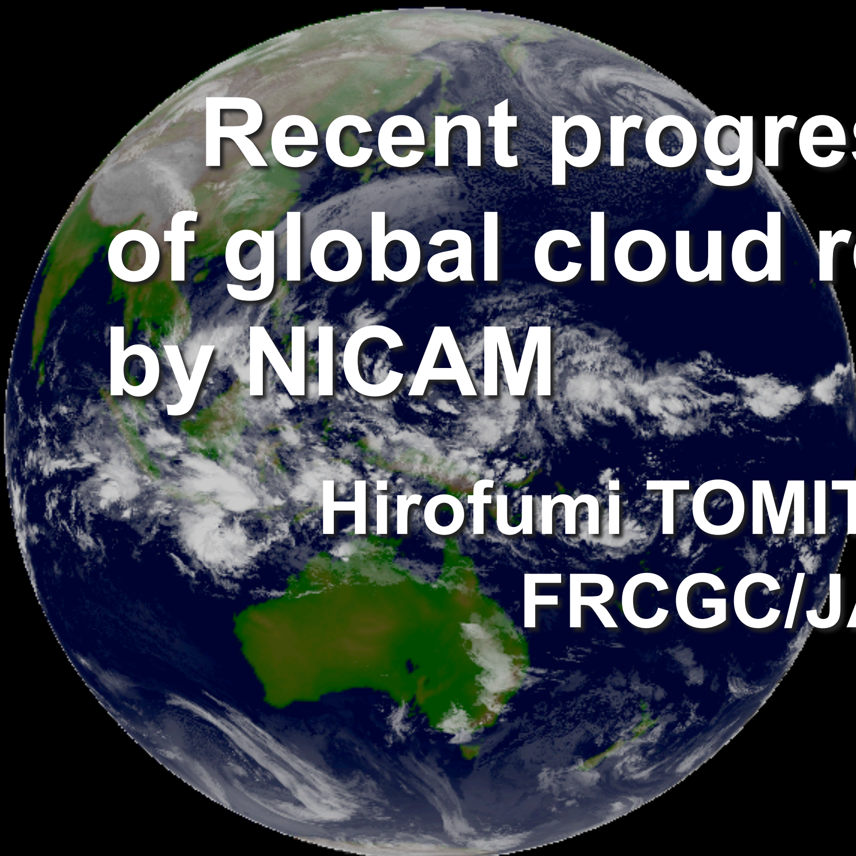
Recent progress and activity of global cloud resolving simulation by NICAM

Hirofumi TOMITA & NICAM working team
FRCGC/JAMSTEC



MTSAT-1R

NICAM : DX=3.5km

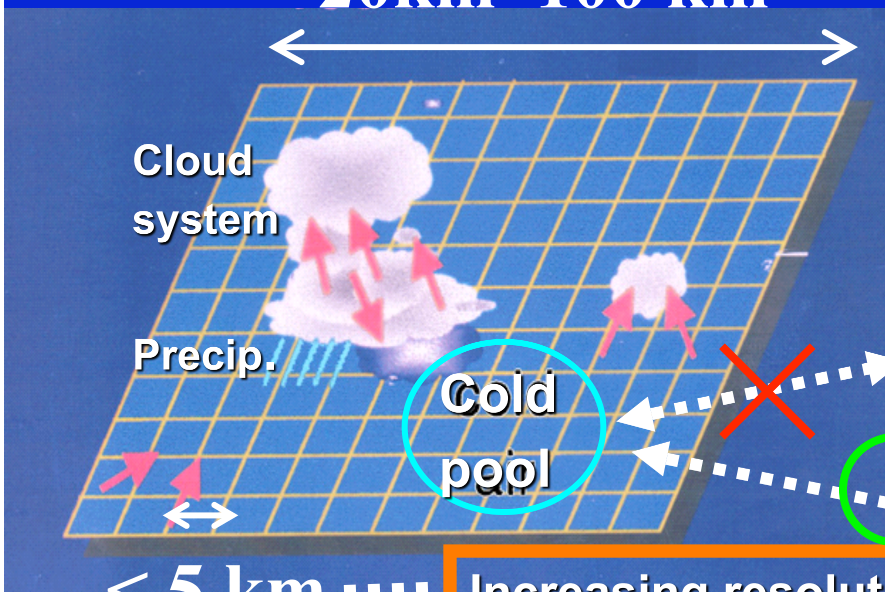
Outline

- Our strategy for global atmospheric model
  - Global cloud resolving
- Brief introduction of our model NICAM
  - Notable feature of NICAM
  - Current development status
- Recent activity
  - MJO simulation
  - Seasonal march simulation
- Model improvement
  - PBL scheme, microphysics
- Future plan
  - Use of 10 PFLOPS machine
- Summary

Our strategy for global model

Resolve the cloud system & related process over the globe

20km~100 km …



< 5 km …

Resolution of traditional GCM

→ Use "cloud parameterization"

→ Limit the representation of
- spatial structure
  hierarchy of cloud system
- lifetime of cloud system

Increasing resolution drastically

→ Avoid "cloud parameterization"

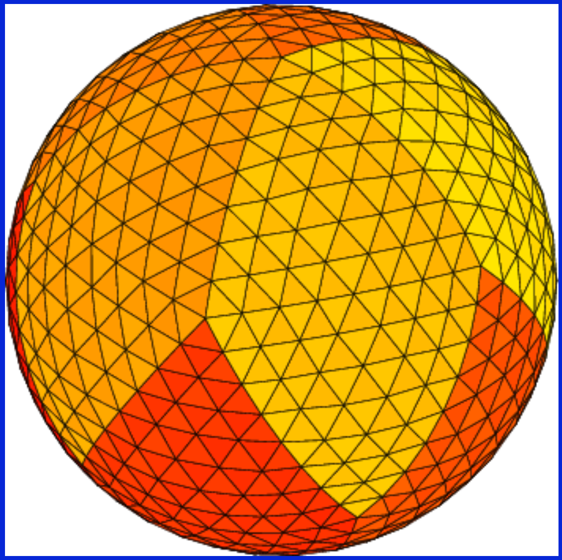
→ Resolve the cloud system explicitly

→ Represent
- multi-scale cloud phenomena
- lifecycle of individual clouds

NICAM project

NICAM project

- NICAM project (~2000)
  - Dynamical core
    - Horizontal grid : icosahedral grid
    - Dynamics : Non-hydrostatic equation
  - Cloud representation
    - Avoid “cumulus parameterization”
    - Microphysics only.



- The 1st global cloud resolving simulation (2004)
  - Aqua-planet experiment (Tomita et al. 2005)
- Successful simulation of MJO (2007)
  - 2006 boreal winter (Miura et al. 2007)
- Computational tuning
  - for the massively parallel vector computer system (ES)

Current status of NICAM

Ref. Satoh et al. 2008 *J. Comput. Phys.* / Tomita & Satoh 2004 *Fluid Dyn. Res.*

■ **Dynamics**	
Governing equations	Fully compressible non-hydrostatic system
Spatial discretization Horizontal grid configuration Vertical grid configuration Topography	Finite Volume Method Icosahedral grid with spring dynamics smoothing (Tomita et al. 2001/2002) Lorenz grid Terrain-following coordinate
Conservation	Total mass, total energy (Satoh 2002, 2003)
Temporal scheme	Slow mode － explicit scheme （RK2, RK3） Fast mode － Horizontal Explicit Vertical Implicit scheme
■ **Physics**	
Turbulence/shallow clouds	MY2Smith, MYNN (Nakanishi and Niino 2004); Mellor & Yamada 2,2.5,3
Surface flux	Louis (1979), Uno et al. (1995)
Radiation	MSTRNX (Sekiguchi and Nakajima, 2005)
Cloud microphysics	Kessler; Grabowski (1998,1999); Lin et al. (1983); NSW6 (Tomita 2008); NDW6 (Mitsui 2008); WSM3-6 (Hong et al. 2004)
Cloud parameterization	Prognostic AS, Kuo, LS condensation (>30km-mesh)
Surface process	SST given or slab ocean / bucket; MATSIRO

Series of GCRM simulation by NICAM

IDEAL SIMULATION

- Aqua-planet experiment (APE-MIP, 2005)
  - Tomita et al.(2005), Miura et al. (2005), Satoh et al.(2005, 2007), Nasuno et al. (2007, 2008a, b), Mapes et al.(2008)

REALISTIC SIMULATIONS WITH LAND & SST DISTRIBUTIONS

- Perpetual July experiment(CFMIP, 2007)
  - Iga et al.(2007), Tsushima et al.(2008)
- April 2004 simulation (realistic initial value)
  - Miura et al.(2007), Sato et al.(2007)
- December 2006 1-month simulation of an MJO event
  - Miura et al.(2007), Satoh(2008), Inoue et al.(2008), Masunaga et al.(2008), Fudeyasu et al.(2008), Sato et al(2008), Nasuno et al.(2008)
- Seasonal simulation from June 2004~ (3~5 months)
  - Oouchi et al.(2008a,b), Noda et al.(2008)
- TC simulation
  - Yanase(2009)
- Greenhouse-warmed climate experiment : ongoing!
  - Yamada(2009)

MJO event in the Dec. 2006-Jan.2007

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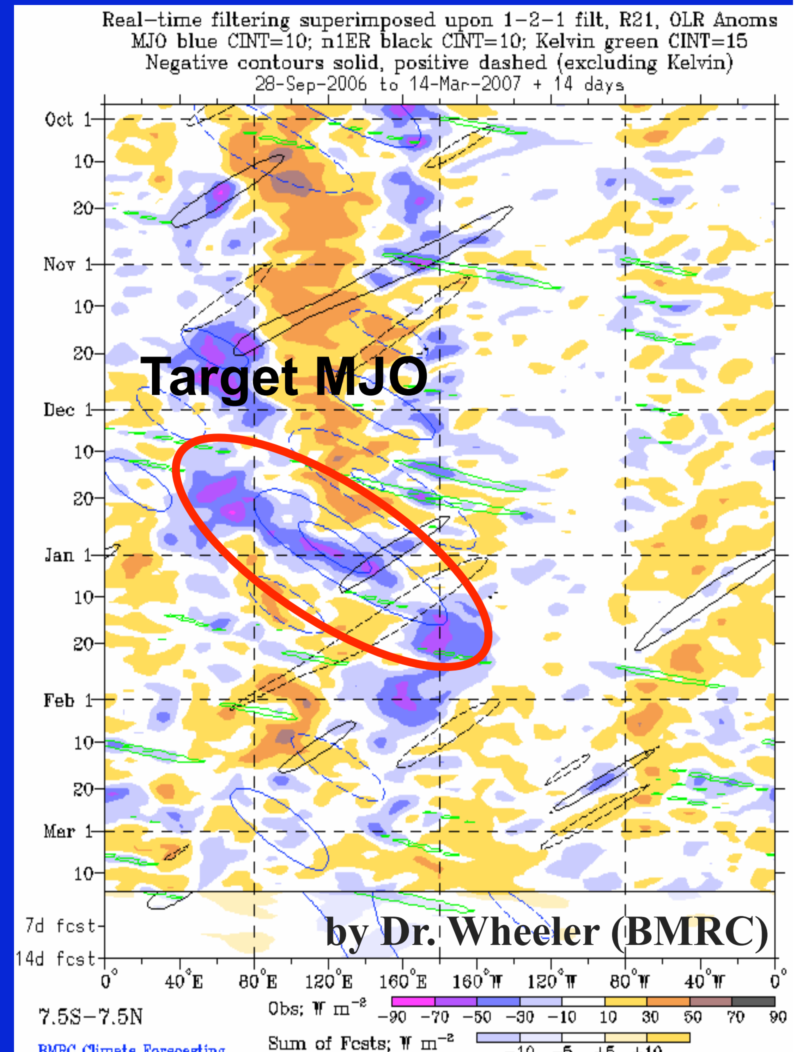
- **Model setup**
  - Horizontal grid :
    - 14km, 7km 3.5km
  - Vertical grid:
    - 0~38km with 40 levels
  - Initial conditions:
    - NCEP toropospheric analyses data (6 hourly, 1X1 grids)
    - Dec. 15th 00UTC (14km & 7km run)
      - 1-month integration
    - Dec 25th 00UTC
      - 7 day integration
  - Boundary conditions:
    - Reynolds SST, Sea ICE (weekly data)
    - ETOPO5 topography
    - Matthews vegetation
    - UGAMP O3 climatology



