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Improving Dust Emission Models: Wind Speed Bias and Alluvial Flows

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UFS Webinar, October 10th 2024

Outline

- Dust and its role in our climate system
- Dust in the wind, how wind speed bias impacts modeled dust emission
  - Study results
  - Mini-summary #1
- Alluvial flows, what are they and how can modeling them better help?
  - Study results
  - Next steps
  - Mini-summary #2
- Key takeaways

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Feb 2nd, 2012 dust storm over Arabian Peninsula. Image credit: MODIS Aqua

Introduction

Dust and its role in our climate system

- Dust particles can make up as much as **35% of all the continental aerosol mass of particles less than 10 microns in diameter.**
- Impacts the overall **radiative balance** of the planet, **hurricane formation**, and acts as **condensation nuclei** to form clouds.
- Back on the surface, dust acts as a **fertilizer for rainforests and ocean flora.**
- **Critical human health effects** from reduced air quality in our communities are important to understand our role in our climate system.

https://worldview.earthdata.nasa.gov – MODIS Corrected Reflectance

Bucher et al, 2011, Shao et al., 2011, Swap et al., 1992, Rocha-Lima et al., 2023, Kok et al., 2021, Turco et al., 2016, A. Moridnejad et al., 2015

Wind Speed Bias

Evaluation of 10-meter Wind Speed from ISD Meteorological Stations and the MERRA-2 Reanalysis: Impacts on Dust Emission in the Arabian Peninsula

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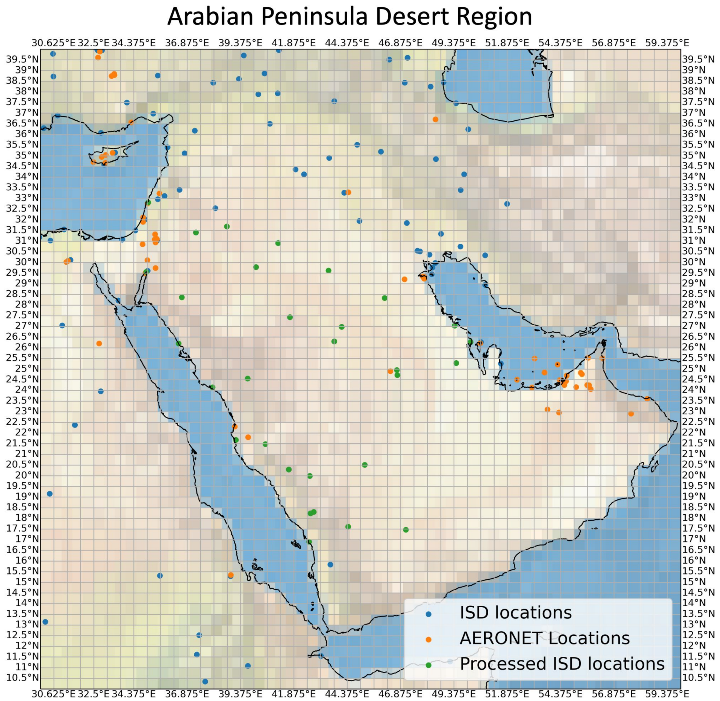
Key Points:

- Evaluated 20 years of 10-meter wind speed ISD observations against the MERRA-2 Reanalysis wind fields.
- Located sites of agreement, seasonal bias, flatness, and overestimation of winds.
- Quantified the impact of wind speed differences on dust emission at stations in the Arabian Peninsula.

