

Abstract:

The Modern-Era Retrospective Analysis for Research and Application, Version 2 (MERRA-2) provides the first long-term global reanalysis to assimilate space-based observations of aerosols and represents their interactions with other physical processes in the climate system.

In this study, we have examined the variations of atmospheric aerosols for the last 20 years since 2002 using the sub-daily MERRA-2 data and found seven extreme African dust storms that were transported westward across the Atlantic Ocean from the Sahara, crossing 70°-80°W. In particular, the well-known 'Godzilla' dust storm occurred in June 2020, and its dust cloud, with the highest-on-record aerosol optical depths, was transported toward the Americas. This storm greatly degraded air quality over large areas of the Caribbean Basin and the United States. The air quality index reached unhealthy levels for sensitive groups in more than ten U.S. states. In our study, the vertical structure and transport characteristics of the dust layers during this extreme dust event are investigated. The geopotential height and temperature were found anomalously low (around 600 hPa) over the Atlantic Ocean off northwest Africa before the June 2020 dust storm. This anomalous circulation pattern was persistent for more than 12 days starting from around May 30, breaking the regular easterly waves that transport dust from the Sahara Desert to the west. To verify the data quality, daily MERRA-2 PM2.5 data were calculated and compared with PM2.5 observations from the U.S. Environmental Protection Agency (EPA) at several selected ground stations in Florida.

We provide this case study to illustrate how to effectively use various MERRA-2 data services at Goddard Earth Sciences Data and Information Services Center (GES DISC) where MERRA-2 data are archived, hoping to help data users in exploring their own topics of interest using data services at GES DISC.

Data

MERRA-2 Reanalysis Model Hourly Data:

M2TINXAER.5.12.4, (single level) [1]:
DUSMASS25, OCSMASS, BCSMASS, SSSMASS25, SO4SMAS
DUCMASS25, OCCMASS, BCCMASS, SSCMASS25, SO4CMS
M213NVAER.5.12.4, (72 model layers) [2]: DU001, DU002, DU003
M213NVAER.5.12.4, (72 model layers) [3]: U, V, H, T
M213NPAS.5.12.4, (42 pressure levels) [4]: U, V, H, T

The MERRA-2 surface and column total PM2.5 were calculated with the formula in [5][6] as follows:
 $PM2.5_{surf} = DUSMASS25 + OCSMASS + BCSMASS + SSSMASS25 + SO4SMAS * 1.375$
 $PM2.5_{column} (PM25C) = DUCMASS25 + OCCMASS + BCCMASS + SSCMASS25 + SO4CMS * 1.375$

Observation Data:

Surface daily PM2.5 from EPA: <https://www.epa.gov/outdoor-air-quality-data/download-daily-data>

Daily Climatology of Dust from MERRA-2

The daily climatology was calculated with the following steps:

- daily mean of a variable
- multiple years average over a defined climatology base period to create the raw daily climatology; the base period is 30 years from 1991 to 2020 for the meteorology variables and 20 years from 2002 to 2021 for the aerosol variables
- perform a running mean over a 5-day window [7], [8]

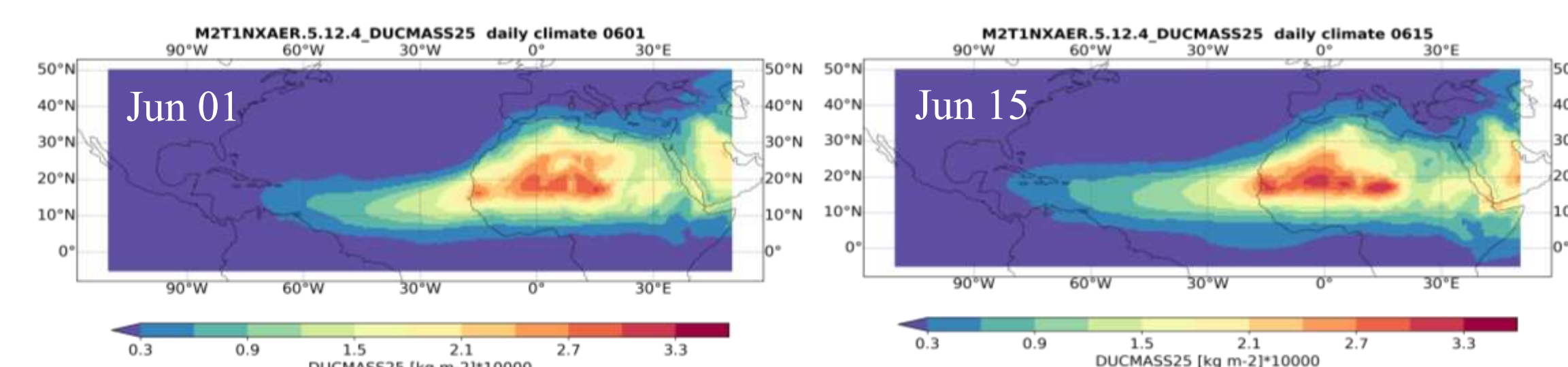


Figure 1: Daily climatology of the dust column mass density - PM 2.5 (M2TINXAER.5.12.4_DUCMASS25) for June 1 and 15. The elevated dust values over the Atlantic Ocean are approximately between 5°N-22°N.

