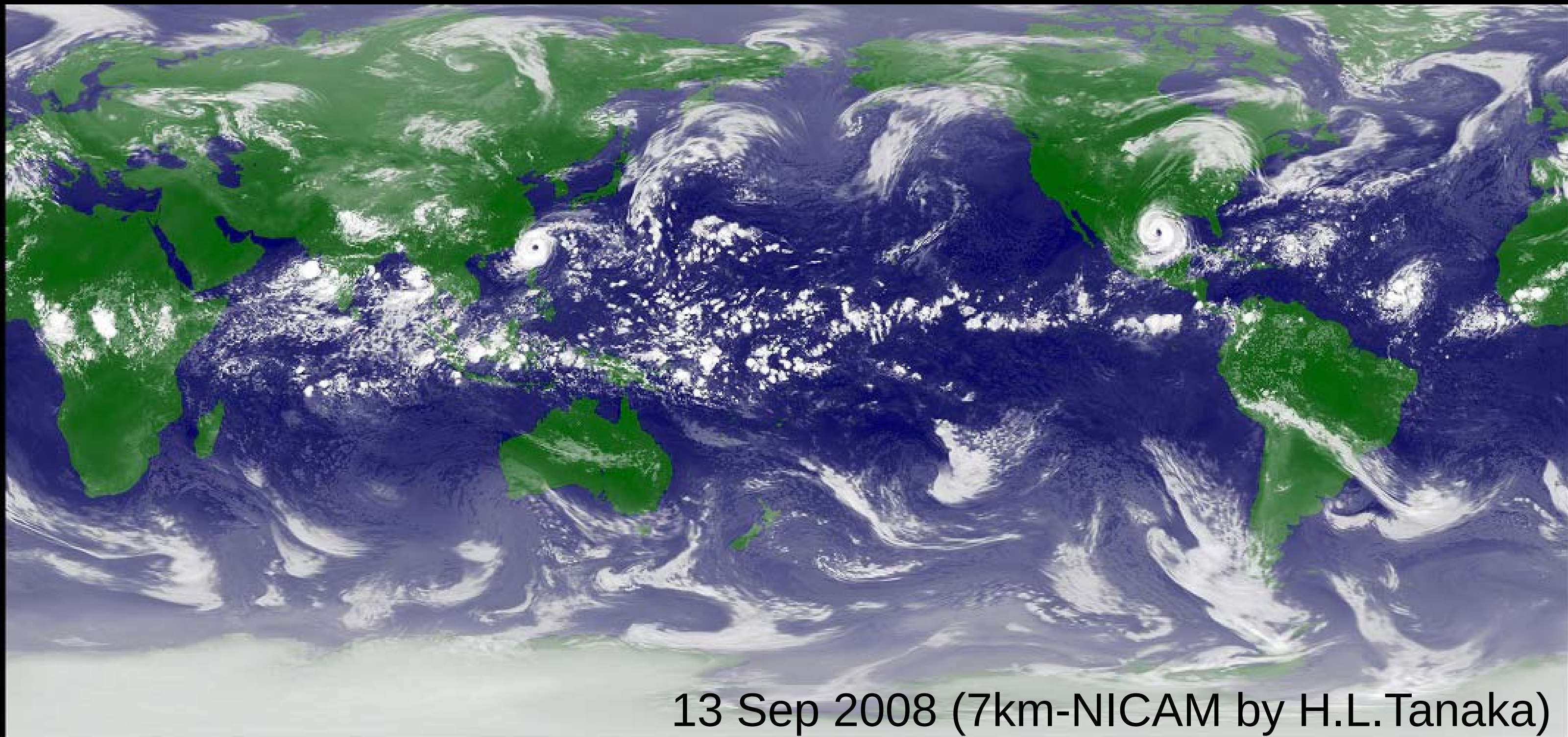
# NICAM - Nonhydrostatic Icosahedral Atmospheric Model


Masaki Satoh

(AORI, the Univ. of Tokyo/RIGC, JAMSTEC)

13 Sep 2008 (7km-NICAM by H.L.Tanaka)

**1th Workshop on Dynamical Cores for Climate Models**

**December 14th-16th, 2011,** Carlo V Castle - Lecce

Group web page http://nicam.jp

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- **3.5km mesh NICAM simulation**
  - **Tropical cyclone and synoptic scale waves**
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# NICAM: Nonhydrostatic Icosahedal Atmospheric Model

- Development since 2000

  Tomita and Satoh(2005, *Fluid Dyn. Res.*), Satoh et al.(2008, *J. Comp. Phys.*)

- First global dx=3.5km run in 2004 using the Earth Simulator (JAMSTEC)

  Tomita et al.(2005, *Geophys. Res. Lett.*), Miura et al.(2007, Science)

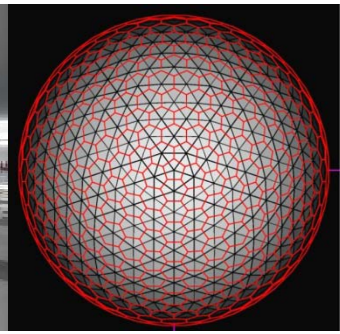
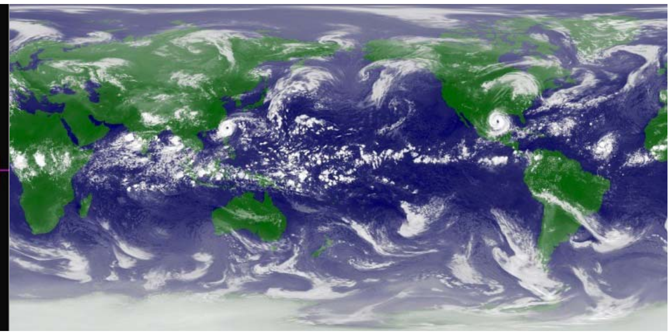
- Toward higher resolution global simulation

  dx=1.7km, 880m, 440m using K-computer (10PF; Kobe,Riken,2012)

- International collaborations

  –Athena project (2009-10): COLA, NICS, ECMWF, JAMSTEC, Univ. of Tokyo

  –G8 ICOMEX (2011-): Germany, UK, France, US, Japan

# Nonhydrostatic Icosahedarl Atmospheric Model

- Icosahedral grid with spring dynamics smoothing

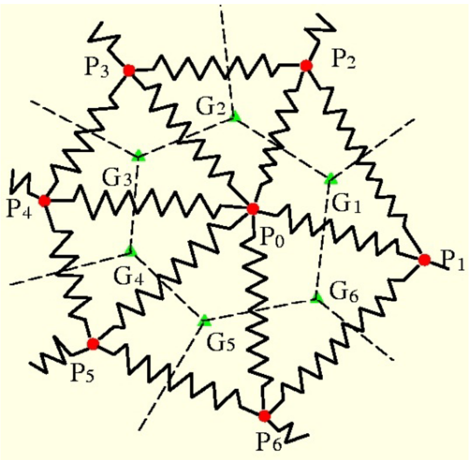
  Tomita et al.(2001, *J. Comp. Phys.*)

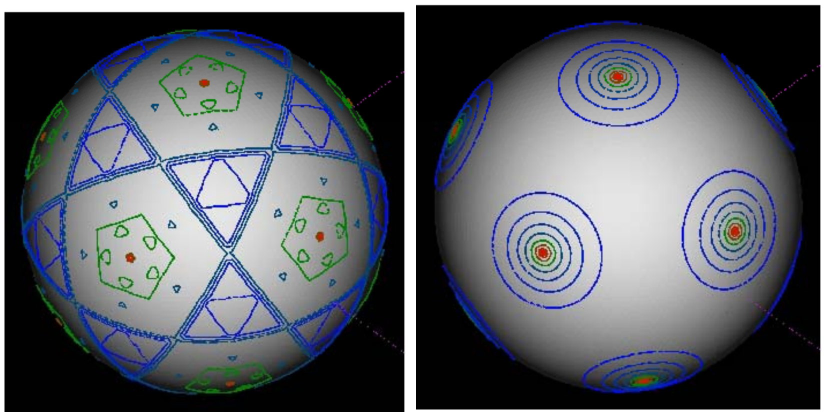
  Tomita et al.(2002, *J. Comp. Phys.*)

- Flux-form conservative nonhydrostatic scheme
  - Split-explicit time integration
  - mass and total energy & momentum conserving

  Satoh (2002, *Mon. Wea. Rev.*)

  Satoh (2003, *Mon. Wea. Rev.*)



Area distribution of cell: before and after

# Nonhydrostatic scheme

$$\frac{\partial}{\partial t} R + \nabla_h \cdot \mathbf{V}_h + \frac{\partial}{\partial \xi}\left(\frac{W}{G^{1/2}} + \mathbf{G}^3 \cdot \mathbf{V}_h\right) = 0$$

$$\frac{\partial}{\partial t} \mathbf{V}_h + \nabla_h P + \frac{\partial}{\partial \xi}\left(\mathbf{G}^3 P\right) = \mathbf{ADV}_h + \mathbf{F}_{Coriolis}$$

$$\frac{\partial}{\partial t} W + \frac{\partial}{\partial \xi}\left(\frac{P}{G^{1/2}}\right) + Rg = ADV_z + F_{z,Coriolis}$$

$$\frac{\partial}{\partial t} E_{total} + \nabla_h \cdot \left[\left(h + k + \Phi\right)\mathbf{V}_h\right] + \frac{\partial}{\partial \xi}\left[\left(h + k + \Phi\right)\left(\frac{W}{G^{1/2}} + \mathbf{G}^3 \cdot \mathbf{V}_h\right)\right] = 0$$

Prognostic variables

- density $R = G^{1/2}\rho$
- horizontal momentum $\mathbf{V}_h = G^{1/2}\rho\, \mathbf{v}_h$
- vertical momentum $W = G^{1/2}\rho\, w$
- total energy $E_{total} = \rho G^{1/2}\left(e_{in} + k + \Phi\right)$

Metrics

$$G^{1/2} = \left(\frac{\partial z}{\partial \xi}\right)_{x,y}$$

$$\mathbf{G}^3 = \left(\nabla_h \xi\right)_z$$

$$\xi = \frac{H(z - z_s)}{H - z_s}$$

Satoh (2002, 2003)

