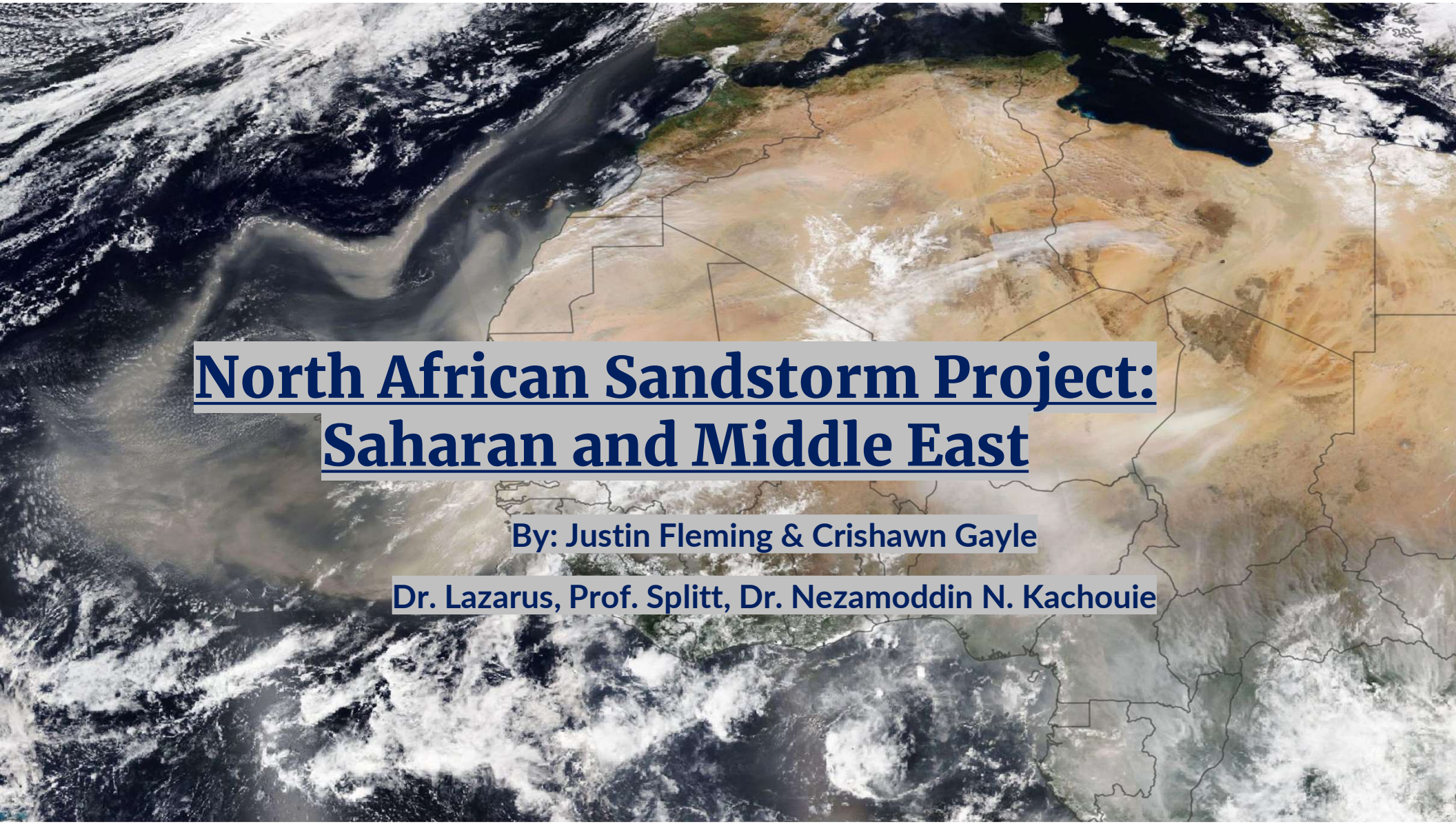


North African Sandstorm Project: Saharan and Middle East

By: Justin Fleming & Crishawn Gayle

Dr. Lazarus, Prof. Splitt, Dr. Nezamoddin N. Kachouie

What is a dust storm?

The World Meteorological Organization (WMO) definition: “The result of surface winds raising large quantities of dust into the air and reducing visibility at eye level (1.8 m) to less than 1000 m (McTainsh and Pitblado 1987).”

Definitions of the particle size of mineral dust vary, but here the range of <1 – 63 microns is used as a guide, which is approximately equivalent to the silt (2 – 63 microns) plus clay (<2 microns) size fractions in soils and sediments.

The majority of particles transported more than 100 km from the source are <20 microns in diameter

As a guide, sand size particles are larger than about 0.06 mm (60 microns).

Slide 2

1 You have to tell folks what they are - their characteristics!

Also we are looking at dust storms not sand storms. Please make sure you are referring to dust storms.

I added these - please shorten and tighten!
Steven Lazarus, 7/5/2023

Factors related to dust storms

TABLE 1: KEY PHYSICAL FACTORS INFLUENCING WIND EROSION

Climate	Sediment or Soil	Vegetation	Landform
Wind speed (+)	Soil type	Type	Surface roughness
Wind direction	Particle composition	Coverage (–)	Slope (–)
Turbulence (+)	Soil/sediment structure	Density	Ridge
Precipitation (–)	Organic matter (–)	Distribution (+/–)	
Evaporation (+)	Carbonates (–)		
Air temperature	Bulk density		
Air pressure (+)	Degree of aggregation (–)		
Freeze-thaw action	Surface moisture (–)		

Source: UNEP, WMO, UNCCD, 2016; Shi et al., 2004; Middleton and Goudie, 2006.[35]

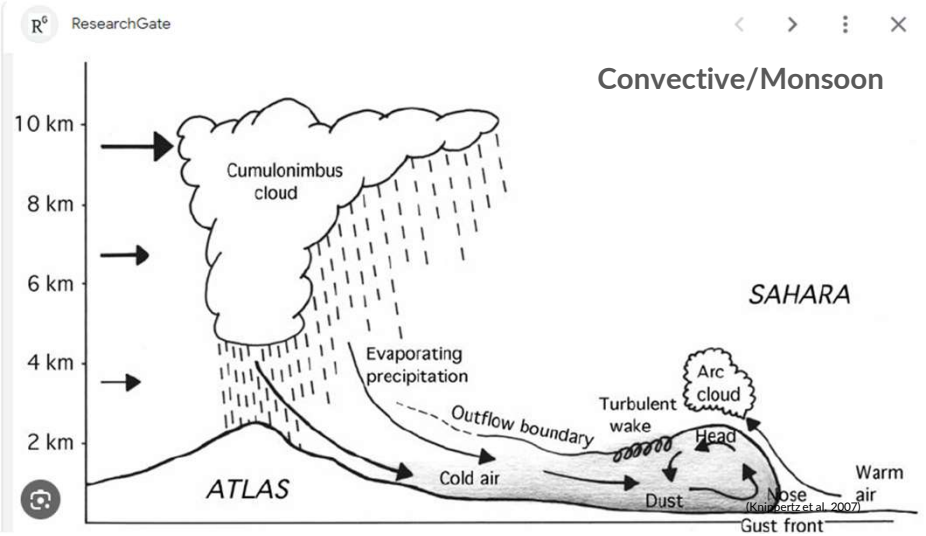
(ScioU, 2018)

Video of a sand storm in the Sahara desert

Different scales: Fronts, Jet streams, Convection

West Africa and Sahel:

- Africa Easterly Jet (AEJ)
- Monsoon convection
- Flat/ arid area (Bodelle Depression)
- Strong winds capable of picking up dust and debris from bare, dry erodible soil



Dust storm Impacts

Saharan Air Layer (SAL)

Video showing 'Godzilla' dust storm come from North Africa to the US

(Edwards, Charlotte, July 14 2020)

- Strong winds mid level easterly flow transport dust across the Atlantic toward the Caribbean and the US.

- The dust particles from SAL impact solar radiation (intensity) and affect tropical cyclones.
  - The minerals in the dust particles also heat the atmosphere which increases the rate of evaporation. This affects cloud lifetime, causing clouds to last longer.

- An estimated average of 500 million tonnes of minerals, nutrients, organic matter, and inorganic materials are transported to the oceans by sand and dust storms.
  - The nutrients from the sand storm fertilizes algal blooms.
    - They've been linked to the extensive blooming of Sargassum across the Atlantic ocean.

Research Question

(Duns, Aug 2022)

(Marty, 2020)

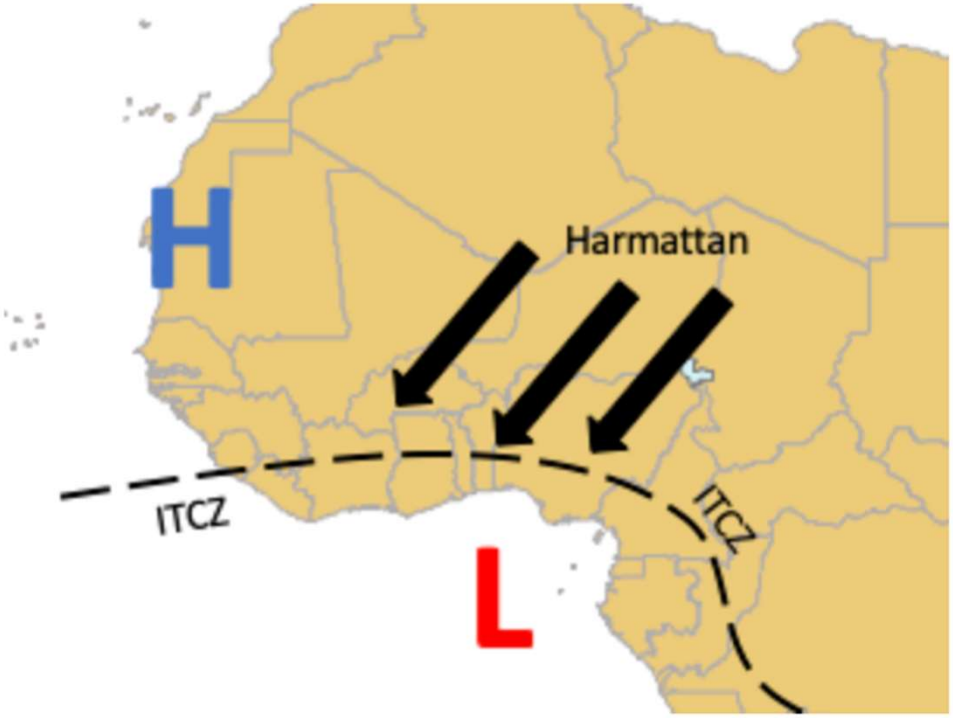
What are the meteorological variables that are important to predict monthly counts of sandstorms in the Sahel and West African Region?

Focus Regions

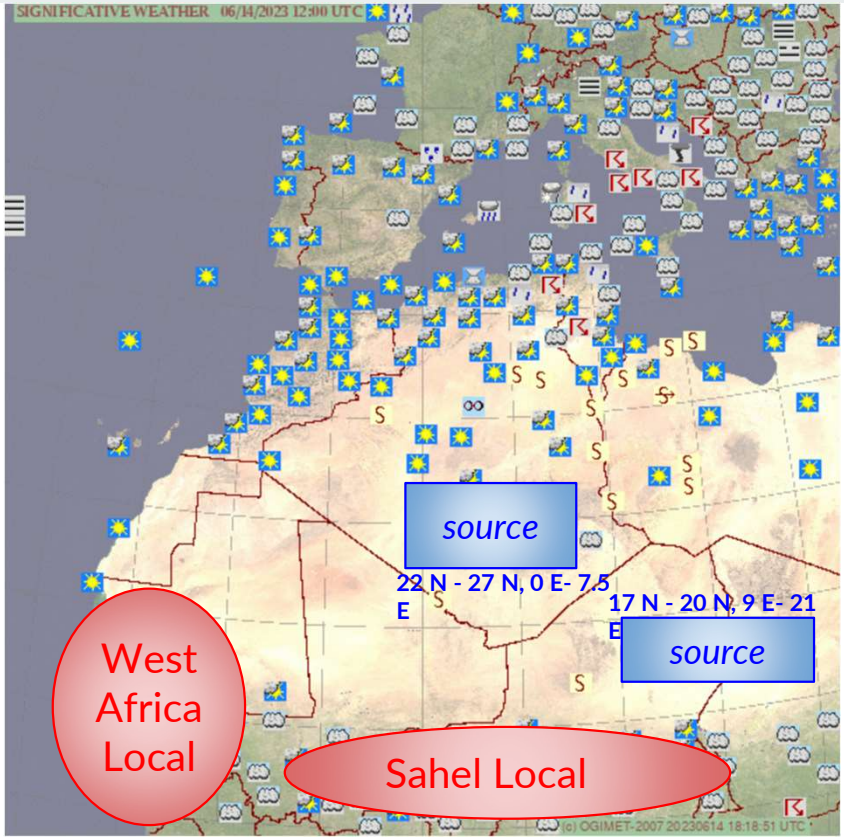
- Agreed to narrow down to regions by the Sahel Belt and Western Africa

- More climatology trends are potent in these areas.

- Using the ERA5 database to identify variables that will help to highlight the tendencies of Sandstorms



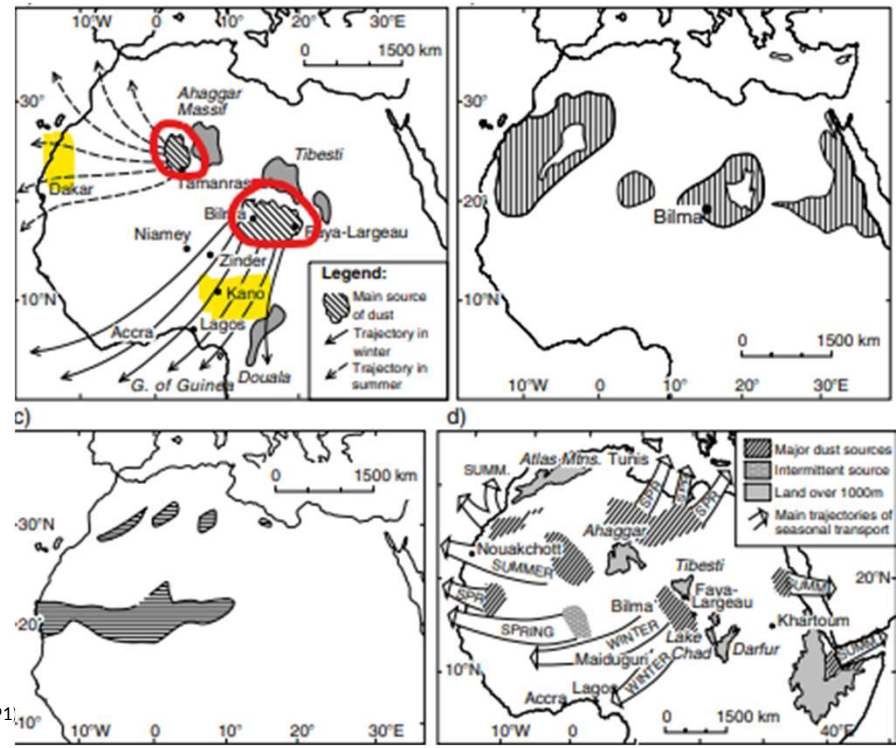
Focus Regions



(OGIMET)

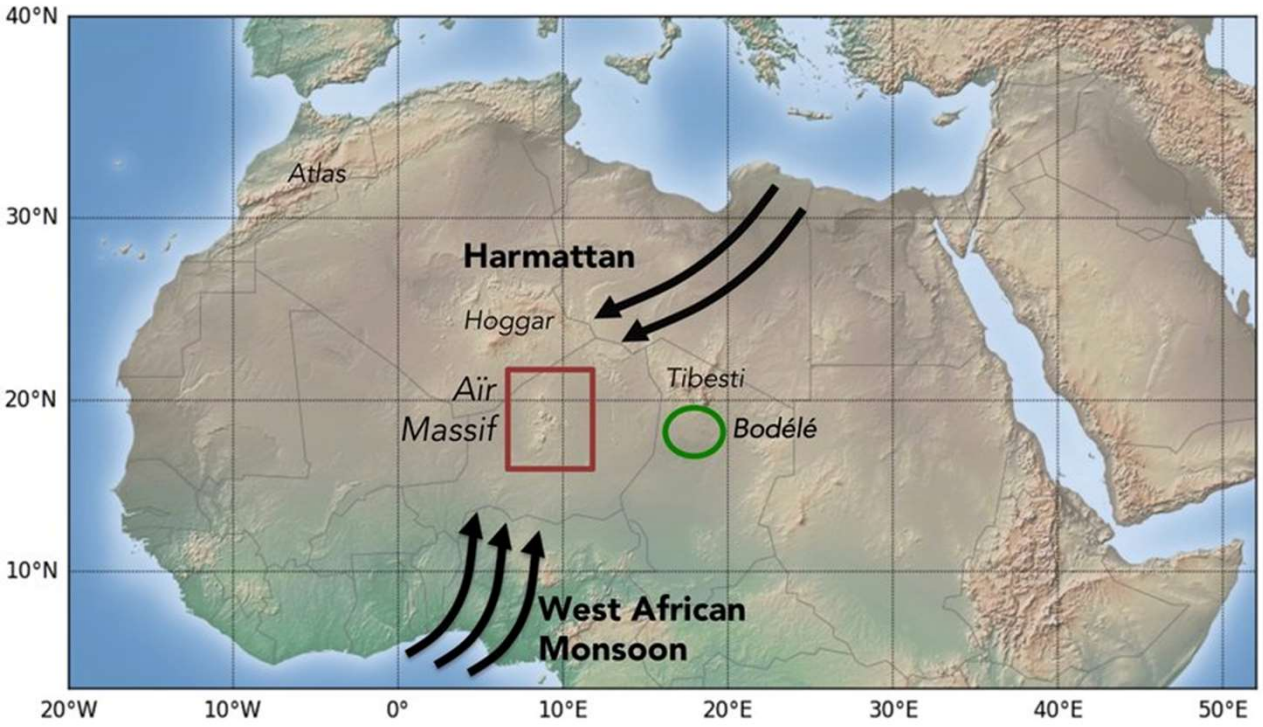
- Finding the correlation between variables in the source region and dust accounts in the local region

