# Development of a new global forecast system with a double-Fourier spectral dynamical core

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# The YOnsei University Research model System (YOURS)

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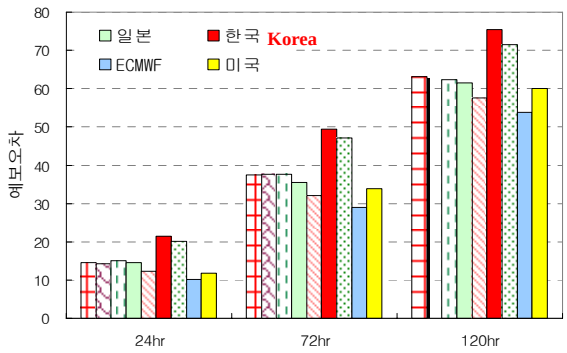
## Presentation list

- Background of YOURS-GSM
- YOURS-Dynamics
- YOURS-Physics
- Test run for medium-range forecasts



## Background (1): Performance of KMA GDAPS

500 mb GH – RMS Error in 2001



## PI : Hong, Song-You (Yonsei University)

Experience in operational modeling

- KLAM (Seoul National Univ., 1986-1989)
- NCEP/EMC (NCEP/EMC, 1993-2000)
  - Cumulus convection (Hong and Pan 1998, MWR) : 1998
  - Cloud microphysics (Hong et al. 1998, MWR) : 1996
  - PBL (Hong and Pan 1996, MWR) : 1995
  - GWDO (Alpert et al. 1996, NWP meeting) : 1998
  - Lateral BDY (Hong and Juang, MWR) : 1996
  - Model intercomparison (COMPARE, PIRCS) : NCEP representative
  - NCEP MRF manual (Hong 2000, http://emc.ncep.noaa.gov)
- NCEP seasonal forecast system (1998-2001)
- Weather research and forecasting (WRF) (2001-)
- YOURS (2002-)

## Kanamitsu et al. (2002)- starting point

Based on NCEP MRF

Kanamitsu (coordinator), Juang (MPI), Hong (physics)

Flexibility
CVS – System (C & Unix ) – multiple platforms with vector and MPI or hybrid

Optional physics
(Cumulus, microphysics, Land-surface, Radiation, PBL, Gravity wave)

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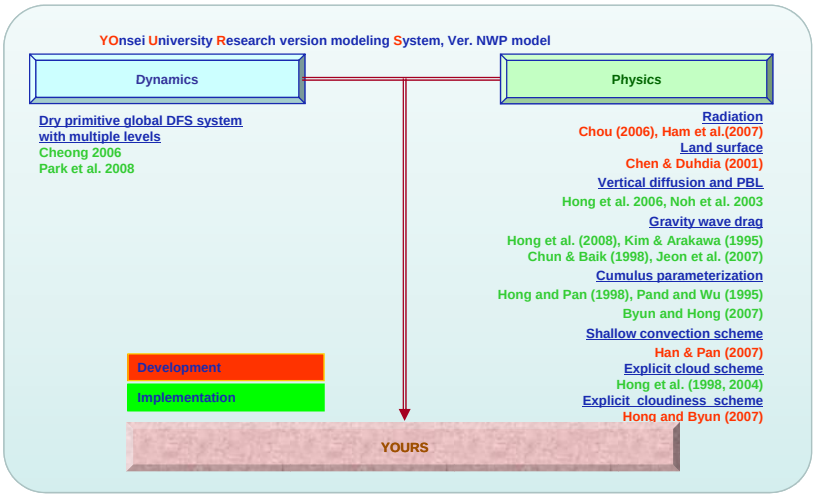
# YOURS-GSM






# Model Development Strategy

• Offline tests

Resolution: grid size from 200 m to T62 (200 km)
Model: SCM, WRF, MM5, RSM and GSM

Single column Model : Direct impact of the new physics
TOGA COARE, ARM, etc.
Regional NWP : Impact on daily forecast
14–15 July 2001, 23–25 June 1997 heavy rainfall
Regional climate : RCM with reanalysis boundary condition
JJA 2002, 2003 East–Asian monsoon, 25–yr climatology
Global NWP : heavy rainfall events, GSM with reanalysis initial data
January 2006, July 2006
Seasonal simulation : Stability of the scheme, tropical precipitation
1996, 1997, 1999 summer and winter , AMIP run

## Dynamic core : Cheong (2006, Mon. Wea. Rev.)

### *Double-Fourier-Series Dynamical Core*

- Global primitive equations – 3 D dry model system
- Vertical sigma coordinate system
- Horizontal discretization: DFS spectral method
- Vertical discretization: finite difference method with cubic-spline
- Temporal discretization: leap-frog with semi-implicit method

$$
\begin{aligned}
\frac{\partial \zeta}{\partial t} &= -\frac{1}{\sin^2\phi}\left[\frac{\partial}{\partial \lambda}F_u + \sin\phi\frac{\partial}{\partial \phi}F_v\right] + S_\zeta \\
\frac{\partial D}{\partial t} &= +\frac{1}{\sin^2\phi}\left[\frac{\partial}{\partial \lambda}F_v - \sin\phi\frac{\partial}{\partial \phi}F_u\right] \\
&\quad - \nabla^2\left[\frac{U^2+V^2}{2\sin^2\phi} + \Phi - \overline{T}\ln p_*\right] + S_D \\
\frac{\partial T'}{\partial t} &= -\frac{1}{\sin^2\phi}\left[\frac{\partial}{\partial \lambda}UT' + \sin\phi\frac{\partial}{\partial \phi}VT'\right] + DT' \\
&\quad - \sigma^\kappa\dot{\sigma}\frac{\partial}{\partial \sigma}(T\sigma^{-\kappa}) + \kappa T\left(\frac{\partial \ln p_*}{\partial t} + \boldsymbol{V}\cdot\nabla\ln p_*\right) + S_T \\
\frac{\partial \Phi}{\partial \sigma^\kappa} &= -\frac{1}{\kappa}T\sigma^{-\kappa} \\
\frac{\partial \ln p_s}{\partial t} &= -\boldsymbol{V}\cdot\nabla\ln p_s - D - \frac{\partial \sigma}{\partial \sigma}
\end{aligned}
$$

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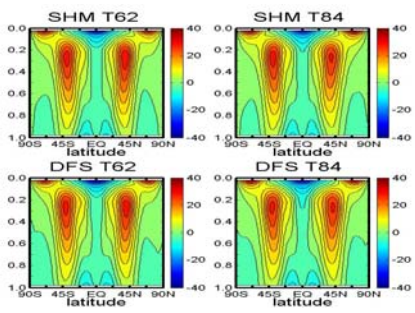
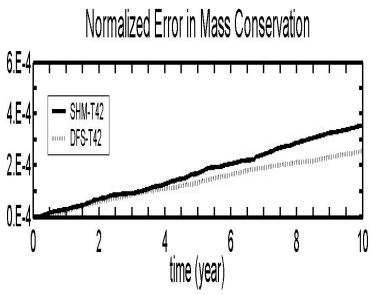
## Comparison of SHM and DFS (idealized tests)

Zonal-mean flow of 1200 day simulations




*Conservation of total mass*




- Linear increase with time → 0.5 hPa error in 10-year integration
[ 2 hPa error for operational model; e.g. NCEP global model ]

Numerical Modeling Lab., Yonsei University

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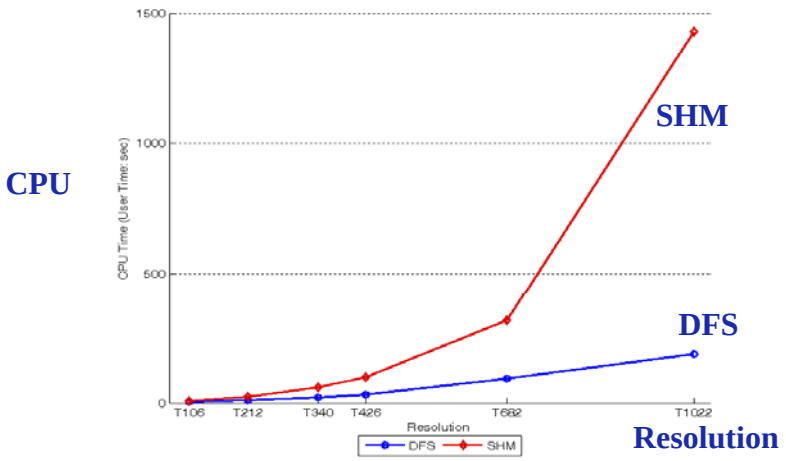
## Computational efficiency over SHM:
[ Speed up: user-time per 10 steps ]




Cheong 2006



## ECMWF - Clive Temperton (2005)

### Horizontal discretization

We will of course continue to monitor these developments. However, we remain convinced that there is no urgency to abandon the spectral method, provided that a more accurate equation set (non-hydrostatic, deep-atmosphere) can be incorporated within this framework. The supposed disadvantages of spectral modelling at high resolution (communication problems on massively parallel machines, rapid growth in the relative cost of the Legendre transforms) show no signs of appearing in our experience (Salmond, 2004). In addition we intend to explore the use of double Fourier series as a more efficient alternative to spherical harmonics (e.g., Cheong 2000).

