Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

New developments in RAP/HRRR physical parameterizations: MYNN-EDMF and mixing length revision

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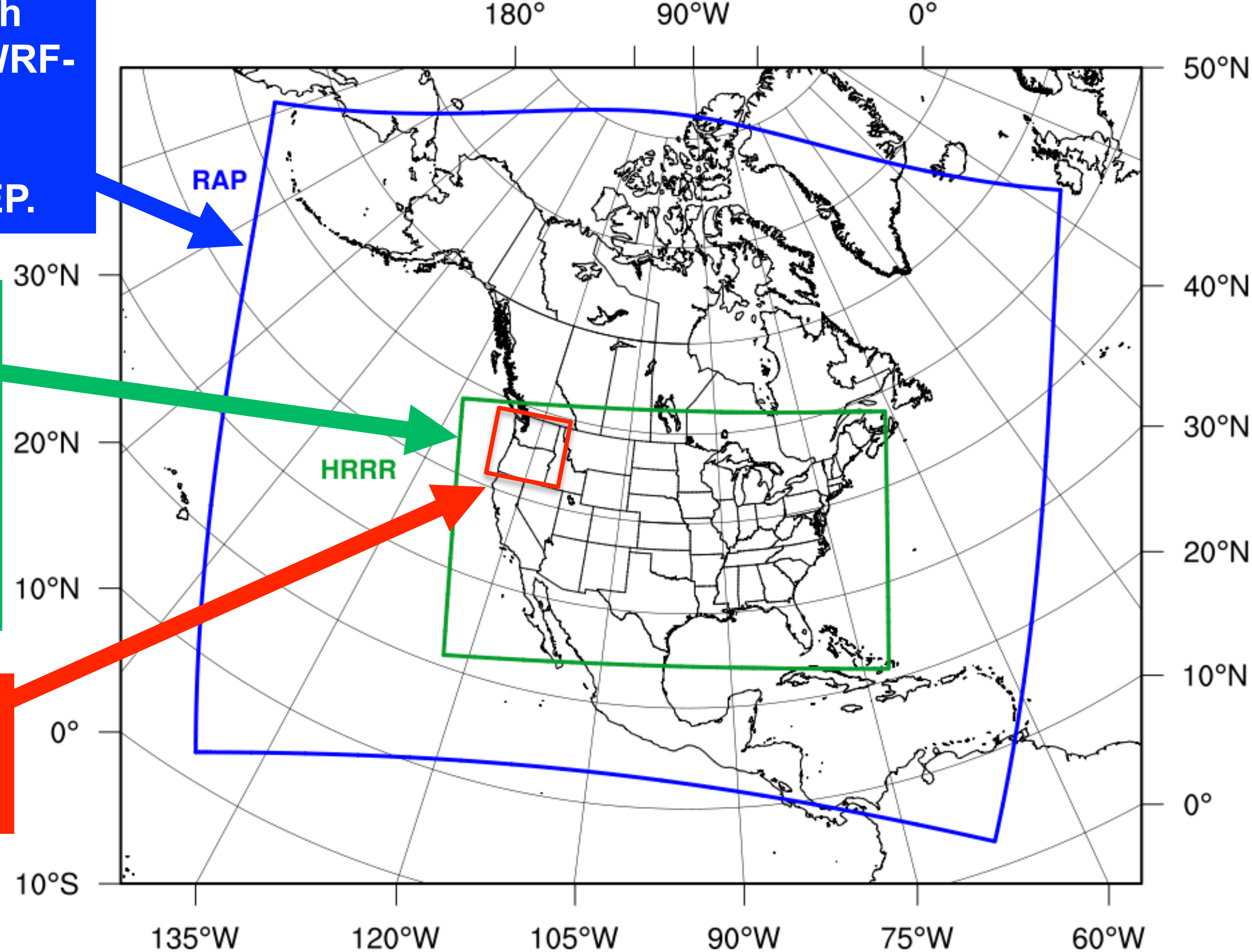
NWP Development at NOAA-ESRL

13 km Rapid Refresh (RAP) (mesoscale) – WRF-based with hourly updating. Runs operationally at NCEP.

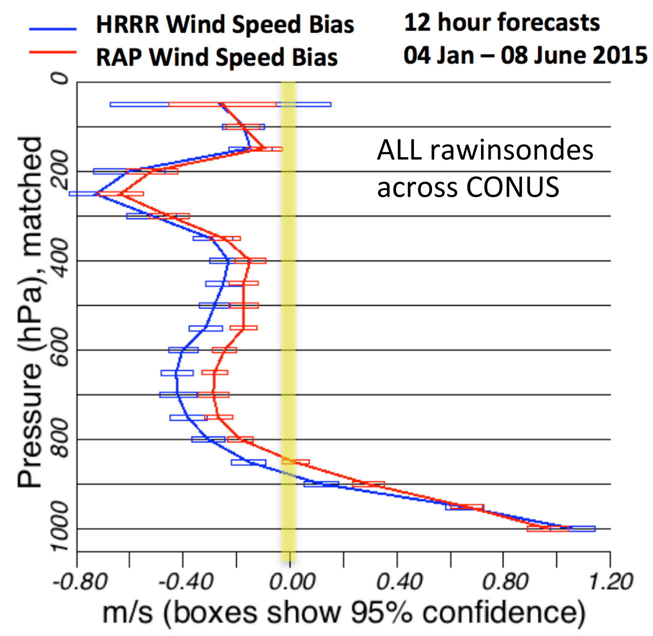
3km High-Resolution Rapid Refresh (HRRR) (storm-scale) – WRF-based with hourly updating. Runs operationally at NCEP (30 Sept 2014).

Experimental 750m nest for modeling complex flows (WFIP2)

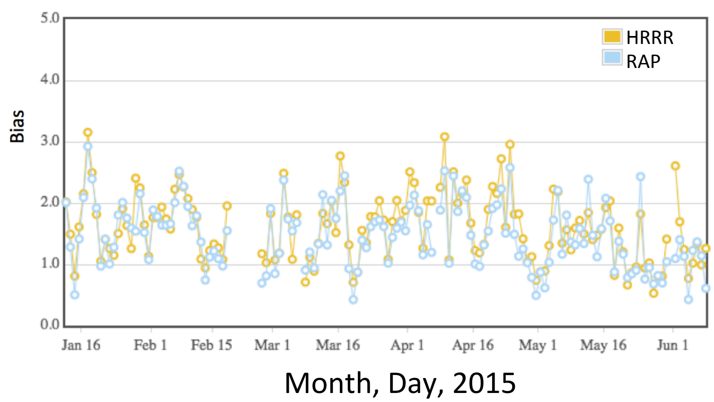


Motivation/Outline

1. **RAP/HRRR bias that is clearly related to PBL scheme.**
   - High wind speed bias in PBL.
     - Rawinsonde, aircraft, tower data
2. **Mixing length revision.**
   - Update length scales & blending procedure.
   - Make z-less.
   - Scale-aware (Ito et al. 2015, *BLM* and Honnert et al. 2011, *JAS*) – work for 13, 3, and 0.75 km grid spacing.
   - Cloud-specific mixing length.
3. **Eddy Diffusivity-Mass Flux (EDMF)**
   - Improve representation of nonlocal mixing.
   - Scale-aware (Honnert et al. 2011, *JAS*).
   - Investigate momentum transport.



