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Evaluation of Three Planetary Boundary Layer Schemes in the WRF Model

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Introduction

- Different PBL schemes adopt different assumptions regarding the transport of mass, moisture, and energy, which may lead to differences in the boundary layer and subsequently the whole model domain.
- A few recent studies also examined the sensitivity of next-generation Weather Research and Forecast(WRF)model predictions to PBL schemes.
- However, none of these studies attempted to attribute the root causes of model performance differences to the different assumptions in each scheme.

Introduction

- In this study WRF, version 3.0.1, is used to simulate the meteorological conditions of the Texas region in summer 2005, during the Second Texas Air Quality Study(TexAQS2; Parrish et al. 2009).
- Observations collected during TexAQS2 provide a comprehensive validation dataset for model experiments.
- The sensitivities of the WRF simulations to the use of two frequently used PBL schemes, the YSU scheme and the Mellor–Yamada–Janjic(MYJ) scheme, as well as the recently added ACM2 scheme, are examined.

Description of the three PBL schemes

- The MYJ PBL scheme uses the 1.5-order (level 2.5) turbulence closure model of Mellor and Yamada (1982) to represent turbulence above the surface layer (Janjic 1990, 1994, 2001). The MYJ scheme determines eddy diffusion coefficients from prognostically calculated turbulent kinetic energy (TKE).Mellor and Yamada (1982) argue that the scheme is appropriate for all stable and slightly unstable flows, but that errors are more likely as the flow approaches the free-convection limit.

Description of the three PBL schemes

- The YSU PBL scheme (Hong et al. 2006) is a first-order nonlocal scheme, with a countergradient term in the eddy-diffusion equation. The YSU scheme is modified in WRF version 3 from the Hong et al. (2006) formulation by increasing the critical bulk Richardson number from zero to 0.25 over land, thereby enhancing mixing in the stable boundary layer (Hong and Kim 2008).

Description of the three PBL schemes

- The ACM2 PBL scheme (Pleim 2007a,b) includes a first-order eddy-diffusion component in addition to the explicit nonlocal transport of the original ACM1 scheme (Pleim and Chang 1992). This modification is designed to improve the shape of vertical profiles near the surface. For stable or neutral conditions, the ACM2 scheme shuts off nonlocal transport and uses local closure.

WRF model simulations with the three PBL schemes

Data for model validation includes surface observations at National Weather Service (NWS) and Federal Aviation Administration (FAA) sites and at Texas Commission on Environmental Quality (TCEQ) sites, aircraft data from the Aircraft Communications Addressing and Reporting System (ACARS), and mixing heights estimated from radar wind profilers.

