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Changes of anvil-size statistics due to global warming in global cloud-resolving simulations

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Background

- Mapes and Houze (1993)
  - Diurnal cycle of cloud clusters
  - Eastward propagating ISV
  - Long-lived cloud clusters (>2dys) due to interconnection of active convection
- Mechado et al. (1993); Mechado and Rossow (1993)
  - Identify two major sources: deep convective clouds and mesoscale anvil clouds and importance of radiative effect by the latter
  - Relation of largescale field (e.g., tropical trough) and convection organization
- Peters and Neelin (2009)
  - Evident relation between cloud size and precipitable water
- etc…

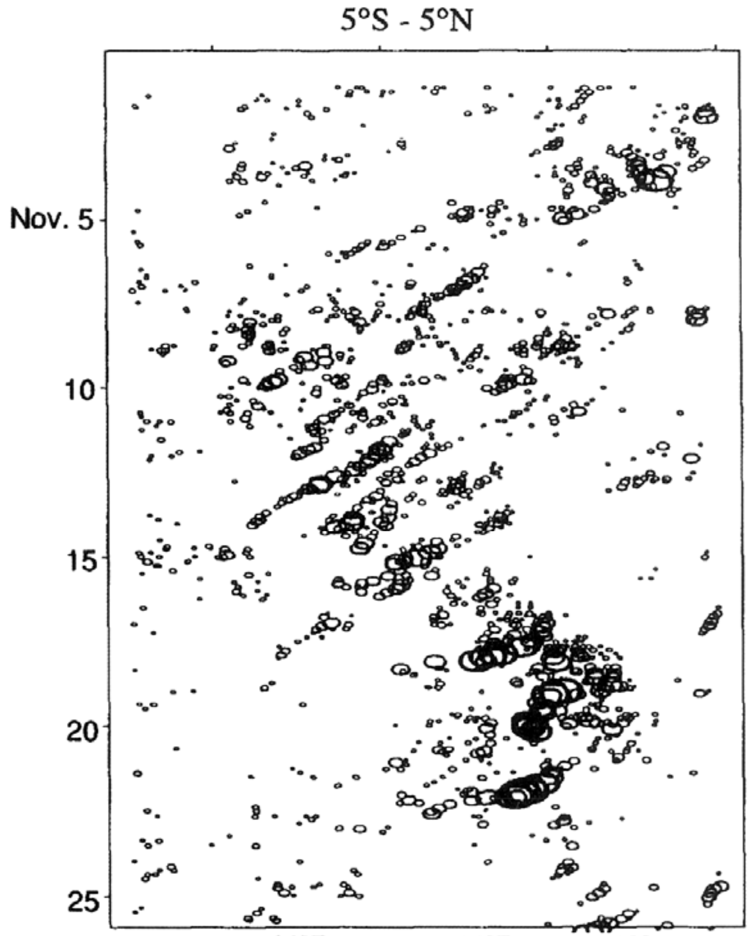


FIG. 20. Time–longitude section of very cold (<208 K) cloud clusters centered between 5°S and 5°N during November 1986. Compare to rightmost two-thirds of Fig. 19.

Mapes and Houze (1993)

Diurnal cycle of high clouds

Mapes and Houze (1993)
Noda et al. (2012)

GMS obs

NICAM(7km mesh)

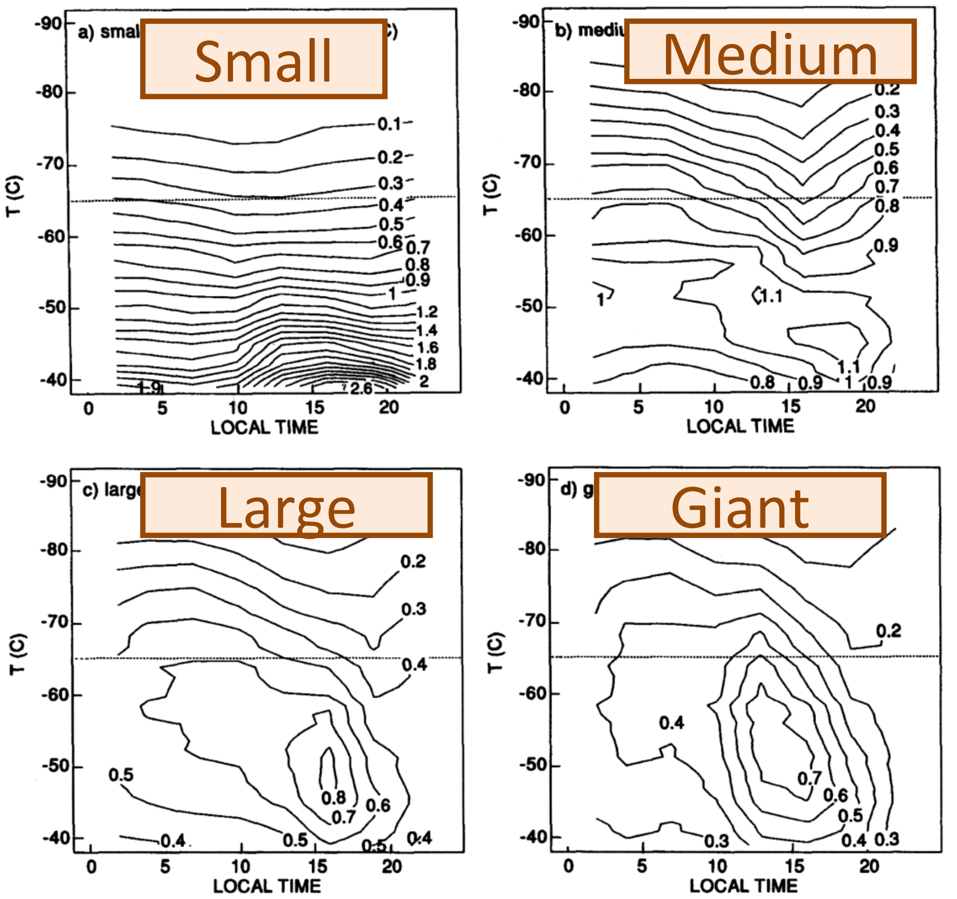
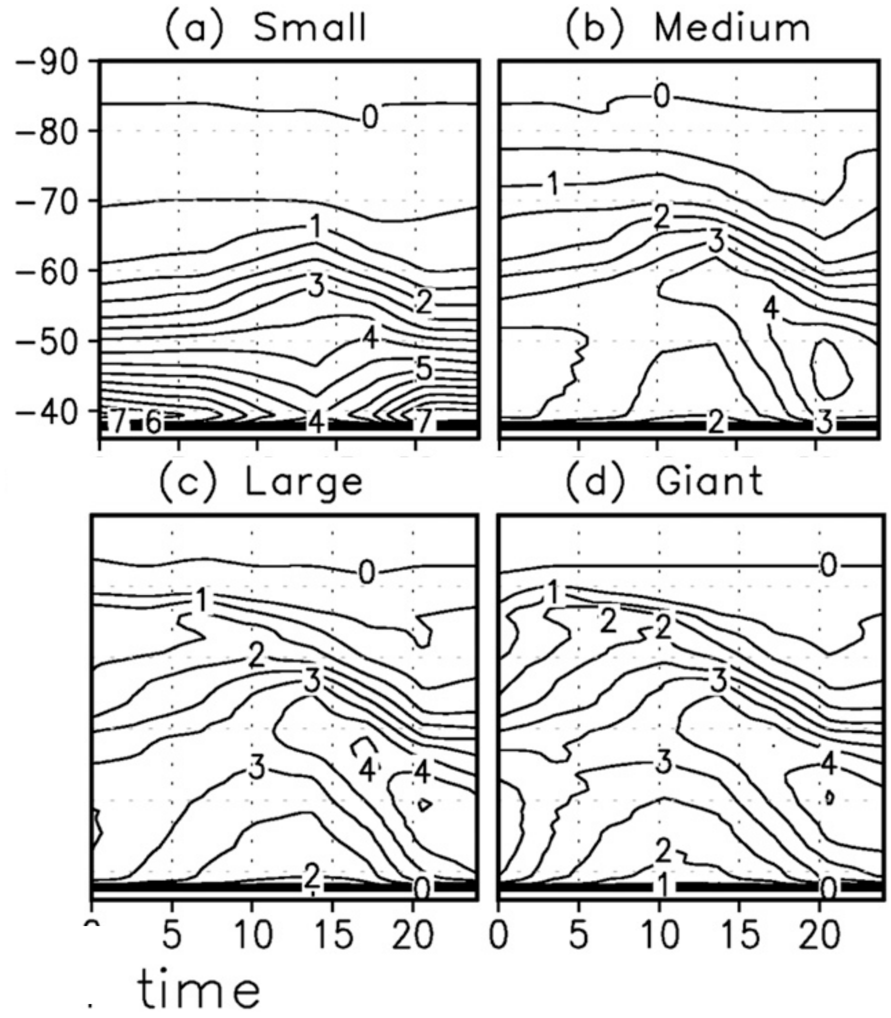


FIG. 11. As in Fig. 10 but subdivided according to moderately cold (<235 K) cloud-cluster size. Vertical scale d
from Fig. 10, because only temperatures colder than 235 K lie within the 235-K cloud clusters.



Local

Size distribution and their global map

- Follows a power law
- But scale-breakdown occurs across 1500-2000km size

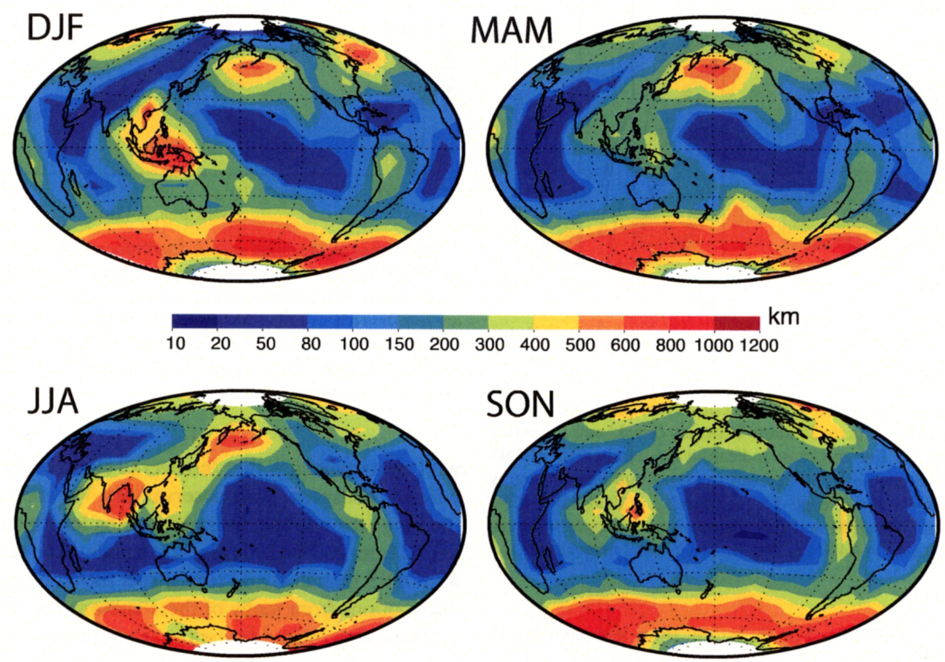
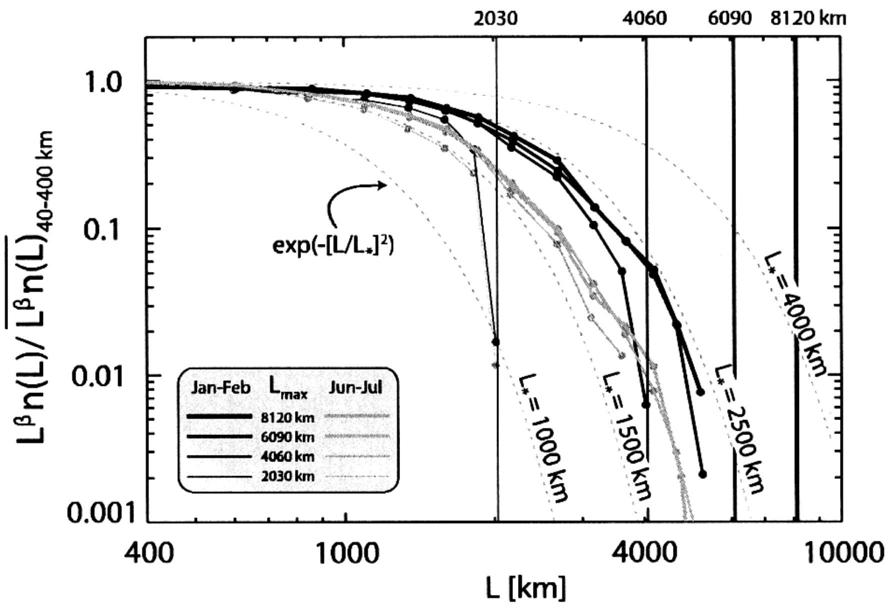
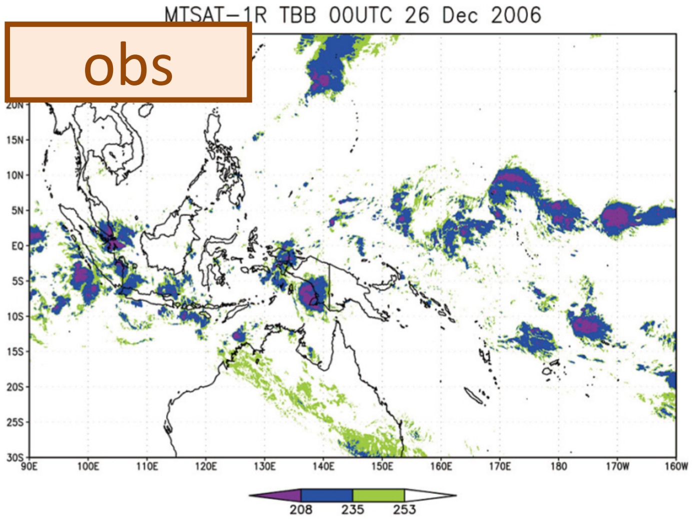


