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RAINFALL EVENTS DURING THE WEST AFRICAN DRY-SEASON: FORCING FROM THE EXTRATROPICS AND PREDICTABILITY

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1. INTRODUCTION

Precipitation in the Soudano-Sahelian zone of West Africa is rare during the boreal winter half year, but can have substantial impacts on the local hydrology and human activities reaching from greening pastures to flooding and rotting harvests (Knippertz and Martin 2005; Knippertz and Fink 2008). A recent case study by Knippertz and Fink (2008) of unusual dry-season rainfalls in West Africa in January 2004 unveiled a close link to the synoptic evolution in the extratropics, as detailed in the schematic depiction shown in Fig. 1. Upper-level troughs that penetrate from the extratropics into low latitudes support pressure fall over West Africa in two ways: (I) diabatically through the anomalous radiative warming under a diagonal cloud band on the eastern flank of a first upper-level trough, often referred to as a tropical plume (Fig. 1a), and (II) dynamically through subsidence and warm advection associated with a second upper-level trough, the latter being situated over Algeria in the case displayed in Fig. 1b. As a consequence of the surface pressure fall moist low-level monsoon air from the Gulf of Guinea penetrates inland and allows the formation of deep moist convection and heavy precipitation in the Guineo-Soudanian zone (Fig. 1b). In the case depicted in Fig. 1 extreme precipitation also occurred in the subtropics to the east of the second upper-trough.

Based on this case study Knippertz and Fink (2008) hypothesized that the strong extratropical influences may imply a comparably good predictability of such events that would allow a timely warning of the population and therefore a mitigation of detrimental impacts as well as an exploitation of beneficial effects To test this hypothesize we present here a statistical evaluation of boreal winter precipitation forecasts made by the European Centre for Medium-Range Weather Forecasts (ECMWF). The objectives of this study are (a) to identify episodes of a temporary northward excursion of the ITCZ rainfall belt onto the West African continent during the dry season, i.e. November–April, to (b) evaluate the

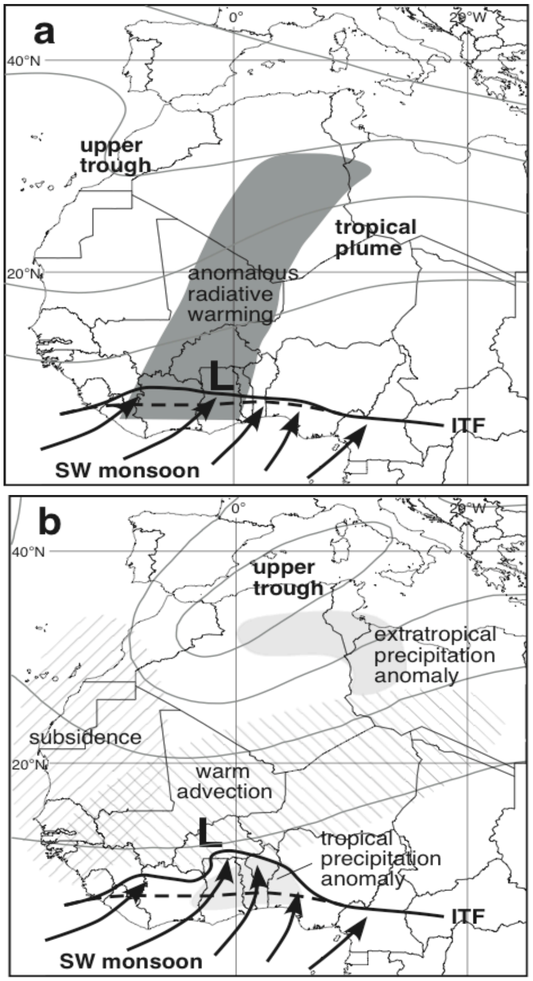

FIG. 1: Schematic depiction of the mechanism proposed by Knippertz and Fink (2008). (a) “Tropical plume phase” and (b) “dynamic phase”. Gray lines depict upper-level geopotential height. The thick dashed and solid lines show the climatological and the actual position of the Intertropical Front (ITF), respectively. The heat low and the enhanced monsoon flow are also indicated. In (b) regions with negative dynamic pressure tendencies due to subsidence or warm advection are hatched and regions with precipitation are lightly shaded.