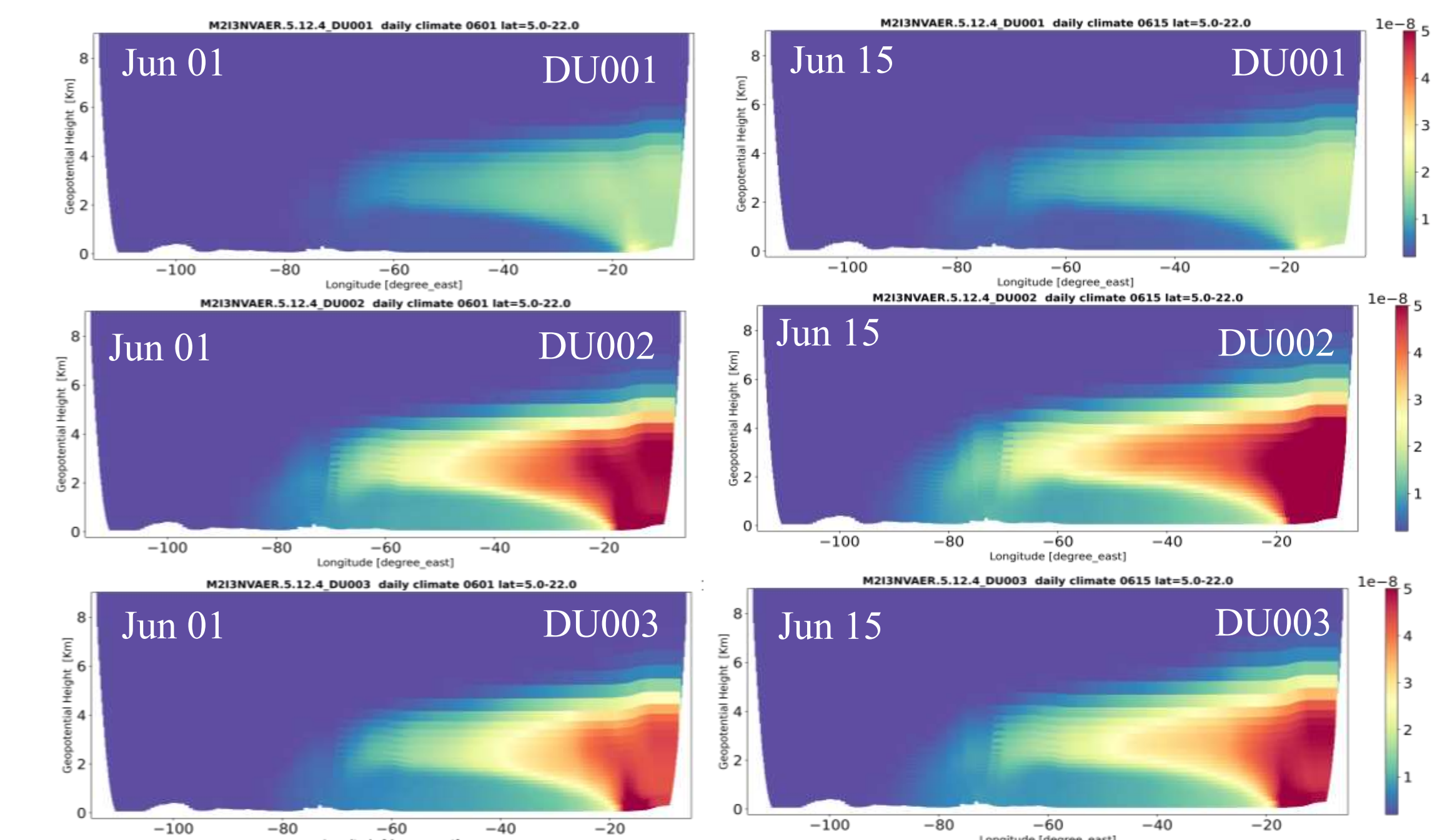


Figure 2: Daily climatology of the dust mixing ratio vertical cross section of M213NVAER.5.12.4 DU001 (top), DU002 (middle), and DU003 (bottom), averaged over latitude 5°N-22°N for the same days as in Figure 1. The climatology dust layer is between 1.5 and 4.5 km above the surface. The aerosol bin sizes are radius 0.73, 1.4, 2.4 (μm) for DU001, DU002, and DU003, respectively [5].