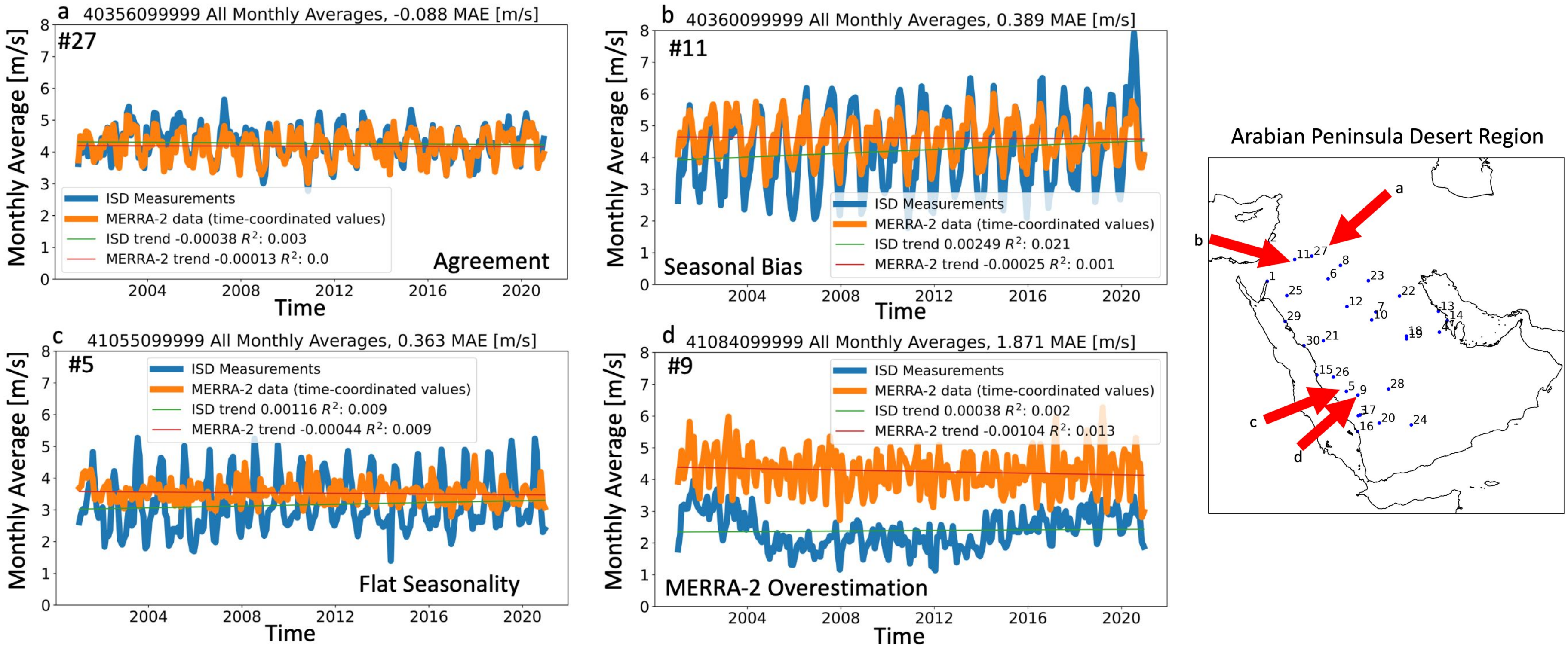
Want to read more? There's a forthcoming paper in JGR-Atmospheres

Can we quantify the bias in dust mass emission due to the observed wind speed bias within the MERRA-2 Reanalysis and the GOCART dust emission scheme?

- NOAA's Integrated Surface Database (ISD)
  - Many of the stations in the ISD are located at airports
  - Each station's data goes through a rigorous quality control process before it is included in the NOAA database
- MERRA-2 does not assimilate surface wind measurements over land but does assimilate pressures.
- **Using ISD wind speed, what biases do we see?**

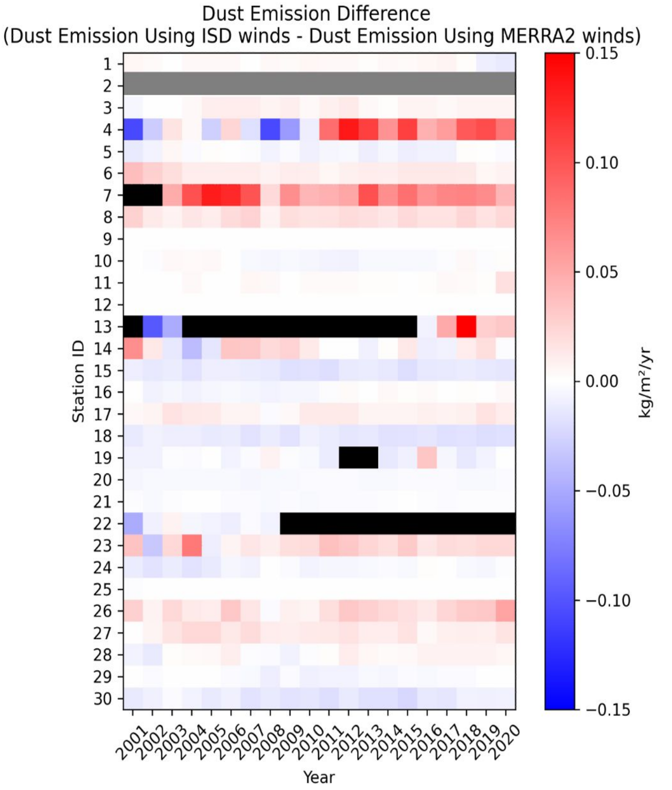


Wind Speed disagreement is NOT uniform!