Source of dust and the relative trajectory of it's transport



(Goudie and Middleton, n.d, pg 91)

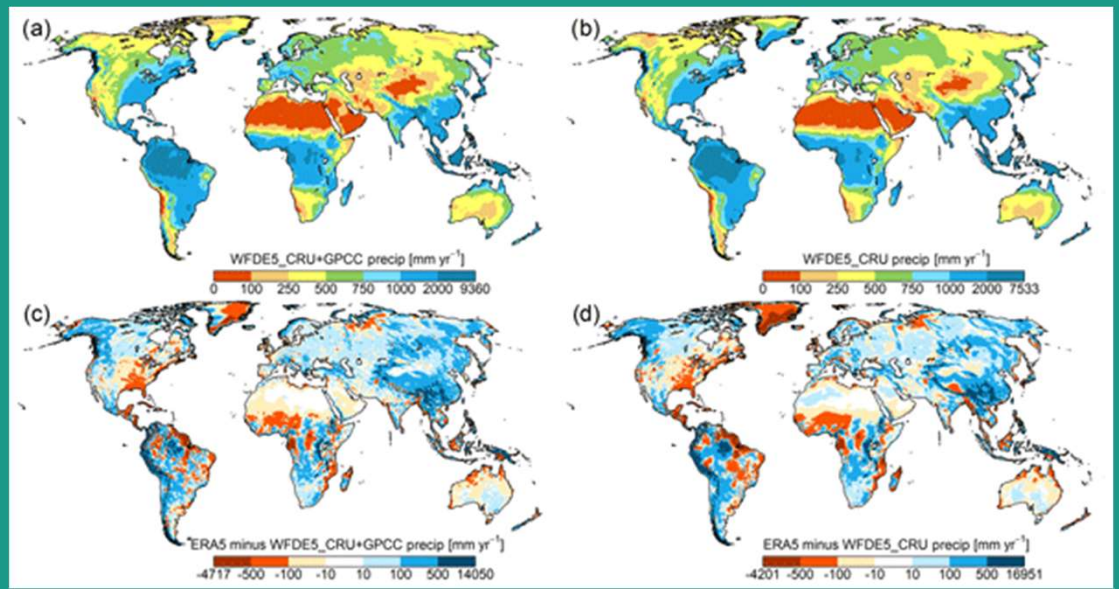
Source of dust

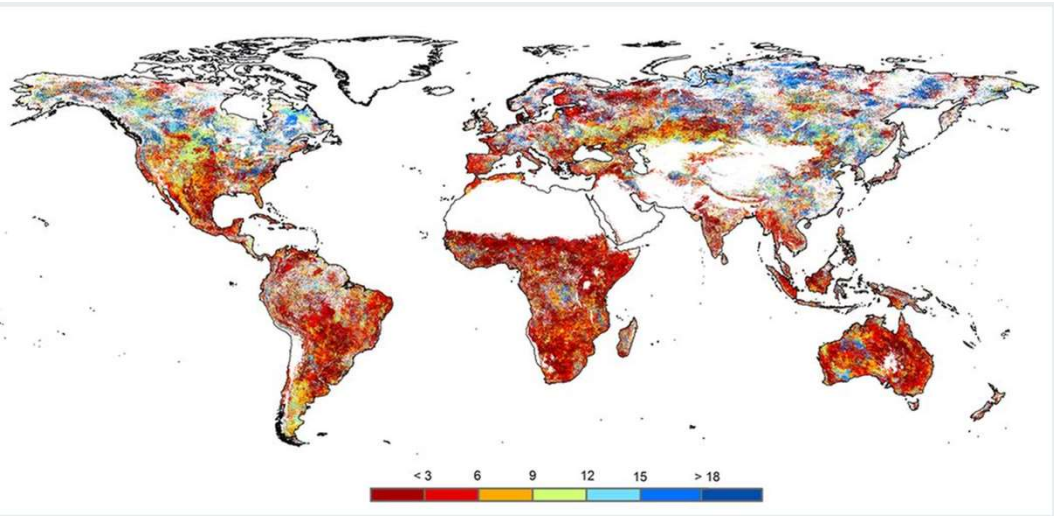


Bodélé Depression (located in Chad)

- A small, unvegetated depression (500 km long, 150 km wide and around 160 m deep)
- Considered to be responsible for half of the mineral aerosols produced from the Sahara.

Databases


(a)
WFDE5_CRU+GPCC precip [mm yr⁻¹]
0 100 250 500 750 1000 2000 9360
(b)
WFDE5_CRU precip [mm yr⁻¹]
0 100 250 500 750 1000 2000 7533
(c)
ERA5 minus WFDE5_CRU+GPCC precip [mm yr⁻¹]
-4717 -500 -100 -10 10 100 500 14050
(d)
ERA5 minus WFDE5_CRU precip [mm yr⁻¹]
-4201 -500 -100 -10 10 100 500 16951



(Begueria,Latorre et al. ,SPEI)

The Standardised Precipitation-Evapotranspiration Index (SPEI)

SPEI draws data from two indices:
PDSI and SPI

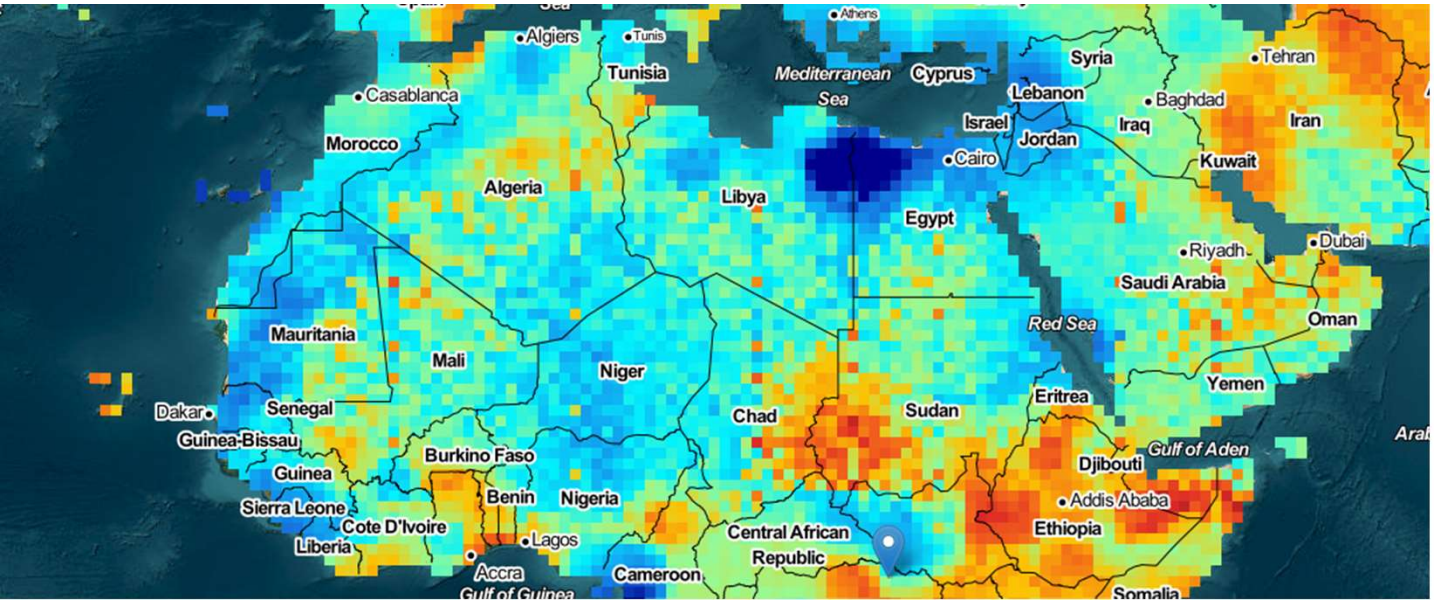
https://spei.csic.es/spei_database/#map_name=spei01#map_position=1451

The Palmer Drought Severity Index (PDSI)

- Wetness→ positive values
  Dryness→ negative values
- Incorporates precip, moisture supply, runoff and evaporation at the surface
- Assumption made is that temp is negligible due to it not having much temporal trend

Multi-scalar drought indices: the Standardised Precipitation Index (SPI)

- Focuses on usable water resources
- Extremely sensitive to data collection due to accumulation at a specific time frame

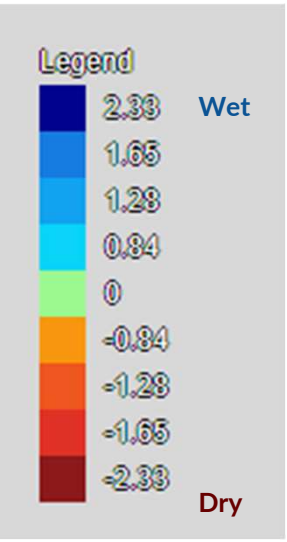


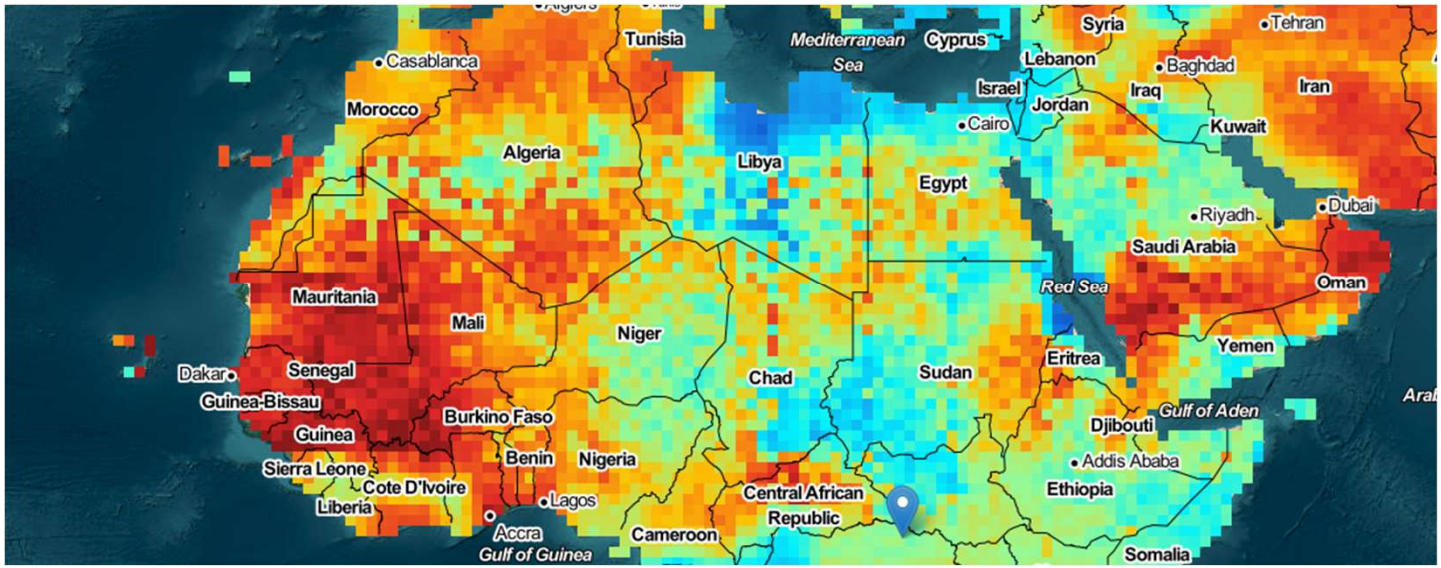
1924-11

Laboratory of Climate Services and Climatology

Data stretches back from 1901 to 2021

2021-12

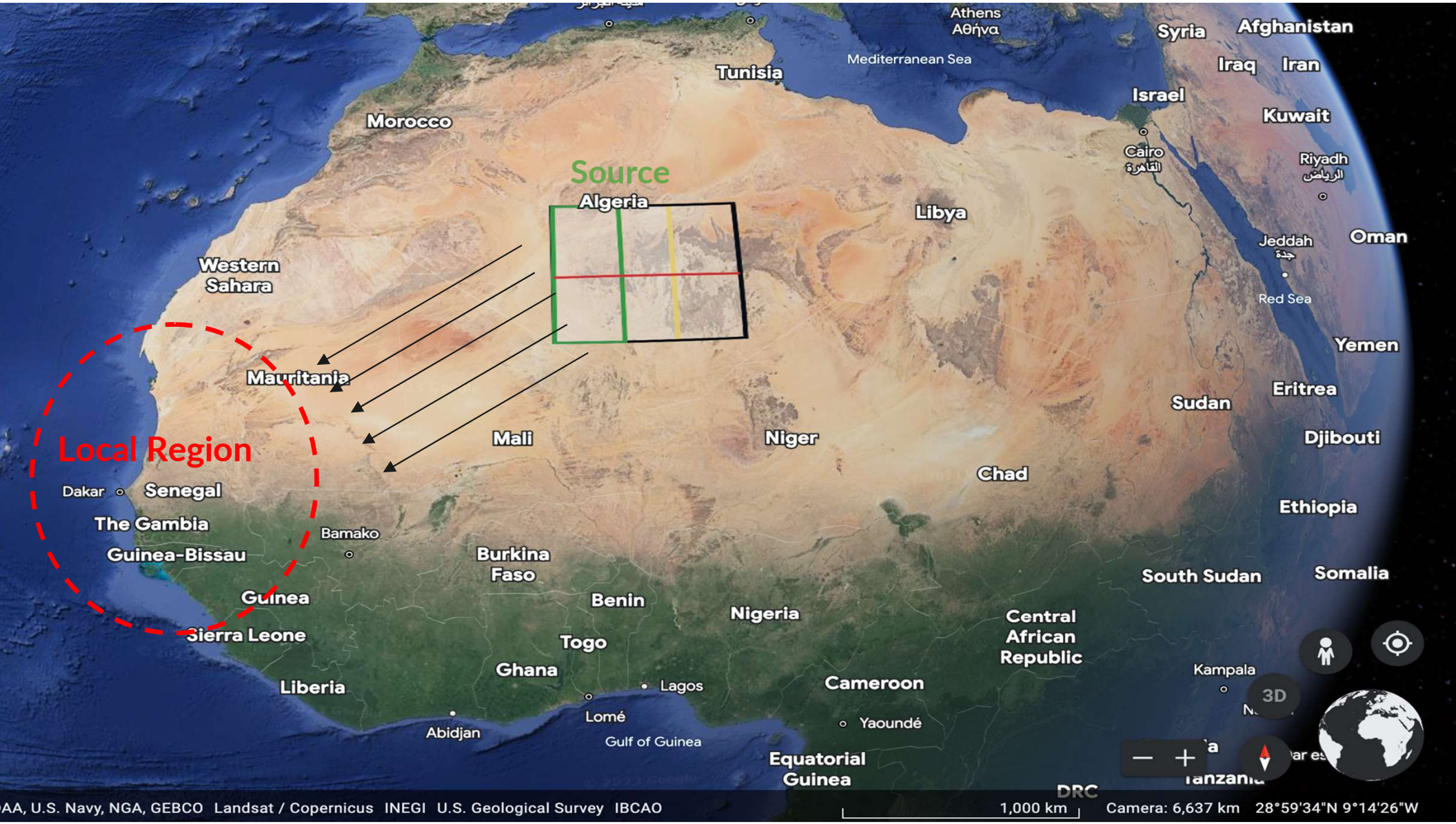


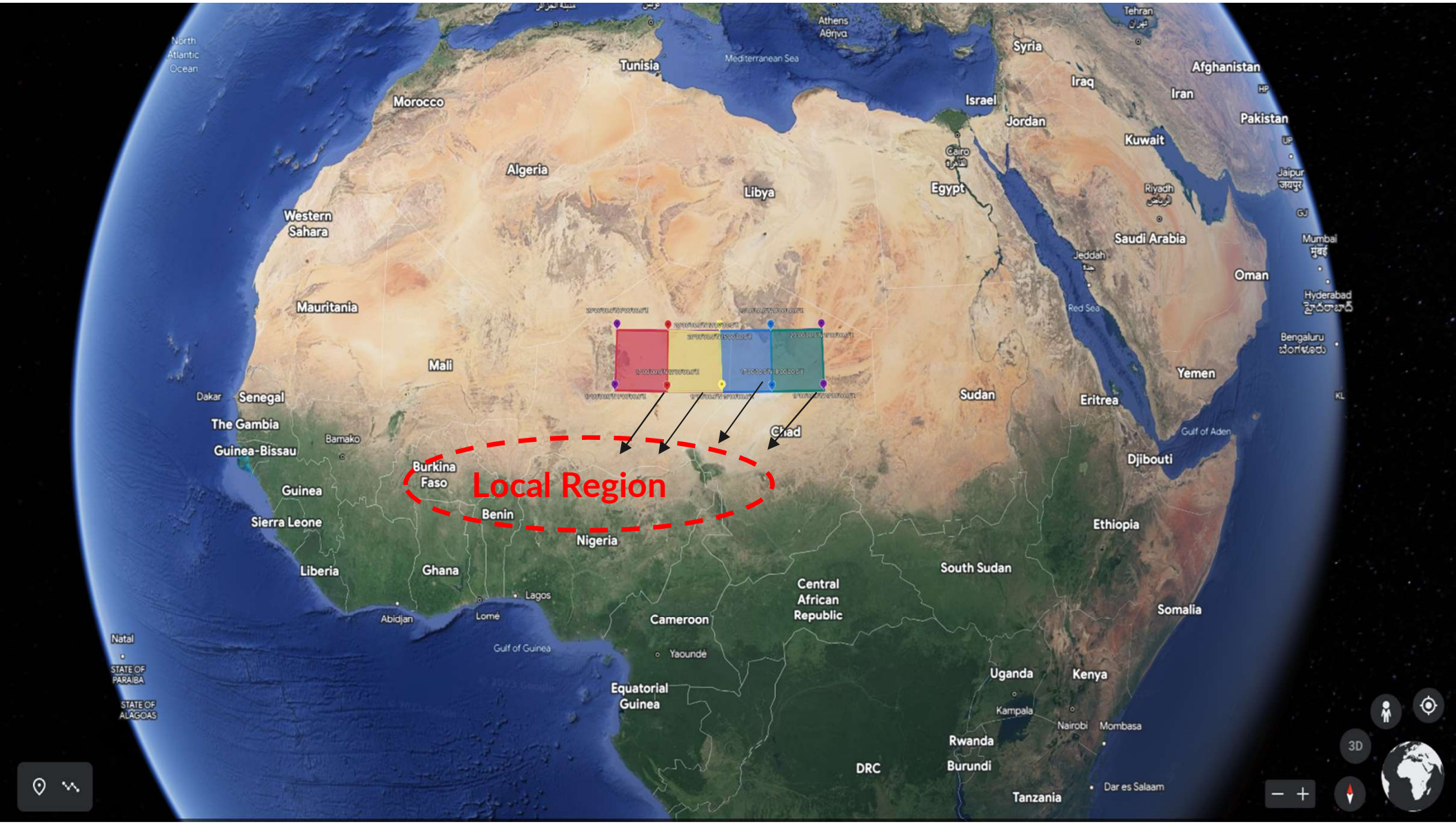


ECMWF Reanalysis v5 (ERA5)

