High cloud responses to global warming simulated by two different cloud microphysics schemes implemented in NICAM

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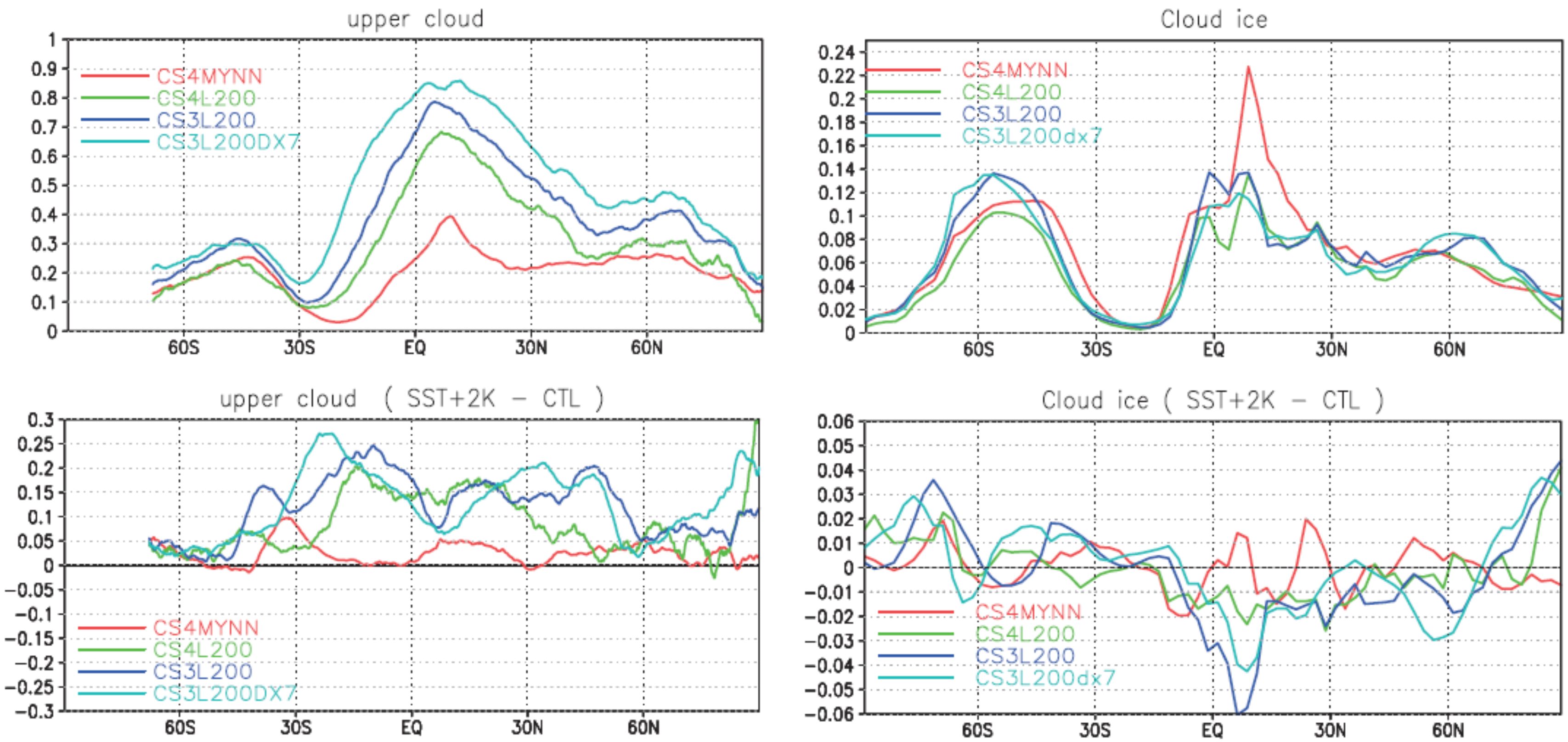
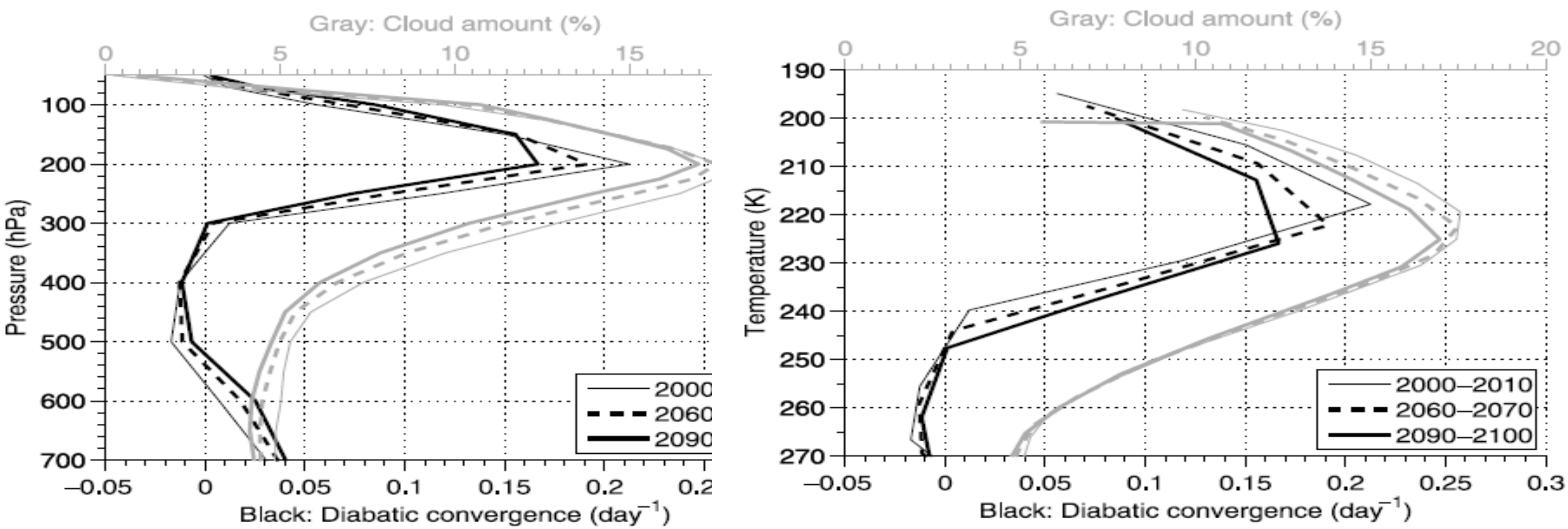
Future changes in upper clouds and ice water path