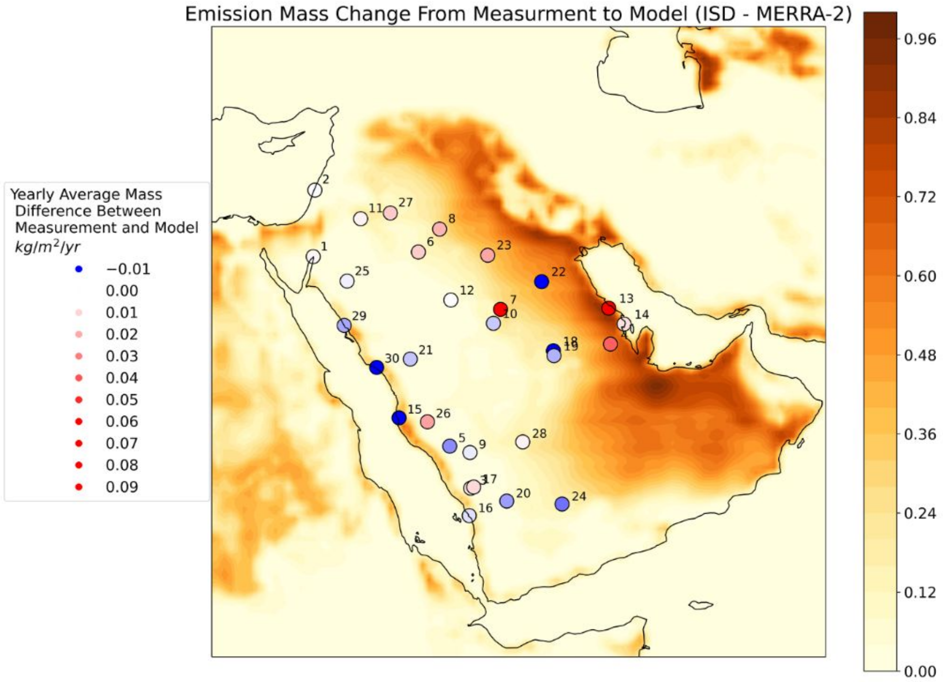


The monthly averages of each month for 20 years of the 10 m wind speed from both the ISD and MERRA-2 for the 4 case study stations. These plots show that there is consistency in the differences through time - there isn't one anomalous season that dominates the average.

UMBC Differences in Wind Speed Lead to Emission Bias…

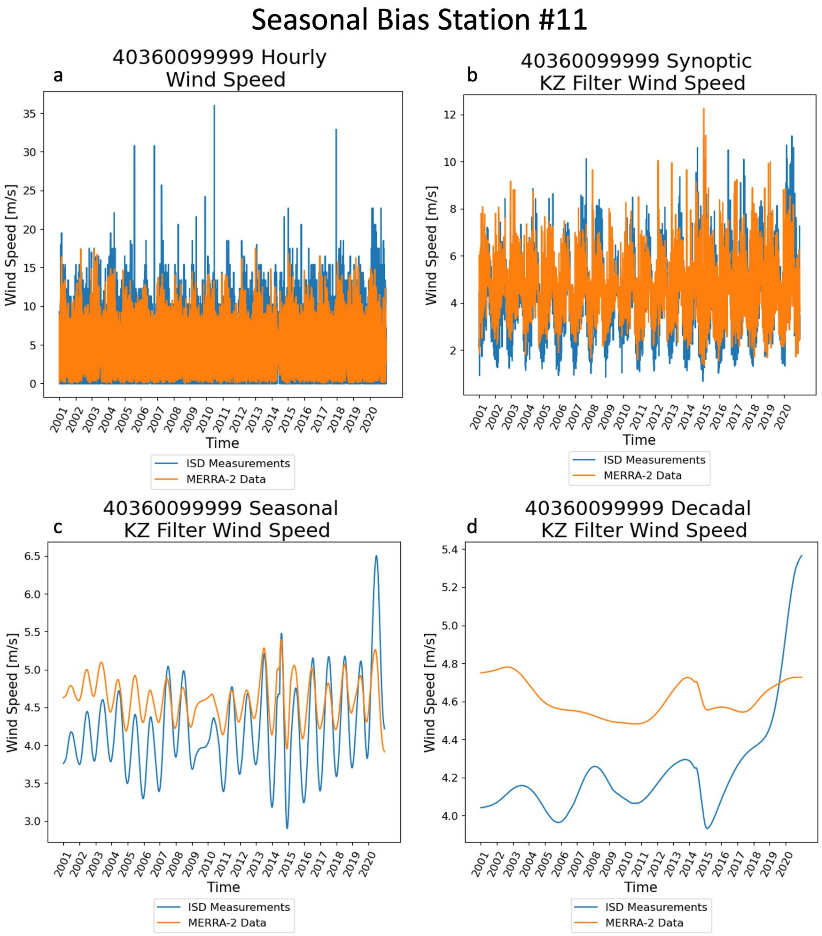


Average differences in dust emissions. Red boxes show stations where ISD winds would increase emission, blue shows where using ISD winds would decrease the emissions.



Twenty-year average of the difference in mass of dust emitted that results from only changing the 10-meter wind speeds at these locations.

… Because of the 10m wind speed parameterization



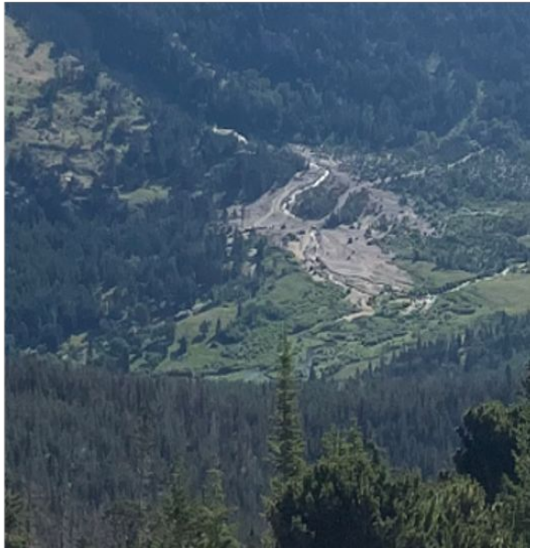
Panel a shows similar values of hourly wind speed throughout the entire study period. The synoptic cycle in panel b shows missing magnitude in MERRA-2 both in peaks and troughs. The seasonal cycle shown in panel c of MERRA-2 misses troughs by almost 1 m/s throughout time. The decadal shows a similar 1 m/s miss throughout most of the time period in panel d.

