The E-epsilon PBL Scheme in the WRF Model

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Outline

- ❑An introduction to the E-epsilon scheme (EEPS)
- ❑The evaluation over the Southeast Pacific (SEP)
- ❑The evaluation over the South Great Plains (SGP)
- ❑Summary

Why the EEPS scheme?

- The **<u>mixing length</u>** is no longer required in the *E*–*ε* scheme, which significantly reduced the number of lines of code.

- The *E*–*ε* scheme is the **<u>first</u>** scheme in the WRF model that uses *ε for the closure of the TKE-equation.*

- The *E*–*ε* scheme can better retain "**<u>memory effects</u>**" in length and velocity scales when surface condition changes.

The E-epsilon (EEPS) PBL scheme

(Zhang et al. 2020, MWR)

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K_v \frac{\partial \theta}{\partial z}\right),$$

K_v is the vertical mixing coefficient with the subscript v substituted by m for momentum (K_m)
h for heat and moisture (K_h)

(1) $$\frac{dE}{dt} = K_m\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right] - K_h P_{\text{buoy}} + C_1\frac{\partial}{\partial z}\left(K_m\frac{\partial E}{\partial z}\right) - \varepsilon,$$

(2) $$\frac{d\varepsilon}{dt} = \max\left\langle\left\{K_m\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right] - K_h P_{\text{buoy}}\right\}, \left\{K_m\left[\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2\right]\right\}\right\rangle C_3\frac{\varepsilon}{E} - C_4\frac{\varepsilon^2}{E} + C_5\frac{\partial}{\partial z}\left(K_m\frac{\partial \varepsilon}{\partial z}\right),$$

(3) $$K_m = C_2 E^2/\varepsilon,$$

(4) $$K_h = \alpha K_m$$

$$(\boldsymbol{E}, \boldsymbol{\varepsilon}, \boldsymbol{K_m}, \boldsymbol{K_h})$$

Detering and Etling (1985)
Langland and Liou (1996)
Duynkerke and Driedonks (1987)

C1: 1.35
C2: 0.09
C3: 1.44
C4: 1.92
C5: 0.77

$E_{min} = 1\times10^{-4}$

$\varepsilon_{min} = 1\times10^{-6}$

Background K_m = 0.1
K_h = 0.01

A few iterations with smaller time steps are necessary for numerical stability when time step is very large

Prognostic Equations

$$\alpha = \begin{cases} 1.16, \text{--------------} R_i \geq 0.16, \\ 1.318\dfrac{(0.2231 - R_i)}{(0.2341 - R_i)}, \text{-----} R_i < 0.16, \end{cases} \qquad R_i = P_{buoy} \left| \frac{\partial V}{\partial z} \right|^{-2}$$

$$P_{buoy} = g\frac{\partial \ln \theta_v}{\partial z} = g\left[A\left(\frac{\partial \ln \theta}{\partial z} + \frac{L_{vi}}{C_p T}\frac{\partial q_{vis}}{\partial z} \right) - \frac{\partial q_t}{\partial z} \right]$$

Durran and Klemp (1982)
Rotunno and Emanuel (1987)
Tripoli (1992)

$$q_{vis} = (1 - W_l) q_{sw} + w_l q_{si}$$

$$A = \frac{1 + L_{vi} q_{vis} / (RT)}{1 + L_{vi}^2 q_{vis} / (C_p R_v T^2)}$$

$$L_{vi} = (1 - W_l) L_v + w_l L_s$$

$$w_l = MAX\left[0.0, MIN(1.0, \frac{T_0 - T}{T_0 - 233.16}) \right]$$

q_t: the sum of the mixing ratios of cloud water, rain water, cloud ice, snow and graupel

q_{vis}: the saturation mixing ratio of water vapor

L_{vi}: the latent heat of phase change

L_v: the latent heat of condensation

L_s: the latent heat of sublimation

Prognostic Equations

The lower boundary conditions at the lowest model level:

$$E_s = \begin{cases} 3.75u_*^2, \text{-----------------------} R_{is} > 0.0, \\ 3.75u_*^2 + 0.2w_*^2 + (-z_{km}/L)^{2/3}u_*^2, \text{------} R_{is} \le 0.0, \end{cases}$$

$$R_{is} = \frac{gz_{km}\ln(\theta_{vkm}/\theta_{vs})}{|V_{km}|^2}$$

$$\varepsilon_s = \frac{u_*^3}{kz_{km}}$$

km is the lowest model level
u_* is the friction velocity
L is the Monin-Obukhov length
k is the von Kármán constant 0.4

The upper boundary conditions at the model top are E=0 and ε=0

Prognostic Equations

A nonlocal term is included in vertical eddy mixing of heat and moisture

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} K_h \left(\frac{\partial \theta}{\partial z} - \gamma_t\right), ----\gamma_t = \frac{5H_s}{w_* h}$$

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial z} K_h \left(\frac{\partial q}{\partial z} - \gamma_q\right), ----\gamma_q = \frac{5H_q}{w_* h}$$

$$H_s = HFX(\rho C_p)^{-1}$$

$$H_q = QFX(\rho)^{-1}$$

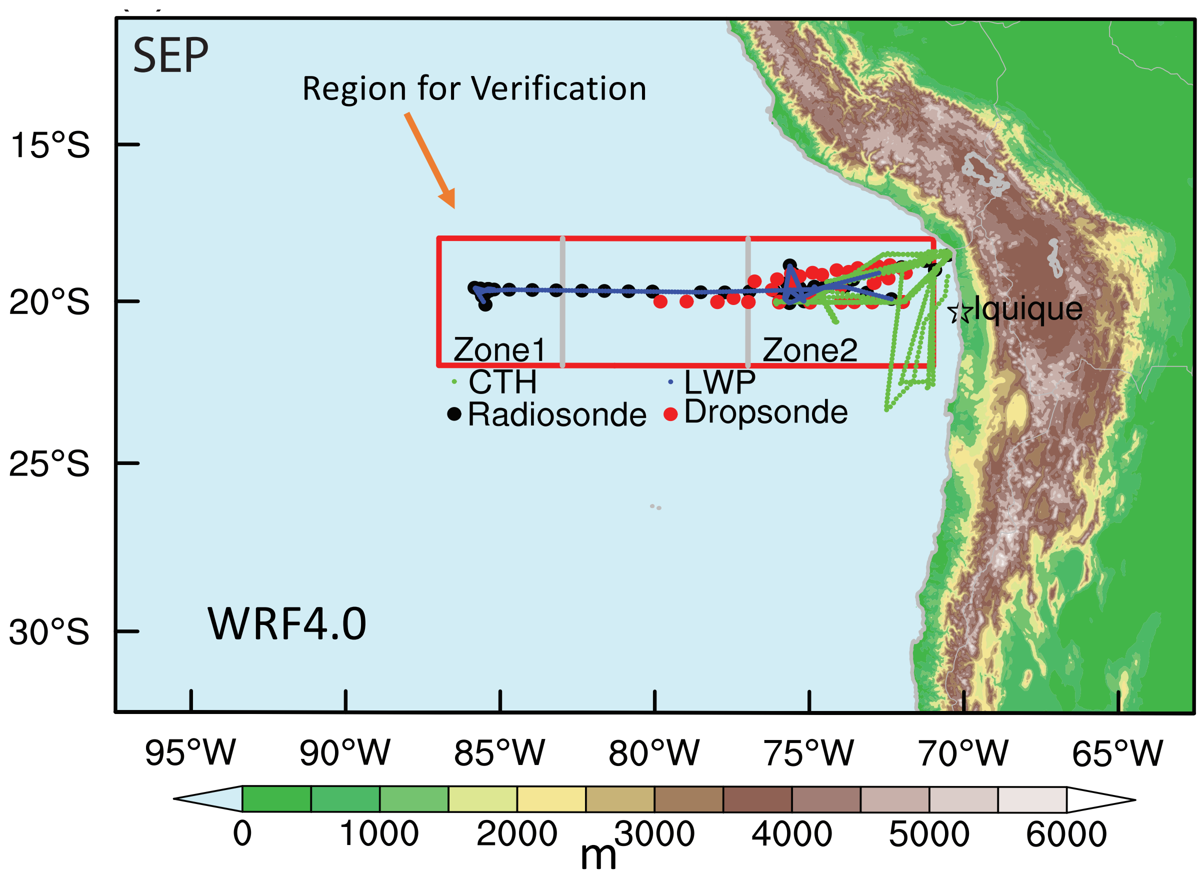
h is the boundary layer height, which is defined as the lowest level the modified Bulk Richardson Number exceeds a critical value of 0.25

