Response to Short Comments of C. Garfinkel

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Title: Signals of El Niño Modoki in the Tropical Tropopause Layer and Stratosphere

We thank the reviewer for the helpful comments which help us greatly improve our paper. We have modified our paper according to the comments. Our replies are summarized as below:

General Comments:

This paper seeks to explore the effects of El Niño Modoki events on the tropical tropopause layer (TTL) and on the stratosphere. Consistent with previous studies, El Niño Modoki events tend to depress convective activities in the western and eastern Pacific but enhance convective activities in the central Pacific. El Niño Modoki activities tend to moisten the lower and middle stratosphere, but dry the upper stratosphere. El Niño Modoki events have a reverse effect on high latitudes stratosphere, as compared with the effects of typical El nino events. However, nonlinear interaction was found between the El Niño Modoki and QBO signals. This is an interesting subject and the study presents novel conclusions.

Specific comments:

1. *My review will focus on one specific aspect of their work: the QBO leads to a reversal of the effect of El Nino Modoki in the NH in WACCM and that El Nino and the QBO interact nonlinearly. First, it is not clear to me that 15 year simulations are long enough to confidently claim such a result. Either a significance test should be included, or the simulations should be extended for longer (or both). In my experience, at least 25 or 30 years of integration length are necessary before a 1K signal at the* *polar vortex (which is the magnitude of the effect the authors discuss) becomes robust.*

Response to Specific comment 1:

Thanks for the helpful comment. Indeed, 15-year simulations are not long enough to confidently claim a result. Actually, this problem also was pointed out by one of other referees. So, in order to confirm our results are robust, we done both the significance test and extended our simulations' for longer time in our revised paper according the comment.

The composite anomalies based to ERA-interim data and the simulation's results are tested by a Student's-t tested. On the other hand, we used the latest version of WACCM model (WACCM4) rerun the six experiments. Now, all the experiments were ran for 33 years with the first 3 years excluded for the model spin-up and the remaining 30 years are used for the analysis. The model climatologies are based on the last 30 years of the model output except when otherwise stated.

The results from composite anomalies based on ERA-interim data and those longer simulations both show a statistically significant reversal of the effect of El Niño Modoki in the NH (See Figure 1 and Figure 2 below, they are Figure 8 and Figure 10 in the revised paper, respectively). We further found the nonlinear interaction between QBO and El Niño Modoki only occur when QBO is in its east phase. During QBO west phase, the El Niño Modoki has same effect on the NH as compared with typical El Niño (See Figure 2 below, it is Figure 10 in the revised paper).

2. *Second, it is possible that the nonlinearity is not necessarily occurring in the stratosphere (e.g. line 20 of page 3635): Garfinkel and Hartmann 2008, 2010 find that the QBO can alter the strength of El Nino teleconnections in the troposphere. In particular they show that El Nino teleconnections are weaker during EQBO than during WQBO (though this is slightly different from the nonlinearity the authors discuss). This effect is present in WACCM, though it is weaker than the comparable effect in reanalysis data (Garfinkel and Hartmann 2010). Since the presumed mechanism whereby El Nino influences the polar vortex is via its North Pacific* *teleconnection, it is possible that EN Modoki teleconnections are being modified in the presence of a QBO in their WACCM integrations and that this leads to a different stratospheric response. GH10's specific mechanism for nonlinear interaction in the troposphere is that WQBO leads to a stronger subtropical jet and a stronger subtropical jet leads to a stronger North Pacific teleconnection to an identical tropical vorticity source. The authors should examine(1) whether El Nino Modoki teleconnections in the North Pacific troposphere are qualitatively different, or are weaker, in the presence of a QBO, and (2) whether introducing a QBO impacts the strength of the subtropical jet.*

Response to Specific comment 2:

Thanks very much for the helpful comment. In the revised paper, we investigated and compared the tropospheric zonal wind and PNA anomalies during two kinds of El Niño events (See the Figure 3 below, it is Figure 9 in the revised paper).

Figure 3 shows the composite anomalies of the tropospheric zonal wind and 300 hPa geopotential anomalies based on ERA-interim data for canonical El Niño events and El Niño Modoki events. It is apparent from Figs. 3a and 3b that typical El Niño give rise to a stronger subtropical jet which results in a stronger PNA. Thus, more planetary waves are transported into the Northern Hemisphere high-latitude stratosphere and result in a weaker polar vortex (Figs. 1a and b). The results here are in accordance with the results in Garfinkel and Hartmann 2008 and 2010 (The two papers have been cited in our revised paper).

