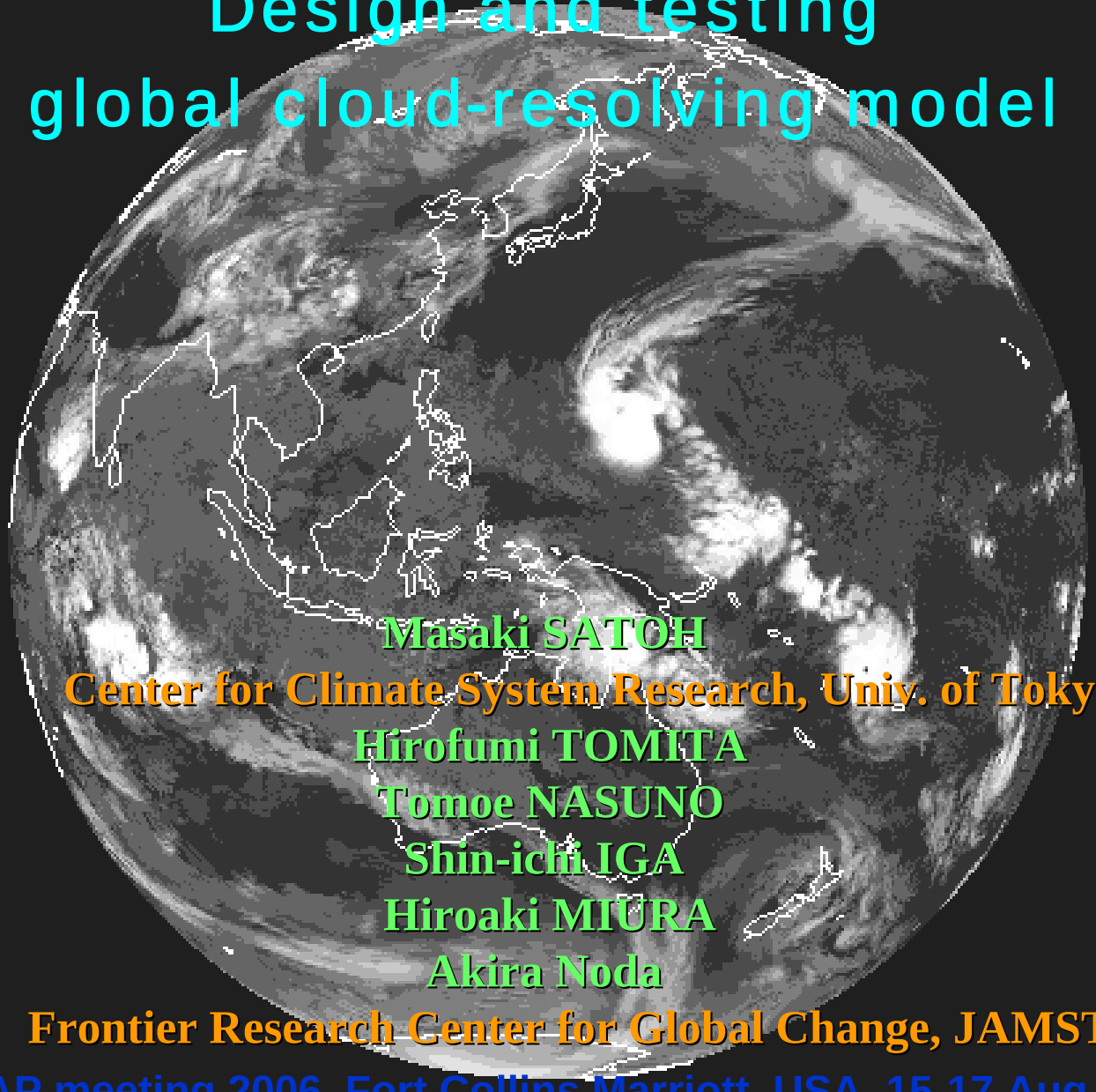
Design and testing of a global cloud-resolving model



Masaki SATOH

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Hirofumi TOMITA

Tomoe NASUNO

Shin-ichi IGA

Hiroaki MIURA

Akira Noda

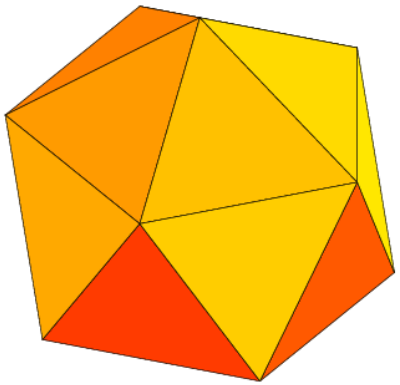
Frontier Research Center for Global Change, JAMSTEC

CMMAP meeting 2006, Fort Collins Marriott, USA, 15-17 Aug. 2006

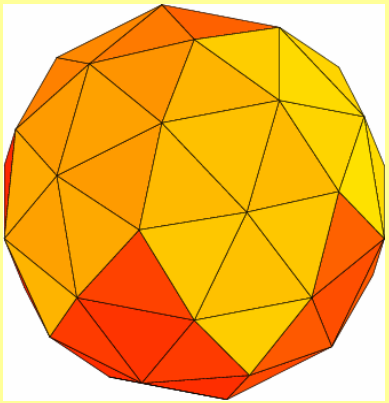
Outlines of NICAM

Global Cloud Resolving Model
NICAM (Nonhydrostatic ICosahedral Atmospheric Model)

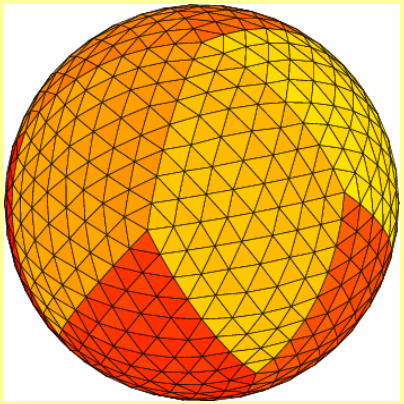
- Icosahedral grid & Nonhydrostatic model & Explicit cloud physics
- Development since 2000: number of test cases
- Cloud microphysics instead of cumulus parameterization used for AGCMs
- Horizontal resolution: up to dx=3.5km



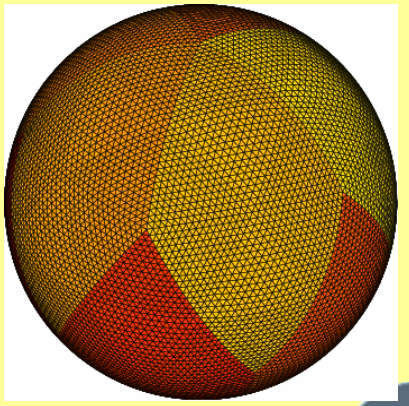
Glevel-0



Glevel-1



Glevel-3



Glevel-5

NICAM family

✓GCM
with cumulus parameterization

- Glevel 4: 480km
- Glevel 5: 240km
- Glevel 6: 120km
- Glevel 7: 60km
- Glevel 8: 30km

✓GCRM
with explicit cloud physics

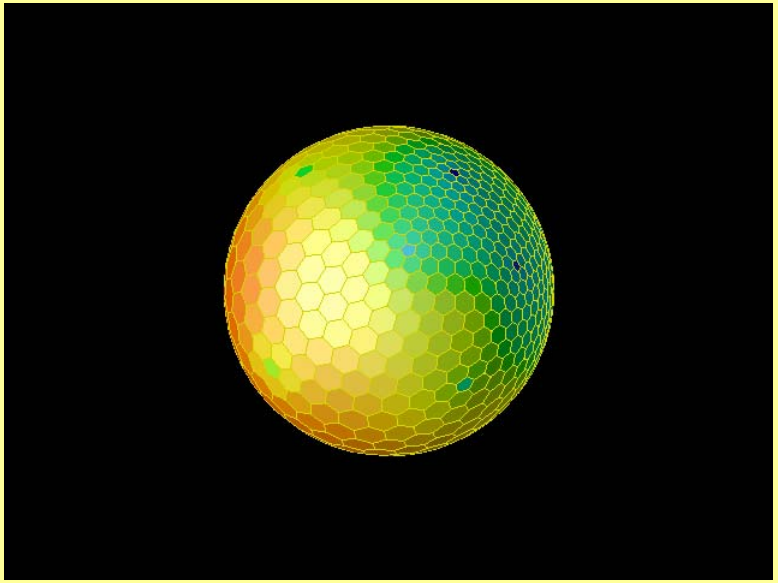
- Glevel 9: 14km
- Glevel 10: 7km
- Glevel 11: 3.5km

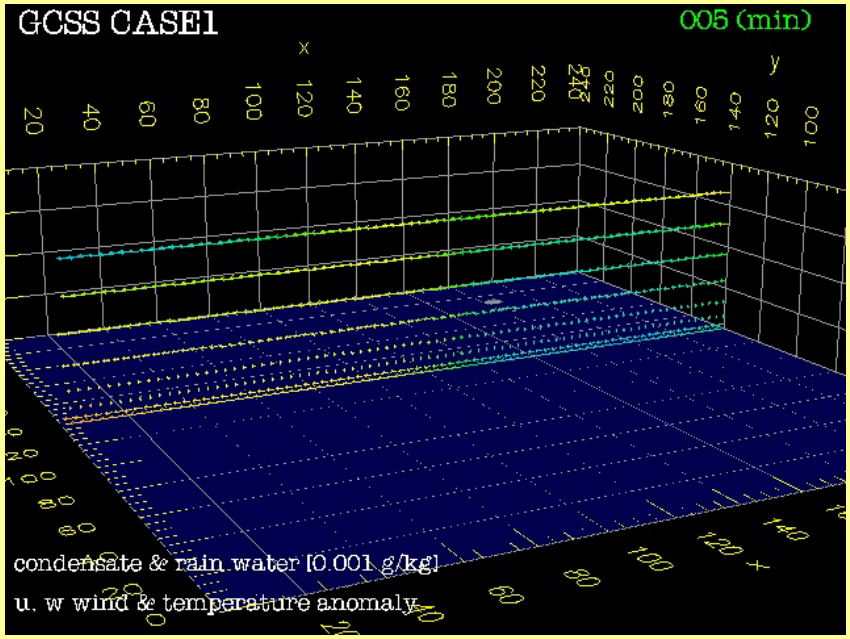
✓Regional model
with stretched grid

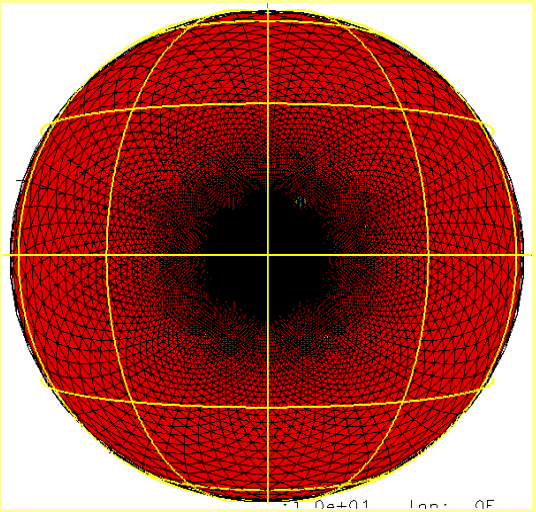
✓Small-planet (or asteroid)
for radiative-convective equilibrium exp.