Satoh et al. (2012,JCLI)



Zelinka and Hartmann (2010,JGR)

Model and Cloud Radiative Kernel

◆Model:

NICAM (14 km resolution; without cumulus parameterization)

◆Cloud microphysics schemes:

Single-moment Water 6 (NSW6; Tomita 2008): Mass concentrations of six categories of water species: water vapor, cloud water, rain, cloud ice, snow, and graupel

Double-moment Water 6 (NDW6; Seiki and Nakajima 2014); mass concentrations and number concentrations of six categories (i.e., Effective radius is prognostic)

◆Analysis duration:

NSW6: one-year and boreal summer (JJA)

NDW6: boreal summer (JJA)

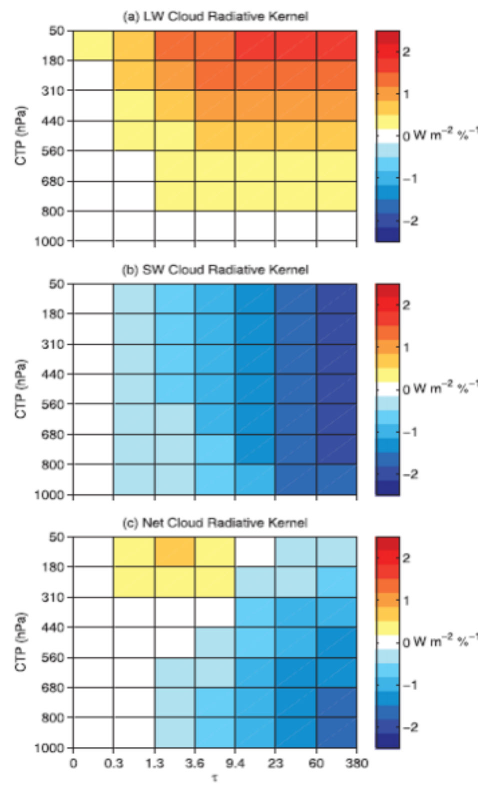


FIG. 1. Global, annual, and ensemble mean (a) LW, (b) SW, and (c) net cloud radiative kernels. In each model, the kernels have been mapped to the control climate's clear-sky surface albedo distribution before averaging in space; thus, the average kernels are weighted by the actual global distribution of clear-sky surface albedo in each model.

