Atmospheric Ozone Response to the Disrupted 2015-2016 Quasi-Biennial Oscillation

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The quasi-biennial oscillation (QBO) - a quasi-periodic alternation between easterly and westerly zonal winds in the tropical stratosphere - is a main driver of inter-annual ozone variability in the stratosphere. During the late-2015 through 2016 time period, the QBO experienced a major disruption unlike any observed since wind measurements began in 1953. We examined the ozone response to this QBO disruption using profile ozone measurements from the Aura Microwave Limb Sounder (MLS) and Ozone Mapping and Profiler Suite Limb Profiler and total column measurements from the Solar Backscatter Ultraviolet (SBUV) Merged Ozone Data Set (MOD). Positive anomalies in stratospheric equatorial O₃ developed between 50 and 30 hPa in May-September of 2016, and negative ozone anomalies were observed in the subtropics of both hemispheres. As a consequence of this QBO disruption, extratropical total ozone values during the spring-summer 2016 were at or near seasonal record lows over the more than 40 years of the total ozone record, resulting in an increase of surface UV index during northern hemisphere summer. We found very consistent responses in all considered ozone observations in terms of time, amplitude and spatial patterns. We will show the ozone changes associated with this disrupted QBO throughout the winter and spring 2017.
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Abstract
The quasi-biennial oscillation (QBO) - a quasi-periodic alternation between easterly and westerly wind anomalies in the tropical stratosphere - is a main driver of inter-annual ozone variability in the stratosphere. During the late-2015 through 2016 time period, the QBO experienced a major disruption unlike any observed since wind measurements began in 1953. We examined the ozone response to this QBO disruption using profile ozone measurements from the Aural Microwave Limb Sounder (MLS) and Ozone Mapping and Profiler Suite (OMPS) and total column measurements from the Solar Backscatter Ultraviolet (SBUV) Mercury Ozone Data Set (MODS). Positive anomalies in stratospheric equatorial O3 developed between 50 and 30 hPa in May-September 2016, and negative ozone anomalies were observed in the sub-tropics of both hemispheres. As a consequence of this QBO disruption, extratropical total ozone values during the spring-summer 2015 were at or near seasonal low values for more than 40 years of the total ozone observations, resulting in an increase of surface UV index during northern hemisphere summer. We found very consistent responses in all considered ozone observations in terms of time, amplitude and spatial patterns.

Conclusions:
This study demonstrates that the 2015-2016 event had a substantial impact on the composition of the stratosphere. It led to a modified circulation that enhanced the equatorial downward transport in association with the positive (westerly) shear, while the negative shear below the easterly maximum led to enhanced upward motion. Following the appearance of the disruption in February 2016, there were two layers of zonal wind shear in the tropics.

- Western shear in the 50-30 hPa layer was linked to increased temperature and decreasing upwelling resulting in positive perturbations in O3 and HCl.
- The easterly shear from the disruption in the 50-30 hPa layer produced negative temperature perturbations in association with increased upwelling, inducing negative perturbation in O3, and HCl.

Because the ozone maximum is in the 50-30 hPa layer, the QBO disruption increased total ozone at the equator. The decrease of tropical ascent was balanced by upward motion in the extratropics. This extratropical upward motion decreased ozone in those regions (although the horizontal component to this circulation contributes as well). In this study we focused mostly on ozone changes; however, the response of other long-lived tracers such as HCl and NO2 is consistent with the QBO mean circulation inferred by the disrupted QBO. The similarities in the responses of observed changes in chemical tracers to the QBO disruption shows that these composition changes are primarily dynamically driven. Trace gases show perturbed behavior compared to the past, but their response is consistent with our understanding of the QBO-induced meridional circulation.

Figure 1. Monthly mean zonal wind (in/s) derived from SBUV/MLS worldwide data: color indicates the period, (a) 2015-2016; (b) 2013-2014; and (c) 2011-2012. [10] The wind anomalies are overlaid onto synoptic weather charts. The heaviest red and blue shades indicate the 0 and ±35% anomalies with respect to the 2013-2014 period. The red arrows are based on a seasonal tendency of the zonal wind shear at 40 hPa. The middle column is the data from May 2016 to February 2017 (2015-2016 QBO cycle, with day/0 in May 2015), and the right column is 2015-2016 minus the composite.

Figure 2. Monthly mean total ozone (DU) derived from SBUV/MLS worldwide data: color indicates the period, (a) 2015-2016; (b) 2013-2014; and (c) 2011-2012. [10] The anomalies are overlaid onto synoptic weather charts. The heaviest red and blue shades indicate the 0 and ±35% anomalies with respect to the 2013-2014 period. The red arrows are based on a seasonal tendency of the zonal wind shear at 40 hPa. The middle column is the data from May 2016 to February 2017 (2015-2016 QBO cycle, with day/0 in May 2015), and the right column is 2015-2016 minus the composite.

Figure 3. Composite of ozone anomalies, monthly mean zonal wind anomalies and stratospheric temperature anomalies (K) obtained from SBUV/MLS and Aura Microwave Limb Sounder (AMSU) observations, respectively. The time period from May 2015 to April 2016 corresponds to the time of the QBO disturbance. The ozone data show a clear response to the disrupted QBO.

Figure 4. Monthly mean zonal wind at Singapore [N,104E] (1987-2017) (a) 1987-1991; (b) 1992-1996; (c) 1997-2001; (d) 2002-2006; (e) 2007-2011; and (f) 2012-2016. [10] The anomalous zonal wind anomalies are overlaid onto synoptic weather charts. The heaviest red and blue shades indicate the 0 and ±35% anomalies with respect to the 2007-2011 period. The red arrows are based on a seasonal tendency of the zonal wind shear at 40 hPa. The middle column is the data from May 2015 to February 2017 (2015-2016 QBO cycle, with day/0 in May 2015), and the right column is 2015-2016 minus the composite.