Deep moist atmospheric convection in a sub-kilometer global simulation

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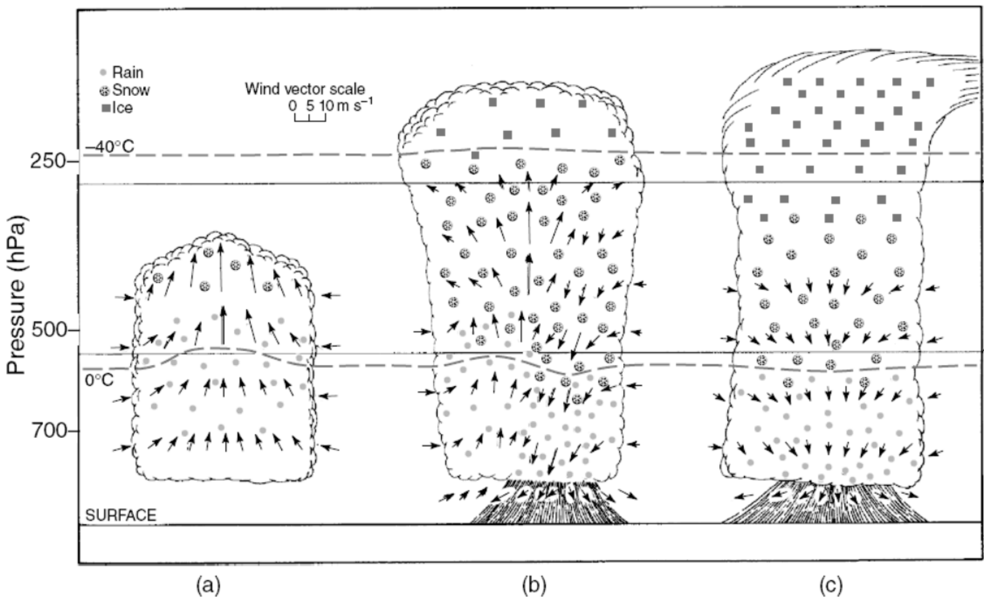
I. Background
II. Experimental Settings
III. Methodology for detection of convection
IV. Results
V. Conclusion

戦略分野3メソ課題研究会 March 7th, 2014 @Kobe

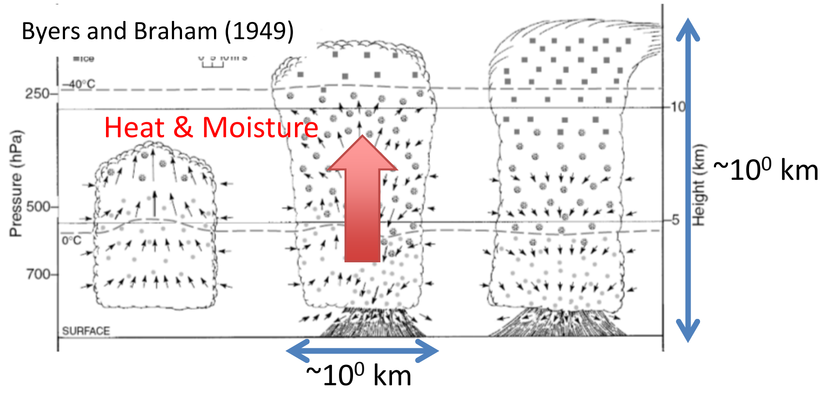
I. BACKGROUND

※deep moist convection := ”Convection”



Byers and Braham (1949)

Convection



Convection

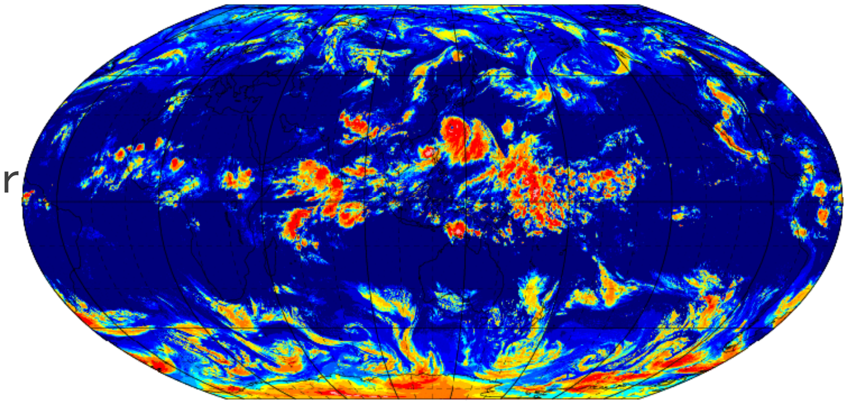
- Element of cloudy disturbances
- Transport heat and moisture

⇔ Horizontal scale (Δx) ～10^0 km

hard to explicitly solve in **<u>global models</u>**

(Δx～10^1 – 10^2 km)

←*cumulus parameterization*



2000～

Model development ＋enhancement of computer power => Δx ～ 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

Objective:

Reveal **the dependence of the simulated convection on resolution in global model** by describing the global statistical characteristics.

Experimental design

model	NICAM (Tomita and Satoh 2004, Satoh et al. 2008)
Initial state	3-day integrated results of 1-step coarser resolution
SST	NCEP analysis + 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）

※72 h integration before producing initial fields

Computational Cost

- Nodes used: 20480 (˜160000 cores)
- Wall-clock time: 53 h
- Sustained performance: 7˜8 %
- Storage: 200 TB

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
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Δ1.7	1.7	2012082500	12 hours	Δ3.5
Δ0.8	0.8	2012082500	12 hours	Δ3.5

Δx　　integration period（12 h）

※72 h integration before producing initial fields

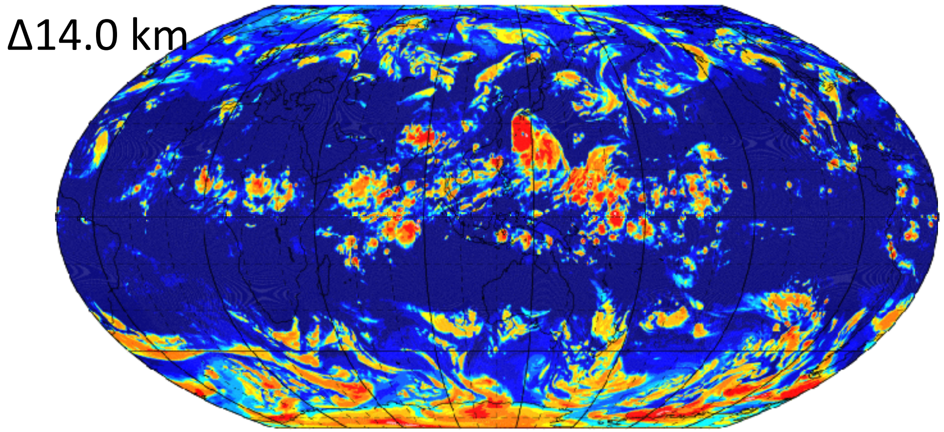
NICAM 870 m - 96 levels

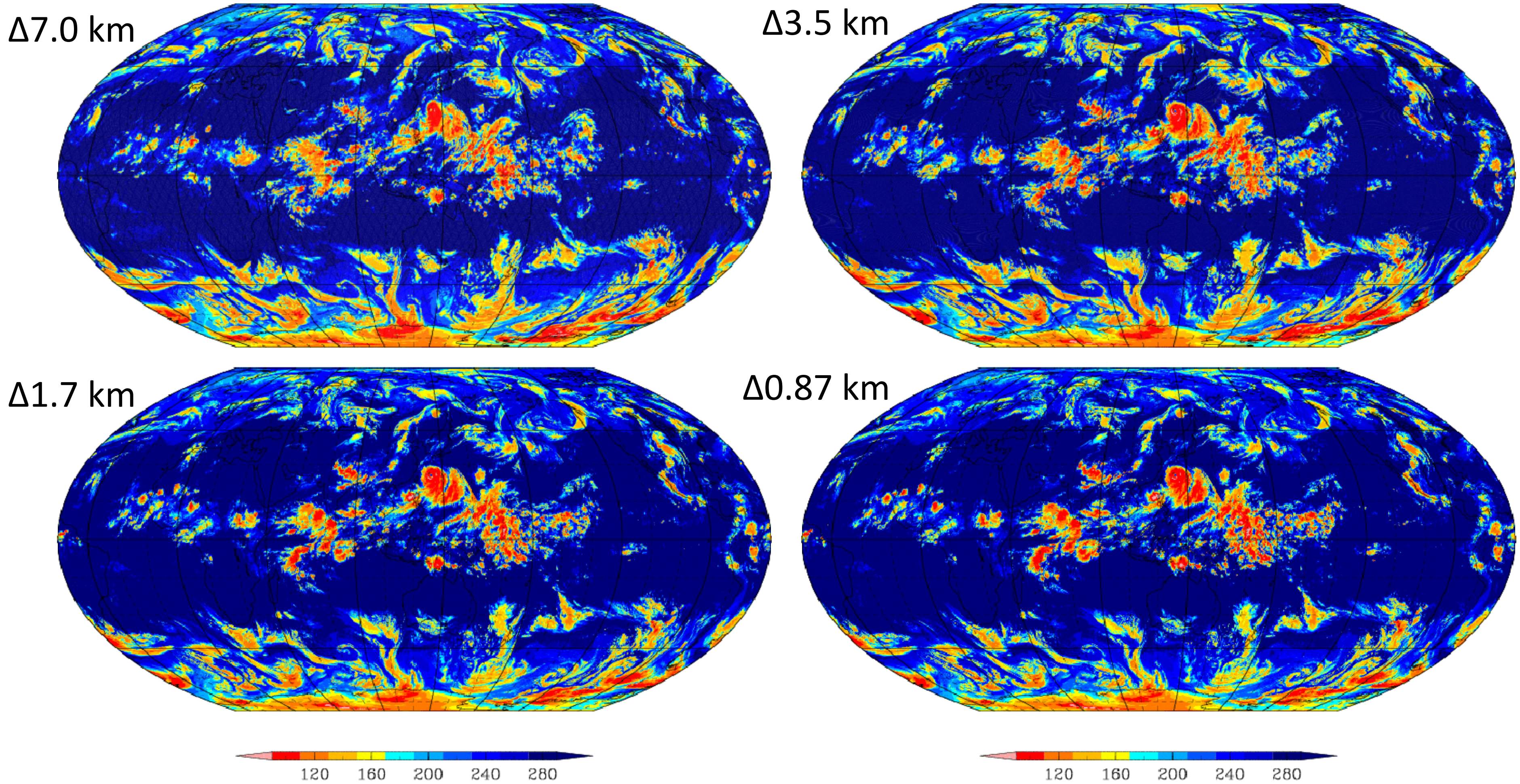
Real Case Simulation: 25 - 26, Aug., 2012

