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Anomalous tropical planetary wave activity during 2015/2016 quasi biennial oscillation disruption

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A B S T R A C T

In the present communication, a record breaking duration (23 months) of the eastward phase of the QBO at 20 hPa is reported and details of the tropical wave activity during the recent anomalous QBO event are discussed. Two-dimensional Fourier analysis revealed the presence of 30–40 and 10–15 day westward propagating wave number 1 structures at 40 hPa pressure level over the equator. A combination of the mid-latitude Rossby waves and the 30–40 day oscillations seems to be the most probable mechanism for the observed disruption of the QBO.

1. Introduction

The interannual variability of the equatorial stratosphere is dominated by the presence of the Quasi Biennial Oscillation (QBO). The QBO is a spectacular long-period oscillation with alternating eastward and westward winds in the 20–40 km height domain. The period of the QBO varies between 22 and 36 months with an average period of ~28 months. Since its discovery in the year 1960, there has been a plethora of studies to unravel its structure, dynamics and generation mechanism [Lindzen and Holton, 1968; Holton and Lindzen, 1972; Hamilton, 1984; Baldwin et al., 2001; Coy et al., 2016]. Lindzen and Holton (1968) were the first to suggest wave mean-flow interaction as the process responsible for generation of the QBO. Further studies on the QBO dynamics confirmed this assertion and also identified that Kelvin, Rossby-gravity and gravity waves are major contributors in driving the QBO[Holton and Lindzen, 1972; Plumb, 1977; Saravanan, 1990; Dunkerton, 1997; Kawatani et al., 2010]. Later studies suggested that midlatitude Rossby waves can also contribute to the momentum required for driving the westward phase of the QBO [Ortland, 1997; O'Sullivan, 1997]. Holton and Tan (1980) suggested that the QBO, which is an equatorial phenomenon, can affect the midlatitude weather through teleconnections. Thus it is right to say that the QBO has its presence felt in the global atmosphere. Recently, Kawatani and Hamilton (2013) reported a weakening of the QBO amplitude in the lower stratosphere and attributed it to the increased tropical upwelling, which not only increases the period of the QBO but also affects its amplitude. A comprehensive review on the QBO and its role in equatorial as well as extra-tropical dynamics can be found in Baldwin et al. (2001).

Being an atmospheric phenomenon with high degree of predictability, the QBO has been simulated by numerous climate models [Takahashi, 1999; Scaife et al., 2000; Giorgetta et al., 2006; Rind et al., 2014] and was thought to be well understood. However the recent disruption of the eastward phase of the QBO in the month of February 2016 in the lower stratosphere questions the ability of climate models to predict such disruptions [Newman et al., 2016; Osprey et al., 2016]. In February 2016, the eastward phase of the QBO at 40 hPa was disrupted by an abrupt westward jet in the lower stratosphere and subsequently the downward propagating westward phase at the 10 hPa was stalled. This rare event has revitalized the interest in the QBO studies [Dunkerton, 2016], especially on the predictability of the QBO. Osprey et al. (2016) reported that the primary cause for the observed QBO disruption was the intrusion of Rossby waves from the extra-tropics into the equatorial stratosphere and the subsequent deposition of their westward momentum in the eastward phase of the QBO. These authors emphatically showed the rarity of this event using 724 monthly profiles of equatorial zonal winds during 1956–2016. Newman et al. (2016) also pointed out that the observed QBO disruption during February, 2016 is the only such disruption in the entire record of the QBO available to date. These authors reported that the disruption event started in December, 2015 and ended in April, 2016; and that the intrusion of the planetary scale Rossby waves from the winter hemisphere into the equatorial region is the possible reason for the observed QBO anomaly. Dunkerton, [2016] discussed the probable reasons for the observed anomalous QBO, which also included the unusual warm ENSO event observed during the year 2015–2016. Further, Coy et al. (2017) diagnosed the anomalous QBO event using MERRA-2 reanalysis data and provided a detailed analysis of

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momentum budget of the tropical wave activity. These authors reported that a record maximum in momentum flux at 40 hPa during the month of February 2016 led to the QBO disruption. Overall, these studies have reported the shortest durations of the westward phase at 10 hPa and the eastward phase at 40 hPa ever recorded in the history of the QBO. Thus the recent disruption of the QBO cycle rekindled the interest in the QBO studies. The present communication focuses on a few new aspects associated with the recent QBO disruption, which were not given attention in the previous studies. Section 2 provides the details on the data, section 3 discusses the results and section 4 provides the summary.

2. Data and methodology

The Modern-Era Retrospective analysis for Research and Applications-Version 2 (MERRA-2) reanalysis dataset has been used for the present study, along with the radiosonde observations over Singapore (1.35° N, 103.81° E). The monthly mean time series of zonal winds at 10, 15, 20, 30, 40, 50 and 70 hPa are used. Historically, the Singapore radiosonde observations have been used to study the QBO features as the time series of zonal winds in the lower stratosphere has been made available since 1956. In the present study, the radiosonde data is used to compare and evaluate the MERRA-2 reanalysis dataset in reproducing the observed anomalous QBO structure. To investigate the latitudinal structure of the observed QBO disruption, the monthly mean MERRA-2 reanalysis dataset is used and the daily mean zonal winds are used for characterizing the tropical planetary wave activity. The details of MERRA-2 reanalysis dataset can be found in Bosilovich et al. (2015). To delineate the planetary wave features, we employed two-dimensional Fourier analysis for estimating the zonal wavenumber-frequency spectra of zonal winds and the wavelet analysis for studying the time evolution of the planetary wave activity.

