# What is the uncertainty in MODIS aerosol optical depth in the vicinity of clouds ?

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## Introduction

- MODIS dark-target (DT) algorithm retrieves aerosol optical depth (AOD) using a Look Up Table (LUT) approach
- Global comparison of AOD (Collection 6 ) with ground-based sun photometer gives an Estimated Error (EE) of ±(0.04 + 10%) over ocean. However, EE does not represent per-retrieval uncertainty
- For retrievals that are biased high compared to AERONET, here we aim to closely examine the contribution of biases due to presence of clouds and per-pixel retrieval uncertainty

## Approach

- We calculate the per-pixel retrieval uncertainty from
  a) Atmospheric correction
  b) Variability in reflectance in 10 km retrieval area
  c) Aerosol model assumption
  d) Surface albedo
  e) Cloud contamination or enhanced radiation in vicinity of clouds
- Our aim is to quantify the uncertainty in retrieved AOD due to as many different sources as we can and identify the relatively dominant source of uncertainty in AOD retrieval

## Per-Pixel Retrieval Uncertainty

Comparing AOD Uncertainty

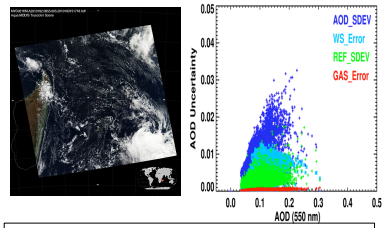


Figure 1 Using Jacobian approach to estimate each of four sources of uncertainty for all retrieved pixels in the example MODIS granule shown at left.

From the above results we find that ,

- Uncertainty is a function of retrieved AOD.
- Uncertainty from error in ancillary data / gas absorption correction is lowest here
- Uncertainty from surface albedo approximation is nearly double that from standard deviation of reflectance within 10 km retrieval region
- Largest uncertainty in over Ocean AOD retrieval comes from the multiple solutions that yield an acceptable retrieval (See Fig 1)

## References


- Levy, R. C., Mattoo, S., Munchak, L. A., Remer, L. A., Sayer, A. M., Patadia, F., and Hsu, N. C.: The Collection 6 MODIS aerosol products over land and ocean, Atmos. Meas. Tech., 6, 2989-3034, doi: 10.5194/amt-6-2989-2013, 2013.
- Cox, C., and W. Munk, Slopes of the sea surface deduced from the photographs of sun glitter, Bull.SuippsInst.Oceanogr.,6,40l – 488, 1956
- P. Koepke, "Effective reflectance of oceanic whitecaps," Appl. Opt. 23, 1816-1824 (1984).


*Questions?*

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## Validating Per-pixel Retrieval Uncertainty

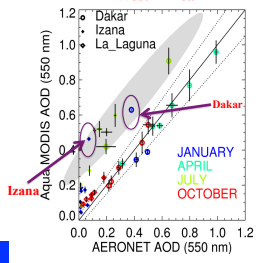
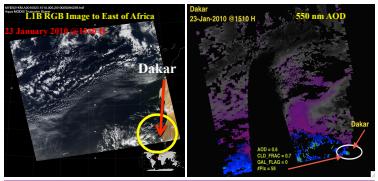



Figure 2 Comparison of AOD and its uncertainty over AERONET stations falling in W. Africa is shown for 4 months (colors blue-red) of 2010. The vertical lines in the plots are the total absolute MODIS AOD uncertainty from 4 listed sources. The horizontal lines are the standard deviation of AERONET AOD averaged over ±30 minutes of MODIS overpass. Different symbols are used for different stations in a region

- When compared to ground-based AERONET sun-photometers, clearly the performance of the algorithm is different over different regions and seasons
- For most data-points within the EE envelope (dashed lines), the uncertainty is within EE of retrievals over ocean
- For retrievals with high uncertainty, the AERONET AOD standard deviation is also large in many cases and there are exceptions to this too
- For outliers, the per-pixel uncertainty is no necessarily large – lets take a close look at an outlier below

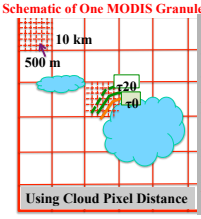
## Cloud Contamination Issue




- Dust seen around the Dakar station
- Broken cloud fields co-exist
- MODIS AOD retrieval is of Low Quality ( QA = 0) Cloud Fraction = 0.7
- Uncertainty value suggests Precise but Inaccurate / Baised retrieval ? Clouds?

