NICAM: A global cloud-resolving model

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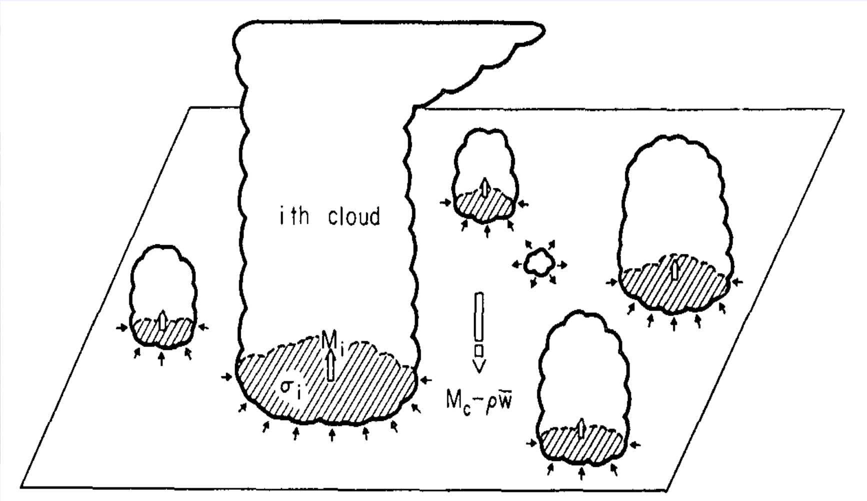
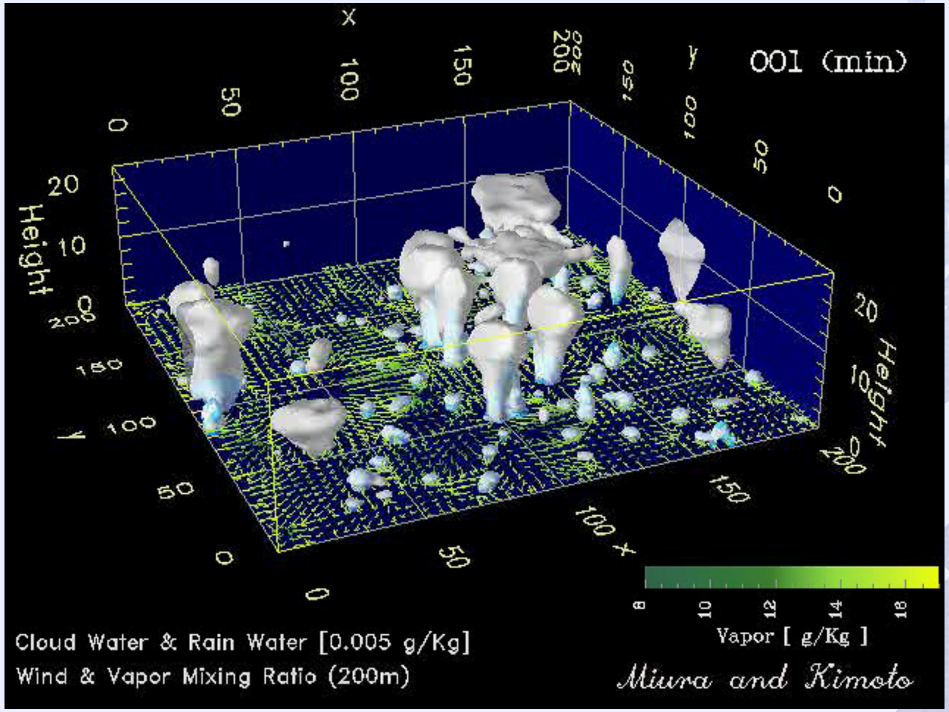
Cloud parameterizations



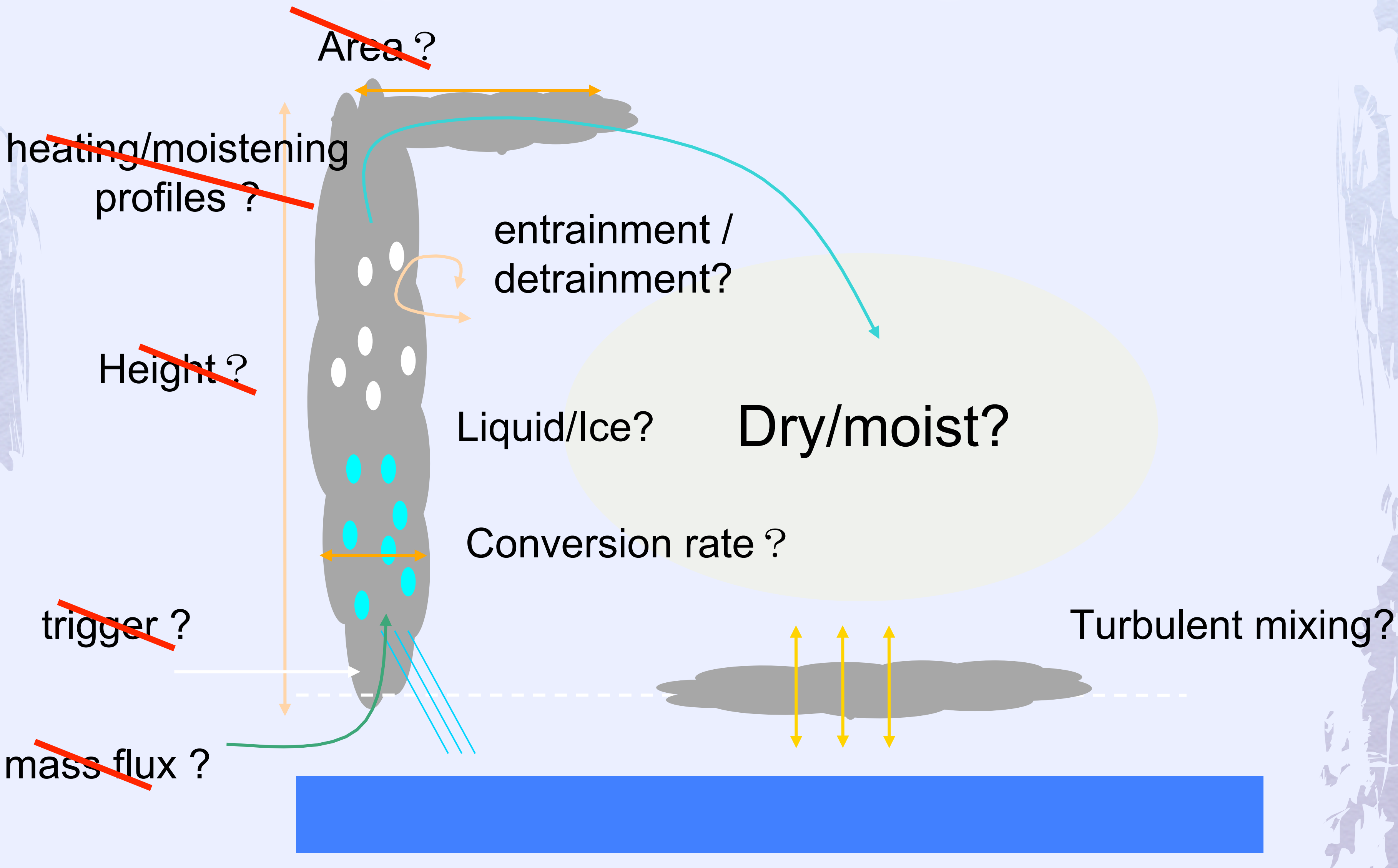
Arakawa and Schubert (1974)



