South American Streamflow and the Extreme Phases of the Southern Oscillation

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Introduction

This study investigates the extent of the affect of the El Niño/Southern Oscillation on South American streamflow. The response of South American precipitation and temperature to the extreme phases of ENSO (El Niño and La Niña events) is well documented (*eg*, Ropelewski and Halpert 1987, Rogers 1988, Kiladis and Diaz 1989, Tapley and Waylen 1990); but the response of South American hydrology has been barely studied (Waylen and Caviedes 1990, Mechoso and Iribarren 1992). Such paucity of research contrasts sharply with that available on the response of North American streamflow to ENSO events (*eg*, Kahya and Dracup 1993, Cayan and Webb 1993, Redmond and Koch 1991).

This present study is based on a hydrologic study by Kahya and Dracup (1993) of North America streamflow and, with their techniques, examines South American streamflow. A schematic of our research approach is presented in Figure 1. In South America, regions with a coherent response to ENSO are identified, and by computing and analyzing the shift

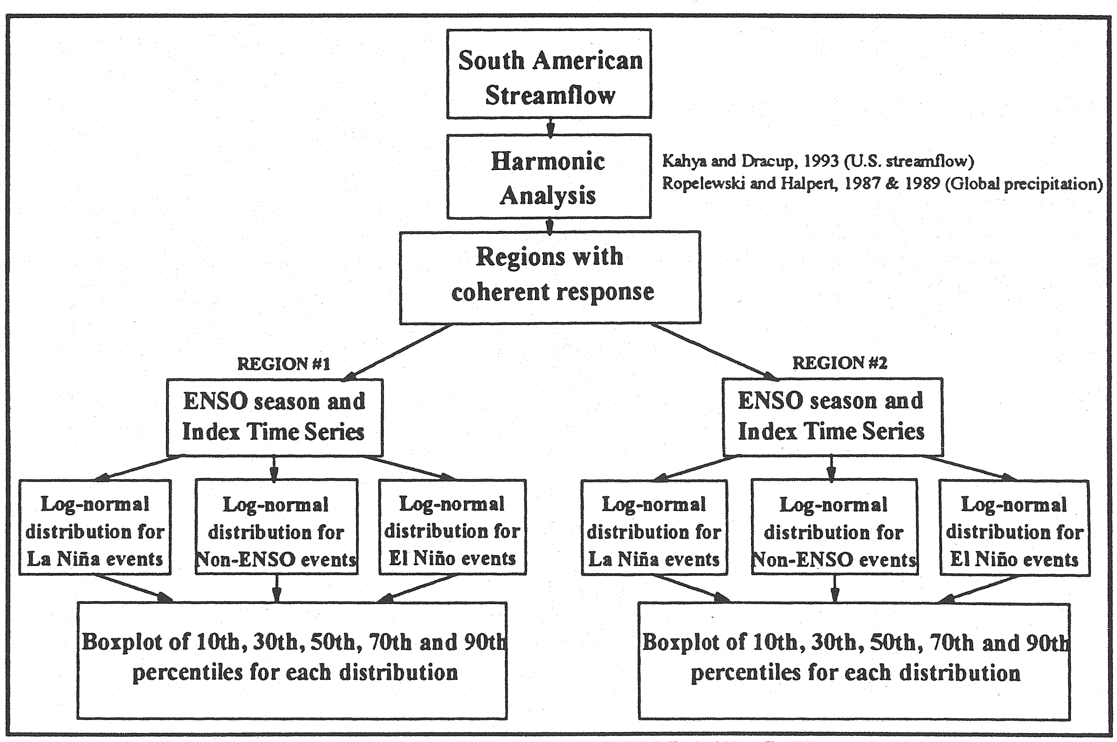

Figure 1. SCHEMATIC OF RESEARCH APPROACH USED TO IDENTIFY REGIONS OF STRONG RESPONSE TO ENSO

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in the probability distribution for La Niña, non-ENSO, and El Niño events, we are able to represent and chart the South American streamflow anomalies.

Data

The impetus for this research was a University of California Pacific Rim Workshop held at UCLA in December 1993. At this workshop, hydrologists from several Pacific Rim countries gathered to study the influence of ENSO on Pacific Rim streamflow. Each participant brought streamflow data collected from his region, which augmented the global runoff dataset of McMahon *et al* (1992), the database for this study.

