Forecasting Dust Emissions from Regional to Global Scale using Satellite Data In NOAA FV3

Barry Baker[1,2,3], Rick Saylor[3], Daniel Tong[2,3,4], Kerstin Schepanski[5]
(1) UMBC JCET; (2) CISESS UMD (3) NOAA ARL (4) GMU; (5) TROPOS

Leibniz Institute for Tropospheric Research

Barry.Baker@noaa.gov

Outline

1) Quick overview of the dust scheme - FENGSHA
   a) Used in the National Air Quality Forecast Capability
   b) Implemented into the future NOAA GEFS-Aerosol
2) Introduction of a new sediment supply map derived from satellite black sky albedo measurements
3) Quick comparisons with measurements
4) Implementation of Chappel and Webb algorithm for lateral cover in FENGSHA
5) Summary

Barry.Baker@noaa.gov

FENGSHA

Flux of Dust

Soil Erosion Potential and Source

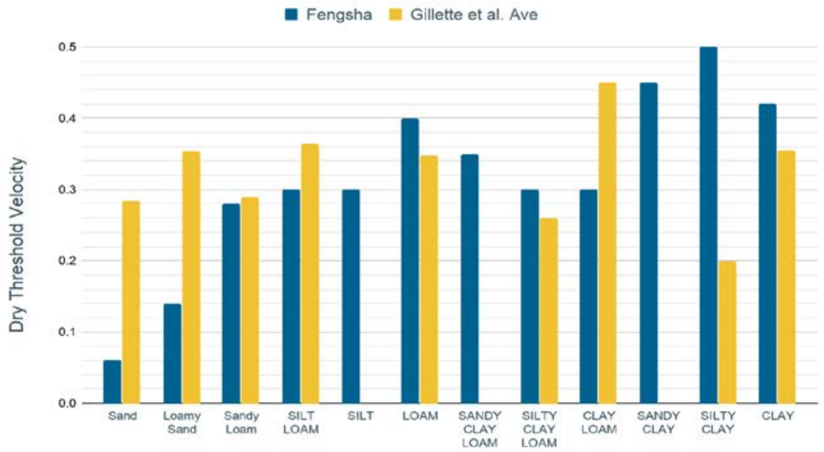
Surface Friction Velocity

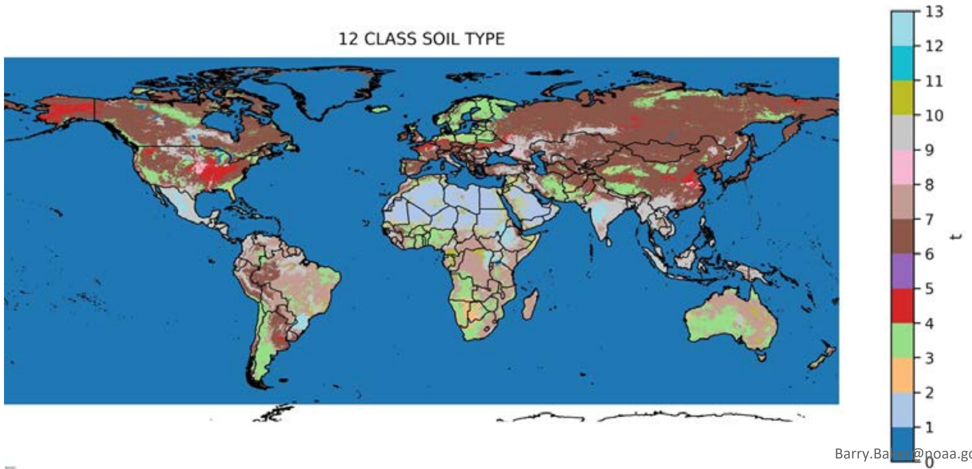
Surface Threshold Velocity

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

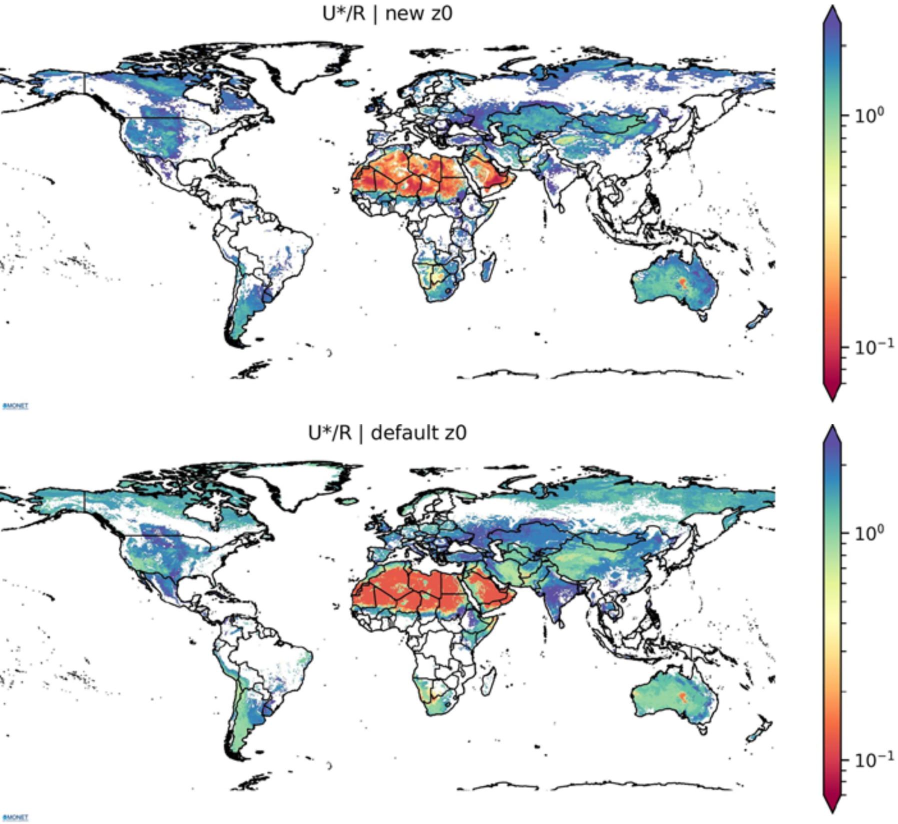
Vertical to Horizontal Flux Ratio

Horizontal Flux (Q)

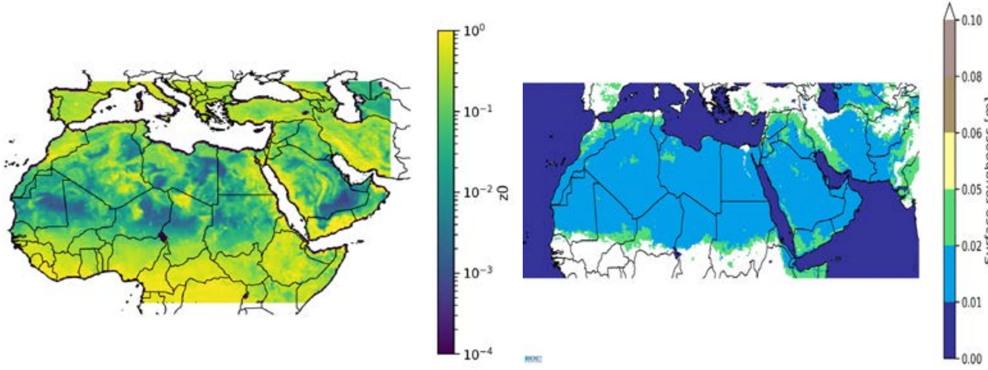




FENGSHA - Prigent et al. 2012,2015



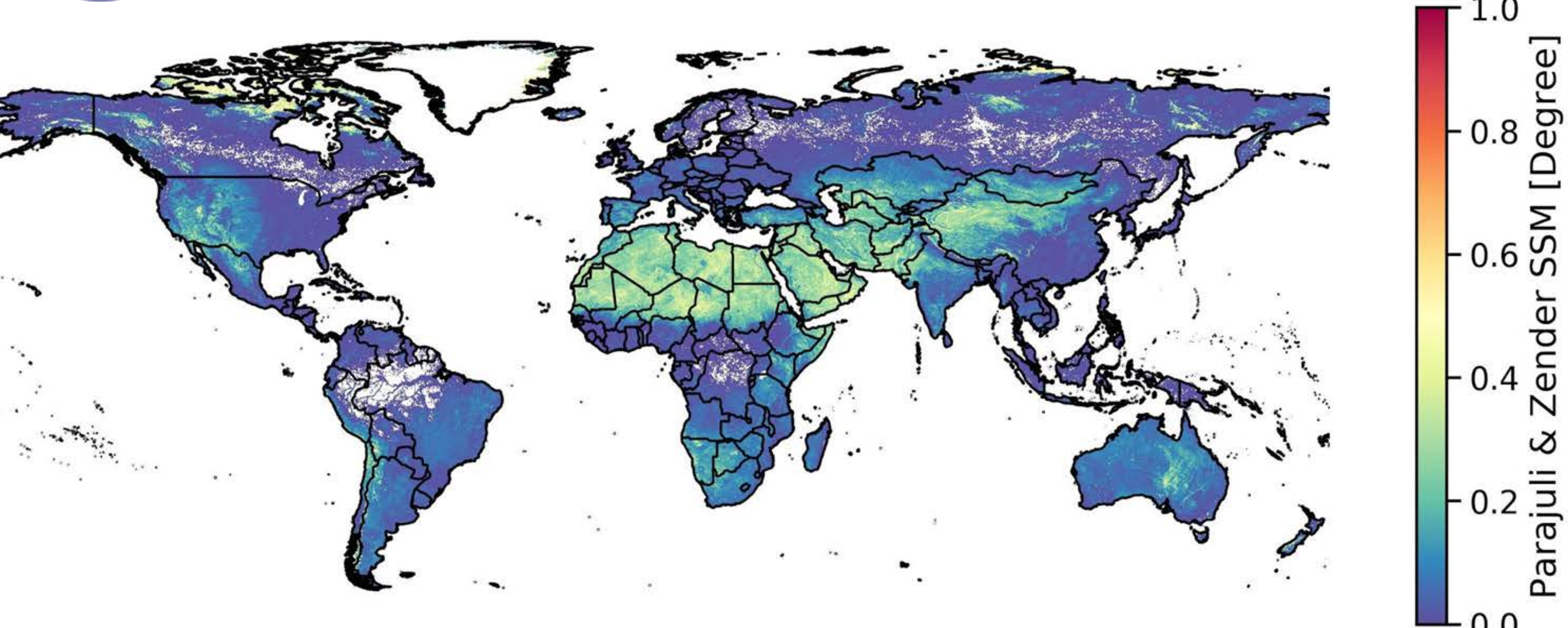
The implementation of Fengsha uses the Prigent et al. surface roughness internally within the scheme. Allowing for greater spatial variability vs the land use based method only.



