Further development and improvement of NICAM toward the PETAFLOPS computing era

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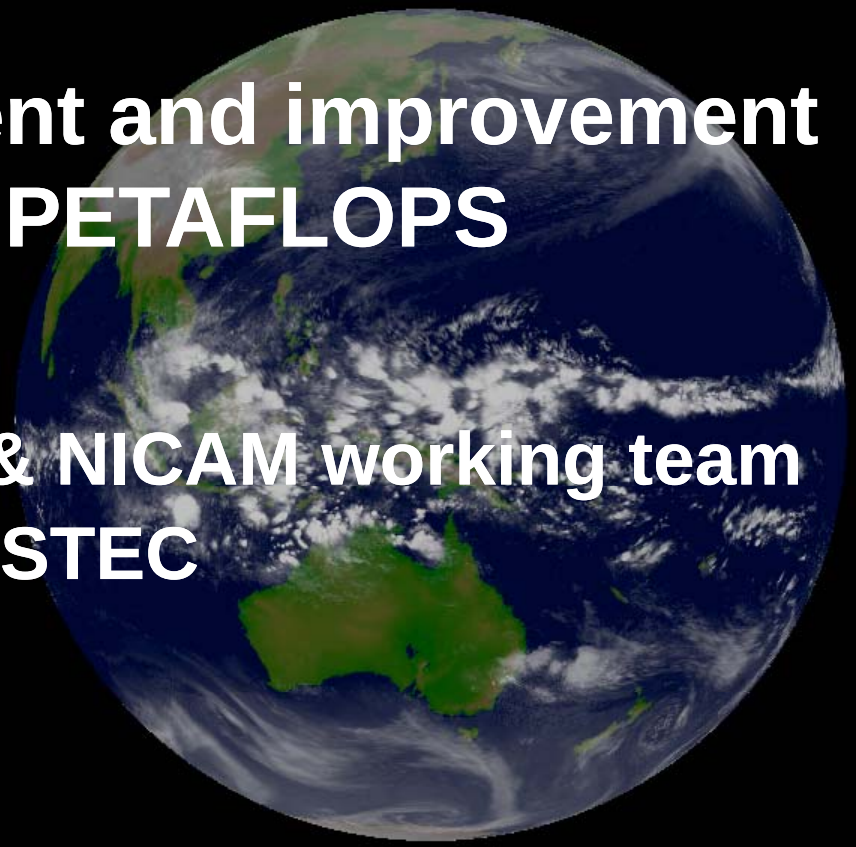
MTSAT-1R



NICAM : DX=3.5km

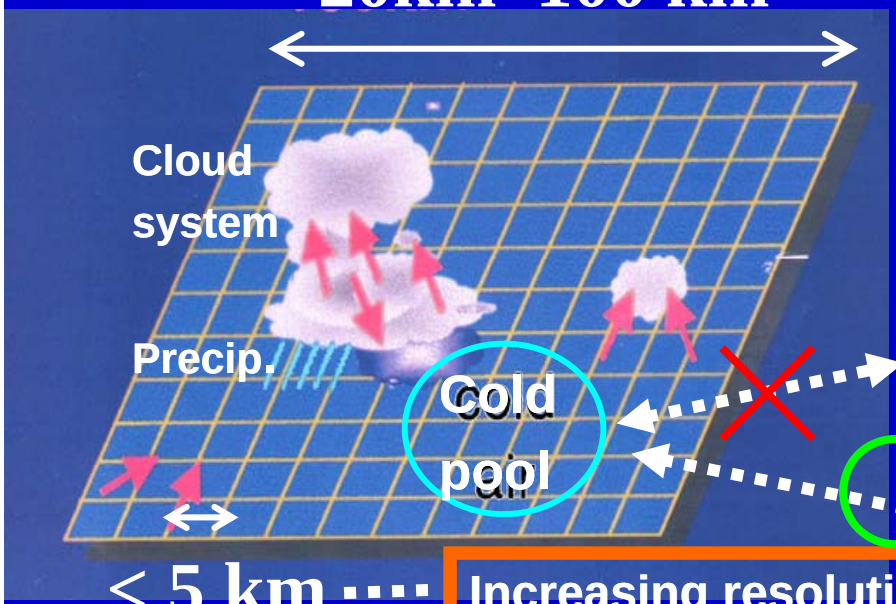
Outline

- Our strategy for global atmospheric model
  - Global cloud resolving
- Brief introduction of our model NICAM
  - Notable feature of NICAM
  - Current development status
- Current problems
  - Physical biases
  - Numerical instability
- What can we plan on the next-generation machine?
- ES2 is now available!
  - The measurement of performance (without tuning)
- Summary

