Modeling constraints of aerosol layer height and night-time aerosol optical depth from space

07 Dec. 2023

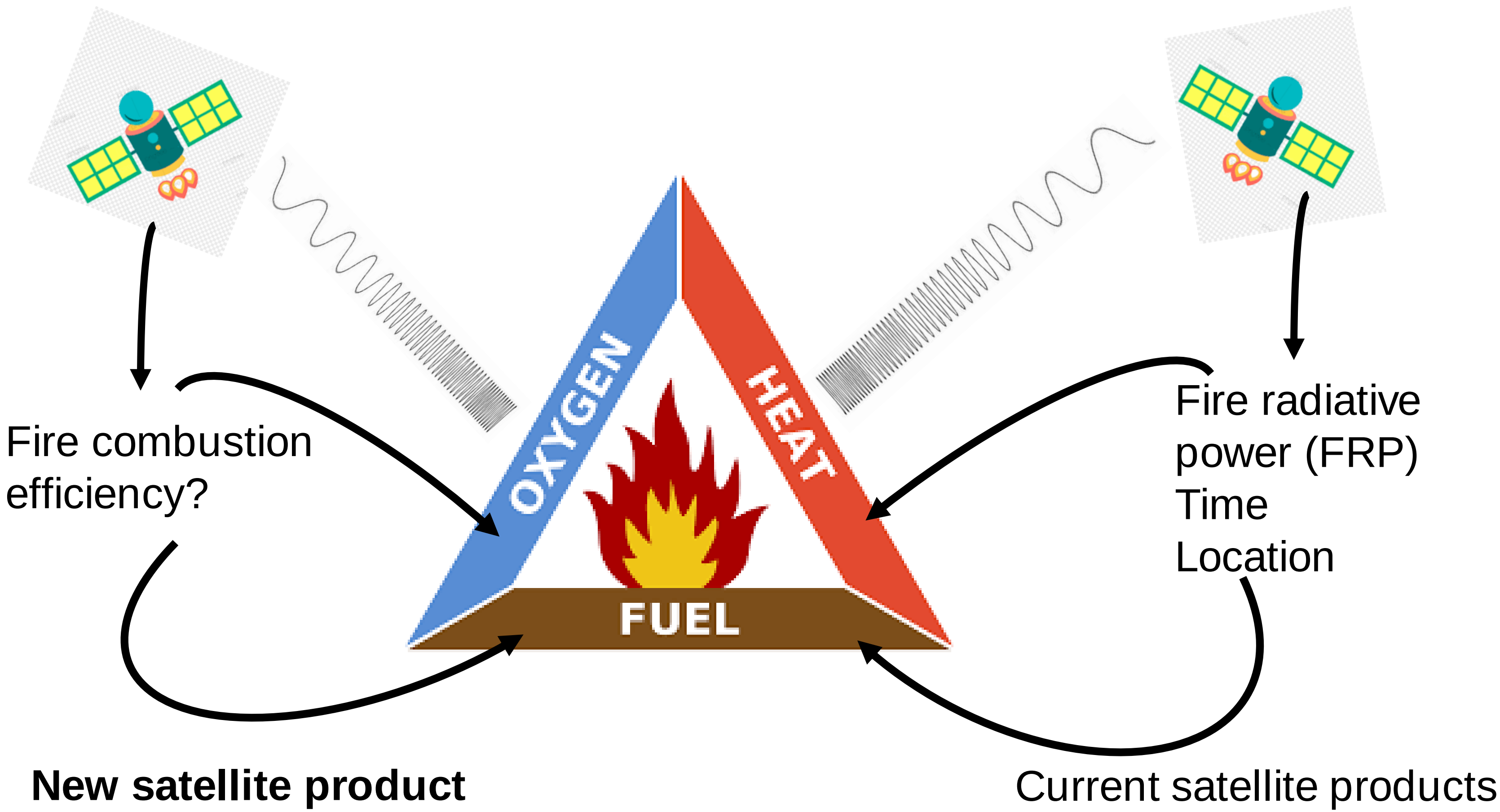
Jun Wang

James E. Ashton Professor
College of Engineering

The University of Iowa

International Aerosol Modeling Algorithms Conference
UC-Davis, 07 December 2023

Three elements of fires: can their interaction be revealed from space?



Emissions vary with fire life cycle

Nature, 1979

Biomass burning as a source of atmospheric gases CO, H_2, N_2O, NO, CH_3Cl and COS

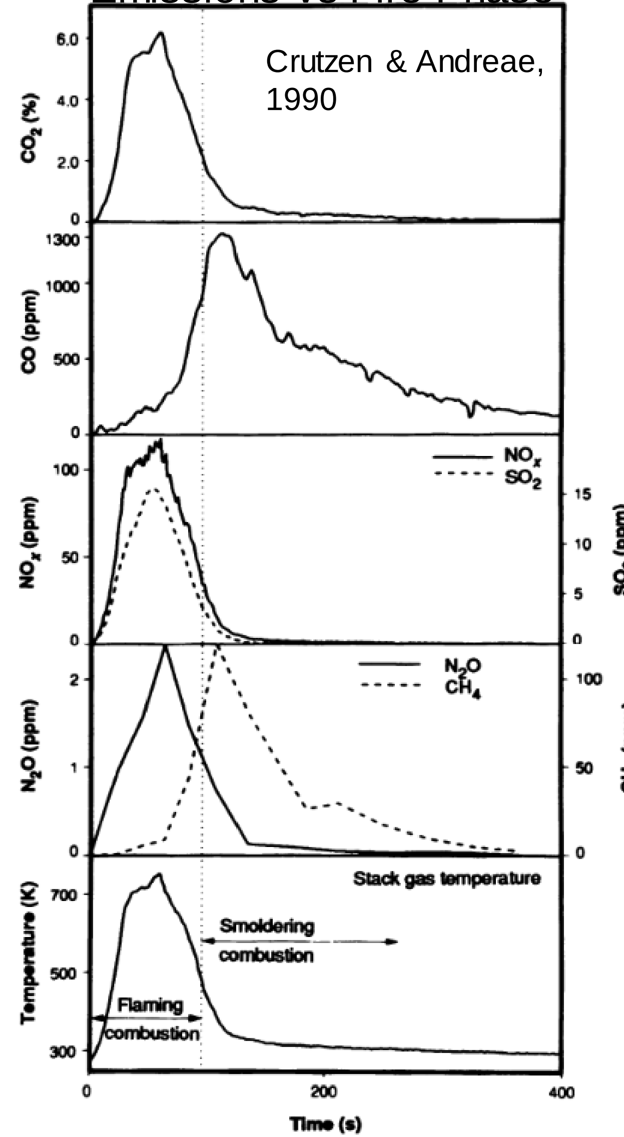
Paul J. Crutzen, Leroy E. Heidt, Joseph P. Krasnec, Walter H. Pollock & Wolfgang Seiler*
National Center for Atmospheric Research, PO Box 3000, Boulder, Colorado 80307

Paul Jozef Crutzen
(1933– 2021)
Recipient of
1995 Nobel Prize in Chemistry

Biomass Burning in the Tropics: Impact on Atmospheric Chemistry and Biogeochemical Cycles

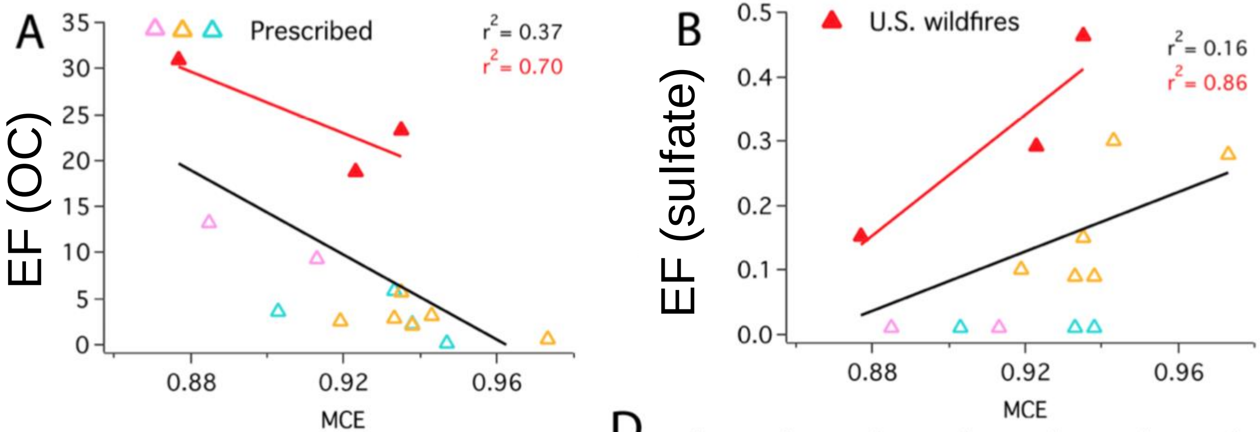
PAUL J. CRUTZEN AND MEINRAT O. ANDREAE

Emissions vs Fire Phase

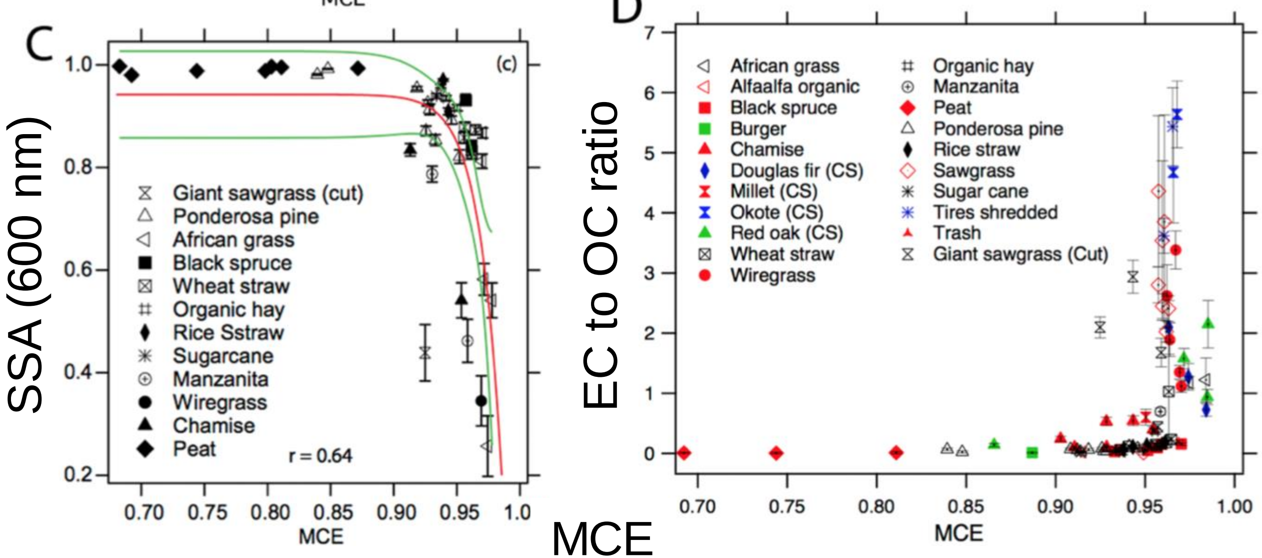


Modified Combustion Efficiency & Its Importance

CO_2 / $(CO+CO_2)$ → Emission Factor



Liu et al., [2017]



Pokhrel et al., [2016]

How emission factors are treated in fire emission estimates?

- Static for the same type; no consideration of wind speed, relative humidity, life cycle of the fire
- Schemes for surface/biome types are oversimplified and vary in different emission algorithms

GFED4s

Specie	Savanna	Boreal forest	Temperate forest	Tropical forest	Peat	Agriculture
CO_2	1686	1489	1647	1643	1703	1585
CO	63	127	88	93	210	102
CH_4	1.94	5.96	3.36	5.07	20.8	5.82
NMHC	3.4	8.4	8.4	1.7	1.7	9.9
H_2	1.7	2.03	2.03	3.36	3.36	2.59
NO_x (as NO)	3.90	0.90	1.92	2.55	1.00	3.11
N_2O	0.20	0.41	0.16	0.20	0.20	0.10
PM2.5	7.2	15.3	12.9	9.1	9.1	6.3

6 biome types

van der Werf et al., 2017.

FLAMBE

Reid et al., 2010

Light Grasses/tundra
Grasslands/Savannah
Cerrado/Woody Shrub
Crops
Temperate/Boreal-Low
Temperate-High
Tropical Forest
Wetland
Boundary regions

9 biome types

Light is an indication of fire combustion phase/completeness

- Combustion phase depends on fuel content, relative humidity, temperature, & reaction interface.
- If the combustion happens heterogeneously at the surface of solid fuels (vegetation and wood), the combustion is smoldering producing incomplete-oxidized products
- If oxidation happens homogeneously between oxygen in the air and the gas pyrolyzate, combustion products are soot and complete-oxidized gases. These products absorb enough energy during the combustion process leading them to emit visible radiation as a flame (Rein 2009; Sato et al. 1969).

Suomi-NPP Launch
28 Oct. 2011

Opens a new era of low light detection for remote sensing of fires, aerosols, and beyond

I was there watching the launch and took this picture!
Vandenberg Air Force Base in California

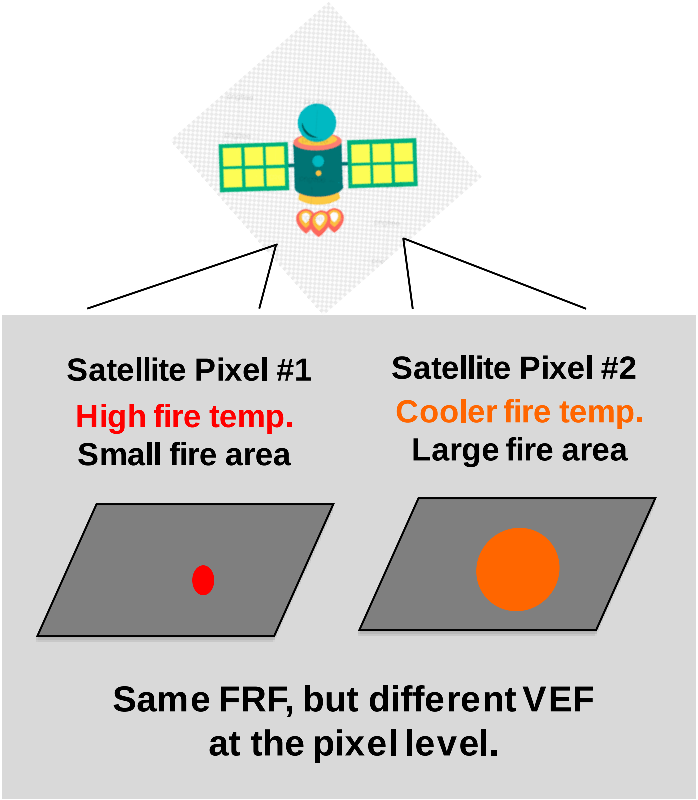
Wang, J., S. Roudini, E. J. Hyer, X. Xu, M. Zhou, L. Castro Garcia, J. S. Reid, D. Peterson, A. Da Silva, Detecting nighttime fire combustion phase by hybrid application of visible and infrared radiation from Suomi NPP VIIRS, *Remote Sensing of Environment*, 237, 111466, 2020.