# Model description

| | |
|---|---|
| ■ Dynamics | |
| Governing equations | Fully compressible non-hydrostatic system |
| Spatial discretization<br>Horizontal grid configuration<br>Vertical grid configuration<br>Topography | Finite Volume Method (Tomita et al. 2001,2002)<br>Icosahedral grid<br>Lorenz grid<br>Terrain-following coordinate |
| Conservation | Total mass, total energy (Satoh 2002,2003) |
| Temporal scheme | Slow mode - explicit scheme （RK2, RK3）<br>Fast mode - Horizontal Explicit Vertical Implicit scheme |
| Advection scheme | Conservative and monotonic<br>Miura (2004), Niwa et al.(2011) |
| ■ Physics | |
| Turbulence, surface flux | MYNN(Nakanishi and Niino 2004; Mellor & Yamada 2,2.5,3)/Louis(1979), Uno et al.(1995), Moon et al. (2007) |
| Radiation | MSTRNX (Sekiguchi and Nakajima, 2005) |
| Cloud physics | Kessler; Grabowski(1998); Lin et al.(1983); NSW6(Tomita 2008);NDW6(Seiki et al. 2011);WSM3-6 (Hong et al. 2004) |
| Subgrid convection | Prognostic AS, Kuo,<br>Chikira (Chikira and Sugiyama 2010), Tiedtke (1989) |

# Global cloud-system resolving simulation of typhoon Fengshen (2008): comparison with ECMWF YOTC operational analysis data

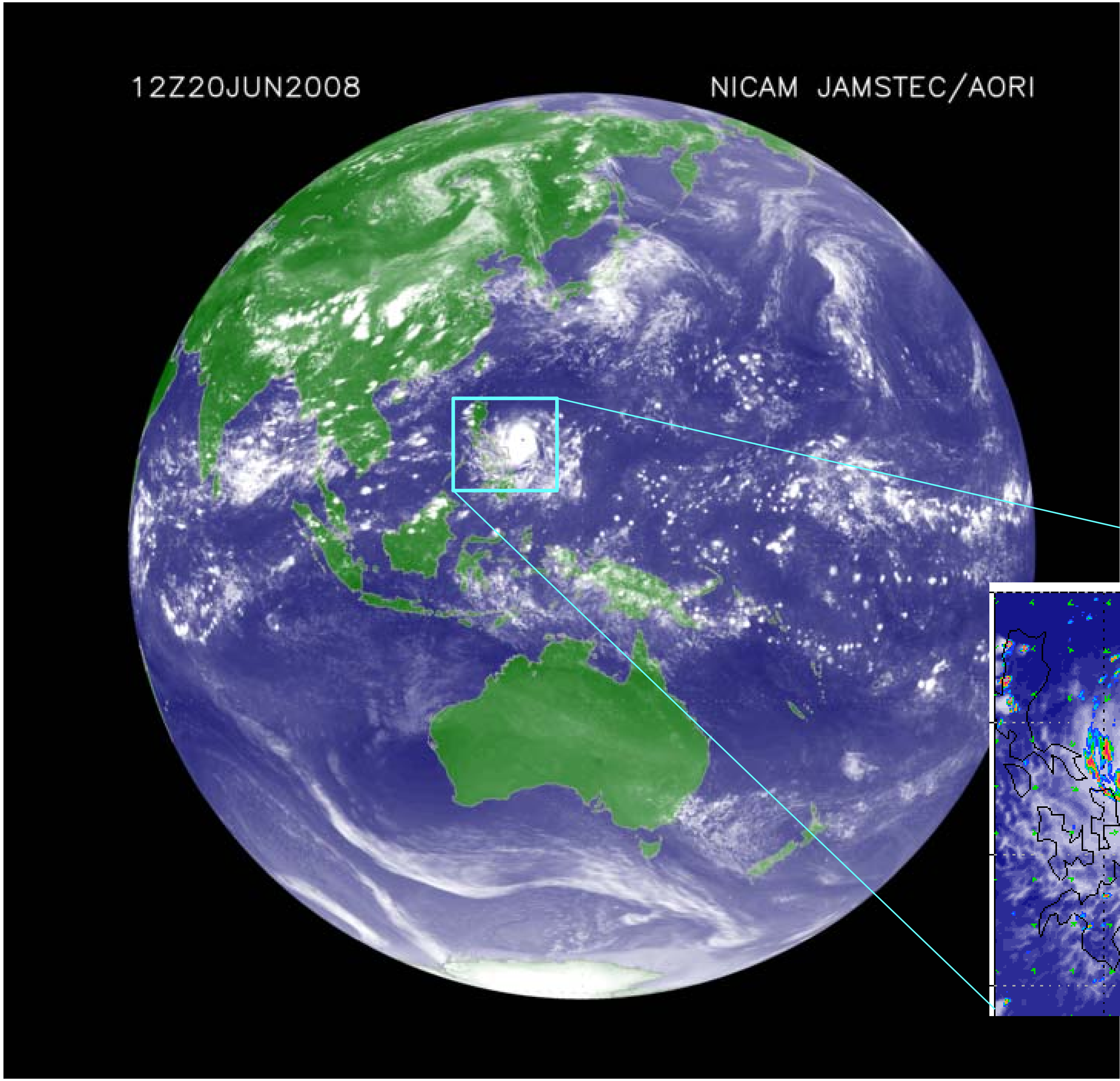
**Tomoe Nasuno**, Hiroyuki Yamada, Wataru Yanase,
Akira T. Noda, and Masaki Satoh
Email: nasuno@jamstec.go.jp

# Genesis of Typhoon Fengshen (2008) from an uptilted synoptic-scale disturbance: PALAU field experiment and global cloud-resolving simulation

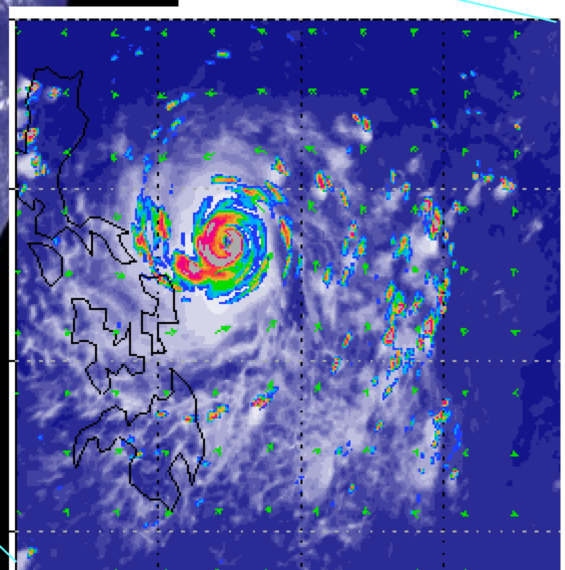
**Hiroyuki Yamada**, Tomoe Nasuno, Wataru Yanase,
Ryuichi Shirooka, and Masaki Satoh
Email: yamada@jamstec.go.jp

(2011, to be submitted)

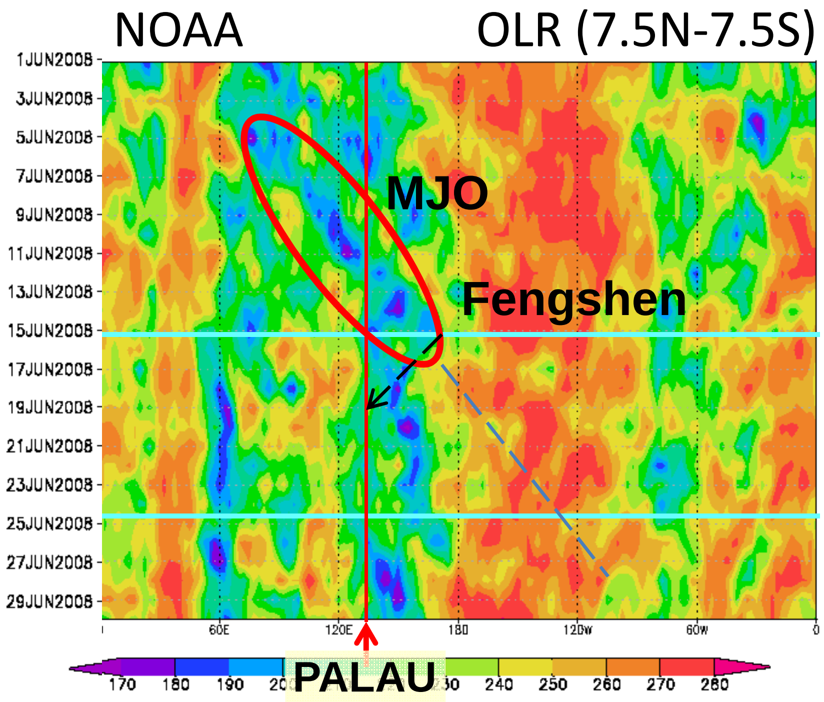
NICAM 3.5 km mesh
2008/06/20 12UTC

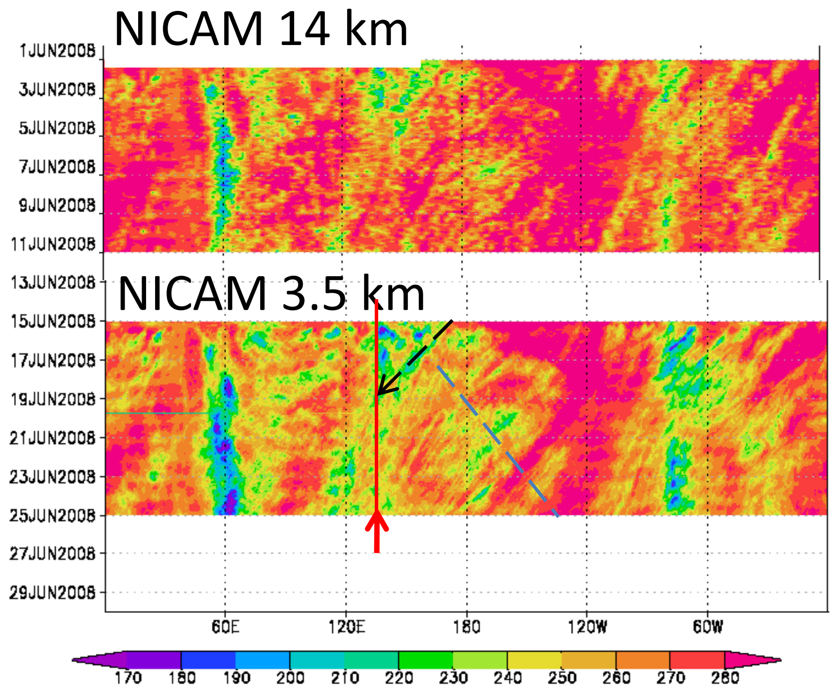



TC Fengshen



# Global cloud-resolving simulation of YOTC period #1




Horizontal grid spacing: **14 km, 3.5 km**

Vertical domain: 0 m ~ 38,000 m (40-levels)