Our strategy for global atmospheric 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

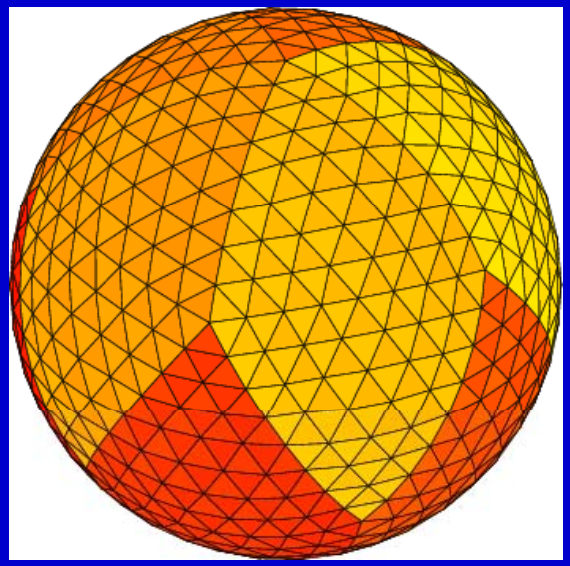
- multi-scale cloud phenomena
- lifecycle of individual clouds

NICAM project

NICAM project

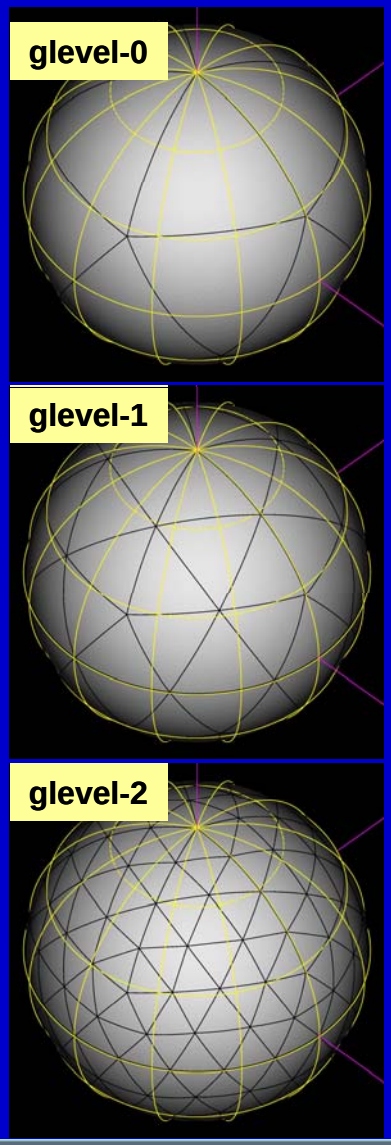
- NICAM project (~2000)
  - Dynamical core
    - Horizontal grid : icosahedral grid with spring dynamics modification
    - Dynamics : Non-hydrostatic equation with conservation of total energy

    → 3D DC (Tomita and Satoh 2004)
  - 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)
  - Now tuning on ES2

