Resolution dependency of clouds and precipitation derived from 14-km- to sub-kilometer-mesh nonhydrostatic global simulations

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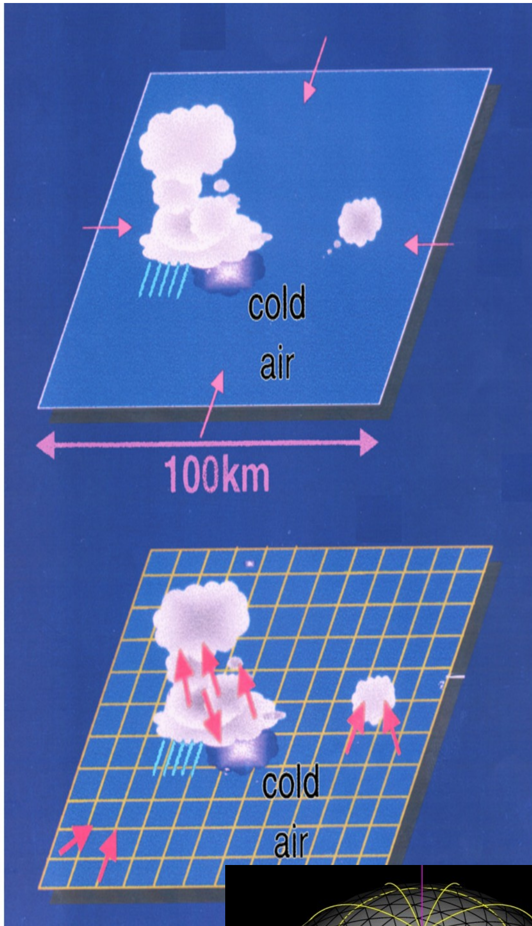
outline

- What's NICAM
- Resolution dependency of
  - Cloud cover
  - Precipitation
  - Isolated deep convection (tornadic supercell) (ARPS result)

Global Cloud Resolving Model (NICAM)

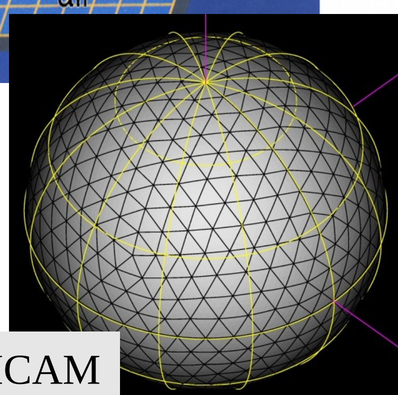


Conventional GCM □□□□□

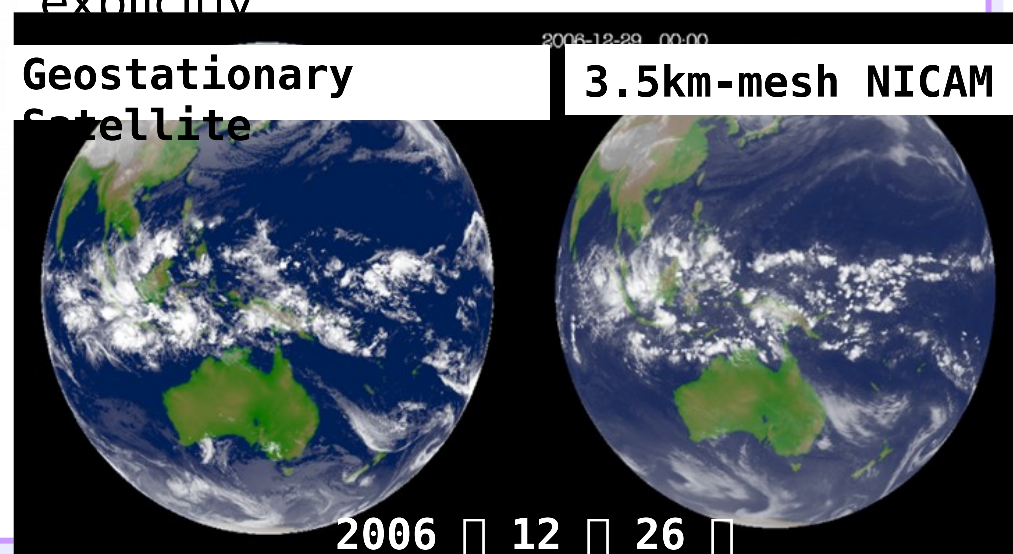
Clouds are parameterized from large-scale conditions

Cloud-Resolving GCM □

Clouds are computed from a microphysics scheme and dynamic and thermodynamic equations explicitly



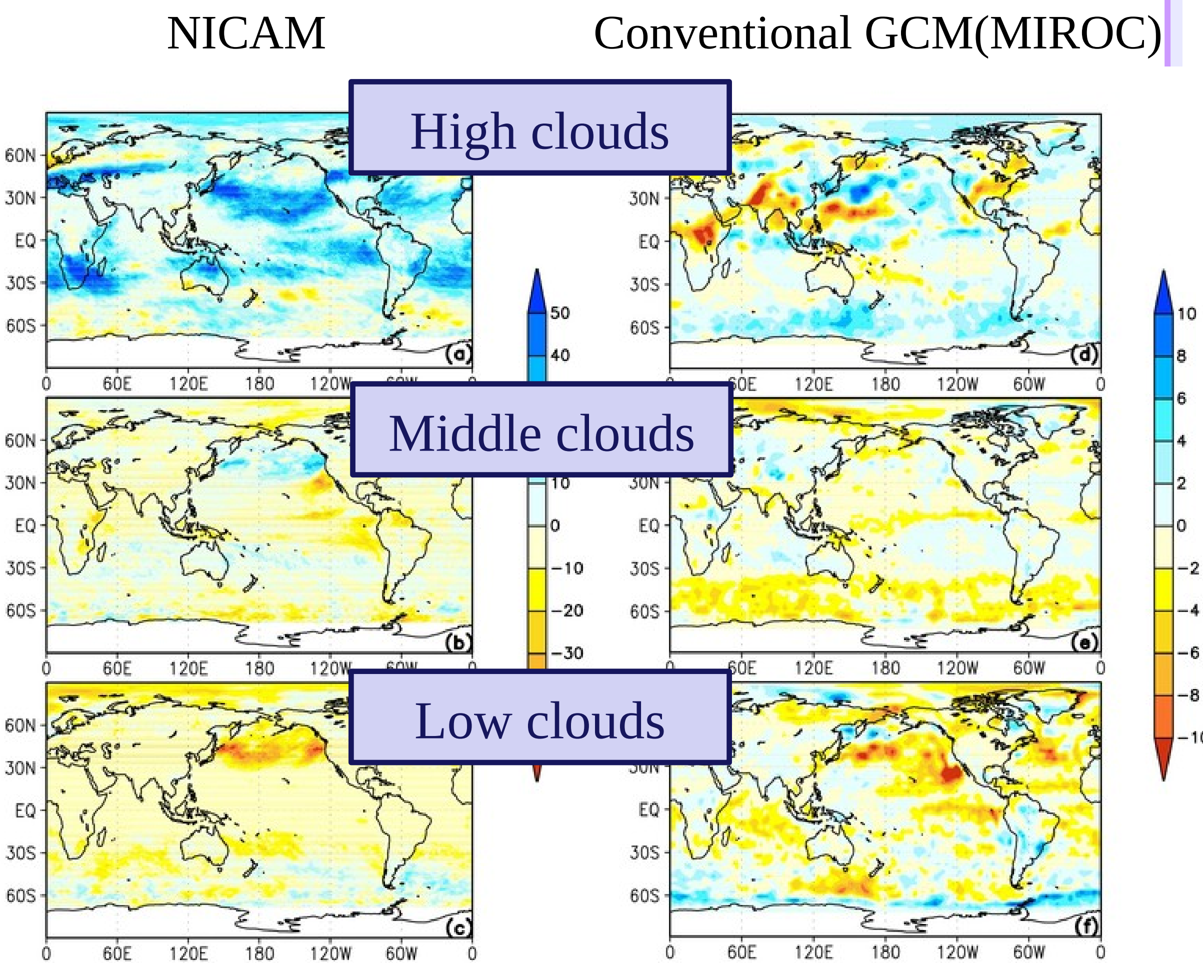
Grid configuration in NICAM



Cloud cover

Cloud change due to global warming

- High cloud feedback in a warmer atmosphere has been still controversial (e.g., Ramanathan and Collins 1991; Lindzen et al. 2001; Ringer et al. 2006)
- Response of high clouds in global nonhydrostatic simulation without cumulus parameterization differs from conventional GCMs (Collins and Satoh 2009; Satoh et al. 2012; Tsushima et al. 2014).
- Why?
- This contrasting response of high clouds may arise from the different treatment of cloud schemes or higher spatial resolution.