Model	HRRR	RAP	12 hour forecasts (daily averages)
Mean Bias	1.65	1.52	All towers across Midwest



Original 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 stability parameter($\zeta = z/L$; L in the M-O length):

$$l_s = \begin{cases} kz(1+\mathrm{cns}\,\zeta)^{-1} & \text{if } 0 \le \zeta \le 1 \\ kz(1-100\,\zeta)^{0.2} & \text{if } \zeta < 0 \end{cases}$$

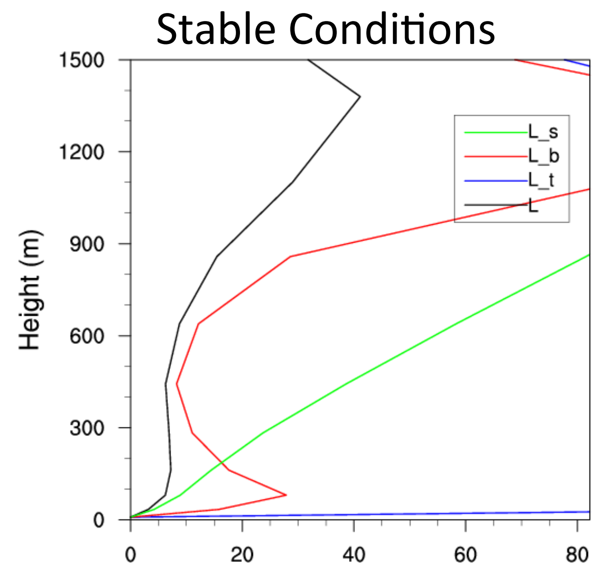
and the turbulent length scale l_t is:

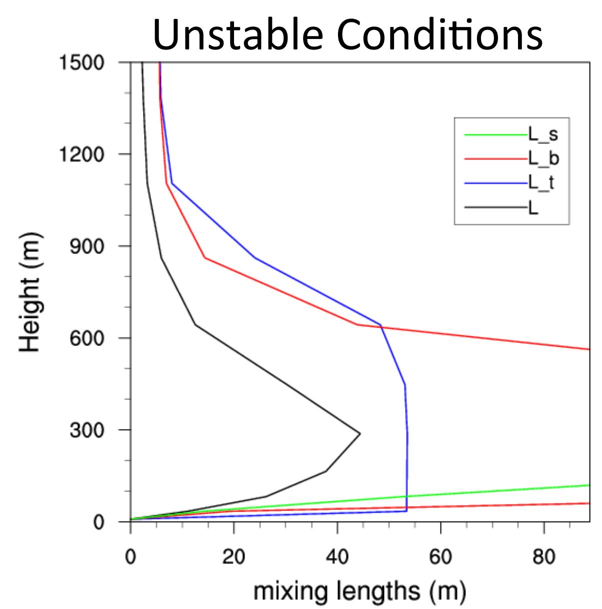
$$l_t = \alpha_1 \frac{\int_{z=0}^{PBLH} zq\,dz}{\int_{z=0}^{PBLH} q\,dz}$$

and the buoyancy length scale l_b is:

$$l_b = \alpha_2 \frac{q}{N}\left[1 + \alpha_3 \left(\frac{q_c}{l_t N}\right)^{1/2}\right]$$

where q_c is a turbulent velocity scale ~$O(w_*)$





Problems associated with this Formulation

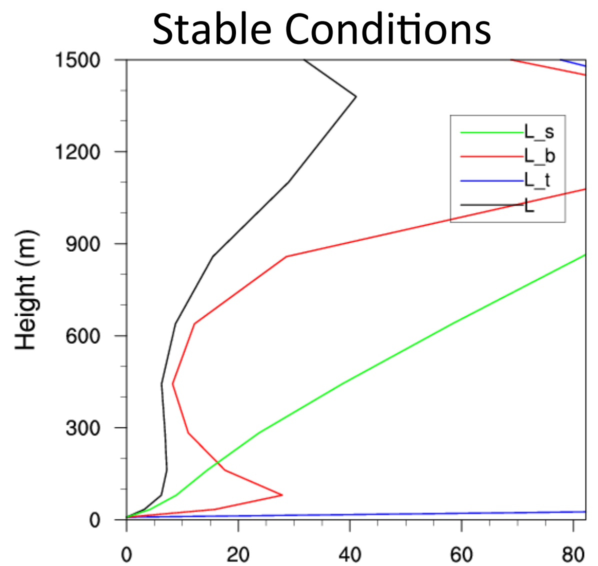
$$\frac{1}{l_m} = \frac{1}{l_s} + \frac{1}{l_t} + \frac{1}{l_b}$$

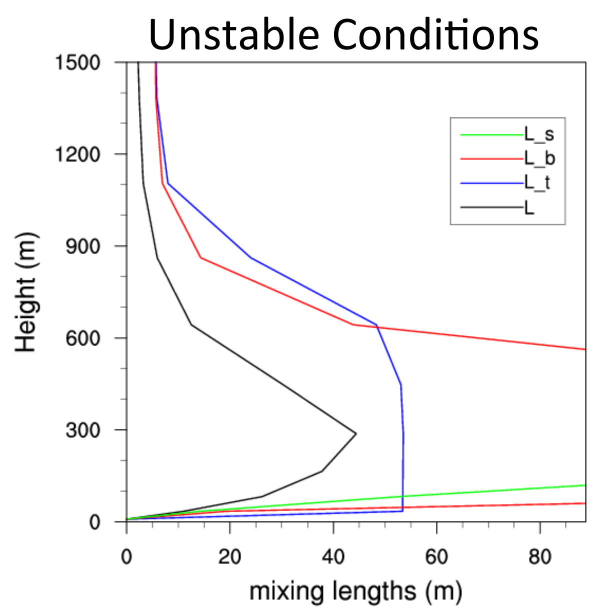
1. "Harmonic" averaging:
   a) The averaged mixing length is typically 20-40% smaller than the smallest length scale. This makes it very difficult to specify an exact mixing length needed in a given regime/part of atmosphere.
   b) Never completely z-less if a z-dependent length scale can significantly impact the averaged mixing length.

