Radiative forcing of tropical ice clouds using the MODIS/AIRS products and modeling capabilities

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Outline

- Light Scattering/Radiative transfer models
- Sensitivity Study
- Ice cloud climatologies derived from the MODIS observations (9/2002-8/2005)
- Radiative forcing of ice clouds estimated from the MODIS and AIRS products
- Comparison between the MODIS Collection 004 and 005 ice cloud products
- Summary

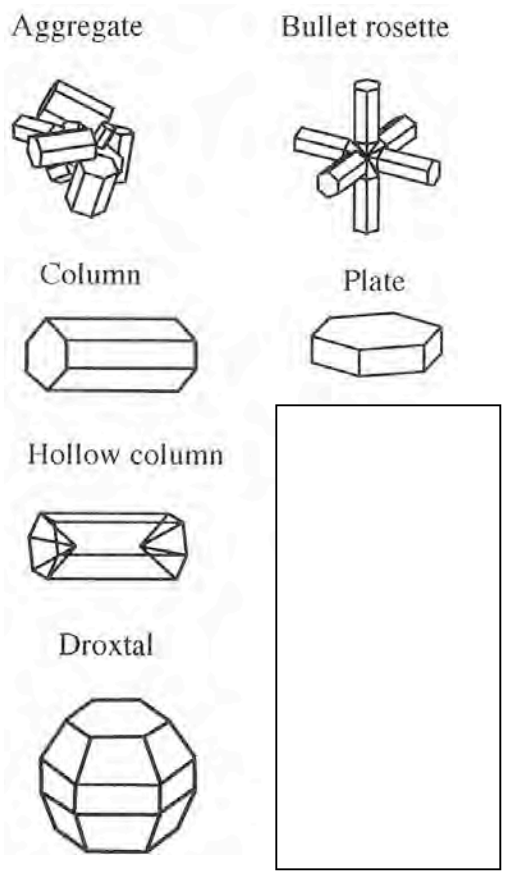
A New Parameterization for Shortwave and Longwave Radiative Properties of Ice Clouds

- Single-scattering properties of ice particles
- Bulk optical properties of ice clouds
- Parameterization scheme

Parameterization for Radiative Properties – Single-Scattering Properties

Modeling of single-scattering properties of ice particles

with different shapes (*Yang et al. 2000*; *Yang et al. 2005)*



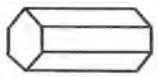
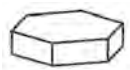
- 65 wavelengths between 0.2 and 100 μm
- 45 particle sizes ranging from 2 to 9500 μm
- Single-scattering properties
  - Extinction efficiency, *Qe*
  - Single-scattering albedo, ω
  - Asymmetry factor, *g*
  - Phase function at 498 scattering angles

Parameterization of the Radiative Properties – Bulk Optical Properties of Ice Clouds

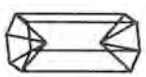
- Particle's maximum dimension $D < 60\ \mu m$

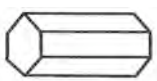
100%

- $60\ \mu m < D < 1000\ \mu m$

15% +  50% +  35%

- $1000\ \mu m < D < 2500\ \mu m$



45% +  45% + 10%

- $1000\ \mu m < D < 2500\ \mu m$

97% + 3%

Mixing scheme for ice cloud particles
(*Baum et al. 2005a,b*)

Using 21 size distributions
(Fu 1996; Fu et al. 1998)

$$\langle Q_e \rangle = \frac{\int_{L_{min}}^{L_{max}} \left[\sum_{i=1}^{N} f_i(L) Q_{ei}(L) A_i(L)\right] n(L)\mathrm{d}L}{\int_{L_{min}}^{L_{max}} \left[\sum_{i=1}^{N} f_i(L) A_i(L)\right] n(L)\mathrm{d}L};$$

$$\langle g \rangle = \frac{\int_{L_{min}}^{L_{max}} \left[\sum_{i=1}^{N} f_i(L) g_i(L) Q_{si}(L) A_i(L)\right] n(L)\mathrm{d}L}{\int_{L_{min}}^{L_{max}} \left[\sum_{i=1}^{N} f_i(L) Q_{si}(L) A_i(L)\right] n(L)\mathrm{d}L};$$

$$\langle \omega \rangle = \frac{\int_{L_{min}}^{L_{max}} \left[\sum_{i=1}^{N} f_i(L) Q_{si}(L) A_i(L)\right] n(L)\mathrm{d}L}{\int_{L_{min}}^{L_{max}} \left[\sum_{i=1}^{N} f_i(L) Q_{ei}(L) A_i(L)\right] n(L)\mathrm{d}L}$$

$$D_e = \frac{3}{2} \frac{\int_{L_{min}}^{L_{max}} \left[\sum_{i=1}^{N} f_i(L) V_i(L)\right] n(L)\mathrm{d}L}{\int_{L_{min}}^{L_{max}} \left[\sum_{i=1}^{N} f_i(L) A_i(L)\right] n(L)\mathrm{d}L}$$

(Yang et al. 2005)

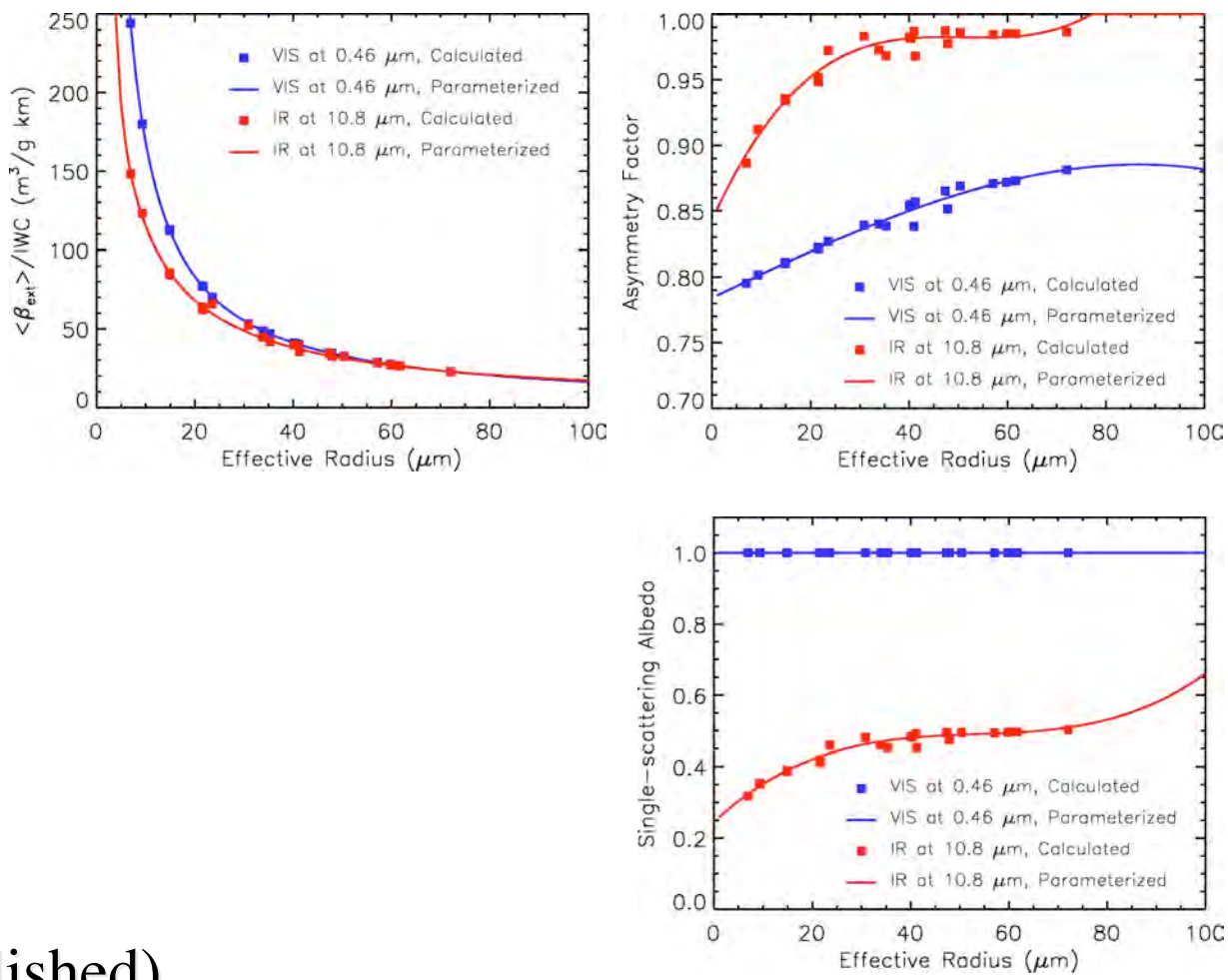
Parameterization for Radiative Properties

Using parameterization schemes
(*Key et al. 2002*)

$$\beta_{ext} / IWC = \sum_{n=0}^{3} a_n \frac{1}{r_e^n}$$

$$\omega = \sum_{n=0}^{3} b_n r_e^n$$

$$g = \sum_{n=0}^{3} c_n r_e^n$$



Lee et al. 2006 (unpublished)

The net shortwave (solar) and longwave (infrared) fluxes at the top of the atmosphere (TOA) are defined as follows

$$F_{sw} = F_{sw}^{\downarrow} - F_{sw}^{\uparrow}$$

$$F_{lw} = -F_{lw}^{\uparrow}$$

For a partially cloudy region with a cloud fraction of *N*, the average-sky net TOA flux is given by

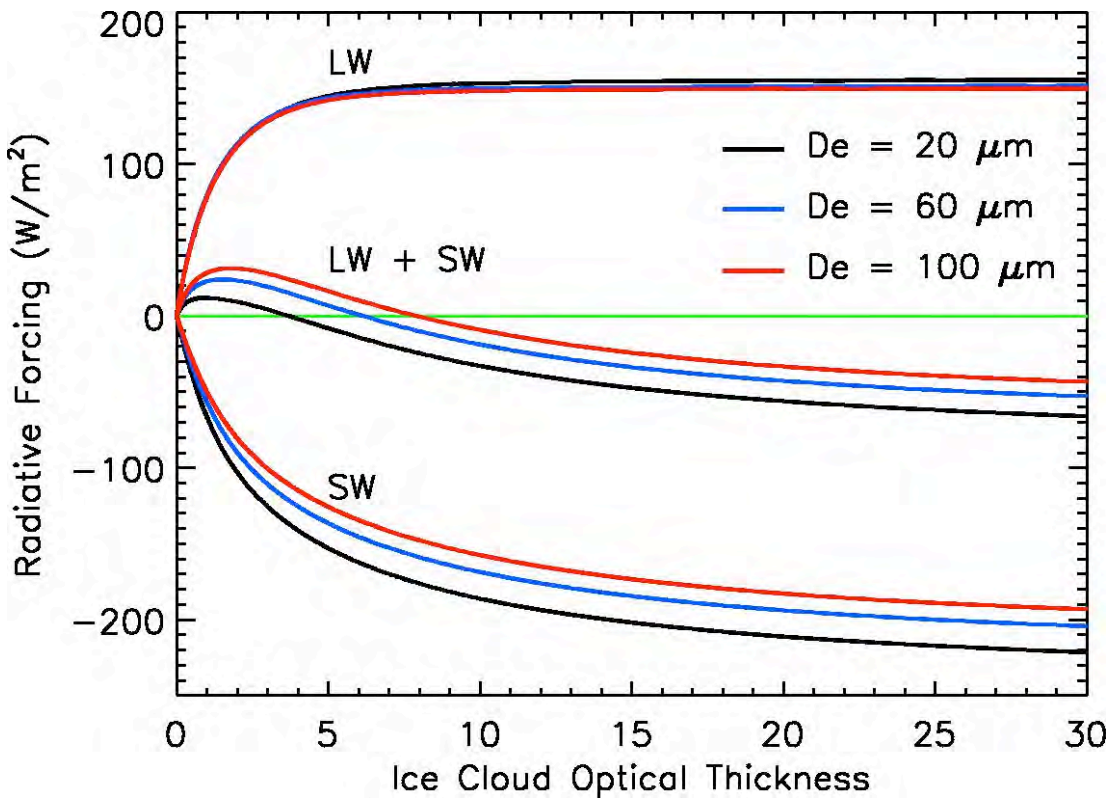
$$F = N(F_{sw,cloud} + F_{lw,cloud}) + (1 - N)(F_{sw,clear} + F_{lw,clear})$$

