Importance of PBL schemes in simulating boundary layer processes,

e.g., urban heat island, sea breeze

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July xx, 2015

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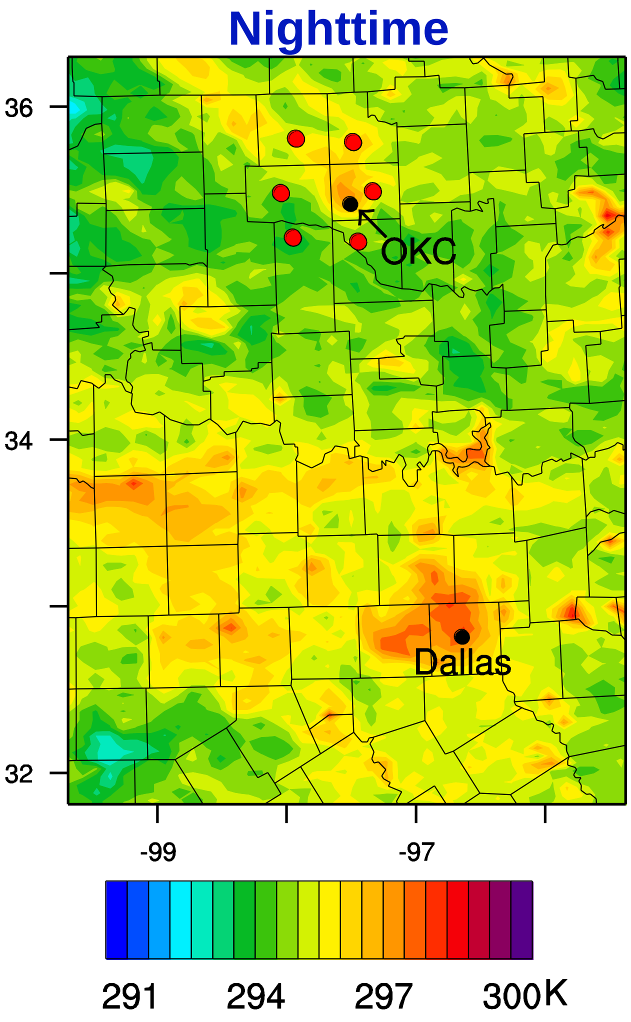
MODIS-derived land surface temperature

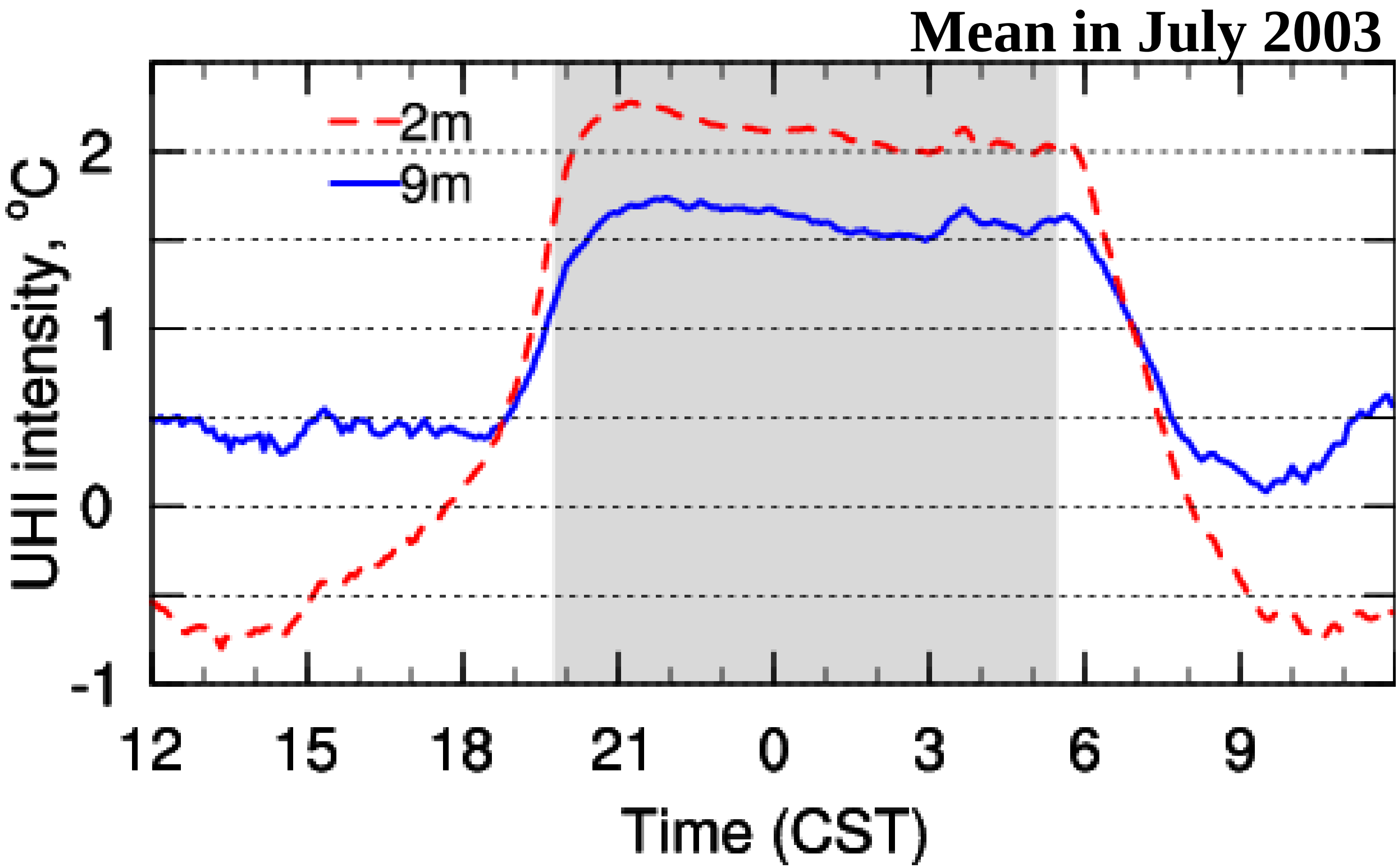


Hu et al. (2013, JAMC)

UHI is prominent during nighttime

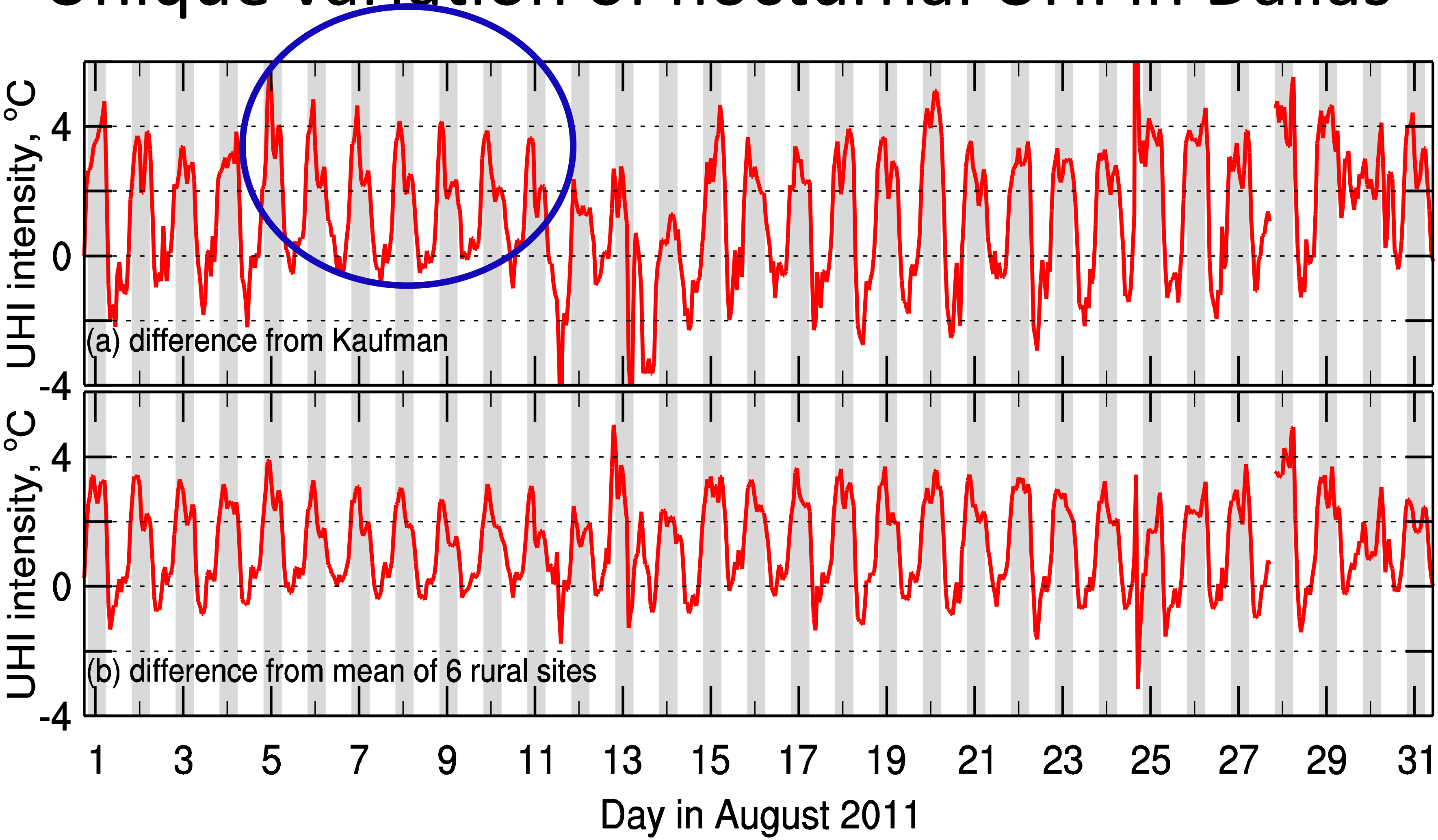
UHI intensity = T at urban location – T at rural sites

Diurnal variation of UHI intensity in OKC



UHI intensity normally increases around sunset quickly and then stays at a roughly constant level throughout the night.

Unique variation of nocturnal UHI in Dallas



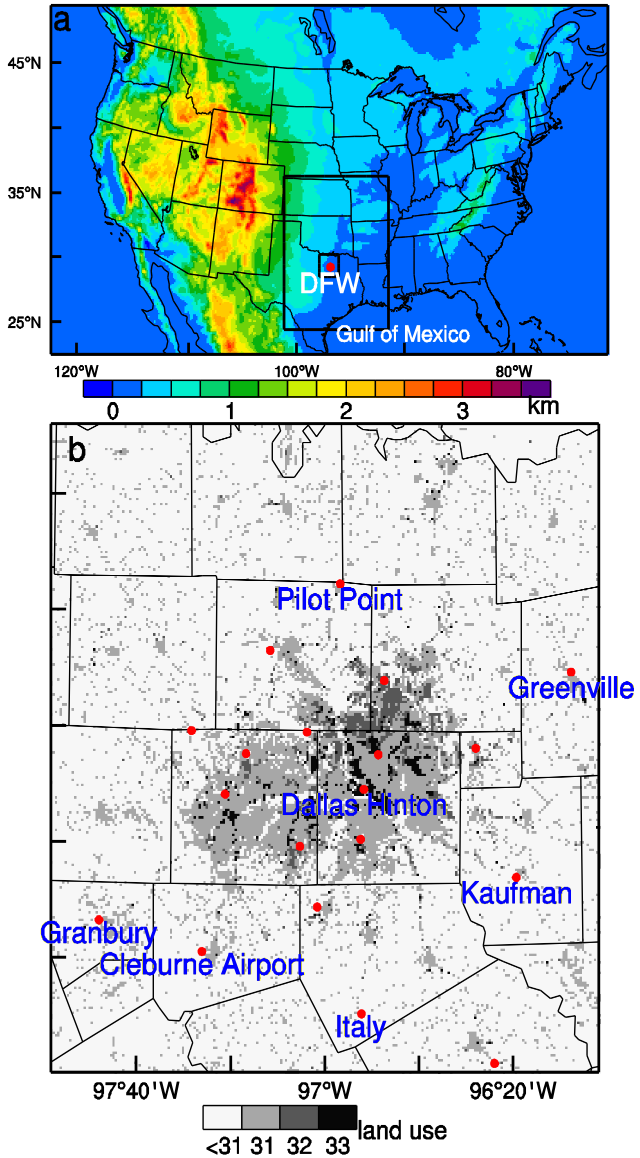
Sharp decrease ("collapse") of the nocturnal UHI intensity

Motivations/objectives of this study

Hu and Xue (2015, MWR, conditionally accepted)

- Understand such a unique temporal variation of the nocturnal UHI intensity in Dallas
  - Sea breeze
  - Nocturnal warming events
- Impact on air quality
- Importance of boundary layer scheme in model simulations

Model domains and configurations

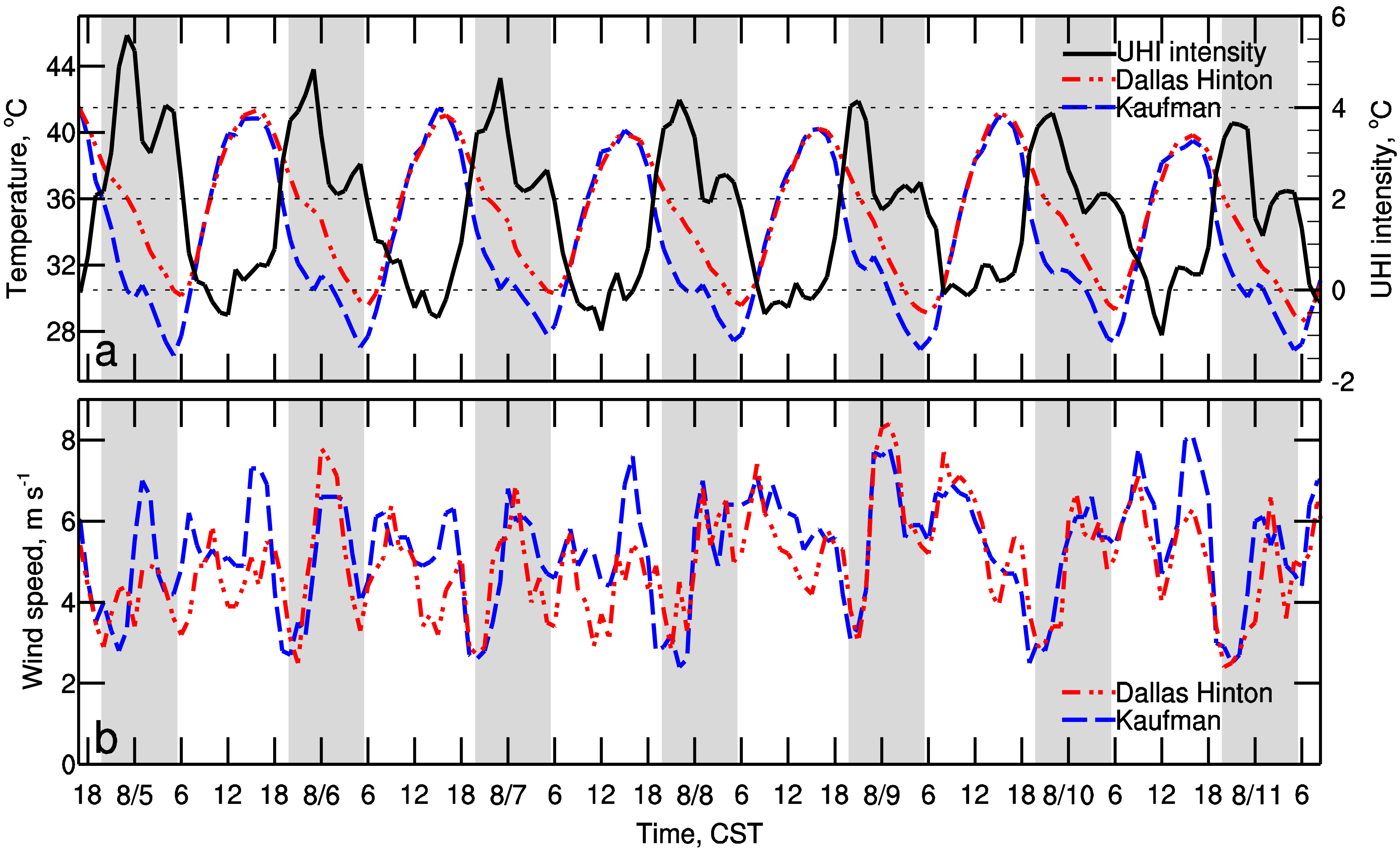


- WRF3.6.1
- 12->4->0.8km
- NOAH+Urban canopy model
- Boundary layer scheme: YSU
- Simulation period: August 7-8 2011

