Uncertainties in planetary boundary layer schemes and current status of urban boundary layer simulations at OU

Xiaoming Hu

September 16th @ 3:00 PM, NWC 5600

Contributors:

Fuqing Zhang, Pennsylvania State Univ

John W. Nielsen-Gammon, Texas A&M Univ

- Part 1: Evaluate three PBL schemes in the WRF model
- Part 2: Improve a PBL scheme through EnKF parameter estimation
- Part 3: Current status of urban BL simulations at OU

Part 1: Evaluate three PBL schemes in the WRF model

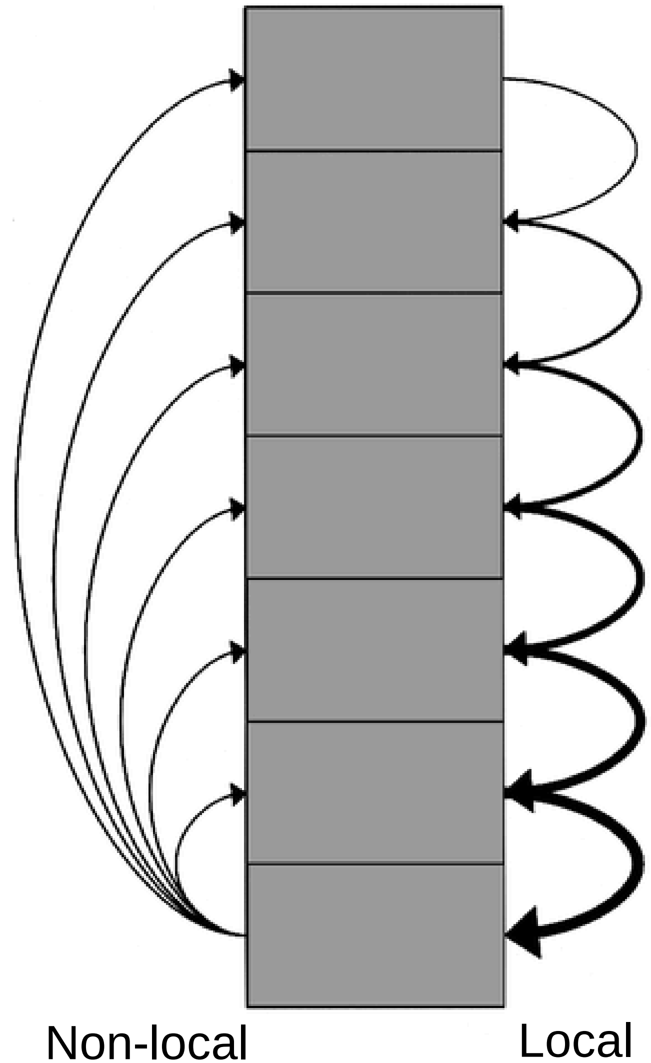
Importance of PBL schemes

- The accuracy of the PBL scheme is critical for forecasts of local thermally driven flows and air quality while it also affects forecasts of larger-scale meteorological phenomena (Hacker and Snyder, 2005)

Three PBL schemes in WRF
MYJ, YSU, ACM2

- MYJ: local, down gradient

- YSU, ACM2: local+non-local
  (YSU implicit,
  ACM2 explicit)



YSU: the Yonsei University scheme
MYJ: the Mellor–Yamada–Janjic scheme
ACM2: the asymmetric convective model scheme, v2

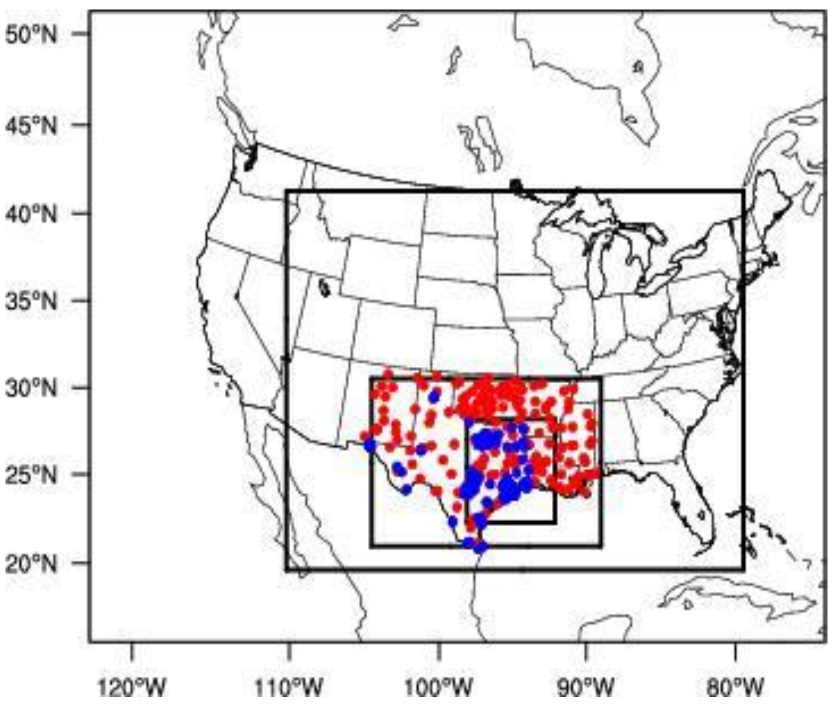
Configurations

Episode & Resolution

- Period: July – Sept., 2005
- Resolution: 108km, 36km, 12km, 4km
- Grids: 53×43, 97×76, 145×100, 166×184

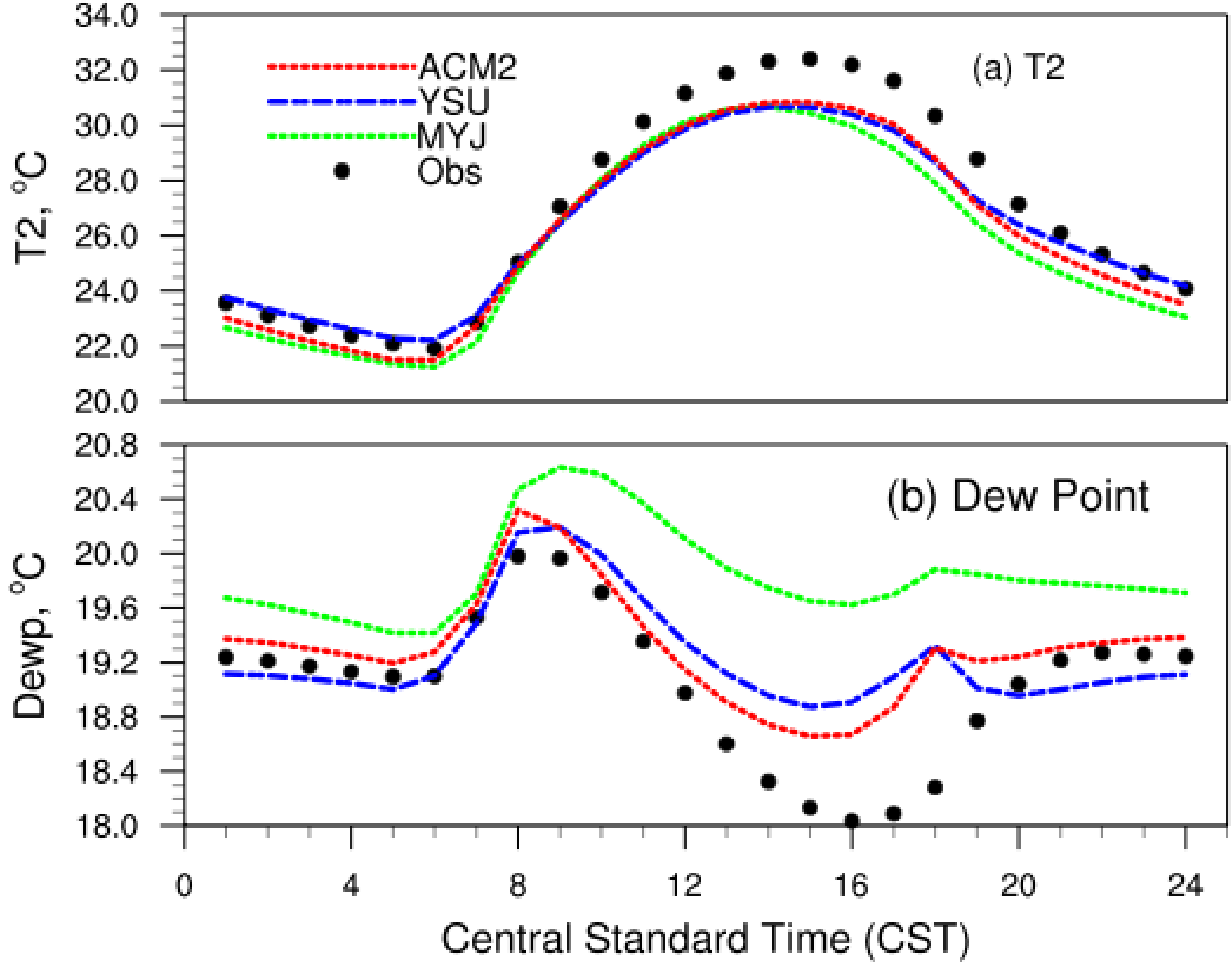
Model Configurations

- YSU, ACM2, MYJ PBL schemes
- WSM 6-class graupel scheme
- NOAH land-surface model (LSM)
- Dudhia short wave radiation
- RRTM long wave radiation
- Grell-Devenyi ensemble cumulus scheme