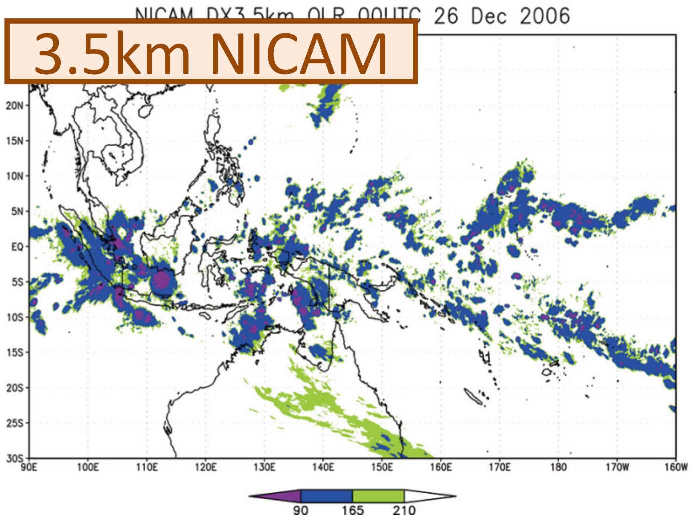
FIG. 9. As in Fig. 8, but broken down by season with maps for (top left) JFM, (top right) MAM, (bottom left) JJA, and (bottom right) SON.



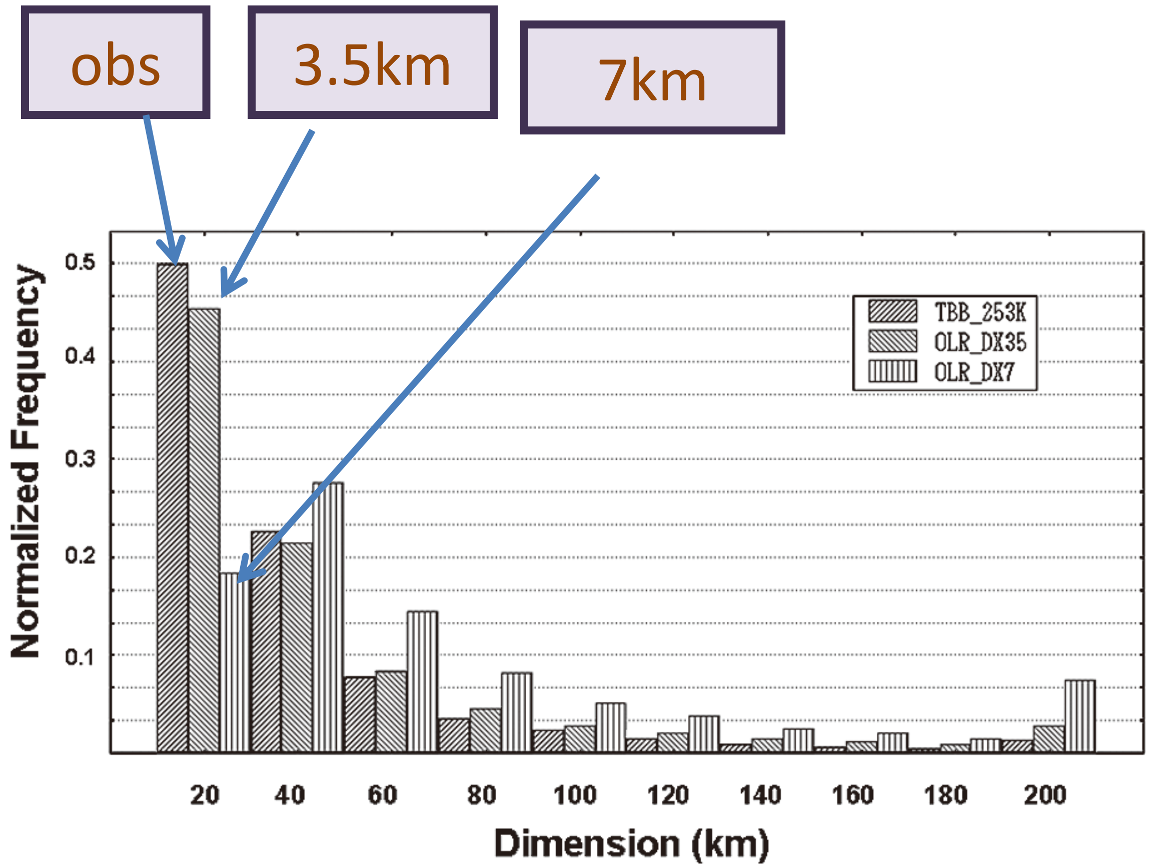
Wood and Hartmann (2011)

Obs vs. Model



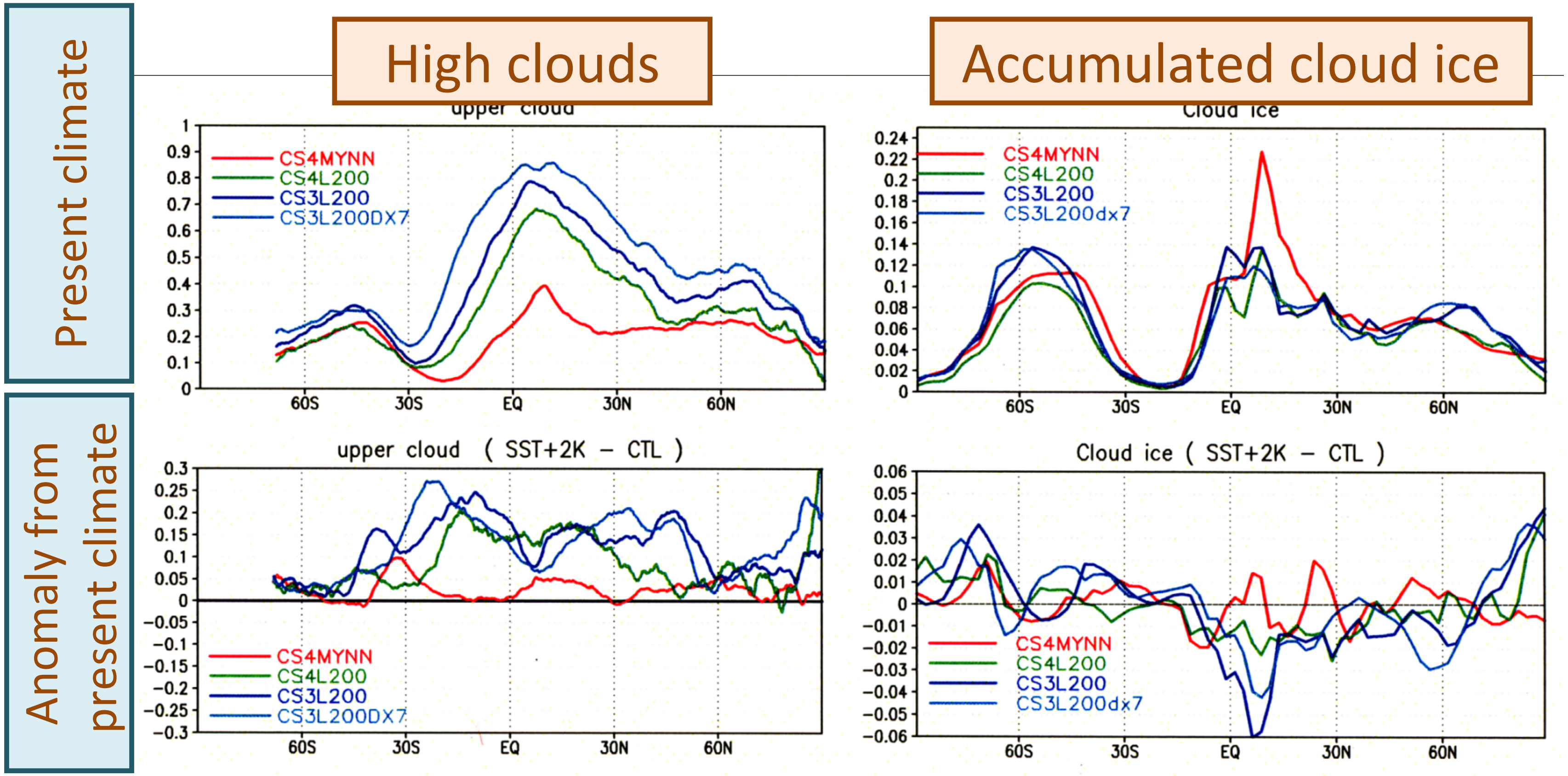


Inoue et al. (2008)

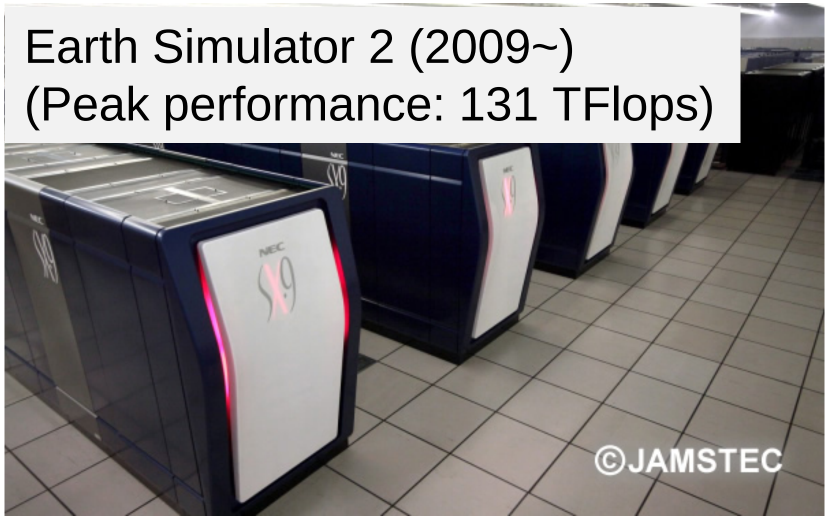


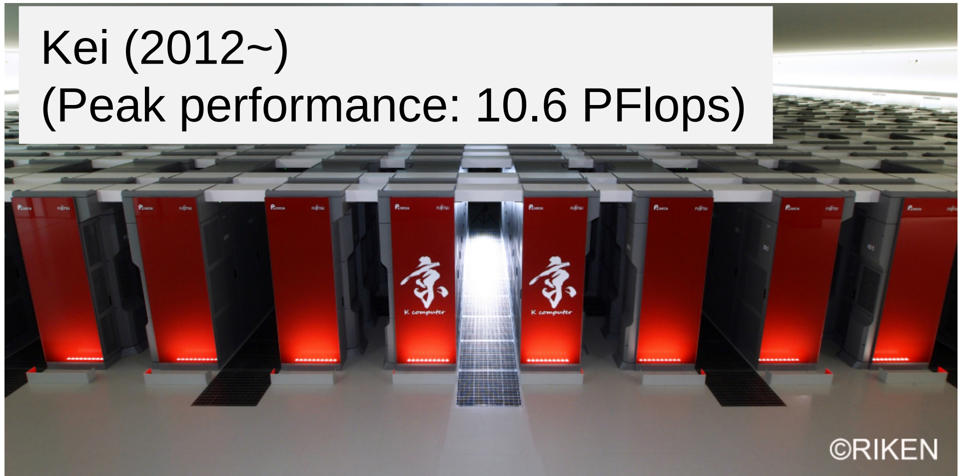
High cloud response to warmer climate

- Clouds in global warming experiment with NICAM
  - High cloud amount increases (positive feedback) but accumulated ice amount decreases (Satoh et al. 2012)



- Latest understanding of cloud size statistics
  - Basic characteristics of the size distribution have been understood
  - More extended features are being investigated with higher-resolution obs. and LESs
    - e.g., Low level clouds by Siebesma et al. 2000, Neggers et al. 2003, etc…
- But, few studies about their possible changes due to atmos. warming
- Modeled response (case of NICAM)
    - Clouds in global warming experiment with NICAM
      - High cloud amount increase (positive feedback) but ice amount decreases (Satoh et al. 2012)
- Purpose
  - What types of clouds contribute to those changes of cloud properties?
  - using Seasonal-long to more than a year-long simulations



