Future activities of HPC in meteorology using K-computer

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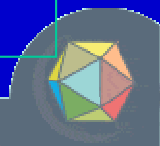
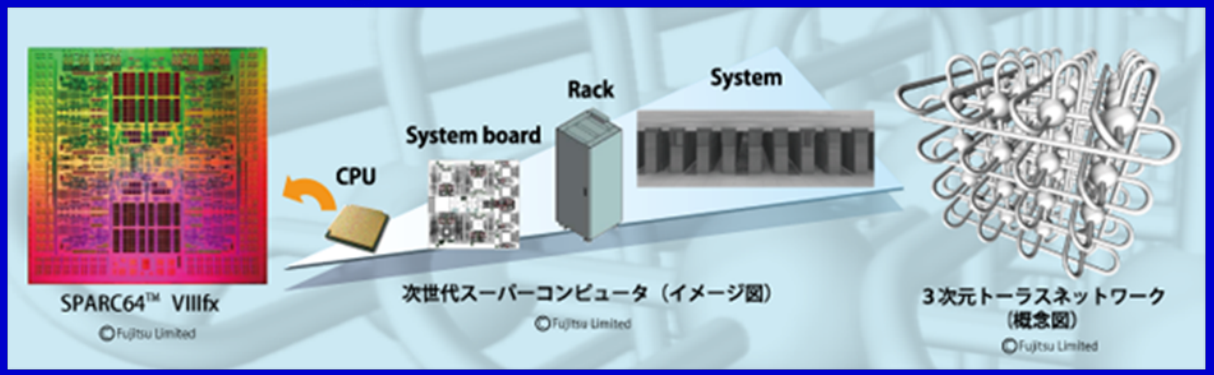
  - Grand challenge
- Summary

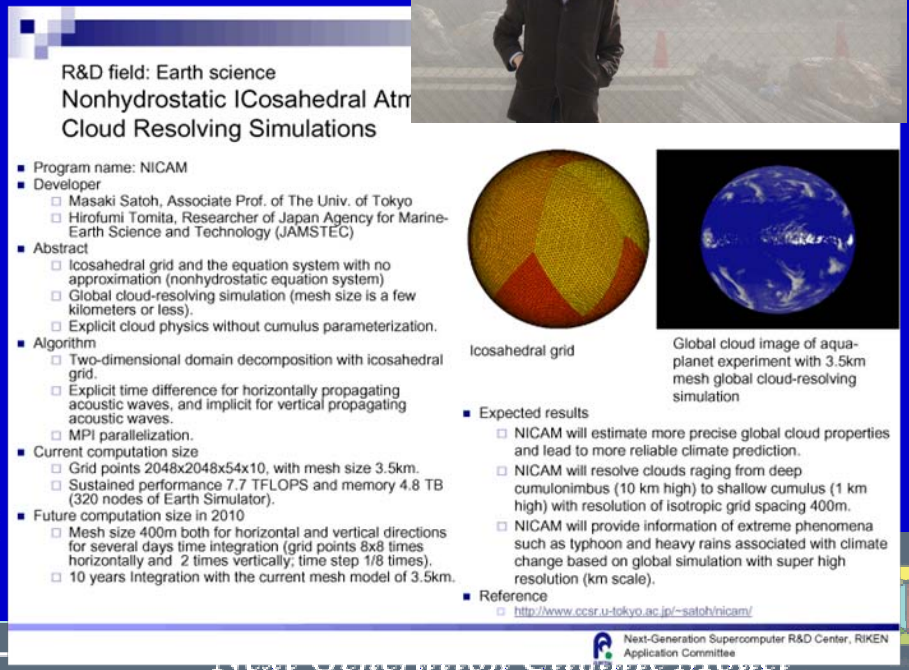


The next-generation supercomputer in Kobe

- **The next-generation supercomputer system (~2012)**



- **System**
  - **One nodes:**
    - **128GFLOPS**
    - **Memory band width : 64GB/s**
    - **B/F : 0.5**
  - **80k nodes/640k core**
  - **Peak performacne : ~10PFLOPS**
  - **Total memory : ~1PB**
  - **Network 3D(6D) torus bi-direction 5GB/s X6**



R&D field: Earth science
Nonhydrostatic ICosahedral Atm
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

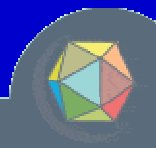
Strategic field : research for prevention of disaster

1. Research of projection of global change

- Change of tropical cyclones in the future climate (Fist priority) by GCRM.
- Predictability of tropical weather such as MJO, TC genesis by GCRM.
- Development of the application package involving all Japanese researches toward the next-generation.
  - Integration of MIROC, NICAM, COCO, and so on

2. Research of highly accurate prediction of meso-scale phenomena

- 4DVAR for CRM
- Ensemble analysis-prediction system
  - with the 4DVAR(ensemble KF)
- Basic studies
  - Large area LES, Bin model and so on.