Integration: **10 days from 00UTC 15 Jun 2008**

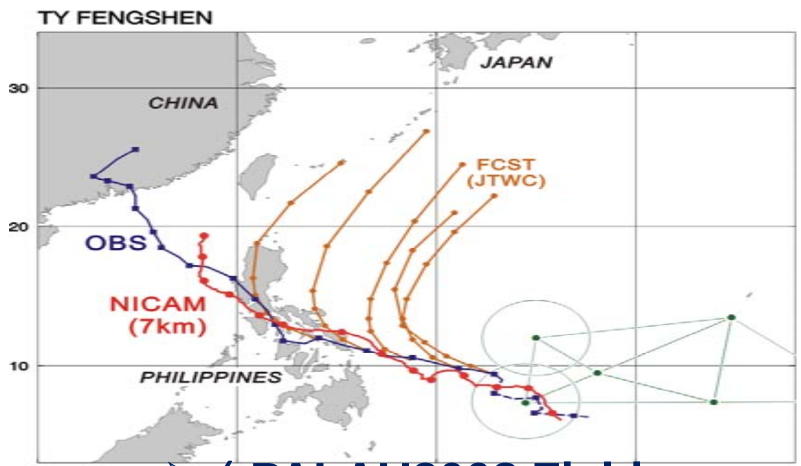
Initial conditions: **ECMWF YOTC Operational data**

NCEP final analysis (land surface, SST)

Boundary conditions: **slab ocean**

(nudging to Reynolds weekly SST)

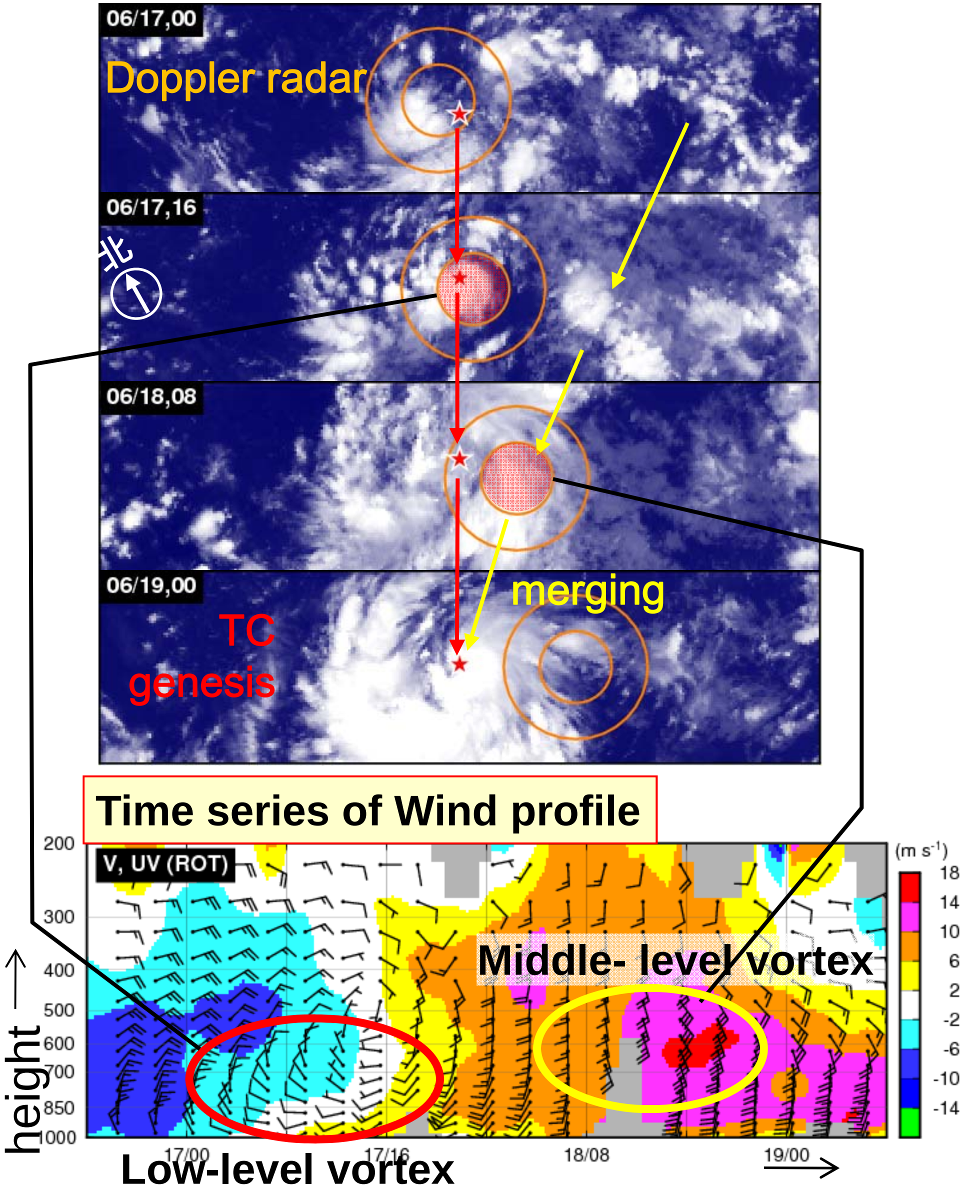
- Fengshen formed on **17 Jun 2008**

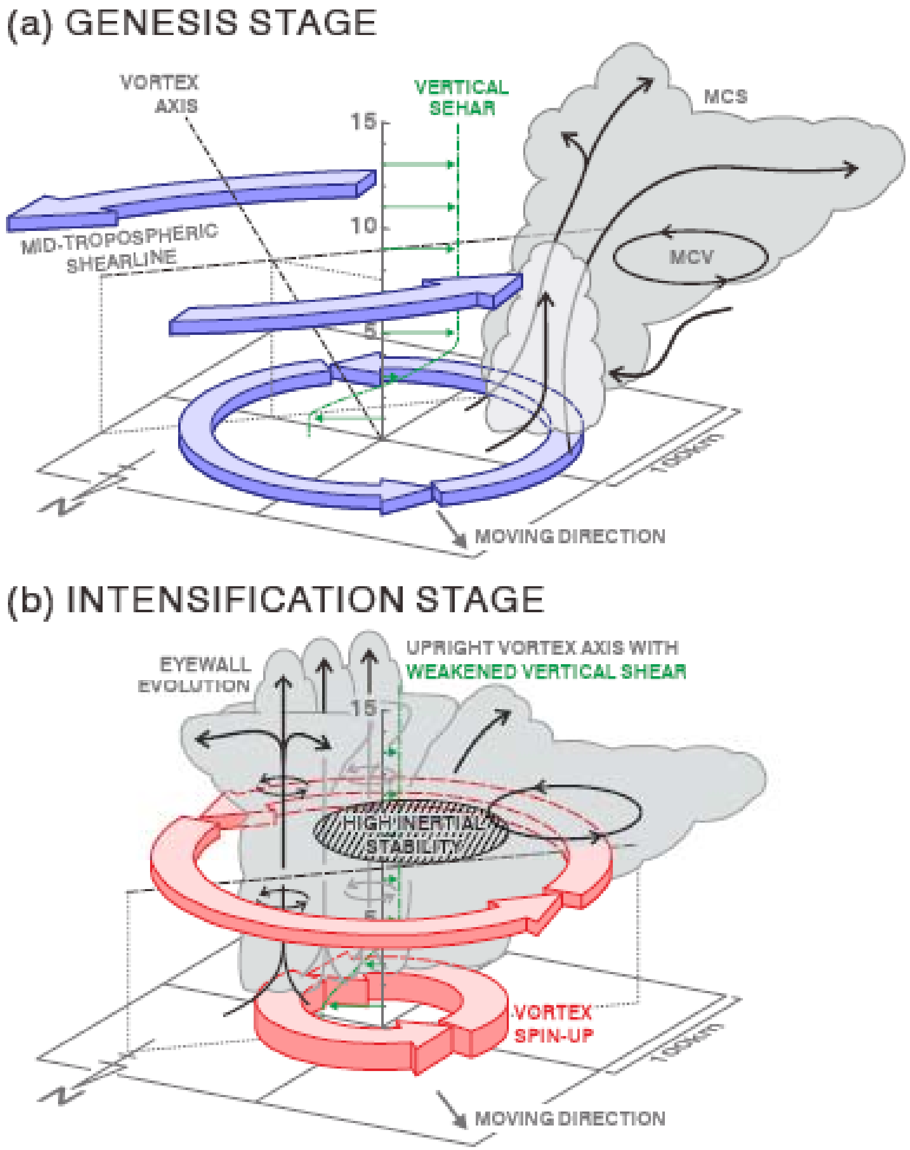



- （PALAU2008 Field campaign）

# Genesis process of Typhoon Fengshen: mesoscale analysis

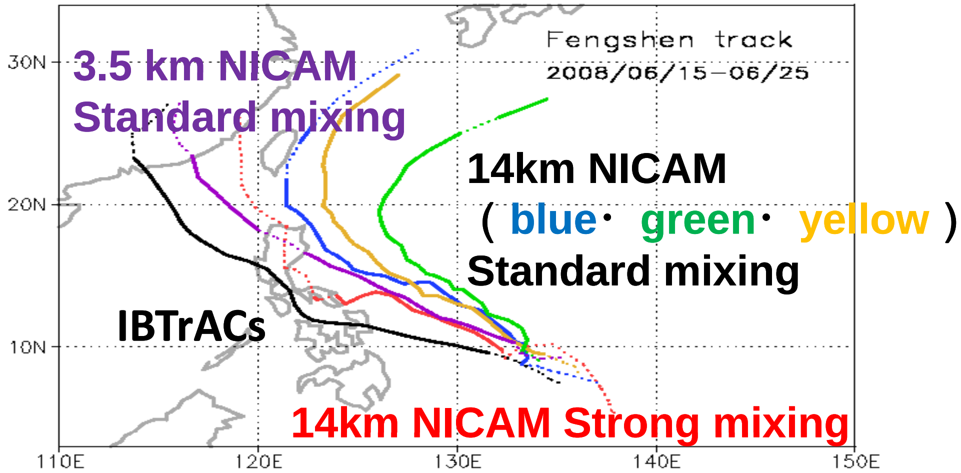
## observation (IR, radar)

