Development of a new KMA GDAPS and its performance on the simulation of tropical rainfall

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Acknowledgements :
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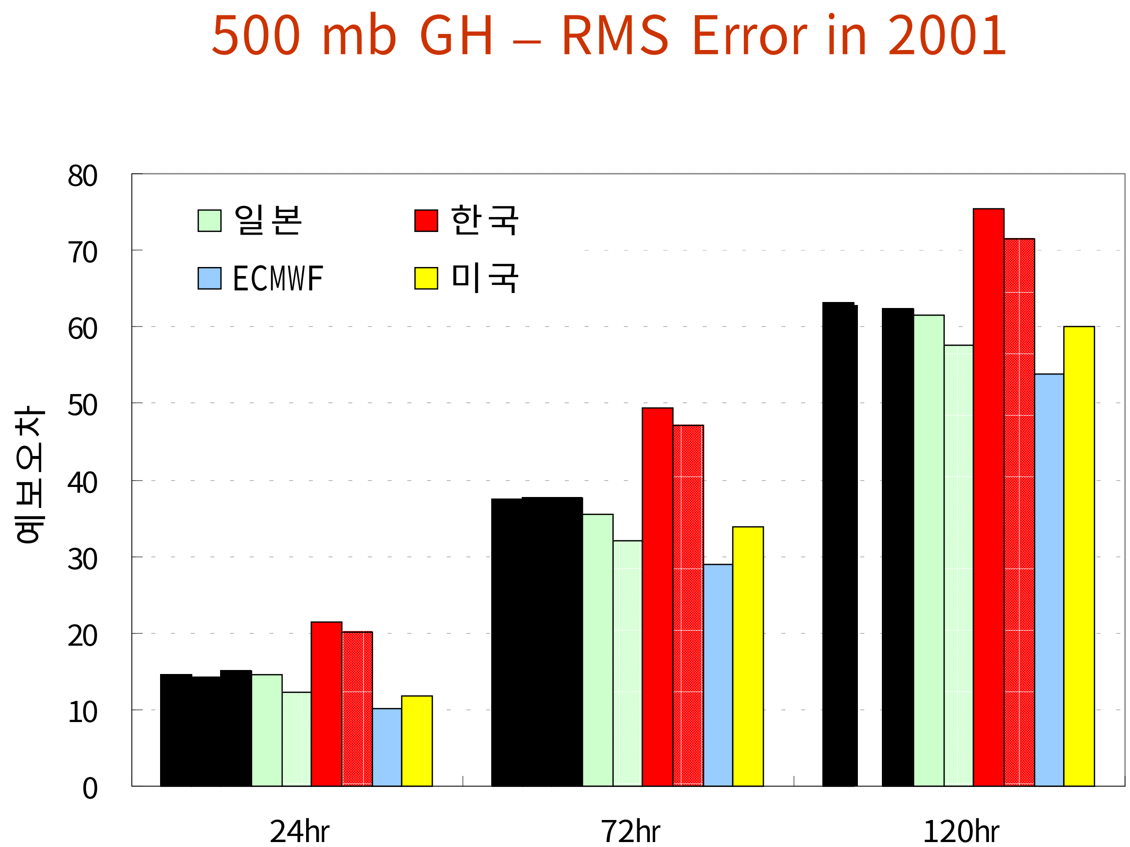
Kanamitsu

Young-Hwa Byun and Masao Kanamitsu

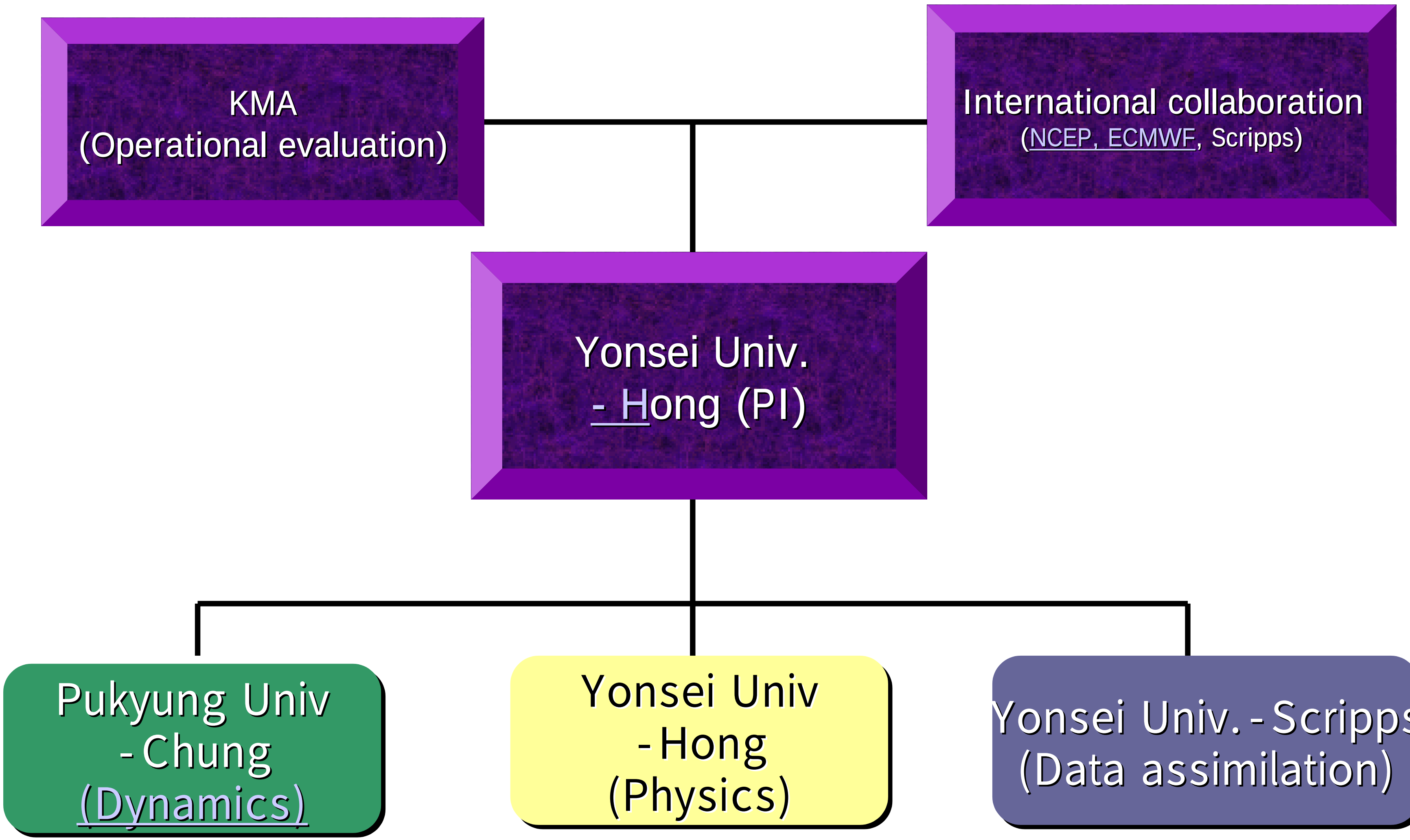
Presentation list

- Background
- Strategy for YOURS/KMA GDAPS
- YOURS - Physics
- YOURS - Dynamics
- Future plan

Background (1): Performance of KMA GDAPS



Development team



Kanamitsu et al. (2002) - starting point

Based on NCEP MRF

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

Flexibility

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

Optional physics

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

Research institutes over the world

YOnsei University Research model System (YOURS)

Development - Evaluation

Resolution: grid size from 200 m to 200 km (T62)

Tests : Case studies (heavy rainfall and snowfall)
NWP with data assimilation
Seasonal and regional climate simulation

Today, I'm going to focus on the simulation of tropical rainfall

Vertical diffusion (PBL)

The MRFPBL

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

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

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

Major modifications in Noh et al. after the Troen and Mahrt

Explicit entrainment process

Large eddy properties

Nonlocal momentum mixing

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
- Inclusion of moisture, tracers, and hydrometeors
- Conservation of fluxes
- Numerical problem (staggered)

YSUPBL after the MRFPBL

- Implementation of the explicit heat flux at h (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

Byun and Hong (2004)