the cloud radiative forcing (CRF) is given by

$$CRF = F - F_{clear}$$

$$CRF = CRF_{sw} + CRF_{lw}$$

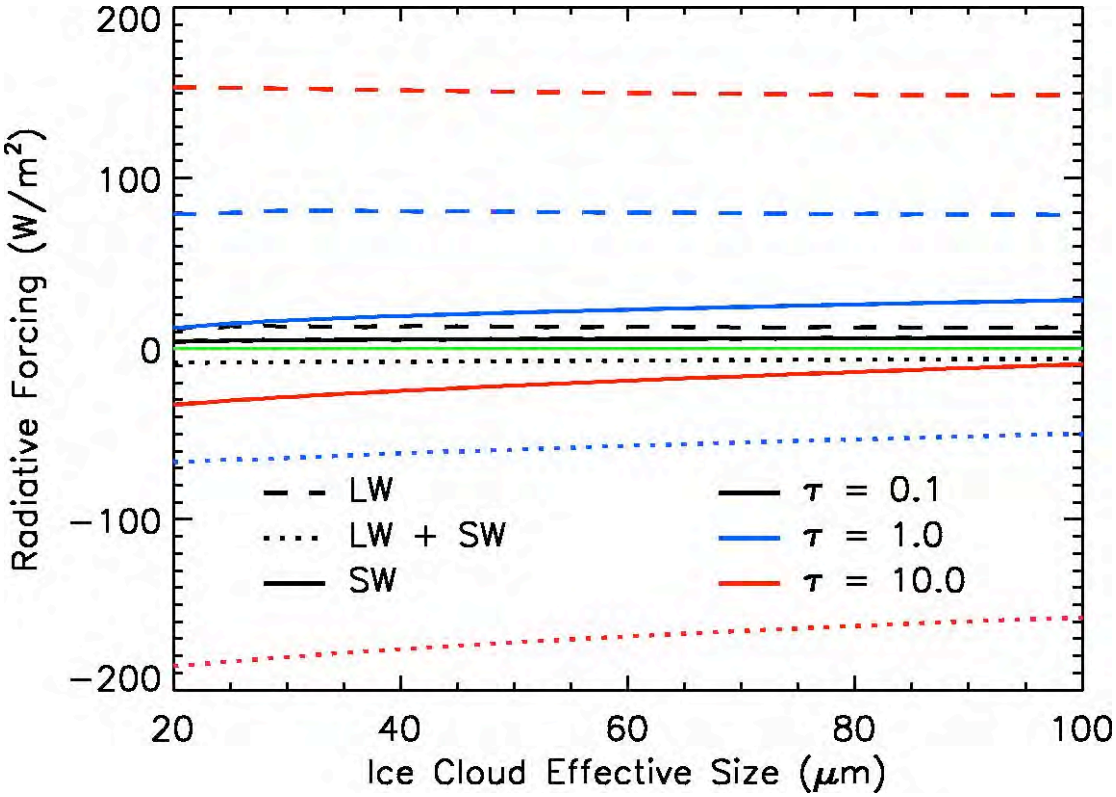
Sensitivity of Forcing to Ice Cloud Properties: Optical Thickness



Effective size De = 20, 60, 100 μm
Optical thickness τ = 0–30
Geometrical thickness Δz = 1 km

Cloud top height H = 12 km
Solar zenith angle θ_0 = 60º
Duration of sunlight is assumed to be 12 hours

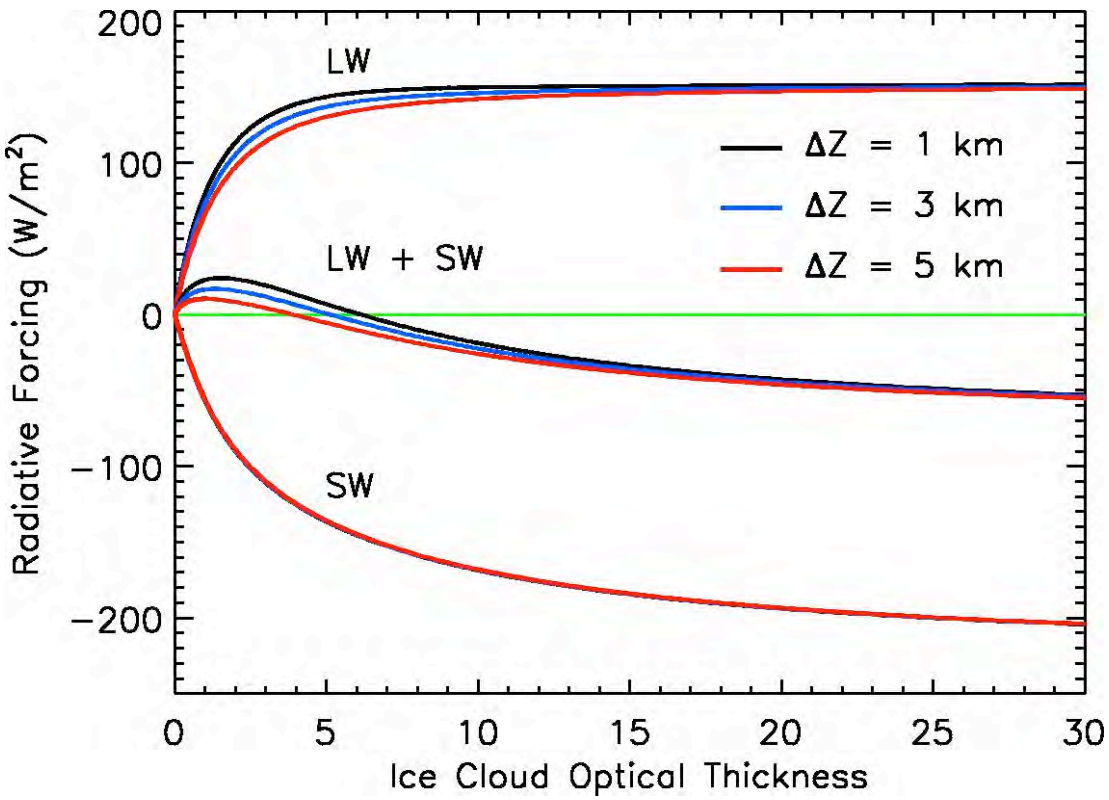
Sensitivity of Forcing to Ice Cloud Properties: Effective Size



Effective size De = 10–100 μm
Optical thickness τ = 0.1, 1, 10
Geometrical thickness Δz = 1 km

Cloud top height H = 12 km
Solar zenith angle θ_0 = 60º
Duration of sunlight is assumed to be 12 hours

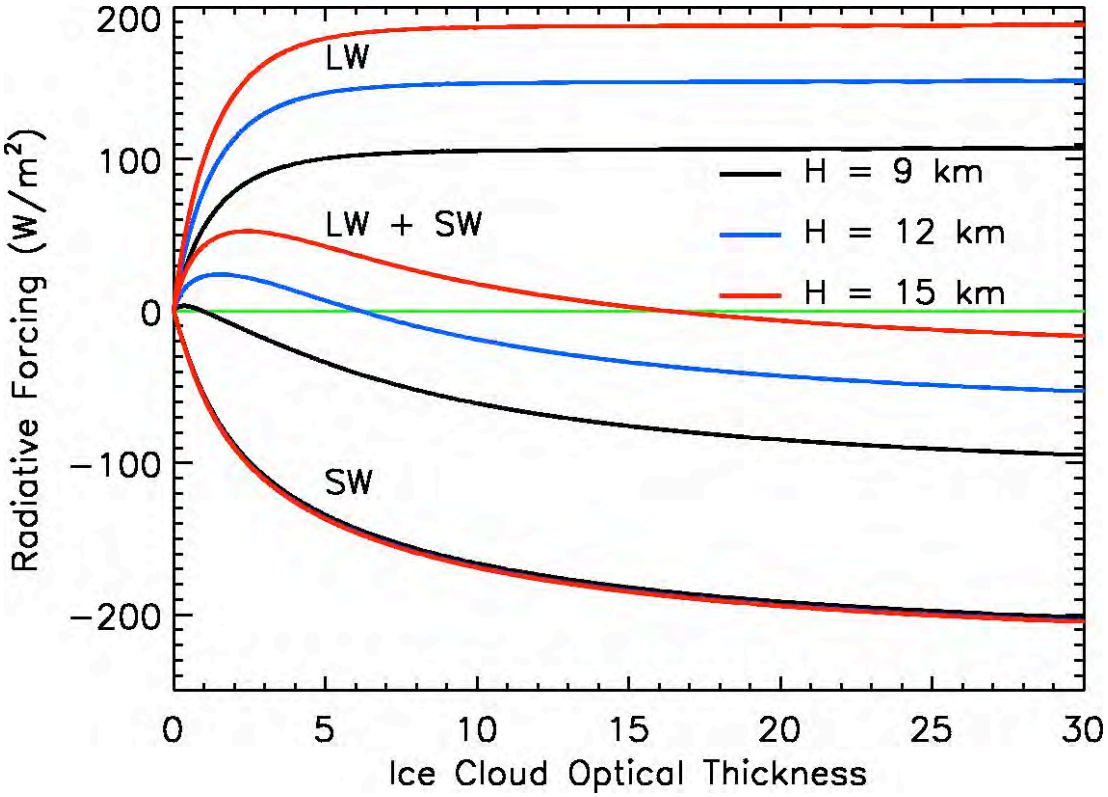
Sensitivity of Forcing to Ice Cloud Properties: Geometrical Thickness



Effective size De = 60 μm
Optical thickness τ = 0.1–30
Geometrical thickness ΔZ = 1, 3, 5 km

Cloud top height H = 12 km
Solar zenith angle θ_0 = 60º
Duration of sunlight is assumed to be 12 hours

Sensitivity of Forcing to Ice Cloud Properties: Cloud Top Height



Effective size De = 60 μm
Optical thickness τ = 0.1–30
Geometrical thickness ΔZ = 1 km

Cloud top height H = 9, 12, 15 km
Solar zenith angle θ_0 = 60º
Duration of sunlight is assumed to be 12 hours

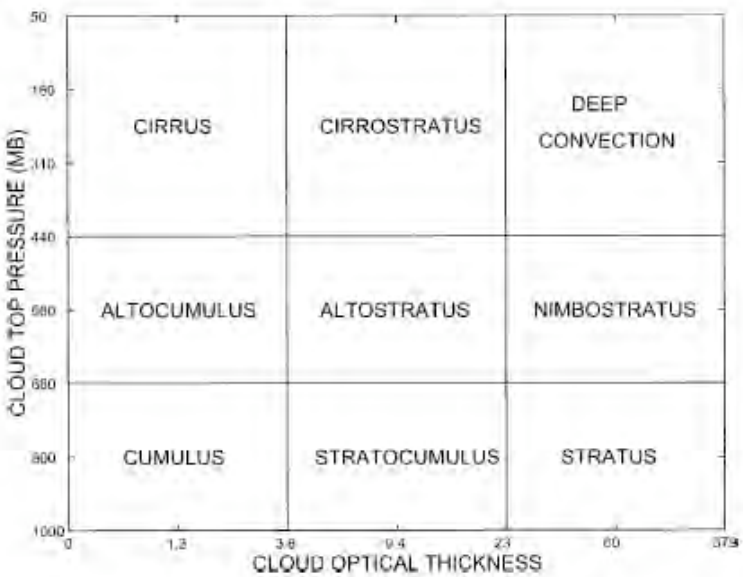
Three-year of Climatologies of Ice Cloud Properties

Data

- Three-year Aqua MYD08 ice cloud properties (τ, D_e) over the tropics from the MODIS measurements (King et al., 2003; Platnick et al., 2003)