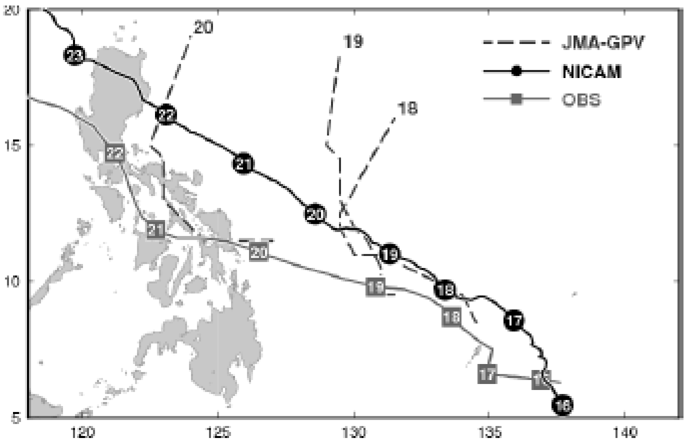


# Impact of resolution on TC track

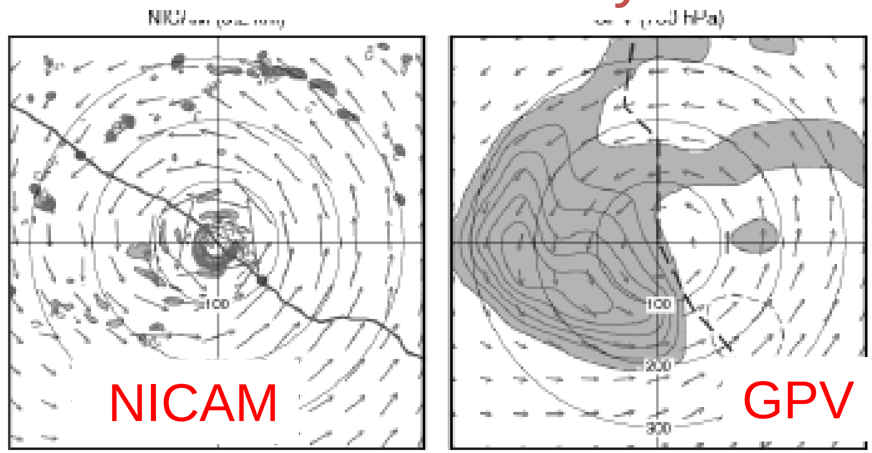
**Fengshen track**

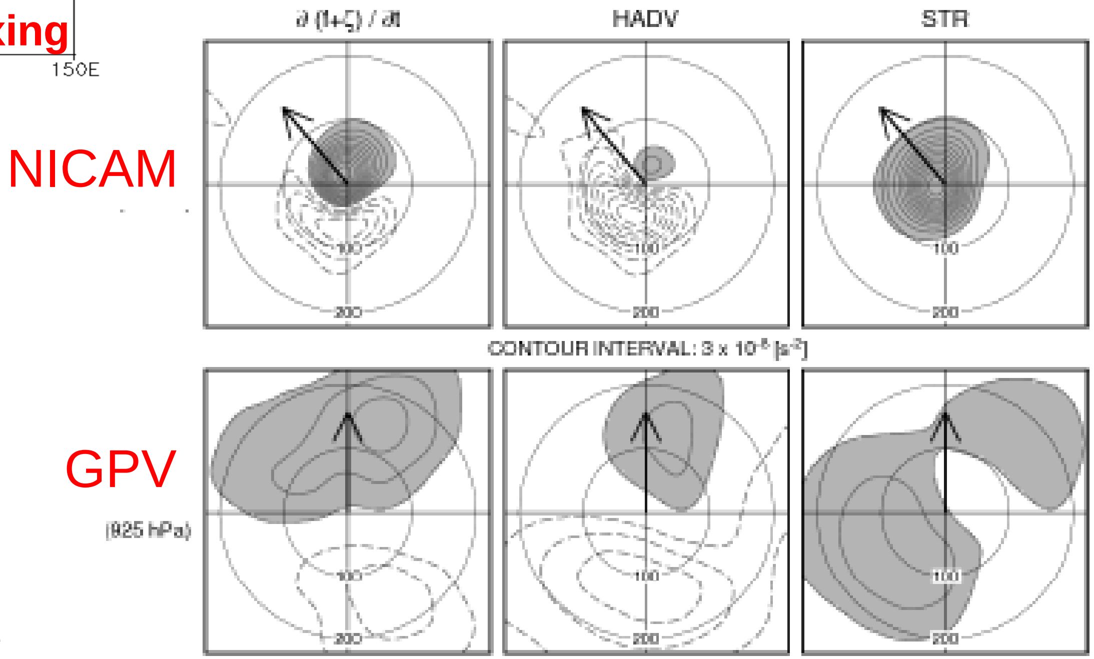



**Fengshen track is better simulated by 3.5 km NICAM than 14 km NICAM and JMA-GMS**

Vertical velocity




Tendencies of vorticity

# Validation of cloud microphysical statistics simulated by a global cloud-resolving model with active satellite measurements

**Tempei Hashino**[1], Masaki Satoh[1], Yuichiro Hagihara[2],
Takuji Kubota[3], Toshihisa Matsui[4], Tomoe Nasuno[5], and
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(2011, to be submitted)

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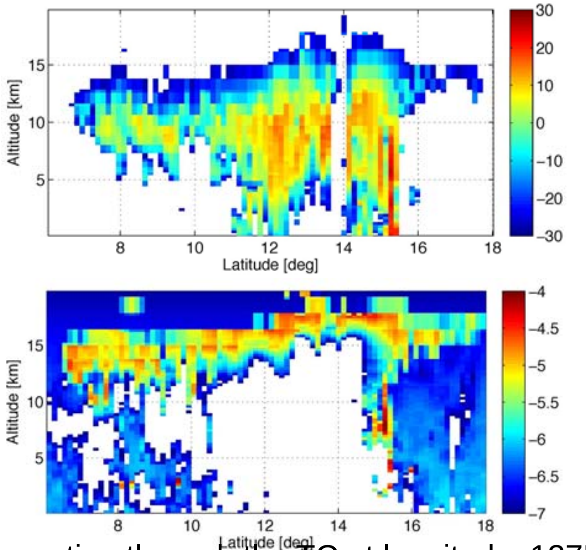
[3]Japan Agency for Marine-earth Science and Technology
[4]NASA Goddard Space Flight Center
[5]Japan Agency for Marine-earth Science and Technology

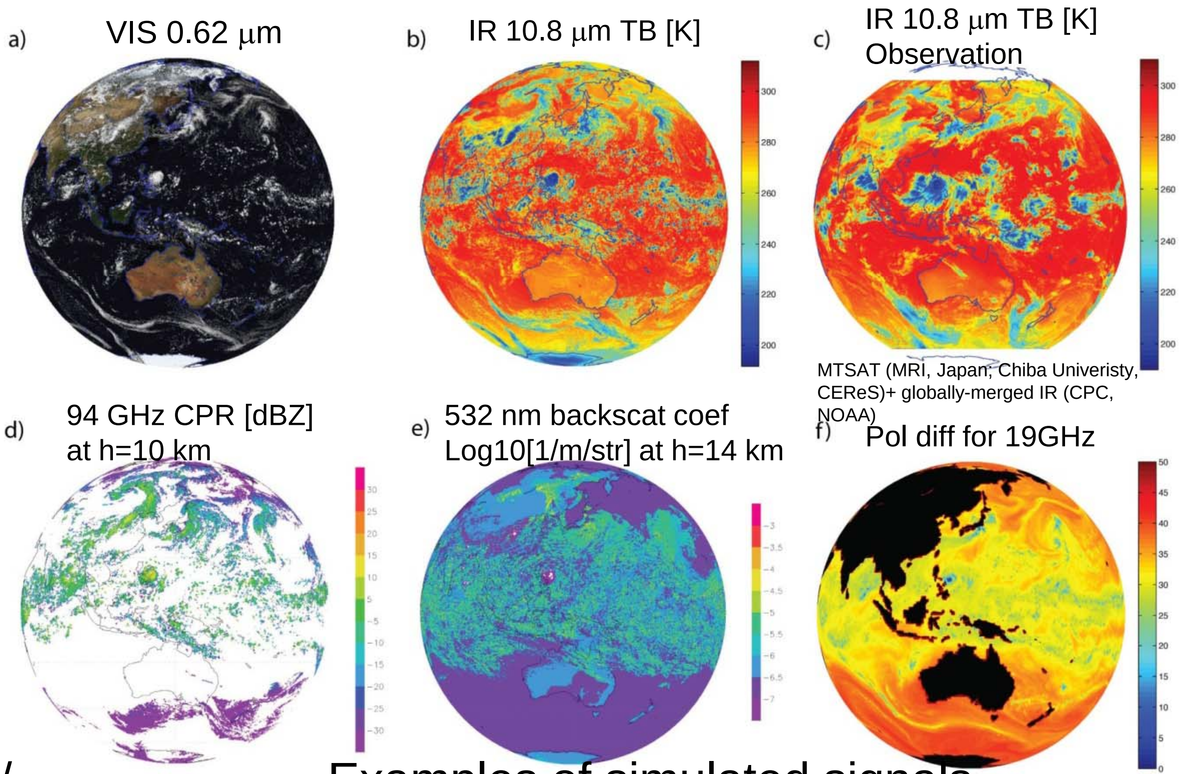
# J-simulator (Joint Simulator for Satellite Sensors)

## by T. Hashino and the EarthCARE team

- Simulate EarthCARE (2014) observations from CRM outputs.
- Built on Satellite Data Simulator Unit (SDSU)
  Masunaga et al. (2010, BAMS)
- Extension at NASA/Goddard: Goddard-SDSU
  courtesy of T. Matsui & NASA GPM team