Change of tropical cyclone in the future climate

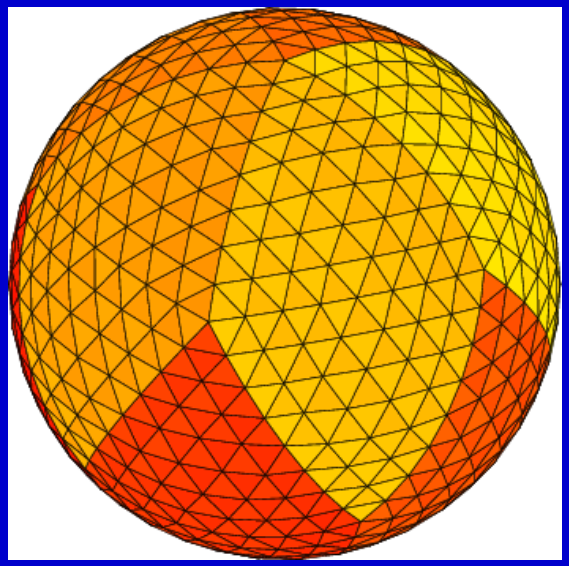
- **Motivation**
  - **Under greenhouse-warmed climate**
    - Tropical clyclone activities change
      (Oouchi et al, 2006; IPCC AR4 2007, Emanuel et al.2008)
      - MRI-GCM time slice experiment
        20km global mesh / hydrostatic dynamics
    - Global frequency : decrease.
    - Intensity : # of more intense TC increases.
  - **However, ……**
    - Depend on each ocean basis(Sugi et al, 2009)
    - # of TC is still underestimated. (Oouchi et al, 2006)
      - Cumulus parameterization?

conventional GCM
→ Global Cloud system resolving model (GCRM)

NICAM project

- NICAM project (~2000)
  - Dynamical core
    - Horizontal grid : icosahedral grid (grid modification : Tomita et al. 2001, 2002)
    - Dynamics : Non-hydrostatic scheme (energy conservation : Satoh 2002, 2003)

    → 3D DC
  - 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, Earth Simulator 2!



Current version of NICAM

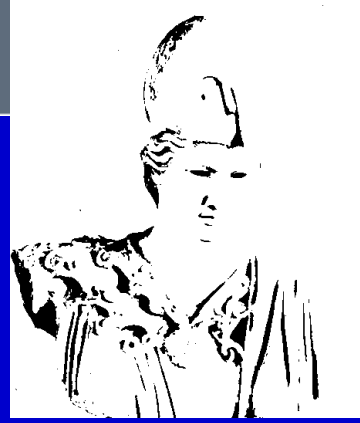
Ref. Satoh et al. 2008 *J. Comput. Phys.* / Tomita & Satoh 2004 *Fluid Dyn. Res.*

■ 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	MYNN 2.0,2.5(Nakanishi and Niino 2004) modified by Noda(2009)
Surface flux	Louis (1979), Uno et al. (1995)
Radiation	MSTRNX (Sekiguchi and Nakajima, 2005)
Cloud microphysics	NSW6 (Tomita 2008) --- 6 caegories of water (1moment-bulk)
Cloud parameterization	NONE
Surface process	MATSIRO(Takata et al.)

Qusetion:
Global cloud system resolving model overwhelms the traditional GCM?

Is it true?

Athena project



- **Purpose**
  - Investigate the impact of global high resolution
    - How is the climatology / diurnal cycles improved?
    - Dependency on the resolution?
    - Hydrostatic / non-hydrostatic?
    - With/without cumulus parameterization?
- **Collaboration**
  - COLA - Center for Ocean-Land-Atmosphere Studies, USA
  - ECMWF - European Center for Medium-range Weather Forecasts, UK
  - JAMSTEC - Japan Agency for Marine-Earth Science and Technology, Research Institute for Global Change, Japan
  - University of Tokyo, Japan
  - NICS - National Institute for Computational Sciences, USA
  - Cray Inc
- **Codes**
  - NICAM: Nonhydrostatic Icosahedral Atmospheric Model
  - IFS: ECMWF Integrated Forecast System
- **Computer**
  - Athena: Cray XT4 - 4512 quad-core Opteron nodes (18048) #30 on Top500 list (November 2009)
  - Kraken: Cray XT5 - 8256 dual hex-core Opteron nodes (99072) #3 on Top500 list (November 2009)