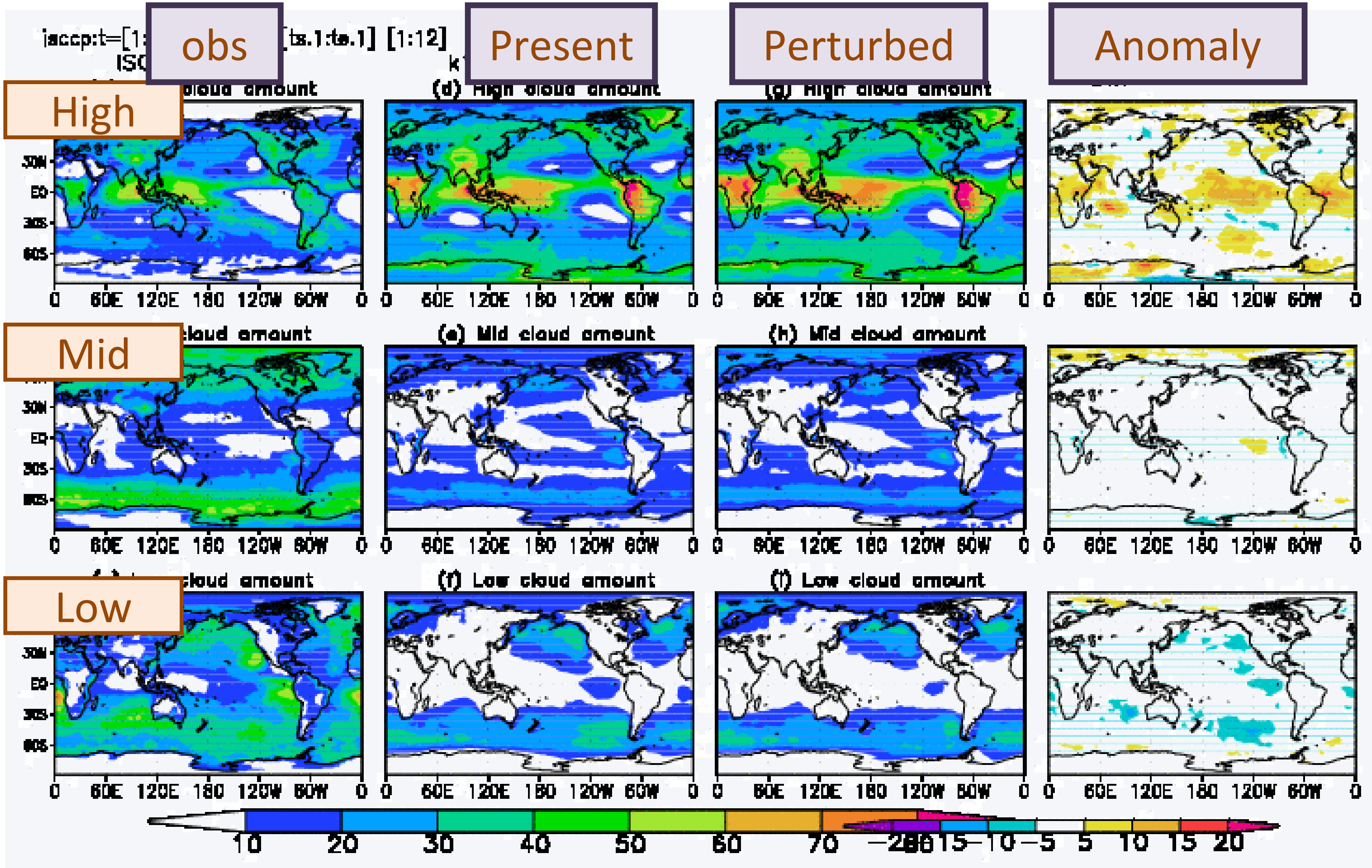


Experimental Design

Initialization	NCEP Global analysis
Time Integration	1 year starting from 1 June 2004
SST	Slab mixed layer model with 15m depth and 7day e-folding time, nudged to NOAA Weekly Reynolds SST for present climate (pseudo-warmer SST for warmer climate run)
Horizontal resolution	14km and 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	348 ppm for present climate run 696 ppm for perturbed climate run

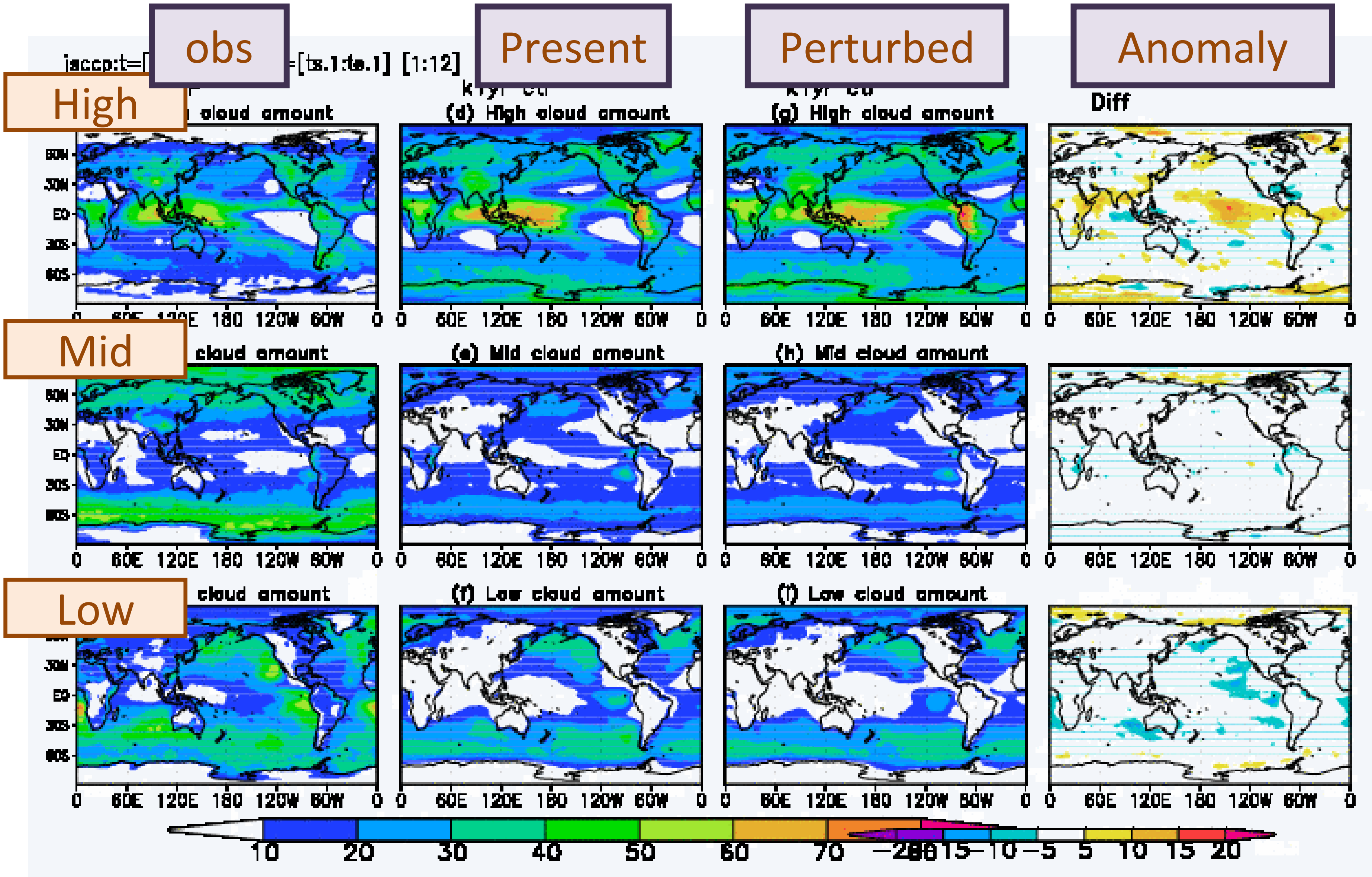
Cloud amount (7km mesh)

1-yr simulation

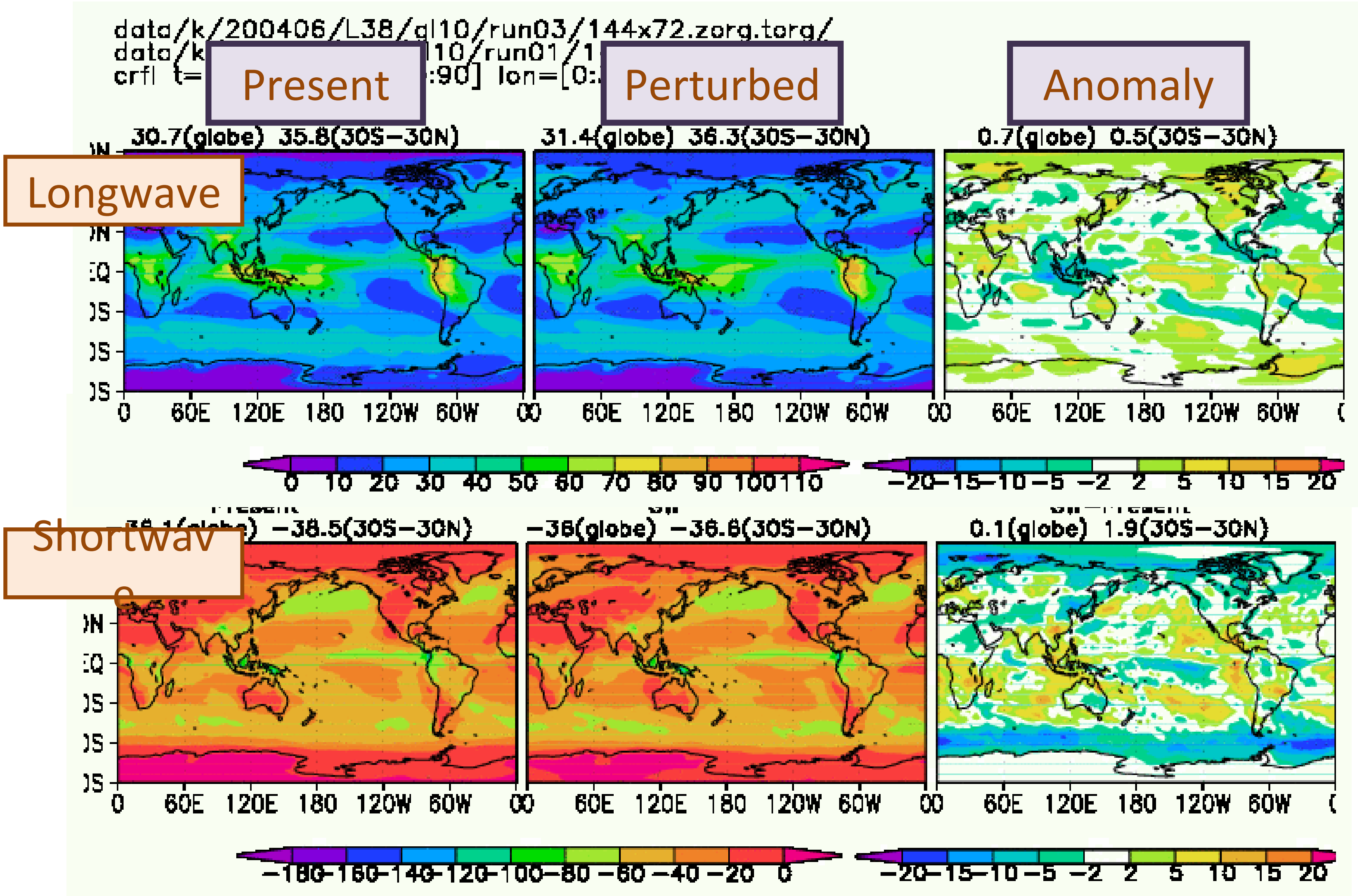


Cloud amount
(14km mesh)