2. Numerical noise can arise from buoyancy enhancement factor in l_b.

$$l_b = \alpha_2 \frac{q}{N}\left[1 + \alpha_3\left(\frac{q_c}{l_t N}\right)^{1/2}\right]$$

3. Not scale-aware.





New MYNN Mixing Length Revision

1. All mixing length scales are defined to function specifically for their purpose.

The surface layer length scale l_s is defined the same way:

$$l_s = \begin{cases} kz(1+\mathrm{cns}\,\zeta)^{-1} & \text{if } 0 \le \zeta \le 1 \\ kz(1-\alpha_4\zeta)^{0.2} & \text{if } \zeta < 0 \end{cases}$$

The turbulent length scale l_t is also defined the same way:

$$l_t = \alpha_1 \frac{\int_{z=0}^{PBLH} zq\,dz}{\int_{z=0}^{PBLH} q\,dz}$$

but now, the buoyancy enhancement factor in the buoyancy length scale l_b is removed:

$$l_b = \alpha_2 \frac{q}{N}$$

where $q = \sqrt{(2\times\mathrm{TKE})}$ and N is the Brunt-Vaisala frequency.

Add a cloud-specific length scale l_c if clouds exist in grid cell, following Teixeira and Cheinet (2003, *BLM*):

$$l_c = \tau\sqrt{TKE}$$

where τ = 325 seconds.

In the free atmosphere, the “BouLac” length scale is retained (Bougeault and Lacarrere 1989, *MWR*).

New MYNN Mixing Length Revision (continued)

2. Define stable and unstable mixing lengths, using blending of *no more than two length scales*.

$$l_{stable} = (1 - w) l_s + w l_b$$

where w = z/h_s, h_s is height of surface layer (= 0.2×PBLH).

$$l_{unstable} = \frac{l_s}{1 + l_s / l_t}$$

3. Then the minimum is taken to get a mixing length for the PBL:

$$l = \text{MIN}(l_{stable}, l_{unstable})$$

4. Blend the PBL mixing length with the free-atmospheric mixing length:

$$l = (1 - w) l + w l_{BouLac} \qquad \text{where } w = \tanh\left[\frac{z - 1.3 \times PBLH}{0.15 \times PBLH}\right]$$

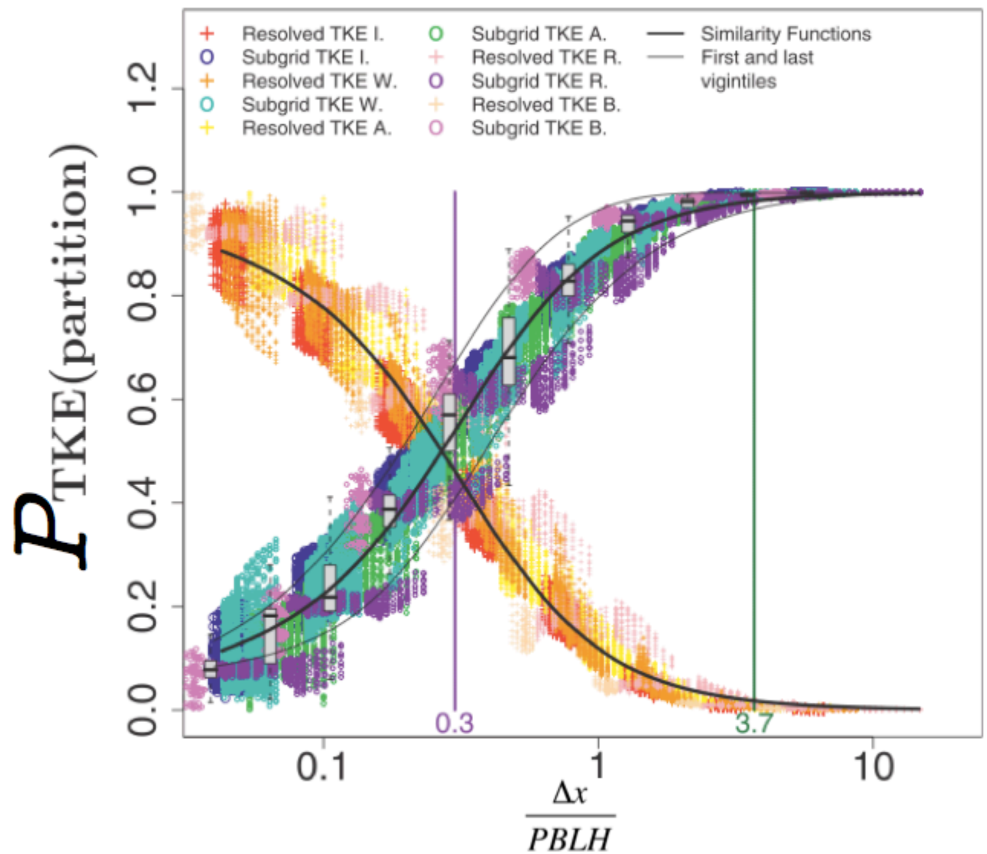
5. Subsequent adjustment of mixing length parameters: α_2 (for l_b), α_4 (for l_s), "*cns*" (for l_s), and possibly α_1 (for l_t).

New MYNN Mixing Length Revision (continued)

6. Add scale-aware functionality, following Ito et al. (2015, *BLM, accepted*), using the similarity functions of Honnert et al. (2011, *JAS*).

