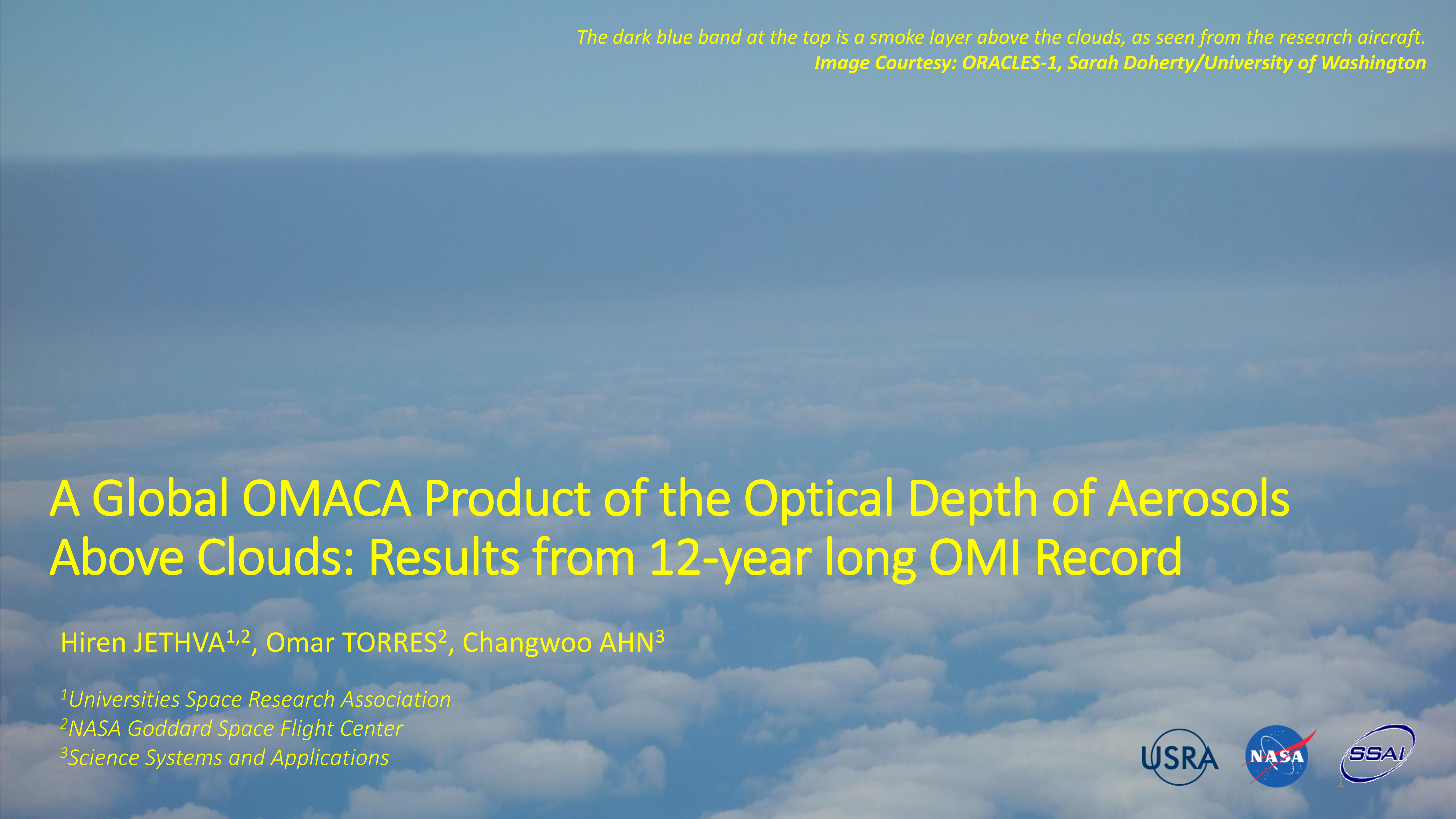


The dark blue band at the top is a smoke layer above the clouds, as seen from the research aircraft.
Image Courtesy: ORACLES-1, Sarah Doherty/University of Washington

A Global OMACA Product of the Optical Depth of Aerosols Above Clouds: Results from 12-year long OMI Record

Hiren JETHVA[1,2], Omar TORRES[2], Changwoo AHN[3]

[1]*Universities Space Research Association*
[2]*NASA Goddard Space Flight Center*
[3]*Science Systems and Applications*

Excerpts from IPCC AR5 WG1 Ch.7

Inter-model standard deviation of Aerosol Radiative Forcing

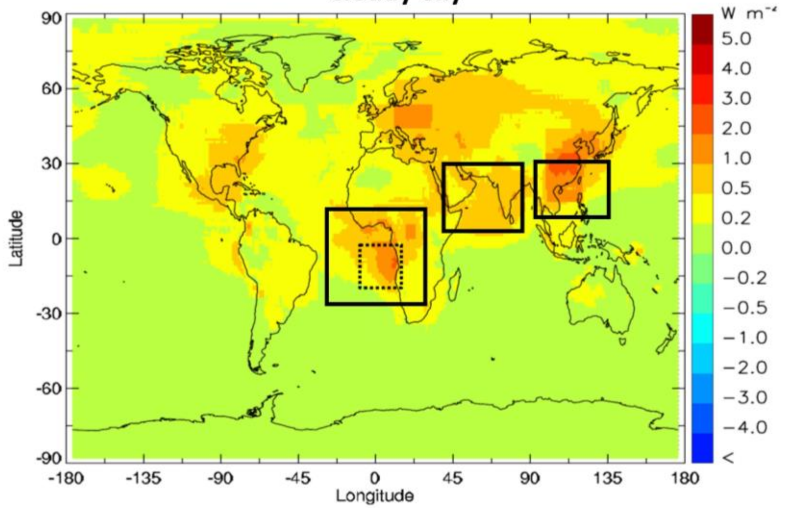
Clouds and Aerosols **Chapter 7**

Attempts to estimate the REari in cloudy sky remain elusive (e.g., Peters et al., 2011b), although passive and active remote sensing of aerosols over clouds is now possible (Torres et al., 2007; Omar et al., 2009; Waquet et al., 2009; de Graaf et al., 2012). Notable areas of positive TOA REari exerted by absorbing aerosols include the Arctic over ice surfaces (Stone et al., 2008) and seasonally over southeastern Atlantic stratocumulus clouds (Chand et al., 2009; de Graaf et al., 2012). While

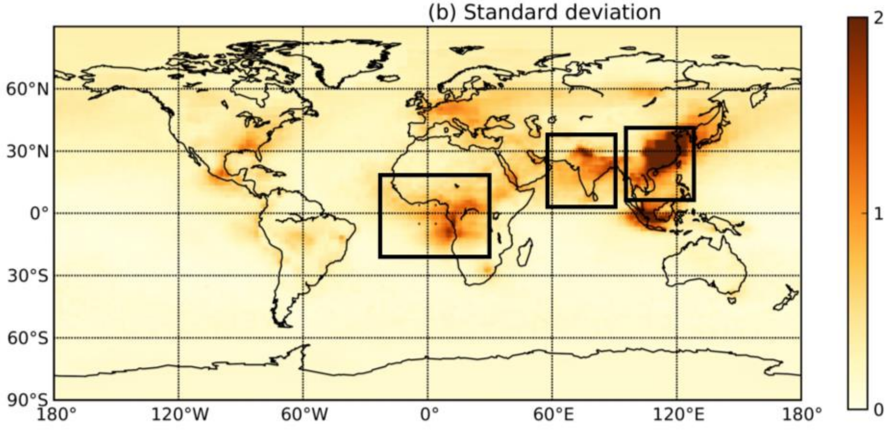
diversity in large-scale numerical model estimates of REari increases with aerosol absorption and between cloud-free and cloudy conditions (Stier et al., 2013).

Unlike aerosols in cloud-free conditions over dark surfaces which result in a net cooling at TOA, absorbing aerosols when advected over cloud can potentially lead to atmospheric warming

Schulz et al., 2006
AEROCOM Phase I Simulations
Cloudy-sky



Myhre et *al.*, 2013
AEROCOM Phase II Simulations
All-sky



Aerosol Optical Depth above Cloud from OMI's Near-UV Observations

Physical Basis

Enhanced near-UV 'color ratio'/UV-AI in the presence of absorbing aerosols above clouds

Product Name: Aura/OMI OMACA

Retrieved Products

Above-cloud Aerosol Optical Depth (388 nm)

Aerosol-corrected Cloud Optical Depth (388 nm)

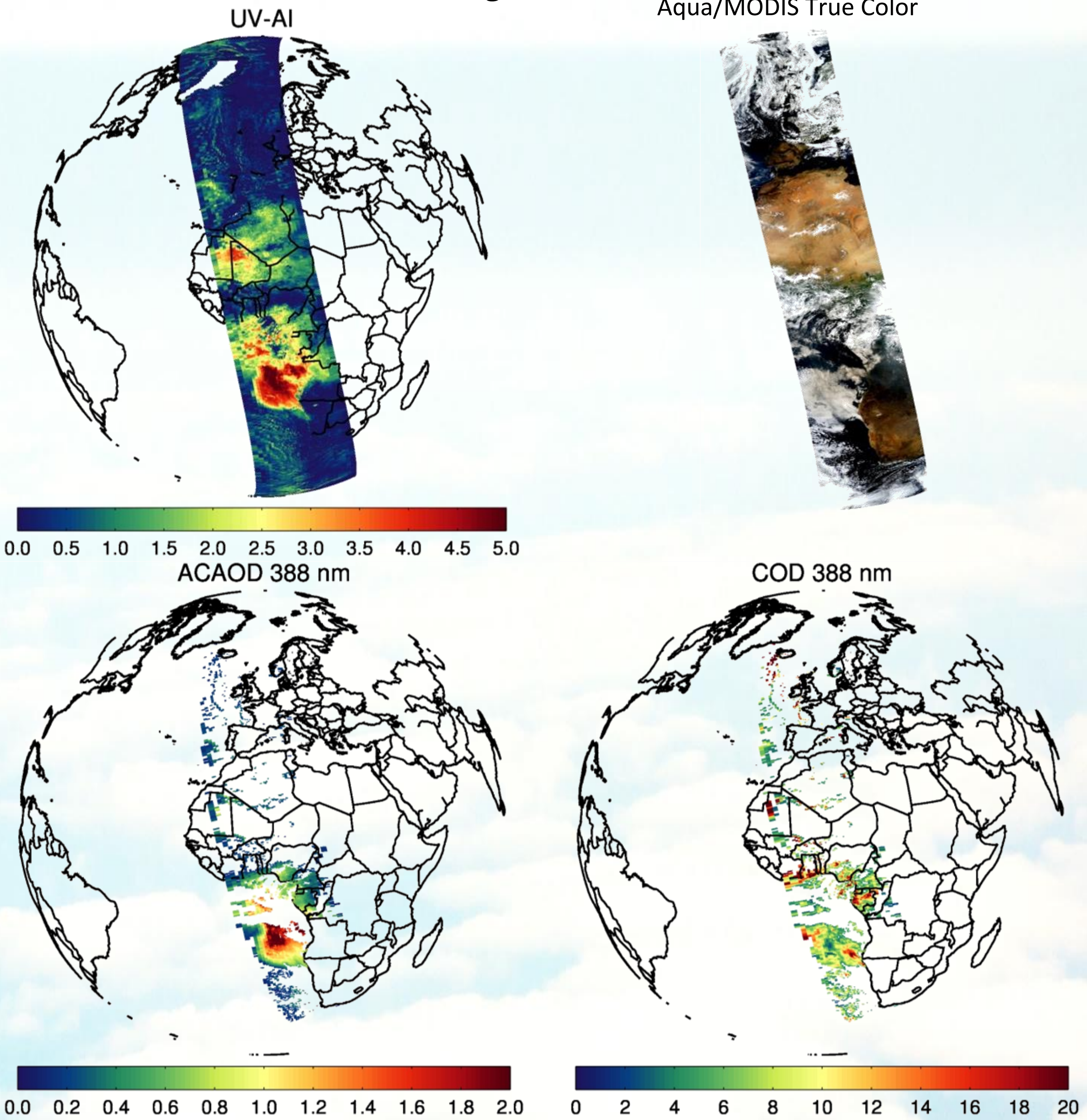
Data availability: Oct 2004 to present, also in forward processing

The product was officially released in July 2016 and can be accessed at
https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2/OMACA/

Torres, O., H. Jethva, and P. K. Bhartia (2012), Retrieval of aerosol optical depth above clouds from OMI observations: Sensitivity analysis and case studies, J. Atmos. Sci., 69, 1037–1053, doi:10.1175/JAS-D-11-0130.1.