Prigent et al. 2015 (DOI 10.1109/TGRS.2014.2338913)

Barry.Baker@noaa.gov

Sediment Supply Maps

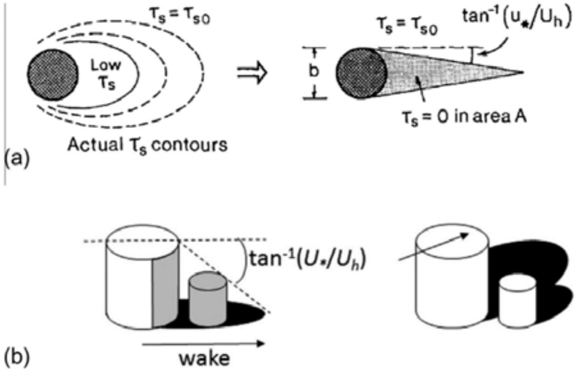


Barry.Baker@noaa.gov

The Baker-Schepanski Map (BS Map)

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

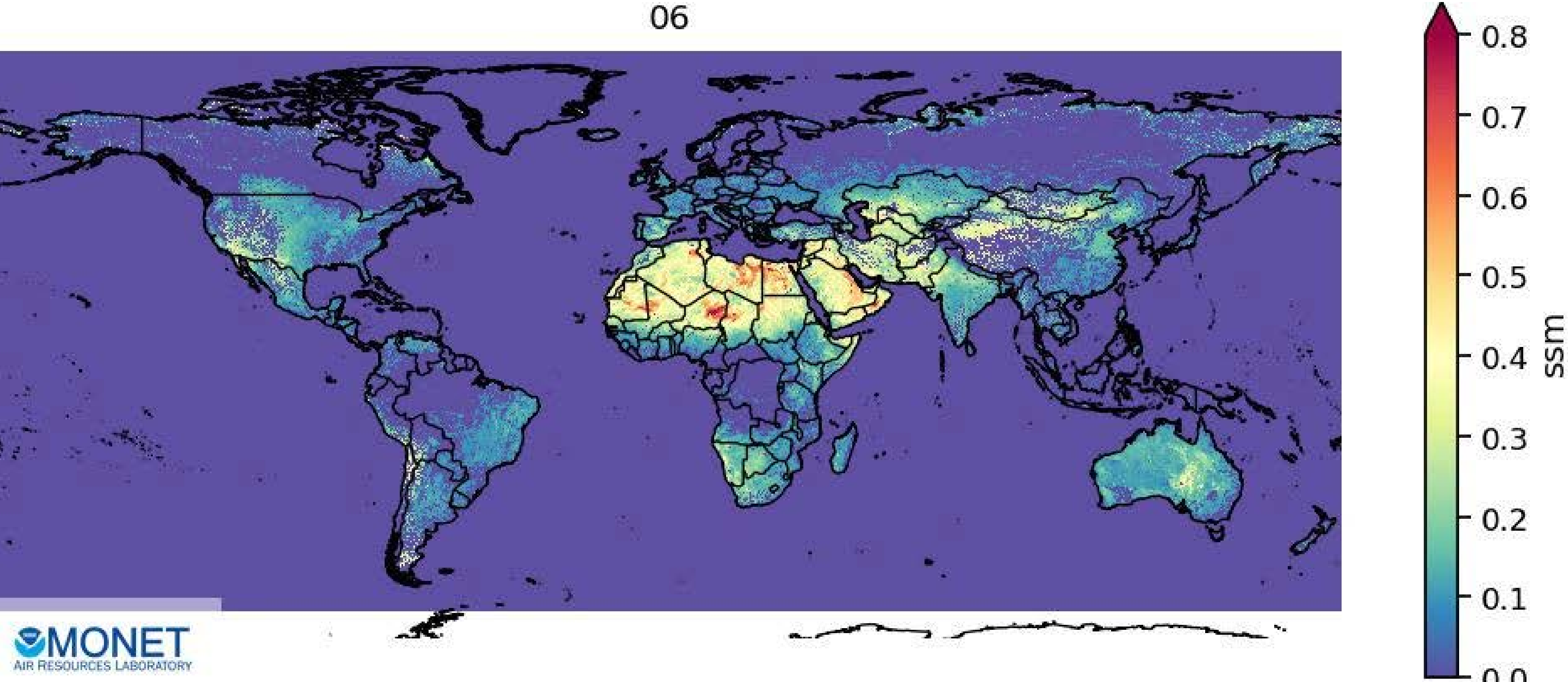
- It uses the normalized albedo to better describe the lateral cover heterogeneity
- The albedo was taken from a 3 year climatology of the Modis BRDF Albedo.



Albedo: MODIS BRDF Albedo MCD43A3 → Monthly 3 year average → Inverse → Mask with Snow/Ice → Normalize → **BS Map**: Monthly Maps of Potential Dust Sources

Barry.Baker@noaa.gov

The Baker-Schepanski Map

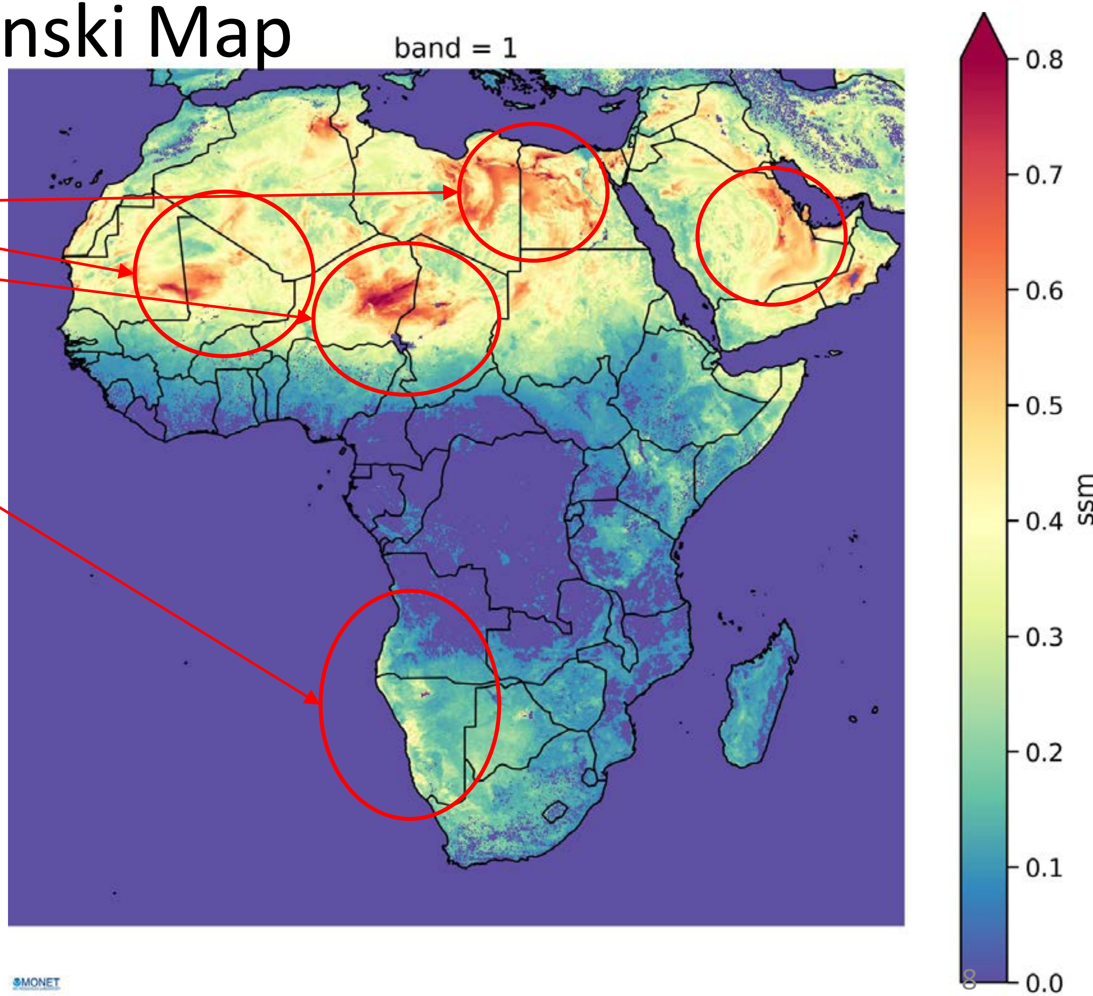


MONET
AIR RESOURCES LABORATORY

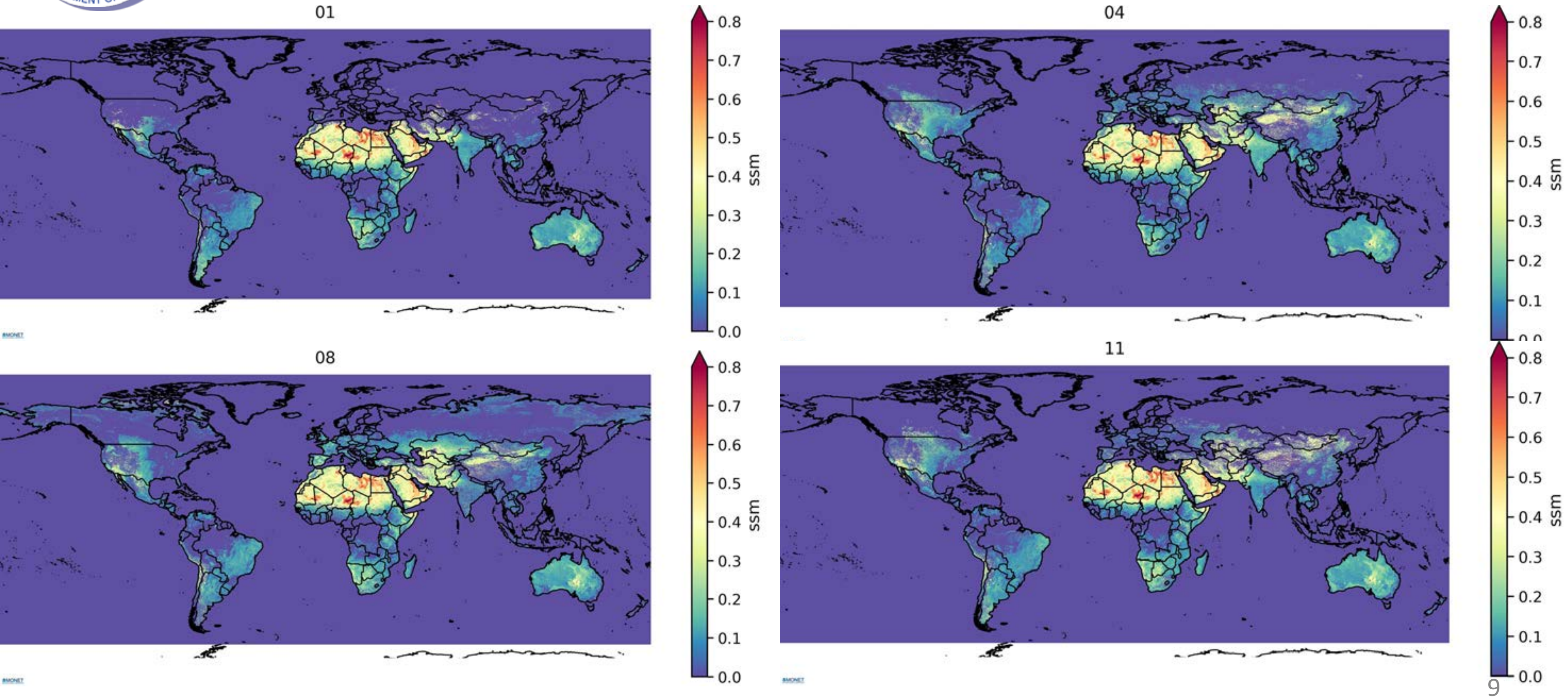
Barry.Baker@noaa.gov

The Baker-Schepanski Map

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



The BS Map CHANGES SEASONALLY!

