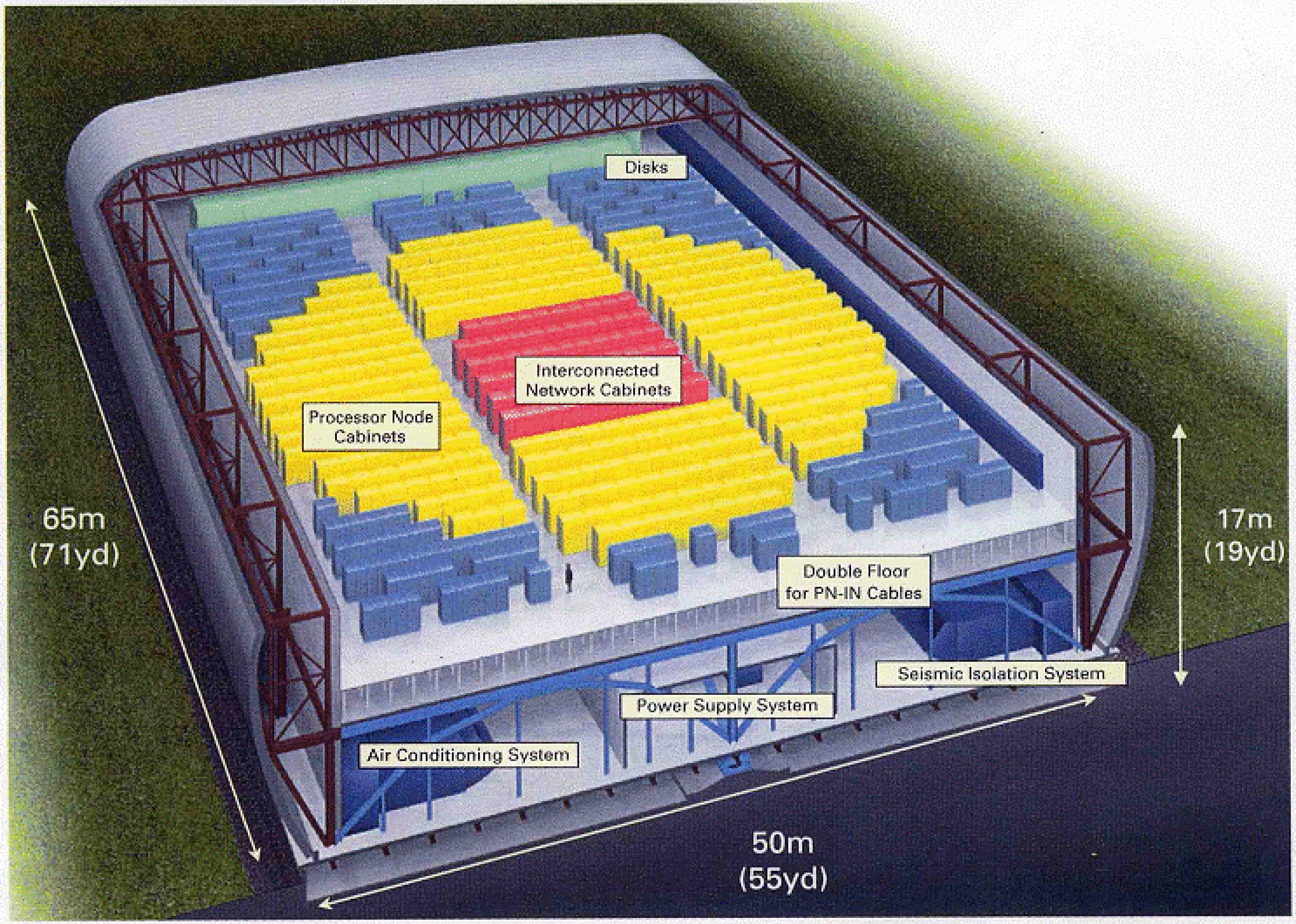
Development of climate models to be run on the Earth Simulator

Taroh Matsuno

Frontier Research System
for Global Change

Artist's Representation of the Earth Simulator



Earth Simulator System

Performance of the Earth Simulator

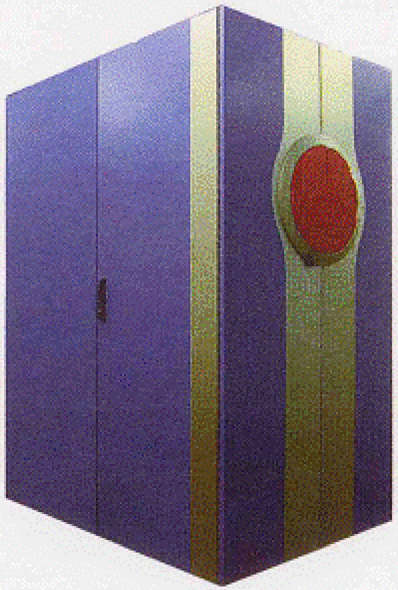
- Linpack Benchmark Test

  World Rank, No.1

  —Sustained performance : 35.86 Tflops

  —Sustained efficiency : 87.5%

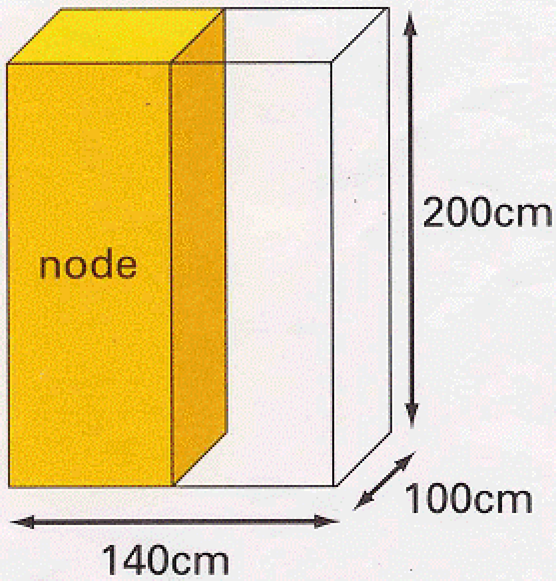
- Interconnected network : Single-Stage Crossbar Network

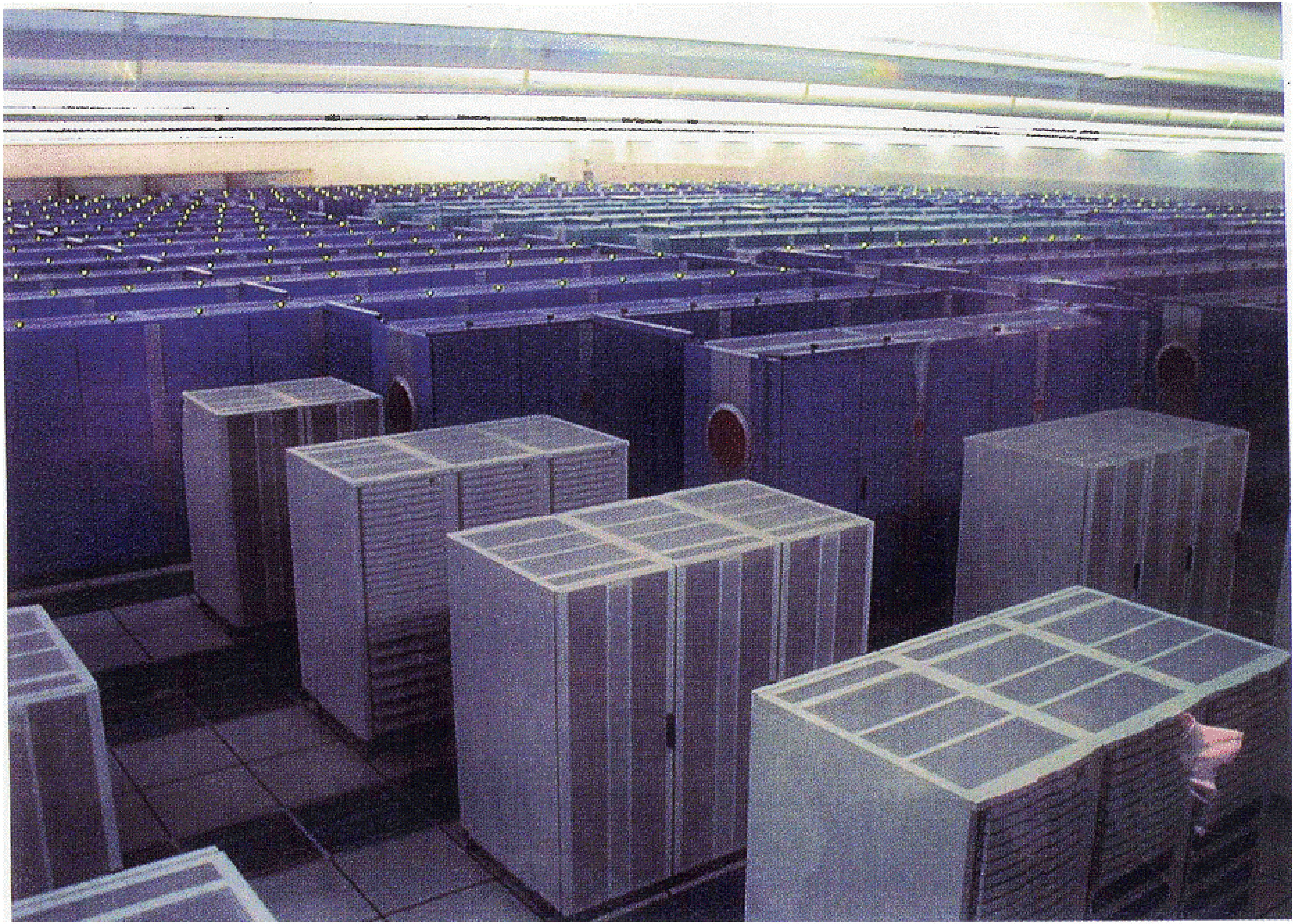


1 cabinet (2nodes included)

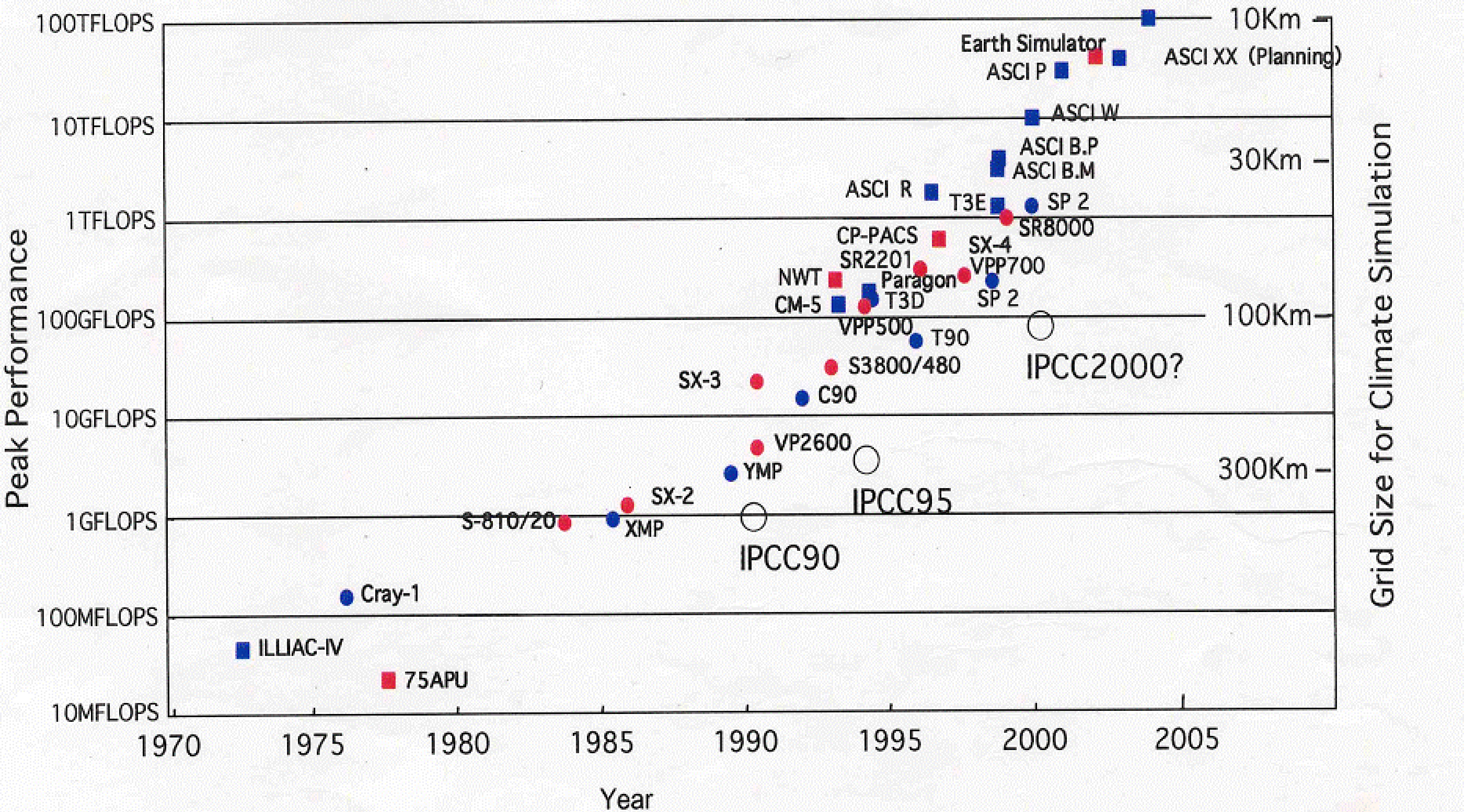
#Processors	5,120
Processor nodes	640
Processors per node	8

Peak Performance	40 Tflops
Per node	64 Gflops
Per processor	8 Gflops
Main Memory	10 TB
Per node	16 GB





Increasing Trends of Super Computer's Performance and Climate Model Simulation



Activity

a. High-resolution Coupled model and Global Warming Experiment

(CCSR/UT-NIES-FRSGC)

b. 20km-mesh Atmospheric GCM

(Meteor. Res. Inst/JMA)

c. Next-generation Atmosphere & Ocean Models

(FRSGC)

d. Integrated Earth-System Model

(FRSGC-CCSR/UT-NIES---)

High-resolution Coupled model and Global Warming Experiment (CCSR/UT-NIES-FRSGC)

The CCSR/NIES/FRSGC Coupled Ocean-Atmosphere GCM on the Earth Simulator: *MIROC 3.2*

- **Atmosphere: Spectral T106 (120km) 56 levels with interactive Aerosol modules**
- **Ocean & Ice: Grid 1/4^{o}x1/6^{o} 48 levels**
- **Land: 1/2^{o}x1/2^{o} MATSIRO SVATS model**
- **River: 1/2^{o}x1/2^{o} TRIP river routing model**
- **Parallelized with MPI on 80PE for atmos. and 608PE for ocean (13% of whole ES)**

No flux correction applied

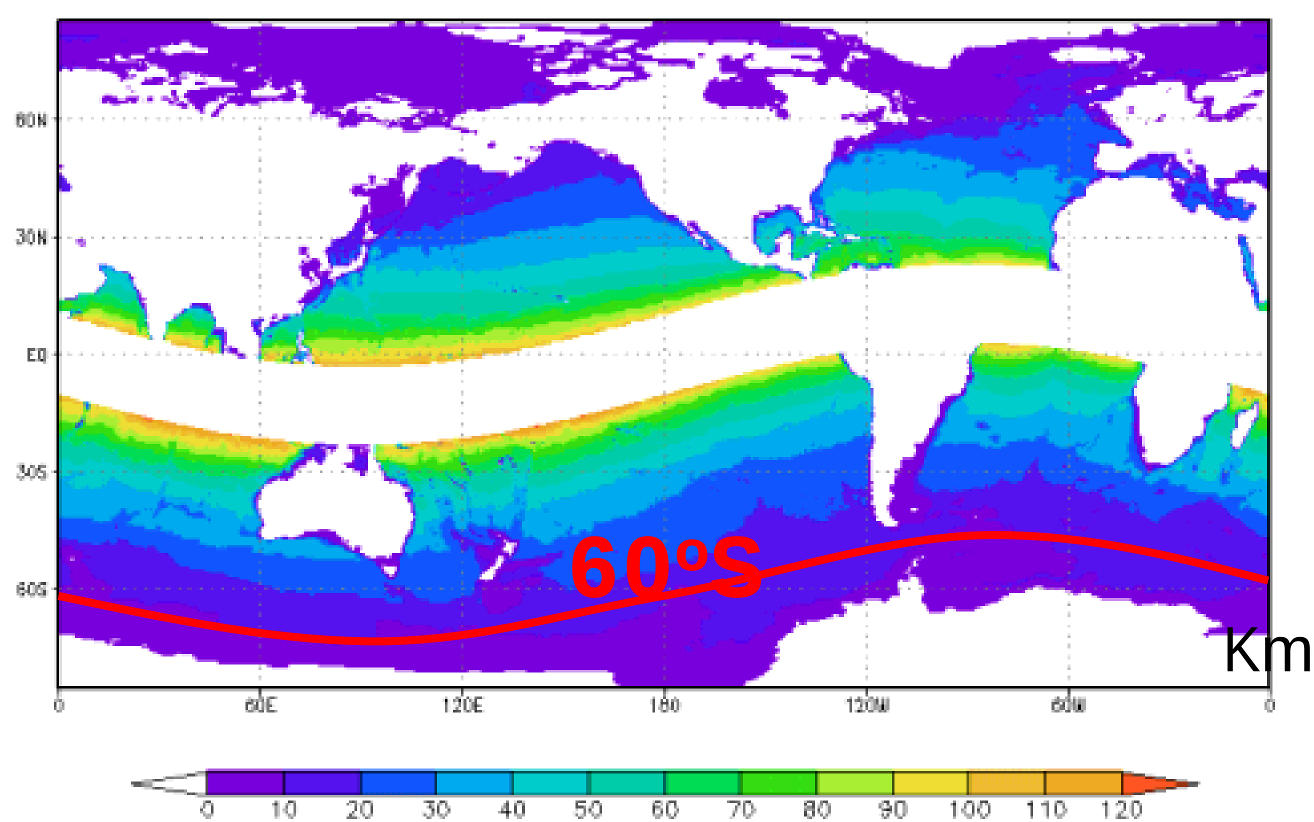
The Ocean component is too coarse to resolve eddies in the high-latitudes

Model grid size
1/4º(zonally)
1/6º(meridionally)

at 60º
dx=15.4km
dy=20 km

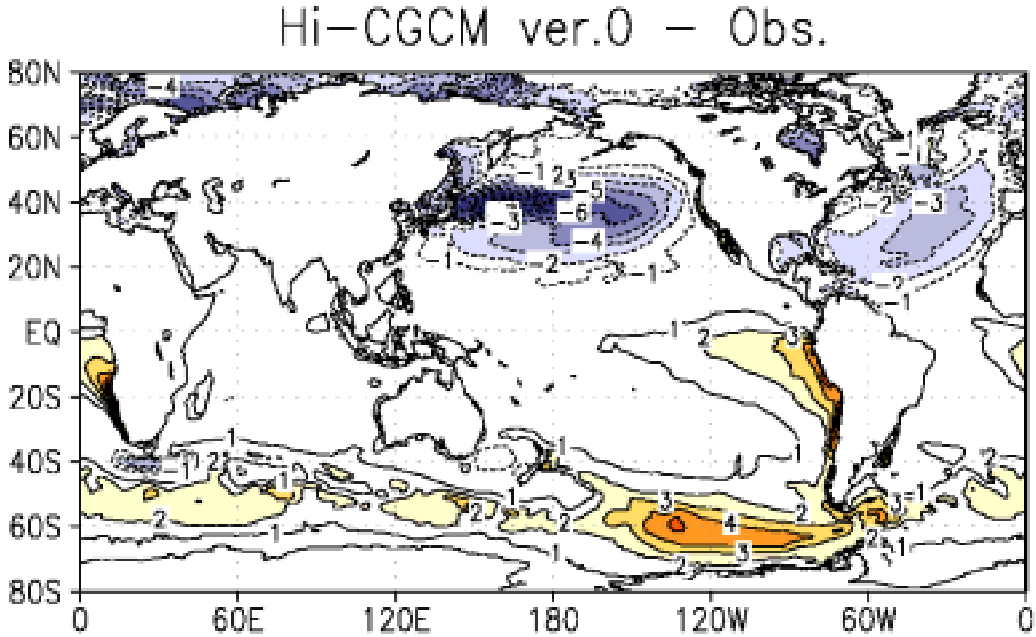
Introduce thickness-diffusion (Gent-McWilliams) only In the high-latitudes