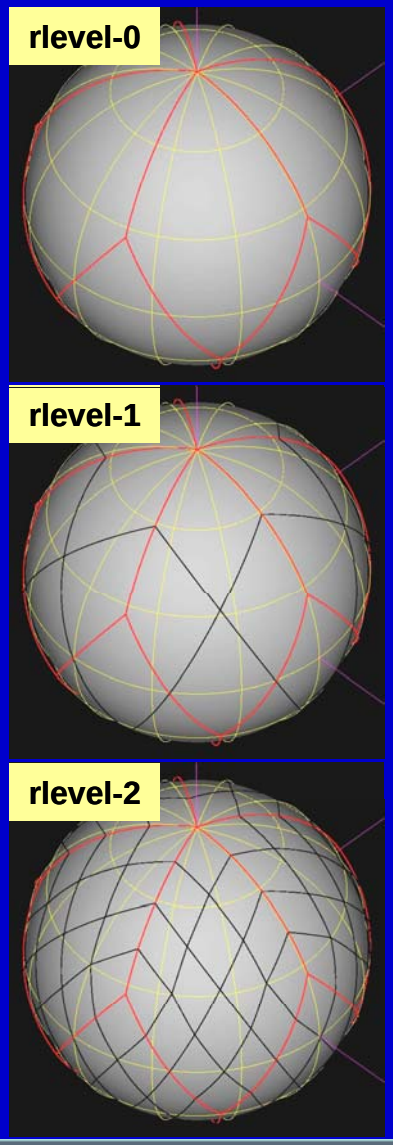


Grid, domain, parallelization in NICAM

GRID



Region



- **Grid generation**
  - **Glevel0**
    - **Original icosahedron**
  - **Glevel1**
    - **Divide each triangle to 4 sub-triangle**
  - **Glevel2~**
    - **Iterate the same process**
- **Region generation**
  - **Rlevel0**
    - **Connection of two neighboring diamonds**
  - **Rlevel1**
    - **Divide each rectangle to 4 sub-rectangle**
  - **Rlevel2**
    - **Iterate this process**
- **Parallelization**
  - **2D-domain decomposition with flat MPI**
  - **OpenMP is needed?**

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	Finite Volume Method
Horizontal grid configuration	Icosahedral grid with spring dynamics smoothing (Tomita et al. 2001/2002)
Vertical grid configuration	Lorenz grid
Topography	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)

A successful simulation of MJO event (Dec 2006)