UHI intensity = T at Dallas Hinton – T at Kaufman to be consistent with Winguth (2013, JAMC)

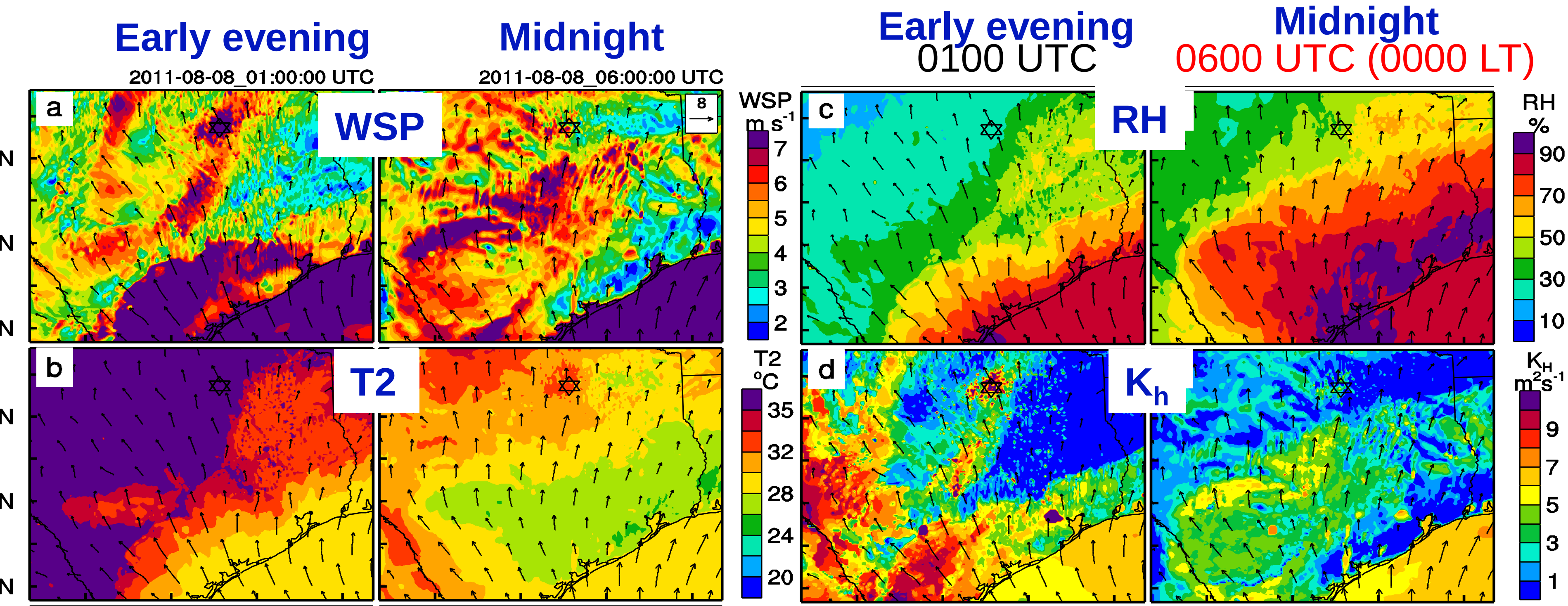
WRF/Chem for air quality impact

Observed variation of UHI, T, wind speed



Collapses of UHI coincided with wind maximum and rural nocturnal warming events

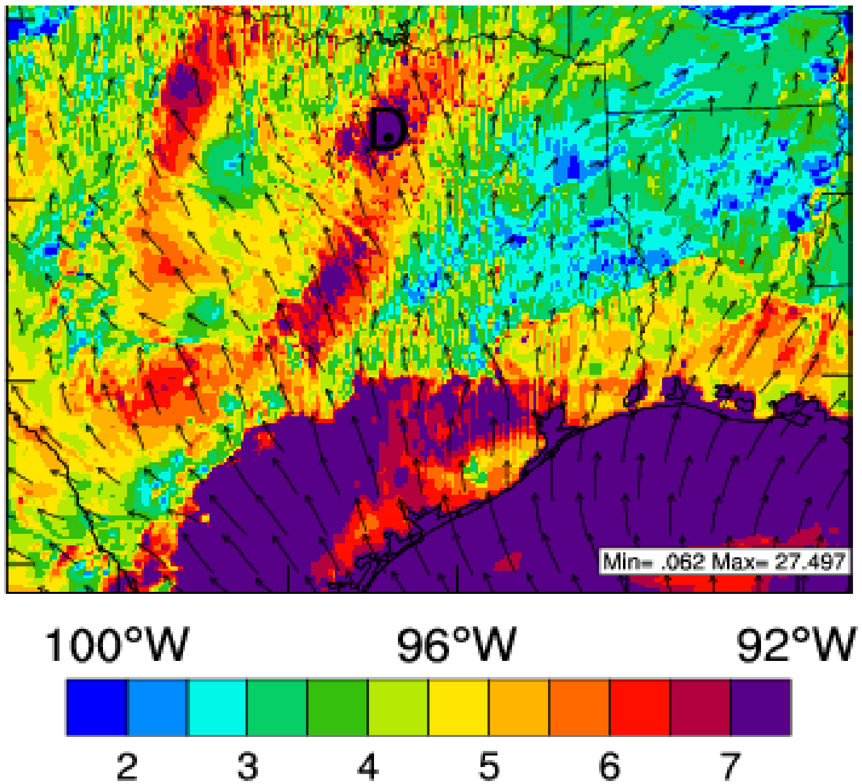
Map of wind, T2, RH, K_h at 00 and 06 UTC

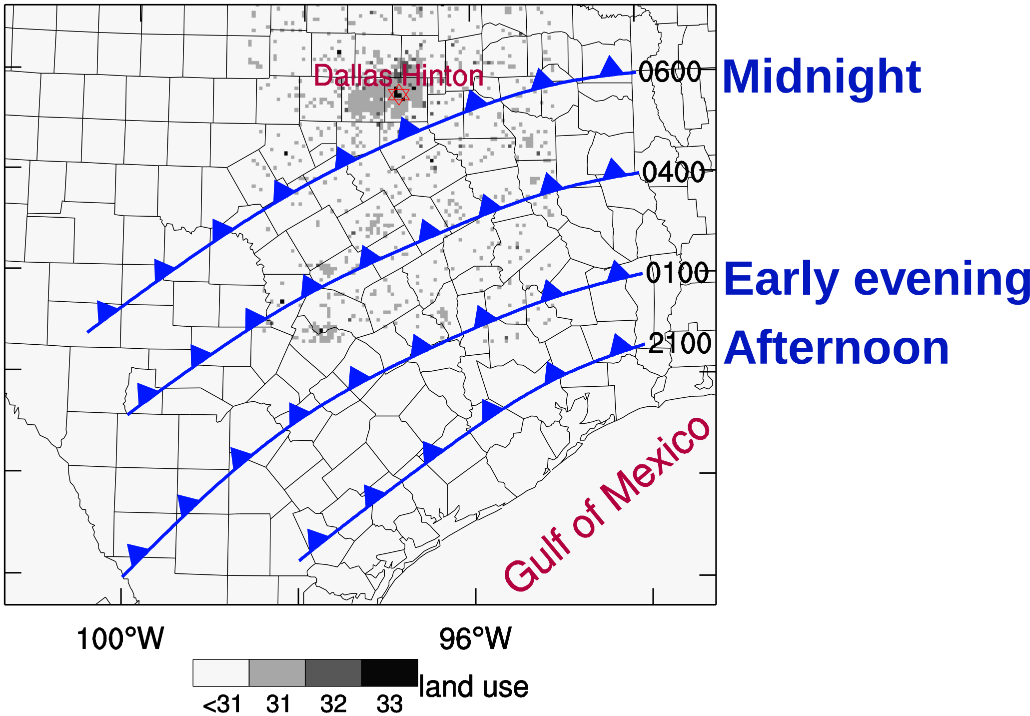


Indications of a sea breeze front:

Cooler and moister air behind the front with stronger momentum and vertical mixing

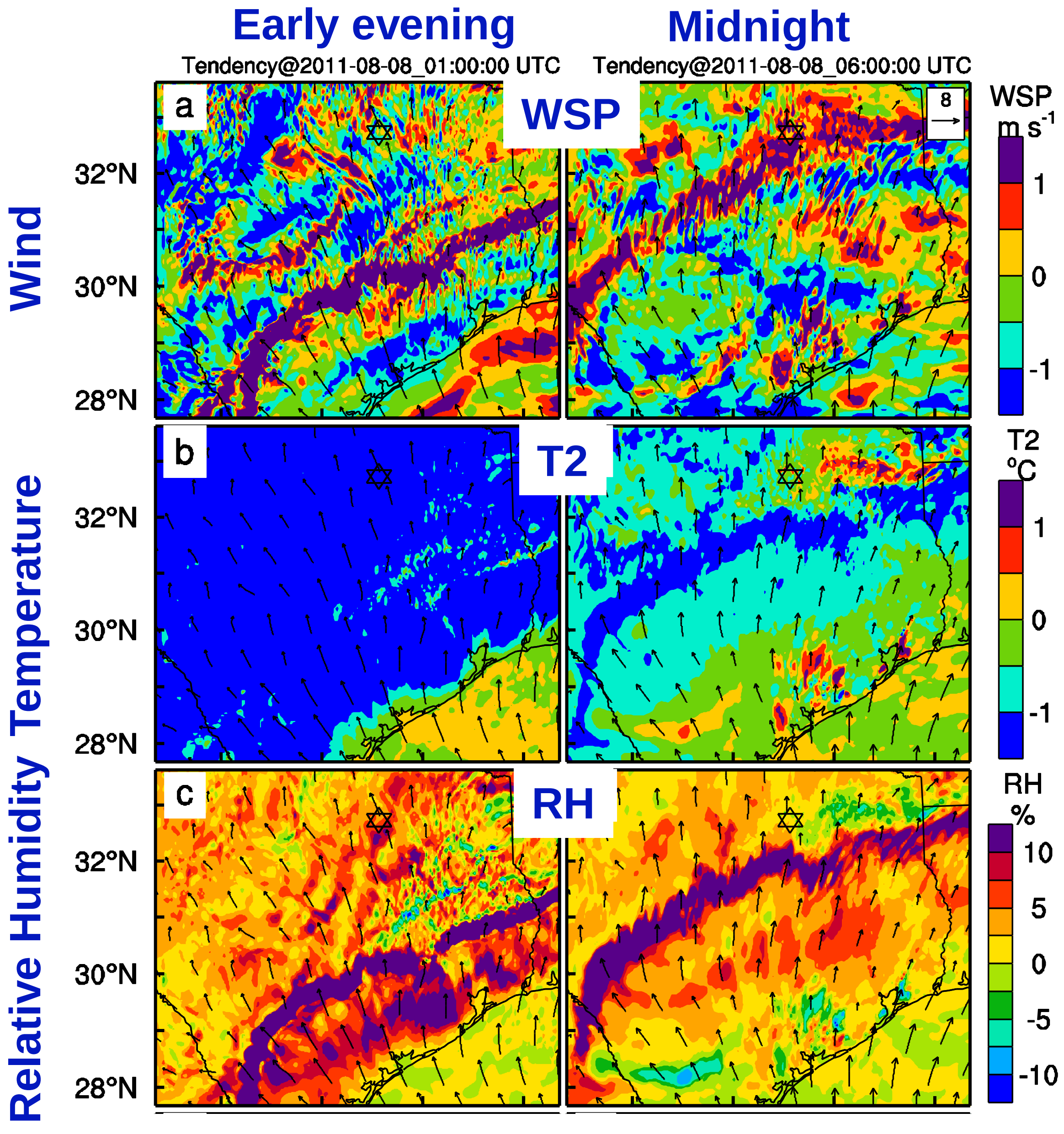
Inland penetration of the sea breeze front





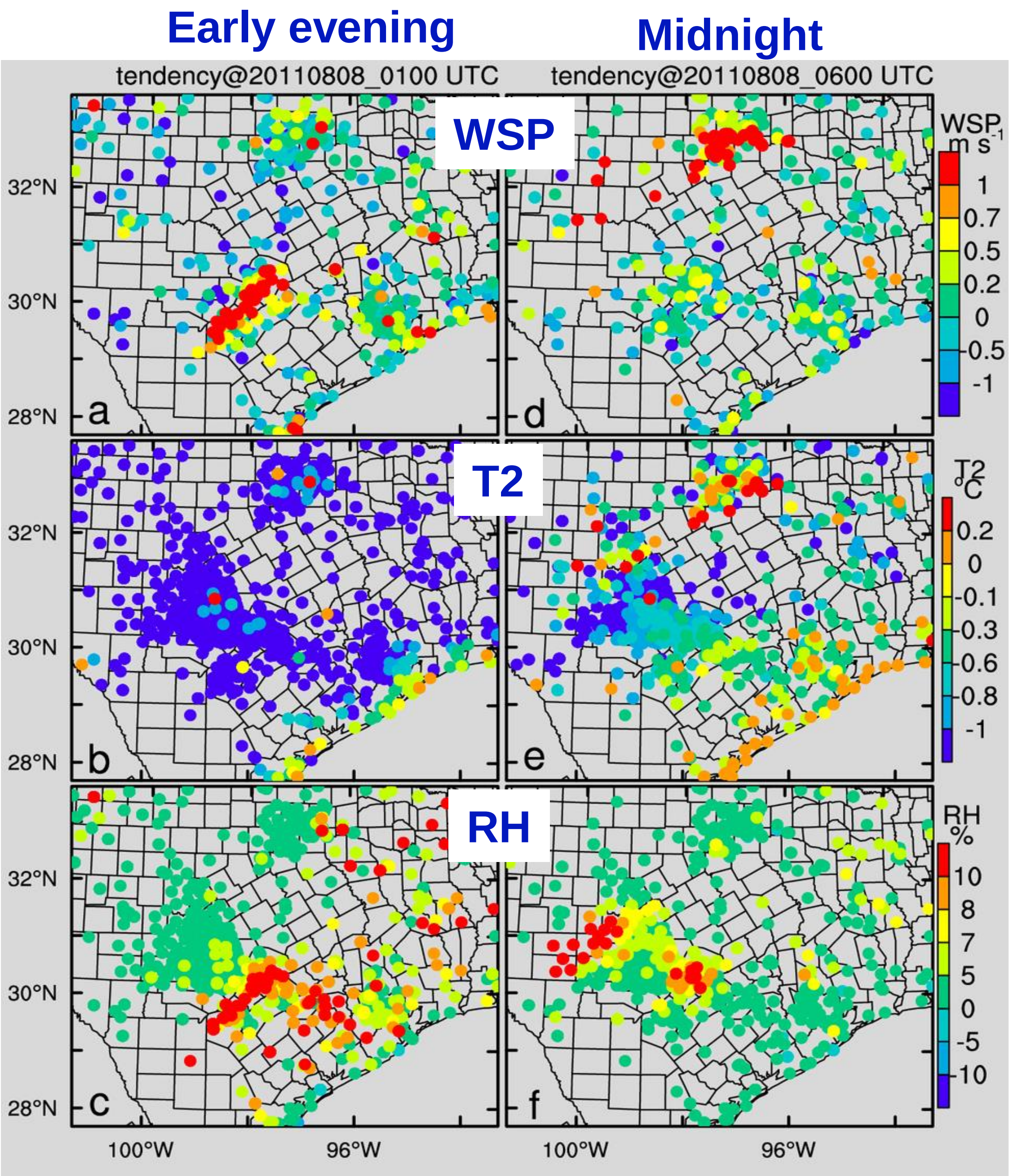
The sea breeze front approached Dallas around midnight (0600 UTC)

Tendency: difference between current and next hours



The inland penetration of sea breeze front can be clearly illustrated in the tendency of WSP, T2, RH.