Data on 95 streamflow stations in South America and Panama were compiled (Figure 2). These data represent monthly runoff volumes with records of varying lengths, although most cover periods of 30 to 40 years. The La Niña and El Niño years are based on definitions presented in Ropelewski and Halpert (1989) and Rasmusson and Carpenter (1983).

Figure 2. GEOGRAPHIC DISTRIBUTION OF THE 95 STREAMFLOW STATIONS
Data for each station consist of monthly runoff volumes.

Harmonic Analysis

Using harmonic analysis, we examined the tendency for a streamflow anomaly to occur biennially during ENSO events. We explain this biennial occurrence as the response of streamflow to ENSO events as they move from positive to negative (above or below the norm), or vice versa, within a 2-year period. Two notable studies have incorporated this biennial tendency into their methods for examining the forcings of ENSO: Ropelewski and Halpert (1987) and Kahya and Dracup (1993).

Our research proceeded as follows. First, original records are transformed into percentiles based on a log-normal distribution for each month at each station. With this transformation, all streamflow records having a different original mean and variance are put into an equal basis. A 2-year period is chosen to represent a lifetime period for the ENSO event.

Using common conventions, the ENSO year is designated by (0), the year before is (-), and the year after is (+). A 24-month percentile composite, based on the ENSO episodes, is then established for each individual station. The first harmonic extracted from such a composite is represented as a harmonic vector, which is mapped, identifying core regions of spatially coherent streamflow responses to the ENSO forcing. The amplitude and phase of a harmonic vector refer to the respective strength and time of the response. The statistical significance of the harmonic amplitude and phase is assigned by use of Schuster's test for an autocorrelated series. The degree of significance of each station, or the probability that the first harmonic representation of the El Niño composite is produced by chance, is measured by Schuster's quantitative test of significance. Within each region, the vectorial coherence is found by computing the ratio of the vector mean to the scalar mean. The concept of coherence is defined and discussed in Kahya and Dracup (1993).

Figure 3 presents the first harmonic vectors for the 95 streamflow stations. Regions that have similar phase and amplitude (*ie*, areas showing vectors with similar length and pointing in the same direction) are identified for further analysis. Four regions are identified: North-Central Chile (NCH); South-Central Chile (SCH); Guyana (GUY); and Panama (PAN).

Within each of these regions, the normalized streamflow is aggregated to form a 36-month composite, with the middle 12 months still representing the ENSO year. The aggregate composite then identifies a season with a persistent streamflow anomaly; that is, a season in which the streamflow index is consistently above or below the 50th percentile value. Figure 4 is the aggregate composite for the SCH region. In this composite, a consistent negative (dry) anomaly in the latter part of year (–) is followed by a positive (wet) anomaly in the latter part of year (0).