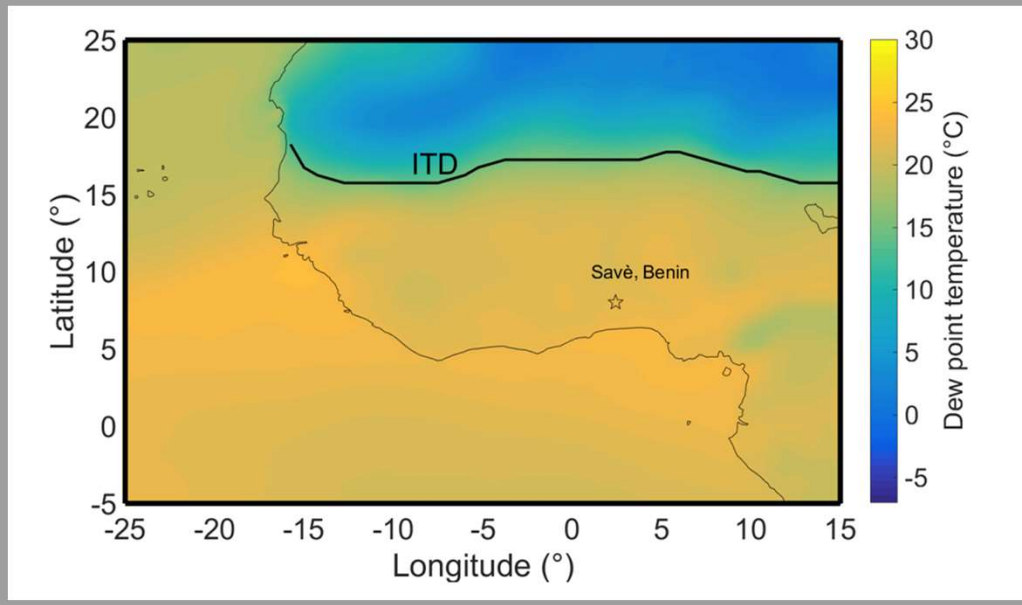
- Covers from 1940-Present
- Created by Copernicus Climate Change Service (ECMWF)
- ERA5 uses sophisticated modeling to incorporate enormous amounts of historical observations into hourly global estimations.
- Provides estimates for oceanic climate, atmospheric, and land variables.

Variables

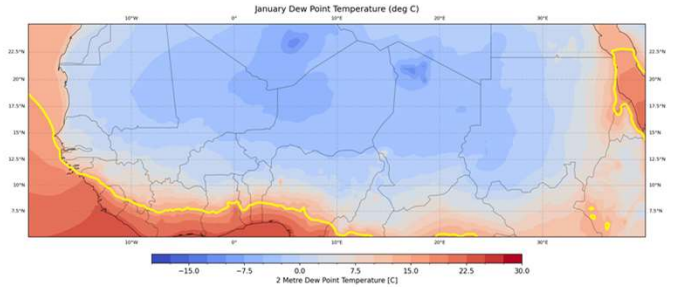

Source
Local Region
Athens
Αθήνα
Syria
Afghanistan
Mediterranean Sea
Tunisia
Iraq
Iran
Israel
Kuwait
Morocco
Cairo
القاهرة
Riyadh
الرياض
Algeria
Libya
Jeddah
جدة
Oman
Western
Sahara
Red Sea
Yemen
Mauritania
Eritrea
Sudan
Mali
Niger
Djibouti
Chad
Dakar
Senegal
Ethiopia
The Gambia
Bamako
Guinea-Bissau
Burkina
Faso
South Sudan
Somalia
Guinea
Benin
Nigeria
Central
African
Republic
Sierra Leone
Togo
Ghana
Kampala
Liberia
Lagos
Cameroon
Lomé
Yaoundé
Abidjan
Gulf of Guinea
Equatorial
Guinea
DRC
3D
AA, U.S. Navy, NGA, GEBCO
Landsat / Copernicus
INEGI
U.S. Geological Survey
IBCAO
1,000 km
Camera: 6,637 km
28°59'34"N 9°14'26"W

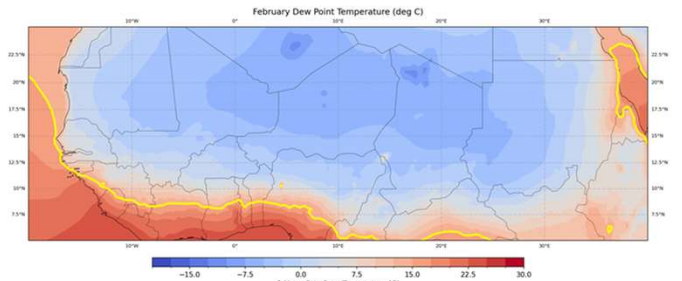

Local Region
North Atlantic Ocean
Mediterranean Sea
Tunisia
Morocco
Algeria
Libya
Egypt
Western Sahara
Mauritania
Mali
Senegal
Dakar
The Gambia
Guinea-Bissau
Bamako
Guinea
Sierra Leone
Liberia
Burkina Faso
Benin
Nigeria
Ghana
Lagos
Abidjan
Lomé
Gulf of Guinea
Cameroon
Yaoundé
Equatorial Guinea
Central African Republic
Chad
Sudan
South Sudan
Eritrea
Ethiopia
Djibouti
Gulf of Aden
Somalia
Kenya
Uganda
Kampala
Nairobi
Mombasa
Rwanda
Burundi
DRC
Tanzania
Dar es Salaam
Yemen
Red Sea
Saudi Arabia
Jeddah
Riyadh
Oman
Kuwait
Iraq
Iran
Syria
Jordan
Israel
Afghanistan
Pakistan
Tehran
Athens
Cairo
Jaipur
Mumbai
Hyderabad
Bengaluru
Natal
STATE OF PARAIBA
STATE OF ALAGOAS
3D

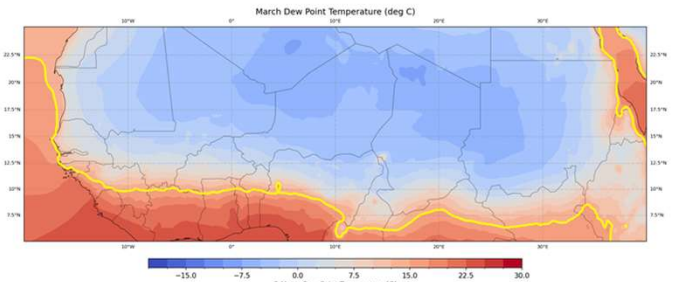
Inter-Tropical Discontinuity Line

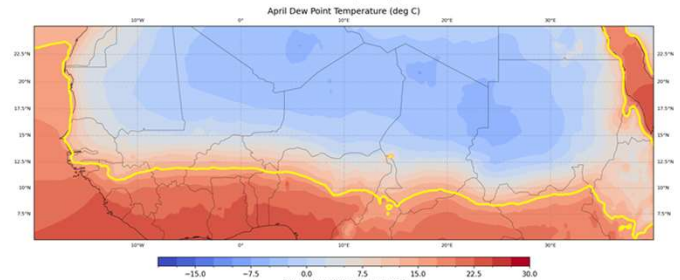


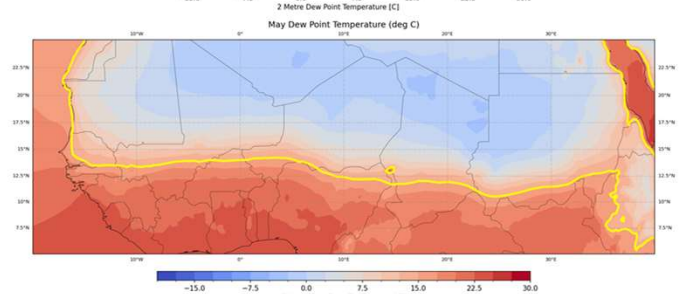
Next slide graphics created by: Dr. Lazarus

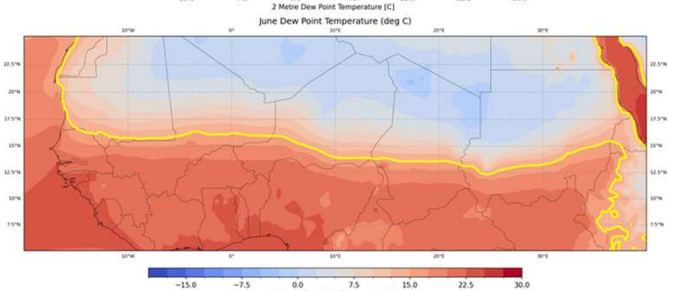

January Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]

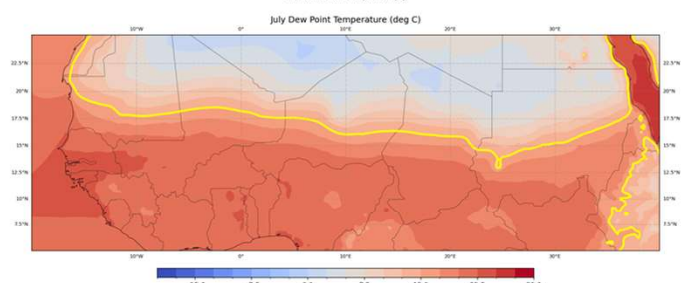

February Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]

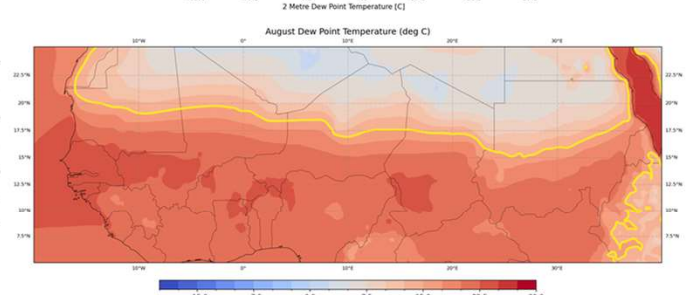

March Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]

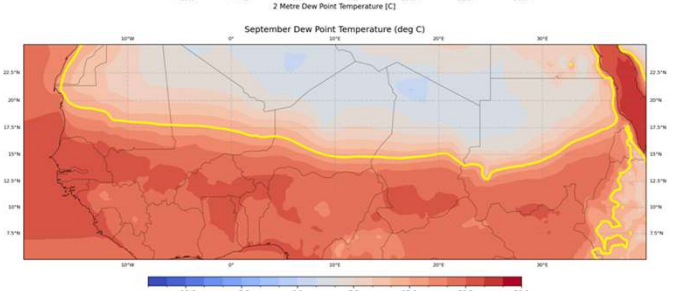

April Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]

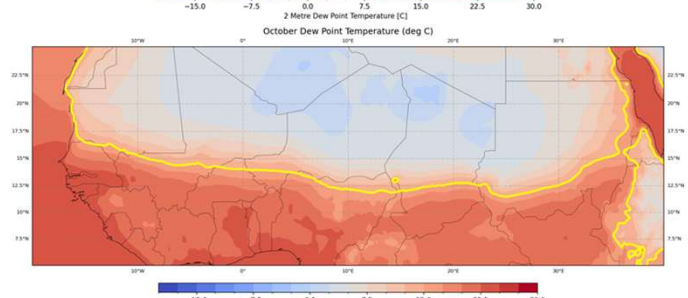

May Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]

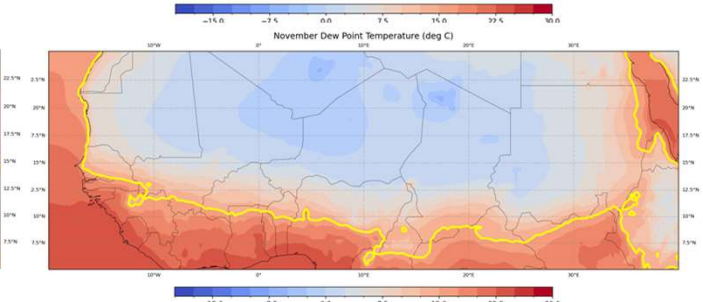

June Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]

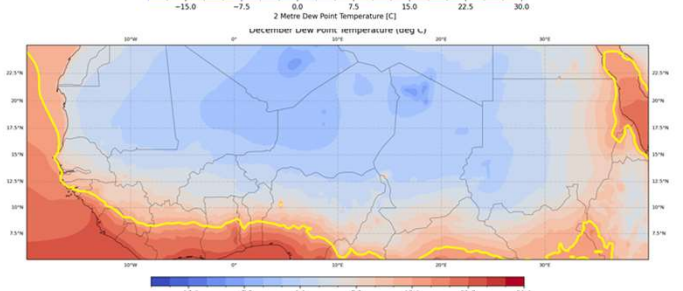

July Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]

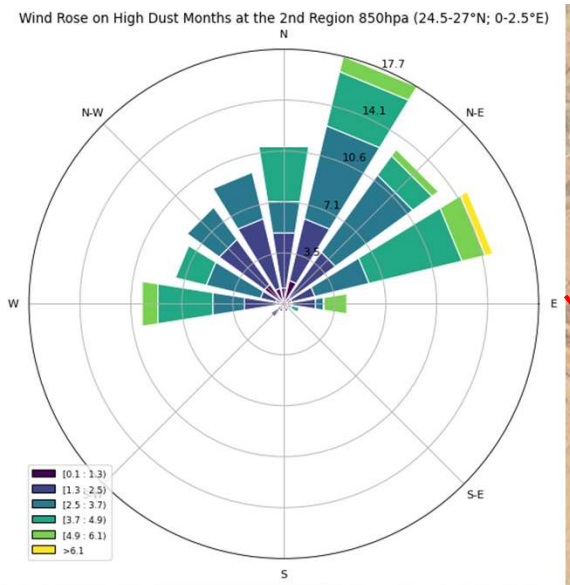

August Dew Point Temperature (deg C)


September Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]


October Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]


November Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]


December Dew Point Temperature (deg C)
−15.0 −7.5 0.0 7.5 15.0 22.5 30.0
2 Metre Dew Point Temperature [C]


Wind Rose on High Dust Months at the 2nd Region 850hpa (24.5-27°N; 0-2.5°E)
N
N-E
E
S-E
S
W
N-W
17.7
14.1
10.6
7.1
3.5
[0.1 : 1.3)
[1.3 : 2.5)
[2.5 : 3.7)
[3.7 : 4.9)
[4.9 : 6.1)
>6.1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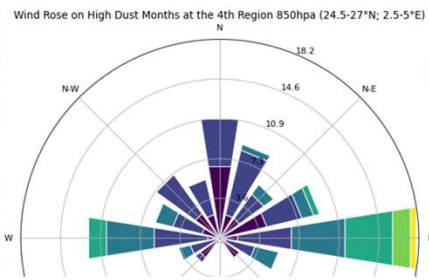
Wind Rose on High Dust Months at the 4th Region 850hpa (24.5-27°N; 2.5-5°E)
N
N-E
E
W
N-W
18.2
14.6
10.9