Cloud parameterizations are valuable to test our understandings about the nature of clouds.

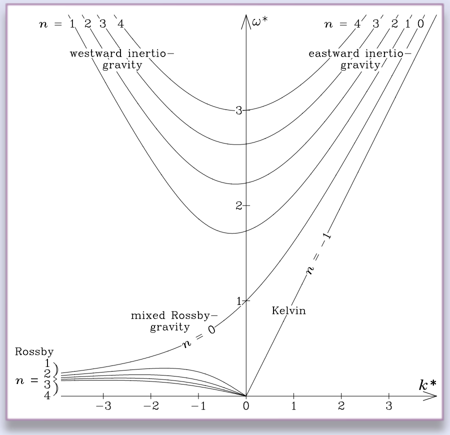
Cloud parameterization deadlock (Randall et al. 2003)

Cloud(-system)-resolving models



Matsuno's dream

(NIES Web site)



Matsuno (1966)
(Fig. 2 of Kiladis et al. 2009)

Spontaneous behavior of clouds

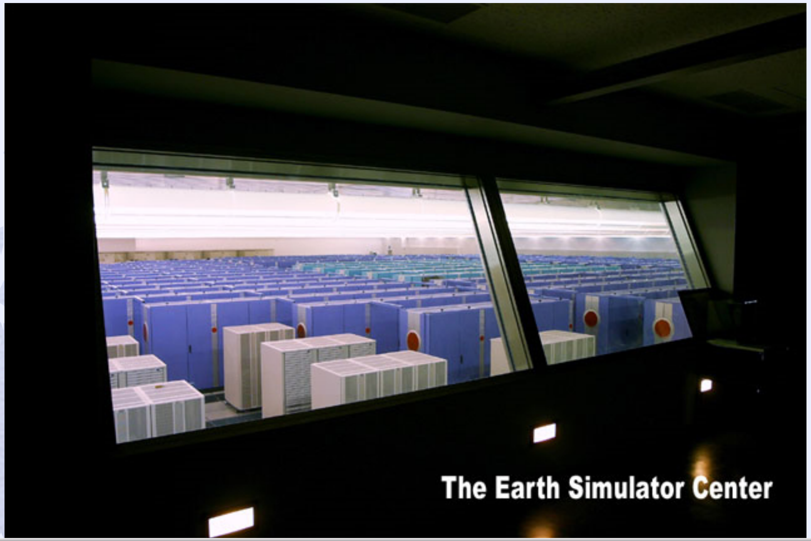
- Global circulation model
- dx < 10 km
- no cumulus parameterization

M. Satoh (U. Tokyo)

More than 90%(*) of NICAM dynamical core was coded by him.
*in my point of view

H. Tomita (AICS, Riken, Kobe)

The Earth-Simulator



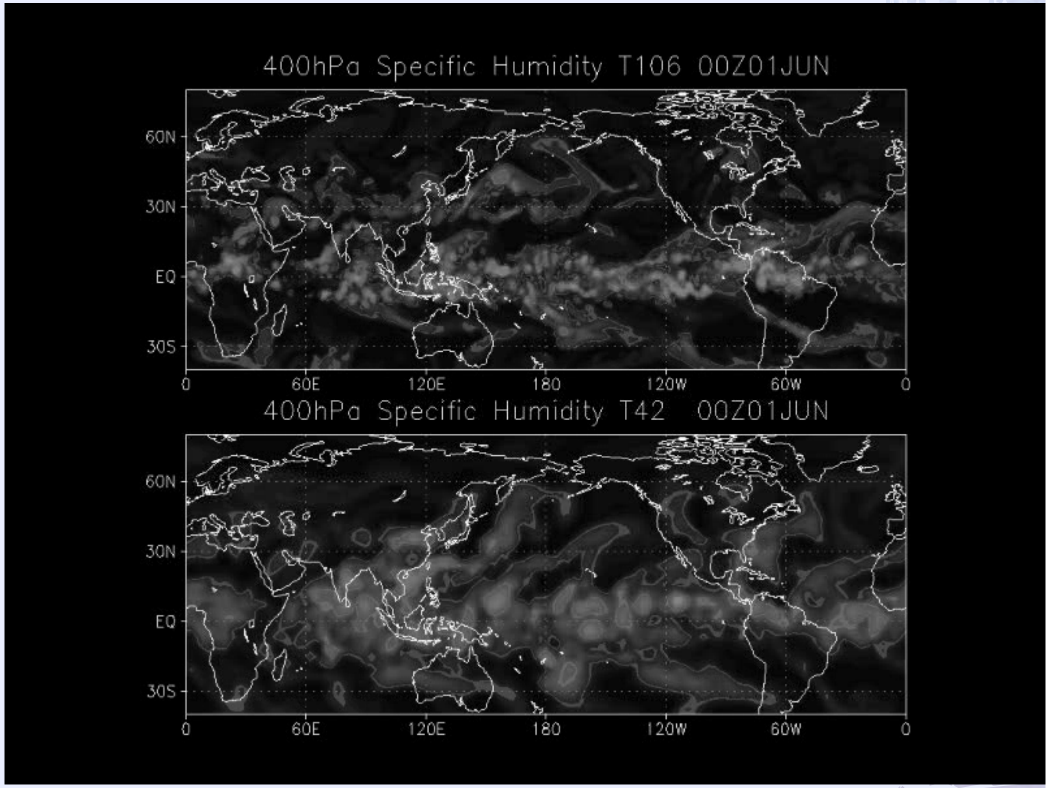
TOP500 List for November 2002

R_{max} and R_{peak} values are in GFlops. For more details about other fields, please click on the button "Explanation of the Fields"

