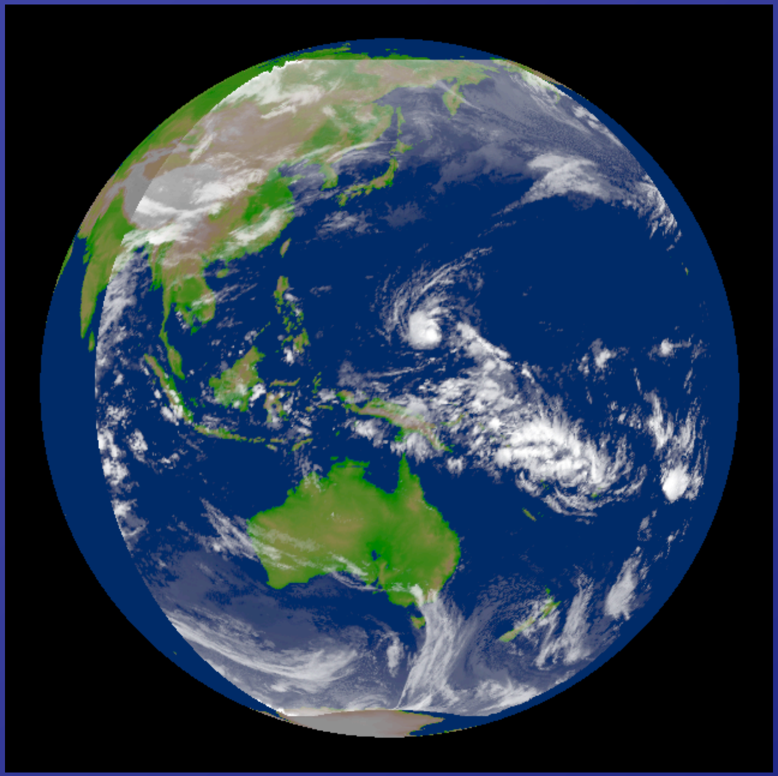
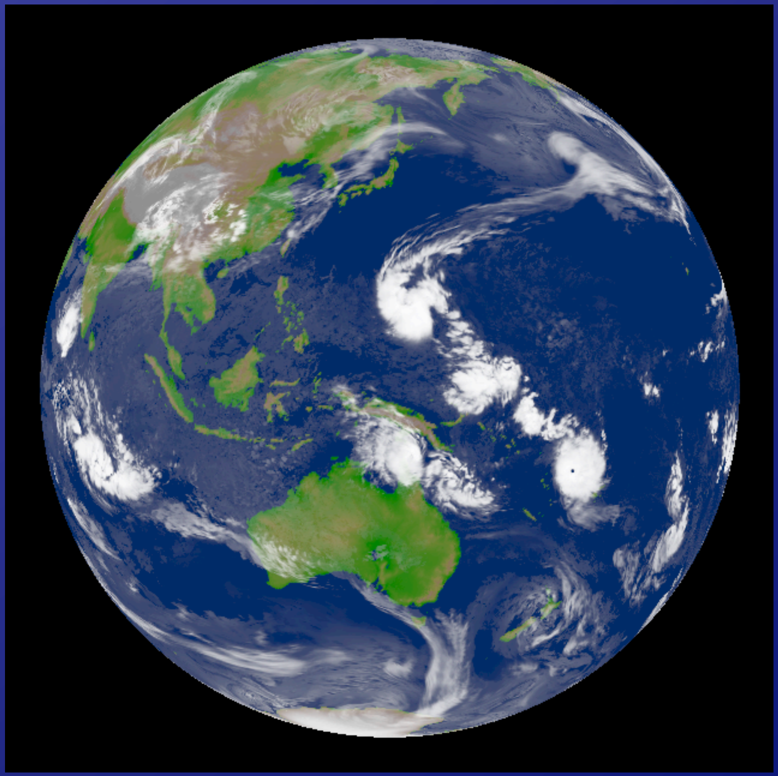
A Global Cloud Resolving Simulation Using Realistic Land and Sea Distribution

Observation: TBB from GOES-9



Simulation: OLR from a simulation with a 3.5 km grid



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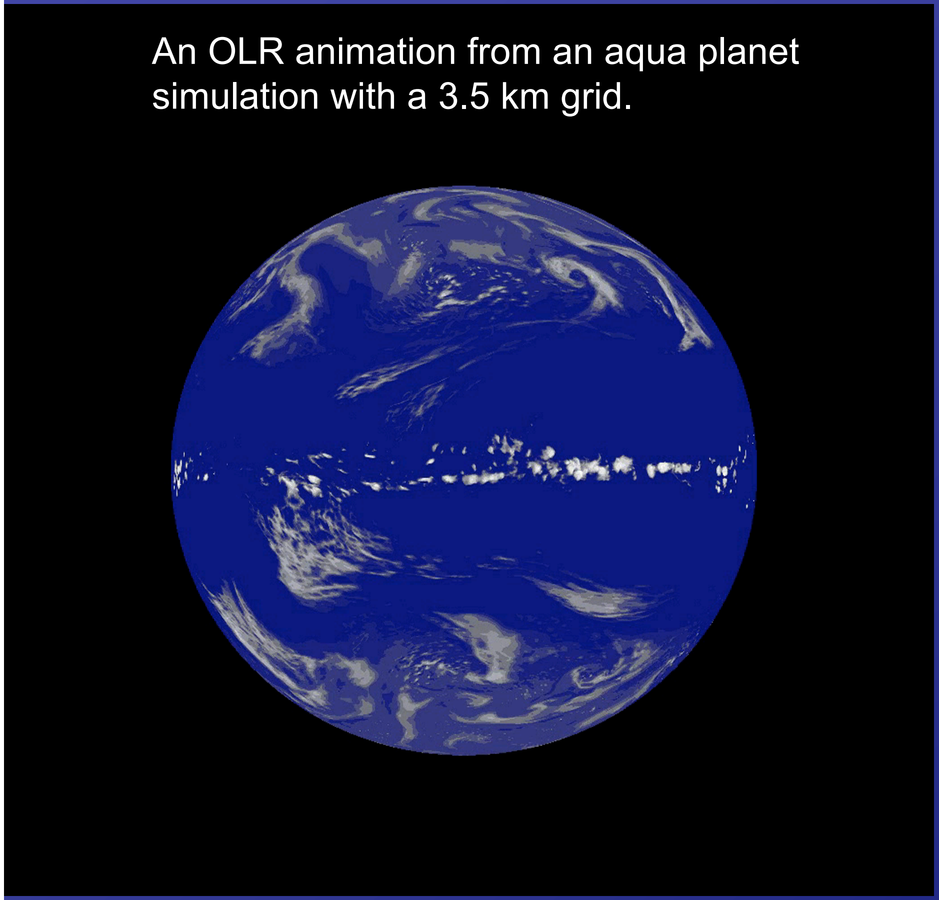


- **Motivation**
- **Realistic simulations for April 2004.**
  - **Experimental settings**
  - **Model description**
  - **A typhoon**
  - **An issue relating turbulence closure schemes**
- **Summary**

- **Current status (including numerical issues) and future plan will be introduced by Satoh.**

Application of CRMs over the globe

Major issues of current AGCMs are

- ambiguity of cloud parameterizations
    - implicit treatment of cloud scale interactions
- lack of direct interactions between “physical” processes (clouds, radiation, turbulence, …)

CRMs are beneficial for further understandings of intraseasonal variations.
CRMs should reduce uncertainties due to clouds in climate simulations.

Strategy-A

Multi-scale Modeling Framework (MMF)

- Statistical forcing from a CRM is used instead of forcing from conventional parameterizations.