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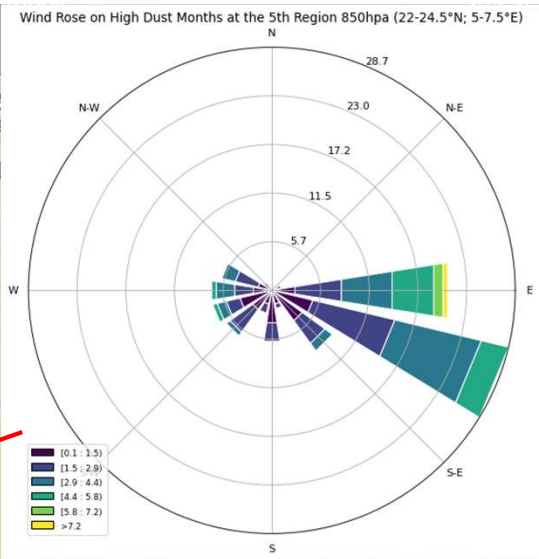
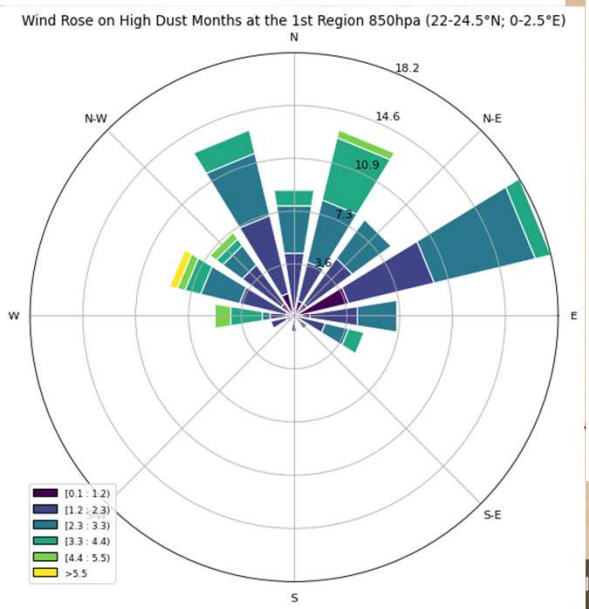
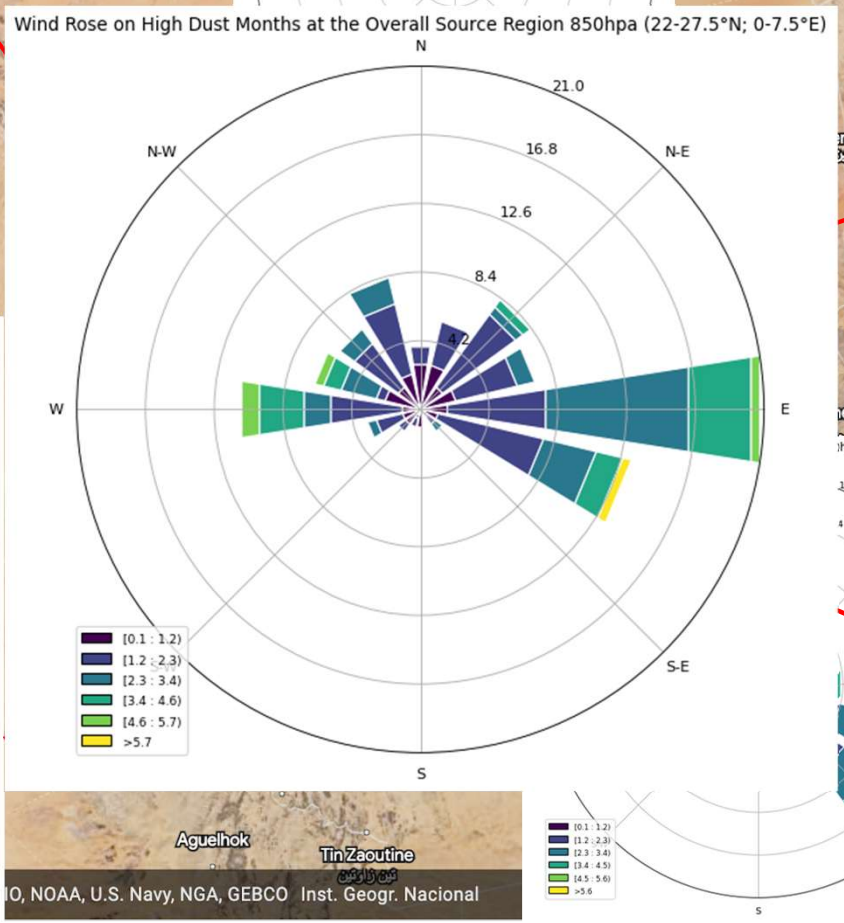
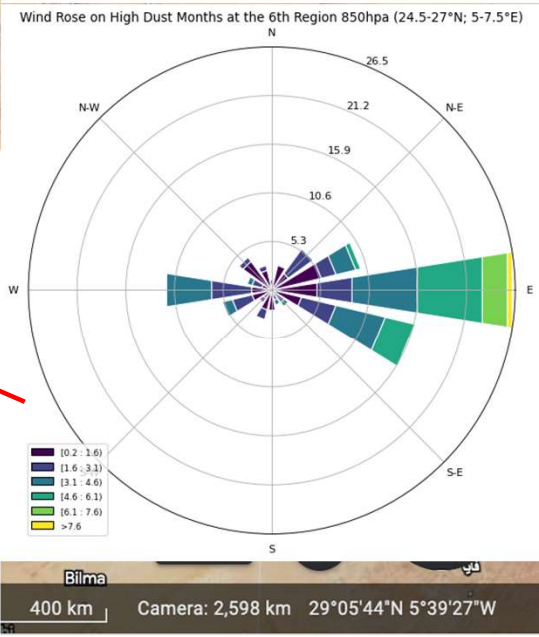
Ghat
غات

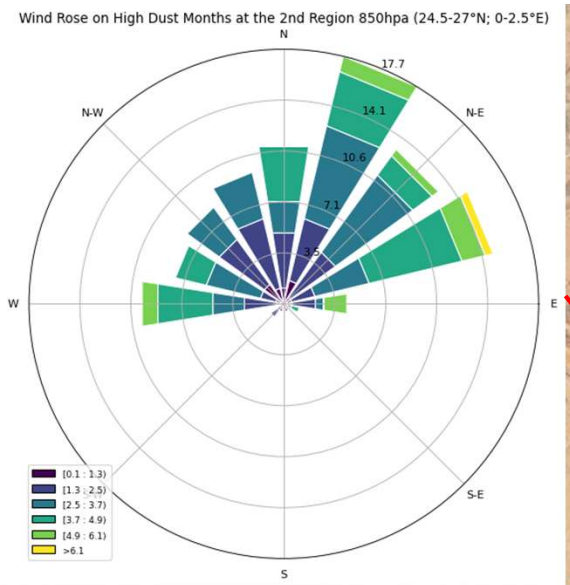

Wind Rose on High Dust Months at the 5th Region 850hpa (22-24.5°N; 5-7.5°E)
N
N-E
E
S-E
S
W
N-W
28.7
23.0
17.2
11.5
5.7
[0.1 : 1.5)
[1.5 : 2.9)
[2.9 : 4.4)
[4.4 : 5.8)
[5.8 : 7.2)
>7.2


Wind Rose on High Dust Months at the 1st Region 850hpa (22-24.5°N; 0-2.5°E)
N
N-E
E
S-E
S
W
N-W
18.2
14.6
10.9
7.3
3.6
[0.1 : 1.2)
[1.2 : 2.3)
[2.3 : 3.3)
[3.3 : 4.4)
[4.4 : 5.5)
>5.5

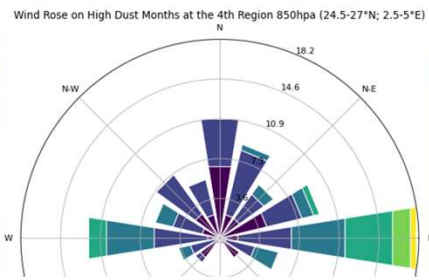

Wind Rose on High Dust Months at the Overall Source Region 850hpa (22-27.5°N; 0-7.5°E)
N
N-E
E
S-E
S
W
N-W
21.0
16.8
12.6
8.4
4.2
[0.1 : 1.2)
[1.2 : 2.3)
[2.3 : 3.4)
[3.4 : 4.6)
[4.6 : 5.7)
>5.7
Aguelhok
Tin Zaoutine
تين زاوتين
IO, NOAA, U.S. Navy, NGA, GEBCO Inst. Geogr. Nacional

hpa (22-24.5°N; 2.5-5°E)
15.5
N-E
E
S-E
S
[0.1 : 1.2)
[1.2 : 2.3)
[2.3 : 3.4)
[3.4 : 4.5)
[4.5 : 5.6)
>5.6

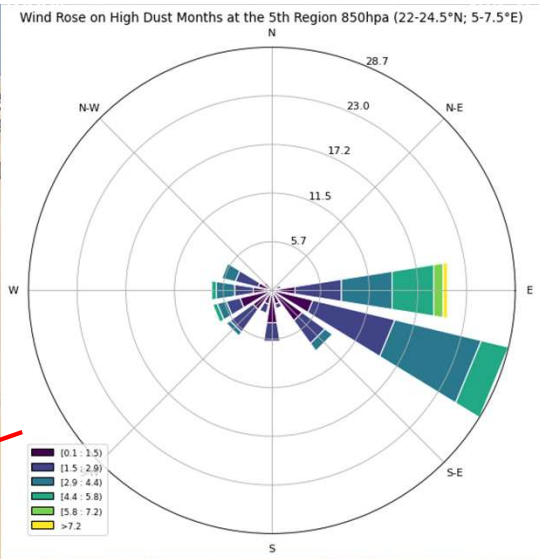

Wind Rose on High Dust Months at the 6th Region 850hpa (24.5-27°N; 5-7.5°E)
N
N-E
E
S-E
S
W
N-W
26.5
21.2
15.9
10.6
5.3
[0.2 : 1.6)
[1.6 : 3.1)
[3.1 : 4.6)
[4.6 : 6.1)
[6.1 : 7.6)
>7.6
Bilma
400 km
Camera: 2,598 km 29°05'44"N 5°39'27"W

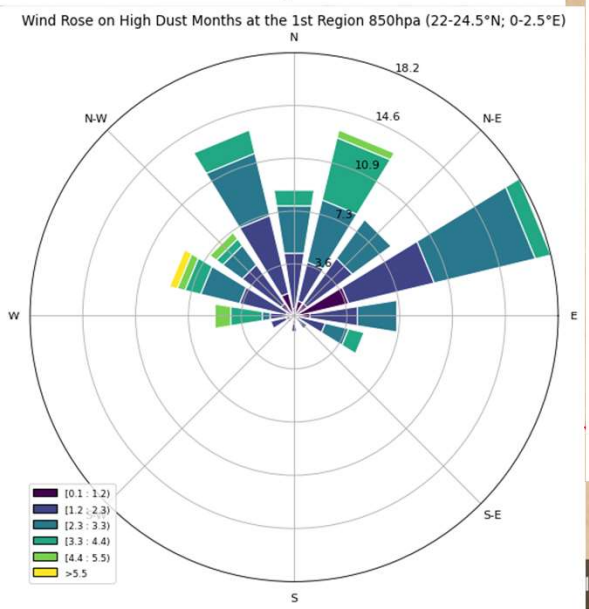

Wind Rose on High Dust Months at the 2nd Region 850hpa (24.5-27°N; 0-2.5°E)
N
N-E
E
S-E
S
W
N-W
17.7
14.1
10.6
7.1
3.5
[0.1 : 1.3)
[1.3 : 2.5)
[2.5 : 3.7)
[3.7 : 4.9)
[4.9 : 6.1)
>6.1

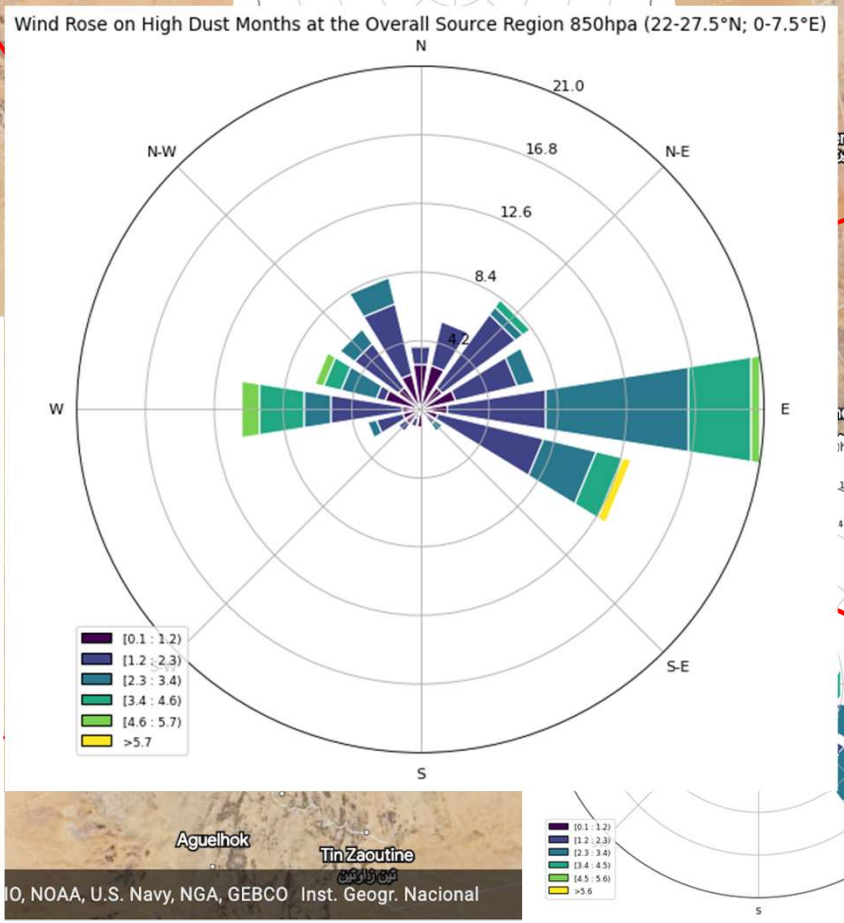

Béchar
بشار


Wind Rose on High Dust Months at the 4th Region 850hpa (24.5-27°N; 2.5-5°E)
N
N-E
E
W
N-W
18.2
14.6
10.9

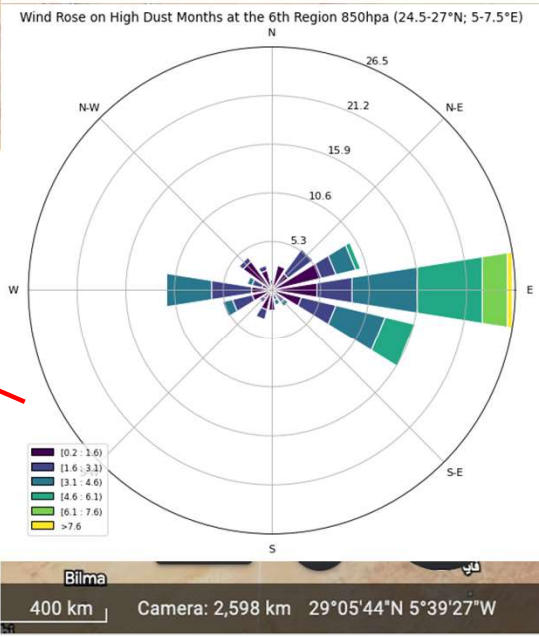

Alawenat
العوينات
Ghat
غات


Wind Rose on High Dust Months at the 5th Region 850hpa (22-24.5°N; 5-7.5°E)
N
N-E
E
S-E
S
W
N-W
28.7
23.0
17.2
11.5
5.7
[0.1 : 1.5)
[1.5 : 2.9)
[2.9 : 4.4)
[4.4 : 5.8)
[5.8 : 7.2)
>7.2


Wind Rose on High Dust Months at the 1st Region 850hpa (22-24.5°N; 0-2.5°E)
N
N-E
E
S-E
S
W
N-W
18.2
14.6
10.9
7.3
3.6
[0.1 : 1.2)
[1.2 : 2.3)
[2.3 : 3.3)
[3.3 : 4.4)
[4.4 : 5.5)
>5.5

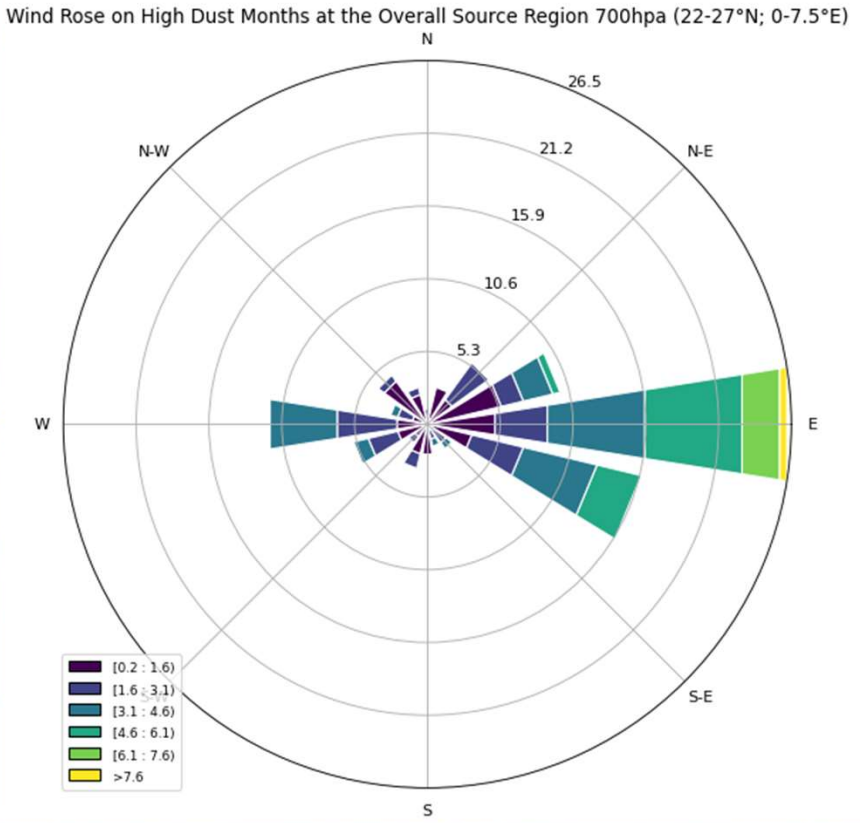

Wind Rose on High Dust Months at the Overall Source Region 850hpa (22-27.5°N; 0-7.5°E)
N
N-E
E
S-E
S
W
N-W
21.0
16.8
12.6
8.4
4.2
[0.1 : 1.2)
[1.2 : 2.3)
[2.3 : 3.4)
[3.4 : 4.6)
[4.6 : 5.7)
>5.7
Aguelhok
Tin Zaoutine
تين زاوتين
IO, NOAA, U.S. Navy, NGA, GEBCO Inst. Geogr. Nacional

hpa (22-24.5°N; 2.5-5°E)
15.5
N-E
E
S-E
S
[0.1 : 1.2)
[1.2 : 2.3)
[2.3 : 3.4)
[3.4 : 4.5)
[4.5 : 5.6)
>5.6