Horizontal representation by Double Fourier series on the sphere

History (continued)•Shen (1999) –various applications•Cheong (2000) –elliptic & vorticity equations•Cheong (2000) –SWE•Layton & Spotz (2003) –SWE (semi-Lagrangian, still with spherical harmonic filter)

## Implementation DFS in YOURS GSM

- **The DFS dynamic core is plugged in GSM as a dynamic option**
  - DFS and spherical harmonics dynamic core (SPH) share the same physics package as Hong et. al. (2005)
- **Baroclinic wave test for with no orography**
- **No physics test to compare with result of SPH**
- **NWP and seasonal simulation**
- **Paper is in preperation**

Park et al 2007

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## other numeric

- **Arakawa(1974) vertical finite difference method**
- **semi-implicit time integration**
- **4th order harmonic spectral filtering**
- **rectangular wave space**
- **offset grid in physical grid (not include poles)**

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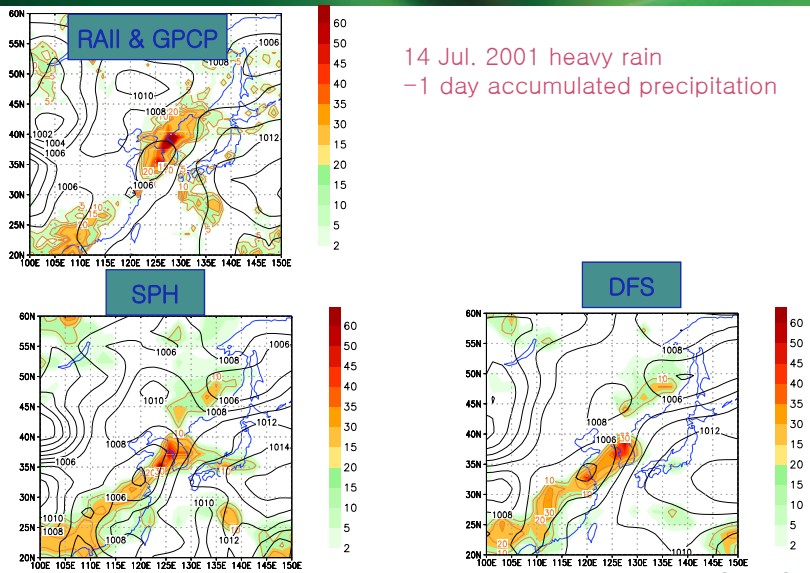
## Implementation of DFS core into YOURS

Mr. Hoon Park

Prof. Hyungbin Cheong

## Case run with Physics (March 18, 2006)




14 Jul. 2001 heavy rain
–1 day accumulated precipitation

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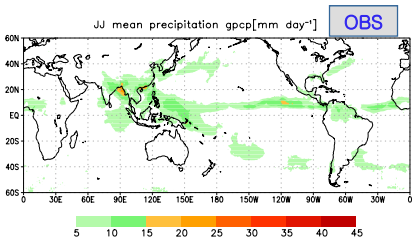
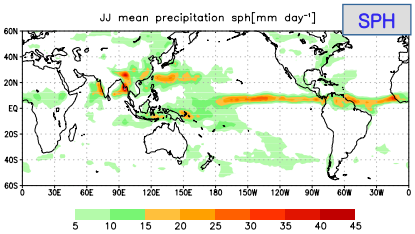
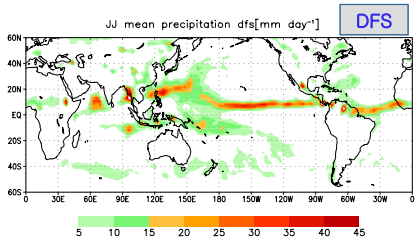
# Seasonal simulation (2001. 7-8)




2001 Jun. and Jul. mean precipitation

- Similar pattern
- Enhanced intensity by DFS

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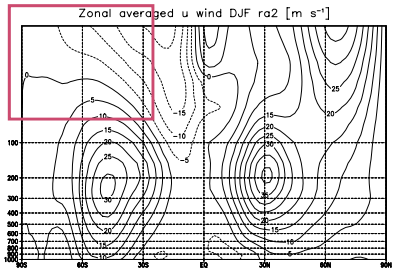
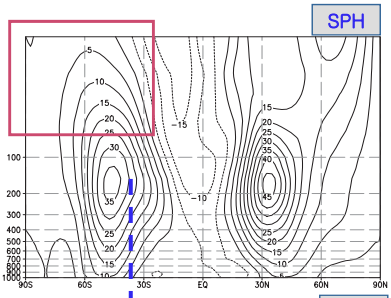
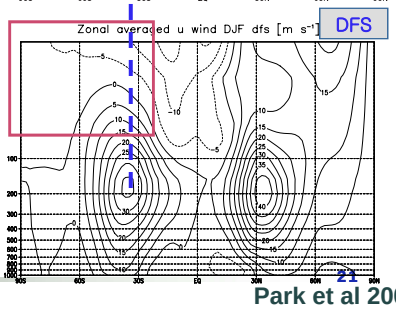
# Seasonal simulation (1996.12-1997. 2)

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## Parallelization of DFS

- **Domain decomposition**
  - Two dimensional decomposition( wave and grid domain)
- **Solve tri-diagonal matrix**
  - Transpose method
  - Laplacian operator ( wind computation, diffusion, semi-implicit time integration)
- **Fast Fourier Transform**
  - Transpose method
  - East-west and south-north direction
- **Transpose method**
  - Rearrange matrix to match with the calculation direction.

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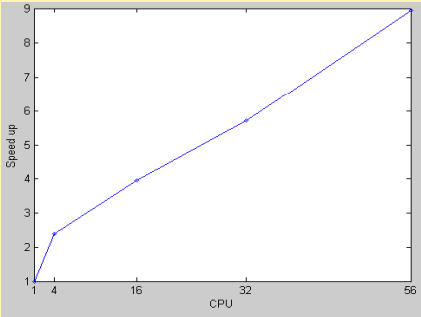
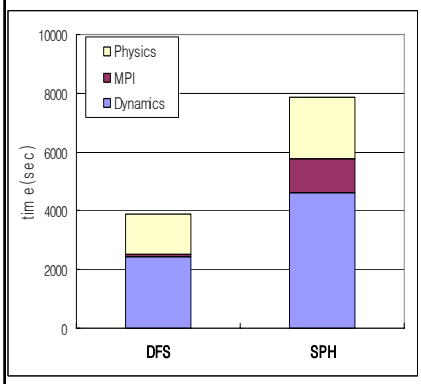
## Parallel efficiency of DFS




- M426/L42 (1280x640)
- 40 step after leap-frog time integration (only dynamics)
- Opteron 2.4GHz (4 dual core cups per node)
- PGI FORTRAN compiler
- Parallel efficiency decrease by inter-node communication cost

## Runtime comparison (T214, MPI)




- **Wave transpose and load imbalance by computation cost affect on MPI efficiency**

- T214/L42 (648 x 324)
- 24 hour prediction
- 32 PE (4 nodes with 8 cups) in 2D decomposition
- Dual core Opteron 2.4GHz CPU
- PGI FORTRAN compiler with same compiler options
- SPH Dynamics costs more than DFS by about **200% computation** for T214

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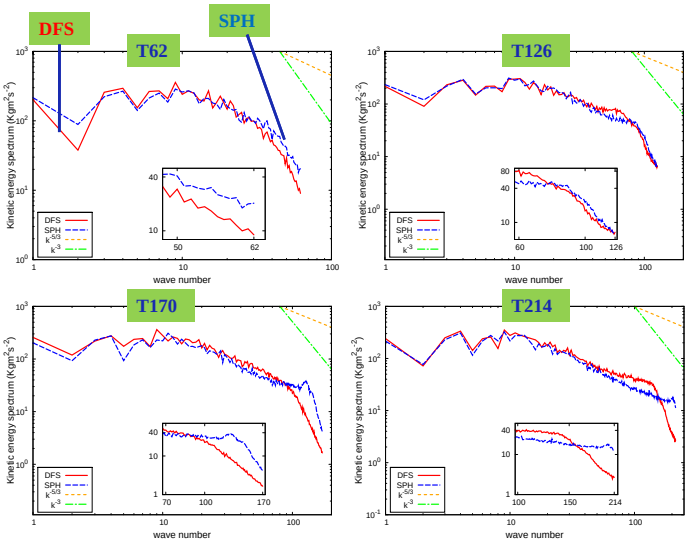
## KE spectrum




**-Sigma 0.2**
**-At 10 day fcst**

## YOURS-physics

- Vertical diffusion (PBL)
- Prognostic cloud scheme
- Cumulus parameterization scheme
- Cloudiness
- Shallow convection
- Gravity wave drag
- Radiation

GO

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## Vertical diffusion - PBL

**The MRFPBL**
(Hong and Pan 1996)

Known problems and analysis of Stevens (2000)
Based on the Troen and Mahrt (1986)

Explicit representation of the entrainment process
Based on Noh et al. (2003)

Too much mixing when wind is strong
Too early development of PBL
Too deep and dry moisture in PBL
Too high PBL height