Definitions

- Fire Radiative Power: **FRP**, total power from all wavelengths due to all fires in a pixel.
- Fire Visible Light Power: **VLP**, radiative power in the visible due to all fires in a pixel
- Visible Energy Fraction **VEF**:

$$VEF = \frac{VLP \times \Delta t}{FRP \times \Delta t} = \frac{VLP}{FRP}$$

- FRP is NOT necessarily a good indicator of flaming and MCE; VEF has more potential to characterize MCE.

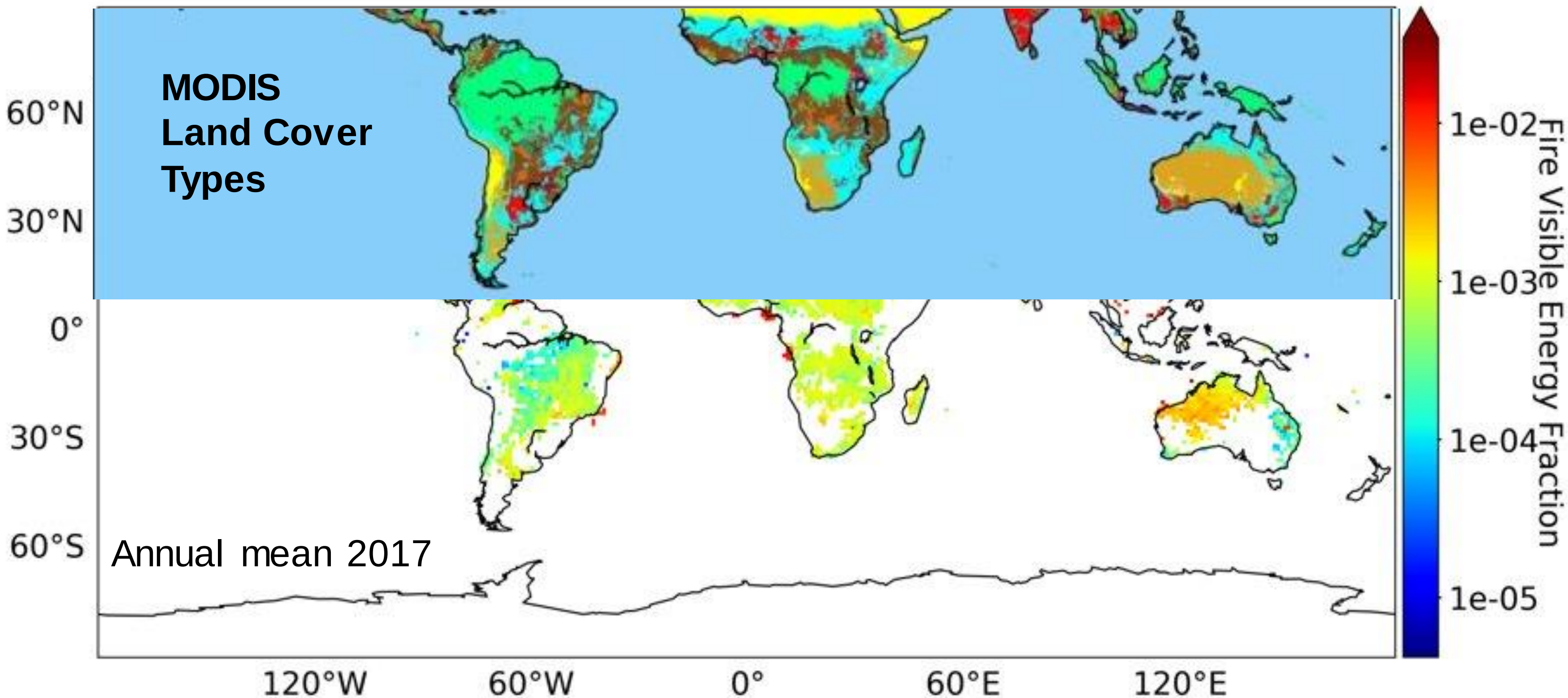


Detecting nighttime fire combustion phase by hybrid application of visible and infrared radiation from Suomi NPP VIIRS, *Remote Sensing of Environment*, Wang et al., 2020.

First global analysis of saturation artifacts in the VIIRS infrared channels and the effects of sample aggregation, *IEEE Geoscience and Remote Sensing Letters*, Polivka et al., 2015.

A Sub-pixel-based calculate of fire radiative power from MODIS observations: 2. Sensitivity analysis and potential fire weather application, *Remote Sensing Environment*, Peterson & Wang, 2013.

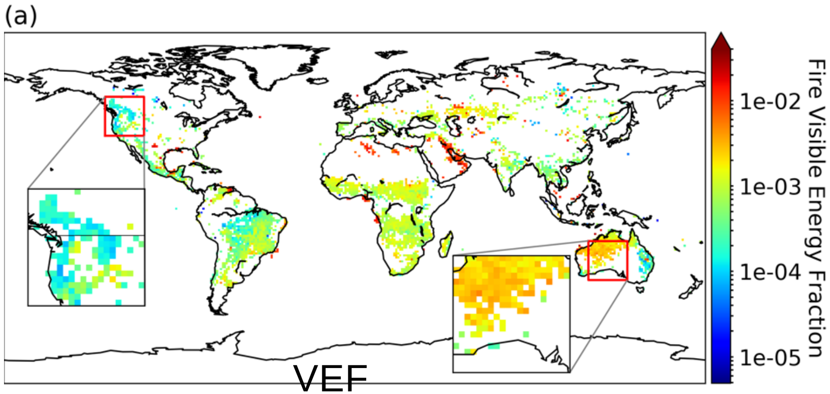
Insights for Fire MCE Climatology as revealed by Visible Energy Fraction (VEF)

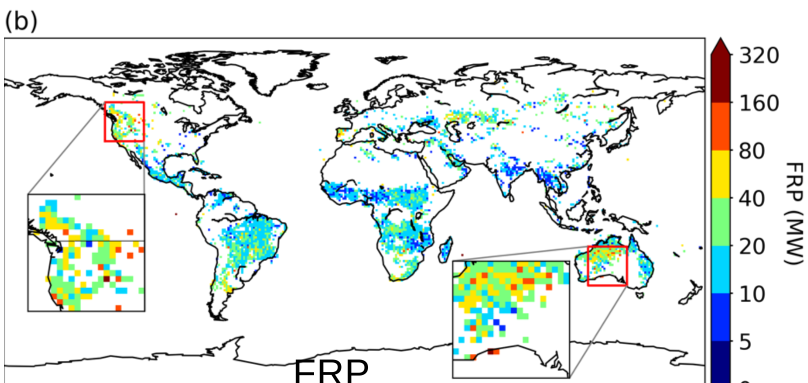


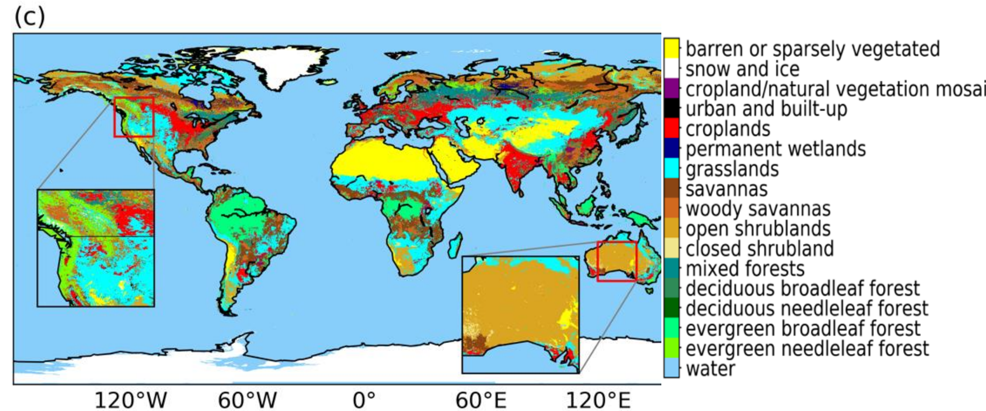
Our research algorithm: Firelight Detection Algorithm (FILDA)

VEF is indicative of MCE

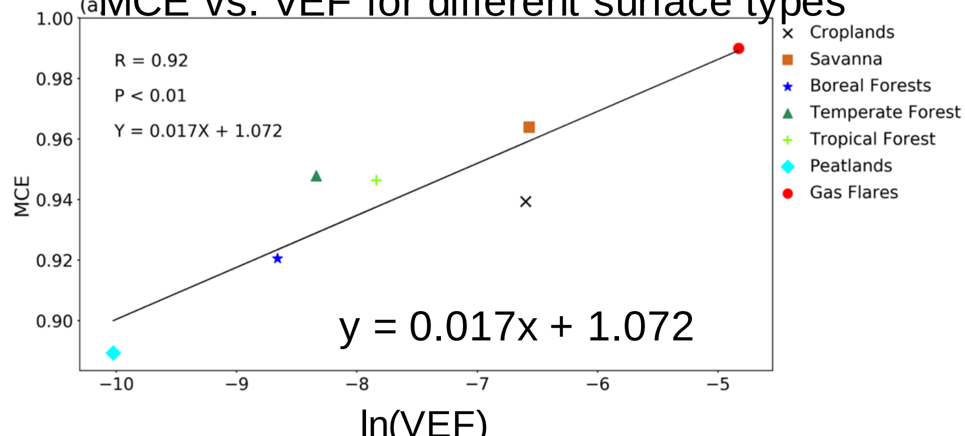
- VEF spatial distribution clearly shows the impact of biome types on fire MCE
- FRP has difficulty to describe MCE variation, such as shrubland vs. evergreen forests





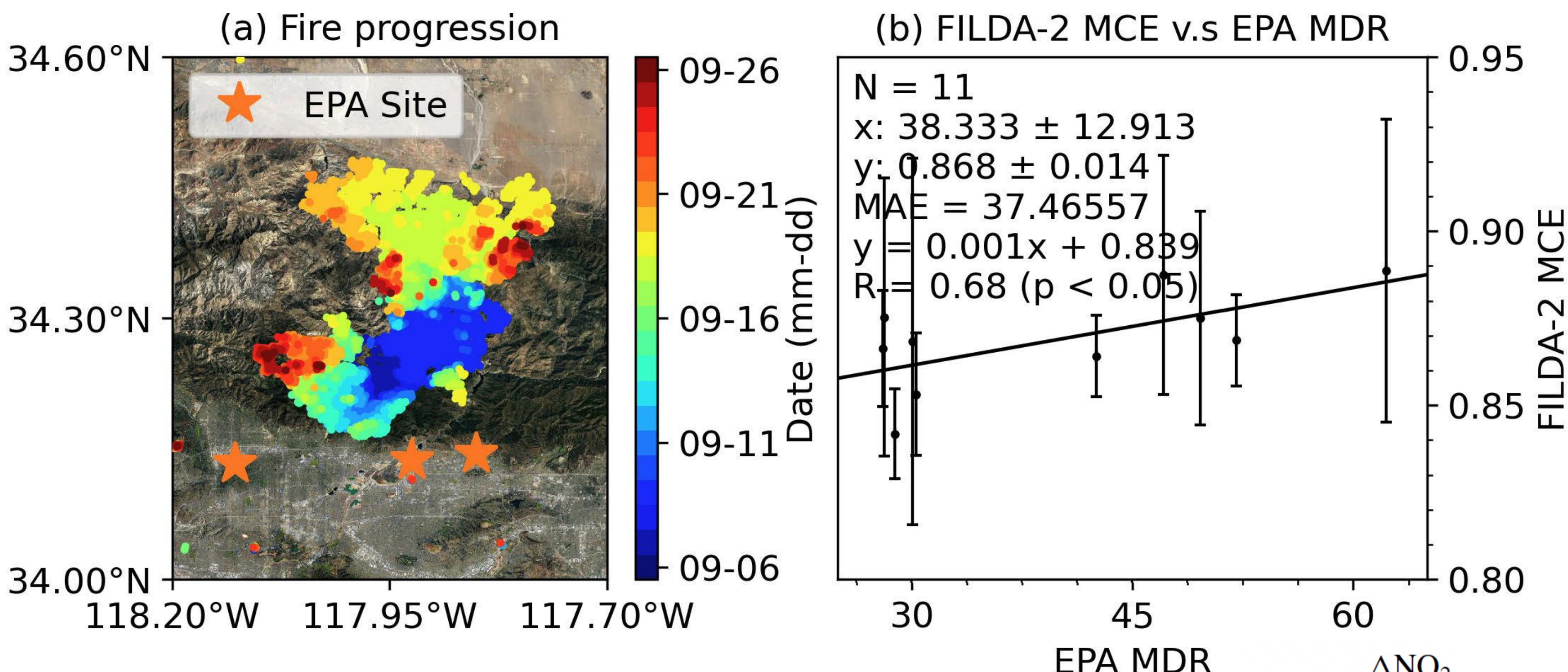


MCE vs. VEF for different surface types



Wang et al., 2020, RSE.