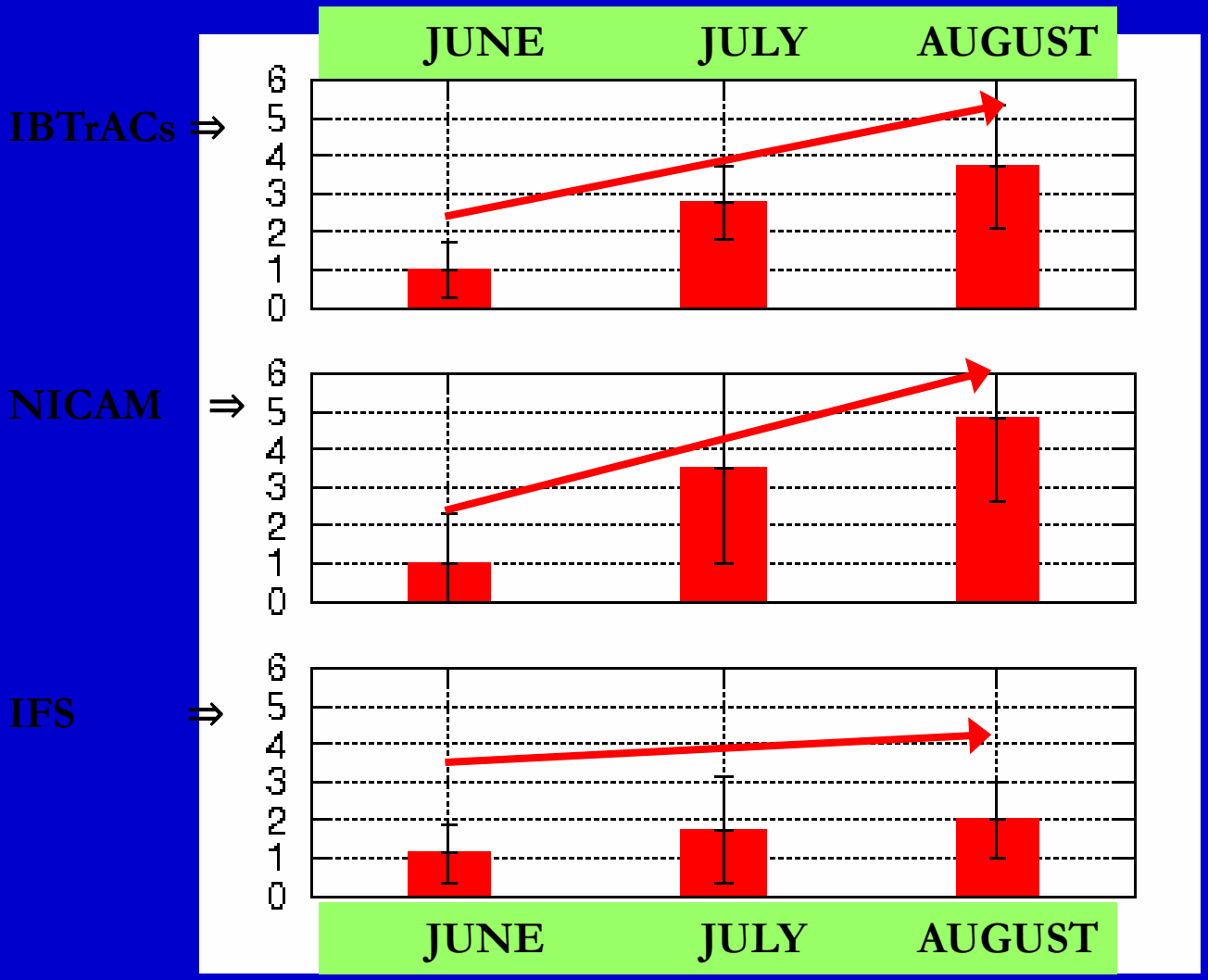
Model description of IFS & NICAM

Model	NICAM	IFS
Horizontal resolution	7 km	10 km
# of Vertical layer	40 layers	62 layers
Basic equation	Non-hydrostatic	Hydrostatic
Cumulus pram.	Not use	Tiedtke, 1989
Radiation scheme	Sekiguchi & Nakajima, 2008	Morcrette et al, 2008
Turbulent model	Nakanishi & Nino, 2004 A. T. Noda et al, 2009	Siebesma & Cuijpers, 1995
Boundary condition (SST)	Slab ocean with nudging	Fixed
Period	May 21 – August 31 of the years 2001 – 2009 excluding 2003	