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*

**YSUPBL**
**(Hong et al. 2006)**

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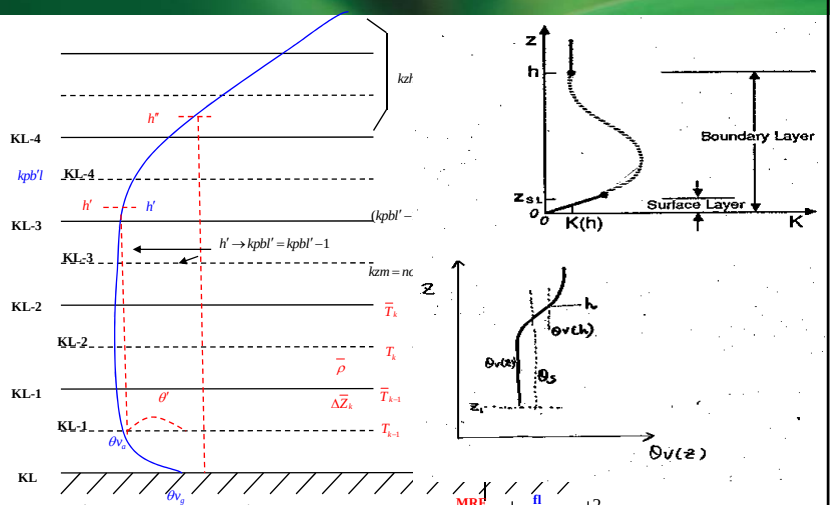
## Troen and Mahrt nonlocal diffusion (MRFPBL)




$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(K_c\left(\frac{\partial C}{\partial z} - \gamma_c\right)\right) \qquad h = Rib_{cr}\frac{\theta_{va}\left|U^{MRF}(h)\right|^2}{g\left(\theta_v(h) - \theta_s\right)}$$



## 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
- Balance with precipitation physics

## YSUPBL after the MRFPBL

- Implementation of the explicit entrainment flux (N2003)
- Inclusion of moisture effect in cloudy environment
- Mixing of hydrometeors
- Removal of nonlocal mixing for moisture
- Turbulence at PBL top considering large-scale
- Moisture effect in saturated soundings

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## YSUPBL – development

| | |
|---|---|
| 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) |
| 2002.9-2003.6 | To evaluate the scheme and balance with nature (A new scheme) |
| 2003.7-2004.2 | To revised the scheme based on the various evaluations (A revised new scheme) |
| 2006.2 | Further revisions (A finalized new scheme) |

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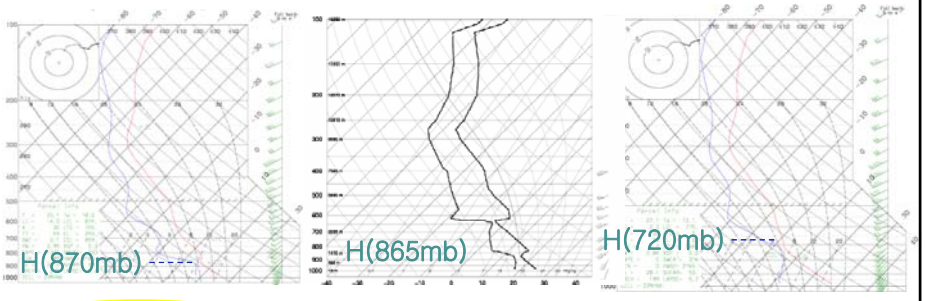
## Sounding profile at 18Z in the pre-frontal regions (near Nashville Tennessee)

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



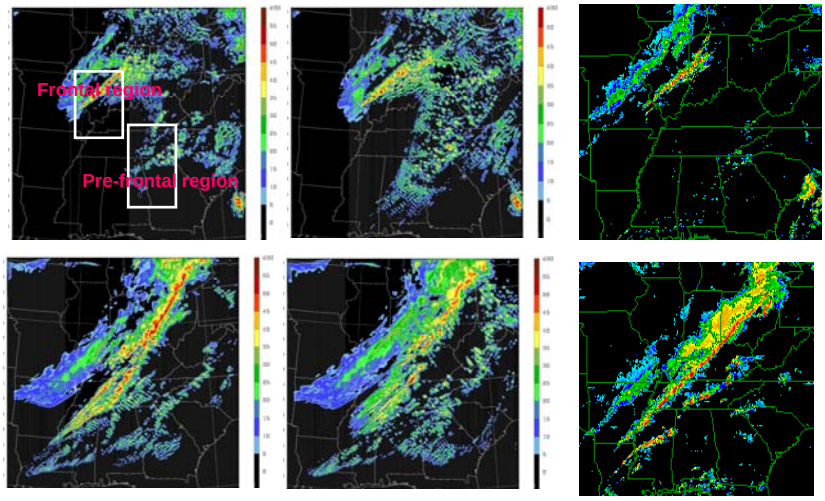
Hong et al. 2006

## Maximum radar reflectivity (dBz)

YSU | MRF | OBS

18Z 10 Noon

00Z 11 Evening






Hong et al. 2006

## Seasonal simulation – Byun and Hong (2004, J. Climate)

### Experiments

| Name | PBL scheme | Convection scheme |
|---|---|---|
| CNT_S | MRF PBL(Hong and Pan 996) | SAS (Hong and Pan 1998) |
| NEW_S | YSU PBL (Hong et al. 2006) | SAS |
| CNT_R | MRF PBL | RAS (Moorthi and Suarez 1991) |
| NEW_R | YSU PBL | RAS |

### Ensemble runs

- boreal summer (JJA)
- 10 member ensemble run with NCEP Reanalysis II data
  LAF : 5.1~10 0000 UTCs
- for three years with different SST conditions
  1996 : normal
  1997 : El Nino
  1999 : La Nina

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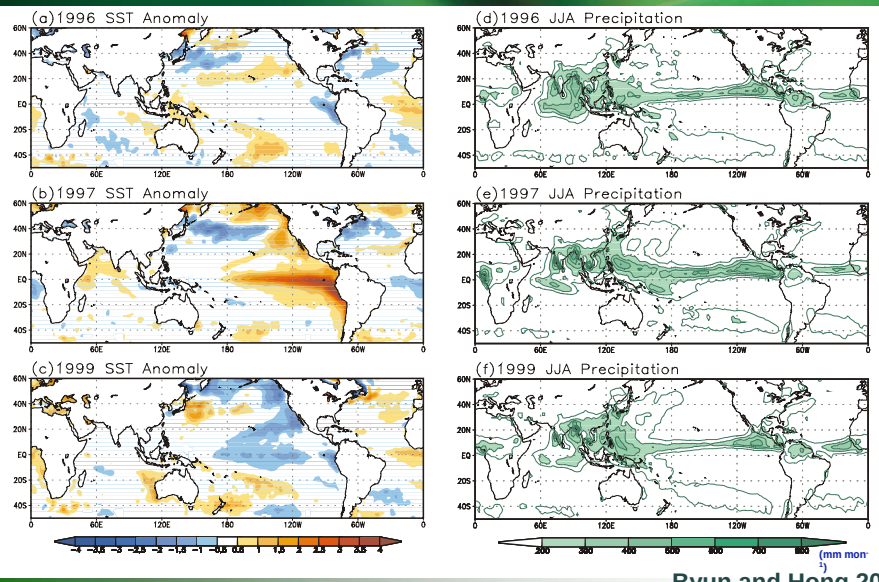
## Experimental Design