w_* is the convective velocity

The TKE dissipative heating

$$\frac{\partial T}{\partial t} = \frac{\varepsilon}{c_p}$$

The evaluation over the Southeast Pacific (SEP)



Verification data are from

The VOCALS 2008

Compared the EEPS with

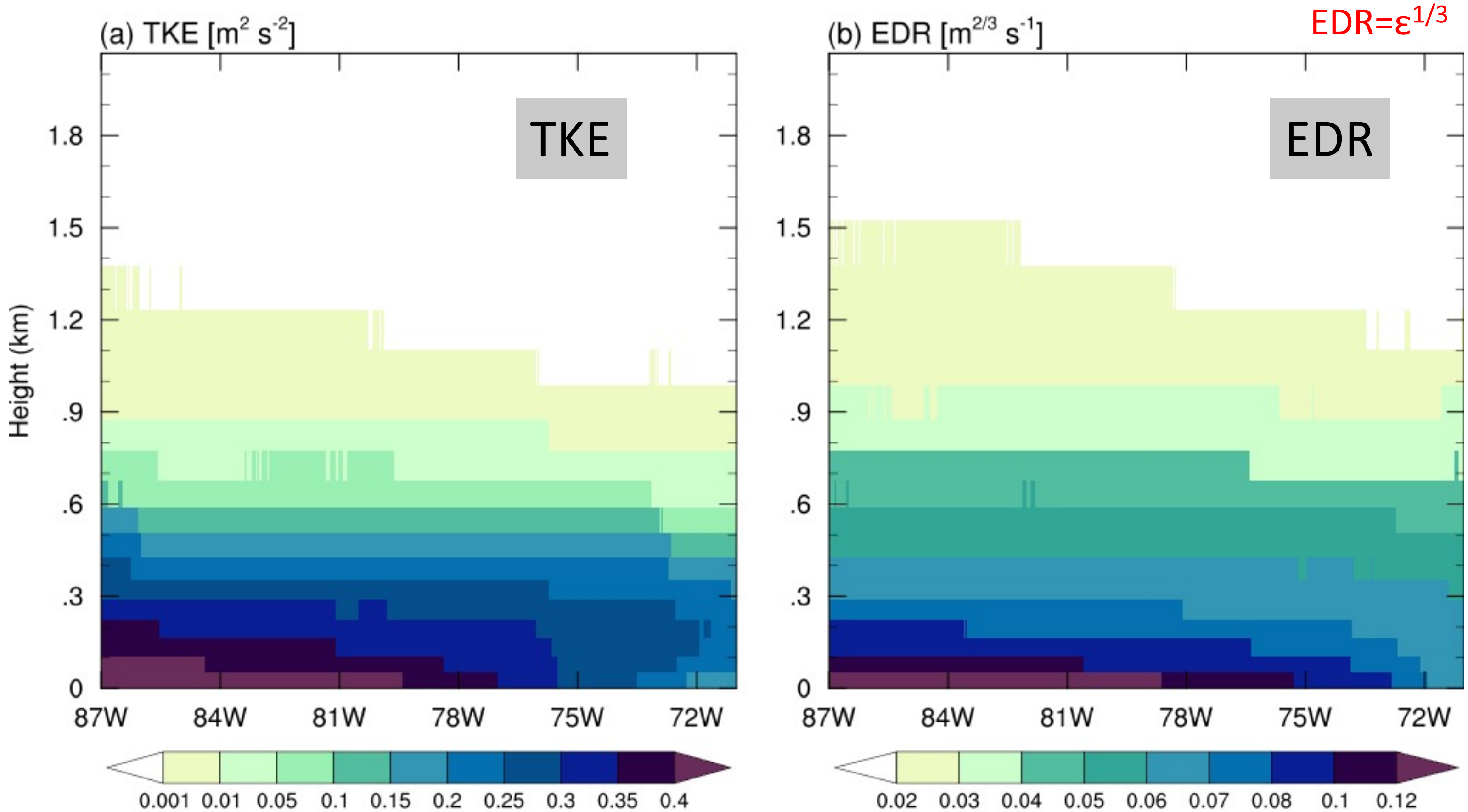
The YSU, MYNN and UW

3 km grid spacing
51 vertical levels
21 levels below 2.5 km

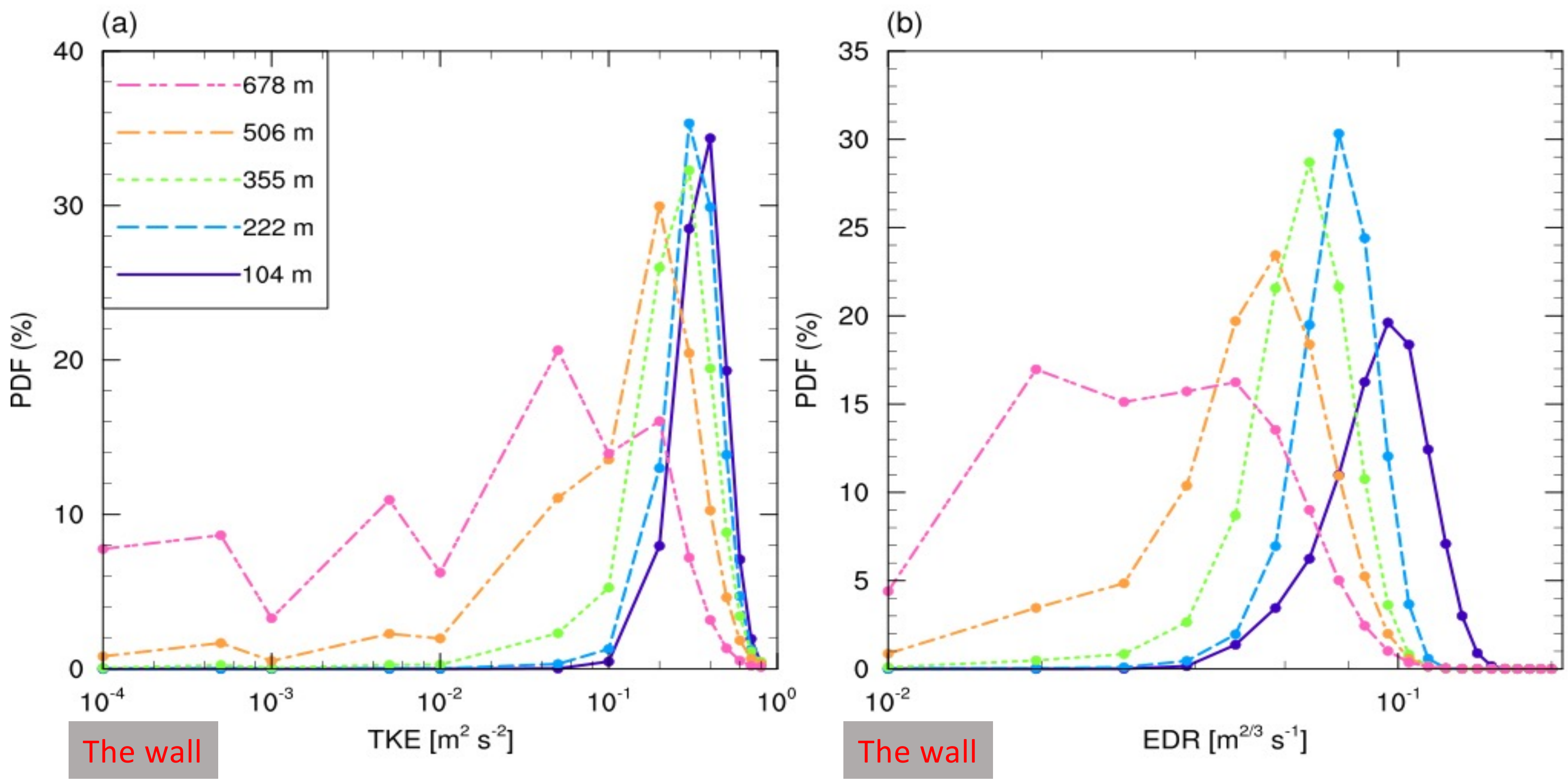
Continuously run:
00 UTC Oct 24 – 00 UTC Nov 15