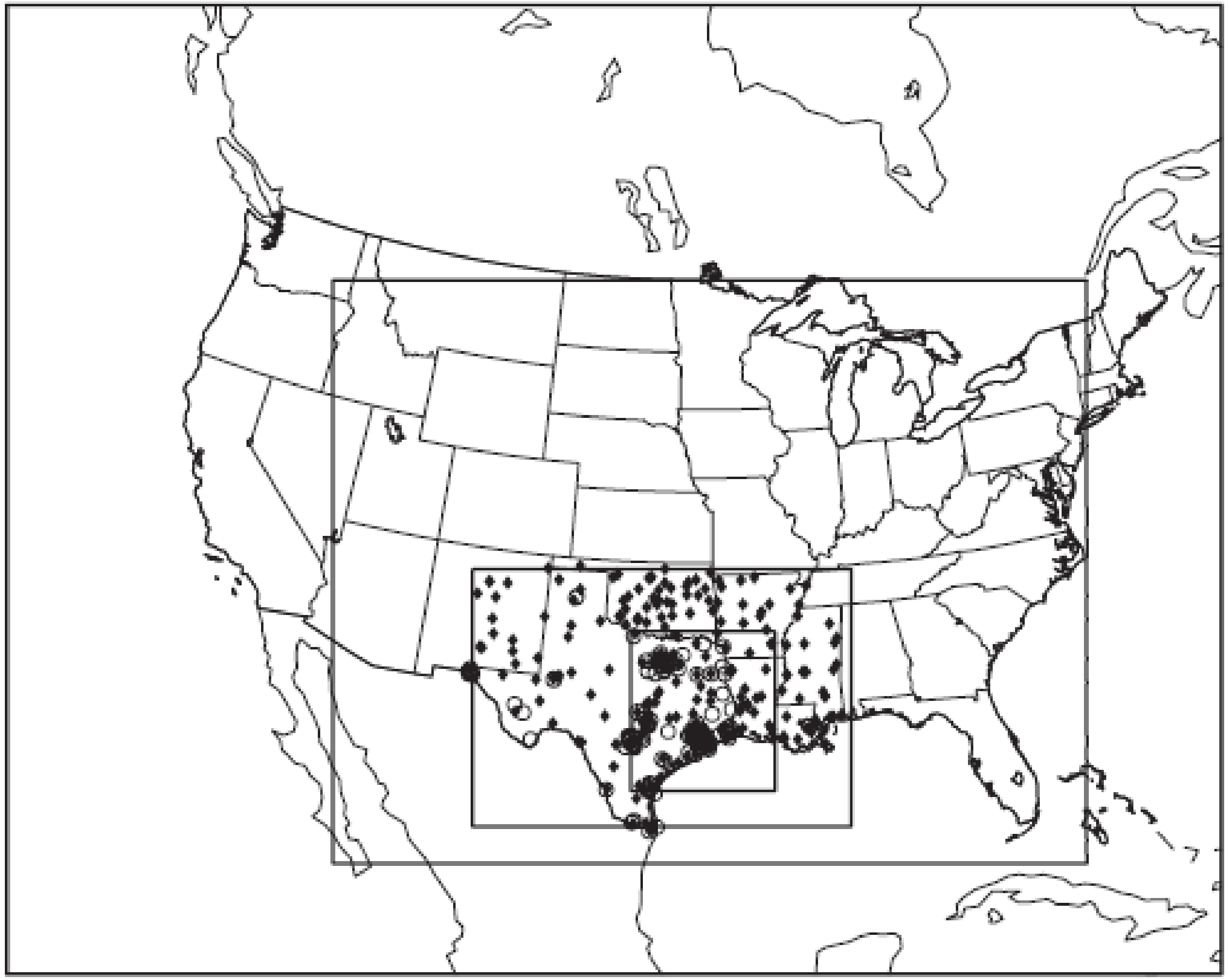

FIG. 1. Map of model domains and locations of TCEQ (circles) and NWS–FAA (diamonds) observation sites.

