Advances in passive remote sensing of aerosol vertical profile

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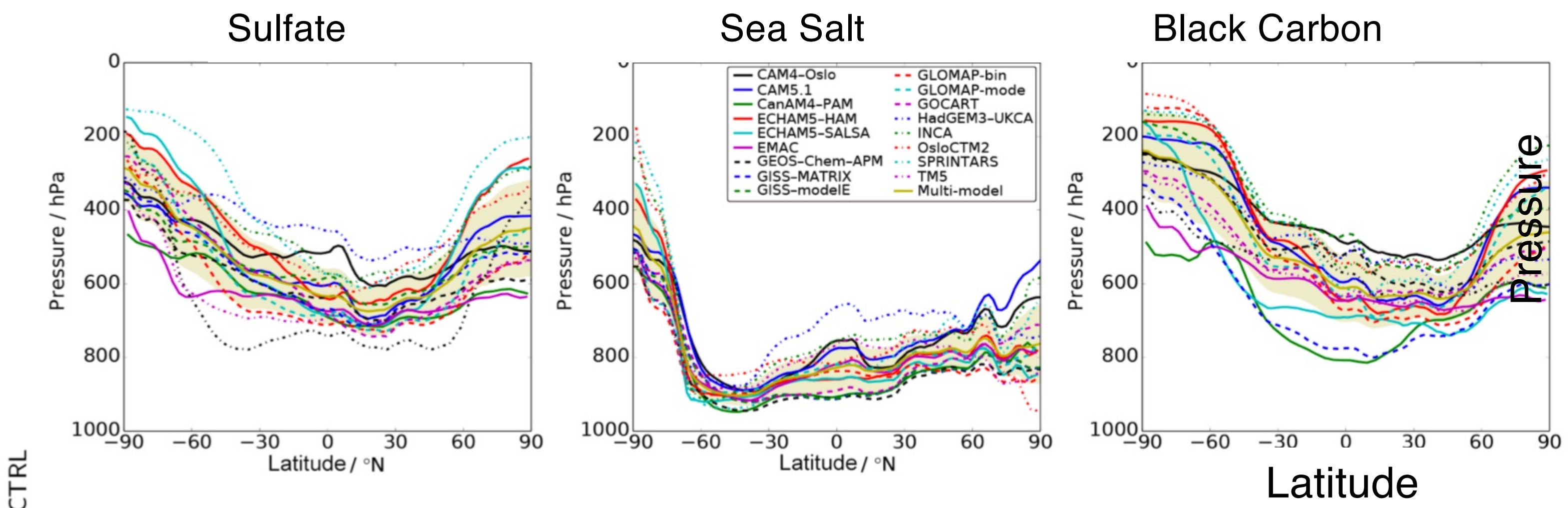
THE UNIVERSITY OF IOWA

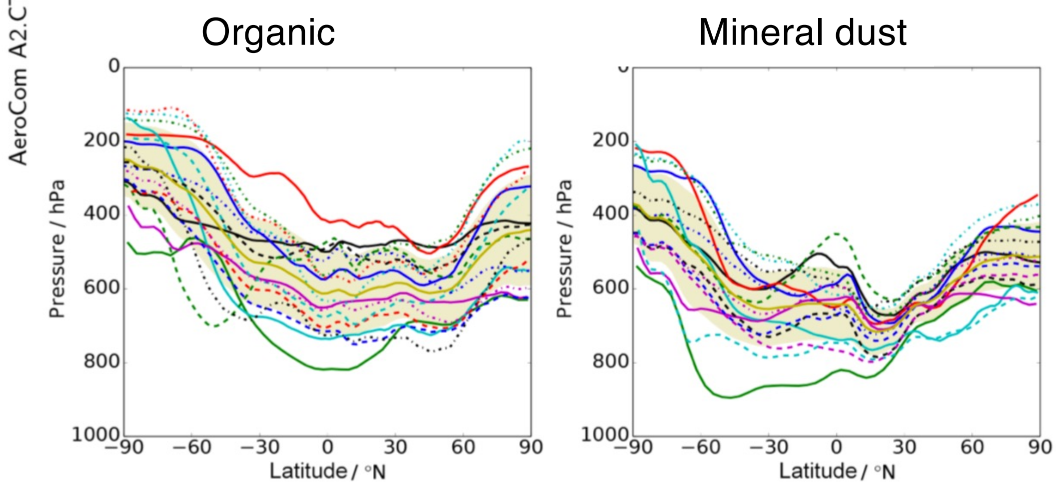
ICAP meeting
Nov. 2023

Importance of aerosol vertical distribution

- Monitoring surface air quality from space
- Aerosol direct and indirect effects on climate
- Aerosol effects on atmospheric chemistry & gas retrievals & aerosol retrievals (especially at UV bands)
- Long-range transport and biosphere-atmosphere interactions
- Air quality & climate forecast
- …

Large uncertainty in aerosol vertical profile





Annual- and zonal-mean mass-weighted mean pressure level (vertical center of mass in pressure coordinates)

Kipling et al., 2016; ACP. AeroCOM-II

Our 15-year journey of passive sensing of aerosol layer height

2023

First Mapping of Monthly and Diurnal **Climatology** of Saharan Dust Layer Height Over the Atlantic Ocean From EPIC/DSCOVR in Deep Space, GRL., Lu Wang et al.

2021

Hourly Mapping of the Layer Height of Thick Smoke Plumes Over the Western U.S. in 2020 Severe Fire Season, FRS Lu, Wang, et al.,

First retrieval of absorbing aerosol height over dark target using TROPOMI oxygen B band, *RSE*, Chen, Wang et al.

Can multi-angular polarimetric measurements in the oxygen-A and B bands improve the retrieval of aerosol vertical distribution? *JQSRT*, Chen, Wang, et al.

2019, Detecting layer height of smoke aerosols over vegetated land and water surfaces via oxygen absorption bands: Hourly results from EPIC/DSCOVR satellite in deep space

Passive remote sensing of aerosol height, in Remote Sensing of Aerosols, Clouds, and Precipitation, Xu, Wang, et al. in Remote Sensing of Aerosols, Clouds, and Precipitation

2017, Passive remote sensing of altitude and optical depth of dust plumes using the oxygen A and B bands: First results from EPIC/DSCOVR at Lagrange-1 point, GRL, Xu, Wang, et al.,

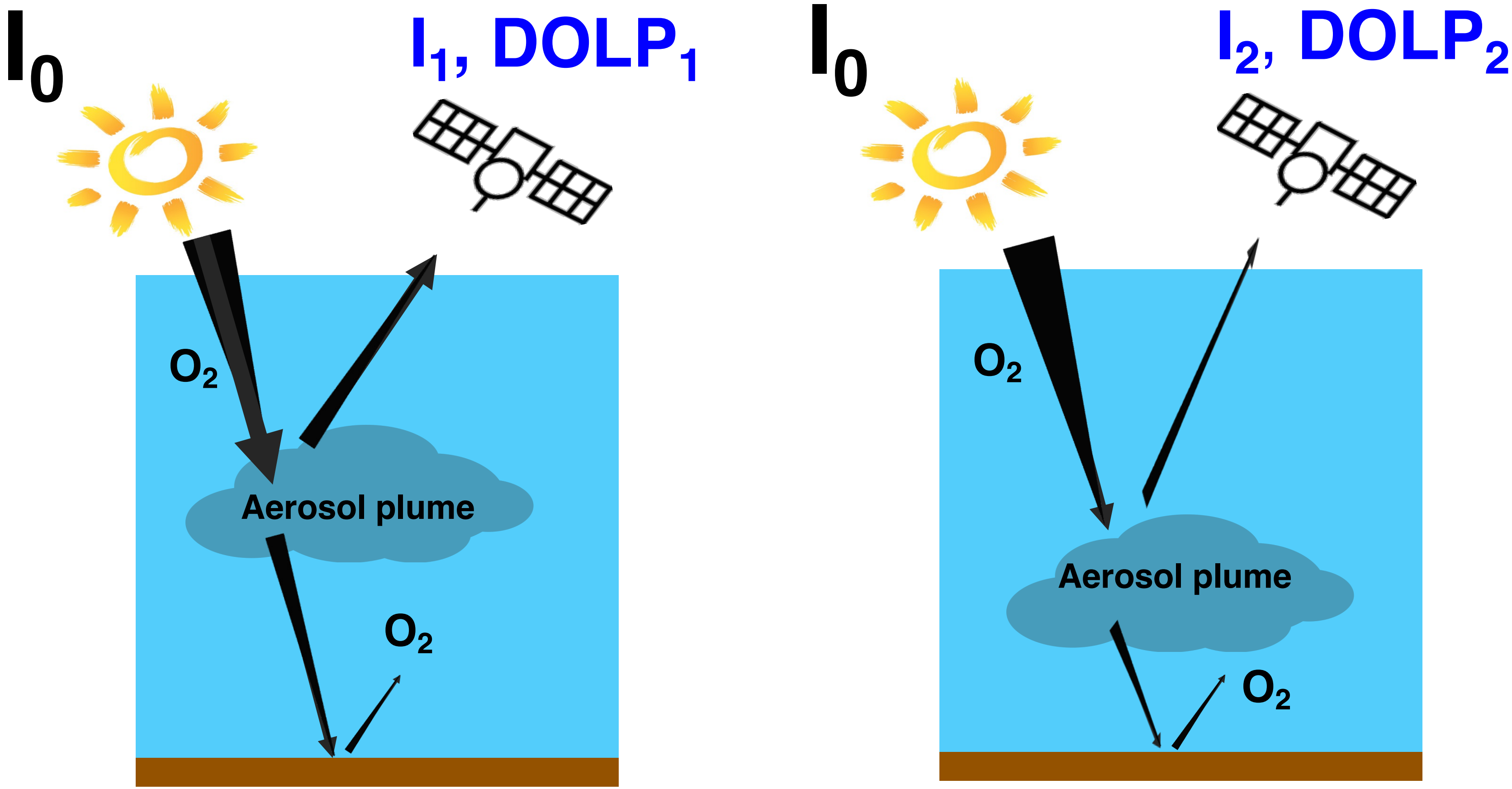
2016, Polarimetric remote sensing in **O2 A and B** bands: Sensitivity study and information content analysis for vertical profile of aerosols, AMT, Ding, Wang et al.

2014, A numerical testbed for remote sensing of aerosols, and its demonstration for evaluating retrieval synergy from a geostationary satellite constellation of GEO-CAPE and GOES-R, JQSRT, Wang et al.