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ability of state-of-the-art operational weather prediction models to forecast such events, (c) to understand the dynamics of the rainfall generation including the role of the extratropics, and (d) to investigate whether the strength of the extratropical influence is positively correlated to the forecast skill.

2. DATA

This study is based on both precipitation forecasts from the ECMWF and rain gauge observations from synoptic weather stations in West Africa to evaluate the forecasts. All investigations are restricted to the winter half year from November to April. On the forecast side we use both 12-UTC operational forecasts for the 24-year period 1984–2007 and 12-UTC forecasts made as part of the ERA-40 re-analysis project for the 24-year period 1979–2002. The latter dataset has the great advantage that all forecasts were made with the same numerical model and data assimilation system, while the operational forecasts are inhomogeneous in the sense that model physics and resolution, as well as assimilation techniques have changed substantially over time.

On the observational side the Global Summaries of Days (GSOD) from the National Climatic Data Center (NCDC) for the entire 29-year period 1979–2007 are analyzed. We used all available stations and dates of this dataset, but unfortunately many days do not contain reports for all four synoptic hours and the station time series are often incomplete. For a comparison to climatological conditions we used monthly data from the Global Historical Climate Network (GHCN) for the period 1930–2007. The analysis is restricted, however, to stations with at least 30 years of data coverage to ensure stable climatological means. In addition to the precipitation data ERA-40 sea-level pressure and 500-hPa geopotential heights are examined for the dynamical analysis.

3. IDENTIFICATION METHOD

The first step to identify significant dry-season precipitation events is to calculate area averages from the 72-hour ECMWF precipitation forecasts for the region 7–15°N, 10°W–10°E (red box in Fig. 2). The example from January 2000 shown in Fig. 2 depicts a period, when the ECMWF model predicted rainfalls to penetrate unusually far into this box. We chose to base the investigation on 72-hour periods to allow for an effective warning of the population in an operational setting. In principle, it would be desirable to identify events from observational instead of forecast data, but the rather incomplete rainfall observations available motivated us to take this approach.

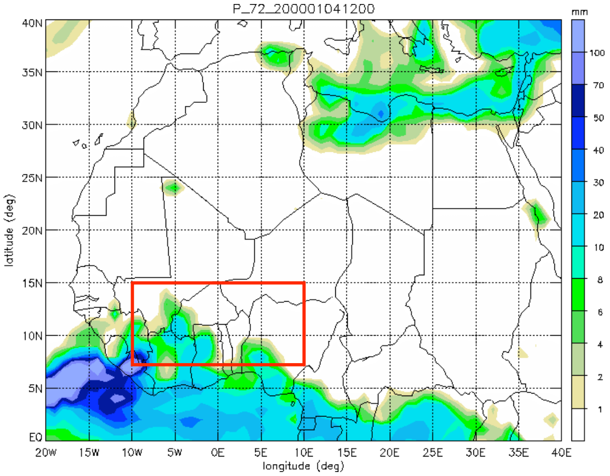

FIG. 2: Operational ECMWF total precipitation forecast accumulated over the 72-hour period 12 UTC 01 January to 12 UTC 04 January 2000 [mm]. The red box borders the region, for which area averages are calculated.

The second step of the identification procedure is to identify anomalously wet periods in the study region from time series of daily 72-hour forecasts for November to April. Figure 3 shows an example of such a time series. The blue line depicts two times the average monthly 72-hour precipitation sums and clearly reflects the well-known annual cycle in West African precipitation with an extremely dry period in December–February. The black line shows the actual time series for the winter of 1999–2000 as anomalies from the monthly means. We simply define all 72-hour periods with more than three times the monthly average (i.e., the black line above the blue line in Fig. 3) as wet events. This method accounts for the annual cycle and uses lower thresholds in the drier months than in the post- and pre-monsoon months. The example of 04 January 2000 shown in Fig. 2 clearly stands out in Fig. 3 and is identified as a wet event.

