# TEMPO Aerosols and Clouds

| | | |
|---|---|---|
| 1. **Jun Wang** | Introduction, ALH/AOD | Univ. of Iowa |
| 2. **Omar Torres** | TMEPO aerosol product | NASA GSFC |
| 3. **Shobha Kondragunta** | TEMPO & GOES-R | NOAA NESDIS |
| 4. **Yeseul Cho** | GEMS Aerosol Products | Yonsei Univ. |
| 5. **Juan Carlos Antuña M.** | Welcoming TEMPO from Cuba | Cuba GOAC |
| 6. **Mian Chin** | Hourly PM2.5-AOD relationship | NASA GSFC |
| 7. **Joanna Joiner** | Retrieval in full cloudy conditions | NASA GSFC |

# Importance of aerosols and clouds

- **Aerosols are omnipresent,**
  - affect satellite retrieval of gases
  - affect life cycle of gases
  - Integrated part of TEMPO objectives for AQ forecast & process studies
  - Integrated part of TEMPO objectives for climate forcing studies

- **Clouds are present 60%-70% of time,**
  - Affect life cycle of gases and aerosols
  - Key source of uncertainty for aerosol retrievals
  - Integrated part of TEMPO objectives for climate forcing studies

Table D.1-1 in TEMPO proposal

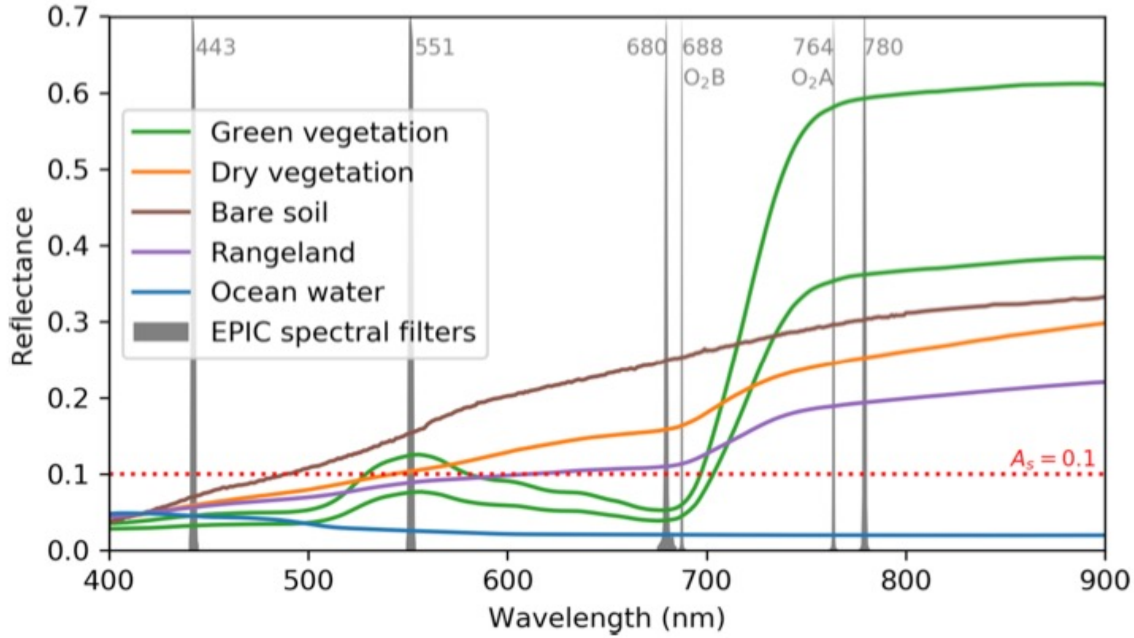
| TEMPO Science Goals | TEMPO Objectives |
|---|---|
| Characterize the temporal and spatial variations of emissions important for AQ and climate; observe continental inflow and outflow of pollution. 1,2,5,6,7,8,9 | Collect simultaneous high temporal and spatial resolution measurements of pollutants over Greater North America. |
| Understand how processes determine AQ over range of time and space scales. 1,2,5,6,7,8 | Measure the major elements in tropospheric $O_3$ chemistry & aerosol cycles. |
| Characterize the effect of episodic events, e.g. volcanic eruptions, wild fires and dust outbreaks, on AQ. 1,2,6,8 | Observe aerosols & gases for quantifying and tracking evolution of pollution. |
| Determine how observations from space can improve AQ forecasts and assessments for societal benefit. 3,4,5,7,8,9 | Integrate observations from TEMPO and other platforms into models to improve representation of processes. |
| Understand how air pollution drives climate forcing and how climate change affects AQ on a continental scale. 4,5,6,8 | Determine the instantaneous radiative forcings associated with $O_3$, aerosols & clouds on the continental scale. |

# Enabled by TEMPO are …

- **Unique aerosol data/science**
  - hourly retrieval of aerosol absorption
  - hourly retrieval of spectral AOD and surface reflectance
  - hourly retrieval of aerosol centroid layer height
  - ….
- **Cloud data/science uniquely enabled by TEMPO**
  - hourly retrieval of cloud optical centroid pressure from O2-O2 band
  - …
- **Strong synergy with other sensors**
  - surface networks, AOD-PM2.5 relationship
  - with GOES-16/17, TROPOMI, GMES, Sentinel-4 (S4), Sentinel-5 (S5), …
  - with MODIS, MISR, VIIRS, MAIA
- **Collaboration, capacity building and workforce preparation for future missions**
  - GEOS-XO
  - poster presentations (nighttime AOD, Machine-Learning, …)

# Aerosol Optical Centroid Height (AOCH) and AOD
## using 420, 680, and 688 nm channels

**Surface reflectance in O2 B-band is as low as in that in blue band**



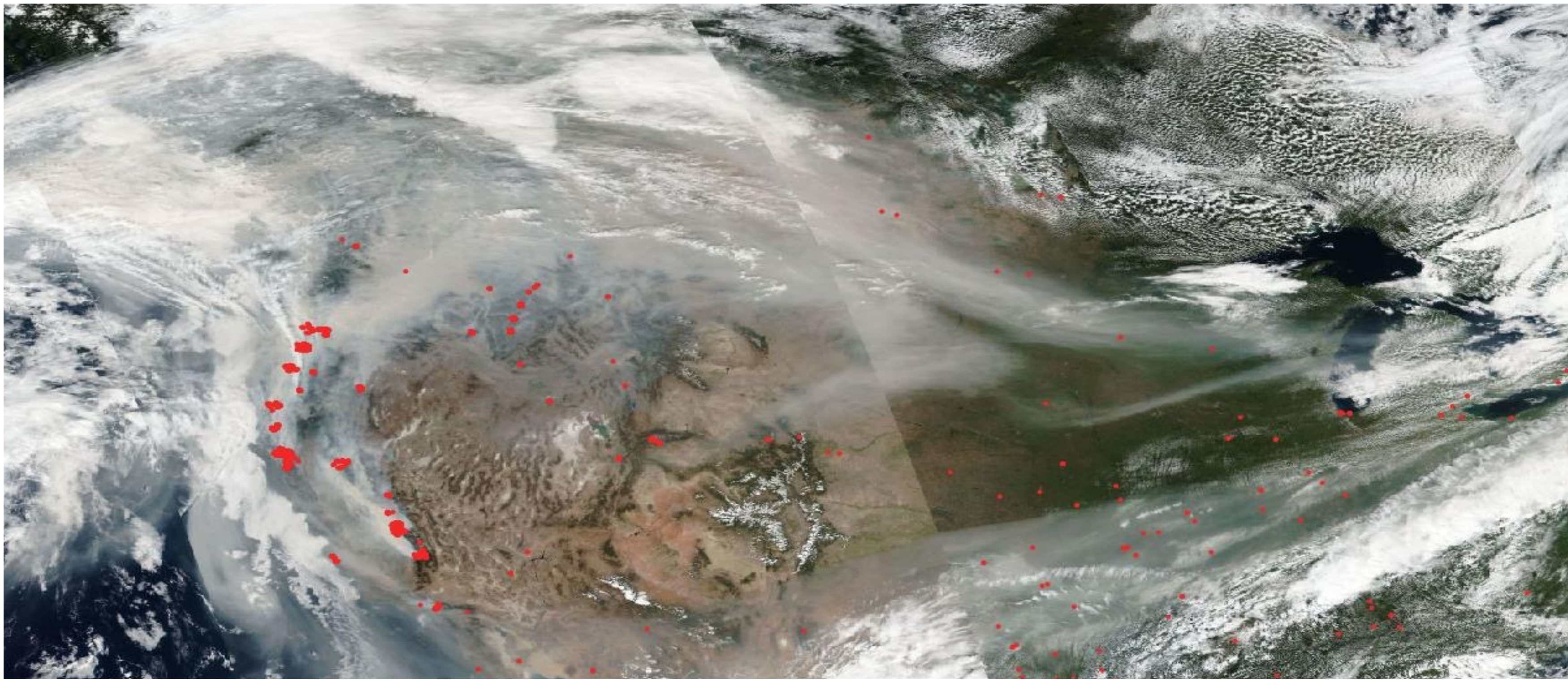

Xu, Wang, et al., 2019

Xu, X., J. Wang, et al., 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, *AMT, 2019*.

Xu, X., J. Wang, et al., 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, 2017.*

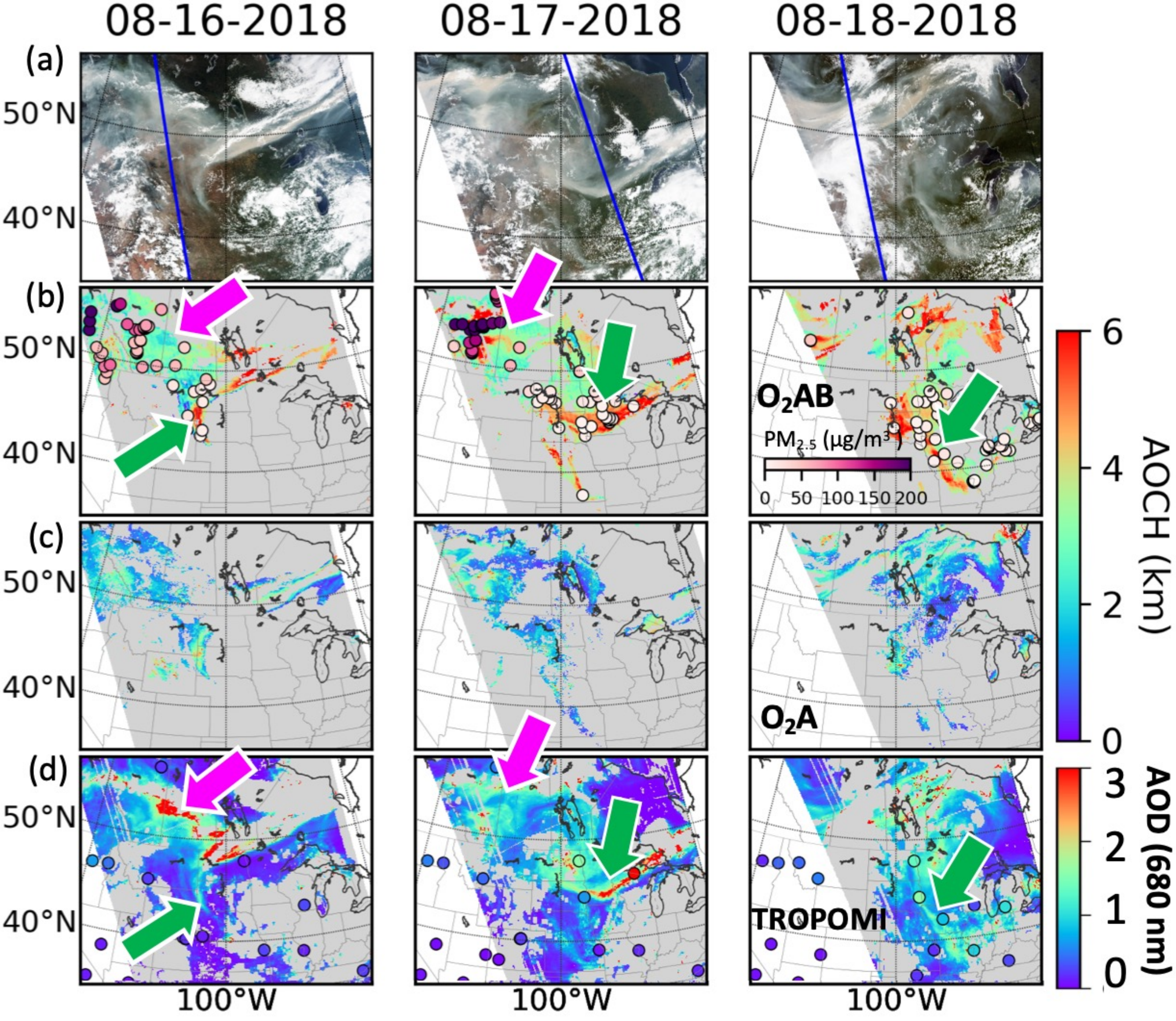
# Is the smoke layer near the surface?

**Smoke transport like this can be norm in 2020s**



**MODIS true color image and detected fires (red dots) on 16 Sep. 2020. Source: NASA World View.**

**Need 3D in real time !**



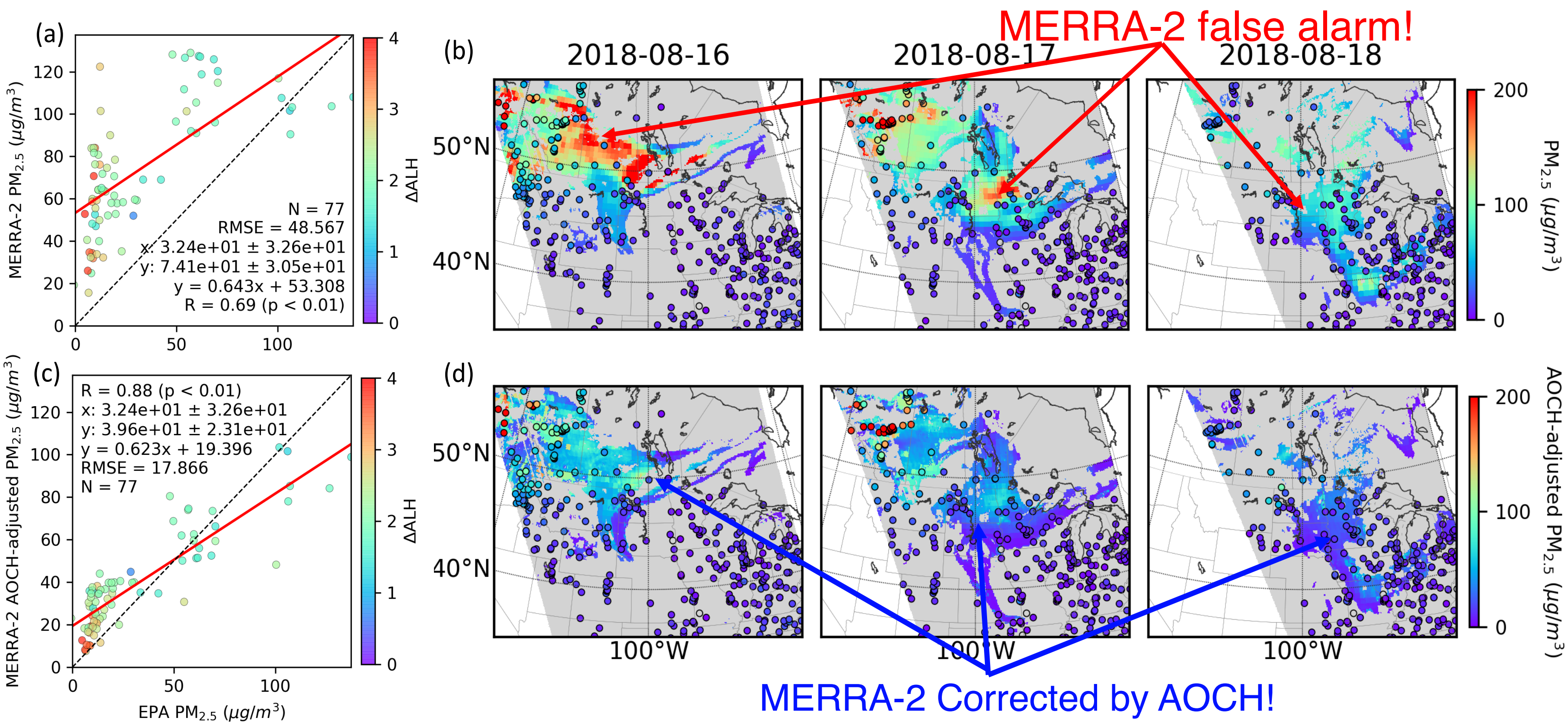

# Case Demonstration

Air quality forecast is needed by the state & local communities to make advisories & decisions for mitigating public exposure to air pollution.

