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
CRs and large-scale vertical motion

Cloud optical thickness

Cloud fraction (

\( \text{Pa/s} \)

Omega
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) \[ \text{AOD} = \frac{(\text{Aqua}_{-1} \text{AOD} + \text{Aqua}_{-2} \text{AOD} + \text{Terra}_{-1} \text{AOD})}{3}. \]
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

AOD distribution (%)

GPCP Precipitation (mm/day)

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

Red = meets expectations

Global

Ocean

Land
Cloud Top Pressure

(Gyspeerd et al. 2014)
Cloud optical thickness

Red=meets expectations

Global

Ocean

Land

Red=meets expectations
Cloud effective radius

Blue=meets expectations
Summary and parting thoughts

- We propose that Aerosol-Cloud-Precipitation relationships be examined on a “cloud regime” basis
  - 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)
  - But not always consistent with expectations (optical thickness, low cloud precip)
  - 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

Note that the Y-axis scale is not linear and different for CR2.
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<table>
<thead>
<tr>
<th>Cloud Regime (MODIS)</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR1</td>
<td>3</td>
</tr>
<tr>
<td>CR2</td>
<td>3</td>
</tr>
<tr>
<td>CR3</td>
<td>5</td>
</tr>
<tr>
<td>CR4</td>
<td>4</td>
</tr>
<tr>
<td>CR5</td>
<td>4</td>
</tr>
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<td>CR6</td>
<td>7</td>
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<td>CR7</td>
<td>2</td>
</tr>
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<td>CR8</td>
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<td>CR9</td>
<td>8</td>
</tr>
<tr>
<td>CR10</td>
<td>7</td>
</tr>
<tr>
<td>CR11</td>
<td>10</td>
</tr>
<tr>
<td>CR12</td>
<td>42</td>
</tr>
</tbody>
</table>

The pie chart on the left represents the MODIS Cloud Regime RFO (%). CR12 has the highest frequency at 42%, followed by CR11 at 10% and CR1 at 7%. The bar chart on the right visually compares the frequency of different cloud regimes, with CR12 being the most common and CR1 being the least common.
GPCP daily mean Precipitation ($P>=0$)

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
Assigned 1Q AOD
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.