3B.2

TROPICAL-EXTRATROPICAL INTERACTIONS CAUSING PRECIPITATION IN NORTHWEST AND WEST AFRICA: PART II: DYNAMICS

Peter Knippertz[1]*, Andreas H. Fink[2], and Jonathan E. Martin[1]
[1]University of Wisconsin, Madison, Wisconsin; [2]University of Cologne, Cologne, Germany

1. INTRODUCTION

The synoptic evolution of a particular type of tropical-extratropical interaction and its relevance for precipitation in subtropical northwest Africa and tropical West Africa have been presented in a companion paper (3B.1) by means of case studies of two extreme precipitation events [March/April 2002 in Morocco/ Algeria (case I), see also Fink and Knippertz 2003; January 2002 in Senegal/Mauritania (case II)]. One important finding is that both events involve a succession of two comparably potent 500hPa troughs to the west of (north-) West Africa within 3–5 days. While the first trough does not produce significant precipitation, it initiates a mid-level poleward transport of moisture from the African Tropics. Thereby it modifies the thermodynamic environment upon which the vertical motion field of the next wave can act, resulting in the release of potential instability and the production of record precipitation. In the present study, the upper-tropospheric large-scale dynamics leading to the formation of such a succession of deep upper-level troughs are investigated using ECMWF analyses. Besides infrared (IR) satellite images, maps of potential vorticity (PV) of the isentropic layer 340–350K are used together with fields of 345K-velocity potential (VP) to indicate divergence and convergence within this layer. The chosen isentropic layer represents a typical level for outflow from tropical convection and is therefore apt to display the type of tropical-extratropical interactions that can lead to the extreme precipitation events. It will be shown that despite the different season and the different geographical location, the two cases reveal striking similarities in the large-scale upper-level flow preceding the extreme precipitation.

2. RESULTS

Figure 1 shows the 4 and 0.25 PVU contours together with convergence/divergence, cloud bands and locations of poleward tropical outflow for the time of precipitation onset over (north-) West Africa (March 30, 12UTC; January 05, 00UTC; right panels) and 96 h earlier (left panels). The two PV contours were chosen to represent the locations of the polar (PJ) and subtropical jet (STJ), respectively, even though the former is presumably more distinct at lower isentropic levels. Nevertheless, the succession of two troughs to the west of Africa is clearly depicted in the deformation of the 4 PVU contour. The respective second ('wet') trough appears more pronounced in the upper-level PV field than in the 500hPa geopotential height field (cf. Fig. 1 of 3B.1) as compared to the first ('dry') trough and displays a stronger SW–NE tilt. In both cases a merging of the PJ and STJ is observed to the east of the second trough due to a distinct ridge in the STJ over Africa, resulting in very strong upper-level winds (Figs. 1b&d).

The fundamental mechanism responsible for the generation of the unusual meandering of the STJ involves an interaction between outflow from tropical convection and the subtropical circulation. Pre-existing large-scale waves force advection of low PV air from equatorial regions into the downstream ridges over Central America (and Mexico in case I; Figs. 1a&c), thereby decreasing resistance to poleward ventilation of outflow from tropical convection over the equatorial eastern Pacific (c.f. Mecikalski and Tripoli 1998). As the kinetic energy gained in the convective updraft is consumed more slowly in an environment of low inertial stability, the outflow might eventually proceed into the subtropical stratosphere. Under the constraint of PV conservation the strong gradient in vertical stability this flow encounters, leads to a compression of the atmospheric column and a sharp anticyclonic turning back into the Tropics. This process amplifies and zonally contracts the ridges. To the east of the ridges stratospheric air is dragged into the tropical troposphere leading to column stretching, strong convergence (see locations marked with 'C' in Figs. 1a&c) and sharp cyclonic turning in the environment of lower vertical stability. This results in an amplification and zonal contraction of the downstream troughs close to South America, which in turn initiates a northeastward advection of low PV air over the tropical Atlantic Ocean, thereby changing conditions for tropical outflow in the western portion of the downstream ridges in the way already described. As a consequence, the usually very strong tropical convection over South America (notice the divergence in Figs. 1b&d) can further add energy to the waves leading to ridges penetrating into the subtropics over Africa several days later. On the eastern flank of the troughs pronounced STJ streaks and elongated cloud plumes form over the Atlantic Ocean and propagate toward Africa (Figs. 1b&d). Both 'first' troughs show similar, but much weaker cloud bands on their eastern sides (Figs. 1a&c). The generation of the tropical cloud band in Fig. 1b is described in more detail in P1.36.

