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Monsoon Dynamics in the Ganges-Brahmaputra-Meghna Basin

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Abstract: A recently funded US National Science Foundation project seeks to investigate monsoon variability within the Ganges-Brahmaputra-Meghna (GBM) river basin as a potential predictor for annual shoreline erosion rates in the lower coastal delta region. Many previous studies have examined the interannual variability of South Asian precipitation either within political boundaries or across large spans of latitudes and longitudes, but few have taken a more hydrologic approach by analyzing the atmospheric-oceanic forcings that lead to precipitation falling only within the GBM basin. The temporal climate patterns would likely be different from previous studies and are hypothesized to have a more direct effect on outlet discharge and erosion rates. In the present study, mean monsoon precipitation (June-July-August-September) for the 2,309 0.25° grid boxes of the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record (PERSIANN-CDR) was extracted using geospatial methods. A Principal Component (PC) analysis was performed over the period 1983 to 2015. The first PC explains 88.7% of the variance and resembles climatology with the center of action over Bangladesh. The eigenvector shows a downward trend consistent with studies reporting a recent decline in monsoon rainfall. The second PC explains 2.9% of the variance and concentrates rainfall in the western portion of the basin. The 2nd component has greater temporal variability than the 1st component and an apparent decadal cycle. An analysis of global precipitation indicates that the rainfall patterns obtained within the GBM are localized. Surface and upper-air atmospheric height fields suggest the 2nd PC pattern is forced by a Rossby wave train stemming from the North Atlantic.

Keywords: precipitation, monsoon, Ganges-Brahmaputra-Meghna, GIS, climate variability

1. Introduction

The Ganges-Brahmaputra-Meghna (GBM) basin is approximately 1.6 million km^2 (roughly the size of Iran) and crosses five national boundaries: India, China, Nepal, Bangladesh, and Bhutan. It drains the combined Ganges, Brahmaputra, and Meghna rivers. The vast majority of GBM discharge flows through the main trunk of the Lower Meghna river/estuary in Bangladesh to the Bay of Bengal, with a discharge of up to 138,700 m^3/s of water, the largest in the world through a single outlet [1,2]. Precipitation which feeds this immense and powerful river system primarily falls in the monsoon season, with 77% of the total rainfall received in June, July, August, and September (JJAS). Therefore, the strength of the monsoon is an important predictor for discharge dynamics in the delta environment, including flooding, which has received much attention in the literature [3]. Riverbank erosion at the GBM outlet is another consequence of high flow rates, but, unlike flooding, land resources are permanently lost, leading to forced societal disruption and reorganization.

To better predict erosion events on an annual scale, it is important to take a hydrologic approach to the monsoon system. Many previous climate studies have characterized monsoon rainfall within political boundaries [4] or over large latitude-longitude domains [5], but few have examined the monsoon limited to the spatial extent of the GBM basin. Limiting to this spatial extent is important hydrologically because only rainfall (and snowmelt) within the basin is hypothesized to contribute to erosion in the main Lower Meghna outlet in Bangladesh. Here we will examine the spatial and temporal patterns of JJAS rainfall in the GBM using geospatial and statistical approaches and relate them to climate forcings.

2. Data and Methods

Satellite-based estimates of precipitation are useful for examining transnational water issues and hazards in developing countires [6] as they are consistent and complete in time and space. Here we selected the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record (PERSIANN-CDR), which has some advantages over other products [7]. First, it has been found to be effective in representing South Asia monsoon rainfall and judged "well-suited as input into hydrologic models for the purposes of generating river discharge estimates" [8, p. 80]. Second, the resolution is high at 0.25° latitude/longitude grid spacing. Third, the data record extends from 1983 to 2015. Fourth, the monthly precipitation values are consistent with the Global Precipiation Climatology Project (GPCP) estimates, which are commonly used in climate studies [9]. GPCP was therefore used to examine precipitation anomalies in a global context.

PERSIANN-CDR precipitation was averaged over the monsoon season June-July-August-September (JJAS) and extracted from the GBM boundary using the HydroBASIN GIS layer from the World Wildlife Fund [10]. GBM precipitation patterns were then contructed through Principal Component (PC) analysis in ArcGIS for the 2,309 selected cells (see Fig. 1). Sea surface temperature, 850 hPa heights, 850 hPa zonal wind stress, and 200 hPa heights were retrieved for the same JJAS season and 1983-2015 time period from the ECMWF ERA-Interm reanalysis [11]. These fields and GPCP were related to the PC eigenvectors through linear correlation and regression analyses.

