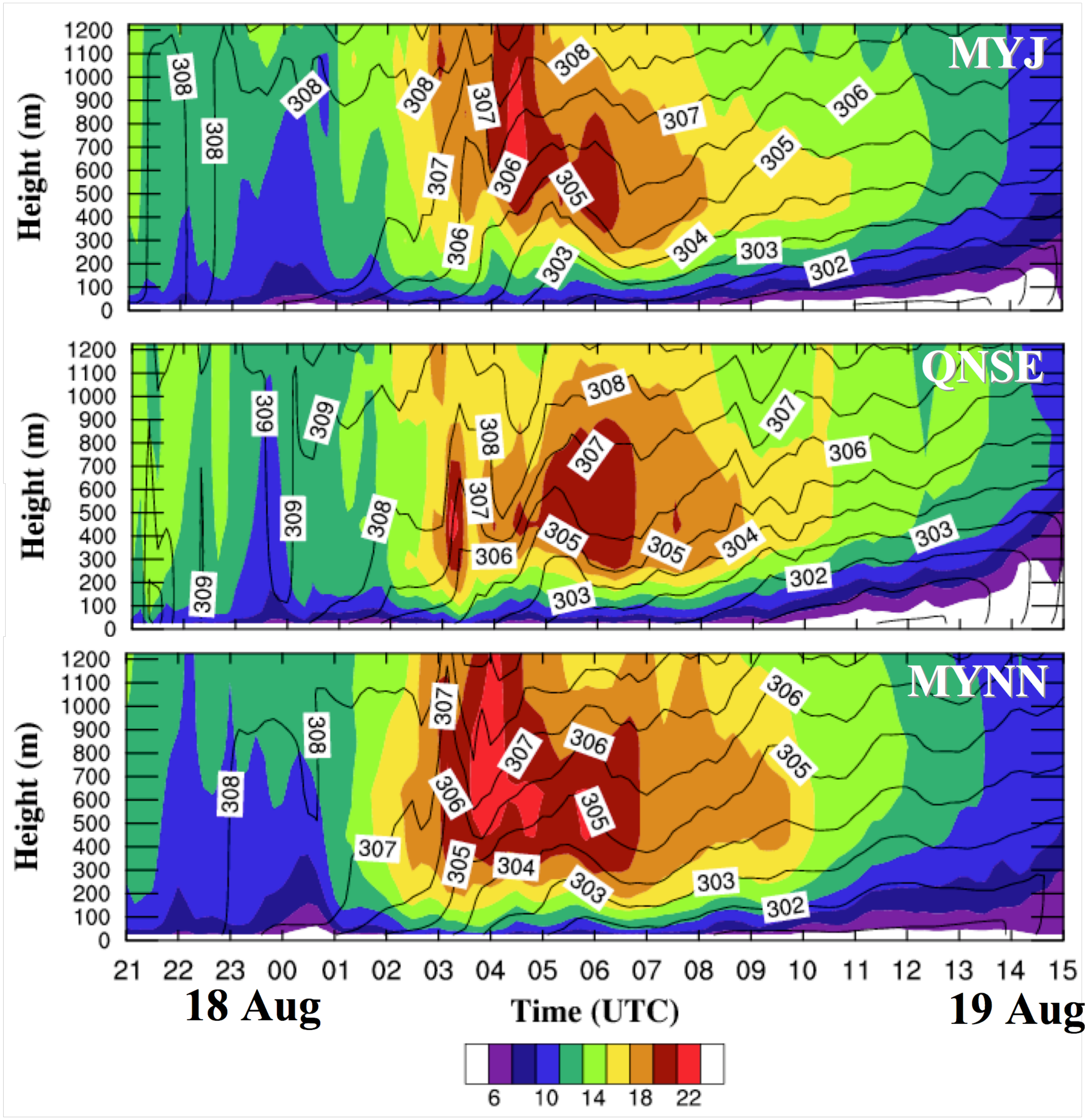
- Spatial extent of high wind speeds is similar in all TKE-based schemes.
- The MYNN produces the strongest LLJ, generally 1 m s^{-1} stronger than MYJ or QNSE.