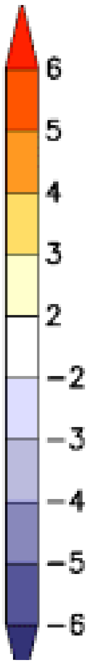
Rossby's deformation radius for the first baroclinic mode (based on WOA)



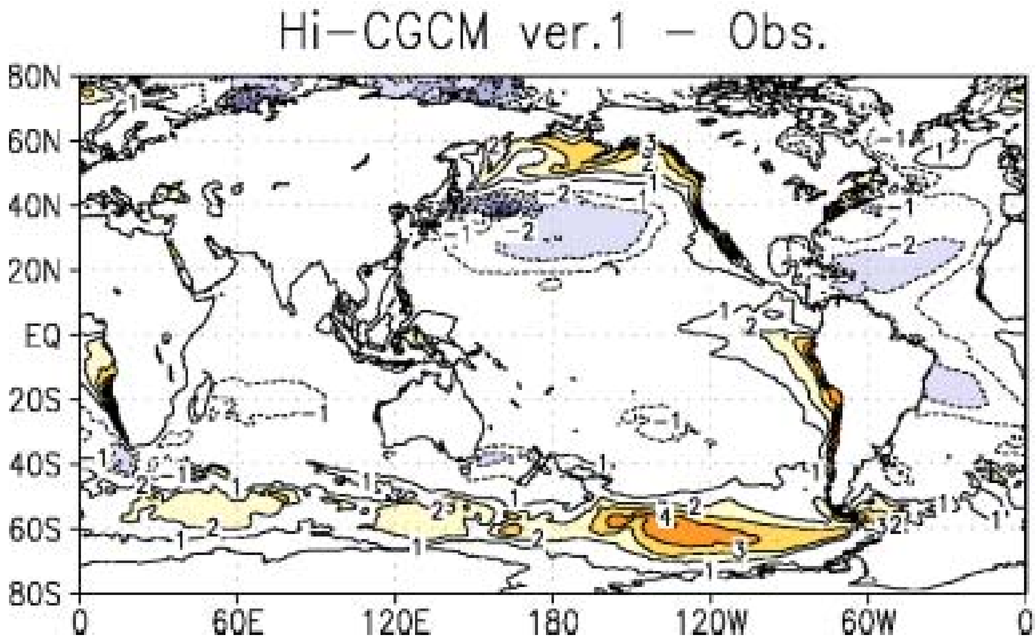
SST bias

ver.0
40yr mean



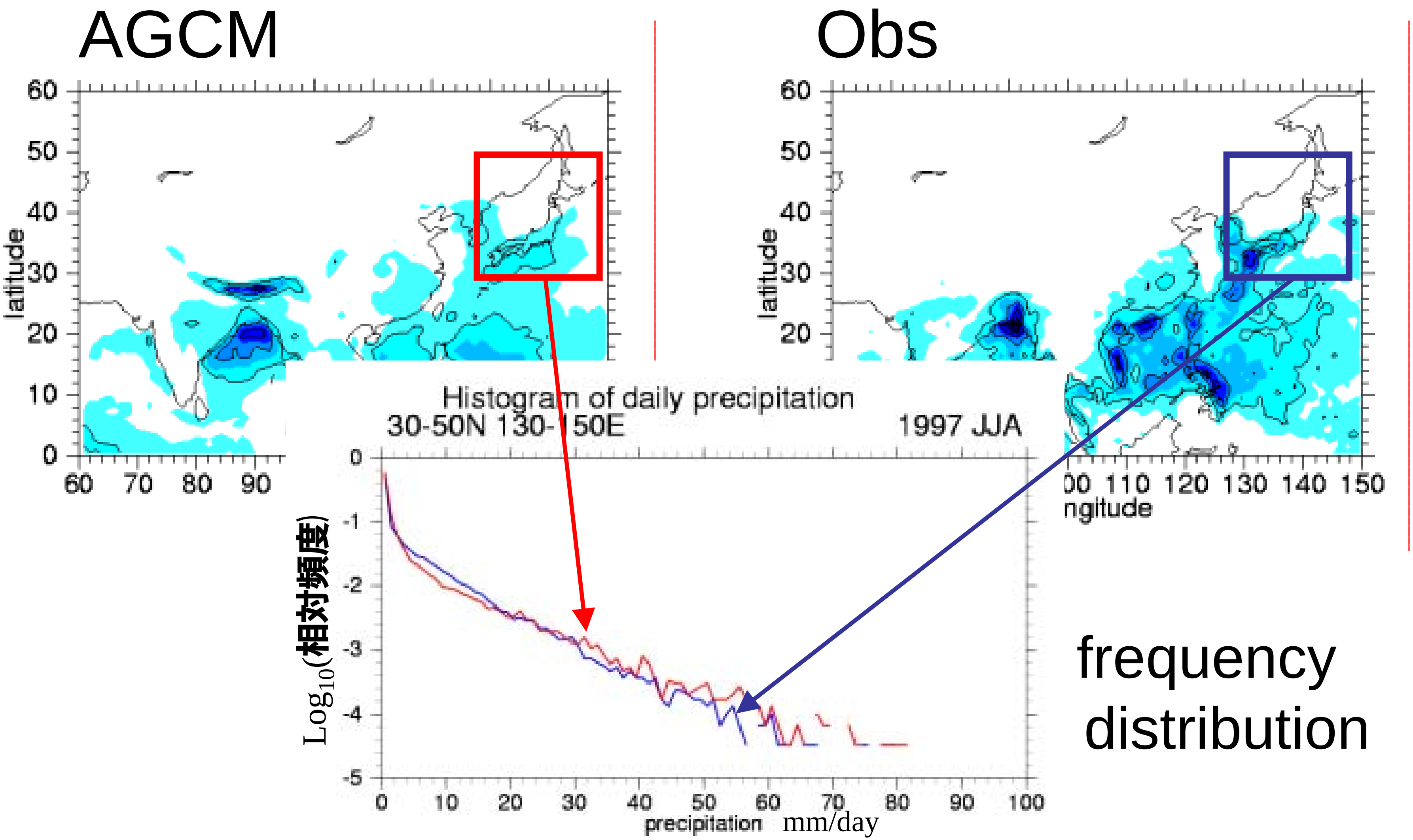


ver.1
last 4yrs



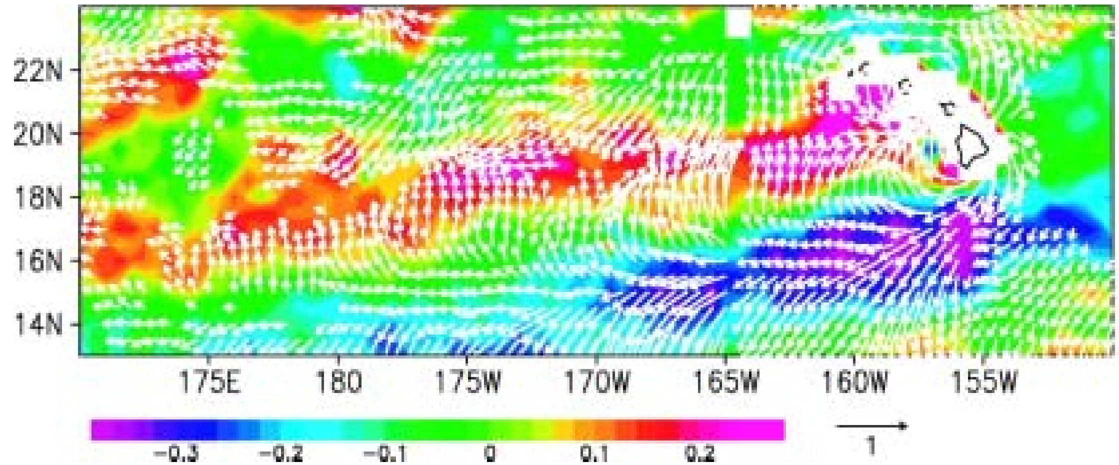
Extreme events? (daily precipitation)

Frequency of daily precipitation > 50mm/day

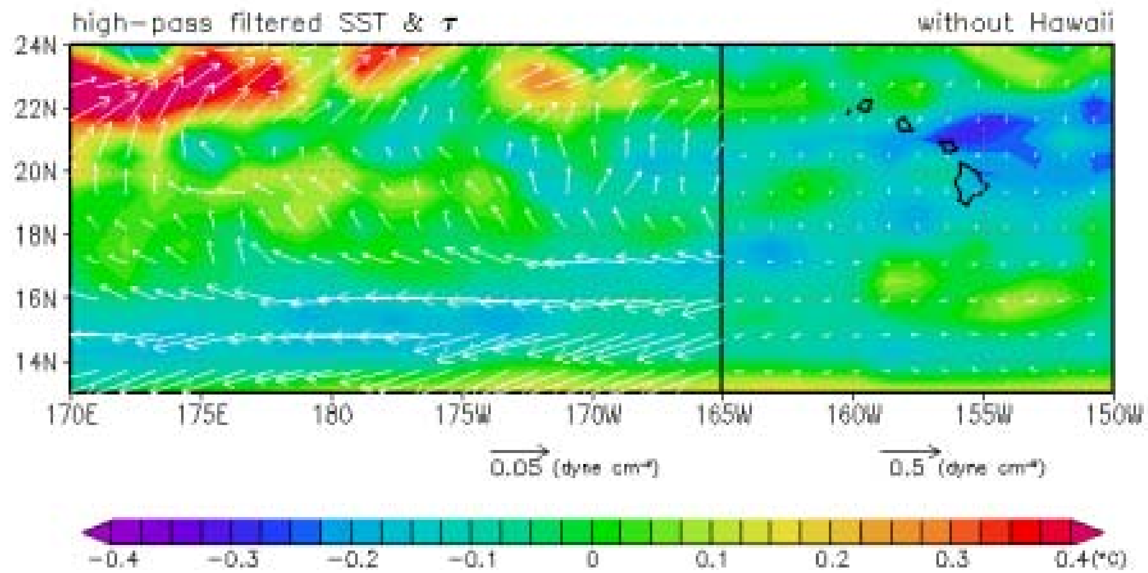


Hawaiian Lee Counter Current (Xie et al., 2001)

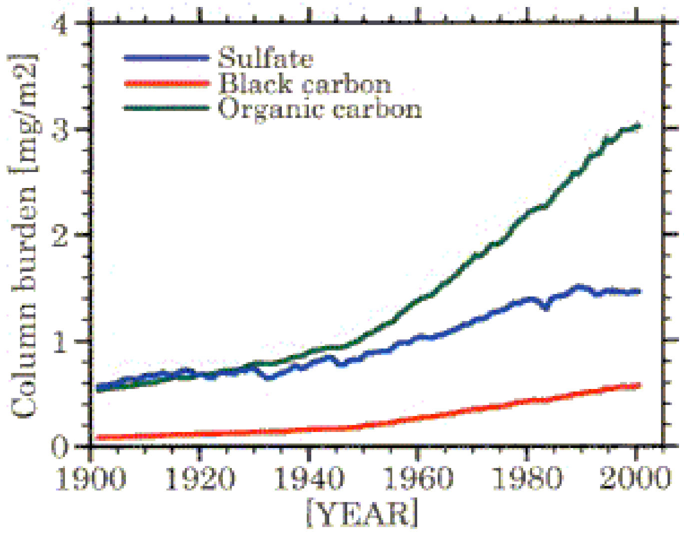
Obs

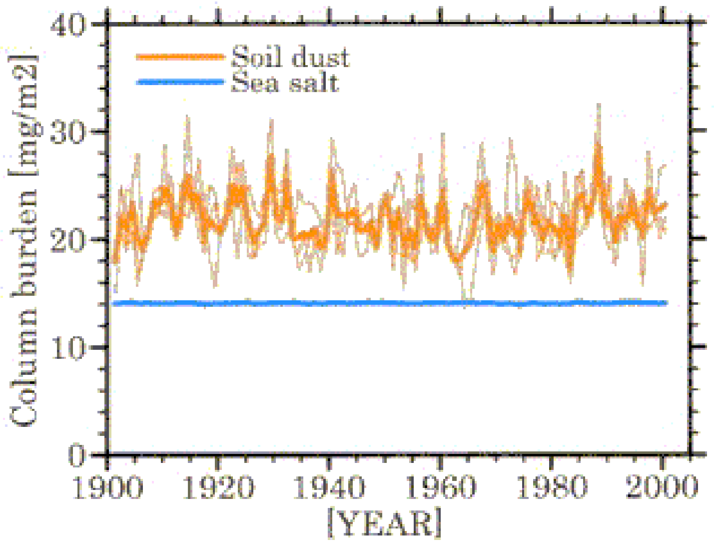


CGCM w/o the Hawaii Islands

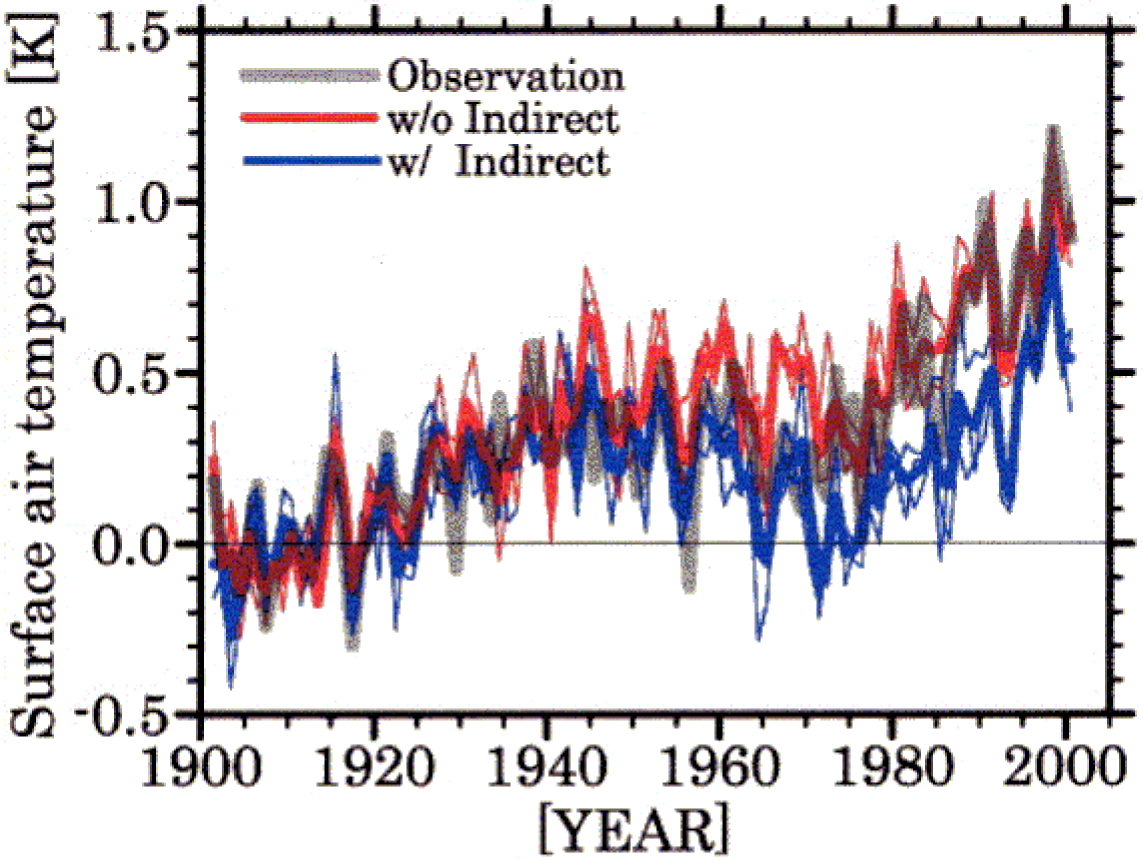


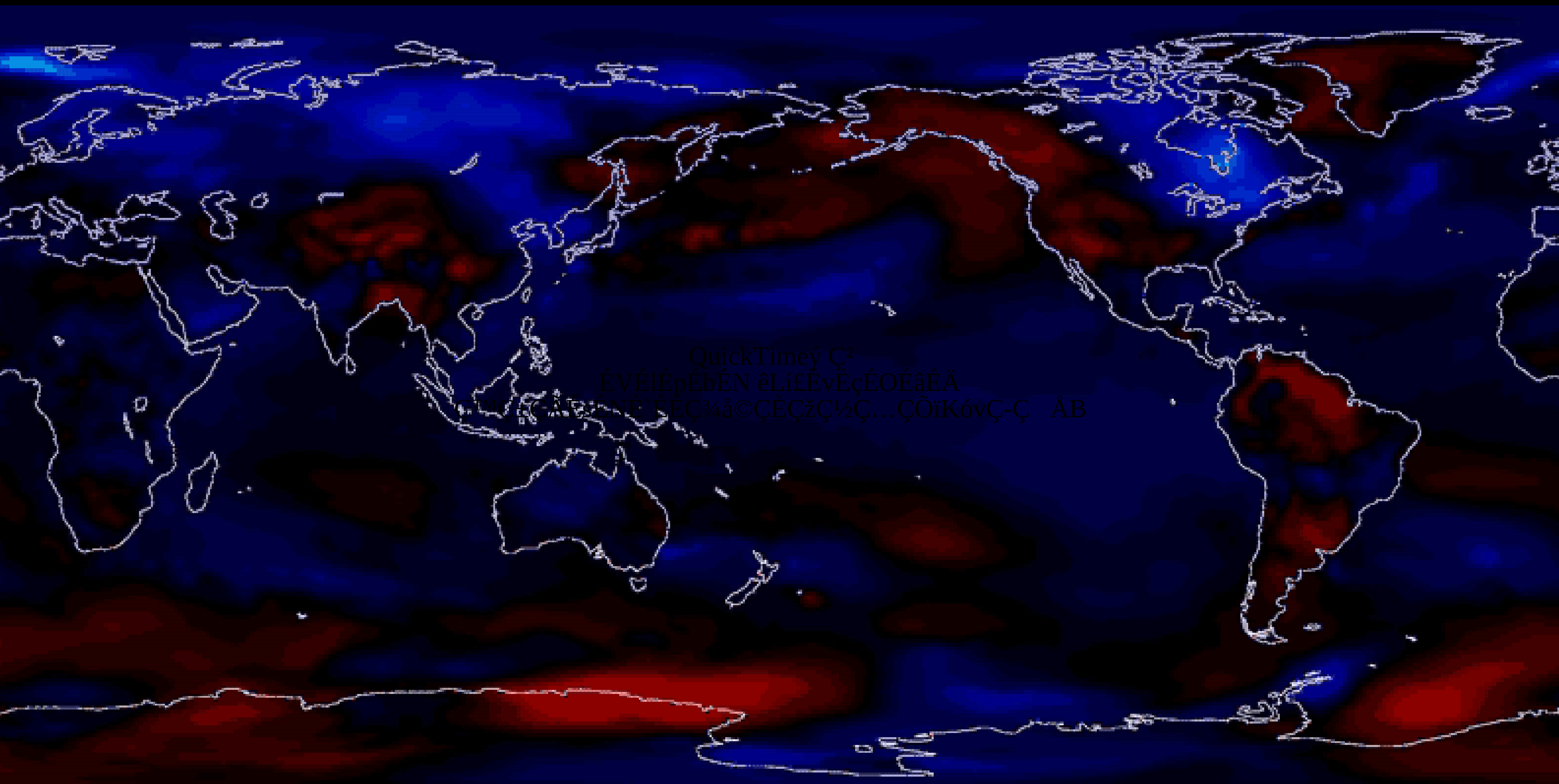
Time variation of the vertically integrated aerosol density





