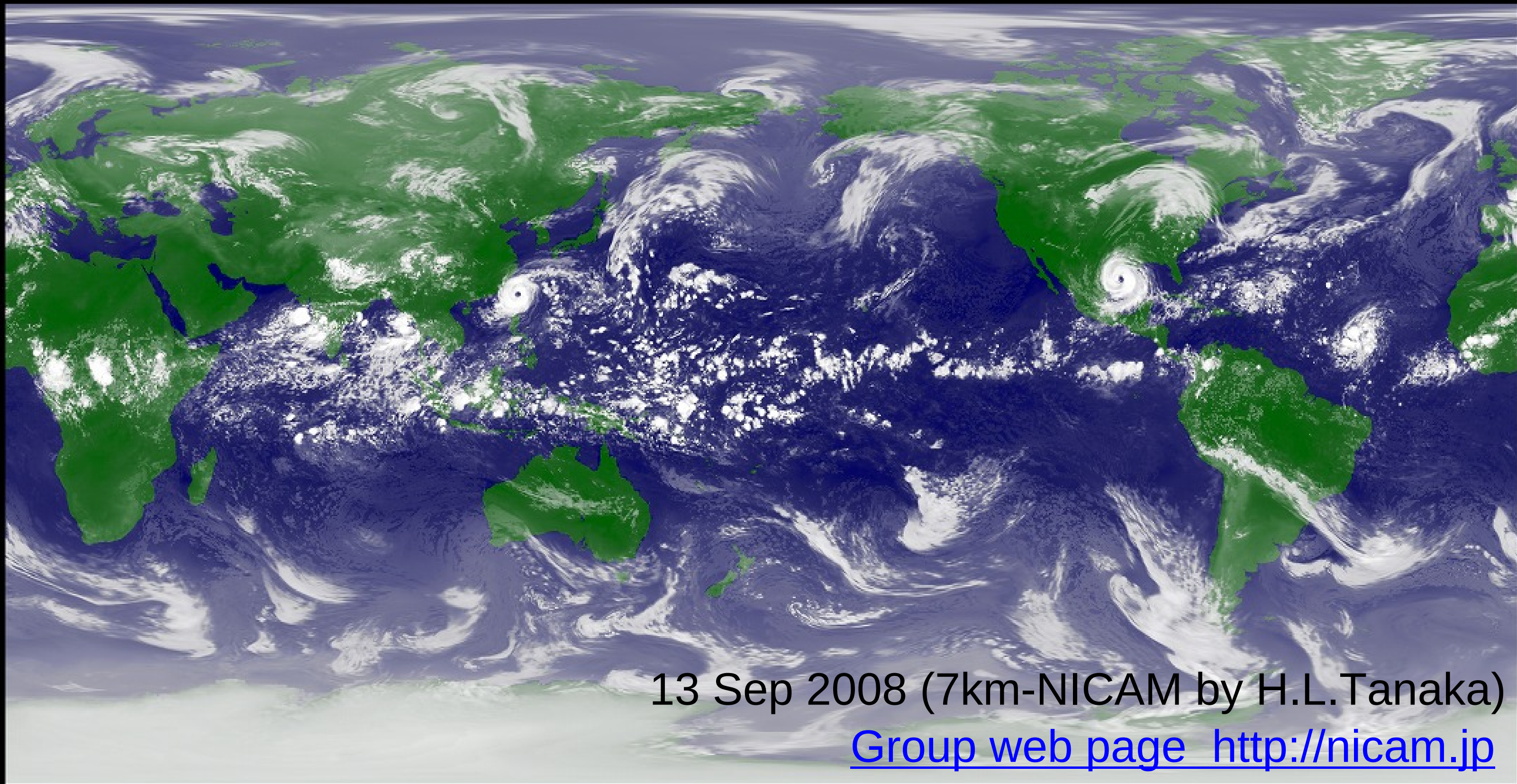
Response of upper clouds in global warming experiments obtained using a global non-hydrostatic model with explicit cloud processes

Masaki Satoh (AORI,Univ. of Tokyo/JAMSTEC)
Shin'ichi Iga , Hirofumi Tomita, Yoko Tsushima



13 Sep 2008 (7km-NICAM by H.L.Tanaka)
Group web page http://nicam.jp

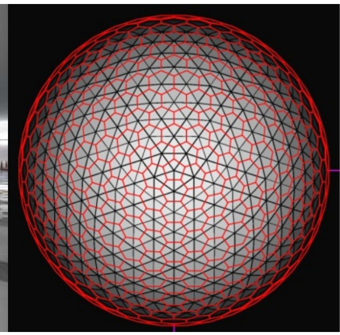
CFMIP/GCSS/EUCLIPSE Meeting on Cloud Processes and Climate Feedbacks
The Met Office, Exeter, United Kingdom, 6th-10th June, 2011
http://cfmip.metoffice.com/meetings.html

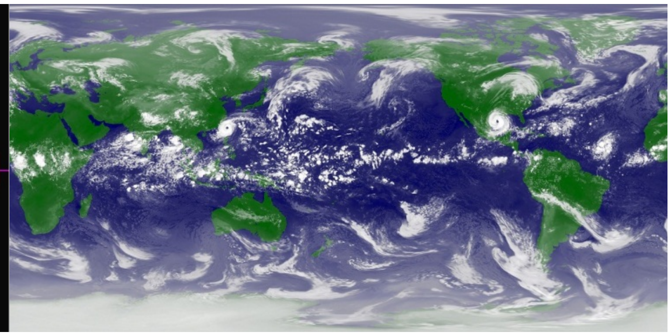
Contents

- **NICAM 3.5km simulation: 15-25 June 2008**
  - **TC Fengshen, YOTC, PALAU2008-field campaign**
  - **Cloud properties and evaluation**
    - **J-simulator by T. Hashino and the EarthCARE team**
    - **Ice effective radius distributions**
- **Future change experiments**
  - **Upper clouds and ice water paths**
  - **Circulation & Ice effective radius feedback**

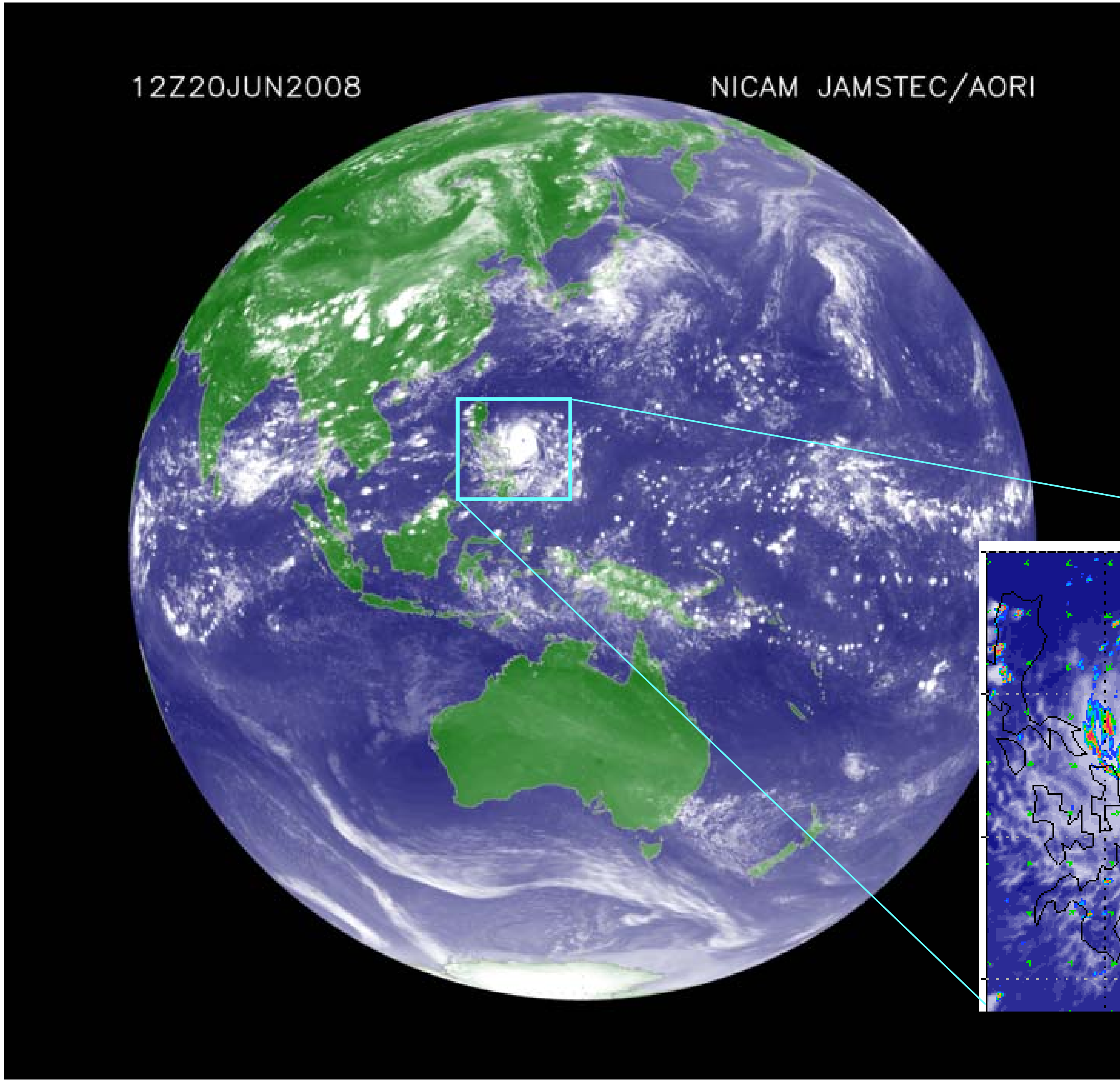
Global Cloud-Resolving Modeling

- NICAM: Nonhydrostatic Icosahedal Atmospheric Model
  - -Development since 2000
    - Tomita and Satoh(2005, *Fluid Dyn. Res.*), Satoh et al.(2008, *J. Comp. Phys.*)
  - -First global dx=3.5km run in 2004 using the Earth Simulator (JAMSTEC)
    - Tomita et al.(2005, *Geophys. Res. Lett.*), Miura et al.(2007, Science)
  - -Toward higher resolution global simulation
    - dx=1.7km, 870m, 430m using K-computer (Kobe,Riken,2012)
- International collaborations
  - –Athena project (2010): COLA, NICS, ECMWF, JAMSTEC, Univ. of Tokyo
  - –G8 ICOMEX (2011-): Germany, UK, France, US, Japan