Vertical cross-section @ 09Z 20070819



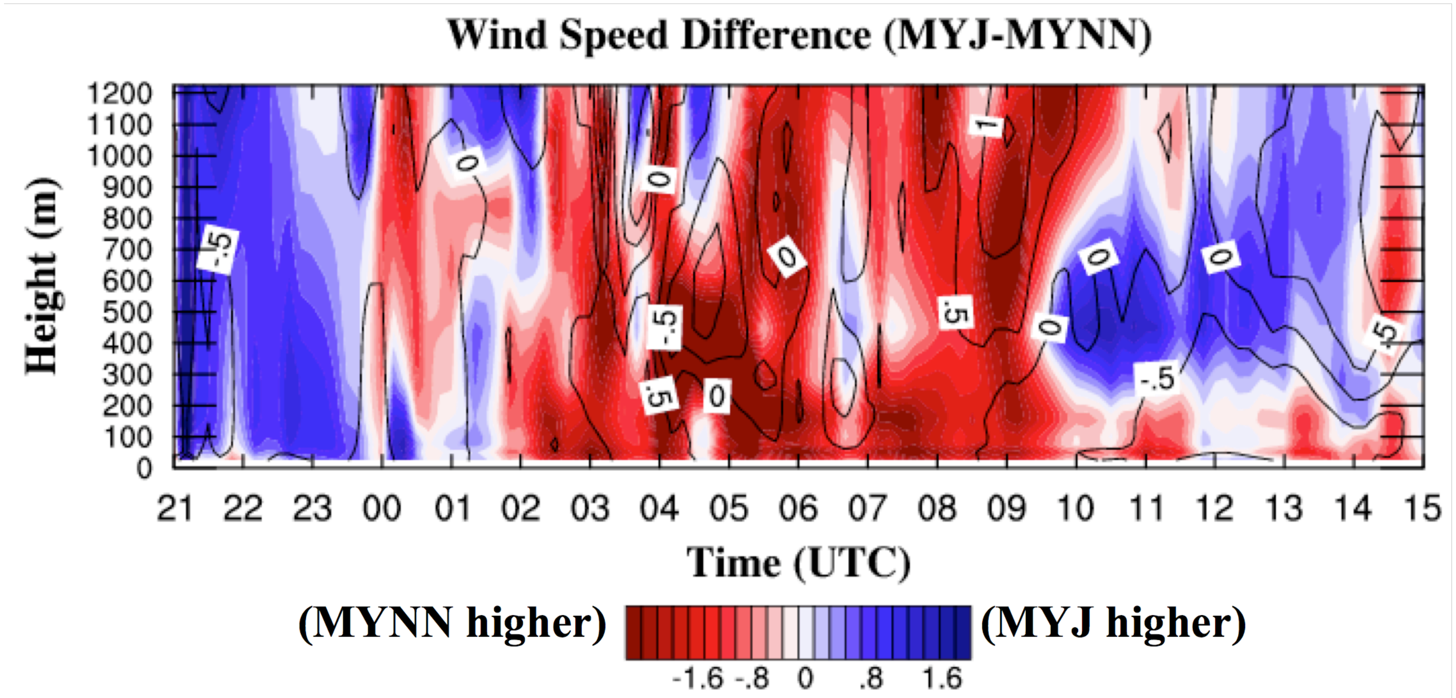
- The MYNN produces the strongest and tallest LLJ maxima.
- The MYNN has stronger vertical mixing, with the jet top ~100 m higher than MYJ or QNSE.
- Strength of daytime vertical mixing is similar in rank, but has more variation (not shown).