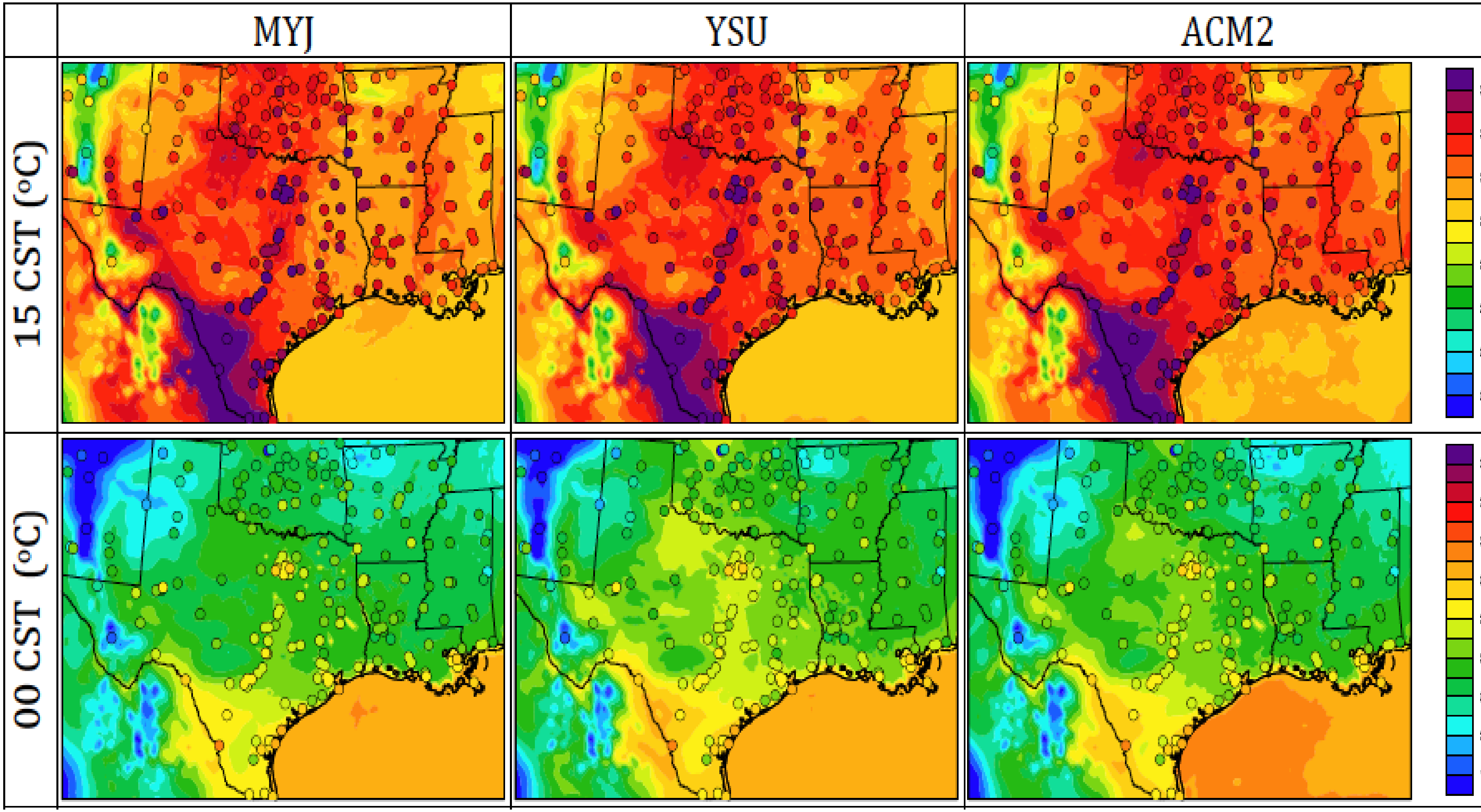
Domains and TCEQ, NWS/FAA sites

Mean T2 and dew point over 211 NWS/FAA sites



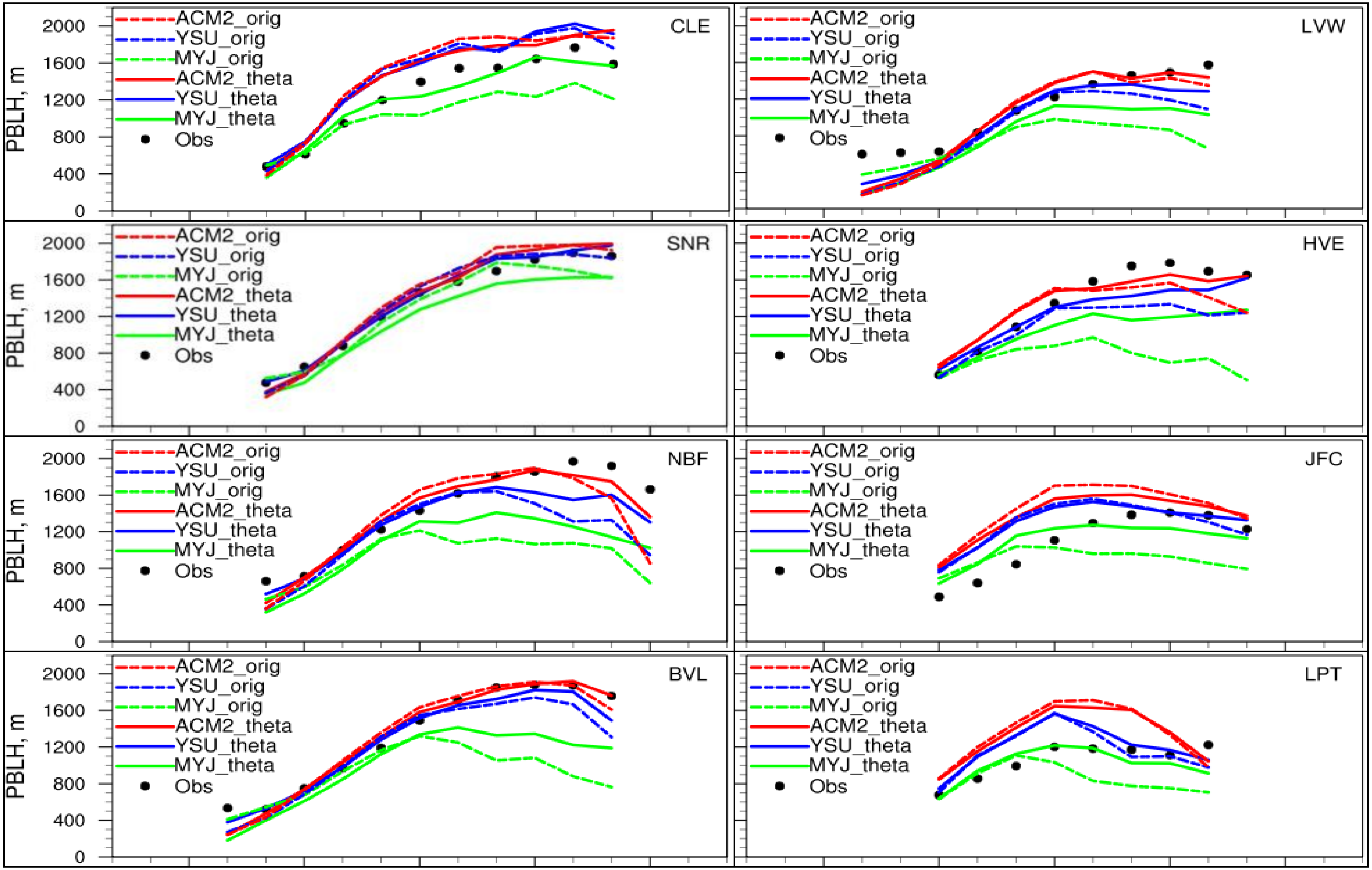
MYJ gives the coldest and moistest biases near the surface

Mean T2 at 15 and 00 CST



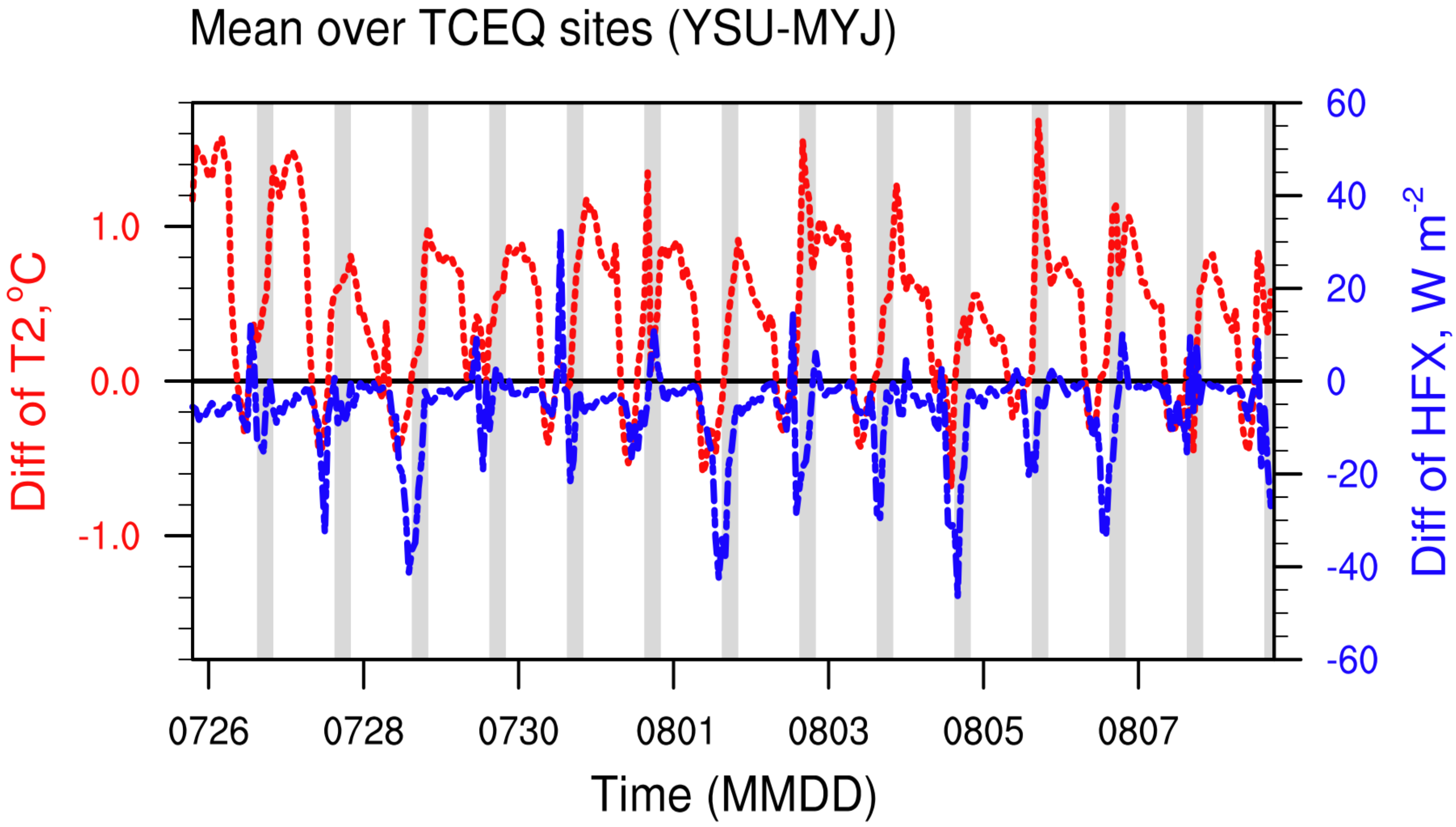
The model captures the spatial variation of temperature,
but MYJ predicts the lowest temperature near the surface

Mean PBL Height



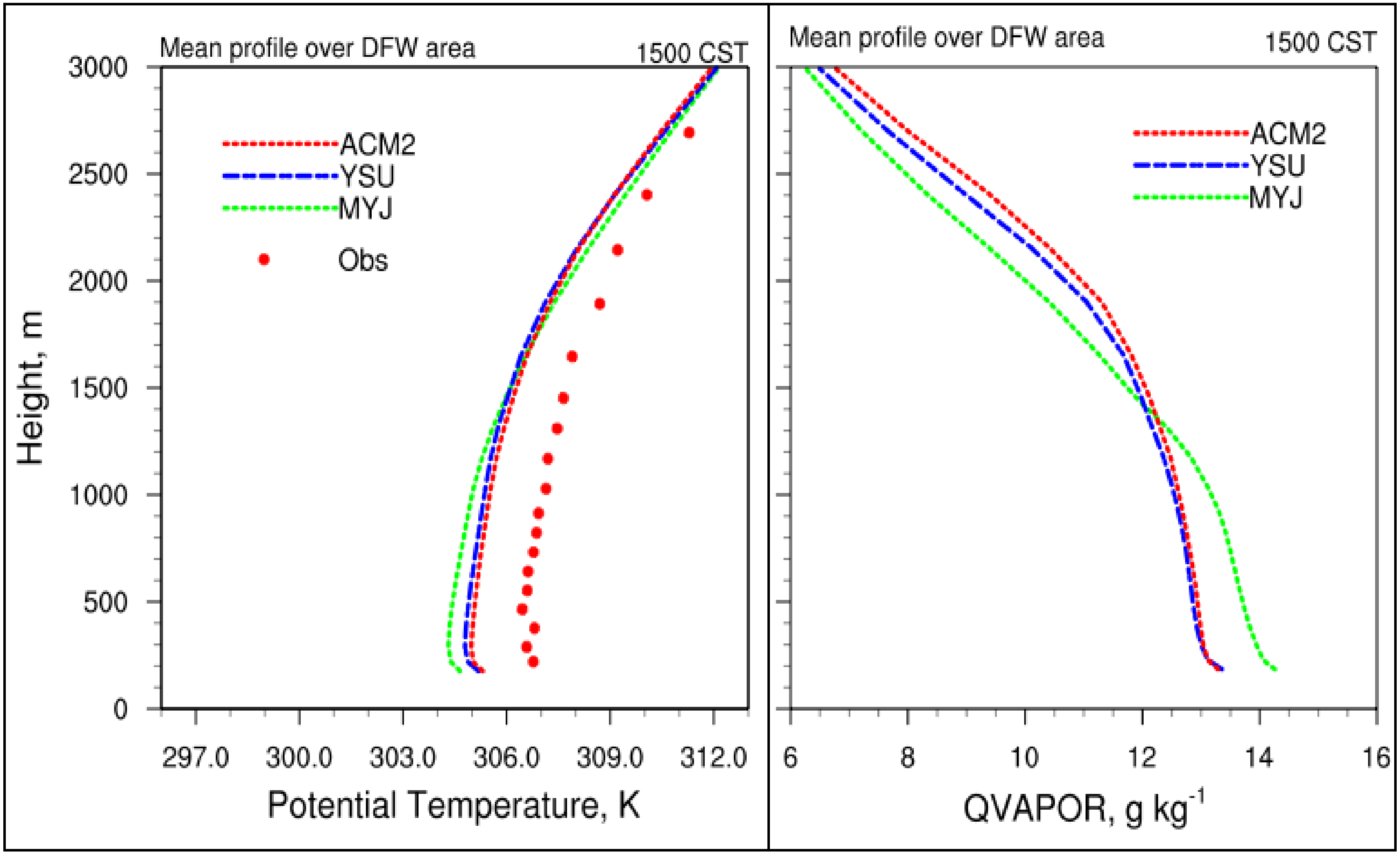
MYJ underpredicts PBL height over most sites