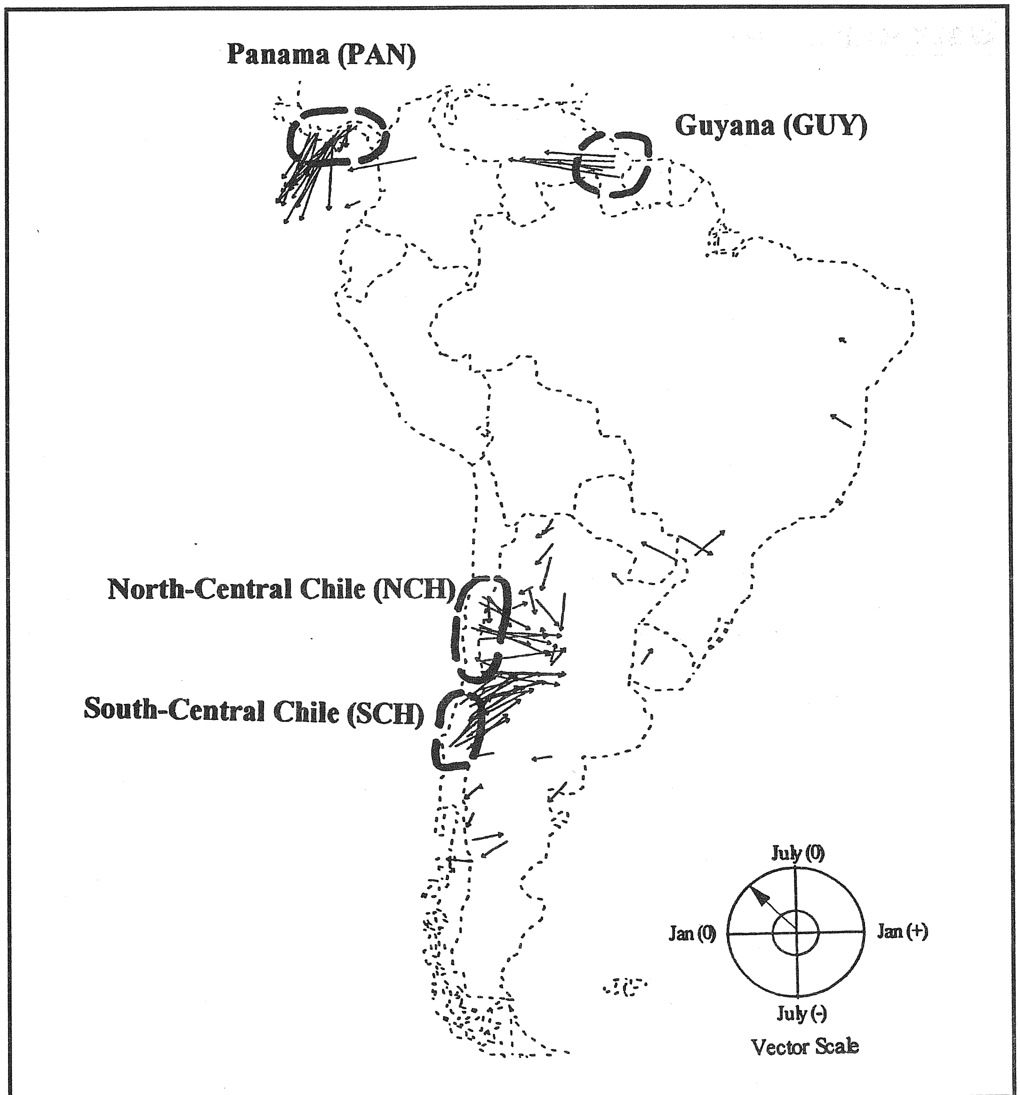

Figure 3. STREAMFLOW VECTORS BASED ON A 24-MONTH FIRST HARMONIC FIT TO THE EL NIÑO COMPOSITE
Vector orientation is represented by the harmonic dial. Regions with a coherence value greater than 0.80 are outlined.

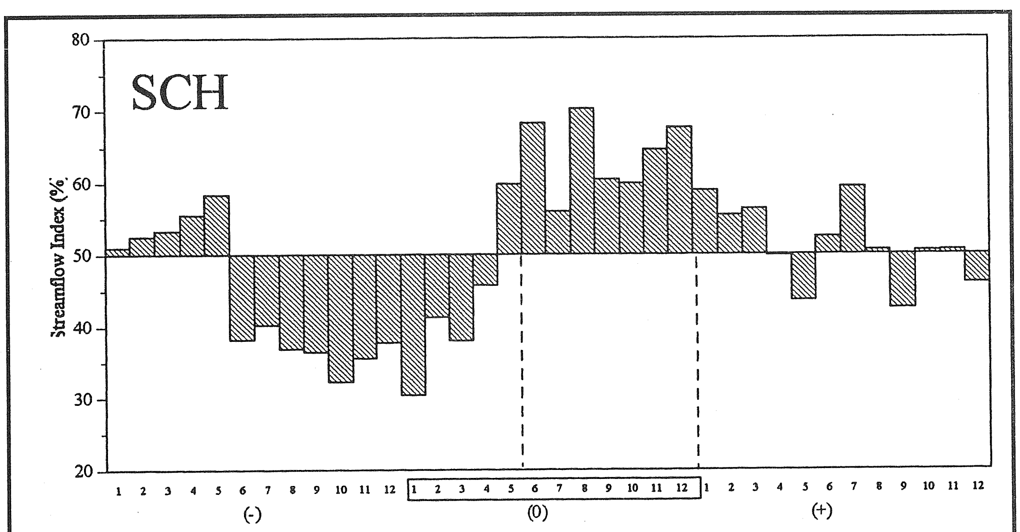

Figure 4. EL NIÑO AGGREGATE COMPOSITE FOR THE SOUTH-CENTRAL CHILE REGION OUTLINED IN FIGURE 3.
The 36-month composite starts at Jan(–) and ends at Dec(+). Dashed lines identify the season that has a consistent anomaly, above or below the mean.