DETAILS EXPLANATION OF THE FIELDS

Rank	Manufacturer Computer/Procs	R_{max} R_{peak}	Installation Site Country/Year
1	**NEC** Earth-Simulator/ 5120	**35860.00** 40960.00	Earth Simulator Center Japan/2002
2	**Hewlett-Packard** ASCI Q - AlphaServer SC ES45/1.25 GHz/ 4096	**7727.00** 10240.00	Los Alamos National Laboratory USA/2002
3	**Hewlett-Packard** ASCI Q - AlphaServer SC ES45/1.25 GHz/ 4096	**7727.00** 10240.00	Los Alamos National Laboratory USA/2002
4	**IBM** ASCI White, SP Power3 375 MHz/ 8192	**7226.00** 12288.00	Lawrence Livermore National Laboratory USA/2000
5	**Linux NetworX** MCR Linux Cluster Xeon 2.4 GHz - Quadrics/ 2304	**5694.00** 11060.00	Lawrence Livermore National Laboratory USA/2002

dx~110 km MIROC model



dx~250 km

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Back to 2000~2002

- Spectral method would not be efficient.
  - High-resolution
  - Massive parallel machines
- Only one icosahedral grid model
  - Z-grid (Heikes and Randall 1995; Masuda and Ohnishi 1986)
- Poisson solver would not work.
- Arakawa C-grid on hexagons? (Nicovic et al. 2002)
- Discontinuous Galerkin?
- O(km) grid was “cloud-resolving”.

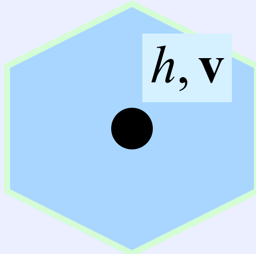
We know

- ECMWF spectral model is fast for ~T4000 on parallel machines.
- Multi-grid method is efficient for more than 80,000 cores (CSU).
- Thuburn et al. (2009) and Gassmann (2012)
- SE or DG is a choice.
- O(km) gird is not enough.

As simple as possible

Highest priority on computational efficiency

- Icosahedral grid (hexagonal/pentagonal cells)
- Arakawa A-grid arrangement
  - No Poisson solver
- Finite-volume method
- Minimum stencils
  - 2nd-order centered spatial discretizations



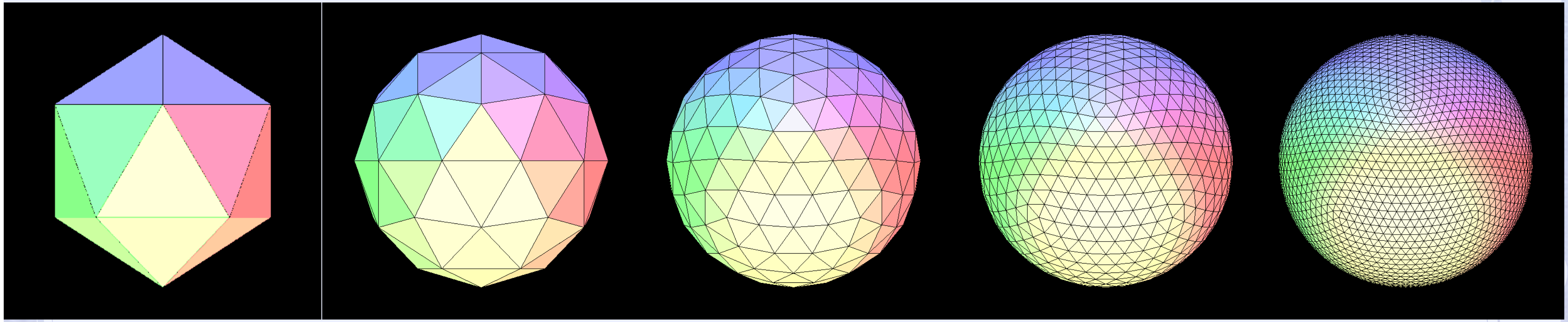
We learned much from JMA, CSU and NCAR.

- Icosahedral grid
- Terrain-following vertical coordinate
- Sound waves
  - Split-explicit and divergence damping
- and more