● Cloud radiative kernel:

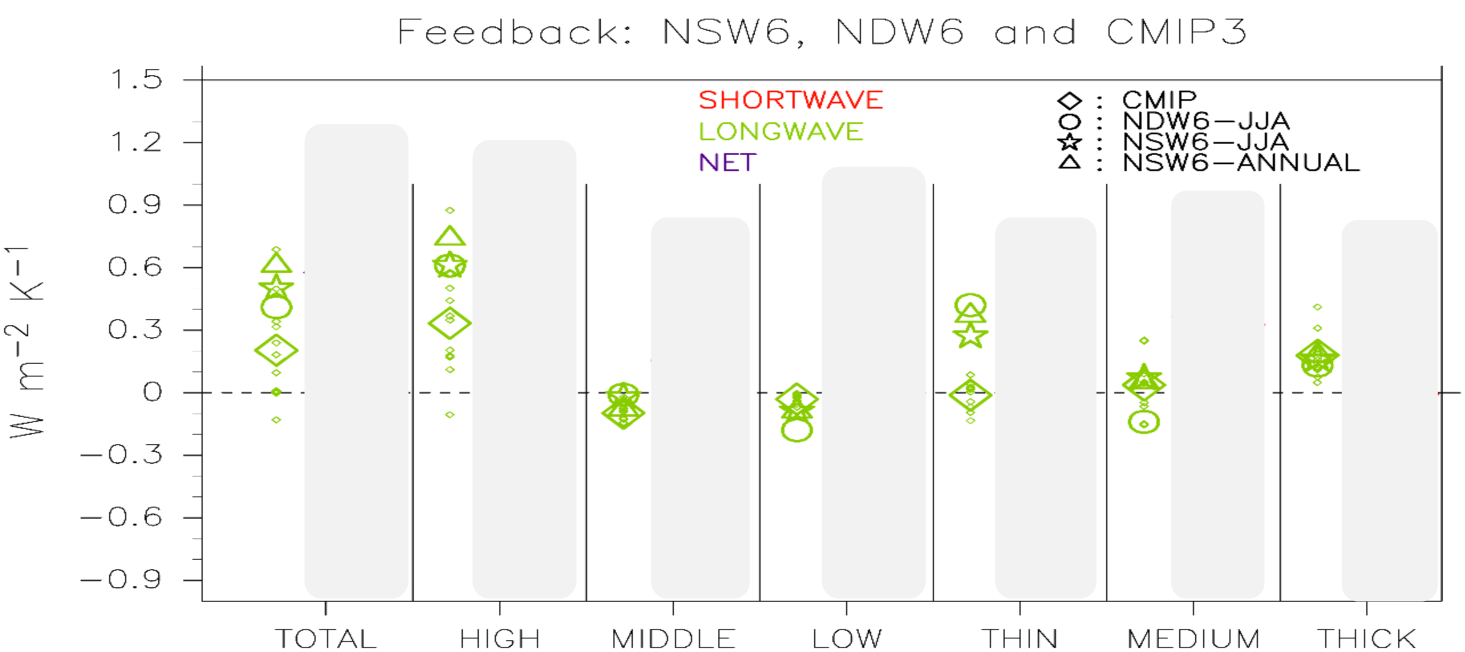
Proposed by Zelinka et al. (2012)

Calculate the cloud radiative feedbacks directly from the cloud responses to the global warming

Compare cloud radiative feedbacks in different models by the same platform

→ Compare cloud radiative feedbacks in NSW6, NDW6 and 1 models in CMIP3 (CFMIP1)

Cloud Feedbacks: NSW6, NDW6 and CMIP3 (CFMIP1)

