Summary

The authors appreciate the many detailed suggestions. They will be incorporated into the revised manuscript. The revised manuscript will include refined figures, less redundant information, and references to hydrological studies that will highlight the importance of the study to the hydrology and earth system science community. The revised manuscript will also include a URL to the first author's website where the computer software for the adopted methodology can be obtained. More detailed responses to comments are provided below. The reviewer comments are in bold text and our responses to the comments are in plain text.

Reviewer 1

The purpose of this paper is to apply novel methods for bivariate, nonlinear wavelet analysis to understand whether apparent changes in the relationship between indices for ENSO and the Indian Monsoon represent fundamental changes in their relationship. The methods are based on those published in previous peer-reviewed papers by the authors, and so this paper can be viewed as an application of these methods to a relevant and interesting scientific problem. These tools for higher-order wavelet analysis allow the authors to quantify the nonlinearity of ENSO and indices for the Indian monsoon. The authors conclude from this analysis that ENSO nonlinearity is related to ENSO flavors, and that the apparent changes in the relationship between ENSO and Indian rainfall are also related to ENSO flavors. Finally, the authors use these findings to re-interpret findings by Yun and Timmerman (2018) which suggest that the breakdown of the ENSO-India rainfall relationship is related to shifts in the linearity of the ENSO regime. Specifically, the authors argue that the nonlinear relationship identified by their higher-order wavelet model will have non-Gaussian noise components, potentially confounding the alternative analysis. While this paper is unlikely to be the final word on this debate, it is a clear, well-written, and important contribution to the study of the ENSO-Indian rainfall relationship, and to time series analysis more broadly, and should be published pending minor stylistic edits. I also note a lack of a data availability policy [https://www.natural-hazards-and-earthsystem-sciences.net/about/data_policy.html]. Making the code and data used to others would help other researchers apply these methods to other time series.

The revised manuscript will include a URL to the first author's website where the computer software for the adopted methodology can be obtained. A link to the data sets used will also be provided.

L9: It took me a while to understand the similarities and differences between the terms auto-bicoherence, bicoherence, coherence, etc. The auto-bicoherence is defined later, but perhaps a simple table or sentence near the introduction explaining the difference between these different terms would be helpful. (I am flagging this in the abstract but the clarification could happen elsewhere)

To better distinguish coherence traditionally used from the new methods, traditional coherence will be referred to as "linear coherence" in the revised abstract. Furthermore, a sentence mentioning how auto-bicoherence detects quadratic nonlinearities in time series will also be added to the abstract and main text. The type of nonlinearities (e.g. cubic nonlinearities) that cannot be detected by the methods will also be discussed in the methods section. A table will be added to the revised manuscript to clarify the nomenclature used in the paper.

L48: consider rephrasing "investigators"

“investigators” will be changed to “researchers” in the revised manuscript.

L58-59: there are also concerns about data quality – would be worth at least referencing or discussing them https://www.natural-hazards-and-earth-system-sciences.net/about/data_policy.html

A careful literature search did not reveal any studies citing data quality issues regarding the All-India rainfall (AIR) data set. Nevertheless, as a gauge-based product, AIR has both the advantages and disadvantages of any product based on in situ weather stations—that is, the data that go into it are collected in a well-understood way, without use of proxies, but there is the potential for non-representative station distribution or faulty gauges. That said, AIR is widely used product that has been applied successfully to many studies of weather and climate in India.

L95 and beyond: please consider converting from month−1 to year−1

After careful consideration, we decided that we will still use months in the revised manuscript because of months seems to work better with how the wavelet scales and periods are calculated using powers of 2.

L117: are there possible data quality issues with the rainfall data?

To the authors knowledge, there are no serious data quality issues. The All-India rainfall data is frequently used in Indian Monsoon studies. Because of the importance of the Indian monsoon, careful data collection has been conducted since the 1800’s.

L135: the formatting here has changed.

Thank you for identifying the formatting change. It will be corrected in the revised manuscript.