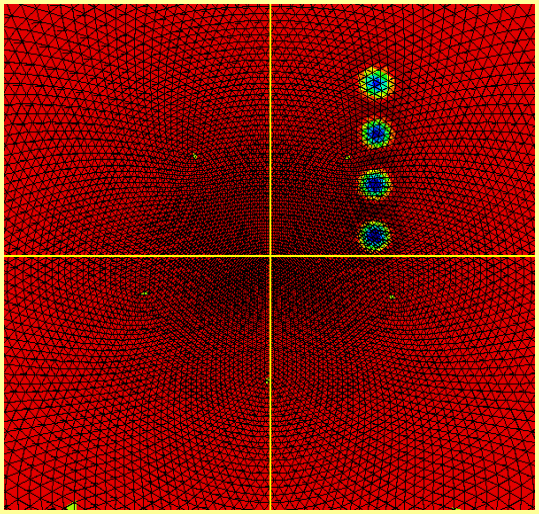
✓Cartesian coordinate model

NICAM as a regional model



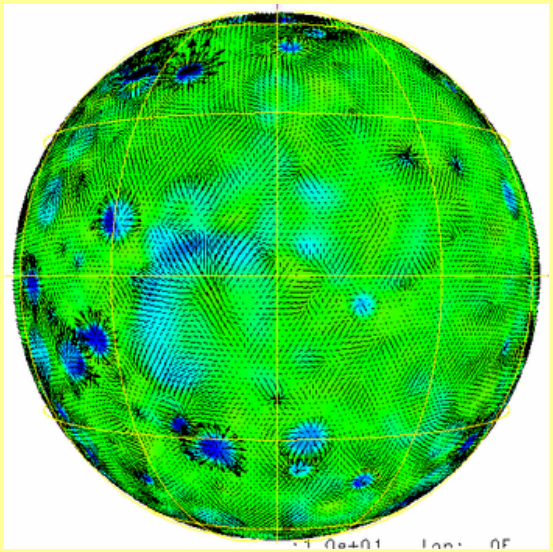




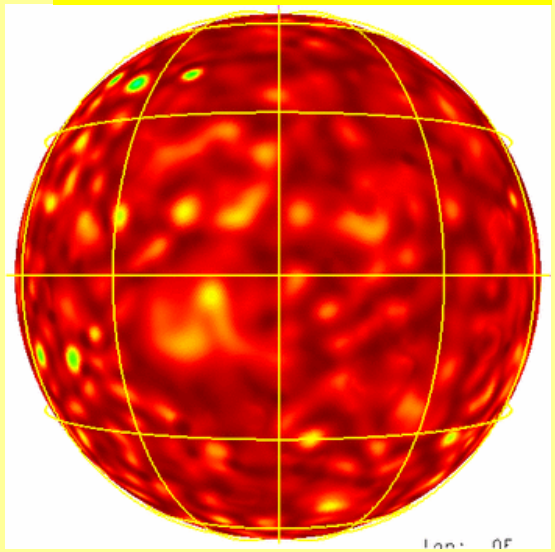


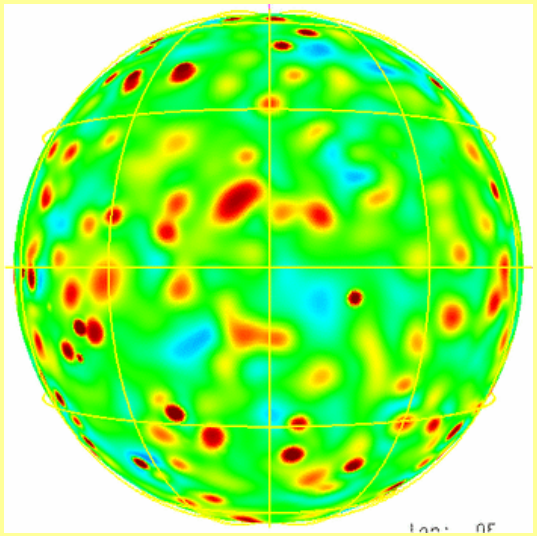
Radiation-Convection Equilibrium Test

Temperature and horizontal velocity at the lowest layer 35m

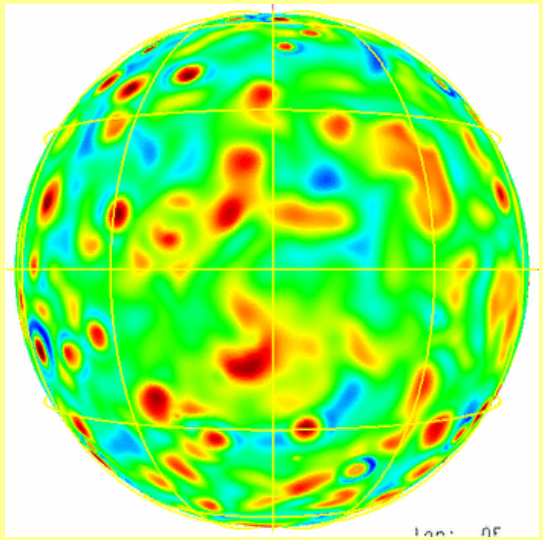


Relative humidity at z=350m





Relative humidity at z=5km



Relative humidity at z=10km

Configuration

Initial condition:

- An appropriate temperature profile

Surface condition :

- Temperature:300K
- Water vapor: saturated

→ tropical evironment

Physics:

- Turbulece : MY-lev2
- Micorphysics: G1998
- Radiation: constant or MSTRN-X
- Surface flux : Louis et al.

Grid used:

- Small planet with R=400km
- Grid size = 3.5km

- **GCRM exp. using NICAM**
  - Aqua planet experiments by H.Tomita(GRL, 2005)
  - Short term experiments for Apr. 2004 (weather forecast modes) by H.Miura(GRL, 2006, submitted)
  - Perpetual July Long term exp. (climate statistics) by S.Iga
- **Planned exp.**
  - Sensitivity on microphysics with Lin-type scheme
  - MJO, cyclogenesis of typhoons
  - Aerosols (NICAM-SPRINTARS) by K.Suzuki