(Collins and Satoh 2009)

Cloud cover by ISCCP simulator

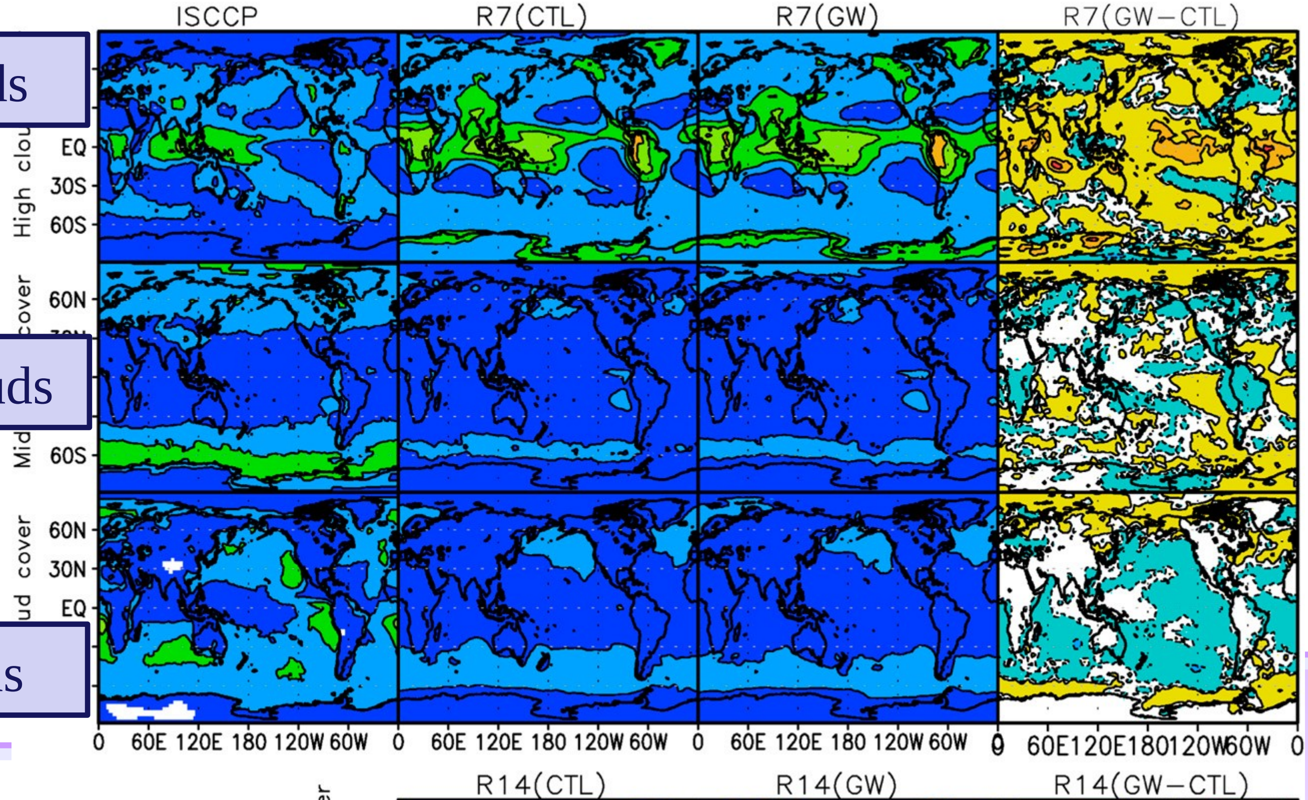
Obs | 7km mesh | GW-CTL

CTL | GW

High clouds

Middle clouds

Low clouds

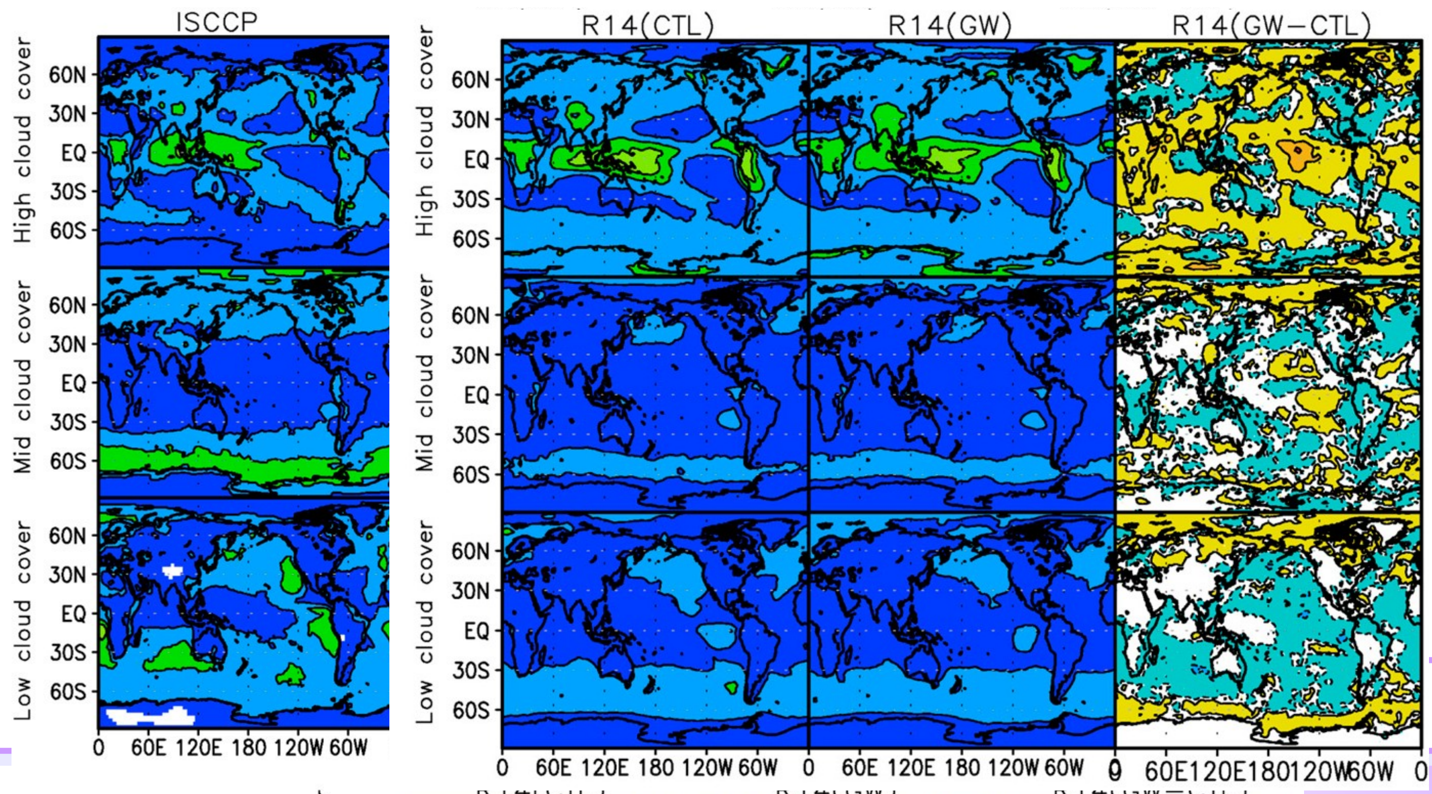


Noda et al. (2014, JCLI)

Cloud cover by ISCCP simulator

Obs | 14km mesh | GW-CTL

CTL | GW



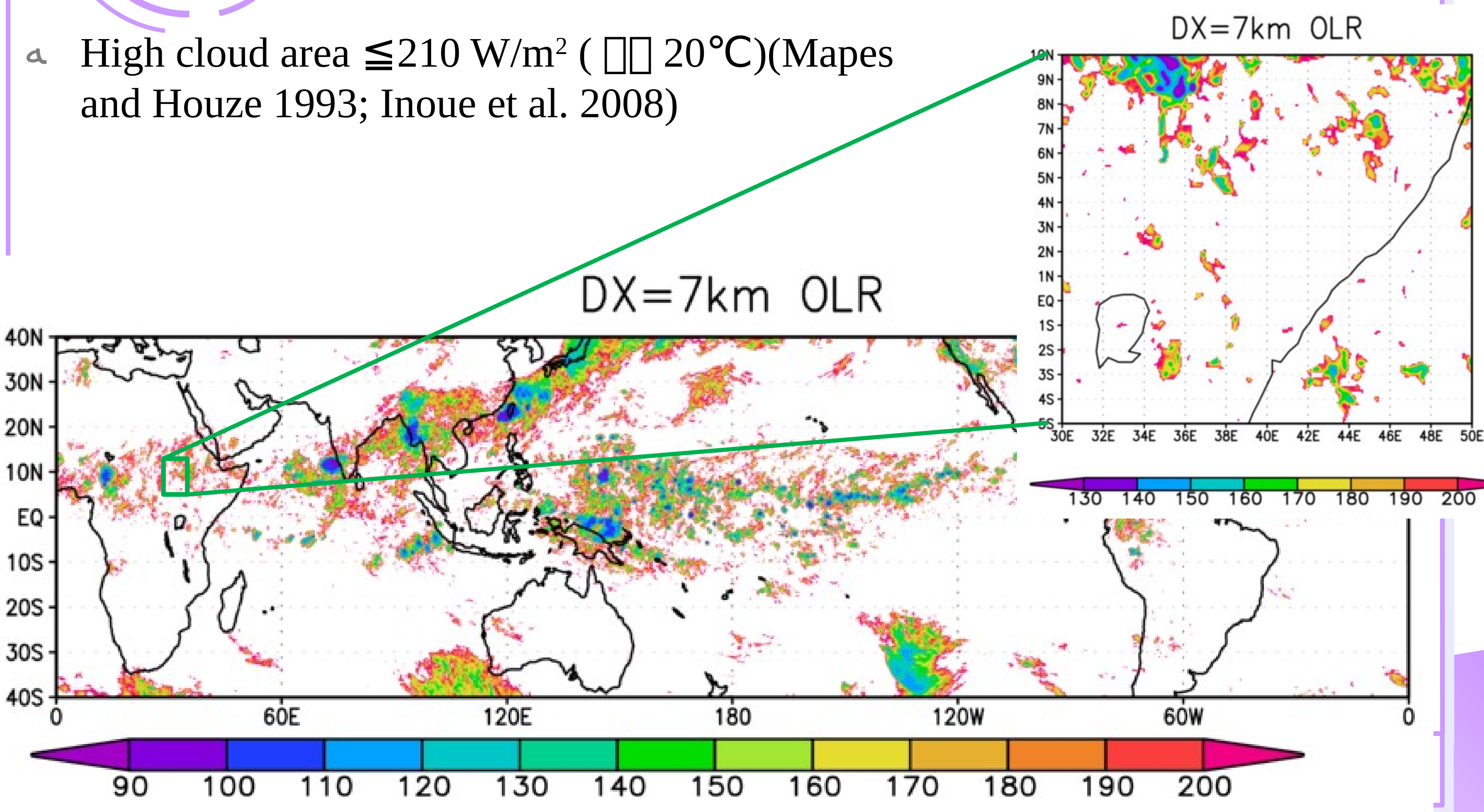
- 14km resolution data needs 10.2GB/day (restart data not included)
- →110TB for 30-yr data set
- →220TB for present and future climate data set