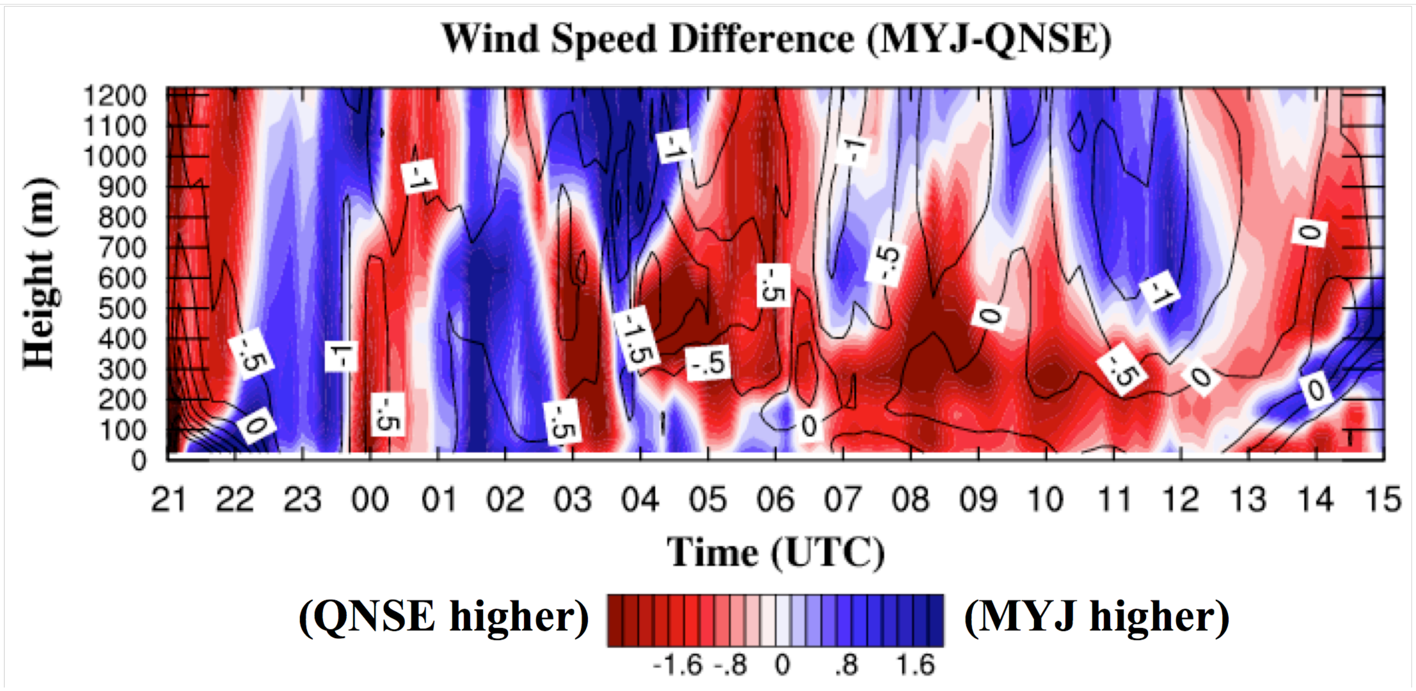
Wind Speed Profile Evolution (N. Missouri)



- Daytime PBL height builds faster in the QNSE.
- The MYNN has the strongest and deepest LLJ.
- Strongest (weakest) surface winds in MYNN (QNSE).

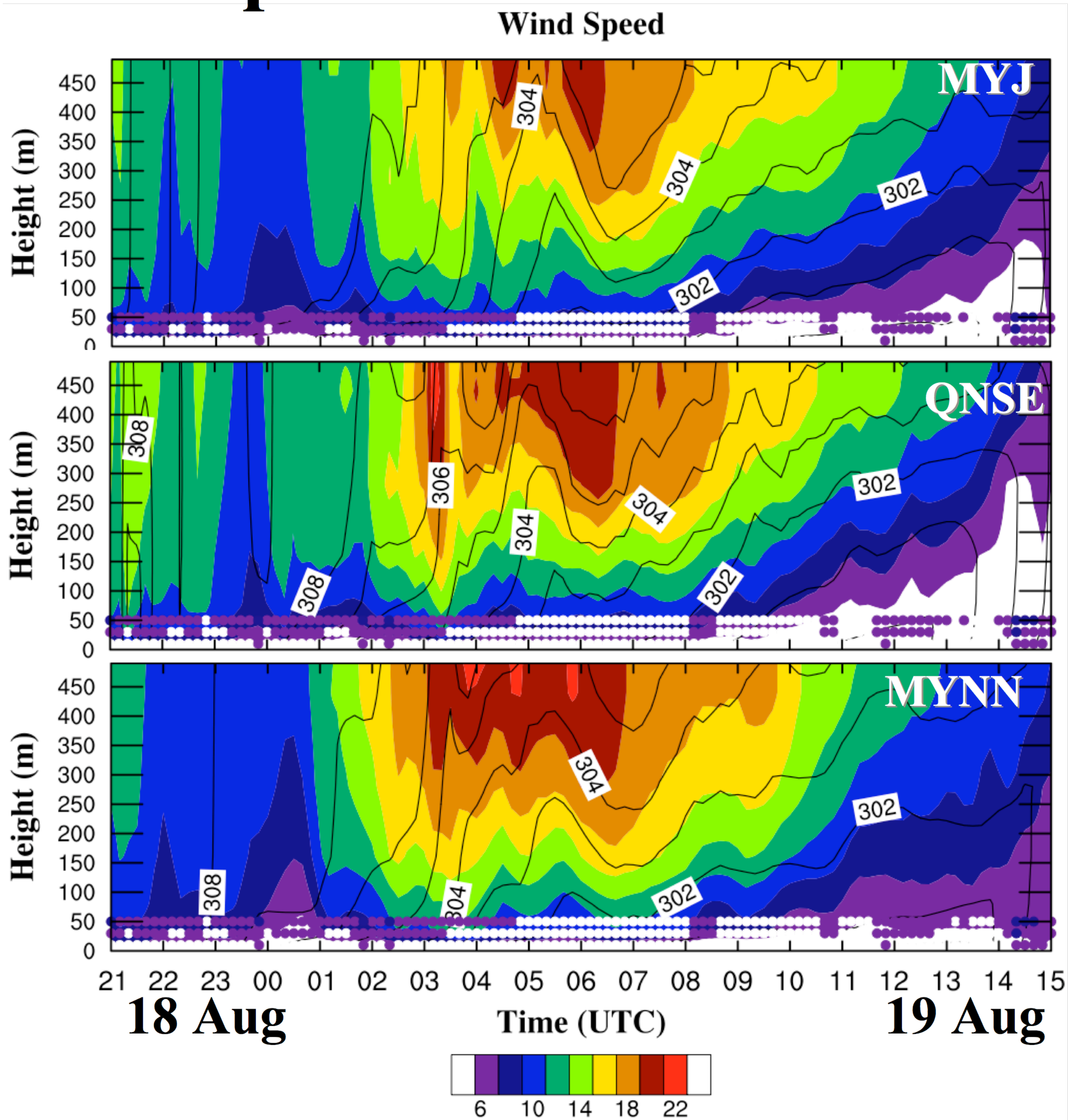
Profile Difference (N. Missouri)