Further (indirect) validation

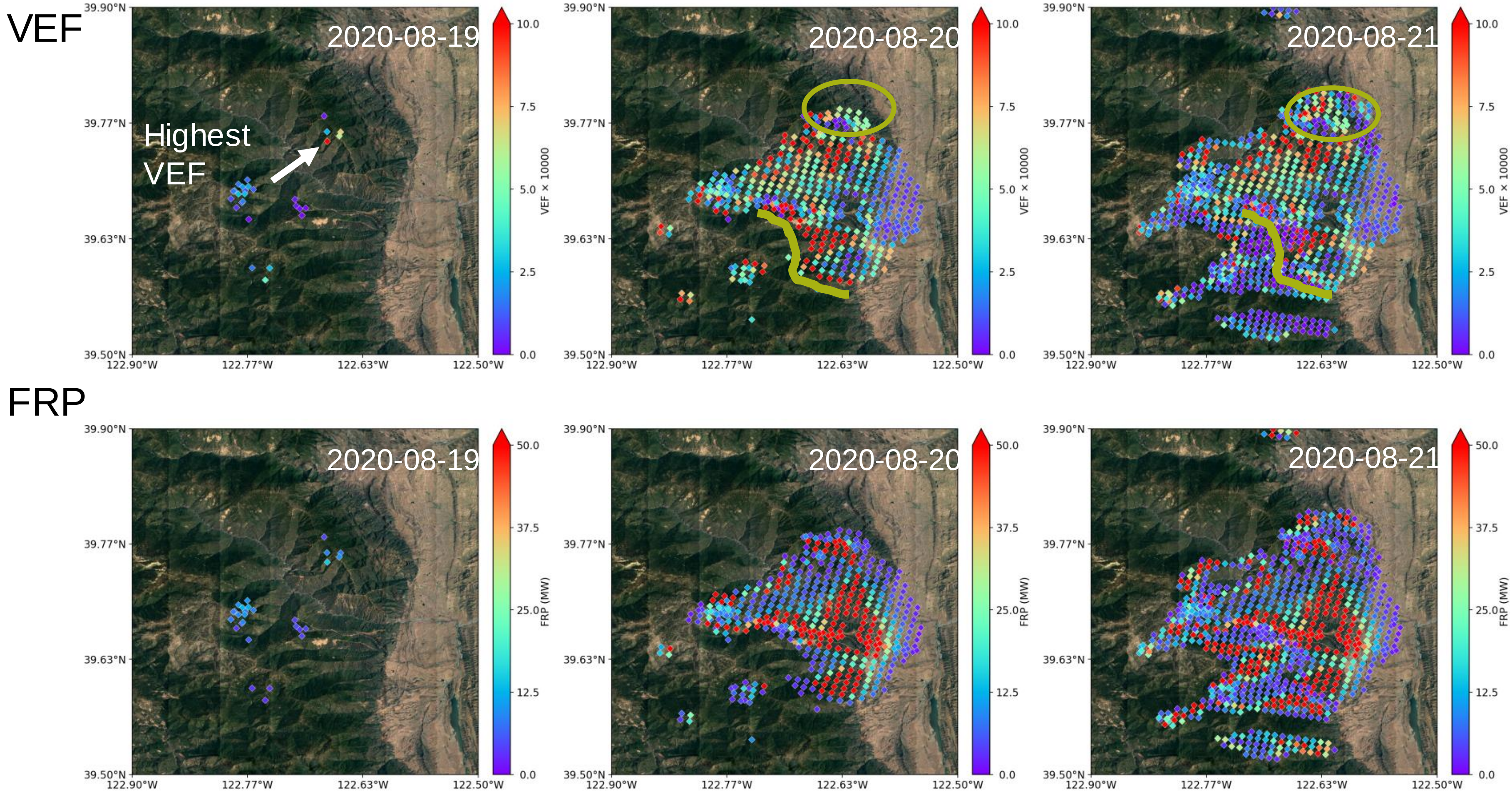


$$MDR = \frac{\Delta NO_2}{\Delta CO}$$

the Bobcat fire in Angeles National Forest, California, USA, 2020

VEF has the potential to better predict fire growth

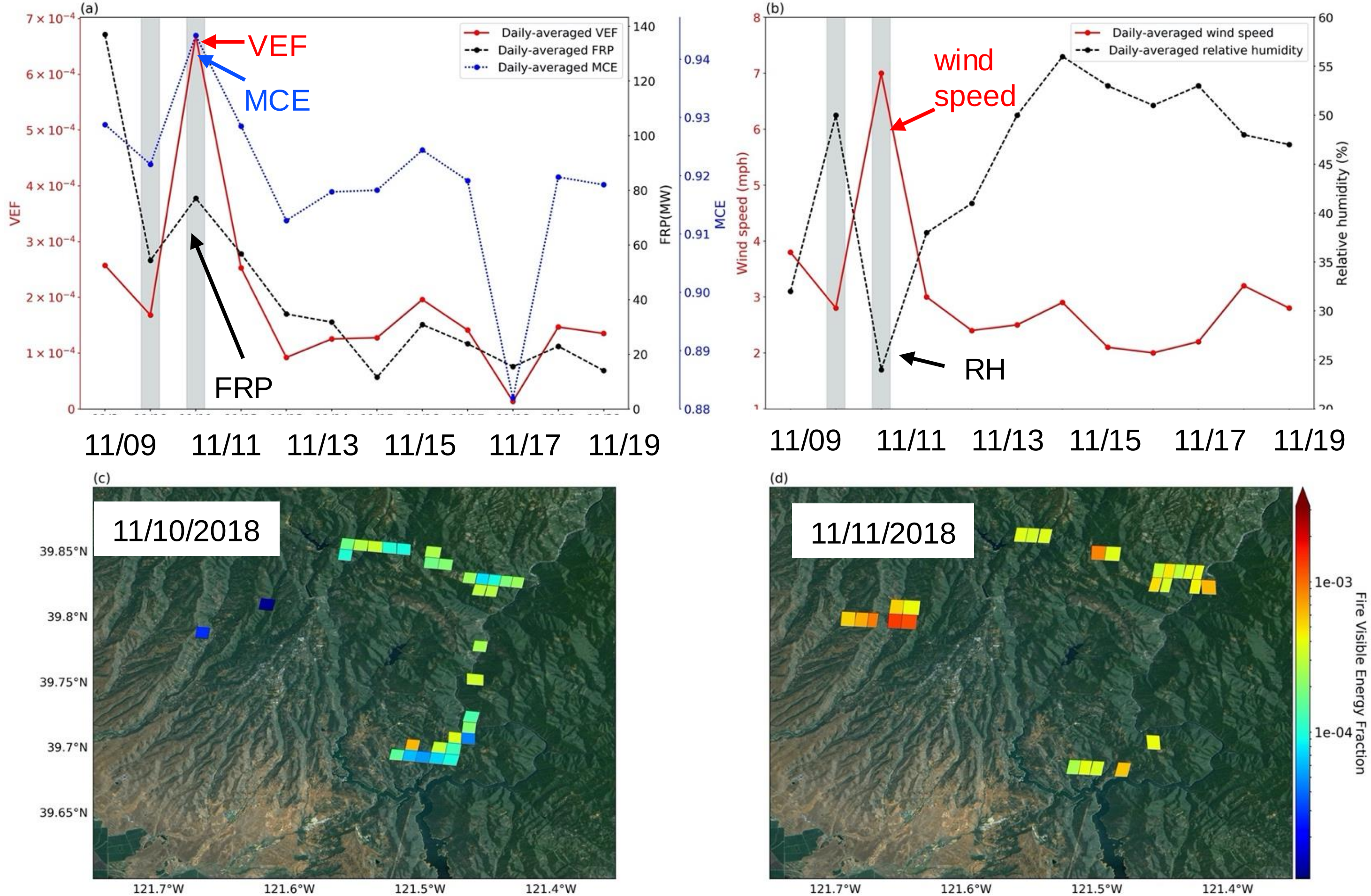
High VEF -> flaming → predicting movement of fire lines



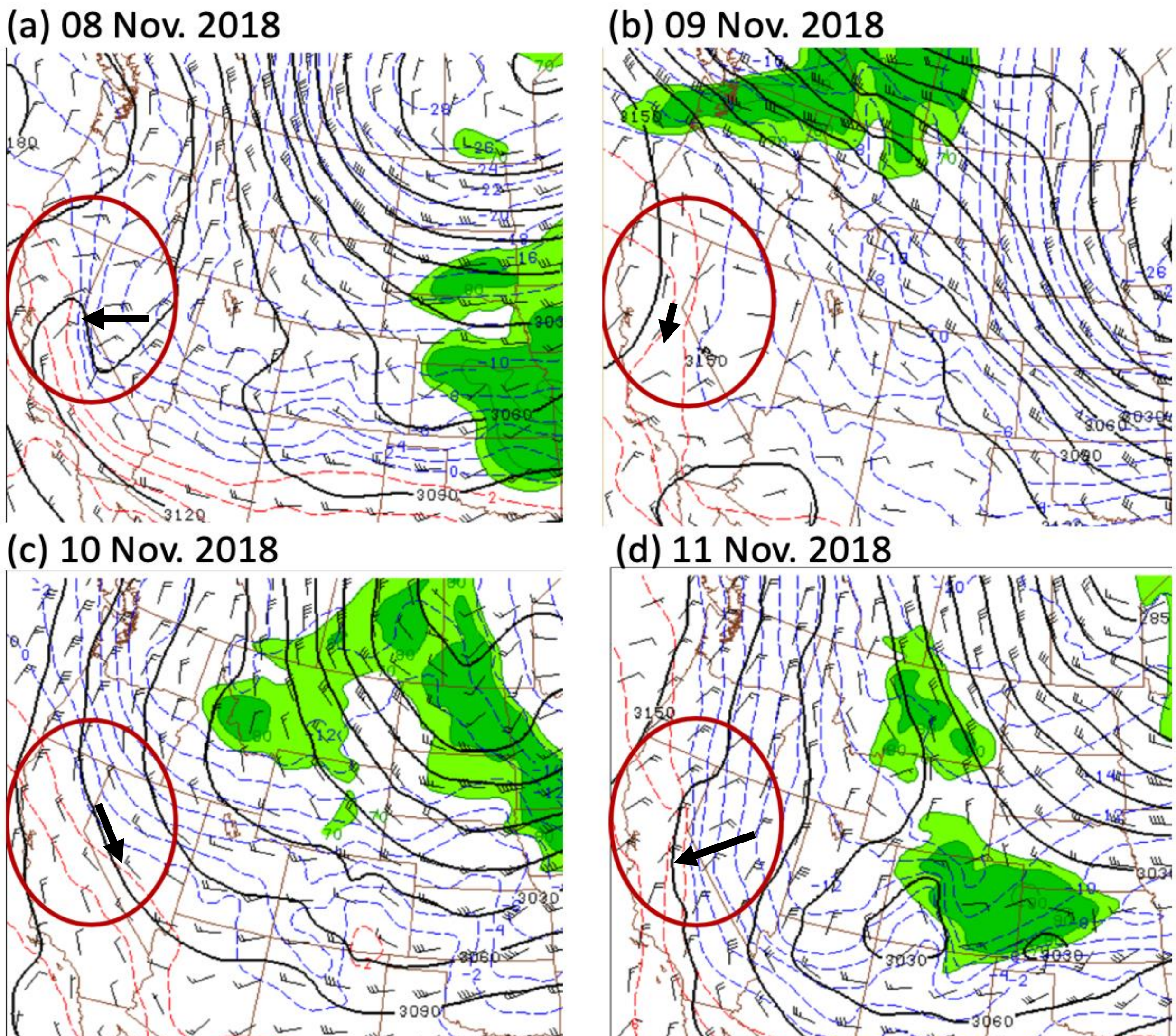
What is left after fire lines is the smoldering fires

VEF & MCE variations show meteorological impact on combustion

High & dry winds lead to increase of flaming on 11 Nov. 2018. **Camp Fire**



Synoptic map at 700 mb.



10 am local each day

Diablo Winds

A new satellite data product: Fire MCE

Now in production. Soon to be available at:
https://viirsland.gsfc.nasa.gov/Products/NASA/NASAprod.html
Product prefix: VNP47IMG; VJ147IMG; VNP47MOD; VJ147MOD

SensorProductSequenceResolution.AYearDoy.Overpass.Collection.ProcessTime.nc

https://esmc.uiowa.edu/filda/filda.php

FILDA-2
Introduction
Physics Background
Algorithm
Outputs
Recommendation
Why spots in cities?

Fire Light Detection Algorithm Version 2 (FILDA-2) Modified Combustion Efficiency (MCE) User Guide V1.0

This guide is living document of the FIre Light Detection Algorithm Version 2 (FILDA-2) product based on the Visible Infrared Imaging Radiometer Suite. It is revised as progress is made in the development of these products. The purpose of this documentation is to give the potential user an understanding of the VNP/VJ147 products and the current state of the data in those products.

FILDA-2 is an experimental advanced fire product that provides fire detection and retrievals of Radiative Power (FRP), fire Visible Energy Fraction (VEF), and Modified Combustion Efficiency (MCE) at nighttime in 375 m and 750 m resolution.

Note: The VNP/VJ147 FILDA fire modified combustion efficiency product is current being integrated NASA LAND SIPS at GSFC. The processed product will be available from the LP DAAC.

Importance of nighttime fires

Article

Warming weakens the night-time barrier to global fire

Nature, 2022

https://doi.org/10.1038/s41586-021-04325-1
Received: 3 July 2020

Jennifer K. Balch[1,2] ✉, John T. Abatzoglou[3,9] ✉, Maxwell B. Joseph[1,4,9], Michael J. Koontz[1,9], Adam L. Mahood[1,2,9], Joseph McGlinchy[1,5,9], Megan E. Cattau[6] & A. Park Williams[7,8] ✉

Globally, daily minimum VPD (vapor pressure deficit) increased by 25 per cent from 1979 to 2020.

Large wildfire driven increases in nighttime fire activity observed across CONUS from 2003–2020

RSE, 2022

Patrick H. Freeborn [a,*], W. Matt Jolly [a], Mark A. Cochrane [b], Gareth Roberts [c]

From 2003–2020, MODIS detected significant ($p < 0.01$) increasing trends in nighttime wildfire fire activity, with a +54%, +42% and +21% increase in the annual nighttime sum of FRP, annual nighttime active fire pixel counts and annual mean nighttime per-pixel values of FRP, respectively, detected in the latter half of the study period.

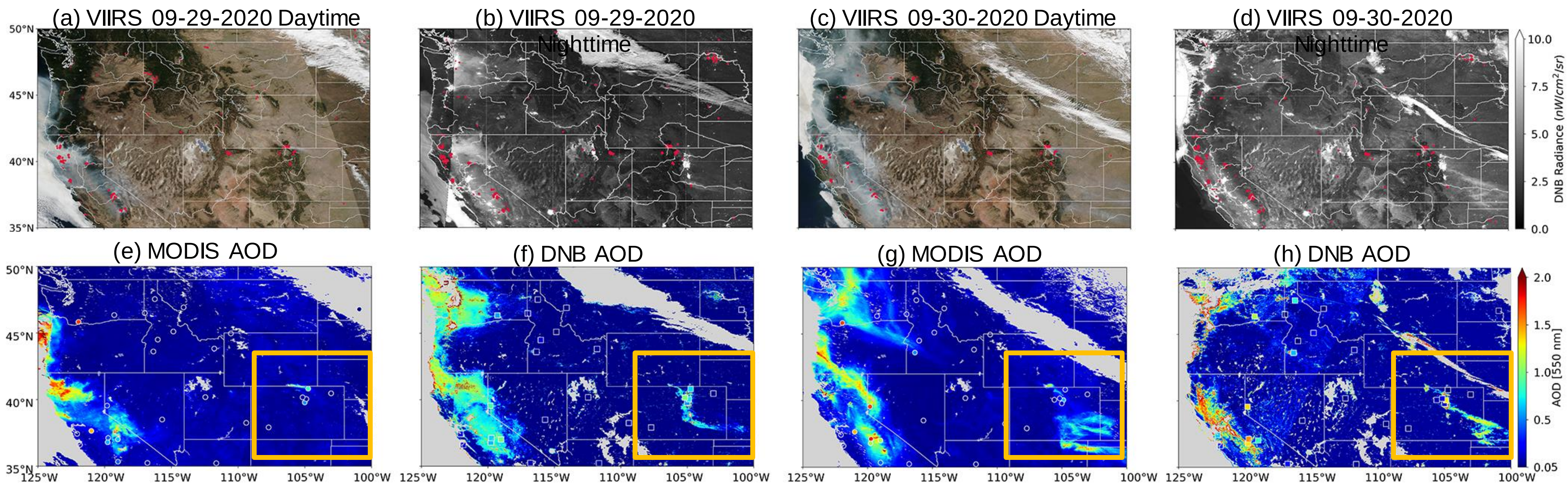
Retrieval of smoke AOD at night from backscattered moonlight measured by VIIRS over rural areas

Wang, J., M. Zhou, X. Xu, S. Roudini, S. Sander, T. Pongetti, S. Miller, J. Reid, E. Hyer, R. Spurr, Development of a nighttime shortwave radiative transfer model for remote sensing of nocturnal aerosols and fires from VIIRS, *Remote Sensing of Environment*, 241, 111727, 2020.

Zhou, M., J. Wang, X. Chen, X. Xu, P. R. Colarco, S. D. Miller, J. S. Reid, S. Kondraguntah, D. M. Gilese, and B. Holben, Nighttime smoke aerosol optical depth over U.S. rural areas, first retrieval from VIIRS moonlight observations, *Remote Sensing of Environment*, in press, 2021.

