GEO-based Aerosol Sensing:
Combining TEMPO and ABI observations

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Satellite Aerosol Remote Sensing

In aerosol remote sensing, measured reflectances depend on multiple aerosol properties:

-Particle size: particle size distribution
Fine and coarse modes, std. dev., coarse mode fraction: at least 5 parameters

-Particle shape: aspect ratio, 1 parameter

-Particle composition: Complex refractive index (wavelength dependent), 2 parameters

-Extinction Optical Depth (wavelength dependent, AE), AOD , 1 parameter

-Aerosol vertical distribution (stronger in the UV)

Other requirements:

-Surface reflectance must be characterized

-Cloud-free conditions

To derive AOD and AE assumptions on the values of the other parameters must be made

Use of near UV Satellite Observations for retrieving aerosol properties

Observations in the 340-400 nm range can be used to derive aerosol properties

Advantages:
- Low surface albedo at all terrestrial surfaces (.01 to .03 for vegetation; .08 - .12 deserts)
- Sensitivity to aerosol absorption.
- Negligible gas absorption interference.

Disadvantages:
- Ocean color interference
- Aerosol absorption detection is aerosol layer height sensitive.

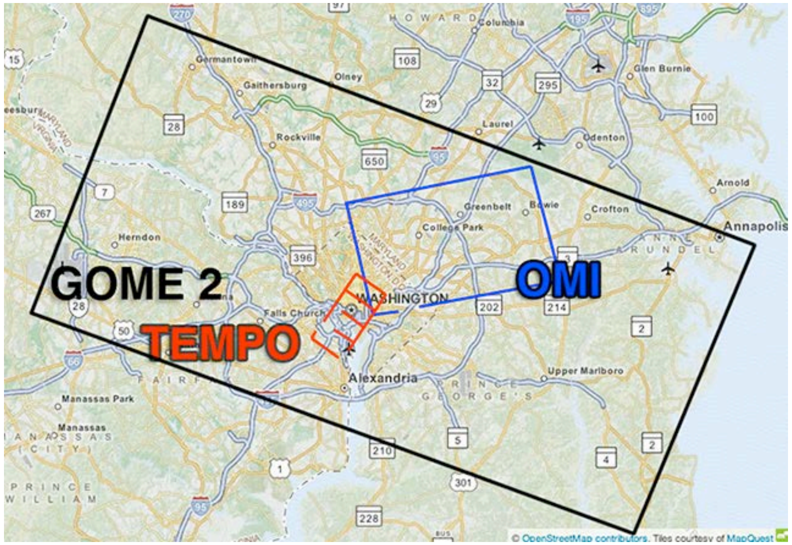
Historically, near UV measurements have been associated with coarse spatial resolution sensors (TOMS, OMI) primarily designed for trace gas retrieval.

At these multi-kilometer resolution sub-pixel cloud contamination (SCC) is the most important error source in aerosol remote sensing.

Full exploitation of this retrieval technique awaits the development of high spatial resolution UV instruments that can minimize cloud contamination effects.

Improvements in spatial resolution of near UV measurements

Agency	Sensor	Satellite	Spectral range of observations (nm)	Resolution	Period
KNMI/NASA/FMI	OMI	Aura	290-500 (Hyp.)	13x24 km	2005-Present
NOAA-NASA	OMPS	Suomi-NPP	300-380	50 km	2011-Present
NASA	EPIC	DSCOVR	340, 388	~ 10 km	2015-Present
EU (Copernicus)	TROPOMI	Sentinel 5 P.	270-500; 675-775 & 2305-2385 (Hyp.)	3.5X7 km	2017 (Sched.)
KARI	GEMS	GKOMPSAT2	300-500 (Hyp.)	7x7 km	2019 (Sched.)
JAXA-NIES	CAI-2	GOSAT-2	343, 380	0.5x0.5	?
NASA-SAO	TEMPO	TBD (GEO)	290-490 & 540-740 (Hyp.)	4.5x2 km	2020 (Sched.)
ESA	Sent-4	TBD (GEO)	305-500, 675-775	3.5x7	?
NASA-JPL	MAIA	TBD (LEO)	360, 380	1.0X1.0km	?