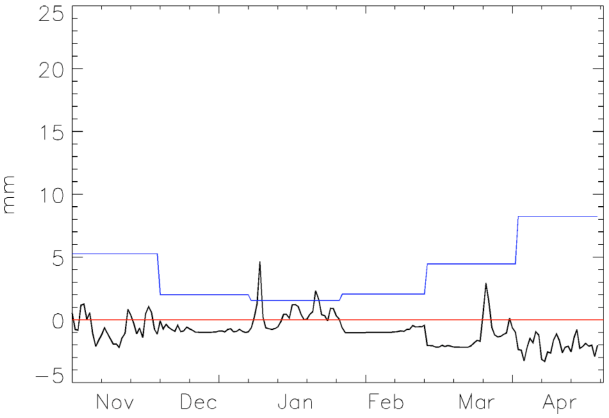

FIG. 3: Daily time series of 72-hour precipitation [mm] operationally forecasted by the ECMWF and spatially averaged over the red box shown in Fig. 2 for the winter half-year 1999/2000. The blue line shows two times the 72-hour forecast average for the respective month and the black line 72-hour monthly anomalies. All periods above the blue line are defined as wet events as the example of 04 January 2000 shown in Fig. 2.

4. CLIMATOLOGY

The identification method explained in section 3 is applied to both the operational and the ERA-40 forecasts separately. Figure 4 shows the mean seasonal cycle for the two datasets. In both operational and ERA-40 forecasts most wet events are identified during December–February, when identification thresholds are lowest. It is striking that the operational forecast dataset contains substantially more events than ERA-40.

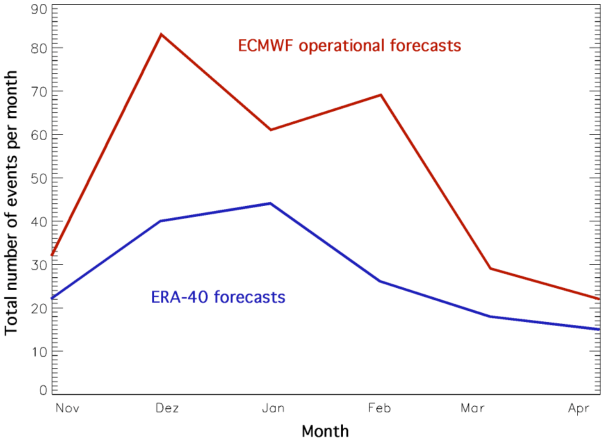

FIG. 4: Mean total monthly number of wet events in the red box in Fig. 2 for ECMWF operational (period 1984–2007) and ERA-40 (period 1979–2002) forecasts.

The reason for this surprising result can be understood when regarding the interannual variability and trends of identified we events in the two datasets. The high number of events in the operational forecast is mainly due to the period before 1996 (Fig. 5, upper panel). Subsequent changes to the forecast system appear to have cured an unrealistic tendency to shift the rain zone to far north over West Africa. The higher precipitation sums in the early part of the period lead to over-all higher identification thresholds and consequently reduce the number of events identified in the latter part of the period.