Case Study

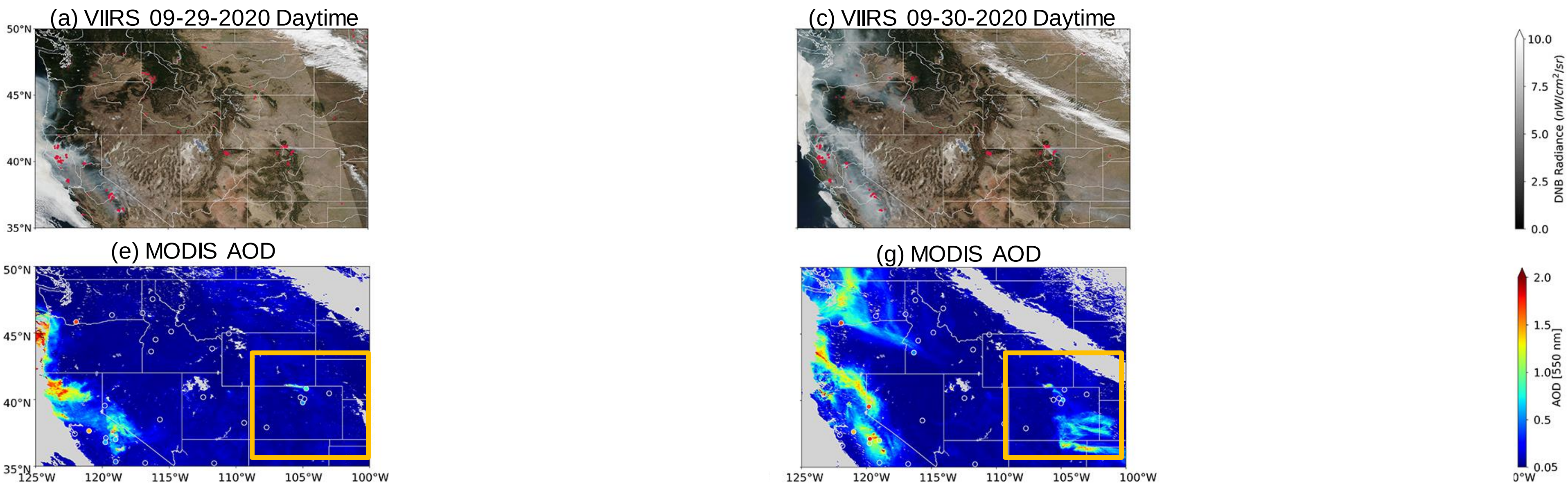
2020 Fire case – Day and Night AOD Map



● AERONET Daytime Site ■ AERONET Nighttime Site

Case Study

2020 Fire case – Day and Night AOD Map



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Case Study

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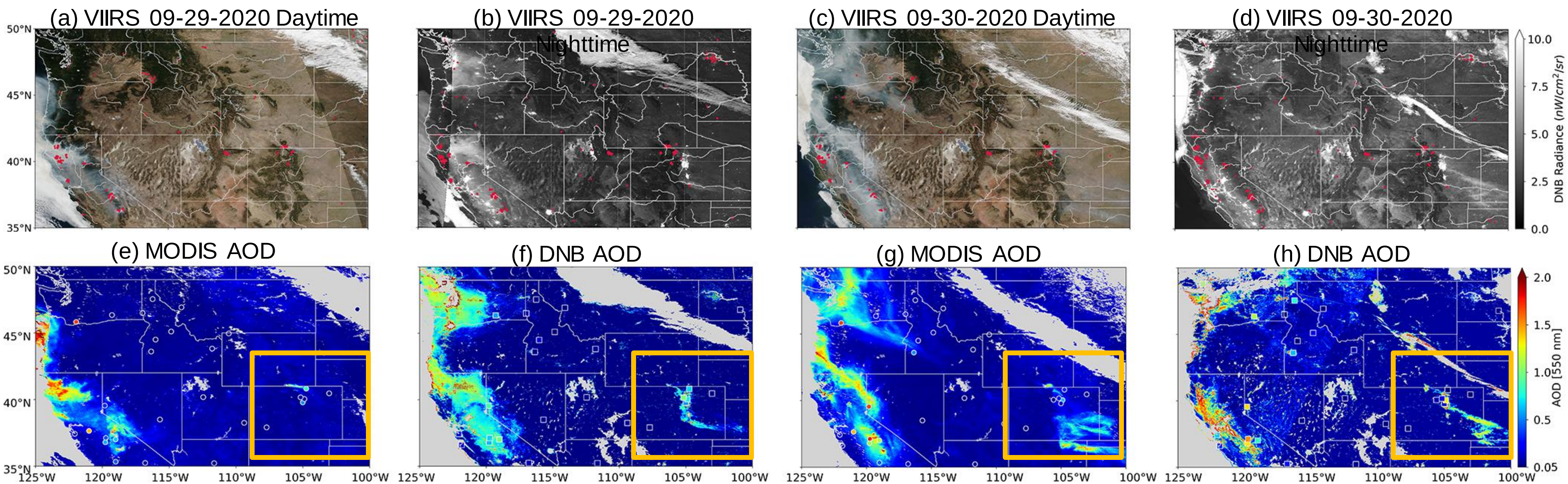

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Case Study

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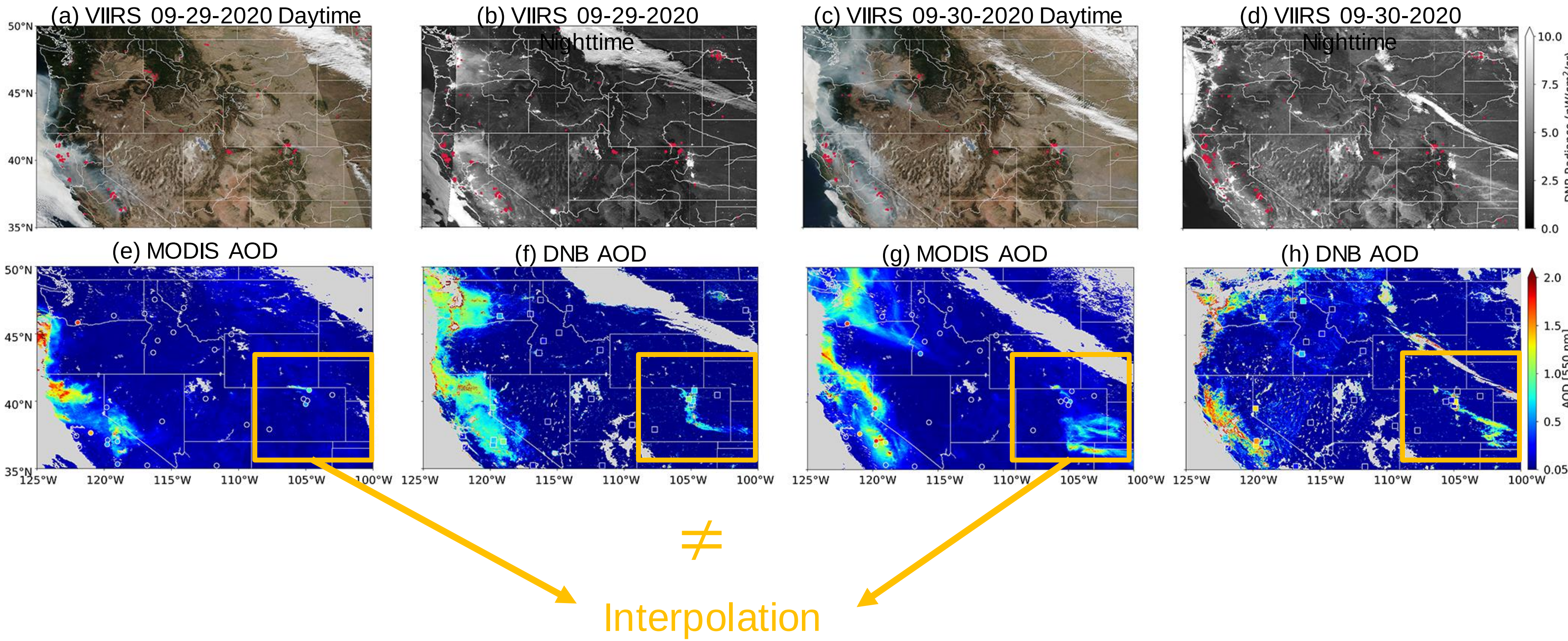
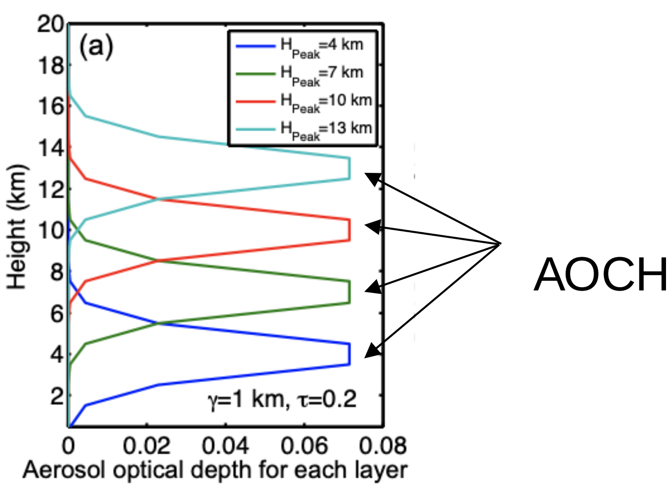


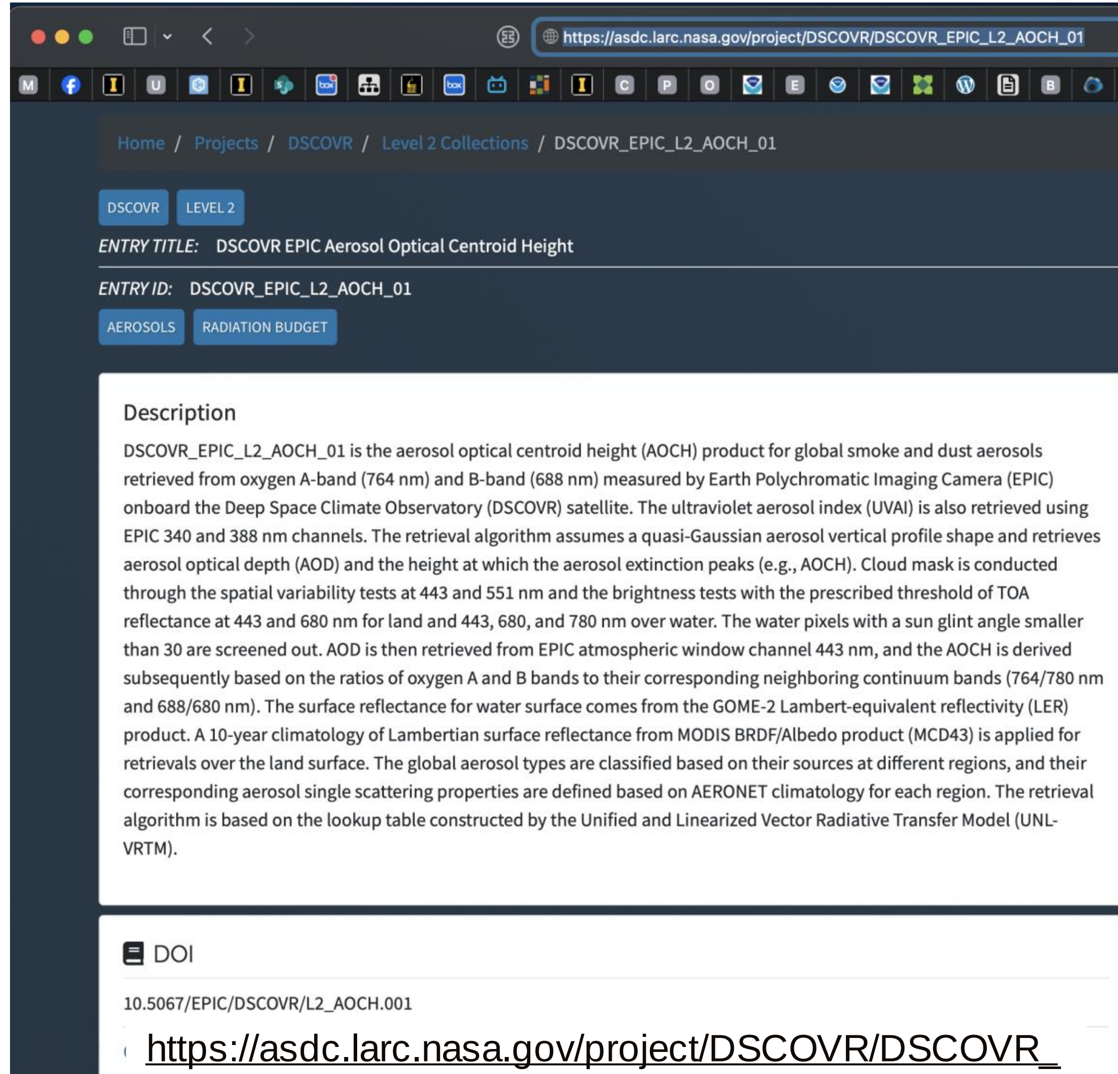
Aerosol Optical Centroid Height (AOCH) data product

Level-2 data product:

DSCOVR_EPIC_L2_AOCH_01 data production in ASDC/LaRC.

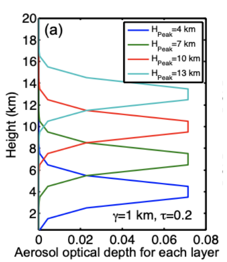
Thanks to Marshall Sutton and EPIC project team in GSFC to make the RTO happen.

