The Radiative Feedback of the Tropical Anvil Clouds: Negative or Positive?

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CERES Science Team Meeting
Newport News, VA, May 2, 2001

Acknowledgement

- David Young, Tak Wong, and David Kratz gave many suggestions and comments on this study.

- Ed Kizer helped to set up ERBE-like codes.

- Erika Geier, Seiji Kato, Norman Loeb, and Alice Fan provided the support in SSF data processing.

Outline

1. Background

   Lindzen et al.' (2001) climate feedback: observation & model

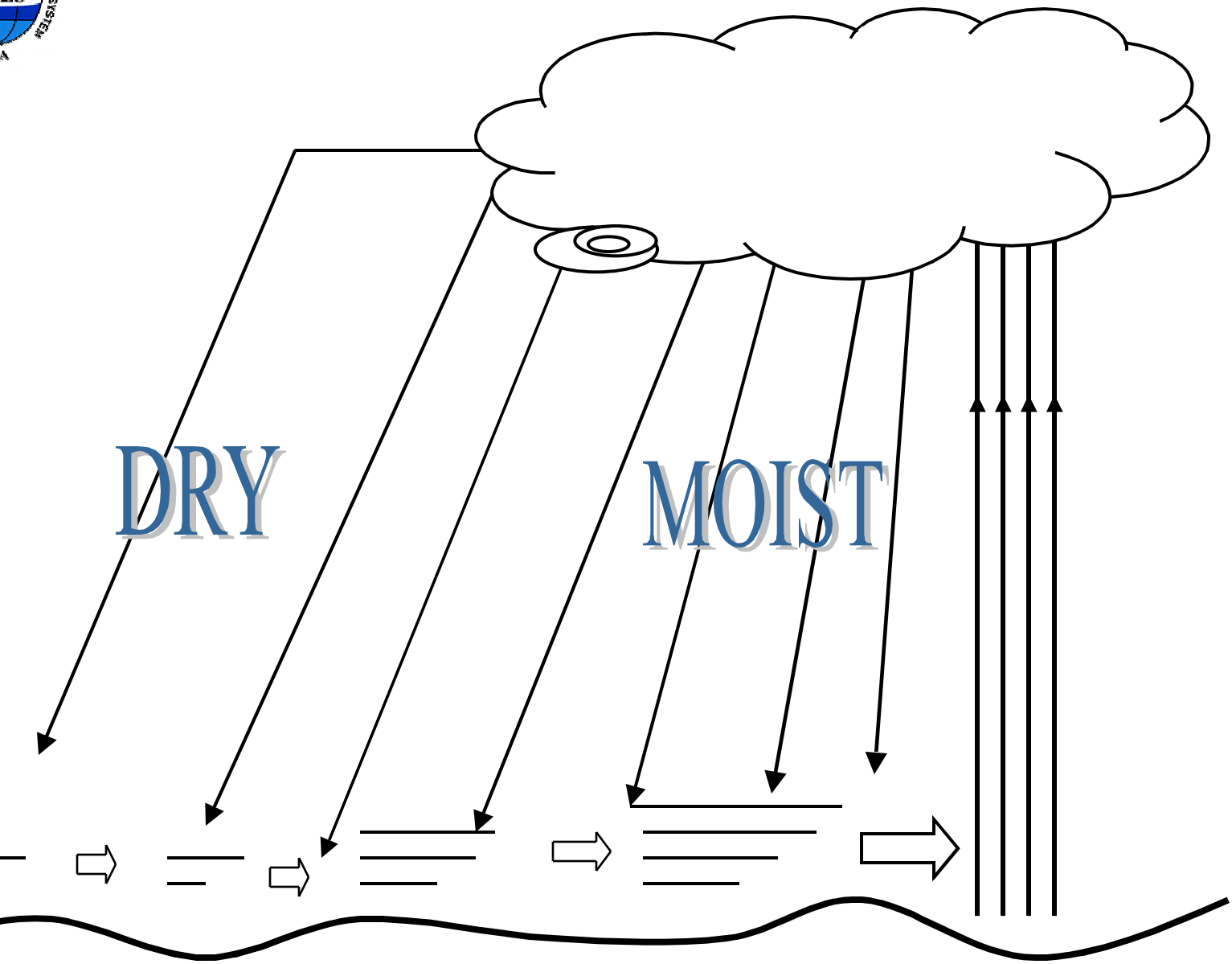
2. CERES Data

3. 3.5-box Model Calculation

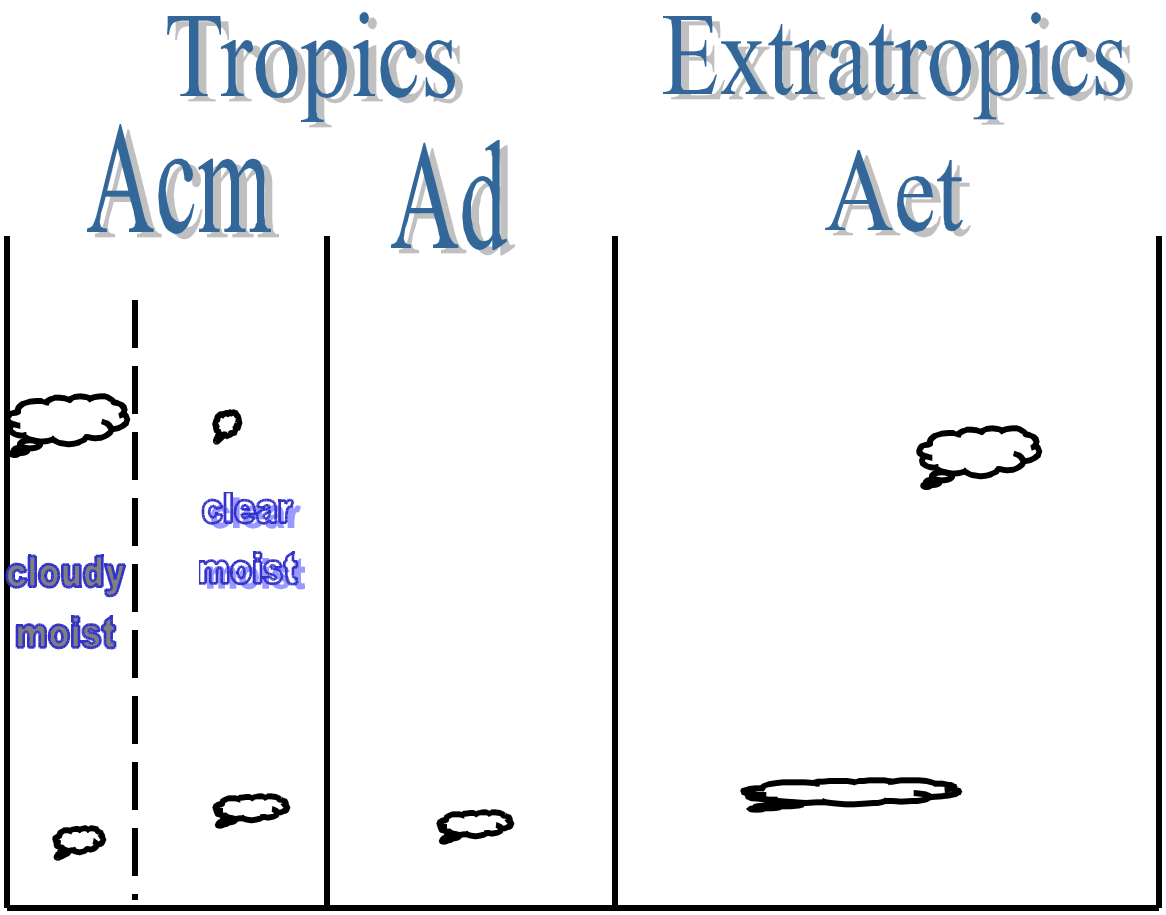
4. Perturbation Analysis

5. Summary

1. Background



Atmospheric Moisturization



Tst = Ts + 10K Tset = Ts – 10K

1. Background (cont.)

Based on the anvil variations with SST observed from GMS data and 3.5-box greenhouse model, Lindzen et al. (2001) proposed a very strong negative radiative feedback of the clouds on climate change (–0.45 ~ –1.1; or **IR iris**).

Note: cloud amount with SST → c.f. Chambers et al.

1. Background (cont.): main points

Q: Do CERES data show the similar cloud change with SST, and feedback processes?

(Since we do not know where many values in Lindzen et al. come from)

1. Confirms the anvil clouds over oceans decrease with increase SST with the rate.
2. Large differences in CERES observed SW & LW fluxes from those of Lindzen et al.
3. Significant differences in calculated cloud feedback from those Lindzen et al.' results.

2. CERES Data

CERES/TRMM ERBE-like observations: the area coverage of tropical dry, clear moist, and cloudy moist regions, albedo, incoming shortwave (SW↓) and outgoing longwave (LW↑).

SSF Data: Tb(10.8μm) + broadband LW & SW measurements (±30°N; 01 ~ 08, 1998)

2. CERES Data (cont.)

Definitions of clouds & climate regimes:

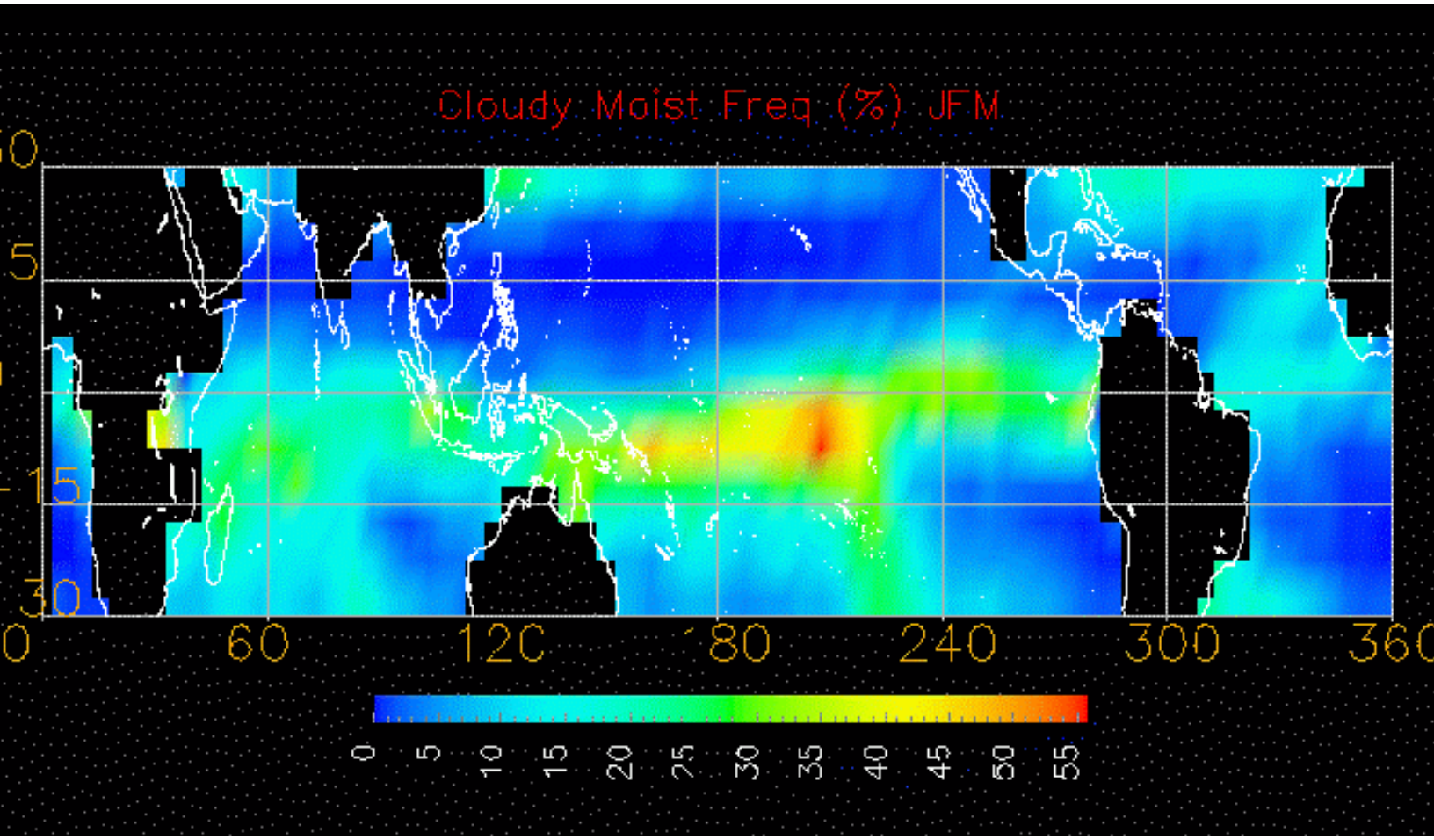
convective clouds: Tb(10.8) < 220K

cloudy moist: Tb(10.8) < 260K (anvil)

