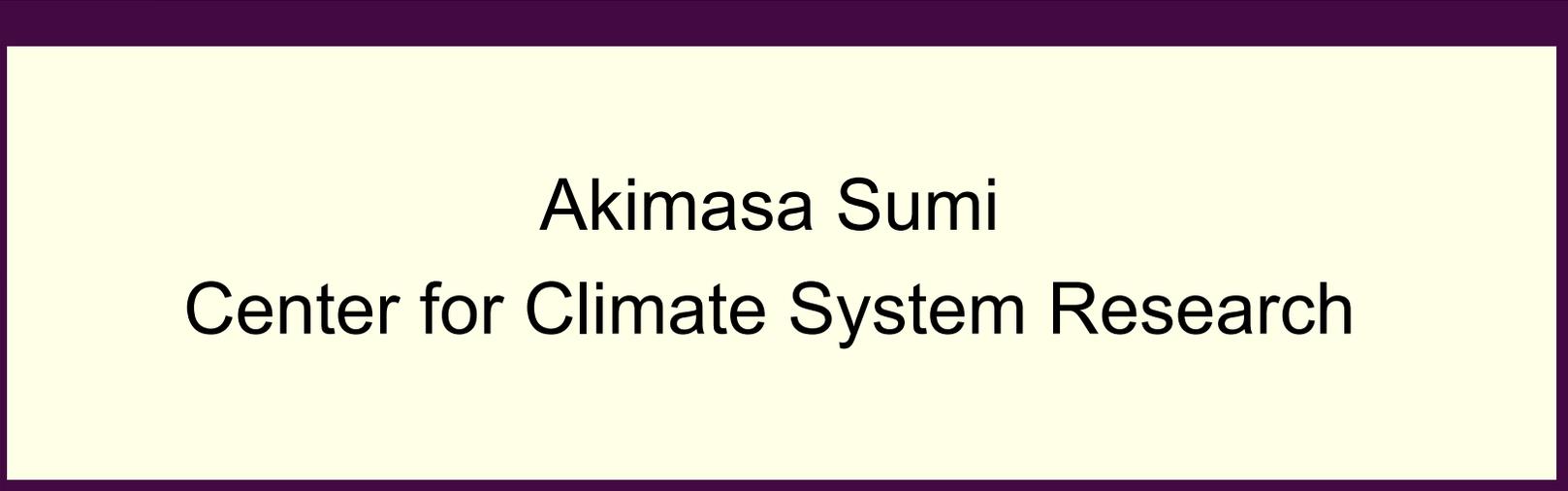
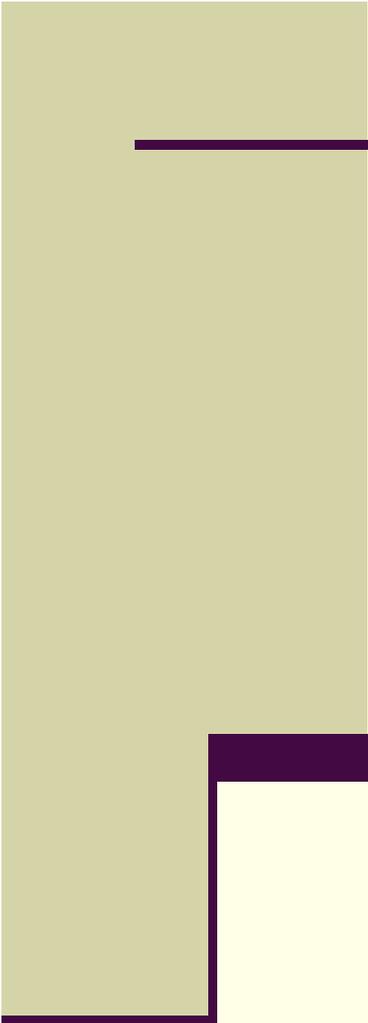




# Personal view on Future of Cumulus parameterization



Akimasa Sumi  
Center for Climate System Research

# Contents

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- Summary of the meso-scale model development in Japan
- The Earth Simulator Project
- Model development project relating to the ES
- Comparison of Convective Heating in the simulation of super cluster on an aqua-planet by using a regional model

# Activities relating to the Non-Hydrostatic Model

---

- **MRI/JMA** has been developing the **MRI-NHM**  
Drs. Ikawa, Saito, Kato and so on.

## **Consortium for NHM development**

NHM is released to Universities, National Institutes etc.

Jointly developed.

Finally, we are looking for the new NHM.

- 
- Dr. Yamazaki developed 3 dim. NHM for typhoon and tropical disturbance
  - Univ. of Tokyo → FRFGC (Dr. Nasuno)
  
  - ORI, University of Tokyo uses ARPS
  - GAME (GEWEX Asian Monsoon Experiment) community decided to introduce RAMS (1998)

# The Earth Simulator Project

---

- What is the **future of a super computer**?
- It started in **1997**. Before that, 3 year preliminary study was done.
- Massive parallel has no future
- Vector vs. scalar  
Hitachi and Fujitsu gave up the vector.
- Parallel with large grain  
-→ Vector Parallel

# The Situations around the Earth Simulator

---

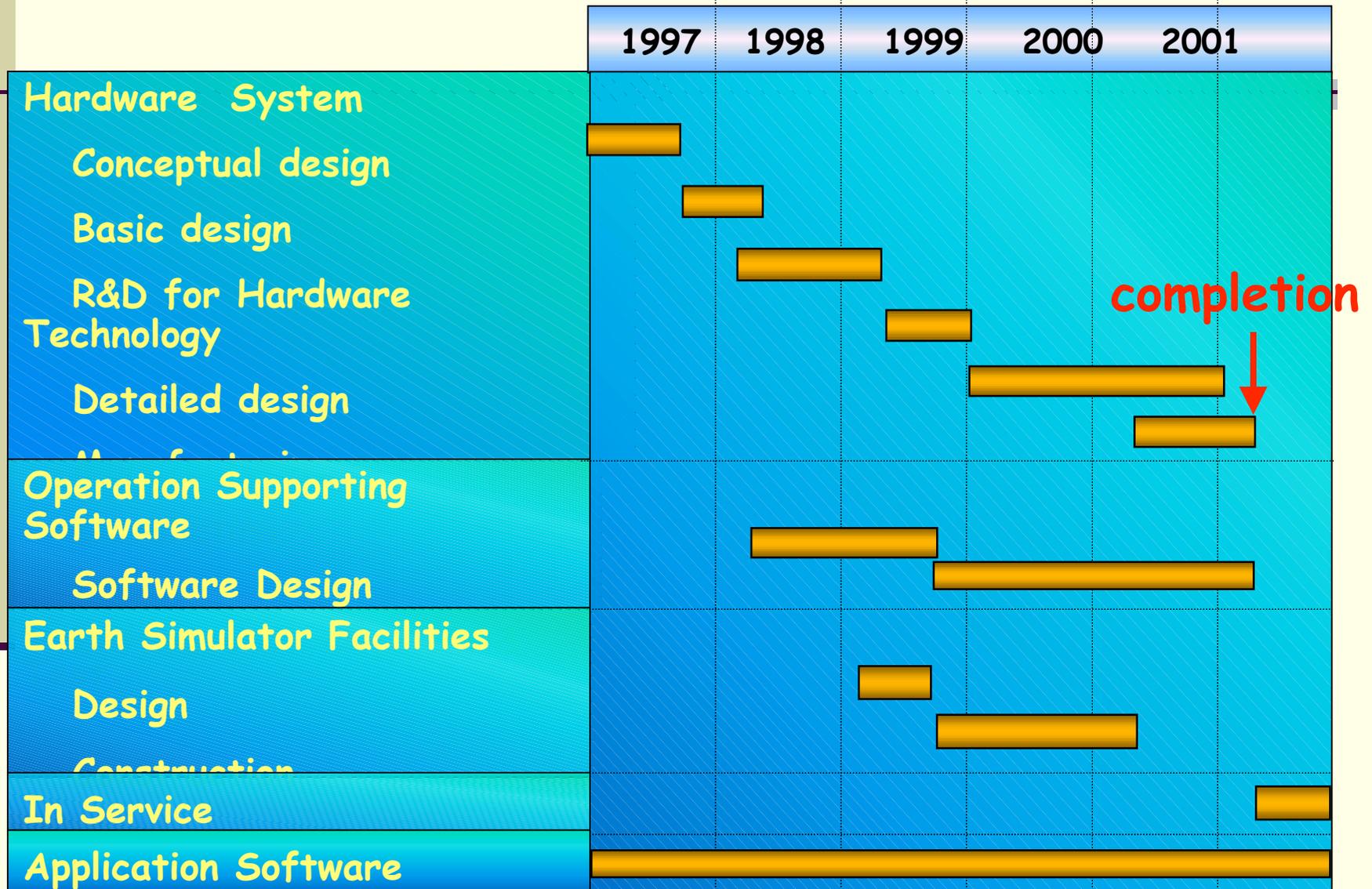
- Many Players with different intentions
  - We used NASDA and Nuclear Money
  - At that time(1995-1997), STA was so ambitious for promoting the Earth Science.
- ESTO(Earth Science and Technology Organization)
- IARC and IPRC
- EORC in NASDA
- FRSGC and OFRS

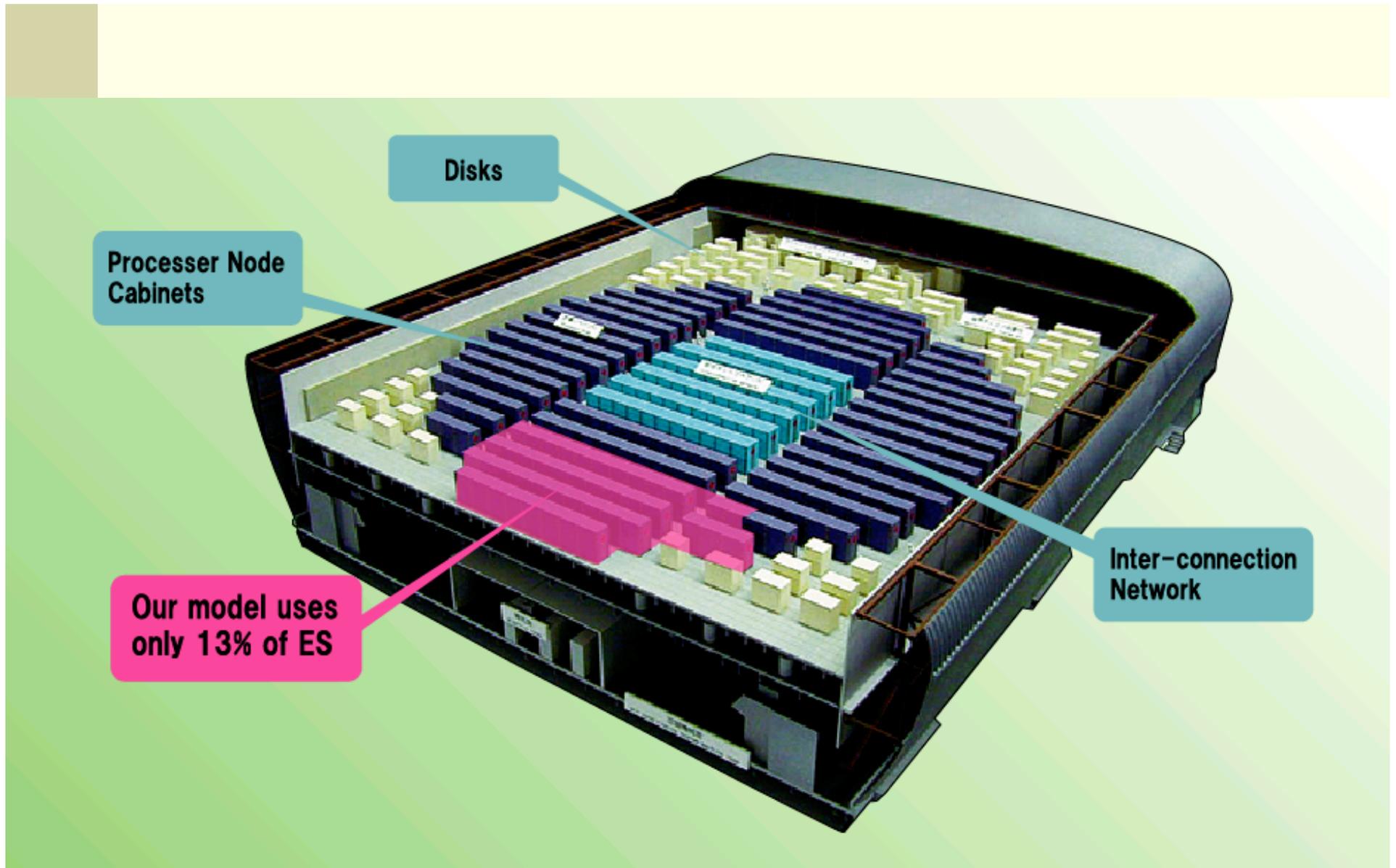
# Present situation

---

- Its cost was about **400M\$**.
- In reality, NEC paid the double (rumor).
- Economic situation had changed completely.
- Budget Cut
- Increasing a research fund for competition
- Running Cost is **40M\$/year**
- **Quick results** to the society
- We have to earn money
- EC is now trying to get private customers

# Schedule of Development





**The Earth Simulator: Inter-connected 640-node NEC SX-6s  
(1node = 8 vector processors)**

# System Specification of Earth Simulator

**IN: Interconnection Network**  
 Single stage Crossbar Network  
 16GB/sec X 2 (node to node)

**Total System:**

40Tflop/s=8Gflop/s X 5120APs  
 (AP: Arithmetic Processor)

Memory 10TB

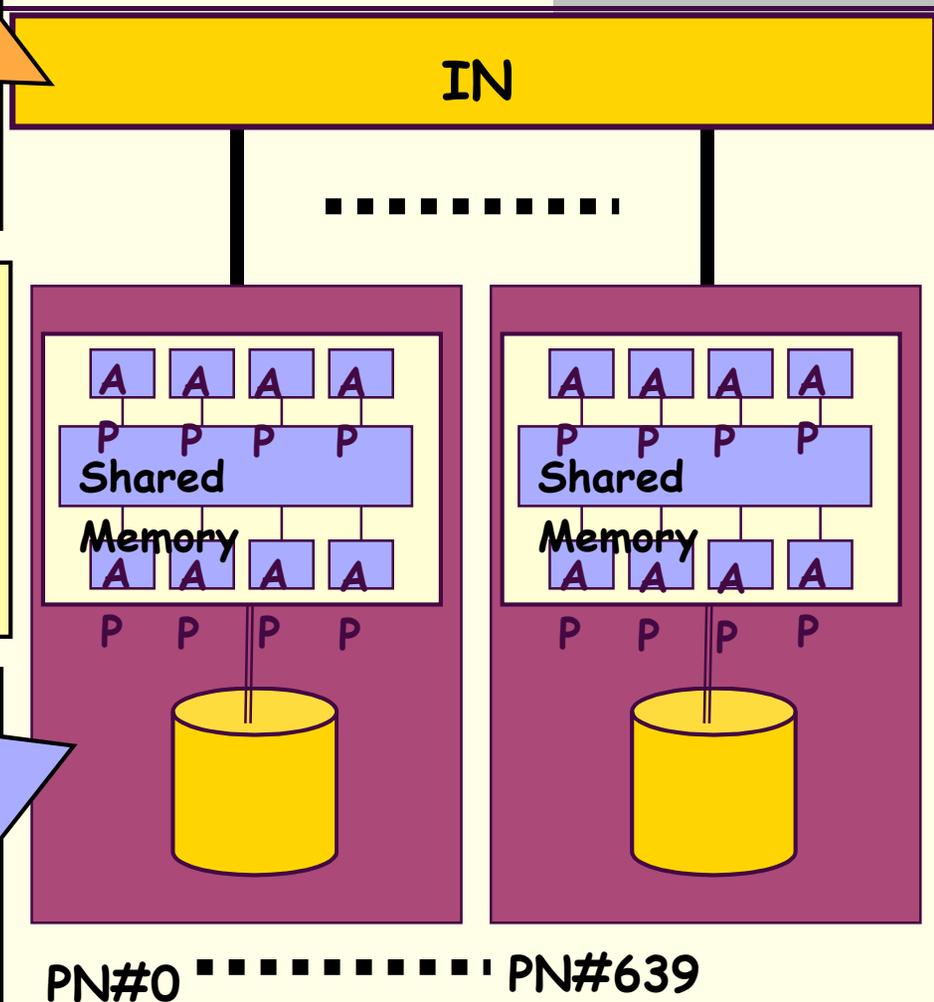
System Disk 360TB

**PN: Processor Node (640)**

Shared Memory 16GB

System Disk 576GB

64Gflop/s=8Gflop/s X 8APs



# Comparison of cabinets for one Node

## Present Supercomputer

SX-5 1PN (16APs)

Peak Performance: 128 Gflop/s

Main Memory: 128 GB

Power Consumption: ~90 KVA

Air Cooling:

## Earth Simulator

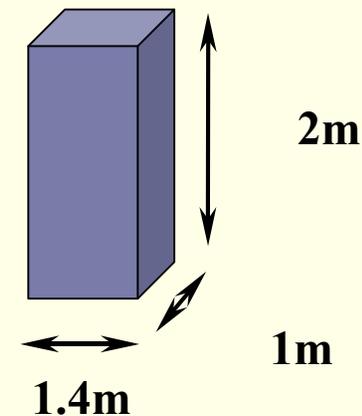
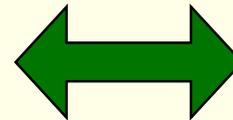
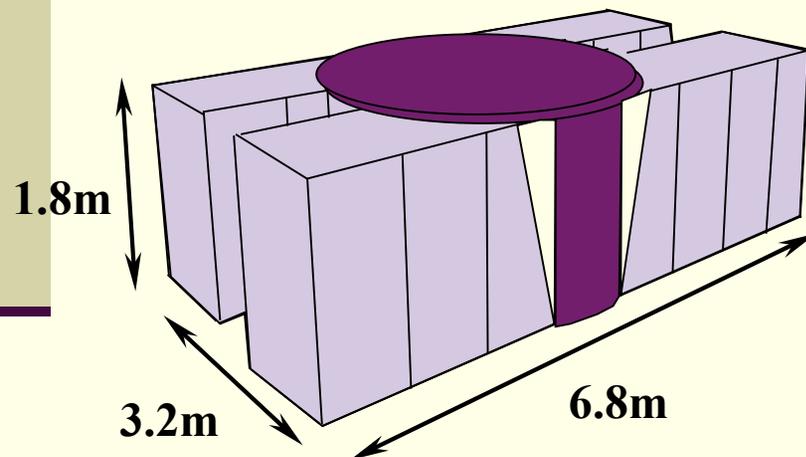
2PNs (16APs)

Peak Performance: 128 flop/s

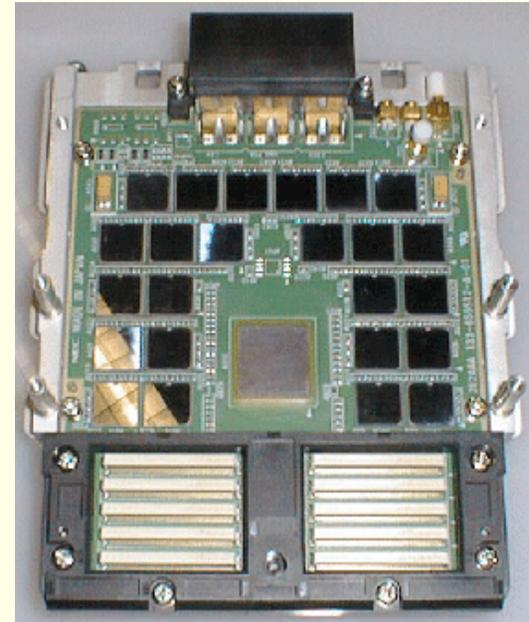
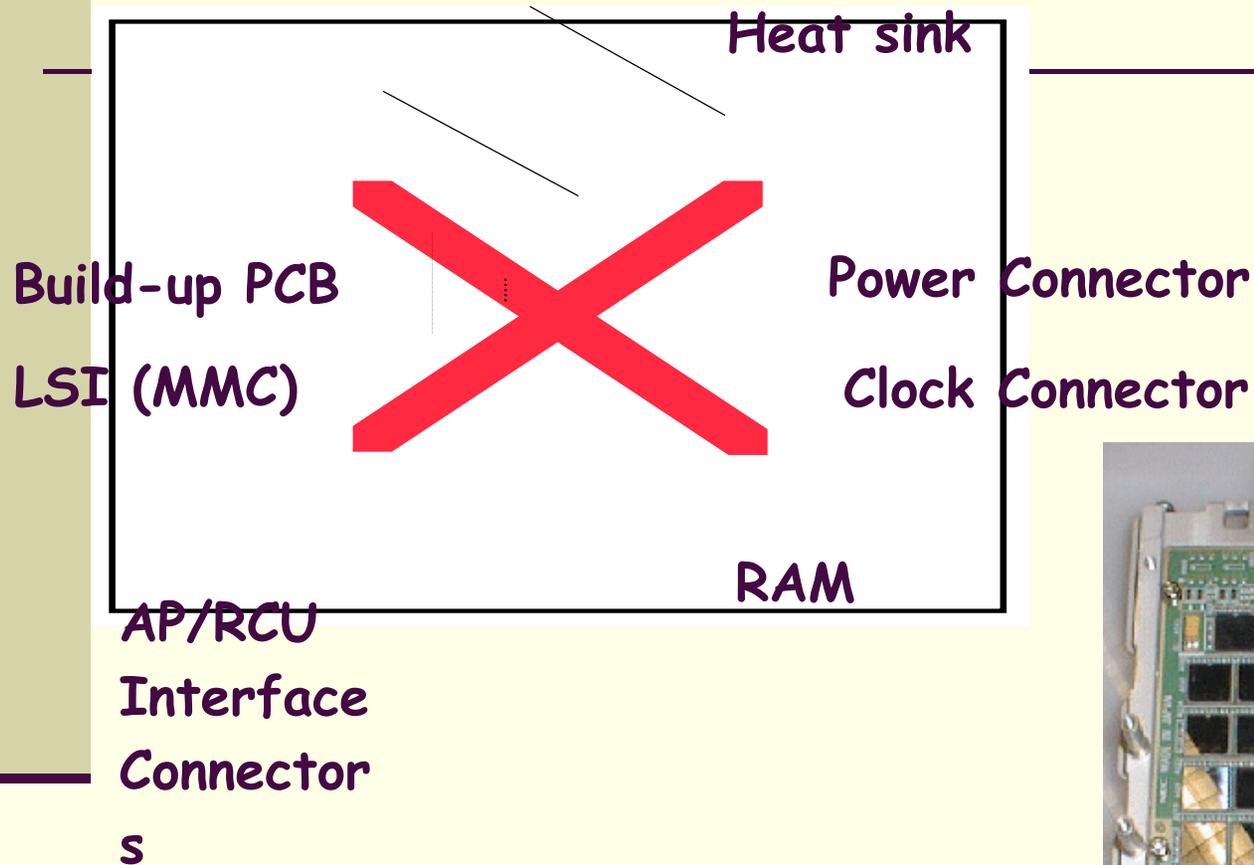
Main Memory: 32 GB