2009 boreal summer precipitation

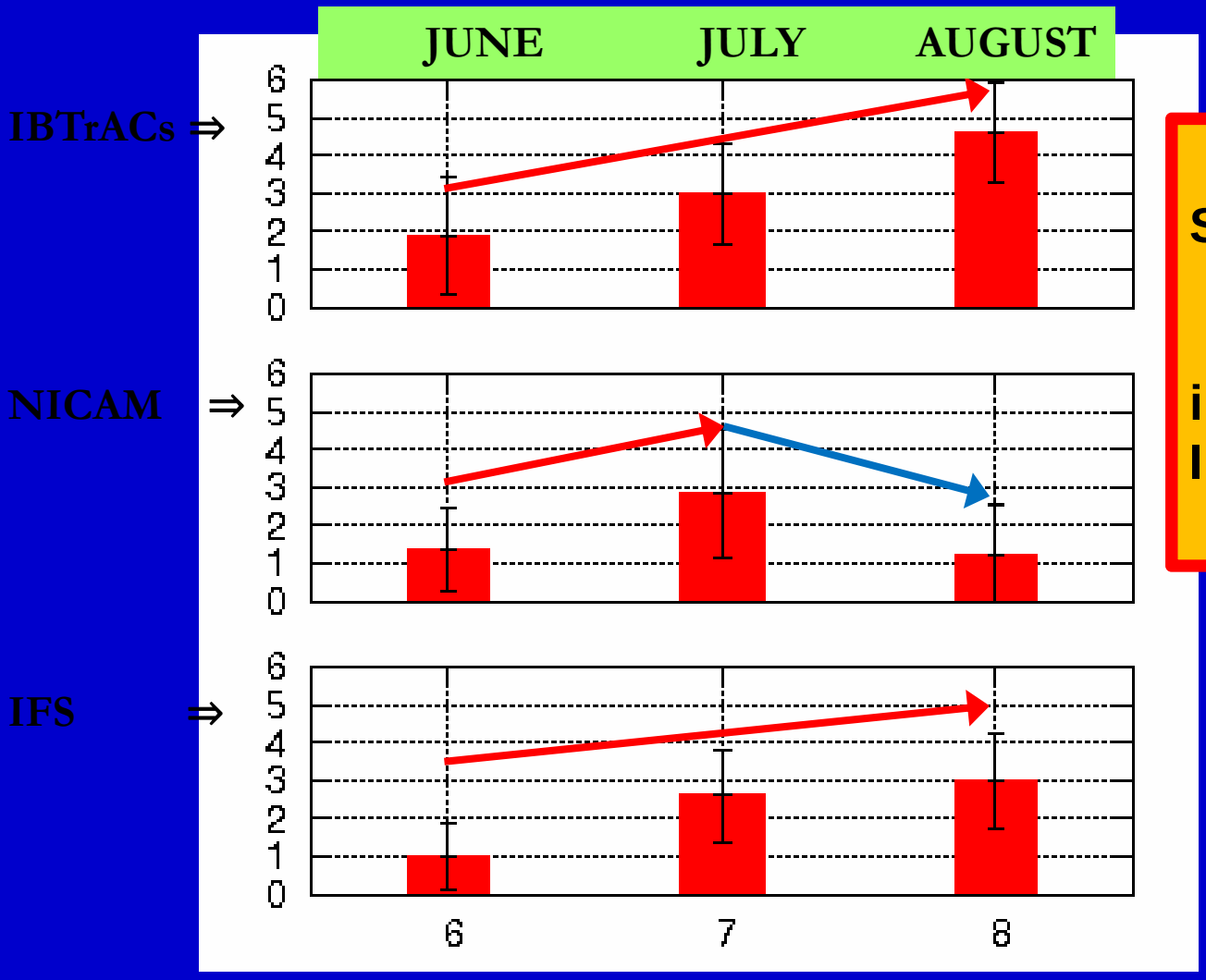
Cyclogenesis (per Year) & its seasonal change

Over the eastern Pacific basin



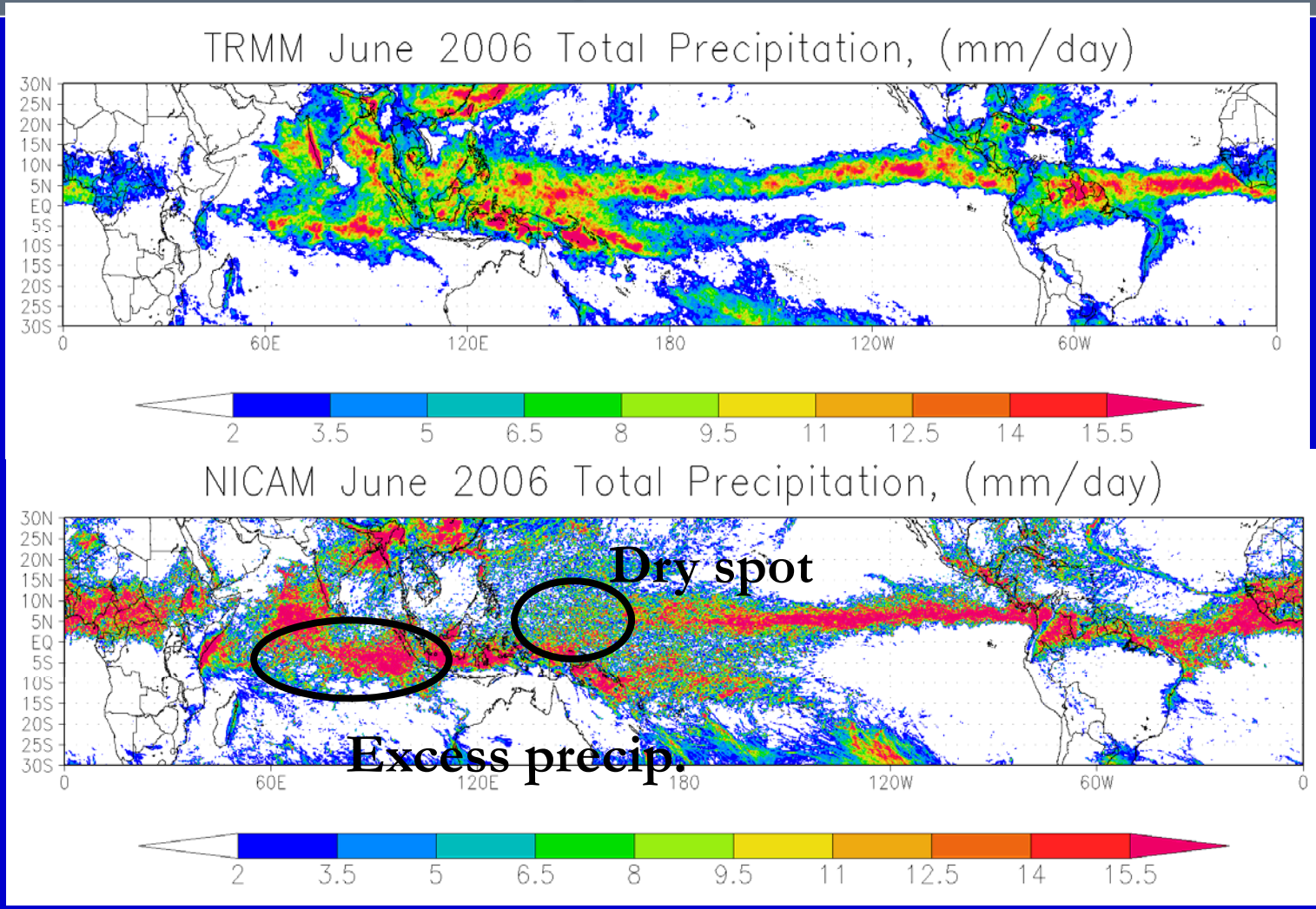
Seasonal cycle:
IBTrACs:increase
NICAM: increase
IFS: slight increases