- Data from 3 years: 9/2002 - 8/2005

ISCCP Classification



Cirriform

Cirrus

$\tau < 3.6$ and

Cloud top < 440 mb

Cirrostratus

$3.6 < \tau < 23.0$ and

Cloud top < 440 mb

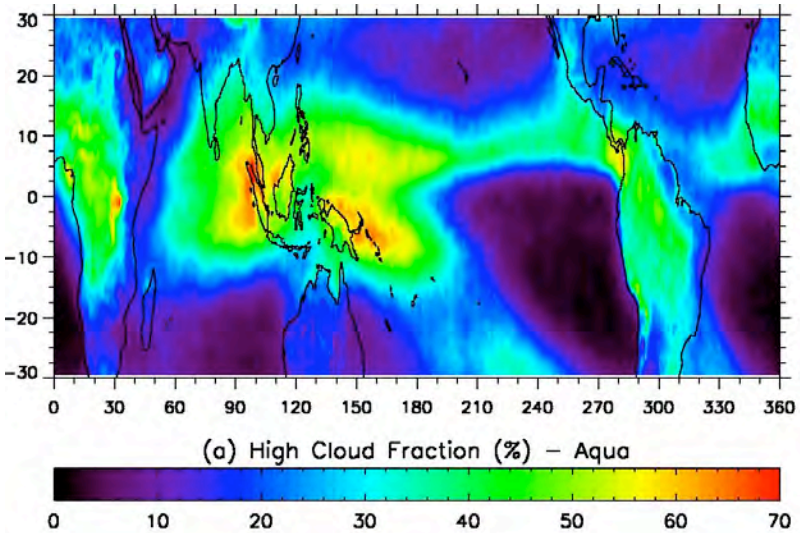
Deep convection

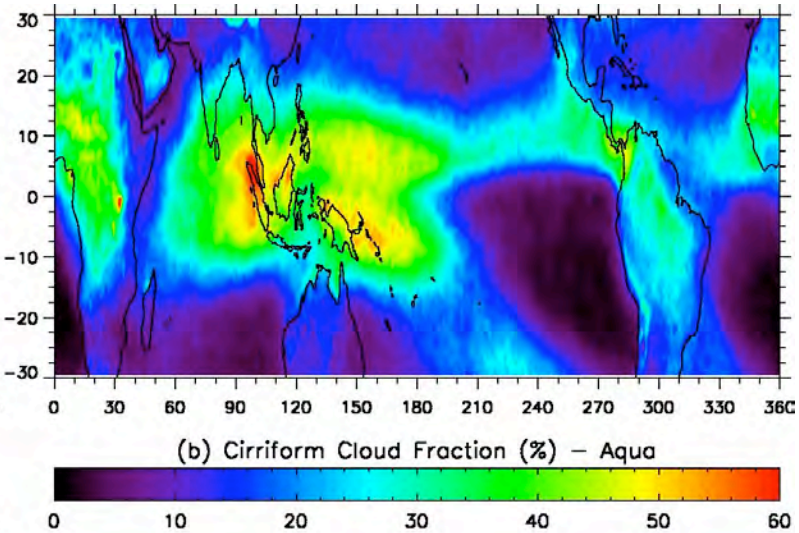
$23.0 < \tau$ and

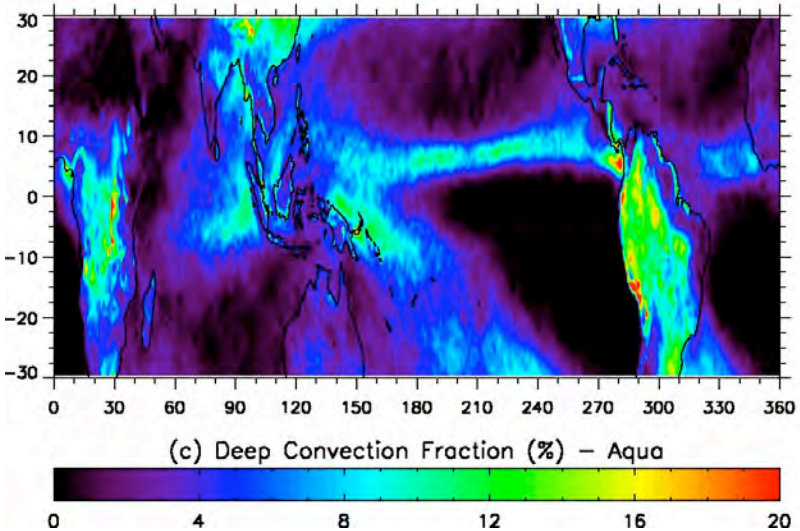
Cloud top < 440 mb

We will use the ISCCP classification scheme (Rossow and Schiffer, 1999) for our analyses because modelers are familiar with it.

Three-year Climatologies of Ice Cloud Properties



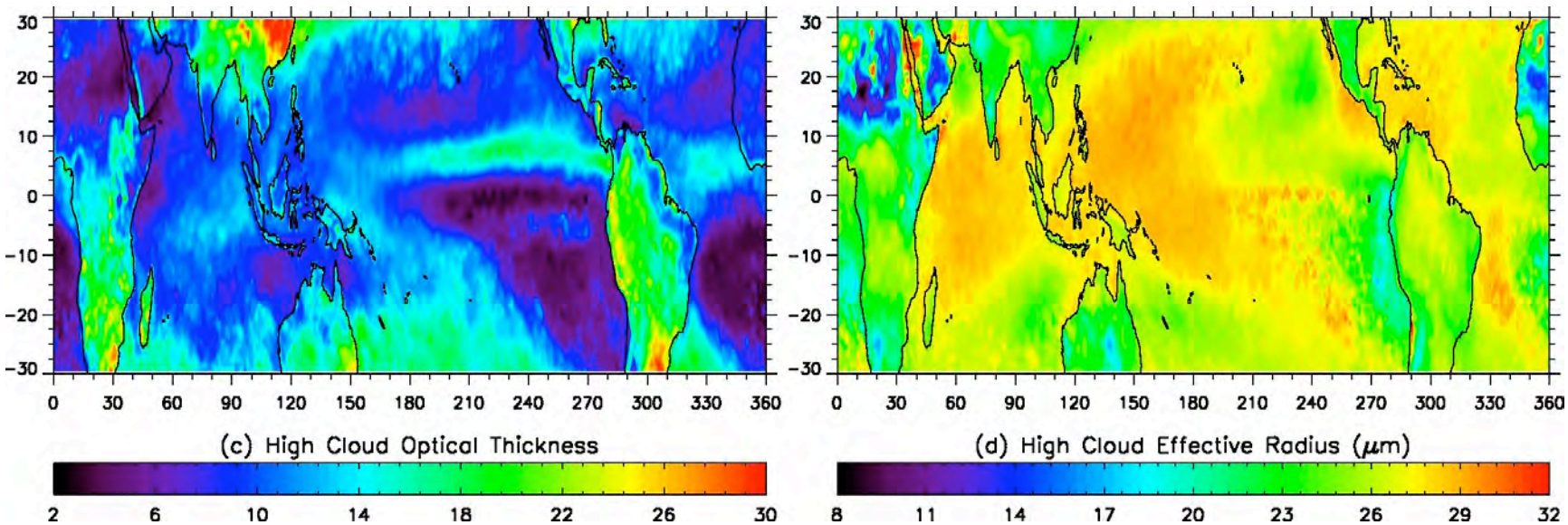




Ice cloud fraction from Aqua 13:30 PM

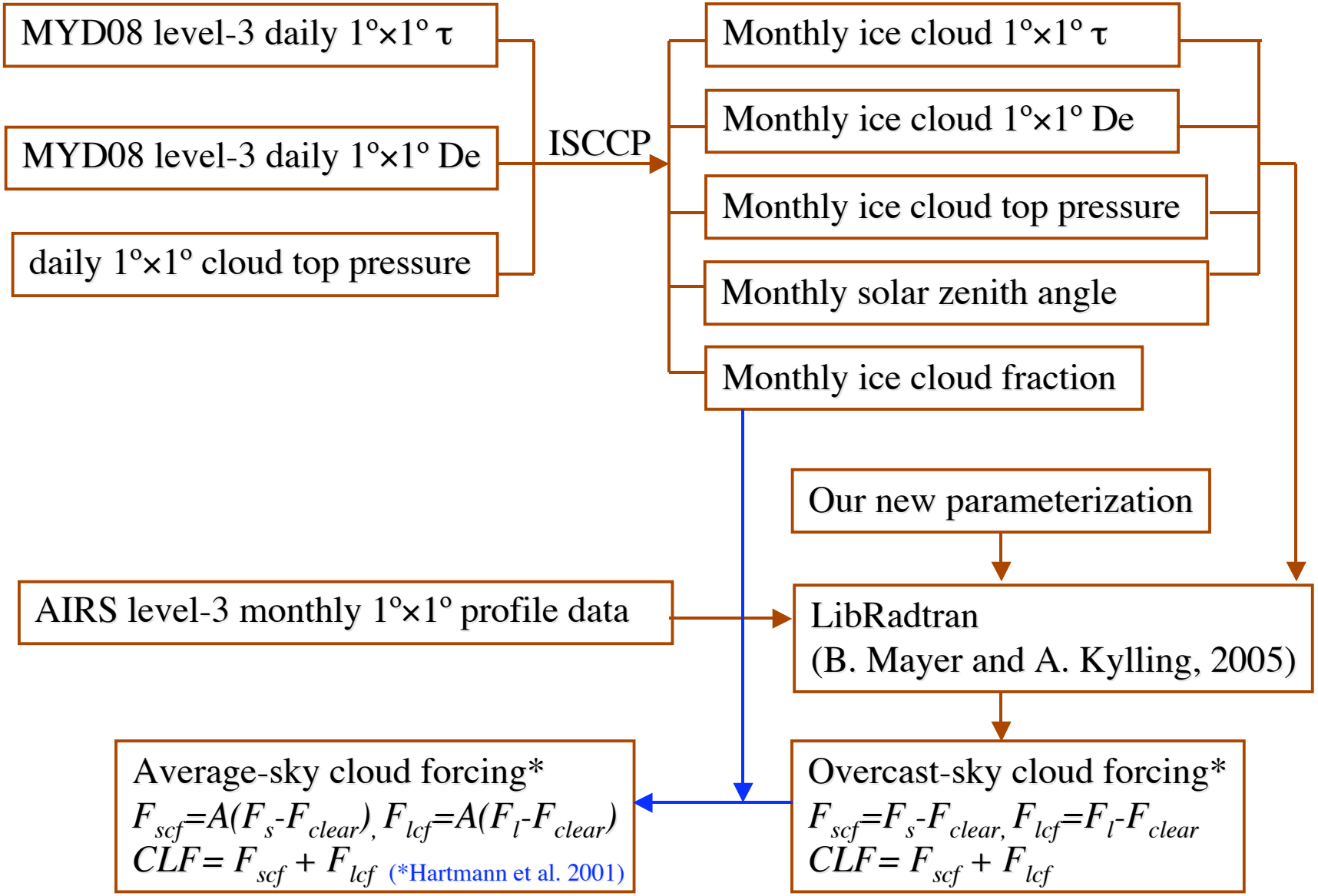
Ice cloud fraction (cirriform and deep convective clouds)

