

## RESEARCH LETTER

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## Key Points:

- A new proxy record for Amazon River discharge is used to assess the influence of sunspots on Amazon hydrology over a 200 year period
- The direction of the relationship between sunspots and the hydrological proxy changes over time, casting doubt on the mechanism of control
- This work shows that long, annually resolved  $\delta^{18}\text{O}_{\text{TR}}$  proxy records can provide more insights than instrumental data alone

## Supporting Information:

- Supporting Information S1
- Data Set S1

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## Questioning the Influence of Sunspots on Amazon Hydrology: Even a Broken Clock Tells the Right Time Twice a Day

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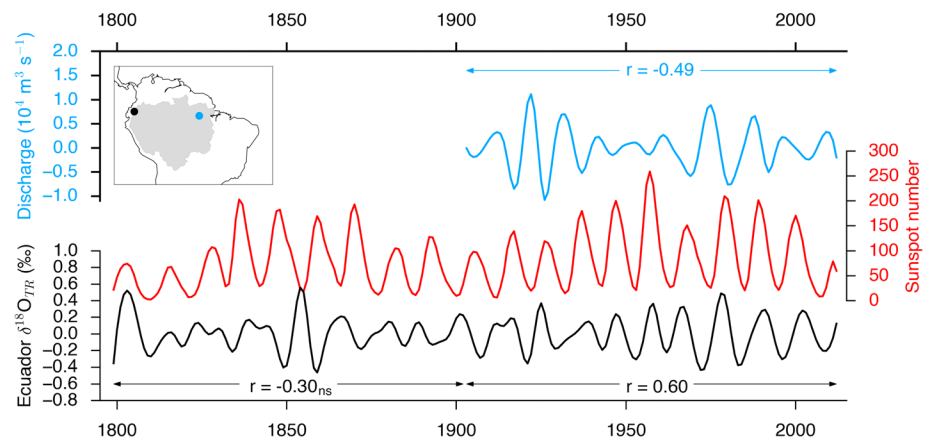
**Abstract** It was suggested in a recent article that sunspots drive decadal variation in Amazon River flow. This conclusion was based on a novel time series decomposition method used to extract a decadal signal from the Amazon River record. We have extended this analysis back in time, using a new hydrological proxy record of tree ring oxygen isotopes ( $\delta^{18}\text{O}_{\text{TR}}$ ). Consistent with the findings of Antico and Torres, we find a positive correlation between sunspots and the decadal  $\delta^{18}\text{O}_{\text{TR}}$  cycle from 1903 to 2012 ( $r = 0.60, p < 0.001$ ). However, the relationship does not persist into the preceding century and even becomes weakly negative ( $r = -0.30, p = 0.11, 1799\text{--}1902$ ). This result casts considerable doubt over the mechanism by which sunspots are purported to influence Amazon hydrology.

**Plain Language Summary** In a recent paper, researchers identified a possible connection between the amount of water flowing in the Amazon River and changes in solar activity, measured by number of sunspots. However, the precise details of this relationship and how it might work were not fully understood, and the analysis only covered the 20th century. Amazon tree rings (the annual growth bands visible in the wood of many temperate and tropical trees) have been shown to record information about basin rainfall (and hence Amazon River flow), in the year of their formation, and therefore offer a way to extend the hydrological record back in time. In this study, we used a new tree ring data set from Ecuador to test the link between sunspots and the Amazon water cycle over a 200 year period. We show that the relationship between sunspots and Amazon River flow is not constant over time and suggest it might even arise by chance, just as the hands of a broken clock point to the right time twice a day. This work highlights how proxy climate data sets can sometimes provide more insights than instrumental climate data alone.

### 1. Introduction

Frequency and mode analysis of time series are often used in climate studies to explore covariation between variables and thus identify potential causal relationships. Although seemingly elegant, their use is not without pitfalls: two series with a similar frequency may periodically coincide by chance, just as the hands of a broken clock point to the correct time twice a day. In a recent study, Antico and Torres (2015) used the ensemble empirical mode decomposition (EEMD) method (Wu & Huang, 2009) to detect modes of variation in Amazon River discharge measured at Óbidos, from 1903 to 2012. EEMD is a noise-assisted data analysis approach, which involves decomposing a noise-added time series into its constituent oscillations, and calculating the average of these over a large number of trials. Using this technique, the authors found a good correlation between the decadal mode of Amazon River flow and variation in sunspot number. Their findings led them to suggest that solar activity influences the Amazon hydrological cycle at decadal timescales by modulating Atlantic sea surface temperatures (SSTs). Specifically, they suggest that maxima and minima in the sunspot cycle respectively increase or decrease the difference between SSTs in the tropical North and tropical South Atlantic, thus weakening or strengthening the trade winds that transport moisture into the Amazon basin. In turn, this affects the amount of precipitation and runoff over the Amazon.