dry area: broadband LW↑ > LW50

LW50: 50% percentile of 8-month LW↑ statistics

clear moist: all other pixels


Cloudy Moist Freq (%) JFM
60
120
180
240
300
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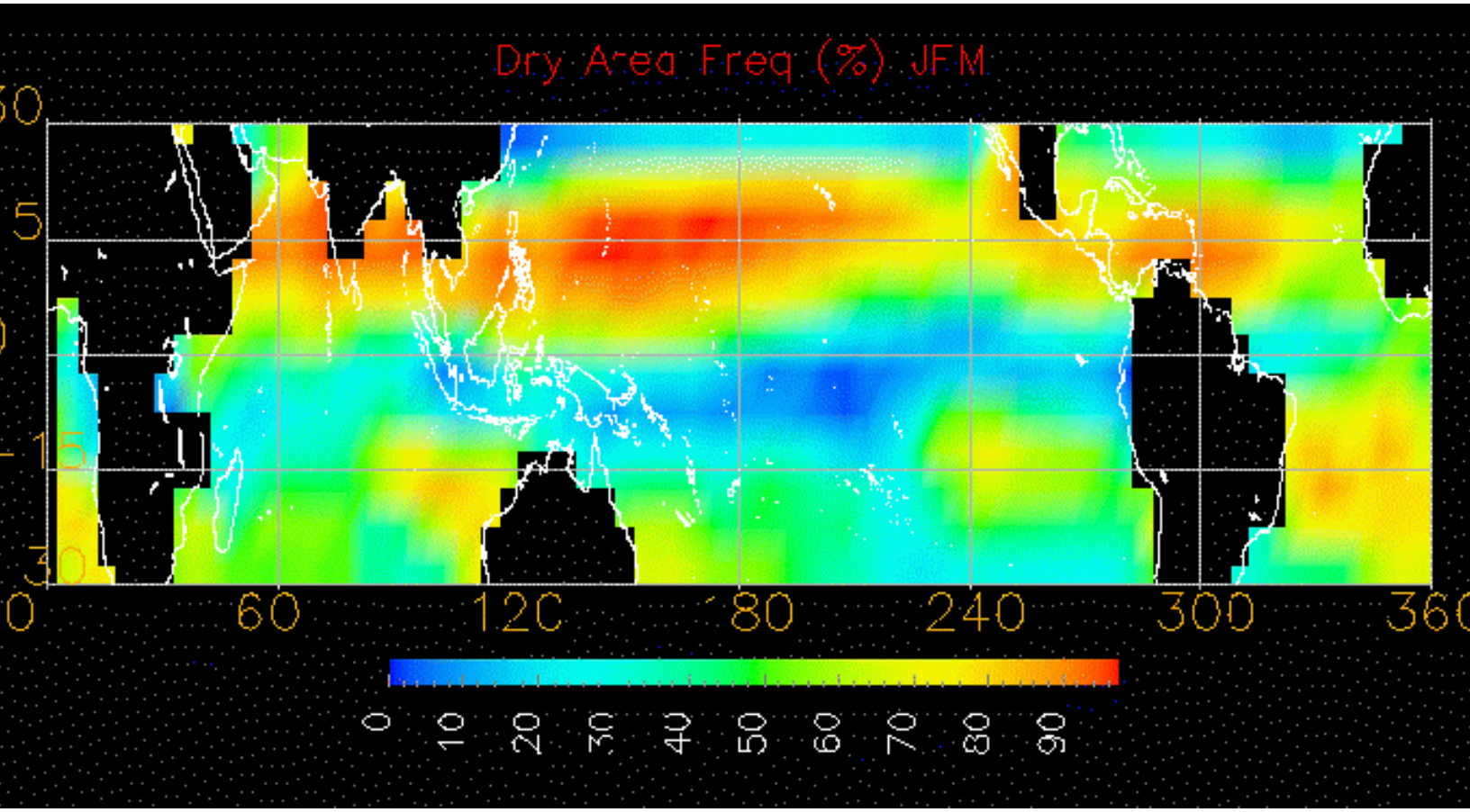
35
40
45
50
55