Three-year Climatologies of Ice Cloud Properties

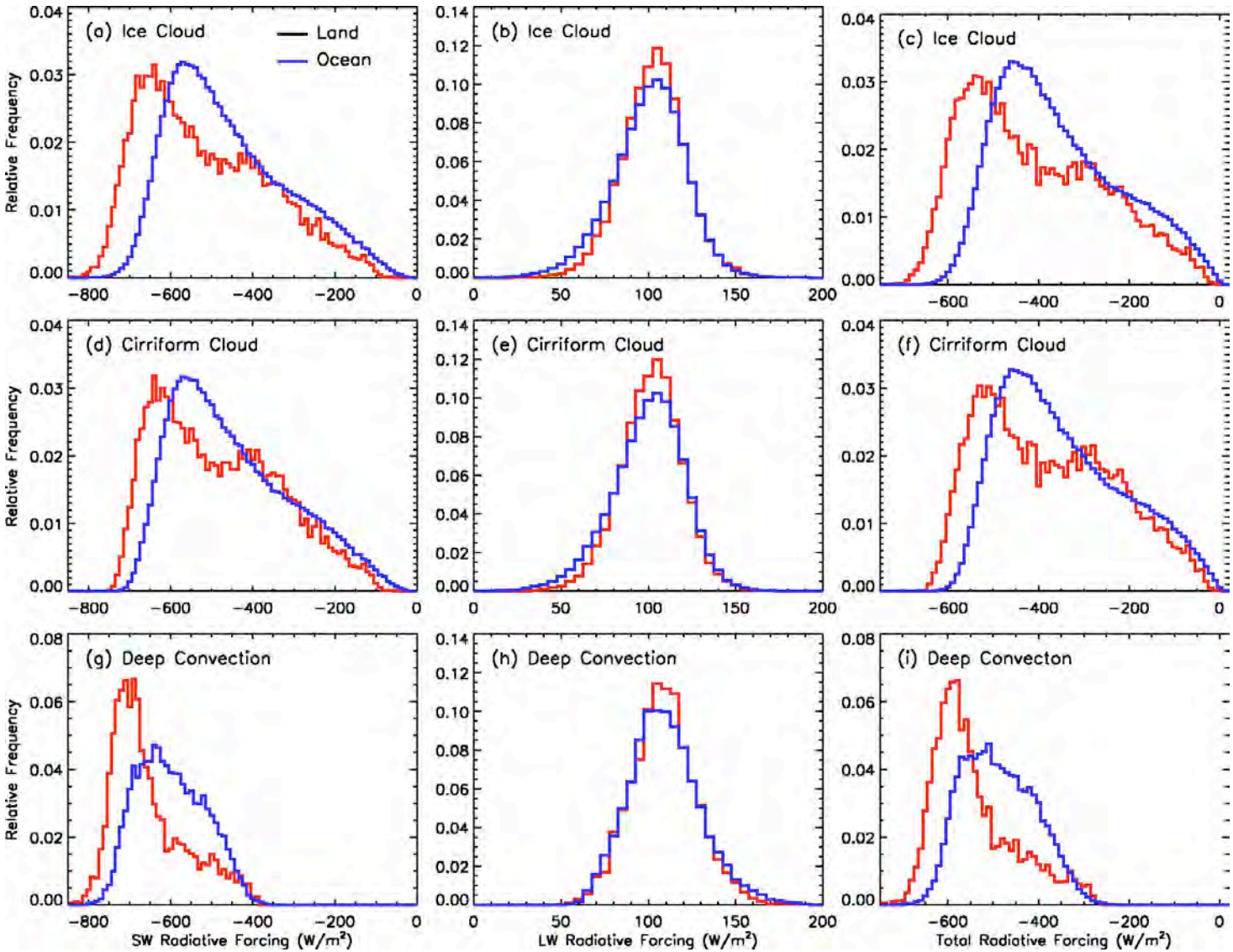


Ice cloud optical thickness and particle effective size from Aqua

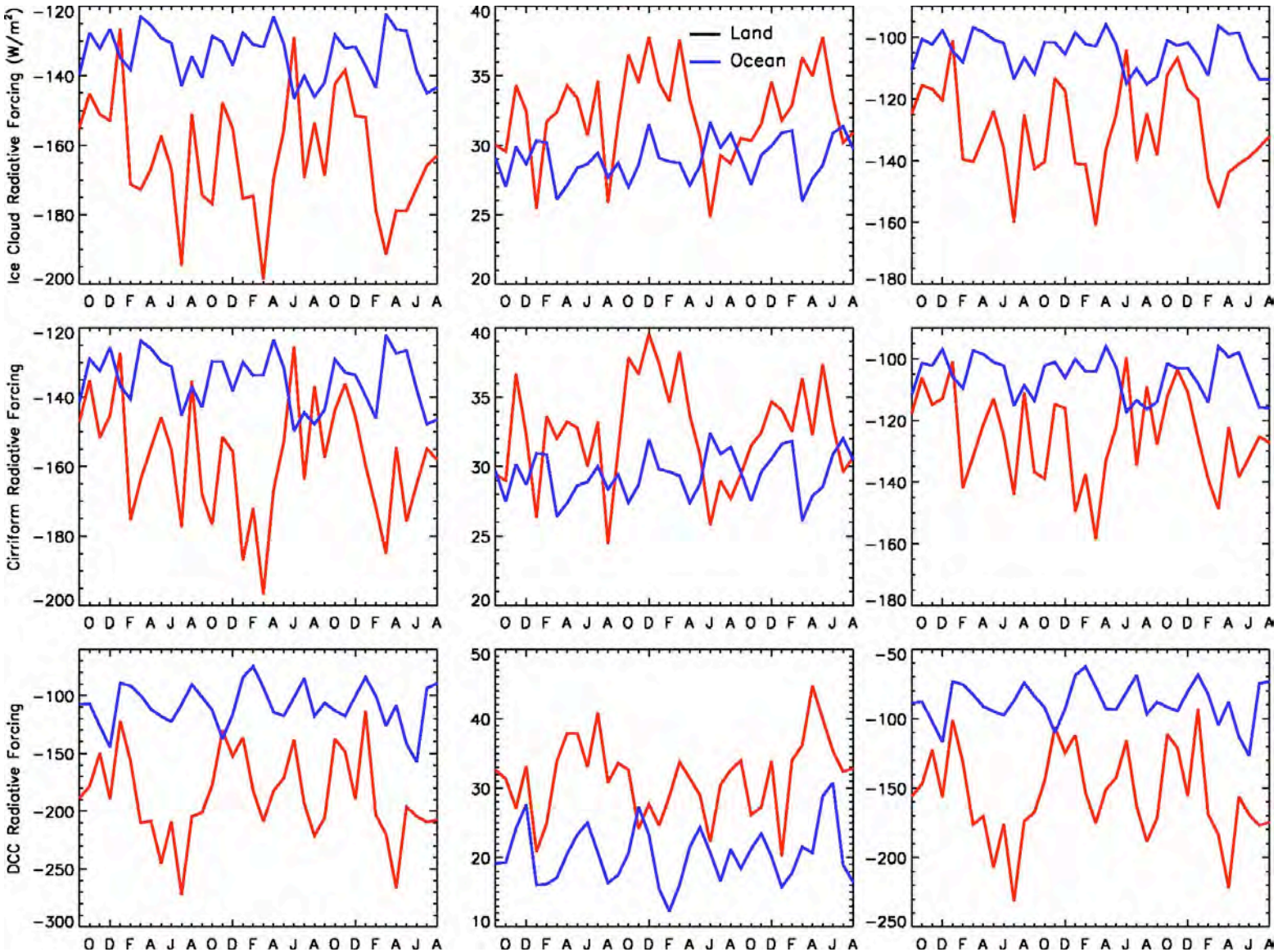
Three-year of Climatologies of Ice Cloud Radiative Forcing



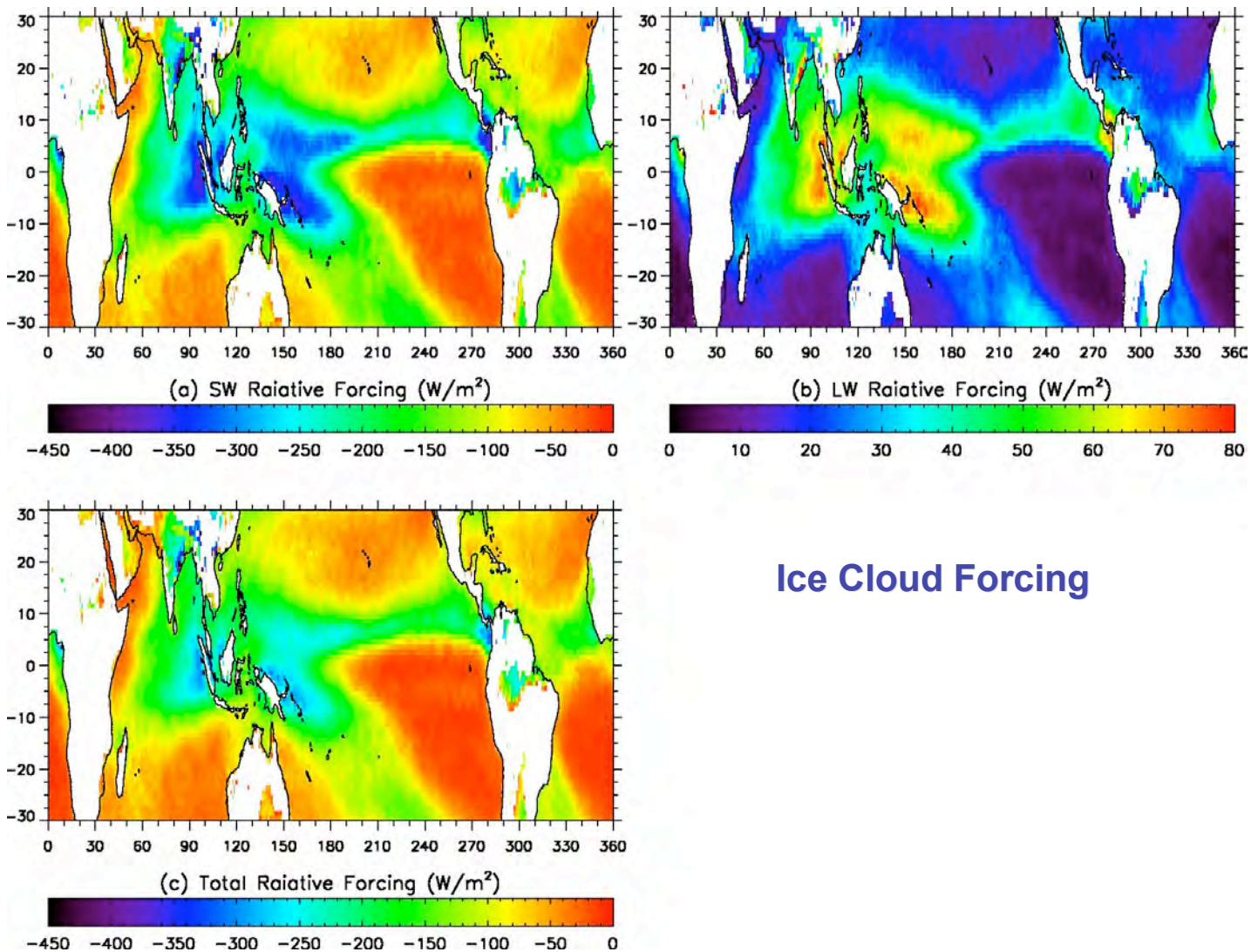
Climatologies of Ice Cloud Radiative Forcing



Climatologies of Ice Cloud Radiative Forcing

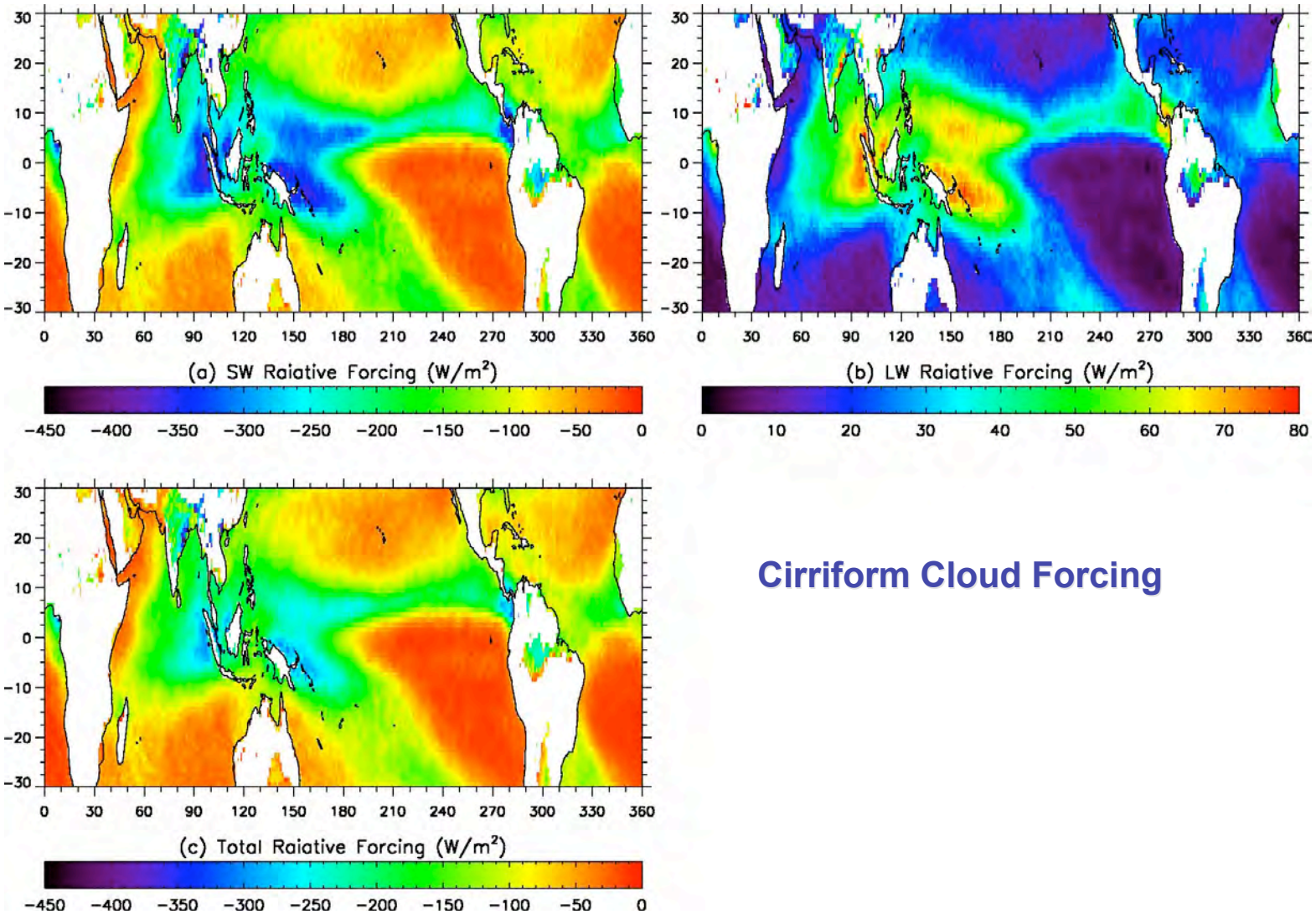


Climatologies of Ice Cloud Radiative Forcing



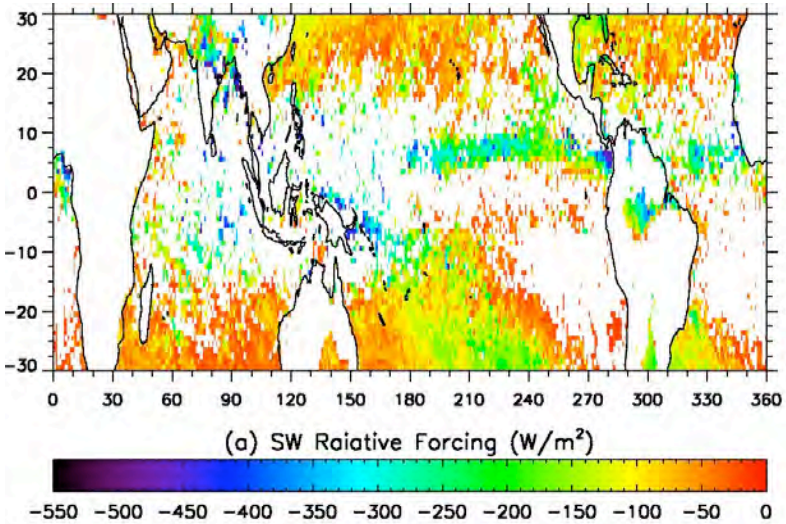
Ice Cloud Forcing

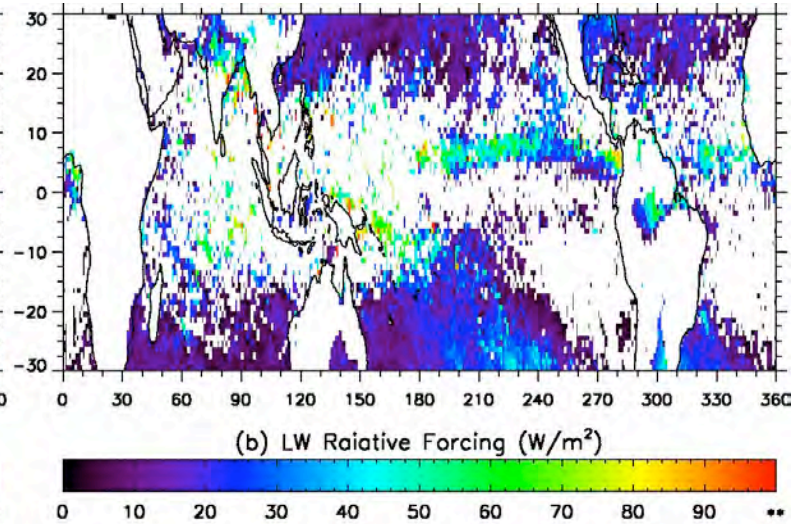
Climatologies of Ice Cloud Radiative Forcing