Cloud size analysis

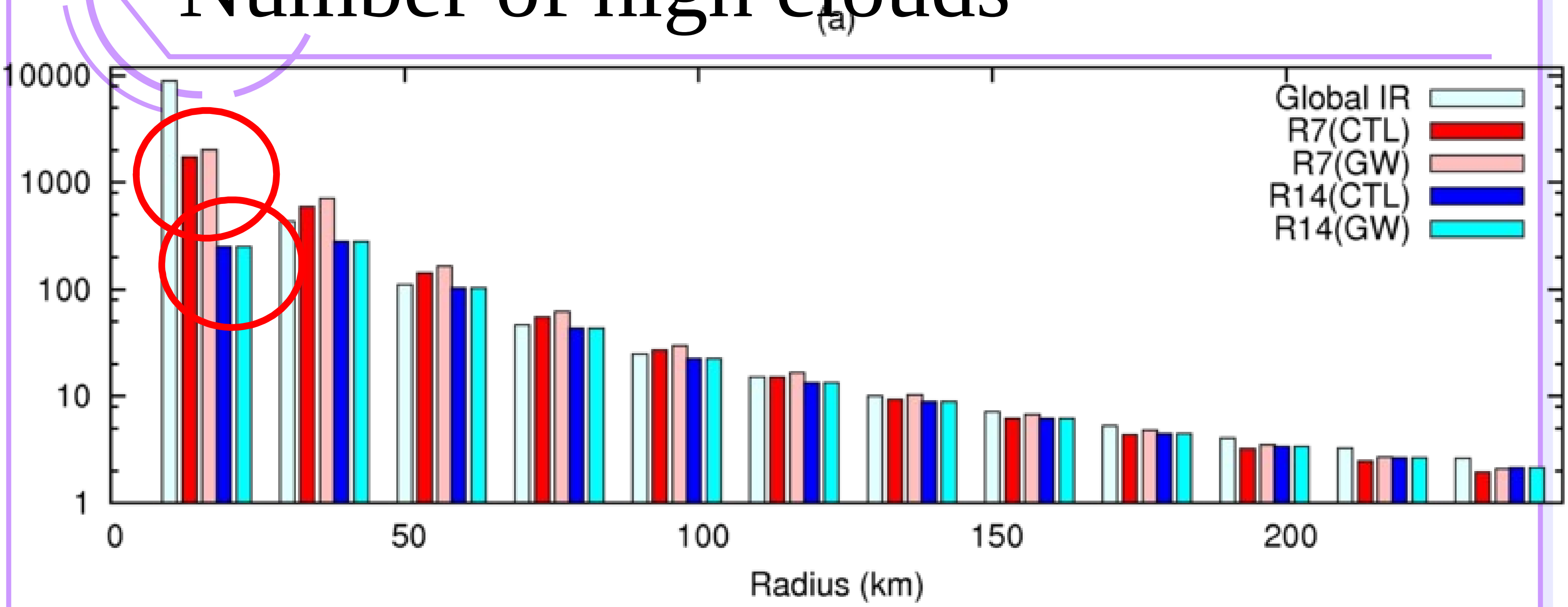
Noda et al. 2014, JCLI

Definition

- High cloud area ≦210 W/m[2] (□□ 20℃)(Mapes and Houze 1993; Inoue et al. 2008)



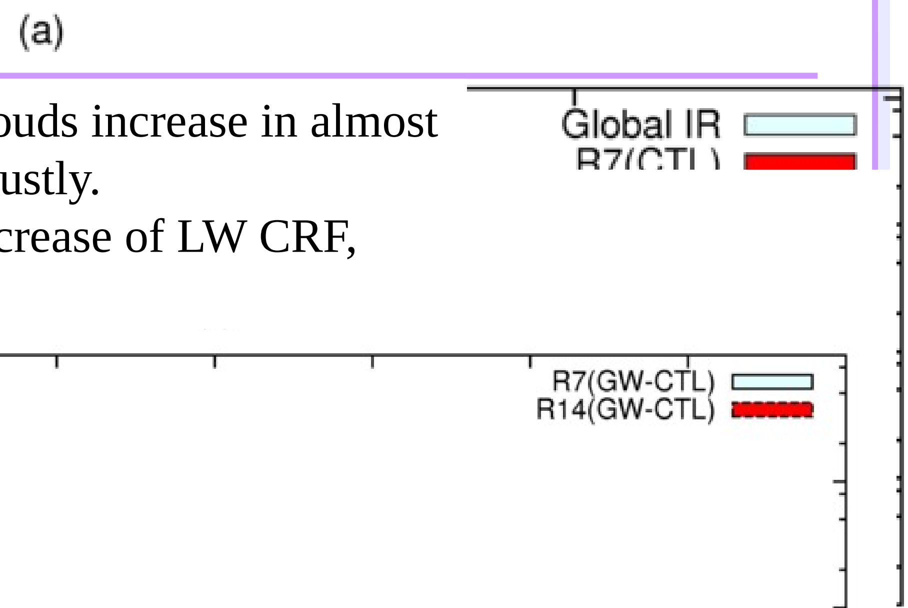
Number of high clouds

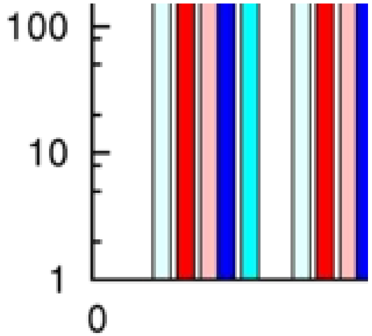


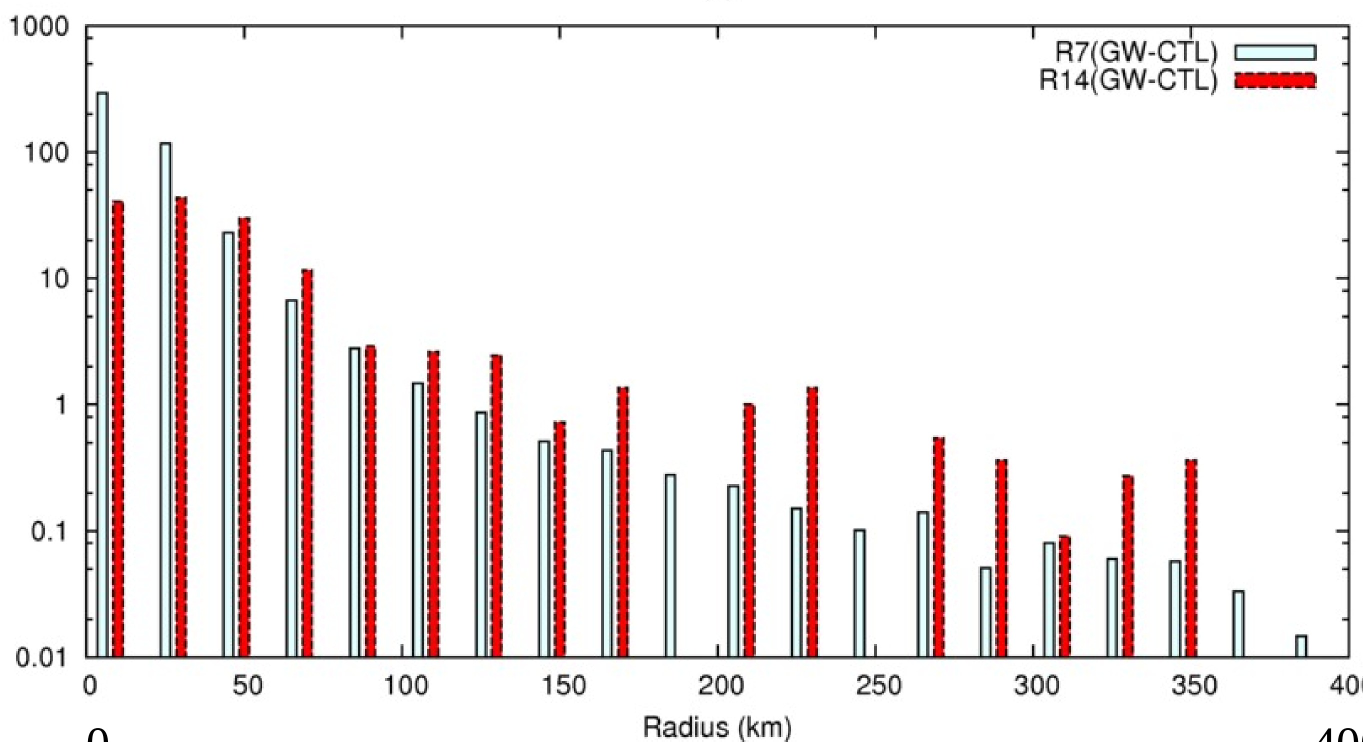
- The number of high clouds decreases with radius in a power-law.
- The 14-km mesh model underestimates smaller clouds, compared to the satellite observation.
- But this negative bias is reduced in higher resolution model, such as 7-km mesh run.

