Resolution dependence of deep convections in a global simulation from over 10-kilometer to sub-kilometer grid spacing

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Now, we can run such simulations of several decades with “K”, and make a breakthrough from the case study.

Earth Simulator

Athena Cray XT-4

Case study
(Miura et al 2007)

Several weeks and month
Athena Project: (Sato et al 2012)
Related Papers


A high-resolution global non-hydrostatic model has a potential to reveal multi-scale phenomena in the atmosphere if it is used as a climate mode.

NICAM: Clouds are explicitly calculated by cloud microphysics scheme.

Spatial scale

Weather

Diurnal cycle

Synoptic disturbance

Intraseasonal variability

Seasonal cycle

Interannual variability

Decadal variability

Trend

Climate

PDO, AMO

ENSO, IOD, NAO

MJO

Typhoons, Tropical Cyclones

Meso-scale phenomenon

Temporal scale
**Grand Challenge project:**

- **Low-pressure**
- **Cloud cluster**
- **stratus**
- **Blocking**
- **Tropical cyclone**
- **cumulus**

- GL08 (30km)  GL11 (3.5km)
- GL09 (14km)  GL12 (1.7km)
- GL10 (7km)   GL13 (800m)
Today’s talk

Toward super **high-resolution** global atmospheric simulation by the NICAM using the K-computer.


Introduction and purpose of this study

Convection

- Element of cloudy disturbances
- Transport heat and moisture
- Horizontal scale $\sim 10^0$ km

[Issue] how to solve in **global models**

$(Dx \sim 10^1 \sim 10^2$ km$)$

Cumulus parameterization

After 2000s ...

(1) Model development & (2) enhancement of computer power

$\Rightarrow$ $Dx \sim 10^0$ km (clouds are explicitly solved in global models)

$\Rightarrow$ Still coarser or comparable to obs.

Regional model (Weismann et al., 1997) : change around $\Delta x \leq 4$ km
What is the statistical features of deep convections in a global model and their resolution dependence?
Grid refinement Experiment by NICAM & K

<table>
<thead>
<tr>
<th>model</th>
<th>NICAM (Tomita and Satoh 2004, Satoh et al. 2008)</th>
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<tbody>
<tr>
<td>Initial state</td>
<td>3-day integrated results of 1-step coarser resolution</td>
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<tr>
<td>SST</td>
<td>JMA GPV+ nudging (Reynolds weekly SST)</td>
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<td>land</td>
<td>Model adjusted produced by 5 year run</td>
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<td>Cloud physics</td>
<td>NSW6 (Tomita 2008)</td>
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<td>Boundary layer turbulence</td>
<td>MYNN (Nakanishi and Niino 2004, Noda et al. 2008)</td>
</tr>
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<td>Surface flux</td>
<td>Louis (1979)</td>
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<td>Long and short-wave radiation</td>
<td>MSTRNX (Sekiguchi and Nakajima 2008)</td>
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<tr>
<td>Cumulus parameterization</td>
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<table>
<thead>
<tr>
<th>Experiments</th>
<th>horizontal mesh size (km)</th>
<th>initial time (UTC)</th>
<th>period</th>
<th>initial data</th>
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<tr>
<td>Δ14.0</td>
<td>14.0</td>
<td>2012082500</td>
<td>12 hours</td>
<td>Δ30.0</td>
</tr>
<tr>
<td>Δ7.0</td>
<td>7.0</td>
<td>2012082500</td>
<td>12 hours</td>
<td>Δ14.0</td>
</tr>
<tr>
<td>Δ3.5</td>
<td>3.5</td>
<td>2012082500</td>
<td>12 hours</td>
<td>Δ7.0</td>
</tr>
<tr>
<td>Δ1.7</td>
<td>1.7</td>
<td>2012082500</td>
<td>12 hours</td>
<td>Δ3.5</td>
</tr>
<tr>
<td>Δ0.8</td>
<td>0.8</td>
<td>2012082500</td>
<td>12 hours</td>
<td>Δ3.5</td>
</tr>
</tbody>
</table>

integration period (12 h)
Successfully conducted the GL13(870m) simulation
Comparison with the previous model resolution

GL13 (0.87km) with K computer

Each cumulus in the tropical cyclone are expressed in detail.

Previous model resolution (3.5km)
How to detect a convection core

a) ISCCP convective grids (●)
b) Find grids (●) at which all the surrounding 8 grids satisfy the ISCCP condition
c) Estimate horizontal gradient of vertical velocity averaged vertically in the troposphere
d) Convective grids (●) := where vertically averaged \( w \) is larger than those at surrounding 8 grids
Convection core grid

- Convection cores are reasonably detected around low OLR.
- High potential temperature deviations appear around strong w region.
- Convection features capture the observed structure qualitatively.
Essential change of convection statistics

- Convection is represented at 1 grid
- Little dependence on resolution

- Convection is represented at multiple grids
- Intensify w/ resolution

Figure 3: Radius-height cross-sections for composites of vertical velocity \( w \) for all detected convections in each simulation. The horizontal axis is the number of horizontal grids.
Essential change of convection statistics

The convection structure, number of convective cells, and distance to the nearest convective cell dramatically changed around 2.0km