NICAM 3.5 km mesh simulation 2008/06/20 12UTC

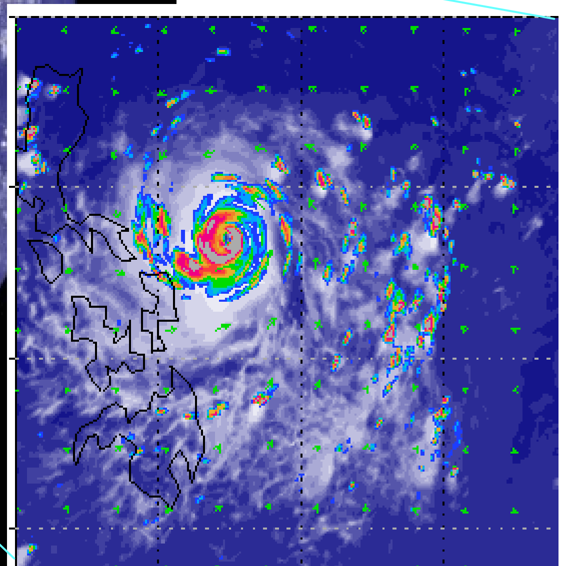


T. Nasuno (JAMSTEC)
T. Hashino (AORI)

Cloud evaluations using J-simulator

Joint Simulator for Satellite Sensors
J-Simulator

TC Fengshen



Cloud properties & evaluations
by T. Hashino and the EarthCARE team

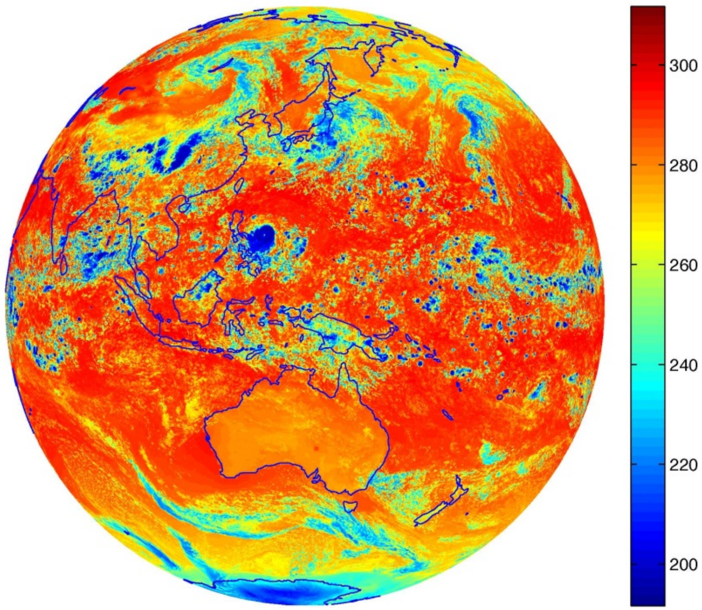
- J-simulator (Joint Simulator for Satellite Sensors)

  http://www22.atwiki.jp/j-simulator/pages/14.html

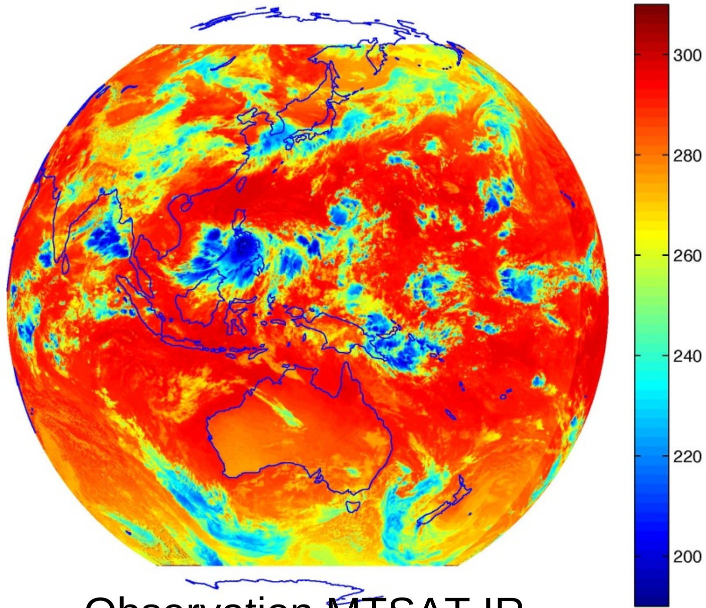
  - Simulate EarthCARE (2014) observations from CRM outputs.
  - Built on Satellite Data Simulator Unit (SDSU)

    Masunaga et al. (2010, BAMS)
  - Extension at NASA/Goddard: Goddard-SDSU (T. Matsui & GPM team)

Joint Simulator for Satellite Sensors
J-Simulator

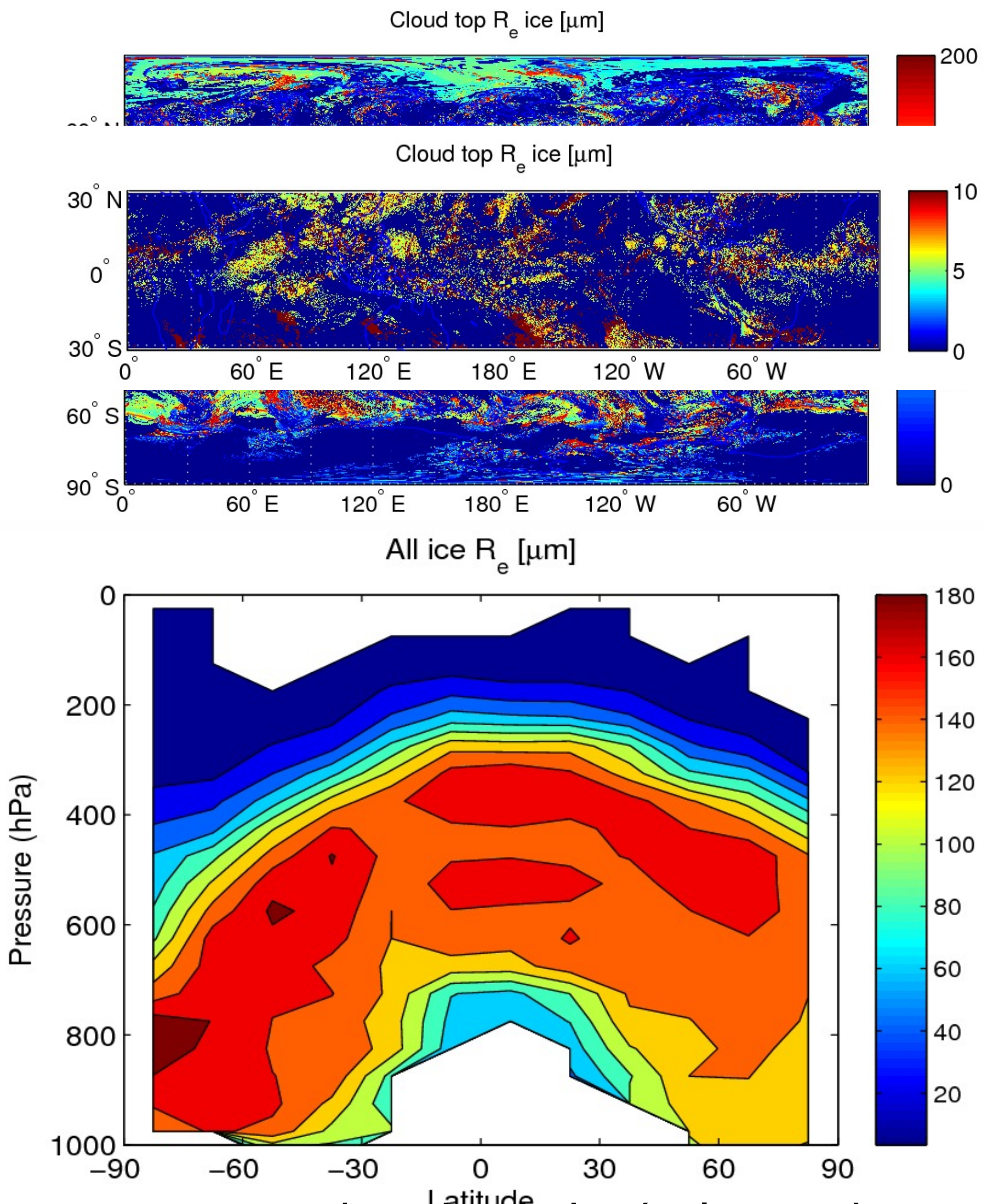


NICAM simulated IR 10.8 μm TBB[K]