Global cloud resolving simulations

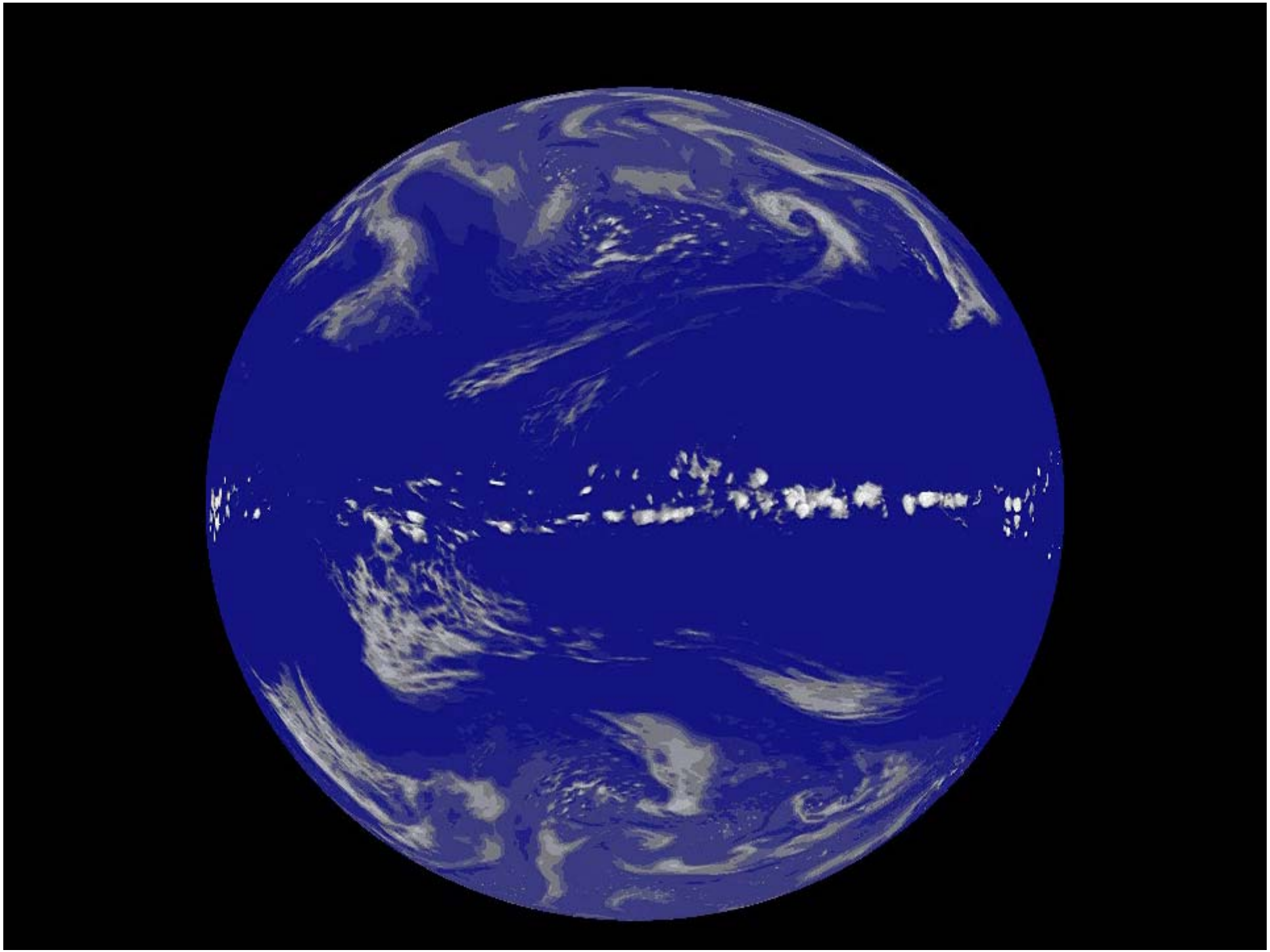
Aqua Planet Experiments

14km-mesh exp. 90days
7km-mesh exp. 40days
3.5km-mesh exp. 10days

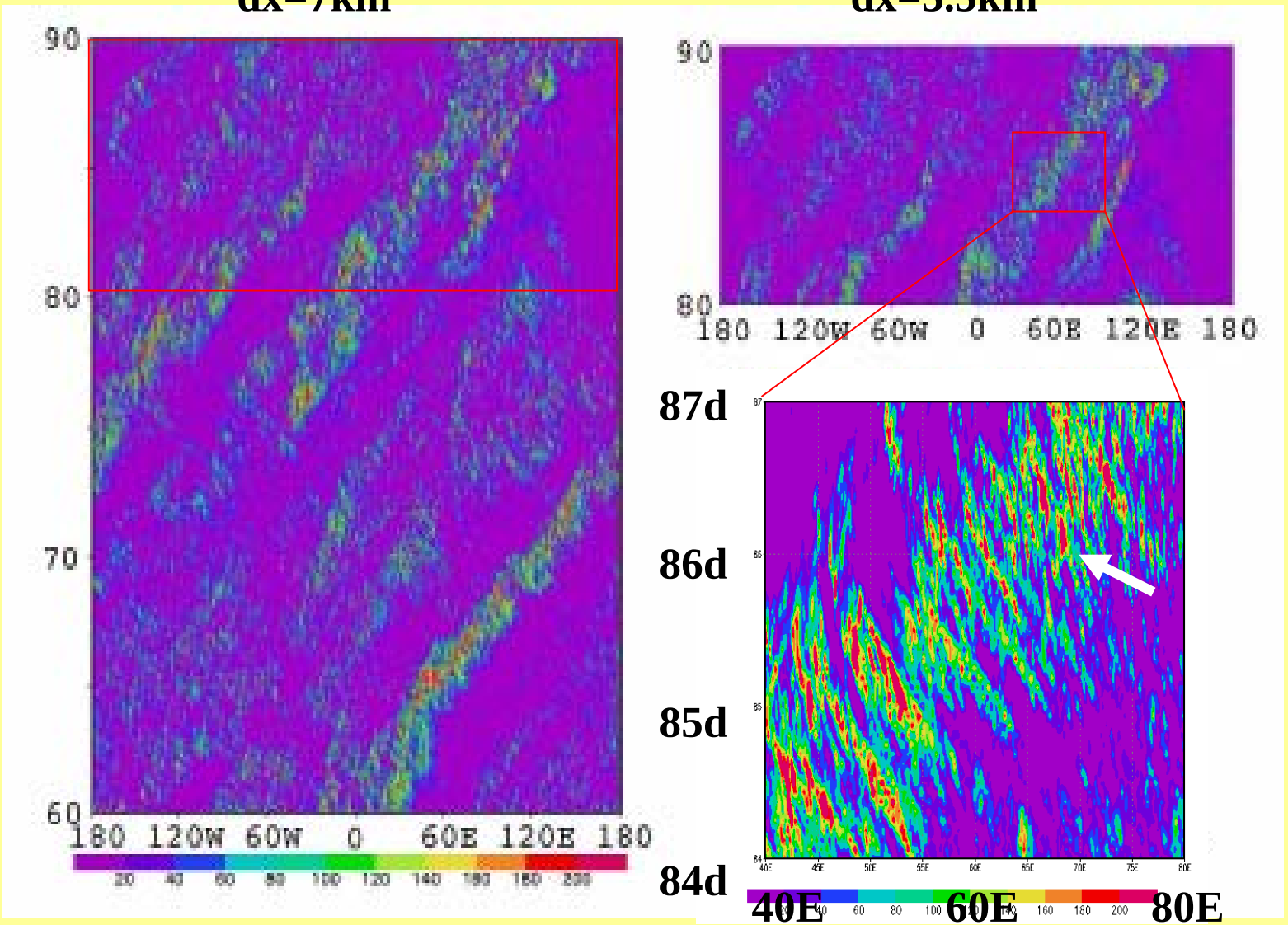
Multiscale convection

MJO & super cloud clusters
Cloud clusters
Meso-scale circulations
Individual cumulonimbus

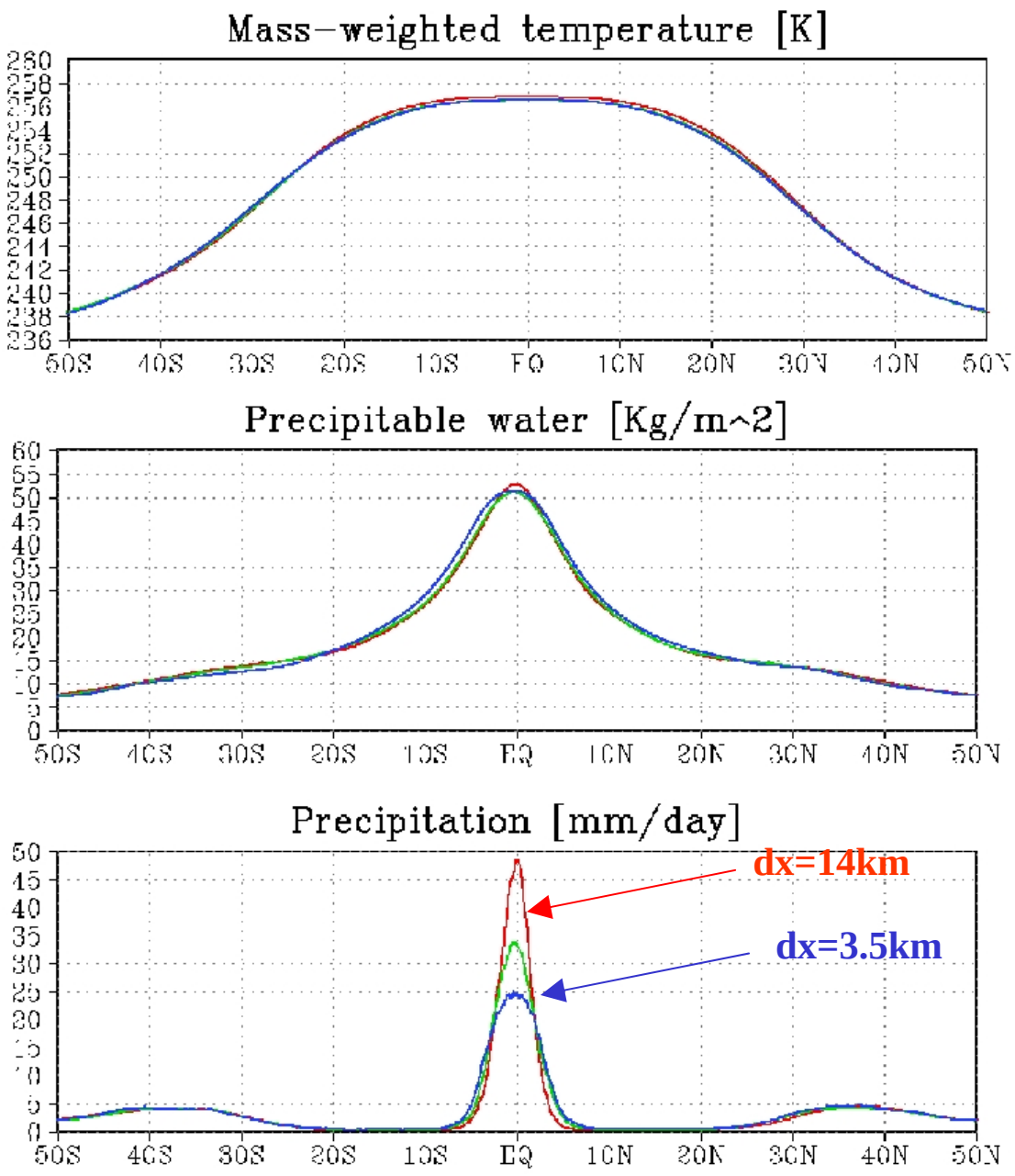
Tomita et al. (GRL, 2005)
Satoh et al. (JES, 2005)
Miura et al. (GRL, 2005)
Nasuno et al. (JAS, 2006, submitted)



Precipitation (2S-2N)



APE: resolution dependency of precipitation



Tomita et al. (2005,GRL)

- Temperature, precipitable water: converged
- The maximum precipitation decreases as dx decreeases from 14km to 3.5km

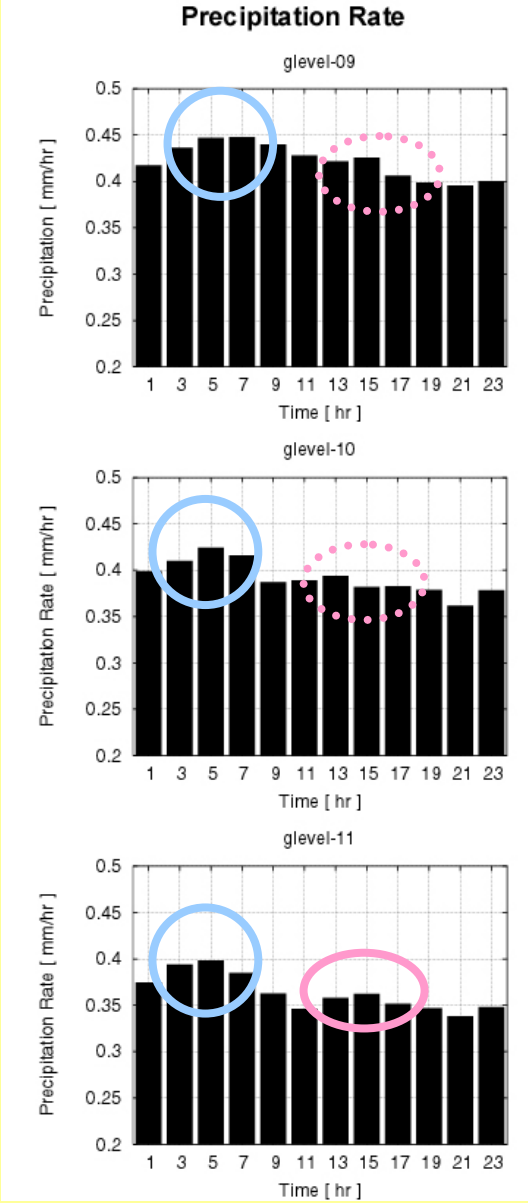
Diurnal cycle

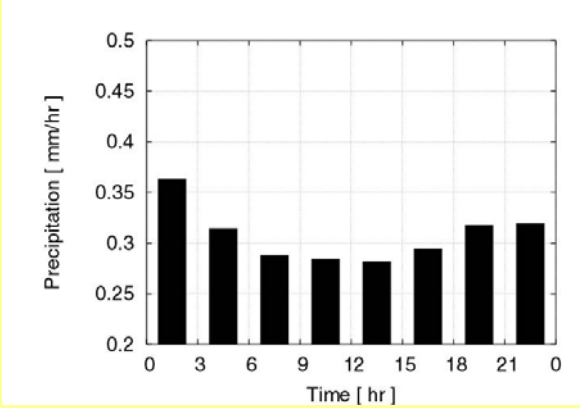
南緯10度～北緯10度

gl-09
(~14km)

gl-10
(~7km)

gl-11
(~3.5km)