Summary part 1

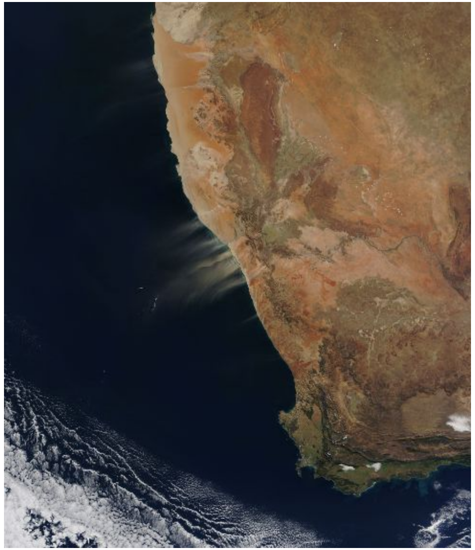
- Quantified differences in wind speed between measurement and model differ throughout space and time for our 20 year study. Differences exist for different reasons in different locations.
- The differences in wind speed propagated to differences in dust mass emitted as calculated by the procedure in the GOCART dust emission scheme. These also vary in space and time.
- The time series analysis shows that the seasonal to sub-seasonal wind speeds need improvement within the GEOS model.
- A more ‘realistic’ comparison of 10m wind speed and threshold wind speed within the GOCART dust emission scheme should be explored.

How this can help UFS:

Meso-scale circulation biases are not unique to MERRA-2 or GEOS, they are generally difficult to model, along with sub-grid parameterizations which must be included to better understand dust in our climate system.



Alluvial fan in Rocky Mountain National Park, USA

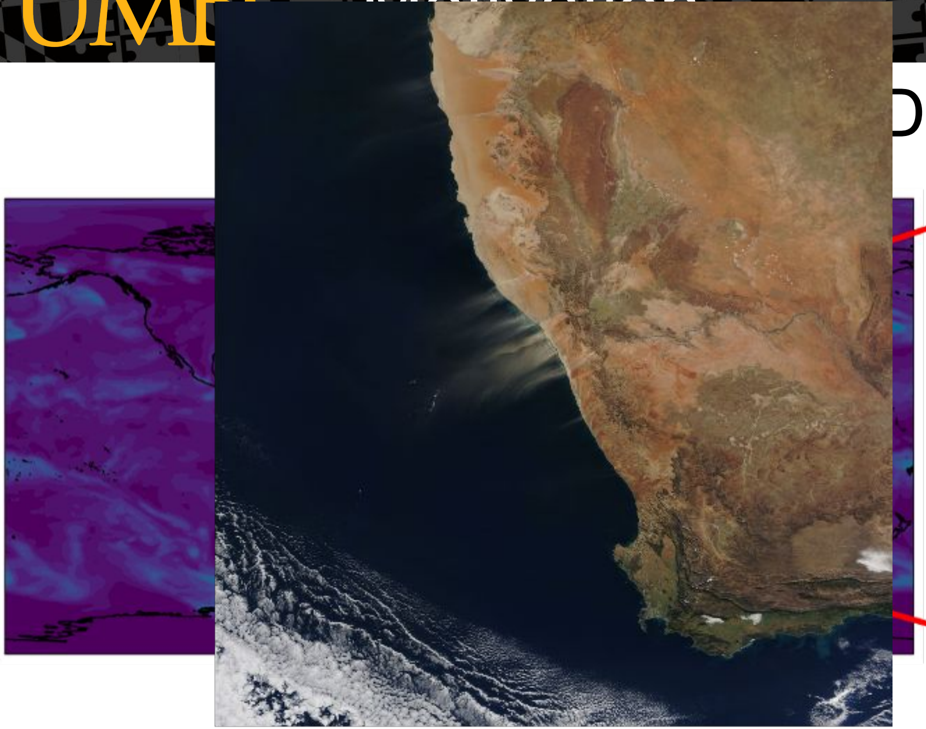


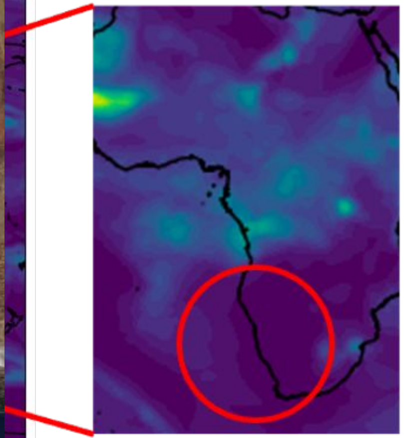
Alluvial sediments streaming off the coast of Namibia (image credit: MODIS)