While the correspondence between sunspots and the decadal-scale mode of Amazon River discharge is intriguing, the proposed mechanism has not been tested or confirmed with, for example, climate model simulations, and therefore might be considered somewhat speculative. The analysis by Antico and Torres (2015) is also restricted by the length of instrumental river records, which only extend back to 1903 (HidroWeb, 2017). In recent years, correlation analyses and air mass trajectory modeling have been used to



**Figure 1.** Decadal variation in Amazon River flow measured at Óbidos (blue line), smoothed (3 year moving average) international sunspot number (red line) and decadal variation in  $\delta^{18}\text{O}_{\text{TR}}$  from Ecuador (black line). The inset map shows the Amazon basin (gray shading) and the locations of the river flow and  $\delta^{18}\text{O}_{\text{TR}}$  records (blue and black circles, respectively). The decadal river flux and  $\delta^{18}\text{O}_{\text{TR}}$  data are the third ensemble empirical mode decomposition modes of the raw time series shown in Figure S3. Values indicate the Pearson correlation coefficients between sunspot number and the other time series for periods shown by arrows.

show that oxygen isotopes in tree rings ( $\delta^{18}\text{O}_{\text{TR}}$ ) are a good proxy for precipitation over the Amazon basin and Amazon River discharge (e.g., Baker et al., 2016; Brienen et al., 2012). Successive precipitation events during transport of moisture across the Amazon cause the cumulative depletion of atmospheric water vapor, and a gradient in the isotopic composition of precipitation (Salati et al., 1979).  $\delta^{18}\text{O}_{\text{TR}}$  records from the western margins of the basin are able to capture this basin-scale variability in upstream rainout (Baker et al., 2016; Brienen et al., 2012) and can thus be used to extend the Amazon hydrological record back in time. Here we use a new, annually resolved  $\delta^{18}\text{O}_{\text{TR}}$  chronology to test the relationship between sunspots and the Amazon hydrological cycle over the past two centuries.

## 2. Methods

The  $\delta^{18}\text{O}_{\text{TR}}$  chronology used in this study was constructed from 16 *Cedrela montana* trees from Cuyuja, Ecuador (0.45°S, 78.04°W, 2,950 m above sea level). *C. montana* forms annual tree rings (Bräuning et al., 2008, 2009), making it a suitable species for developing precisely dated isotope records. The record was constructed using previously described methods (see Text S1 in the supporting information; Baker et al., 2015; Gärtner & Nievergelt, 2010; Kagawa et al., 2015; Li et al., 2011; Loader et al., 2002; Stokes & Smiley, 1968; Wigley et al., 1984) and covers the period 1799–2012 (Figure S1). A quantitative assessment of temporal variation in chronology quality is given in Text S2. Following Antico and Torres (2015), we applied EEMD to decompose the  $\delta^{18}\text{O}_{\text{TR}}$  record into its intrinsic oscillatory modes. The modes are extracted iteratively, beginning with the highest frequency component of the signal and progressively removing modes of variability until only the trend remains (Wu & Huang, 2009). Figure 1 shows the third EEMD modes (as used by Antico and Torres) of Amazon River discharge measured at Óbidos (October–September annual mean, blue line) and Ecuador  $\delta^{18}\text{O}_{\text{TR}}$  (black line), alongside the smoothed (3 year moving average) record of international sunspot number (red line). River data are from the Agência Nacional de Águas in Brazil (HidroWeb, 2017) with missing values reconstructed using linear relationships with hydrometric data from stations at Taperinha and Manaus (Antico & Torres, 2015). Monthly mean international sunspot number data for 1799–2015 were accessed from the Solar Influences Data Analysis Centre (Berghmans et al., 2002). Significance thresholds for the correlation coefficients were adjusted to account for the reduced effective sample size ( $n_{\text{effective}}$ ) of the smoothed time series, following the approach of Zwiers and Storch (1995).

## 3. Results

Our results are in good agreement with those of Antico and Torres (2015) over the twentieth century, with sunspot number showing an anticorrelation with decadal discharge ( $r = -0.49$ ,  $p < 0.01$ ,  $n_{\text{effective}} = 32$ ), and a positive correlation with decadal  $\delta^{18}\text{O}_{\text{TR}}$  ( $r = 0.60$ ,  $p < 0.001$ ,  $n_{\text{effective}} = 32$ ) from 1903 to 2012.

