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AN UNUSUAL DRY-SEASON PRECIPITATION EVENT OVER WEST AFRICA: THE ROLE OF AN EXTRATROPICAL UPPER-LEVEL DISTURBANCE FOR THE HEAT LOW AND A SURGE IN THE MONSOONAL SOUTHWESTERLIES

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1. INTRODUCTION

The monsoonal climate of southern West Africa is characterized by a distinct rainy season during the boreal summer half-year. Rainfall during the winter months November to March is usually quite rare and thus long-term January mean precipitation around 10°N ranges between 1 and 5 mm. The present paper presents preliminary results of a detailed study of a significant rainfall event that occurred during the dry season of 2003/04.

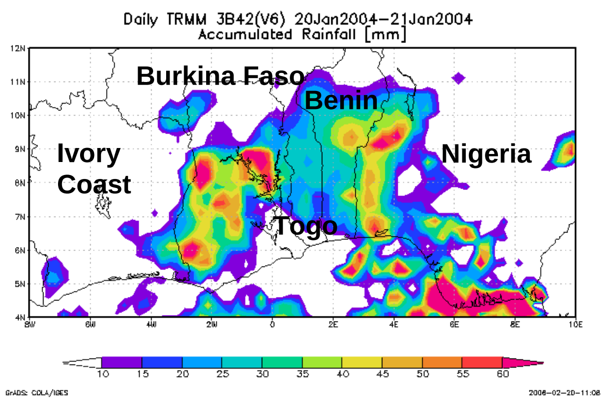

FIG. 1: Two-day accumulated precipitation [mm] over tropical West Africa for January 20 and 21, 2004. Database is the 3B42(V6) daily rainfall estimate from the Tropical Rainfall Measuring Mission (TRMM) satellite. The plot was taken from NASA's TOVAS webpage.

Figure 1 shows estimates of accumulated rainfall from the TRMM satellite for 20 and 21 January 2004. Large parts of tropical West Africa including the countries of Ivory Coast, Burkina Faso, Ghana, Togo, Benin, and Nigeria received significant precipitation amounts, exceeding 40 mm in various places as far north as 10°N, with maxima of over 60 mm. These estimates show reasonable agreement with station observations from the region, which indicate accumulated values of up to 100 mm. Fig. 2 shows high temporal resolution observations from a station near Doguè (central Benin), where in total 57.8 mm fell during several single precipitation events, one of which with a 10-min rainfall intensity of over 50 mm h^{-1} (Fig 2, middle panel).

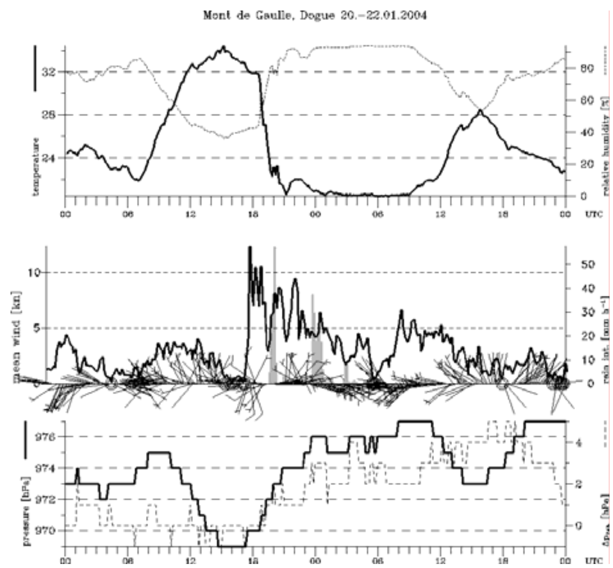

FIG. 2: Observations from the Mont de Gaulle measuring site near Doguè (9.1°N, 1.9°E) from 00 UTC 20 to 00 UTC 22 January 2004. Upper panel: temperature (solid, in °C), relative humidity (dotted, in %); middle panel: mean wind speed (solid, in kt), 10-min rain intensity (gray bars, in mm h^{-1}) and wind barbs; lower panel: station pressure (solid, in hPa), pressure tendency over the past 24 hours (dashed, in hPa). The accumulated precipitation during the period shown is 57.8 mm.

