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

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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

DRY

MOIST

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 ($SW_\downarrow$) and outgoing longwave ($LW_\uparrow$).

SSF Data: Tb(10.8µm) + broadband LW & SW measurements ($\pm30^\circ$N; 01 ~ 08, 1998)
2. CERES Data (cont.)

Definitions of clouds & climate regimes:
convective clouds: $T_b(10.8) < 220\text{K}$
cloudy moist: $T_b(10.8) < 260\text{K}$ (anvil)
dry area: broadband LW$\uparrow > LW50$
  LW50: 50% percentile of 8-month LW$\uparrow$
statistics
clear moist: all other pixels
## 2. CERES Data (cont.)

<table>
<thead>
<tr>
<th></th>
<th>LaRC — CERES</th>
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<tbody>
<tr>
<td></td>
<td>dry</td>
</tr>
<tr>
<td>↓</td>
<td>0.5</td>
</tr>
<tr>
<td>↑</td>
<td>0.154</td>
</tr>
<tr>
<td>↓</td>
<td>338.7</td>
</tr>
<tr>
<td>↑</td>
<td>287.7</td>
</tr>
<tr>
<td>Lindzen et al.</td>
<td></td>
</tr>
</tbody>
</table>
3. 3.5-box Model Calculation

\[ A_{\text{clrm}} SW_{\text{clrm}} \downarrow + A_{\text{cldm}} SW_{\text{cldm}} \downarrow + A_d SW_d \downarrow + A_{\text{et}} SW_{\text{et}} \downarrow = Q_0(1 - \alpha_0) = \]

\[ \sigma(A_{\text{clrm}} T^4_{\text{eclrm}} + A_{\text{cldm}} T^4_{\text{ecldm}} + A_d T^4_{\text{ed}} + A_{\text{et}} T^4_{\text{eet}}) \]  \(1\)

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

clr → clear; cld → cloudy; m → moist; d → dry;
  t → tropical; et → extratropical; e → emission;
3.5-box greenhouse model (cont.)

\[ A_{\text{cldm}} = A^\circ_{\text{cldm}} (1 + \mu); \]
\[ A_{\text{cm}} = A^\circ_{\text{cm}} (1 + \gamma \mu); \]
\[ A_{\text{clrm}} = A_{\text{cm}} - A_{\text{cldm}} ; \quad A_d = A_t - A_{\text{cm}} ; \]

\( \gamma = 0 \) 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 $\downarrow = SW\downarrow - LW\uparrow$

$C = CC^o + \Delta CC$ and $Ts = T^o_s$ $\Delta CC =$ change in anvil amount

anvil clouds $\downarrow \rightarrow$ global albedo $\downarrow$ & $SW\downarrow$

Lindzen et al.: $LW\uparrow$ $\rightarrow$ the net $\downarrow$ radiation $\downarrow$

CERES: NOT seen!
Simulated cloud feedback

CERES

Lindzen et al.

CERES
4. Perturbation Analysis

\[ A_{\text{clrm}} SW_{\text{clrm}} \downarrow + A_{\text{cldm}} SW_{\text{cldm}} \downarrow + A_d SW_d \downarrow + A_{et} SW_{et} \downarrow = Q_0 (1 - \alpha_0) = \sigma (A_{\text{clrm}} T^4_{\text{eclrm}} + A_{\text{cldm}} T^4_{\text{ecldm}} + A_d T^4_{\text{ed}} + A_{et} T^4_{\text{eet}}) \quad \ldots \quad (1) \]

\[ \Delta A_{\text{clrm}} SW_{\text{clrm}} \downarrow + \Delta A_{\text{cldm}} SW_{\text{cldm}} \downarrow + \Delta A_d SW_d \downarrow = -Q_0 \Delta \alpha_0 = \sigma (\Delta A_{\text{clrm}} T^4_{\text{eclrm}} + \Delta A_{\text{cldm}} T^4_{\text{ecldm}} + \Delta A_d T^4_{\text{ed}}) + 4\sigma (A_{\text{clrm}} T^3_{\text{eclrm}} + A_{\text{cldm}} T^3_{\text{ecldm}} + A_d T^3_{\text{ed}} + A_{et} T^3_{\text{eet}}) \Delta T_s \ldots \quad (2) \]