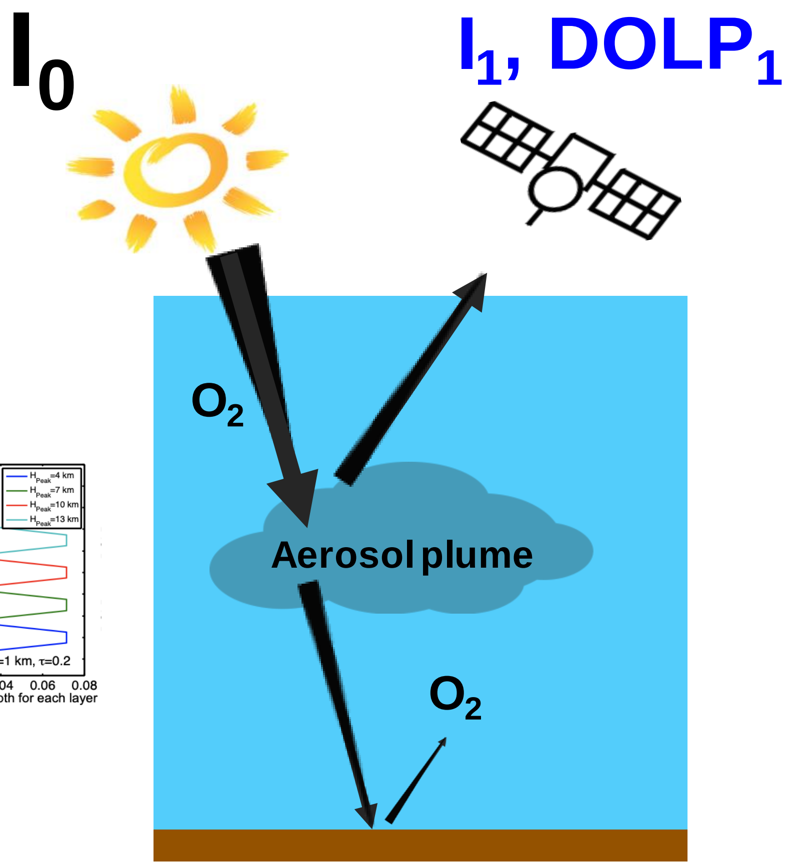


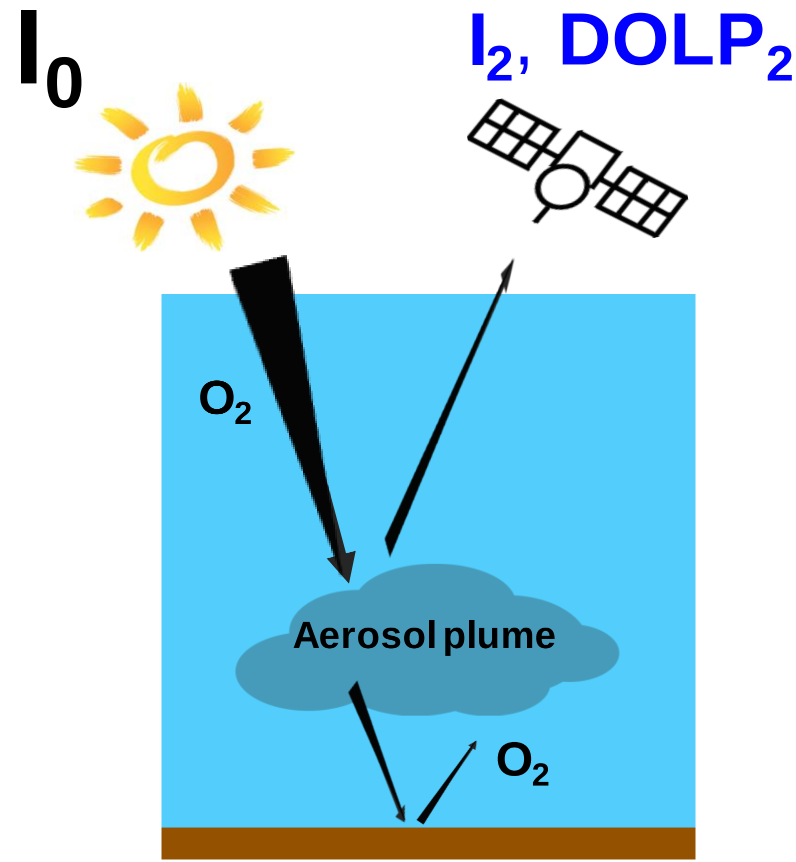


https://asdc.larc.nasa.gov/project/DSCOVR/DSCOVR_EPIC_L2_AOCH_01

At O2 absorption band:



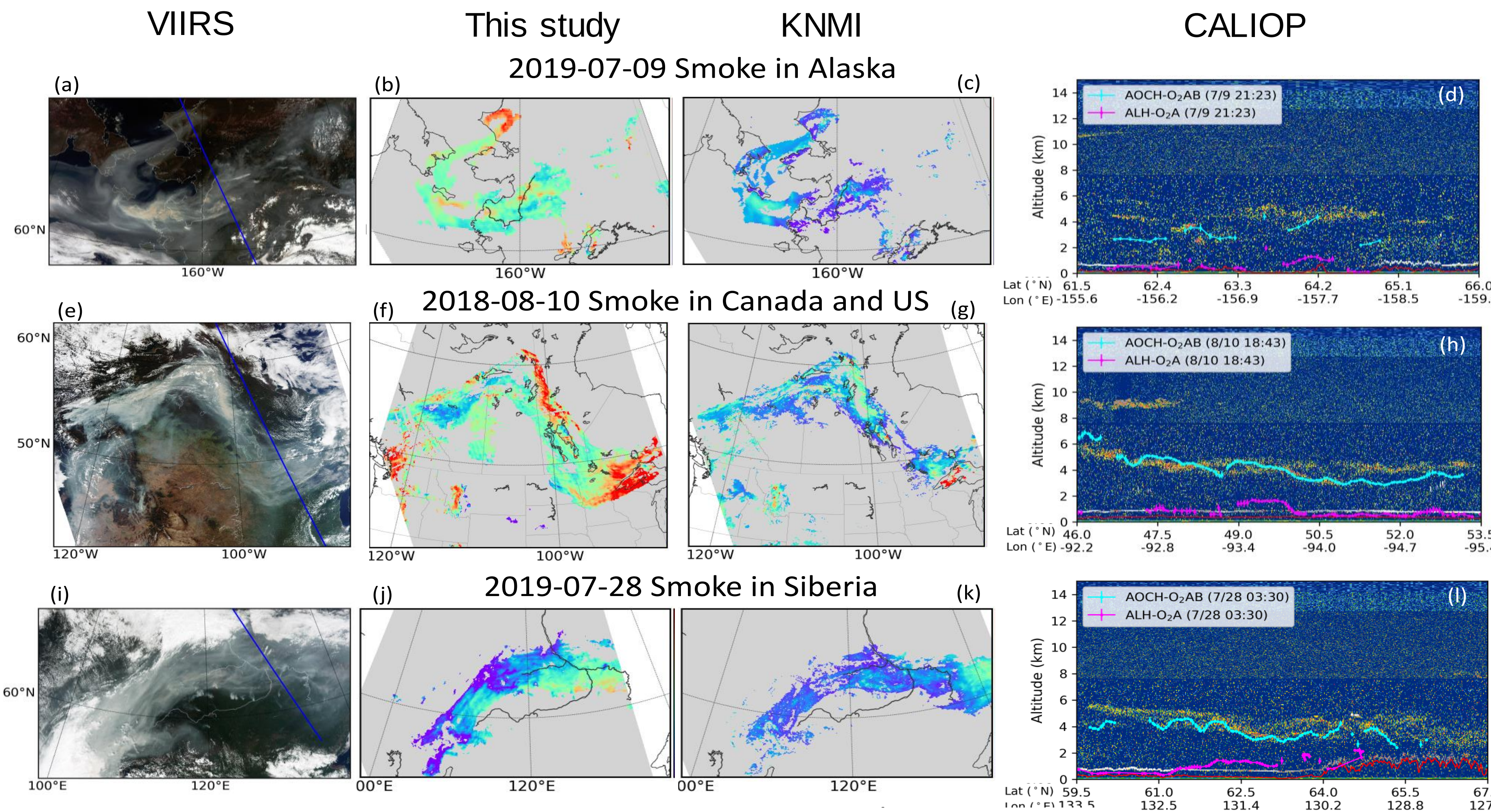




$I_1 > I_2$, $DOPL_1 < DOLP_2$ (in most cases)

More demonstration

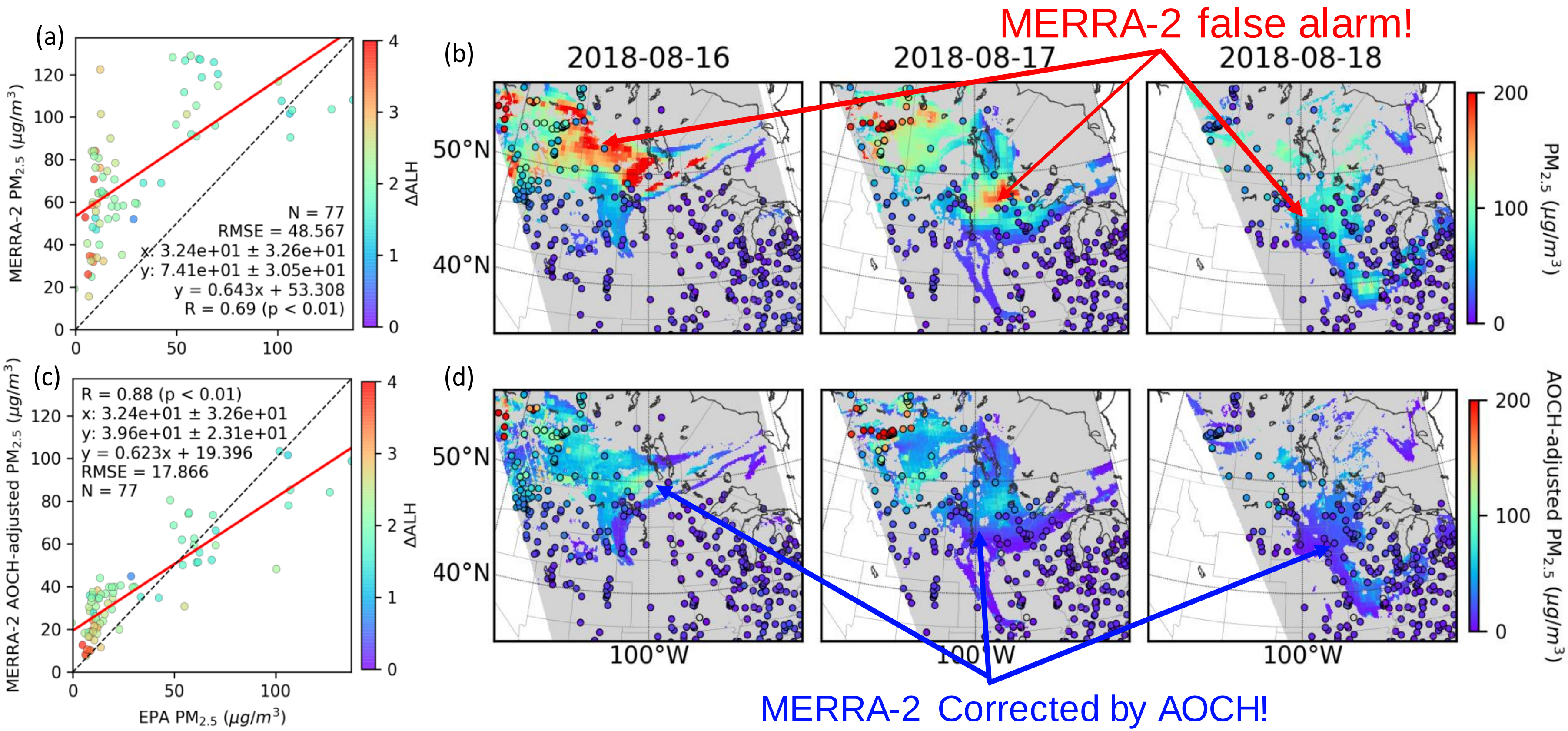
$$AOCH_{CALIOP} = \frac{\sum_{i=1}^{n} \beta_{ext,i} \Delta Z_i Z_i}{\sum_{i=1}^{n} \beta_{ext,i} \Delta Z_i}$$



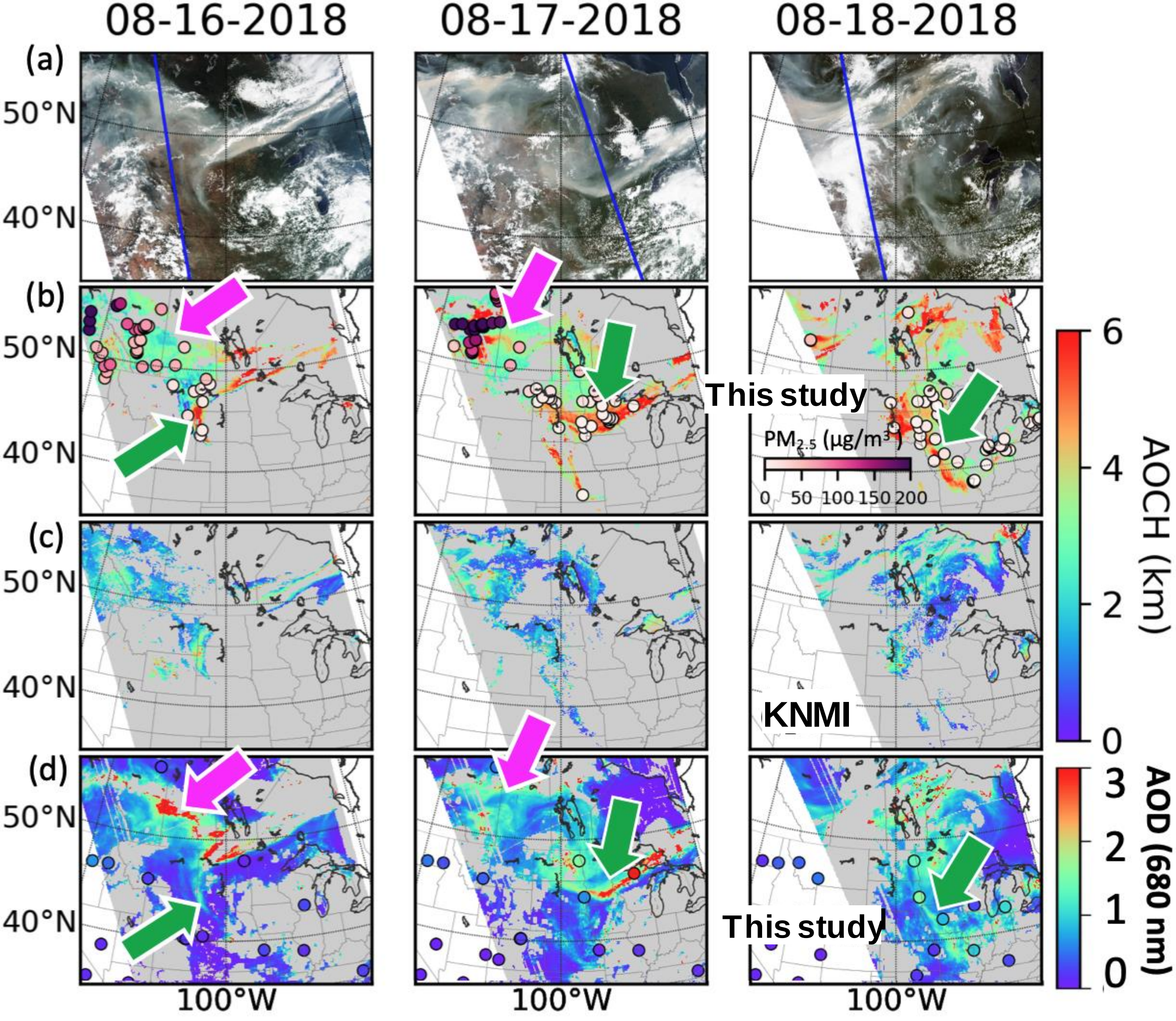
Chen et al., 2021, RSE.

Improvement on prediction and analysis

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



Chen, Wang, et al., 2021.



Case Demonstration

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

Exceptional event analysis requires "satellite imagery of plume with evidence of the plume impacting the ground".

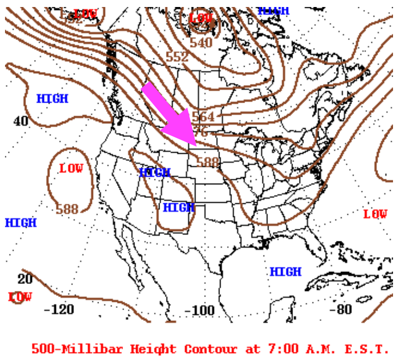
Chen, Wang, et al., 2021.