TEMPO will be, at launch, the highest spatial resolution space borne hyper-spectral sensor ever built

TEMPO Mission General Description

- **Measurement technique**
  - Imaging grating spectrometer measuring solar backscattered Earth radiance
  - Spectral band & resolution: 290-490 + 540-740 nm @ 0.6 nm

- **Spatial Coverage**
  - Mexico City/Yucatan, Cuba to the Canadian oil sands, Atlantic to Pacific
  - Radiance maps of Greater North America in every hour

- **Spatial resolution**
  - 2.1 km N/S × 4.7 km E/W native pixel resolution (9.8 km^2)

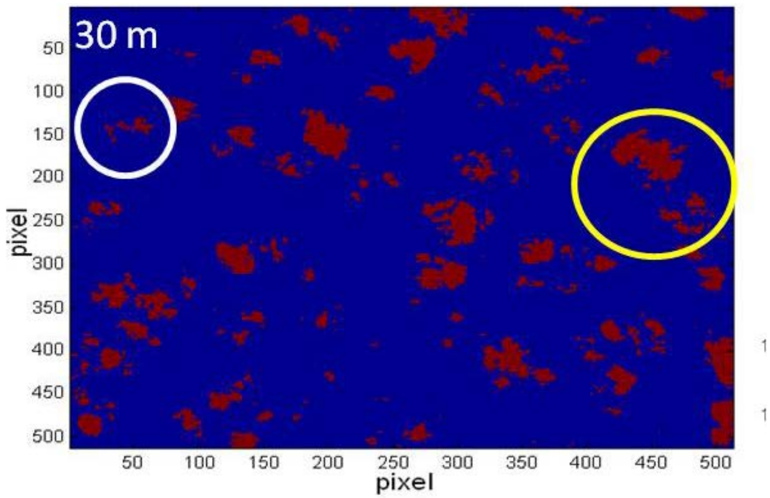
- **Standard data products and sampling rates**
  - Most sampled hourly,
  - Measurement requirements met up to 70º SZA for aerosols and other products

- **Geostationary orbit**
  - NASA is responsible for host selection, launch arrangements and hosting services
  - 80-115º W acceptable latitude

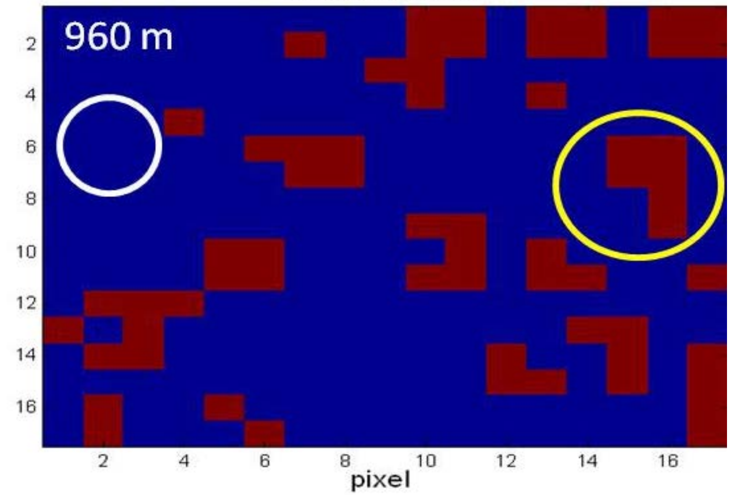
Effects of sub-pixel cloud contamination

-Reduces the availability of scenes for retrieval.
- AOD retrieval contamination in large pixels considered clear