\[ A_{\text{clrm}} + A_{\text{cldm}} + A_d = A_t; \quad \Delta A_{\text{clrm}} + \Delta A_{\text{cldm}} + \Delta A_d = 0 \quad \ldots \quad (3) \]

\[ 4\sigma (A_{\text{clrm}} T^3_{\text{eclrm}} + A_{\text{cldm}} T^3_{\text{ecldm}} + A_d T^3_{\text{ed}} + A_{et} T^3_{\text{eet}}) \Delta T_s = \Delta A_{\text{clrm}} ((SW_{\text{clrm}} \downarrow - LW_{\text{clrm}} \uparrow) - (SW_d \downarrow - LW_d \uparrow)) + \]

\[ \Delta A_{\text{cldm}} ((SW_{\text{cldm}} \downarrow - LW_{\text{cldm}} \uparrow) - (SW_d \downarrow - LW_d \uparrow)) \quad \ldots \quad (4) \]
4. Perturbation Analysis (cont.)

<table>
<thead>
<tr>
<th></th>
<th>LaRC — CERES</th>
<th>Lindzen et al.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Clear Moist</td>
</tr>
<tr>
<td>Freq</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Moist</td>
<td>0.154</td>
<td>0.258</td>
</tr>
<tr>
<td>Net</td>
<td>338.7</td>
<td>297.1</td>
</tr>
<tr>
<td>Cloudy Mois</td>
<td>287.7</td>
<td>253.9</td>
</tr>
<tr>
<td>Radiation</td>
<td>51.0</td>
<td>43.2</td>
</tr>
<tr>
<td>Net versus net</td>
<td>-7.8</td>
<td>-9.6</td>
</tr>
<tr>
<td>Cloudy moist vs. moist</td>
<td>-1.8</td>
<td></td>
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<tr>
<td></td>
<td></td>
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</tbody>
</table>
4. Perturbation Analysis (cont.)

CERES: \[ 3.707 \Delta T_s = -7.8 \Delta A_{clrm} - 9.6 \Delta A_{cldm} \quad \text{....} \quad (5-1) \]

Lindzen et al. \[ 3.703 \Delta T_s = 40.0 \Delta A_{clrm} + 110 \Delta A_{cldm} \quad \text{....} \quad (5-2) \]

1). \( A_d = \text{Const} (\gamma = 0) \rightarrow \text{no dry region terms in Eq. 4.} \)
   And \( \Delta A_{clrm} = -\Delta A_{cldm} \)
   CERES only \(-1.8 \Delta A_{cldm} \), \hspace{1cm} Lindzen et al. \( 70.1 \Delta A_{cldm} \)
   \( \Delta T_s = 0.01K \) \hspace{1cm} \( \Delta T_s = -0.46K \)

2) \( A_{cm} \) increasing rate = \( \Delta A_{cldm} \) increasing rate \( (\gamma = 1) \)
   \( \rightarrow \) the same \( A_{clrm} \) increasing rate \( \rightarrow \) much stronger feedback
   \( \Delta T_s = 0.12K \) \hspace{1cm} \( \Delta T_s = -1.05K \)

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} ≥ 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 = 92 W/m^2 (cooling)
**SW & LW consistency (cont.)**

<table>
<thead>
<tr>
<th>$\tau$</th>
<th>freq</th>
<th>albedo</th>
<th>LW↓</th>
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<tbody>
<tr>
<td>1</td>
<td>0.15</td>
<td>0.261</td>
<td>207.4</td>
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<tr>
<td>2</td>
<td>0.15</td>
<td>0.356</td>
<td>173.8</td>
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<tr>
<td>4</td>
<td>0.15</td>
<td>0.448</td>
<td>148.8</td>
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<tr>
<td>8</td>
<td>0.15</td>
<td>0.549</td>
<td>139.8</td>
</tr>
<tr>
<td>20</td>
<td>0.2</td>
<td>0.666</td>
<td>138.1</td>
</tr>
<tr>
<td>32</td>
<td>0.2</td>
<td>0.711</td>
<td>137.9</td>
</tr>
<tr>
<td>Avg:</td>
<td>12.65</td>
<td>0.5175</td>
<td>155.67</td>
</tr>
</tbody>
</table>

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/m², except SW↓ in cloudy moist area where the value is much larger (~64 W/m²). 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.