SPIRE field-3: Study of extended-range predictability using GCSRAM

RIKEN / AICS: Computational Climate Science Research Team

Snap shot of OLR
12-h integrations





II. METHOD OF DETECTING CONVECTION

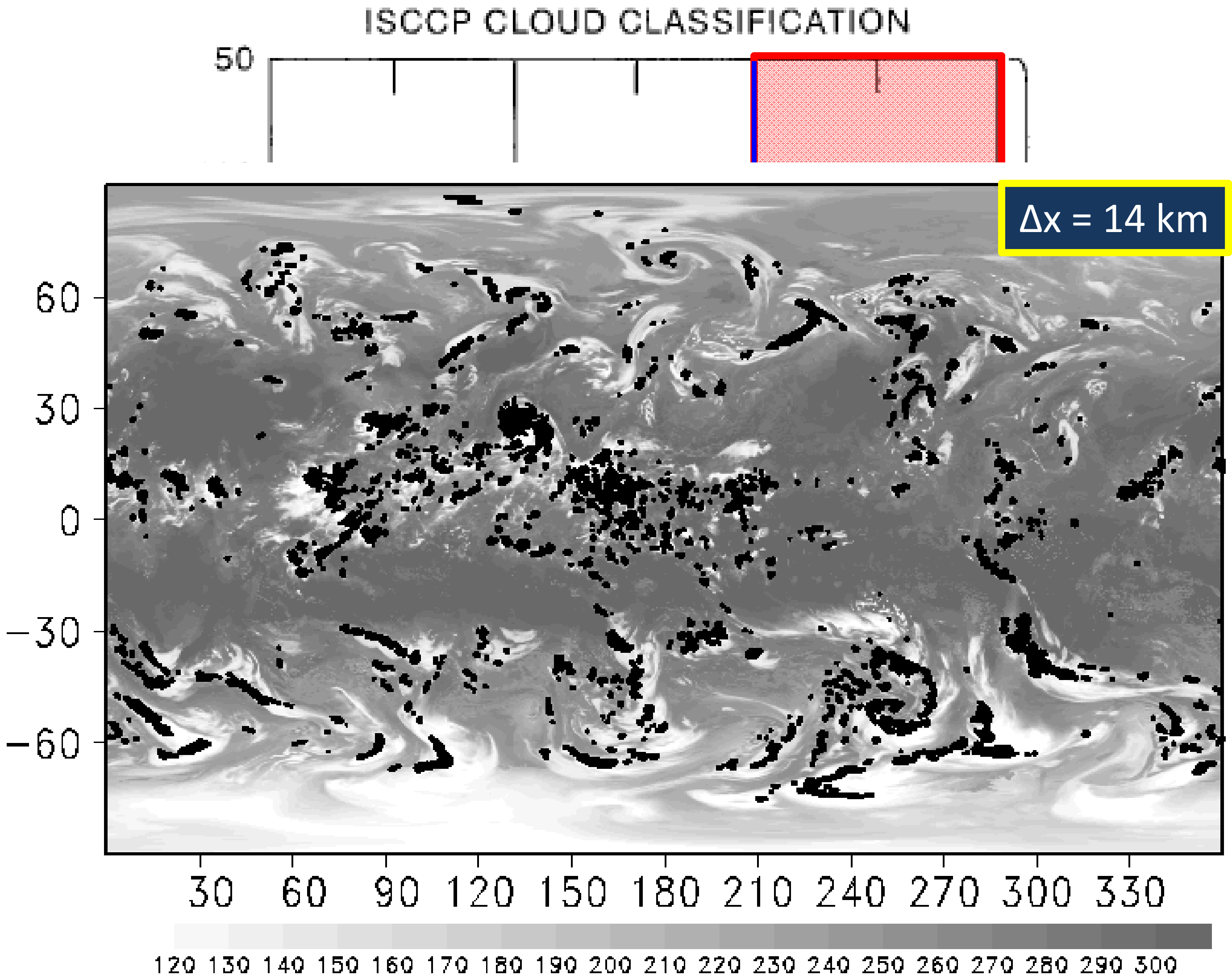
1. Detect “convective grids” by ISCCP table
2. Determine “convective core” grids

Cumulonimbus Clouds over the Pacific Ocean

Latitude: 14.3 ° N   Longitude: 102.4 ° W

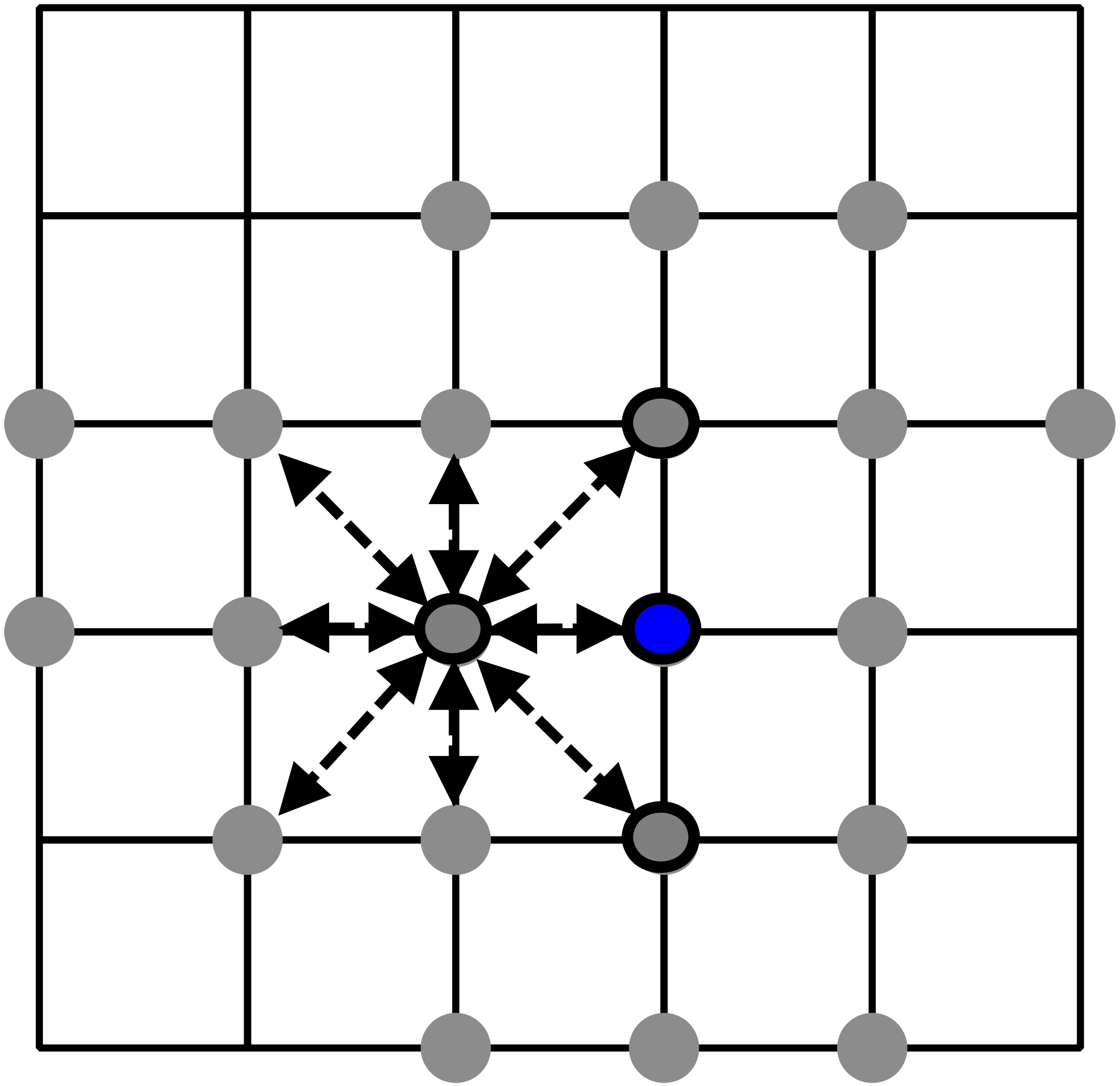
ISS027E035995

Step 1/2: Detect convective grids by ISCCP table



er 1999)

Step 2/2: determine convective core grids



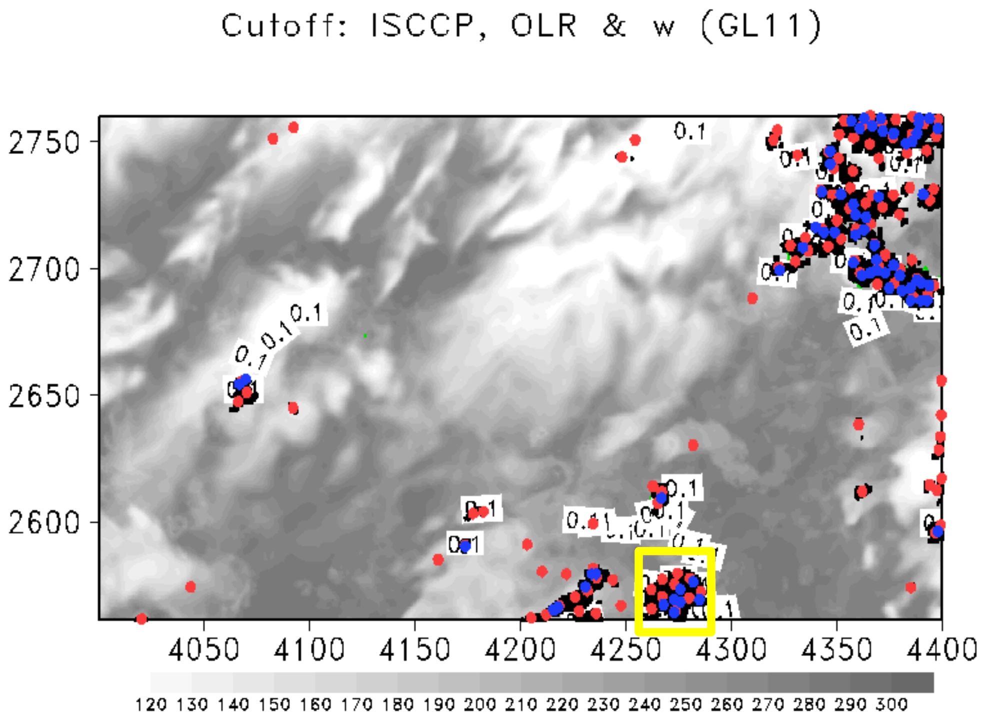
a) ISCCP convective grids (●)

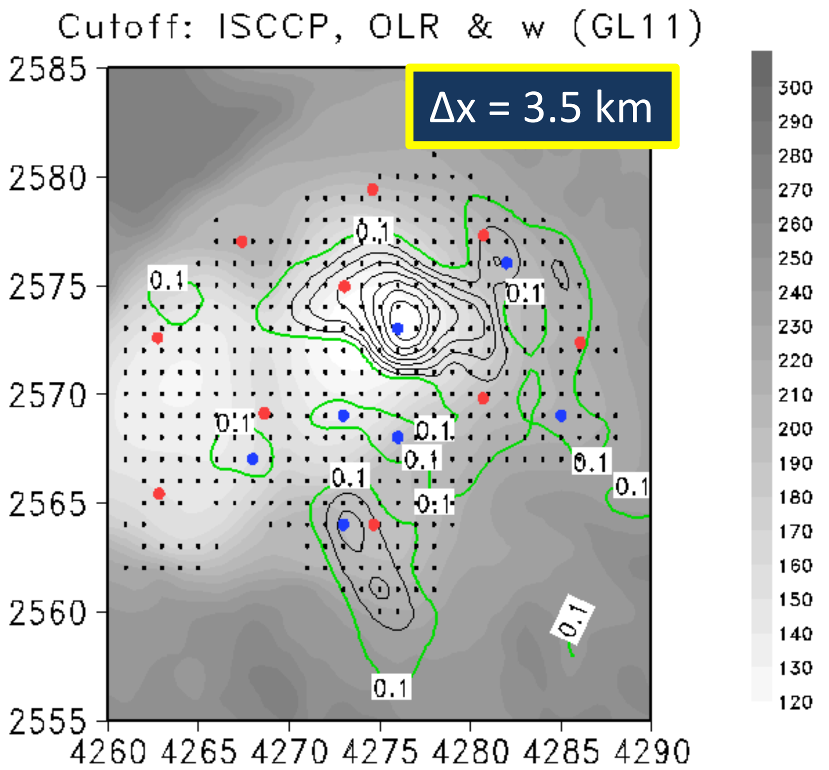
b) Find grids (●) at which all the surrounding 8 grids satisfy the ISCCP condition