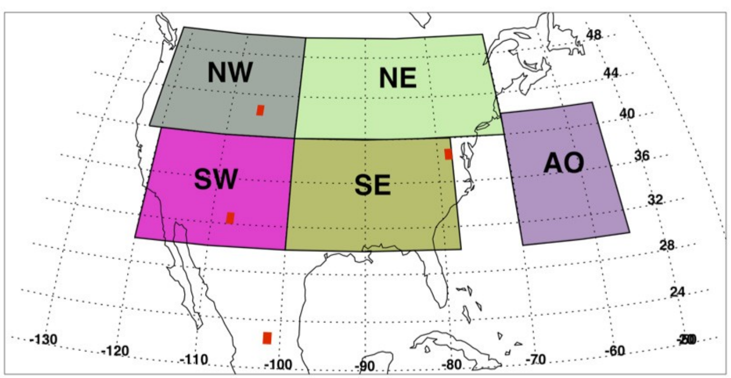
Pixel resolution 30 m, 15% CF

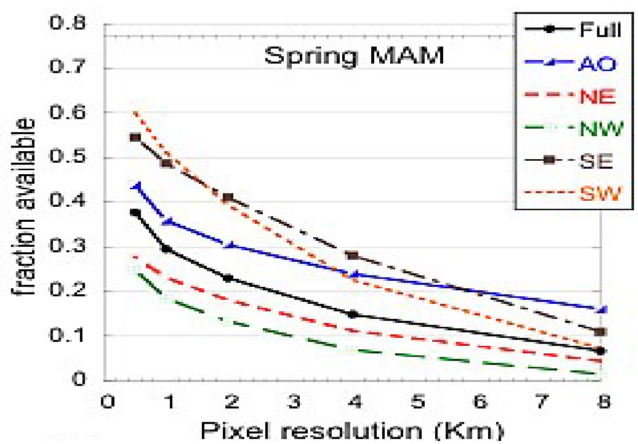


Pixel resolution 960 m, 25% CF



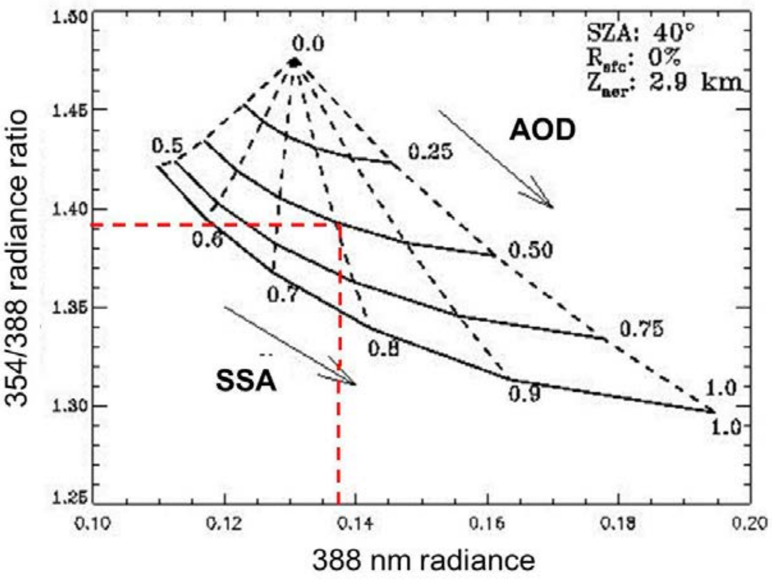
Koren et al, how small is a small cloud?, ACP, 2008





Remer et al., Retrieving aerosol in a cloudy environment: aerosol product availability as a function of spatial resolution, AMT, 2012

OMI near UV aerosol algorithm



-Input: Radiance measurements at 354 and 388 nm

-Considers three aerosol types: carbonaceous, desert dust and sulfate particles

-Retrieved parameters: AOD , SSA (388 nm) and UVAI.

Ancillary Information:
-Surface albedo (OMI-based climatology)
-Aerosol layer height (CALIOP-based climatology)
-Real time AIRS CO data (smoke/dust differentiation)

- A similar algorithm will be applied to TEMPO observations

- The combined use of TEMPO and GOES 16 (and 17) high spatial resolution Advanced Baseline Imager (ABI) observations can yield a better GEO-based aerosol product.

- Smoke/dust differentiation is an issue for both TEMPO and ABI observations. Looking to other TEMPO products suitable as smoke tracer (formaldehyde?) in conjunction with UVAI.

Advanced Baseline Imager

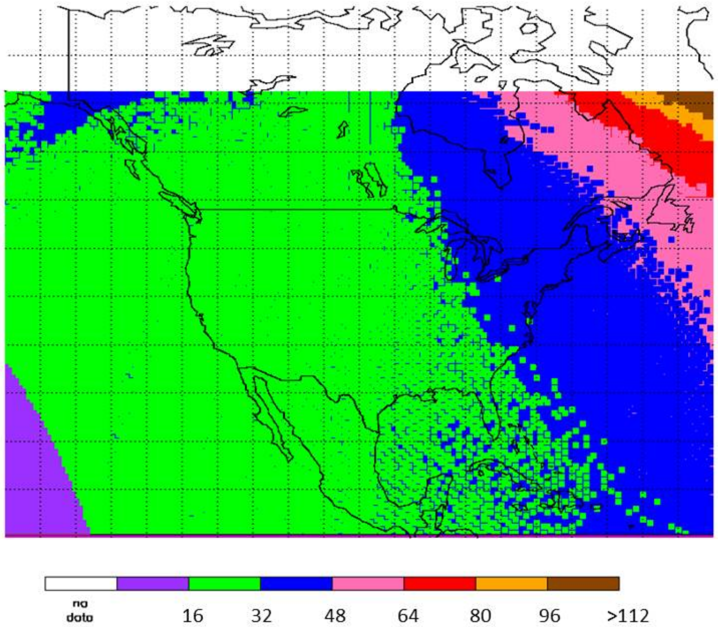
ABI channels:
- Visible: 0.47, 0.64 µm
- Near IR: 0.86, 1.37, 1.6 µm
- SWIR/Thermal IR: 2.2, 3.9, 6.2, 6.9, 7.3, 8.4, 9.6, 10.3, 11.2,12.3, 13.3 µm

