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Climatic modulation of early summer dust emissions over West Africa

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A B S T R A C T

This study describes how climatic conditions affect of the generation and transport of dust over the SW Sahara Desert (12°-22°N, 18°W-20°E), with a focus on early summer in the period 1980–2014. Results are given for the annual cycle and climatology of May–Aug season, trends in aerosol optical depth (AOD) and contributing factors, co-variability of monthly and daily AOD and climate variables, case studies of dust generation in early summer and analysis of diurnal fluxes. The study is underpinned by multi-satellite measured AOD and ECMWF meteorological reanalysis fields.

Linear trends in the period 1980–2014 indicate that AOD (dust) diminished slightly as rainfall and vegetation cover increased. Concommitant climatic trends include a weakening of Atlantic trade winds, acceleration of the easterly jet and inland penetration of the Guinea monsoon. Trends in temperature and winds strengthen above the boundary layer; suggesting that surface changes are damped by greening of the Sahel 1980–2014.

Climatic conditions favoring dust emissions are evident in sensible heat flux, maximum temperature and upward motion at seasonal and daily time scales, with influence from wind vorticity at diurnal time scale. Incremental knowledge on climatic controls of dust mobilization could improve emission budgets and forecasts for the SW Sahara Desert.

1. Introduction

The Sahara Desert emits ~800 Tg/yr of dust (~70% of earth total) that forms a westward plume seen in satellite estimates of aerosol optical depth (AOD, sunlight extinction) (Prospero and Lamb, 2003; Huneeus et al., 2011; Hsu et al., 2012). Fluctuations in dust output are attributed to changes in the regional heating, circulation and convection: being low in winter and wet spells, and high in summer and dry spells (Ginoux et al., 2004; Evan et al., 2006, 2011; Wang et al., 2012). There has been a small increase of vegetation cover over much of Africa since 1980 (de Jong et al., 2011), but high aerosol concentrations suggest unresolved climate and anthropogenic effects on dust mobilization (Prospero et al., 2002; Mahowald et al., 2010; Okin et al. 2011; Ginoux et al., 2012; Seneviratne et al., 2012). Field campaigns (Heintzenberg, 2009; Knippertz and Todd, 2012) have yet to constrain Sahara aerosol emission estimates; models consequently exhibit a range from 200 to 2000 Tg/yr (Huneeus et al., 2011). Calibrated satellite aerosol algorithms (Sakerin and Kabanov, 2002; Torres et al., 2002) and improving meteorological reanalyses enable studies on dust climate, motivating this research.

A warm dry Saharan air layer (925-600 hPa) is prevalent in early summer (Carlson and Prospero, 1972; Adams et al., 2012; Prospero and Mayol-Bracero, 2013), damping convection in passing atmospheric disturbances (Dunion and Velden, 2004; Rauber et al., 2007; Heymsfield et al., 2009; Wong et al., 2009; Twohy et al., 2009; Jury and Santiago, 2010). Surface weather conditions are extreme at dust sources. With maximum temperature > 40 °C and dewpoint < 0 °C; steep lapse rates (< −1 °C/100 m) generate vertical gusts > 1 m/s in a day-time boundary layer > 3 km deep (Engelstaedter and Washington, 2007a,b). In the 3–6 km layer, the African easterly jet blows > 7 m/s, entraining dust toward the Atlantic. Further south are smoke plumes from burned forests that transform into greenhouse gases (Jury and Whitehall, 2009), warming elevated layers and limiting convective potential. Between the moist Guinea coast and the Sahara Desert, easterly waves pass from June to September (Jones et al., 2003), their cyclonic winds stirring up dust (Torres et al., 2002, Zhang et al., 2007; Ismail et al., 2010).

The aim of this work is to better understand and predict climatic controls on dust generation over the SW Sahara during early summer.

