# Deep Blue Aerosol Updates

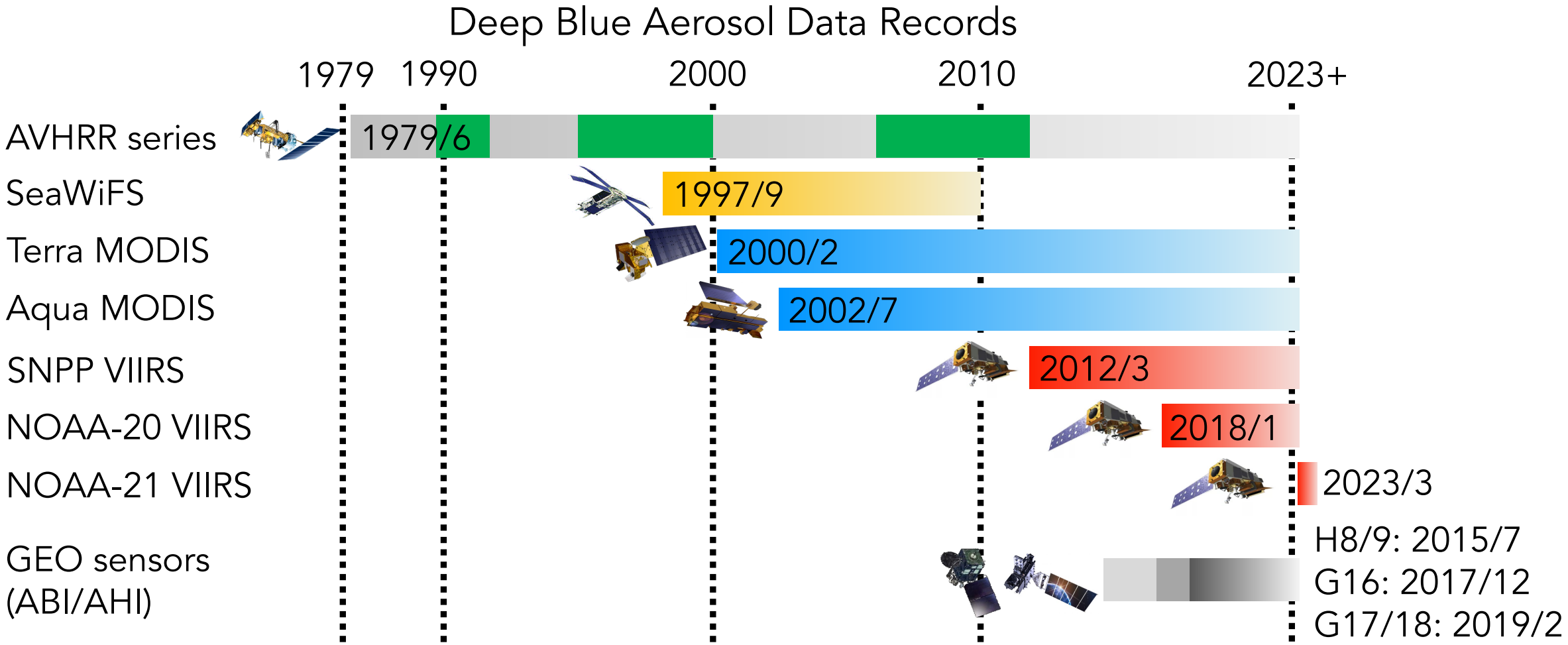
**Deep Blue Aerosol Project team:**
Jaehwa Lee[2,1], N. Christina Hsu[1] (PI), W. Vincent Kim[2,1], Seoyoung Lee[3,1], and Andrew M. Sayer[3,1]

[1]NASA Goddard Space Flight Center
[2]University of Maryland College Park
[3]University of Maryland Baltimore County

# Deep Blue Aerosol Project

*Science Objectives*:

To create long-term aerosol climate data records using consistent DB/SOAR algorithm suite applied to AVHRR, SeaWiFS, MODIS, VIIRS, and GEO sensors

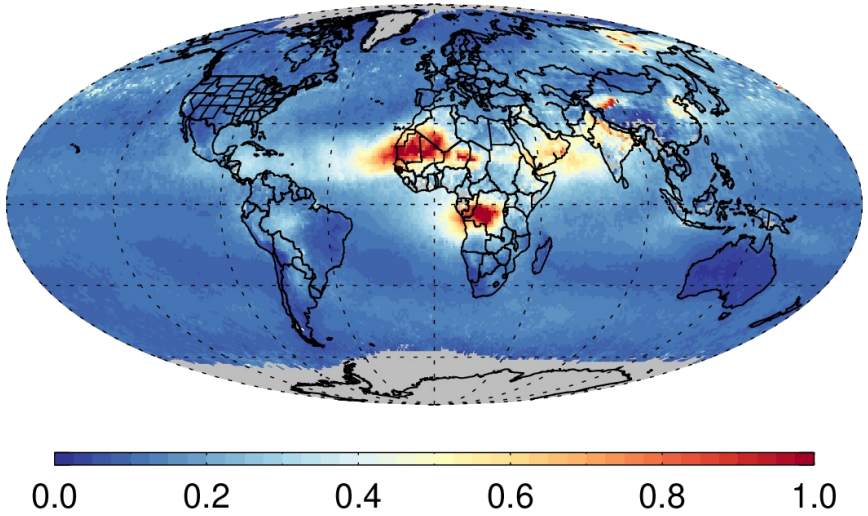


# VIIRS Status

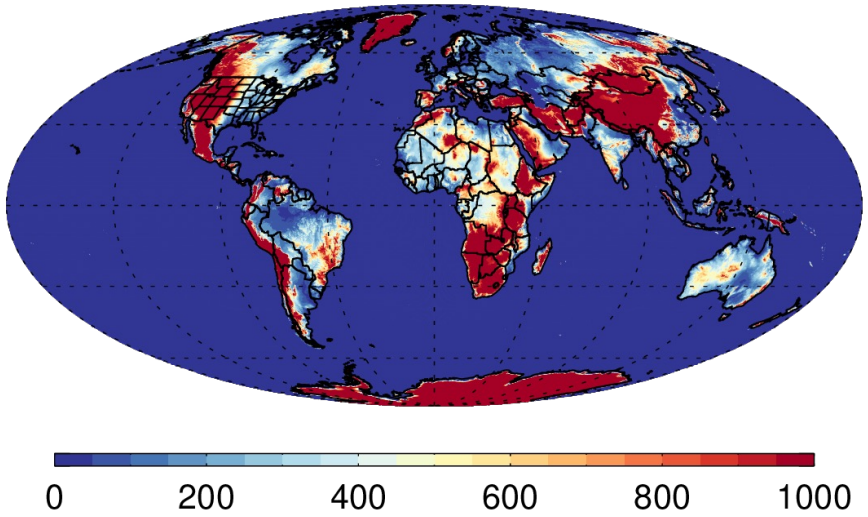
- Version 2 data sets released in April 2023
- Currently producing SNPP and N20 VIIRS data; N21 VIIRS will follow
- Major updates in the retrieval algorithm and data sets
- Algorithm updates include:
  - Better accounting for changing surface pressure
  - Improved surface reflectance determination
  - More realistic aerosol optical models for fine-mode aerosols
- Consistent algorithms are being applied to MODIS and GEO sensors as well

# SNPP VIIRS Version 2 vs. Version 1 AOD

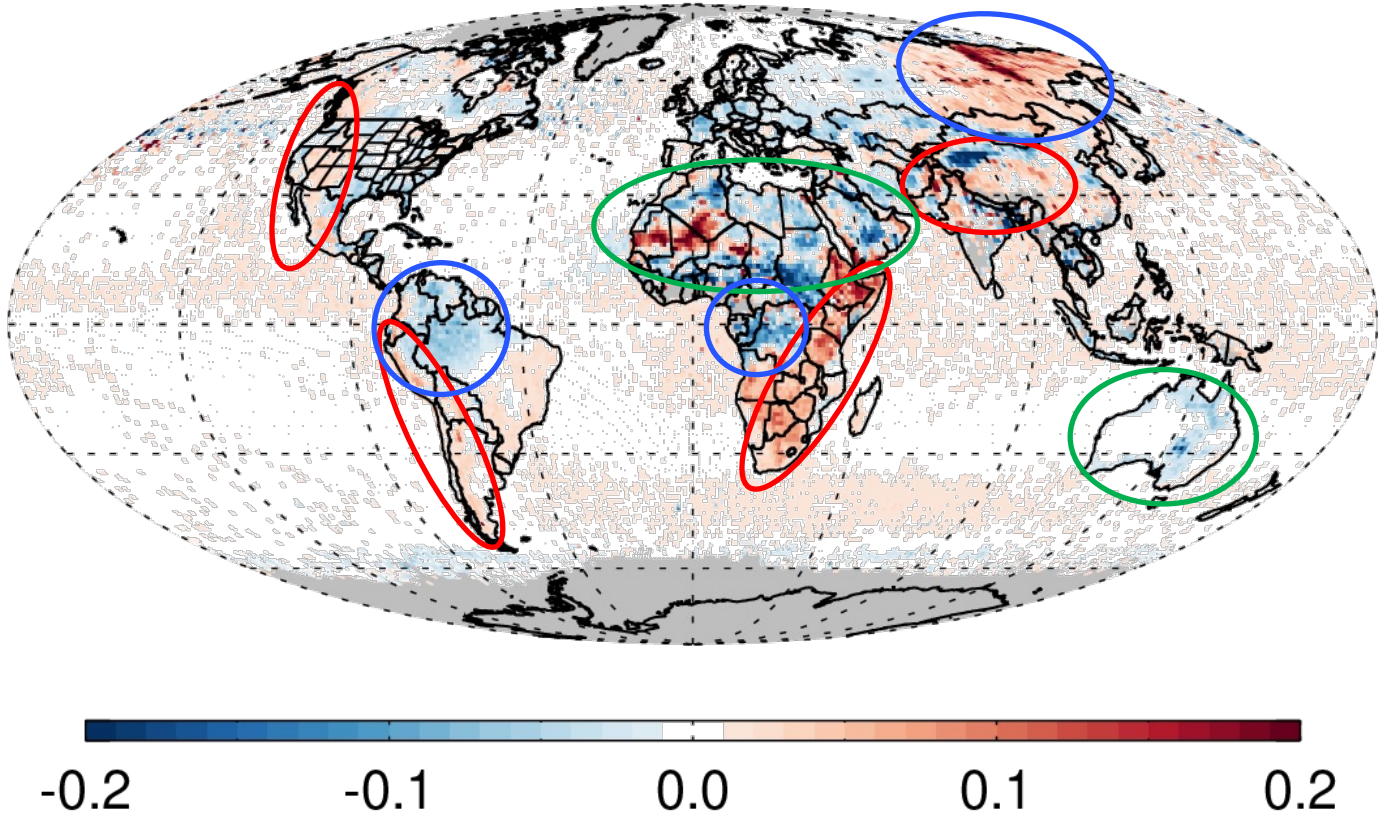
SNPP VIIRS DB AOD (550 nm, JJA 2020)




Surface elevation [m]

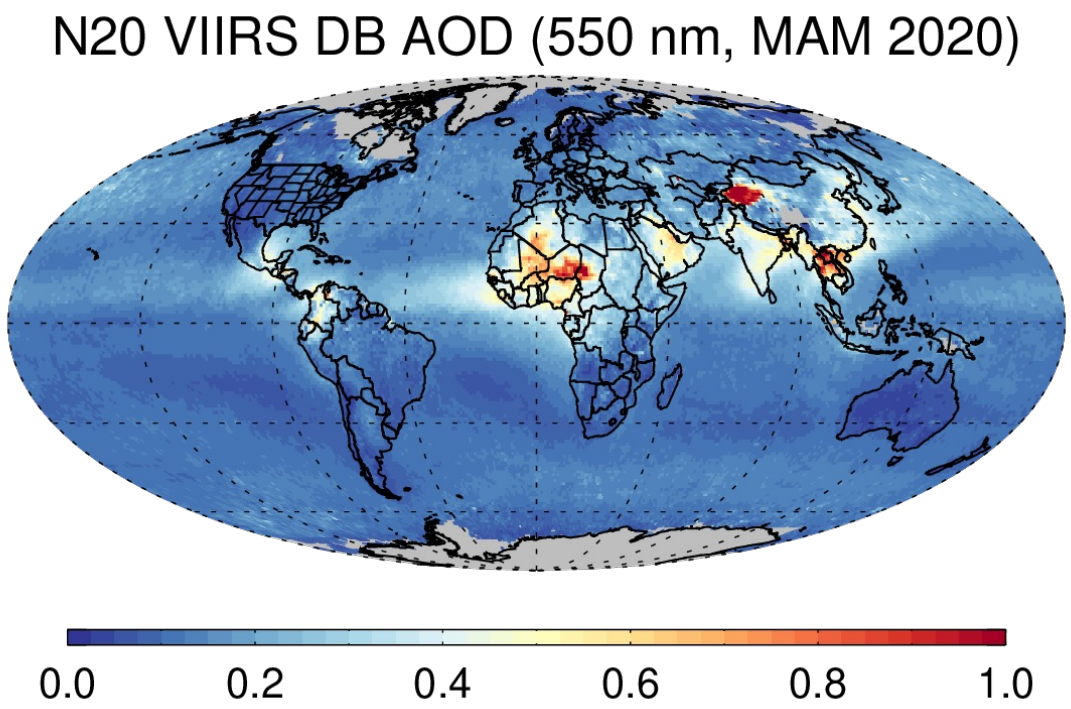


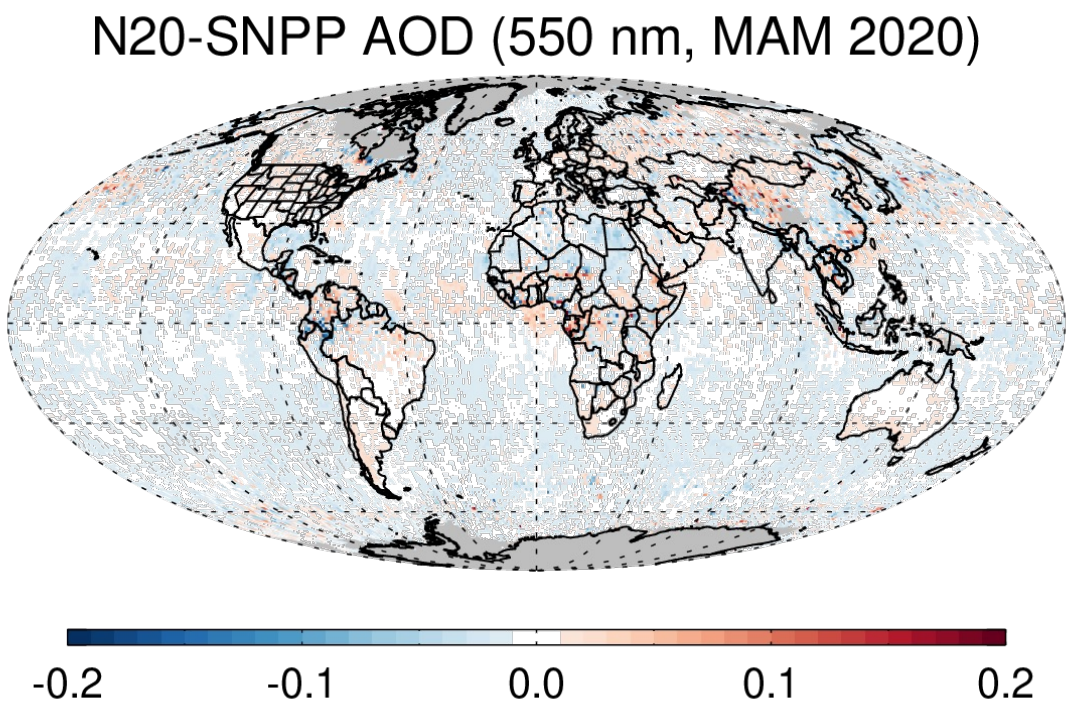

V2-V1 AOD (550 nm, JJA 2020)