Number of high clouds (GW-CTL)

- In a warmer atmosphere, the numbers of high clouds increase in almost all radius bins both in 7-km and 14 km mesh robustly.
- The increase of high clouds contributes to the increase of LW CRF, leading to positive feedback (following slides)







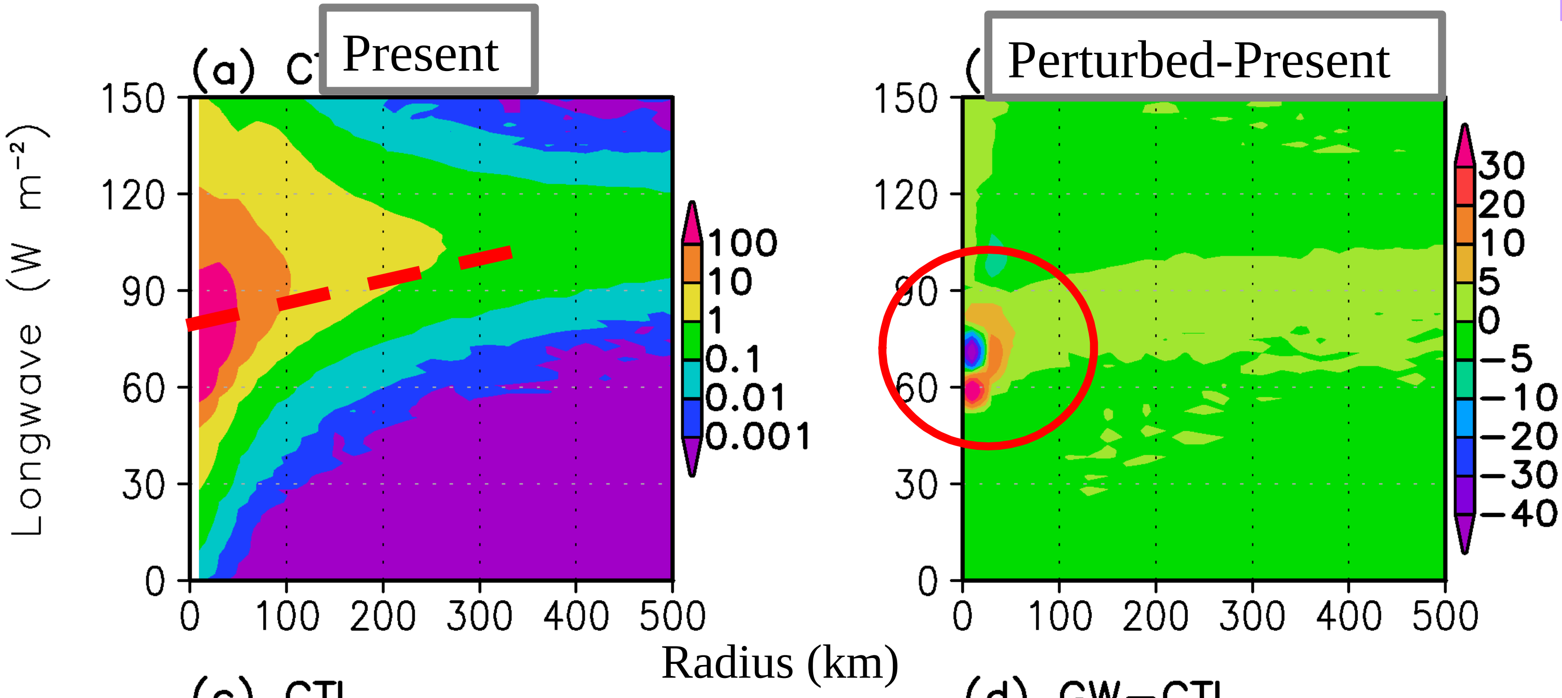
0 400km

GW-Present
7-km mesh
14-km mesh

Joint-PDFs of CRF vs. Radius

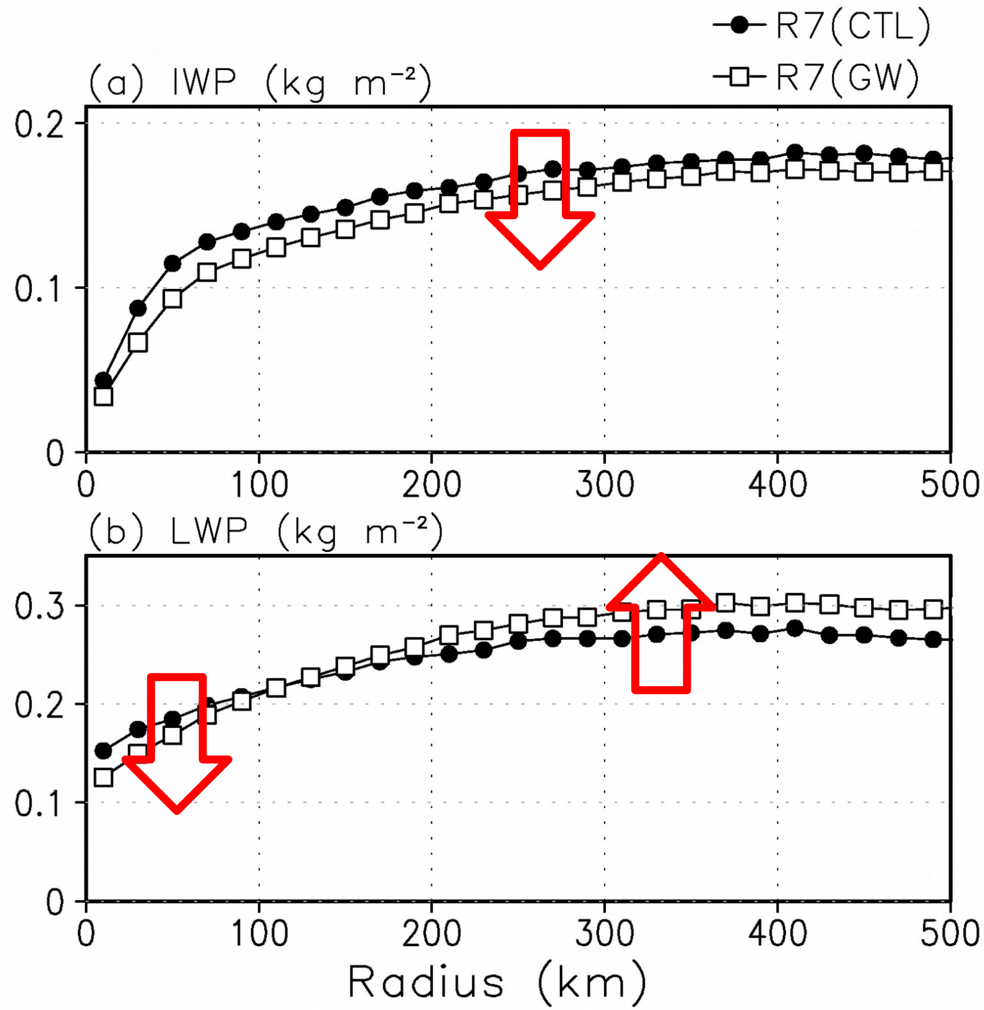
$$\int_0^\infty \int_0^\infty F_i(r, y)\,dr\,dy = \text{mean of } i \text{ in } 30^\circ \text{N} - 30^\circ \text{S}$$

- Positive correlation between LWCRF and cloud radius. LWCRF increases with radius.
- <u>The change in smaller clouds greatly explain the net change of CRF. (The number of such smaller high clouds are much larger compared to bigger size high clouds)</u>



Binned IWP and LWP per high cloud

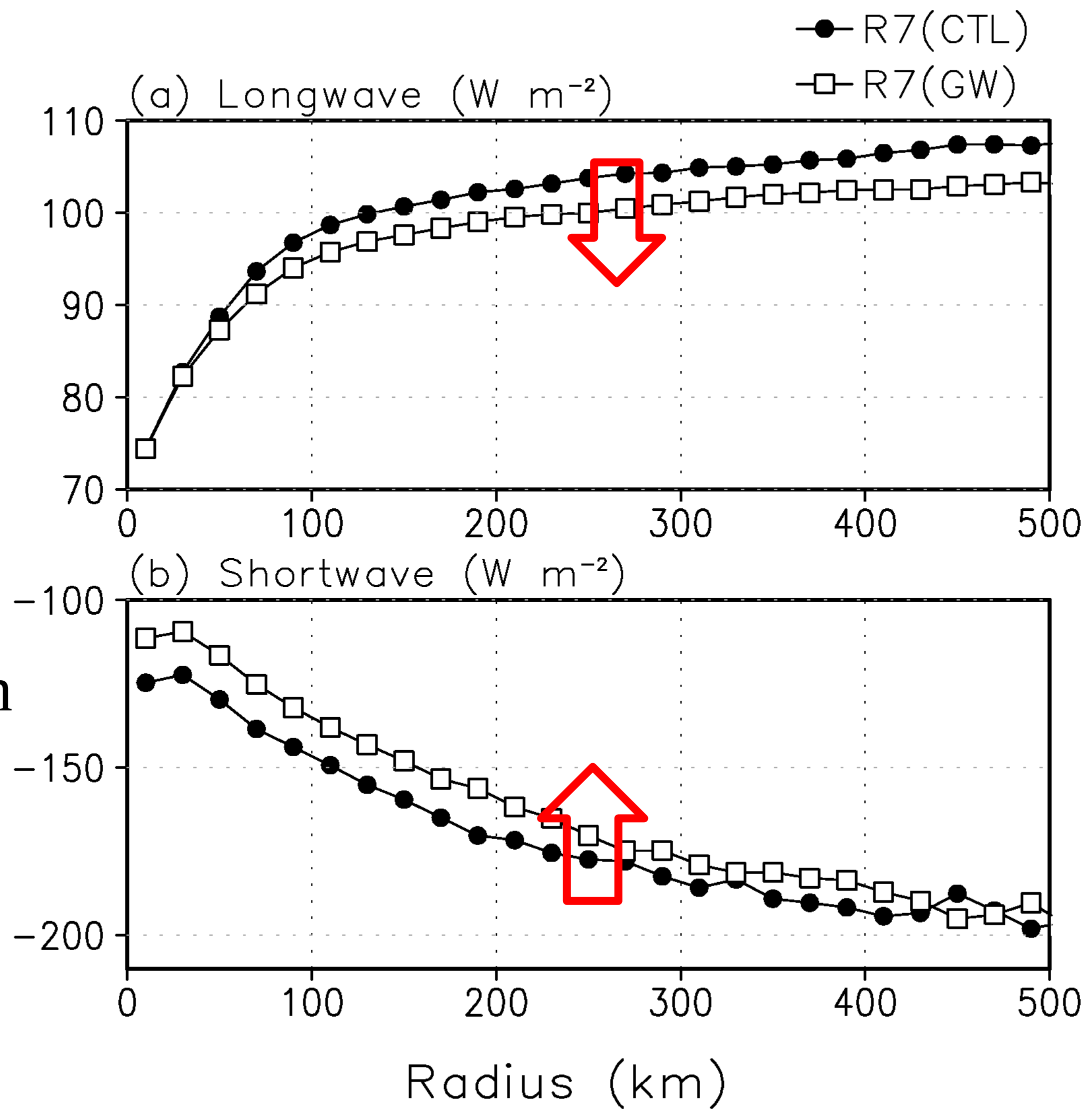
Ice water path/Liquid water path per high cloud