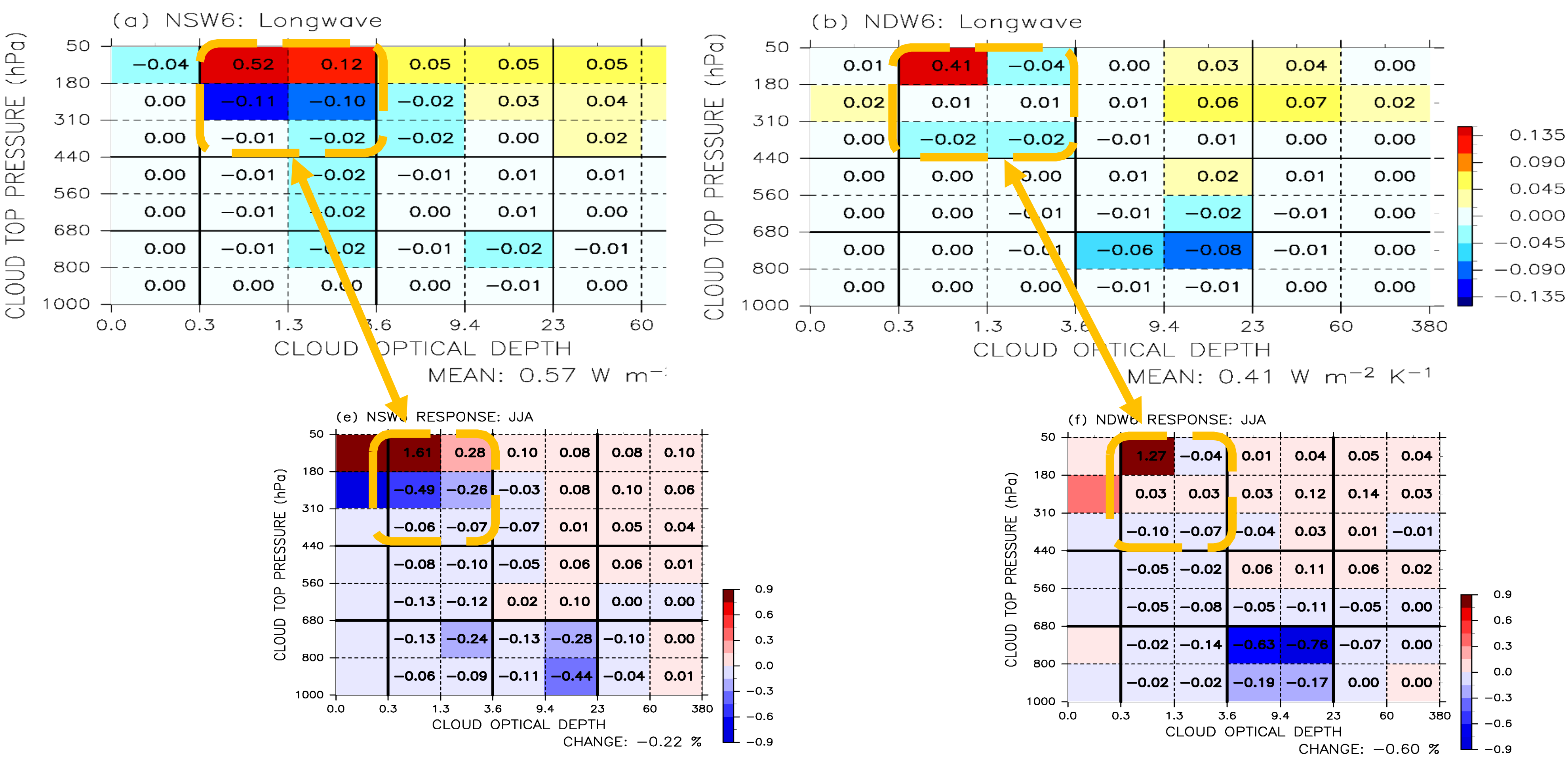


SW:
Large seasonal variation appears
LW:
Seasonal variation relatively small

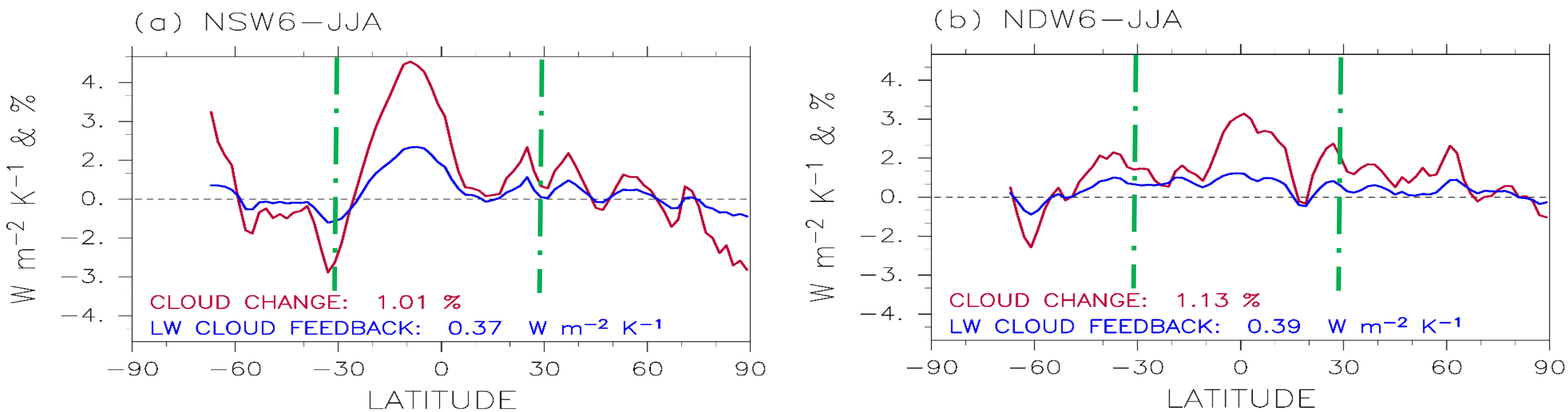
NICAM:
Large LW cloud radiative feedbacks attributed by high and thin clouds (LW cloud radiative feedback attributed by thin clouds are larger than all members in CMIP3 (CFMIP1)

