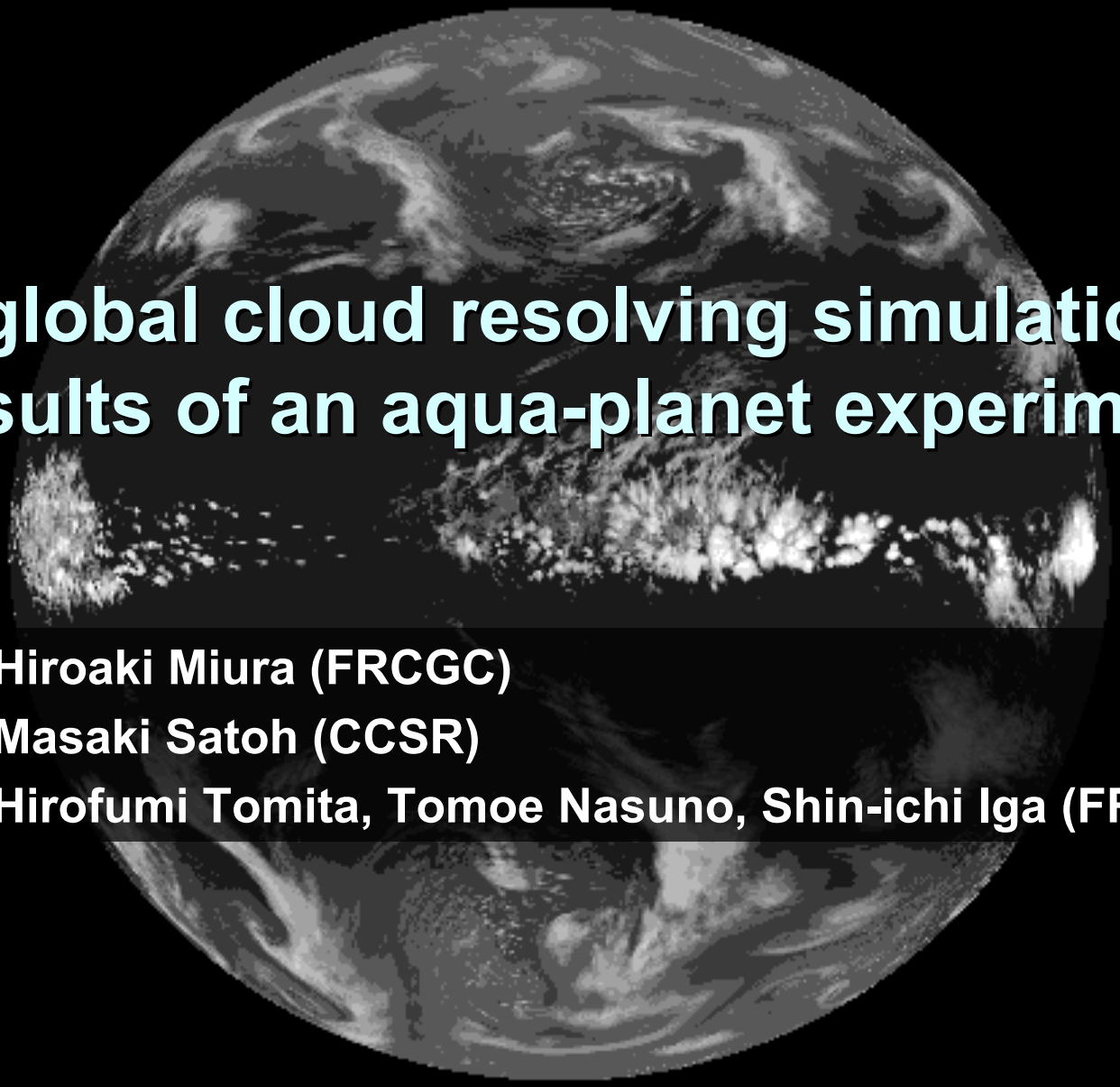
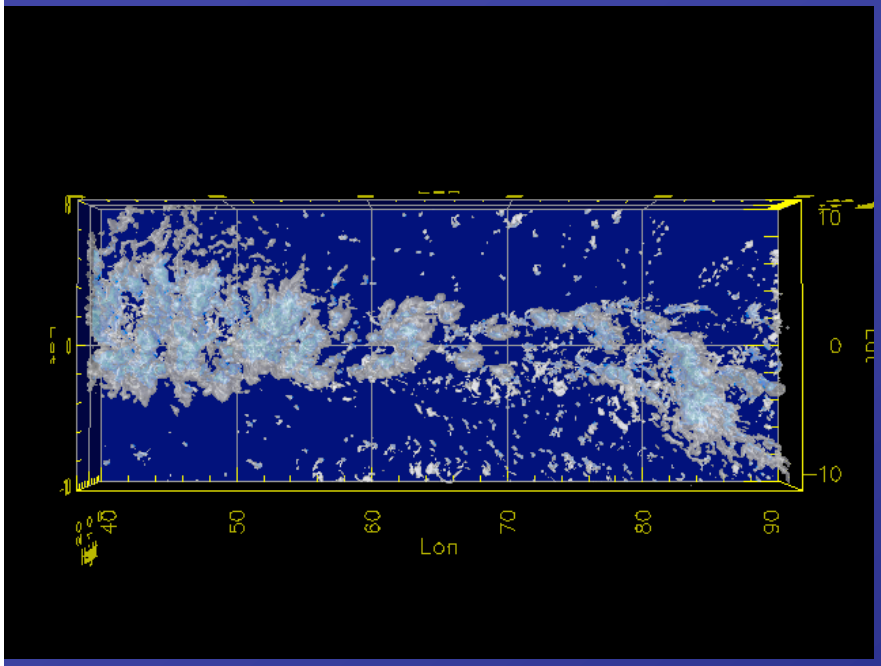


A global cloud resolving simulation: Results of an aqua-planet experiment

Hiroaki Miura (FRCGC)
Masaki Satoh (CCSR)
Hirofumi Tomita, Tomoe Nasuno, Shin-ichi Iga (FRCGC)

FRCGC Frontier Research Center for Global Change

Contents



- Motivation
- Descriptions of our model
  - Icosahedral geodesic grid
  - Non-hydrostatic dynamical core
  - Physical parameterizations
- Aqua planet experiment
  - Experimental settings
  - Multi-scale structure of clouds
  - Diurnal variation
- Summary and future plan

The Earth simulator

Motivation

Major issues of current AGCMs are

- ambiguity of cloud parameterizations
  - implicit treatment of cloud scale interactions
    (cloud nucleation, condensation heating, …)
- lack of direct interactions between "physical" processes
  (clouds, radiation, turbulence, …)

Strategy-A

Multi-scale Modeling Framework (MMF)

- A cloud resolving model is embedded in a "parent" model.
- In future, it can be extended to LES, etc.

- There remains ambiguity in the way to embed "child" models.

Strategy-B (our choice)

Global cloud resolving simulation (full explicit approach)

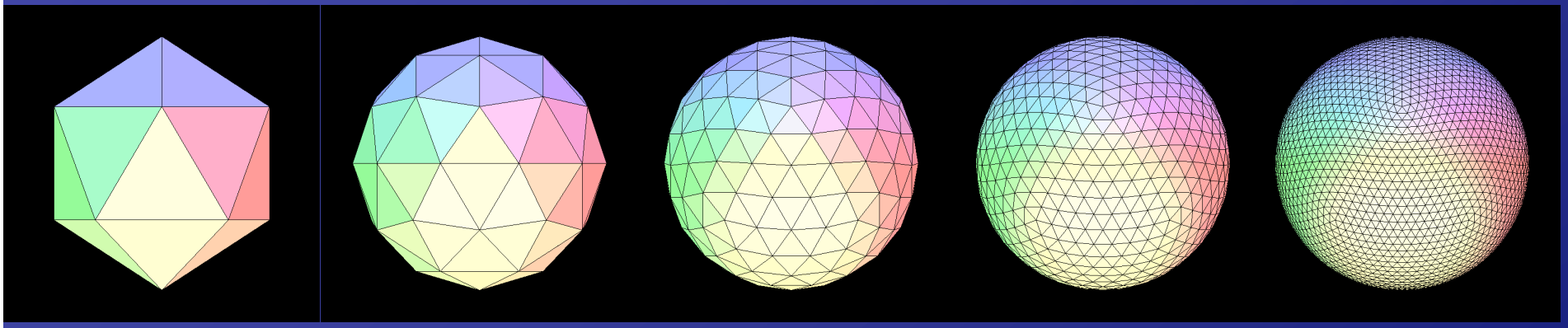
- Clouds are explicitly resolved.
- In future, large eddy is resolved.
- In future, …

- It requires huge computer resources.

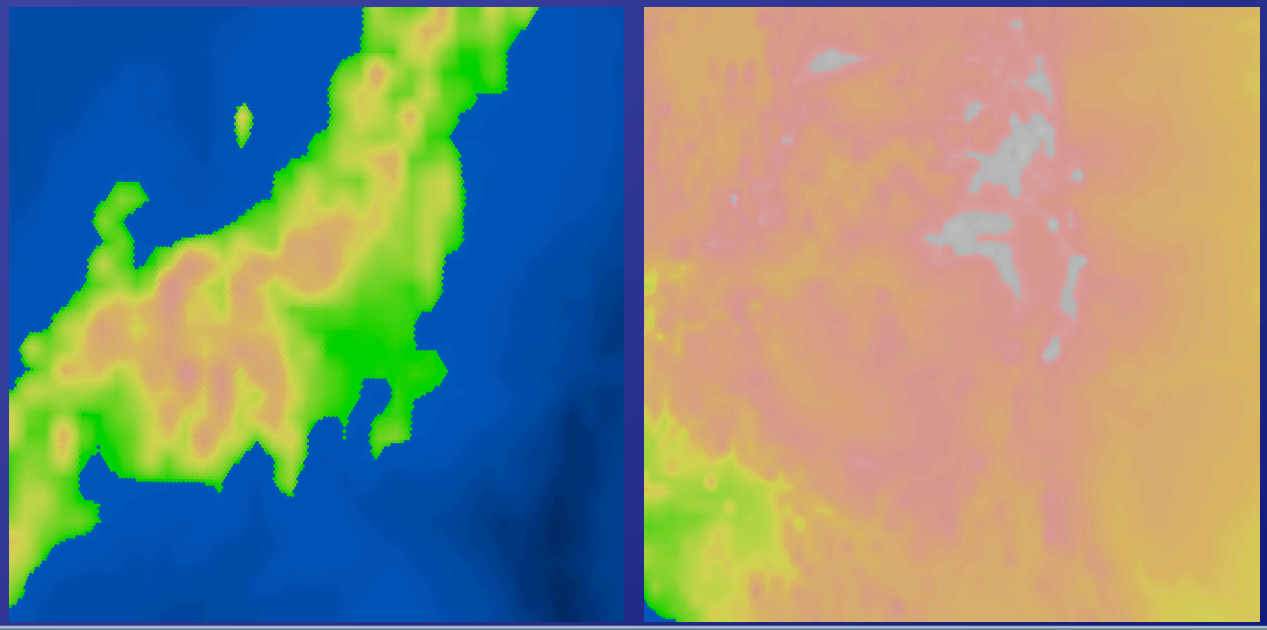
Icosahedral grids

For efficient computation in parallel computers.

initial → partitioning (Heikes and Randall, 1995) → optimization (Tomita et al. 2001)



Hexagonal/pentagonal control volumes



glevel-4 (~dx=480km)
glevel-5 (~dx=240km)
glevel-6 (~dx=120km)
glevel-7 (~dx=60km)
glevel-8 (~dx=30km)
glevel-9 (~dx=14km)
glevel-10 (~dx=7km)
glevel-11 (~dx=3.5km)

Model description

Non-hydrostatic ICosahedral Atmospheric model (NICAM)

• Dynamics	
Governing equations	Full compressible non-hydrostatic system (with acoustic wave)
Spatial discretization Horizontal grid configuration Vertical grid configuration Topography	Finite Volume Method Icosahedral grid (Tomita et al. 2001) Lorenz grid Terrain-following coordinate
Conservation	mass, total energy (Satoh 2002, 2003)
Temporal scheme	Slow mode － explicit scheme （RK2） Fast mode － Horizontal Explicit Vertical Implicit scheme
• Physics	
Turbulence, surface flux	Mellor & Yamada 2, 2.5, 3(plan)/Louis(1979), Uno et al.(1995)
Radiation	MSTRNX (Sekiguchi and Nakajima, 2005?)
Cloud physics	Kessler; Grabowsky(1998,1999); Lin et al.(1983); bin(plan)
Cloud parameterization	Arakawa & Schubert (plan); Kain & Fritch (plan)
Land process	Mixed layer/bucket; MATSIRO (under implementation)

