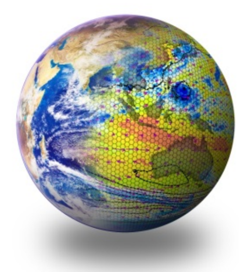
Resolution dependence of deep convections in a global simulation from over 10-kilometer to sub-kilometer grid spacing

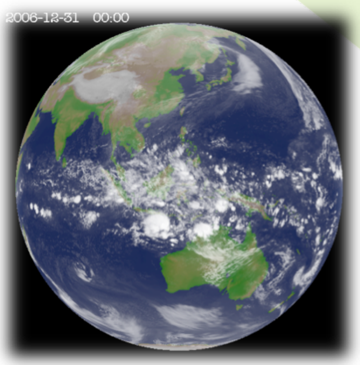
[1]Kajikawa, Y., [1]Y. Miyamoto, [1]R. Yoshida, [1]T. Yamaura, [1]H. Yashiro, and [1,2]H. Tomita

[1]RIKEN Advanced Institute for Computational Science,
[2]Japan Agency for Marine-Earth Science and Technology,



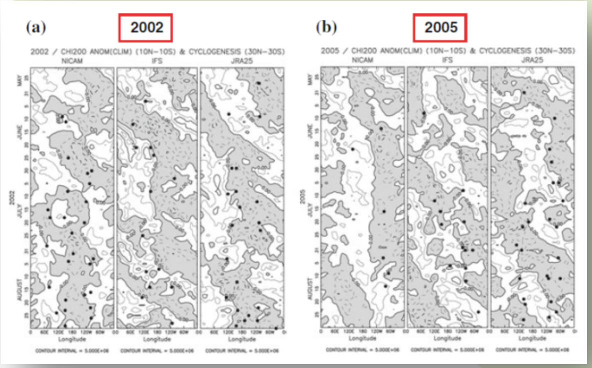
From the demonstration to scientific knowledge

Earth Simulator



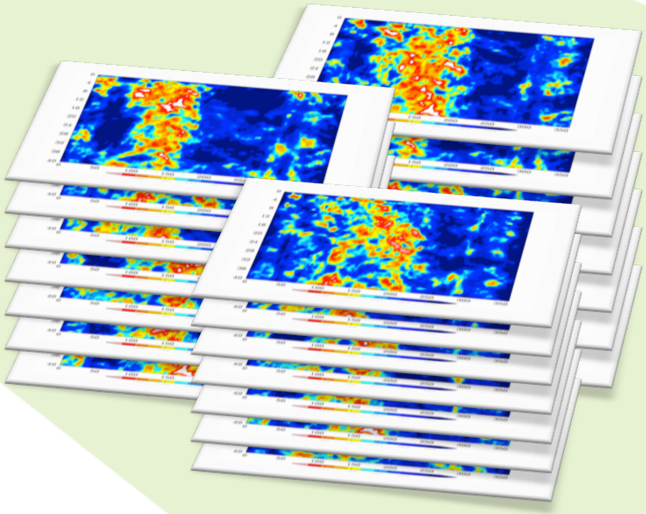
Case study
(Miura et al 2007)

Athena Cray XT-4



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

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



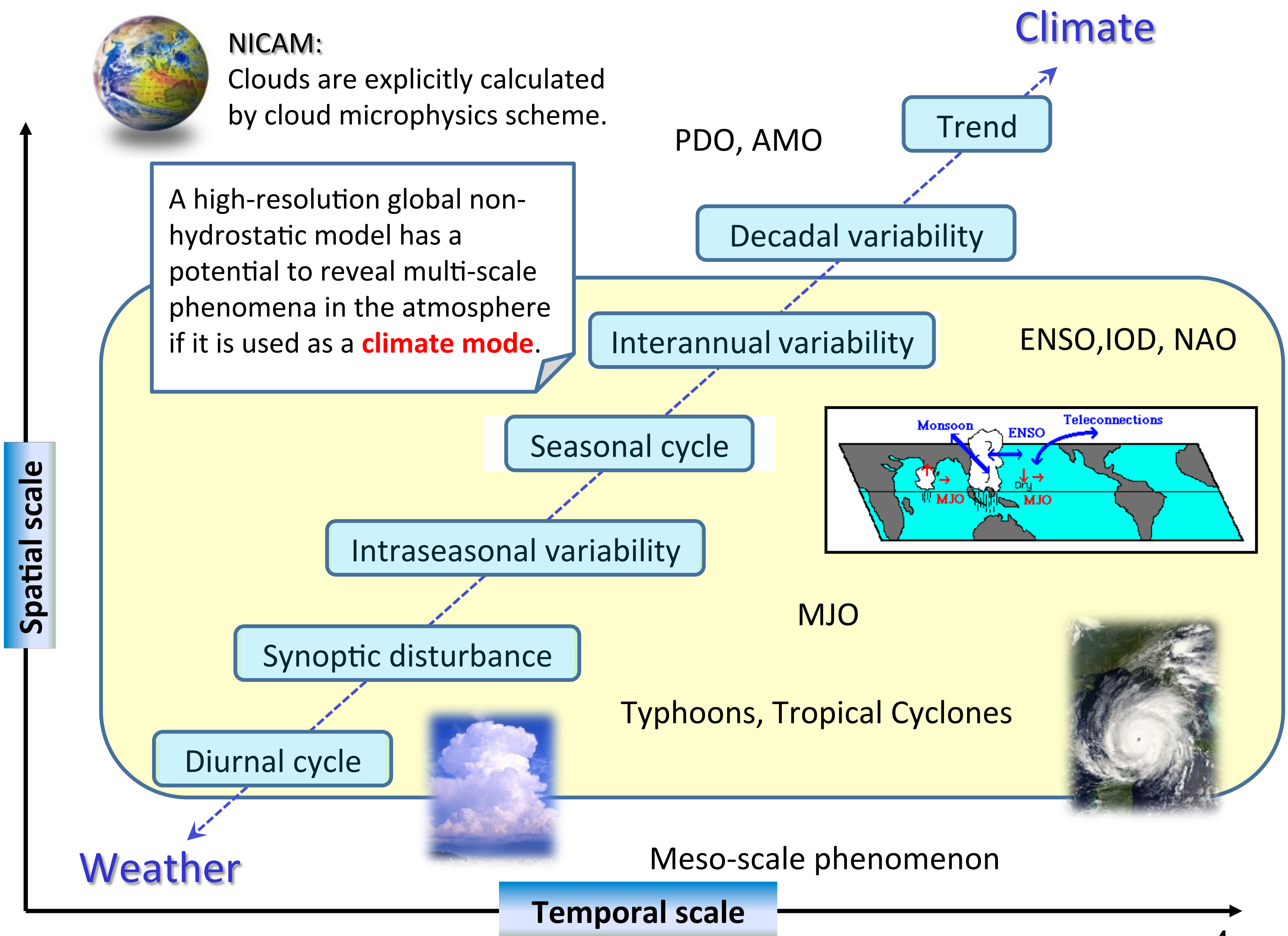
Related Papers

- Kodama, C., and co-authors, 2015: 20-year climatology of a NICAM AMIP-type simulation, *J. Meteor. Soc. Japan*, **93**, doi:10.2151/jms 2015-024