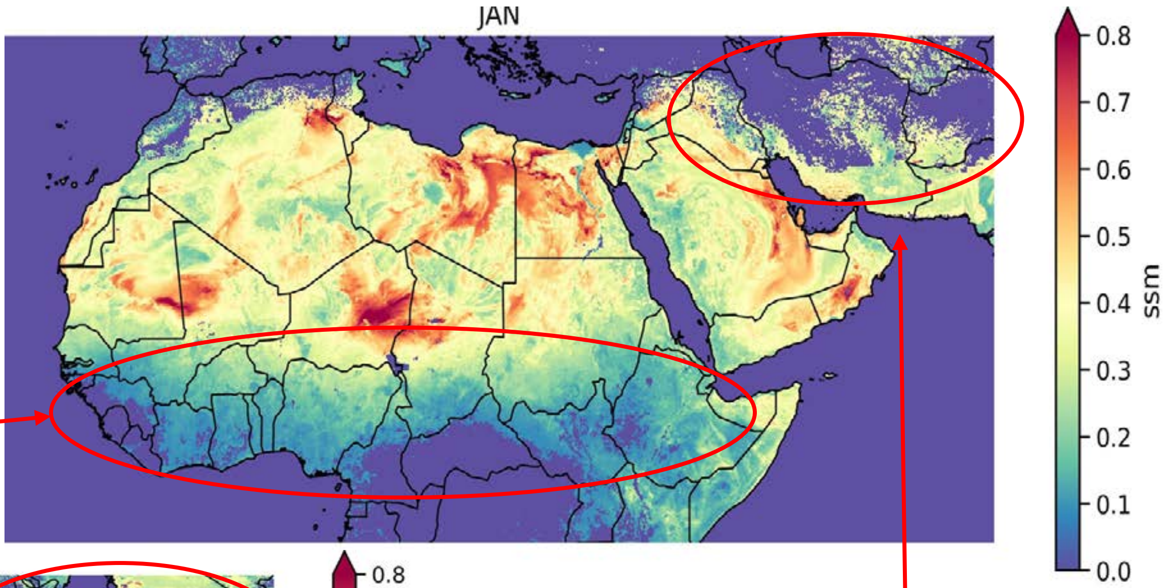


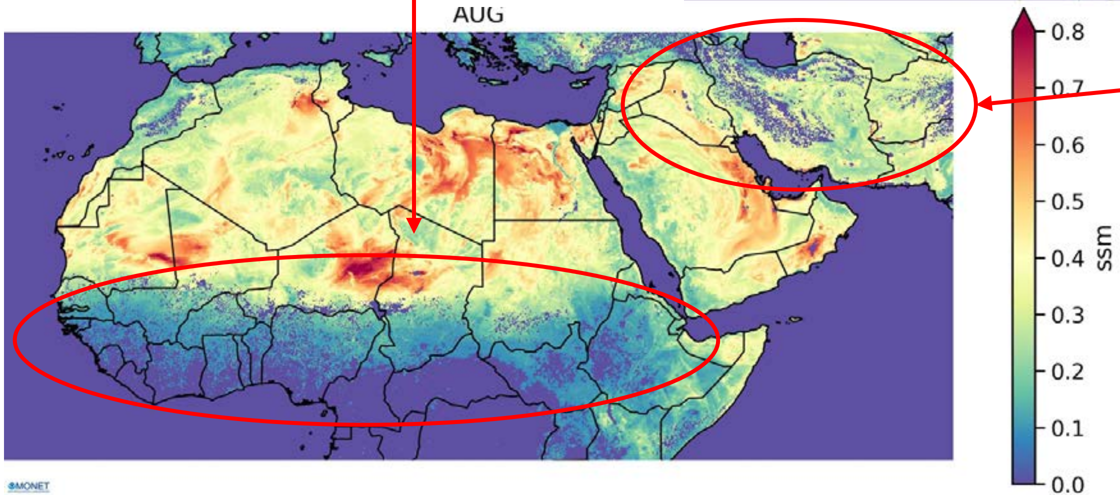
Barry.Baker@noaa.gov

The BS Map

Change of vegetation is clearly captured.

Increased resolution when creating the map (Currently used the Gridded Global Climate Grid ~6km)

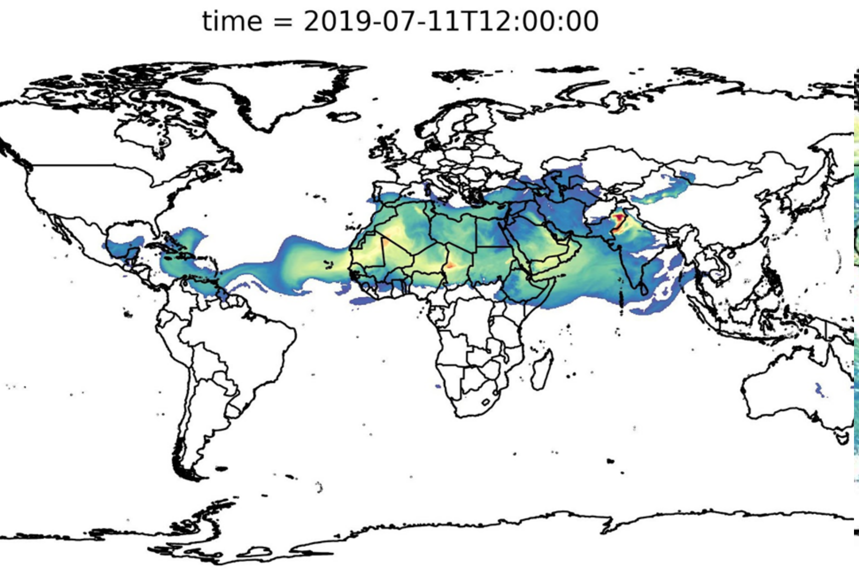


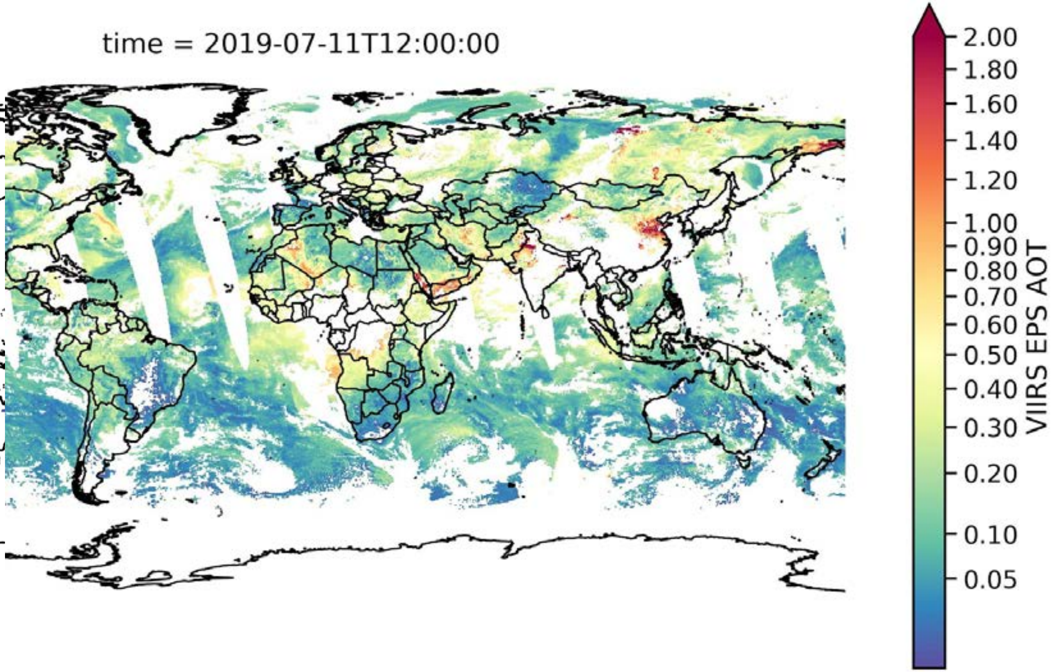


Snow Cover is also captured :)