The second anomaly in the 36-month composite is identified as the El Niño season. Using this season, an index time series is formed to observe the consistency of the response in relation to the entire time series (Figure 5). Eight of the nine El Niño events, as identified by the dark bars, are associated with a wet streamflow anomaly in the SCH region. Three of the largest streamflow anomalies occurred during El Niño years. This represents a strong relationship between ENSO and extreme streamflow events. A summary of the results for each region is provided in Table 1.

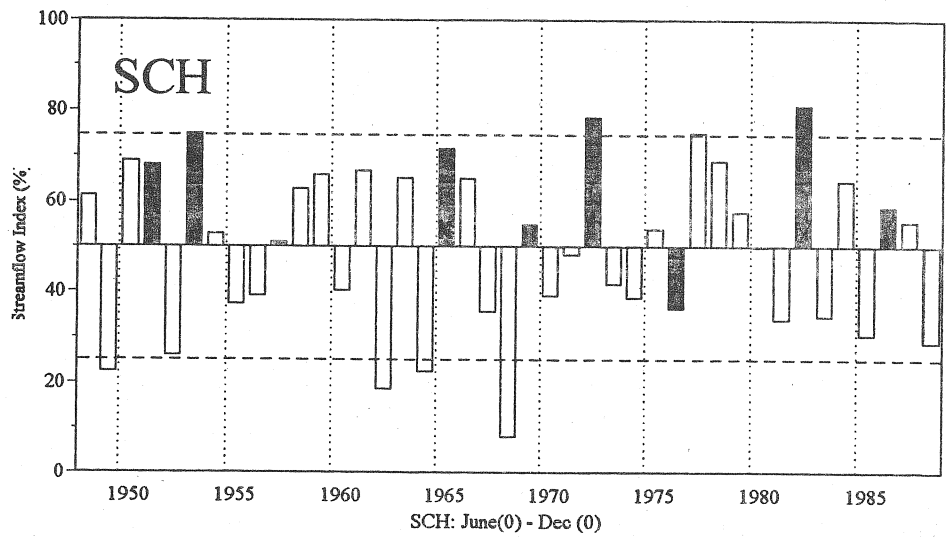

Figure 5: INDEX TIME SERIES FOR THE SOUTH-CENTRAL CHILE REGION BASED ON THE SEASON DETECTED IN FIGURE 4.

El Niño years are represented by dark bars. Horizontal dashed lines represent the upper (90%) and lower (10%) limits of the distribution based on the ranked data.

Table 1
PROPERTIES OF THE FOUR REGIONS IDENTIFIED USING HARMONIC ANALYSIS

(0) refers to the El Niño year; (+) refers to the following year.

Candidate Region	Number of Stations	Degree of Significance DOS <0.15	El Niño Signal	El Niño Season	Consistency
Panama (PAN)	23	16	Dry	Apr(0)-Dec(0)	4 of 5
Guyana (GUY)	5	5	Dry	Aug(0)-Mar(+)	5 of 6
South-Central Chile (SCH)	19	19	Wet	Jun(0)-Dec(0)	8 of 9
North-Central Chile (NCH)	13	13	Wet	Dec(0)-Jul(+)	6 of 9

Seasonal Cycle

In assessing the impact of ENSO, timing of the maximum anomaly in relation to the annual cycle is also important. Does the anomaly occur during the normal wet or dry period? This is answered by plotting the normal annual cycle along with the corresponding annual cycle that occurs during El Niño and La Niña events (Figure 6). For the SCH region, the annual cycle is enhanced during the El Niño events at the time of maximum runoff (July-September). Conversely, the annual cycle is depressed at the time of maximum runoff during La Niña events. Finally, normal conditions prevail in the year following the El Niño event.