Similar results can by obtained by other experiments with other cloud microphysics scheme
Satoh et al. (2012)
Tsushima et al. (2014)

Cloud Feedback and Cloud Fraction Change: ISCCP



Cloud Feedback and Cloud Fraction Change: Zonal Distribution



	Cloud_trop.	Cloud_out_trop.	LWFB_trop.	LWFB_out_trop
NSW6-JJA	1.05	-0.04	0.37	0.00
NDW6-JJA	0.80	0.33	0.27	0.12

- ✓ Positive LW Feedback ⬄ Increasing high-thin clouds
- ✓ Different LW Feedbacks in NSW6 and NDW6 (NSW6>NDW6)
  - ➢ Does this difference come from the difference responses in cloud ice in NSW6 and NDW6？

Layer averaged Effective Radius (R_{ec})

Calculation process:

- Step 1: calculate optical depths contributed by each component (τ_x)
  calculate ice water paths contributed by each component (IWP_x)

- Step 2: insert the optical depths and ice water paths calculated in Step 1
  in to the equation below,

$$R_x = \frac{3}{2} \frac{IWP_x}{\rho_i \cdot \tau_x}$$

Suffix x denotes i, s and g for cloud ice, snow and graupel, respectively
ρ_i is the density of ice hydrometeors, which is a constant, 916.7 kg/m^3

