Science, Service, Stewardship

Overview of the FENGSHA dust emission scheme used within the NOAA GEFS-Aerosol, NAQFC, RRFS and UFS-Aerosols, the Unified Forecast System's global aerosol component

Barry Baker, on behalf of the UFS R2O Atmospheric Composition, NAQFC and RRFS-SD teams

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Office of Oceanic and Atmospheric Research (OAR)
Air Resources Laboratory (ARL)

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Science, Service, Stewardship

Outline:

- History of the FENGSHA dust emission scheme
- Description
- Implementation into the UFS
  - Development of AI based inputs
  - UFS
  - GEFSv13 Prototype

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FENGSHA dust emission model

Developed at ARL by Daniel Tong and Dale Gillette for NAQFC/CMAQ (2012)

Adapted for GEFS-Aerosol and inline code (2020)

NAQFC Updated for inline process and bring advancements from GEFS-Aerosol (2021)

NOAA/NASA GOCART

- UFS-Aerosols
- Online-CMAQ
- RRFS-SD
- UFS-Chem / CATChem

$$F = \alpha A S \frac{\rho_a}{g} u_*^3 \left(1 - \frac{u_{*t}^2}{u_*^2}\right)$$

Flux of Dust (F)

Vertical to Horizontal Flux Ratio (α)

Areal Coverage (A)

Soil Erosion Potential and Source (S)

Surface Friction Velocity (u_*)

Threshold Velocity (u_{*t})

Horizontal Flux (Q)

FENGSHA

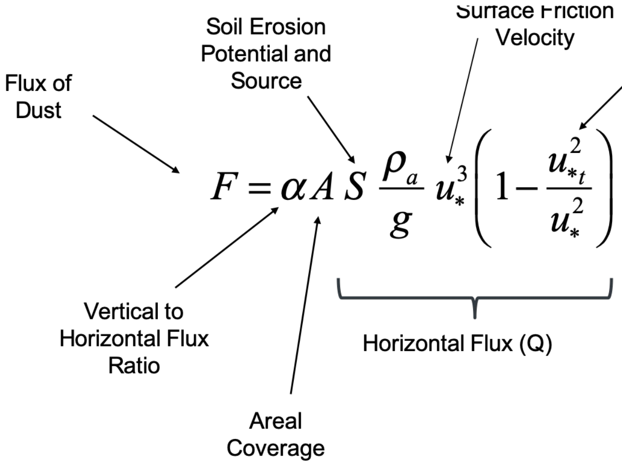
Current Operational Models: NAQFC, GEFS-Aerosol

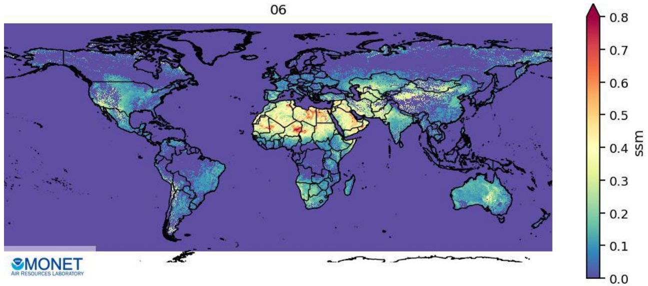
Research Grade Models: HYSPLIT, RAP-CHEM, UFS-Aerosol, RRFS-SD, RRFS-CMAQ

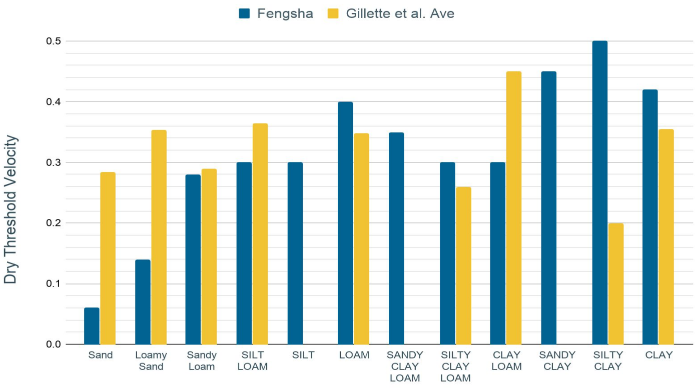
Science, Service, Stewardship

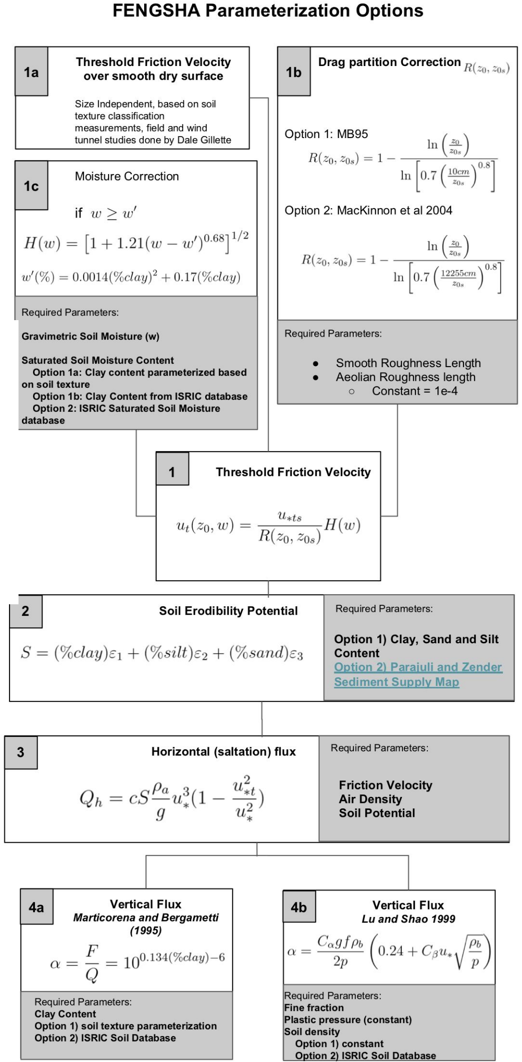
Description of the FENGSHA scheme in the current NOAA operational Models: GEFS-Aerosols and NAQFC

Fengsha Flux Equation





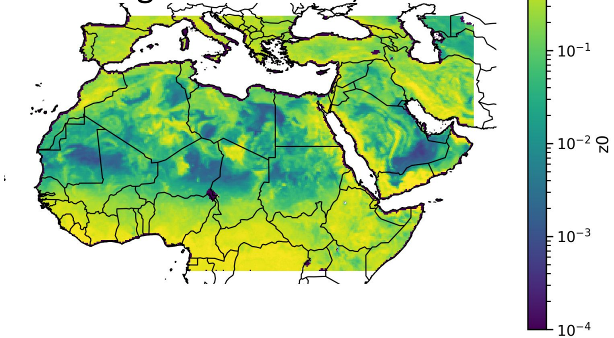




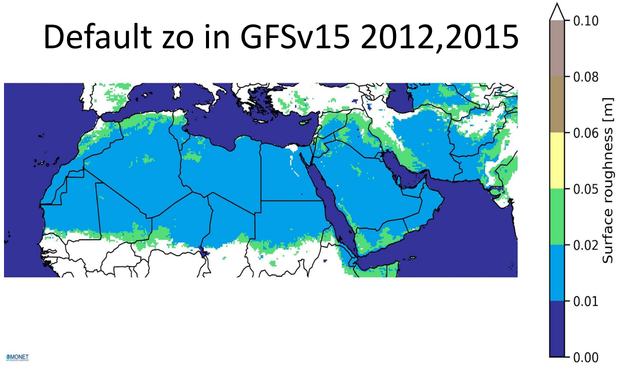
Surface Roughness

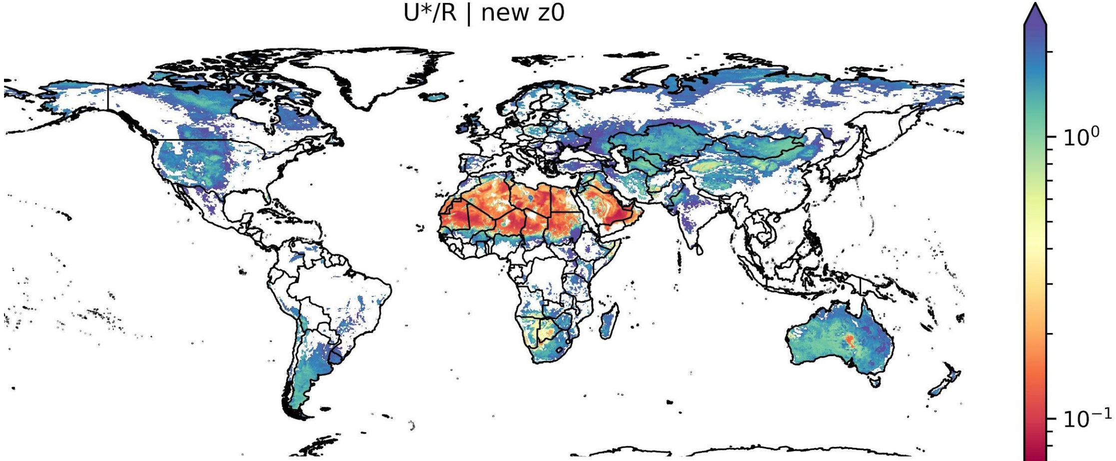
Surface Roughness is an issue. Dust models are very sensitive to ustar and therefore z0.

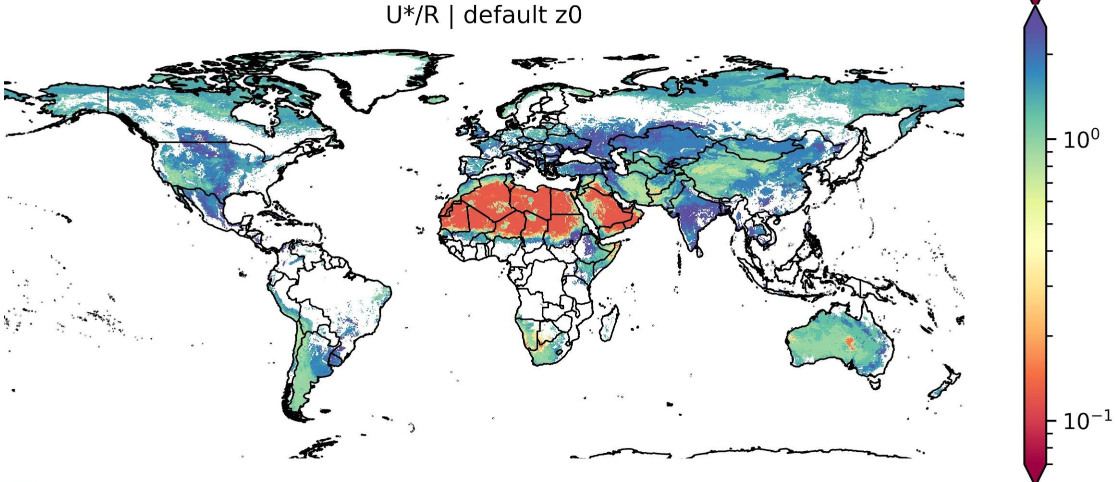
Priget et al. 2012,2015



Default zo in GFSv15 2012,2015





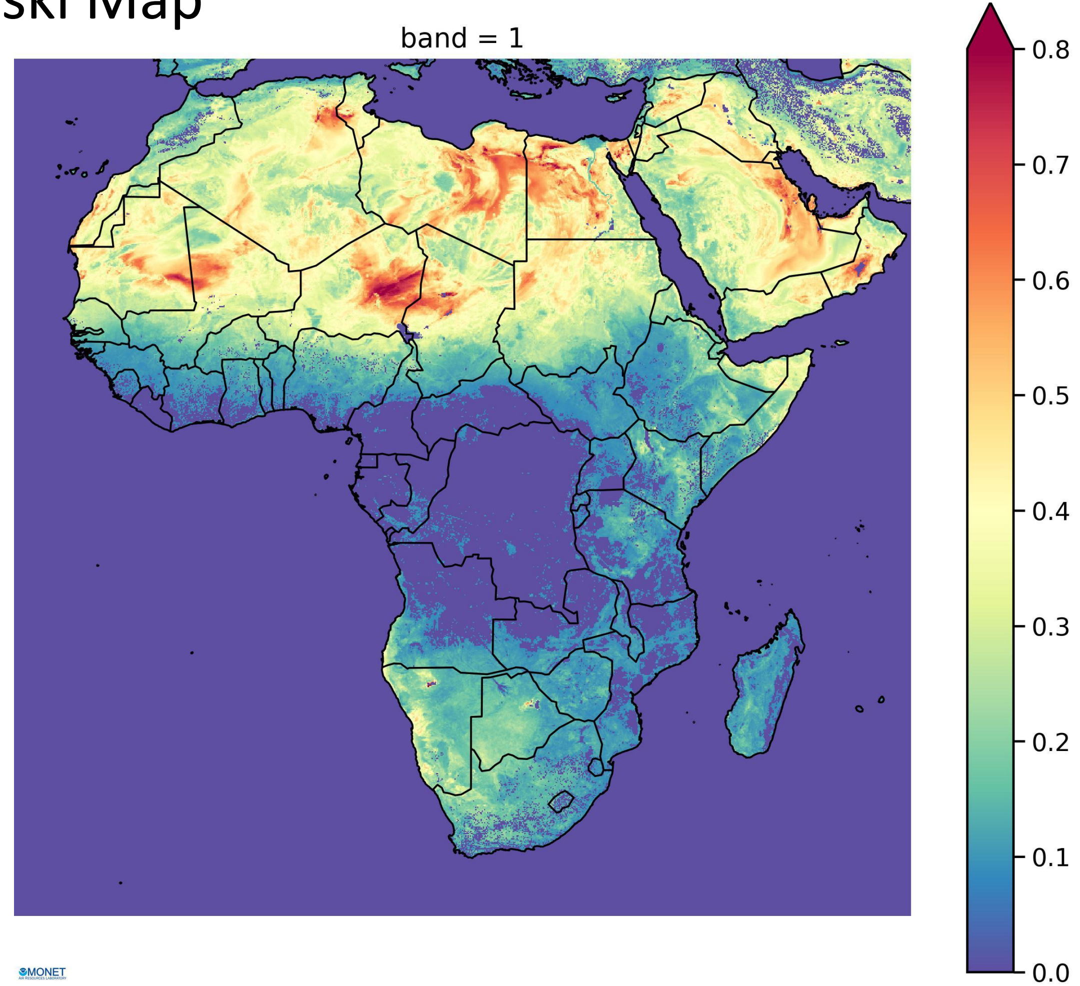


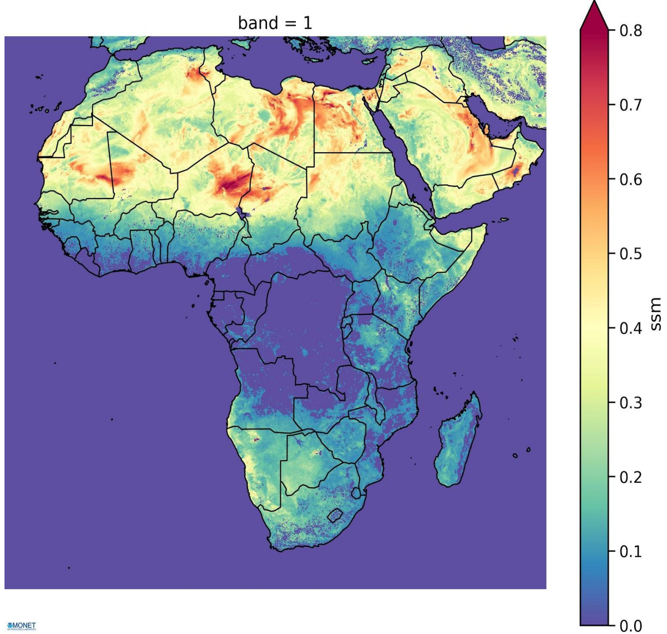
Introducing the Baker-Schepanski Map

The new method is developed from the ideas of Chappell and Webb 2016.