Aqua Planet Experiment – Settings

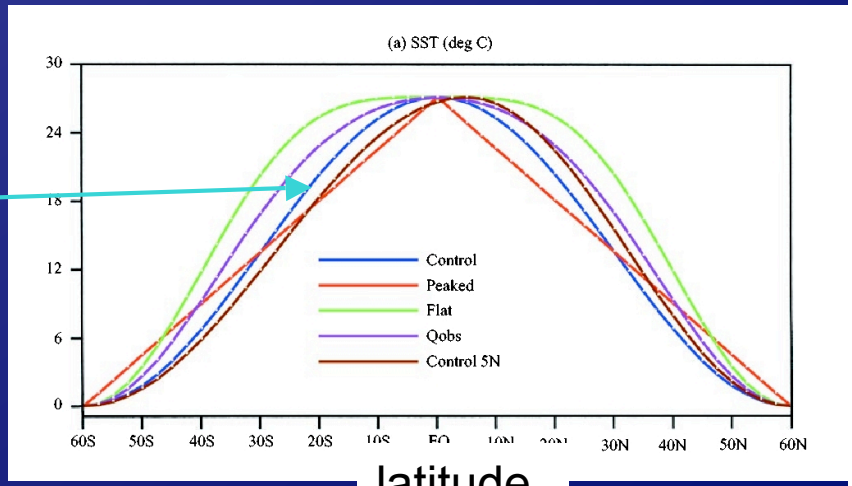
Test as a global cloud resolving model

- **History**
  - Hayashi & Sumi (1986), Swinbank et al.(1988)
    - MJO etc.
  - Gotswami et al.(1984), Numaguchi(1995)
    - Hadley circulation (formation and intensity)
- **Intercomparison**
  - Neale & Hoskins (2001)
    - Prescribed SST（several cases, zonal symmetric）
    - Prescribed Ozone
    - Equinoctial solar radiation
    - Statistics for three year average

Our choice:

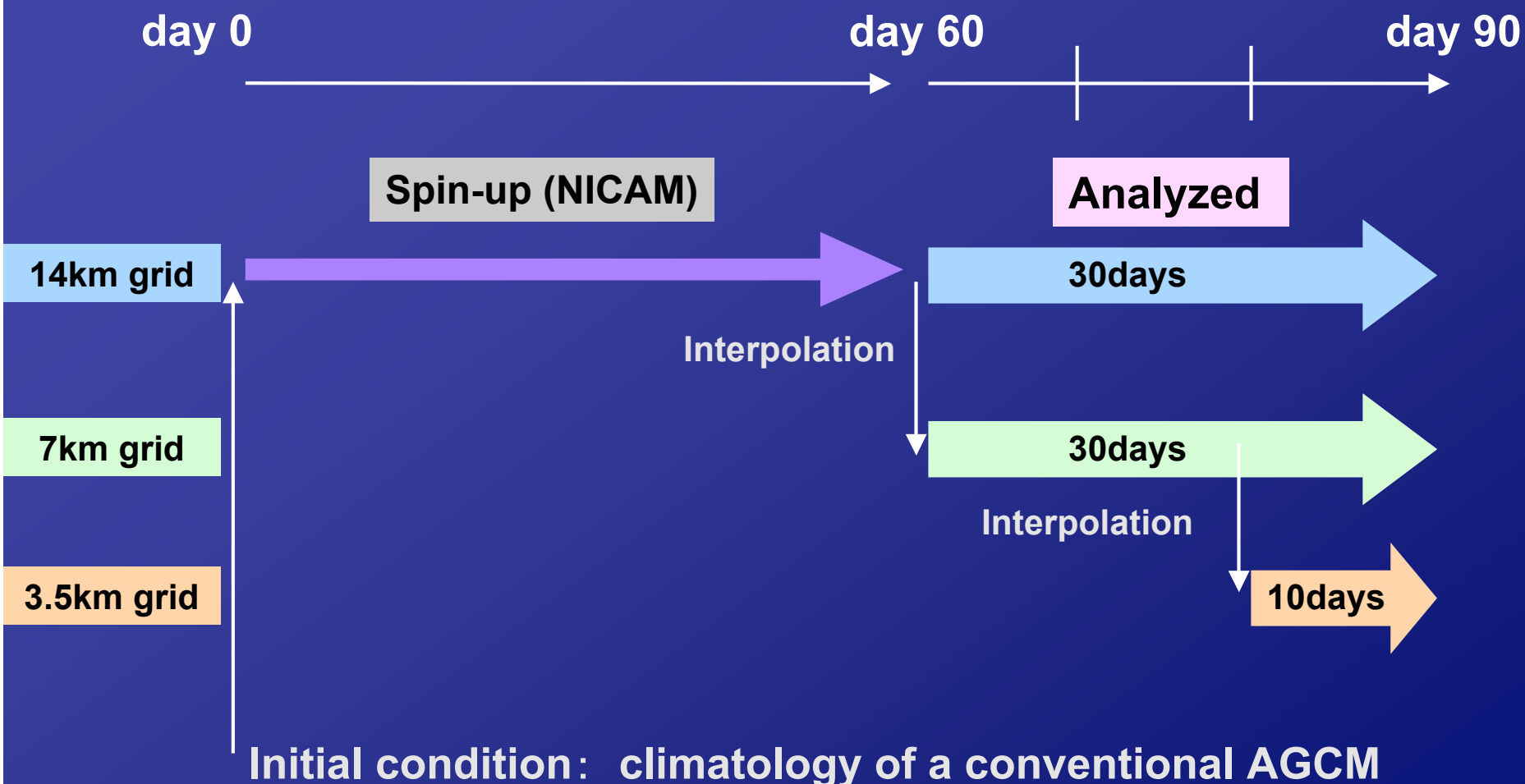
- Control SST
- 3 horizontal resolutions:
  dx~14km, 7km, 3.5km
- Explicit cloud microphysics
  (without parameterizations for shallow and deep clouds)

SST



Strategy

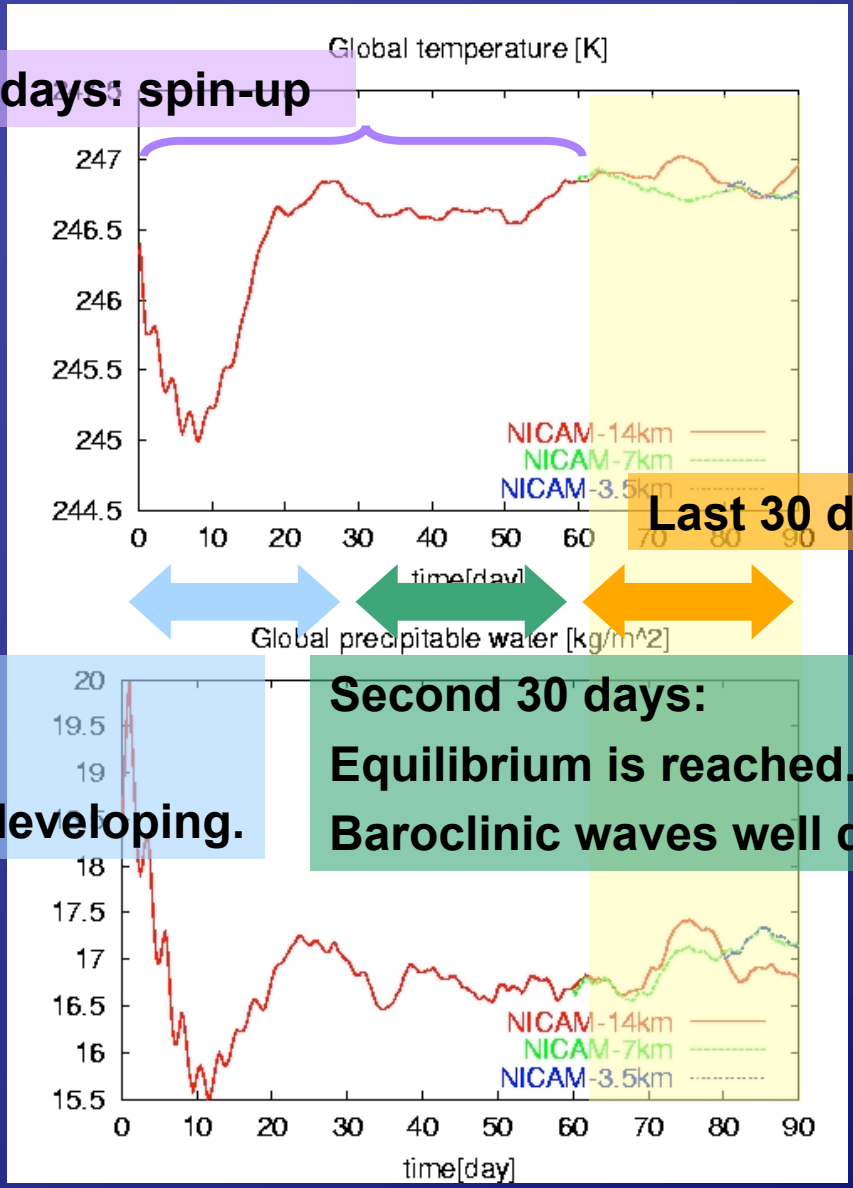
Series of experiments



Initial condition: climatology of a conventional AGCM
(CCSR/NIES/FRCGC AGCM ver 5.7)

Equilibrium ?

First 60 days: spin-up



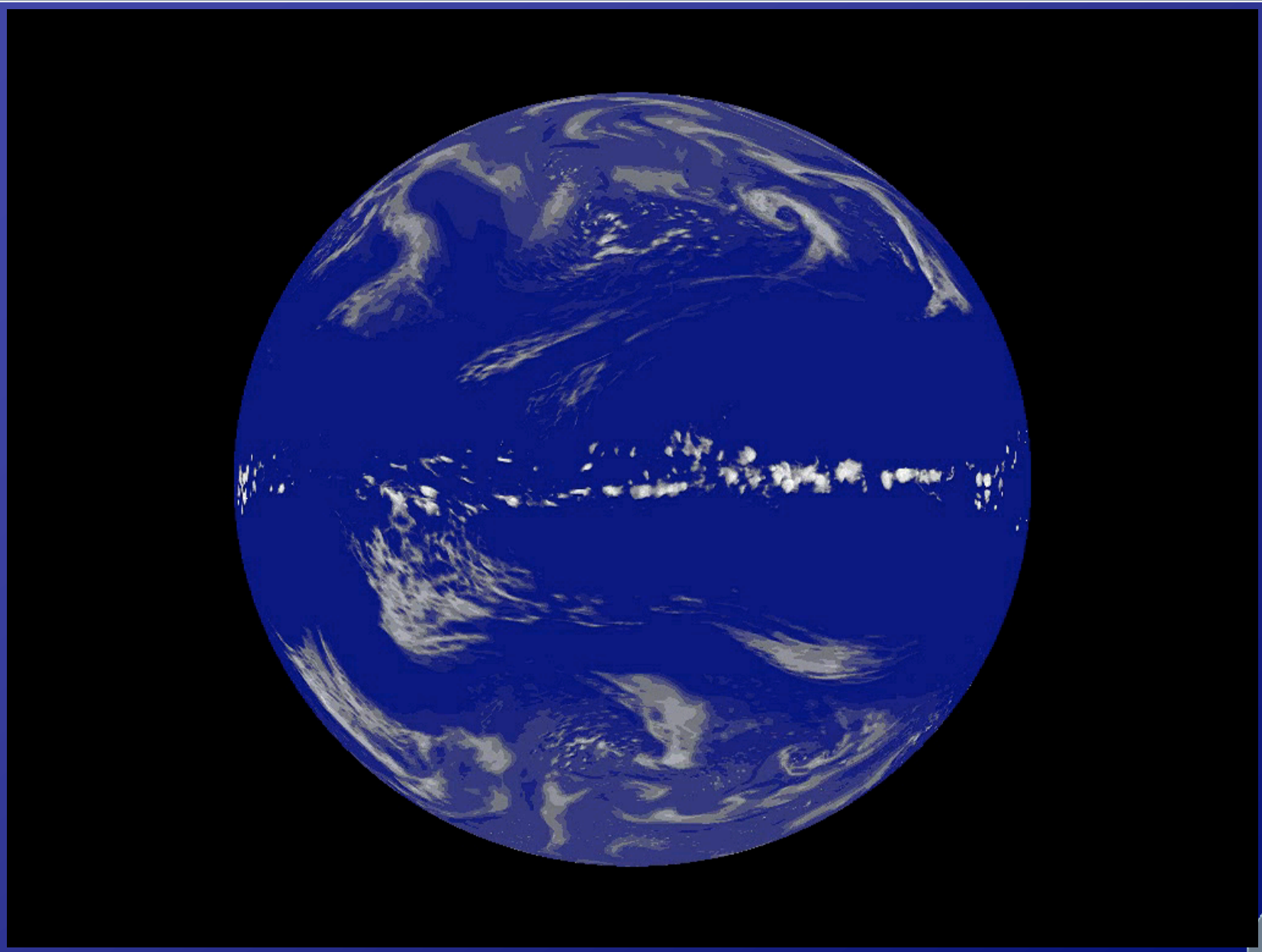
Last 30 days: analyzed term

First 30 days:
Fluctuation is large.
Baroclinic waves are developing.