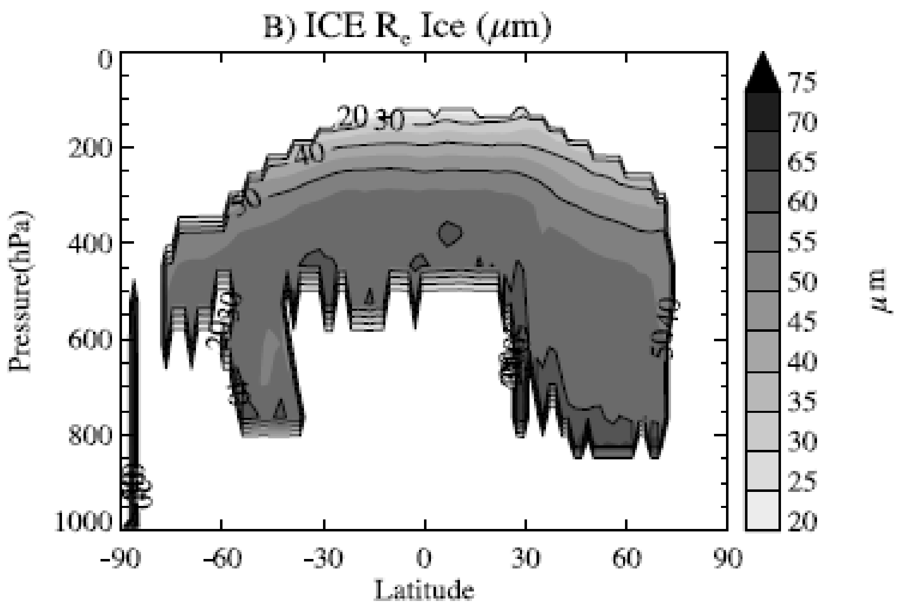
Observation MTSAT IR
Japan; Chiba Univeristy, CEReS)+ globally-merged IR (CPC, NOAA)

Effective Radius of ice clouds (all categories)



- Temperature dependent:
  As higher, Re becomes smaller.
- Cloud top R_e ice:
  Re becomes higher in polar jet area.
- In the tropics:
  Re is larger near convective cores.

Gettleman et al. (2010)



NICAM 3.5km simulation(July 2008), T. Hashino & T. Nasuno

Zonal mean distributions

Gettleman et al. (2010)

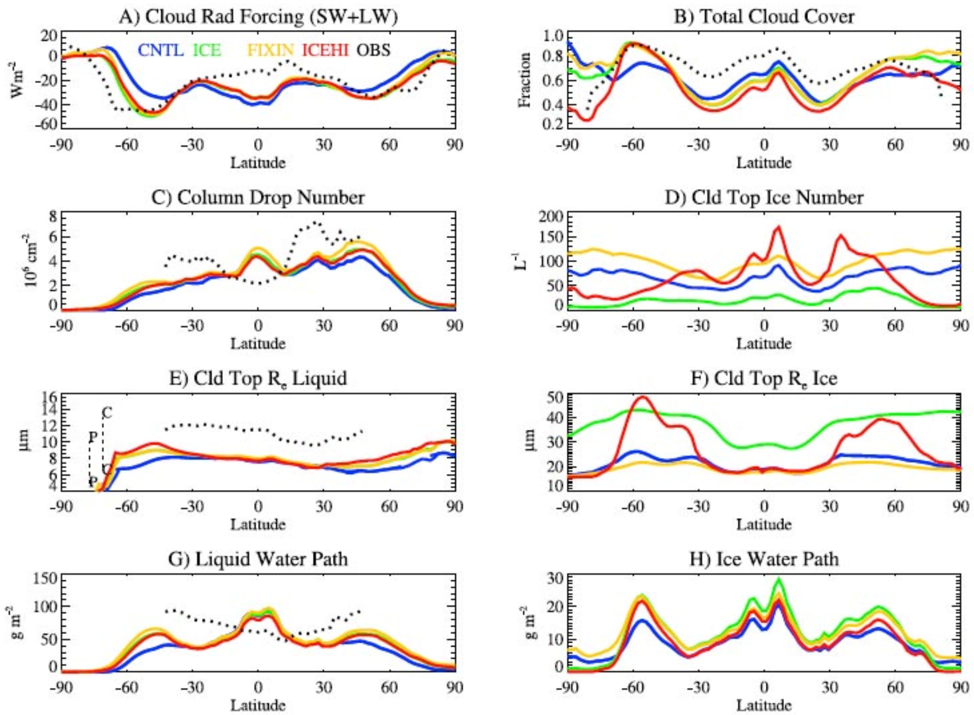
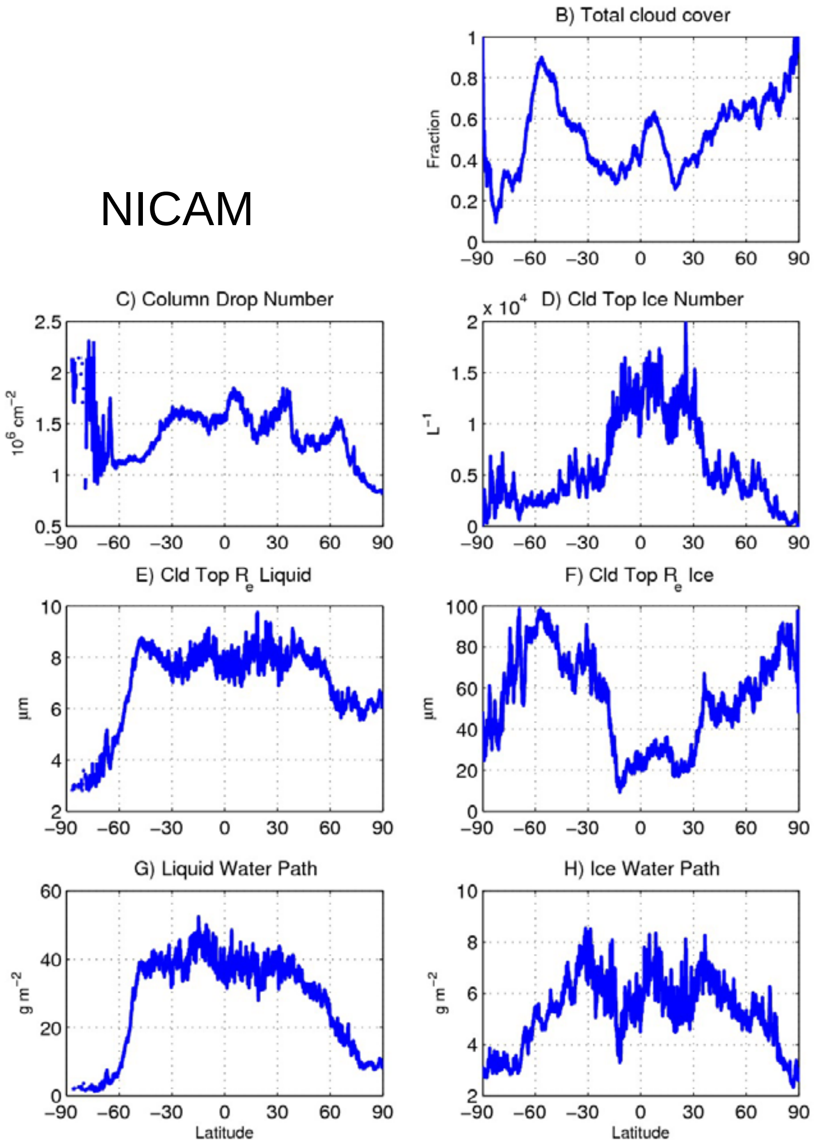


Figure 12. Zonal mean distributions of key cloud ice and liquid properties from cases as discussed in the text and in Table 2. CNTL: blue, ICE: green, FIXIN: yellow, ICEHI: red. Observations are shown in black. (a) Net cloud radiative forcing compared to CERES observations. (b) Total cloud cover compared to CloudSat/CALIPSO. (c) Column cloud drop number compared to AVHRR. (d) Cloud top ice number. (e) Cloud top liquid effective radius compared to AVHRR and range of "C"lean and "P"olluted in situ observations described by *Gettelman et al.* [2008]. (f) Cloud top ice effective radius. (g) Liquid water path compared to AVHRR. (h) Ice water path. References for observations are described in the text.

NICAM



Note: definition of C, G, H is likely different (need to make sure).

Cloud top ice number tends to be much higher than Gettelmen's. In NICAM # of cloud ice is not predicted. Re of cloud ice diagnosed in J-simulator based on T and IWC. In middle latitude, snow category likely to contribute to the large Re.