Difference of T2 and HFX between simulations with YSU and MYJ



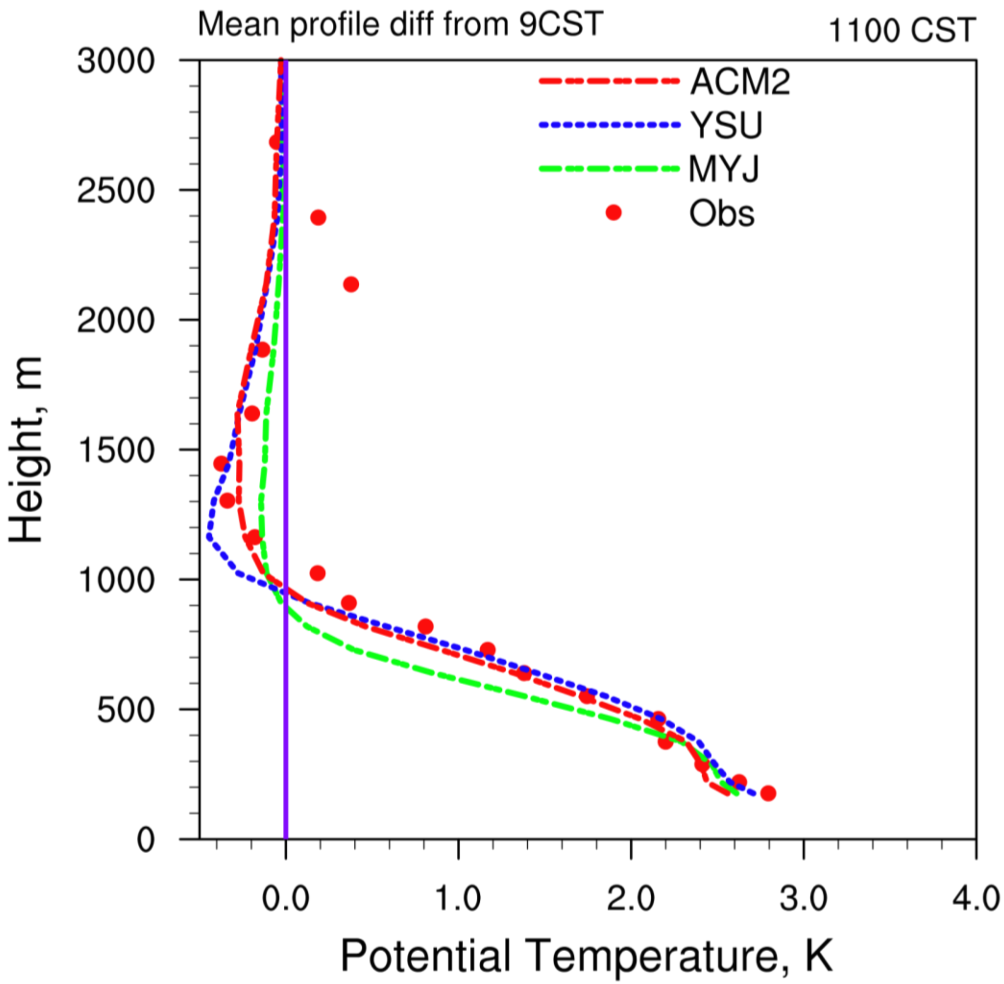
Difference of sensible heat flux (HFX) cannot explain difference of T2

Mean profiles of T and moisture



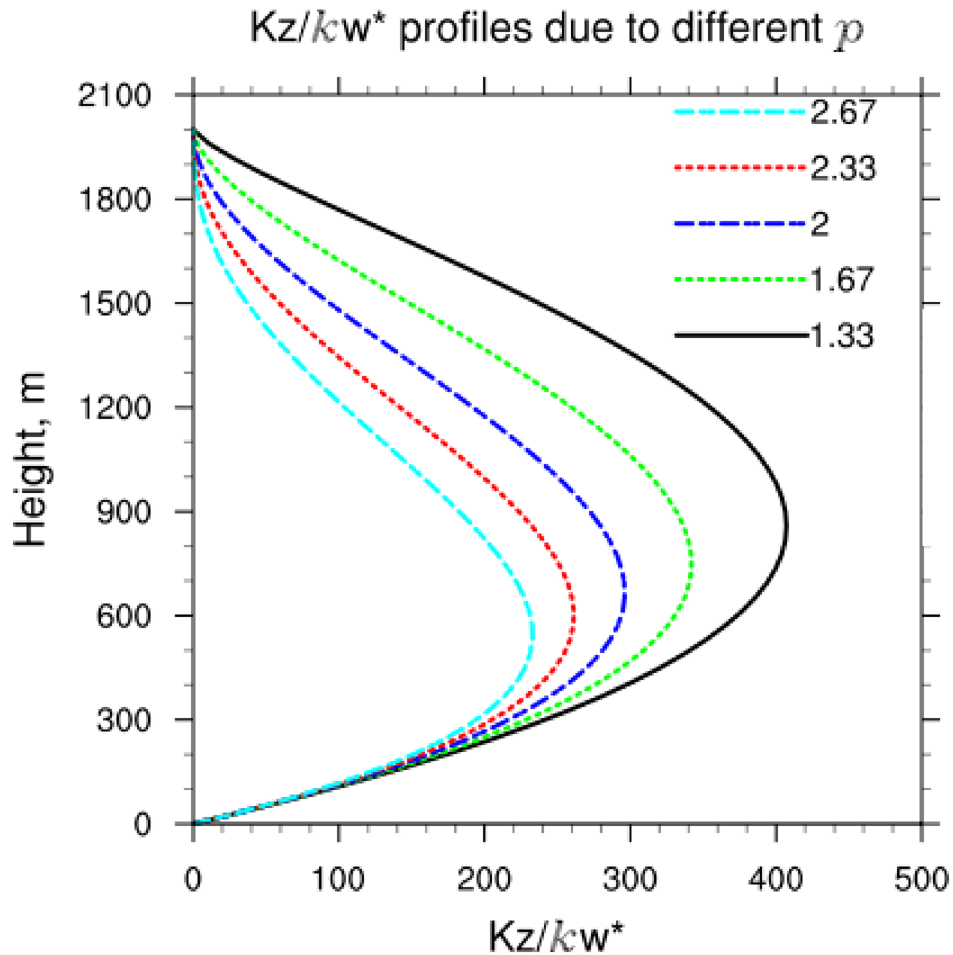
MYJ doesn't mix as high as YSU and ACM2 during daytime

Mean temperature profile difference from 9 CST at 11 CST



MYJ underestimates entrainment fluxes.

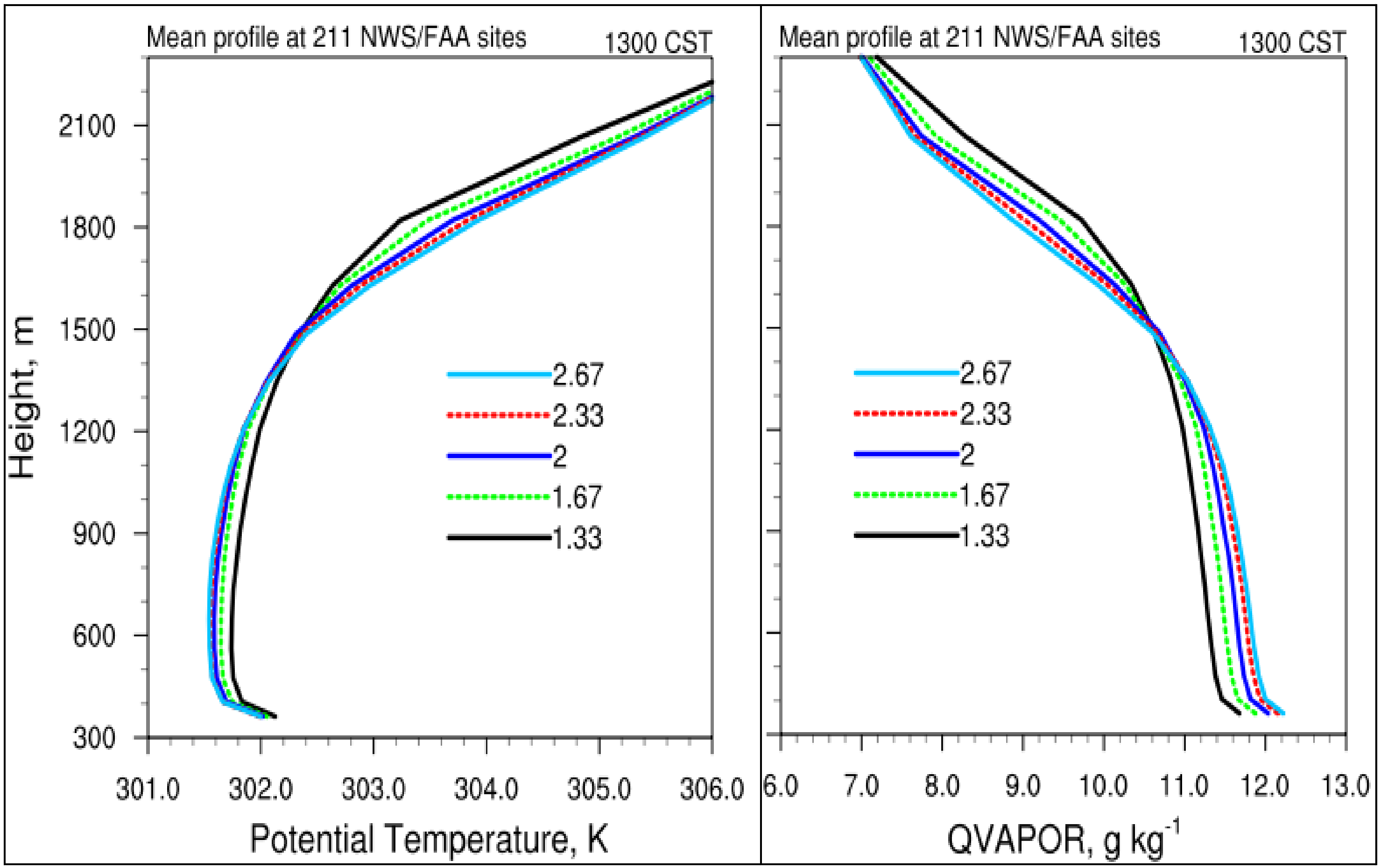
Normalized Kz profile due to different *p*



