Reply to Anonymous Referee #1

We would like to thank anonymous referee #1 for his constructive comments and suggestions helping to improve the quality of the manuscript. The answer to these comments is given below with indications of how the manuscript is revised in bold.

Major comments

Referee's comment

My major concern is on the methodology:

At page 9158 (bottom) it is written that a multi-parameter fit is performed to extract, among other signals, also the 30 hPa and the 10 hPa QBO signals in the three constituents. But it is not clear if thereafter the results from this signal extraction are actually used to calculate the correlation shown in Figures 3 and 5 as well as the time series in Figure 2 and 4. Why are the results shown in terms of either values normalized by their seasonal mean evolution or deviation from their mean seasonal cycle, instead than in term of the extracted signals from the multi-parameter fit? What is the role of the multi-parameter fit?

Answer

We apologize for a bad formulation in the manuscript of the methodology applied to the data. We tested a multi-parameter fit to the data but finally we decided not use it in the manuscript because it does not change significantly the results concerning the O_3 and NO_2 response to QBO due to the small amplitude of annual and semi-annual variations of these constituents in the equatorial region. The results presented are simply the deviations from the mean for the whole period without applying any correction, showing more clearly the dominant contribution of QBO in the variability of O3 and NO2 in the 25-40 km altitude range.

The section concerning the multi-parameter fit is removed in the revised version.

Referee's comment

Therefore my concern is that, by showing deviations from the mean seasonal cycle in the tropics, the QBO signal is not singled out, because of the influence of other interannual variability, most notably ENSO. This is especially true in the tropical lower stratosphere (unknown in the upper stratosphere and lower mesosphere). Hence, although the reported correlations are of interest, their interpretation is not warranted, given the results show.

Answer

We agree with the reviewer that they may be some influence of other interannual variability, in particular ENSO but also solar variability and increase of greenhouse gases. However we consider that it goes behind the goal of this paper to study these other terms due to the limited length of the data series (6 years and 4 months). **We add in the text a sentence concerning the possible influence of other variability and the caution to take in the interpretation of the response to QBO signal.**

Referee's comment

In addition to the above, I am wandering what is the meaning of interpreting the correlations above 30 km (pressures below 10 hPa) with the status of the QBO at 10 and 30 hPa. Here, the structure of the QBO induced residual circulation should be better discussed. This is implicitly mentioned at page 9163, but no evidence is given that at 45-50 km there should be ascending motion associated with the QBO, by the way which QBO phase and where?

Answer

The status of the QBO is only known from radiosondes from 100 to 10 hPa. There is no direct wind measurement above 10 hPa where the wind can only be derived indirectly from the assimilation of satellite radiances in numerical weather forecast models. Therefore we prefer to not use ECMWF wind data at higher levels and to use only QBO wind data at 10 hPa, the

higher level available from radiosondes, and at 30 hPa that is almost orthogonal to 10 hPa (correlation coefficient 0.10). If there is a QBO signal in the evolution of one constituent it will appear in the correlation with the wind either at 10 hPa or at 30 hPa. Due to adiabatic effects, the temperature is a good indicator of vertical motions. A cooling indicates an upward motion and a warming a downward motion. We are aware that the relation between the QBO signal and observed variations in constituents at 45-50 km is not very clear. However we consider interesting to look at the sign of the correlation with temperature, good indicator of vertical motions, even if the causes of these temperature changes are not fully understood.
The structure of the QBO is better presented in the revised version. The relation between temperature, wind and wind gradient is explained. The significance of the variations observed at 45-50 km in relation with QBO is discussed.

Referee's comment
I also have problems with using the QBO winds to compute the correlations. Given that the QBO induced residual circulation (and consequently the QBO signal in temperature and tracers) is in phase with the QBO wind shear and not the QBO wind itself, I am wandering if more revealing results can be obtained by examining correlations with the QBO-wind shear.