Dry Area Freq (%) JFM
60
120
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10
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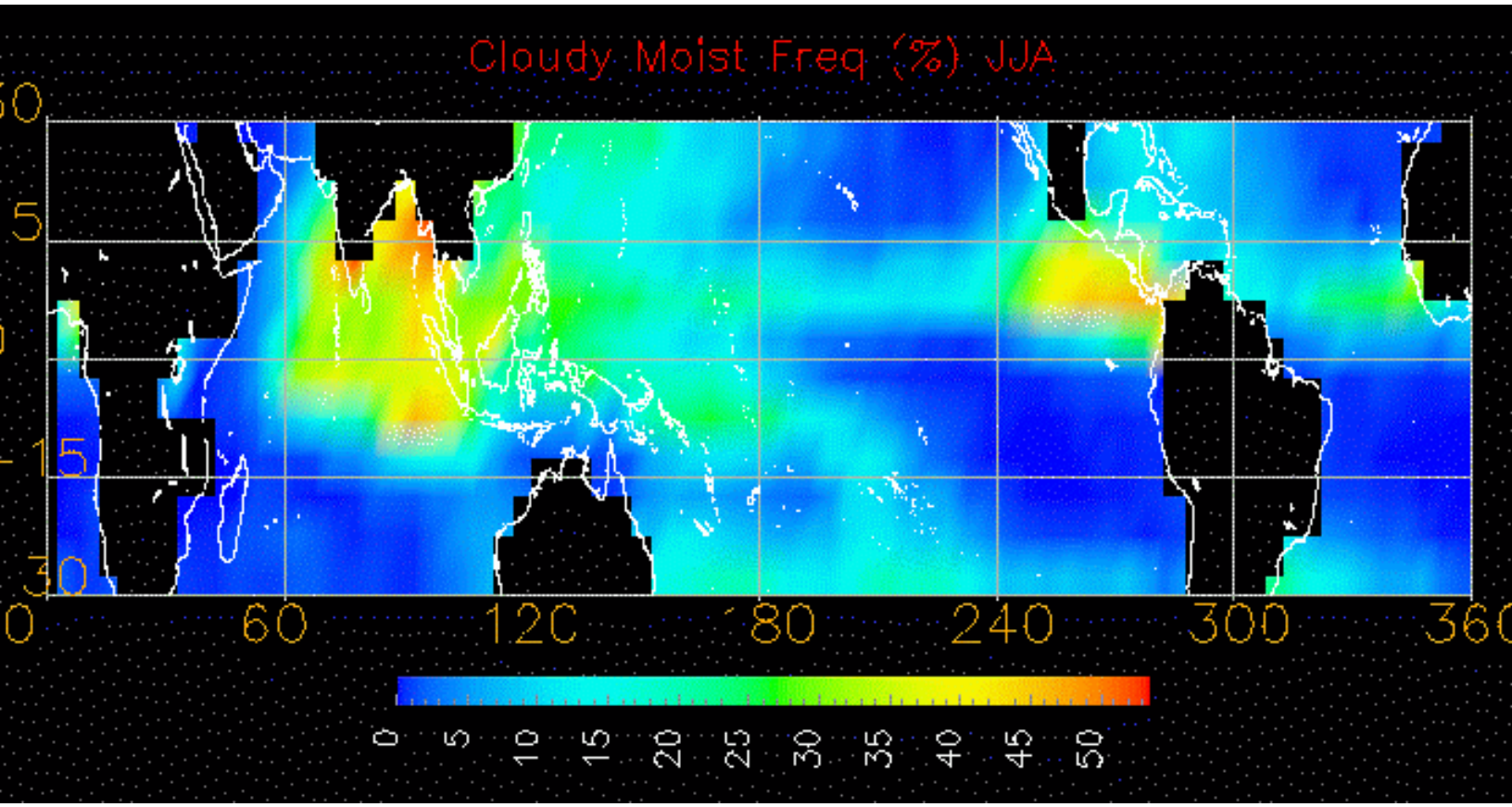
50
60
70
80
90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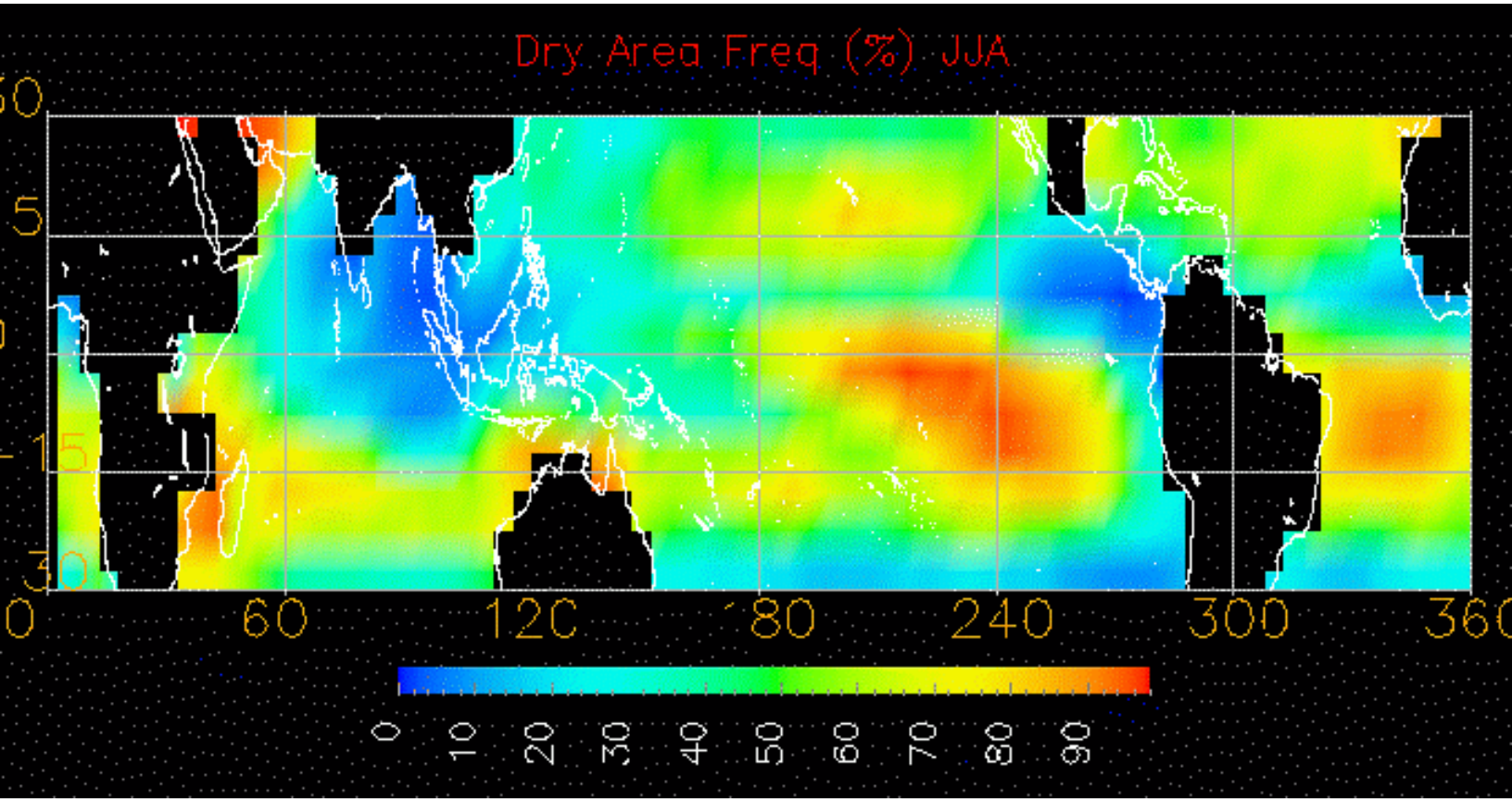
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90