Power Consumption: ~20 KVA

Air Cooling:



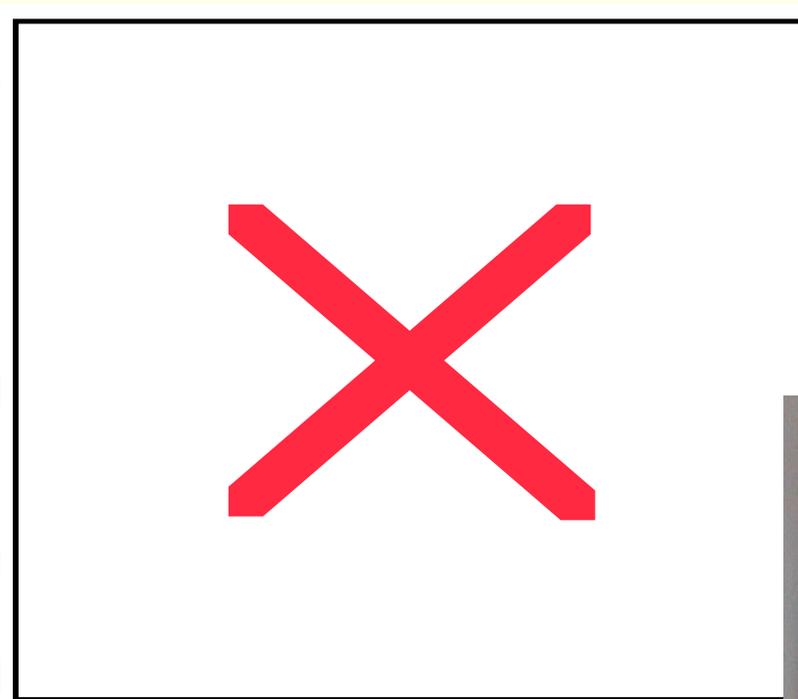
# Main Memory Unit Package



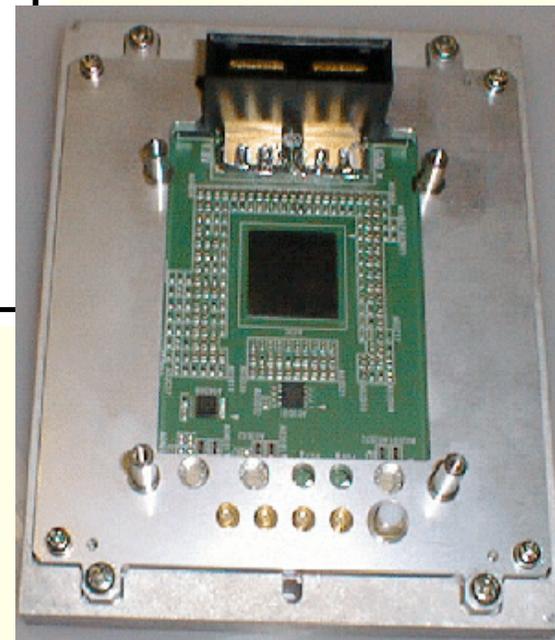
RCU: Remote access Control Unit

MMC: Main Memory Control LSI

# Arithmetic Processor Package



Arithmetic Processor (AP)



Clock Con

Build-u

MMU

Connectors (reverse side)

Connecto  
r

MMU: Main Memory Unit

# The Earth Simulator

## TOP500 List for November 2002

$R_{max}$  and  $R_{peak}$  values are in GFlops. For more details about other fields, please click on the button "Explanation of the Fields"



DETAILS



EXPLANATION OF THE FIELDS

Rank	Manufacturer Computer/Process	$R_{max}$ $R_{peak}$	Installation Site Country/Year
1	<b>NEC</b> Earth-Simulator/ 5120	<b>35860.00</b> 40960.00	<b>Earth Simulator Center</b> Japan/2002
2	<b>Hewlett-Packard</b> ASCI Q - AlphaServer SC ES45/1.25 GHz/ 4096	<b>7727.00</b> 10240.00	<b>Los Alamos National Laboratory</b> USA/2002
3	<b>Hewlett-Packard</b> ASCI Q - AlphaServer SC ES45/1.25 GHz/ 4096	<b>7727.00</b> 10240.00	<b>Los Alamos National Laboratory</b> USA/2002
4	<b>IBM</b> ASCI White, SP Power3 375 MHz/ 8192	<b>7226.00</b> 12288.00	<b>Lawrence Livermore National Laboratory</b> USA/2000
5	<b>Linux NetworX</b> MCR Linux Cluster Xeon 2.4 GHz - Quadrics/ 2304	<b>5694.00</b> 11060.00	<b>Lawrence Livermore National Laboratory</b> USA/2002

65m (71%)

Magnetic Shield

for cables

system

on system

# Model development for the Earth Simulator (1)

---

- There was criticism. **Hardware oriented!**
  - Establishment of the Frontier Research System for Global Change (FRSGC)
  - It was too ambitious!
- JAMSTEC management!

# Model development for the Earth Simulator (2)

---

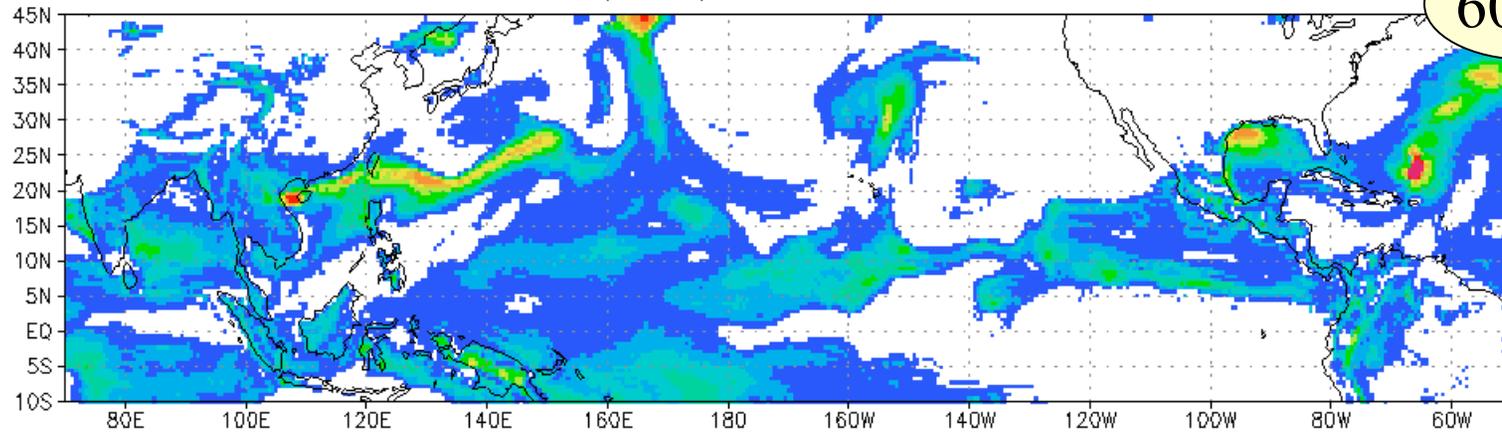
- Strategy 2 Track Strategy
- First Track
  - Extension of existing models
  - High resolution
- Slow track
- The next-generation global atmospheric model
  - Icosahedral NHM by FRSGC(Dr.Sato)
  - Spherical Cubic for the Ocean Model

# Model development for the Earth Simulator (2)

---

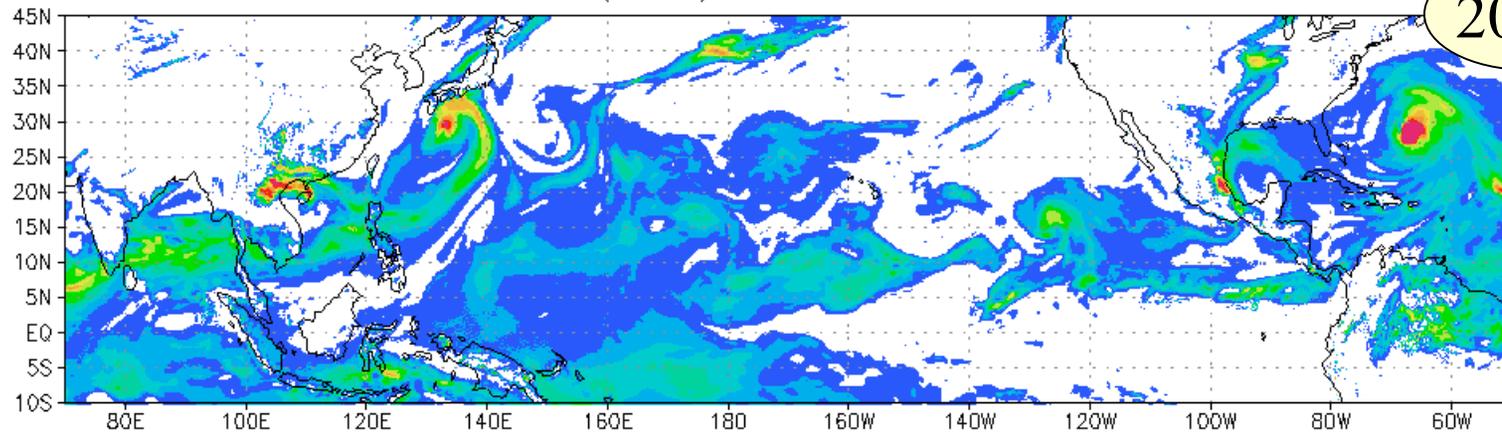
- Funding for other organizations
- Looking for the **Global NHM**
- **Unified Model (MRI + NPD)**
  - Regional Prediction Model(Dr.Saito)
- **CReSS** has been developed at Nagoya Univ.
- Tropical NHM model (CCSR+RIST)
- Cloud model

T213 RAIN(12h) 2001.9.7.12Z T=264



60km

T682 RAIN(12h) 2001.9.7.12Z T=264



20km

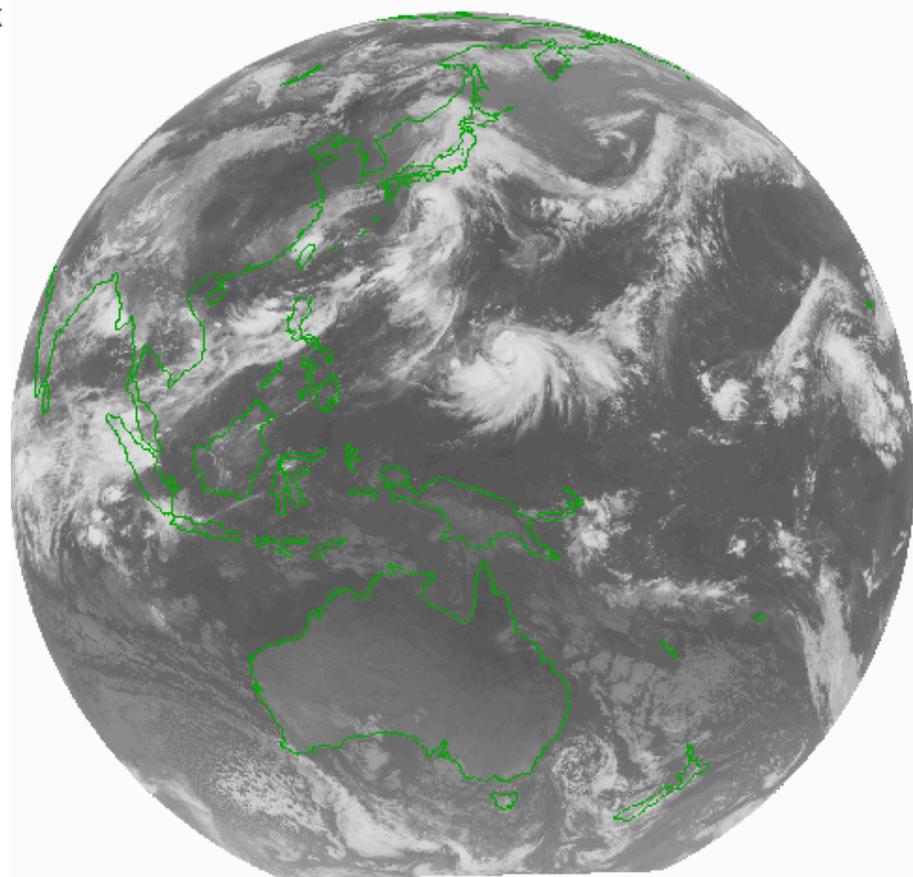
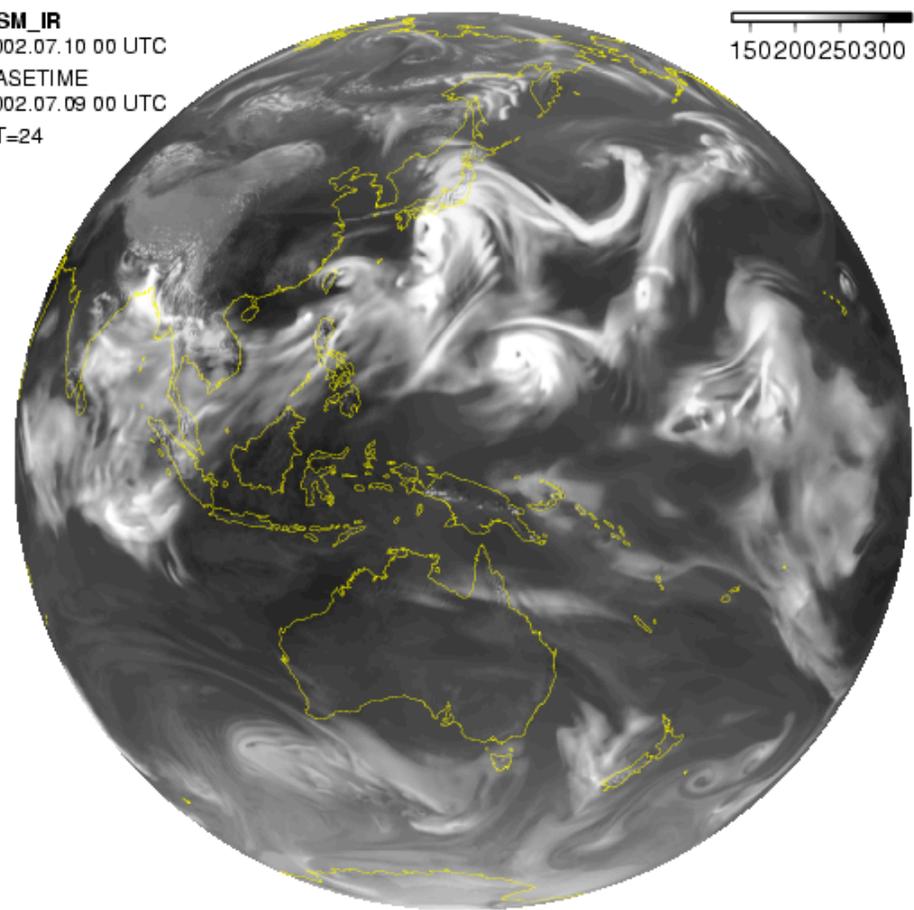
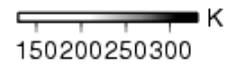


高解像度全球モデルによる予測例：降水量 (mm/12hour)  
20km実験で熱帯擾乱のスパイラル構造等が現実的に表現された

# TL1023L40 Typhoon forecast

(09 Jul 2002 00UTC, FT=24, GMS-IR forecast images)

GSM\_IR  
2002.07.10 00 UTC  
BASETIME  
2002.07.09 00 UTC  
KT=24



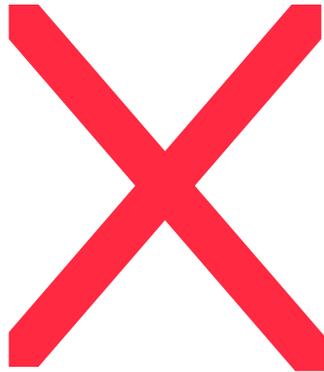
ZORKM=GSM TL1023L40 2002.7.9.00Z  
FT=24

GMS-5 obs. 10 Jul 2002 00UTC

# Dependence by the Horizontal Resolution

Total Water Path : 5 hour forecast (15JST 14 JAN. 2001 )

5km-NHM



1km-NHM

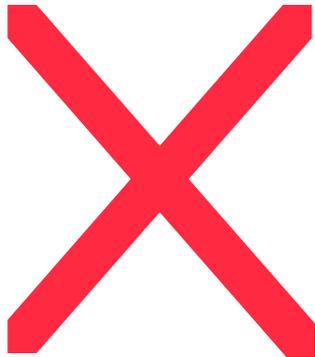


- The 5km-NHM also well reproduced the features of cloud bands and other clouds
- More detailed features have been well reproduced by 1km-NHM.

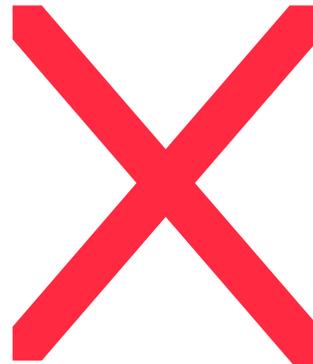
# Precipitation Forecasting

Hourly accumulated precipitation (14-15JST 14 JAN. 2001)

Radar  
Observation



1km-NHM



● The precipitation areas and intensity simulated by the 1km-NHM nearly corresponded with the observations.

# Characteristics of CReSS

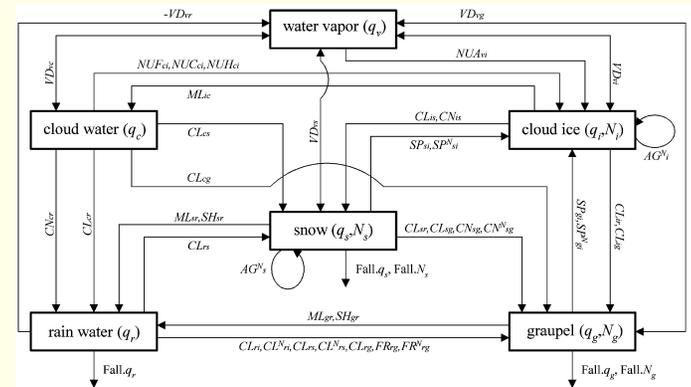
- ◆ CReSS is formulated in the non-hydrostatic and compressible equation system.
- ◆ Coordinate system is a terrain-following in a two or three dimensional geometry.
- ◆ Prognostic variables are:
  - } three-dimensional velocity components
  - } perturbation of pressure
  - } perturbation of potential temperature
  - } subgrid-scale turbulent kinetic energy, TKE
  - } mixing ratios for water vapor and several types of hydrometeors

- ◆ Finite difference method for the spatial discretization:
  - } explicit both in horizontal and vertical, HE-VE
  - } explicit in horizontal and implicit in vertical, HE-VI
- ◆ Time integration is the leap-frog method with the Asselin time filter.
- ◆ Map projection is available.
- ◆ Turbulence is the first order closure and 1.5 order closure with TKE.
- ◆ Divergence dumping term is implemented to suppress acoustic waves.

◆ Cloud physics is formulated by a bulk method of cold rain.

◆ Prognostic variables for mixing ratios are:

- } water vapor
- } cloud water
- } rain water
- } cloud ice
- } snow
- } graupel



◆ Numerical smoothing is the second or fourth order computational mixing.