Time variation of the global mean temperature at 2m

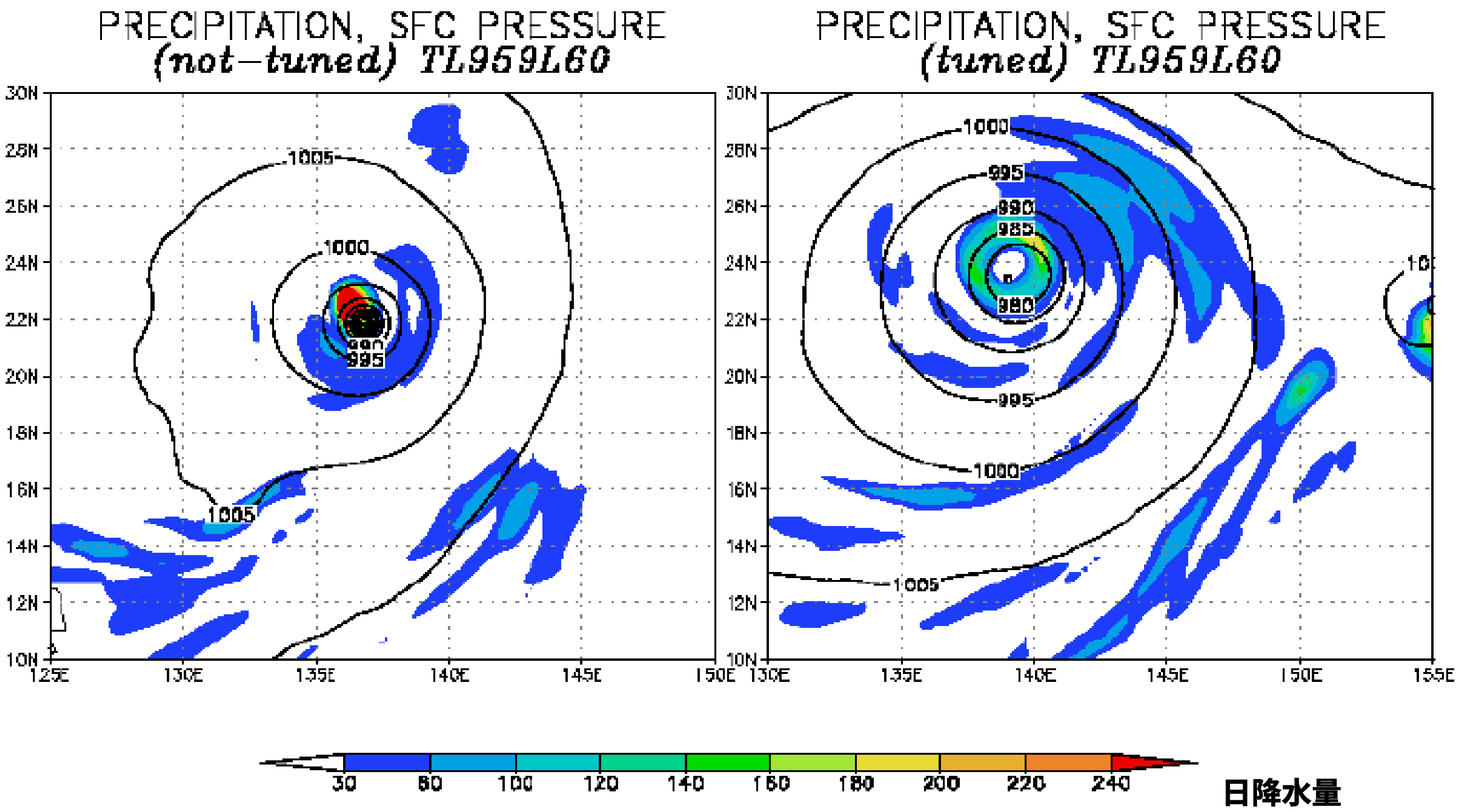




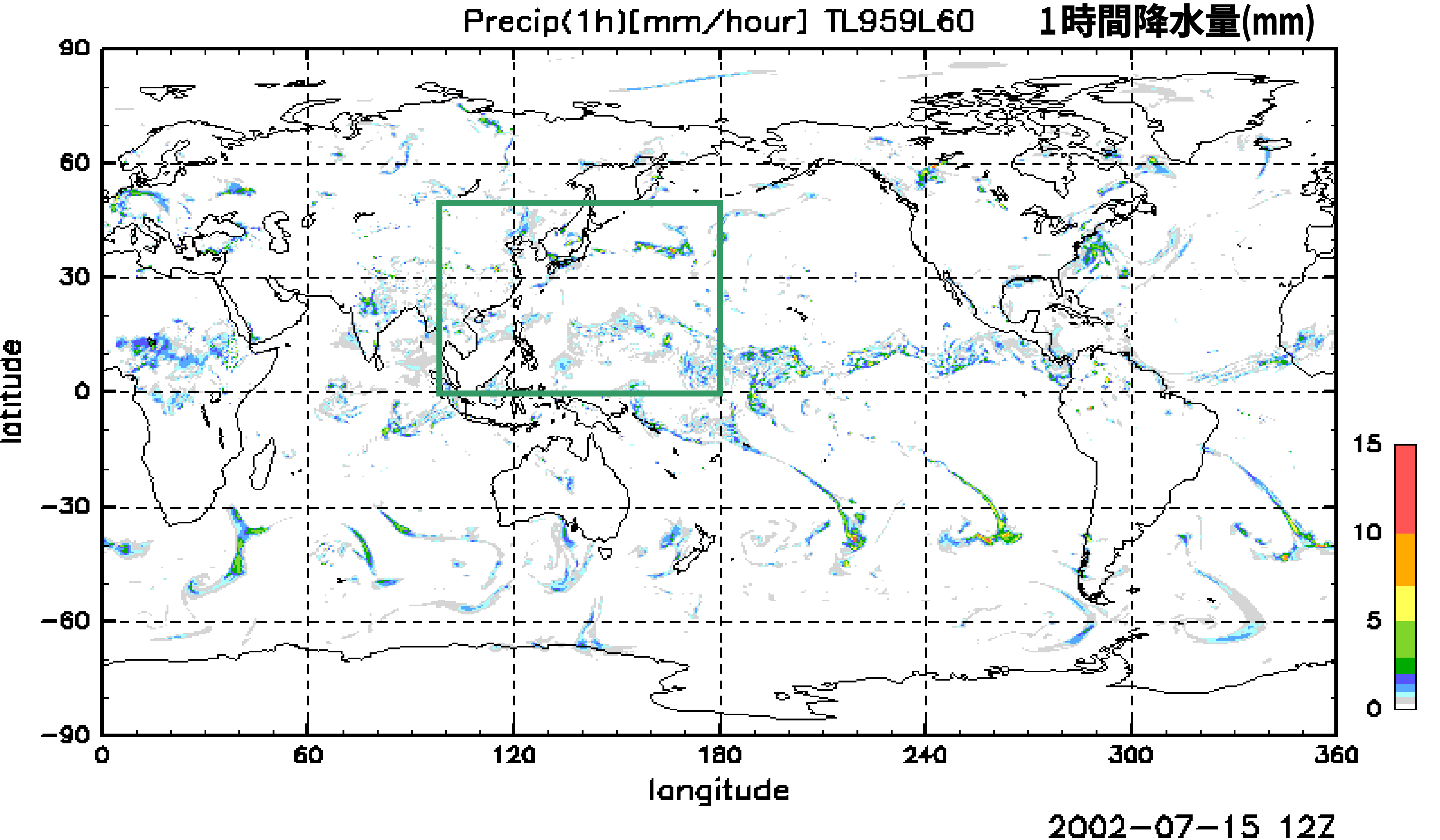
b. 20km-mesh Atmospheric GCM (Meteor. Res. Inst/JMA)

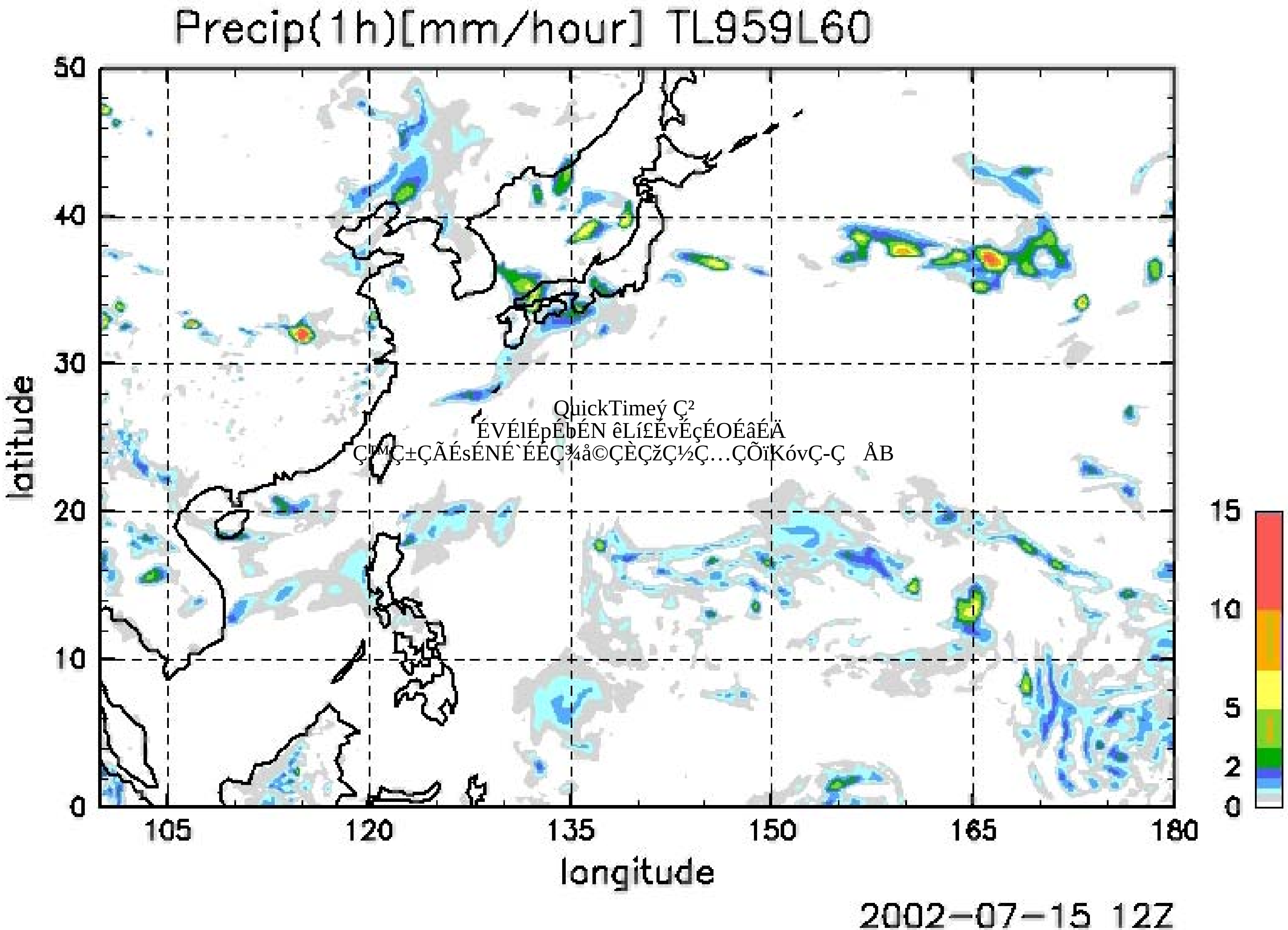
Impact on typhoon simulation

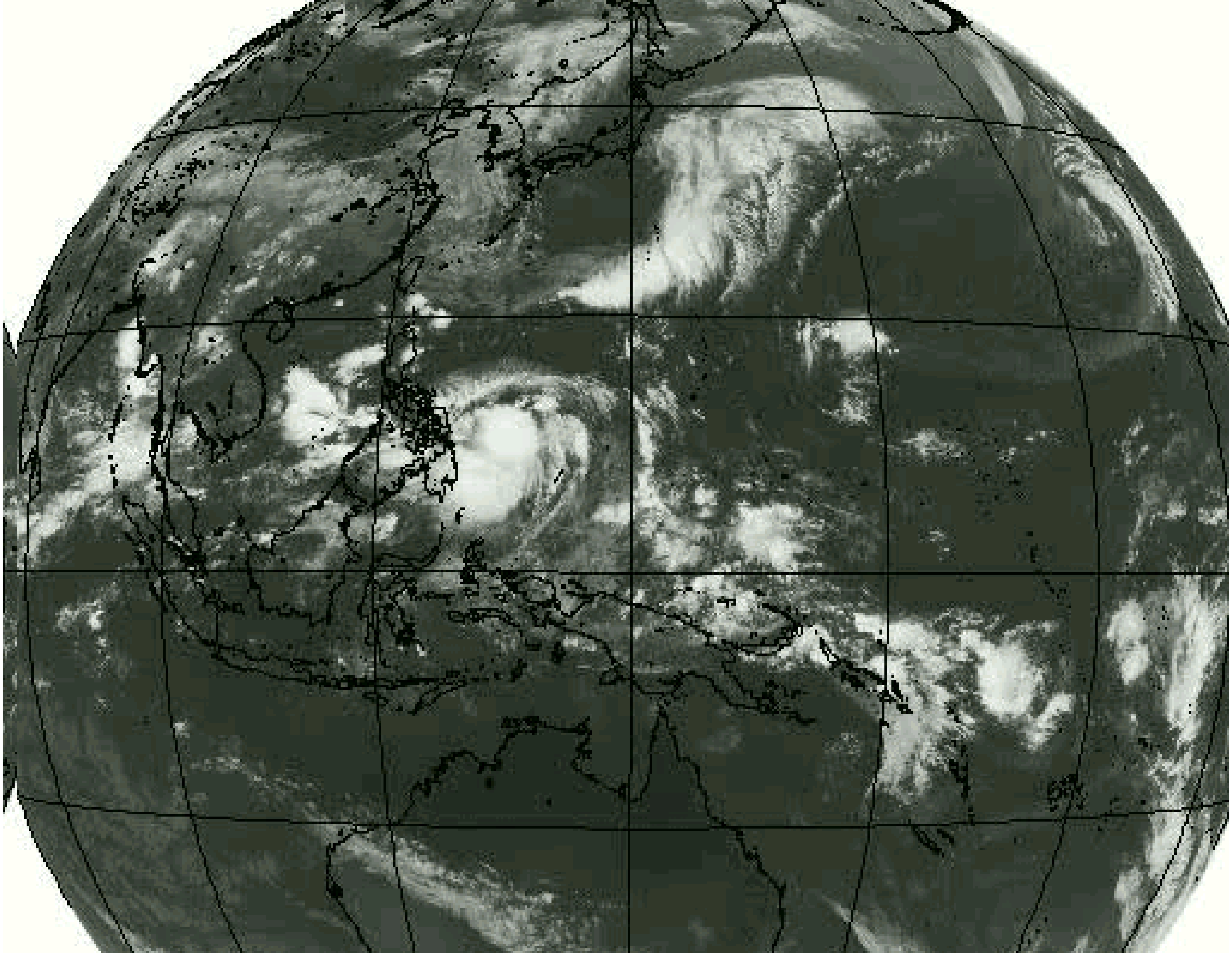
old new



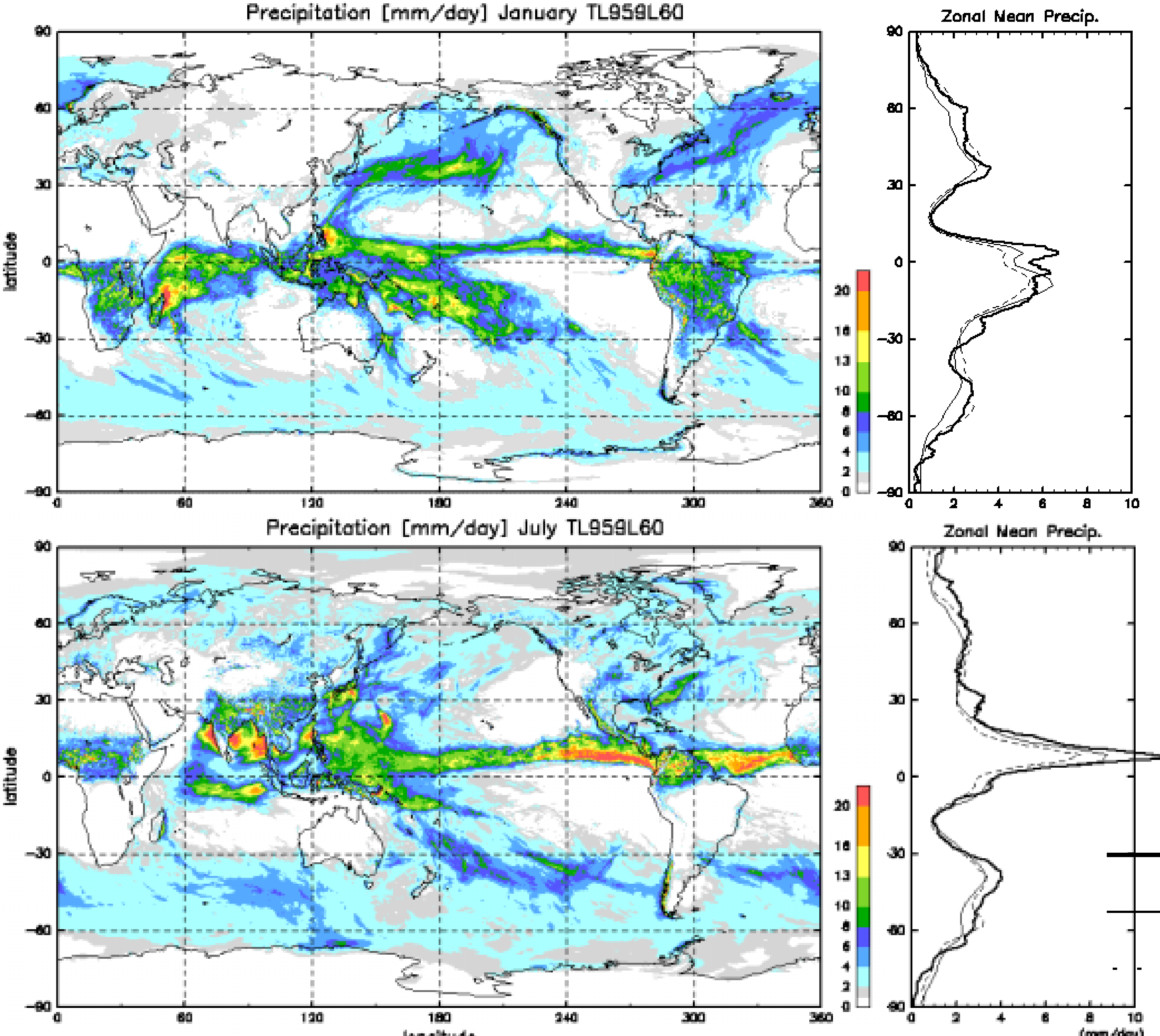
Simulation of the present day climate




Precip(1h)[mm/hour] TL959L60
50
40
30
20
10
0
latitude
105
120
135
150
165
180
longitude
15
10
5
2
0
QuickTimeý Ç²
ÉVÉlÉpÉbÉN êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç ÅB
2002-07-15 12Z