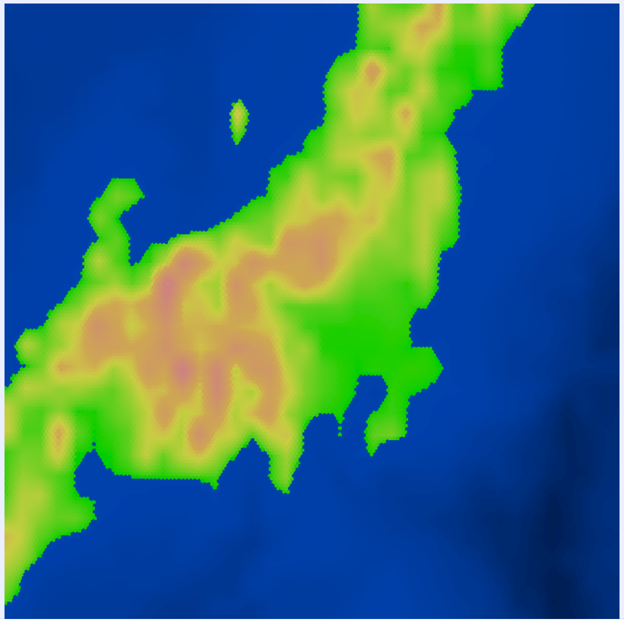
Icosahedral grid

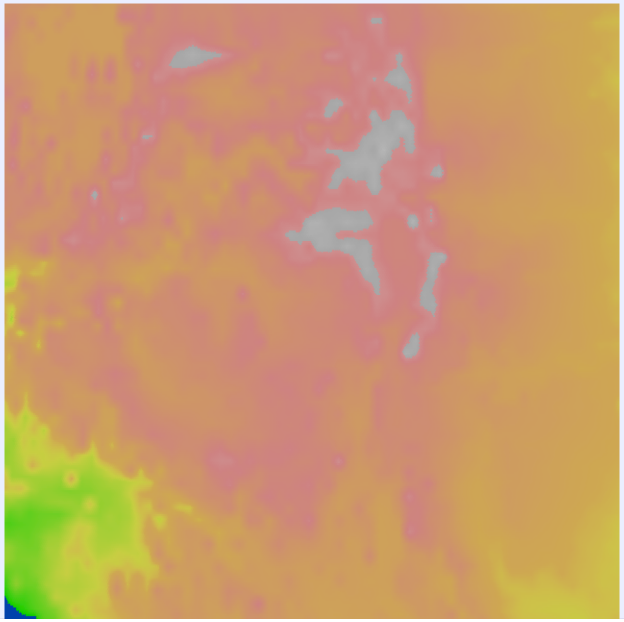
initi

partitioning



Hexagonal/pentagonal control volumes





dx~480 km

dx~240 km

dx~120 km

dx~60 km

dx~30 km

dx~15 km

dx~7.5 km

dx~3.75 km

Non-Voronoi mesh

Voronoi cell

Non-Voronoi cell

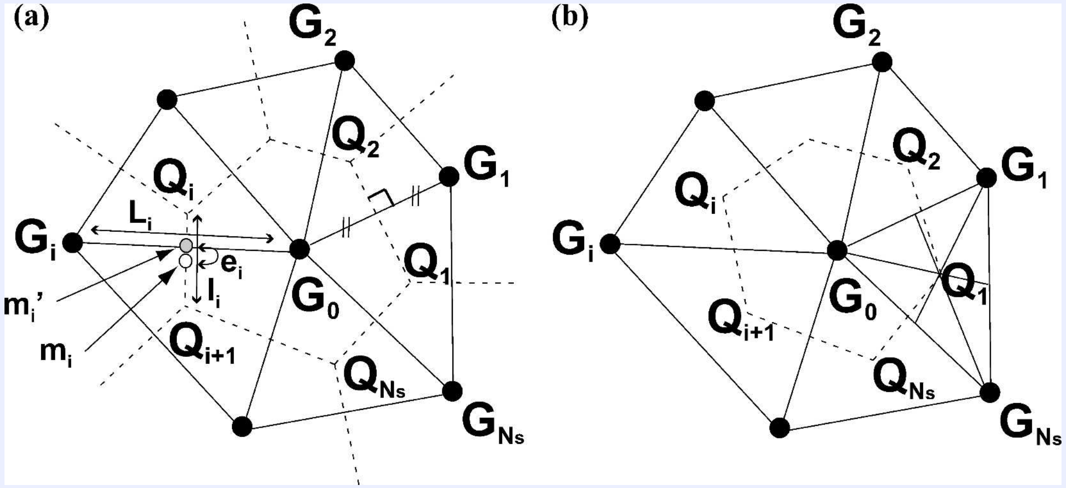


FIG. 2. Configurations of hexagonal cells: (a) Voronoi cell and (b) barycentric cell.

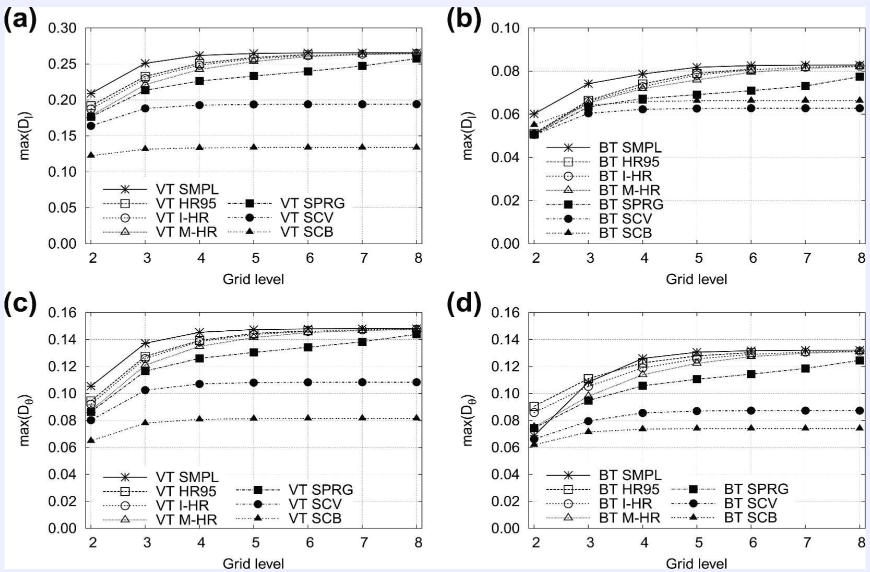


FIG. 8. Largest D_l on the (a) VT and (b) BT grid systems. Largest D_θ on the (c) VT and (d) BT grid systems.

Miura and Kimoto (2005)

