Effect of cloud fraction on near-cloud aerosol behavior based on MODIS and CALIPSO observations

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... 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. The latter results from humidification effects on aerosol optical properties, contamination by undetectable cloud fragments and the remote effects of radiation scattered by cloud edges on aerosol retrieval.
What happens to aerosol in the vicinity of clouds?

All observations show that aerosols seem to grow near clouds or (to be safer) “most satellite observations show a positive correlation between retrieved AOT and cloud cover”, e.g.,

Chand et al. (2012) using MODIS data found a 25% enhancement in AOT between CF 0.1-0.2 and CF 0.8-0.9.

from Ignatov et al., 2005
from Loeb and Manalo-Smith, 2005
from Zhang et al., 2005
What happens to aerosol in the vicinity of clouds?

However, it is not clear yet how much growth comes from

• “real” microphysics, e.g.
  • increased hydroscopic aerosol particles
  • new particle production
  • other in-cloud processes.

• “artificial” effects, e.g.
  • cloud contamination (sub-pixel clouds)
  • extra illumination from clouds (a clear pixel in the vicinity of clouds)
  • sampling issue

The “artificial” effects may significantly overestimate AOT.
Sampling Issue

Far-from-cloud aerosol statistics is dominated by data from scenes with lower CF (and thus lower AOT), while near-cloud aerosol statistics is dominated by data from scenes with higher CF (and thus higher AOT).
Schematic illustration

Here $A$ is cloud fraction and $x$ is distance to cloud.

Schematic illustration of the potential effect of sampling on the averaged AOT as a function of distance to cloud and cloud cover.
What is the true statistical behavior of aerosol properties as a function of cloud fraction and distance to clouds?
MODIS
Ocean Color Aerosol Product

2 Sep. weeks for 10 years (2002-2011) of MODIS obs.: southwest of UK
STRAYLIGHT flag

Stray light from adjacent, bright sources such as cloud edges is known to contribute to error in MODIS ocean color retrievals. In MODIS/Aqua Reprocessing 1.1 (2005), pixels within a 7x5-pixel region around bright pixels were flagged as straylight and masked in Level-3.
MODIS
(OC products)

(a) Number of pixels vs. distance to nearest cloud [km]

(b) Aerosol optical thickness at 869 nm vs. distance to nearest cloud [km]

(c) Angstrom exponent vs. distance to nearest cloud [km]
MODIS

*(OC and C6 products)*

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**Left Diagram:**
- **Y-axis:** Mean AOT near 0.87 μm
- **X-axis:** Distance to nearest cloud [km]
- Lines represent different cloud fractions (CF) for OC and C6 products.

**Right Diagram:**
- **Y-axis:** Mean AE
- **X-axis:** Distance to nearest cloud [km]
- Lines represent different cloud fractions (CF) for OC and C6 products.
CALIPSO

A large region around the Azores

Three year-long observations: 2006.6.21-2009.6.21
Near-cloud enhancements of $\beta$ and $\chi$ occur for any CF but are most pronounced for higher CF.
Attn BKS coeff., $\beta(x,A)$

- $y = 0.002 + 0.00015\log(A)$  \( R = 0.91 \)
- $y = 0.002 + 6.5\times10^{-5}\log(A)$  \( R = 0.76 \)
- $y = 0.002 + 1.9\times10^{-5}\log(x)$  \( R = 0.17 \)

Cloud fraction, $A$

Total color ratio, $\chi(x,A)$

- $y = 0.49 + 0.07\log(A)$  \( R = 0.96 \)
- $y = 0.44 + 0.02\log(A)$  \( R = 0.59 \)
- $y = 0.42 - 0.00\log(A)$  \( R = 0.18 \)

Cloud Fraction, $A$
Backscatter and Color Ratio with and without correction

Correction = Resampling: the distr. of cloud fraction \( n(x,A) \) is the same for any distance to clouds
Take home messages

- Aerosol properties (thus radiative forcing) near clouds might be significantly different from those far from clouds;

- Remote sensing retrievals near clouds is challenging but excluding aerosols near clouds dramatically reduces the data volume and underestimates the forcing, while including them may overestimate it;

- Near-cloud aerosol statistics are dominated by samples from scenes with higher cloud fractions;

- Near-cloud enhancements of attenuated backscatter occur for any cloud fraction but are most pronounced for higher cloud fractions;

- Near-cloud enhancements can be well approximated by logarithmic functions of cloud fraction and distance to clouds;

- The sampling issue explains 15-30% of the near-cloud enhancement.

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Aerosol Properties in MODIS ocean product

Aqua, Northeast Atlantic, September 14-29, 2002-2011
MODIS
(OC products)
Inseparability of cloudy and clear skies under partial cloud cover (from Charlson et al., 2007)

The existence of partly cloudy regions and the fact that the clear-cloudy distinction is ambiguous and aerosol dependent raise the possibility that the conventional expression may lead to errors.” (Charlson et al., 2007)
MODIS
(OC products)
Near-cloud aerosol statistics are dominated by samples from scenes with higher cloud fractions.
Near-cloud aerosol statistics are dominated by samples from scenes with higher cloud fractions.
Motivation

- Climate studies (e.g., aerosol indirect effect) demand a precise separation of clear and cloudy air;

- Remote sensing retrieval of aerosol properties near clouds is a big challenge;

- Excluding aerosols near clouds will dramatically reduce the database and underestimate the forcing, while including them may overestimate it because of unaccounted cloud contamination.

![Histogram graph showing distance to nearest cloud](image)

- From **MODIS**: 60% of all clear sky pixels are located 5 km or less from all clouds
- From **CALIPSO**: 50% of all clear sky pixels are located 5 km or less from low clouds