1-yr simulation

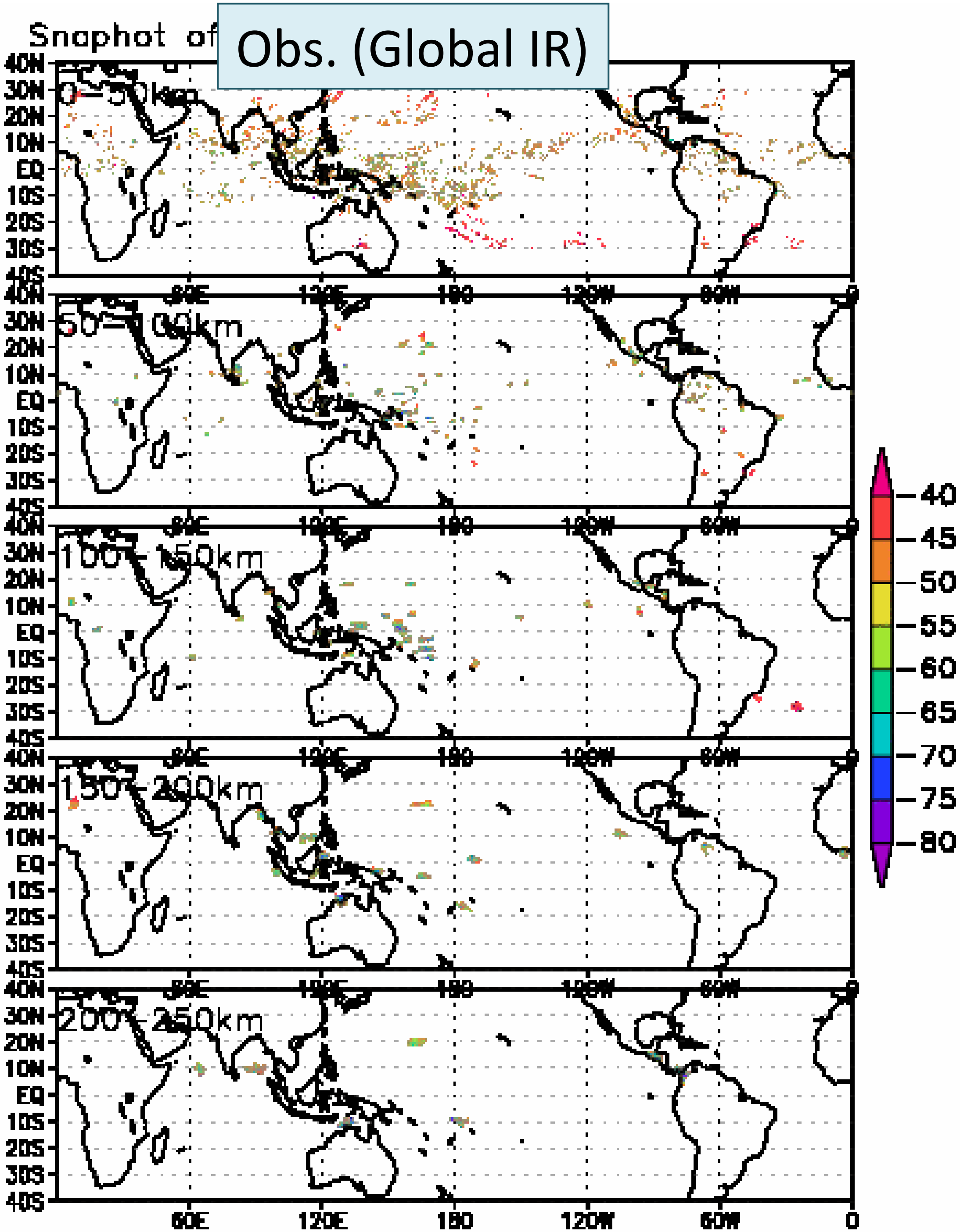


Cloud radiative forcing
(7km mesh)



Changes in size distribution of high clouds

Example of anvil distribution (Snapshot)



0-50km

50-100km

100-150km

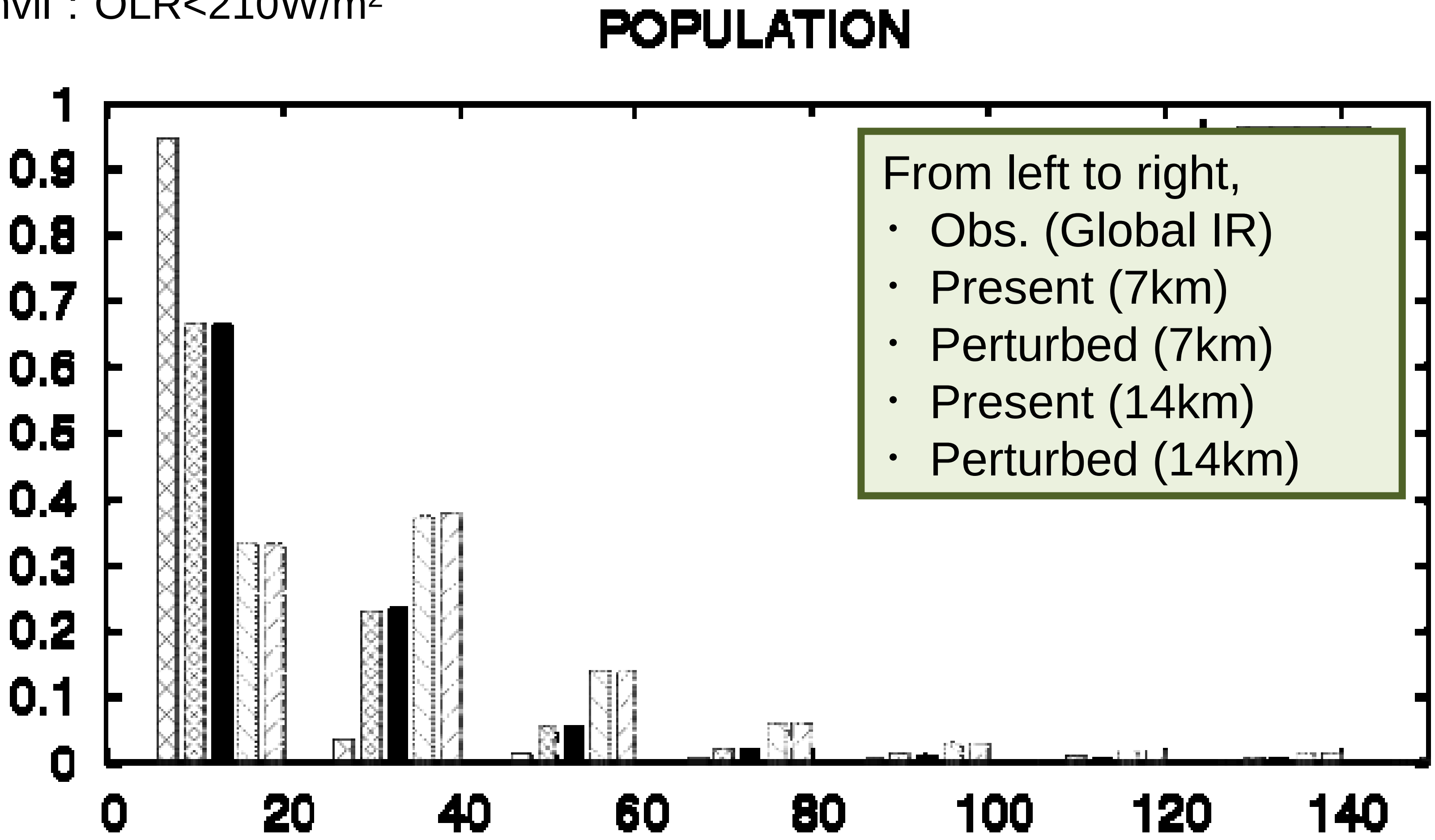
150-200km

200-250km

Population
(1-year experiment)

30N-30S

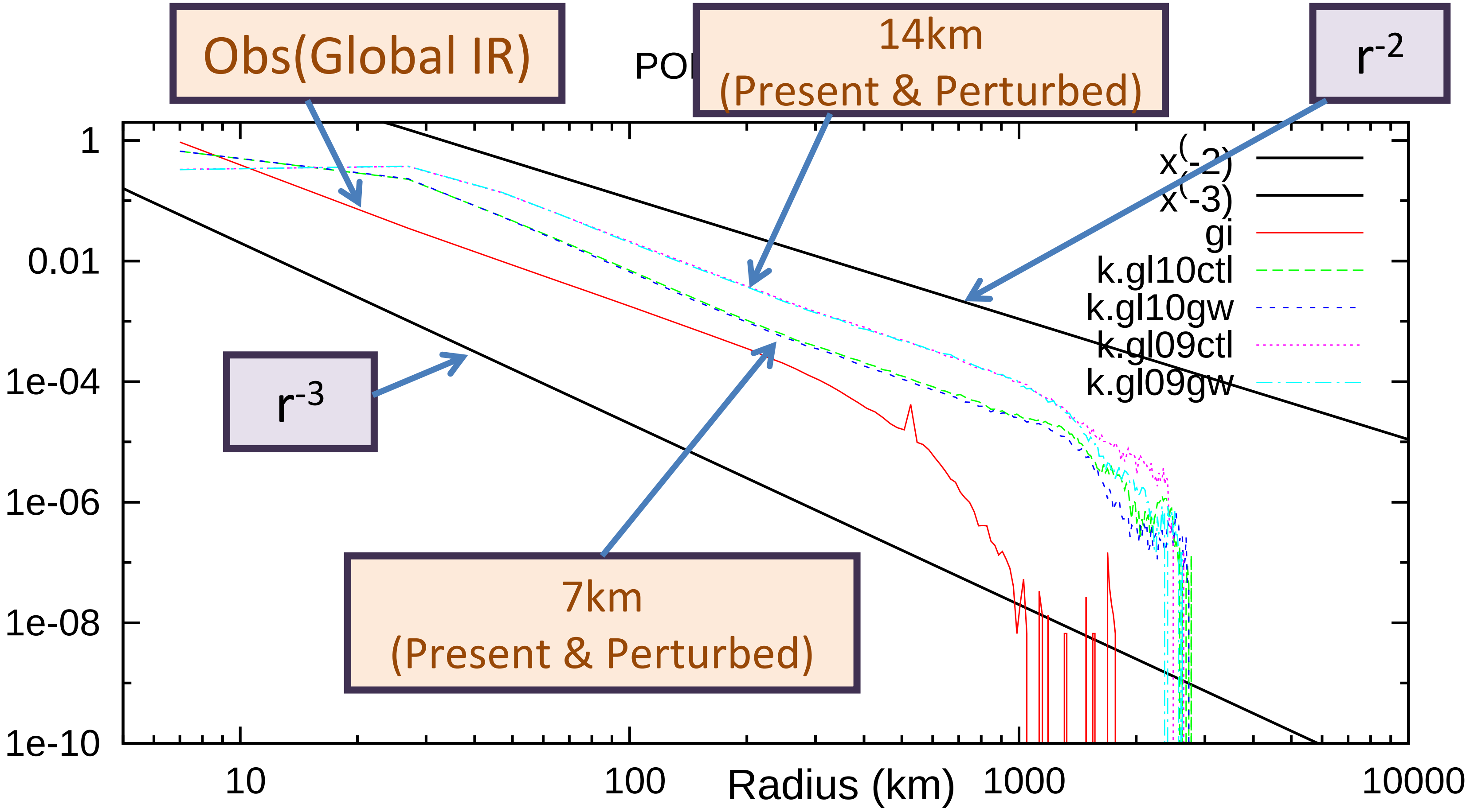
Anvil：OLR<210W/m^2



Radius (km)

Population
(Log scale)

- ✓ Slopes of all results is about $r^{-2} \sim r^{-3}$
  - ✓ Slope in both 7km and 14km is similar to obs.
- ✓ Modeled anvils
  - ✓ tends to be larger than obs
- ✓ Much more dependency on grid size, compared to that on climate change
- ✓ Scale breakdown across 500-1000km radius

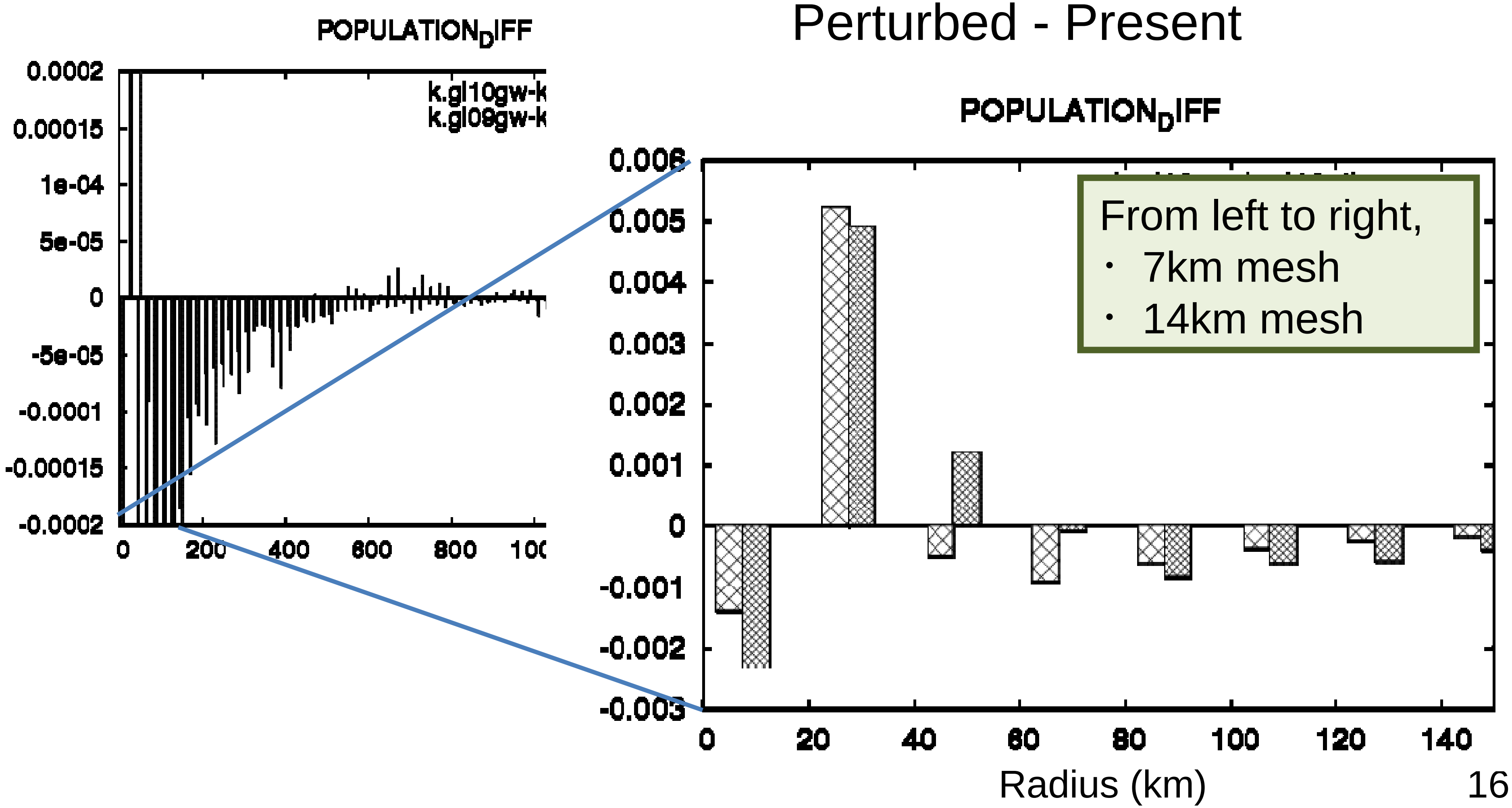


Population (1-year experiment)