- It uses the normalized albedo (or rather 1-albedo) to better describe the lateral cover heterogeneity
- The albedo was taken from a 3 year climatology of the MCD43A3 Modis BRDF Albedo.
- Then 1/(normalized albedo) masked with snow cover climatology
- Renormalize

- High contrast between very active dust source regions and surrounding areas
- Higher coastal values



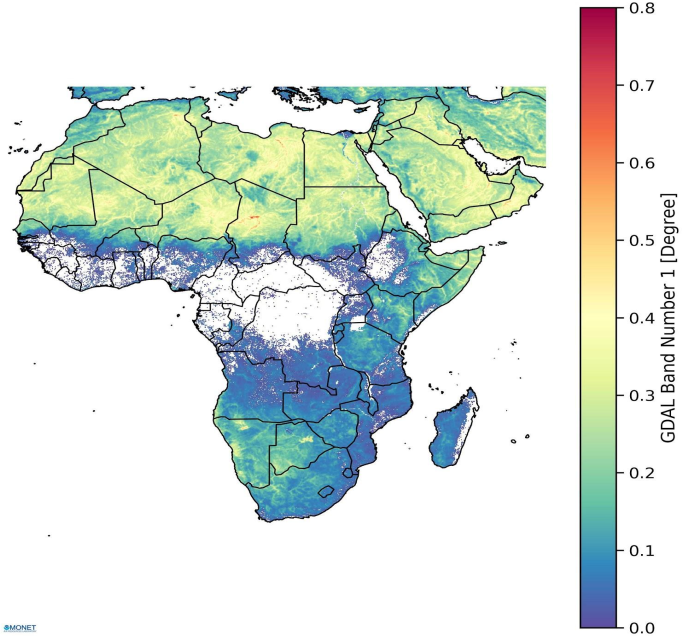


Baker-Schepanski Map

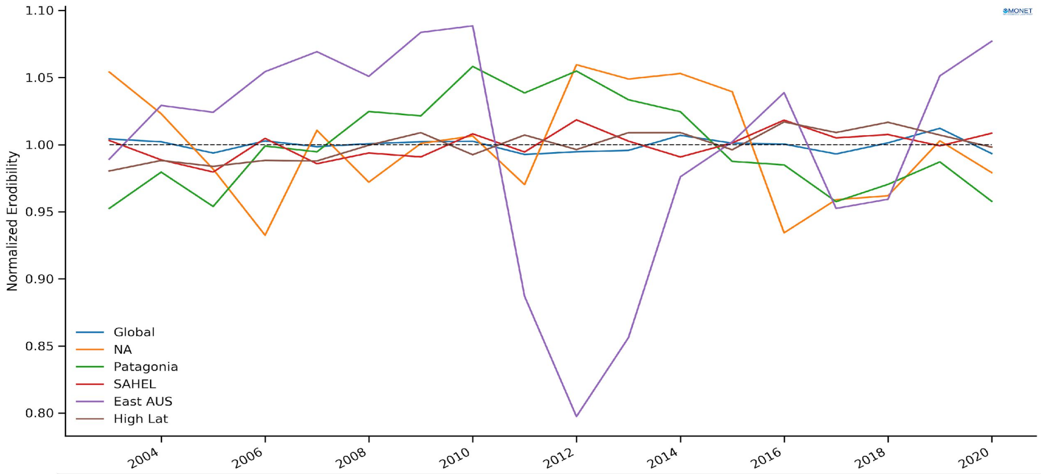
- High contrast between very active dust source regions and surrounding areas
- Higher coastal values
- Seasonally changing
- Accounts for changes in lateral cover, i.e. vegetation, flooding, snow, etc...

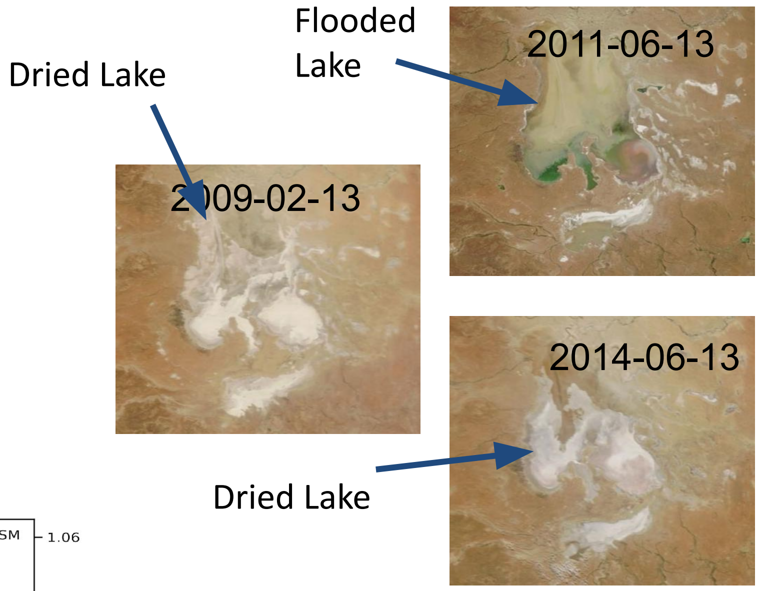
Parajuli-Zender Map

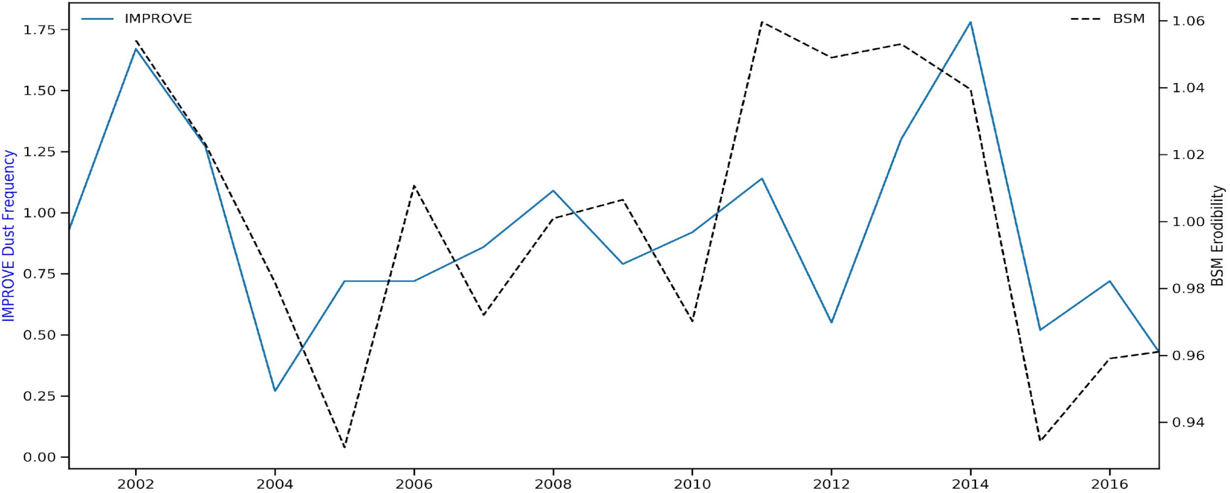
- Low contrast between high dust sources and low dust sources
- Static (does not change seasonally)
- Washes out distinct source regions
- Low values in coastal areas



Dust Detection and Erodibility tracking

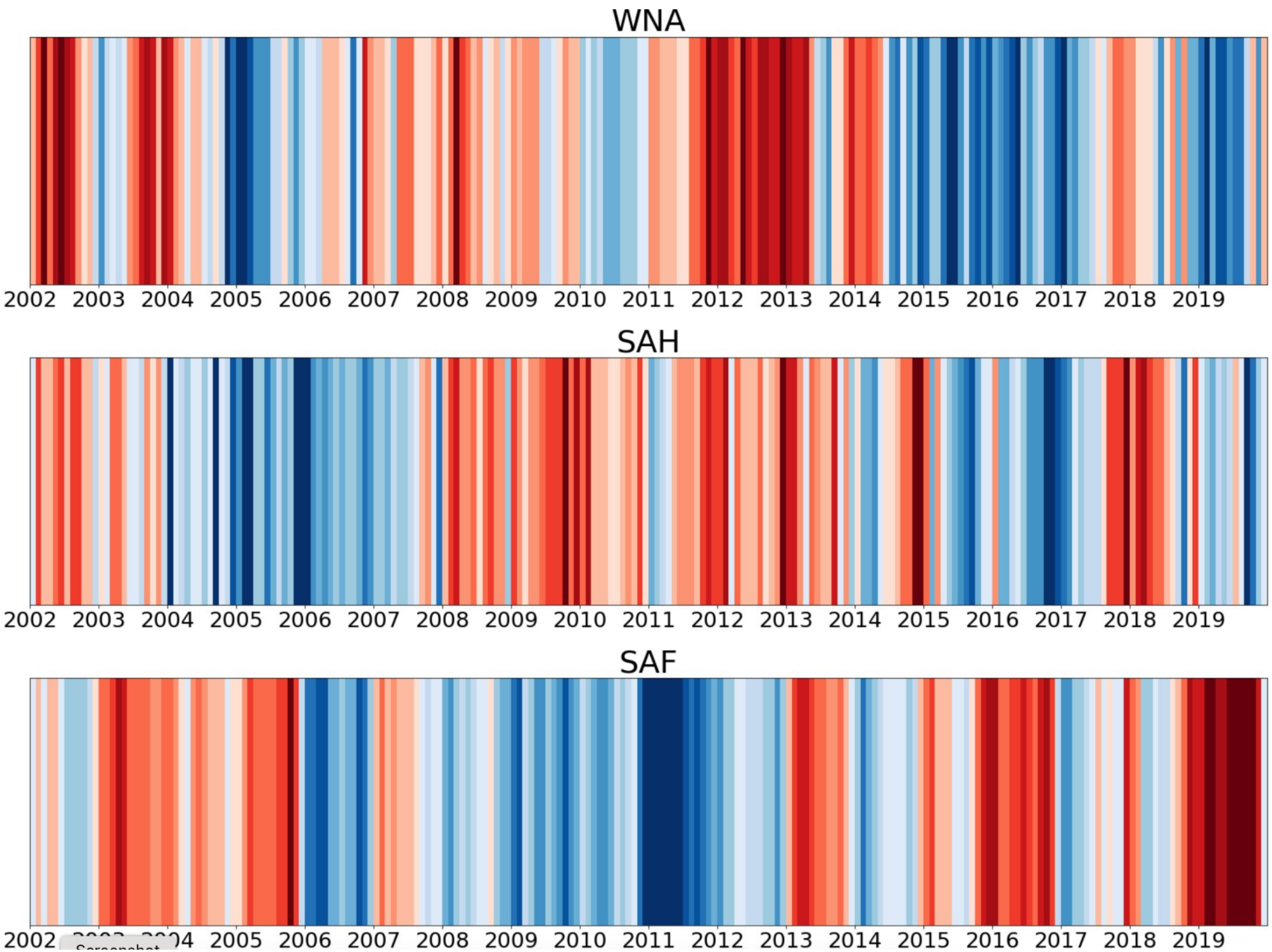




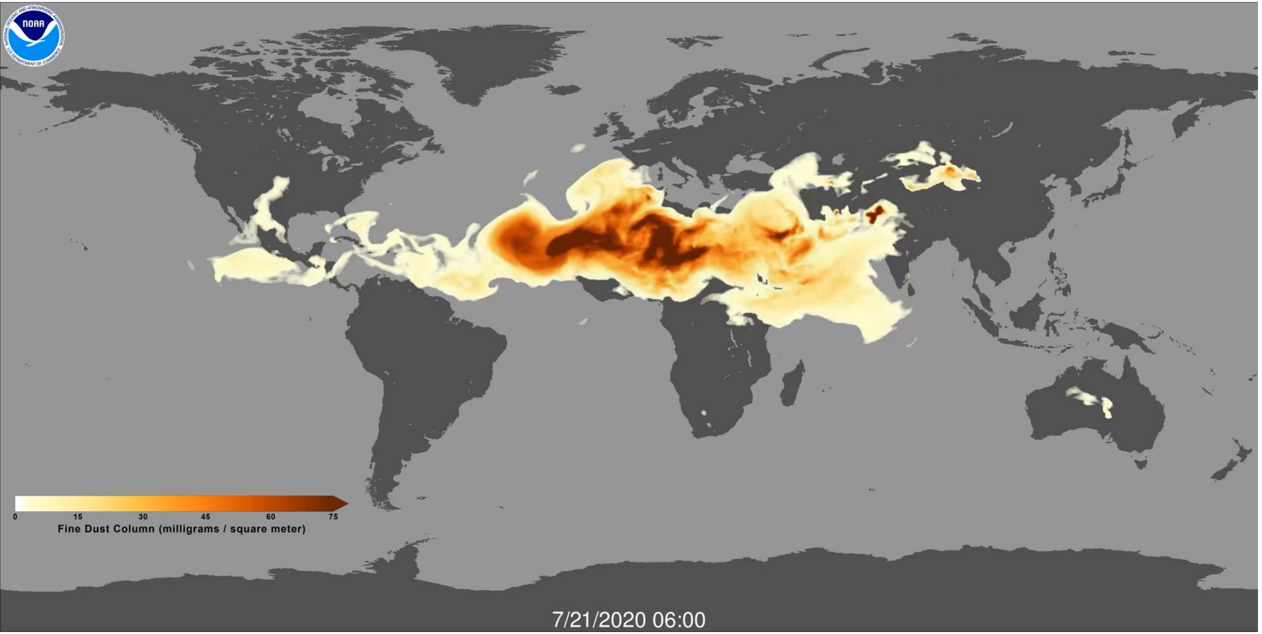


Using the erodibility as a proximity for the dust record it can be shown that it follows very closely with dust records from surface monitors. In this case versus the IMPROVE network.

We can also look at this differently and view it as the erodibility through time using the climate warming stripes. This allows a quick visual query of how the erodibility changes over time. Here hotter colors are more erodible versus blue which is less erodible versus a climatological mean over the region.



Global Ensemble Forecast System (GEFS)-Aerosol

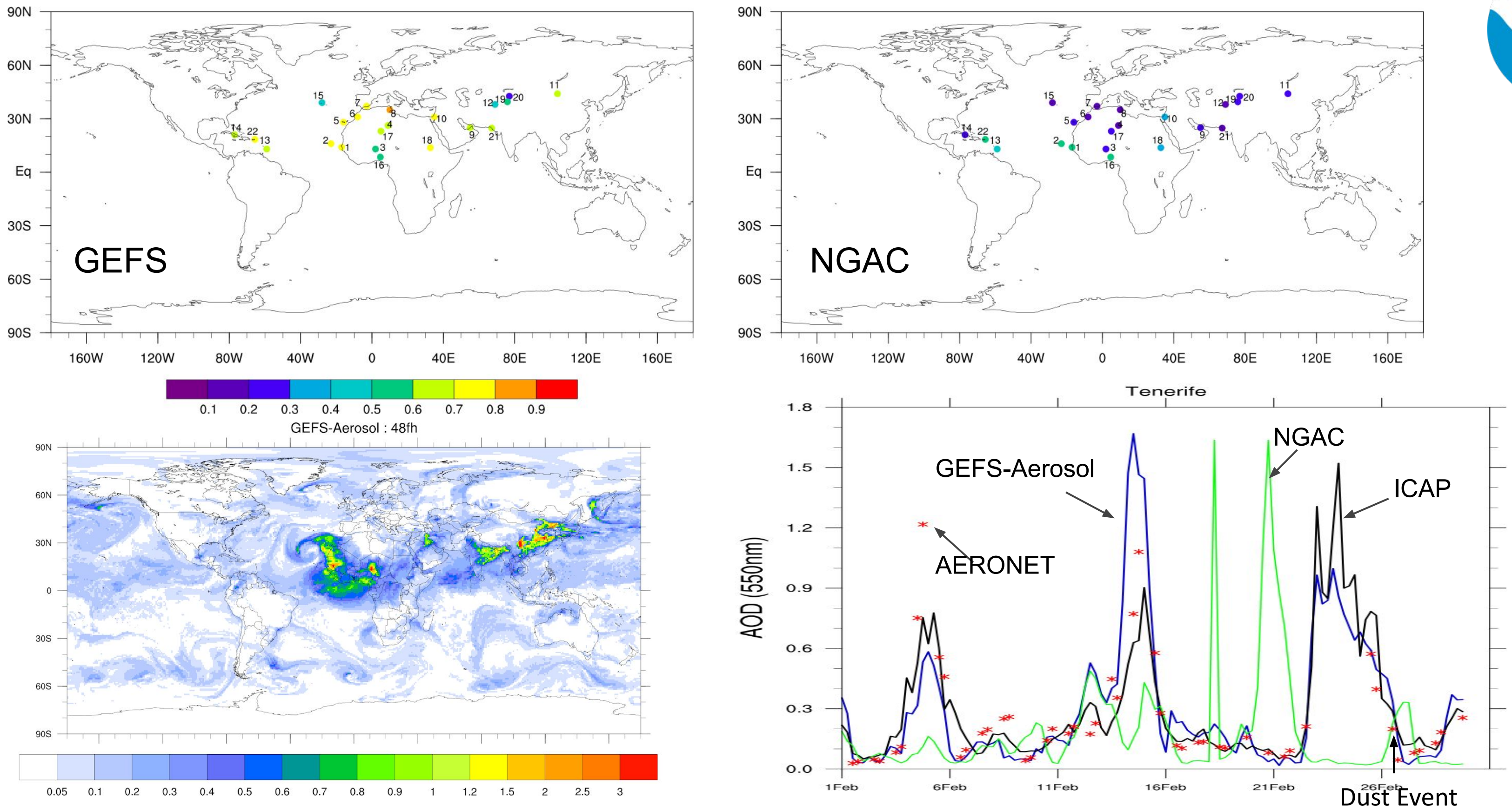


Provides PM BCs for NAQFC

- Inline aerosol representation based on WRF-Chem version of NASA's GOCART
- GEFS-Aerosol member developed by NOAA's GSL, ARL, CSL, EMC, NESDIS.
- Implemented into operations in September 2020 – updated in Nov 2022
- Meteorology (based on GFSv15) at C384 (~25 km), 64 levels, to 120 hrs, 4x/day
- Sulfate, Organic Carbon, Black Carbon, Dust, Sea Salt
- Emissions: CEDS-2014 (SO2, PSO4, POC, PEC), GBBEPx biomass burning, FENGSHA dust, GEOS-5 sea salt, marine DMS

