

General comments

Thank you for dedicating your time to thoughtfully addressing my previous suggestions and for incorporating them into the revised manuscript. I recommend that the manuscript be considered publishable after major revisions.

Specific comments

L104-105: 'However, this study does not provide an in-depth view of the QBO association with the GM system from both a phenomenological and mechanical perspective.'

As the authors have noted, a key strength of this study is its ability to provide an in-depth view of the underlying mechanical processes. I encourage the authors to further enhance the manuscript by addressing aspects related to this strength that are currently underexplained.

1 The role of Instability: The authors argue that the key mechanism through which the QBO modulates regional GM circulations lies in UTLS temperature anomalies and the resulting changes in atmospheric instability. They suggest that because these instability changes vary regionally, the associated convection and large-scale circulation responses also differ across specific latitude–longitude sectors, with particularly pronounced signals over the Northwest Pacific, Northeast Pacific, and North Atlantic.

However, instability changes alone do not appear sufficient to explain the modulation of GM circulations. For instance, instability (N''^2) does not show a one-to-one correspondence with upward motion (W''), as illustrated in the right panels of Fig. 10. More specifically, while the instability anomaly over the Northwest Pacific seems consistent with the sign of the upward motion (Fig. 10d), this relationship is not evident over the Northeast Pacific and North Atlantic. In some longitudes, significant instability anomalies do not coincide with any meaningful upward or downward motion, whereas substantial motion anomalies appear in regions where instability itself is not statistically significant (cf. arrows and shadings in the 4th column of Fig. 10).

Furthermore, the same UTLS cold anomaly induces a surface cyclonic circulation anomaly over the Northwest Pacific but an anticyclonic circulation anomaly over the other two regions. This raises the question of whether UTLS temperature and instability anomalies genuinely lead the modulation of GM circulations, as claimed, or whether the documented relationships may instead reflect concurrent, but not necessarily causal, features of the system.

Given these issues, additional clarification is needed regarding the physical role of instability in the

proposed mechanism and how it can adequately explain the contrasting circulation responses among the three regions.

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2 Subtropical route in Northwest Pacific in JJA: As described in the Introduction, the subtropical route is fundamentally governed by the interaction between the subtropical jets (STJs) and synoptic- and planetary-scale waves. However, this pathway becomes notably weaker during boreal summer. The STJs shift poleward (Contours in Figs. 3 &4), making it difficult for UTLS temperature and zonal wind anomalies to influence the jet, and both synoptic and planetary waves are relatively weak during this season.

Given these seasonal characteristics, it is unclear whether the GM circulation changes over the Northwest Pacific in summer can be legitimately interpreted as a manifestation of the subtropical route. Additional justification is needed to clarify whether the mechanism proposed by the authors indeed corresponds to the subtropical route in summer, or whether a different physical pathway is at play in this season.

'In the subtropical route, when a QBO MMC pattern arrives at the tropopause, it alters the meridional temperature gradient, and consequently the distribution of zonal wind by the thermal wind law. The resulting changes in static stability and wind shear in the UTLS can affect deep convection (Giorgetta et al. 1999a, Collimore et al. 2003, Nie and Sobel, 2015). The resulting QBO zonal wind anomalies can influence the STJs, which can, in turn, interact with synoptic and planetary-scale waves which originate in the extratropics and dissipate in the subtropics (Garfinkel and Hartmann, 2011; Inoue and Takahashi, 2013; Haynes et al., 2021).'

3 PNA: The authors claim that the QBO excites a PNA pattern. While the spatial pattern in SLP indeed resembles the canonical PNA structure, it is important to recognize that the classical PNA pattern is typically generated through a sequence of processes whereby deep convection-induced diabatic heating in the mid-upper troposphere (500–200 hPa) initiates Rossby wave trains that propagate into the midlatitudes. It remains unclear whether the QBO triggers the Northeast Pacific SLP anomalies through this same physical pathway.

To justify the use of the term “PNA pattern,” I recommend that the authors examine whether there is corresponding wave propagation in the 500-hPa geopotential height field, or alternatively, assess whether the anomalous pattern exhibits strong correlations with a conventional PNA index.

