Tropical cirrus variation with sea surface temperature and the cirrus radiative effect: the “iris hypothesis” revisited

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Introduction

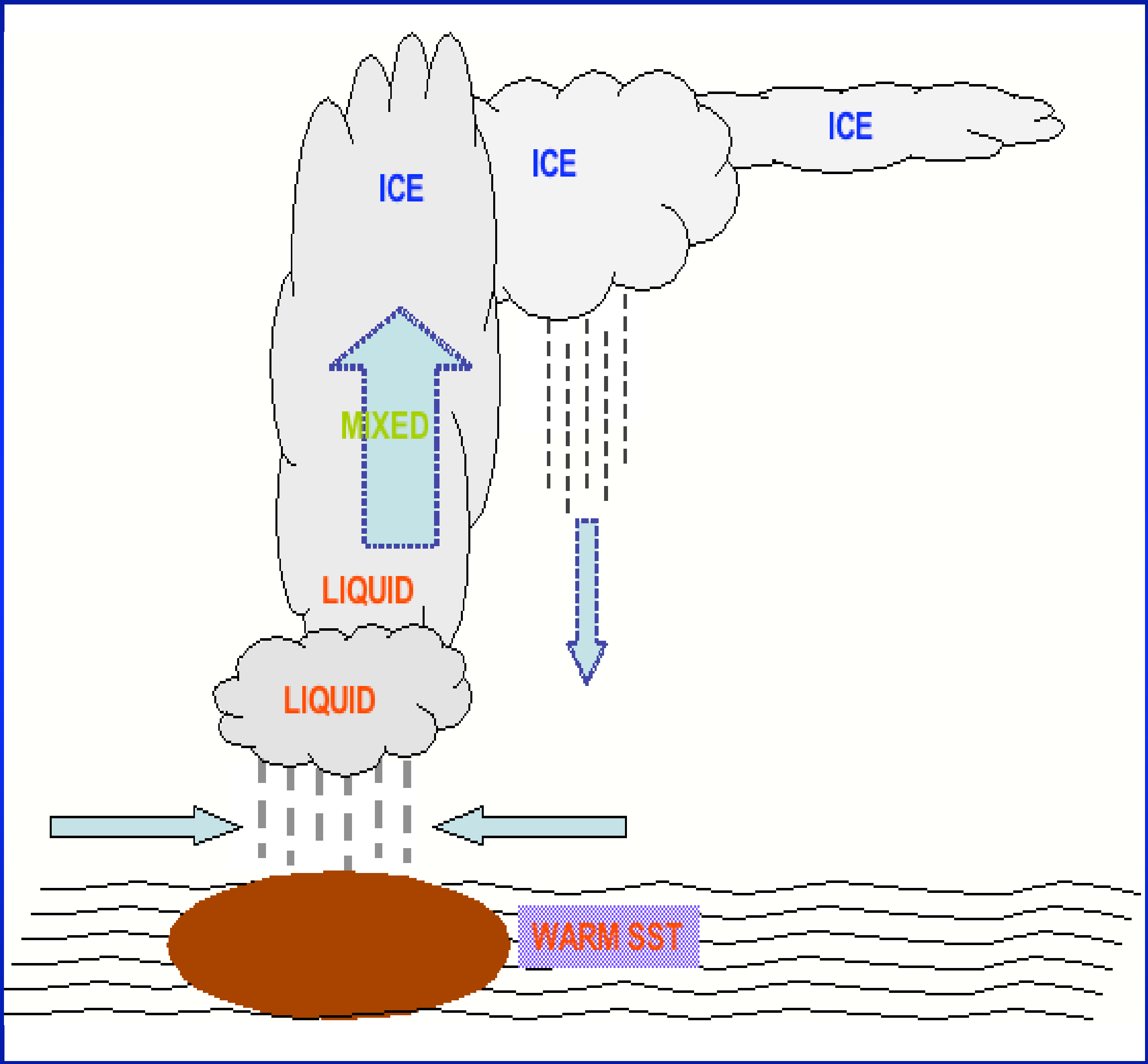
- Cloud feedback is one of the greatest uncertainties in climate modeling and climate prediction

- Upper tropospheric (UT) clouds are closely related to UT humidity and its greenhouse effect.

- UT clouds reduce outgoing longwave radiation (OLR) to space, causing a warming effect; they also increase planetary albedo and reduce incoming solar radiation, producing a cooling effect.

- It is important to quantify the net radiative effects of UT clouds and their changes with surface temperature, and the associated feedbacks