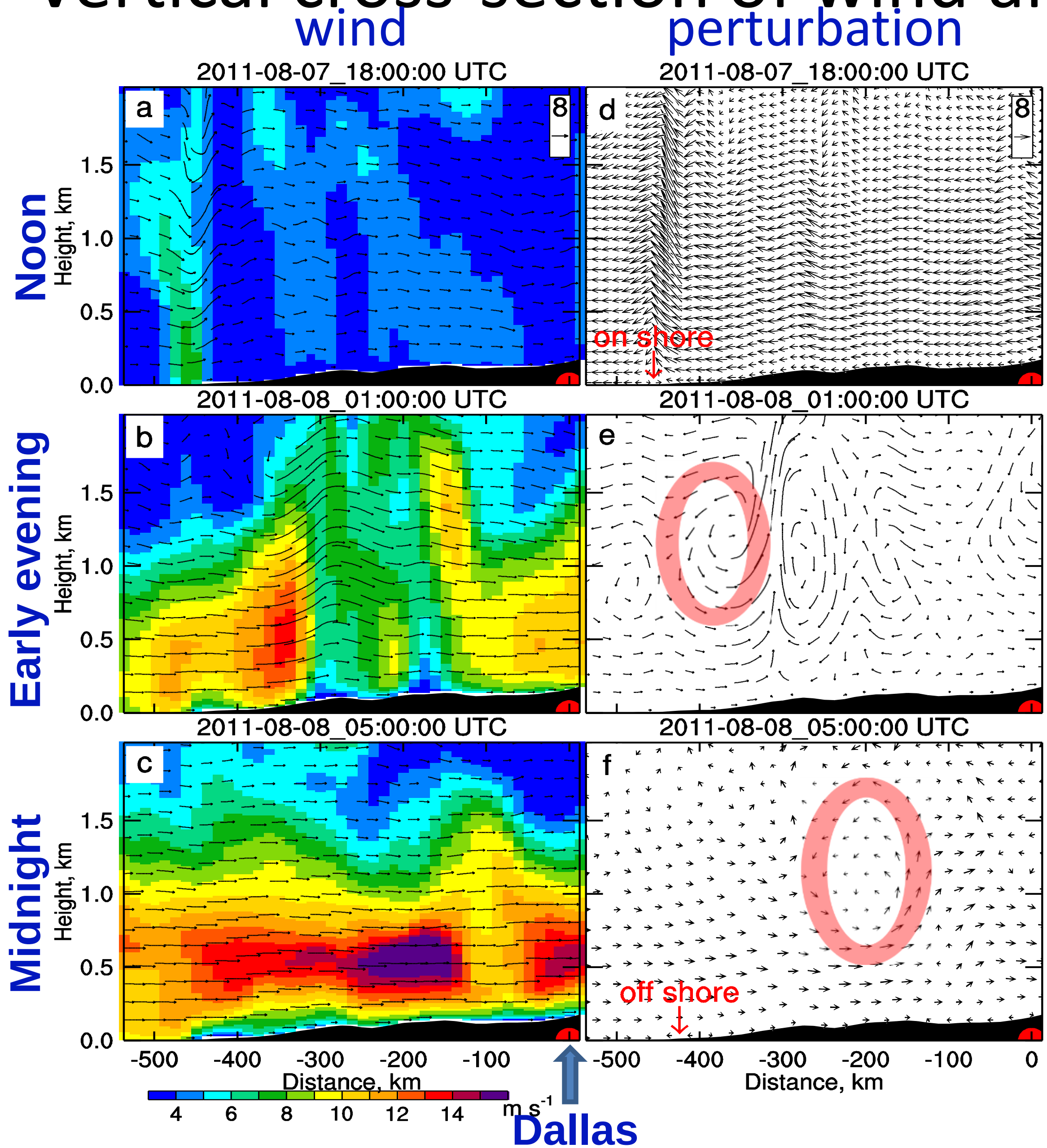
Observed tendency in MADIS data



MADIS integrated data from many providers

In the spatial distribution of tendency, the small scale local heterogeneity in instantaneous values is removed and only the spatial information of temporal variation is remaining.

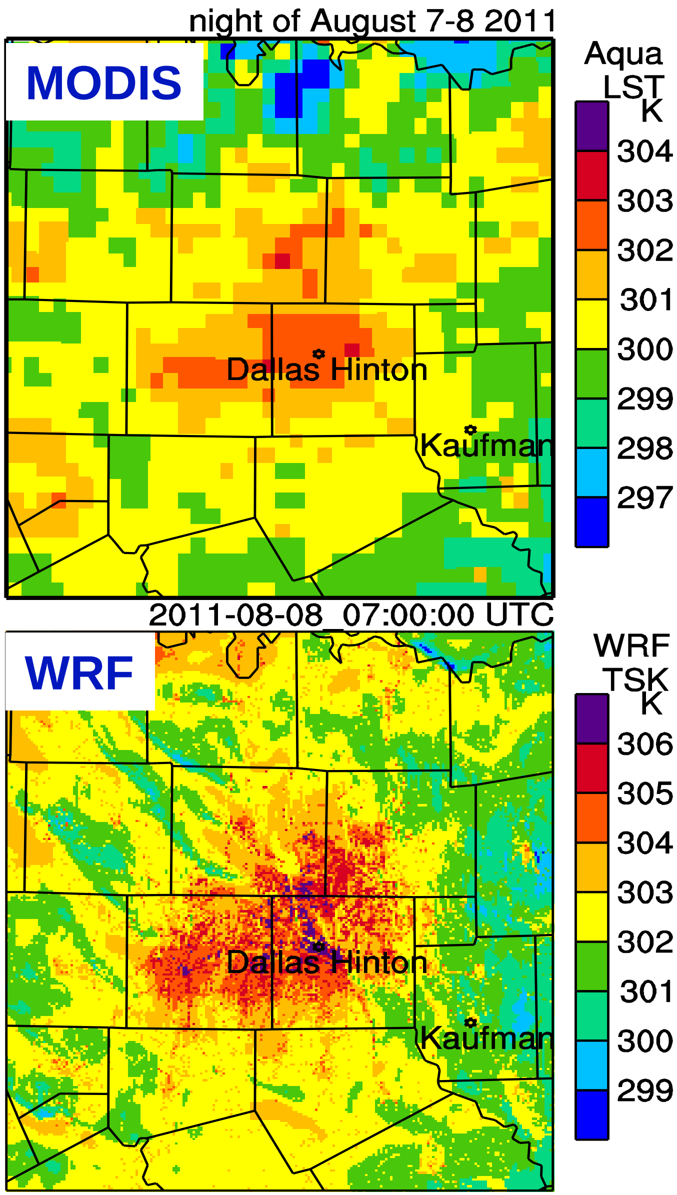
Vertical cross-section of wind and its perturbation

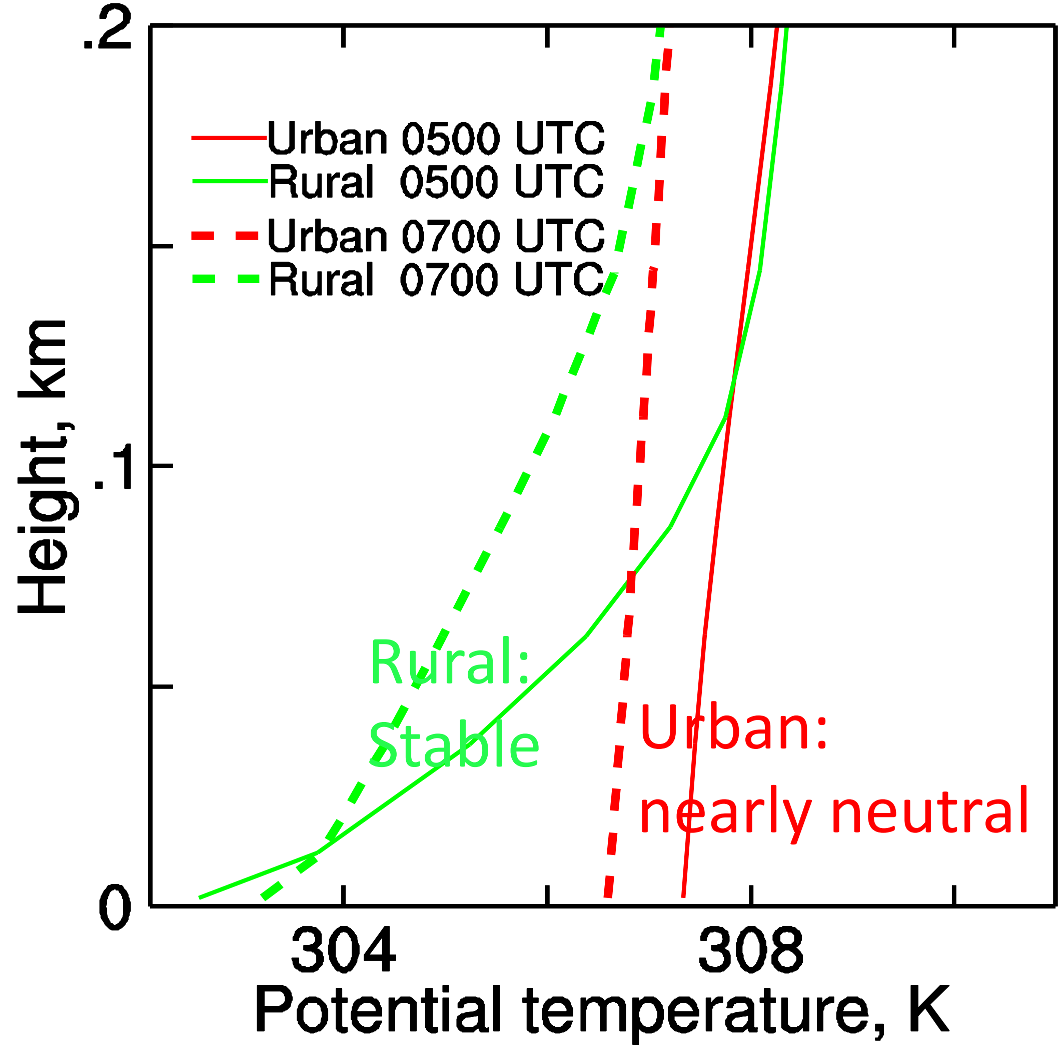


Sea breeze develops in the morning and is advected by Low-Level Jet at night

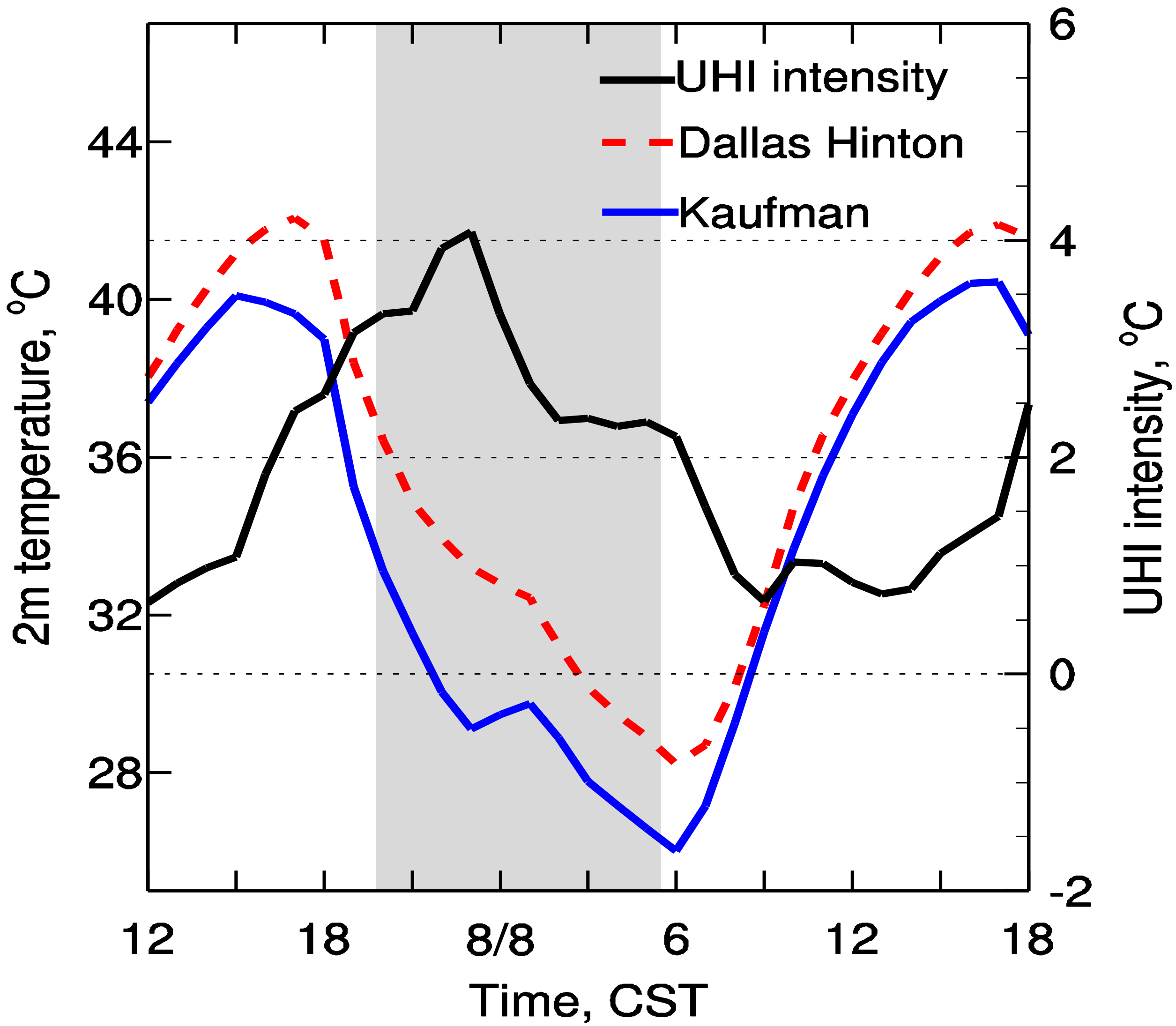
Synoptic sea breeze

Different response to the front in rural and urban



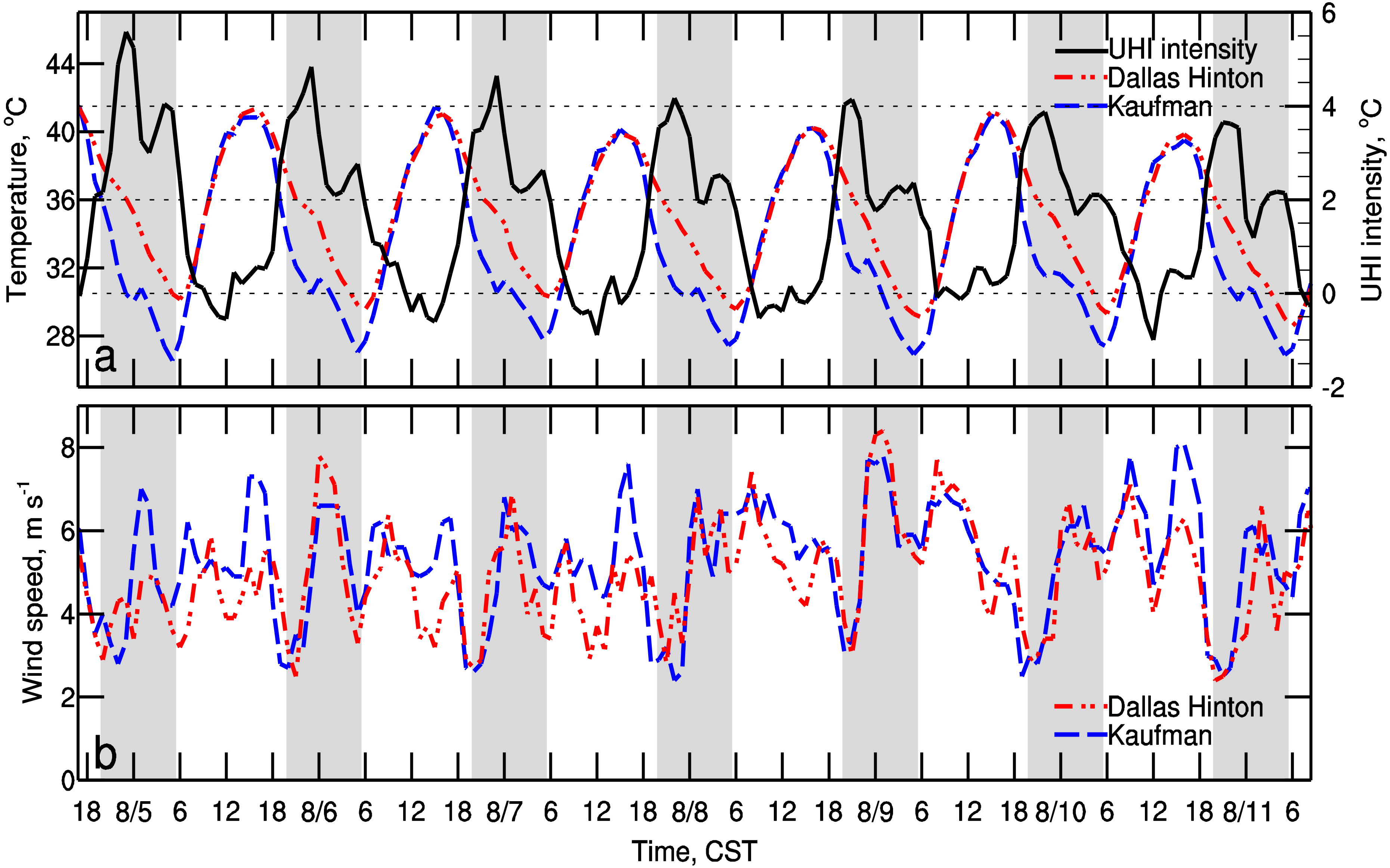


Simulated variation of T, and UHI intensity



Nocturnal warming in rural and non-warming in urban led to collapse of UHI

Observed variation of UHI intensity in Dallas



Conclusions

1. “collapse” of nocturnal UHI intensities occurred frequently around midnight in August 2011 in Dallas.