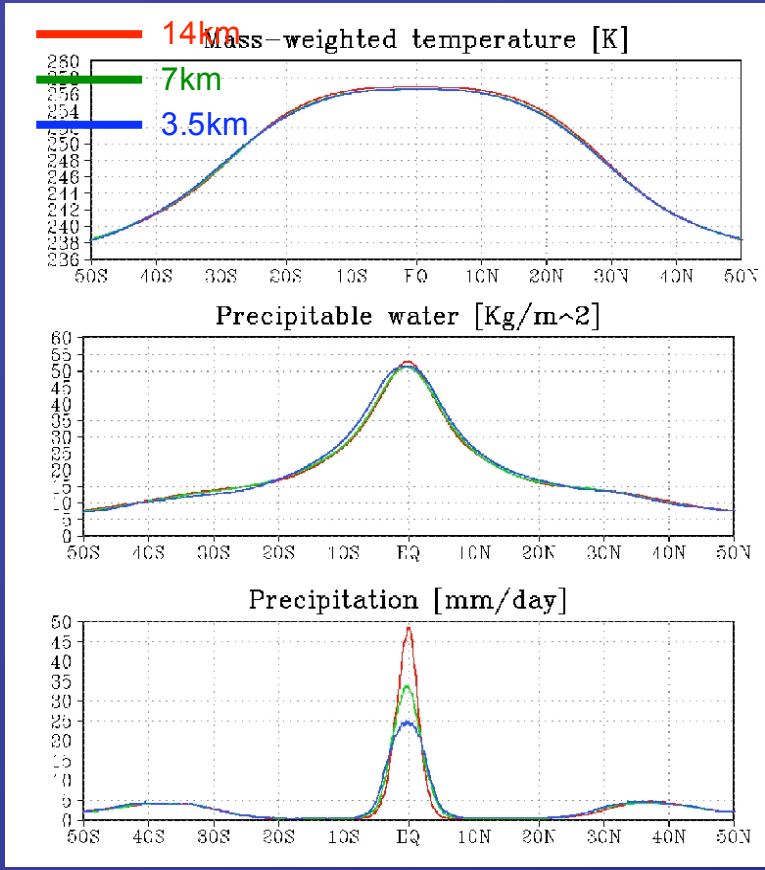
Second 30 days:
Equilibrium is reached.
Baroclinic waves well developed.

FRCGC Frontier Research Center for Global Change

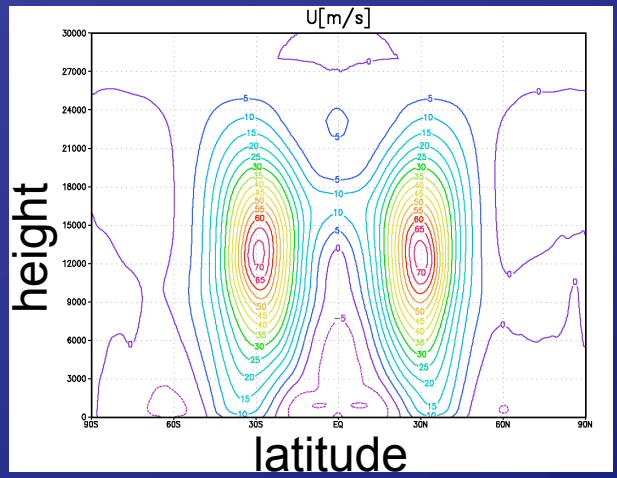
OLR (gl-11, dx~3.5km): 80-90 days



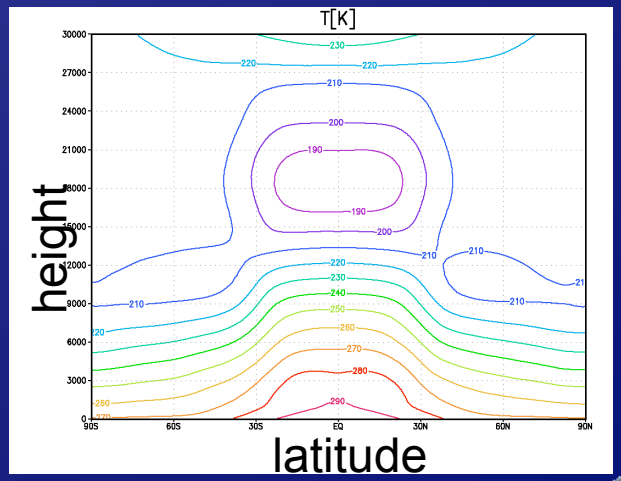
Model climatology & resolution dependence



gl-09 (~15km): 30days average zonal wind [m/s]



temperature [K]



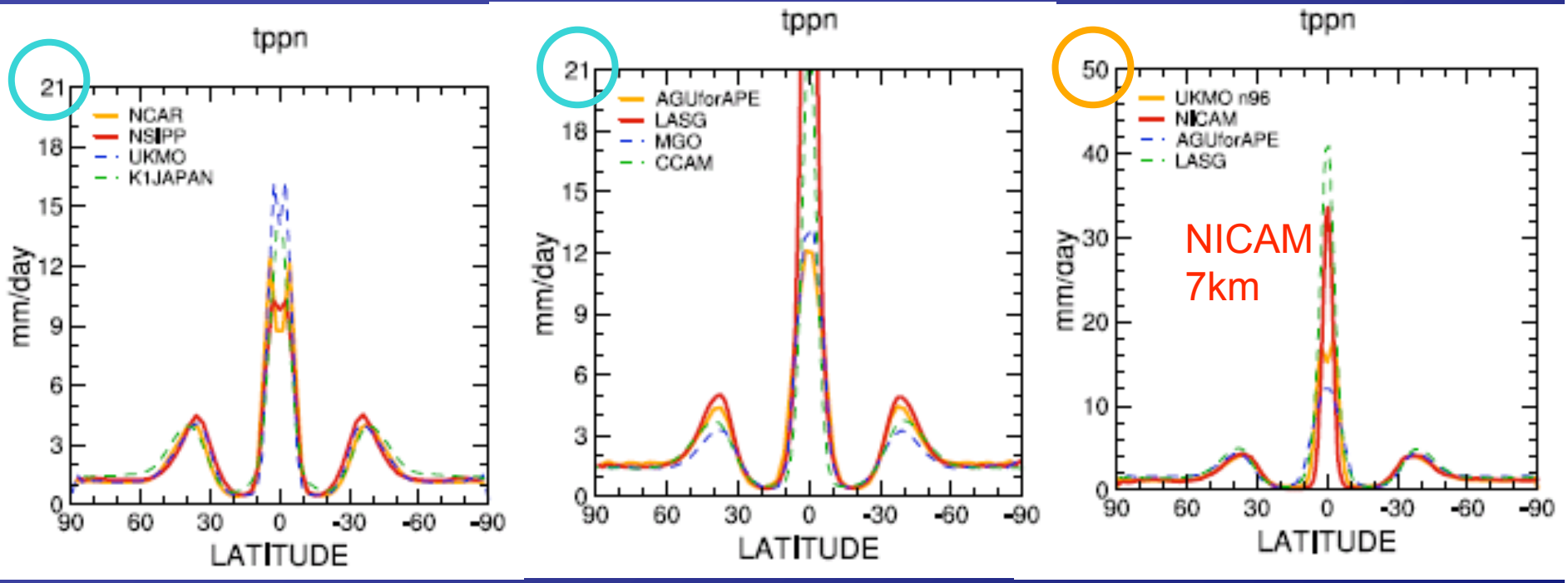
- Temperature
- Precipitable water

→ almost converged

- Precipitation

→ not converged in dx~3.5km

APE intercomparison



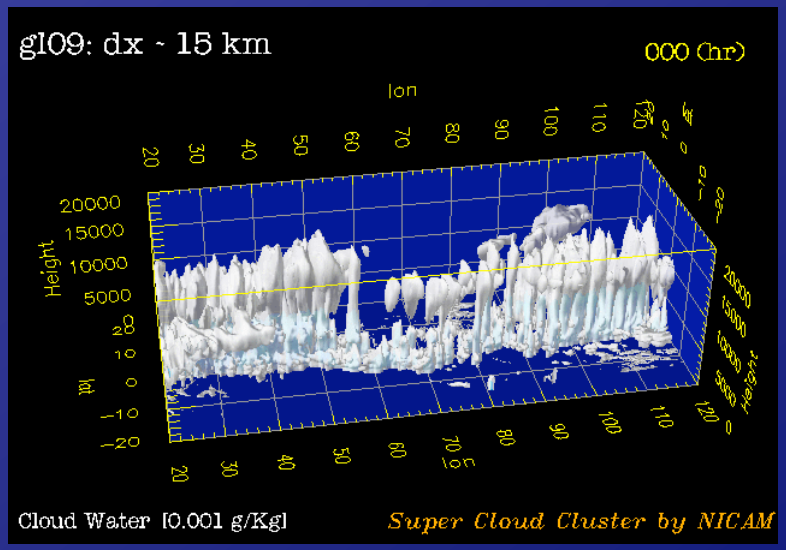
NICAM: narrower ITCZ

- Are GCMs wrong (due to insufficient resolution, etc.) ?
- Is NICAM wrong ?
  - shallow clouds ?
  - tuning ?

Multi-scale structure of clouds

SCCs: Super-Cloud Clusters (MJO, convectively-coupled Kelvin wave)

- ~O(1000km)
- eastward propagation



CCs: Cloud Clusters

- ~O(100km)
- westward movement

MCs: Meso-scale convective systems / Cloud systems

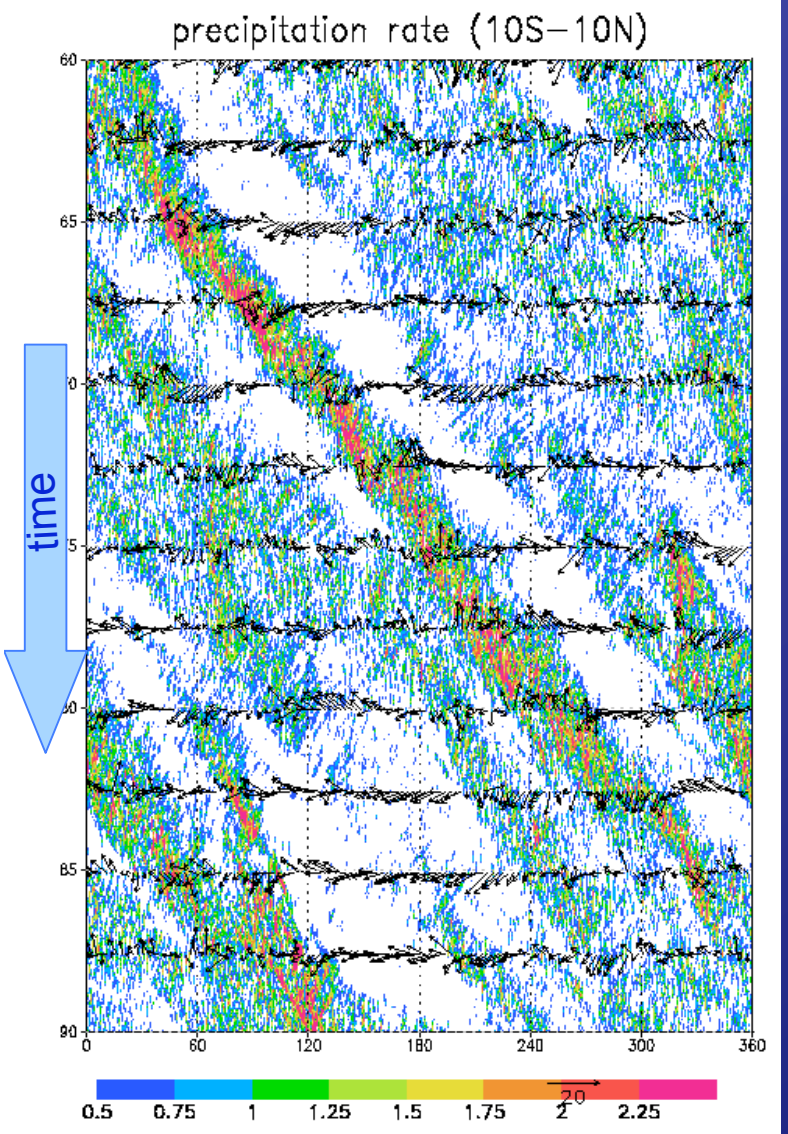
- ~O(10km)