Strategy-B (our choice)

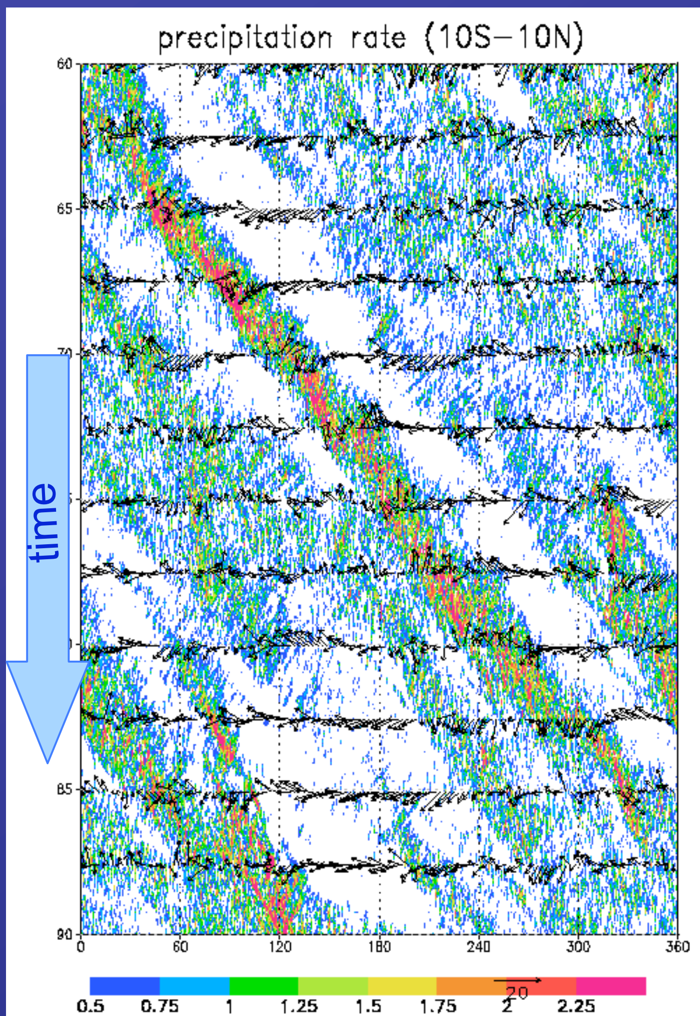
Global cloud resolving model

- Clouds are explicitly represented.

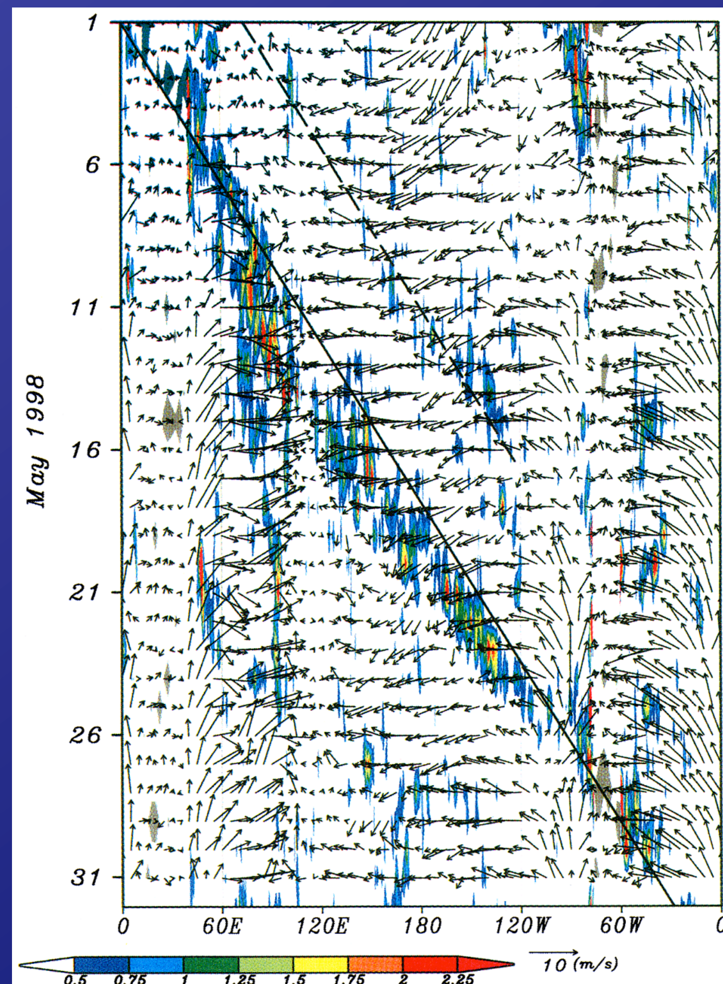
In aqua planet simulations …

eastward propagating waves spontaneously developed with a multi-scale structure of clouds. (~convectively coupled Kelvin wave)

Model (7 km grid)



Observation (Takayabu et al. 1999)



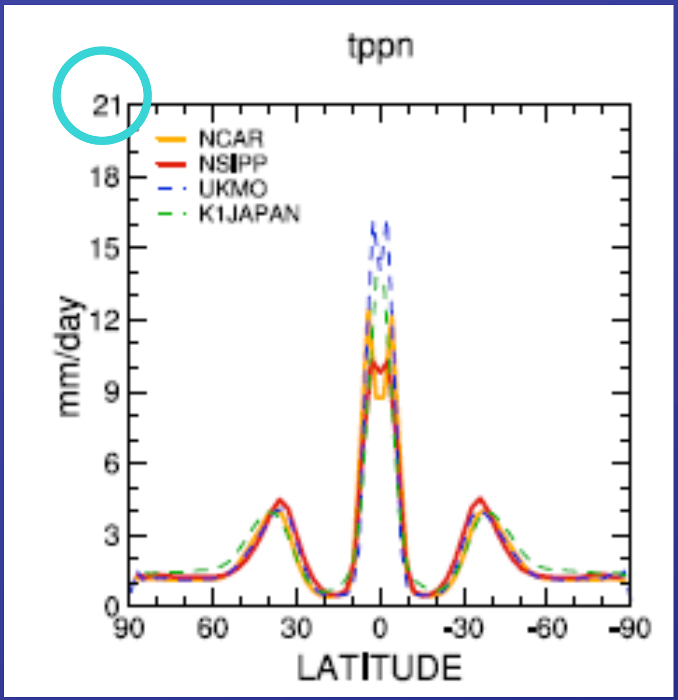
May 1998

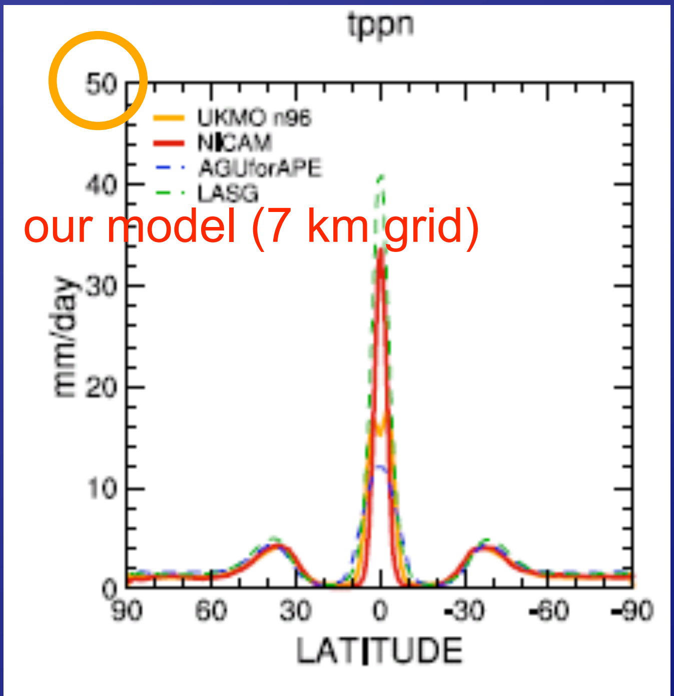
Phase speed

~15 m/s

However,

surface precipitation rate was overestimated in our model compared to other conventional AGCMs (except one model).





A result from APE intercomparison (by Dr. Williamson)

- Due to deficiencies in our model ?
- Due to unrealistic SST ?

We could not know the reason under such idealized conditions.

Motivation

Future issue

- Understanding and prediction of intraseasonal variations
  - Diurnal variation
  - Typhoon
  - MJO

Results of Khairoutdinov and Randall (2005) suggested that realistic time-scale for consuming water vapor is a key for simulations of MJO. Cloud-cloud interaction may be important.

Current issues

- Understanding characteristics of (global) CRMs
  - sensitivity to horizontal/vertical resolution
  - sensitivity to subgrid-scale parameterizations (microphysics, turbulence, etc.)
- **Validation (and improvements) of our global CRM**

How should we go about this issue ?

As a first step, simulations under realistic conditions were performed. Simulation results were compared with realistic data.