Models

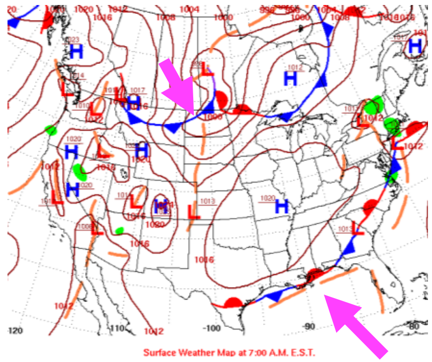
http://fireaq.uiowa.edu for weekly briefing of FireAQ this summer

Air Quality Reflection: Wednesday August 16, 2023

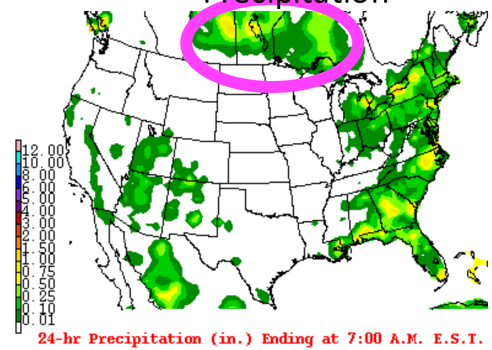
500 hPa Contours



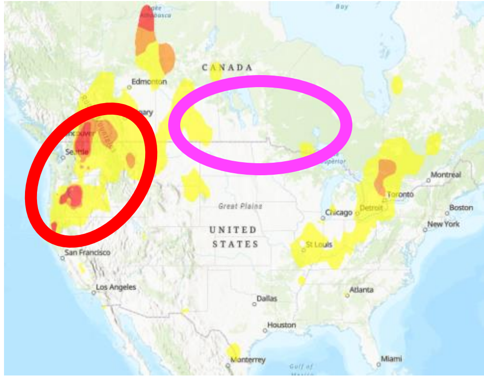
Surface Weather



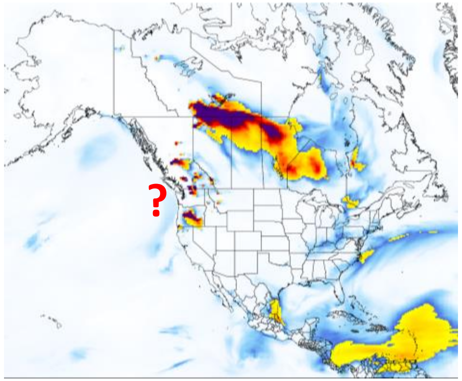
Precipitation



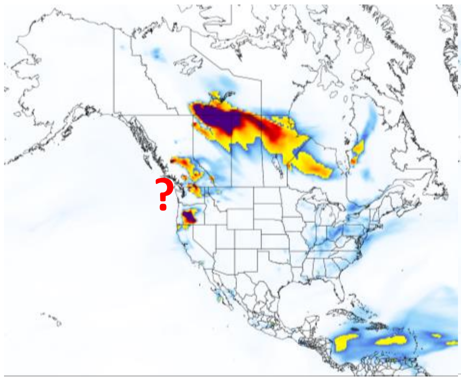
AirNow AQI



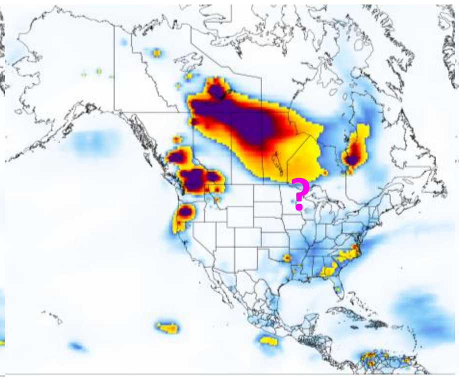
GEOS-FP



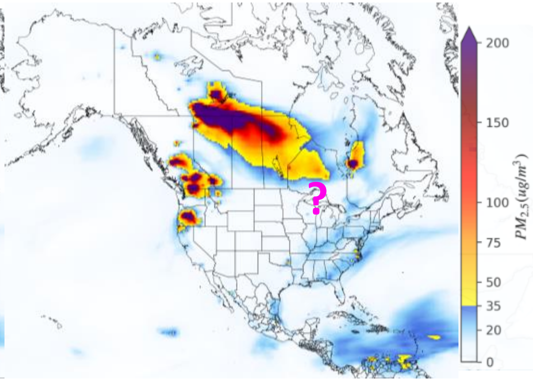
GEOS-CF



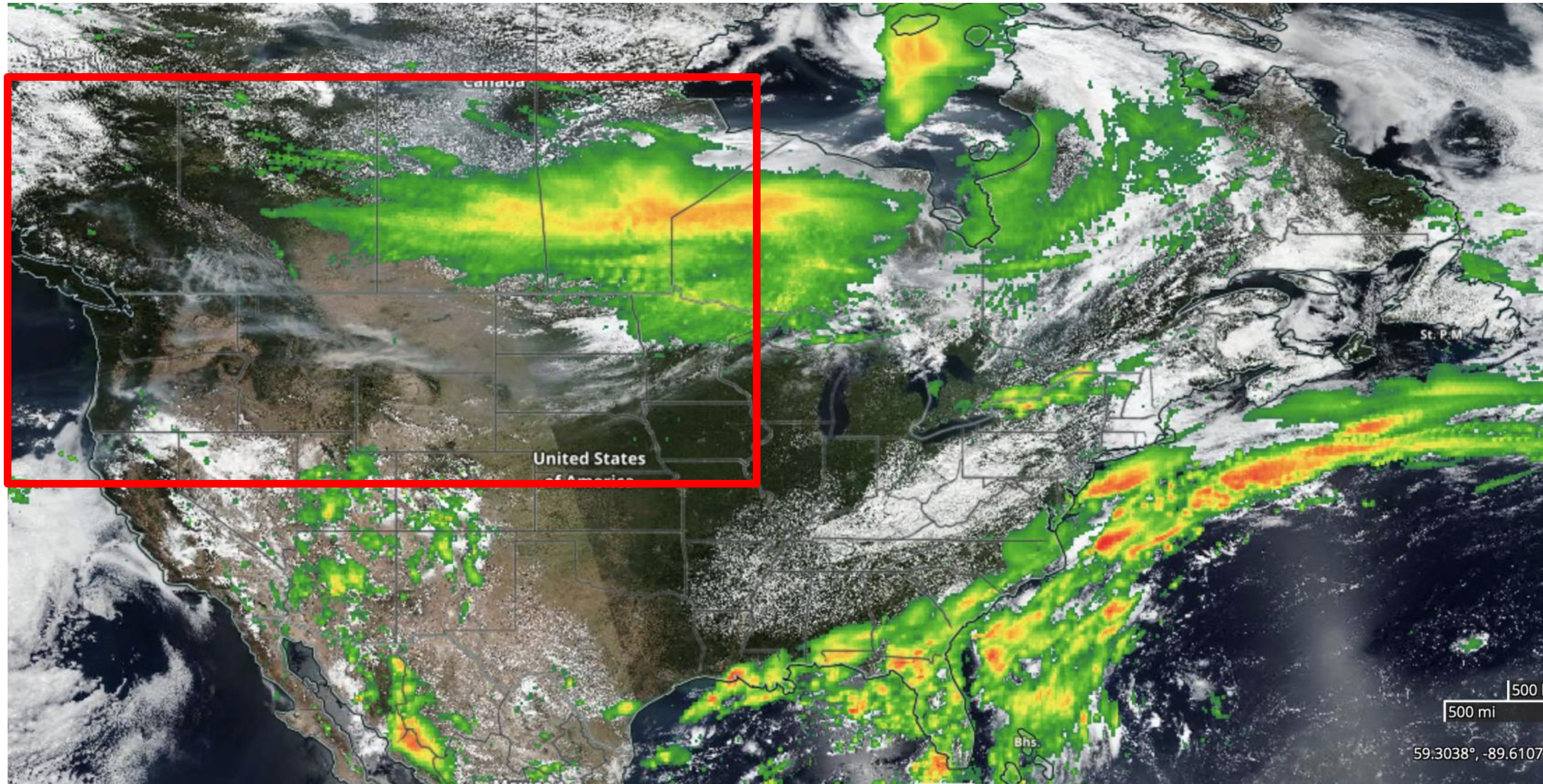
NAAPS



Ensemble



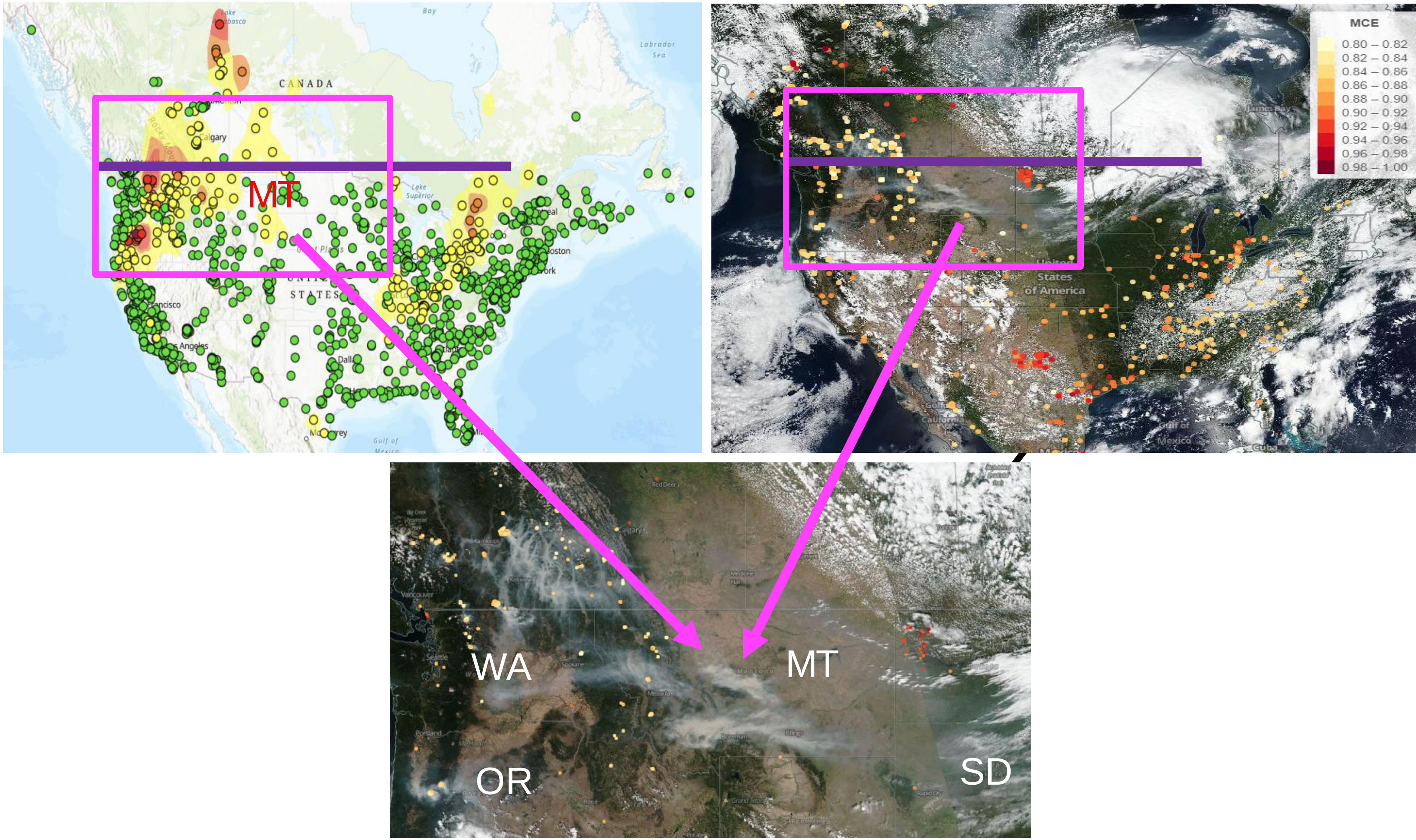
GPM, 16 August 2023

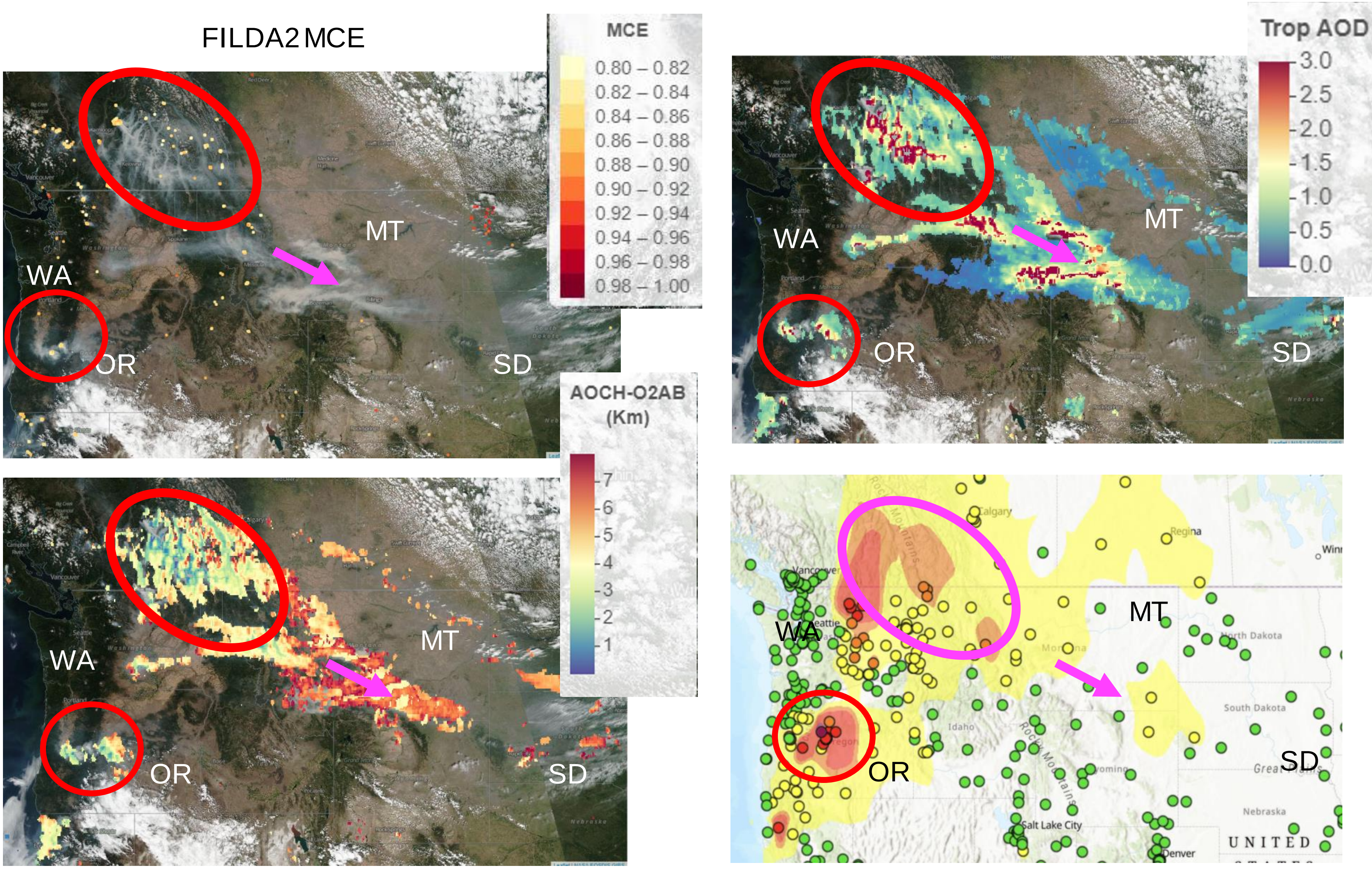


NASA WorldView

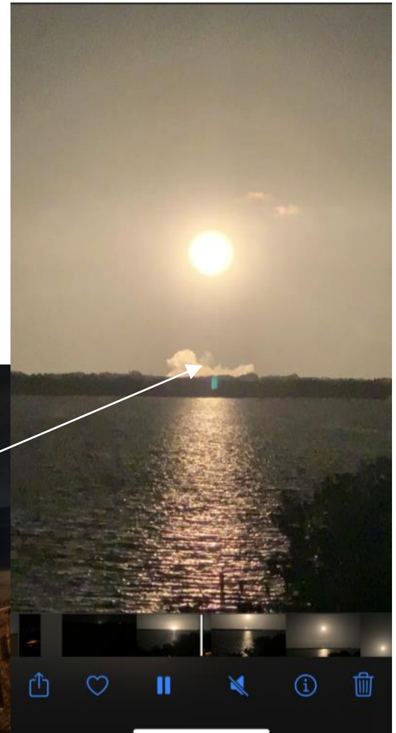
Observations

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

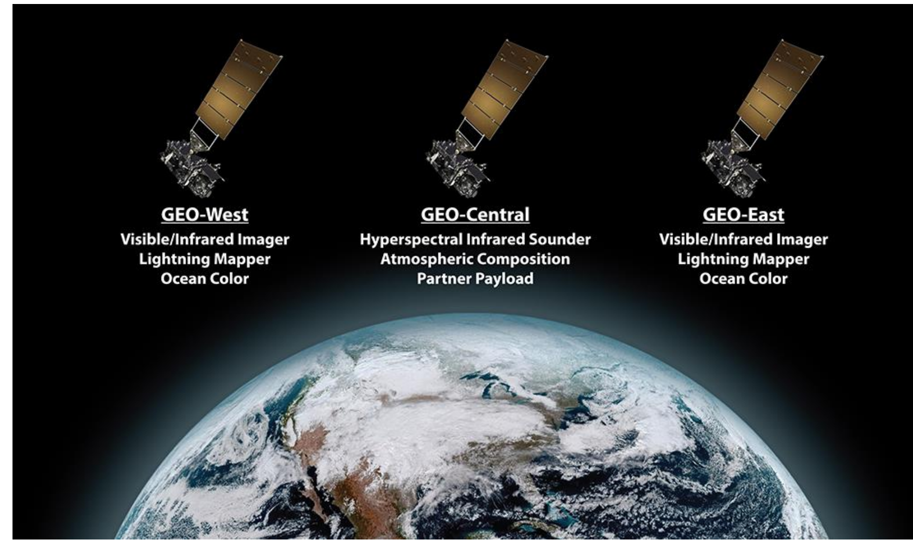



FILDA2 MCE
MCE
0.80 – 0.82
0.82 – 0.84
0.84 – 0.86
0.86 – 0.88
0.88 – 0.90
0.90 – 0.92
0.92 – 0.94
0.94 – 0.96
0.96 – 0.98
0.98 – 1.00
WA
OR
MT
SD
Trop AOD
3.0
2.5
2.0
1.5
1.0
0.5
0.0
WA
OR
MT
SD
AOCH-O2AB
(Km)
7
6
5
4
3
2
1
WA
OR
MT
SD
WA
OR
MT
SD
Calgary
Regina
Vancouver
Seattle
Idaho
Montana
North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

AOCH algorithm is now being implemented for TEMPO and planned for GEO-XO



Launched by SpaceX on 7 April 2023 @ 12:30am



2030s

Summary

- **VIIRS Fire MCE product (including FRP)**
  - Now in production. Soon to be available at: https://viirsland.gsfc.nasa.gov/Products/NASA/NASAprod.html
  - Product prefix: VNP47IMG; VJ147IMG; VNP47MOD; VJ147MOD
  - https://esmc.uiowa.edu/filda/filda.php

- **AOCH and AOD data product from EPIC**
  - https://asdc.larc.nasa.gov/project/DSCOVR/DSCOVR_EPIC_L2_AOCH_01
  - https://epic.gsfc.nasa.gov/science/products/aoch