L146: are there cases where very small events (say a single month) emerge? If so how are these handled?

To make the manuscript more concise, the event decomposition approach will be removed from the manuscript. Nevertheless, the single-month events were consider to be short events whose intensities were the values of the data points composing the events.

L156: Consider re-wording to continuous wavelet transform of a time series X = ... as a function of wavelet scale s is given by

The authors appreciate the suggestion for rewording the sentence. The sentence will be reworded in the revised manuscript.

L160: if this transform is commonly used please cite. Are results sensitive to choice of wavelet form or to choice of ω?

The Morlet wavelet is the most commonly used analyzing wavelet in climate and hydrological studies because it balances time and frequency localization. We will add a citation to reflect the common use of the Morlet wavelet. The choice of ω would impact the results given that it alters the time and frequency localization behavior of the Morlet wavelet. However, given that $\omega = 6$ is such a common choice in wavelet applications, the authors feel that it is beyond the scope of the paper to understand its effect on the interpretability of wavelet analysis results.

L188: it would help to be clearer here about what sorts of nonlinearities this analysis can pick up, which sorts of nonlinearities it cannot pick up, and what sorts of nonlinearities have been hypothesized or observed in ENSO time series.

We agree that a clarification is needed. In the revised manuscript, it will be mentioned that the bicoherence method detects quadratic type nonlinearities.

L200: see above comment regarding distinction between coherence, auto-coherence, etc.

A table will be added to the revised manuscript to clarify the nomenclature used in the paper.

L464: if there are spatial shifts happening that are related to ENSO, this could potentially complicate some of this analysis correct?

While we agree that spatial patterns could be shifting, the purpose of the analysis was to quantify the auto-bicoherence of SSTs at various grid points. An additional study would be needed to see if there are spatial shifts in the patterns, which is beyond the scope of the paper.

L545: Consider re-wording "despite how"

"Despite how" will be reworded in the revised manuscript**.**

L595: what is your interpretation of the finding that the modes found are not harmonics of 12 months? Given that the seasonal (12 month) cycle is important here and many of the other modes may be coupled to it, it would be useful to explain to the reader why other modes emerge as important.

Although understanding the specific dynamics underlying the nonlinear modes is beyond the scope of paper, the revised manuscript will include references to studies that focused on understanding nonlinear ENSO dynamics.

L610: this is an important point which the authors should consider emphasizing in the abstract

The authors agree that it is important point. As such, the finding will be discussed in the revised abstract.

Figure 5: consider adding color

We agree that this figure could be clearer. To remedy the drawback, line weights and styles will be changed in the revised manuscript.

Figure 6: consider plotting the global (average) wavelet spectrum adjacent

The authors agree that the global wavelet power spectra would help highlight the dominant peaks in the wavelet power spectra. Therefore, global wavelet power spectra will be placed adjacent to the full wavelet power spectrum in the revised manuscript.

Figure 7: please fix titles

Thank you for referring us to the errors in the titles. The problem will be corrected in the revised manuscript.

Figure 8: the figure has gotten clipped at the left margin.

Thank you for referring us to the clipping problem. The problem will be corrected in the revised manuscript.

Figure 9: this is the wrong place to bring this up but it would be helpful to add some discussion in the methods section, specifically around hypothesis testing, about what the 5% cumulative area-wise significance means and how to interpret it.

The authors agree that some discussion is warranted given the novelty of the statistical tests. A short discussion will be added in the revised manuscript, but the reader will be referred to Schulte (2019) for more details.

Figure 11: please clarify why these pairs were chosen

As stated on Line 481, the pairs were chosen because they are local maxima in auto-bicoherence that are statistically significant. Choosing local maxima allows the spatial patterns shown in Figure 11 to emerge more clearly. A sentence clarifying our choice of pairs will be inserted into the revised manuscript.

References

References Yun, Kyung-Sook and Axel Timmermann (2018). "Decadal Monsoon-ENSO Relationships Reexamined". Geophysical Research Letters 45.4. doi: 10.1002/2017GL076912.