$$K_z(z) = k\frac{u_*}{\phi}z(1 - z/h)^p$$

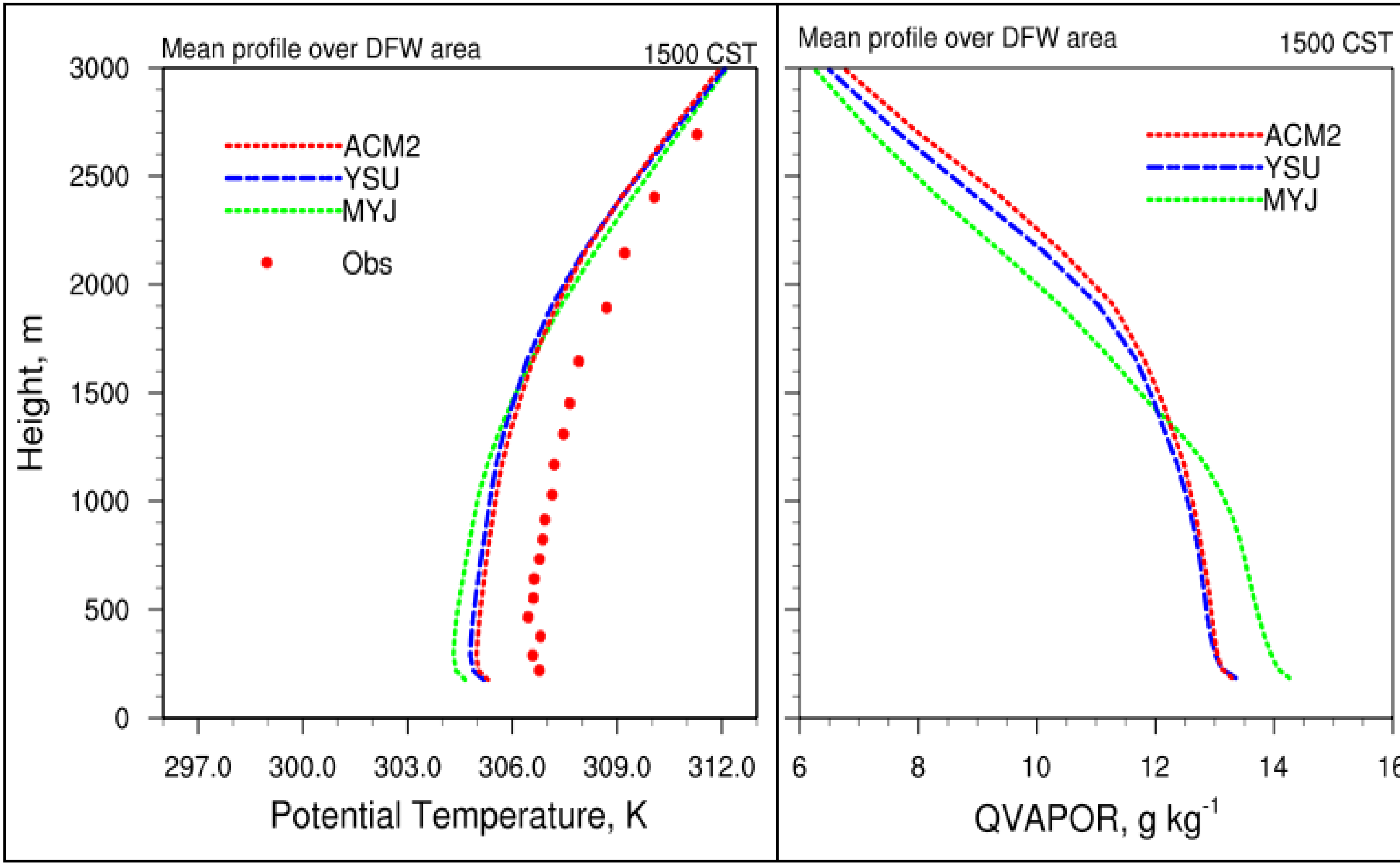
p controls the local vertical mixing coefficient in ACM2 PBL scheme

Mean profile of T and QVAPOR from runs with altered *p*



The similarity between the sensitivity of WRF to varied mixing strength and the sensitivity of WRF to different PBL schemes confirms that much of the sensitivity of WRF to different PBL schemes is attributable to their different vertical mixing strengths.

Mean profiles of T and moisture



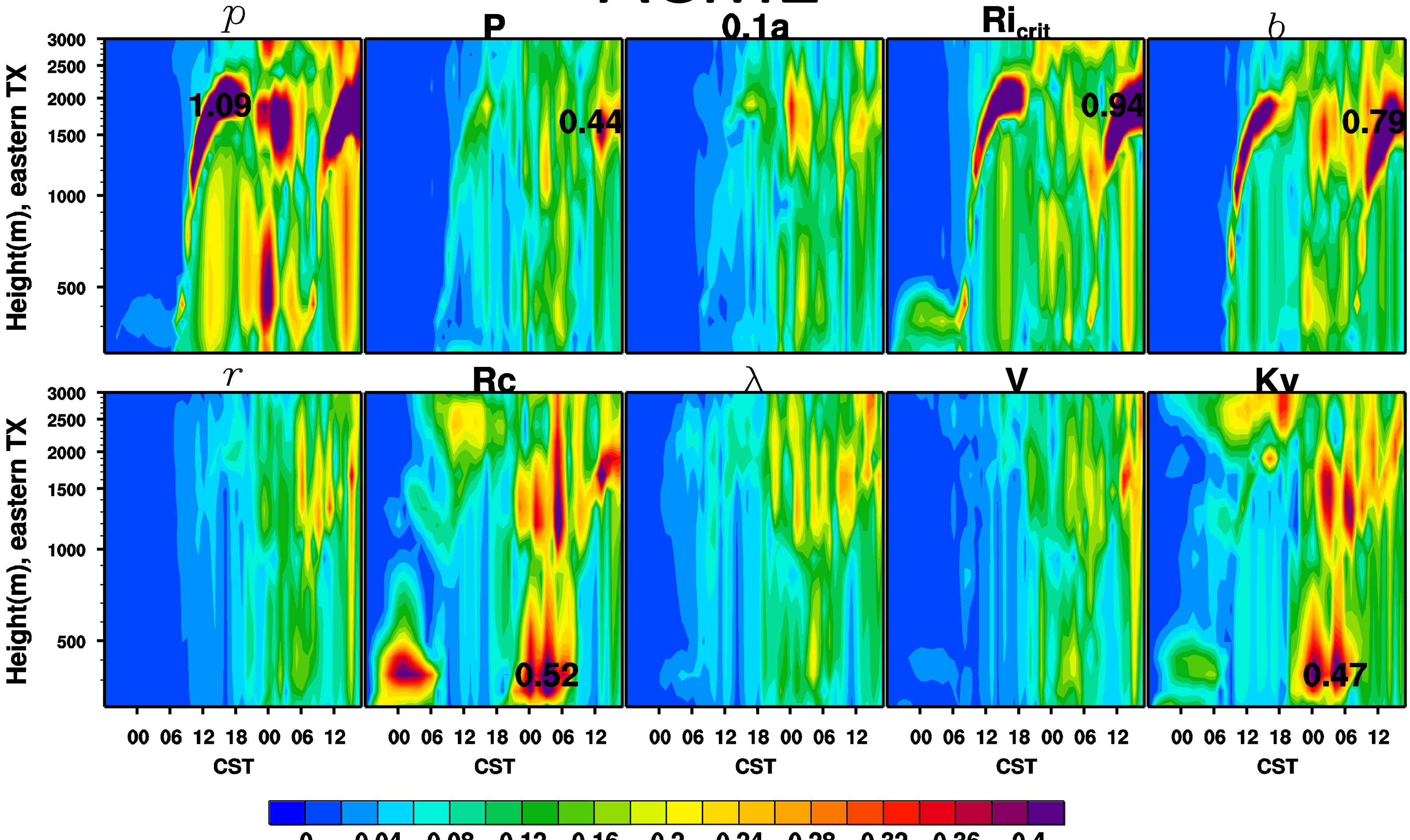
MYJ doesn’t mix as high as YSU and ACM2 during daytime

Conclusions

1. The YSU and ACM2 schemes both tend to predict higher T and lower moisture, and thus smaller biases, than the MYJ scheme in the lower atmosphere during daytime because of their stronger vertical mixing.
2. The above conclusion is verified by the experiments with the WRF model with altered vertical mixing strength.

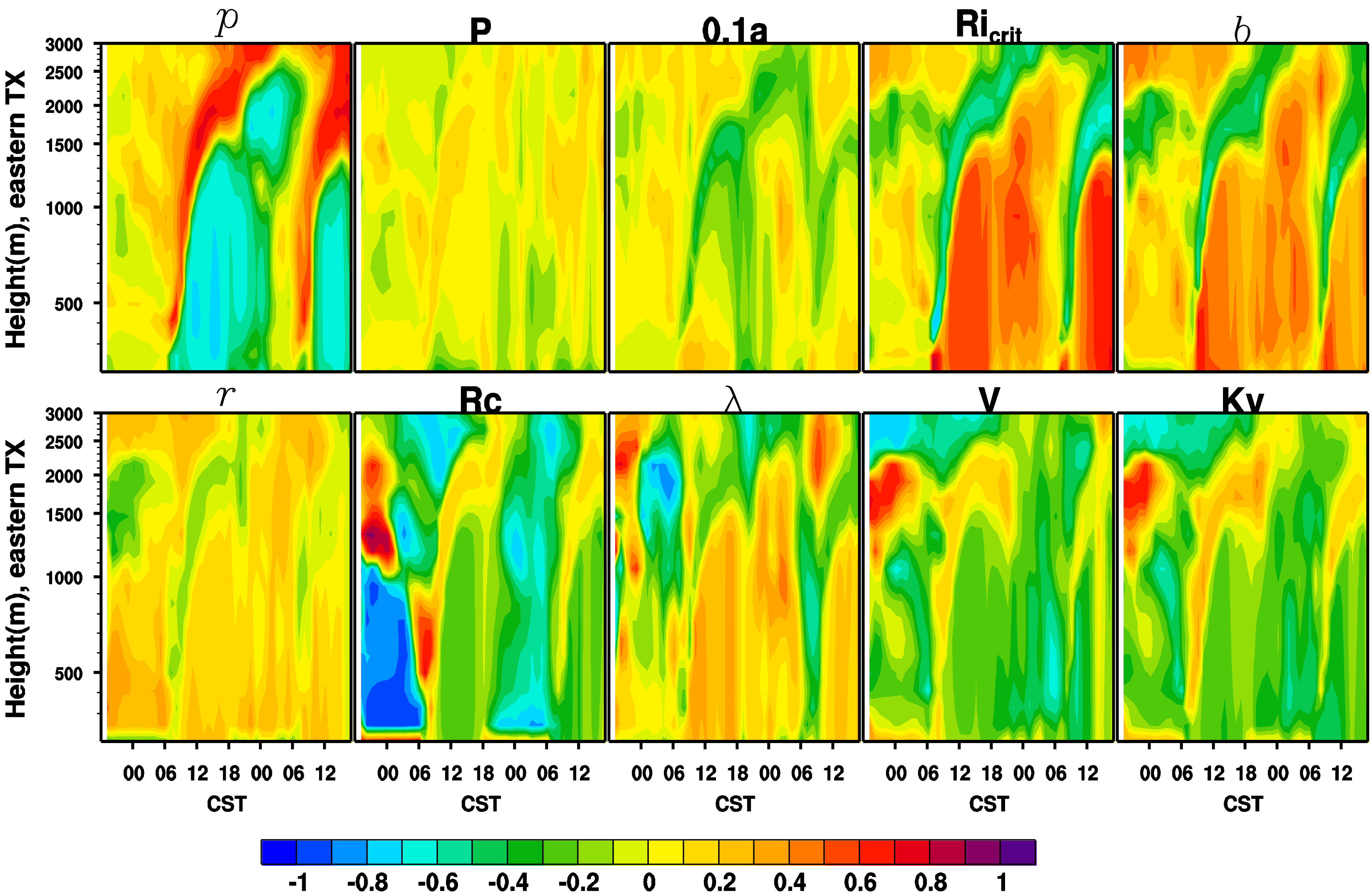
- Part 2: Improve the performance of a PBL scheme through EnKF parameter estimation

WSP sensitivity to 10 parameters in ACM2



WSP is mostly sensitive to p, Rc.