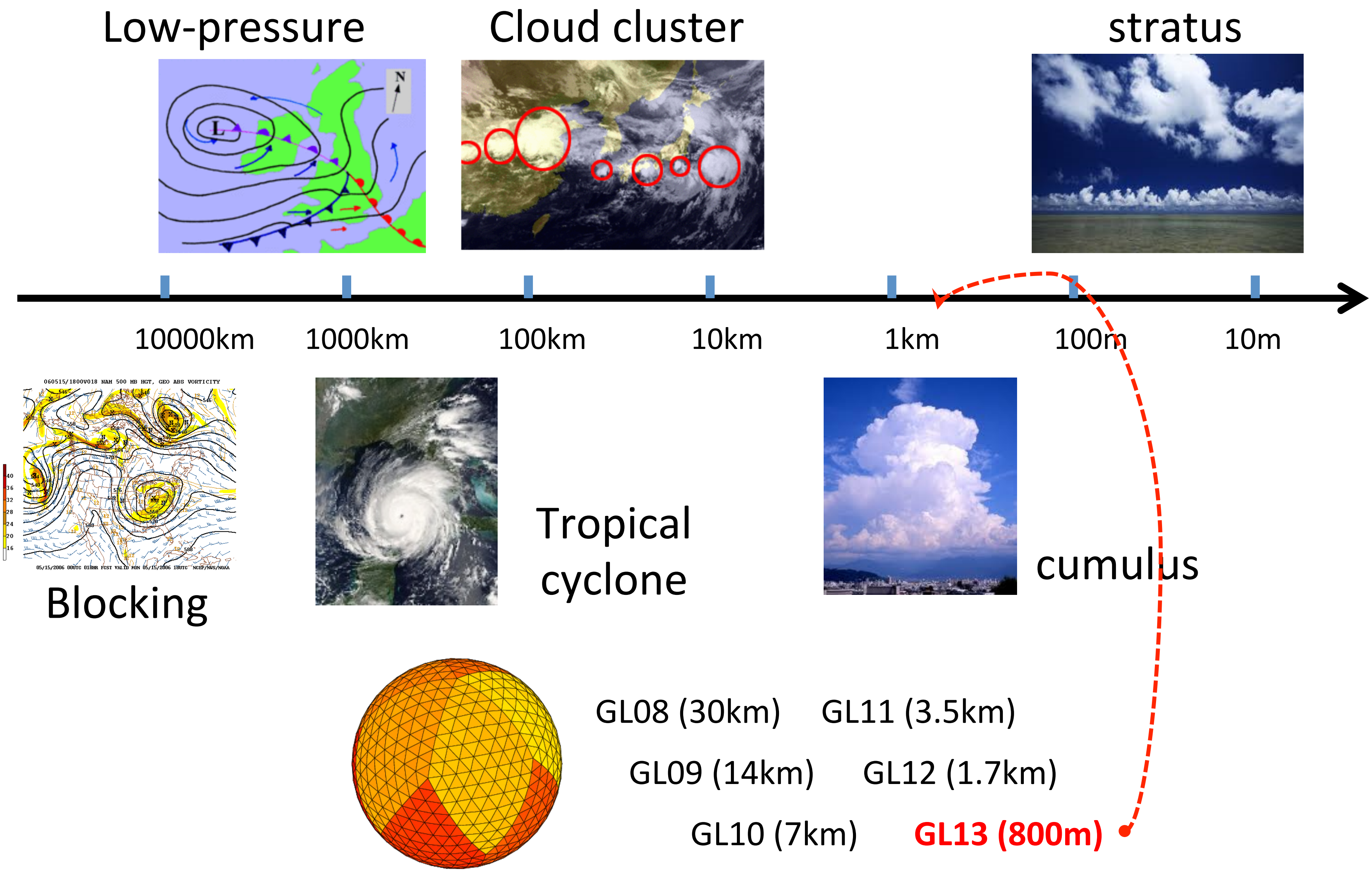
- Miyakawa, T., and co-authors, 2014: Madden-Julian Oscillation prediction skill of a new-generation global model demonstrated using a supercomputer. *Nature Commun*., **5**, 3769, doi:10.1038/ Ncomms4769.

- Nakano, M., M. Sawada, T. Nasuno, and M. Satoh, 2015: Intraseasonal variability and tropical cyclogenesis in the western North Pacific simulated by a global nonhydrostatic atmospheric model. *Geophys. Res. Lett*., **42**, doi:10.1002/2014GL062479 .

- Kajikawa. Y., T. Yamaura, H. Tomita and M. Satoh, 2015: Impact of tropical disturbance on the Indian summer monsoon onset simulated by global cloud-system-resolving model, *SOLA*, **11**, 80-84, doi:10.2151/ sola.2015-020


NICAM:
Clouds are explicitly calculated by cloud microphysics scheme.
Climate
Trend
PDO, AMO
Decadal variability
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.
Interannual variability
ENSO,IOD, NAO
Seasonal cycle
Monsoon
ENSO
Teleconnections
MJO
MJO
Intraseasonal variability
MJO
Synoptic disturbance
Typhoons, Tropical Cyclones
Diurnal cycle
Weather
Meso-scale phenomenon
Spatial scale
Temporal scale

Grand Challenge project:



Today's talk

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

- **Miyamoto. Y.,** Y. Kajikawa, R. Yoshida, H. Yashiro, T. Yamaura and H. Tomita, 2013: Deep moist atmospheric convection in a sub-kilometer global simulation, *Geophys. Res. Lett.*, doi:10.1002/grl.50944.

- **Miyamoto. Y.**, R. Yoshida, T. Yamaura, H. Yashiro, H. Tomita and and Y. Kajikawa, 2015: Does convection vary in different cloudy disturbances? *Atm. Sci. Lett.*, DOI: 10.1002/asl2.558

- Kajikawa. Y., **Y. Miyamoto**, R. Yoshida, H. Yashiro, T. Yamaura and H. Tomita, 2015: Resolution Dependencies of Deep Moist Convections in the Sub-kilometer Global Simulation, *Prog. Earth Planet. Sci., in revision*

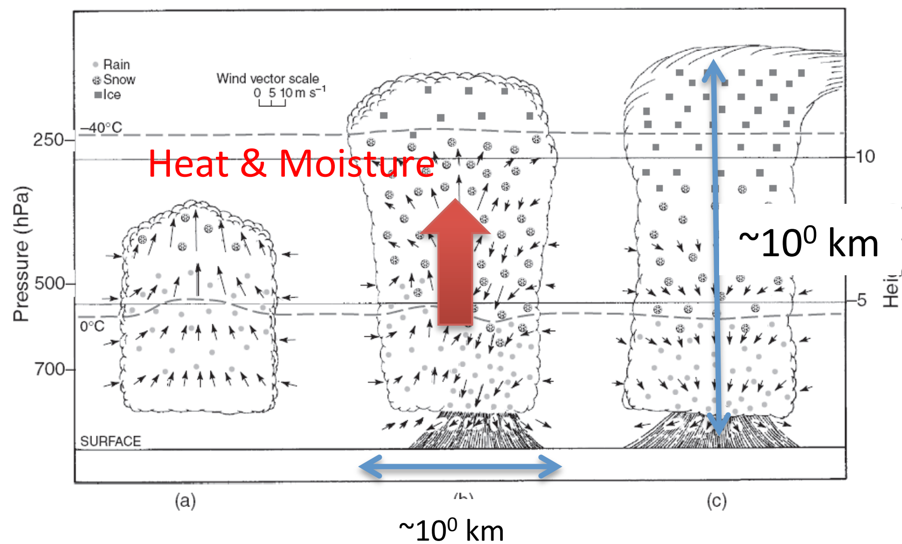
Introduction and purpose of this study

Convection

BSISO, TC etc.

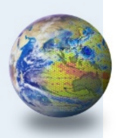
- Element of cloudy disturbances
- Transport heat and moisture
- Horizontal scale ～10^0 km

[Issue] how to solve in **global models**
（Dx～10^1 – 10^2 km）



Byers and Braham (1949)

Cumulus parameterization



After 2000s …
(1) Model development & (2) enhancement of computer power
➔ Dx ～ 10^0 km (clouds are explicitly solved in global models)
➔ Still coarser or comparable to obs.

Regional model (Weismann et al., 1997) : change around Δx <= 4 km

Question 1

What is the statistical features of deep convections in a global model and their resolution dependence?

Grid refinement Experiment by NICAM & K

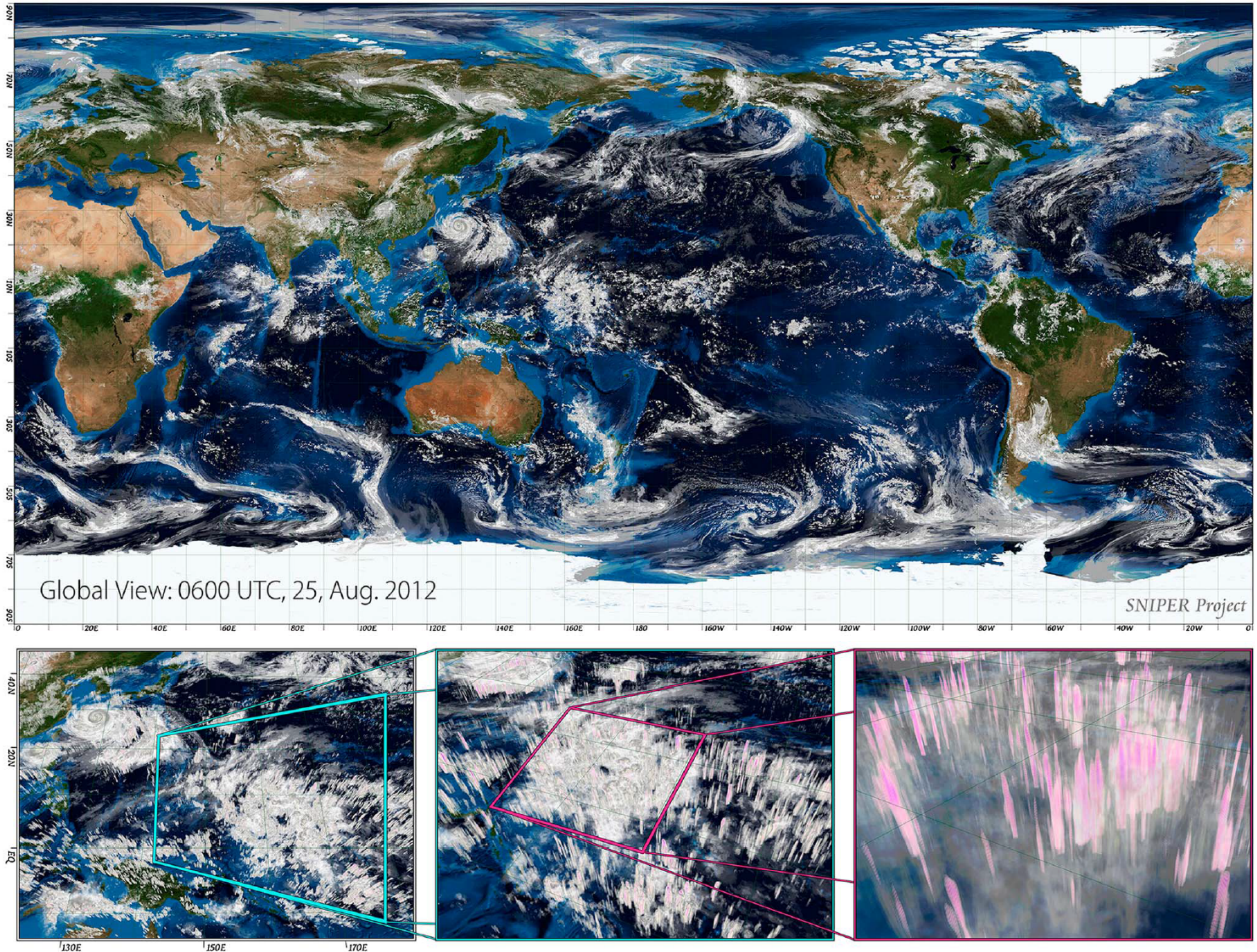
model	NICAM (Tomita and Satoh 2004, Satoh et al. 2008)
Initial state	3-day integrated results of 1-step coarser resolution
SST	JMA GPV+ nudging (Reynolds weekly SST)
land	Model adjusted produced by 5 year run
Cloud physics	NSW6 (Tomita 2008)
Boundary layer turbulence	MYNN (Nakanishi and Niino 2004, Noda et al. 2008)
Surface flux	Louis (1979)
Long and short-wave radiation	MSTRNX (Sekiguchi and Nakajima 2008)
Cumulus parameterization	--