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

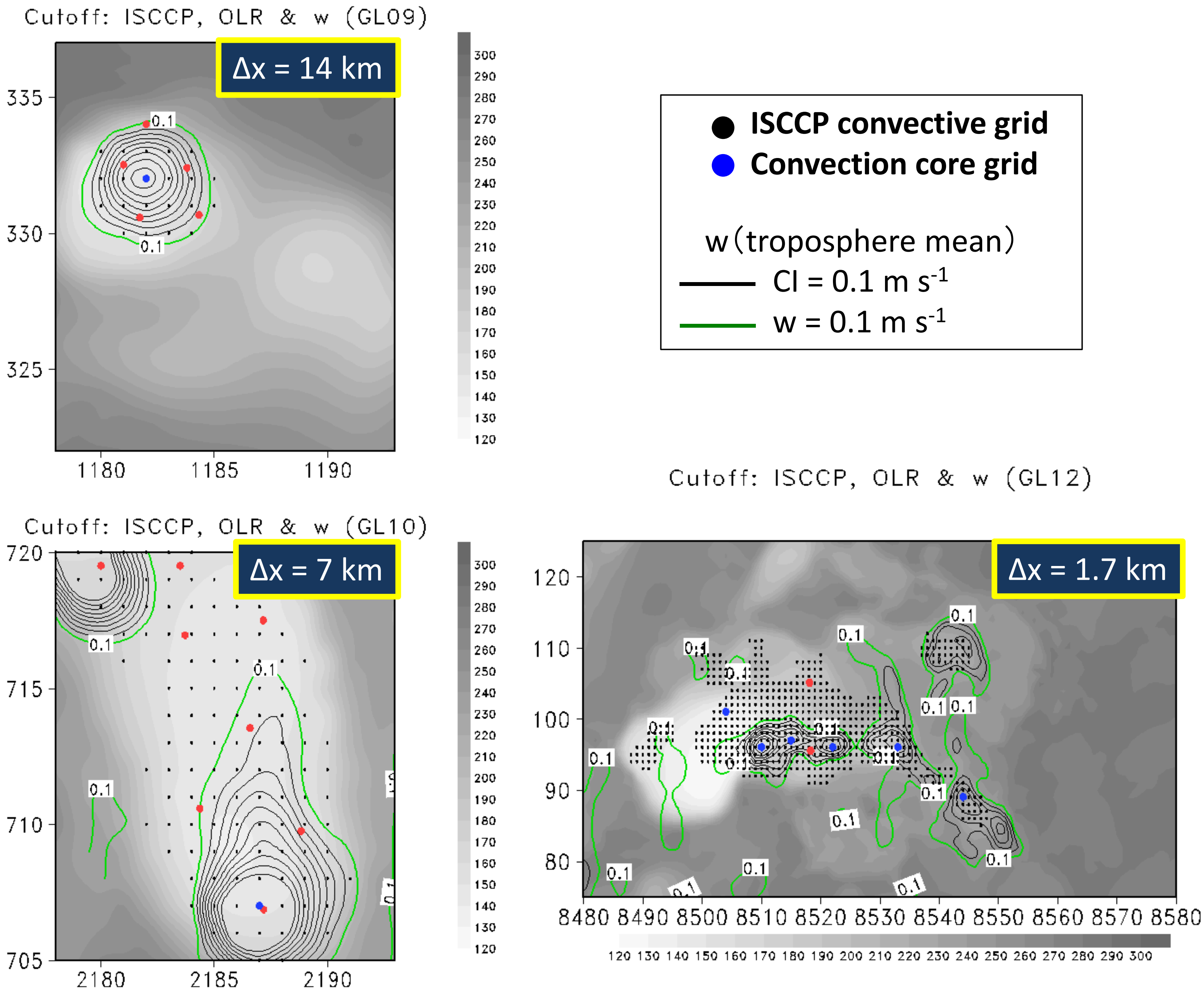
example（Δx=3.5 km）





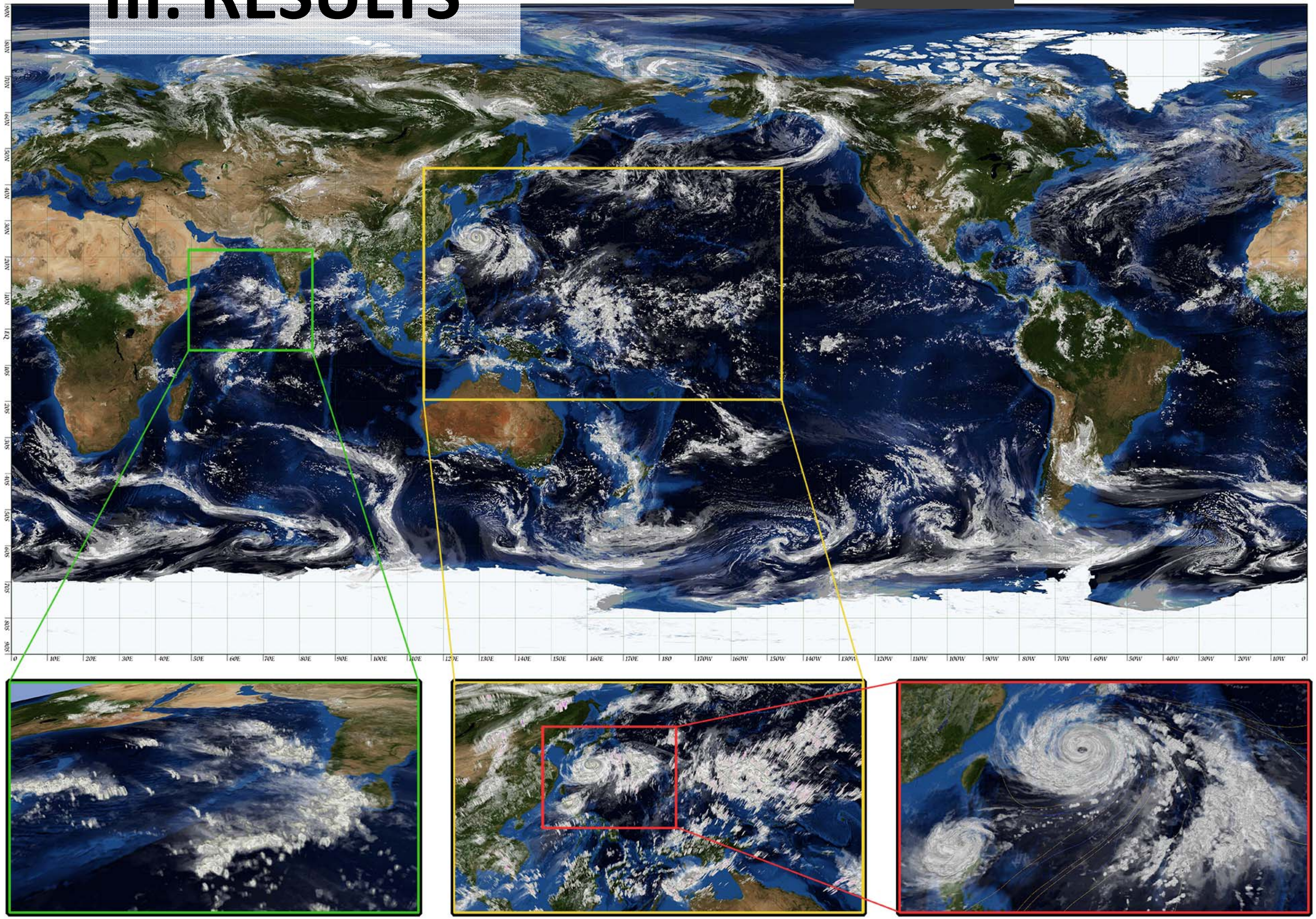
● **ISCCP convective grid**
● **Convection core grid**

w（troposphere mean）
— CI = 0.1 m s^{-1}
— w = 0.1 m s^{-1}

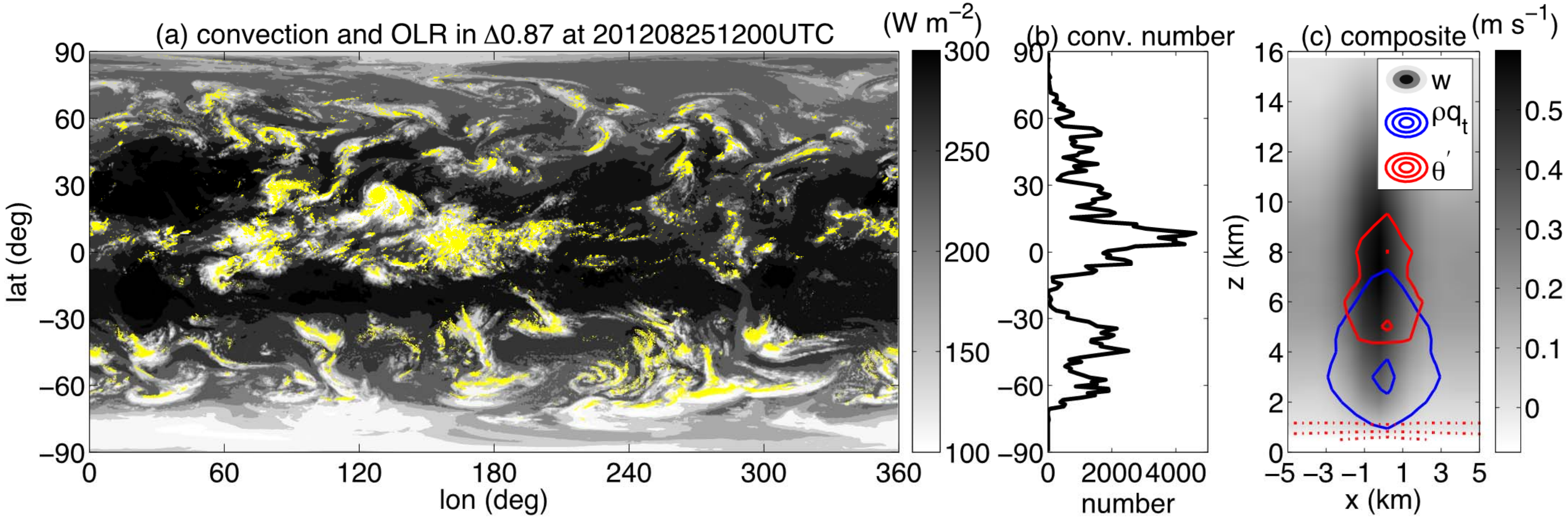

Cutoff: ISCCP, OLR & w (GL09)
Δx = 14 km
Cutoff: ISCCP, OLR & w (GL10)
Δx = 7 km
Cutoff: ISCCP, OLR & w (GL12)
Δx = 1.7 km
ISCCP convective grid
Convection core grid
w (troposphere mean)
CI = 0.1 m s-1
w = 0.1 m s-1

III. RESULTS

Δ0.87 km



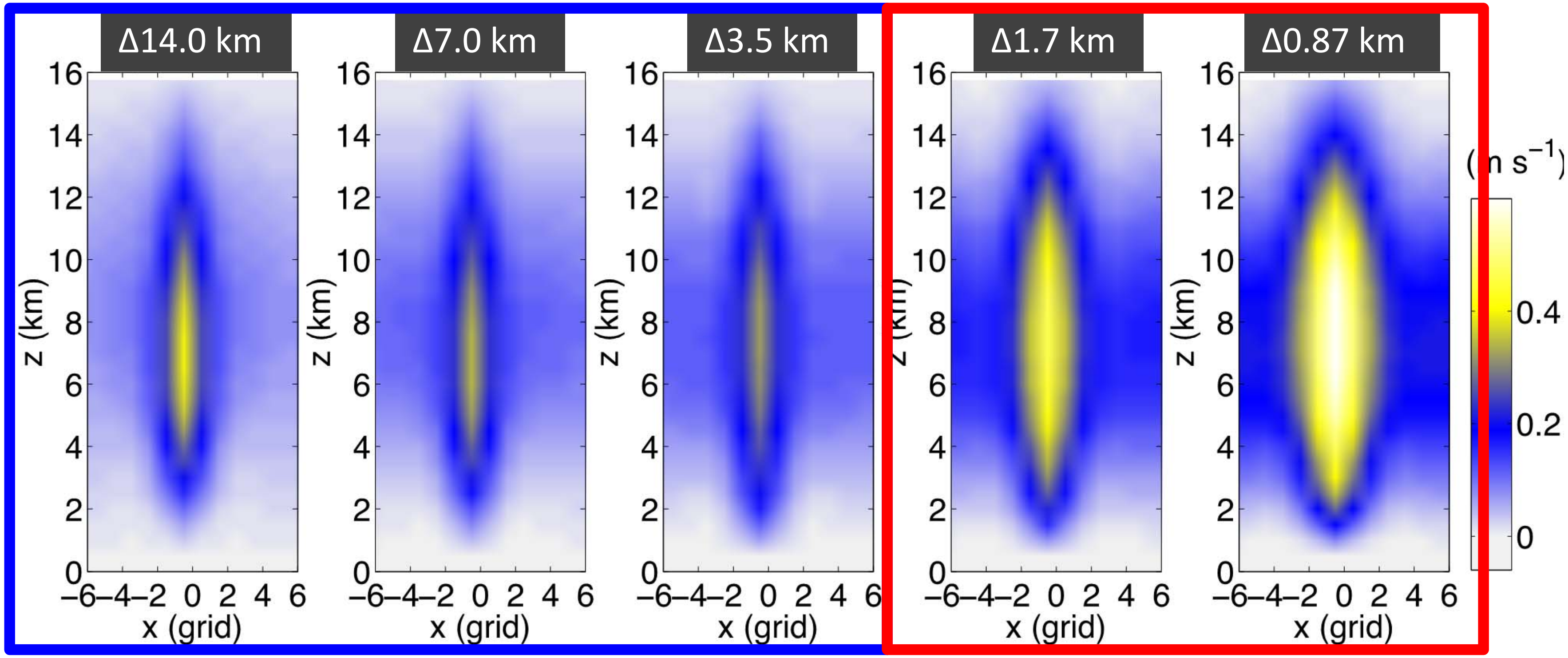
Composited structure of convection (GL13)



