On the decadal scale correlation between African dust and Sahel rainfall: the role of Saharan Heat Low-forced winds

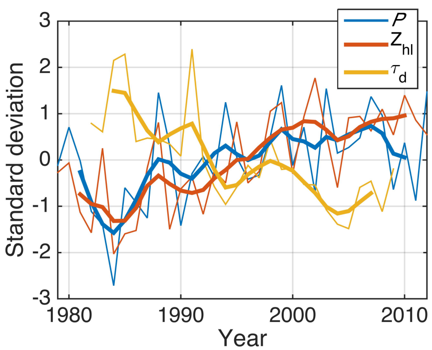
Weijie Wang, Amato Evan, Cyrille Flamant and Christophe Lavaysse
contact: wjwang@ucsd.edu

Introduction

By mass, aeolian dust is the most pervasive aerosol in the atmosphere. The presence of suspended dust affects the local energy balance through direct and indirect effects, modifies the hydrological cycle via radiative forcing and modification of cloud microphysical properties, and is a vehicle for the long-range transport of nutrients to global oceans and terrestrial land surfaces.

North Africa is the world's largest dust source; accounting for more than 55% of the global dust emissions. Long-term in-situ observations at and coral reef proxy and satellite have shown that dust emission from North Africa peaked during the mid-1980s and has followed a downward trend through at least the late 2000s. Studies have found dust cover over the Atlantic is anticorrelated with precious-year Sahelian precipitation. However, there are several aspects of such a theory that are not consistent. For example, satellite imagery suggests that the vast majority of dust-emitting regions lie to the north of the vegetated region of the Sahel.

Here we reconcile this contradiction by showing that both Saharan surface wind fields over the major regional dust emitting regions, and the northward propagation of the monsoon flow and thus Sahel rainfall, are forced by the thermodynamic state of a meteorological feature termed the Saharan Heat Low.



Upper: Seasonal (June-August) time series of Zhl (red), precipitation (*P*, blue) and td (yellow). The monthly mean precipitation series is averaged over 5° W to 20° E, 10° to 20° N, and td is averaged over 10° to 65° W and 0° to 30°N. The thin lines are the seasonal means and the thick lines are the 5-season smoothed time series (via a 1-4-7-4-1 filter).

Data and Methods

The Saharan heat low (SHL)

The SHL is defined as the atmospheric thickness between the 700 hPa and 925hPa levels, using geopotential height from ERA Interim reanalysis.

Precipitation

The Version-2 Global Precipitation Climatology Project (GPCP).

Dust aerosol optical depth

Retrieved from satellite radiance measurements from the Advanced Very High Resolution Radiaometer (AVHRR).

Dust emission rates

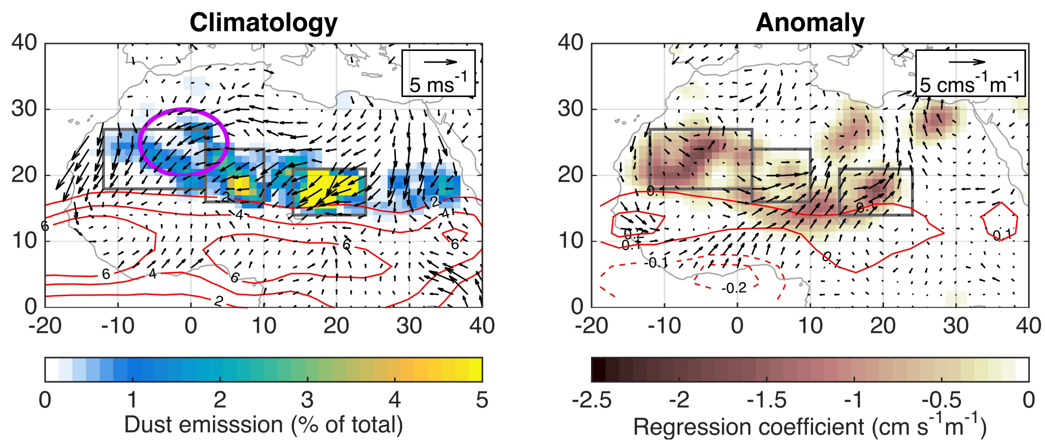
Derived from Spinning Enhanced Visible and Infrared Imager infrared dust index images.