Experiments	horizontal mesh size (km)	initial time (UTC)	period	initial data
Δ14.0	14.0	2012082500	12 hours	Δ30.0
Δ7.0	7.0	2012082500	12 hours	Δ14.0
Δ3.5	3.5	2012082500	12 hours	Δ7.0
Δ1.7	1.7	2012082500	12 hours	Δ3.5
Δ0.8	0.8	2012082500	12 hours	Δ3.5

Δx

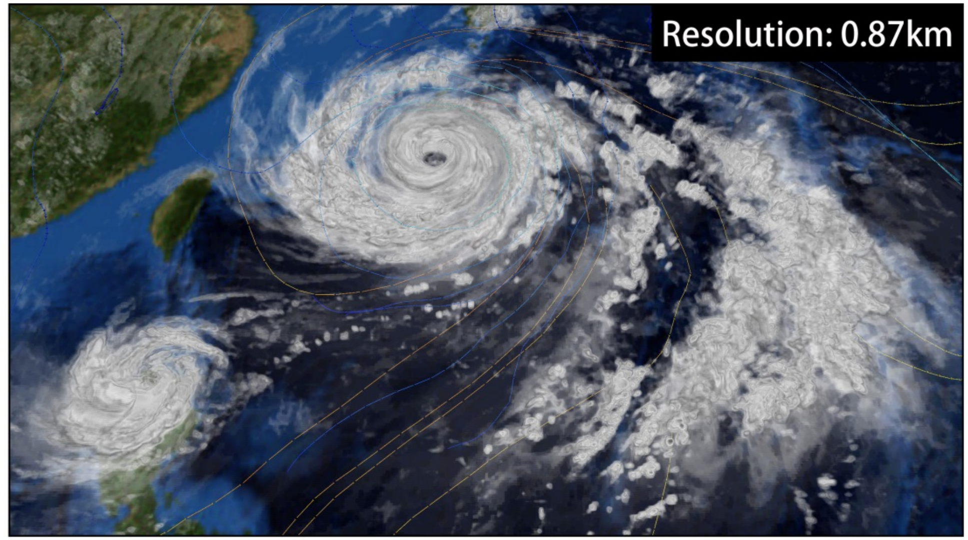
integration period（12 h）

Successfully conducted the GL13(870m) simulation



Comparison with the previous model resolution

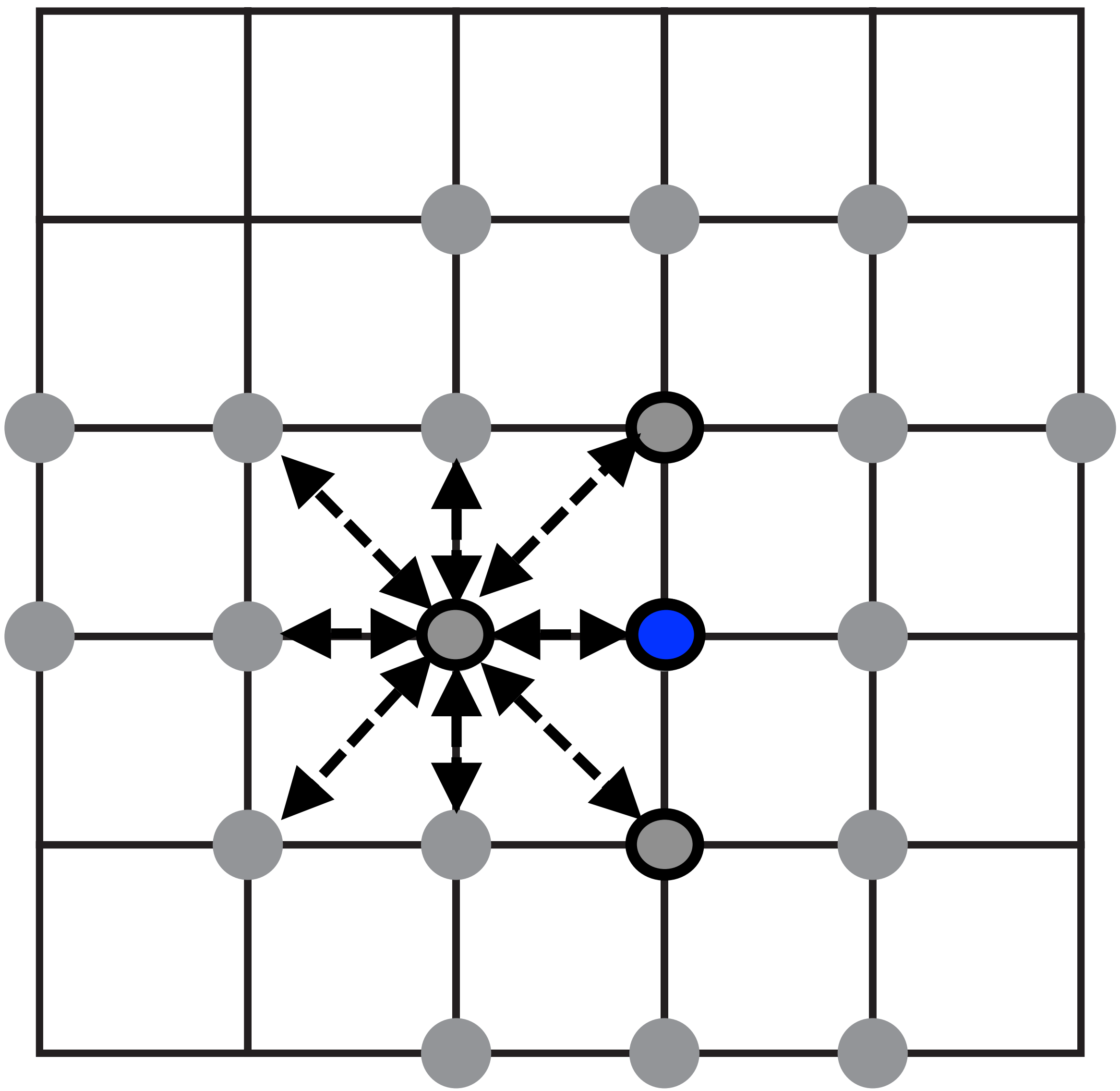
GL13 (0.87km)
with K computer



Each cumulus in the tropical cyclone are expressed in detail.

Previous model resolution (3.5km)

How to detect a convection core



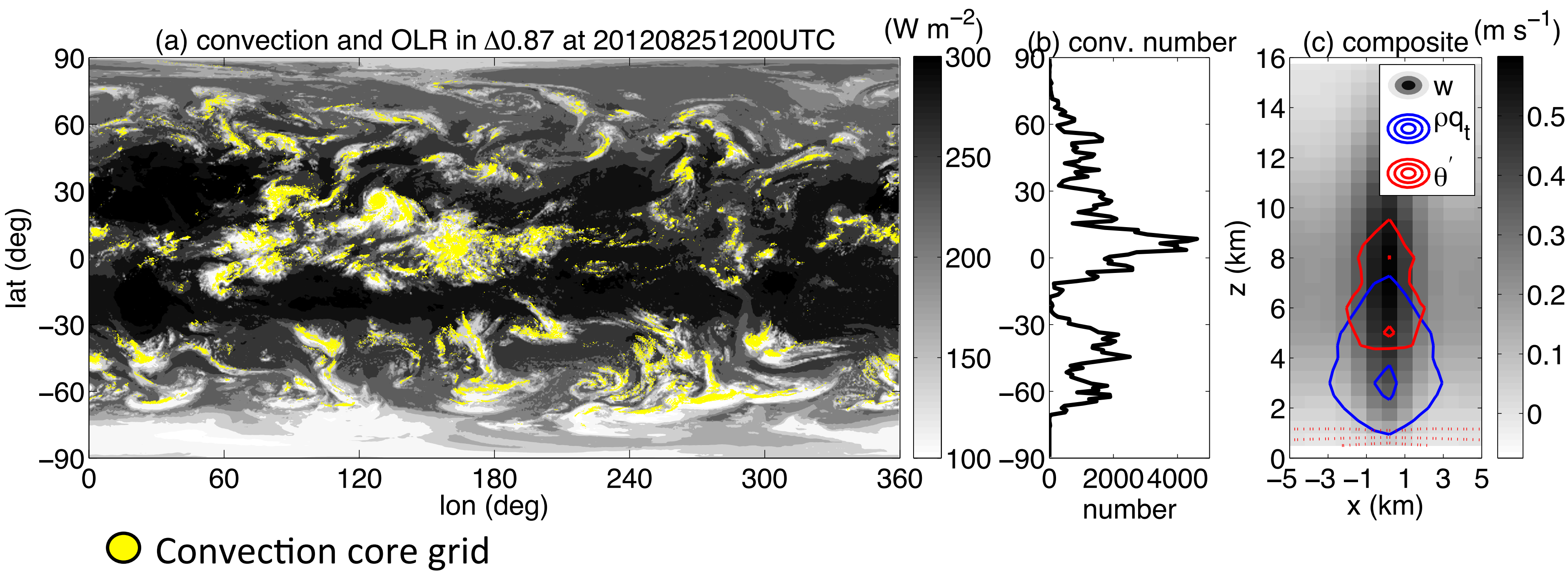
a) ISCCP convective grids (●)