Experimental setup

Initial conditions:

Interpolated from NCEP tropospheric analyses (6 hourly, 1.0x1.0 degree grids)

Initial data: 2004-04-01 00:00:00 (only initialized, without nudging techniques)

Boundary conditions:

Reynolds SST, Sea ICE (weekly data)

ETOPO-5 topography, Matthews vegetation

UGAMP ozone climatology (for AMPI2)

Horizontal grid spacing:

dx~14 km (DX14), 7 km (DX7), 3.5 km (DX3.5)

Vertical domain:

0 m ~ 38,000 m

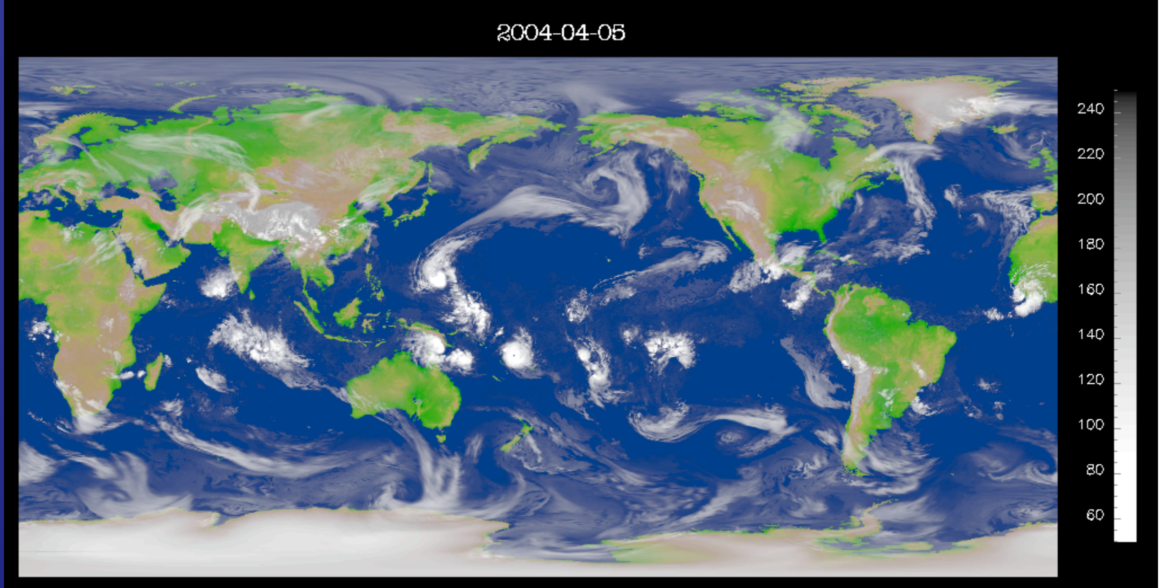
40-levels (stretching grid)

Duration:

30 days for DX14

10 days for DX7

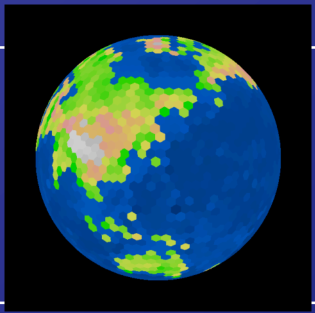
7 days for DX3.5

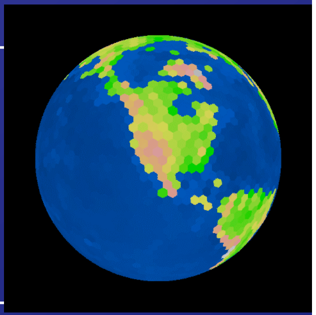


OLR from a simulation with a 3.5 km grid

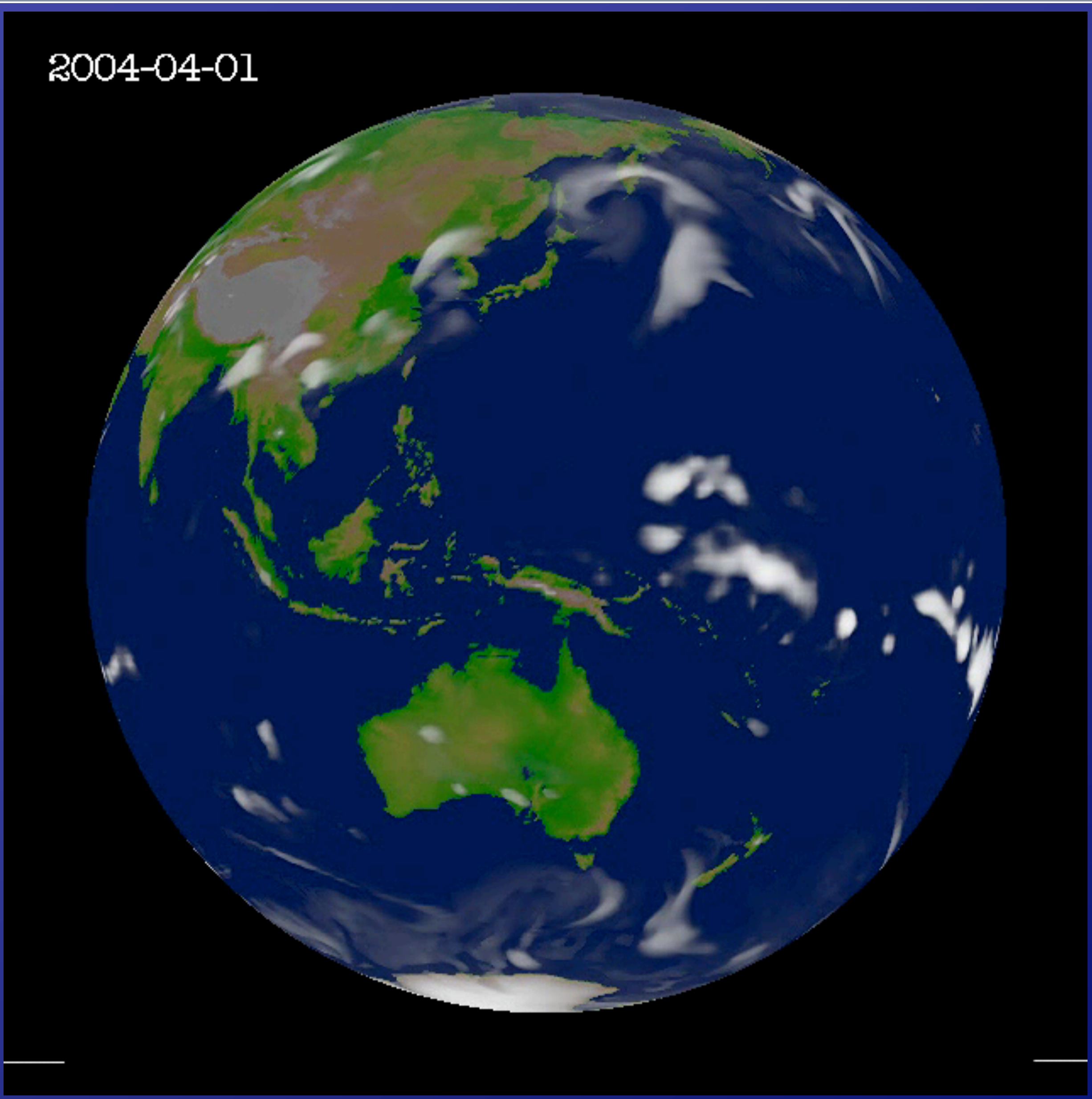
Model configuration

• **Dynamics (grid-scale)**	
Governing equations	Full compressible non-hydrostatic system (with acoustic wave)
Spatial discretization	Finite Volume Method
Horizontal grid configuration	Icosahedral grid
Vertical grid configuration	Lorenz grid
Topography	Terrain-following coordinate
Conservation	mass, total energy (Satoh 2002, 2003)
Temporal scheme	Slow mode — explicit scheme （RK2, RK3） Fast mode — Horizontal Explicit Vertical Implicit scheme
• **Physics (subgrid-scale)**	
Turbulence / surface flux	Modified Mellor & Yamada 2, 2.5, 3(plan)/Louis(1979), Uno et al.(1995)
Radiation	MSTRNX (Sekiguchi and Nakajima, 2006) (with ISCCP)
Cloud physics	Kessler; Grabowsky(1998,1999); Lin et al.(1983); bin(plan)
Cloud parameterization	Arakawa & Schubert; Kain & Fritch (plan); large-scale cond.
Shallow clouds	no
Land process	Mixed layer/bucket; MATSIRO (under implementation)





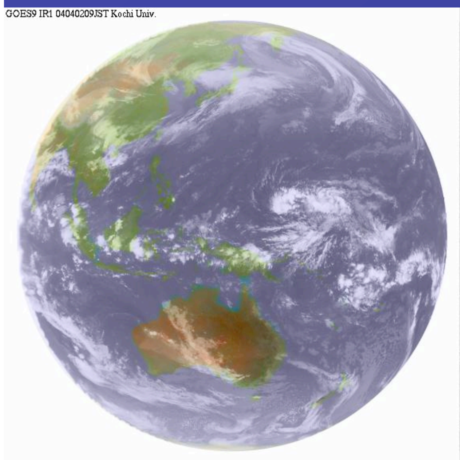
An animation of OLR (DX3.5, 7 days)