◆ Initial conditions are:

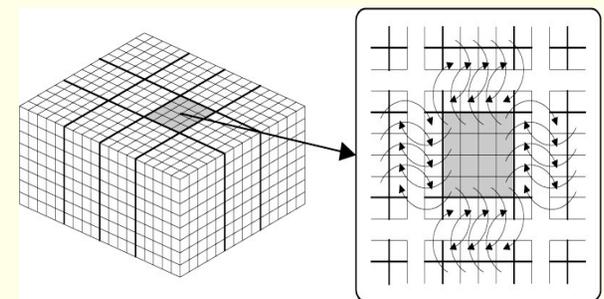
- } horizontally uniform field from upper air sounding or theoretical function
- } three-dimensionally inhomogeneous data

◆ Lateral boundary conditions are:

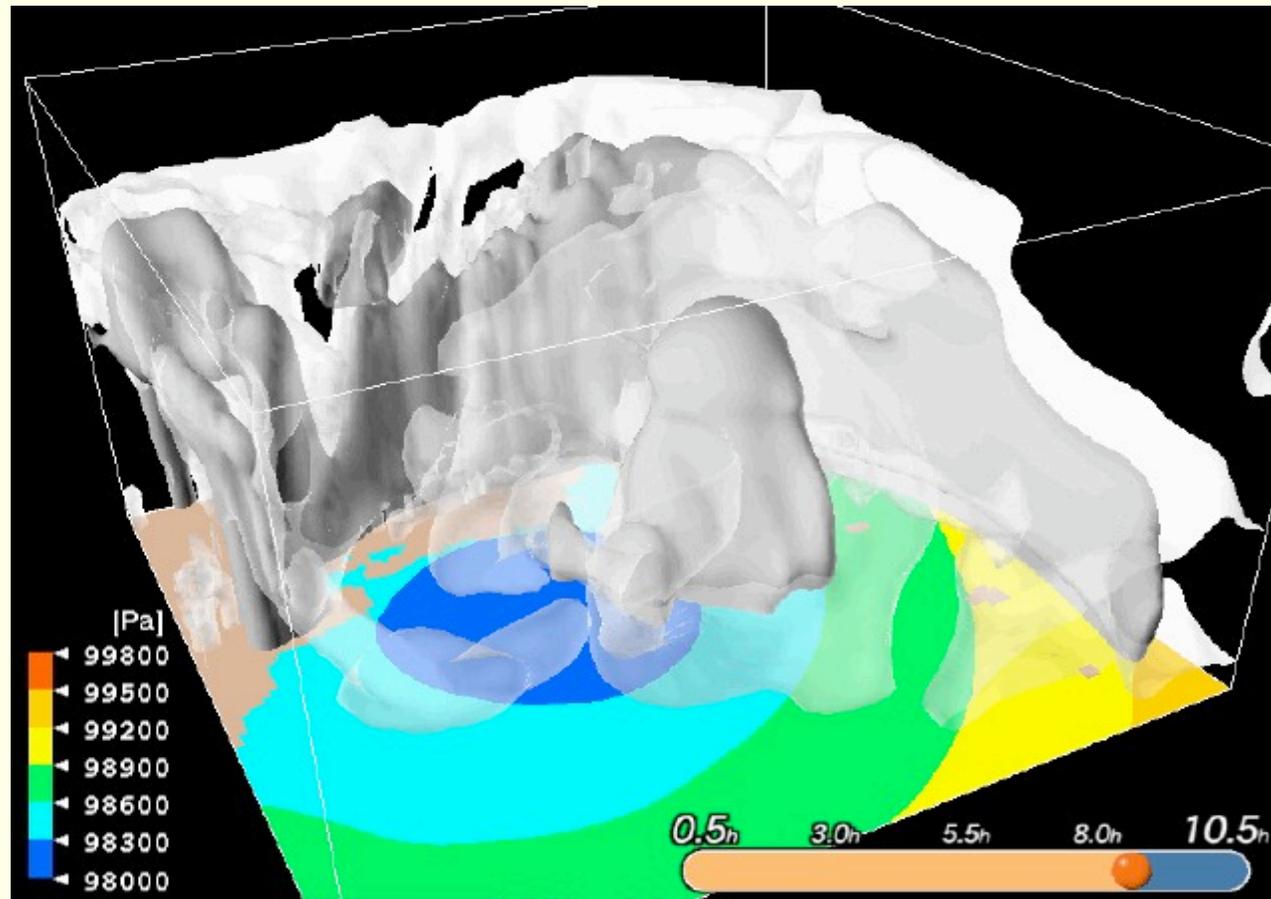
- } rigid wall, periodic, zero normal gradient
- } wave-radiating
- } externally forced time-dependent condition

◆ Ground model and surface processes have been implemented.

◆ **Parallel processing is performed by the Message Passing Interface, MPI.**



# The 3D animation of Typhoon 0111



# Kyousei Program: For maintaining the Earth Simulator

---

- K-1 CCSR+NIES+FRSGC  
T106L56+1/4 x 1/6 L46 Climate Model  
T42L20+ 1 x 1 Ocean  
→ IPCC AR4
- K-1 CRIEP+NCAR
- K-2 FRSGC Carbon cycle modeling
- K-3 Process Studies
- K-4 JMA &MRI
- We can hire post-docs and programmers!

# How to use it?

---

- Proposal base
- Every year we have to submit a proposal.
- Guideline of CPU time
  - Atmosphere-ocean (climate) 35%
  - Solid Earth 20%
  - Computer Science 10%
  - Advanced Study 15%
  - Reserved to Center's Director 20%

# Issues

---

- No Internet connection
- So crowded
- Conversion from scalar code to vector code
- Allocation CPU time
- Data issue

---

# Comparison of convective heating in the simulation of a super cluster on the Aqua-planet

**Akimasa Sumi and Xueshun Shen**  
**CCSR and RIST**

# Original purposes

---

- Investigate a propagation organization mechanism of a super cluster and MJO
- Sensitivity to a parameterization scheme
- What happens in the model without convection parameterization?

# Strategy for parameterization studies

---

- It is very difficult to obtain **sufficient observation** for convective processes
- **Comparison of different models** is a powerful tool
  - Large-scale model
  - Meso-scale model

# Strategy(2)

---

- Here,
  - CCSR/NIES AGCM** for the Large-scale model
  - RAMS** for the meso-scale model
- Experimental condition
  - Aqua-planet**
    - The reason is simplicity
    - dynamics of a super cluster

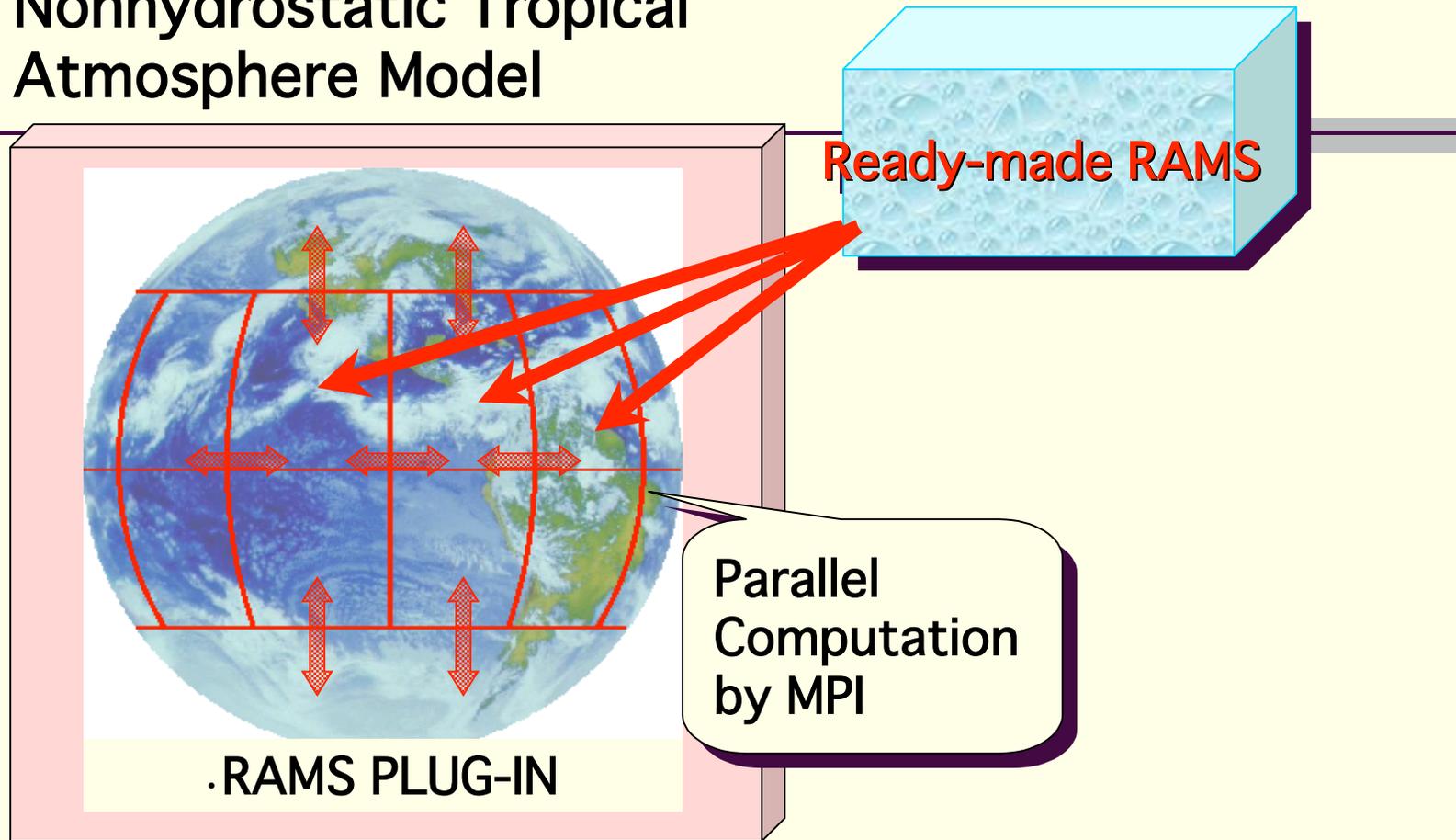
# Strategy(3)

---

- The Earth Simulator
  - Possibility of **Global non-hydrostatic model**
  - There are many issues.
  - Global tropical non-hydrostatic model

Conversion of programs needs more time!  
vector code vs. scalar code

# A High Resolution Nonhydrostatic Tropical Atmosphere Model



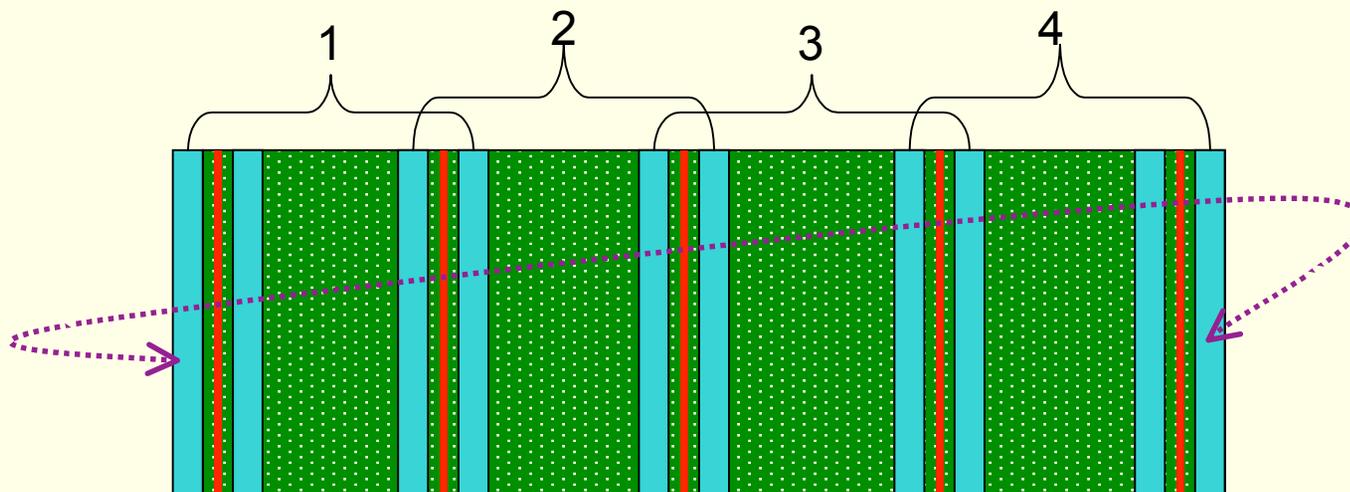
Platform for large-domain computation!

# Parallel computation

HITACHI SR8000  
University of Tokyo

For parallel execution

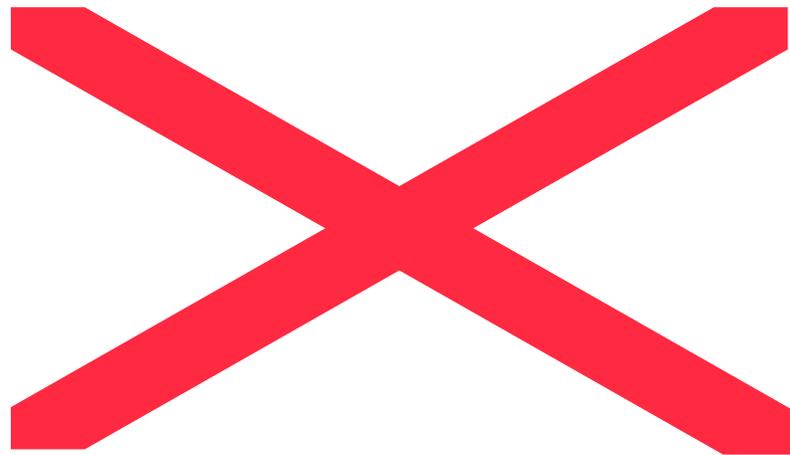
- (1) **Area** covered the global tropics (-180-180, 45S-45N) is divided into **Node subregions** with **overlapped points**.
- (2) **Serial code** is executed at **each node** with east-west boundary points communicated using **MPI**.



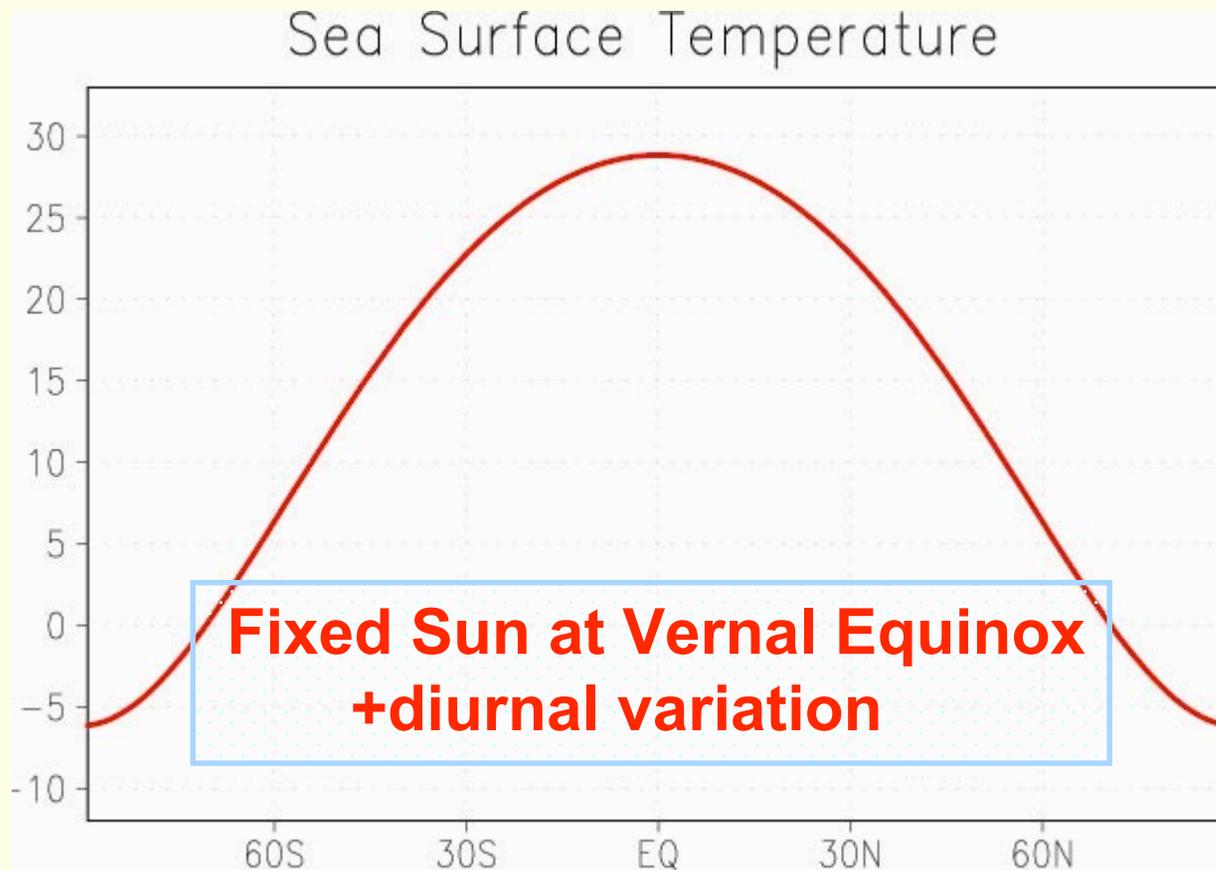
# Computational Efficiency by Cyclic Communication of RAMS

---

Dynamics only

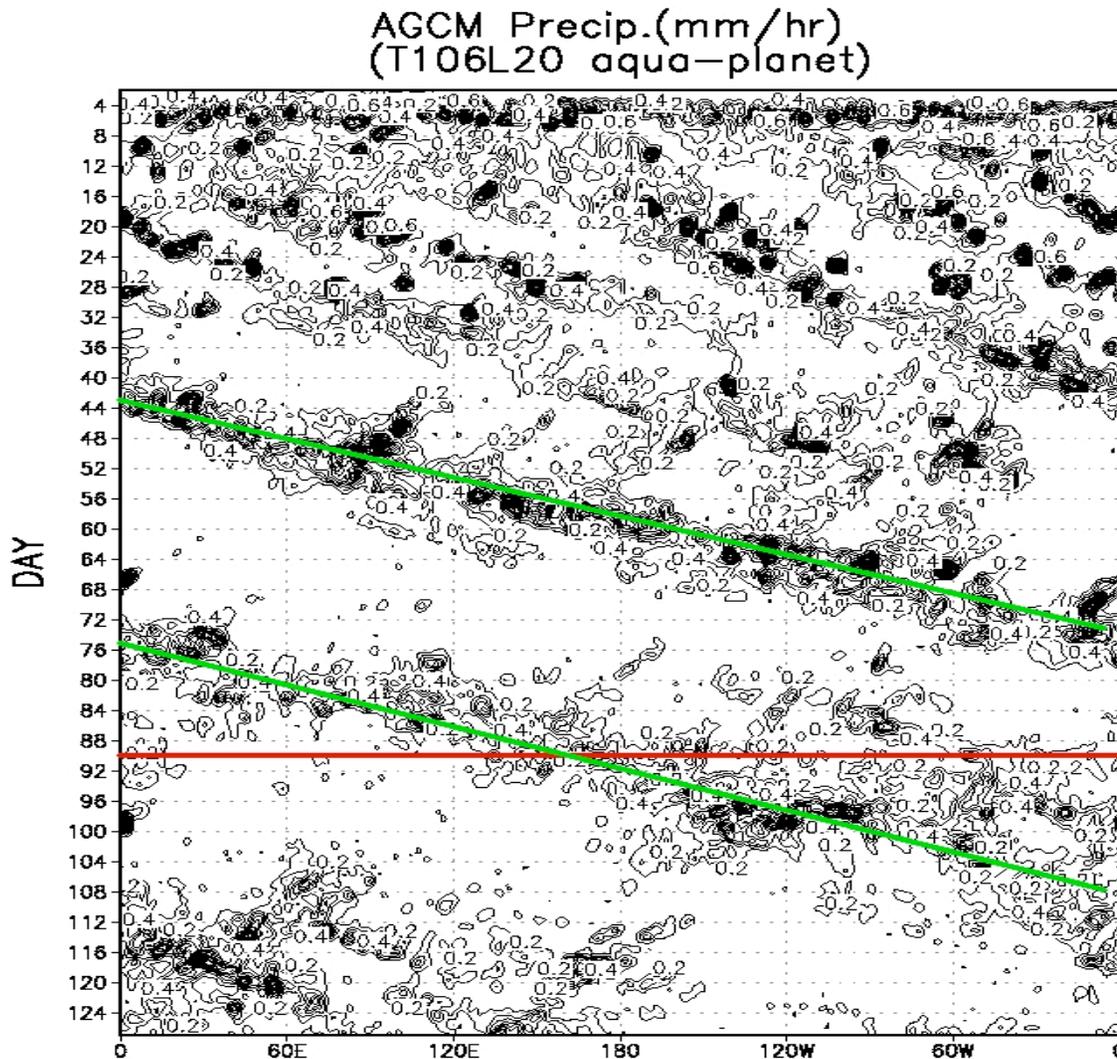


# Aqua-planet Sea Surface Temperature

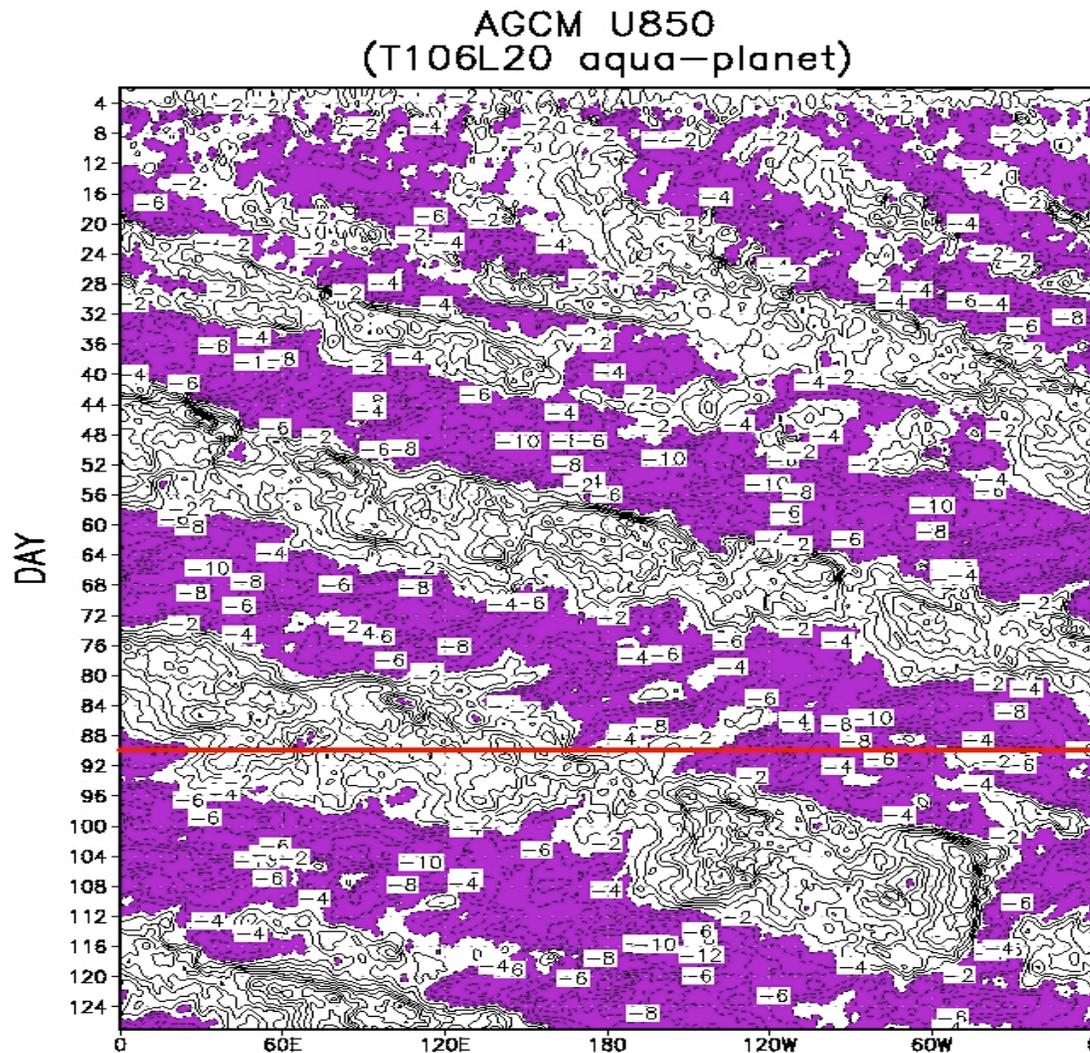


# P r e c i p i t a t i o n along EQ.

(aqua-AGCM T106L20)