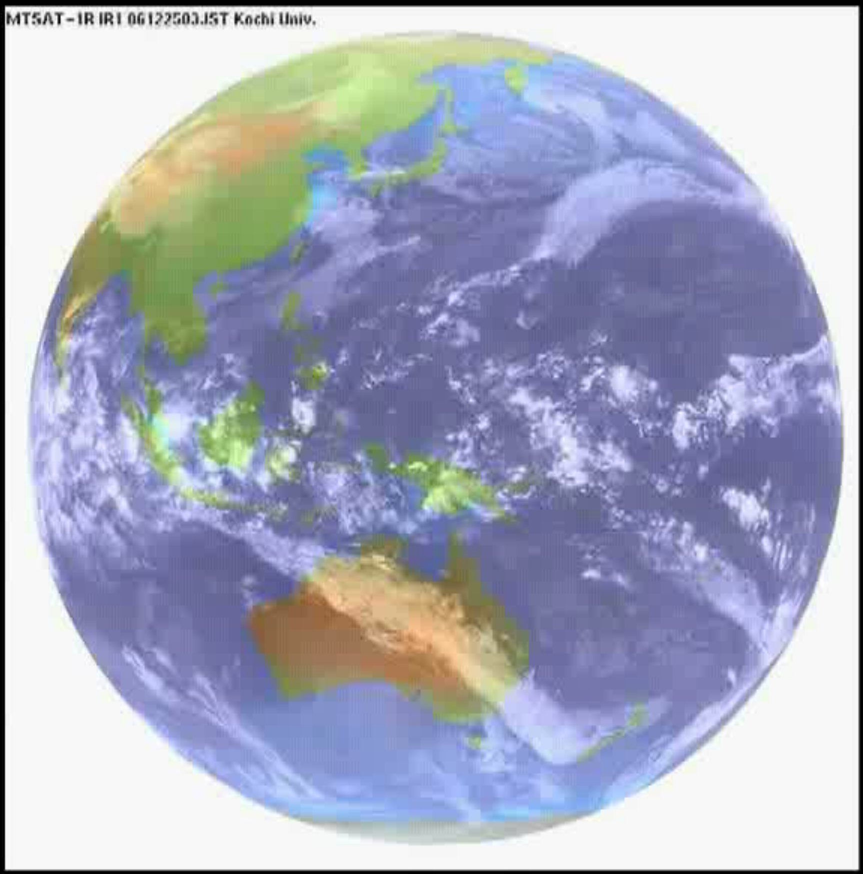
http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR_modes/h.6.ALL.EQ.html

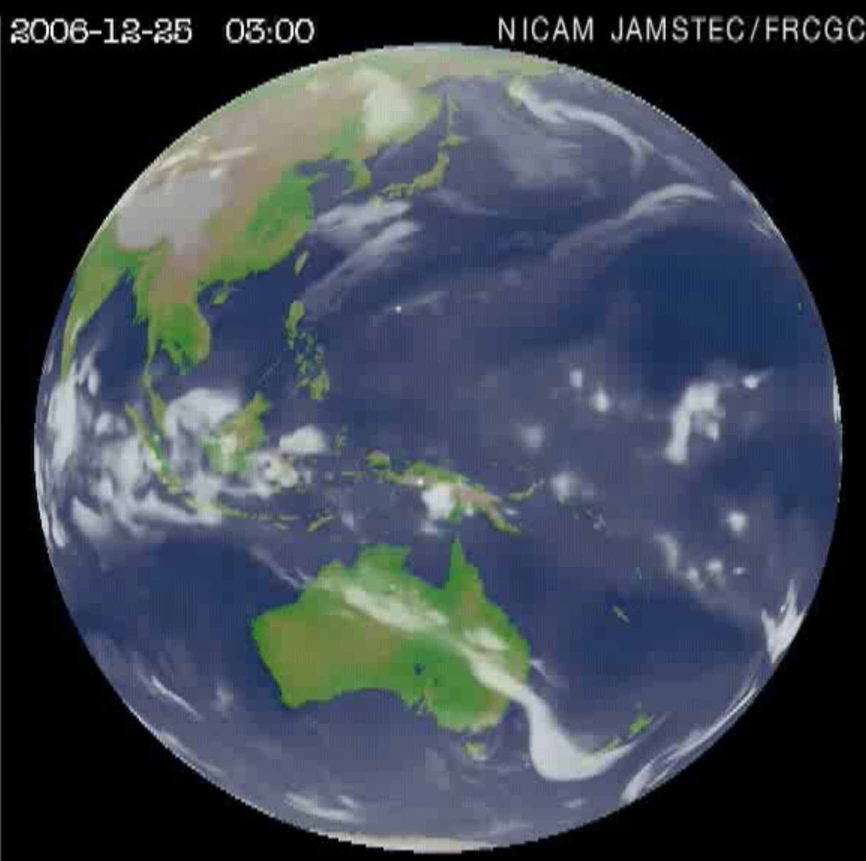
Miura et al.(2007)

3.5km simulation of an MJO event

MTSAT cloud image

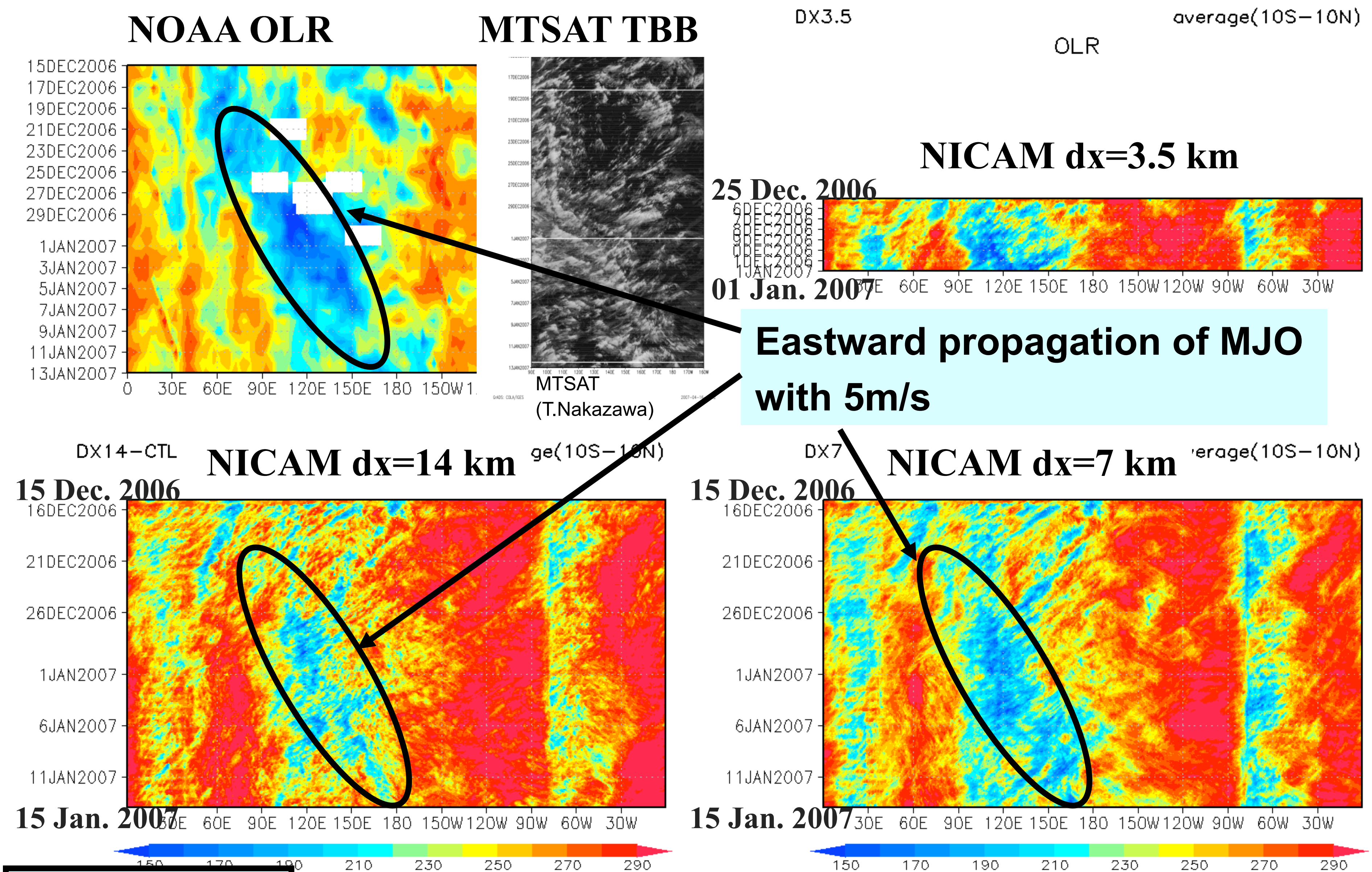
NICAM 3.5km simulation (OLR)





Miura et al.(2007)

Hovmeller diagram of cloud image

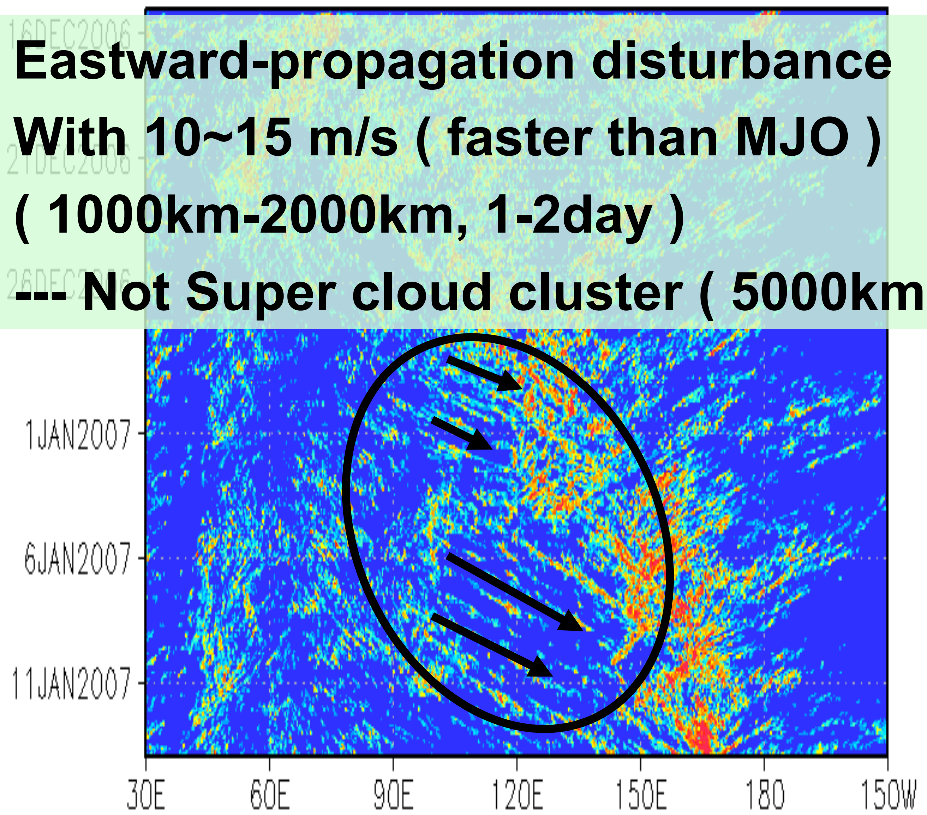


Miura et al.(2007)