全球モデルによる月降水量



January

July

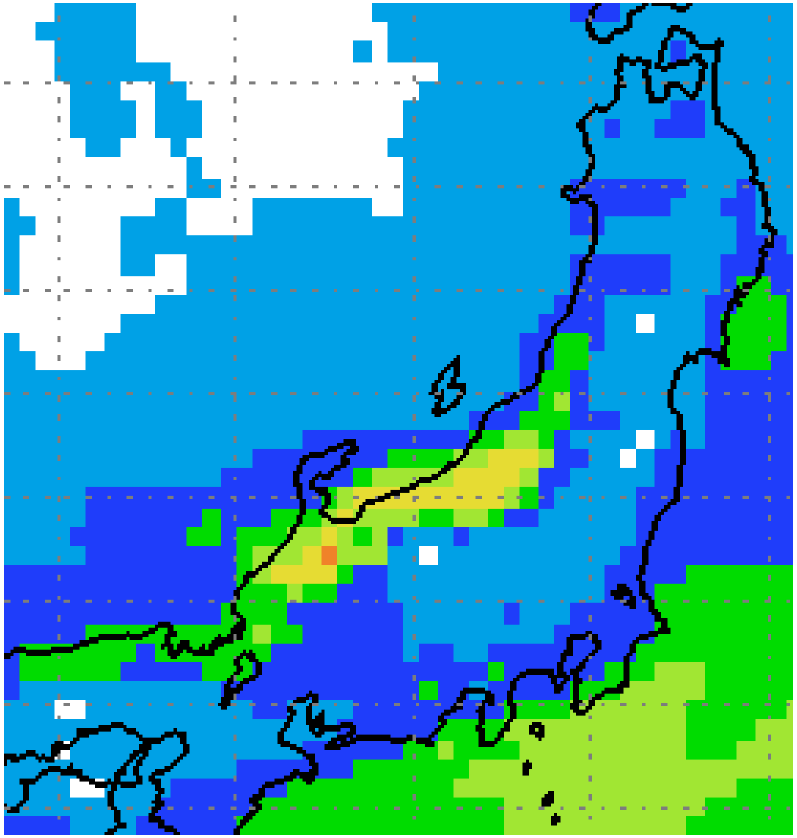
TL959L60

CMAP 気候値

GPCP 気候値

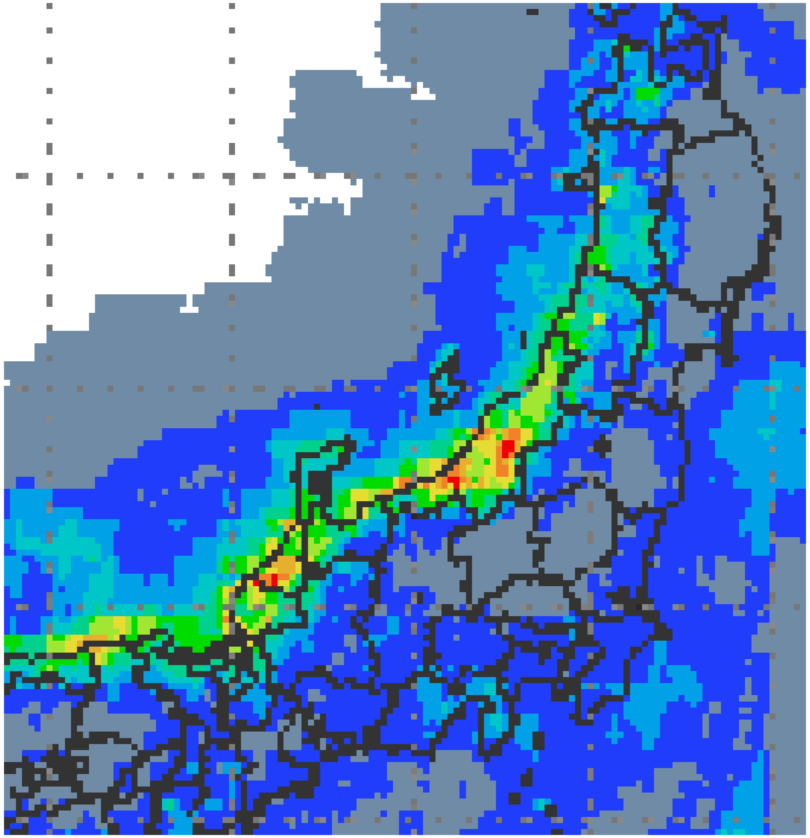
Regional climate simulated by the 20 km mesh model (January precipitation)

Model (TL959L60)

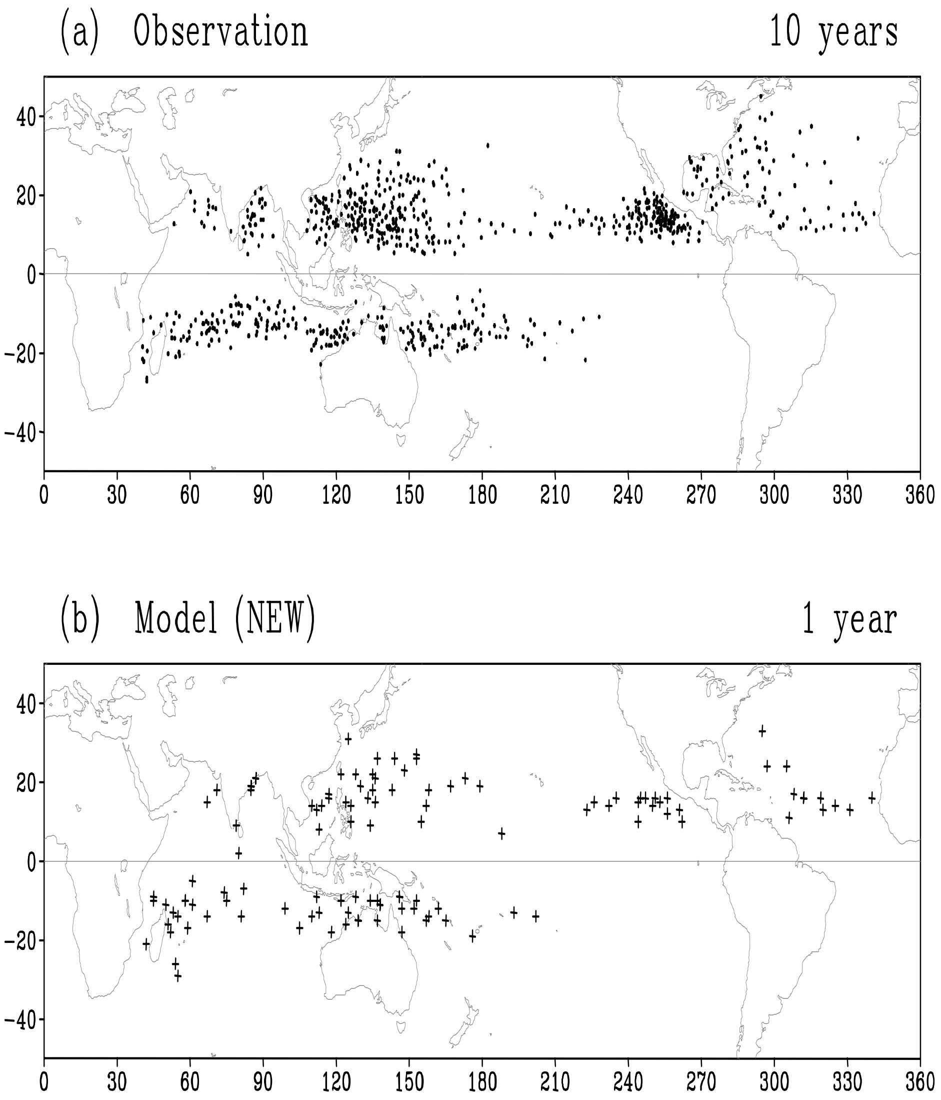


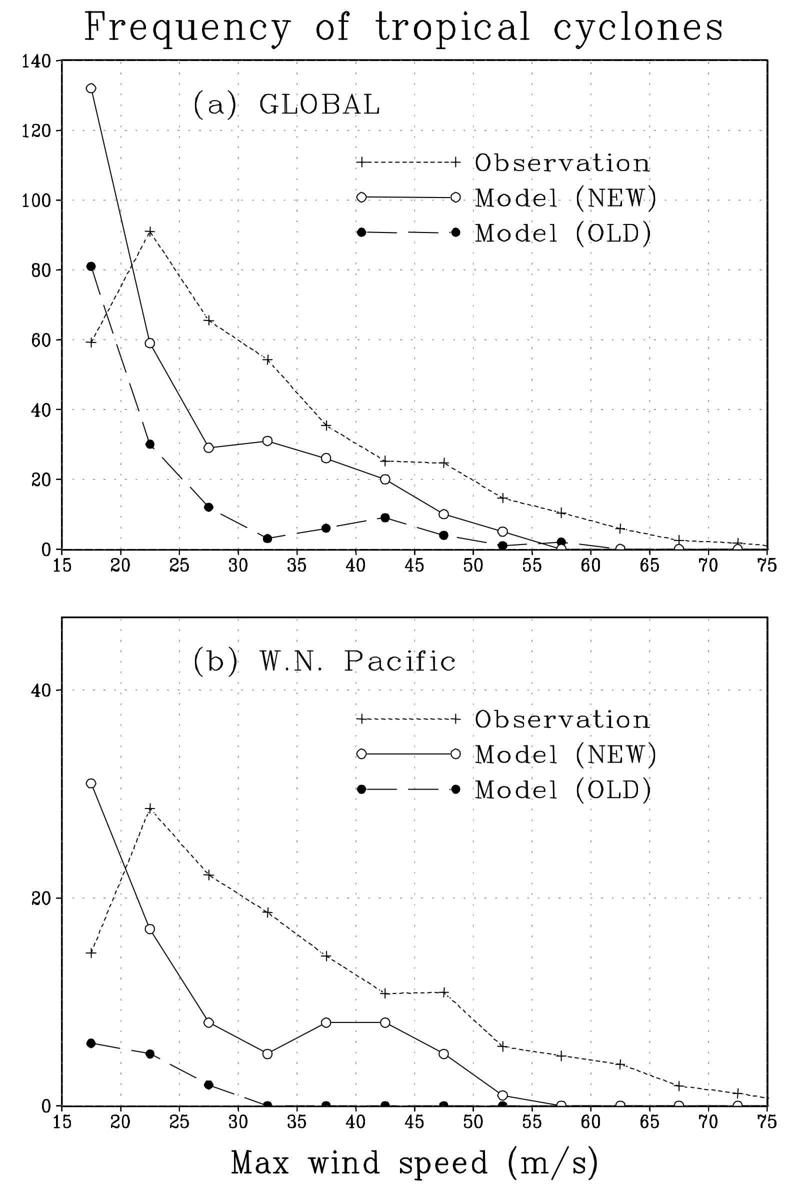
Observation

(1991-2000年の平均)



Tropical cyclones simulated by the model





Kyosei Project 2

Development of an
“Integrated Earth System Model”
for projection of
global environmental change

Kyousei 2 Project:
Incorporation of biogeochemical processes into a GCM

PI: T. Matsuno

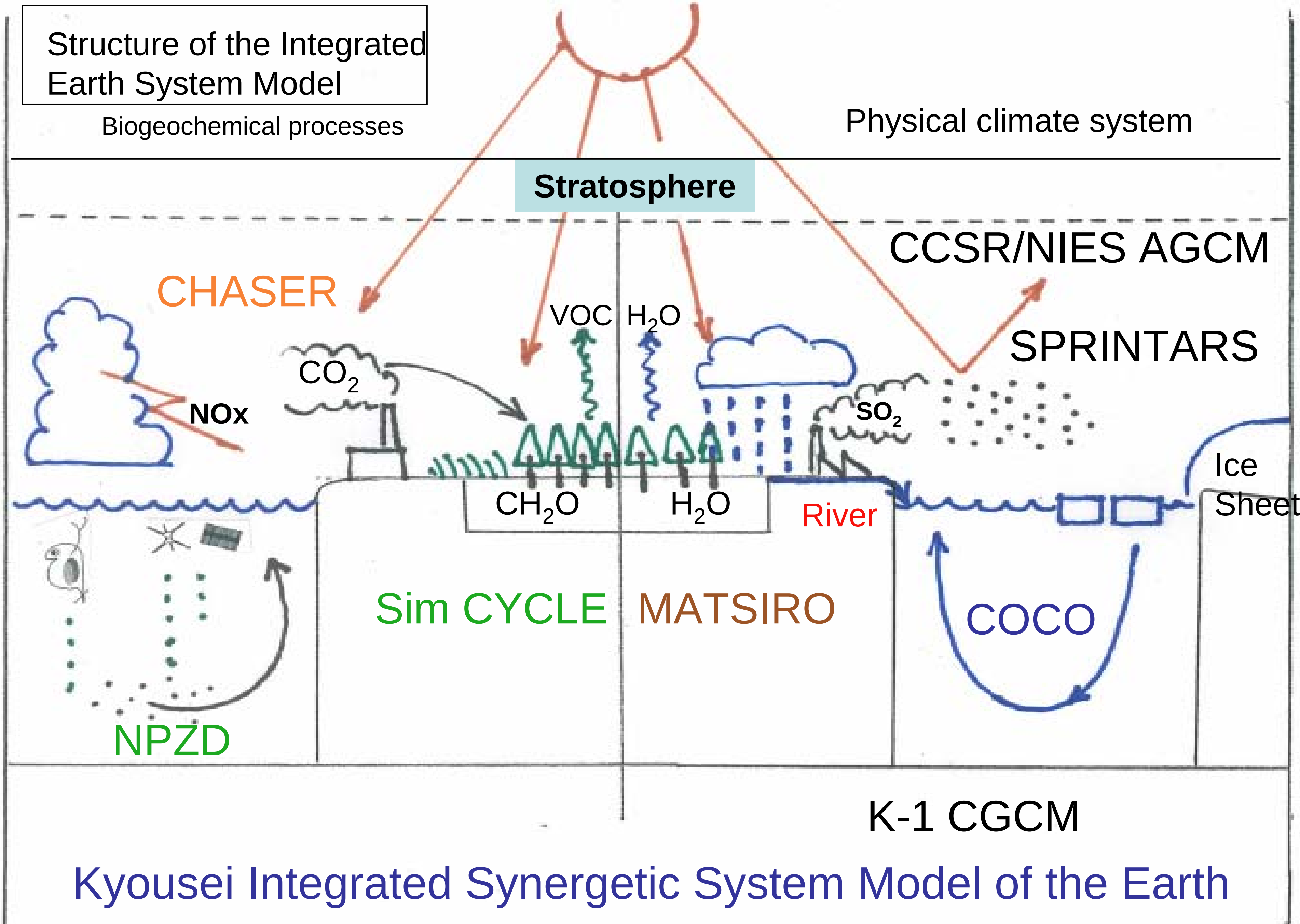
M. Aita, A. Abe-Ouchi***, A. Ito, S. Emori, T. Oikawa**, R. Ogaito, M. Kawamiya
M. Kishi*,N. Kuba, T. Kohyama*, H. Kondo, H. Sato, Ta. Suzuki, Ts. Suzuki,
K. Sudo, T. Segawa, K. Takata, M. Takahashi***, M. Takigawa, K. Tanaka,
Y. Tsushima, Y. Yamanaka*, C. Yoshikawa, S. Watanabe (FRSGC)

M. Kimoto, K. Suzuki, T. Nakajima, H. Hasumi (CCSR/Univ. of Tokyo)

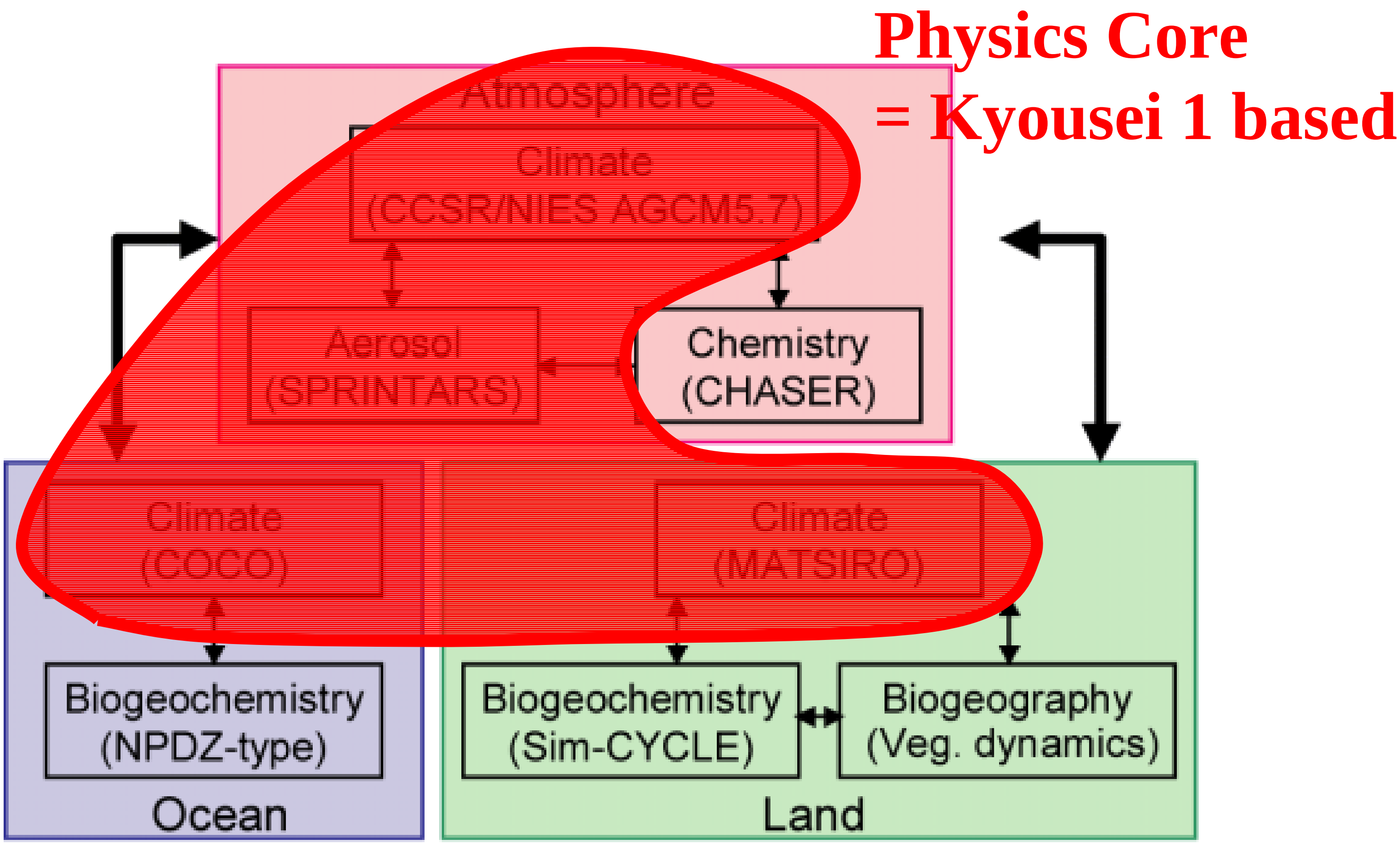
T. Nagashima, T. Nozawa (NIES)

K. Ichii (Nagoya Univ.), T. Takemura (Kushu Univ.)

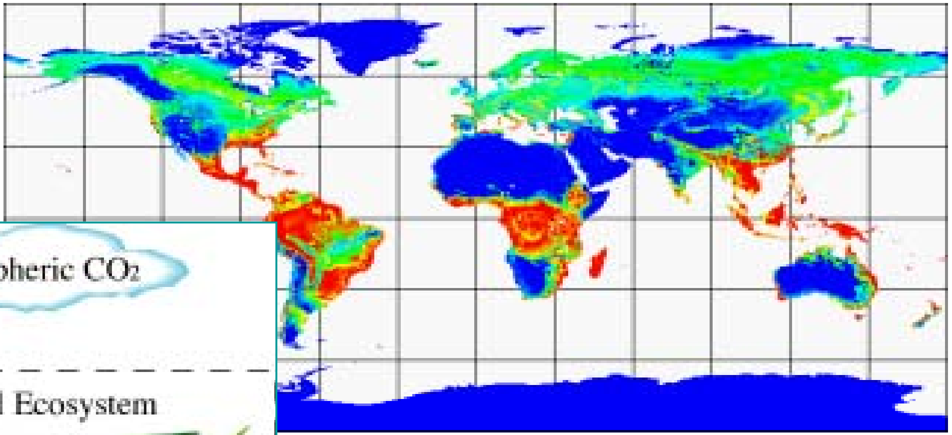
Double affiliates of FRSGC researchers: *Hokkaido Univ., **Univ. of Tsukuba,
***CCSR/Univ. of Tokyo

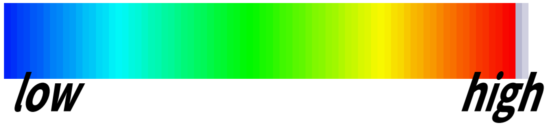

Structure of the Integrated Earth System Model
Biogeochemical processes
Physical climate system
Stratosphere
CCSR/NIES AGCM
CHASER
SPRINTARS
VOC
H_2O
CO_2
NOx
SO_2
CH_2O
H_2O
River
Ice Sheet
Sim CYCLE
MATSIRO
COCO
NPZD
K-1 CGCM
Kyousei Integrated Synergetic System Model of the Earth

