Intrinsic Uncertainty Associated with Different Ways of Deriving Cloud Radiative Forcing: A Perspective from High-Resolution GCM Simulations

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Outline

• Motivations
  – Different ways of estimating CRF
  – High-resolution GCM simulations

• Methodology

• Results

• Conclusions and Discussions
Motivations (I)

- **Cloud Radiative Forcing (CRF)**
  - Defined as: \( \text{Flux}_{\text{clear-sky}} - \text{Flux}_{\text{all-sky}} \)
    - Clear-sky vs. all-sky: everything is identical except clouds
  - Straightforward to get \( \text{Flux}_{\text{clear-sky}} \) in the models
  - Not easy to get in observations
    - Cloud-cleared radiances: cloud fractions, built-in assumptions, retrieval quality
    - Flux of clear-sky pixel

\[
\text{Flux}_{\text{true clear-sky}} - \text{Flux}_{\text{clear-sky pixel}} = ?
\]
\[ \text{Flux}_\text{true clear-sky} - \text{Flux}_\text{clear-sky pixel} = ? \]

- Deep convective region
  - Drier clear-sky pixels vs. humid cloudy pixels
  - \( \text{OLR}_{\text{true clr-sky}} < \text{OLR}_{\text{clr-sky pixel}} \)

- Always a cold bias? How much?

- **Observation-based bias estimation**
Dry Bias in Satellite-Derived Clear-Sky Water Vapor and Its Contribution to Longwave Cloud Radiative Forcing

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ABSTRACT

In this paper, the amount of satellite-derived longwave cloud radiative forcing (CRF) that is due to an increase in upper-tropospheric water vapor associated with the evolution from clear-sky to the observed all-sky conditions is assessed. This is important because the satellite-derived clear-sky outgoing radiative fluxes needed for the CRF determination are from cloud-free areas away from the cloudy regions in order to avoid cloud contamination of the clear-sky fluxes. However, avoidance of cloud contamination implies a sampling problem as the clear-sky fluxes represent an area drier than the hypothetical clear-sky humidity in cloudy regions. While this issue has been recognized in earlier works this study makes an attempt to quantitatively estimate the bias in the clear-sky longwave CRF. Water vapor amounts in the 200–500-mb layer corresponding to all-sky condition are derived from microwave measurements with the Special Sensor Microwave Temperature-2 Profiler and are used in combination with cloud data for determining the clear-sky water vapor distribution of that layer. The obtained water vapor information is then used to constrain the humidity profiles for calculating clear-sky longwave fluxes at the top of the atmosphere. It is shown that the clear-sky moisture bias in the upper troposphere can be up to 40%–50% drier over convectively active regions. Results indicate that up to 12 W m\(^{-2}\) corresponding to about 15% of the satellite-derived longwave CRF in tropical regions can be attributed to the water vapor changes associated with cloud development.

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Motivations (II): high-resolution GCM runs

• High-resolution: 25-50km
  – Comparable to satellite footprint
  – AMIP type runs are now affordable

• GFDL HiRam model
  – Cubic-sphere dynamic core
  – AM2 physics, but unified convection schemes (one for both shallow and deep convections) and diagnostic cloud fraction for stratiform clouds
  – Forced with observed SST
  – Improved simulation on cloud and UTH climatology
  – Hurricane climatology and interannual variability

• Archive 3-hourly output from the HiRam run (July 1995-June 1996)
  • Sample it in the satellite way
  • $X_{satellite\_sample} - X_{truth}$
OLR (Wm^{-2})

Geostationary Satellite
BT of 11\mu m
Fig. 5. Observed and model simulated seasonal cycle (number of hurricanes per month) for each ocean basin from the four-member ensemble mean (1 = January, 12 = December).
Methodology

• Grid A: 2.5°(lon)×2°(lat) (16 native grid cells)
• Flux_{clr-sky-pixel} = Flux(cells:cld_frac < 1%)
• Flux_{true_clr-sky} as computed from the model
• Estimation of monthly-mean clear-sky flux and CRF
  – ensure equal weighting of phases of diurnal cycle
    • First compute monthly mean of each 3-hourly snapshot
    • Average 8 month-mean snapshots equally to obtain the monthly mean
  – Hereafter, “_{est}” denotes quantities obtained from this approach
    • OLRC_{est} CRF_{est} SWFlx_{est} WVP_{est}
Difference in Total Precipitable Water

(WVP\textsubscript{true} – WVP\textsubscript{est}, Jul95-Jun96)

As expected, clear-sky portion is drier than cloudy portion (except two snow region)
Difference in LW CRF

(LW CRF\textsubscript{true} – LW CRF\textsubscript{est}, Jul95-Jun96)

Global annual mean: -4.12 W m\textsuperscript{-2} (True – Estimation)
Small month-to-month variation < 10%
Scatter plot of $\Delta WVP$ vs. $\Delta OLR_{clr\text{-}sky}$

- $30^\circ S$ to $30^\circ N$
- $>60^\circ N$ or $<60^\circ S$
Composite Analysis (Sub Antarctic region)

- Clear-sky pixels: Less humid but also colder
- Run through MODTRAN
  - OLR 189 Wm\(^{-2}\)
  - OLR 205 Wm\(^{-2}\)
Sensitivity to the size of grid box

-3.8
-4
-4.2
-4.4
-4.6
-4.8
-5
-5.2
2.5 x 2
3.75 x 3
5 x 4
7.5 x 6
11.25 x 9

gridbox size

LW CRF true - LW CRF est

- global mean (90S-90N)
- near global-mean (60S-60N)
Conclusions

• High-resolution GCM runs provide another way to assess the intrinsic bias due to sampling disparity between model and observations

• While clear-sky grid cells are drier than cloudy ones, the temperature difference also needs to be factored in

• In tropics and most parts of mid-latitude, $\Delta T$ is small, so dry bias dominant
  - LW CRF (OLRc) +5-10Wm$^{-2}$ bias

• In sub-polar region, drier and colder in the clear-sky grid cells
  - LW CRF (OLRc) −(5-10) Wm$^{-2}$ bias

• Global mean, estimation would have a ~4Wm$^{-2}$ bias