3. Results

The first PC (PC1) explains 88.7% of the variance of precipitation in the GBM (Fig. 1) and represents the background climatology. The maximum is located in northeast Bangladesh with two axes of higher values to the northeast and northwest along the Himalayan ridge. The eigenvector is positive every year, meaning this pattern is a constant feature, with little interannual variability and a slight downward trend, which is consistent with other studies that suggest a downward trend in monsoonal rainfall over this time period [5]. The second PC (PC2) explains 2.9% of the variance. The values are much lower than PC1, with two maxima. The first coincides with the maximum in PC1 over far-eastern India, and the second is over central India. The eigenvector has a mean near zero and large interannual variability. There is also an apparent decadal-scale cycle, with the 1980s and 2000s being mostly negative and the 1990s and 2010s mostly positive. This pattern then is important in describing the most substantial year-to-year variations to the background climatology (PC1).

The PC1 and PC2 eigenvectors were correlated to JJAS averaged GPCP precipitation to determine if the GBM patterns were part of a larger global rainfall signal. The GPCP analysis confirms that when PC1 is strong, rainfall is abundant over Bangladesh and when PC2 is strong it is abundant over central India (Fig. 2a,b). While there is some extension of this dipole structure to the east and west outside the basin, there is little relationship to other parts of the world, such as the Pacific Ocean and El Nino. The same applies for SST (Fig. 2c,d). However, the Bay of Bengal has a significant positive correlation with PC1 and negative correlation with PC2. Near-surface heights are positively correlated with PC1 over central India suggesting higher pressures supress rainfall in the region (Fig.

2e). Significant corelations with PC2 are more widespread over South Asia, with negative values over much of India, but also extending into the Arabian Sea, Iran and Kazakhstan (Fig. 2f). The addition of 200 hPa heights regressed onto PC1 and PC2 suggests a succession of tropospheric pressure anomalies emanating from the North Atlantic to the GBM region (Fig. 2e,f). Finally, 850 hPa zonal wind stress correlations (Fig. 2g,h) are consistent with the 850 hPa height correlations. To the north (south) of the positive PC1-850 hPa correlation over India are found significantly positive (negative) wind stress correlations. Likewise, to the north (south) of the negative PC2-850 hPa correlation in the same area are found significantly negative (positive) wind stress correlations. In the next section we will propose forcing mechanisms that could contribute to the two primary monsoonal rainfall patterns in the GBM.