- High elevation regions: mitigated negative biases by better accounting for effects of changing surface pressure
- Bright surfaces: mitigated positive biases by improved surface reflectance
- Aerosol optical model: New fine-mode aerosol model + regional aerosol model adjustments
- Over water: Generally, slight increase in AOD for surface pressure < 1 atm

# SNPP vs. NOAA-20 VIIRS AOD




- Over water, SNPP VIIRS is cross-calibrated against Aqua MODIS to mitigate a positive bias in SNPP VIIRS; no cross-calibration is applied for N20 VIIRS.
- Over land, N20 VIIRS is cross-calibrated against SNPP for minor modifications to the algorithm.
- AOD is comparable between SNPP and N20 VIIRS.
- Mean offset = 0.001 – 0.005 over land, (-0.006) – (-0.009) over ocean, and (-0.004) – (-0.006) overall, depending on season

# Pixel-level Uncertainty

## Framework for the evaluation of uncertainty estimates (Sayer et al. 2020a, b)

Uncertainty estimates: finding 1σ confidence interval around retrieved value within which the true value is expected to lie ~68% of the time, following Gaussian statistics

### Diagnostic uncertainty

Over land:

$\epsilon_S = \pm(0.03 + 0.15\tau_A)$

Over ocean:

$\epsilon_S = \pm(0.03 + 0.1\tau_A)$

$$\Delta_N = \frac{AOD\ error}{expected\ discrepancy}$$

$$= \frac{\tau_S - \tau_A}{\sqrt{\epsilon_S^2 + \epsilon_A^2}}$$

### Pixel-level uncertainty

Over land:

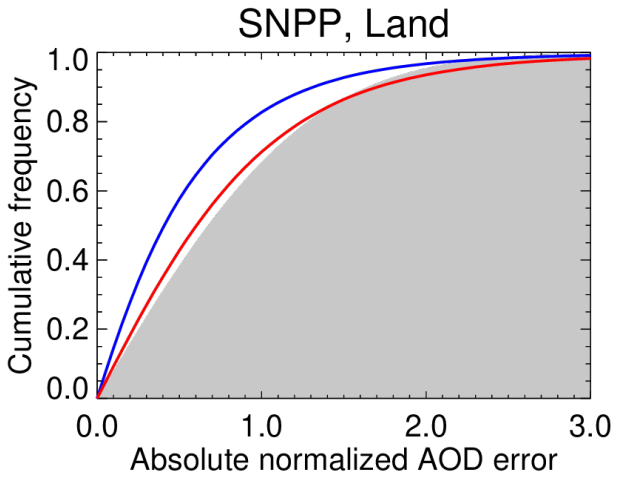
$$\epsilon_S = \pm\left(\frac{a + b\tau_S}{\frac{1}{\mu_0} + \frac{1}{\mu}}\right)$$

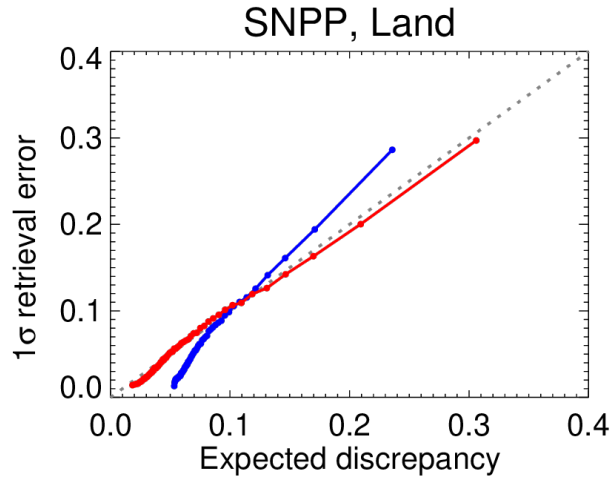
*a* and *b* are dependent on surface type

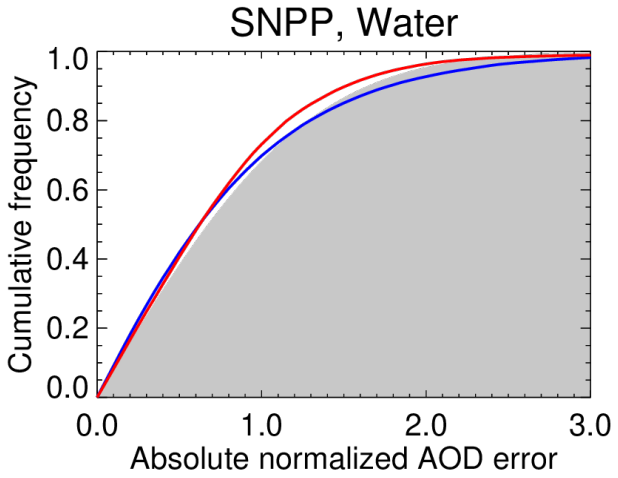
Over ocean:

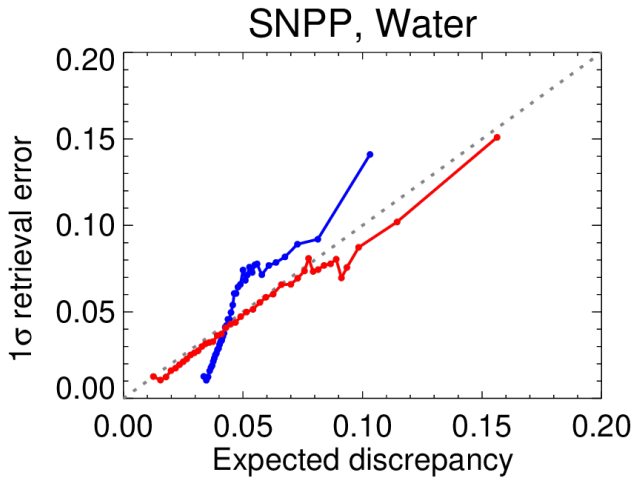
$\epsilon_S = \pm(a + b\tau_S)$

*a* and *b* are dependent on aerosol type and turbidity of water

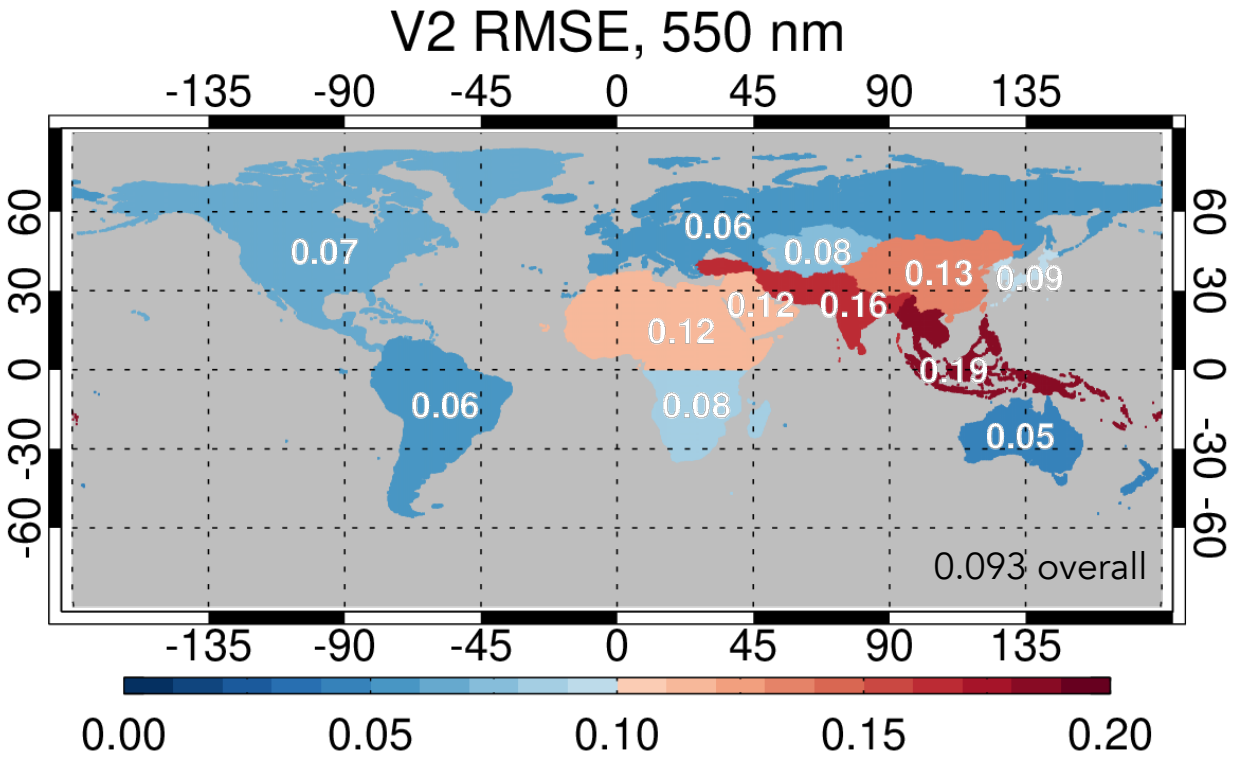


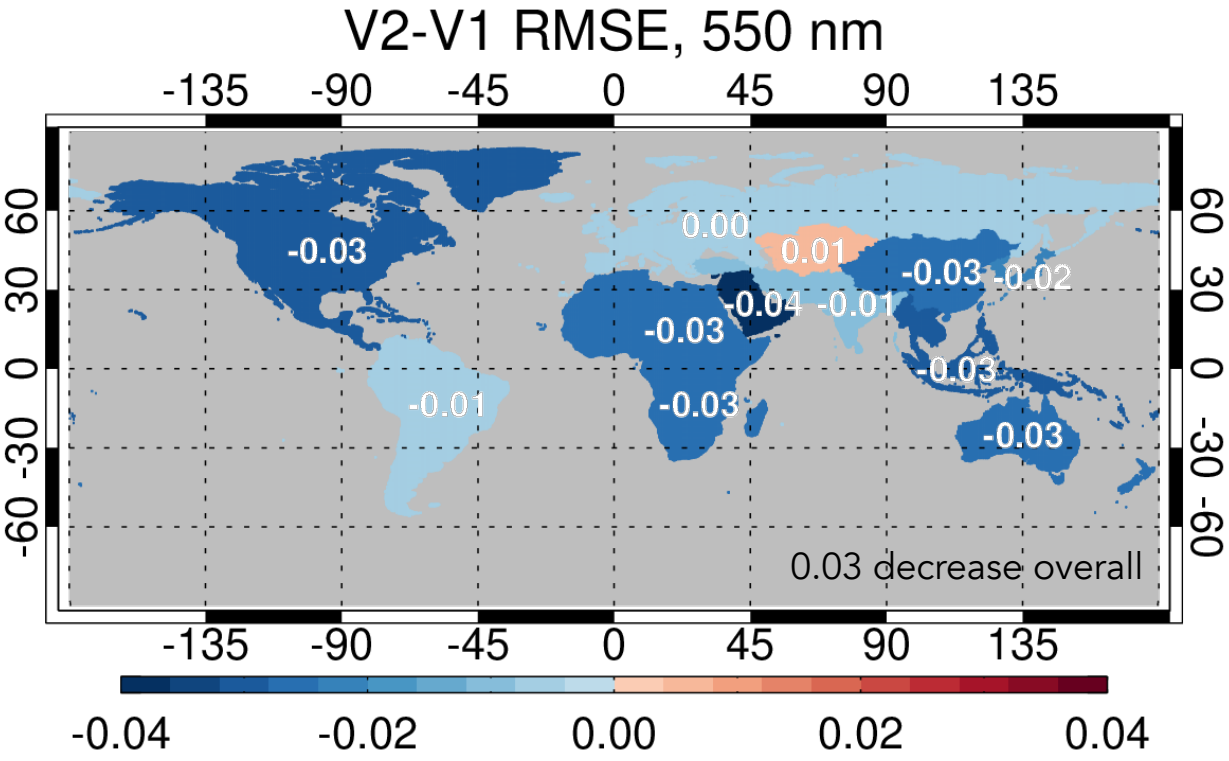



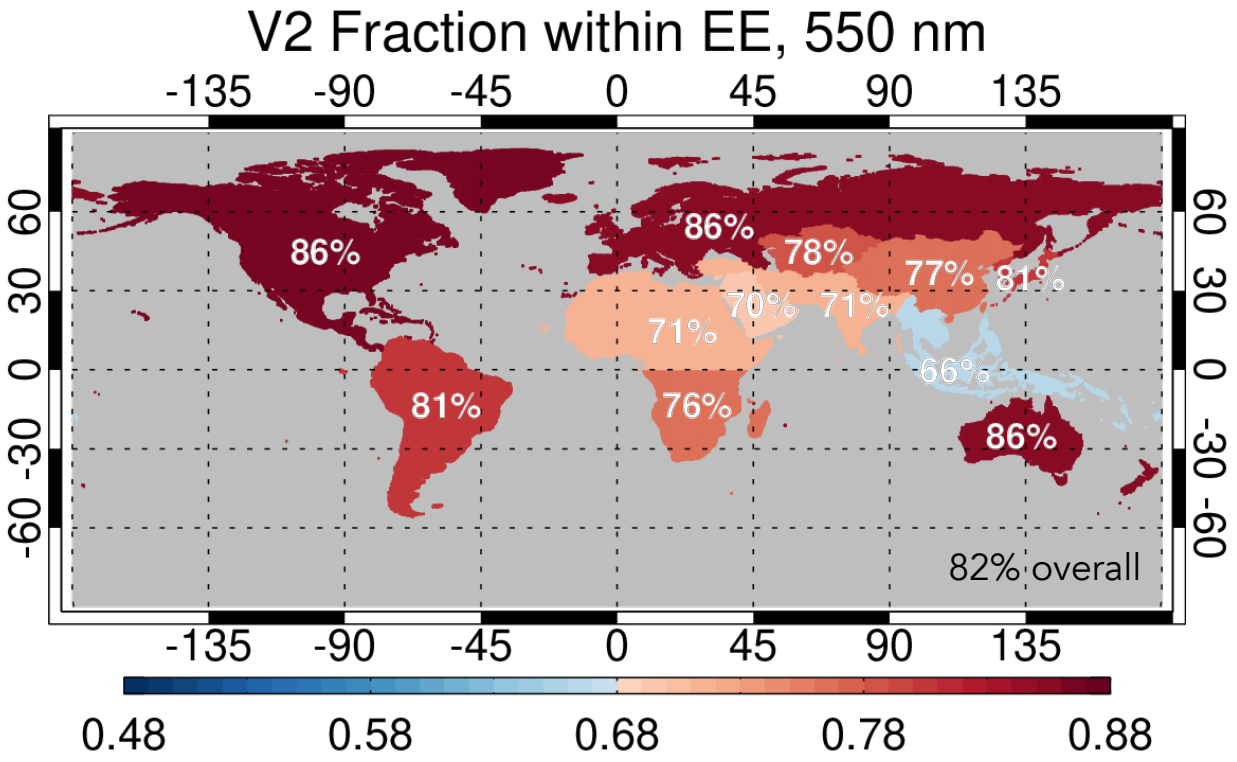
# AOD Validation against AERONET (SNPP VIIRS, 2012-2020)