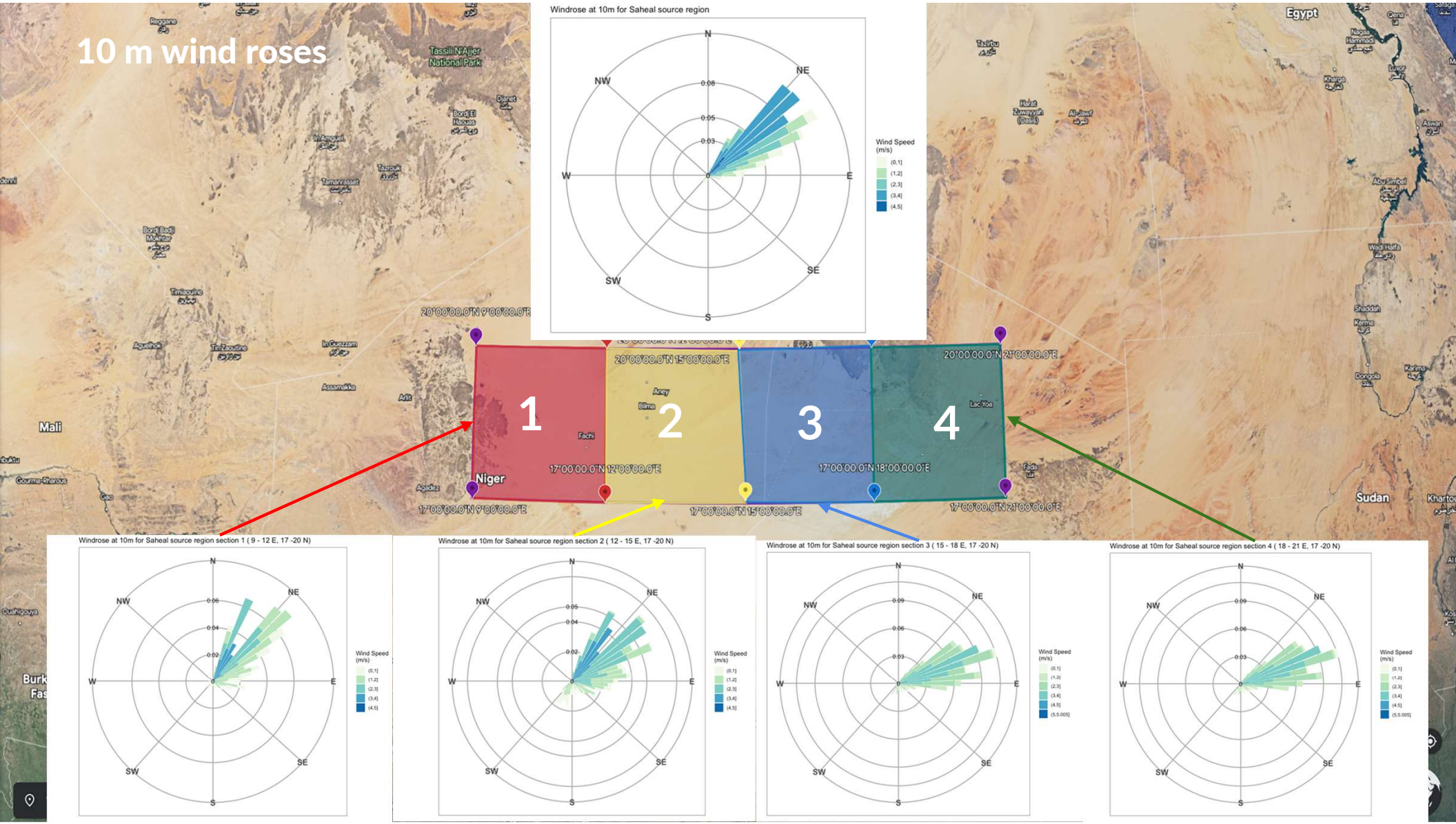

Wind Rose on High Dust Months at the 6th Region 850hpa (24.5-27°N; 5-7.5°E)
N
N-E
E
S-E
S
W
N-W
26.5
21.2
15.9
10.6
5.3
[0.2 : 1.6)
[1.6 : 3.1)
[3.1 : 4.6)
[4.6 : 6.1)
[6.1 : 7.6)
>7.6
Bilma
400 km
Camera: 2,598 km 29°05'44"N 5°39'27"W

700hpa high dust months wind roses

At the 700mb level the winds does not change. They are the same for each region

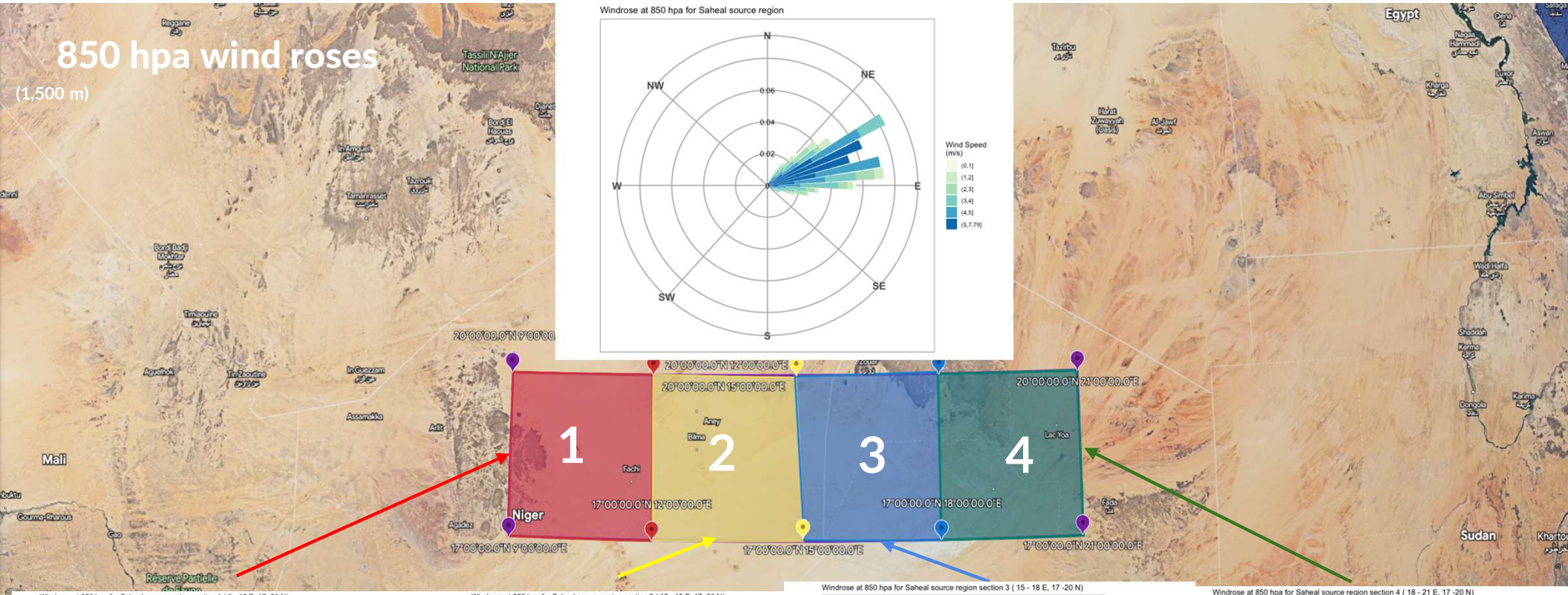


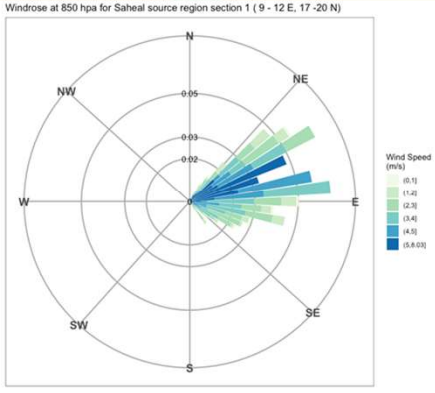
10 m wind roses

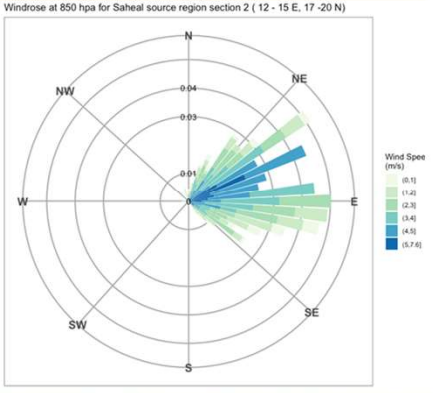


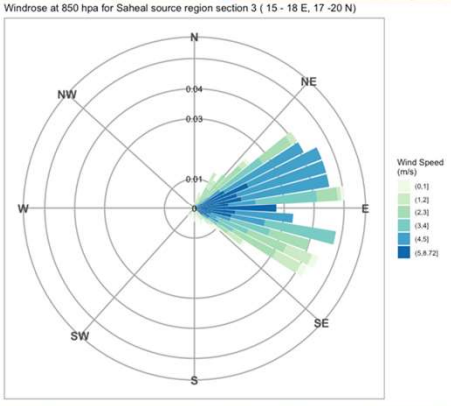
850 hpa wind roses

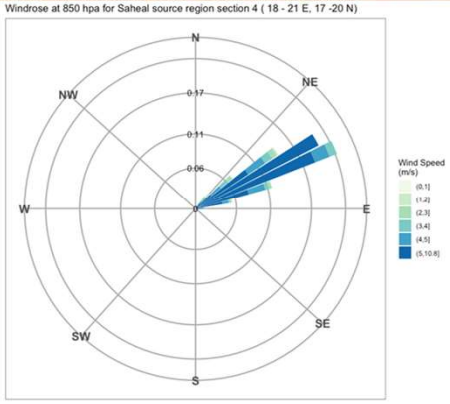
(1,500 m)





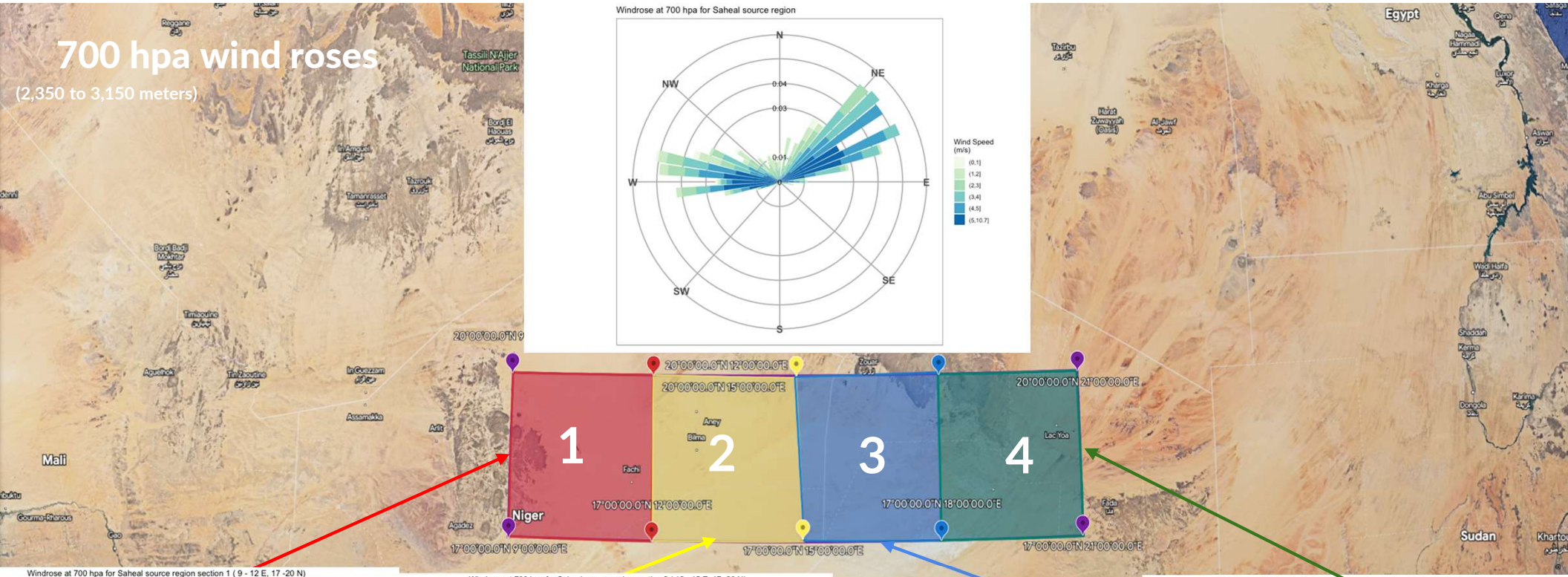






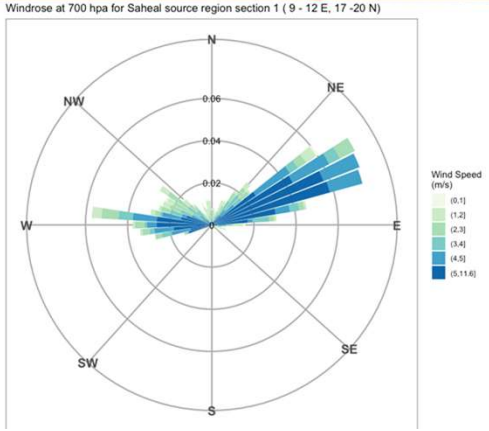
700 hpa wind roses

(2,350 to 3,150 meters)

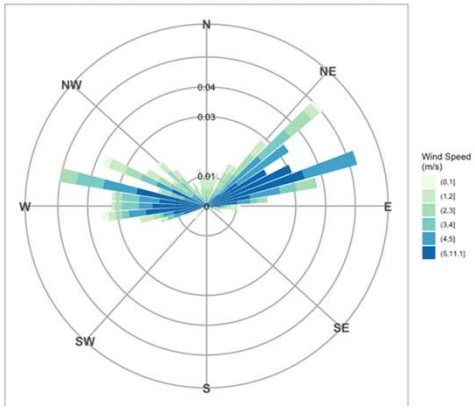


Windrose at 700 hpa for Saheal source region

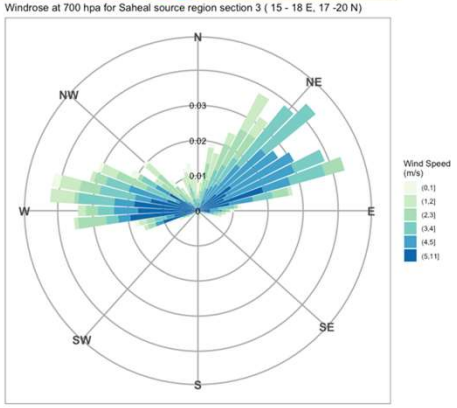
Windrose at 700 hpa for Saheal source region section 1 (9 - 12 E, 17 -20 N)



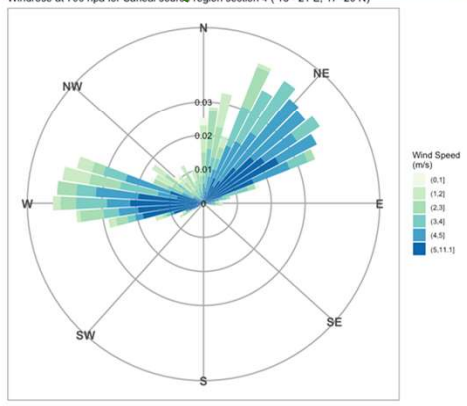
Windrose at 700 hpa for Saheal source region section 2 (12 - 15 E, 17 -20 N)