Eastward-propagating disturbance

Precipitation

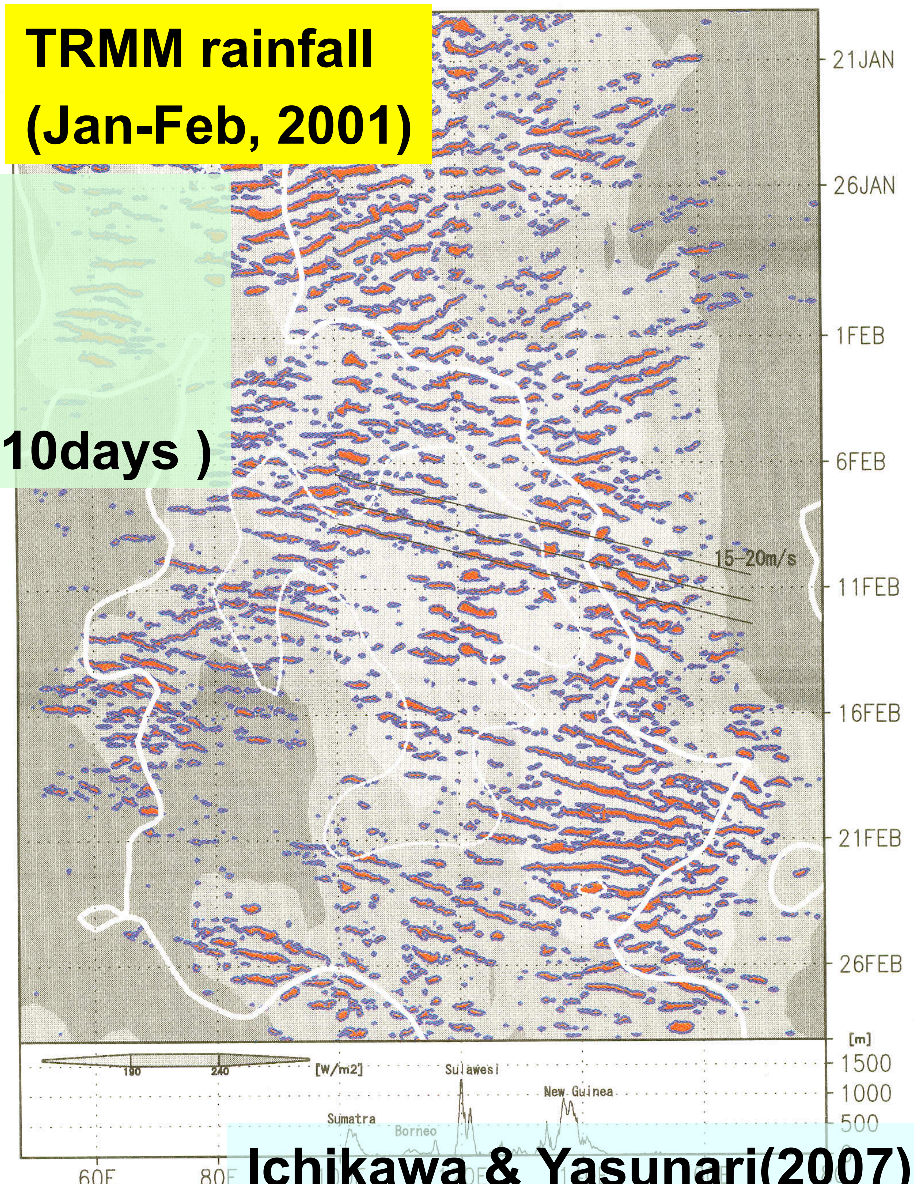
Eastward-propagation disturbance
With 10~15 m/s (faster than MJO)
(1000km-2000km, 1-2day)
--- Not Super cloud cluster (5000km, 10days)



NICAM DX=7km

Miura et al.(2007)

TRMM rainfall (Jan-Feb, 2001)



Ichikawa & Yasunari(2007)

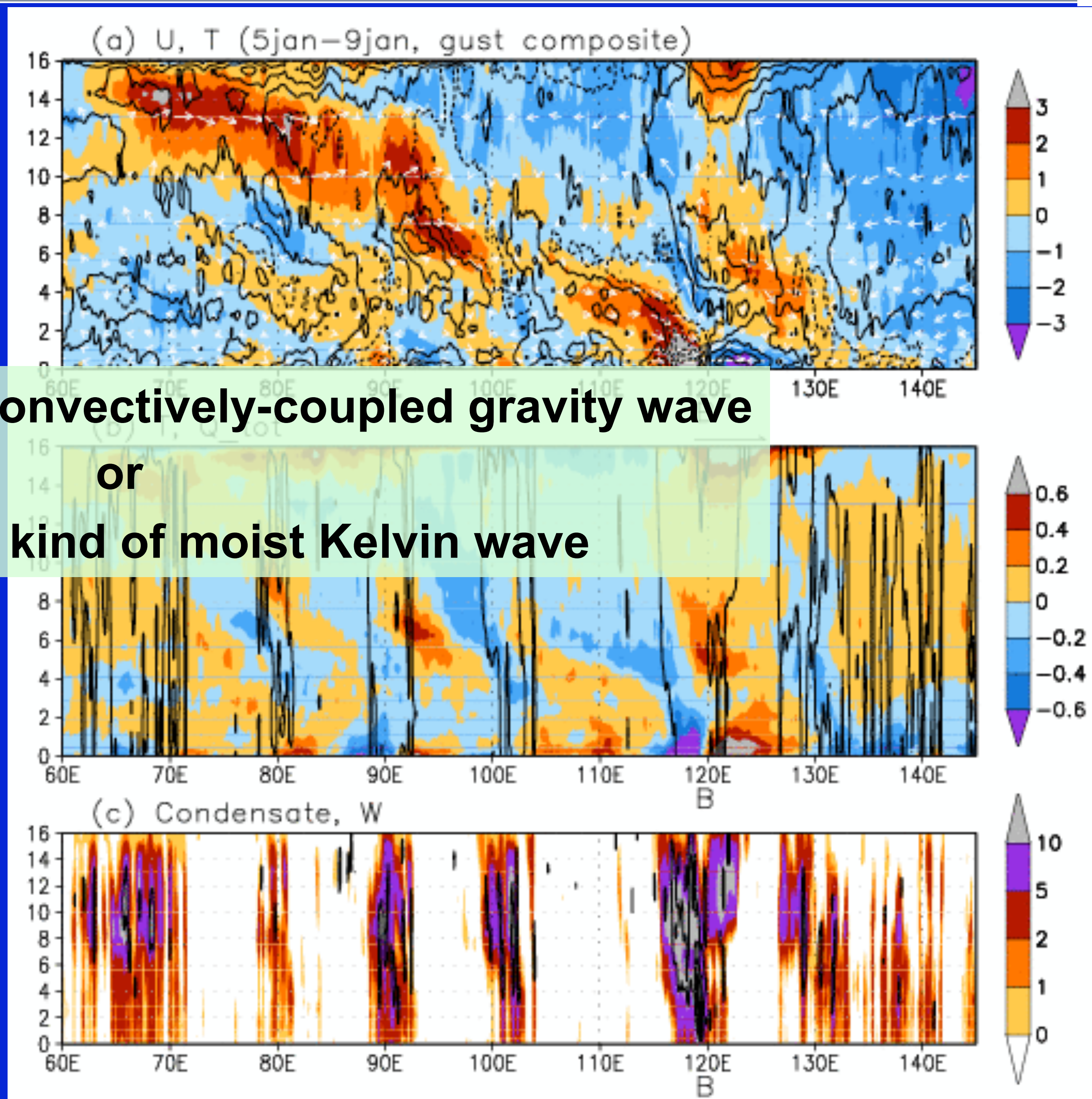
Vertical structure of gust front (EPD)

Color: zonal velocity
Contour: temperature

3N-3S average
Deviation from
Time average(a,b)

Color: Temperature
Contour: condensate

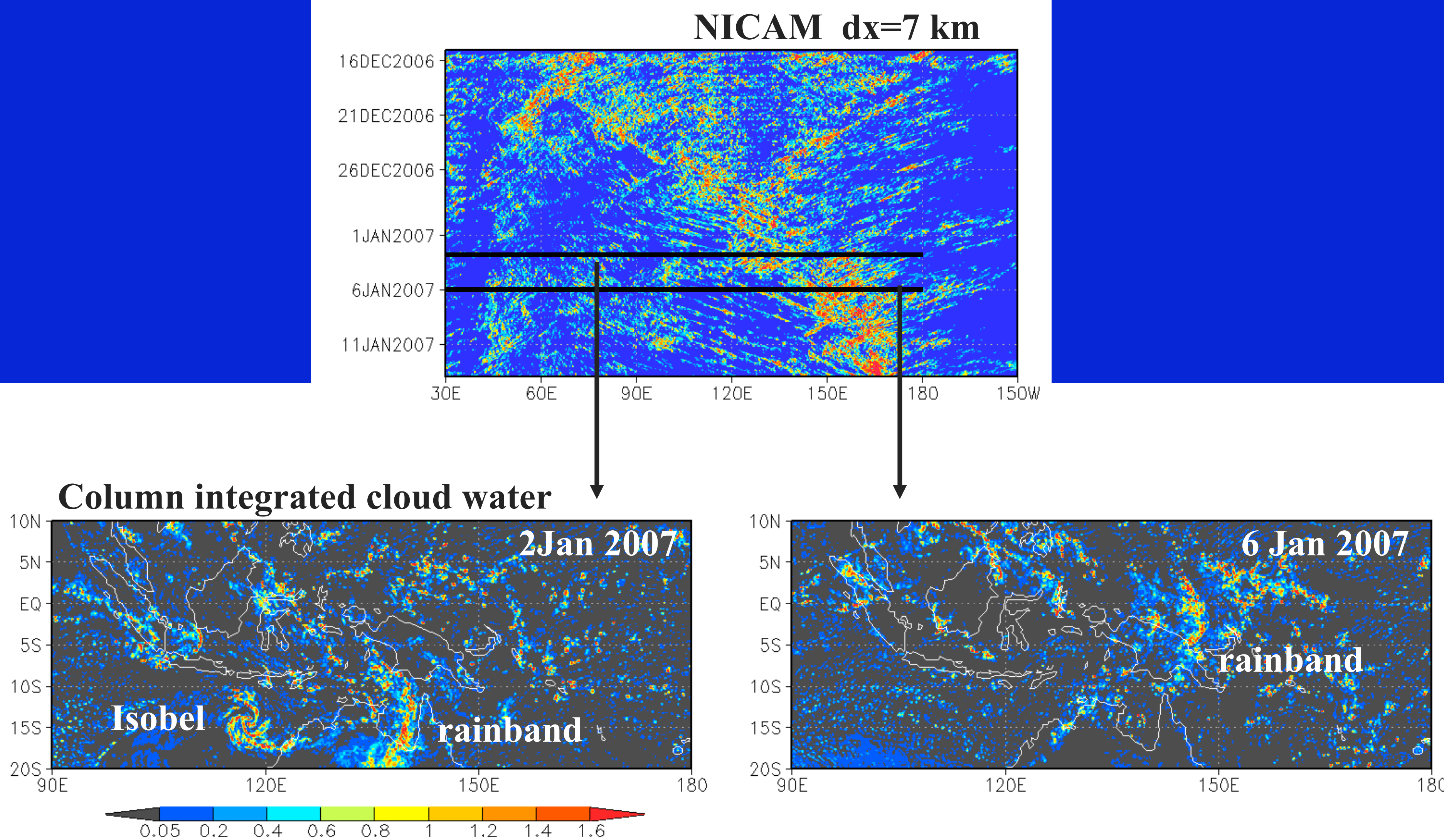
Color: condensate
Contour: vertical velocity



