Aerosol Environment of Tropical MCSs Using CALIPSO Observations

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Abstract

Aerosol-cloud interactions have been difficult to quantify using satellite data due to artifacts and cloud contamination of the aerosol observations. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite provides high resolution profiles of cloud and aerosol layers By carefully selecting CALIPSO profiles unlikely to be contaminated by clouds, it is possible to examine the large-scale aerosol environments of tropical mesoscale convective systems (MCSs) identified by other satellites in NASA's afternoon (A-Train) constellation.

Over the Arabian Sea and the Bay of Bengal, and to a lesser degree over India itself, MCSs are most frequently observed when aerosol optical depths are lower than their climatological monthly-means and when fewer dust layers are detected. This observation is consistent with the prevalence of MCSs during active monsoon periods, when the monsoon flow advects cleaner oceanic air into the region. In contrast, MCSs over Africa and the western and eastern Pacific intertropical convergence zone (ITCZ) are associated with slightly elevated aerosol concentrations.

Identifying MCSs in A-Train Data

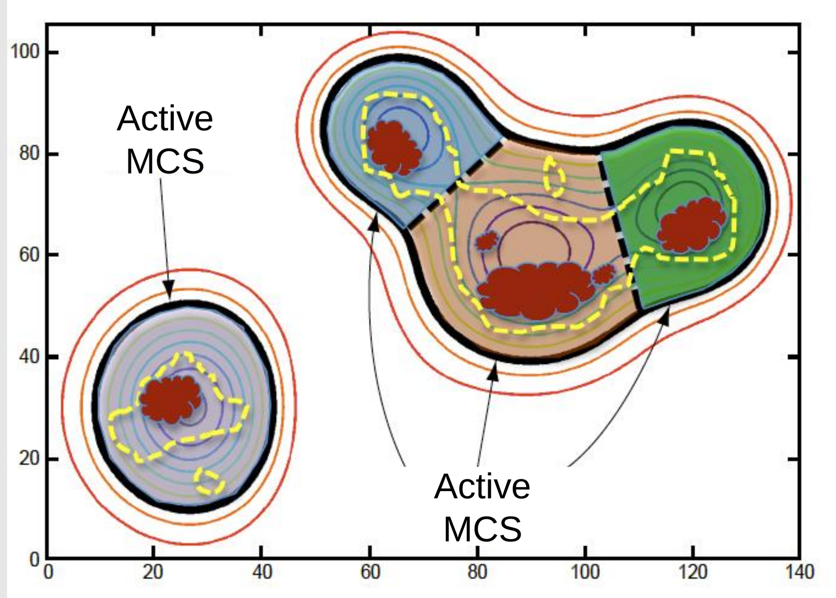


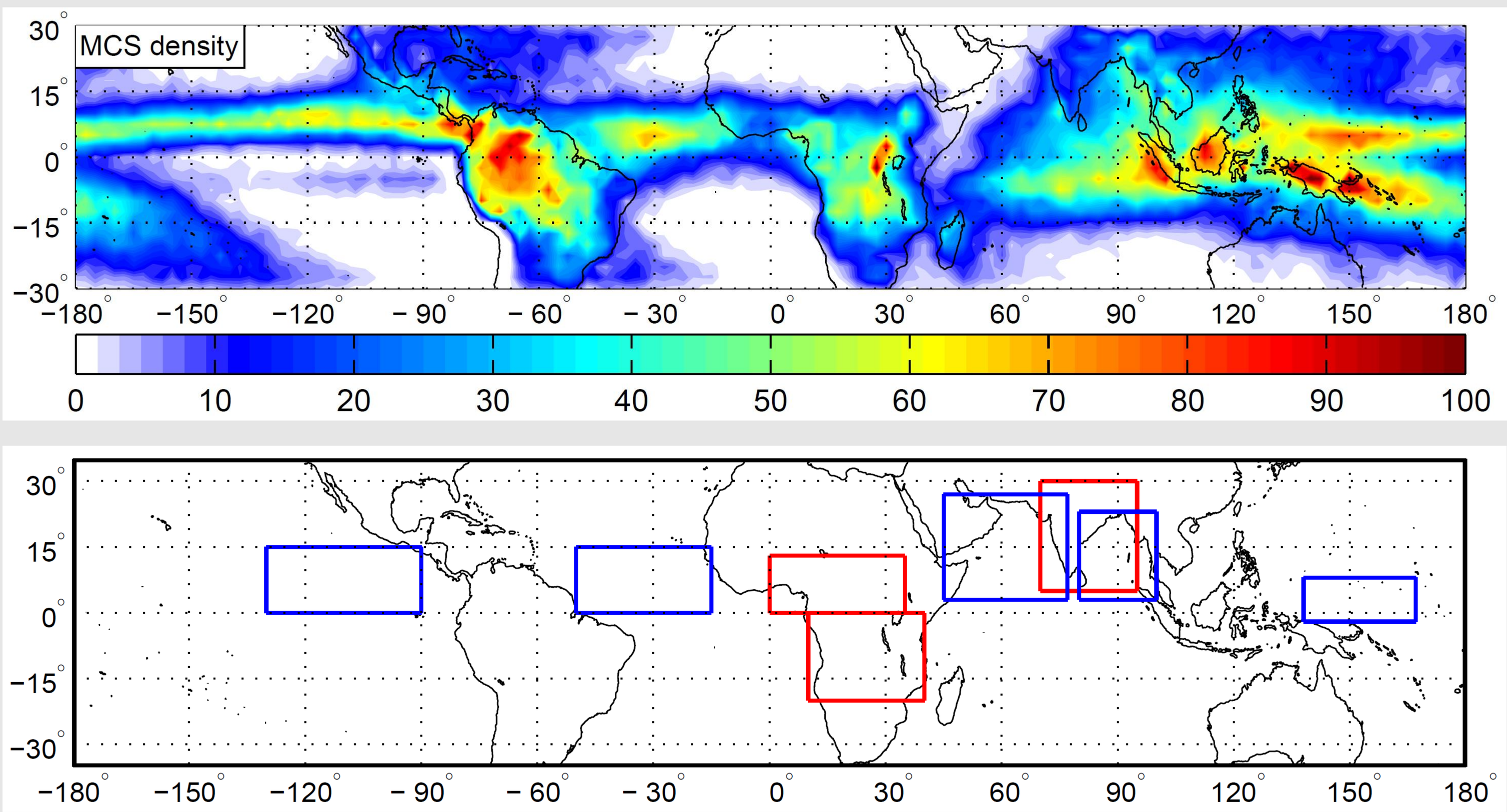
Fig. 1 Idealized MCSs. Solid contours are TB_{11} isotherms, with 260 K indicated by thick black lines. Blue, brown, green, and gray shading indicate active MCSs. Gold dashed contours enclose areas with rain rates > 1 mm h^{-1}. Dark red patches indicate rain rates > 6 mm h^{-1}.

