1B.3 WEST AFRICAN MONSOON DEMISE: CLIMATOLOGY, INTERANNUAL VARIATIONS, AND RELATIONSHIP TO SEASONAL RAINFALL

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1 INTRODUCTION

The West African monsoon plays an important role in the regional climate and water resources of the Sahel. The monsoon has a significant influence on agricultural management as it brings most of the rainfall to West Africa during the course of a year. Therefore, an improved understanding of the physical processes that control the West African monsoon season is important because it will ultimately improve weather and climate forecasts for this region.

The onset of the Sahel monsoon season occurs typically in early July with an abrupt shift of the rainfall maximum from the Guinean coast (~5°N) to the Sahel (~10°N); this is called the West African monsoon jump (Sultan and Janicot 2003; Hagos and Cook 2007). From late September to October, rainfall over the Sahel decreases gradually. Both the onset and demise dates are critical for agricultural planning. For example, a late onset may lead to late planting, and an early end of the rainy season might cause crop failure. While West African monsoon onset processes have been explored in several studies (Sultan and Janicot 2003; Ramel et al. 2006; Hagos and Cook 2007), less attention has been paid to the demise process.

The purpose of this paper is to better understand the basic dynamics of the West African monsoon demise, and its relationship to seasonal rainfall totals, from the perspectives of the climatology and interannual variations**.** The findings of this paper improve our understanding of the physical processes associated with the West African monsoon demise, and serve as a basis for modeling investigations. In addition, the physical processes that regulate the monsoon demise provide support for operational weather and climate forecasts of the monsoon demise

2. DATA AND METHODOLOGY

Two observational datasets of precipitation are used to characterize the seasonal evolution of the West African monsoon demise. The first is the 3-hourly Tropical Rainfall Measuring Mission (TRMM) precipitation product (3B42V7, Huffman et al. 2007) from 1998 to 2012. It covers latitudes from 50°S to 50°N with 0.25° latitude by 0.25° longitude horizontal resolution. The second dataset is the 5-day Global Precipitation Climatology Project (GPCP) precipitation analysis (2.5° latitude by 2.5° longitude) which is available from 1979 to 2012 (Xie et al. 2003). The ECMWF ERA-Interim reanalysis (ERAI; Dee et al. 2011) is used to analyze the atmospheric circulation associated with the West African monsoon demise.

Various thresholds have been proposed to define West African monsoon onset and/or demise (e.g., Marteau et al. 2009; Liebmann et al. 2012). Here we use a uniform threshold

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because it facilitates relating rainfall to the atmospheric circulation directly. Synoptic variations in the rainfall time series are removed by using a 15-day running average. Then, the demise date of each grid point is defined as the calendar date when the smoothed rainfall falls below the selected threshold without any recovery later in that year. Both of the TRMM and GPCP climatologies are used to explore the spatial distribution of the monsoon demise. Several choices of the threshold value are tested before choosing 2 mm day^{-1} as the threshold.

The 5-day pentad GPCP precipitation dataset is used to characterize interannual variations because it has a better balance between data record length and frequency for this study. The Sahel region is defined as 20ºW-22.5ºE, 7.5ºN-17.5ºN.

Composite analysis is used to address the interannual variations of the West African monsoon demise. Each year is classified as an early, normal or late demise year by comparing its demise date with the climatological demise date. Differences between the early and late demise composites are analyzed to identify the physical processes responsible for interannual variations. The moisture budget is used to connect rainfall and circulation anomalies.

3. RESULTS

In the climatology, the demise of the West African monsoon occurs from September to early November as the rainfall maximum progresses southward from the Sahel to the Gulf of Guinea. The southerly monsoon flow into the Sahel (8ºN) decreases from more than 2 m s^{-1} in early September to less than 1 m s^{-1} in late October. Distinct from the abrupt onset, the monsoon demise is smooth with no evident meridional jump of the rainfall maximum. Applying uniform thresholds to indicate monsoon demise, the demise date is zonally uniform over the central and eastern Sahel, while the western Sahel has a later demise. Using a 2 mm day^{-1} threshold, the demise date varies from early September over the northern Sahel to early November over the southern Sahel. The climatological demise date for the Sahel region is October 20th if the 2 mm day^{-1} threshold is applied to the area-averaged time series of the GPCP climatology.