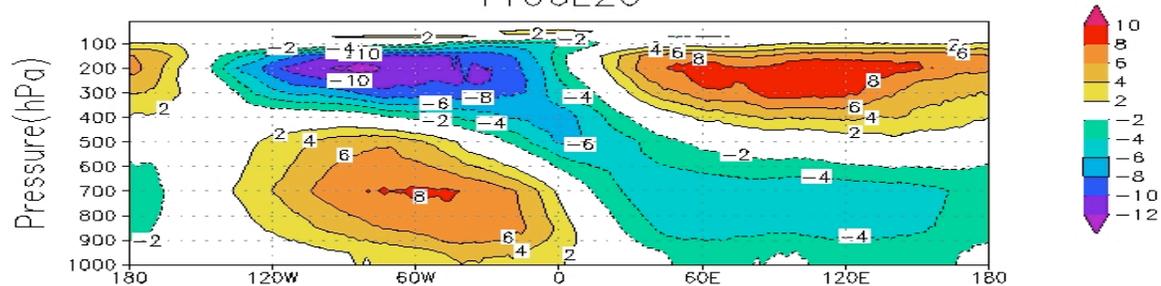


# U 8 5 0 along EQ. (aqua-AGCM T106L20)

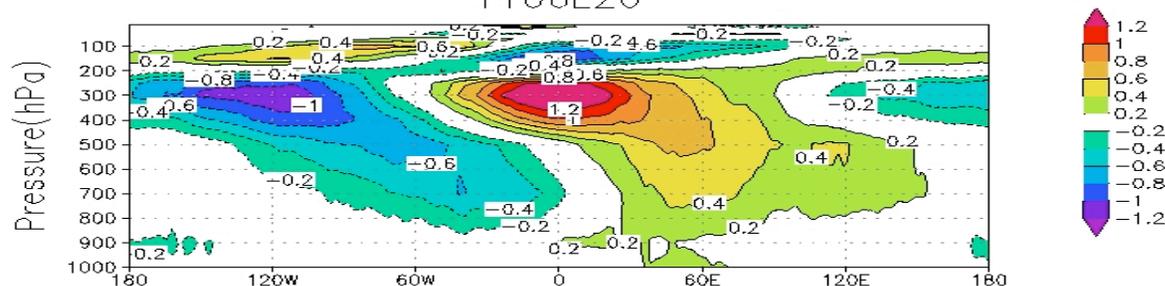


# Composite M-J Structure (aqua-AGCM T106L20)

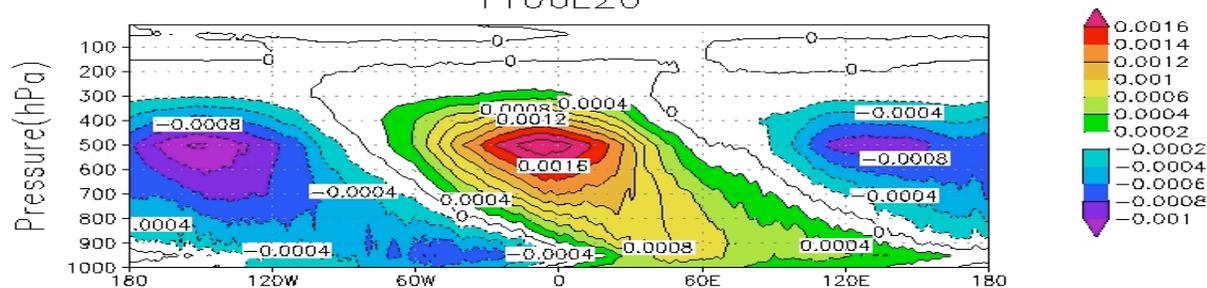
Composite AGCM U-[U] (5S-5N)  
T106L20



Composite AGCM T-[T] (5S-5N)  
T106L20



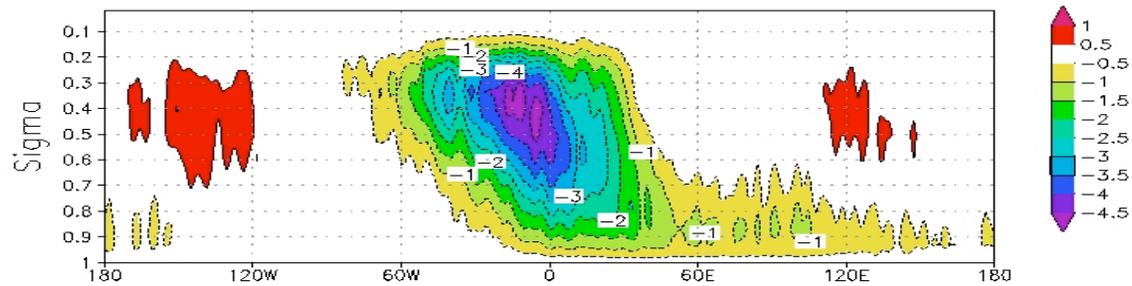
Composite AGCM Q-[Q] (5S-5N)  
T106L20



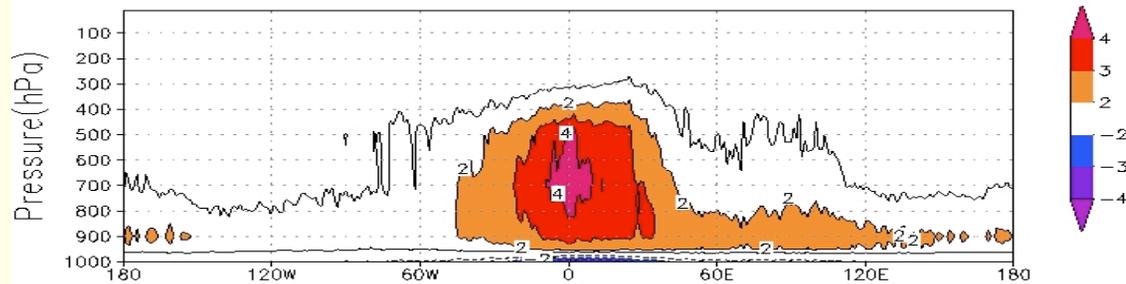
# Composite M-J Structure

(~~anna-AGCM T106L20~~)

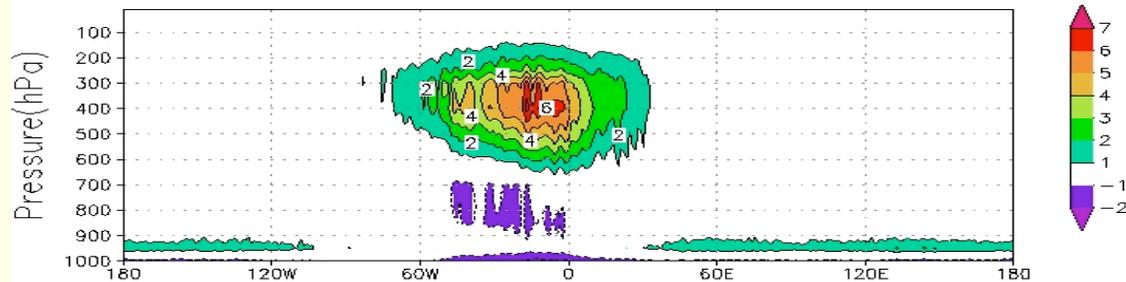
Composite AGCM OMG.(mb/h) (5S-5N)  
T106L20



Composite AGCM dT(Cumulus; K/day) (5S-5N)  
T106L20



Composite AGCM dT(LSC; K/day) (5S-5N)  
T106L20

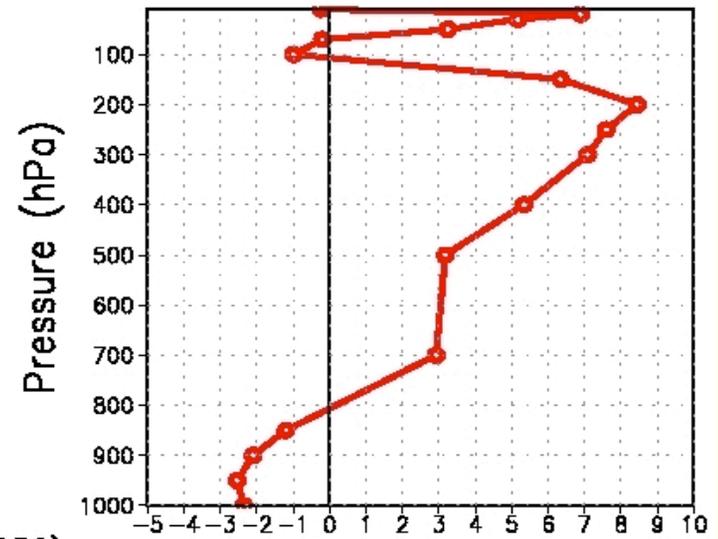
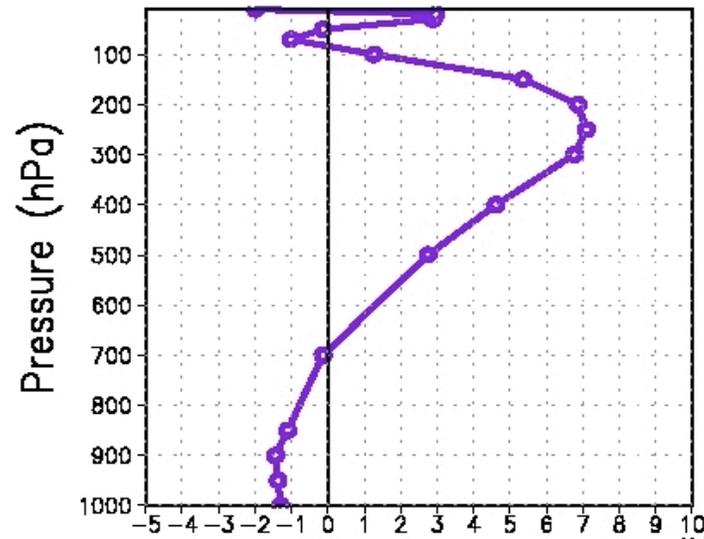


# Experiments for validating model performance

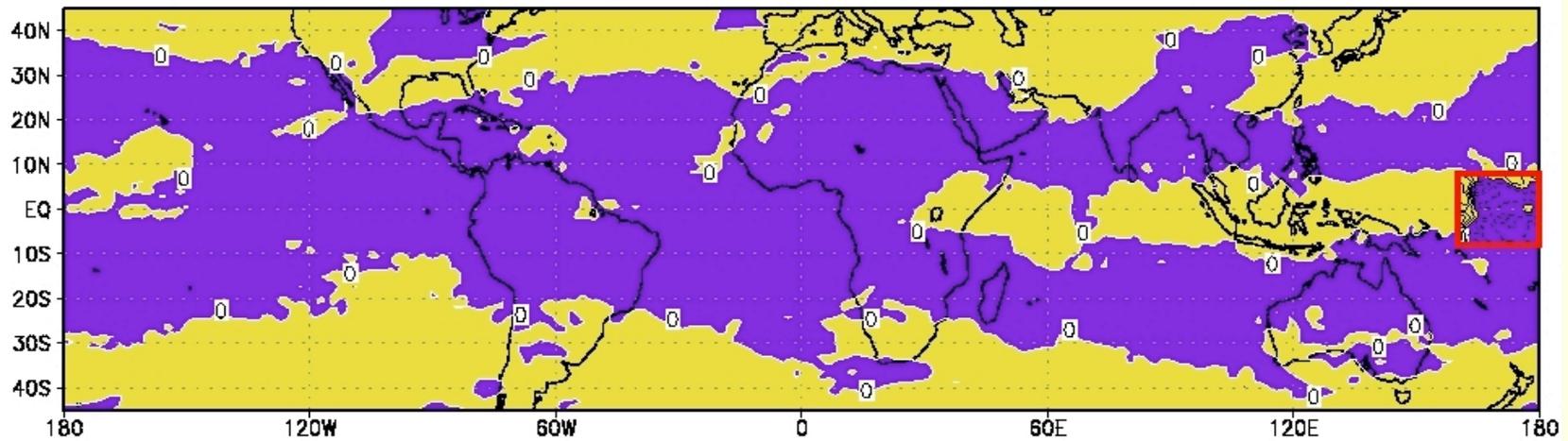
1 Global tropics bounded between 45S – 45N  
50km horizontal resolution  
30 levels in the vertical  
Simplified Kuo cumulus parameterization  
Microphysics

2 2000km × 2000 km 160E-180E ; 8S-8N  
5km horizontal resolution  
30 levels in the vertical  
Microphysics

# Initial Field

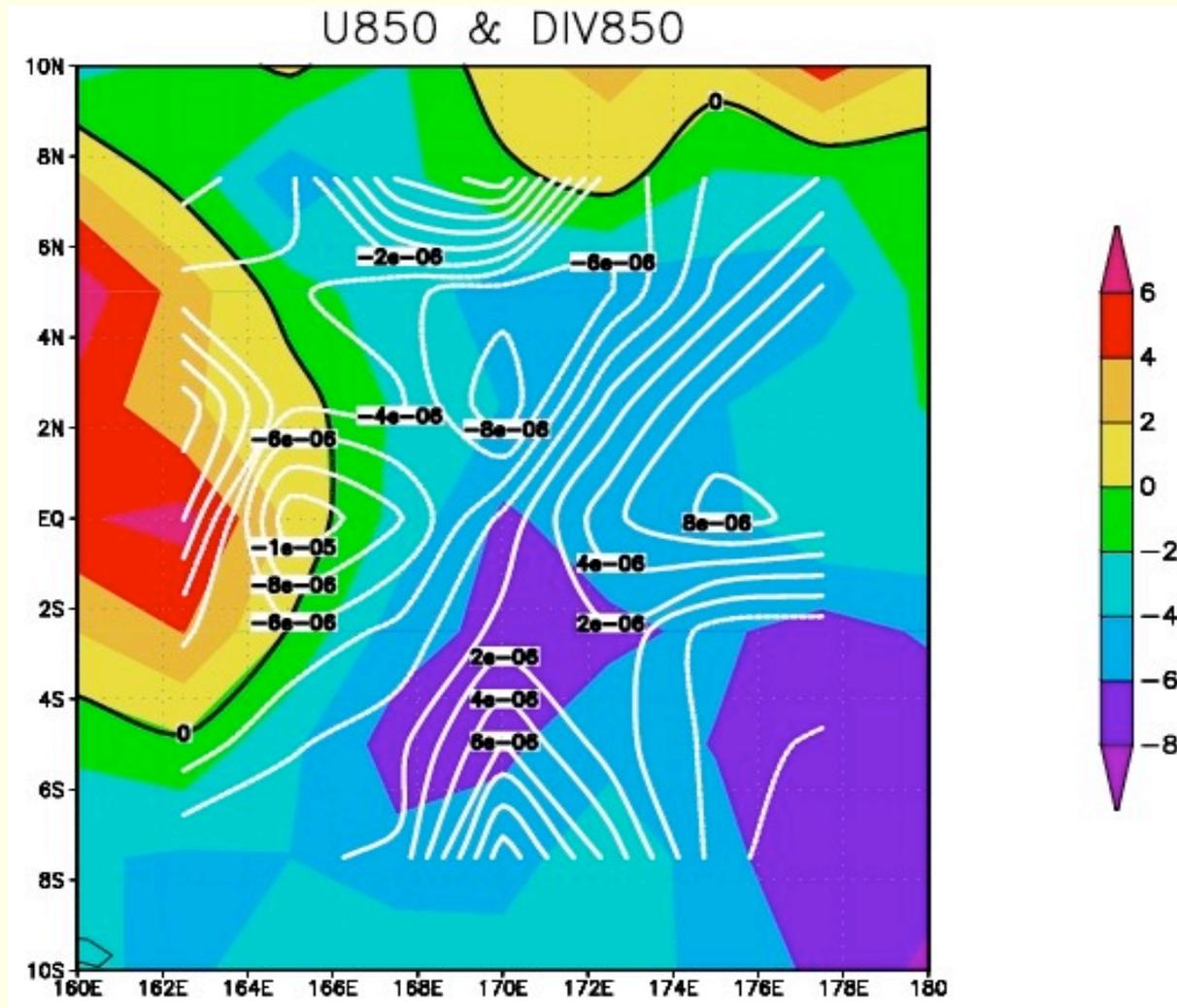


INITIAL FIELD (U850)  
(by T106L20 aqua-planet)

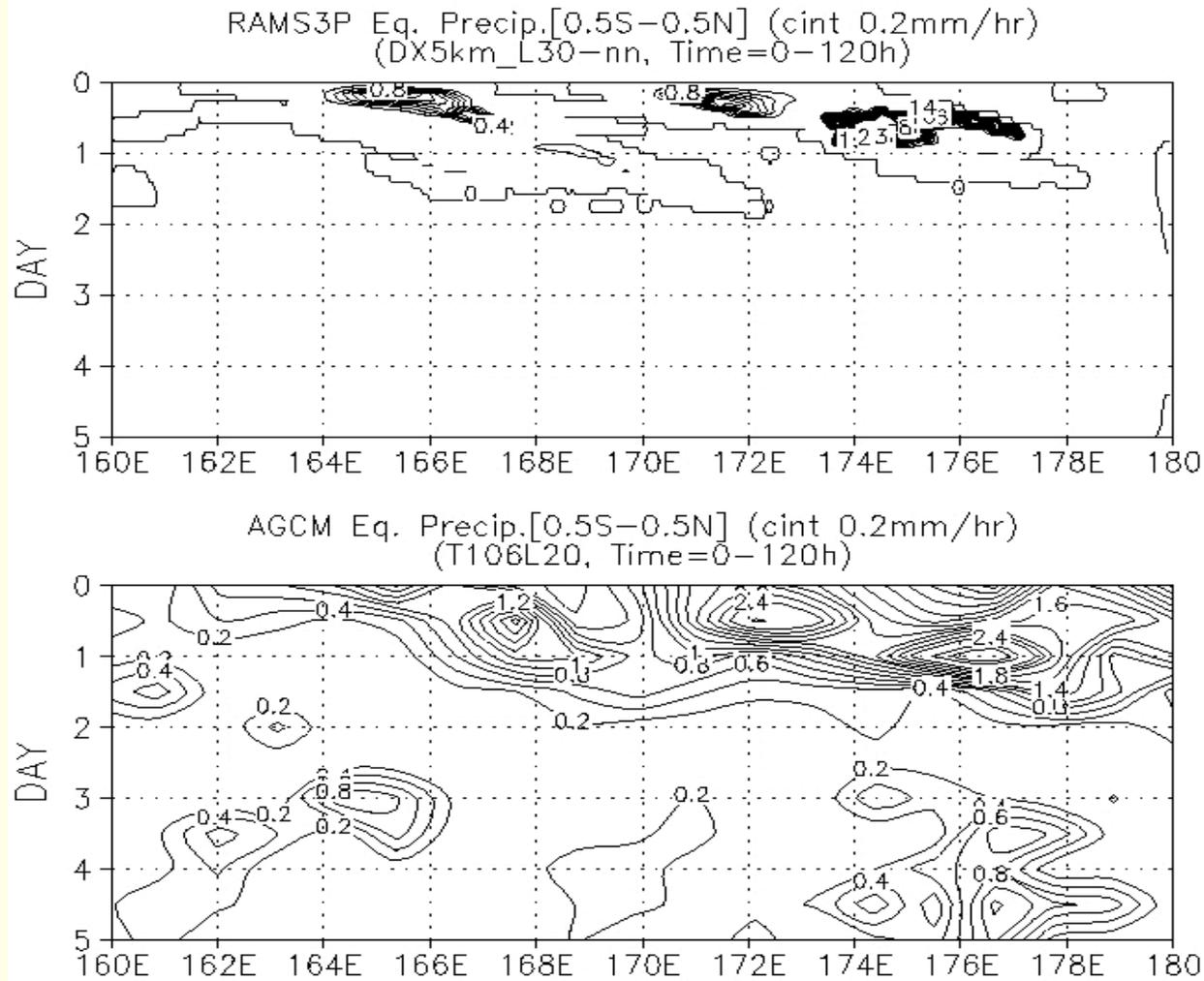


# U850 & DIV850

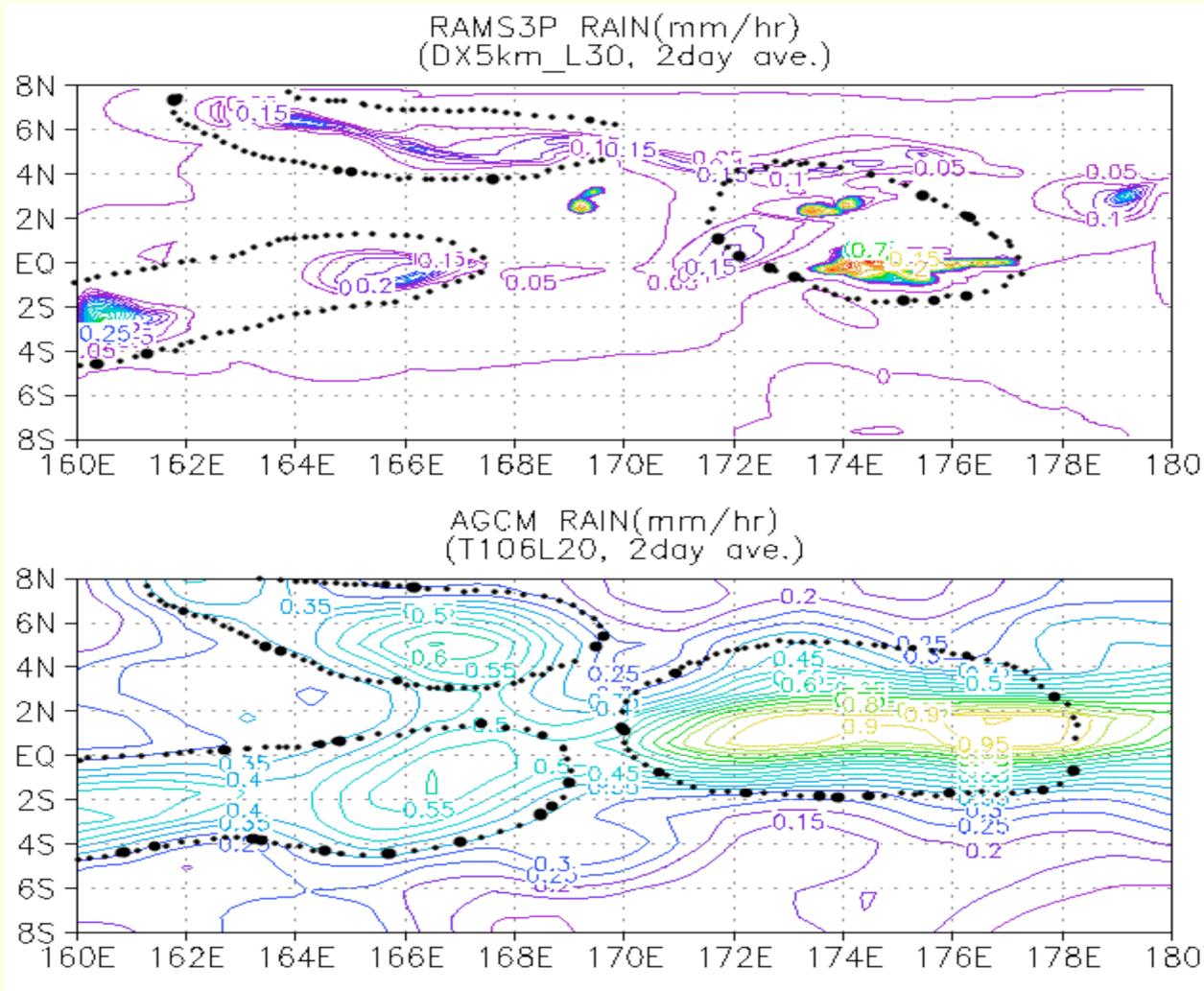
(initial state for 5km experiment)