● Convection core grid

※transform the coordinate into the cylindrical around the core grid
mean of all the detected convection
symmetric around the x axis

Composite of convection (vertical velocity)



Δx ≧ 3.5 km:

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

Δx ≦ 1.7 km:

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

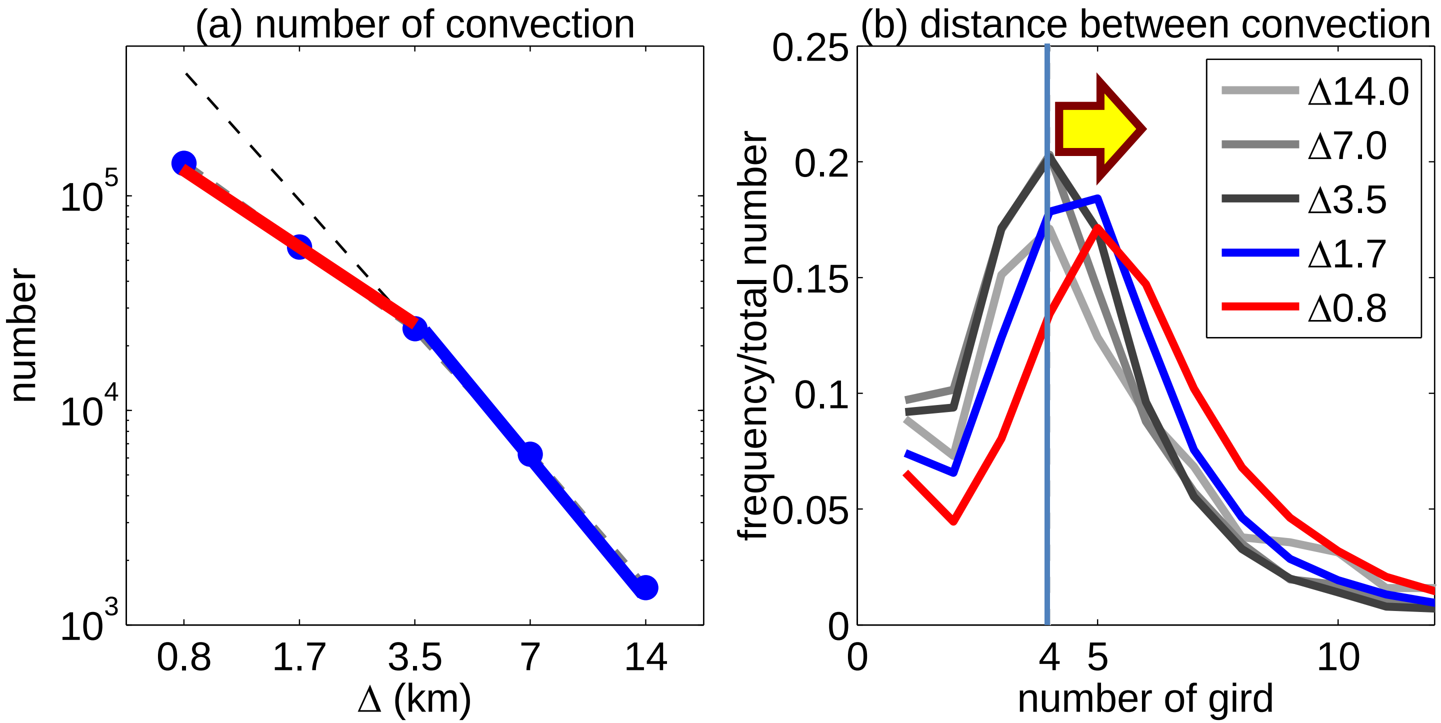
※transform the coordinate into the cylindrical around the core grid

mean of all the detected convection

symmetric around the x axis

X axis is normalized by resolution

Number and distance of convection



$\Delta x \geqq 3.5$ km:

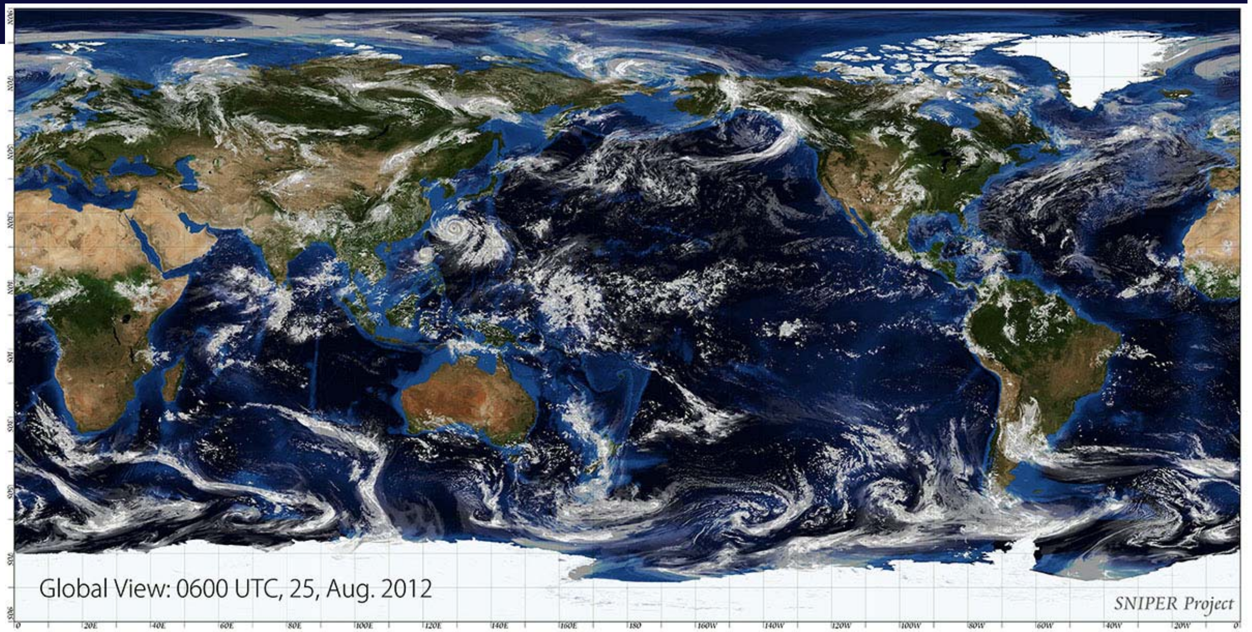
- number: increase by factor of 4
- distance: 4 grids

$\Delta x \leqq 1.7$ km:

- number: decrease in increasing rate
- distance: 5 grids

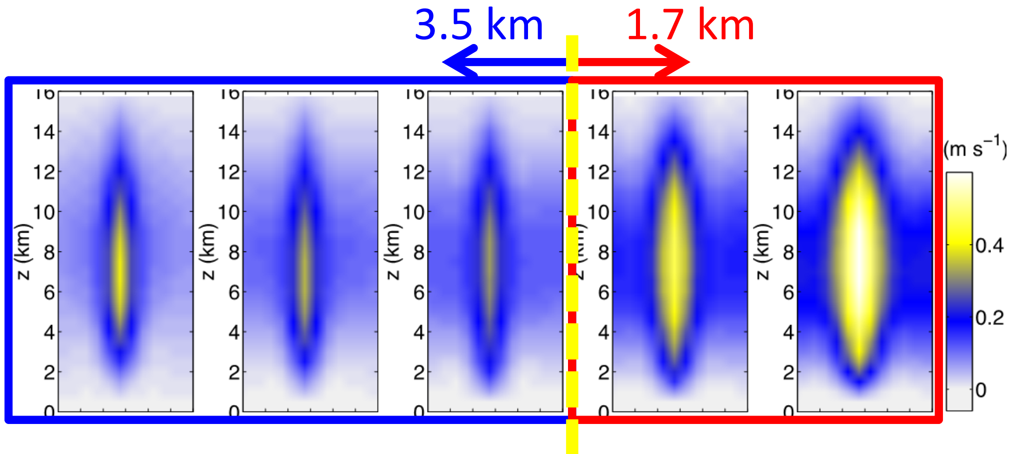
Summary

Global simulation with a sub-kilometer resolution



Finding

- ☐ Convection features (structure, number, distance)
  change between Δ3.5 km ⇔ Δ1.7 km
  - Δx should be 2.0～3.0 km to resolve convection in global models



Thank you very much for your attention!

Miyamoto, Y., Y. Kajikawa, R. Yoshida, T. Yamaura, H. Yashiro and H. Tomita, 2013: Deep moist atmospheric convection in a sub-kilometer global simulation, *Geophysical Research Letters*, **40**, 4922-4927.

Special thanks to Drs. H. Miura, S. Iga, S. Nishizawa, M. Satoh, our colleagues, and two anonymous reviewers for fruitful discussions. The authors are grateful to researchers and technical experts at RIKEN and FUJITSU for their kind help. The simulations were performed using the K computer at the RIKEN Advanced Institute for Computer Science.

SUPPLEMENT

What is the general characteristics of convection?

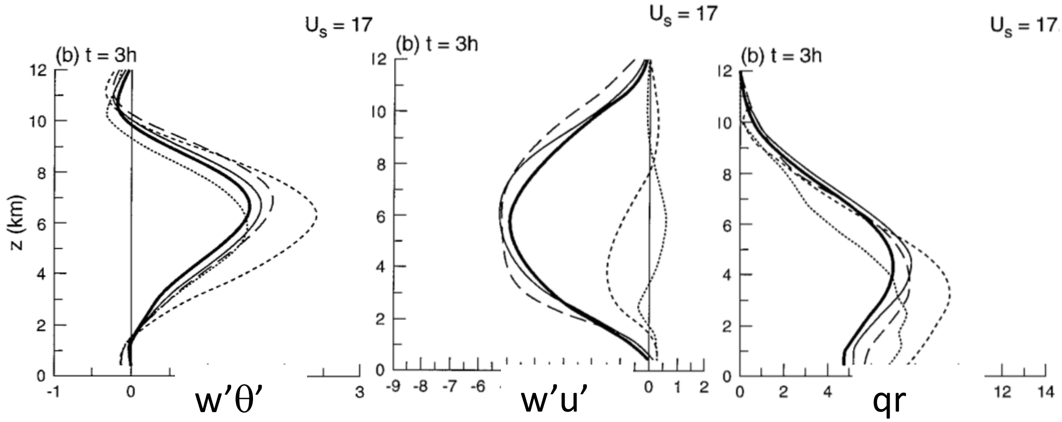
- Isolated convection
  - Element of amospheric cloudy disturbances
  - Transport of heat/moisture

What is the general characteristics of convection?

- ☐ Jorgensen and LeMone (1989): 50% of convection (core) has horizontal scale less than 1 km

- Resolution dependence
  - ☐ Weismann et al. (1997): dependence of squall line (Klemp and Wilhelmson (1979) cloud model)
    - Characteristics changes Δx less than and equal to 4 km

Is there any threshold of resolution in realistic conditions?