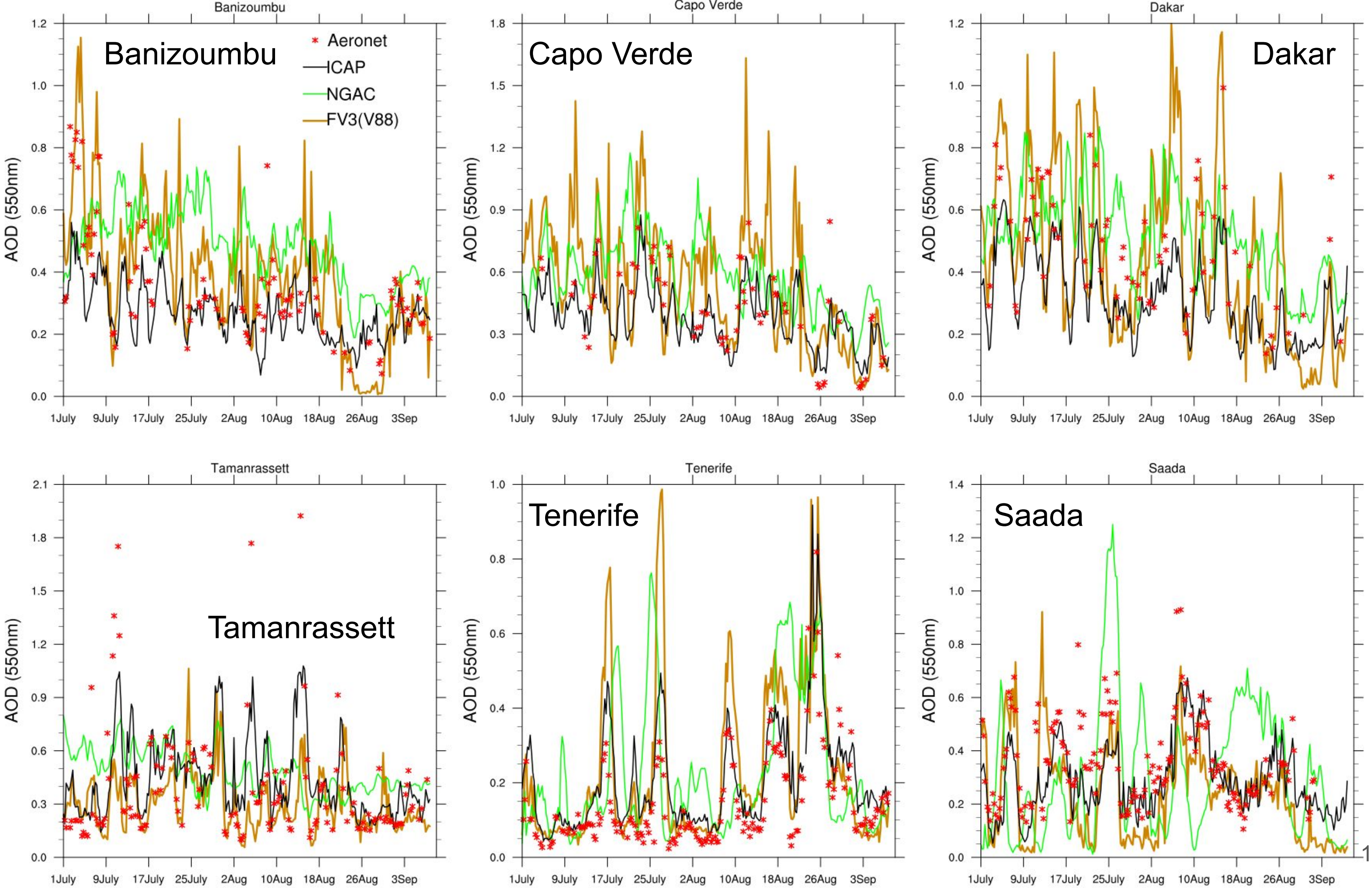
Please see Zhang et al. (2022) for more details
https://doi.org/10.5194/gmd-15-5337-2022

Global Ensemble Forecast System (GEFS)-Aerosol

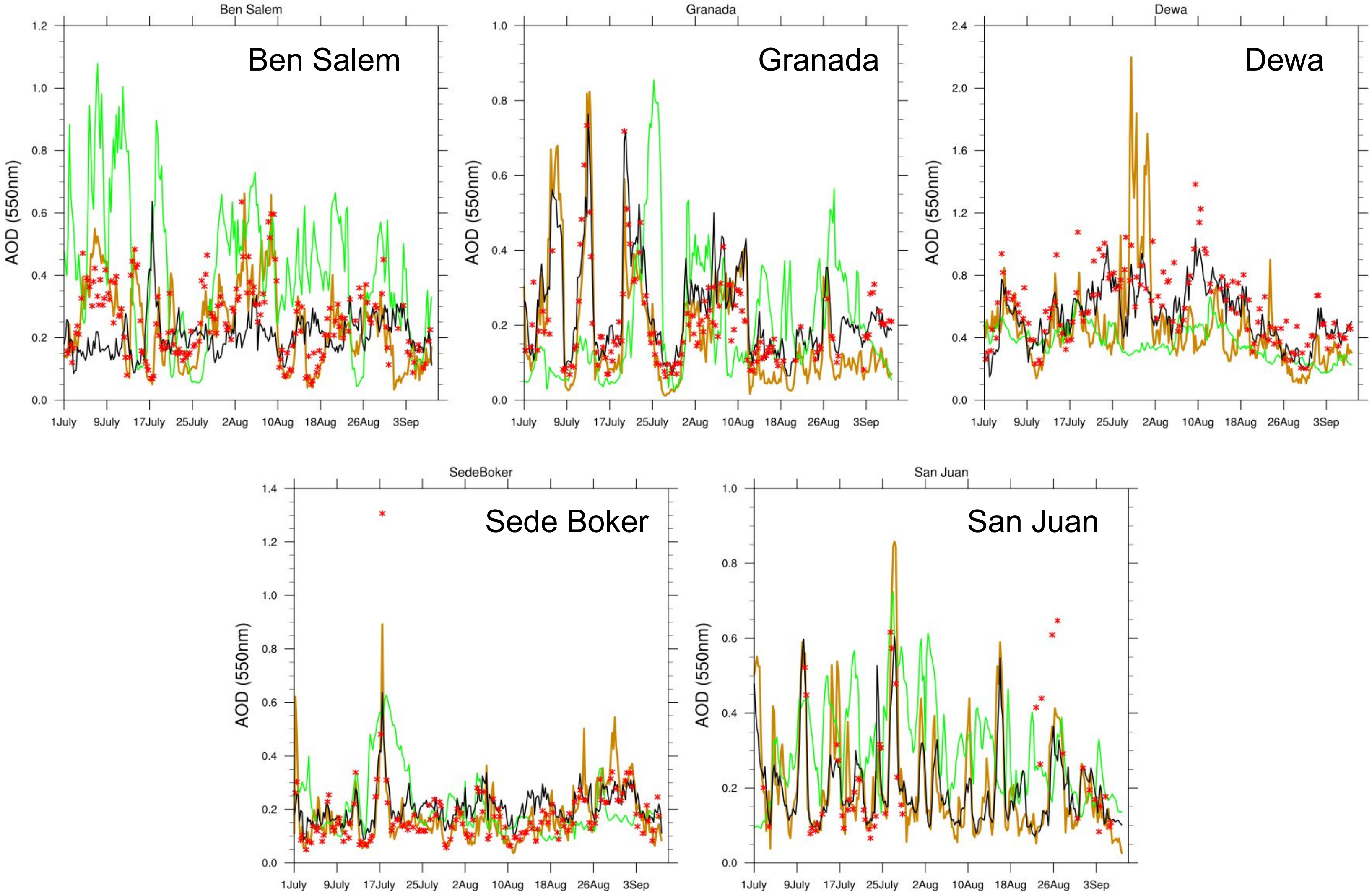


Stations: 1. Dakar ; 2. Cape Verde; 3. Banizoumbu; 4. Tamanrassett; 5. Tenerife; 6. Saada; 7. Granada; 8. Ben Salem; 9. Dewa; 10. SedeBoker; 11. Dalanzadgaad; 12. Dushanbe; 13. Ragged Point; 14. Camaguey; 15. ARM Graciosa; 16. Ilorin; 17. Zinder Airport; 18. Quena; 19. Kashi; 20. Issykul; 21. Karachi; 22. Cape San Juan

Comparison to AERONET Stations



Banizoumbu
Aeronet
ICAP
NGAC
FV3(V88)
Capo Verde
Dakar
Tamanrassett
Tenerife
Saada
AOD (550nm)
1July
9July
17July
25July
2Aug
10Aug
18Aug
26Aug
3Sep


Ben Salem
Granada
Dewa
Sede Boker
SedeBoker
San Juan
AOD (550nm)
1July
9July
17July
25July
2Aug
10Aug
18Aug
26Aug
3Sep

Science, Service, Stewardship

FENGSHA as implemented in the NASA GOCART2G, RRFS-SD, and UFS-CMAQ

Fengsha Flux Equation

$$F = \alpha A \frac{\rho_a}{g}\left(R u_*^3\right)\left(1 - \frac{u_{*t}^2}{u_*^2}\right)\left(1 + \frac{u_{*t}^2}{u_*^2}\right)$$

Area

Density

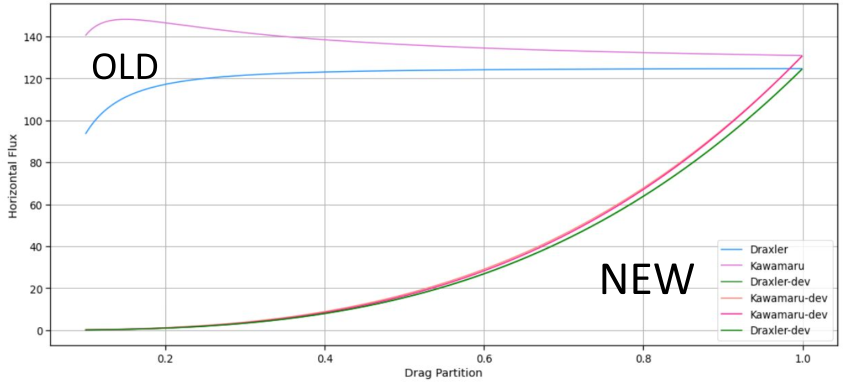
Friction Velocity

Threshold Velocity

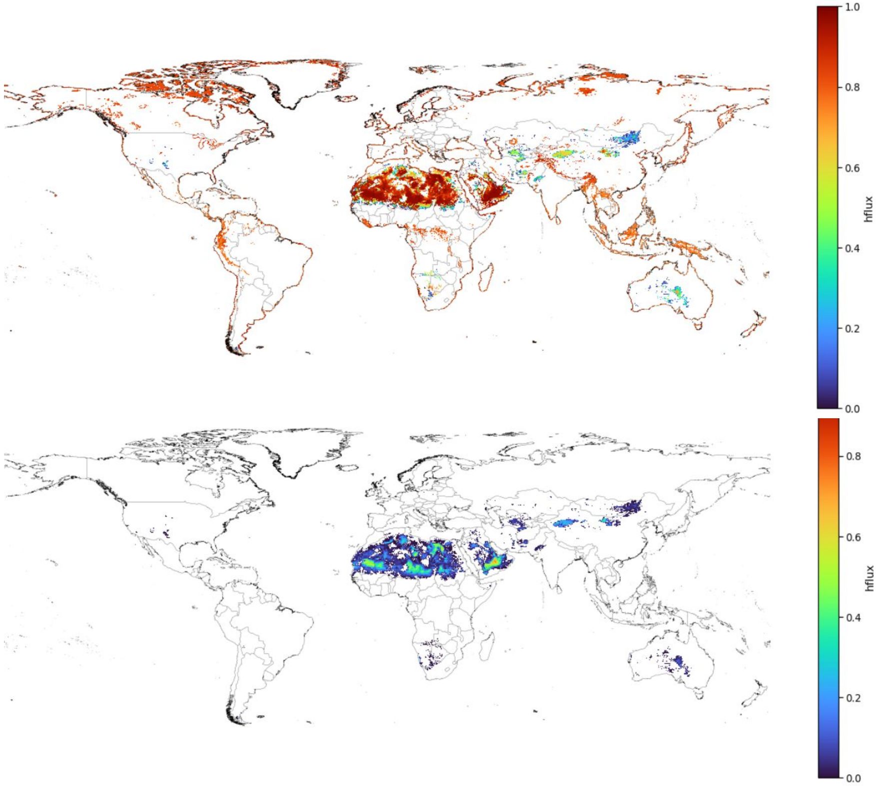
Vertical To Horizontal Flux Ratio

Gravity

Drag Partition



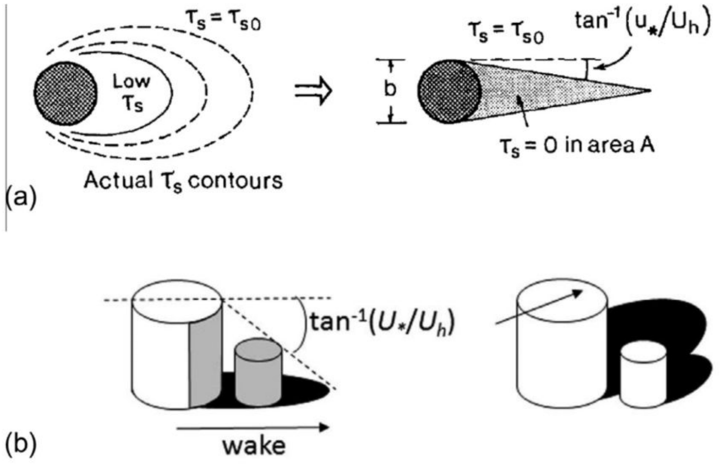
[Webb et al. 2020]

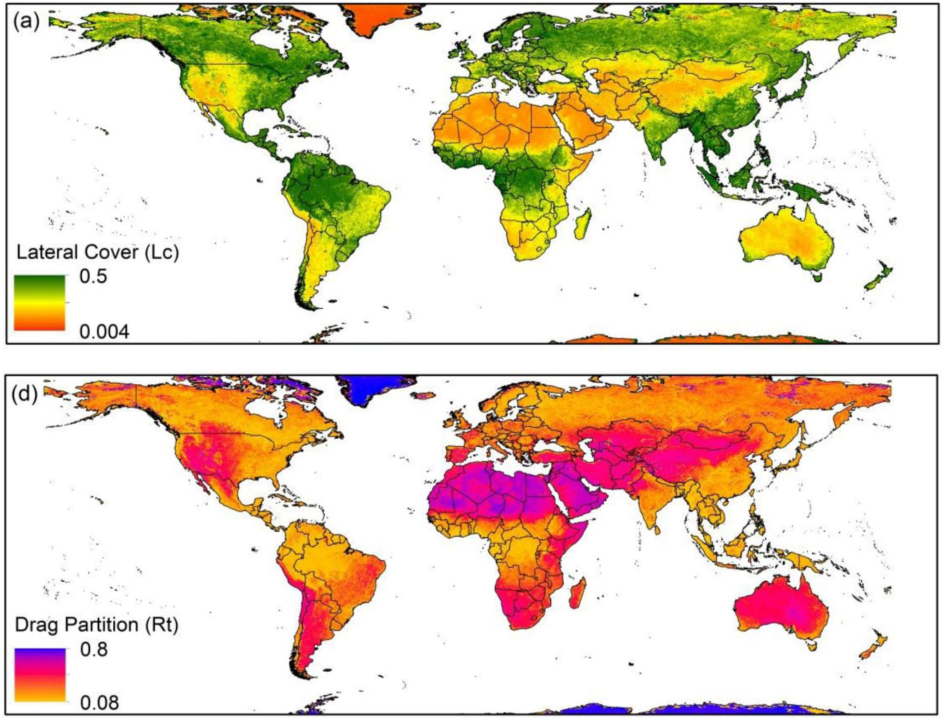


Chappel and Webb

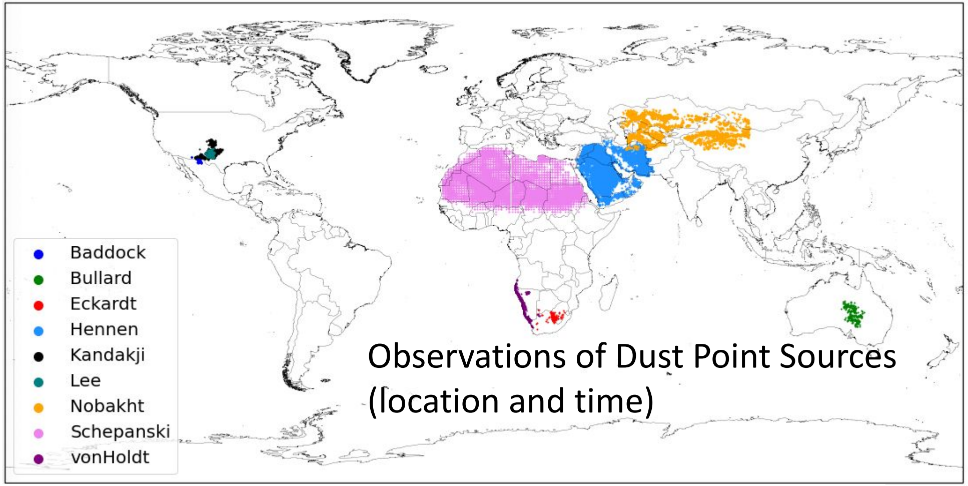
Use an albedo-based approximation of aerodynamic sheltering (Lw) to adjust surface roughness and dust emissions (Chappell et al., 2016).