Existing Studies on Cirrus and SST Relation

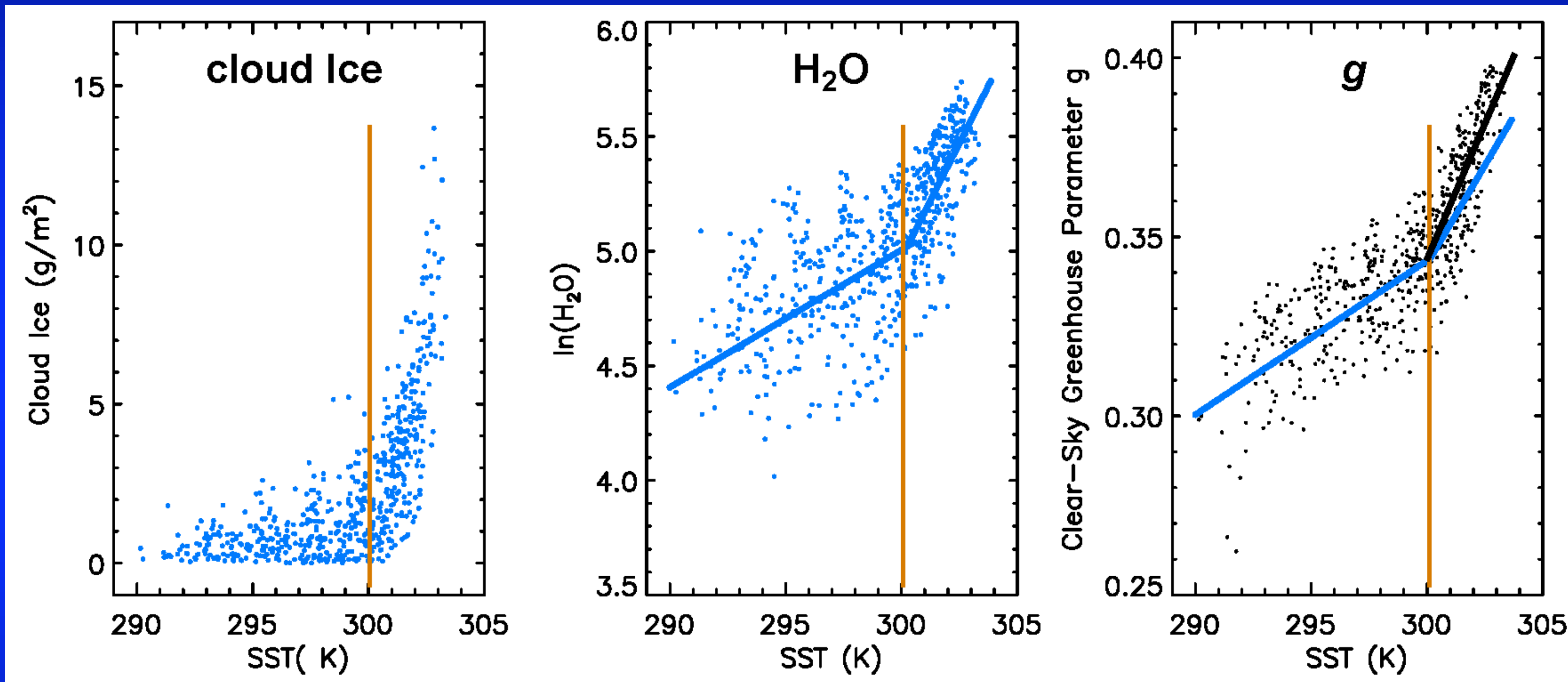


Tropical deep convection increases with SST
(Ramanathan and Collins 1991; Waliser et al. 1993; Collins et al. 1996; Lin et al. 1995; Lau et al. 1997; Bony et al. 1997; Tompkins and Craig 1999)

Does cirrus increase or decrease with SST?
(Lindzen et al. 2001; Hartmann and Michelsen 2002; Lin et al. 2001, 2004; Del Genio et al. 2002)

Do cirrus clouds provide positive or negative climate feedback?

Spatial Variation of UT Clouds with SST



Su et al. (2006) **showed that UT cloud ice increases with SST when SST is greater than ~300 K, leading to a moistened UT and enhanced water vapor greenhouse effect.**

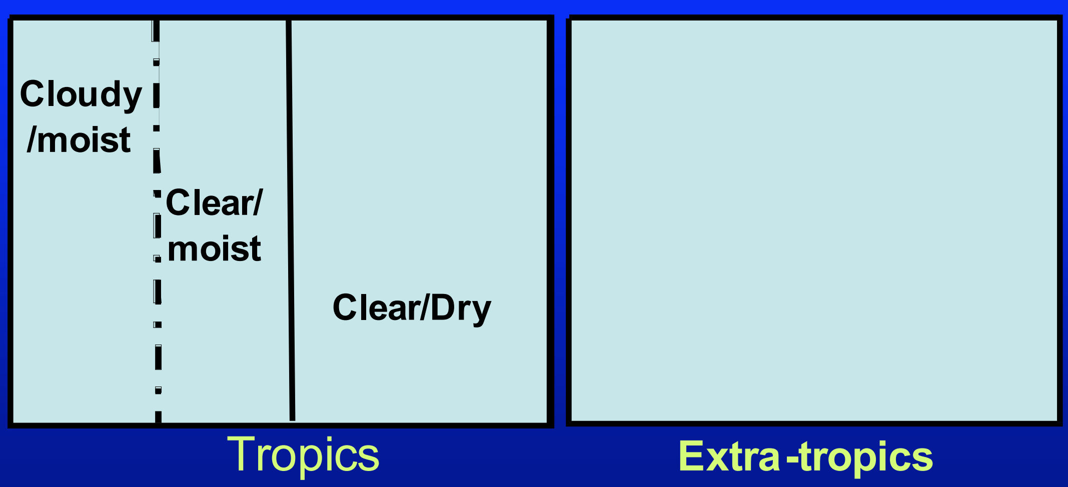
Highlights of Lindzen et al. (2001) Analysis

• Examined daily mean cloud fraction and cloud-weighted SST relation over W. Pacific