Spatial Resolution
0.47 µm 1.0 km
0.64 µm 0.5 km
> 2.0 µm 2.0 km

Spatial Coverage

Full Disk: 4 per hour
CONUS: 12 per hour
Mesoscale: 30 or 60 sec

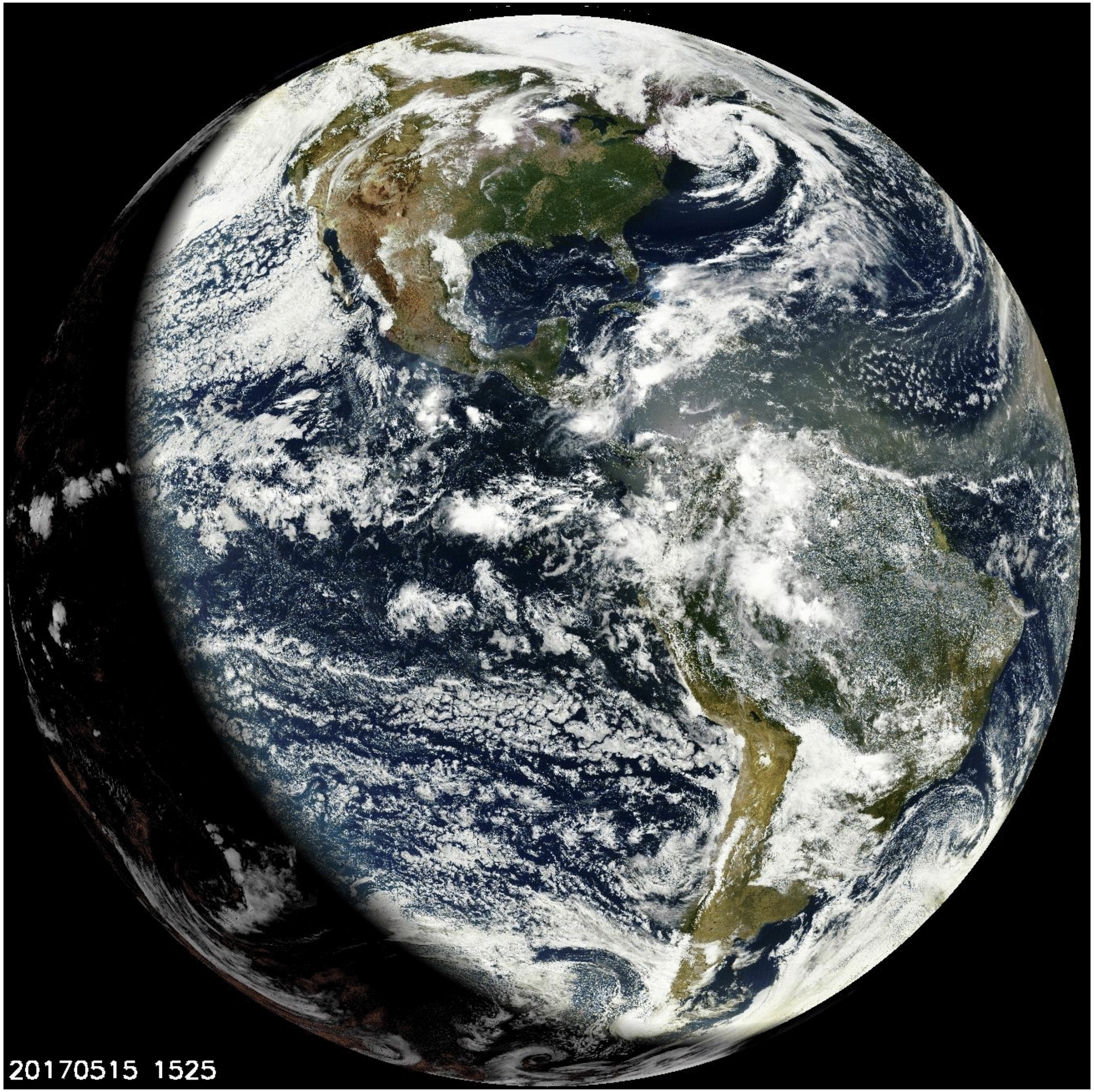
Satellite: GOES-16
Launch date: November 19, 2016