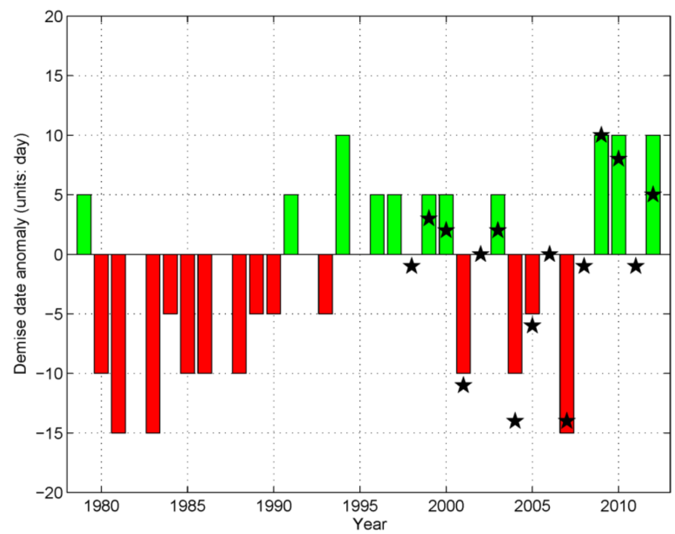

Figure 1. West African monsoon demise date anomaly (day) in GPCP for 1979-2012. Bar (star) indicates the monsoon demise date anomaly in GPCP (TRMM). Both the GPCP and TRMM data place the climatological demise date on October 20th.

As shown in Figure 1, the demise date varies by up to 25 days during the 1979-2012 period, with earliest and latest demise on October 5th and 30th, respectively. The interannual variations are analyzed by compositing early, normal and late monsoon demise years. Two periods are studied: October 5th-20th (Period 1) and October 20th -30th (Period 2).

Figure 2 (see the end of this abstract) displays that, an early (late) demise of the West African monsoon is associated with a strengthening (weakening) of the North Atlantic Subtropical High (NASH), which extends over the Mediterranean and Sahara, during both Period 1 and 2. Anticyclonic (cyclonic) flow anomalies corresponding to a stronger (weaker) NASH are shown as northerly/northeasterly (southerly/southwesterly) wind anomalies over the Sahel. The southerly monsoon flow shows no difference between the early and late demise composites.

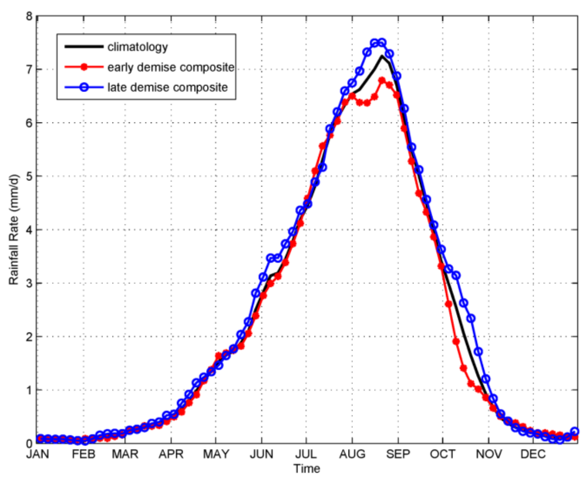

Figure 3. Seasonal cycle of the area-averaged Sahel rainfall (mm day^{-1}) in the GPCP climatology, early demise composite and late demise composite. A 15-day running average is applied.

As indicated by Figure 3, years with an early monsoon demise have less total rainfall than years with a late demise. The monsoon season total rainfall is significantly correlated with the demise date with a correlation coefficient of 0.56 .

The atmospheric moisture budget is examined using values from the 6-hourly ERA-Interim reanalysis. The rainfall anomalies are mainly supported by anomalies in the vertically-integrated moisture flux convergence. Over the southern Sahel, the vertically-integrated moisture fluxes are divergent in the climatology for both Periods 1 and 2. In the early (late) demise composite, the northerly (southerly) moisture flux anomalies, which enhance (reduce) moisture divergence, are associated with northerly (southerly) wind anomalies in the lower troposphere due to a strengthening (weakening) of the NASH. Analysis of the moisture convergence profiles in the southern Sahel (10.5°N) reveals that, corresponding to an early monsoon demise, a stronger NASH is associated with mid-level divergent and low-level convergent anomalies of the meridional moisture term (C_y); and negative anomalies of the meridional moisture advection (A_y) over the southern Sahel. The opposite applies for a late monsoon demise. These results connect the NASH variations with the rainfall anomalies over the Sahel.