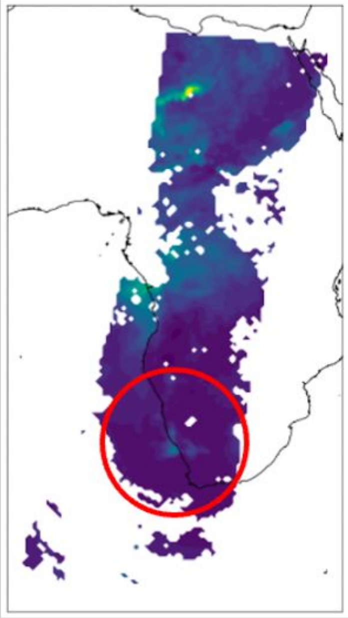
Alluvial Representation in UFS

Motivation

D Comparison





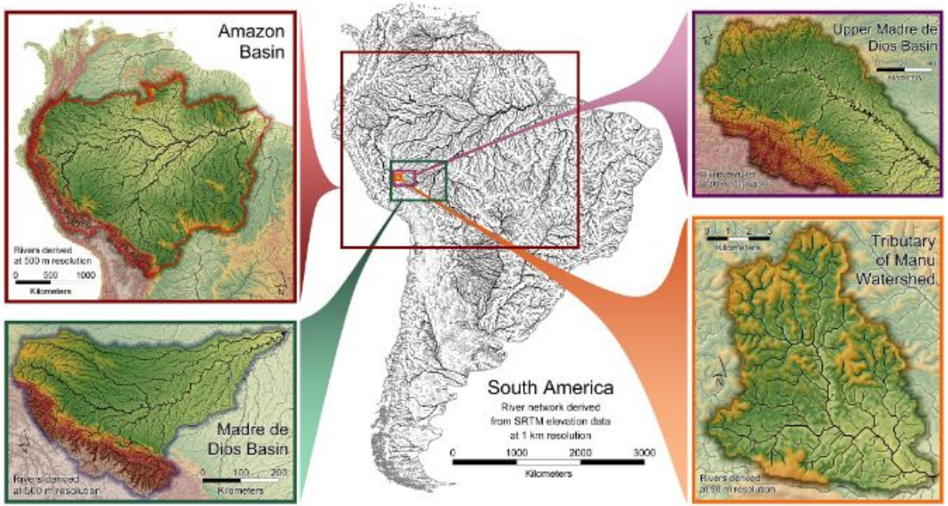


Left: Modeled AOD on June 16th, 2020. Middle: Highlights the coast of Namibia and the missing emission due to alluvial flows. Right: MODIS AOD over the same region at the same time with highlighted retrieved AOD in line with the emissions seen in the RGB

1. ***Can we better represent alluvials in the dust emission scheme?***
2. ***Can we use the source map to better understand our climate system?***

UMBC HydroSheds

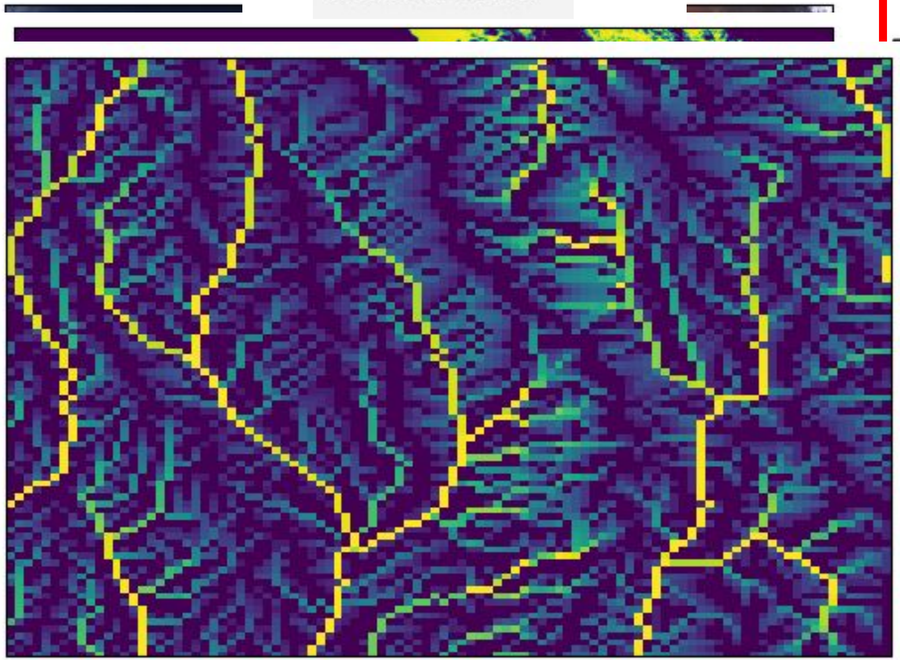
- The **HydroSHEDS** project was initiated in 2006 by **World Wildlife Fund US**
- The core data products of **HydroSHEDS v1** were derived primarily from the **SRTM** (Shuttle Radar Topography Mission) digital elevation model at a resolution of **3 arc-seconds (~90 meters at the equator)**
- At the time of creation, HydroSHEDS **outperformed** HYDRO1k (a widely used global hydrographic dataset from the USGS)
- The **flow accumulation** maps distributed with HydroSHEDS define the extent of upstream area (either in number of cells or in hectares) draining into each cell.
    - **Flow accumulation** considers the latitudinal distortions of cells.