- ✓ Anvils
  - ✓ smaller than 20km and those larger than 60km decrease
  - ✓ in 20-60km increase

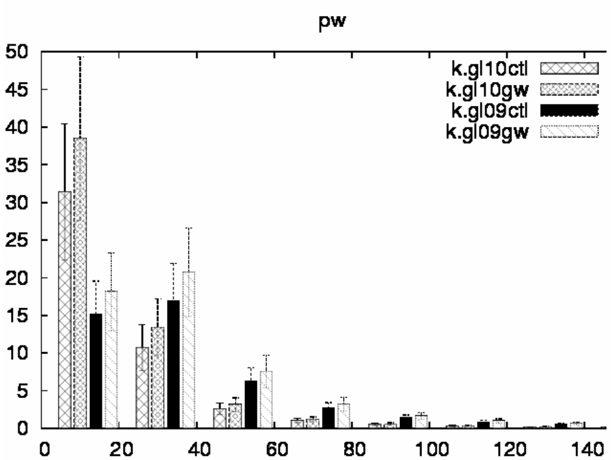
30N-30S

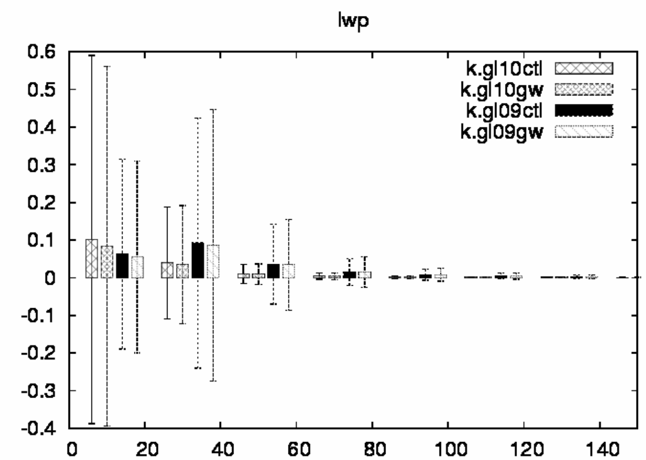
Perturbed - Present

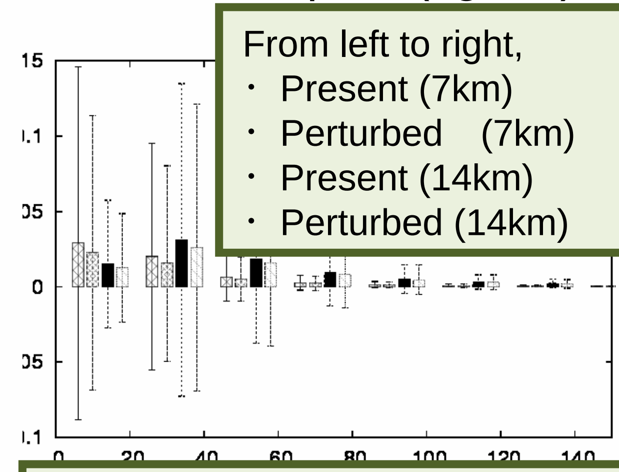


PW/LWP/IWP

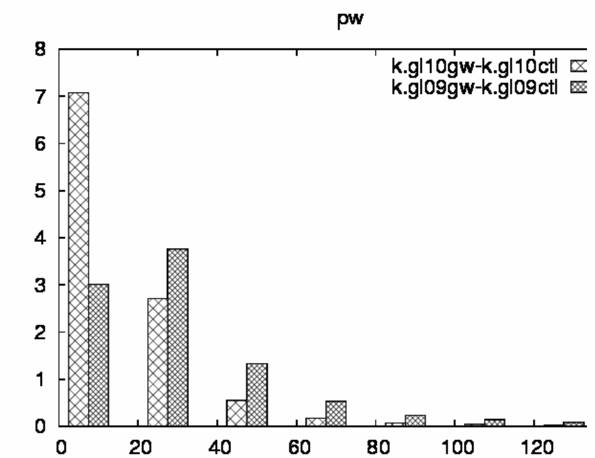
Precipitable water (kg/m2) | Liquid water path (kg/m2) | Ice water path (kg/m2)

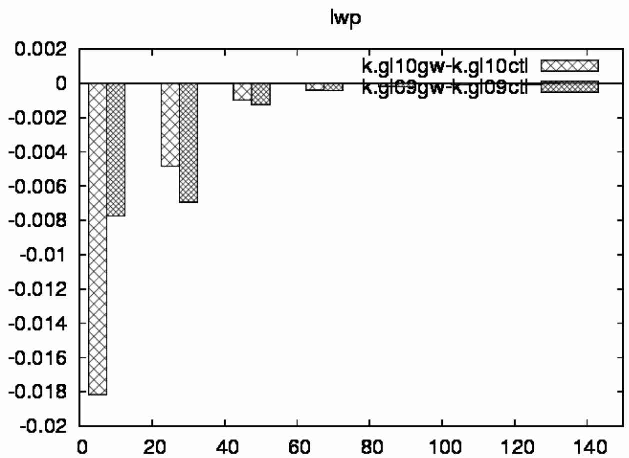


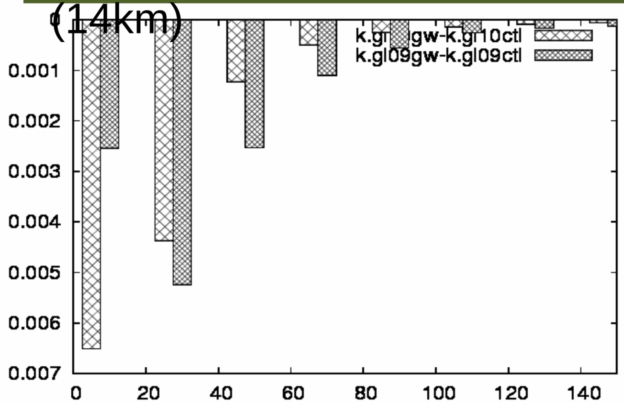




From left to right,
- Present (7km)
- Perturbed (7km)
- Present (14km)
- Perturbed (14km)





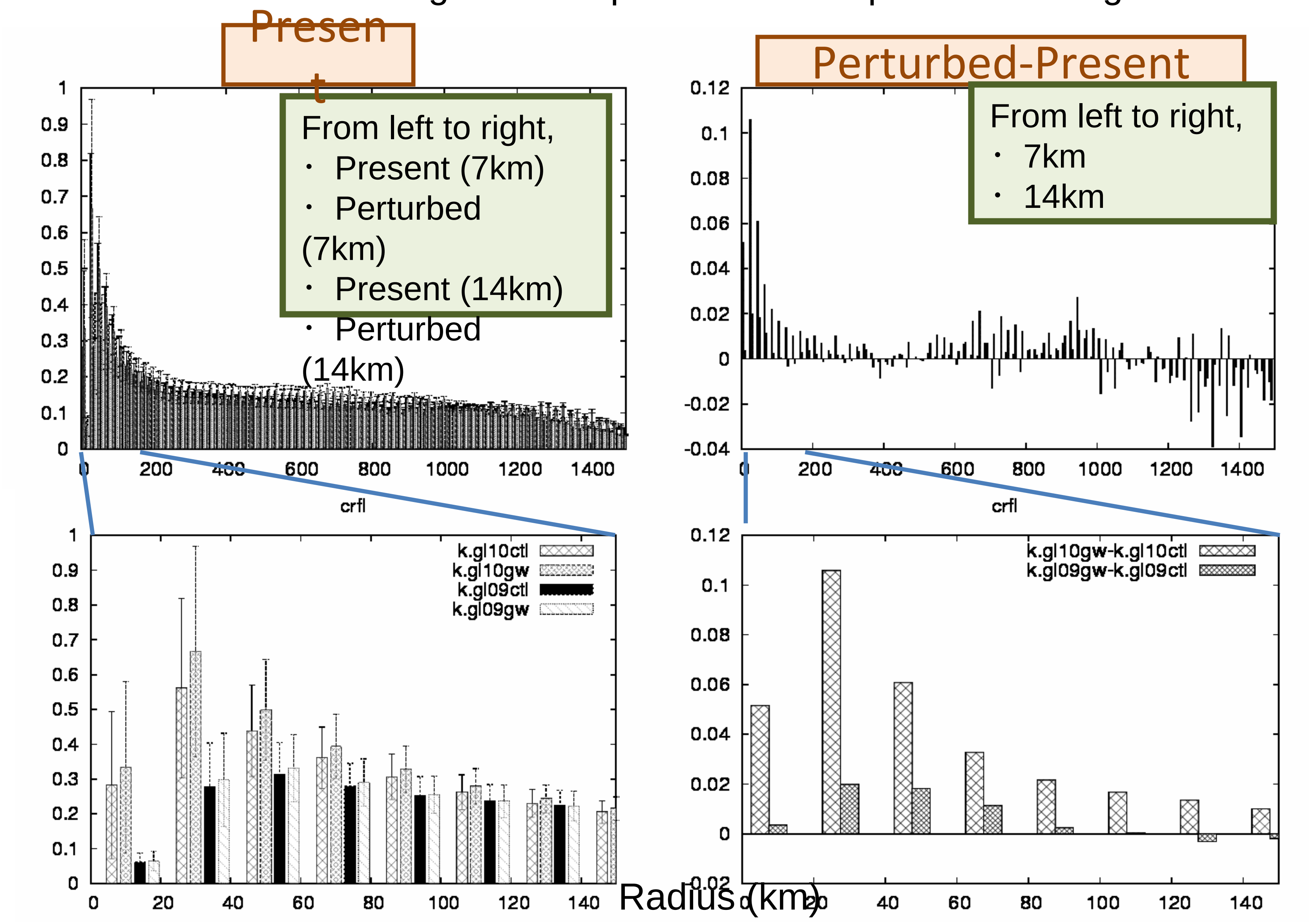


From left to right,
- Perturbed – Present (7km)
- Perturbed – Present (14km)

Radius (km)