Example of lateral cover





Data Driven Threshold Velocity



Hennen, M., Chappell, A., Webb, N., Schepanski, K., Baddock, M., Eckardt, F., Kandakji, T., Lee, J., Nobakht, M., and von Holdt, J.: Evaluating dust emission model performance using dichotomous satellite observations of dust emission, Geosci. Model Dev. Discuss. [preprint], https://doi.org/10.5194/gmd-2021-423, in review, 2022.

ERA5 Reanalysis

- 10 meter u component
- 10 meter v component
- First layer volumetric soil moisture

MODIS BRDF

- Drag Partition Calculation from Chappel and Webb 2016
- u*/Uf derivation from Chappel and Webb 2016

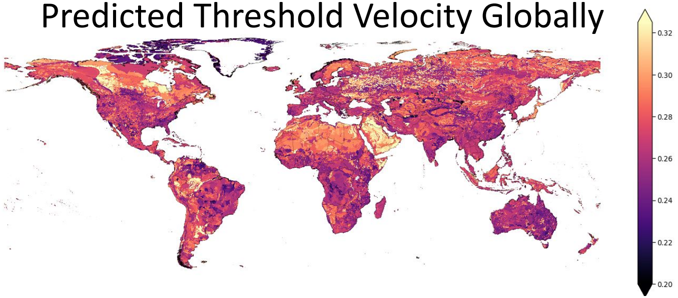
SOILGRIDSv2

- Bulk Density
- Clay Content
- Sand Content
- Silt Content
- Soil Organic Carbon
- Organ Carbon Density
- Cation Exchange Capacity
- PH
- Coarse Fragments
- World Soil Database type
- Nitrogen

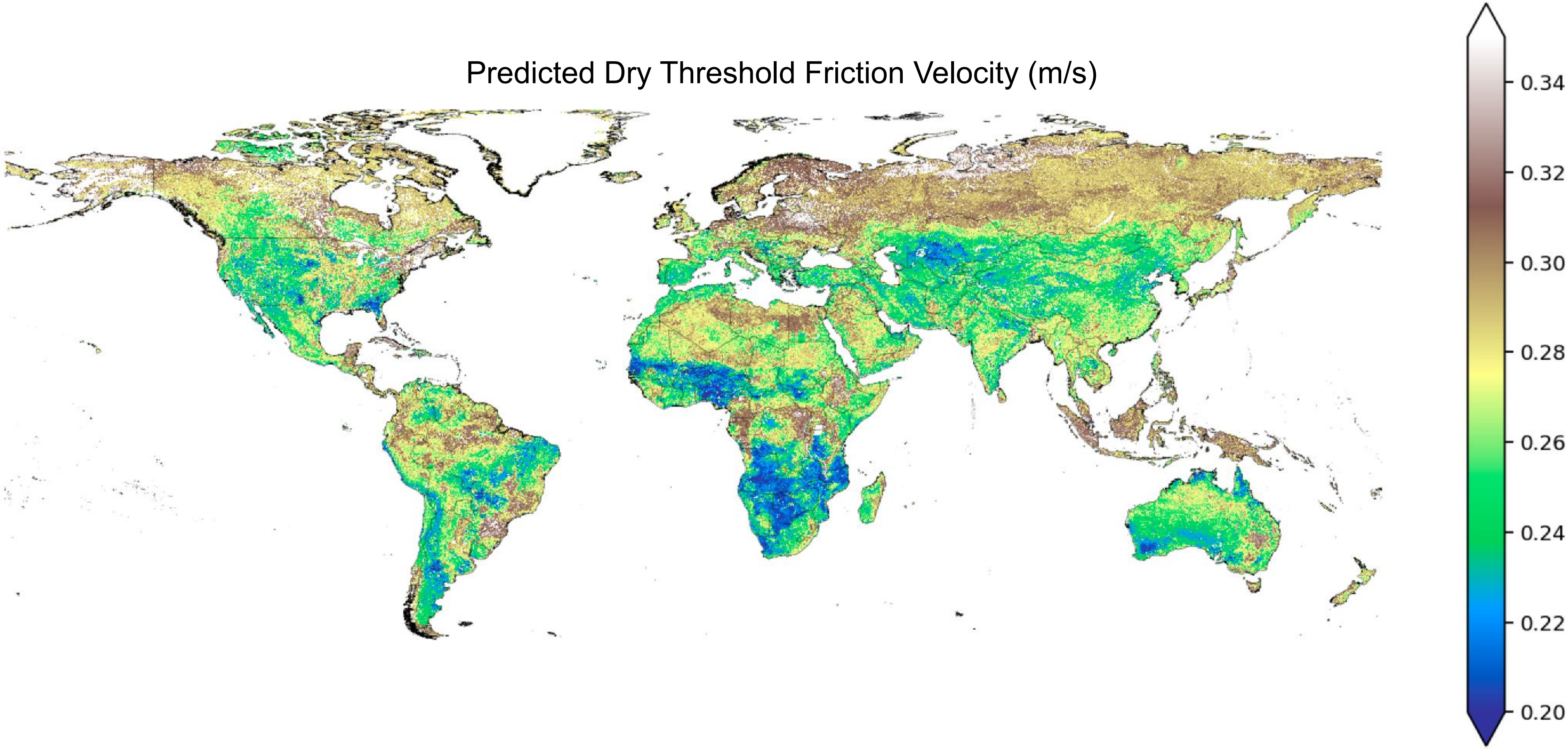
Calculate Dry Threshold Velocity

Random Forest

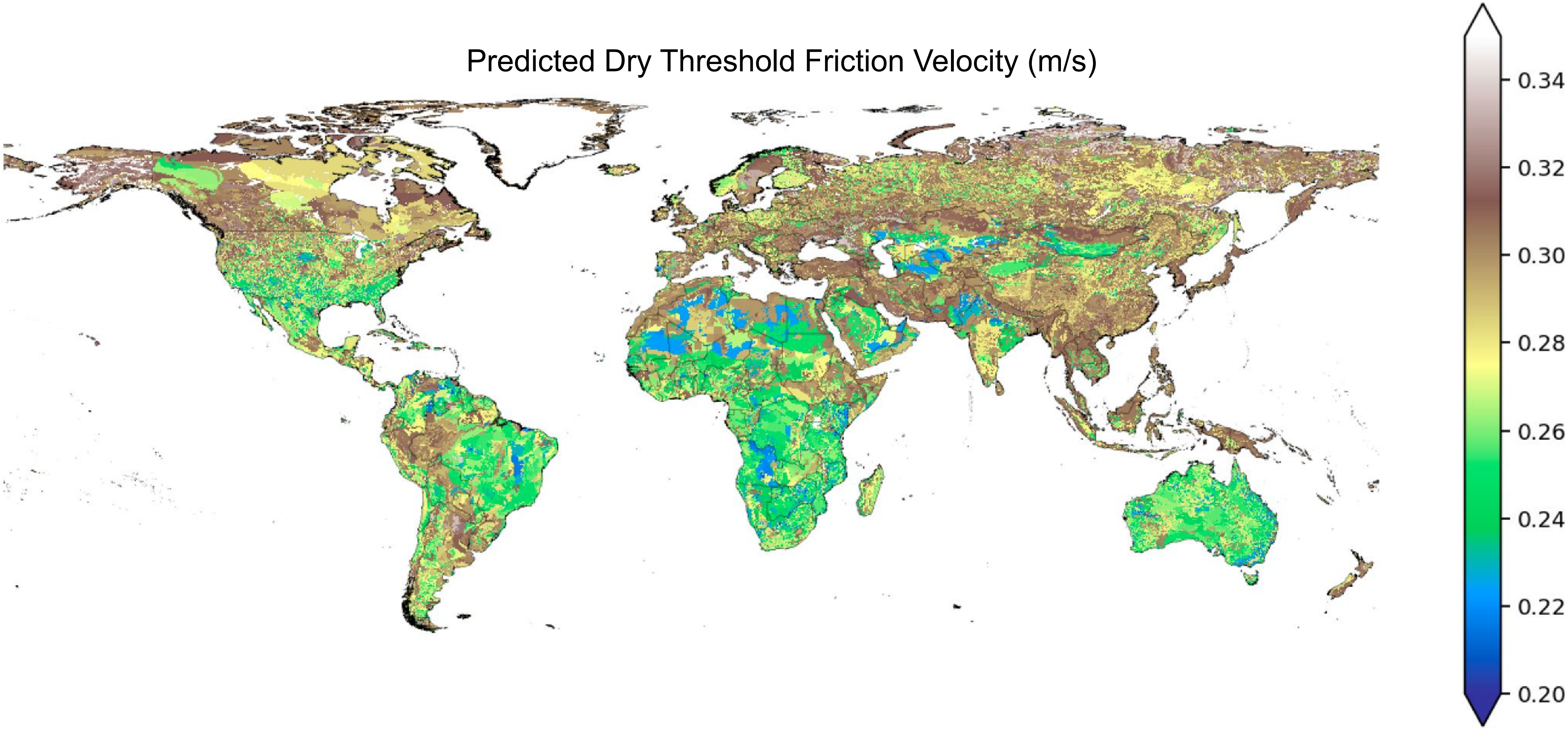
Predicted Threshold Velocity Globally



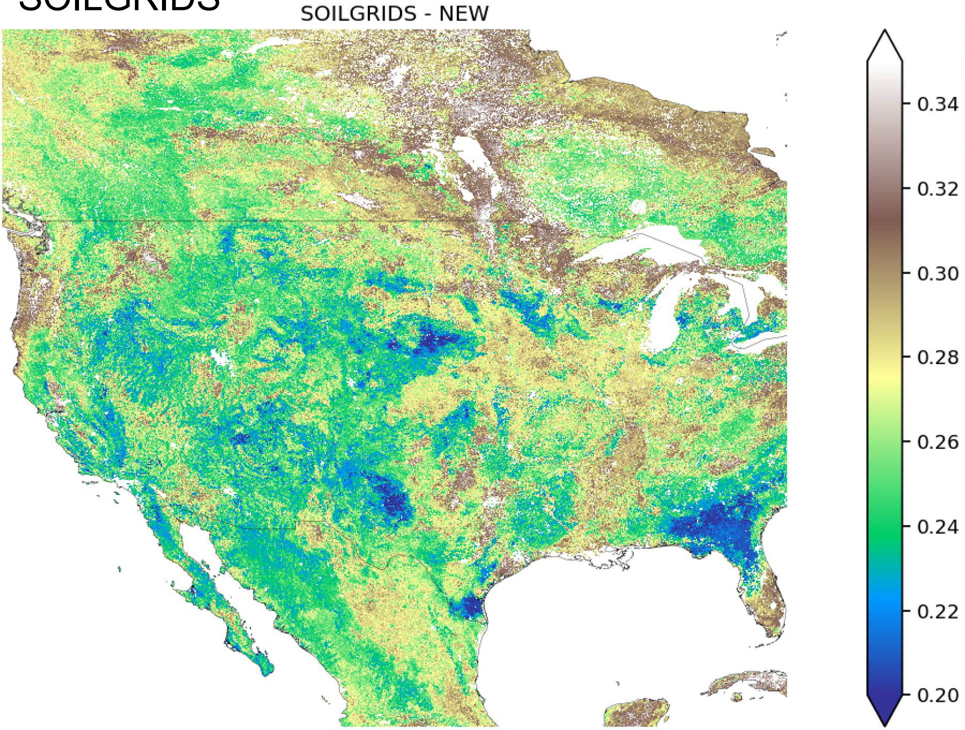
Results - SOILGRIDS 2.0



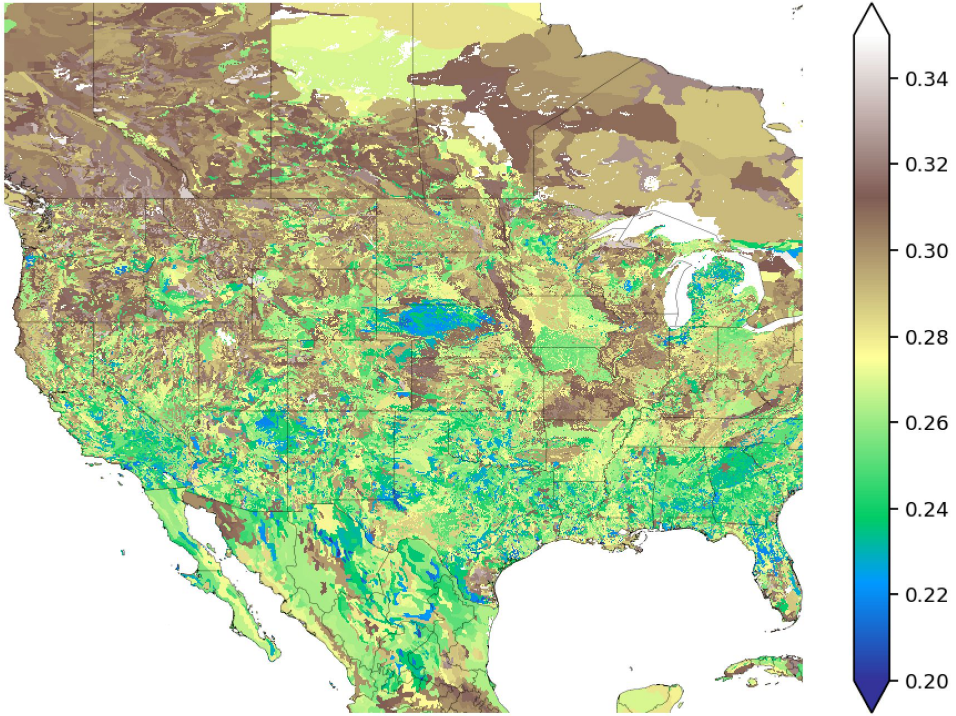
BNU SOIL


Predicted Dry Threshold Friction Velocity (m/s)
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20