Jethva, H., Torres, O., and Ahn, C.: A 12-Year Long Global Record of Optical Depth of Absorbing Aerosols above the Clouds Derived from OMI/OMACA Algorithm, Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2018-172, Accepted, 2018.

Aug 12, 2006

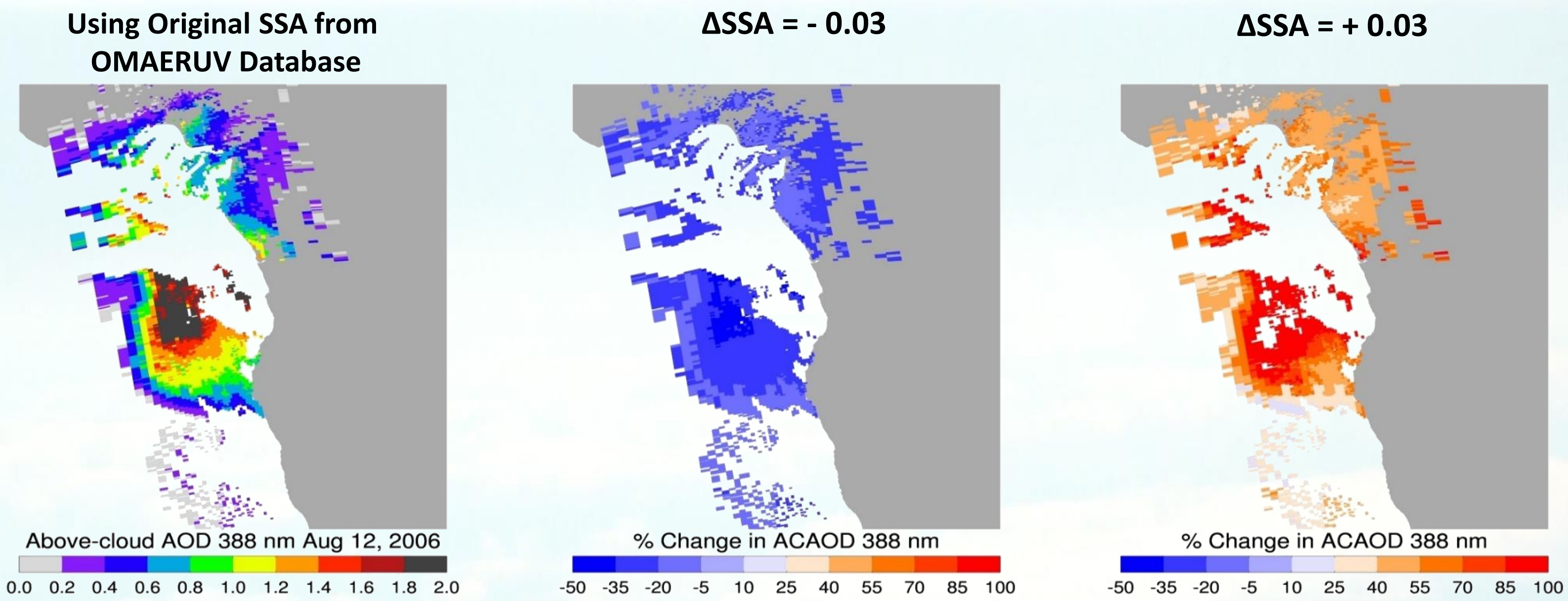


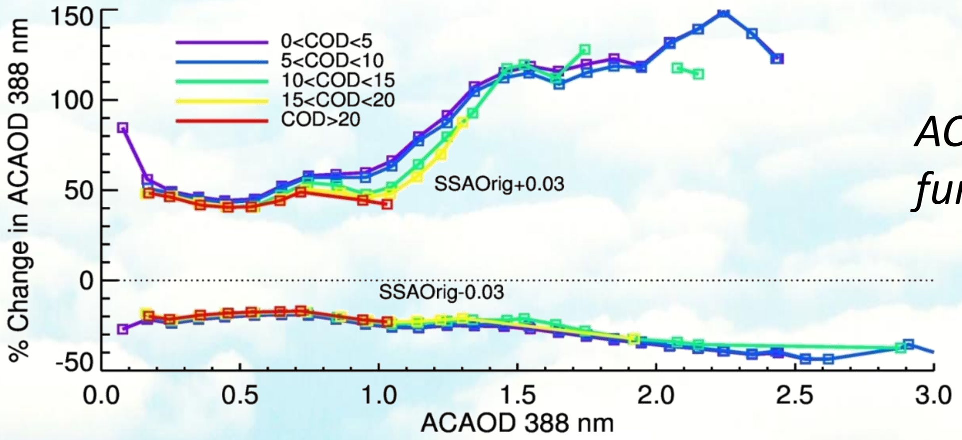
Sources of Uncertainties

TABLE 2. Percentage error in retrieved AOD and COD associated with the uncertainty of the prescribed values of Z, SSA, and AAE.

	AOD = 0.5, COD = 5		AOD = 0.5, COD = 10	
	AOD	COD	AOD	COD
Z_{und} (2 km)	40	4	26	9
Z_{ovr} (2 km)	−19	−1	−12	−3
SSA_{und} (0.03)	−25	4	−23	1
SSA_{ovr} (0.03)	48	−5	43	−1
AAE_{und} (0.4)	23	3	19	14
AAE_{ovr} (0.4)	−14	−1	−65	−5

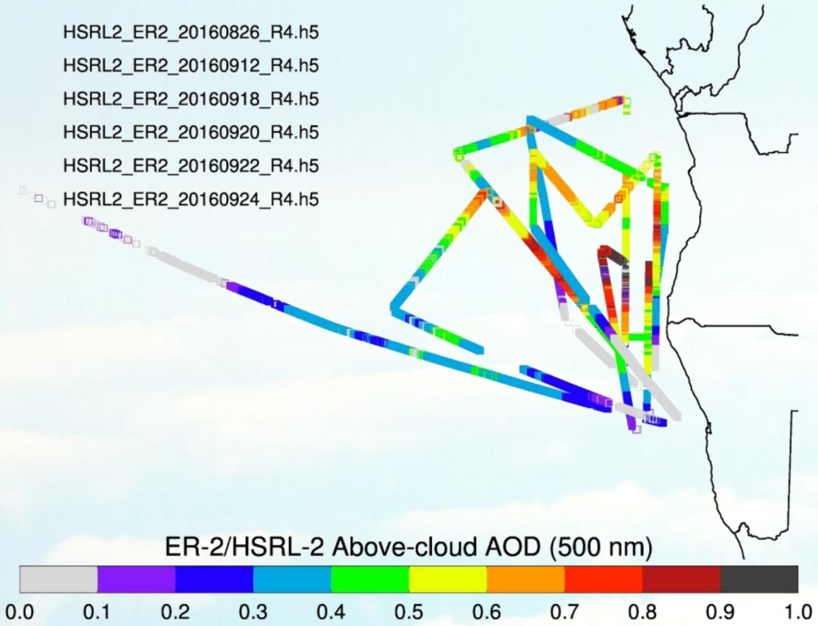
Torres *et al.* (2012)





ACAOD uncertainty a dynamic function of AOD and COD

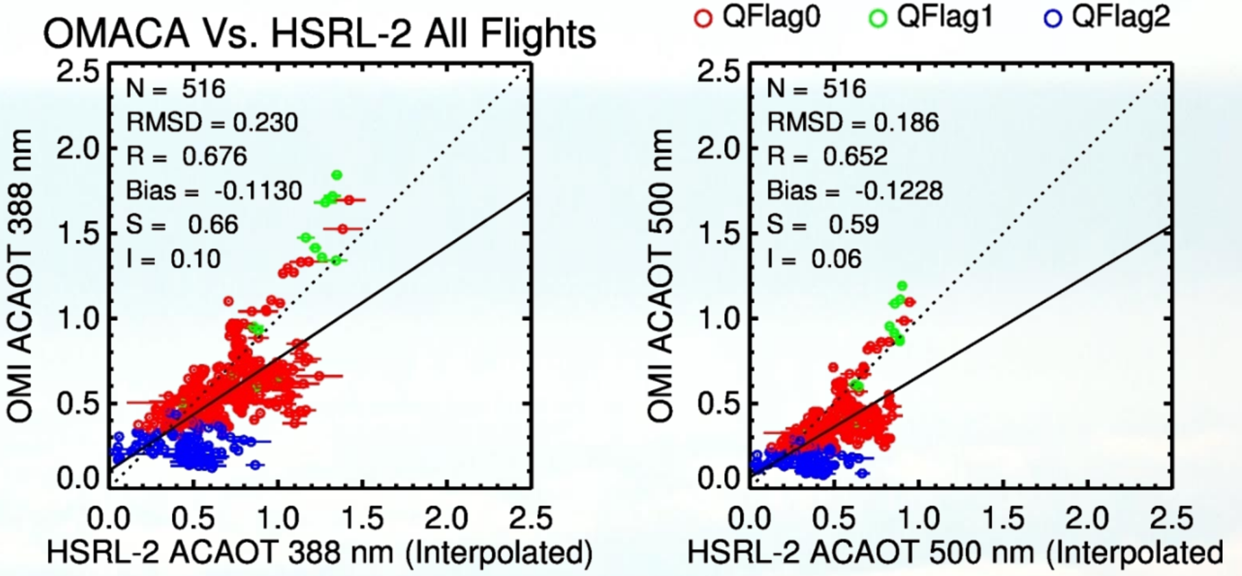
OMI/OMACA
Above-cloud AOD Validation using ORACLES-1/HSRL-2 Measurements



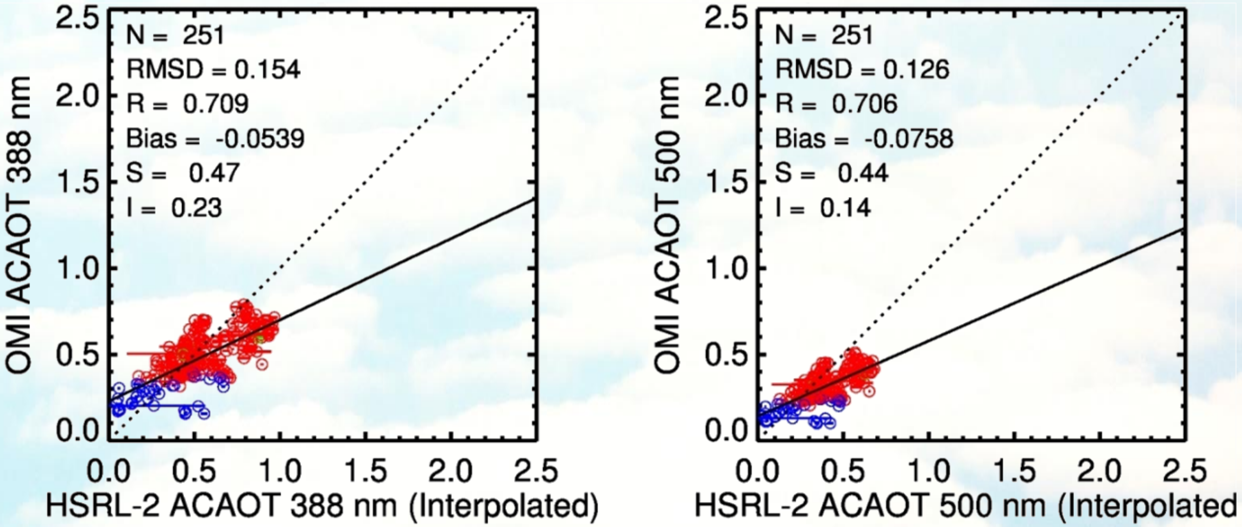
HSRL-2 onboard ***ER***-2 platform during ORACLES phase I operation in Aug/Sep 2016.