Barry.Baker@noaa.gov

Model Application: FENGSHA



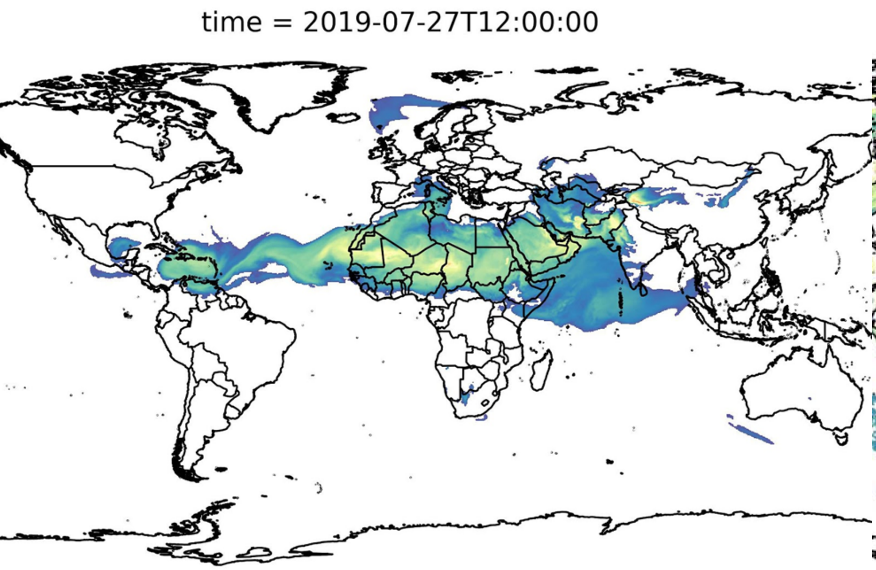


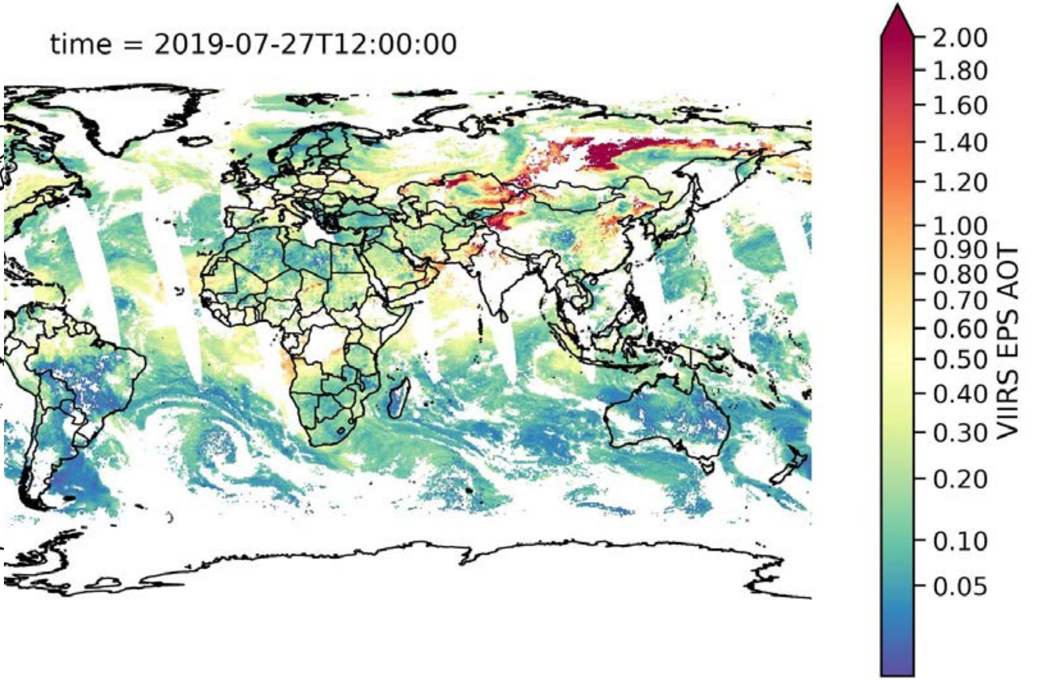
Dust AOD from FENSHA using BS-map

VIIRS AOD (dust + carbonaceous aerosol + sea spray + …

Barry.Baker@noaa.gov

Model Application: FENGSHA



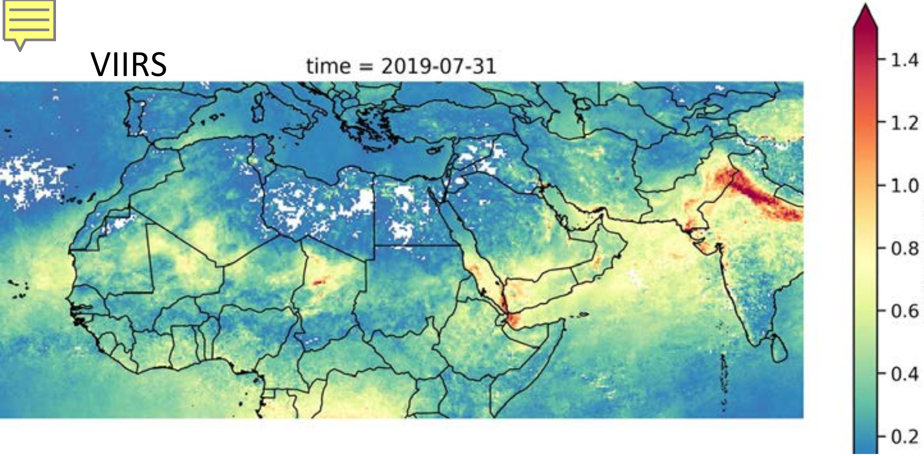


Dust AOD from FENSHA using BS-map

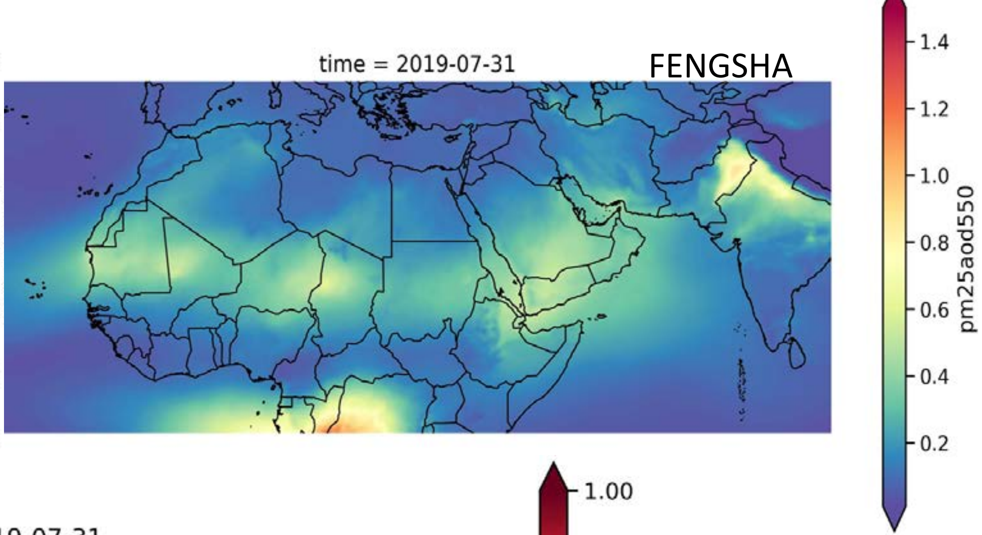
VIIRS AOD (dust + carbonaceous aerosol + sea spray + …

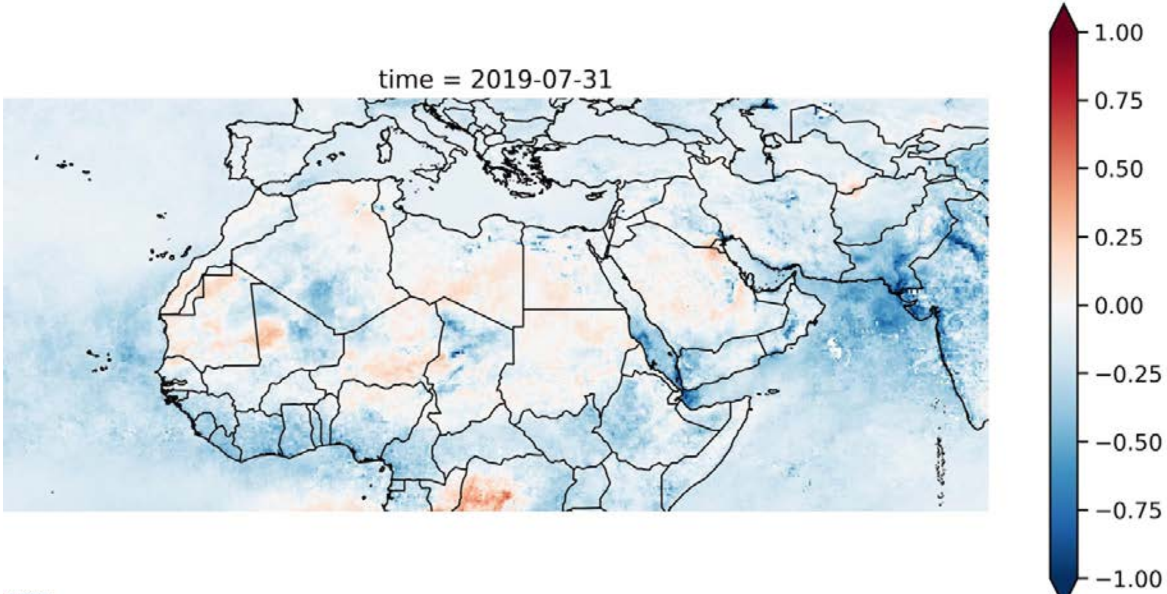
Barry.Baker@noaa.gov

VIIRS



FENGSHA

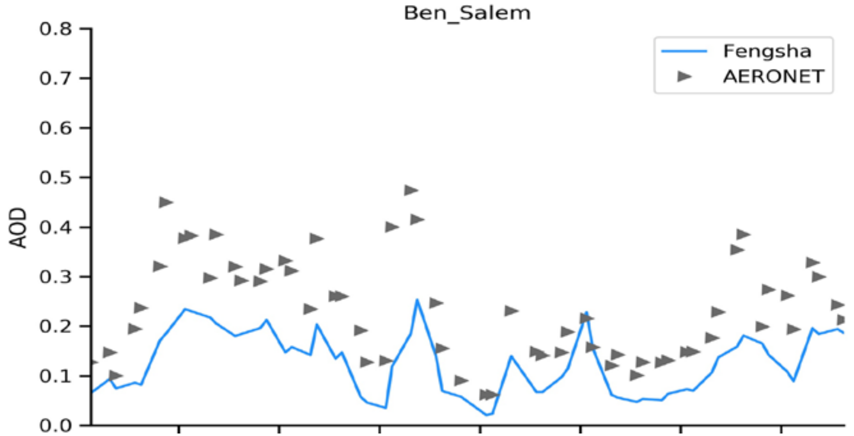


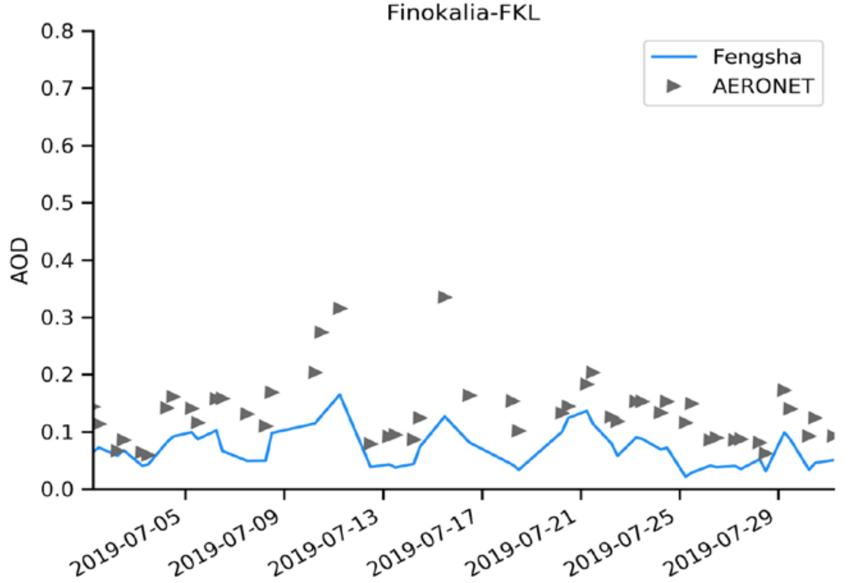


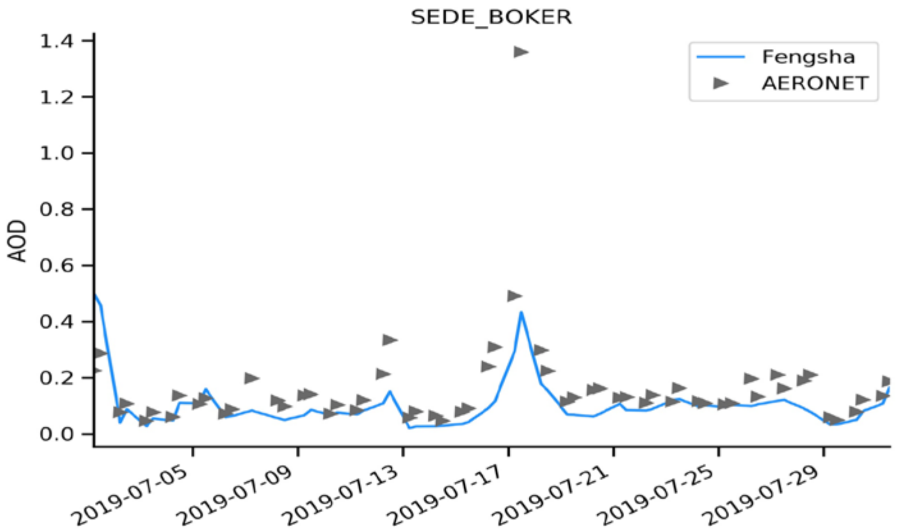
Barry.Baker@noaa.gov

FENGSHA

Fengsha does fairly well in most dust regions. Looks like it is a general magnitude underprediction of events (BUT NOT THE EVENTS THEMSELVES). Tuning is still underway for the new model application