Clouds

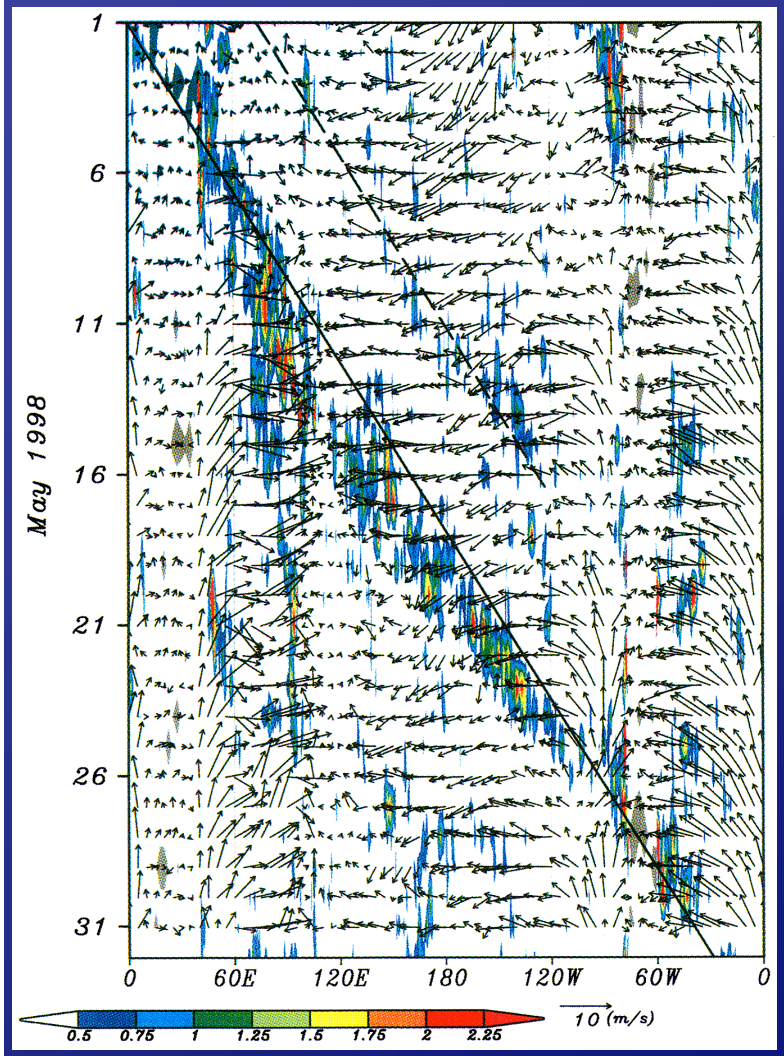
- ~O(1km)

Super-cloud clusters (SCCs)

NICAM (dx~7km)



Observation (Takayabu et al. 1999)



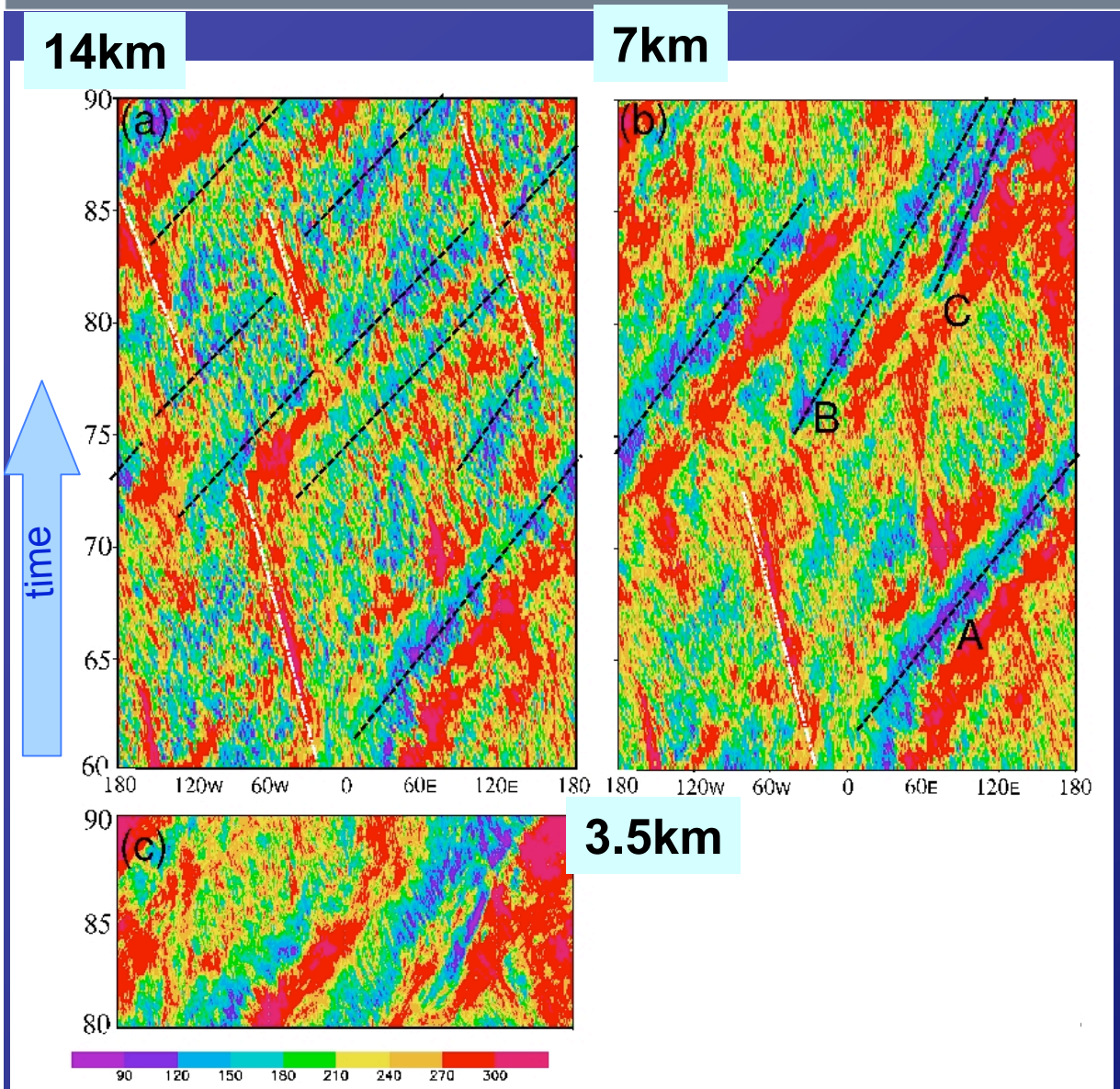
May 1998

Eastward propagation

~15m/s

~moist Kelvin wave

Resolution dependence (SCCs)



- Rotation period of SCCs:

  dx~14km

  20~25days

  fast propagation

  ~ convectively-coupled Kelvin wave

  dx~7km, 3.5km

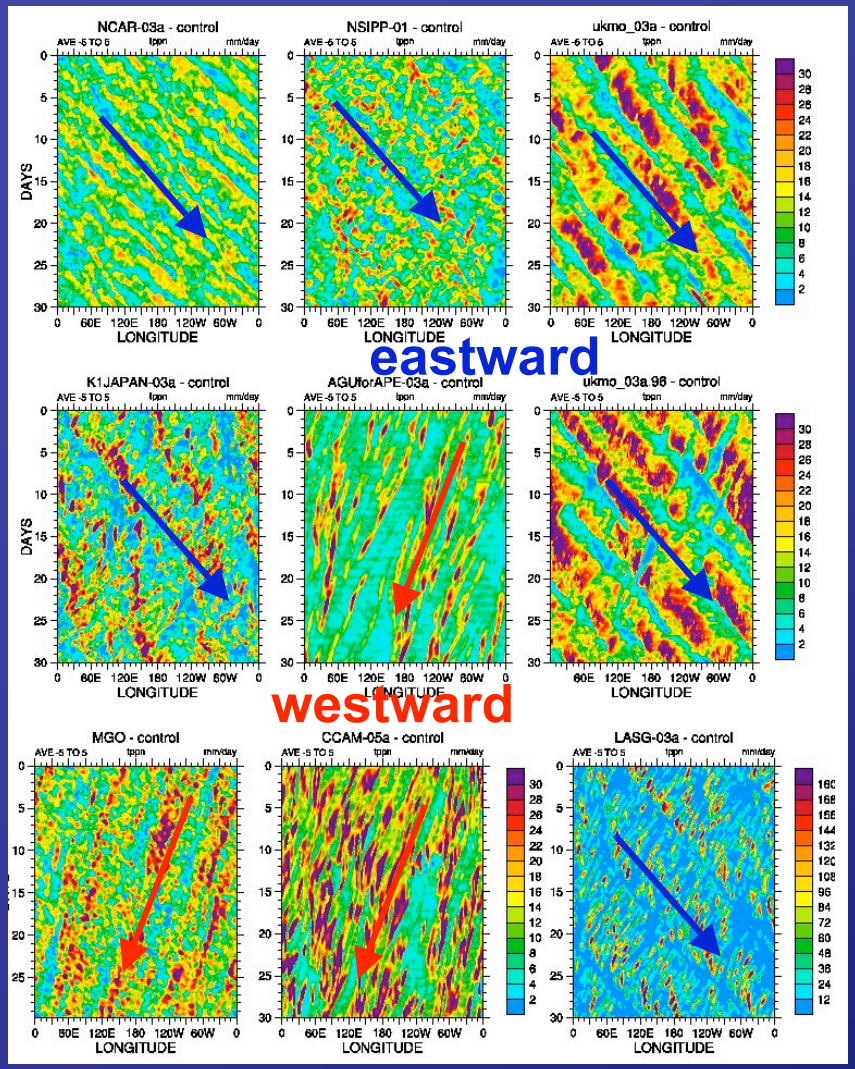
  25~40days

  ~ MJO-like (?)

- Organization is more precise in dx~7km than in dx~14km.

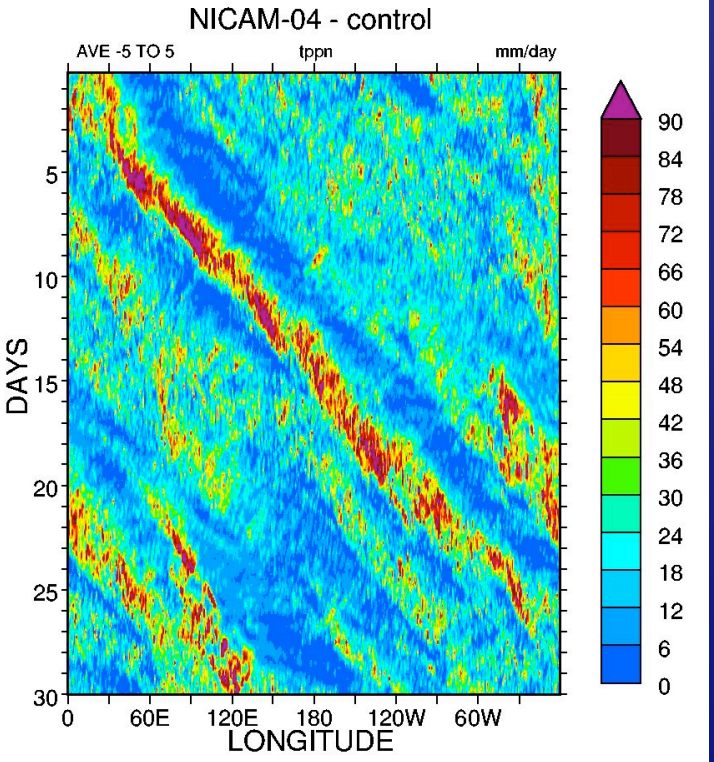
Comparison with conventional AGCMs (SCCs)