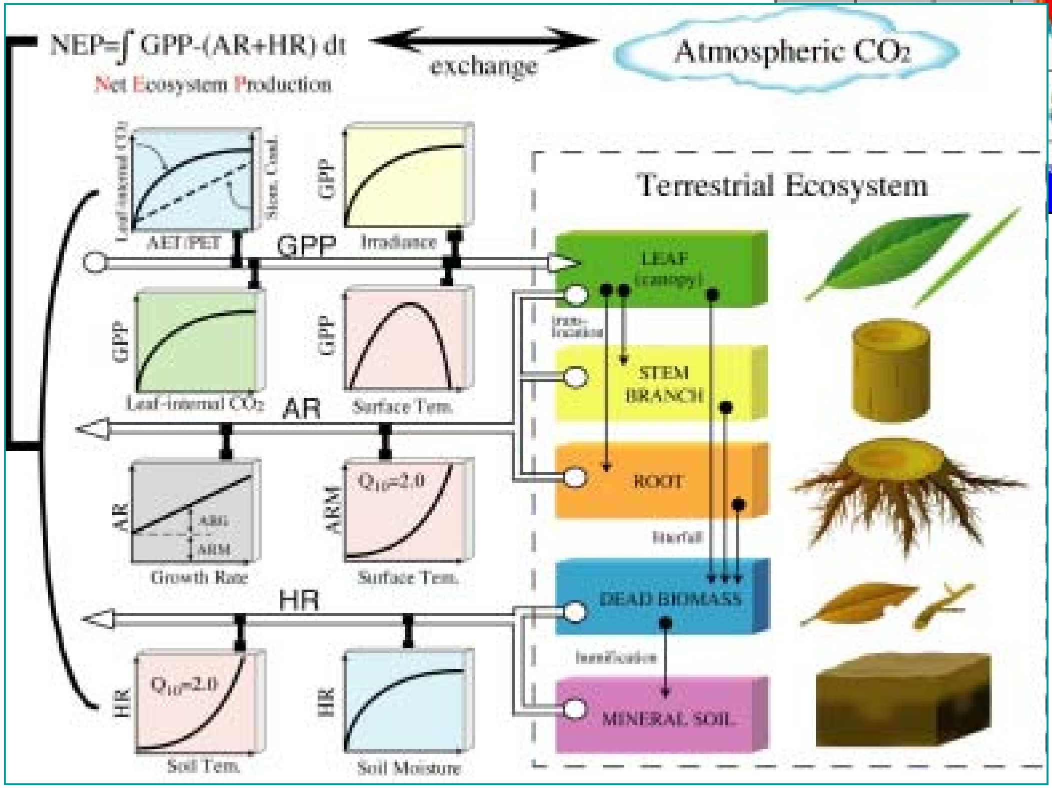
FRSGC integrated Earth System Model



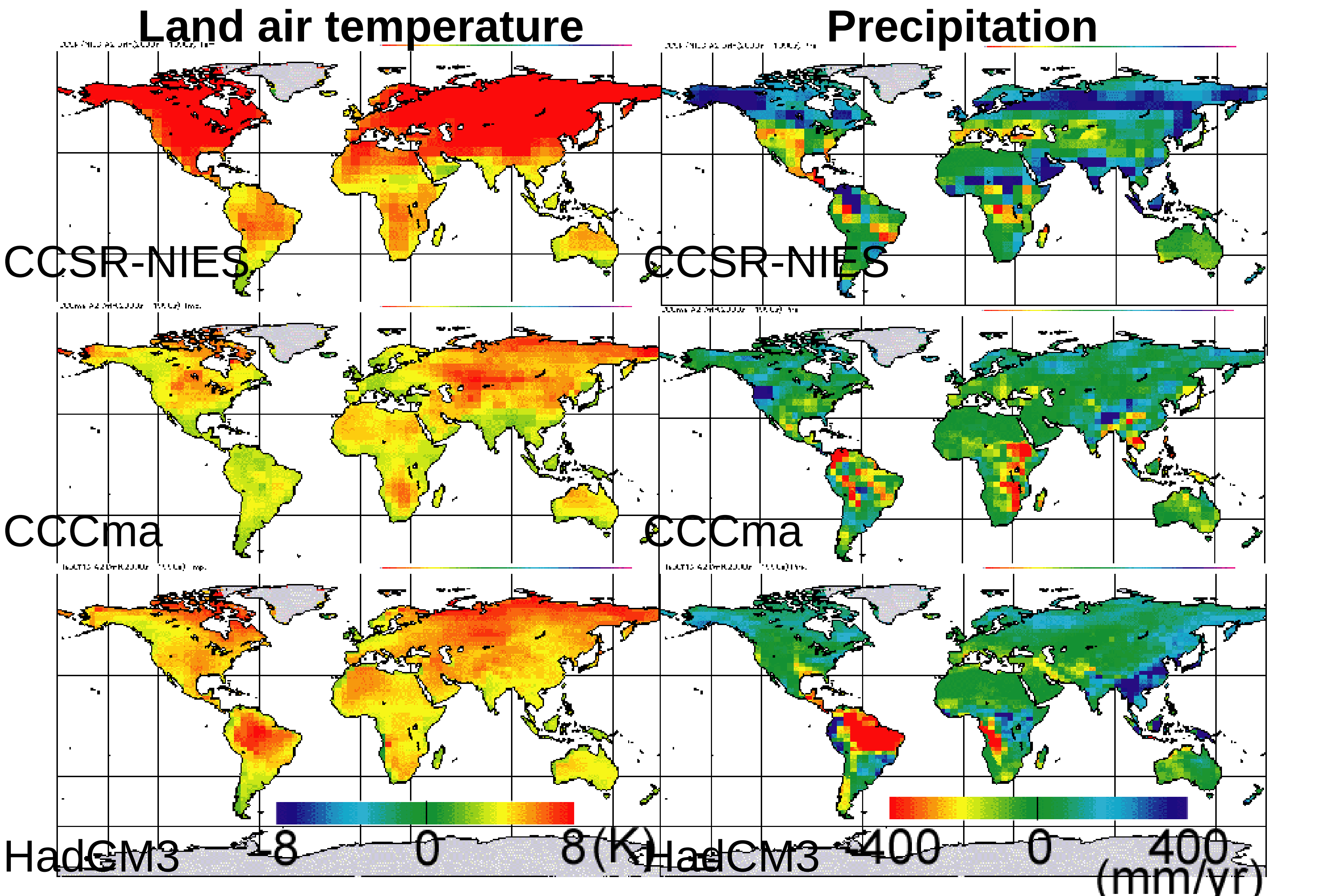
Terrestrial Carbon Cycle model (Sim-CYCLE)



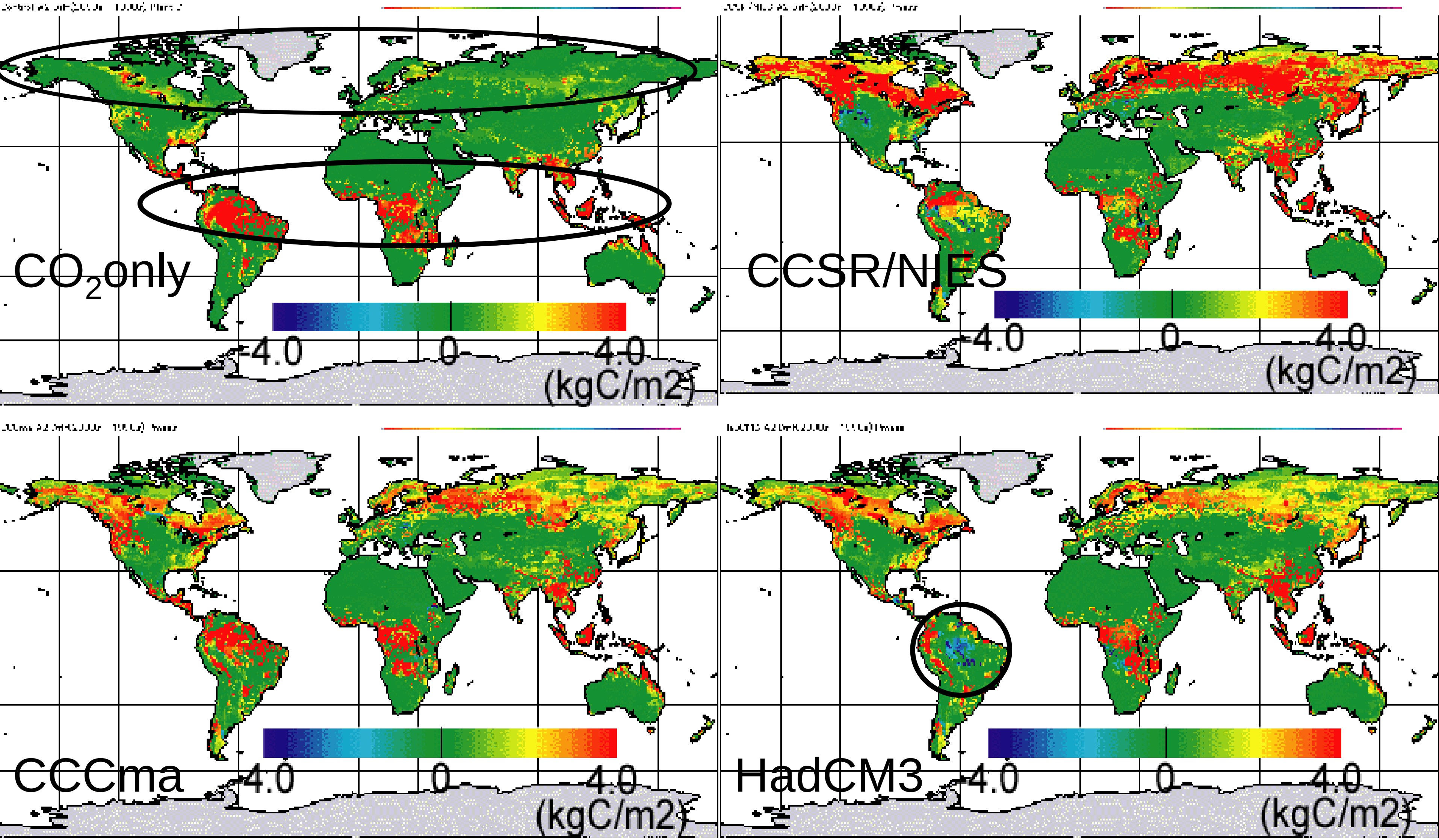




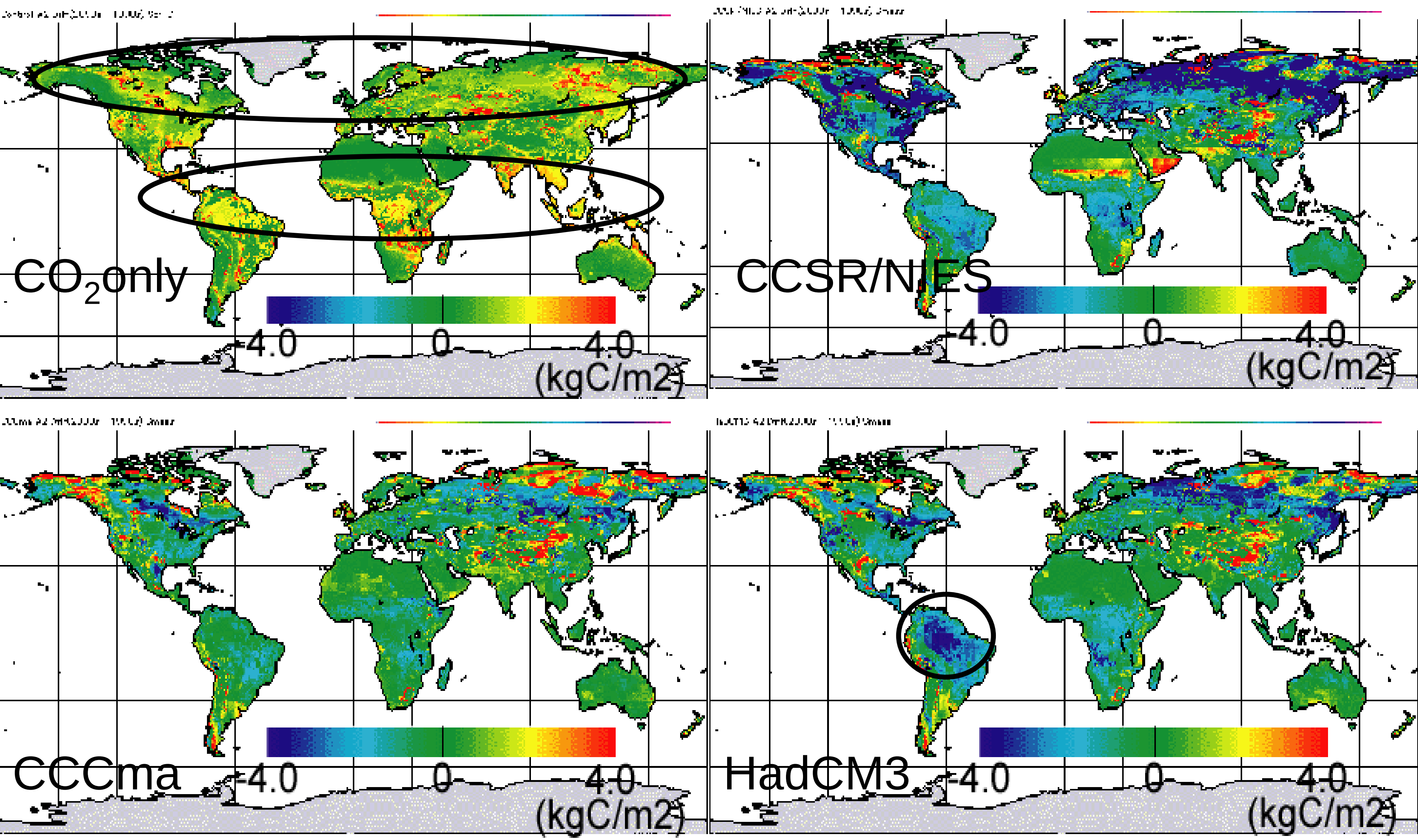
Future climate scenario under SRES-A2 (2090s – 1990s)



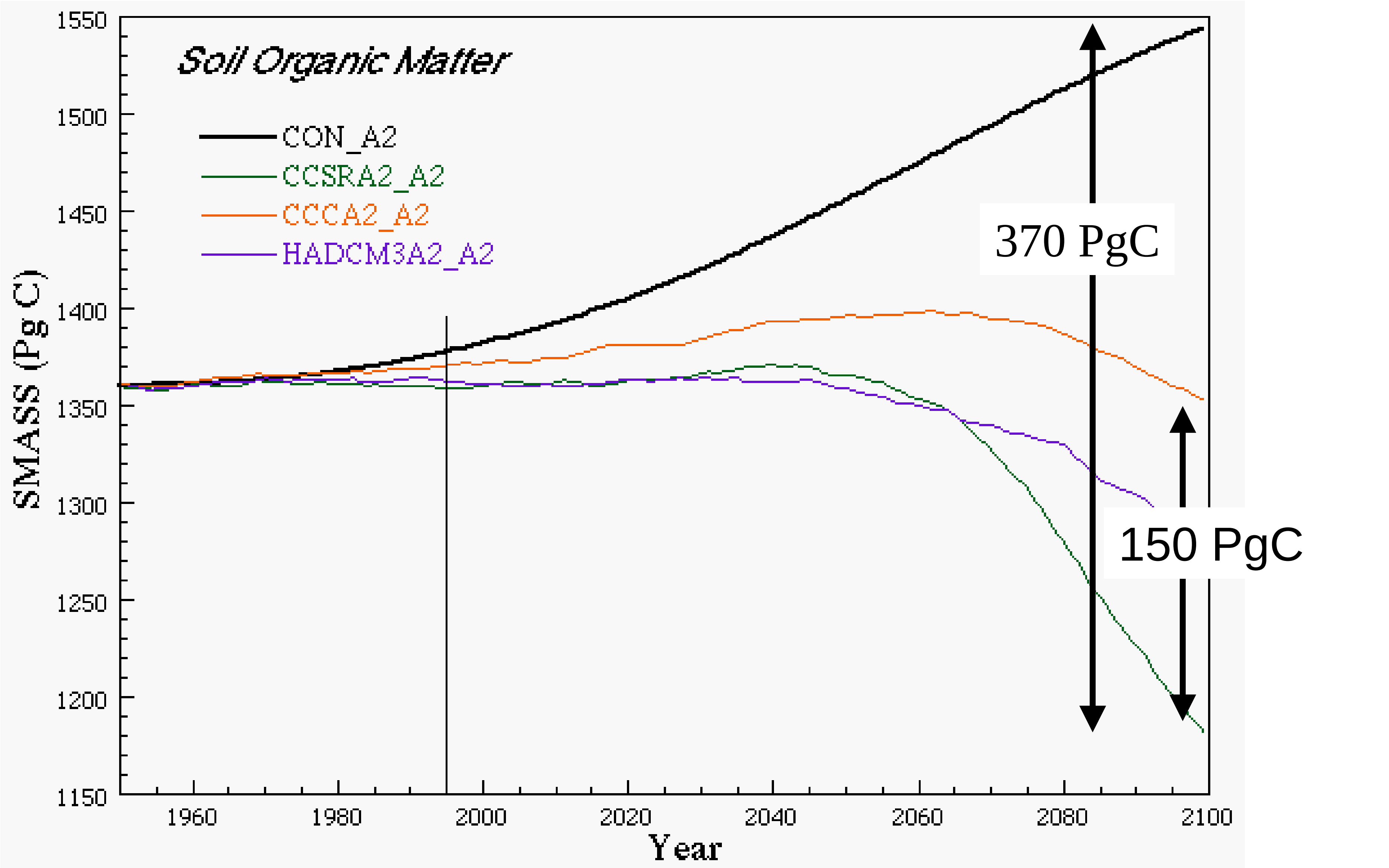
Plant Carbon Differences (2090s – 1990s)



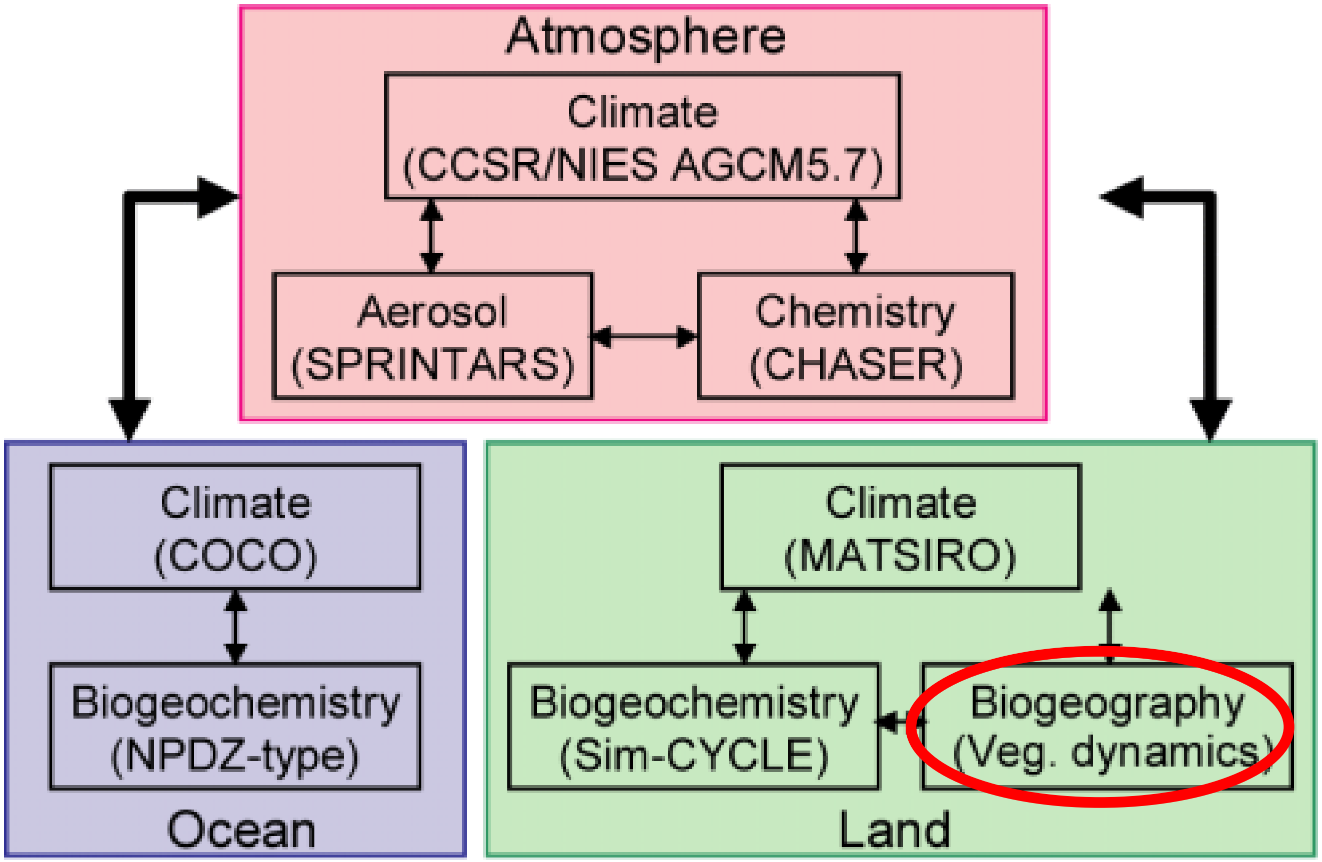
Soil Carbon Differences (2090s – 1990s)



Results


Soil Organic Matter
CON_A2
CCSRA2_A2
CCCA2_A2
HADCM3A2_A2
370 PgC
150 PgC
SMASS (Pg C)
Year
1550
1500
1450
1400
1350
1300
1250
1200
1150
1960
1980
2000
2020
2040
2060
2080
2100