2008, High-spectral resolution simulation of polarization of skylight: sensitivity to aerosol vertical profile, GRL, Zeng, Wang, & Han.

supported by ONR, NASA, and NOAA

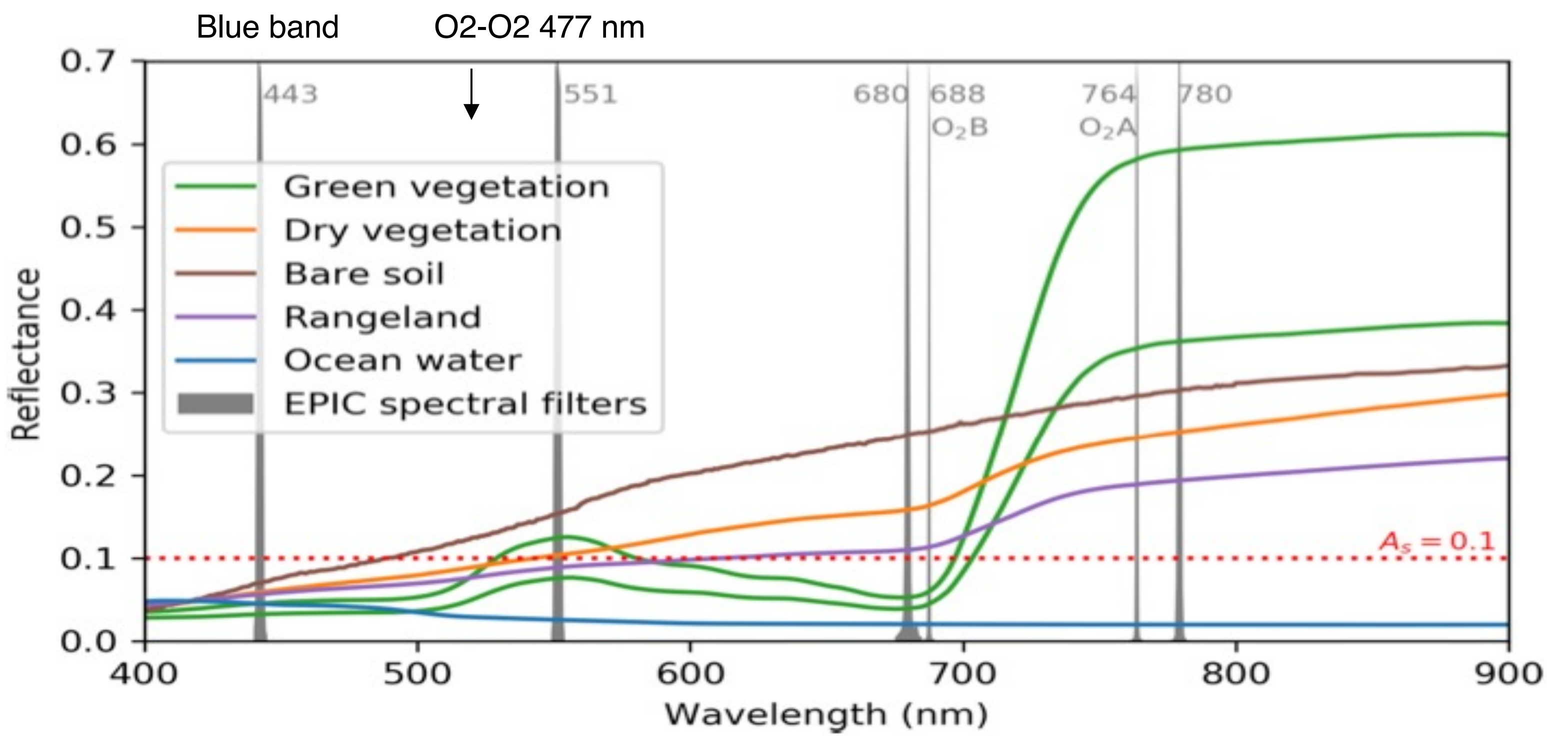
At O2 absorption band:



$I_1 > I_2$, DOPL$_1$ $<$ DOLP$_2$ (in most cases)

Advantages of O2 B band vs. A Band & O_2-O_2 band

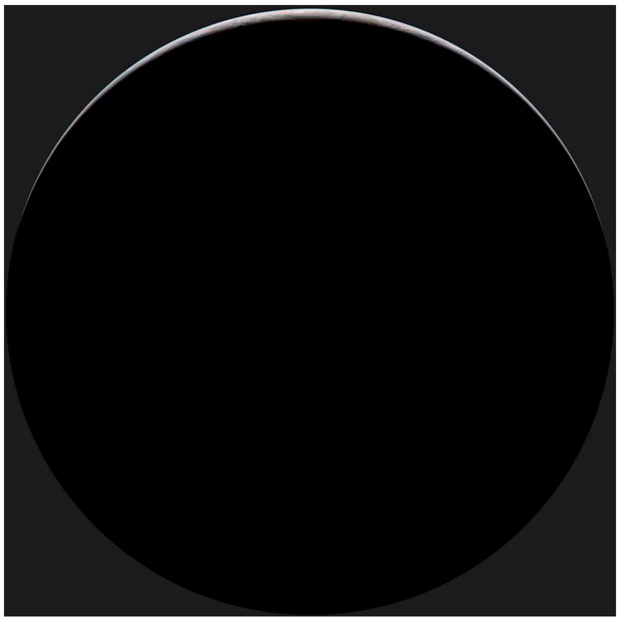
Xu, Wang, et al., 2019, AMT

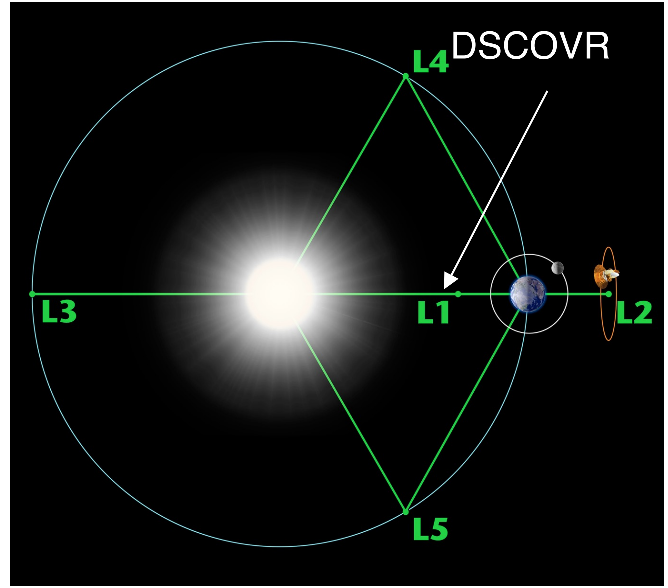


O2 B-band has moderate absorption, stronger than O2-O2 at 477 nm and weaker than O2 A. O2 B-band also has very low surface reflectance, comparable if not lower than blue bands, due to Chlorophyll-a absorption.

EPIC/DSCOVR

- Launched, 11 Feb. 2015.
- 1st image, 15 June 2015.
- Parked at L1 point: 1.5 million kilometers from Earth, enabling 24/7 observation of sunlit portion of Earth's surface every hour.
- 18-24 km/pixel, every hour
- It has 10 channels
  - 4 UV: 371, 325, 340, and 388 nm
  - 6 Vis: 443, 551, 680, 688, 764, and 780 nm

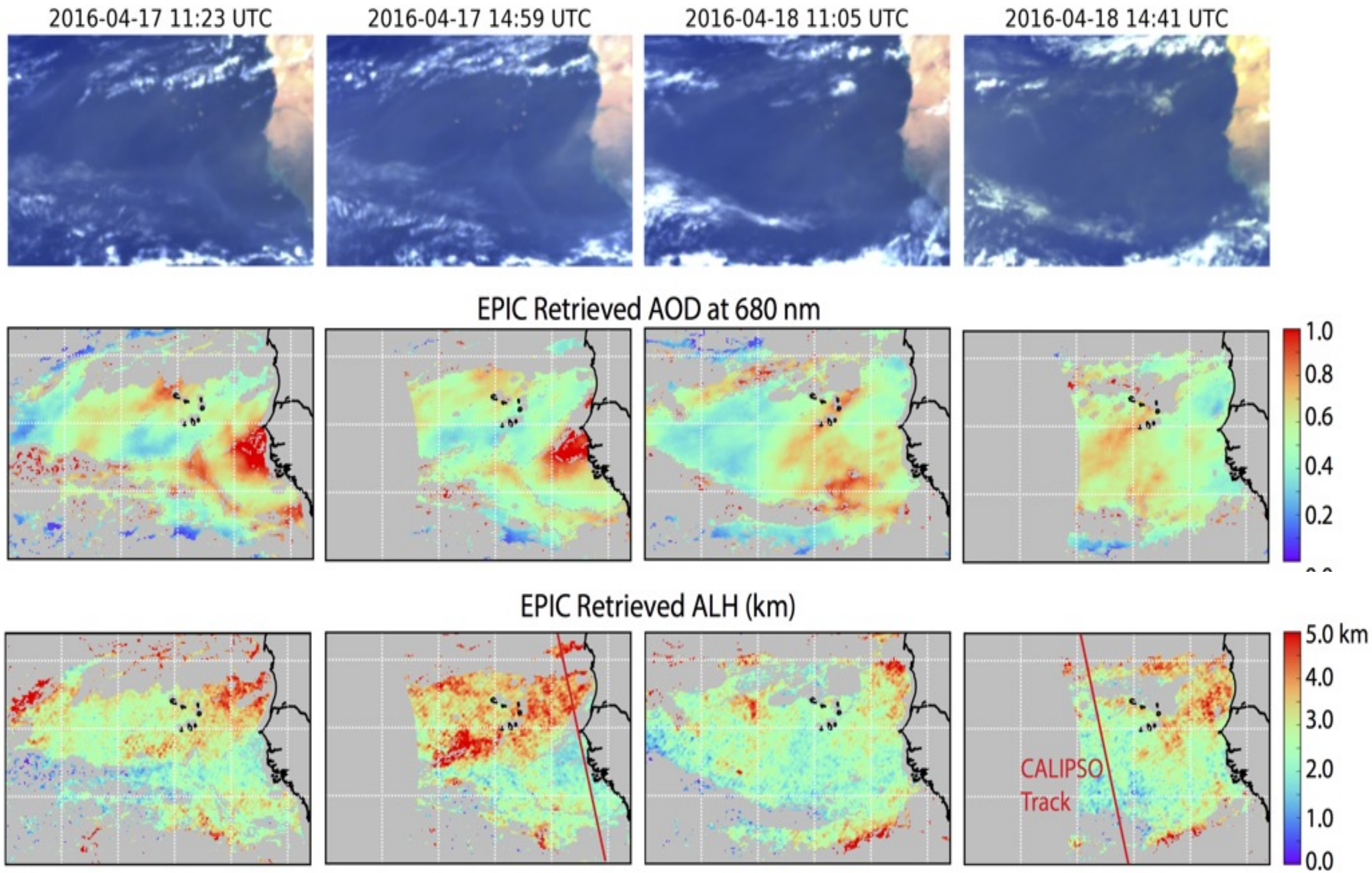




- Use O_2 A band pair and O_2 B band pair to retrieve ALH over both land and ocean

