How to develop the physics algorithms in atmospheric models ?

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PBL scheme development (Louis➔MRF ➔ YSU➔ ?)

Stable BL

Grey-zone physics

Development of physics algorithms

- Theoretical development (concept) : Step 1

- Systematic deficiency
- LES study/ theory
- Numerical discretization
- Idealized experiments

- Balance with nature (module) : Step 2

- Real case experiments
- Process study
- Refinement/reformulation

- Evaluation at real-time testbed (package) : Step 3

- Short-range forecast
- Medium-range forecast
- Long-range forecast

Local (Louis 1979) vs. non-local (Troen and Mahrt 1986)

Local

$$K_{m,t} = l^2 f_{m,t}\,(\mathrm{Rig}) \left| \frac{\partial U}{\partial z} \right|$$

Non-Local

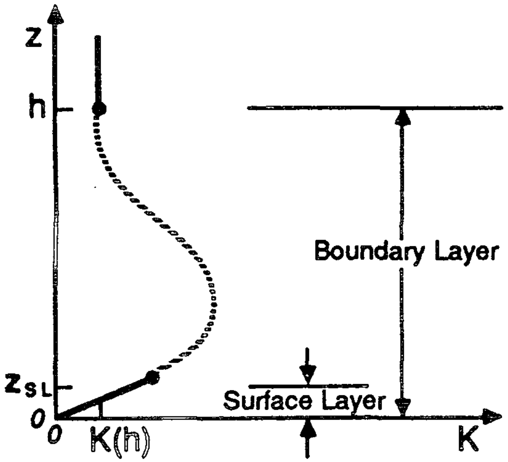


FIG. 1. Typical variation of eddy viscosity *K* with height in the boundary layer proposed by O'Brien (1970). Adopted from Stull (1988).

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left[K_c \left(\frac{\partial C}{\partial z} - \gamma_c \right) \right],$$

$$K_{zm} = k w_s z \left(1 - \frac{z}{h} \right)^p ,$$

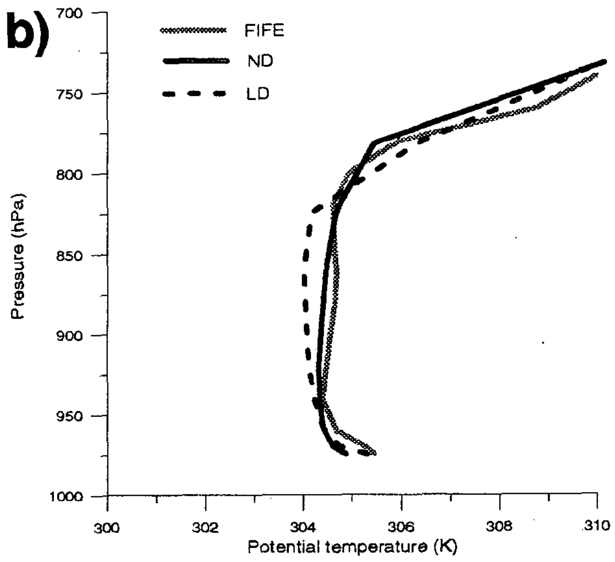
$$\gamma_c = b \, \frac{\overline{(w'c')}}{w_s} ,$$

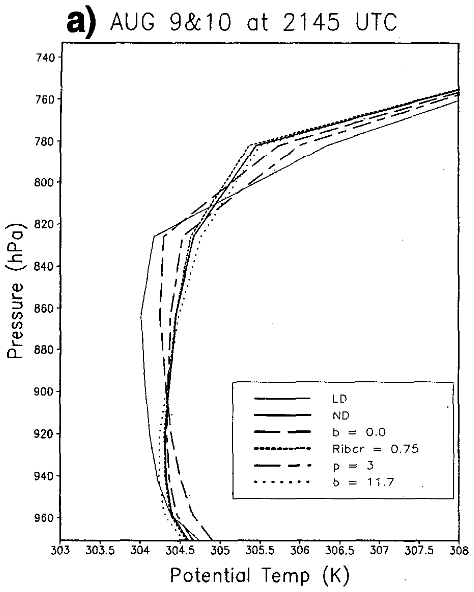
$$h = \mathrm{Rib}_{\mathrm{cr}} \frac{\theta_{va} |U(h)|^2}{g(\theta_v(h) - \theta_s)} ,$$

Local vs. non-local (Hong and Pan 1996) : Step 1 and 2

TABLE 1. Summary of experimental designs.

Experiment	Code	Description	Convection scheme	Vertical diffusion
FIFE 1987	LD	Local diffusion experiment	Updated	Local
	ND	Nonlocal diffusion experiment	Updated	Nonlocal
Heavy-rain case	OPN	Operational physics experiment	Operational	Local
	LD	Local diffusion experiment	Updated	Local
	ND	Nonlocal diffusion experiment	Updated	Nonlocal
Parallel run	MRY	Operational physics experiment	Operational	Local
	MRX	Nonlocal diffusion experiment	Updated	Nonlocal





b is critical, but Ribcr is little sensitive ➔counter-gradient term is crucial ➔ consistent with previous PBL studies

Step 2: Heavy rain case (Hong and Pan 1996)

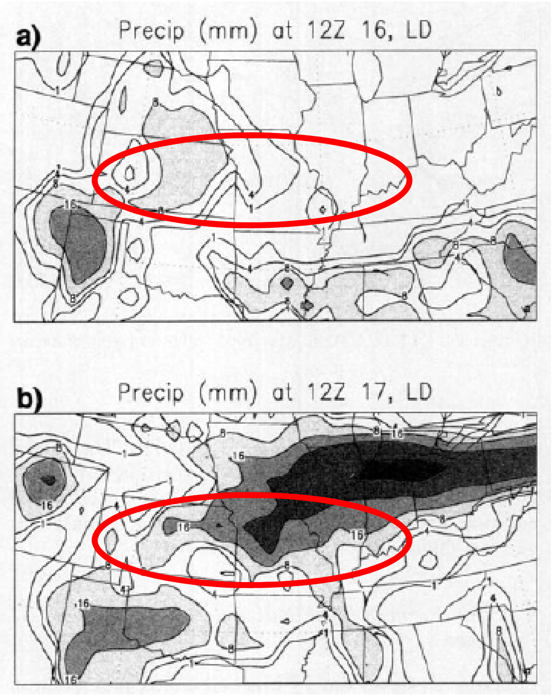


FIG. 9. As in Fig. 7 but for the local diffusion experiment, which utilizes the improved convection scheme.

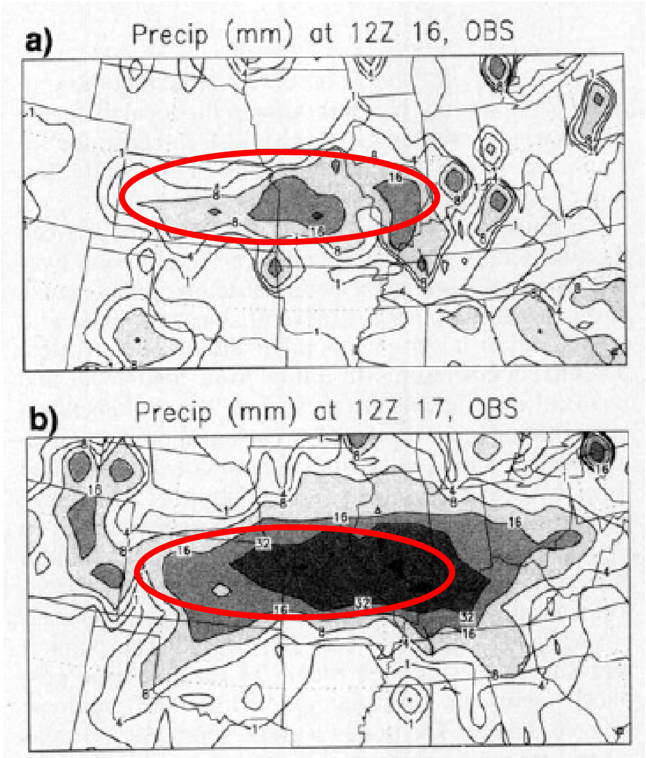


FIG. 7. The analyzed 24-h accumulated rainfall (mm) ending at (a) 1200 UTC 16 May and (b) 1200 UTC 17 May 1995. Areas of rainfall over 8 mm are shaded. Values are box averages on the T126 spectral grid from station data.

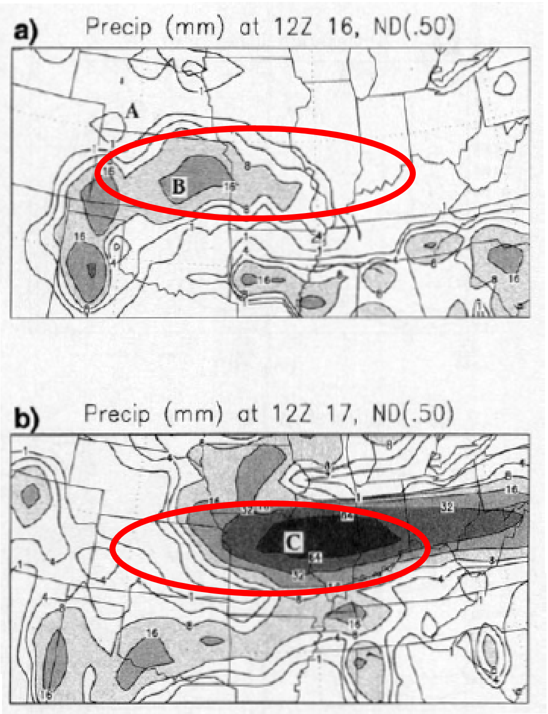


FIG. 10. As in Fig. 7 but for the control nonlocal diffusion experiment with Rib_{cr} = 0.50. Points *A*, *B*, and *C* designate the station points for time–height cross-sectional analyses in Figs. 11 and 13.

LD

OBS

ND

Step 3: Parallel run (Hong and Pan 1996)

ETS

Bias

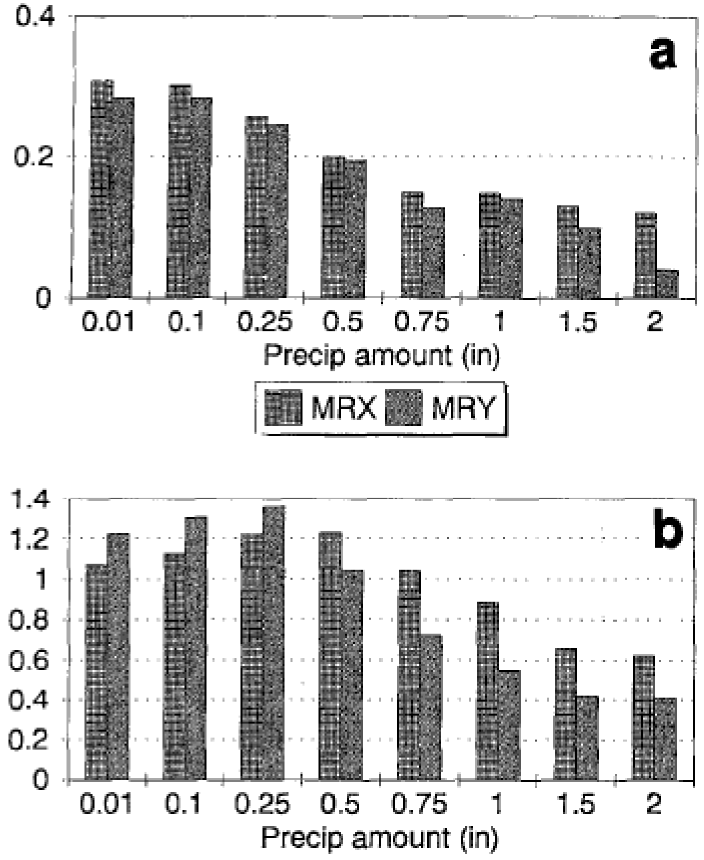


FIG. 15. Comparison of the (a) precipitation equitable threat scores and (b) precipitation bias scores derived from the parallel run with the nonlocal diffusion scheme and modified convective parameterization scheme (MRX) and from the current operational model physics (MRY) for the month of August 1995.