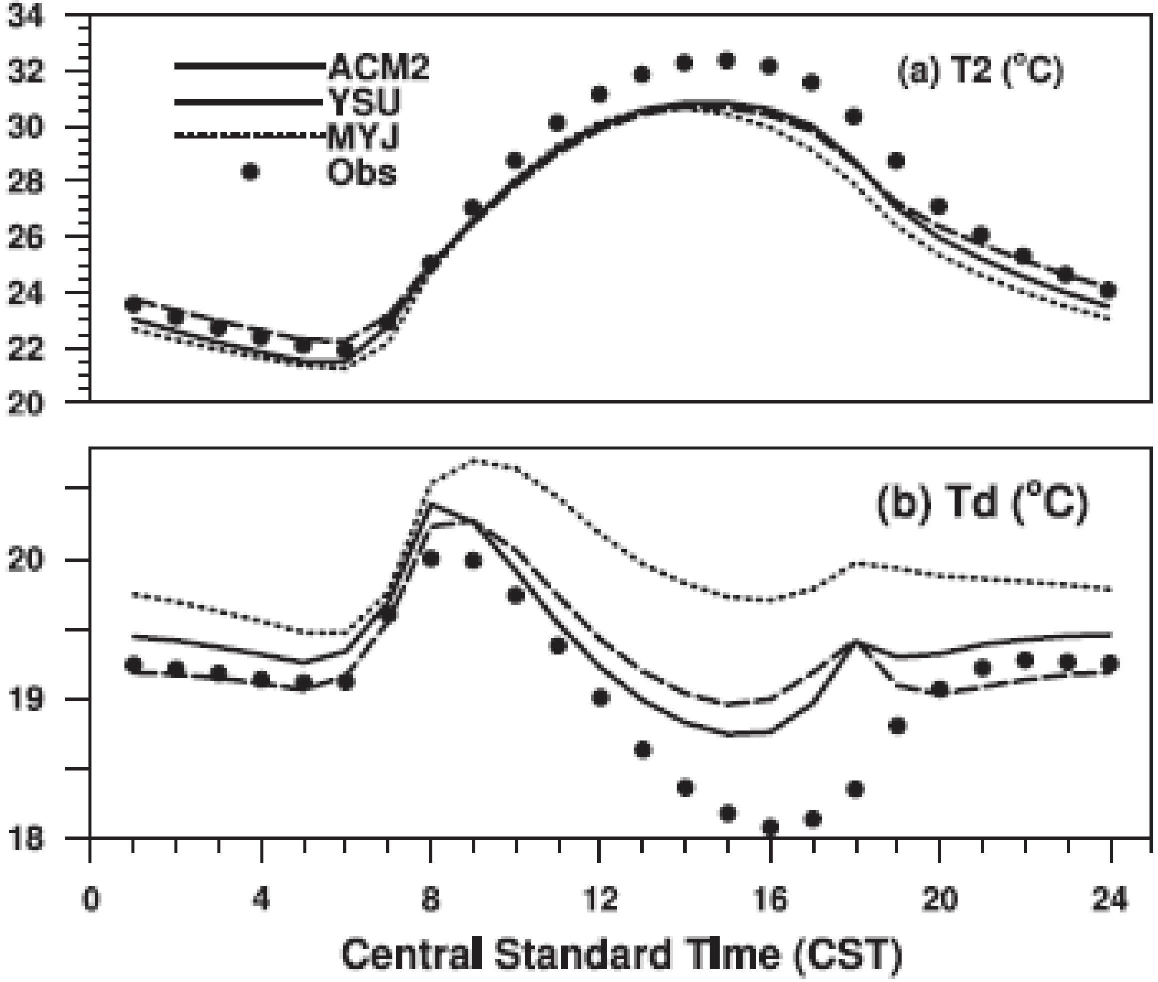

FIG. 2. Mean diurnal variation of 2-m (top) temperature and (bottom) dewpoint at 211 NWS–FAA sites throughout the 3-month simulation period.

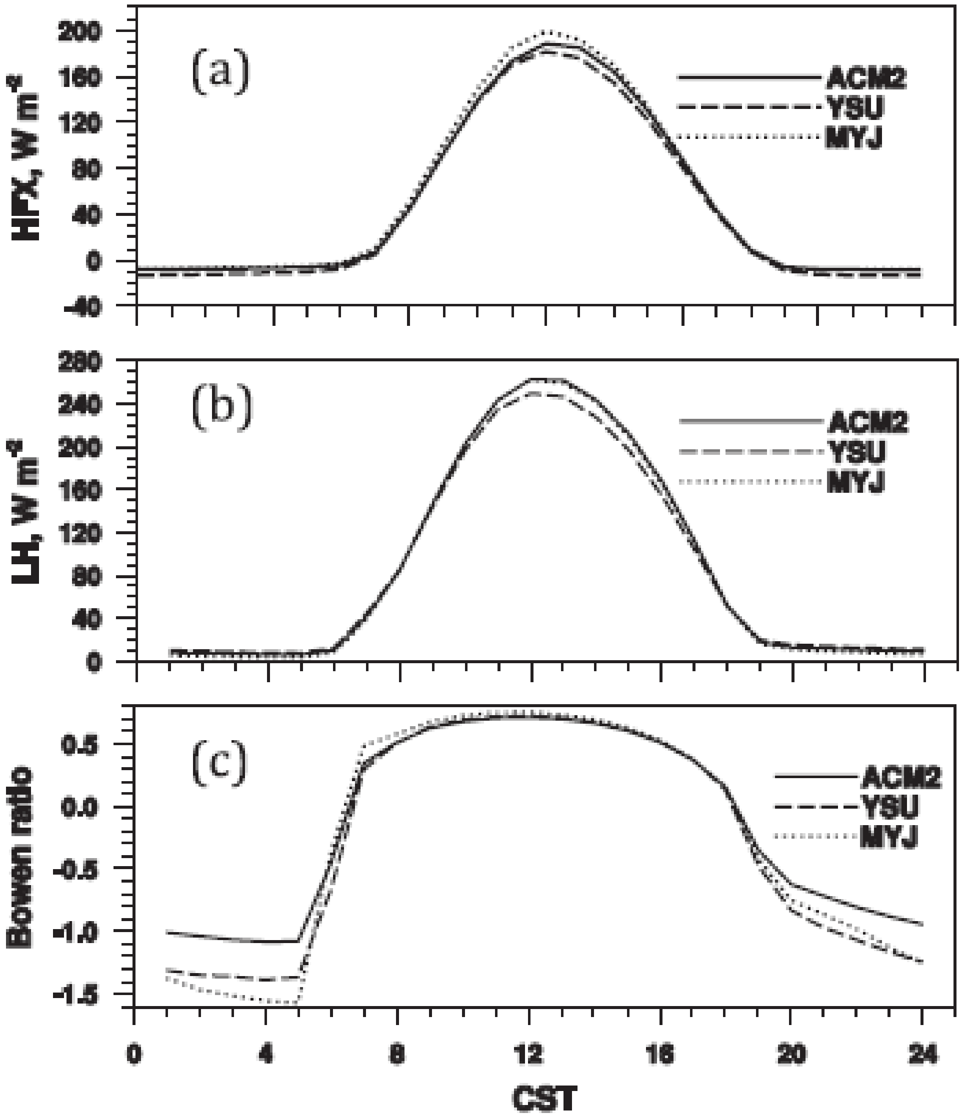

FIG. 5. Mean diurnal variation of (a) surface sensible HFX, (b) LH, and (c) Bowen ratio at 211 NWS–FAA sites for all three months.