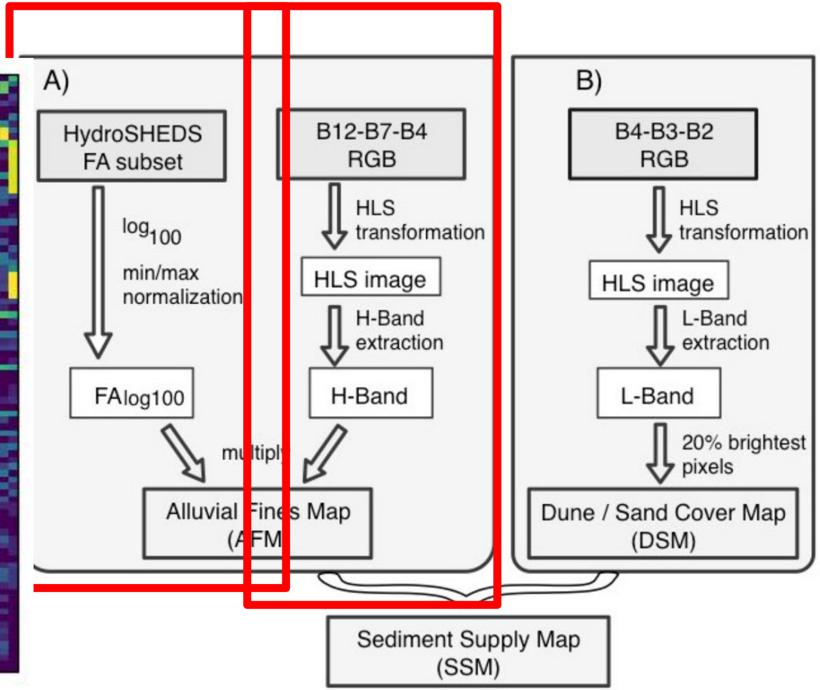


Lehner, B., Verdin, K., Jarvis, A. (2008): New global hydrography derived from spaceborne elevation data. Eos, Transactions, 89(10): 93-94. Data available at https://www.hydrosheds.org.