Hovmeller diagram for precipitation in the tropics



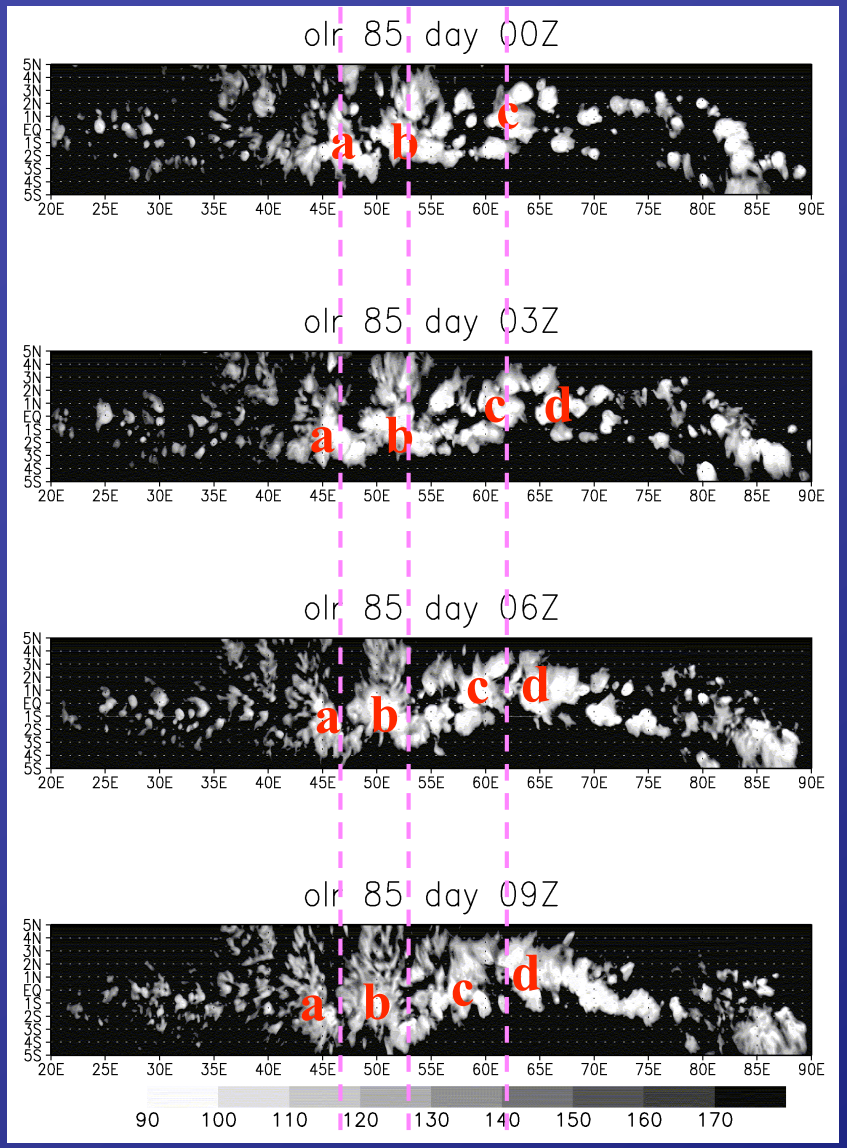
time

NICAM (dx~7km)



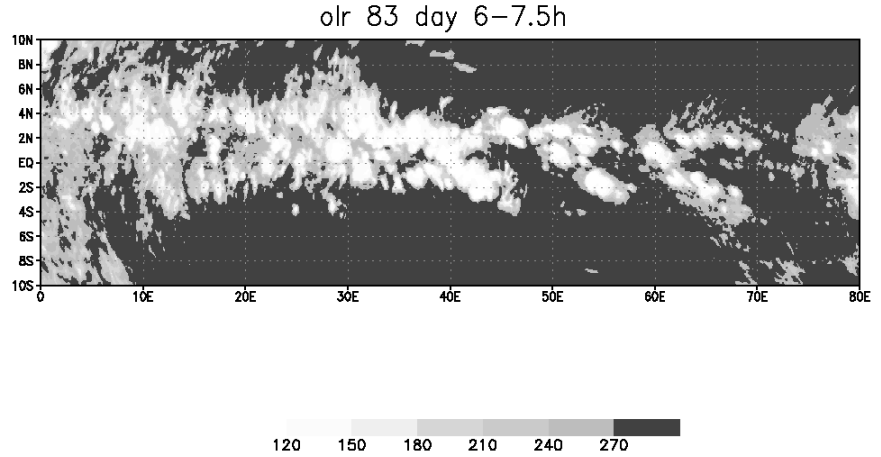
Produced by Dr. Williamson

Cloud clusters (CCs)



time

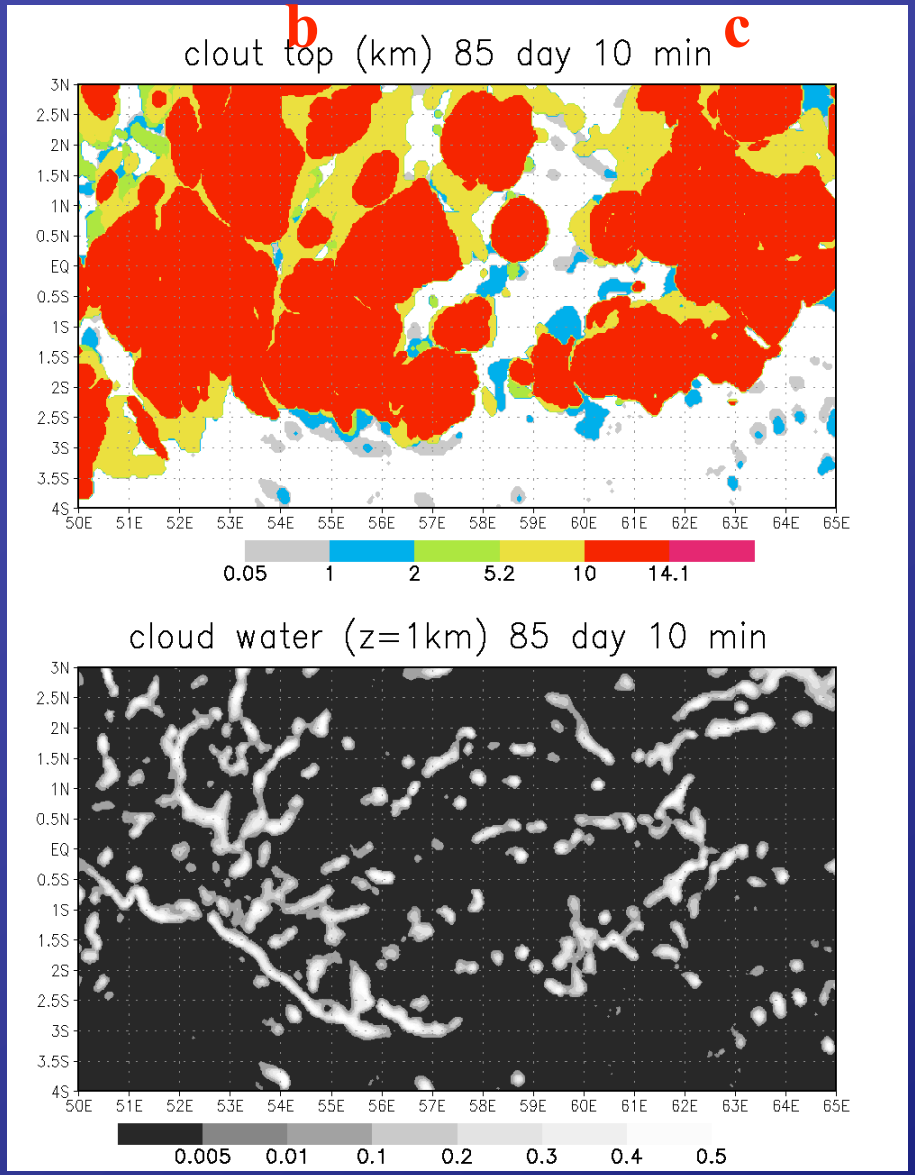
NICAM dx~3.5km

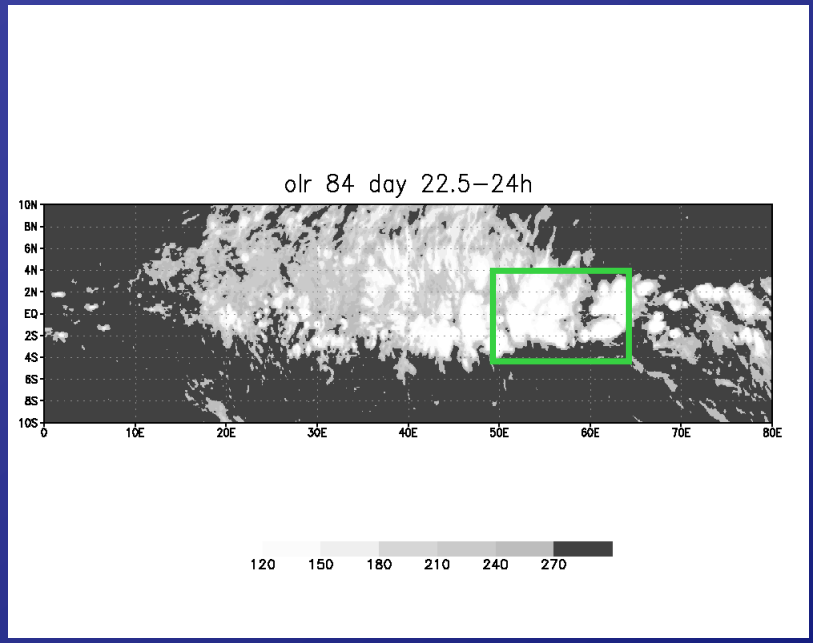


Cloud clusters move westward.

Cloud clusters & Meso-scale convective systems

(CCs & MCs)

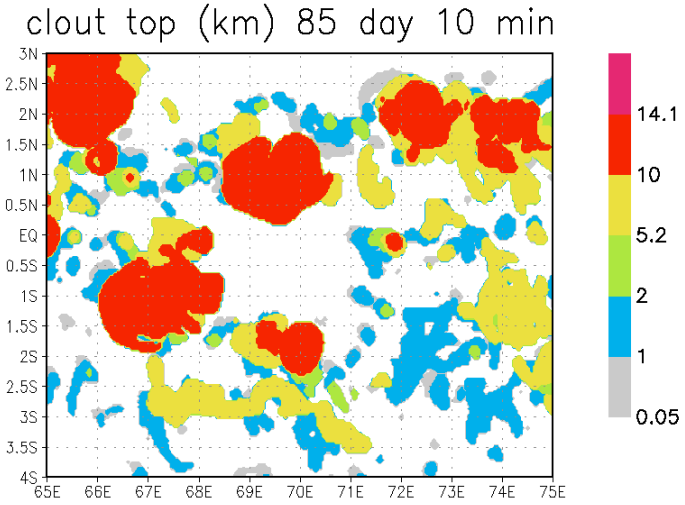


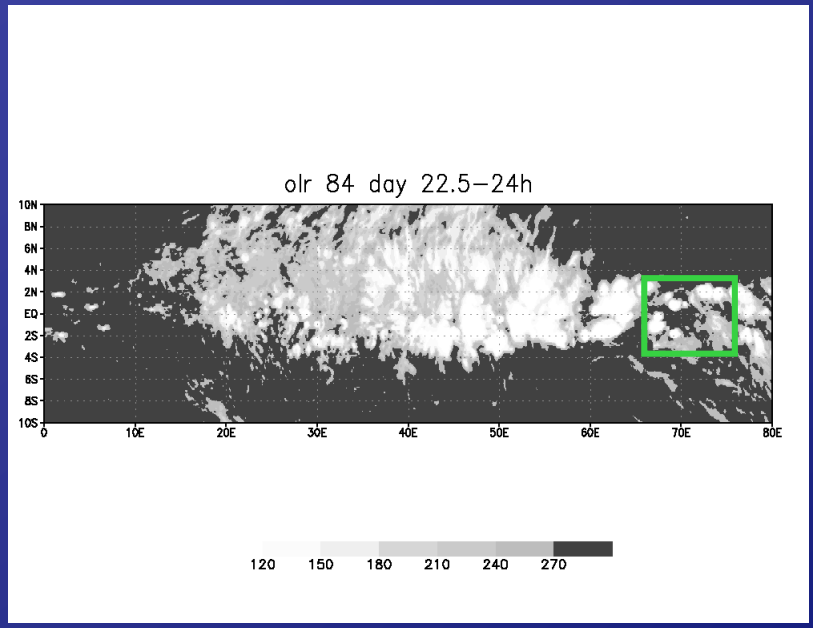


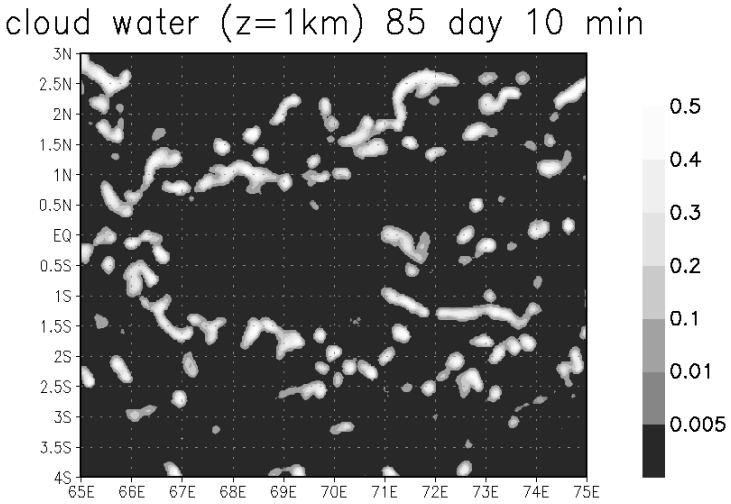
Cloud clusters consist of meso-scale convective systems.