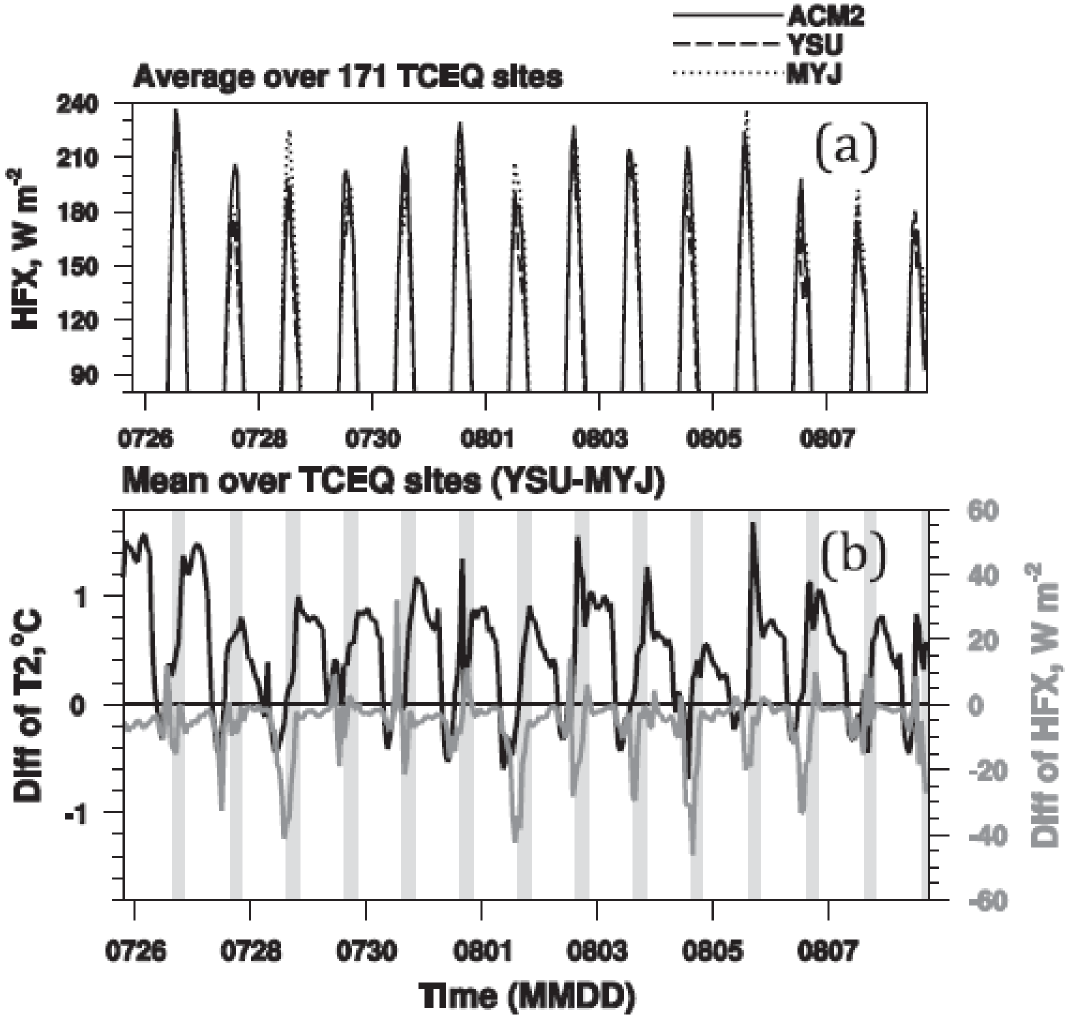

FIG. 6. (a) Mean time series of HFX at 171 TCEQ sites for 26 Jul–8 Aug and (b) difference of 2-m temperature and HFX at TCEQ sites between simulations with the YSU and MYJ schemes at the same time. The time period of 1500–2000 CST in each day is shaded.

- Incoming solar radiation was also compared among the schemes and against observations at certain TCEQ sites, as a check for possible differences caused by cloud cover.
- Simulations with both MYJ and YSU produced incoming solar radiation slightly smaller than what was observed, while the solar radiation with the ACM2 scheme was slightly higher than what was observed (not shown).