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 aved w is larger than those at surrounding 8 grids

Detected Convection cores



- 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

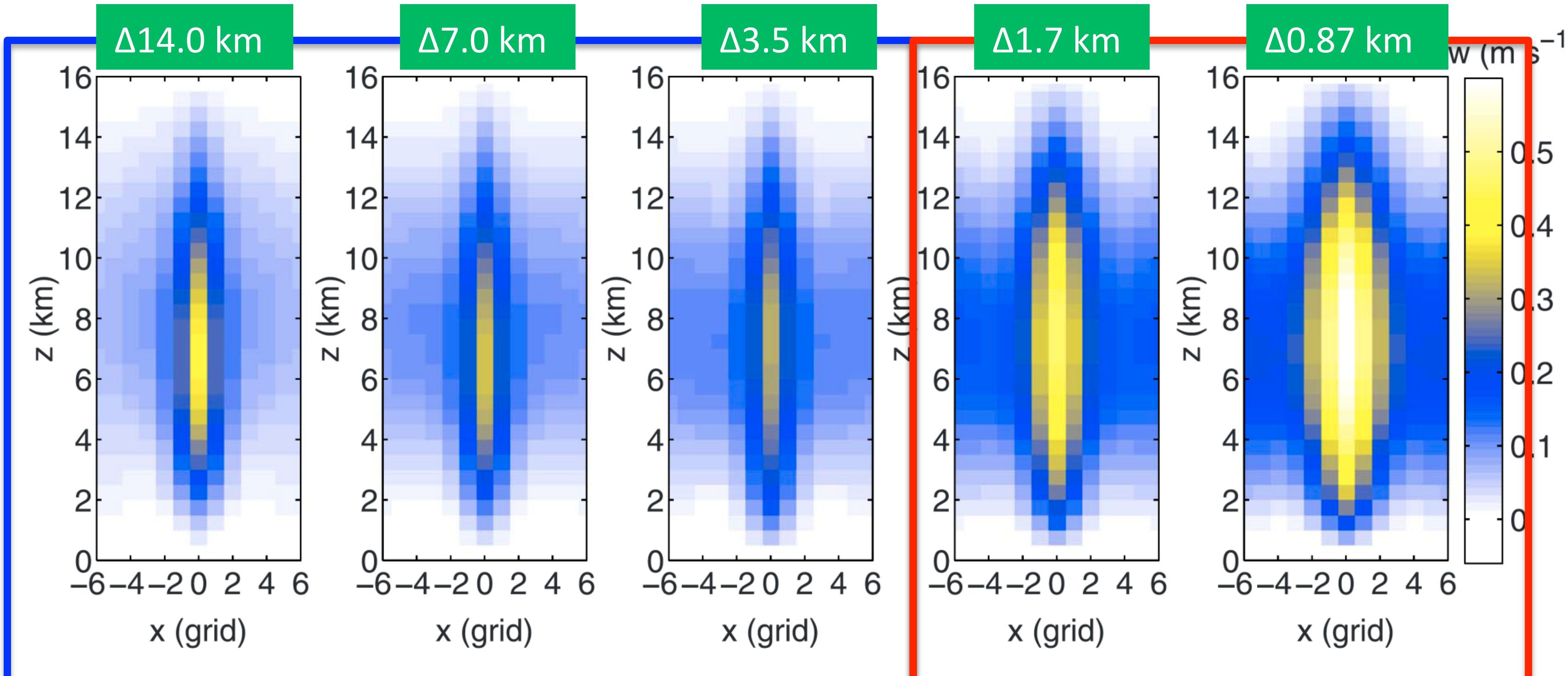


Figure 3. Radius-height cross sections for composites of vertical velocity *w* for all detected convections in each simulation. The horizontal axis is the number of horizontal grids.