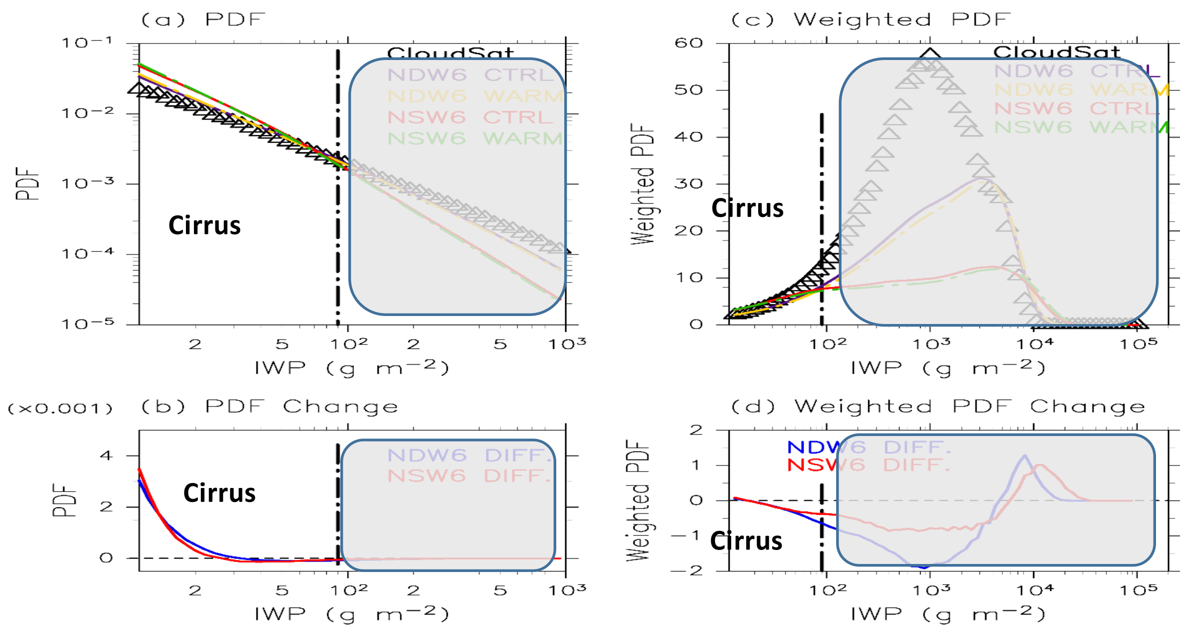
Ice: responses to the global warming

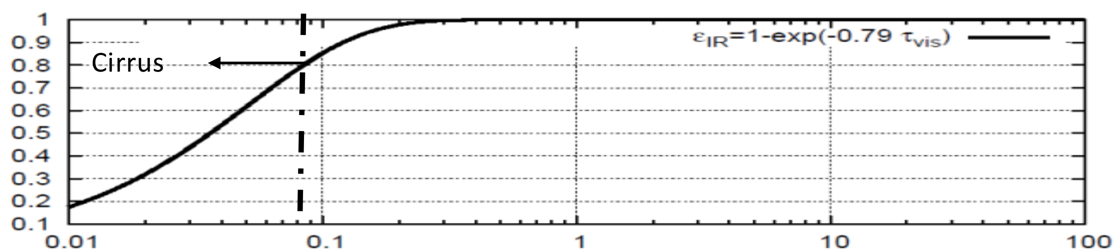
Cloud ice (cloud ice and snow) simulated by NDW6 shows a better distribution when comparing with cloud ice detected by CloudSat

IWP that may be detected by CloudSat is not sensitive to the change of LWCRF
(the emissivity of clouds is saturated while the cloud optical depth is large)

LW cloud feedbacks are sensitive to thin cloud fraction change

$$\left(\begin{aligned} &e.g., \mathrm{LWCRF} \sim C_{frac}\varepsilon_{IR}\sigma(T_c^4 - T_s^4) \\ &\delta\mathrm{LWCRF} \sim \delta C_{frac}\frac{\Delta \mathrm{LWCRF}}{\Delta C_{frac}} \\ &\qquad + \delta\varepsilon_{IR}\frac{\Delta \mathrm{LWCRF}}{\Delta \varepsilon_{IR}} \\ &\qquad + \delta T_s\frac{\Delta \mathrm{LWCRF}}{\Delta T_s} \end{aligned}\right)$$





Longwave Cloud Radiative Forcing

$$\delta LWCRF = \left.\frac{\partial LWCRF}{\partial \varepsilon_{IR}}\right|_{C_{frac},T_s} \Delta\varepsilon + \left.\frac{\partial LWCRF}{\partial C_{frac}}\right|_{\varepsilon_{IR},T_s} \Delta C_{frac} + + \left.\frac{\partial LWCRF}{\partial T_s}\right|_{\varepsilon_{IR},C_{frac}} \Delta T_s$$

$$\left[\ \varepsilon = 1 - \exp(1 - 0.79\tau_i) \quad ; \quad \tau_i = \frac{3}{2}\frac{IWP}{\rho_i\, R_{ec}} \qquad \varepsilon \propto \frac{1}{R_{ec}}; \quad R_{ec} \uparrow, \varepsilon \downarrow\ \right]$$

emissivity change: -0.03

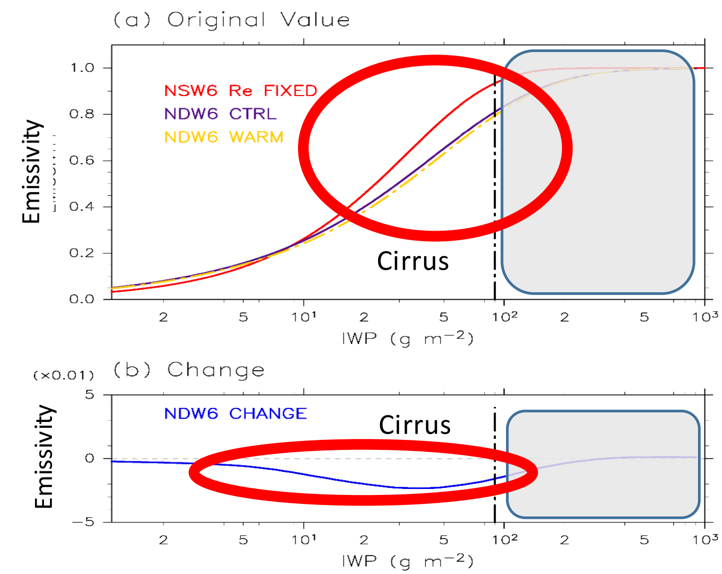
$$\left.\frac{\partial LW\,CRF}{\partial \varepsilon_{IR}}\right|_{C_{frac},T_s} \Delta\varepsilon \rightarrow -2.08\ {}^{W}/_{m^2}$$

cloud fraction change: 1.54 %

$$\left.\frac{\partial LW\,CRF}{\partial C_{frac}}\right|_{\varepsilon_{IR},T_s} \Delta C_{frac} \rightarrow 2.7\ {}^{W}/_{m^2}$$

surface temperature change: ~ 2 - 4K

$$\left.\frac{\partial LW\,CRF}{\partial T_s}\right|_{\varepsilon_{IR},C_{frac}} \Delta T_s \rightarrow 1.14 - 2.28\ {}^{W}/_{m^2}$$