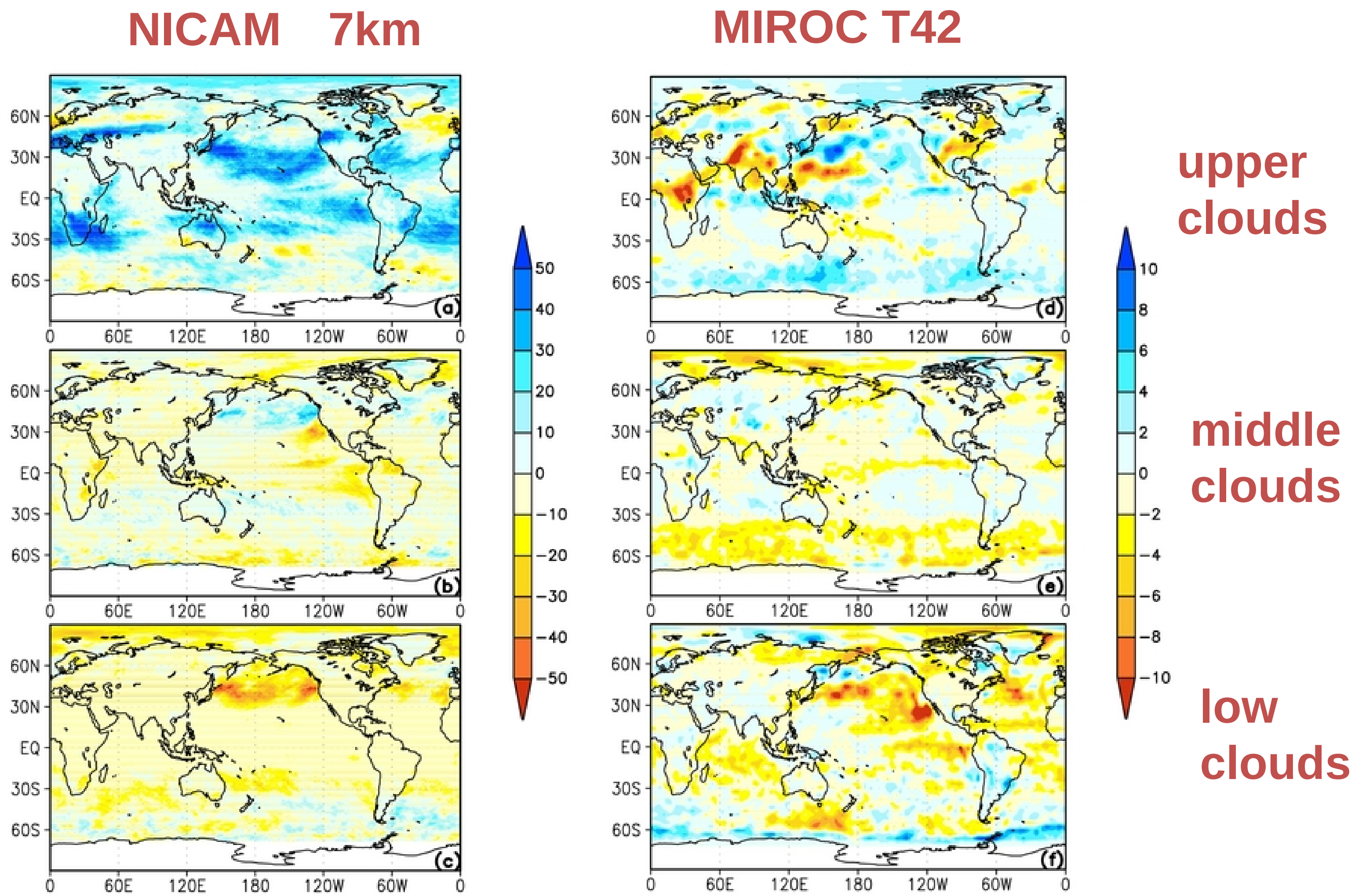
Response of upper clouds due to global warming tested by a global atmospheric model with explicit cloud processes

Satoh, M., Iga, S., Tomita, H., Tsushima, Y.

J. Climate, in review

Iga et al. (2007,Geophys, Res.Lett.)
Iga et al.(2011,JCLI, accepted)
Satoh et al.(2011,JCLI,submitted)
Tsushima et al.(in prep.), Collins and Satoh(2008)

Cloud changes under GW condition (SST+2K exp – CTL exp)



Tsushima et al.(in prep.), Collins and Satoh(2008)

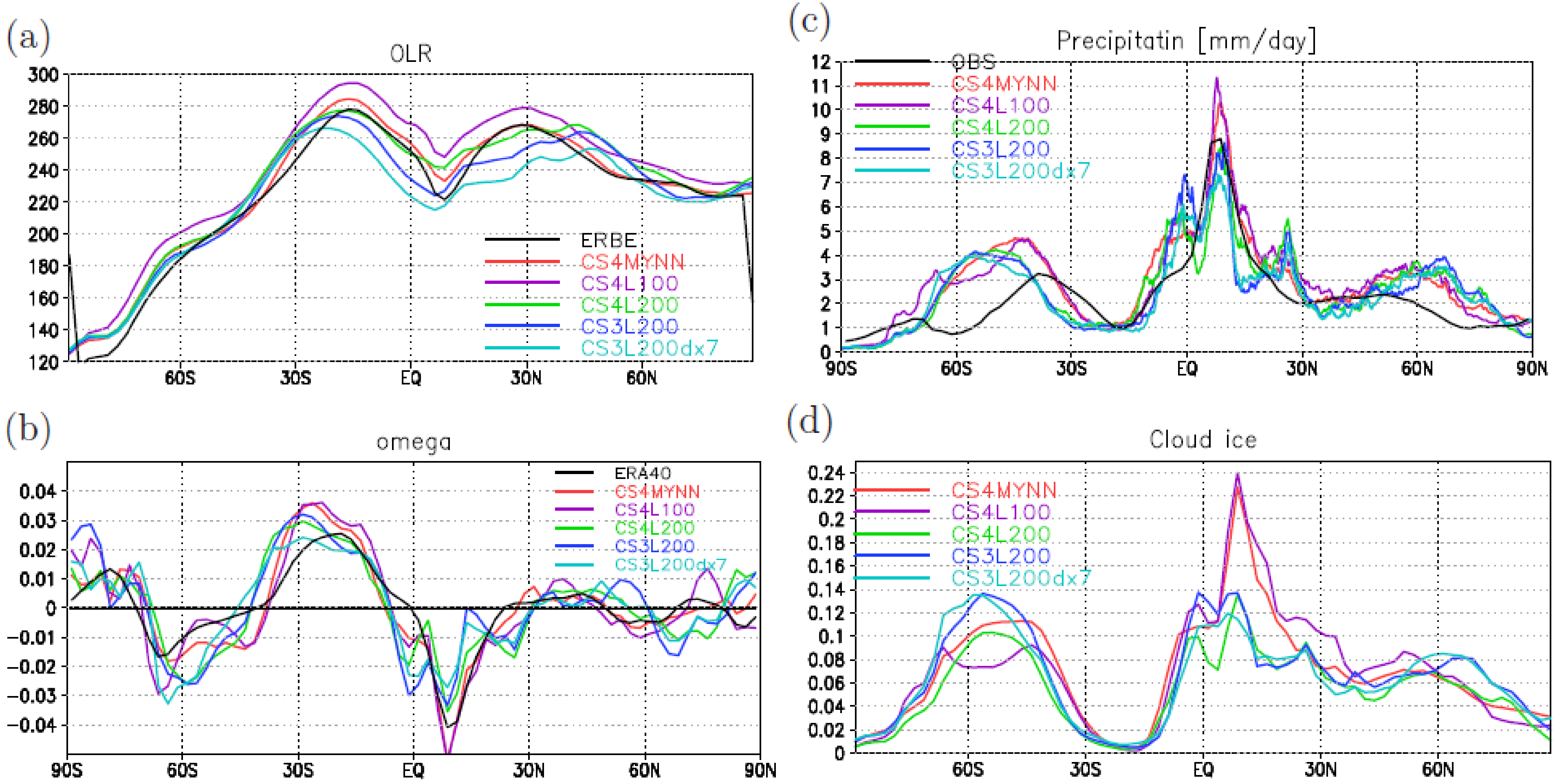
Experimental designs

- NICAM 14km/7km
  - CFMIP perpetually July experimets
  - Cloud microphysics: Grabowski(1998,G98), PBL (MY2-Smith, MYNN), radiation: MSTRN
- Sensitivity experiments under present condition
  - Relation between upper clouds and ice water path
- Global warming experiments with +2K SST
  - Cloud change in the future climate
- Understanding using a simple column model
  - Use of different cloud microphysics schemes
    - G98 vs NSW6