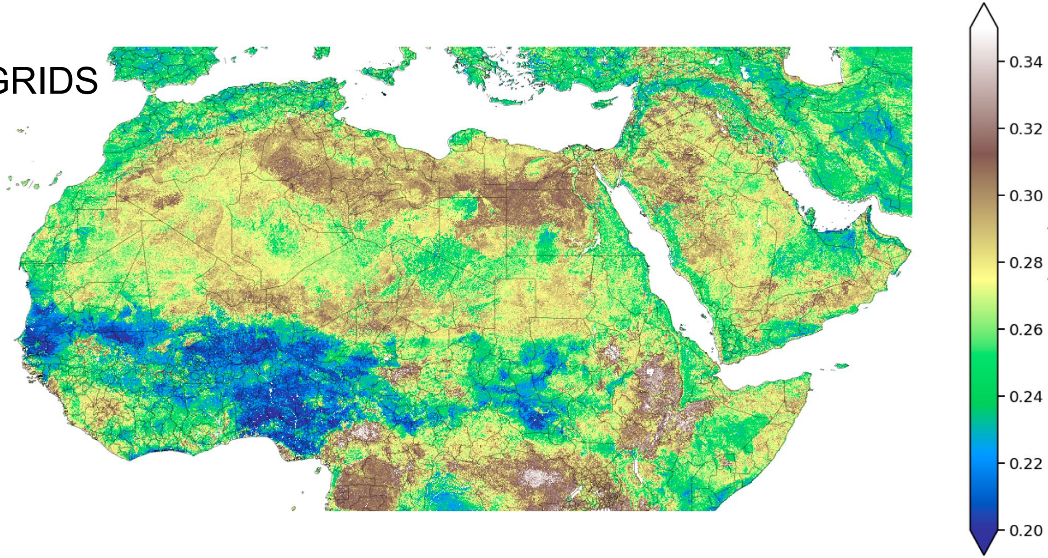
SOILGRIDS



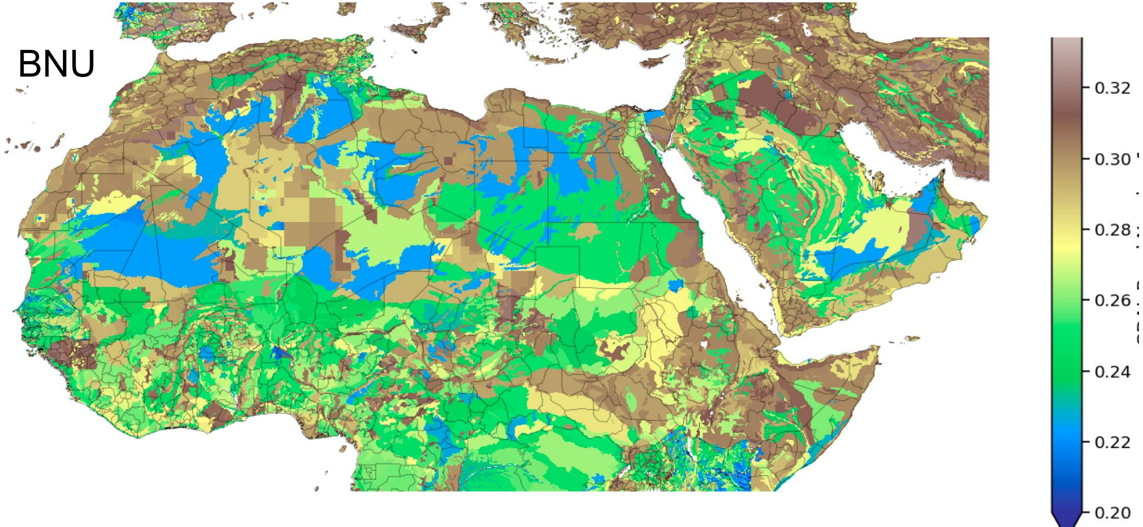
BNU



SOILGRIDS



BNU



Fengsha Flux Equation

$$F = \alpha A \frac{\rho_a}{g} \left(R u_*^3 \right) \left(1 - \frac{u_{*t}^2}{u_*^2} \right) \left(1 + \frac{u_{*t}^2}{u_*^2} \right)$$

Area

Density

Friction Velocity

Threshold Velocity

Vertical To Horizontal Flux Ratio

Gravity

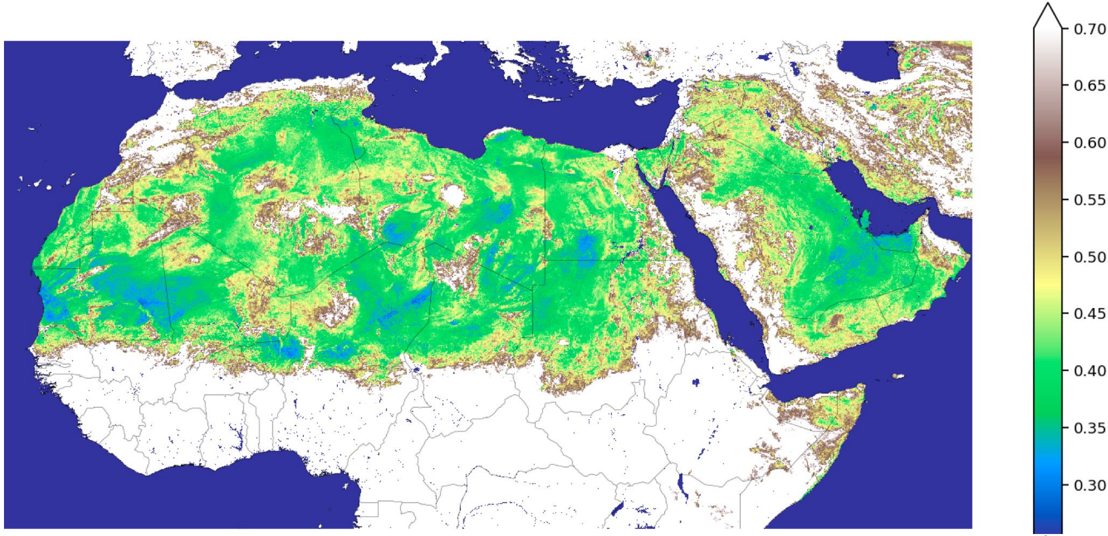
Drag Partition

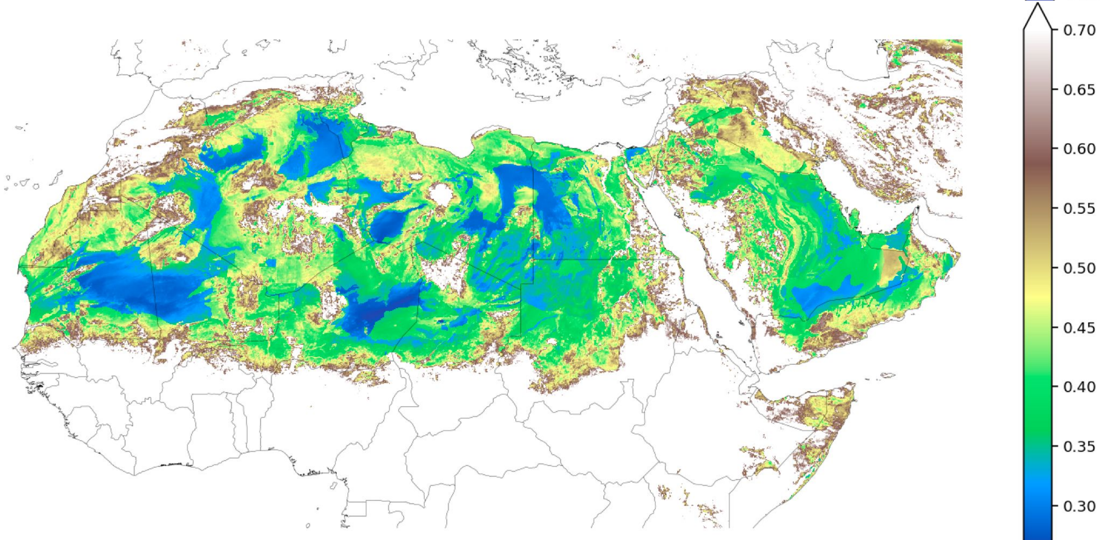
Dust emission occurs when u* = u*t x H / R

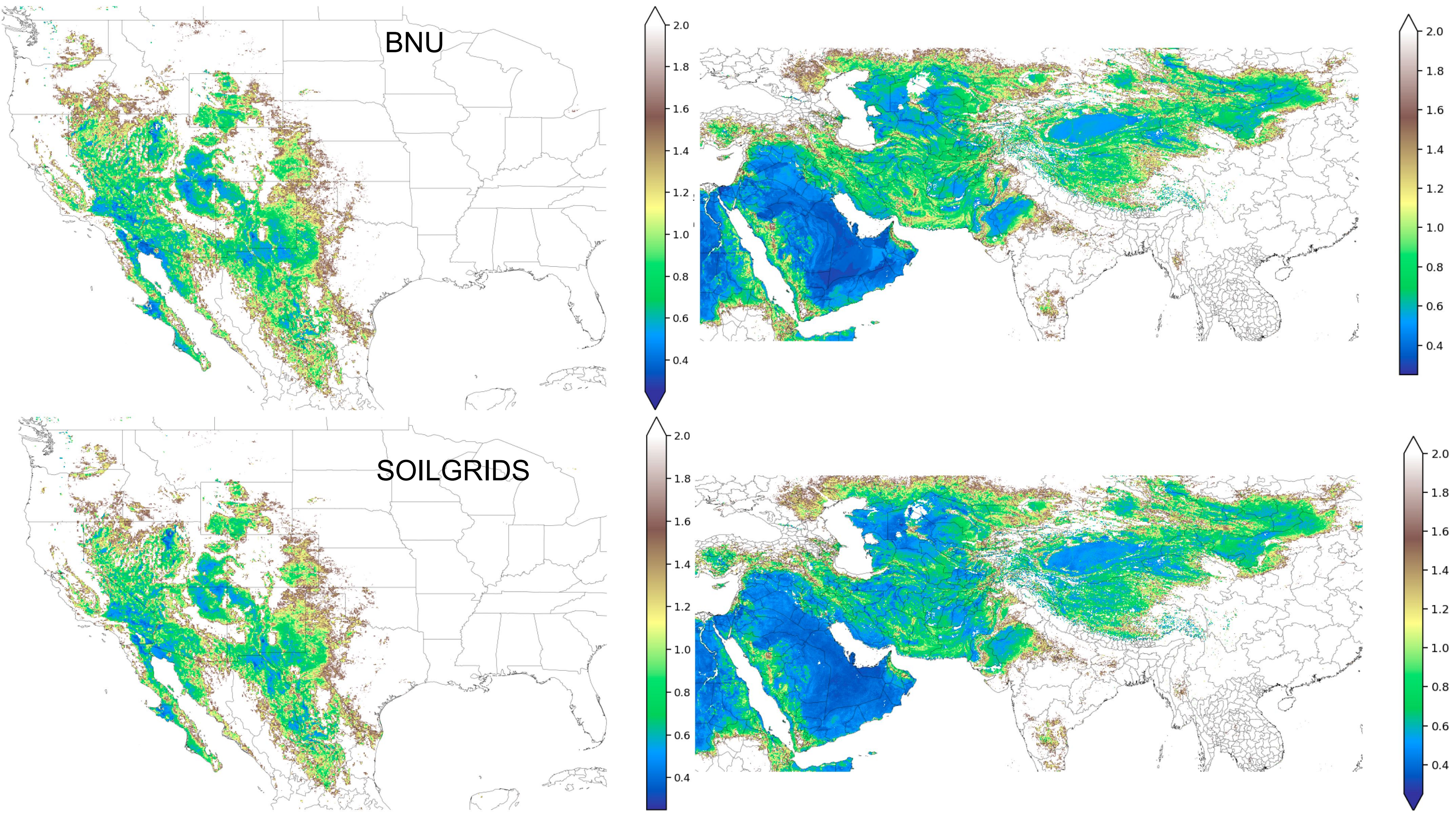
We will assume “dry” conditions to analyze where dust emissions are changing

Dust emission occurs when **u* = u*t x H / R**

We will assume "dry" conditions to analyze where dust emissions are changing





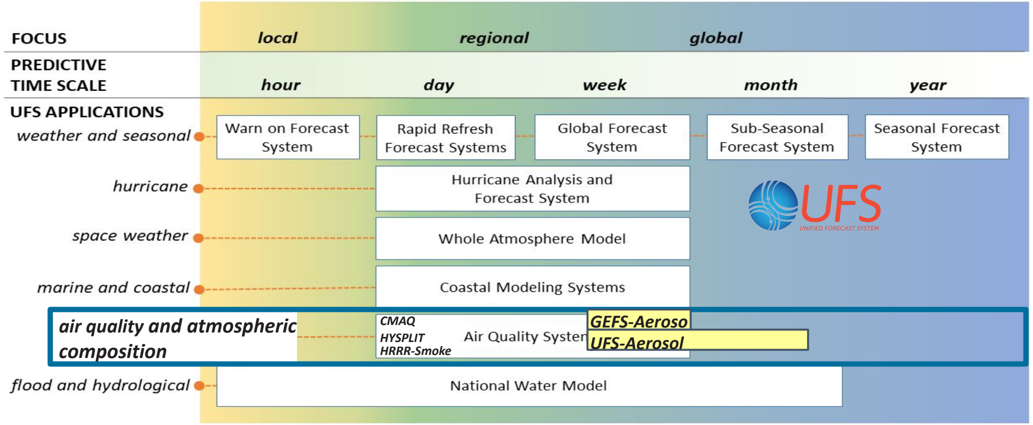

BNU
SOILGRIDS
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4

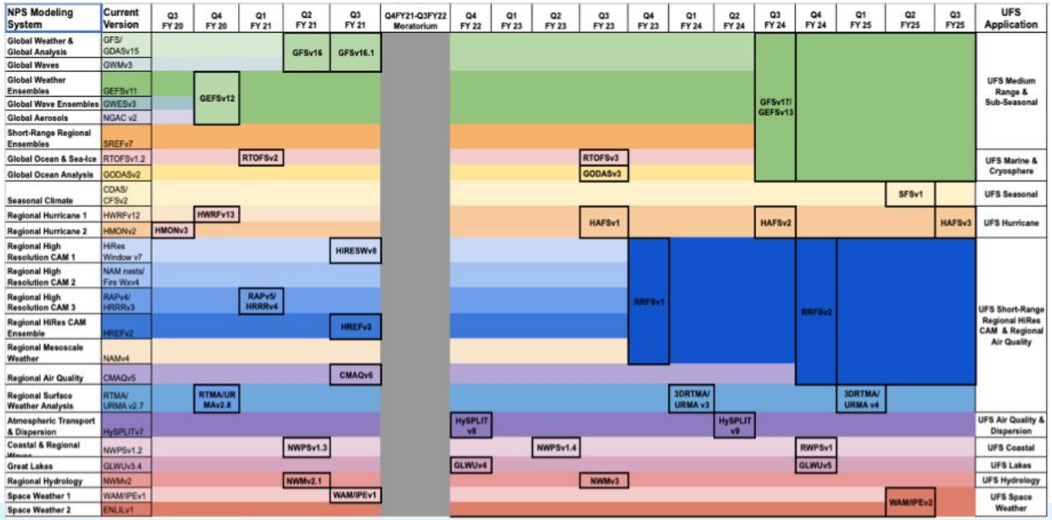
UFS

UNIFIED FORECAST SYSTEM

https://ufscommunity.o

- Community-based, coupled, comprehensive Earth system modeling
- Applications span local to global domains and predictive time scales from sub-hourly analyses to seasonal predictions
- Designed to support the [Weather Enterprise] and be the source system for [NOAA]'s operational numerical weather prediction applications
- Will eventually encompass the full scope of NOAA's operational prediction capabilities that are currently represented by a myriad of separate modeling systems