• Found cirrus coverage normalized by cumulus coverage decreases about 22% per degree increase of SST - "Iris hypothesis"

• Used 3.5-box radiative-convective equilibrium model to illustrate the climate feedback associated with the "iris hypothesis"

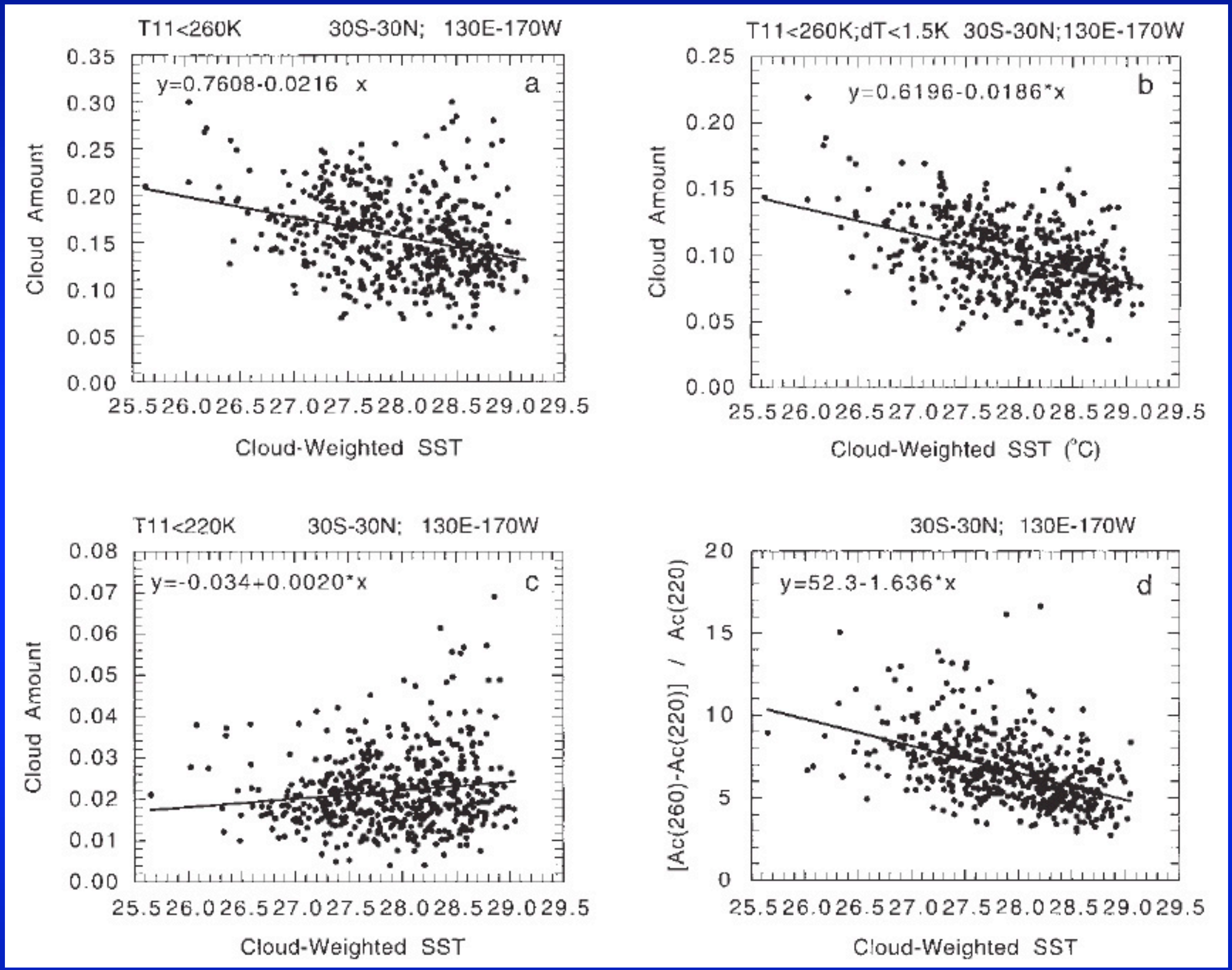
- Radiative transfer calculations were based on assumed optical properties of clouds to match radiation budget from ERBE



The Iris Hypothesis

(*Lindzen et al. 2001, BAMS*)

Cloud Coverage



Cloud Coverage

Scatterplots showing how cirrus coverage varies with cloud-weighted SST (From Fig. 5 in *Lindzen et al., BAMS, 2001).* They argued that cirrus cloud coverage normalized by a measure of cumulus coverage decreases about 22% per degree increase of SST, implying a negative climate feedback that would more than cancel all the positive feedbacks in current climate models.

