A Multi-Scale Dynamical Analysis of the Saharan Dust Outbreak Towards the Cape Verde in Early November 2017

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Abstract

On 13 November 2017, a strong continental-scale Saharan dust outbreak was observed in satellite imagery over Mindelo, Cape Verde, located about 650 km off the coast of Senegal in West Africa. Horizontal visibility was reduced to 1100 m leading to major disruptions of the local air traffic. Dust mobilization was already observed over the foothills of the Saharan Atlas Mountains at 0600 UTC on 10 November 2019 but did not appear clearly in SEVIRI pink dust images in the subsequent days. In this study, we examined the multi-scale dynamical processes associated with this particular dust storm using ECMWF ERA-Interim reanalysis data, newly performed very-high resolution WRF-CHEM simulations with horizontal grids of 18 km and less, NAAPS aerosol forecast output, ship-based observation dataset from the North Atlantic Expedition MSM 68/2, as well as surface observations, and upper-air soundings from weather stations in North Africa. Our analyses of this storm highlights the following meteorological processes: (1) the event was associated with a typical Harmattan surge, i.e., the post-frontal strengthening of the northerly winds behind an eastward moving cyclone, (2) a series of earlier Rossby Wave Breaking events (RWBs) made the environment favorable for the Harmattan surge, (3) the dust storm was composed of two distinct dust surges, (4) the dust aerosol from the first surge was later mixed with the dust from the second surge while simultaneously propagating south-westward and later westward, (5) the PBL became adiabatic along the leading edge of the leftover cold front between the southern/southeastern flank of the Atlas Mountains and western/northwestern flank of the Hoggar Mountains, and (6) vertical dust mixing then occurred due to very strong surface heating associated with the development of a deep daytime PBL in the region behind the cold front. The results of this research demonstrate that very-high spatial resolution WRF-CHEM model can resolve the dynamical processes and realistically simulate large-scale North African dust storm.

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Introduction and Motivation

- Every year a **large-scale dust storm associated with Harmattan wind** occurs in North Africa and impacts the downwind human environment through the degradation of air quality, public health, aviation, road safety, and other infrastructure.
- The large-scale dust storms associated with the Harmattan wind are **challenging to forecast because of aperiodic nature of surges in the background climatological trade winds**.
- We provide a **multi-scale dynamical analysis of 13 November 2017 dust outbreak over Mindelo, Cape Verde,** located about 650 km off the coast of Senegal in West Africa. During this outbreak, horizontal visibility was reduced to 1100 m leading to major disruptions of the local air traffic.

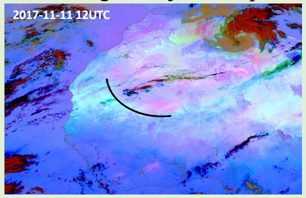

Figure 1: False-color dust RGB from the SEVIRI instrument for 12 UTC 11 November, where magenta color indicates dust. The black solid curve shows the leading edge of the propagating dust front.

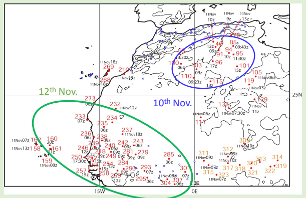

Figure 2: Surface observations over North Africa and Cape Verde Islands, where red dots indicate the reduced visibility on the 10th and 12th of November 2017.

Research Objectives

- Understand the synoptic setup for the windy, cold surge.
- Understand the dust deflation mechanisms on the lee side of the Saharan Atlas Mountains and the evolution of dust frontogenesis.
- The possible use of the WRF-CHEM model in operational dust forecasting.

Datasets and Numerical Simulation

- False-color dust RGB from the SEVIRI instrument.
- METAR and SYNOP data from Integrated Surface Database.
- ECMWF ERA-Interim reanalysis products [2].
- AOD data from the North Atlantic Expedition (2017).
- WRF-CHEM model utilizing the GOCART dust scheme [4].