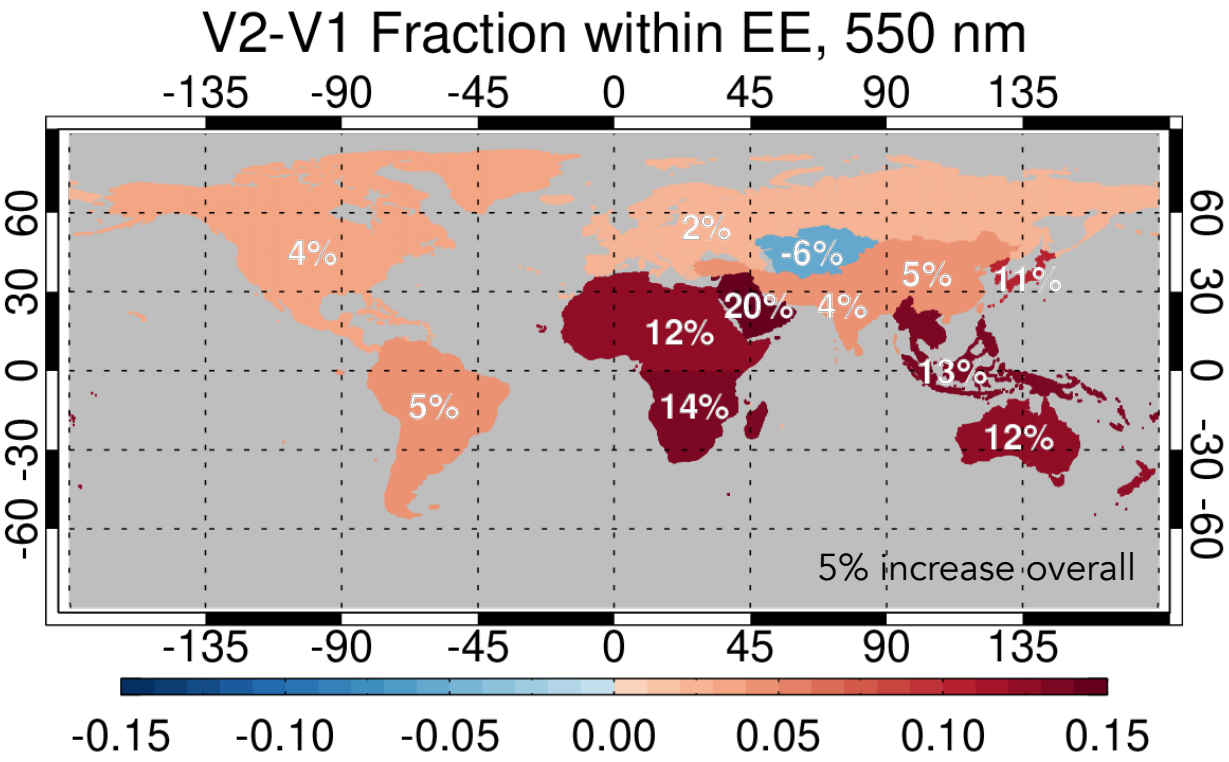



- Over land, VIIRS V2 AOD is generally much improved compared to V1.
- Overall, RMSE decreased from 0.12 to 0.09 (or by ~0.03).
- Higher RMSE results from brighter surface, higher aerosol loading, and/or complex aerosol type
- Over water, RMSE slightly increased from 0.067 to 0.07 (or by ~0.003).

# AOD Validation against AERONET (SNPP VIIRS, 2012-2020)




Expected error (EE) = ±(0.05+15%) over land; ±(0.03+10%) over water

- Over land, VIIRS V2 AOD is generally much improved compared to V1.
- Overall, $f_{EE}$ increased from 77% to 82% (or by 5%).
- Over water, $f_{EE}$ decreased from 69% to 66% (or by 3%).

# Status: Other Sensors

MODIS

- C7 algorithm development is underway for reprocessing scheduled for H2 2024 – H1 2025
- Algorithm based on VIIRS V2 including over-water retrievals
- Primary focus is data continuity with minor upgrades
- VIIRS V2.1 will match the MODIS C7 schedule for a seamless transition

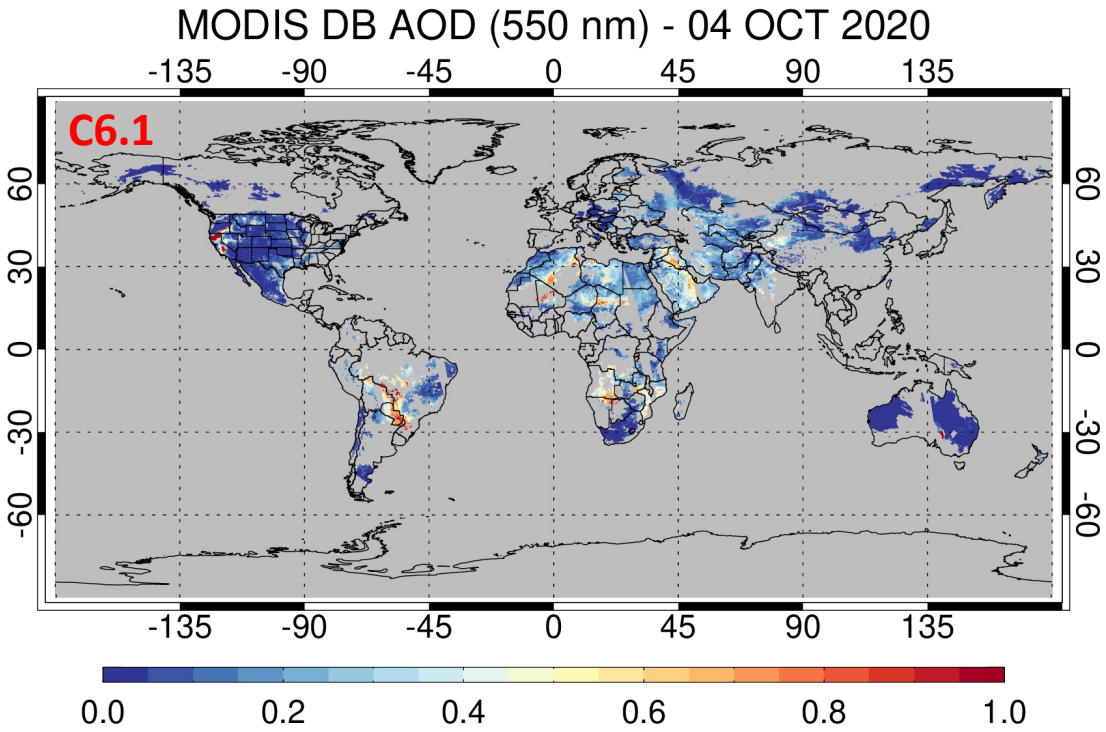
GEO

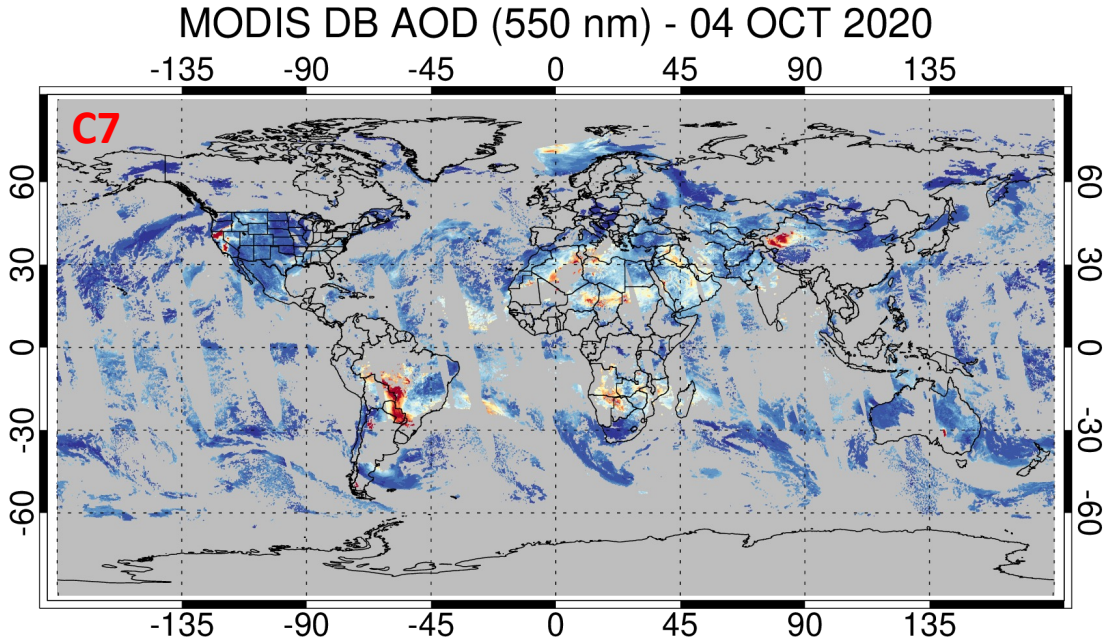
- Demonstration data sets have been processed using G16/17 ABI and H8 AHI
- Algorithm based on VIIRS V2 including over-water retrievals
- Consistent performance with LEO sensors despite lacking 412 nm band

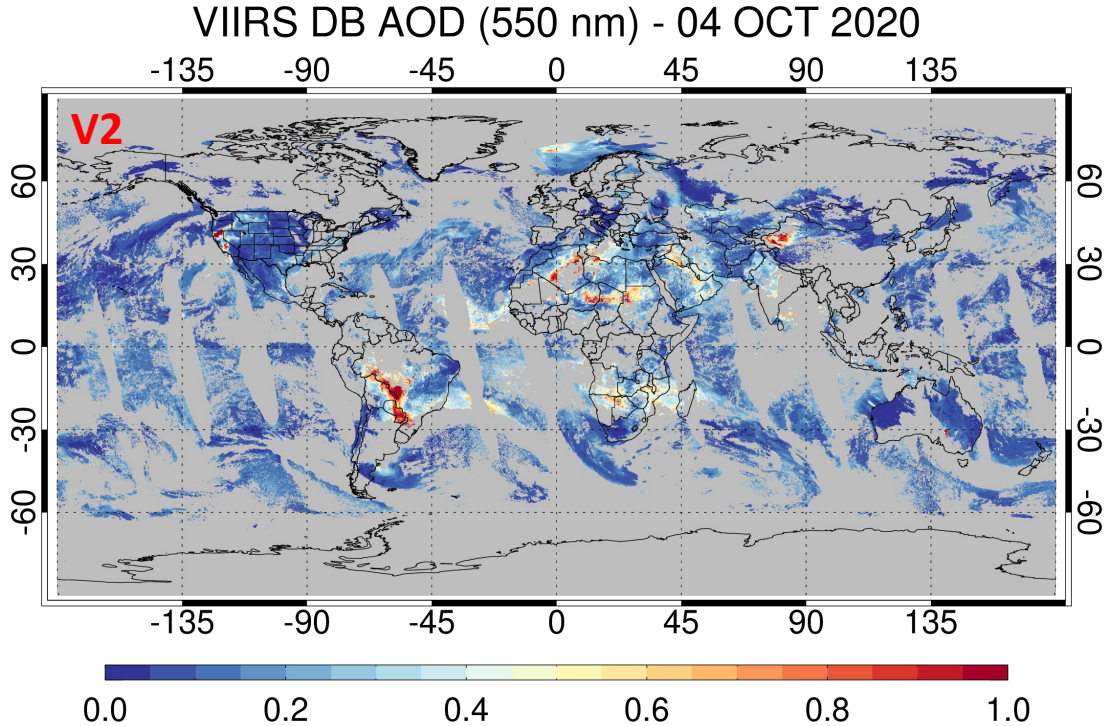
AVHRR and SeaWiFS (newly funded through NASA's MEaSUREs Program)

- A subset of NOAA-11/14/18 AVHRR DB data has been available over both land and water
- Recently funded for complete data records (40+ years since 1979)
- New SeaWiFS data including some of the updates since made

# MODIS C7 AOD: Preliminary




## MODIS C7 algorithm

- New over-water retrievals
- Better consistency with VIIRS V2
- Upgrades will be transferred to VIIRS V2.1