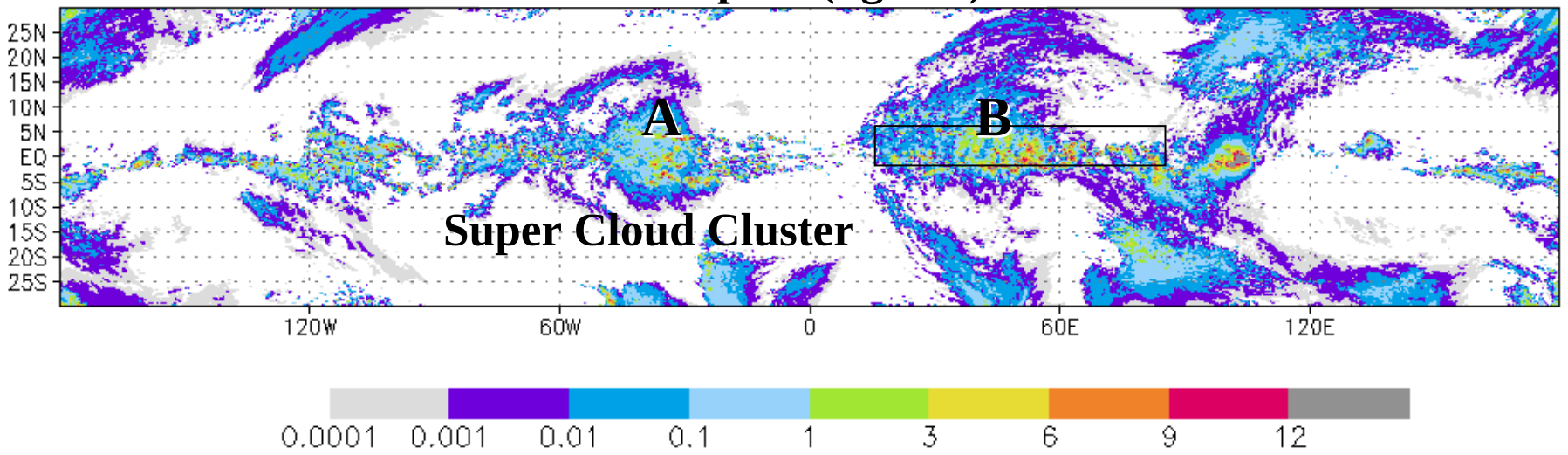




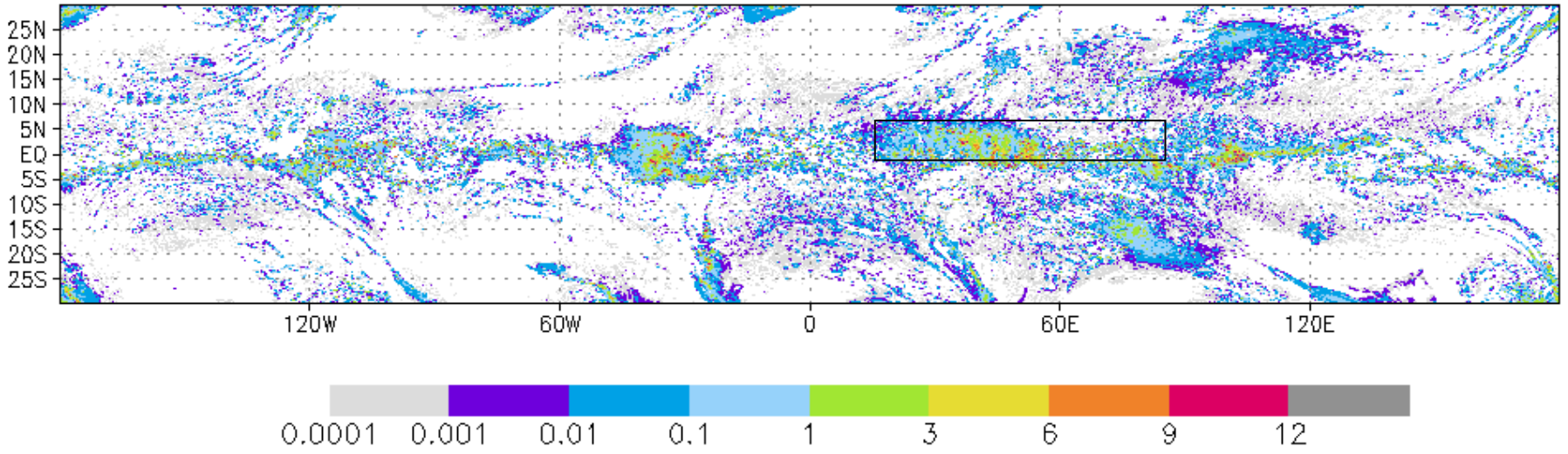
CCSR/NIES AGCM (T42)

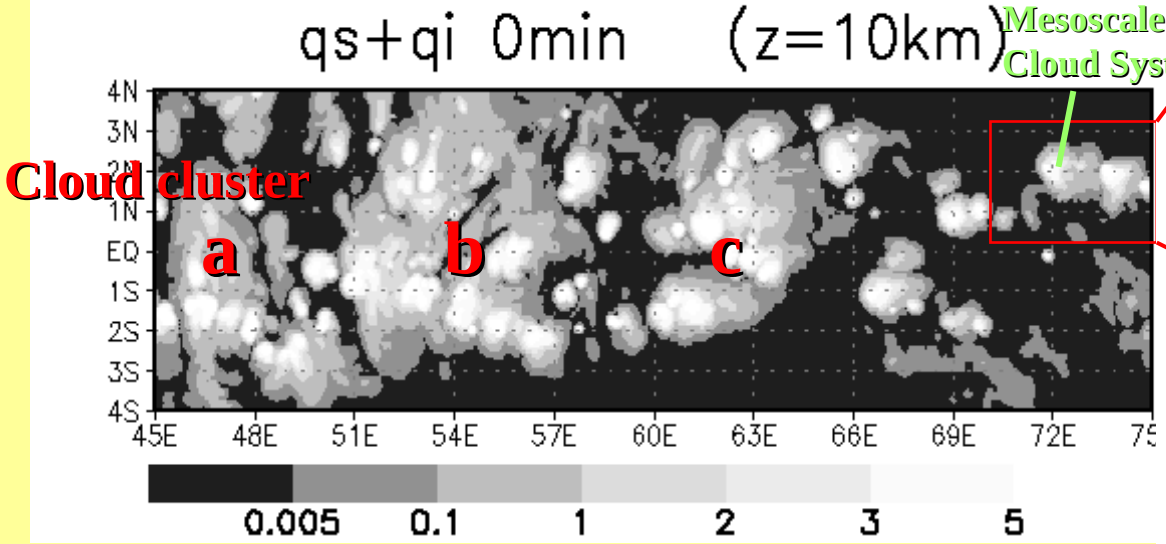
3.5-km mesh aqua planet experiment (NICAM)

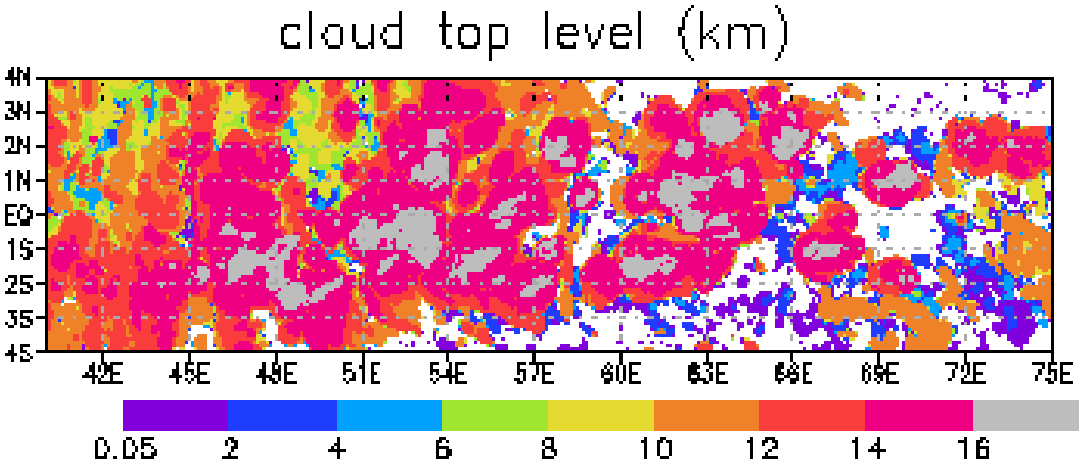
Ice water path (kg m $^{-2}$)



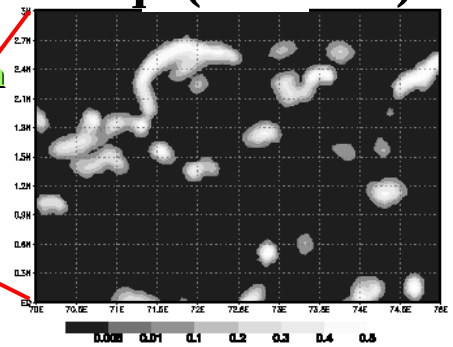
Liquid water path (kg m $^{-2}$)



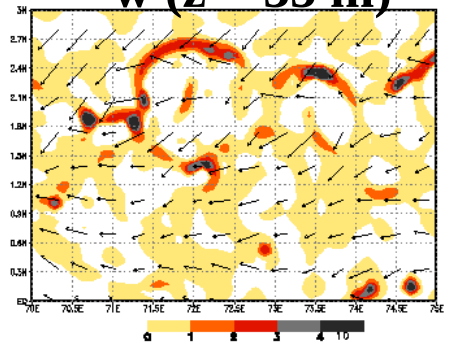




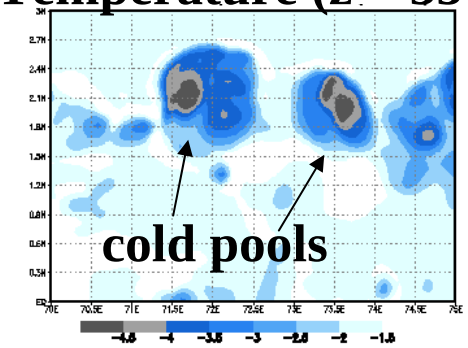
qc (z = 1 km)