Data Access: The daily climatology was calculated by accessing 3-D hourly data remotely in OPeNDAP service using a Python notebook without downloading data to the local machine. Examples can be found in the [Python-related data How-to document](#).

Finding Extreme Dust Events Transported Across the Atlantic Ocean

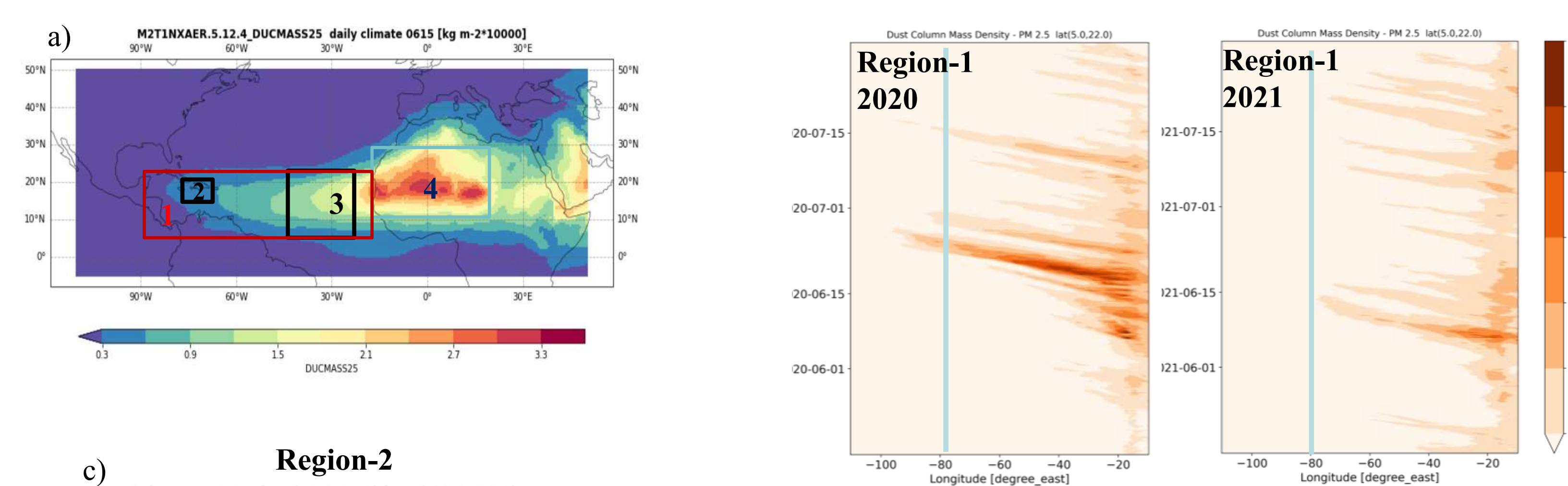


Figure 3:
a) Regions shown on the map are used in this study;
b) Hovmöller plot of the total column dust PM2.5 (DUCMASS25) over Region-1, showing the transportation of dust from west Africa to the west toward the Caribbean Sea and east coast of America for June and July in the extreme year (2020) and a regular year (2021);
c) Time series of the total column PM25 (PM25C) of Region-2 [70°-80°W, 15°-21°N] in summers of 2015, 2018, and 2020.

The time series of PM25C over Region-2 were calculated for 20 years (2002-2021) during summer from May 16 – Aug 31, which found 7 cases with PM25C > 200 mg/m². Among the 7 cases, two cases that had more than one day with PM2.5C > 200 mg/m² and maximum PM25C > 250 mg/m² (red font) as listed below:
2020: 06.22-24, 06.28,
2018: 06.27, 07.12, 08.08,
2015: 06.19-20

Data Access: The Hovmöller and time series plots were processed by accessing data remotely in time-aggregated THREDD data server (TDS) service using a Python notebook.