Winds

ERA Interim reanalysis

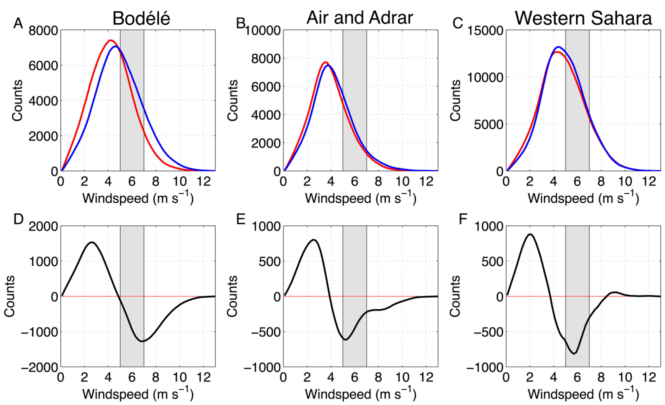
Results

Climatology (A) and anomaly (B) of precipitation and winds



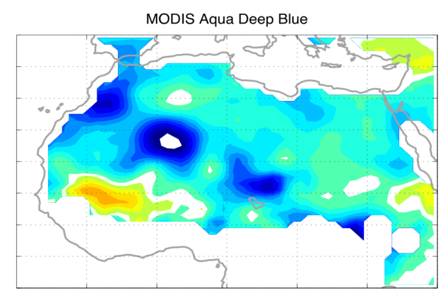
Left: Climatology (A) and anomaly (B) of precipitation and winds. (A) Map of annual dust emission, climatological precipitation and 925 hPa climatological wind vectors. Dust emission rates are derived from Spinning Enhanced Visible and Infrared Imager infrared dust index images in units of % of annual North Africa dust emission. The magenta contours are precipitation in units of mm day-1 averaged for the summertime from 1979 through 2012 and wind vectors in units of m s-1 are averaged for the same period of time. The red circle indicates the location of the SHL during the summer. The brown boxes are the major dust hotspots of the Bodélé Depression (14° to 24° E, 14° to 21° N), the depression in the lee of Aïr and Adrar Mountains (2° to 10° E, 16° to 24° N), and the Mauritania and Western Sahara source region (12°W to 2° E, 18° to 27° N). (B) Map of the coefficients of the regression of the 925 hPa climatological wind vector, the wind speed and precipitation onto Zhl for the summertime from 1979 through 2012. Shaded regions with color contours are statistically significant at the 90% level.

Histogram count of 10m wind speed



Left: Histogram counts (per 0.2m/s) of 10 m wind speed from ERA-Interim reanalysis for the 300 strongest (red) and weakest (blue) phases of the SHL in the Bodélé Depression (A), a depression in the lee of Aïr and Adrar Mountains (B), and the Mauritania and Western Sahara (C) in the summertime from 1979 through 2012. The means of the wind speed for strong and weak SHL are statistically significantly different in ABC based on the 2-tailed t-test. Shown in panels DEF are the wind speed histogram differences for the warm minus cool SHL cases. The grey shaded region represents wind speed threshold for dust emission.

MODIS Aqua Deep Blue



Right: Difference in aerosol optical depth (DAOD) for 300 warmest minus 300 coolest SHL from MODIS Aqua Version 5.1 over North Africa from 2003 through 2014.

Conclusion

We show that interannual variability in Sahelian rainfall, and surface wind speeds over the Sahara, are the result of changes in lower tropospheric air temperatures over the SHL. As the SHL warms an anomalous tropospheric circulation develops that reduces windspeeds over the Sahara and displaces the monsoonal rainfall northward, thus simultaneously increasing Sahelian rainfall and reducing dust emission from the major dust "hot-spots" in the Sahara.

Publication

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