ND improves both ETS and bias scores for parallel run for the month of August 1995

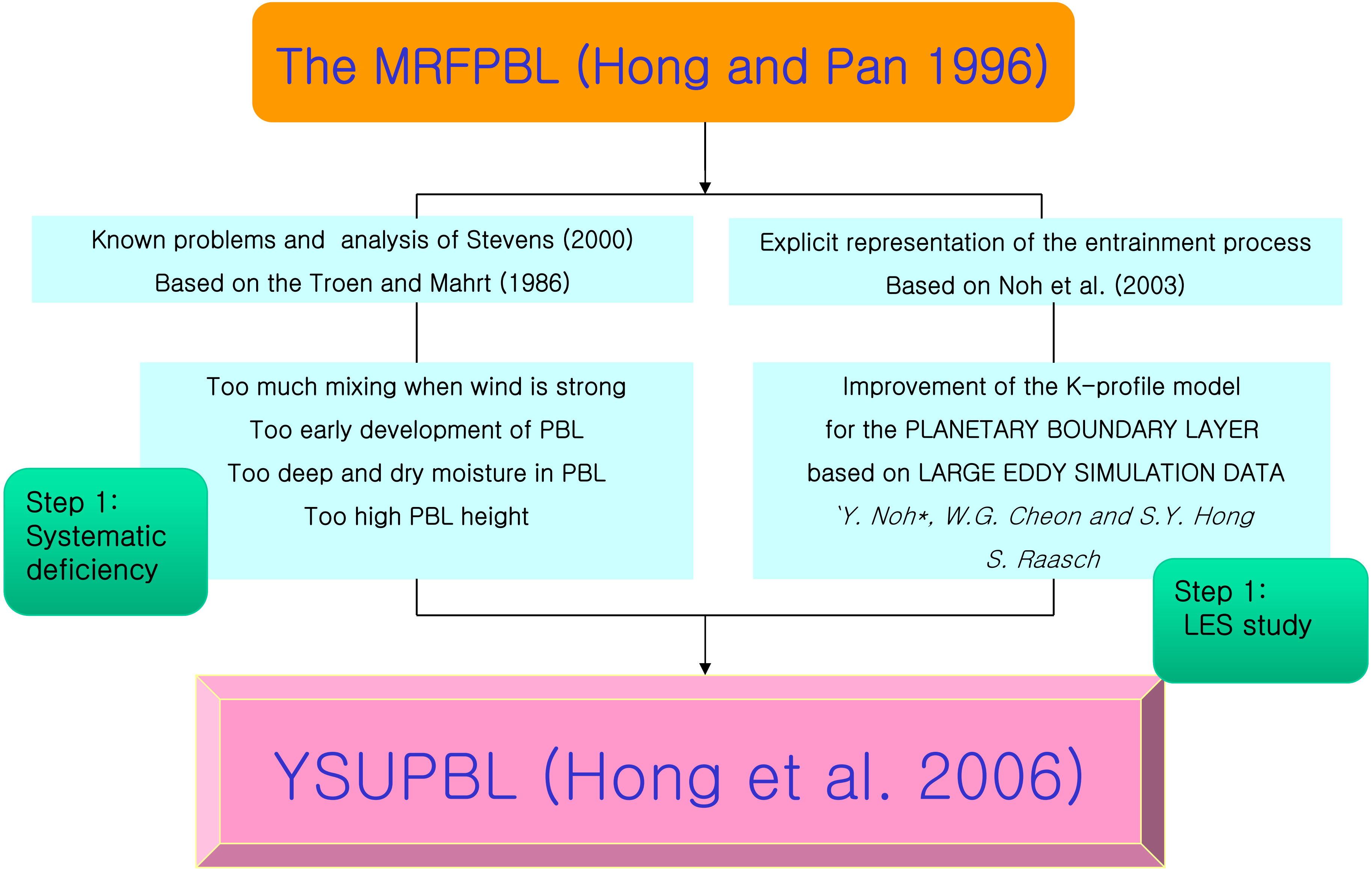
The MRF PBL (non-local diffusion) became operational since October 1995

PBL and precipitation interaction (Hong and Pan 1996)

In contrast to the dry case, the resulting rainfall is significantly affected by the critical Ri, which is due to the fact that the simulated precipitation is more sensitive to the boundary layer structure when the PBL collapses than when it develops.

PBL determines the location of convective overturning, which further affects the grid-scale large-scale rainfall downstream

Overall, the increase of Ri_cr reduces the weak precipitation and increases heavy precipitation



The MRFPBL (Hong and Pan 1996)

Known problems and analysis of Stevens (2000)

Based on the Troen and Mahrt (1986)

Too much mixing when wind is strong

Too early development of PBL

Too deep and dry moisture in PBL

Too high PBL height

Step 1:
Systematic deficiency

Explicit representation of the entrainment process

Based on Noh et al. (2003)

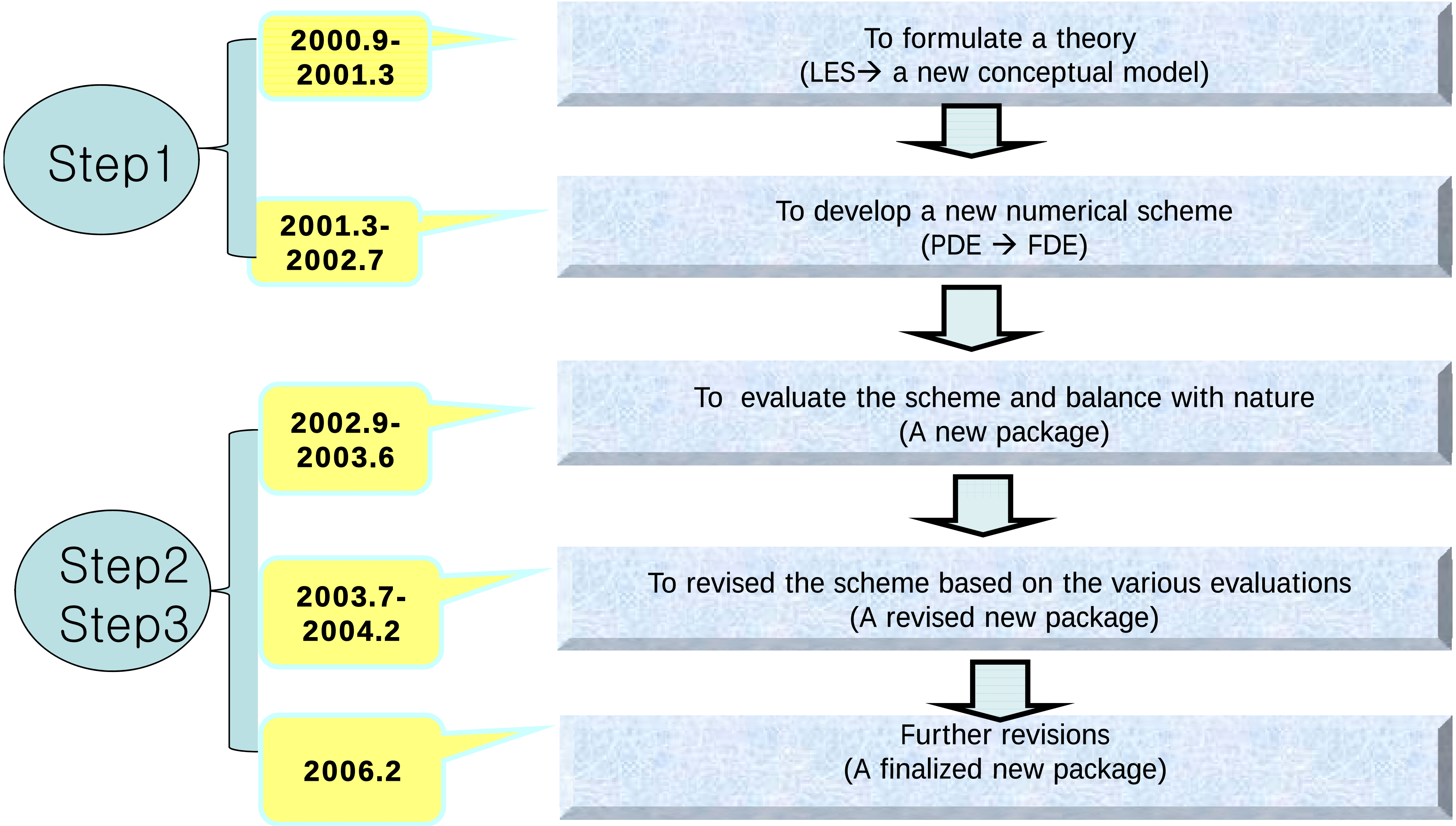
Improvement of the K-profile model
for the PLANETARY BOUNDARY LAYER
based on LARGE EDDY SIMULATION DATA

‘Y. Noh, W.G. Cheon and S.Y. Hong*
S. Raasch

Step 1:
LES study

YSUPBL (Hong et al. 2006)

YSUPBL - development



Step1

2000.9-2001.3

To formulate a theory
(LES→ a new conceptual model)

2001.3-2002.7

To develop a new numerical scheme
(PDE → FDE)

Step2
Step3

2002.9-2003.6

To evaluate the scheme and balance with nature
(A new package)

2003.7-2004.2

To revised the scheme based on the various evaluations
(A revised new package)

2006.2

Further revisions
(A finalized new package)

Step 1: Generalization and reformulation of the explicit entrainment (N2003)

$$-\overline{w'\theta'} = K_h\left(\frac{\partial\theta}{\partial z}-\gamma_h\right) - \overline{w'\theta'}_h\left(\frac{z}{h}\right)^3 \quad \text{for } z < h$$

- Alleviate resolution dependency (staggered)
- Inclusion of moisture, tracers, and hydrometeors
- Conservation of fluxes
- Matching with free convection diffusion

Model setup : BAMEX 2002

- Cold front (10-11 Nov 2002)
- 4 km grid (cloud-resolving)
- YSU PBL compared to MRF PBL
- WSM6 microphysics
- NOAH land surface
- No cumulus parameterization scheme

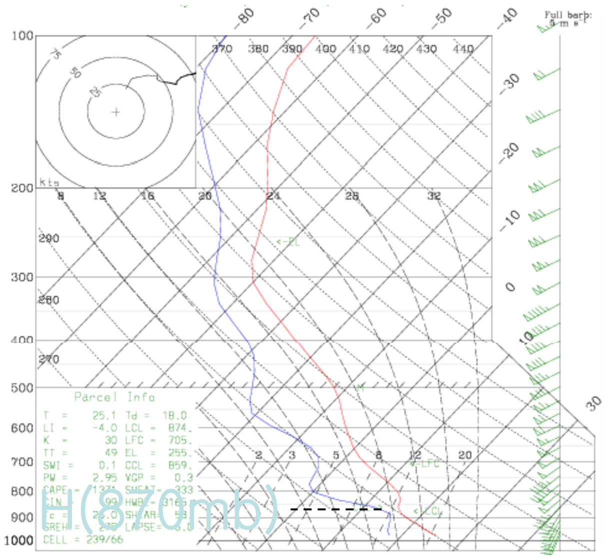
Initial time : 12Z 10 November 2002

Initial and boundary data : EDAS analyses

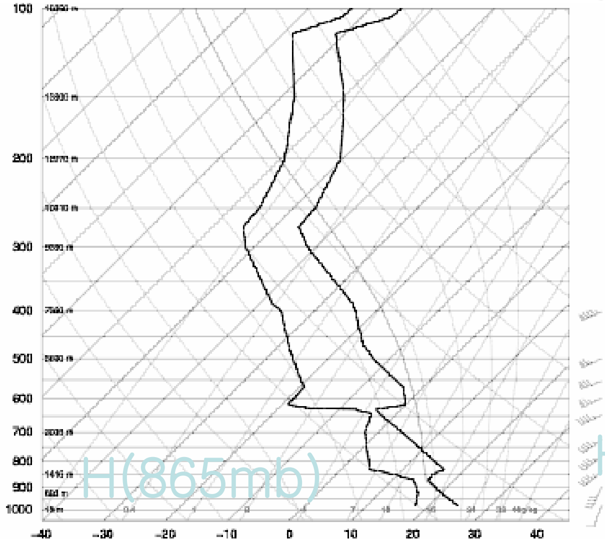
Focus : Precipitation response due to the differences
in YSU and MRF PBL

Sounding profile at 18Z in the pre-frontal regions (near Nashville Tennessee)