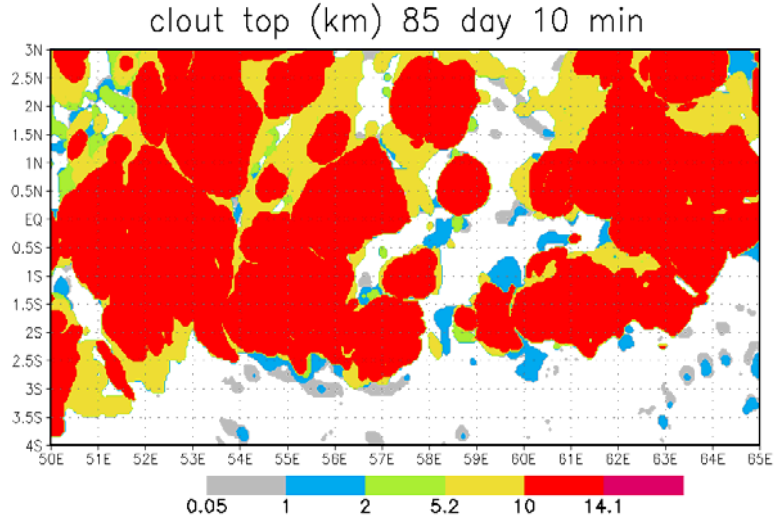


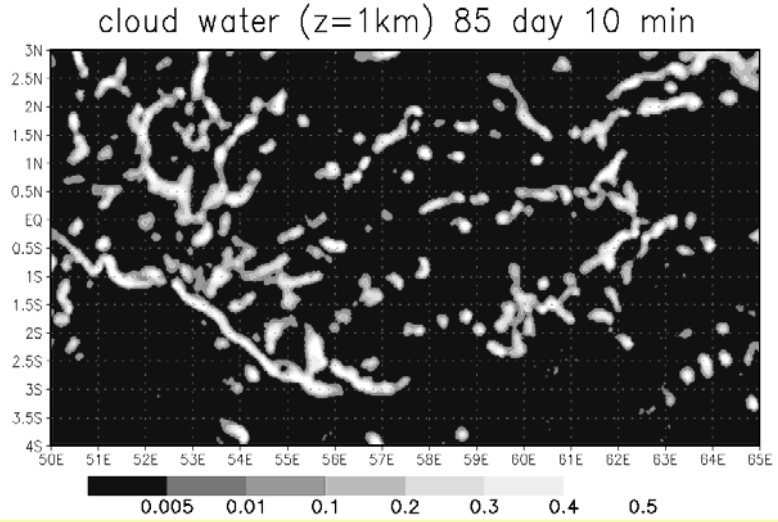
w (z = 35 m)

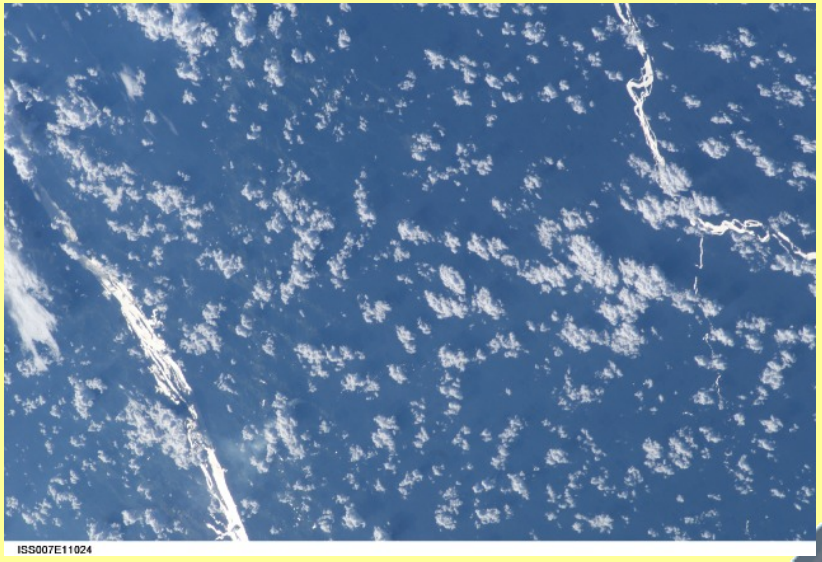


Temperature (z = 35 m)



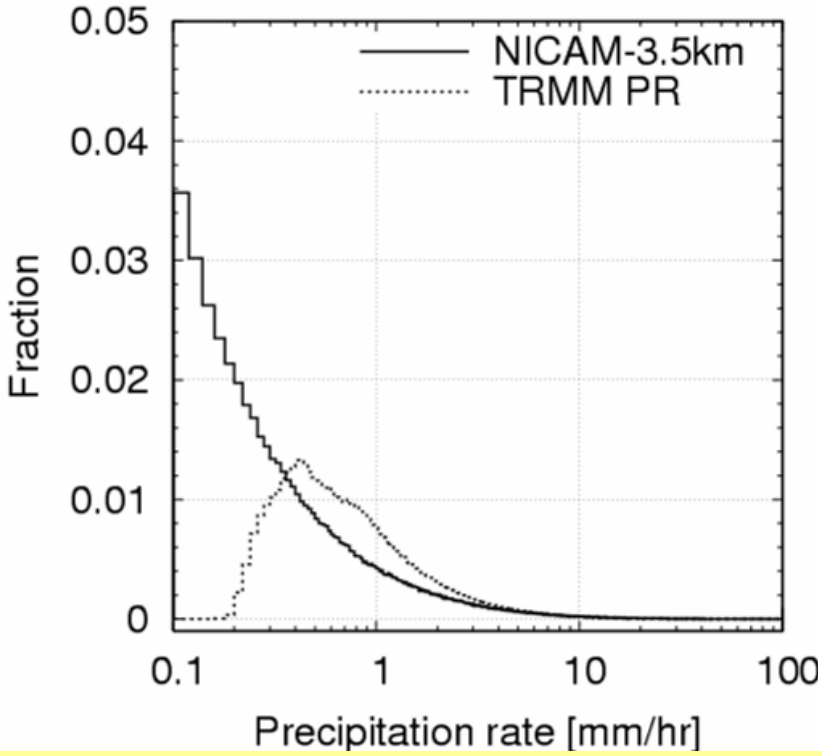

clout top (km) 85 day 10 min
3N
2.5N
2N
1.5N
1N
0.5N
EQ
0.5S
1S
1.5S
2S
2.5S
3S
3.5S
4S
50E 51E 52E 53E 54E 55E 56E 57E 58E 59E 60E 61E 62E 63E 64E 65E
0.05 1 2 5.2 10 14.1

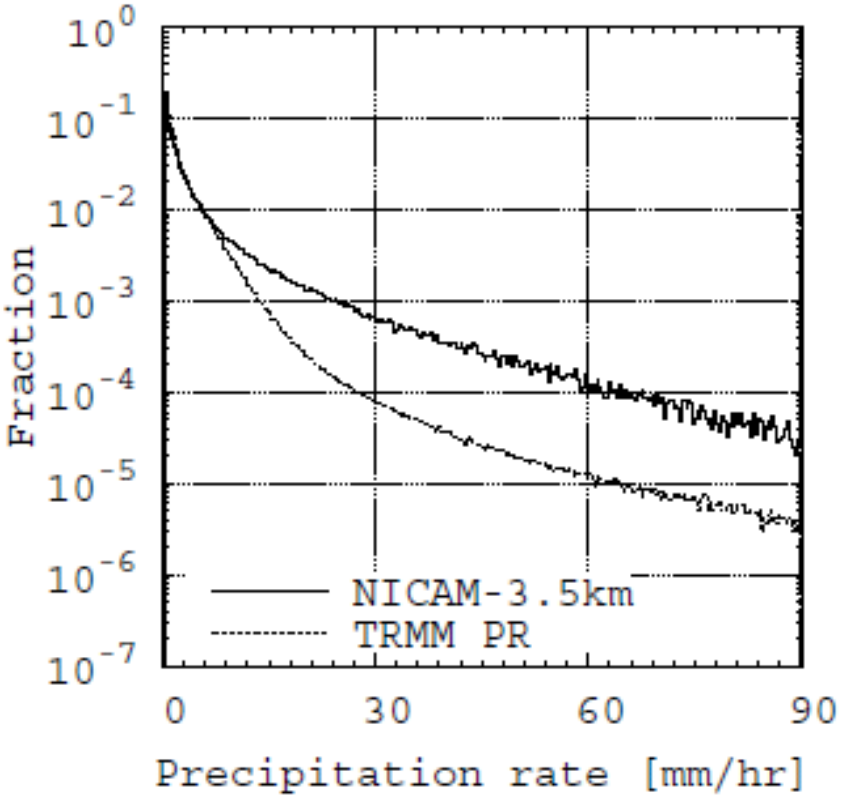

cloud water (z=1km) 85 day 10 min
3N
2.5N
2N
1.5N
1N
0.5N
EQ
0.5S
1S
1.5S
2S
2.5S
3S
3.5S
4S
50E 51E 52E 53E 54E 55E 56E 57E 58E 59E 60E 61E 62E 63E 64E 65E
0.005 0.01 0.1 0.2 0.3 0.4 0.5


ISS007E11024

TRMM PR vs NICAM APE 3.5km

Precipitation frequency





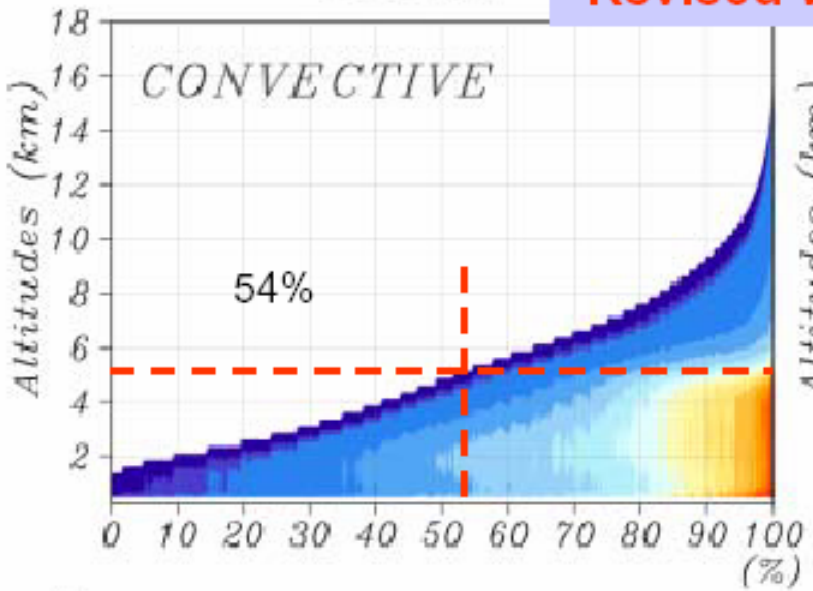
Satoh et al.(2006,Springer special issue)