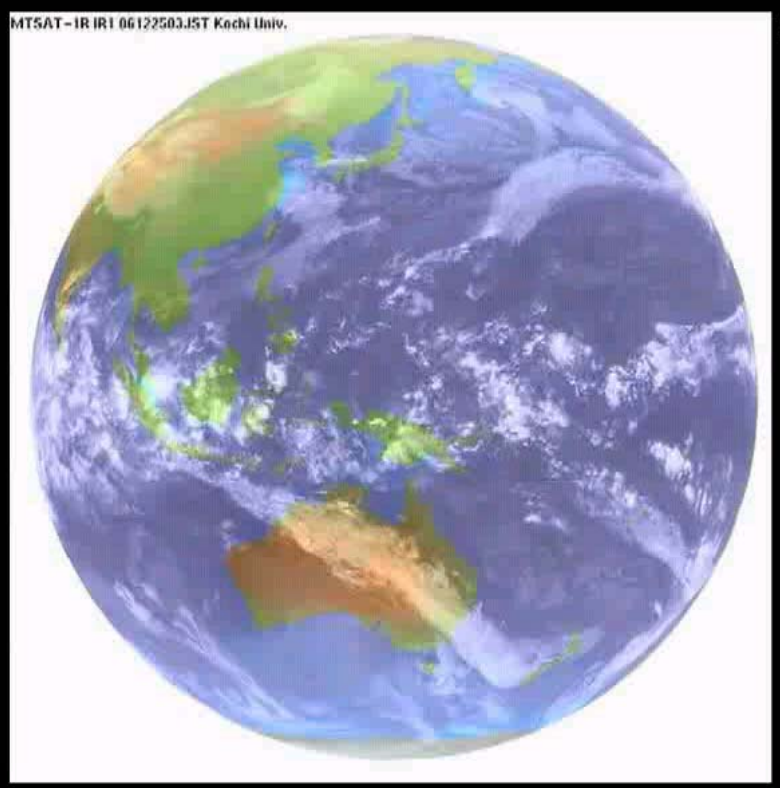
3.5km simulation of an MJO event

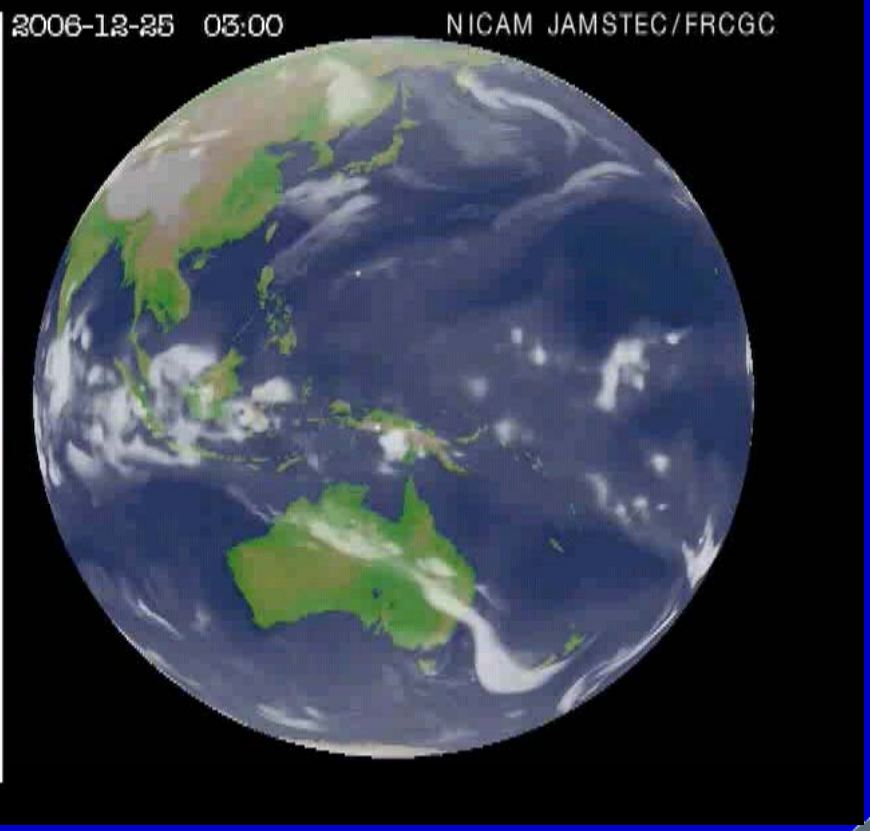
MTSAT cloud image

http://weather.is.kochi-u.ac.jp/

NICAM 3.5km simulation (OLR)

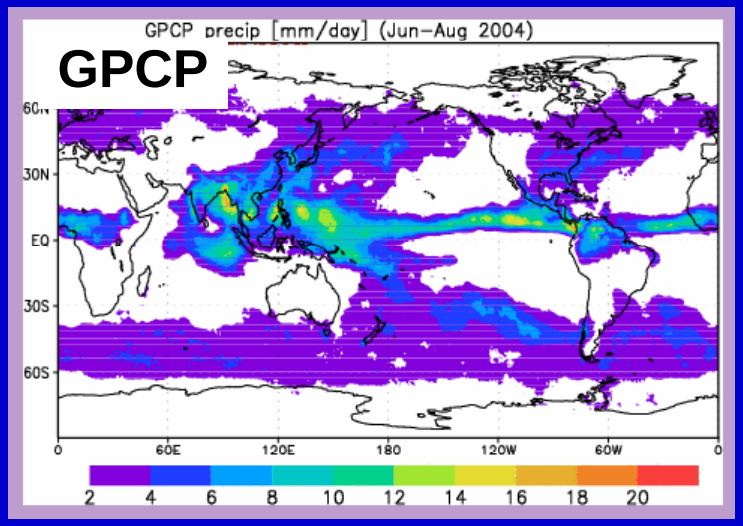
Miura et al.(2007)