Convectively-coupled gravity wave
or
A kind of moist Kelvin wave

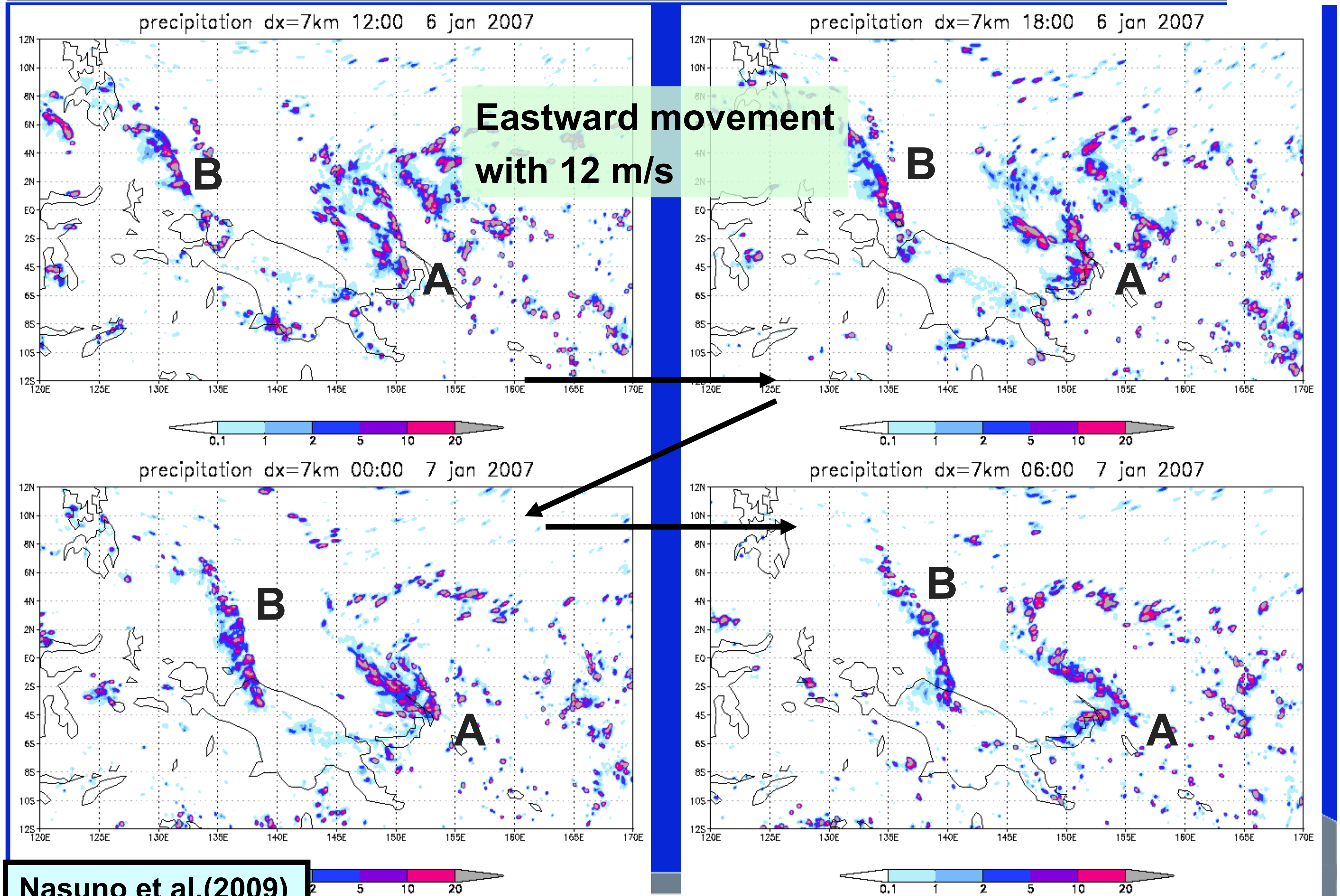
Nasuno et al.(2009)

Large scale rainband



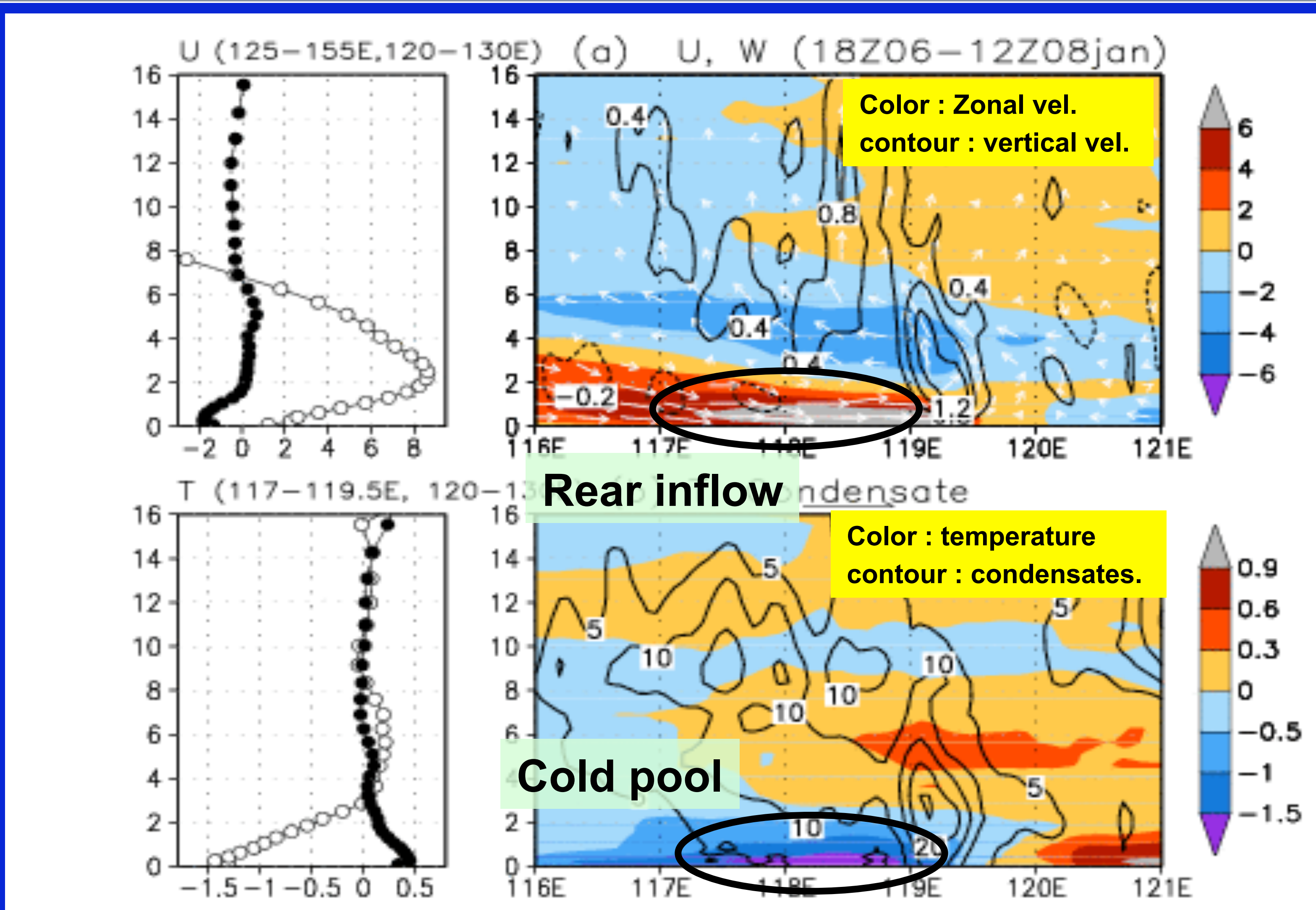
Miura et al.(2007)

Eastward propagation of rainband



Nasuno et al.(2009)

Vertical structure of rainband B (composites)



Very similar to a squall line

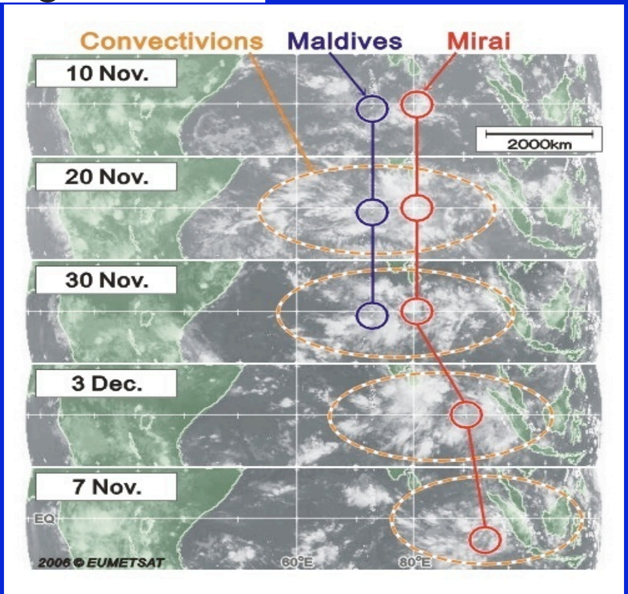
→ SQUALL-TYPE CLUSTER

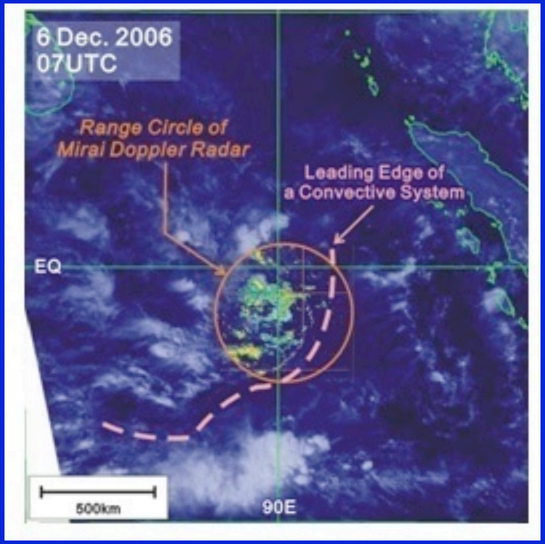
Nasuno et al.(2009)