Strong point

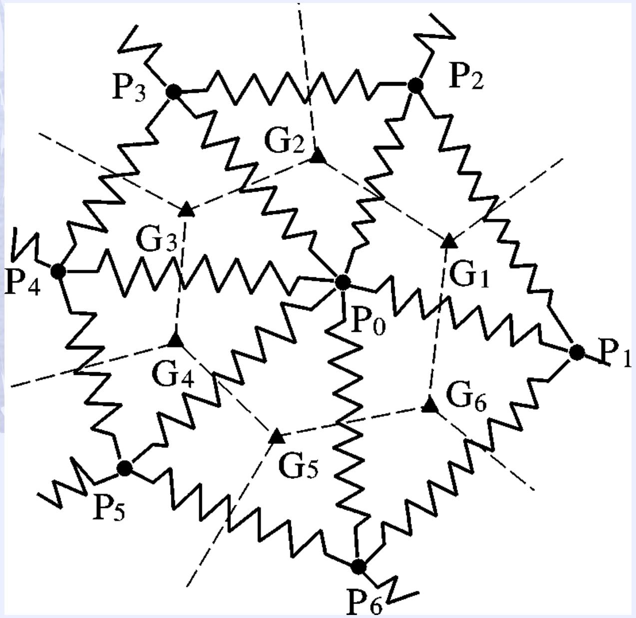
- More regular hexagons

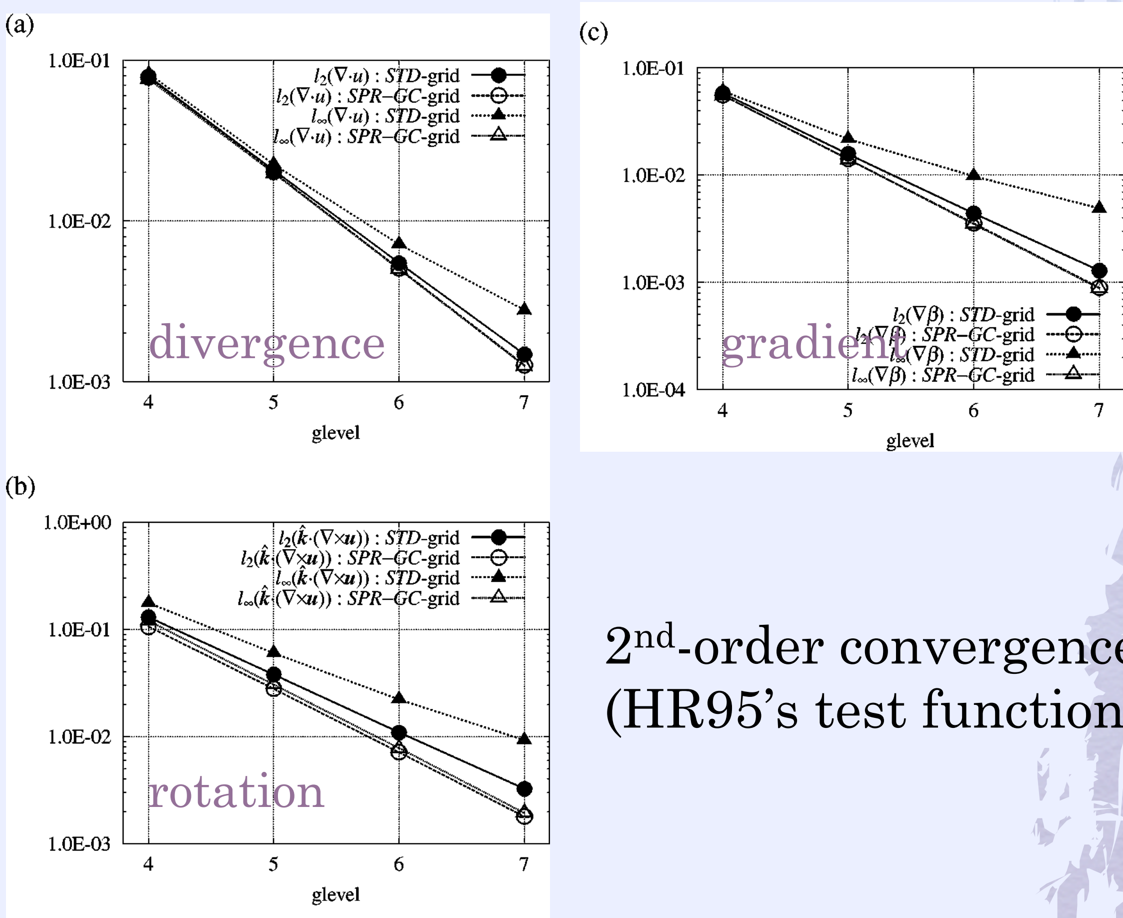
Weak point

- Orthogonality is lost.

Spring-dynamics

Tomita et al. (2001,2002)





2nd-order convergence
(HR95's test function)

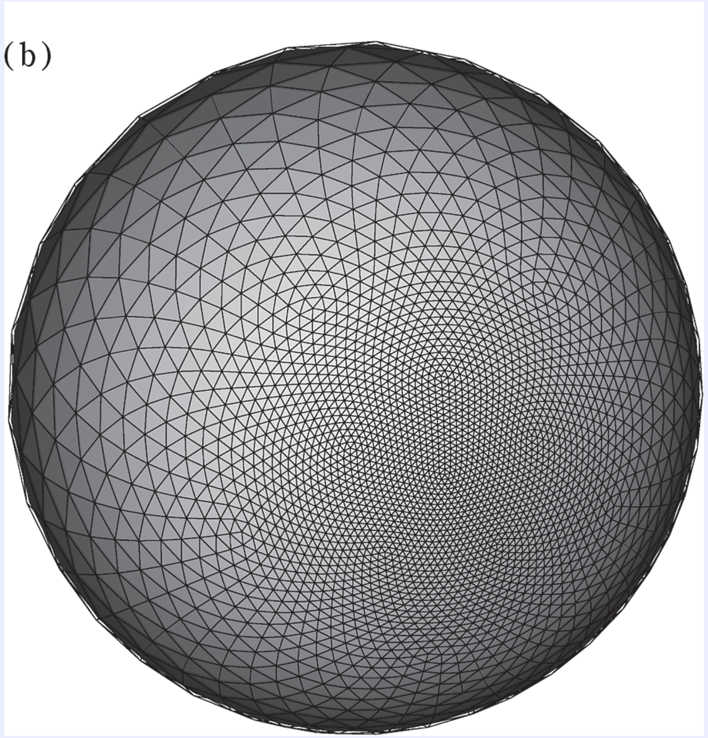
Dynamics

- Tomita et al. (2001)
  - Horizontal discretization
  - 2D shallow water tests
- Tomita et al. (2002)
  - Spring-dynamics
- Satoh (2002,2003)
  - Prognostic equations
- Tomita and Satoh (2004)
  - 3D dynamical core
- Miura (2007)
  - Tracer transport