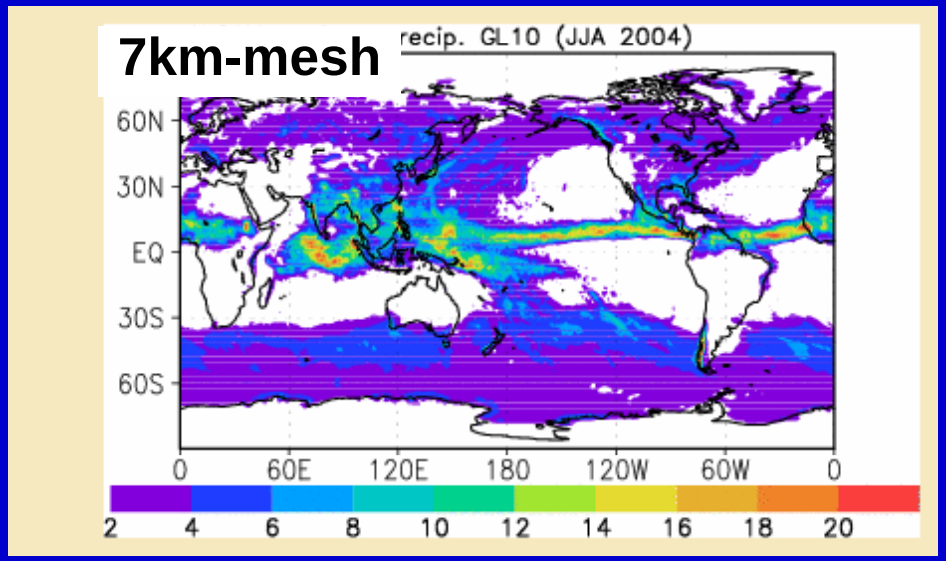




Current problems in NICAM

- **Physical bias**
  - **Too strong precipitation in the tropics**
    - **ITCZ : sharp peak**
    - **Indian ocean : much excess of precipitation**
      - **Affect to the Asia monsoon properties**





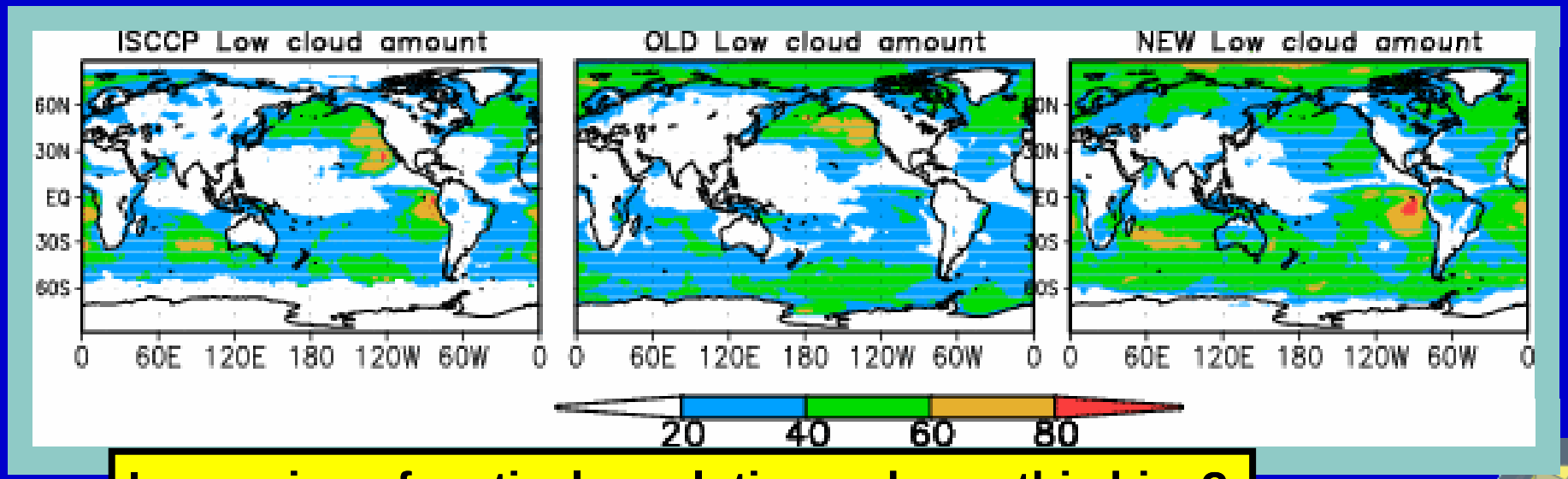
Result from the seasonal simulation by 7km grid NICAM

High resolution resolves this problem?

Current problems in NICAM

- **Physical bias(2)**
  - **Excess of low clouds in the mid-latitude**
    - **The shallow cloud in the off shore of Peru and California coast**
      - » **The old version of PBL scheme: X**
      - » **MYNN2 PBL scheme : O**
    - **MYNN2 PBL scheme : large excess of low cloud amount in the southern hemisphere.**