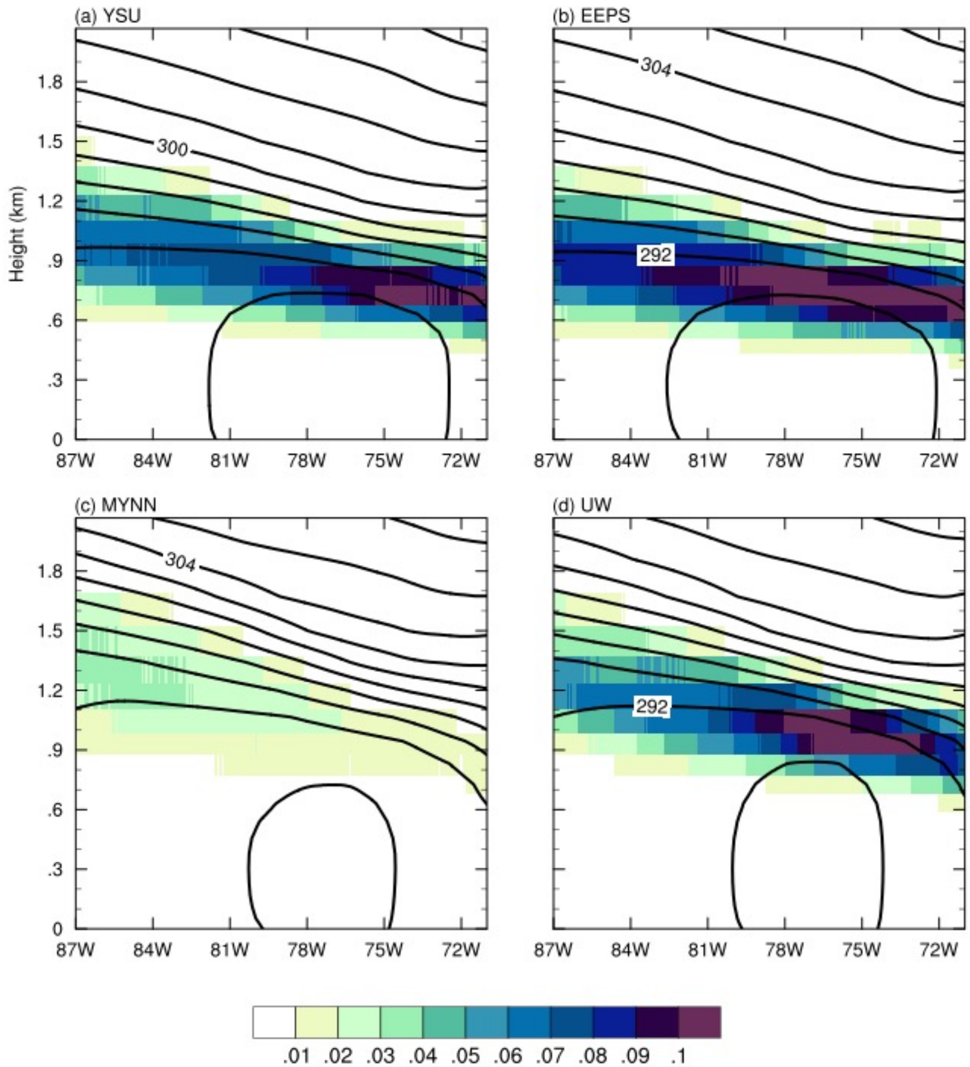
IC&BC: ERA-Interim
SST: NOAA reanalysis

TKE and EDR are meridionally averaged between 18° and 22°N



Distribution of the TKE(EDR) at different levels



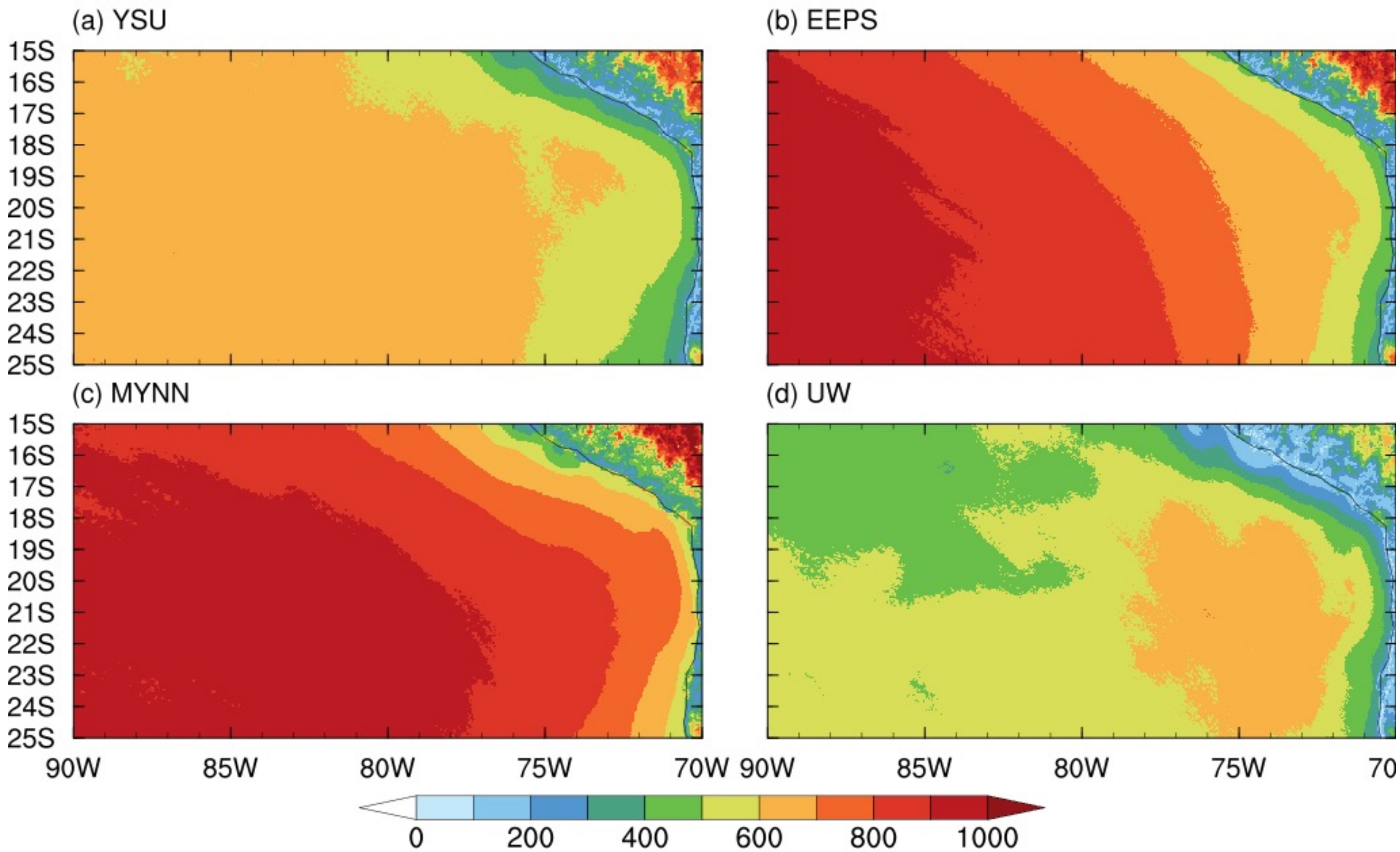