Byun and Hong 2004

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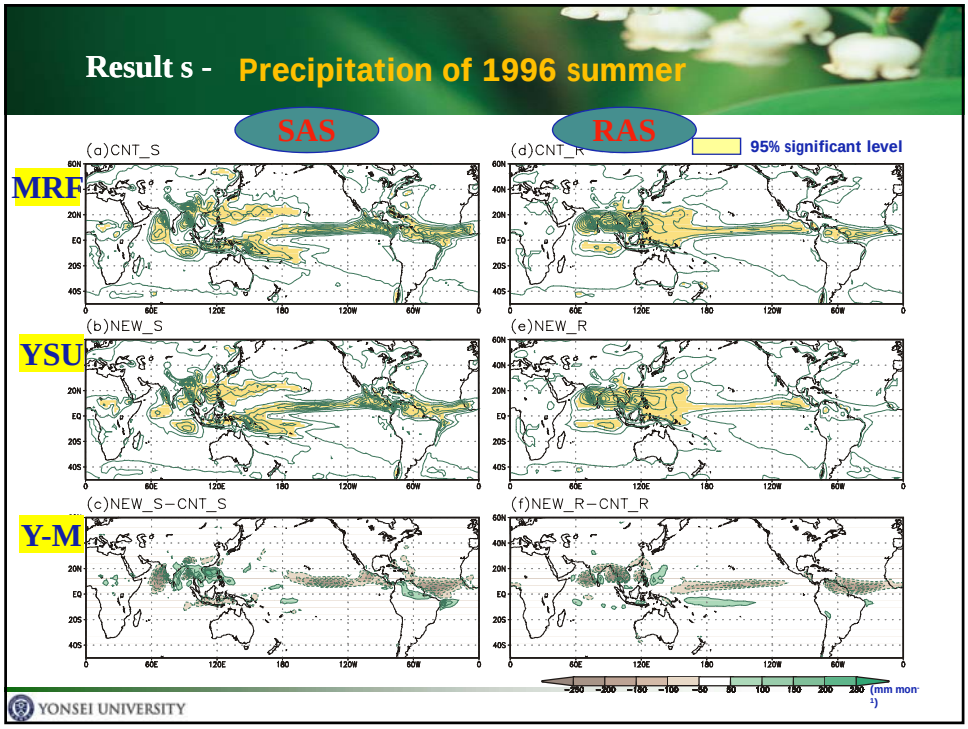
Result s - Precipitation of 1996 summer
SAS
RAS
95% significant level
MRF
YSU
Y-M
(a)CNT_S
(d)CNT_R
(b)NEW_S
(e)NEW_R
(c)NEW_S−CNT_S
(f)NEW_R−CNT_R
(mm mon-1)
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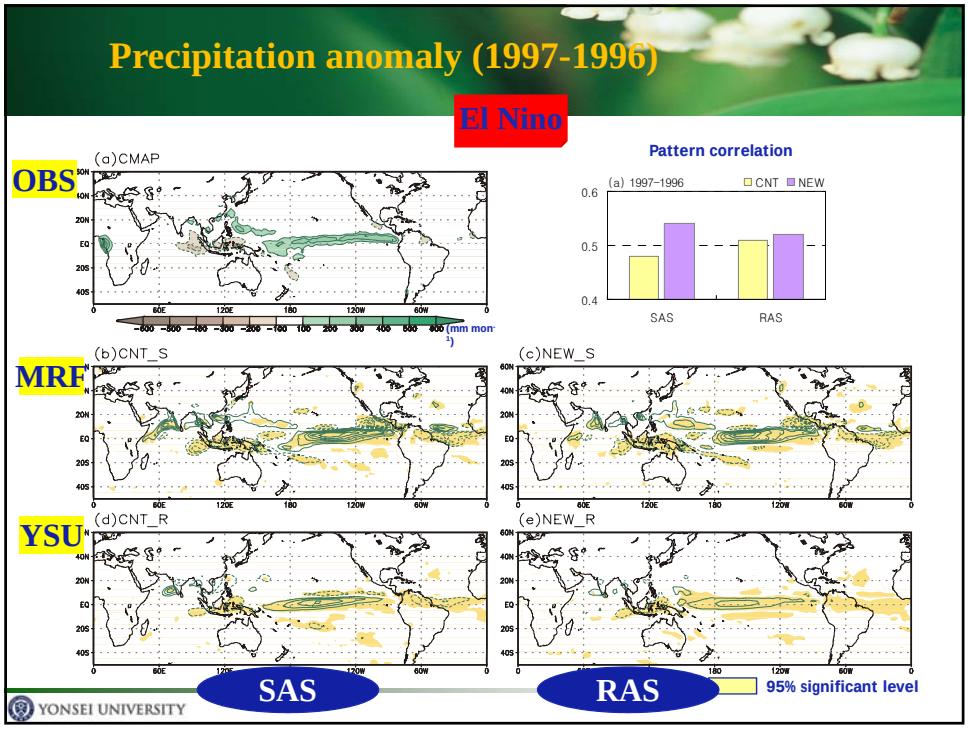
Precipitation anomaly (1997-1996)
El Nino
OBS
MRF
YSU
(a)CMAP
(b)CNT_S
(c)NEW_S
(d)CNT_R
(e)NEW_R
(mm mon-1)
Pattern correlation
(a) 1997−1996
CNT
NEW
0.6
0.5
0.4
SAS
RAS
SAS
RAS
95% significant level
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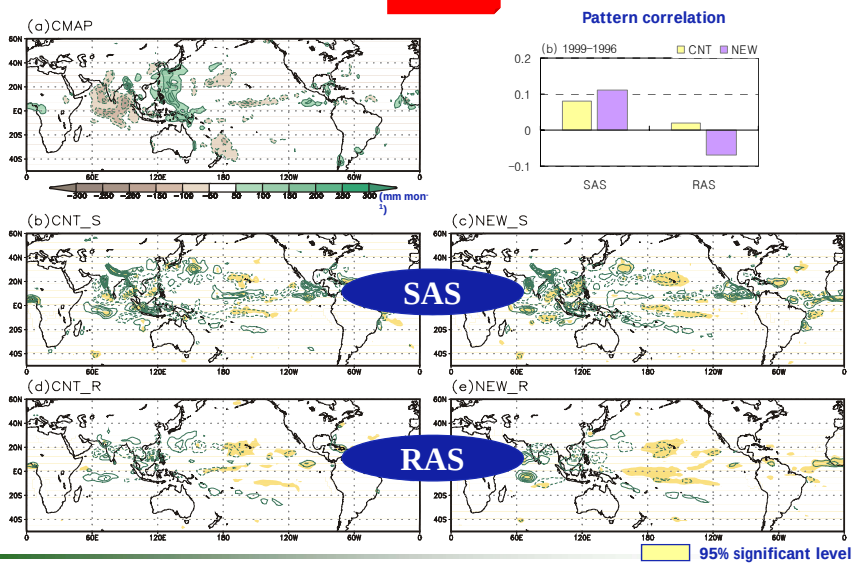
# Precipitation anomaly (1999-1996)

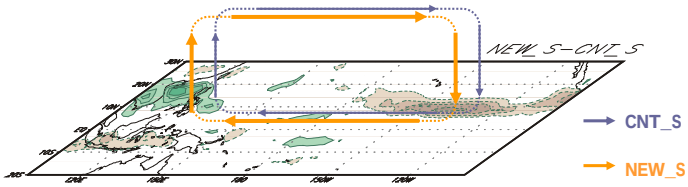
La Nina






# Thermodynamics and dynamics interaction

New PBL +
SAS convection




**Western Pacific**

- Increase of tropical rainfall
- Larger low-level moisture advection due to the intensified Walker circulation
  -> More CAPE (More convective activities)
- Lower SLP
  -> Intensifying Walker circulation

**Eastern Pacific**

- Decrease of tropical rainfall
- Less mixing due to New PBL
  -> Less CAPE (Less convective activities)
- Higher SLP
  -> Intensifying Walker circulation

Byun and Hong 2004

## Stable boundary layer mixing in a vertical diffusion package

Released in WRF version 3.0, in April 2008

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## Kim et al. (2006, WRF workshop)

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

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

$$K_{m_loc,t_loc} = l^2 f_{m,t}(Rig)\left(\frac{\partial U}{\partial z}\right) \qquad Rig = \frac{g}{\theta_v}\left[\frac{\partial \theta_v / \partial z}{(\partial U / \partial z)^2}\right] \qquad \frac{1}{l} = \frac{1}{kz} + \frac{1}{\lambda_0}$$

**May be inappropriate**

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## A mail from Fred Zhang

**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.**



## Determination of SBL height (Vickers and Mahrt)

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

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

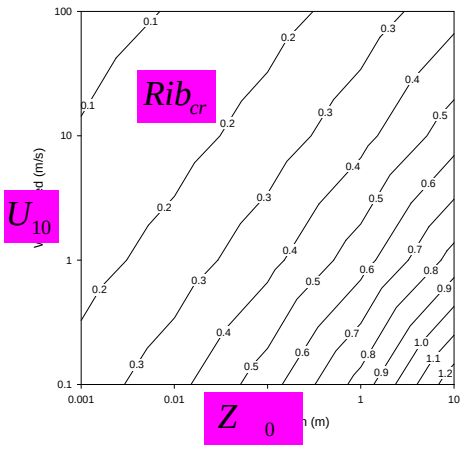
the surface bulk Richardson number
where the critical value for Rib is defined by

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

, where

$$R_o = U_{10}/(fz_0)$$

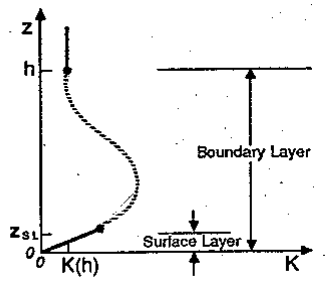
with f=10**-4.



## A new stable BL for YSU PBL

**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** $Rib_{cr} = 0.25$

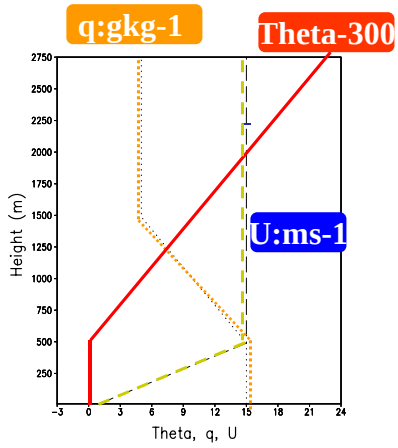


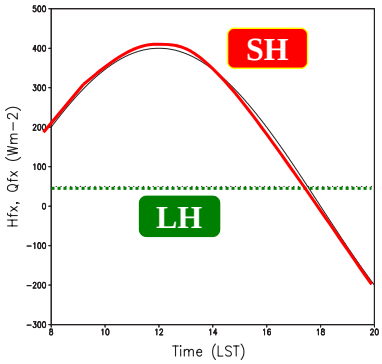
## Experimental setup

**CNTL : Ribcr = 0 (local Ri dependent mixing), WRF 2.2**
**STBL : Ribcr > 0 (parabolic shape diffusivity), WRF 3.0**
**STBL2: twice Ribcr in STBL for sensitivity test**

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

## Initial & boundary condition (Hong et al. 2006)

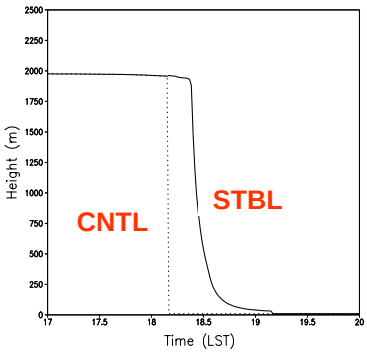


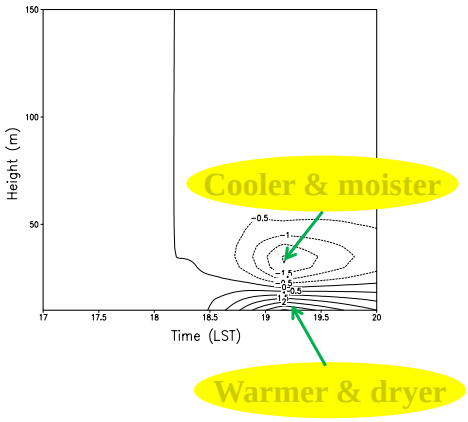



## One-d test : dz = 25 m, sunset = 18 h

PBL



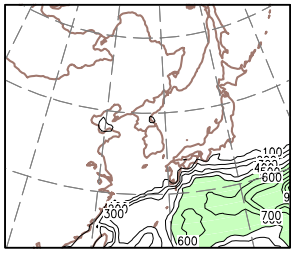

Theta (STBL-CNTL)