As a consequence of the unusual precipitation, soil moisture recovered from extremely low dry season values as shown by measurements from a cornfield close to Doguè (Fig. 3). The heavy rainfall affected the soil down to a depth of one meter and caused moisture contents of more than 30 Vol-% in the upper-layers. Soil moisture slowly decreased during the following weeks, but even in the uppermost layer (0–20 cm) it took more than a month until the soil had dried to values close to the time before the event. Consequently, pastures in

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the open tree savannah greened for weeks after the rainfall, which is a truly unusual sight for the West African dry season (Fig. 4). While the savannah greening was beneficial for the local cattle nomads, a more detrimental effect for the resident farmers was the rotting of cotton and other harvests.

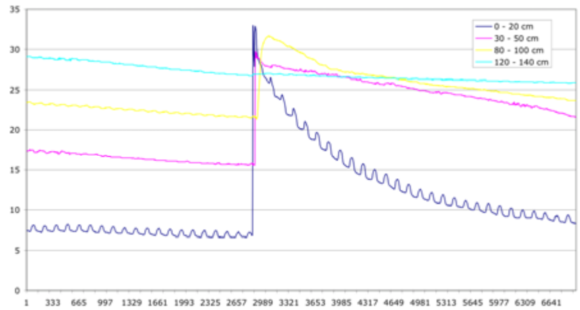

FIG. 3: Soil moisture [Vol-%] in a cornfield in central Benin (9.1°N, 1.9°E). The depth, where the measurement was taken, is indicated in the legend in the upper-right corner. The abscissa runs from January 1st until February 18th 2004 in 10-min intervals. The station is close to the one shown in Fig. 2.

FIG. 4: Unusual sight of a freshly greened pasture in the savannah near Doguè (central Benin) on 14 February 2004, three and a half weeks after the rainfall event.

3. HEAT LOW

The West African heat low is an important part of the summer monsoon system (Parker et al. 2005), but during wintertime it is usually rather weak and on occasion northeasterly Harmattan winds prevail all the way south to the Guinea Coast (cf. Knippertz and Fink 2006).

Surface observations between 17 and 20 January 2004 reveal unusually hot temperatures over Burkina Faso and neighboring countries. The weather chart for 12 UTC 19 January shows temperature observations of up to 35°C in this region (Fig. 5a) and some stations recorded maxima of more than 37°C on that day (not shown). The hot temperatures were accompanied by unusually low mean-sea-level pressures that fell to 1004 hPa in the afternoon of 19 January (not shown). The associated cyclonic circulation is evident in the low level winds (Fig. 5a). To the southeast of the intensified heat low southwesterly to southerly flow is observed over Ghana, Togo, and Benin that brings relatively moist air from the Gulf of Guinea far into the continent, similar to spring or fall situations.

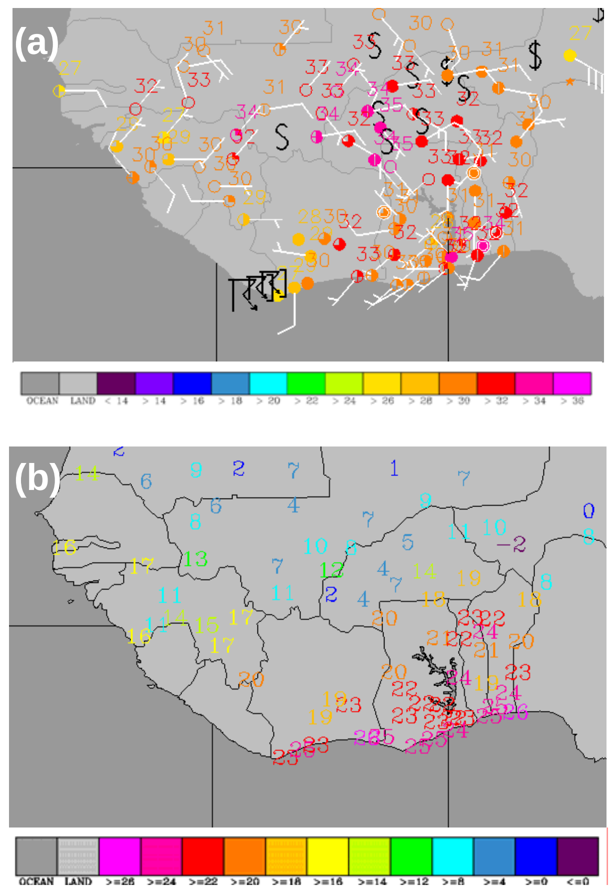

FIG. 5: Synoptic station observations during the days before the unusual precipitation event. (a) 2-m temperature (colored numbers, in °C), cloud cover (octas) wind (barbs) and significant weather (symbols) at 12 UTC 19 January 2004. (b) Dew point (colored numbers, in °C) at 18 UTC 20 January 2004.

