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The electrification of dust-lofting gust fronts (‘haboobs’) in the Sahel

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ABSTRACT

Two Doppler radars and a suite of auxiliary surface observations are used to document the electrical, aerosol and aerodynamic properties of dust-lofting gust fronts near Niamey, Niger during the AMMA (African Monsoon Multidisciplinary Analysis). Electrification with dominant negative polarity is a common behavior, consistent with earlier studies on dust devils and the Harmattan wind in dry environments.

1. Introduction

Violent dust storms (‘haboobs’) are commonplace (Sutton, 1925, 1931; Hamilton and Archibald, 1945; Slingo et al., 2006; Bou Karam et al., 2008; Williams, in press) in the Sahelian belt of West Africa. Their preferential occurrence there, between the dry Sahara Desert to the north and the moist tropical belt to the south is attributable to two transitional features: the ground is sufficiently dry to suppress vegetation and thereby to expose dry soil, and the boundary layer is moist enough to sustain deep convection that ultimately raises the dust. When African easterly waves are present, rainfall episodes on one day are often followed by dry periods of subsidence for 2–4 days, allowing drying of the soil between events. The mechanism for dust-lofting in the wet season is the gust front driven by the cold outflow from deep convection, produced by both isolated thunderstorms early in the wet season (June, July) and westward propagating squall lines later in the season (August, September) when the conditions over the Sahel are more baroclinic.

Interest arose in the haboobs during the AMMA because they are readily detected and tracked with the MIT Doppler radar, they produced marked signatures in many instruments at the nearby ARM (Atmospheric Radiation Measurement) facility, and because they are highly electrified as indicated by lightning-detection equipment. The haboobs are of scientific interest because of their possible role in the export of dust from Africa (Williams et al., 2006; Williams, in press) and of agricultural interest because of their role in soil erosion (Sterk, 2003), but in this study the electrical behavior is the central issue. The electrification of blowing sand and dust is hardly a new topic (Rudge, 1914; Keith, 1944; Demon et al., 1953; Latham; 1964; Harris, 1967; Kok and Renno, 2008), and the electric field of the dust devil has been widely studied (Freier, 1960; Crozier, 1964; Renno et al., 2004; Jackson and Farrell, 2006). The present study appears to be the first systematic investigation of the electrical behavior of West African haboobs.

2. Observational methods

The principal means for detecting these dust-raising gust fronts from afar was the MIT C-band Doppler radar, which

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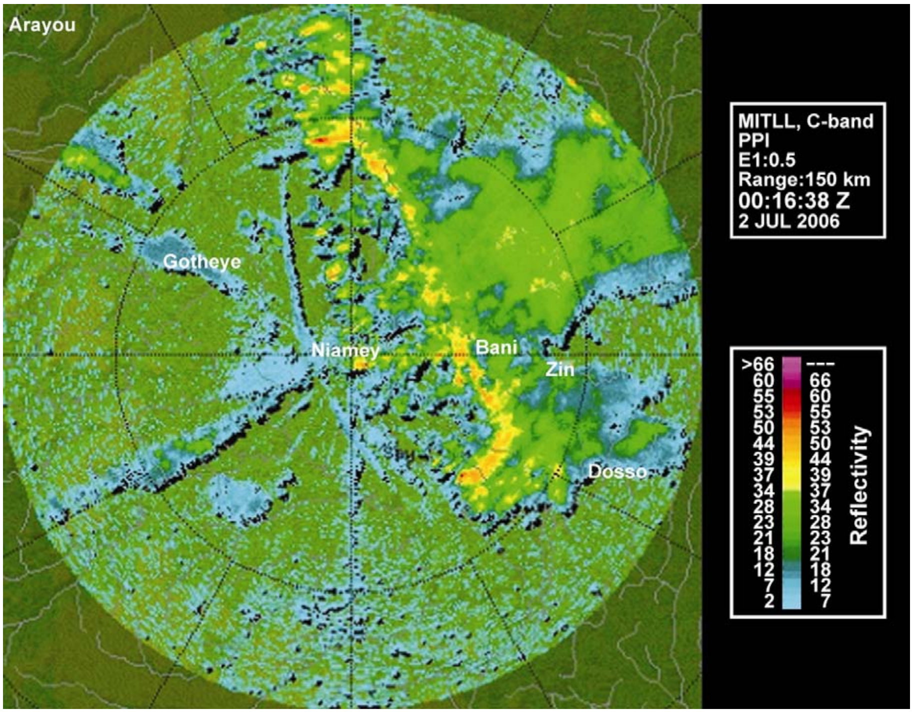

Fig. 1. Surveillance scan showing a gust front out ahead of a storm on July 02, 2006.

was operated continuously in Niamey, Niger during the African Monsoon Multidisciplinary Analysis (AMMA) project from late June to late September, 2006. The gust fronts in Africa showed similar characteristics as those in mid-latitude regions where dust is not raised, i.e., long thin lines with radar reflectivities in the range 0–15 dBZ. The dust itself is probably not the main radar target. Further evidence for this claim comes from the radar observations at mid-latitude showing that the radar targets are anisotropic—a behavior expected for insects, sticks and blades of grass, but not for dust and sand grains which are equidimensional.

An electric field mill of the inverted (goose neck) variety manufactured by Mission Instruments was used to record the electric field perturbation at ground level for these events. Its output sensitivity is one volt per 2 kV/m for a full scale range in these measurements of ±20 kV/m. This was an adequate range to bracket the values exhibited by these dusty gust fronts.

The radar and electric field measurements at the MIT radar site were supplemented by a suite of observations at the nearby ARM (Atmospheric Radiation Measurements) site approximately 1600 m south of the radar. These measurements included 1-minute samples of surface wind speed and direction, temperature, relative humidity and a visibility measurement with a Vaisala PWD 10/20 instrument. A local value for dust mass loading in micrograms per cubic meter was inferred from the visibility measurement using an empirical power law relationship from Shao et al. (2003). A vertically pointing radar operating at 95 GHz was used to obtain the vertical air motions in the gust fronts as they traversed this site.

3. Preliminary results

A radar PPI surveillance scan through the gust front on July 02 is shown in Fig. 1. The gust fronts in Africa are similar to

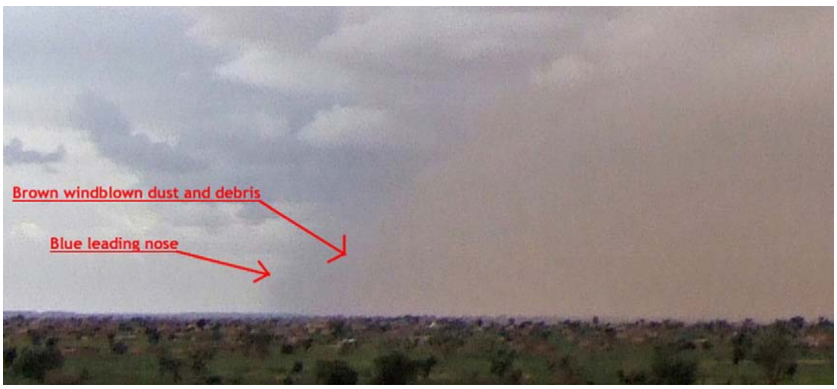

Fig. 2. Photograph of an haboob generated by a gust front ahead of a vigorous squall line on September 12, 2006.