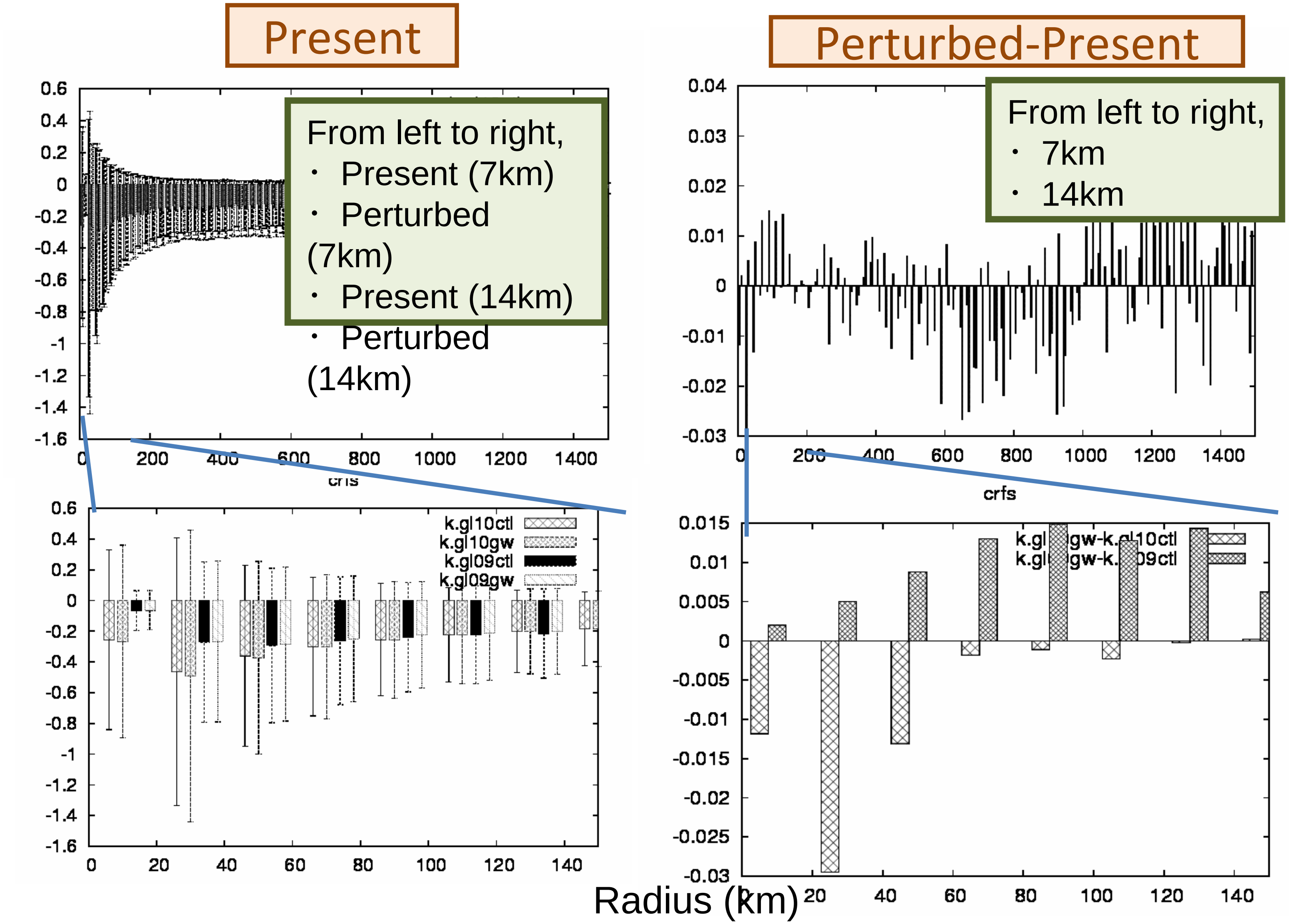
Cloud radiative forcing (Longwave)

✓ 7km mesh shows a much greater response to atmospheric warming



Cloud radiative forcing (Shortwave)

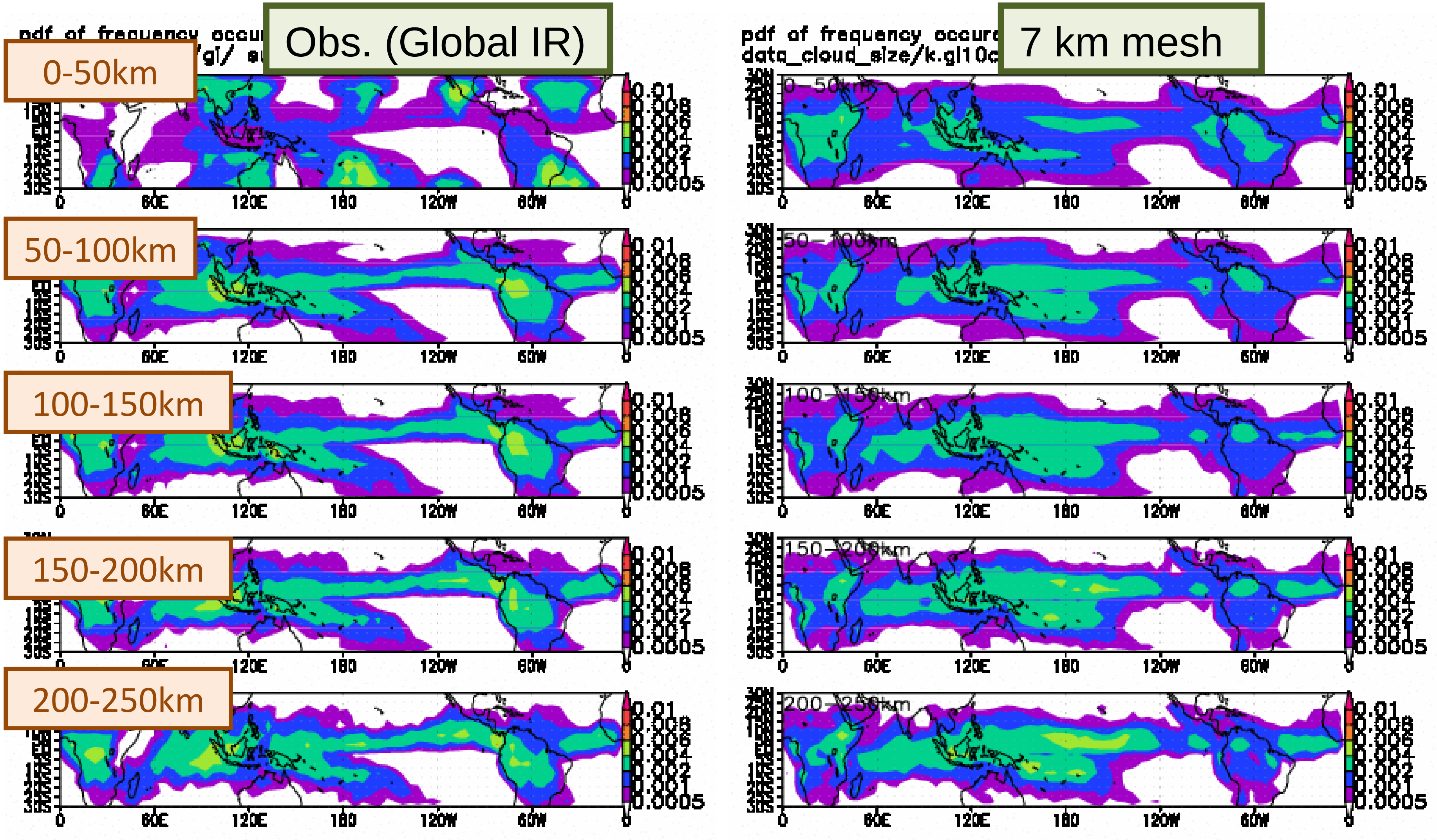
✓ Response differs among 7km and 14km meshes



Global map of PDF of anvil size (Obs. vs. 7km mesh)

- ✓ Broad spatial characteristics are well simulated, except for small size (0-50km)

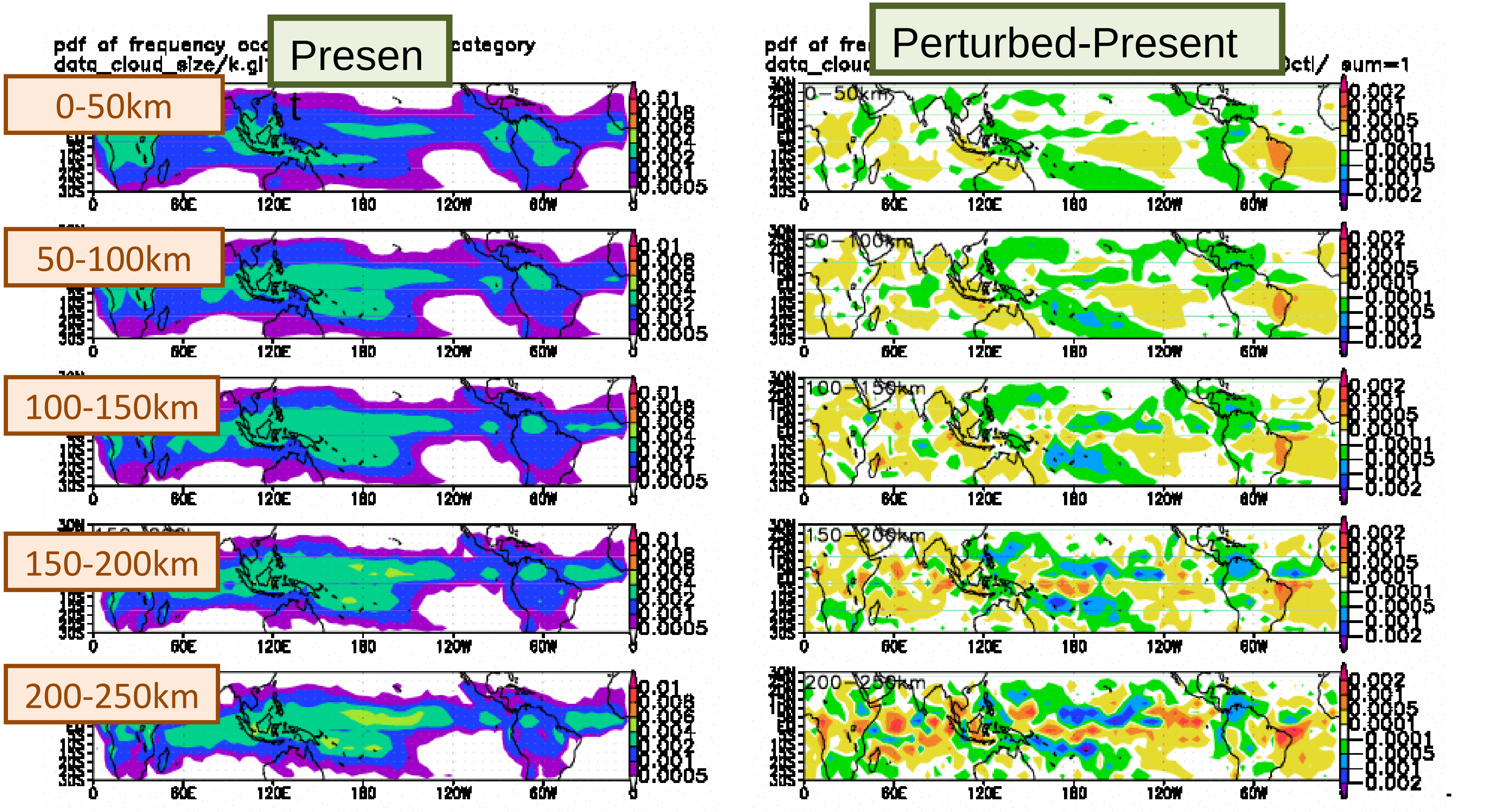
$\iint F(x,y)dydy=1$ at each category



Global map of PDF of anvil size (7km mesh)

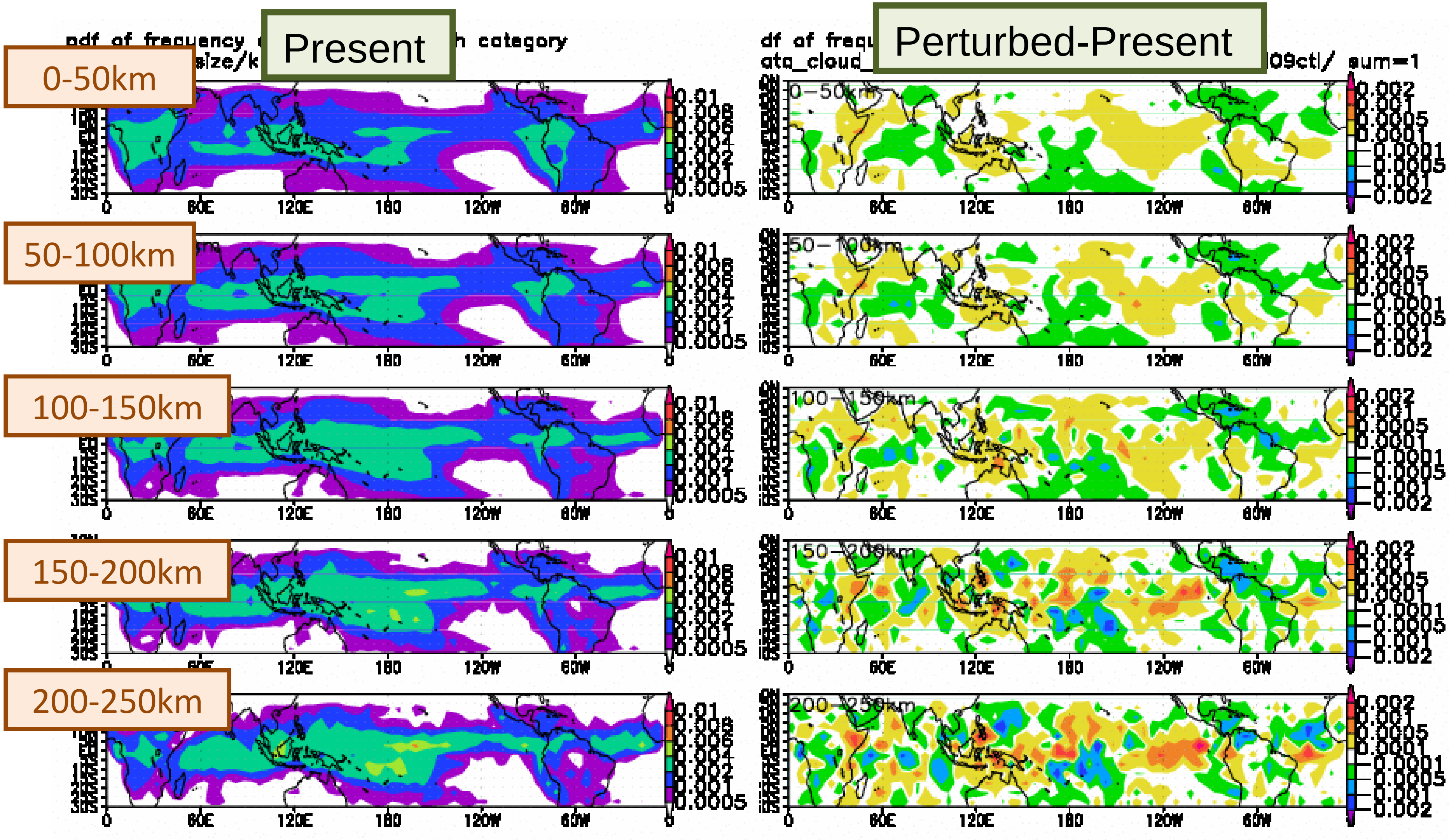
$\iint F(x,y)dydy=1$ at each category

- ✓ Few differences in changes of anvil pdf among size categories
- ✓ tends to decrease over SPCZ, MC and northern SA
- ✓ increases over IO, west PO and Middle SA