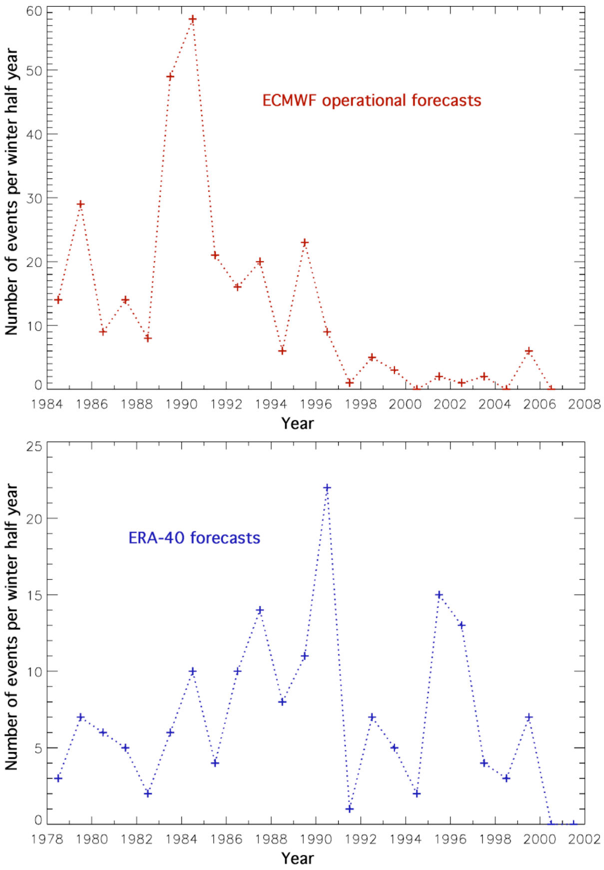

FIG. 5: Number of wet events per winter half-year in the red box in Fig. 2 for ECMWF operational (period 1984–2007) and ERA-40 (period 1979–2002) forecasts. Note the different abscissas of the two plots.

In contrast the homogeneous ERA-40 forecasts show no trend, but still quite substantial interannual variability (Fig. 5, bottom panel). Consistently the winter of 1990/91 stands out in both datasets as the one with most events. Due to the evident large inhomogeneities found in the operational forecasts all further investigations are restricted to the ERA-40 dataset.

5. FORECAST EVALUATION

The next important step is to evaluate the 72-hour ERA-40 forecasts with NCDC station data. Being daily summaries, these data do not allow the calculation of rainfall for periods starting at 12 UTC as in the forecasts. As the daily values usually include the latter part of the previous day, we use the sum over the three last days of the respective periods to be as close as possible to the ECMWF data. Figure 6 shows the same period as Fig. 2, but now for ERA-40 forecasts, zoomed in on the red box, and with NCDC station data overlaid. Slight differences to the operational forecast are evident.

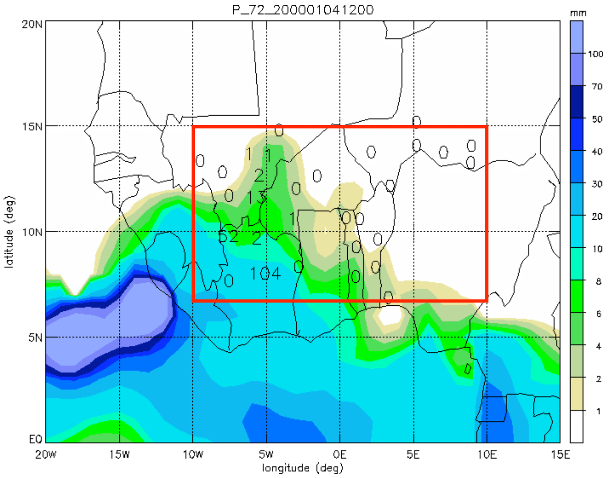

FIG. 6: ERA-40 total precipitation forecast accumulated over the 72-hour period 12 UTC 01 January to 12 UTC 04 January 2000 [mm]. The red box borders the region, for which area averages are calculated. The numbers indicate the sum of the NCDC daily summaries for 02–04 Jan. 2002.