# MODIS vs. VIIRS File Formats

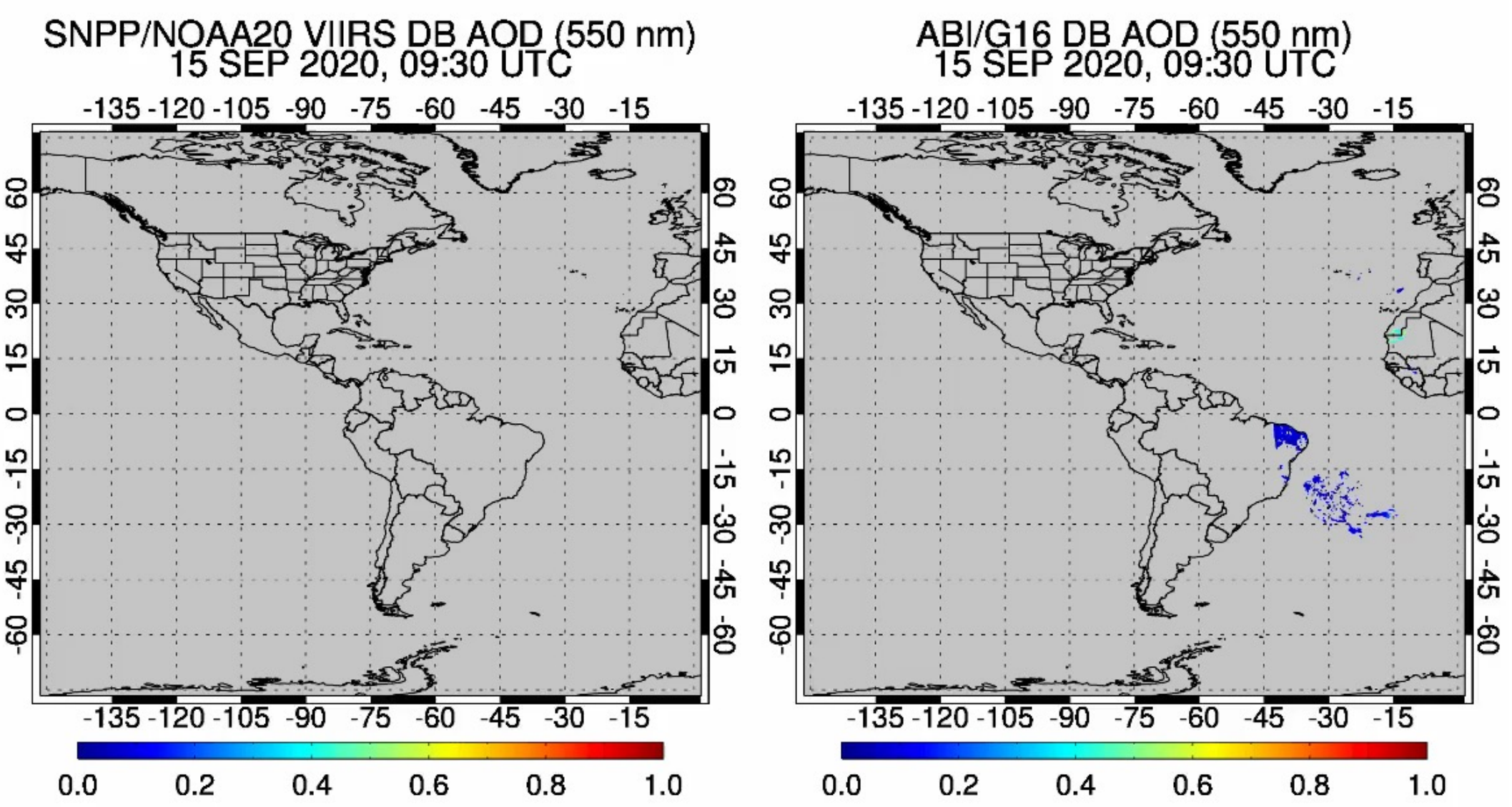
VIIRS Version 2

- AERDB_L2_VIIRS_SNPP.A2018001.0000.001.2023180103723.nc
  - Aerosol_Optical_Thickness_550_Expected_Uncertainty_Land
  - Aerosol_Optical_Thickness_550_Expected_Uncertainty_Ocean
  - Aerosol_Optical_Thickness_550_Land
  - Aerosol_Optical_Thickness_550_Land_Best_Estimate
  - Aerosol_Optical_Thickness_550_Land_Ocean
  - Aerosol_Optical_Thickness_550_Land_Ocean_Best_Estimate
  - Aerosol_Optical_Thickness_550_Ocean
  - Aerosol_Optical_Thickness_550_Ocean_Best_Estimate
  - Aerosol_Optical_Thickness_550_STDV_Land
  - Aerosol_Optical_Thickness_550_STDV_Ocean
  - Aerosol_Optical_Thickness_QA_Flag_Land
  - Aerosol_Optical_Thickness_QA_Flag_Ocean
  - …

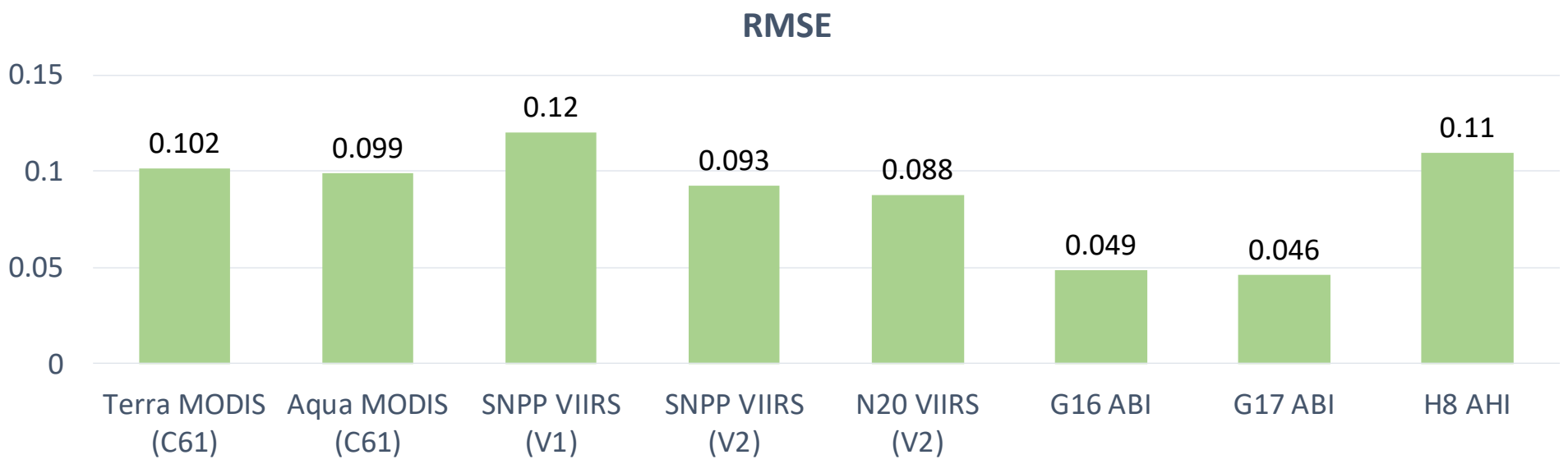
MODIS Collection 7 candidate

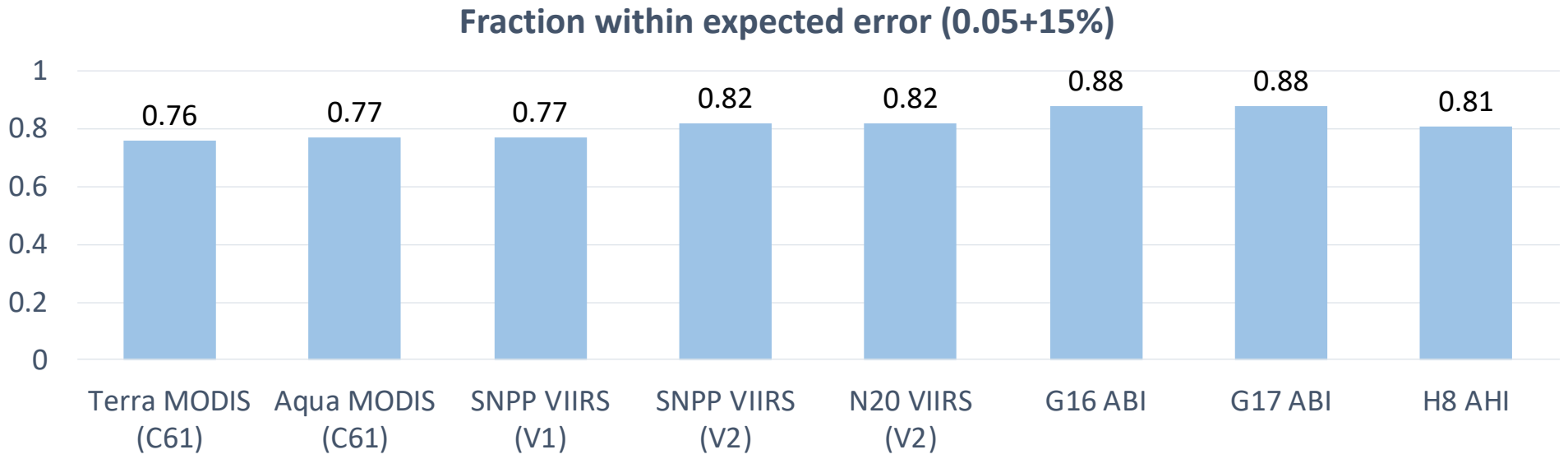
- MYD04_L2.A2017277.1135.007.2023296132146.nc
  - geolocation_data
  - geophysical_data_Dark_Target
  - geophysical_data_Dark_Target_Deep_Blue_Combined
  - geophysical_data_Deep_Blue
    - Aerosol_Optical_Thickness_550_Expected_Uncertainty_Land
    - Aerosol_Optical_Thickness_550_Expected_Uncertainty_Ocean
    - Aerosol_Optical_Thickness_550_Land
    - Aerosol_Optical_Thickness_550_Land_Best_Estimate
    - Aerosol_Optical_Thickness_550_Land_Ocean
    - Aerosol_Optical_Thickness_550_Land_Ocean_Best_Estimate
    - Aerosol_Optical_Thickness_550_Ocean
    - Aerosol_Optical_Thickness_550_Ocean_Best_Estimate
    - Aerosol_Optical_Thickness_550_STDV_Land
    - Aerosol_Optical_Thickness_QA_Flag_Land
    - Aerosol_Optical_Thickness_QA_Flag_Ocean
    - …

# GEO Deep Blue AOD (G16 ABI)

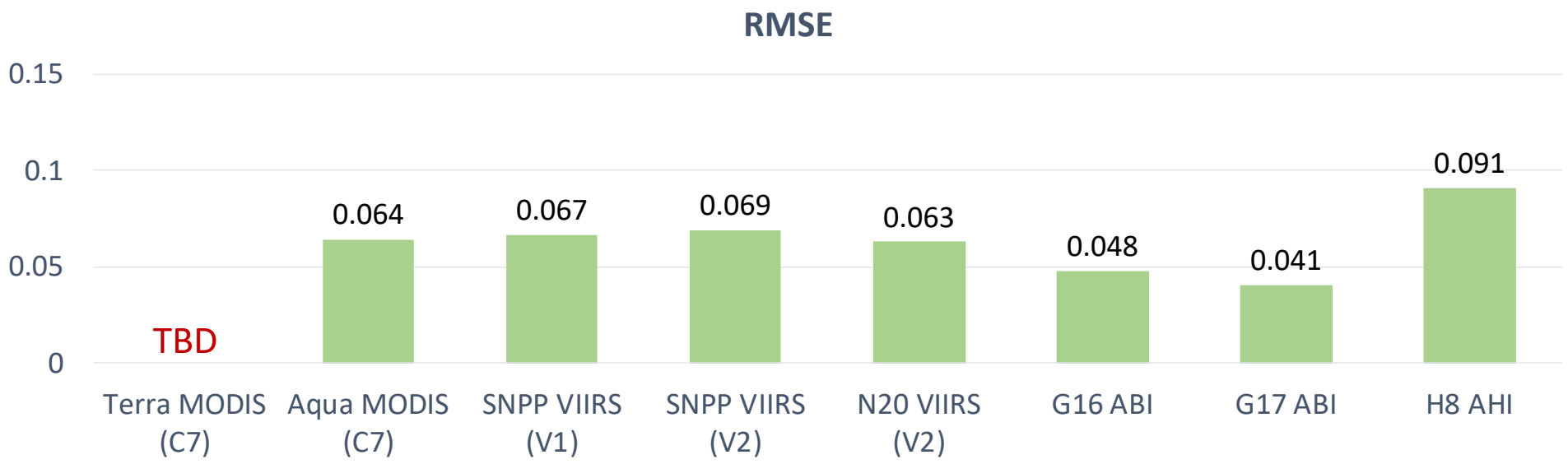


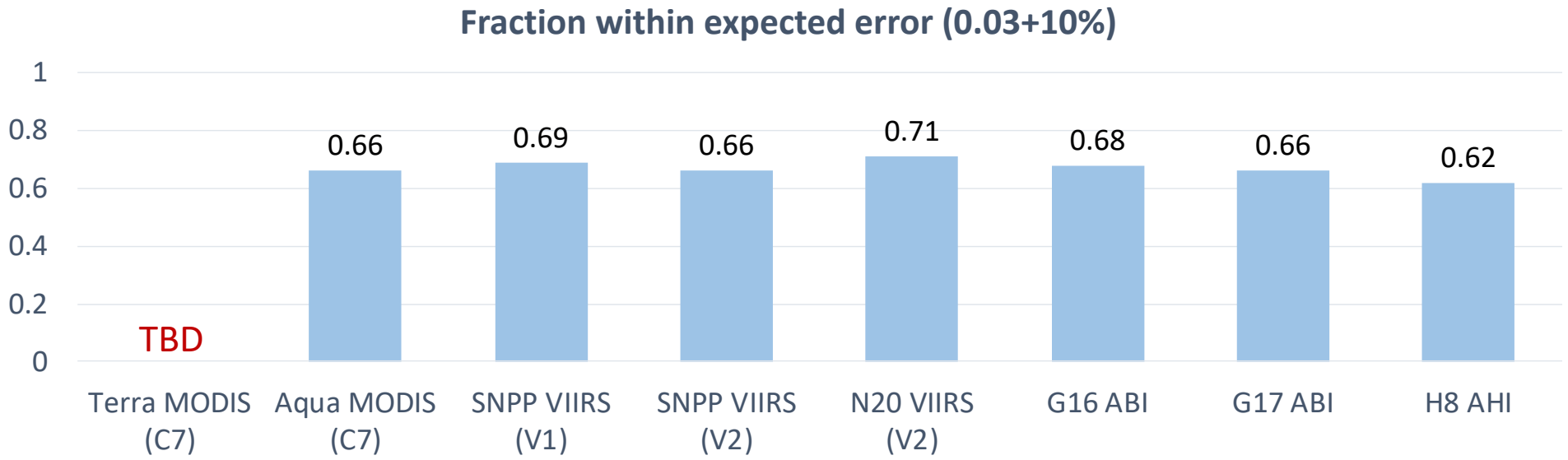
# Validation Statistics against AERONET (Land)



