A see-saw oscillation between the Amazon and Congo basins

Elfatih A. B. Eltahir, Brian Loux, Teresa K. Yamana, and Arne Bomblies

Ralph M. Parsons Laboratory, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Received 30 July 2004; revised 13 October 2004; accepted 28 October 2004; published 1 December 2004.

INDEX TERMS: 1854 Hydrology: Precipitation (3354); 1860 Hydrology: Runoff and streamflow; 1836 Hydrology: Hydrologic budget (1655); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3360 Meteorology and Atmospheric Dynamics: Remote sensing. **Citation:** Eltahir, E. A. B., B. Loux, T. K. Yamana, and A. Bomblies (2004), A see-saw oscillation between the Amazon and Congo basins, *Geophys. Res. Lett.*, *31*, L23201, doi:10.1029/2004GL021160.

[1] The climate of Earth is shaped to a significant degree by the occurrence of intense storms over three regions: the Amazon and Congo basins and the Pacific Ocean. However, little is known about natural oscillations in the amounts of rainfall over the Amazon and Congo basins. Here, we present new satellite observations on tropical rainfall distribution and historical river flow observations to document a natural see-saw oscillation across the Atlantic Ocean: floods over the Amazon basin tend to coincide with droughts over the Congo basin and vice versa. This phenomenon is most significant during the southern hemisphere summer, and was observed most clearly during the decades of 1945–1955, 1960s, and 1970s. The mechanism responsible for this see-saw phenomenon is based on the Gill model of tropical circulations since rising motions associated with floods over either of the two basins is likely to force subsidence and droughts over the other basin.

[2] The large scale rising air motion near the Equator is associated with large scale convection and rainfall. This rising motion is not uniform in space or time and tends to concentrate over the Western Pacific Ocean, the Congo basin and the Amazon basin. This is best illustrated by *Wyrtki* [1982, Figure 3]. Together these three regions receive a large fraction of tropical rainfall. During the last few decades the variations in rainfall over the Pacific Ocean associated with ENSO received significant attention. Several studies documented the global and regional impacts of this phenomenon on climate and hydrology [*Ropelewski and Halpert*, 1987; *Simpson et al.*, 1993; *Whitaker et al.*, 2001; *Eltahir*, 1996a; *Amarasekera et al.*, 1997; *Richey et al.*, 1989]. El Niño (La Niña) has been linked to regional droughts (floods) in the Murray basin [*Simpson et al.*, 1993], the Ganges basin [*Whitaker et al.*, 2001], the Nile basin [*Eltahir*, 1996a], the Congo basin [*Amarasekera et al.*, 1997], and the Amazon basin [*Richey et al.*, 1989]. Similarly, large variations in rainfall over the continental centers of convection and rainfall of the Amazon and the Congo are likely to have significant impacts on the hydrology and climate of surrounding regions.

[3] Here, we study natural variability of floods and droughts over the Amazon and the Congo basins (Figure 1), focusing on their cross-correlation. In comparison to any other river, the Amazon and the Congo carry the largest and second largest (about 6300 cubic kilometers and 1250 cubic kilometers [*Amarasekera et al.*, 1997]) annual discharges of water, respectively. They both discharge water to the Atlantic Ocean. The corresponding annual rainfall amounts, which are about 12,000 and 5,600 cubic kilometers, are linearly related to the large-scale latent heating of the atmosphere above the two continents. Hence, rainfall and the associated atmospheric convection over the two basins play a significant role in the global energy balance and the climate of Earth in general.

[4] The observational rain-gauge networks over these two remote basins are sparse and provide an incomplete picture of the rainfall distributions. However, recent satellite missions have been designed to address these limitations and to overcome problems of poor spatial sampling. Here, we use data from the Tropical Rainfall Measuring Mission (TRMM) which was launched in 1997 to provide reliable estimates of rainfall distribution over tropical regions [*Simpson et al.*, 1988]. The monthly rainfall estimates for the period January 1998 to December 2002 has been averaged over each of the two basins (Figure 1), the monthly mean removed from each series, and the resulting series of rainfall anomalies were normalized by their standard deviations. Figure 2 shows the standardized rainfall anomalies for both basins. Positive anomalies correspond to flood events while negative anomalies correspond to droughts. Figure 2 describes a clear see-saw pattern of negative correlation between the rainfall over the two basins. For most of the record, significant floods (droughts) in the Amazon occur at the same time as droughts (floods) in the Congo.