2. CERES Data (cont.)

	LaRC ¾ CERES			Lindzen et al.		
	dry	clear moist	cloudy moist	dry	clear moist	cloud moist
q	0.5	0.4	0.1	0.5	0.28	0.22
edo	0.154	0.258	0.510	0.211	0.211	0.349
↓	338.7	297.1	196.2	315.9	315.9	260.6
↑	287.7	253.9	154.8	303.1	263.1	137.7

3. 3.5-box Model Calculation

$$A_{clrm}SW_{clrm}\downarrow + A_{cldm}SW_{cldm}\downarrow + A_{d}SW_{d}\downarrow + A_{et}SW_{et}\downarrow$$

$$= Q_0(1-\alpha_0) =$$

$$\sigma(A_{clrm}T^4_{eclrm} + A_{cldm}T^4_{ecldm} + A_{d}T^4_{ed} + A_{et}T^4_{eet}) \quad (1)$$

Note: $LW\uparrow = \sigma T^4_e = \sigma(T_s - \Delta T_e)^4$

clr → clear; cld → cloudy; m → moist; d → dry;

t → tropical; et → extratropical; e → emission;

3.5-box greenhouse model (cont.)

$A_{cldm} = A°_{cldm} (1 + \mu)$;

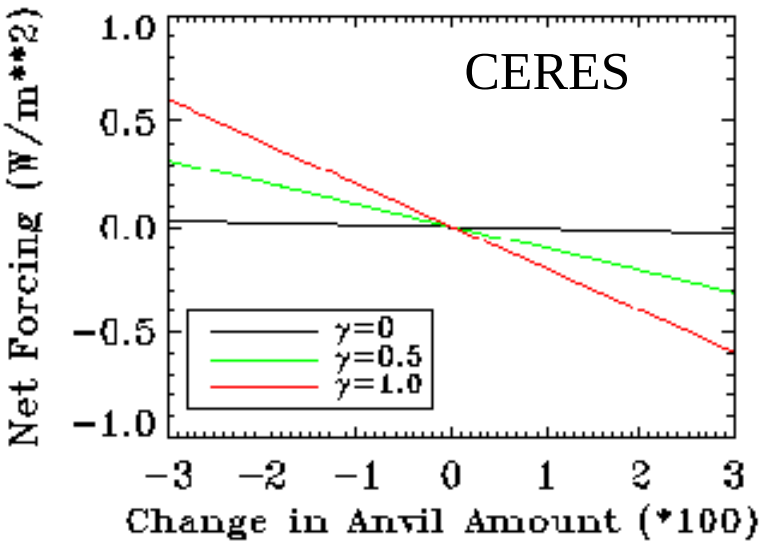
$A_{cm} = A°_{cm} (1 + \gamma\mu)$;

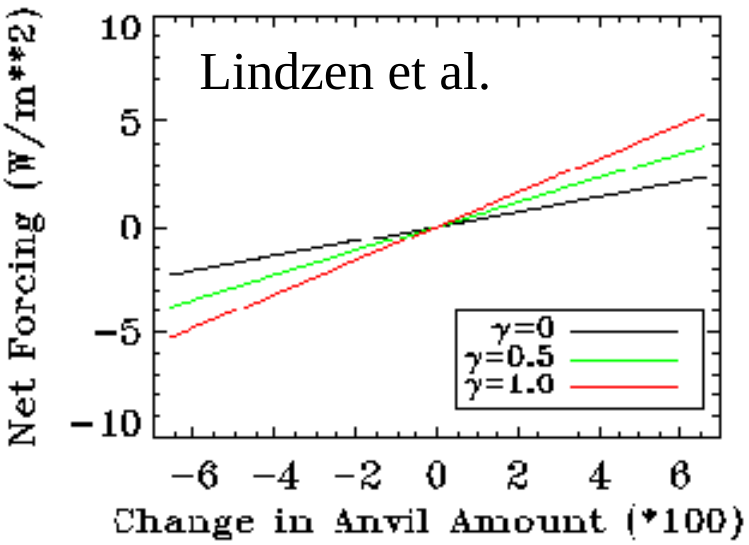
$A_{clrm} = A_{cm} - A_{cldm}$; $A_d = A_t - A_{cm}$;

$\gamma = 0$ corresponding cloudy moist to clear moist changes

$\gamma > 0 \rightarrow$ 3-way, i.e., clear moist, cloudy moist, and dry regions, changes, which produces stronger feedback.

radiative forcing: IR iris?