Figure 4. Resolution dependencies of convective features: (a) number of convective features and (b) grid distance to the nearest convective feature. The thin dashed line in (Figure 4a) indicates a log $\Delta^4$ crossing at the point of $\Delta 14$ as a reference.
Is there difference in convection structure and intensity in cloud disturbances, such as MJO, TC, or Mid-latitude front?
How to detect cloud disturbances

Madden Julian Oscillation (MJO)
- Temporally filtered re-analysis data (Kikuchi et al. 2012)
- OLR > 10 W m^{-2}
- -20 < lat < 20
- 30 < lon < 240

Mid-latitude Low (MDL)
- Coarsened to 2.5 x 2.5 grid
- SLP – mean SLP surrounding 1000 km < - 10 hPa
- SLP < 1000 hPa
- 40 < lat < 70
- Region inside 1000 km radius

Tropical Cyclone (TC)
- SLP – mean SLP surrounding 3° < -1 hPa
- Vertically averaged MWS > 5 m s^{-1}
- Vertically averaged vertical relative vorticity | > 10^{-5} s^{-1}
- Region inside the 600 km radius

Front (FRT)
- Coarsened to 2.5 x 2.5 grid
- Thermal Front Parameter (TFP) > 10^{-10} K m^{-2}
- OLR < 200 W m^{-2}
- Longest oblique side of enclosed area satisfying the 2 conditions >= 10 deg
Convection structure in each disturbance

- **Globe**
  - Height: High
  - Max W: Strong

- **MJO**
  - Height: High
  - Max W: Weak

- **TC**
  - Height: High
  - Max W: Weak

- **MDL**
  - Height: Low
  - Max W: Strong

- **FRT**
  - Height: Low
  - Max W: Weak

Downward motion below cloud base.
Environmental field of convections

- **MJO**: Large CAPE
  - Weak convergence
- **TC**: Strong convergence
  - Small CAPE
- **MDL & FRT**: Strong vertical wind shear
  - Small CAPE
In what area does convection make the largest contribution to the global mean?

(What environmental condition is effective in producing the diversity of convection properties)
Resolution Dependence in the Global Field
Resolution Dependence in the Global Field

- OLR
- Precipitation
- Zonal wind
- Mass flux

Decreasing trend
1. Overall, OLR in Δ0.87 and Δ1.7 is higher than in other resolution experiments.
2. OLR in each simulation is consistent with observation, except for the area between 30S and 10S; OLR in the simulation is about 30 W m^−2 larger than observations in peak. This strongly affects the positive bias of the global mean OLR.
Area of each ISCCP cloud type over the globe

1. Cb decreased & CLR increased between Δ3.5 and Δ1.7
2. Ci also increased

[Mid-Latitude] the increase CLR [Tropics] canceled out between the increased CLR and Cir with Cb

3. The area of low cloud (e.g., Stratocumulus) gradually decreases with higher resolution, especially from Δ14 and Δ3.5.
1. Strong precipitation is shown in $\Delta 1.7$ (around 50mm h$^{-1}$) and $\Delta 0.87$ (more than 100mm h$^{-1}$).
2. The ratio of strong rainfall, which is in excess of 20 mm h$^{-1}$, is drastically increased from $\Delta 3.5$ to $\Delta 1.7$. 
Resolution Dependence on Convection Properties
Land and Ocean Difference

(a) OCEAN

(b) OCEAN

(c) OCEAN

(d) LAND

(e) LAND

(f) LAND

\[ \Delta (\text{km}) \]

\[ \text{frequency/total number} \]

\[ w \text{ (m s}^{-1}\text{)} \]

\[ z \text{ (km)} \]

\[ x \text{ (grid)} \]

\[ 1 \text{ (m s}^{-1}\text{)} \]
Latitudinal difference

(a) lat -70 -30  
(b) lat -15 +15  
(c) lat +15 +30  
(d) lat +30 +70

(e) lat -70 -30  
(f) lat -15 +15  
(g) lat +15 +30  
(h) lat +30 +70
Different Cloudy Disturbance

(a) Globe

(b) Other

(c) MJO

(d) TC

(e) MLD

(f) diff. from Globe
Summary I

- Global sub-kilometer simulation has conducted.
- Significant change of Convection features (structure, number, distance) significantly between the 3.5-km and 1.7-km resolutions ➔ less than 2-3km to resolve convection.
- Convection differences in various atmospheric cloudy disturbances (MJO, TC, MDL, and FRT) in terms of cloud top height, upward motion, precipitation.
- Global mean: Precipitation etc ... conserved in diff resolution. Ratio of the cloud type is different. Cb decrease, CLR increase, Low cloud decrease ...
- Diversity of convection properties: Tropics large resolution dependence, mid-high lat smaller. No significant diff between land and Ocean. Essential change around 1km in cloudy disturbances.
We found a difference in resolution dependency in the simulated convection property.

It is important that the convections, even in cloudy disturbances, show a convergent trend for the number and are resolved not by a single grid, but by multiple grids between $\Delta 1.7$ and $\Delta 0.87$, at least, despite the existence of the above difference.

[Future] Necessary of the examination of the interactions between convection and disturbances based on longer period datasets with a spatial resolution high enough to resolve it.