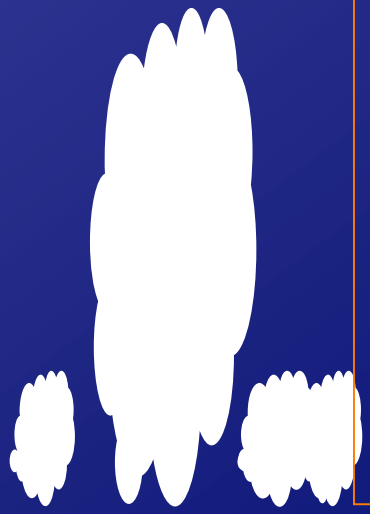
Meso-scale convective systems & clouds

(MCs & Clouds)









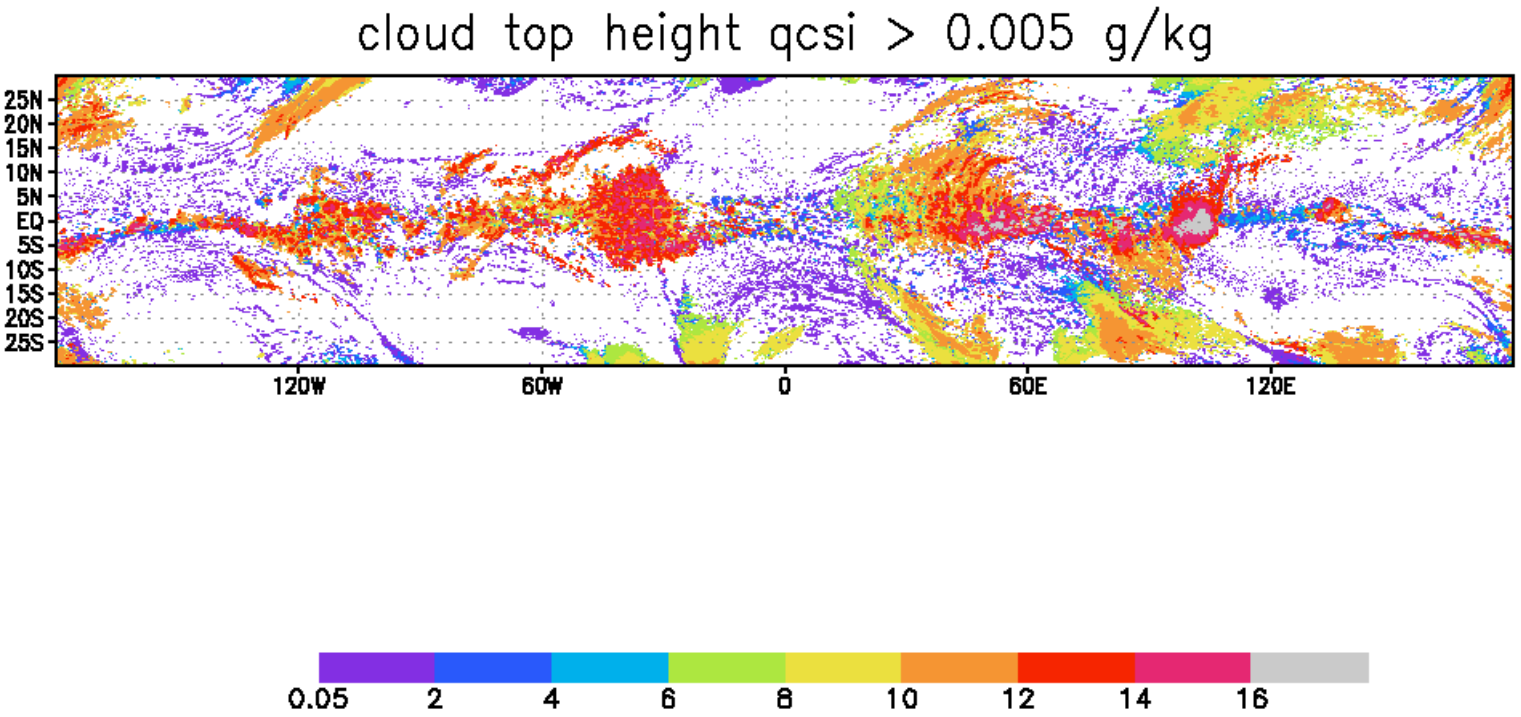
- Clouds are formed along edges of meso-scale convective systems.
- Meso-scale convective systems are complexes of small clouds and deep cloud(s).

Shallow clouds ?

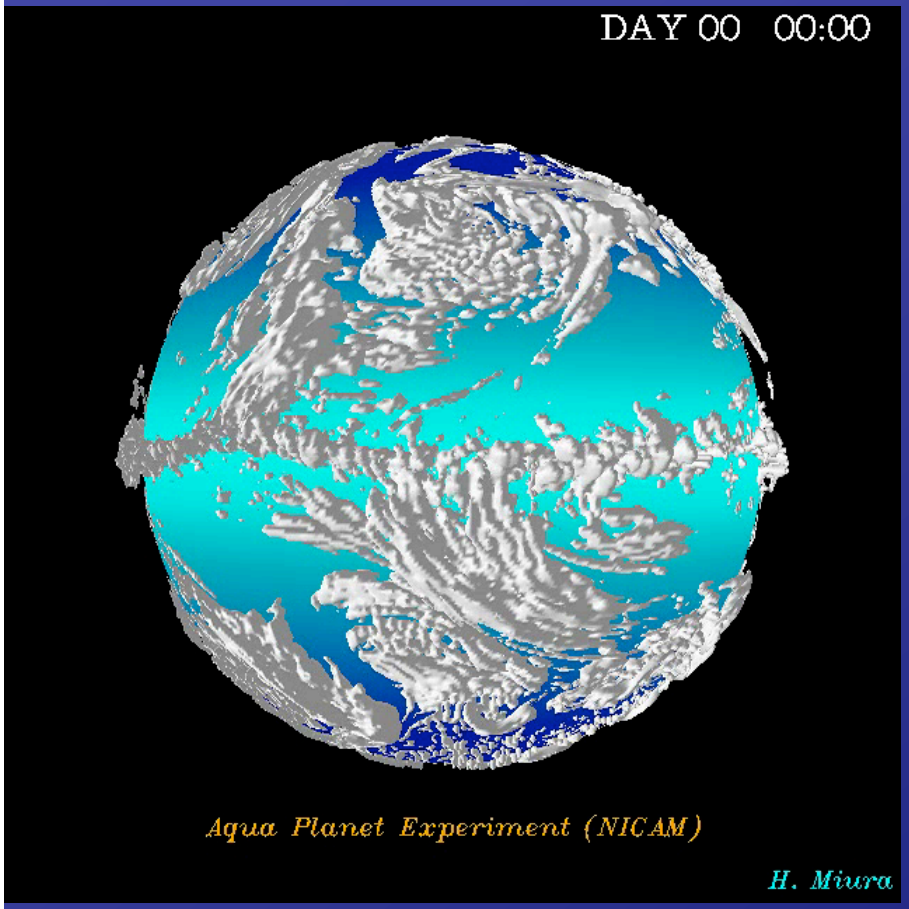
Shallow clouds are simulated at the outside of SCCs.

However, stratocumulus (e.g. near the west coast of California, Peru) is unnoticeable in this simulation.

- insufficient resolution ?
- aqua planet experiment ?



Diurnal variation



Observations:

- **early morning peak**
  - TRMM (Nesbit and Zipser 2003)
  - TOGA-COARE (Sui et al. 1997)
  - GMS (e.g. Albright et al. 1985)
- **afternoon peak**
  - TOGA-COARE (Sui et al. 1997)
  - GMS (e.g. Albright et al. 1985)
  - GATE (e.g. Albright et al. 1981)

Numerical experiments:

- **early morning peak**
  - Xu and Randall (1995)
  - Sui et al. (1998)

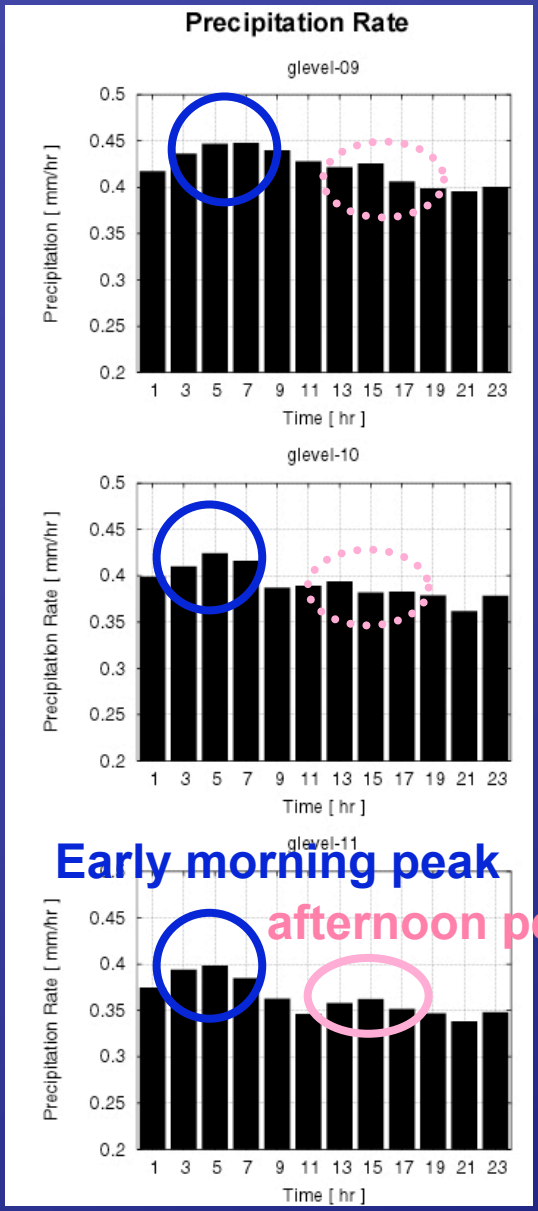
Diurnal variation: precipitation

In the tropics: 10S-10N

gl-09 (~14km)

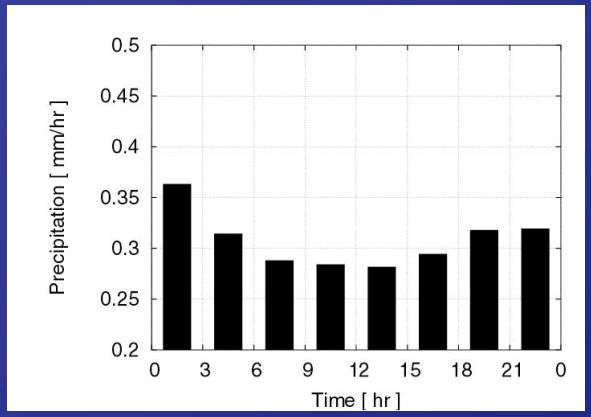
gl-10 (~7km)

gl-11 (~3.5km)



