Response to Reviewer 2 Comments

Toyese Tunde Ayorinde et al.

June 12, 2025

Response to Reviewer 2 Comments (RC2)

We thank Reviewer 2 for their comments on our manuscript. We acknowledge the significant concerns raised and have undertaken a comprehensive revision to address these issues. Below, we respond to each of the major comments.

Comment: "The title does not accurately reflect the content of the article."

Response: We have maintained the revised title "Modulation of Tropical Stratospheric Gravity Wave Activity and ITCZ Position by Climate Variability Modes Using Radio Occultation and Reanalysis Data," which accurately reflects the dual focus of our study on both gravity waves and the ITCZ, as well as their relationship with climate variability modes.

Comment: "Abstract, Introduction - Besides being poor quality and badly structured with multiple repetitions, scientific questions or hypotheses are completely missing. In my eyes, this is the most crucial aspect of scientific articles and the fact that it is completely missing here warrants rejection."

Response: We have completely rewritten the abstract and introduction to address these concerns. The revised introduction now clearly articulates the scientific questions that guide our research:

"The objectives of our study are aimed at addressing the following: (1) How do the positions of the ITCZ and stratospheric GW Ep maxima vary seasonally and interannually across different geographical regions? (2) What is the spatial relationship between the ITCZ and stratospheric GW activity in the tropics? (3) How do climate variability modes (MJO, ENSO, and QBO) modulate the ITCZ position and stratospheric GW activity, and (4) Are there regional differences in how these climate modes influence the ITCZ and stratospheric GWs?"

The introduction now provides a clear rationale for the study, reviews relevant literature, and establishes the context for our research questions.

Comment: "Methodology - many unclear aspects throughout the whole approach - Why refractivity is studied in the troposphere and temperature in the stratosphere, when the refractivity can be used also in the stratosphere, or one can use density which is directly related to it? - Insufficient justification of the methodology for GW induced temperature perturbations. It is not clear at all, how the background profile construction method works (the authors only state - mean temperature profile is decomposed using a continuous wavelet transform) and it is not clear whether other processes cannot contribute to the perturbations (other wave modes, overshooting convection..)"

Response: We have substantially revised the methodology section to address these concerns:

1. We have clarified why we use refractivity in the troposphere and temperature in the stratosphere:

"In the lower troposphere (e.g., 850 hPa), the wet term involving e dominates the variability of N, making refractivity a good proxy for moisture content and thus convective activity associated with ITCZ (Basha et al., 2015). In the stratosphere, where water vapor is minimal, temperature perturbations provide a more direct measure of gravity wave activity. This approach leverages the strengths of each parameter in its respective atmospheric region."

2. We have provided a more detailed explanation of the background profile construction method:

"To extract the background temperature ($\overline{T}$), we applied a continuous wavelet transform (CWT) method (Moss et al., 2016; Torrence and Compo, 1998) to the mean temperature profile. This approach effectively separates the background temperature from wave-like perturbations across a range of vertical scales. The CWT decomposes the temperature profile into different scale components, and we reconstruct the background profile by excluding components with vertical scales smaller than 10 km, which are associated with gravity waves."

3. We have addressed the issue of separating gravity waves from other wave types:

"A significant methodological consideration is the potential contamination of GW signals by other wave types, particularly equatorial Kelvin waves, which can have vertical wavelengths that overlap with the GW spectrum (typically 2-10 km for GW versus 5-15 km for Kelvin waves) (Alexander et al., 2010; Wheeler and Kiladis, 1999). To minimize this contamination, we implement an additional filtering step that targets the characteristic properties of Kelvin waves: eastward propagation, zonal wavenumbers 1-3, and periods of 4-23 days (Alexander et al., 2008). This approach helps isolate GW perturbations from other wave types, though some residual contamination near the equator cannot be entirely ruled out with 1D profile analysis alone."

Comment: "Results - the results are an incoherent flow of poorly described figures and overly descriptive text. Clearly, the absence of a scientific question makes it impossible for the authors to make this section more focused."

Response: We have completely restructured the results section to provide a more coherent narrative flow, with clear subsections that address our research questions:

1. Section 3.1: Climatology and Seasonal Variability of ITCZ and GW Ep 2. Section 3.2: Interannual Variability and Longitudinal Structure of Trends 3. Section 3.3: Modulation of ITCZ and GW Ep by Climate Variability Modes

Each subsection now provides a focused analysis that directly addresses one of our research questions, with clear interpretations of the figures and synthesis of the results.

