Aerosol Properties in Partly Cloudy Regions

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Aerosols are sometimes near clouds

**Arctic haze**

**Saharan dust & clouds**

View from DC-8; A. Wisthaler, NOAA

View from G-IV, J. Dunion, NOAA
Most clear areas are not too far from clouds

DSCOVR spacecraft, EPIC imager, February 1, 2018
Aerosols are different near clouds

“... aerosol measured in the vicinity of clouds is significantly different than it would be were the cloud field, and its proximate cause (high humidity), not present”.

IPCC AR5, Chapter 7
Aerosols are different near clouds due to:

- Aerosol swelling
- Cloud processing of aerosols
- New particle formation

Remote sensing issues can exaggerate the differences:

- Undetected cloud droplets
- 3D cloud adjacency effect
- Instrument blurring
Project goals:

• Advance our understanding on the effect of clouds and cloud-related processes on aerosol properties and aerosol radiative forcing.

• Improve the interpretation of MODIS and VIIRS aerosol observations near clouds through a correction model accounting for the adjacency effect of clouds.
eMAS data often show near-cloud aerosol enhancements

NASA ER-2 eMAS, SEAC4RS, Kentucky & Alabama, August 30, 2013
Satellite images also show near-cloud enhancement
CF-AOD correlation is positive throughout the globe

June-July-August, 2012-2014

Similar behavior for other models (e.g., Quaas et al., ACP, 2010)
AOD increases with both CF and proximity to clouds.

Retrieved 0.55 µm AOD is 50% higher in the half of data that is closer to clouds.

Sept. 14-29, 2002-2011
AE decreases near clouds even if it increases with CF.

- **Angstrom exponent**: "steepness" of spectral slope
- **AOD** vs. **Wavelength**
- **Cloud fraction** vs. Angstrom exponent (443-869 nm)

**CF**: large-scale environment

**D**: effect of individual clouds

Sept. 14-29, 2002-2011
When CF increases, in many areas the aerosol population shifts toward smaller sizes

MODIS Aqua, DJF 2012-2014
AE can increase with CF due to small mode swelling.
AOD often increases with CF more for small mode

- cloud contamination is not dominant (MAIAC, VIIRS 375 m TIR)
- small mode swells more (MAIAC, MERRA-2, CALIOP)
- cloud processing creates small aerosols (MERRA-2)
- 3D adjacency effect

MODIS Aqua, JJA 2012-2014
3D causes significant part of near-cloud enhancements


MODIS

CALIOP

CALIOP can observe enhancements from:

• Aerosol swelling
• Cloud contamination
• Cloud processing

It is not affected by:

• 3D enhancement
• Instrument blurring

Distance to nearest cloud [km]

Relative enhancement in particle scattering [%]
Analytical model is tested for removing 3D enhancements.
3D correction over land reduces retrieved AOD-s and increases Angstrom exponents.

15 eMAS flight segments over South-Central US during SEAC4RS (2013)
Online 3D radiative transfer simulator is available

- Quick 1D & 3D Monte Carlo simulations through web interface (15 sec - 4 min)
- Reflectance at 5 MODIS wavelengths: 0.47, 0.55, 0.65, 0.86, 2.13 µm
- Goal: help initial exploration of ideas, class projects
- Part of the Intercomparison of 3D Radiation Codes (I3RC) project: i3rsimulator.umbc.edu

Sample input LES fields
Summary

• Cloud fraction and AOD are positively correlated through most the globe and for all aerosol types. Correlation is stronger for MODIS than MERRA-2.

• In many areas, aerosol size distributions shift toward smaller sizes as CF increases, but it always shifts toward larger size near clouds.

• 3D radiative effects have a significant impact on satellite radiances near clouds, where a large portion of clear-sky columns occur.

• An analytical model is being developed to help aerosol retrievals by estimating 3D reflectance enhancements.
MODIS CF & AOD well-correlated for all MERRA-2 aerosol types
Aeronet: AOD jumps when clouds appear, but aerosol size distribution does not change

Eck et al. (2014), DISCOVER-AQ
Impact of 3D effect varies with retrieval algorithm

3D effects vary with
- Wavelength (deep blue vs. dark target)
- Polarization (POLDER vs. MODIS)
- View directions (MISR vs. MODIS)

POLDER: 3D effects do not cause problems if

\[
\text{CF} < 5\% \text{ or } \tau_{\text{cloud}} < 5
\]

For CF = 25\% and \(\tau_{\text{cloud}} = 10\):

\[
\Delta \text{AOD} = 0.12 (\approx 25\%), \quad \Delta \text{SSA} = 0.09
\]

Stap et al. (JQSRT, 2016):
Aeronet: small mode increases near clouds

Large increases in AOD are associated with sites that are in close proximity to larger Cu clouds

Eck et al. (2014)
Analytical model is tested for removing 3D enhancements
3D correction over ocean reduces retrieved AOD-s and can change Angstrom exponents either way.

31 MODIS granules off the West coast of North & South America, August 1-8, 2013

Aerosol optical depth (0.55 µm)

AOD

Original: <AOD> = 0.086
Corrected: <AOD> = 0.069

Angstrom exponent

Original: <AE> = 0.62
Corrected: <AE> = 0.66
Airborne HSRL: aerosol optical depth (AOD) can be larger near clouds, but not always

Su et al. (2008)