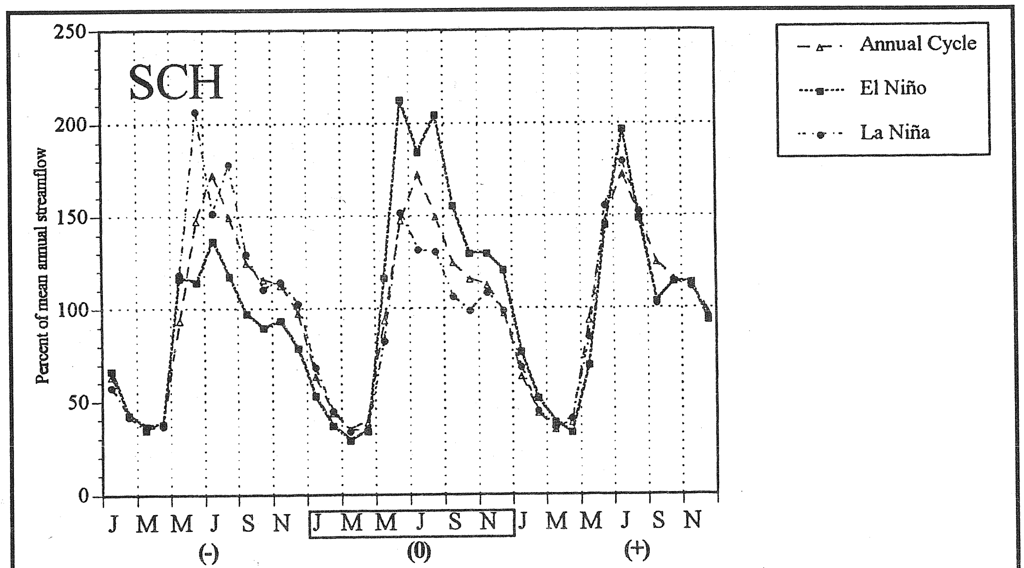

Figure 6. COMPARISON OF THE STREAMFLOW ANNUAL CYCLE FOR NON-ENSO, EL NIÑO, AND LA NIÑA CONDITIONS IN THE SOUTH-CENTRAL CHILE REGION.
Values are a percentage of mean annual streamflow.

Shift in the Probability Distributions

After each region has been identified through harmonic analysis, it is quantified for the ENSO signal by computing the expected streamflow value based on the percentile anomaly. Because of the variability of the strength of ENSO events and the inherent variability in streamflow, computed results may be misleading. The ENSO signal may be more usefully measured by the shift in the probability distribution of streamflow during La Niña, non-ENSO, and El Niño events. The shift is made by breaking our original streamflow data into three sub-sets corresponding to the different conditions in the tropical Pacific. The shift in the probability distribution can be observed by computing the 10th, 30th, 50th, 70th, and 90th percentiles for each sub-set and by presenting the values in a boxplot. Figure 7 displays the shift in the probability distribution for streamflow stations in three of the four regions. This method of analysis is similar to that used in the study by Halpert and Ropelewski (1994); that study quantified the impact of ENSO on regions identified throughout the world in their earlier study (Ropelewski and Halpert 1987).

We offer one interpretation for the shift of the Rio Maule Armerilla, located in the SCH region (Figure 7): the median (50th percentile) streamflow during El Niño years is shifted to the 75th percentile of the non-ENSO distribution. This means there is a 75% probability that the Rio Maule Armerilla will receive non-ENSO median runoff during El Niño years. Conversely, the median during La Niña years is shifted to the 30th percentile of the non-ENSO distribution. Only 30% probability exists that