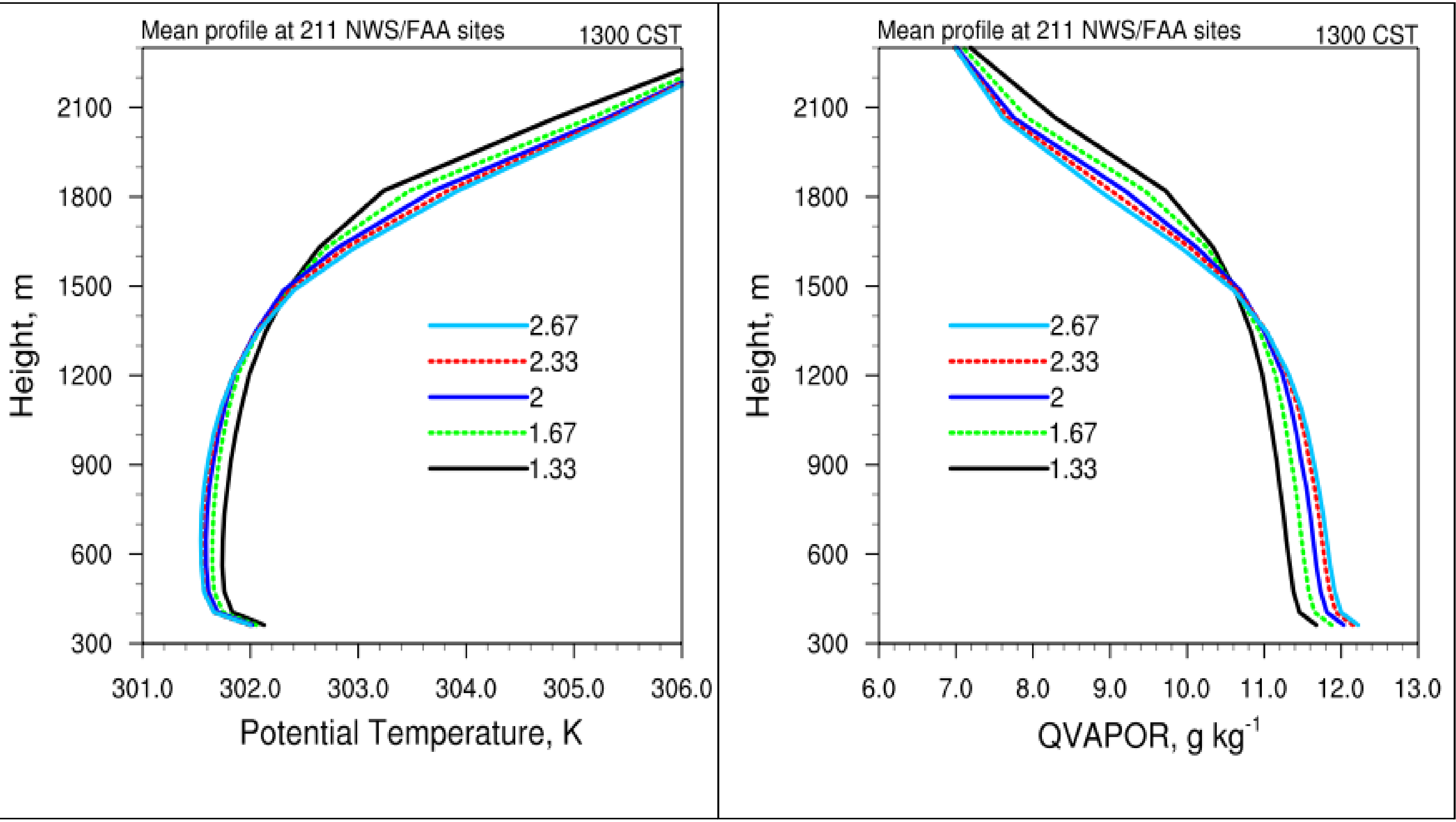
Correlation between parameters & WSP



WSP shows the largest correlation with p, Rc. Thus p, Rc have the largest identifiability

Sensitivity to *p*

$$K_z(z) = k\frac{u_*}{\phi}z(1 - z/h)^p$$

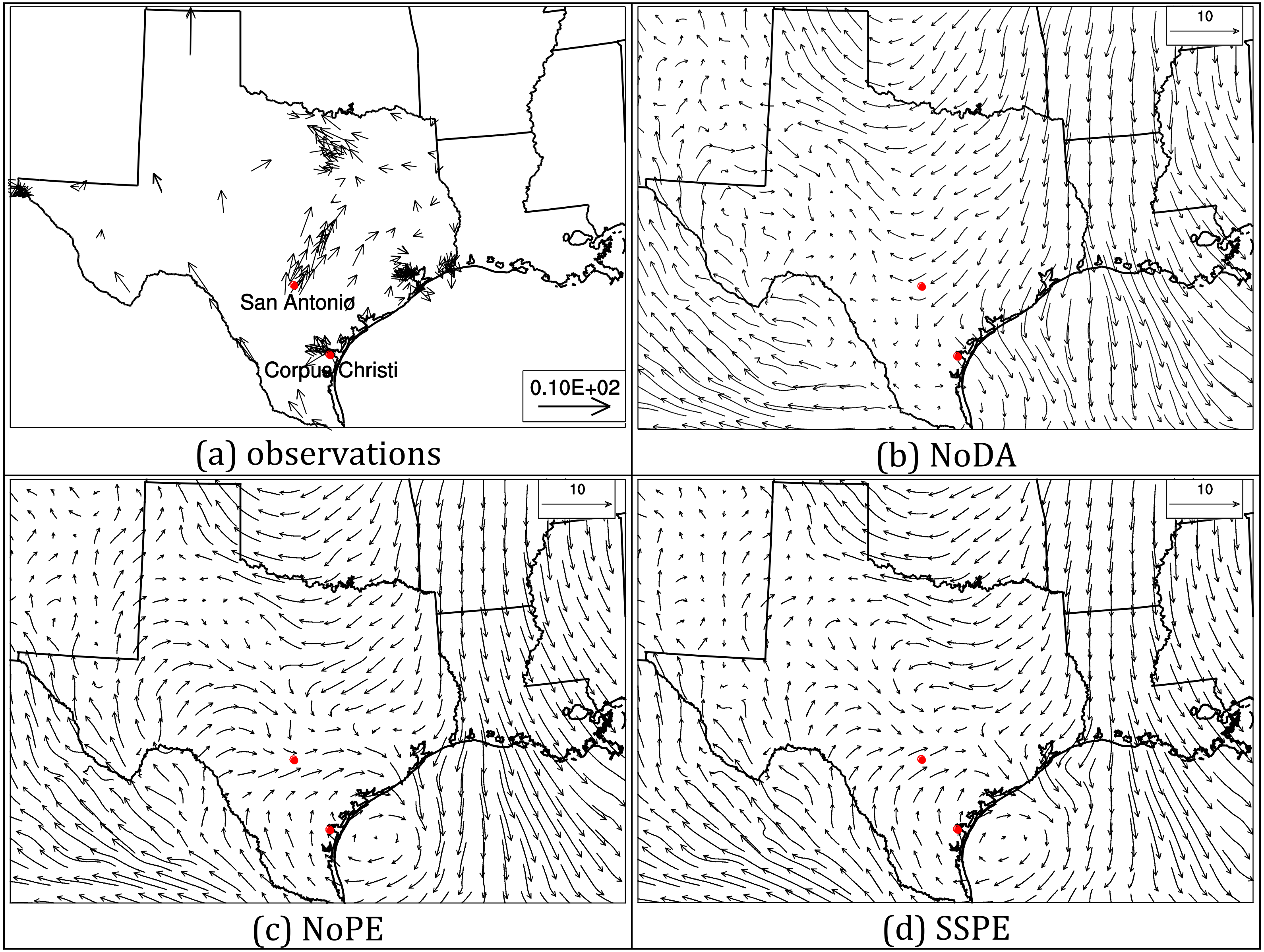


Lower *p* => stronger vertical mixing => higher PBL height.

Use EnKF to update *p, Rc*

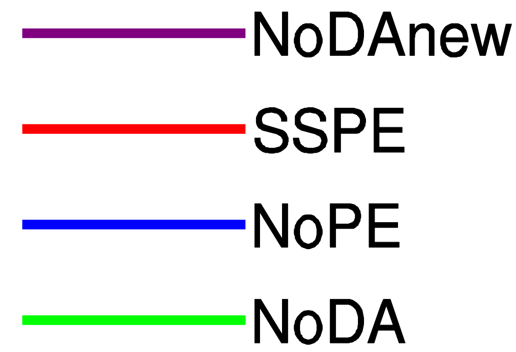
- Deterministic simulation (NoDA)
- Regular EnKF (NoPE)
- Parameter estimation EnKF (SSPE)
  - Update *p, Rc* simultaneously as updating regular states
  - Assimilate wind profiler data only every 6-hour between Aug. 30-Sept. 2, 2006 over Texas
- Deterministic simulation with estimated parameters (NoDAnew)

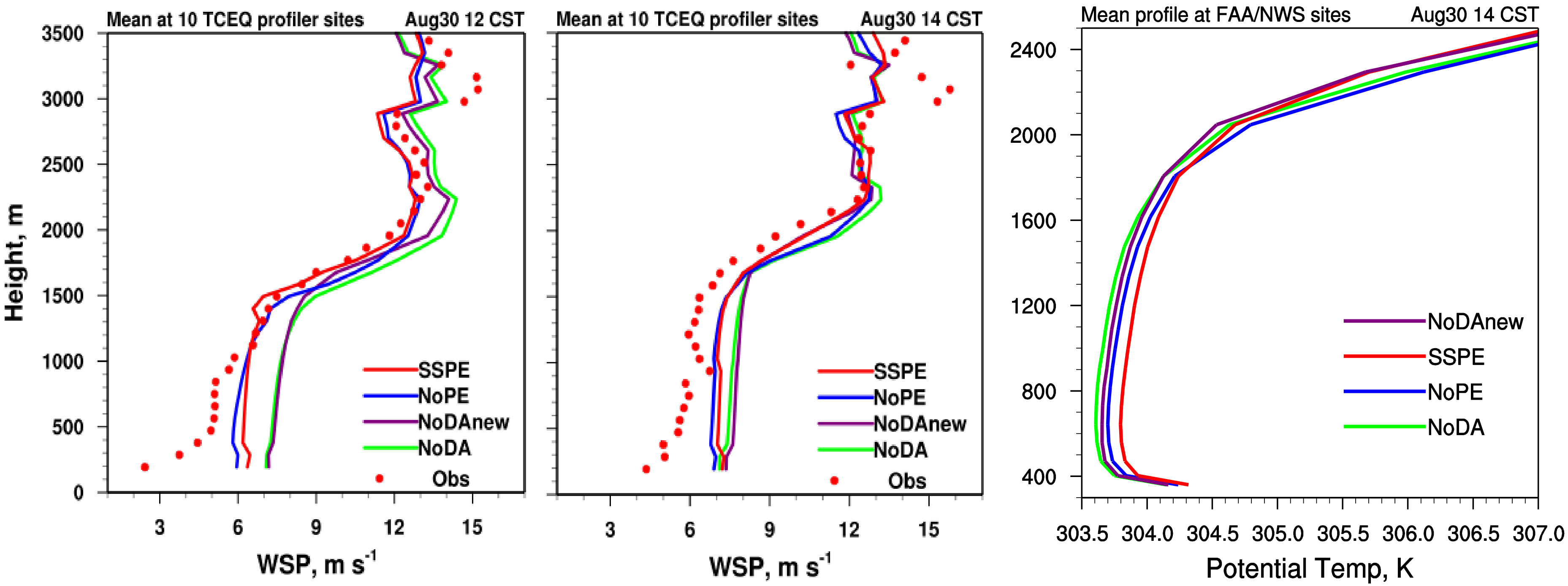
Wind vectors at Sept 1, 10 CST



SSPE shows the best agreement for surface wind.