MCS identification technique developed by Yuan and Houze (2010)

- High, cold cloud tops: 10.5 µm brightness temperature from Moderate Resolution Imaging Spectroradiometer (MODIS)
- Precipitation: rain rates from Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E)
- Identify collocated areas of high cloud and heavy precipitation
- Additional size and intensity criteria to ensure the feature qualifies as an MCS

Applied to four years of data (2007-2010)

Fig. 2, right Top: Number of MCSs observed per 2.5° x 2.5° grid box per year. Bottom: Regions selected for compositing. Composites include only MCSs centered over land (red regions) or ocean (blue regions).



CALIPSO Aerosol Observations

Instrument Background

- Two-wavelength polarization lidar
- Can detect cloud and aerosol layers with optical depths of 0.01 or less
- Along-track resolution: 5 km; observes curtain of data, not swath
- Data analyzed: column aerosol optical depth (AOD) at 532 nm

Cloud-Aerosol Discrimination (CAD) algorithm (Liu et al. 2009)

- Applied to each detected scattering feature
- Compares layer attenuated backscatter and color ratio to distributions expected of cloud and aerosol layers
- Classifies layer as cloud or aerosol (positive or negative CAD score, respectively) and gives degree of confidence (-100 to 100, where 0 indicates layer is equally likely to be cloud or aerosol)

For this analysis, discard any profile containing a cloud or an aerosol layer with CAD score > -70 (Yang et al. 2012)