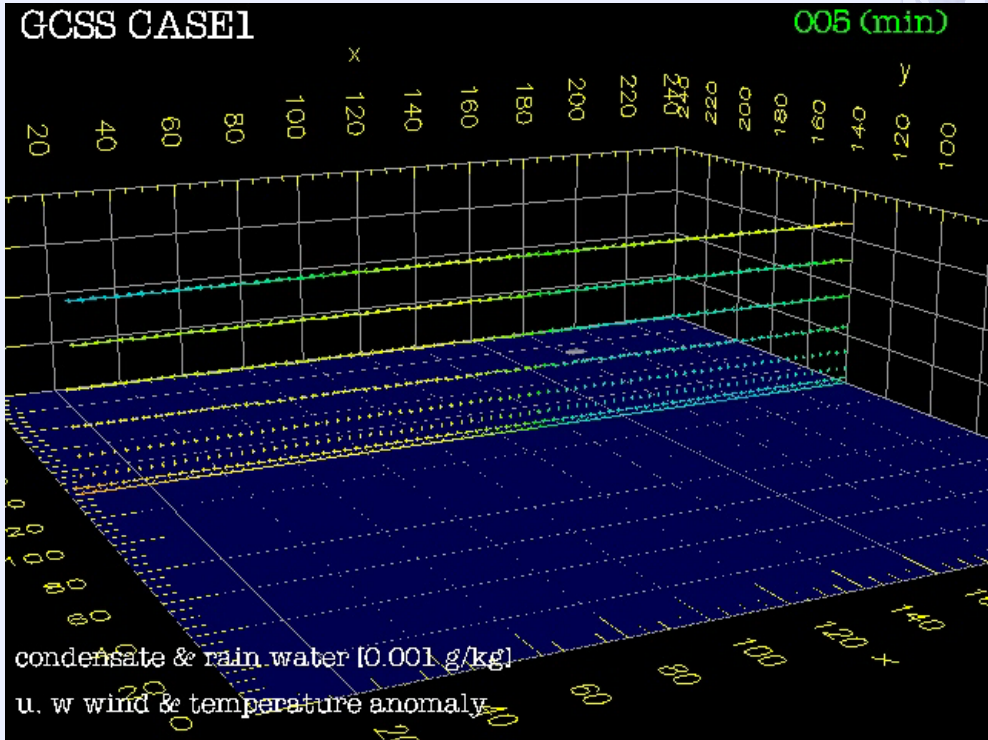
Physics

Most of the physics schemes were ported from MIROC model.
Cloud microphysics: Grabowski (1998)

Tomita (2008)

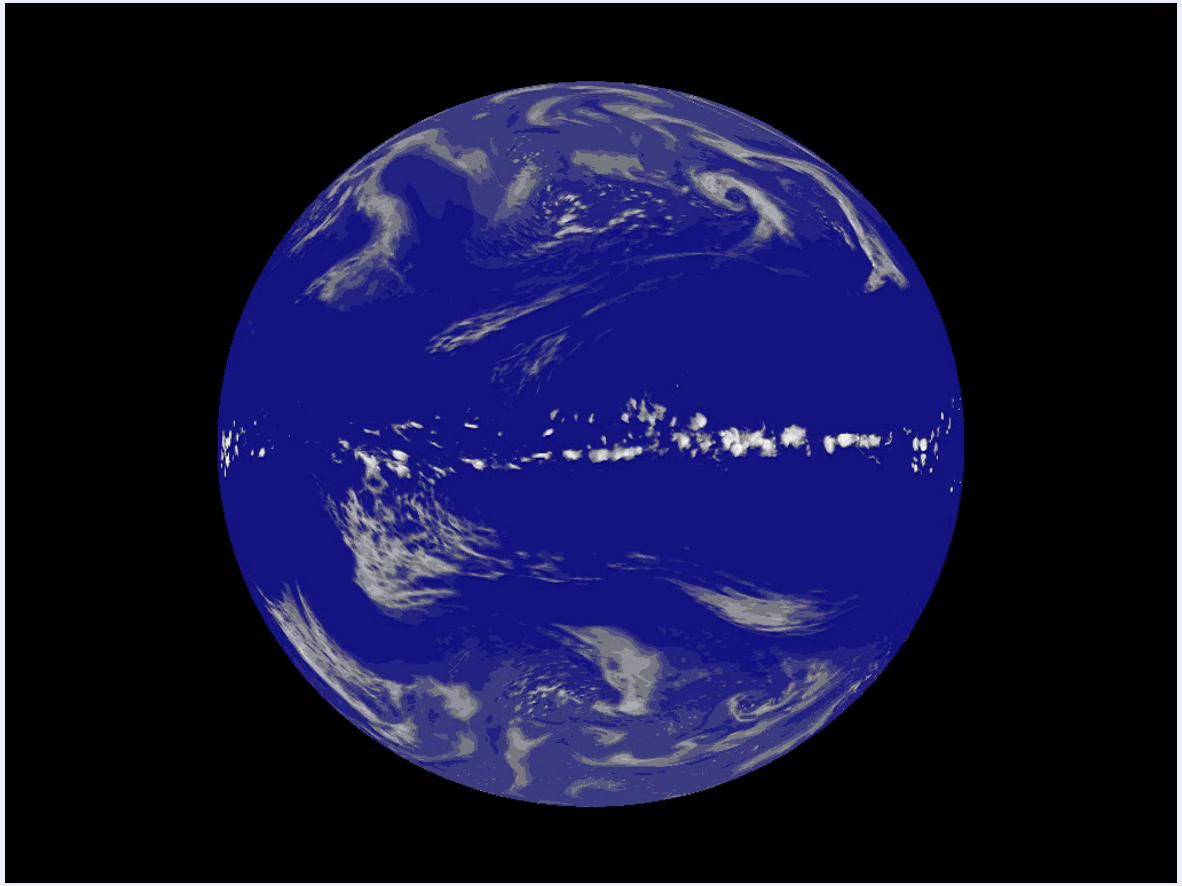


GCSS case-1: squall line



Aquaplanet

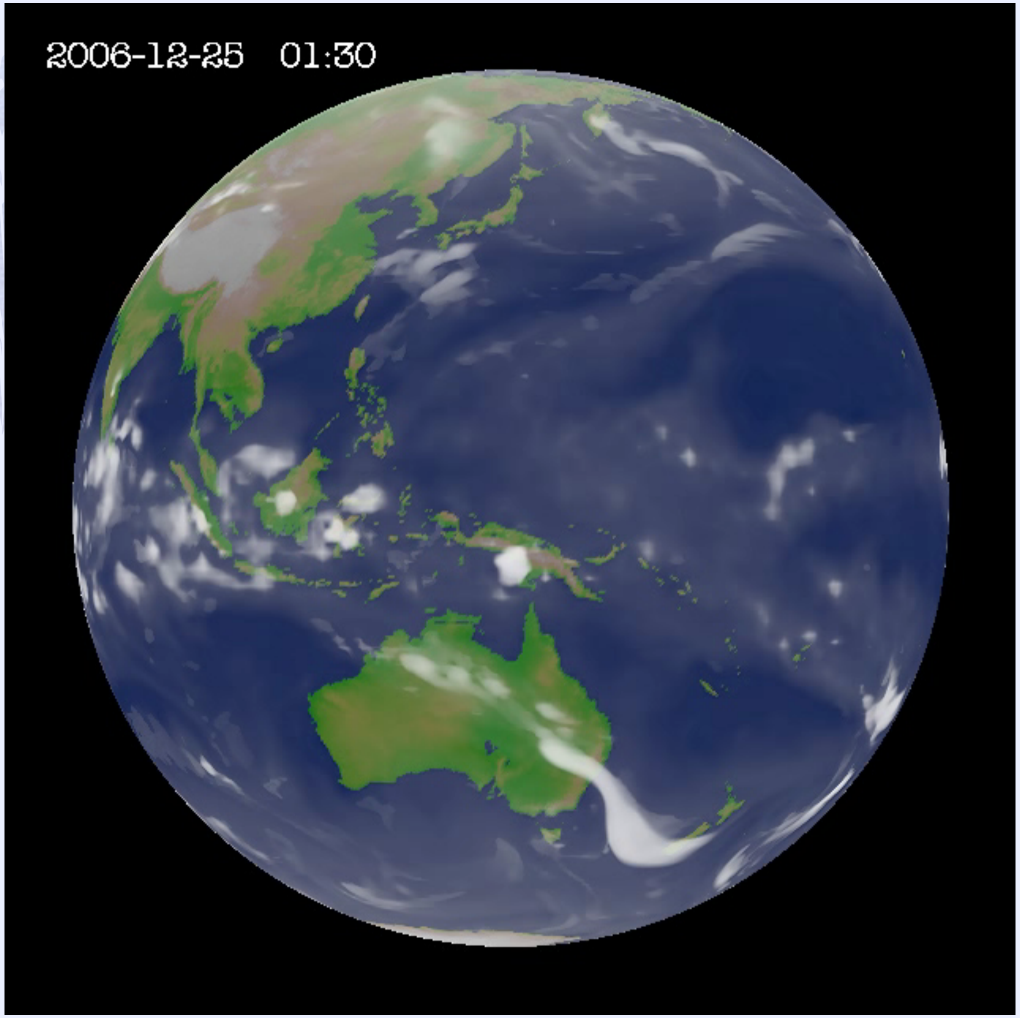
Tomita et al. (2005)