Revisit the Iris Hypothesis using the AIRS Cloud Fraction and the MLS Ice Water Content Data

Analysis Approach

- Similarities to the Lindzen et al. (2001)
  - Examine the area-averaged cloud amount (CFR, IWC) change vs. SST
  - Examine daily variations
  - Normalization is considered: TRMM precipitation is used
- Differences from the Lindzen et al. (2001)
  - The averaging boundary is not fixed, based on CFR or IWC > 0
  - The microwave SST from the AMSRE is used
  - The weight for SST averaging is simplified to 0 and 1
  - Radiation calculations use both time-varying CFR and IWC observations

Datasets

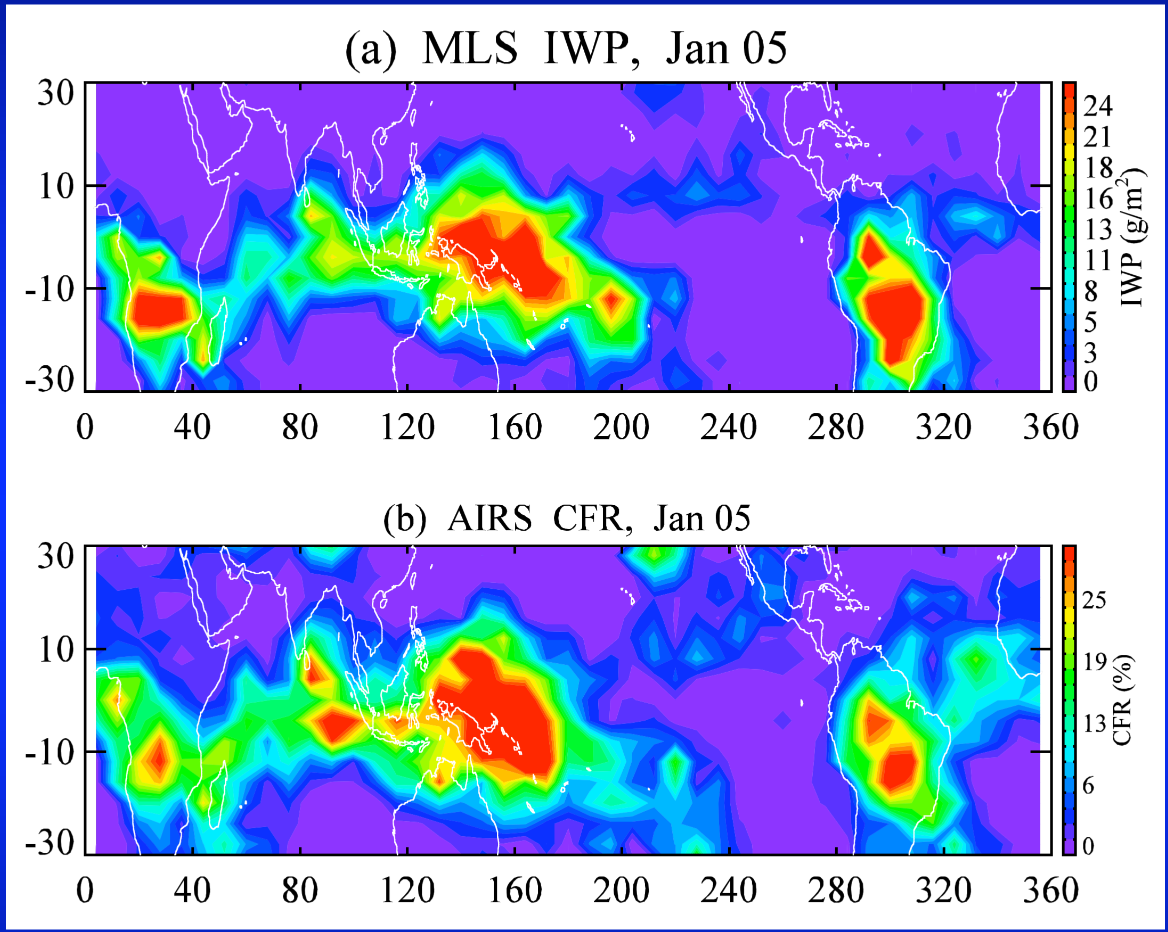
• Aqua AIRS 4-year (Sep 1, 2002 to Sep 30, 2006) daily cloud fraction and cloud top pressure (version 4)
  Horizontal grids: 1ºx1º

• Aura MLS 2-year (Aug 8, 2004 to Sep 30, 2006) daily ice water content (IWC) (version 1.5)
  Horizontal resolution: ~ 200 km
  Vertical Levels: 215, 147, 100 hPa

• TRMM daily precipitation (3B42): concurrent with AIRS or MLS data and interpolated onto AIRS or MLS grids