Parameter sensitivity under the present condition

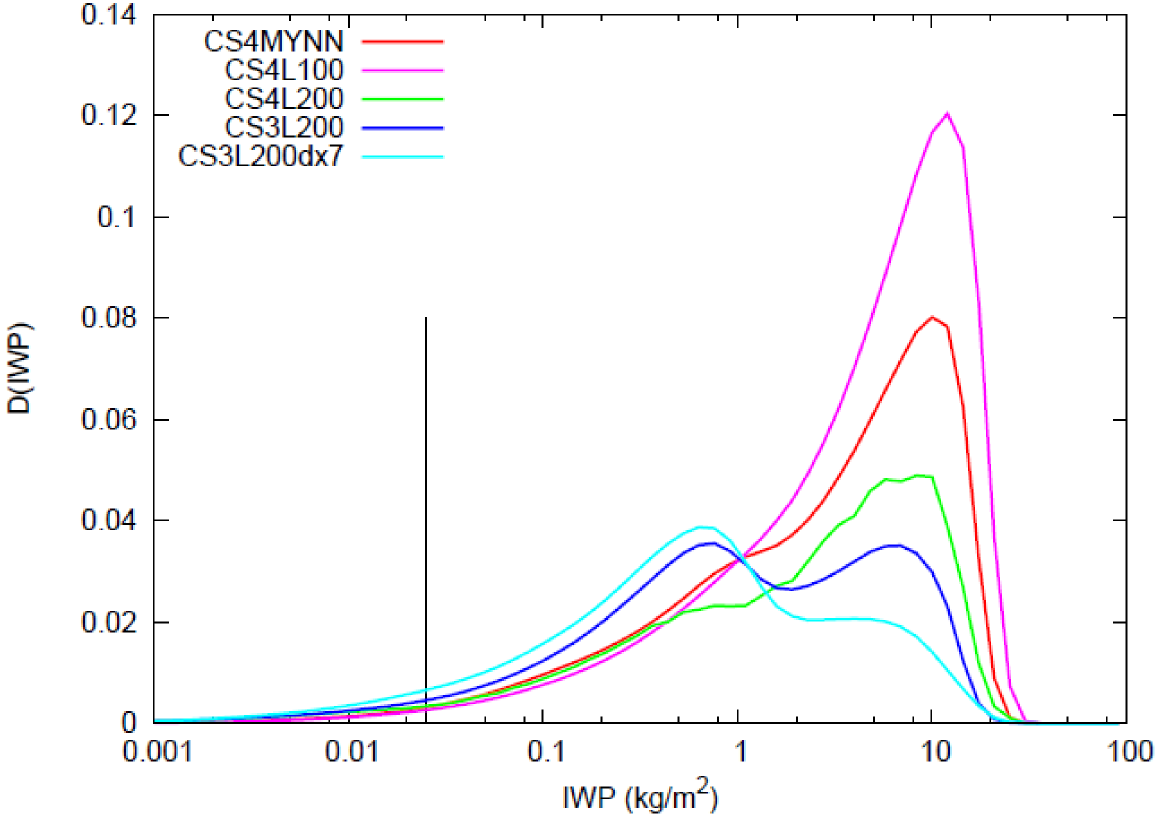
- Dx=14km,7km
  - Perpetual July experiment
  - Cloud microphysics : Grabowski(1998)
- Parameter sensitivity
  - CTL (Cs=4, L=100m,dx=14km)
  - CS4L200: Increased mixing length L=200km
  - CS3L200：Decrease in fall speed of snow
  - CS3L200,dx=7km： Higher resolution
  - CS4MYNN: Planetary Boundary Layer scheme: MYNN

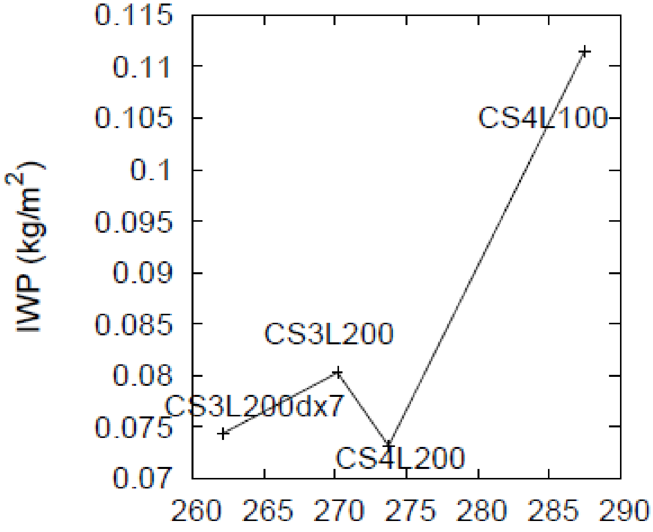
OLR, Cloud ice, precipitation
NICAM dx=14km



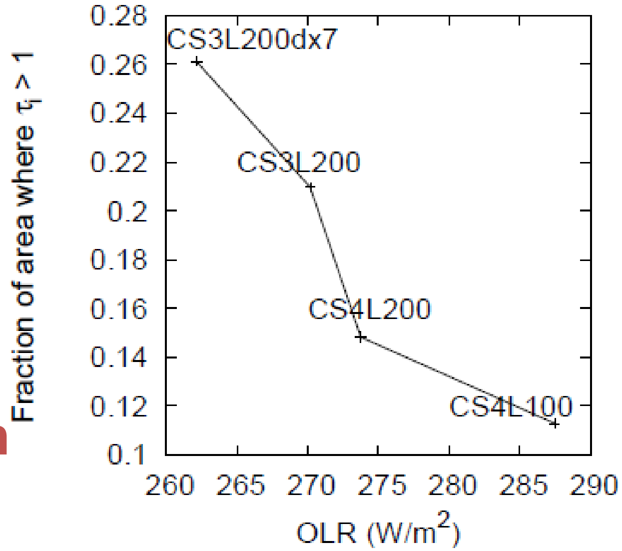
As OLR decreases, precipitation, circulation, and IWP decreases

Weighted histogram of IWP



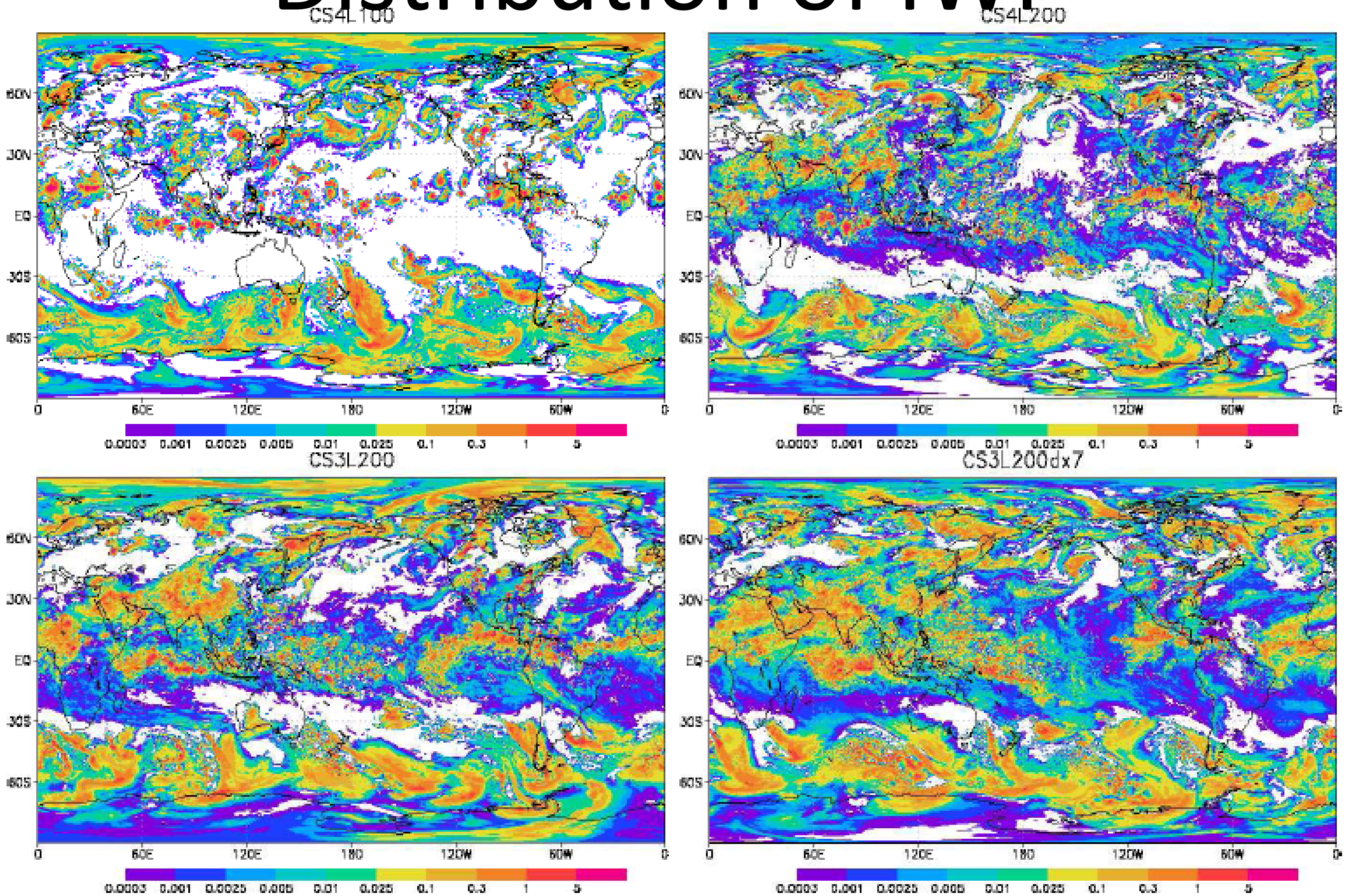


IWP > 0.025kg/m²: radiatively active clouds



IWP and upper cloud fraction: negative correlation
OLR is more related to thinner cloud ice

Distribution of IWP

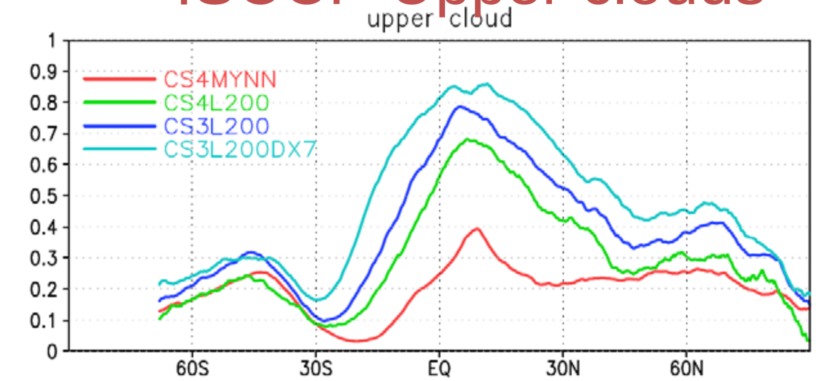


As IWP increases, cloud fraction decreases

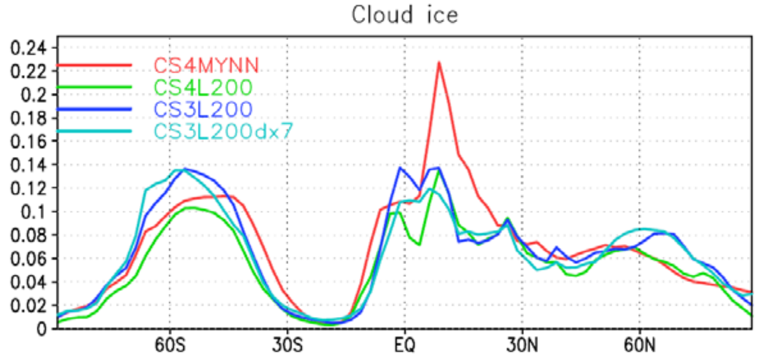
Probably related to categories of hydrometeors: As heavier ice clouds increase, cloud fraction decreases: Satoh and Matsuda (2009,JAS)

