Employing daily gridded MODIS data to study the impact of morning aerosol to afternoon clouds, precipitation and radiation

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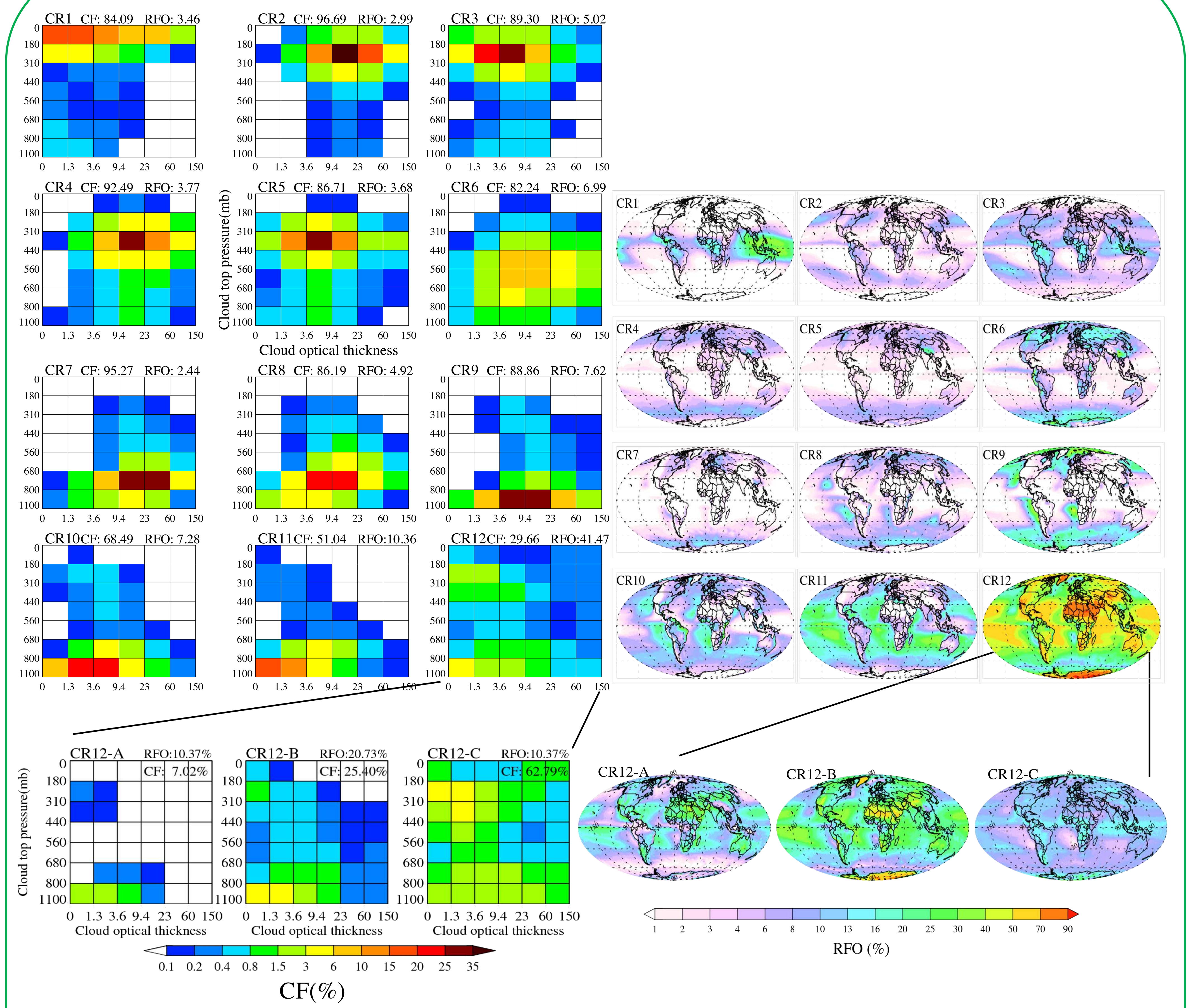
What the work is about

We provide a ***near-global*** picture of Aerosol-Cloud-Precipitation-Radiation interactions (ACPRI) apparent signals by employing MODIS Cloud Regimes (CRs) and Cloud Properties. We assess whether ACPRI can be diagnosed by investigating the variation with AM/morning (MODIS or MERRA-2) AOD of PM/afternoon cloud-affected quantities; the results are segregated by AM (Terra) CR.