2. Synoptic sea breeze circulation cells can be advected to Dallas and influence its UHI, such a sea breeze category is rarely studied in the past.

Conclusions

3. Sea breeze frontal passage induced nocturnal warming events in rural area, while it did not alter urban boundary layer much, leading to collapse of UHI.

Nocturnal warming events were reported before, but as a result of synoptic cold fronts. In both cases the mechanism is similar, i.e., enhanced vertical mixing associated with momentum fronts plays a dominant role.

Motivations/objectives of this study

Hu and Xue (2015, MWR, under review)

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  - Nocturnal warming events
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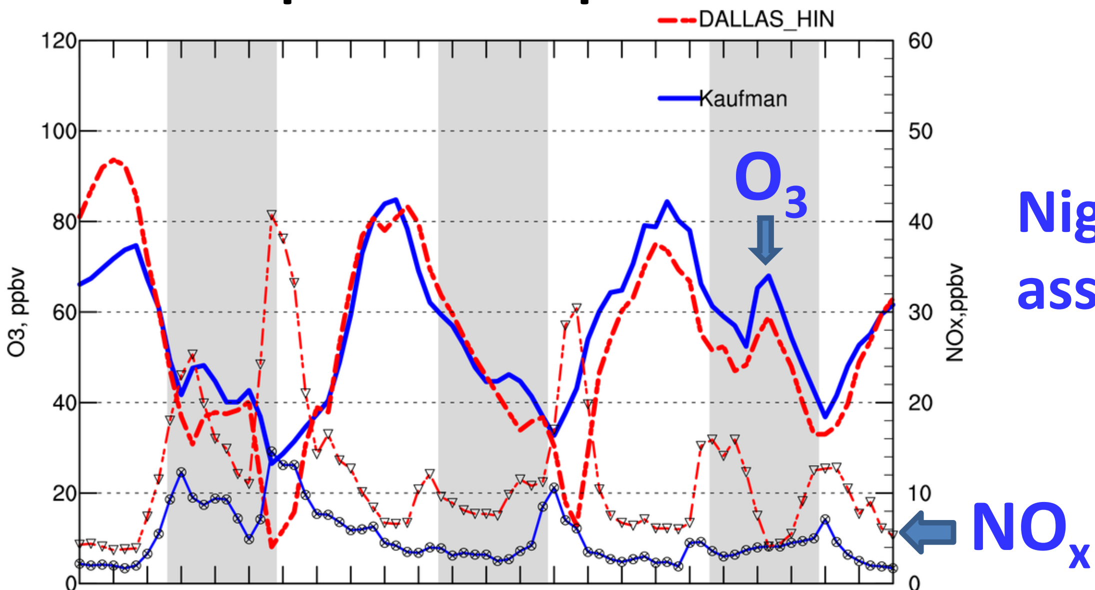
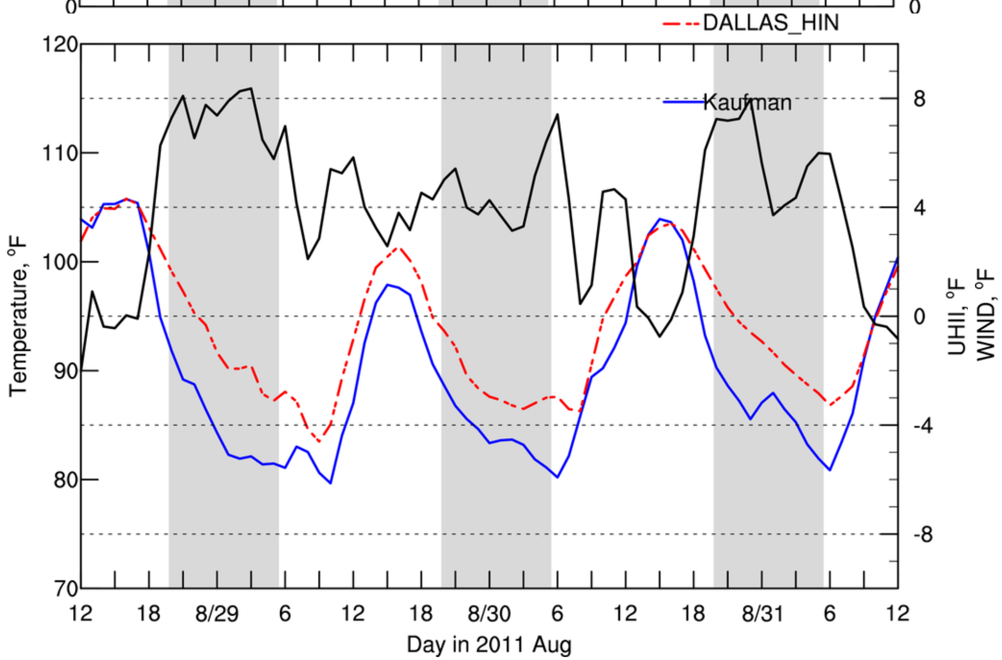
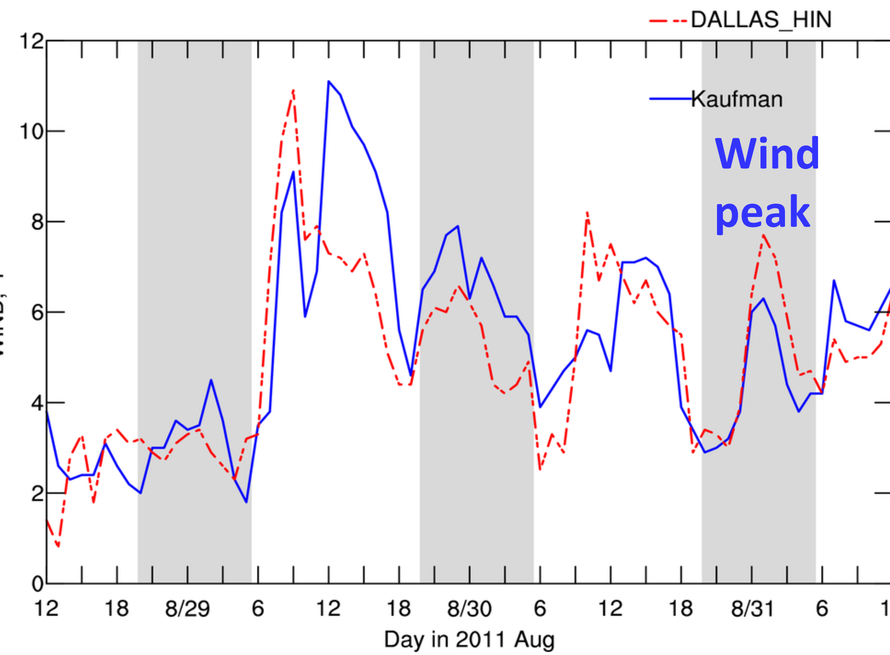
Unique temporal variation of nocturnal O_3



Nighttime O_3 maxima associated with collapse of UHI



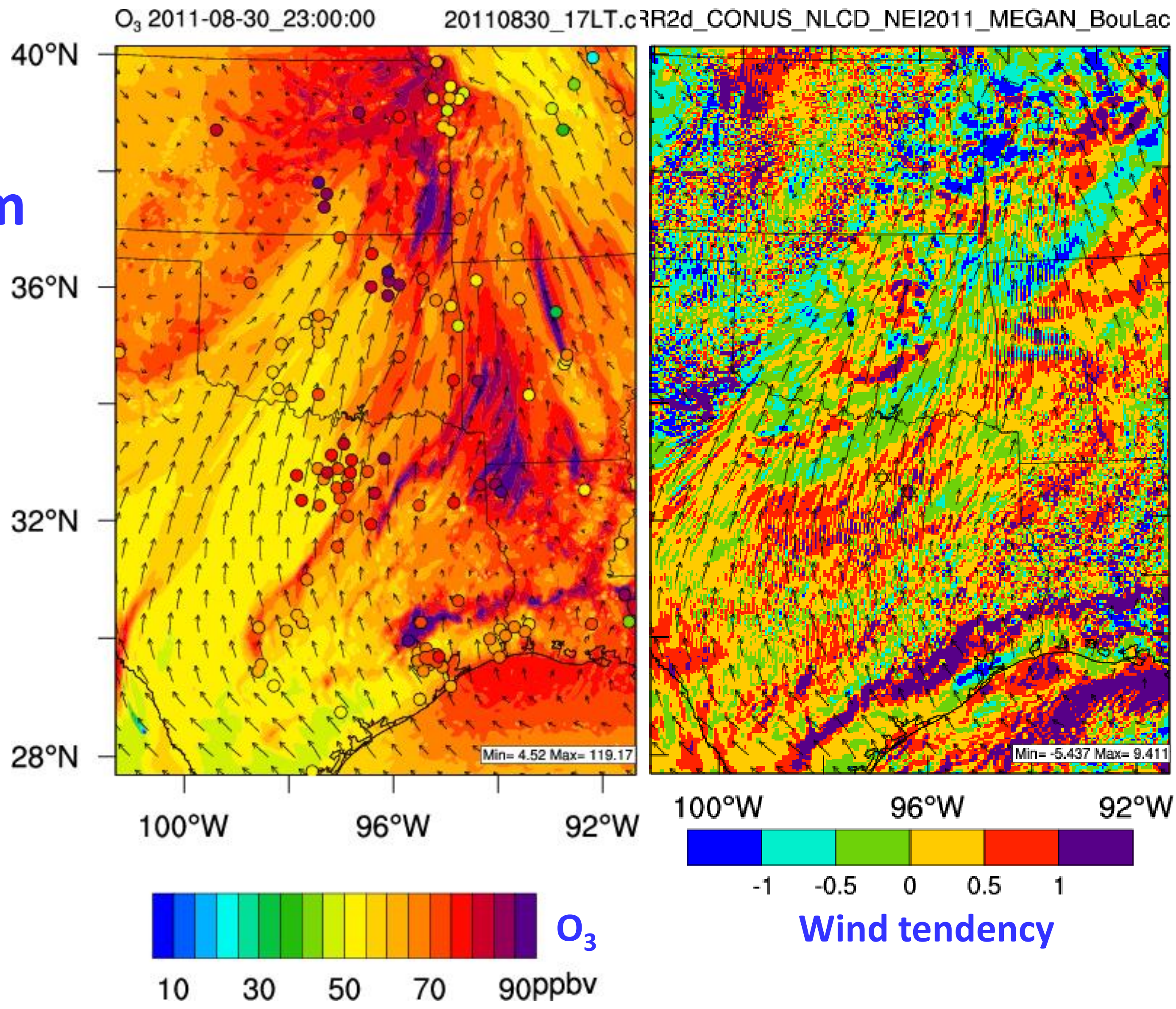


Impact of sea breeze fronts on O_3 in the afternoon

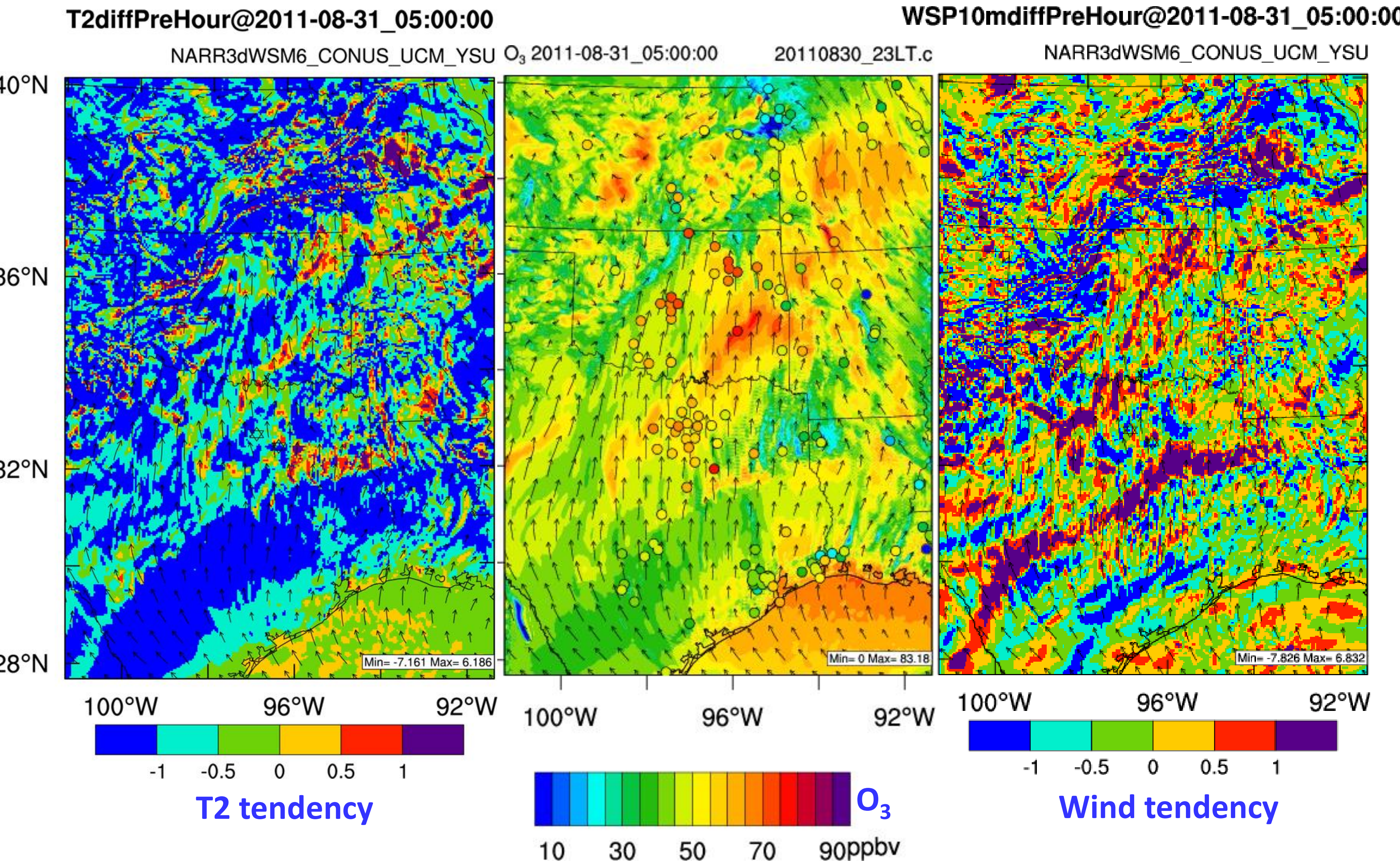
WRF/Chem 3.7

Emission:
NEI2011
MEGAN

IC/BC:
NARR



Impact of sea breeze front on O_3 at night



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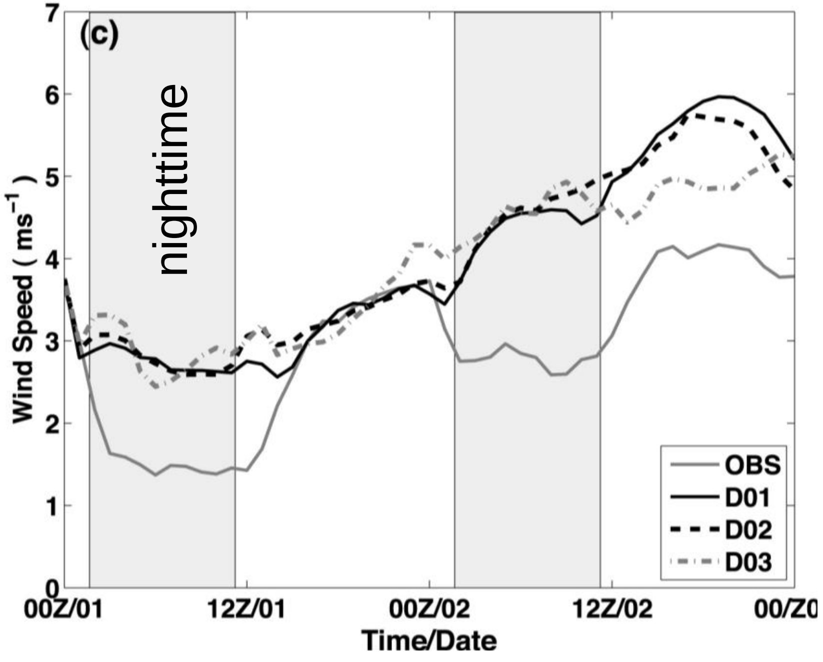
Current status of performance of PBL schemes

