Cloud Systems: Models Vs CERES Cloud/Flux Data

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Part 1. Subgrid Characteristics of Cloud Systems from CERES Data
Part 2. Simulation of Cloud Systems Driven by ECMWF Data
Motivation

1. Importance of radiative feedback of clouds in the climate system
2. Uncertainties in modeling cloud-radiation interactions in global climate models (GCMs)
3. Nonlinearity of cloud processes requiring observations on all relevant modeling scales (in space and in time)
4. Inadequate methods of cloud model evaluation
Approach

- Analyze the statistics of subgrid characteristics of cloud systems, not just the mean
- Match the CERES SSF (Single Scanner Footprint ...) cloud and radiative data with ECMWF meteorological data (T, q, u, v and advective tendencies)
- Perform cloud model simulations driven by ECMWF soundings and advective tendencies
- Also evaluate the ECMWF parameterizations using their predicted cloud fields
Satellite data analysis method

- Define a cloud system as a contiguous region of the Earth with a single dominant cloud type (e.g. stratocumulus, stratus, and deep convection)

- Determine the shapes and sizes of the cloud systems by the satellite data and by the cloud property selection criteria (Wielicki and Welch 1986)
Cloud system selection criteria

- **Tropical deep convection**
  - $Z > 10 \text{ km}$, $\tau > 10$, $25^\circ \text{S} \sim 25^\circ \text{N}$, overcast pixels

- **Trade/shallow cumulus**
  - $Z < 3 \text{ km}$, cloud cover: 0.1 – 0.4, $40^\circ \text{S} \sim 40^\circ \text{N}$

- **Transition stratocumulus**
  - $Z < 3 \text{ km}$, cloud cover: 0.4 – 0.99, $40^\circ \text{S} \sim 40^\circ \text{N}$

- **Solid Stratocumulus**
  - $Z < 3 \text{ km}$, cloud cover: 0.99 – 1.0, $40^\circ \text{S} \sim 40^\circ \text{N}$
Satellite data analyzed

- March 1998 and March 2000 CERES/TRMM data (> 190 GB per month)
- Parameters analyzed from CERES SSF data product: TOA SW, TOA albedo, OLR, emissivity, cloud optical depth, IWP, ice particle diameter, LWP, water droplet radius, cloud amount, cloud top pressure, cloud top temperature, and cloud top height
- Probability Density Function (PDF), Mean, Sigma, Skewness, Medium, Max, Min, and Sample Number.
Boundary layer cumulus (BLC)

Number of boundary layer cumulus identified from satellite data over the SE Pacific Region:

<table>
<thead>
<tr>
<th>Boundary Layer Cumulus Type</th>
<th>March 1998 (Strong El Nino)</th>
<th>March 2000 (Weak La Nina)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Cumulus</td>
<td>262</td>
<td>509</td>
</tr>
<tr>
<td>Transition StratoCumulus</td>
<td>1,902</td>
<td>1,932</td>
</tr>
<tr>
<td>Solid StratoCumulus</td>
<td>989</td>
<td>892</td>
</tr>
<tr>
<td>Total</td>
<td>3,153</td>
<td>3,333</td>
</tr>
</tbody>
</table>
Subgrid characteristics of BLC
PDF of OLR and Cloud Top Temperature

March 2000

TOA Outgoing LW Radiation

Cloud Top Temperature

March 2000

Probability Density

Probability Density

2000 SE PAC
0.99 - 1.0
0.4 - 0.99
0.1 - 0.4

OLR (W m$^{-2}$)

Temperature (K)
Subgrid characteristics of BLC
PDF of OLR and Cloud Top Height

March 2000

TOA Outgoing LW Radiation

Cloud Top Height

Probability Density

OLR (W m\(^{-2}\))

Probability Density

Height (km)

2000 SE PAC
0.99 - 1.0
0.4 - 0.99
0.1 - 0.4

2000 SE PAC
0.99 - 1.0
0.4 - 0.99
0.1 - 0.4
Subgrid characteristics of BLC
PDF of albedo and cloud optical depth

March 2000

TOA Albedo

Cloud Optical Depth

March 2000

<table>
<thead>
<tr>
<th>2000 SE PAC</th>
<th>0.99 – 1.0</th>
<th>0.4 – 0.99</th>
<th>0.1 – 0.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability Density</td>
<td></td>
<td></td>
<td></td>
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<td>Probability Density</td>
<td></td>
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</tbody>
</table>

Albedo

Optical Depth
Subgrid characteristics of BLC
PDF of albedo and cloud liquid water path