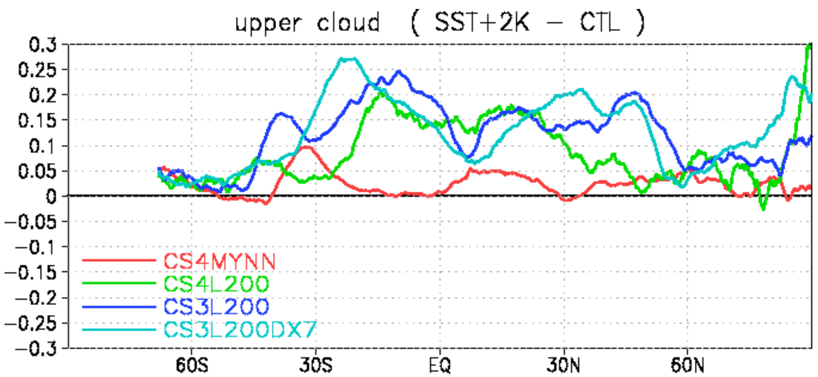
Global Warming Experiments
Change in upper clouds and IWP
between SST+2K and CTL exp.

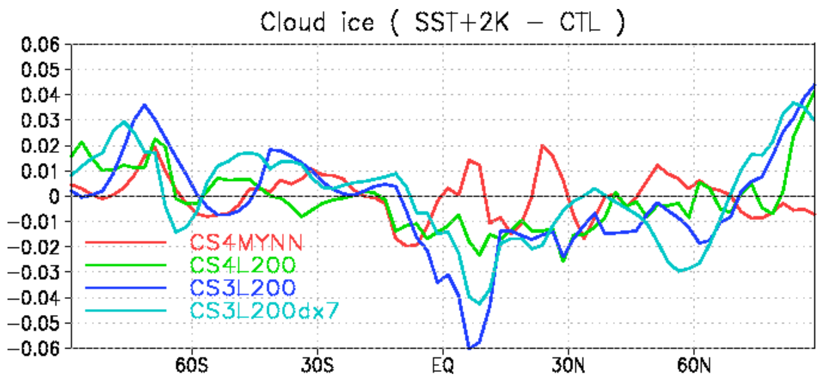
ISCCP Upper clouds



Ice Water Path







As SST becomes warmer, upper clouds increase, while IWP decreases in the tropics

NICAM CFMIP +2K EXP.

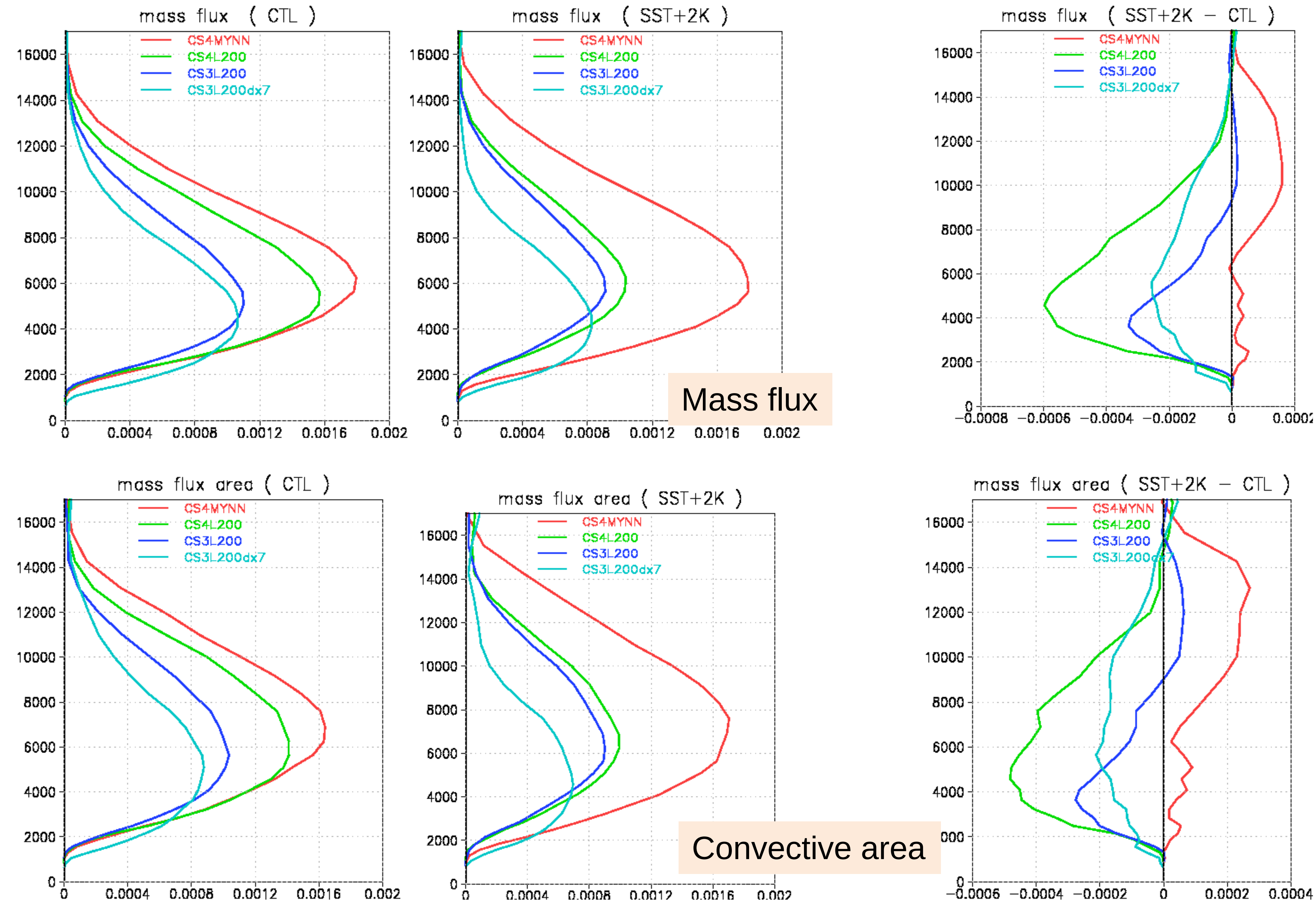
- Response to global warming change
  - Increase in upper clouds
  - Decrease in IWP
  - The same correlation seen in the sensitivity experiments under the present condition

Why IWP decreases as SST becomes warmer?

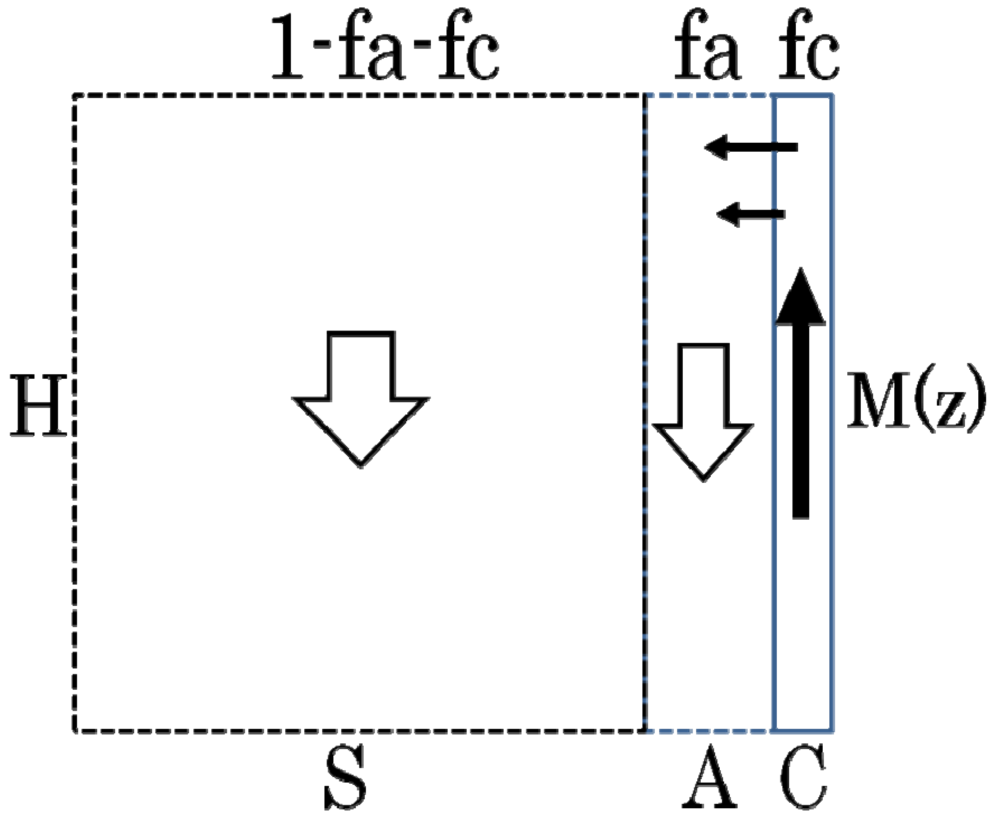
Possible mechanisms for the change in upper clouds under GW condition