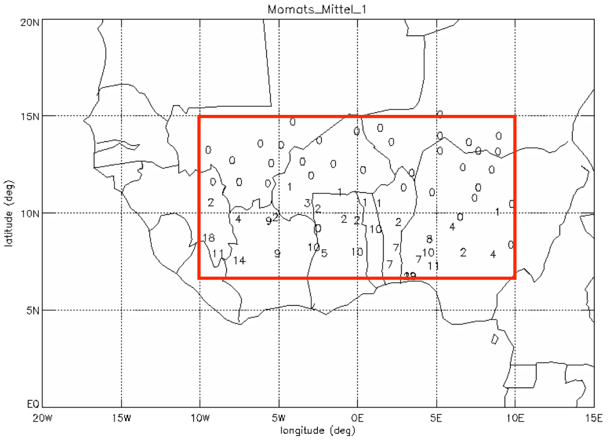

FIG. 7: Long-term January mean precipitation [mm] based on GHCN station data with at least 30 years of data coverage during the period 1930–2007.

The general spatial inhomogeneity of rainfall over tropical Africa, the low spatial data coverage, and the incomplete time series make it very difficult to directly compare forecasts and observations. We therefore decided to test, if observations do also indicate unusual rainfall at more than one station. To do this we first calculate long-term monthly means from the GHCN data. The means for January are shown in Fig. 7 and clearly reflect the general north–south gradient and very low rainfall over the entire region. The monthly means are then used to calculate the ratio of the observed 72-hour precipitation and the climatology, and express it in percent as in Fig. 8.

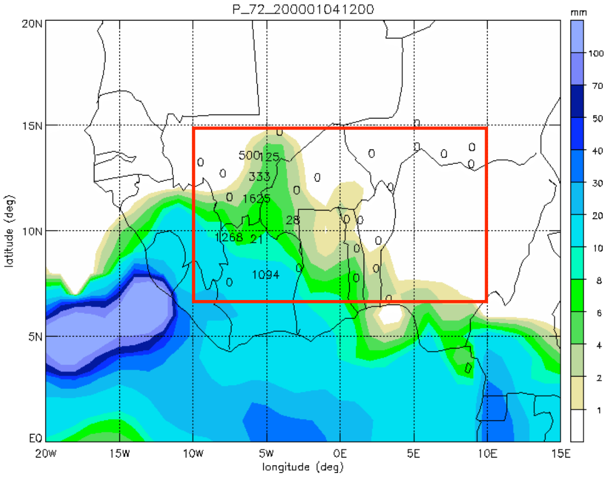

FIG. 8: As Fig. 6 but with precipitation observations expressed in percent of the long-term monthly mean calculated from GHCN data.

The example of 04 January 2000 shown in Figs. 6 and 8 reveals that six stations in Ivory Coast, Burkina Faso, and Mali recorded precipitation above the long-term January mean (> 100%), two stations even above ten times the average (> 1000%). At the northern stations rainfall in January is so rare that a mere 1 mm is sufficient to exceed the long-term mean.

For the actual evaluation consecutive wet events are combined to episodes with gaps of one day allowed. This way we obtain 85 episodes during the 24 years of ERA-40 data used. Twelve episodes are subjectively removed from this set because of model precipitation in data-sparse regions only, so that an evaluation is impossible. We then simply count the number of stations within each episode that observe ≥ 50% of the long-term monthly mean. If this number is ≥ 2 during December–February or ≥ 3 in November, March and April the forecast is considered a “hit”, otherwise a “miss”. The chosen arbitrary thresholds give similar results than a subjective evaluation of the forecasts.

The analysis described so far identifies 43 hits and 30 misses. This is a comparably high rate for daily precipitation forecasts in the Tropics, where convective dynamics are often badly captured by state-of-the-art numerical weather prediction models. Most misses occur during December–February when identification thresholds are low and detection is more difficult, if rain occurs in data-sparse regions. We are currently trying to corroborate these results with additional information from other databases and from satellites. First tests with Tropical Rainfall Measuring Mission (TRMM) data has shown that not all significant events are captured by our station data indicating an even better performance of the ERA-40 forecasts than documented here.

6. DYNAMICS

An important next step is to analyze the dynamics of the identified wet events on the basis of ERA-40 data. Addressed research aspects will include the degree and nature of the extratropical influence and its impact on the forecast quality following the findings of Knippertz and Fink (2008, see section 1). These questions are currently investigated and here only to two short examples are discussed.