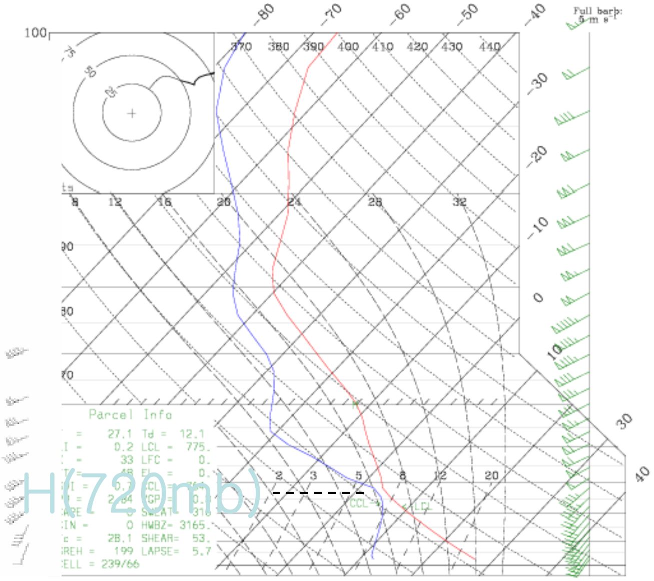
YSU



OBS



MRF

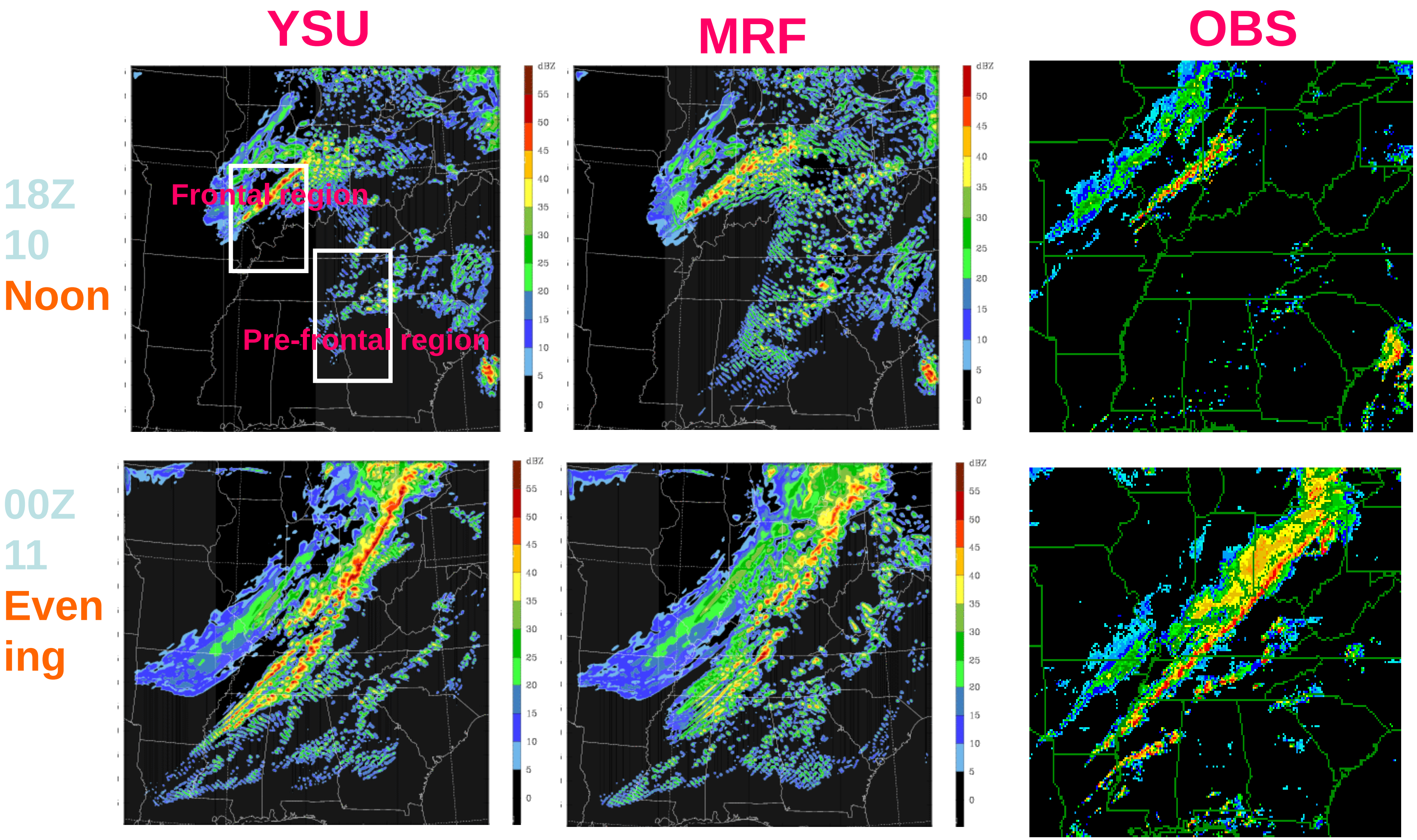


Cooler & moister

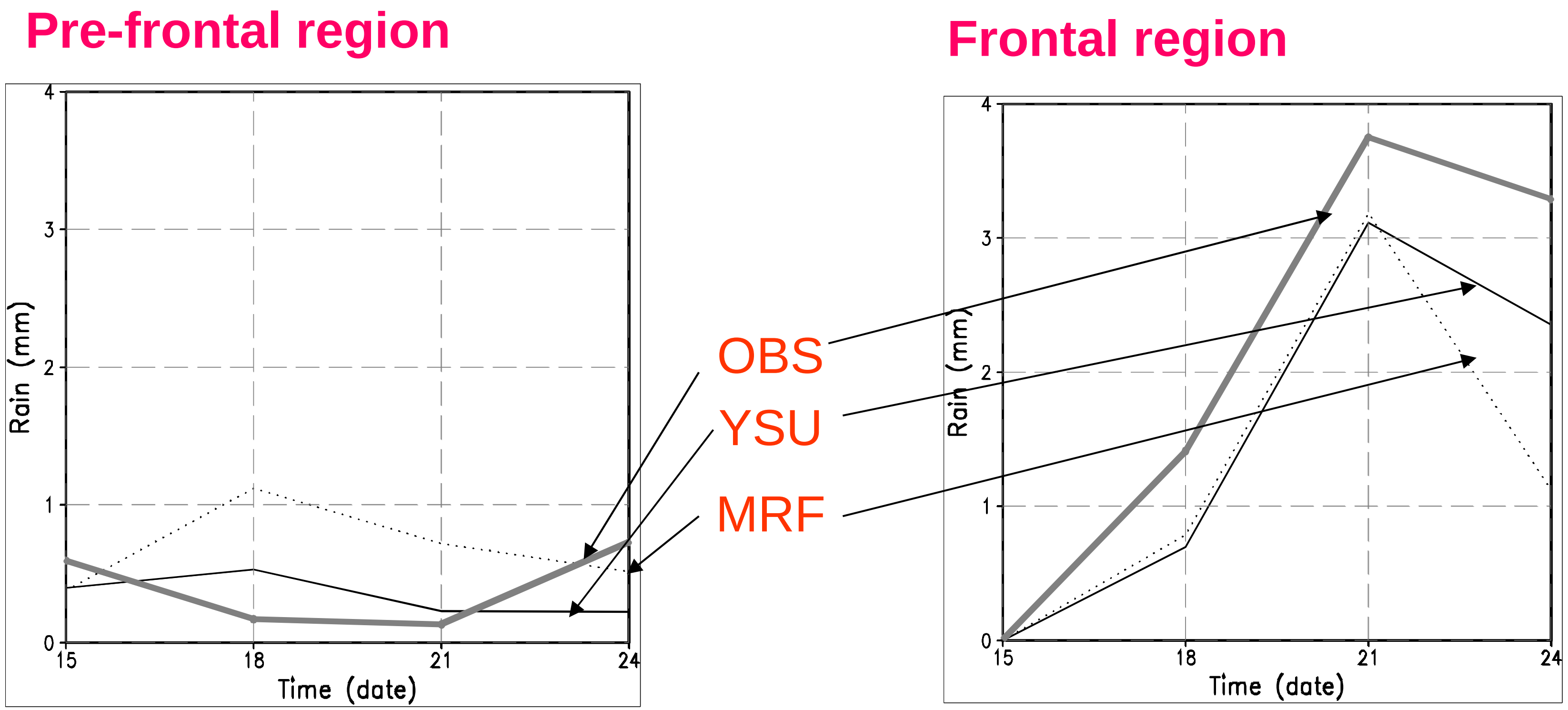
Warmer & drier

- PBL structure is better reproduced by YSU than MRF in the pre-frontal region → Improved the inversion above h

Maximum radar reflectivity (dBz)



Time series of domain averaged precipitation



- Why precipitation with the YSU is better than with MRF PBL ?

See Hong et al. (2006)

Remarks

Impact of PBL on precipitation processes is intimately related with not only the onset of convection, but also the type of convection

(shallow vs. deep ; local vs. synoptic forcing)

The environmental structure in the lower troposphere indirectly affects the intensity of precipitating convection

(dry PBL enhances the evaporation of falling hydrometeors, which results in the weakening of surface precipitation and storm intensity)

Stable boundary layer mixing in a vertical diffusion package

Step 1 : Systematic deficiency

- YSU underestimates the chemical species in stable conditions (over water)

Stable BL in YSU PBL (WRF 2.2) : Local approach

$$K_{m\_loc,t\_loc} = l^2 f_{m,t}(Rig)\left(\frac{\partial U}{\partial z}\right)$$

$$\mathbf{Rig} = \frac{g}{\theta_v}\left[\frac{\partial\theta_v / \partial z}{(\partial U / \partial z)^2}\right]$$

$$\frac{1}{l} = \frac{1}{kz} + \frac{1}{\lambda_0}$$

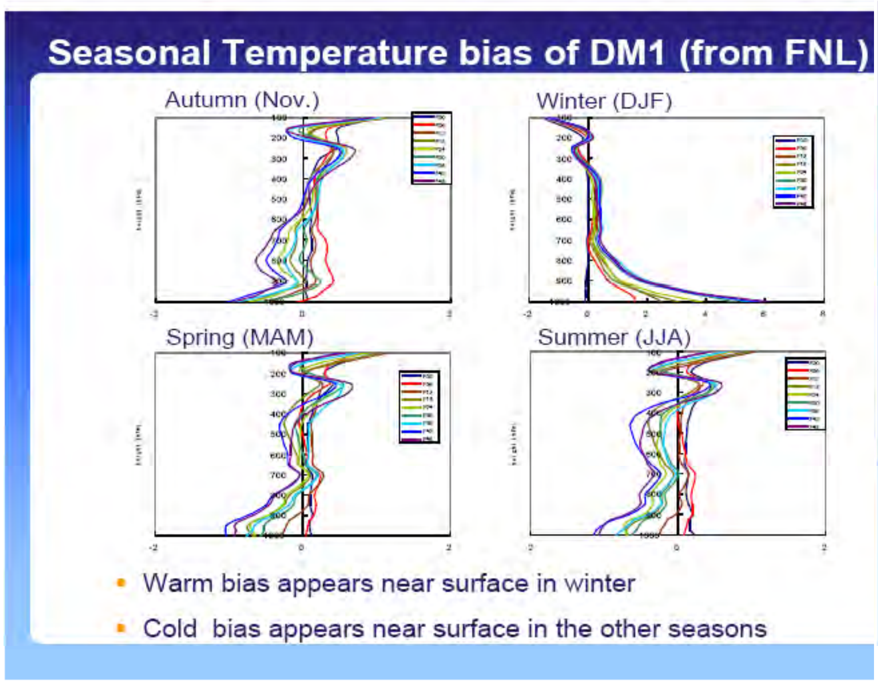
May be inappropriate

Step 1 : Systematic deficiency

Dear Dr. Hong,

This is Fred. I started to use the fully coupled chemistry within the WRF (WRF/Chem) since I came to Los Alamos to examine the transport and transformation of gaseous and particulate pollutions emitted by megacities such as Mexico City on local and regional scales. One thing I have noticed is that the nocturnal PBL heights in WRF using YSU scheme are nearly constant between 0 and 20 meters. Lidar data from the recent Mexico City field campaign reveal nocturnal PBL heights actually vary between 20 and 500 meters with strong winds corresponding to large PBL heights. I just attended a workshop in Boulder related with the Mexico City field campaign in which many people expressed their concerns for the nearly constant PBL heights in WRF since realistic PBL heights are important for capturing the transport of chemical species.

Step 1 : Systematic deficiency



Seasonal Temperature bias of DM1 (from FNL)

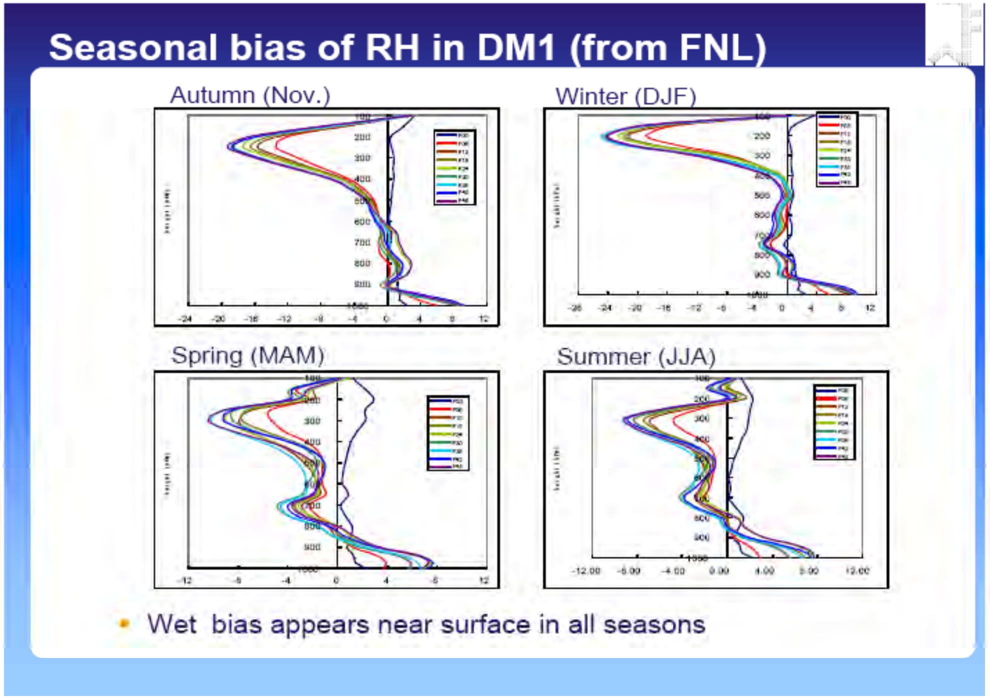
Autumn (Nov.)