Chen et al., in revision.
See Xi Chen's poster

# Improvement on prediction and analysis

- Aerosol layer height is one of the most needed information air quality mangers wants (based on HAQST group discussion on air quality forecast in smoke conditions).




Chen et al., in revision! See Xi Chen's poster. Also, Shobha's presentation

TEMPO 2021 Science Team Meeting

# TEMPO Aerosol Algorithm

Omar Torres (NASA-GSFC), Hiren Jethva (USRA), Changwoo Ahn (SSAI)
NASA/GSFC

June 3, 2021

## 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.

*At TEMPO pixel size resolution (2.1X4.7km), 8 pixels can be combined for the application of spatial homogeneity cloud-masking, yielding a nearly-square product resolution of 8.2X9.4 km.*

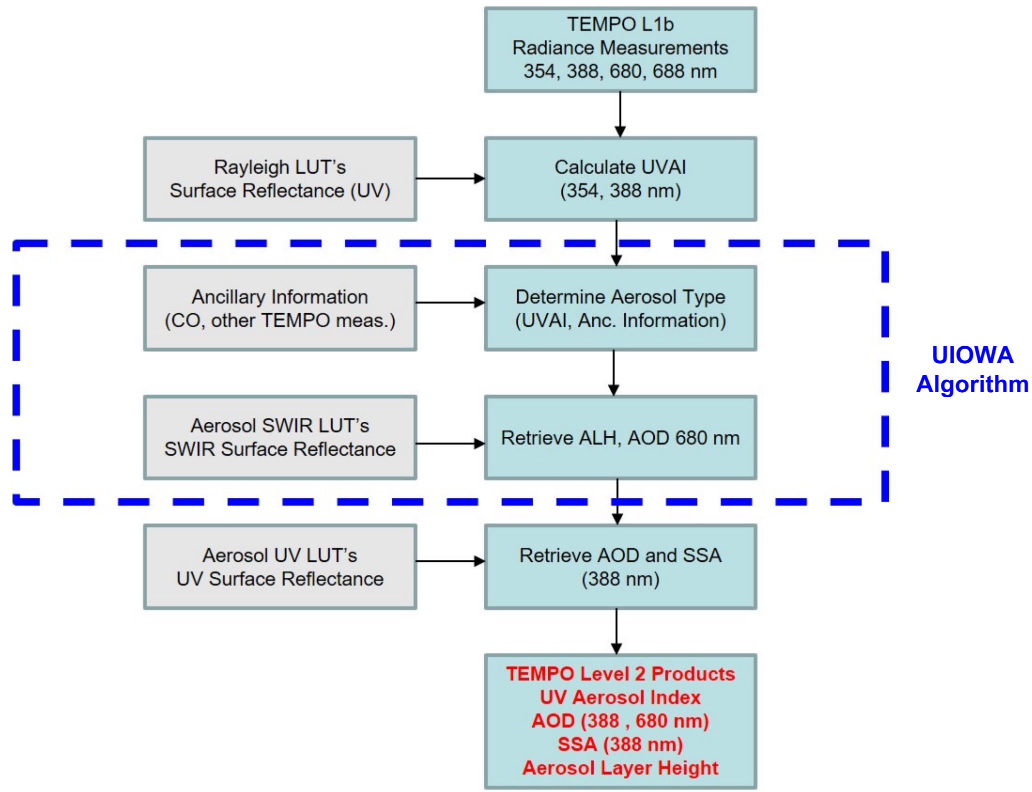
# Planned TEMPO Aerosol Products

*Combined NASA GSFC-UIOWA Algorithms*

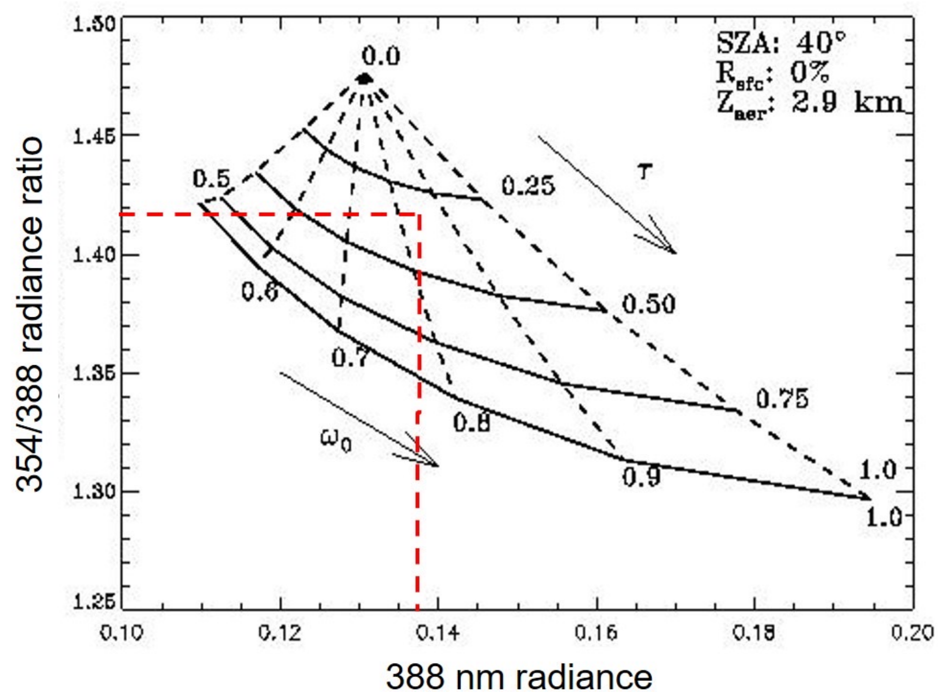
TEMPO measurements
Radiance 290-490 + 540-740 nm

Heritage Algorithms:
NASA Aura-OMI
S5P-TROPOMI,
DSCVOR-EPIC

Aerosol products:
-UV Aerosol Index (UVAI)
-Aerosol Layer Height and
-Aerosol Optical Depth (680 nm)
-Aerosol Optical Depth (388m)
-Single Scattering Albedo (388 nm)



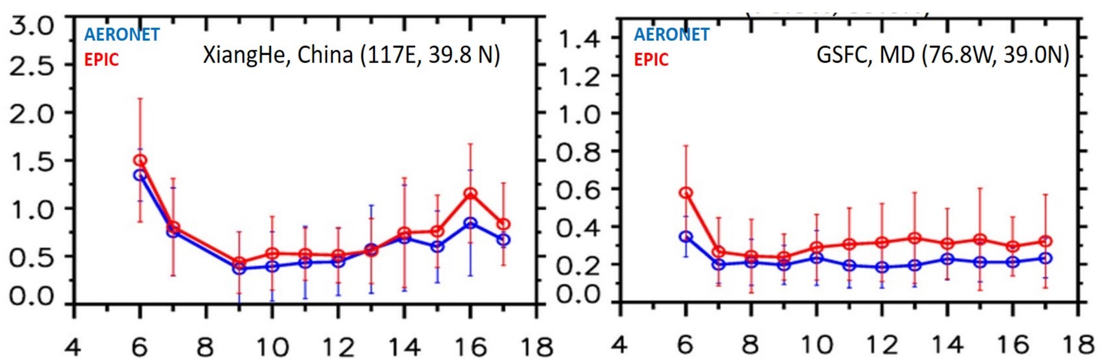
# Near UV Inversion Scheme




*Aerosol layer height will be retrieved from TEMPO radiances in O2B band*

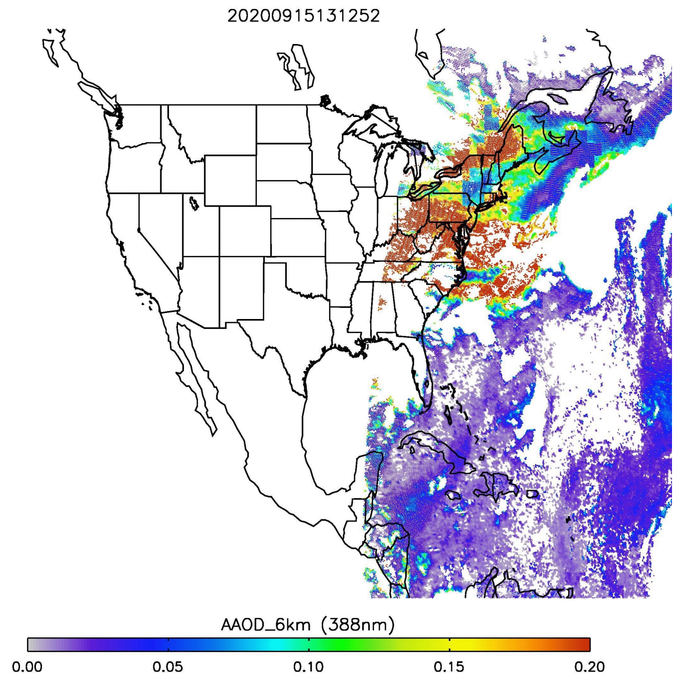
*For a given aerosol type and layer height, satellite measured radiances at 354 and 388 nm are associated with a set of AOD and SSA values.*

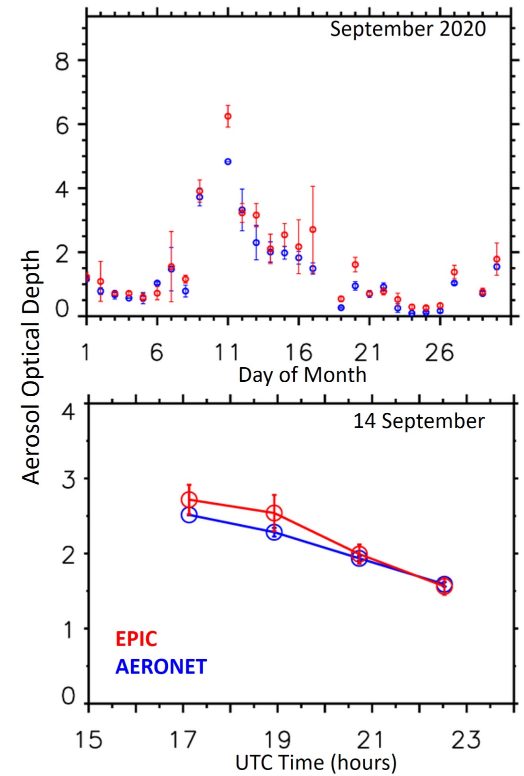
## Expected Applicability of TEMPO Aerosol Products




**Diurnal variability of AOD in urban environments as seen by EPIC (a good TEMPO proxy)**

# Diurnal Monitoring of USA Wildfires




On August and September 2020, a hemispheric scale smoke plume was detected by EPIC. The animation shows near-hourly retrievals of aerosol absorption optical depth (right) on September 15, 2020

EPIC and AERONET observed AOD daily (top) and diurnal (bottom) variability on September 2020 at Fresno, CA.

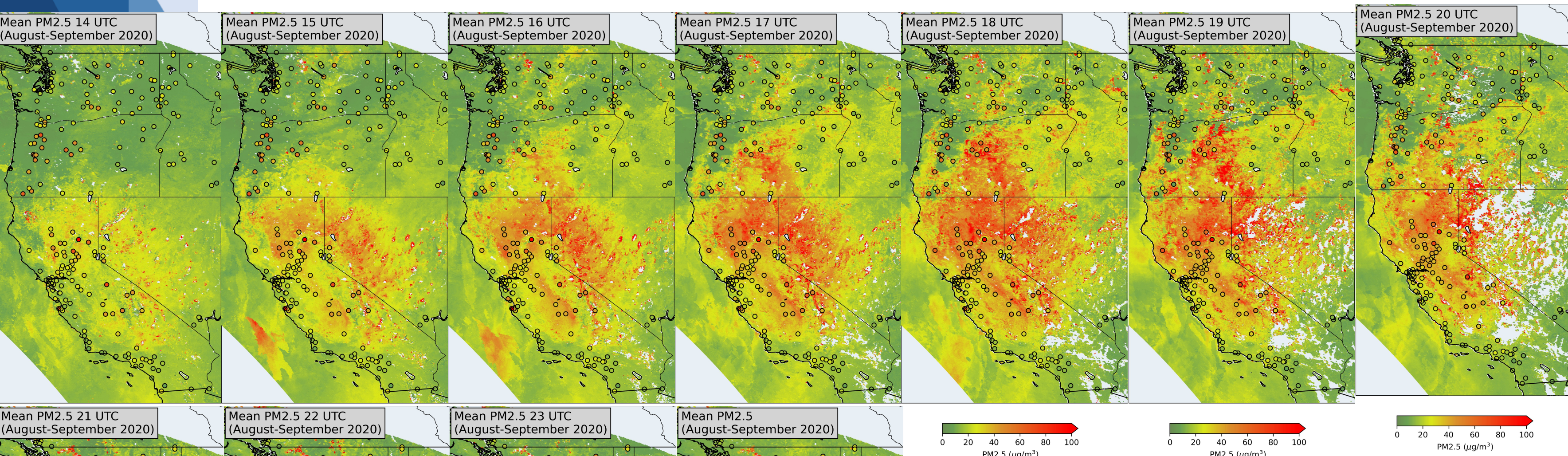
**EPIC View of the 2020 USA Continental Scale Fires, Sept. 15, 2020**

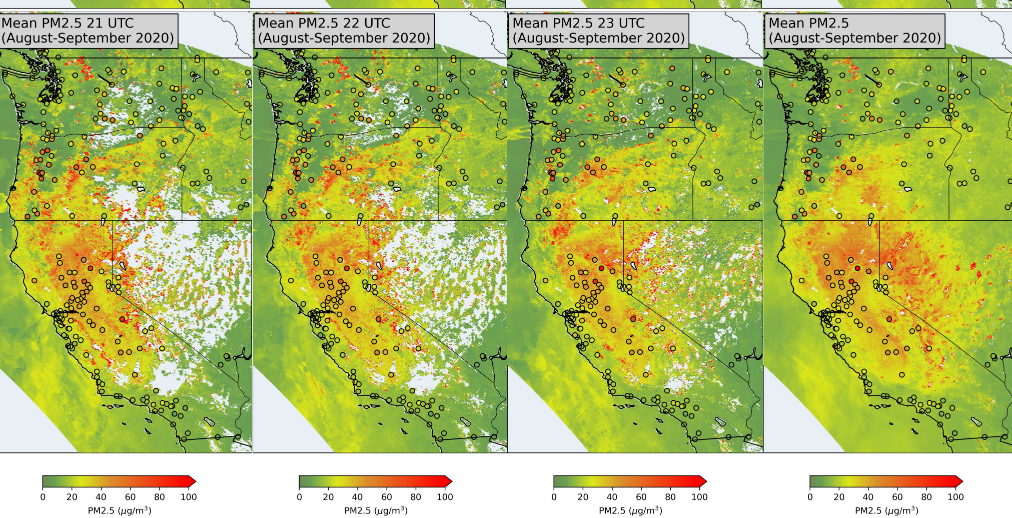
# ABI/TEMPO Synergy Experiment


Shobha Kondragunta[1], Hai Zhang[2], Jun Wang[3], Zhendong Lu[3]