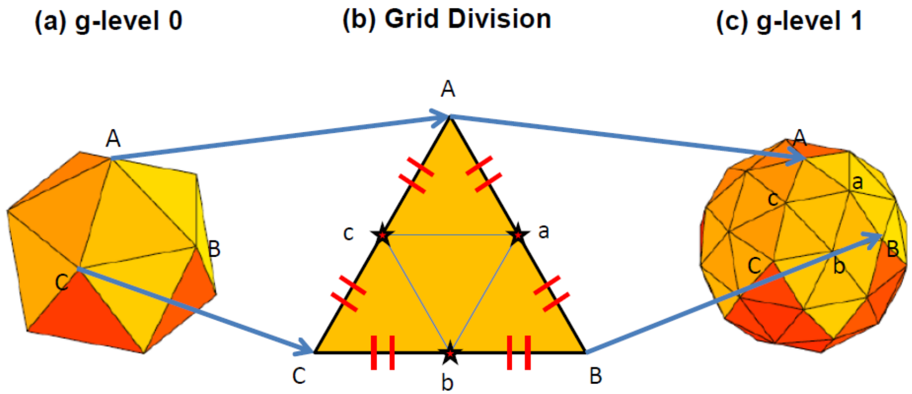


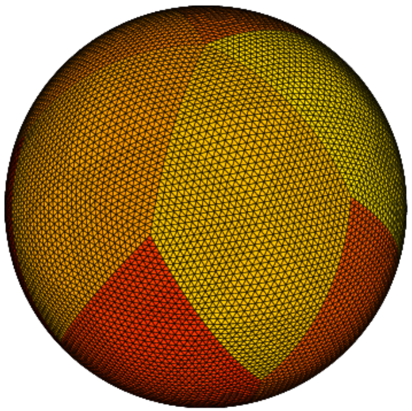
Weismann et al. (1997)

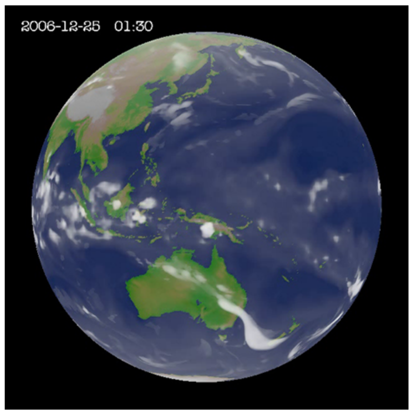
Model（NICAM, Tomita & Satoh 2004, Satoh et al. 2008）

Global cloud-system resolving model

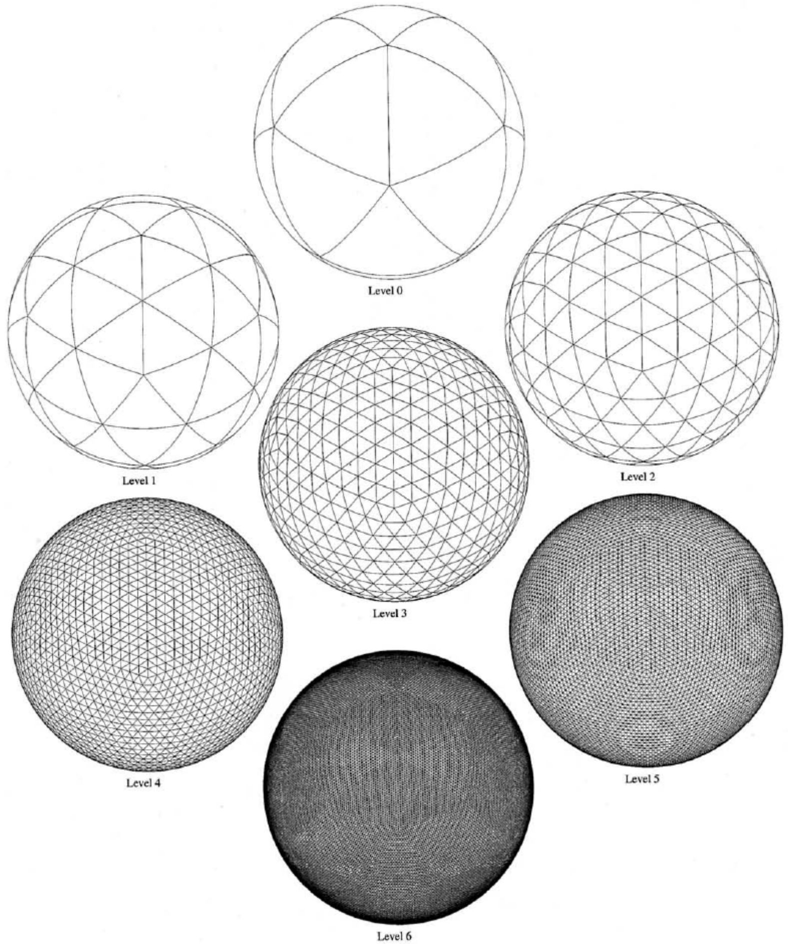
- Icosahedral grid
- nohydrostatic DC
- explicit cloud expression:





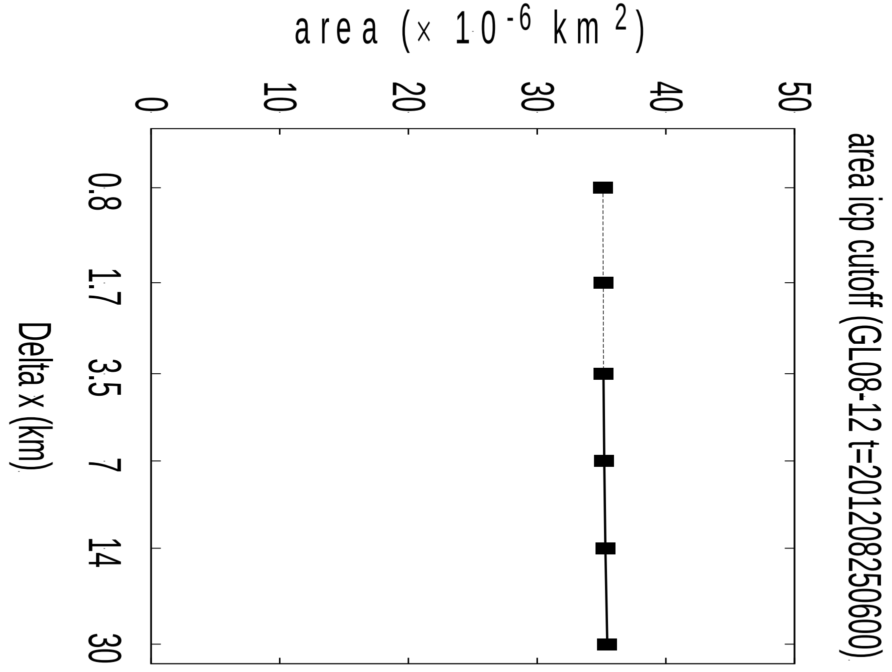


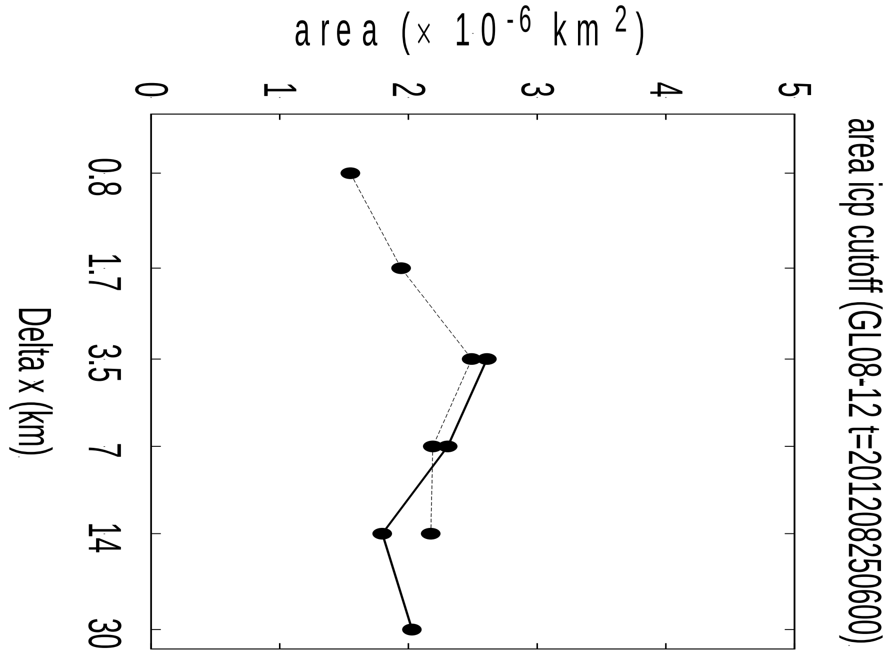
Miura et al. (2007)