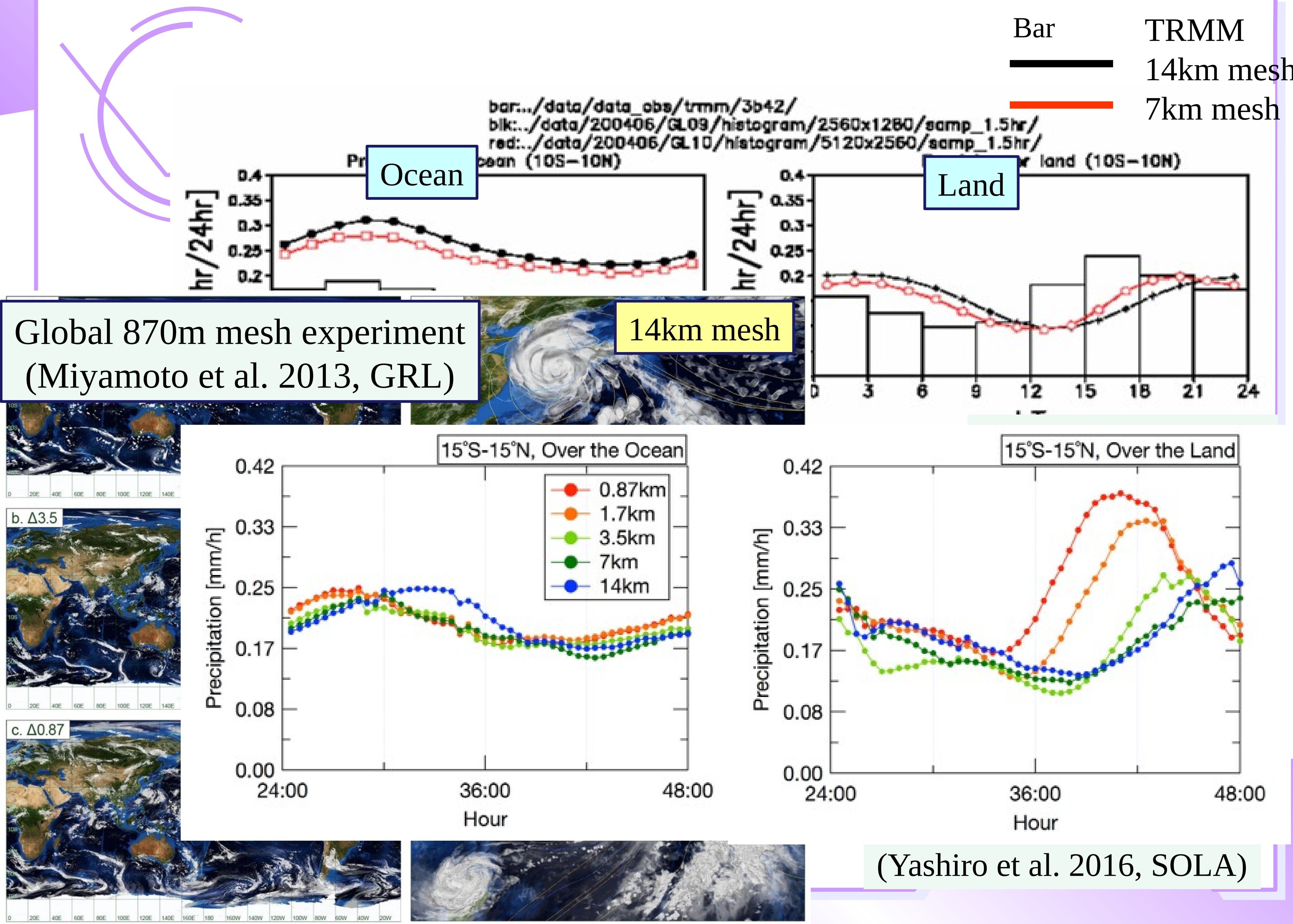
- IWP decreases in every radius bin → cloud optical depth of a mean high cloud becomes thinner, leading to reduced LWCRF
- LWP changes to increase across 120 km radius.

Binned Cloud radiative forcing per high cloud

- Both LW and SW CRF becomes weaker in every radius bin.
- In particular, the weakening of LW CRF occurs more remarkably in larger clouds.



Diurnal cycle of Tropical Precipitation


Bar TRMM
14km mesh
7km mesh
bar:../data/data_obs/trmm/3b42/
blk:../data/200406/GL09/histogram/2560x1280/samp_1.5hr/
red:../data/200406/GL10/histogram/5120x2560/samp_1.5hr/
Ocean
Land
Global 870m mesh experiment
(Miyamoto et al. 2013, GRL)
14km mesh
b. Δ3.5
c. Δ0.87
15°S-15°N, Over the Ocean
15°S-15°N, Over the Land
0.87km
1.7km
3.5km
7km
14km
Precipitation [mm/h]
Hour
24:00
36:00
48:00
(Yashiro et al. 2016, SOLA)

Sensitivity of changes of cold and warm rain in global warming to model resolution

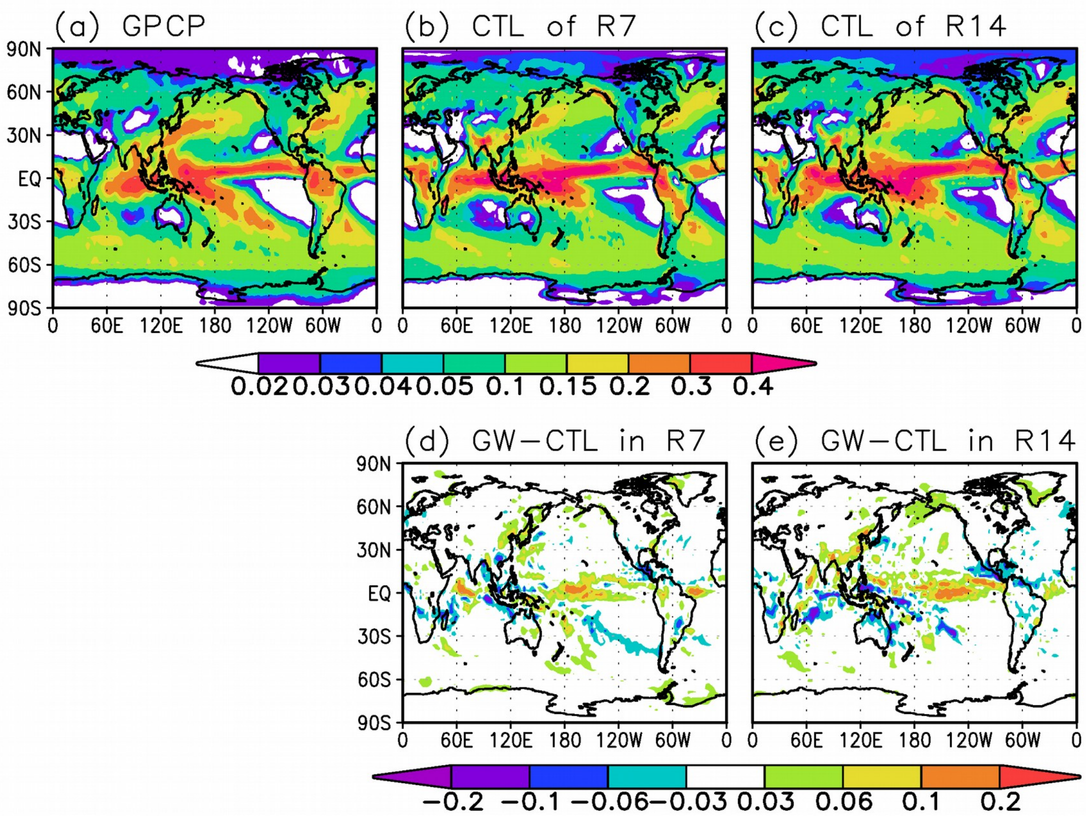
Responses to global warming

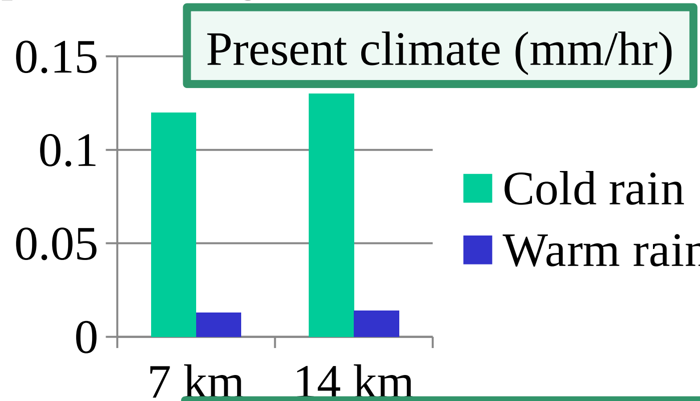
- ✓Low-latitude precipi. increases both in 7km and 14km mesh models
- ✓Resolution dependency in changes of cold and warm rain