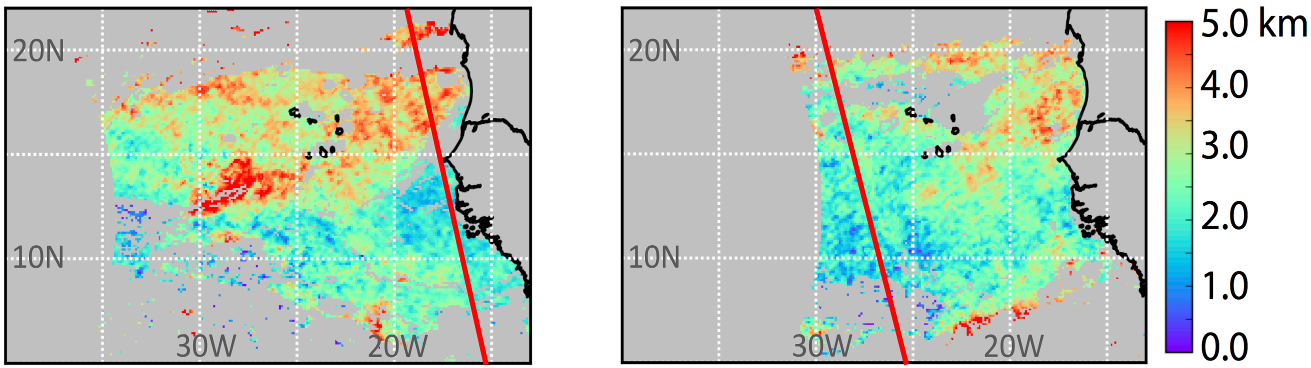
- Blue + O_2 B band pair are most suitable for ALH retrieve over land

Retrieval of diurnal variation of plume height and AOD from EPIC's O_2 A and B bands



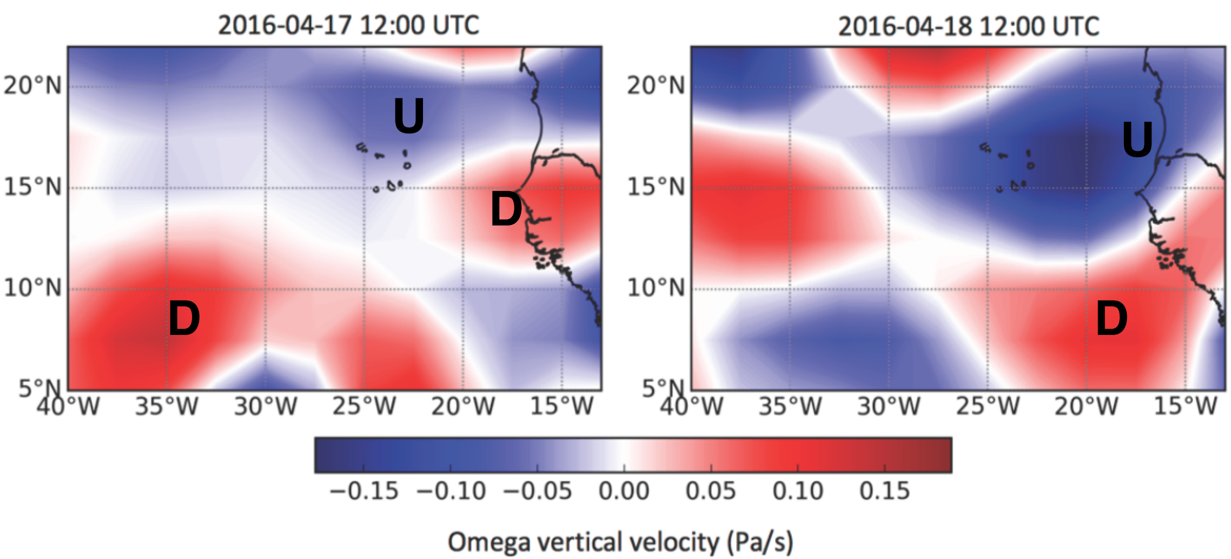
- AOD field clearly indicates mass continuity; high close to the source, and low in downwind.
- ALH shows no relationship with AOD
- ALH varies 1 – 5 km.

Evaluation of AOCH



$$\text{AOCH} = \frac{\sum_{i=1}^{n} \tau_i Z_i}{\sum_{i=1}^{n} \tau_i}$$

Vertical velocity



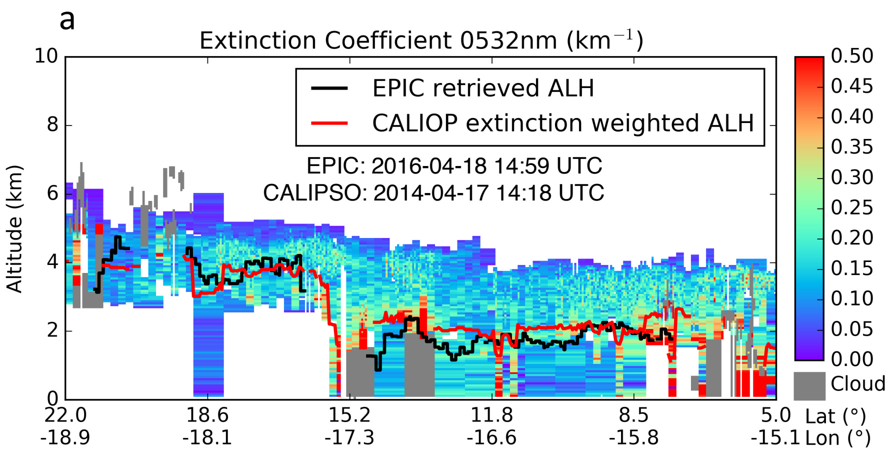
AOCH varies from 1 – 5 km

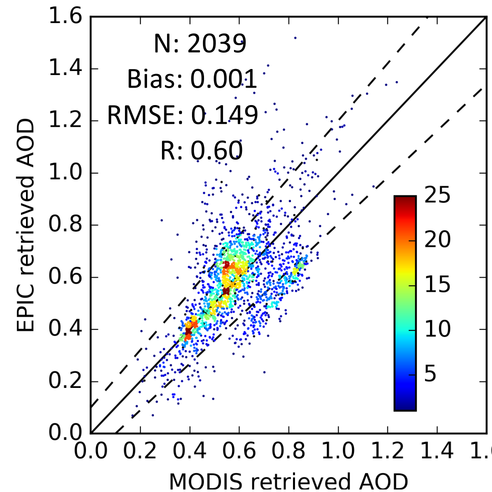
Resonates with vertical velocity field well

- Upward motion, high ALH up to 5 km
- Downward motion, low ALH down to 1-2 km

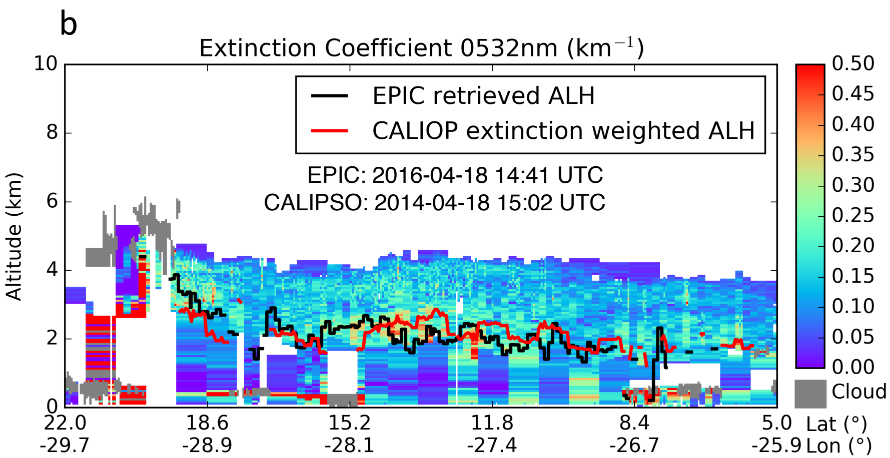
Xu et al., 2017, GRL

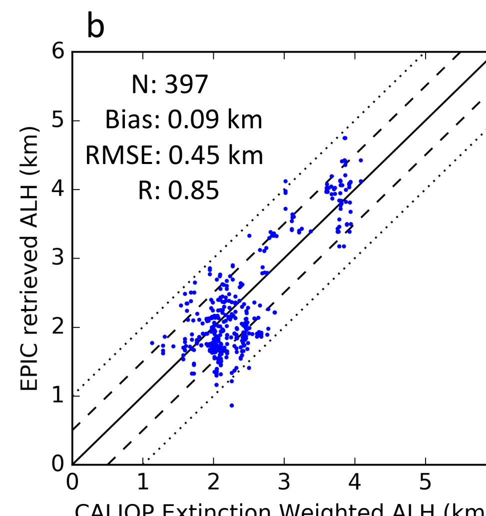
Validation with MODIS and CALIOP data





AOD is in good agreement with MODIS; nearly no bias.





Retried AOCH has a bias of 0.1 km. RMSE of 0.45 km.

Xu et al., 2018

16 March 2023

Geophysical Research Letters

RESEARCH LETTER
10.1029/2022GL102552

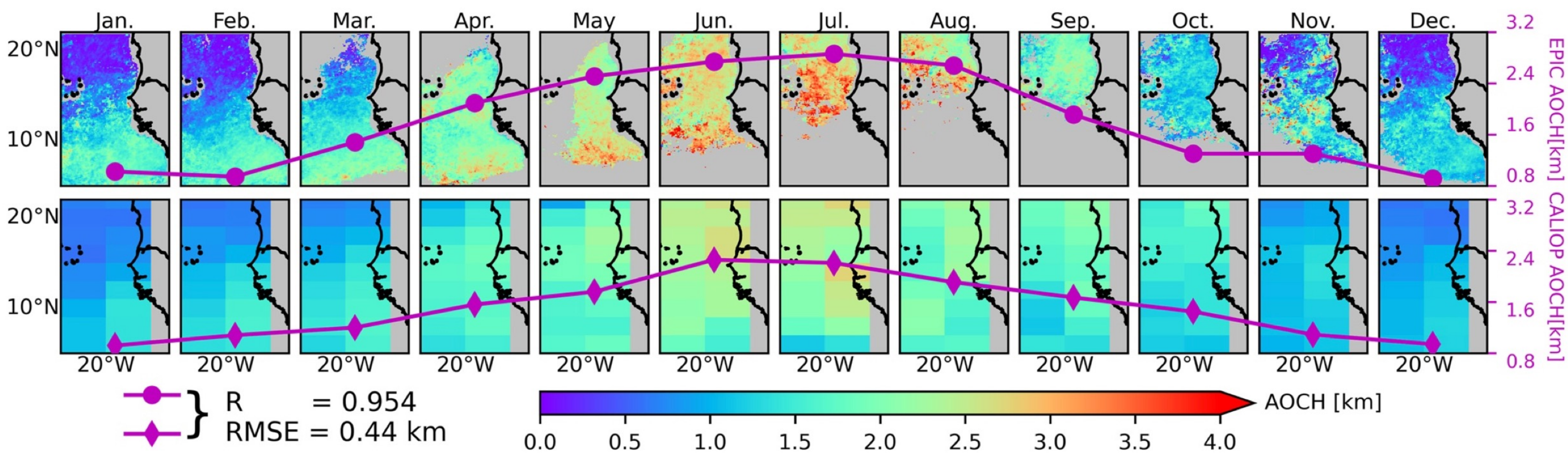
Key Points:

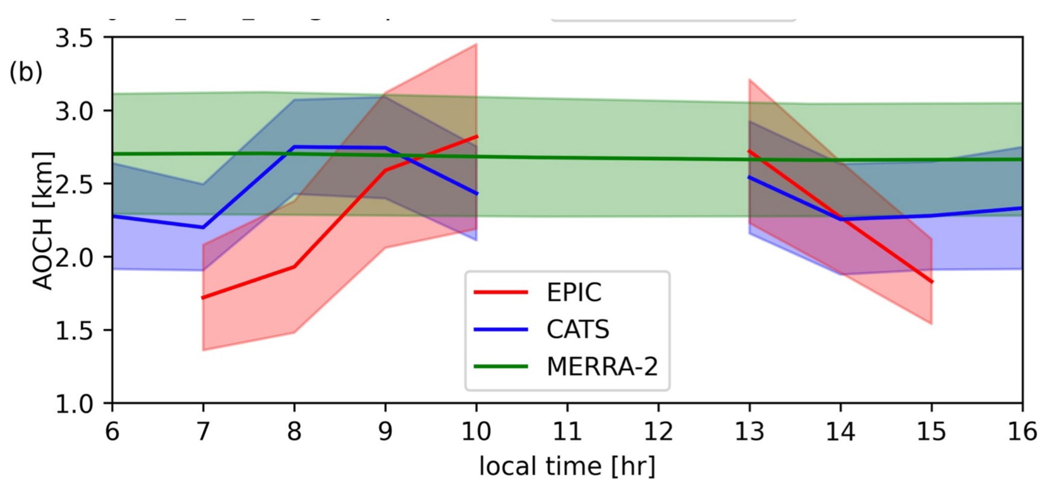
- Hourly and monthly climatology of Saharan dust layer height distribution over the ocean is first mapped from passive remote sensing (Earth Polychromatic Imaging Camera)
- The climatology agrees with that from spaceborne lidars and attests to the deficiency in model reanalysis of dust height diurnal change
- A combination of active and passive sensing techniques to study process for time-varying 3D aerosol distribution climatology

First Mapping of Monthly and Diurnal Climatology of Saharan Dust Layer Height Over the Atlantic Ocean From EPIC/DSCOVR in Deep Space

Zhendong Lu[1], Jun Wang[1,2], Xi Chen[2], Jing Zeng[2], Yi Wang[2,3], Xiaoguang Xu[4], Kenneth E. Christian[5,6], John E. Yorks[5], Edward P. Nowottnick[5], Jeffrey S. Reid[7], and Peng Xian[7]

[1]Interdisciplinary Graduate Program in Informatics, The University of Iowa, Iowa City, IA, USA, [2]Department of Chemical and Biochemical Engineering, Center for Global and Regional Environmental Research and Iowa Technology Institute, The University of Iowa, Iowa City, IA, USA, [3]Now at Hubei Key Laboratory of Regional Ecology and Environmental Change, School of Geography and Information Engineering, China University of Geosciences, Wuhan, China, [4]GESTAR-II and Department of Physics, University of Maryland Baltimore County, Baltimore, MD, USA, [5]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [6]Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, USA, [7]U.S. Naval Research Laboratory, Monterey, CA, USA





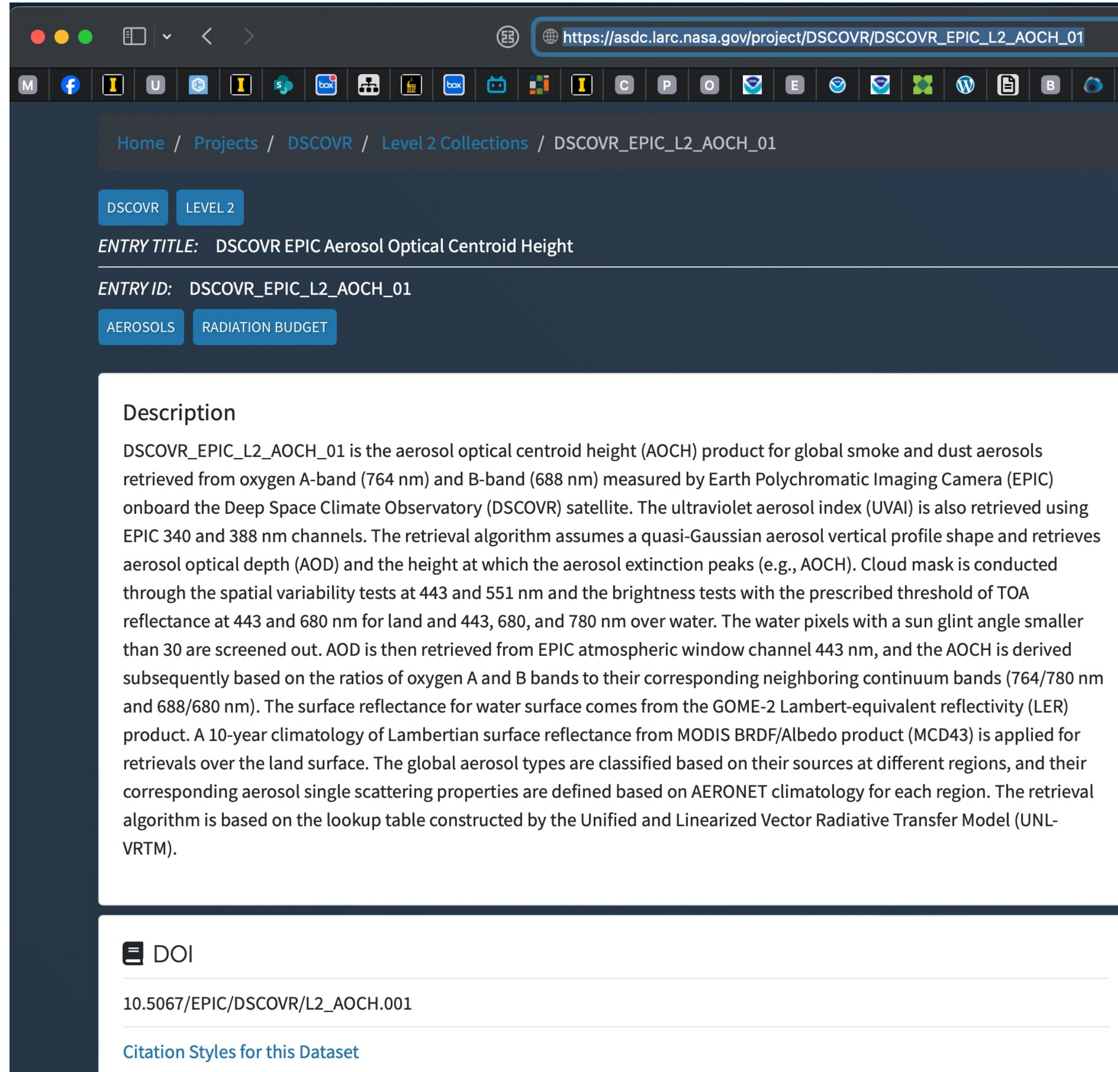
- The EPIC-retrieved dust layer heights agree well with spaceborne lidar data.
- This study is among the first to demonstrate the strong synergy between the passive sensing featuring large spatial coverage and active sensing with detailed profiling for characterizing the diurnal variation of aerosol vertical distribution and processes as well as the need of such synergy for the climate modeling studies.

- https://asdc.larc.nasa.gov/project/DSCOVR/DSCOVR_EPIC_L2_AOCH_01

Level-2 data product:

DSCOVR_EPIC_AOCH_01 data production in ASDC/LaRC.

Thanks to Marshall Sutton and EPIC project team in GSFC to make the RTO happen.



https://asdc.larc.nasa.gov/project/DSCOVR/DSCOVR_EPIC_L2_AOCH_01

Home / Projects / DSCOVR / Level 2 Collections / DSCOVR_EPIC_L2_AOCH_01

DSCOVR LEVEL 2

ENTRY TITLE: DSCOVR EPIC Aerosol Optical Centroid Height

ENTRY ID: DSCOVR_EPIC_L2_AOCH_01

AEROSOLS RADIATION BUDGET

Description

DSCOVR_EPIC_L2_AOCH_01 is the aerosol optical centroid height (AOCH) product for global smoke and dust aerosols retrieved from oxygen A-band (764 nm) and B-band (688 nm) measured by Earth Polychromatic Imaging Camera (EPIC) onboard the Deep Space Climate Observatory (DSCOVR) satellite. The ultraviolet aerosol index (UVAI) is also retrieved using EPIC 340 and 388 nm channels. The retrieval algorithm assumes a quasi-Gaussian aerosol vertical profile shape and retrieves aerosol optical depth (AOD) and the height at which the aerosol extinction peaks (e.g., AOCH). Cloud mask is conducted through the spatial variability tests at 443 and 551 nm and the brightness tests with the prescribed threshold of TOA reflectance at 443 and 680 nm for land and 443, 680, and 780 nm over water. The water pixels with a sun glint angle smaller than 30 are screened out. AOD is then retrieved from EPIC atmospheric window channel 443 nm, and the AOCH is derived subsequently based on the ratios of oxygen A and B bands to their corresponding neighboring continuum bands (764/780 nm and 688/680 nm). The surface reflectance for water surface comes from the GOME-2 Lambert-equivalent reflectivity (LER) product. A 10-year climatology of Lambertian surface reflectance from MODIS BRDF/Albedo product (MCD43) is applied for retrievals over the land surface. The global aerosol types are classified based on their sources at different regions, and their corresponding aerosol single scattering properties are defined based on AERONET climatology for each region. The retrieval algorithm is based on the lookup table constructed by the Unified and Linearized Vector Radiative Transfer Model (UNL-VRTM).