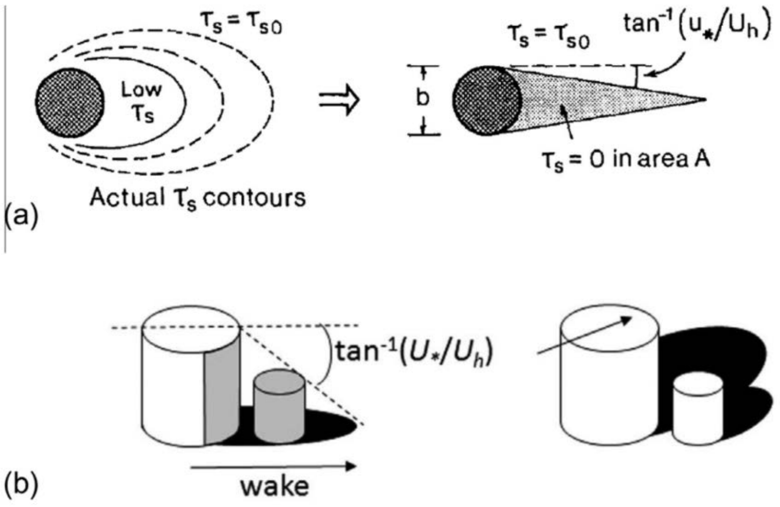


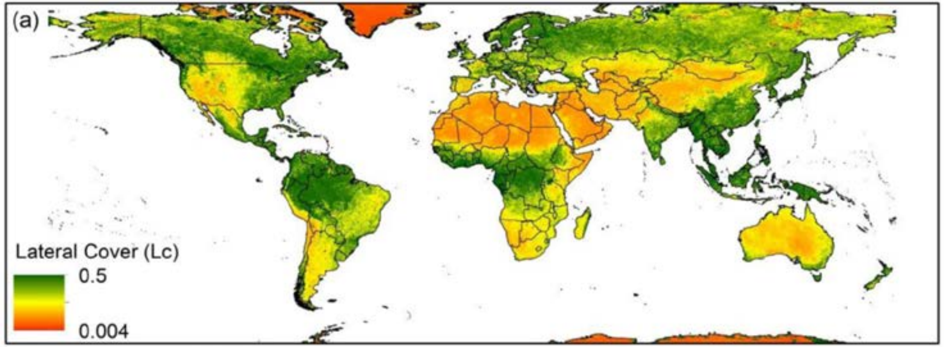


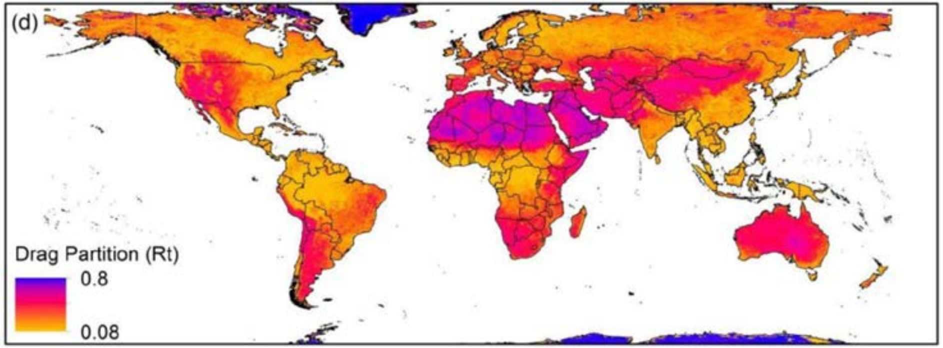
Chappel and Webb

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

Example of lateral cover





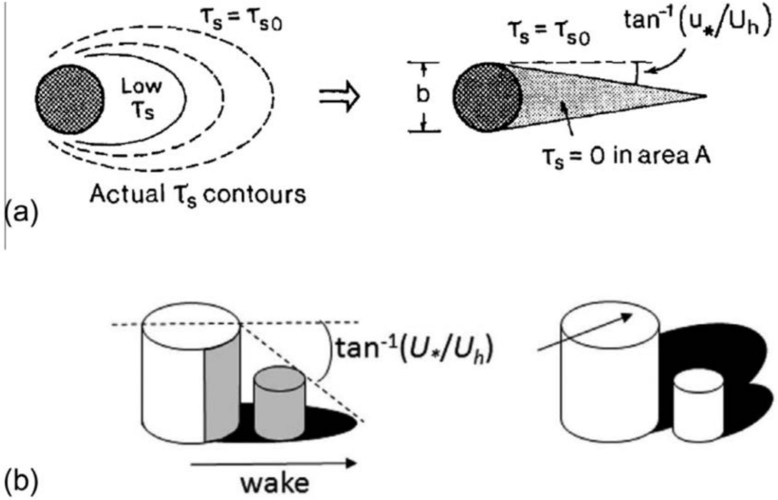


Barry.Baker@noaa.gov

Chappel and Webb

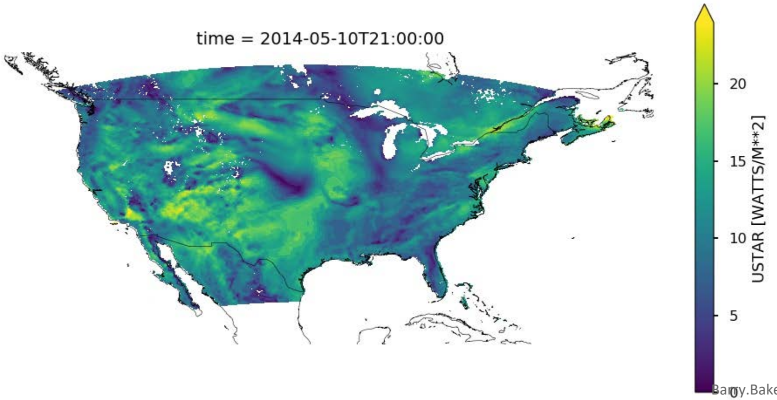
Use an albedo-based approximation of aerodynamic sheltering (Lw) to adjust surface roughness and dust emissions (Chappell et al., 2016).

Example of lateral cover

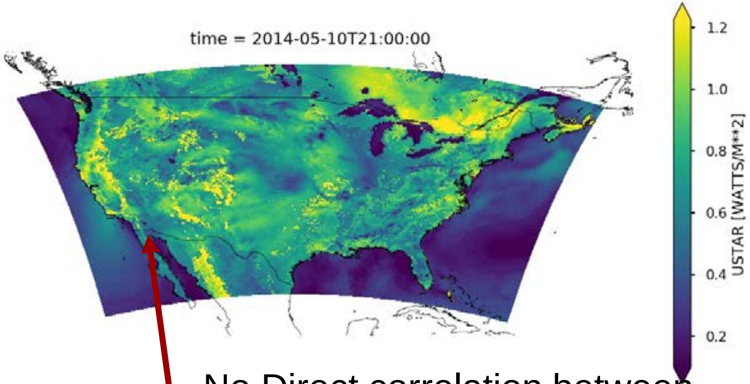


$$Q_h(U_f, D, \omega_{ns}, w) = c_{shao} \frac{\rho_a u_{S*}^3}{g} \left(1 - \left(\frac{u_{*ts} H(w)}{u_{S*}}\right)^2\right)$$

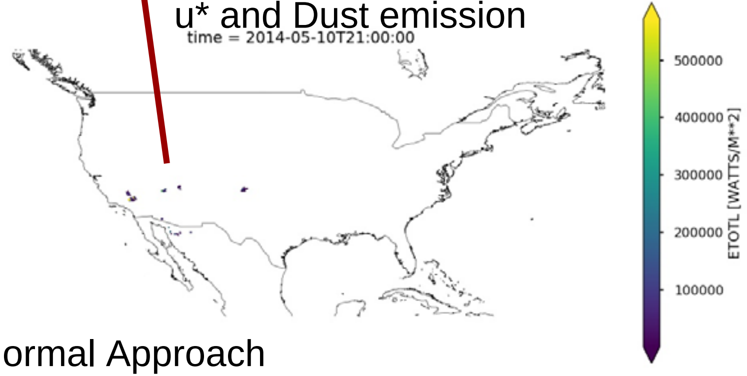
$$\frac{u_{S*}}{U_f} = 0.0311 \left(\frac{e^{-\omega_{ns}^{1.131}}}{0.016}\right) + 0.007,$$