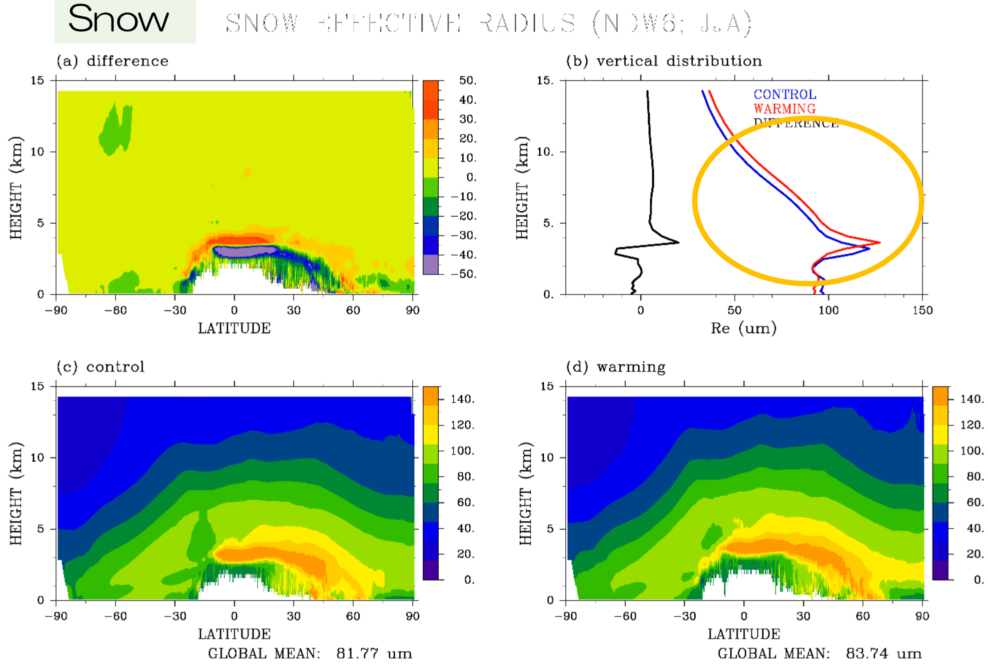


NSW6 and NDW6 comparison: cloud emissivity is different weather the effective radius of cloud ice is predicted

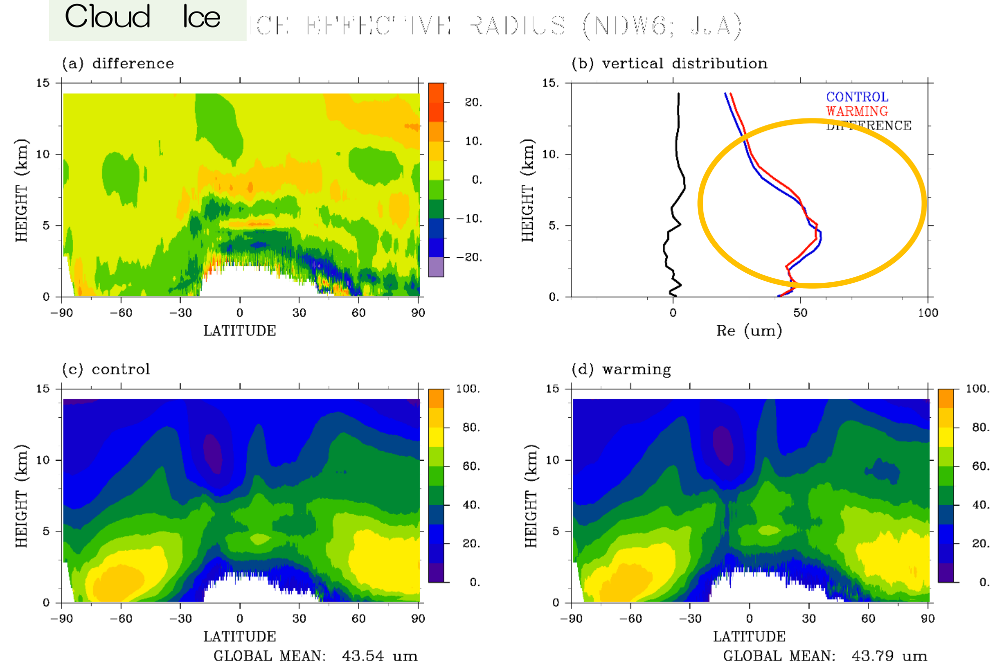
NDW6 : the cloud emissivity in NIDW6 changes when the atmosphere warms due to the effective radius responses to the global warming