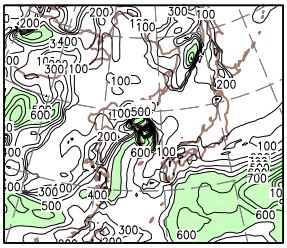
## NWP test on 15 July 2001 : RSM 50 km (18hr fcst)

3 AM

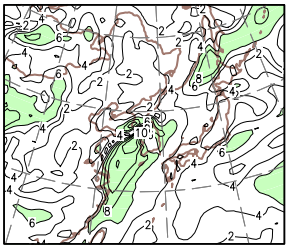
CNTL



STBL



HPBL



10m U

CNTL : PBL height of a const value during night

STBL : PBL height increases when winds are strong

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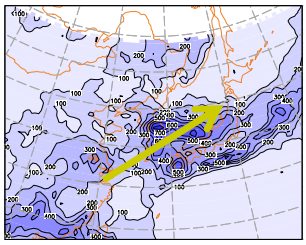
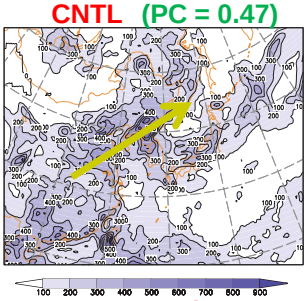
## RCM simulation in July 2006: RSM 50 km

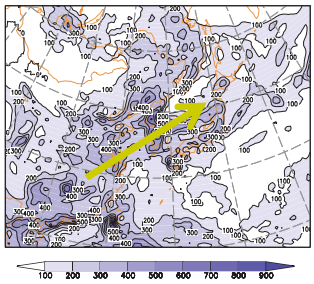
OBS (TRMM)



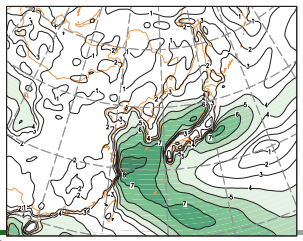
CNTL (PC = 0.47)



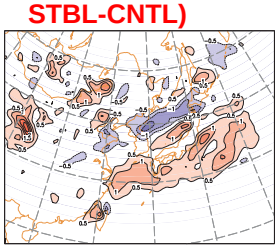
STBL (PC = 0.57)



850 hPa WP (STBL)



STBL-CNTL)



Nighttime rainfall is enhanced

Oceanic rainfall is enhanced

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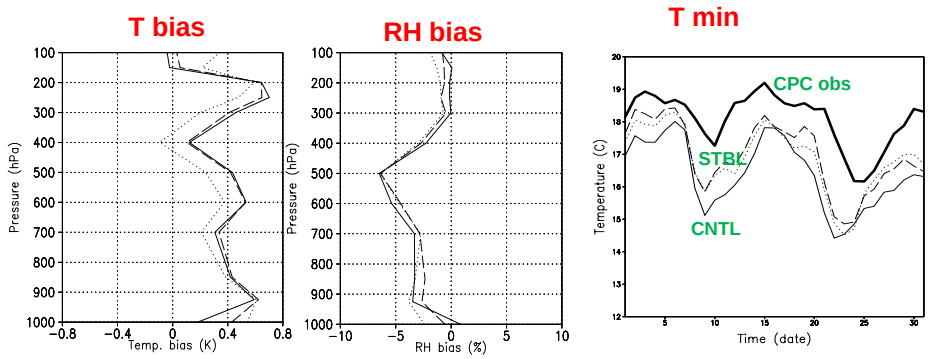
## RCM simulation in July 2006: RSM 50 km



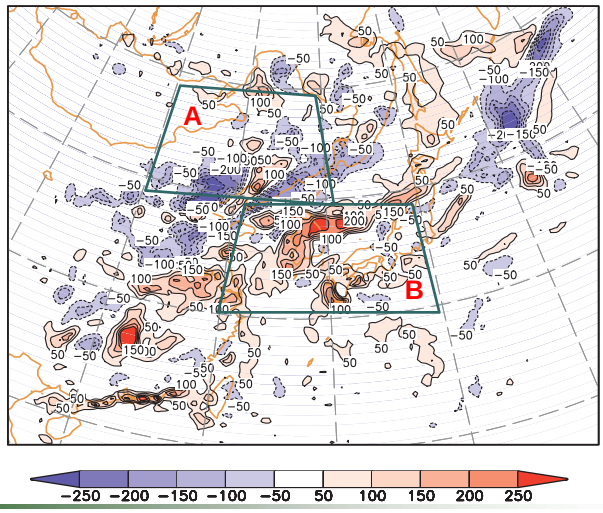

Large-scale features are slightly improved

Minimum temperature is increased to the observed

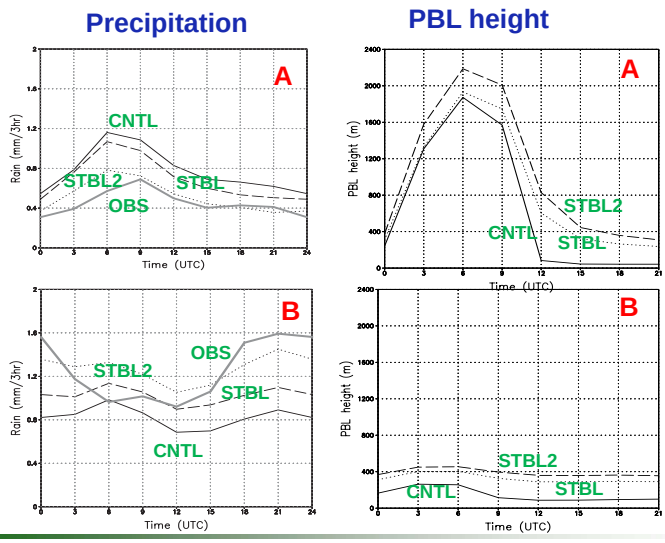


## RCM simulation in July 2006: RSM 50 km

Precip (STBL-CNTL)



# RCM simulation in July 2006: RSM 50 km




PBL height increases as the SBL mixing is strong

But, precipitation response is opposite

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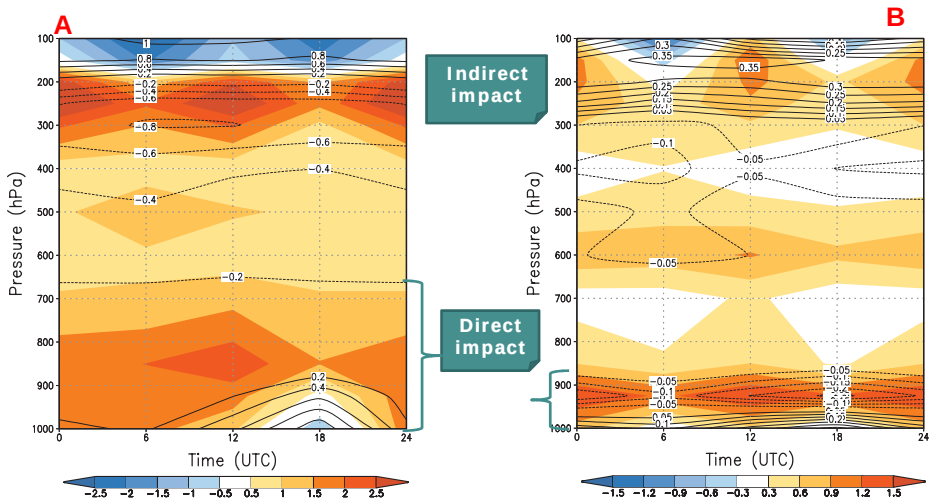
# RCM simulation : Temperature bias

Shaded : CNTL-RA2
Contour : STBL-CNTL

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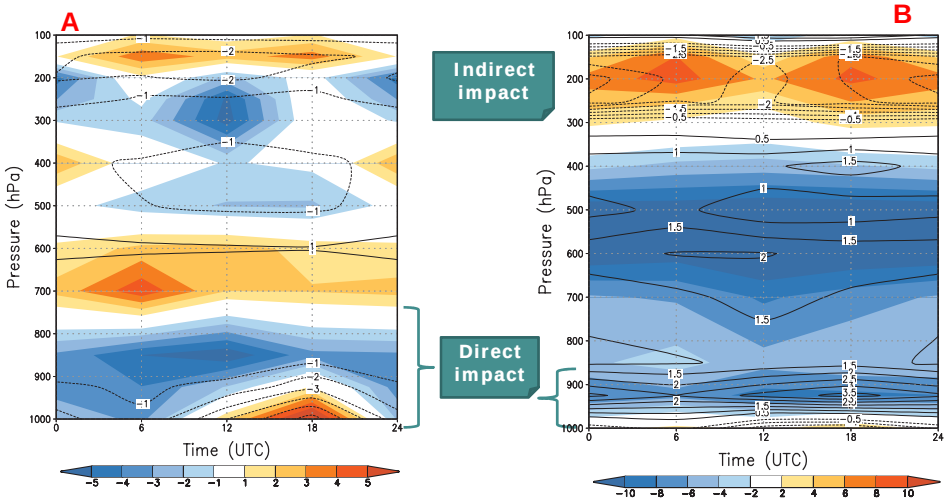
# RCM simulation : RH bias