[1]NOAA [2]IM Systems Group [3]University of Iowa


NOAA
National Satellite and Information Service
June 3-4, 2021



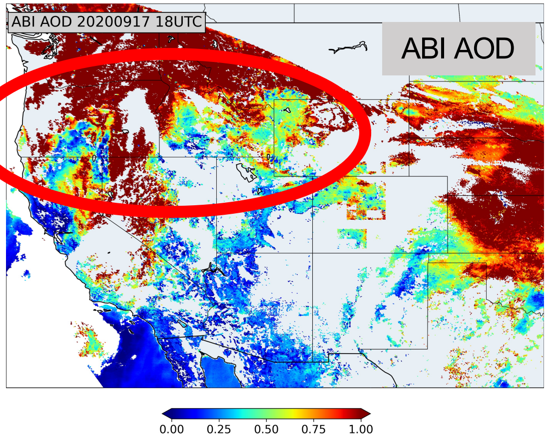



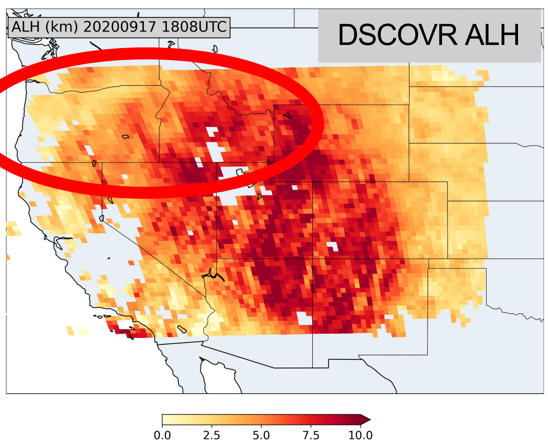

Time series of GOES-17 hourly composite $PM_{2.5}$ except the last panel which is the average of all hours (14 to 23 UTC) for August to September 2020

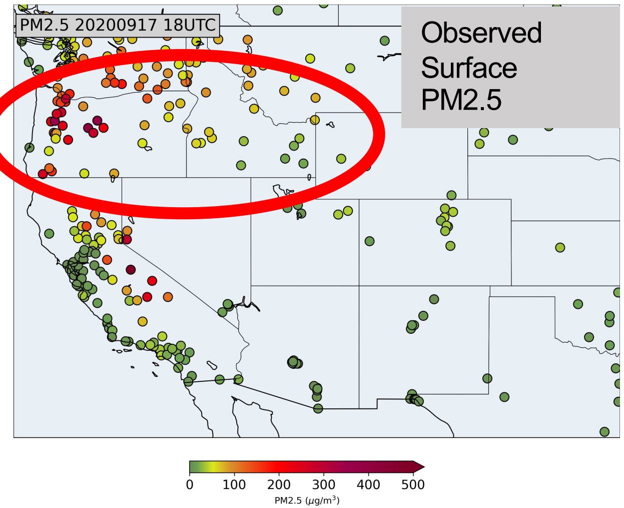
- Current NOAA statistical model (Geographically Weighted Regression method) uses only ABI AOD. *No aerosol layer height information*
- GEO-XO ACX $O_2$-$O_2$ or $O_2$ A/B-band absorption features could help improve the $PM_{2.5}$ estimates. The valuation studies we are starting soon will explore this using EPIC/DSCOVR aerosol height information (as proxy for TEMPO and ACX)

$$\boxed{AOD} = PM_{2.5}\, H\, f(RH)\, \frac{3Q_{ext,dry}}{4\rho\, r_{eff}} = \boxed{PM_{2.5}\, H\, S}$$

# Observed AOD, ALH, and Surface PM2.5

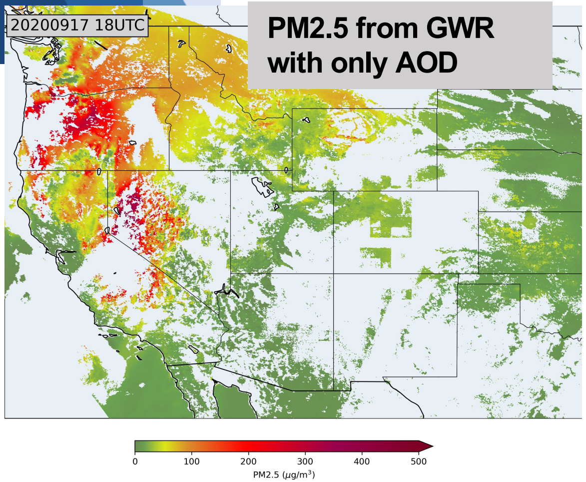


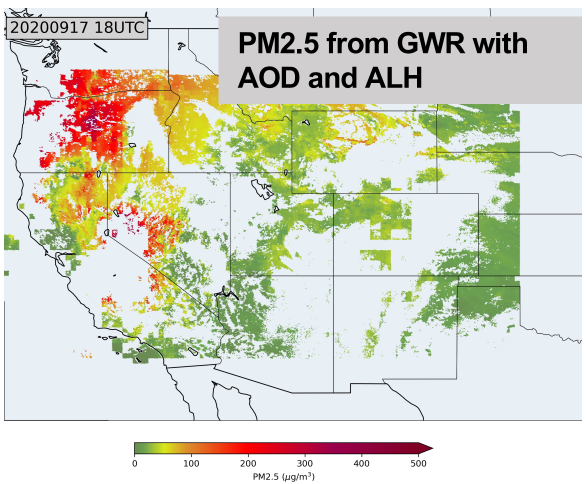



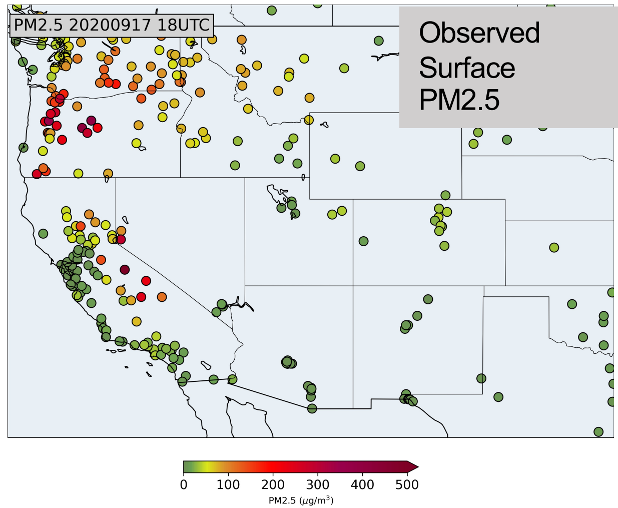




- High AODs due to smoke from fires
- EPIC/DSCOVR aerosol layer height (ALH) spatially varying with low altitude near source
- Consistent with ALH, surface PM2.5 higher when ALH is lower

# Scaling ABI AOD to Surface PM2.5



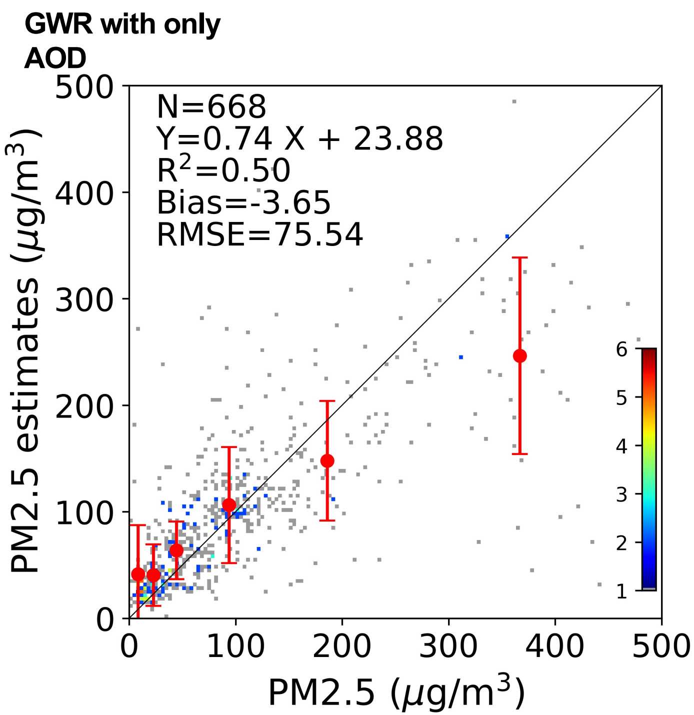



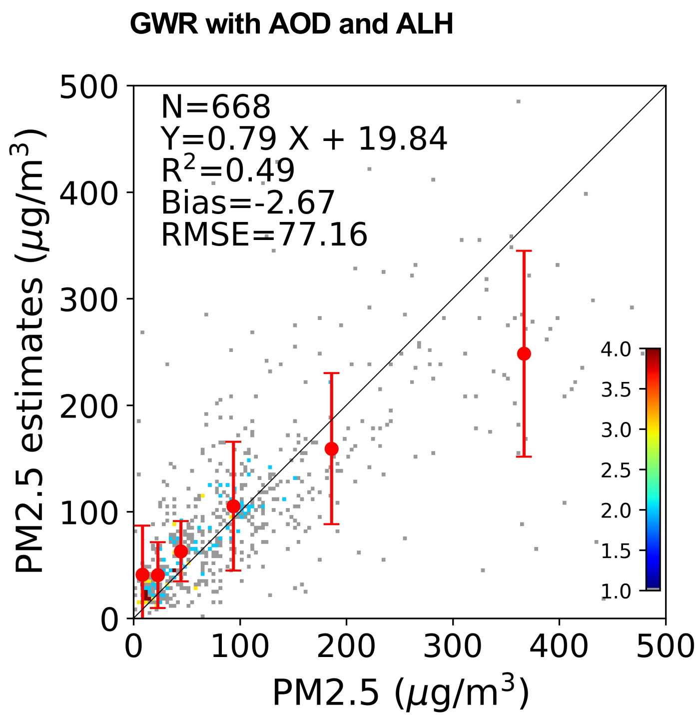




- Surface PM2.5 estimates from ABI AOD are consistent with observed PM2.5
- While spatial coverage is slightly different, results remain the same with or without the use of ALH

*NOAA GWR algorithm:*
Zhang, H., & Kondragunta, S. (2021). Daily and hourly surface PM2.5 estimation from satellite AOD. *Earth and Space Science*, 8, e2020EA001599. https://doi.org/10.1029/2020EA001599

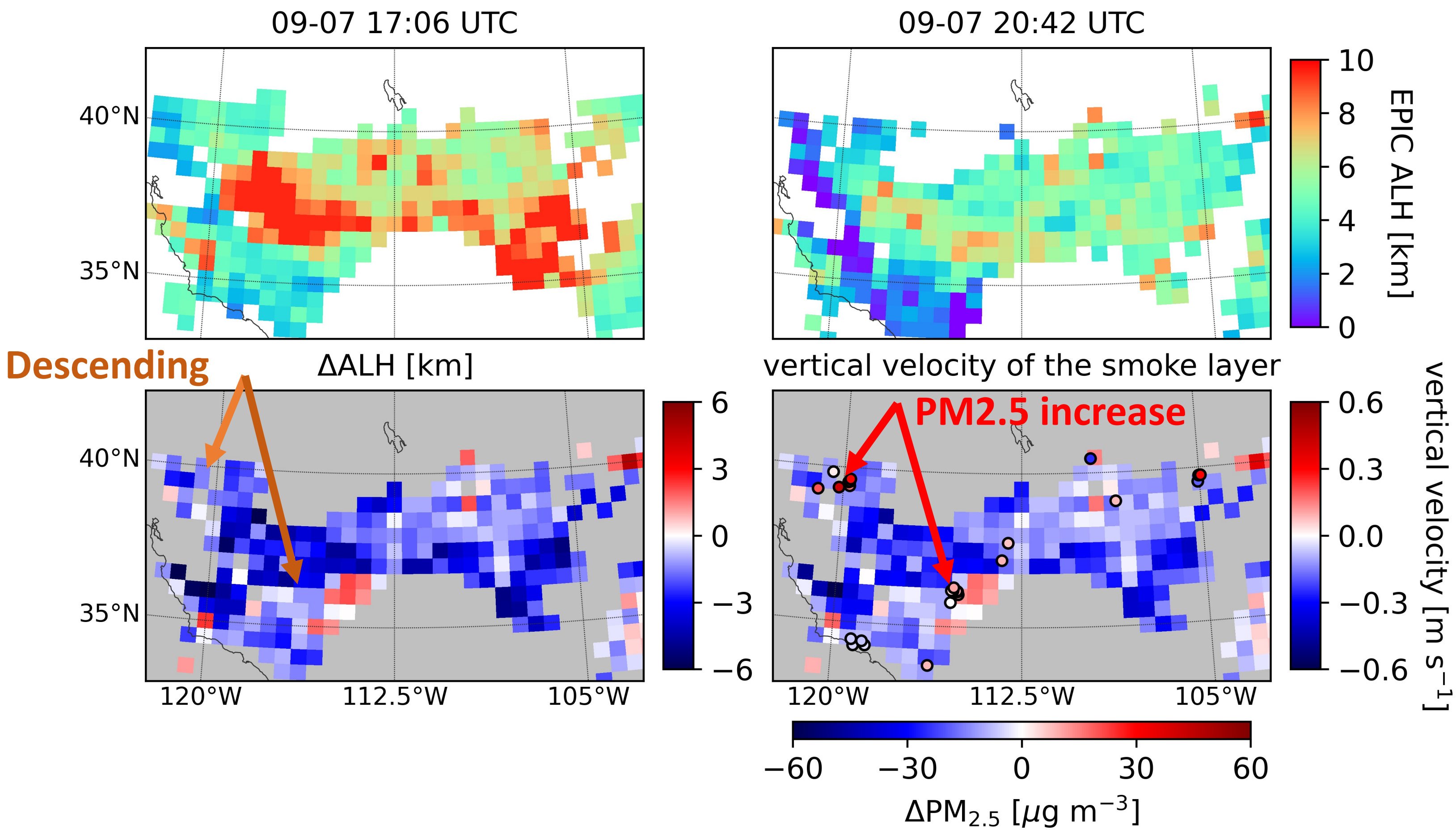
# Evaluation of GWR Predicted PM2.5




- When all ABI AOD retrievals (>0) are used there was no improvement using ALH (figure not shown). One reason could be that data are dominated by small AODs
- When ABI AOD retrievals (>1) are used GWR with AOD plus ALH provides slightly improved surface PM2.5 estimates
- Predicted PM2.5 at higher concentrations are biased low

# ΔALH/Δt vs. ΔPM2.5 /Δt corresponds well spatially



GEMS

# Preliminary Investigation of GEMS Aerosol Products using GEMS data over Asia

**Yeseul Cho[1], Jhoon Kim[1*], Sujung Go[2,3], Mijin Kim[3], Hyunkwang Lim[1], Seoyoung Lee[1], Omar Torres[3], Jongmin Yoon[4], Kyung-Jung Moon[4], Kyung Hwa Lee[4], Dong-Won Lee[4]**

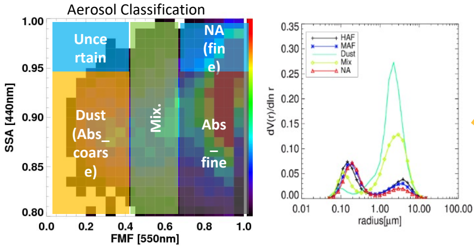
[1]Yonsei University, Seoul, Republic of Korea
[2]University of Maryland Baltimore County (UMBC), Maryland, USA
[3]NASA Goddard Space Flight Center (GSFC), Maryland, USA
[4]National Institute of Environmental Research, Incheon, Republic of Korea
[5]Korea Aerospace Research Institute, Daejeon, Republic of Korea