This circulation causes a conspicuous northward excursion of the Intertropical Discontinuity (ITD), the sharp boundary between the moist air from the south and the dry Saharan air from the north, which is often identified through the 14°C-dew-point contour. At 17 January the ITD is still close to its climatological position just to the north of the Guinea Coast at about 7ºN (not shown). Until 20 January the ITD slowly moves northward and reaches a very unusual northerly position of 13ºN in the afternoon of that day (Fig. 5b). These observations indicate a progressive intensification and northward shift of the heat low associated with an unusual poleward penetration of moist, monsoonal air into the continent prior to the precipitation event.

4. UPPER-LEVEL DISTURBANCE

The unusual behavior of the heat low is associated with the penetration of an upper-level trough from the extratropics to low latitudes over North Africa. Fig. 6 shows streamlines and isobars for the 300-K isentropic level at 06 UTC 20 January 2004 calculated from European Centre for Medium-Range Weather Forecast (ECMWF) re-analysis data. A region of very cold air (i.e., elevated 300-K surface) is found over Algeria, downstream of a large ridge over the eastern North Atlantic. This high-amplitude wave is associated with very distinct northerly flow from the British Isles into tropical West Africa. Streamlines in this region show a large angle to the isobars, indicating strong subsidence. Over Mali this flow subsides below 900 hPa, where the 300-K isentropic surface cannot be analyzed due to the weak stratification near the ground. Water vapor satellite images around this time reveal a conspicuous dry area to the south and west of the upper-disturbance, consistent with the subsidence evident in Fig. 6 (not shown).

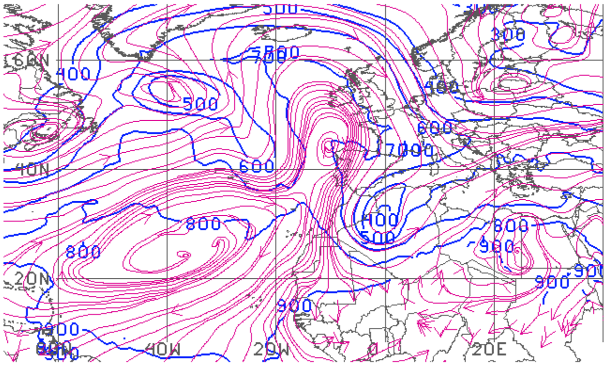

FIG. 6: Flow on the 300-K isentropic surface at 06 UTC 20 January 2004: Streamlines (red) and isobars (blue, in hPa).

There are several physically plausible ways in which the strong subsidence and drying over West Africa can affect the intensification of the heat low over Burkina Faso:

(1) The subsided extratropical air is likely to contain relatively little water vapor and aerosols, which allows high solar irradiation and a strong heating of the ground.

(2) The subsidence is associated with adiabatic warming that stabilizes the atmosphere and, together with the dryness, suppresses cloud formation, which in turn enhances solar heating of the surface. If low-level vertical mixing is suppressed, too, the heating affects a shallower planetary boundary layer, leading to higher temperatures at the ground.

(3) Possibly the advection of adiabatically warmed air from the north contributes directly to higher temperatures.

The different mechanisms will be discussed in more detail at the conference and in an upcoming paper.

5. PRECIPITATION

As shown in the example of Fig. 2 precipitation began during the evening hours of 20 January. Diurnal solar heating and low-level (moisture) convergence to the south of the northward shifted ITD promoted the growth of cumulonimbus clouds that merged to large and long-living convective clusters as evident from the infrared satellite image for 00 UTC 21 January 2004 (Fig. 7).

Figure 2 reveals that the time immediately prior to the first precipitation period was characterized by strong southerly winds, decreasing pressure, and increasing relative humidity. The high wind speeds and the pronounced drop in 2-m temperatures suggest the arrival of a convective outflow boundary related to convection farther south. In combination with favorable upper-level outflow conditions discussed below, the northward progressing outflow boundary has most likely promoted the convective development and organization to larger scales, as well as the overall northward progression of the convective activity (not shown). Note that migratory mesoscale convective clusters in the region usually propagate westward during most of the year. It is speculated that the poleward migration of the convective activity ceased toward the ITD located at around 13°N due to the decreasing low-level moisture availability.