Moving to UFS Applications

NPS Modeling System	Current Version	Q4 FY 21	Q4FY21-Q3FY22 Moratorium	Q4 FY 22	Q1 FY 23	Q2 FY 23	Q3 FY 23	Q4 FY 23	Q1 FY 24	Q2 FY 24	Q3 FY 24	Q4 FY 24	Q1 FY 25	Q2 FY25	Q3 FY25	Q4 FY 25	Q1 FY 26	Q2 FY26	Q3 FY26	UFS Application
Global Weather, Waves & Global Analysis	GFS/ GDASv16.2																			
Global Weather and Wave Ensembles, Aerosols	GEFSv12						Coupled Reanalysis and SubX Reforecast Production				GFSv17/ GEFSv13				Seasonal Reforecast Production				GFSv18/ GEFSv14/ SFSv1	UFS Medium Range & Sub-Seasonal
Short-Range Regional Ensembles	SREFv7																			
Global Ocean & Sea-Ice	RTOFSv2						RTOFSv3													UFS Marine & Cryosphere
Global Ocean Analysis	GODASv2						GODASv3													
Seasonal Climate	CDAS/ CFSv2																			UFS Seasonal
Regional Hurricane 1	HWRFv13						HAFSv1				HAFSv2				HAFSv3				HAFSv4	UFS Hurricane
Regional Hurricane 2	HMONv3																			
Regional High Resolution CAM 1	HiRes Window v8																			
Regional High Resolution CAM 2	NAM nests/ Fire Wxv4																			
Regional High Resolution CAM 3	RAPv5/ HRRRv4							RRFSv1							RRFSv2				RRFSv3/ WoFSv1	UFS Short-Range Regional HiRes CAM & Regional Air Quality
Regional HiRes CAM Ensemble	HREFv3																			
Regional Mesoscale Weather	NAMv4																			
Regional Air Quality	AQMV6	AQMv6																		
Regional Surface Weather Analysis	RTMA/ URMA v2.8							3DRTMA/ URMA v3							3DRTMA/ URMA v4				3DRTMA/ URMA v5	
Atmospheric Transport & Dispersion	HySPLITv7			HySPLITv8						HySPLIT v9								HySPLIT v10		UFS Air Quality & Dispersion
Coastal & Regional Waves	NWPSv1.3					NWPSv1.4						RWPSv1				RWPSv2				UFS Coastal Waves
Great Lakes	GLWUv1.0.3			GLWUv1.2								GLWUv2				GLWUv3				UFS Lakes
Regional Hydrology	NWMv2.1						NWMv3													UFS Hydrology
Space Weather 1	WAM/IPEv1	WAM/IPE v1												WAM/IPEv2						UFS Space Weather
Space Weather 2	ENLILv1																			

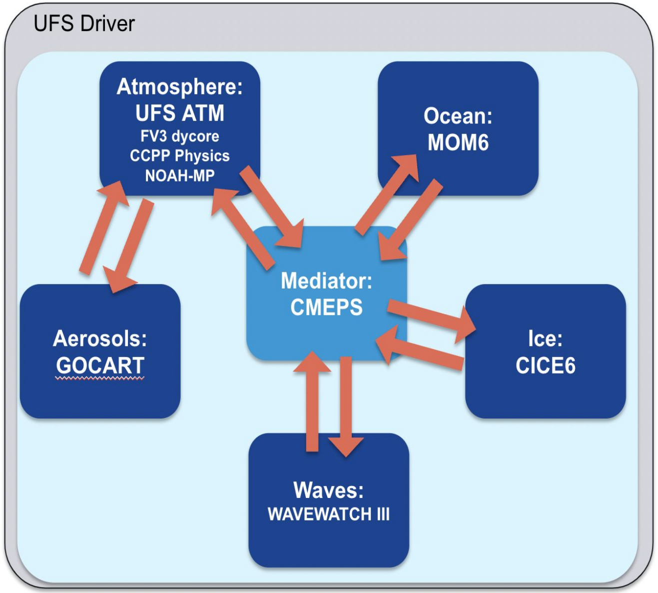
Background

One of the NOAA Unified Forecast System (UFS) modeling applications currently in development is a coupled model for global predictions of weather to seasonal time scales, targeting NOAA/NCEP operational Medium Range (**GFS v17**), Subseasonal (**GEFS v13**), and Seasonal (**SFSv1**) forecasting systems.

In the **Global Coupled UFS development phase**, discrete system prototypes were defined and evaluated within a fixed benchmark framework. Evaluation findings were used to inform subsequent development.

Prototype 8 (P8) is the last of these prototypes before tailored development for GFSv17/GEFSv13/SFSv1

Target configuration (GFSv17, GEFSv13, SFSv1)



ufs-weather-model

https://github.com/ufs-community/ufs-weather-model

Atmosphere
- FV3 dynamical core
- GFS Physics with Thompson microphysics
- CCPP physics driver
- C384 (~25km), 127 levels

Ocean
- MOM6 Modular Ocean Model
- ¼ degree tripolar grid, 75 hybrid levels
- OM4 Set up [Adcroft, 2019]

Waves
- WAVEWATCH III
- ½ degree regular lat/lon grid
- ST4 Physics [Ardhuin, 2010]

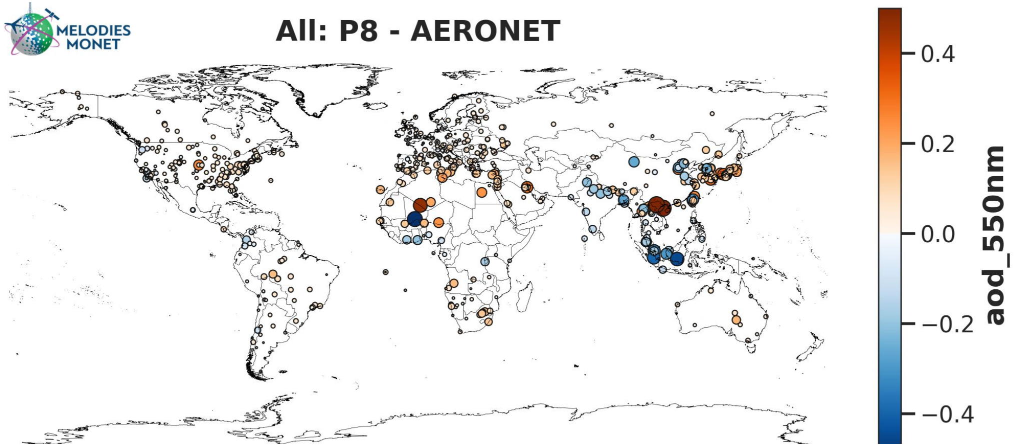
Ice
- CICE6 Los Alamos Sea Ice Model
- ¼ degree tripolar grid (same as ocean)
- 5 thickness categories
- Mushy thermodynamics on (P7 onward)

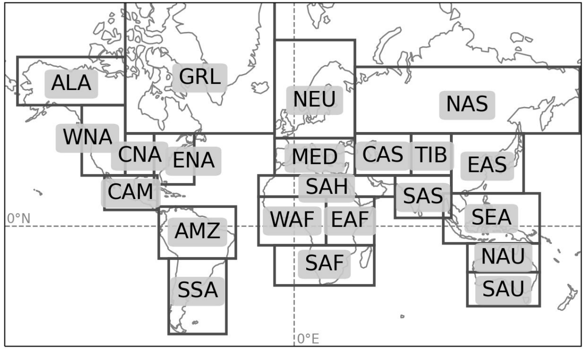
Aerosols
- NASA GOCART2G
- Emissions: CEDS-2019 (SO2, PSO4, POC, PEC), QFED biomass burning, FENGSHA dust, GEOS-5 sea salt, marine DMS
- Sulfate, Organic Carbon, Black Carbon, Dust, Sea Salt, Nitrogen
- MERRA2 ICs

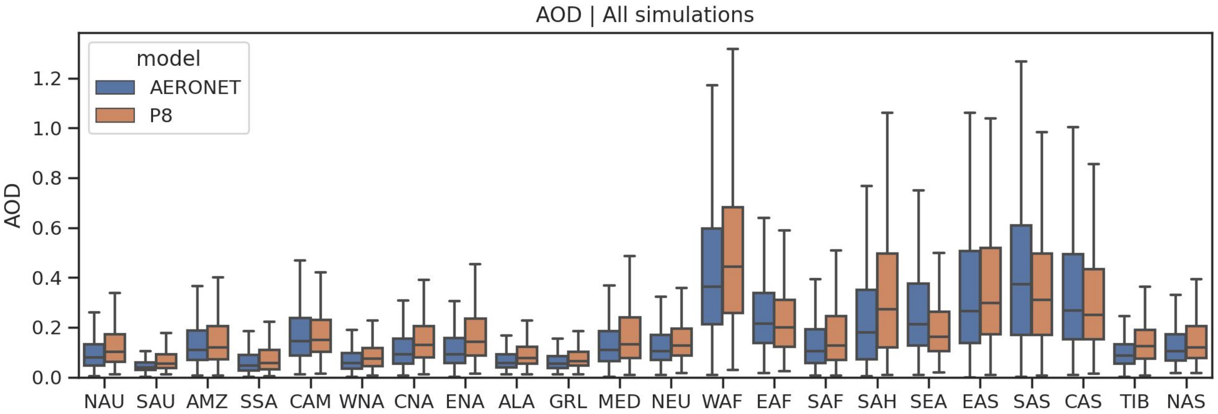
Driver/Mediator
- NEMS driver
- CMEPS mediator

Overall Performance Across all Times vs Aeronet

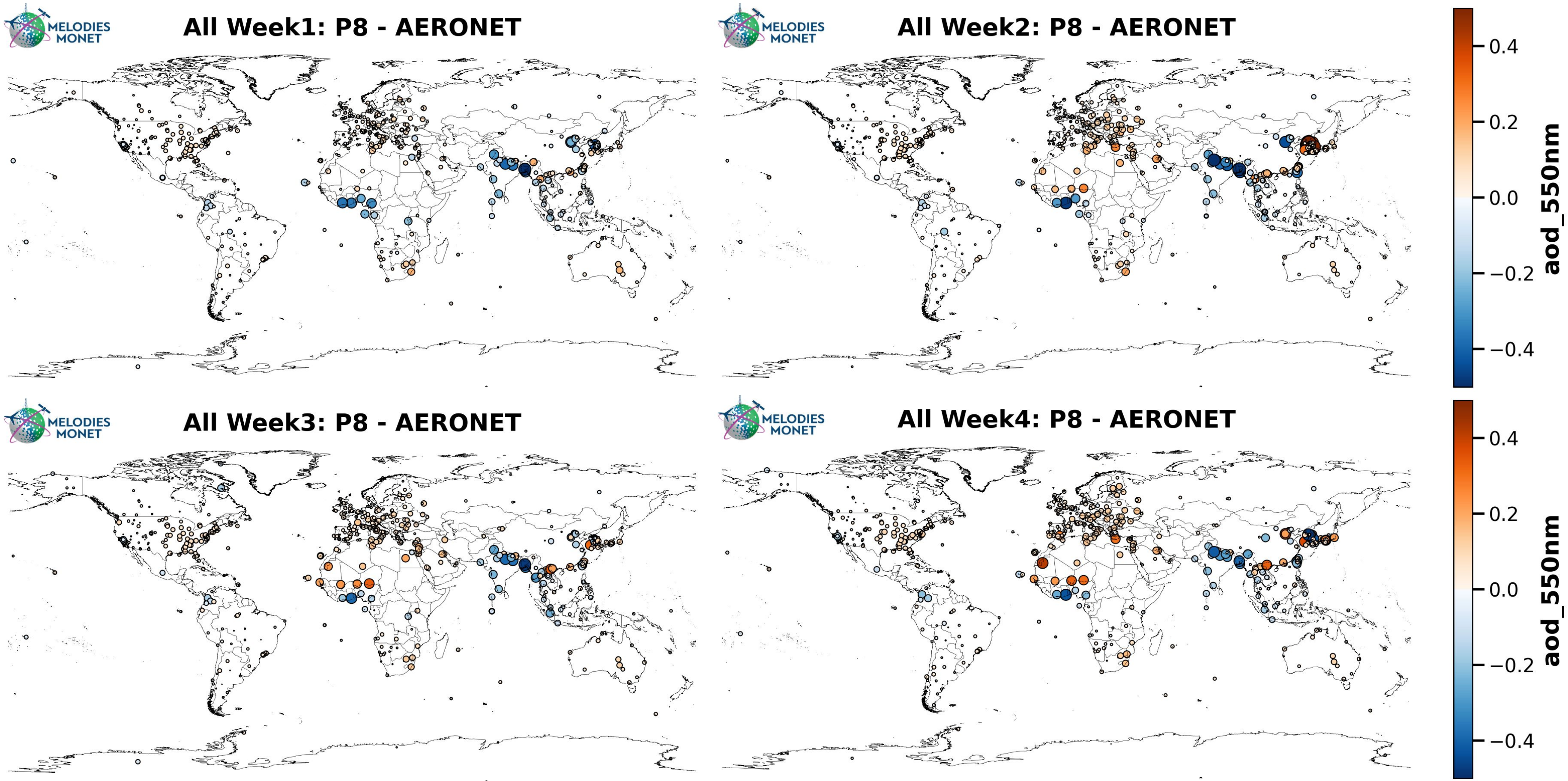
- Overall P8 performed well especially in the Americas and Europe
- Overprediction in the Sahara (dust) and Western Africa (fires)
- Underprediction in SE Asia
- Underprediction in TIB regions





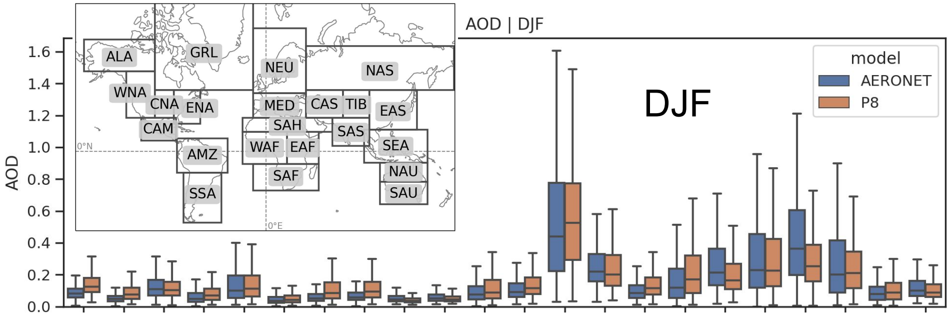


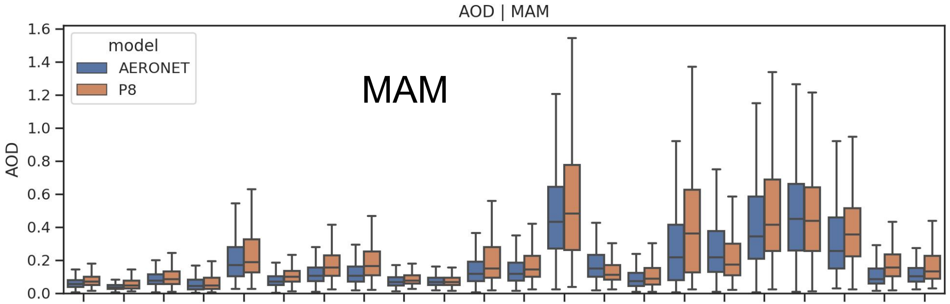
Integration Time Performance Across all Times vs Aeronet

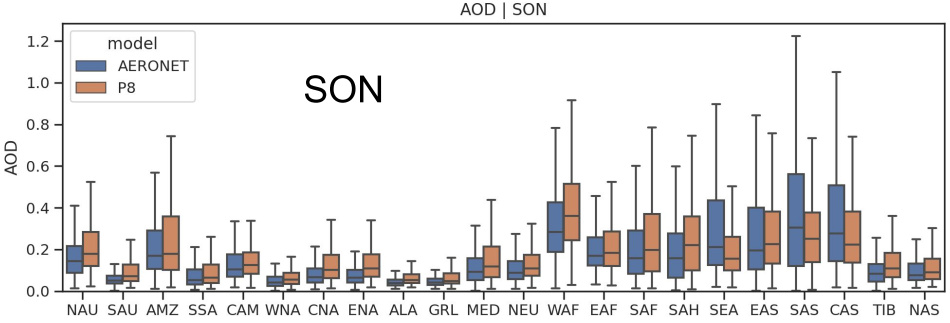


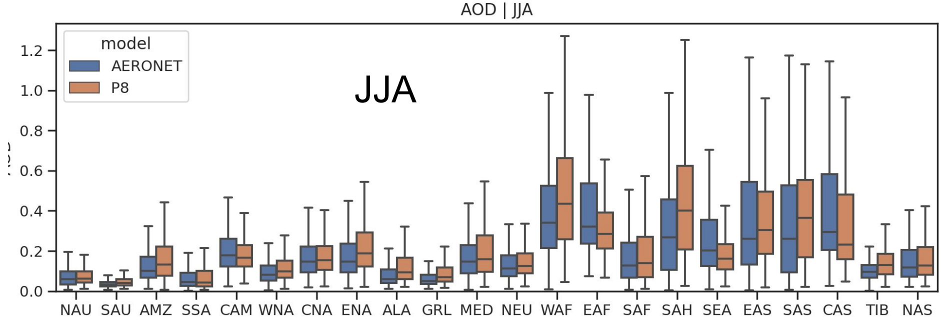
Overall Performance Across all Times vs Aeronet

- Overprediction of wildfires in western africa most pronounced in all season (less in DJF in the offseason)
- P8 follows the seasonal dust predictions in most dust regions
- Largest overprediction of dust occurs in JJA and MAM compared to other seasons
- Overpredict AOD in SE Asia in JJA and MAM