Papers for Background

- Oreopoulos, L., N. Cho, D. Lee, and S. Kato (2016), Radiative effects of global MODIS cloud regimes, J. Geophys. Res. Atmos., 121, 2299–2317, doi:10.1002/2015JD024502.
- Oreopoulos, L., N. Cho, and D. Lee (2017), Using MODIS cloud regimes to sort diagnostic signals of aerosol-cloud-precipitation interactions, J. Geophys. Res. Atmos., 122, 5416–5440, doi:10.1002/2016JD026120.

MODIS Cloud Regimes

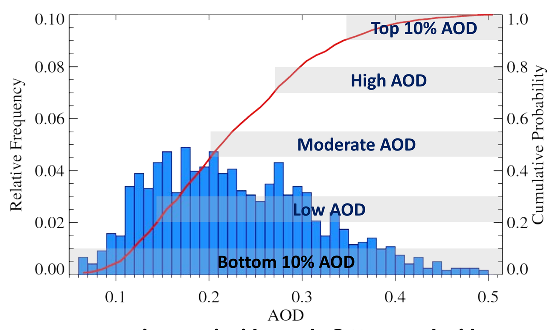


Left : Centroids (mean histograms) of the 12 cloud regimes (CRs) derived from clustering analysis on 12 years of MODIS C6 Aqua-Terra CTP-COT daily joint histograms at a resolution of 1°. CR12 was split further into three "sub-regimes".
Right : The geographical multiannual mean Relative Frequency of Occurrence (RFO) of each of the 12 MODIS C6 CRs and the three CR12 subregimes.
Reference : *Oreopoulos et al., (2016)*

Data sets and Analysis methodology

Cloud Regimes (CRs) : MODIS Level-3 ensemble set of Terra and Aqua joint CTP-COT daily histograms from December 2002 to November 2014.
Cloud properties : MODIS C6 Level-3 from Aqua (MYD08) data sets.
Radiation : CERES SYN1deg-3Hour data sets
Aerosol Optical Depth (AOD) : AM 1° AOD from MODIS-Terra (Dark Target) or regridded MERRA-2 for Terra overpass
Precipitation : TRMM Multi satellite Precipitation Analysis (TMPA-3B42) corresponding to Aqua (PM) overpasses.

How were relative High and Low AODs defined?



To create relative AOD variations, we construct multiannual ***seasonal*** histograms of MERRA2 morning AOD for ***each grid cell***.

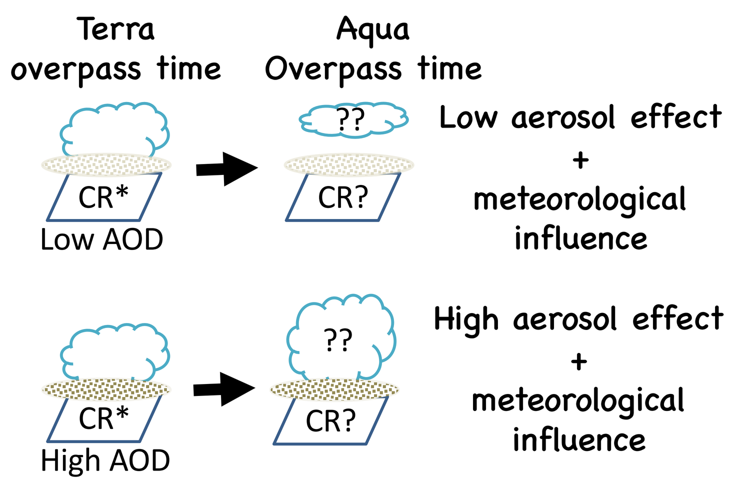
How were Cloud-affected quantity sensitivities to AOD calculated?

Following the method of Quaas et al., 2008, The sensitivity ($S_\emptyset$) of a cloud-affected quantity ($\emptyset$) to AOD (A) is defined here as

$$S_\emptyset = \frac{dln\emptyset}{dlnA}$$

The methodology entails calculating the linear regression slope of a scatter plot of $ln\emptyset$ $vs.$ lnA. Each point in the scatterplot represents a grid cell, and regressions are performed separately for each AM CR.