Total number of flights = 7
(Aug 26, Sep 12, 16, 18, 20, 22, 24)

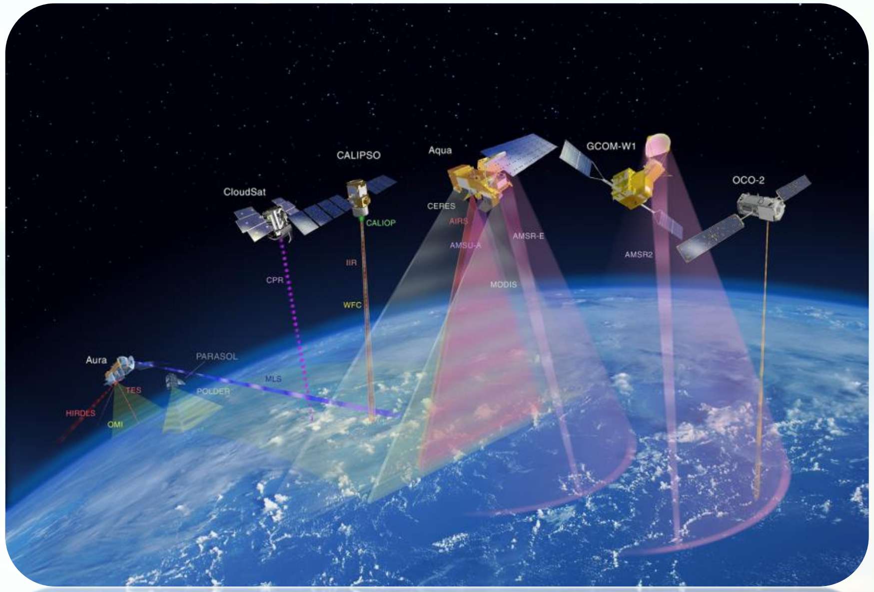
ΔT = ± 6 hours



ΔT = ± 2 hours



Related Work by Other Groups



Hu et al. (2007) JGR
Use of CALIOP de-polarization ratio at **532** nm to deduce AOD above cloud

Chand et al. (2008) JGR
Use of CALIOP **color ratio between 1064 and 532** nm to deduce AOD above cloud

Both are research techniques not yet operationalized

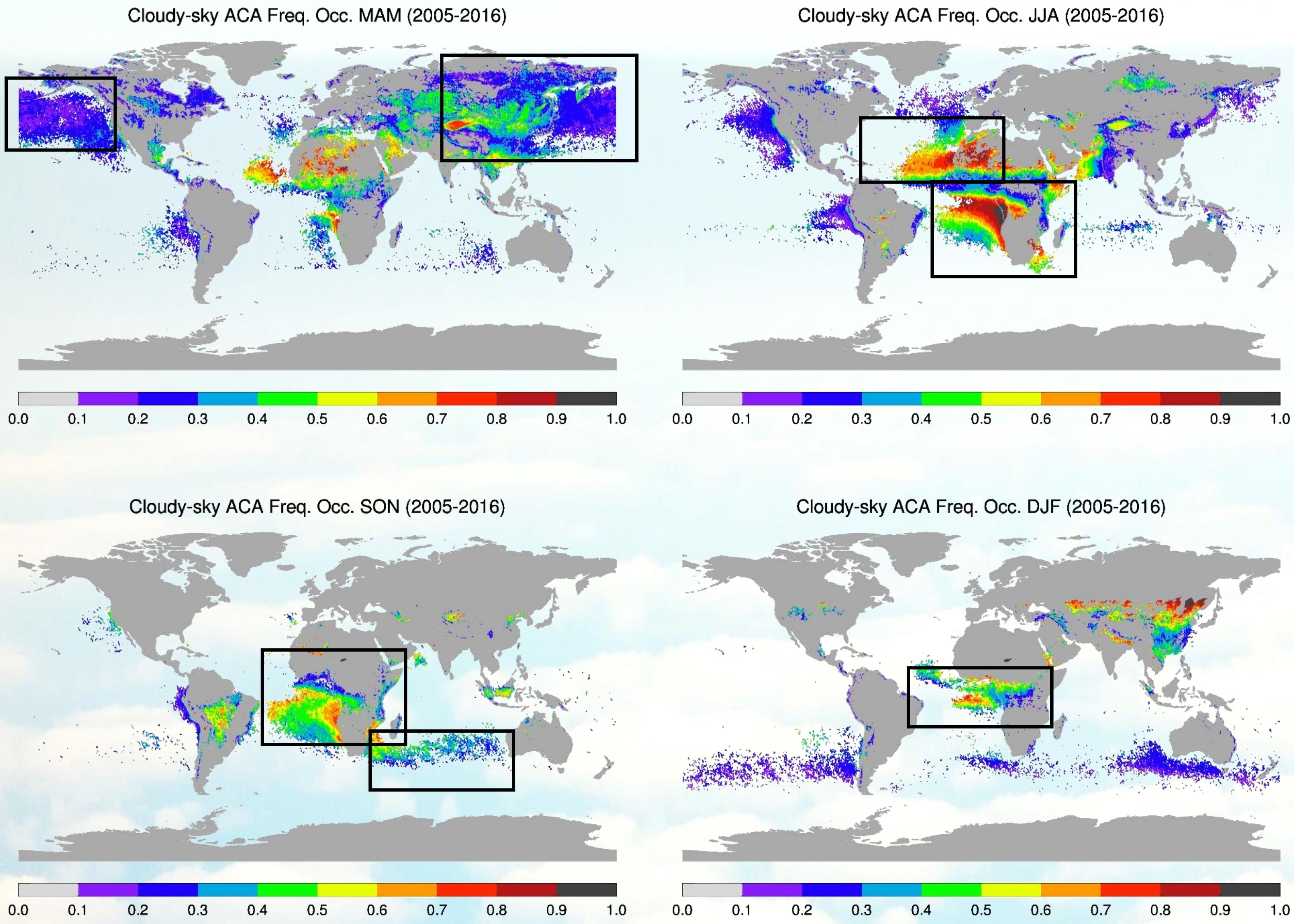
Waquet et al. (2009) JAS
Smoke aerosol optical depth from POLDER/PARASOL **polarized light signal** at 860 nm → Operation period: 2005-2013

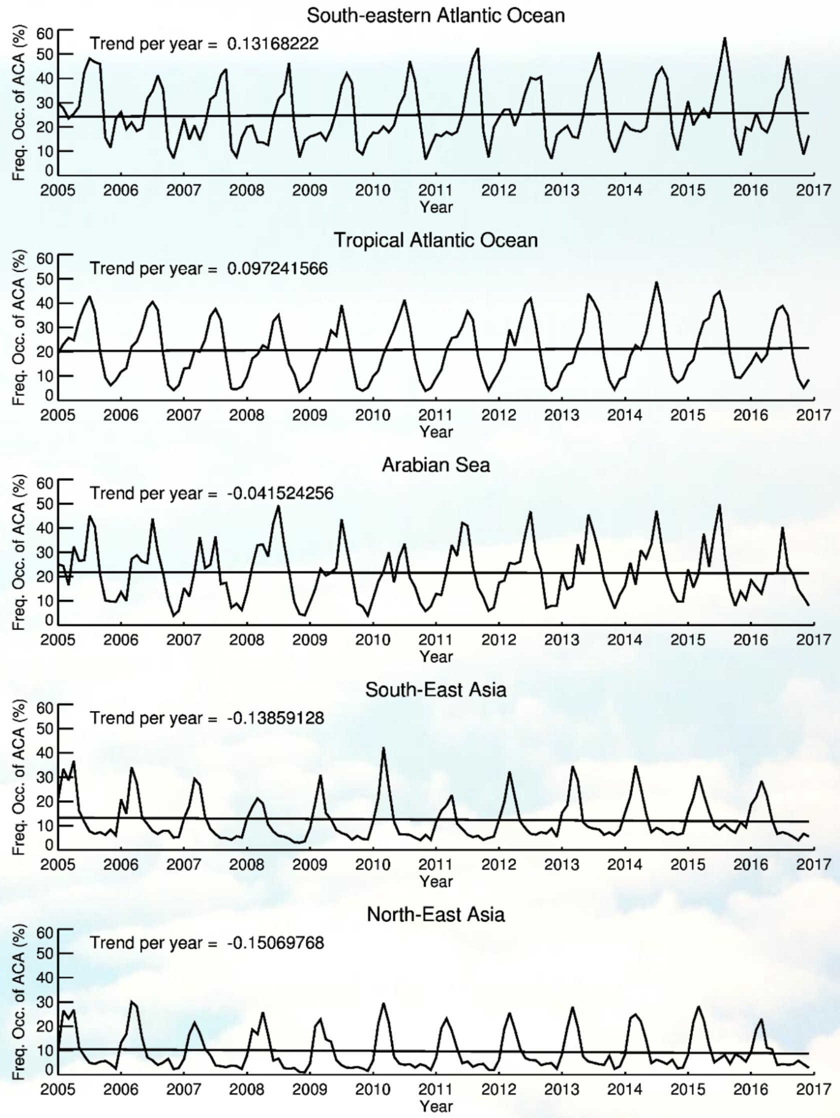
Jethva et al. (2013) IEEE-TGRS
Extension of OMI's color ratio technique to MODIS VIS observations → Standalone algorithm not yet applied globally

Meyer et al. (2015) JGR
MODIS-based **Multi-spectral Inversion** of ACAOD → Aqua record processed for Southeastern Atlantic Ocean

Sayer et al. (2016) JGR
MODIS **multi-spectral inversion** using Optimal Estimation method → Extends Deep-blue aerosol retrieval coverage to cases of absorbing aerosols above clouds