Collectively, the comparisons of HFX, LH, and incoming solar radiation suggest that the differences in performance between different schemes likely arise directly within the PBL schemes themselves, instead of differences in the surface-layer schemes (surface heat fluxes) or partially external feedback mechanisms such as changes in cloud cover.

- MYJ is a local closure PBL scheme. Local closure schemes are reported to produce insufficient mixing in the convective boundary layer (Brown 1996).
- The other source of air with differing thermodynamic characteristics is air entrained through the top of the PBL.
- If caused by entrainment, the biases imply weaker entrainment in the MYJ simulations than in the YSU and ACM2 simulations.

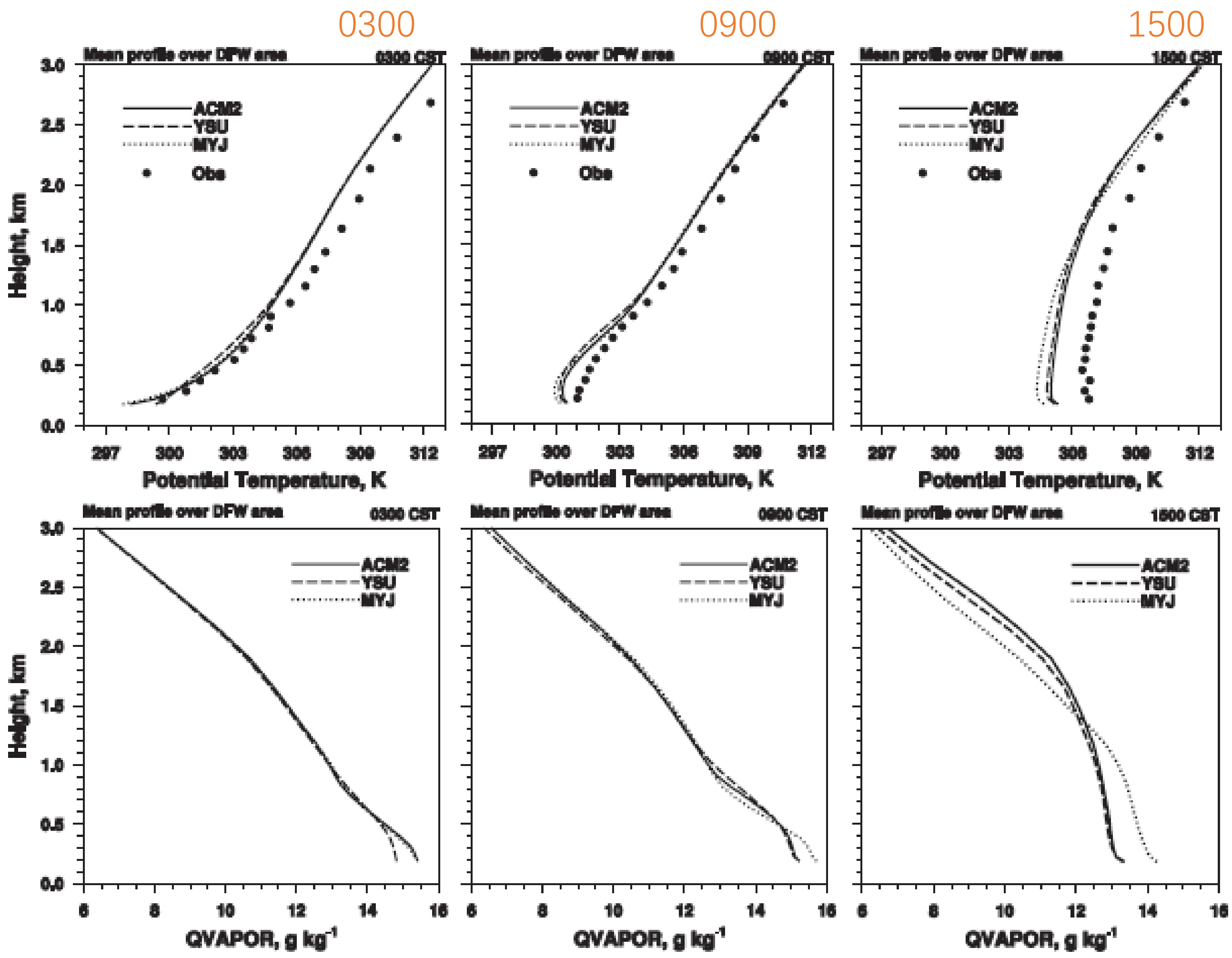

FIG. 8. Mean profiles of (top) temperature and (bottom) moisture at (left to right) 0300, 0900, and 1500 CST. The period of 23–25 Sep is excluded because of the influence of Hurricane Rita.