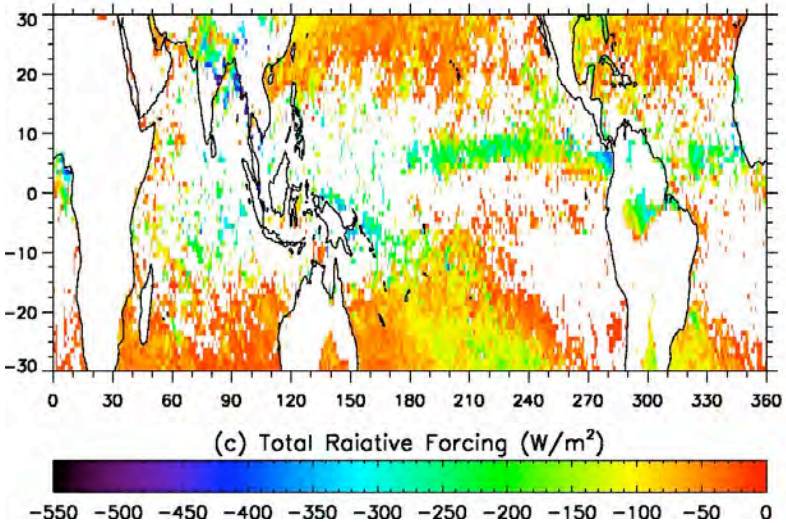


Cirriform Cloud Forcing

Climatologies of Ice Cloud Radiative Forcing



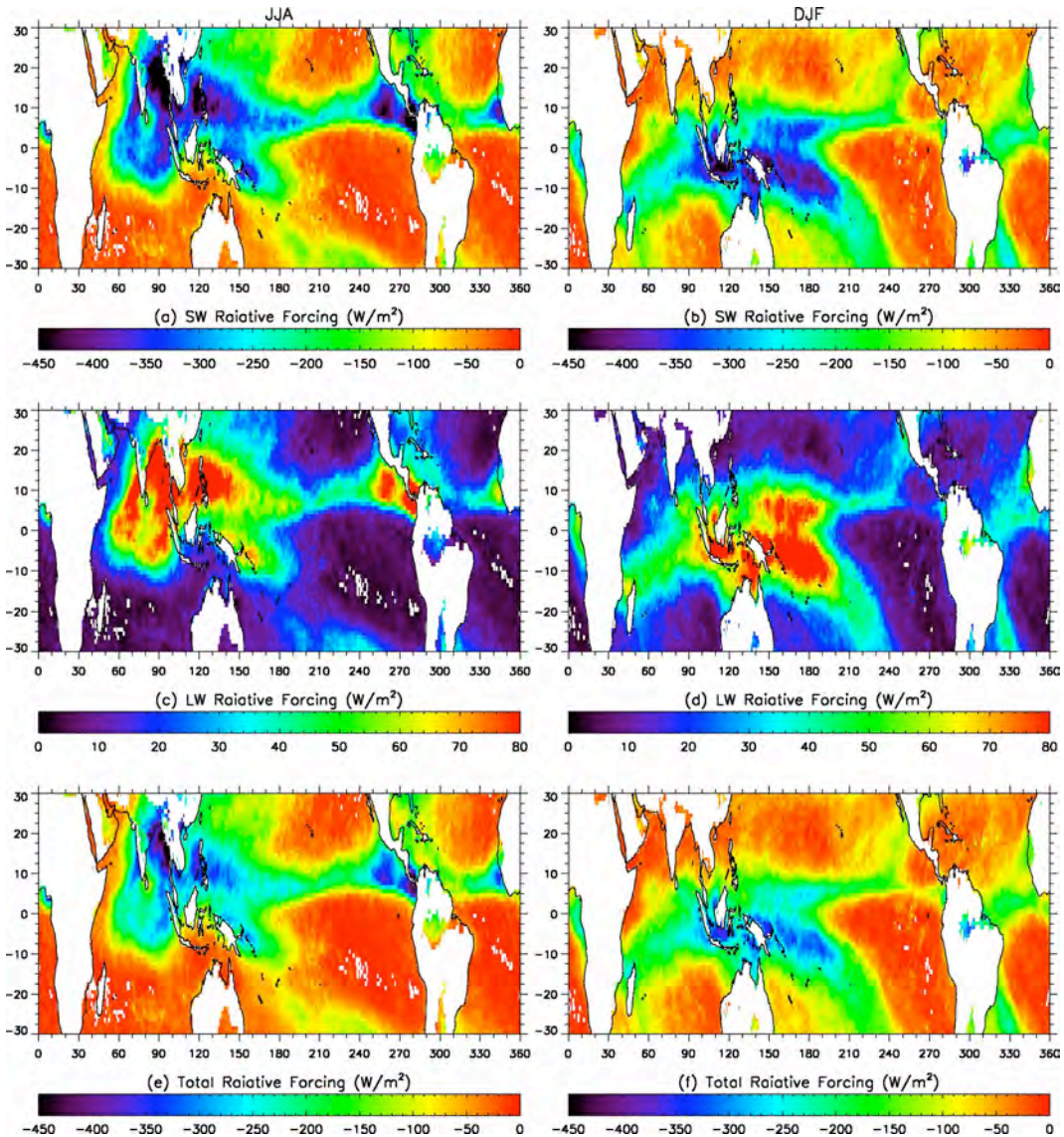




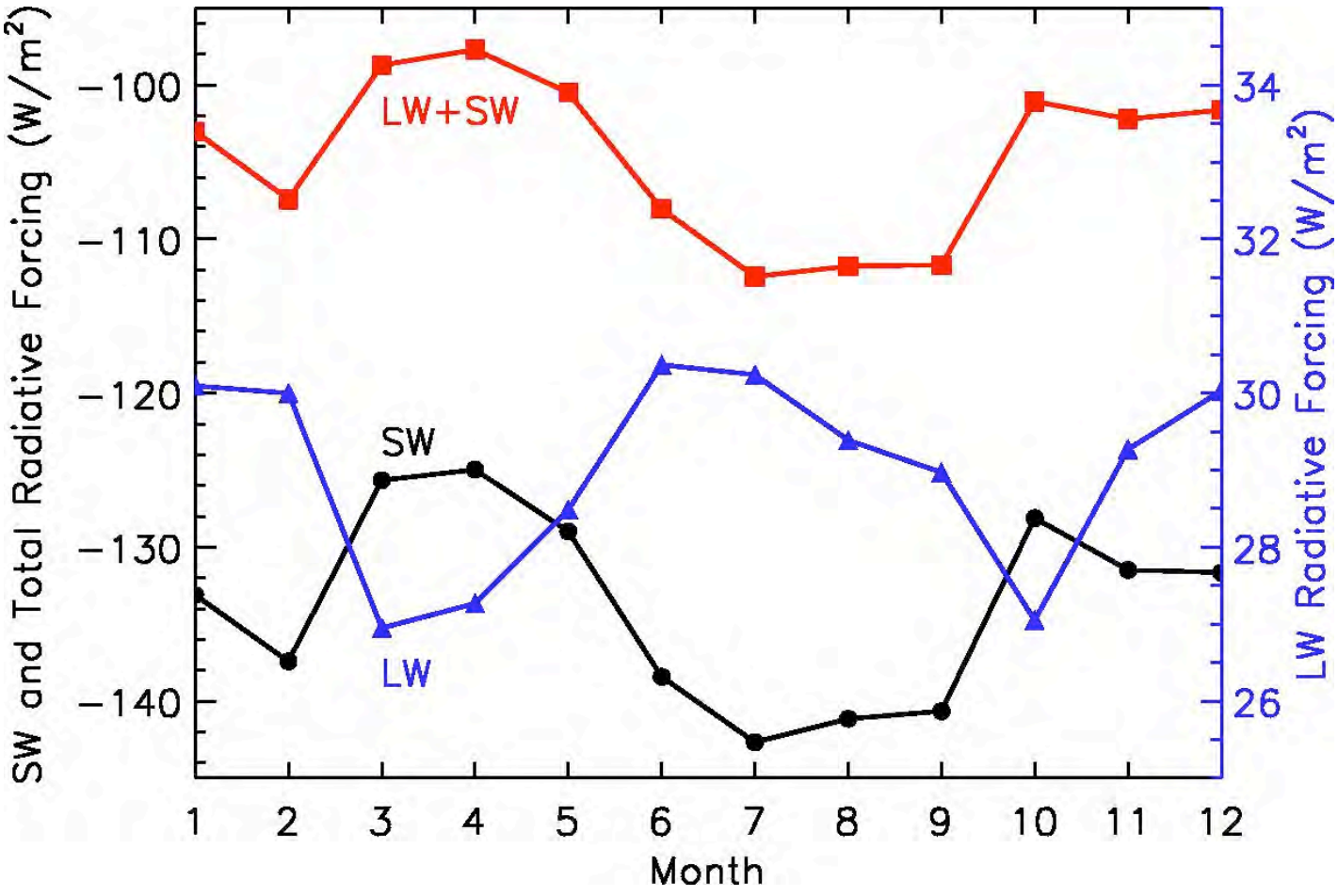
Deep Convection Forcing

Climatologies of Ice Cloud Radiative Forcing

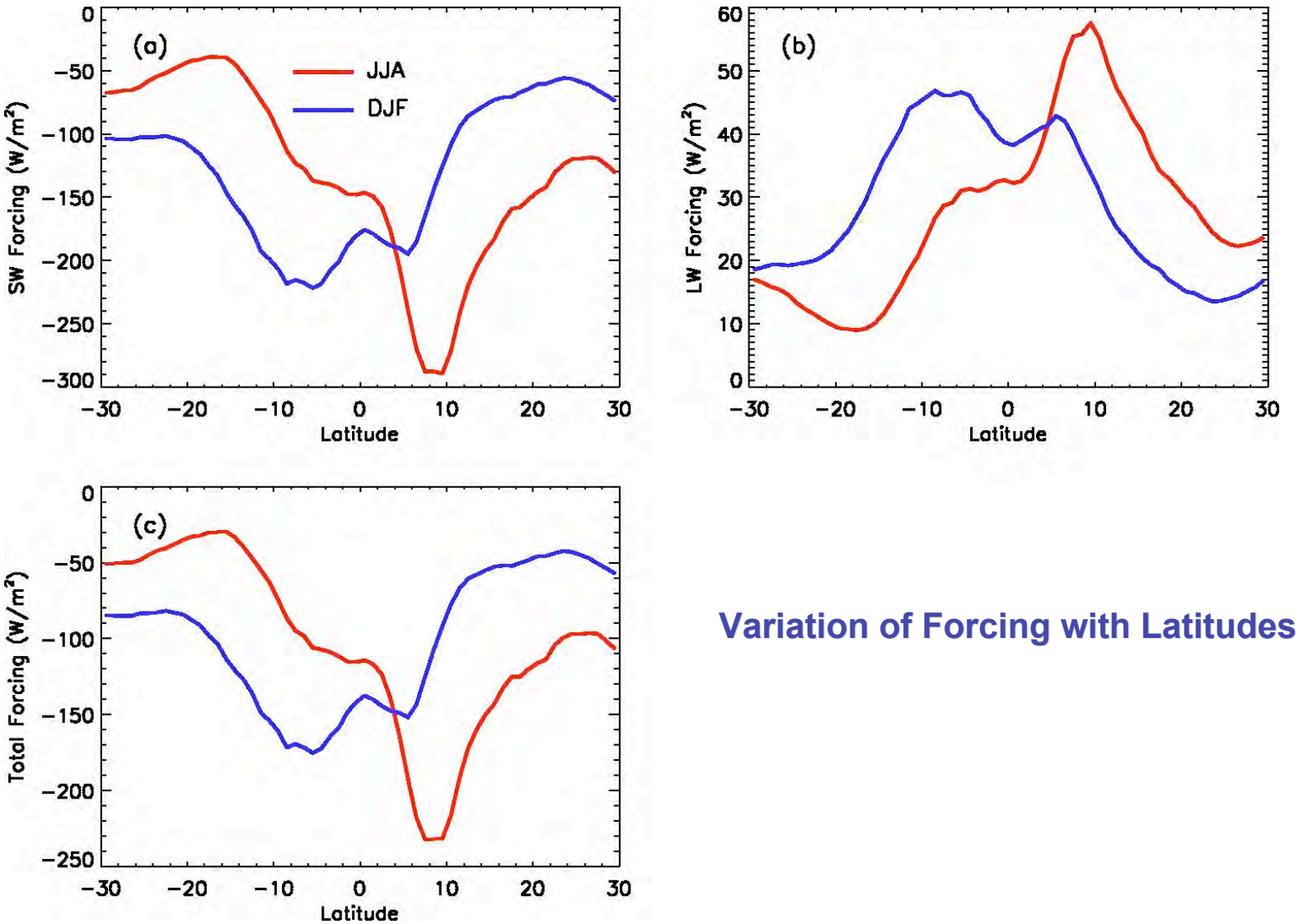
Seasonal Variations



Ice Cloud Radiative Forcing

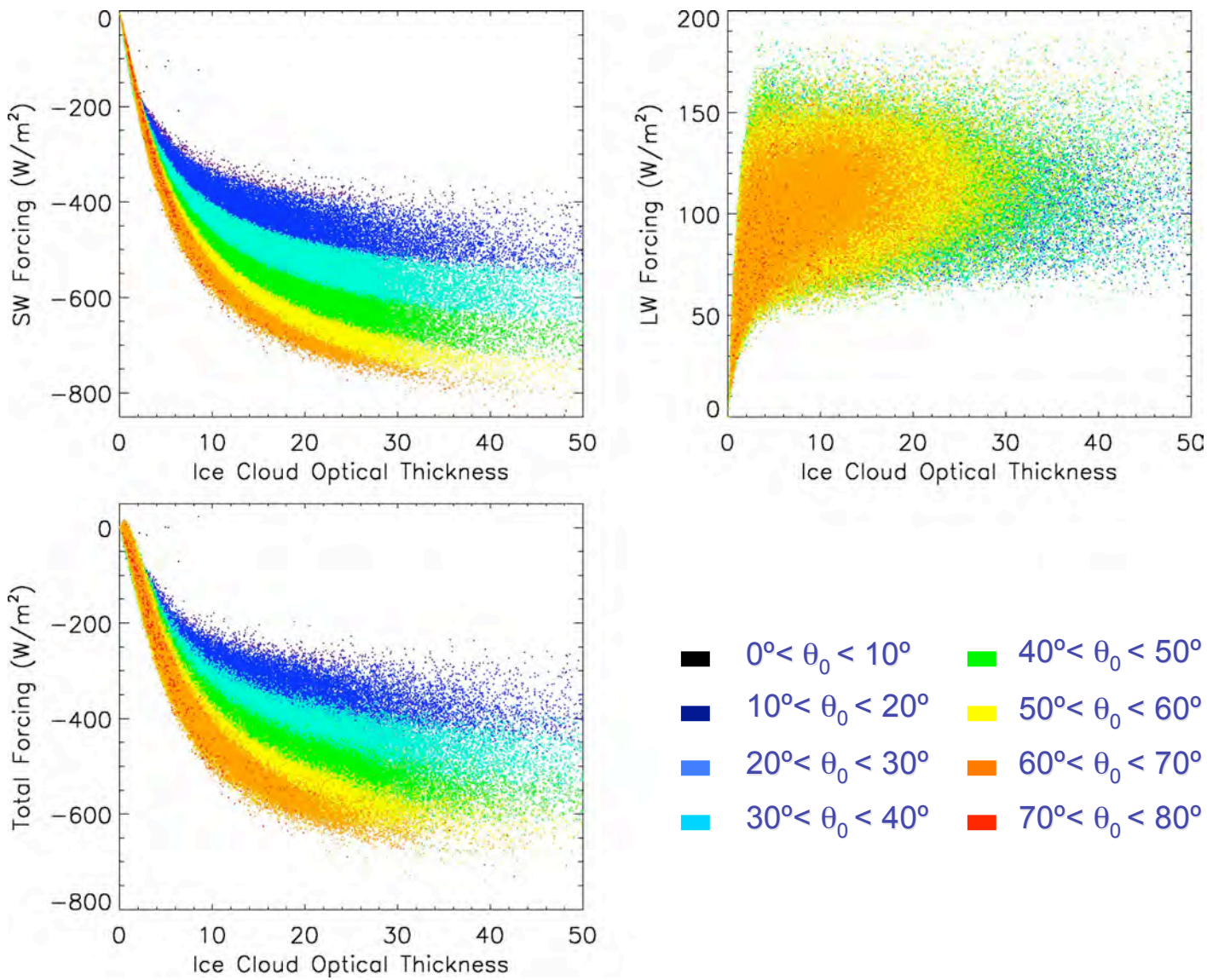


Climatologies of Ice Cloud Radiative Forcing

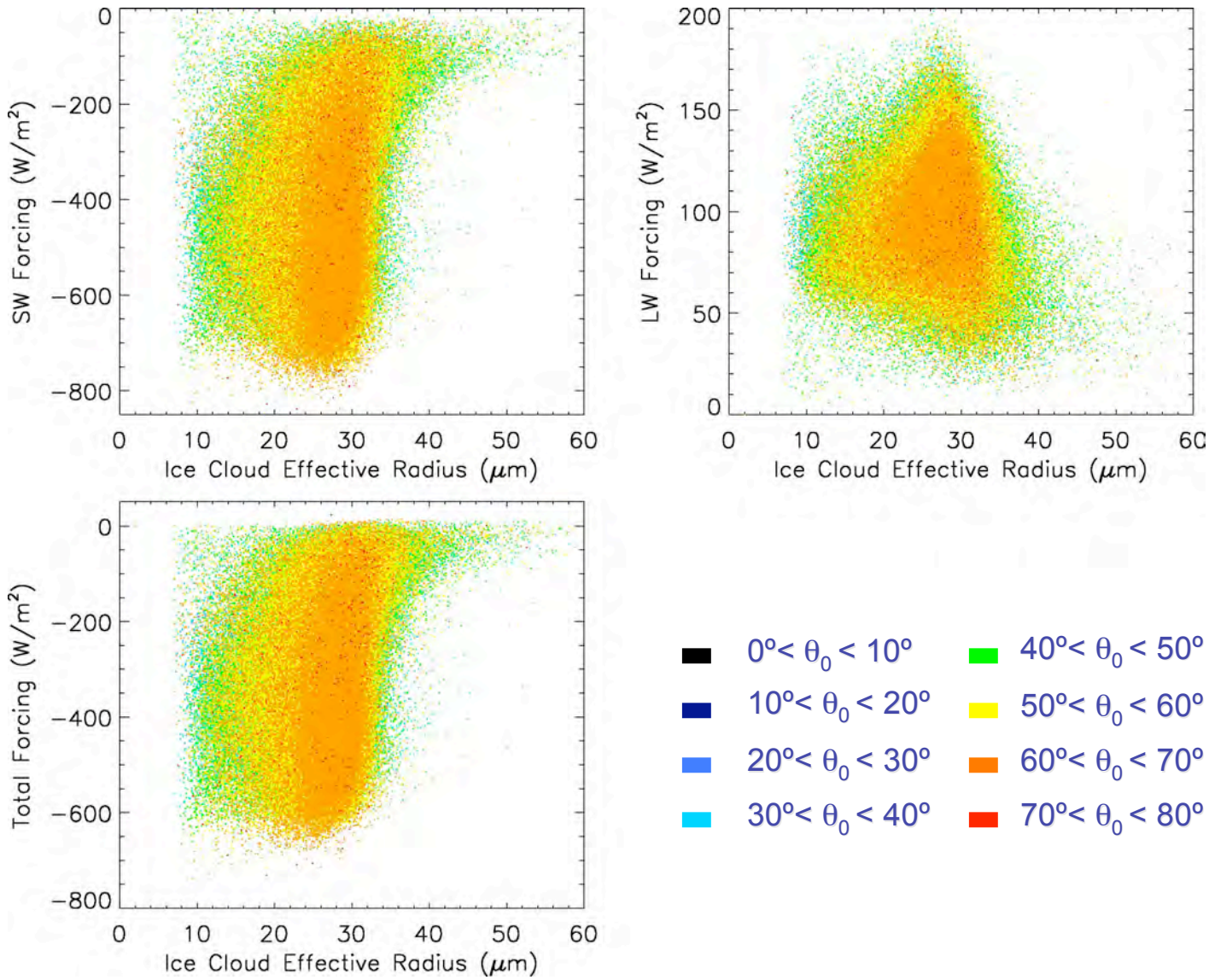