YONSEI UNIVERSITY

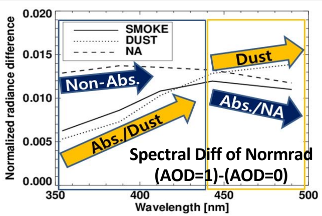
(Kim et al., 2018; Go et al., 2019; Go et al., 2020)

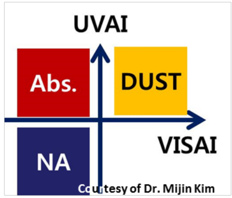
# Flowchart of GEMS aerosol retrieval algorithm

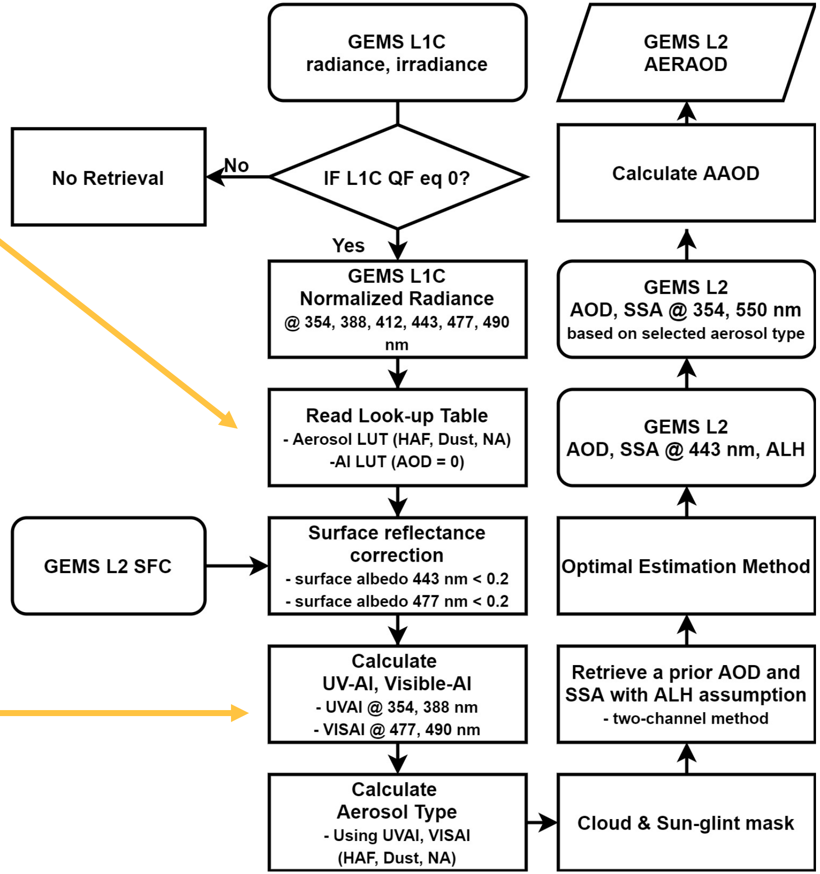
**From AERONET Inv. Data →**
**Using 3 models (HAF, DUST, NA)**




**Pre-selected aerosol type**



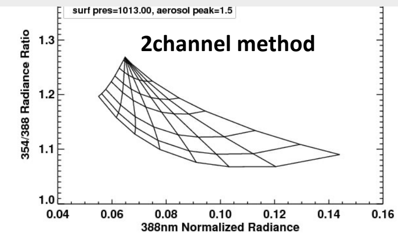

**GEMS Final Aerosol Products**

- **AOD and SSA at 354 nm, 443 nm, 550 nm**
- **UV aerosol index (354/388 nm)**
- **Visible aerosol index (477/490 nm)**
- **Aerosol Layer Height**

**Retrieve ALH with *Optimal Estimation***

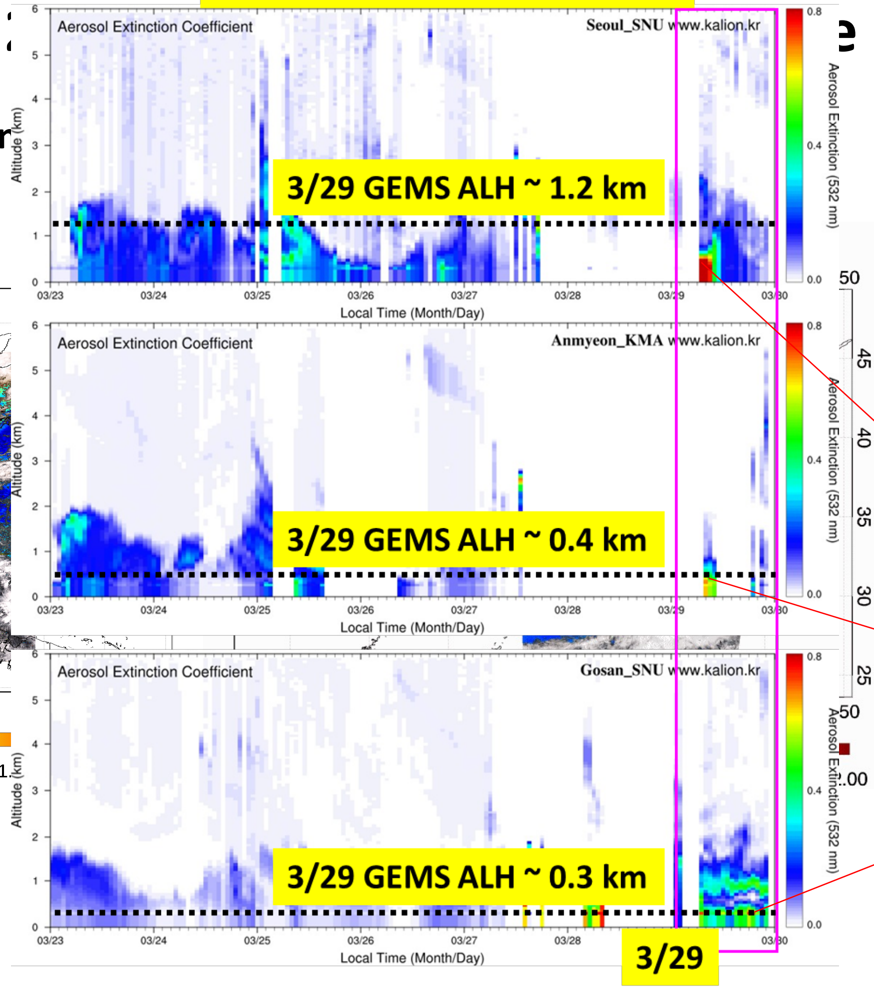
$$Z_{aer} = \sum_{i-1}^{n} H(i)\left[\frac{B_{sc}(i)}{\sum_{i=1}^{n} B_{sc}(i)}\right]$$

**Initial guess values**
**Retrieve AOD, SSA for assumed ALH**

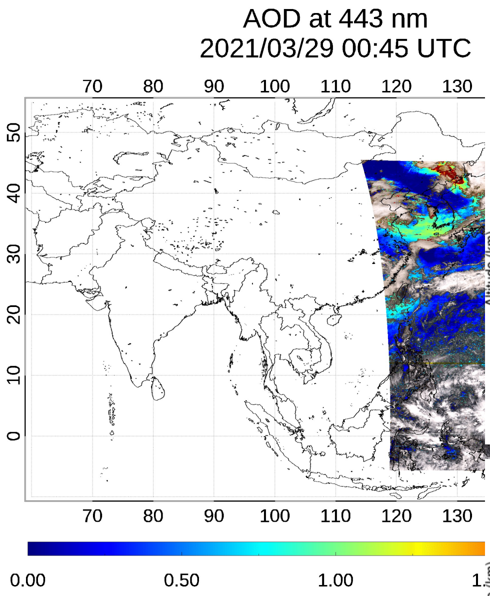


# GEMS & GOCI… e : 2021. 03. 29

## Aerosol Extinction Coefficient
(Korea Aerosol LIDAR Observation Network)

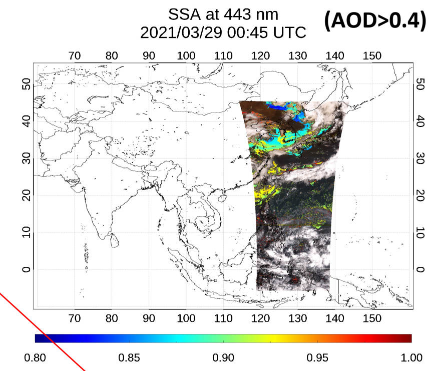



### GEMS AOD at 443 nm

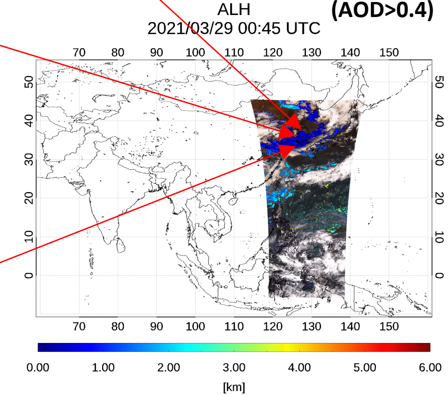



✓ **Consistent features**

### GEMS SSA at 443 nm

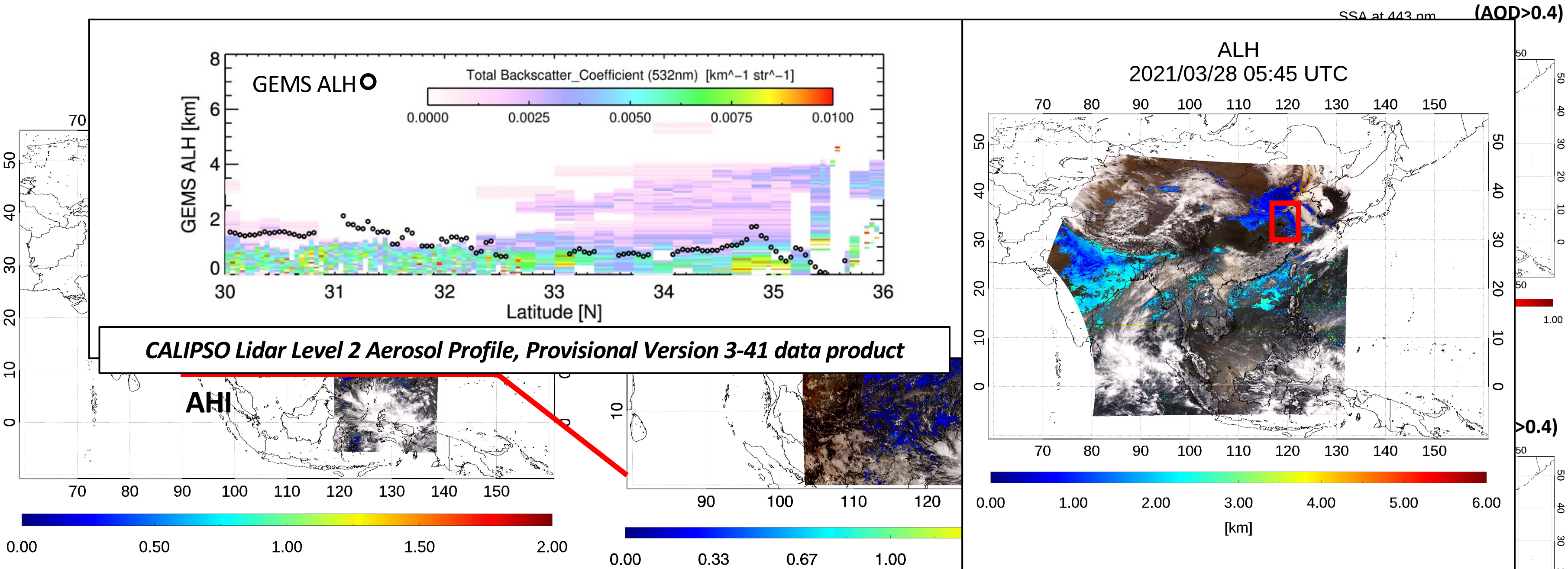


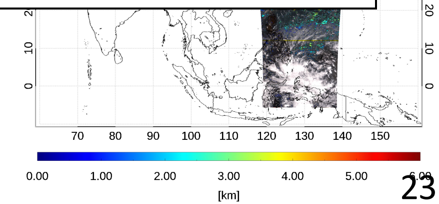

### GEMS ALH



# GEMS & AHI AOD High aerosol loading case : 2021. 03. 28

**GEMS AOD at 443 nm** **AHI AOD at 550 nm** **GEMS SSA at 443 nm**

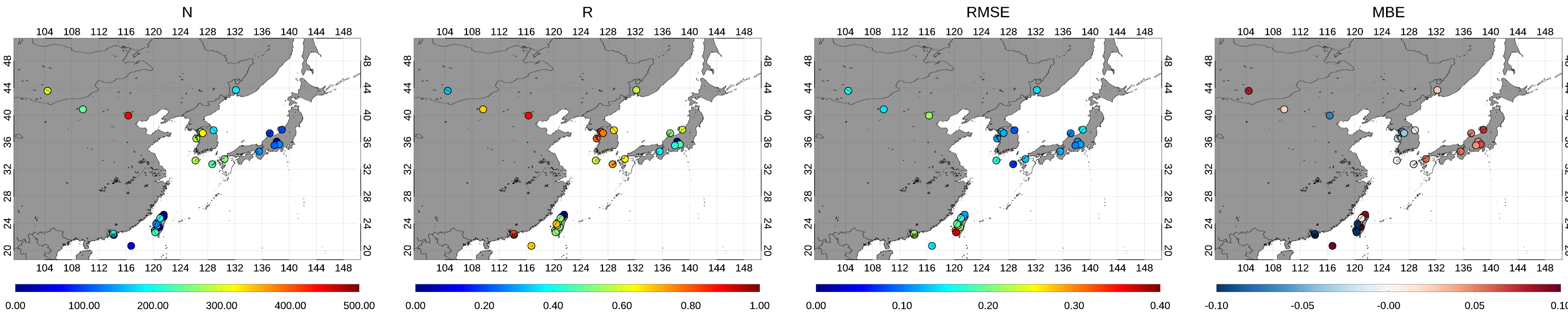


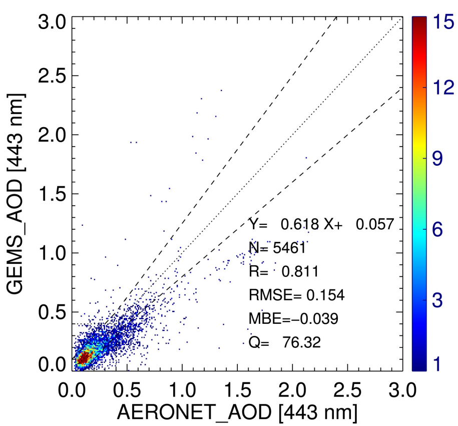




Lim et al. (RS, 2018)

✓ **Retrieval over bright surface**

# Comparison results for retrieved GEMS AOD with AERONET AOD




- Validation area : East Asia (100° E – 150° E, 20° N – 50° N)
- Validation period : 2020.08.01 – 2020.12.31
- For over 15 points (~ 10%), retrieved AODs within a 0.25° × 0.25° area from the AERONET site are averaged and compared with the averaged AERONET values within the observation time of 30 minutes from GEMS.