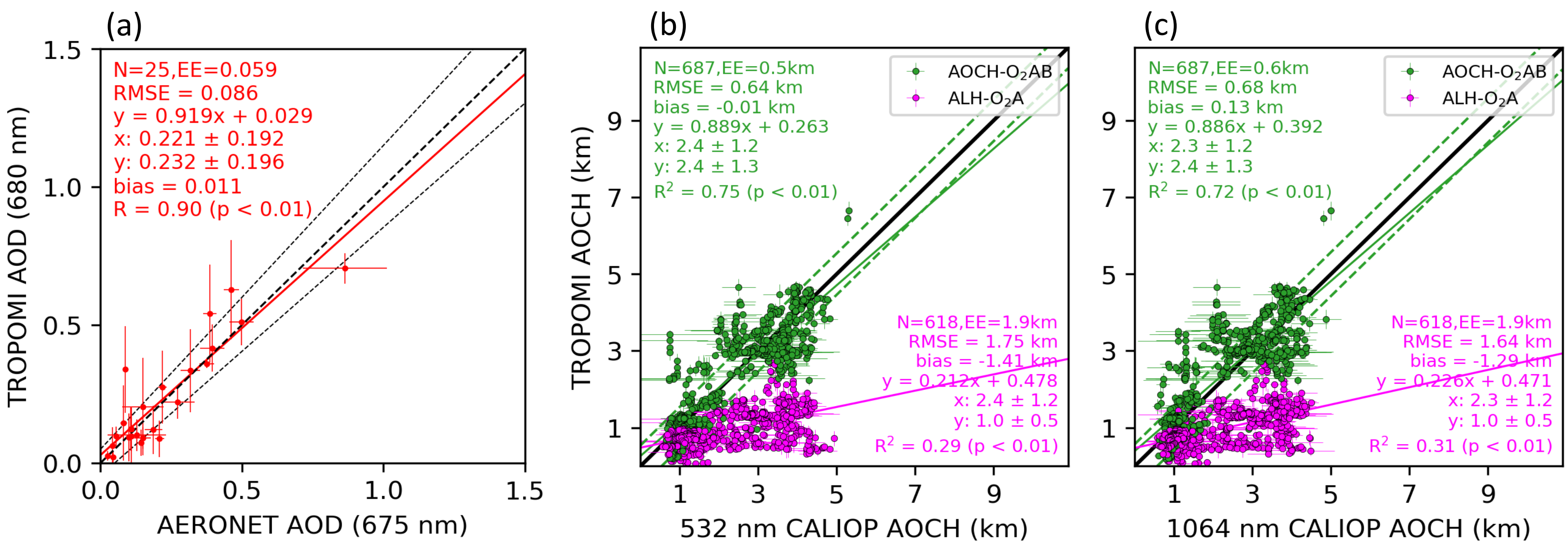
DOI

10.5067/EPIC/DSCOVR/L2_AOCH.001

Citation Styles for this Dataset

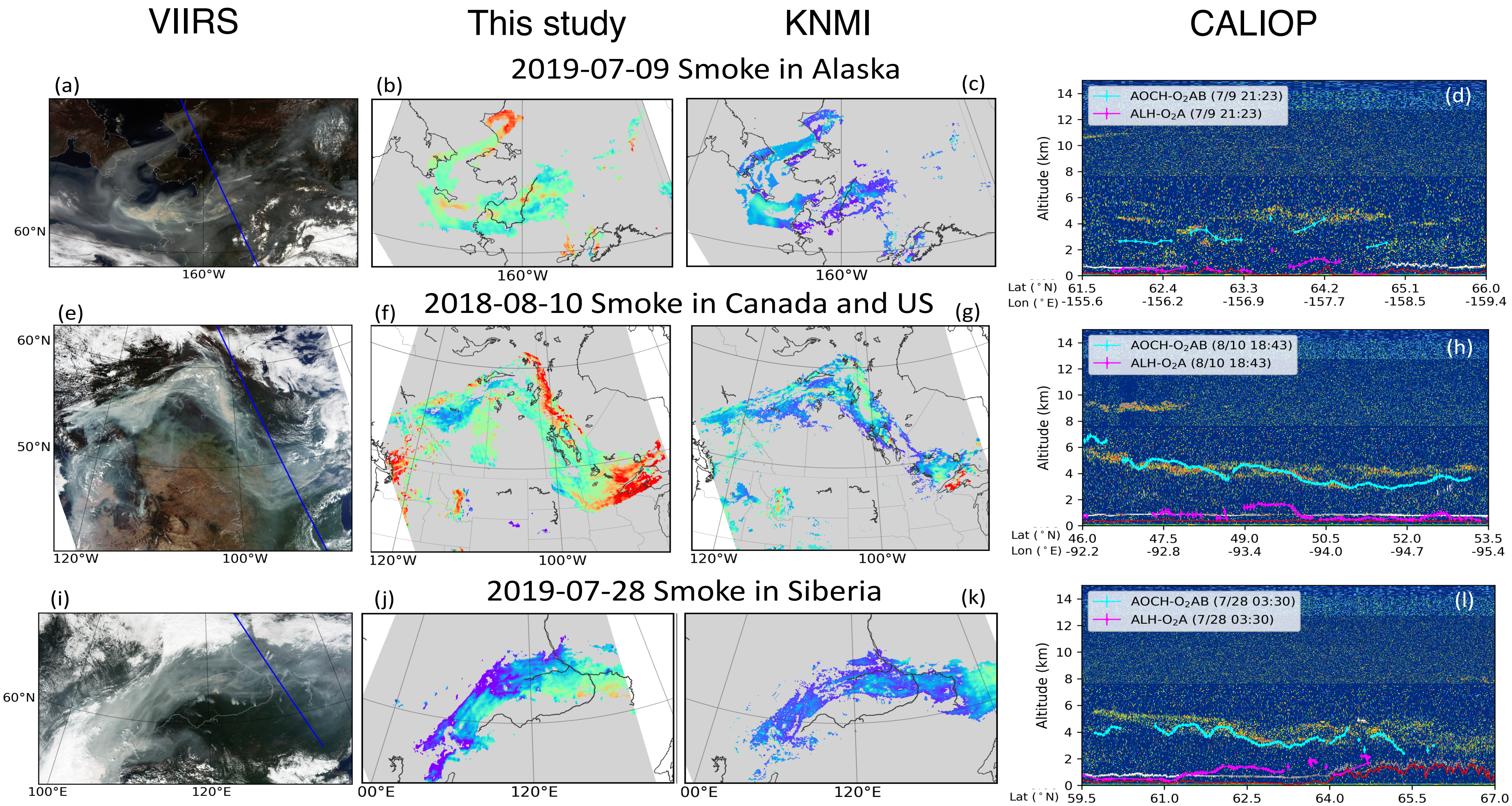
New Development/Results with primary use of TROPOMI O2 B-band

- Deriving Aerosol Optical Centroid Height (AOCH) and AOD by primarily using 420, 680, and 688 nm
- Surface reflectance from MODIS climatology and ASTER/USGS spectral reflectance library
- Aerosol optical properties derived from AERONET climatology (varying with region)
- Quasi-Gaussian distribution for the shape of aerosol vertical extinction profile
- Compared with CALIOP data for many many cases



Chen, Wang, et al., 2021, RSE

More demonstration



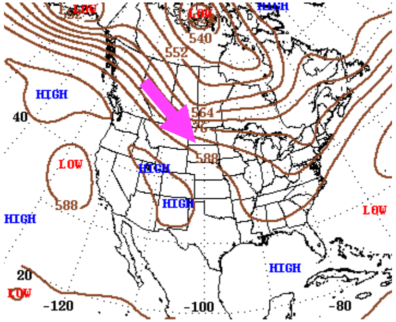
Chen et al., 2021, RSE.

Models

http://fireaq.uiowa.edu for weekly briefing of FireAQ this summer

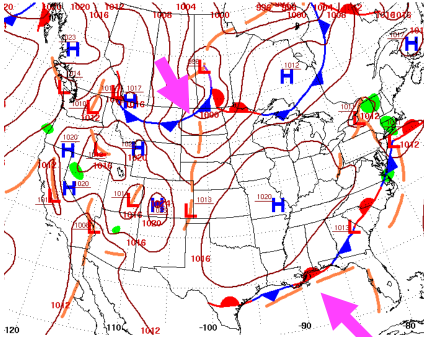
Air Quality Reflection: Wednesday August 16, 2023

500 hPa Contours



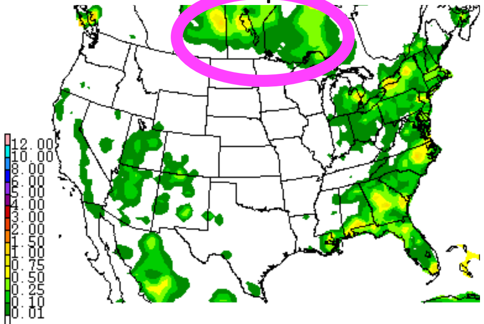
500-Millibar Height Contour at 7:00 A.M. E.S.T.

Surface Weather



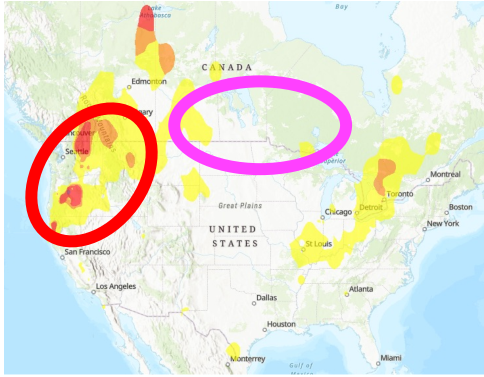
Surface Weather Map at 7:00 A.M. E.S.T.

Precipitation

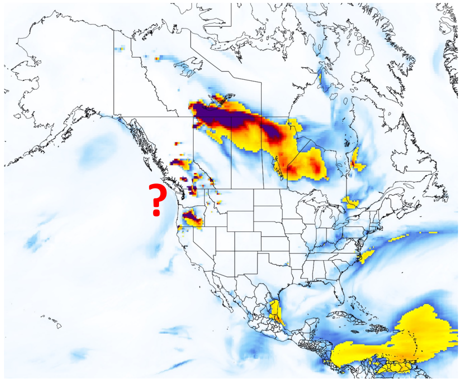


24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.

