Response to Referee #2 (Joowan Kim)

We thank Referee #2 (Joowan Kim) for the helpful comments which helped to improve the manuscript significantly. We are particularly grateful for the suggestion about the hydrostatic adjustment mechanism, which clarifies our results in section 3.2. Also, we included a new section 4.3 to discuss how much of the TIL is left without the equatorial wave signal, other mechanisms that could enhance the remaining TIL, and the forcing of the secondary N^2 maximum (as requested in the specific comments). We find that this new subsection puts our results in a better context and makes the paper rounder as a whole.

In the following, we first explain general changes made in the manuscript, and continue with the point-by-point responses to the reviewer's comments. The referee's comments are in blue font, and our replies are in normal font. Every change made in the revised manuscript is highlighted (please find the highlighted version in the Author Response).

General comments:

New subsection 4.3 and Figure 7

Motivated by the specific comments 2 and 3 by Joowan Kim in his review, we added subsection 4.3 to the manuscript in order to discuss how much of the TIL is left without the equatorial wave signal, other mechanisms that could enhance the remaining TIL, and the forcing of the secondary N^2 maximum. Figure 7 compares the time evolution of the equatorial N^2 structure with and without the equatorial wave signal (Thomas Birner asked about this during the SHARP2016 workshop, and we found that making this kind of plot would be the best fit for the purposes of section 4.3).

In Fig. 7 the difference in the TIL region when the equatorial wave signal is subtracted is clear, but the secondary N^2 maximum below the descending westerly QBO phase remains the same, and therefore is not directly modulated by Kelvin waves, as we were suggesting in the discussion manuscript version. Since proven untrue, the paragraphs that discussed the forcing of the secondary N^2 maximum by the filtered Kelvin waves have been erased (now missing from lines 368, 403, 479 and 563), and now we discuss possible forcings in lines 518-527. We still suggest an indirect effect of Kelvin waves (T signal from wave dissipation), but this cannot be captured by our wavenumber-frequency domain filters once the wave dissipates.

New Appendix C

We added a caveat about the filtering of waves with periods of less than 2 days from our daily dataset. Spectral ringing can be an issue with these settings, and could leave a spurious signal in our results (Figure 6), but we checked that the contribution of these periods to the calculated equatorial wave signature of inertia-gravity waves is zero, and therefore doesn't affect our results at all.

Point-by-point responses to Ref#2 (Joowan Kim) comments

Specific comments (minor)

1. The title is too broad for the contents of the manuscript. Authors are mainly focusing on dynamical mechanisms that could enhance TIL in the tropics. Although they demonstrate the mechanisms clearly, the contents in the manuscript are still too limited to cover the whole spectrum of the tropical TIL (e.g., annual cycle, influence of deep convection and radiation, role of shallow Brewer-Dobson circulation). It is strongly recommend for authors to further specify the title of this manuscript.

We changed the title to "The Tropical Tropopause Inversion Layer: Variability and Modulation by Equatorial Waves", so it's specific to the main results of sections 3 (3D structure and variability) and 4 (effect of equatorial waves).

2. Authors suggest that Kelvin waves cause the enhancement of N2 just below the westerly shear (or zero-wind line) of the QBO. This may be one possible cause, however, the zonal mean temperature anomaly associated with vertical wind shear of the QBO (cf. Fig. 4 in Baldwin et al. 2001) has a strong impact on N2. Several Kelvin of temperature changes in 10 km depth, and this could significantly modulate N2 in the lower stratosphere. In fact, this may have a bigger impact on N2 than Kelvin waves, particularly in zonal mean field. Some analysis and discussion on this effect will be helpful (a simple comparison of tropical mean temperature profiles in westerly and easterly QBO will be good enough).

We prepared a new Figure 7 comparing the N^2 structure with and without the equatorial wave signal, in order to see how much of the TIL and the secondary N^2 maximum are left without it. We found that the secondary N^2 maximum was not affected by the subtraction of equatorial wave anomalies. Therefore, our earlier suggestion that the filtered wave anomalies also contributed to the secondary N^2 maximum was found to be wrong, and any reference to this throughout the paper has been erased (now missing from lines 368, 403, 479 and 563).

We still suggest an indirect effect of Kelvin waves (T signal from wave dissipation), but this cannot be captured by our wavenumber-frequency domain filters once the wave dissipates. This and other possible mechanisms forcing the secondary N^2 maximum are discussed in lines 518-527. We are thankful for the suggestion about the T anomaly associated to wind shear and the reference regarding this, it was added as well into the discussion.

We hope that the new section 4.3 and Figure 7 fulfill the referee's request in this comment, while compensating the erased discussions about the forcing of the secondary N^2 maximum by the filtered equatorial waves.

3. Although influence of deep convection on TIL is beyond the scope of this study, some discussions on tropical convection will still be helpful. For example, the zonal structures in N2 (shown in Fig. 2) are largely related to deep convection in DJF and JJA. In fact, climatology of N2 shows similar structures as in Fig. 2, and this is largely due to tropopause cooling cause by deep convection (deep convection make tropopause colder; e.g., Johnson and Kriete 1982; Gettelman et al. 2002; Paulik and Birner 2012). Only a part of the N2 structure is explained by tropical waves.

In addition, the coherence between N2 and near-tropopause divergence (which is a noble contribution of this paper) is consistent with the hydrostatic adjustment mechanism, which is proposed by Holloway and Neelin (2007) to explain cold-top (tropopause) over deep convection. Those discussion could be helpful for readers.

We added a discussion about other TIL forcing mechanisms in the new section 4.3. Figure 7b shows the remaining, much weaker TIL without the equatorial wave signal. We also include the hydrostatic adjustment mechanism when convection is not wave-coupled and radiative forcing as possible TIL enhancers in this discussion (lines 496-502).

Also, we are very grateful for the suggestion about the hydrostatic adjustment mechanism, regarding the relation between stronger TIL and near-tropopause divergent flow. We added a paragraph in section 3.2 (lines 300-307) discussing this, which improves the explanation about the sTIL relationship with divergence and makes it clearer.

Technical suggestions

Line 35: Satellite GPS => Global Positioning System (GPS) (In many place, satellite GPS => GPS)

We only keep the word 'satellite' the first time we refer to GPS-RO in case any reader is not familiar with this dataset, and we follow the suggestion the rest of the times GPS is referred to.

Line 105: tropopause height (TPz) using the WMO lapse-rate tropopause criterion...

Corrected.

Line 169: latitude (y) and time (t). The maximum distance allowed from the grid point in each dimension is 5°longitude, 10°longitude, and 12 hours, respectively.

Corrected.

Line 214: 3.1 ?

True, there was a title missing! We titled section 3 “Structure and Variability of the Tropical TIL”, and subsection 3.1 “Vertical and Horizontal Structures”.

Line 234: 2011=>2010?

Thank you for finding this mistake, it was corrected (now in lines 235 and 241).

Line 375: highest amplitude => maximum amplitude

Corrected.

Line 379: very high => very large

Corrected.

Line 393: high amplitude => large amplitude

Corrected.

Line 476: higher that within => larger than that in

Corrected.

Fig 5: why do you show N2 tendency (dN2/dt) instead of N2?
(also in Fig 6: dT/dt instead of T)?

We now show these parameters as anomalies (or averaged anomalies) in both figures 5 and 6. The way we interpreted these quantities was confusing in the earlier manuscript, we hope it is more straightforward now.