Answer
We agree with the referee that the wind shear is more directly related to the vertical motion that the wind itself. However, as wind data are not available in the full altitude range of GOMOS data (see answer to the previous comment), it is not possible to compare the wind shear at the same altitude than GOMOS data. We choose to use QBO wind to show the existence of a QBO signal and to use the correlation with temperature to show the sign of the effect in the mixing ratio of constituents. As said in the answer to previous comment**, the relation between temperature, wind and wind gradient is explained in the revised version.**

Specific comments
Referee's comment
There is no information on which equatorial wind data are used.

Answer
Wind data are Singapore (1°N) zonal wind radiosonde data compiled by the Berlin Free University updated from Naujokat (1986). Data are downloaded from Web site: http://www.geo.fu-berlin.de/en/met/ag/strat/produkte/qbo/
This will be indicated in the revised version.
New Reference: Naujokat, B.: An update of the observed quasi-biennial oscillation of the stratospheric winds over the tropics., J. Atmos. Sci., 43, 1873-1877, 1086.

Referee's comment
I find Figure 2 not very revealing, because from U at 10 hPa it is not straitforward to visualize the O3-QBO wind relationship. Because, as mentioned above, the QBO induced residual circulation (and consequently the QBO signal in temperature and tracers) is in phase with the QBO wind shear and not the QBO wind itself. Basically, the reader has to visualize in his/her head the QBO in the region of interest, from the QBO at 10 hPa (not straitforward, to know what is going on at 45 km from the QBO at 10 hPa).

Answer
We added a time-height section of the evolution of the Equatorial wind between 100 to 10 hPa and the plot of the wind evolution at 10 and 30 hPa (Additional material Figures 1 and 2). We added also the plot of the evolution of O_3, NO_2, NO_3 and temperature at 25 km, 32 km and 40 km to better visualize the correlation with QBO signal (Additional material Figures 3 to 5) and the correlation coefficient between the temperature between

20 and 55 km and the equatorial zonal wind at 10 hPa and 30 hPa (Additional material Figure 6).

Referee's comment
A suggestion for improving Figures 2 and 4, and possibly make them much more revealing, is to show the pressure-altitude evolution of the zero wind contour of the equatorial winds for all the vertical domain shown. The zero wind line is of interest because an indication of where the wind shear is located. If then in another panel the winds themselves would be shown, it would be ideal. Indeed, given that the QBO is the central topic, I think that to show its evolution in zonal wind for the time of interest is mandatory.

Answer
See answer to the previous comment for a better visualisation of the QBO wind.

Referee's comment
Figure 5: I do not understand why below 30 km, O_3 is positively correlated with both U at 10 hPa and at 30 hPa. If the time series of U at these elevation are almost orthogonal (stated at page 9158), should not the ozone be correlated with U at 30 hPa and anti-correlated with U at 10 hPa?

Answer
As said previously, U at 10 hPa and 30 hPa are almost orthogonal. This means that if the variation of U at these two levels were sinusoidal a maximum of correlation at one level would correspond to a zero correlation (not an anti-correlation) with the other level. However the evolution of the zonal wind at each level is not sinusoidal and there are some periods with the same sign in zonal wind at 10 and 30 hPa (see additional material Figure 2).

Referee's comment
I would suggest to revise the manuscript proceeding in the following steps:
1. Show the QBO in Equatorial winds for the period in question. Take care of explaining how the QBO signal is extracted, and show results that are consistent with the described methodology.
2. Establish the temperature - zonal wind (vertical shear) relationship for the QBO signal: Are these as expected from what we know from the QBO theory? Is there anything new illustrated here, especially in the region above 30 km?
3. Once the status of the QBO for the time period and atmospheric region of interest is presented, focus on the correlation between temperature and the three constituents, given that among these quantities we can expect either in phase or out of phase relationships (depending on transport, chemistry and background distributions)
4. Revise interpretation.

Answer
We thank the reviewer for suggestions for a clearer organisation of the manuscript. **We follow largely these suggestions in the revised version.** Concerning point 2, our goal is not to present something new concerning the QBO dynamical theory where we don't bring new results. It is rather to better describe the relations between the QBO signal and ozone and minor constituents variations in the equatorial stratosphere, where we think that GOMOS data can bring new information compared to previous space instruments, and to try to confirm or identify transport and chemical mechanisms leading to these relations.