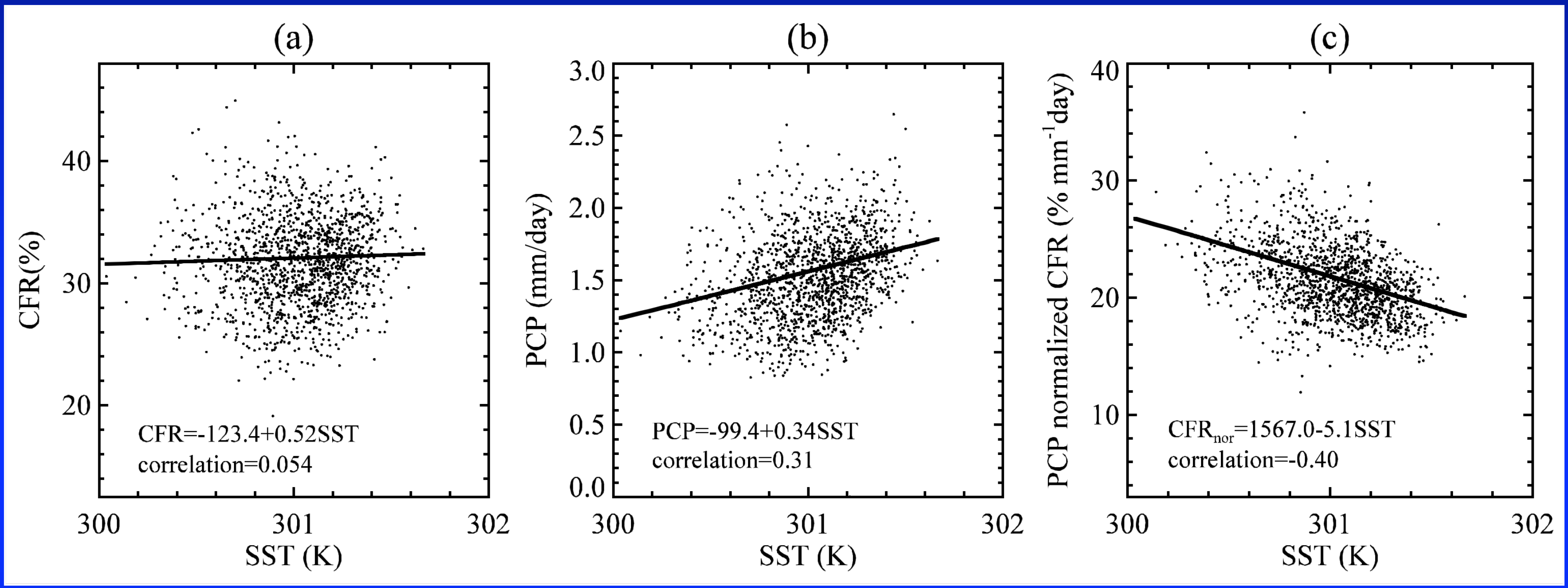
• AMSR-E daily SST analysis (RSS): concurrent with AIRS or MLS data and interpolated onto AIRS or MLS grids

Monthly-Mean AIRS CFR and MLS IWP



Similar in spatial patterns; AIRS captures more thin cirrus than MLS.

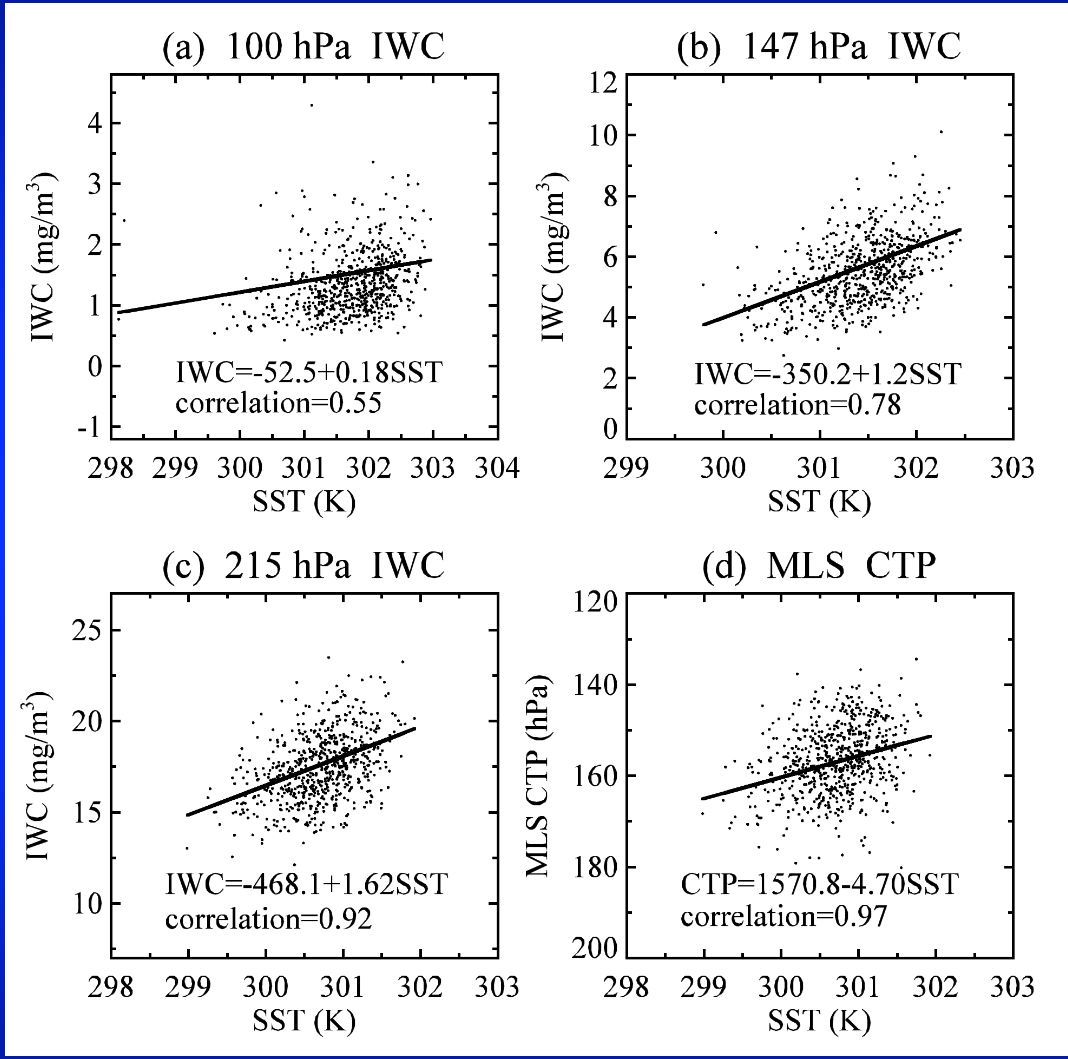
AIRS Effective Cloud Fraction – SST Relation



Scatter plots of (a) the tropical-averaged (30ºS-30ºN) CFR (CTP < 300 hPa) versus the AMSRE mean under-cloud (MUC) SST; (b) the tropical cloudy-area averaged precipitation versus the MUC SST; and (c) the precipitation-normalized CFR (in % mm^{-1} day) versus the MUC SST.