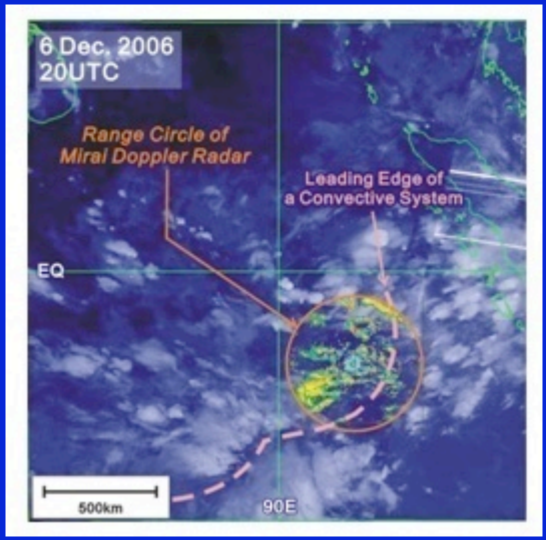
Squall type cluster is observed?

http://www.jamstec.go.jp/jamstec-e/PR/0701/0122/image4.html

- **MISMO project**
  - Mirai Indian ocean cruise for the Study of the MJO-convection Onset by JAMSTEC
  - During Oct.-Dec. in 2006







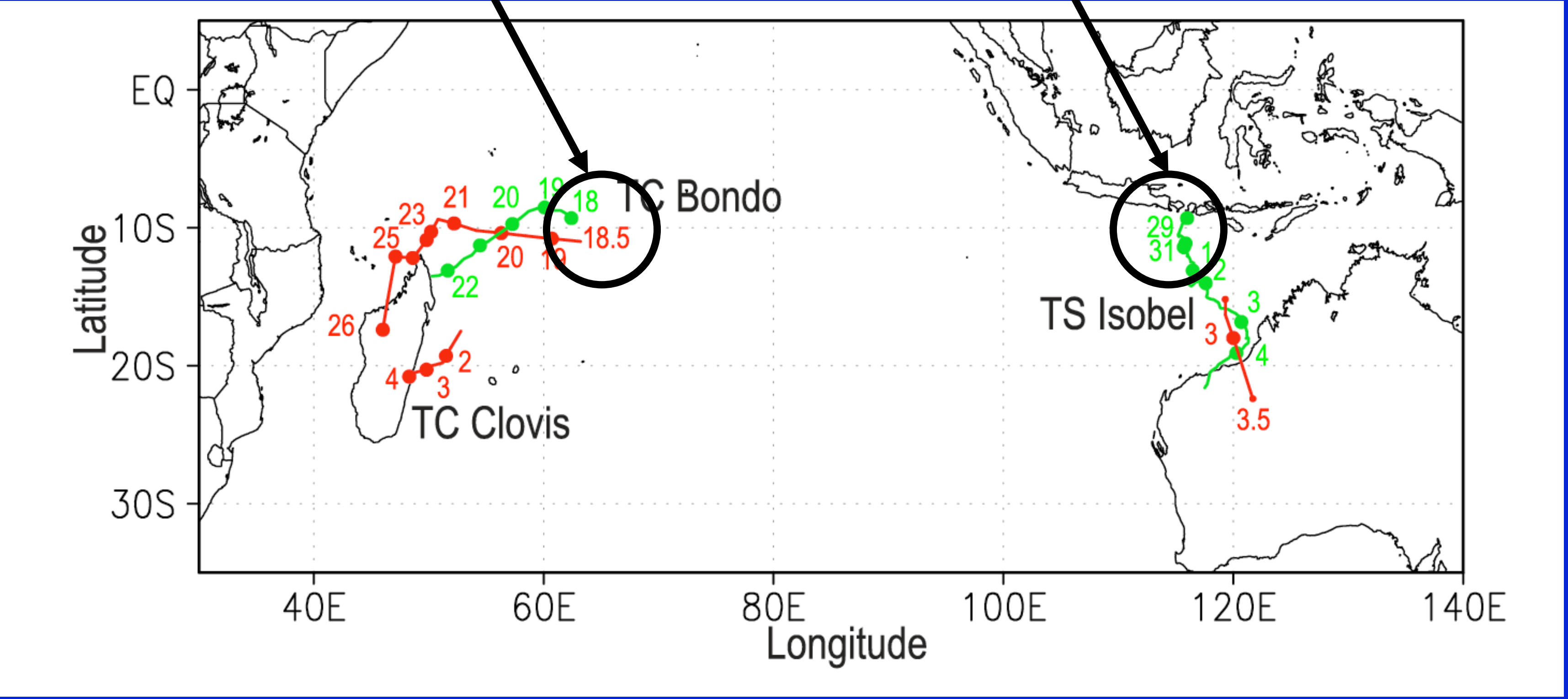
Dr. H.Yamada(JAMSTEC)

Simulated tropical cyclone

The simulation can predict the two real TC locations.

TC Bond
After 3 days

TC Isobel
After 2 weeks



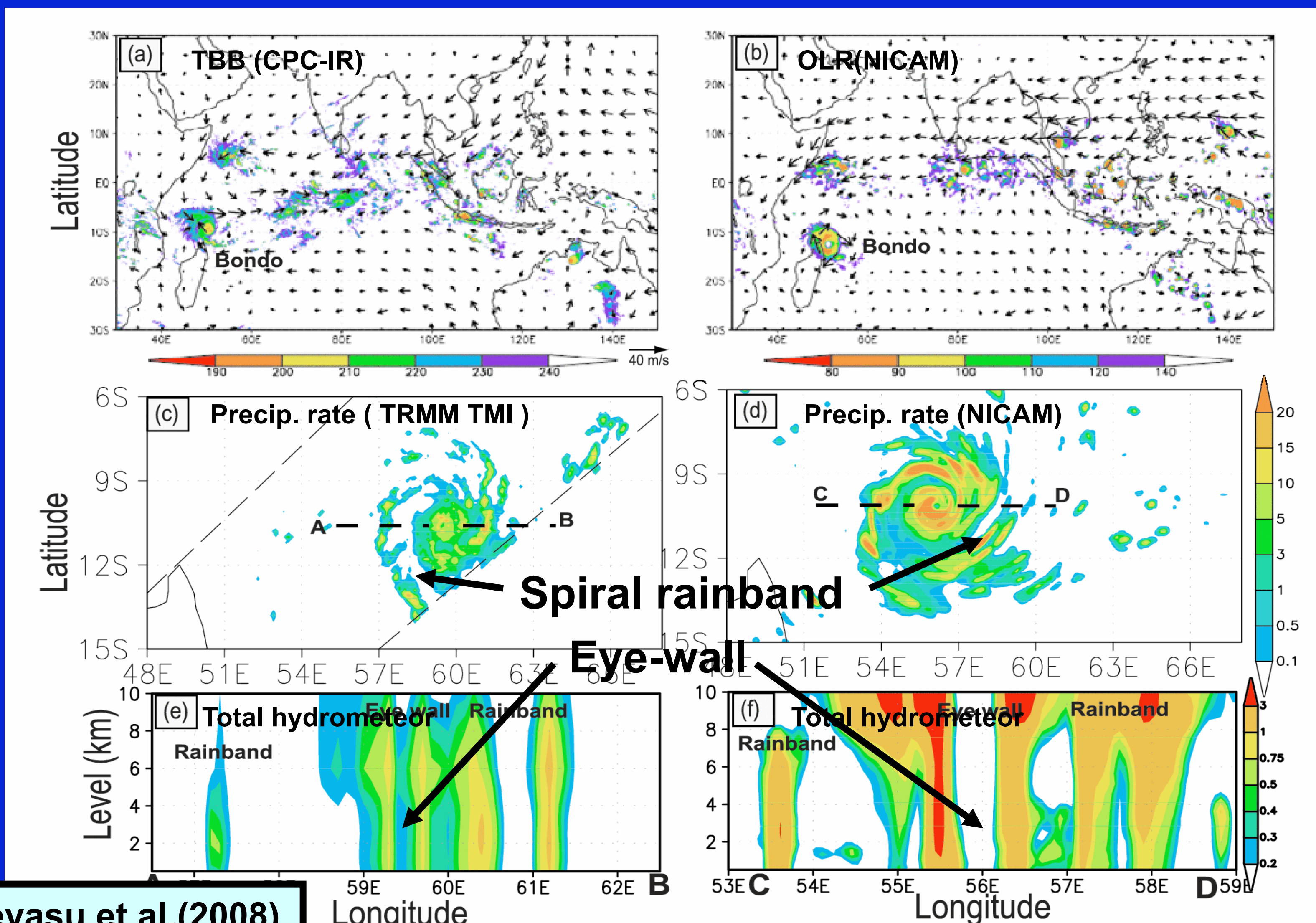
Red : JTWC best track
Green : NICAM simulation

Fudeyasu et al.(2008)

Cloud patterns of TC Bond in the mature stage

Overall, cloud feature of the simulated Bond is in good agreement with observation.