Variation of Forcing with Latitudes

Climatologies of Ice Cloud Radiative Forcing



Climatologies of Ice Cloud Radiative Forcing



Differences between Collection 004 and 005 MODIS ice cloud optical/microphysical products and their impact on radiative forcing simulations

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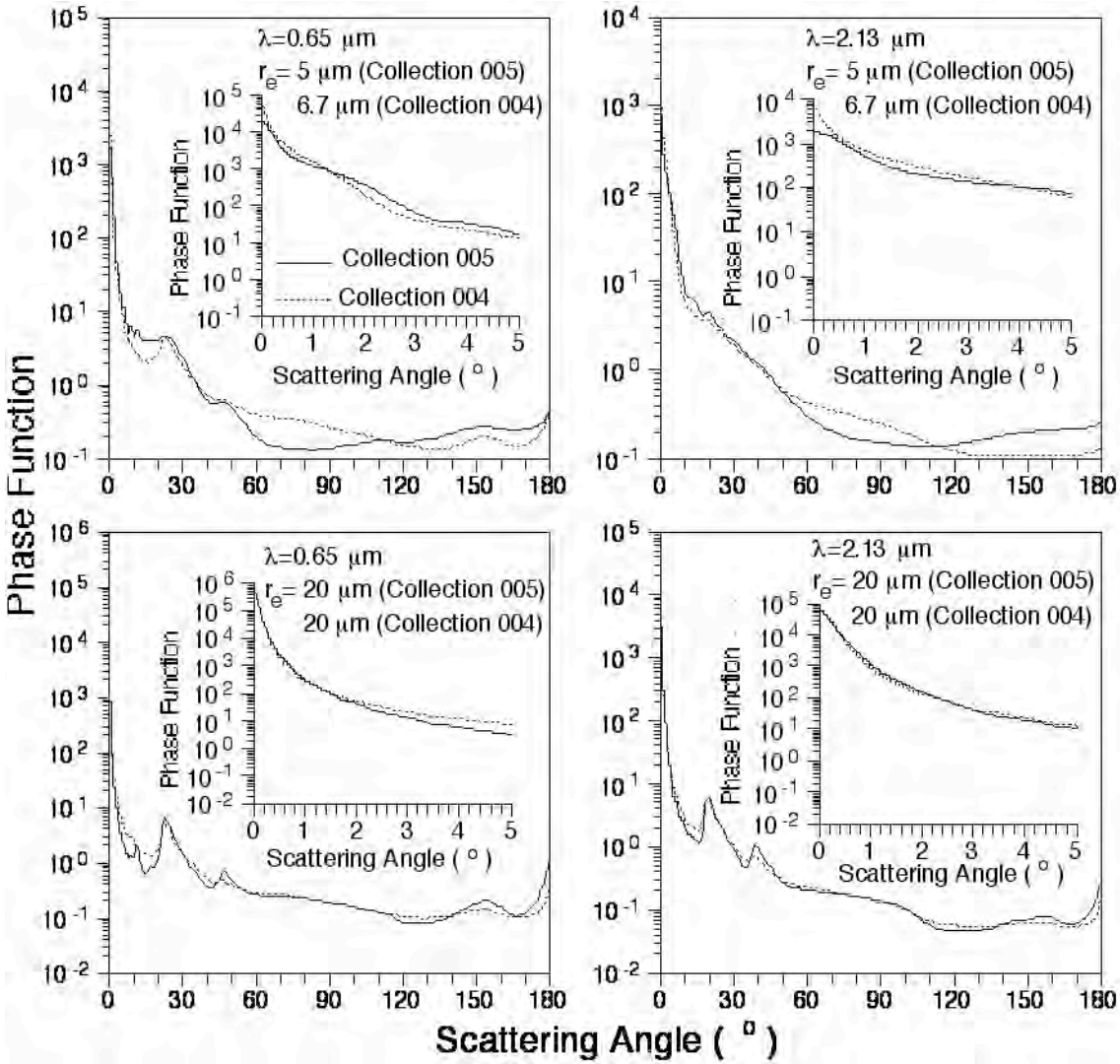
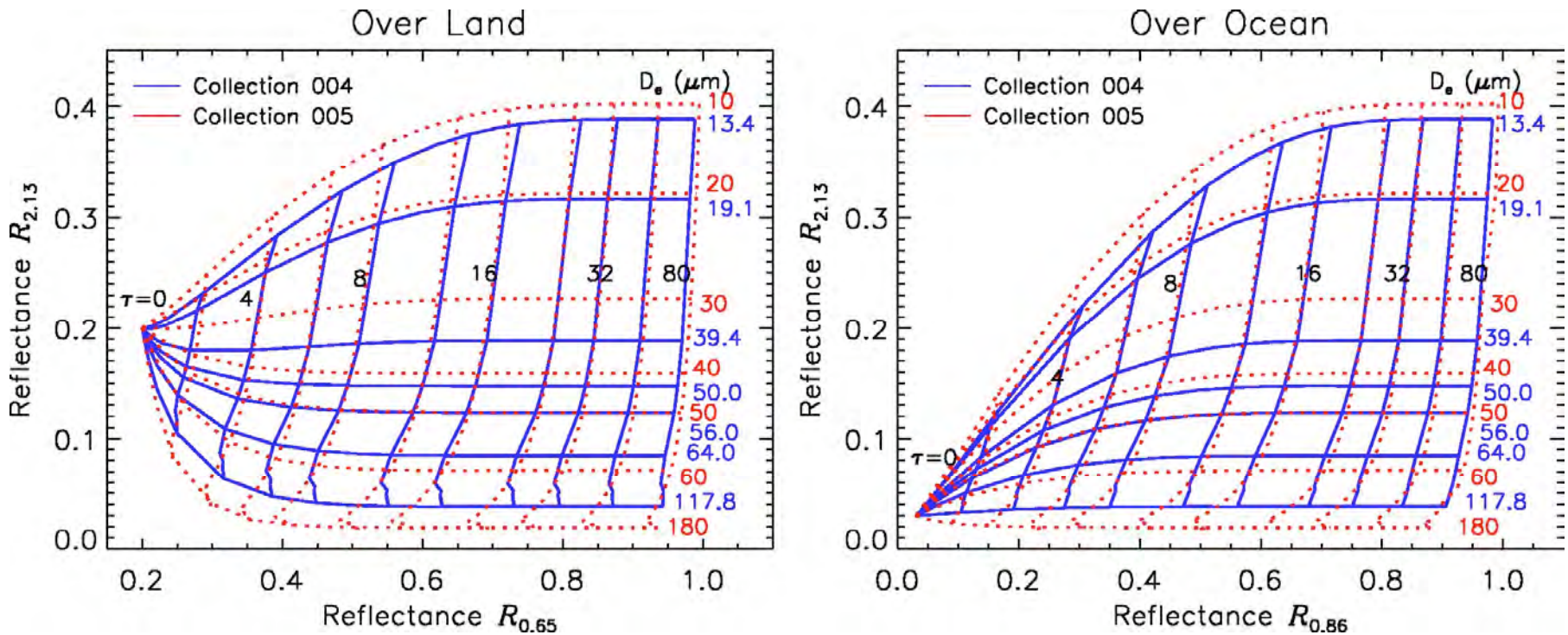
Space Science and Engineering Center, University of Wisconsin-Madison, Madison, WI 53706