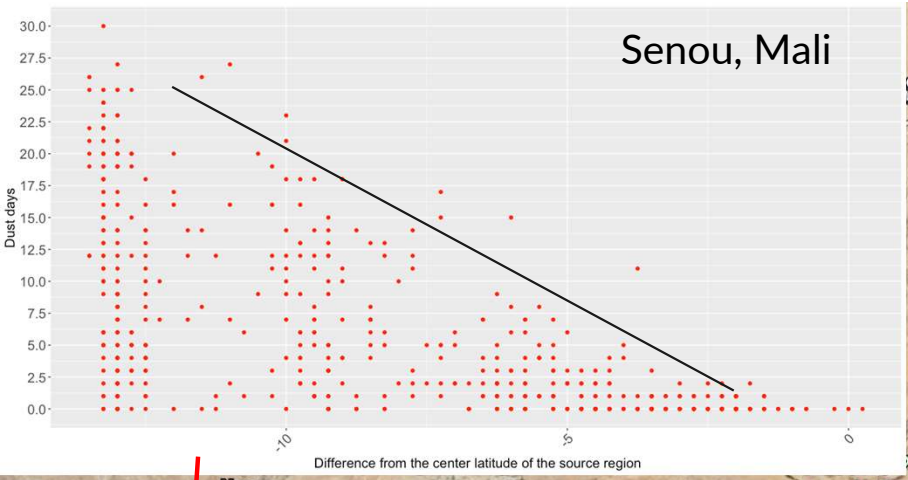
Windrose at 700 hpa for Saheal source region section 3 (15 - 18 E, 17 -20 N)

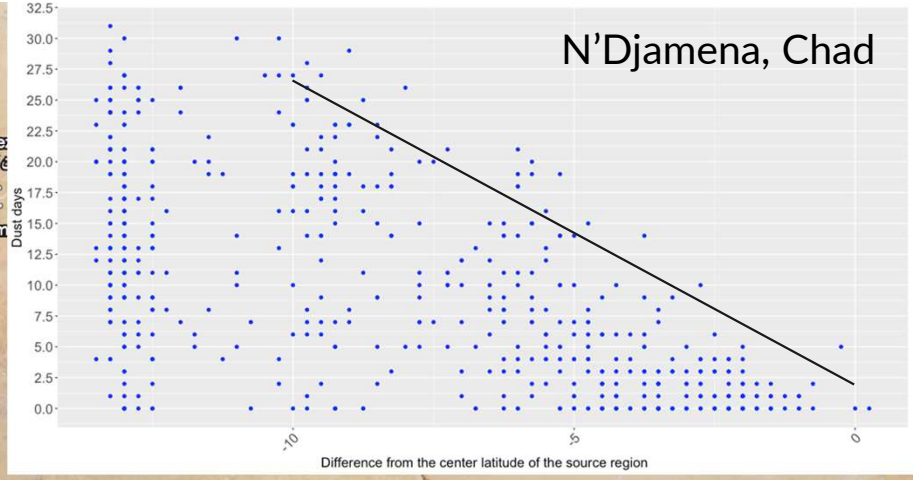


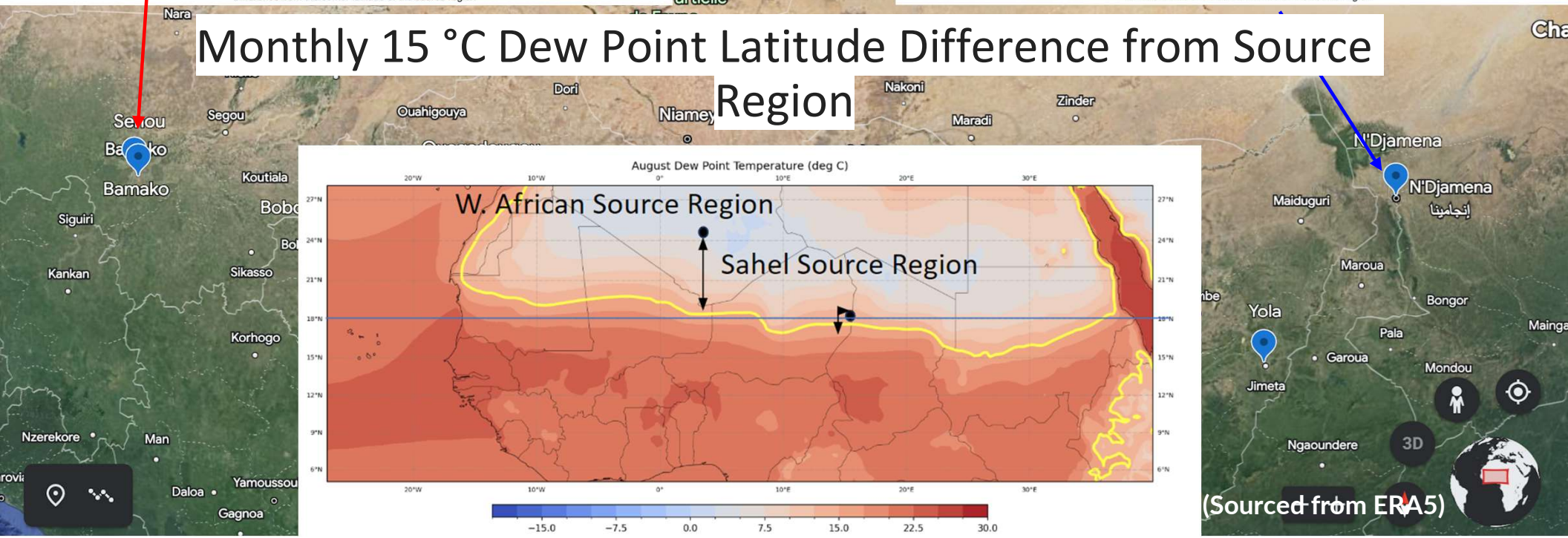
Windrose at 700 hpa for Saheal source region section 4 (18 - 21 E, 17 -20 N)

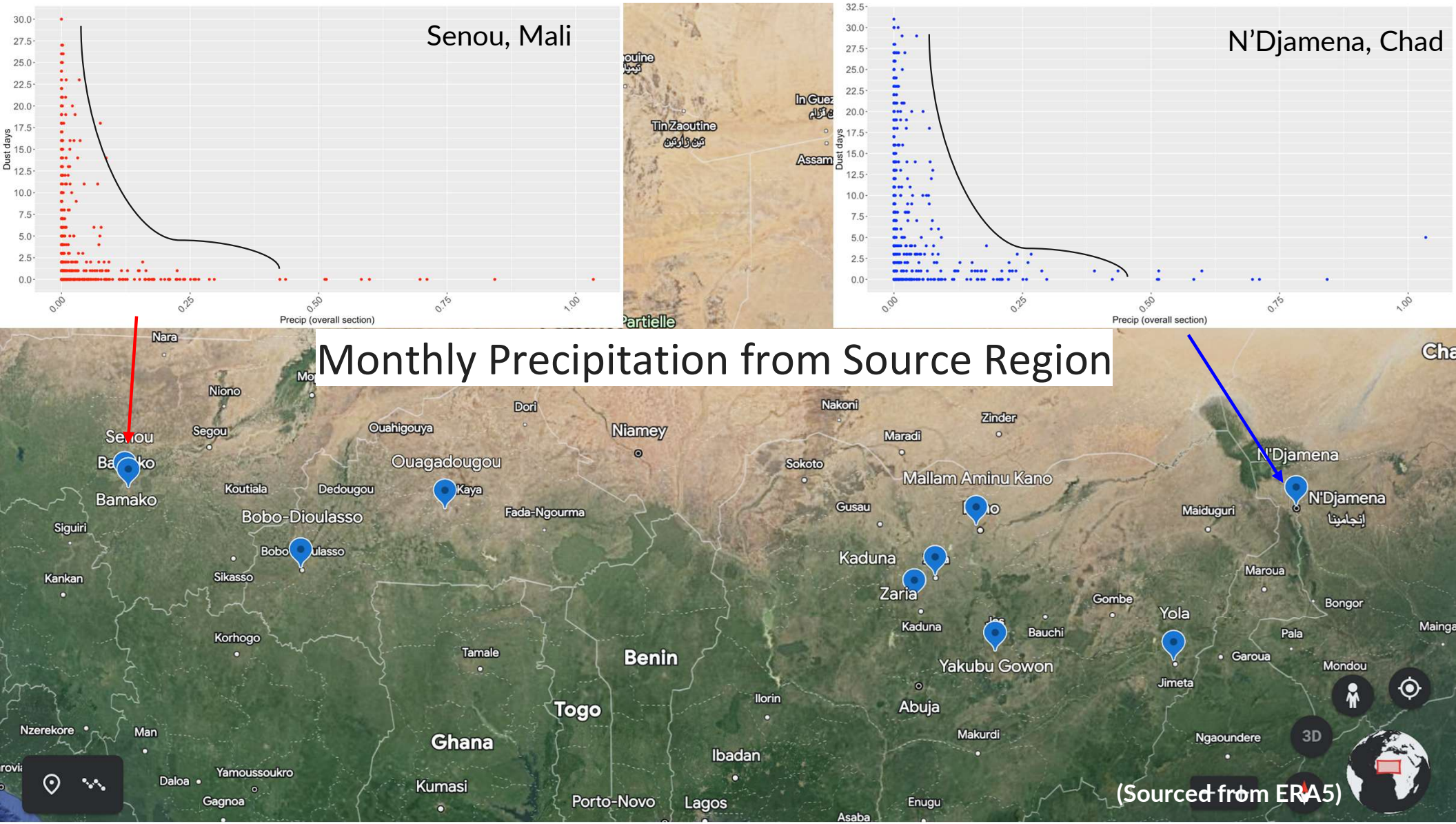


Monthly 15 °C Dew Point Latitude Difference from Source Region

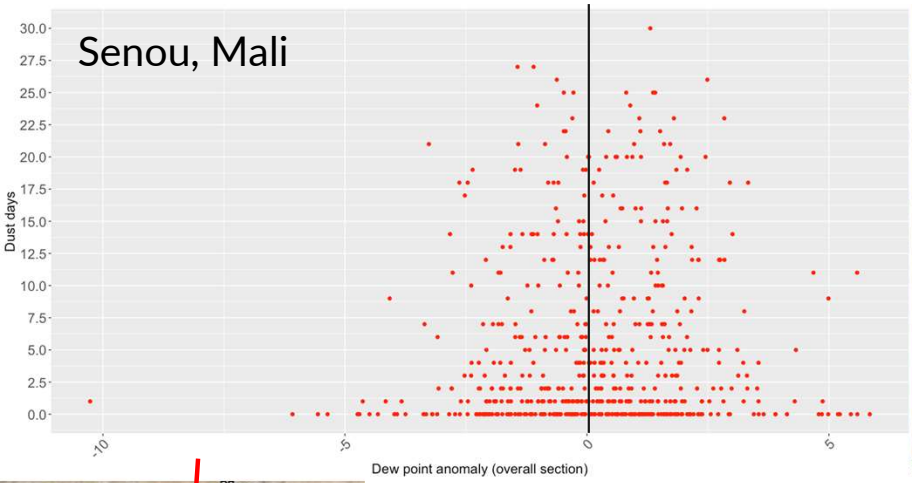


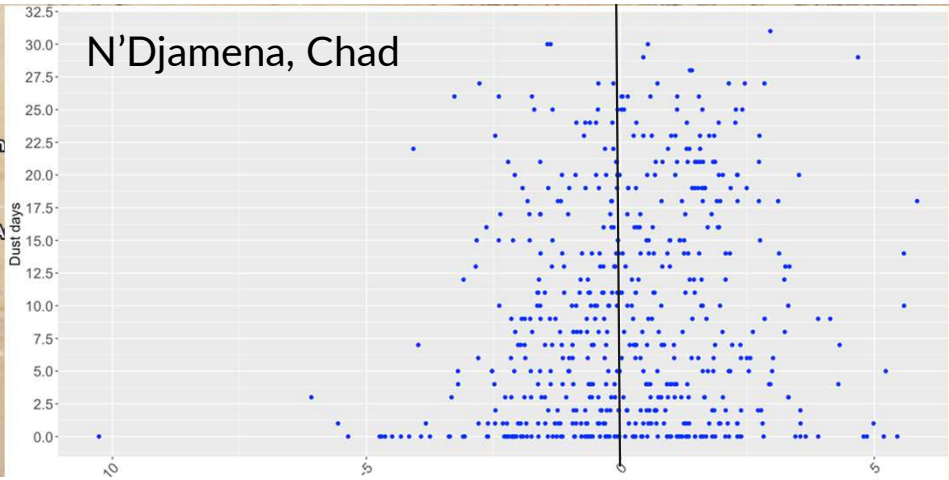


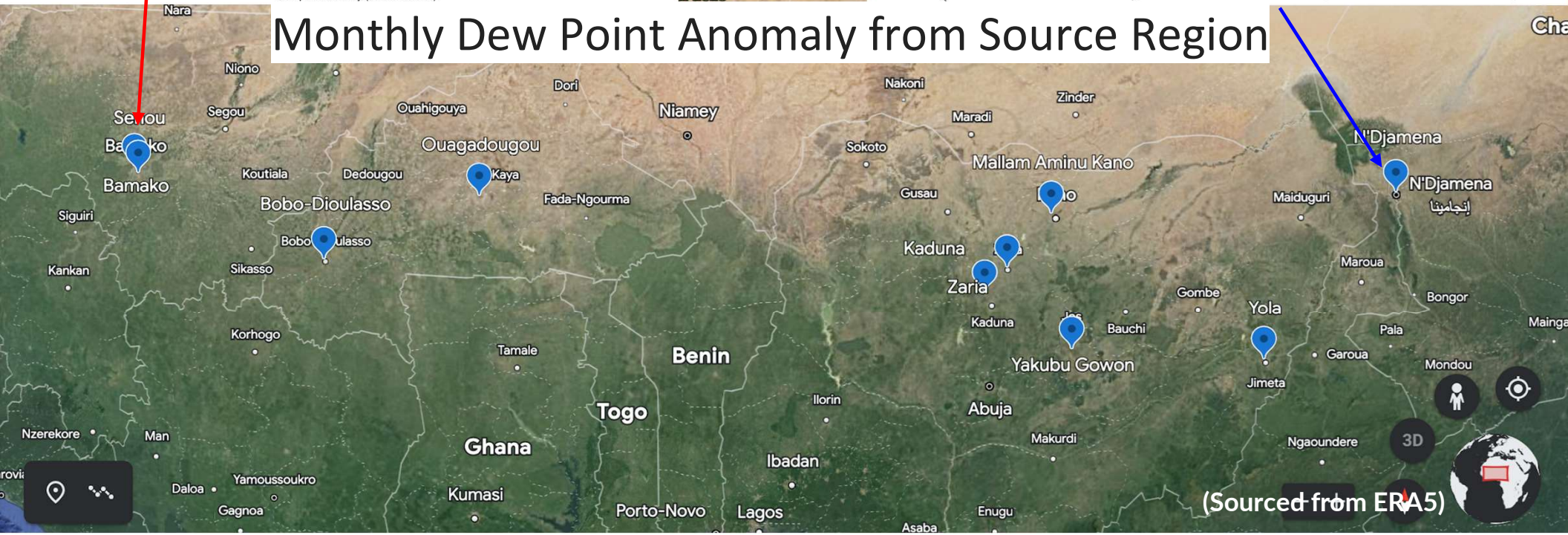


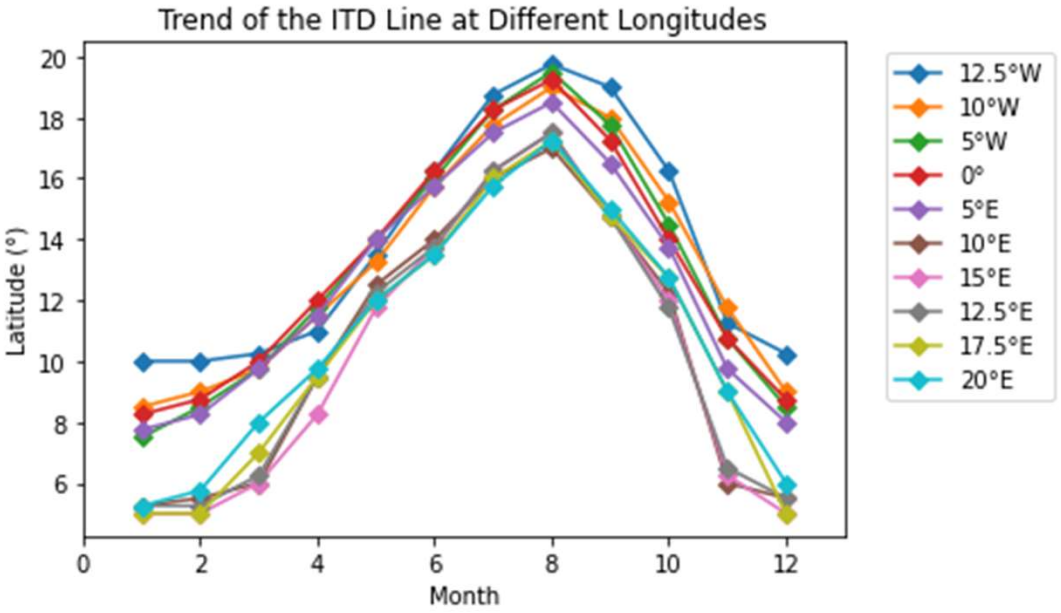

Senou, Mali
N'Djamena, Chad
Dust days
Precip (overall section)
Monthly Precipitation from Source Region
Bamako
Ouagadougou
Niamey
Kaya
Bobo-Dioulasso
Sikasso
Kankan
Siguiri
Koutiala
Dedougou
Fada-Ngourma
Segou
Niono
Nara
Dori
Ouahigouya
Nakoni
Zinder
Maradi
Sokoto
Mallam Aminu Kano
Gusau
Kaduna
Zaria
Bauchi
Yakubu Gowon
Abuja
Ilorin
Jimeta
Yola
Gombe
Maiduguri
N'Djamena
Maroua
Bongor
Pala
Garoua
Mondou
Mainga
Makurdi
Ngaoundere
Benin
Togo
Ghana
Ibadan
Kumasi
Porto-Novo
Lagos
Enugu
Asaba
Tamale
Korhogo
Nzerekore
Man
Daloa
Yamoussoukro
Gagnoa
Tin Zaoutine
3D
(Sourced from ERA5)