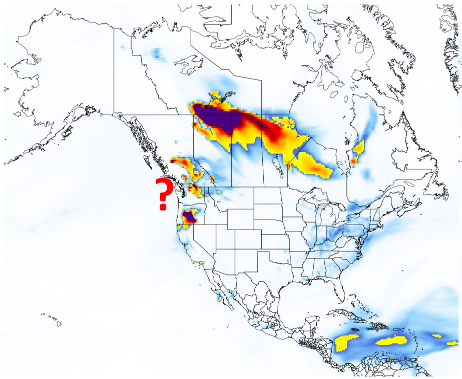
AirNow AQI



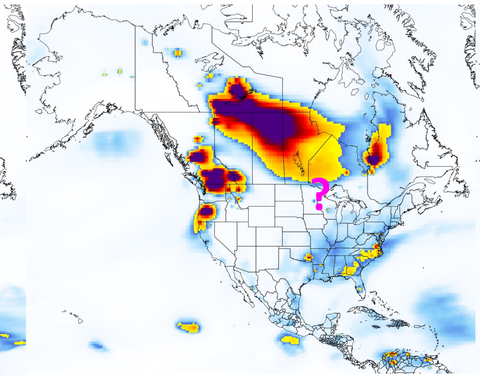
GEOS-FP



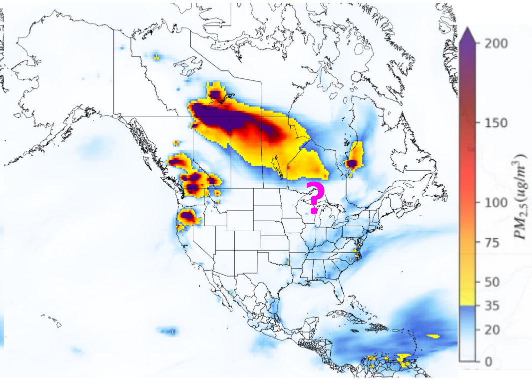
GEOS-CF



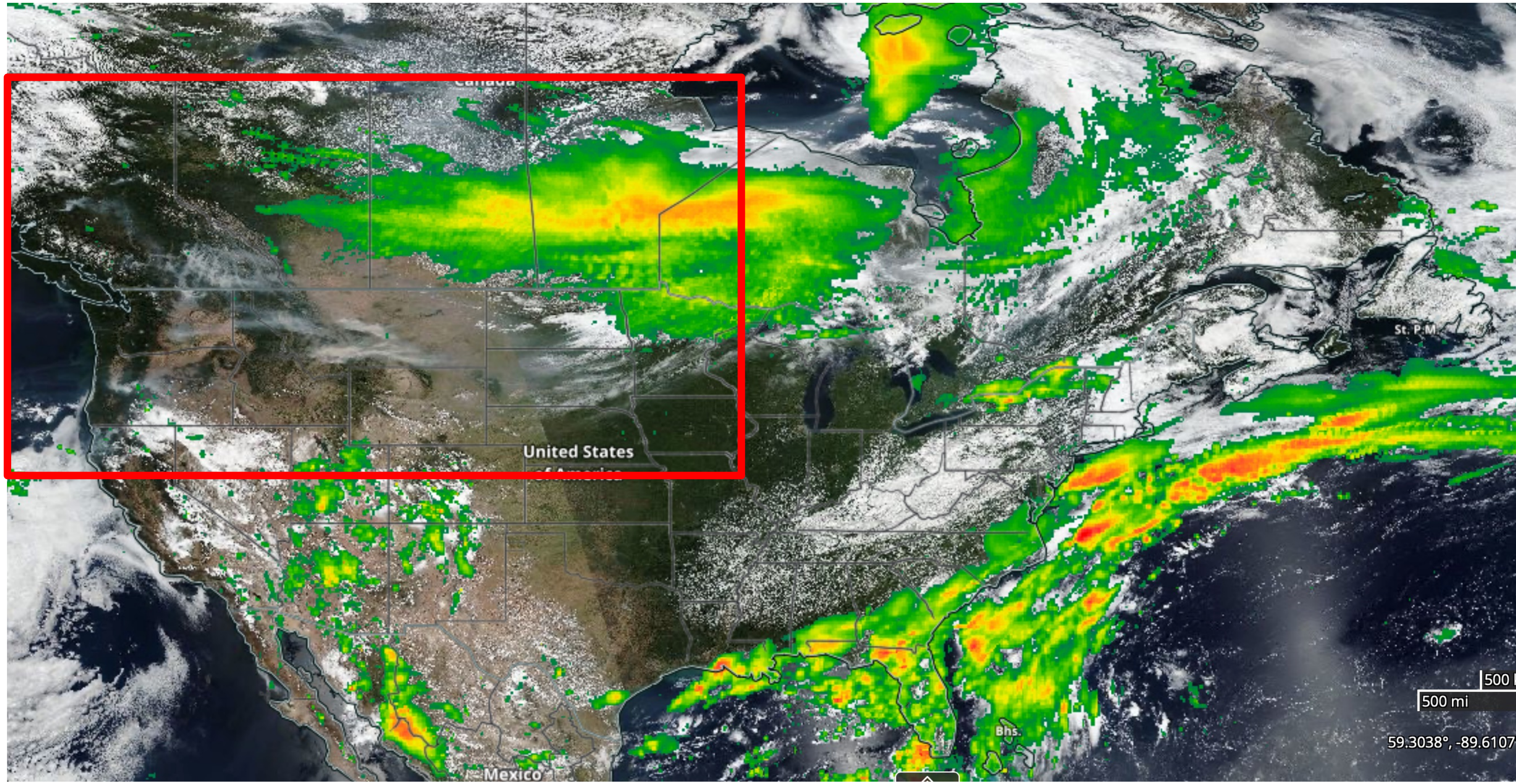
NAAPS



Ensemble



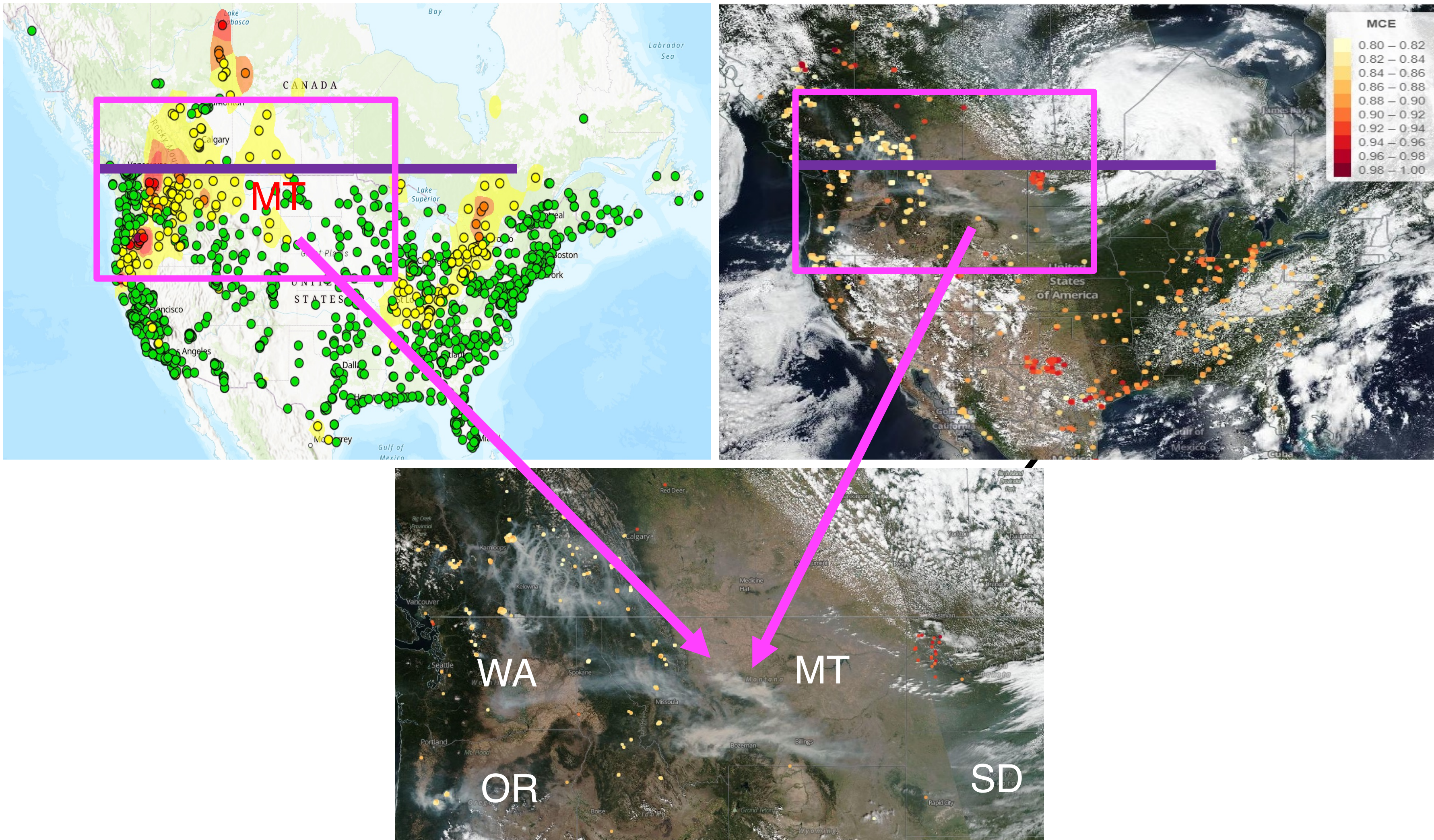
GPM, 16 August 2023



NASA WorldView

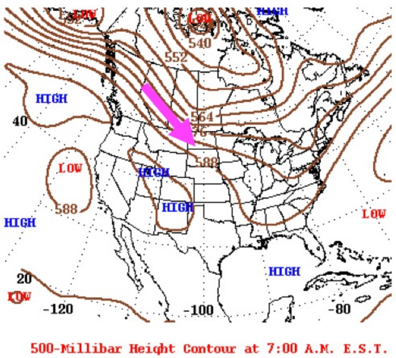
Observations

http://fireaq.uiowa.edu for weekly briefing of FireAQ this summer

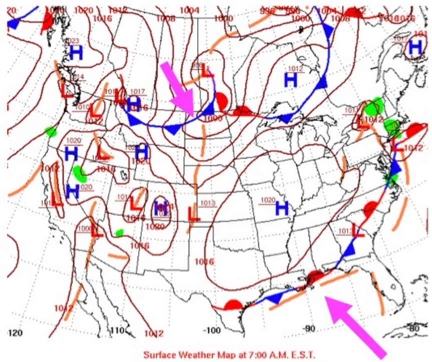


Air Quality Reflection: Wednesday August 16, 2023

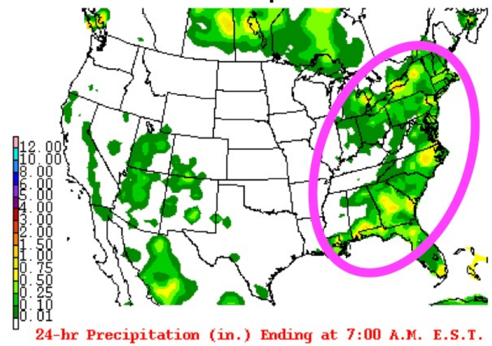
500 hPa Contours



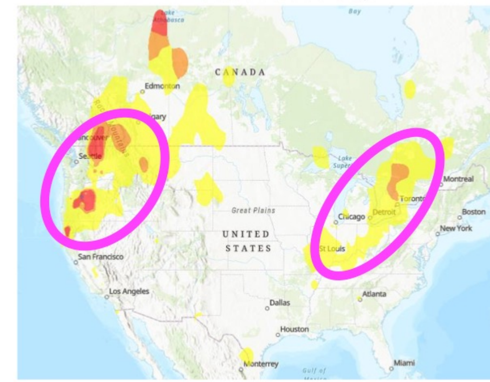
Surface Weather



Precipitation

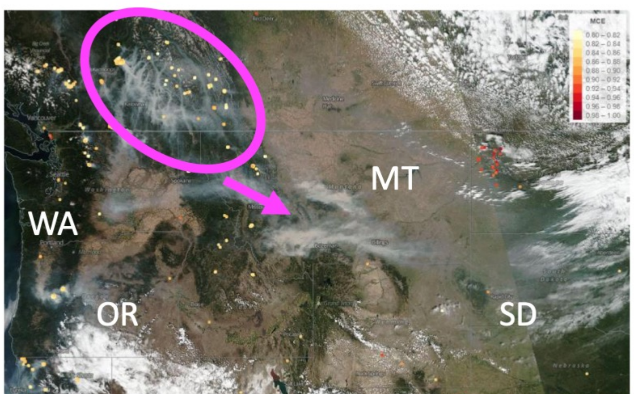


AirNow AQI

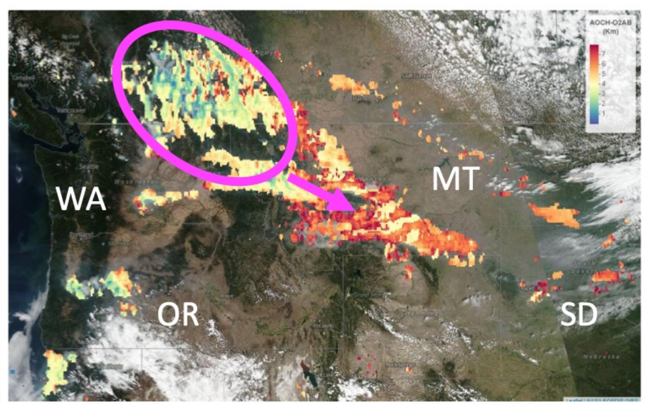


Uiowa Algorithm

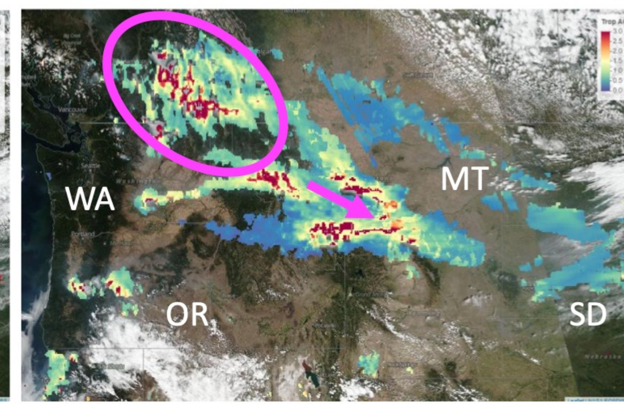
FILDA2 MCE



Tropomi AOCH

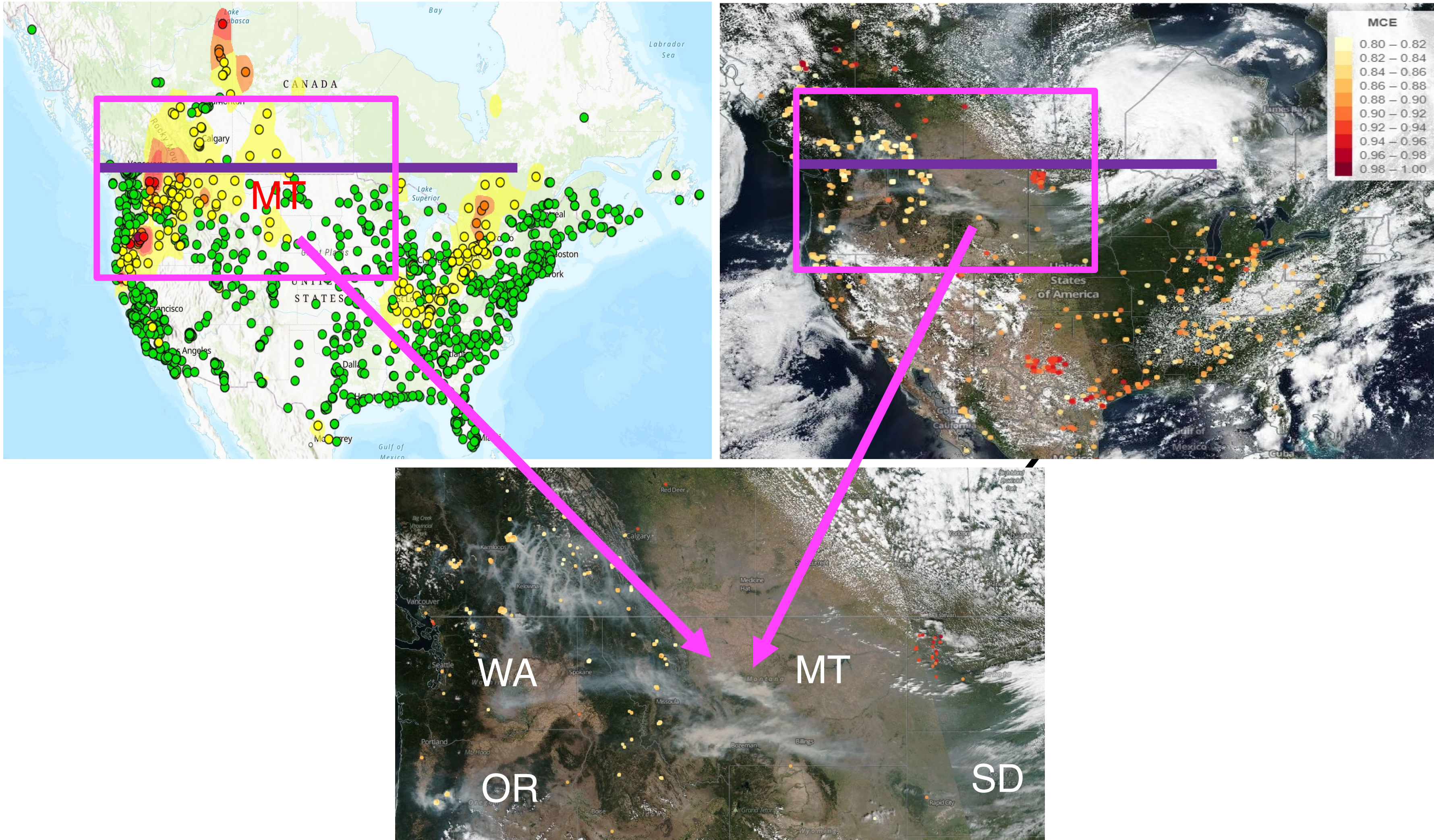


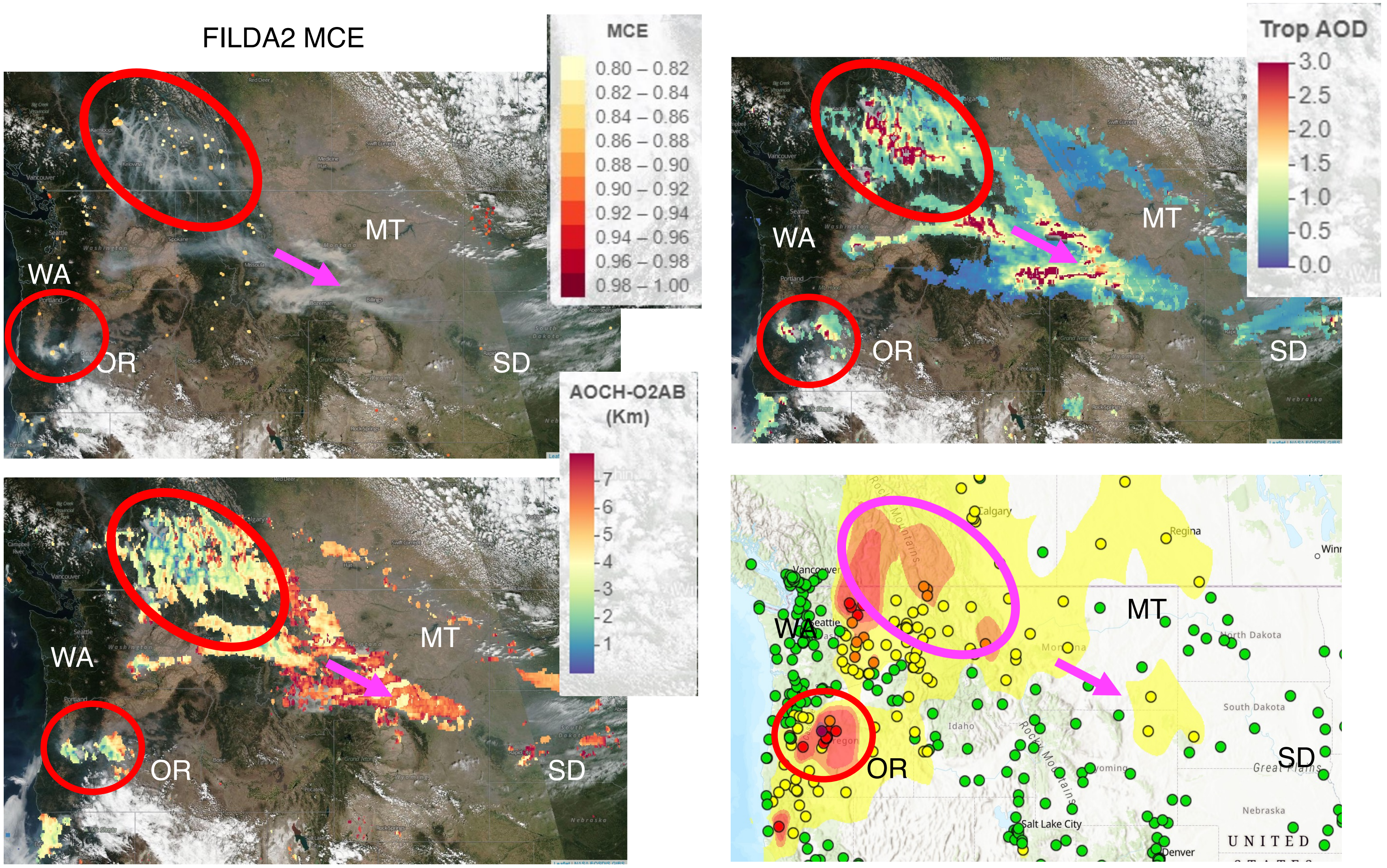
Tropomi AOD



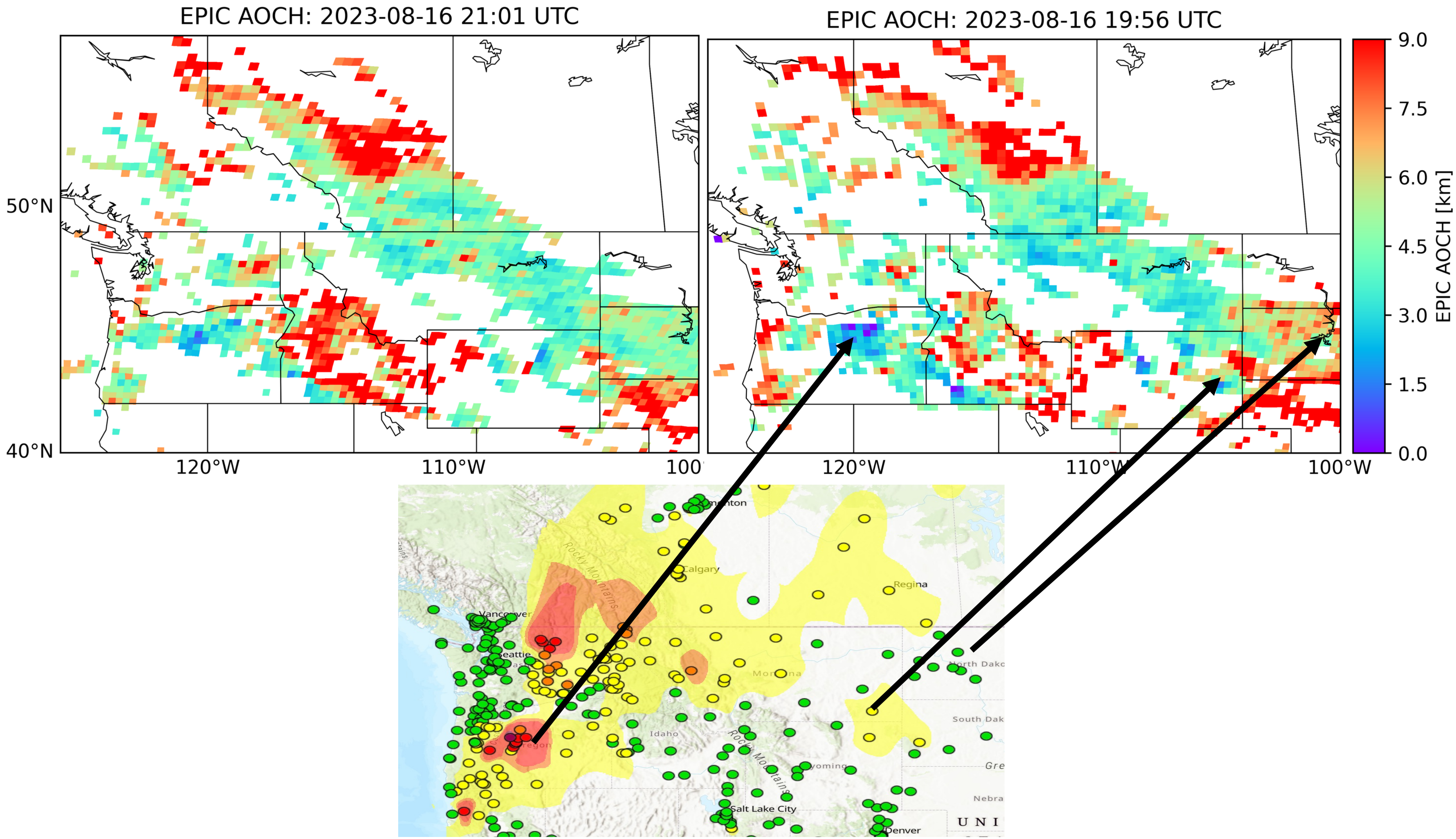
AQ Applications

http://fireaq.uiowa.edu for weekly briefing of FireAQ this summer





FILDA2 MCE
MCE
0.80 – 0.82
0.82 – 0.84
0.84 – 0.86
0.86 – 0.88
0.88 – 0.90
0.90 – 0.92
0.92 – 0.94
0.94 – 0.96
0.96 – 0.98
0.98 – 1.00
WA
MT
OR
SD
Trop AOD
3.0
2.5
2.0
1.5
1.0
0.5
0.0
AOCH-O2AB (Km)
7
6
5
4
3
2
1
Calgary
Regina
Vancouver
Seattle
Montana
North Dakota
South Dakota
Idaho
Oregon
Wyoming
Rocky Mountains
Salt Lake City
Nebraska
Great Plains
Denver
UNITED



EPIC AOCH: 2023-08-16 21:01 UTC
EPIC AOCH: 2023-08-16 19:56 UTC
50°N
40°N
120°W
110°W