FRSGC integrated Earth System Model KISSME



“DGVMization” of Sim-CYCLE

DGVM: Dynamical Global Vegetation Model

-> Incorporation of the effect of biome-shift into Sim-CYCLE

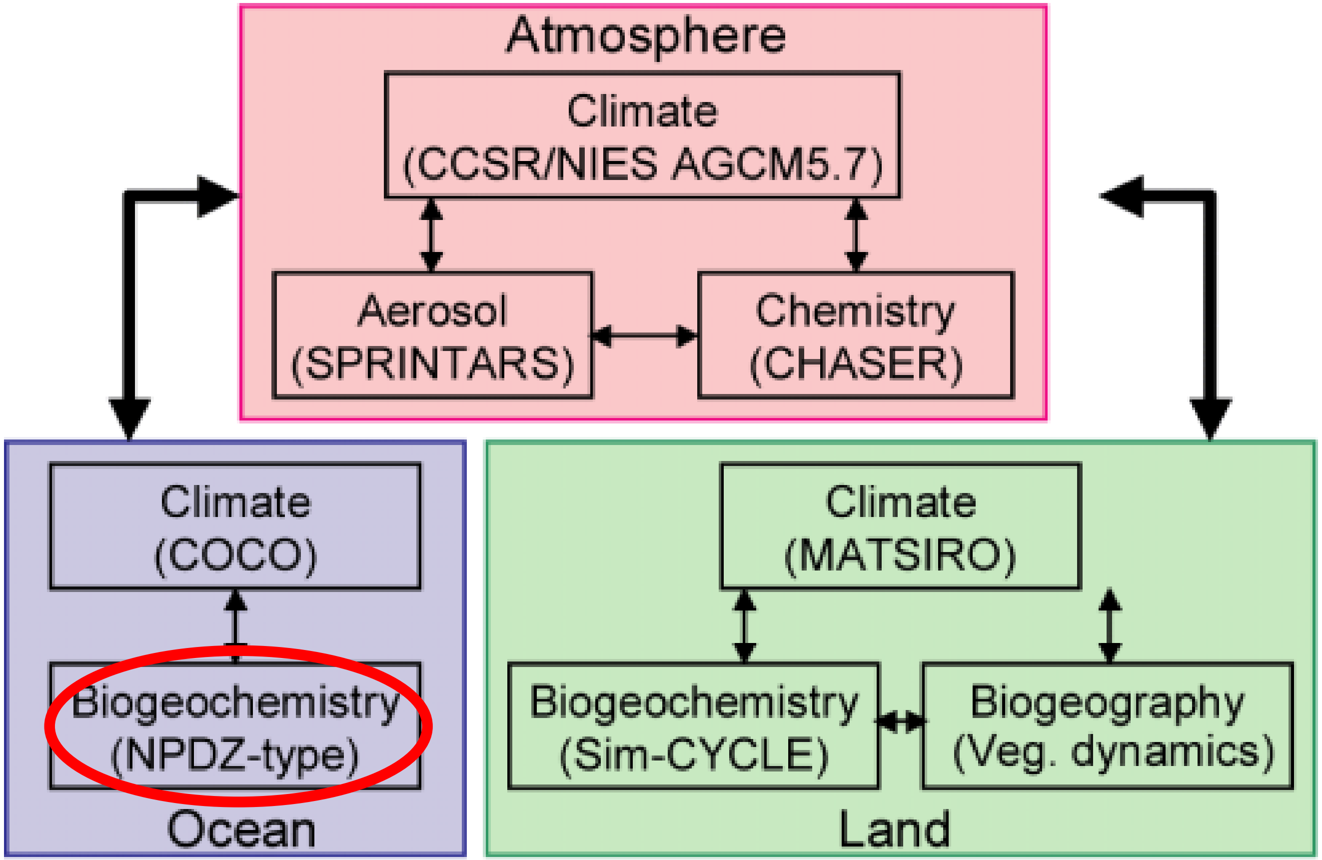
Individual basis model, which explicitly treat
3D forest-structure within 30m x 30m patches

Individual characteristics

Foliage : biomass, crown diameter, crown depth
Stem : biomass, height, sapwood & heartwood diameter
Root : biomass

--- Shape of crown and stem are approximated by cylinder

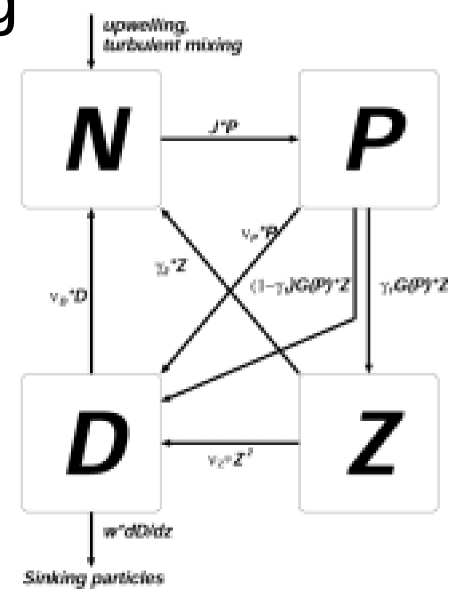
FRSGC integrated Earth System Model KISSME



Oceanic Carbon Cycle Model

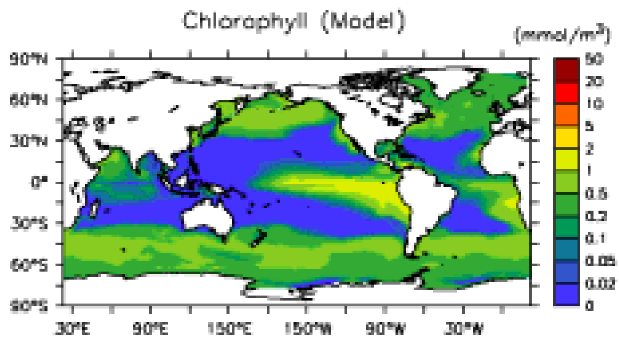
- Biological Model: Oschlies & Garçon (1998)
  with the carbonate system
- OGCM: COCO3.4 (Hasumi, 2000)

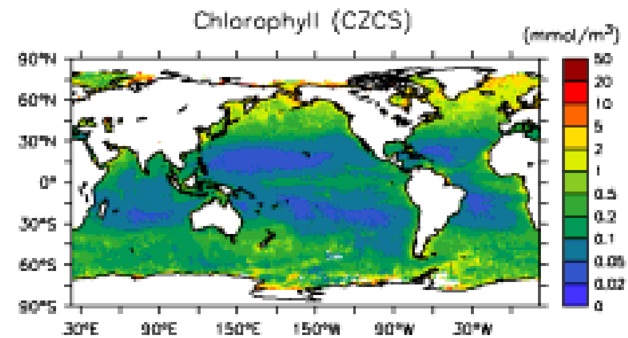
- Horizontal Resolution: 1 deg. x 1 deg
- 54 Vertical Levels
- Forcing: Monthly mean climatology
- Integration Period: 19 years



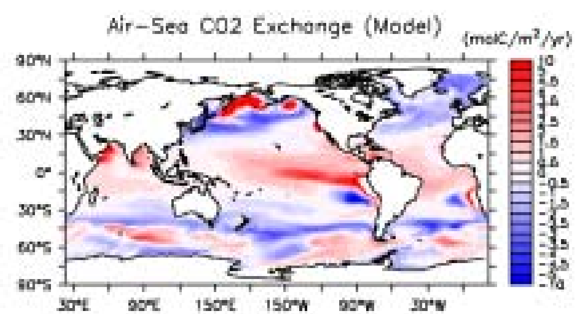
Some Model Results

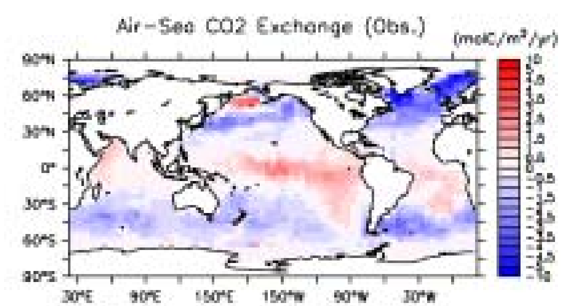
Surf. Chl.





Air-Sea CO_2 Exchange



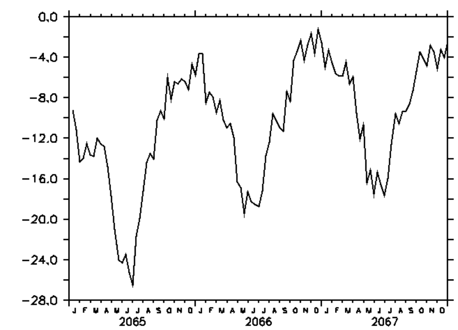


Model

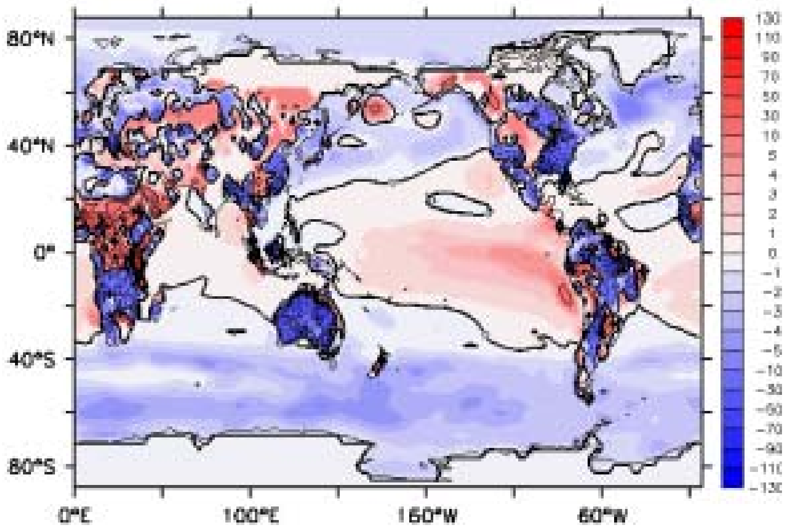
Obs.

Coupling of the Oceanic and terrestrial

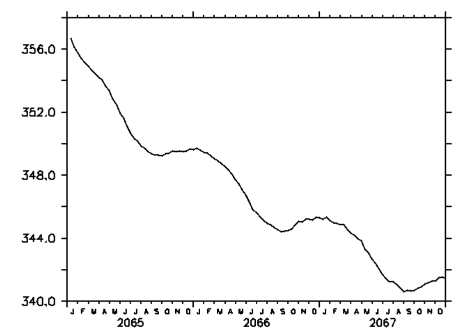
global mean CO2 flux [PgC/yr]



CO2 flux at the sea surface [molC/m^2/yr]



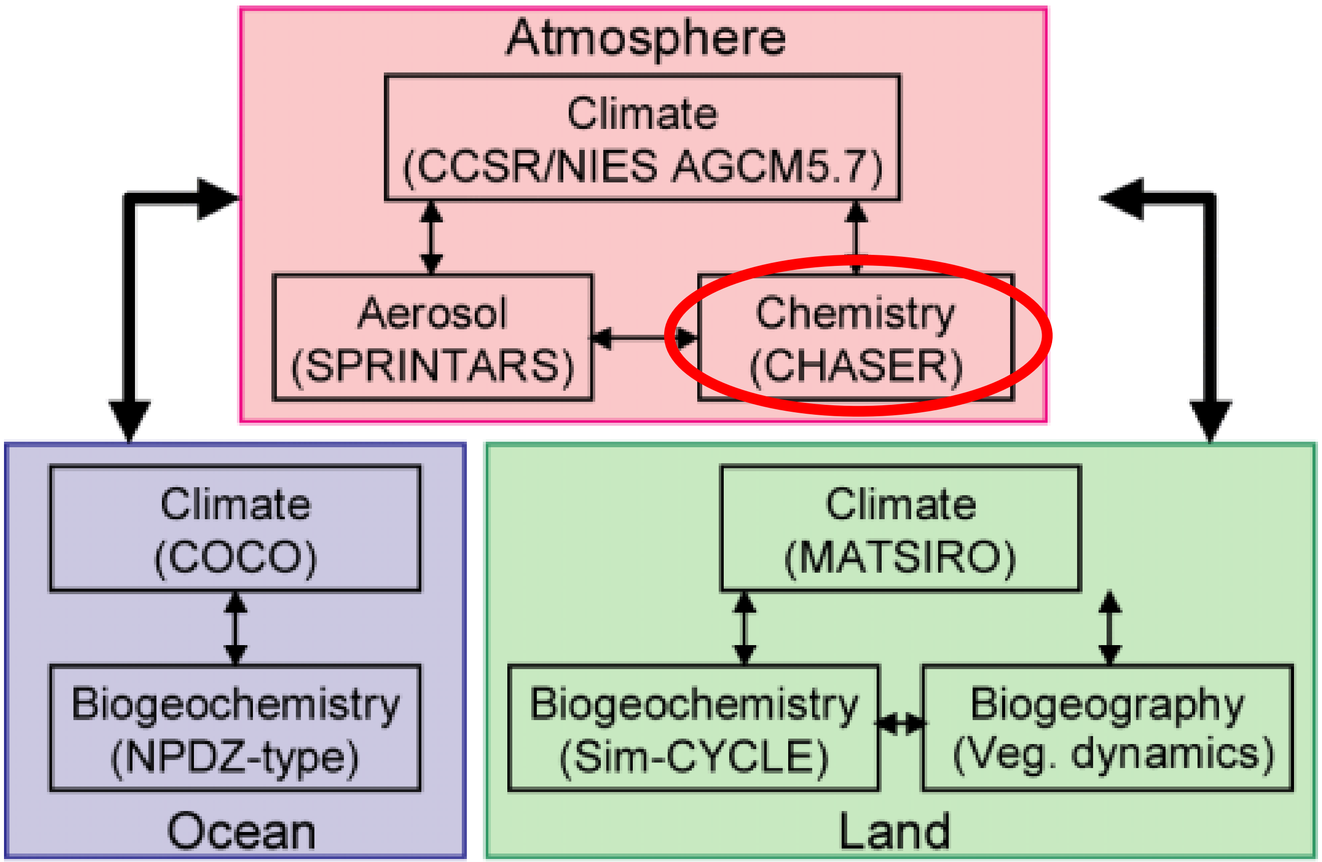
global mean CO2 concentration [ppmv]



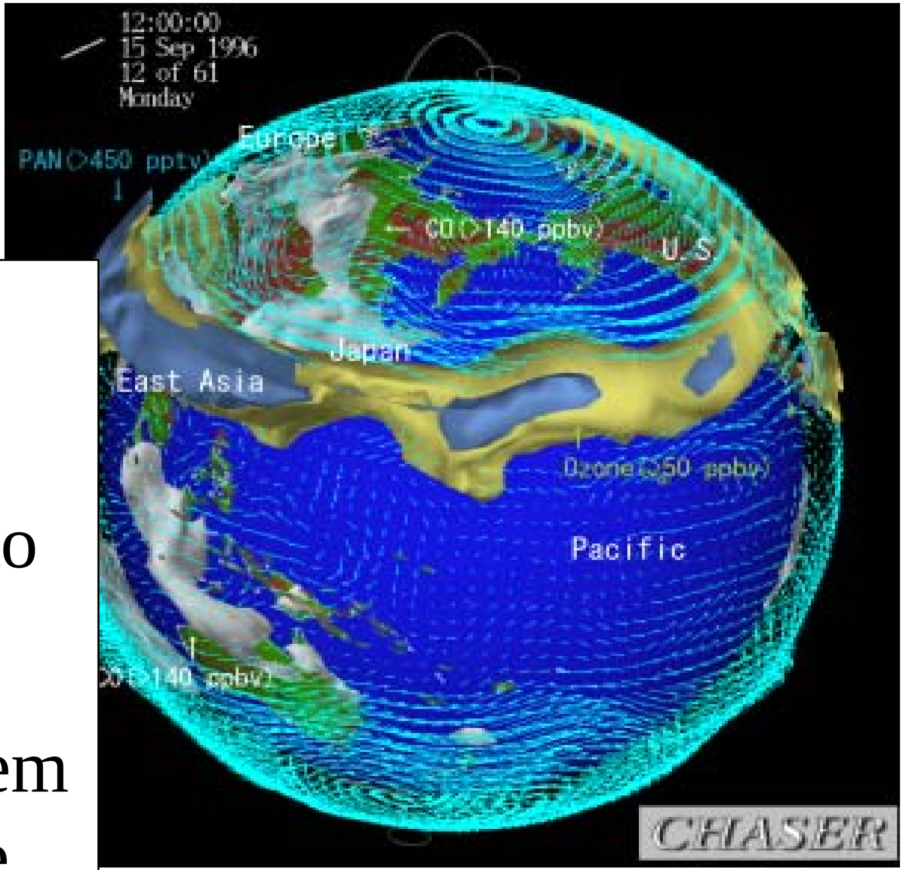
AGCM: T42L20,

OGCM: 0.5-1.0 deg, L44

FRSGC integrated Earth System Model
KISSME



Atmospheric chemistry model (CHASER)



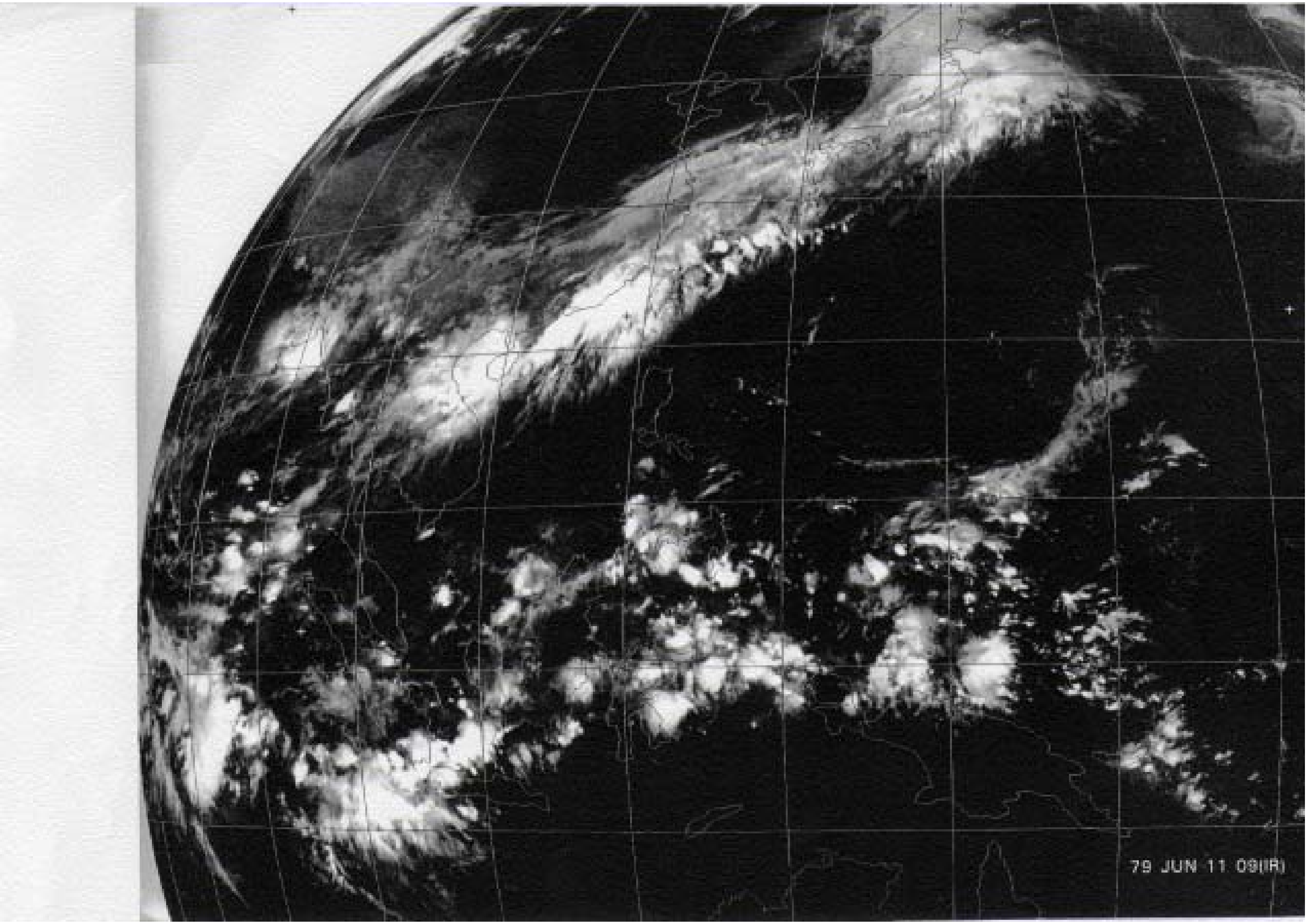
- 53 chemical species (ozone, NOx, etc.)
- Chemical reactions up to ~20 km altitude
- A simple reaction system in the stratosphere will be added.