Shaded : CNTL-RA2
Contour : STBL-CNTL

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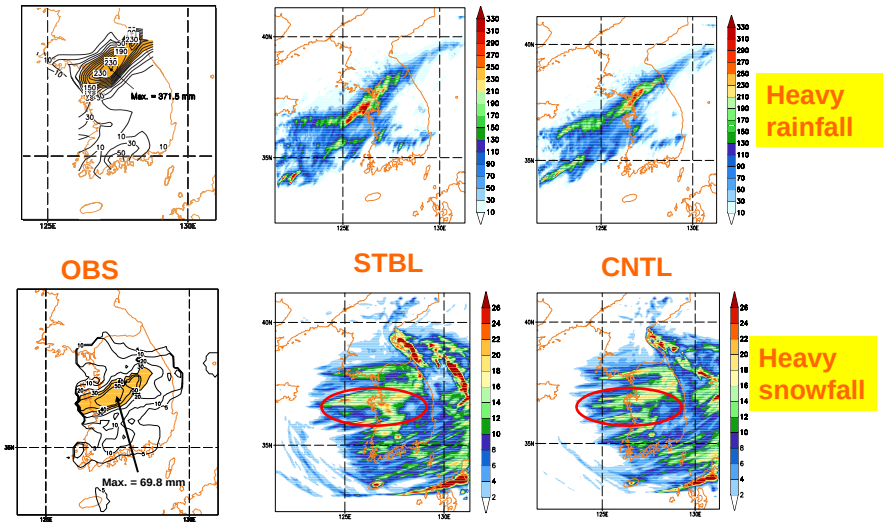
# WRF 4 km




Intensify the heavy precipitation core

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## Seasonal simulation (T62; about 200 km)

**Model : YOURS-2005**

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

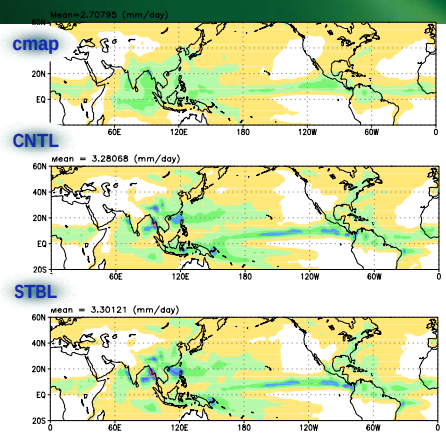
**Ensemble : 5 members**

**Experiments: CNTL : Hong et al. 2006**

**STBL : this study**



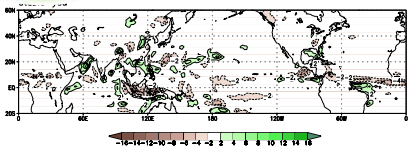
## Seasonal simulation for JJA 1996 (rainfall)




| | ysu | stable | stable_150 |
|---|---|---|---|
| Global mean | | | |
| OBS | = 2.70795 | = 2.70795 | = 2.70795 |
| MODEL | = 3.28068 | = 3.30121 | = 3.31642 |
| Pattern correlation | | | |
| GL | = 0.736781 | = 0.739652 | = 0.738123 |
| EA | = 0.625432 | = 0.60589 | = 0.678413 |

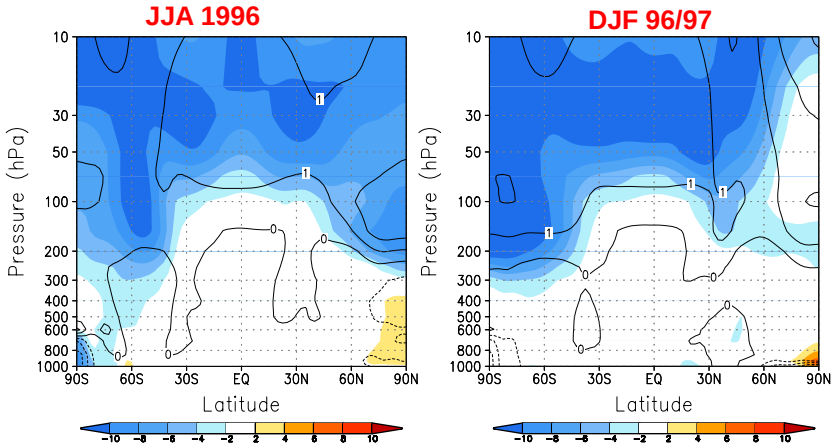
**Scheme is stable !!!**
**Skill is comparable**

stable - cntl



## Zonal mean temperature

Shaded : CNTL-RA2
Contour : STBL-CNTL




**Error is reduced by 10 % due to stable BL**

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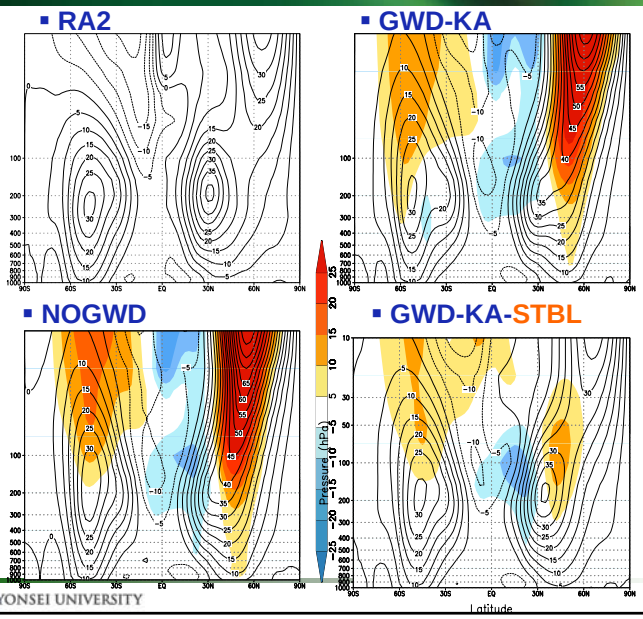
## Zonal-averaged zonal wind (96/97 DJF) :
## (HONG et al. 2008, Wea and Forecasting)

- 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

Hong et al. 2008

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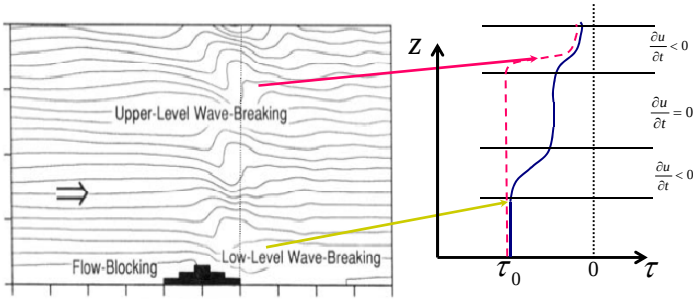
## Enhanced lower tropospheric gravity wave drag (Kim and Arakawa 1995, J. Atmos. Sci.)




$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial \tau_x}{\partial z}$$

$$\frac{\partial v}{\partial t} = -\frac{1}{\rho}\frac{\partial \tau_y}{\partial z}$$

**Stress at reference level** $\tau_0 = -E\frac{1}{\Delta x}\frac{\rho_0 U_0^3}{N_0}\frac{Fr^2}{Fr^2 + 0.5/OC}$, $U_0 = \frac{1}{h}\int_{k=1}^{k=kpbl} Udz$

**Reference level (KA95) : Max (2, KPBL)**

**Too shallow PBL height ➔ too small Tau_0 ➔ too small drag in the upper troposphere ➔ too strong westerly bias**



## Concluding remarks

**PBL working group meeting (WRF workshop)**

**Problems in YSU (Hong et al. 2006, WRF v 2.2)**

- Too shallow PBL height (Liang)
- Too weak wind speed (Angevine)
- Too cold bias (Pleim)
- Chemical species mixing (Kim et al. 4.4, Wednesday)

**Might be improved in WRF version 3.0**

## WSMMP: WRF-Single Moment-Microphysics

Hong, Dudhia, Chen (HDC, 2004, Mon. Wea. Rev.)

