A Multi-satellite Analysis of Absorbing Aerosols Above Clouds

Ian Chang and Sundar A. Christopher

Department of Atmospheric Science, The University of Alabama in Huntsville

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Background and Motivation

- Quantifying absorbing aerosol within and above clouds, including optical properties, radiative effects, and heating rates remains to be a challenge.
- Multi-sensor analysis and radiative transfer models provide extensive scope on the study of aerosols above clouds since each tool has unique characteristics.
- Geostationary satellite enable the assessment of the diurnal variation of aerosols above clouds, which a key missing aspect of investigation.
- The Visible Infrared Imaging Radiometer Suite (VIIRS), a successor to MODIS, will be a crucial sensor for future multispectral analysis.

Data and Methods

- Data fusion of MODIS, VIIRS, OMI and SEVIRI.
- To isolate homogenous region, a heterogeneity metric (σ/μ) is applied to a group of 5 × 5 pixels for MODIS and VIIRS pixel-level data fusion.
- The diurnal variation is assessed by the variation of solar reflectance within a designated domain from SEVIRI.
- Radiative transfer models are used to assess the direct radiative forcing and radiative heating rates and to retrieve aerosol and cloud optical properties.

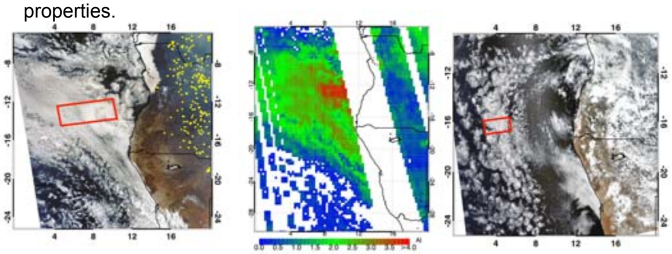

Fig. 1. (left) A MODIS RGB depicting absorbing aerosols above clouds over the southeast Atlantic and fire locations on 21 August 2015. (middle) OMI Aerosol Index on 21 August 2015 in the southeast Atlantic. (right) MODIS RGB depicting pristine clouds over the southeast Atlantic on 5 March 2015.

Diurnal Variations

While color ratio does not appear to vary significantly on an hourly basis, means and standard deviations of the reflectance peaks before noon.

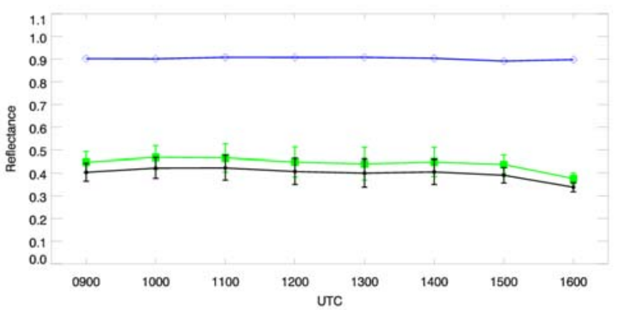

Fig. 2. Diurnal variation of $R_{0.64}$ (black), $R_{0.81}$ (green), and color ratio ($R_{0.64}/R_{0.81}$) in the red box from 0900-1600UTC on 21 August 2015 from SEVIRI.

Satellite Intercomparison

- Consistency between VIIRS and MODIS data will be critical to extend the legacy of multi-spectral measurements.
- The cloud optical depth of the VIIRS EDR tends to be underestimated relative to the MOD06 cloud optical depth for absorbing aerosols above clouds.
- Pristine cloud retrieval does not reveal a distinct trend between the two sensors.

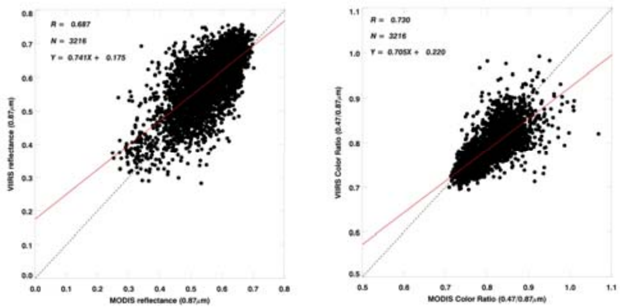

Fig. 3. (left) A comparison of the 0.87μm reflectance for VIIRS as a function of MODIS in the red box. Each observation is collocated based on a group of 5x5 pixels that undergoes a heterogeneity metric test. (right) A color ratio (0.47/0.87μm) comparison between the two sensors. The dashed line indicates the 1:1 line.