CRM framework can simulate spontaneous organization of clouds if it is used over the globe.

MJO

Miura et al. (2007)



Cloud systems in GCRMs possibly have some reality.

What's next?

K-computer (AICS, Riken, Kobe)

TOP500 List - June 2012 (1-100)

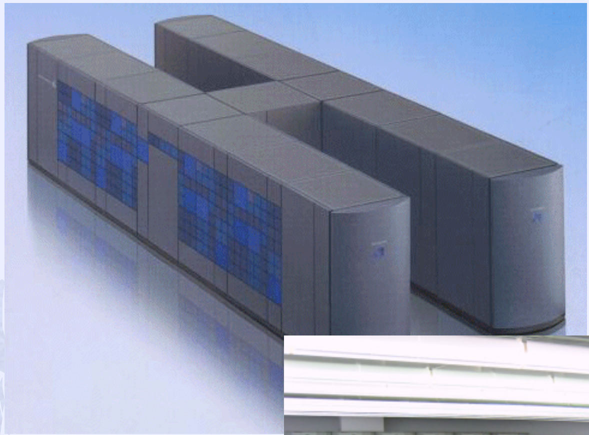
R$_{max}$ and **R**$_{peak}$ values are in TFlops. For more details about other fields, check the TOP500 description.

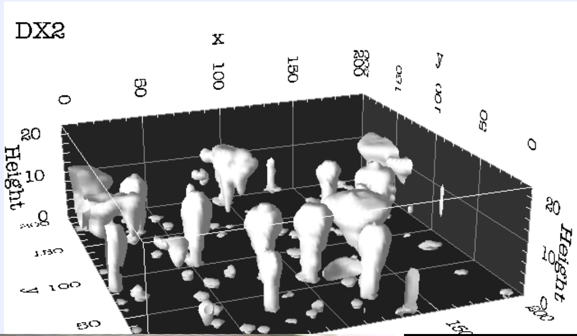
Power data in KW for entire system

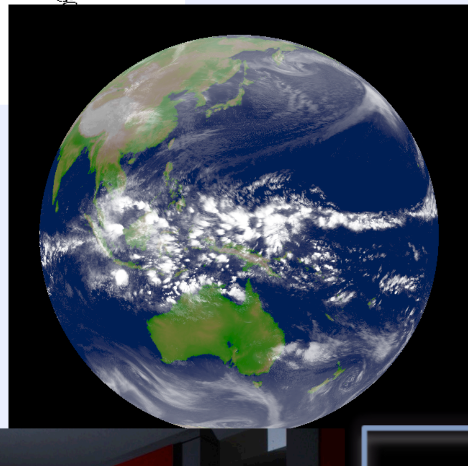
next

Rank	Site	Computer/Year Vendor	Cores	R_{max}	R_{peak}	Power
1	DOE/NNSA/LLNL United States	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom / 2011 IBM	1572864	16324.75	20132.66	7890.0
2	RIKEN Advanced Institute for Computational Science (AICS) Japan	K computer, SPARC64 VIIIfx 2.0GHz, Tofu interconnect / 2011 Fujitsu	705024	10510.00	11280.38	12659.9