Winter (DJF)

Spring (MAM)

Summer (JJA)

- Warm bias appears near surface in winter
- Cold bias appears near surface in the other seasons



Seasonal bias of RH in DM1 (from FNL)

Autumn (Nov.)

Winter (DJF)

Spring (MAM)

Summer (JJA)

- Wet bias appears near surface in all seasons

WRF real-time operation at JHWC-GPP

Cold and wet biases

Step 1 : Form a new concept

Vickers and Mahrt (2004, BLM, 1736-1749)

$$Rib = h\left(\frac{g}{\overline{\theta}}\right)\frac{\left[\theta(h)-\theta_s\right]}{U(h)^2}$$

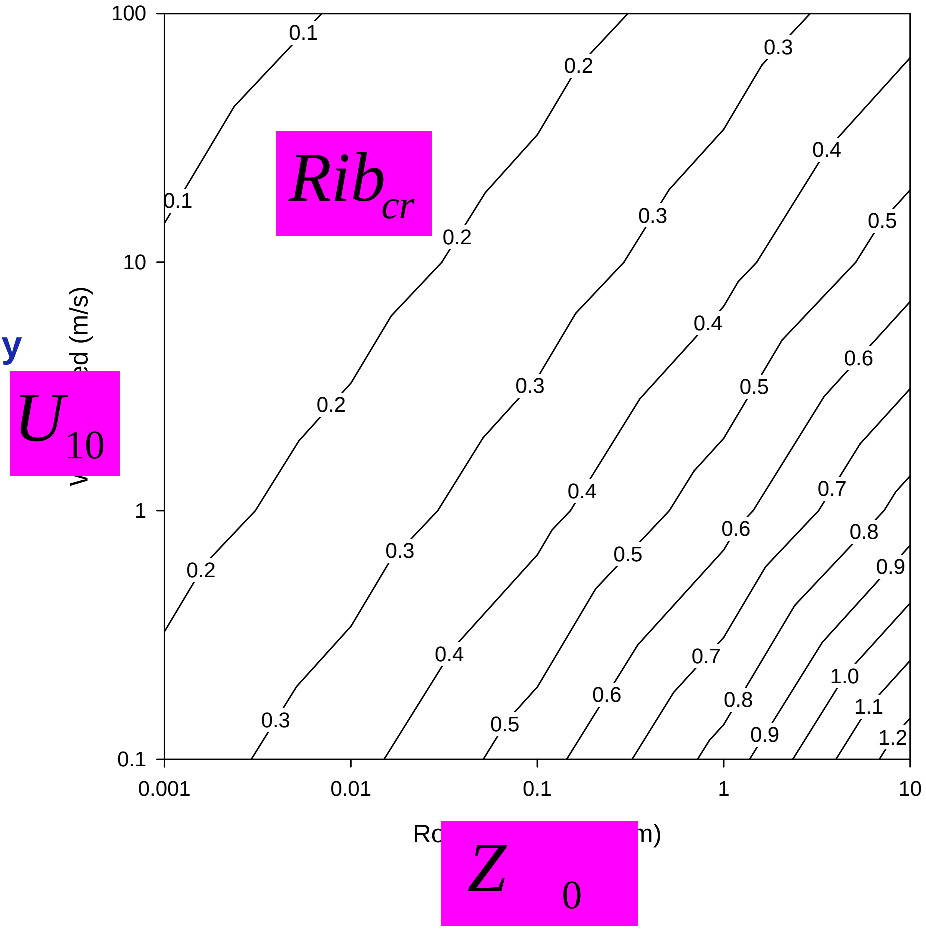
the surface bulk Richardson number
where the critical value for Rib is defined by

$$Rib_{cr} = 0.16\left(10^{-7}R_o\right)^{-0.18}$$

, where

$$R_o = U_{10}/\left(fz_0\right)$$

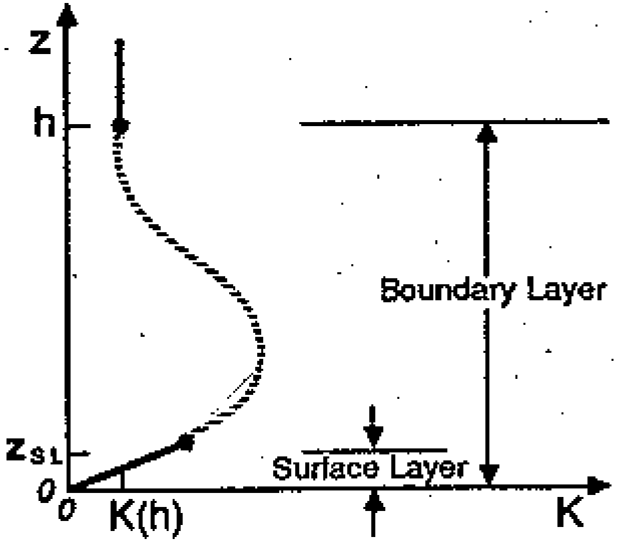
with f=10**-4.



Step 1 : Design a new algorithm

Bulk Ri number approach

$$Ri = \frac{g(\theta_v(h) - \theta_s)}{\theta_{va} \, |U(h)|^2} z$$



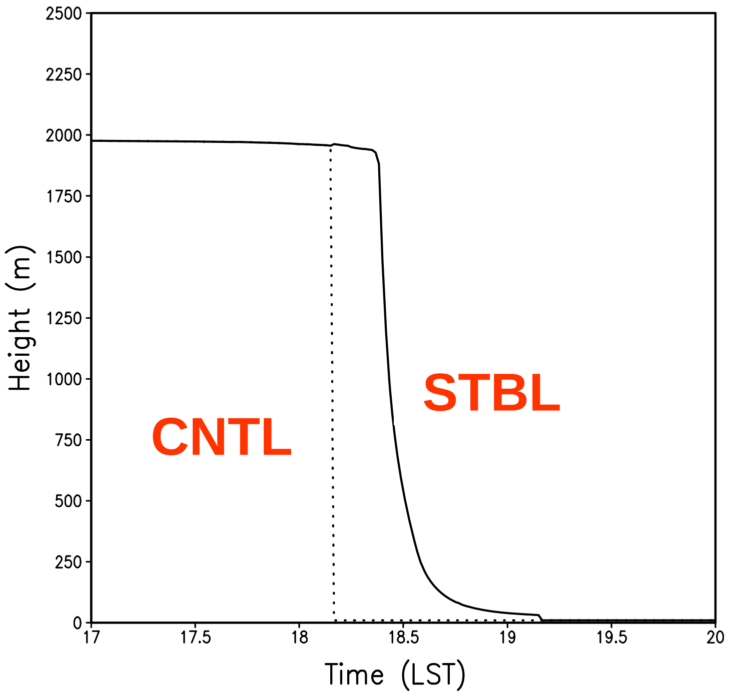
Over water $Rib_{cr} = 0.16\left(10^{-7} R_o\right)^{-0.18}$

Over land $Rib_{cr} = 0.25$

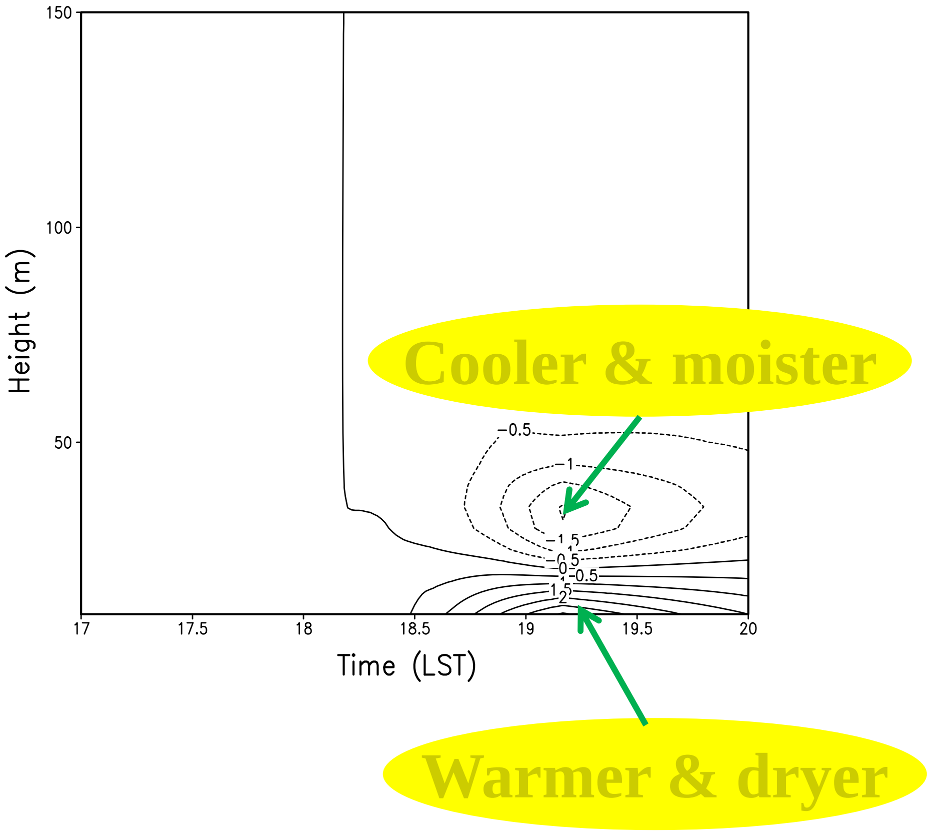
Step 1 : Idealized case

One-d test : dz = 25 m, sunset = 18 h

PBL



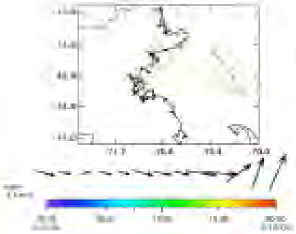
Theta (STBL-CNTL)