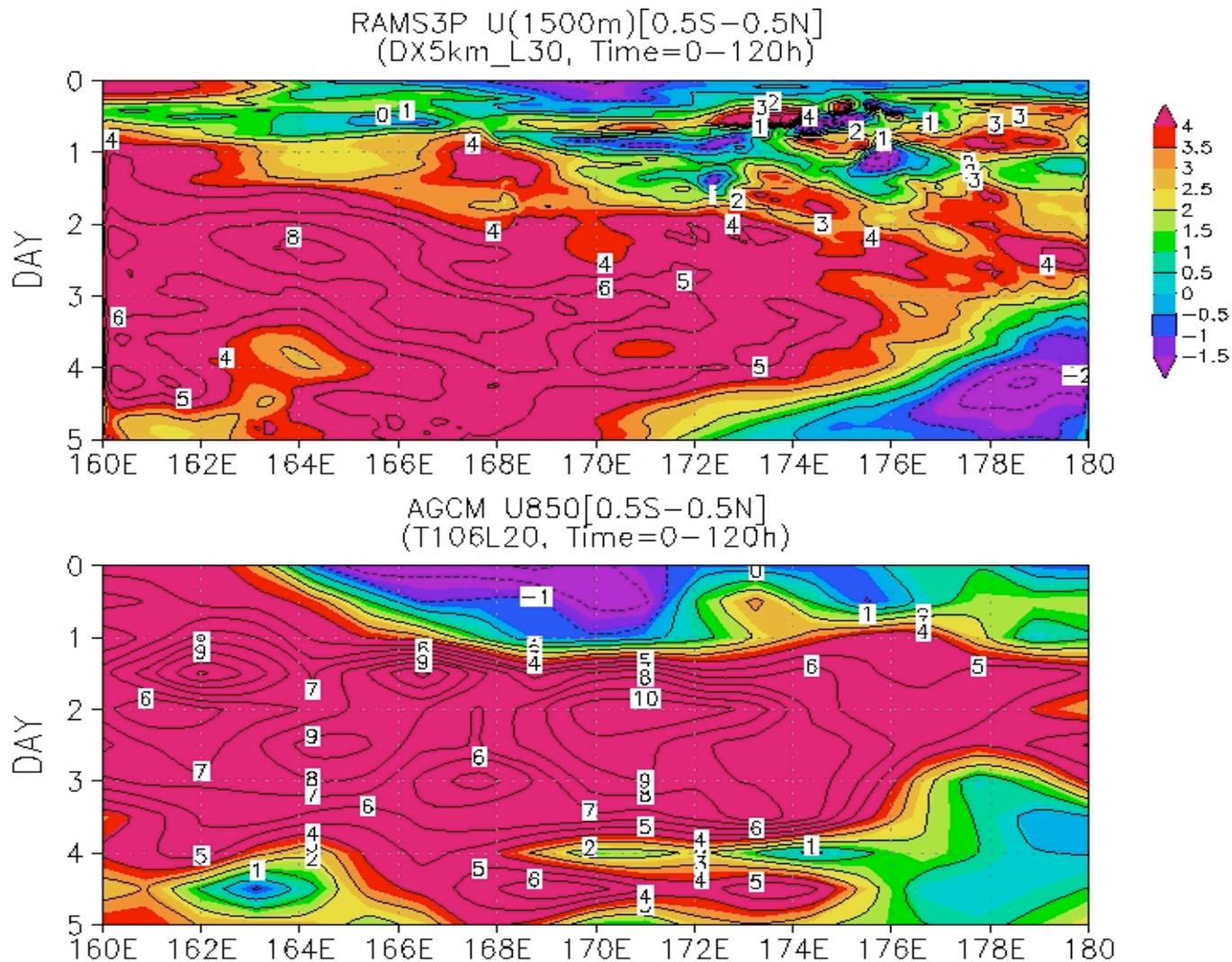
# Precipitation along Equator by $\Delta x = 5 \text{ km}$



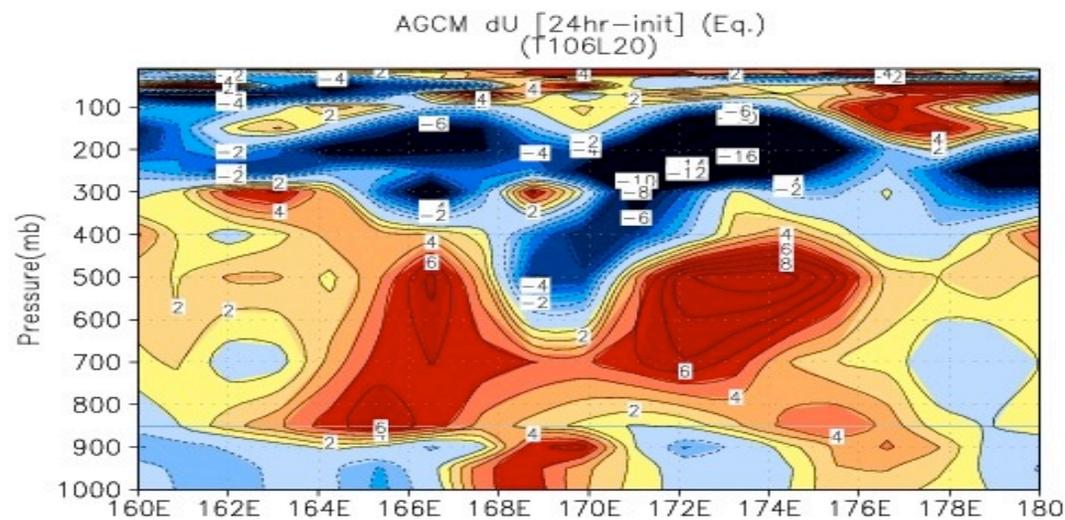
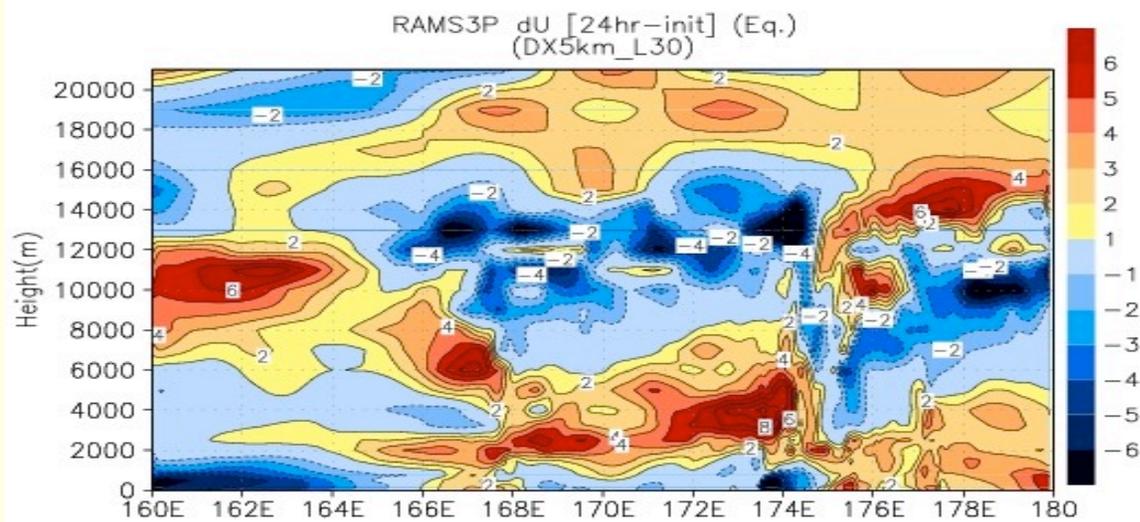
# 2 d y avg. Precipitation by $\Delta x = 5 \text{ km}$



# U(1500m) along Equator by $\Delta x = 5 \text{ km}$

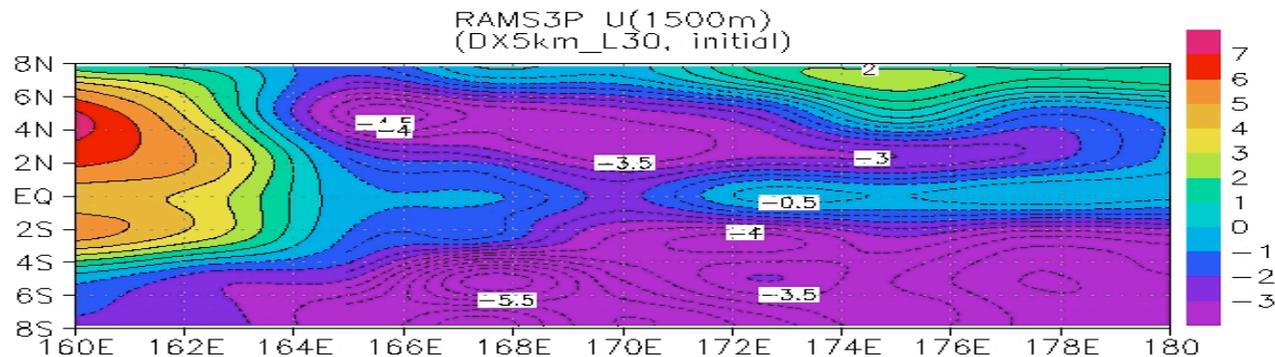
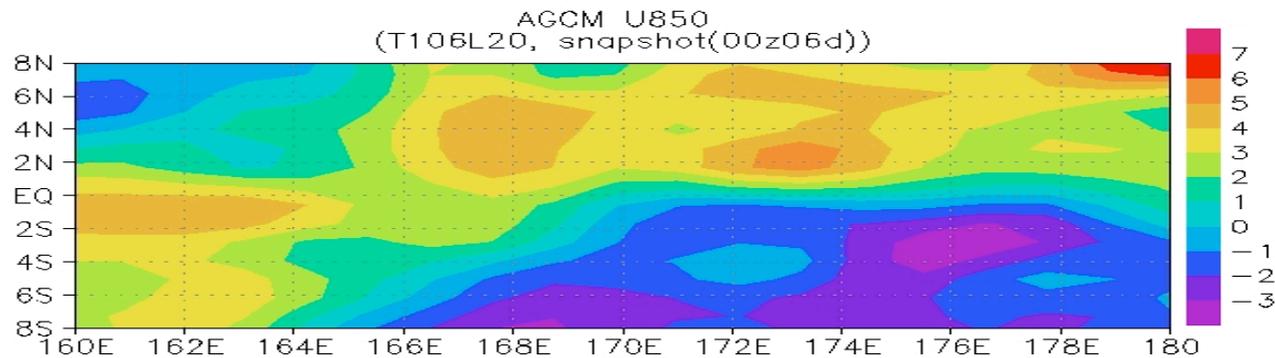
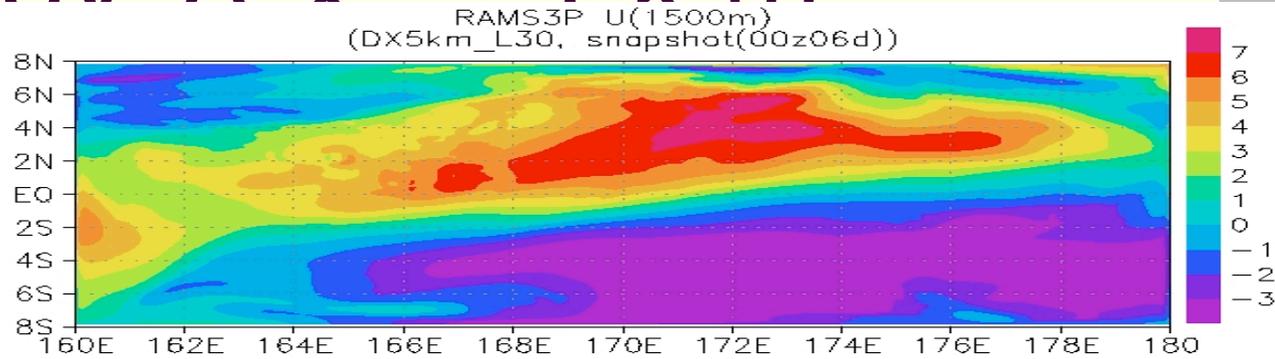


# Zonal Wind Change Longitude-Height Cross-section for 5km experiment

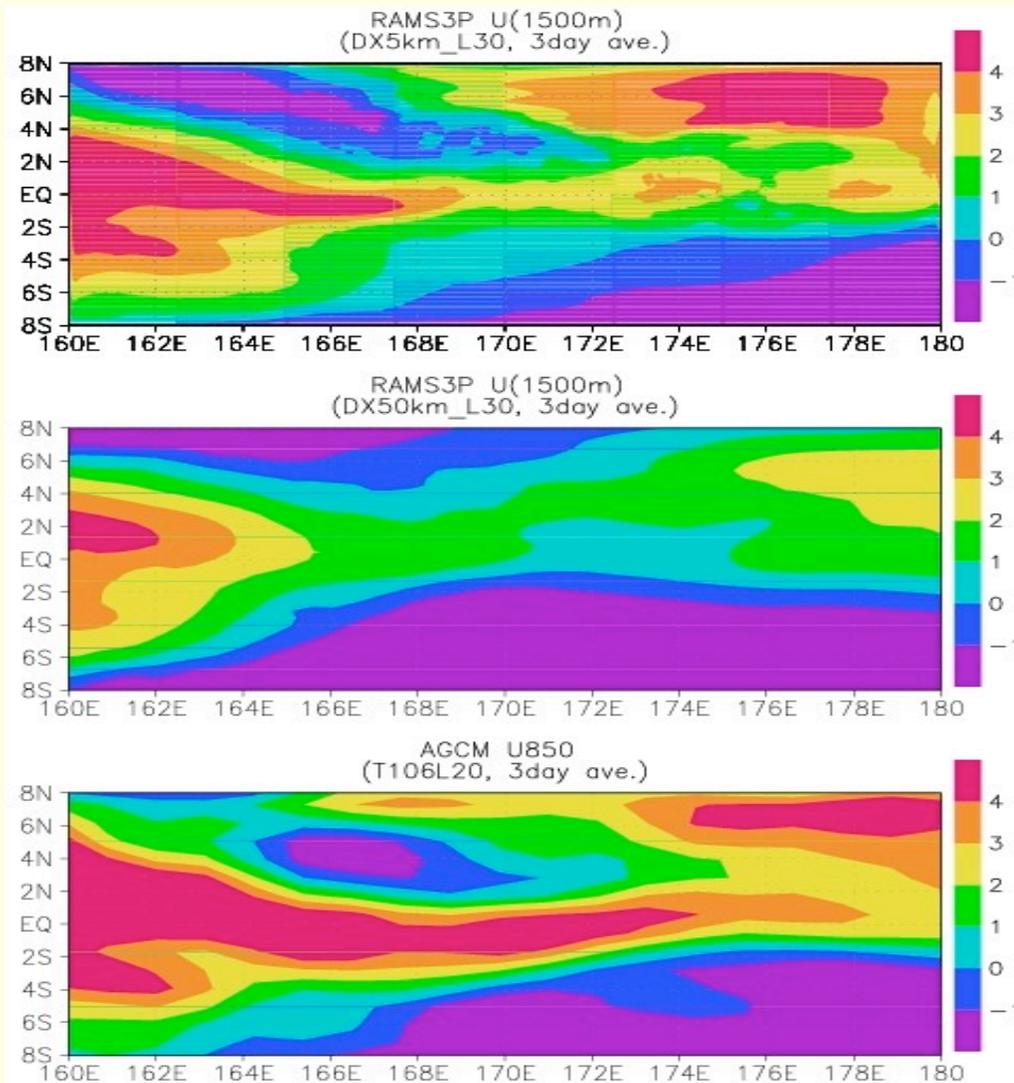


# 6 d y Snapshot of U (1500 m)

~~h<sub>v</sub> Δx = 5 km~~

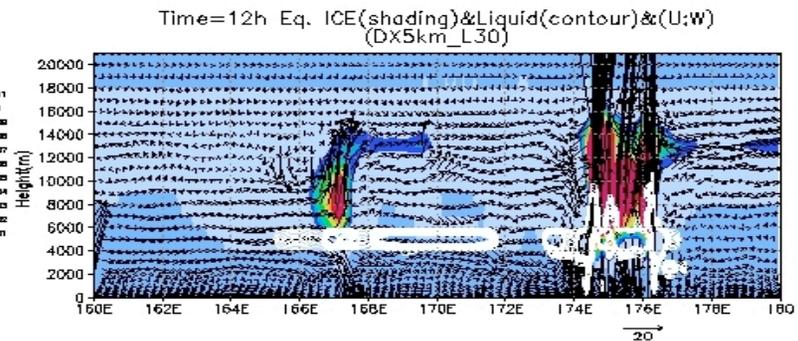
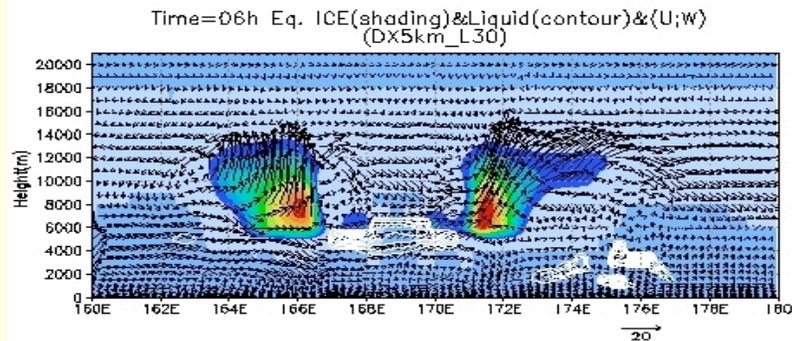
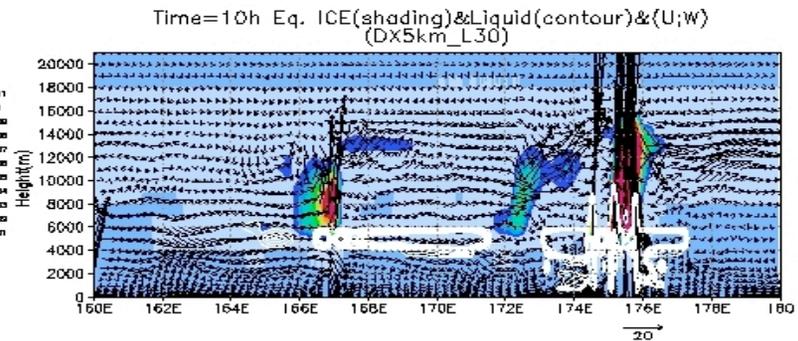
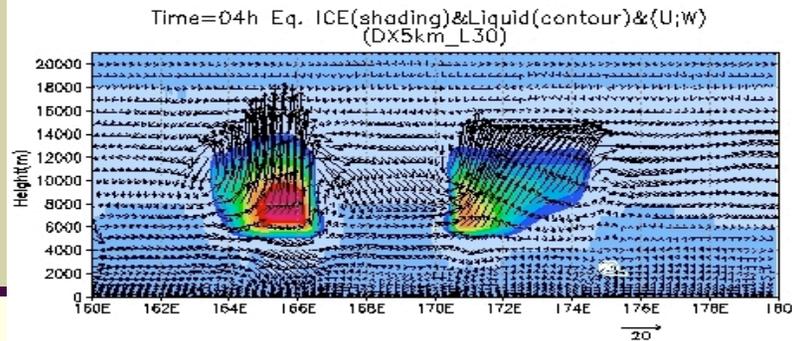
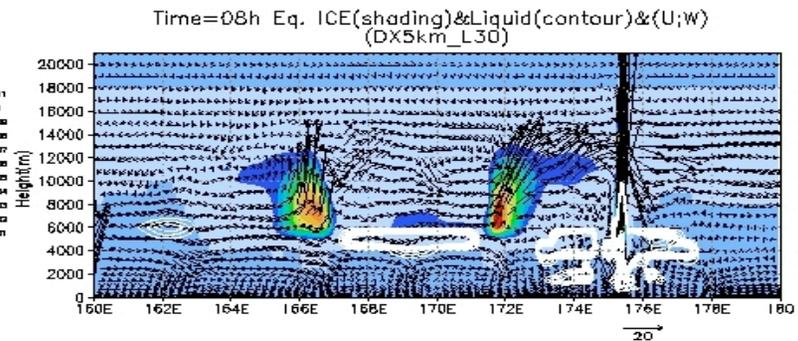
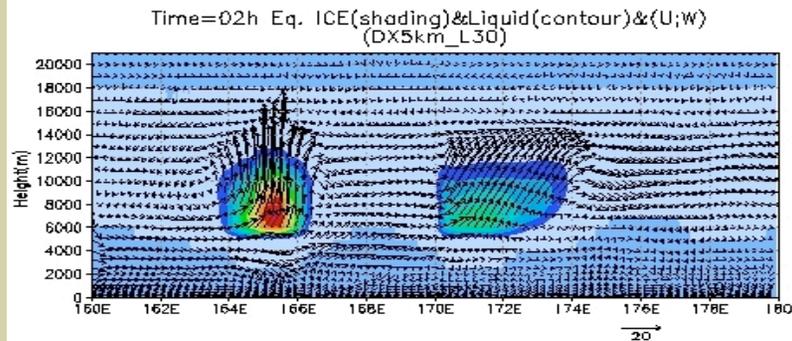