Experimental Design

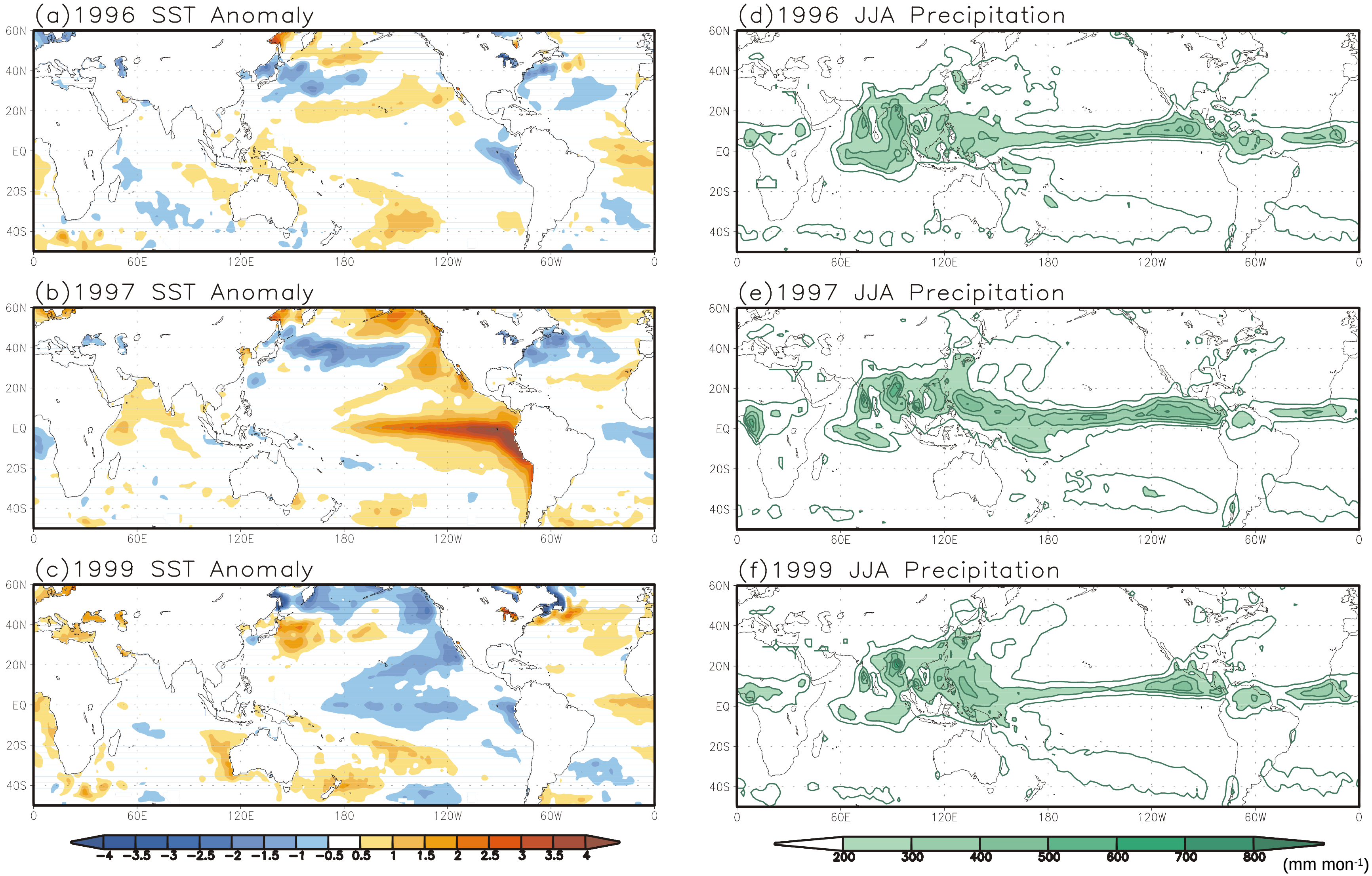
Experiments

Name	PBL scheme	Convection scheme
CNT_S	MRF PBL	SAS
NEW_S	New PBL	SAS
CNT_R	MRF PBL	RAS
NEW_R	New PBL	RAS

Ensemble runs

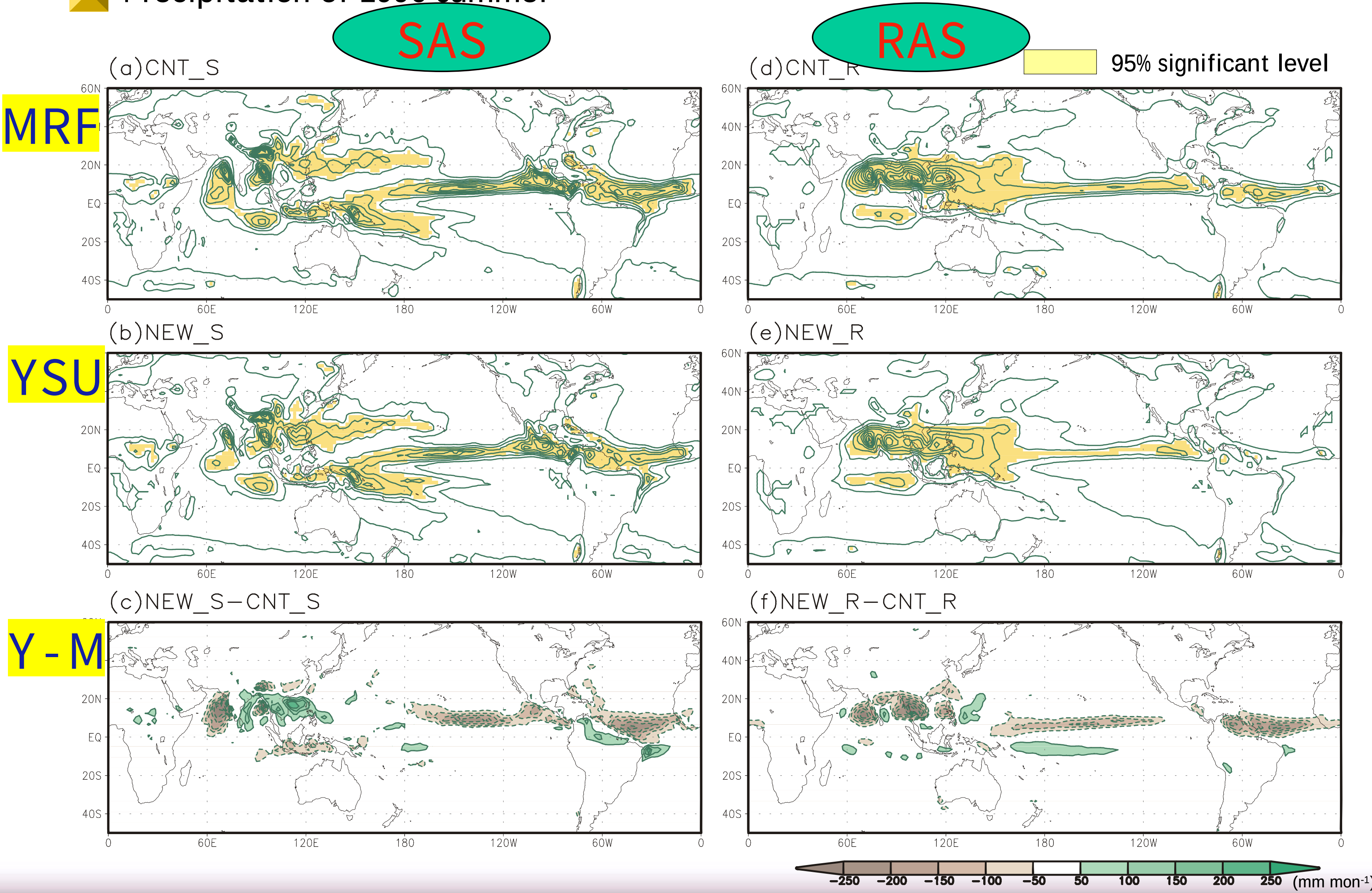
- boreal summer (JJA)
- 10 member ensemble run with NCEP Reanalysis II data
  LAF : 5.1~10 0000 UTCs
- for three years with different SST conditions
  1996 : normal
  1997 : El Nino
  1999 : La Nina