[5] The null hypothesis that the two series of floods and droughts in Figure 2 are independent of each other (correlation coefficient = 0) is rejected at the 5% level of significance. This conclusion suggests a significant relationship between hydrological anomalies over the two basins. Given the complex nature of the climate system and the seasonality of the solar forcing, we expect this see-saw mode of natural variability to exhibit significant variability at monthly to decadal time scales. Unfortunately, the period covered by the TRMM data, which is about 5 years, is relatively short. Such record is not sufficient to explore, in a statistically meaningful way, how the see-saw pattern may vary within a year and between different years and decades. Other data sources are needed to explore natural variability at these time scales.

[6] River flow measurements provide a good integrated surrogate for rainfall over large areas. Although river flow is

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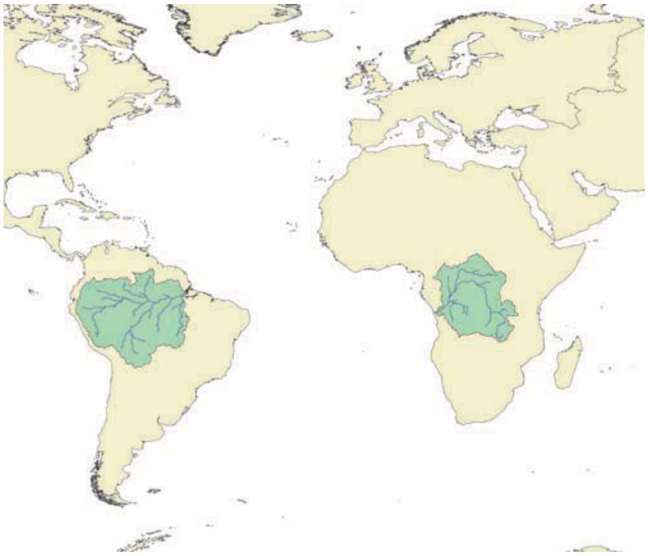

Figure 1. The locations and boundaries of the Amazon and Congo basins.

related to rainfall in a complex way, most of the fluctuations in river flow are mainly shaped by variability in rainfall amounts [*Amarasekera et al.*, 1997]. Here, we use the long term measurements of river flow in the Amazon and Congo basins as surrogates for the rainfall over the two basins. The river flow data for the Amazon are derived from the daily records of the stage of the Rio Negro at Manaus [*Richey et al.*, 1989] (lat. 3°S, long. 60°W) for the period 1904–1985. The integrated runoff represented by the Manaus record covers about 50% of the total area of the Amazon basin. The discharge data for the Congo River are derived from the daily records of the stage of the Congo River at Kinshasa [*Amarasekera et al.*, 1997] (lat. 4°N, long. 15°E) for the period 1905–1985. The two records overlap for the period 1905–1985.

[7] The two time series of river flow were analyzed in a manner similar to the analysis of rainfall data. The monthly mean is removed, and the resulting anomalies were normalized by their standard deviations. Figure 3a shows the two series of standardized anomalies for river flow. The correlation coefficient between the two series of floods and droughts is negative for most decades but varies significantly between the different decades (Figure 3b). For the decades of 1945–1955 and 1960–1980, the negative correlation between the two series is large enough such that the null hypothesis of independence between floods and droughts over the two basins (correlation coefficient = 0) is rejected at 5% level of significance. For the decades of 1960–1980, the correlation coefficient is as large as −0.6. Figure 3a demonstrates clearly the see-saw mode of variability exhibited by the river flow series during the decades of 1945–1955 and 1960–1980. The relatively long record of river flow over the two basins facilitates a detailed analysis on how the negative correlation between river flow in the two basins varies in the different months. Figure 4 shows the correlation coefficient between the two series of Figure 3a sorted for the different months. The negative correlation coefficient is statistically significant during the months of February, March, and April. The river flow during these months corresponds to the rainfall occurring during the southern hemisphere summer which is the main rainy season for the two basins.

[8] The atmospheric circulations over the Congo and Amazon basins can be described by the Gill theory on the response of the tropical atmosphere to localized heating [*Gill*, 1980]. The same theory is often used to describe the response of the tropical circulation over the Pacific Ocean to