- AIRS CFR is nearly in-variant with the MUC SST.
- The cloudy-area averaged precipitation increases with the MUC SST.
- The precipitation-normalized CFR decreases with the MUC SST at a rate of ~ –20% K^{-1}. Similarly for other tropical bands (10ºS-10ºN, 20ºS-20ºN) and the area used in Lindzen et al. (2001).

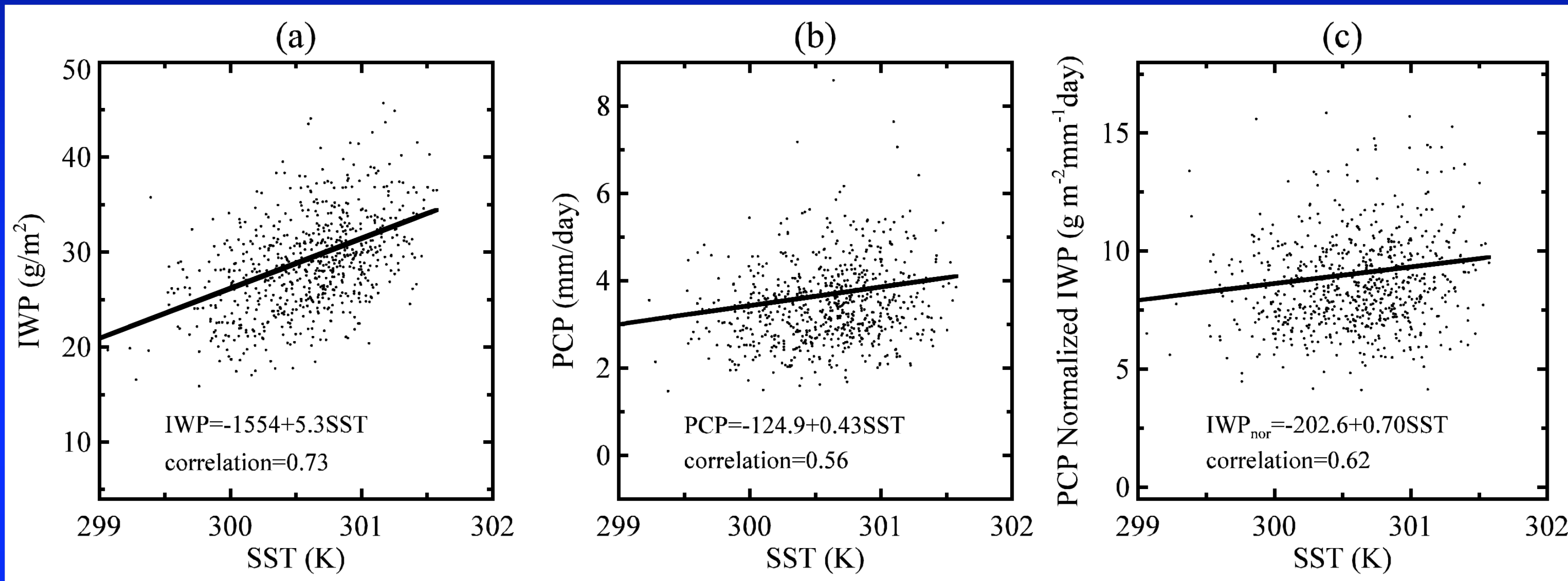
MLS Ice Water Content – SST Relation



IWC

The tropical-mean IWC increases with the MUC SST.
So does the MLS-derived cloud top height.

MLS Ice Water Path – SST Relation



- MLS IWP increases with the MUC SST at the rate of ~ 20% K^{-1} .
- The cloudy-area averaged precipitation increases with the MUC SST, at the rate of ~12% K^{-1}.
- The precipitation-normalized IWP increases with the MUC SST at a rate of ~ 8% K^{-1}.
- Similarly for other tropical bands (10ºS -10ºN, 20ºS - 20ºN) and the area used in Lindzen et al. (2001).

Summary of AIRS CFR and MLS IWP Relations to SST

	CFR	Precipitation - normalized CFR	IWP	Precipitation - normalized IWP
30°S-30°N	2%	–24%	19%	8%
20°S-20°N	4%	–21%	22%	14%
10°S-10°N	8%	–23%	31%	19%
30°S-30°N, 130°E-170°W (as in LCH)	6%	–12%	19%	6%

- The AIRS CFR varies little with the MUC SST, while the normalized CFR decreases with SST at a rate of ~20% K^{-1}.
- The MLS IWP increases with the MUC SST, at a rate faster than the cloudy-area averaged precipitation increases with SST.