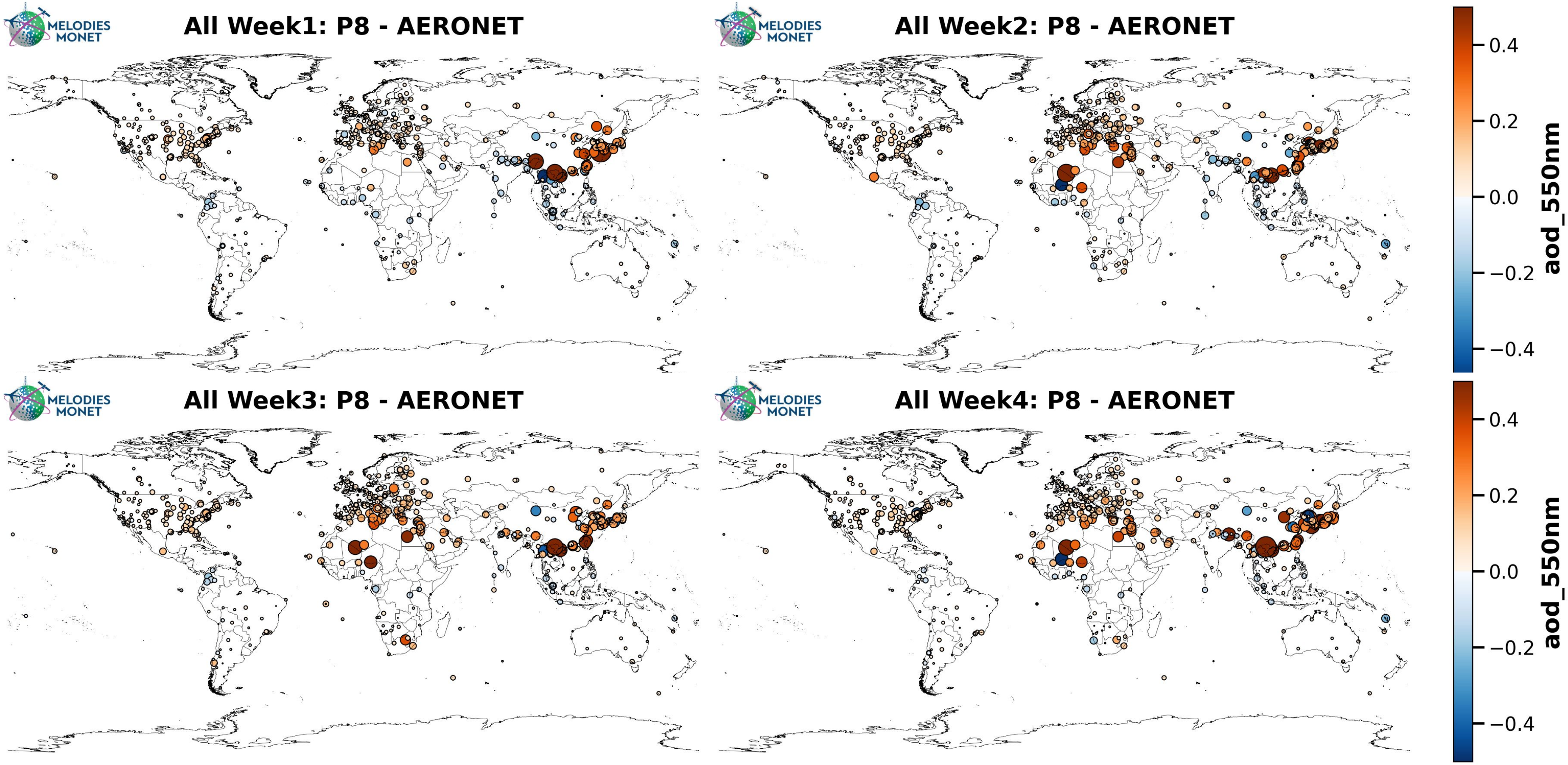




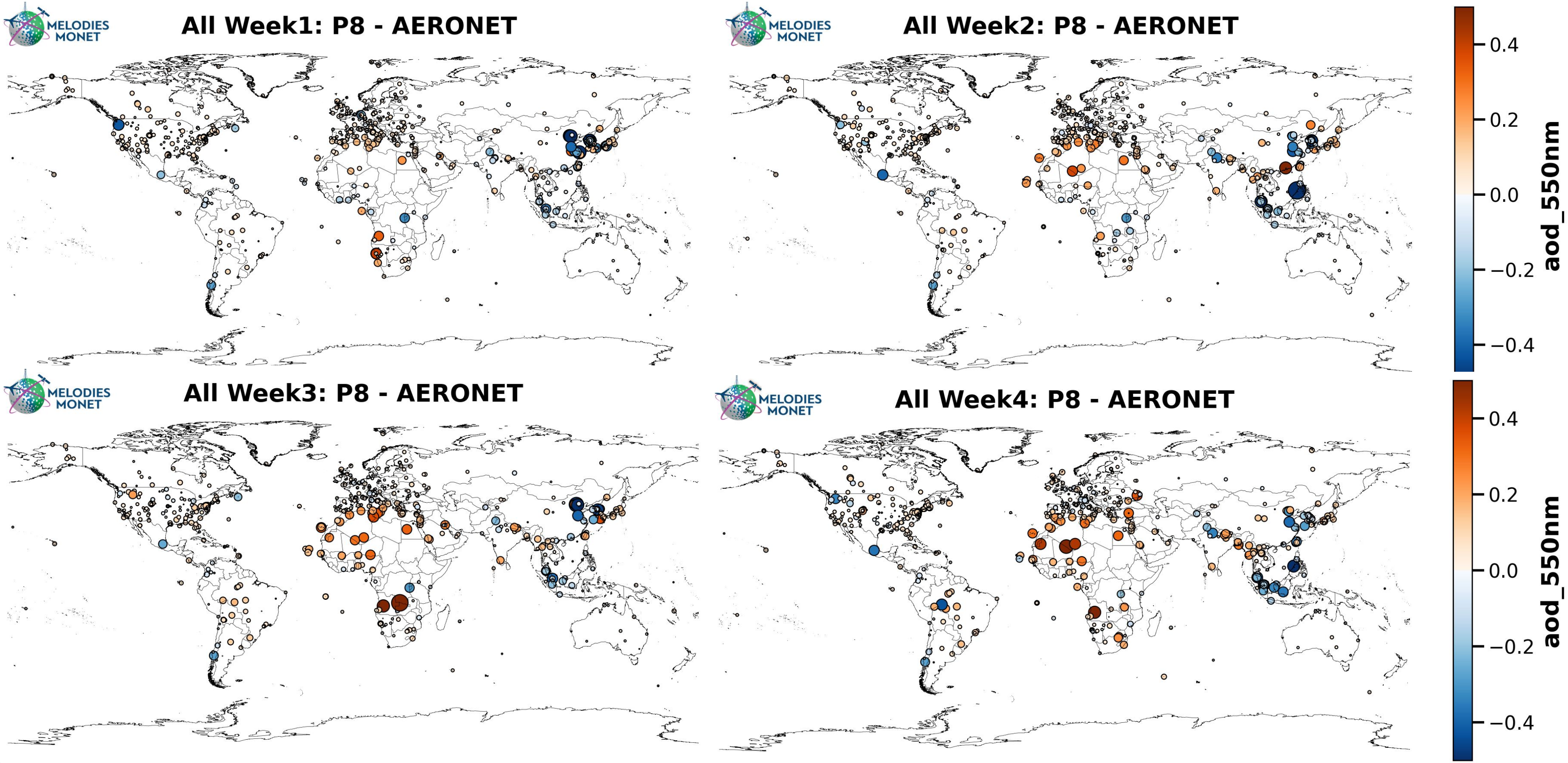




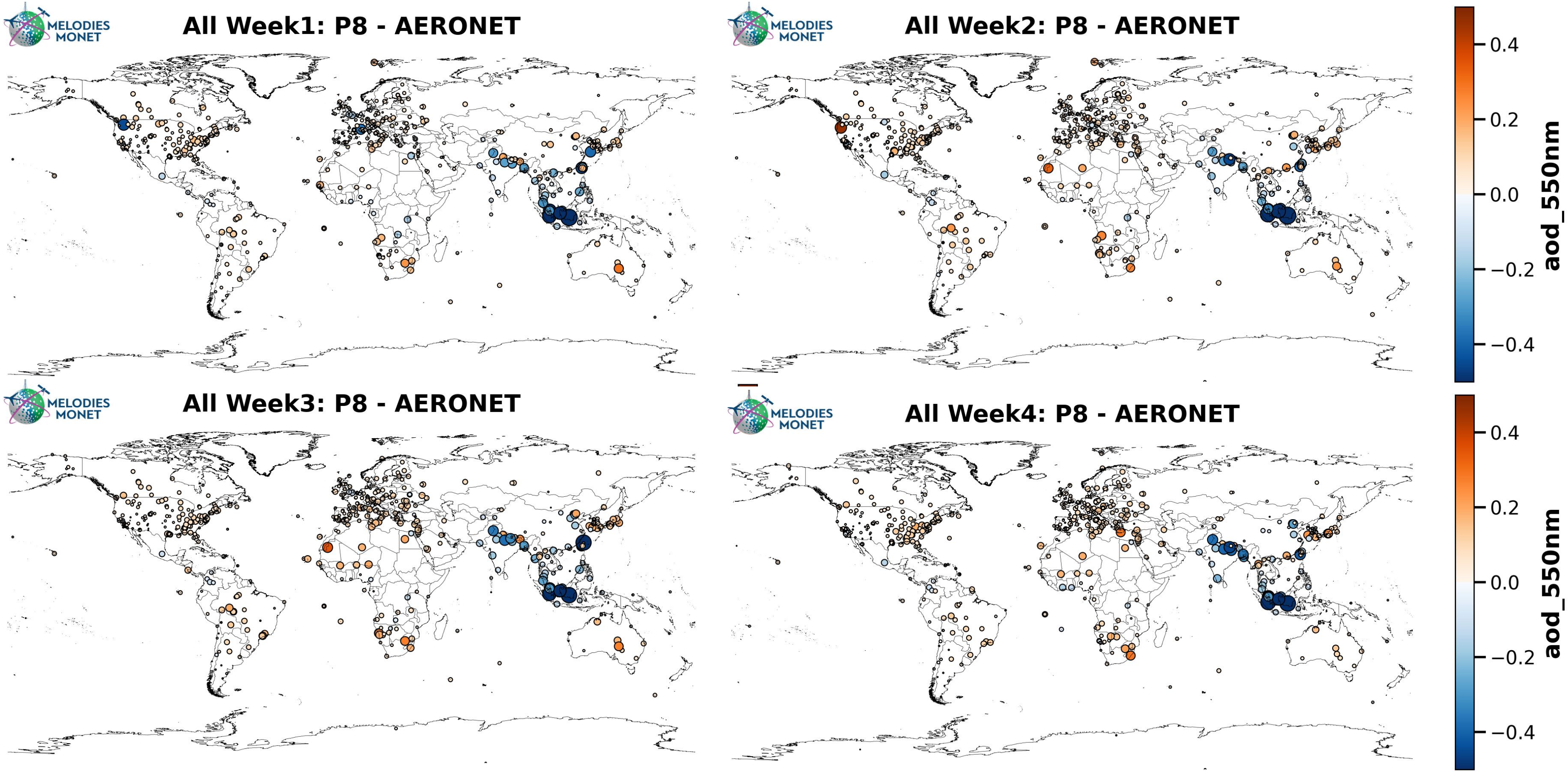
Seasonal Performance Across all Times vs Aeronet - MAM



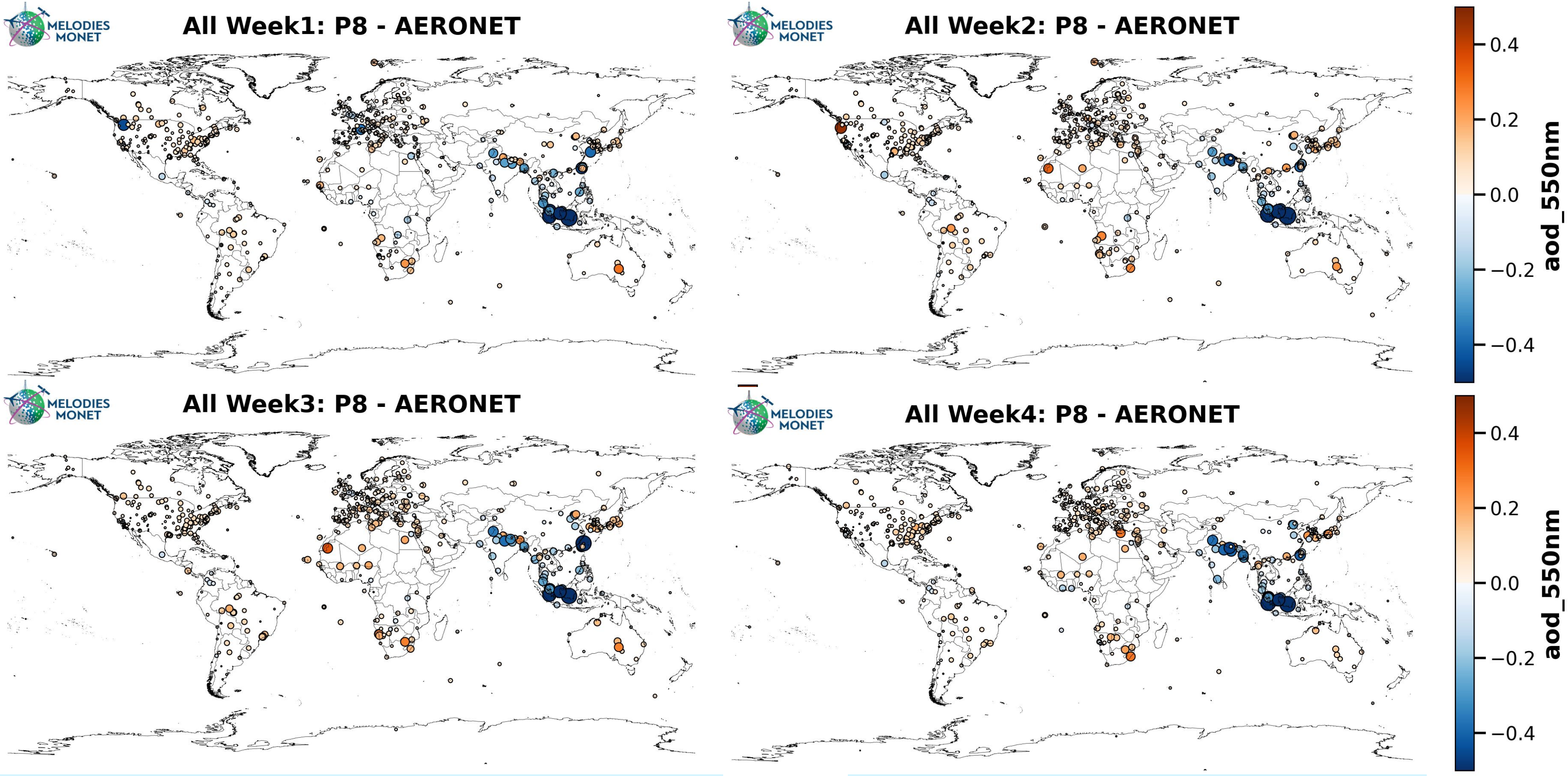
Seasonal Performance Across all Times vs Aeronet - JJA



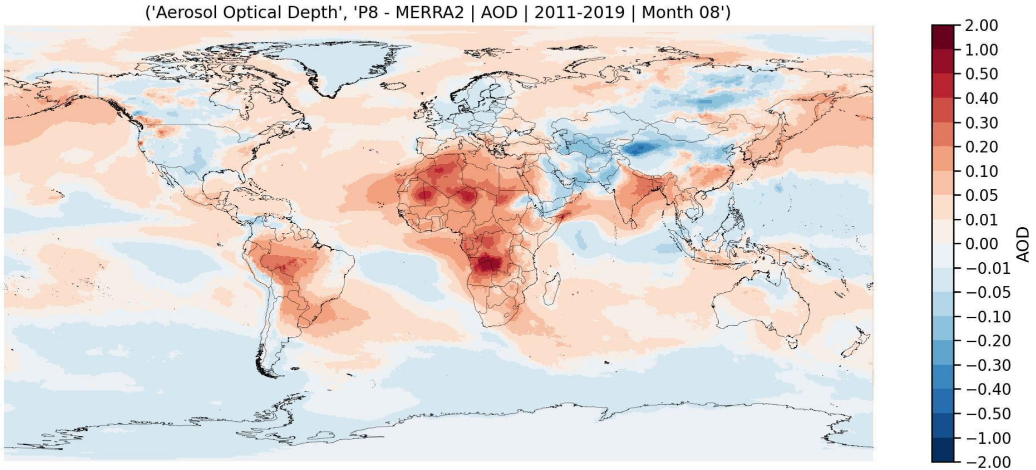
Seasonal Performance Across all Times vs Aeronet - SON