Meridionally averaged between 18° and 22°N

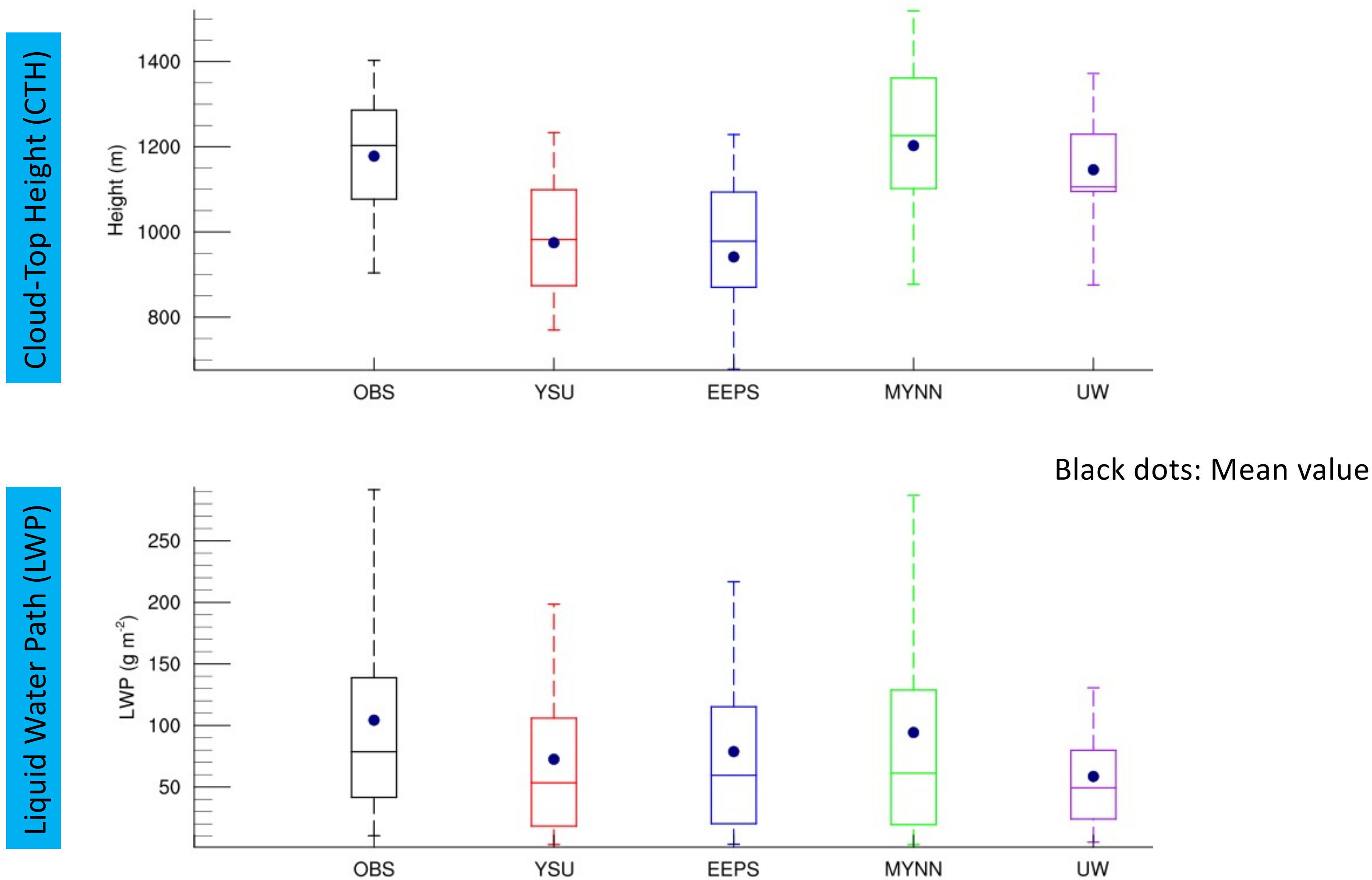
Shading: cloud mixing ratio

Contour: virtual potential temperature

The PBL height diagnosed by each scheme

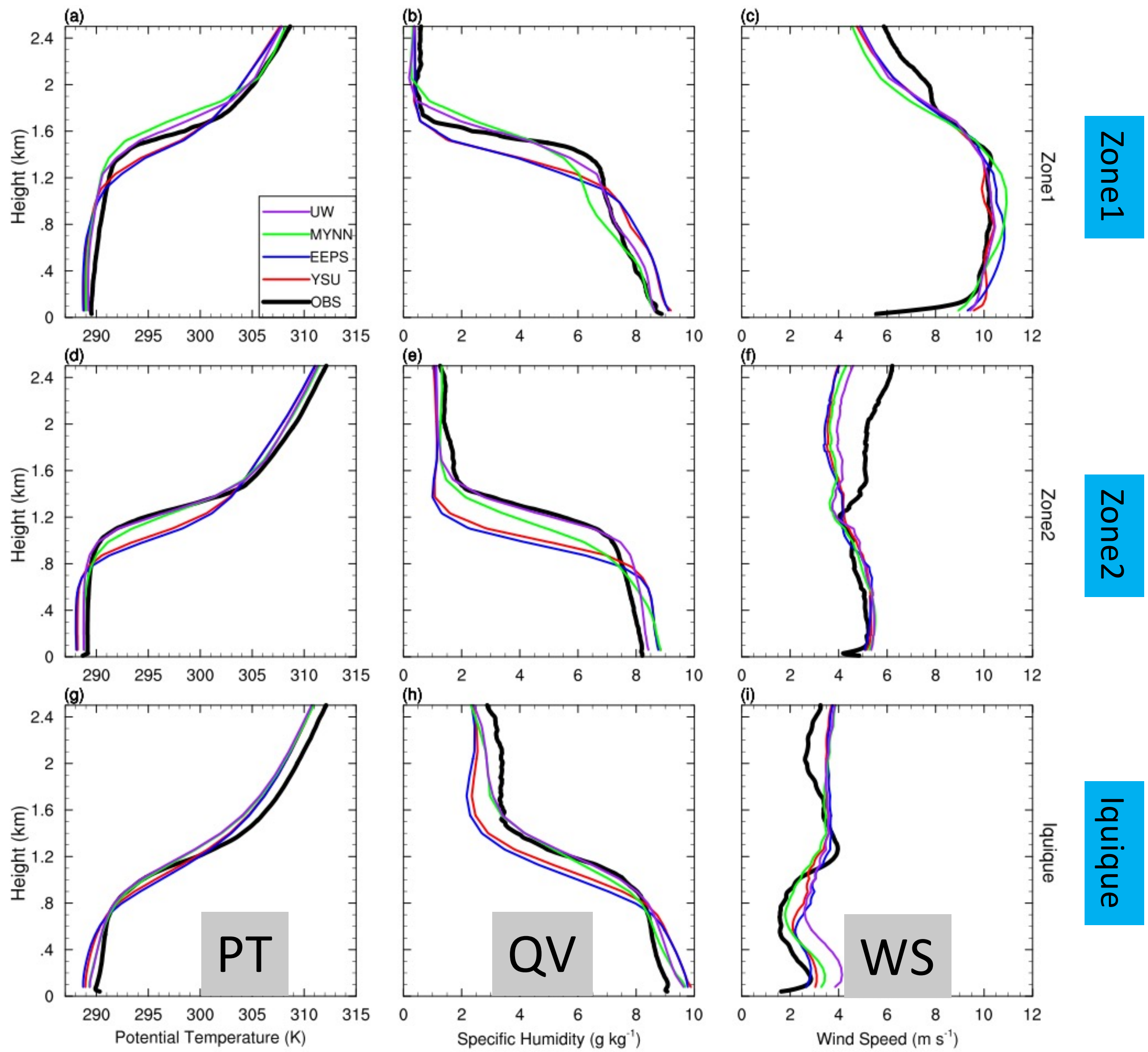


The planetary boundary layer height (PBL