Global Net Forcing↓ = SW↓ – LW↑

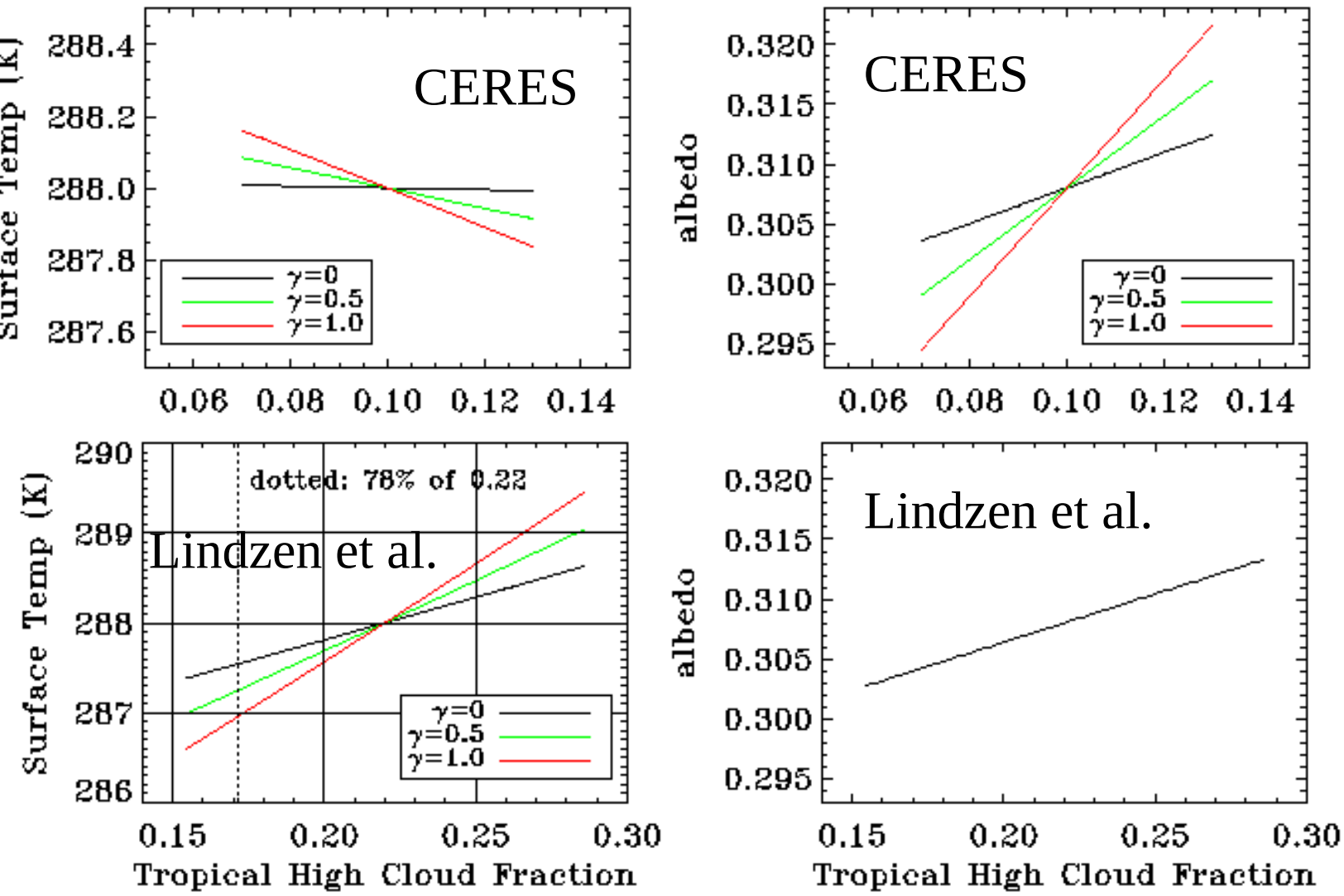
C = CC° + ΔCC and Ts = T°s ΔCC = change in anvil amount

anvil clouds↘ → global albedo↘ & SW↓↗

Lindzen et al.: LW↑↗ → the net↓ radiation↘

CERES: NOT seen!