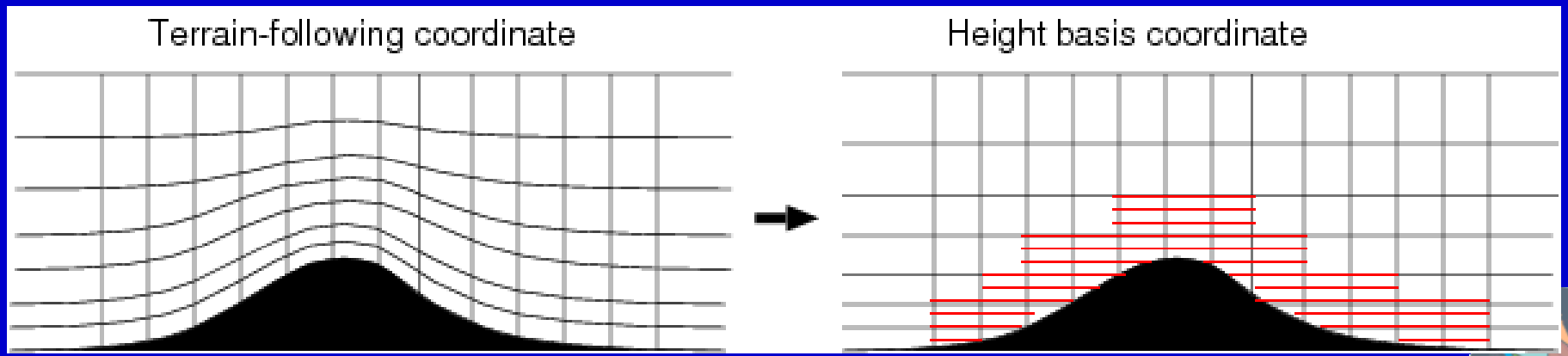
Obs. MY2smith(Iga et al. 2007) MYNN2



Increasing of vertical resolution reduces this bias?

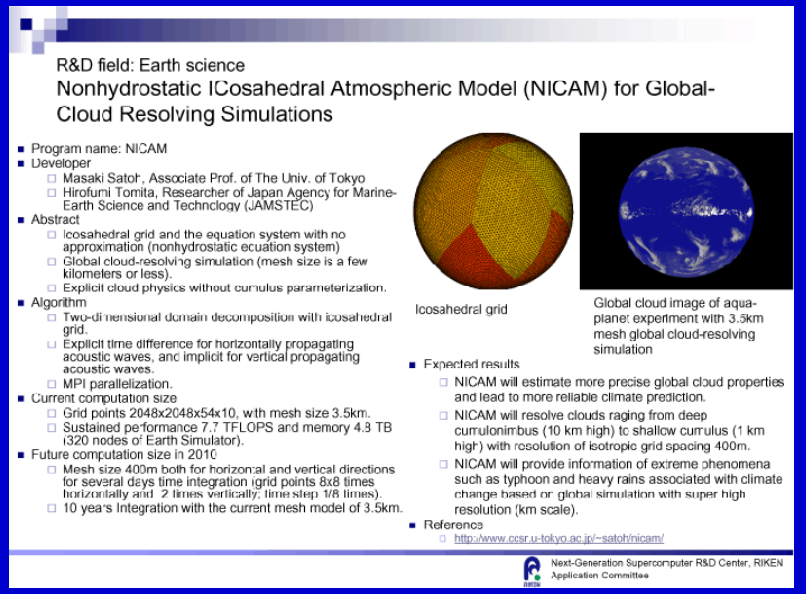
Current problems in NICAM

- **Numerical problem**
  - **3.5km mesh run : sometimes, crash!**
    at the steep mountain area (e.g. Tibetan plateau)
    - **Possible cause**
      - **The CFL condition in the vertical direction?**
        - » **Reduction of time step or appication of vertical implicit method?**
      - **The large Horizontal-PGF error in the terrain-following coordinate.**
        - » **If the horizontal resolution increases more and more, ….**
    - **Reconsideration of vertical descritization from the terrain-following coordinate to height basis coordinate.**
      - **Vertical adaptive mesh for the PBL scheme.**



Toward the PFLOPS era!

- **In 2011, the next-generation super-computer system**
  - ◆Peak performance
    : over 10 PFLOPS
    - 250 times power of the Earth Simulator
    - Scalar machine based



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 4.3 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

- **NICAM is one of target applications.**
  - ◆ So far,
    NICAM has been tuned
    in the vector-based machine
    - Sustained performance on ES : 30~40%
  - ◆ NICAM should be tuned on the scalar computer system.
    - ongoing : the tuning on the scalar machine in collaboration with RIKEN Next-Generation Supercomputer R&D center.

What can we expect to the next super computer?