Links between AM Aerosol and PM cloud-affected quantities



Summary

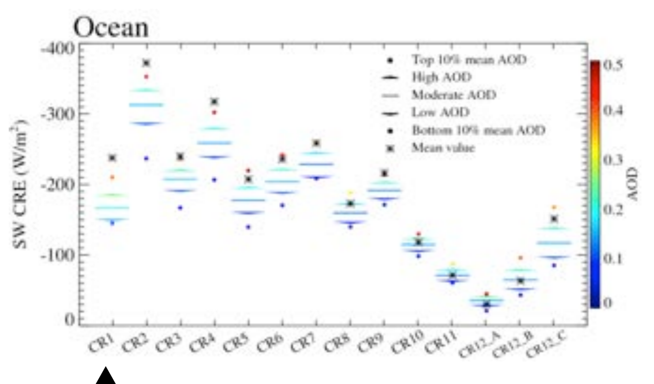
- This work extends *Oreopoulos et al., 2017*, by accounting for the temporal lag between AM aerosol and PM cloud-relevant observations and by exploring the spatial variability of sensitivities to AOD changes .
- Caveats:
  - (a) AOD-based analysis, while CCN(z) or IN(z) are more relavant
  - (b) AOD biases in the neighborhood of clouds
  - (c) Meteorology not stronglyconstrained even when breaking by CR.

PM cloud-affected quantities vs AM *relative* AOD

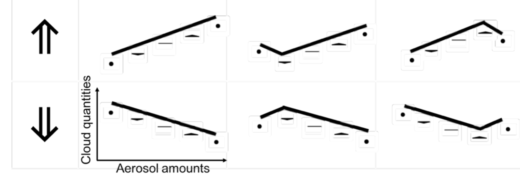
Ocean

	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10	CR11	CR12-A	CR12-B	CR12-C
Prec. > 0	⇑	⇑	⇑	–	–	⇑	–	–	⇑	⇑	⇑	⇑	⇑	⇑
Prec. ≥ 0	⇑	⇑	⇑	⇑	–	⇑	–	⇑	⇑	⇑	⇑	⇑	⇑	⇑
POP	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	–	⇑	⇑
CTH	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑
CF_TOT	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑
COT_TOT	–	⇑	–	–	–	–	–	–	⇑	⇑	⇑	⇑	–	–
CER_ICE	⇑	⇑	⇑	⇑	⇑							⇑	⇑	⇑
CER_LIQ				⇓	⇓	⇓	⇓	⇓	⇓	⇓	–	–	–	–
LWP						⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑
SW CRE	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑
Normalized SW CRE	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑
LW CRE	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑	⇑

- Ice regime : CR1 – CR3, Liquid regime : CR6 – CR11, Mixed regime : CR4 – CR5
- Red arrow: consistent with invigoration; Blue arrow: consistent with 1st and 2nd indirect effect



What does the arrow mean?



- PM cloud-affected quantities composited by relative AM AODs and CRs. Over Ocean only, AM AOD from Terra DT.
- Significance test: 95% confidence interval ($\bar{x} \pm Standard\ error \times 1.96$)

* *SW CRE is scaled to diurnal values by normalizing with diurnally averaged incoming solar flux at the TOA for that location and day of the year.*
* *POP : Probability Of Precipitation.*