3. Results and discussion

The monthly mean zonal winds measured using radiosonde ascents over Singapore as well as those obtained from MERRA-2 reanalysis dataset are depicted in Fig. 1(a) and (b), respectively for the recent decade (2011–2017). Even though the radiosonde observations are available since 1956 and MERRA-2 from 1979 onwards, the data for the recent decade alone is used so as to highlight the anomalous QBO event which occurred during December 2015–April 2016. Fig. 1 shows the well-known features of the QBO viz., the alternating eastward and westward winds descending with time, as discussed in section 1. The MERRA-2 reanalysis dataset shown in Fig. 1(b) reproduce most of the features of the QBO as given by the radiosonde observations depicted in Fig. 1(a). It can be noted that during the month of February 2016, the eastward winds at 40 hPa pressure level are replaced by the westward winds, and the descending westward winds at 10 hPa level are stalled. Interestingly, after this replacement of the eastward winds, the westward winds at 40 hPa start descending as it happens in the normal QBO. This is the first anomalous QBO ever observed in the history of recorded stratospheric winds, and the one that has been reported by Newman et al. (2016) and Osprey et al. (2016). The MERRA-2 reanalysis captured this event precisely as shown in Fig. 1(c), which shows the time series of monthly mean zonal winds at 40 hPa. The winds derived from both radiosonde and MERRA-2 goes hand in hand and exhibits a high degree of co-variability. However, it is clear that the transition from the westward phase of QBO to eastward phase shows a delay in MERRA-2 in comparison to the radiosonde observations. Same effect was found in association with other reanalysis data sets [Kawatani et al., 2016]. From this figure, it can be seen that the deceleration of the eastward winds at 40 hPa started in November, 2015 and changed to westward winds during the month of February, 2016. The westward winds remained in the same phase till June, 2016 with the peak westward magnitude during the month of April, 2016. This marks the shortest duration (~6 months) of the eastward phase of the QBO in the lower stratosphere and the shortest westward phase in the middle stratosphere.

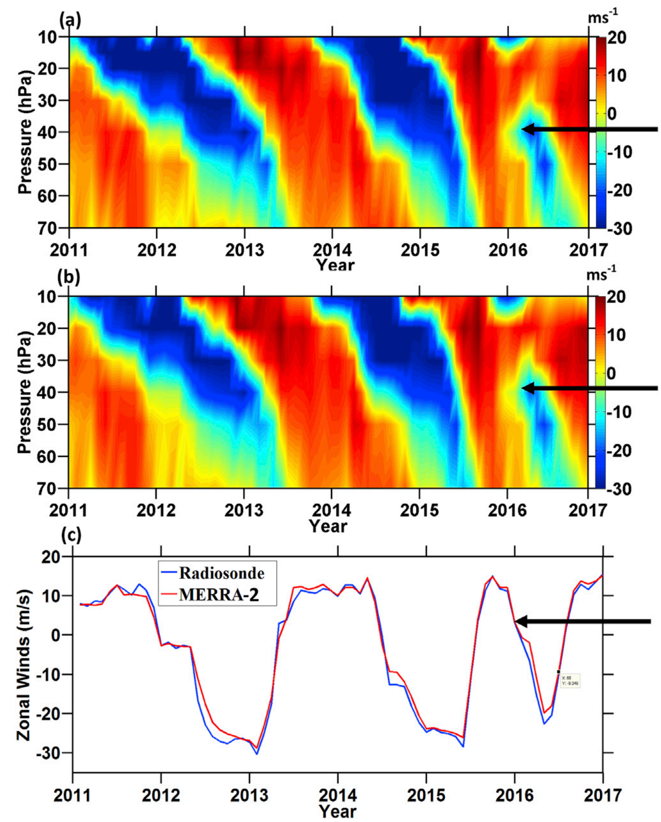

Fig. 1. Pressure level-month sections of zonal winds over Singapore using (a) Radiosonde observations and (b) MERRA-2 reanalysis. (c) Time series of zonal winds at 40 hPa over Singapore derived from radiosonde observations and MERRA-2 reanalysis data. Black arrows indicates the beginning of the QBO disruption event.

To further elucidate the anomalous QBO event, the latitude-month section of the zonal mean zonal winds derived from MERRA-2 reanalysis datasets are constructed at10,20,30 and 40 hPa pressure levels and are shown in Fig. 2(a–d), respectively for the recent decade. The zonal winds during January, 2011 to May, 2017 with latitudinal resolution of 1.25°are used to generate Fig. 2. The strong stratospheric jets at the high and middle latitudes in the winter hemisphere can be noted in Fig. 2. The Austral winter stratospheric jets are more coherent and strong as compared to their boreal winter counterparts. The purpose of showing the mid-high latitude winds in Fig. 2 is to examine the presence of any anomalous wind regimes at these latitudes. There seems to be no sign of abnormal behaviour of the zonal winds over high and mid-latitude during the QBO disruption period, as compared to the normal QBO periods, in both the hemispheres at all the four pressure levels during the recent decade. However, the striking feature observed over the equatorial latitudes, apart from the shortest duration of the westward phase at 10 hPa and the eastward phase at 40 hPa, is the longest duration of the eastward phase of the QBO at 20 hPa. This feature was not reported in the recent studies on the QBO disruption, which may be due to the data length considered for the study. The present study employs the data till May, 2017 and could capture the longest eastward phase (~23 months) of the QBO at 20 hPa highlighted by an ellipse in Fig. 2 (b). This record breaking duration of the eastward phase of the QBO at 20 hPa is a consequence of stalling of westward winds at 10 hPa, which is in turn due to the cut-off of the westward momentum by the westward winds below 40 hPa. The formation of the westward winds in the center of the eastward shear zone, as shown in Fig. 1, during the winter months of 2015–16 is the trigger for the QBO disruption [Newman et al., 2016; Osprey et al., 2016].

Recent studies have identified the intrusion of the mid-latitude