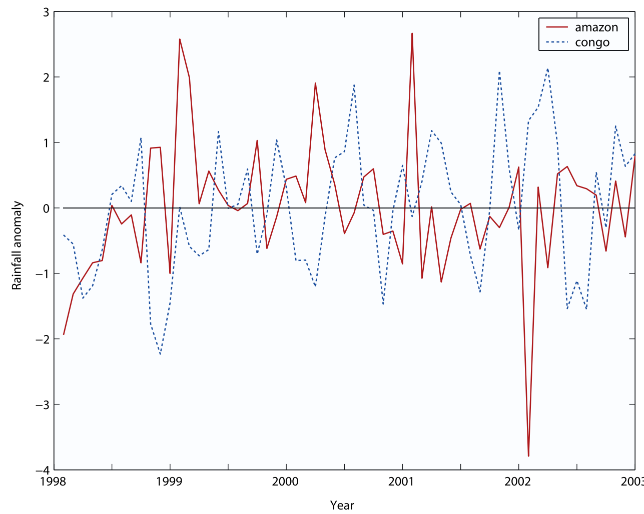

Figure 2. Rainfall anomalies over the Amazon and Congo basins. The monthly rainfall estimates for the period January 1998 to December 2002 from TRMM have been averaged over each of the two basins (Figure 1), the monthly mean removed from each series, and the resulting series of rainfall anomalies were normalized by their standard deviations. The monthly data was produced by Algorithm 3B-43 (TRMM and Other Satellites Precipitation). The purpose of Algorithm 3B-43 is to produce the "Tropical Rainfall Measuring Mission (TRMM) and Other Data" best-estimate precipitation rate and root-mean-square (RMS) precipitation-error estimates. These gridded estimates are on a calendar month temporal resolution and a 1-degree by 1-degree spatial resolution global band extending from 40 degrees south to 40 degrees north latitude. Algorithm 3B-43 is executed once per calendar month to produce the single, best-estimate precipitation rate and RMS precipitation-error estimate field (3B-43) by combining two independent precipitation fields. These two independent precipitation fields are the daily average adjusted merged-infrared (IR) estimates (3B-42) and the monthly accumulated Climate Assessment and Monitoring System (CAMS) or Global Precipitation Climatology Centre (GPCC) rain gauge analysis (3A-45). The input rain gauge data are on the calendar month temporal resolution. To obtain the requisite calendar month average of adjusted merged-IR data, 3B-43 averages the daily adjusted merged-IR data that span the calendar month of interest. After this preprocessing is complete, the two independent precipitation fields are merged together to form the best-estimate precipitation rate and RMS precipitation-error estimates. A complete description of Algorithm 3B-43 is provided in the Algorithm 3B-43 User's Guide available from the TRMM Data and Information System (TSDIS).

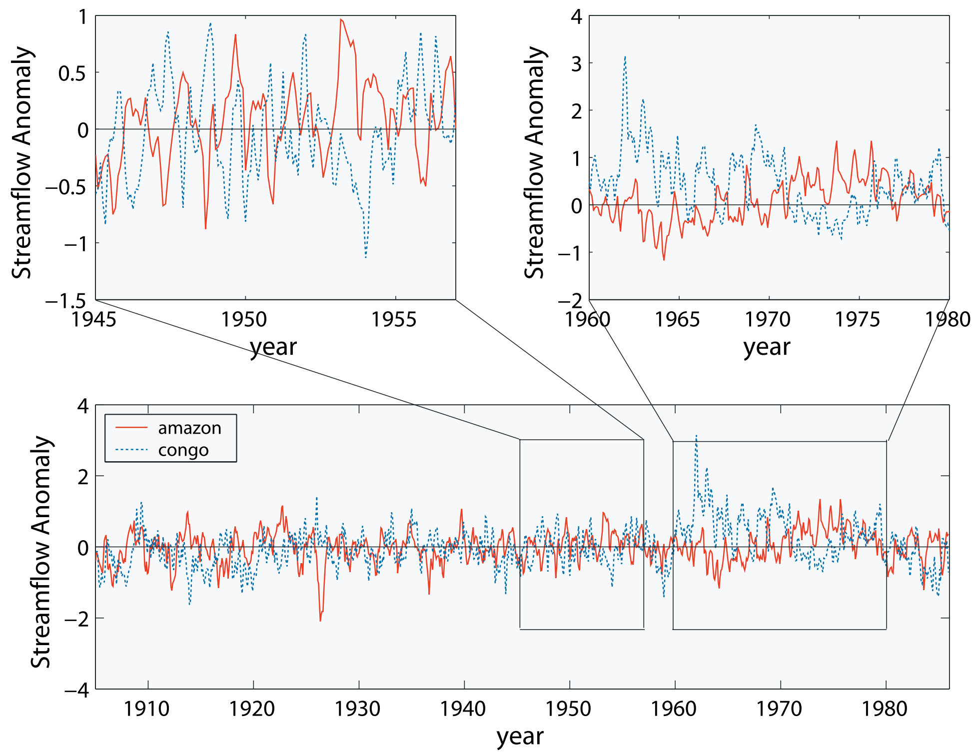

Figure 3a. River flow anomalies over the Amazon and Congo basins, 1905–1985. The flow measurements were analyzed in a manner similar to the analysis of rainfall data in Figure 2: the monthly mean is removed, and the resulting anomalies were normalized by their standard deviations. The anomalies for the decades 1945–1955 and 1960–1980 are presented separately to illustrate the see-saw oscillation.