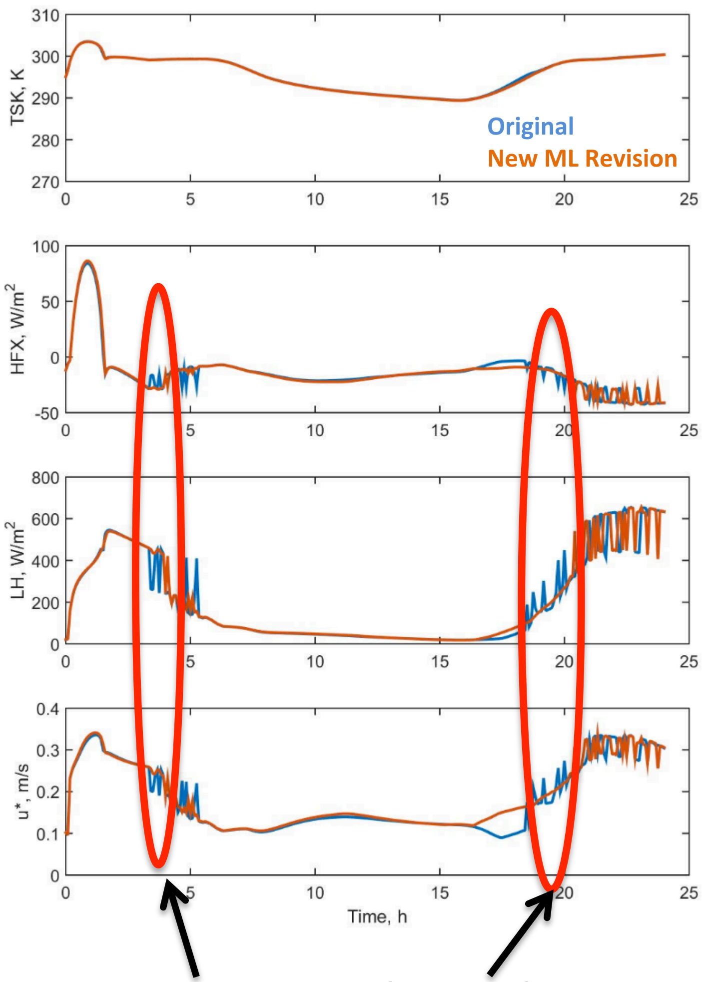
$$l \;\; = l \times P_{TKE}$$

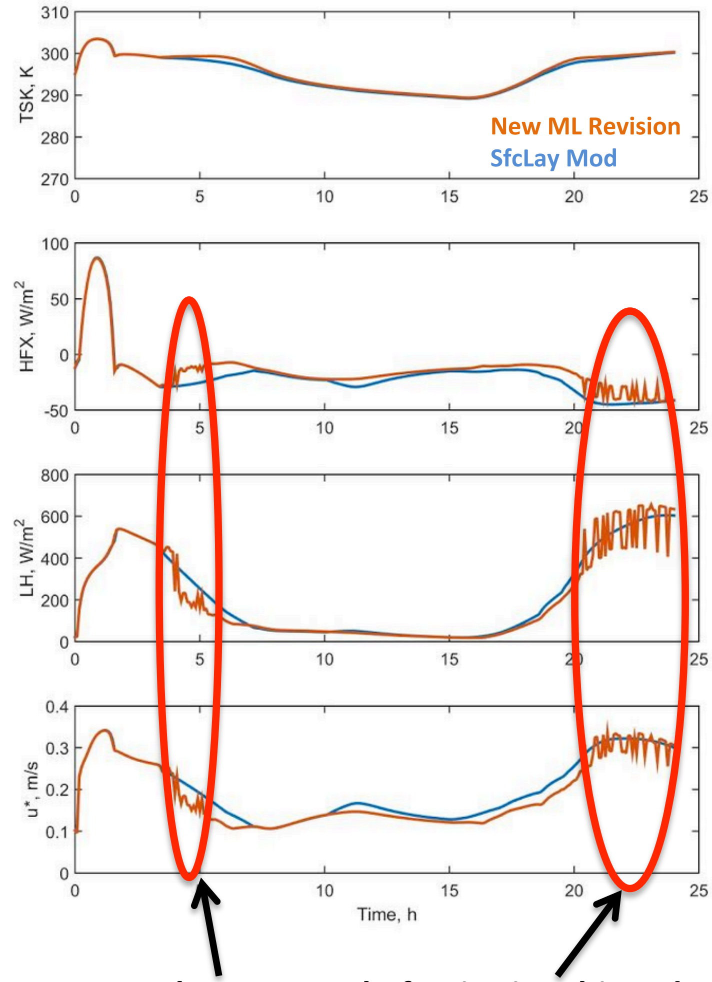
Where P_{TKE} is a function of the model grid spacing Δx and boundary layer height, PBLH.



Adapted from Honnert et al. (2011, JAS). Non-dimensional similarity function for TKE within the boundary layer