- Convection is represented at <u>1 grid</u>
- Little dependence on resolution

- Convection is represented at <u>multiple grids</u>
- Intensify w/ resolution

Essential change of convection statistics

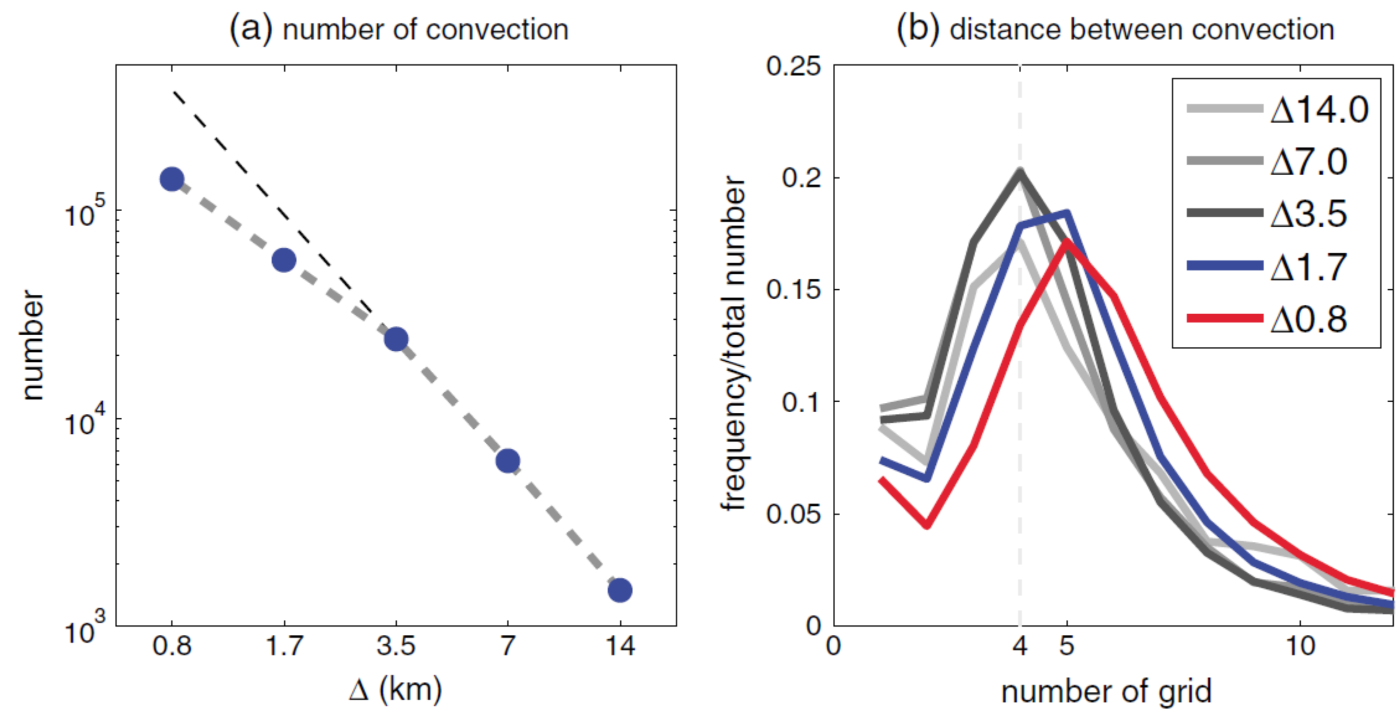


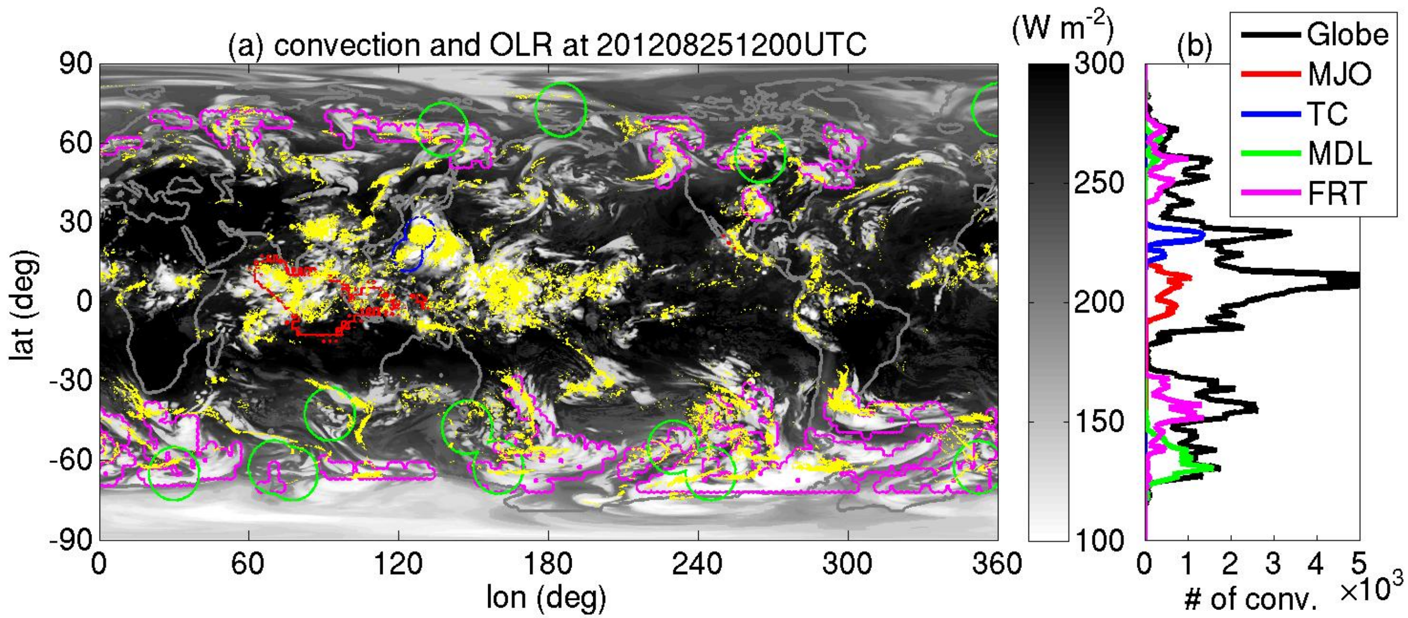
Figure 4. Resolution dependencies of convective features: (a) number of convective features and (b) grid distance to the nearest convective feature. The thin dashed line in (Figure 4a) indicates a log Δ^4 crossing at the point of Δ14 as a reference.

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

Question 2

Is there difference in convection structure and intensity in could 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

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

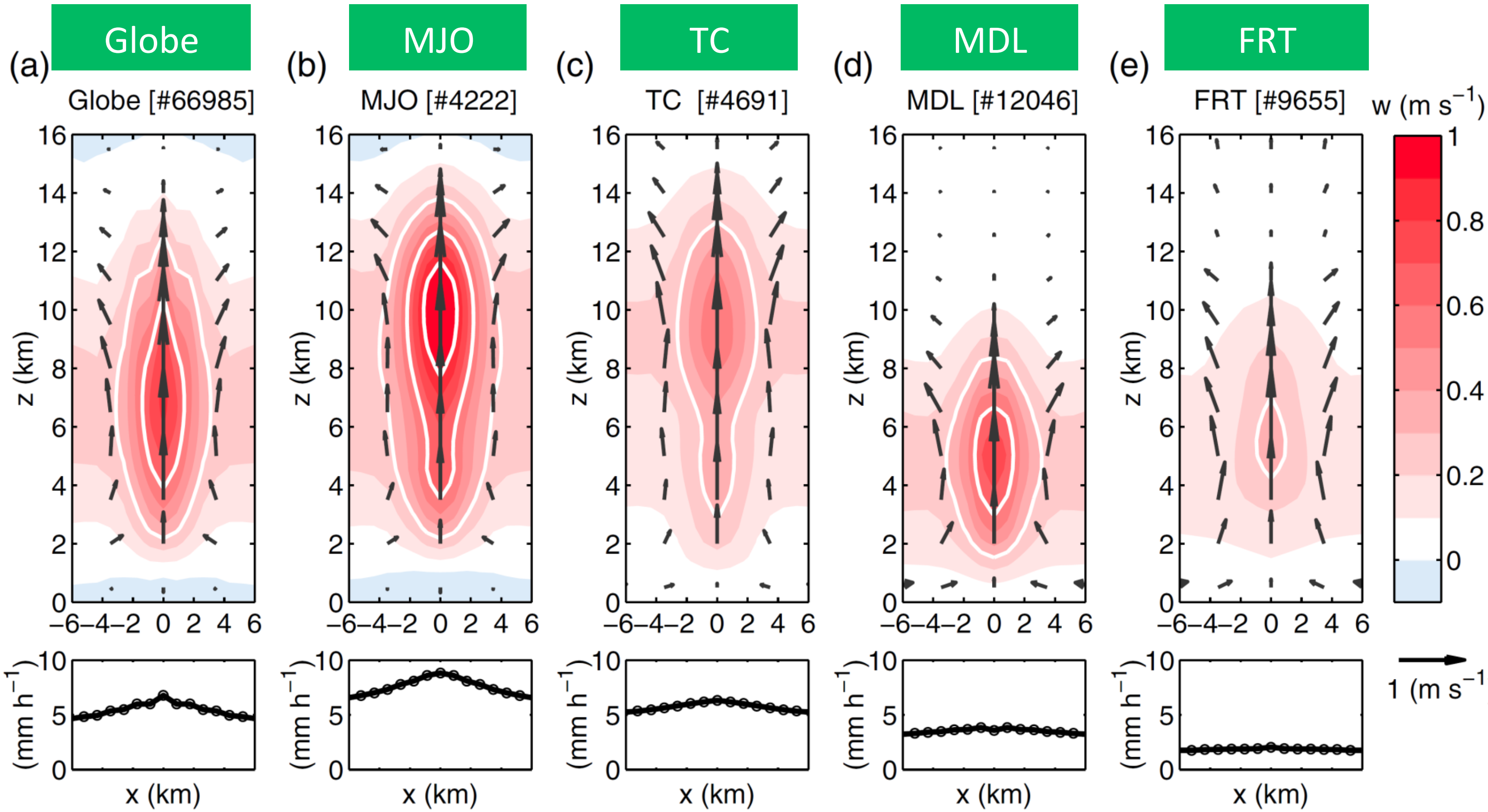
MiD-latitude Low（MDL）

- 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

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

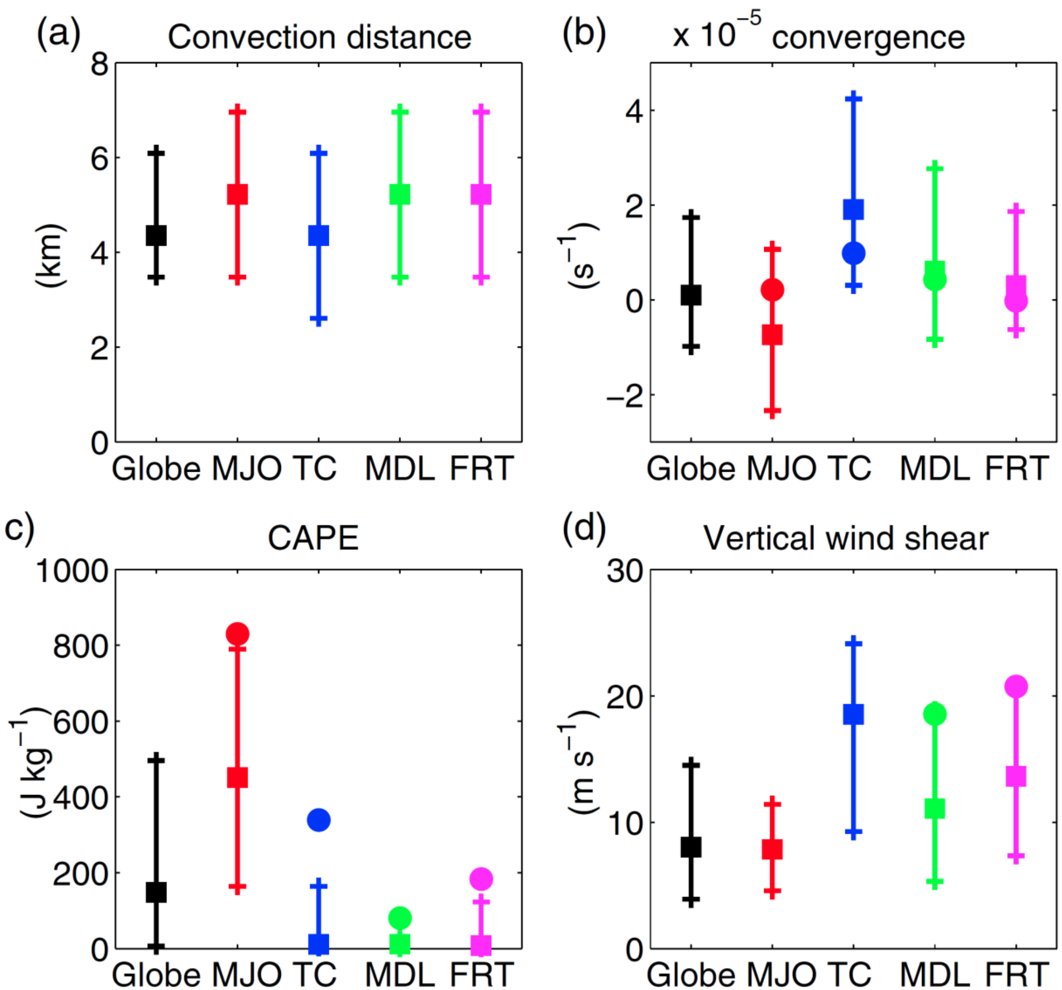
Convection structure in each disturbance