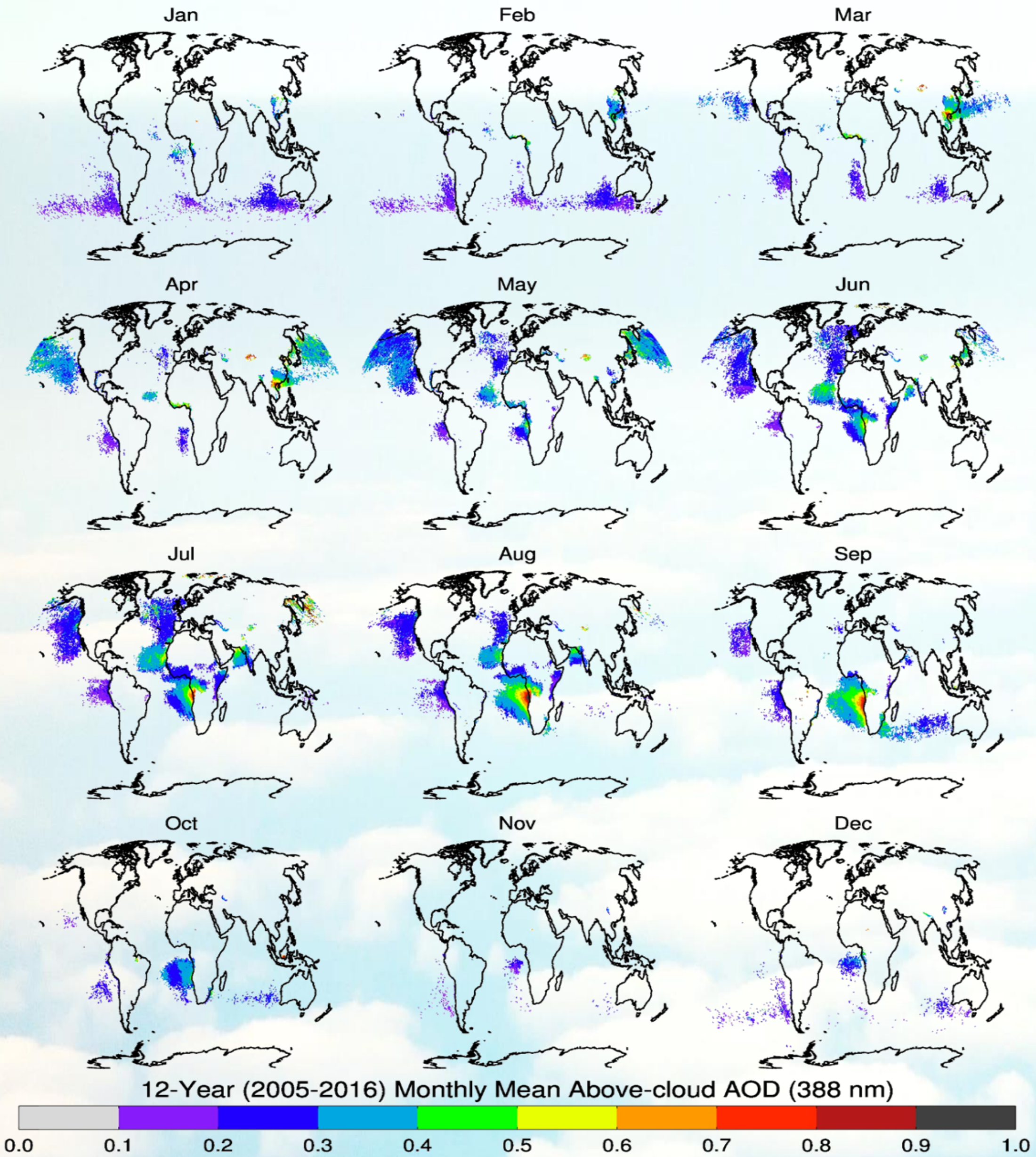
Frequency of Occurrence of ACA

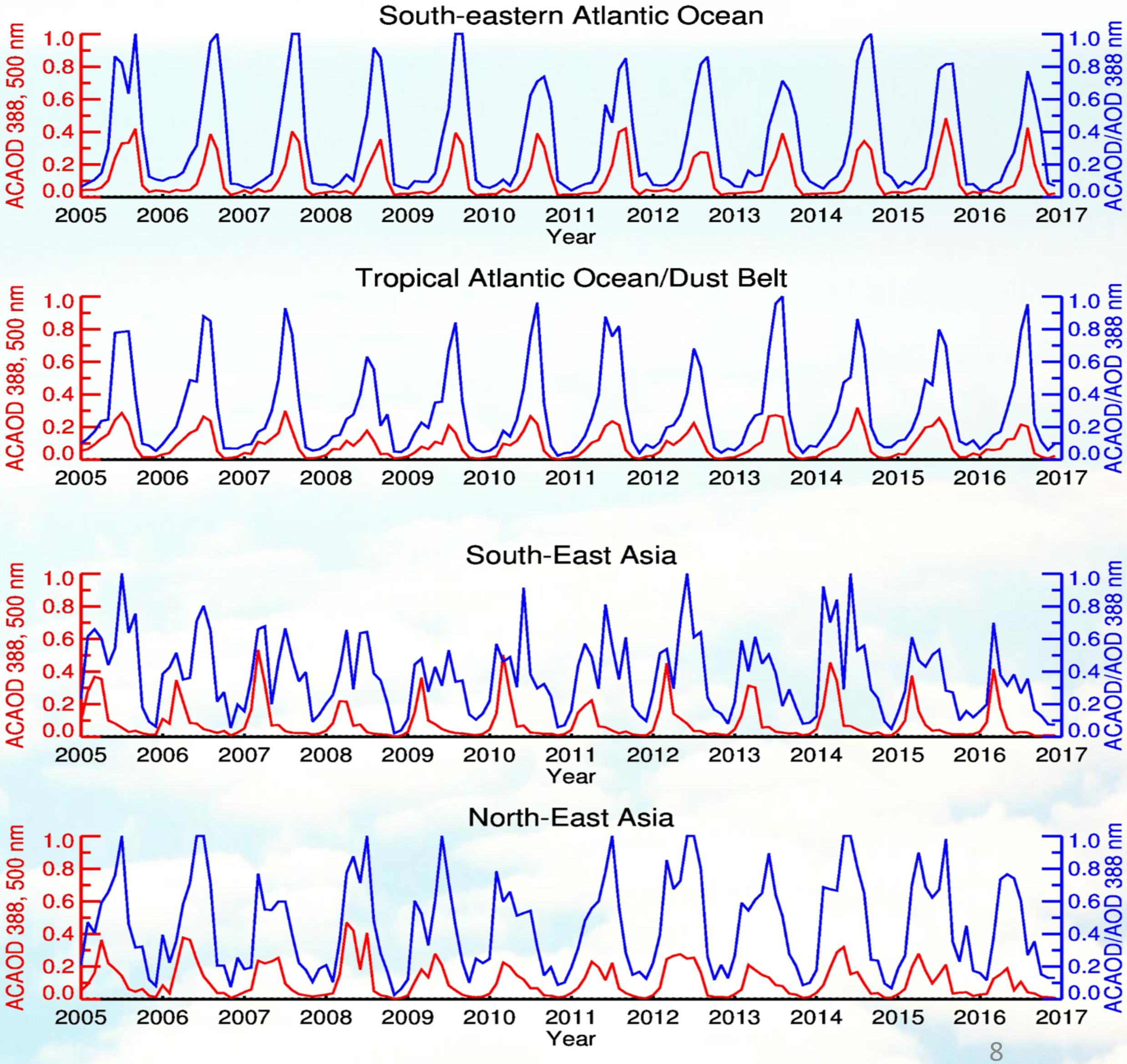




No significant trend over aerosol-cloud overlap areas

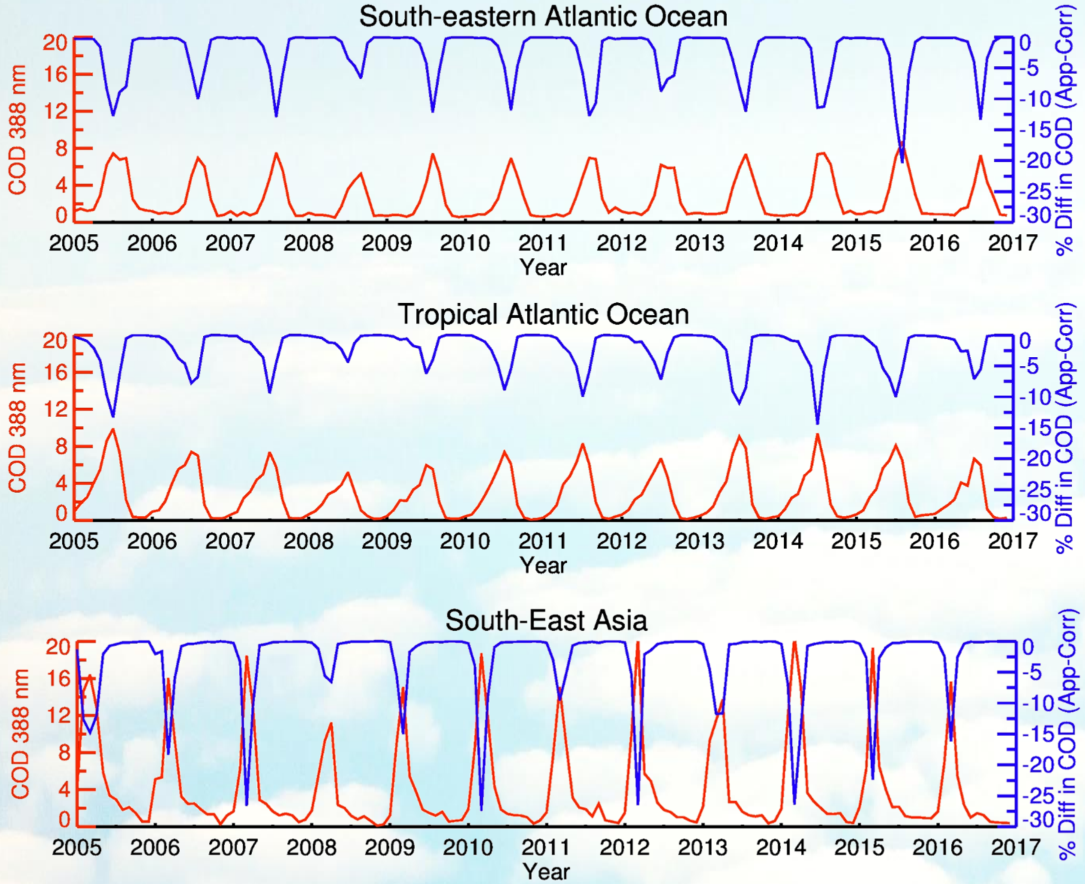
Long-term Monthly ACAOD

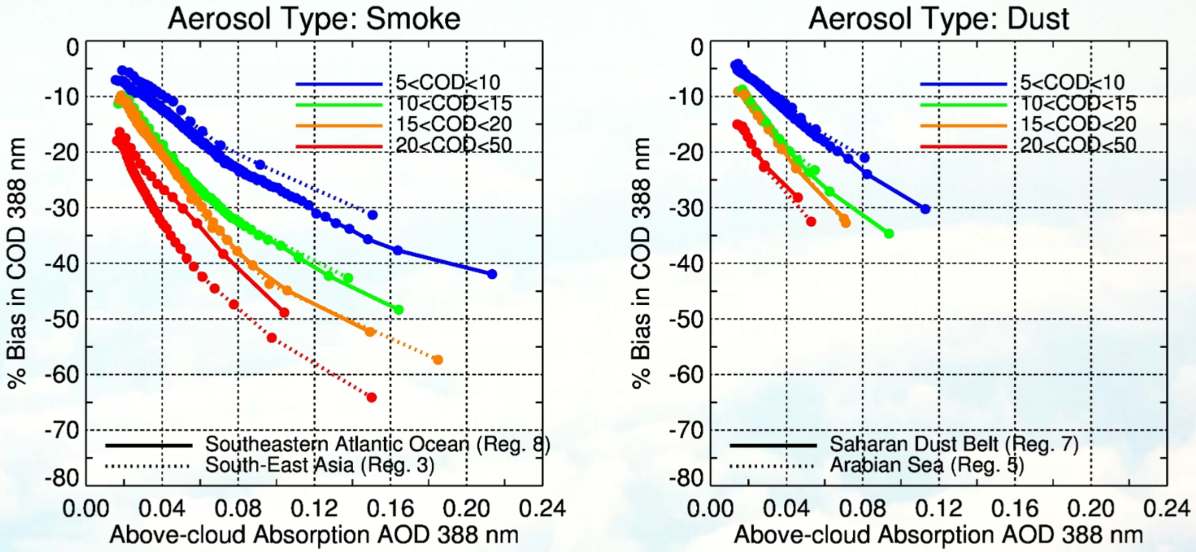




Impact of Aerosol Absorption on Cloud Retrievals

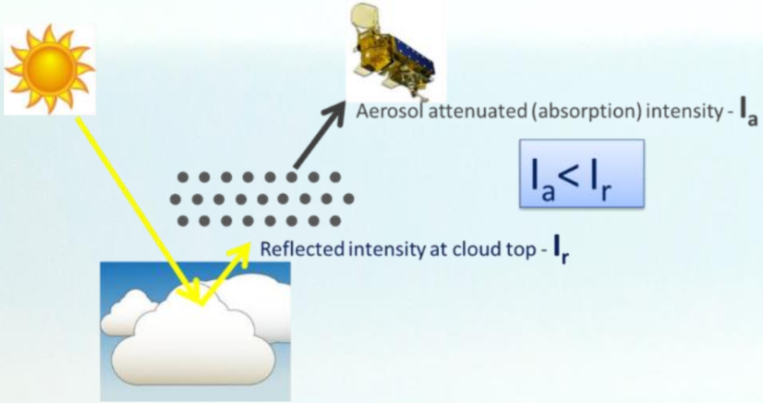
Presence of absorbing aerosols above cloud obstructs the light reflected by the cloud top, and thus reduces cloud-reflected upwelling UV [*Torres et al.*, 2012], VIS, and NIR radiation [*Jethva et al.*, 2013, 2016; *Meyer et al.*, 2015] reaching the TOA

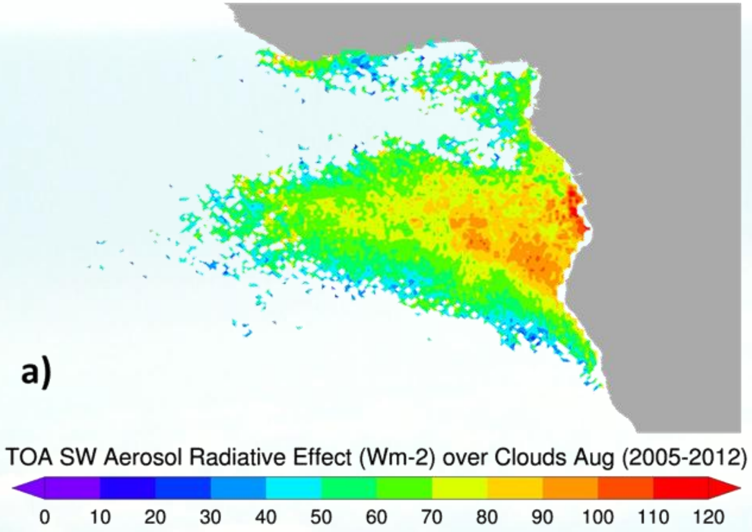


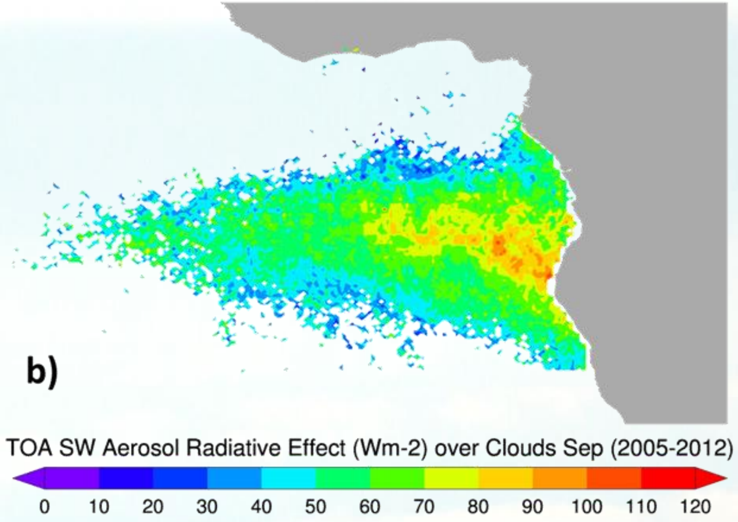


Bias in COD (if aerosols not accounted) = *f* (AOD,SSA,COD)