Alluvial Flows Methods

min/max normalization



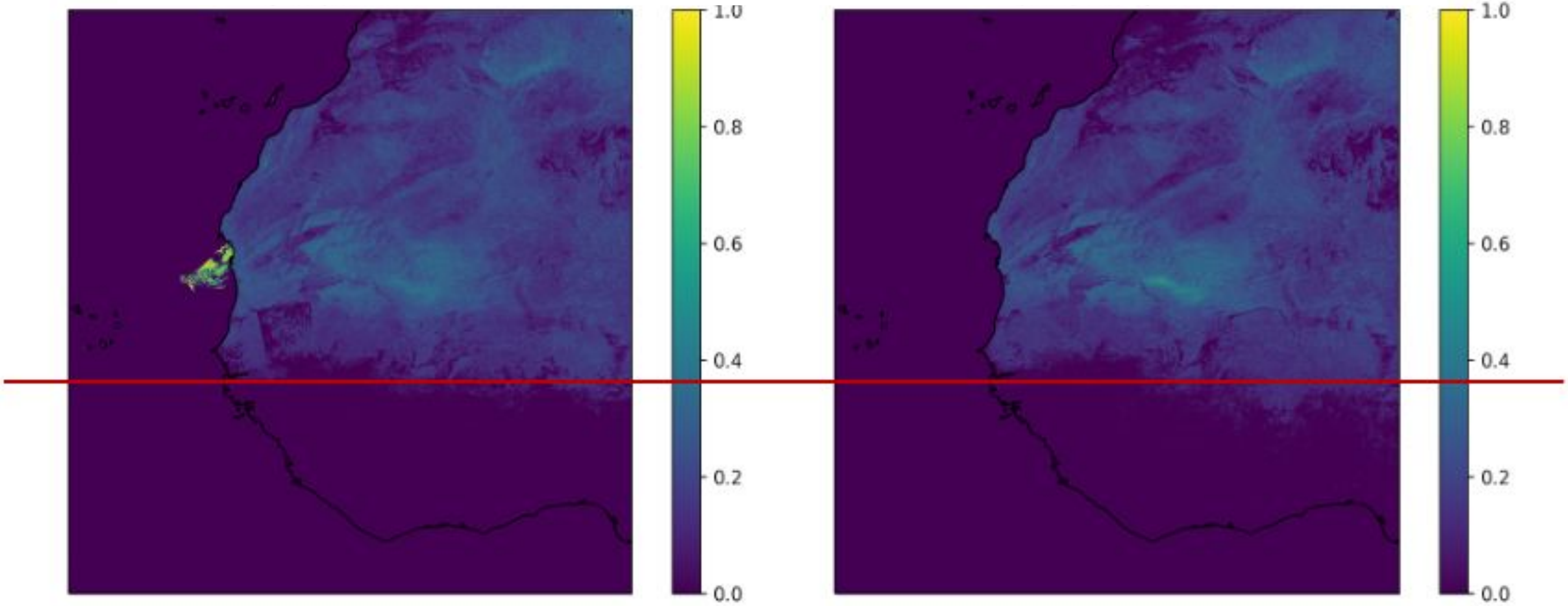


location with known alluvial flows

Feuerstein, S., & Schepanski, K. (2018). Identification of Dust Sources in a Saharan Dust Hot-Spot and Their Implementation in a Dust-Emission Model. *Remote Sensing*, *11*(1), 4. https://doi.org/10.3390/rs11010004

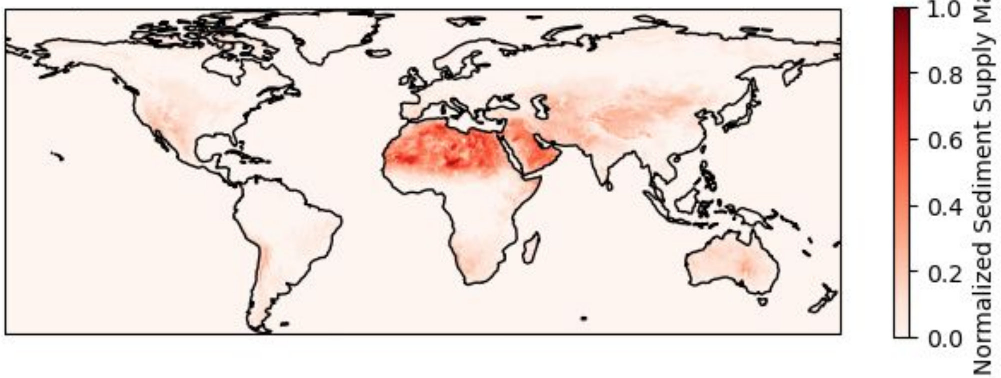
Scale and Validation Steps

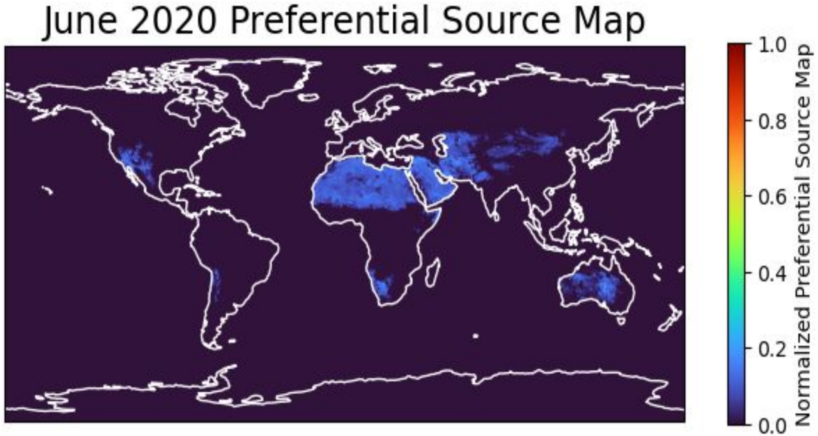
Seasonal Shifting of Source Regions in the Sahel [June vs January 2020]



Next steps, put it back into model

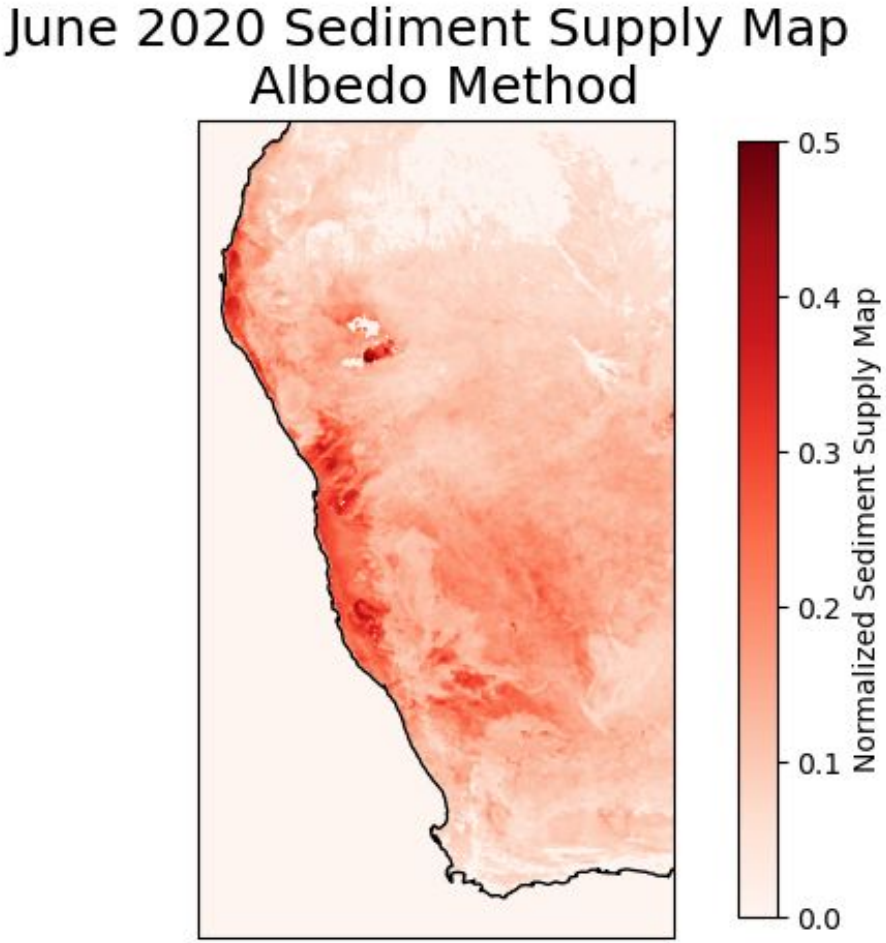
June 2020
Albedo Method SSM [Current to UFS]