height; unit: m) diagnosed by each PBL scheme.



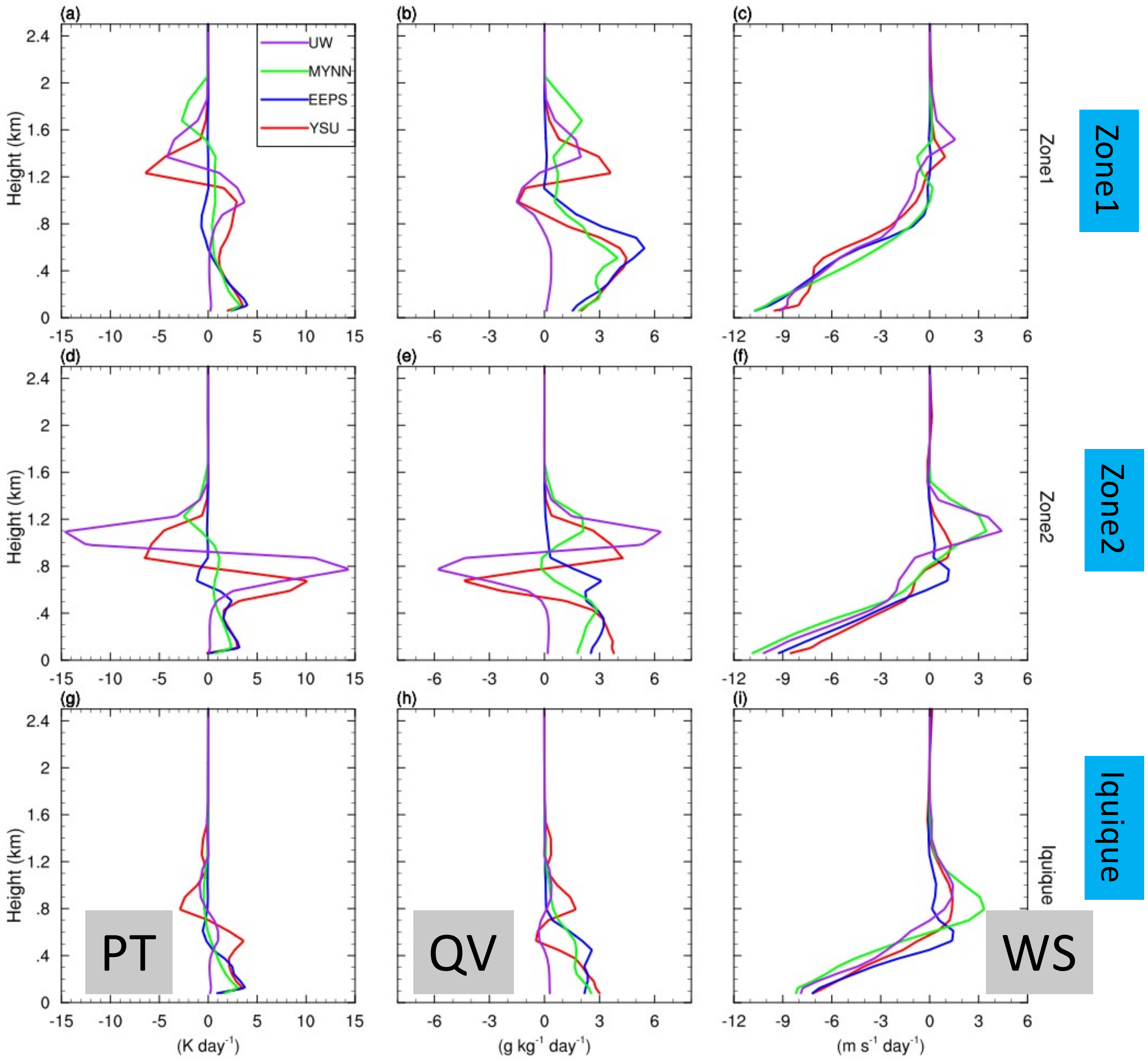
Cloud-Top Height (CTH)
Height (m)
1400
1200
1000
800
OBS
YSU
EEPS
MYNN
UW
Black dots: Mean value
Liquid Water Path (LWP)
LWP (g m-2)
250
200
150
100
50
OBS
YSU
EEPS
MYNN
UW