Cross section through the TC at longitude 127E



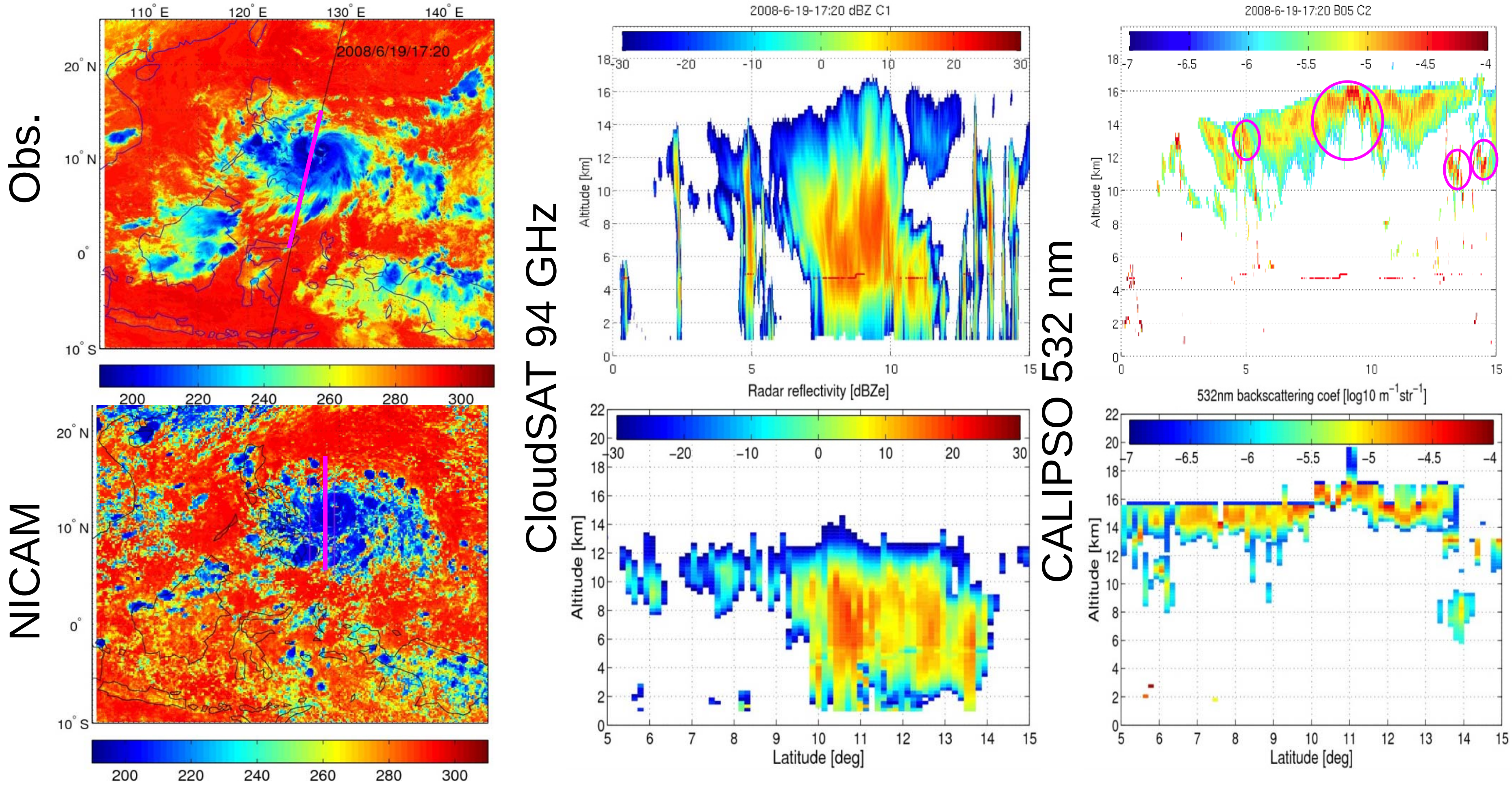

Examples of simulated signals

Joint Simulator for Satellite Sensors J-Simulator

http://www22.atwiki.jp/j-simulator/

# Example 1: Tropical Cyclone

MTSAT IR $T_b$ (10.8 $\mu$m)

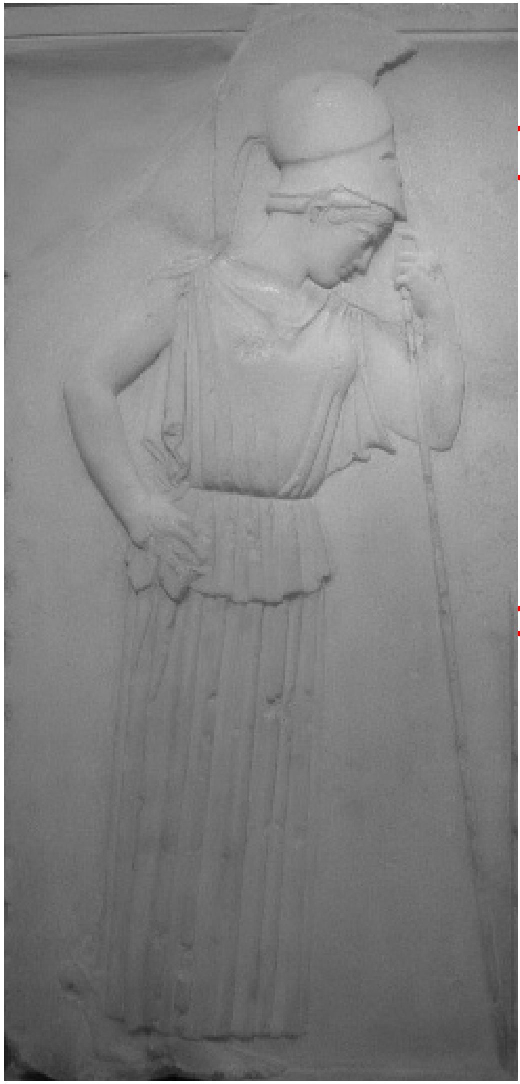



OBS:
- Bright band exists.
- High $\beta_{532}$ above convective cores.
- Overlap regions of C1 and C2 mask exist.

NICAM:
- Bright band exists.
- Low cloud top for C1, but high for C2.
- Few overlap regions of C1 and C2 mask exist.

# The Athena Project

## COLA, ECMWF, JAMSTEC, University of Tokyo, NICS, Cray



## List of experiments

NICAM 7km
dt=30sec

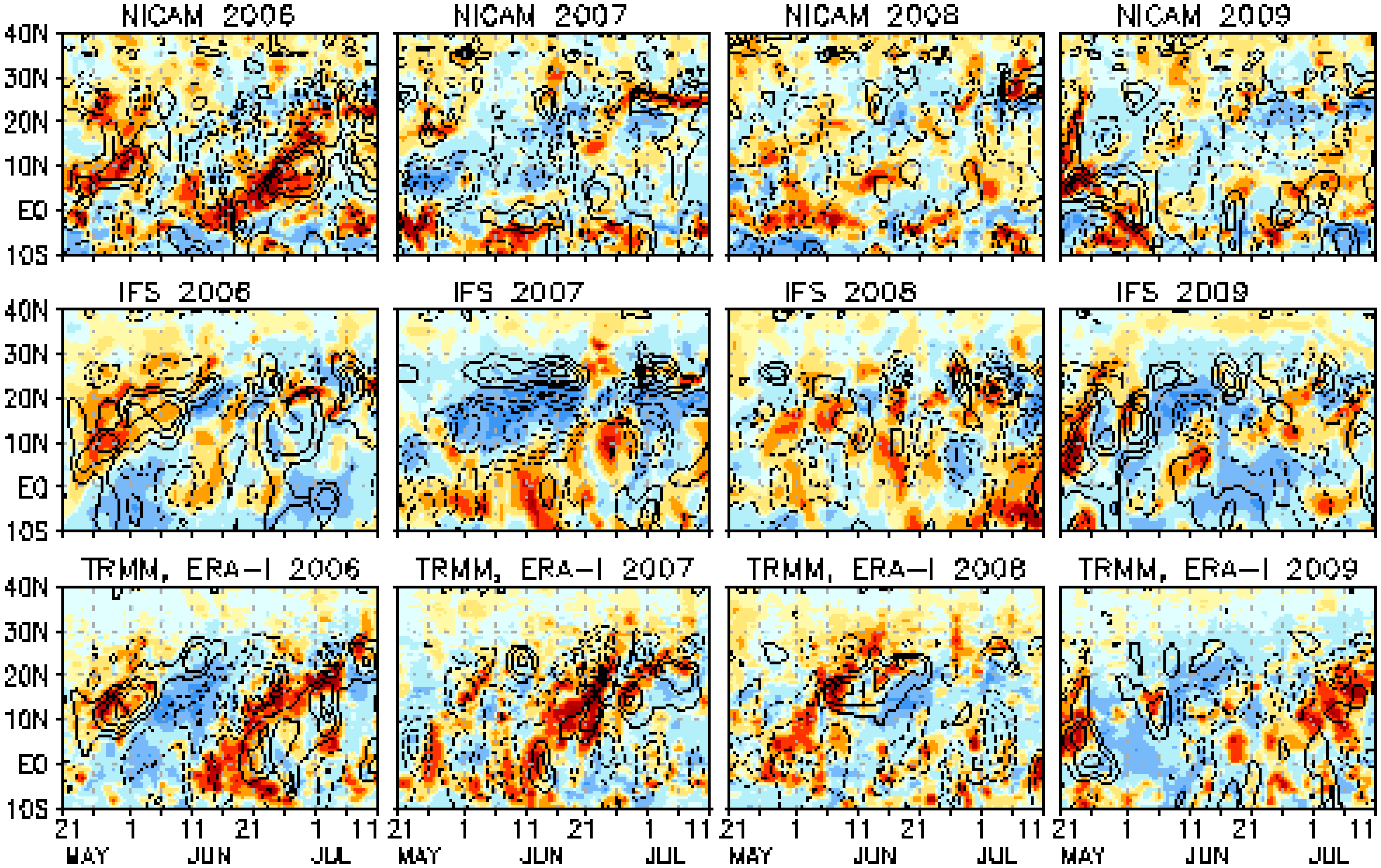
| Model/Exp. | Resolution | # Cases | Period | Notes |
|---|---|---|---|---|
| NICAM / Hindcasts | 7 km | 8 | 103 days | 21 May - 30 Aug 2001 - 2009 |
| | | | | |
| IFS / Hindcasts | 125 km<br>39 km<br>16 km | 48 | 395 days | 1 Nov - 30 Nov (following year) 1960 - 2007 |
| IFS / Hindcasts | 10 km | 20 | | 1 Nov - 30 Nov (following year) 1989 - 2007 |
| IFS / Hindcasts | 125 km<br>39 km<br>16 km<br>10 km | 9 | 103 days | 21 May - 30 Aug 2001 - 2009 NICAM analogs |
| IFS / Summer Ensembles | 39 km<br>16 km | 6 | 132 days | 21 [illegible] su[illegible] |
| IFS / Winter Ensembles | 39 km<br>16 km | 6 | 151 days | 1 [illegible] subsequent year) |
| IFS / AMIP | 39 km<br>16 km | 1 | 47 years | 1961 - 2007 |
| IFS / Time Slice | 39 km<br>16 km | 1 | 47 years | 2071 - 2117 |