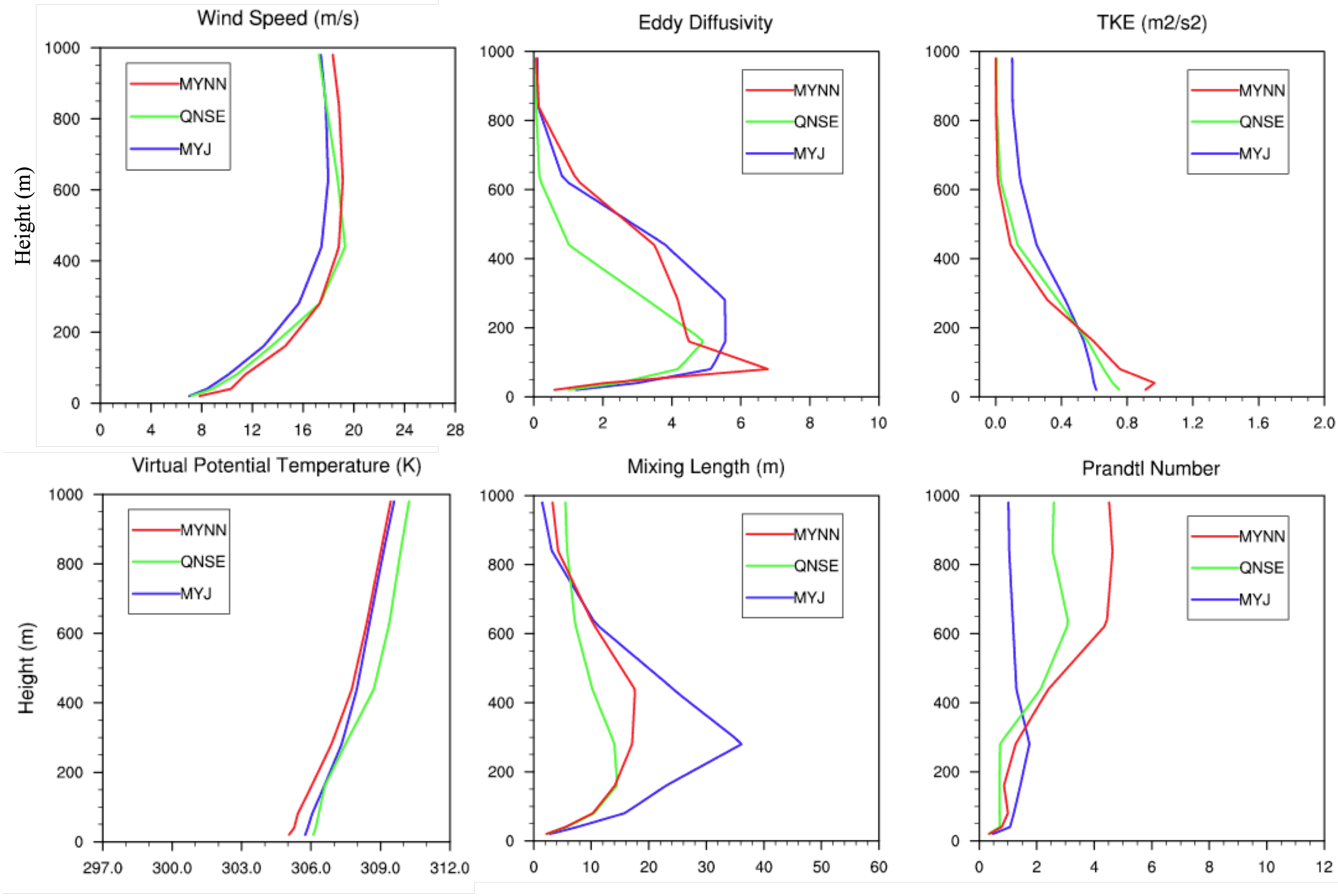
- The MYNN has a stronger LLJ throughout most of the night.
- During the morning transition (after 10 UTC), the LLJ remains stronger in the MYJ with stronger stability below 500 m.
- The QNSE also has a stronger jet below 600 m and has a more rapid warming during the morning transition period.