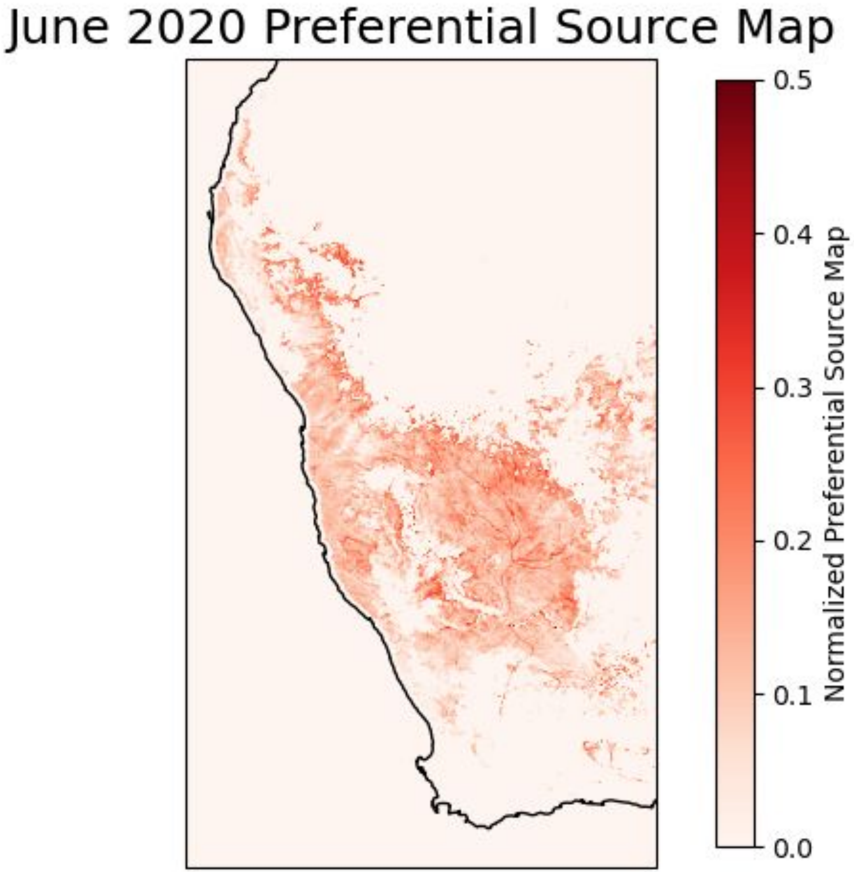




Left: June 2020 SSM as it is used in the baseline run and the UFS FENGSHA scheme. This map is derived using an albedo method. **Right**: June 2020 preferential source map (PSM) highlighting the areas of alluvial sediments.

Next steps, put it back into model





Summary part 2

- Alluvial flows are not currently well defined in the UFS, though they are impactful sources of dust emission in observed AOD.
- Alluvial surfaces can be mapped using reflectance. They capture seasonality and fine scale features.
- Monthly mappings are good representations of physical processes and seasonality

Next: Add the monthly preferential source map back into the FENGSHA dust emission scheme and re-run the same experiment to study the AOD differences.

How this can help UFS: Alluvial sediments make up around 31% of the emitted dust and accounting for where on the planet's surface these emissions are coming from will improve the estimation of the mass of dust emitted.

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Key takeaways

- Wind speed and source control work together in models to estimate mass of dust emitted.
- Wind speed estimation can be improved by better parameterizing seasonal to subseasonal scale circulations and by using an updated threshold wind speed calculation.
- Preferential source maps can be improved with the addition of alluvial sediment identification.
- Ultimately, the UFS can help to further our understanding of where in the world dust comes from and how much of it there is.
- Addition of the alluvial map will help answer questions we have about source apportionment, human health impacts, and climate change effects.

Thank you

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CV