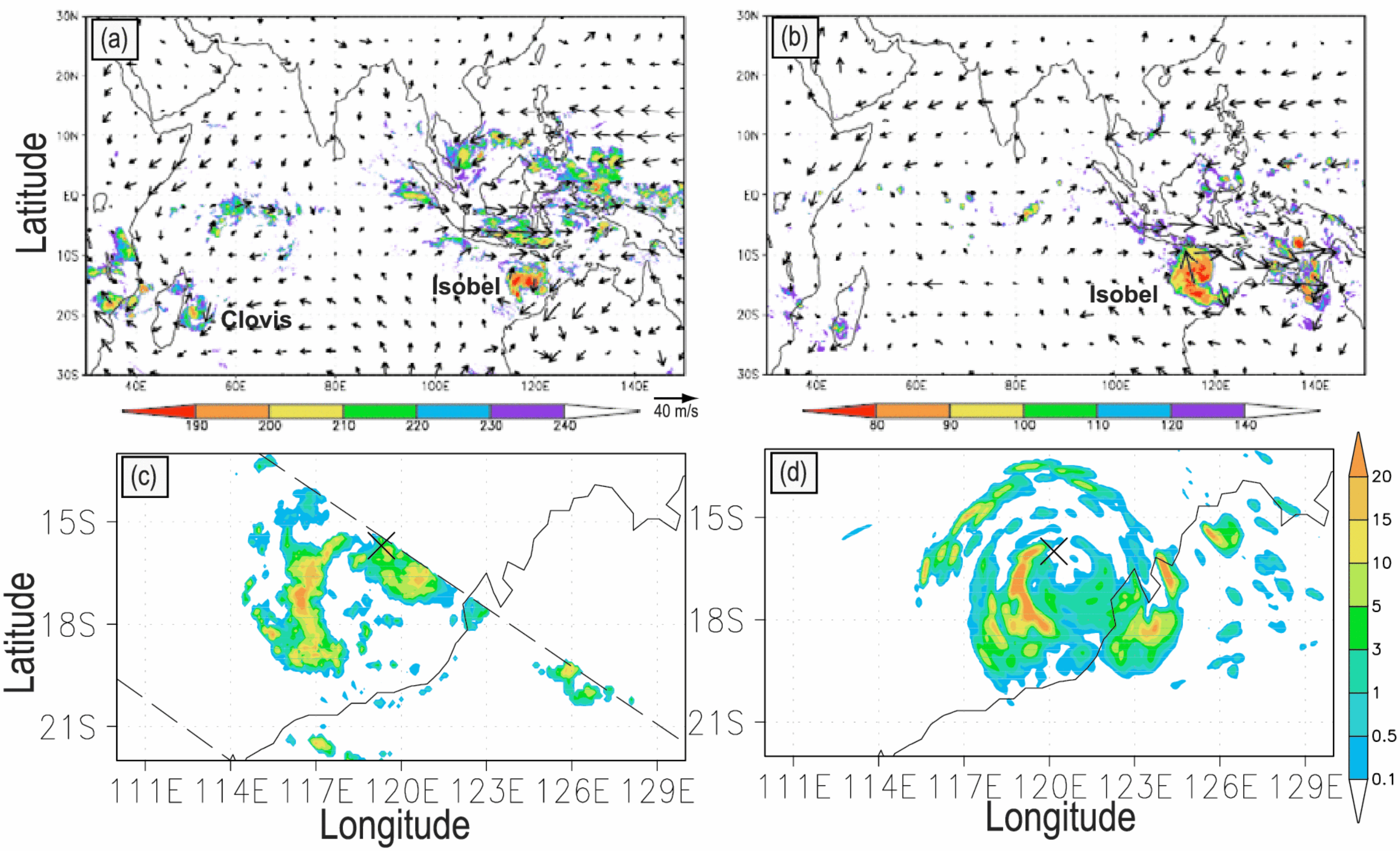
After 6 days



Fudeyasu et al.(2008)

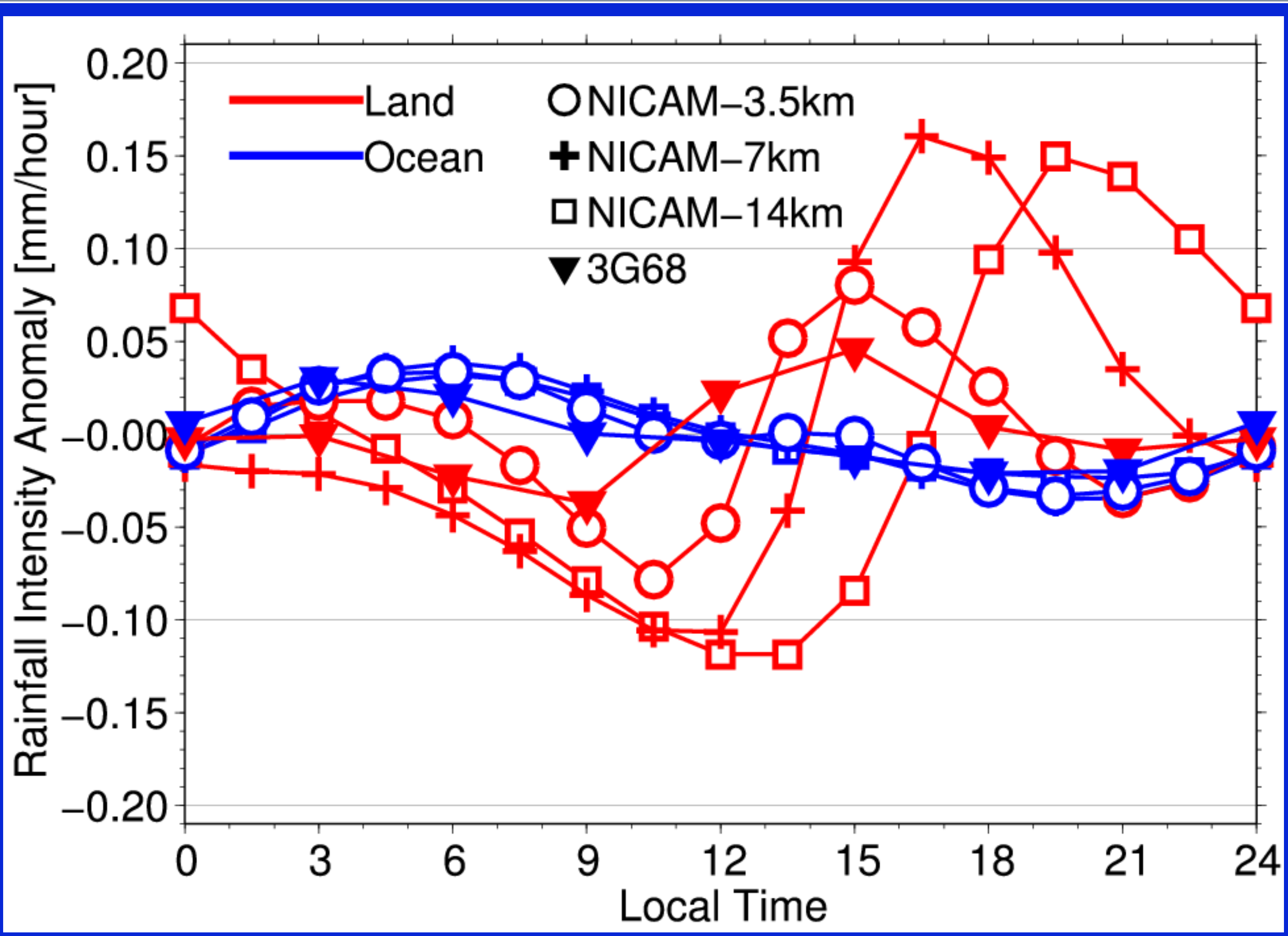
Cloud patterns of TC Isobel in the mature stage

TC Isobel also can be captured in the simulation after two weeks of simulation time.



Fudeyasu et al.(2008)

Diurnal cycle of precipitation



Ocean : NICAM result agrees with observation

Land : amplitude : too strong at 14km grid

phase : too much delayed at 14km grid

→ At 3.5km, well improved.

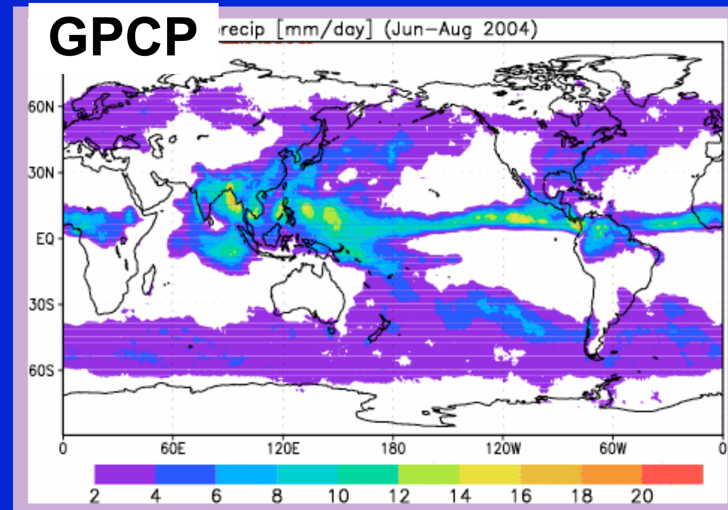
Sato et al.(2008) submitted to J. Climate

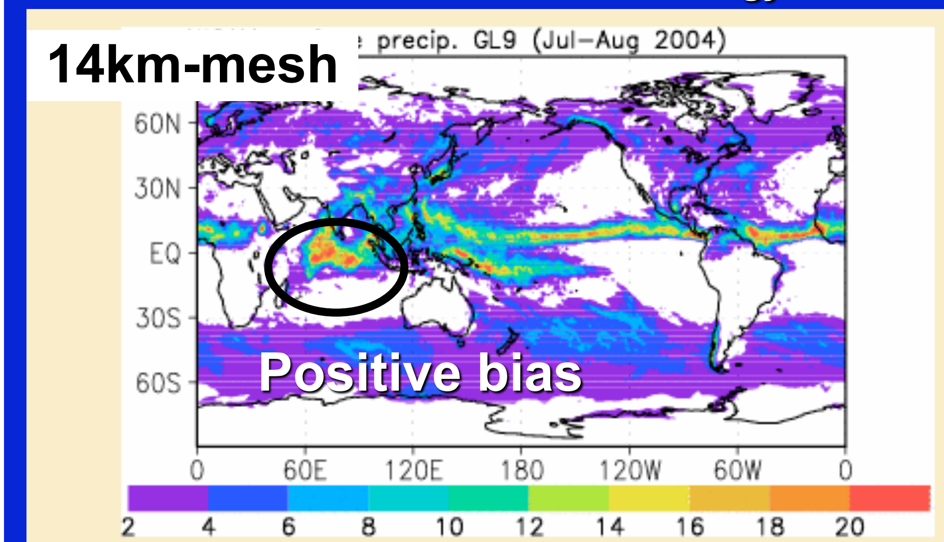
Next Generation Climate Model

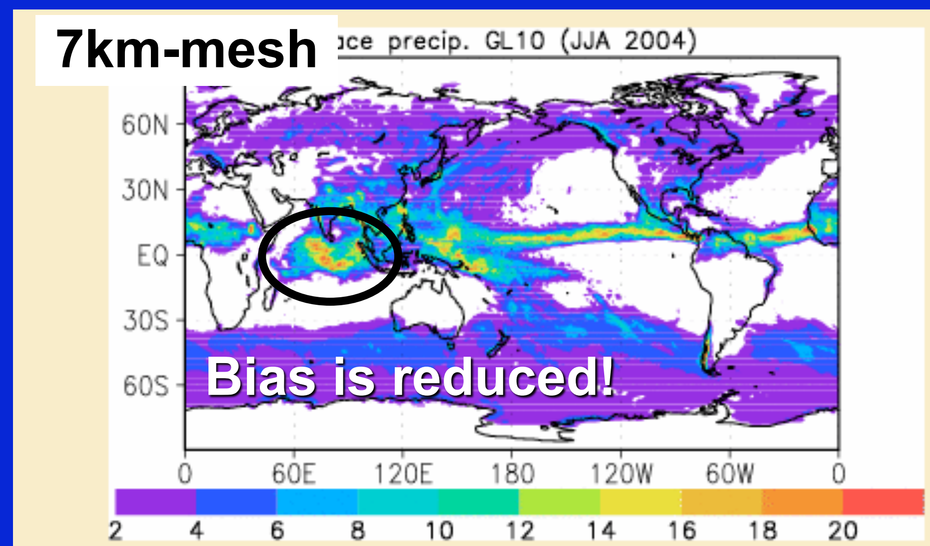
Seasonal march simulation in 2004

- **Model setup**
  - Horizontal grid : 14km, 7km
  - Vertical grid:0~38km with 40 levels
  - Initial conditions:
    - NCEP toropospheric analyses data (6 hourly, 1X1 grids)
    - June 1st 00UTC
      - 5-month integration(14km run)
      - 1-month integration(7km run)
  - Boundary conditions:
    - Reynolds SST, Sea ICE (weekly data)
    - ETOPO5 topography
    - Matthews vegetation
    - UGAMP O3 climatology

GPCP.vs.NICAM
Precipitation (JJA average)