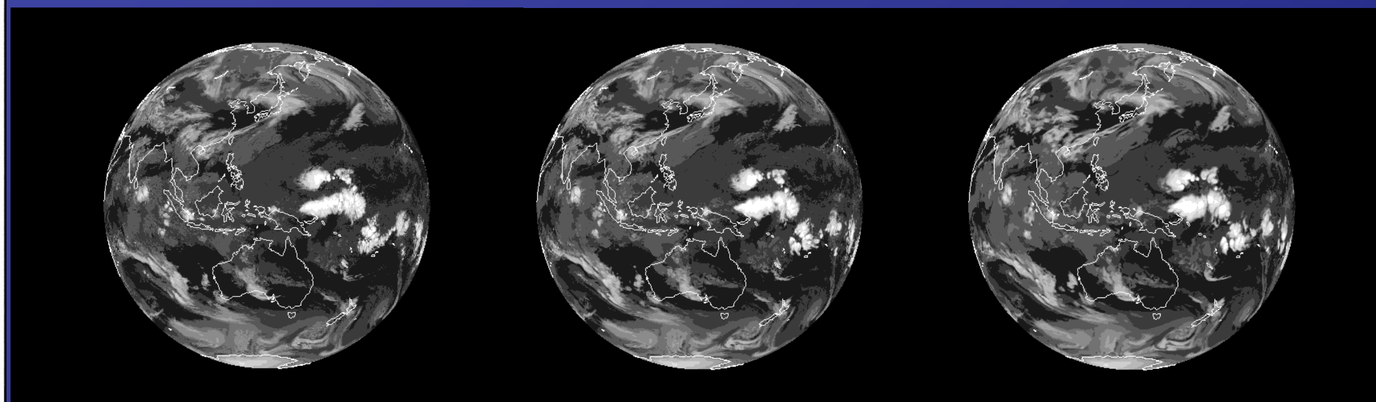
Time evolution

TBB (GOES-9)

04/02/2004 00UTC

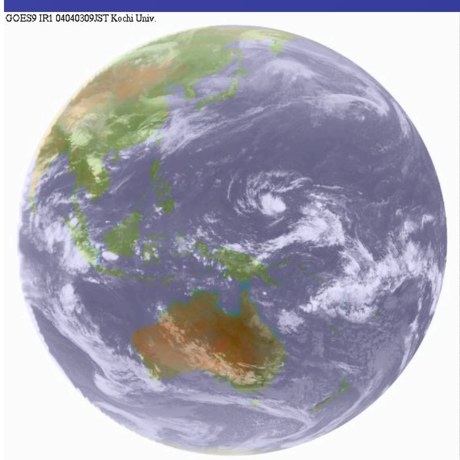


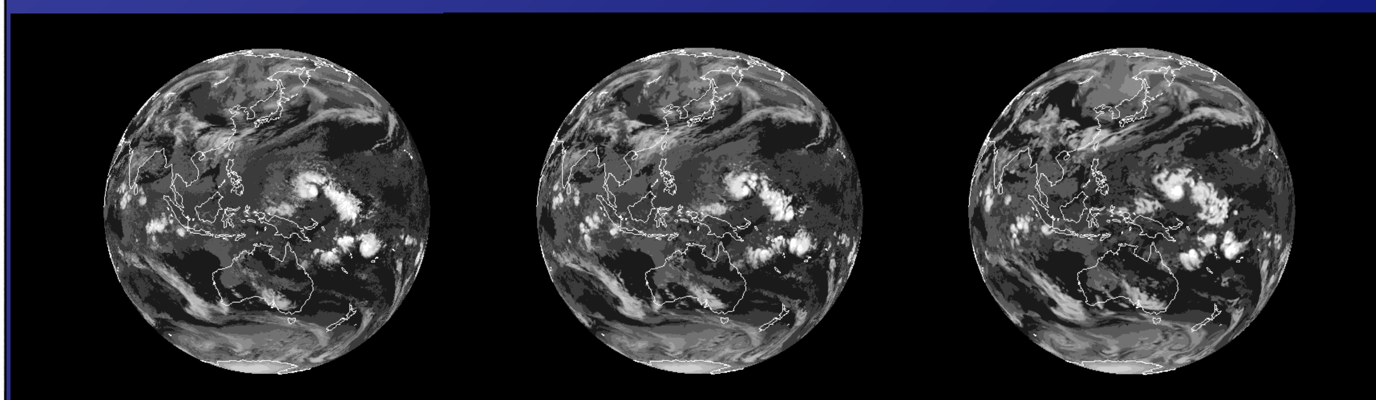
Simulated OLR



04/03/2004 00UTC

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

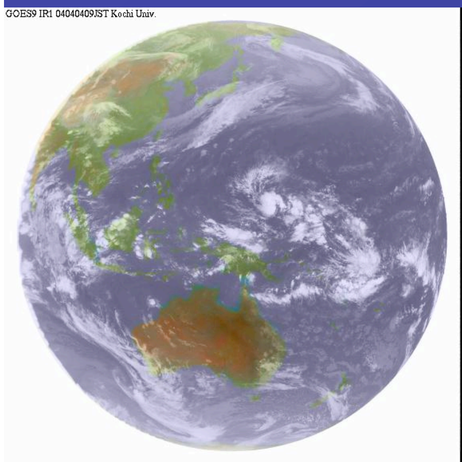


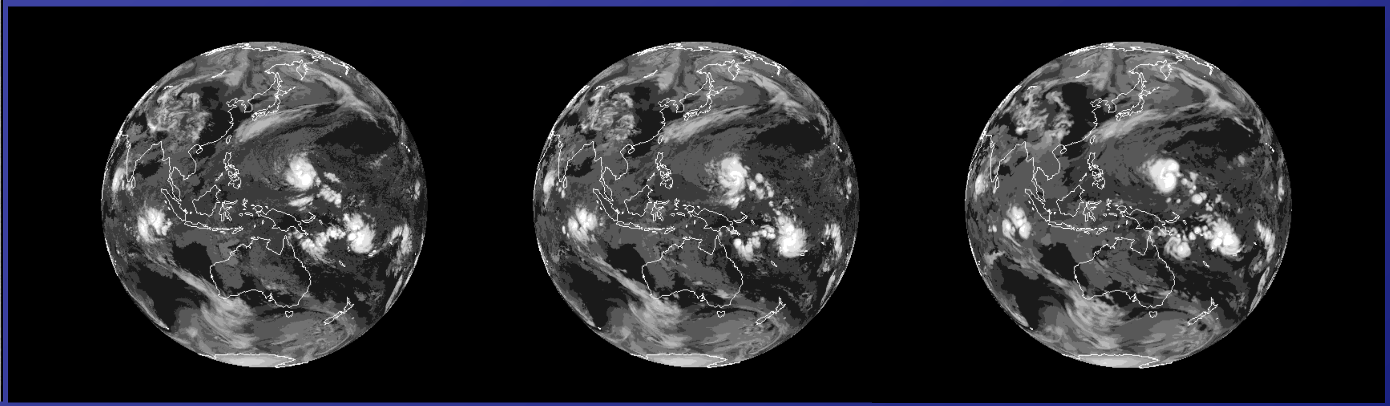


Kochi University Meteorological Web
(http://weather.is.kochi-u.ac.jp/)

04/04/2004 00UTC

Mid-latitude cyclones were successfully simulated.