+ Clausius Clapeyron
- Melting level becomes higher
+ Tropopause becomes higher
? Change in cloud microphysics processes
  - Convergent from cloud ice to cloud water
  - Precipitation efficiency：detrain from deep clouds to anvil
  - Change in sedimentation of ice, more graupel
? Change in circulations, mass flux

Change in mass flux, convective areas: threshold w= 1 m/s (30S-30N)

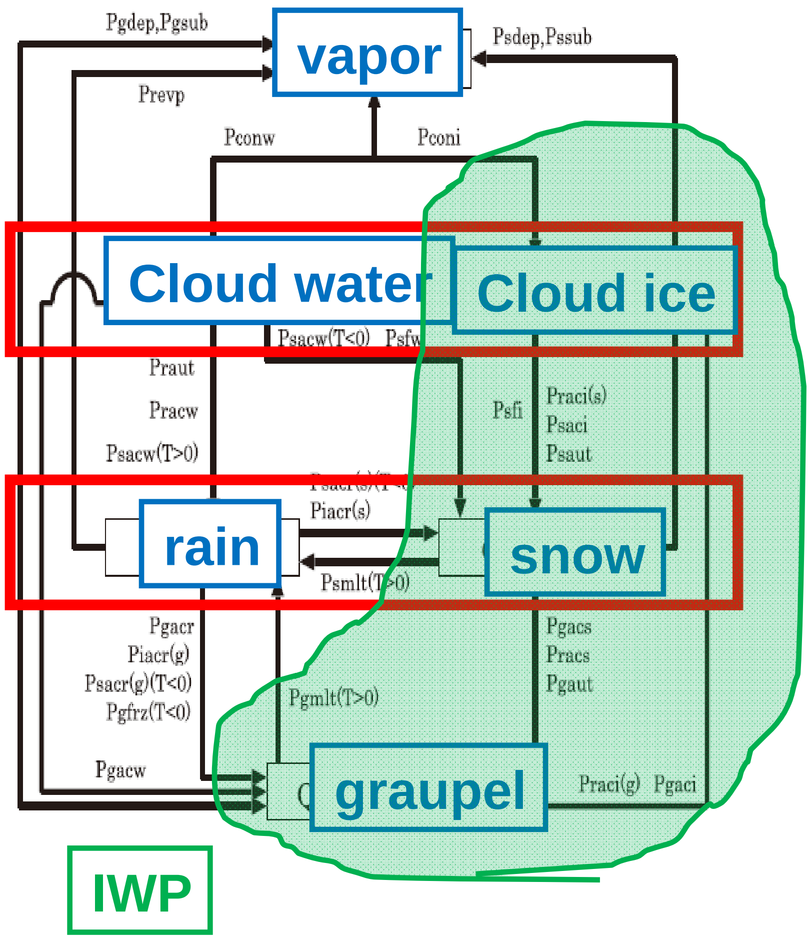


Interpretation using a column model



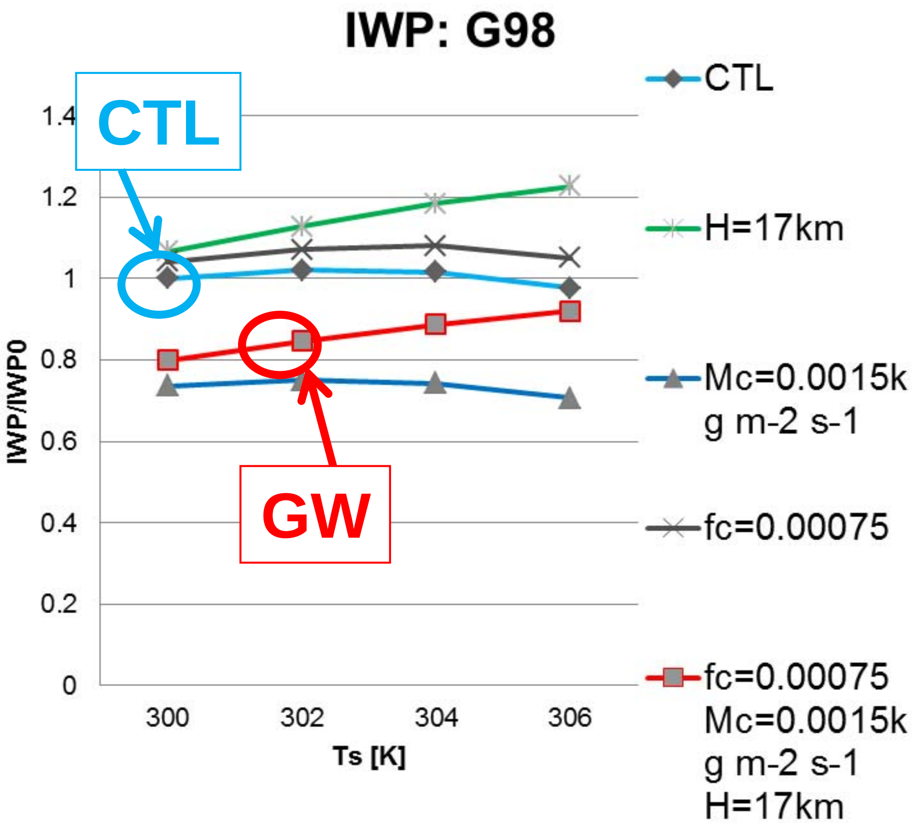
$M(z)=M_0 \sin(z/H)$ $M_0 = 0.002 kg/m^2 s$
H=15km
fc=0.001, fa=0.2

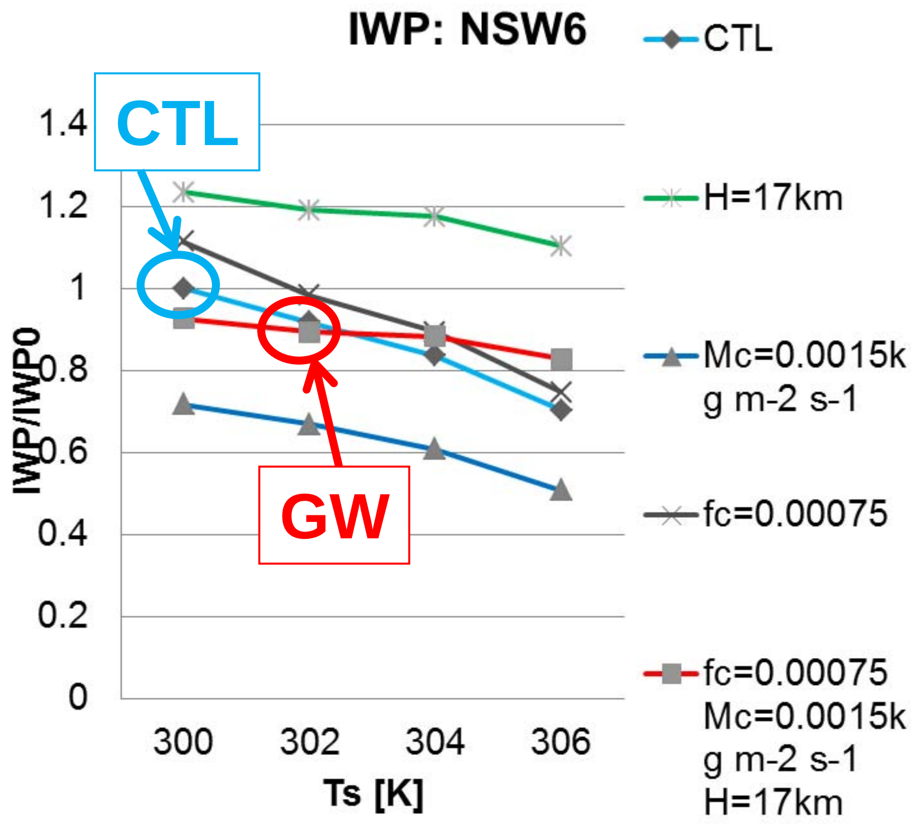
Grabowski (1998)
NSW6 (Tomita 2008,JMSJ)



Dependency of IWP

	Tropopause height(H)	Mass flux (Mc)	Convective area (fc)	SST (Ts)
CTL	15km	0.002kg/m^2 s	0.001	300K
GW (+2K)	17km	0.0015kg/m^2 s	0.00075	302K

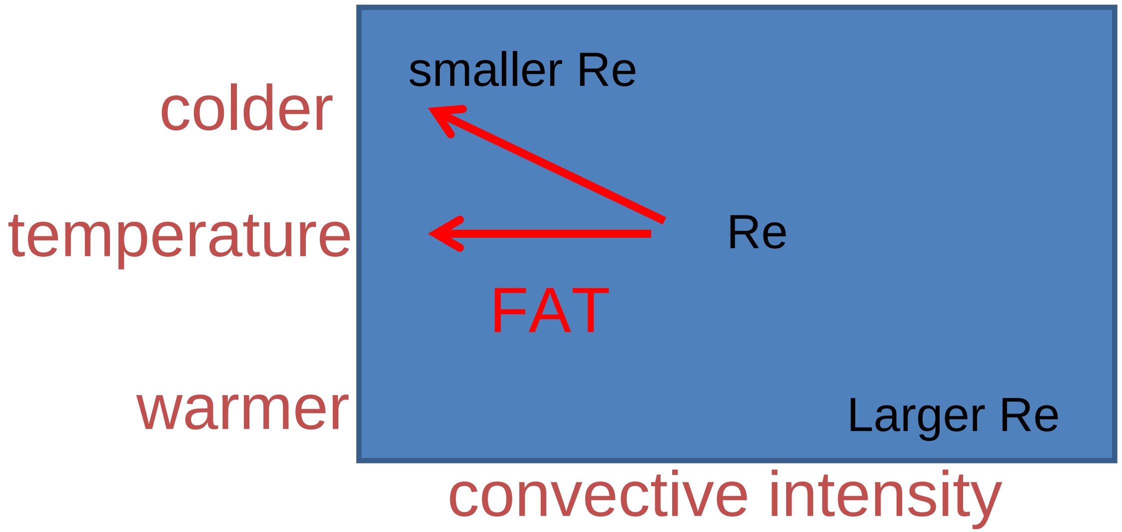




Circulation & Ice Re feedback

- In warmer climate,
  - Convective mass flux decreases
  - IWP decreases
  - Re becomes smaller
  - Slower sedimentation and aggregations of ice
  - Wider upper clouds fractions
  - LW vs SW CRF: which tends to be stronger => positive feedback?