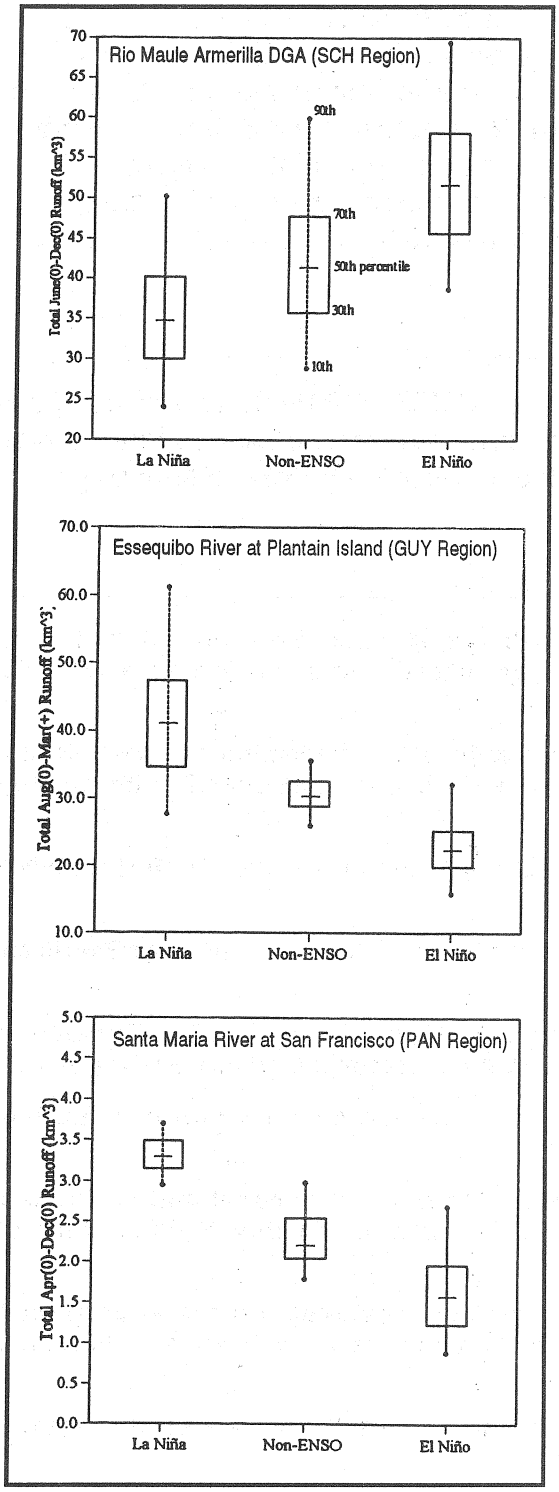

Figure 7. BOXPLOTS OF THE THREE STREAMFLOW DISTRIBUTIONS FOR LA NIÑA, NON-ENSO, AND EL NIÑO YEARS AT RIO MAULE ARMERILLA, ESSEQUIBO RIVER, AND SANTA MARIA RIVER
Short horizontal line inside box represents the 50th percentile.
Top of box represents the 70th percentile.
Bottom of box represents the 30th percentile.
Top of line represents the 90th percentile.
Bottom of line represents the 10th percentile.

the Rio Maule Armerilla will receive non-ENSO median runoff during La Niña years.

The GUY and PAN regions have shifts opposite those of the two Chilean regions (Figure 7). The opposite shift reflects the dry anomaly present during El Niño. The shift is large for the Santa Maria River, in the PAN region. The median value during El Niño years is shifted to the 10th percentile of the non-ENSO distribution. This represents a 10% probability that the Santa Maria River will receive non-ENSO median runoff during El Niño years. The Essequibo River, in the GUY region, has the median value shifted below the 10th percentile of the non-ENSO distribution during El Niño years. The probability of the Essequibo River receiving non-ENSO median runoff during El Niño years is less than 10%.

Conclusions

The response of South American streamflow to extreme phases of the ENSO is observed by using harmonic analysis to identify regions of coherent response. Four regions are identified as having a strong response: SCH, NCH, GUY, and PAN. In two Chilean regions (SCH and NCH) a wet streamflow anomaly occurs during El Niño events. In the GUY and PAN regions, which represent northern South America, a dry streamflow anomaly occurs during El Niño events. This streamflow anomaly coincides with the shift in the probability distribution for the extreme phases of ENSO and non-ENSO conditions.

These results are similar to those of Ropelewski and Halpert (1987), who used precipitation data to identify northeastern South America and Central America as regions with a coherent response to ENSO. Their northeastern South American region has an El Niño season of Jul(0) to Mar(+). This is similar to our GUY region, which has a Aug(0) to Mar(+) season. Our PAN region, with a season of Apr(0) to Dec(0), is similar to their Central America region, which has a Jul(0) to Oct(0) season. Although the area of western South America was not well represented by Ropelewski and Halpert (1987), the study presented here has sufficient data on Chile to identify it also as a coherent region.

The scant availability of data representing all of South America limits this study. The four regions identified here may not be the only areas of South America with a strong response to ENSO; nonetheless, our results are an excellent starting point for exploring the influence of ENSO on South American hydrology. When sufficient data are available covering Brazil, Columbia, Venezuela, Ecuador, Peru, and Bolivia, yet other regions of coherent response to ENSO forcings may be located within South America.

Acknowledgments

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