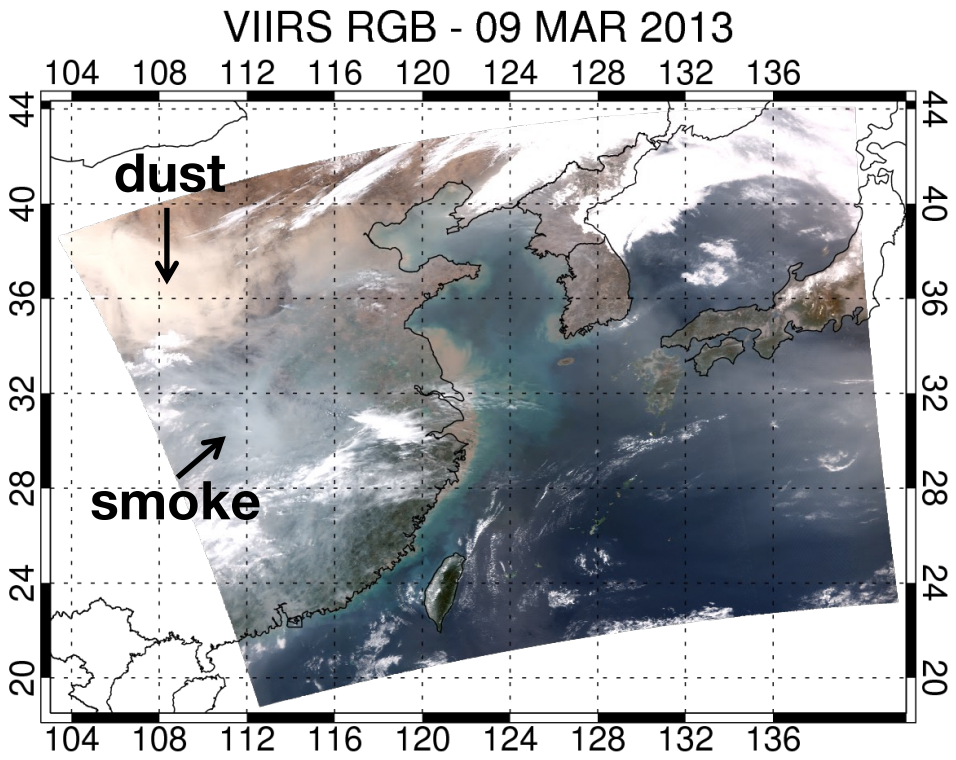



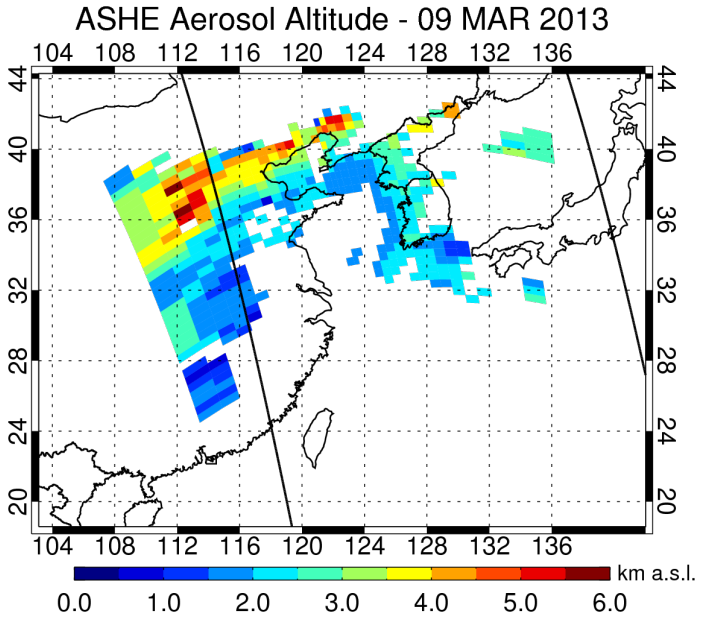
# Validation Statistics against AERONET (Water)

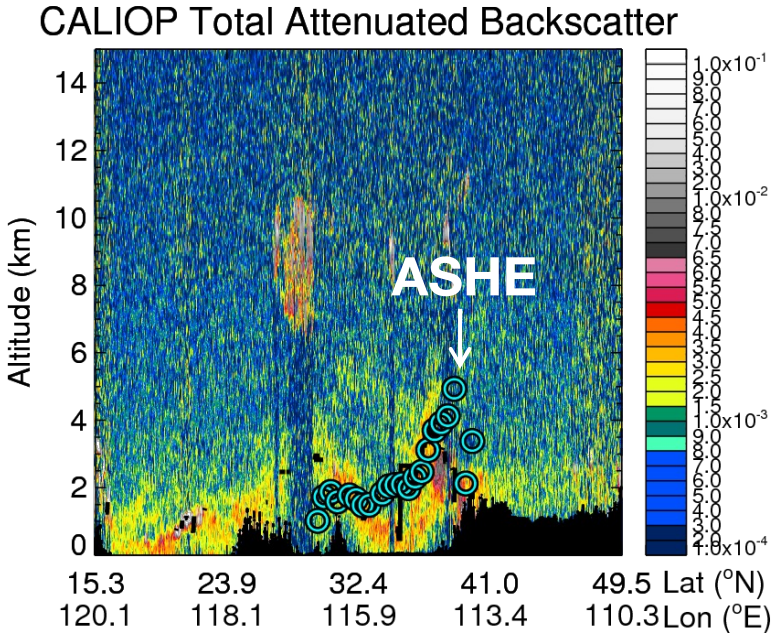


# New Aerosol Layer Height and SSA Products



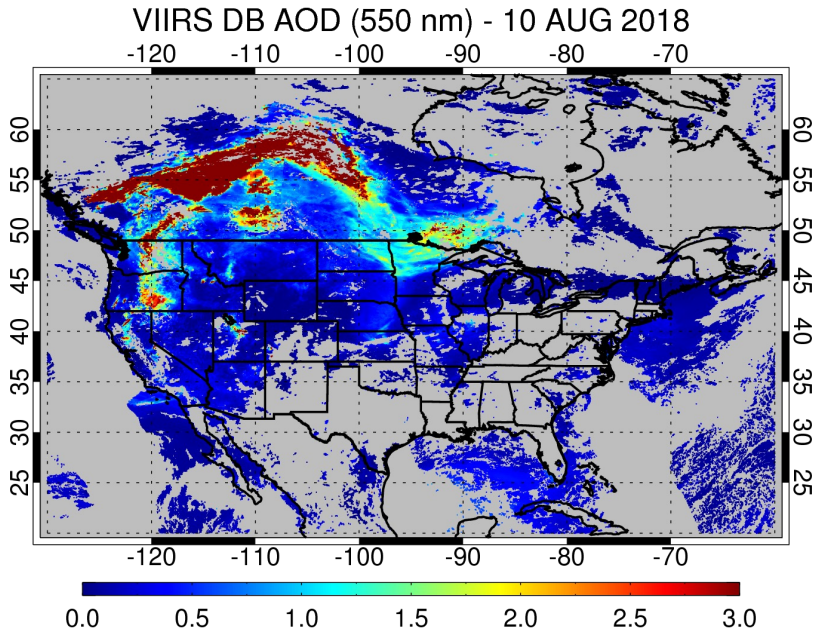



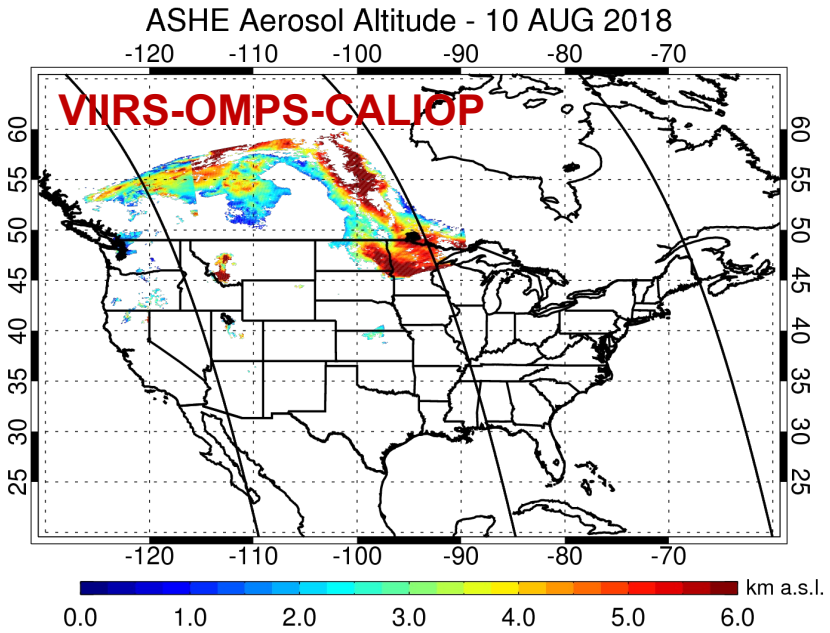



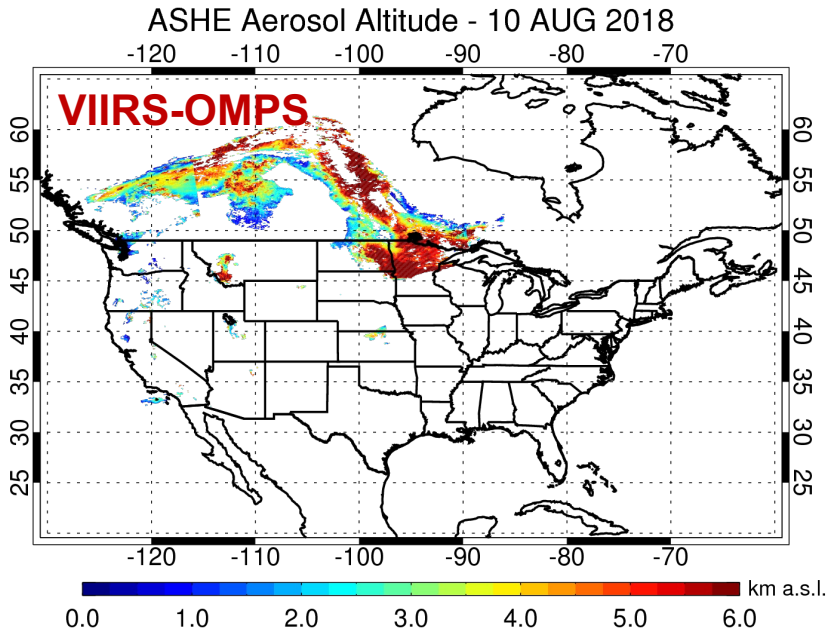

- UVAI ~ f(AOD, SSA, ALH)
- Applied to smoke and dust over both land and water
- Originally using VIIRS, OMPS, and CALIOP
- Now works without CALIOP for operational processing
- Dependent on AOD retrieval accuracy

Jeong and Hsu (2008), Lee et al. (2015, 2016, 2021)