# Conclusion

- This study shows the **preliminary investigation of GEMS aerosol products using GEMS data over Asia**.
- Taking advantage of the sensitivity of aerosol absorption and aerosol height information in UV-Vis wavelengths, **GEMS aerosol algorithm retrieves aerosol optical properties (AOD, UV and Visible AI, SSA, and ALH).**
- **Our preliminary results show high aerosol loading cases over East Asia**, and the GEMS aerosol products have the advantage to **capture the diurnal variation with high spatio-temporal resolution.**
- **GEMS ALH**s show qualitatively good agreement with other aerosol extinction profiles detected by the KALION (Korea Aerosol LIDAR Observation Network). However, GEMS ALHs should be quantitatively compared to CALIPSO Lidar Level 2 Aerosol Profiles, especially on bright surfaces.
- The **preliminary results of the validation of the GEMS AOD** are presented as compared to other aerosol products obtained from the **GOCI2** onboard GK-2B, the **AHI** onboard Himawari-8, and ground-based **AERONET**.

# Antuña Marrero– Welcoming TEMPO: Cuba validate AOD & IWV

Juan Carlos Antuña-Marrero[1], A. Rodríguez[2], A. de Frutos[1], V. Cachorro[1], R. Estevan[2], C. Toledano[1], F. Garcia[2] J. C. Antuña-Sánchez[1], M. Alvarez[2], and A. Calle[2]

[1]GOA, University of Valladolid, Valladolid, Spain [2]GOAC, INSMET, Camagüey, Cuba

## GOAC-INSMET, Cuba in cooperation with GOA,UVA Spain will contribute to TEMPO:

After TEMPO launch :

TEMPO AOD validation with sun photometer AOD and phyrheliometer BAOD.

TEMPO Integrated Water Vapor (IWV) with sun photometer IWV and GPS IWV.

Develop local services w/ hourly TEMPO AOD & IWV to be scaled later to country.

## Diagnostic Service of Solar Radiation for Cuba:

2012: Three actinometrical stations in the country joined, becoming the "Diagnostic Service of the Solar Radiation for Cuba". Guarantees the update of the stations observation's digital records up to the present.

The direct irradiance measurements used to devive the Brodband AOD (BAOD) at all the 4 sites.

http://www.goac.cu/actino

## Comparing sun photometer AOD & pyrheliometer BAOD:

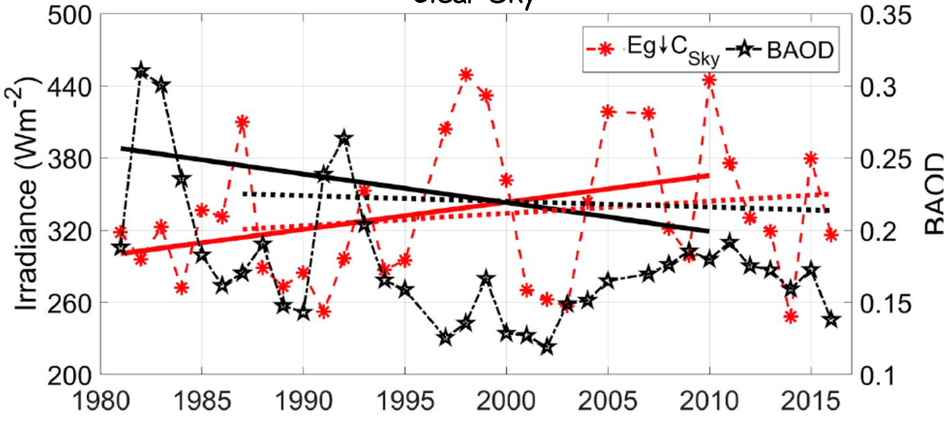
Temporal coincident sun photometer AOD (440, 500, 675 nm) & BAOD at Camagüey, Cuba.

Better results in bold.

| BAOD vs. $AOD_{SP}(\lambda)$ | | | |
|---|---|---|---|
| | 675 nm | 500 nm | 440 nm |
| RMSE | 0.048 | **0.044** | 0.056 |
| MAE | 0.037 | **0.030** | 0.040 |
| BIAS | 0.032 | **-0.002** | -0.022 |


- García, F., R. Estevan, **J. C. Antuña-Marrero**, J. Rosas, I. Y. Platero, J. C. Antuña-Sánchez, N. Díaz, 2015, Determinación de la Línea Base del Espesor Óptico de Aerosoles de Banda Ancha y comparación con datos de fotómetro solar. *Opt. Pura Apl.*, **48**(4), 249-258. https://doi.org/10.7149/OPA.48.4.249


## BAOD trend to explaining Brightening under clear sky at Camagüey.




Clear Sky Global Irradiance increasing trend 2.2 W $m^{-2}$ $year^{-1}$ (BRIGHTENING) for 1981-2010.
BAOD had a decreasing trend of $-2.8 \times 10^{-3}$ $year^{-1}$


- Antuña-Marrero, J. C., et al., 2019, Simultaneous dimming and brightening under all and clear sky at Camagüey, Cuba (1981–2010), J. of Atmos. and Sol.-Terr. Phys., Volume **190**, 45-53. https://doi.org/10.1016/j.jastp.2019.05.004

# Validation of MODIS AOD (Terra & Aqua) w/ sun photometer AOD & BAOD:

BAOD at the 4 solar radiation stations:

Camagüey, La Fe, Topes de Collantes & Jovellanos

| | BAOD vs. $AOD_t$ | | BAOD vs. $AOD_a$ | | BAOD vs. $AOD_{ta}$ | |
|---|---|---|---|---|---|---|
| | DB | DT | DB | DT | DB | DT |
| RMSE | 0.080 | 0.087 | **0.073** | 0.088 | 0.078 | 0.088 |
| MAE | 0.055 | 0.063 | **0.048** | 0.066 | 0.052 | 0.064 |
| BIAS | **0.001** | 0.027 | 0.014 | 0.049 | 0.005 | 0.035 |
| *R* | 0.455 | 0.325 | **0.501** | 0.417 | 0.468 | 0.355 |
| Cases | 373 | 436 | 191 | 268 | 564 | 704 |

$AOD^{SP}$ shows, in general, a better performance for the DT than for the DB algorithm.

Small differences between $AOD_t$ and $AOD_a$, justifying combining these observations in a single data set for climaological studies. DT & DB algorithms are better than expected (f ~ 80 %) from November to January, but in other months f = 68 %, ~ one standard deviation for DT and significantly lower for DB

| | $AOD_{SP}$ vs. $AOD_t$ | | $AOD_{SP}$ vs. $AOD_a$ | | $AOD_{SP}$ vs. $AOD_{ta}$ | |
|---|---|---|---|---|---|---|
| | DB | DT | DB | DT | DB | DT |
| RMSE | 0.084 | 0.060 | 0.065 | 0.062 | 0.078 | 0.061 |
| MAE | 0.062 | 0.045 | 0.046 | 0.047 | 0.056 | 0.046 |
| BIAS | −0.053 | −0.001 | −0.033 | 0.006 | −0.046 | 0.002 |
| *R* | 0.730 | 0.729 | 0.785 | 0.779 | 0.741 | 0.753 |
| *f* | 0.656 | 0.803 | 0.763 | 0.795 | 0.694 | 0.800 |
| Cases | 311 | 335 | 169 | 254 | 480 | 589 |

**Tables Legend:**

$AOD_t$: AOD Terra $AOD_a$: AOD Aqua $AOD_{ta}$:Terra & Aqua

$AOD_{SP}$: AOD Sun photometer DB: Deep Blue DT: Dark Target

f: MODIS/AERONET AOD retrievals in %

BAOD-MODIS comparison showed higher uncertainties than for MODIS-sun photometer, **but at the same order of magnitude.**


- Antuña-Marrero, J. C. at al., 2018: Comparison of aerosol optical depth from satellite (MODIS), sun photometer and broadband pyrheliometer ground-based observations in Cuba. *Atmos. Meas. Tech.*, **11**, 2279–2293, https://doi.org/10.5194/amt-11-2279-2018


Grupo de Optica Atmosférica de Camagüey

INSMET

TEMPO

GOA-UVA Grupo de Optica Atmosférica Universidad de Valladolid

UVa

ARTICLES

# COOPERATION ON GPS METEOROLOGY BETWEEN THE UNITED STATES AND CUBA

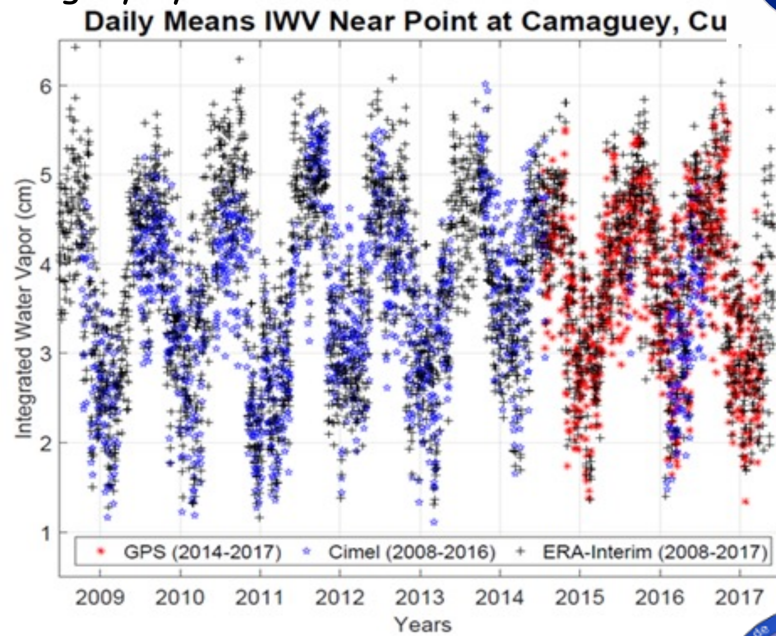
BY RICHARD ANTHES, ALAN ROBOCK, JUAN CARLOS ANTUÑA-MARRERO, OSWALDO GARCÍA, JOHN J. BRAUN, AND RENÉ ESTEVAN ARREDONDO

The events leading to the installation of a U.S. GPS receiver to measure precipitable water in Camagüey, Cuba, and the related collaboration of U.S. and Cuban scientists are described.

GPS operative at GOAC: May 22nd 2014 to the present.

- Anthes, R., Robock, A., Antuña-Marrero, J. C., García, O., Braun, J.J., and Estevan Arredondo, R., 2015: Cooperation on GPS Meteorology between the United States and Cuba. Bull. Amer. Meteor. Soc., **96**, 1079–1088. http://dx.doi.org/10.1175/BAMS-D-14-00171.1

## Preliminary validation of IWV from ERA-I w/ sun photometer & GPS Measured at Camagüey by GOAC




| Instrument | RMSE | MAE | BIAS | R | N |
|---|---|---|---|---|---|
| SP/GPS | 0.406 | 0.335 | -0.240 | 0.93<br>5 | 146 |
| SP/ERA-I | 0.806 | 0.623 | -0.123 | 0.68<br>3 | 1638 |
| GPS/ERA-I | 0.885 | 0.682 | -0.108 | 0.54<br>8 | 911 |

GOAC Grupo de Optica Atmosférica de Camagüey
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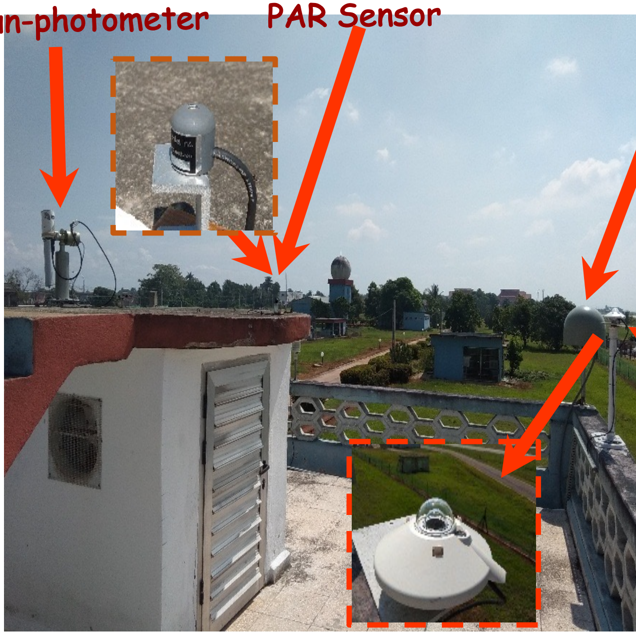
TEMPO
Grupo de Optica Atmosférica Universidad de Valladolid GOA-UVA
UVa

# SUMMARY: GOAC measurements capabilities:

## Radiation, Aerosols, Clouds and IWV(GPS)

GOA - Univ. Of Valladolid, Spain
(GOA-UVA)

Sun-photometer PAR Sensor



GPS (IWV)
UNAVCO
NCAR, US

Pyranometer
Prof. Alan Robock,
Rutgers Univ., US


Sun-photometer
Contributing to
AERONET

Supported by Cooperation Agreement
GOA-UVA & INSMET (2007-present)
http://www.goac.cu/uva/

Cloud Sky Camera
Built & operated
in cooperation with
GOA-UVA
Operative from 2018

GOAC Grupo de Optica Atmosférica de Camagüey

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## Main Contributors to the GOAC Observational Facilities:

Stratospheric lidar setup, operation & maintenance 1988-1991. Know-how & soft transfer.
***Tyfun, Obninsk former Soviet Union.***

More than 10 years of sustained cooperation.

- Sun photometer & its calibration (2008-2021)
- PM impactor.
- Photosynthetic Active Radiation sensor
- Calibration bench for radiation sensors.
- Computing & hardware resources
- PhD fellowship: Cloud Camera photometry.
- Broad know-how transfer & multiple trainings.
- Support for GOAC & LALINET publications

***Prof. Ángel de Frutos, Prof. Victoria Cachorro, & GOA-UVA team, Univ. Valladolid, Spain.***

Promoting and facilitating GOAC International Cooperation :

- PhD fellowship: Pinatubo lidar & satellite validation.
- Earlier contacts and exchanges with AERONET.
- Contributor to design, promote, support and setup LALINET.
- Key role in US-Cuba contacts for GPS setup at GOAC.
- Promoted GOAC invitation to Norway funded XCUBE project.
- Earlier contacts with TEMPO Science Team.
- Pyranometer CM-21 & Data logger LOGBOX SD (Kip & Zonen).

***Prof. Alan Robock, Rutgers University, USA***

Data Rescue know-how transfer and promotion of cooperation:

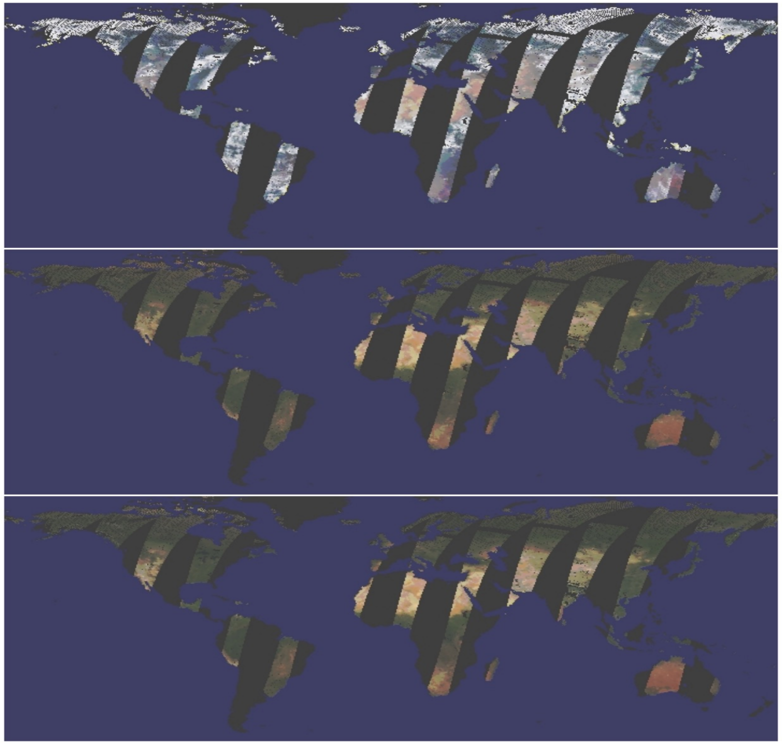
- PhD fellowship: for Pinatubo lidar & satellite validation.