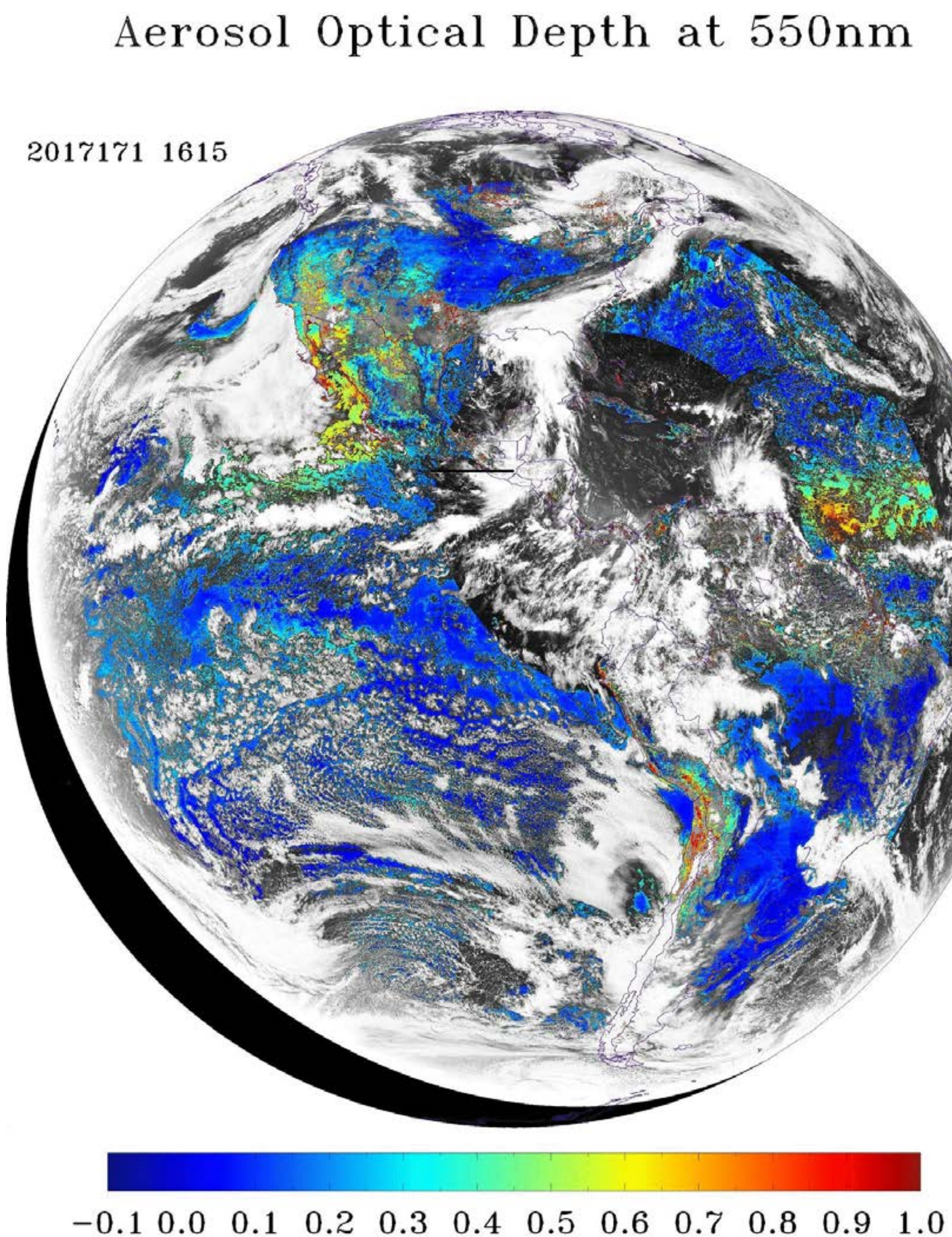
Number of GOES-16 (75°W) 0.64 µm pixels per TEMPO pixel

ABI's much higher spatial resolution measurements allow the application of spatial homogeneity and spectral techniques for cloud masking.

GOES-16 ABI Full Disk RGB 5-minute Animation: May 15, 2017



Credit: NOAA/NESDIS/STAR aerosol team



Credit: NOAA/NESDIS/STAR aerosol team

Using TEMPO and ABI observations

1. Use TEMPO near UV algorithm to retrieve AOD and SSA from near UV observations

2. Use an algorithm (DT, MAIAC) on ABI observations to retrieve AOD from VIS-near IR observations

3. Use collocated TEMPO ABI to retrieve AOD and SSA from near UV observations using ABI cloud mask

4. Use collocated TEMPO -ABI observations to retrieve AOD from visible observations and SSA and Absorption Angstrom Exponent (AAE) or aerosol layer height (ZAE) from near UV observations

Options	AOD Yield	SCC	Absorption	AAE/ZAE
1. TEMPO	Low	High	Yes	No
2. ABI	High	Low	No	No
3. TEMPO+ABI cm	Low	Low	Yes	No
4. TEMPO+ABI cm + ABI AOD	High	Low	Yes	Yes

Combined VIS-UV retrieval of aerosol properties

Independently measured AOD in the visible can be extrapolated to the near UV,
and combined with near-UV measured radiances to improve aerosol characterization.