No. of domains	3
Total simulation hours	120 hours
Horizontal resolutions	18, 6, and 2-km
Model vertical structure	40 levels
Model initialization dataset	ERA-Interim

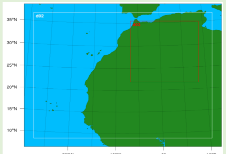

Figure 3: WRF-CHEM simulation domain

Results

Rossby Wave Breaking

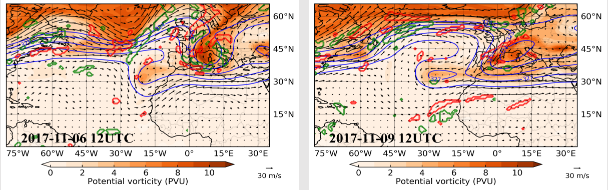

Figure 4: ERA-Interim derived 330 K IPV, horizontal wind, Montgomery streamfunction, and 250 hPa divergence before the dust storm.

Dust Frontogenesis

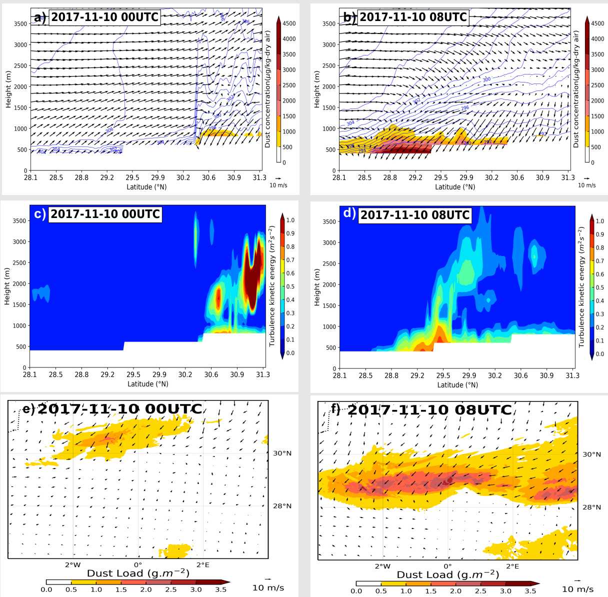

Figure 5: Simulated (2-km) vertical cross-section of potential temperature, dust concentration (a, b), PBL TKE (c, d) cut along 1W, and 10m wind and total dust load (e, f). Confluence region lies around 30.4N, ahead of near-surface PBL TKE, during the incipient strong dust frontogenesis (a, c, e).

Formation of Multiple Dust Plumes

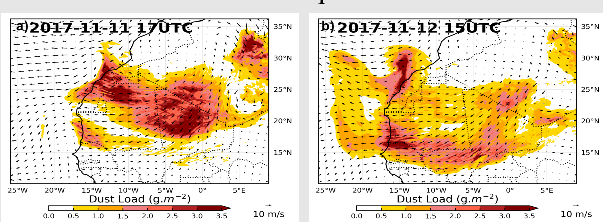

Figure 6: Simulated (6-km) 10m wind and total dust load. Small-scale dust plume formed ahead of the major dust plume near 15E, 17N (a). Dust plume in Cape Verde Islands arrived in succession (b).

Model Comparison with Observation

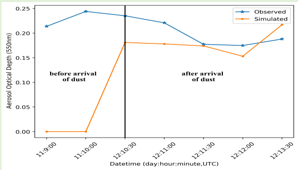

Figure 7: Comparison between WRF-CHEM simulated dust AOD (18-km) and observed AOD from ship measurement in Cape Verde during the North Atlantic expedition of the research vessel *RV MARIA S. MERIAN* (2017).

Discussion and Conclusions

- Synoptic precursors to the near-surface wind and dust transport followed a series of **RWB and non-linear Rossby wave reflection**, as noted by Abatzoglou & Magnusdottir (2004).
- Before the incipient dust frontogenesis, **hydraulic jumps** forced the N-NE surface flow down the Saharan Atlas Mountains ahead of a larger-scale cold front and started to create confluent flow.
- **Incipient strong dust frontogenesis** occurred around 0000Z on the 10th when confluence strengthened ahead of weak surface TKE and strengthening boundary between N and WSW flow.
- After sunrise, TKE deepened explosively, and **front enhanced when cold air and TKE behind the larger-scale cold front get into phase.**
- As evening approached, gradually **flow turned to the west caused by the Coriolis force**, which forced the dust front to become oriented more E-W and propagate westward.
- The **offshore dust plume was the sum of multiple dust plumes**, where dust arrived in the Cape Verde Islands at a low-level in succession, as revealed by both observations and simulation.

References

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