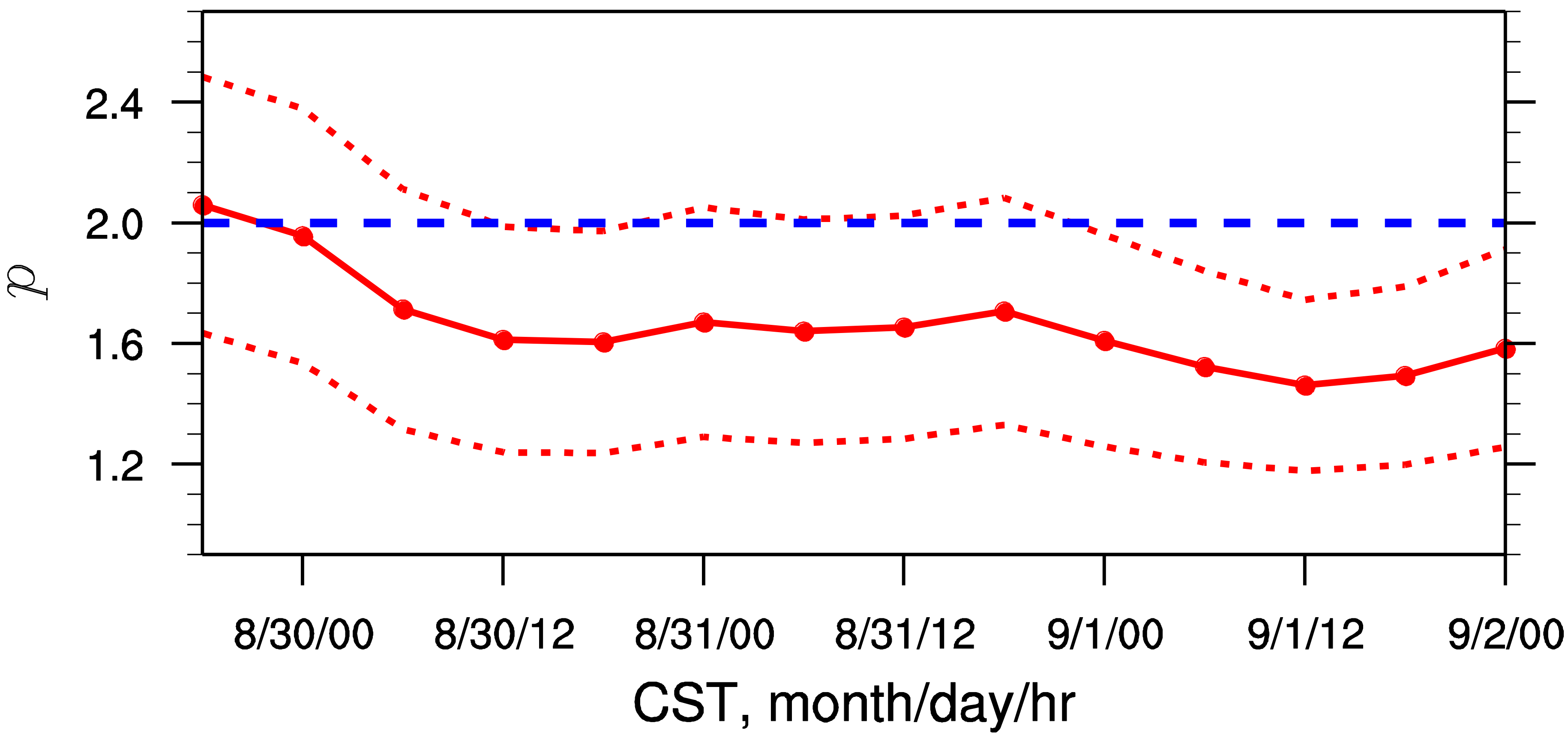
Profiles of WSP and T





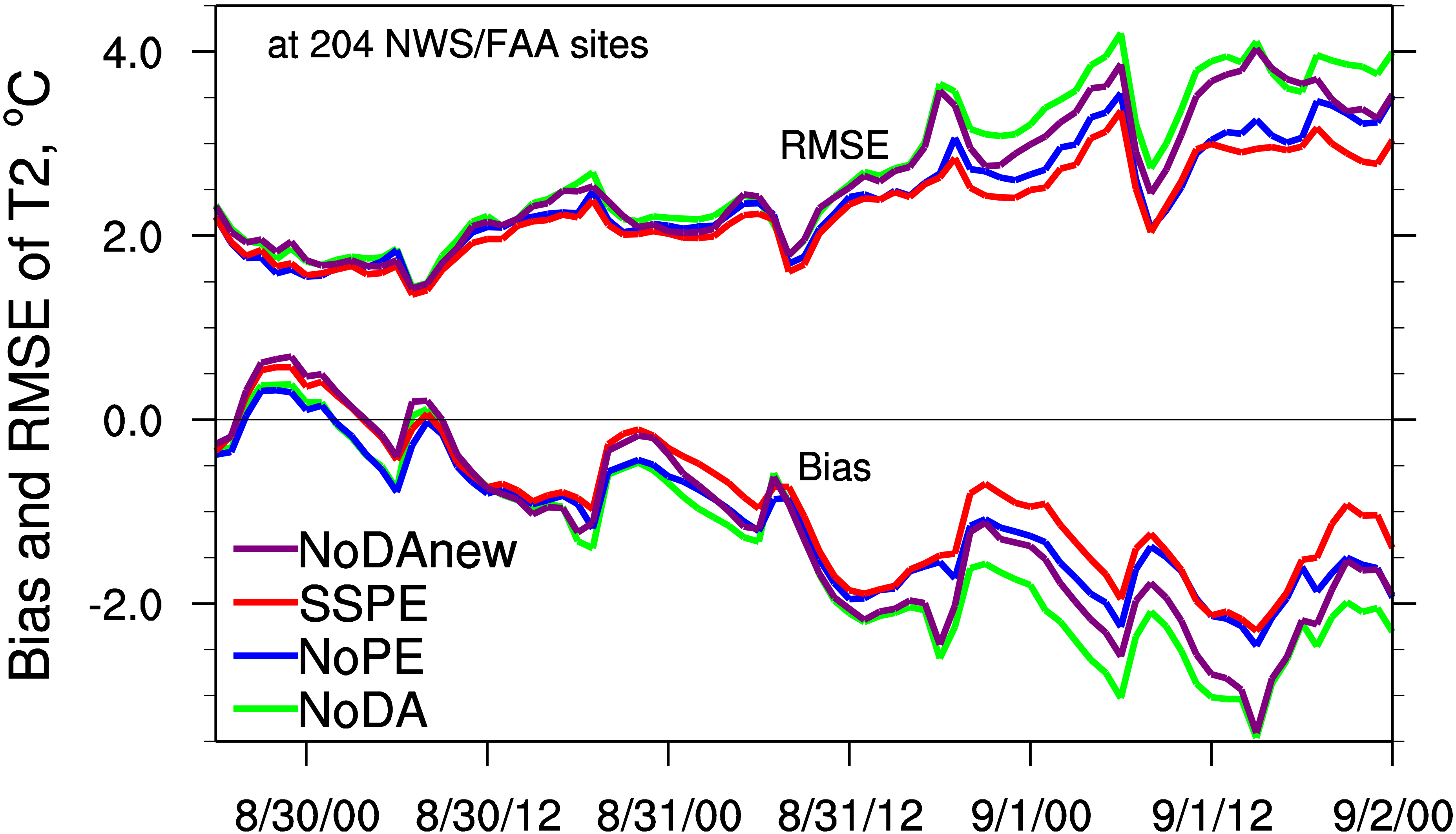
SSPE predicts higher PBLH to match profiler data.

Evolution of p



During most of time, SSPE predicts p value lower than 2.0 (default).

Bias and error of T2



SSPE predicts the least cold bias.

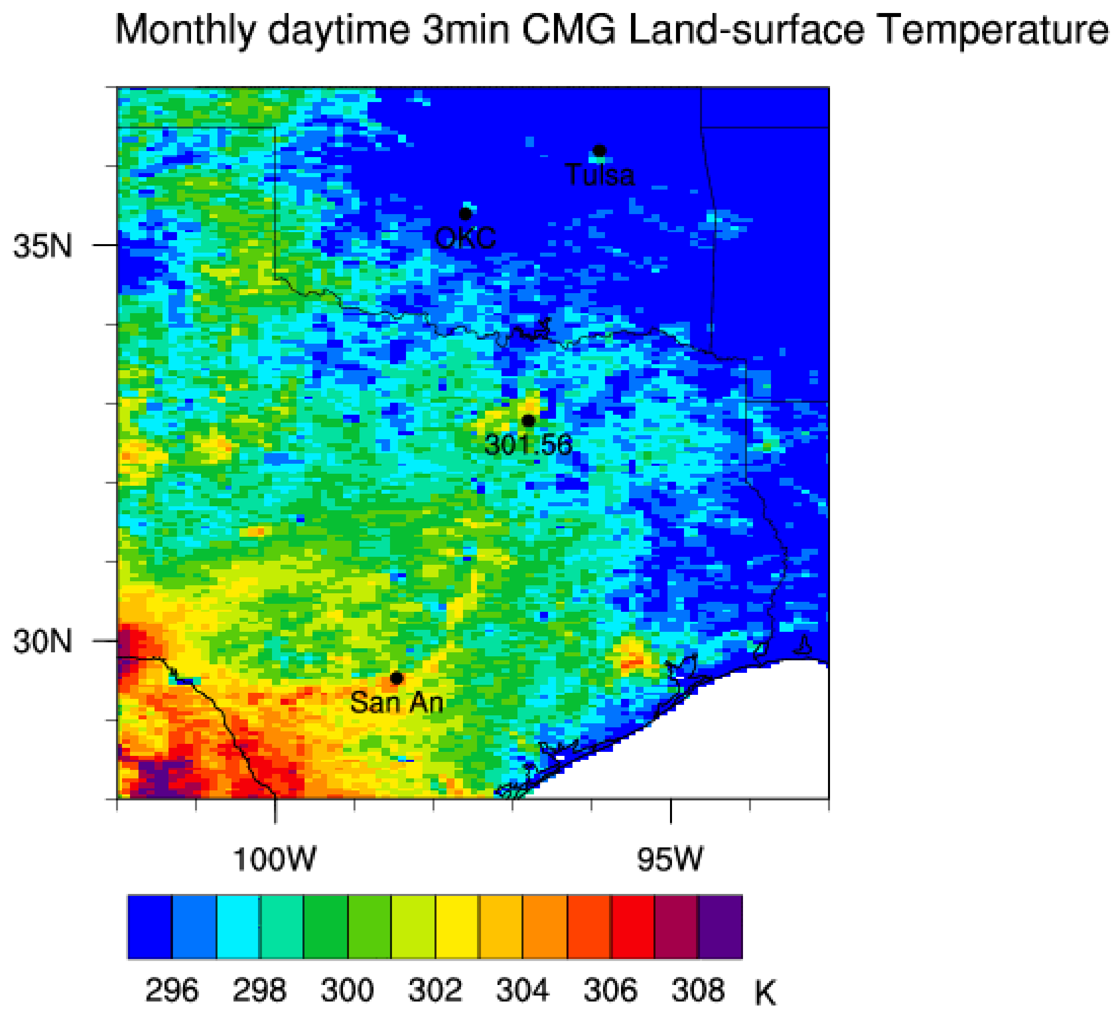
Conclusions

1. PBL schemes remain one of the primary sources of inaccuracies in model simulation. Vertical mixing strength plays an important role in performance of PBL schemes

2. Real-data experiments show that simultaneous state and parameter estimation with EnKF performs better than deterministic simulation and regular EnKF by providing optimized flow dependent parameters in the PBL scheme