Experimental Design



Result

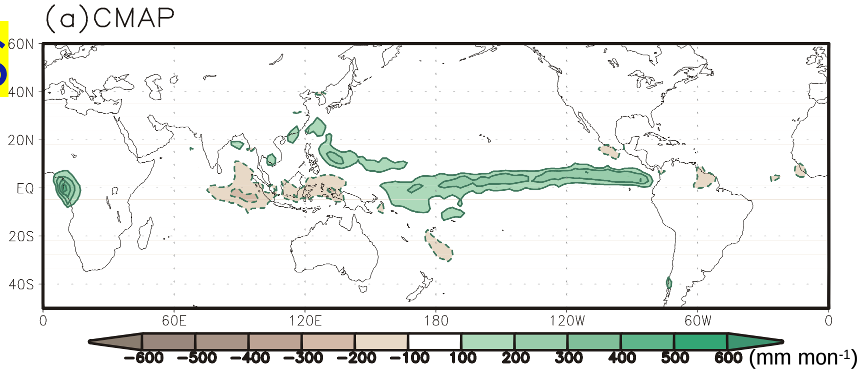
Precipitation of 1996 summer

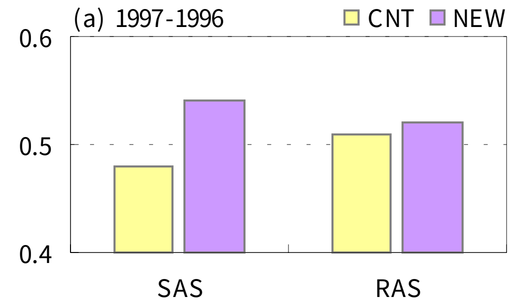


Result

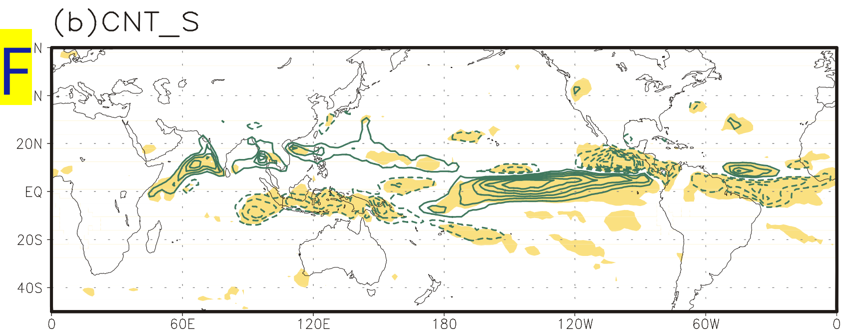
Precipitation anomaly (1997-1996) El Nino