Comment: "After I finished a second reading of the text, I am still scratching my head about the motivation for the study. Namely, what is the added value of diagnosing ITCZ from GPS RO wet profiles over the reanalyses, when the wet profiles are not pure observations but also rely on assimilation of model information? Is the motivation the intention to show that dry GPS RO profile in the stratosphere can be used for ITCZ detection, because the location of maxima of GW activity in the stratosphere is perfectly collocated? But, this can never be possible with reasonable accuracy due to GWs propagating also significantly horizontally!"

Response: We have clarified the motivation for our study in the introduction:

"While numerous studies have examined these climate modes individually, their combined influence on the ITCZ and stratospheric GWs remains insufficiently understood. The use of RO data offers advantages in terms of global coverage and vertical resolution compared to traditional methods based on precipitation or OLR. By analyzing both RO and reanalysis data, we can assess the consistency between different data sources and identify potential biases or limitations in each. Furthermore, understanding the relationship between the ITCZ and stratospheric GW activity can provide insights into the mechanisms of wave generation and propagation in the tropics, which are crucial for improving climate model simulations."

We acknowledge that GWs can propagate horizontally, and we do not claim that stratospheric GW activity can be used as a direct proxy for the ITCZ. Rather, we investigate the spatial and temporal relationships between these phenomena to better understand their interactions and how they are modulated by climate variability modes.

Comment: "Discussion and Conclusions sections do not follow the required structure for ACP papers and are nothing more than a very extensive and chaotic summary of results. No new discovery or finding can be identified. As there is no hypothesis or scientific question, the conclusion cannot return to its validity. Synthesis, context and implications are missing completely as well."

Response: We have completely rewritten the discussion and conclusion sections to follow the required structure for ACP papers. The discussion now includes:

1. Interpretation of our findings in the context of existing literature 2. Discussion of the mechanisms linking the ITCZ, GWs, and climate variability modes 3. Analysis of the implications of our results for understanding tropical atmospheric dynamics 4. Acknowledgment of the limitations of our approach

and suggestions for future research

The conclusion now provides a concise summary of our key findings, their significance, and their implications for the scientific community. We have organized the conclusion to directly address each of our research questions and highlight the novel contributions of our study.

We believe that these comprehensive revisions have transformed our manuscript into a coherent, well-structured, and scientifically rigorous study that makes a valuable contribution to the understanding of tropical atmospheric dynamics.

References

P Alexander, A de la Torre, and P Llamedo. Interpretation of gravity wave signatures in GPS radio occultations. *Journal of Geophysical Research: Atmospheres*, 113:22299–22309, 2008. doi: 10.1029/2007JD009390.

P. Alexander, D. Luna, P. Llamedo, and A. de la Torre. A gravity waves study close to the Andes mountains in Patagonia and Antarctica with GPS radio occultation observations. *Annales Geophysicae*, 28 (2):587–595, feb 2010. doi: 10.5194/angeo-28-587-2010.

Ghouse Basha, Pangaluru Kishore, M Venkat Ratnam, Taha BMJ Ouarda, Isabella Velicogna, and Tyler Sutterley. Vertical and latitudinal variation of the intertropical convergence zone derived using GPS radio occultation measurements. *Remote Sensing of Environment*, 163:262–269, 2015. doi: 10.1016/j.rse.2015.03.024.

Andrew C Moss, Corwin J Wright, and Nicholas J Mitchell. Does the madden-julian oscillation modulate stratospheric gravity waves? *Geophysical Research Letters*, 43(8):3973–3981, 2016. doi: 10.1002/2016GL068498.

Christopher Torrence and Gilbert P Compo. A practical guide to wavelet analysis. *Bulletin of the American Meteorological society*, 79(1):61–78, 1998. doi: 10.1175/1520-0477(1998)079<0061:APGTWA>2.0.CO;2.

Matthew Wheeler and George N Kiladis. Convectively coupled equatorial waves: Analysis of clouds and temperature in the wavenumber–frequency domain. *Journal of the Atmospheric Sciences*, 56(3): 374–399, 1999. doi: 10.1175/1520-0469(1999)056<0374:CCEWAO>2.0.CO;2.