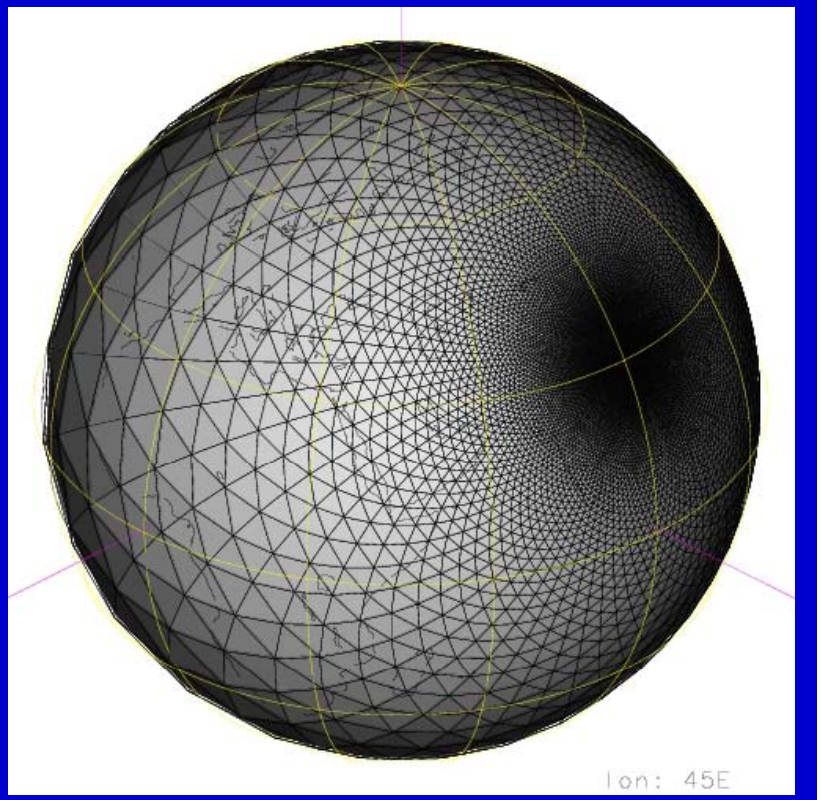
- **Long term simulations by a few km resolution.**
  - Current
    - 10 days simulation by the 3.5km NICAM.
      - Deterministic problem only or demonstrative.
  - On the PETAFLOPS era
    - Several years simulation by the 3.5km NICAM
      - Climate simulation by the GCRM
        - » Insight to cloud feedback problem
- **Super high-resolution simulation (up to 400m).**
  - Corresponding to the 3.5km simulation on the ES era.
    - Suggestion and demonstration to the next-next computer system.
  - We can expect ….
    - Good representation of deep convections.
      - Strong precipitation bias will be reduced (hopefully).
    - Improvement of shallow clouds
      - PBL clouds can be resolved marginally.

ES2 will be coming soon!

- ES has just been replaced by ES2 on this month.
  - Officially, from the next month.
- The performance measurement without tuning,
  - Condition
    - 14km grid model with 80 layers
    - 4 day simulation
    - 1/8 ES resources (80 nodes)
      1/8 ES2 resources (20 nodes)
  - Results
    - ES : 35794 [sec] (38% against peak)
    - ES2 : 34323 [sec] (12% against peak)
    - comparable? / need to tune!
  - Actually, the performance on ES2 can be brought up to twice of ES at least .
    (communication with Itakura-san(ESC))

Summary

- We have been developing the GCRM on the ES.
  - The computational performance achieves 40%.
- Although NICAM has horizontal resolution enough high to resolve the deep cloud system, there are still several physical biases.
  - Excessive precipitation on the tropics
  - Much large amount of low clouds in the mid-latitude.
- Numerical instability due to the steep mountain occurs sometimes.
  - Toward the much higher resolution simulation, we should reconsider the vertical descritization.
- 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)

Other activities of NICAM

- **NICAM as a regional climate model**
  - stretched-icosahedral grid
    - Schmidt transformation
  - Same dynamical core as NICAM
  - start from this year
    - Regional Climate Modeling Group in JAMSTEC
- **Support many platforms**
  - ES, T2K, PACS-CS, SR
  - Linux-cluster
  - Cygwin on Windows XP/Vista
  - Mac OS X
  - CUDA on GPGPU
  - iPhone (cross compile on Mac OS X)
- **Viewer system**
  - NICAM native viewing program
    - Draw result on an icosahedral grid system
    - → icoview
  - now preparing user-friendly interface
  - VICAM : Viewer of ICosahdral Atomspheric Model