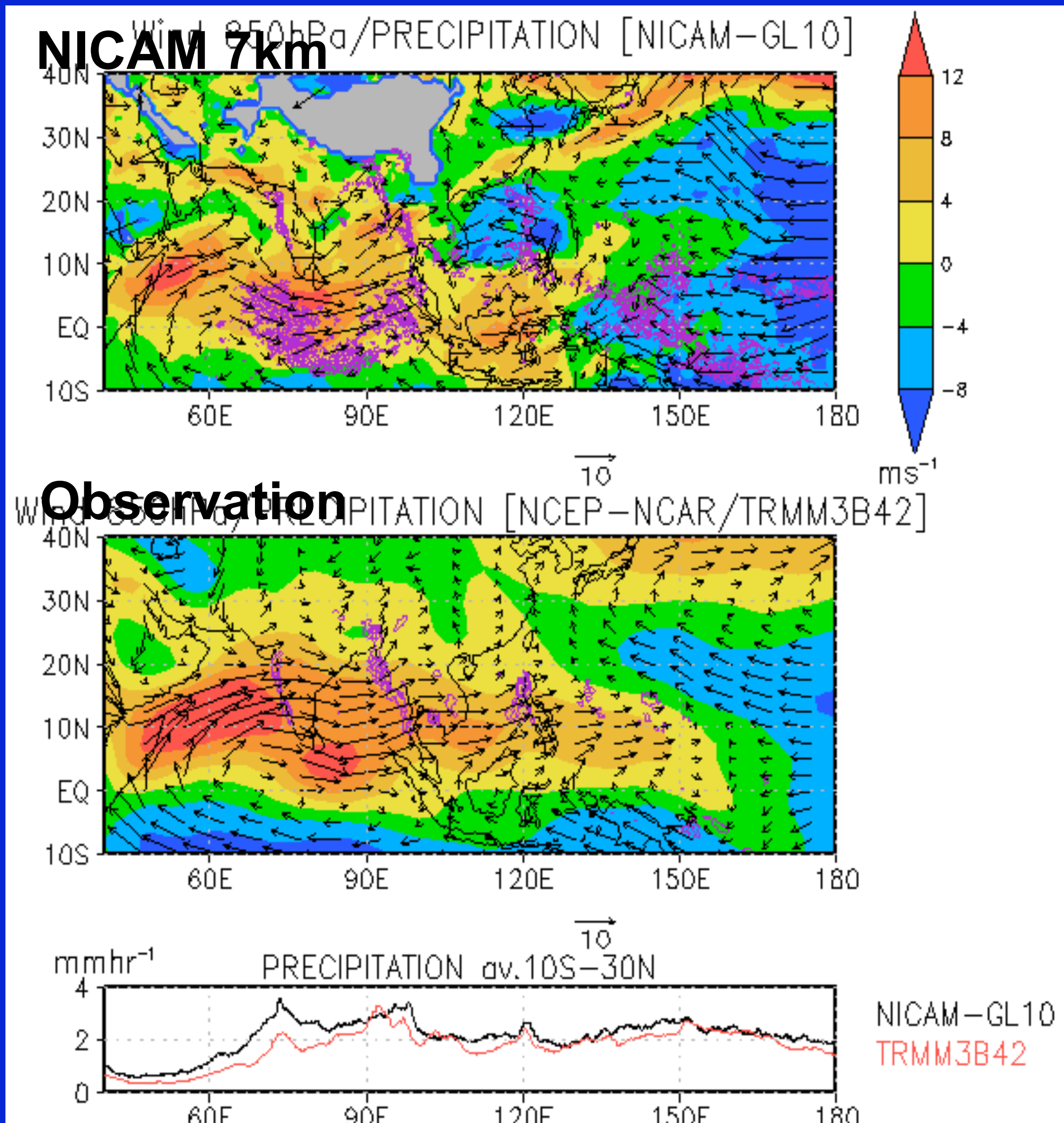






Oouchi et al.(2008), Noda et al.(2008)

Reproducibility of Asian monsoon



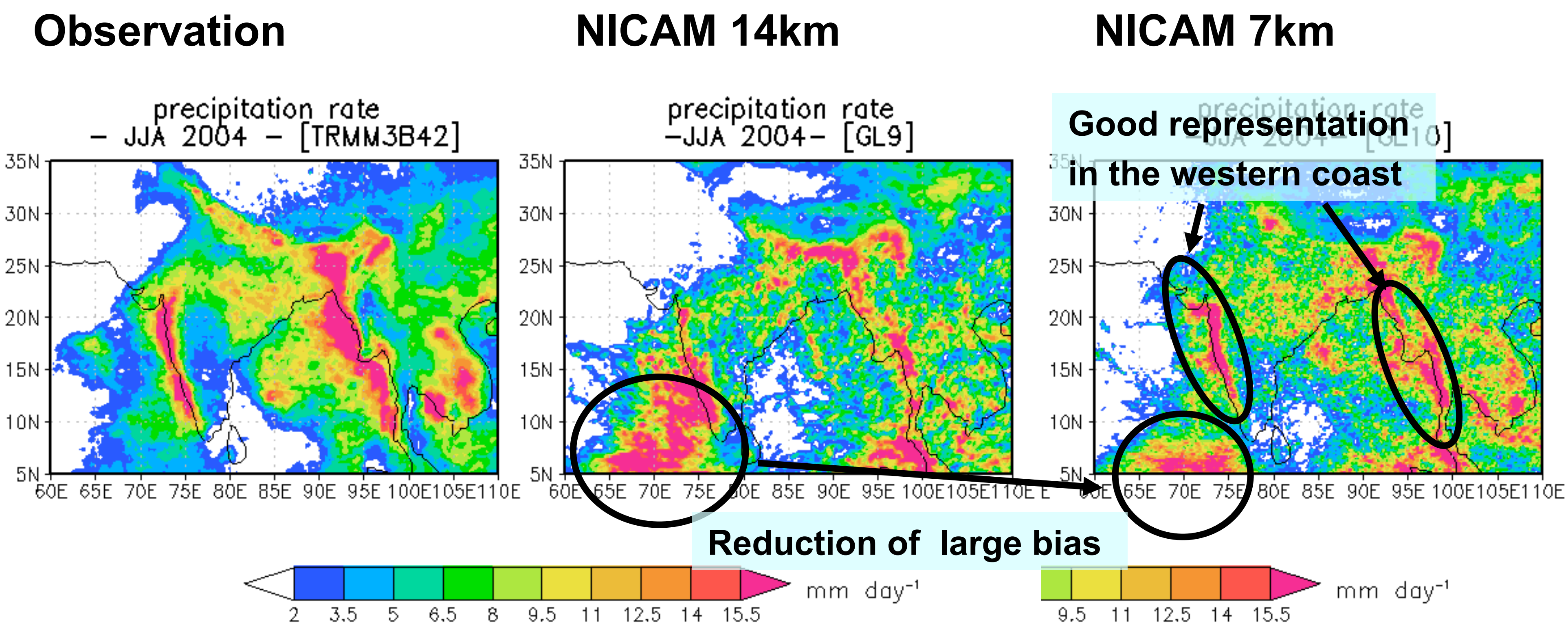
Color : U at 850hPa

Vector : horizontal wind

- **Somali jet**
  - Well reproduced.
- **Westerly jet**
  - Not extended to the western Pacific ocean.
- **Positive precipitation bias**
  - in the Indian ocean

Oouchi et al.(2008)

Precipitation in the monsoon area (JJA)



Oouchi et al.(2008)

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New physics are used from this year!

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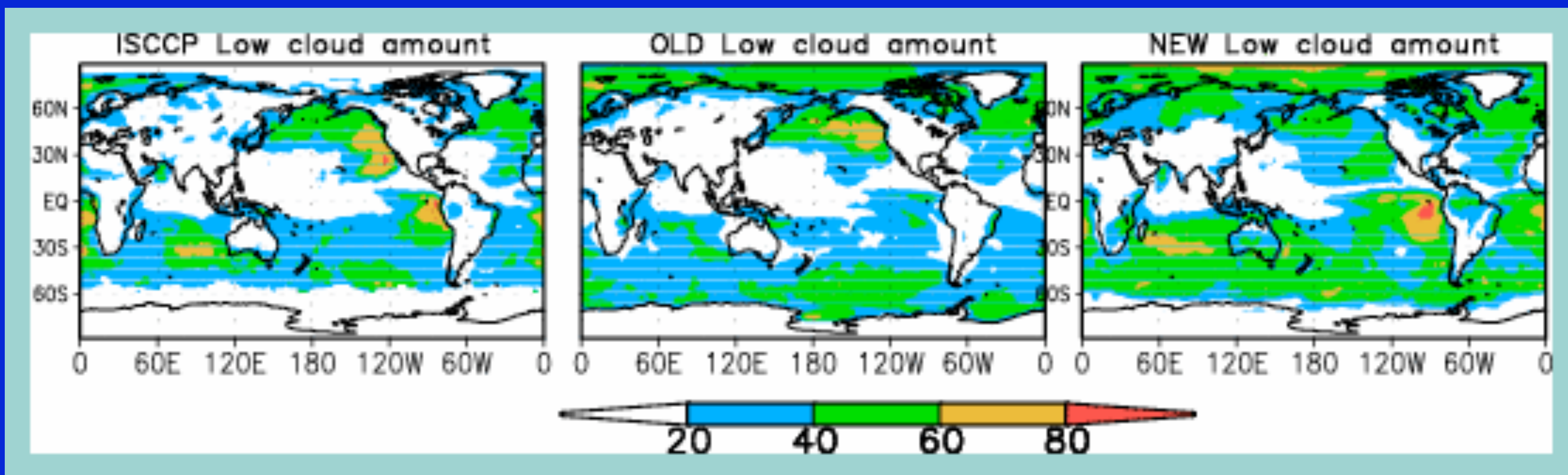
- Some physical processes will be replaced by new version from the 2nd stage.
  - Planetary Boundary Layer scheme
    - Traditional MY2 → MYNN2(Nakanishi & Niino)
    - MYNN level 3 (testing)
  - Microphysics scheme
    - Grabowski (1998) scheme → 6 category scheme (NSW6; NICAM Single-moment Water 6)
    - NDW6; NICAM Double-moment Water 6) developed by Mr. Mitsui(CCSR).
  - SST & SIC
    - Fixed SST → mixed layer ocean
  - Land process
    - Manabe's bucket scheme → MATSIRO (Takata et al.)
  - Vertical layer
    - 40 layers (40km) → 80 layers (60km)

Improvement of boundary layer scheme

- **Mellor Yamada with Nakanishi & Niino(2006) modification**
  --- Old version : MY (Smith) level2 scheme
  - **Both schemes : reproducible for the mid-latitude synoptic scale low clouds.**
  - Shallow cloud in off shore of California and Peru coast : much improved.

