An Application of spectral analysis method investigating the anomalous change in the QBO for period of 1997 to 2017, especially at 50 hPa related to the ozone’s concentration

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Abstract. This study is mainly concerned an application of the spectral technique analysis in investigating the anomalous change of the Quasi-Biennial Oscillation (QBO) over the equatorial region, especially over the Singapore related to the ozone’s concentration at about 50 hPa. This is important since we need to know that characteristics of ozone concentration at that layer due to the ozone depletion caused by the effect of the global warming. Please note here, ozone is already stated as one of the most important parameter needed to protect our earth from Ultra Violet (UV) light. No much study of ozone’s protection, especially near the equatorial region. In this preliminary results, we show the characteristics of QBO taken from the Singapore ‘s QBO data analysis. The QBO has represented as the downward propagating of zonal wind variation. Then, we investigate impact of QBO on the Ozone’s Concentration anomaly at stratospheric layer. We found the pre-dominant peak oscillation of QBO at around 28 month. We found also an a good agreement (pattern) between QBO and Ozone’s Concentration anomaly, especially at 50 hPa layer with a correlation coefficient of about 0.5. By this formula, we can estimate the next behavior of ozone’s concentration anomaly taken from the QBO index that updated regularly.

1. Introduction
The quasi-biennial oscillation (QBO) or alternation of zonal wind (from easterly to westerly and inversely) in the equatorial stratosphere in the layer from about 100 hPa (16 km) to about 3 hPa (40 km) is known for more than half a century. A review of the current understanding of the QBO can be found in Baldwin et al. [1]. Zonal wind QBO is a prominent feature of the equatorial stratosphere, and being an important component of atmospheric general circulation causes the interannual variability of many parameters and processes in Earth’s atmosphere.

Interannual variability of equatorial total ozone (TOZ) is dominated by the quasi-biennial oscillations that distinctly appear after removing the annual cycle from the original data. The QBO signal varies between ±10 Dobson units (DU), approximately ±4% of the background equatorial TOZ [1,2]. Longitudinal structure of the ozone QBO demonstrates zonally uniform phase changes (Shiotani, M) [3]. A large number of studies have shown that equatorial total ozone variation is characterized by strong coupling with the QBO of the equatorial zonal wind in the lower stratosphere. High correlation ($r > 0.7$) between total ozone and zonal wind in tropical zone has been obtained using the equatorial zonal wind at 30 and/or 50 h.
There is an interaction that occurs between the troposphere and stratosphere layer known as Stratosphere and Troposphere Exchance (STE). One is the vertical dynamics of Ozone concentration anomalies (O3) especially that occurring at the stratosphere layer. Many factors influence it, one of them is the dynamics or behavior of the direction and speed of zonal wind (East-West) in the stratosphere layer known as quasi-biennial oscillation (QBO). In this present study we mainly concerned to investigate the characteristics of QBO taken from the Singapore’s QBO data analysis that taken from this web address (http://www.geo.fu-berlin.de/en/met/ag/strat/produkte/qbo/index.html), and to investigate impact of QBO on the Ozone’s Concentration at stratospheric layer, especially at about 50 hPa.

2. The theory of QBO
The study of the stratospheric region at the equator is dominated by the phenomenon of downward propagation of westerly and easterly that firstly is discovered by Ebdon [4] and Reed et al. [5] which came to be known as quasi-biennial oscillation or QBO. QBO is a westernized oscillation of winds and clouds that propagate downward in the equatorial stratosphere-bottom region with an average period of 28 months [6], where the QBO lead phase has a stronger maximum amplitude than the western phase and the QBO amplitude is of a nature symmetry of the equator following the Gaussian distribution [6,7]. The mechanism of formation of QBO is proposed by Holton and Lindzen [5], where QBO is the result of interaction between the mean flow with the equatorial wave equation mode. Holton and Lindzen [8] were the first to model QBO based on the planetary equatorial wave propagation, Kelvin waves and Rosby-gravity waves.