Global map of PDF of anvil size
(14km mesh)

$\iint F(x,y)dydy=1$ at each category

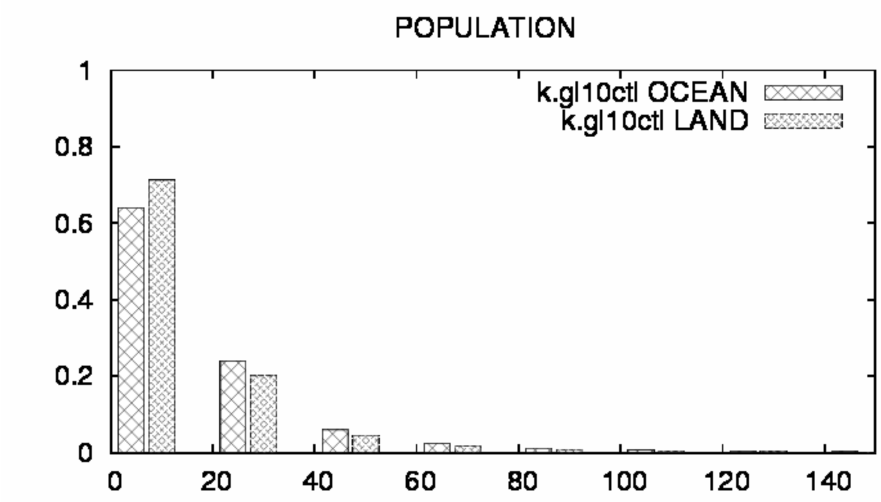


Dependency on topography (7km mesh)

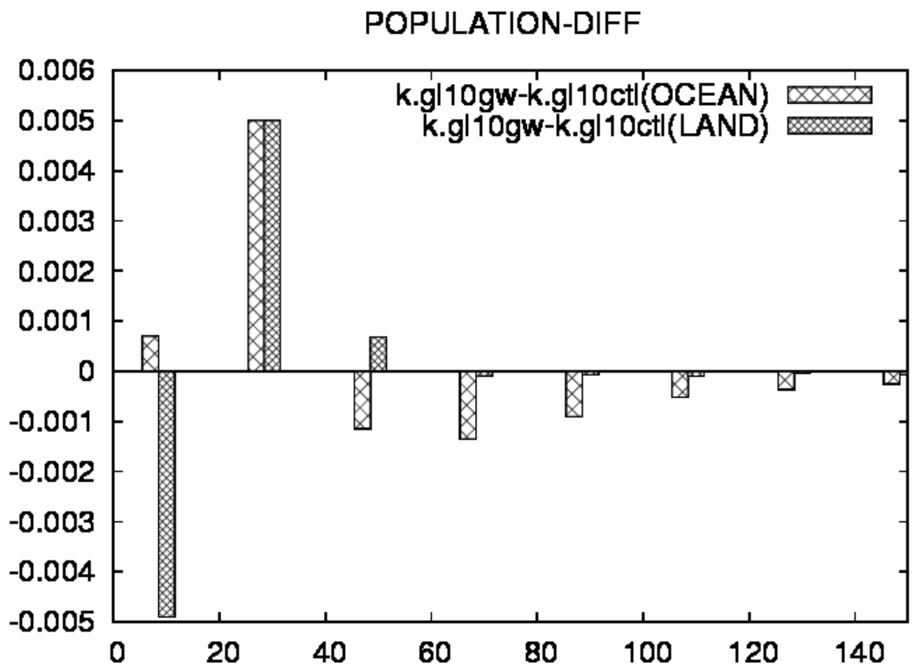
✓ More pronounced changes in small anvils over land than over ocean

From left to right,
- Over ocean
- Over land

Present



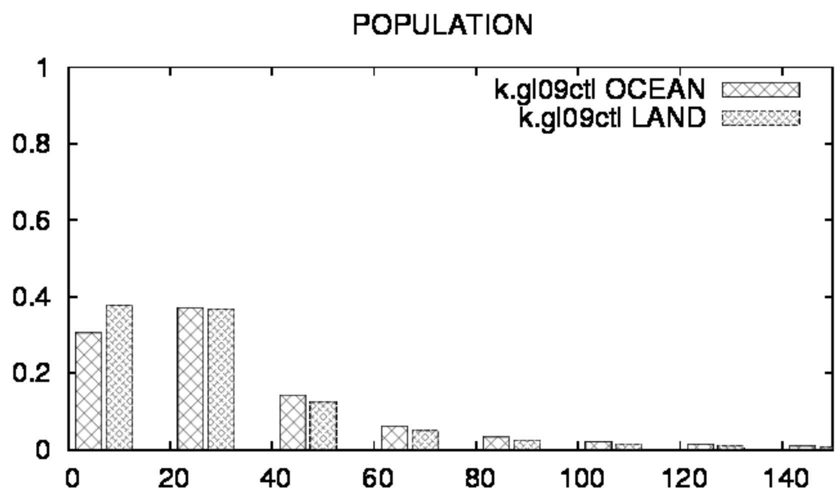
Perturbed - Present



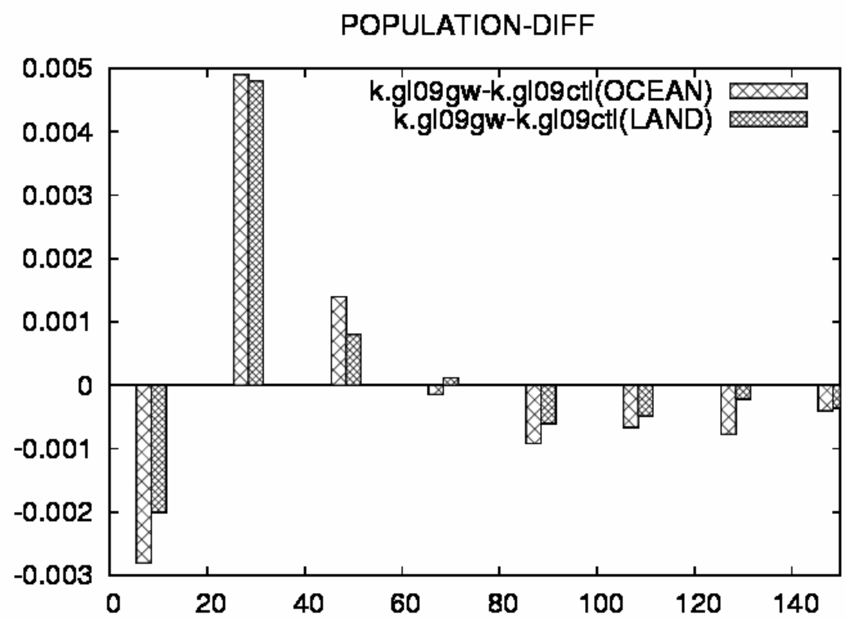
Radius (km)

Dependency on topography (14km mesh)

Present



Perturbed - Present



Hovmeller diagram

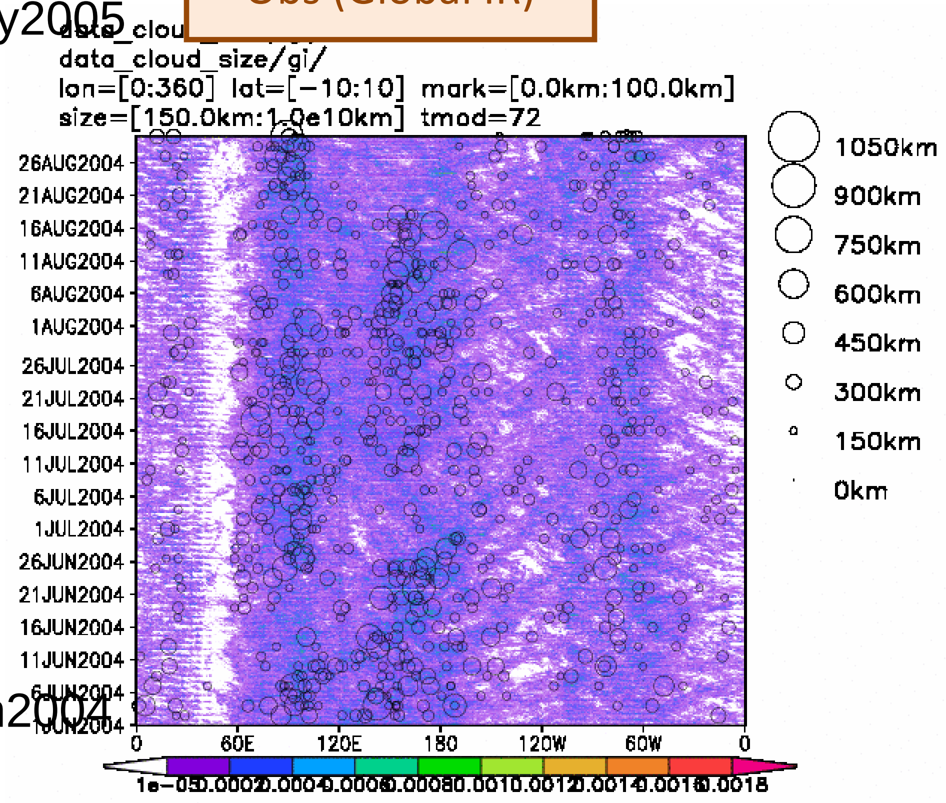
Color: Frequency of anvils with r=0-50km

- ✓ Evident eastward propagating systems
- ✓ But, difference of MCS types depending on size categories is not evident

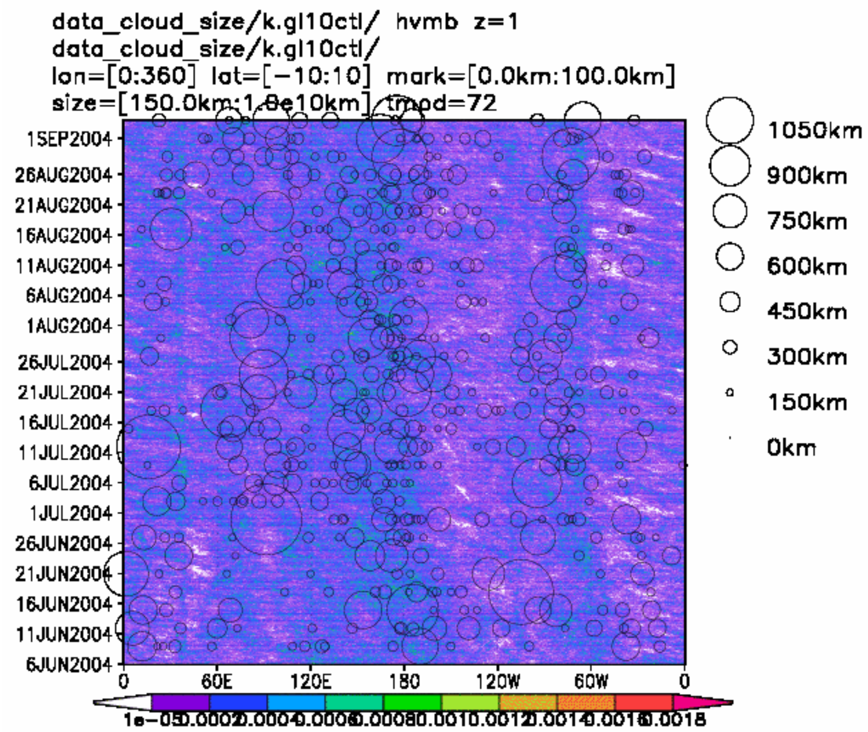
Obs (Global IR)