## Exercise 1 : What can we learn about cloud contamination from our retrievals ?

Schematic of One MODIS Granule




- We have observations at 500 m, &
- Distance of every 500m pixel from a cloud

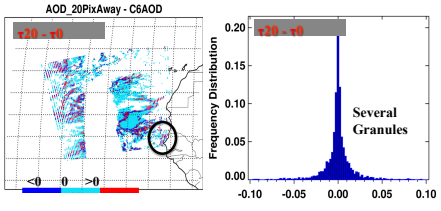
We do the following calculation to estimate cloud contamination

τ0 : ALL pixels used in C6
τ20: pixels with cloud pixel distance > 20 (1 km away)

Hypothesis :

If C6 AOD retrieval has cloud contamination : τ20 - τ0 = Negative

## Exercise 1 : Results

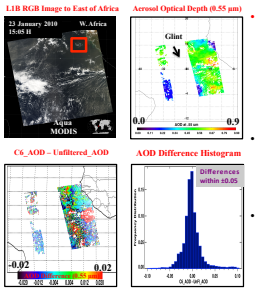



- Notice blues and reds in spatial distribution of AOD difference [Figure 3 (a) ] : there is low and high bias around cloudy regions
- AOD Difference Histogram [Figure 3 (b) ] shows
  - Gaussian shape
  - Δτ ≈ ± 0.05
  - Most differences within ± 0.03

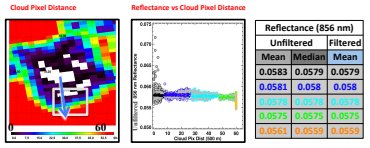
=> Reasonable overall cloud screening

- Low Quality flags => Clouds contamination

## Exercise 2 : Investigating Reflectance "Sorting" in Clear and Cloudy Areas

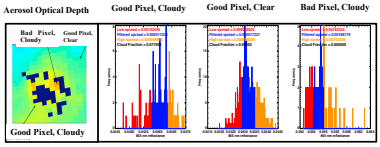



- Sorting: Standard retrieval sorts clear-sky (cloud masked) pixels, keeps only 25-75%, and calculates mean reflectance (Filtered reflectance)
- Here we examine AOD retrieved from Filtered (C6_AOD) vs. Unfiltered reflectance
- AOD difference in (i) Clear-sky areas is less than ±0.004 (ii) Cloudy regions is mostly within ±0.05




| Reflectance (856 nm) | | |
|---|---|---|
| Unfiltered | | Filtered |
| Mean | Median | Mean |
| 0.0583 | 0.0579 | 0.0579 |
| 0.0581 | 0.058 | 0.058 |
| 0.0579 | 0.0574 | 0.0574 |
| 0.0575 | 0.0575 | 0.0575 |
| 0.0561 | 0.0559 | 0.0559 |

- Closely examining reflectance statistics of reflectance near and far from clouds
- Filtering out 865 nm reflectance (gray dots in [b]) yields similar mean reflectance when atleast 10 pixels away from clouds




- Looking at histograms of few pixels with good and bad AOD retrievals, shows that
- Reflectance histogram of Clear-sky pixels is guassian → same means in table above
- Reflectance histogram of Cloudy pixels is skewed → filter cut-off will govern high / low bias in AOD

## Conclusions

- We have characterized AOD uncertainty at 550 nm, due to standard deviation of reflectance in 10 km retrieval region, uncertainty related to gas ($H_2O$ , $O_3$) absorption , surface albedo , and aerosol models
- The uncertainty in retrieved AOD seems to lie within the estimated over ocean error envelope of ±(0.03+10%)
- Regions between broken clouds tend to have higher uncertainty
- Compared to C6 AOD, a retrieval omitting observations in the vicinity of clouds (≤ 1 km) is biased by about ± 0.05
- For homogeneous aerosol distribution, clear-sky retrievals show near zero bias
- Close look at per-pixel reflectance histograms suggests retrieval possibility using median reflectance values

## Future Work

- Develop statistics and perform a global land - ocean evaluation of as many uncertainty sources as we can
- Further Investigate uncertainty due to biases from cloud, snow contamination