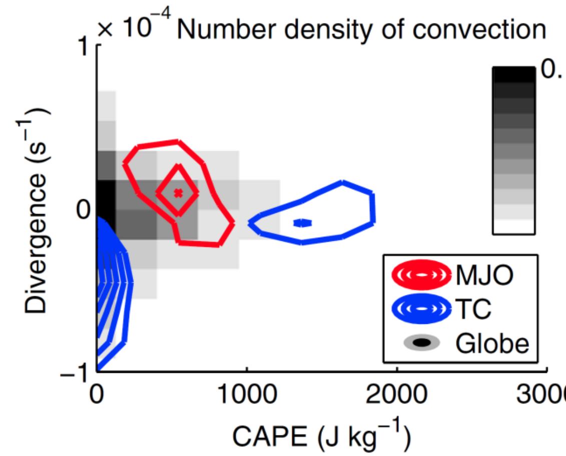


Height	High	High	Low	Low
Max W	Strong	Weak	Strong	Weak

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

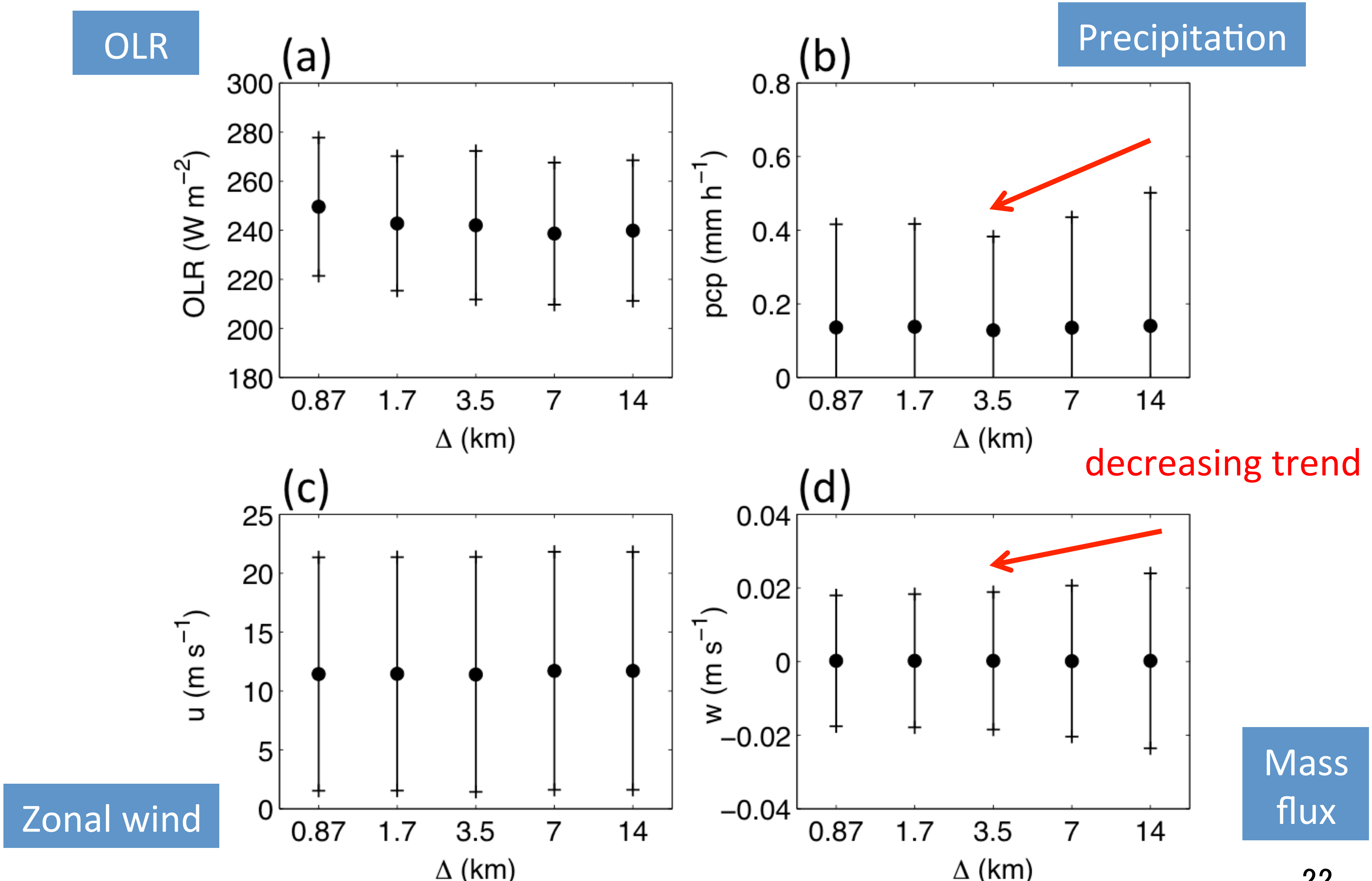
Question 3

In what area does convection make the largest contribution to the global mean?

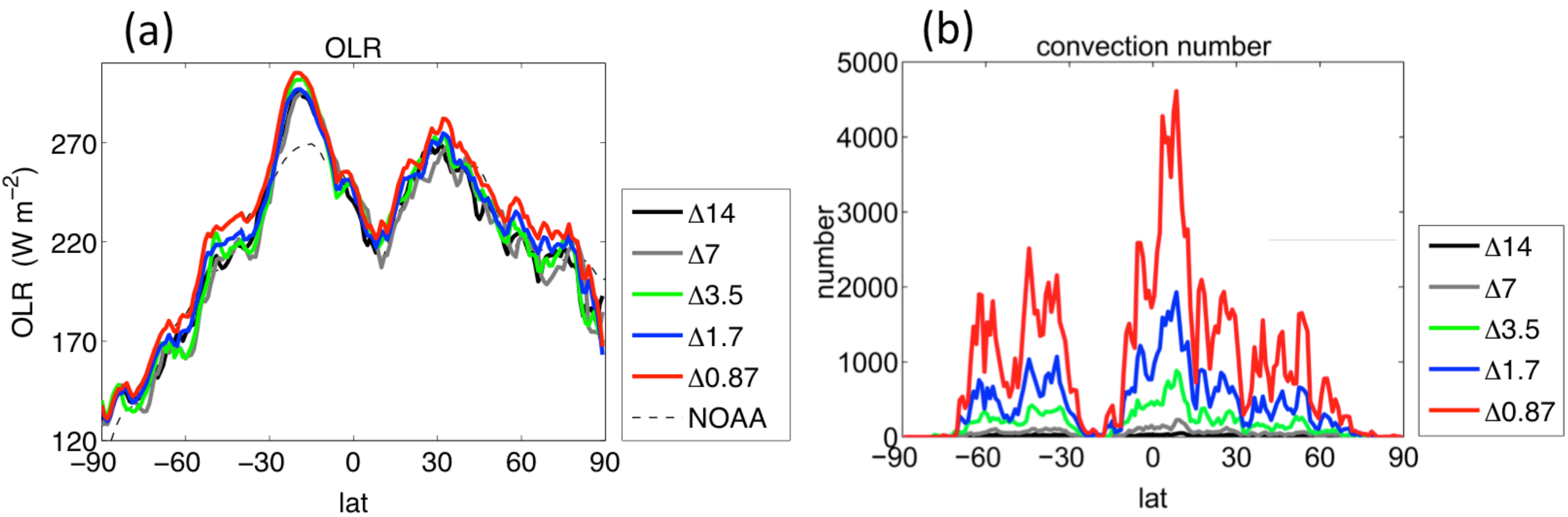
(**What environmental condition** is effective in producing the diversity of convection properties)

