Cloud Regimes as a Tool for Systematic Study of Various Aerosol-cloud-precipitation Interactions

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Our thinking

- Need to understand effects of aerosols on clouds and precipitation and eventually on Earth’s Radiation Budget
- Problem poses obvious observational challenges
- How to separate aerosol from all other effects?
- Breaking down the analysis by “regime” (group together similar conditions) may help
- But how do we define regimes?
  - Exploiting cloud appearance (from passive obs) is a starting point
  - This poses some constraint on environmental conditions
  - Additional constraints can be imposed
- So we proceed with a “cloud regime” (CR) analysis
  - Our CRs are based on MODIS
  - You may also know ISCCP “Weather States”
The 12 MODIS Collection 6 CRs
Where the CRs occur
The full picture
Cloud optical thickness

Cloud fraction (%)
Dataset and methodology

• 12 years of Aqua-Terra L-3 daily (D3) 1° data
  – Collection 6
• Joint histograms of CTP-TAU
• MODIS CRs from $k$-means clustering of CTP-TAU joints
• Aerosol Optical Depth (AOD)
  – We calculate seasonal AOD distributions and perform compositing at the vigintile level (20-bin distribution) of cloud properties and precipitation for each CR separately (Terra CR=Aqua CR)
  – We often focus on the upper (3Q, “high” aerosol) and lower (1Q, “low” aerosol) quartile and perform statistical significance test
  – Two ways to build AOD seasonal distributions: (1) for each gridcell (stronger constraint); (2) for each CR (weaker constraint)
• Precipitation data: GPCP-1DD
• Land/ocean separation illuminating
Sampling issues
(how to build AOD distributions)
1) \( \text{AOD} = \frac{(\text{Aqua AOD} + \text{Terra AOD})}{2} \).

2) \( \text{AOD} = \text{Aqua AOD} \quad \text{OR} \quad \text{AOD} = \text{Terra AOD} \).

3) \( \text{AOD} = \frac{(\text{Aqua AOD}_1 + \text{Aqua AOD}_2 + \text{Terra AOD}_1)}{3} \).
Comparison of two AOD sampling options (CR3)

AOD distribution defined PER CR

AOD distribution defined PER GRIDCELL

1Q AOD

1Q AOD
Precipitation
Precipitation comparison (RR>0) two sampling methods

3Q/1Q AOD defined by per CR per Season

3Q/1Q AOD defined by per Grid per Season
Precipitation (RR>0) comparison (Land-Ocean)
Precipitation (RR>0) vs AOD percentile
Cloud Properties
Cloud fraction

Red=meets expectations

Global

Ocean

Land
Cloud Top Pressure

(Gryspeerdt et al. 2014)
Cloud optical thickness

Red=meets expectations

Global

Ocean

Land
Cloud effective radius

Blue=meets expectations
Summary and parting thoughts

• We propose that Aerosol-Cloud-Precipitation relationships be examined on a “cloud regime” basis
  o This helps us examine aerosol influence under more “similar” conditions

• Even then, the outcomes depend on how one samples AOD distributions (weaker or stronger constraints on meteorology)

• Most times, cloud property and precipitation differences between low and high aerosol loadings are small (albeit statistically significant)
  o But not always consistent with expectations (optical thickness, low cloud precip)
  o Enhancement of precipitation for most CRs for large AOD

• Important: our analysis cannot distinguish how AOD retrievals biases vary due to cloud presence within or across CRs

• Also working with TMPA precip (forthcoming) hoping to resolve more details (e.g. morning/afternoon contrasts)
Additional Slides
CR thermodynamic phase

Cloud fraction (%)

Liquid cloud fraction
Ice cloud fraction
Total cloud fraction

CR thermodynamic phase
CR cloud type breakdown per CloudSat

Percentage (%)

- Cb
- Ci
- As
- Ac
- Ns
- St
- Sc
- Cu

CR cloud types:

- CR1
- CR2
- CR3
- CR4
- CR5
- CR6
- CR7
- CR8
- CR9
- CR10
- CR11
- CR12
- C3M
Note that the Y-axis scale is not linear and different for CR2.
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MODIS Cloud Regime RFO (%)

CR1 3%
CR2 3%
CR3 5%
CR4 4%
CR5 4%
CR6 7%
CR7 2%
CR8 5%
CR9 8%
CR10 7%
CR11 10%
CR12 42%

CR12
CR11
CR10
CR9
CR8
CR7
CR6
CR5
CR4
CR3
CR2
CR1

OCEAN
LAND

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
 Scatter plot comparing Latitudinally-weighted mean precipitation rate (*including zero* precipitation) for upper 3q AOD and lower 1q AOD. The horizontal and vertical error bars indicate one fifth of the interquartile range of the distributions used to calculate the composite means; distance from median to 25% percentile is represented by the error bars below and to the left of the symbol while that to the 75% percentile by the error bar above and to the right. All the values are statistically significant with 95% confidence except CR2 (LAND).

( MYD CR = MOD CR ) + daily grid new AOD + daily mean GPCP
Assigned 3Q AOD

MAM

JJA

SON

DJF
Assigned 1Q AOD

MAM

JJA

SON

DJF
Latitudinally-weighted Mean values of AOD assigned to 3q and 1q (per season per grid, what we used GPCP analysis) for each CR.

Red line : 3Q
Blue line : 1Q
Diamond : mean of AOD.