# 3day-mean Zonal Wind (1500m) for 5km experiment



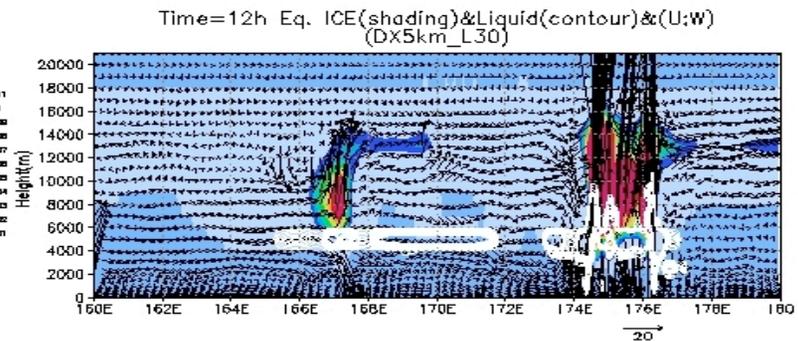
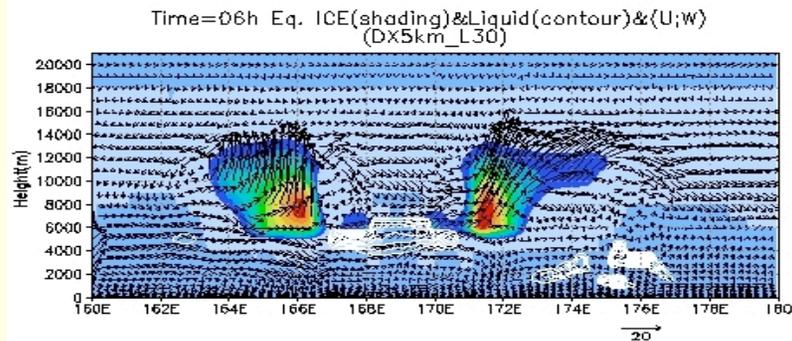
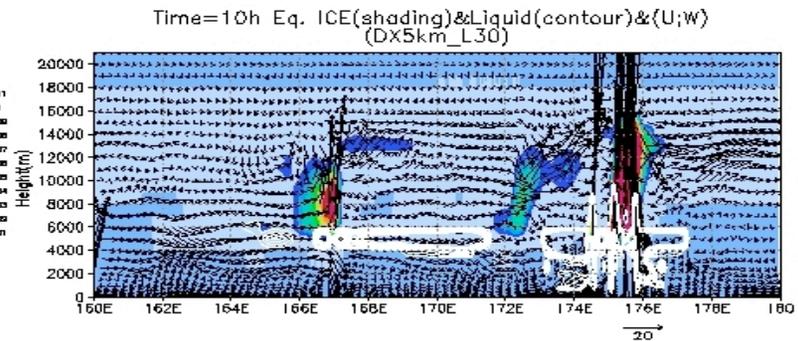
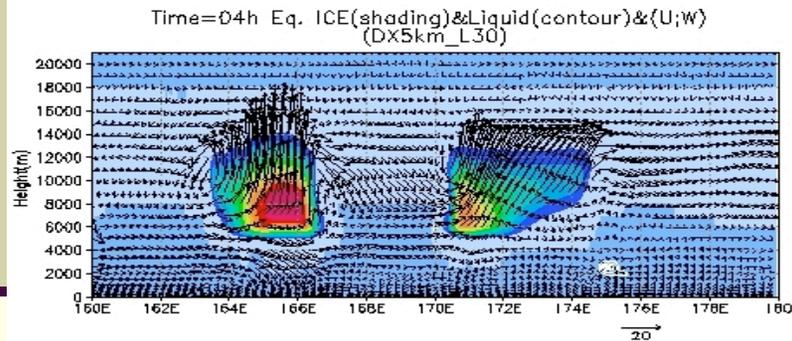
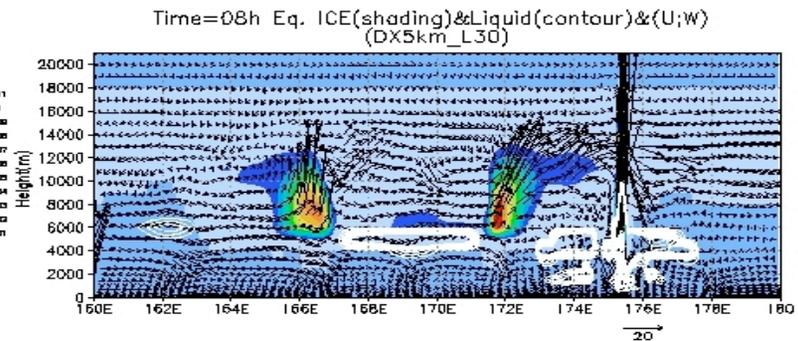
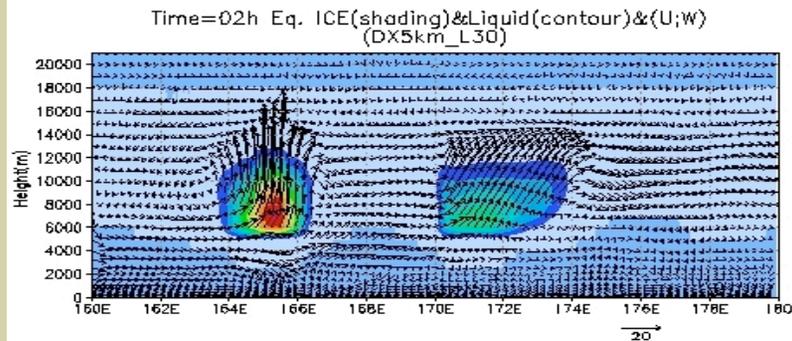
# Cloud ice, water & (u;w) flows

along EQ. by  $\Delta x = 5 \text{ km}$



# Cloud ice, water & (u;w) flows

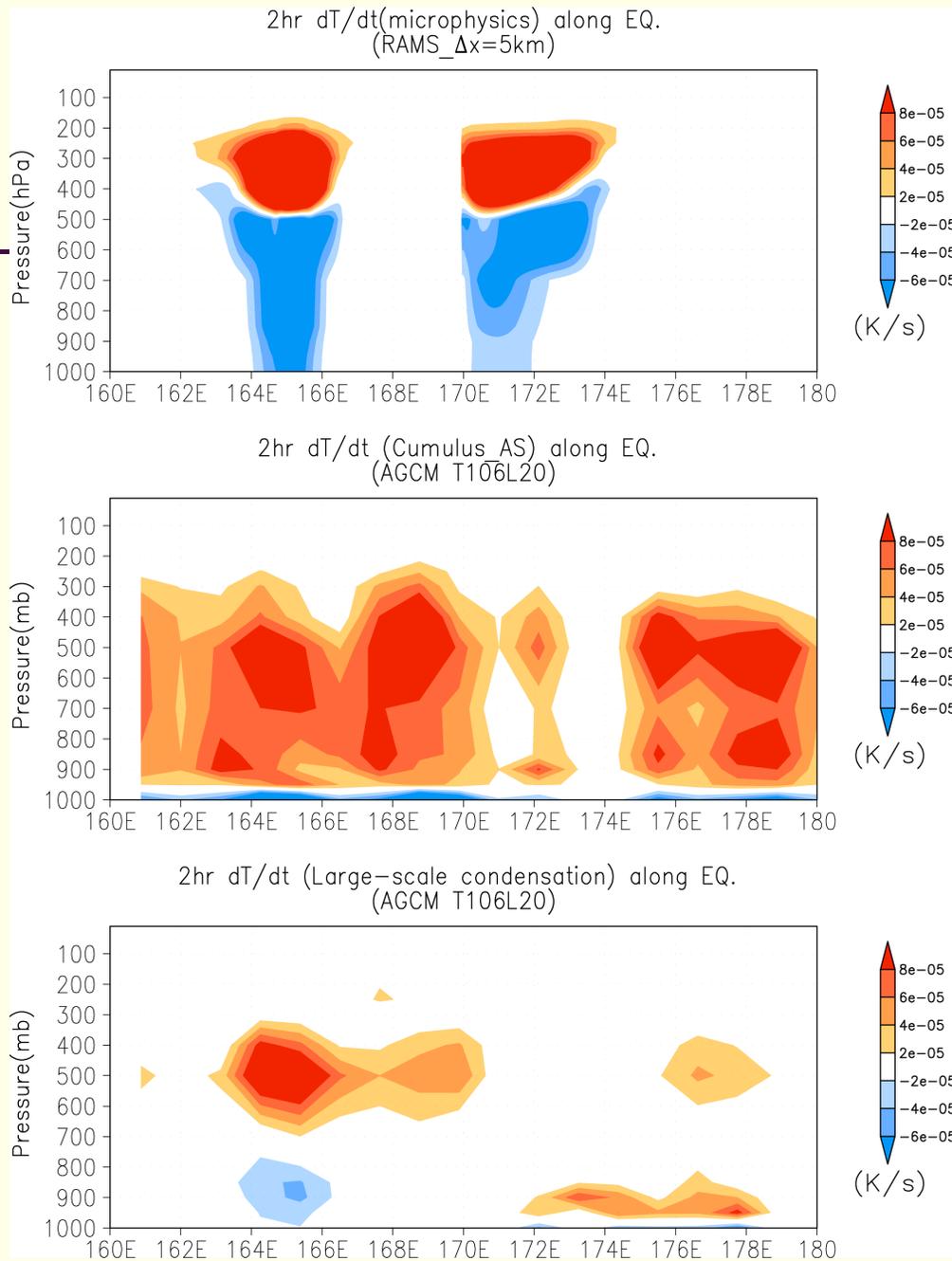
along EQ. by  $\Delta x = 5 \text{ km}$

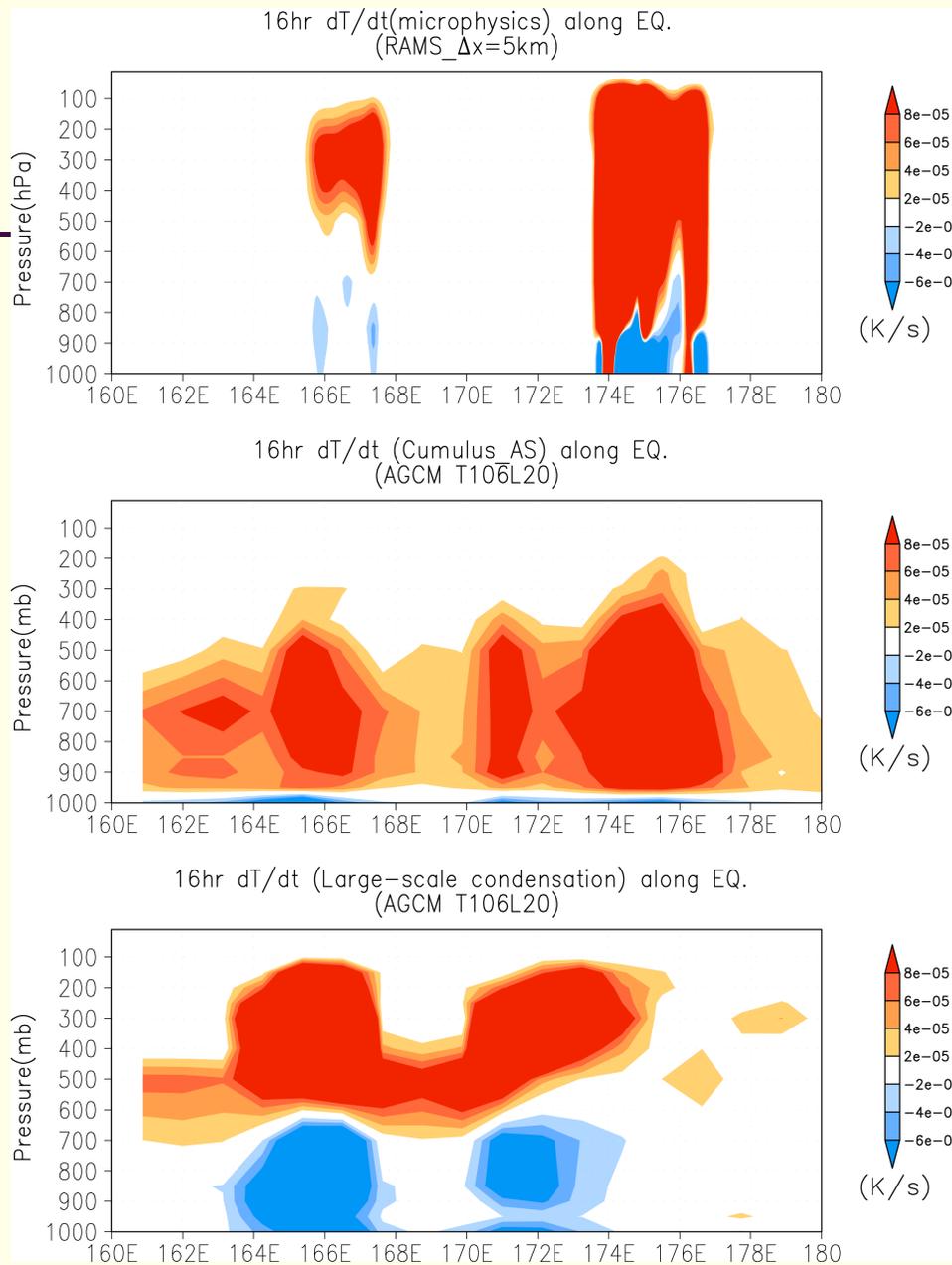


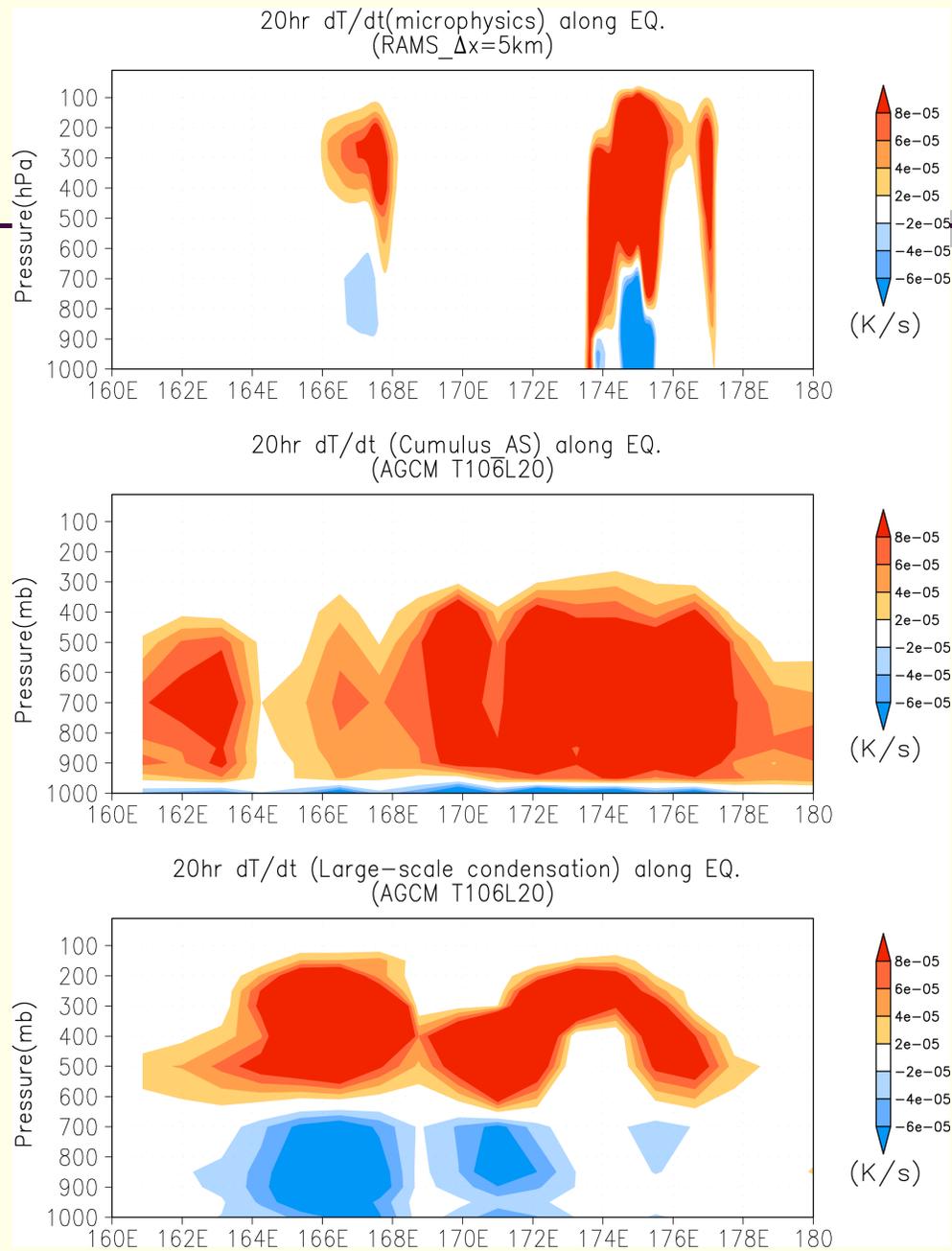
# Comparison of Heating

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- Heating along the equator between RAMS and AGCM



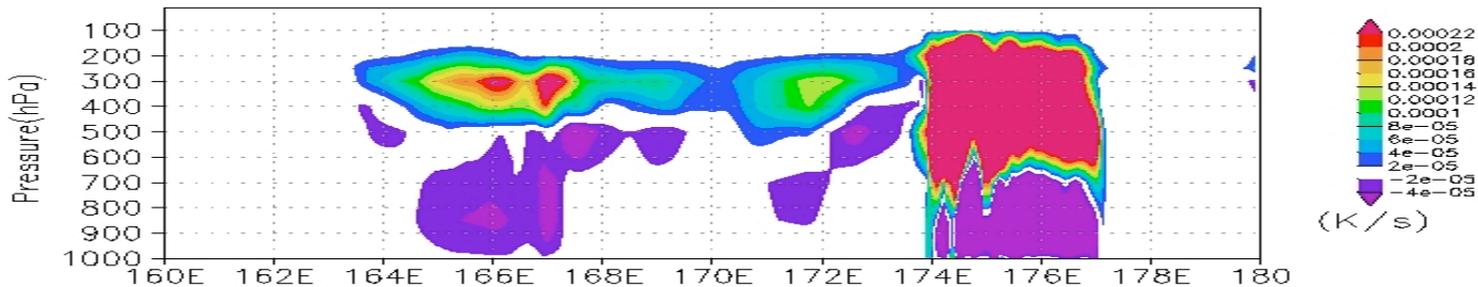




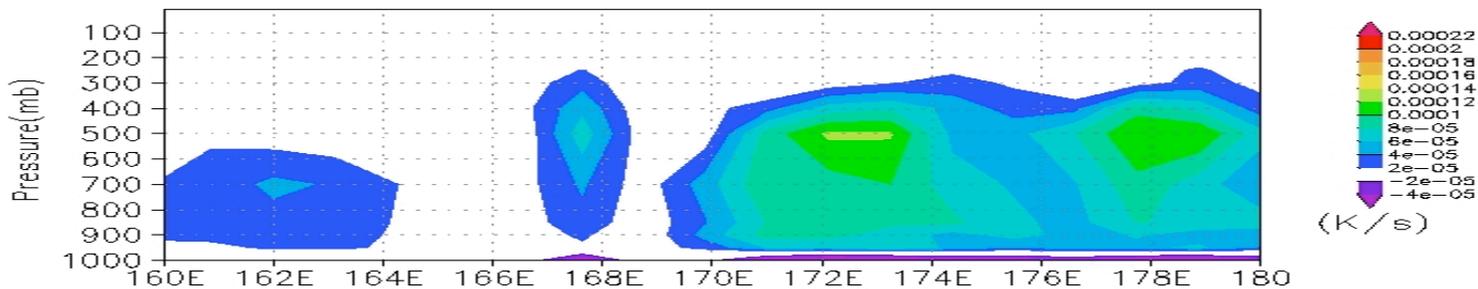
# 2 dy avg. $dT/dt$ along Equator

~~$h\nu \Delta x = 5 \text{ km}$~~

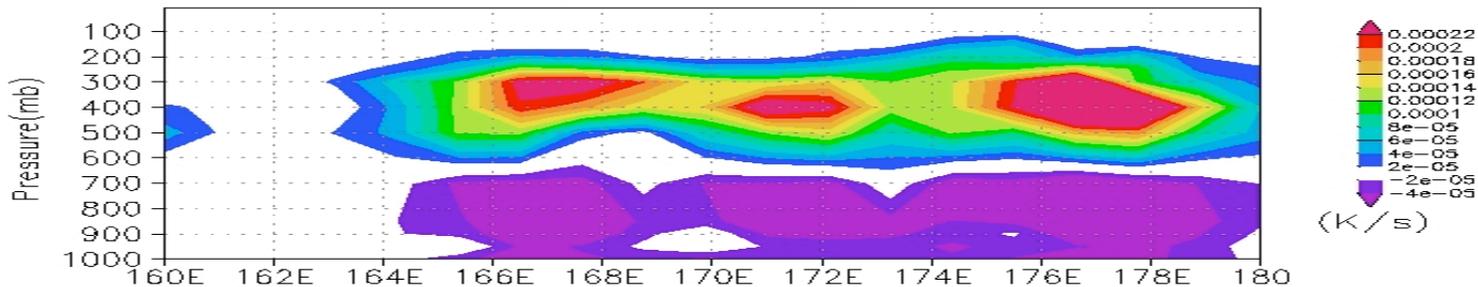
2day-ave  $dT/dt$  (microphysics) along EQ.  
( $\Delta x = 5 \text{ km}$ )