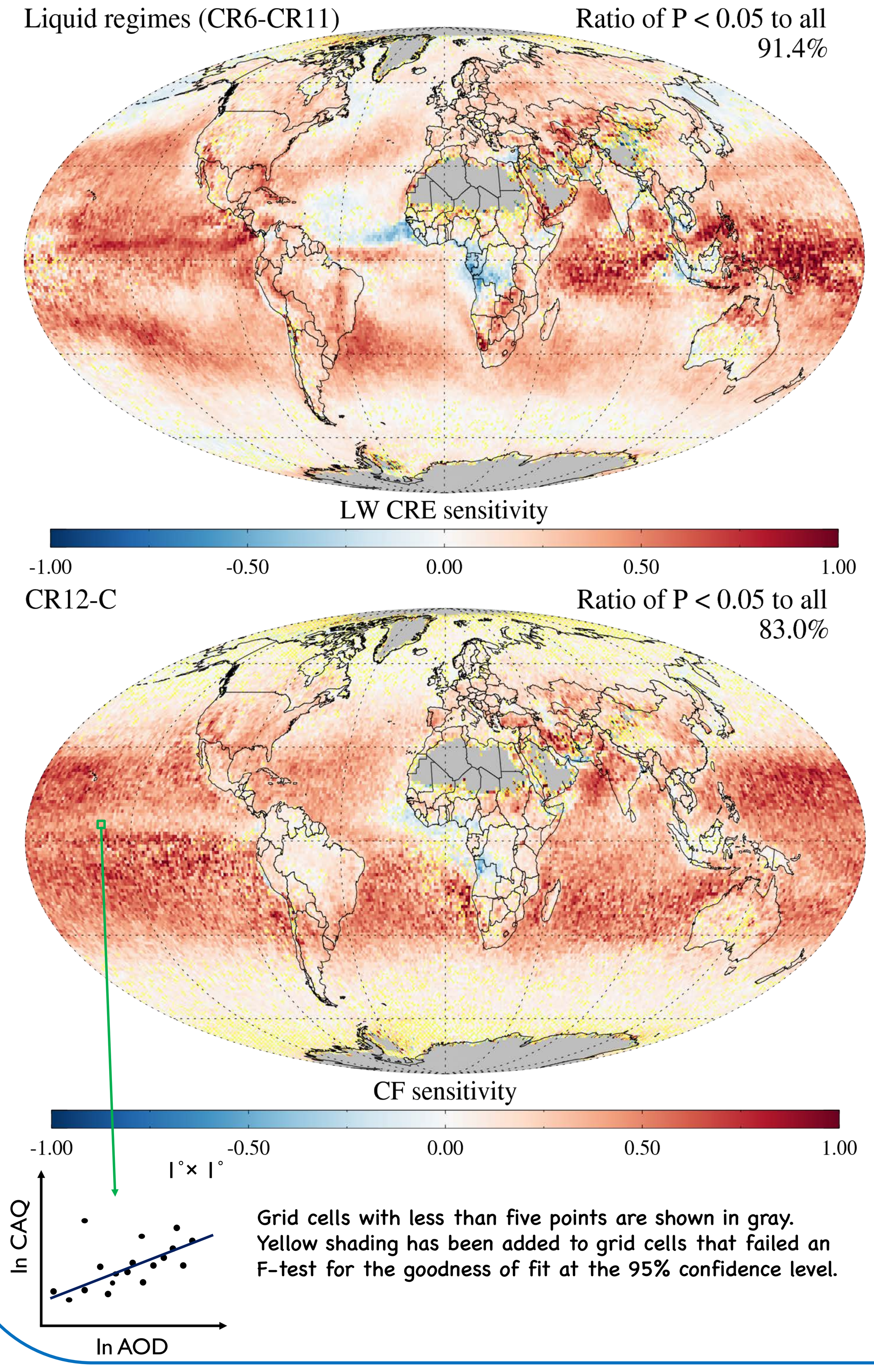
Sensitivity of PM cloud-affected quantities to AM aerosol

Table 2. Classical Paradigms of Aerosol-Cloud-Precipitation Interaction and Expected Changes in Cloud-Affected Quantities[a]