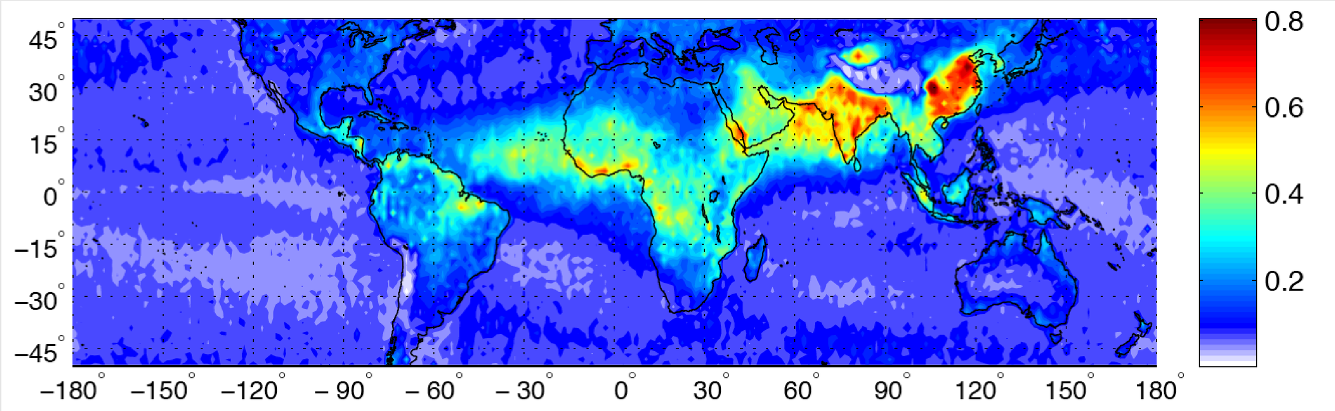


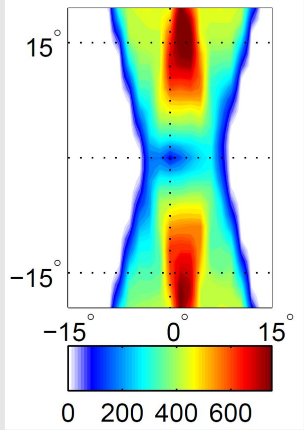
Fig. 3 Annual-mean CALIPSO column AOD at 532 nm.

Classification of aerosol types (Omar et al. 2009)