***Prof. Ricardo García Herrera, Complutense Univ. Madrid, Spain***

Relevant contributors for GPS setup at GOAC.
***Prof. Rick Anthes, UCAR, Dr. John Braun, NCAR,***
***Prof. Oswaldo Garcia, San Francisco State University, CA, US***

# Can we recover surface spectral information in cloudy overcast conditions with (TEMPO) multi-spectral data when our eyes see only clouds?

Joanna Joiner, Zachary Fasnacht, Wenhan Qin, Yasuko Yoshida, Alexander Vasilkov, Nickolay Krotkov, Can Li (NASA/GSFC)



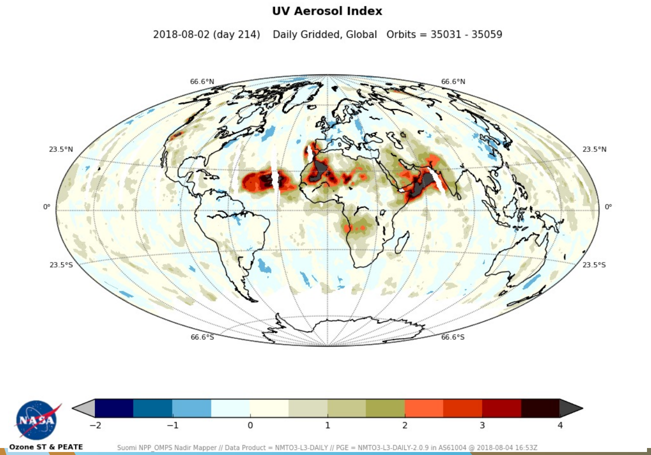
**Left: Top: All sky RGB image from GOME-2 on 2 August 2018; Middle and bottom: RGB derived from MODIS MCD43 surface nadir- and BRDF-adjusted reflectances and GOME-2 reconstructed surface reflectance derived with cloudy GOME-2 spectra. But which is which?**

- If you want to find out more about how we did this, come to the poster. We should be able to do this with TEMPO. It is not magic; it is an approach with a basis in physics.
- Implementing such an approach should lead to very timely estimates of particularly surface-related parameters (both ocean and land) that could enhance spatial coverage for a range of TEMPO applications.
- Works very well for “atmospheric correction” in both cloudy and/or (absorbing) aerosol loaded conditions.
- Uncertainties in reconstructed data are also provided.
- Depends critically on quality of auxiliary collocated (MODIS) data

# 2 August 2018, zoom over northern Africa

Original GOME-2 data, RGB false color image

Reconstructed surface GOME-2 data, RGB

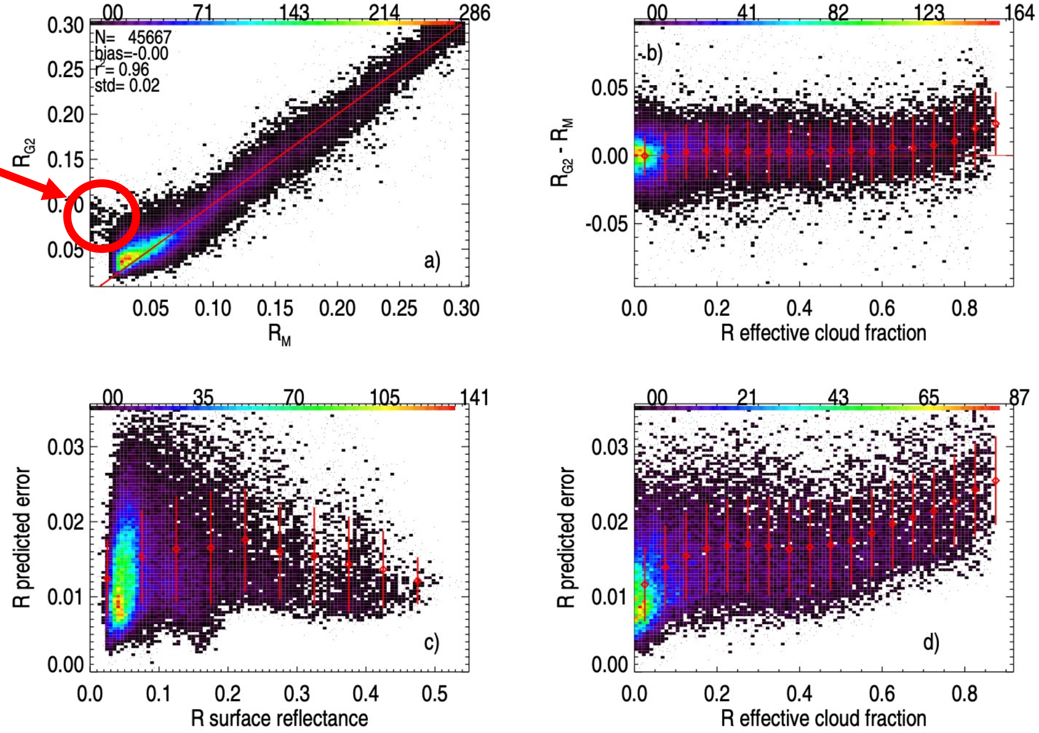



MODIS MCD43C NBAR (nadir BRDF adjusted) data, RGB

# Detail comparison and uncertainty estimates

Great lakes (not intended to work for)

Results for red reflectance 2 August 2018 (a day not trained on)



# Analyzing diurnal variations of AOD-$PM_{2.5}$ relationship from modeling perspective: Implications for TEMPO AQ applications


| | |
|---|---|
| **Mian Chin** | NASA GSFC |
| **Huisheng Bian** | UMBC / NASA GSFC |
| **Alex Coy** | Cornell University (was at Montgomery Blair High School) |
| **Qian Tan** | BAER Institute / NASA Ames |
| **Tianle Yuan** | UMBC / NASA GSFC |
| **Xiaohua Pan** | ADNET / NASA GSFC |
| **Hongbin Yu** | NASA GSFC |
| **Zhining Tao** | USRA / NASA GSFC |
| **Dongchul Kim** | USRA / NASA GSFC |
| **Gao Chen** | NASA LaRC |

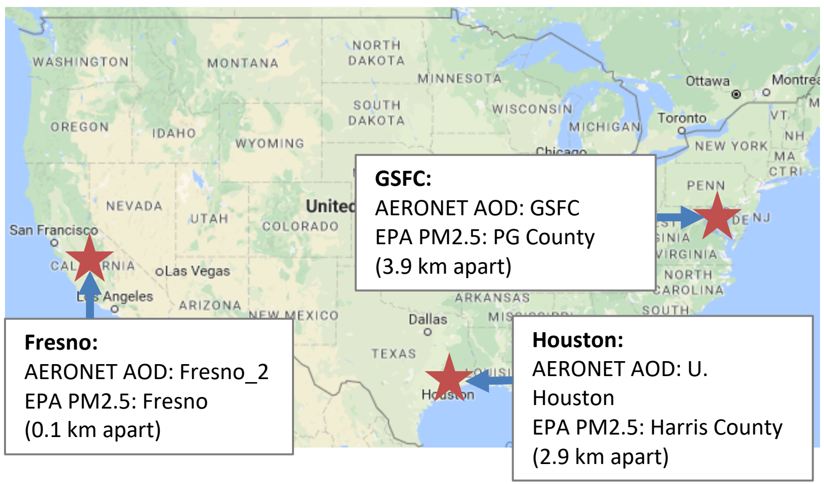

TEMPO Science Team Meeting, June 2-3, 2021

## Key messages in today's talk:

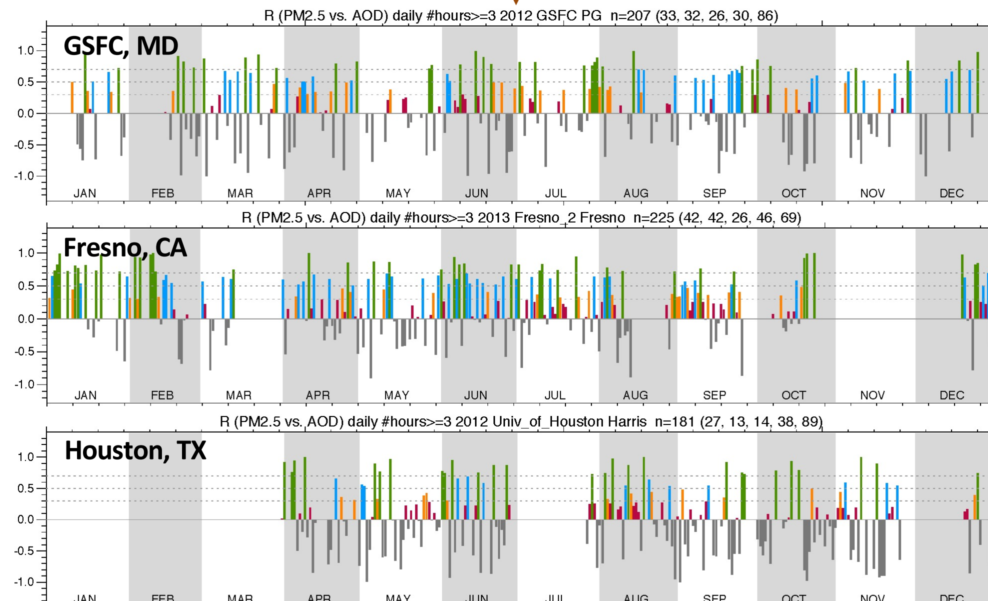
- Observations and model simulations show that column AOD and surface $PM_{2.5}$ are poorly correlated on diurnal time scales, meaning that it is not feasible to directly use the geostationary satellite observed AOD for estimating surface $PM_{2.5}$ concentrations
- Using the GEOS model simulations of AOD and $PM_{2.5}$ and relevant meteorological fields, we analyze the key controlling factors of the diurnal AOD-$PM_{2.5}$ relationship and suggest an approach to make geostationary satellite observations better suited for AQ applications

# Collocated AOD and $PM_{2.5}$ data over the U.S. in 2012

- AERONET: Column AOD @440nm and column water vapor (CWV), hourly mean during the day
- EPA: surface $PM_{2.5}$, hourly mean day and night
- Co-location criteria: AOD and $PM_{2.5}$ sites < 4 km apart
- Sites are chosen for at least having one-year AOD and $PM_{2.5}$ observations available

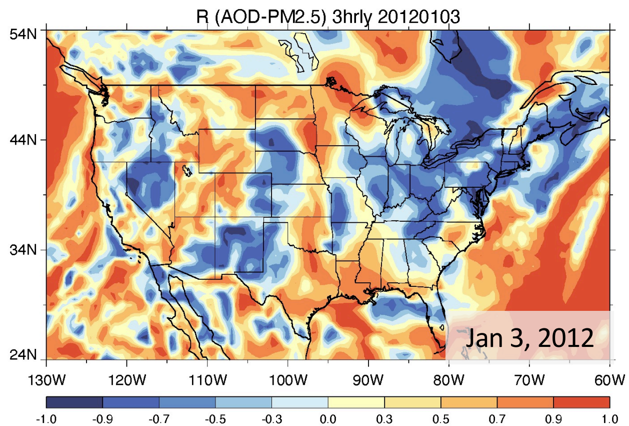


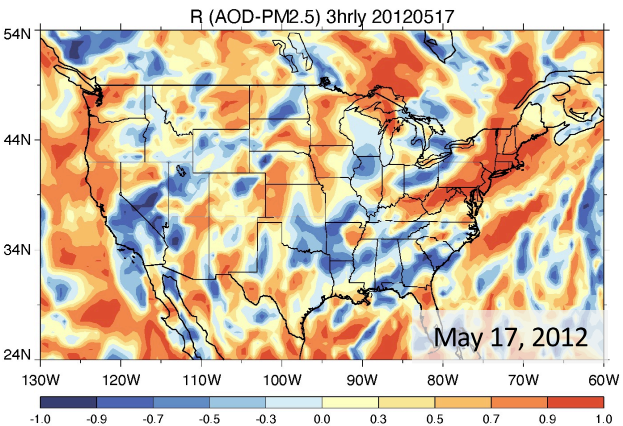

- Only 15-20% days within 2012 the diurnal AOD and PM2.5 are correlated with R ≥ 0.7 (green color)
- In contrast, 30-50% days in 2012 the diurnal AOD and PM2.5 are uncorrelated or anticorrelated with R < 0 (gray color)
- Slope and intercept also changes from day to day



# GEOS model simulation of AOD and $PM_{2.5}$ at 3-hourly output also show poor correlations between them at diurnal time scale

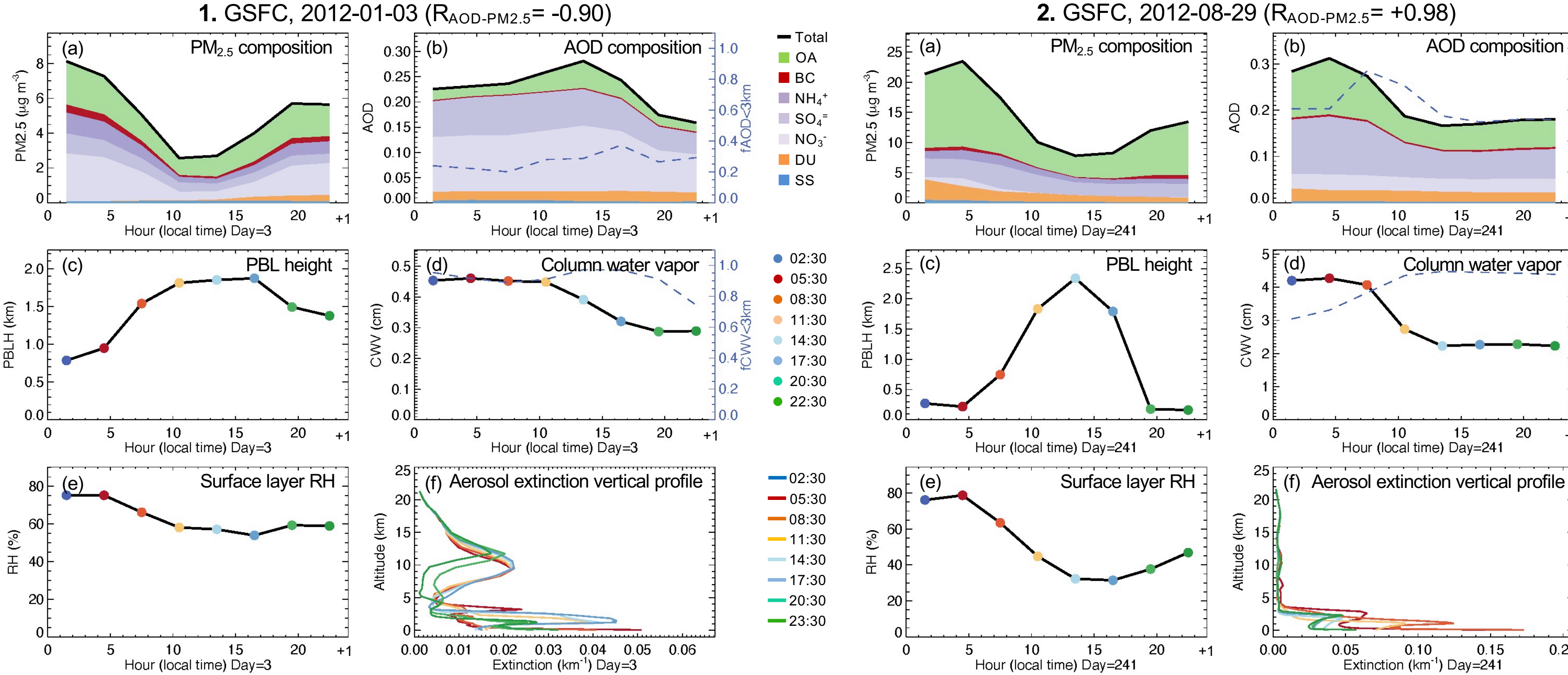
R of 3-hourly AOD-$PM_{2.5}$ (8 times/day)