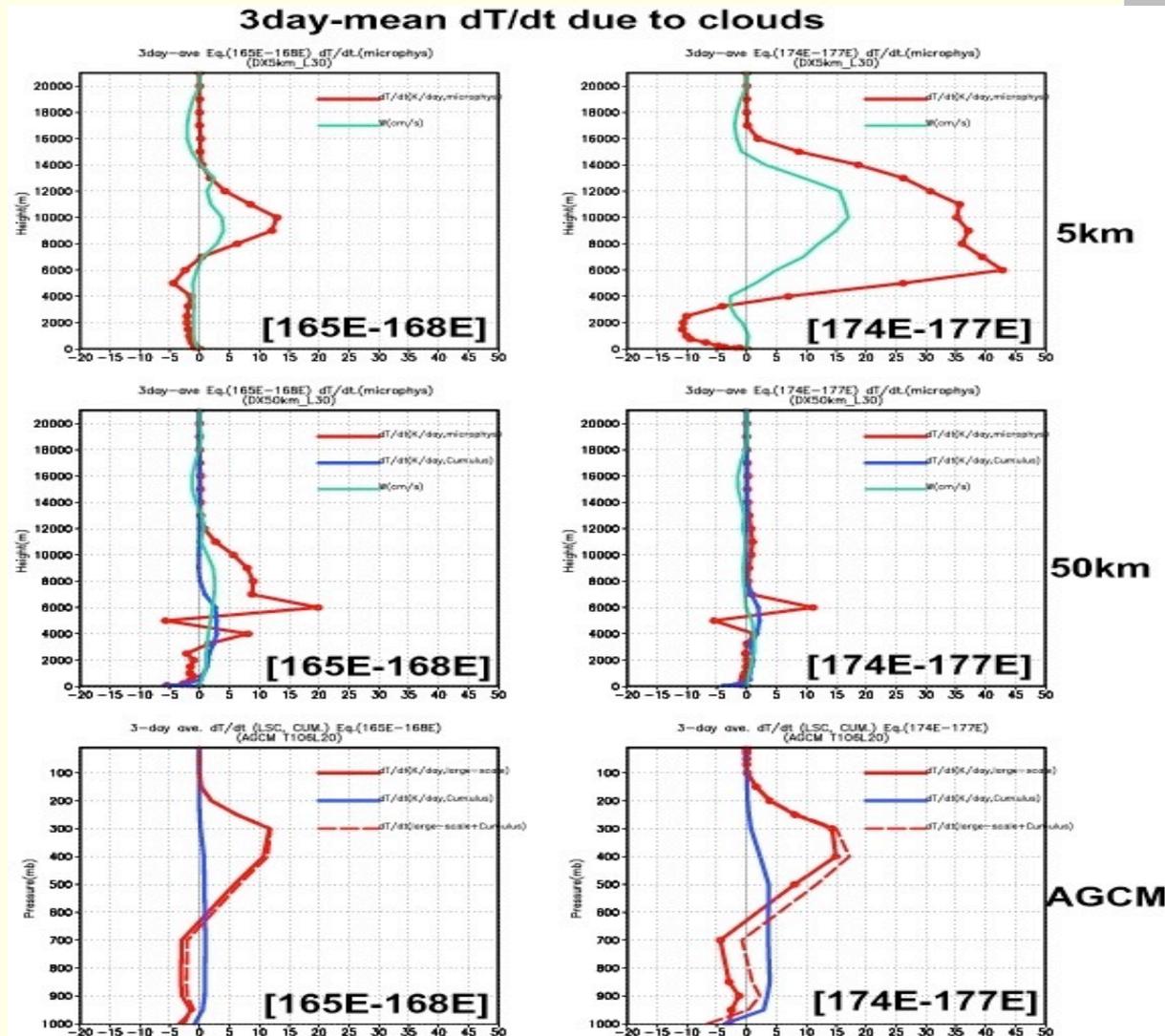
2-day ave.  $dT/dt$  (Cumulus; Arakawa-Schubert) along EQ.  
(AGCM T106L20)

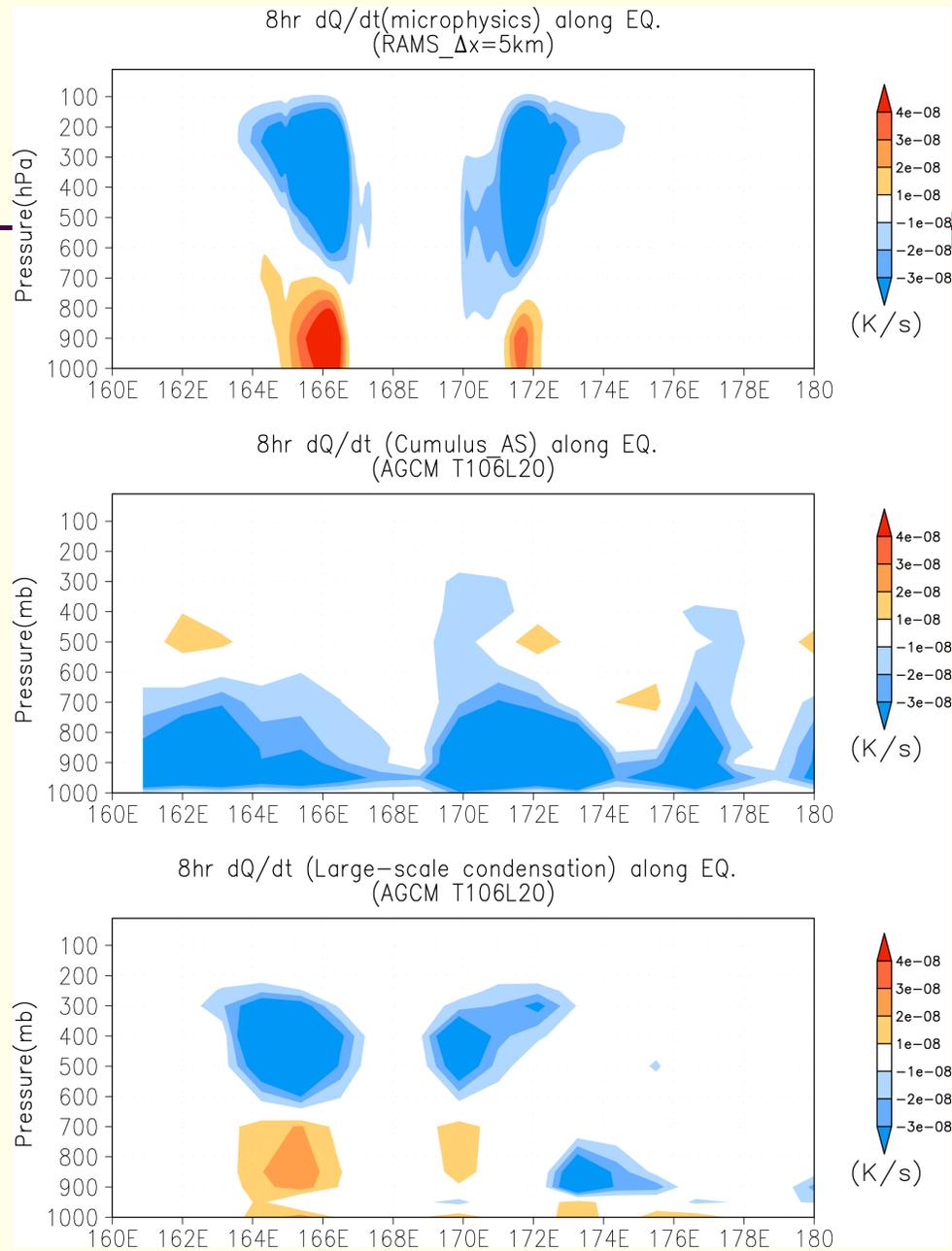


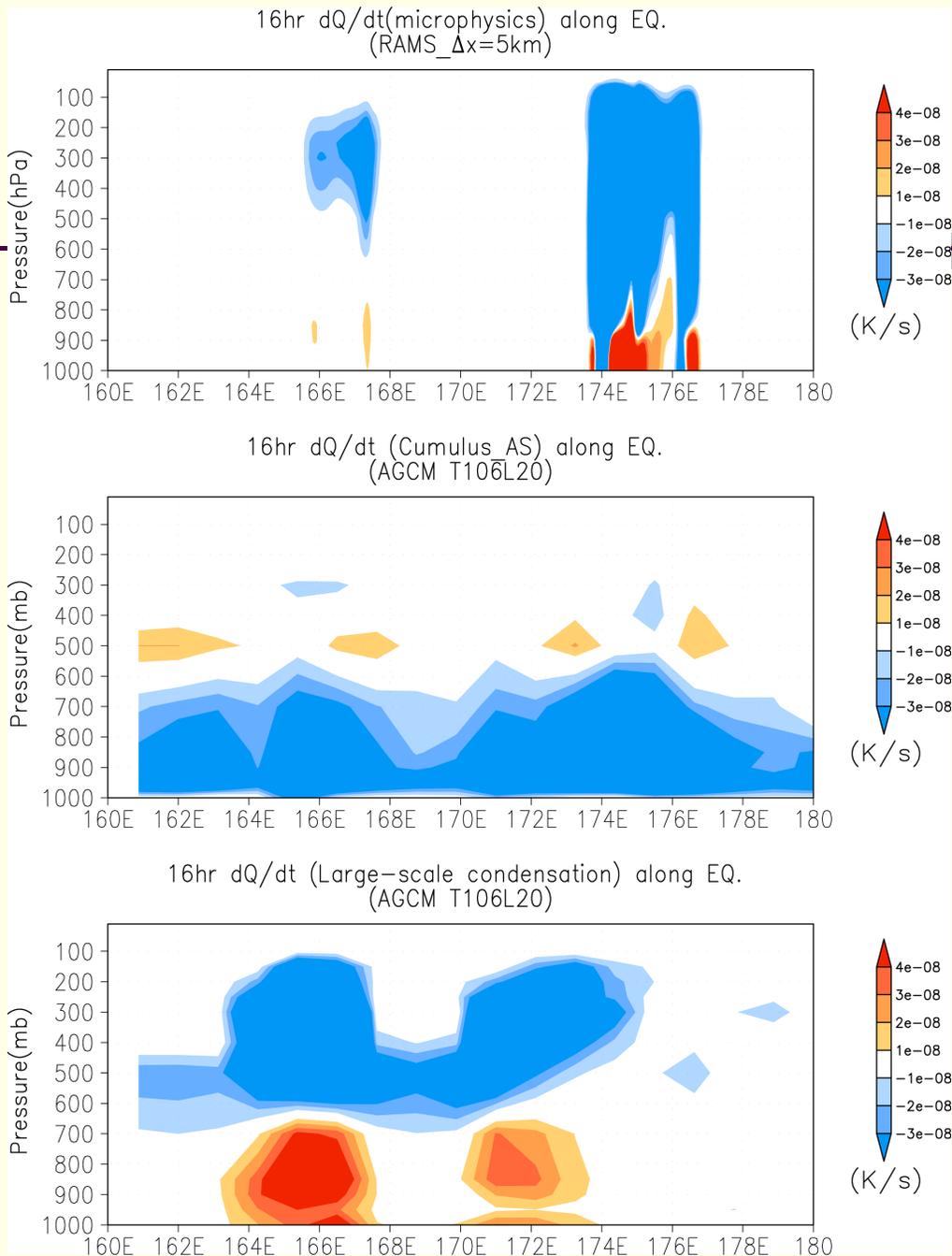
2-day ave.  $dT/dt$  (Large-scale condensation) along EQ.  
(AGCM T106L20)

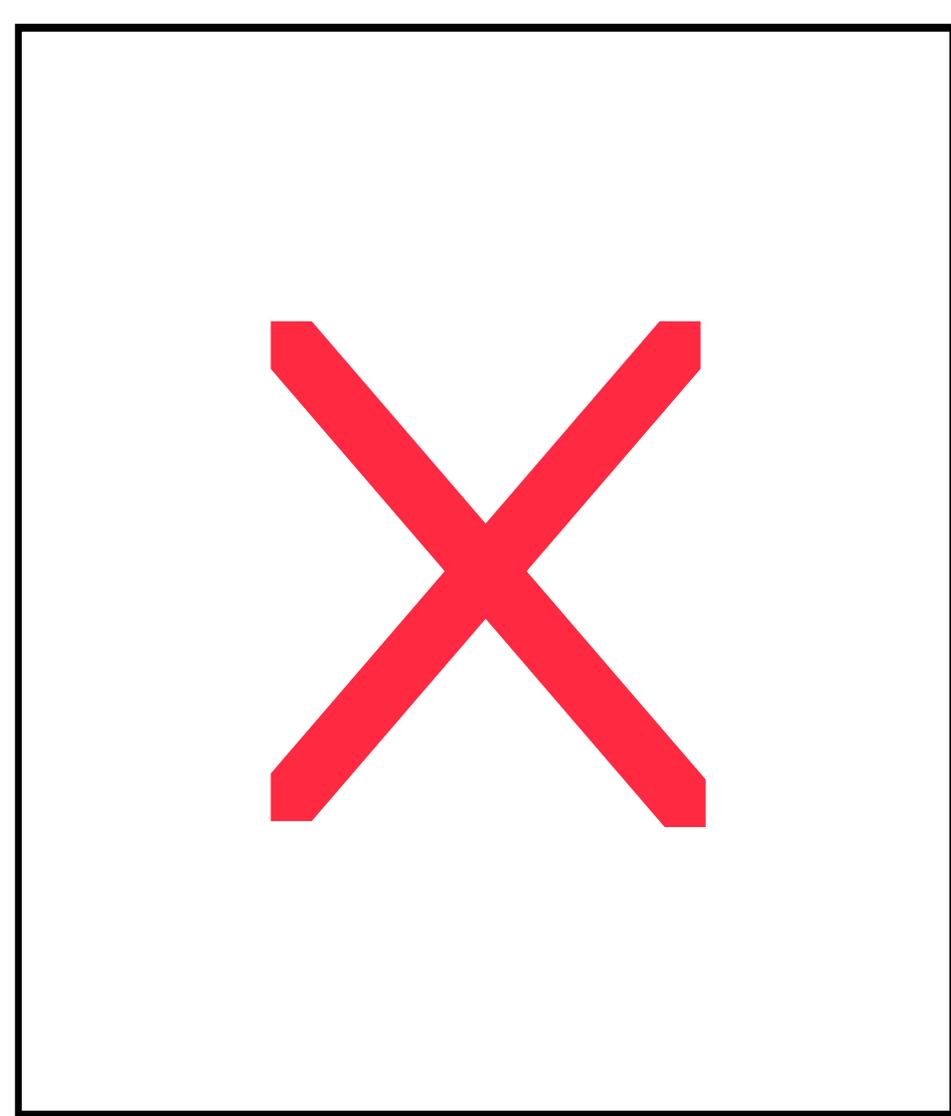


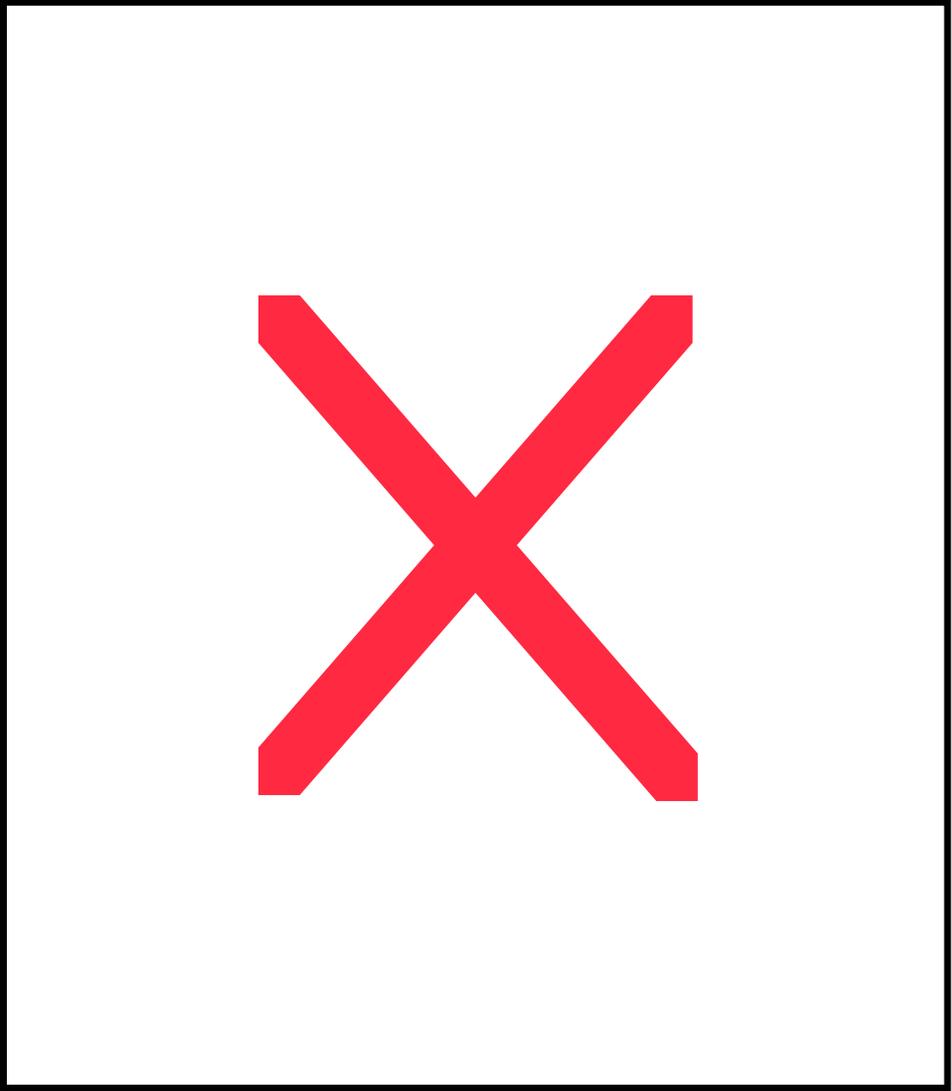
# 3day-mean $dT/dt$ by Clouds [K/day](Eq.) for 5km experiment

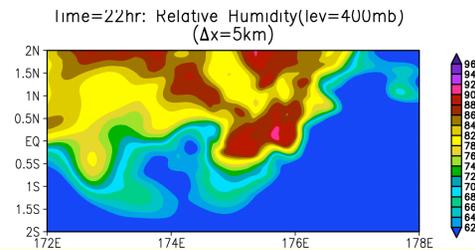
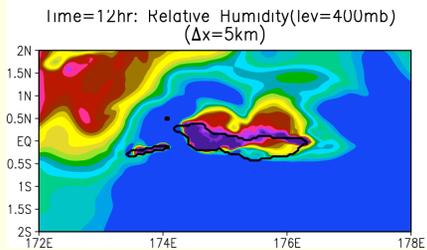
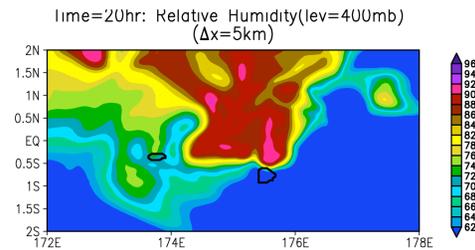
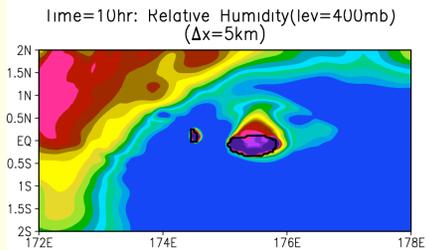
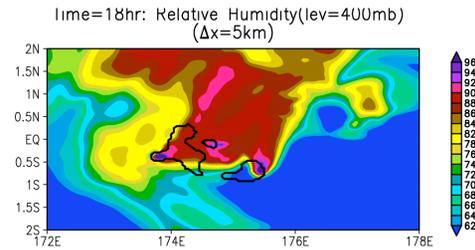
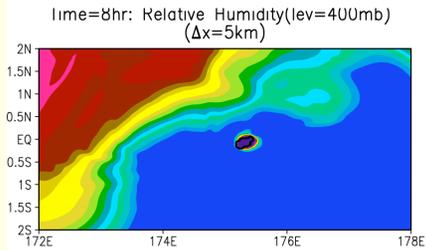
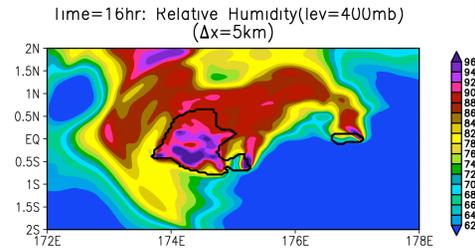
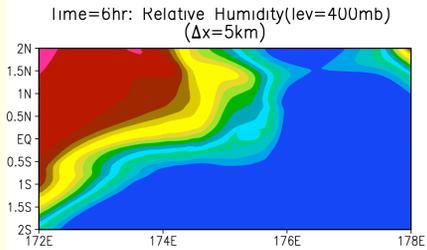
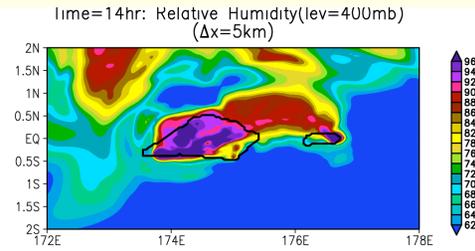
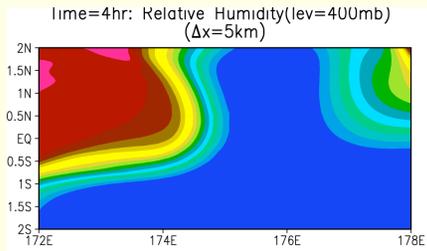












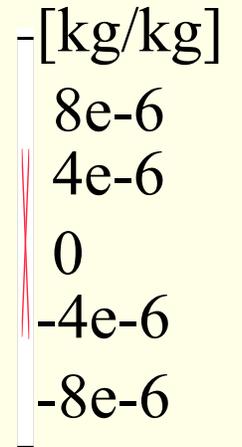
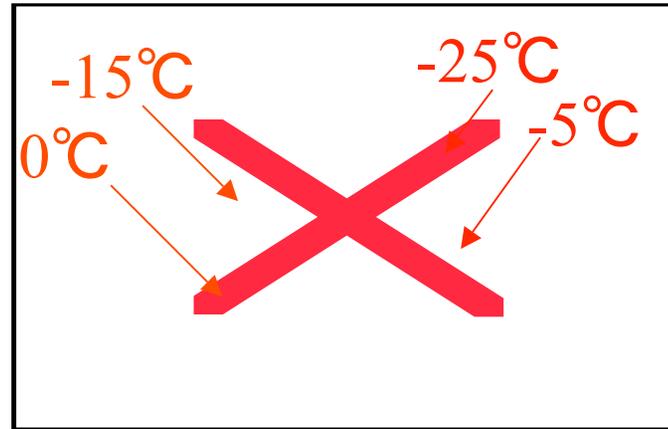
# Large climate sensitivity?