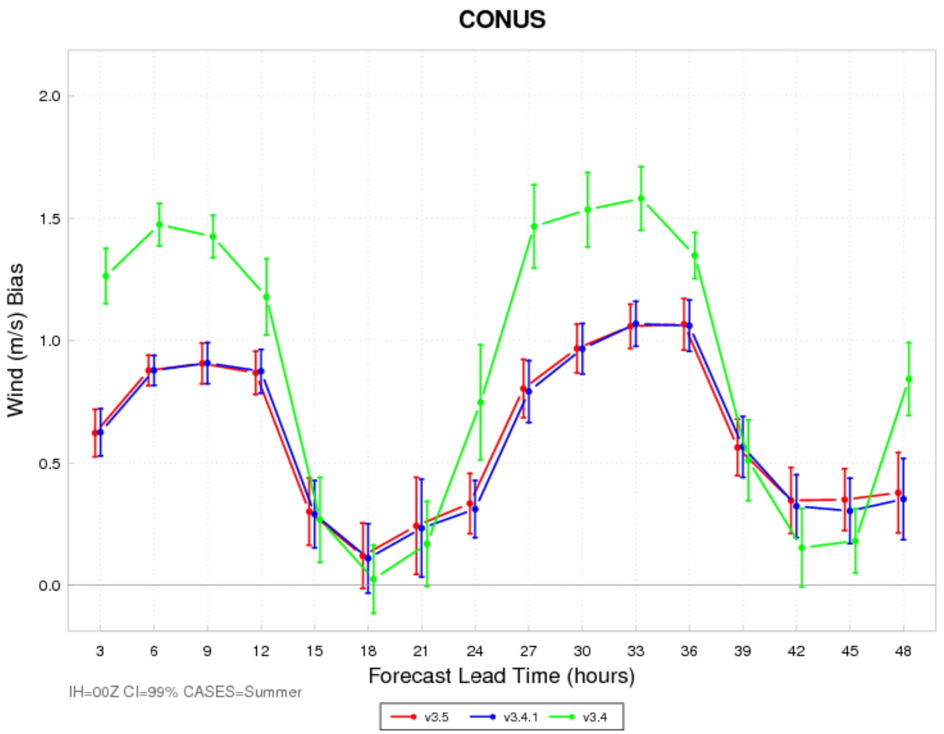
- Errors and uncertainties associated with PBL schemes still remain one of the primary sources of inaccuracies of model simulations
- While much progress has been made in simulating daytime convective boundary layer (CBL), progress with the modeling of nighttime boundary layer has been slower

PBL schemes play critical roles for simulation of wind, turbulence, and air quality in the boundary layer

Systematic over-estimations of near-surface winds during stable conditions with several models

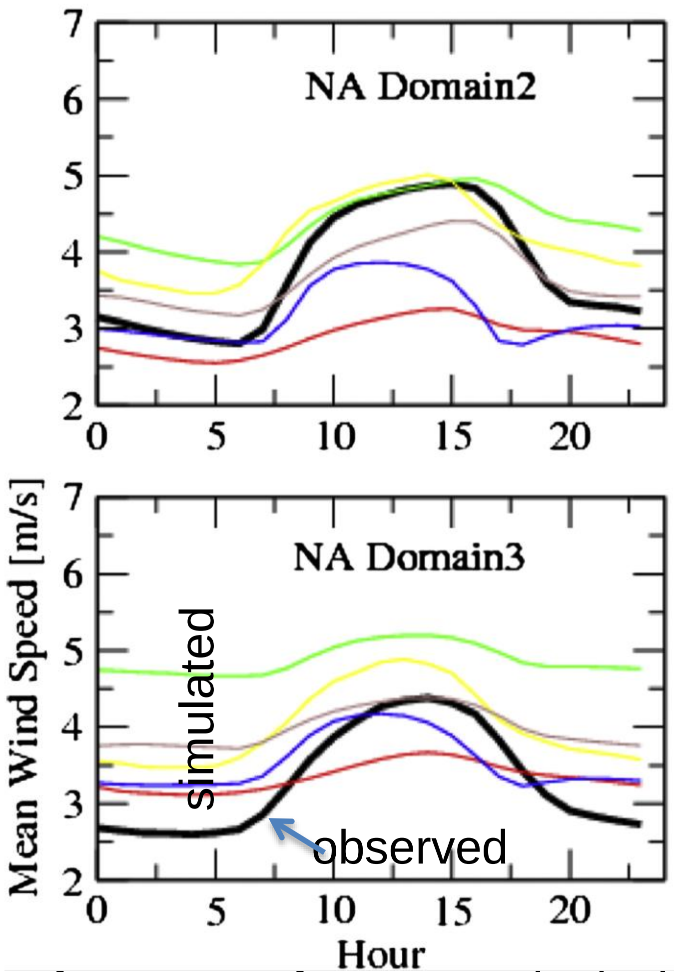


WRFV3.3 with YSU (Zhang et al., 2013)



WRF (Wolff and Harrold, 2013)

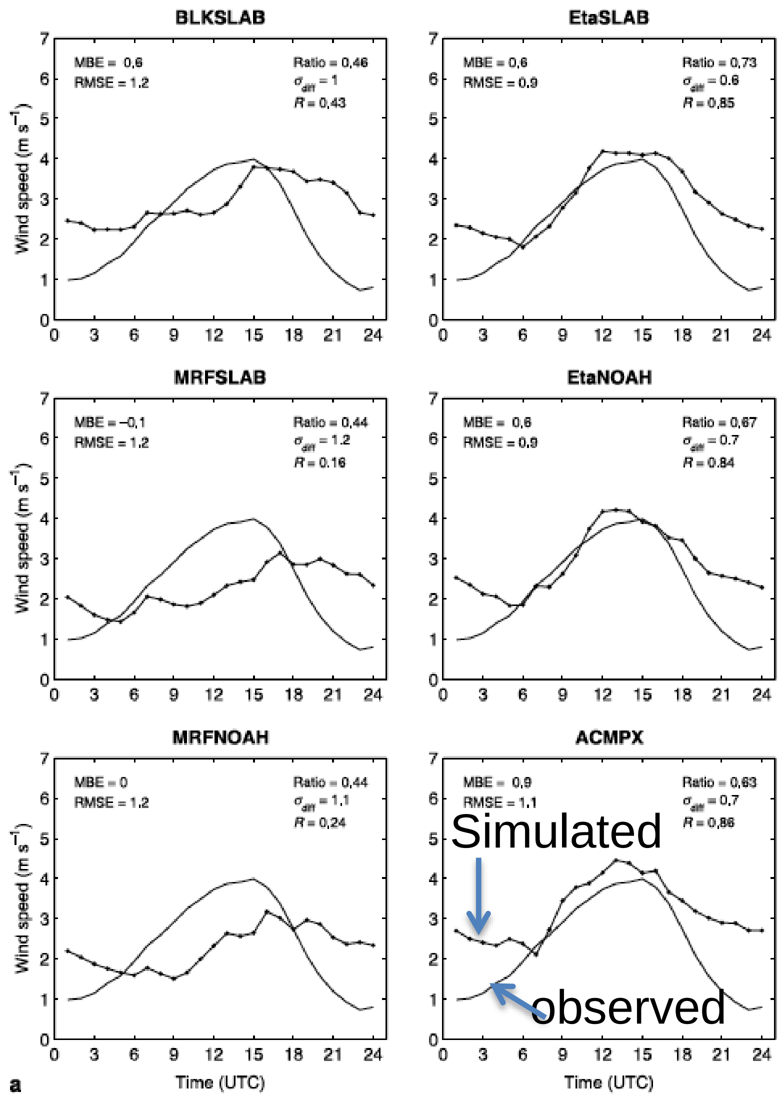
Over-estimation of near-surface winds during stable conditions (2)



Performance of 5 meteorological models (Vautard et al., 2012)

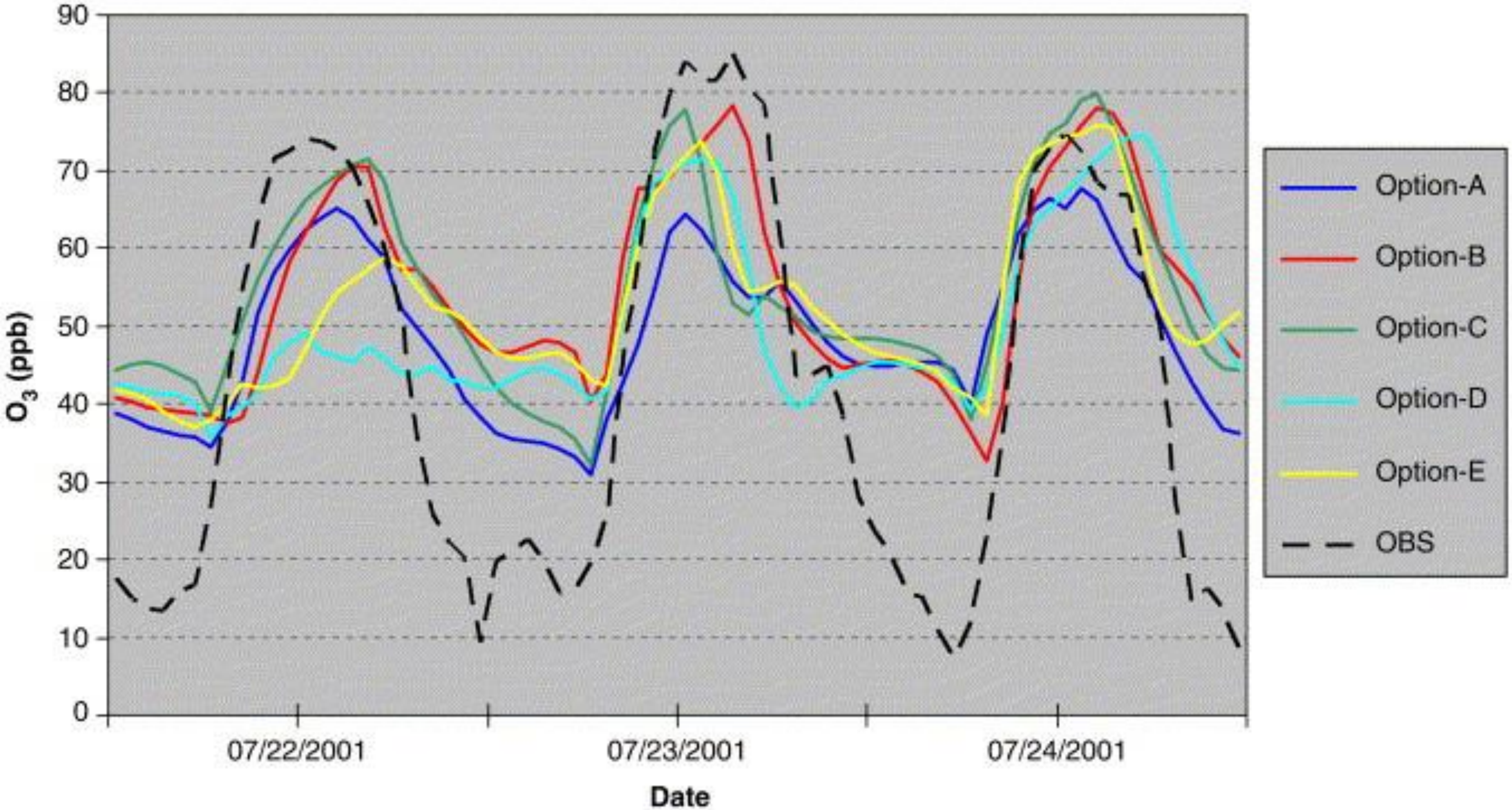
Systematic positive model biases for surface wind speed during nighttime.

Over-estimations of near-surface winds during stable conditions (3)



Performance of MM5 applied in Sweden (Miao et al., 2008)

Overestimation of nighttime surface O_3

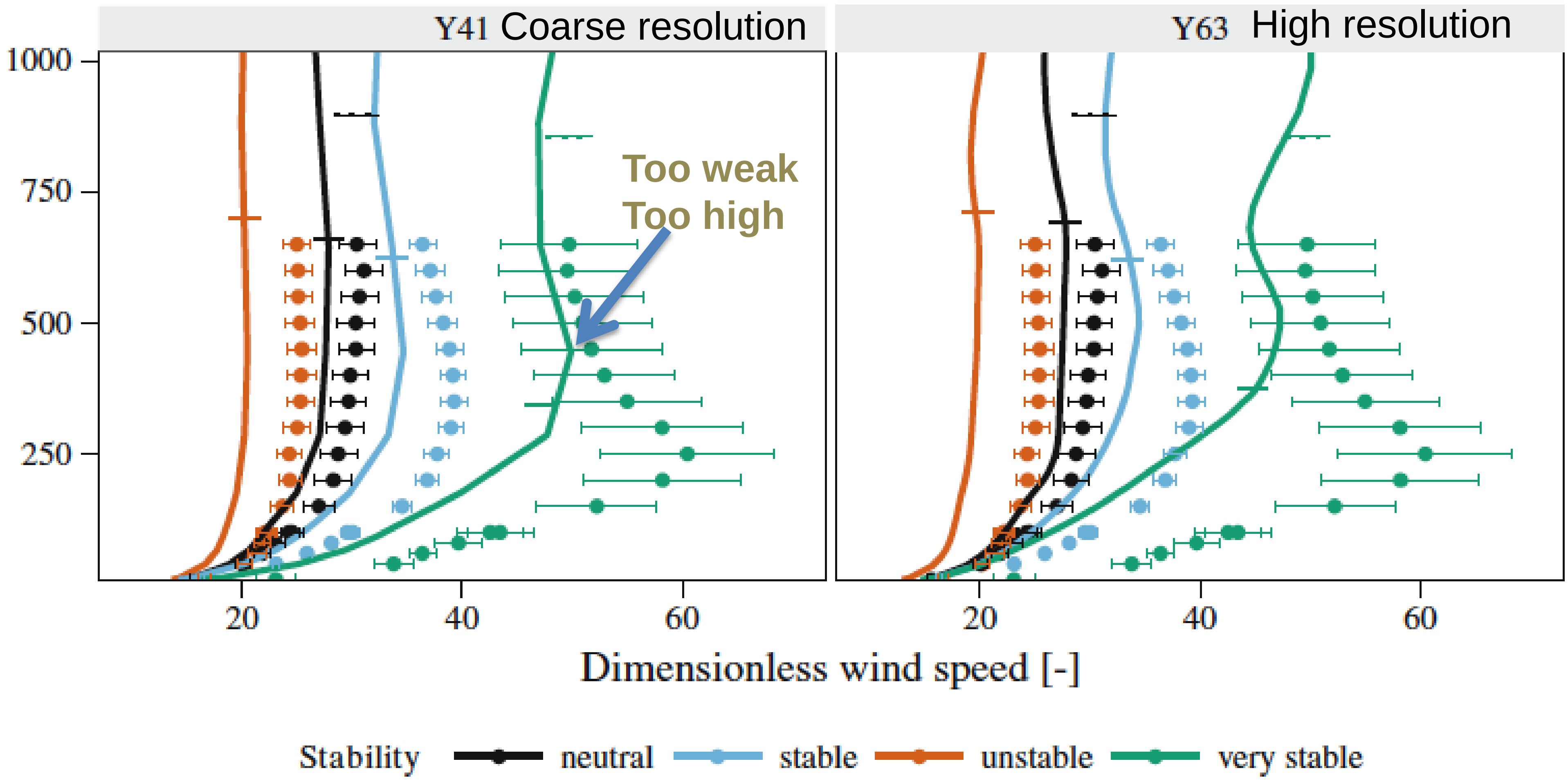


MM5-CMAQ (Mao et al., 2006)