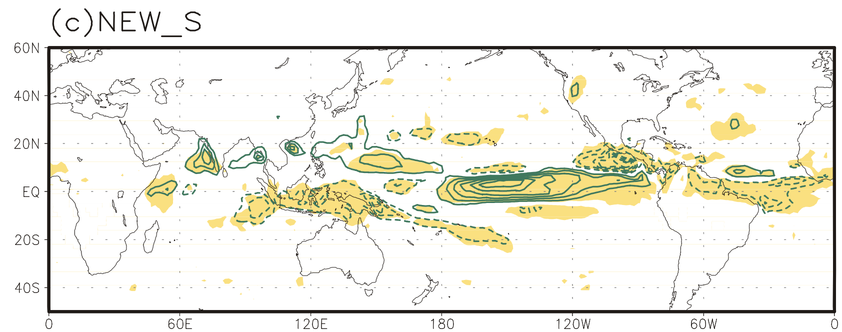
OBS



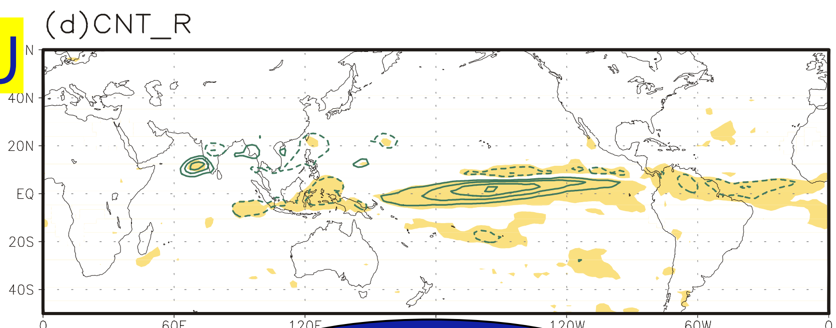


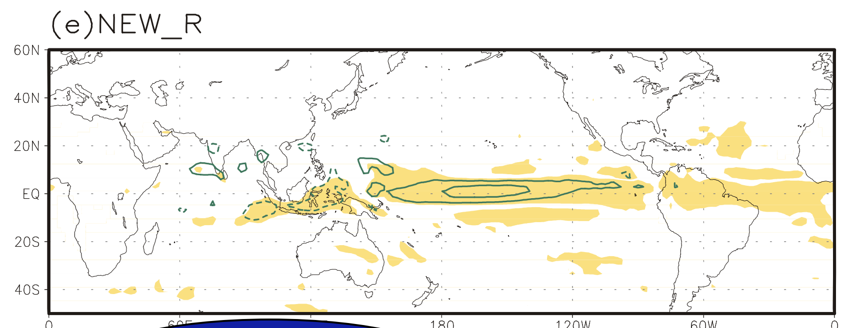
MRF





YSU





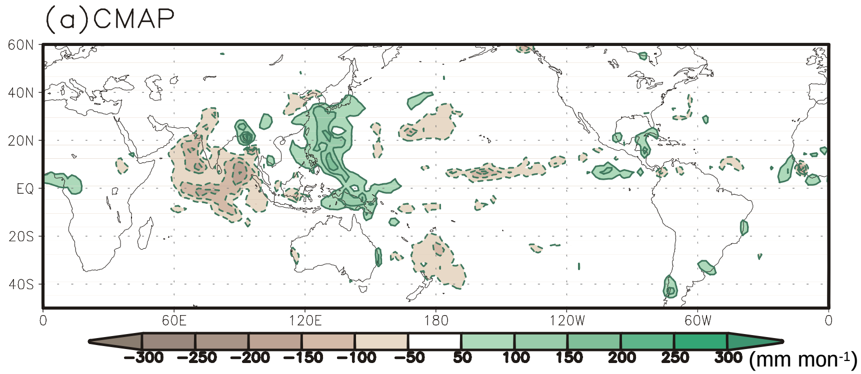
SAS

RAS

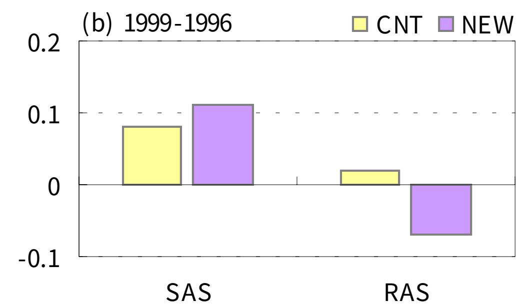
95% significant level

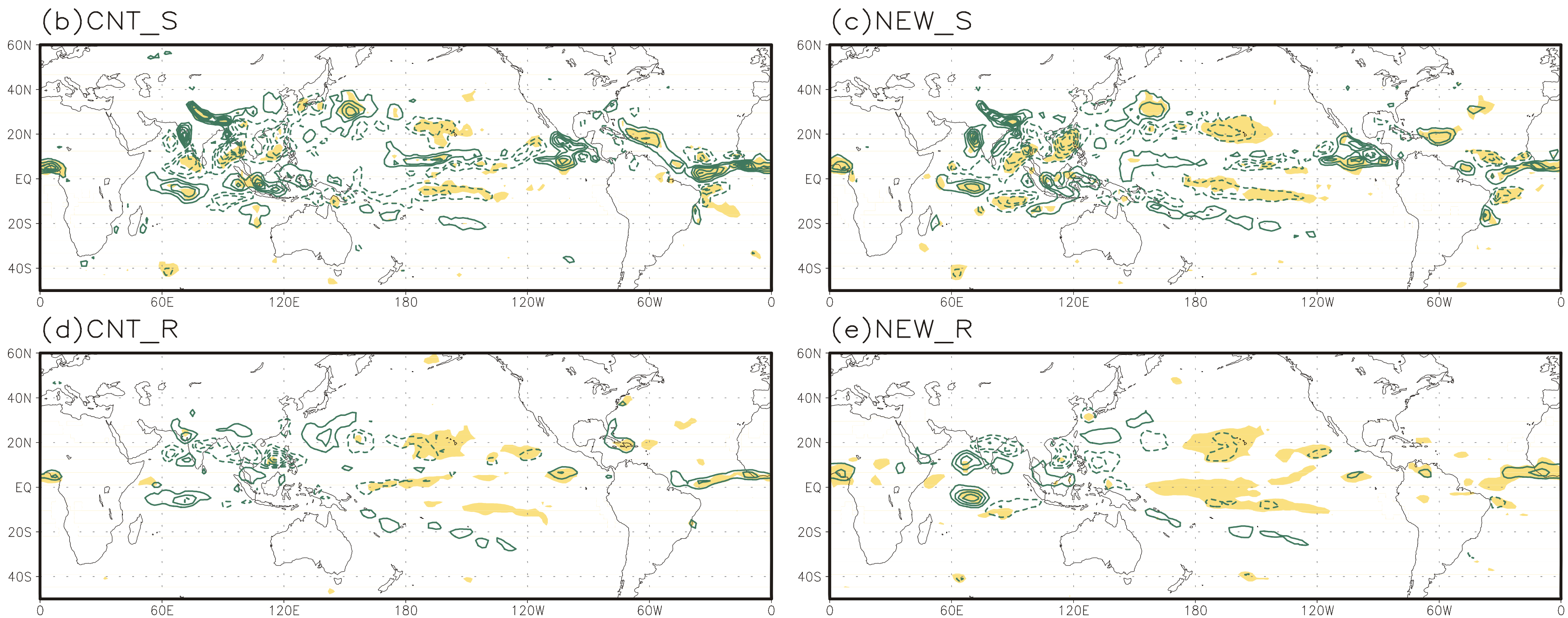
Result

Precipitation anomaly (1999-1996) La Nina



Pattern correlation

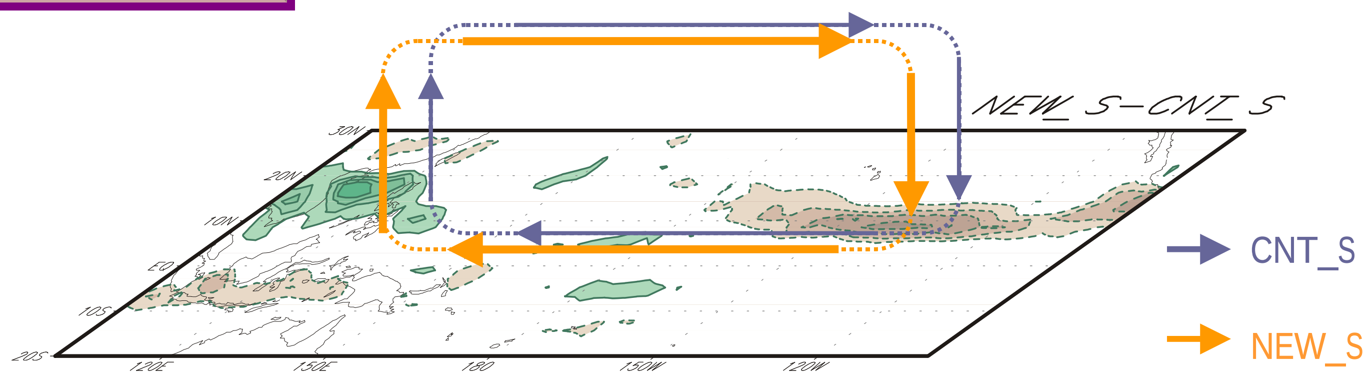




95% significant level

Summary

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

Grid-resolvable clouds and precipitation

WSMMP: WRF-Single Moment-Microphysics

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

Major modifications suggested by Hong et al. (2004)

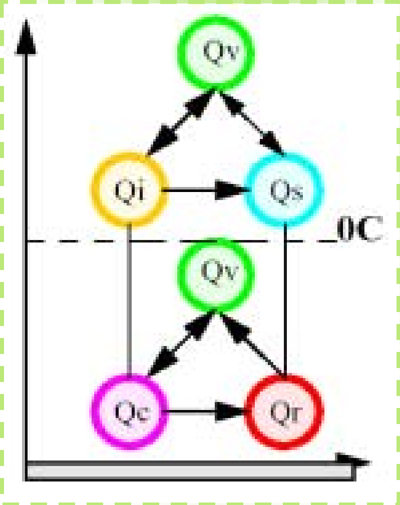
	(Rutledge and Hobbs, 1983)	(Hong et al, 2004)
Number concentration of cloud ice	$N_I(m^{-3}) = 10^{-2}\exp[0.6(T_0 - T)]$	$N_I = c(\rho q_I)^d$

WSM microphysics (Hong et al. 2004)

- **WSM3 (simple ice)**

- 3 species of hydrometeors

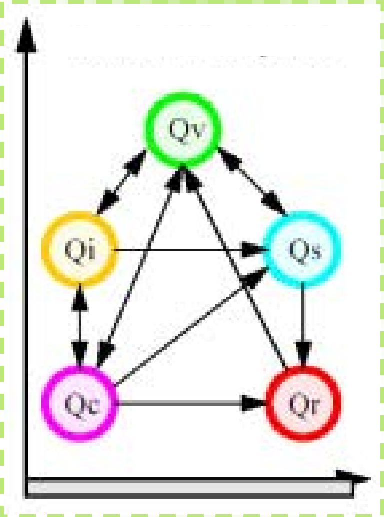
➡ q_v, q_{ci}, q_{rs}



- **WSM5 (mixed phase)**

- 5 species of hydrometeors

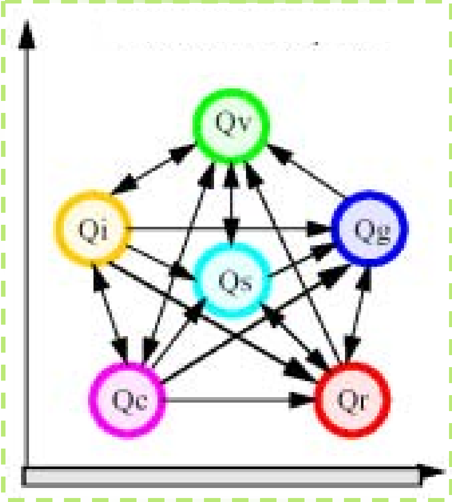
➡ q_v, q_c, q_i, q_r, q_s



- **WSM6 (graupel phase)**

- 6 species of hydrometeors

➡ $q_v, q_c, q_i, q_r, q_s, q_g$



WSM3 → WSM2

Hong and Byun (2004)

- Based on WSM3, but diagnose rain/snow (qci)

$$\frac{\partial q_v}{\partial t} = -m^2\left(u\frac{\partial q_v}{\partial x} + v\frac{\partial q_v}{\partial y}\right) - \sigma\frac{\partial q_v}{\partial \sigma} + F_{qv}^{vdif} + F_{qv}^{hdif} + F_{qv}^{impl} + F_{qv}^{\exp l}$$

$$\frac{\partial q_{ci}}{\partial t} = -m^2\left(u\frac{\partial q_{ci}}{\partial x} + v\frac{\partial q_{ci}}{\partial y}\right) - \sigma\frac{\partial q_{ci}}{\partial \sigma} + F_{qci}^{\exp l}$$

$$\frac{\partial q_{rs}}{\partial t} = -m^2\left(u\frac{\partial q_{rs}}{\partial x} + v\frac{\partial q_{rs}}{\partial y}\right) - \sigma\frac{\partial q_{rs}}{\partial \sigma} + F_{qrs}^{\exp l} - \frac{g}{p_s}\frac{\partial \rho q_{rs} V_t}{\partial \sigma}$$