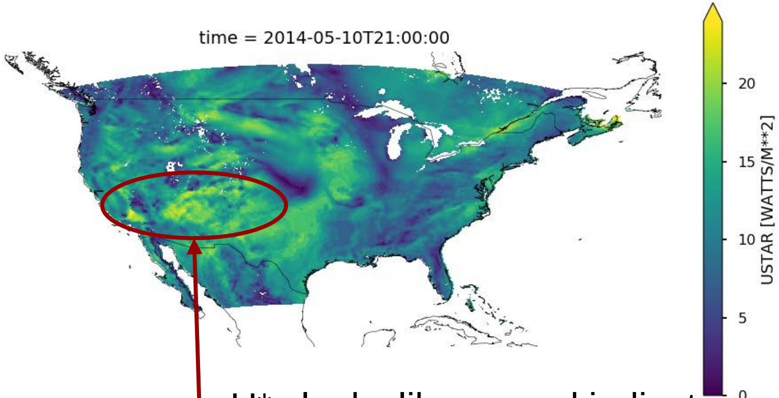
Chappel and Webb Approach



No Direct correlation between u* and Dust emission



Normal Approach



U*s looks like a good indicator

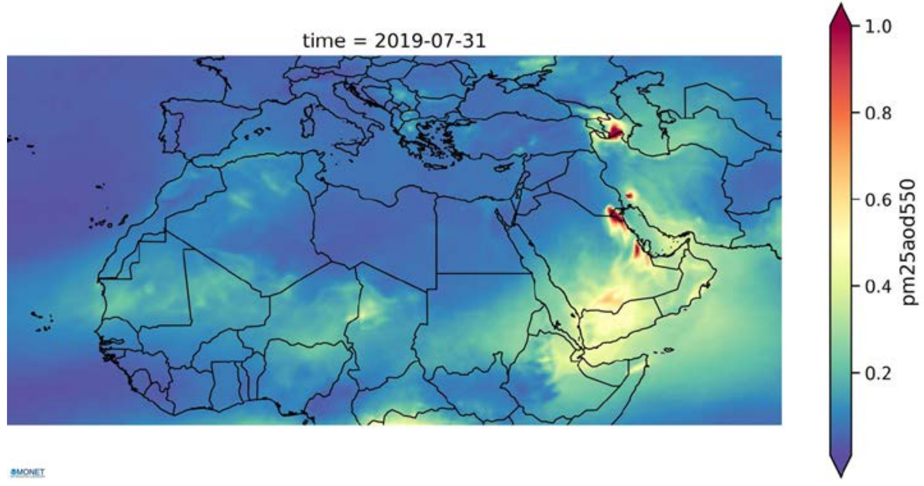
Albedo Approach

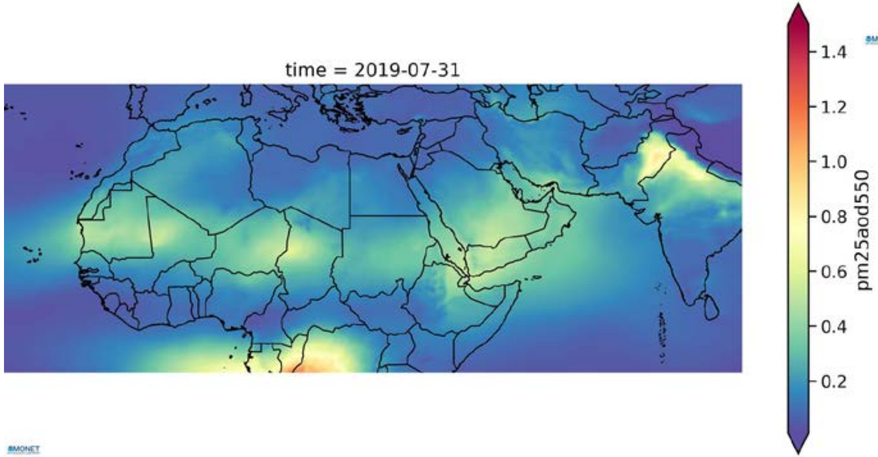
Tuning may be needed

Chappel and Webb Approach

The main advantage of the albedo approach are:

- Ability to see individual plumes
    - Doesn't smear out the information
- Allows for the BS Map to be used directly since they are essentially the same information (just an additional knob)





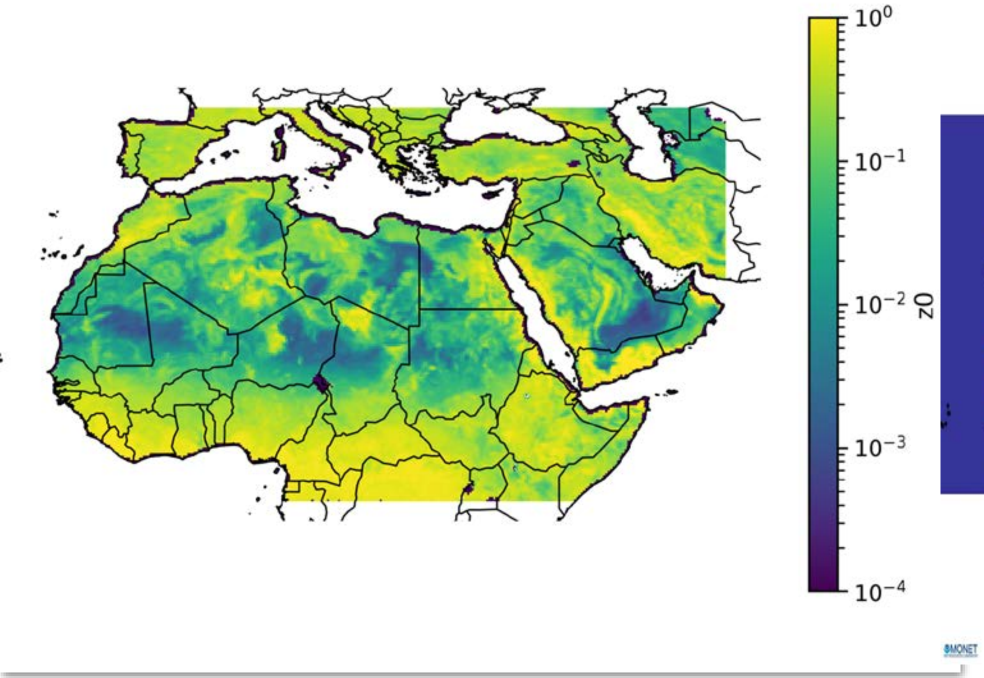
The albedo method is still in a testing stage and will not be implemented for operations at first.

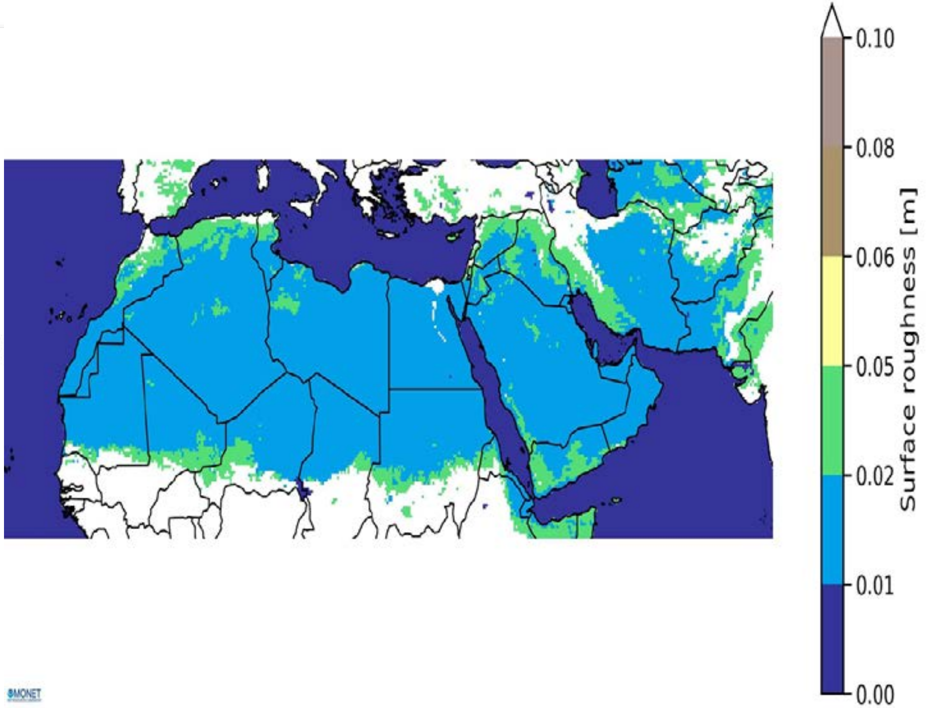
Summary

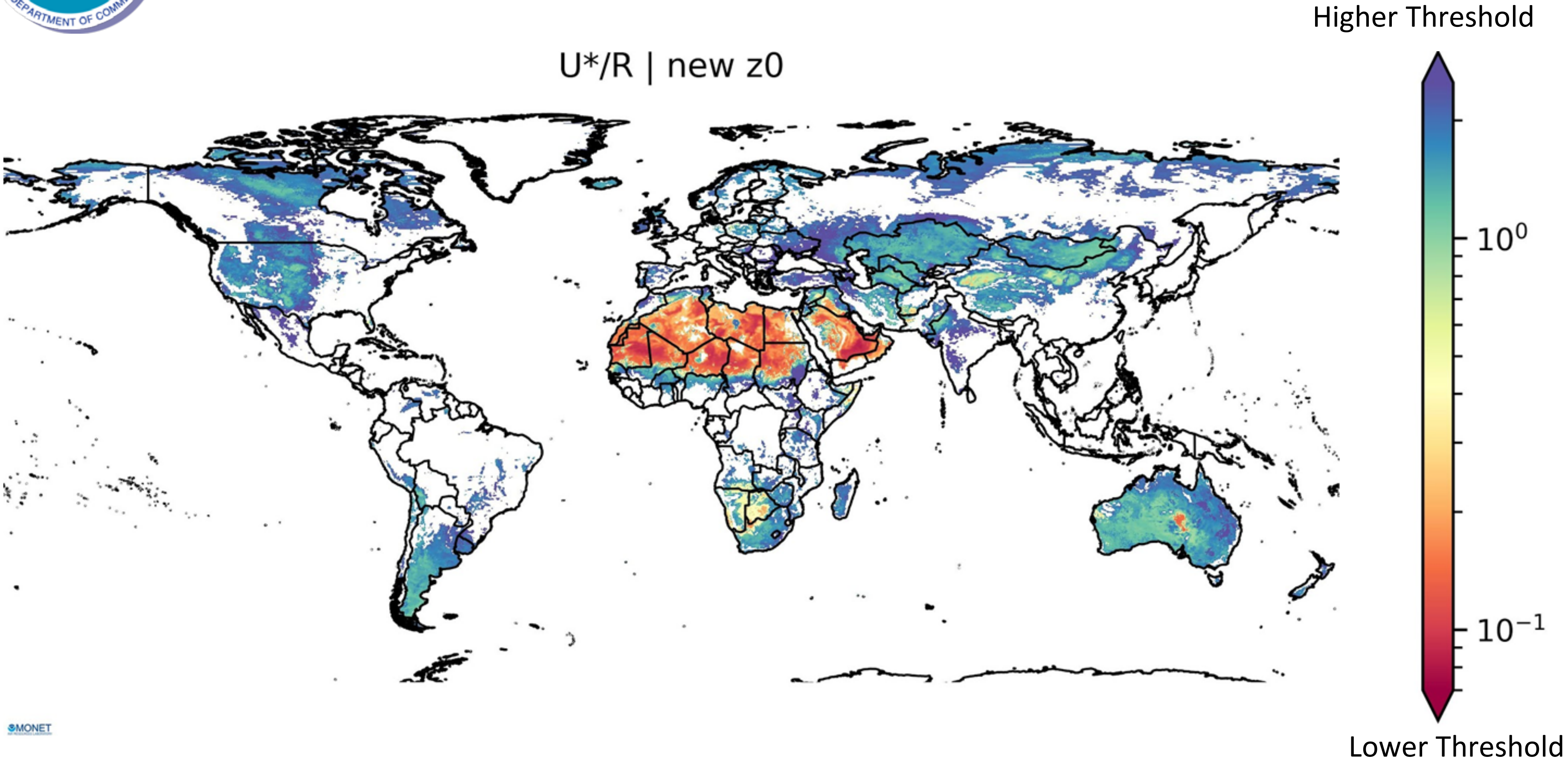
- Fengsha is the dust model developed at NOAA ARL used within NAQFC
- Fengsha has been implemented into the next generation NOAA Aerosol model (GEFS-Aerosol) with many updates - paper in progress
- A new source map, the BS map, is developed for use in regional or global dust forecasting - paper in progress
  - Uses the satellite albedo to determine dust sources
  - Can be used to change dynamically in near real time or climatology
- Fengsha compares well vs both AERONET and VIIRS
- The algorithm developed by Chappel and Webb is implemented into Fengsha to better describe the surface stress
  - Compares well against traditional methods
  - Adds ability to change lateral cover (~z0) dynamically
    - Could have more applications than just dust