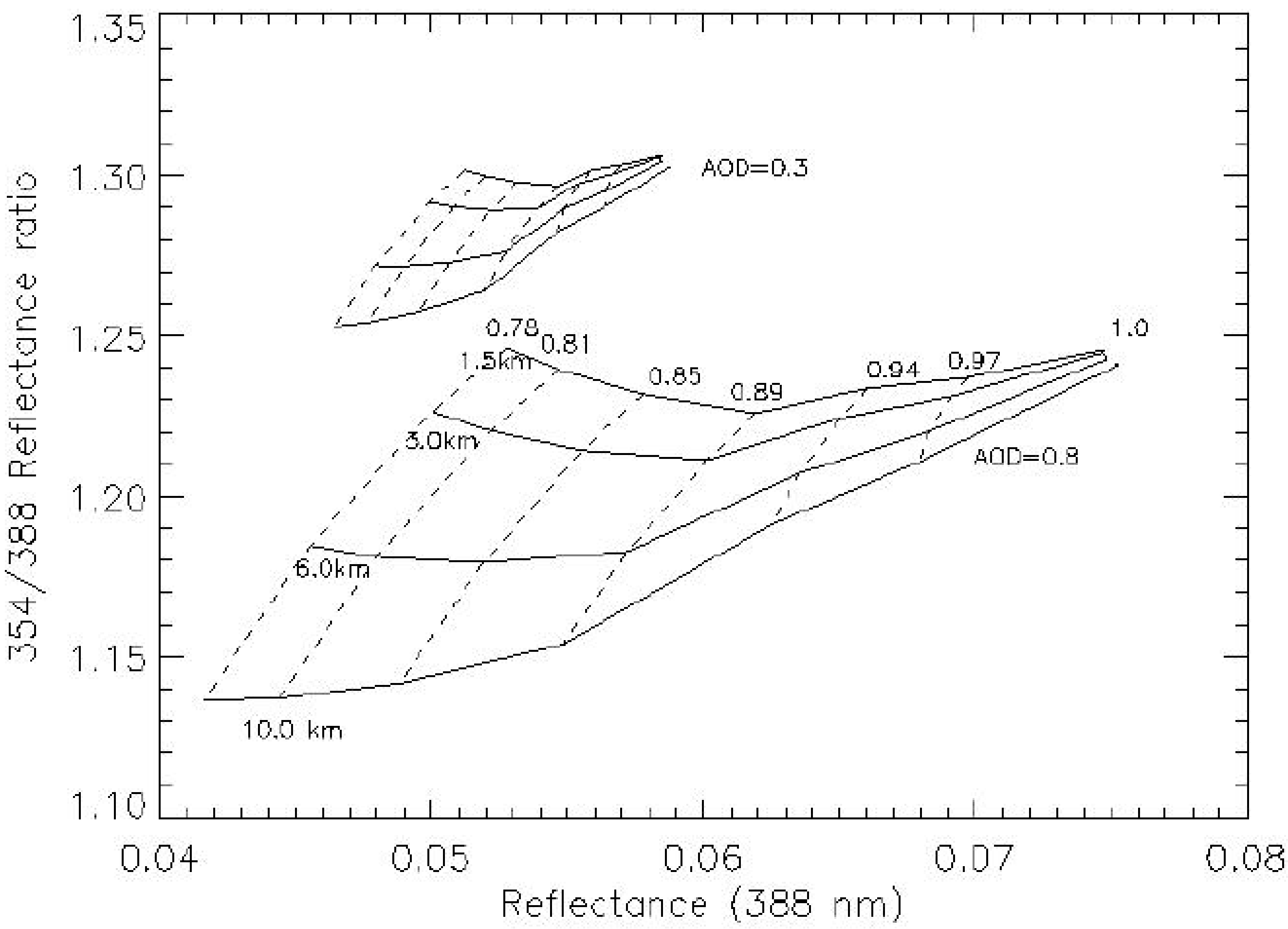
For elevated aerosols, retrieve SSA and ZAE
For BL aerosols, retrieve, SSA and AAE (or SSA at two near UV channels)