On contrast, the subtropical jet anomalies in El Niño Modoki events are much smaller than those in canonical El Niño events in the both hemisphere and the PNA anomalies are not significant during El Niño Modoki events. The zonal wind anomalies in the middle-high latitudes in El Niño Modoki events are also very much different from those in typical El Niño (Fig. 3). Given the above differences in subtropical jet, PNA and zonal wind, the wave propagation from troposphere to the stratosphere during El Niño Modoki events should be different from that during canonical El Niño events. This is the main reason that the circulation anomalies during El Niño Modoki events are much different from those in canonical El Niño events in the high-latitude stratosphere (Fig. 1).

References:

Garfinkel, C.I., and D.L. Hartmann (2008), Different ENSO Teleconnections and TheirEffects on the Stratospheric Polar Vortex, J. Geophys. Res. Atmos, 113, D18114,doi:10.1029/2008JD009920.

Garfinkel, C.I. and D.L. Hartmann (2010), The Influence of the Quasi-Biennial Oscillationon the North Pacific and El-Nino teleconnections, J. Geophys. Res. Atmos , 115, D20116,doi:10.1029/2010JD014181

Technical issues:

1. *Line 20: should "typical Modoki events" be "typical El Nino events"?*

Thanks. We have modified this.

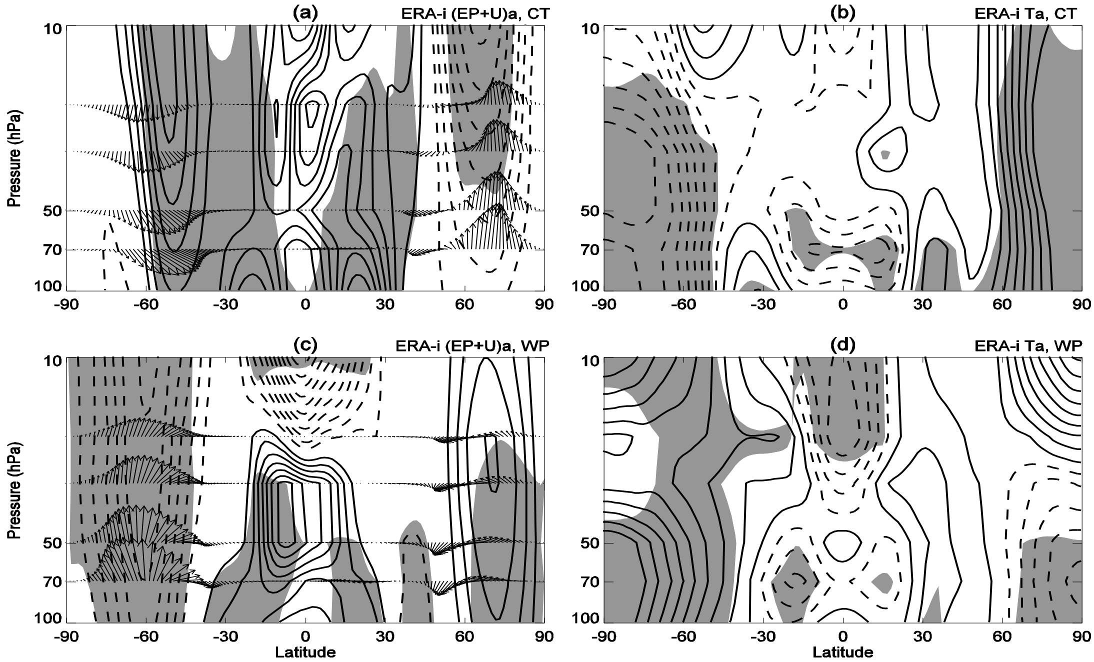

Figure 1. Composite anomalies of the E–P flux and zonal wind for (a) canonical El Niño events and (c) El Niño Modoki events, based on ERA-Interim data for 1979–2010. The unit horizontal vector is 10^7 kg s^{-1} and the unit vertical vector is 10^5 kg s^{-1}. The contour interval for zonal wind anomalies is ±0.25 m s^{-1}. Composite anomalies of temperature for (b) canonical El Niño events and (d) El Niño Modoki events, based on ERA-Interim data for 1979–2010. Contour interval for temperature anomalies, ±0.15 K. Anomalies that are significant at the 90% confidence level according to Student's t-test are shaded. Solid and dashed lines represent positive and negative anomalies, respectively.