7km mesh

May2005



Jun2004

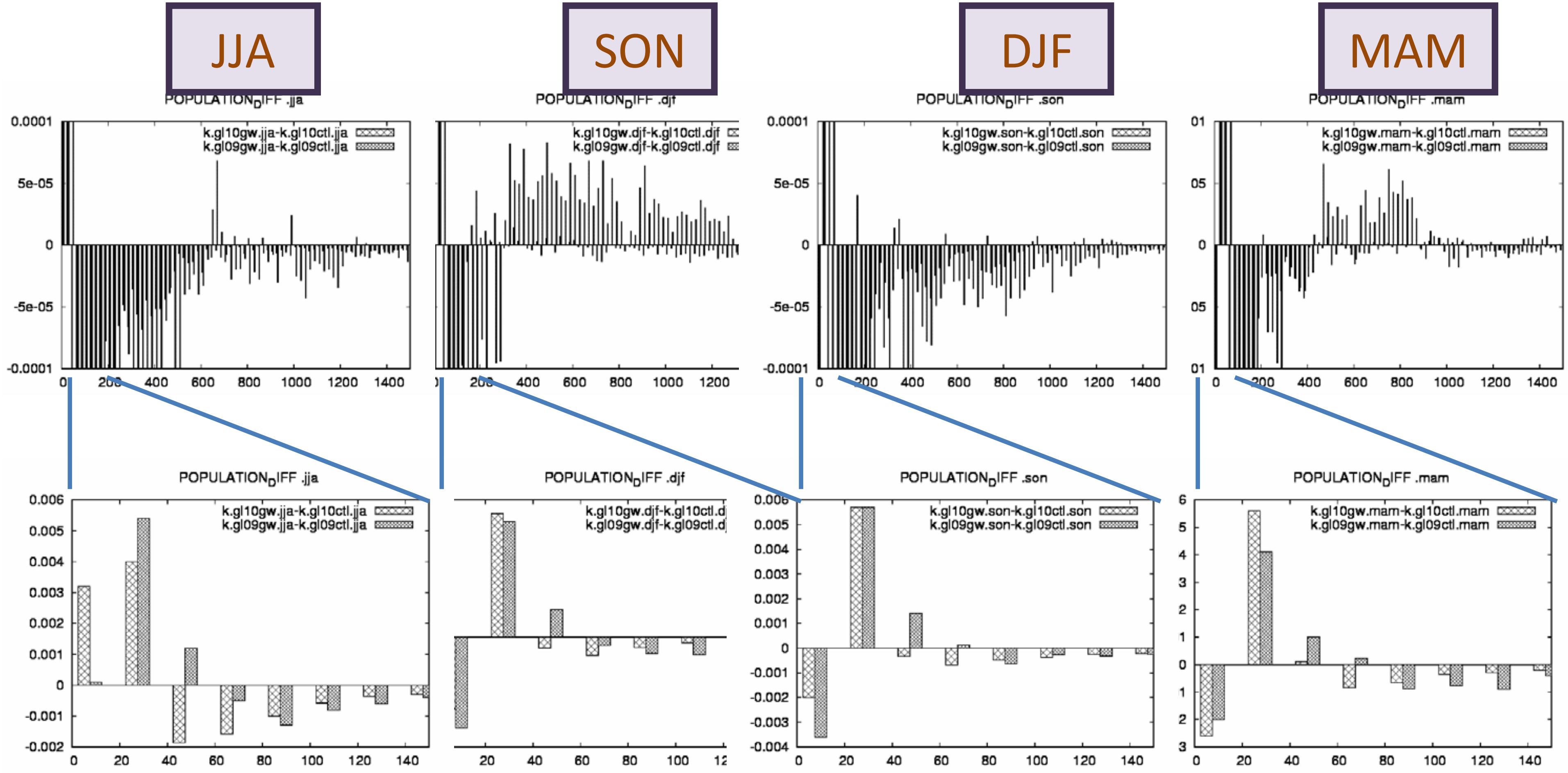


Sensitivities

Seasonal variation

- Less differences below r=150km
- Possibly differ in cloud clusters with larger radius

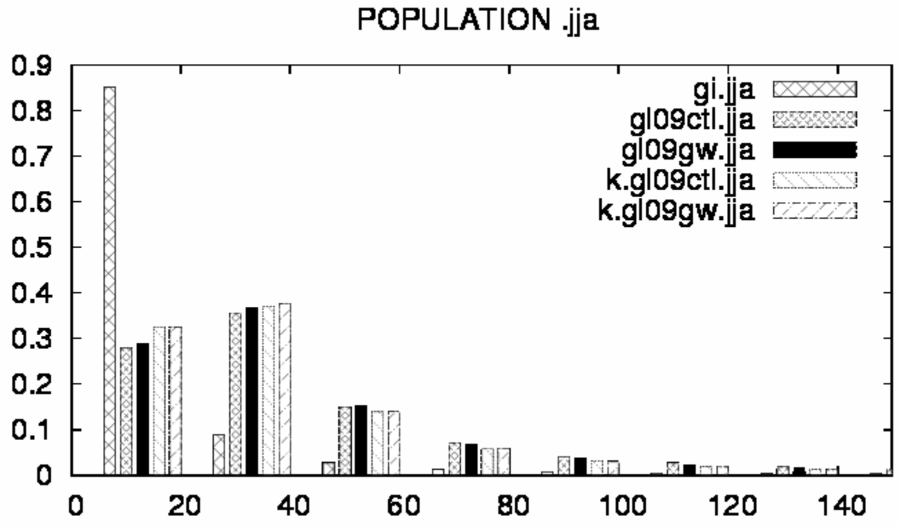
From left to right,
- Perturbed – Present (7km)
- Perturbed – Present (14km)



Radius (km)

Dependence of cloud microphysics schemes

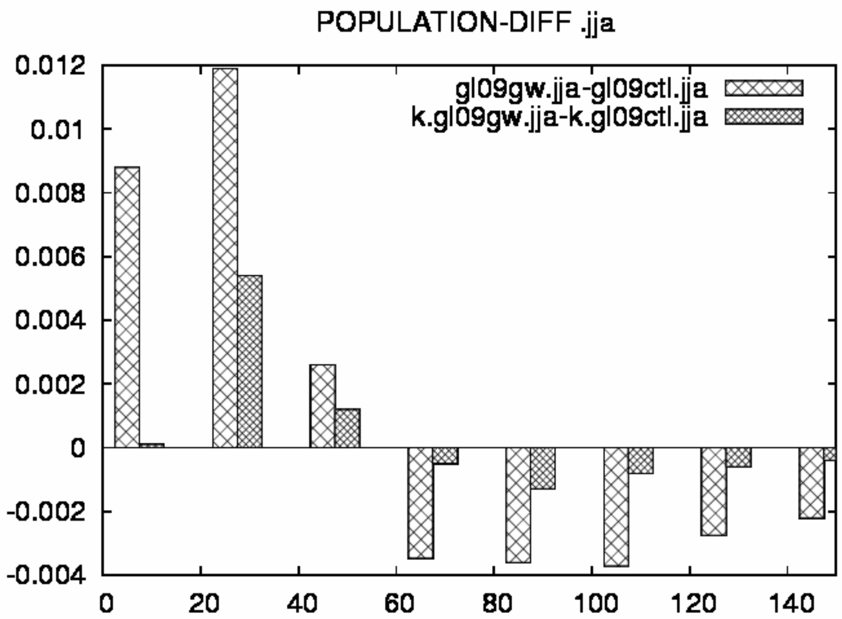
✓ G98 predicts much larger changes in cloud sizes



Present (14km)
From left to right,
・ Obs. (Global IR)
・ Present (G98)
・ Perturbed (G98)
・ Present(T08)
・ Perturbed(T08)

G98:
Grabowski (1998) predict condensates and separate into liquid and ice species

T08:
Tomita (2008) predict liquid and ice species separately based on 1-moment bulk

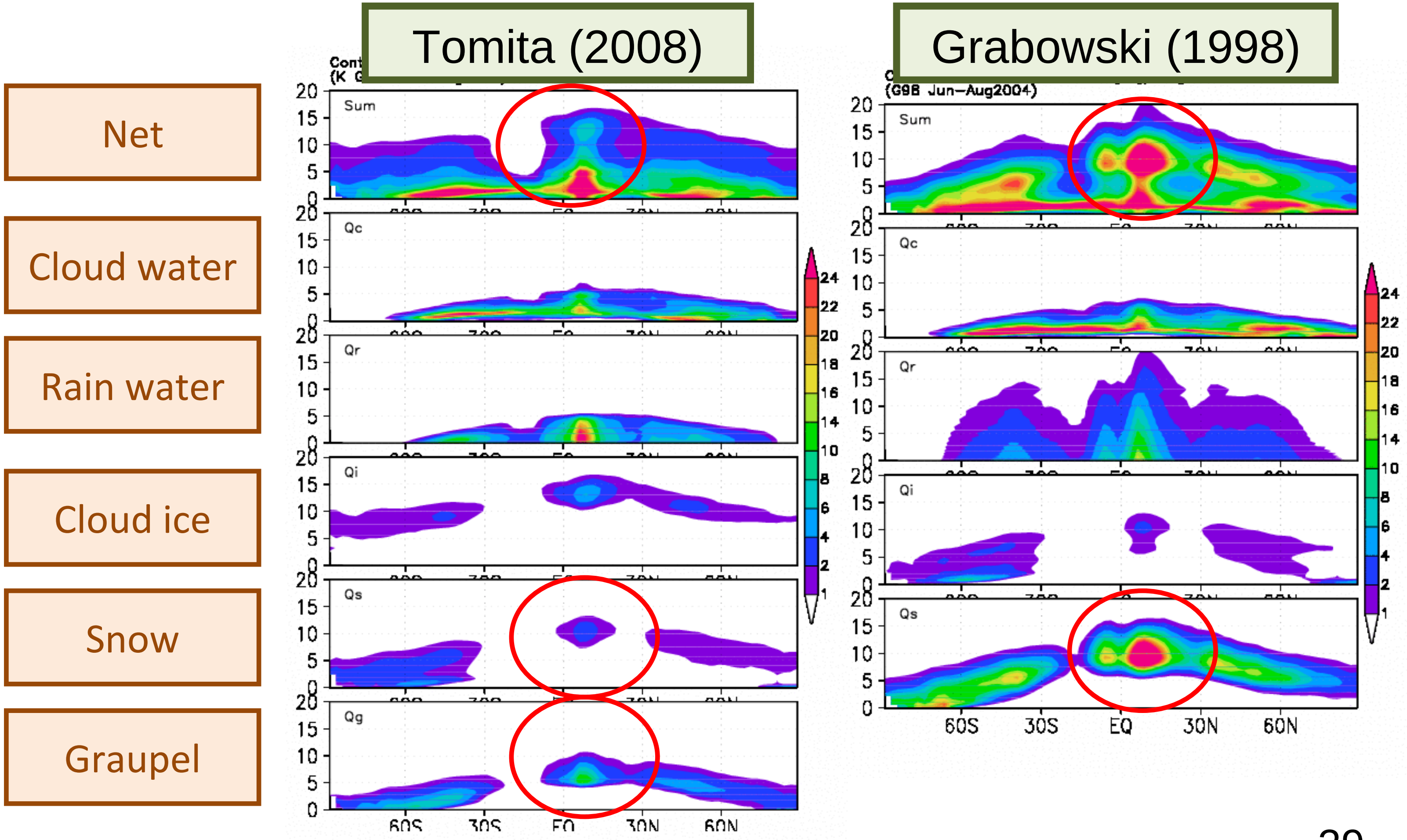


Perturbed – Present (14km)
From left to right,
・ G98
・ T08

Dependence of cloud microphysics schemes Tomita (2008) vs. Grabowski (1998)

- ✓ G98 predicts much larger changes in cloud sizes
  - ✓ due to the much larger amplitude of snow

JJA2004
Zonal means
(mg/kg)



Summary

- Global nonhydrostatic simulations (e.g.,7km-mesh) with a period longer than a year is now available using our latest supercomputer, K (peak calculation speed 10peta flops)
- Overall changes due to warmer climate in NICAM simulations
  - In the ISCCP category, high cloud amount increases while low cloud amount decreases
  - i.e., Both effects result in a positive feedback in the climate system
  - Weaker response in middle cloud amount
- Analysis of the size distribution of high cloud
  - Power law with ~ r^{-2} – r^{-3} both in present and perturbed climate
  - Response to warmer climate
    - Frequency of small convection (~20km) decreases, while slightly larger anvils increases (~40-60km)
    - Numbers of anvils larger than r=60km overall decrease
    - Possibility of less convective organization in warmer climate
  - Dependence on cloud microphysics schemes
    - Notable differences between Grabowski 1998 and Tomita 2008, the former predicts more changes of ice clouds
    - …Need to contrive way to interpret the modeled result