120s

10s

→

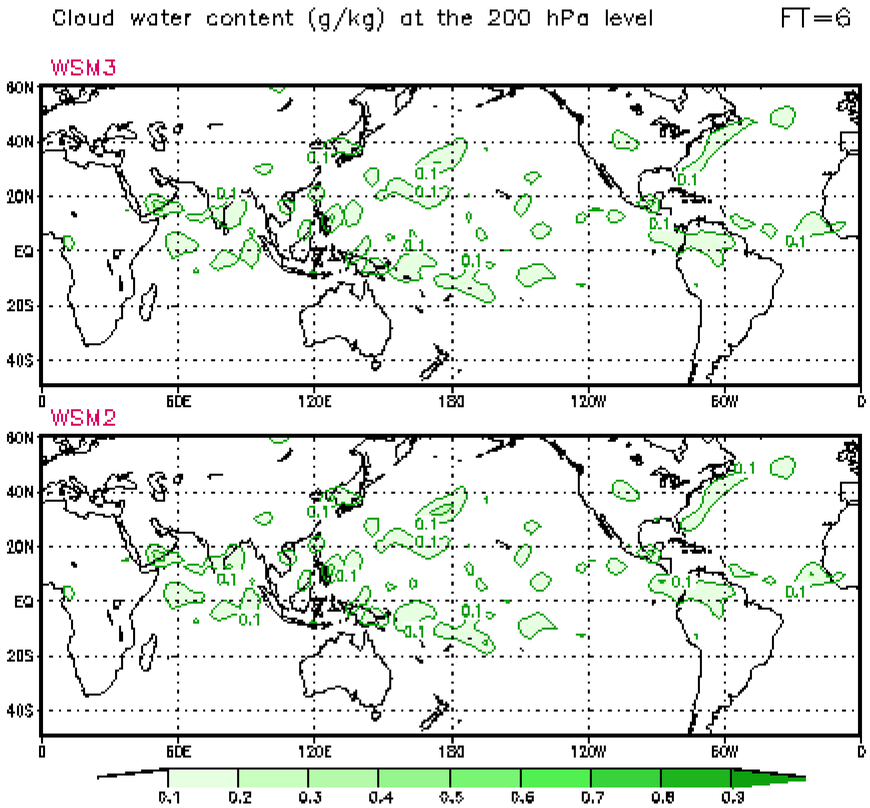
$$F_{qrs}^{\exp l} - \frac{g}{p_s}\frac{\partial \rho q_{rs} V_t}{\partial \sigma} = 0$$

WSM3 : 27 min / 6hr

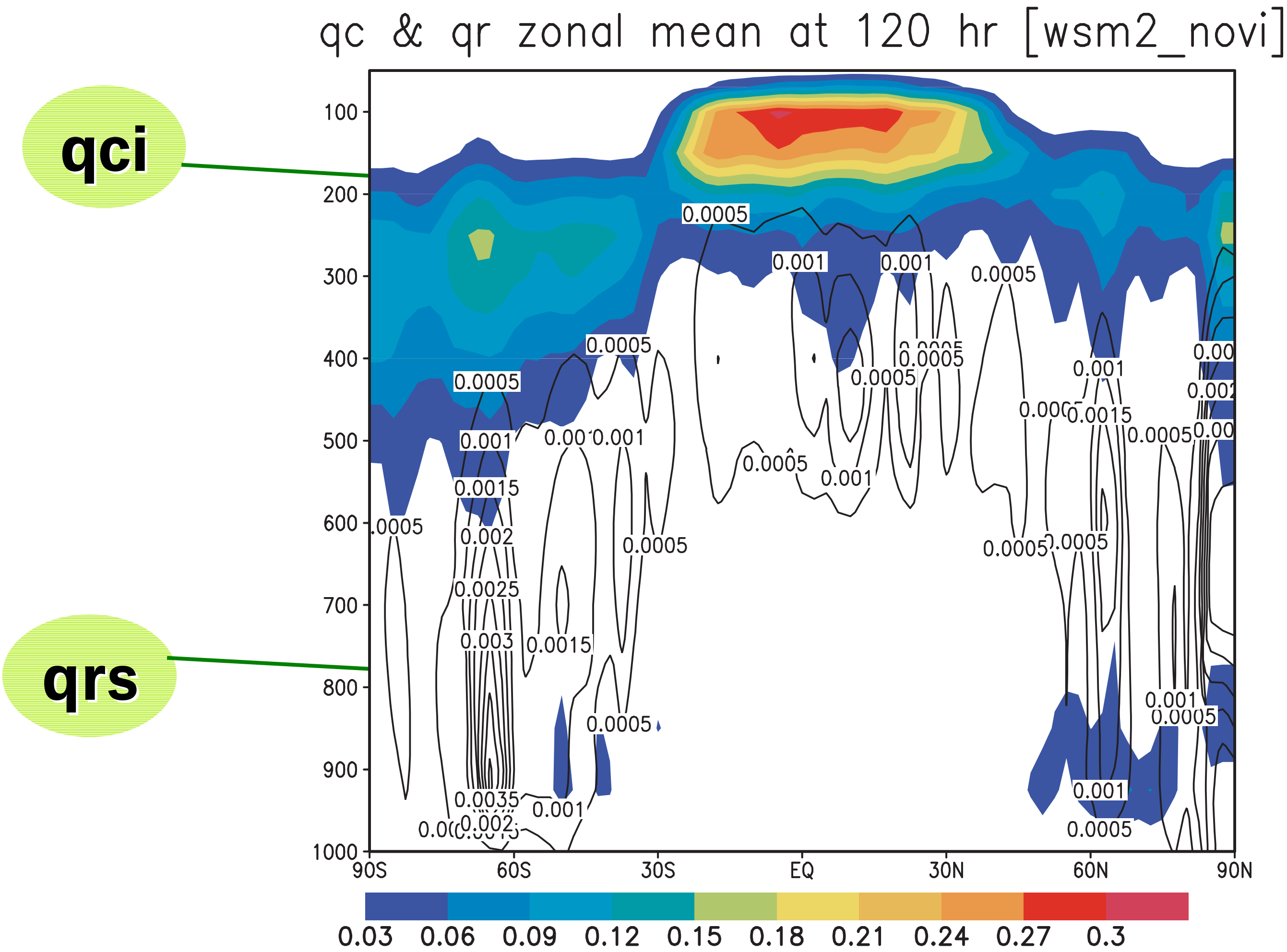
WSM2 : 24 min / 6hr

GSM

(T62)