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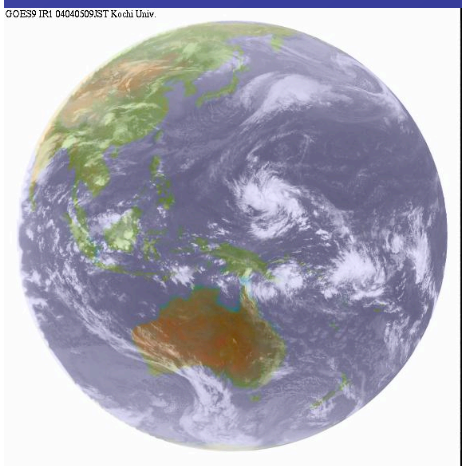
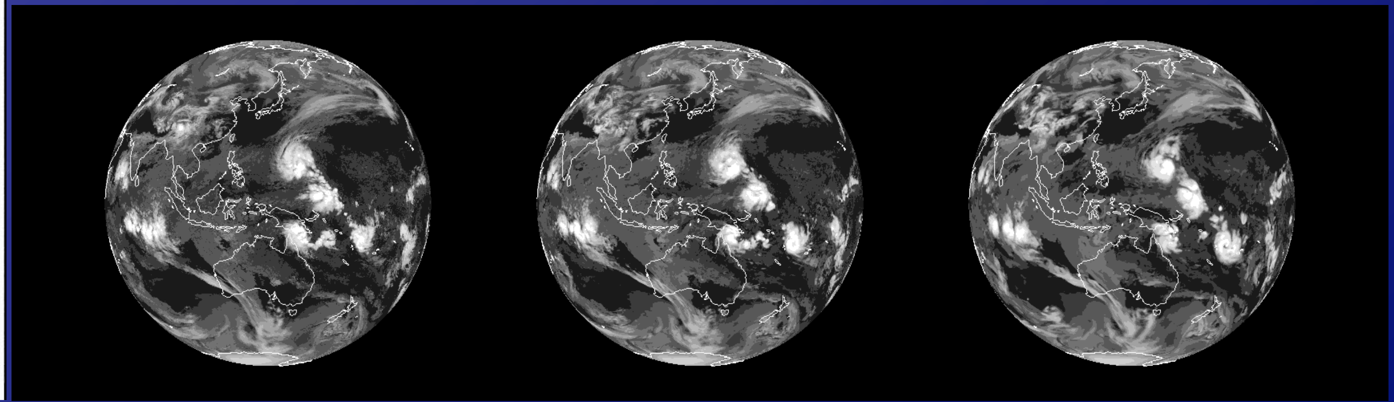
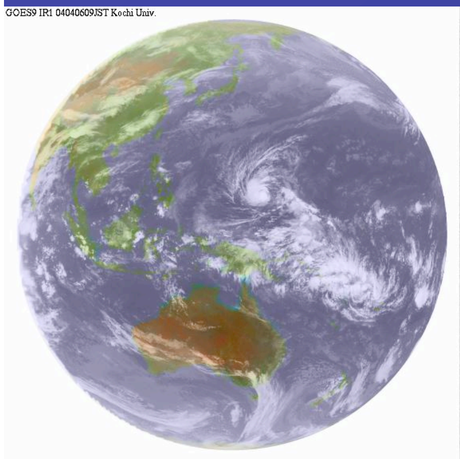
DX3.5 **DX7** **DX14**

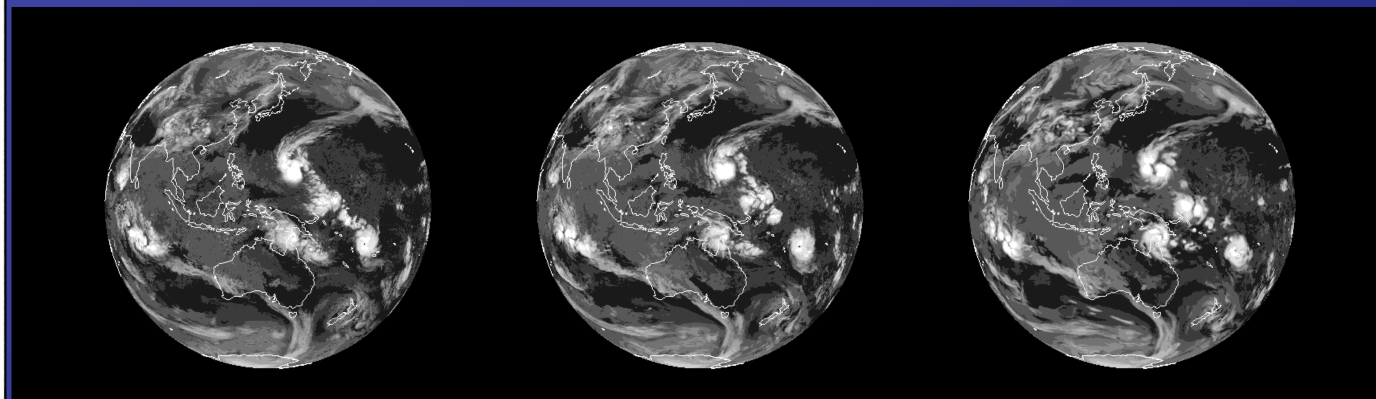




04/06/2004 00UTC

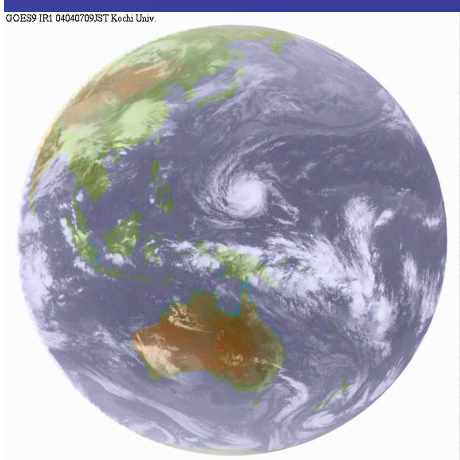


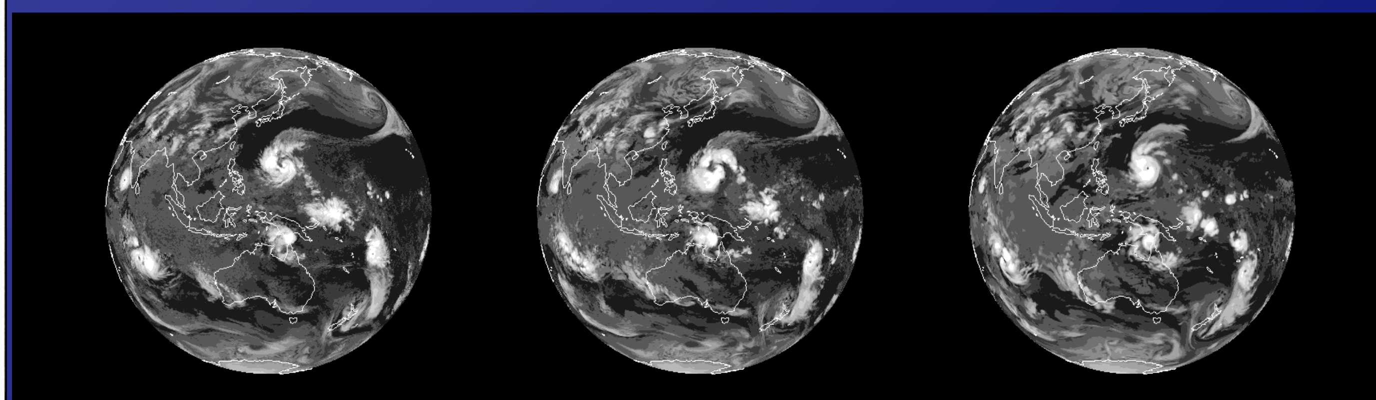
Generation and time evolution of a typhoon could be simulated, though its path was biased to the north.