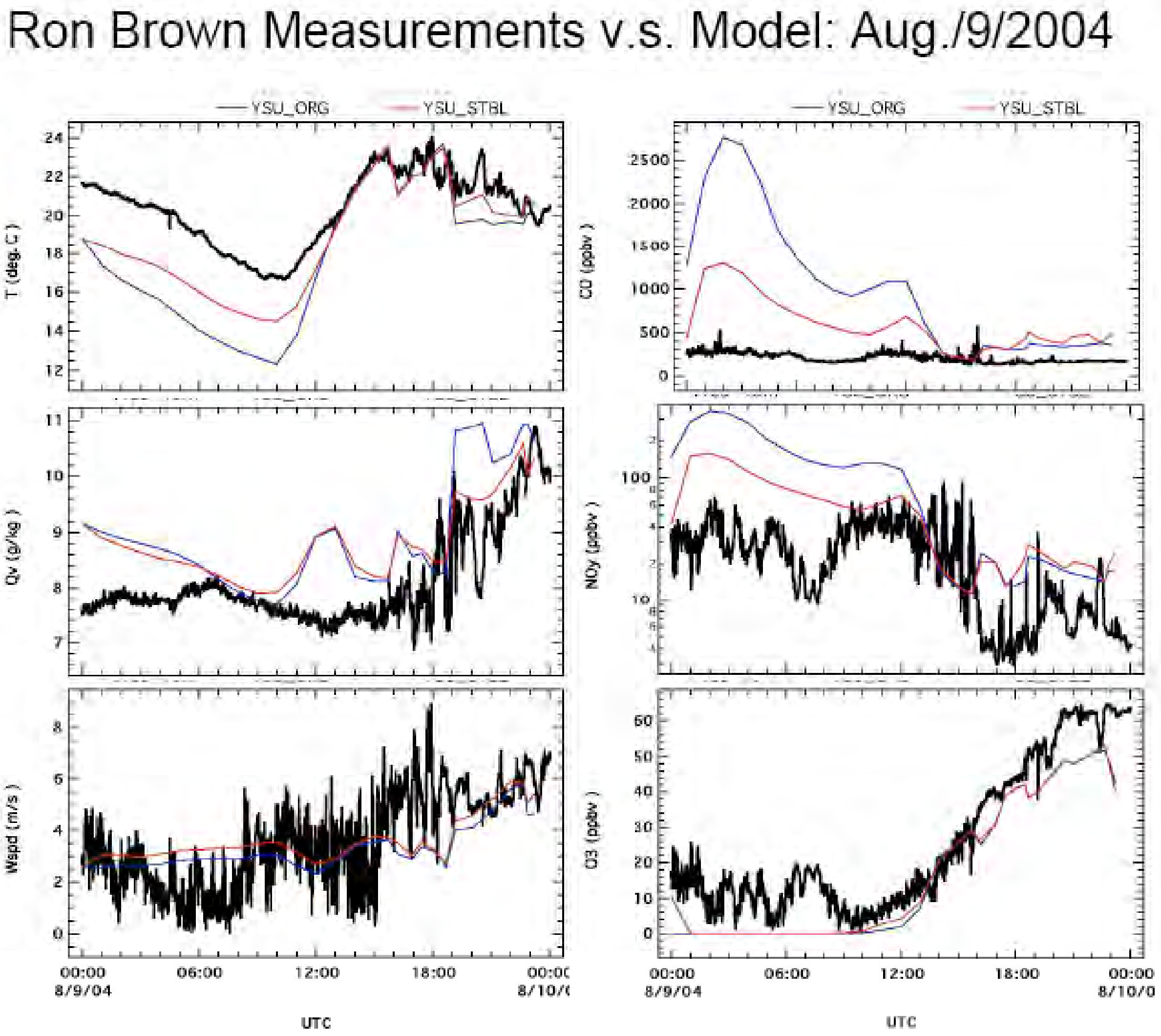


Cooler & moister

Warmer & dryer

Step 2: Real case – Validation with IOP





Black : OBS
Blue : old_STBL
Red : New_STBL

Kim et al. (2008)
WRF workshop

Step 2: Real case-3D

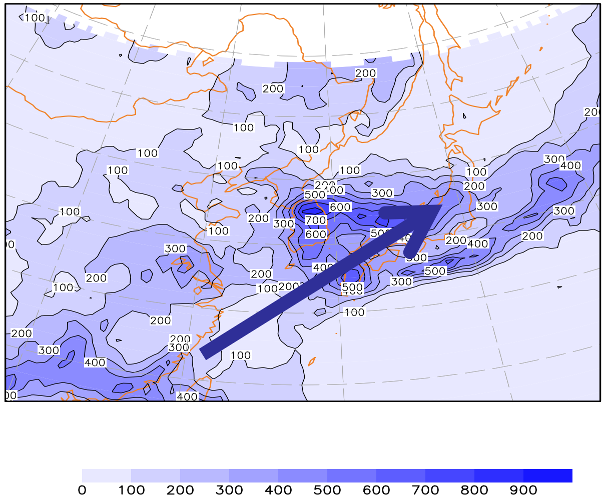
CNTL : Ribcr = 0 (local Ri dependent mixing), WRF 2.2
STBL : Ribcr > 0 (parabolic shape diffusivity), WRF 3.0

Offline test : idealized surface flux forcing
WRF : Cloud resolving resolution (4km)
RSM : Regional climate simulation (50km)
GSM : Seasonal simulation (T62 ~ 200 km)

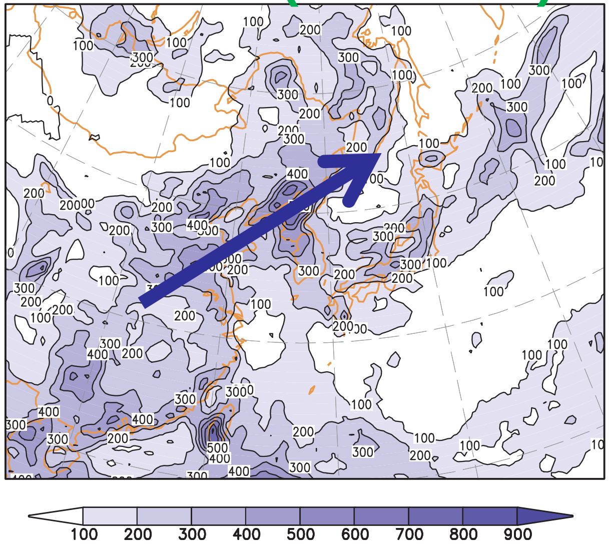
Step 2: Interaction with precipitation – regional

RCM simulation in July 2006: RSM 50 km

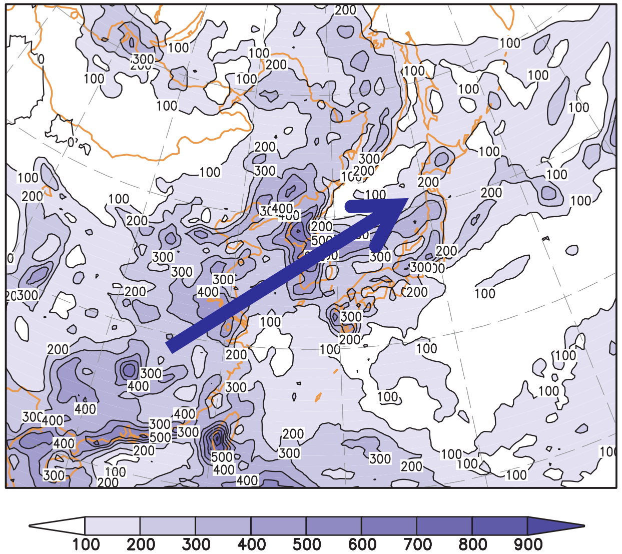
OBS (TRMM)



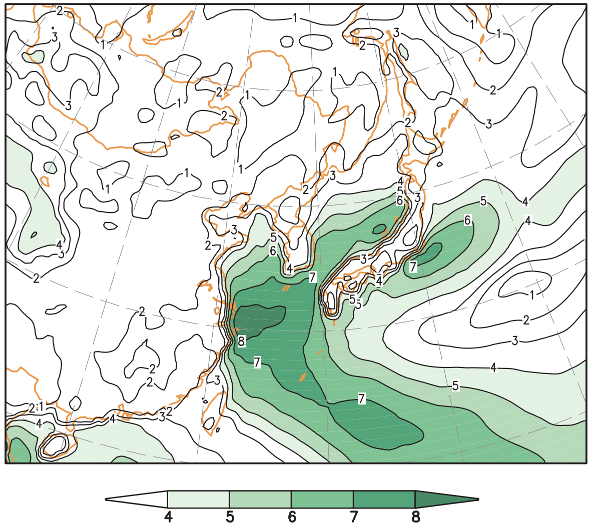
CNTL (PC = 0.47)



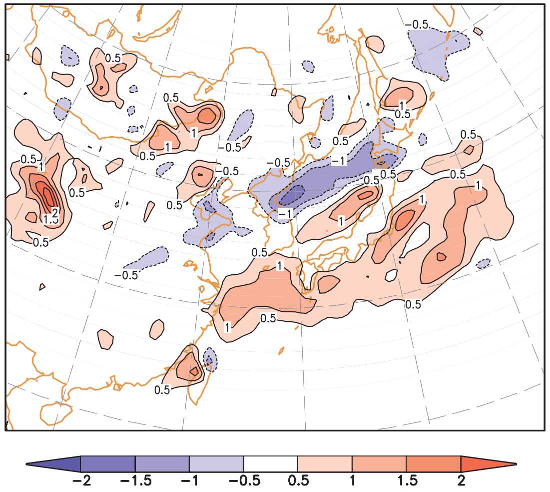
STBL (PC = 0.57)



850 hPa WP (STBL)



STBL-CNTL



Nighttime rainfall is enhanced

Oceanic rainfall is enhanced

Hong (2010 QJRMS)

Step 2: Interaction with other physics

Seasonal simulation (T62; about 200 km)

Model : GRIMs-v2 (Global/Regional Integrated Model system)

Period : 1996. 5 – 8 (JJA), 1996.11-1997. 2 (DJF)

Ensemble : 5 members

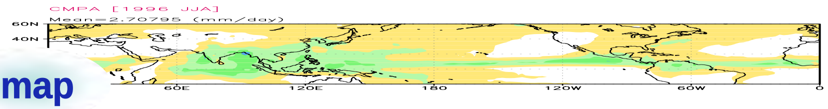
Experiments: CNTL : Hong et al. 2006

STBL : Hong 2010 (enhanced mixing)

Step 2: Interaction with other physics

Seasonal simulation for JJA 1996 (rainfall)

cmap

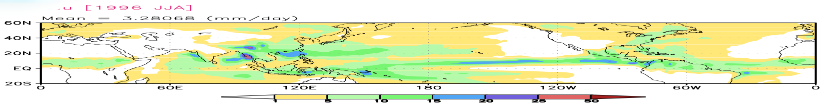


ysu
Global mean
OBS = 2.70795
MODEL = 3.28068
Pattern correlation
GL = 0.736781
EA = 0.625432

stable
Global mean
OBS = 2.70795
MODEL = 3.30121
Pattern correlation
GL = 0.739652
EA = 0.60589

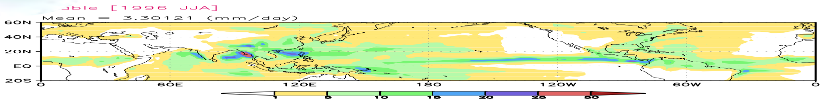
stable_150
Global mean
OBS = 2.70795
MODEL = 3.31642
Pattern correlation
GL = 0.738123
EA = 0.678413

CNTL

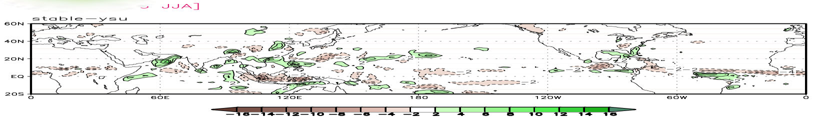


Scheme is stable !!!
Skill is comparable

STBL

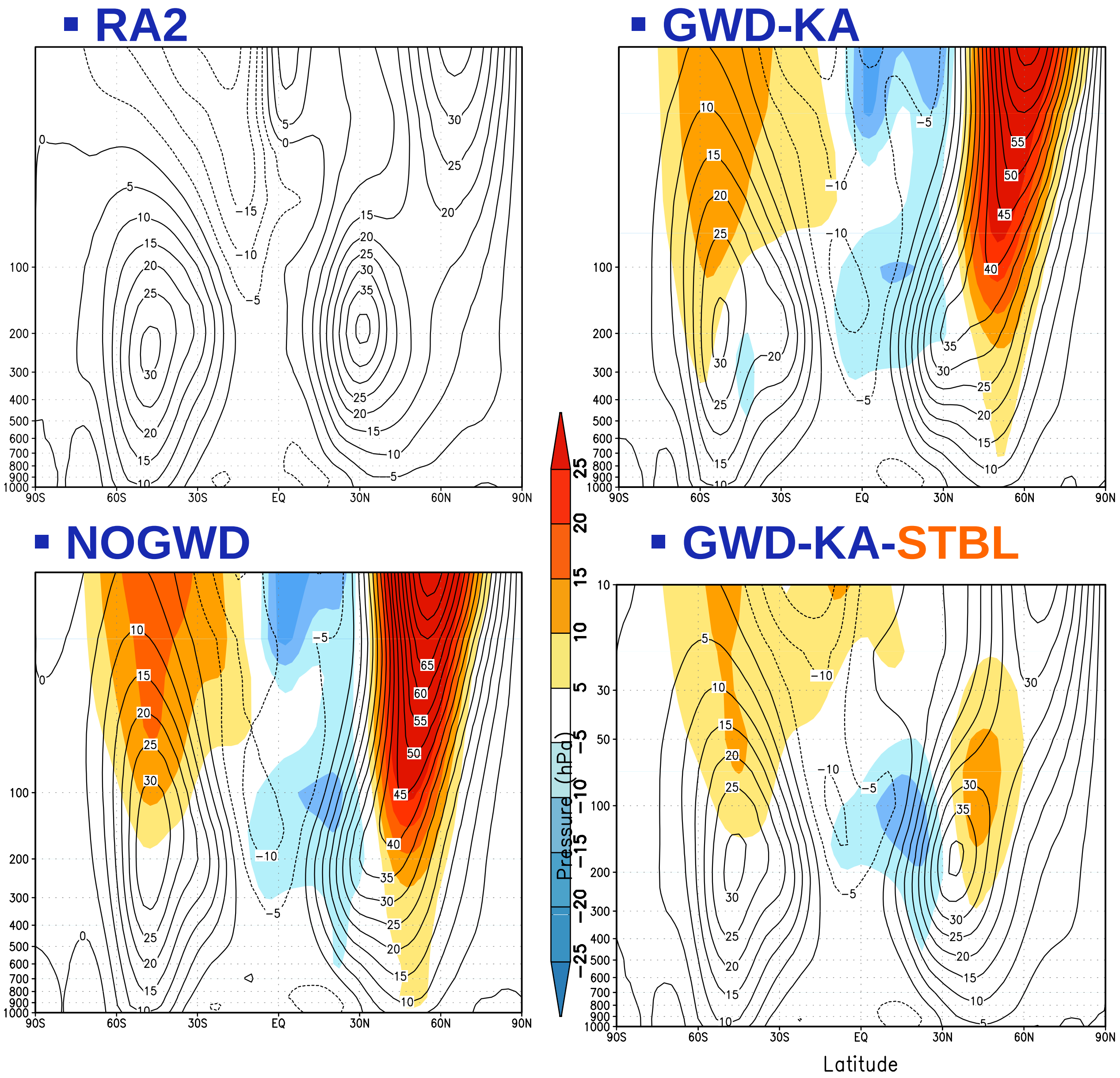


stable - cntl



Step 2: Harmony

Zonal-averaged zonal wind (96/97 DJF) :