The early (late) demise of the West African monsoon is accompanied by cold (warm) SSTAs in the subtropical North Atlantic. There is potential to use these findings for seasonal prediction of the date of the monsoon demise in the Sahel and, therefore, seasonal rainfall totals.

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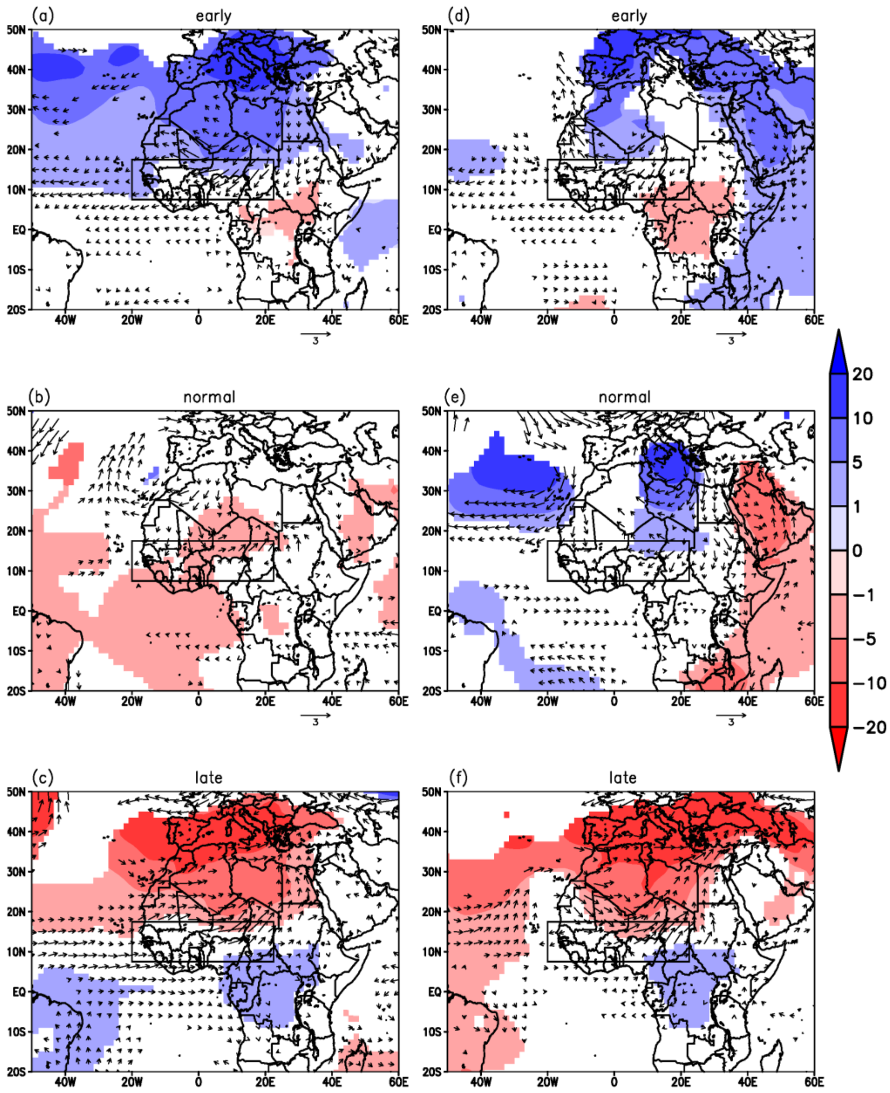

Figure 2. Anomalies of 925 hPa geopotential height (gpm, shaded) and wind (m s^{-1}, vectors) averaged over Period 1 (October 5^{th} -20^{th}) in the (a) early demise composite, (b) normal demise composite, and (c) late demise composite. (d)-(f) As in (a)-(c), but

for Period 2 (October 20^{th}-30^{th}). Only anomalies statistically significant at the 95% confidence interval are shown.