Direct Radiative Effects of Above-cloud Aerosols: OMI-CERES Synergy





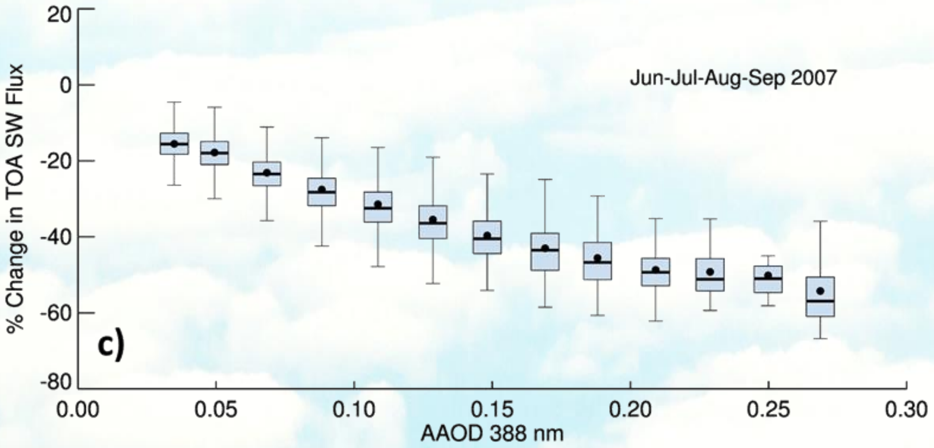


CERES SW fluxes on OMI footprint

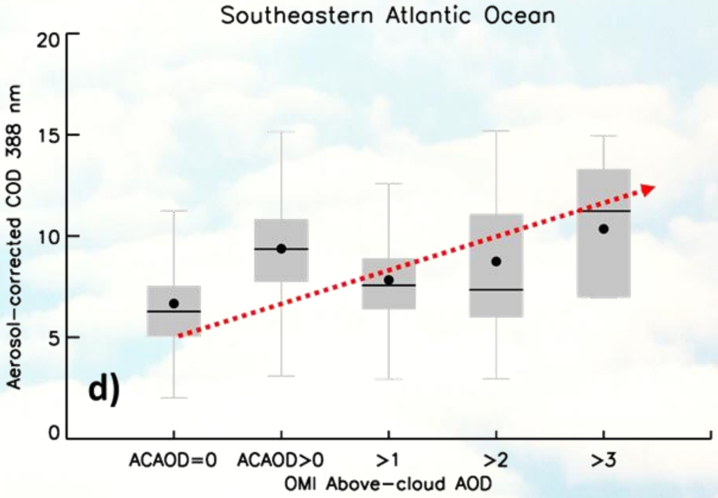
Cloud-top fluxes parameterized using COD retrievals and CERES TOA SW fluxes for scenes with UV-AI<0.5

Atmospheric warming= CloudTop flux – TOA flux

Abs. aerosols reduce TOA SW flux over clouds



Semi-direct effect of aerosols on clouds



Direct Radiative Effects of Above-cloud Aerosols

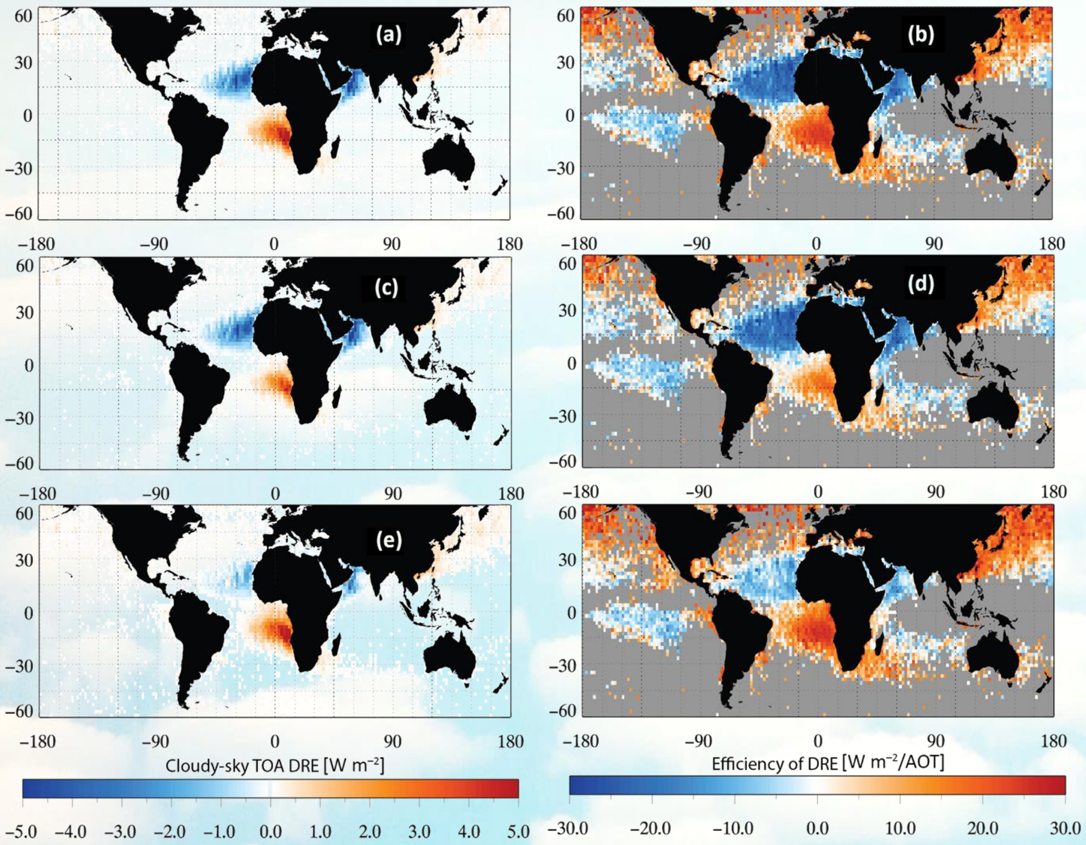
Atmos. Chem. Phys., 16, 2877–2900, 2016
www.atmos-chem-phys.net/16/2877/2016/
doi:10.5194/acp-16-2877-2016

Atmospheric Chemistry and Physics
Open Access
EGU

CALIOP-MODIS Synergy

Shortwave direct radiative effects of above-cloud aerosols over global oceans derived from 8 years of CALIOP and MODIS observations

Zhibo Zhang[1,2], Kerry Meyer[3,4], Hongbin Yu[3,5], Steven Platnick[3], Peter Colarco[3], Zhaoyan Liu[6,7], and Lazaros Oreopoulos[3]



Estimating the direct radiative effect of absorbing aerosols overlying marine boundary layer clouds in the southeast Atlantic using MODIS and CALIOP

Kerry Meyer,[1,2] Steven Platnick,[2] Lazaros Oreopoulos,[2] and Dongmin Lee[1,2]

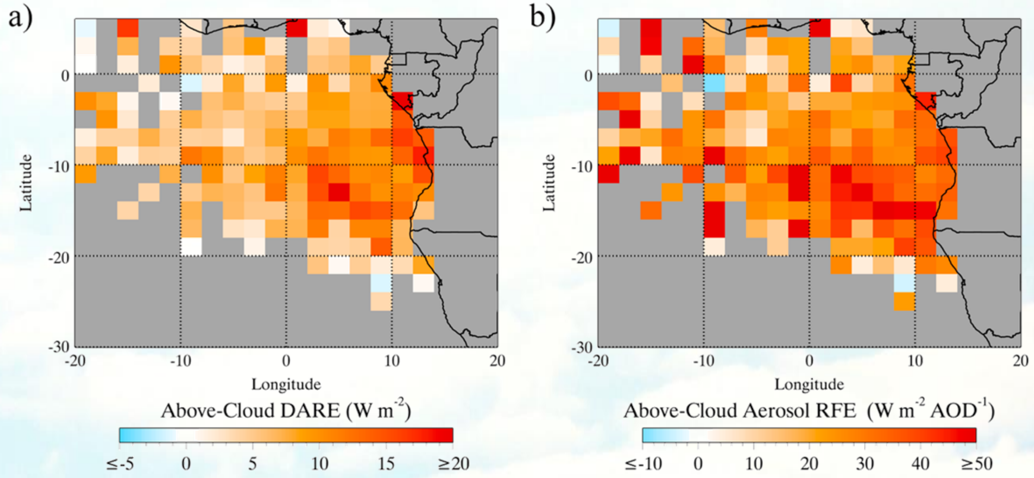
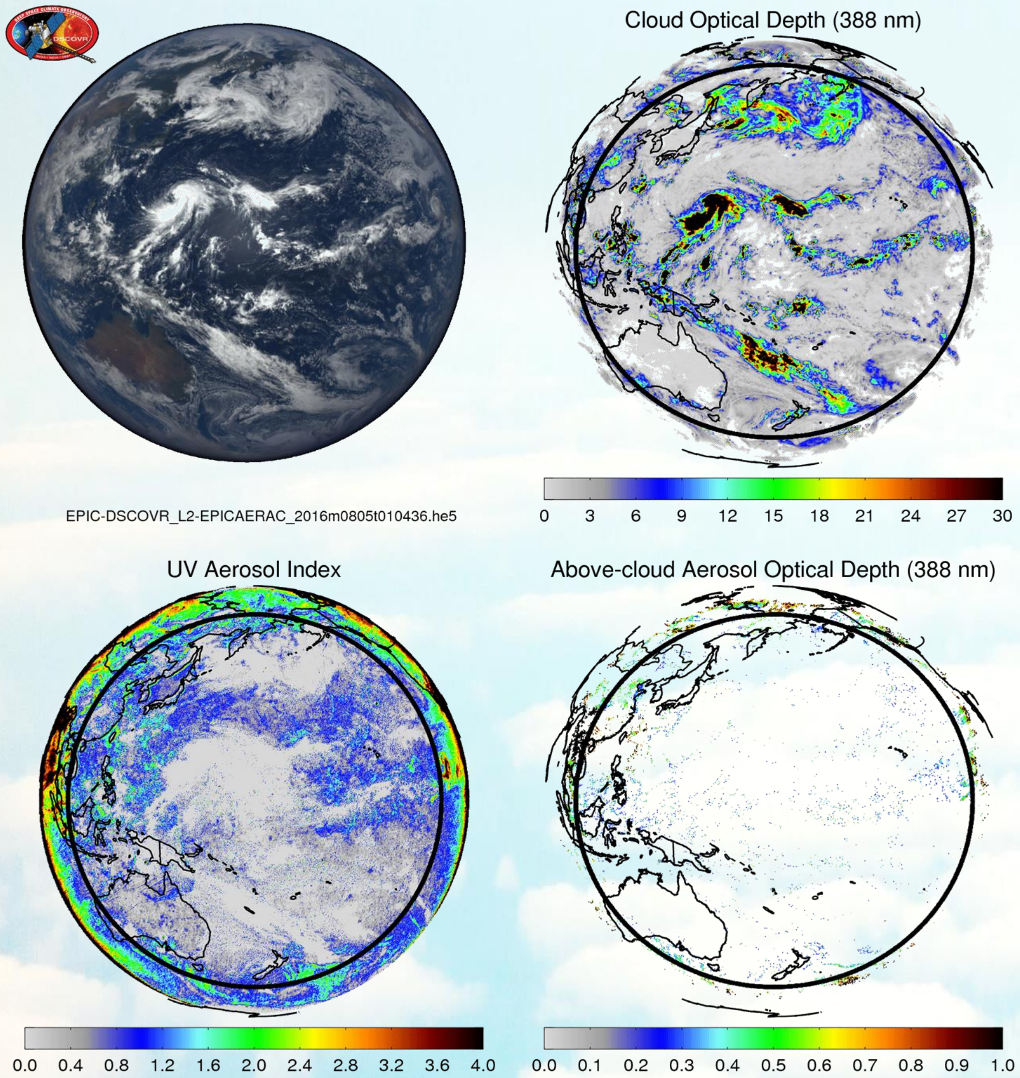
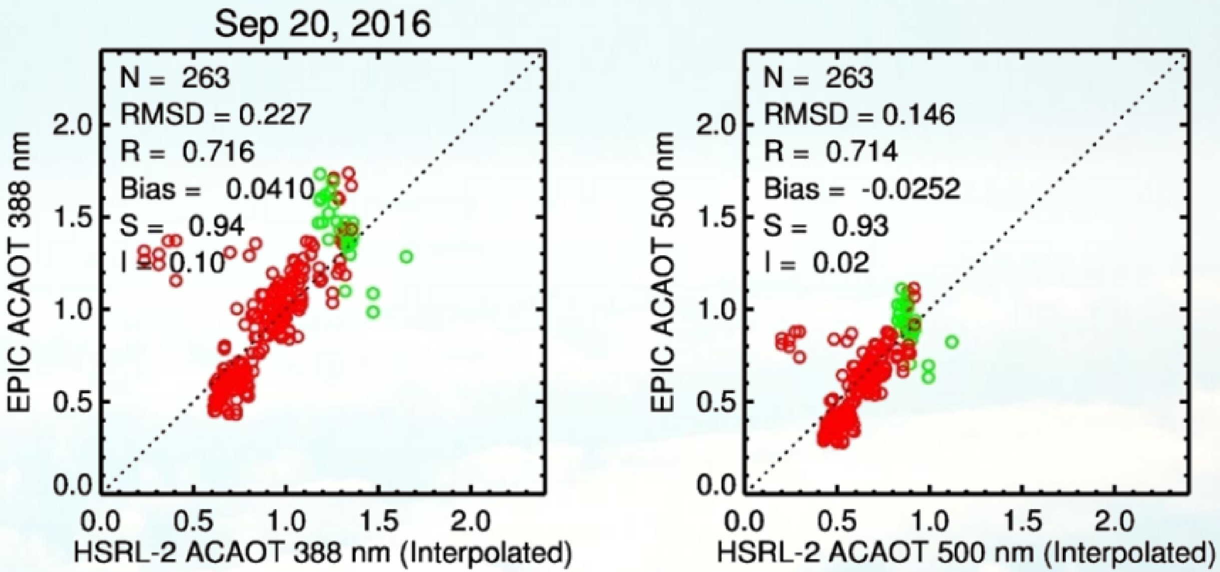