Profiles



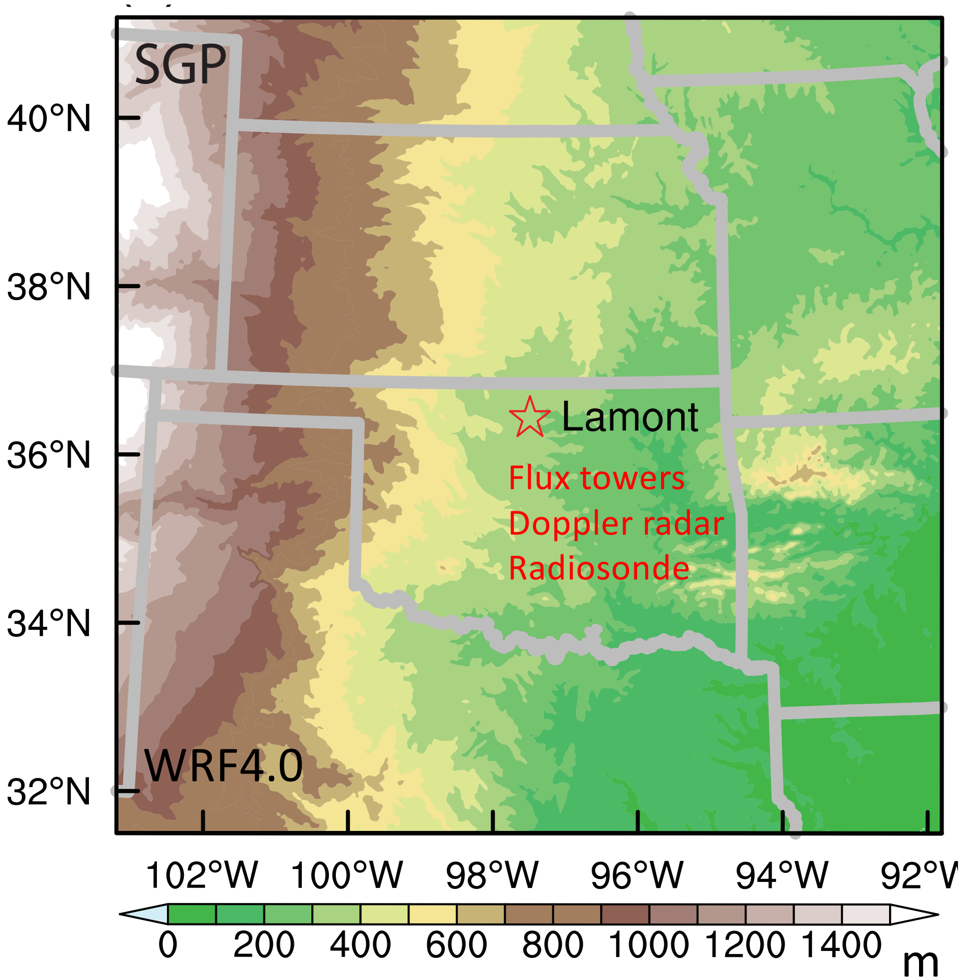
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
Height (km)
UW
MYNN
EEPS
YSU
OBS
Zone1
Zone2
Iquique
PT
QV
WS
Potential Temperature (K)
Specific Humidity (g kg^{-1})
Wind Speed (m s^{-1})

Tendencies



(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
UW
MYNN
EEPS
YSU
Height (km)
Zone1
Zone2
Iquique
PT
QV
WS
(K day-1)
(g kg-1 day-1)
(m s-1 day-1)

The evaluation over the South Great Plains (SGP)



Verification data are from

The LAFE 2017

Compared the EEPS with

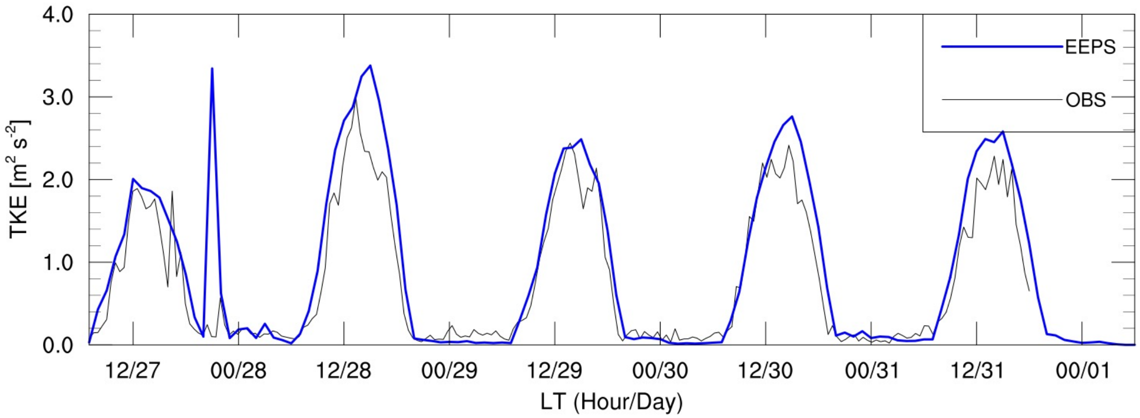
The YSU, MYNN and UW

3 km grid spacing
51 vertical levels
21 levels below 2.5 km

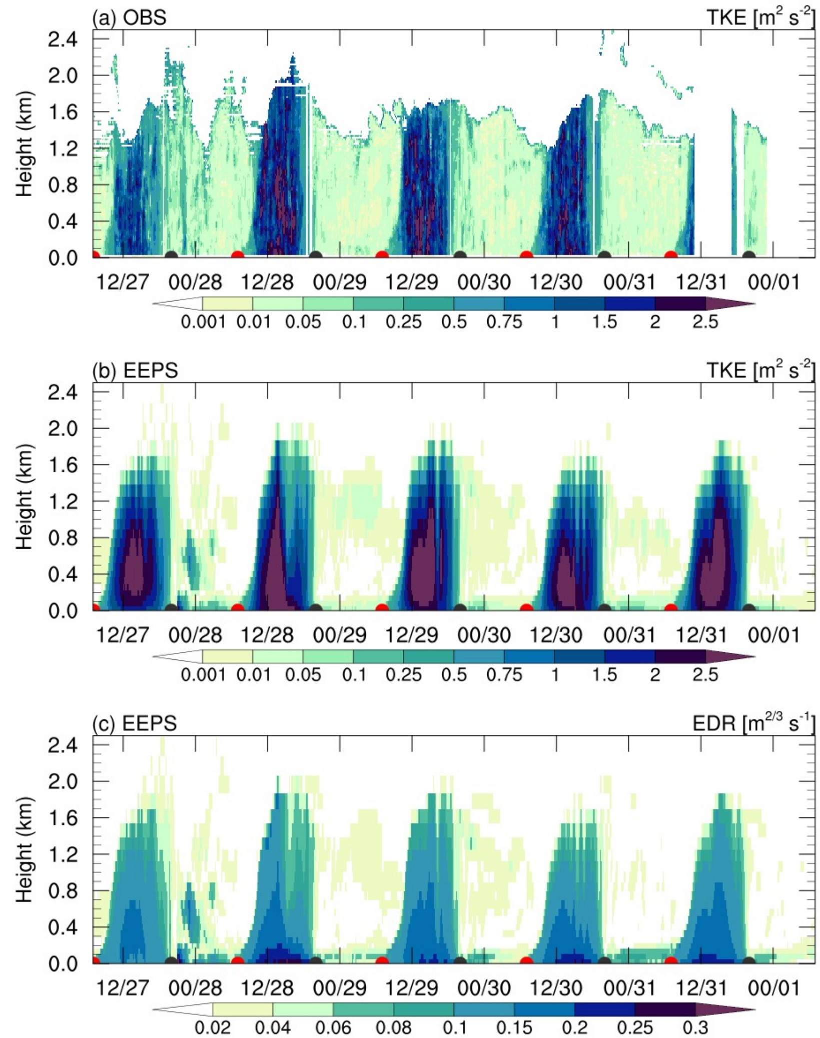
Five consecutive days
12 UTC 27 Aug – 12 UTC 1 Sep
Five runs (36-hr) for each scheme