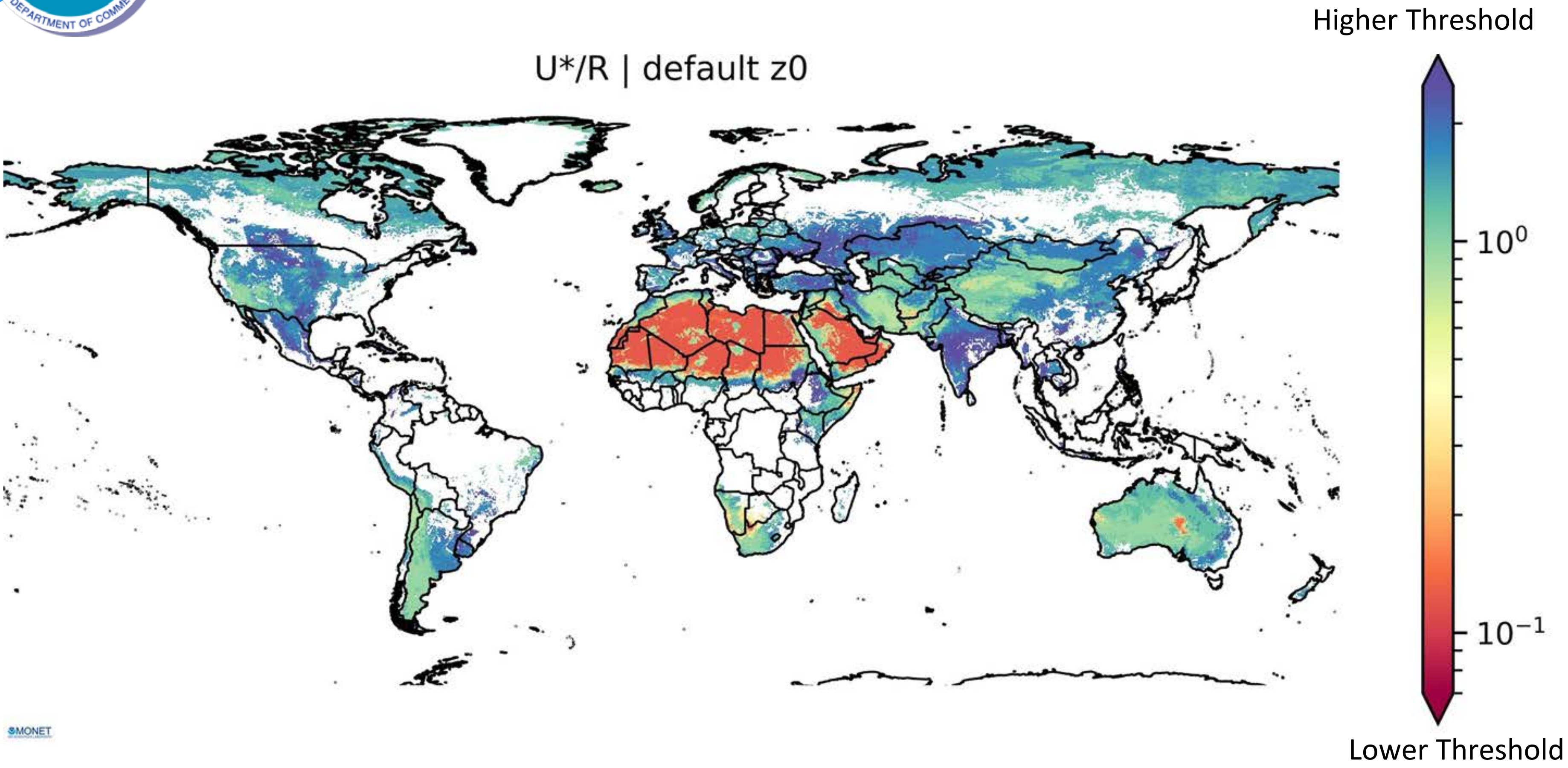
Barry.Baker@noaa.gov

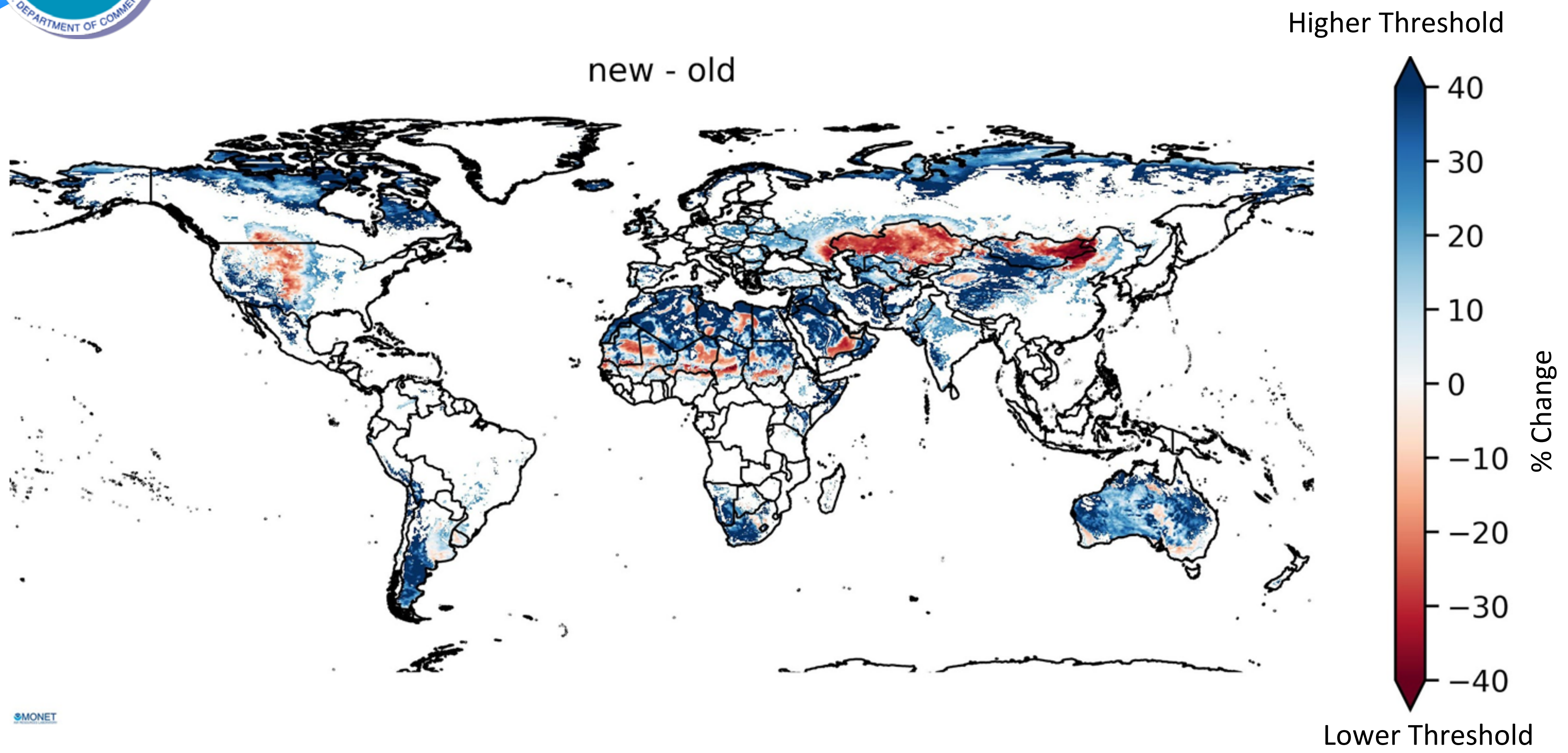
Surface Roughness is an issue. Dust models are very sensitive to ustar and therefore z0. On going work to include more description of the surface, i.e. surface stress derived from Chappel and Webb (2017) or z0 ingested from Priget et al. (2012,2015)