IFS 10km
dt=450sec

http://wxmaps.org/athena/home/

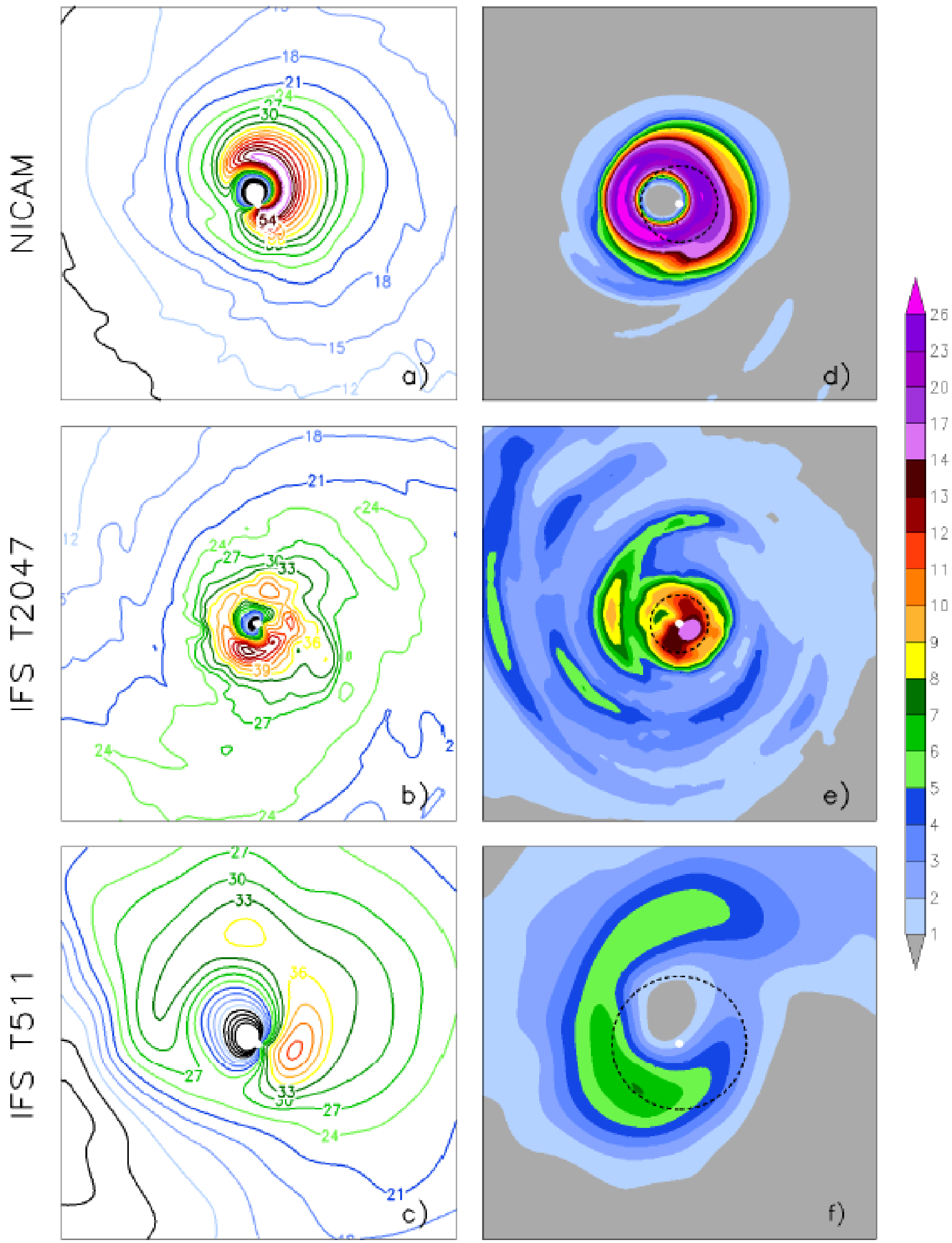
Kinter et al.(2011,submitted)

# Northward propagation of ISV in the Indian ocean




Time-latitude sections of anomalous 60-90E average surface precipitation (color) and zonal wind at 850 hPa (contour lines in the initial 52 days of NICAM (top) and IFS (middle) simulations in comparison with TRMM–3B42 and ERA–Interim data (bottom). The anomalies from the 8-year average (Fig. 2) are plotted. Contour intervals for zonal wind are 2 m $s^{-1}$(solid: positive, broken: negative). Zero contour lines are omitted.

# Most intensive Tropical cyclone structure



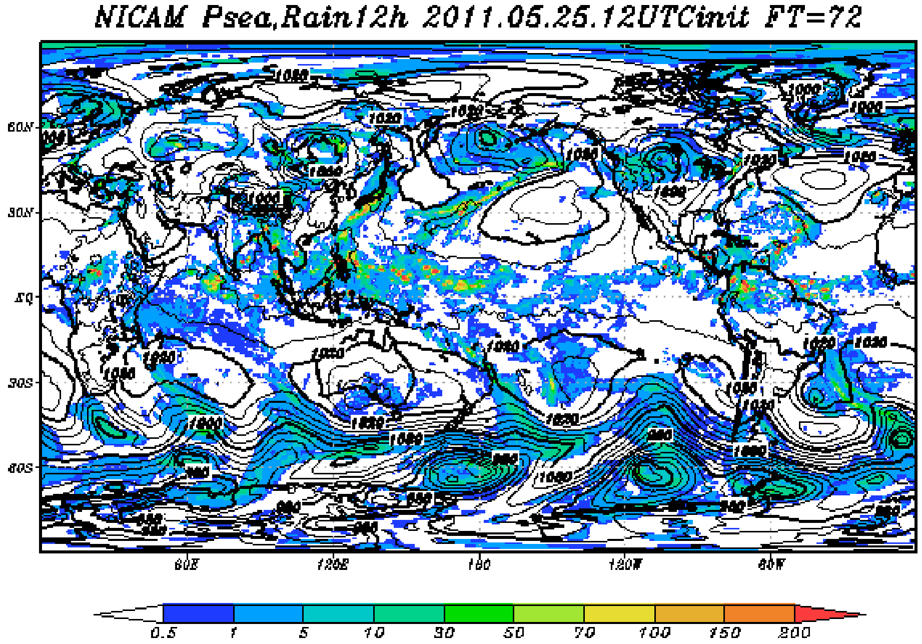

Distributions of 10m tangential wind (left panels; m s^-1) and total column liquid water and ice (TCLWI; right panels; kg m^-2) for the most intense TCs at the peak of their intensity from the NICAM simulation (panels a and d, labeled "NICAM"), the IFS 10--km simulation (panels b and e, labeled "T2047"), the IFS 39km simulation (panels c and f, labeled "T159"), respectively. Radius is 2°Contour interval is 3 m s^1 for wind Dashed black contours in panels d, e and f show the radius of maximum winds for each case with respect to the center of the storm determined from the location of maximum vorticity at 925 hPa (1000 hPa for the IFS cases).

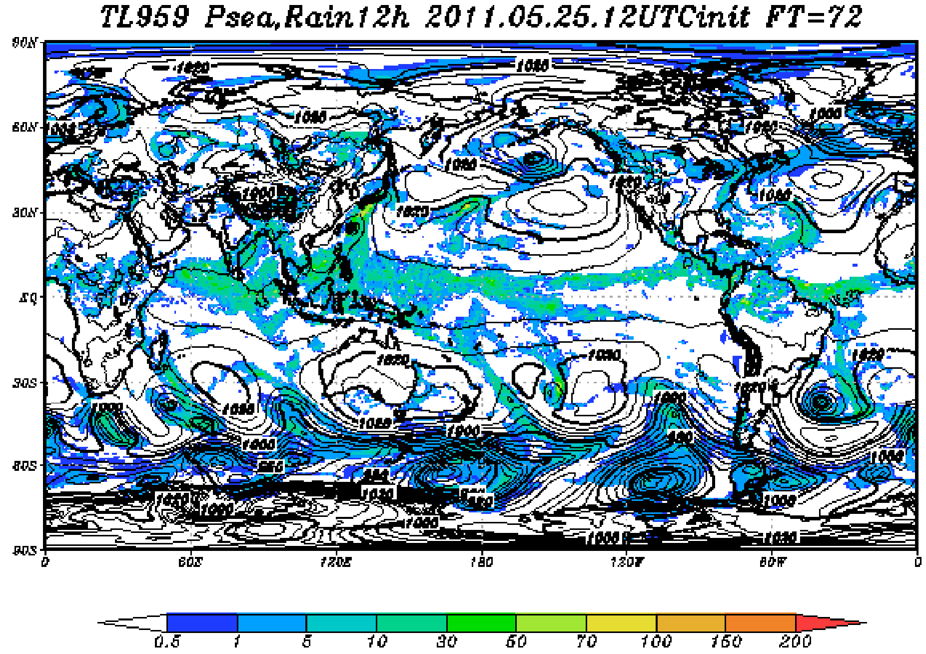
Kinter et al.(2011)

# Collaboration with JMA

- JMA's operational model is GSM, Global Spectral Model.
- Evolution of New Dynamics will be required for JMA's next-generation operational non-hydrostatic global model.
- Spectral model, grid-point model (Yin-Yang) and NICAM will be investigated at JMA.
- Comparison of NICAM and GSM is now conducted under collaboration with JMA.

# Testing NICAM and comparison with JMA-GSM



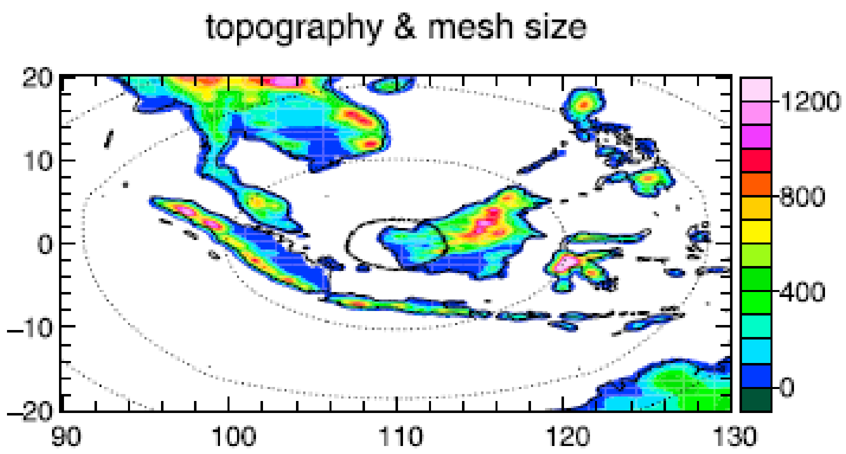



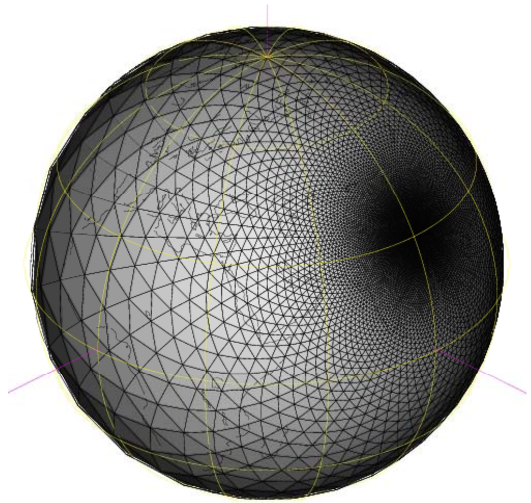

- NICAM dx=28km
  - SR11000 10nodes
    - 150min for 72h forecast
    - Time step 150sec