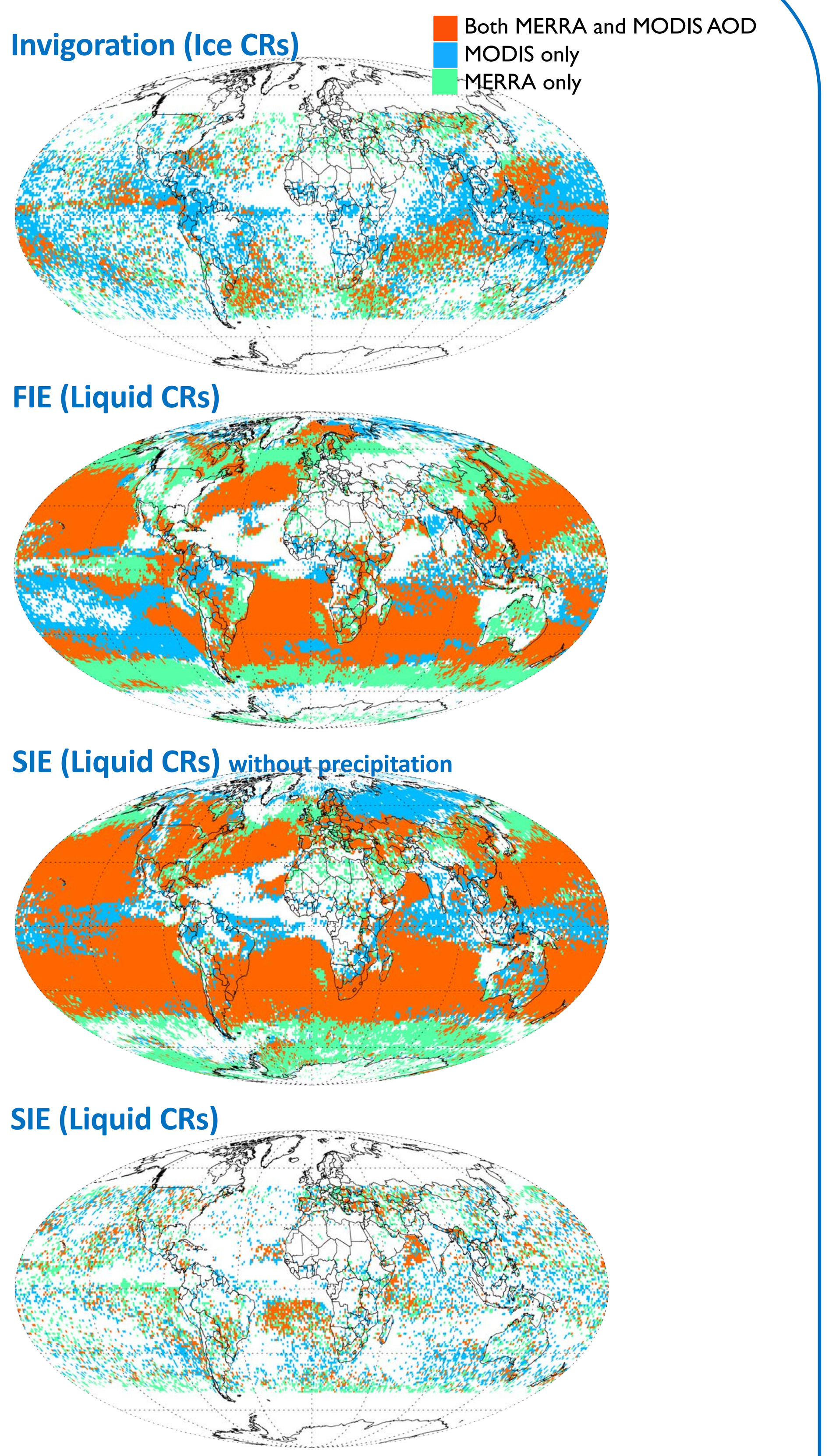
Oreopoulos et al., 2017

Invigoration (Ice and Mixed CRs)	FIE (Liquid CRs)	SIE (Liquid CRs)
• Precipitation increase • CF increase • CTP decrease (CTH increase) • COT increase • SW/LW CRE increase	• CER decrease[b] • COT increase • SW CRE increase	• Precipitation decrease • COT increase • CF increase • SW/LW CRE increase

[a]We do not consider liquid water path (increase) as a criterion for SIE occurrence because it is not retrieved independently from MODIS. The direction of expected changes is the criterion used for coloring the arrows of Table 3.
[b]Also for ice clouds.



Grid cells with less than five points are shown in gray. Yellow shading has been added to grid cells that failed an F-test for the goodness of fit at the 95% confidence level.



Left : Two examples of sensitivity maps of PM cloud affected quantities to AM AOD changes.
Right : Maps showing the grid cells where classical paradigms of ACPRI appear to hold for either one or both of MODIS/MERRA-2 AODs.