Summary of current status

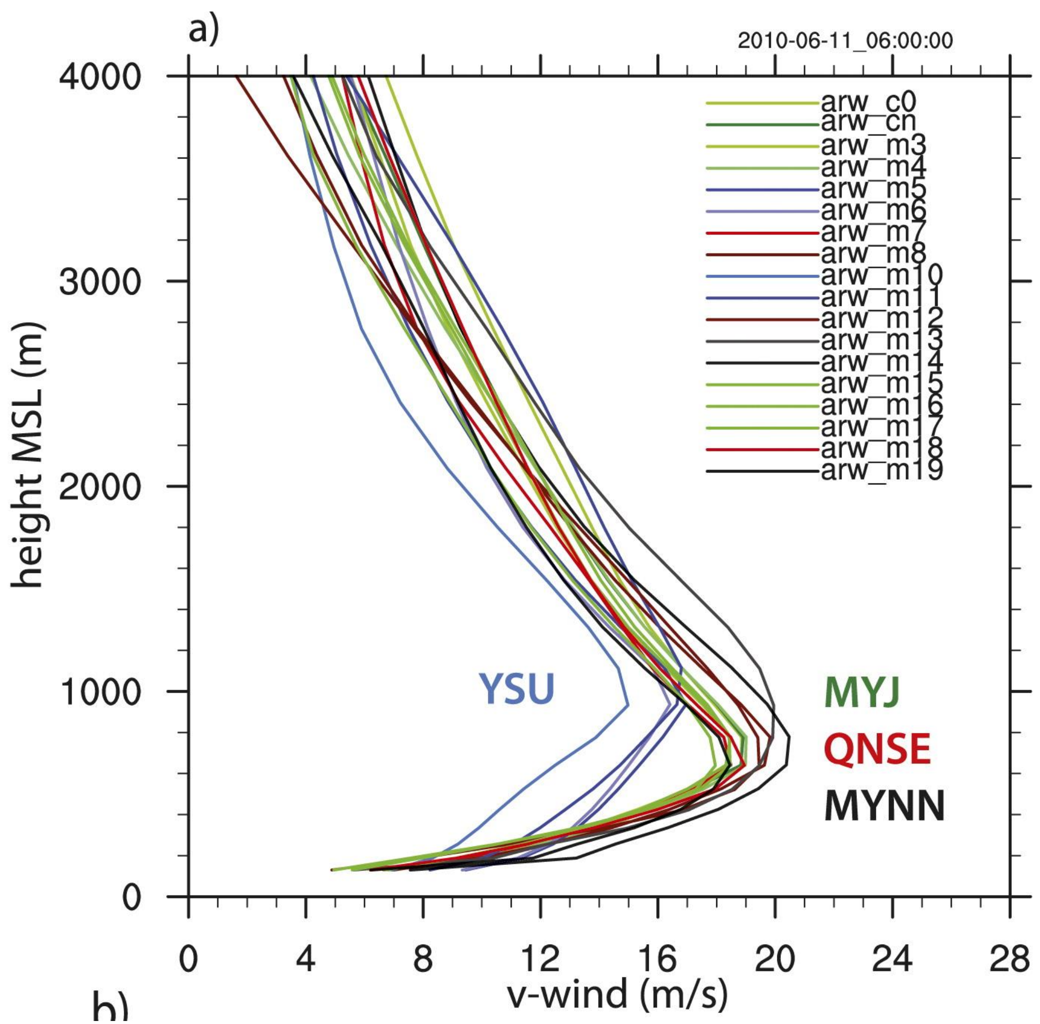
- A few models face the problem of overestimation of near-surface wind and O_3 during nighttime.
- Previous studies did not identify the exact cause and solution.
- PBL schemes play critical roles for simulation of wind, and air quality in the boundary layer. Would PBL schemes be fully responsible for the problems?

Past evaluation of the YSU PBL scheme
One of the mostly widely used schemes



Longstanding problem with YSU in WRF:
simulating weaker and higher LLJs (Floors et al., 2013)

Past evaluation of YSU (2)

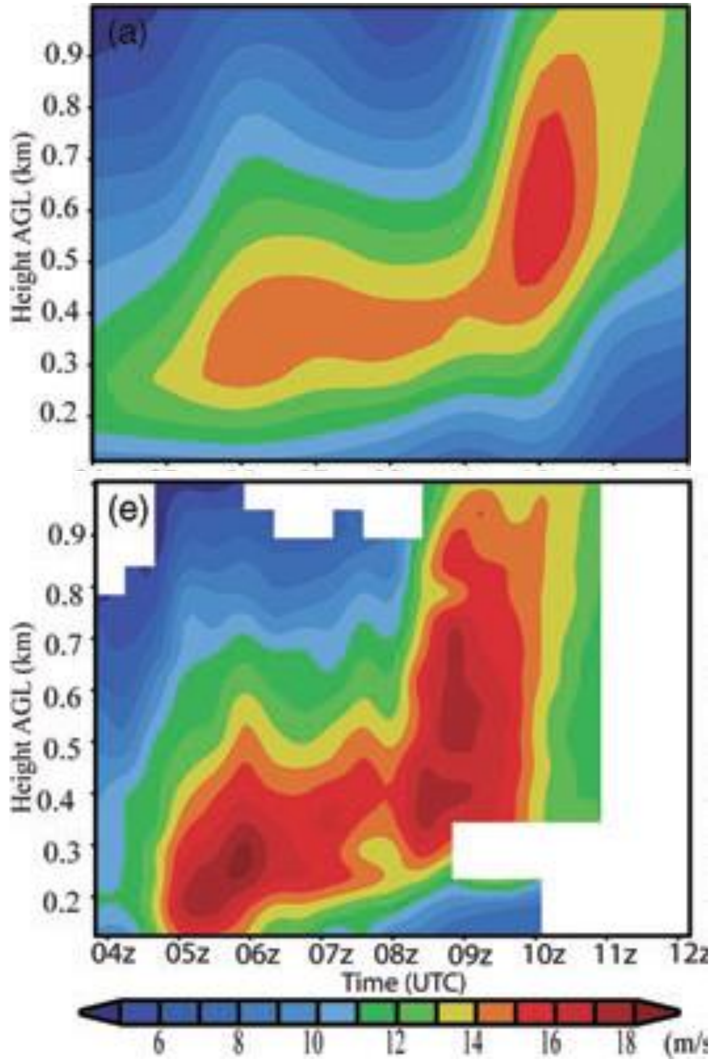


(Schumacher et al., 2013)
Simulations from CAPS 2010 Spring Experiment

Past evaluation of YSU (3)

YSU

Observation



Time-height diagram of wind speed (Storm et al., 2009)

Updates of YSU from V3.4 to V3.4.1

Eddy diffusivity $$K_m = k w_s z \left(1 - \frac{z}{h}\right)^2$$

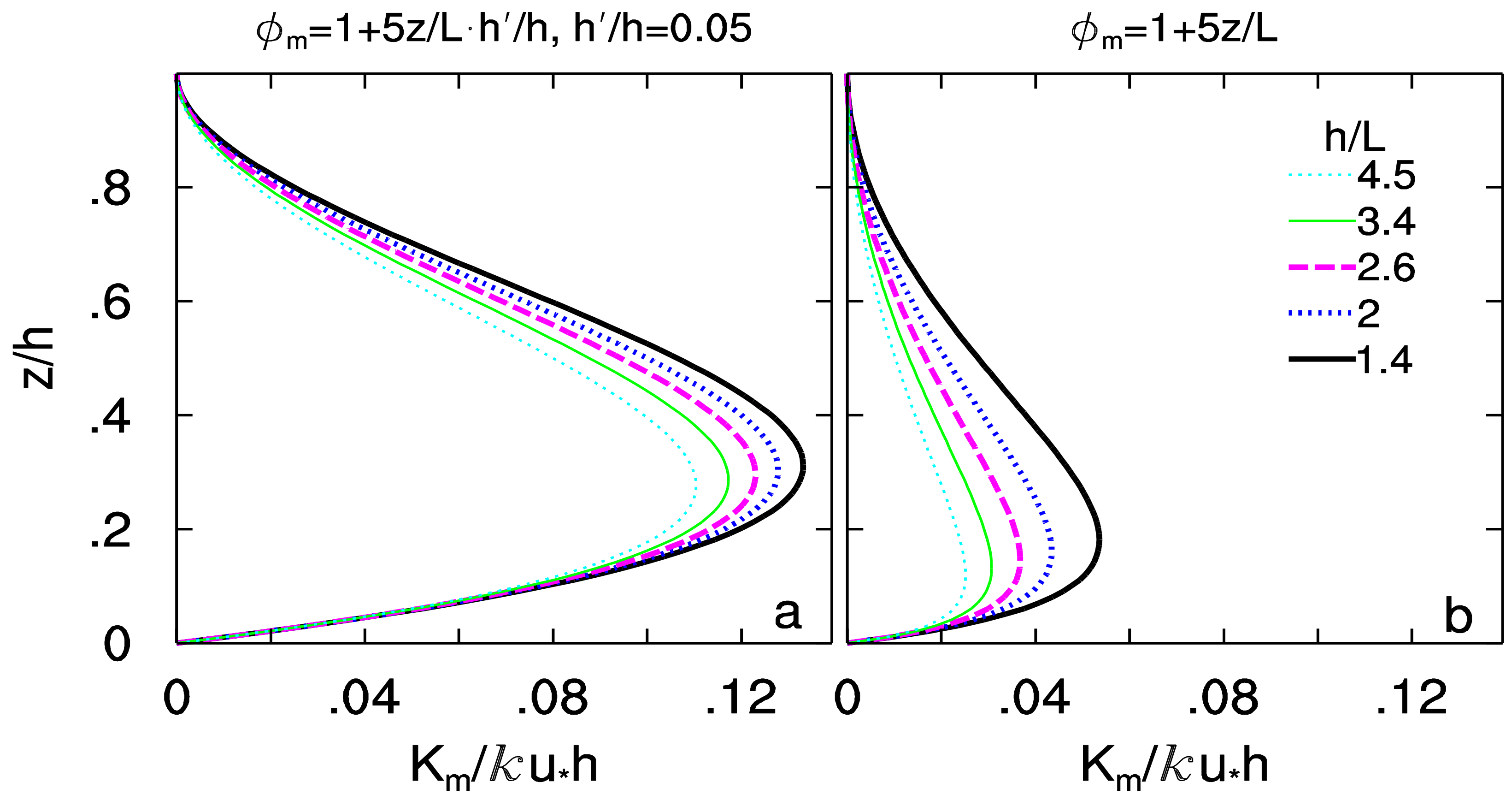
Velocity scale $$w_s = u_* / \Phi_m$$

Version 3.4 and earlier $$\phi_m = 1 + 5 \frac{z}{L} \cdot \frac{h'}{h}$$

Version 3.4.1 $$\phi_m = 1 + 5 \frac{z}{L}$$

h' is diagnosed using a critical Richardson # of 0 while h is diagnosed using Ri # of 0.25

Vertical profiles of K_m under different stabilities



Old YSU in earlier WRF (i.e., 3.4 and earlier)

Updated YSU in WRF 3.4.1

Vertical mixing simulated by the updated YSU in WRF is reduced

Objectives of this part

- **Document the impact of YSU updates on the boundary layer prediction.**
- **Evaluate PBL schemes for wind resource and air quality assessments.**
- **Diagnose possible reasons for the often reported overestimation problem for near-surface wind and O_3**

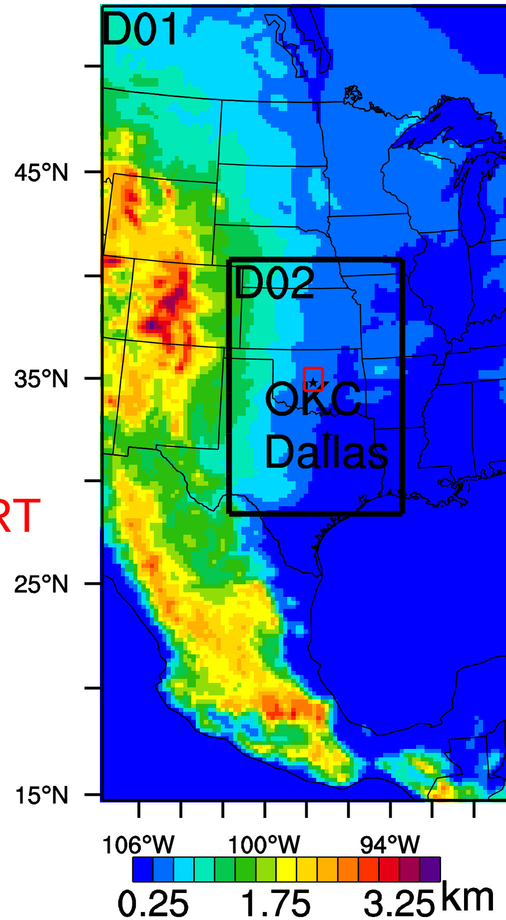
Numerical experiments with WRF/Chem

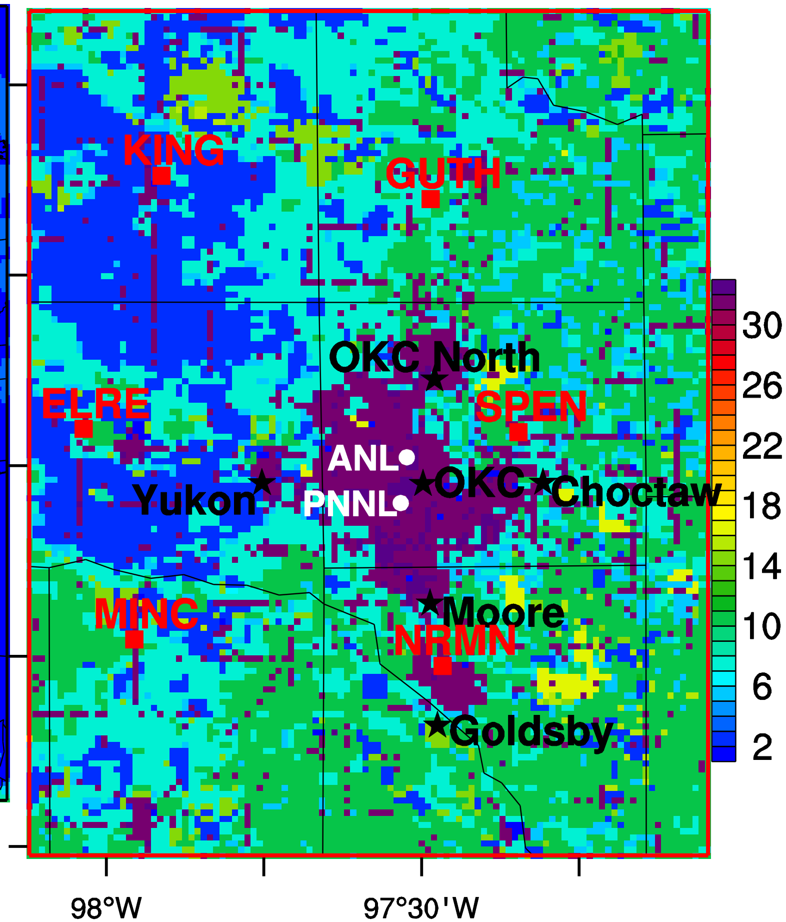
Abbreviation	WRF version	PBL scheme	Surface layer scheme* (option number in WRF)
YSU3.4	**3.4**	**old YSU**	MM5 similarity (1)
YSU3.4+	**3.4**	**updated YSU**	MM5 similarity (1)
YSU3.4.1	**3.4.1**	**updated YSU**	MM5 similarity (1)
MYJ	3.4.1	MYJ	Eta similarity (2)
MYNN2	3.4.1	MYNN2	Eta similarity (2)
BouLac	3.4.1	BouLac	Eta similarity (2)
QNSE	3.4.1	QNSE	QNSE (4)
UW	3.4.1	UW	Eta similarity (2)

To isolate the impact of YSU update, the updated YSU from WRF3.4.1 is implemented into WRF3.4. The experiment with this version is referred to as YSU3.4+