Comparison to Wind Tower (N. Missouri)

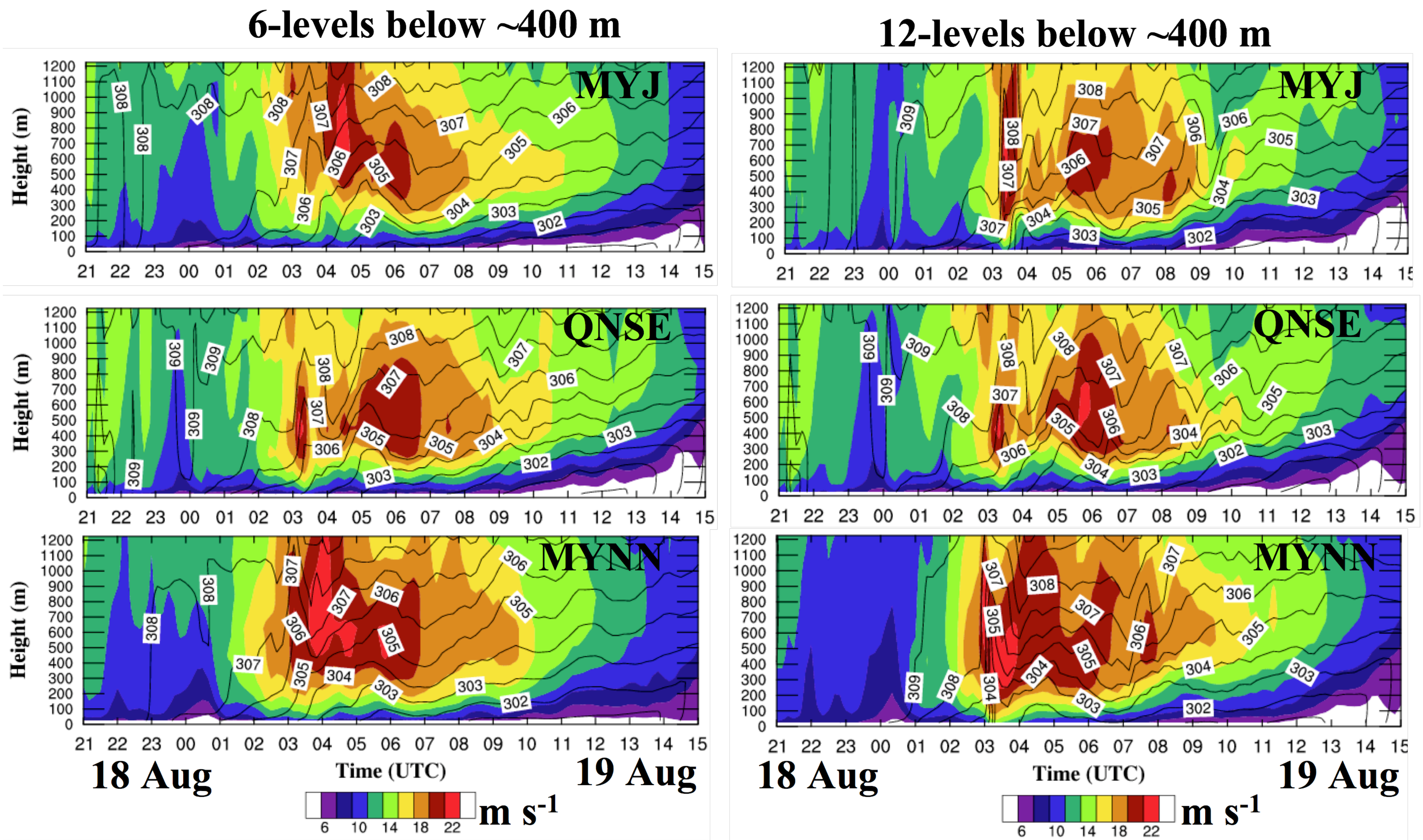


- All simulations overpredict the wind speeds at 10, 30, and 50-m between 01-10 UTC.
- The stronger shear in QNSE produces the weakest low-level winds and closest match the observations beneath the LLJ.