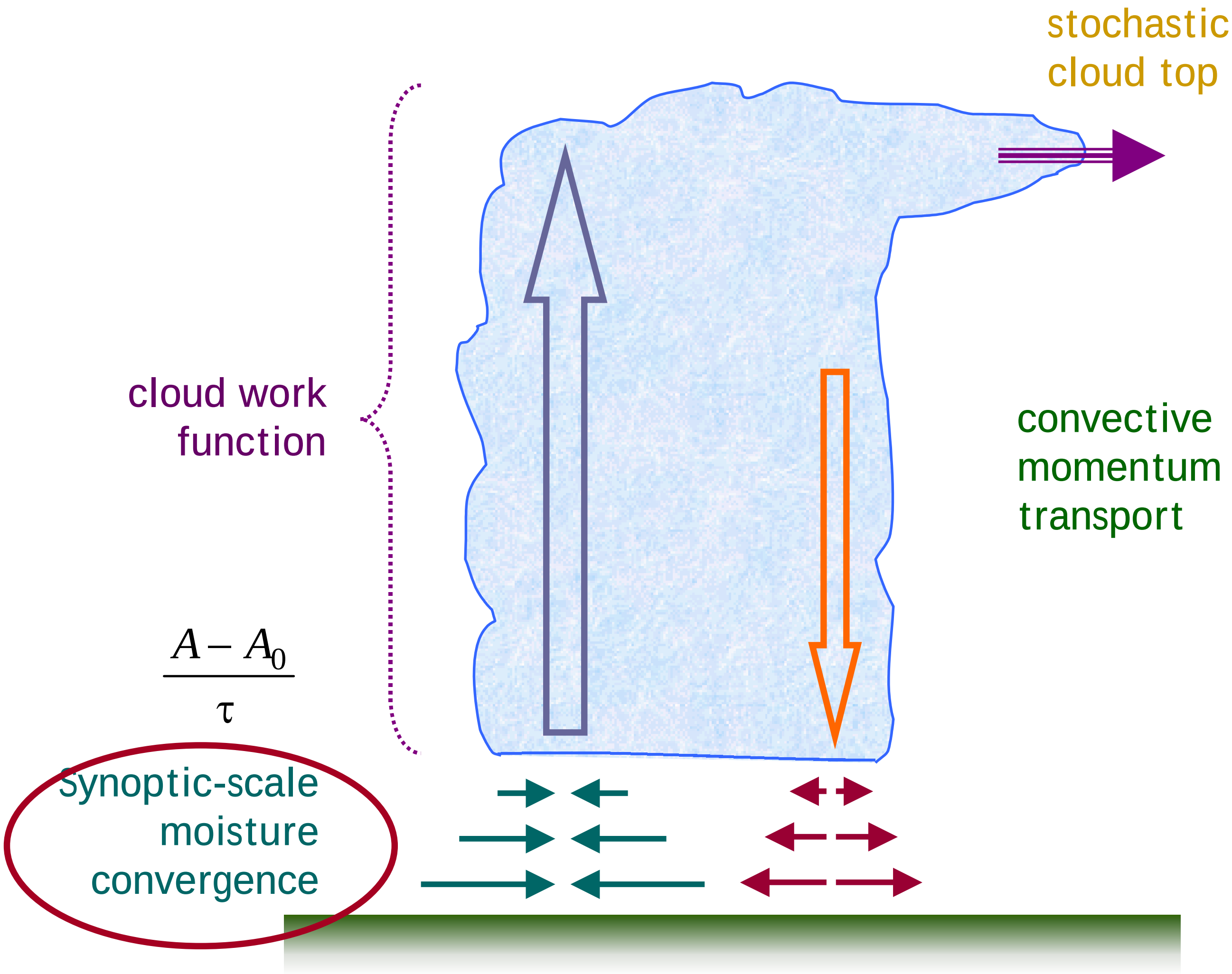
Zonal average after 120 h



Cumulus parameterization

YOURS - CP

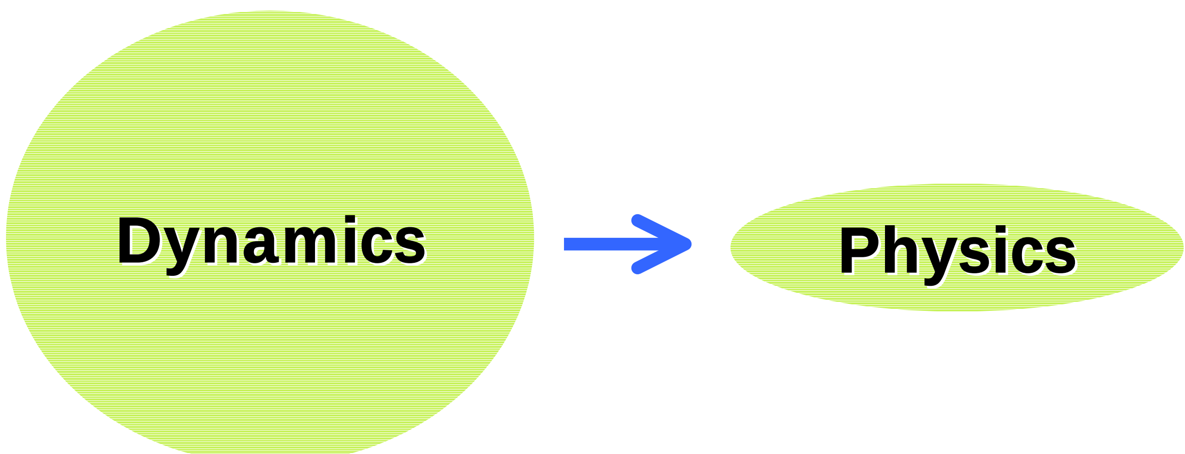
Byun and Hong (2005)



Physical parameterization in atmospheric model

Dynamics : Sso accurate !!!

Physics : Sso muddy !!!



Large-Scale Destabilization Effect

Quasi-equilibrium assumption $$\left[\frac{dA}{dt}\right]_{LS} + \left[\frac{dA}{dt}\right]_{CU} \approx 0$$

A : cloud work function (CWF)

LS, CU : large-scale and cumulus contribution

Large-scale contribution for determining cloud base mass flux

$$\left[\frac{dA}{dt}\right]_{LS} = \frac{A' - f(x)A_0}{\Delta t}$$

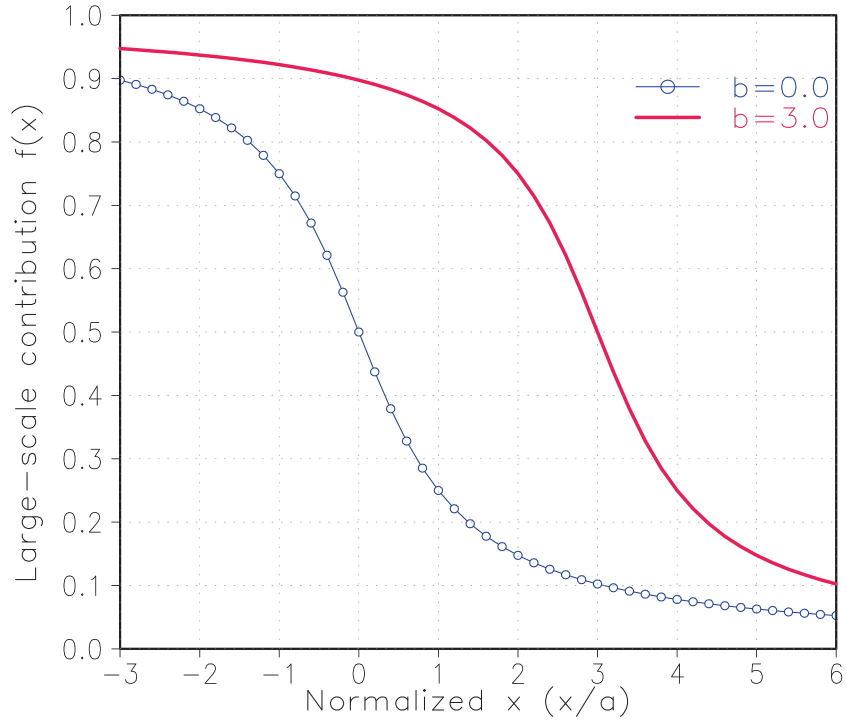
A_0 Climate CWF by Lord et al. (JAS 1982)

$f(x)$ Large-scale contribution function which is a function of large-scale moisture convergence

Δt Adjustment time scale

How to determine $f(x)$

$$f(x) = \frac{1}{\pi}\left[\frac{\pi}{2} - Tan^{-1}\left(\frac{x}{a} - b\right)\right]$$



Large-scale moisture convergence

$$x = \int_{p_{sfc}}^{p_{cloud\_top}} \left\langle -\vec{\nabla}\cdot q\vec{V} \right\rangle_p dp/\Delta p$$

Parameters

$$a = 4.0\times10^{-8}(1/\mathrm{sec}) \qquad b = 3.0$$

Spatial average

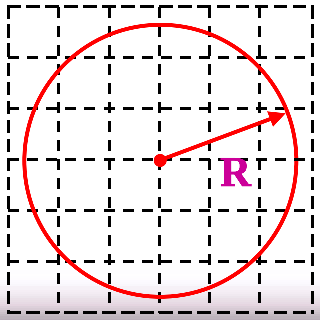
$$\left\langle -\vec{\nabla}\cdot q\vec{V} \right\rangle_i = \frac{\sum_j^R \left[w_{ij}\times(-\vec{\nabla}\cdot q\vec{V})_j\right]}{\sum_j^R w_{ij}}$$

$$w_i = \exp\left[-\frac{r_i^2}{R^2}\right]$$

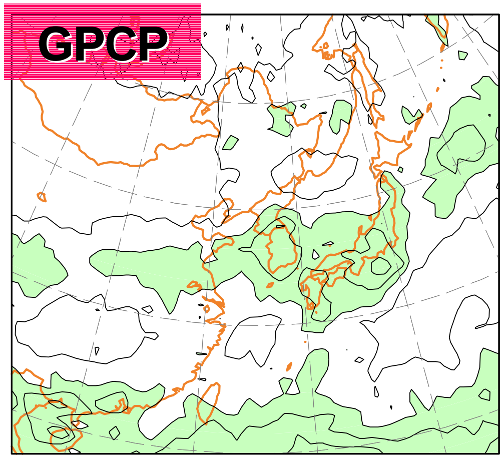
Determine effective radius **R** (750 km) :

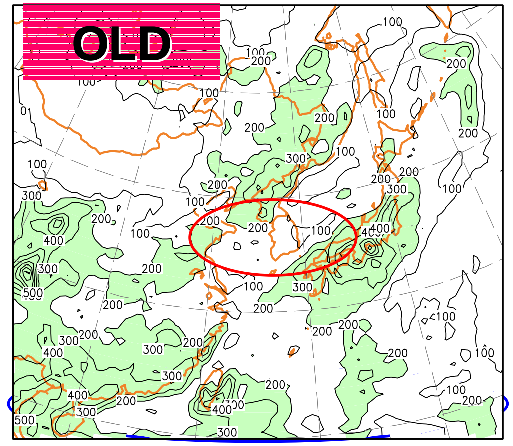
Correlation of large-scale moisture convergence and precipitation