04/07/2004 00UTC

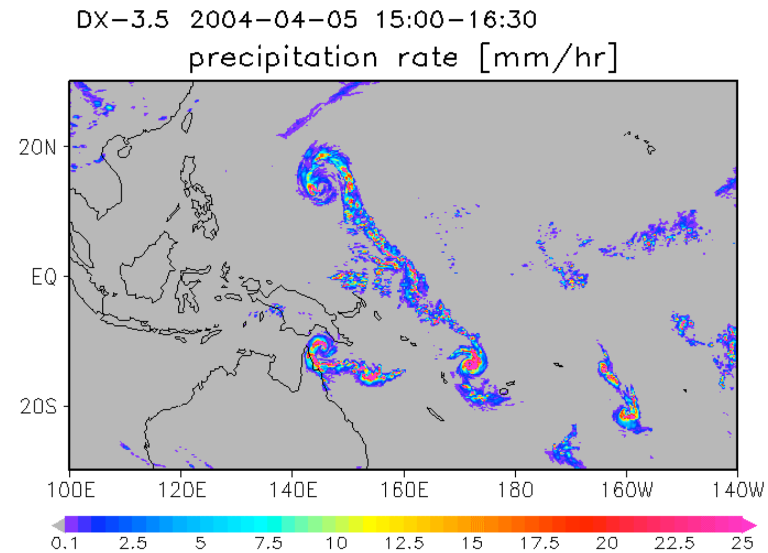
DX3.5 **DX7** **DX14**

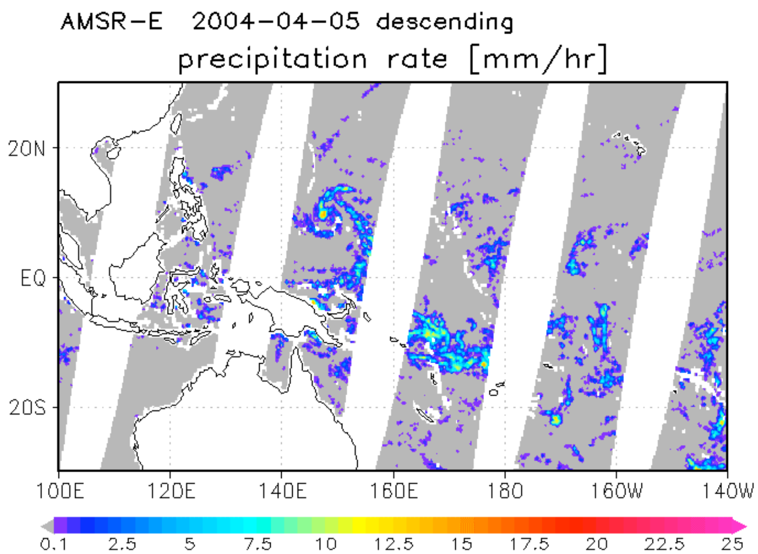




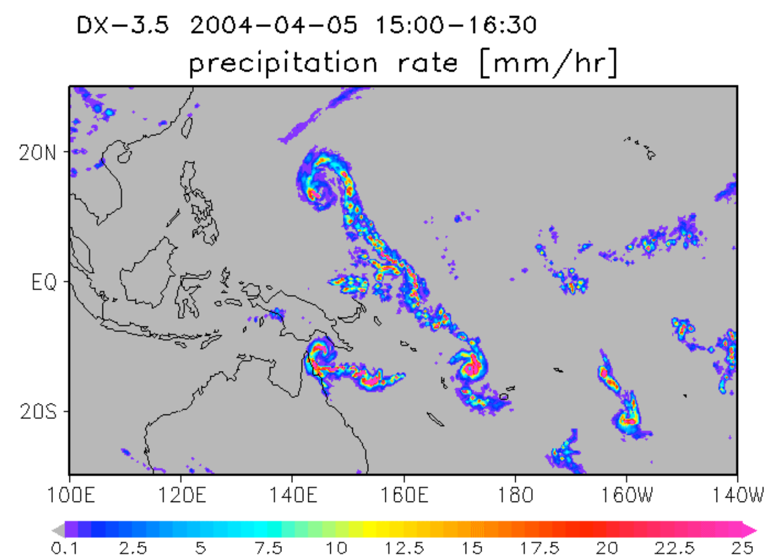
A comparison of surface precipitation

0.035x0.035 grid



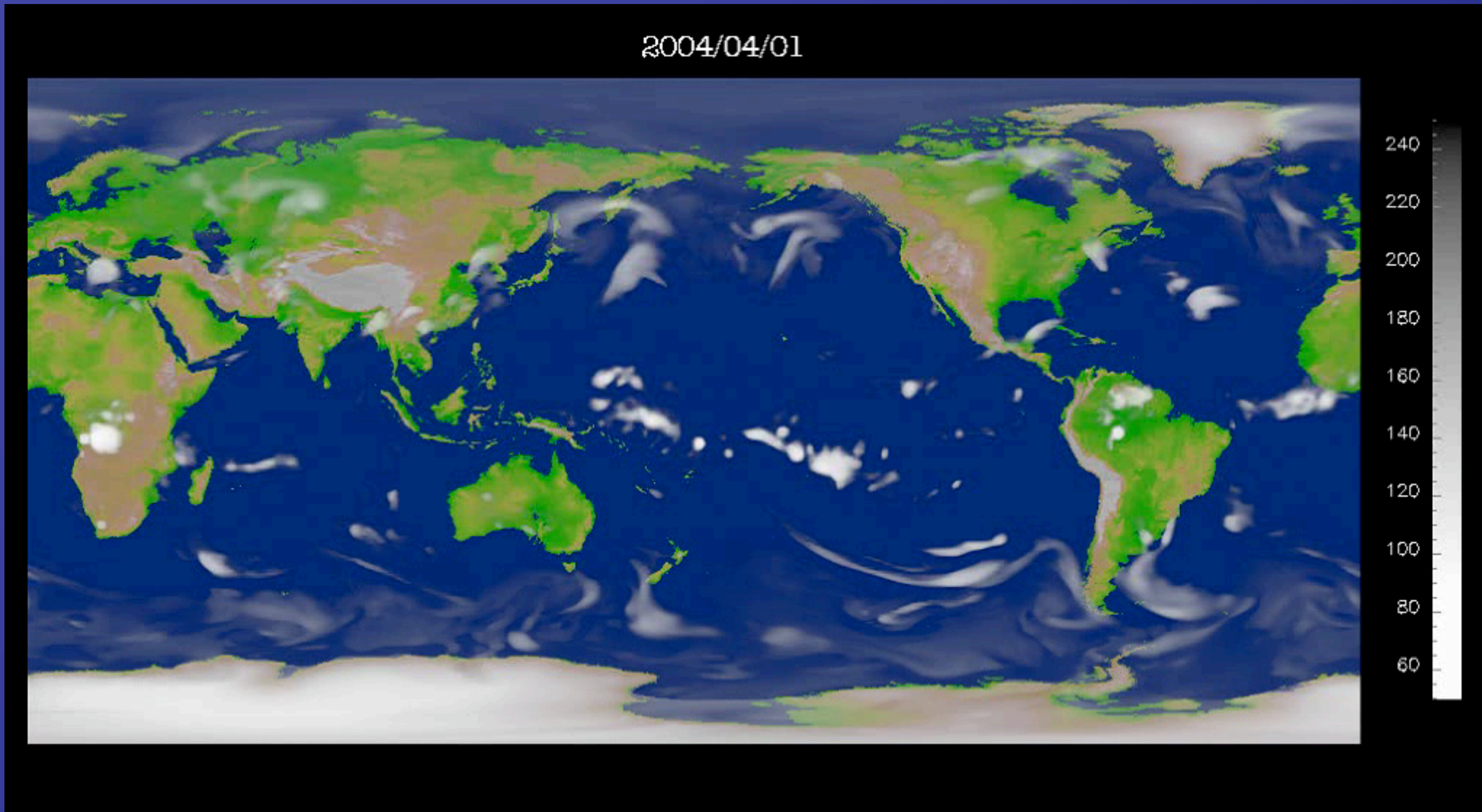


AMSR-E data on 0.25x0.25 grid
(obtained from “ssmi.com”)



0.25x0.25 grid

Time evolution of OLR (DX14, 30 days)



Many cyclones were generated in this simulation.

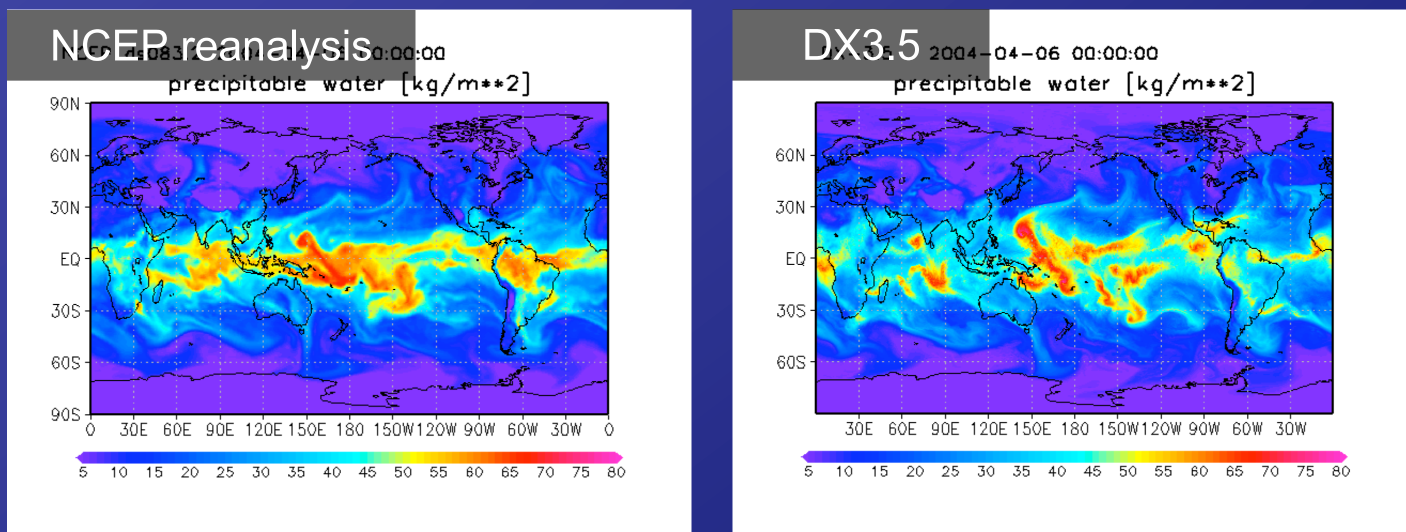
Exaggerated concentration of clouds

Self-aggregation of clouds in CRM simulations was reported.
(Tompkins and Craig 1998, Bretherton et al. 2005)

Radiative-convective equilibrium simulation with SST of 308 K generated a cyclone-like system. (Emanuel and Nolan 2004)

- Does moisture flux controls organization of convective clouds ?