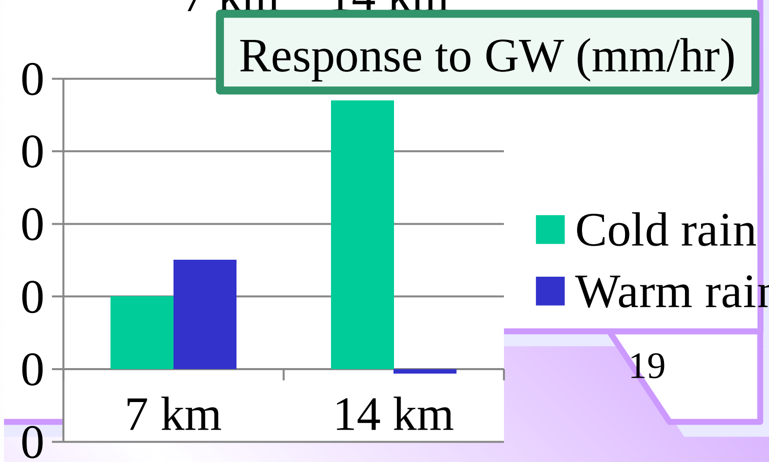
✓In 14km mesh, warm rain decreases while cold rain increase, and the latter explains the increase of total precipi.

✓In 7km mesh, warm rain increases, which explains more than half of total increase,

✓ suggesting <u>roles of warm rain become more important in higher resolution models</u>



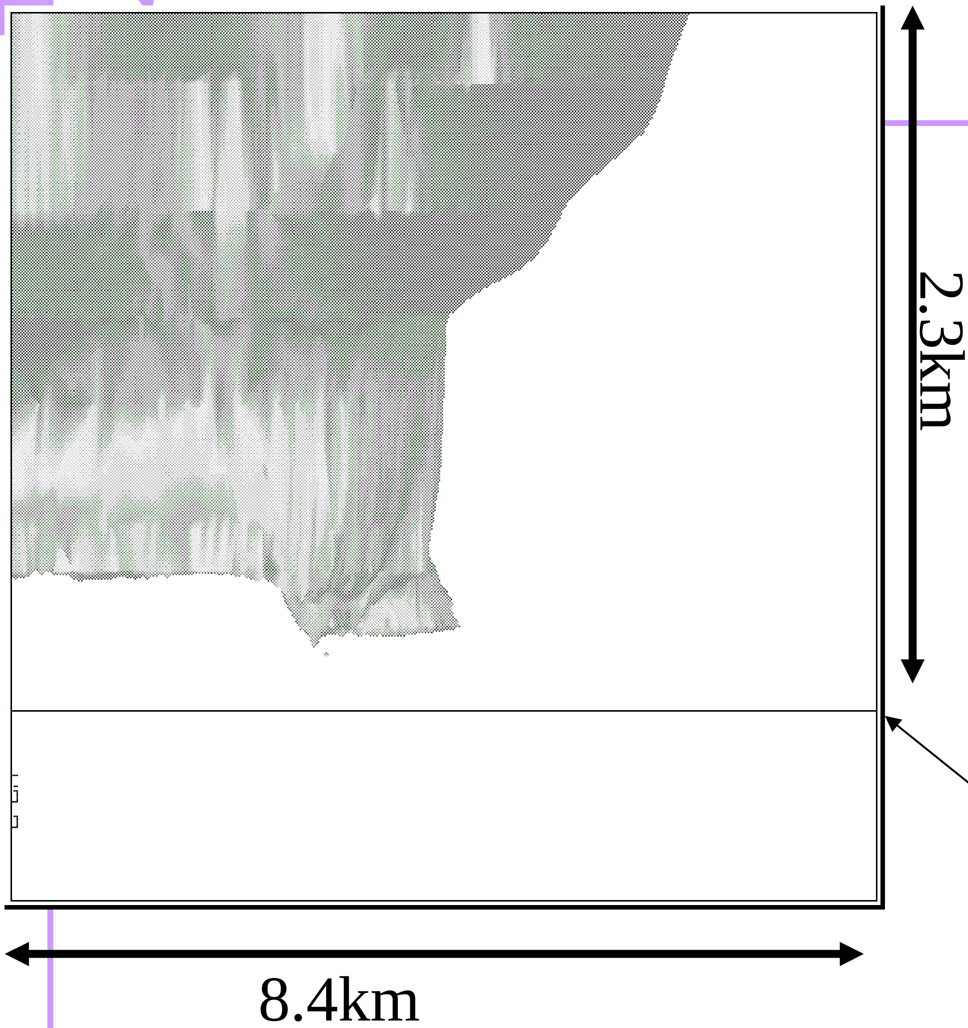




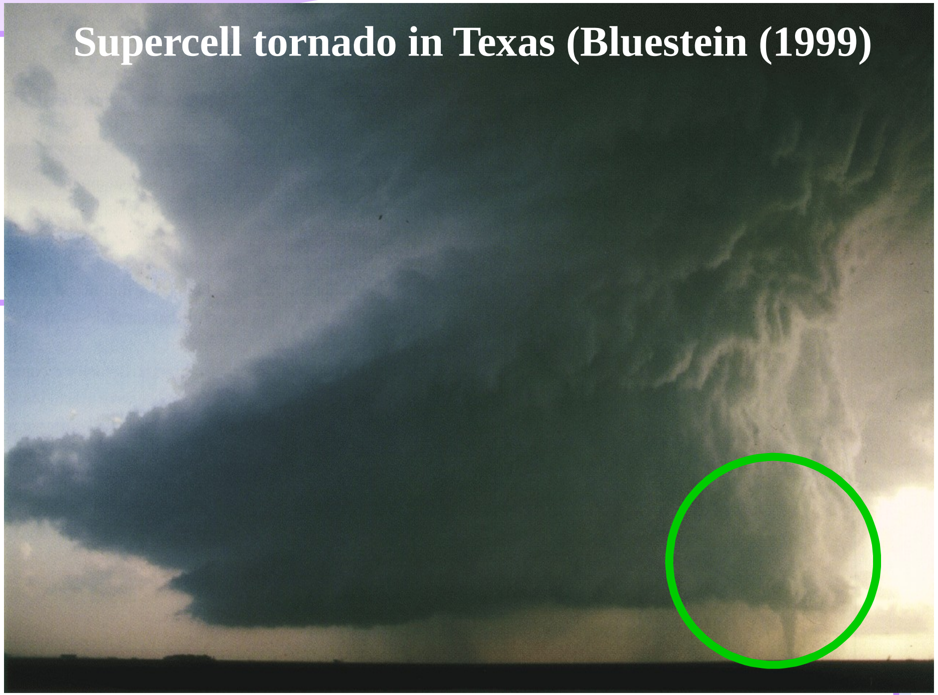
Influences of horizontal resolution on isolated deep convection