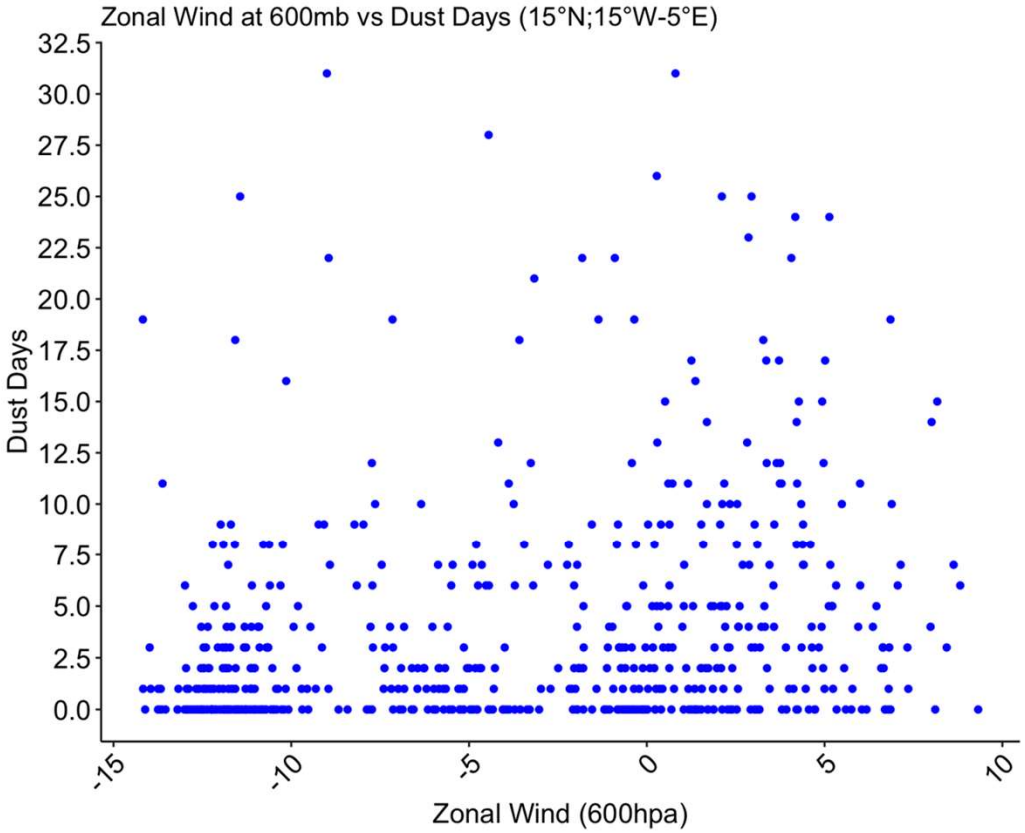
Monthly Dew Point Anomaly from Source Region

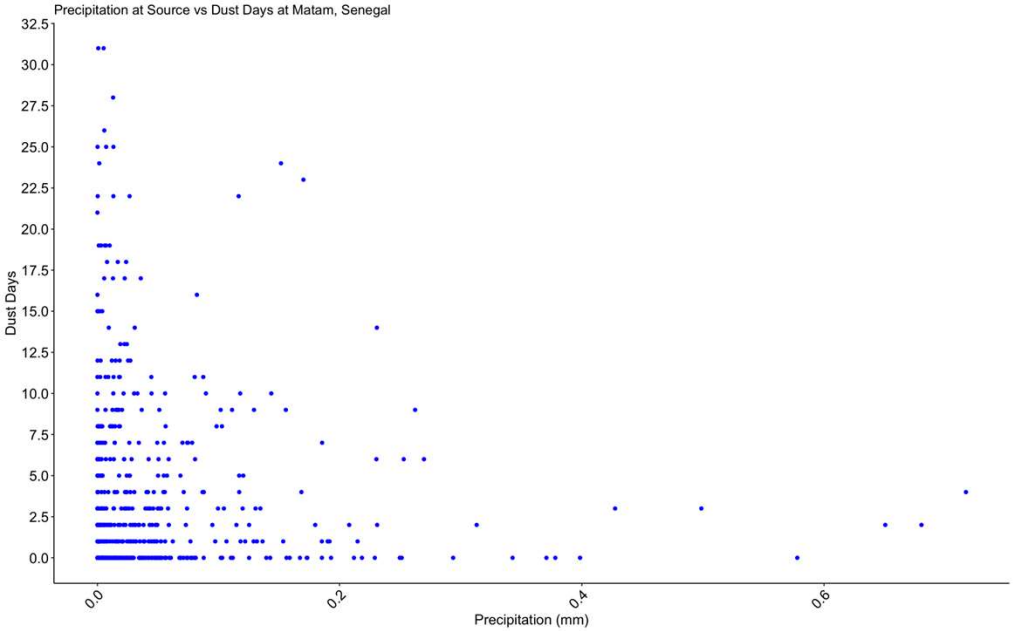


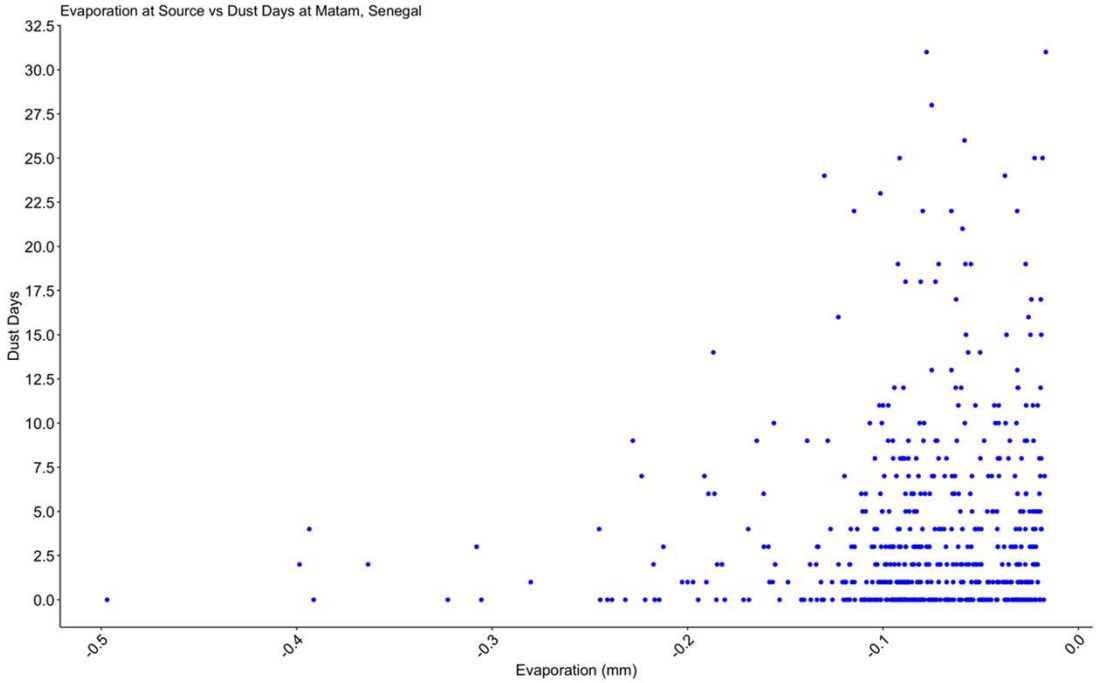


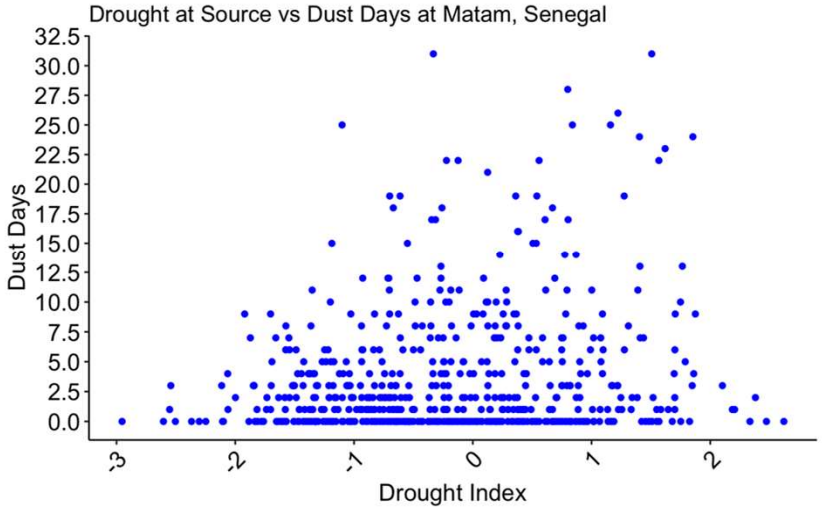


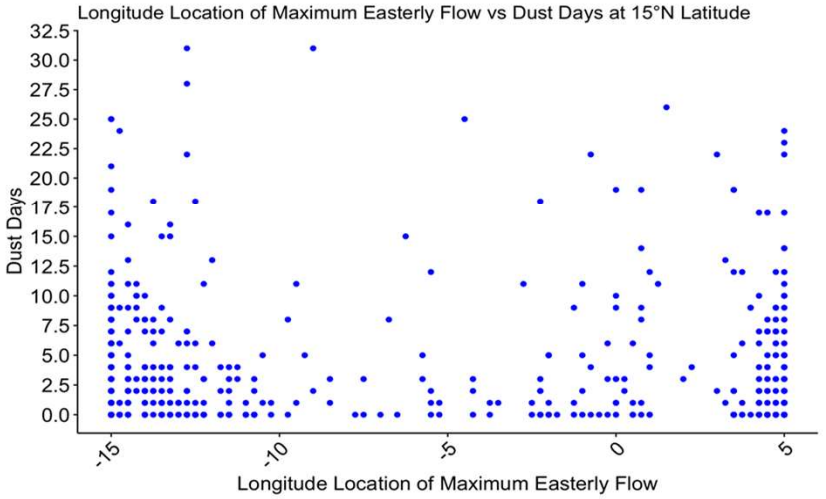

Trend of the ITD Line at Different Longitudes
Latitude (°)
Month
12.5°W
10°W
5°W
0°
5°E
10°E
15°E
12.5°E
17.5°E
20°E


Zonal Wind at 600mb vs Dust Days (15°N;15°W-5°E)
Dust Days
Zonal Wind (600hpa)


Precipitation at Source vs Dust Days at Matam, Senegal
Dust Days
Precipitation (mm)


Evaporation at Source vs Dust Days at Matam, Senegal
Dust Days
Evaporation (mm)


Drought at Source vs Dust Days at Matam, Senegal
Dust Days
Drought Index


Longitude Location of Maximum Easterly Flow vs Dust Days at 15°N Latitude
Dust Days
Longitude Location of Maximum Easterly Flow

On the Relationship between the African Easterly Jet, Saharan Mineral Dust Aerosols, and West African Precipitation

EMILY BERCOS-HICKEY, TERRENCE R. NATHAN, AND SHU-HUA CHEN

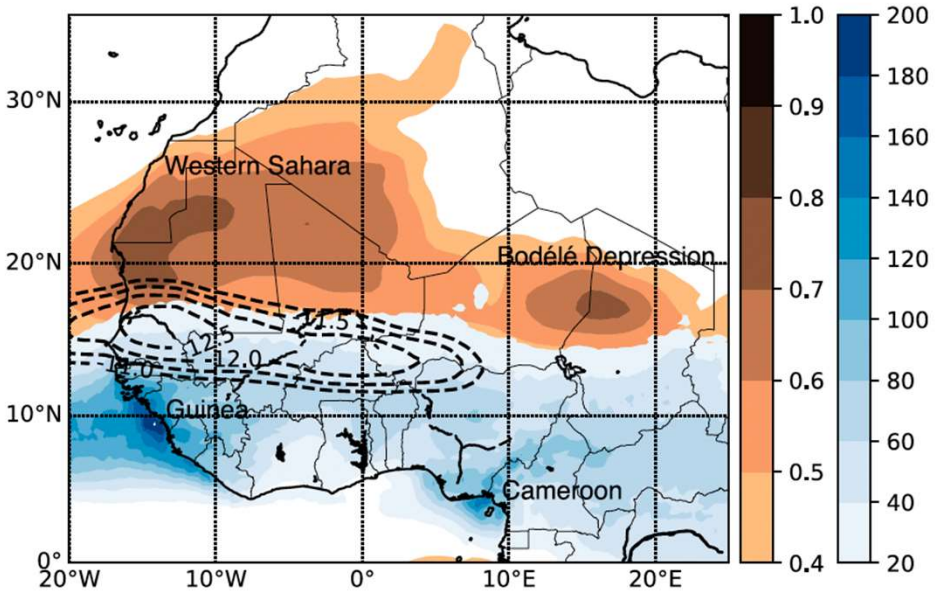


FIG. 1. ERA-Interim 600-hPa zonal wind in $m\,s^{-1}$ (black; dashed contours), MERRA-2 aerosol optical depth (AOD; browns), and TMPA accumulated rainfall in cm (blues), time averaged for July–September for the years 1998–2017. Note that there is a slight overlap between the shaded contours of the AOD and accumulated rainfall.

In dustier years, the AEJ is farther east and stronger, rotates clockwise, and has larger zonal and vertical shears. In wetter years, the AEJ is farther north, has a shorter zonal extent, and has larger meridional shear.

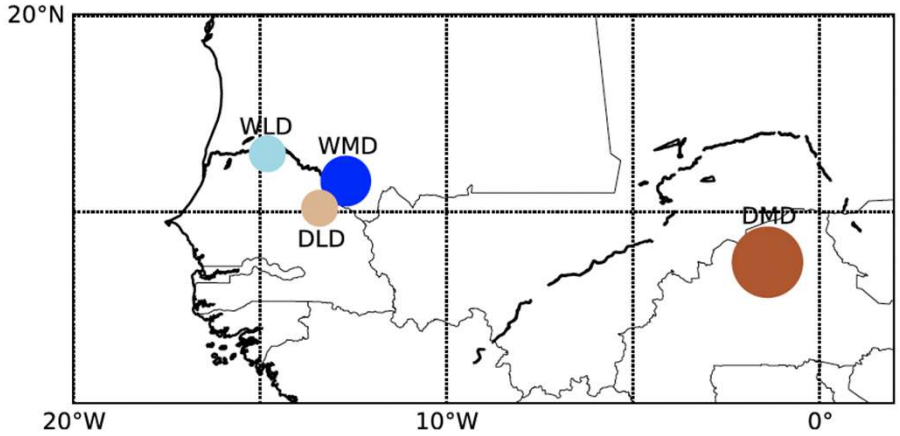


FIG. 4. Location of the AEJ maximum for years that are wetter with less than average dust (WLD), wetter with more than average dust (WMD), drier with less than average dust (DLD), and drier with more than average dust (DMD). Larger circles indicate a larger AEJ maximum wind speed.