- JMA-GSM dx=20km
  - SR11000 60 nodes
    - 25min for 84h forecast
    - Time step 10min

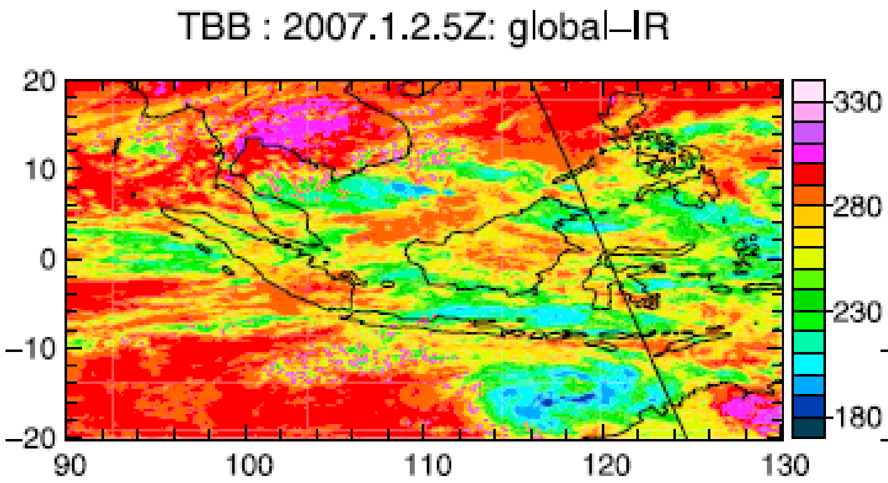
# Sisters of NICAM: stretch-NICAM

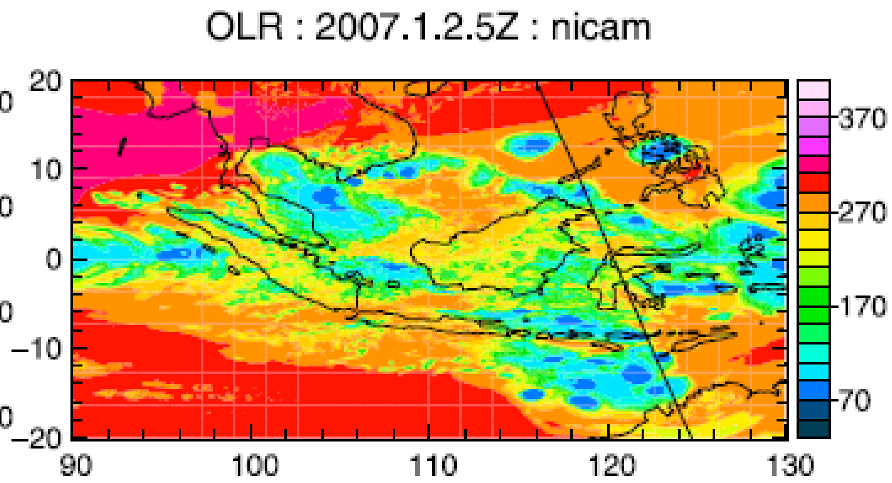
(Tomita 2008; Satoh et al. 2008, J. Geophys.Res.)



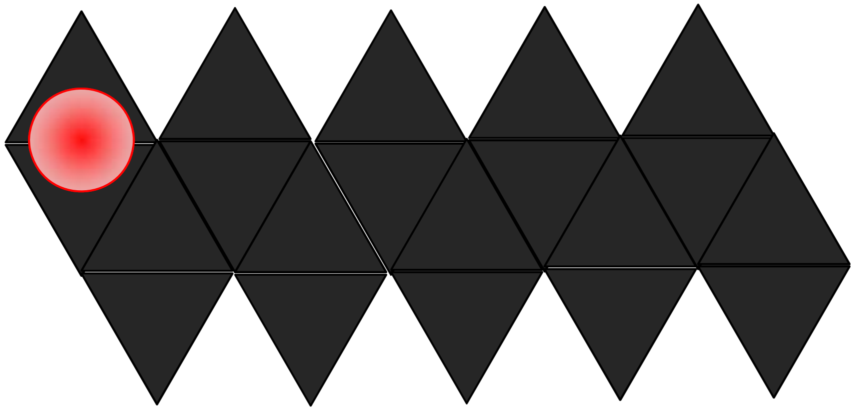



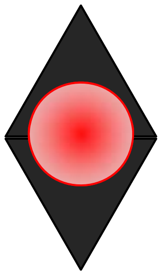
Use of the stretched grid system

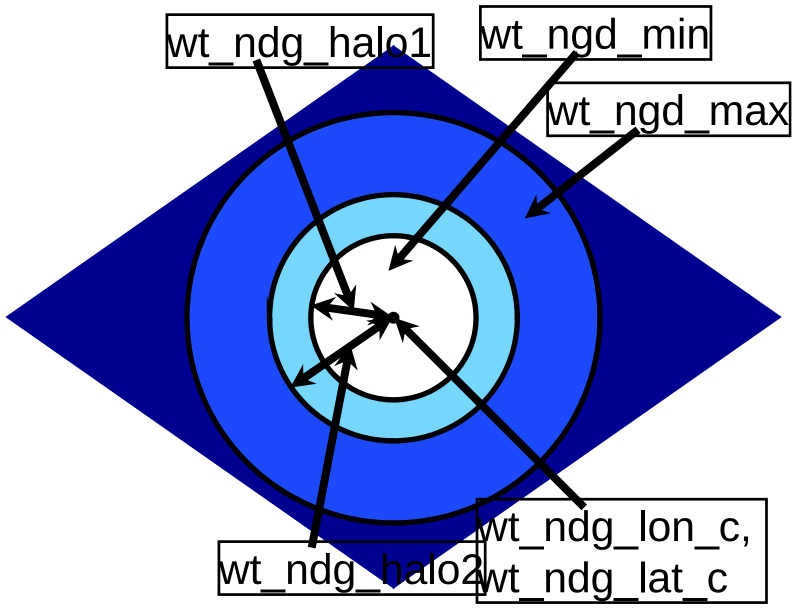


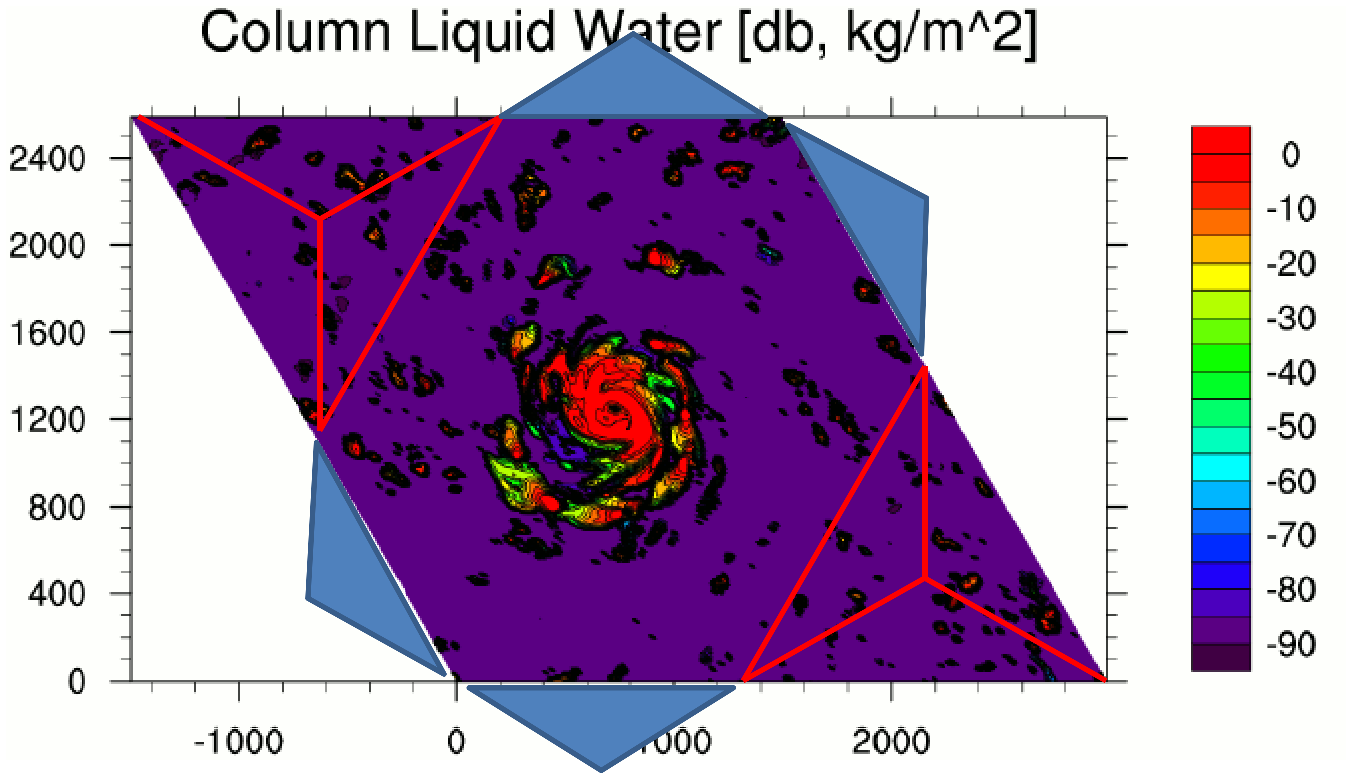
# Regional NICAM







# Plane-NICAM: double periodic model for LES



# Japan models application package

- Target Models
  - Climate models/Earth system models
    - MIROC: AORI/Univ. of Tokyo, JAMSTEC, NIES
    - MRI-GCM: MRI
  - Operational models
    - JMA-GSM: JMA
  - Global nonhydrostatic models
    - NICAM: AORI/Univ. of Tokyo, JAMSTEC, RIKEN/AICS
- Application package
  - Coupler: J-coupler, J-shell
  - Physics libraries

# Plan

## MIROC Atmosphere

- Climate
- Spectral, Grid (tracers)

## NICAM

- “Cloud-resolving”
- Geodesic, A-grid

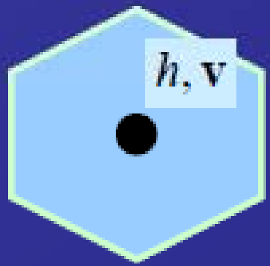
A PetaFlops machine in Kobe, Japan

## Common atmos. core

- Climate/“Cloud-resolving”
- Geodesic, ZM-grid/A-grid(/Z-grid)