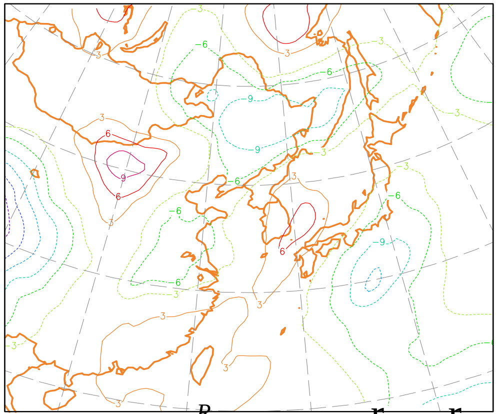
- NCEP Reanalysis II vs. CMAP (1979-2003 monthly mean)

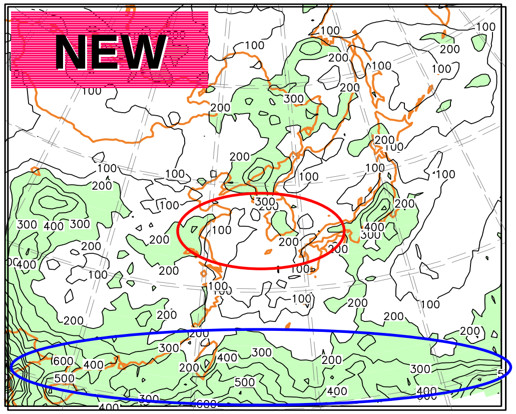


2003 August precipitation – RSM 50km









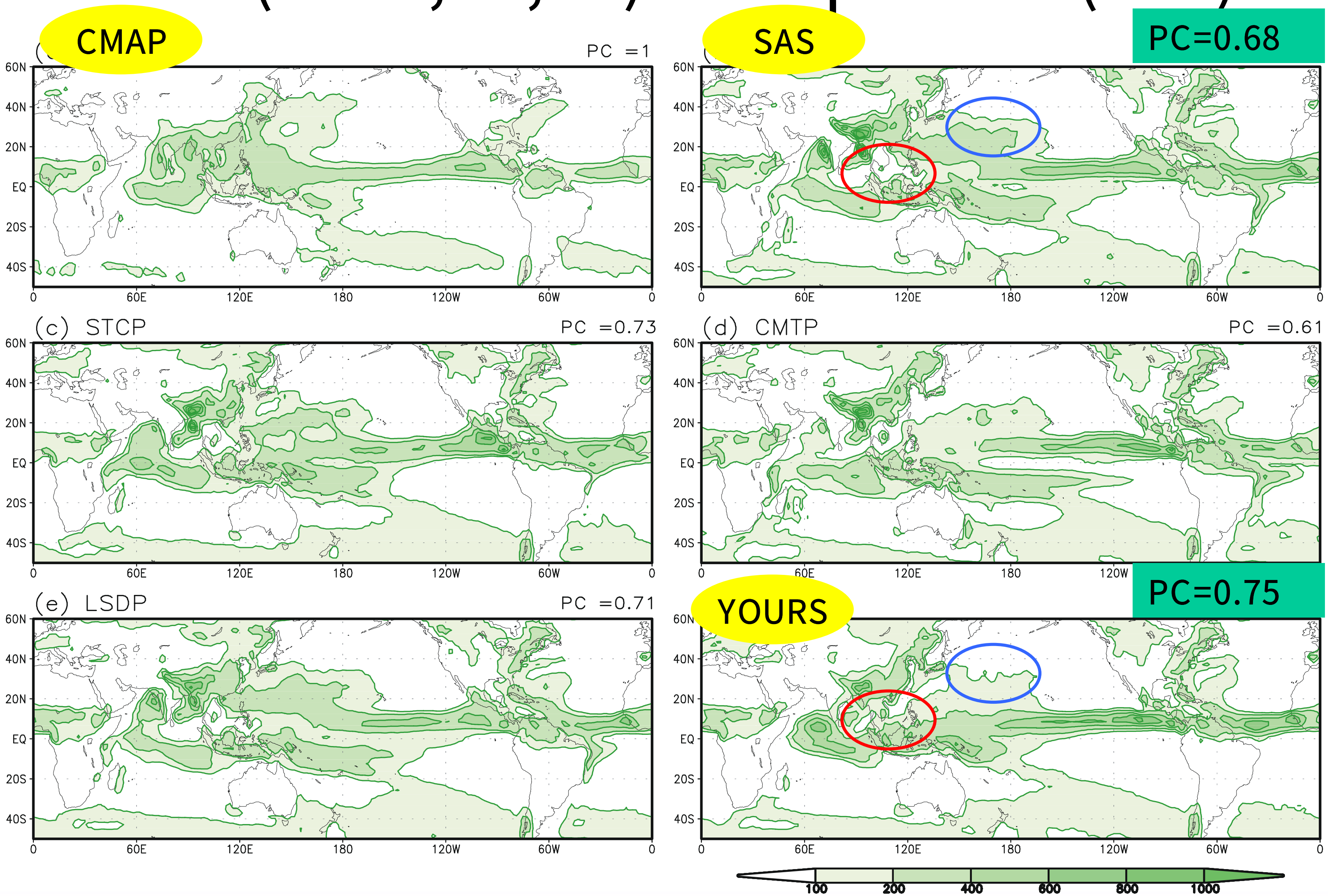
$$\left\langle -\vec{\nabla}\cdot q\vec{V}\right\rangle_i = \frac{\sum_j^R \left[w_{ij} \times (-\vec{\nabla}\cdot q\vec{V})_j \right]}{\sum_j^R w_{ij}}$$

Synoptic scale (dynamics)

↓

Mesoscale (physics)

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



YOURS - Dynamical core (Cheong et al. 2003)

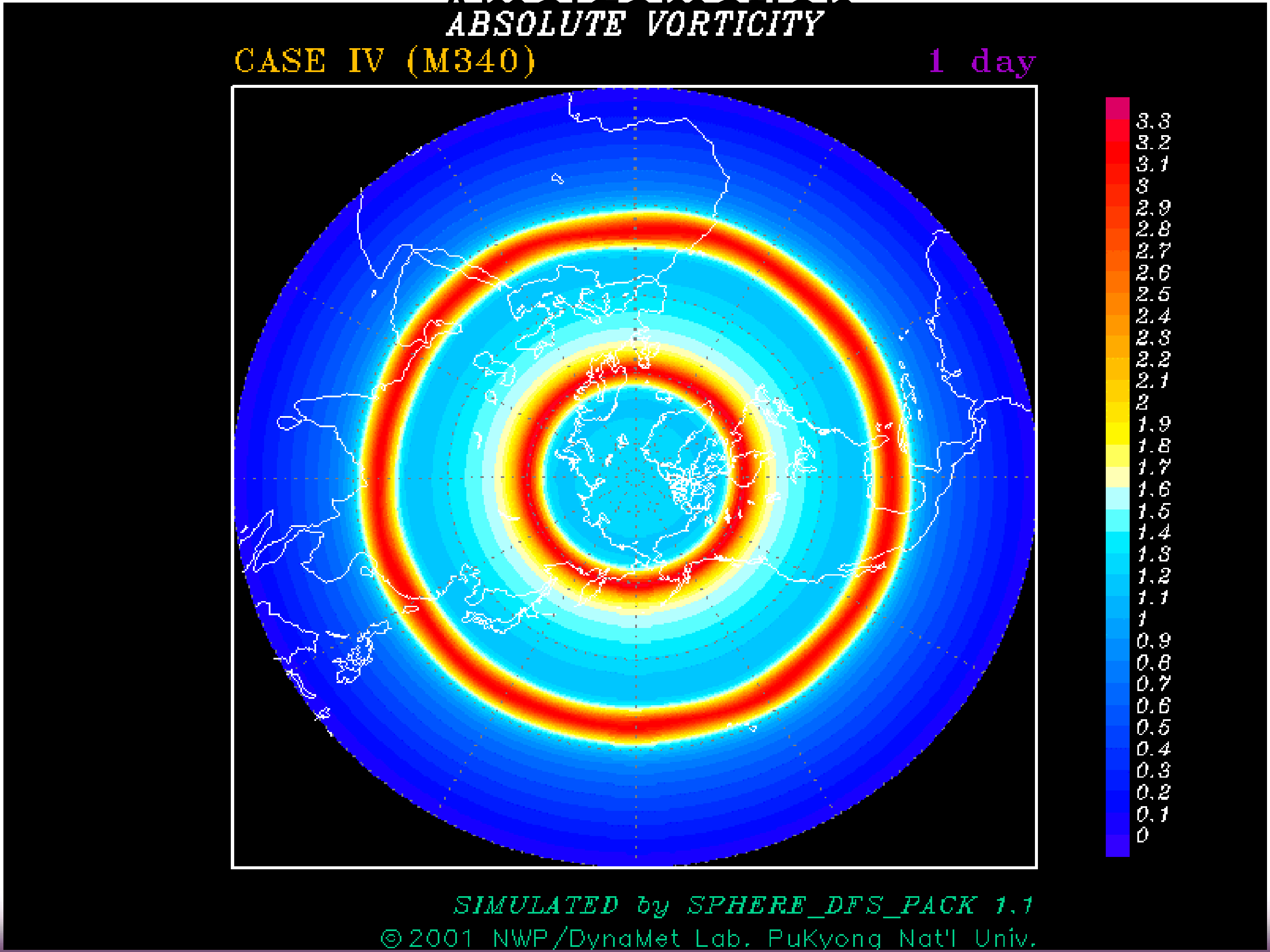
1. Terrain following coordinate system
2. Fully compressible fluid system
3. Numerical method
   - horizontal plane : Double Fourier Spectral method
   - vertical direction : linear finite element method
   - time-discretization : semi-implicit w-velocity solver