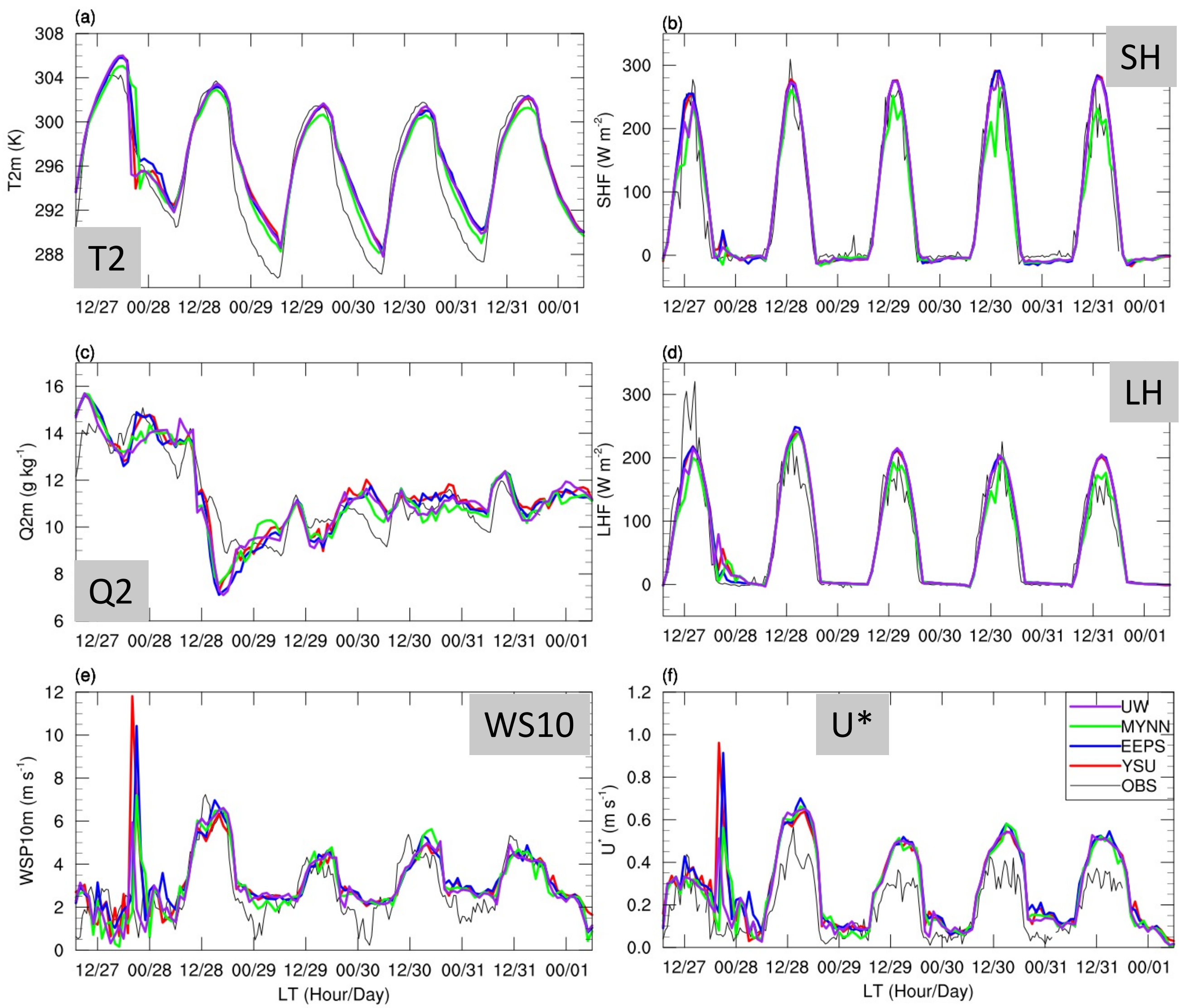
IC&BC: GFS
Soil data: 3-month spin-up

TKE at the lowest model level



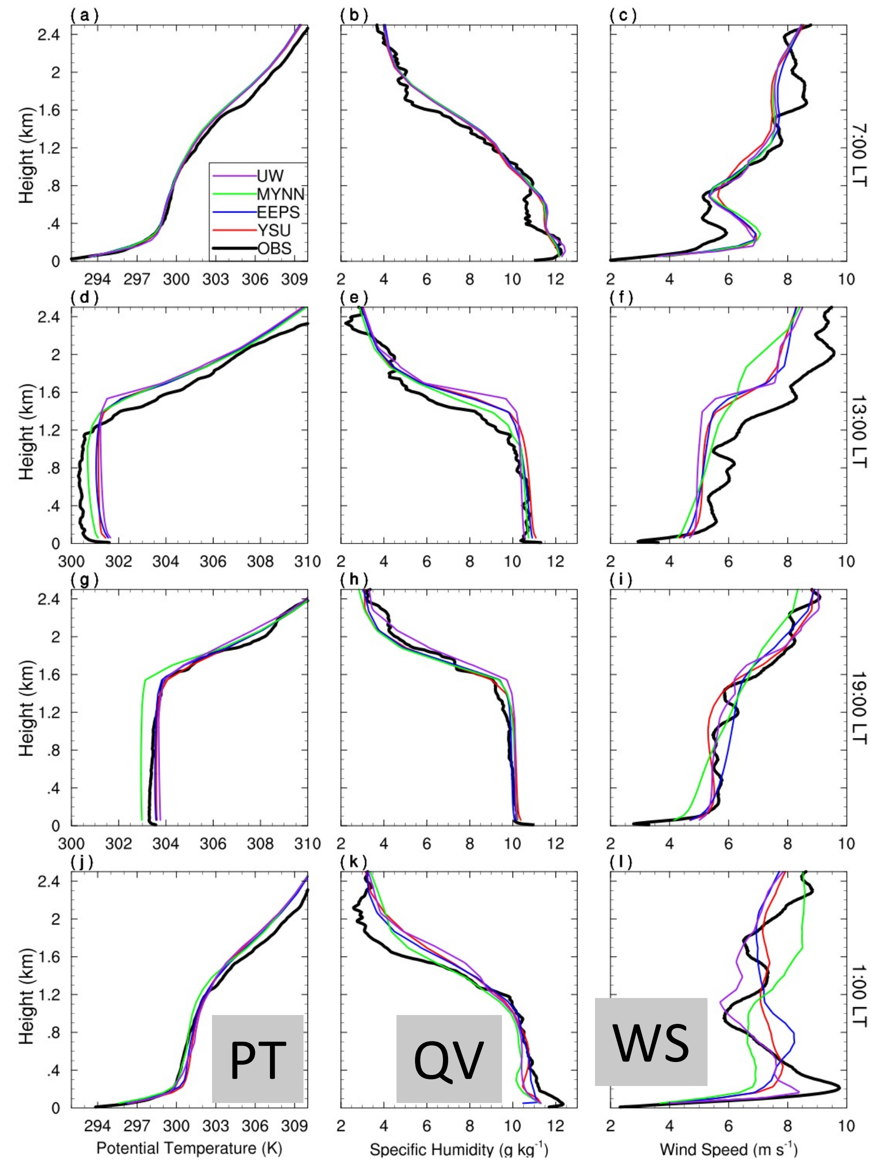
TKE (EDR) on time-height space





(a)
T2m (K)
308
304
300
296
292
288
T2
12/27 00/28 12/28 00/29 12/29 00/30 12/30 00/31 12/31 00/01
(b)
SH
SHF (W m-2)
300
200
100
0
12/27 00/28 12/28 00/29 12/29 00/30 12/30 00/31 12/31 00/01
(c)
Q2m (g kg-1)
16
14
12
10
8
6
Q2
12/27 00/28 12/28 00/29 12/29 00/30 12/30 00/31 12/31 00/01
(d)
LH
LHF (W m-2)
300
200
100
0
12/27 00/28 12/28 00/29 12/29 00/30 12/30 00/31 12/31 00/01
(e)
WS10
WSP10m (m s-1)
12
10
8
6
4
2
0
12/27 00/28 12/28 00/29 12/29 00/30 12/30 00/31 12/31 00/01
LT (Hour/Day)
(f)
U*
U* (m s-1)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
UW
MYNN
EEPS
YSU
OBS