# North American Wildfire Smoke

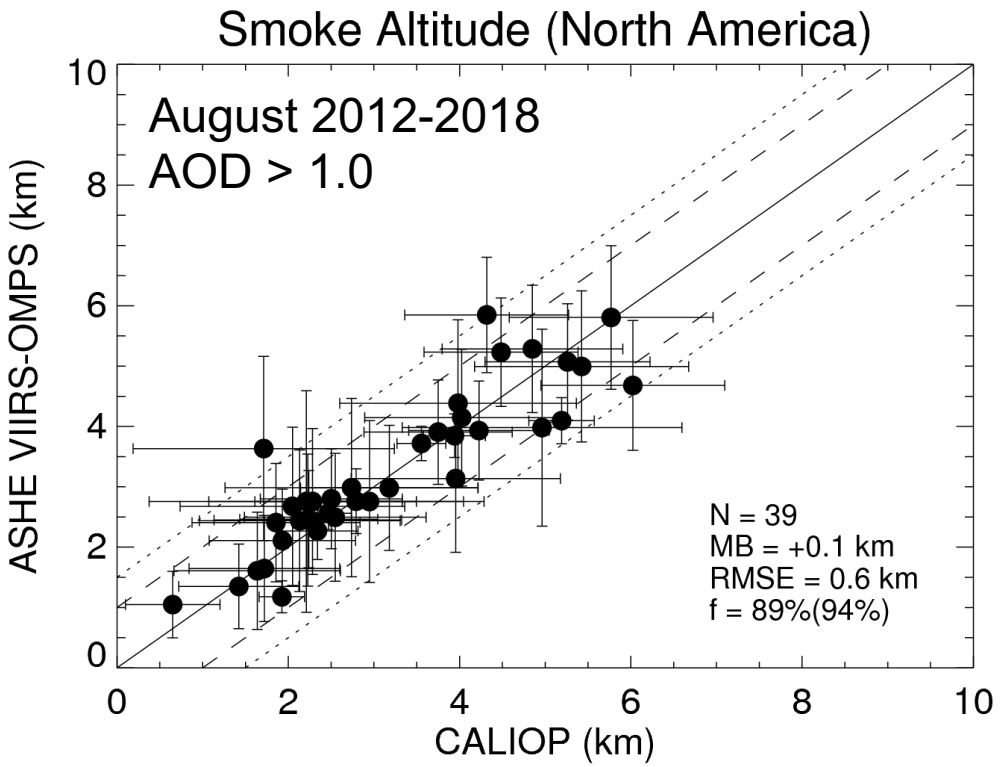


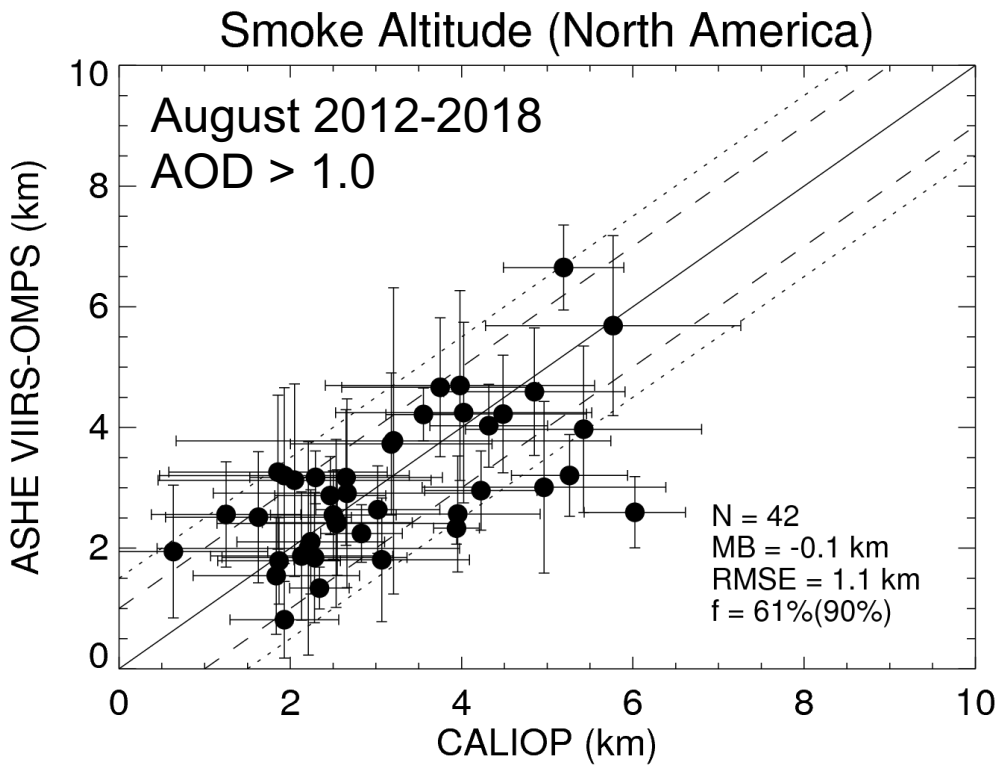



# Evaluation against CALIOP over North America

## VIIRS-OMPS-CALIOP




## VIIRS-OMPS

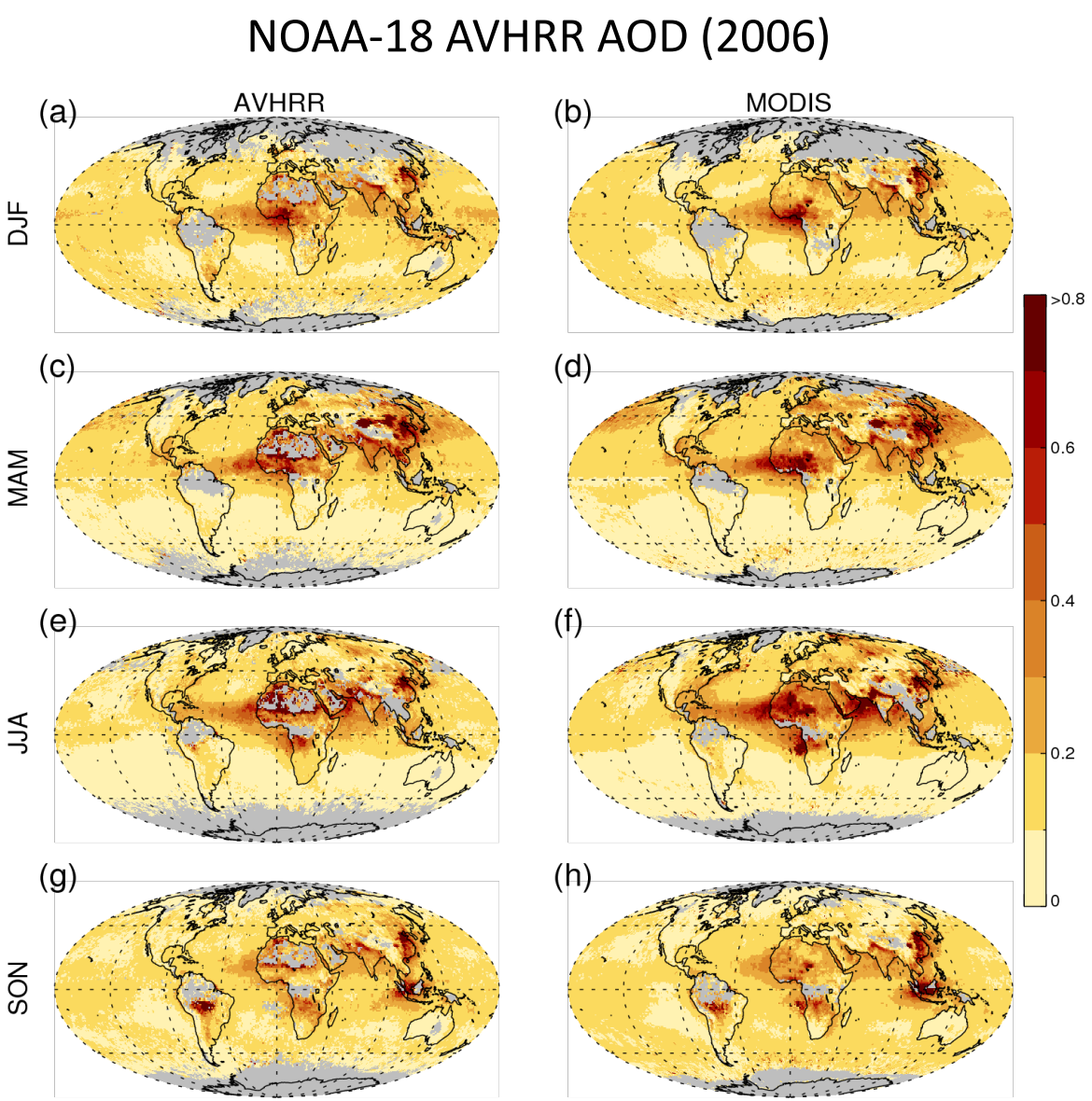


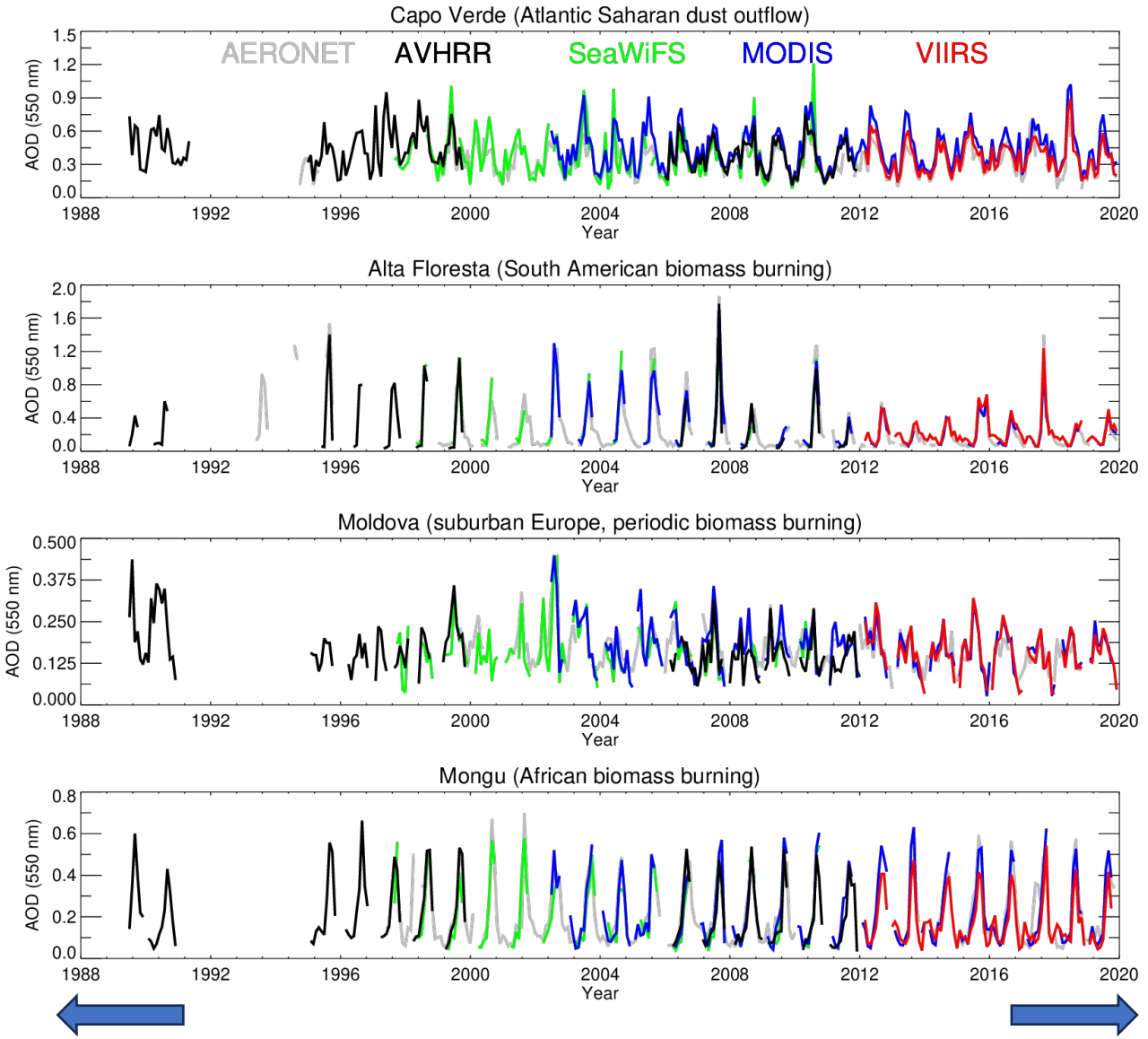
# Summary

- VIIRS Version 2 Deep Blue aerosol products are now operational and available at LAADS DAAC and Earthdata (https://earthdata.nasa.gov).
- The V2 AOD is much improved compared to V1 particularly over high elevation regions and bright surfaces, and for fine-mode aerosols.
- The cross-calibration enables the creation of consistent aerosol data records using the series of VIIRS as well as the twin MODIS.
- Consistent algorithm will be used for MODIS Collection 7 reprocessing and GEO data records.
- New aerosol layer height and aerosol above cloud products will be added in the later versions.
- 40+ years of AVHRR aerosol data records will be created in the future.

# Backup slides

# Historical AVHRR AOD



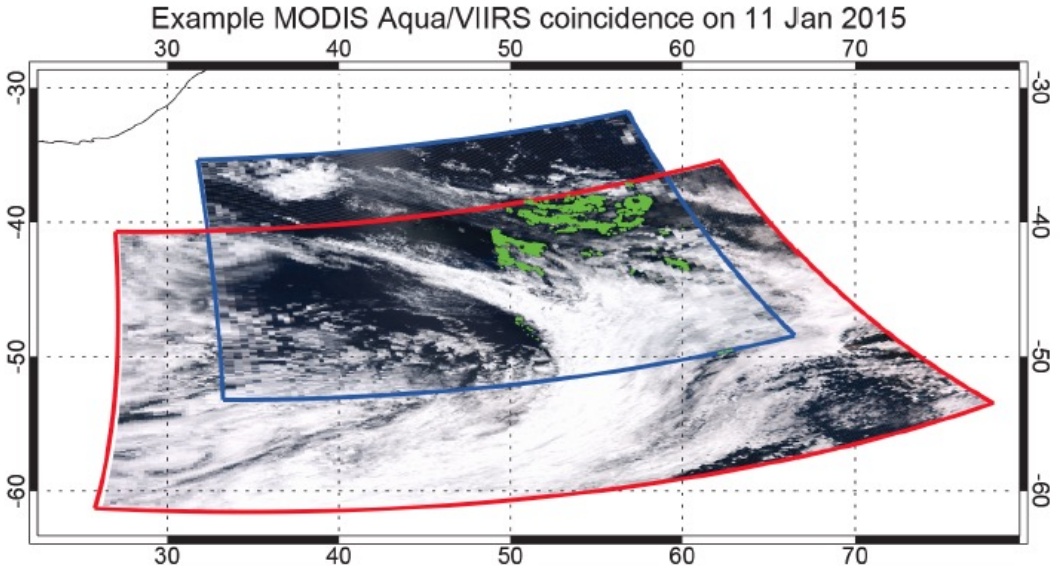



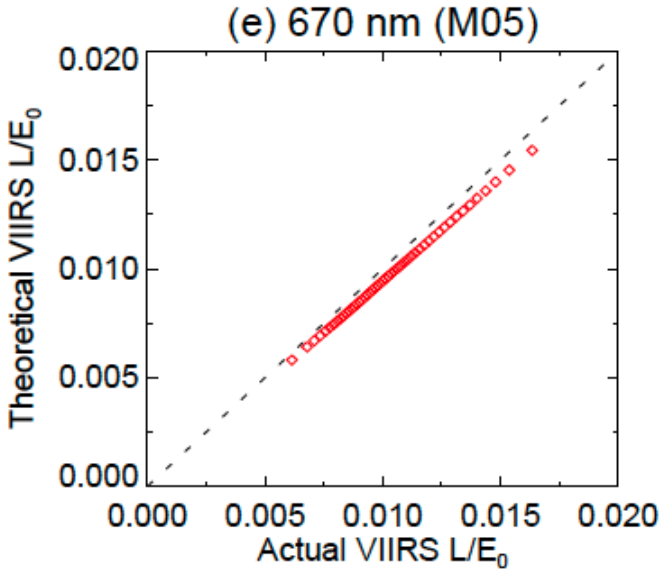

Hsu et al. (2017) and Sayer et al. (2017)

1979

Present

# Cross-calibration of NOAA-20 VIIRS against SNPP VIIRS




Sayer et al. (2017)

| Calibration gain factor for N20 | 412 nm | 443 nm | 490 nm | 550 nm | 670 nm | 870 nm | 1240 nm | 1610 nm | 2250 nm |
|---|---|---|---|---|---|---|---|---|---|
| Dome-C | 1.059 | 1.070 | 1.052 | 1.069 | 1.054 | 1.052 | 1.026 | 1.036 | 1.008 |
| Meyer et al. (2020) over clouds | | | | | 1.053 | 1.041 | 1.030 | 1.041 | 1.021 |

- Cross-calibration of SNPP VIIRS against Aqua MODIS over ocean (no cross-calibration for N20 VIIRS)
- Similar approach is used to match N20 VIIRS against SNPP using the matchup data generated by A-SIPS over Dome-C cal/val site (Aqua MODIS serves as bridge between SNPP and N20).
- This ensures minimal algorithm modifications for N20 VIIRS data processing.