Over the western Pacific basin



Seasonal cycle:
IBTrACs: increase
NICAM: increasing&decreasing
IFS: increase

Precipitation bias

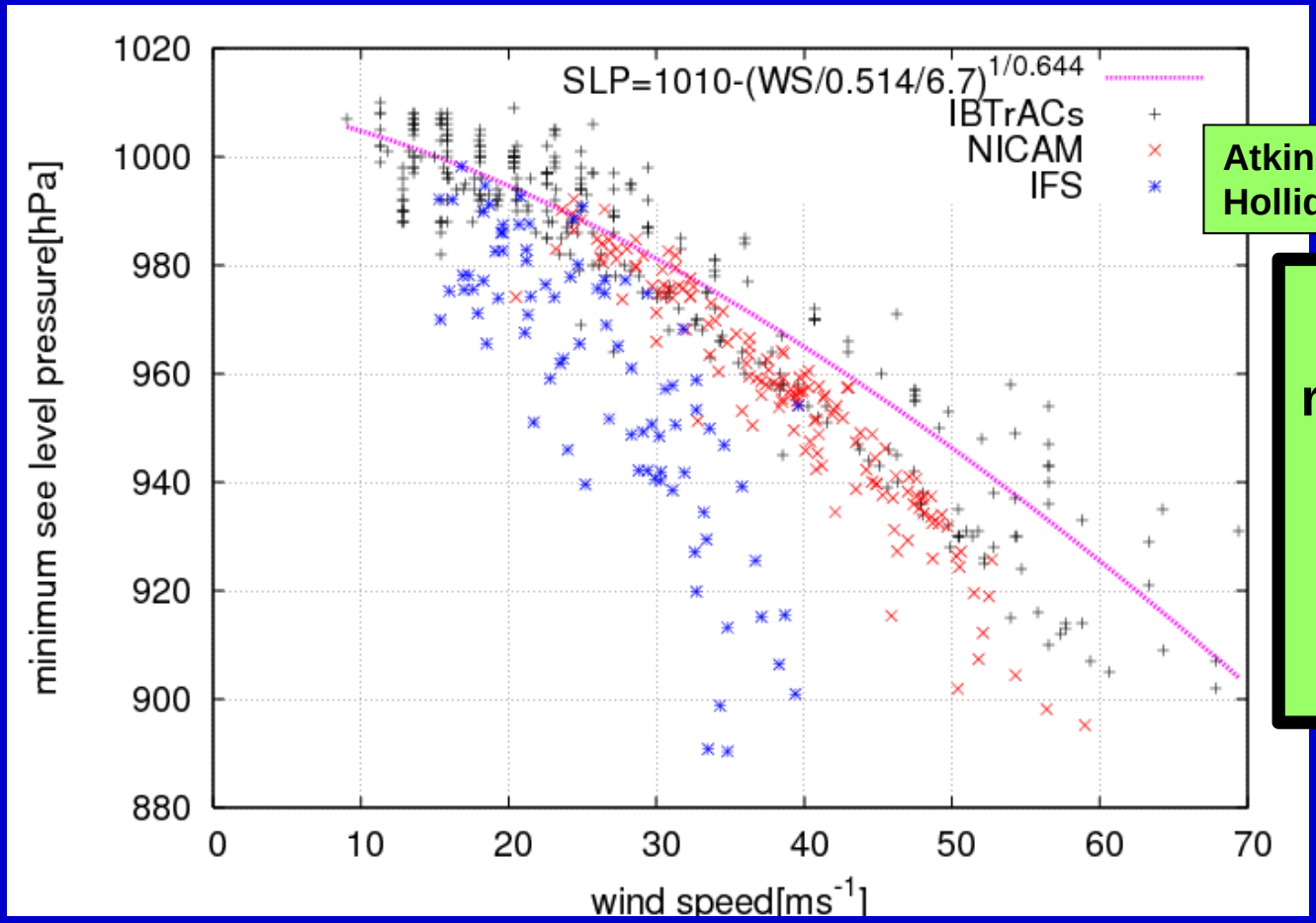


Climatology: still bias

→Possible reason : evaporation formulation? Land surface model?