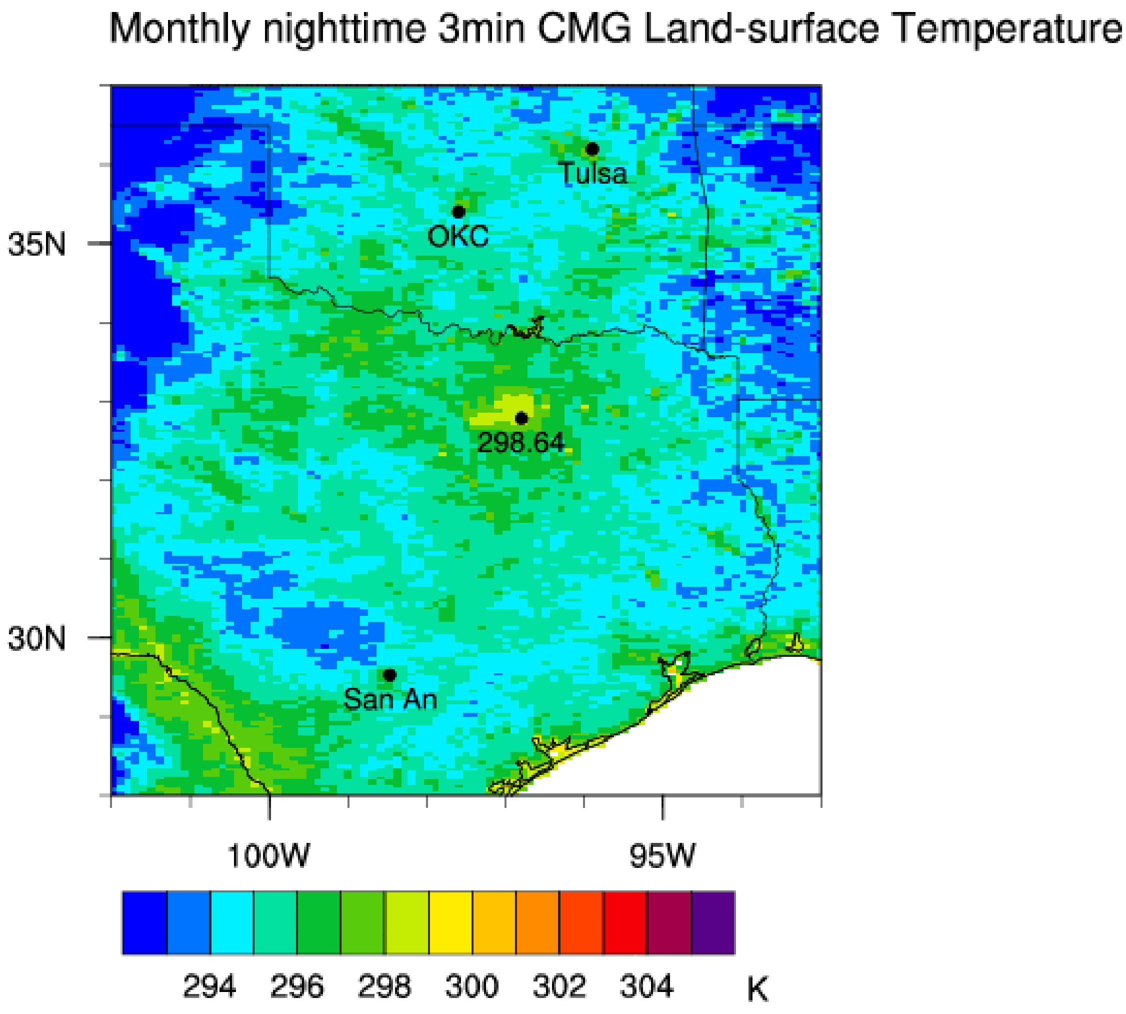
- Part 3: Current status of urban boundary layer simulations at OU

MODIS observed UHI, daytime



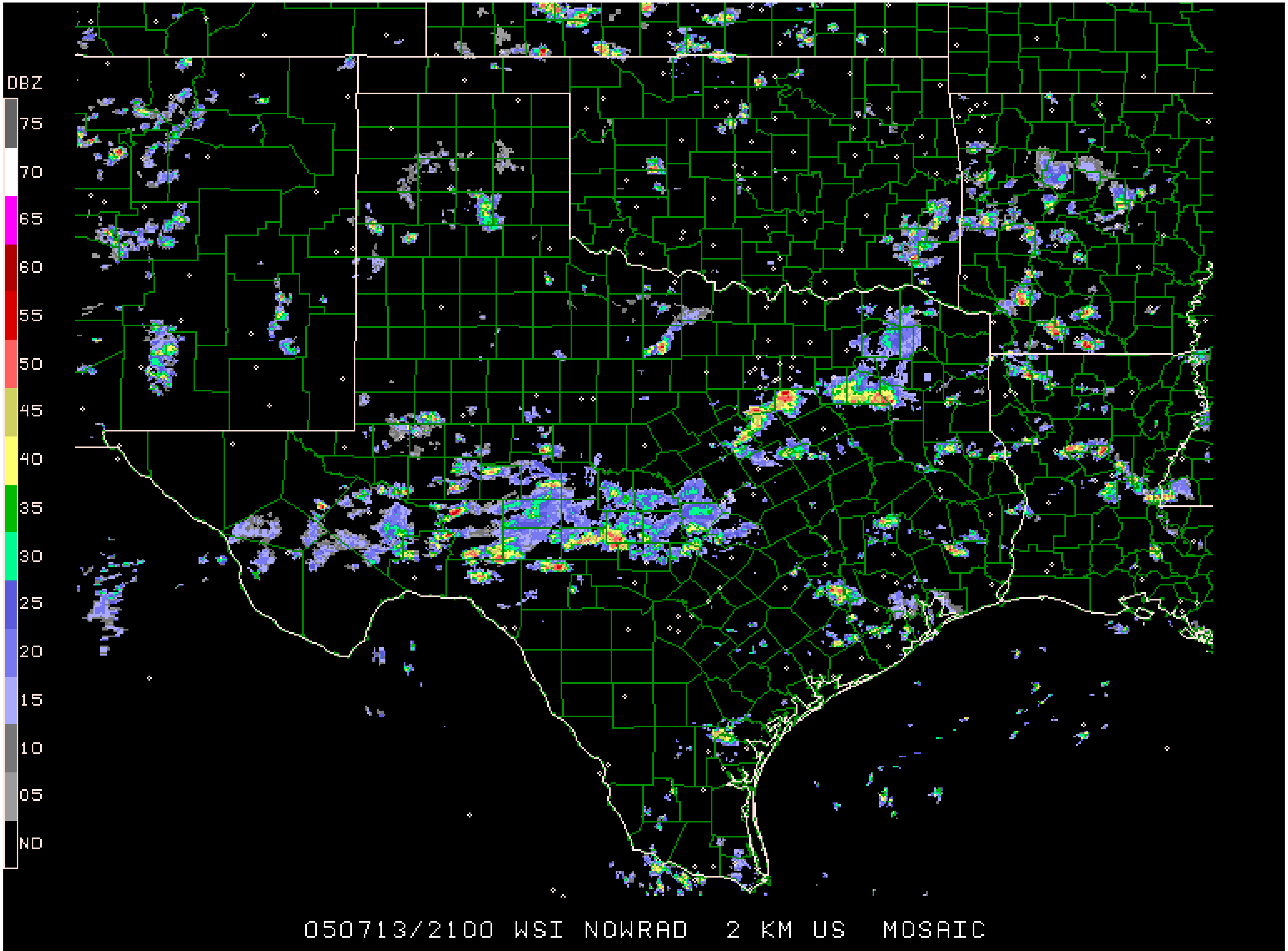
March 2005

MODIS observed UHI, nighttime



July 2006

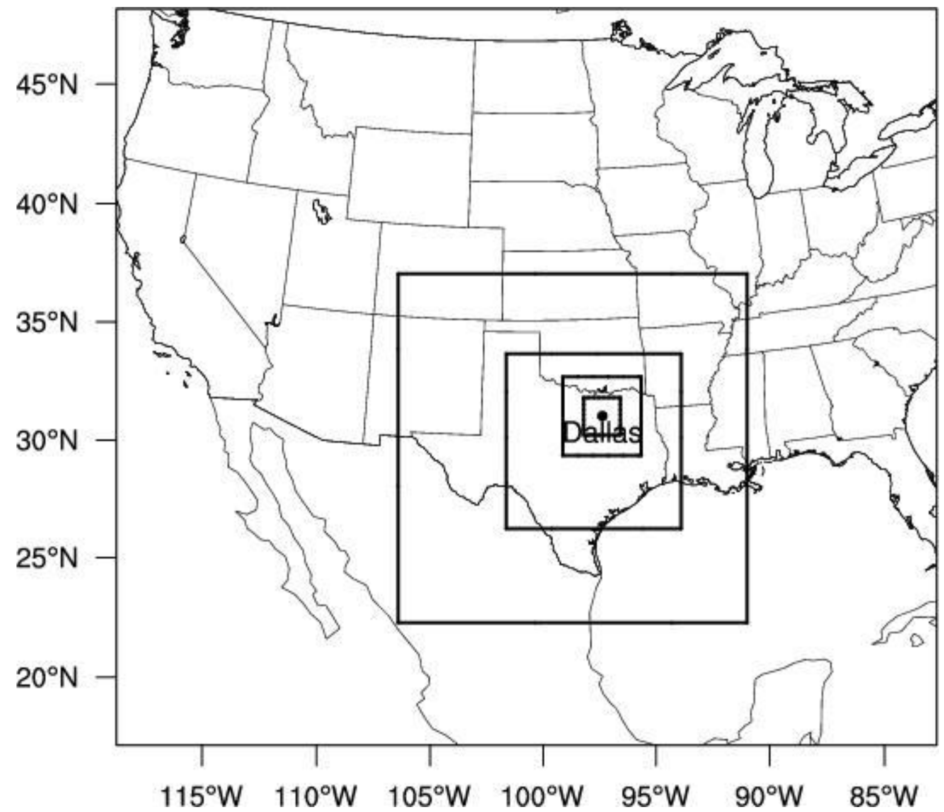
UHI splits precipitation?



Configurations of WRF-UCM

Episode & Resolution

- Period: July 13., 2005
- Resolution: 40.5, 13.5, 4.5, 1.5, 0.5km



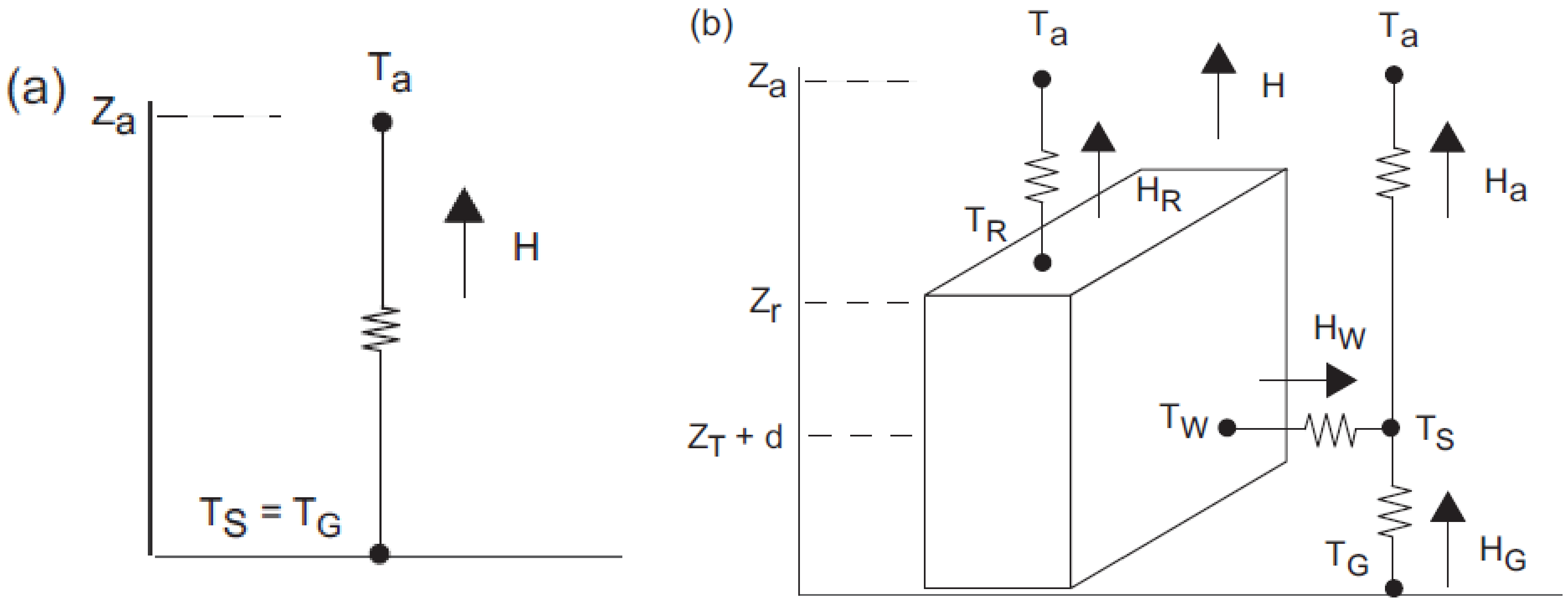
Model Configurations

- YSU PBL schemes
- WSM 6-class graupel scheme
- Dudhia short wave radiation
- RRTM long wave radiation
- **NOAH land-surface model** (LSM)