YZ-Plane Compare: Effective Radius　(Height Axe)

Snow

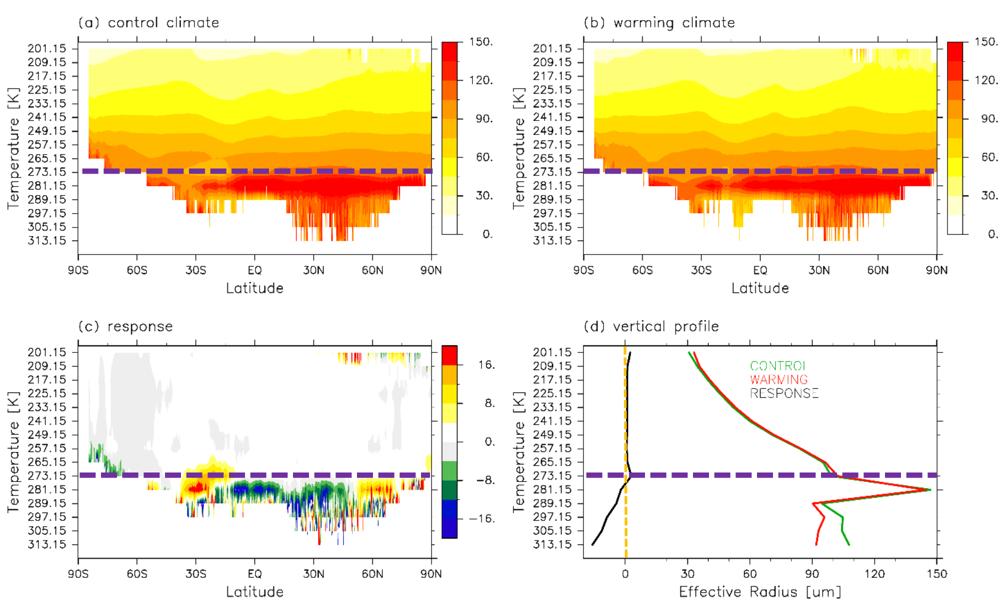


Cloud Ice

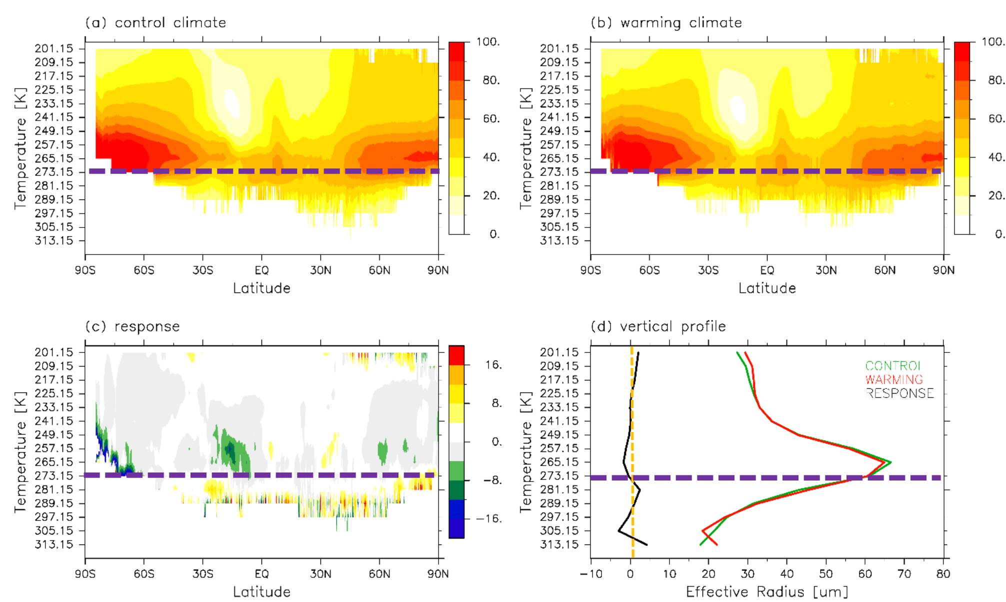


YZ-Plane Compare: Effective Radius　（Temperature Axe）

Snow



Cloud Ice



Summary

Investigate the climate sensitivity in NICAM when different cloud microphysical schemes (NSW6 and NDW6) are implemented

- Similar point : LW cloud radiative feedback in the tropics are attributed by the cirrus increases
- In NDW6: The impact on the LWCRF comes from the cirrus emissivity change due to the effective radius responses to the global warming is non-negligible