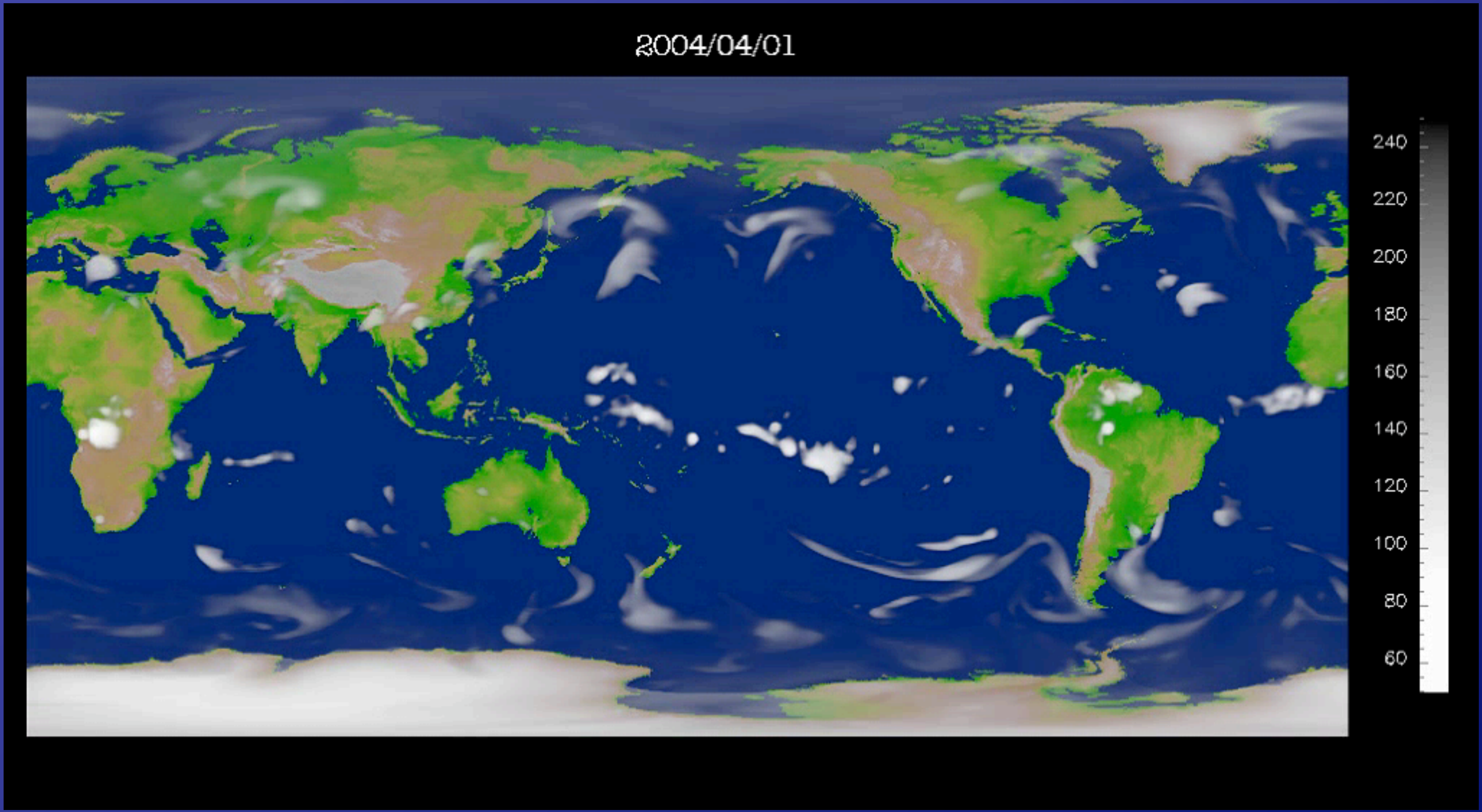
Precipitable water at 2004-04-06 00Z



In the simulations, a modification to the Mellow-Yamada scheme caused (unrealistic) overestimation of upward transport of moisture.

⇨ Additional run without the problematic modification
(with the same physics as those used in aqua-planet runs)

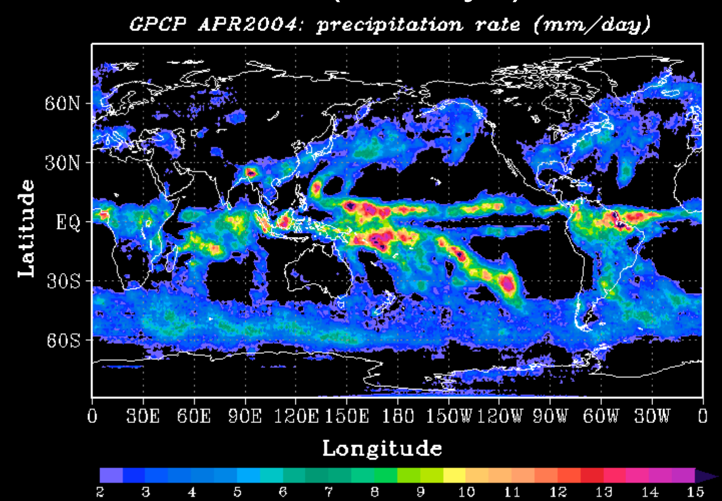
Time evolution of OLR (DX14 additional, 10 days)



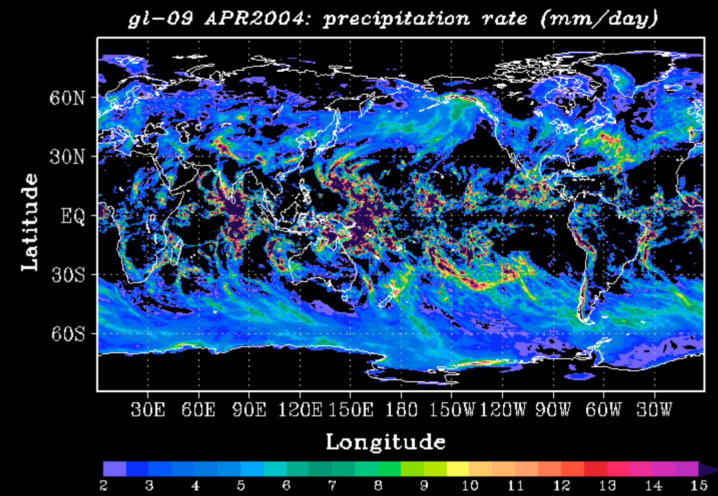
Organization of convective clouds became weak.
But it was also weaker than realistic one.

Mean precipitation

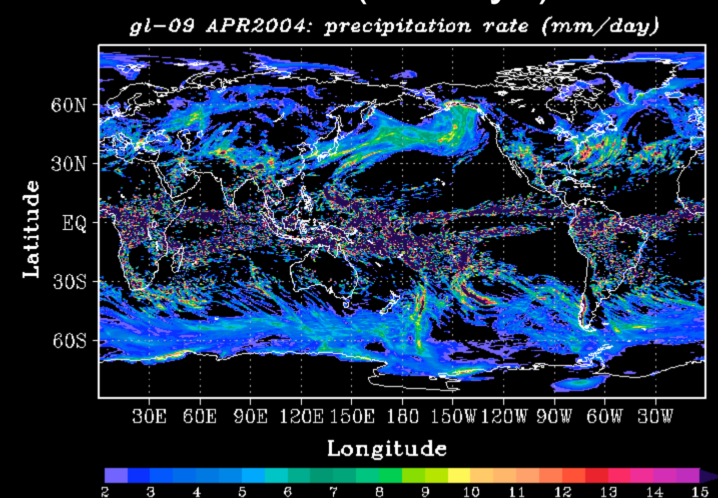
GPCP (30 days)



DX14 (30 days)