Obs. MY2smith(Iga et al. 2007) MYNN2



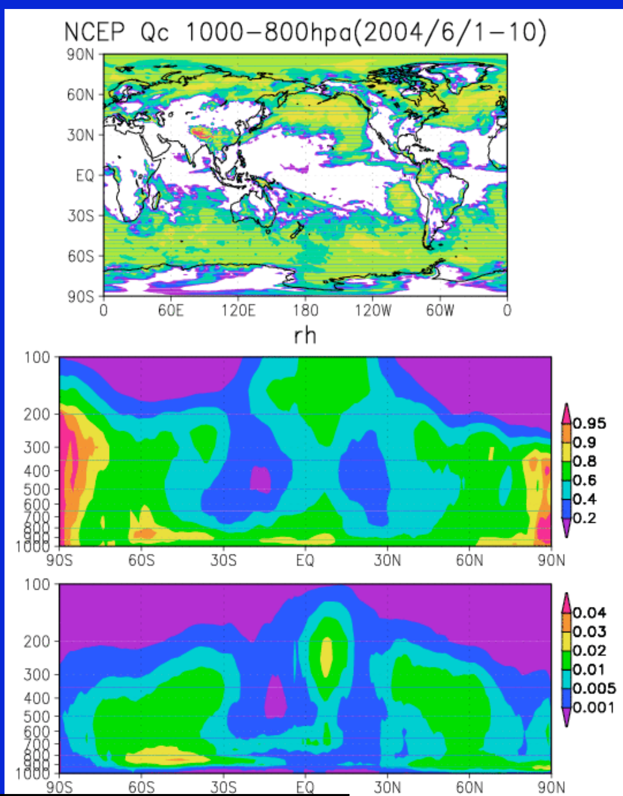
6/6～6/10 average
Cloud amount

Noda et al.(2008)

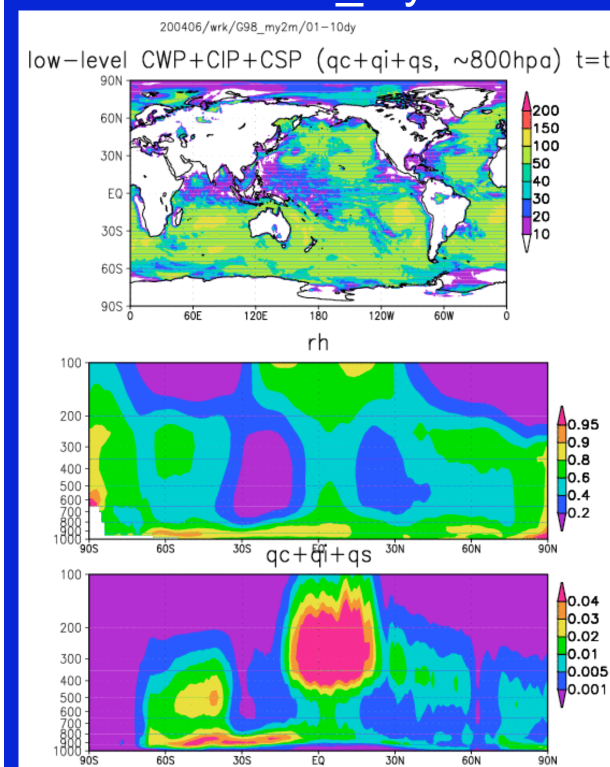
Improvement of microphysics

- **From 3 class scheme to 6 class scheme**
  - **Grabowski(1998)～NSW6(Tomita 2008)**
  - **Vertical profile of cloud condensates is much improved.**

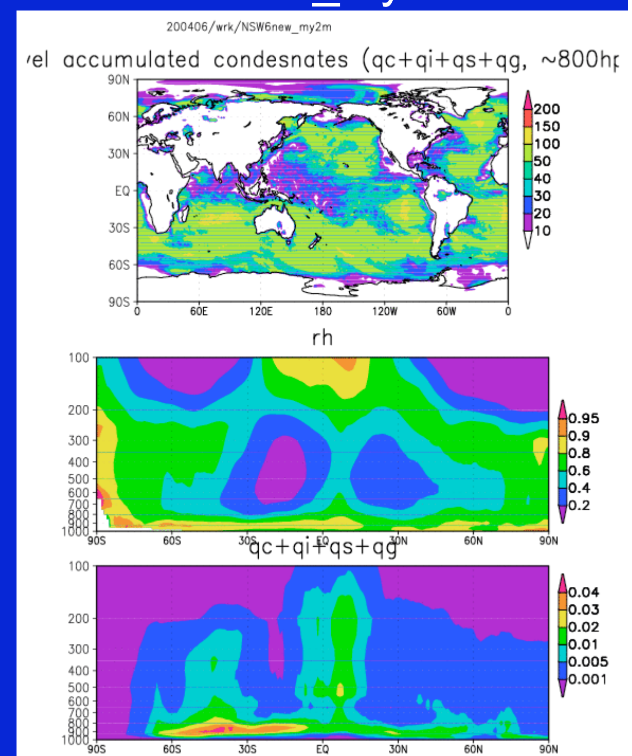
NCEP



G98_my2m



NSW6new_my2m



Noda et al.(2008)

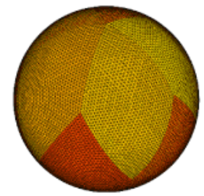
Toward the PFLOPS era!

- In 2011, the next-generation super-computer system will be developed at the Kobe.
  - ◆Peak performance
    : over 10 PFLOPS
    - 250 times power of the Earth Simulator
    - Scalar machine based
- NICAM is selected as one of target applications.
  - ◆Long term simulations by a few km resolution.
    - Climate simulation
  - ◆Super high-resolution simulation (up to 400m).
    - Improvement of shallow clouds?
    - Good representation of deep convections.
- NICAM has been tuned in the vector-based machine so far.
  - ◆Sustainable performance on ES : ~40%
- NICAM should be tuned on the scalar computer system.

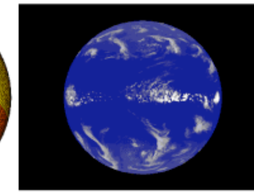
R&D field: Earth science

Nonhydrostatic ICosahedral Atmospheric Model (NICAM) for Global-Cloud Resolving Simulations

- Program name: NICAM
- Developer
  - Masaki Satoh, Associate Prof. of The Univ. of Tokyo
  - Hirofumi Tomita, Researcher of Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
- Abstract
  - Icosahedral grid and the equation system with no approximation (nonhydrostatic equation system)
  - Global cloud-resolving simulation (mesh size is a few kilometers or less).
  - Explicit cloud physics without cumulus parameterization.
- Algorithm
  - Two-dimensional domain decomposition with icosahedral grid.
  - Explicit time difference for horizontally propagating acoustic waves, and implicit for vertical propagating acoustic waves.
  - MPI parallelization.
- Current computation size
  - Grid points 2048x2048x54x10, with mesh size 3.5km.
  - Sustained performance 7.7 TFLOPS and memory 4.8 TB (320 nodes of Earth Simulator).
- Future computation size in 2010
  - Mesh size 400m both for horizontal and vertical directions for several days time integration (grid points 8x8 times horizontally and 2 times vertically; time step 1/8 times).
  - 10 years Integration with the current mesh model of 3.5km.



Icosahedral grid



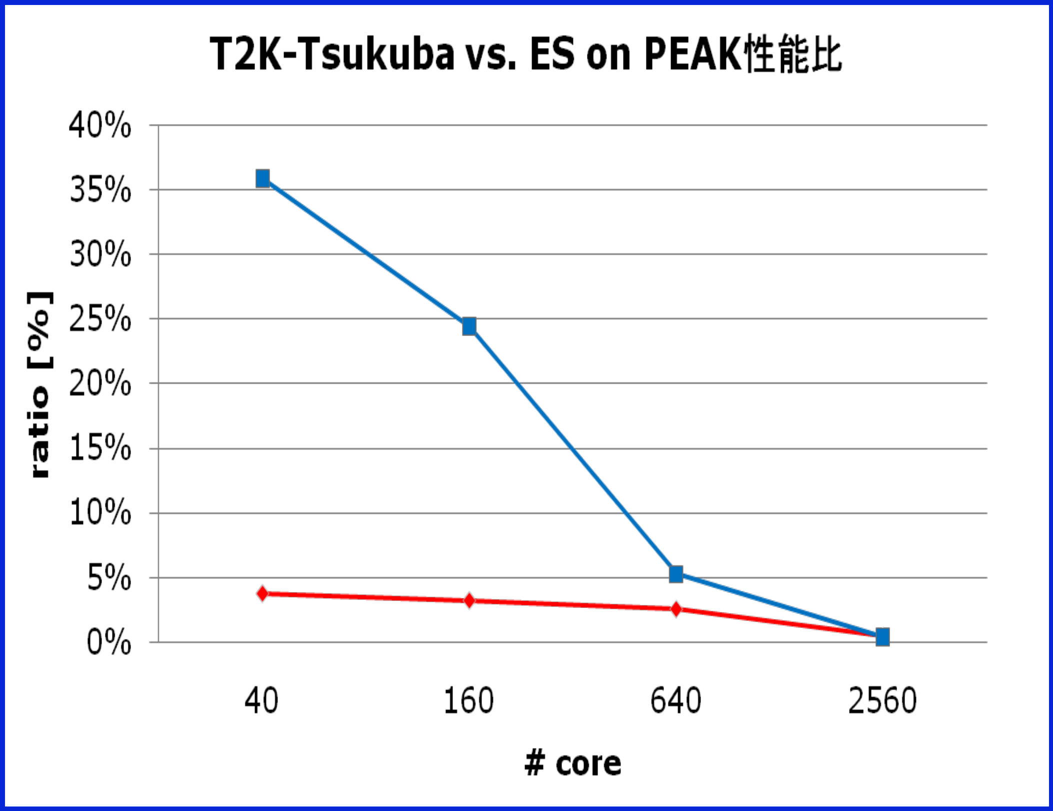
Global cloud image of aqua-planet experiment with 3.5km mesh global cloud-resolving simulation

- Expected results
  - NICAM will estimate more precise global cloud properties and lead to more reliable climate prediction.
  - NICAM will resolve clouds raging from deep cumulonimbus (10 km high) to shallow cumulus (1 km high) with resolution of isotropic grid spacing 400m.
  - NICAM will provide information of extreme phenomena such as typhoon and heavy rains associated with climate change based on global simulation with super high resolution (km scale).
- Reference
  - http://www.ccsr.u-tokyo.ac.jp/~satoh/nicam/

Next-Generation Supercomputer R&D Center, RIKEN Application Committee

Current sustainable performance of NICAM

- Problem size
  - 60km grid / 40 layers
- # of CPUs
  - 40→ 2560
- Earth simulator (blue line)
  - > 160 CPUs
    - Efficiency decreases. Vector length : shorter and shorter.
- T2K (Tsukuba-University)
  - Overall, a few %



→ 10% should be needed!?

- Effective use of cash memory
- Introduction of inner node communication (e.g. OpenMP)

Summary

- **Recent activities were shown.**
  - MJO simulation / monsoon simulation / TC simulation
    - MJO simulation(Miura et al. 2007)
      - Multi-scale cloud physics can be found.
        - MJO, Super cluster, Cloud cluster, Eastward propagating disturbance, Squall-type cluster, Tropical cyclone associated with MJO.
    - Seasonal march simulation (Oouchi, Noda, 2008)
      - Asian monsoon is well reproduced in the boreal summer.
  - Climate sensitivity (ongoing) :
    --- Time slice experiment based on SRES A1B scenario ---
    (present climate & future climate)
    - Focus on Modulation of MJO, tropical cyclones
- **We are improving the model physics in parallel.**
  - Planetary boundary Layer scheme : MY2 with moist process (MYNN2)
    - well improve the shallow clouds in Peru and California coast
  - Microphysics : 6 class scheme
- **We are now preparing toward the next-generation supercomputer**
  - Plan : 1. super high resolution run with 400m horizontal grid.
    2. long term climate simulation with a few km horizontal grid.
  - NICAM should be tuned on the massively parallel scalar computer system.
  - The next next future : GCRM → GLES (Global Large Eddy Simulation)