- Because the consistent processes determining the AOD and $PM_{2.5}$ in the model, we examine the GEOS output for "good" and "bad" AOD-$PM_{2.5}$ correlation days to explain their relationship
- We use several variables from the GEOS model to perform multi-variable regression to estimate the 3-hourly $PM_{2.5}$ concentrations from AOD and compare them with model simulated "true" values

# Examination of aerosol compositions, vertical profiles, and some meteorological fields to explain the AOD-$PM_{2.5}$ relationship in two different days, one with R= -0.90 and one with R = +0.98, GEOS simulation




- Aerosol compositions of $PM_{2.5}$ and AOD are quite different
- ~30% of total AOD below 3 km with different temporal variation from aerosols aloft -> AOD variations are not in-sync with $PM_{2.5}$

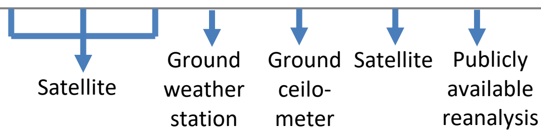
- Aerosol compositions of $PM_{2.5}$ and AOD are similar
- 55-80% of AOD below 3km -> both AOD and $PM_{2.5}$ temporal variations are controlled by the aerosol below 3 km

# Select several "observable" variables from the GEOS model for multi-variable regression to estimate the 3-hourly $PM_{2.5}$ concentrations from AOD and compare them to the "true" simulated $PM_{2.5}$ values at GSFC, Fresno, and Houston

- AOD, CWV, and AE are available from AERONET and mostly available from satellite retrievals
- Surface RHs can be obtained from local weather stations
- PBLH can be obtained from ceilometer or lidar data, although limited
- ALHc (or similar quantity) can be retrieved from satellite (e.g., $O_2$-A or $O_2$-B)
- MEEs is rarely observed, but may obtained from publicly accessible reanalysis data
- Note: estimated $PM_{2.5}$ is from the multivariable linear fitting, although in reality the relationships are not linear

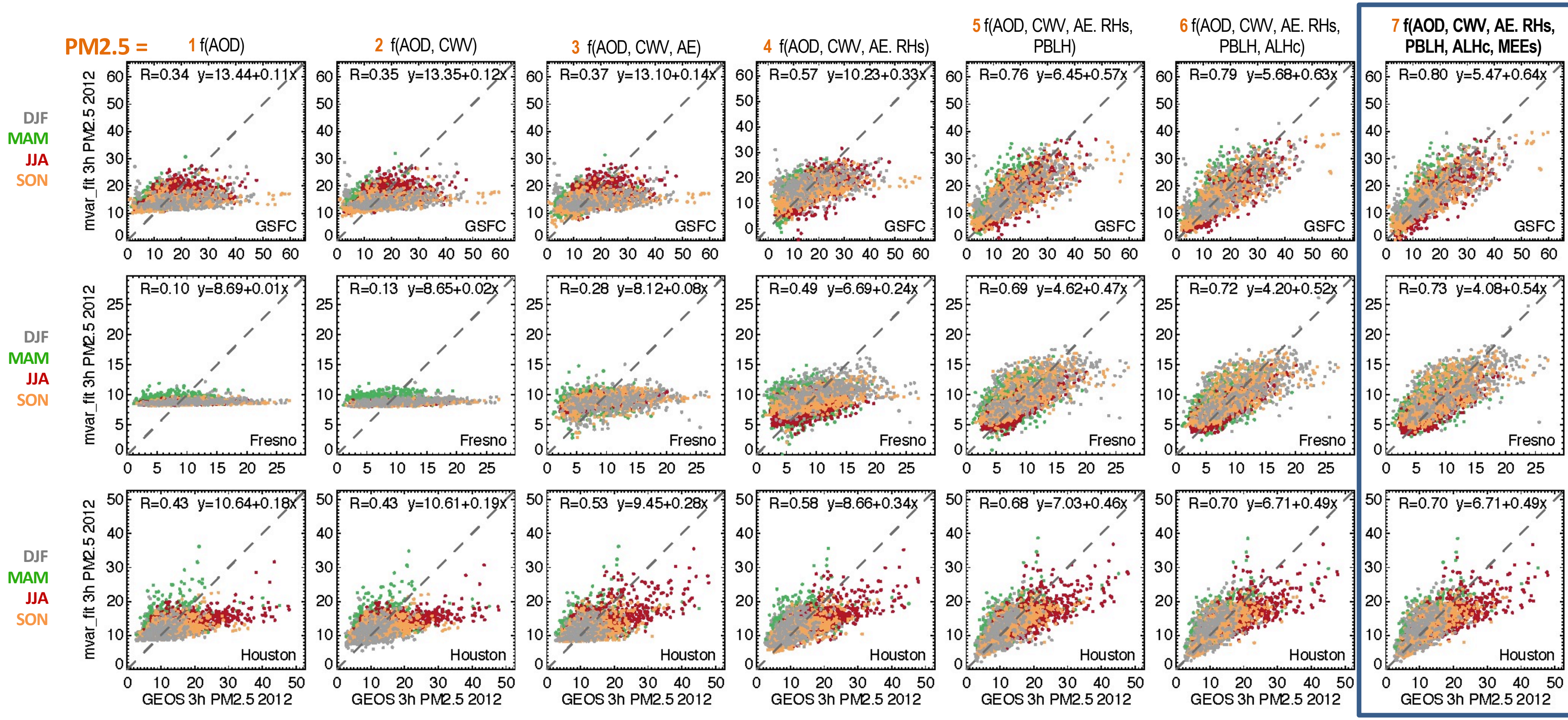
Multivariable regression of 3-hour GEOS output for 2012:

1 $PM_{2.5} = f\,(AOD)$
2 $PM_{2.5} = f\,(AOD, CWV)$
3 $PM_{2.5} = f\,(AOD, CWV, AE)$
4 $PM_{2.5} = f\,(AOD, CWV, AE, RHs)$
5 $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH)$
6 $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH, ALHc)$
7 $PM_{2.5} = f\,(AOD, CWV, AE, RHs, PBLH, ALHc, MEEs)$


CWV = column water vapor; AE = Angstrom exponent; RHs = relative humidity at surface; PBLH = planetary boundary layer height; ALHc = optical centroid aerosol layer height; MEEs = mass extinction efficiency at surface

# Estimated $PM_{2.5}$ from multi variable fitting vs. GEOS-calculated $PM_{2.5}$



# Conclusions

- Observations from collocated AOD and $PM_{2.5}$ measurements shows that it is not feasible to directly convert geostationary satellite observed diurnal AOD to diurnal $PM_{2.5}$
- However, our modeling analysis suggests that it is possible to “retrieve” diurnal $PM_{2.5}$ from GEO satellite diurnal AOD data with much improved accuracy if additional ancillary variables can be included in the retrieval from remote sensing and ground observations and/or from accessible reanalysis data
  - Additional variables included in our analysis: CWV, AE, RHs, PBLH, ALHc, MEEs
  - Most important ones: PBLH, RHs, and ALH (or fraction of AOD in the lowest 3 km)

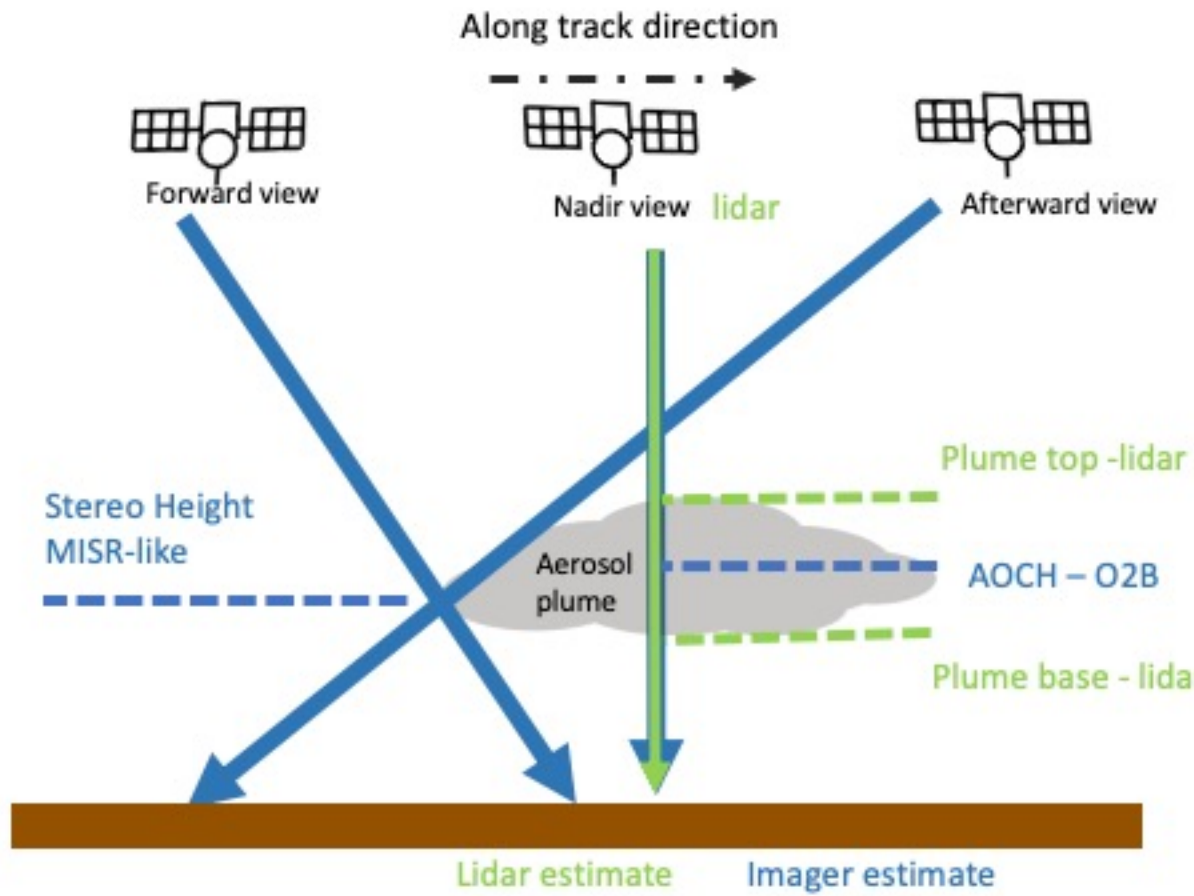
# Summary & Discussions

- Many exciting products can be on the way provided there are resources support
- AOCH retrievals from TROPOMI and DSCOVR show the promise of TEMPO for hourly characterization of aerosol layer height, and improving hourly retrieval of aerosol absorption.
- Hourly AOCH, AOD, and SSA from TEMPO can be of great interest to AQ and climate community.
- We are still in the path to fully explore the TEMPO's potential and capability
  - Night time AOD (see Meng Zhou's poster)
  - Surface spectral reflectance (Chengzhe Li's poster)

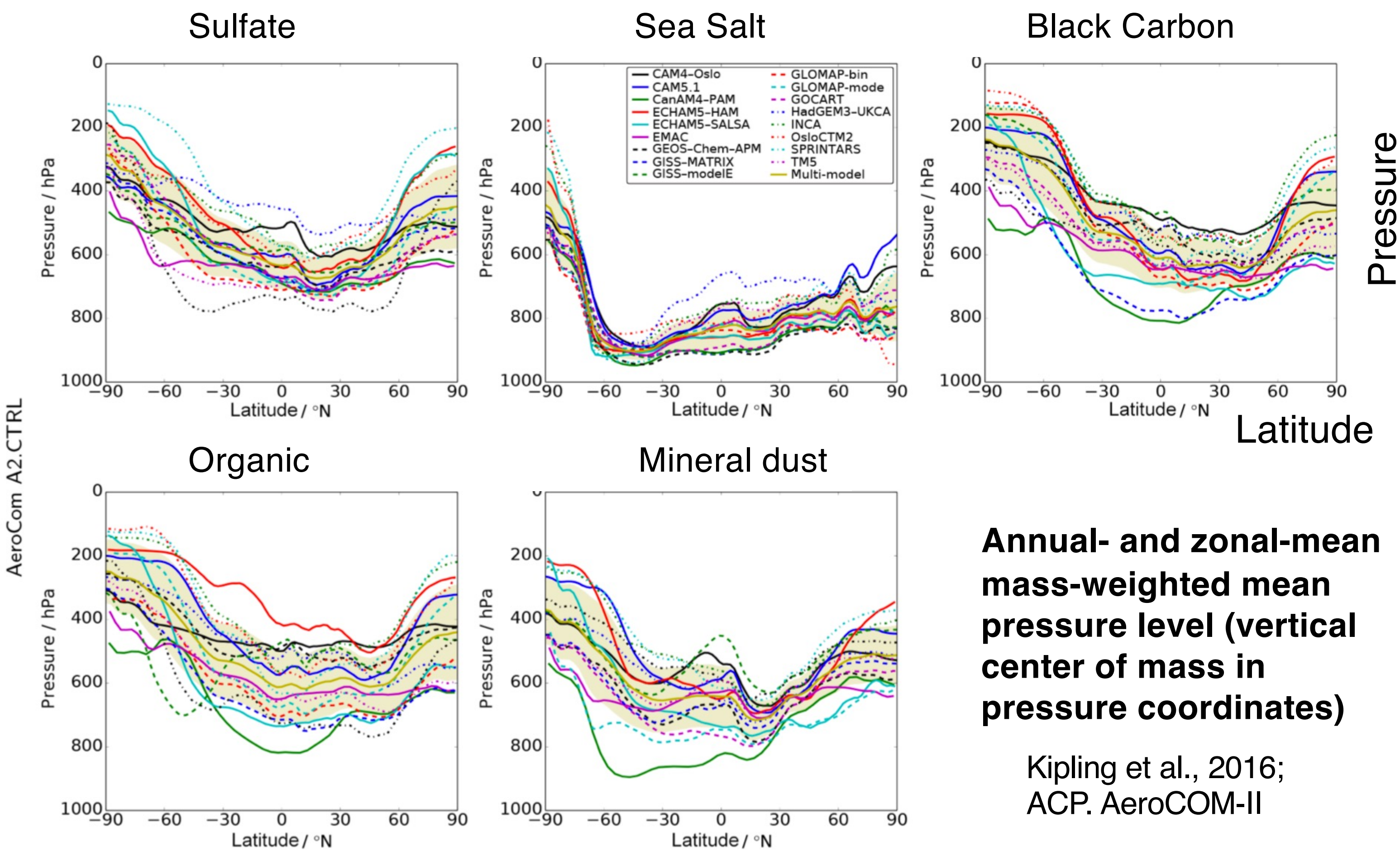
# Backup slides

# Thank you !

TEMPO, GEO-CAPE, ACMAP, KORUS-AQ, Applied sciences


Along track direction
Forward view
Nadir view
lidar
Afterward view
Plume top -lidar
Stereo Height
MISR-like
Aerosol
plume
AOCH – O2B
Plume base - lidar
Lidar estimate
Imager estimate