- The weaker shear and strong wind speeds below 200 m in the MYNN result in the largest overprediction beneath the LLJ, but are the best match during the transition periods.

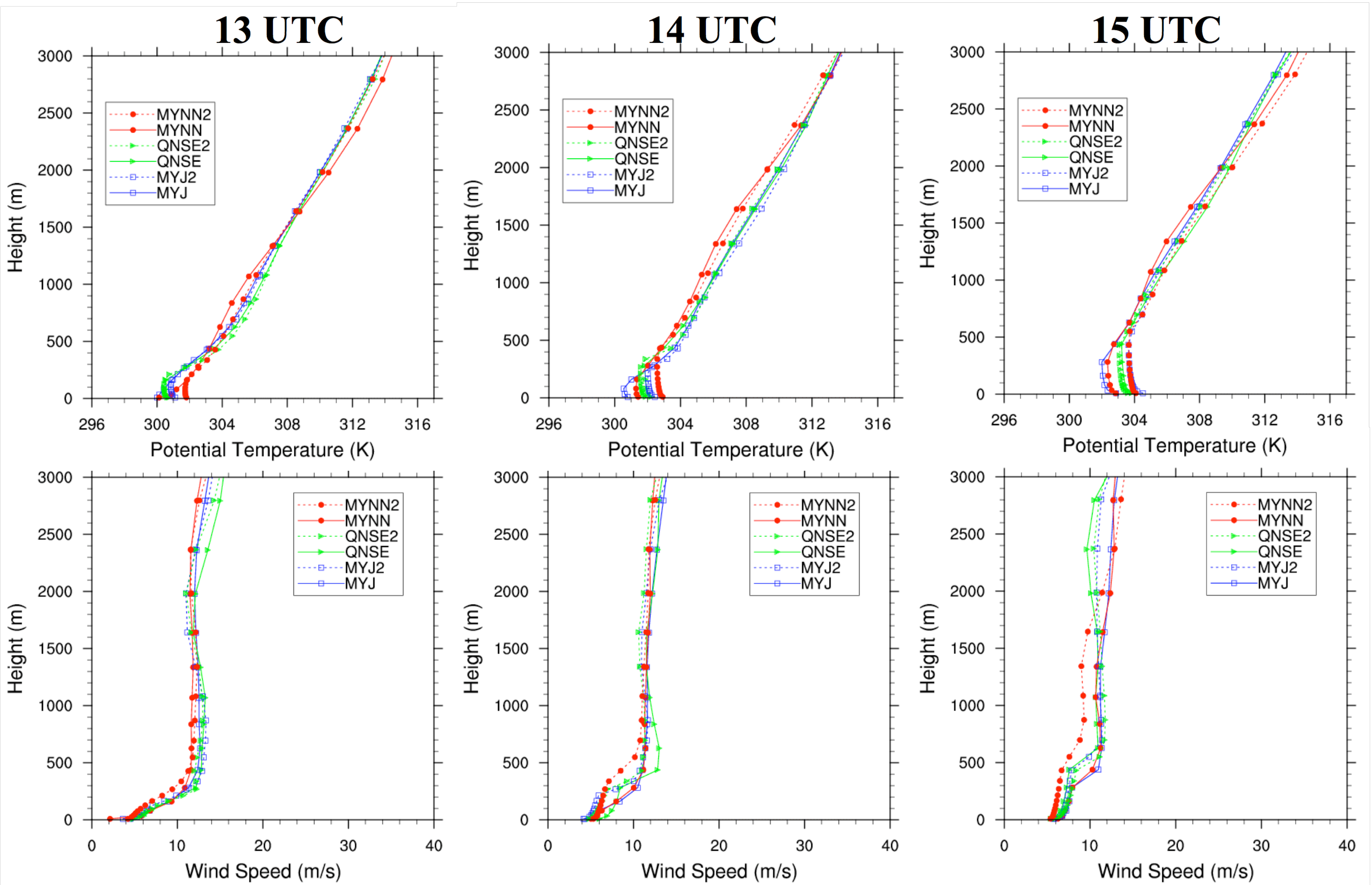
Mean Profiles 03-09 UTC (N. Missouri)