Results: Alleviating Noise from GABLS3 SCM



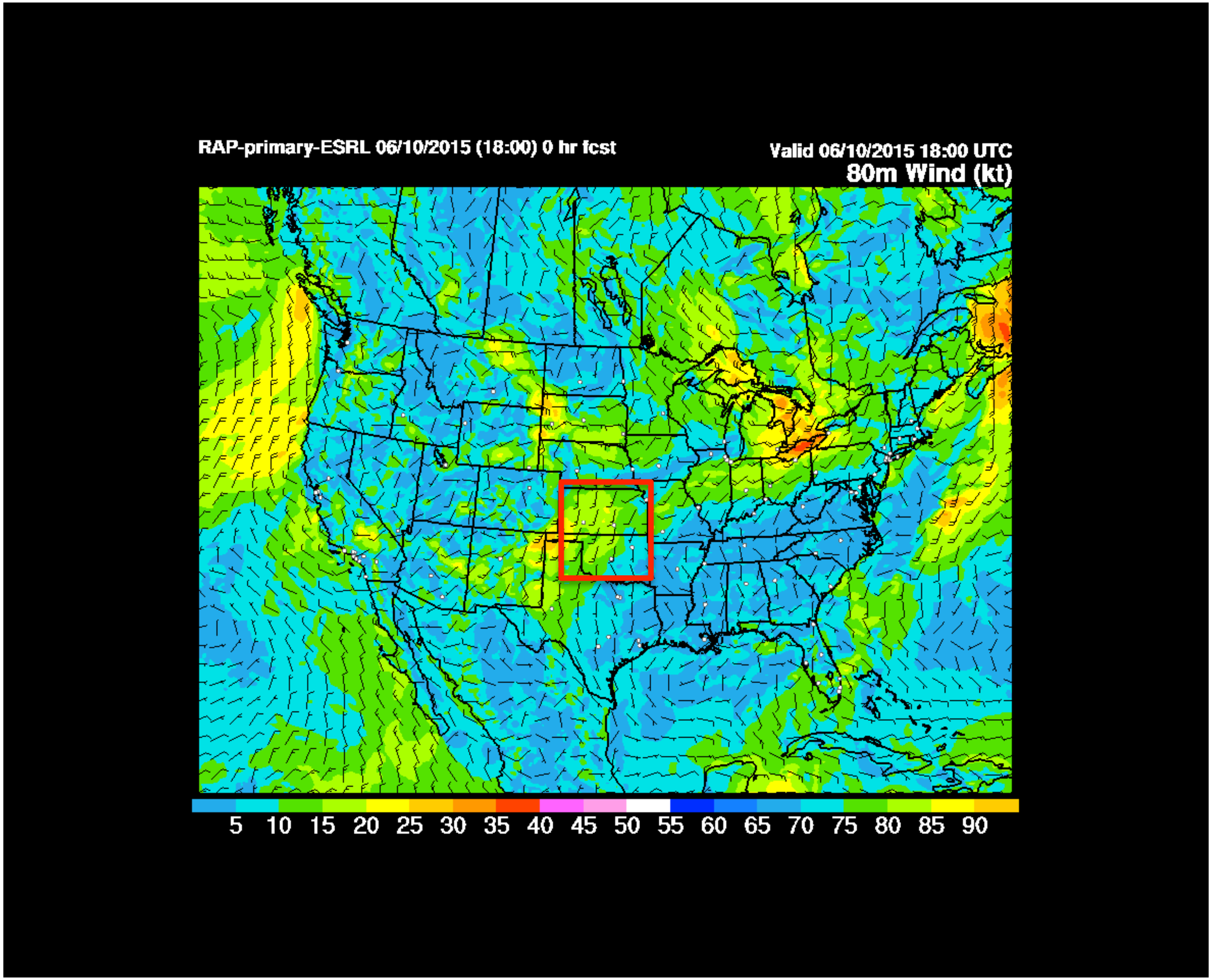


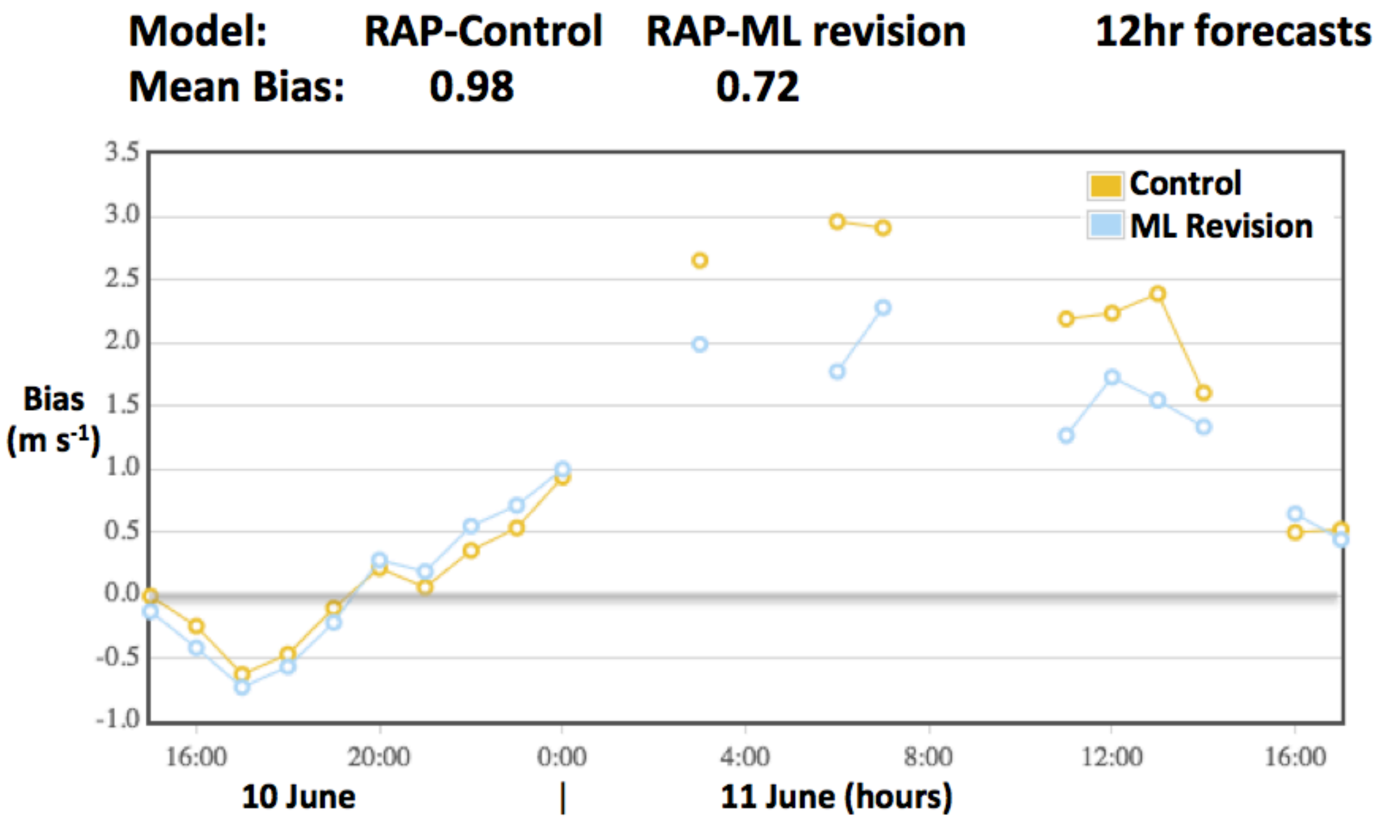
ML revision reduces and delays the onset of noise

Complete removal of noise is achieved by further sfc layer scheme mods.

Tests performed by Wayne Angevine (NOAA/ESRL/CSD). 01 July 2006 over Cabauw, Ned. Fully interactive radiation and LSM, advection terms are prescribed. Credit Hugo Hartmann also for making us aware of a different, but somewhat related, instability in the unstable regime (improved upon but not fully resolved).