Figure 10. Gridded mean instantaneous (i.e., time of observation) above-cloud direct aerosol radiative effect (DARE) at (a) TOA and (b) aerosol radiative forcing efficiency (RFE), averaged over the 6 year CALIOP/MODIS collocated data record (August/September 2006–2011), for cloudy MODIS pixels for which CALIOP produces a reliable above-cloud smoke subtype aerosol retrieval.

Going beyond OMI…

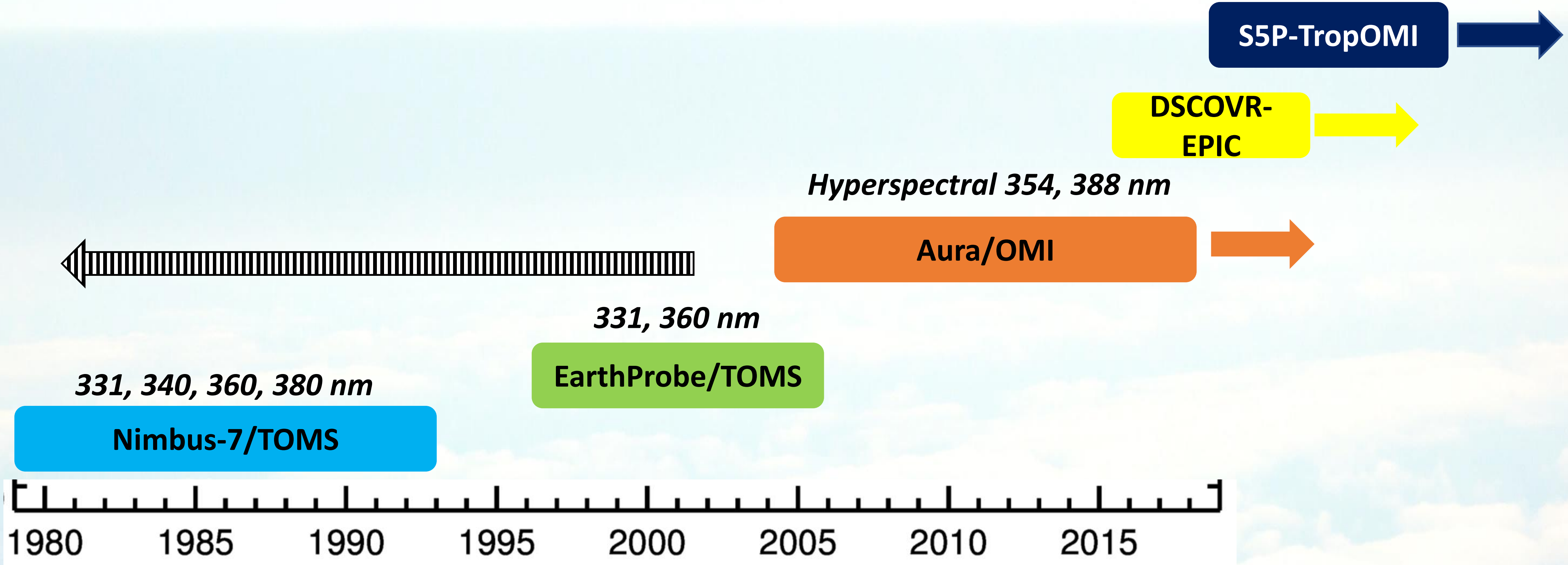
Application of Near-UV 'Color Ratio' Algorithm to ***DSCOVR-EPIC***





- *ACAOD product from EPIC is being processed*
- *Plans are underway to apply OMACA to* ***Sentinel-P 5/ TropOMI***

Long-term Near-UV Above-cloud Aerosol Record



- **Produced a consistent near-UV above-cloud AOD dataset from Aura-OMI and DSCOVR-EPIC**
- **Dataset from S5P-TropOMI underway**
- **Record can be extended to TOMS on *Nimbus-7* and *EarthProbe* beginning 1979**

Airborne Campaigns

The NASA Earth Venture Suborbital-2 **ORACLES** (Observations of Aerosols above Clouds and their interactions; http://espo.nasa.gov/oracles)

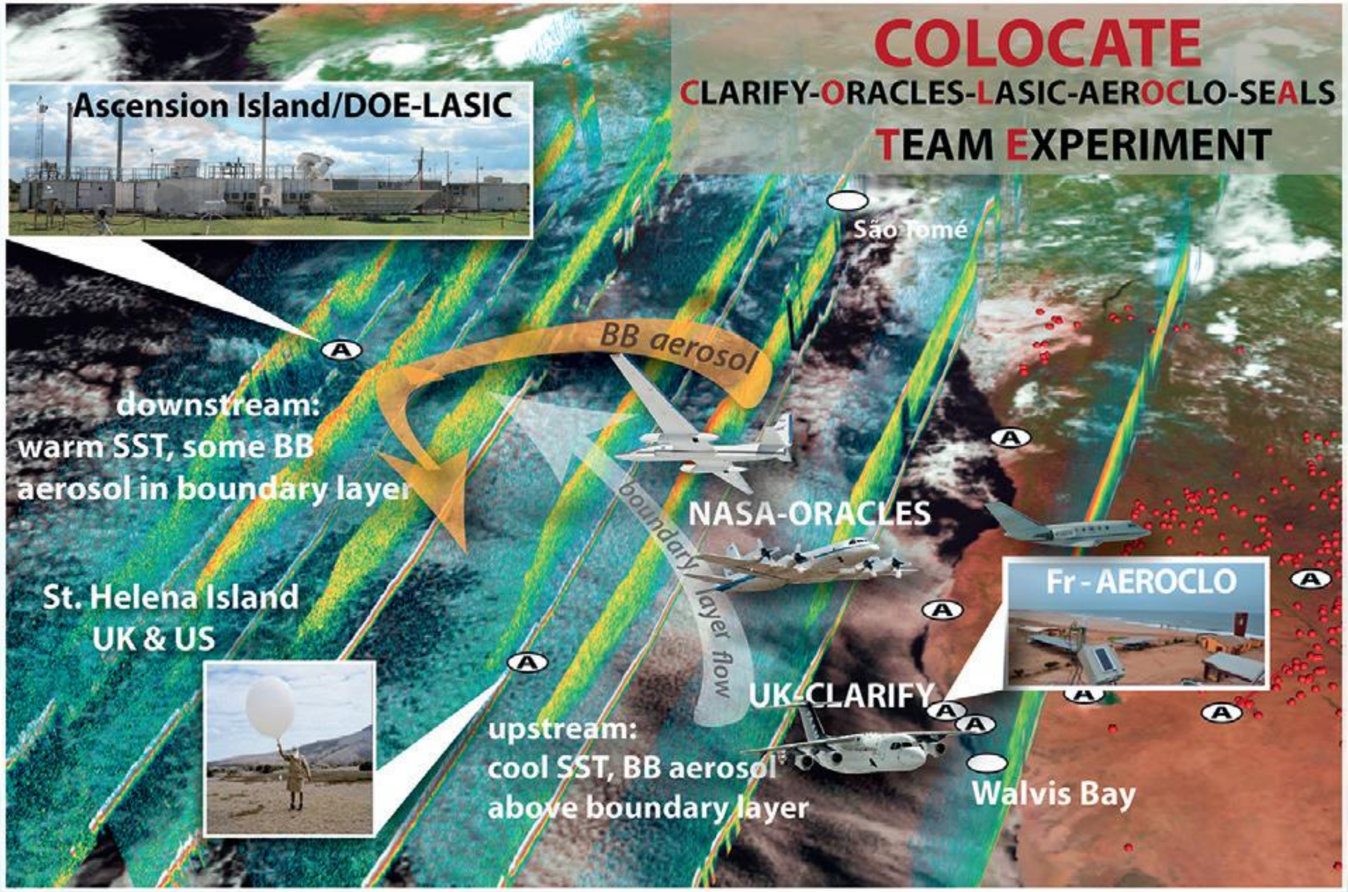
- 3-year intensive observations period (2016-2017-2018, Aug-Oct)
- P-3 and ER-2 platforms

The **UK CLARIFY** (Clouds and Aerosol Radiative Impacts and Forcing: Year 2016) campaign brought the UK FAAM BAe-146 plane to Ascension Island in Aug 2017, overlapping with ORACLES-2017

The **DOE LASIC** (Layered Atlantic Smoke Interactions with Clouds; www.arm.gov/campaigns/amf2016lasic) campaign deployed the ARM Mobile Facility 1 (AMF1) to Ascension Island from 1 June 2016 to 31 October 2017

The **French AEROCLO-sA** (Aerosol Radiation and Clouds in southern Africa) extends a long-term collaboration with South Africa and Namibia taking aerosol column and in situ measurements at the Henties Bay Aerosol Observatory, approximately 100 km north of Walvis Bay, since 2012

The Sea Earth Atmosphere Linkages Study in southern Africa (**SEALS-sA**) proposes to use research vessel measurements to better understand the complex coastal land–atmosphere–ocean coupling



Zuidema, P., et al. (2016), Interactions: Smoke and Clouds above the Southeast Atlantic Upcoming Field Campaigns Probe Absorbing Aerosol's Impact on Climate, Bull. Am. Meteorol. Soc., 19-23, doi:10.1175/BAMS-D-15-00082.1.

Summary

- Exciting time as efforts to characterize aerosols above clouds from multiple groups have taken place.

- A global OMI/OMACA algorithm developed and applied to OMI observations (product stored on publicly accessible AVDC data portal)

  - Validation using ORACLES-1/HSRL-2 measurements shows a good-level of agreement
  - Global freq. of occurrence of above-cloud aerosols shows no trend only if 'clean rows' of OMI are used
  - No significant trend in regional ACAOD (except declining trend over NE Asia)
  - Dataset ready for modelers to compare their simulations
  - Very much aligned with the Science Goals laid out today morning

- Plans to apply similar algorithm to <u>*S5P-TropOMI, and TOMS*</u> sensors to derive ~4 decades long-term record of ACA.