Early morning peak

afternoon peak

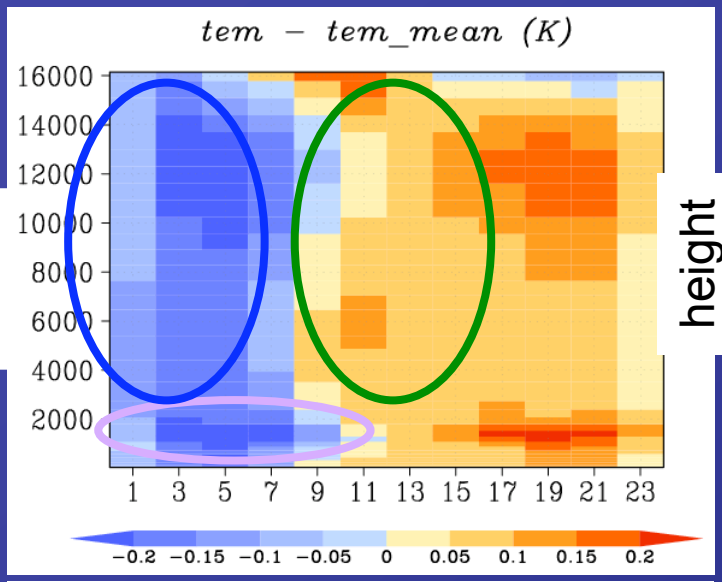


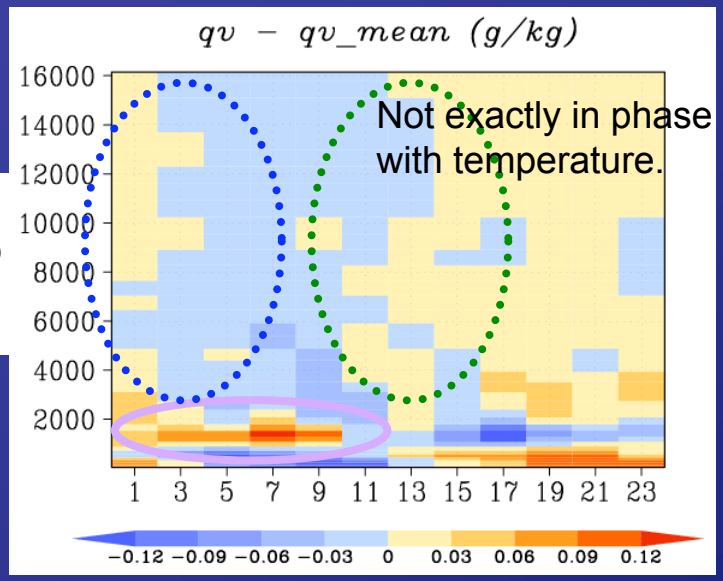
CCSR/NIES AGCM (T42)

NICAM is more consistent with observations (TRMM, GMS, GATE) compared to a conventional AGCM.

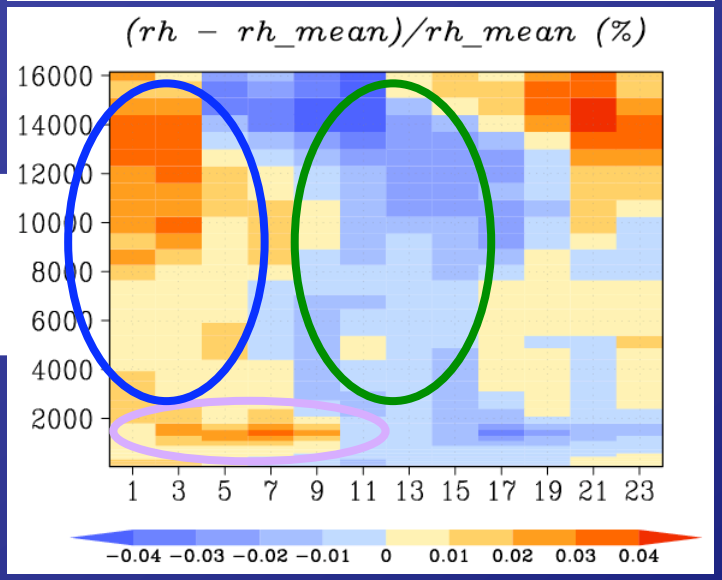
Diurnal variation: vertical structures

Time-height cross section. Diurnal variations of anomaly from daily mean.





gl-09
(~14km)



Consistent results with
Xu and Randall (1995) and Sui et al. (1998).

heating and drying by SW
(larger inhibition in day time)

cooling and moistening by lack of SW
(smaller inhibition in night time)

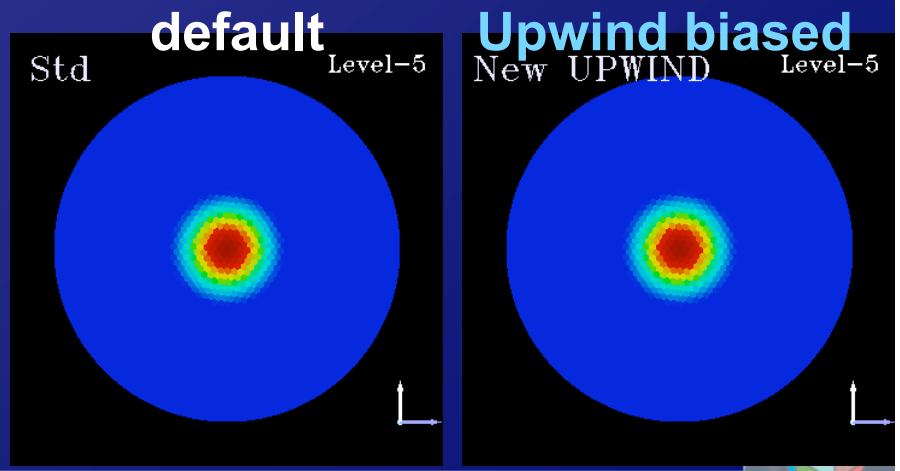
cooling and moistening around boundary top
(smaller inhibition in early morning)

Summary

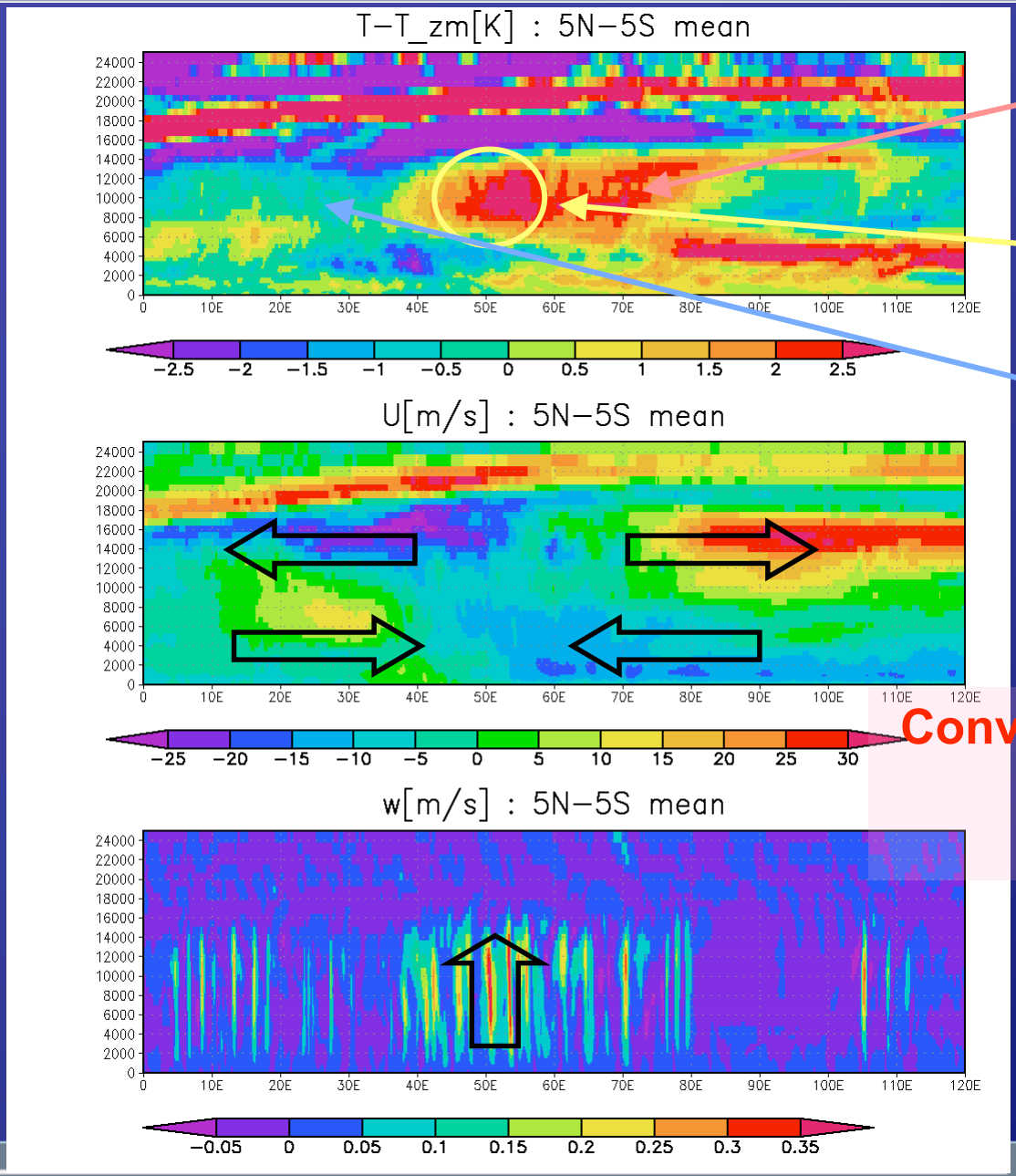
- The first version of "NICAM" has been developed.
  - We can avoid ambiguities related to cumulus parameterizations.
  - Non-hydrostatic equations, Icosahedral grid
- Aqua planet experiment
  - Reasonable climatology
  - Multi-scale structure of clouds
    - Eastward propagation of SCCs (~convectively-coupled Kelvin wave)
    - Westward movement of CCs
    - CCs are composed of MCs.
    - MCs are organized by small clouds and deep cloud(s).
  - Reasonable diurnal variation
  - Horizontal resolution dependence
    - Parameterizations for shallow clouds and turbulence ?
- Computer resources
  - 5 hours for 1 day simulation using half of the ES
  - 3.5km-10days experiment requires 1% of 1year ES resource
  - 1TB data for 3.5km-10days exp., 90min interval

Future plan

- **Realistic simulation with land-ocean distribution**
  - Perpetual July /Jan. for 10-30days calculation with dx=3.5km
  - Seasonal cycle run with dx=7km
  - Comparison with observations
- **Improvement of the model**
  - Shallow clouds
  - Turbulence (level 3 scheme)
  - Advection scheme
    - Based on van Leer (1977), Thuburn (1997)