---

* *Corresponding author address*: Peter Knippertz, Dept. of Atmospheric and Oceanic Sciences, University of Wisconsin, 1225 W. Dayton St., Madison, WI 53706; e-mail: pknipp@aos.wisc.edu

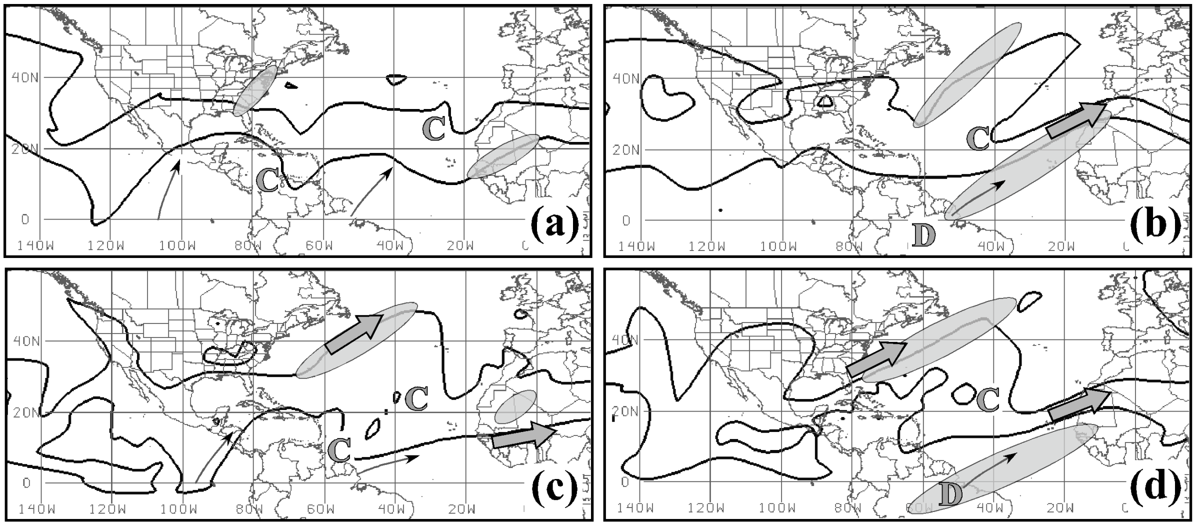

FIG. 1. Potential vorticity in the 340–350K layer (4 and 0.25 PVU isopleths; 1 PVU=10^{-6} m^2 s^{-1} K kg^{-1}) for (a) 26 and (b) 30 March 2002, 12 UTC (case I), and (c) 05 and (d) 09 January 2002, 00 UTC (case II). 'C' and 'D' indicate regions of convergence and divergence, respectively, as indicated by maxima and minima of velocity potential at 345K. Large gray-filled arrows indicate STJ streaks, thin arrows poleward-directed outflow from tropical convection. Tropical and extratropical cloud bands are depicted by gray shaded areas.

The evolution of clouds and upper-level divergence points to an important role of diabatic heating in the extratropics in forcing extratropical troughs to dip deep into the (sub-) Tropics. Except for the 'first' trough of case I, all other developments involve an elongated precipitating cloud band over the mid-latitude Atlantic Ocean to the west of the upstream large-amplitude ridges, approximately parallel to the US east coast (Figs. 1b–d). A precursor of the band in Fig. 1b is located over the North American continent ahead of a weak upper-level trough 96 h earlier (Fig. 1a). The continuing latent heat release at mid-tropospheric levels within these bands produces pronounced upper-level PV ridges over the Atlantic Ocean, which slowly propagate eastward. In analogy to the amplification of the ridges in the subtropics, the diabatically generated negative PV anomalies force low PV air poleward and high PV (stratospheric) air to flow equatorward in association with strong convergence and sharp cyclonic turning, where this flow experiences the lower vertical stability in the troposphere (Fig. 1b–d). The results of this development are elongated PV troughs to the east of the negative PV anomaly. For both 'second' troughs, the circulation around these positive PV anomalies merges with the STJ streaks over the Atlantic Ocean combining wave and jet dynamics to produce the extreme precipitation events (Figs. 1b&d). The suggested role of the upstream diabatic heating for the extratropical parts of the presented developments agrees with findings of Massacand et al. (2001) who investigated a PV streamer that caused heavy precipitation in the Alpine region.

3. CONCLUSIONS

The two case studies show that a complicated synergy of tropical and extratropical diabatic and dynamical processes is needed to produce extreme precipitation in subtropical arid regions or in tropical regions during the dry season. The evolutions of the two cases repeatedly show a deepening of ridges generated by outflow from tropical convection in the subtropics and by diabatic production of negative PV anomalies in the extratropics. The right phasing of the sharp positively tilted extratropical downstream troughs with the STJ streaks on the western side of the downstream subtropical ridges appears crucial for the extreme precipitation. More cases will be investigated in order to determine variations in the importance of the single components of the described interaction.

4. REFERENCES

Fink, A. H, and P. Knippertz, 2003: An extreme precipitation event in southern Morocco in spring 2002 and some hydrological implications. *Weather,* **58,** 377–387.

Massacand, A. C., H. Wernli, and H. C. Davies, 2001: Influence of upstream diabatic heating upon an Alpine event of heavy precipitation. *Mon. Wea. Rev.*, **129,** 2822–2828.

Mecikalski, J. R., and G. J. Tripoli, 1998: Inertial available kinetic energy and the dynamics of tropical plume formation. *Mon. Wea. Rev.,* **126,** 2200–2216.