If the anomalies are confined primarily to SLP without clear evidence of the characteristic mid–upper tropospheric wave train, it would be more appropriate to refer to the feature as a “PNA-like pattern” rather than a true PNA pattern.

4 Completeness of the manuscript

4-1) References

L49-50: ‘ENSO is a major driver of global teleconnections (Mooley and Parthasarathy, 1984; Shen and Lau, 1995; Krishnamurthy and Goswamy, 2000; Yu et al., 2021).’

Mooley and Parthasarathy (1984) do not discuss ENSO, and the references cited in this section focus exclusively on the Indian monsoon. To support the use of the term “global teleconnections,” additional references that address broader large-scale or interbasin teleconnection pathways are needed.

Refs:

L50-51: ‘Over the Northwest Pacific, ENSO significantly modulates regional atmospheric circulation and associated precipitation patterns (Wang et al., 2024).’

The study in question does not examine atmospheric circulation, rather, it focuses on “oceanic circulation”. I recommend that the authors replace or supplement the current citation with the following three references, which are more appropriate for the context.

Refs:

1. Wang, B., Wu, R., & Fu, X. (2000). Pacific-East Asia teleconnection: How does ENSO affect East Asian climate? *Journal of Climate*, 13(9), 1517–1536. [https://doi.org/10.1175/1520-0442\(2000\)0132.0.CO;2](https://doi.org/10.1175/1520-0442(2000)0132.0.CO;2)
2. Wu, R., Hu, Z. Z., & Kirtman, B. P. (2003). Evolution of ENSO-related rainfall anomalies in East Asia. *Journal of Climate*, 16(22), 3742–3758. [https://doi.org/10.1175/1520-0442\(2003\)016<3742:EOERAI>2.0.CO;2](https://doi.org/10.1175/1520-0442(2003)016<3742:EOERAI>2.0.CO;2)
3. Park, C. H., & Son, S. W. (2024). Subseasonal variability of ENSO–East Asia teleconnections driven by tropical convection over the Indian ocean and Maritime Continent. *Geophysical Research Letters*, 51(13), e2023GL108062. <https://doi.org/10.1029/2023GL108062>

L94-95: 'The effects of the QBO on rainfall in different parts of the globe, particularly within the tropical and subtropical regions, have been examined in some previous observational studies (Seo et al., 2013; Gray et al., 2018; Ma et al., 2021).'

While the other two studies are appropriate, Ma et al. (2021) does not examine the effects of the QBO on "rainfall". Instead, it focuses on "surface air temperature". The authors may wish to reconsider the relevance of this reference in the current context.

L91-93: 'For example, when QBO E occurs at 70 hPa, the East Asian STJs weakens and shifts poleward, weakening the East Asian winter monsoon (Ma et al., 2021).'

I recommend adding an appropriate reference to support this statement. "For example, when the QBO easterly phase occurs at 70 hPa, the East Asian subtropical jet weakens and shifts poleward (Park et al., 2022),"

Refs:

1. Park, C. H., Son, S. W., Lim, Y., & Choi, J. (2022). Quasi-biennial oscillation-related surface air temperature change over the western North Pacific in late winter. *International Journal of Climatology*, 42(8), 4351-4359. <https://doi.org/10.1002/joc.7470>

L47-48: 'both the QBO and ENSO can modulate the Rossby source term (Chapter 8, James 1994), and therefore modify climatological structures associated with stationary Rossby wave trains, including the Pacific-North America pattern (PNA) and North Atlantic Oscillation (NAO).'

L83-86: 'QBO modulation of deep convective centers can modulate the planetary wave trains which emanate from them, with poleward energy dispersion along the UTLs. This can, in turn, modulate regional circulation features in the extratropics, including the NAO and PNA patterns.'

Additional relevant references are also needed here to adequately support the authors' statement.

The authors are requested to conduct a careful and comprehensive proofreading to address these remaining issues, and improving the readability of the manuscript.