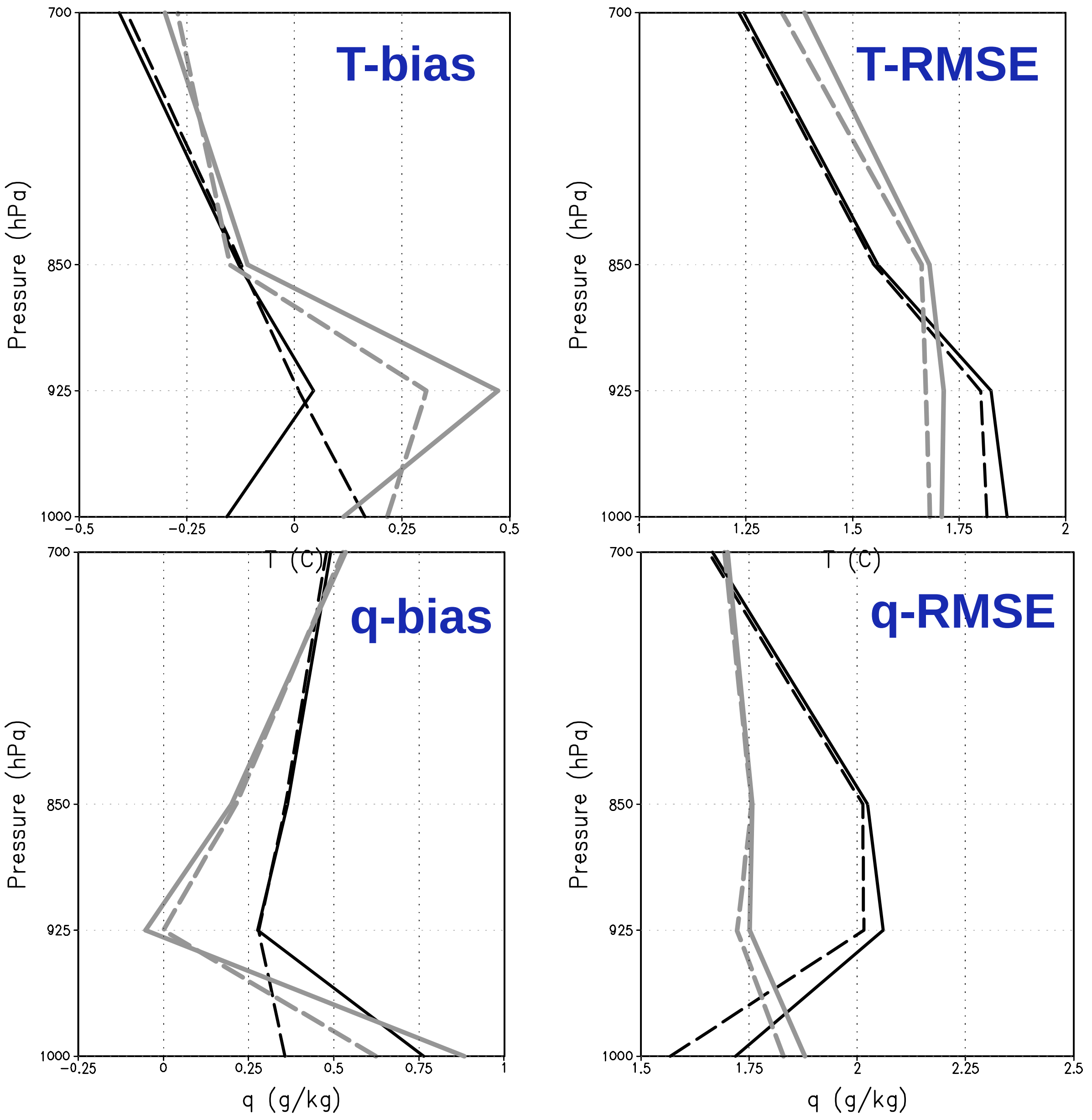
- **RA2**
- **GWD-KA**
- **NOGWD**
- **GWD-KA-STBL**

Contour : Zonal averaged
zonal wind
Shaded: Deviations from
the RA2

Kim and Arakawa
→Improves upper level jets
→Improves the sea level pressure

(Kim and Hong, GR-letter, June 2009)

Step 3: A statistical evaluation – July 2006



Solid : CNTL-OBS
Dashed: STBL-OBS

Cold start run : 00 UTC → 48 hr forecasts (31 cases)

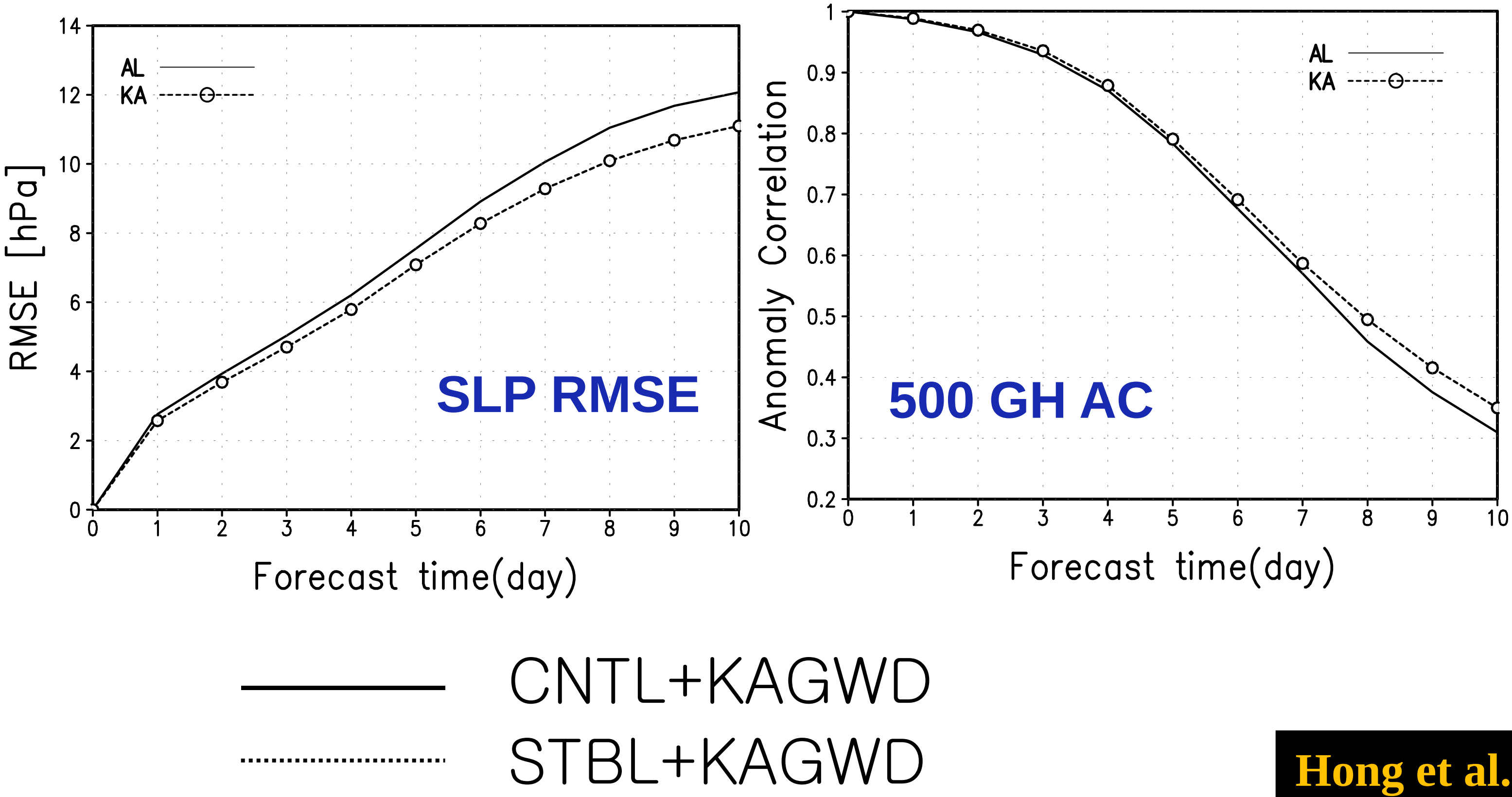
WRF , 50 km over East Asia

OBS : Radiosonde data

(grey : 12 UTC, black : 00 UTC)

Hong 2010
(QJRMS, in press)

Step 3: Medium-range forecast : December 2006
(10 day run every 00, 12 UTC)



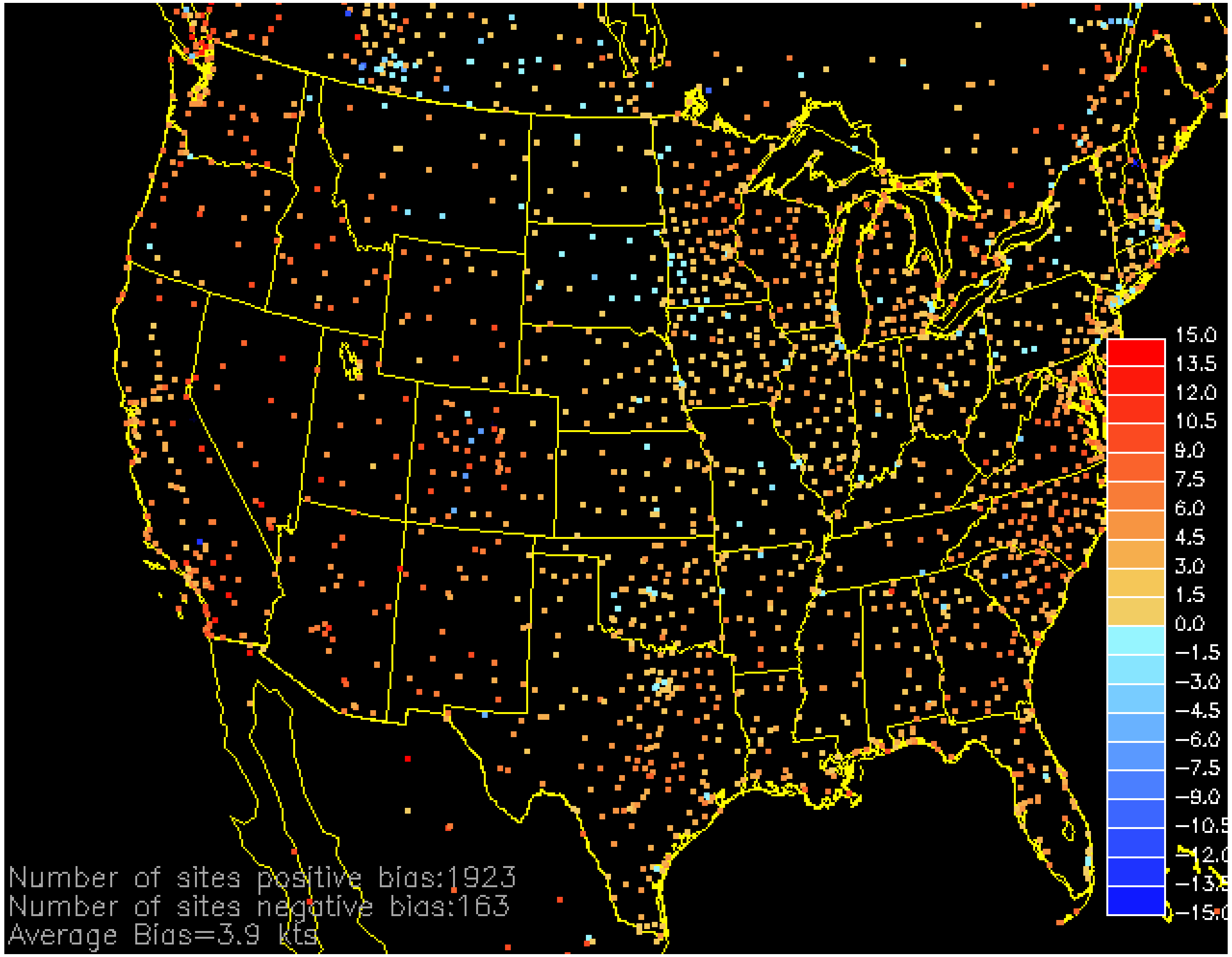
Hong et al. 2008
(Wea Forecasting)

YSU PBL finished ???