# SNPP VIIRS Version 2 vs. Version 1 AOD (2012-2020)

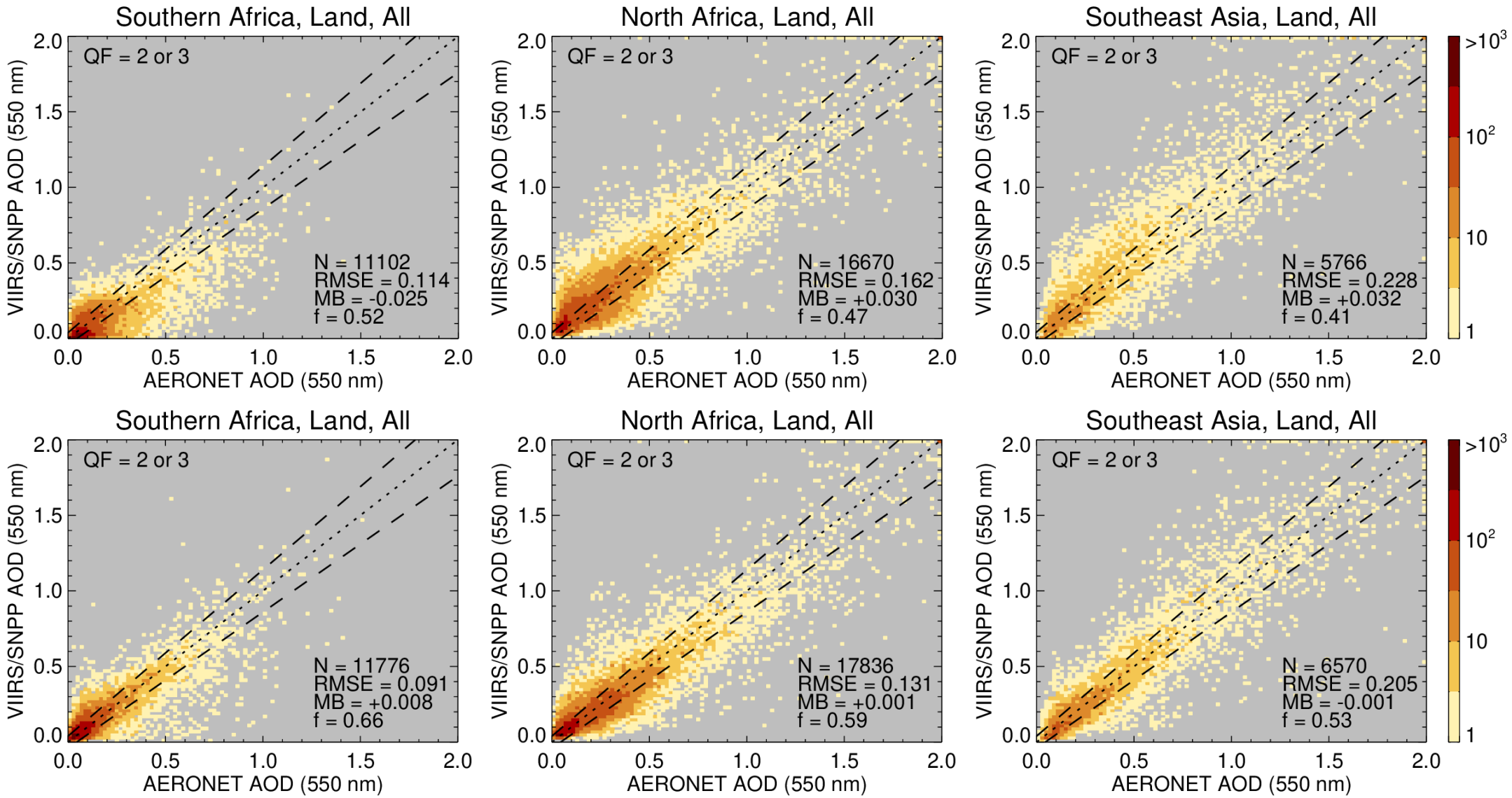
Version 1

Version 2

High elevation region

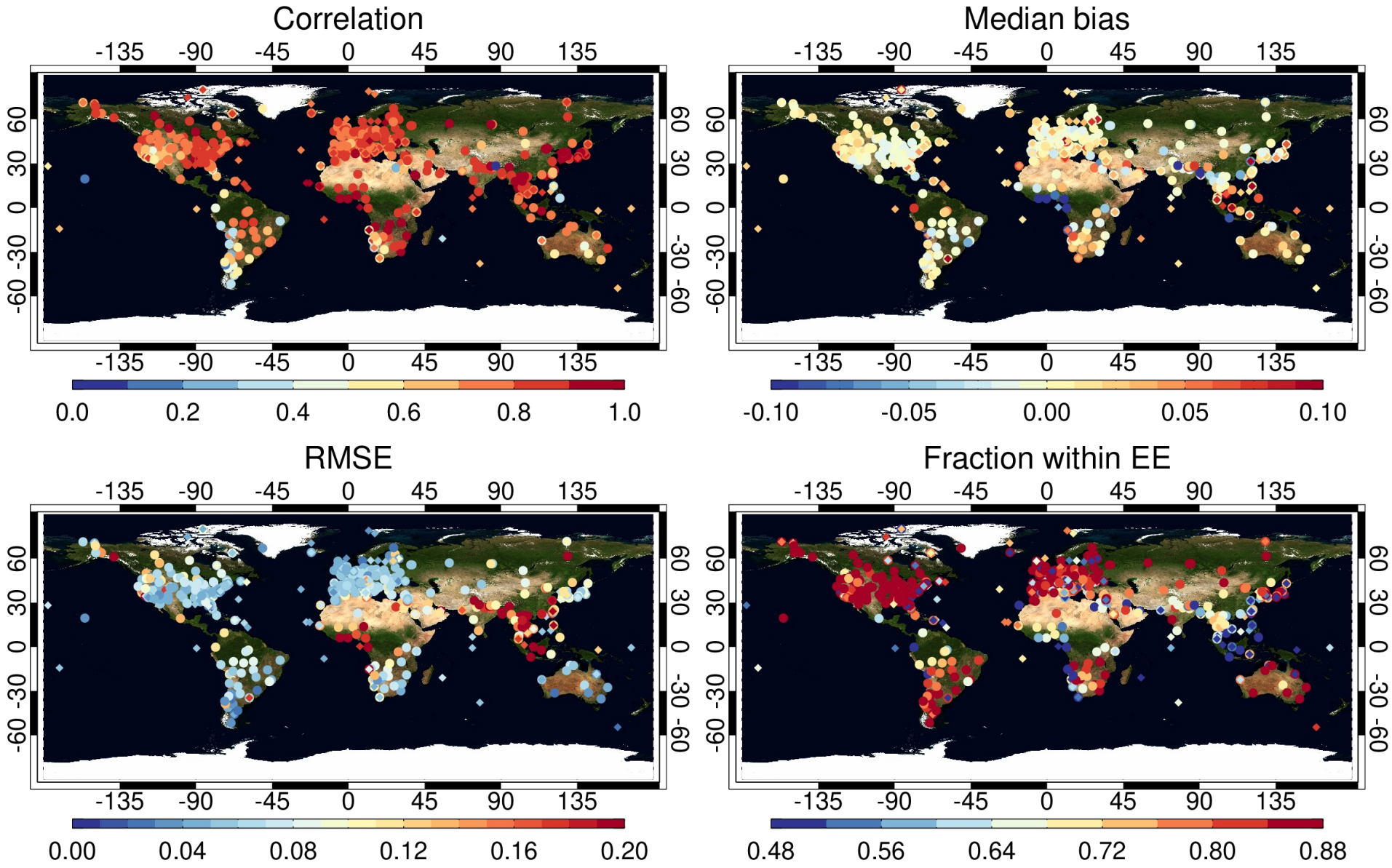
Bright surfaces

Aerosol model

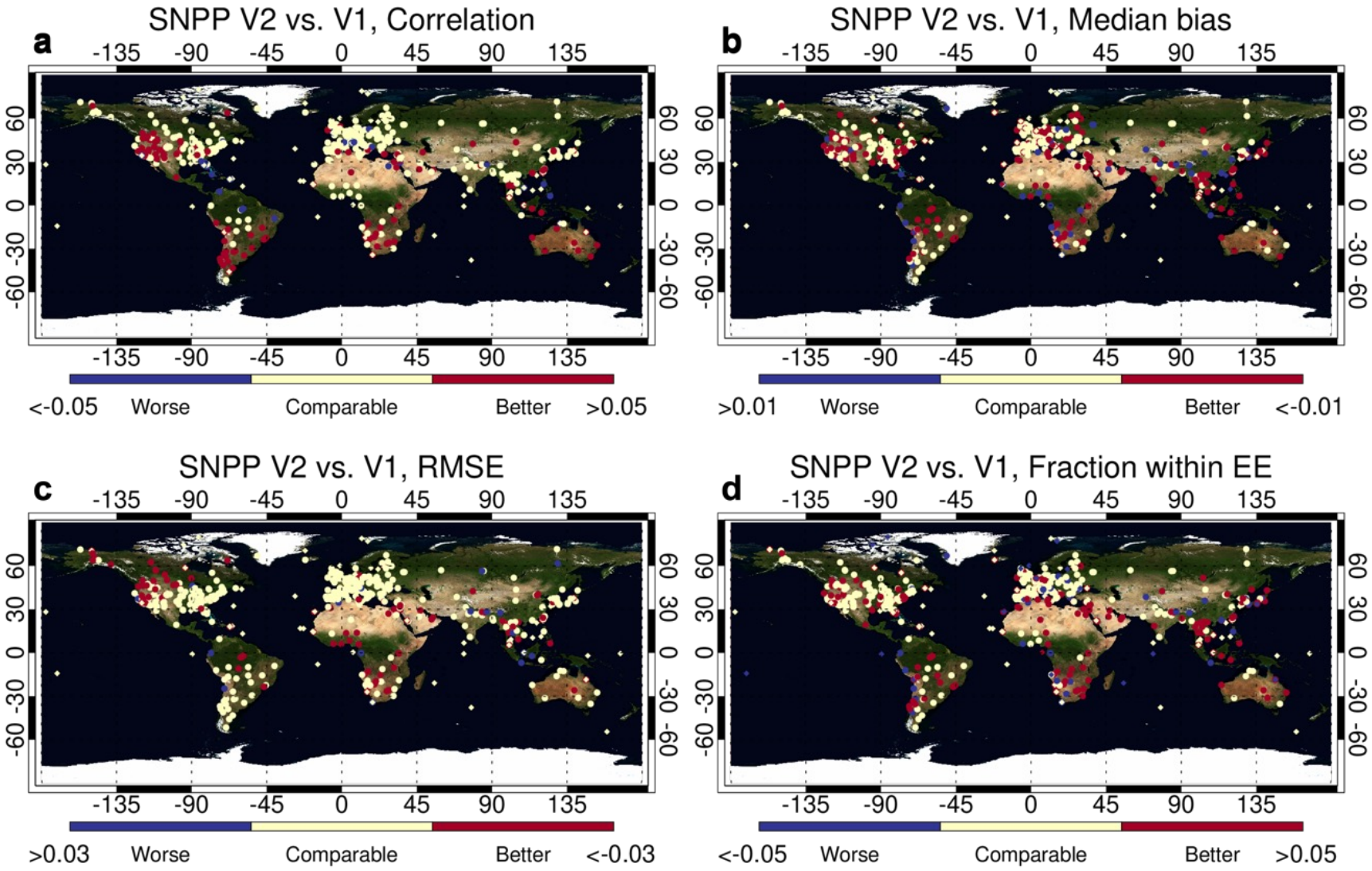



Expected error (EE) = ±(0.04+10%) over land

# SNPP VIIRS Version 2 (2012-2020)



# SNPP VIIRS Version 2 vs. Version 1 AOD (2012-2020)



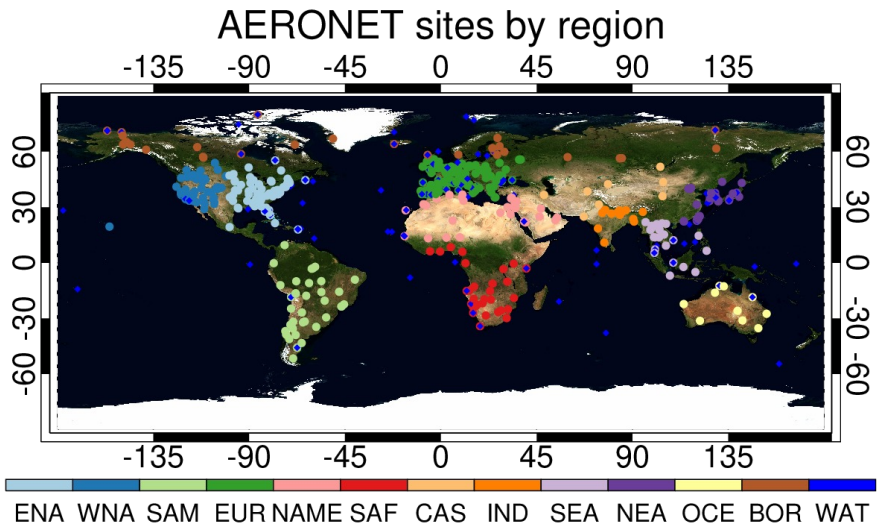

- Over land, V2 statistics are better at 22% (RMSE)-46% (MB) of sites.
- Over ocean, V2 statistics are generally comparable to V1 except for $f_{EE}$ due to a slight positive offset in V2. This has implications for sensor calibration.

# AOD Validation against AERONET (SNPP VIIRS, 2012-2020)

| Region name | Correlation | | MB | | RMSE | | $f_{EE}$ | | $f_G$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | V1 | V2 | V1 | V2 | V1 | V2 | V1 | V2 | V1 | V2 |
| Global | 0.81 | 0.85 | 0.004 | 0.0003 | 0.120 | 0.093 | 0.77 | 0.82 | 0.48 | 0.54 |
| ENA | 0.79 | 0.83 | 0.009 | -0.003 | 0.080 | 0.064 | 0.83 | 0.88 | 0.55 | 0.64 |
| WNA | 0.55 | 0.70 | -0.005 | 0.004 | 0.129 | 0.076 | 0.82 | 0.85 | 0.56 | 0.62 |
| SAM | 0.58 | 0.64 | -0.009 | -0.002 | 0.076 | 0.065 | 0.76 | 0.81 | 0.52 | 0.56 |
| EUR | 0.81 | 0.81 | 0.005 | -0.001 | 0.064 | 0.058 | 0.84 | 0.86 | 0.53 | 0.55 |
| NAME | 0.78 | 0.83 | 0.046 | 0.011 | 0.161 | 0.128 | 0.55 | 0.70 | 0.26 | 0.36 |
| SAF | 0.72 | 0.83 | -0.026 | 0.005 | 0.129 | 0.101 | 0.62 | 0.76 | 0.35 | 0.45 |
| CAS | 0.90 | 0.90 | -0.009 | -0.007 | 0.137 | 0.128 | 0.76 | 0.77 | 0.43 | 0.43 |
| IND | 0.90 | 0.91 | -0.04 | -0.003 | 0.186 | 0.177 | 0.67 | 0.72 | 0.32 | 0.37 |
| SEA | 0.86 | 0.90 | 0.032 | -0.001 | 0.228 | 0.206 | 0.53 | 0.66 | 0.25 | 0.33 |
| NEA | 0.88 | 0.91 | 0.022 | -0.006 | 0.151 | 0.120 | 0.69 | 0.78 | 0.36 | 0.43 |
| OCE | 0.41 | 0.63 | 0.007 | 0.006 | 0.087 | 0.050 | 0.74 | 0.86 | 0.51 | 0.64 |
| BOR | 0.82 | 0.79 | 0.007 | 0.0001 | 0.182 | 0.103 | 0.88 | 0.89 | 0.63 | 0.67 |
| WAT | 0.87 | 0.87 | 0.015 | 0.019 | 0.067 | 0.07 | 0.69 | 0.66 | 0.56 | 0.53 |