Similar to “thermostat effect”



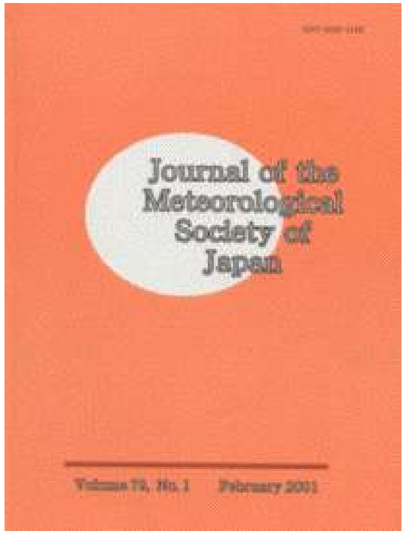
Summary

- Change in upper clouds by NICAM
  - As SST increases, IWP decreases while upper cloud fraction increases
  - Cloud categories
- Possible reason for the IWP decrease
  - Decrease in mass flux is a major cause for the decrease in IWP
  - Robust independent of cloud microphysics schemes

Journal of the Meteorological Society of Japan

(社)日本気象学会

気象集誌



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JMSJ, Since 1882

"Special issue on the recent development on climate models and future climate projections" (2012)
by T. Ose & Hiro Watanabe, edit.

...ttp://www.jstage.jst.go.jp/browse/jmsj
...o submit papers and browse archives (*free access!*)

Model description

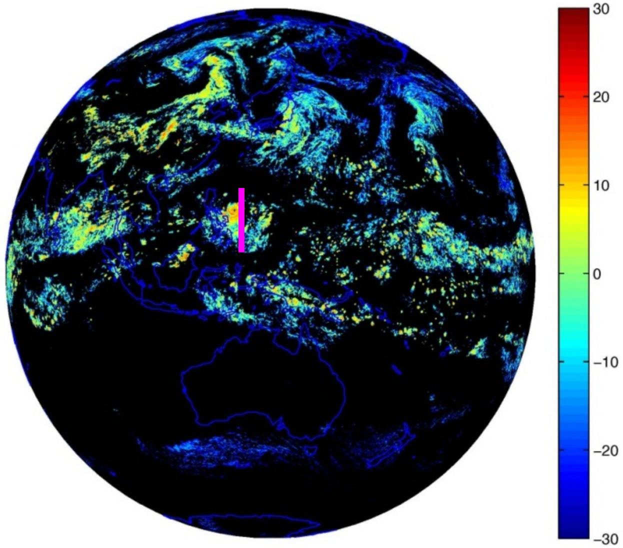
■ Dynamics	
governing equations	Fully compressible non-hydrostatic system
spatial discretization horizontal grid configuration vertical grid configuration topography	Finite Volume Method Icosahedral grid Lorenz grid Terrain-following coordinate
conservation	Total mass, total energy
temporal scheme	Slow mode - explicit scheme （RK2, RK3） Fast mode - Horizontal Explicit Vertical Implicit scheme

■ Physics	
radiation	MSTRNX / MSTRNX-AR5 (Sekiguchi and Nakajima, 2008)
cloud physics	Grabowski(1998); NSW6(Tomita 2008);NDW6(Seiki 2010)
shallow clouds boundary layer	MYNN2 , 2.5 or 3 (Mellor and Yamada 1982; Nakanishi and Niino 2004)
surface flux	Louis(1979), Uno et al.(1995); Fairall et al. (2002) & Moon et al.(2007)
surface processes	SST specified & bucket; slab ocean & MATSIRO
Cumulus scheme	Off [option AS, Tiedtke]
Gravity wave drag	Off [option McFarlen]

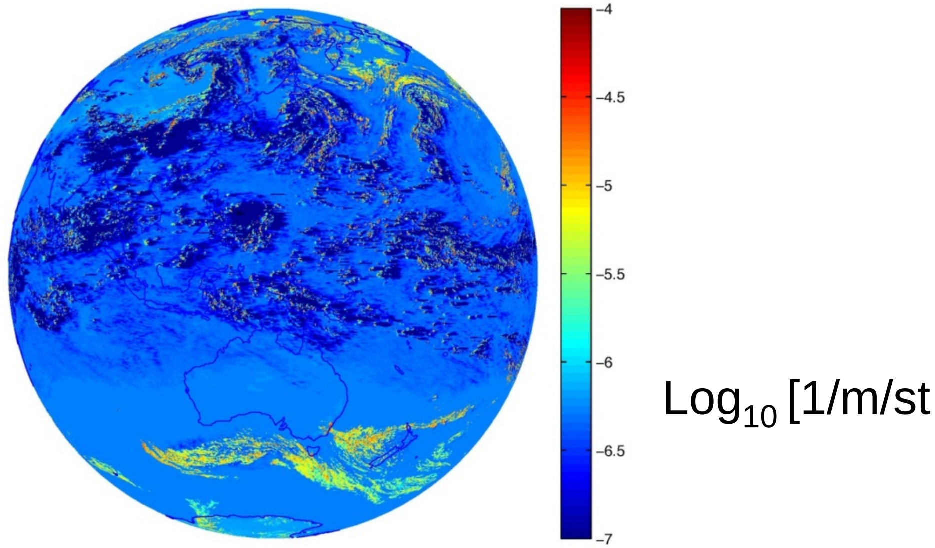
Validation of cloud fields simulated by NICAM with CloudSAT & CALIPSO

NICAM dx=3.5km : 17th 00Z ~ 25th 00Z June 2008

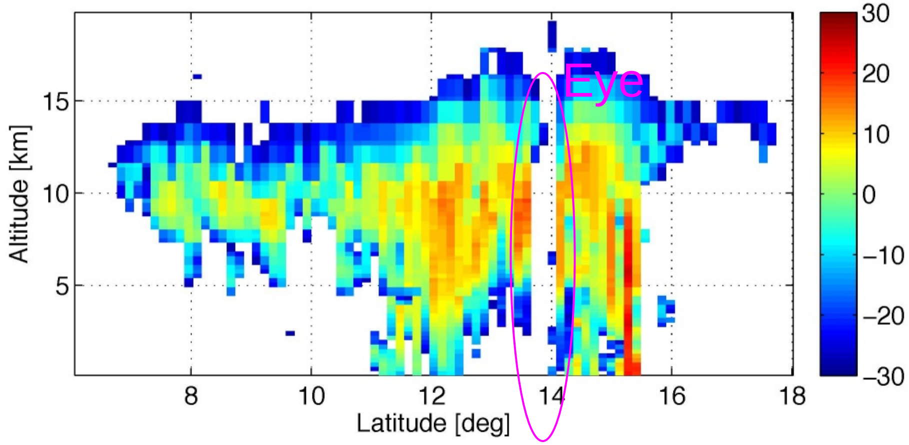
CloudSAT-CALIPSO merged data set provided by H. Okamoto

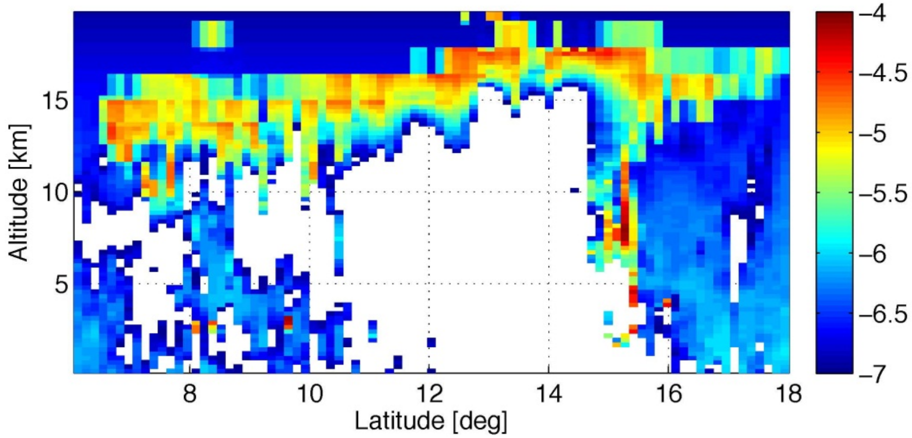


94 GHz CPR [dBZ] at h=10 km



532 nm backscattering coef. at h=10 km





Cross section through the TC at longitude = 127°E

Okamoto et al., 2007, 2008 JGR, Nishizawa et al., 2008 JGR