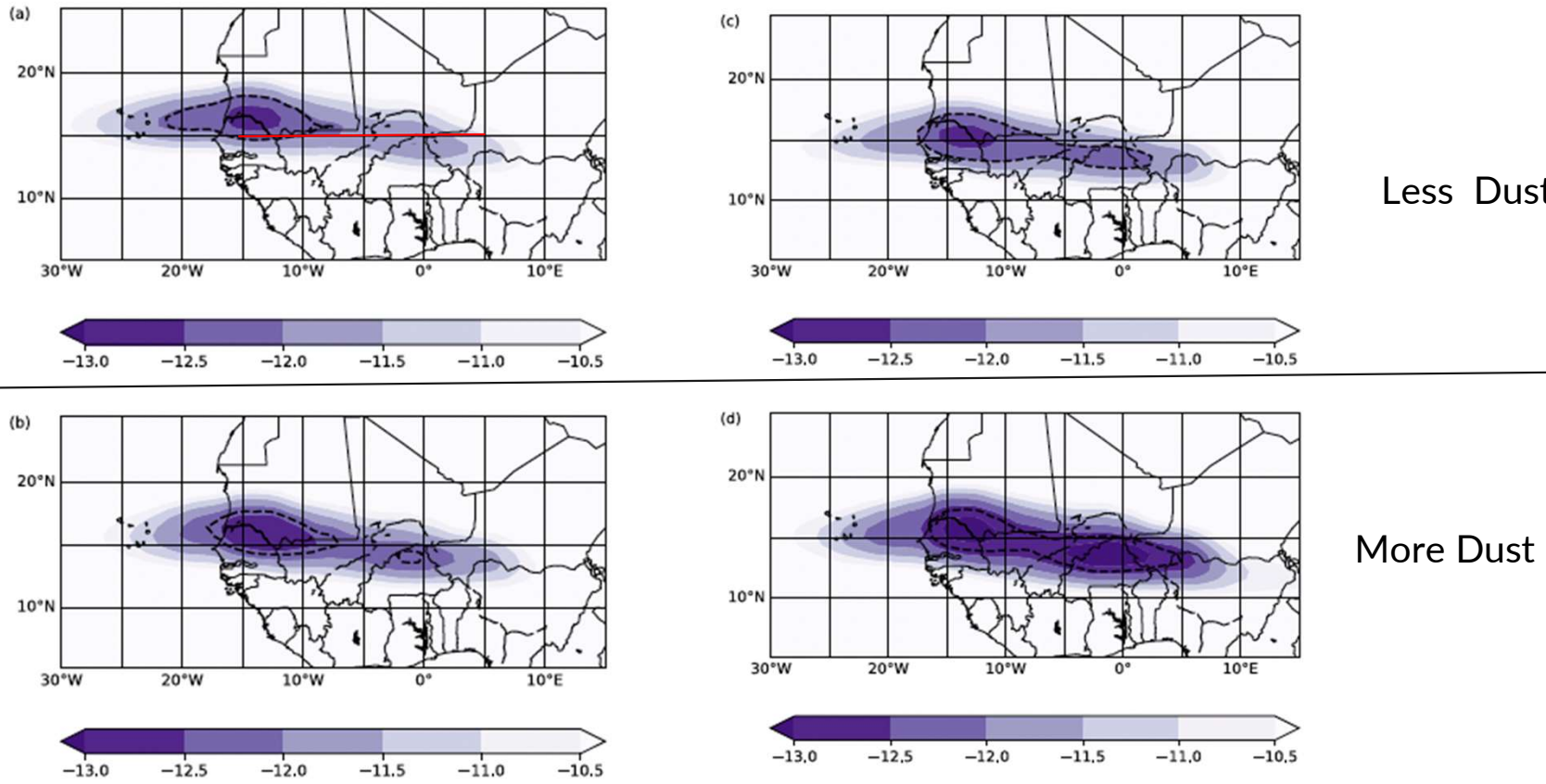
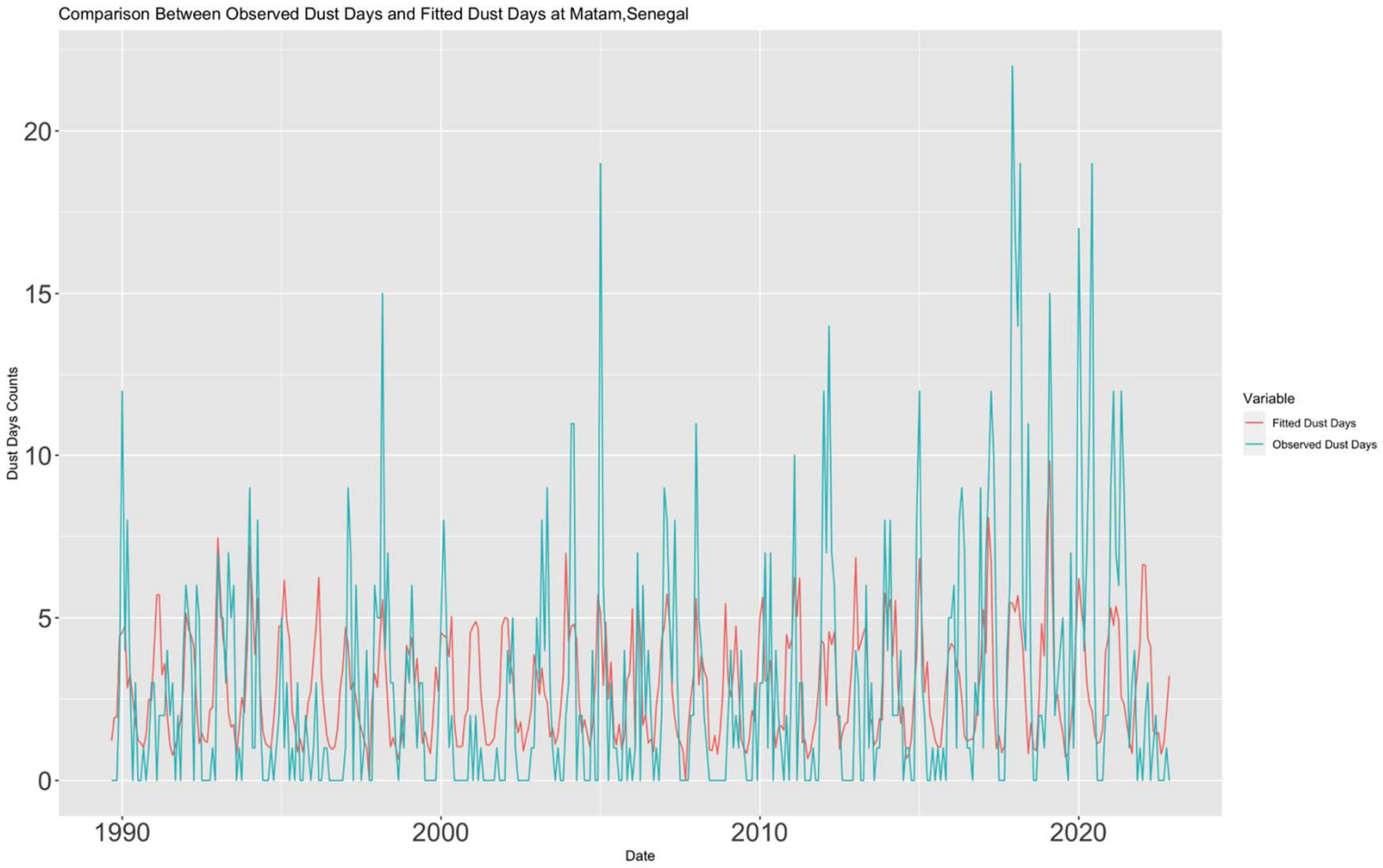


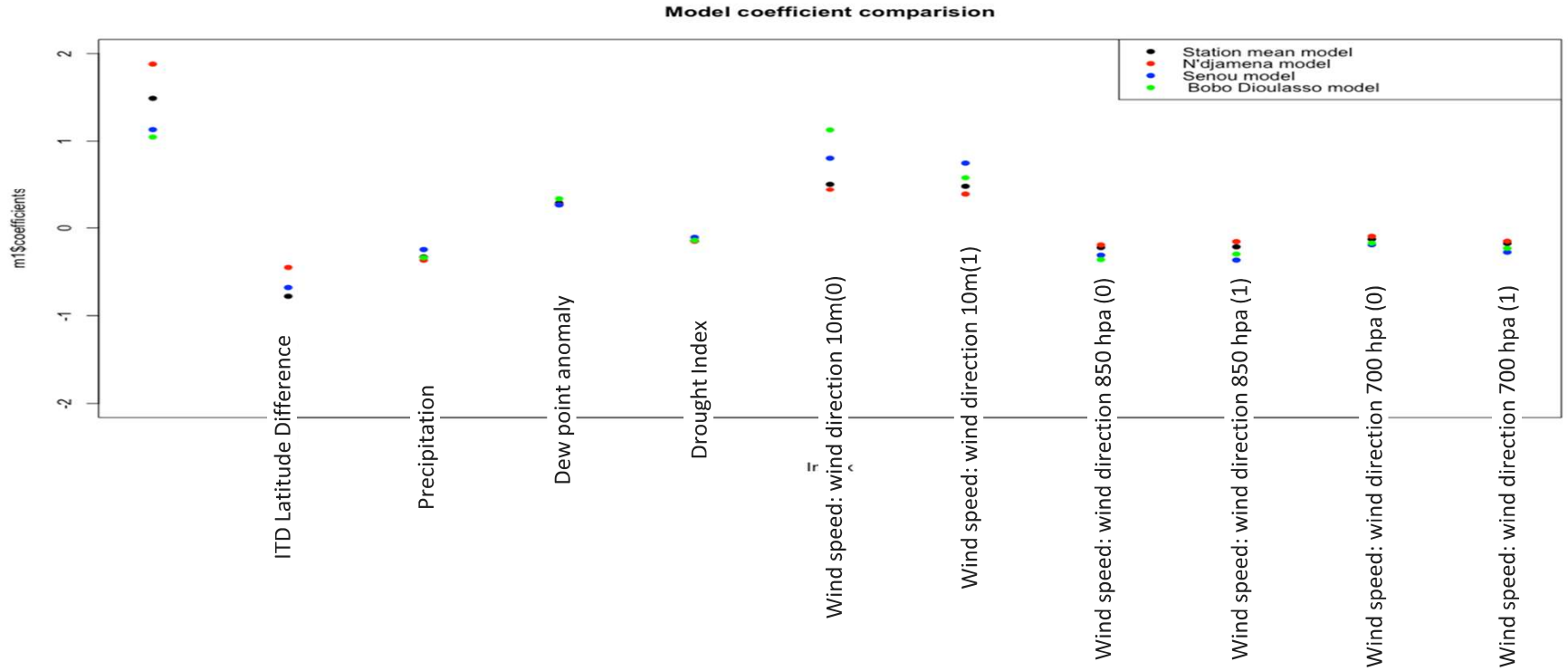
FIG. 6. July–September time-averaged zonal wind composites in $m\,s^{-1}$ at the altitude of the AEJ core for (a) WLD, (b) WMD, (c) DLD, and (d) DMD. Dashed contours indicate 95% of maximum easterly wind speed.

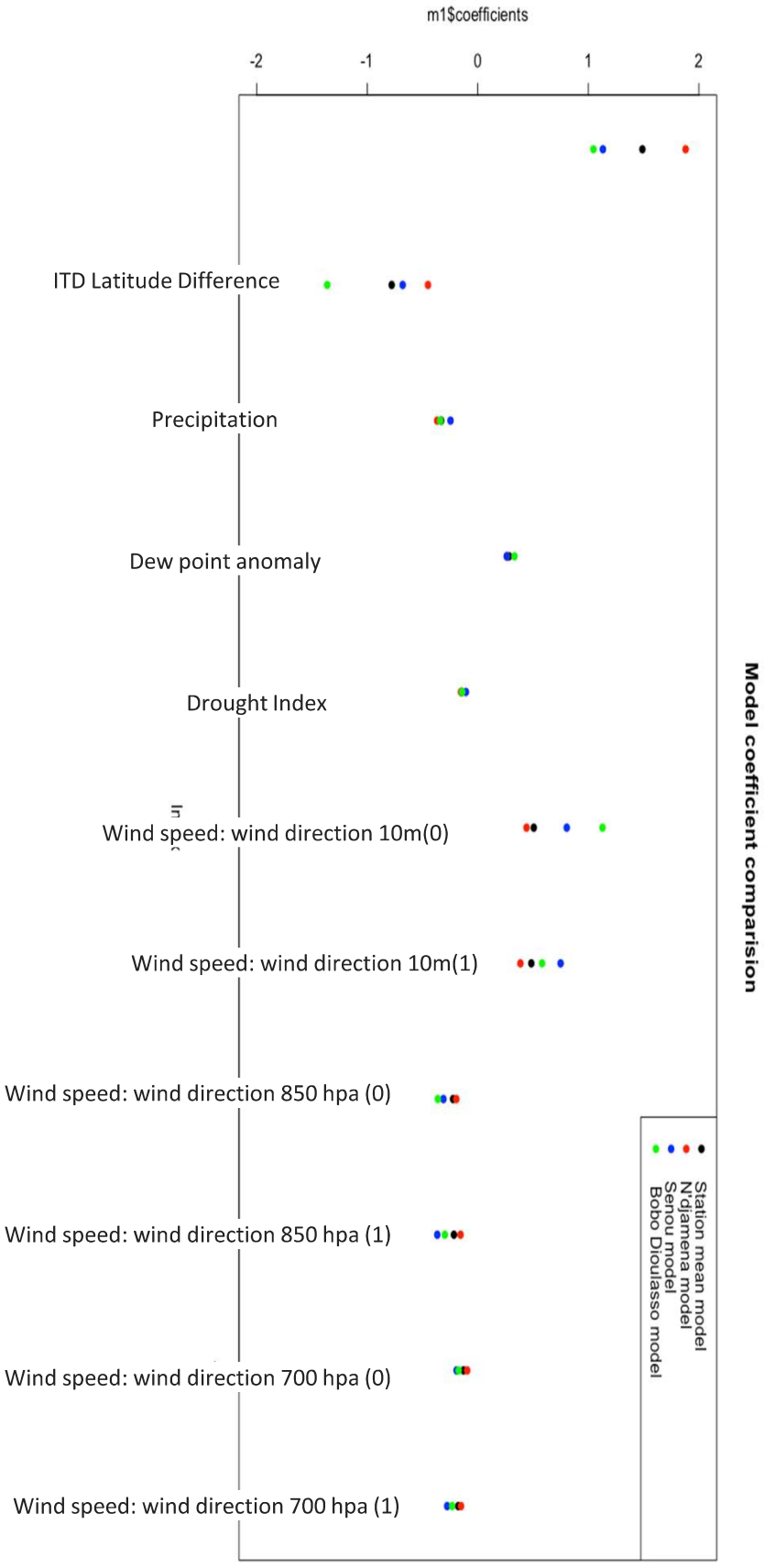
Ideas

- Mention what is going on with the model.
  - Why it is behaving the way it does
  - Why it doesn't work for other places
  - What we need to improve on
- One model to describe both regions
  - Story on why it didn't work efficiently as we thought
  - Graphs of the predicted and the true


Comparison Between Observed Dust Days and Fitted Dust Days at Matam,Senegal
Dust Days Counts
0
5
10
15
20
1990
2000
2010
2020
Date
Variable
Fitted Dust Days
Observed Dust Days

Predictors	Coefficients				P-Value			
	Ndjamena	Senou	Bobo- Dioula	Station avg	Ndjamena	Senou	Bobo- Dioula	Station avg
Itd Lat Difference	-0.45044	-0.67917	-1.33647	-0.77882	<1.73e-08 ***	5.86e-14 ***	<2e-16 ***	< 2e-16 ***
Precipitation	-0.3677	-0.24681	0.37495	-0.33103	2.29e-05 ***	0.02343 *	0.001361 **	5.15e-08 ***
Dew Point Anomaly	0.26307	0.26148	0.33501	0.2831	9.47e-08 ***	3.95e-06 ***	1.16e-11 ***	< 2e-16 ***
Drought Index	-0.15188	-0.10789	-0.13678	-0.14501	0.000633 ***	0.03629 *	0.002101 **	6.68e-07 ***
Wind speed: wind direction 10m (0)	0.44057	0.08442	1.07114	0.50617	0.001666 **	1.02e-05 ***	1.59e-06 ***	1.98e-07 ***
Wind speed: wind direction 10m (1)	0.38523	0.74883	0.54925	0.48395	0.000943 ***	7.96e-08 ***	1.24e-05 ***	5.41e-10 ***
Wind speed: wind direction 850hpa (0)	-0.19419	-0.31089	-0.33327	-0.22382	0.094625 .	0.02937 *	0.017634 *	0.004666 **
Wind speed: wind direction 850hpa (1)	-0.156	-0.36674	-0.29722	-0.21605	0.051657 .	4.12e-05 ***	0.000114 **	3.07e-05 ***
Wind speed: wind direction 700hpa (0)	-0.09576	-0.19219	-0.177	-0.12946	0.079208 .	0.00107 **	0.000319 **	0.000192 ***
Wind speed: wind direction 700hpa (1)	-0.15178	-0.2769	-0.21944	-0.17684	0.046989 *	0.00203 **	0.007234 **	0.000440 ***




m1$coefficients
-2
-1
0
1
2
ITD Latitude Difference
Precipitation
Dew point anomaly
Drought Index
Wind speed: wind direction 10m(0)
Wind speed: wind direction 10m(1)
Wind speed: wind direction 850 hpa (0)
Wind speed: wind direction 850 hpa (1)
Wind speed: wind direction 700 hpa (0)
Wind speed: wind direction 700 hpa (1)
Model coefficient comparision
Station mean model
N'djamena model
Senou model
Bobo Dioulasso model

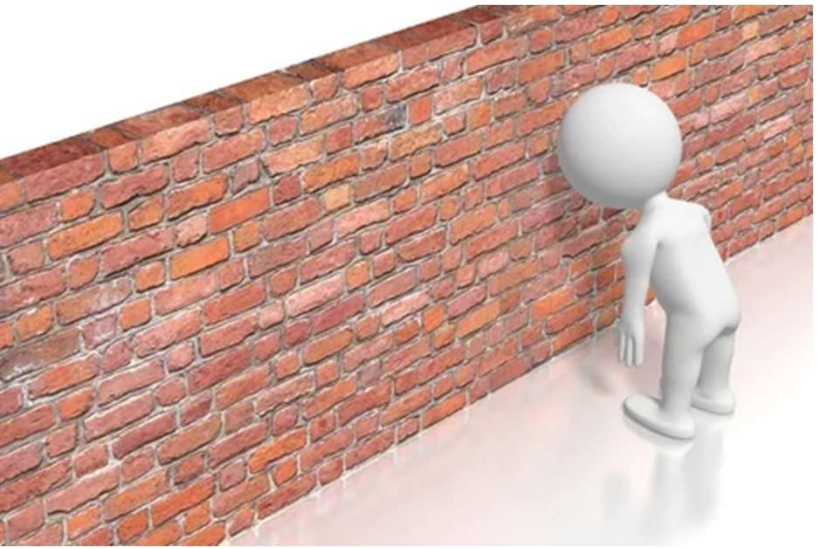
References

Luo, H., & Han, Y. (2021). Impacts of the saharan air layer on the physical properties of the Atlantic Tropical Cyclone Cloud Systems: 2003–2019. Atmospheric Chemistry and Physics, 21(19), 15171–15184. https://doi.org/10.5194/acp-21-15171-2021

Setchell, H. (2023, May 2). ECMWF reanalysis V5. ECMWF. https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5

Supplementary Slides

Roadblocks



Scarcity of climate data

- Africa approximately has ⅛ of the amount of weather stations recommended by the World Meteorological Organization (*The Washington Post*, 2021)

- Organizations like the South African Weather service believes that they should be able to sell their data as they see fit (*Nature.com*, 2019)
    - They contain data from 48 countries

Slide 37

2 Please remove this - or move this to the final slide (conclusions/issues)
Steven Lazarus, 7/5/2023