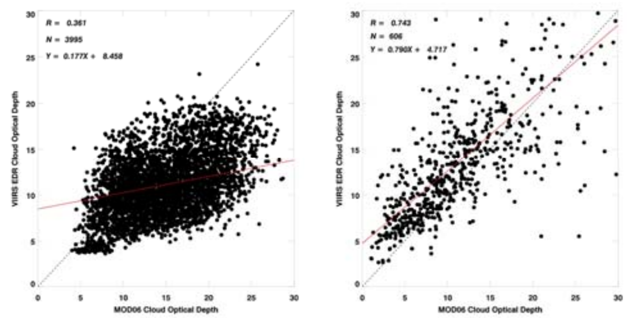

Fig. 4. (left) A comparison of cloud optical depth with overlying absorbing aerosols between VIIRS EDR COD and MOD06 on 21 August 2015 in the red box. (right) A pristine cloud case on 5 March 2015. The dashed line indicates the 1:1 line.

Future Work

- Improvement of sensor calibration and satellite products will advance the consolidation of data sets. Leveraging polarization with existing polar-orbiting and geostationary satellite sensors will also be the next key step to the understanding of aerosols above clouds.
- Quantifying aerosol properties as a function of distance from fire source will further our understanding of aerosol-cloud radiative forcing.
- Upcoming field experiments such as ORACLES, CLARIFY-2016, and LASIC will be important for the quantification and satellite validation of aerosols above and within clouds, including their radiative effects, heating rate profile, microphysical properties, and optical properties.

Radiative Transfer

- The optimal retrieval occurs for aerosols with low AOD and SSA above clouds of high COD. High sensitivity occurs for high AOD and low COD, making the accuracy of retrieval difficult.
- Aerosol radiative forcing and radiative heating rates are affected by aerosol/cloud optical properties and their vertical distributions.

Table 1. RTM input parameters

μm	SSA	Asy	AOT
0.44	0.84	0.64	0.45
0.67	0.79	0.52	0.20
0.86	0.76	0.46	0.12
1.02	0.75	0.45	0.08

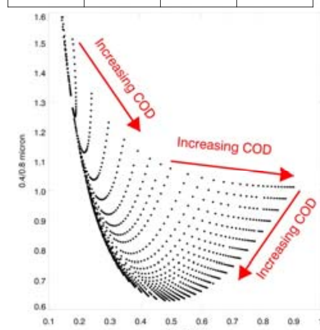

Fig. 5. Look-up-table for simultaneous retrieval of AOD and COD for absorbing aerosols above clouds based on MODIS (SZA=30°, VZA=50°, RAA =130).

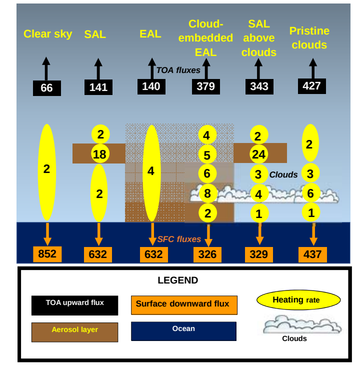

Fig. 6. A schematic showing radiative fluxes (in Wm^{-2}) and radiative heating rates (in Kelvin per day) for six scenarios including clear sky, single aerosol layer (SAL), exponential aerosol layer (EAL), cloud-embedded EAL, SAL above clouds, and pristine clouds using the delta-four stream RTM. The TOA downward fluxes is ~$1122Wm^{-2}$. The input cosine of solar zenith angle and the cosine of viewing zenith angle are 0.82 and 0.90, respectively. Brown boxes illustrate vertical distributions of aerosols where the magnitude of the AOD in each layer is delineated by the intensity of the boxes. The top of the EAL, the top of the SAL, and the cloud top are is approximately 5km, 4km, and 2km, respectively. All values are rounded off to the nearest whole unit. Note that the schematic are not presented in scale. (Chang and Christopher, submitted to QJRMS)

Summary

- Consistency between MODIS and VIIRS will be critical for long-term assessment of above-cloud aerosols from a multi-sensor perspective.
- Diurnal variations of aerosols above clouds is manifested by the peak near-infrared reflectance before noon.
- Retrieval of AOD/COD pair is optimal for high COD and low AOD cases.
- Radiative forcing and heating rates depend on optical properties and vertical distributions of absorbing aerosols and clouds.

Further Readings

- Chang, I. and S. A. Christopher, Identifying absorbing aerosols above clouds from the Spinning Enhanced Visible and Infrared Imager coupled with NASA A-Train multiple sensors. IEEE Transactions on Geoscience and Remote Sensing (Accepted).
- Chang, I. and S. A. Christopher, Impacts of vertical distributions of absorbing aerosols and clouds on the direct radiative forcing and radiative heating rates. Submitted to the Quarterly Journal of the Royal Meteorological Society.

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