Backup Slides

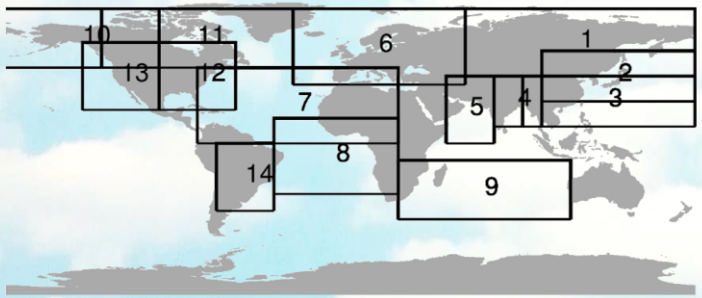
OMACA: A Global OMI Above-Cloud Aerosol Algorithm

Inputs
OMI L1B calibrated & geo-located radiances at 354 and 388 nm

Ancillary information from A-train Sensors
CALIOP-based Aerosol Layer Height climatology

Aerosol type identification using AIRS CO
Smoke or Dust

Regional daily representation of SSA
Use of cloud-free OMAERUV L2 SSA retrievals
Daily regional values of SSA for 14 discrete regions of ACA



Look-up Table
VLIDORT V2.6 Vector Code
OMAERUV 'SMOKE' and 'DUST' models
7 sub-models for each aerosol type (SSA 0.75-1.00)

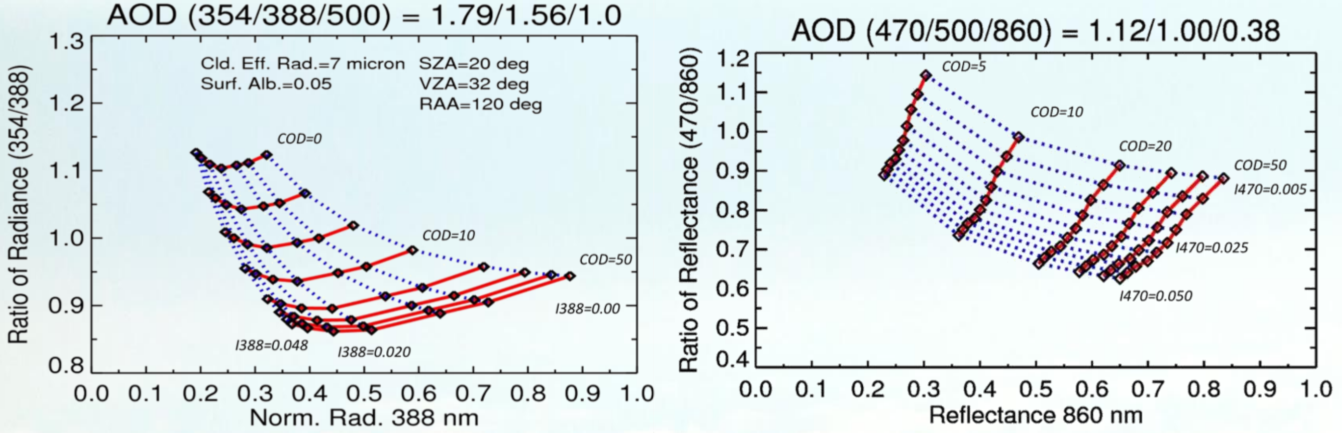
Smoke particles - spherical
Dust – randomly oriented spheroidal dist. (*Dubovik et al.*, 2006)

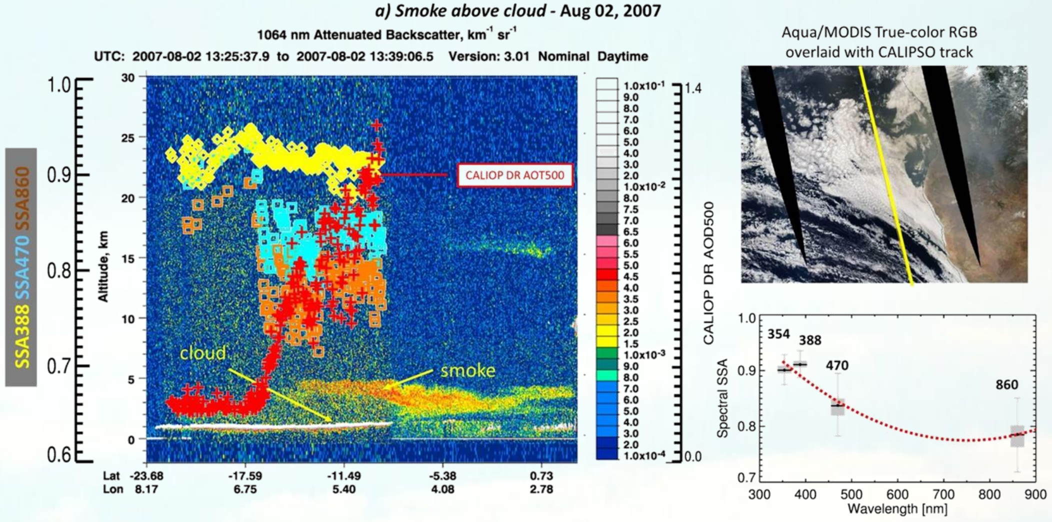
Gaussian profiles of aerosols (3, 4, 5, 6 km) above C1 cloud layer (1-1.5 km)

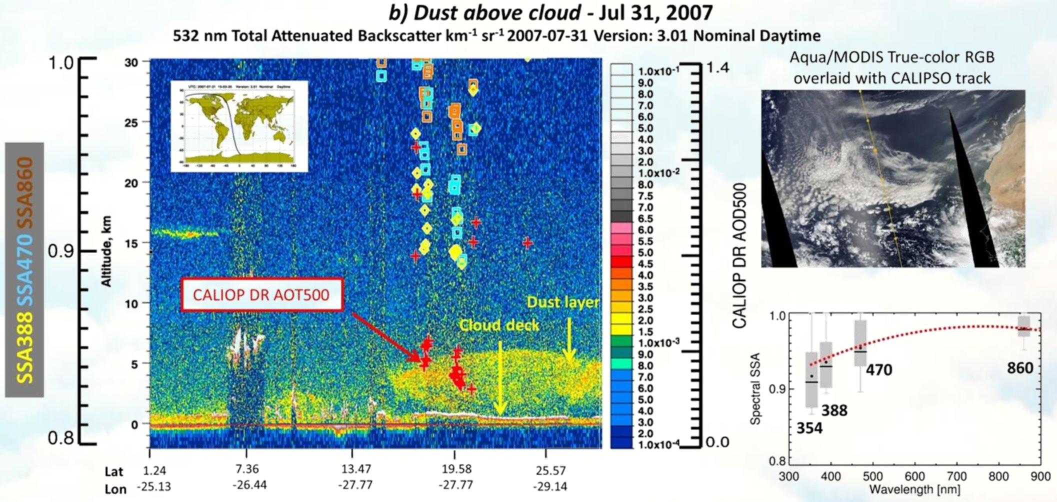
Outputs
Above-cloud AOD (388 nm)
aerosol-corrected COD (388 nm)
ACAODs reported at 354 and 500 nm

The product was officially released in July 2016 and can be accessed at
https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2/OMACA/

Retrieving SSA of Aerosols above Clouds







Inputs

- ***AOD above cloud from De-polarization ratio method [Hu et al., 2007]***
- ***Near-UV and visible reflectances from OMI and MODIS***

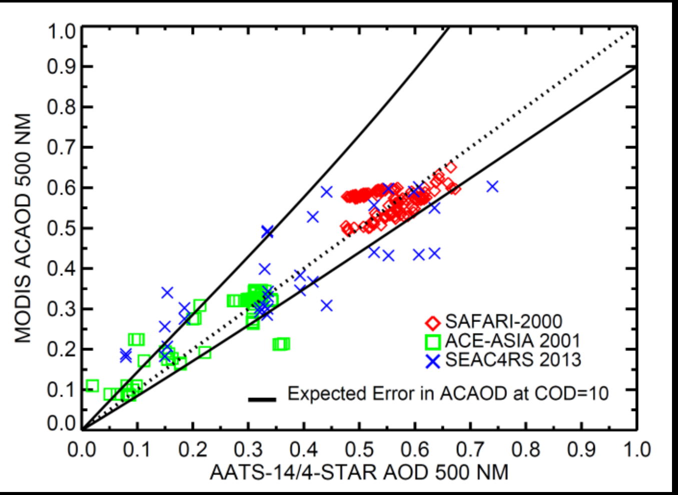
	Error in SSA470/COD(%)					
	Overestimation in AOD			Underestimation in AOD		
AOD500	ΔAOD=+10%	ΔAOD=+20%	ΔAOD=+40%	ΔAOD=-10%	ΔAOD=-20%	ΔAOD=-40%
0.5	0.006/1.45	0.013/2.90	0.025/5.80	-0.006/-1.45	-0.012/-2.90	-0.023/-5.80
1.0	0.006/2.35	0.012/4.70	0.025/9.40	-0.017/0.095	-0.032/0.19	-0.062/0.38
1.5	0.007/3.16	0.013/6.31	0.027/12.62	-0.018/0.35	-0.036/0.69	-0.068/1.38

	Error in SSA470/COD(%)					
	Overestimation in AOD			Underestimation in AOD		
AOD500	ΔAOD=+10%	ΔAOD=+20%	ΔAOD=+40%	ΔAOD=-10%	ΔAOD=-20%	ΔAOD=-40%
0.5	0.006/1.45	0.013/2.90	0.025/5.80	-0.006/-1.45	-0.012/-2.90	-0.023/-5.80
1.0	0.006/2.35	0.012/4.70	0.025/9.40	-0.017/0.095	-0.032/0.19	-0.062/0.38
1.5	0.007/3.16	0.013/6.31	0.027/12.62	-0.018/0.35	-0.036/0.69	-0.068/1.38

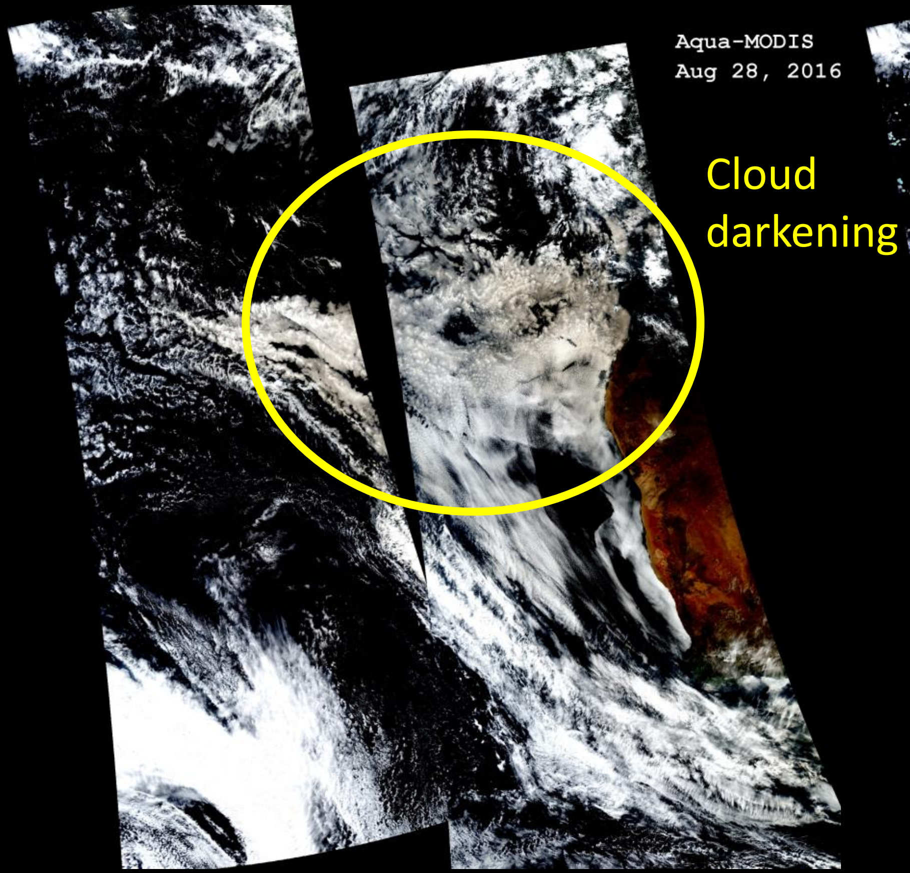
“Color Ratio” Method for Above-cloud AOD Retrieval from MODIS