EXP H

Changes in cloud water/ice  
(CO<sub>2</sub>x2-CO<sub>2</sub>x1)

[hPa]

200  
400  
600  
800

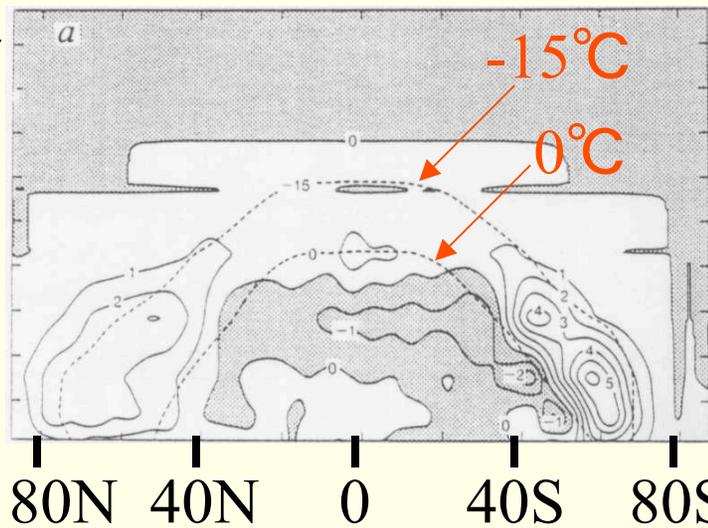


Mitchell et al.1989

Change in cloud water  
(CO<sub>2</sub>x2-CO<sub>2</sub>x1)

sigma

0.2  
0.4  
0.6  
0.8



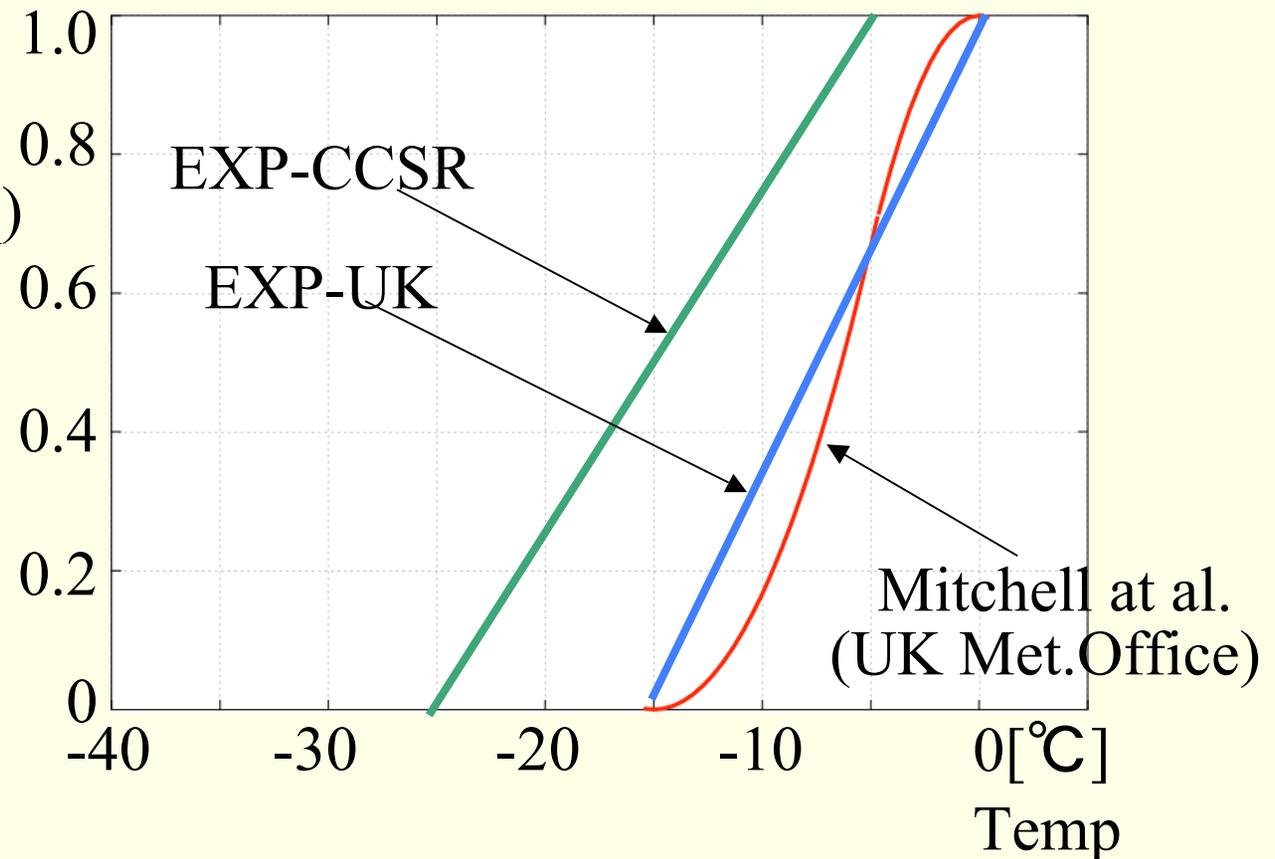
Contour:every 4e-6[kg/kg]

## An experiment

\* Two 2xCO<sub>2</sub> equilibrium experiments with CCSR- and UK- types of cloud ice diagnostic schemes

Diagnostic fn. for cloud ice:

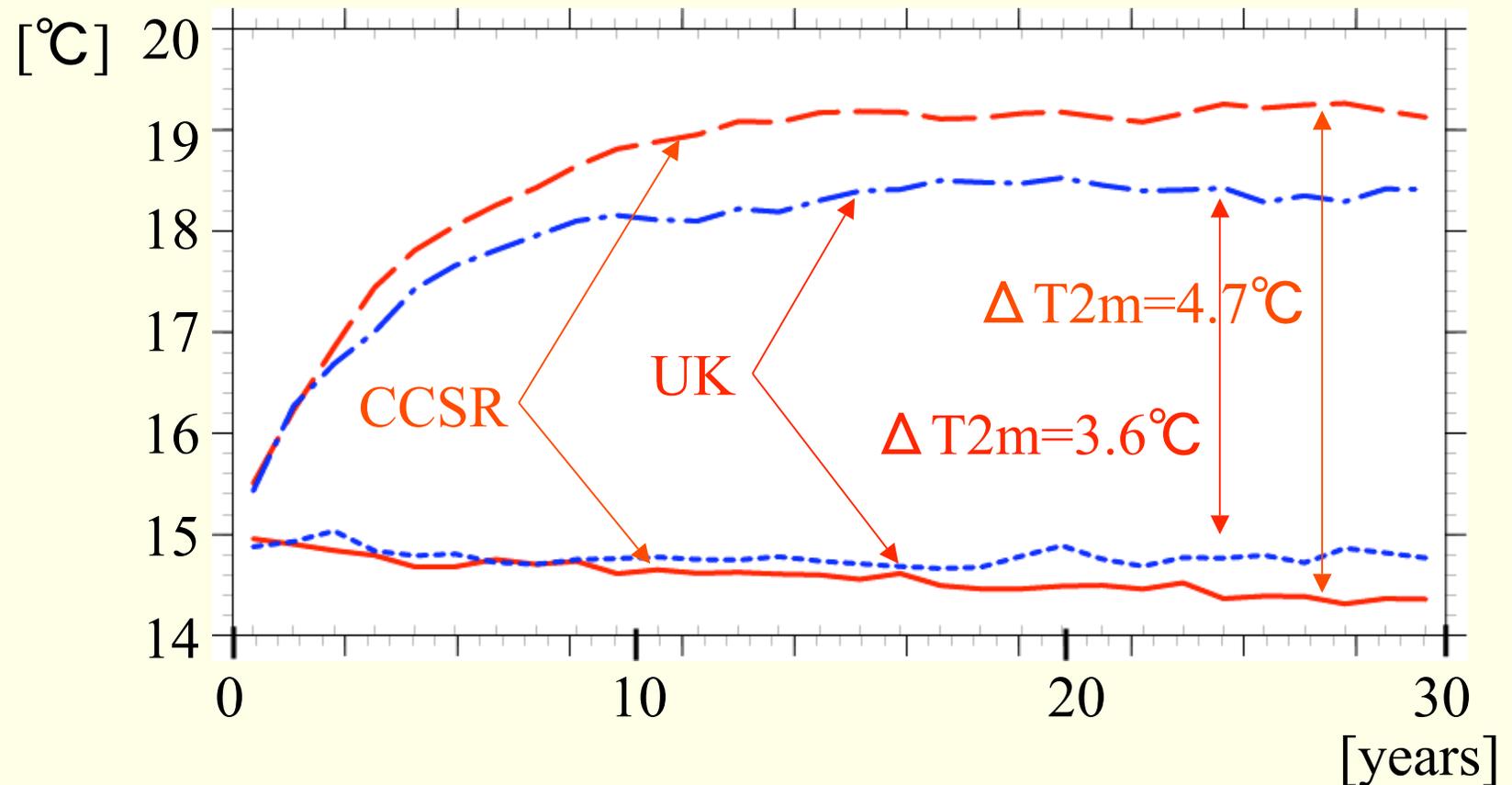
$$\text{FLIQ} = \text{liq}/(\text{ice}+\text{liq})$$



Note: EXP-UK allows lower-level cloud ice than EXP-CCSR.

## Doubled CO2 sensitivity

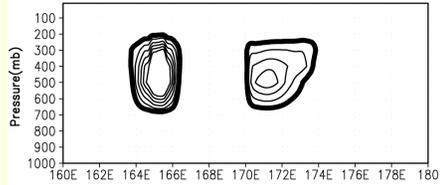
Global-annual mean 2m temperature



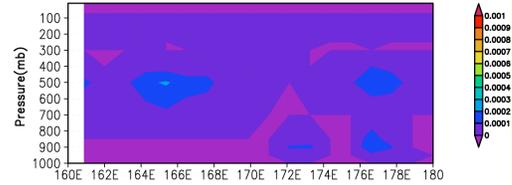
Doubled CO2 sensitivity is 1.1oC lower for UK-type than CCSR.

(Use years 21-30 in the following)

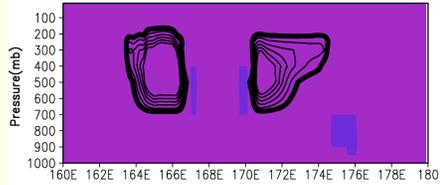
Time=02h Eq. Cloud QI (shading) & Qi (cont.)  
(DX5km\_L30)



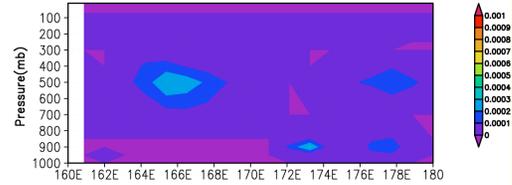
Time=02h Eq. Cloud CLDW (shading)  
(T106L20)



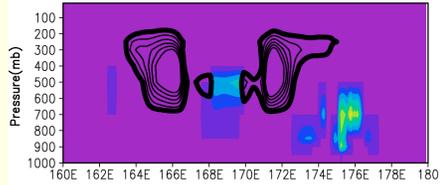
Time=04h Eq. Cloud QI (shading) & Qi (cont.)  
(DX5km\_L30)



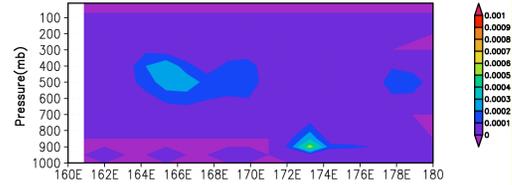
Time=04h Eq. Cloud CLDW (shading)  
(T106L20)



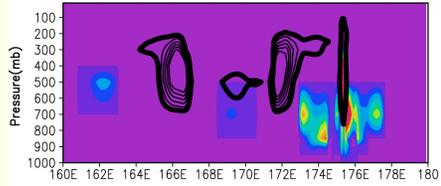
Time=06h Eq. Cloud QI (shading) & Qi (cont.)  
(DX5km\_L30)



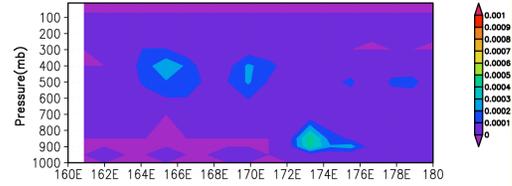
Time=06h Eq. Cloud CLDW (shading)  
(T106L20)



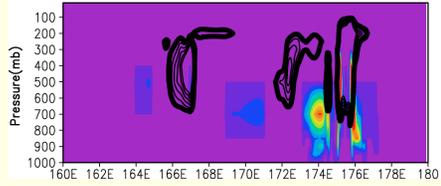
Time=08h Eq. Cloud QI (shading) & Qi (cont.)  
(DX5km\_L30)



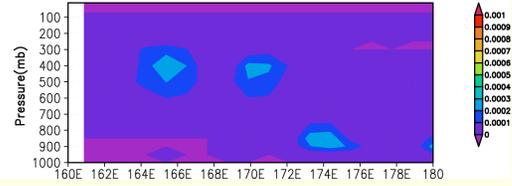
Time=08h Eq. Cloud CLDW (shading)  
(T106L20)



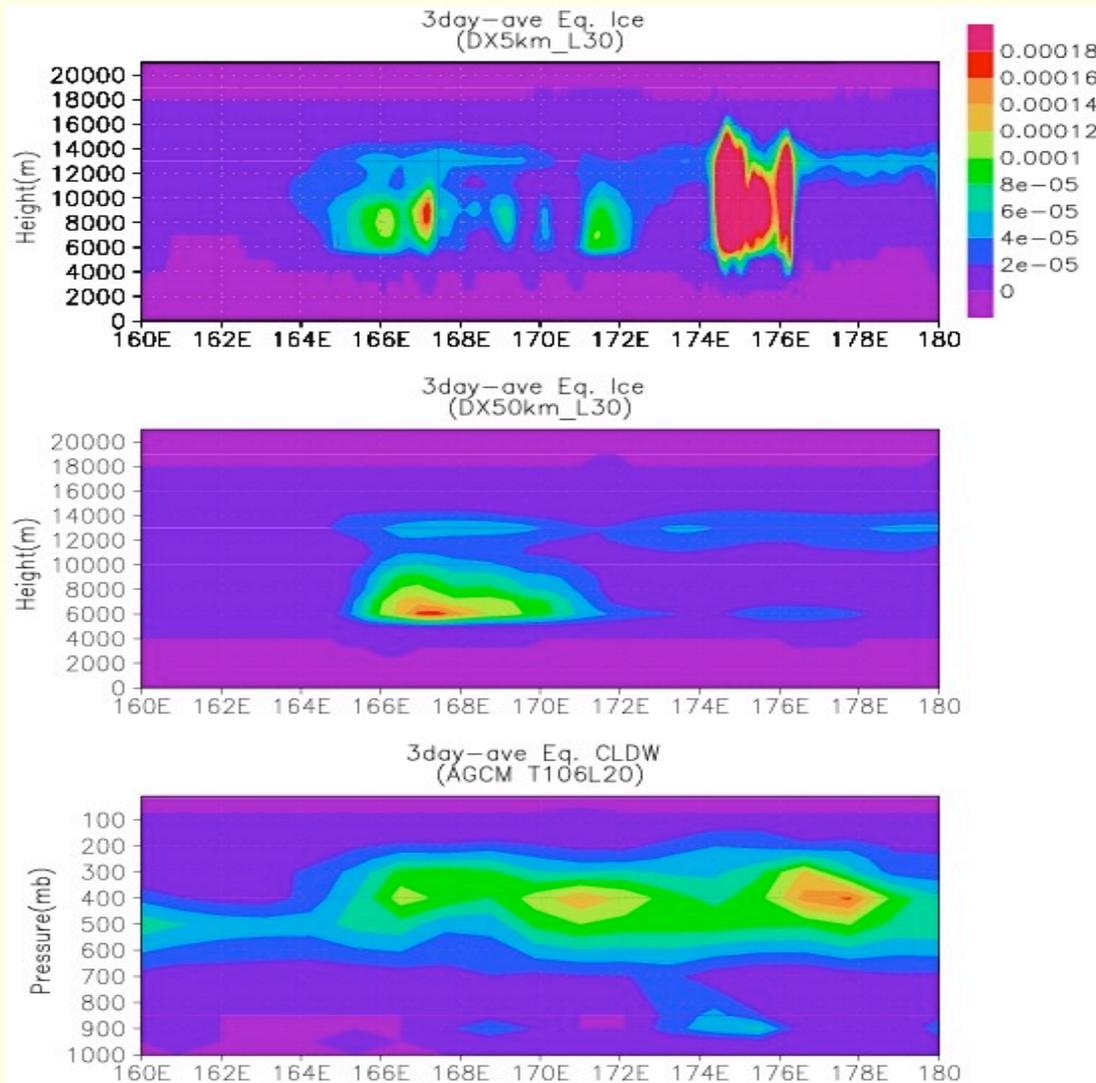
Time=10h Eq. Cloud QI (shading) & Qi (cont.)  
(DX5km\_L30)



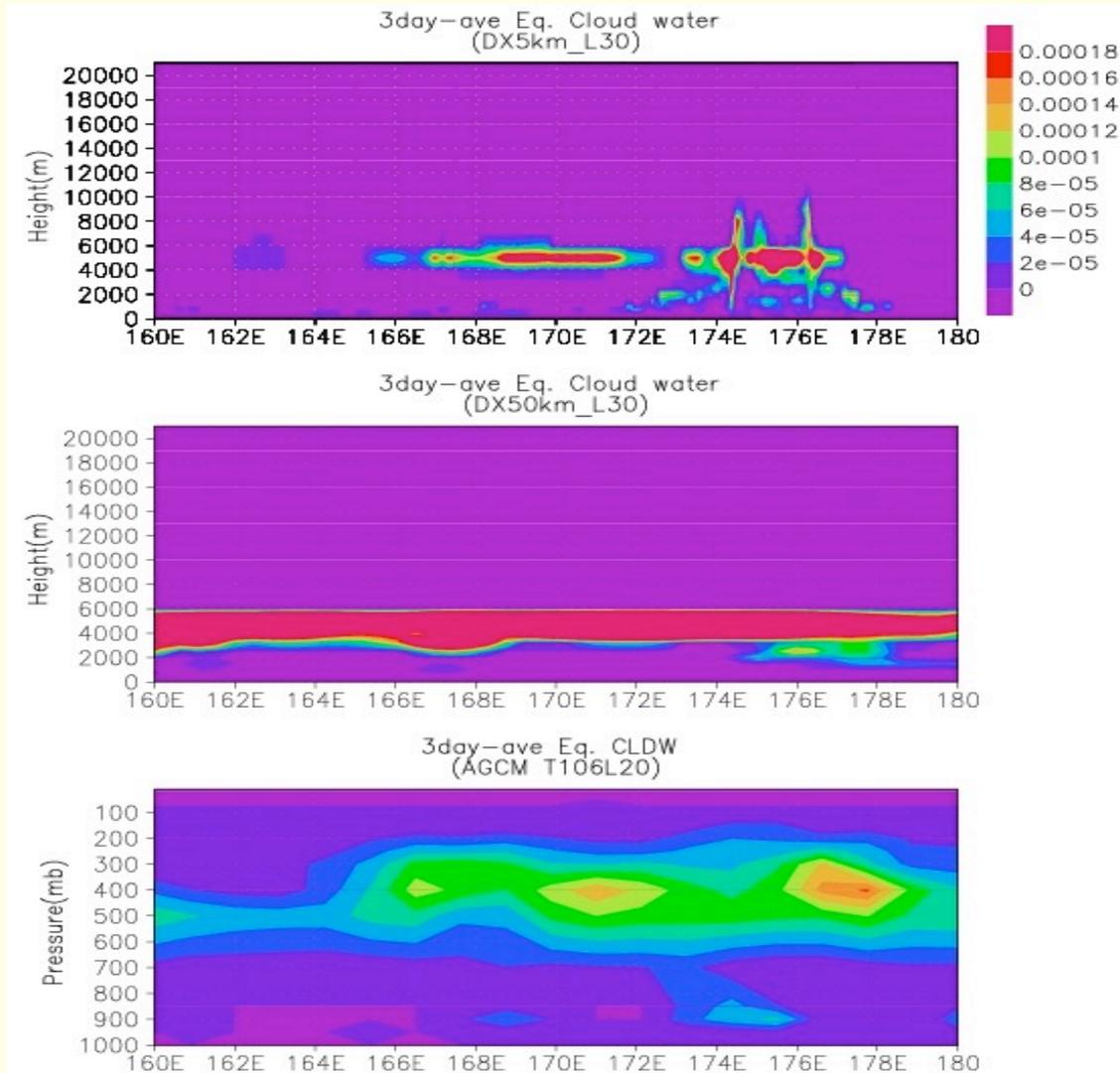
Time=10h Eq. Cloud CLDW (shading)  
(T106L20)



# 3day-mean Cloud Ice [Kg/Kg](Eq.) for 5km experiment



# 3day-mean Cloud Water [Kg/Kg](Eq.) for 5km experiment



# Summary(1)

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- For cumulus parameterization,  
2 way.
  - (1) Global NHM full 3 dim.
  - (2) Using a classical scheme.

Then,

How to improve this?

## Summary(2)

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- 2 day averaged large-scale feature of heating in the RAMS is consistent to the AGCM
- Heating profile is different.
- Heating in RAMS is higher than that in AGCM
- Moistening of the convection in the RAMS is relating to atmospheric motion
- Cloud ice is thicker in the upper atmosphere in the RAMS
- These aspects should be considered in the parameterization scheme