**Major modifications suggested by Hong et al. (2004)**

| | (Rutledge and Hobbs, 1983) | (Hong et al, 2004) |
|---|---|---|
| Number concentration of cloud ice | $N_I(m^{-3}) = 10^{-2}\exp[0.6(T_0 - T)]$ | $N_I = c(\rho q_I)^d$ |
| Ice nuclei number | $N_I(m^{-3}) = 10^{-2}\exp[0.6(T_0 - T)]$ | $N_{I0} = 10^3\exp[0.1(T_0 - T)]$ |
| Intercept parameter for snow | $N_{0S} = 2\times10^7\ \mathrm{m}^{-4}$ | $N_{0S}(m^{-4}) = 2\times10^6\exp\{0.12(T_0 - T)\}$ |



## Ice crystal property

(Mass, Diameter, Mixing ratio, Ice number)

$V_I(ms^{-1}) = 3.29(\rho q_I)^{0.16}$ : **Heymsfield and Donner(1990)** **(HD1990)**

$V_I = xD^y, m = \alpha D^\beta$ : **Heymsfield and Iaquinta (2000)** **(HI2000)**

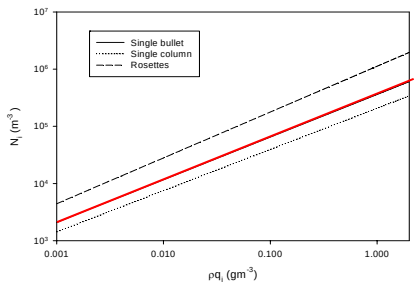
$mN_i = \rho q_i$

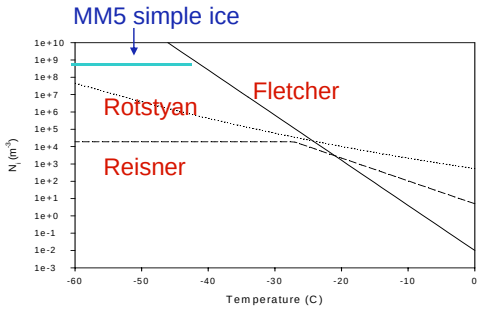
$N_i = c(\rho q_i)^d$ →

$$V_I(ms^{-1}) = 1.49\times10^4 D^{1.31},$$
$$D(m) = 11.9m^{0.5}$$
$$N_I(m^{-3}) = 5.38\times10^7(\rho q_i)^{0.75}$$
$$\rho q_I(kgm^{-3}) = 4.92\times10^{-11}N_I^{1.33}$$

**Hong et al. 2004**

## Ice number concentration (Ni)




$N_I(m^{-3}) = 5.38\times10^7(\rho q_I)^{0.75}$ : **HDC2004**

$N_I(m^{-3}) = 10^{-2}\exp[0.6(T_0 - T)]$ : **Fletcher**



Hong et al. 2004

**- Vapor deposition of a small ice crystal (Pisd):**

$$Pisd = \frac{4\bar{D}_I(S_I - 1)N_I}{A_I + B_I} = \frac{4\bar{D}_{Icon}(S_I - 1)(\rho q_I N_I)^{0.5}}{A_I + B_I}$$

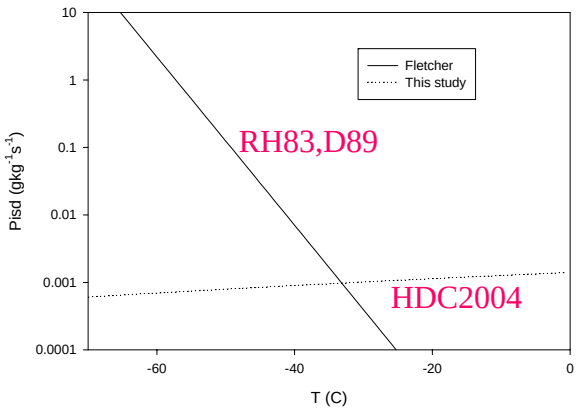
**- Sublimation of snow and depositional growth of snow (Pres):**

$$\Pr es = \frac{4N_{0S}(S_I - 1)}{(A_I + B_I)} \times \left[ \frac{0.65}{\lambda_S^{\,2}} + 0.44 S_c^{\,1/3} \left(\frac{a_S \rho}{\mu}\right)^{1/2} \left(\frac{\rho_0}{\rho}\right)^{1/4} \frac{\Gamma((b_S + 5)/2)}{\lambda_S^{(b_S+5)/2}} \right]$$



Hong et al. 2004

## Comparison of deposition rate of water vapor onto ice

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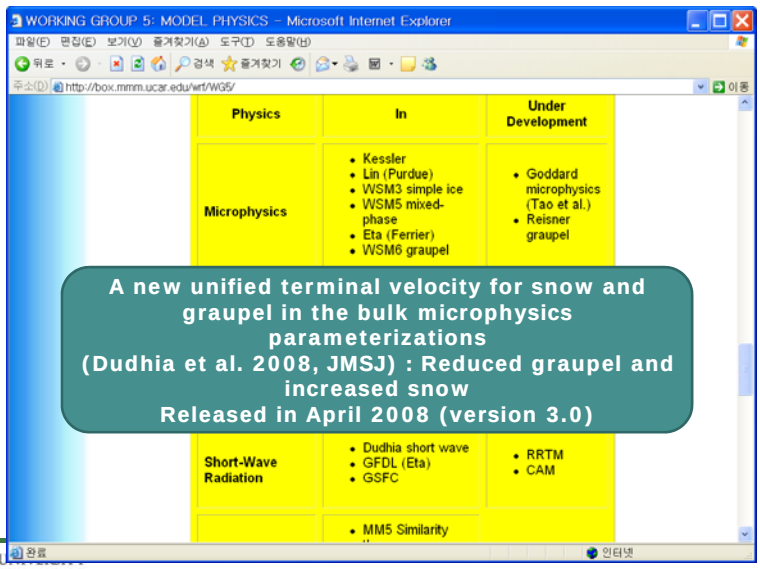
## WSMMP (WSM3, WSM5, WSM6)




**A new unified terminal velocity for snow and graupel in the bulk microphysics parameterizations (Dudhia et al. 2008, JMSJ) : Reduced graupel and increased snow**
**Released in April 2008 (version 3.0)**

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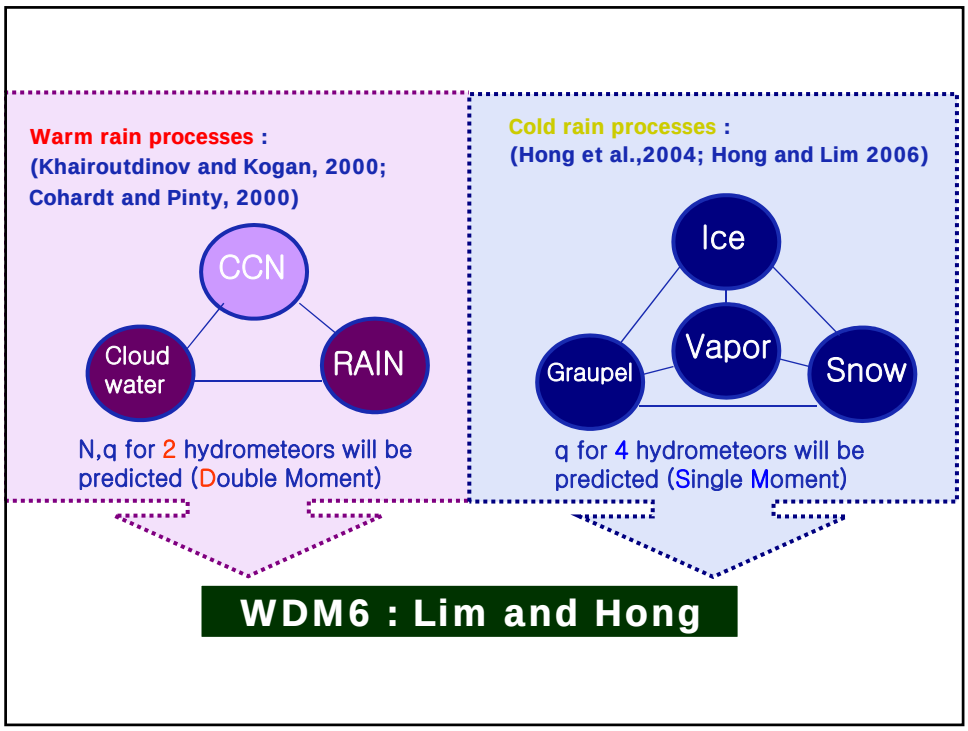
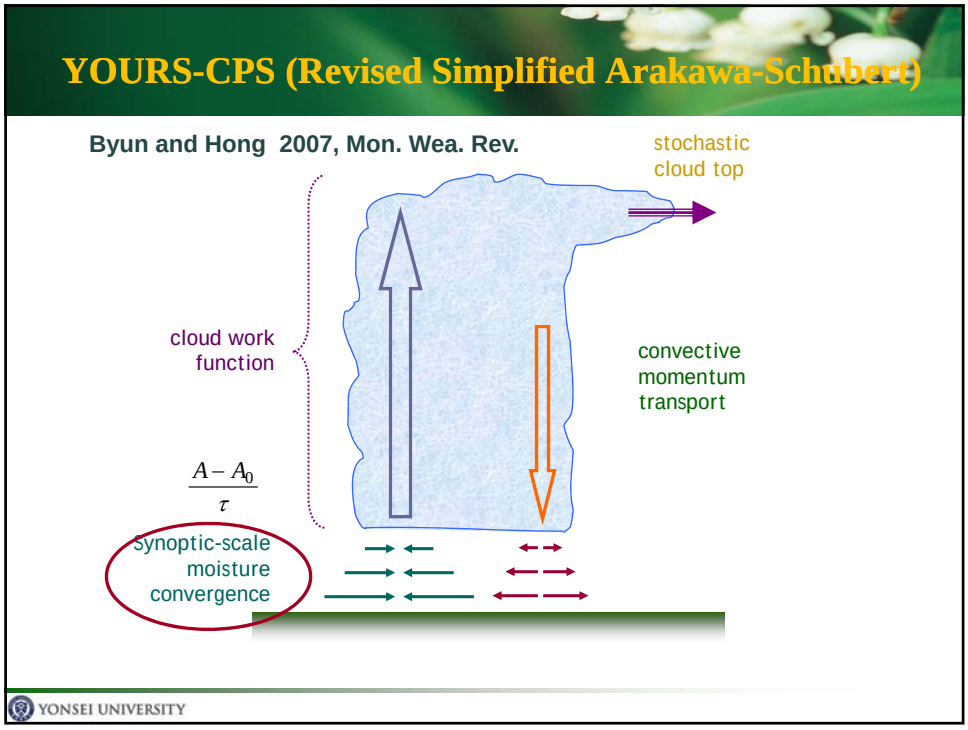