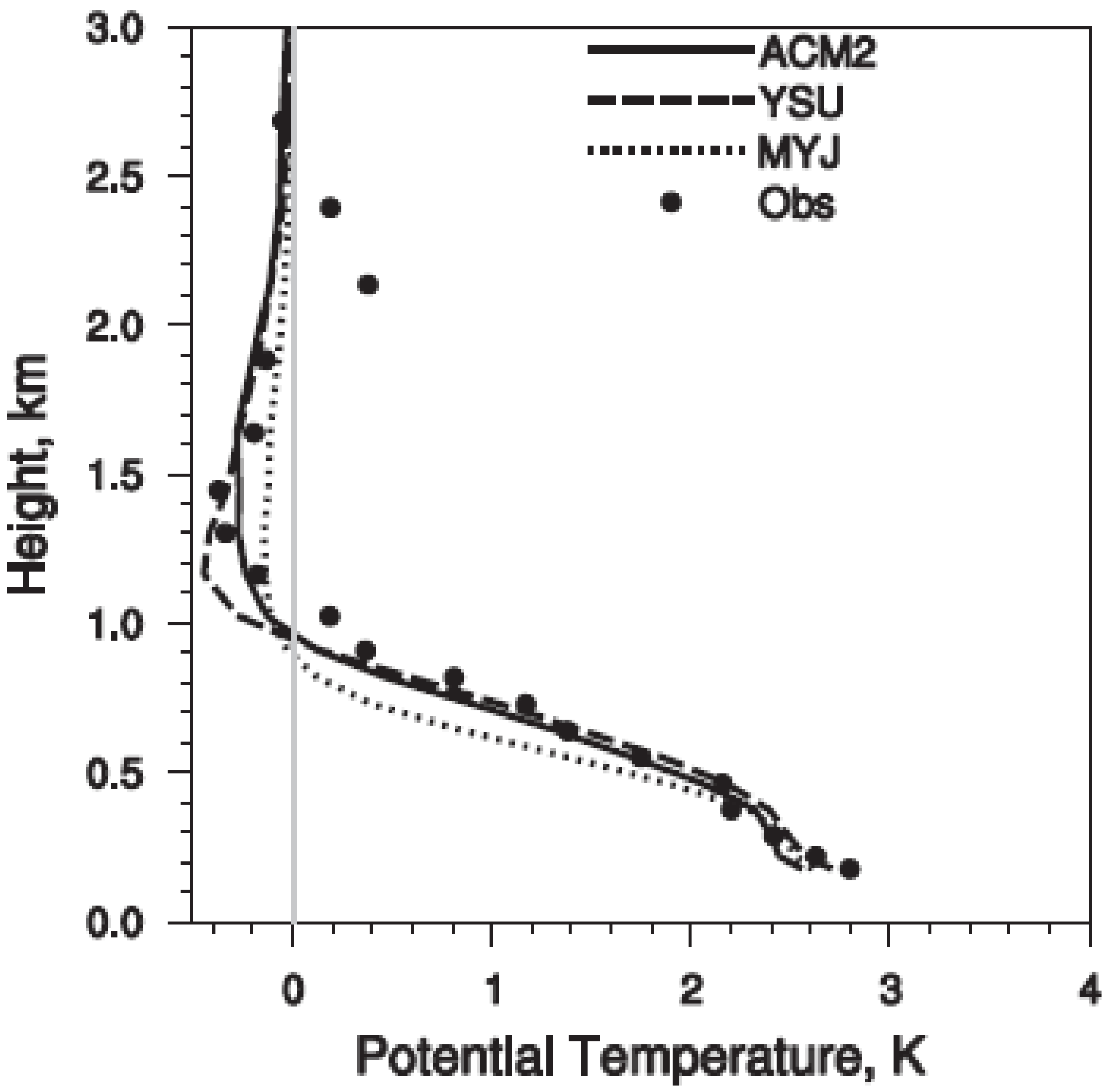

FIG. 9. Mean temperature profile change from 0900 to 1100 CST: simulated (lines) and observed (dots). The period of 23–25 Sep is excluded because of the influence of Hurricane Rita.

- After sunset, the temperature and moisture profiles predicted with ACM2 become closer to those predicted with MYJ. Both of them produce greater static stability near the surface than with YSU. Under nighttime stable conditions, nonlocal transport is shut down in ACM2 and vertical mixing is purely due to local eddy diffusion as in MYJ.
- On the other hand, the recent enhancement of nighttime vertical mixing in YSU (Hong and Kim 2008) has led to higher temperatures and lower moisture in the simulations with the YSU scheme near the surface at nighttime, in better agreement with observations.