M. D. King and S. Platnick
NASA Goddard Space Flight Center, Greenbelt, MD 20711

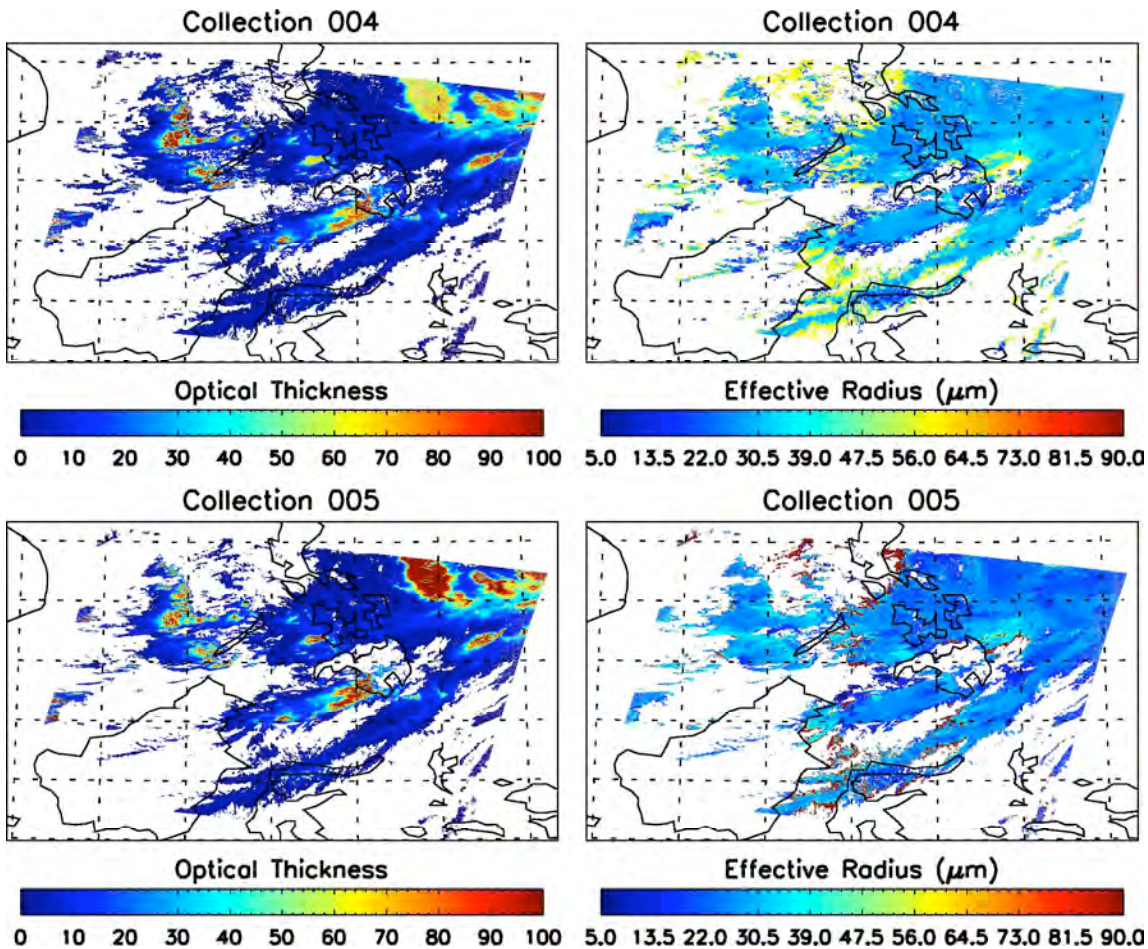


Comparison of the MODIS Collection 004 and Collection 005 scattering phase functions at for the MODIS 0.65 and 2.13-μm bands for two values of effective particle radius.

MODIS Collection 004 vs Collection 005 Lookup Tables



MODIS Collection 004 vs Collection 005
Ice cloud properties



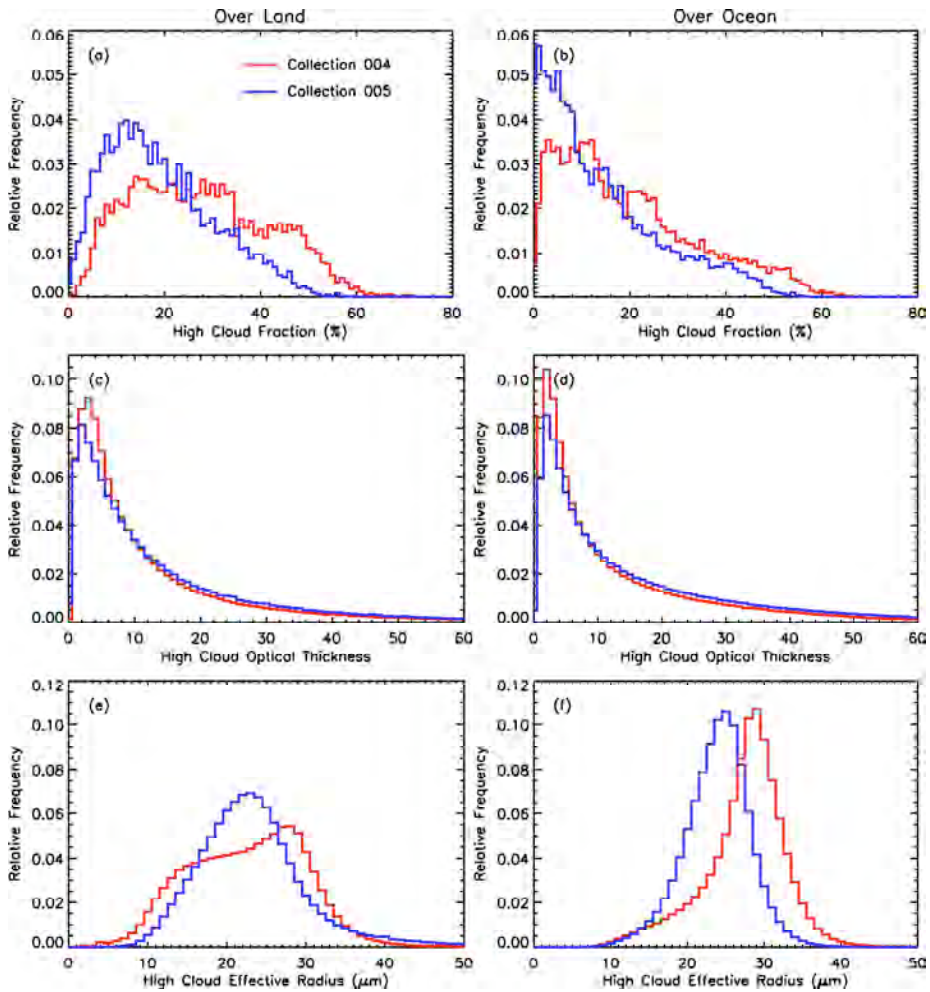
The granule of Day 182 in 2002 over Indonesia from Terra MODIS

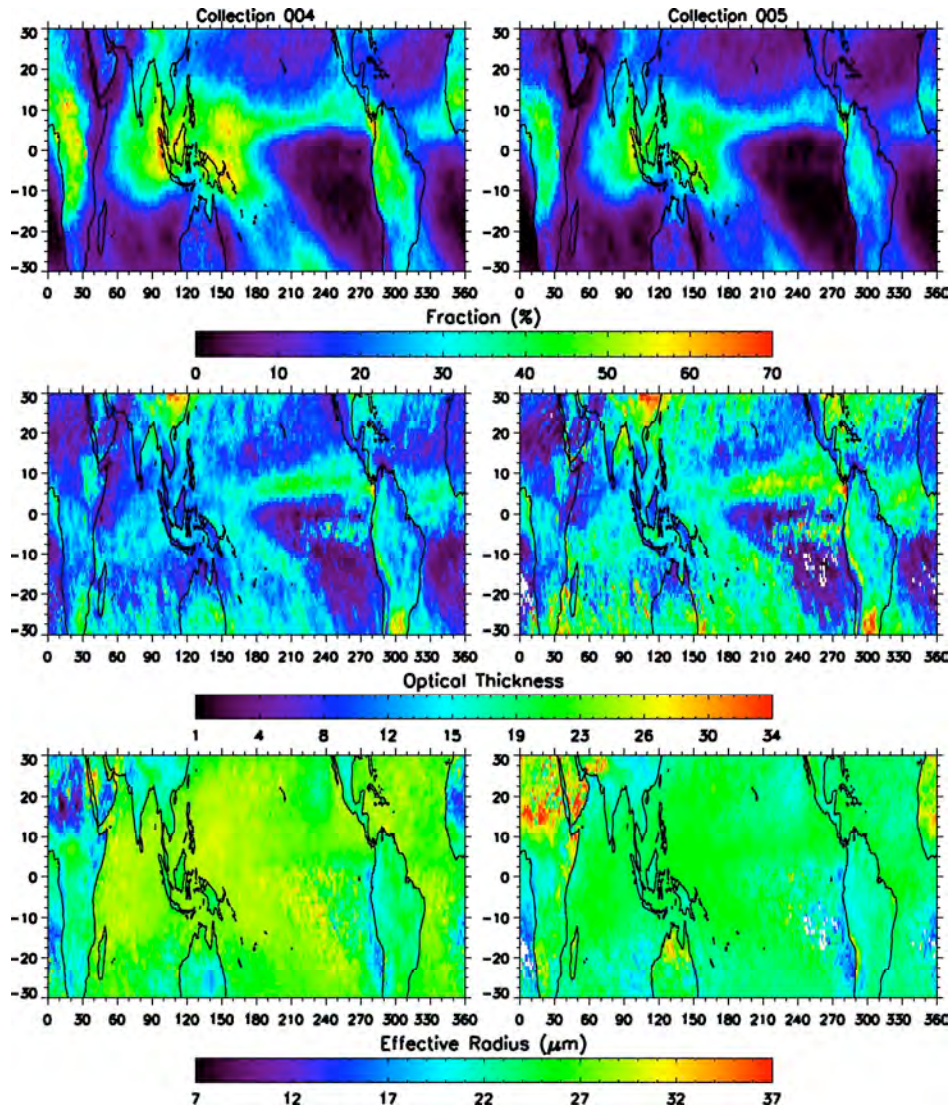
MODIS Collection 004 vs Collection 005
Ice cloud properties

TABLE 1. The one-year mean properties of high clouds from August 2001 to July 2002 over the tropics (30°S–30°N) in from the MODIS on board Terra in daytime.