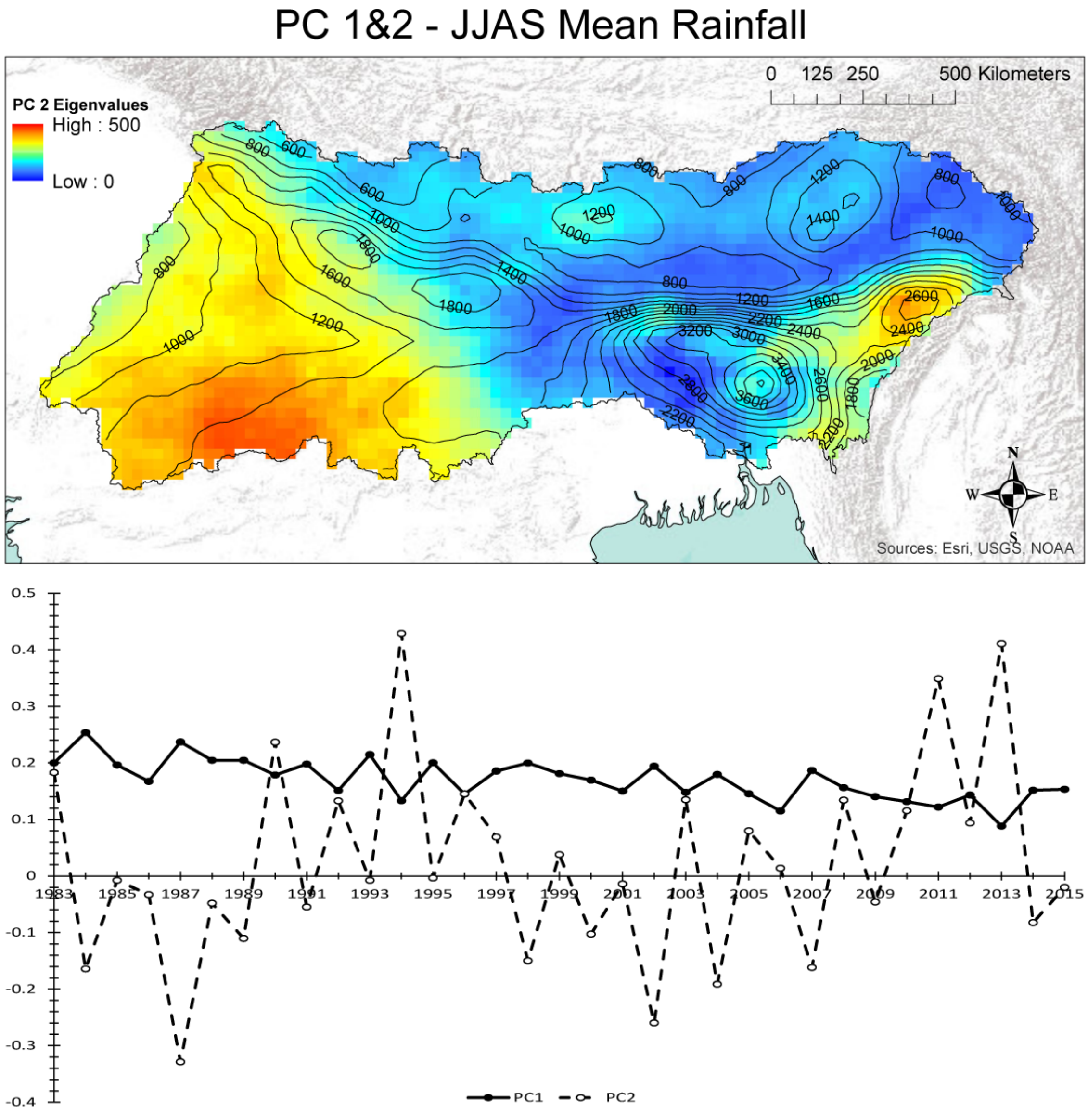

Figure 1. Monsoon precipitation patterns in the GBM as revealed by principal component analysis (top). Contours are for PC1 and colors are for PC2. Corresponding eigenvectors are also traced for the 33 monsoon years (bottom). PC1 is solid and PC2 is dashed.