Impact of the Model's Vertical Resolution on the Wind Speed Profile Evolution (N. Missouri)



Profile Evolution (N. Missouri)

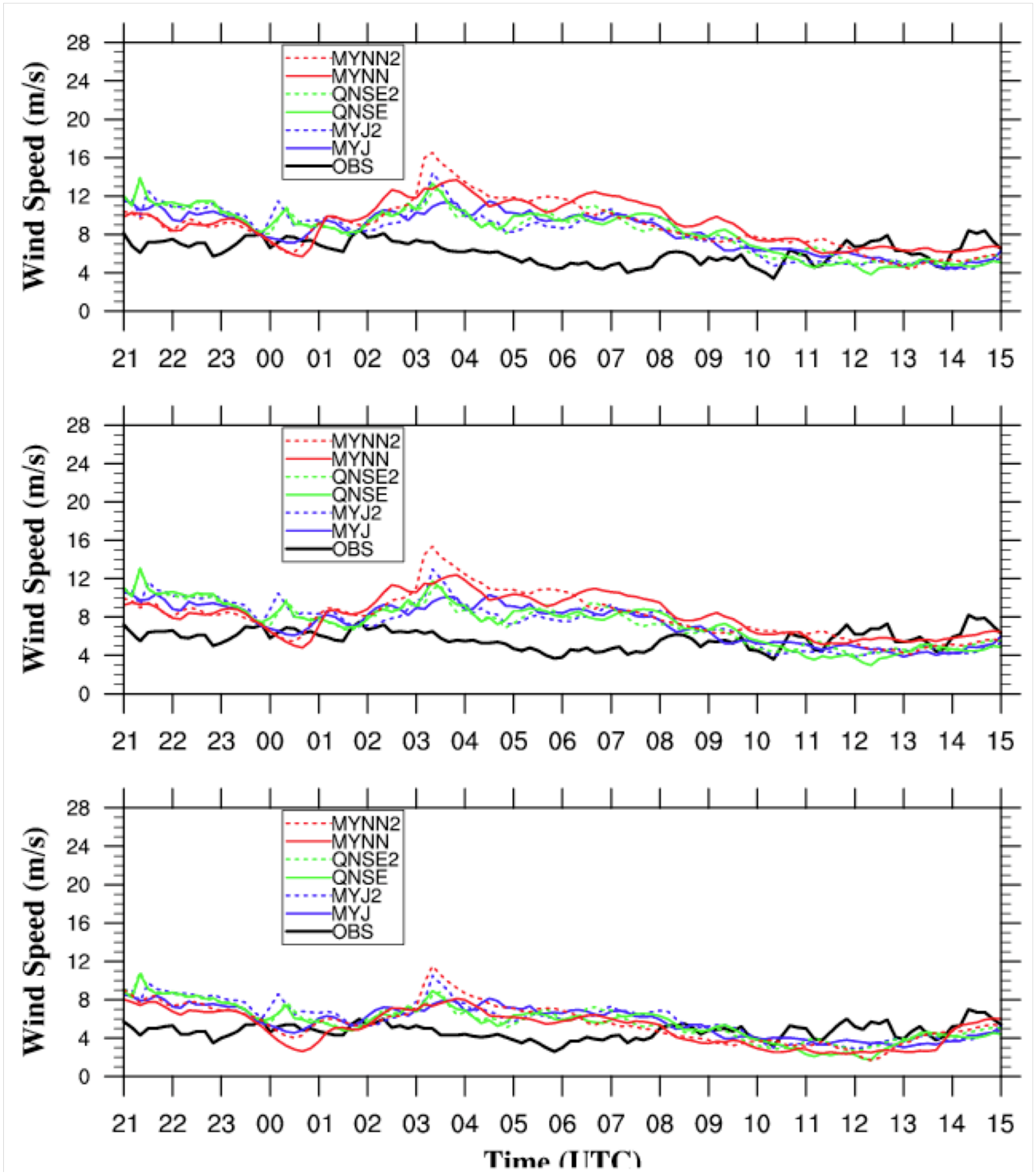


Wind Speed Verification (N. Missouri)

50 m

30 m

10 m



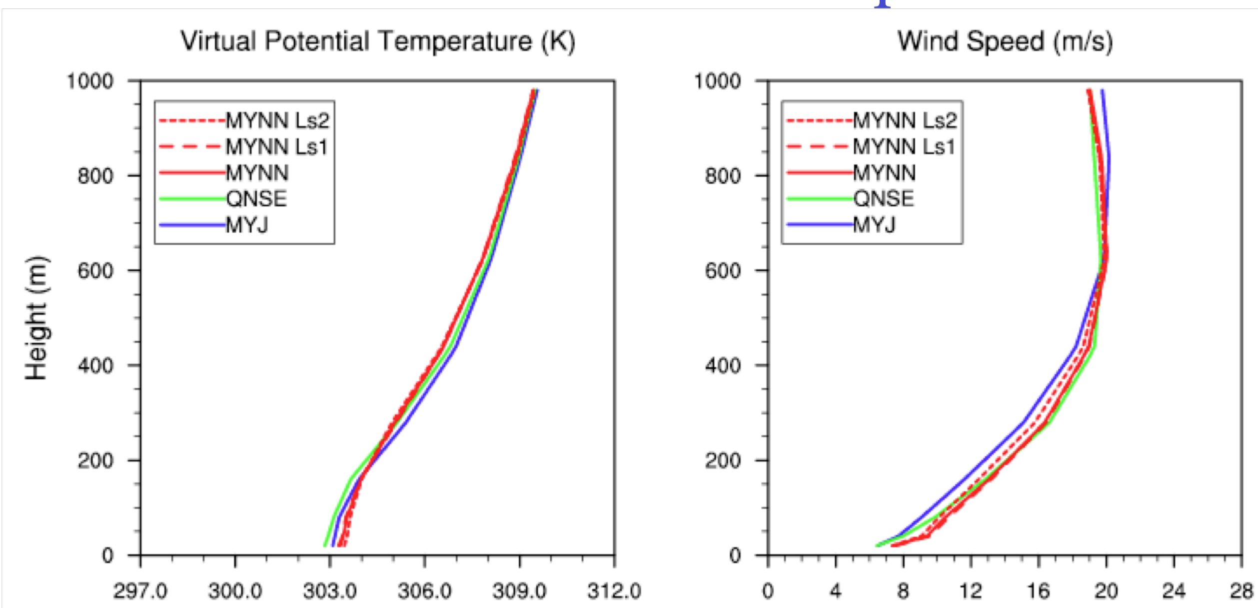
- The QNSE and MYJ gives the best results at 30 and 50-m.
- All simulations behave more similarly at 10-m.
- The MYNN best captures the morning transition at 30 and 50 m.

Summary

- All TKE-based schemes simulate a strong LLJ with large positive wind speed biases compared to wind tower data.
- The LLJ in the MYNN was typically stronger and deeper but decayed earlier due to a more rapid deepening of the PBL in the morning hours.
- The 30 and 50 m wind speeds were best simulated by the MYJ near the LLJ max, but the QNSE performed the best at 10 m.
- The simulations with double vertical resolution resulted in lower-altitude wind-speed maxima and more rapid building of the daytime PBL.

Future work

- Use profiler data to verify upper portion of LLJ to get a more robust verification through the depth of the LLJ.
- Add the TEMF PBL scheme (*Mauritsen et al. 2007 and Angevine 2005*) to the test matrix of simulations.
- Run tests of different MYNN surface layer mixing length formulations to tune the low-level wind speeds.



Acknowledgements

Thanks to Iberdrola Renewables for sharing the wind tower data – especially Justin Sharp & Mike Zulauf.