Case Study: Strong LLJ





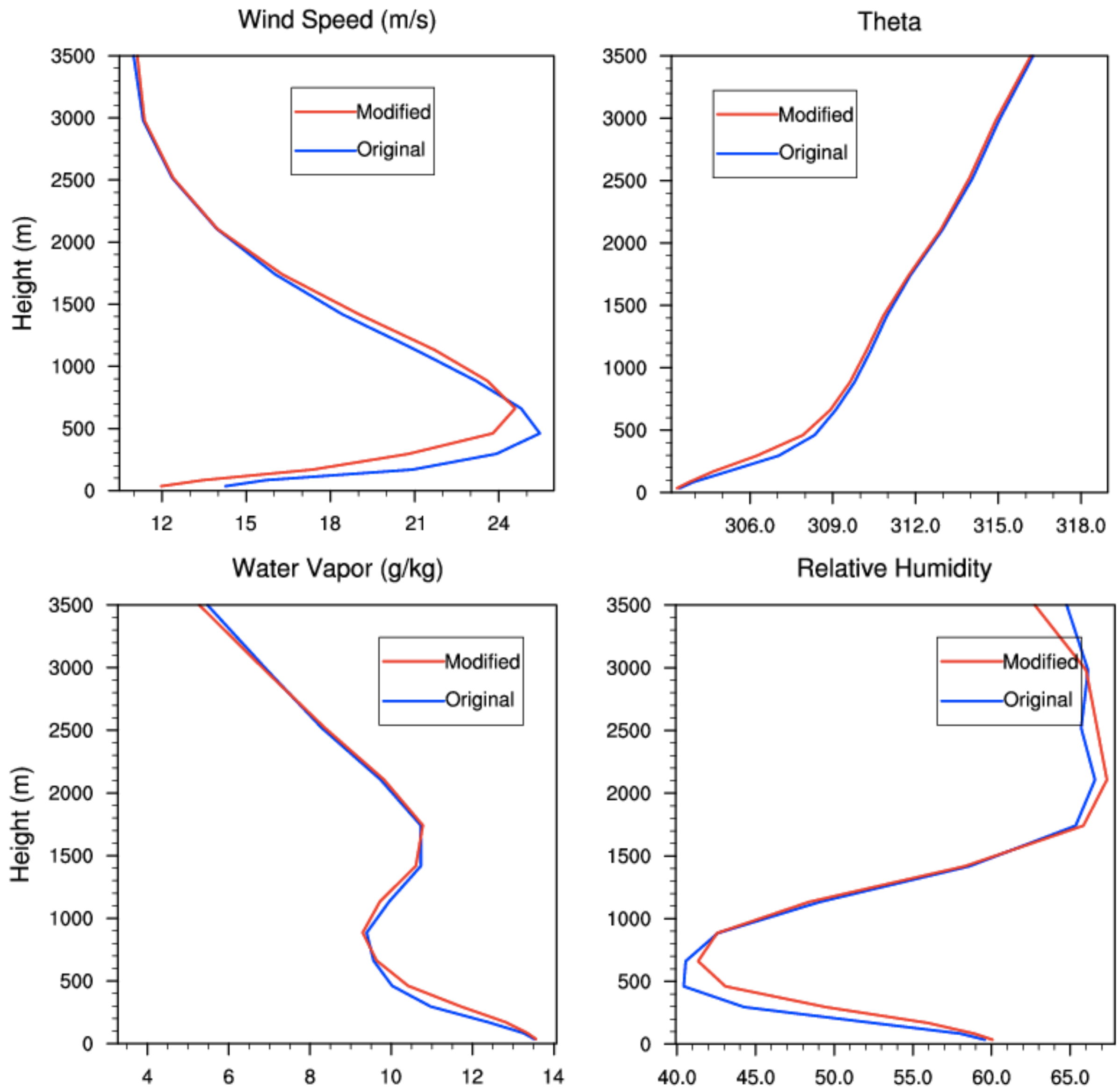
Validated against 28 towers in southern Great Plains, only using data at heights > 70 m.

- The RAP-Control is very high-biased in strong LLJ conditions.
- The revised mixing lengths reduces the wind speed bias by ~0.5 m s-1 near hub-heights.
- Very little difference during the day.

Mean Profile Comparisons

Mean Profiles over the LLJ region (Kansas) between 06-08 UTC 11 June 2015.

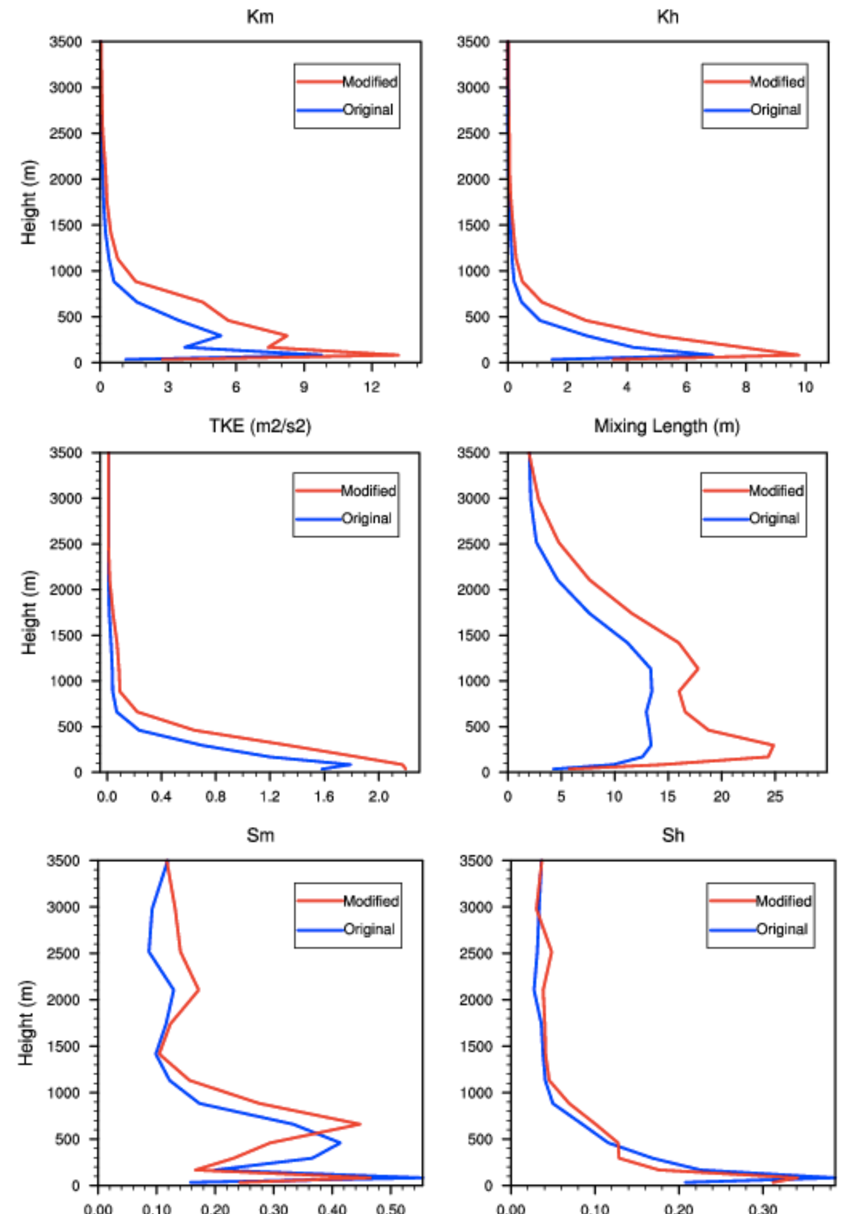
- The revised mixing length reduces the wind speeds by ~2 m s^{-1} below the LJJ max.
- The revised mixing length reduces the LLJ max by ~1 m s^{-1} and elevates it ~150 m