Analyzing Anomalies in June 2015 and June 2020 Dust Events

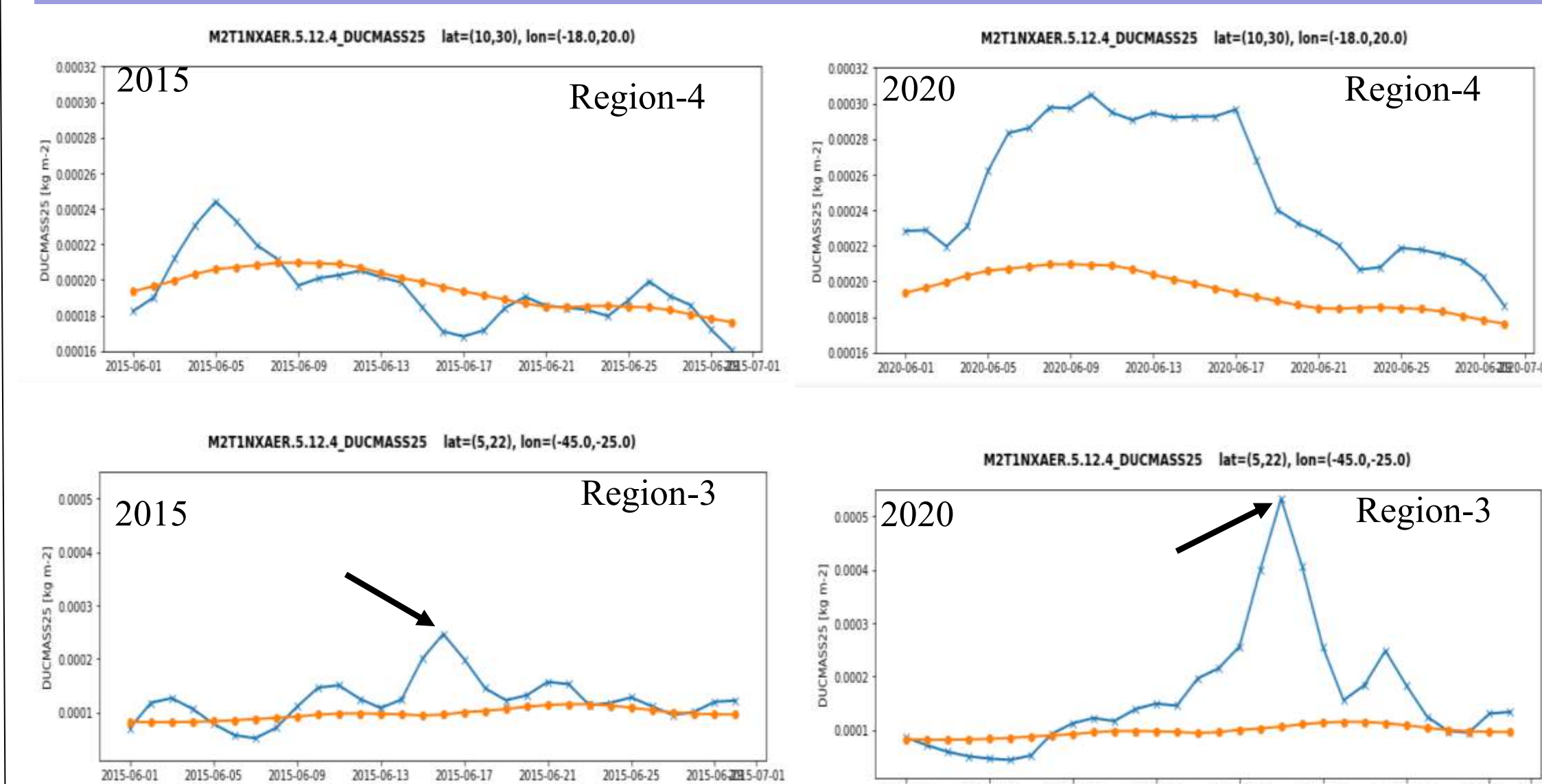


Figure 4: Time series of column dust PM2.5 (DUCMASS25) over Region 4 and Region 3 for June climatology (orange lines) and for June 2015 and June 2020 (blue lines), respectively. A 4-6 days cycle is noticeable over both regions in 2015, but not in 2020. The maximum values in June 2020 in both regions are about two times bigger than those in 2015.