- **AOCH and AOD research data product from TROPOMI**
  - http://esmc.uiowa.edu:3838/tropomi_aoch/

Thank you!

Publication

- Enhancement of Nighttime Fire Detection and Combustion Efficiency Characterization using Suomi-NPP and NOAA20 VIIRS Instruments, *IEEE Transactions on Geoscience and Remote Sensing*, vol. 61, 4402420, 2023.
- Nighttime smoke aerosol optical depth over U.S. rural areas: First retrieval, *Remote Sensing of Environment*, 267, 112717, 2021.
- Development of a nighttime shortwave radiative transfer model for remote sensing of nocturnal aerosols and fires from VIIRS, *Remote Sensing of Environment*, 241, 111727, 2020.
- Nighttime smoke aerosol optical depth over U.S. rural areas, first retrieval from VIIRS moonlight observations, *Remote Sensing of Environment*, 267, 112717, 2021.
- Potential application of VIIRS Day/Night Band for monitoring nighttime surface $PM_{2.5}$ air quality from space, *Atmospheric Environment*, 124, 55–63, 2016.
- Mapping nighttime $PM_{2.5}$ from VIIRS DNB using a linear mixed effects model, *Atmospheric Environment*, 178, 214–222, 2018.
- Improving Nocturnal Fire Detection with the VIIRS Day-Night Band, *IEEE Transactions on Geoscience & Remote Sensing*, 9, 5503-5519, 2016

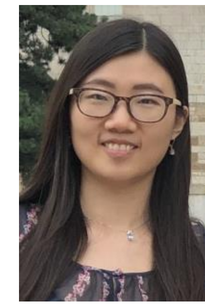
Funding support:

NASA, NOAA, DoD, U. Iowa

Group members

Meng Zhou
UMBC & NASA GMAO

Xiaoguang Xu, UMBC

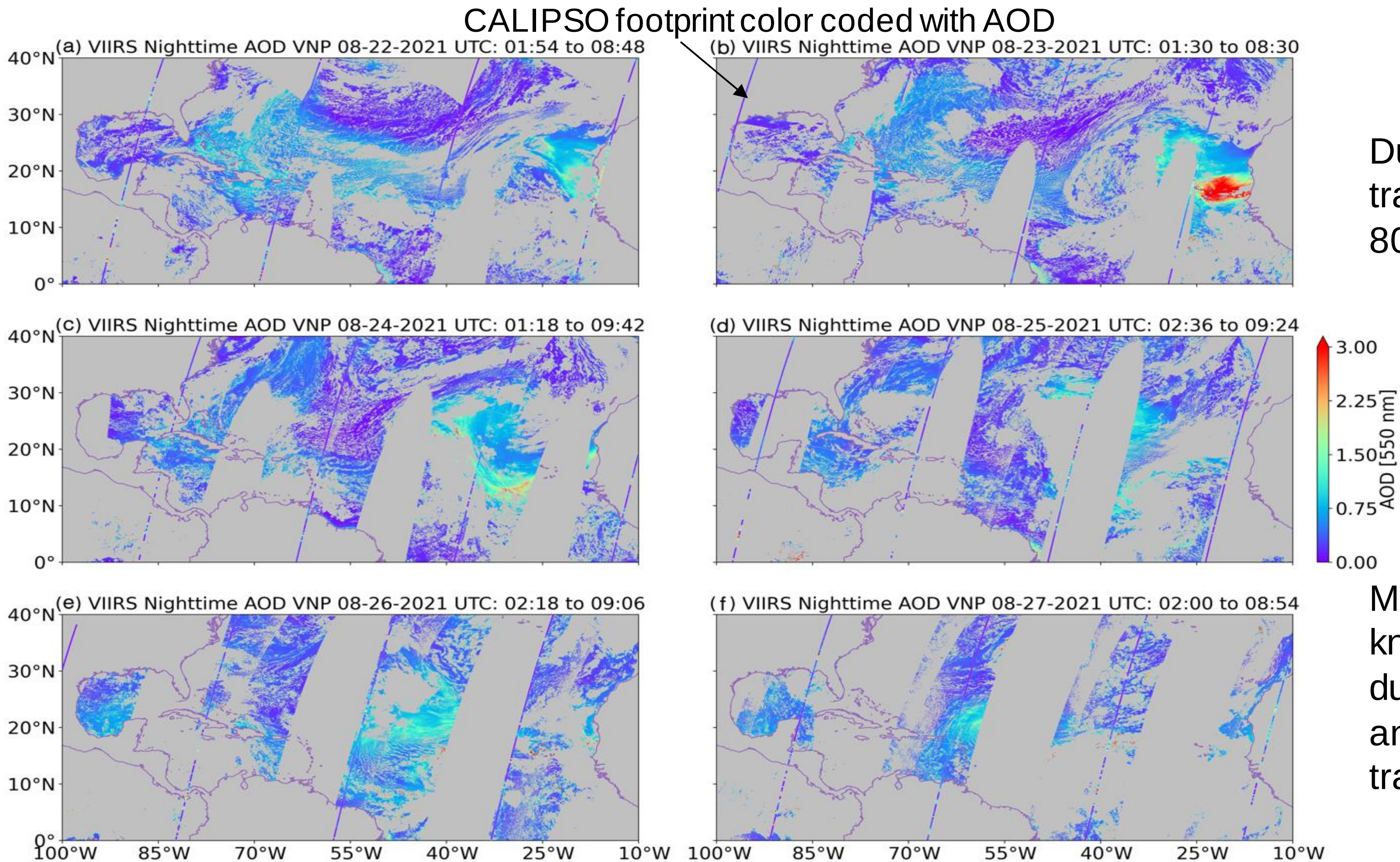


Xi Chen; U. Iowa

Zhendong Lu, U. Iowa

Tom Polivka, Raytheon

First mapping of nighttime visible AOD over the ocean



August 22 – 27, 2021; 0.75 km spatial resolution

Dust front can transport at 50-80 km/hr

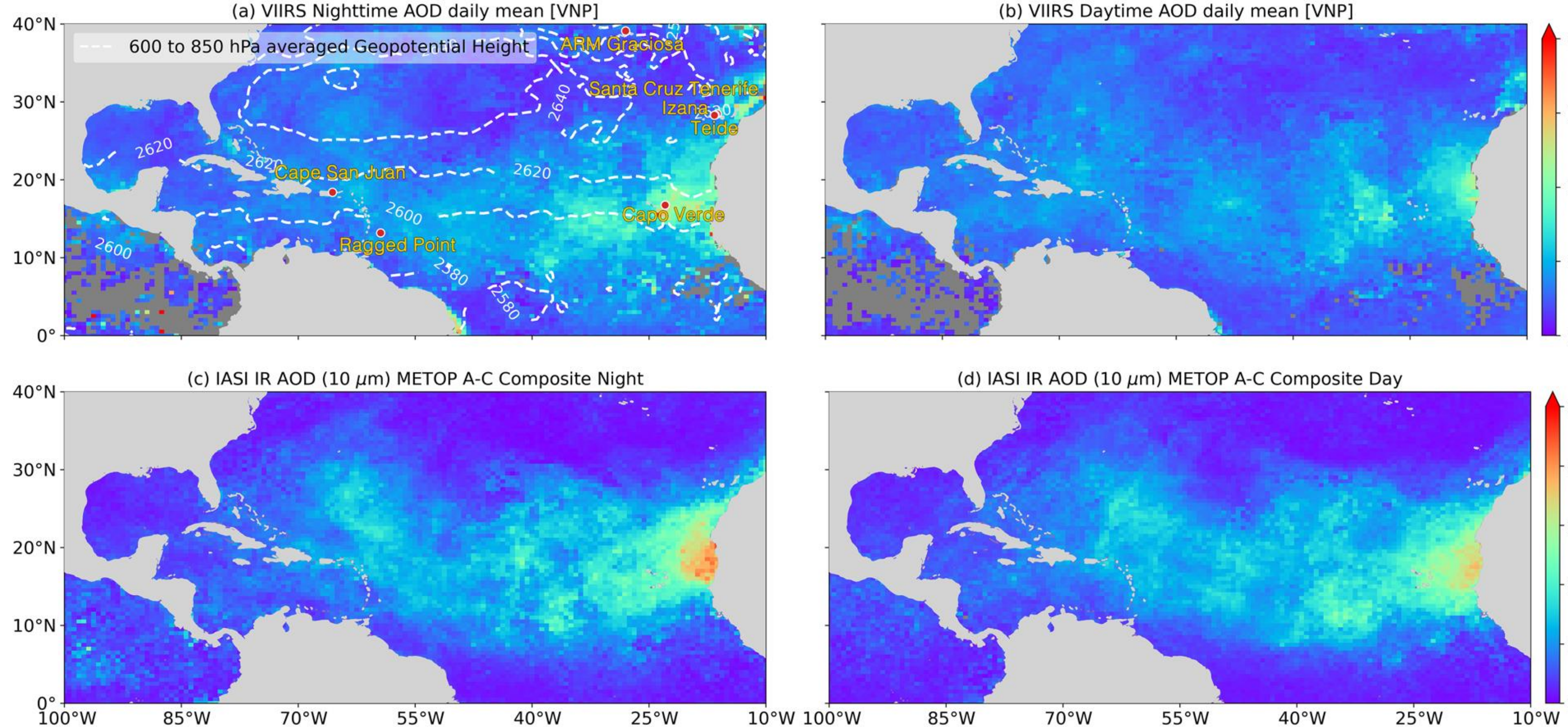
Much less is known about dust IR impact and nighttime transport.