An apparent systematic bias :

Too strong surface wind in nighttime

AFWA : WRF 6Z Run, 24 Hour Fcst (mid night)
Wind Speed >= 10kts

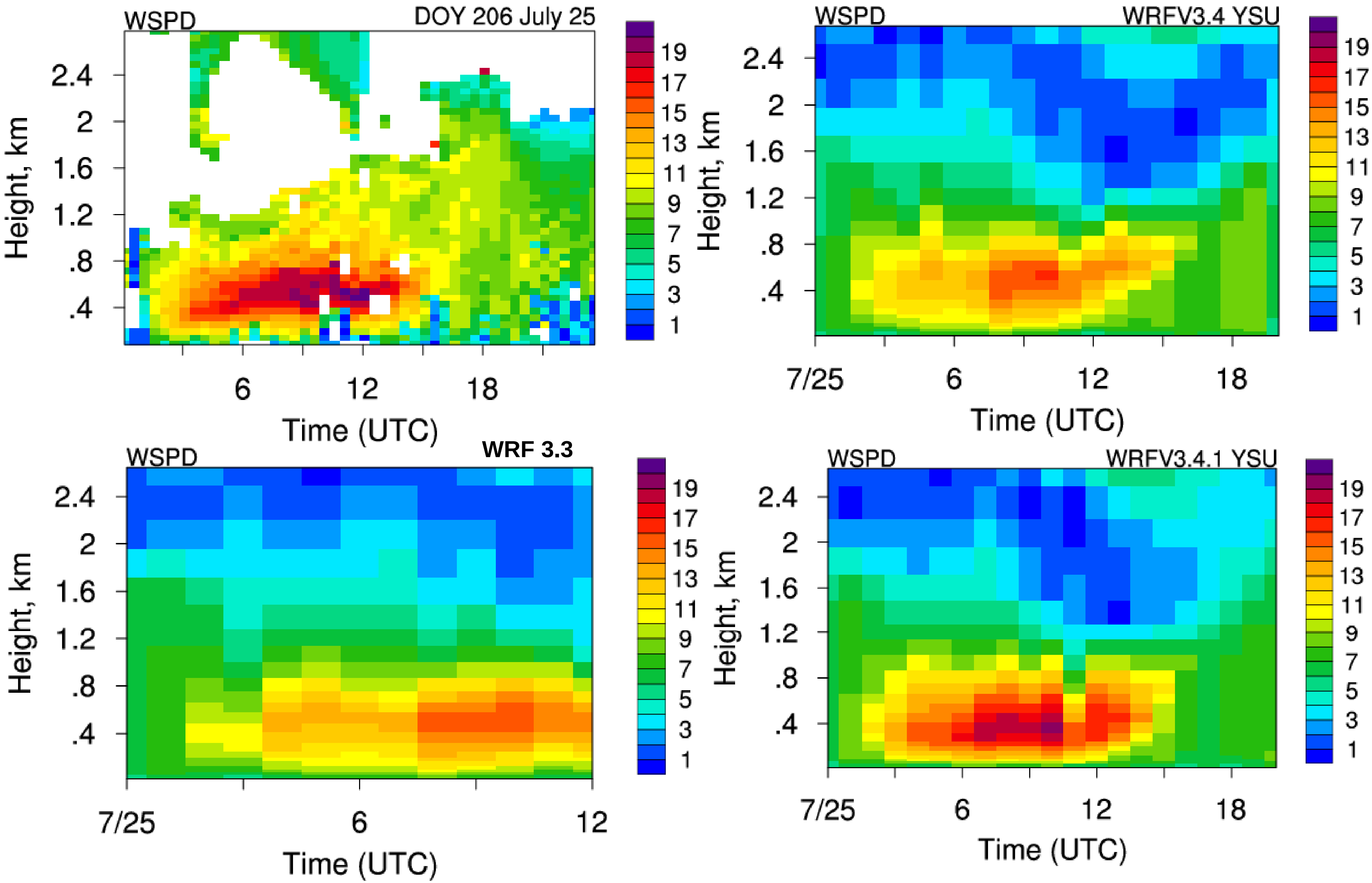


Stable mixing in nighttime

Collaboration with Peggy Lemone

: Ws = u*/phim, phim= (1+5z/L)

YSU PBL revisions : from V3.3 (2011) to v 3.4.1 (2012)



Development strategy

Physically based

Simplicity

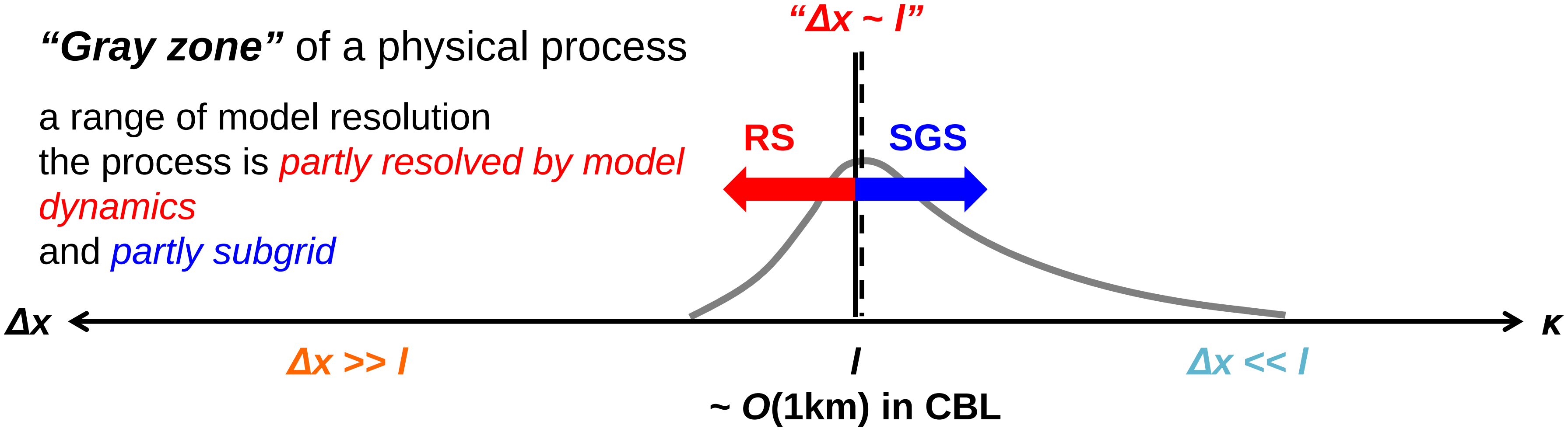
Harmony

“Gray zone” in modeling turbulent PBLs

(see Hong and Dudhia 2012, BAMS for review)

“Gray zone” of a physical process

a range of model resolution
the process is *partly resolved by model dynamics*
and *partly subgrid*



l/Δx << 1

- **resolving: mean flows**
- parameterizing:
all the turbulence

- Resolved fields: ***laminar***
- Parameterization:
one-dimensional

“1DPBL”

l/Δx ~ 1

none of two are valid
“Terra incognita”
(Wyngaard 2004)
“Gray zone”

transition to turbulence

three-dimensional

l/Δx >> 1

(Δ in the inertial subrange)

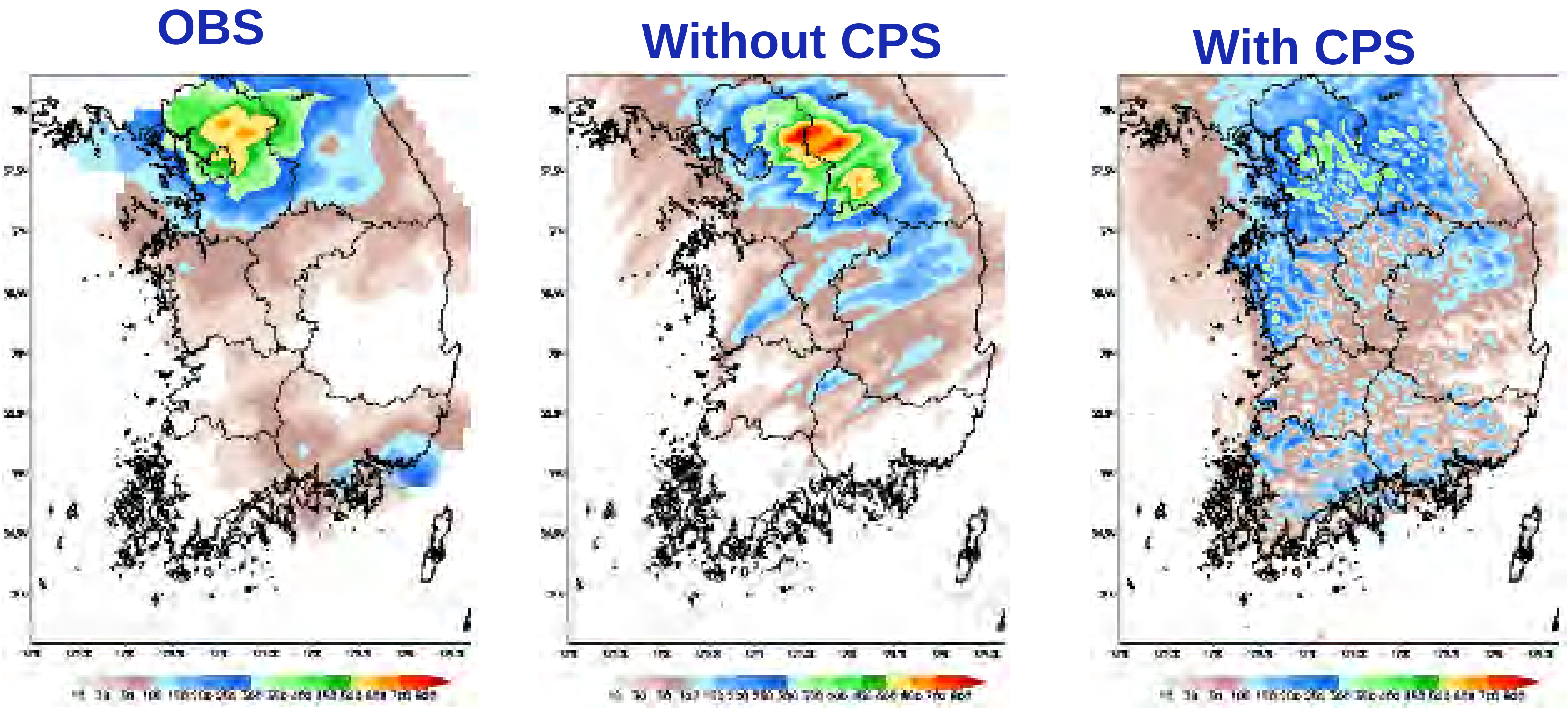
- **resolving: large eddies**
- parameterizing:
small eddies

turbulent

three-dimensional

“3DLES”

3-km heavy rainfall simulation



OBS

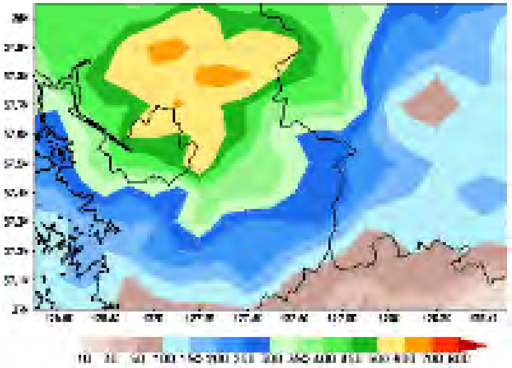
Without CPS

With CPS

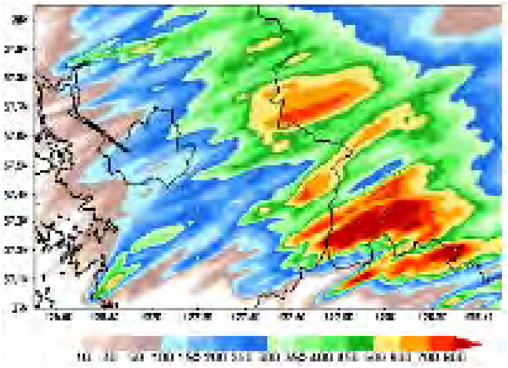
No-CPS run looks better, but on the other hand we may say that the current-state of CPS cannot handle the grey-zone physics