Dust Daily Anomalies

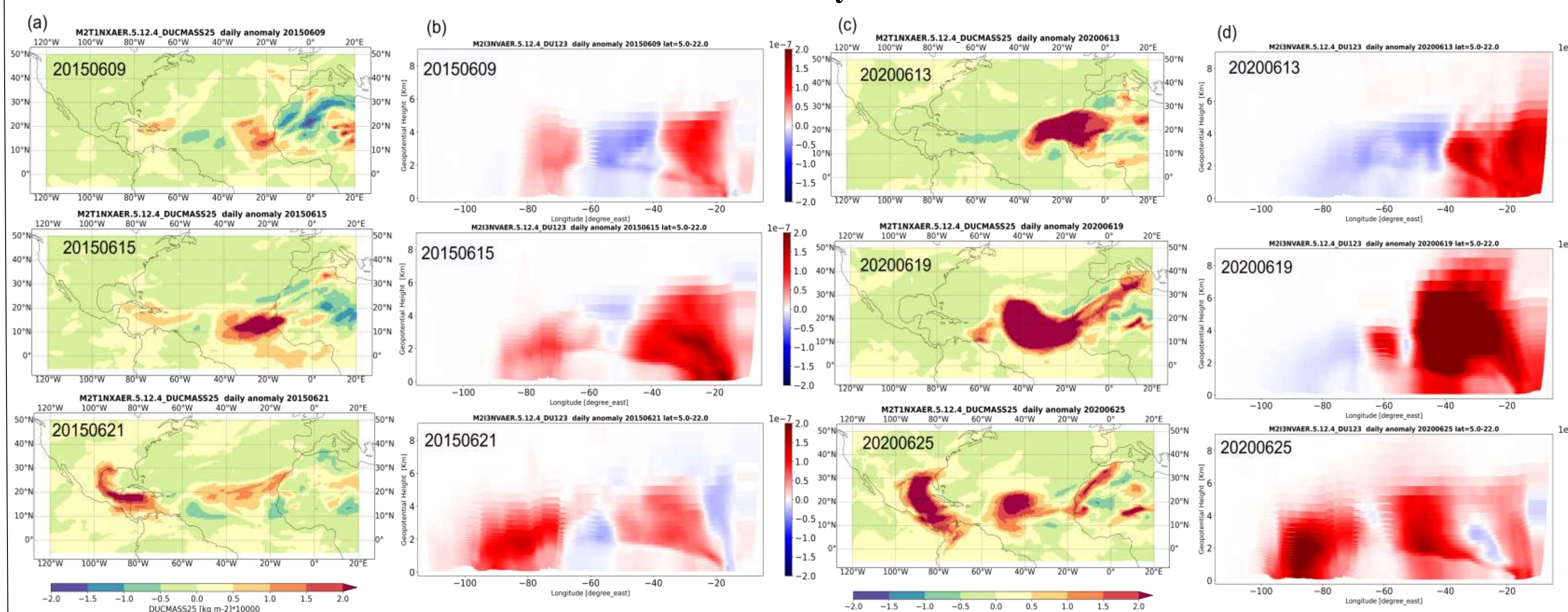


Figure 5a) & 5c): Daily anomaly of column dust density PM2.5 (M2TINXAER.5.12.4_DUCMASS25) for June 9, 15, and 21 in 2015 (a) and for June 13, 19, and 25 in 2020 (c); **5b) & 5d):** Daily anomaly of dust mixing ratio vertical cross section, the sum of DU001, DU002, and DU003 from M213NVAER.5.12.4, averaged over latitude 5°N-22°N for the same days as in (a) and (c). In the June 2015 event, the dust layer was elevated at about the same vertical heights (~4km, or ~600hPa) as in the climatology, while in the June 2020 event, the maximum dust values were about double those in June 2015, and reached a much higher location, to over 8 km above the surface.

Data Access: The daily mean of June 2015 and June 2020 were downloaded using the GES DISC Subsetter service.

Why was the June 2020 African Dust Event so strong ?