Task: This climatological bias must be reduced within 1 or 2 years!

Minimum Sea Level Pressure (SLP) vs. Maximum Wind Speed (MWS)



Atkinson & Holliday 1977

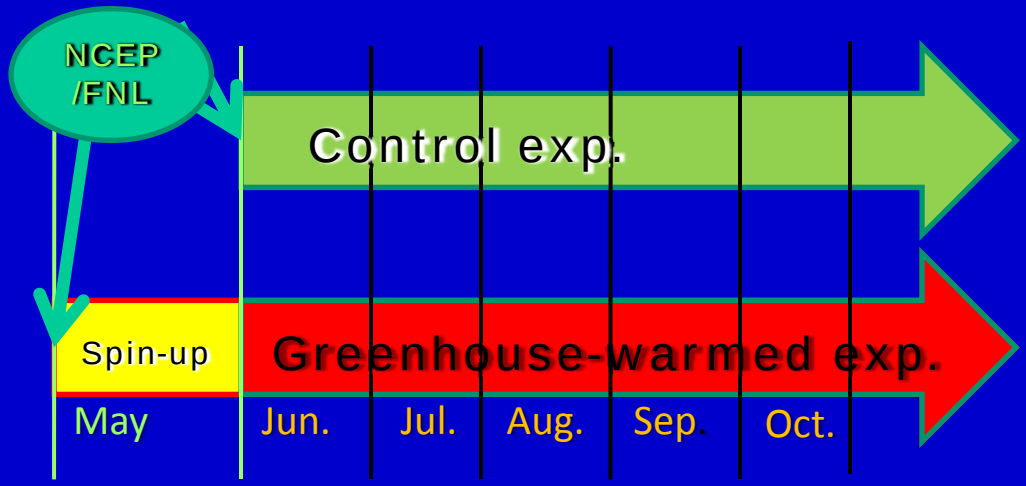
For individual TC, relationship between the wind speed when the TC attained minimum SLP in its life-cycle

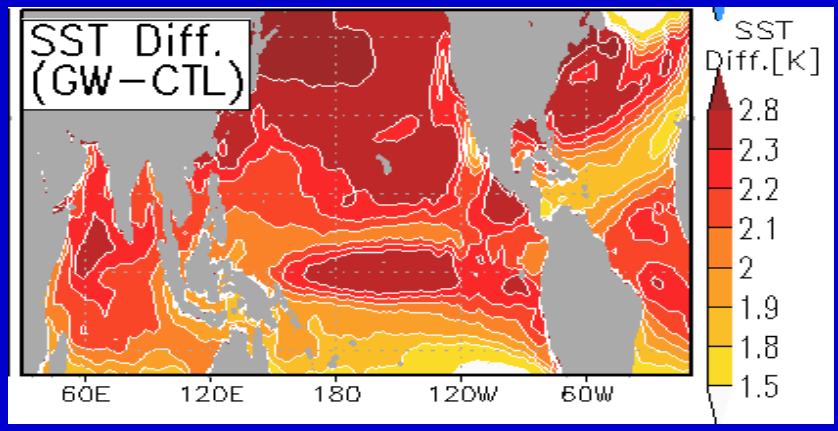
Cloud-system-resolving model (NICAM) represents MWS-SLP relationship better than parameterization model (IFS).
→ TC structure is captured by GCRM

First attempt for TC change study by GCRM (Yamada et al. 2010)

Time slice experiment

	CTL run	GW run
Initial condition	NCEP/FNL(2004 June)	NCEP/FNL(2004 May) with 1-month spinup
SST	Reynolds OI SST	Reynolds OI SST + ΔT * CMIP3 model ensemble (Mizuta et. al 2008)
CO2 concentration	348ppm	696ppm
Integration time	5 months	5 months