100°W
9.0
7.5
6.0
4.5
3.0
1.5
0.0
EPIC AOCH [km]
Calgary
Regina
Vancouver
Seattle
Rocky Mountains
Montana
Idaho
Oregon
Wyoming
North Dako
South Dak
Nebra
Salt Lake City
Denver

Retrieval algorithm comparison

ALH retrieval algorithms	Used channels (nm)	Aerosol model	Aerosol type	Retrieved parameters	Spatial resolution	Profile assumption
GEMS-AEH	477 (O_2-O_2)	Fixed aerosol model for three aerosol types (same with GEMS AOD retrieval)	Dust, smoke, non-absorbing	• AOD @ 354nm, 443 nm, 500 nm (from AERAOD) • Aerosol effective height	3.5 × 8 km	[(1-exp^{-1}) ×τ] on Quasi-Gaussian distribution with 1 km half-width
EPIC-AOCH	688/680 (O_2 B) 764/780 (O_2 A)	AOD-dependent smoke model (dust) from AERONET climatology	Dust, smoke (UVAI > 1.5 or 1)	• AOD @ 680 nm • Aerosol optical central height	30 × 30 km	Peak height on Quasi-Gaussian distribution with 1 km half-width
TROPOMI-AOCH O_2AB					0.05° × 0.05°	

Quasi-Gaussian distribution

$$\beta(z) = \frac{\exp(-\sigma_H|z-\mathrm{H}|)}{[1+\exp(-\sigma_H|z-\mathrm{H}|)]^2}$$

η: half width (1 km), $\sigma = \ln(3+\sqrt{8})/\eta$

EPIC & TROPOMI, Aerosol Optical Central Height (AOCH)

H same as in the definition in the algorithm

β_{AOCH} : extinction coefficient of peak height

GEMS, Aerosol Effective Height (AEH) V2.0

$$\frac{\int_0^{AEH}\beta(z)dz}{\int_0^{TOA}\beta(z)dz} = 1 - e^{-1}$$

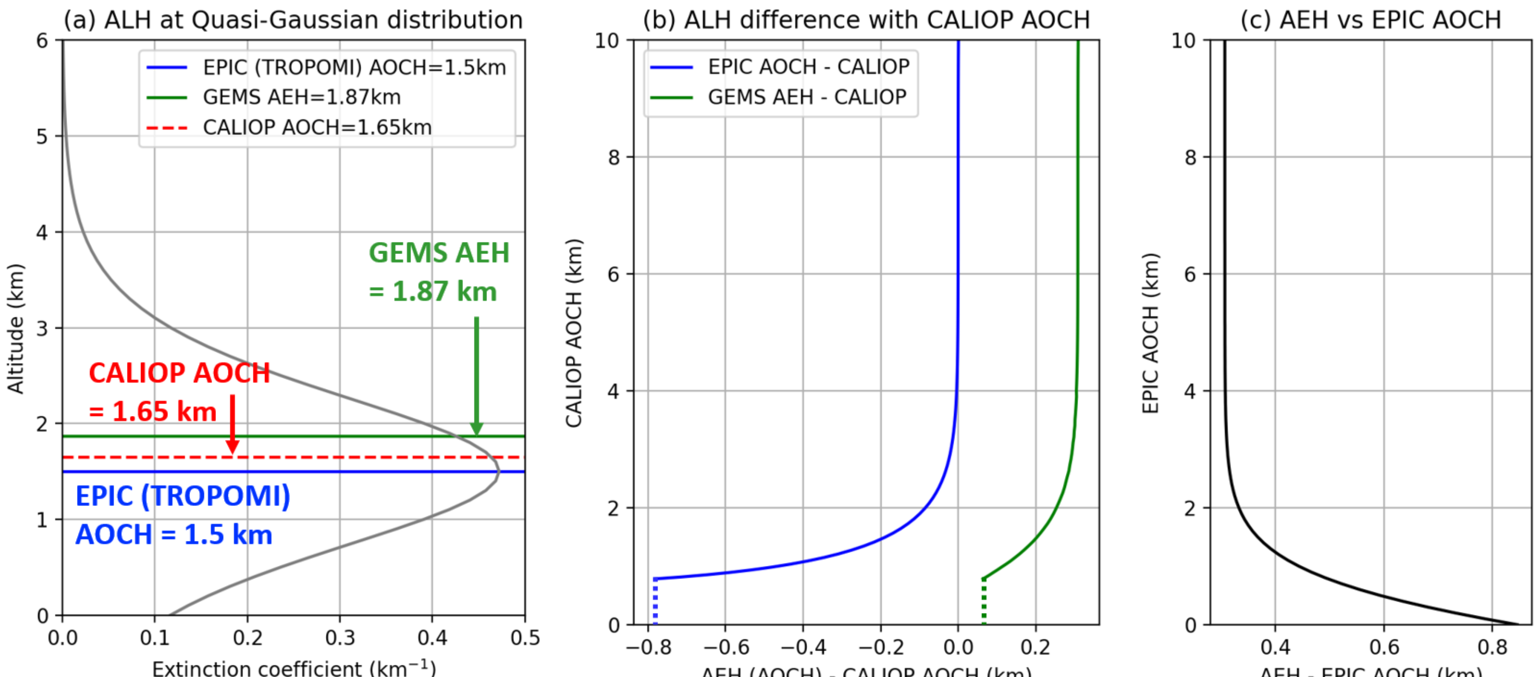
β_{AEH} : extinction coefficient of the e-folding height

CALIOP, Aerosol Extinction Weighted Height :