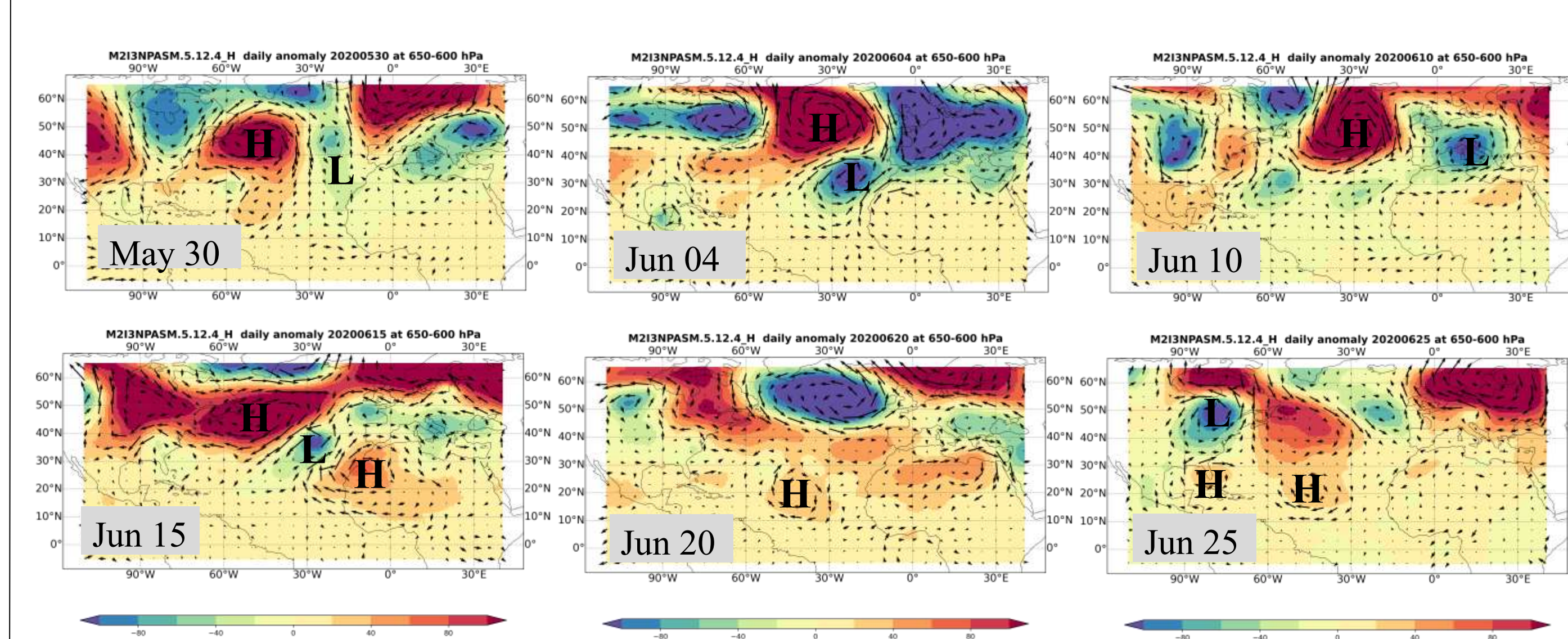


Figure 6: The wind anomaly (vectors) overlain on the geopotential height anomaly (shaded colors) at pressure levels 600-650 hPa for May 30, June 4, 10, 15, 20, and 25 in 2020, respectively.

The daily atmospheric circulation from late May 2020 to the end of June 2020 was investigated using MERRA-2 data. The dust outbreak happened around June 15. It was noticed that a cold air mass from higher latitudes moved to the south around May 30, forming an anomalous low over the Atlantic Ocean off northwest Africa. The circulation pattern lasted more than 12 days. This persistent anomalous low most likely formed westerlies between 10°N-20°N off the western African coast, which broke the regular easterlies over this region and blocked the dust moving out of the Sahara, accumulating dust over this region. An anomalous high then formed over northwestern Africa around June 14 and moved westward in the subsequent days. The anomalous stronger easterlies at the south edge of this high transported abnormally high dust quantities to the west.