Sources of Uncertainty of Independently measured AOD

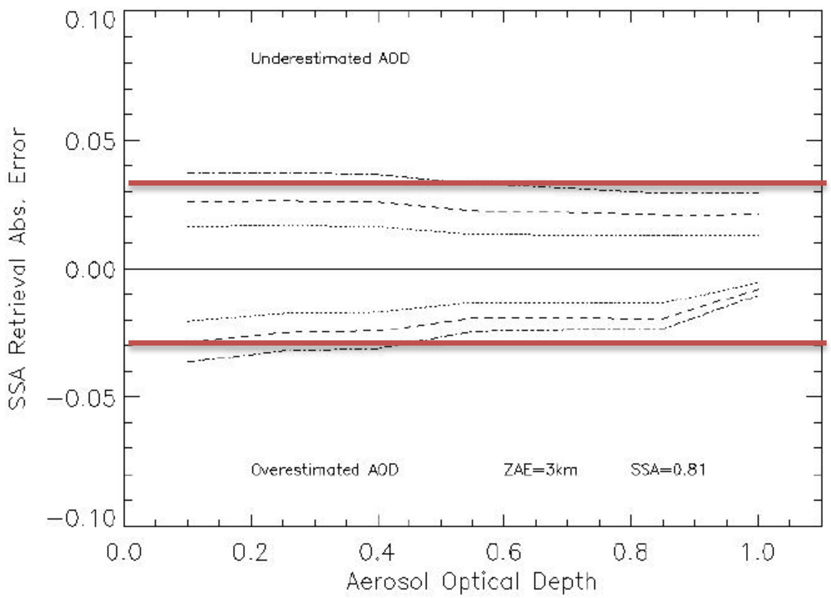
- -Sensor Calibration
- -Surface Characterization
- -Aerosol Model (SSA and PSD)
- -Cloud Contamination
- -Extrapolation Error

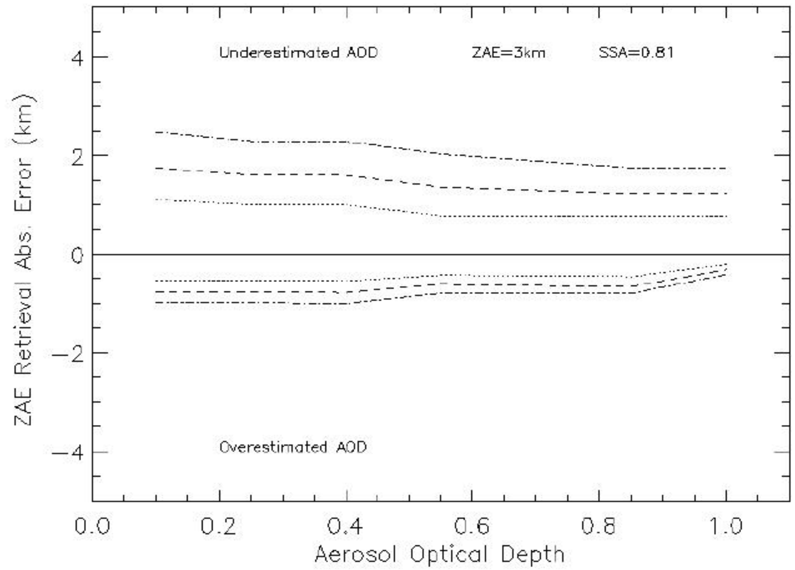
In the following sensitivity analysis combined uncertainties of 10%, 15% and 20% are assumed

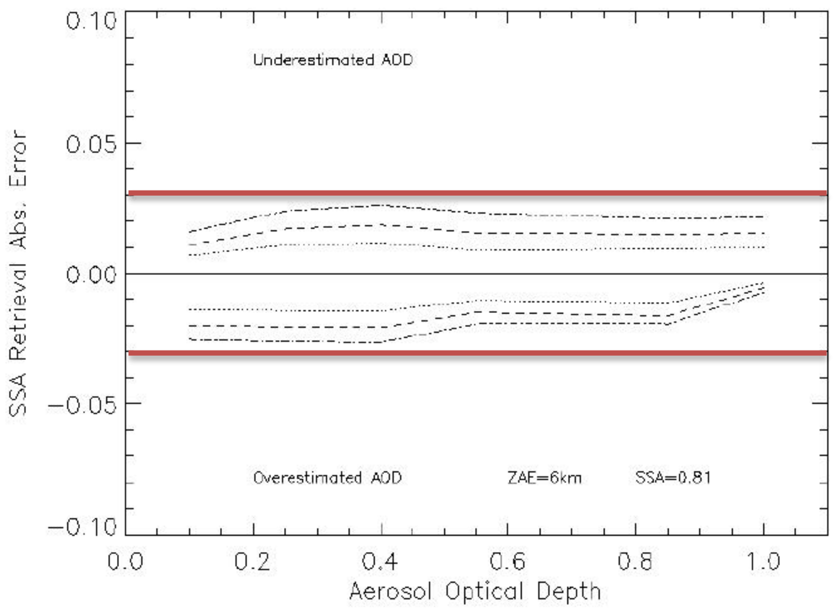
Simultaneous retrieval of aerosol layer height and single scattering albedo