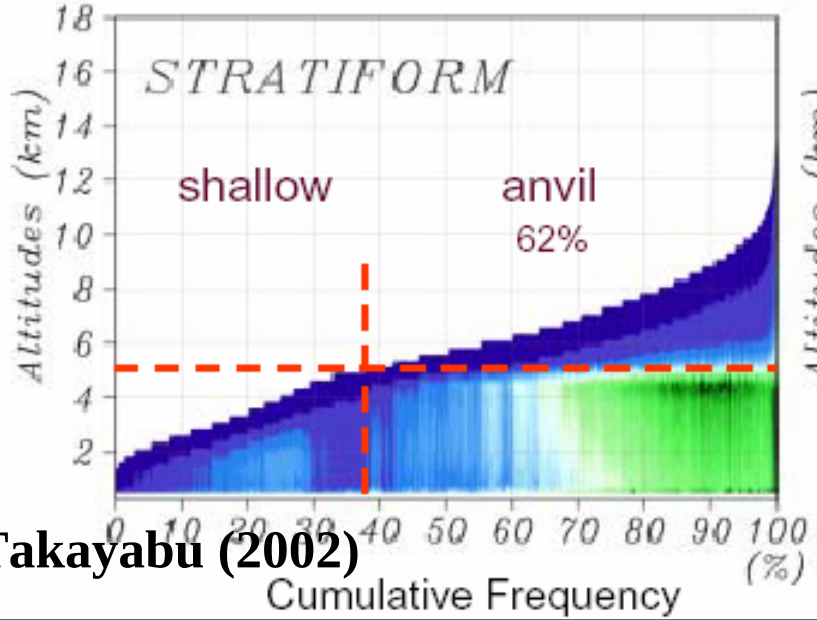
Cumulative Plots of Rain Profiles

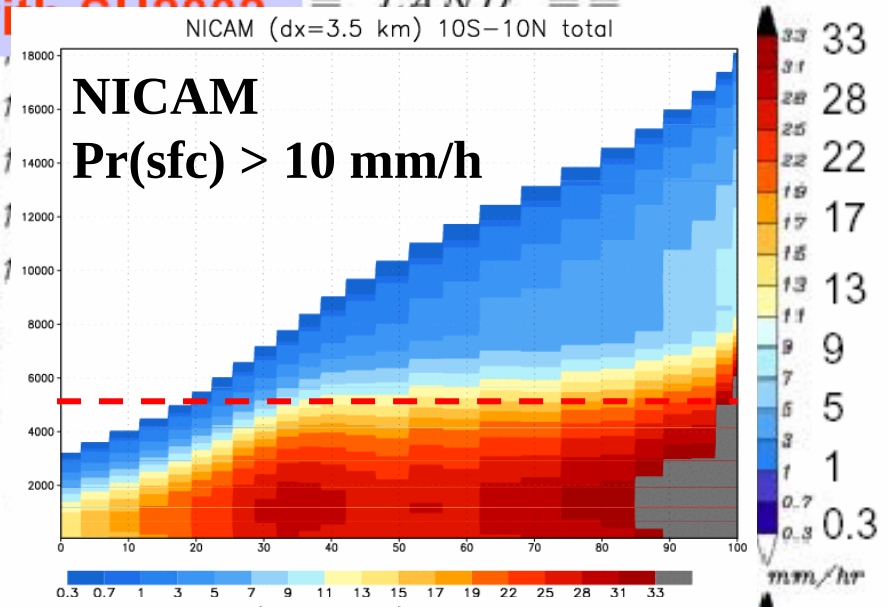
Threshold for rain-top detections: 0.3mm/hr

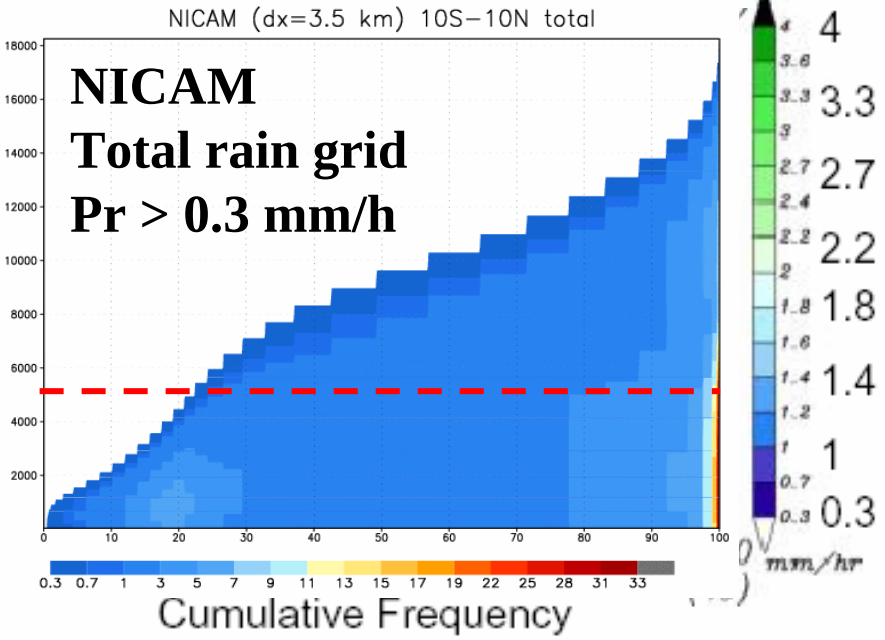
PR2A25_v5Ndr_WR−Revised RAIN 10N−10S 1998−2000

== OCEAN = Revised wi = LAND ==









Takayabu (2002)

GCM experiments with realistic land/sea distribution

Short term runs for Apr. 2004

14km-mesh exp. 30 days

7km-mesh exp. 10 days

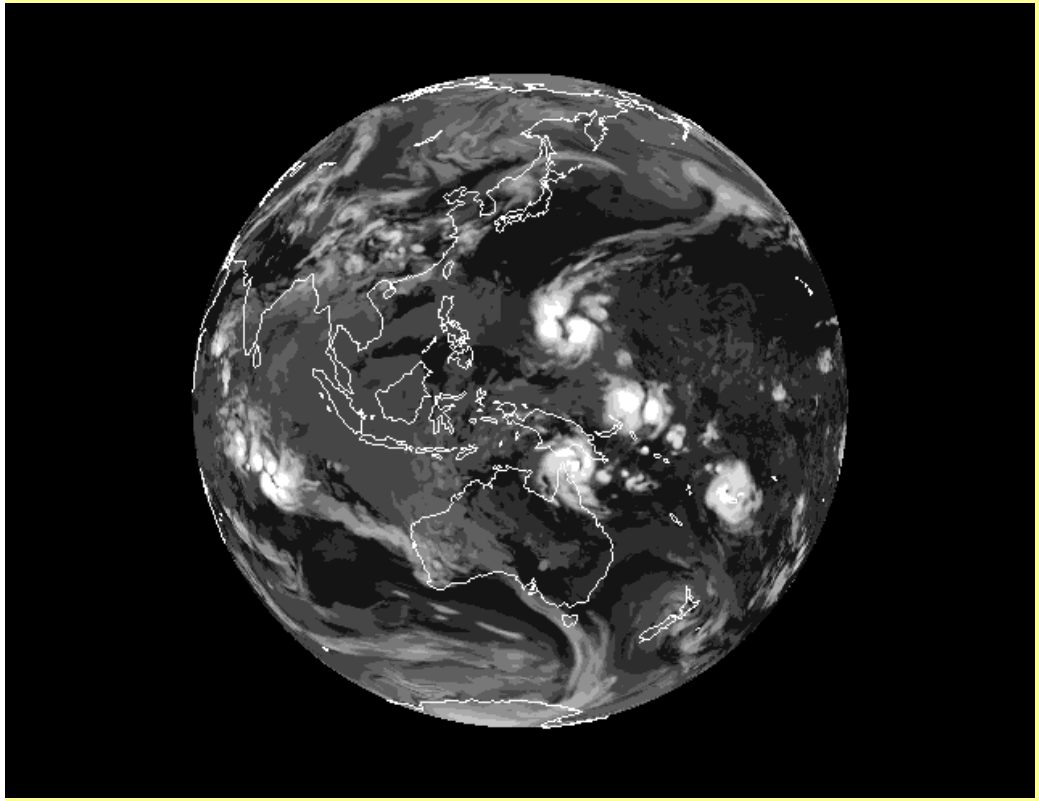
3.5km-mesh exp. 7 days

Miura et al. (GRL, 2006, submitted)

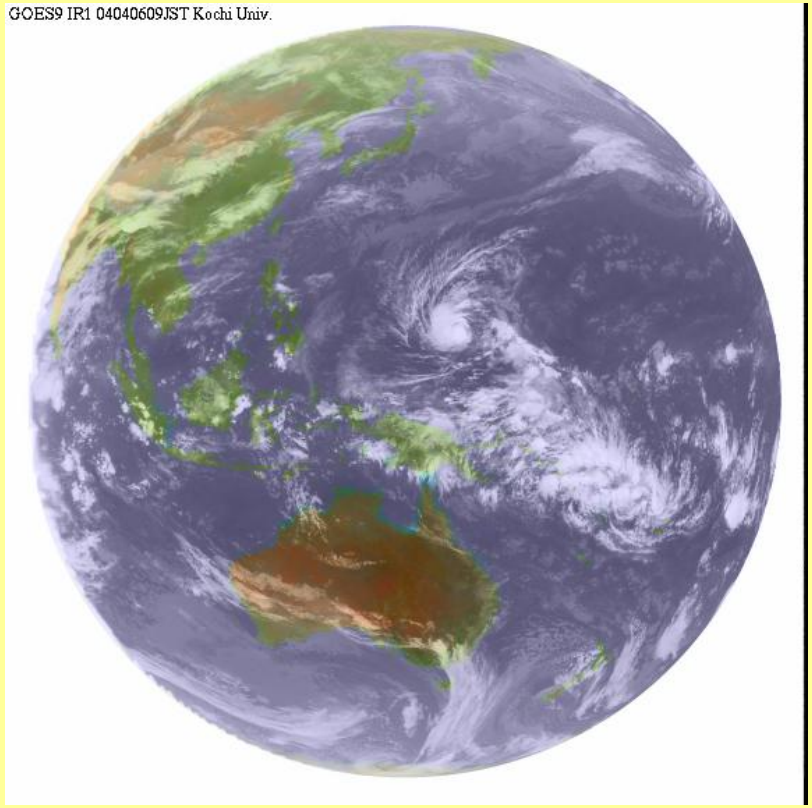
Apr. 2004 short term exp.