2. Data and methods

The study uses daily and monthly aerosol concentrations estimated by numerous NASA and NOAA satellites in the study period (TOMS 1978–2005, SeaWifs 1997–2010, MISR 2000–2014, MODIS 2000–2014, OMI 2004–2014). The satellite aerosol data have varying

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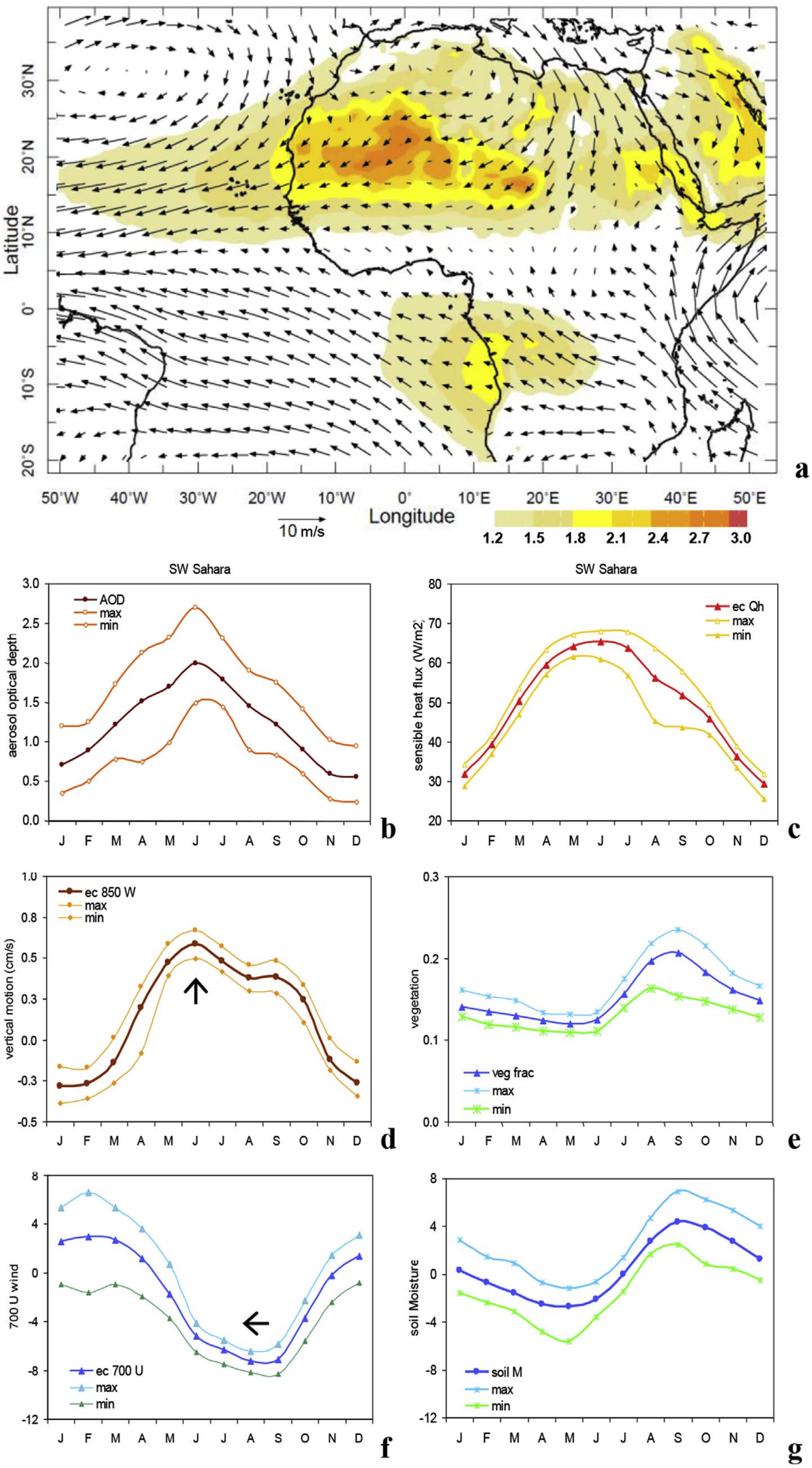

Fig. 1. May–Aug climatology of: (a) multi-satellite AOD (shaded color) and NCEP 925-700 hPa winds (1980–2014). Annual cycle of: (b) AOD from multi-satellite data; (c) ECMWF sensible heat flux, (d) ECMWF 850 hPa vertical motion, (e) NASA vegetation fraction, (f) ECMWF 700 hPa zonal wind (m/s), (g) GRACE soil moisture (cm), all averaged over the SW Sahara 12°-22°N, 18°W-20°E (box in Fig. 3c). Curves represent lower and upper 2.5% and mean; interrelationships are covered in Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)