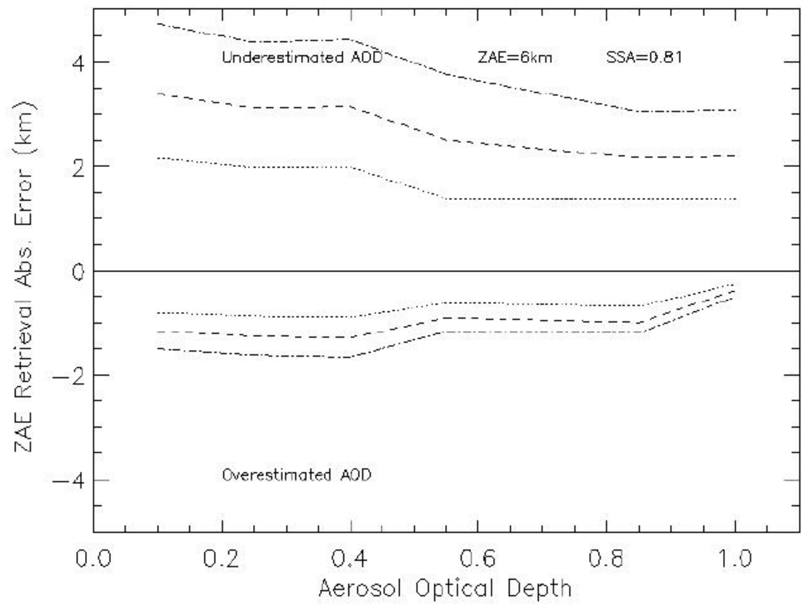


Sensitivity of retrieved SSA and ZAE to AOD Accuracy



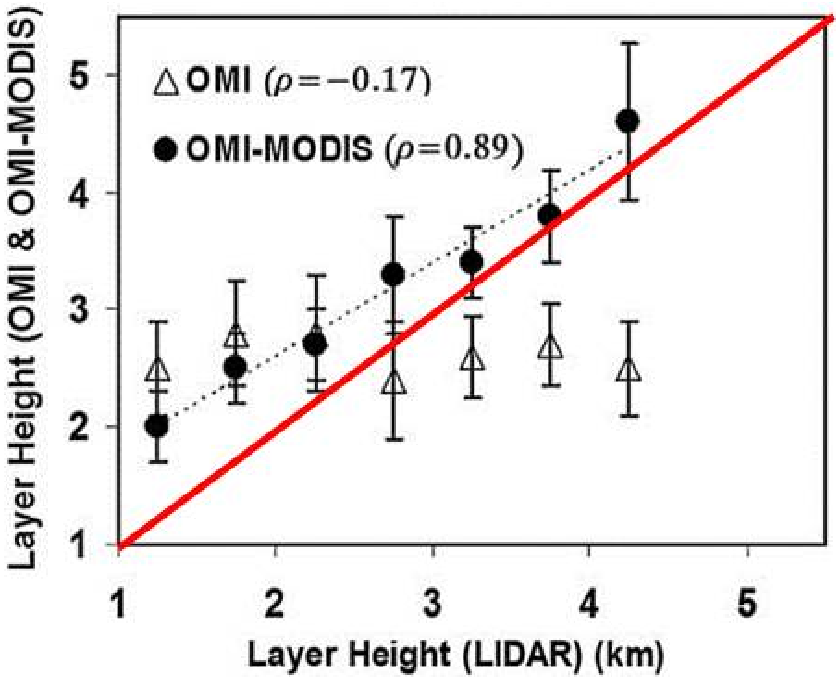






AOD uncertainties: 10%, 15%, 20%

Application to collocated OMI – Aqua-MODIS observations



Comparison of retrieved aerosol layer height to lidar observations

Satheesh, S. K., O. Torres, L. A. Remer, S. S. Babu, V. Vinoj, T. F. Eck, R. G. Kleidman, and B. N. Holben (2009), Improved assessment of aerosol absorption using OMI-MODIS joint retrieval, *J. Geophys. Res.*, 114, D05209, doi:10.1029/2008JD011024.