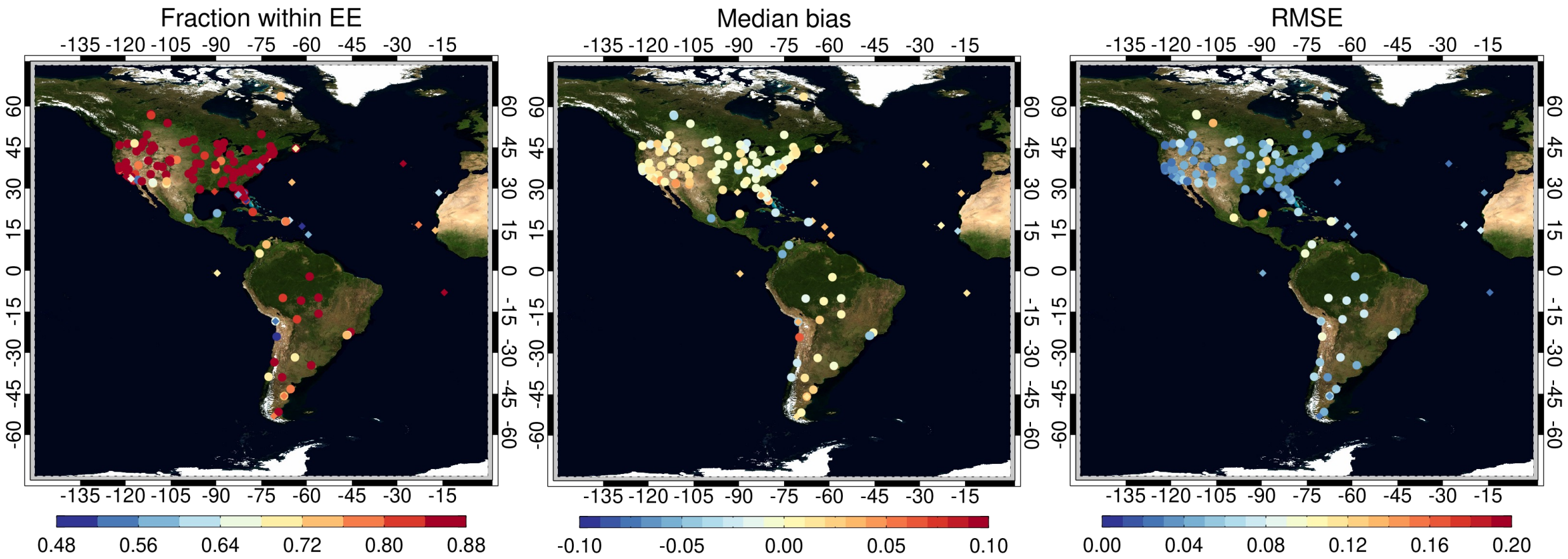
Better Comparable Worse

$f_{EE}$ = ±(0.05+15%) over land
±(0.03+10%) over water
$f_G$ = 0.03 or 10%



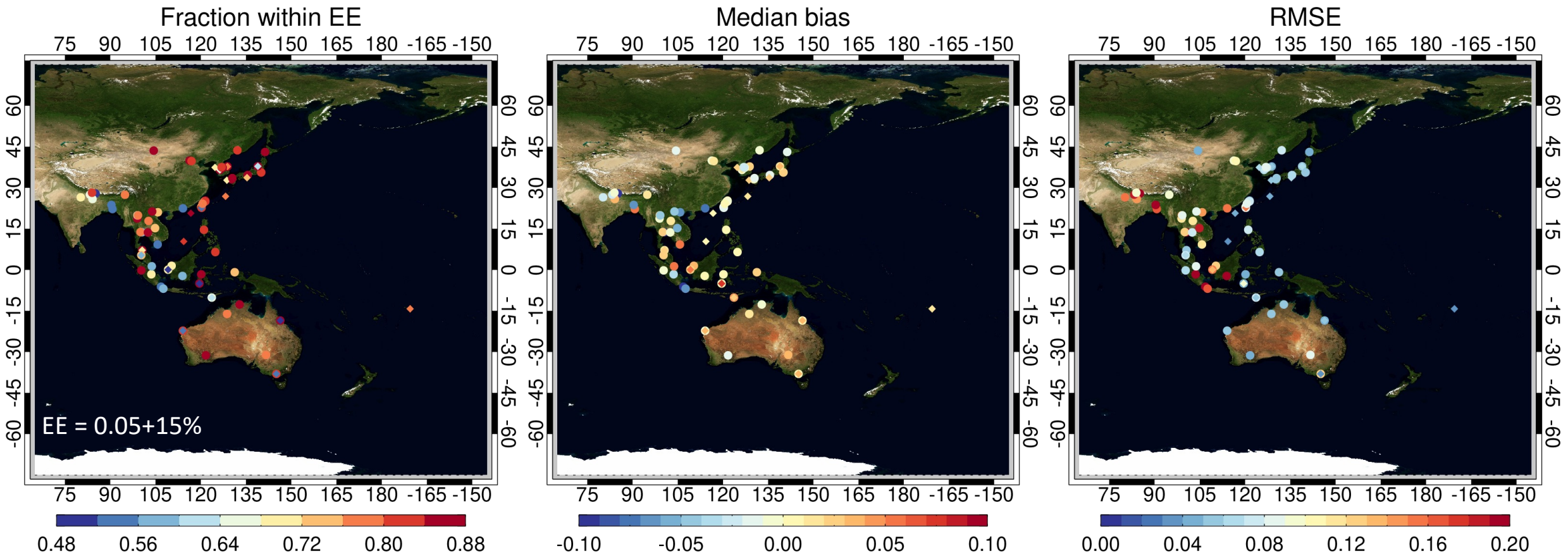

- V2 AOD is comparable or better than V1
- NAME/SAF: all statistics are improved
- WNA/BOR: RMSE decreased over 0.05
- NAME/SAF/SEA/OCE: $f_{EE}$ increased over 10%
- Slight degradation over water (V2 AOD is slightly higher than V1)

# Comparisons of GEO DB AOD against AERONET (ABI/GOES-16)




- Modified VIIRS V2 algorithm has been applied to GEO sensors (G16/17 ABI and H8 AHI)
- Validation statistics of GEO AOD are comparable with VIIRS V2 AOD except for extreme observation angles
- One year of GEO demonstration data sets (May 2019 – April 2020) will be released in mid-2023

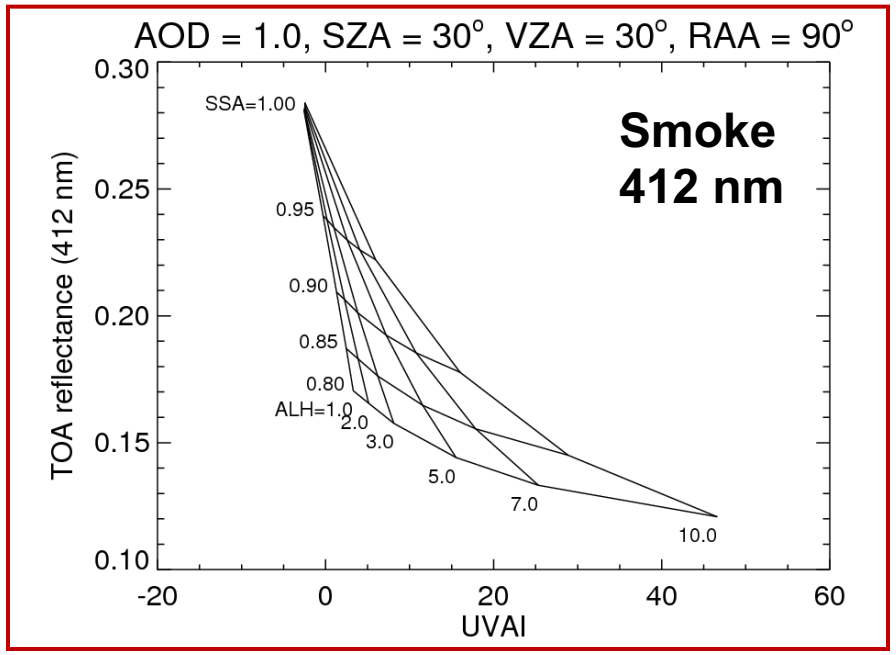
# Comparisons of GEO DB AOD against AERONET (AHI/Himawari-8)

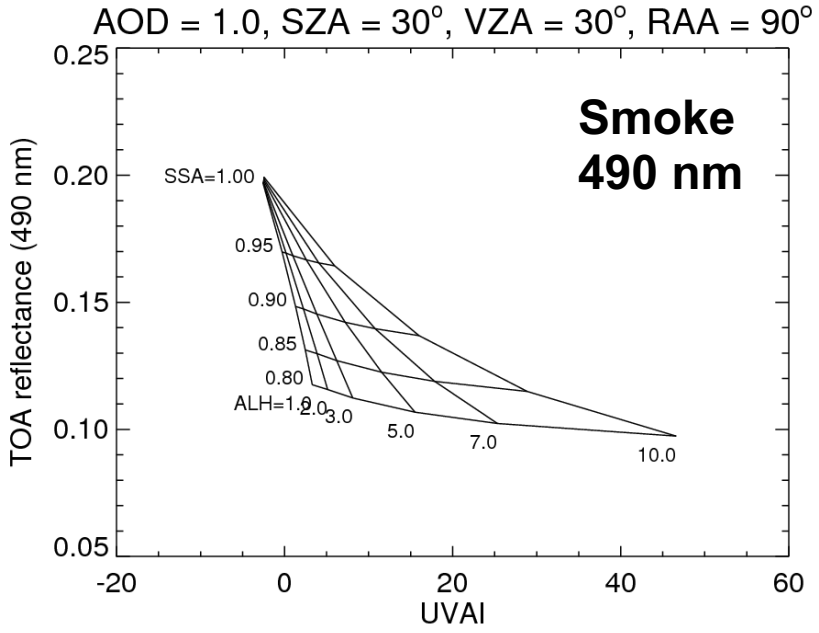



- Modified VIIRS V2 algorithm has been applied to GEO sensors (G16/17 ABI and H8 AHI)
- Validation statistics of GEO AOD are comparable with VIIRS V2 AOD except for extreme observation angles
- One year of GEO demonstration data sets (May 2019 – April 2020) will be released in mid-2023

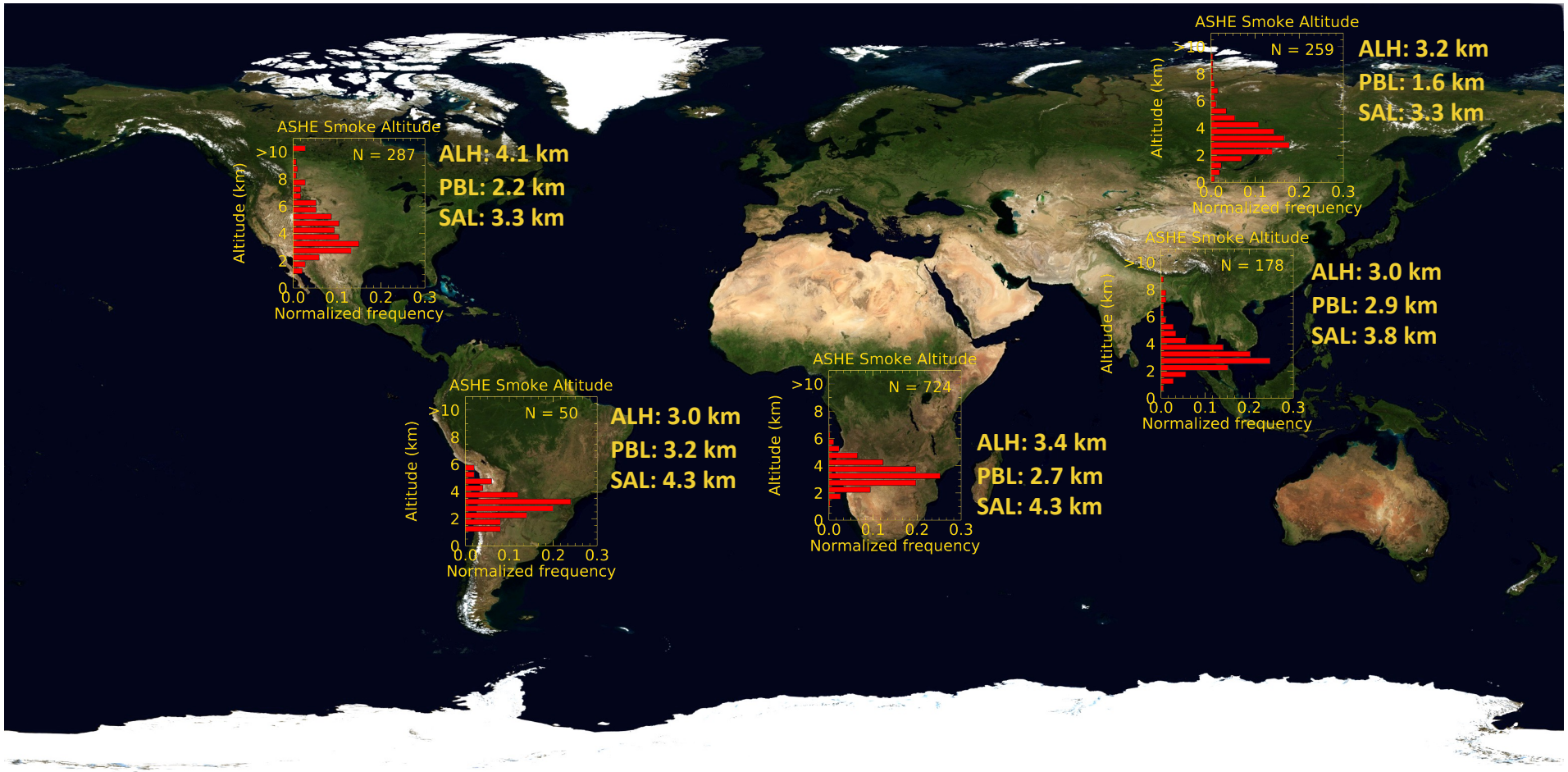
# Transition to Operational Environment (Retrieval without CALIOP)

- Retrieves aerosol layer height and SSA using UVAI and 412 nm TOA reflectance
- AOD and surface reflectance constrained by VIIRS Deep Blue product
- AOD from 490 nm band (less sensitive to ALH)
- Aerosol optical model:
  - Bimodal lognormal distribution
  - 550 nm fine-mode AOD fraction
  - Absorption AE
  - Smoke and nonspherical dust



# Smoke Altitude over Major Source Regions




| 2012-2017 | N. America | S. America | S. Africa | SE Asia | Siberia |
|---|---|---|---|---|---|
| Number of smoke pixels | 598483 | 85077 | 1563502 | 233594 | 948922 |
| Percentage above PBL | 79% | 25% | 37% | 36% | 72% |
| Percentage above SAL | 38% | 9% | 9% | 8% | 27% |