Preliminary Comparisons with Surface Observations

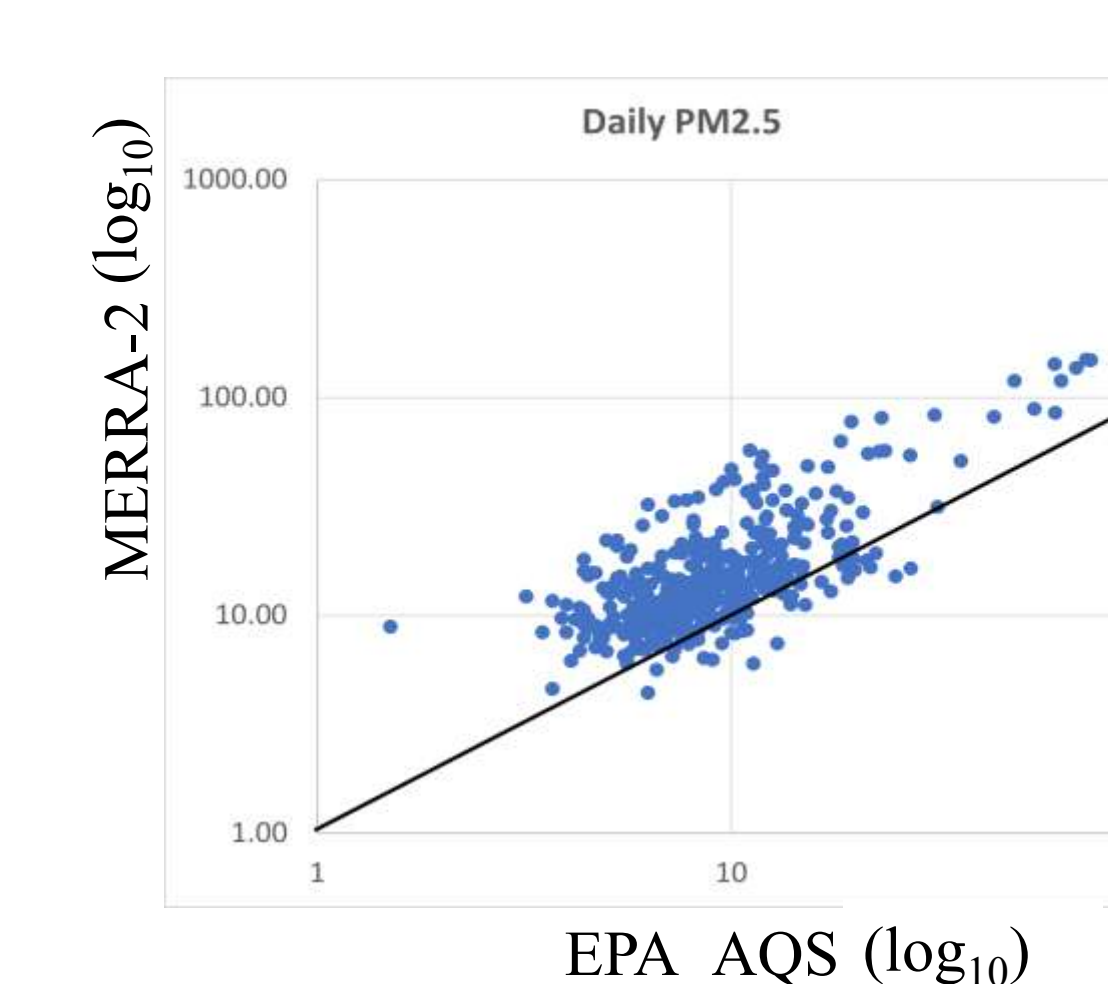


Figure 7: Scatter plot of log10 daily surface PM2.5 from EPA_AQS and MERRA-2.

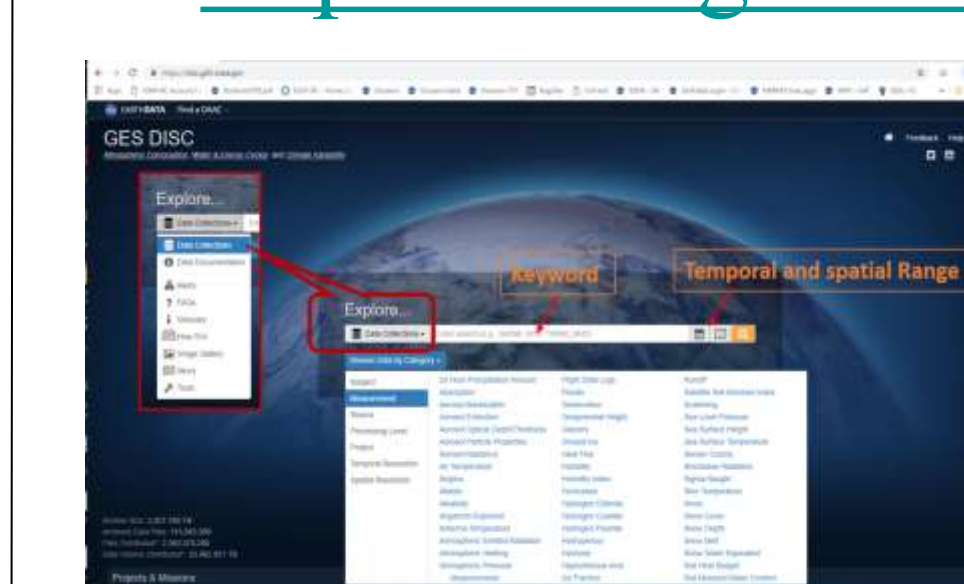
The MERRA-2 daily mean surface PM2.5 data were calculated by averaging the hourly data in local time. Summer 2020 (June 1 to Sep 30) MERRA-2 daily PM2.5 values are compared to the surface observed PM2.5 at four EPA stations in Florida (Table 1). The selected stations consisted of those with a maximum AQI > 150 in June 2020. Results indicate that the values of MERRA-2 PM2.5 are larger than those from the EPA surface data, but the differences seem systematic and are likely to be narrowed by performing bias corrections.