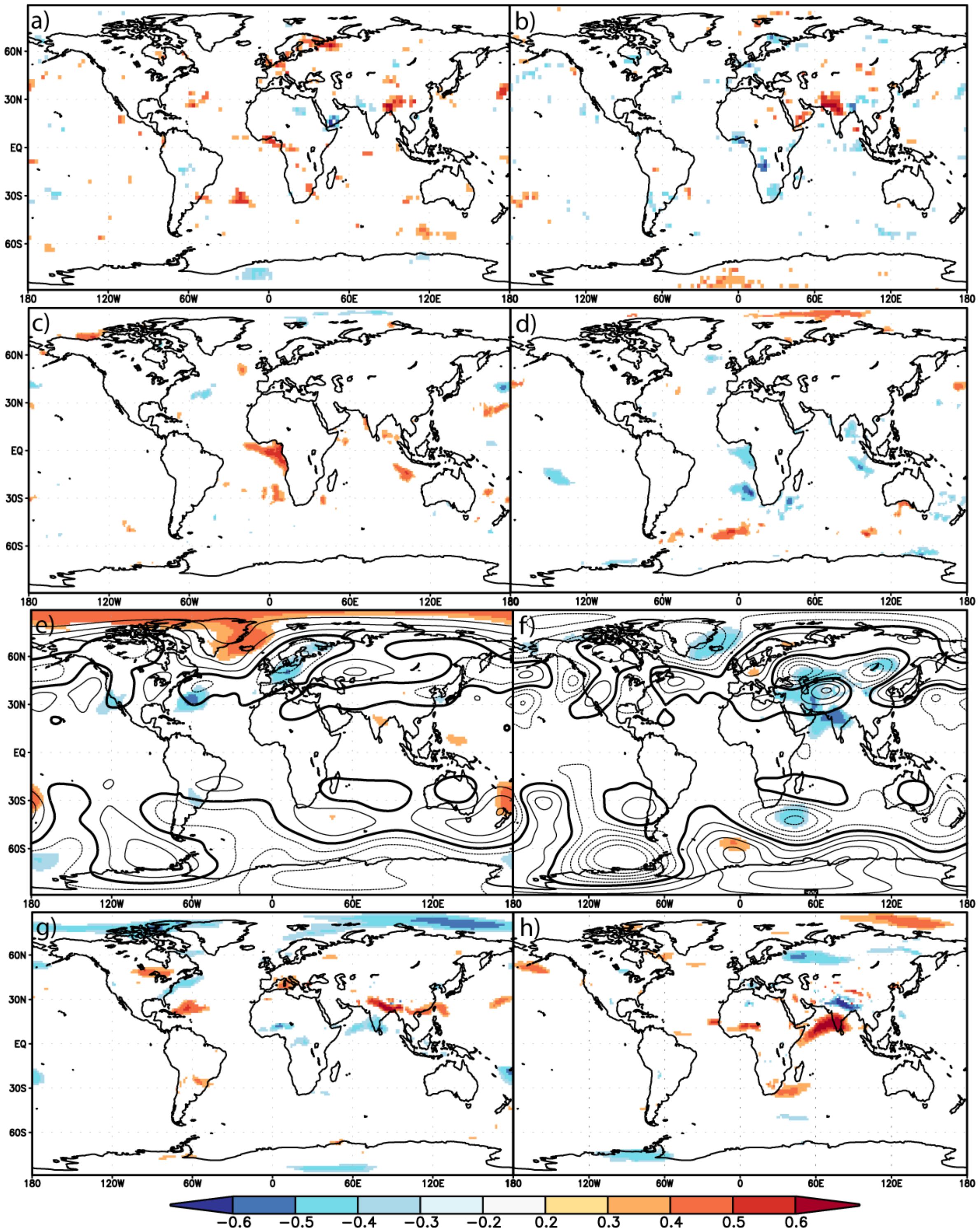

Figure 2. Correlations in color between global air-sea fields and PC1 (left) and PC2 (right). a) and b) are for precipitation, c) and d) for SST, e) and f) for 850 hPa heights, g) and h) for 850 hPa zonal wind. Contours in e) and f) are regressions wih 200 hPa heights. The zero line is bolded and solid (dashed) lines represent positive (negative) values. Increments are 2000 m in e) and 200 m in f).

4. Discussion and Conclusions

The center of action of GBM rainfall is over Bangladesh in every year, however monsoonal rainfall is much more variable in the western portion of the basin. When rainfall over Bangladesh is particularly abundant there is a lack of precipitation over central India and vice versa, suggesting a dipole structure. The cause of this inverse pattern appears to be associated with the variability of a Rossby wave train that extends from the North Atlantic to South Asia; identified in previous studies [4]. When the western portion of the GBM receives more rain, it can be traced to a baroclinic trough over the North Atlantic, ridge over northern Europe, and trough over western Russia. A more barotropic signal can be found to the northwest of India with higher heights at 200 hPa and lower heights at 850 hPa. This was previously related to warm Iranian surface temperatures [4]. The near surface lower-heights extend into India and become strong, inducing cyclonic flow. This leads to westerly winds sweeping across the Arabian Sea, bringing abundant moisture into the Indian peninsula and enhancing rainfall. The opposite conditions appear to be the case for years when Bangladesh receives more rainfall than normal.

In conclusion, the discharge of the GBM river system is important for projecting annual riverbank erosion rates in the lower Meghna. Most of the rainfall occurs in the monsoon months of June, July, August, and September, but there is high spatial variability. We argue it is important to identify the sources of moisture and atmospheric uplift that impact the locations of rainfall in the basin to better understand the ultimate erosion hazard. Interestingly, the sources of interannual variability of GBM monsoonal rainfall do not appear to come from the tropics, but instead the high-latitudes, specifically from the North Atlantic. Future work will examine the pre-monsoon season to better understand the wave train source and extend predictability. The strength of the two patterns of rainfall identified here will eventually be related to erosion rates, and sub-basin precipitation will be analyzed for refined predictive capability.

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Abbreviations

The following abbreviations are used in this manuscript:

GBM: Ganges-Brahmaputra-Meghna
PERSIANN-CDR: Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record
GIS: Geographic Information Science
PC: Principal Component
GPCP: Global Precipitation Climatology Project
JJAS: June-July-August-September

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