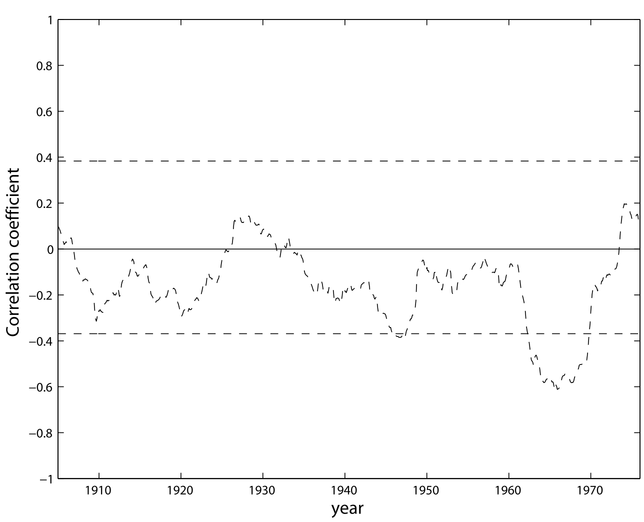

Figure 3b. The correlation coefficient between the river flow anomalies in the Amazon and Congo basins. The correlation is computed for each decade (120 months) and plotted against the first year of the decade (e.g., the value plotted against 1975 represents the correlation for the decade 1975–1985). The two dash lines should enclose 95% of the correlation coefficients that would be computed from a sample of size 120 months if the two anomalies were truly independent of each other. These two boundaries were estimated using Monte Carlo techniques.

ENSO events [*Cane et al.*, 1986]. The latent heating that forces these tropical circulations is fueled by the water vapor condensation associated with persistent rainfall occurrence over the two basins. The Gill theory predicts that rising motion over any large tropical region near the

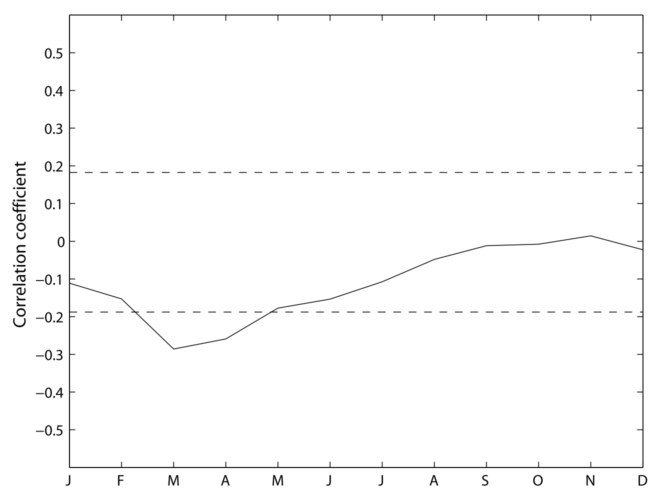

Figure 4. The correlation coefficient between the anomalies of (Figure 3a) computed for each month independently. Again the two dash lines should enclose 95% of the correlation coefficients that would be computed from a sample of size 81 months (e.g., February 1905 to February 1985) if the two anomalies were truly independent of each other.

Equator would force subsidence over the surrounding regions. The following is a plausible mechanism of natural variability in the tropical climate system. An anomalously strong rising motion over the Amazon (Congo) associated with the occurrence of floods results in anomalous subsidence over the surrounding regions including the Congo (Amazon), consistent with the occurrence of droughts over this basin. This mechanism is similar to other mechanisms proposed in previous studies to describe how the tropical atmosphere responds to deforestation in the Amazon [*Eltahir and Bras*, 1993; *Eltahir*, 1996b], and how the same system responds to ENSO events [*Amarasekera et al.*, 1997].

[9] Here, we highlight one new mode of climate variability over the Amazon and Congo basins. The see-saw oscillation across the Atlantic Ocean exhibits significant variability at monthly (Figure 4), annual (Figures 2, 3a, and 3b), and decadal (Figure 3b) time scales. Indeed, this is only one of many potential modes that shape climate variability in this tropical sector. The climate of the tropics reflects the dynamics of a complex natural system with many modes of variability. The Amazon drought of 1926 and the Congo floods of the early 1960s, which are evident in Figure 3a, are other examples of extreme natural variability that have received little attention in the research community.

[11] **Acknowledgments.** The first author would like to acknowledge several discussions on this topic and many related topics with Earle Williams of MIT. We would like to thank Professor Jon Foley of the University of Wisconsin and an anonymous reviewer for helpful comments.

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A. Bomblies, E. A. B. Eltahir, B. Loux, and T. K. Yamana, Ralph M. Parsons Laboratory, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA. (bomblies@mit.edu)