0.75 km heavy rainfall simulation

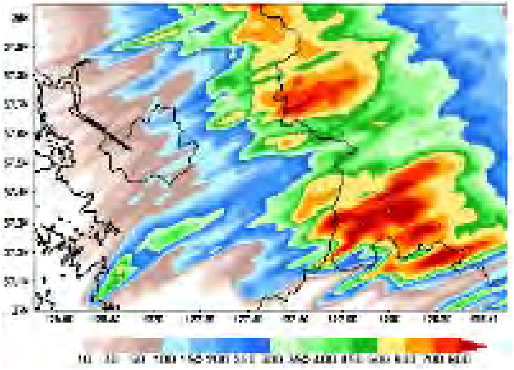
OBS



With PBL scheme



Without PBL scheme



Another issue like initial condition should exist in this resolution, but we may say that column turbulence physics do not work properly in this resolution

Derivation of TKE from the YSU PBL Parameterization

(Shin, Hong, Noh, and Dudhia 2013, JAS, in press)

TKE equation

$$\frac{\partial \bar{e}}{\partial t}=\underbrace{-\frac{\partial}{\partial z}\left(\overline{w'e'}+\frac{1}{\rho}\overline{w'p'}\right)}_{\text{transport (TR)}}+\underbrace{\left(-\overline{u'w'}\frac{\partial \bar{u}}{\partial z}-\overline{v'w'}\frac{\partial \bar{v}}{\partial z}\right)}_{\text{shear production (SP)}}+\underbrace{\frac{g}{\theta}\overline{w'\theta'}}_{\text{buoyant production (BP)}}-\overset{\text{dissipation (DIS)}}{\varepsilon}$$

dissipation (DIS)

transport (TR) **shear production (SP)** **buoyant production (BP)**

TR $\overline{w'e'}+\frac{1}{\rho}\overline{w'p'}=-K_e\left(\frac{\partial \bar{e}}{\partial z}-\gamma_e\right)+\overline{w'e'}_h\left(\frac{z}{h}\right)^3$ **consistent with the YSU PBL algorithm**

$K_e=K_H$ $\gamma_e=C_1^*\frac{1}{\bar{e}}\frac{g}{\theta}w_*\overline{w'\theta'}$ *Therry and Lacarrère (1983)*

$$\overline{w'e'}_h=w_e\,\Delta\bar{e}\big|_h$$

DIS $\varepsilon=\frac{\left(\overline{u_i'^2}\right)^{3/2}}{\Lambda_1}=C_\varepsilon\frac{\bar{e}^{3/2}}{l}$

$$l\begin{cases}\dfrac{1}{l_1}=\dfrac{1}{C_{KP}kz}+\dfrac{1}{l_0} & l_0=\alpha_1\dfrac{\int_0^{z_{top}}\bar{e}z\,dz}{\int_0^{z_{top}}\bar{e}\,dz}\\[2ex] \dfrac{1}{l_2}=\dfrac{1}{kz}+\dfrac{1}{l_0} \\[2ex] \dfrac{1}{l_3}=\dfrac{1}{l_S}+\dfrac{1}{l_B}+\dfrac{1}{l_0}\end{cases}$$

for convective BLs
by matching $K_{prof,CBL}$ and $K_{MY,NBL}$

for neutral BLs *Mellor and Yamada (1982)*

for convective BLs *Nakanishi (2001)*

Derivation of TKE from the YSU PBL Parameterization

(Shin, Hong, Noh, and Dudhia 2013, JAS, in press)

Experiments

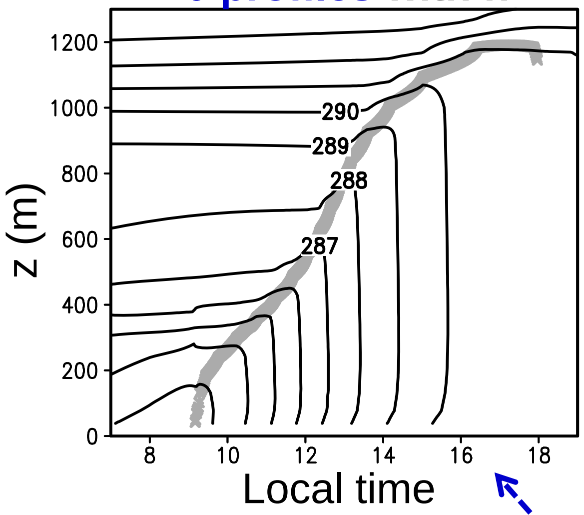
CTL

ML2

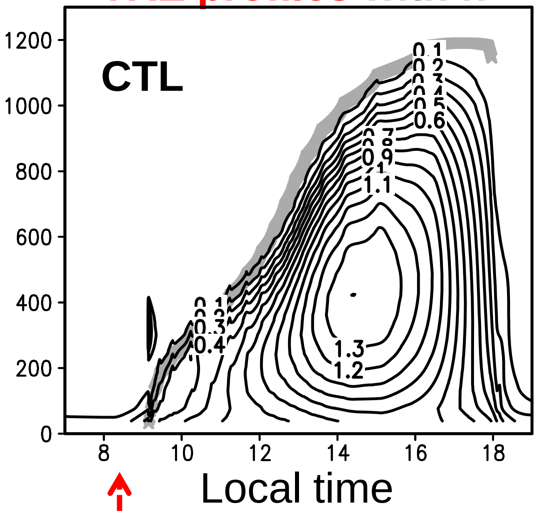
ML3

$$l\begin{cases}\dfrac{1}{l_1}=\dfrac{1}{C_{KP}kz}+\dfrac{1}{l_0}\\[2ex]\dfrac{1}{l_2}=\dfrac{1}{kz}+\dfrac{1}{l_0}\\[2ex]\dfrac{1}{l_3}=\dfrac{1}{l_S}+\dfrac{1}{l_B}+\dfrac{1}{l_0}\end{cases}$$

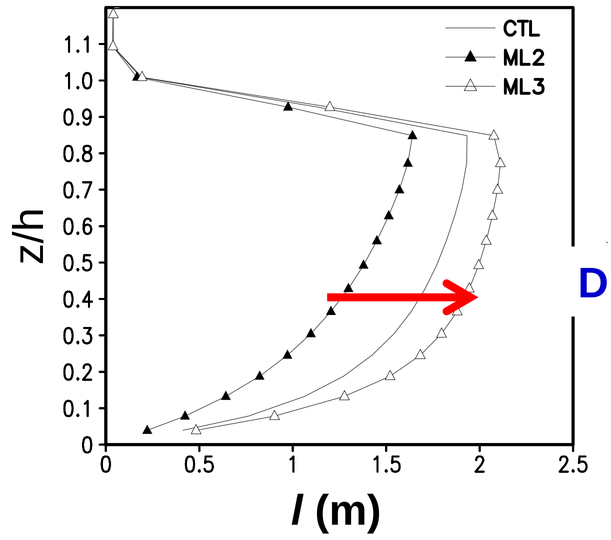
θ profiles with h



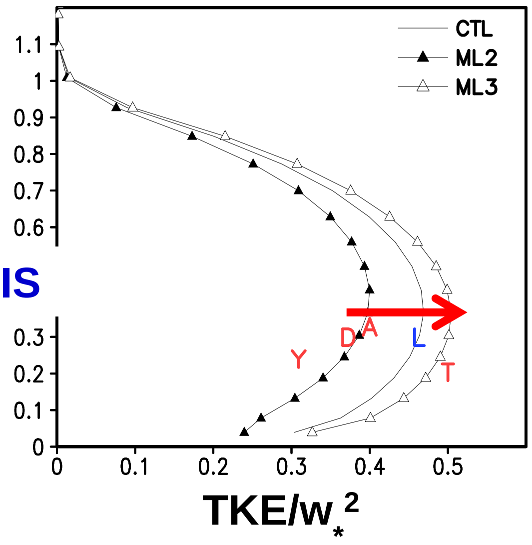
TKE profiles with h



Derived TKE matches well with **mixed-layer development**.



DIS



Length scale (*l*) ↑

→ TKE dissipation (∝1/*l*) ↓

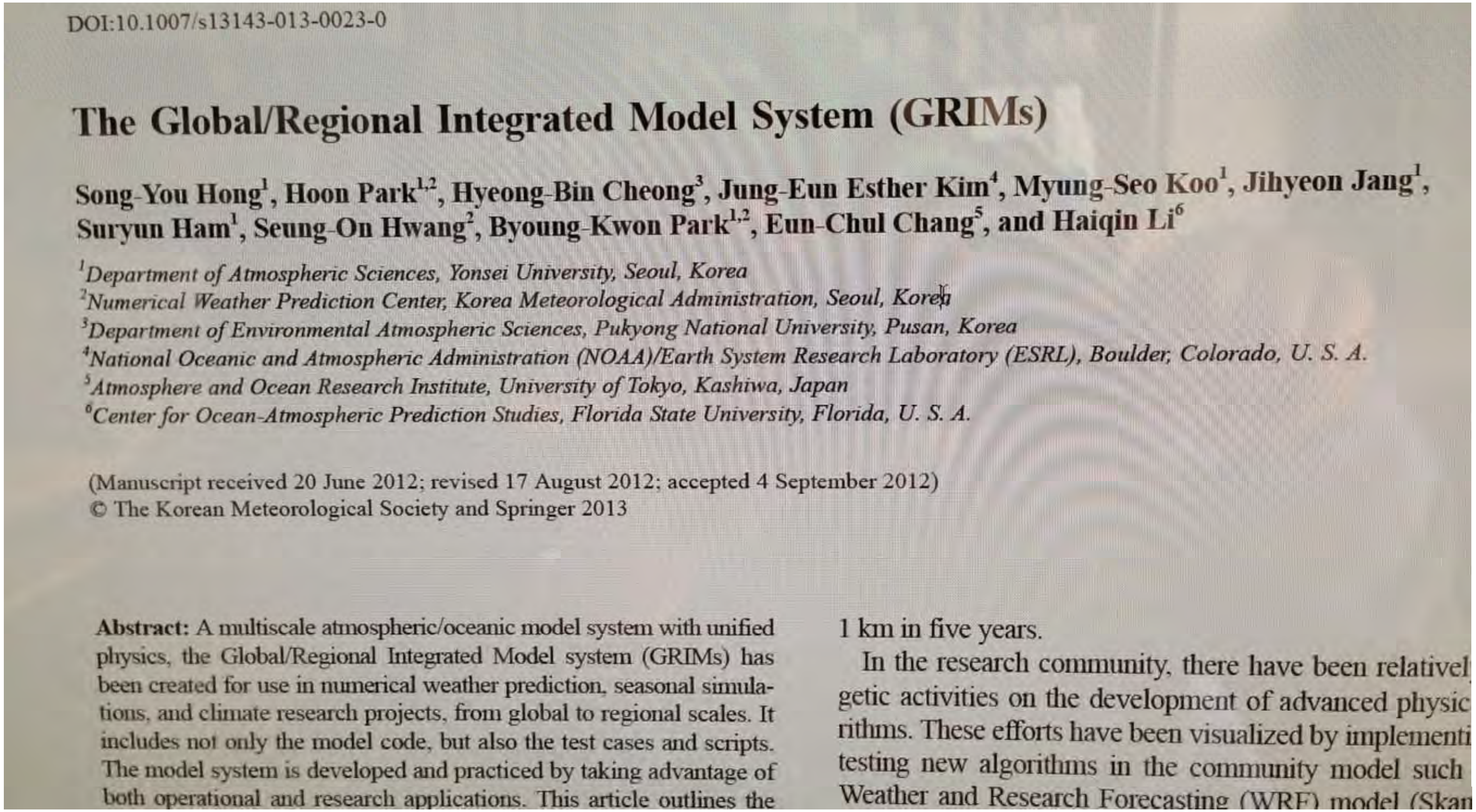
→ TKE ↑

Analysis on Resolved and Parameterized Vertical Transport in Convective Boundary Layers at Gray-Zone Resolution

Hyeyum Hailey Shin and Song-You Hong

(*under review in J. Atmos. Sci.*)

Testbeds for WRF/MPAS physics modules written by myself



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The Global/Regional Integrated Model System (GRIMs)

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Abstract: A multiscale atmospheric/oceanic model system with unified physics, the Global/Regional Integrated Model system (GRIMs) has been created for use in numerical weather prediction, seasonal simulations, and climate research projects, from global to regional scales. It includes not only the model code, but also the test cases and scripts. The model system is developed and practiced by taking advantage of both operational and research applications. This article outlines the

1 km in five years.

In the research community, there have been relativel getic activities on the development of advanced physic rithms. These efforts have been visualized by implementi testing new algorithms in the community model such Weather and Research Forecasting (WRF) model (Skan


The 3rd GRIMs Workshop and Tutorial
::: Date : 6 8 March 2013
::: Host : Yonsei University
National Oceanic and Atmospheric Administration (NOAA)
::: Place : Seogwipo KAL Hotel, Jeju Island
::: Sponsor : Korea Institute of Science and Technology Information (KISTI)
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