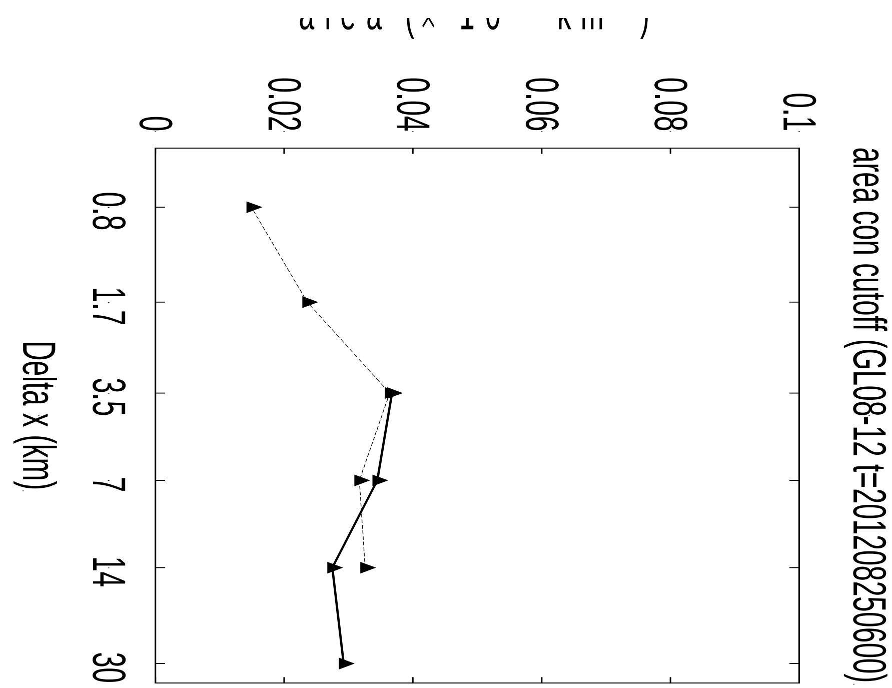


面積

解析範囲:
130—190E, -15—15N



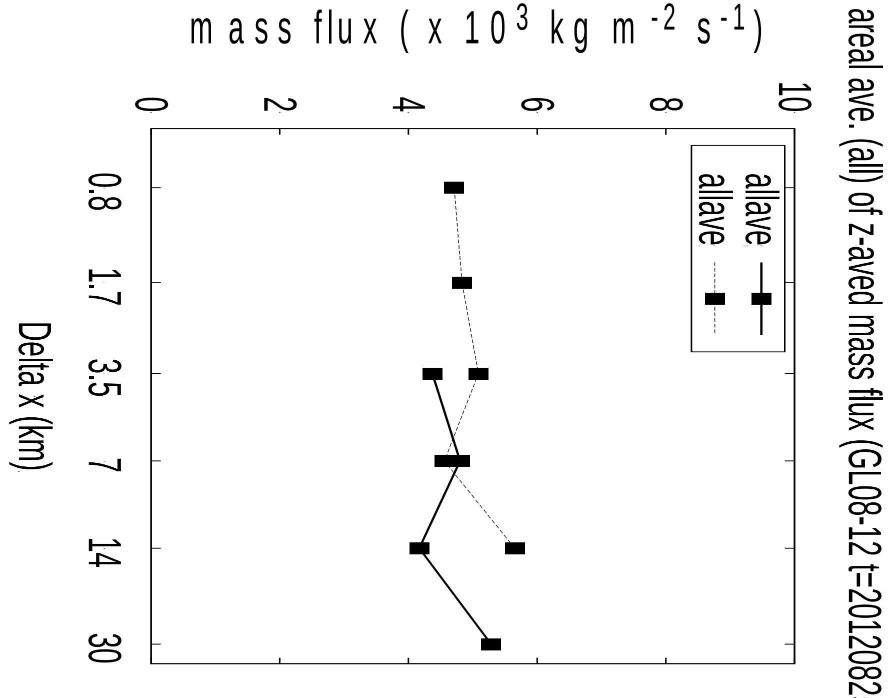


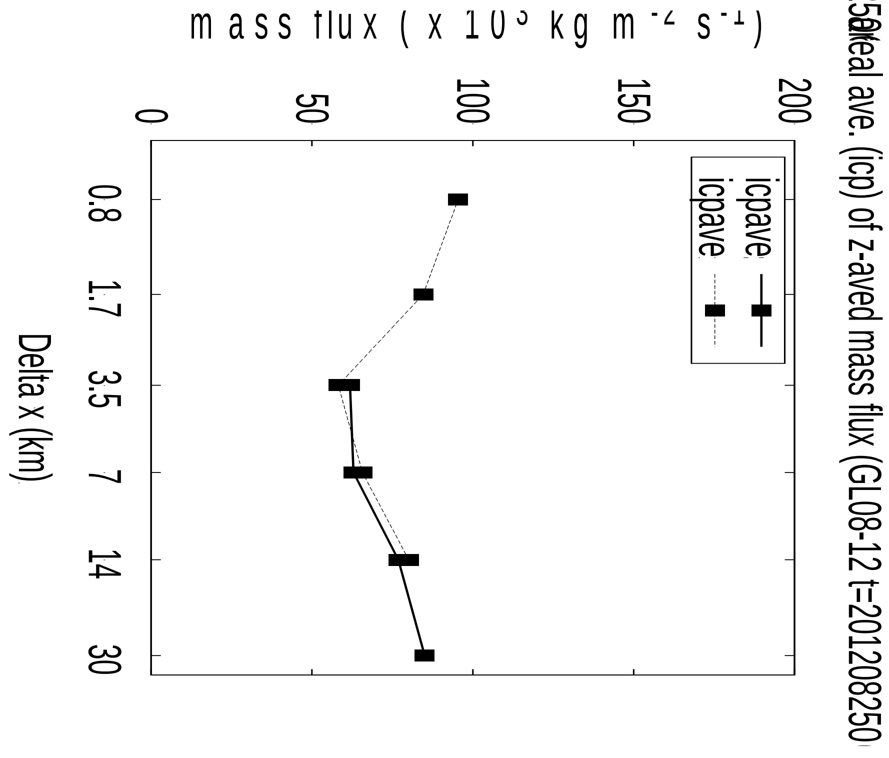


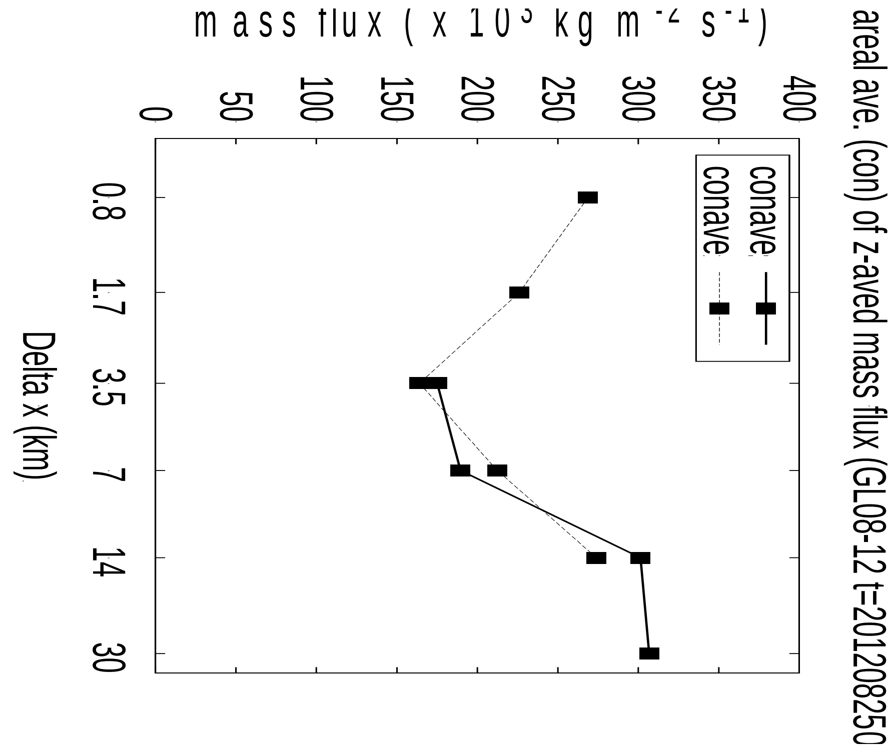
面積平均質量フラックス

解析範囲:

130—190E, -15—15N

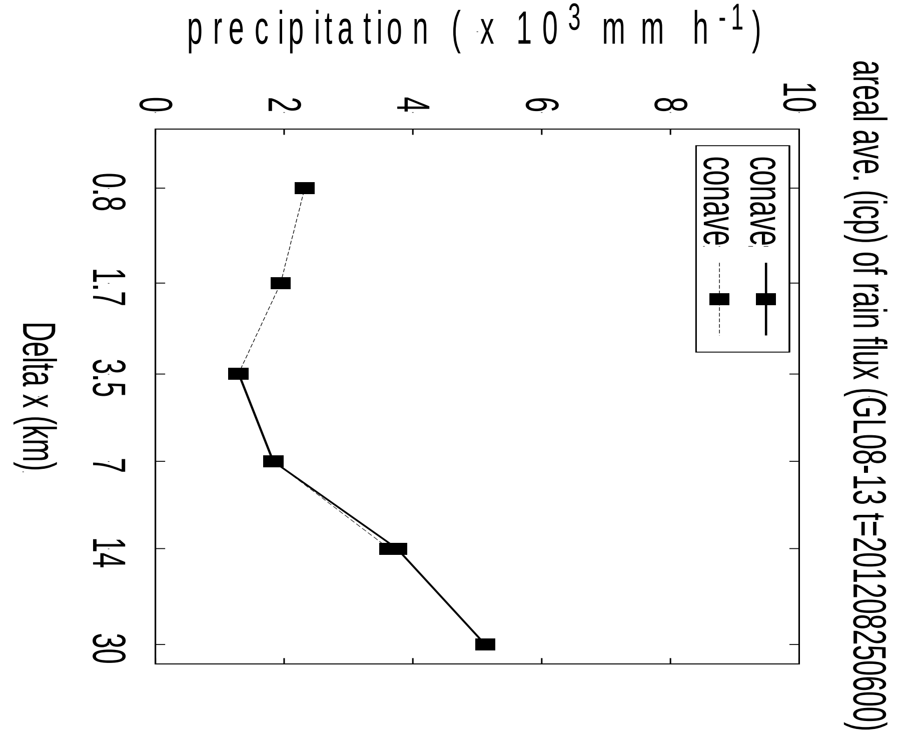


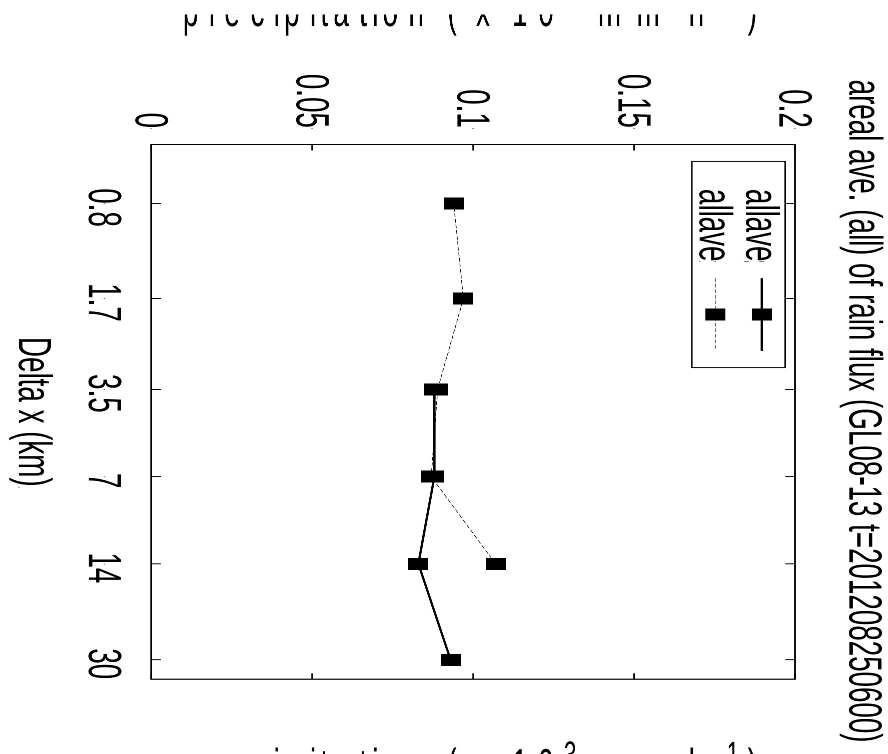


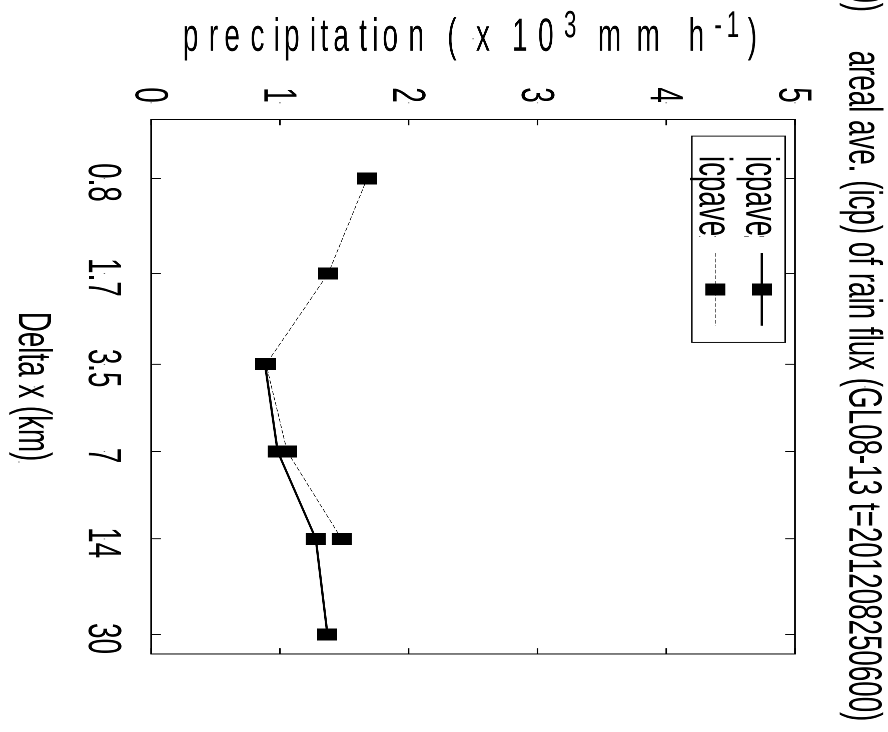


面積平均降水量

解析範囲:
130—190E, -15—15N



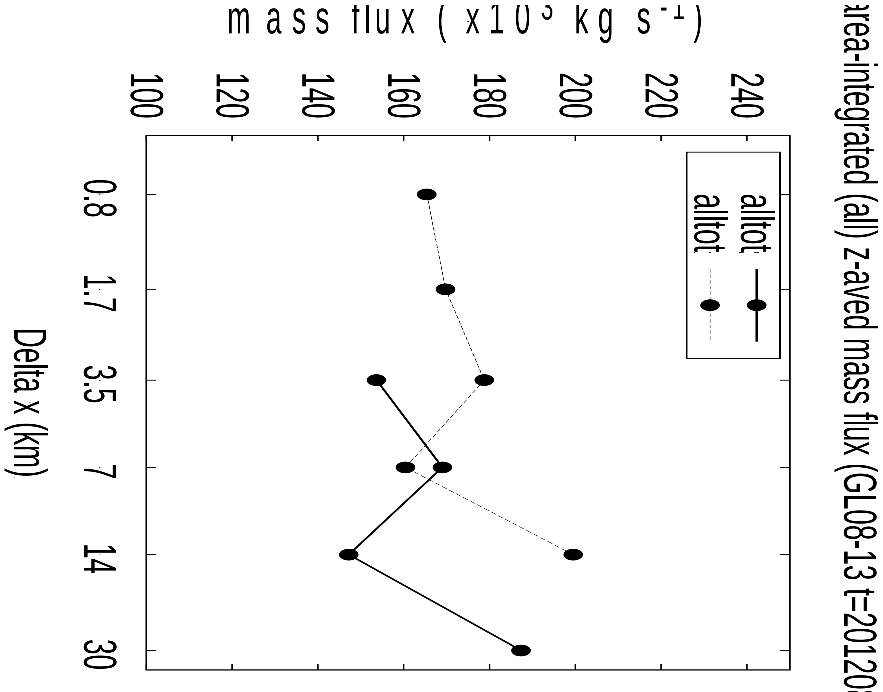


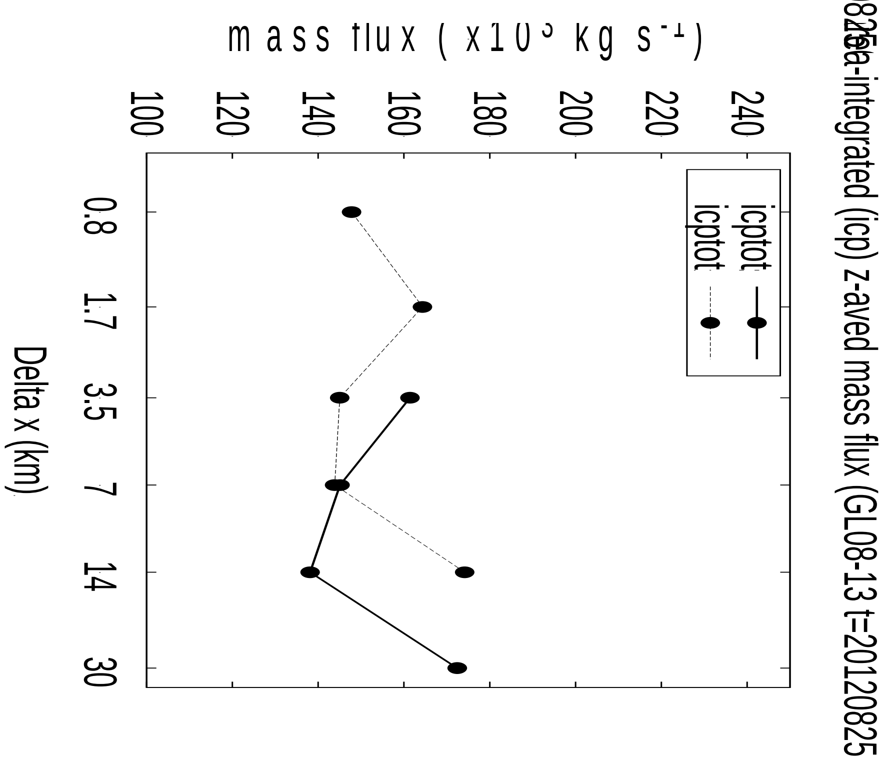


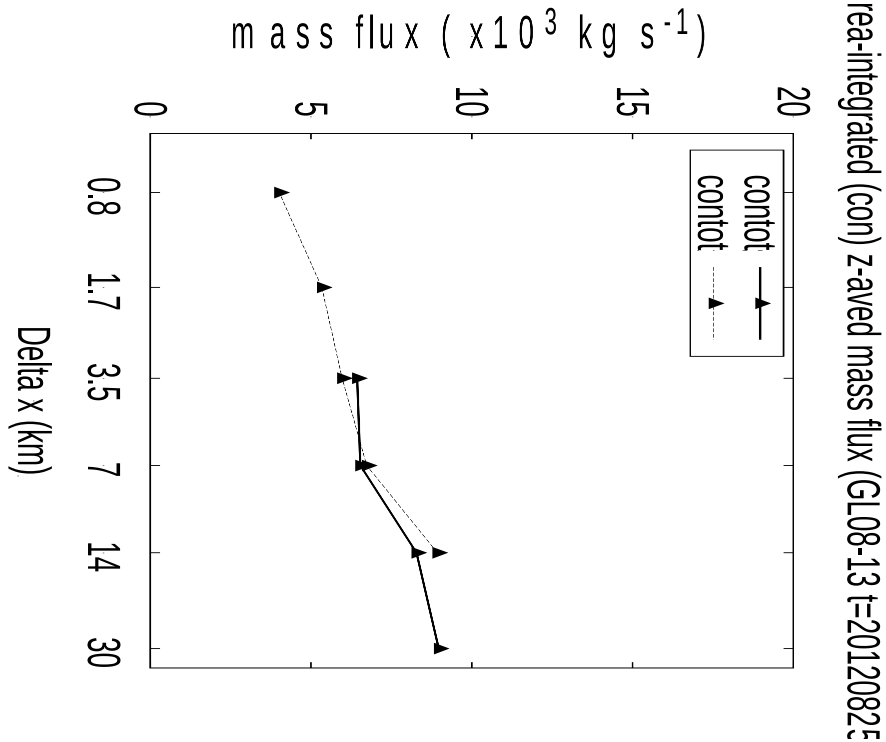
面積積分質量フラックス

解析範囲:

130—190E, -15—15N

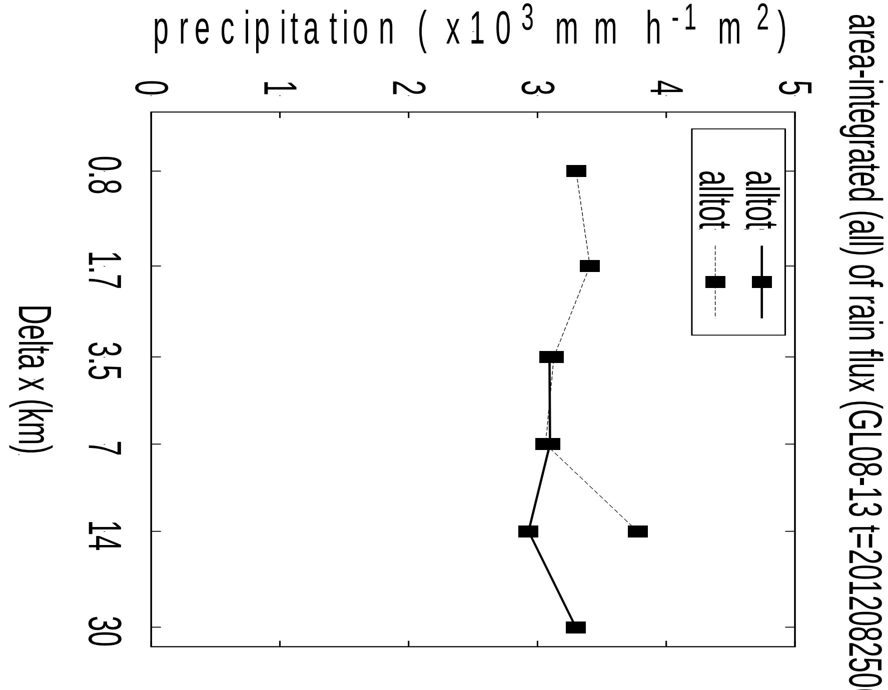


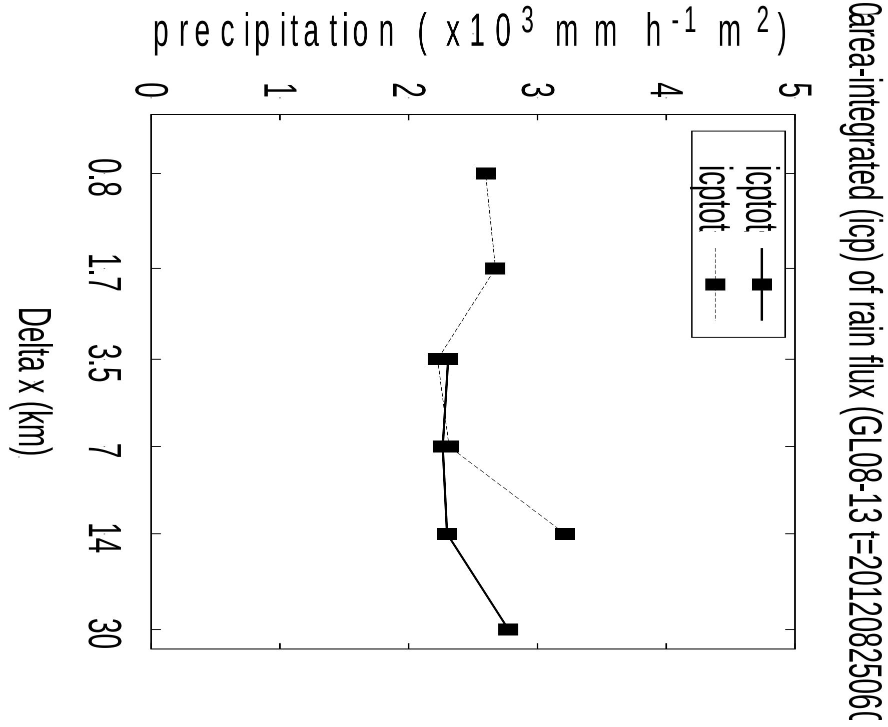


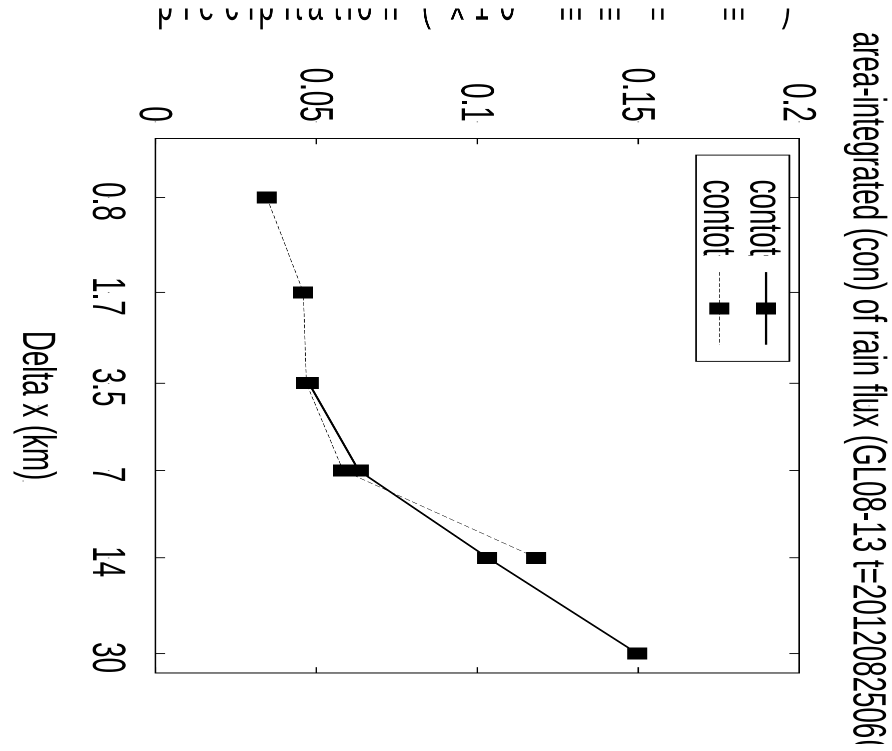


面積積分降水量

解析範囲:
130—190E, -15—15N

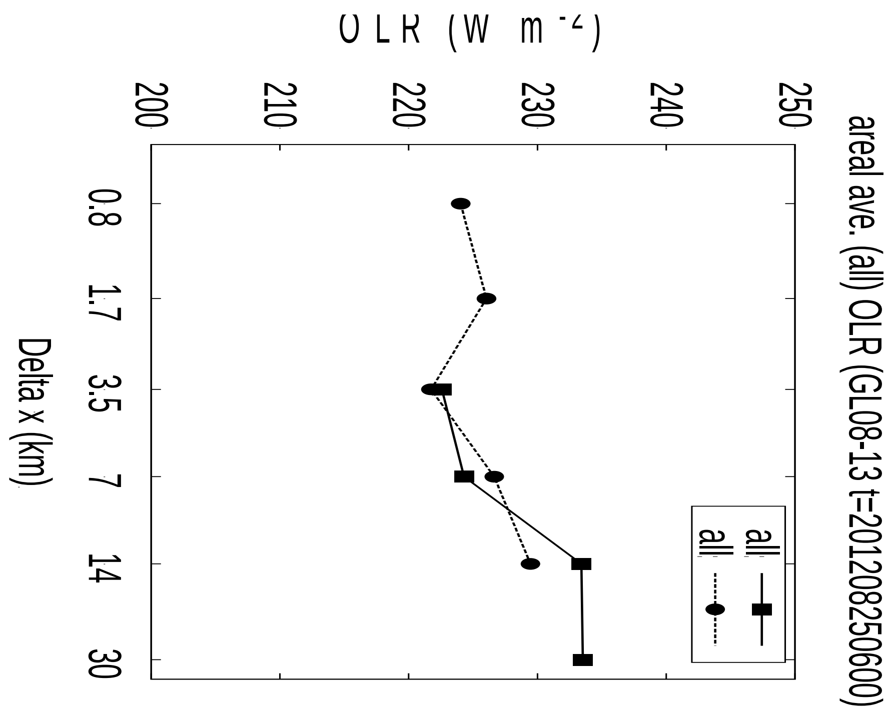


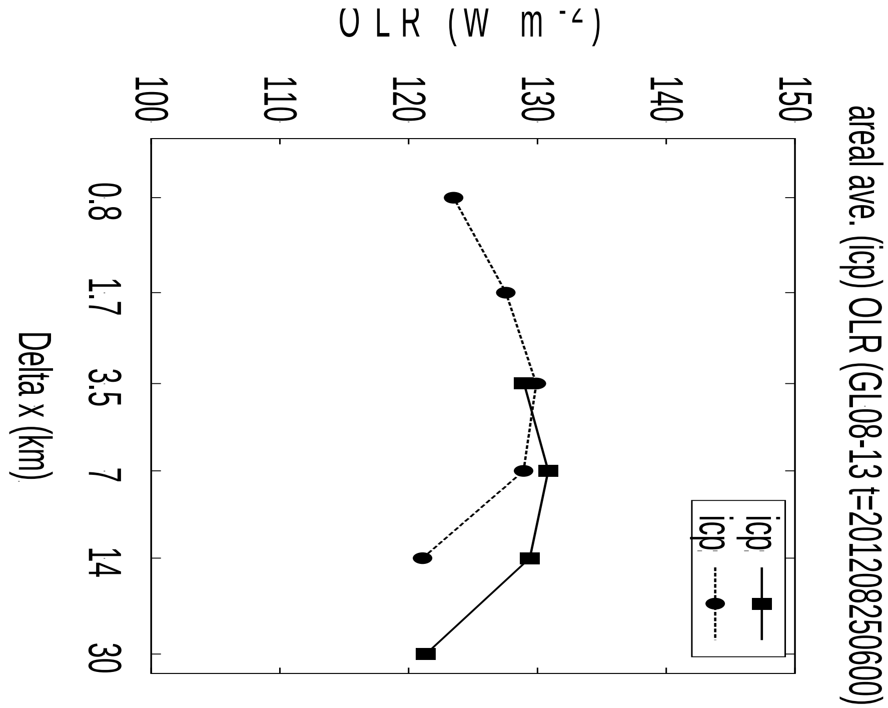


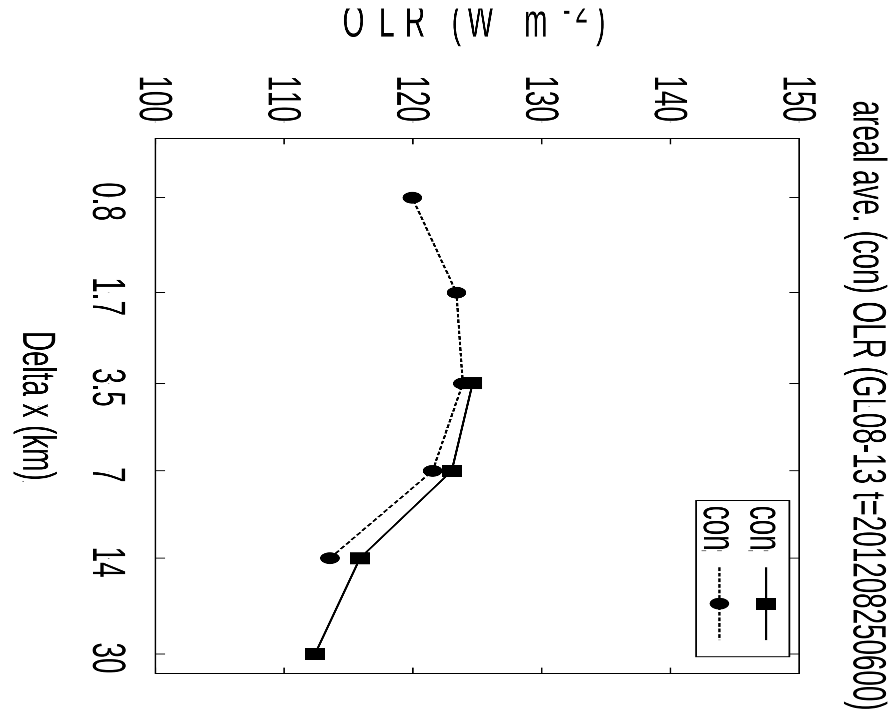


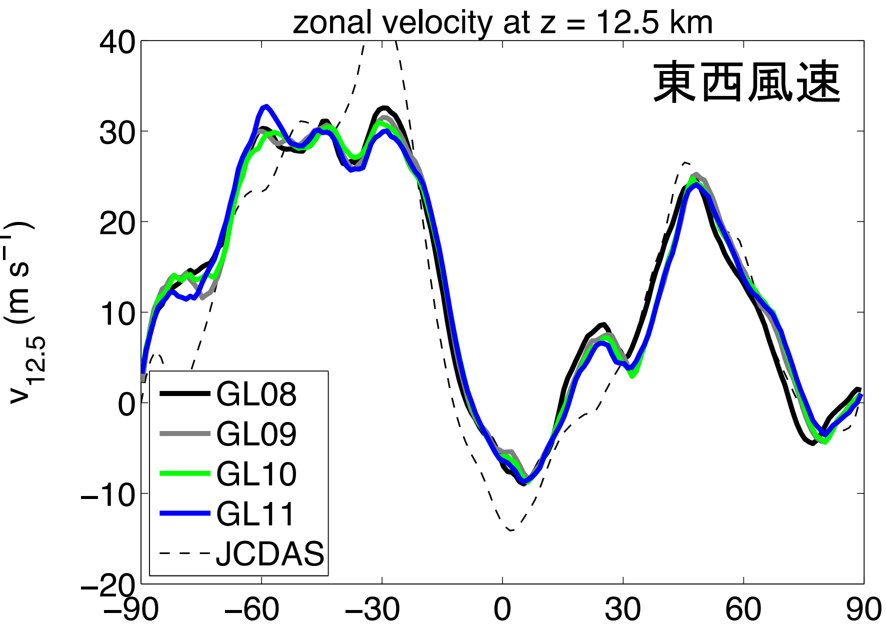
面積平均OLR

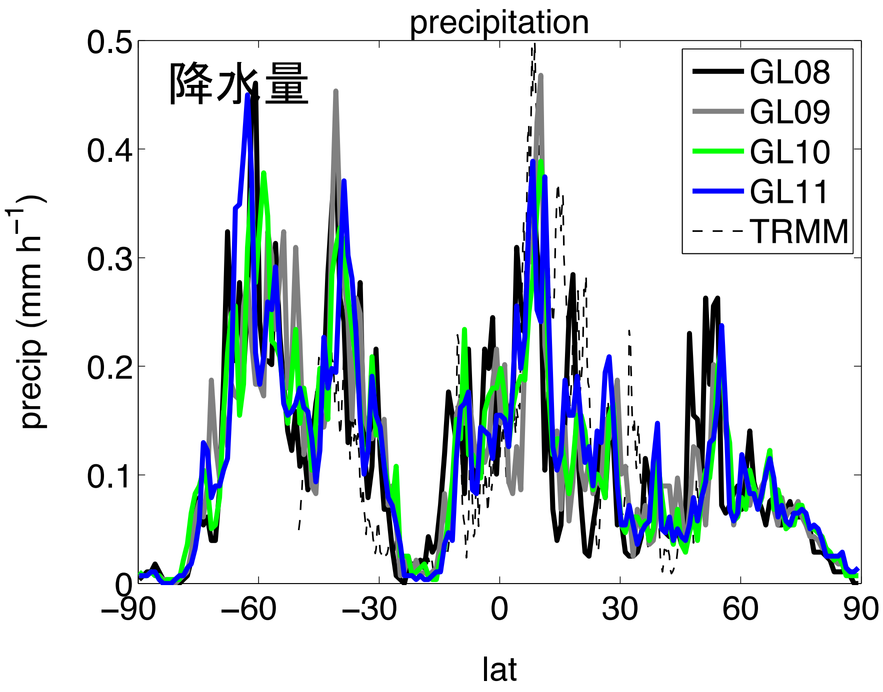
解析範囲:
130—190E, -15—15N

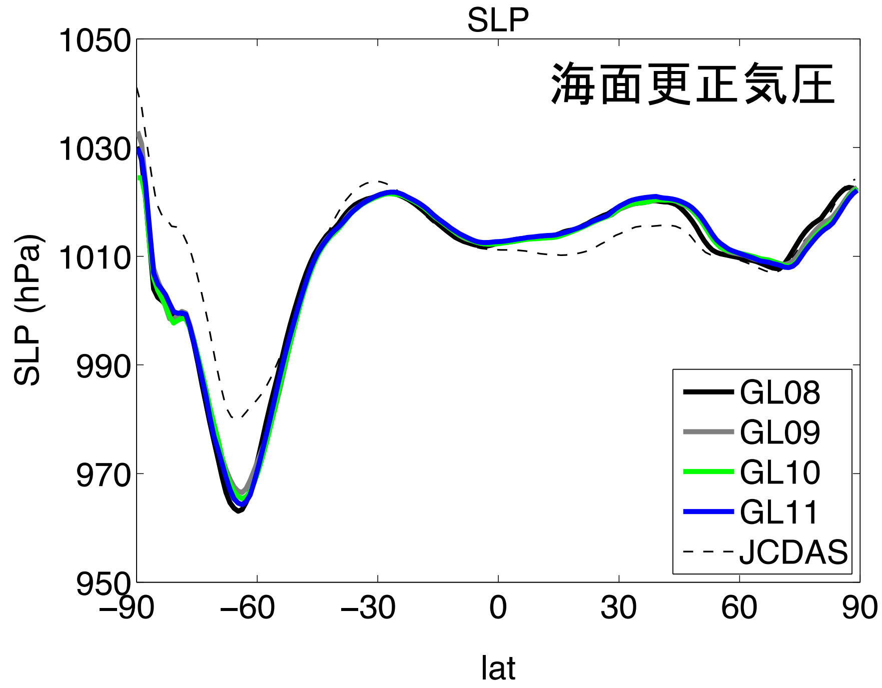












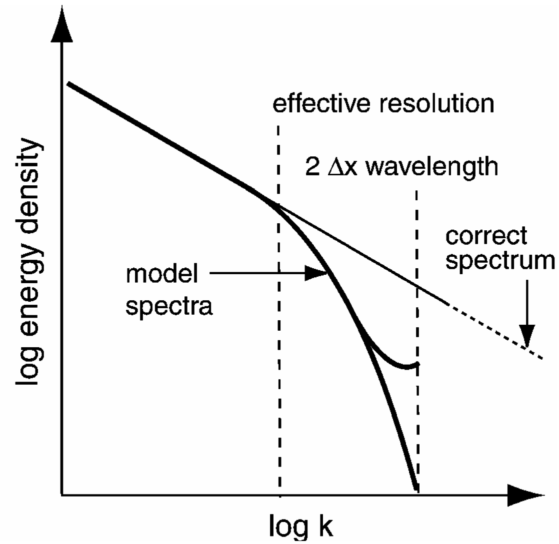
東西風速・降水量・海面更正気圧の緯度分布

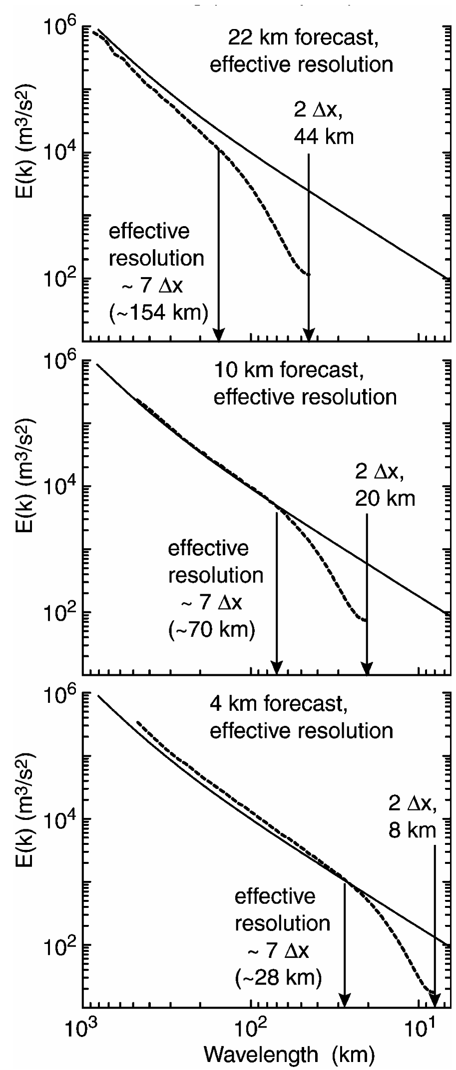
- 各解像度間に大きな差無し
- 解析値・観測値との顕著な差無し

Skamarock (2004)

Effective resolution (~ 6-7Δx):

それより小さい空間スケールの現象が、モデルで計算される運動エネルギースペクトルが-5/3則から外れる解像度





- 実現象で対流の存在する間隔 < 6-7Δx
  - モデルでは現象と同様の間隔を再現できない

  →Effective resolution以上で、且つ、実現象に最も近いスケール(=6-7Δx)に最頻値が出現

- 実現象で対流の存在する間隔 > 6-7Δx
  - モデルで対流間の距離を解像可能