12/27 00/28 12/28 00/29 12/29 00/30 12/30 00/31 12/31 00/01
LT (Hour/Day)

Profiles



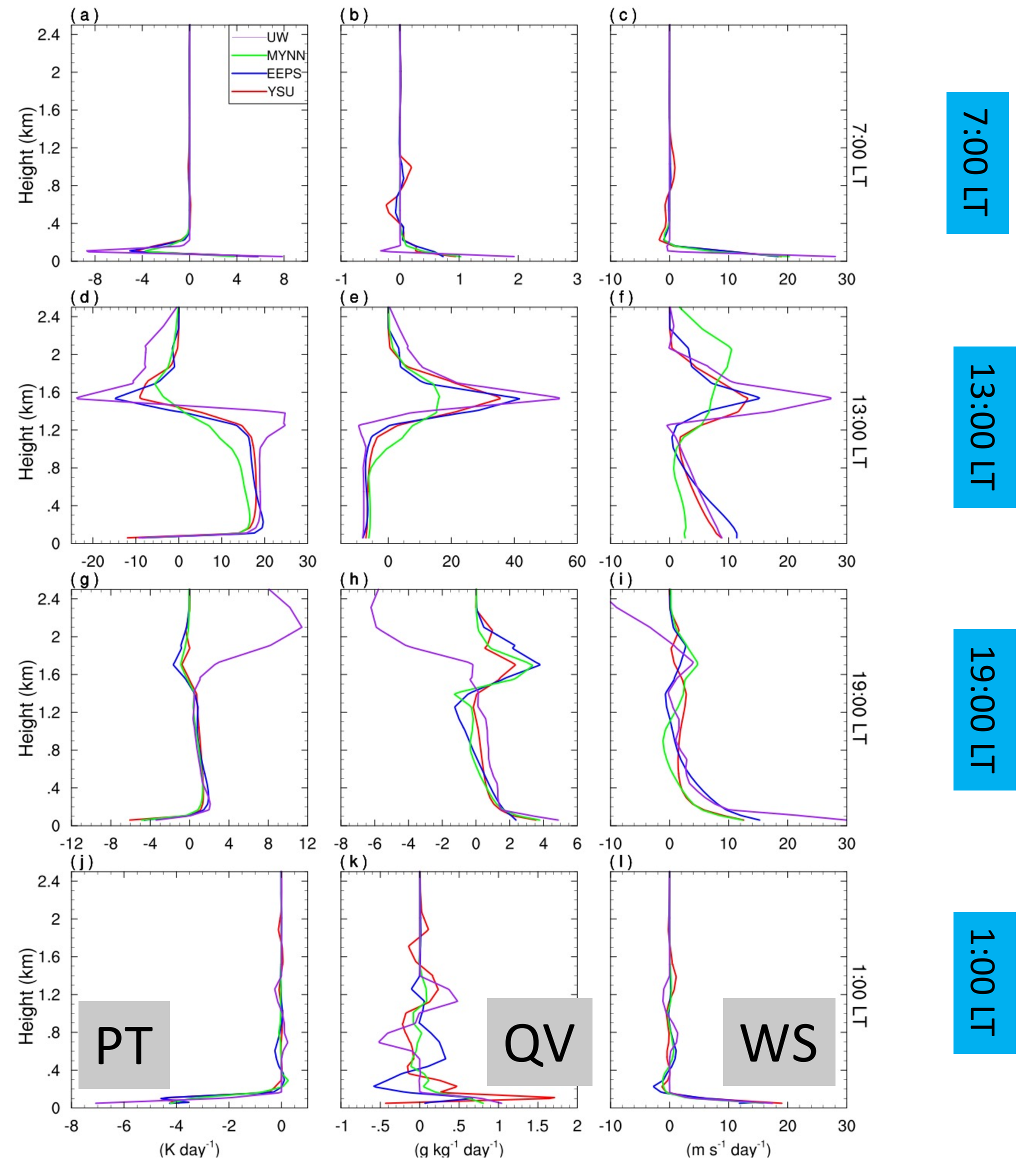
7:00 LT

13:00 LT

19:00 LT

1:00 LT

Tendencies


UW
MYNN
EEPS
YSU
Height (km)
(K day⁻¹)
(g kg⁻¹ day⁻¹)
(m s⁻¹ day⁻¹)
7:00 LT
13:00 LT
19:00 LT
1:00 LT
PT
QV
WS

Summary

- The EEPS and YSU schemes perform comparably over both regions, while the MYNN scheme performs differently in many aspects, especially over the SEP.
- Compared with observations, the UW scheme produces the best PBL height over the SEP. The MYNN produces too high PBL height over the western part of the SEP while both the YSU and EEPS schemes produce too low PBL and cloud-top heights.
- The differences among the PBL schemes in simulating the PBL features over the SGP are relatively small.