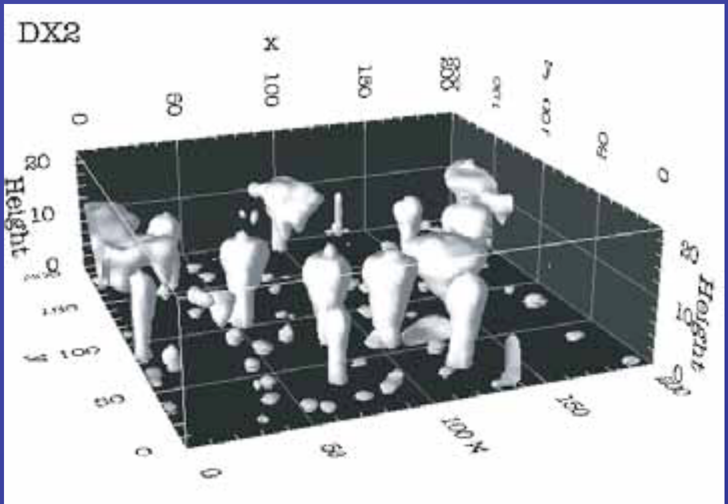


DX14 additional (10 days)



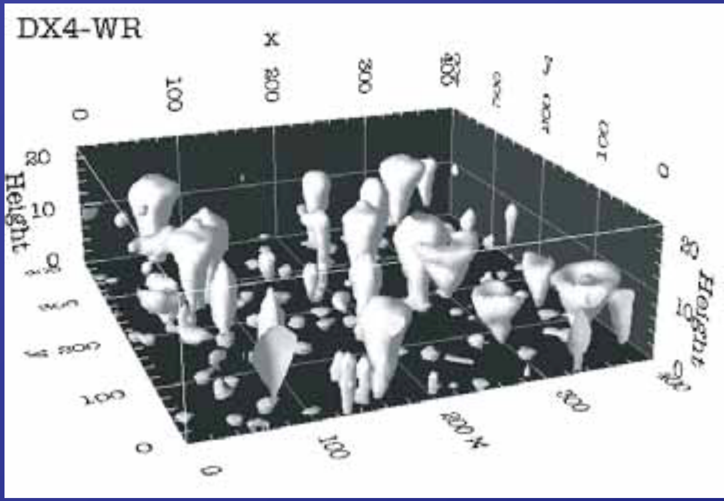
Self-aggregation in a CRM (MRI/NPD-NHM of JMA)

Radiative-convective equilibrium simulations (100 x 100 grid points domain)

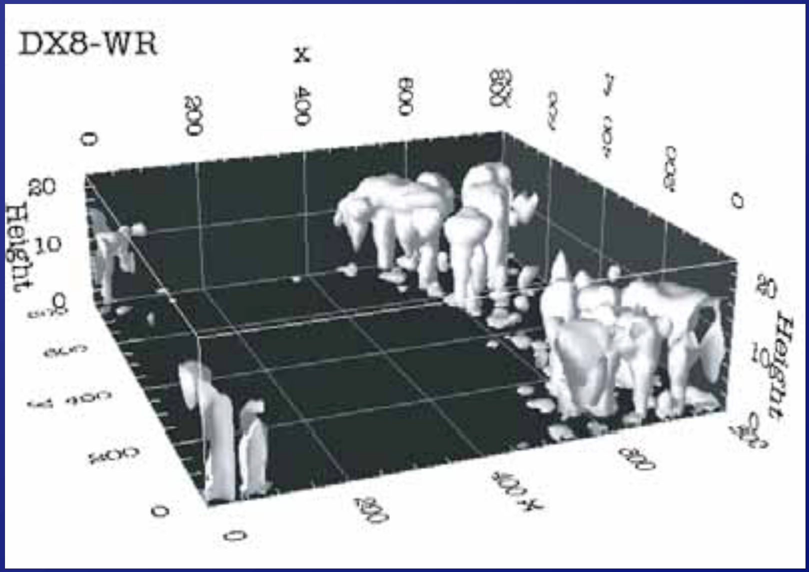


dx=2 km, 200 km x 200 km

- Without large-scale forcing
- With interactive radiation and fixed SST

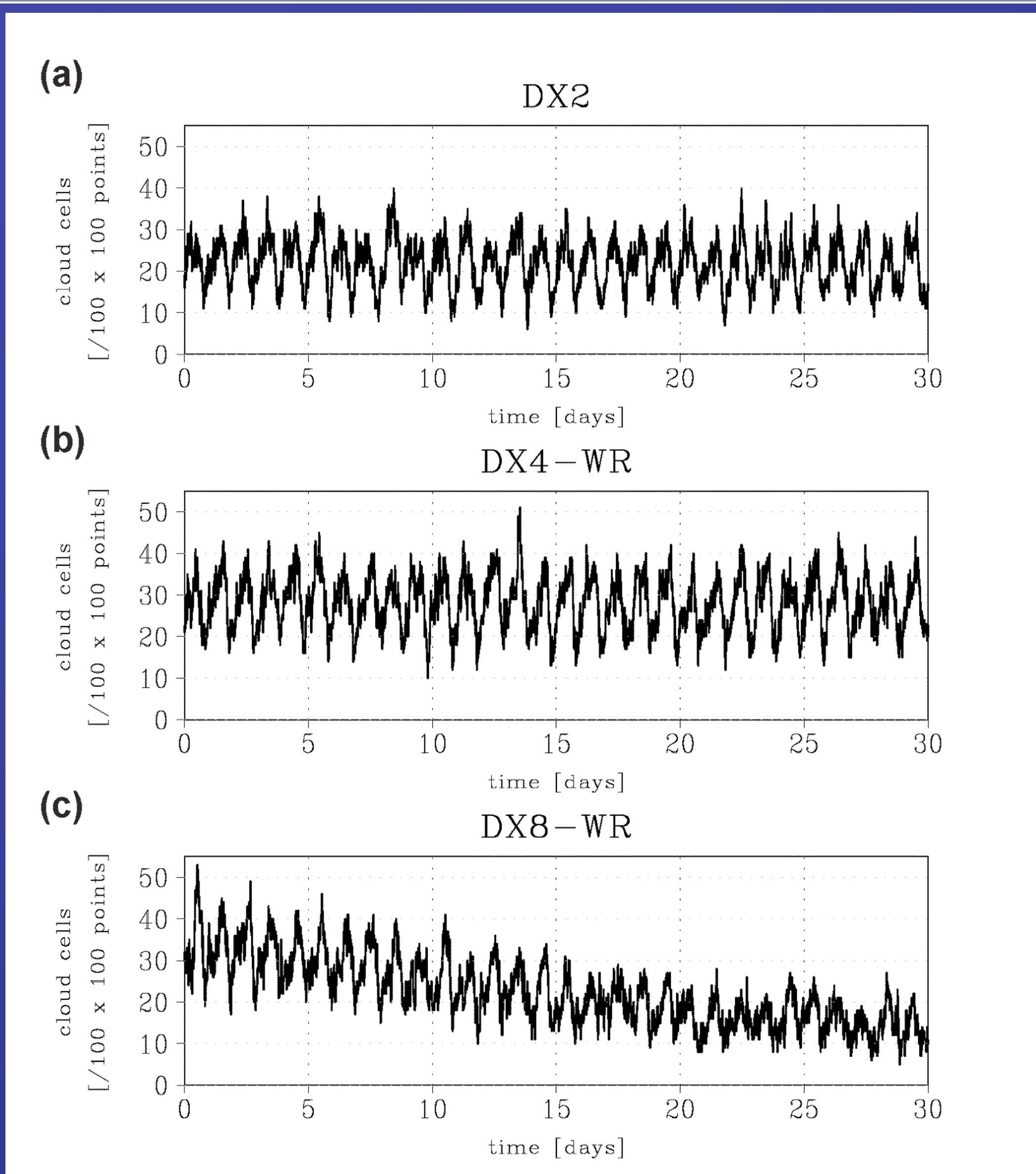


dx=4 km, 400 km x 400 km



dx=8 km, 800 km x 800 km

Time variation of number of cloud cells



Last 30 days of 60 days simulation

- Number of clouds was almost constant for DX2 and DX4-WR.
- Number of clouds decreased for DX8-WR.

- Self-aggregation of convection was slower compared to results of Bretherton et al. (2005).
- Clouds did not merge into a single convection in the period.

What are reasons for such differences ?

Summary

- **To validate a global CRM, simulations under realistic conditions were performed.**
  - Simulated results were compared with observations and reanalysis data.
- **After the first trial …**
  - We become to know problems in our model.
  - Quantitative comparisons are difficult at the present.
    - Model should be improved further.
- **A scientific issue**
  - It was suggested that organizations of convective clouds are sensitive to upward transport of moisture.
  - It is possible that turbulence schemes not only affect individual convection but also change developments of mesoscale and large-scale circulations.
  - Self-aggregation of convection is an attractive research subject. The approach of Bretherton et al. (2005) may be helpful.