High Cloud Properties	Collection 4			Collection 5		
	Land	Ocean	Total	Land	Ocean	Total
Fraction (%)	28.9	19.9	22.1	20.5	14.4	15.8
Optical thickness	13.0	13.2	13.1	14.6	16.6	16.0
Effective radius (μm)	23.1	27.9	26.4	23.9	24.4	24.2
Ice water path (g m^{-2})	183.6	225.1	211.4	213.3	247.6	236.7

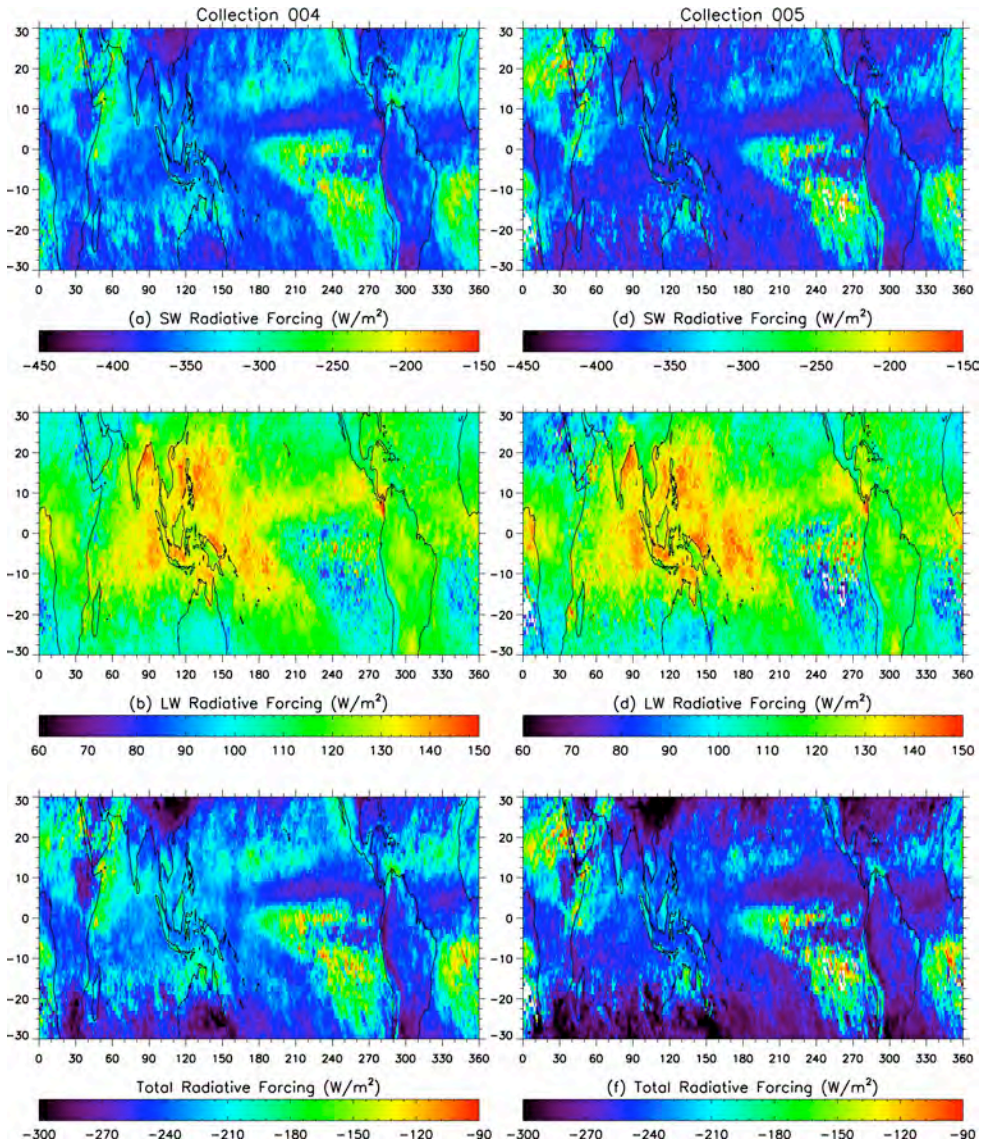
MODIS Collection 004 vs Collection 005
Ice cloud properties





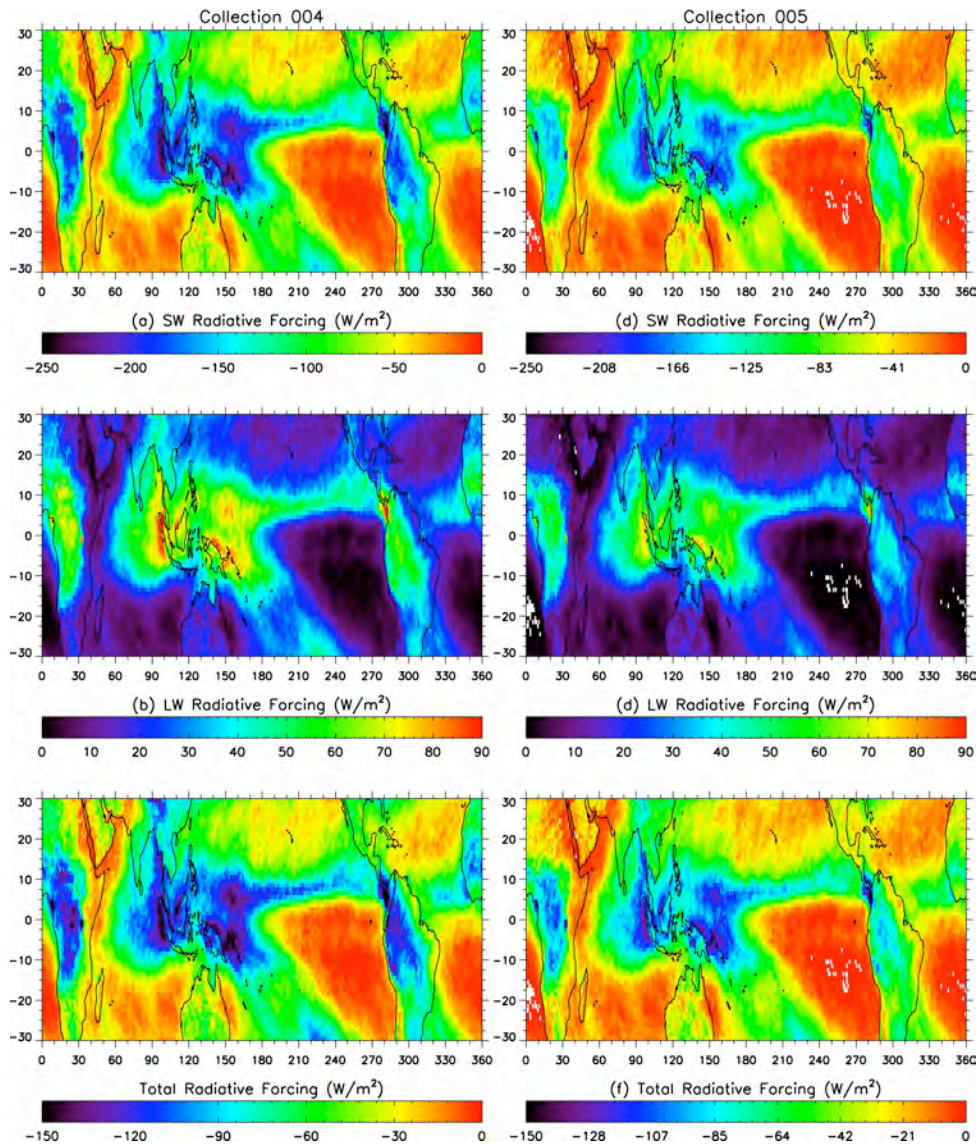
MODIS Collection 004 vs Collection 005
Overcast-sky Ice cloud Radiative Forcing

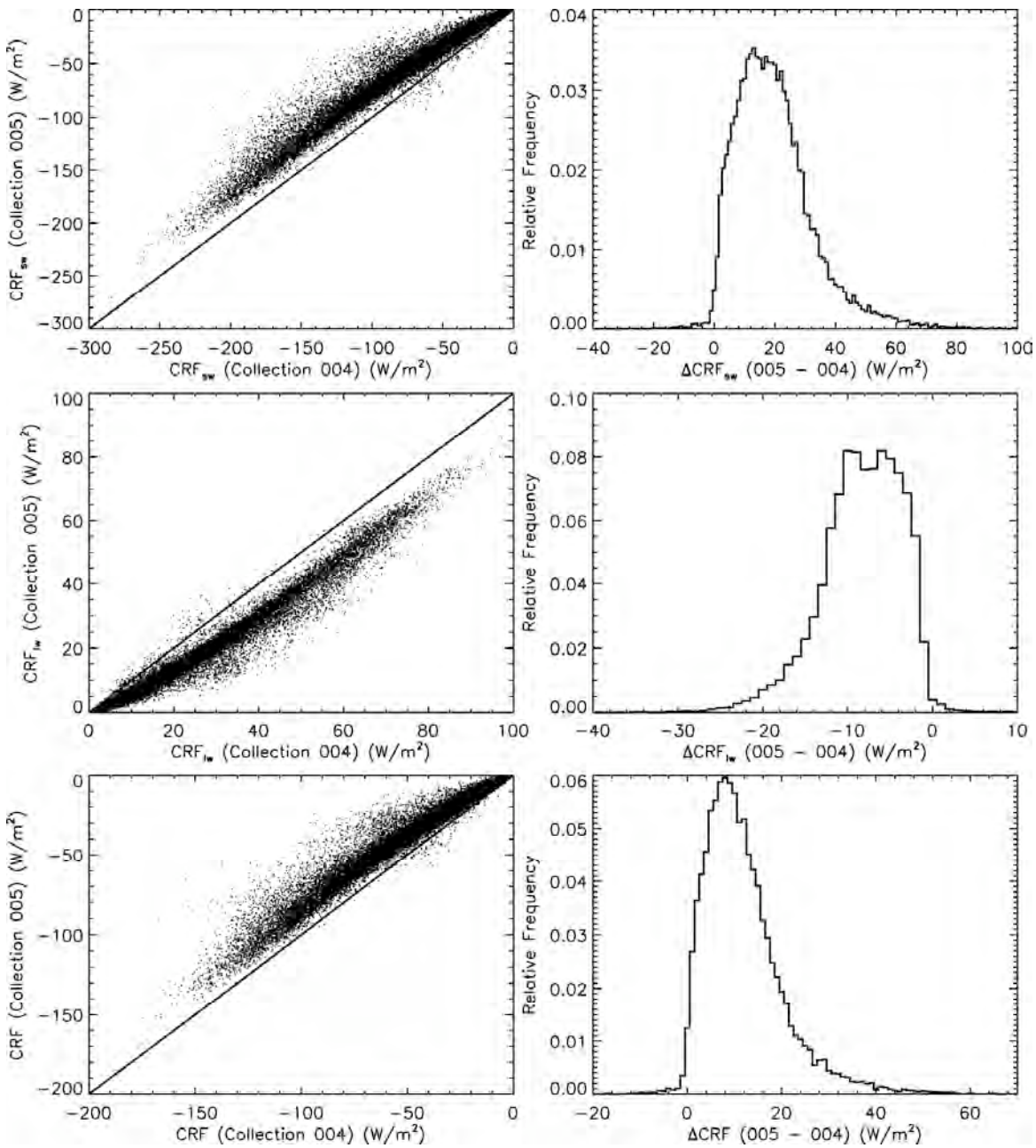
Effective size (MOD08)
Optical thickness (MOD08)
Cloud top height (MOD08)
Solar zenith angle θ_0 = 60º
Duration of sunlight is assumed to be 12 hours
Tropical standard atmospheric profile



MODIS Collection 004 vs Collection 005
Average-sky Ice cloud Radiative Forcing

Effective size (MOD08)
Optical thickness (MOD08)
Cloud top height (MOD08)
Solar zenith angle θ_0 = 60º
Duration of sunlight is assumed to be 12 hours
Tropical standard atmospheric profile




CRF$_{sw}$ (Collection 005) (W/m^2)
CRF$_{sw}$ (Collection 004) (W/m^2)
Relative Frequency
ΔCRF$_{sw}$ (005 − 004) (W/m^2)
CRF$_{lw}$ (Collection 005) (W/m^2)
CRF$_{lw}$ (Collection 004) (W/m^2)
Relative Frequency
ΔCRF$_{lw}$ (005 − 004) (W/m^2)
CRF (Collection 005) (W/m^2)
CRF (Collection 004) (W/m^2)
Relative Frequency
ΔCRF (005 − 004) (W/m^2)

Summary

- We have investigated the radiative forcing of tropical ice clouds.
- We also compared the MODIS Collection 004 and 005 ice cloud properties.
- This is ongoing research. The present results are preliminary.