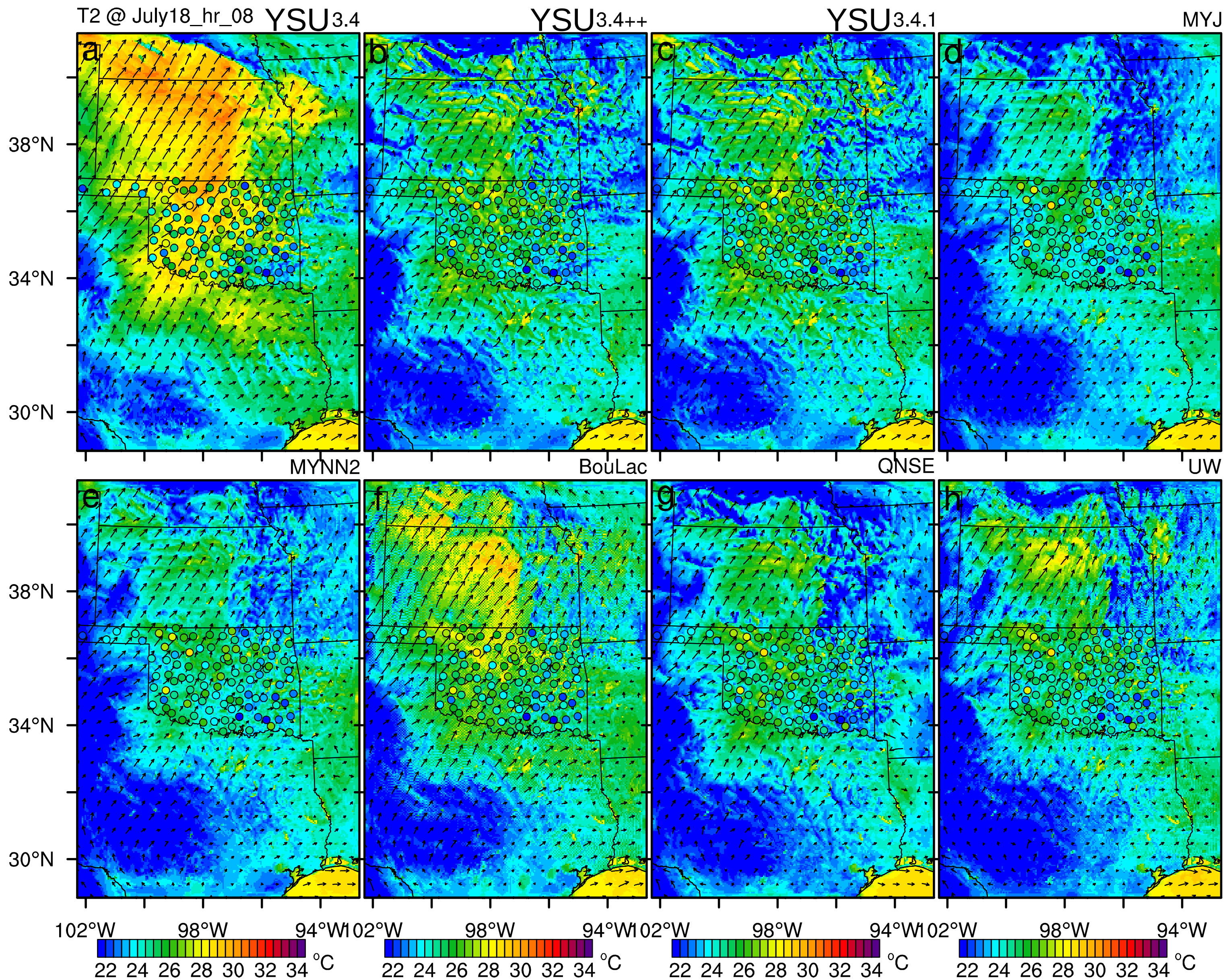
Domain configuration and observation sites around OKC

Resolution: 22.5->4.5km
Episode: July 17-19, 2003
Initial conditions
meteo: FNL
chemical: MOZART
Emission: NEI2005

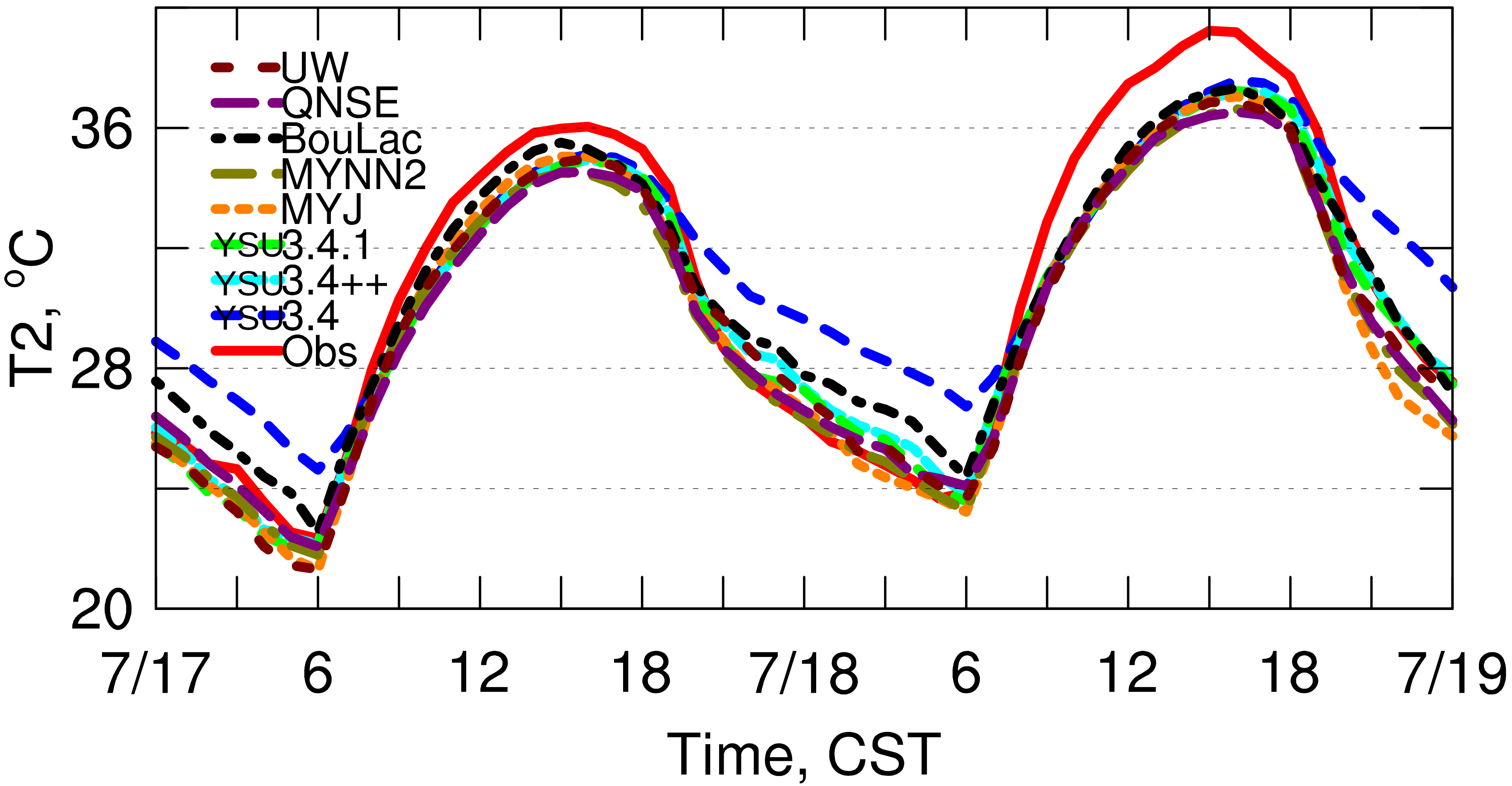




YSU3.4 overestimates nighttime T2

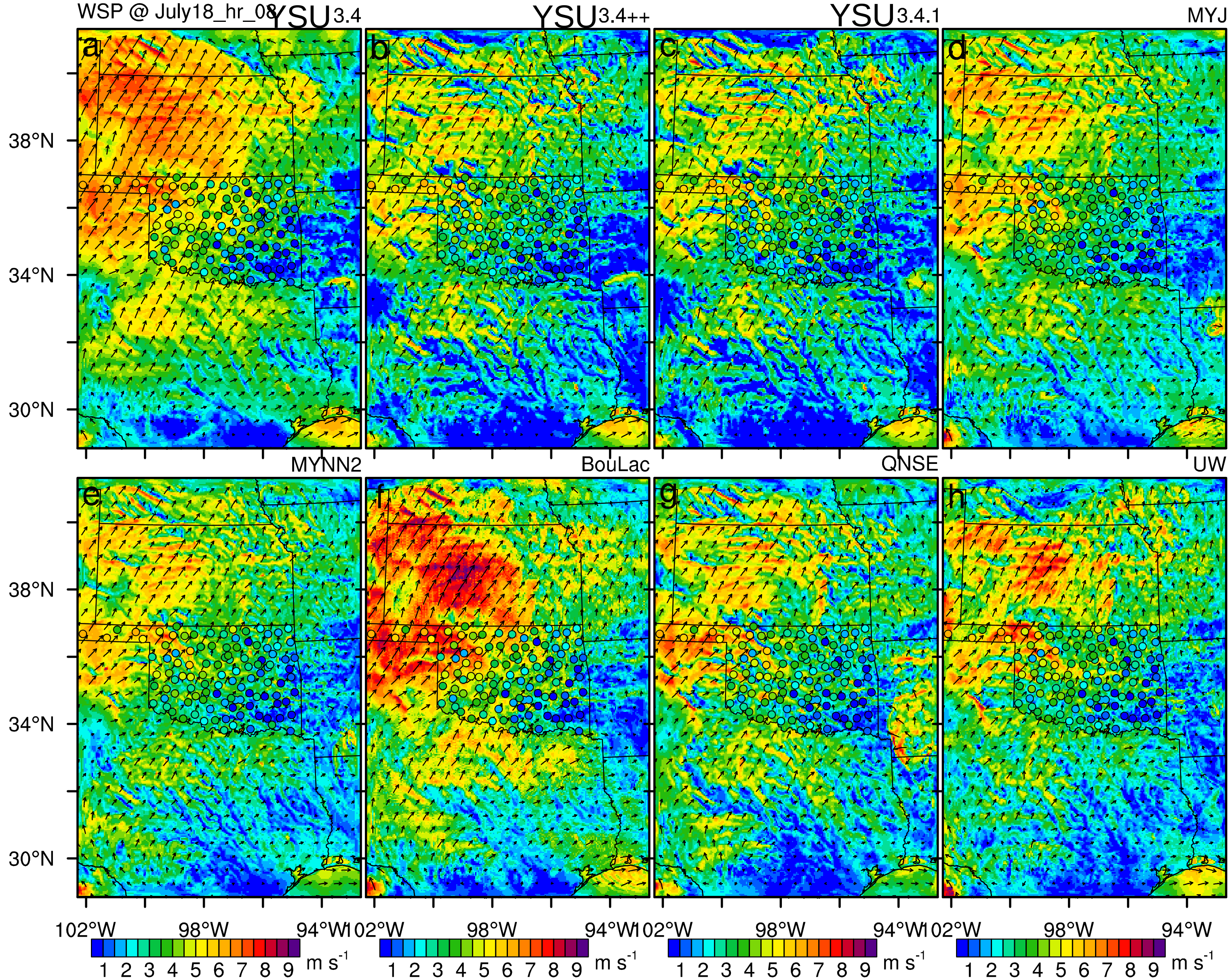


Temporal variation of T2

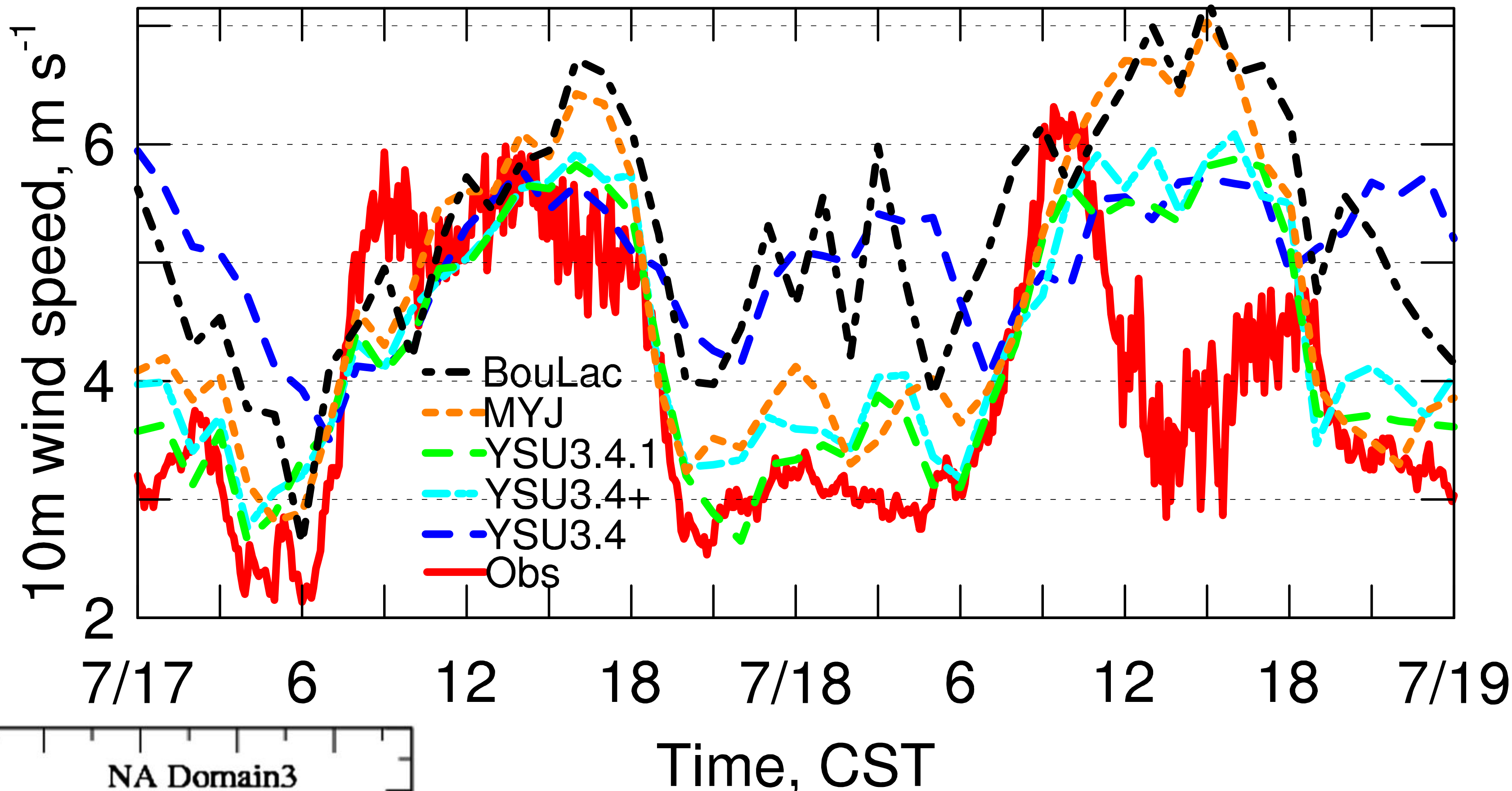


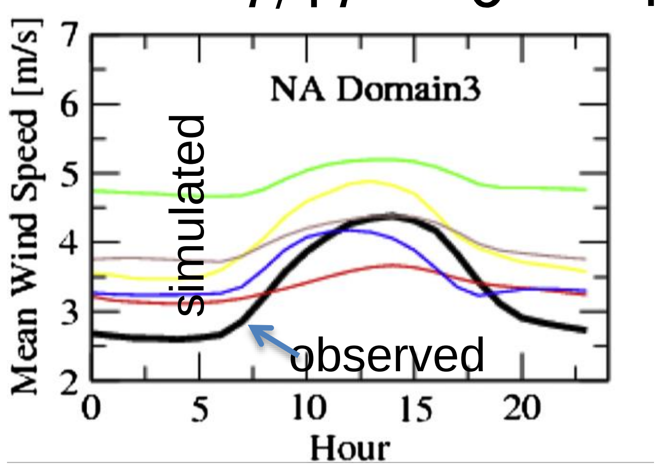
YSU3.4 stands out during nighttime, BouLac has a similar but less severe problem
The nighttime performance is improved with the updated YSU.

