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
Contents

• NICAM
• 3.5km mesh NICAM simulation
  – Tropical cyclone and synoptic scale waves
  – Cloud properties and evaluation
• Athena Project
• NICAM-JMA collaboration
• Japan models application package
NICAM: Nonhydrostatic Icosahedal Atmospheric Model

• Development since 2000

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

• Toward higher resolution global simulation
  $dx=1.7$km, 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 Icosahedral 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

Area distribution of cell: before and after
Nonhydrostatic scheme

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

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

\[
\frac{\partial}{\partial t} W + \frac{\partial}{\partial \xi} \left( \frac{\mathbf{P}}{G^{1/2}} \right) + Rg = \text{ADV}_z + \mathbf{F}_{z,\text{Coriolis}}
\]

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

Prognostic variables
- density
- horizontal momentum
- vertical momentum
- total energy

Metrics
- \( R = G^{1/2} \rho \)
- \( \mathbf{V}_h = G^{1/2} \rho \mathbf{v}_h \)
- \( W = G^{1/2} \rho w \)
- \( E_{\text{total}} = \rho G^{1/2} (e_{\text{in}} + k + \Phi) \)

- \( G^{1/2} = \left( \frac{\partial z}{\partial \xi} \right)_{x,y} \)
- \( \mathbf{G}^3 = (\nabla_h \xi) \)
- \( \xi = \frac{H(z - z_s)}{H - z_s} \)

## Model description

### Dynamics

<table>
<thead>
<tr>
<th>Governing equations</th>
<th>Fully compressible non-hydrostatic system</th>
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<td>Spatial discretization</td>
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<td>Horizontal grid configuration</td>
<td>Finite Volume Method (Tomita et al. 2001,2002)</td>
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<td>Vertical grid configuration</td>
<td>Icosahedral grid</td>
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<td>Topography</td>
<td>Lorenz grid</td>
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<td>Conservation</td>
<td>Terrain-following coordinate</td>
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<td>Temporal scheme</td>
<td>Slow mode - explicit scheme (RK2, RK3)</td>
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<td>Fast mode - Horizontal Explicit Vertical Implicit scheme</td>
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<td>Advection scheme</td>
<td>Conservative and monotonic</td>
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<td></td>
<td>Miura (2004), Niwa et al.(2011)</td>
</tr>
</tbody>
</table>

### Physics

<table>
<thead>
<tr>
<th>Turbulence, surface flux</th>
<th>MYNN(Nakanishi and Niino 2004; Mellor &amp; Yamada 2,2.5,3)/Louis(1979), Uno et al.(1995), Moon et al. (2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td>MSTRNXX (Sekiguchi and Nakajima, 2005)</td>
</tr>
<tr>
<td>Cloud physics</td>
<td>Kessler; Grabowski(1998); Lin et al.(1983); NSW6(Tomita 2008);NDW6(Seiki et al. 2011);WSM3-6 (Hong et al. 2004)</td>
</tr>
<tr>
<td>Subgrid convection</td>
<td>Prognostic AS, Kuo, Chikira (Chikira and Sugiyama 2010), Tiedtke (1989)</td>
</tr>
<tr>
<td></td>
<td>Miscellaneous: MATSIRO (Takeda et al. 2010)</td>
</tr>
</tbody>
</table>
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)

Time series of Wind profile

(a) GENESIS STAGE

(b) INTENSIFICATION STAGE

Middle-level vortex

Low-level vortex
Fengshen track is better simulated by 3.5 km NICAM than 14 km NICAM and JMA-GMS.
Validation of cloud microphysical statistics simulated by a global cloud-resolving model with active satellite measurements

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(2011, to be submitted)

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⁴NASA Goddard Space Flight Center
⁵Japan 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

http://www22.atwiki.jp/j-simulator/  
Examples of simulated signals
Example 1: Tropical Cyclone

MTSAT IR $T_b$ (10.8 µm)

**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

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<tr>
<th>Model/Exp</th>
<th>Resolution</th>
<th>Nb Case</th>
<th>Period</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>NICAM / Hindcasts</td>
<td>7 km</td>
<td>8</td>
<td>103 days</td>
<td>21 May – 30 Aug 2001 - 2009</td>
</tr>
<tr>
<td>IFS / Hindcasts</td>
<td>125 km</td>
<td>48</td>
<td>395 days</td>
<td>1 Nov – 30 Nov (following year) 1969 - 2007</td>
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<tr>
<td></td>
<td>39 km</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>16 km</td>
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<td></td>
<td>10 km</td>
<td></td>
<td></td>
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<td>IFS / Hindcasts</td>
<td>125 km</td>
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<tr>
<td></td>
<td>10 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IFS / Summer</td>
<td>39 km</td>
<td>6</td>
<td>132 days</td>
<td>21 May – 30 Aug 2001 - 2009</td>
</tr>
<tr>
<td>Ensembles</td>
<td>16 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IFS / Winter</td>
<td>39 km</td>
<td>6</td>
<td>151 days</td>
<td>1 Nov – 30 Nov (following year) 1989 - 2007</td>
</tr>
<tr>
<td>Ensembles</td>
<td>16 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IFS / AMIP</td>
<td>39 km</td>
<td>1</td>
<td>47 years</td>
<td>1961 - 2007</td>
</tr>
<tr>
<td></td>
<td>16 km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IFS / Time Slew</td>
<td>39 km</td>
<td>1</td>
<td>47 years</td>
<td>2071 - 2117</td>
</tr>
<tr>
<td></td>
<td>16 km</td>
<td></td>
<td></td>
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</tbody>
</table>

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

wt_ndg_halo1
wt_ngd_min
wt_ngd_max
wt_ndg_halo2
wt_ndg_lon_c, wt_ndg_lat_c
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
MIROC Atmosphere
- Climate
- Spectral, Grid (tracers)

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

Common atmos. core
- Climate/“Cloud-resolving”
- Geodesic, ZM-grid/A-grid/Z-grid

A PetaFlops machine in Kobe, Japan
Horizontal discretization

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

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

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. $A \text{ vs } C \sim 2:1$
Icosahedral grid models (NICAM)

Lat-lon grid models (MIROC-A)

Nicam-Agrid
Nicam-ZMgrid
Hicam-ZMgrid
Stretched-Nicam

Atmospheric model 1
Atmospheric model 2

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
Regional-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
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.

The Meteorological Society of Japan was founded in 1882, for the wide information exchange of research, translation, introduction, and research plans relating to meteorology. The Society issued Series I of the Journal between 1882 and 1922. Since 1923 the society has been publishing Series II of the Journal.

JMSJ, Since 1882

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