Simulated cloud feedback



4. Perturbation Analysis

$$A_{clrm}SW_{clrm}\downarrow + A_{cldm}SW_{cldm}\downarrow + A_dSW_d\downarrow + A_{et}SW_{et}\downarrow = Q_0(1-\alpha_0) =$$
$$\sigma(A_{clrm}T^4_{eclrm} + A_{cldm}T^4_{ecldm} + A_dT^4_{ed} + A_{et}T^4_{eet}) \quad \ldots\ldots \quad (1)$$

$$\Delta A_{clrm}\, SW_{clrm}\downarrow + \Delta A_{cldm}SW_{cldm}\downarrow + \Delta A_dSW_d\downarrow = -Q_0\Delta\alpha_0 =$$
$$\sigma(\Delta A_{clrm}T^4_{eclrm} + \Delta A_{cldm}T^4_{ecldm} + \Delta A_dT^4_{ed}) +$$
$$4\sigma\,(A_{clrm}T^3_{eclrm} + A_{cldm}T^3_{ecldm} + A_dT^3_{ed} + A_{et}T^3_{eet})\,\Delta Ts \ldots \quad (2)$$

$$A_{clrm} + A_{cldm} + A_d = A_{t;} \qquad \Delta A_{clrm} + \Delta A_{cldm} + \Delta A_d = 0 \ldots\ldots \quad (3)$$

$$4\sigma\,(A_{clrm}T^3_{eclrm} + A_{cldm}T^3_{ecldm} + A_dT^3_{ed} + A_{et}T^3_{eet})\,\Delta Ts =$$
$$\Delta A_{clrm}((SW_{clrm}\downarrow - LW_{clrm}\uparrow) - (SW_d\downarrow - LW_d\uparrow)) +$$
$$\Delta A_{cldm}((SW_{cldm}\downarrow - LW_{cldm}\uparrow) - (SW_d\downarrow - LW_d\uparrow)) \quad \ldots\ldots \quad (4)$$

4. Perturbation Analysis (cont.)

	LaRC — CERES			Lindzen et al.		
	Dry	Clear Moist	Cloudy Moist	Dry	Clear Moist	Clouc Moist
	0.5	0.4	0.1	0.5	0.28	0.22
lo	0.154	0.258	0.510	0.211	0.211	0.349
	338.7	297.1	196.2	315.9	315.9	260.6
	287.7	253.9	154.8	303.1	263.1	137.7
Radiation	51.0	43.2	41.4	12.8	52.8	122.9
net versus et		-7.8	-9.6		40.0	110.1
ly moist vs. moist			-1.8			70.1

4. Perturbation Analysis (cont.)

CERES: $3.707\ \Delta Ts = -7.8\Delta A_{clrm} - 9.6\Delta A_{cldm}$ …. (5-1)

Lindzen et al. $3.703\ \Delta Ts = 40.0\ \Delta A_{clrm} + 110\Delta A_{cldm}$ …. (5-2)

1). A_d = Const ($\gamma = 0$) → no dry region terms in Eq. 4.
And $\Delta A_{clrm} = -\Delta A_{cldm}$

CERES only $-1.8\Delta A_{cldm}$, Lindzen et al. $70.1\Delta A_{cldm}$

ΔTs =0.01K ΔTs =-0.46K

2) A_{cm} increasing rate = ΔA_{cldm} increasing rate ($\gamma = 1$)
→ the same A_{clrm} increasing rate → much stronger feedback

ΔTs =0.12K ΔTs =-1.05K

These sensitivities or feedback factors are the same as those of previous model simulations (c.f. Figures)

SW & LW consistency

Fu-Liou ice clouds: for Lindzen et al.' values

Hc = 15km (upper limit for warming)

With LW↑ = 138 W/m^2 → $r_{cldm} \geq 0.39$

if add τ =15 ~50 into distribution, r_{cldm} doubled with small change in LW↑.

Increased SW cooling effects: e.g,

τ =16, r_{cldm} → 0.63, Δ LW↑ = -35 W/m^2 (warming)

ΔSW↑ = (0.63–0.4)400= 92W/m^2 (cooling)

SW & LW consistency (cont.)

Fu-Liou model **Cloudy Moist**

τ	freq	albedo	LW↓
1	0.15	0.261	207.4
2	0.15	0.356	173.8
4	0.15	0.448	148.8
8	0.15	0.549	139.8
20	0.2	0.666	138.1
32	0.2	0.711	137.9
Avg: 12.65		0.5175	155.67

check CERES estimates with Hc= 12±3km

Summary

1. Based on observations, tropical regions may be separated into moist and dry regimes although quantitative cutoff between the two is still an open question. It seems more difficult to identify cloudy moist and clear moist.
2. During January to August 1998, the tropical anvil clouds over oceans decrease with increase in SST (~25%/K).
3. The CERES observed LW↑ and SW↓ fluxes generally differ from Lindzen et al. 10 ~ 25 W/m^2, except SW↓ in cloudy moist area where the value is much larger (~64 W/m^2). The striking feature is that all CERES observed net changes from those of Lindzen et al. point to the same positive feedback direction for the anvil decrease.

Summary (cont.)

4. Observations and consistency estimations suggest that Lindzen et al. may use a too small albedo for anvil clouds.
5. Using CERES observed radiative properties both 3.5-box greenhouse model calculation and perturbation analysis show that the decrease of anvil clouds with increasing SST results a slightly positive feedback compared to the strong negative feedback of Lindzen et al.