Initial condition: 2004/04/01 0UTC, 30 days simulation with 14km-mesh

2004/04/05 00UTC



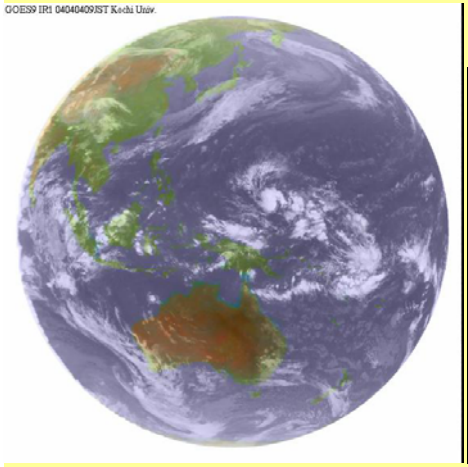
NICAM 14km

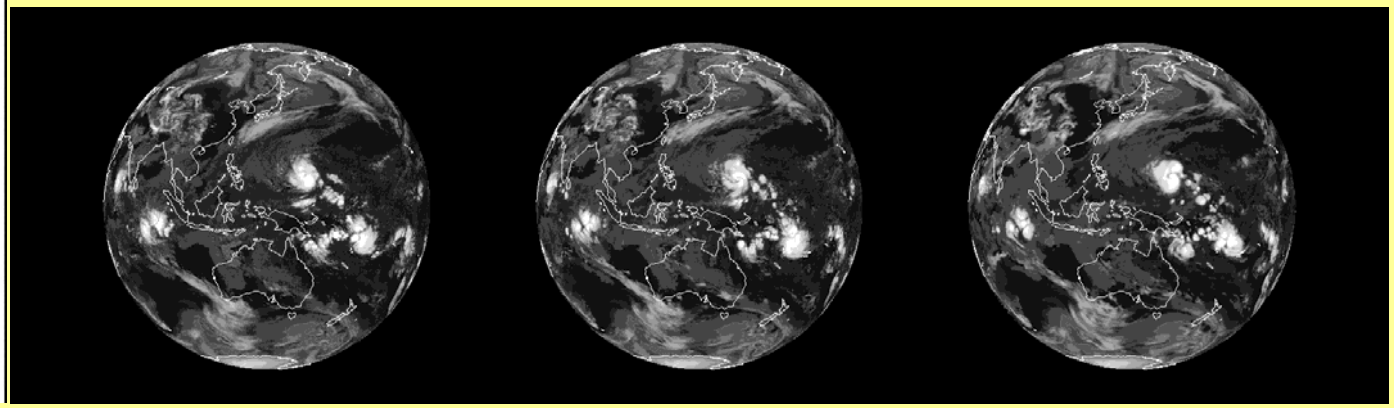


GMS/GOES

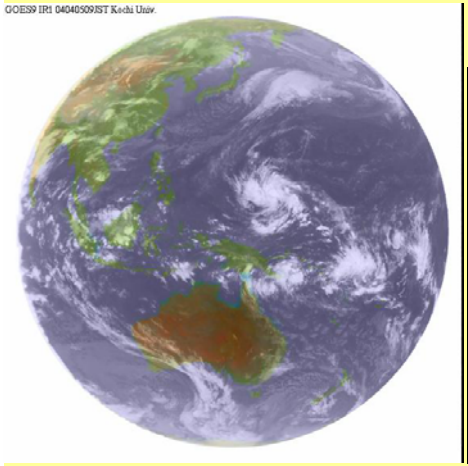
Apr. 2004 short term exp.

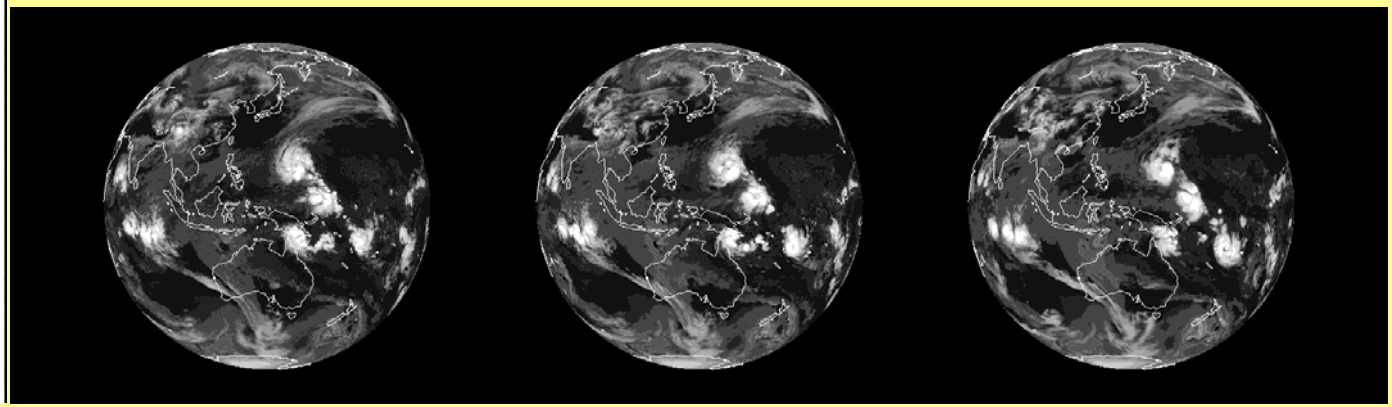
04/04/2004 00UTC





04/05/2004 00UTC





DX3.5 **DX7** **DX14**

GCM experiments with realistic land/sea distribution
Perpetual July exp.

14km-mesh exp. 120 days

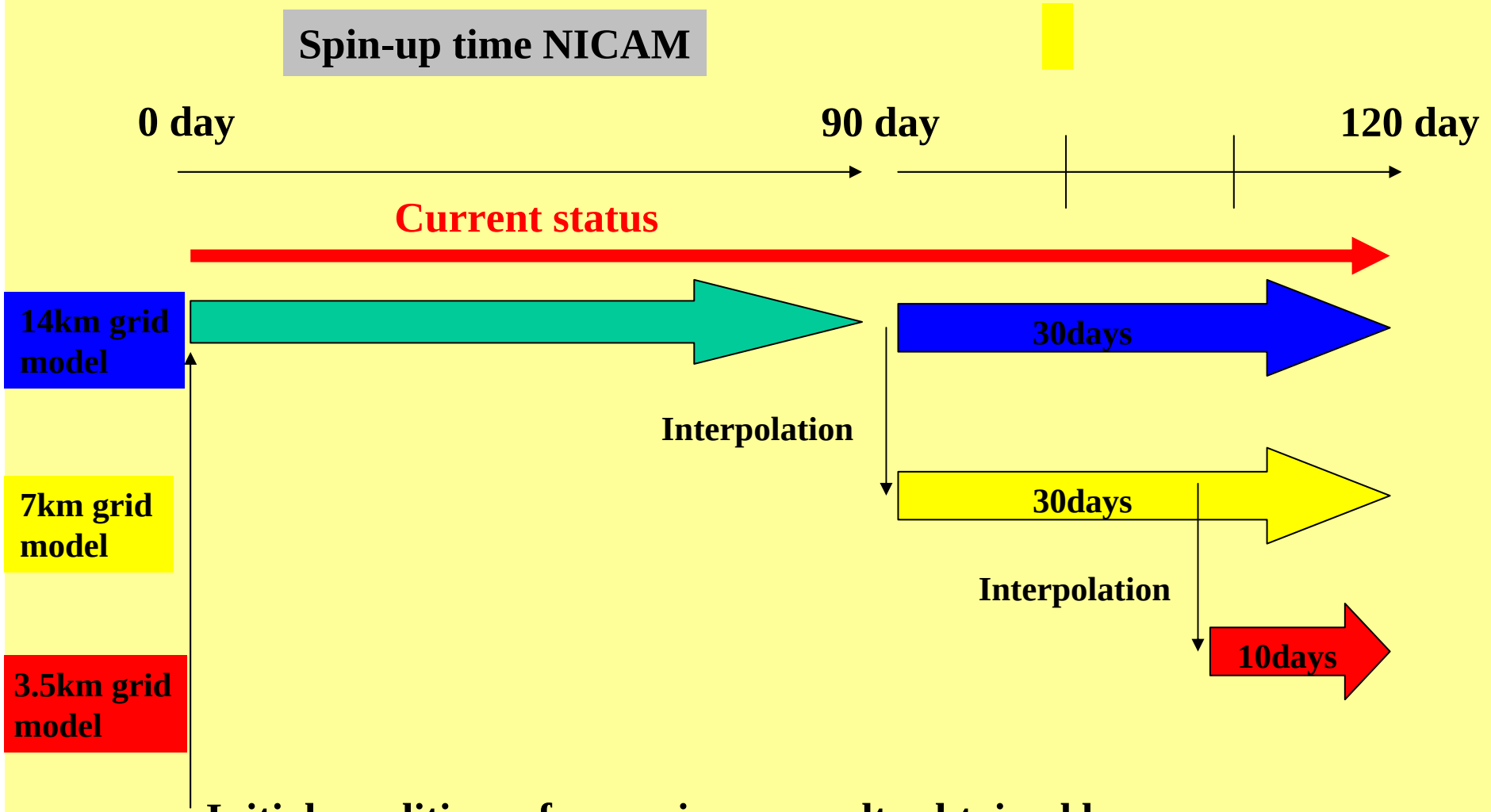
7km, 3.5km-mesh, on-going

By S. Iga

Numerical stability for longer integrations

- Topography: nonlinear filter to reduce steep gradient
- Time integration scheme: 3rd order RK for large time step with 6 small time division *or* 2nd order RK with N2-filter (for strong inversion)
- Choice of large time step interval (dt=20s for dx=3.5km)
- 4th order numerical diffusion, coefficient proportional to ΔT: calculate in each of large time iterations (3 times for RK3)
- Upper damping layers: Laplacian-type numerical diffusion, decreasing with height above 20km, without Rayleigh friction
- Iterate turbulent processes within a large time step by monitoring strength of inversions
- Scalar advection: upstream-biased with positive limiter in flux-form (Miura, 2004)

Perpetual July Statistical exp.

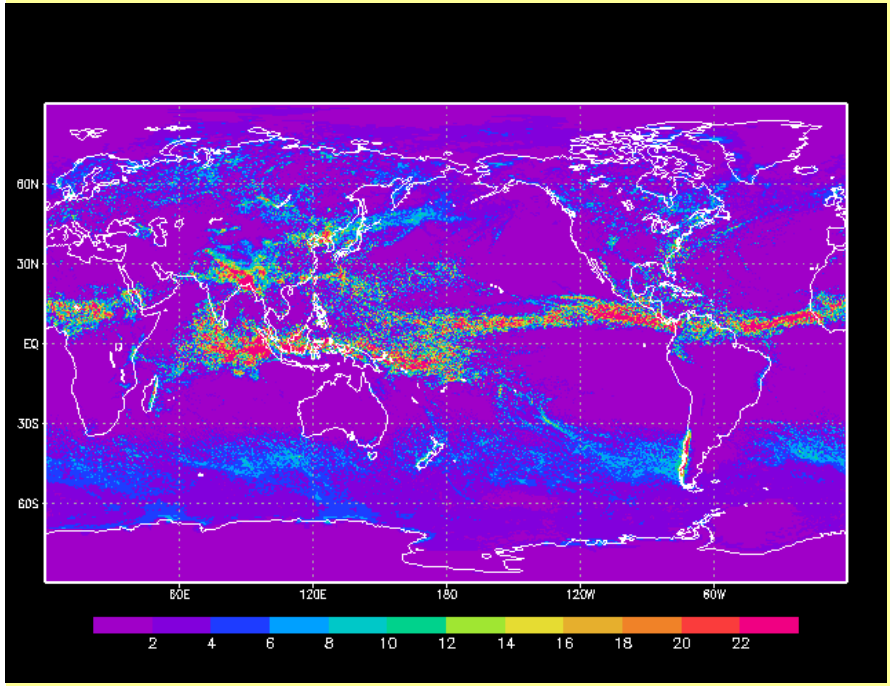


Initial condition: from spin-up results obtained by CCSR/NIES/FRCGC AGCM ver 5.7 with T42