Warm rain processes :
(Khairoutdinov and Kogan, 2000;
Cohardt and Pinty, 2000)
CCN
Cloud water
RAIN
N,q for 2 hydrometeors will be predicted (Double Moment)
Cold rain processes :
(Hong et al.,2004; Hong and Lim 2006)
Ice
Vapor
Graupel
Snow
q for 4 hydrometeors will be predicted (Single Moment)
WDM6 : Lim and Hong


YOURS-CPS (Revised Simplified Arakawa-Schubert)
Byun and Hong 2007, Mon. Wea. Rev.
stochastic cloud top
cloud work function
convective momentum transport
$\frac{A - A_0}{\tau}$
Synoptic-scale moisture convergence
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## YOURS-CPS (Revised Simplified Arakawa-Schubert)

**Physical parameterization in atmospheric model**

**Dynamics : So accurate !!!**

**Physics : So muddy !!!**

**Dynamics** → **Physics**

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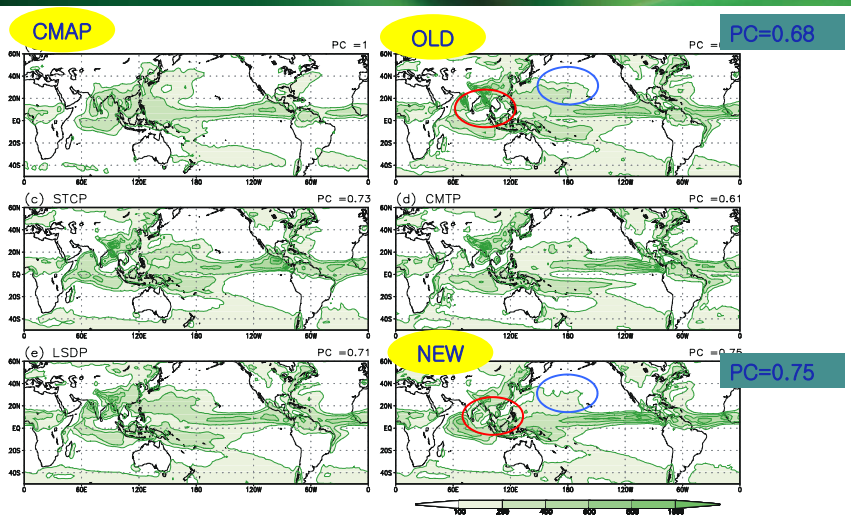
Byun and Hong 2007

## JJA (1996,97,99) Precipitation (T62)

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Byun and Hong 2007

## Test run for medium-range forecasts

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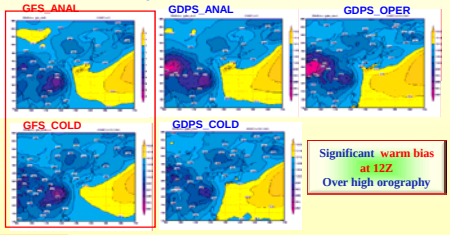
# Test Run

### Experimental setup

Initial data : GDAPS_ANAL (KMA G3VR - operational)
GFS_ANAL (NCEP GFS )
Model : GDAPS : T426L4 (operational)
YOURS : T214L42 (YOURS_2004 and 2005 version)
Exp : 5-day fcst at 00z and 12 z (2006. 7) - (62 sample)

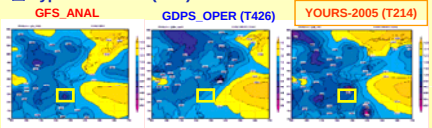
| Name | Assimilation (Initial condition) | Forecast model |
|---|---|---|
| GFS_COLD | GFS | YOURS |
| GDPS_COLD | GDPS 3D VAR | YOURS |
| GDPS_OPER | GDPS 3D VAR | GDPS |

### Initial data experiment

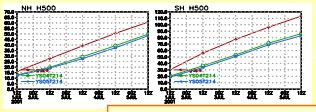



Significant warm bias at 12Z Over high orography

### Typhoon : SLP (hPa)

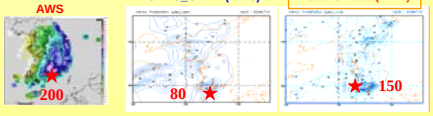



### Statistical evaluation: 500 hPa RMSE (m)




NH : 61 (GDPS) 48 (YOURS)
SH : :113 (GDPS) 82 (YOURS)
Global 75 (GDPS) 57 (YOURS)

### Heavy rainfall : Precip (mm)




Setup the semi-operational version
- Model : YOURS_2005 (SPH-T214)
- Initial condition: NCEP GFS

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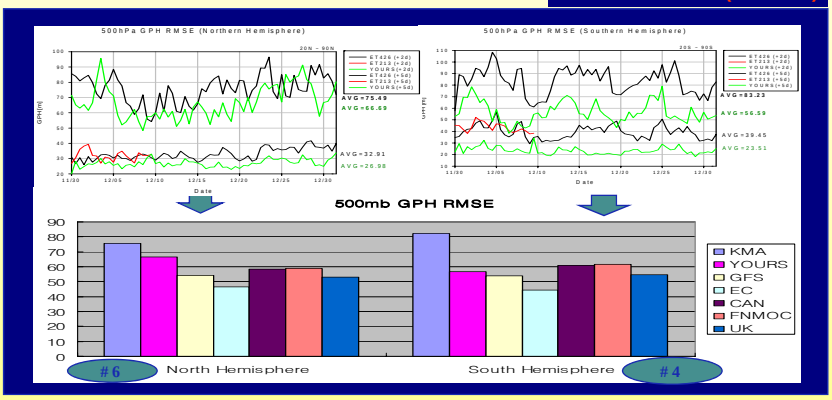
# Semi-parallel run (Nov.27, 2006~)

- Based on the test run test bed (July 2006)
  Setup the model version of YOURS-2005 (SPH-T214 )
- YOURS_2006 (DFS) will be evaluated in March 2007
  (Meeting with KMA/NWP staffs on Oct. 27, 2006)

• Model: YOURS-2005 • Initial: NCEP GFS
• Resolution: T214 • Fcst: 00Z, 12Z → 10-d fcst

500 MB GH RMSE (Dec 2006)

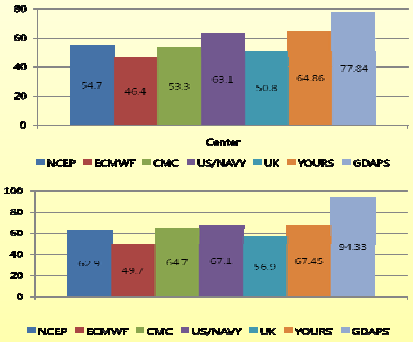





# Semi-parallel run (continued…)

500 mb GH RMSE

2007. 3. 8 ~ 4. 8




The test run in July 2007 and semi-parallel run since Dec 2006
→ The differences in RMSE between GDAPS and YOURS are consistent
→ NH 10 m, SH 25 m or more

Error is larger in NH than SH in YOURS

Differences in NCEP and YOURS

GDPS data assimilation + YORUS model ==: warm start

NH : 78 (GDAPS) 65 (YOURS)
SH : 94 (GDAPS) 67 (YOURS)

## Model description of the YOURS

| | YOURS-2004 | YOURS-2005 | YOURS-2006 | YOURS-2007 | YOURS-2008 |
|---|---|---|---|---|---|
| Dynamics | Spherical Harmonics Juang (2005) | | Double Fourier Cheong (2006), Park et al. (2007) | | |
| Radiation | SW : 1-Albedo<br>LW : GFDL | SW : 4-Albedo<br>LW : GSFC | | | SW : GSFC |
| SFC | M-O similarity<br>Hong and Pan (1996) | + Improved Z0t and Vsfc<br>Seol and Hong (2006) | | | |
| LSM | Homogeneous<br>Mahrt and Pan (1985) | Heterogeneous<br>Chen and Dudhia (2001) | | | |
| PBL | MRF : Hong and Pan (1996) | YSU<br>Hong et al. (2006) | | + Stable BL<br>Hong et al. (2007) | |
| GWDO | Alpert et al.(1989) | | | Kim and Arakawa (1995)<br>Hong et al. (2008) | |
| GWDC | x | | | Chun and Baik (1998)<br>Cheon et al. (2008) | |
| Deep Convection | SAS<br>(Hong and Pan 1998) | | | | Byun and Hong (2007) |
| Shallow convection | Tiedke (1989) | | | | Han and Pan (2007) |
| Micro Physics | WSM1<br>Hong et al (1998) | | | | WSM3<br>Hong et al. (2004) |
| Cloudiness | Implicit<br>Hong et al. (1998) | | | | Explicit |
| Chemistry | Diagnostic | | | Prognostic ozone | |

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## Publications

20+alpha SCI, 10 Domestic Journal papers

**International collaboration**

DFS (Cheong 2006, Park et al. 2007) – ECMWF (IFS) , JMA/MRI

WSM3 (Hong et al. 2004, Mon. Wea. Rev.) – NCAR(WRF), FRCGC(NICAM)

WSM6 (Hong and Lim 2006, J. KMS) – NCAR(WRF), FRCGC (NICAM)

YSUPBL (Hong et al. 2006, Mon. Wea. Rev.) – NCAR(WRF)

GWDO (Hong et al. 2008, Wea. Forecasting ) – NCAR(WRF)

SCM (Byun and Hong 2007, Mon. Wea. Rev.) – Scripps (ECPC)

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# Thanks

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