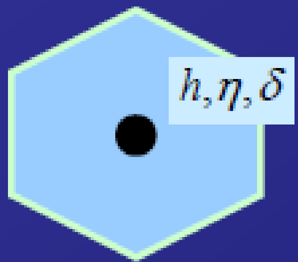
# Horizontal discretization

A



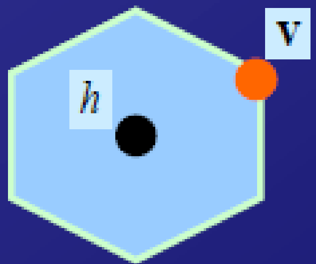

NICAM
- Geodesic
- A-grid
  - Tomita et al. (2001)
  - 2nd-order centered advection
  - piecewise linear method for tracers (Miura 2007)

Z




Common atmos. core (shallow water model at present)
- Geodesic
- ZM-grid(/Z-grid)
  - several changes from Ringler and Randall (2002)
  - 2nd-order upwind-biased advection for momentum
  - 3rd-order upwind-biased advection for mass
  - piecewise parabolic method for tracers

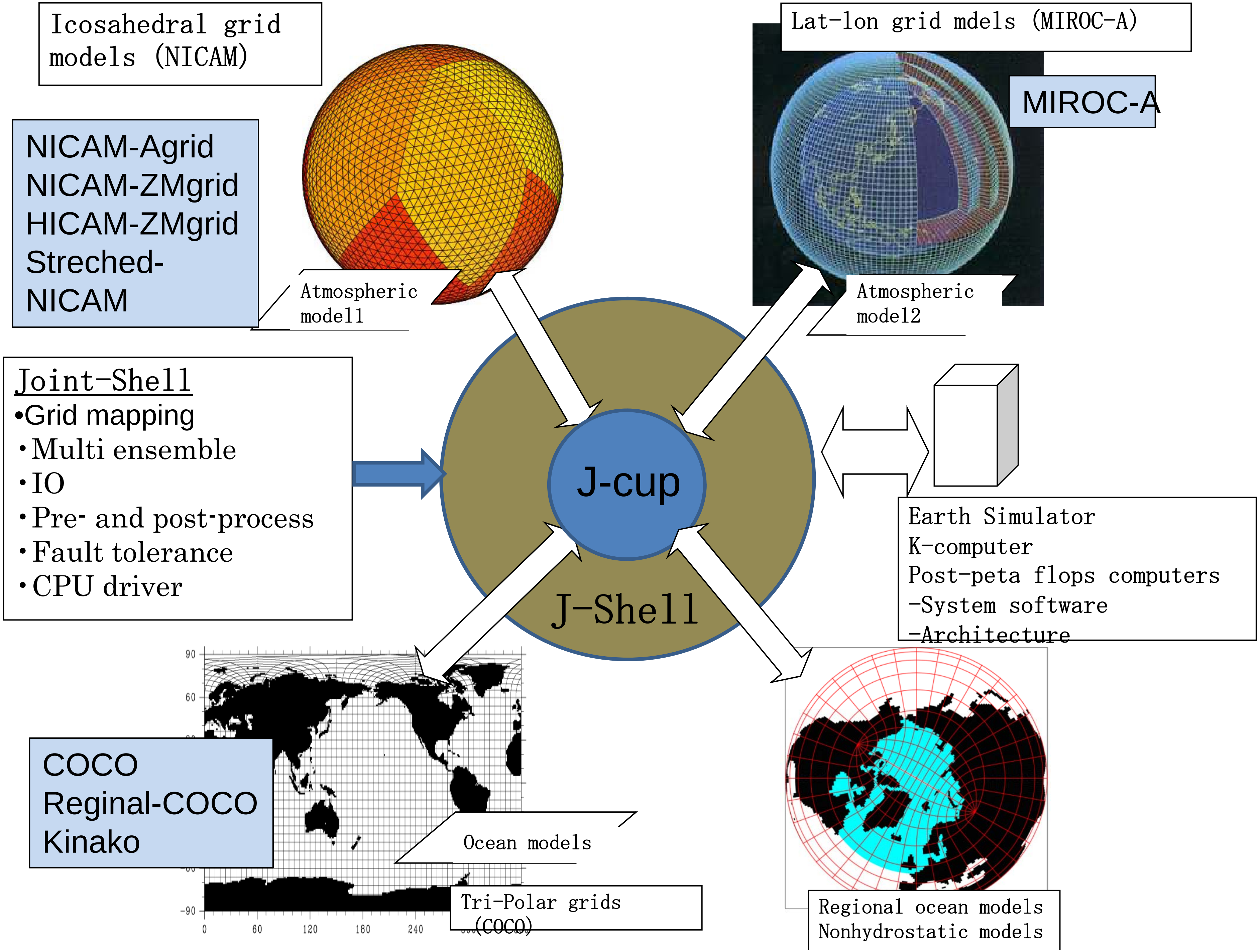
ZM




Courtesy of H. Miura (AORI)

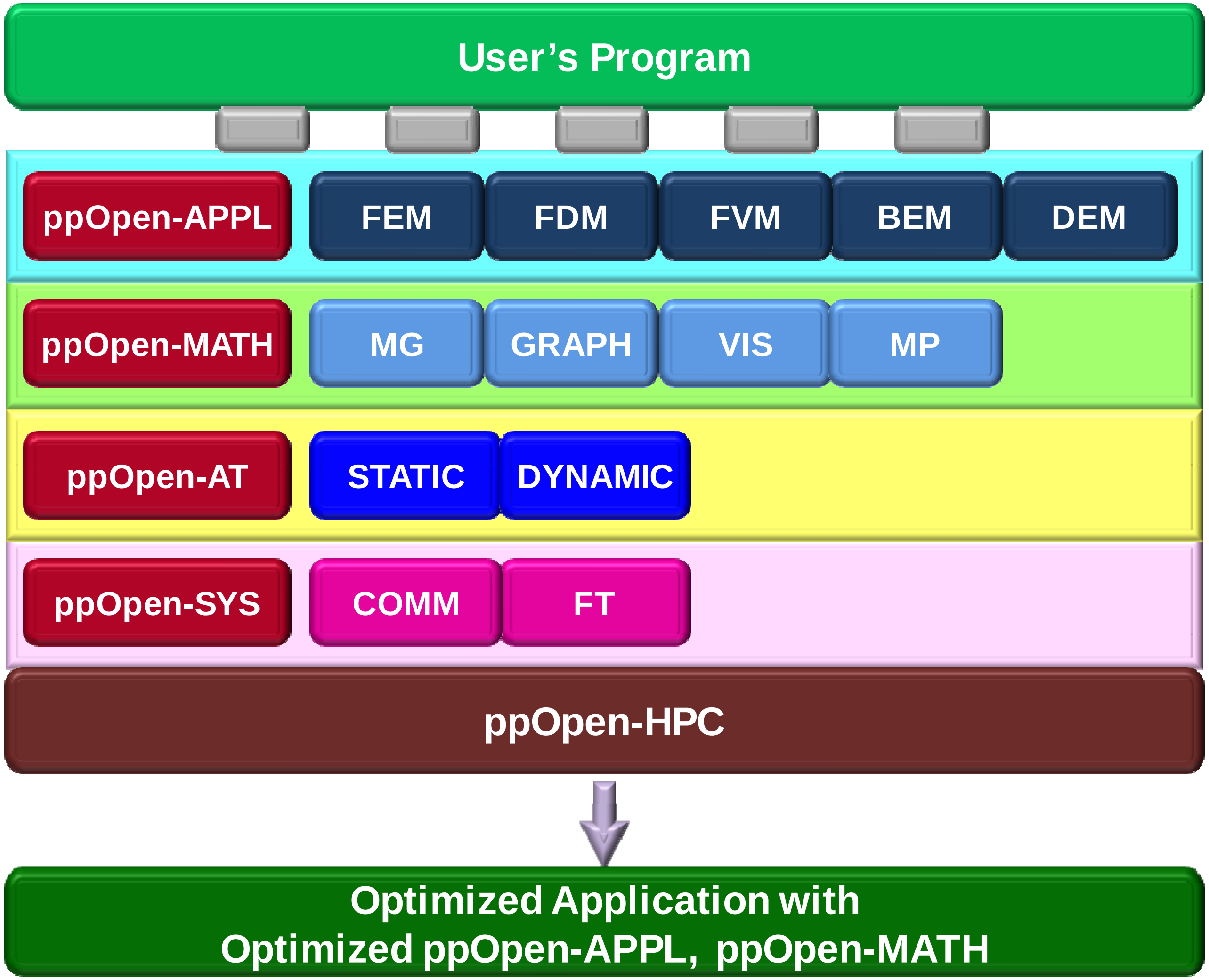
# Grid staggering issues

- A-grid vs C-grid or others
  - A-grid: NICAM, NIM
  - C-grid: ICON, MPAS
  - Z-grid, ZM-grid, others
- Issues
  - Geostrophic flows
  - Divergent flows
  - Energy spectrum
  - Convergence
  - Numerical diffusions
- Personal view
  - Moist models will not converge until resolution becomes O(10m).
  - If we stay around O(1km), differences of grids are tuning or parameterization of cloud and turbulence schemes.
  - Differences between grids are resolvable scales. A vs C ~ 2: 1



Icosahedral grid models (NICAM)
NICAM-Agrid
NICAM-ZMgrid
HICAM-ZMgrid
Streched-NICAM
Atmospheric model1
Lat-lon grid mdels (MIROC-A)
MIROC-A
Atmospheric model2
Joint-Shell
•Grid mapping
・Multi ensemble
・IO
・Pre- and post-process
・Fault tolerance
・CPU driver
J-cup
J-Shell
Earth Simulator
K-computer
Post-peta flops computers
-System software
-Architecture
COCO
Reginal-COCO
Kinako
Ocean models
Tri-Polar grids (COCO)
Regional ocean models
Nonhydrostatic models

## ppOpen-HPC: Open Source Infrastructure for Development and Execution of Large-Scale Scientific Applications on Post-Peta-Scale Supercomputers with Automatic Tuning (AT)




http://www.jst.go.jp/kisoken/crest/en/areah22/2-03.html

# Summary

- NICAM : 10 years history and beyond
- Good points of global nonhydrostatic models
  - Multiscale structure of cloud system
  - MJO, tropical cyclones
  - Cloud properties with cloud microphysics
  - KAKUSHIN & K-computer projects
- Physics
  - Use of satellite observations for evaluations
  - Sisters of NICAM(strech, regional, plane) are used for improvement of physics
  - Unified approach to global and regional models
- Japan models application package

Journal of the
Meteorological Society of Japan

(社)日本気象学会

気象集誌


# Journal of the Meteorological Society of Japan (JMSJ)

JMSJ is an international English journal of the Meteorological Society of Japan. JMSJ publishes original research articles relating to meteorology. The articles are selected carefully by a thorough paper review based on the latest scientific knowledge.

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