Eddy Diffusivity/Viscosity

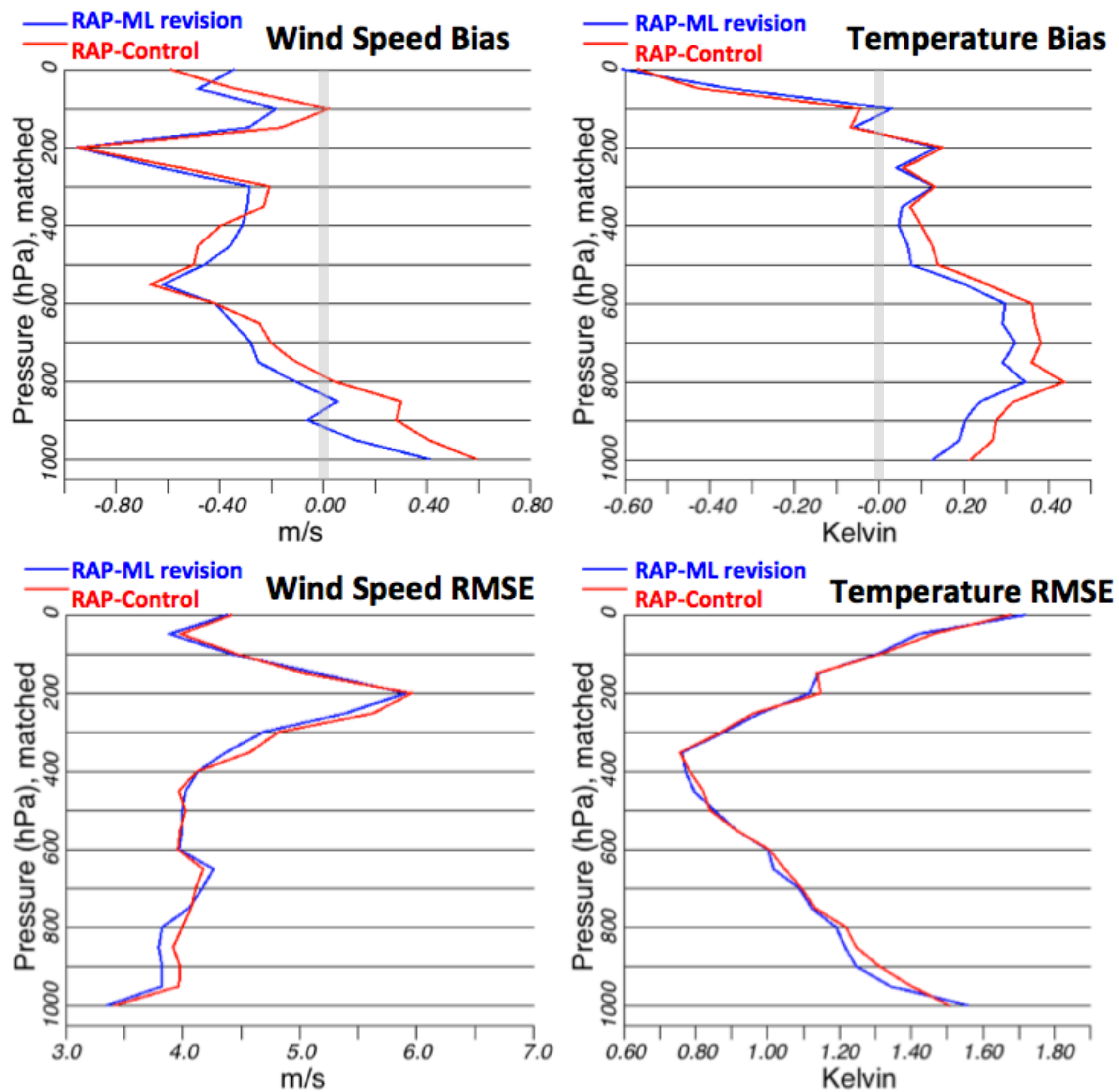
$$K_{\phi} = S_{\phi} (2*TKE)^{1/2} l_m$$

- The revised eddy diffusivities/viscosities are much larger (by 25-50%) at night (much smaller difference during the day – not shown).
- The %-difference of mixing length is largest below the height of the LLJ max.
- Double-maxima in mixing length profile seems more appropriate for the shear layers above/below the LLJ.



Model Validation: Rawindsonde

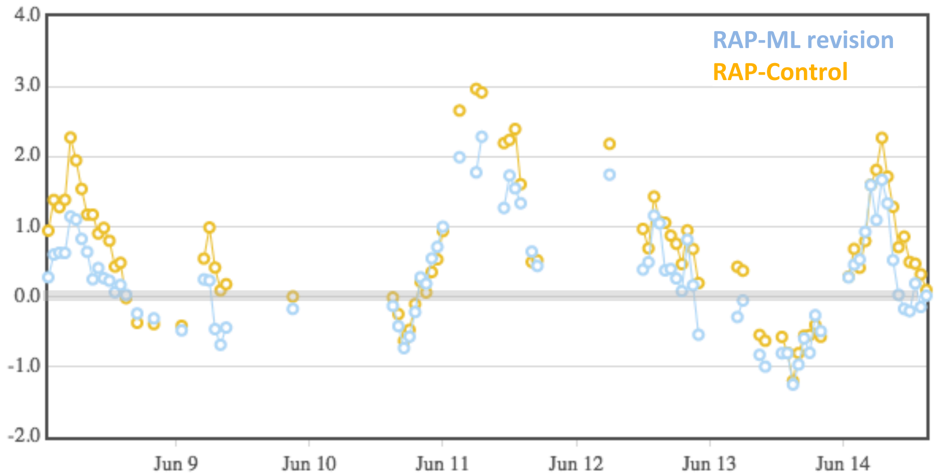
12 hr fcsts compared to soundings across E-CONUS, 00 and 12 Z between 08-15 June 2015



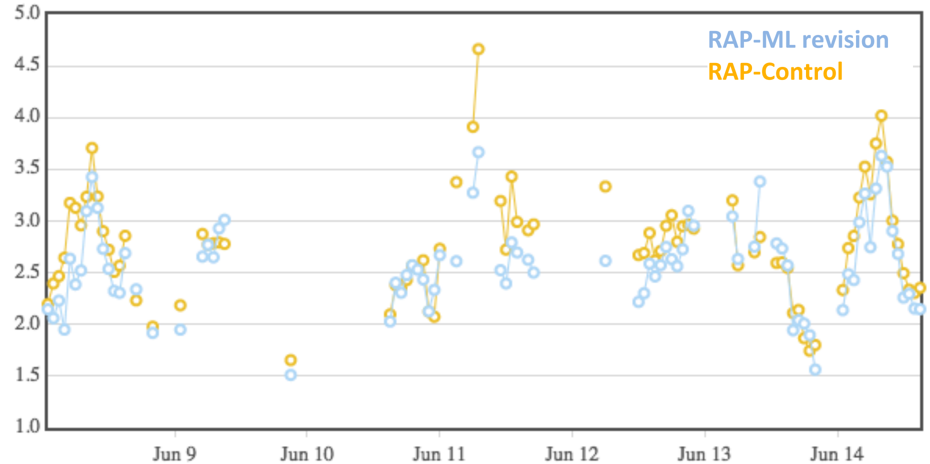
Model Validation: Towers (>70m)

12 hr fcsts compared to 37 towers across Midwest, between 08-15 June 2015

Model:	RAP-Control	RAP-ML revision
Bias:	0.68	0.30



Model:	RAP-Control	RAP-ML revision
MAE:	2.76	2.57



MYNN-EDMF

Improving the non-local transport in the MYNN PBL scheme by adding a mass-flux component.