Priority use from 30 July, 2012
Formal operation from September, 2012




DX2
x
Height
Height

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K computer
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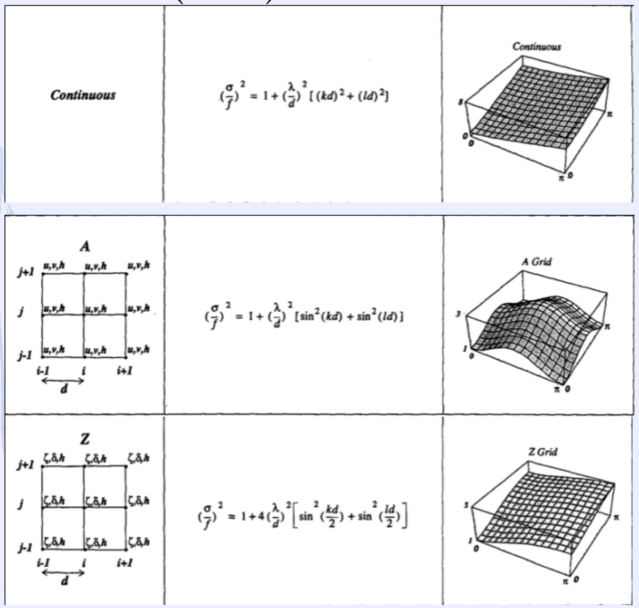
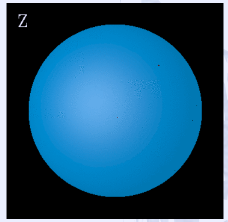
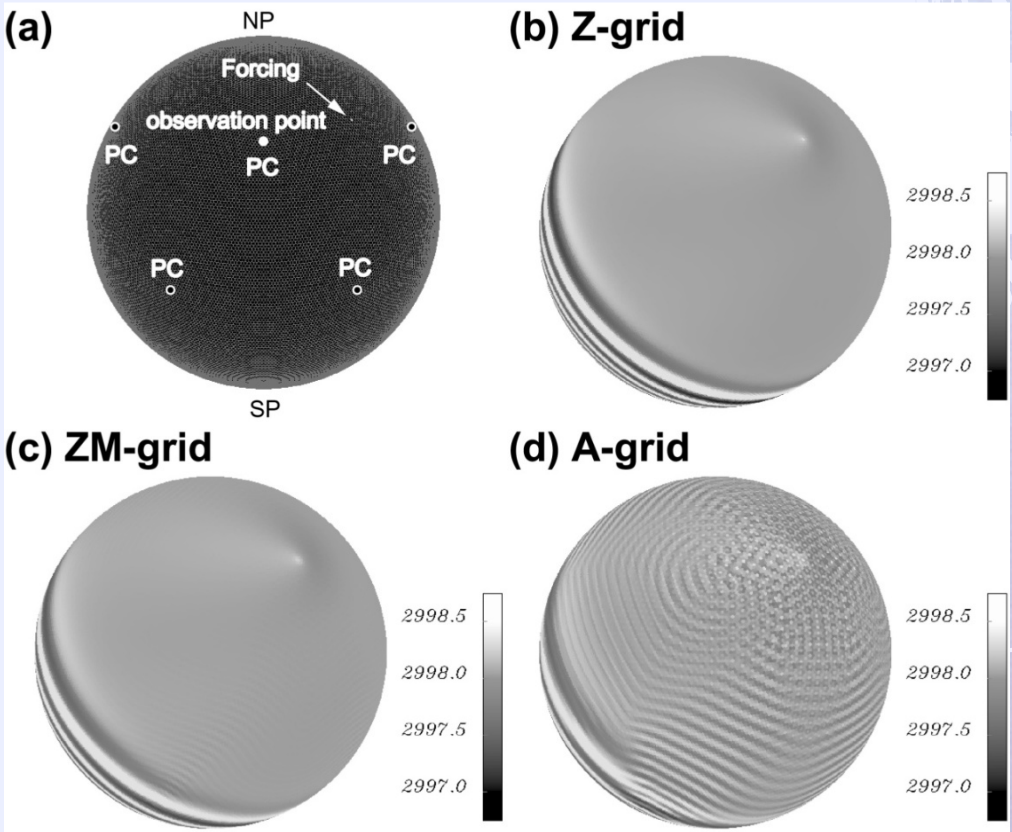
Future updates

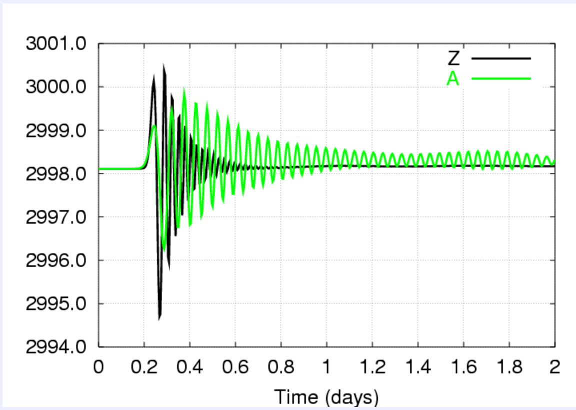
Randall (1994)



Geostrophic adjustment of SWMs
(response to a 1-grid forcing)



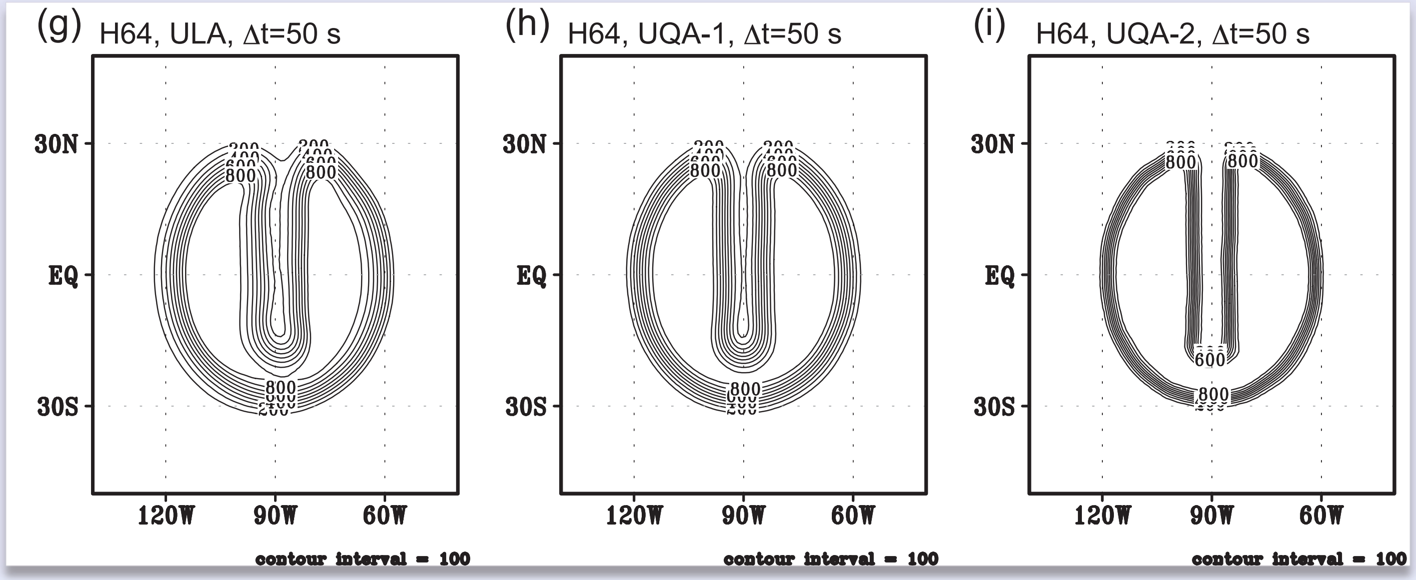




Miura (2004)

Future updates

Slotted-cylinder advection test (Lipscomb and Ringler 2005)



Miura (2007)

Skamarock and Menchaca (2010)

Miura and Skamarock (MWR, in revision)

Thank you!