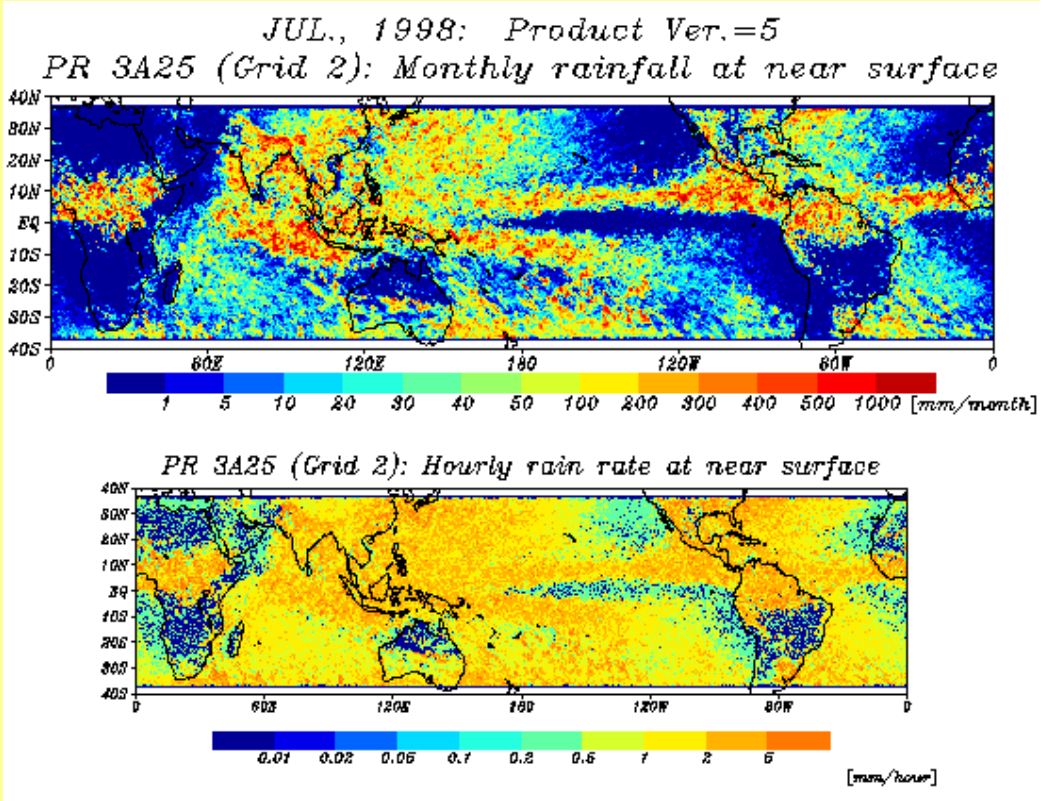
July mean precipitation

30 day mean precipitation

(NICAM)

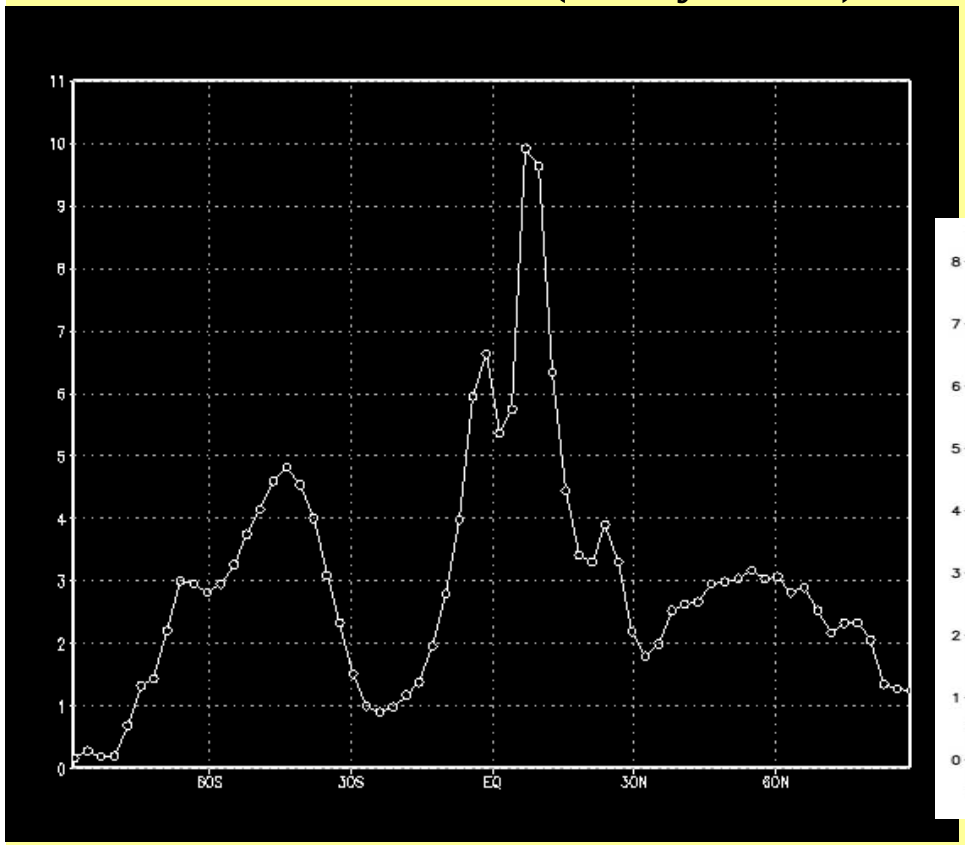


TRMM PR Jul. 1998

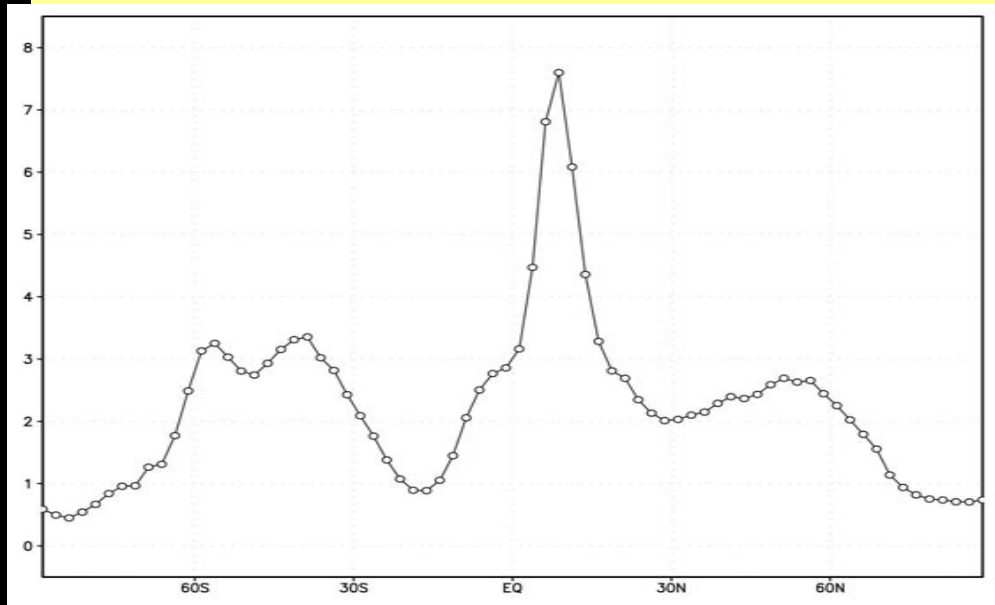


Precipitation (July)

NICAM dx=14km (30day mean)



GPCP(1979-2005)



Future computers in Japan

- ES since 2002
- 2007: ES2, 5 times of ES
- 2012: 10PF machine, 250 times of ES

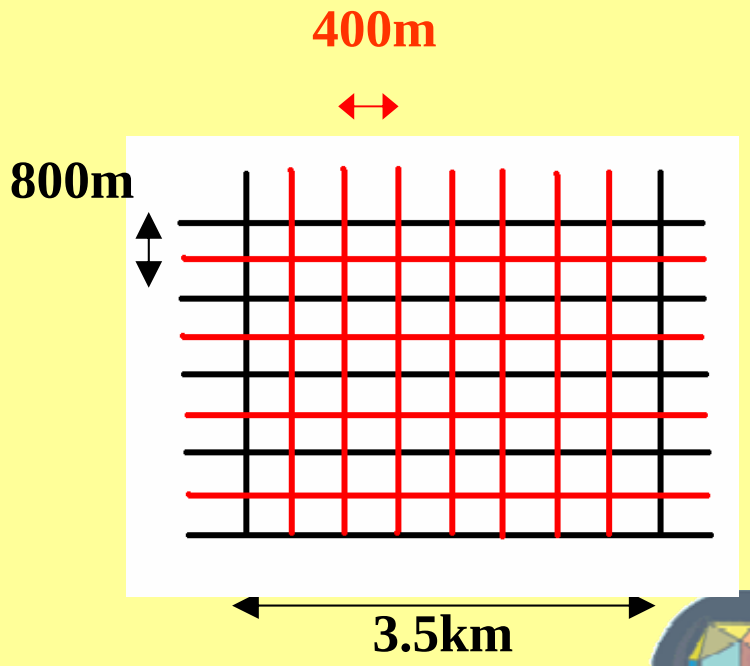
14

NICAM line-up

✓GCM
- Glevel 4: 480km
- Glevel 5: 240km
- Glevel 6: 120km
- Glevel 7: 60km
- Glevel 8: 30km

✓GCRM
- Glevel 9: 14km
- Glevel 10: 7km
- Glevel 11: 3.5km

✓GLEM
- Glevel 12: 1.7km
- Glevel 13: 800m
- Glevel 14: 400m



Perspectives

Collaboration with CMMAP

- Comparison: MMF, GCRM & GCM, suitable exp.?
- Add MMF to NICAM-family
- New physics: boundary layer, microphysics, radiation, aerosols
  - Exchange of information through WS, visits
  - Exchange of datasets: numerical results & obs.
  - Exchange of modules: physics, analysis tools, or models

GCRM runs

- An aqua-planet-experiment dx=3.5km and 54 layers
- GCRM runs on the realistic land-ocean distribution with dx=3.5km
- Short term exp. (weather forecasting mode) & long term exp. (statistics)

Issues

- Realistic representation of tropical convection
  - Diurnal cycle & land/sea contrast
  - Cyclogenesis of tropical depressions
  - MJO/intraseasonal variability
- Satellite observations