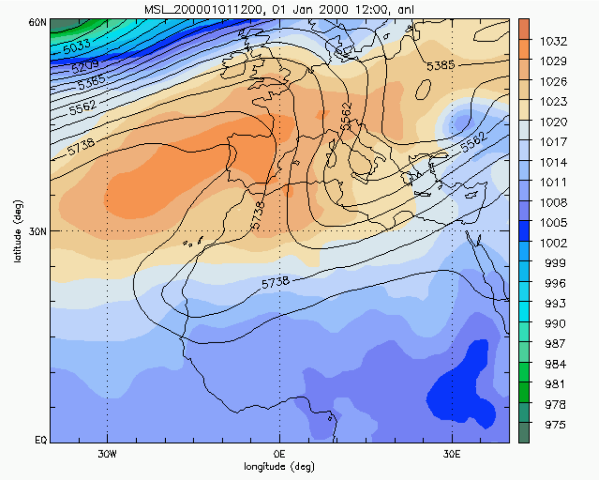

FIG. 9: Geopotential height (lines contoured every 8 gpm) and sea-level pressure (shading in hPa) for 12 UTC 01 January 2000 from ERA-40.

The first example is the case already shown in Figs. 2, 3, 6 and 8. The 500-hPa geopotential height reveals a clear trough reaching from southeastern Europe almost to the Cape Verde in tropical West Africa. The rainfall occurs to the southeast of the trough axis (Fig. 6). In contrast to Knippertz and Fink (2008), however, no distinct signal in sea-level pressure is found suggesting a more direct dynamical relation to the upper-level trough.

The second example from February 1999 shows a similar trough in the 500-hPa geopotential field but with an even stronger positive tilt. This trough is connected with clearly reduced sea-level pressure over the Sahel and Sahara, which most likely allowed a northward penetration of low-level moisture that fed the unusual rainfalls similar to the case described in Knippertz and Fink (2008). The reasons for the differences in the surface pressure response are subject of future investigations. Both examples show unusual rainfall in the subtropics as in Fig. 1.

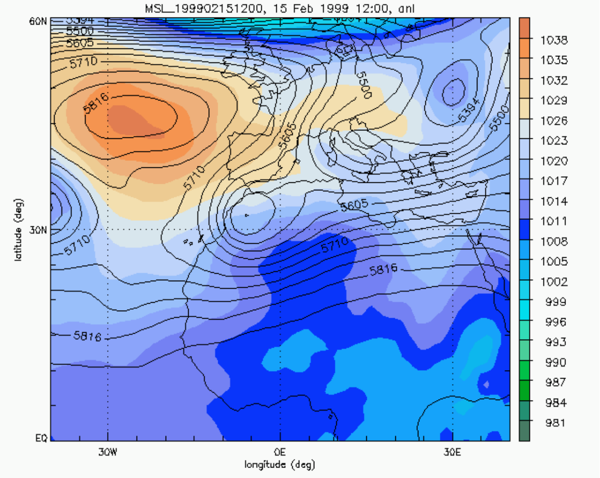

FIG. 10: As Fig. 9 but for 12 UTC 15 February 1999.

7. CONCLUSIONS

Wintertime precipitation events in the Soudano-Sahelian zone of West Africa are rare, but can have high impacts on the local population. We have developed an algorithm to identify such events from ECMWF forecasted precipitation data. The homogenous ERA-40 forecasts are able to reproduce unusual wintertime rainfall events in at least 43 out of 73 cases with a lead-time of several days, while operational forecasts overpredicted this phenomenon during the 1980s–90s. The incorporation of other precipitation data into this study might reveal an even better performance of the ECMWF model. The quality of forecast appears sufficient to issue warnings to the population in order to mitigate or benefit from impacts. Case studies show that the high predictability may be related to influences from the well-predicted large-scale circulation in the extratropics. This aspect is subject of ongoing research.

8. REFERENCES

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