Yamada et al.2010

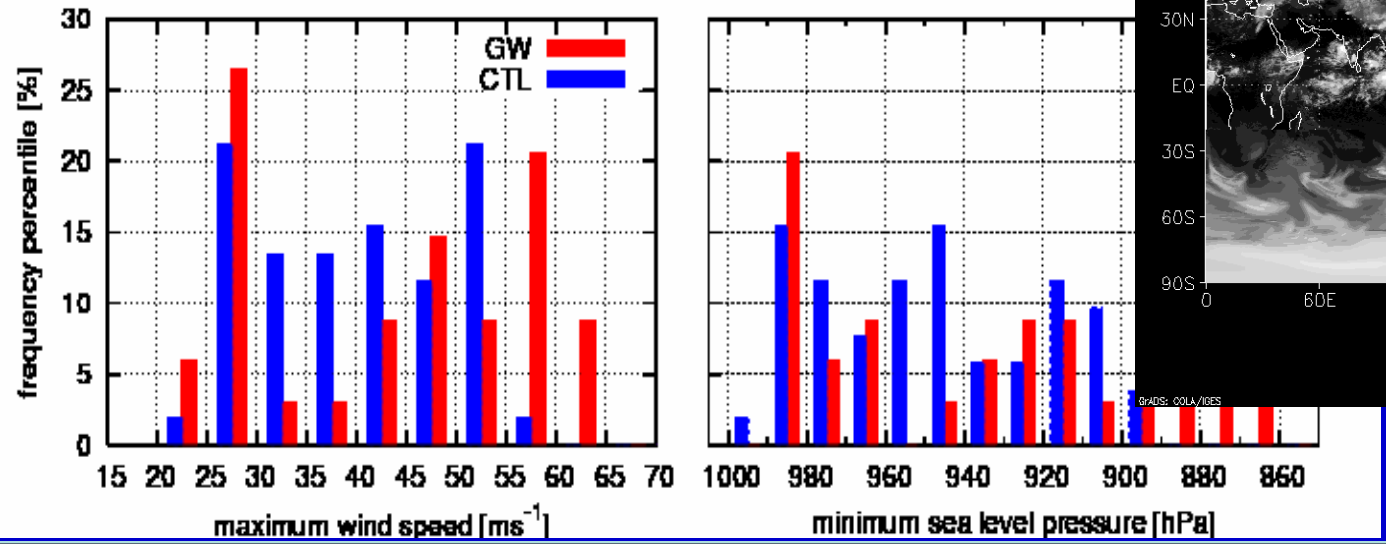
Change of tropical cyclones

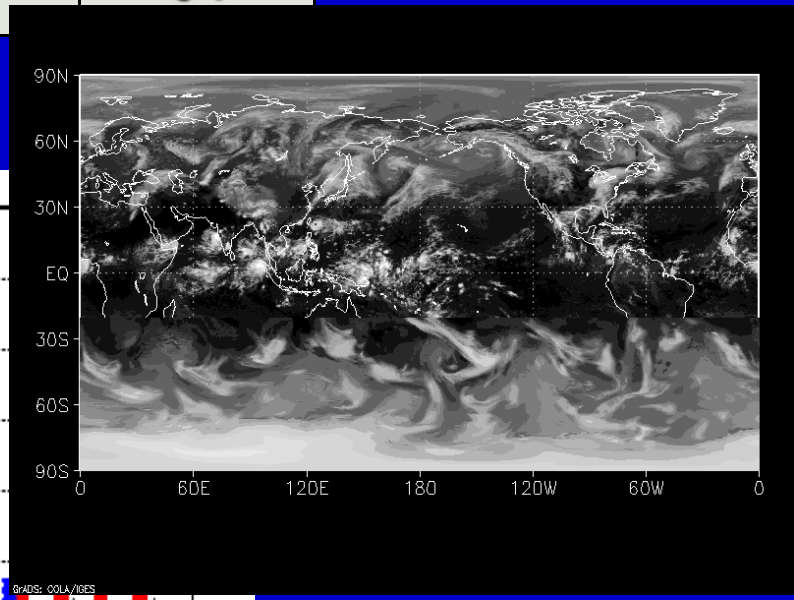
Change of number of TC

Yamada et al.2010

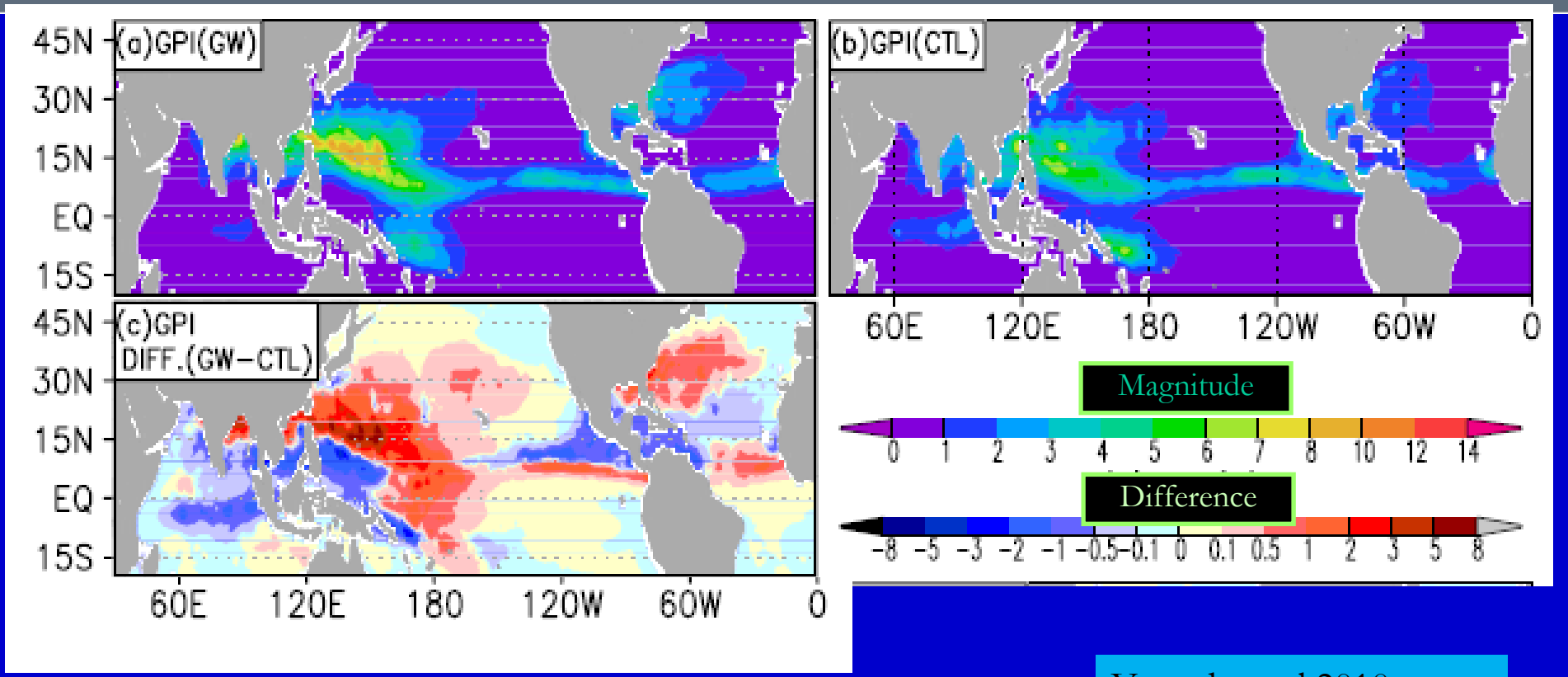
	IndianOcean	West. Pacific	East. Pacific	Atlantic Ocean	Global
OBS	5	20	12	14	51
CTL	12	22	7	10	52
GW	3	22	7	2	34

Change of intensity





GPI distributions



Yamada et al.2010

- **Pacific ocean**
  - **Higher GPI region : west → east**
    - **El Nino like distribution of SST**
- **Atlantic ocean**
  - **South region : increase/ north region : decrease**
  - **TCs are generated well, but suppressed.**

Yamada et al.(2010,GRL) is a landmark! However,…

- **Too less integration time!**
  - Just 6 months
  - → Several 10 years on K-computer
- **Too less horizontal resolution!**
  - Dx =14km
  - → 7km, 3.5km, 1.8km
- **Too simple microphysics!**
  - 3 categories
  - → 6 categories (3 ice/ 2 water/ vapor)

- **More statistical analysis for TC changes!**
- **More detail analysis for TC structure!**

K-computer will resolve them!

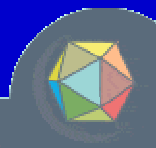
Grand challenge!

Global 400m mesh run

- Collaboration project with RIKEN and JAMSTEC
  - Horizontally 400m with 100 vertical levels
    - Truly, global cloud-resolving!
  - Use of the full computational resource
    - 1PB memory
    - All computational nodes
  - Integration time ：1 week?
- Purpose ：
  - Improve PBL cloud?
  - Improve detail structure of cumulus?
  - Diurnal cycle?
  - Computationally,