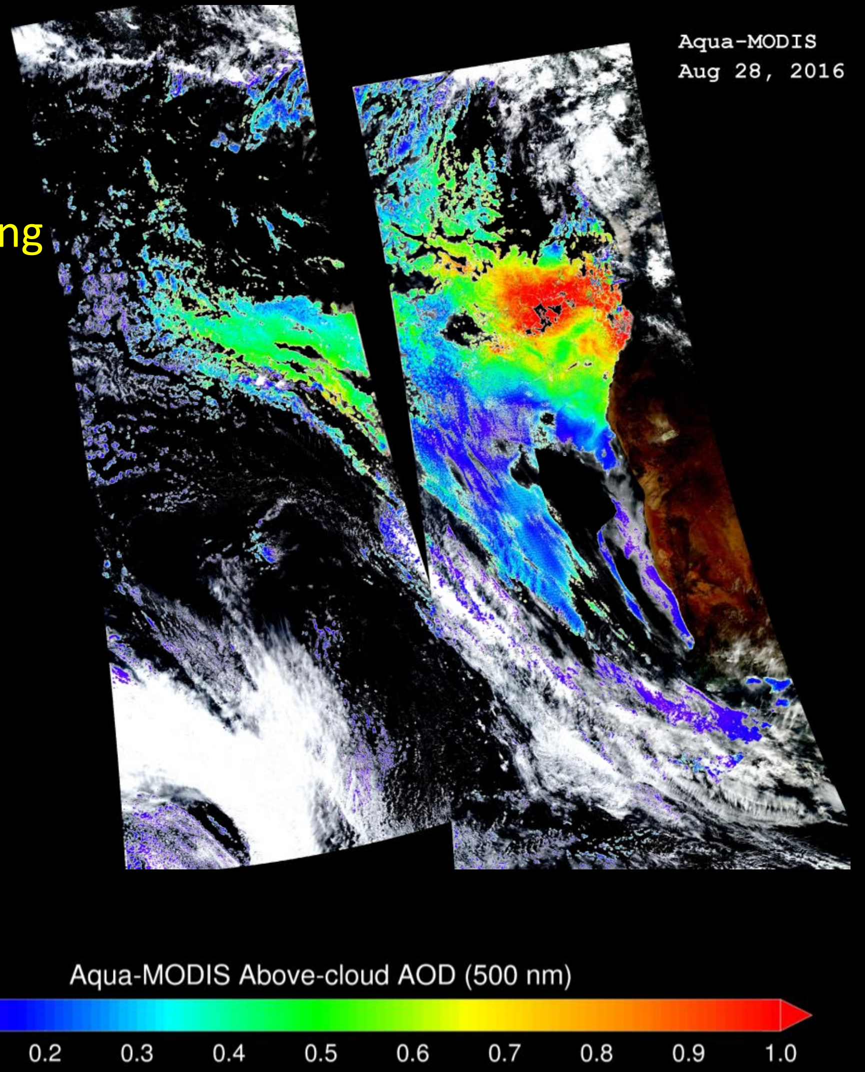
- Aerosol absorption above cloud produces a strong “color ratio” effect in spectral TOA reflectance
- Use of two channels: 470 and 860 nm
- Simultaneous retrieval **of <u>above-cloud AOD</u>** and **<u>aerosol-corrected COD</u>** [*Jethva et al.* 2013 IEEE TGRS]

Validation using airborne Sunphotometer meas.



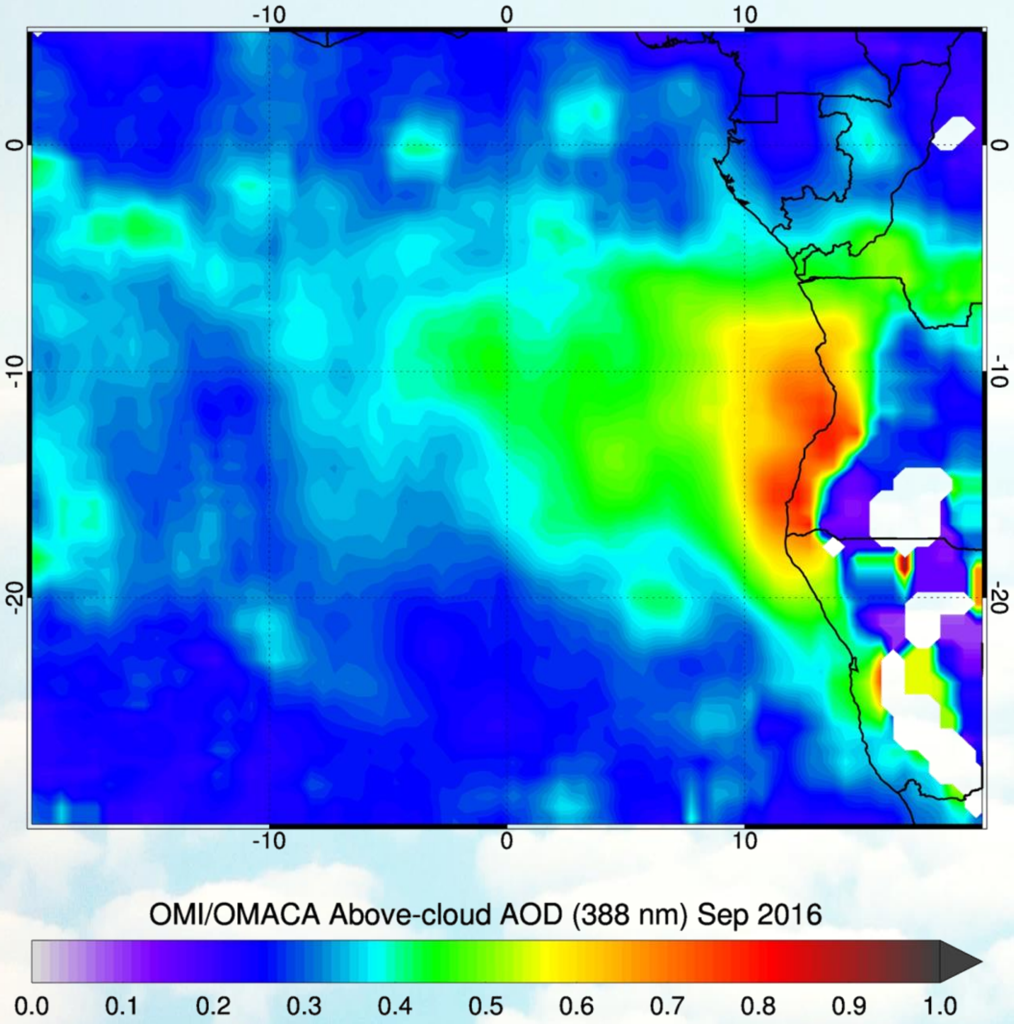
Jethva et al [2016] AMT



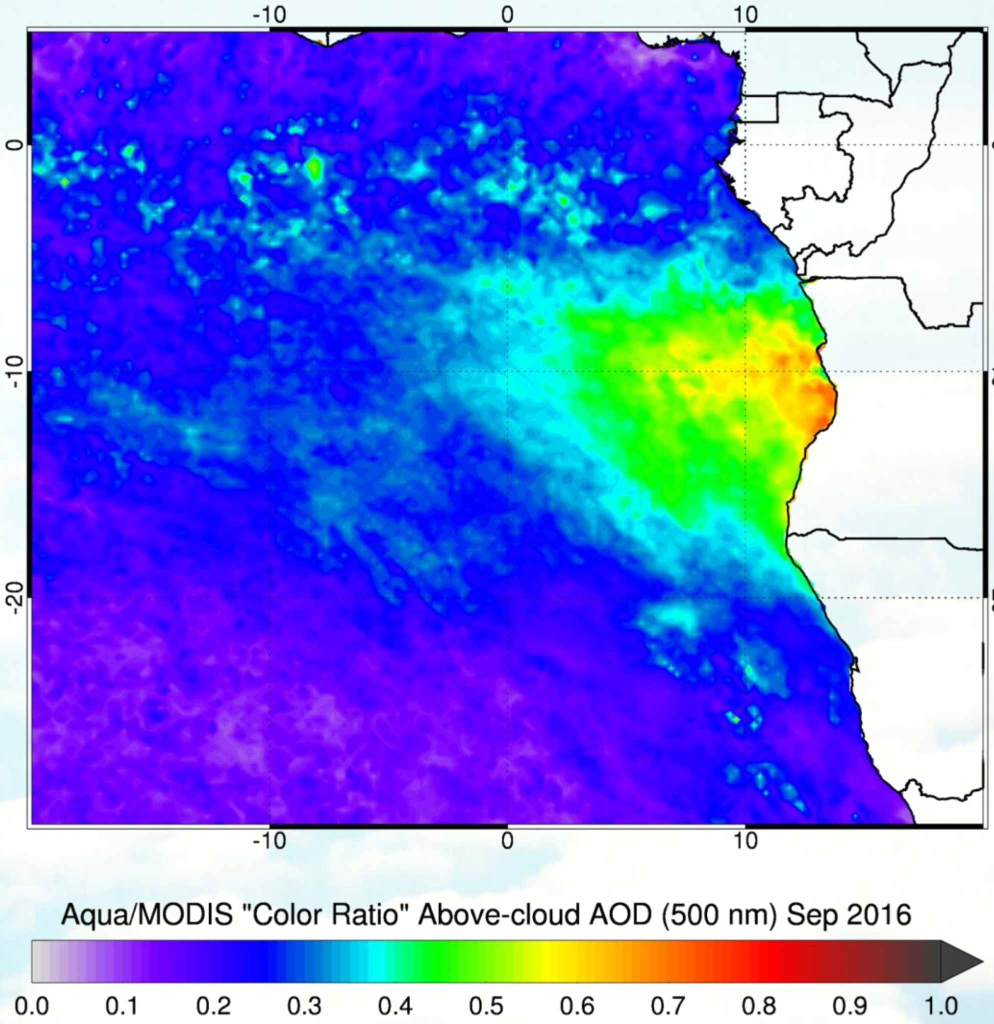


September 2016 ORACLES Y1 Deployment

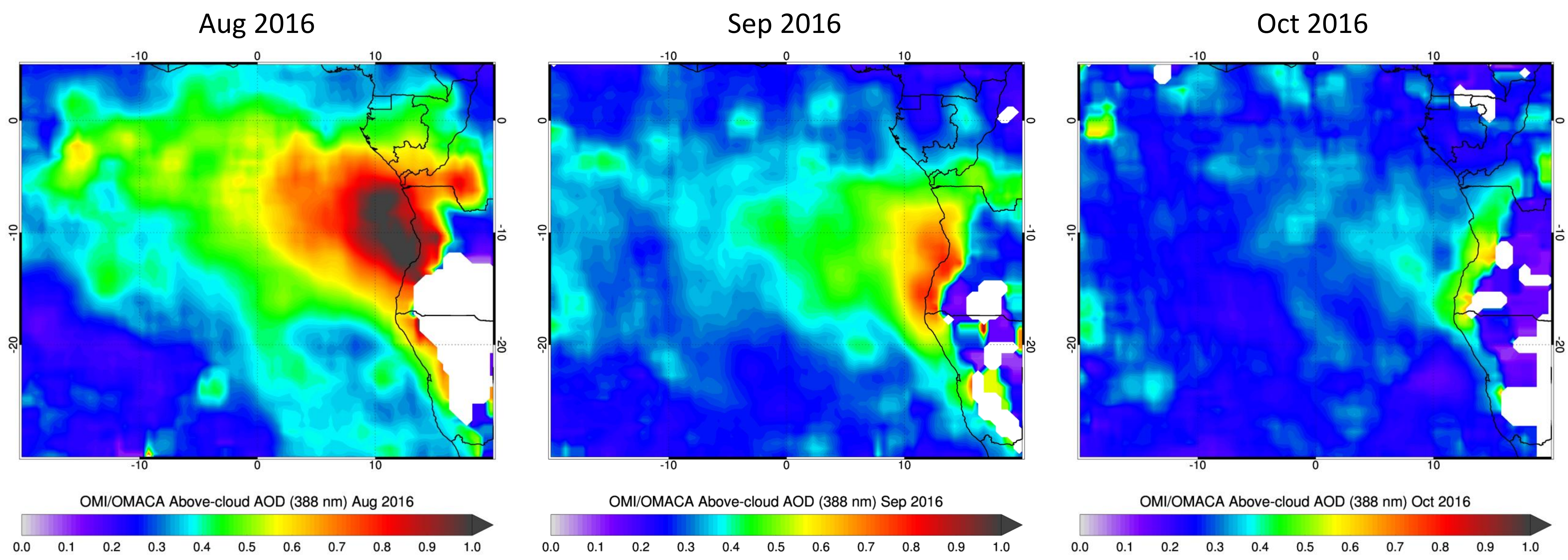
OMI ACAOD (388 nm)



MODIS ACAOD (500 nm)



OMI Above-cloud AOD (388 nm)



OMI Above-cloud AOD (388 nm)