Resolution Dependence in the Global Field

Resolution Dependence in the Global Field

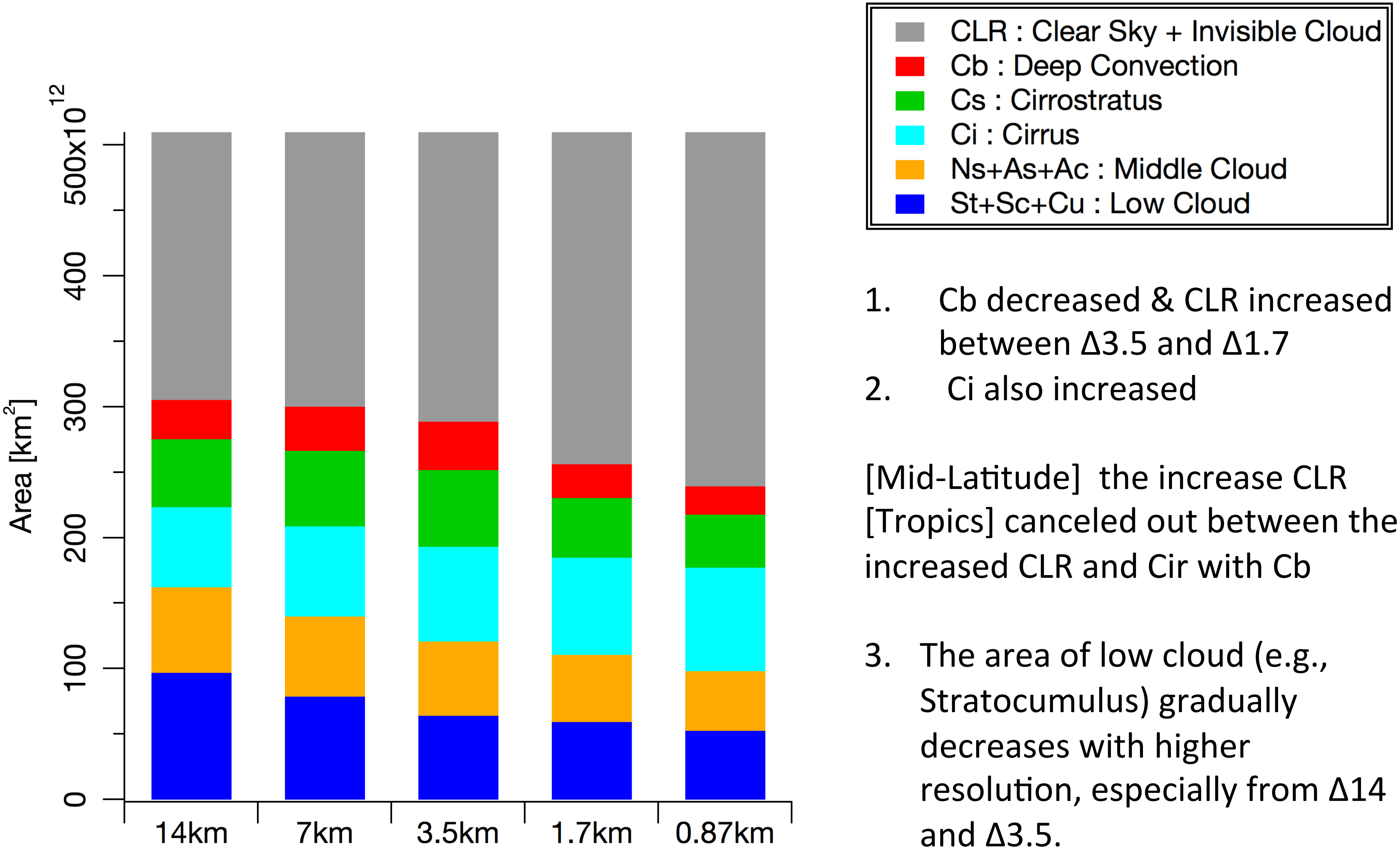


Zonal mean OLR and the # of detected convections



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

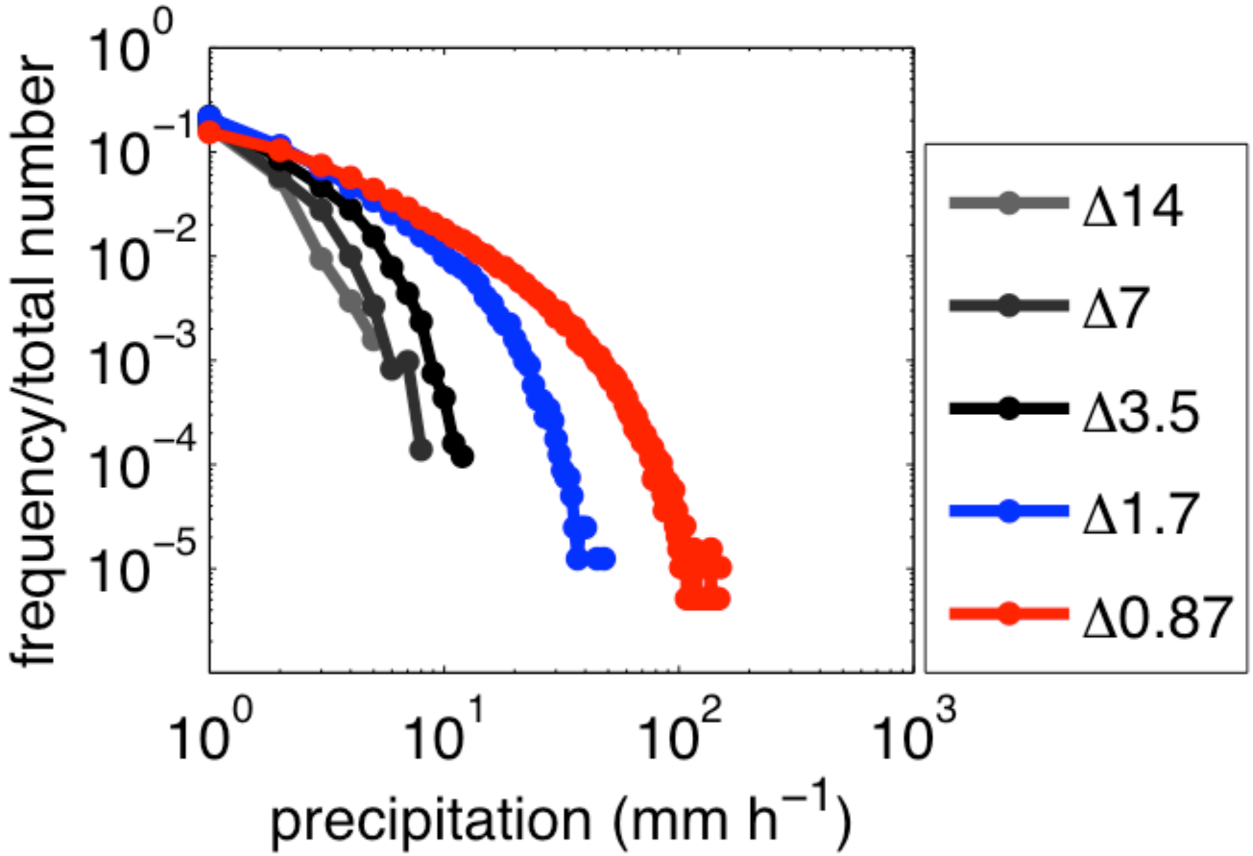


1. Cb decreased & CLR increased between Δ3.5 and Δ1.7
2. Ci also increased

[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.

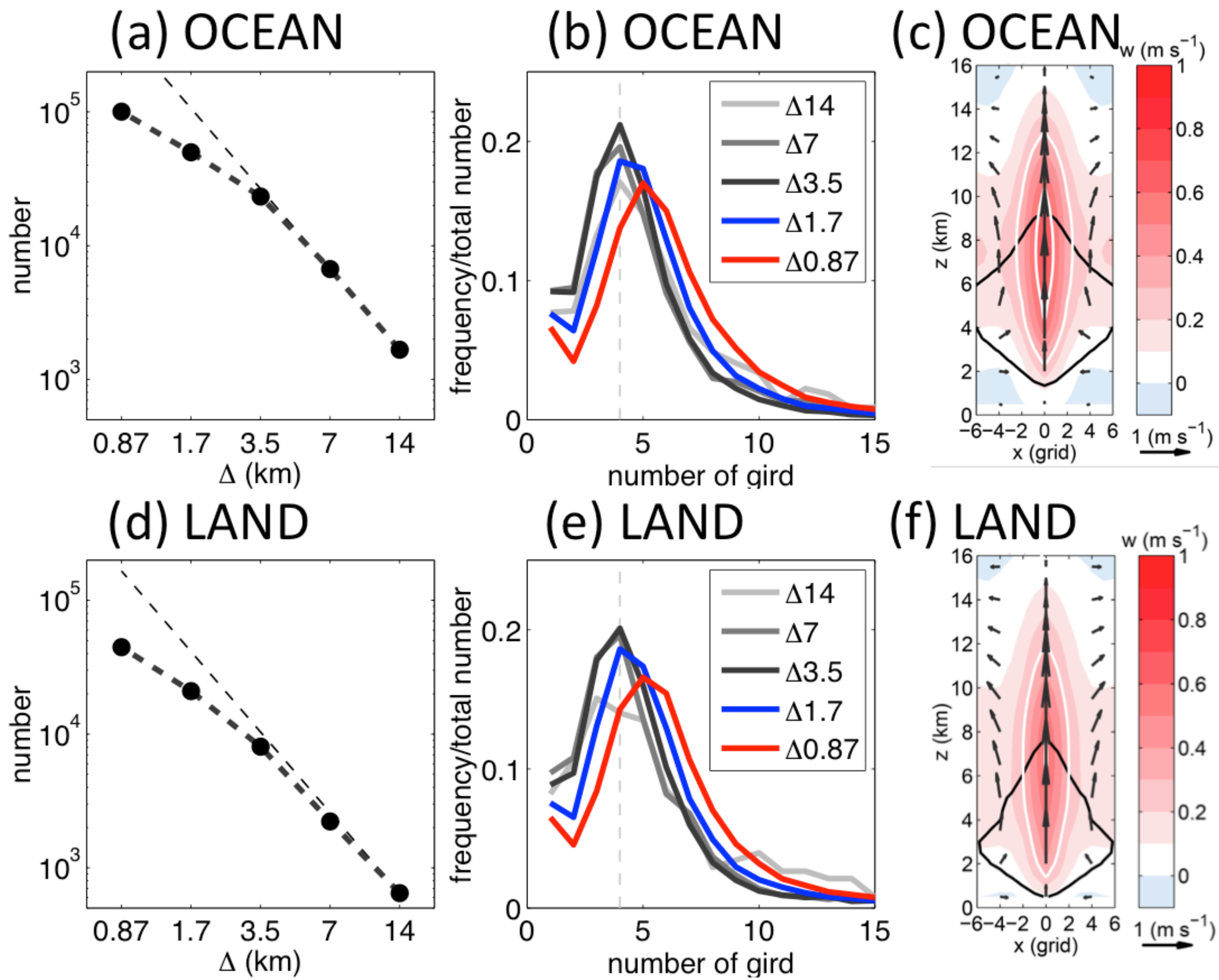
Resolution dependence of the precipitation rate