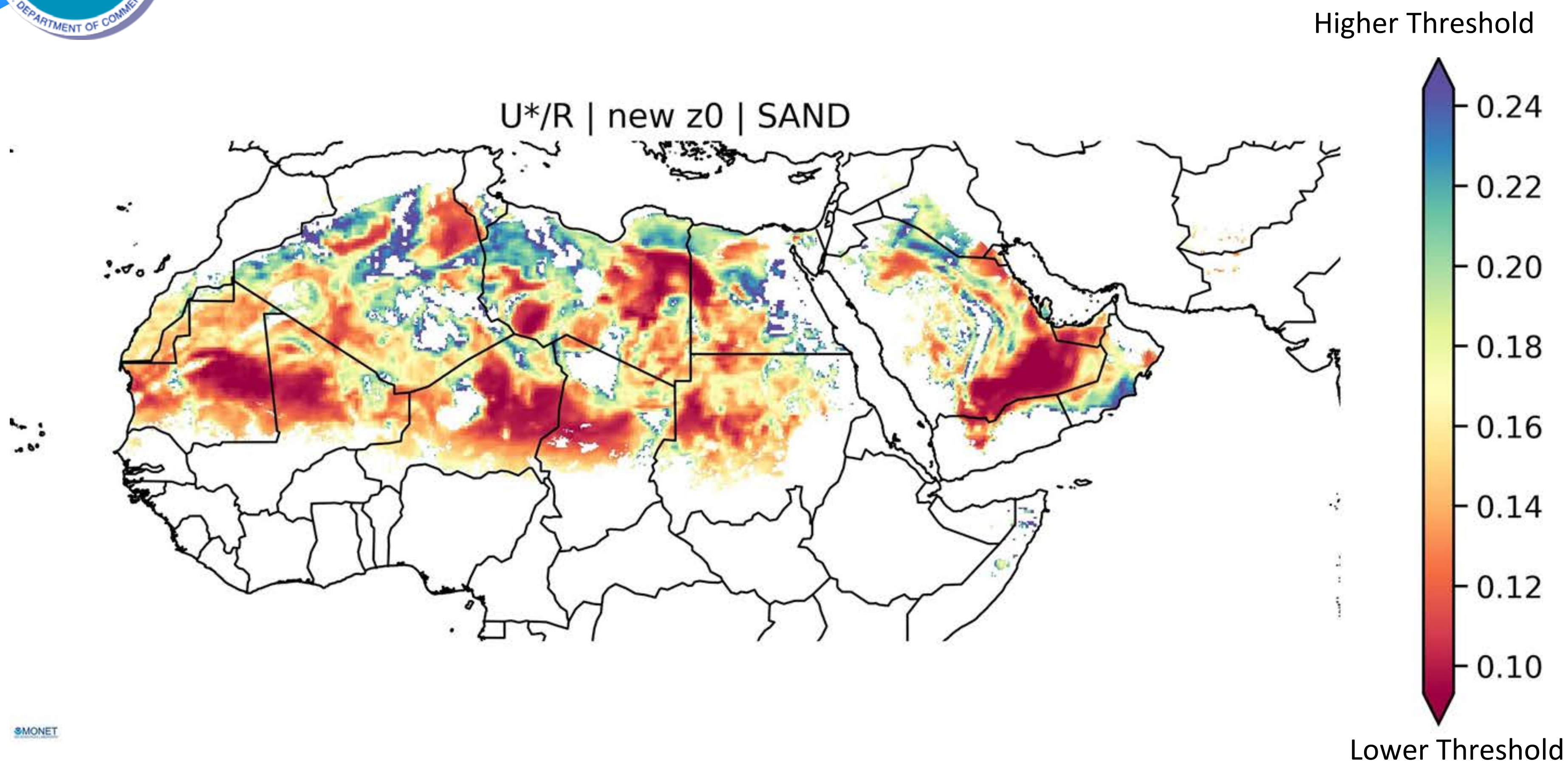




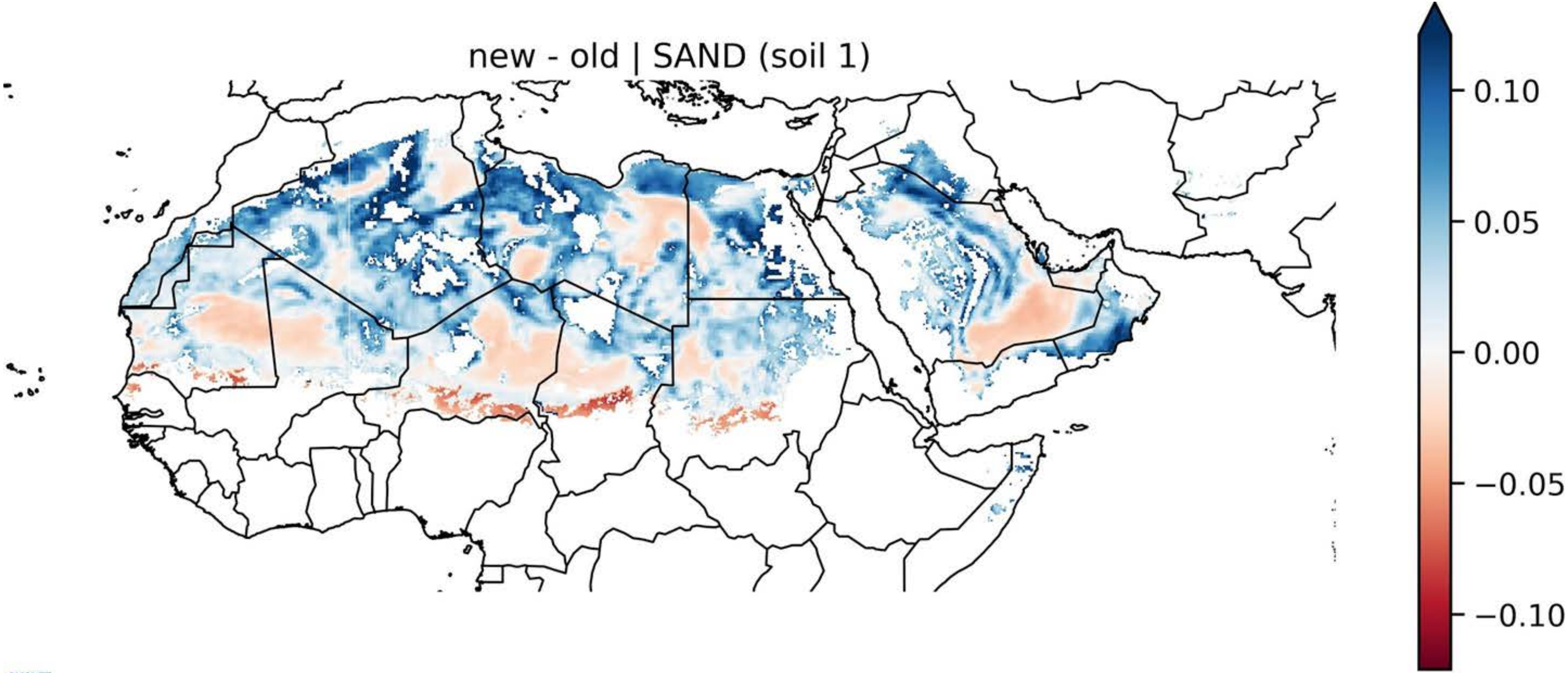

U*/R | new z0
Higher Threshold
10^0
10^{-1}
Lower Threshold
MONET


U*/R | default z0
Higher Threshold
10^0
10^{-1}
Lower Threshold


Higher Threshold
new - old
40
30
20
10
0
−10
−20
−30
−40
% Change
Lower Threshold
MONET

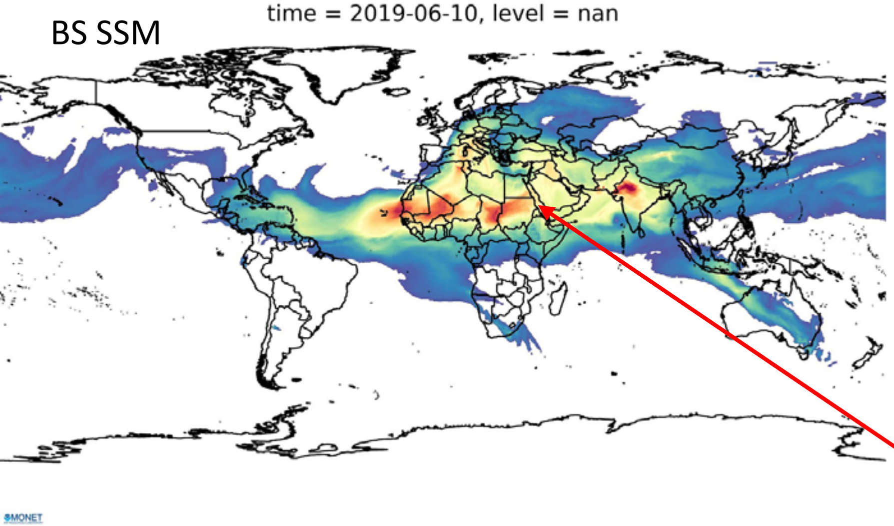

U*/R | new z0 | SAND
Higher Threshold
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
Lower Threshold

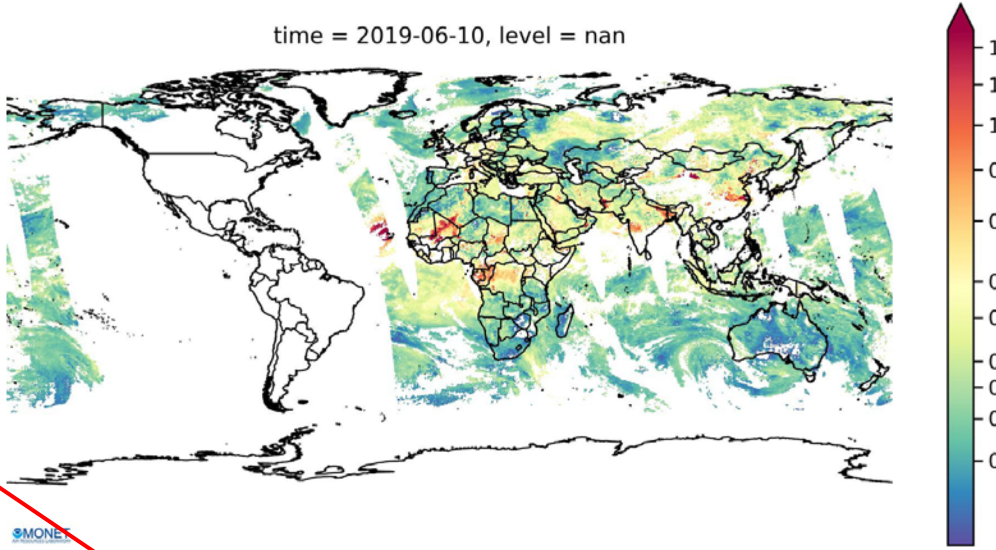
Higher Threshold



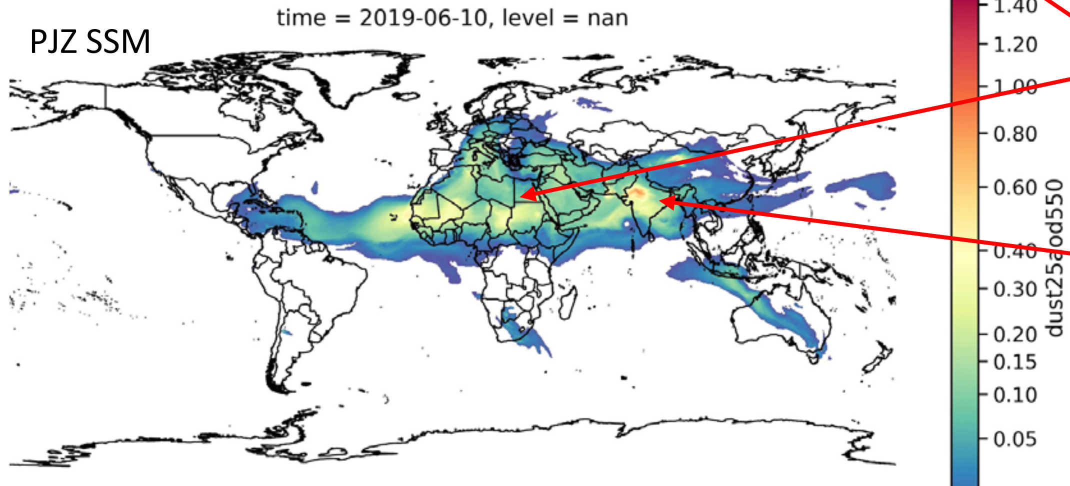
Lower Threshold

BS SSM





PJZ SSM



Better spatial heterogeneity

Erroneous emission over Pakistan/India (problem being fixed as we speak) - Fengsha allows for easy tuning of threshold values (in this case Soil type 9 and 7)

Fengsha Options

2 Soil Erodibility Potential

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

Or a sediment supply map

Required Parameters:

Option 1) Clay, Sand and Silt Content

Option 2) Parajuli and Zender Sediment Supply Map

Option 3) Newly developed Baker-Schepanski Map

3 Horizontal (saltation) flux

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

Required Parameters:

Friction Velocity
Air Density
Soil Potential

4b Vertical Flux

Lu and Shao 1999

$$\alpha = \frac{C_\alpha g f \rho_b}{2p}\left(0.24 + C_\beta u_* \sqrt{\frac{\rho_b}{p}}\right)$$

Required Parameters:

Fine fraction
Plastic pressure (constant)
Soil density
- **Option 1) constant**
- **Option 2) ISRIC Soil Database**

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

Fengsha Options

1c

Moisture Correction

if $w \geq w'$

$$H(w) = \left[1 + 1.21(w - w')^{0.68}\right]^{1/2}$$

$$w'(\%) = 0.0014(\%clay)^2 + 0.17(\%clay)$$

Required Parameters:

Gravimetric Soil Moisture (w)
Saturated Soil Moisture Content
Option 1a: Clay content parameterized based on soil texture
Option 1b: Clay Content from ISRIC database
Option 2: ISRIC Saturated Soil Moisture database

1b

Drag partition Correction $R(z_0, z_{0s})$

Option 1: MB95

$$R(z_0, z_{0s}) = 1 - \frac{\ln\left(\frac{z_0}{z_{0s}}\right)}{\ln\left[0.7\left(\frac{10cm}{z_{0s}}\right)^{0.8}\right]}$$

Option 2: MacKinnon et al 2004

$$R(z_0, z_{0s}) = 1 - \frac{\ln\left(\frac{z_0}{z_{0s}}\right)}{\ln\left[0.7\left(\frac{12255cm}{z_{0s}}\right)^{0.8}\right]}$$

Required Parameters:

- Smooth Roughness Length
- Aeolian Roughness length
  - Constant = 1e-4

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

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