Vertical structure of a SCC

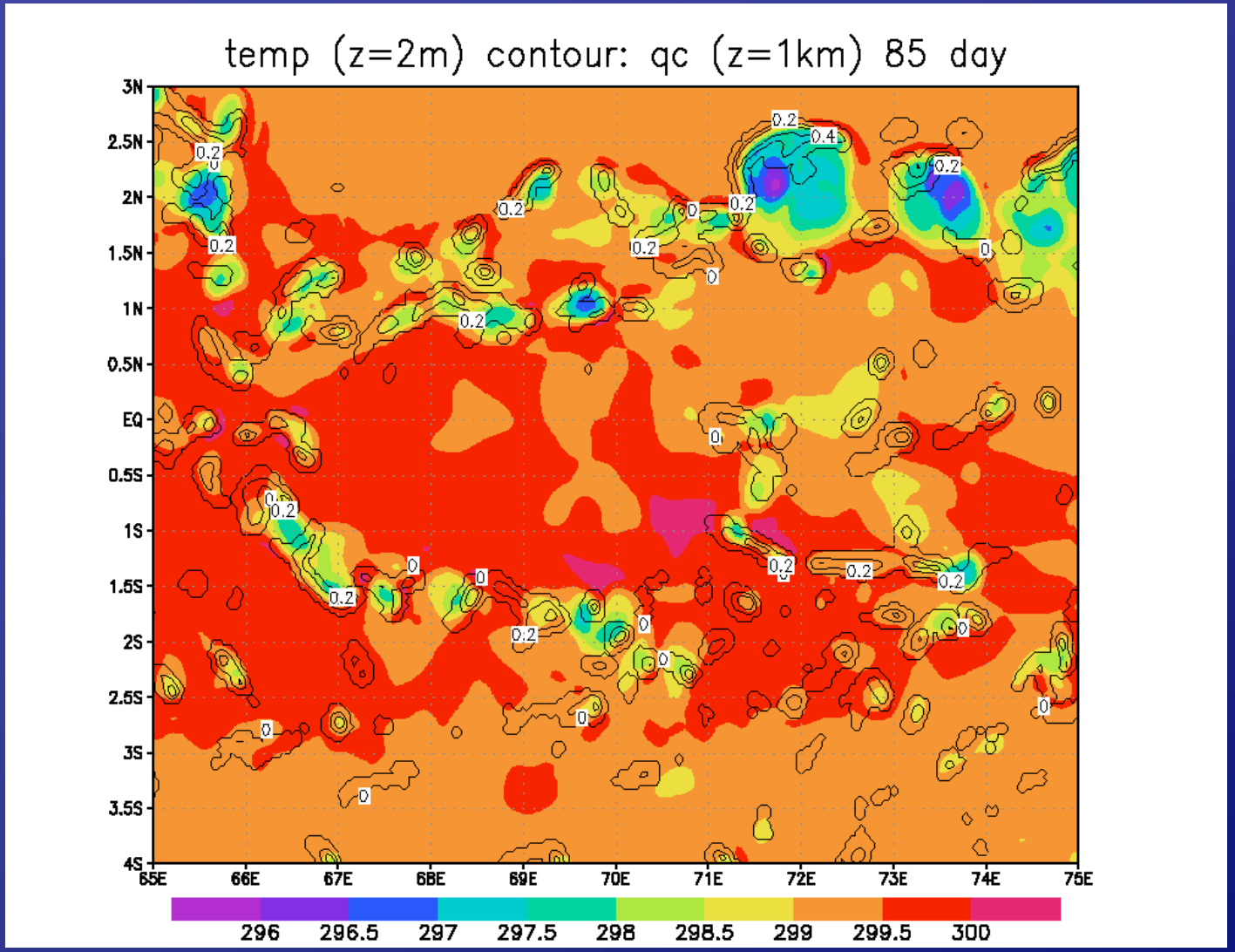


Warm : east of SCC

Diabatic heating by latenet heat release

Cold: west of SCC

Convectively coupled Kelvin wave with diabatic heating in upward motion region

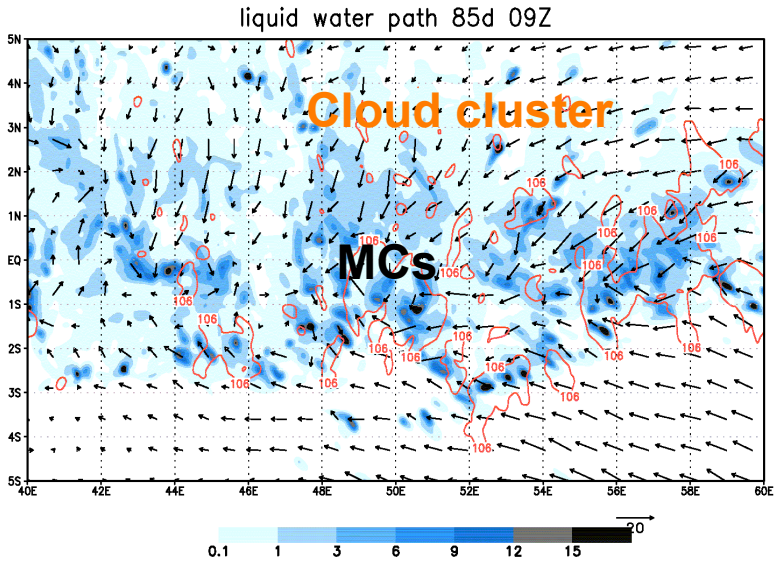

temp (z=2m) contour: qc (z=1km) 85 day
3N
2.5N
2N
1.5N
1N
0.5N
EQ
0.5S
1S
1.5S
2S
2.5S
3S
3.5S
4S
65E
66E
67E
68E
69E
70E
71E
72E
73E
74E
75E
296
296.5
297
297.5
298
298.5
299
299.5
300

Meso-scale convective systems (MCs)

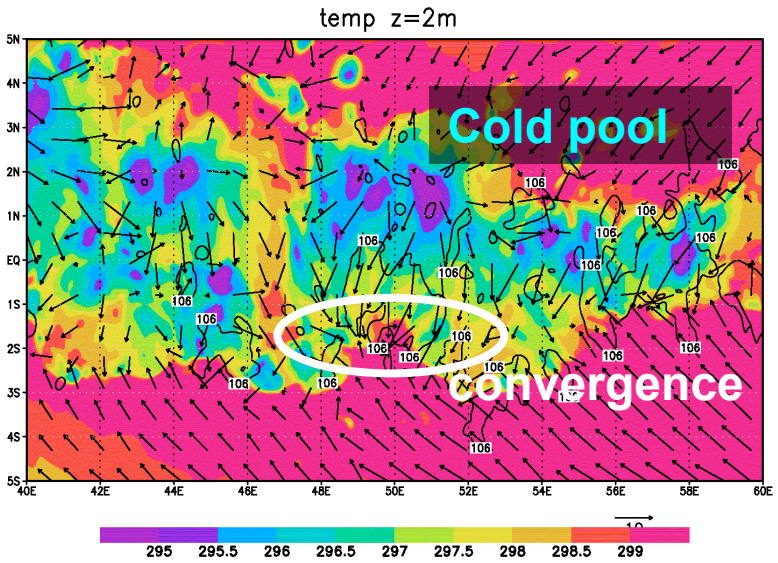
Cold-pool dynamics dominate the formation of meso-scale convective systems.

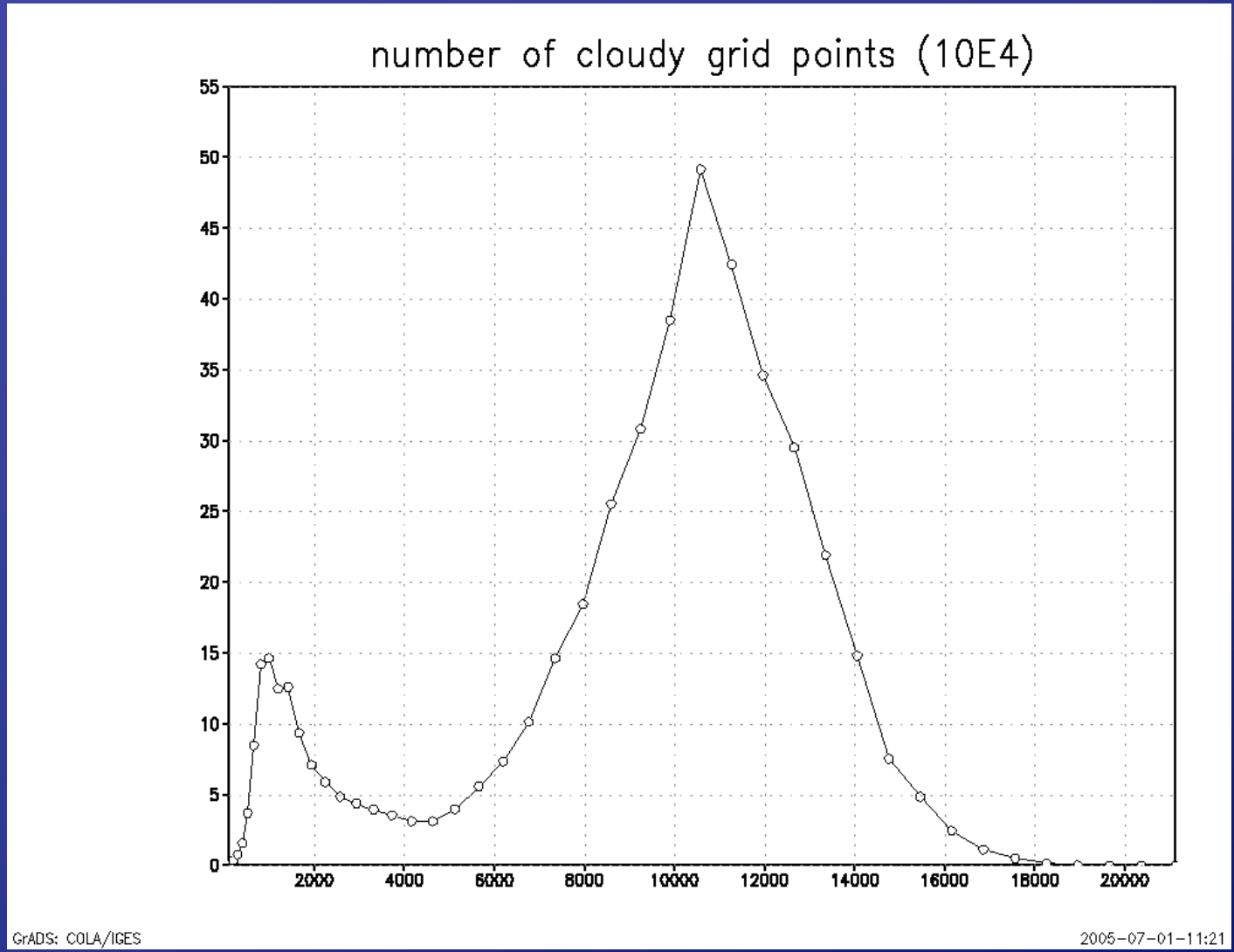
- Outflow from a cold pool forms a convergence zone.
- Meso-scale convective systems are developed around the front.
- The meso-scale convective systems newly constitute a cloud cluster.

Liquid water path



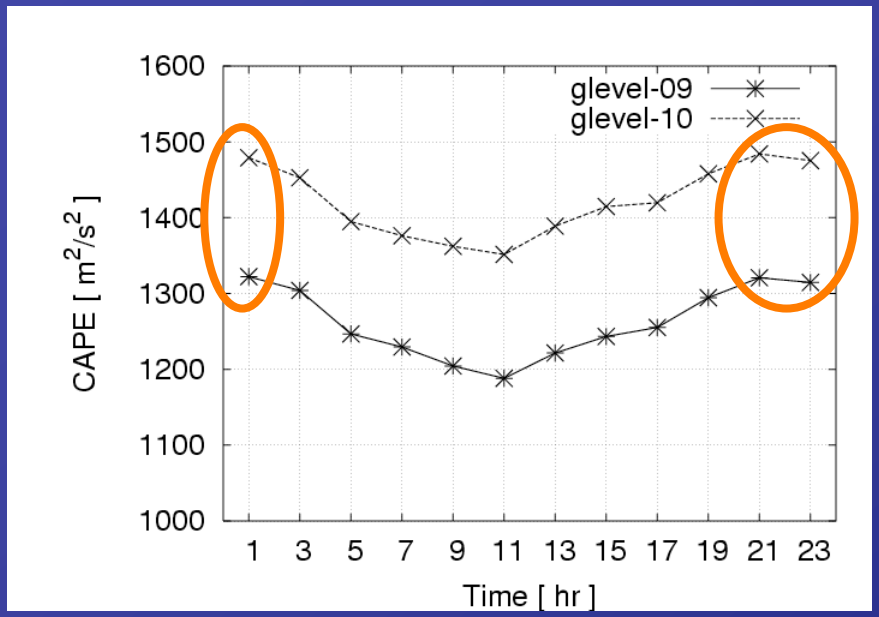
Surface temperature




number of cloudy grid points (10E4)
55
50
45
40
35
30
25
20
15
10
5
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
GrADS: COLA/IGES
2005-07-01-11:21

CAPE / CIN

Convective Available Potential Energy

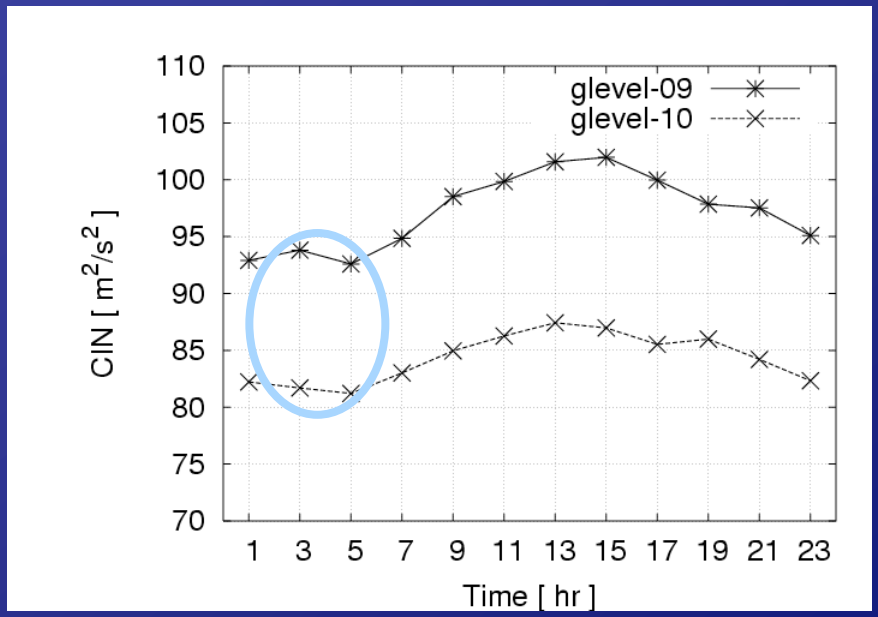


midnight

temperature maximum in the evening

water vapor maximum in boundary layer

Cumulus INhibition



early morning

water vapor maximum around boundary top

low level clouds ?
vertical shear of MSE?