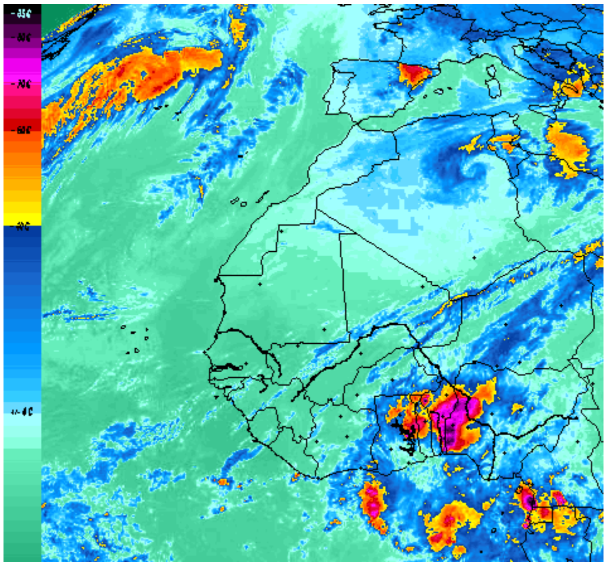

FIG. 7: Meteosat infrared image over West Africa for 00 UTC 21 January 2004, showing strong convection over Ghana, Togo, Benin, and Nigeria, as well as the cyclonic cloud feature associated with the upper-level trough over eastern Algeria.

Figure 8 shows streamlines and isotachs at the 345-K isentropic surface, which is close to the outflow level of tropical convection (~200 hPa). A strong subtropical jet streak (STJ) is found across northern Africa that reaches a maximum of 74 m s^{-1} over the Algerian–Libyan border. The acceleration of the STJ over the previous days appears to be related to the equatorward penetration of the upper-level disturbance over North Africa, which is evident from the 345-K streamlines in Fig. 8. The convection shown in Fig. 7 occurred in a region of inertial instability (red lines in Fig. 8) along the southern flank of the STJ.

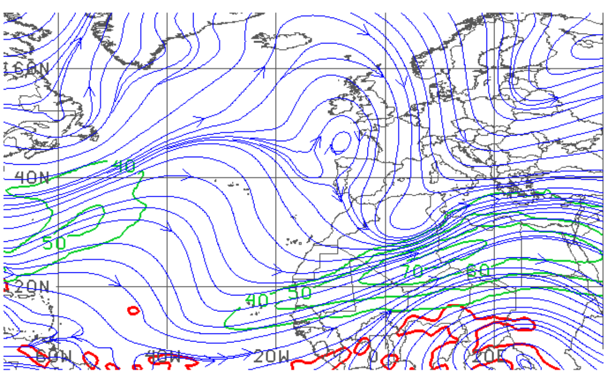

FIG. 8: Flow on the 345-K isentropic surface at 00 UTC 21 January 2004: Streamlines (blue) and isotachs (green, in m/s), and the -1×10^{-5} s^{-1} absolute vorticity contour (red) that indicates regions of inertial instability.

Advection of negative-vorticity air from the southern hemisphere is likely to have contributed to the inertial instability as shown by the distinct cross-equatorial flow between 10°W and 20°E.

Various studies have proposed that inertial instability near the tropopause allows a quick horizontal displacement of convective outflow and thereby aids the organization and maintenance of convection (Mecikalski and Tripoli 1998; Knippertz and Martin 2005). During 21 January the convection over Benin ceased (see Fig. 2) and intensified farther to the west (for example over western Ghana, see Fig. 1). A surge in the Harmattan winds following the eastward movement of the upper-trough appears to have augmented low-level convergence late on 21 January, which might have supported the growth of convection on that day. From 22 January onwards the whole region was affected by dry Harmattan conditions.

6. CONCLUSIONS

This study revealed a complex interplay between the extratropical upper-level disturbance, the near-surface wintertime heat low dynamics, and the vertical coupling of the lower and upper troposphere by deep convection and possible by radiative effects. More case studies of such unusual dry season precipitation events in tropical West Africa should be carried out in order to identify typical ingredients for the involved tropical extratropical interactions. An interesting extension to observational work would be to use numerical models for a quantitative sensitivity analysis of the factors that contribute to the intensification of the heat low observed in this study.

7. REFERENCES

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