YSU3.4 and BouLac overestimates nighttime wind speed at 10 m AGL



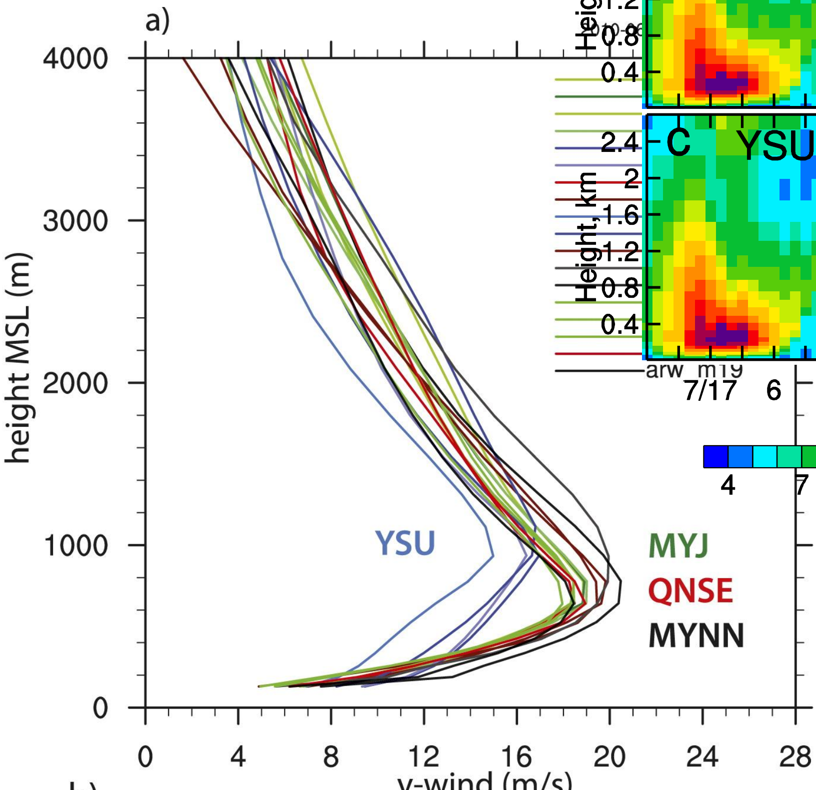
Improvement for nighttime wind

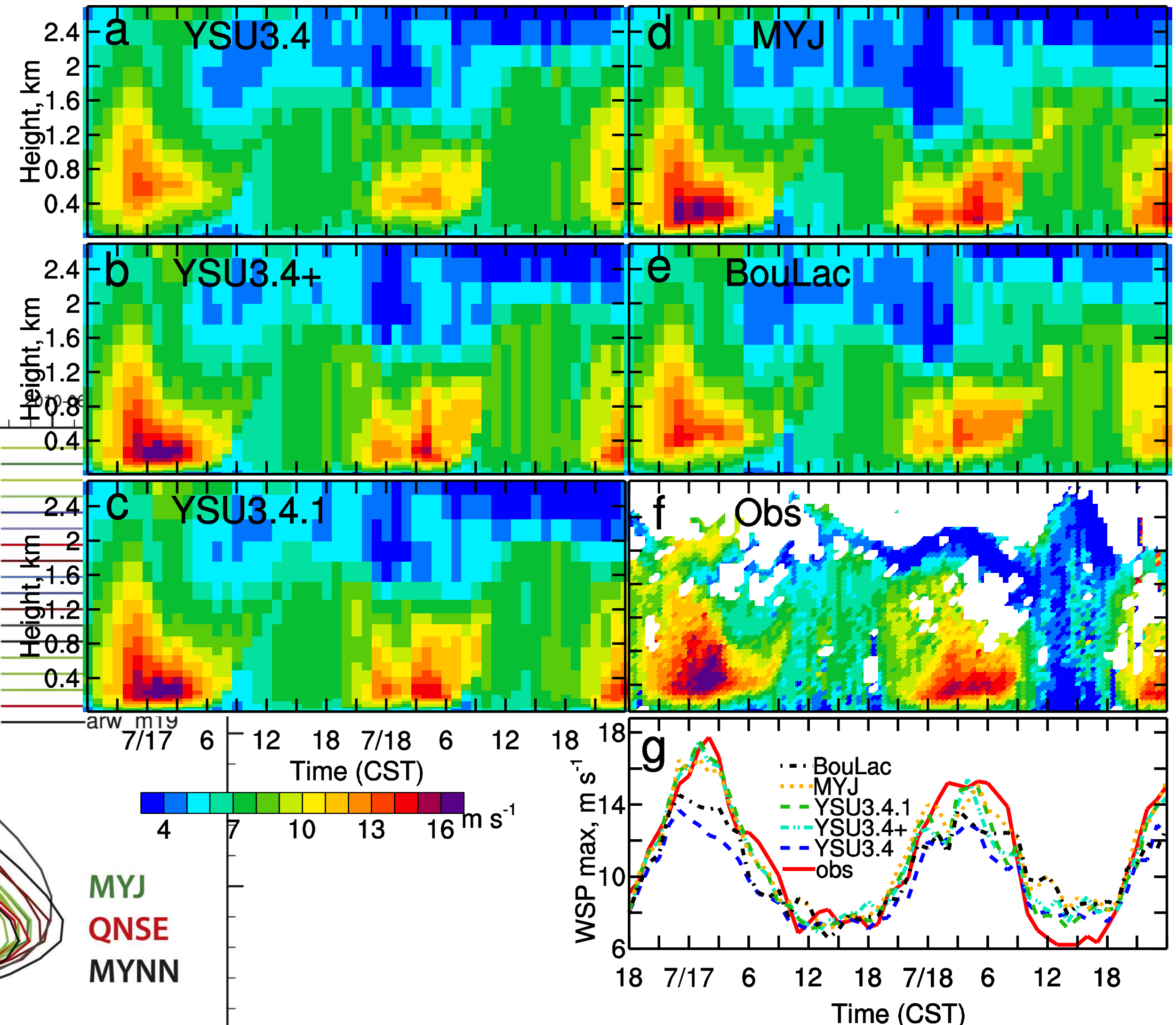




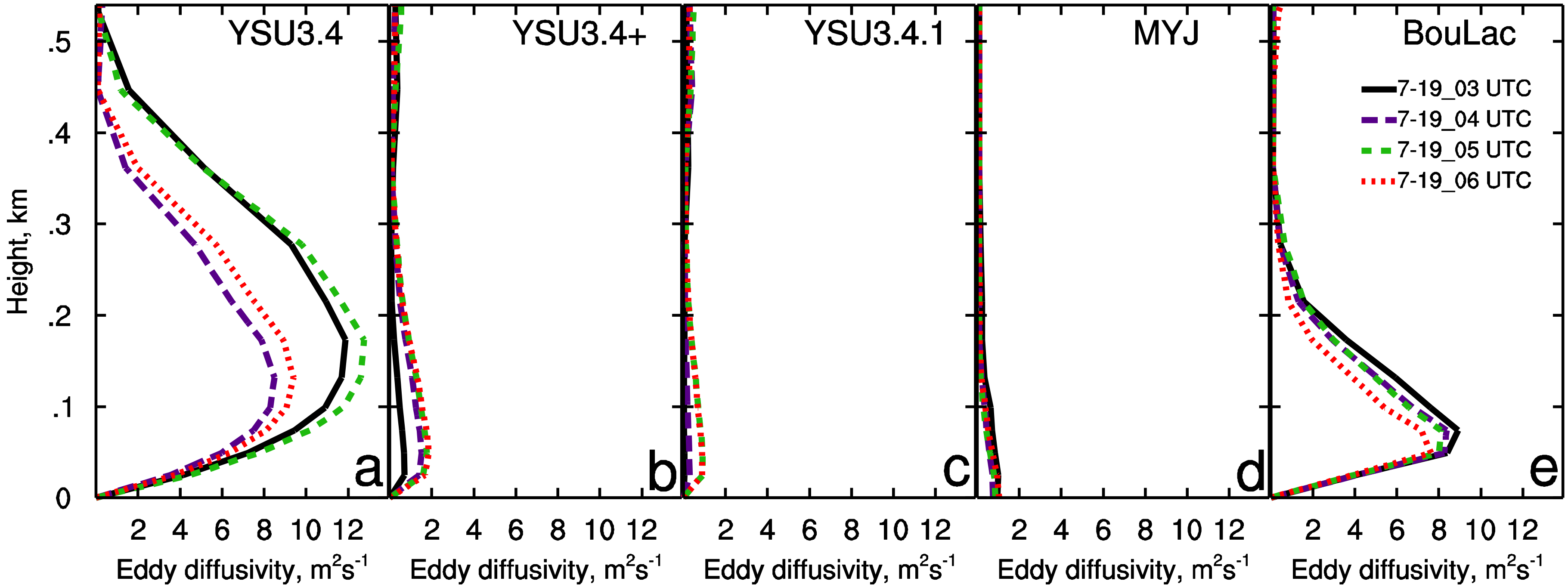
The update of YSU did not affect daytime simulation but improved performance during nighttime

The updated YSU better reproduces LLJs



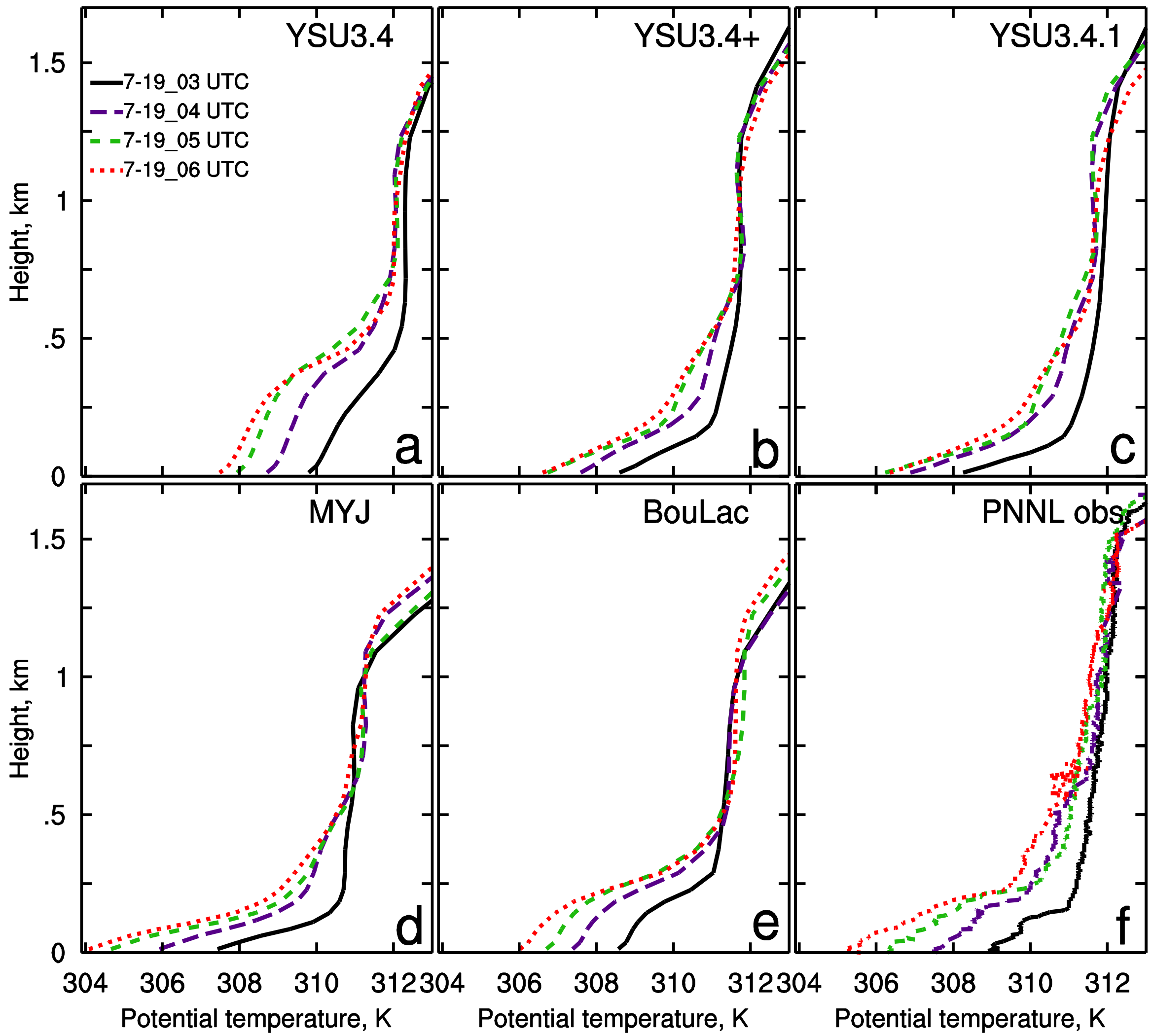


Root cause of the improvement



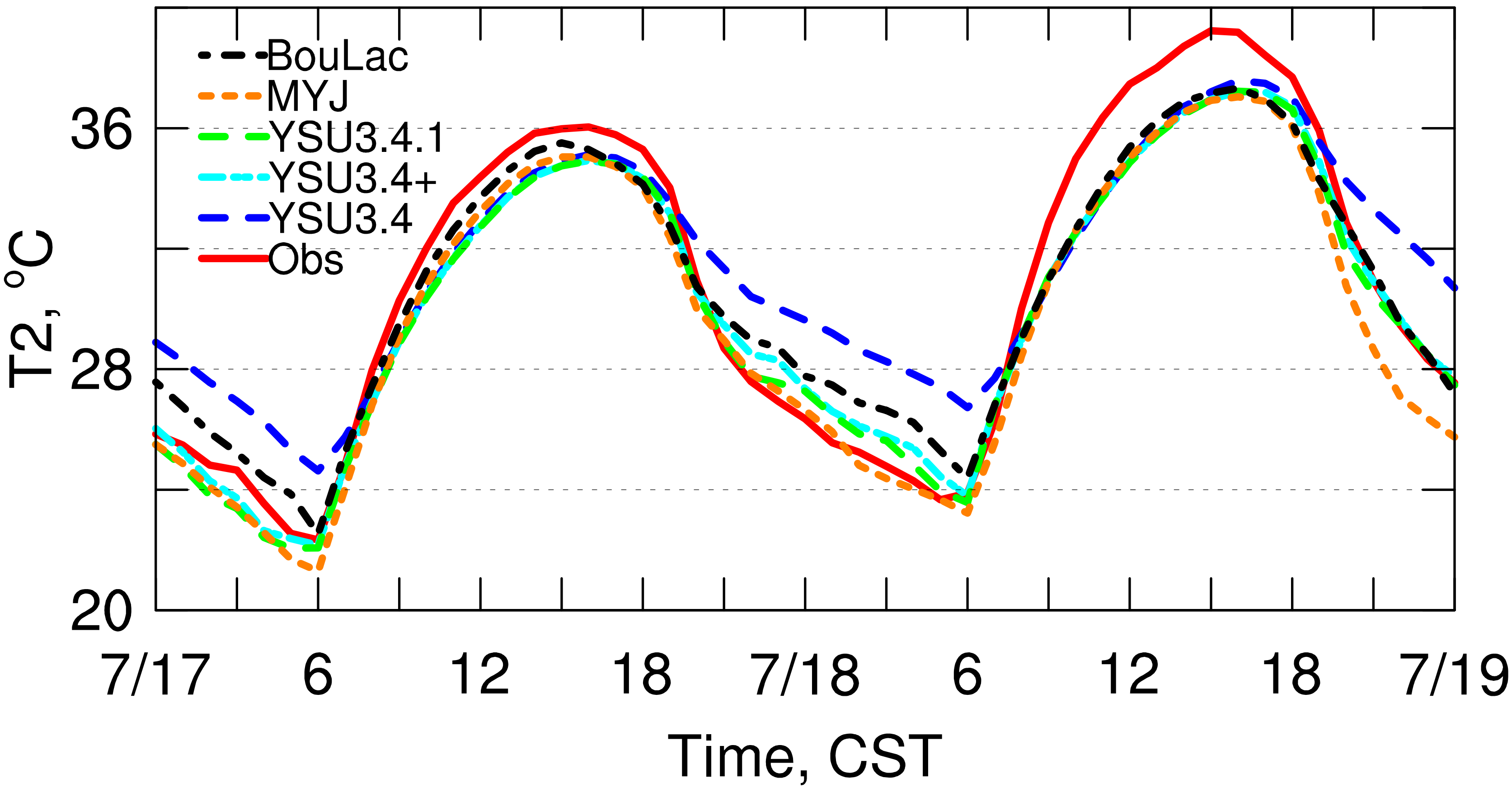
The updated YSU reduces nighttime vertical mixing
The BouLac has a similar problem as the old YSU

Improvement in vertical thermal structure



The old YSU simulates too neutral boundary layer, while the updated YSU simulates a more stable boundary layer.

Temporal variation of T2



The nighttime performance is improved with the updated YSU.

Conclusions

1. The update of the YSU scheme in WRF3.4.1 improved predictions of the nighttime boundary layer and can thus provide better wind resource and air quality assessments
2. The BouLac scheme gives the strongest vertical mixing in the nighttime boundary layer. It consequently overestimates near-surface wind and temperature and underestimates the wind shear exponent at night.

References

1. **Hu, X.-M.**, et al. (2013), Impact of Low-Level Jets on the Nocturnal Urban Heat Island Intensity in Oklahoma City. *J. Appl. Meteor. Climatol.*, 52, 1779–1802.
2. **Hu, X.-M.**, et al. (2013a), Enhanced vertical mixing associated with a nocturnal cold front passage and its impact on near-surface temperature and ozone concentration, *J. Geophys. Res.*, 118, 2714– 2728.
3. **Hu, X.-M.**, P. M. Klein, and M. Xue (2013b), Evaluation of the updated YSU Planetary Boundary Layer Scheme within WRF for Wind Resource and Air Quality Assessments, J. Geophys. Res., 118, doi:10.1002/jgrd.50823.
4. **Hu, X.-M.**, et al. (2014), Impact of the Loess Plateau on the Atmospheric Boundary Layer Structure and Air Quality in the North China Plain: A Case Study, *Science of the Total Environment*, 10.1016/j.scitotenv.2014.08.053
5. **Hu, X.-M.**, and M. Xue (2015), Influence of synoptic sea breeze fronts on the urban heat island intensity in Dallas-Fort Worth, Texas, *Mon. Wea. Rev.*, conditionally accepted.