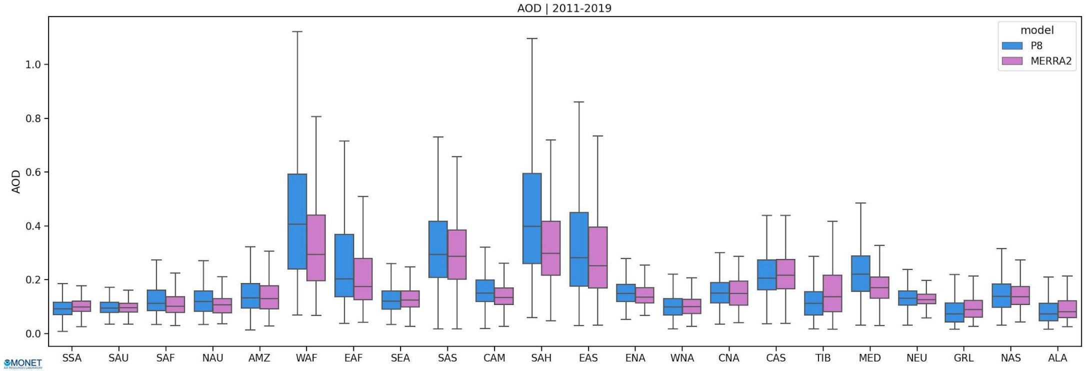
Seasonal Performance Across all Times vs Aeronet - DJF

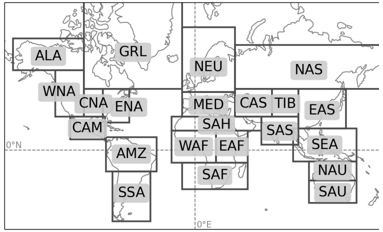


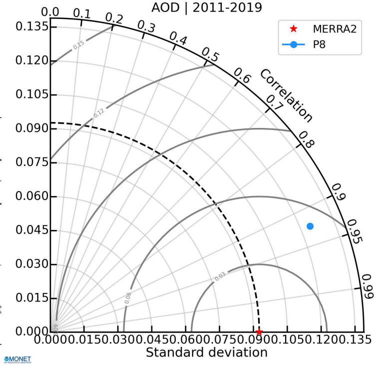
All Times vs MERRA2



- P8 shows high correlation at all time with MERRA2 (>0.85)
- Over predictions in dust and wildfire regions are seen except over the Taklamakan Desert.

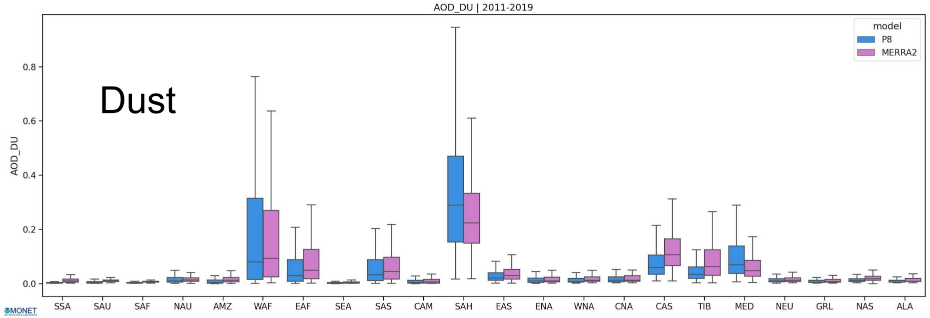


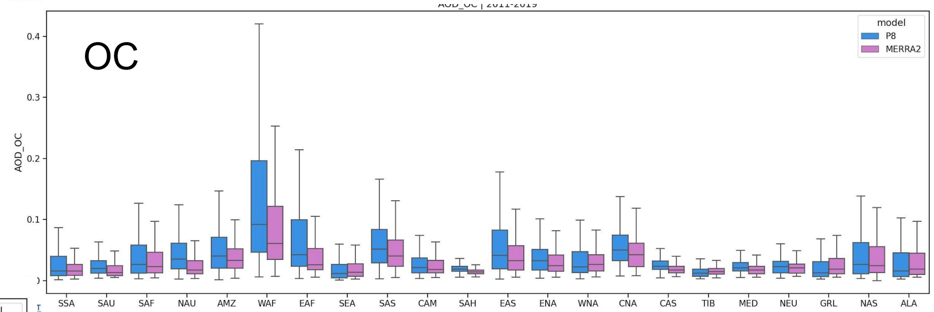


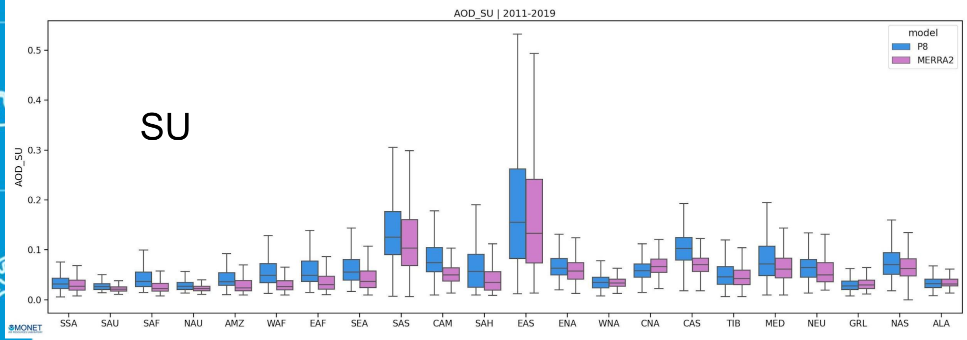


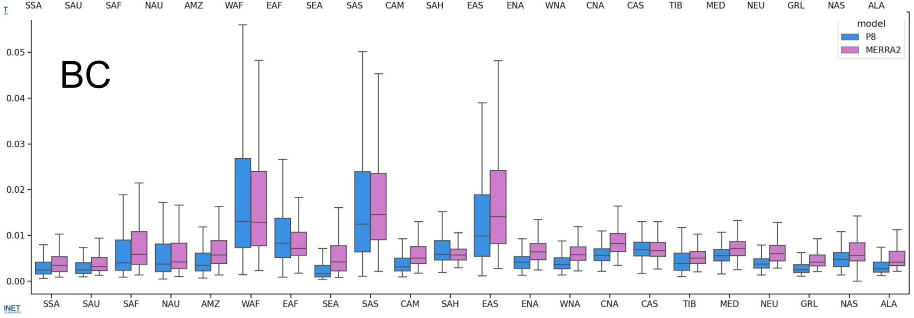
All Times vs MERRA2

- Dust is generally over predicted in the Sahara but did well in the Sahel
- OC has a high bias in WAF
- BC is high as low bias in EAS but overall AOD bias in that region is high.









UFS-Aerosols in GEFSv13 Prototypes

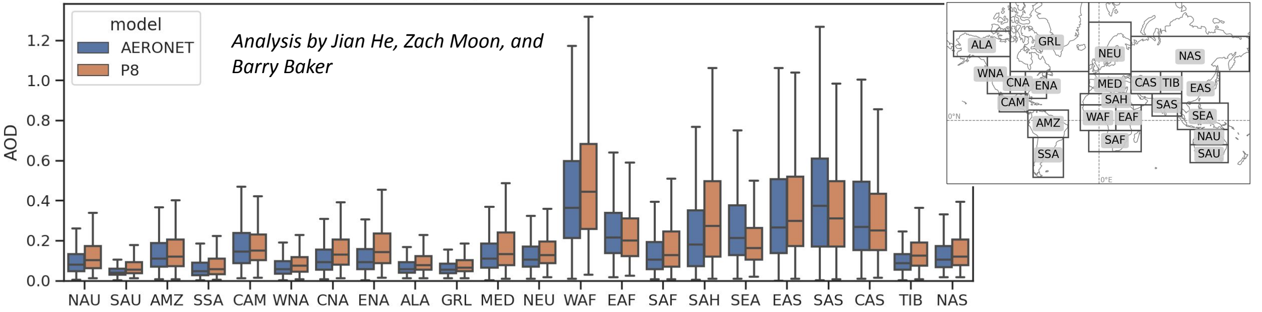
Community components used in this coupled system:

- **Finite Volume cubed sphere (FV3) dynamical core for atmosphere**
- **Global Forecast System (GFS) physics for atmosphere**
- **Modular Ocean Model (MOM6)**
- **Los Alamos Sea Ice Model (CICE6)**
- **WAVEWATCH III for waves**
- **NOAH-MP for land**
- **Goddard Chemistry Aerosol Radiation and Transport (GOCART2G) model for atmospheric aerosols**
- **NUOPC/ESMF compliant coupling infrastructure**

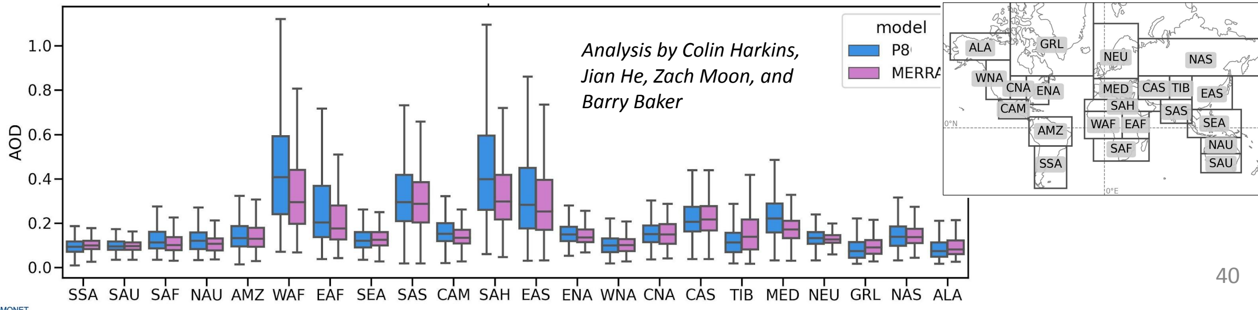
Development is proceeding through coupled prototypes, each adding new model components or refining representation of components or initialization. UFS prototype 8 includes prognostic aerosols.

UFS-Aerosols is a join collaboration between NASA and NOAA to coupled GOCART2G to the UFS. Currently planed to be in every member of GEFSv13 with direct aerosol feedback at ~25 km resolution.

Regional comparisons of **prototype simulations Weeks 1-4 UFS-Aerosols** AOD to **AERONET** AOD



Regional comparisons of **prototype simulations Weeks 1-4 UFS-Aerosols** AOD to **MERRA-2** AOD

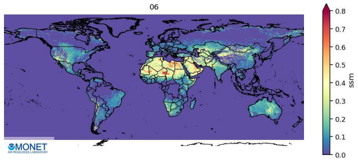


Thank You

FENGSHA Options

2 **Soil Erodibility Potential**

$$S = (\%clay)\varepsilon_1 + (\%silt)\varepsilon_2 + (\%sand)\varepsilon_3$$



Required Parameters:

Option 1) Clay, Sand and Silt Content (NOT USED)

Option 2) Albedo Based Dust Source Map (GEFS/NAQFC)

3 **Horizontal (saltation) flux**

$$Q_h = cS\frac{\rho_a}{g}u_*^3(1 - \frac{u_{*t}^2}{u_*^2})$$

Required Parameters:

Friction Velocity
Air Density
Soil Potential

1a **Threshold Friction Velocity over smooth dry surface**

Size Independent, based on soil texture classification measurements, field and wind tunnel studies done by Dale Gillette

1 **Threshold Friction Velocity**

$$u_t(z_0, w) = \frac{u_{*ts}}{R(z_0, z_{0s})}H(w)$$

4a **Vertical Flux**

Marticorena and Bergametti (1995)

$$\alpha = \frac{F}{Q} = 10^{0.134(\%clay)-6}$$

Required Parameters:
Clay Content
Option 1) soil texture parameterization
Option 2) ISRIC Soil Database

$$F = \alpha \times A \times S \times \frac{\rho}{g}u_{*T}^3\left(1 - \left(\frac{u_{*t}}{u_{*T}}\right)^2\right)$$

Flux of Dust

Vertical to Horizontal Flux Ratio

Soil Erosion Potential and Source

Surface Friction Velocity

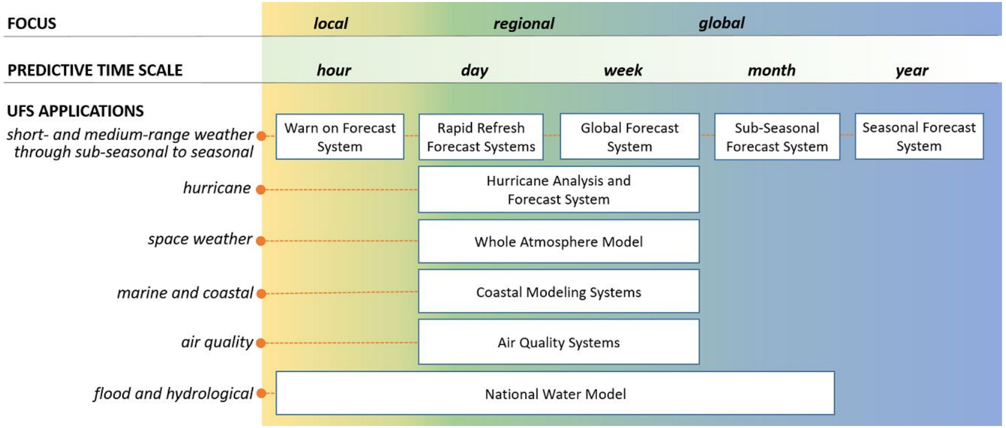
Threshold Velocity

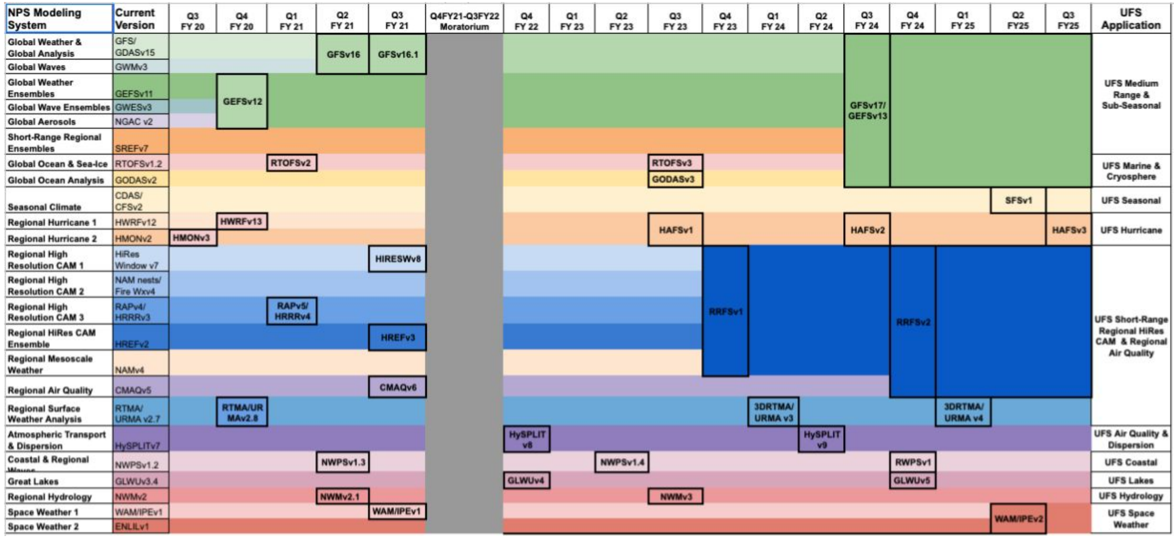
Horizontal Flux (Q)

UFS — UNIFIED FORECAST SYSTEM

https://ufscommunity.org

- Community-based, coupled, comprehensive Earth system modeling
- Applications span local to global domains and predictive time scales from sub-hourly analyses to seasonal predictions
- Designed to support the [Weather Enterprise](#) and be the source system for [NOAA](#)'s operational numerical weather prediction applications
- Will eventually encompass the full scope of NOAA's operational prediction capabilities that are currently represented by a myriad of separate modeling systems





NOAA
Air Resources Laboratory

Description and Evaluation Fengsha Dust emission scheme in the Aerosol Component in the Latest Prototype UFS-based Global Coupled Modeling System

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