Simulations with ACM2 with different mixing strength

the local vertical diffusivity in ACM2 and YSU is computed from

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

In ACM2, the value of the exponent p in (1) is 2, but values ranging from 1 to 3 have been considered (Troen and Mahrt 1986).

Thus p plays an important role in governing the vertical mixing strength in the daytime PBL in ACM2.

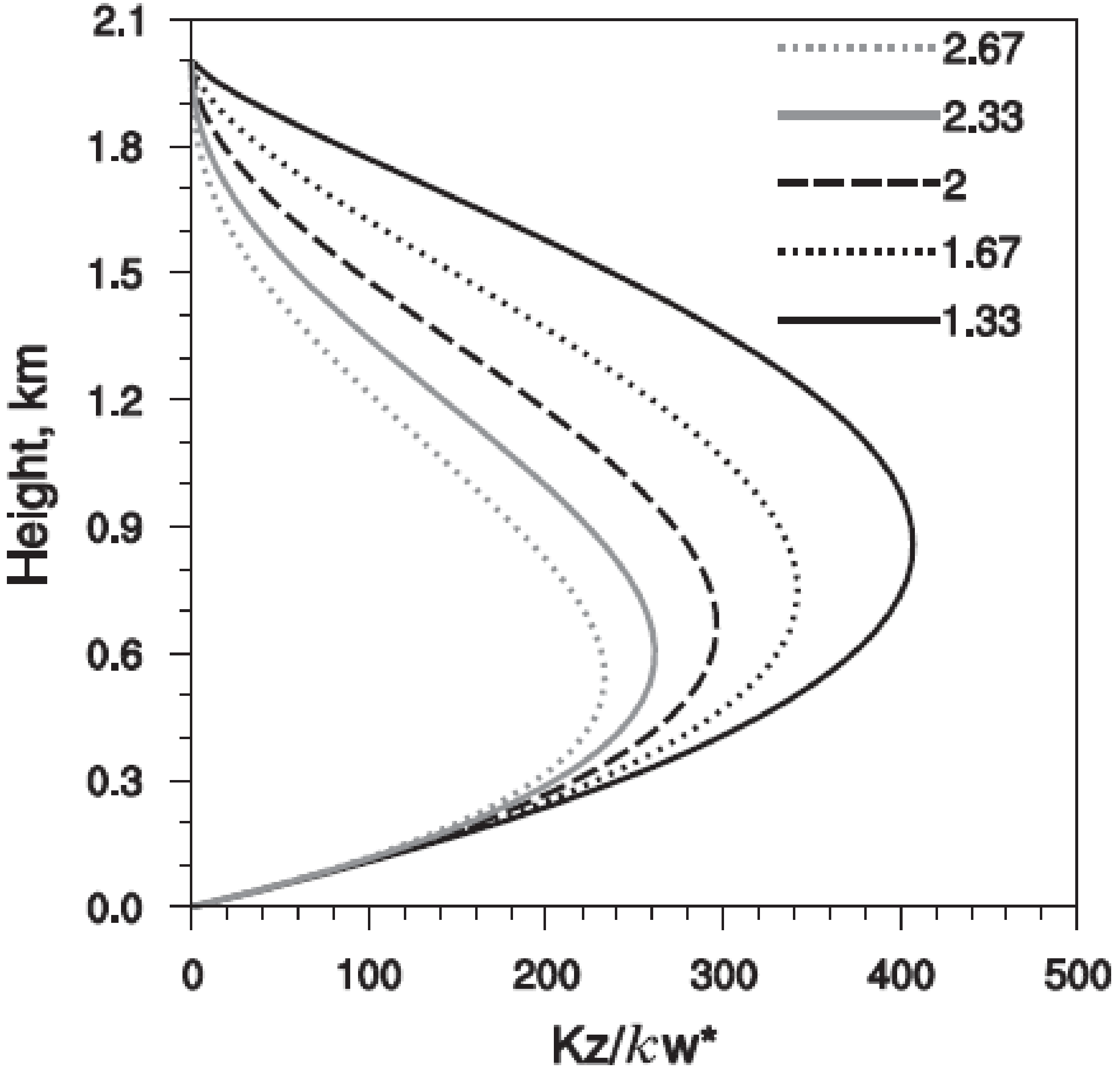

FIG. 11. Normalized K_z profiles computed using different values of p. The PBL height is set at 2000 m.

Entrainment is sensitive to the parameterization of mixing within the PBL.