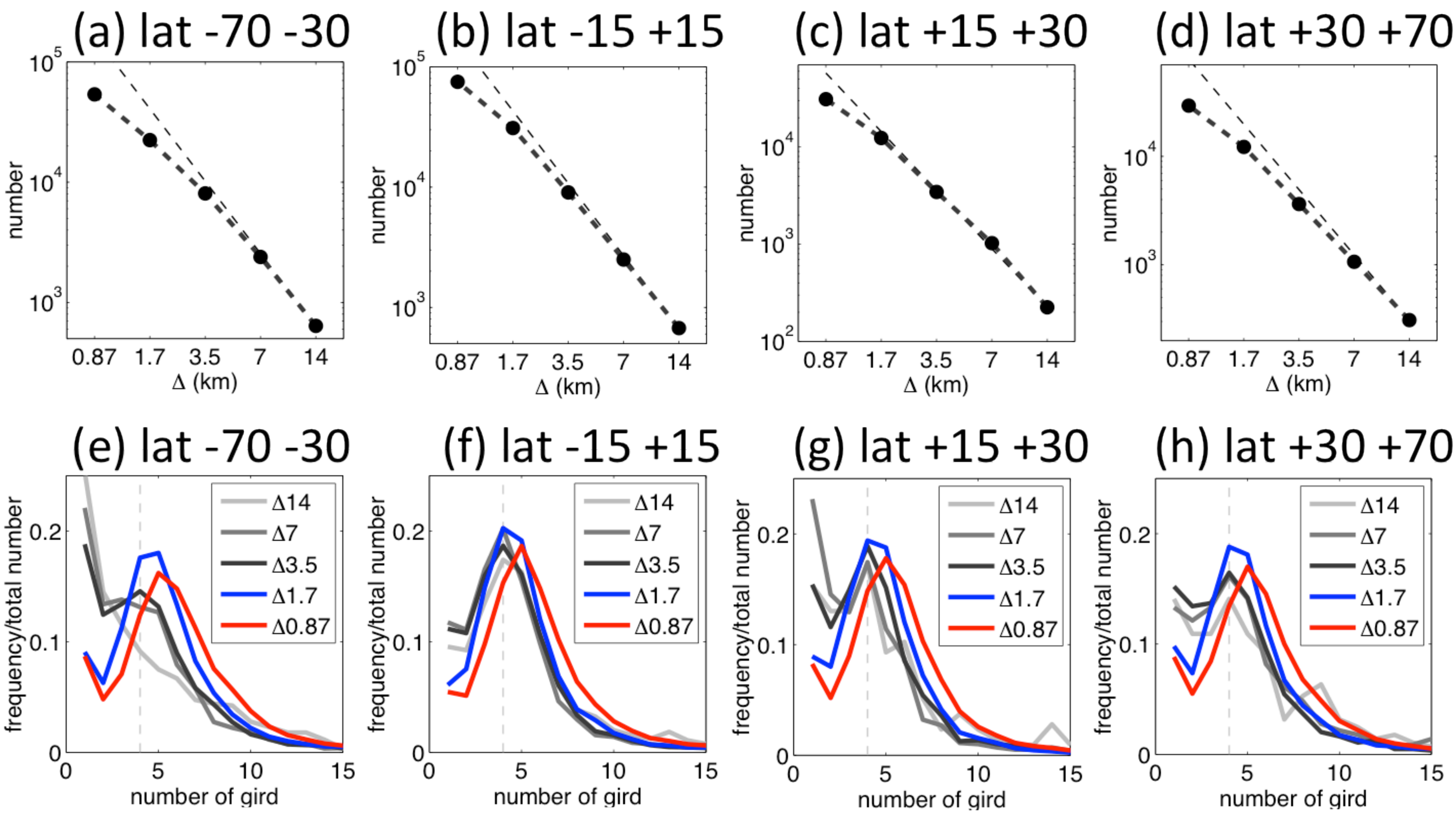
1. Strong precipitation is shown in Δ1.7 (around 50mm h-1) and Δ0.87 (more than 100mm h-1).
2. The ratio of strong rainfall, which is in excess of 20 mm h-1, is drastically increased from Δ3.5 to Δ1.7.

Resolution Dependence on Convection Properties

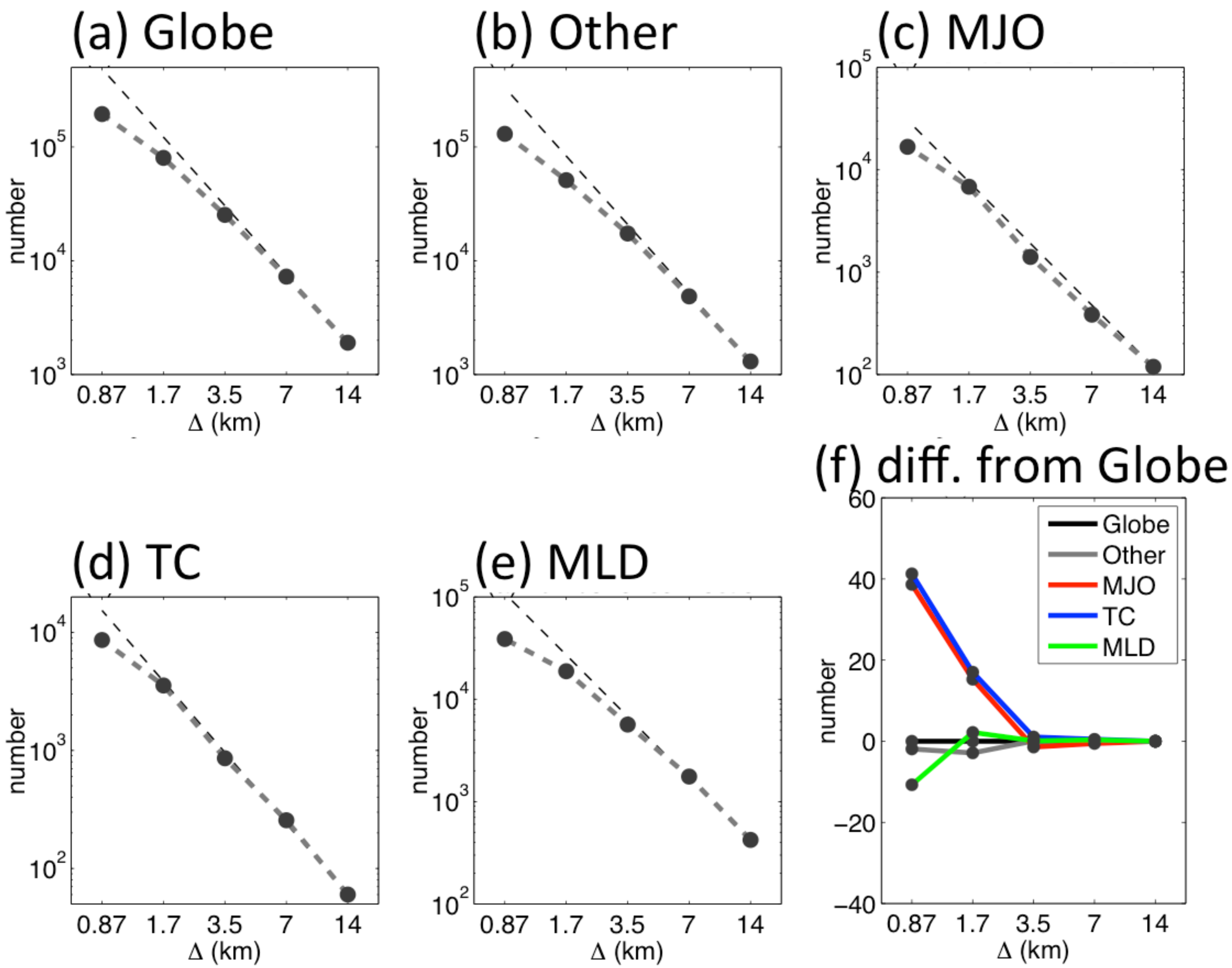
Land and Ocean Difference



Latitudal difference



Different Cloudy Disturbance



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.

Summary II

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 Δ1.7 and Δ0.87, 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.