March 2000

TOA Albedo

March 2000

Liquid Water Path
Tropical deep convections (TDC)

Number of tropical deep convections over the Pacific Ocean identified from satellite data:

<table>
<thead>
<tr>
<th>Regions</th>
<th>March 1998 (Extreme El Nino)</th>
<th>March 2000 (Weak La Nina)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Pacific</td>
<td>88</td>
<td>70</td>
</tr>
<tr>
<td>Central Pacific</td>
<td>129</td>
<td>110</td>
</tr>
<tr>
<td>Western Pacific</td>
<td>135</td>
<td>195</td>
</tr>
<tr>
<td>Total</td>
<td>352</td>
<td>375</td>
</tr>
</tbody>
</table>
Subgrid characteristics of TDC

PDF of outgoing longwave radiation

March 1998

Outgoing LW Radiation

March 2000

Outgoing LW Radiation

Probability Density

OLR (W m\(^{-2}\))

OLR (W m\(^{-2}\))
Subgrid characteristics of TDC

PDF of cloud top height

March 1998

March 2000
Subgrid characteristics of TDC
PDF of cloud top temperature

March 1998

Cloud Top Temperature

March 2000

Cloud Top Temperature

- Eastern Pac.
- Central Pac.
- Western Pac.
Subgrid characteristics of TDC

PDF of OLR and cloud top height (Size > 300km)
Subgrid characteristics of TDC

PDF of OLR and cloud top temperature (Size>300km)
Subgrid characteristics of TDC

PDF of albedo

March 1998

March 2000

TOA Albedo
Subgrid characteristics of TDC

PDF of albedo and cloud optical depth (Size>300km)

TOA Albedo

<table>
<thead>
<tr>
<th>Probability Density</th>
<th>TOA Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>3.00</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

Albedo

0.3 0.4 0.5 0.6 0.7 0.8 0.9

Entire Pacific
> 300 km
March 1998
March 2000

Cloud Optical Depth

<table>
<thead>
<tr>
<th>Probability Density</th>
<th>Cloud Optical Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.050</td>
<td></td>
</tr>
<tr>
<td>0.040</td>
<td></td>
</tr>
<tr>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

Optical Depth

0 20 40 60 80 100 120

Entire Pacific
> 300 km
March 1998
March 2000
Sensitivity of TDC to SST

Number of tropical deep convections as a function of sea surface temperature over the Pacific Ocean:

<table>
<thead>
<tr>
<th>SST (K)</th>
<th>March 1998 (Extreme El Nino)</th>
<th>March 2000 (Weak La Nina)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300-301</td>
<td>16</td>
<td>46</td>
</tr>
<tr>
<td>301-302</td>
<td>66</td>
<td>88</td>
</tr>
<tr>
<td>302-303</td>
<td>196</td>
<td>163</td>
</tr>
<tr>
<td>&gt; 303</td>
<td>47</td>
<td>26</td>
</tr>
</tbody>
</table>
Sensitivity of TDC to SST

PDF of outgoing longwave radiation

March 1998

Outgoing LW Flux

March 2000

TOA Outgoing LW

<table>
<thead>
<tr>
<th>SST &gt; 303 K</th>
<th>302 - 303 K</th>
<th>301 - 302 K</th>
<th>300 - 301 K</th>
</tr>
</thead>
</table>

OLR (W m$^{-2}$)

Probability Density

OLR (W m$^{-2}$)

Probability Density
Sensitivity of TDC to SST
PDF of cloud top height

March 1998

Cloud Top Height

March 2000

Cloud Top Height

Probability Density

Height (km)
Summary

Observed Cloud Systems from CERES data

- Cloud system/object analysis based on large ensemble of EOS observed cloud systems provides a new and robust way for examining climate and climate feedback processes and improving cloud parameterizations in GCMs.

- BLC: Significant differences in PDF are found between three types of boundary layer cumulus.

- TDC: Differences in cloud height distribution leaded to changes in distribution of OLR between the ENSO year and the La Nina year.

- Climate Sensitivity: OLR and Cloud top height Distribution of TDC are not sensitive to SST change above 301K.
Future plan

- Extending the analysis of satellite data and matched ECMWF meteorological fields over much longer periods
- Analyzing the observed cloud systems and relating them to climate feedback measures; i.e., as a function of sea surface temperature, atmospheric stability, and convective instability, for all major cloud types
- Providing a comprehensive data set, combining CERES and TRMM, as well as CRM results for shallow and deep cloud systems, for validating simulations of GCMs with both conventional and super parameterizations