Table 1: Name and location of selected EPA air quality stations in Florida

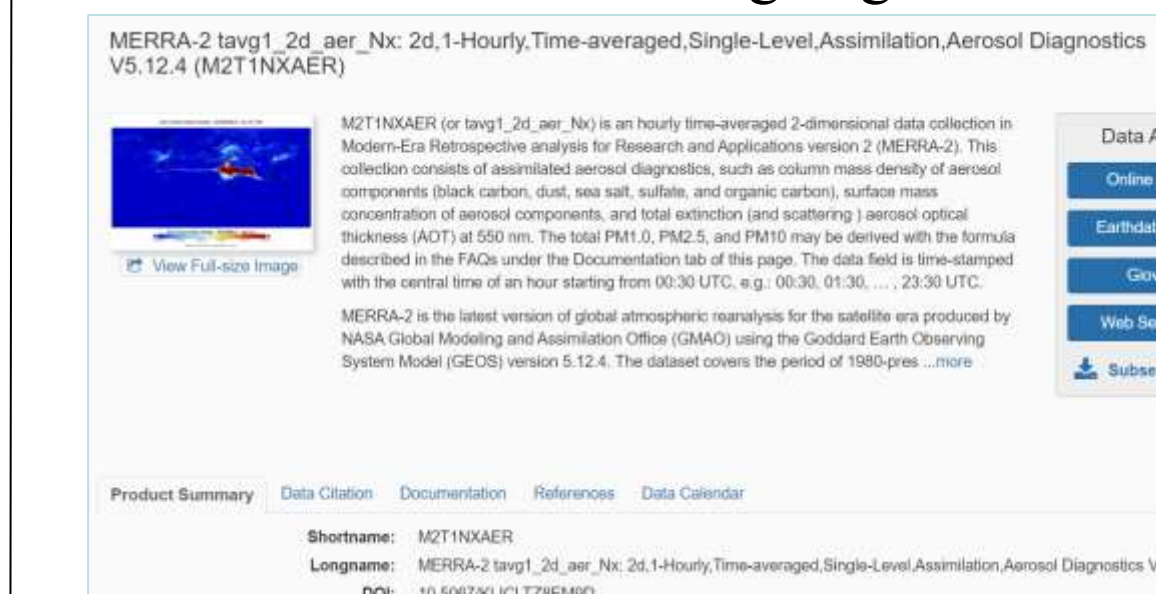
Site Name	CBSA_NAME	COUNTY	SITE_LATITUDE	SITE_LONGITUDE
St. Marks Wildlife Refuge	Tallahassee, FL	Wakulla	30.0925	-84.161111
Tallahassee Community College	Tallahassee, FL	Leon	30.439722	-84.346389
Lake City - Veteran's Domicile	Lake City, FL	Columbia	30.178056	-82.619167
White Springs		Hamilton	30.42659044	-82.79471473

Data Services at GES DISC

<https://disc.gsfc.nasa.gov/>



Dataset Landing Page



Data Access Services:

- ✓ Subsetting
- ✓ Daily statistics (mean, min, max)
- ✓ Direct download (HTTPS)
- ✓ OPeNDAP
- ✓ GDS (GrADS Data Server) for time series
- ✓ TDS (THREDDs Data Server) for time series
- ✓ WMS, WCS
- ✓ Giovanni: online visualization
- ✓ Data in cloud – enabled direct access in S3

Online Documentation:

- ✓ Related documents are linked from the data product landing page, such as User Guide, Algorithm, Known Issues, References, etc.
- ✓ Data How-to (step-by-step instructions on accessing, reading, & viewing data with various data tools)
- ✓ FAQ

References:

- [1] Global Modeling and Assimilation Office (GMAO) (2015), MERRA-2 tsv1_2d_aer_Nv: 2d-1-Hourly, Time-averaged, Single-Level, Assimilation, Aerosol Diagnostics V5.12.4, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: Aug. 2022, data doi: [10.5067/KLCL17Z8EM50](https://doi.org/10.5067/KLCL17Z8EM50)
- [2] Global Modeling and Assimilation Office (GMAO) (2015), MERRA-2 ins3_3d_aer_Nv: 3d-3-Hourly, Instantaneous, Model-Level, Assimilation, Aerosol Mixing Ratio V5.12.4, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: Sep. 2022, data doi: [10.5067/TVB4GCP07K2](https://doi.org/10.5067/TVB4GCP07K2)
- [3] Global Modeling and Assimilation Office (GMAO) (2015), MERRA-2 ms3_3d_aer_Nv: 3d-3-Hourly, Instantaneous, Model-Level, Assimilation, Assimilated Meteorological Fields V5.12.4, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: Sep. 2022, data doi: [10.5067/TKL17Z8EM50](https://doi.org/10.5067/TKL17Z8EM50)
- [4] Global Modeling and Assimilation Office (GMAO) (2015), MERRA-2 ms3_3d_aer_Nv: 3d-3-Hourly, Instantaneous, Pressure-Level, Assimilation, Assimilated Meteorological Fields V5.12.4, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: Oct. 2022, data doi: [10.5067/0B2M5G944H0](https://doi.org/10.5067/0B2M5G944H0)
- [5] <https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/FAQ/>
- [6] Buchard, V., Randes, C. A., da Silva, A. M., Darmenov, A., Colarco, P. R., Govindaraju, R., et al. (2017). The MERRA-2 Aerosol Reanalysis, 1980 Onward: Part II: Evaluation and Case Studies. *Journal of Climate*, 30(17), 8814-8872. doi: [10.1175/JCLI-D-16-0919.1](https://doi.org/10.1175/JCLI-D-16-0919.1)
- [7] Müller, W.A., Appenzeller, C., Schäfer, C. (2005). Probabilistic seasonal prediction of the winter North Atlantic Oscillation and its impact on near surface temperature. *Clim. Dyn.* 24(2-3):213-226. doi: [10.1007/s00382-004-0492-z](https://doi.org/10.1007/s00382-004-0492-z)
- [8] ETCCDI (The Expert Team on Climate Change Detection and Indices)