Variation in discharge is itself inversely related to  $\delta^{18}\text{O}_{\text{TR}}$  at both interannual ( $r = -0.51$ ,  $p < 0.001$ ,  $n = 110$ , Figure S3) and decadal ( $r = -0.39$ ,  $p < 0.05$ ,  $n_{\text{effective}} = 32$ ) timescales. If sunspots drive variation in Amazon hydrology, we would expect the positive relationship between sunspot number and  $\delta^{18}\text{O}_{\text{TR}}$  to continue back in time. However, in the period before 1900 the relationship between the two records breaks down and even becomes weakly negative ( $r = -0.30$ ,  $p = 0.11$ , 1799–1902,  $n_{\text{effective}} = 30$ ). Furthermore, the correlation over the full 200 year period is nonsignificant ( $r = 0.20$ ,  $p = 0.12$ ,  $n_{\text{effective}} = 62$ ). Since sample replication and hence  $\delta^{18}\text{O}_{\text{TR}}$  chronology quality decline over the earliest part of the record (i.e., prior to 1850, Figure S2), it is important to check whether the results hold if this part of the record is excluded. Indeed, curtailing the analysis at 1850 produces a significant correlation between the sunspot and isotope record, with the correlation coefficient equal in magnitude and opposite in sign to that for the 20th century ( $r = -0.61$ ,  $p < 0.05$ , 1850–1902,  $n_{\text{effective}} = 16$ ). Thus, if we limited our analysis to the more statistically robust part of the  $\delta^{18}\text{O}_{\text{TR}}$  record, we would still be able to say with confidence that the postulated sunspot-discharge relationship does not hold into the 19th century.

To check whether the identified relationships could be an artifact of the EEMD method, we shuffled the  $\delta^{18}\text{O}_{\text{TR}}$  record with respect to time and correlated the third oscillatory mode of the shuffled data with the smoothed sunspot data. The mean  $r$  and  $p$  values from 1,000 shuffling iterations show that there is no statistical relationship between the randomized  $\delta^{18}\text{O}_{\text{TR}}$  record and solar activity ( $r_{\text{mean}} = 0.00093$ ,  $p_{\text{mean}} = 0.99$ ,  $n_{\text{effective}} = 62$ ), indicating that the correlations shown in Figure 1 are not simply caused by the time series decomposition methodology.

It is clear from these results that different conclusions would have been drawn about the influence of sunspots on Amazon hydrology if data had only been available up until 1900, or only available after 1900. This suggests either that the relationship between  $\delta^{18}\text{O}_{\text{TR}}$  and Amazon hydrology is not robust, or that the postulated relationship between sunspots and Amazon hydrology does not hold. A decision must therefore be made as to whether one of these time series could be the “broken hands” in our clock analogy. In other words, is it possible that the  $\delta^{18}\text{O}_{\text{TR}}$ -discharge relationship or the sunspot-discharge relationship might have arisen by chance? The relationship between  $\delta^{18}\text{O}_{\text{TR}}$  and the Amazon hydrological cycle has been observed at interannual, as well as at decadal timescales (Brienen et al., 2012), and the mechanism linking  $\delta^{18}\text{O}_{\text{TR}}$  with Amazon hydrology is increasingly well understood: Rayleigh rainout during moisture transport across the Amazon basin drives an inverse relationship between basin runoff and  $\delta^{18}\text{O}_{\text{TR}}$  (i.e., Baker et al., 2016; Brienen et al., 2012). On the other hand, the means by which sunspots might affect Amazon hydrology are still relatively little studied. It is possible that the effect of sunspots on Amazon hydrology is not stationary, or else that the finding by Antico and Torres (2015) is the coincidental result of comparing two decadal time series. Further work is required to resolve this ambiguity. Finally, it should be acknowledged that the Ecuador  $\delta^{18}\text{O}_{\text{TR}}$  record could itself still be improved, particularly over the 19th century and earlier (see Text S2), and that additional long  $\delta^{18}\text{O}_{\text{TR}}$  records from sites across the basin would further enhance our understanding of historical Amazon hydrology.

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#### 4. Conclusions

The relationship between sunspot number and  $\delta^{18}\text{O}_{\text{TR}}$  (a proxy for Amazon precipitation and runoff) was shown not to be robust over a period exceeding two centuries. This result casts substantial doubt on the role of the sunspot cycle in modulating Amazon River flow at decadal timescales and illustrates the importance of fully exploring the mechanisms behind observed relationships between drivers and climate. Climate and palaeoclimate scientists must adopt a cautious approach when drawing conclusions from relatively limited data sets and remain open to revising their ideas when new data become available.

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