Next-Generation Model Development at FRSGC

1. Global Cloud-Resolving Atmosphere Model
   (Icosahedral Geodesic Grid)
2. Eddy-Resolving World Ocean Circulation Model
   (Equal- Area Cubic Grid)

Why we need cloud-resolving model?

- Parameterization of convective clouds is impossible for 10~50km grids
  (no scale separation)
- Meso-scale convective cloud systems (cloud clusters) have particular structure and behave autonomously.
  -> “Large-scale control” does not hold


79 JUN 11 09(IR)

Mesoscale and Convective-Scale Downdrafts as Distinct Components of Squall-Line Structure

Schematic picture of cloud cluster
Entirely different from
Benard cell

E. J. Zipser

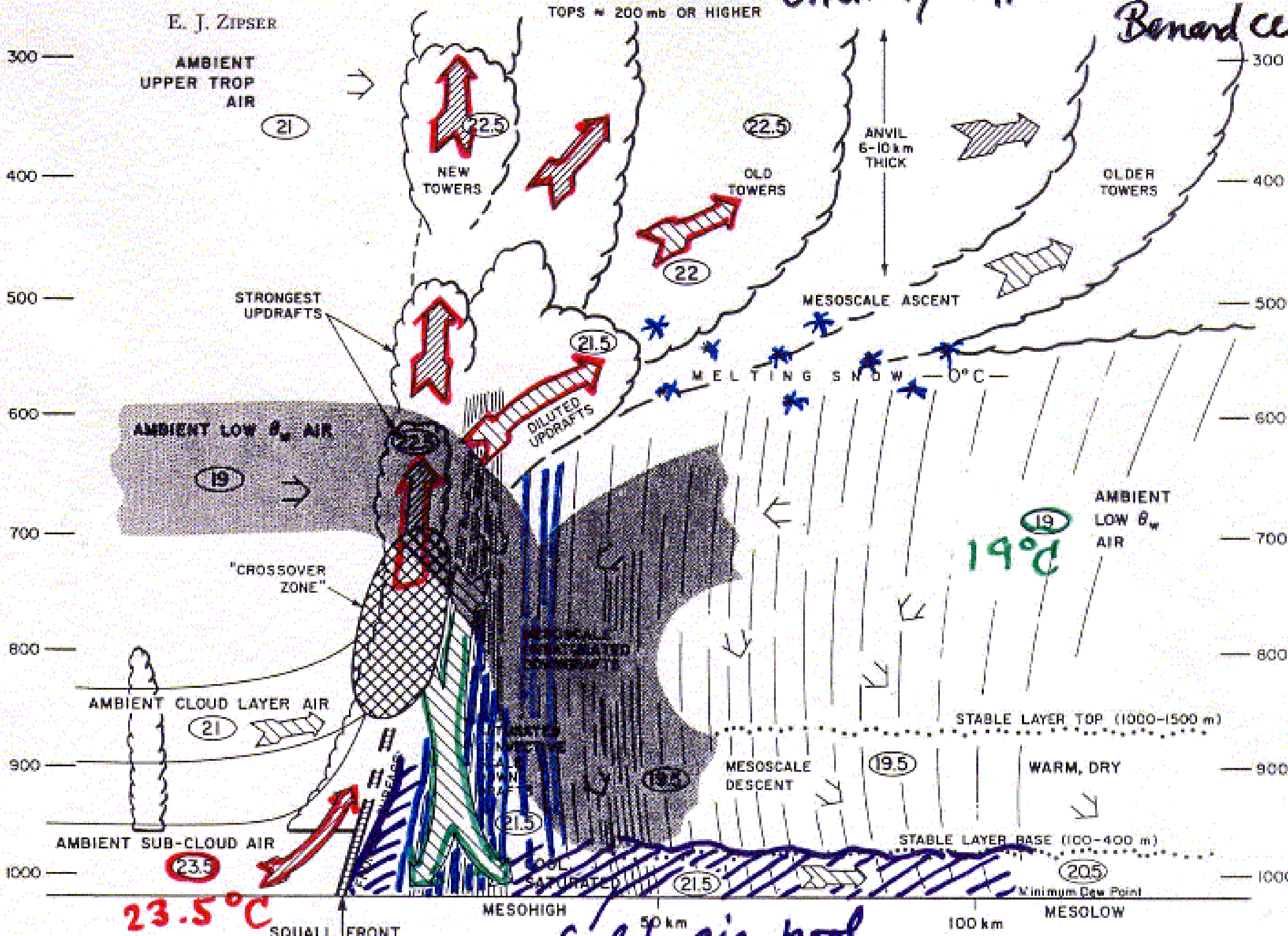
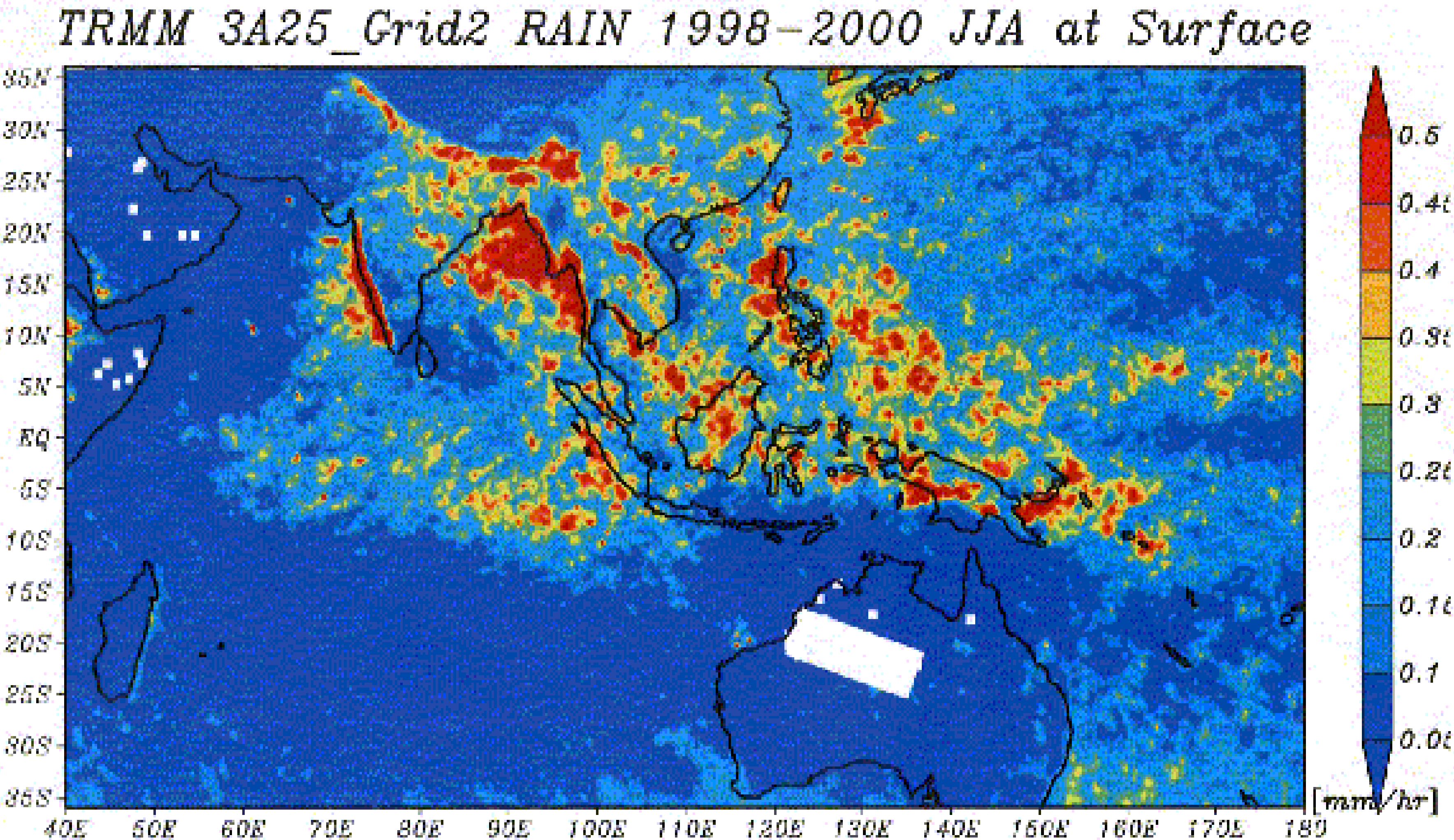


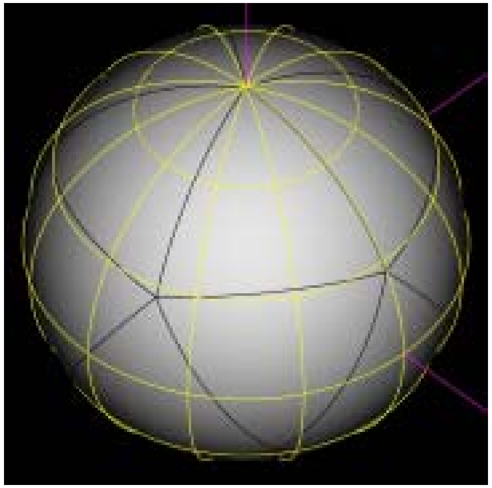
FIG. 13. Schematic cross section through a class of squall system. All flow is relative to the squall line which is moving from right to left. Circled numbers are typical values of θ_w in °C. See text for detailed discussion.


TRMM 3A25_Grid2 RAIN 1998-2000 JJA at Surface
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
25S
30S
35S
40E
50E
60E
70E
80E
90E
100E
110E
120E
130E
140E
150E
160E
170E
0.5
0.4
0.3
0.2
0.1
[mm/hr]

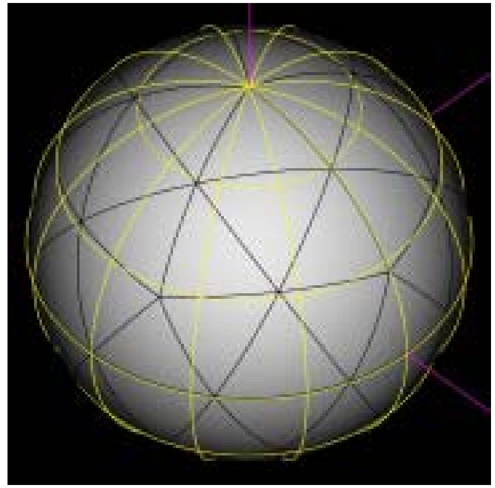
Development of the Global Cloud Resolving Model Using the Icosahedral Grid

Frontier Research System for Global Change
Hirofumi TOMITA
Masaki SATOH
Koji Goto
Shin-ichi IGA
Tomoe NASUNO

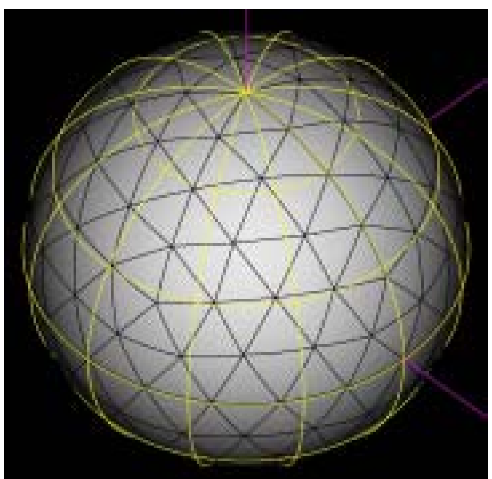
(0) grid division level 0



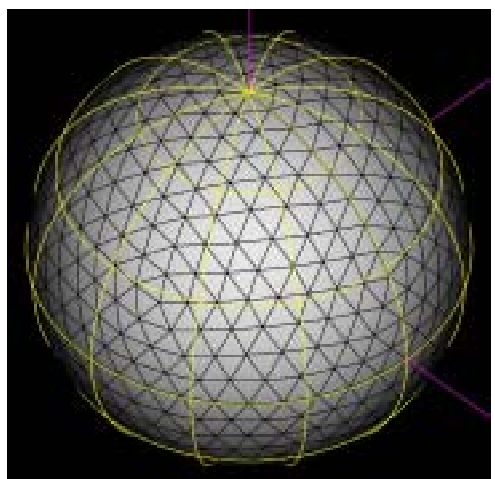
(1) grid division level 1



(2) grid division level 2

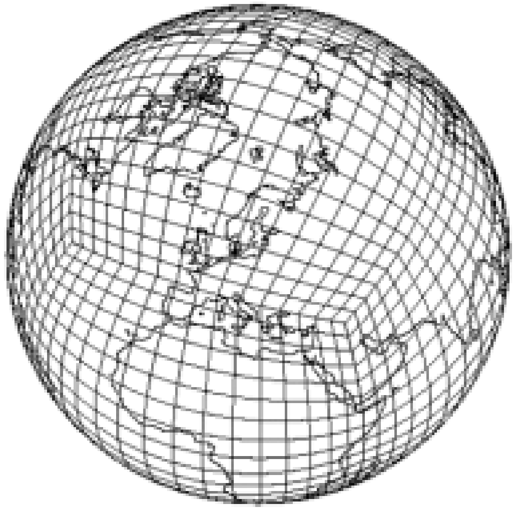


(3) grid division level 3



- Grid generation method
  1. Start from the spherical icosahedron. (glevel-0)
  2. By connecting the mid-points of the geodesic arcs, four sub-triangles are generated. (glevel-1)
  3. By iterating this process, a finer grid structure is obtained. (glevel-n)
- # of gridpoints
  - 11 interations are requried to obtain the 5km grid interval.

Variations of cubic grid



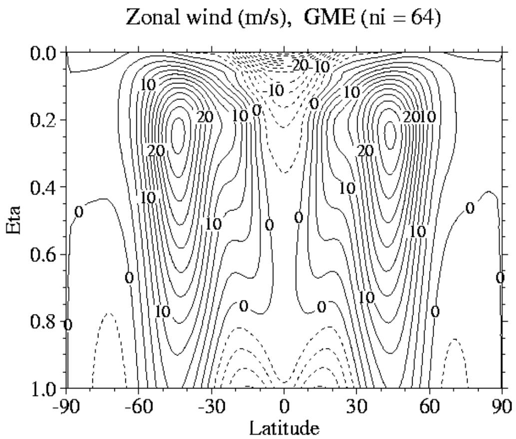
gnomonic projection

Conformal projection

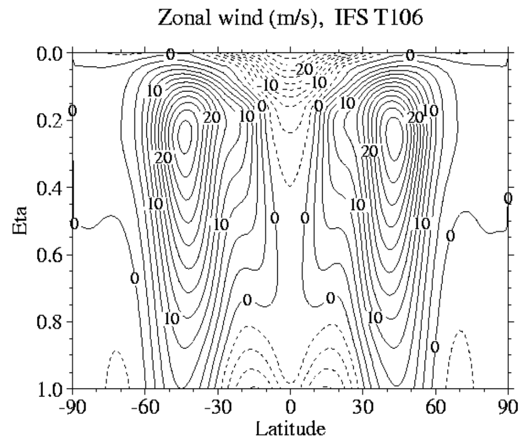
homogeneous projection

Held & Suarez Dynamical Core Exp.

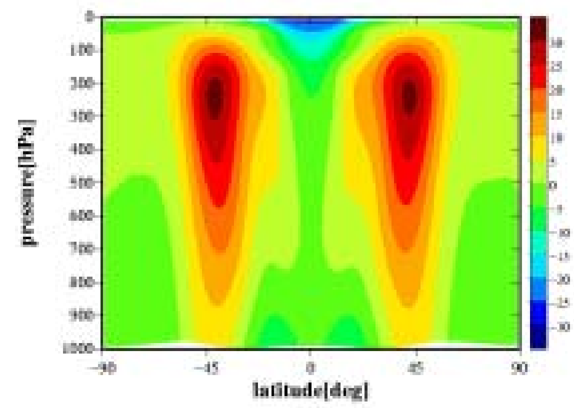
(a) GME(ni=64)



(b) IFS



(c) Our model



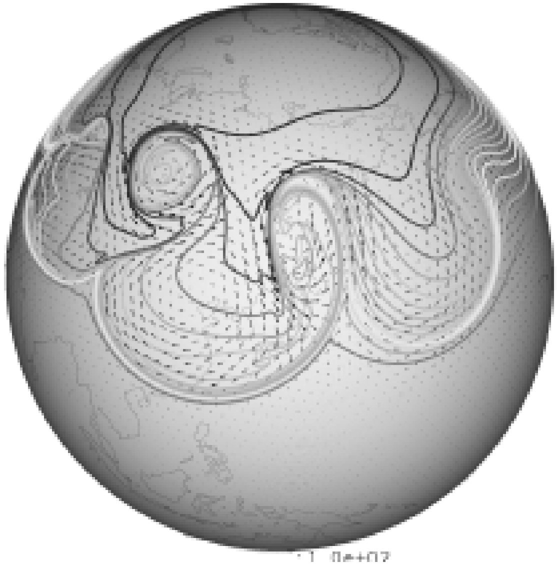
- **The jet is located at 45[deg] and 250[hPa] in all cases.**
- **There is no difference of distribution and intensity between the model results.**