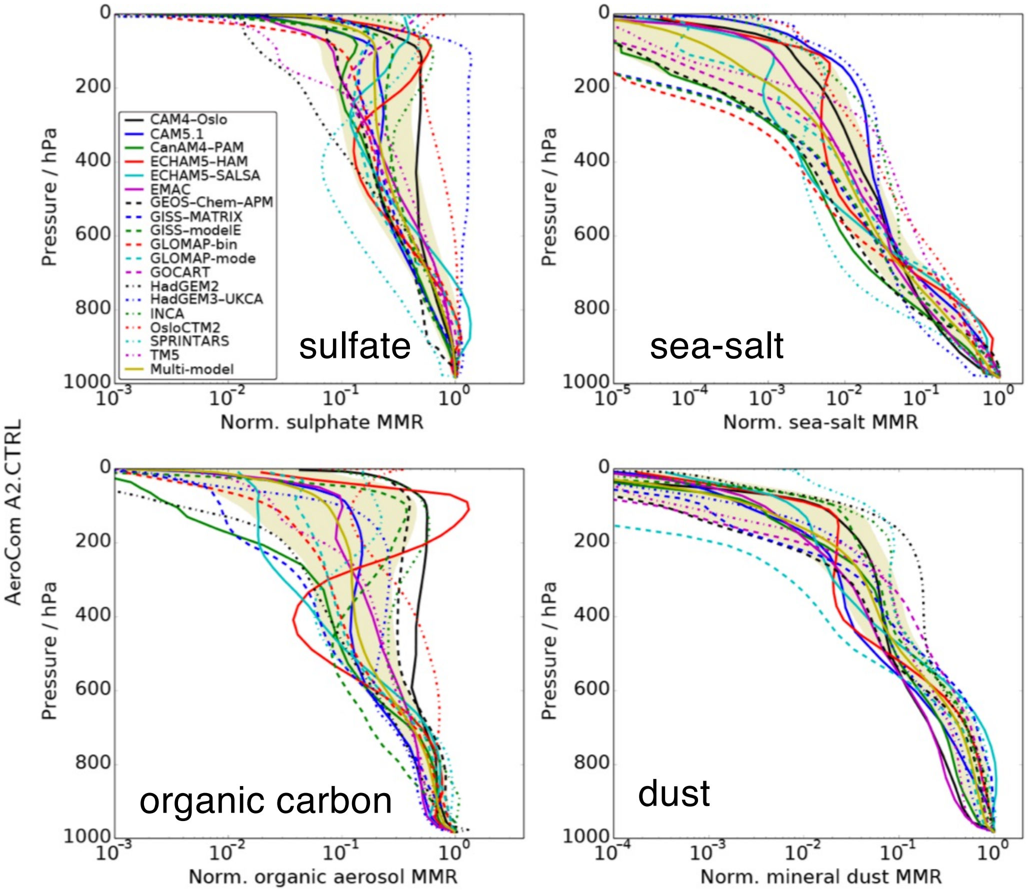
# Large uncertainty in aerosol vertical profile




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

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

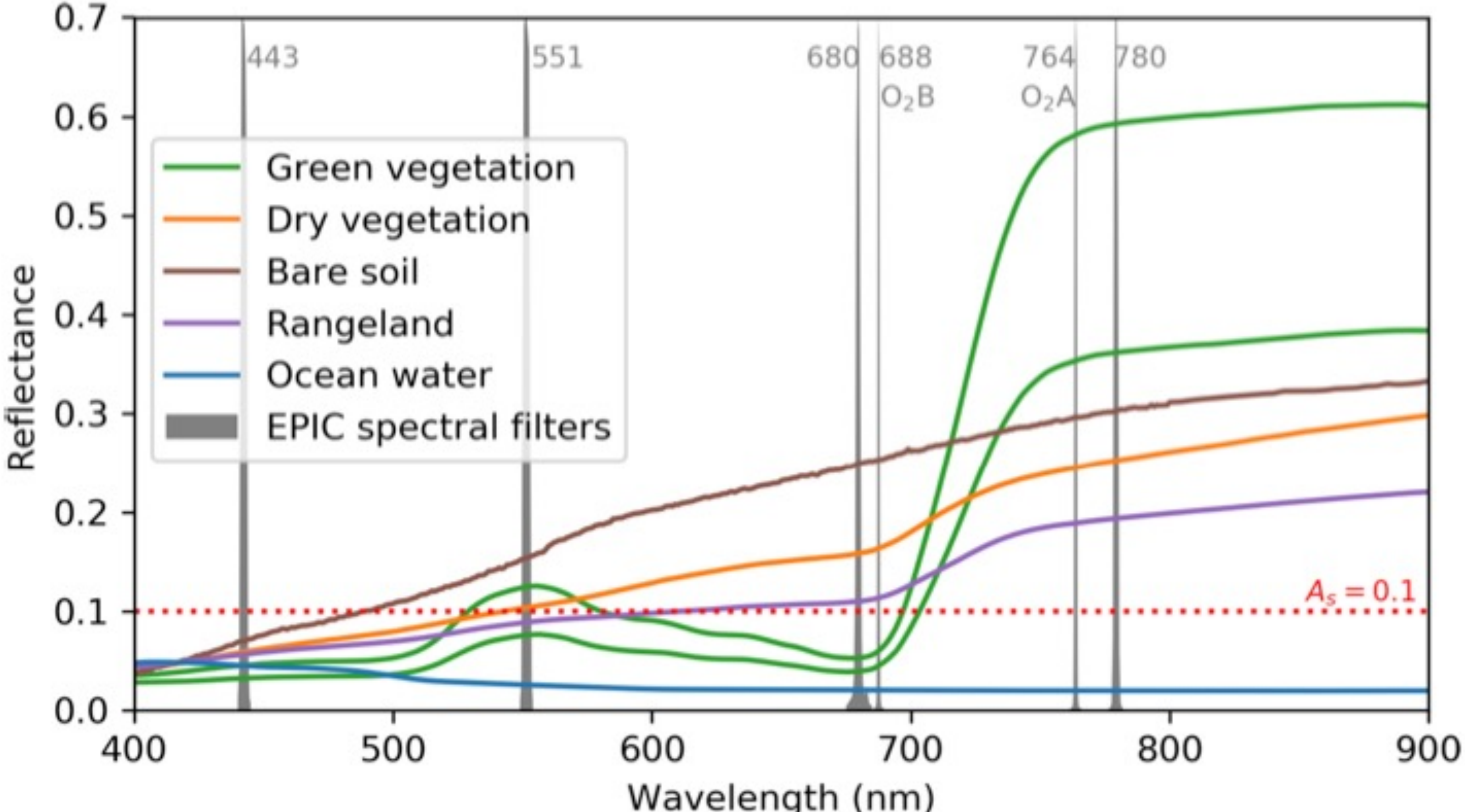
# Large uncertainty in our modeling of aerosol vertical profile highly relevant to climate and air quality prediction



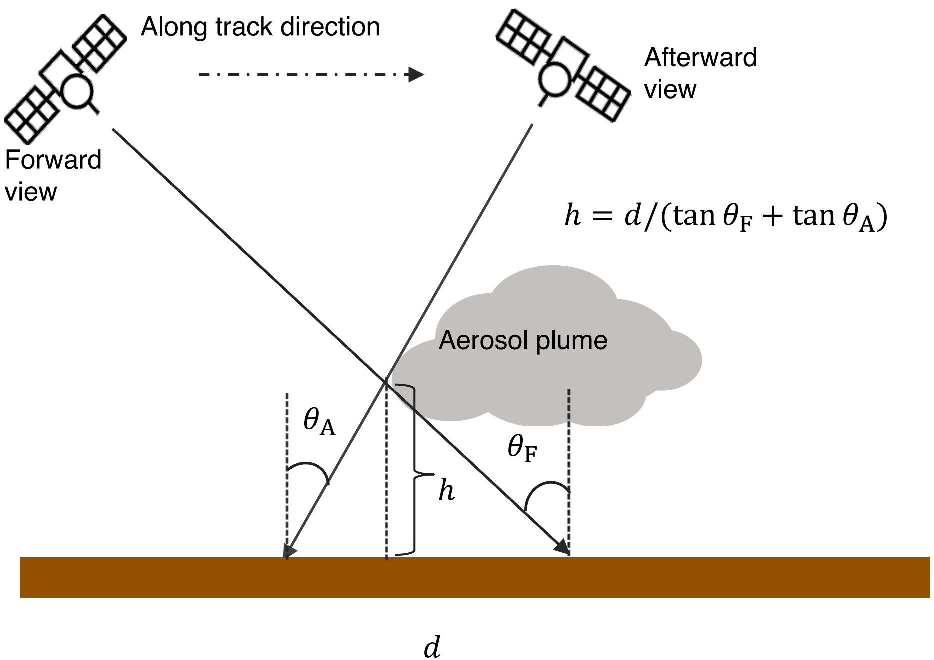

Uncertainty in free troposphere and UTLS is the very large; but this part of the atmosphere is also where lidar is best at for observing.

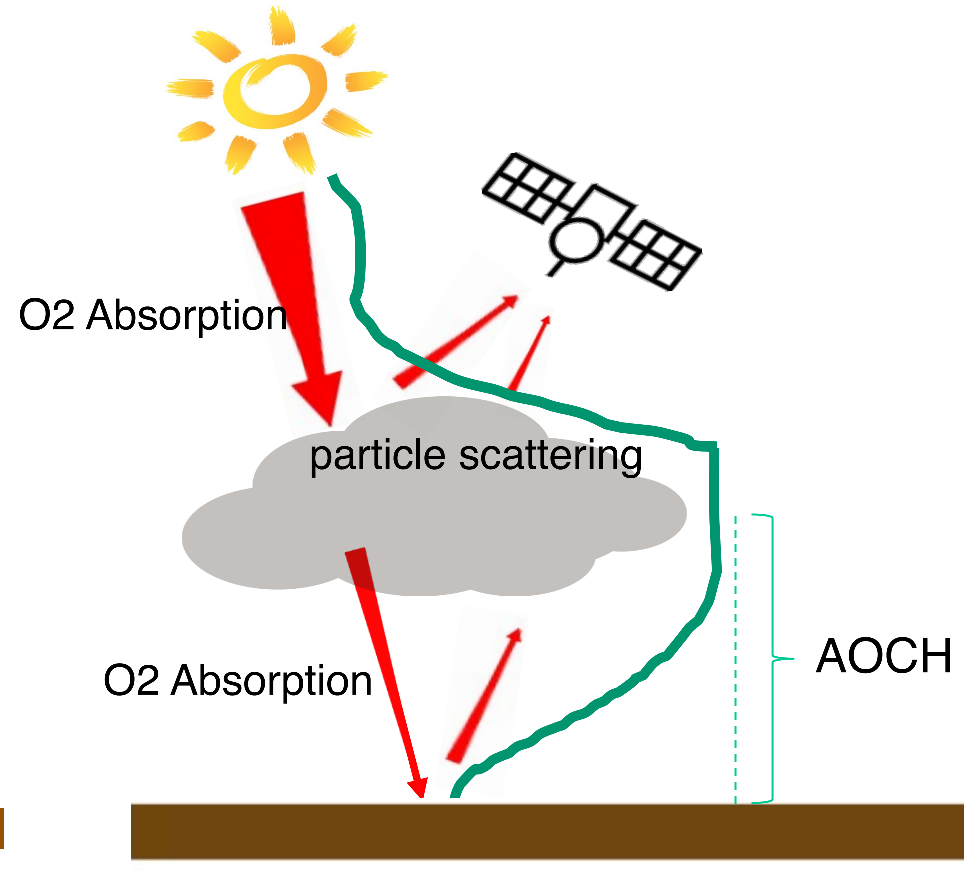
**Annual and global mean normalized shape of aerosol vertical profile**

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




Xu, Wang, et al., 2019


Along track direction
Afterward view
Forward view
$h = d/(\tan\theta_F + \tan\theta_A)$
Aerosol plume
$\theta_A$
$\theta_F$
$h$
$d$

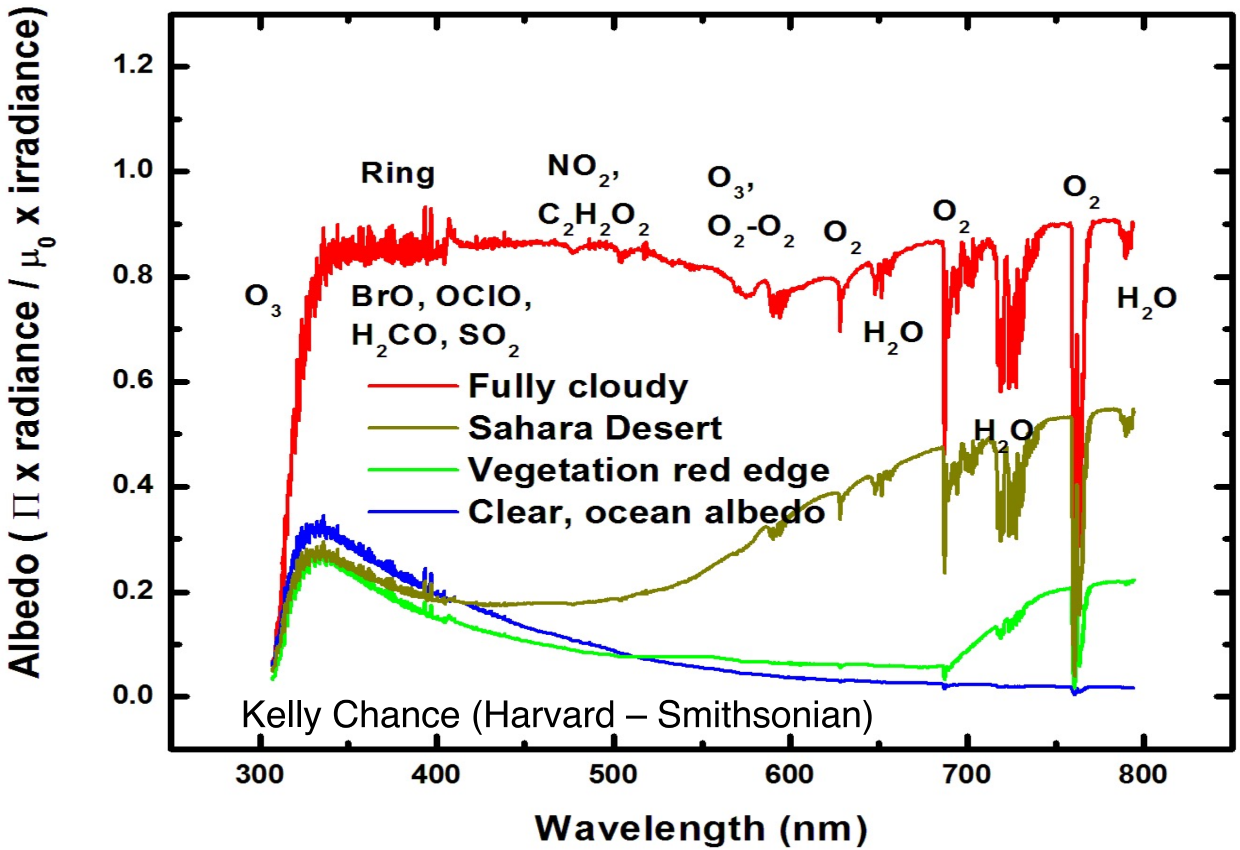

O2 Absorption
particle scattering
O2 Absorption
AOCH

# TEMPO, GEO-TASO, and GCAS

I--------GCAS--------- I------GCAS----- -----------------------------------I

IGEO-TASOI I------GEO-TASO ----------I

I---- TEMPO -----I I-------- -TEMPO -------I




**TEMPO**
**290–490 nm 540–740 nm**
**λ sampling: 0.2 nm**
**resolution/FWHM: 0.57 nm**

**GEO-TASO**
**290-400 nm 415-695 nm**
**λ sampling: 0.14/0.28 nm**
**Resolution/FWHM: ~0.4nm/ 0.8 nm**

**GCAS**
**300-490 nm, 480-900 nm**
**λ sampling: 0.2/0.8 nm**
**Resolution/FWHM: 0.6/2.8 nm**