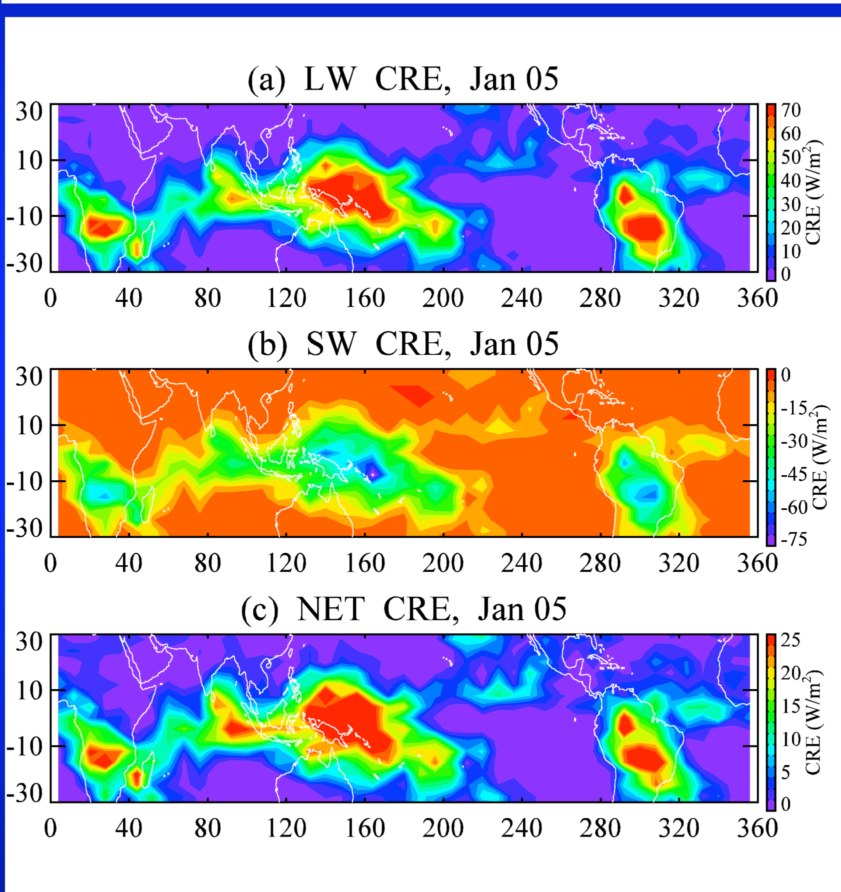
MLS-observed Cirrus Radiative Effect

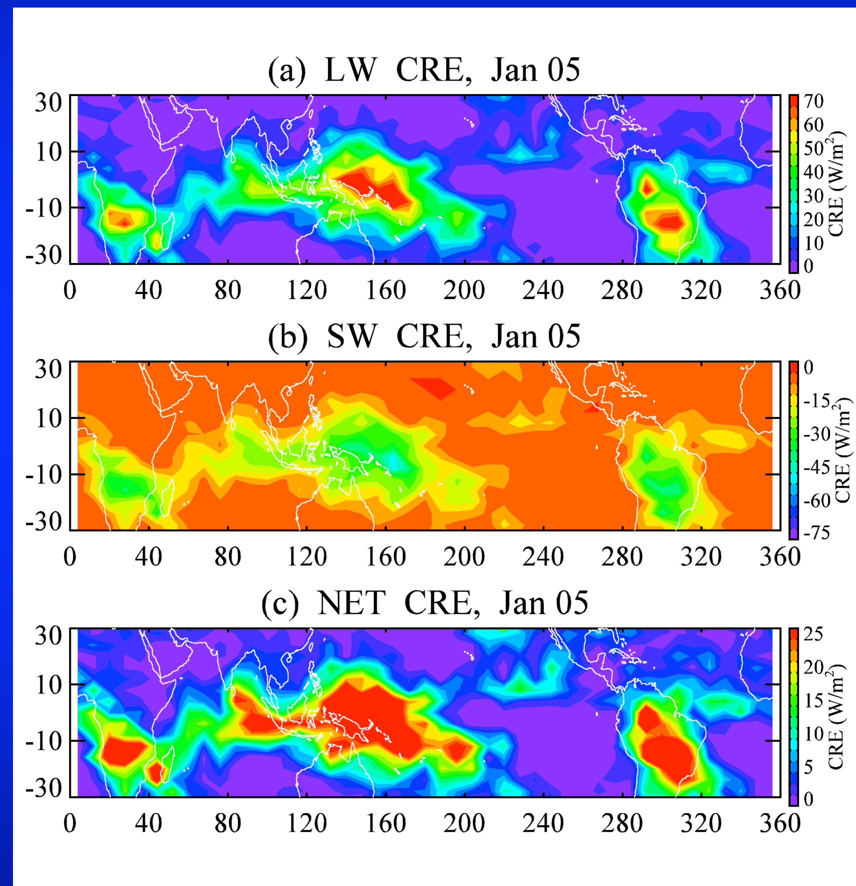
Define Cirrus Radiative Effect (CRE) as

$$CRE = F^{cl} - F = \eta(F^{cl} - F^{ov})$$

where

$$F = (1-\eta)F^{cl} + \eta F^{ov}$$

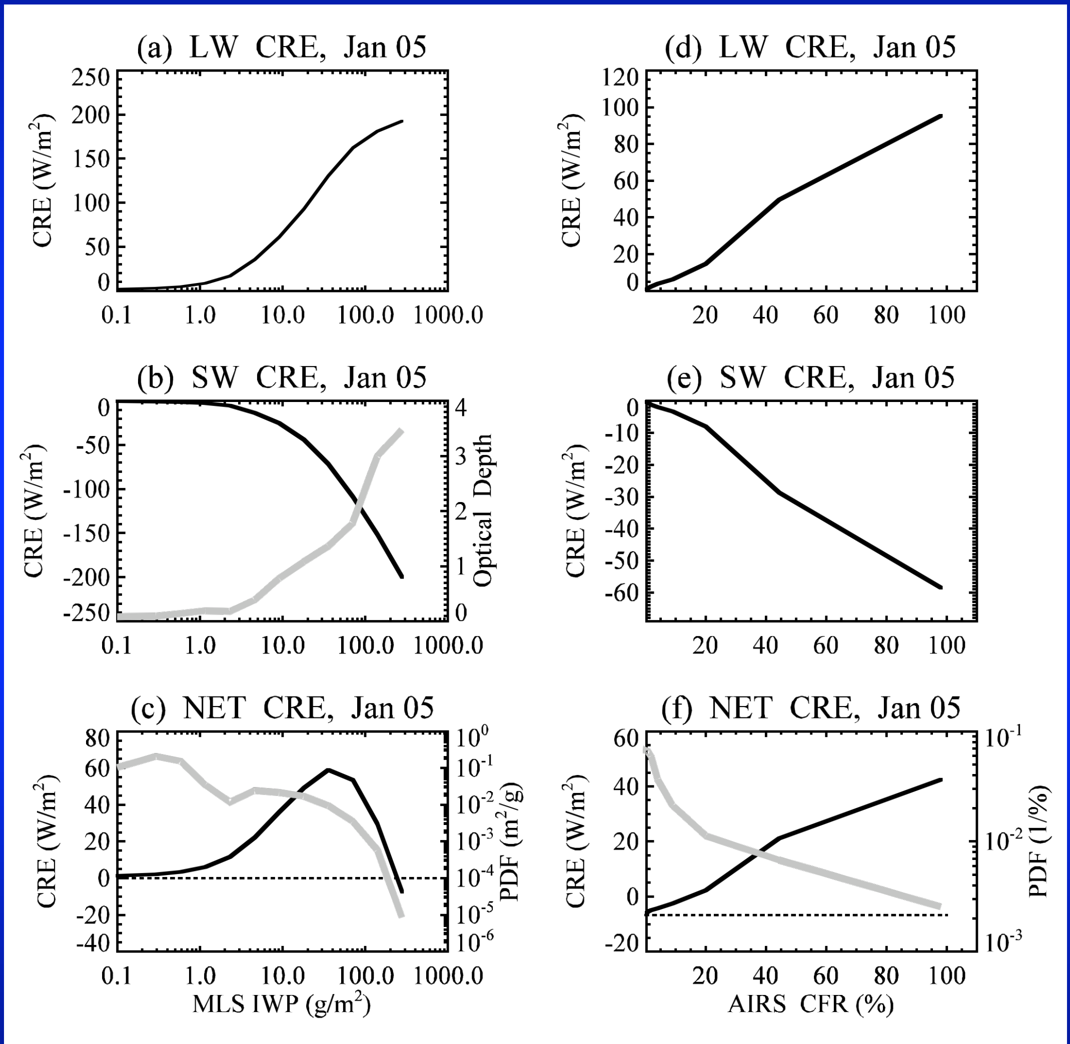




	IR_{TOA}	SW_{TOA}	NET
30S-30N (W/m^2)	16.5 (Warming)	-9.6 (Cooling)	6.9 (Warming)

	IR_{TOA}	SW_{TOA}	NET
30S-30N (W/m^2)	15.3 (Warming)	-7.0 (Cooling)	8.3 (Warming)

CRE Distribution binned on CFR and IWP



- CRE varies approximately linearly with CFR.
- CRE varies non-linearly with IWP.
- The maximum net warming occurs around IWP of 40 g m^{-2}. When IWP is greater than 250 g m^{-2}, the net CRE becomes negative (cooling).
- Most of MLS-observed cirrus has visible optical depth less than 4.
- About 95% of MLS-observed cirrus has IWP less than 100 g m^{-2}, corresponding to optical depth of 2.0.
- Moderate increase of IWP would not change the sign of the net CRE. Whether the amplitude of net warming increases or decreases depends on the distribution of IWP changes.

Summary

- It is important to examine both the cirrus fraction and IWC to quantify cirrus variation with SST and the associated cirrus radiative effect.
- The tropical-mean cirrus fraction is nearly in-variant with the underlying SST, while the tropical-mean IWC and IWP increase with SST.
- The MLS-observed cirrus clouds have a net warming effect to the climate system. Because of their optical thinness, moderate increase of IWP does not change the sign of the cirrus forcing.
- The climate feedback of cirrus depends on the spatial distribution and occurrence frequency change of cirrus.
- Our analyses do not support the “Iris Hypothesis”. The extrapolation of these correlations to global warming scenario requires scrutiny. The analysis results provide useful reference values for climate model simulations.