~A case study of supercell storm~

Close-up view of tornado



Ground



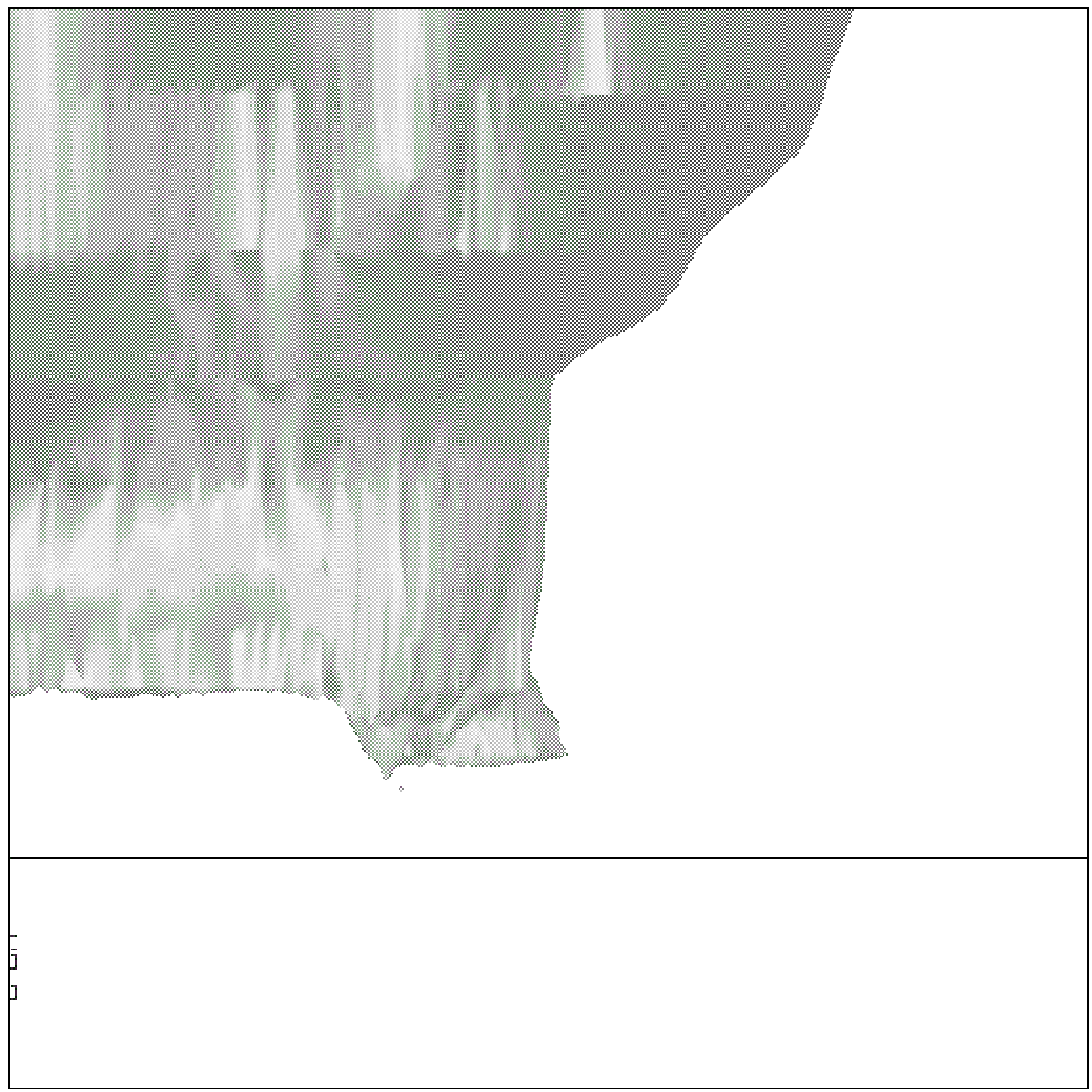
Tornado

Grey:Cloud water (0.3g kg^{-1})

Red : Vert. Vorticity (0.7 s $^{-1}$)

Noda and Niino (2005, SOLA)

Noda and Niino (2010, JMSJ)



Movie
4406s □ 4550s
□□ (144s)

Grey: □ Cloudwater (0.3g kg □ 1)

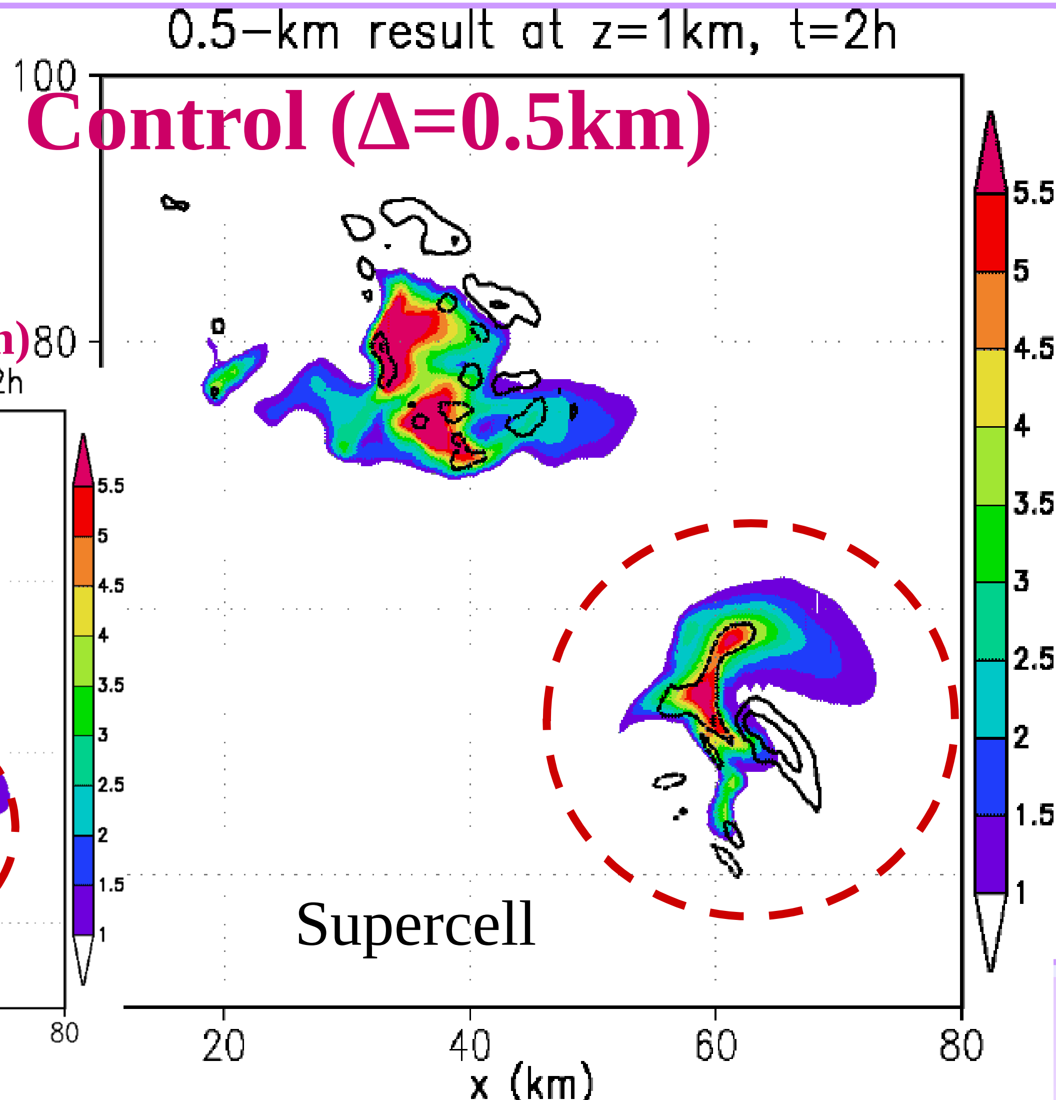
Red : Vert. Vorticity(0.7 s □ 1)

Noda and Niino (2005, SOLA)

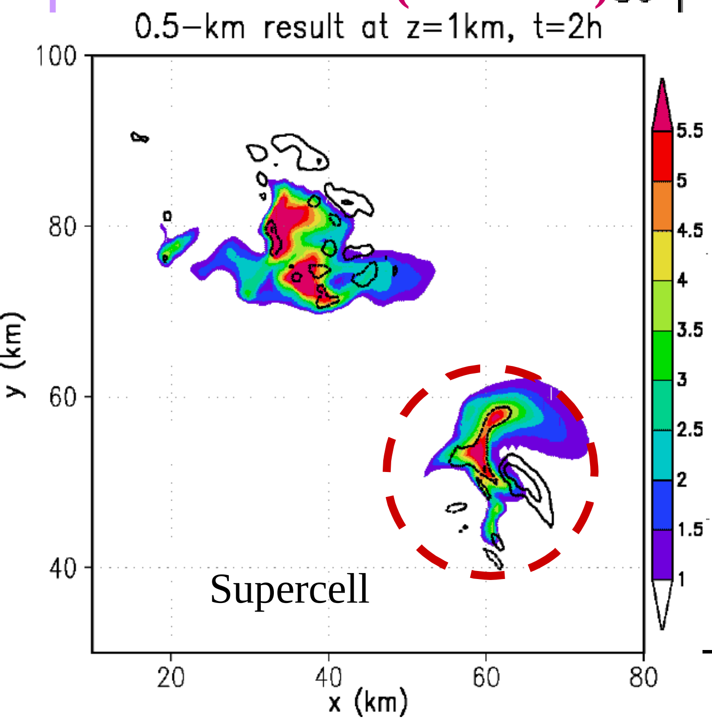
Noda and Niino (2010, JMSJ)

70m resolution simulation of the Del City storm

Rainwater (color) and vertical velocity (lines) at 1km altitude after 2hours



Control run (Δ=0.5km)