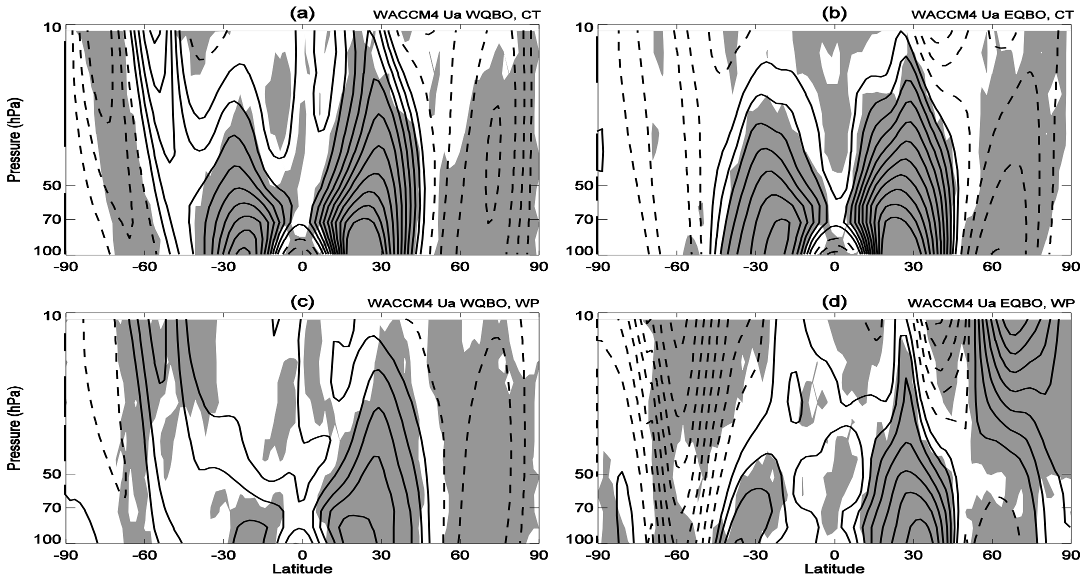

Figure 2. Differences of the zonal wind for R2 - R1 when QBO in (a) west phase and (b) east phase. The contour interval for zonal wind anomalies is ±0.25 m s^{-1}. Solid and dashed lines represent positive and negative anomalies, respectively. Anomalies that are significant at the 90% confidence level according to Student's t-test are shaded. (c) and (d) are same as (a) and (b), but for R3 – R1.

P.S.: R1 is the control experiment. The SST is observed monthly mean climatology for the time period from 1979 to 2010. In experiment R2, SST is as in R1, except that the tropical Pacific SST represents composite of observed SST associated with canonical El Niño conditions, for the period 1979–2010. In experiment R3, the SST is as in R1, but the tropical Pacific SST represents composite of observed SST associated with El Niño Modoki conditions. QBO phase signals for 28 months fixed circle are included in three experiments as an external forcing for zonal wind. Detailed descriptions of experiments please see Section 2 in the revised paper.

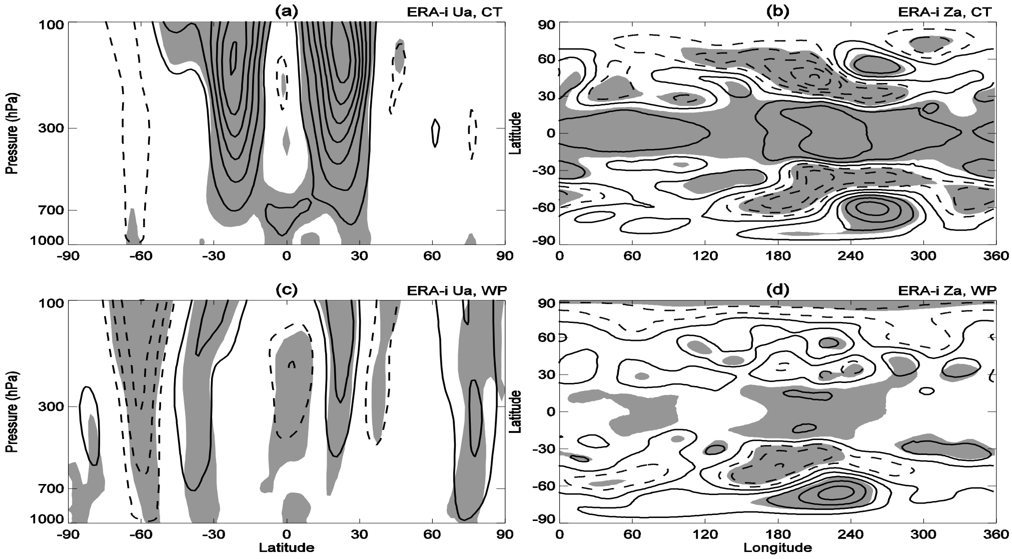

Figure 3. Composite anomalies of the zonal wind for (a) canonical El Niño events and (c) El Niño Modoki events, based on ERA-Interim data for 1979–2010. The contour interval for zonal wind anomalies is ±0.4 m s^{-1}. Composite anomalies of the Geopotential at 300 hPa for (b) canonical El Niño events and (d) El Niño Modoki events, based on ERA-Interim data for 1979–2010. The contour interval for Geopotential anomalies is ±100 m^2/s^2. Anomalies that are significant at the 90% confidence level according to Student's t-test are shaded. Solid and dashed lines represent positive and negative anomalies, respectively.