Lifecycle experiment of baroclinic wave

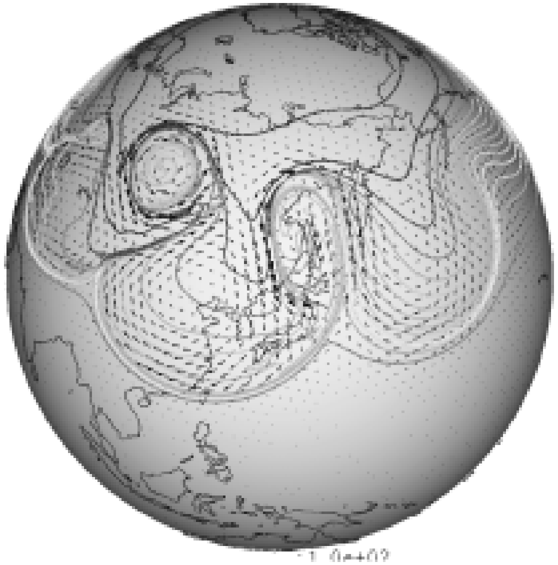
Global structure : almost same

- Results after 10 days
  - Temperature & velocity fields at z=180m

Glevel-6 :120km



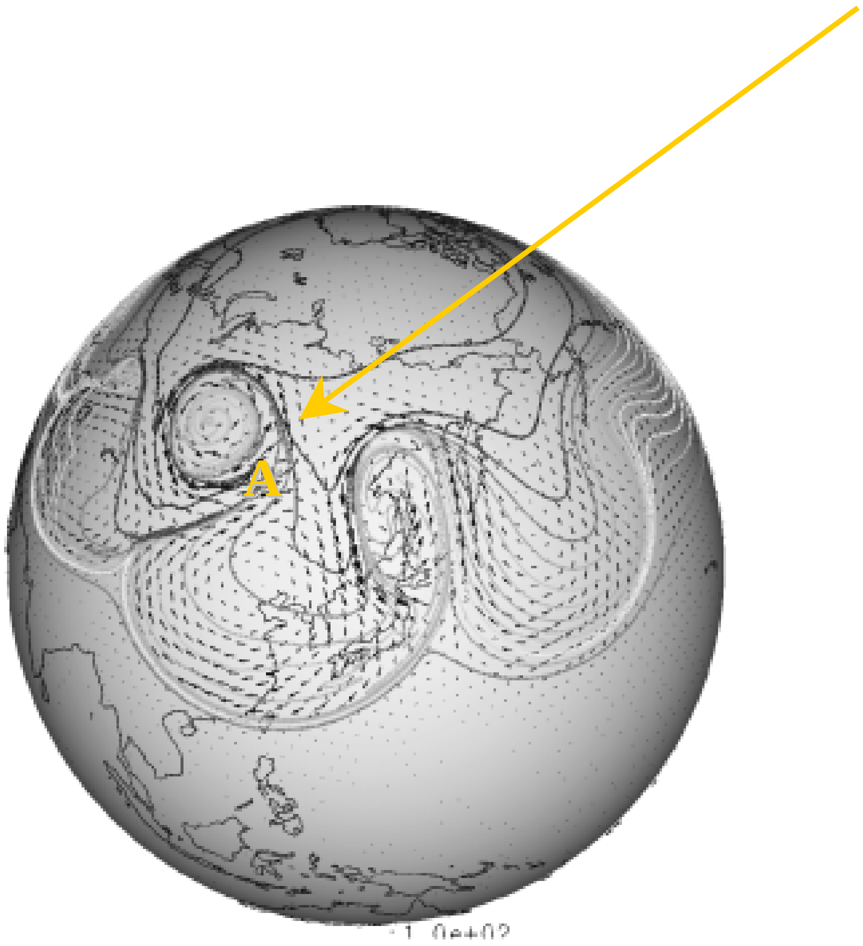
Glevel-8 :30km

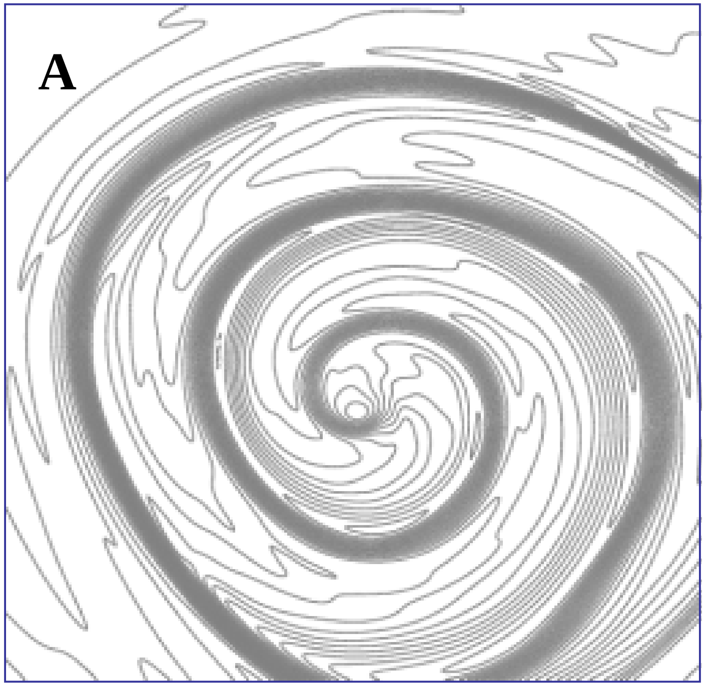


Glevel-10 :7.5km

Lifecycle experiment of baroclinic wave

- **Local structures of glevel-10(7.5km)**





Computational Performance

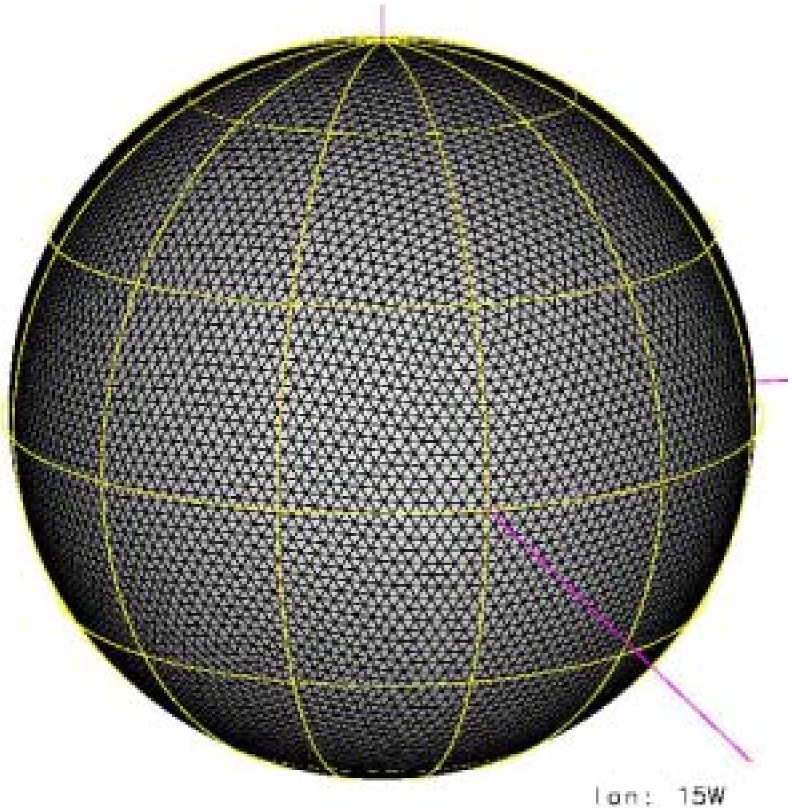
- How long time in 3.5km/L50？（measured in ES）
  - Target mesurement：
    LCE 1day simulation(dry version : only dynamical core)

Horiz. grid	Δt [s]	# of Node(CPU)	Elapse time [h:m:s]	FLOPS	Sustained performace
Gl-6（120km）	900	5 (40CPU)	00:00:19	90G	28%
Gl-7（60km）	450	20 (160CPU)	00:00:32	410G	32%
Gl-8（30km）	200	80 (640CPU)	00:00:68	1720G	33%
Gl-9（14km）	100	80 (640CPU)	00:06:30	2260G	44%
Gl-10（7km）	50	80 (640CPU)	00:46:50	2450G	48%
Gl-11（3.5km）	25	320(2560CPU)	01:34:10	9750G	48%

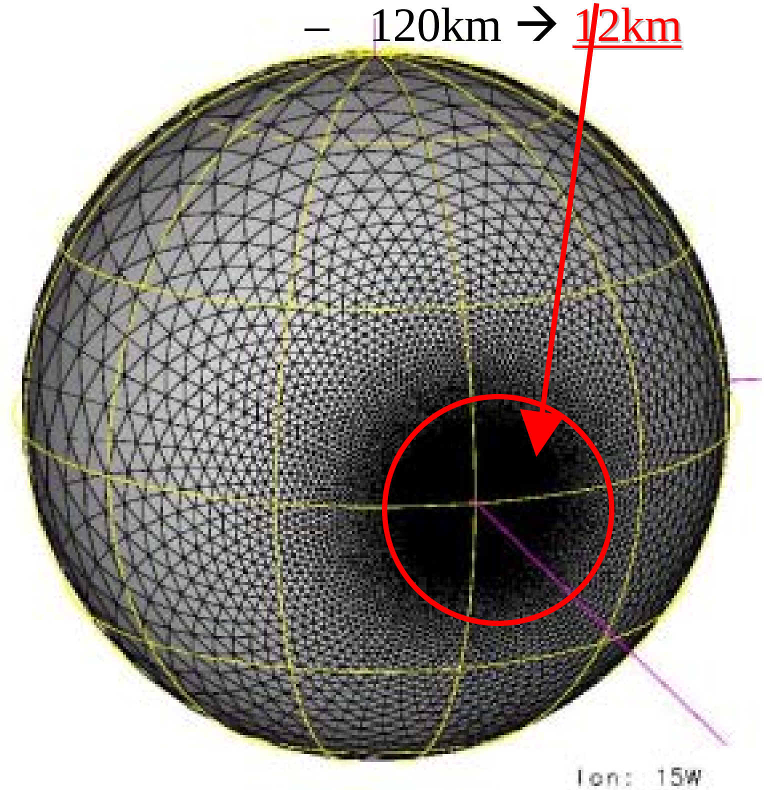
Optimized version : 1.5h → 1.1h

In the case of including physical processes,
→ Within 2 or 3 hours (rough estimate)

- Default grid : glevel-6
  - 120km grid intv.
    - Homogenious

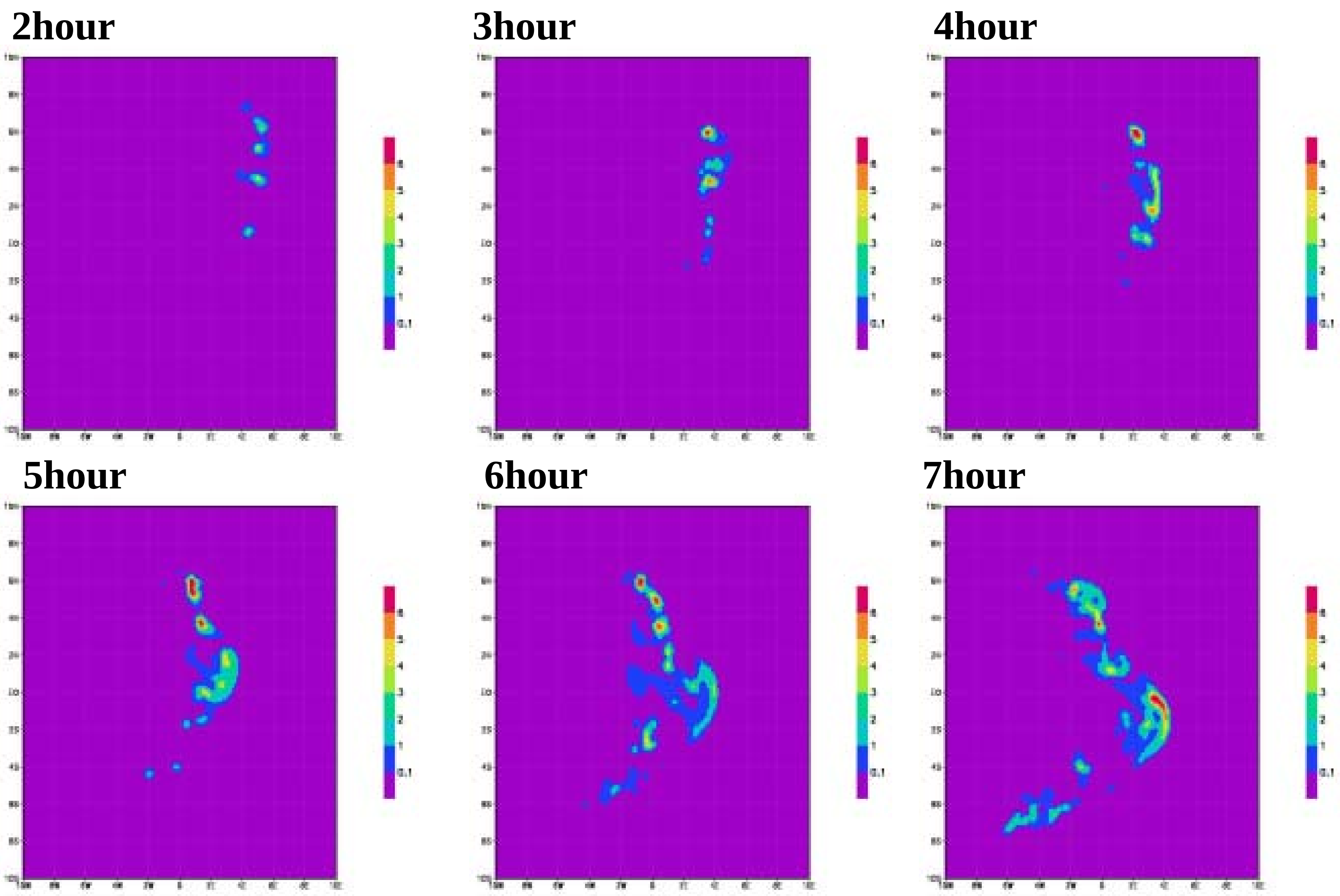


- Stretched grid
  - After the transformation
    - Grid interval :
      - 120km → 12km



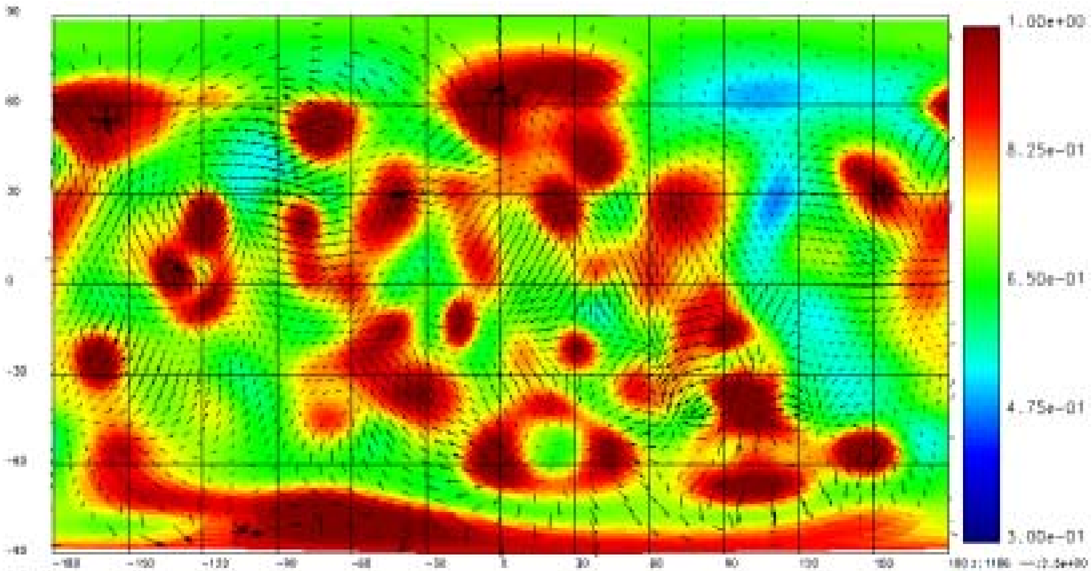
Reduction of earth radius : 1/10
1.2km grid interval

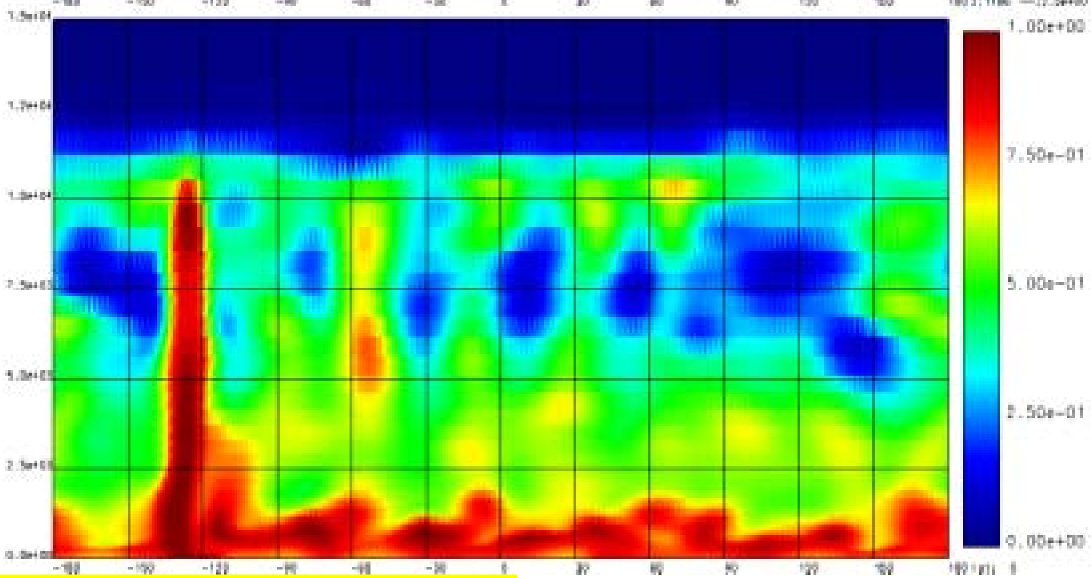
Total hydrometeor at z=1.4km (G1998)



Radiation-Convection Equilibrium Test

Relative humidity & horizontal wind at z=1km





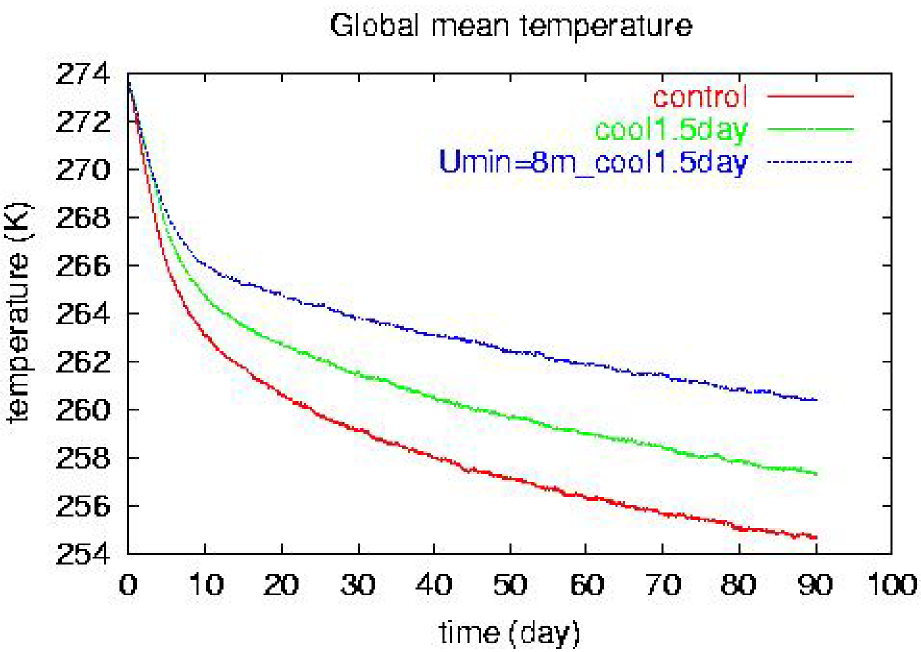
Vertical section at the equator

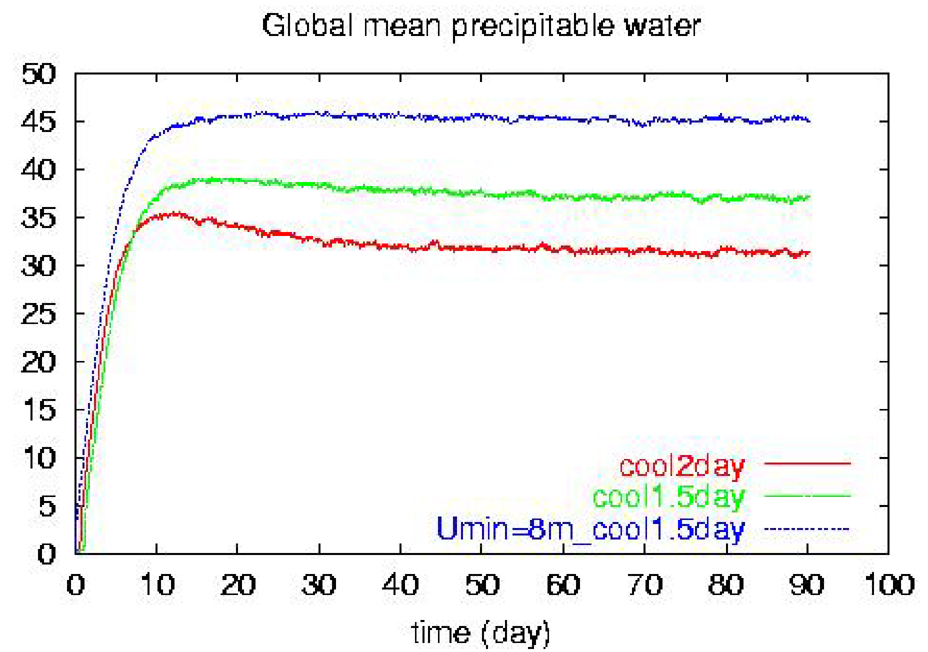
- Configuration
  - Initial condition:
    - An appropriate temperature profile
  - Ratiation:
    - No-interaction with cloud
    - Newtonian cooling cooling rate :

      2K/day in the troposphere
  - Surface condition :
    - Temperature:300K
    - Water vapor: saturated

    → tropical evironment
  - Scheme used:
    - Turbulece : MY-lev2
    - Micorphysics: G1998
    - Surface flux : Louis et al.
  - Grid used:
    - 3.5km/ R=100km

    → Very very small earth





- Global mean temperature
  - Control case < Reduced cooling case < Increased flux case
- Global mean precipitable water
  - Control case < Reduced cooling case < Increased flux case

Equillibrium : not yet achieved

Less precipitable water than the typical value (60kg/m^2)

→ Better result, if interacted with radiation process?

Cubic grid OGCM

Sea Surface Hight
(after 500 yr integration)

Resolution: ~100 km

Initial condition:
- *isothermal(10 deg)*
- *motionless*

Surface Boundary Conditior
- *Hellerman and*
  - *Rosenstein windstres*
- *Levitus temperature*

Simplified Physics