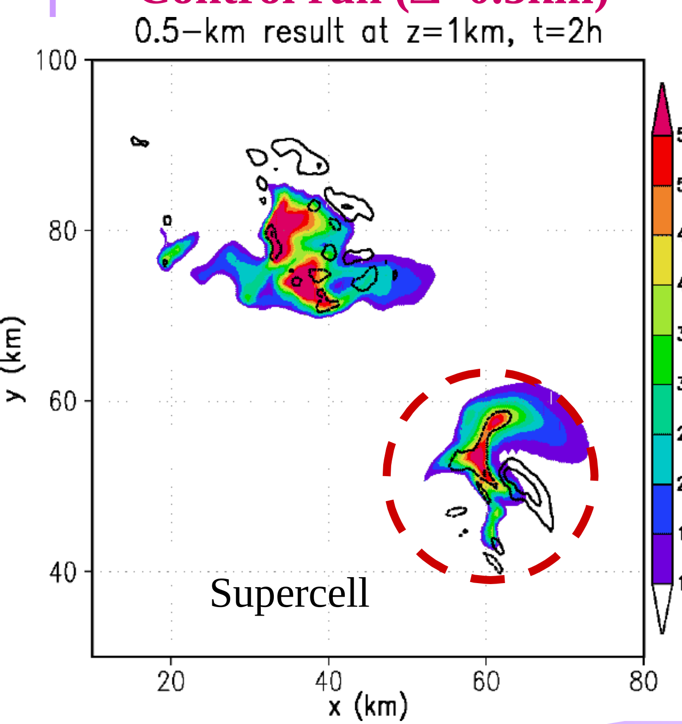


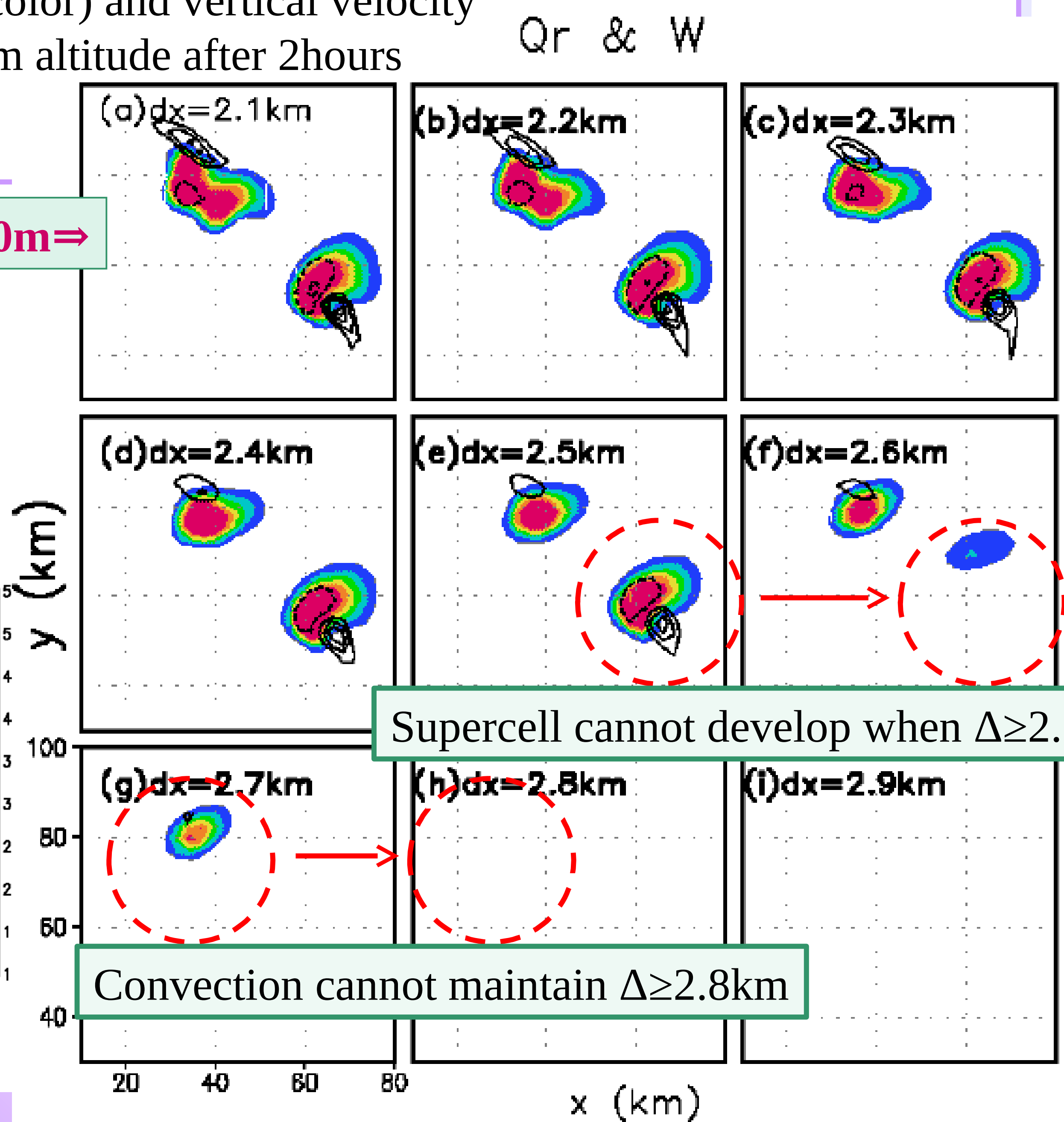
Noda and Niino (2003,GRL)

Rainwater (color) and vertical velocity (lines) at 1km altitude after 2hours

Resolution changed by 100m⇒

Control run (Δ=0.5km)



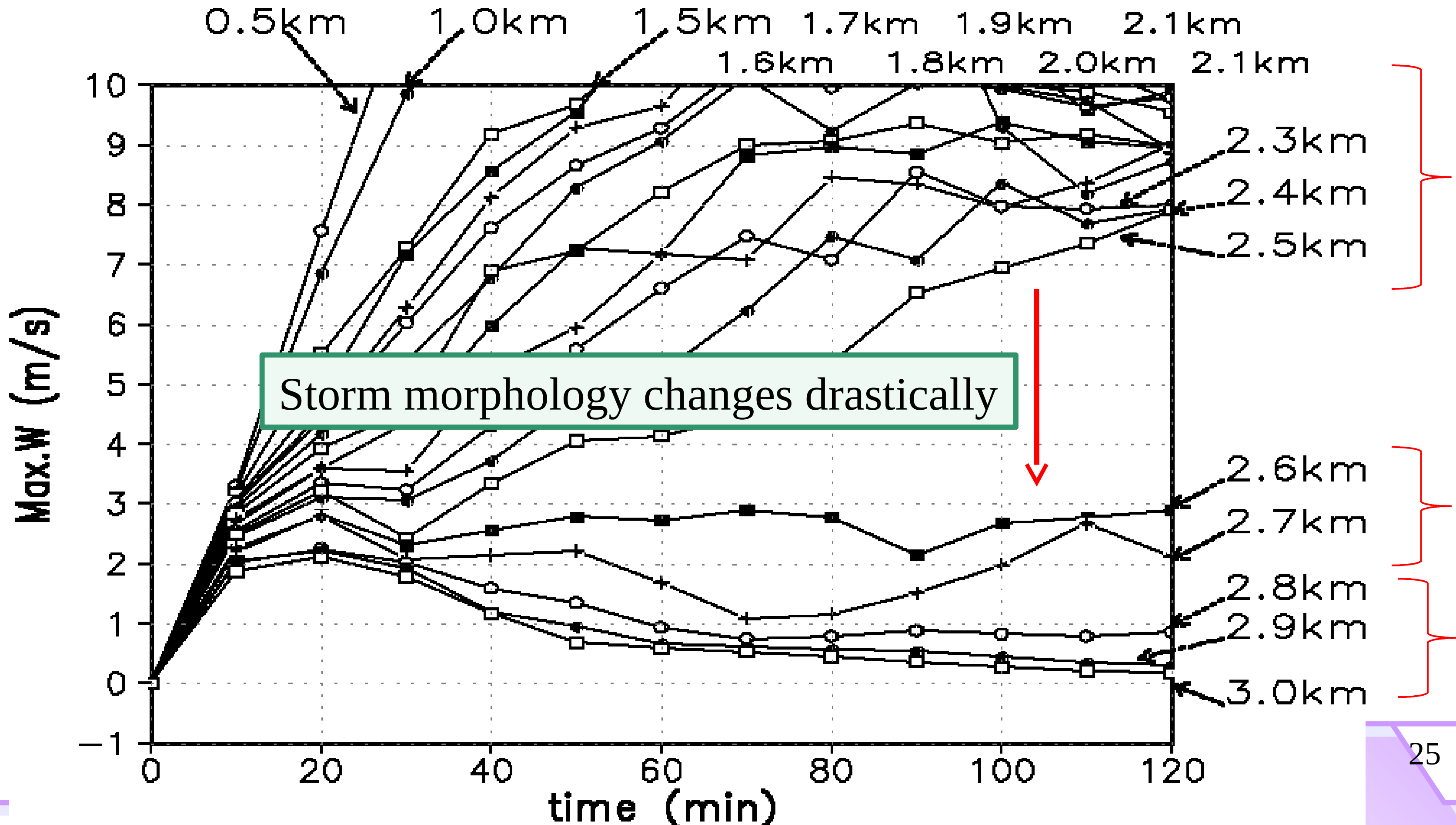


Supercell cannot develop when Δ≥2.

Convection cannot maintain Δ≥2.8km

Maximum vertical velocity (1km altitude over the domain)

Slight change of grid spacing (by 100m) can cause drastic changes in convection



Summary

- Global Cloud-Resolving Model: NICAM
- Resolution dependency
  - Cloud cover
    - 14km and 7km resolution models show qualitatively similar results
    - High cloud cover increases while low cloud cover decreases in both models under global warming
    - Increased high cloud cover is a consequence of the increased number of small scale (high-topped) clouds. Use of high resolution model is a key to evaluate cloud feedback in global warming more accurately
  - Precipitation
    - Diurnal cycle of tropical land precipitation becomes better with increasing resolution.
    - Quantitative behavior of land precipitation notably changes across Δ~1km
    - Roles of precipitation by low-topped clouds are more important in a warmer world, and thus improving resolution is also important.
  - Isolated convection (case study of supercell storm)
    - Changes of grid spacing by 100m can alter behavior of supercell morphology drastically

Experimental Design (Present climate simulation)

Initialization	NCEP Global analysis
Time Integration	1 year starting from 1 June 2004
SST	Slab mixed layer ocean model with 15m depth and 7day e-folding time, nudged to NOAA Weekly Reynolds SST
Horizontal resolution	7km
Vertical resolution	80m □ 2.9km (Stretched)
Cloud	One-moment, 6 categories (Tomita 2008) (cumulus parameterization not used)
Turbulence	Improved version of Mellor-Yamada Level 2 with subgrid-scale condensation (Nakanishi & Niino 2006; Noda et al. 2010) ※partial cloudiness not considered
Surface turbulent flux	Bulk parameterization by Louis (1979)
Radiation	MSTRN-X (Sekiguchi and Nakajima 2008)
Land surface	MATSIRO (Takata et al. 2003)
CO2 concentration	348 ppm

Experimental Design (Global warming simulation

Initialization	NCEP Global analysis
Time Integration	1 year starting from 1 May 2004 1-month spin-up + 1 year (Time slice approach)
SST	Slab mixed layer ocean model with 15m depth and 7day e-folding time, nudged to I Present+Increase by CMIP3 ensemble
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696 ppm (twiced homogeneously over the globe)