  + an urban canopy model (UCM)

$$HFX = F_{urb} \times HFX_{ucm} + (1 - F_{urb}) \times HFX_{NOAH}$$

Schematic of urban canopy model



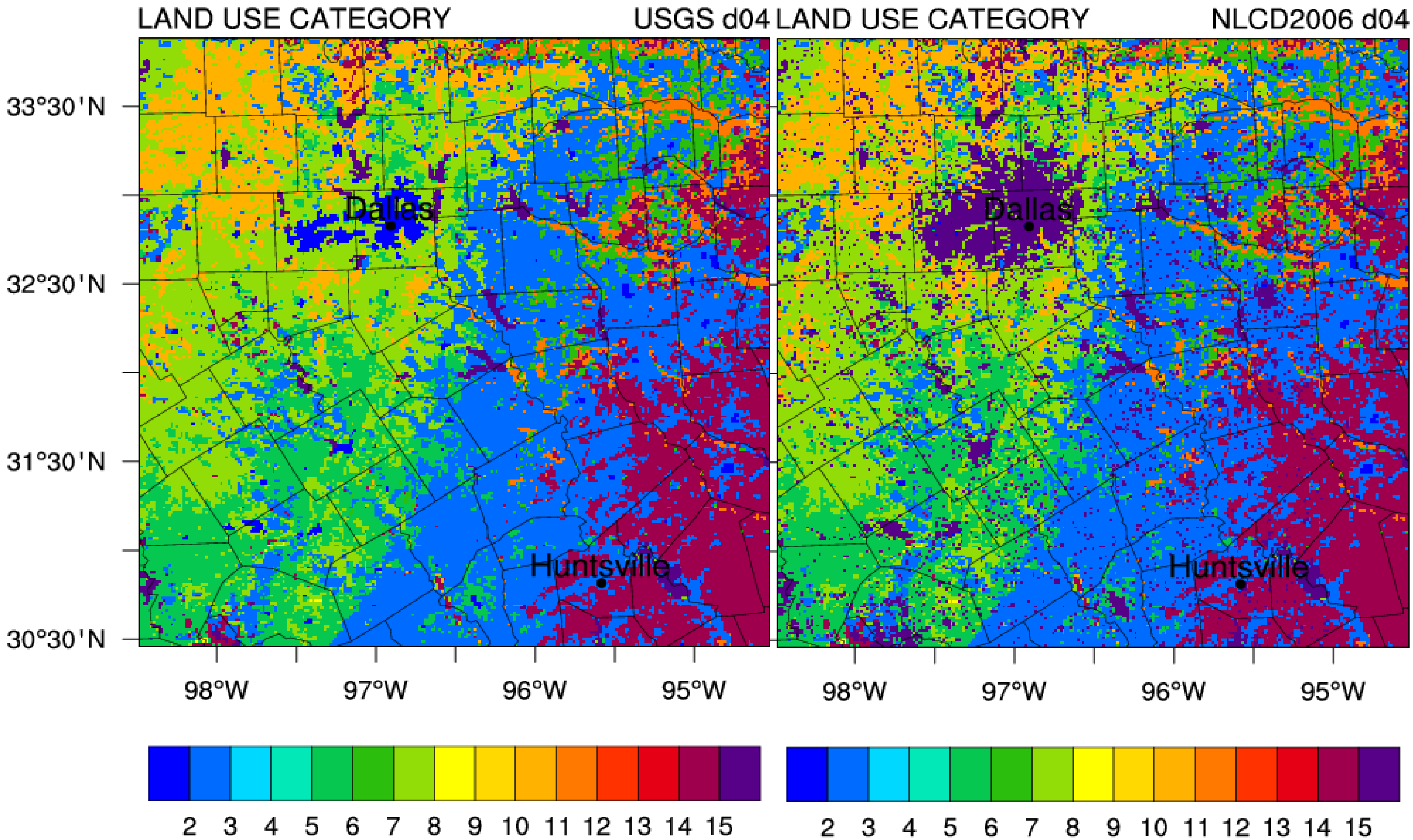
Slab model like NOAH

Urban canopy model (UCM)

$$HFX = F_{urb} \times HFX_{ucm} + (1 - F_{urb}) \times HFX_{NOAH}$$

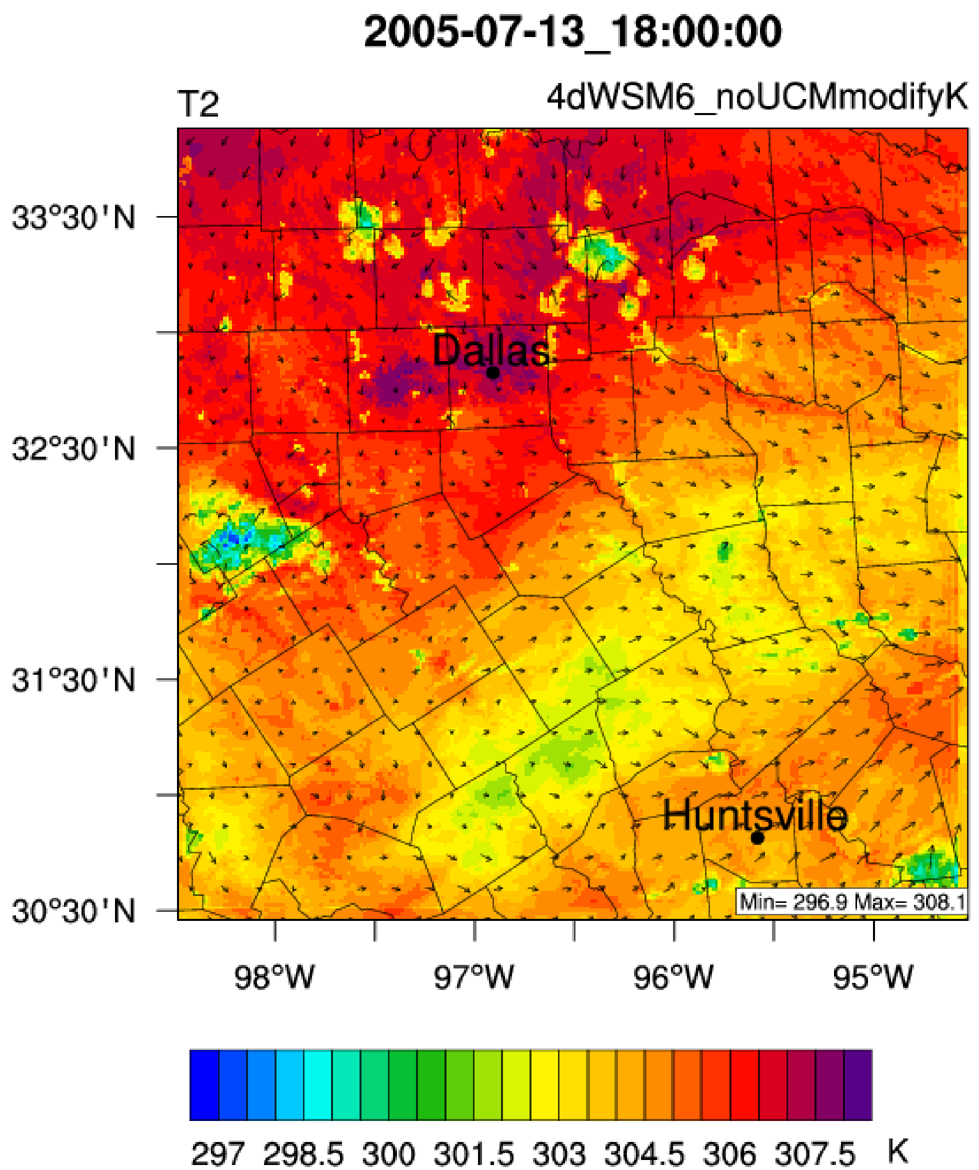
Detailed land use data

USGS 1994 NLCD 2006

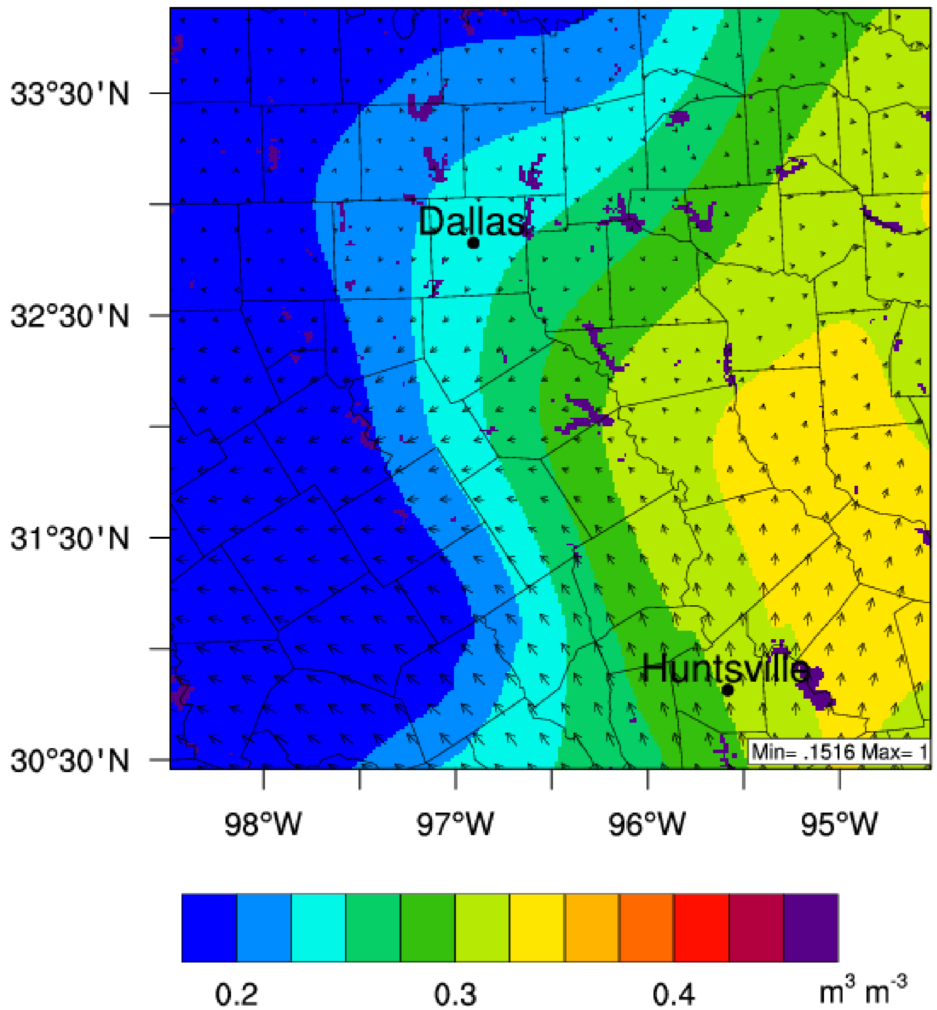


Urban expansion since 1994

Simulated urban heat island



Challenges in initializing WRF-UCM



Default soil moisture cannot represent urban

Solution for initializing soil moisture?

- Run an uncoupled (offline) LSM constrained by observed forcing conditions long enough to develop an equilibrium soil properties?

Chen et al. (2011) run NOAH/UCM in an offline mode for 18 months.

Run NASA Land Information System (LIS) in an offline mode?

References

1. **Hu, X.-M.**, J. W. Nielsen-Gammon, and F. Zhang (2010), Evaluation of Three Planetary Boundary Layer Schemes in the WRF Model, *J. Appl. Meteor. Climatol.*, 49, 1831–1844.
2. Nielsen-Gammon, J. W., **X.-M. Hu**, F. Zhang, and J. E. Pleim (2010), Evaluation of Planetary Boundary Layer Scheme Sensitivities for the Purpose of Parameter Estimation, *Mon. Wea. Rev.*, 138, 3400–3417.
3. **Hu, X.-M.** , F. Zhang, and J. W. Nielsen-Gammon (2010), Ensemble-based simultaneous state and parameter estimation for treatment of mesoscale model error: A real-data study, *Geophys. Res. Lett.*, 37, L08802, doi:10.1029/2010GL043017.

Links

1. http://faculty-staff.ou.edu/H/Xiaoming.Hu-1/
2. http://journals.ametsoc.org/doi/abs/10.1175/2010JAMC2432.1
3. http://journals.ametsoc.org/doi/abs/10.1175/2010MWR3292.1
4. http://www.agu.org/pubs/crossref/2010/2010GL043017.shtml

Simulations of WRF-UCM

5. http://www.caps.ou.edu/micronet/WRF-UCM.html