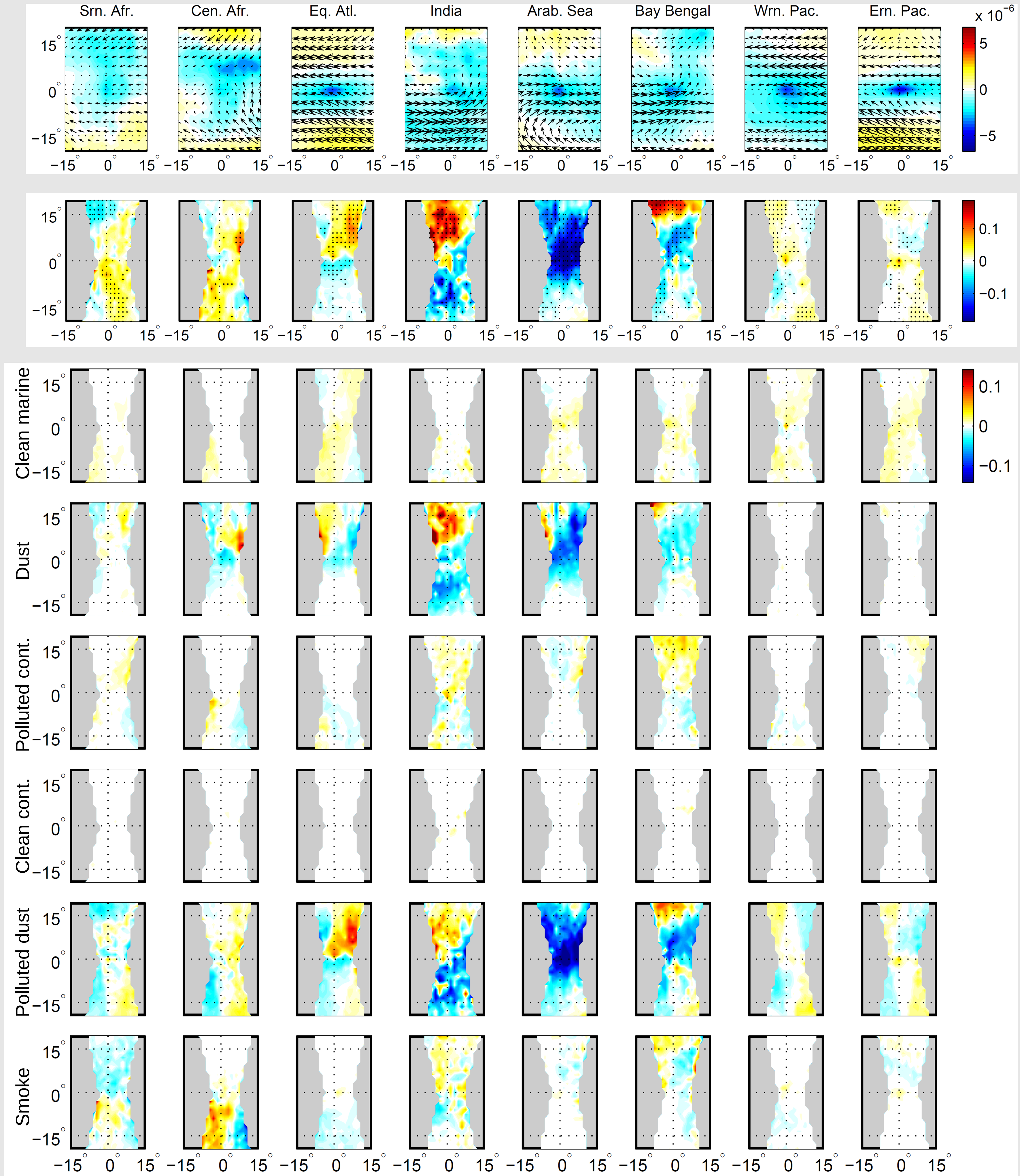
- Based on layer volume depolarization ratio, integrated attenuated backscatter, elevation, and surface type (land/ocean/ice/desert)
- Types: clean marine, dust, polluted continental, clean continental, polluted dust (dust mixed with biomass burning smoke), and smoke

MCS-relative coordinates

- For each MCS, create coordinate system with center of MCS at (0°, 0°) relative latitude and longitude
- Re-grid CALIPSO observations in MCS-relative coordinates
- Composites for MCSs in selected regions
- Mean number of CALIPSO AOD observations per region (**Fig. 3,** right) has relative minimum in center because cloudy profiles have been discarded



Results: Composites of AOD in MCS-Relative Coordinates



Southern and central Africa

- MCSs associated with anomalously large AOD, particularly in dust and smoke layers
- AOD anomalies removed from center of MCS; generally weak winds

Equatorial Atlantic

- Anomalously large AOD north of MCS due to Saharan dust and polluted dust layers
- Wind shift at latitude of MCS, with cleaner air to south

India, the Arabian Sea, and the Bay of Bengal

- Fewer dust and polluted dust layers, with lower AODs, when MCSs are present
- Over India, anomalously high AOD north of the MCS, but advection is from the west
- MCSs primarily observed during active monsoon season (JJAS), when southerly and westerly flow brings cleaner, moist air

Western and eastern equatorial Pacific

- Weakly elevated AOD associated with MCSs, with patches of anomalously low AOD
- MCSs associated with weaker winds and fewer clean marine layers

Day vs. night (not shown)

- AOD anomalies generally larger in magnitude at night, when lidar measurements are less noisy due to the lack of solar radiation

Outstanding question

- Can the influence of the aerosol environment be disentangled from the influence of the background environment? Previous studies using satellite aerosol observations have struggled with this (e.g., Wall et al. 2014).

Fig. 5, left Composites of AOD and environmental variables in MCS-relative coordinates for the regions shown in Fig. 2. Top: ERA-Interim 850-hPa winds (vectors) and divergence (colors). Middle: CALIPSO AOD anomalies, with black dots indicating grid points significant at the 95% level. Bottom: CALIPSO AOD anomalies, separated by aerosol type. Anomalies are calculated based on climatological monthly-mean values.

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