$$AOCH_{CALIOP} = \frac{\sum_{i=1}^{n}\beta_{ext,i}\Delta Z_i Z_i}{\sum_{i=1}^{n}\beta_{ext,i}\Delta Z_i}$$

Z_i: altitude, ΔZ_i:layer of thickness of vertical layer i,
$\beta_{ext,i}$: extinction coefficient (km $^{-1}$) at vertical level i

Comparisons of height definition



- EPIC (TROPOMI) and CALIOP AOCH converge (are the same) for AOCH at ~ 4 km and above.
- GEMS AEH show height dependent positive bias compared to CALIOP AOCH. This bias becomes constant (0.3 km) for height beyond ~ 3 km.
- For further analysis, we converted into same definition for apple-to-apple comparison.

Summary and outlook

- **Virtual constellation is on the rise to provide 3D description of aerosol pollutants, with good hourly spatial converge, especially from passive sensors on geo. platform.**

- **The AOCH data from EPIC is now in production as part of EPIC/DSCOVR program**
- **The AOCH data from TROPOMI is generated in house semi-operationally in U. Iowa over the areas from N. America to Sahara desert**

  http://esmc.uiowa.edu:3838/tropomi_aoch/

- **The AOCH data from TEMPO is planed for production…**

Thank you !

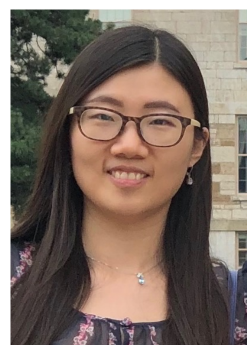
MRUI: Multidisciplinary University Research Initiative

Applied sciences, ACMAP, MAIA, TEMPO, DSCOVR

C4, GEO-XO program

Special thanks to: Jeffrey Reid, John Yorks, Shobha Kondragunta, Peter Colarco, Arlindo Da Silva, Robert Levy, Omar Torres, David Diner, Kelly Chance, Xiong Liu, and the following team members

Xiaoguang Xu, UMBC



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