Dynamical core

Title		Journal	TIme
High-order spectral filter with double Fourier series on a sphere	Hyeong-Bin Cheong, I.-H. Kwon, T.-Y. Goo, M.-J. Lee	*J. Comput. Phys.* (Vol. 177, 313-335)	2002. 4
Application of double Fourier series to the shallow water equations	Hyeong-Bin Cheong,	*J. Comput. Phys.* (Vol. 165, 261-287)	2000. 11
Double Fourier series on a sphere: Applications to elliptic and vorticity equation	Hyeong-Bin Cheong,	*J. Comput. Phys.* (Vol. 157, 327-343)	2000. 1
Excitation of the 10-day and 16-day waves	Hyeong-Bin Cheong, Ryuji Kimura	*J. Atmos. Sci.* (Vol. 58, 1129-1145)	2001. 5
Oscillation of separation distance between binary vortices of typhoon-scale	Min-Kyu Kang, Hyeong-Bin Cheong,	*J. Meteor. Soc. Japan.* (Vol. 79, 967-983)	2001. 10

DFS model (I)

Barotropic Instability and Vortex Amalgamation



Future plans

Model Development Strategy

DFS

YOURS

Dry primitive global DFS system with multiple levels
(Cheong et al. 2003)

Radiation (Kim et al. 2005, Byun and Hong 2005)

Land surface (J. Hong 2005, Seol 2005)

Vertical diffusion and PBL
(Hong and Pan (1996), Noh et al. 2003, Hong et al. 2005)

Gravity wave drag
(Kim and Arakawa 1995, Chun and Baik 1998)

Cumulus parameterization
(Hong and Pan 1998, Byun and Hong 2005)
Shallow convection scheme (Kim et al. 2004)

Explicit cloud scheme
(Hong et al. 2004, Hong and Byun 2004)

KMA/YOURS GDAPS

Model Development Strategy

Time schedule

2005.3 :

Implement DFS and YOURS

– A meta version

2006.3 :

Construct the code

– Final version

Implementation (Evaluation)

Resolution :

WRF, RSM and GSM

(grid size from 200m to T62)

Tests :

Case studies,

NWP, Seasonal forecast,

Regional climate

Data Assimilation

Hwang and Kanamitsu (2005)

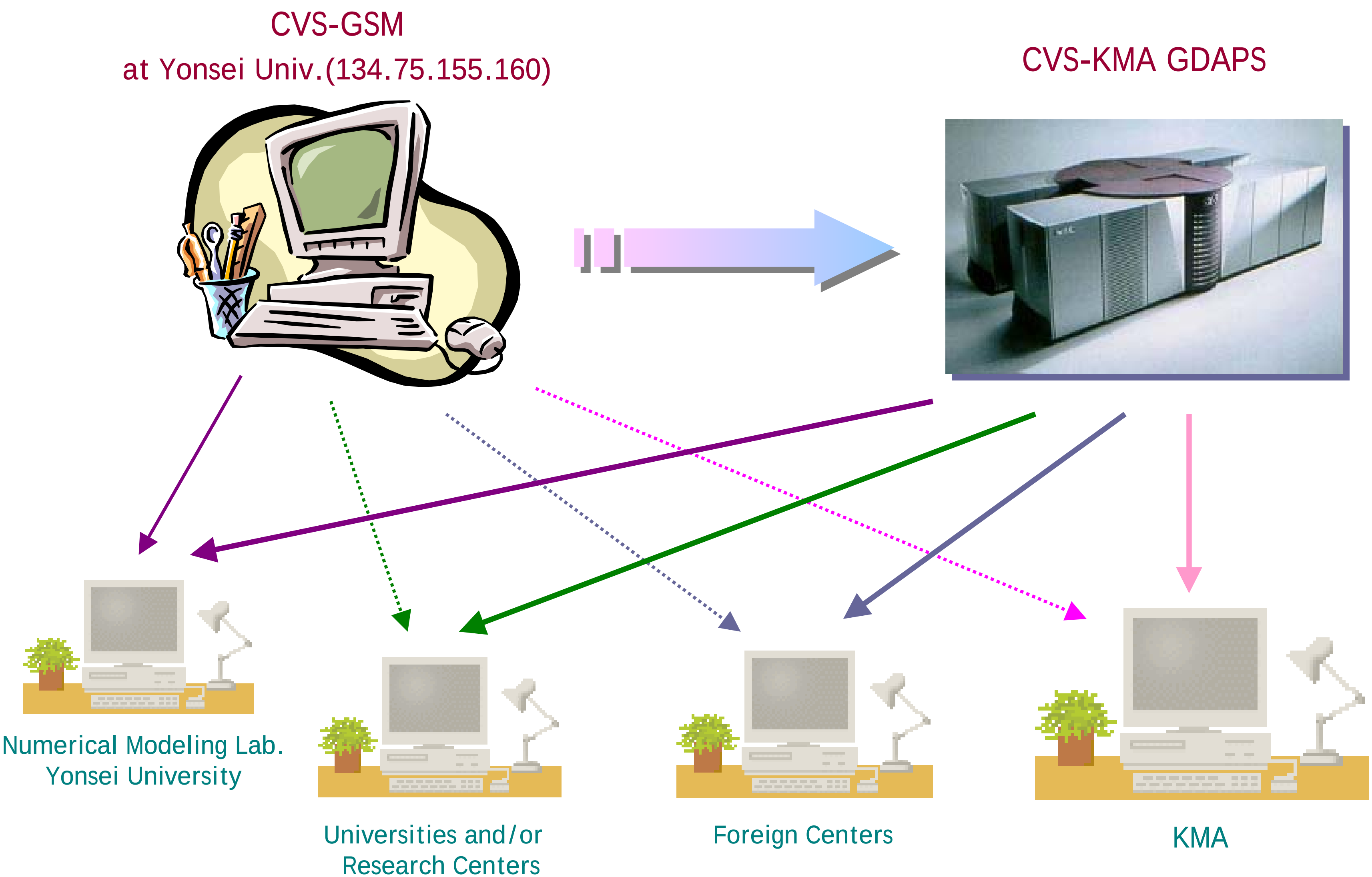
~ Dec 2005

KMA-preprocess + SSI → Standard 3-D Var System

~ Dec. 2007

Ensemble Kalman filter / Adjoint code writing for 4D-Var

CVS system


CVS-GSM
at Yonsei Univ.(134.75.155.160)
CVS-KMA GDAPS
Numerical Modeling Lab.
Yonsei University
Universities and/or
Research Centers
Foreign Centers
KMA

The End

감사합니다.