    - Well work in the case of full use?
    - Suggestion to the next-next computer systems

Computational performance on each machine

- **Vector-based machine**
  - Problem size　7km/L40
  - ES：30～40%
  - ES2:10～15%
- **Scalar-based machine (as is)**
  - Cray XT4 : 2.9%　(@Oct. 2009)
    - In collaboration with COLA
  - T2K tsukuba : 3.3%
  - IBM :BlueGene/P : 6%
  - Recent PC : Core i7(nehalem core)　6%



Roughly estimated computational performance on K-comuter

- **Now, scalar tuning of NICAM is starting with RIKEN.**
  - Each subroutine : 20% (estimated)
  - Overhead of communication part : ???
    - @ communication part is 30%, total performance : 15%
    - @ communication part is 50%, total performance : 10%
- **Assumption : 10%(minimum estimate) of peak performance**
  - 7km mesh run
    - 15 hours for 1 year integration (@ 1/5 resources)
  - 3.5km mesh run
    - 5 days for 1 year integration (@ 1/5 resources)
  - 1.8km mesh run
    - 8 days for 1 year integration (@ full resources)

Summary

- K-computer with 10PFLOPS will be operated from 2012.
- The Japanese government set 5 strategic research fields up, including the climate problem.
  - In order to get much more reliable information about TC in the global warmed period, global cloud system resolving model NICAM is the tool for this purpose.
  - The current NICAM still has a bias in the climatology.
    - To resolve the problem is the first priority.
- The global 400m grid run is also scheduled as a grand challenge.
  - For next-generation (Hexa FLOPS era)