Questions:

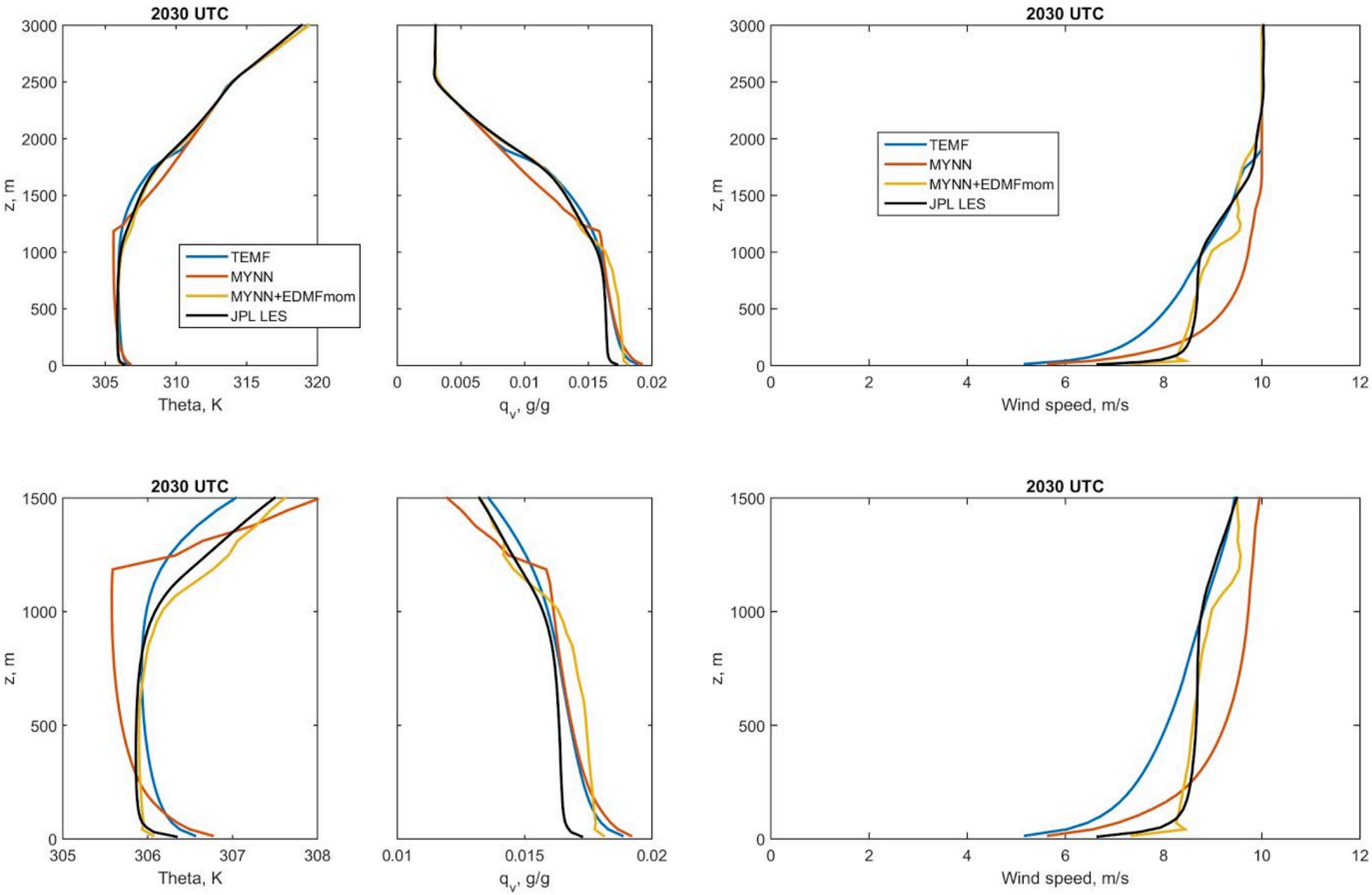
1) Can adding non-local transport to a local scheme that is designed to be more diffusive (in order to compensate) improve forecast skill?
2) What components of the mass-flux scheme are necessary to best fit in the RAP/HRRR framework (multi-parcel, stochastic entrainment/detrainment rates, momentum transport, ensemble of closures, etc.)?

Plan to incorporate 3 different mass-flux schemes into MYNN and determine the best combination of features (not a bake-off of individual mass-flux schemes):

1) Grell-Frietas-Olson scheme (NOAA-ERSL/GSD). Ensemble of closures, partially scale-aware.
2) TEMF (Wayne Angevine, NOAA-ESRL/CSD). Momentum transport, most tested, simplest.
3) StEM (Kay Suselj, Joao Teixeira, NASA-JPL). Multi-parcel, stochastic, with momentum transport, and partially scale-aware.

MYNN-EDMF

Preliminary SCM results from ARM case (21 June 2006), testing MYNN-EDMF with NASA-JPL's StEM scheme with momentum transport activated.



Credit Wayne Angevine (NOAA-ESRL/CSD) for running the SCM tests, Kay Suselj (NASA JPL) for providing mass-flux code, and Georgios Matheou (NASA JPL) for LES output.

Summary

- **Mixing length revision improves RAP/HRRR biases.**
  - Reduces high nighttime wind speed bias in PBL.
  - Improves high daytime temperature bias in PBL.
  - Reduces noise found in idealized SCM case.
- **New mixing length parameter estimation in progress.**
  - WFIP1 & WFIP2 data will be used to determine final configuration.
- **Promising SCM test results for MYNN-EDMF.**
  - Future work will test various components of different mass-flux schemes in an attempt to develop a "best fit" mass-flux companion for MYNN.