First mapping of nighttime visible AOD climatology over the ocean

DNB AOD from VIIRS
Sampling rate: 6-10 days/month

JJA 2021

VIIRS DB



12 × 12 km @ nadir
39 × 20 km @ edge

Night

IASI IR AOD at 10 um
Vandenbussche et al., 2013

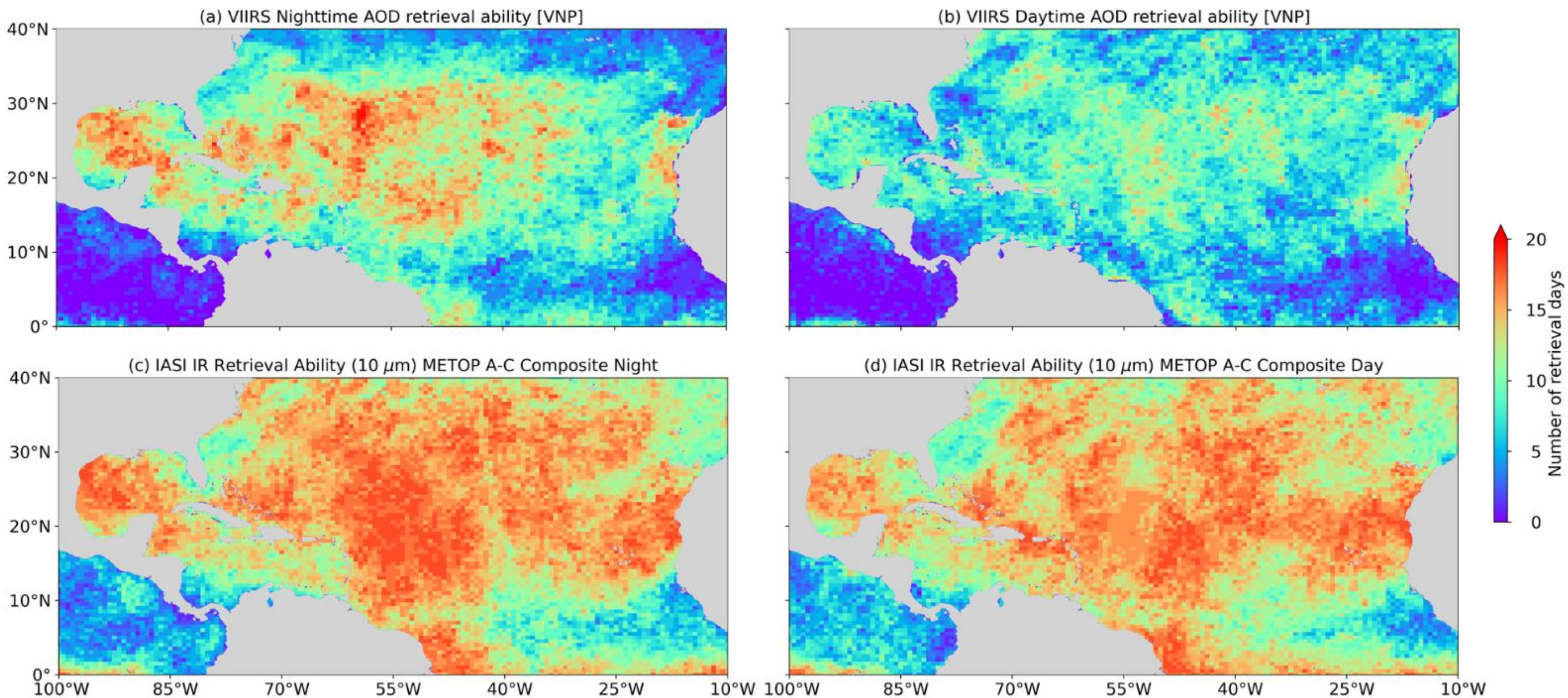
Day

Number of Days available for retrieval

DNB AOD from VIIRS
Sampling rate: 6-10 days/month

JJA 2021

VIIRS DB

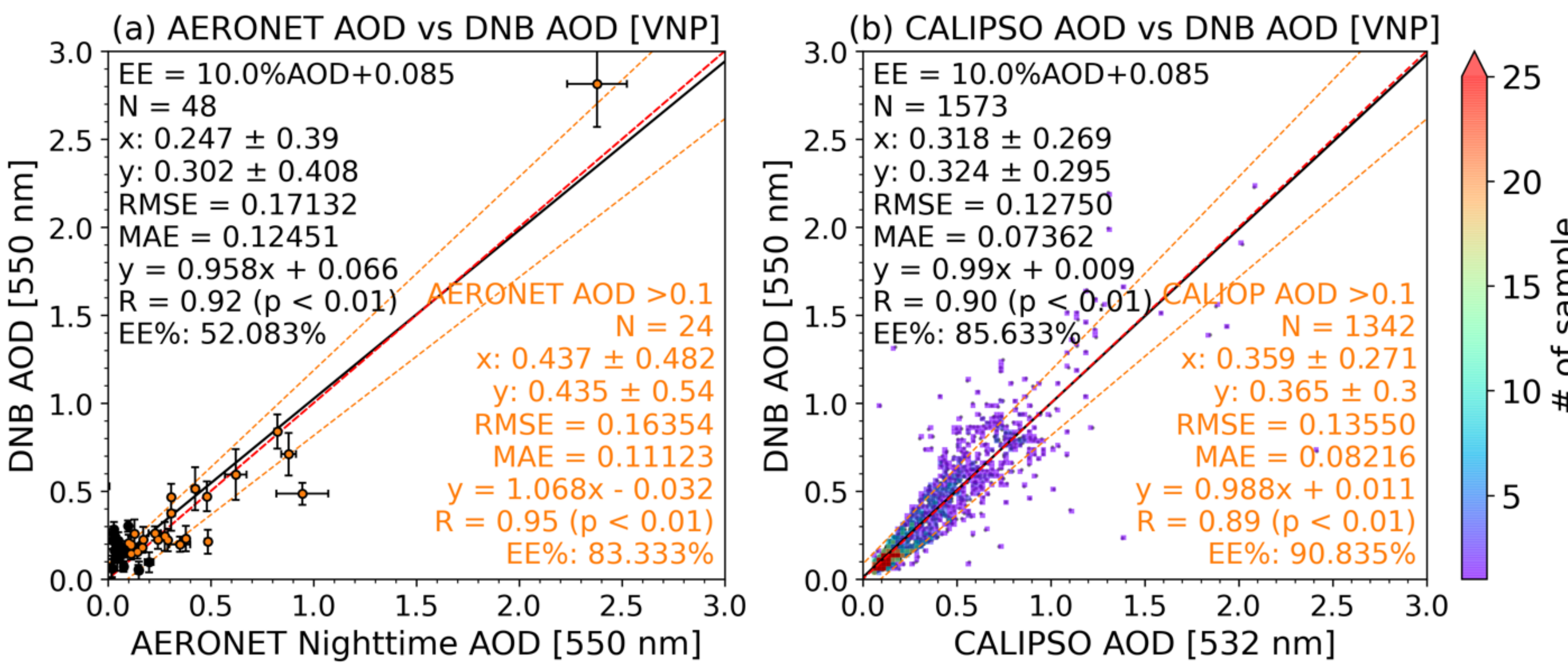


Night

IASI IR AOD at 10 um
Vandenbussche et al., 2013

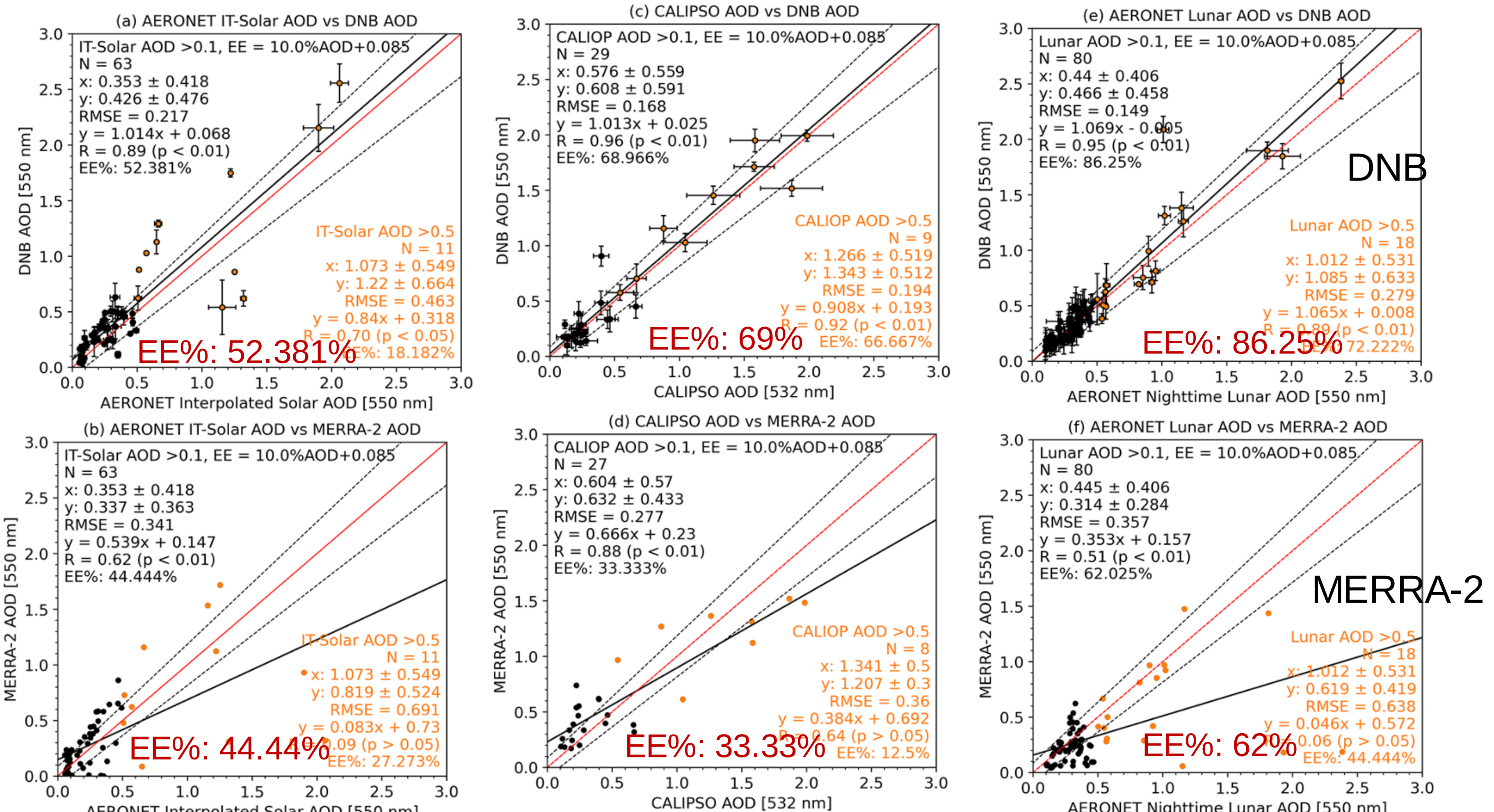
Day

Validation with AERONET & CALIPSO AOD



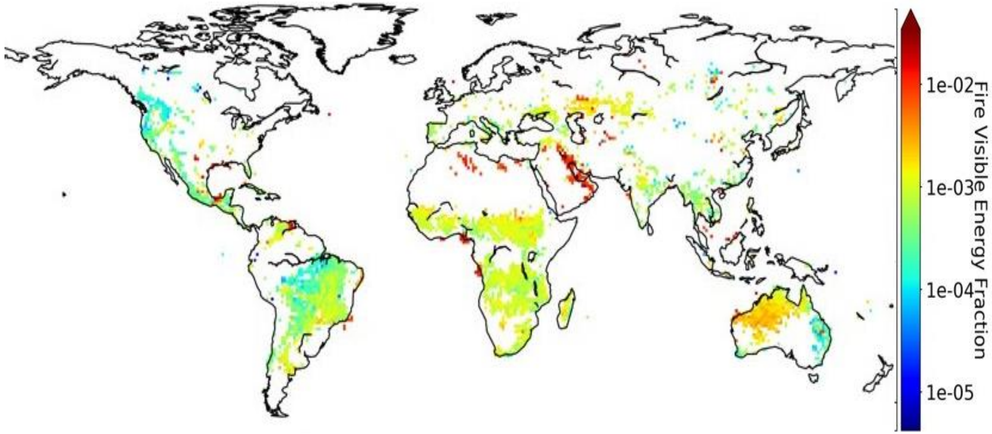
What is the retrieval uncertainty?

$\pm(0.085 + 10\% \text{ AOD})$

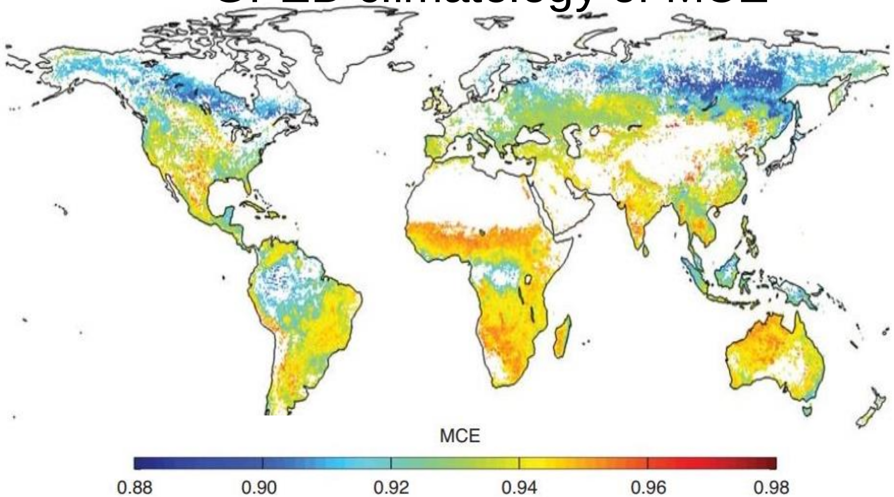


More Validation

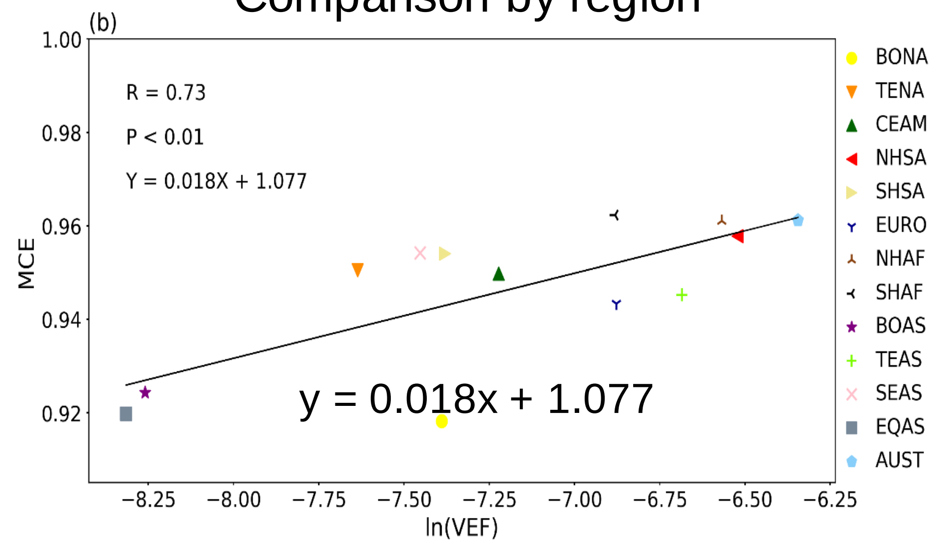
VIIRS VEF



GFED climatology of MCE



Comparison by region



(van Leeuwen and van der Werf 2011)

Instrument Modularity

- **Level 1: Instrument**
  - **Individual components such as sensors, lenses, power supply, processors, networking, connectors**
- **Level 2: Enclosure**
  - **Sensor head, umbilical, processing box**
  - **A standardized enclosure into which the instrument is being installed. Facilitates precise orientation of instrument components and enables standardized I/O connector arrangement**
- **Level 3: Deployment**
  - **Rack mounting: For use on OPL Bonanza, MI-2, and most NASA aircraft**
  - **P3-Pod for use on OPL L-29 and L-39 aircraft (P3 funds)**
  - **Agile pod for use on OPL L-39 and many new govt flights (approx. $200k)**
  - **Cubesat and Smallsat: For space flight (may require removal of enclosure)**

Potential characterization of smoldering vs. flaming