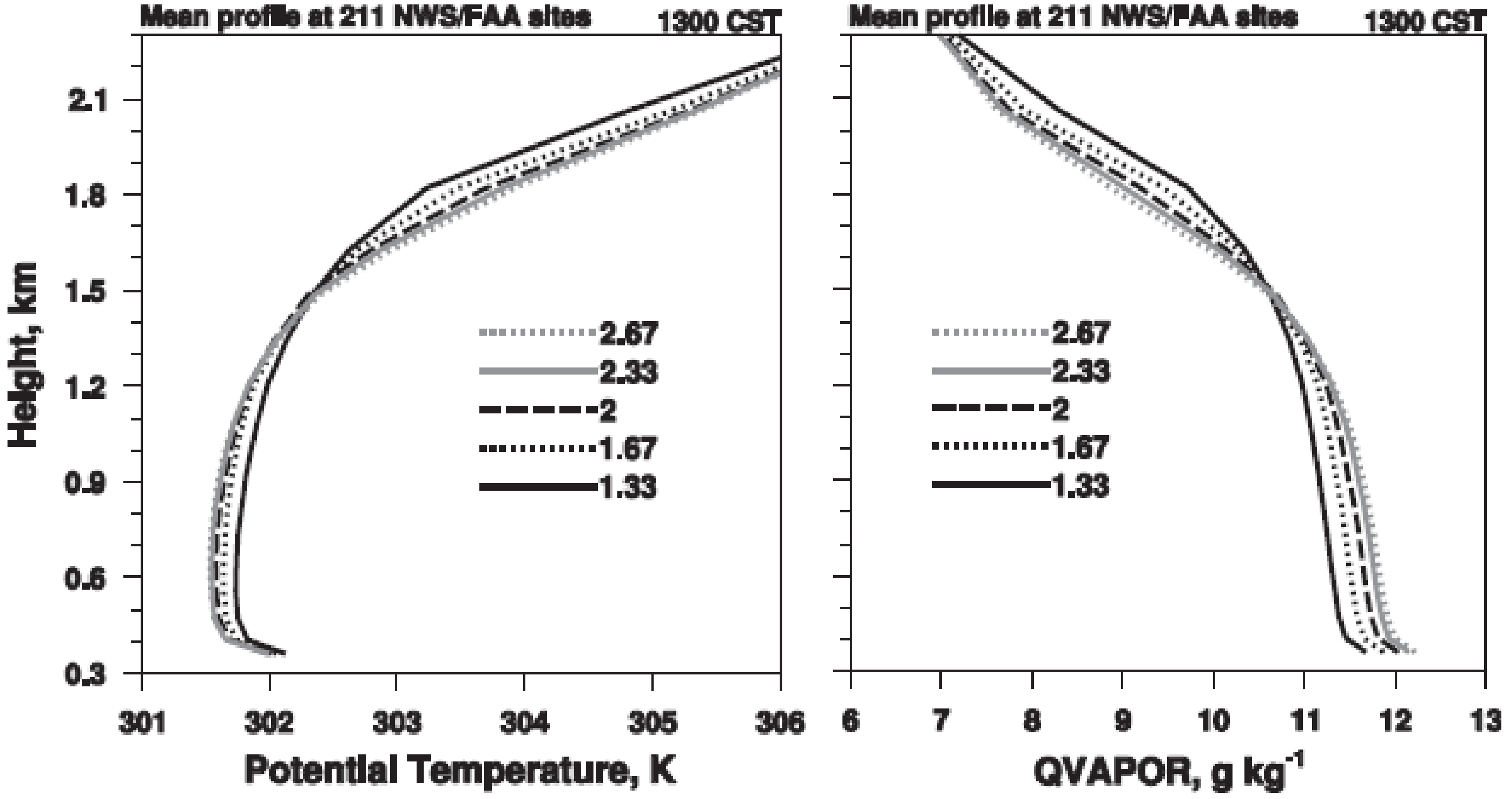

FIG. 12. Mean profiles of (left) potential temperature and (right) water vapor mixing ratio at 1300 CST 30 Aug 2006 from sensitivity runs with ACM2 modified to use different values of p.

Summary

- With the configuration used in this study, the WRF simulations underpredict temperature and overpredict moisture near the surface.
- Use of the local-closure MYJ scheme produces the largest bias. YSU and ACM2 schemes both lead to smaller biases, than the MYJ scheme in the lower atmosphere during daytime because of their stronger vertical mixing.
- Underestimated entrainment is shown to at least partially cause the colder PBL predicted by the WRF model with the MYJ scheme.

My future work

- Simulate the summer meteorological conditions of the Beijing-Tianjin-Hebei region where the ozone pollution is becoming more and more serious.
- Compare the differences of the model performance to different PBL schemes.
- Analyze the influence of the ozone pollution on the model performance to different schemes.

THANKS!