Holton [9] states that QBO occurs only in the equatorial region because Kelvin waves and Rosby-gravity waves only form in the region of about 12°N - 12°S. The area provides considerable energy derived from the release of latent heat in large-scale convective cloud clouds in the tropics to form planeter-scale waves and push them down to the lower stratosphere. Therefore QBO is not formed in high latitudes because the resulting energy is not strong enough to push the equatorial wave into the stratosphere, although in high latitudes there is cloud formation and front region formation.

In addition to discussing the phenomenon of zonal wind oscillations, QBO also has an influence on chemical and physical processes in the lower stratosphere. Holton [9] has proven that QBO can satisfy thermal wind equations if the vertical shifts of zonal winds (wind shear) are associated with the temperature in the stratosphere. Meanwhile Baldwin et al. [1] show that to analyze QBO can use temperature and ozone data. Although QBO occurs only in the stratosphere-below the equator region, but QBO can affect the stratosphere region globally [10]. Because QBO affects the process of distribution and transport of substances in the stratosphere and may be a factor that causes ozone depletion.

Previous study of QBO has been done by Pascoe et al. [6] using ERA-40 data. But in this study not only QBO quantifying by using different methods, but also linking QBO with chemical and physical processes that occur in the lower stratosphere. It is hoped that by analyzing the characteristics of QBO and its relation to chemical and physical processes in the lower stratosphere can provide a better understanding of the phenomenon of QBO. In addition, it is expected to open ideas and insights in order to continue the study or research on broader QBO.

3. Data and Method
The main data of his study is taken from the Singapore’s QBO data analysis (http://www.geo.fu-berlin.de/en/met/ag/strat/produkte/qbo/index.html). The availability data is started from Januari 1979 until now which devided from 1000 to 1 hPa [11]. While, the monthly of Ozone Total Coloum is taken from AIRS satellite of Giovanni NASA (https://giovanni.gsfc.nasa.gov/giovanni/ for period of January 1997 to June 2017. In this study, we apply the spectral technique analysis that represented as the Power Spectral Density (PSD) and Wavelet. Wavelet analysis known as an effective tool to analysed power variations in time series. Time series were decomposed into time frequency space, then will determine variability dominant modes and variation modes in time as well. The wavelet transform has
been used in previous studies, including tropical convection [12], the El Niño–Southern Oscillation (ENSO) [13,14], atmospheric cold fronts [14], central England temperature [15], the dispersion of ocean waves [16], wave growth and breaking [17], and coherent structures in turbulent flows [18]. In this present study we estimate the power spectral density using FFT (Fast Fourier Transform) that appeared at Matlab software. Detailed this technique can be seen at this web site (https://www.mathworks.com/help/signal/ug/power-spectral-density-estimates-using-fft.html).

4. Results and Discussion

Figure 1 is showing the PSD the monthly of QBO data for period of January 1997 to June 2017 which starting from 100 to 10 hPa’s layer for every 10 hPa in altitude height. From this figure, we can see the pre-dominant peak oscillation an about 28 month. In the same figure, we found also the second pre-dominant oscillation an about 21 month, but the value smaller than 28 month. Since our analysis is focussed on 50 hPa layer, we make the contour plot of that QBO data as showing at figure 2.

![Figure 1. The Power Spectral Density (PSD) of QBO (Jan 1997-Jun 2017).](image-url)
Figure 2. The time-height section of QBO signal for period of January 1997 to June 2017.

From figure 2 above, we can see the sharp increased of QBO signal at around 50 hPa with the wind speed averaged is about 20 m/s. To investigate when that strong signal is occurred, we applied the wavelet technique analysis. Then, we obtain the pre-dominant peak oscillation of 50 hPa is still 28 month and occurring at around 2003 as showing at figure 3.

Figure 3. As the same as Figure 1, but for wavelet technique analysis.

Basically, we expand our analysis using the longer data started from 1987 to 2017 by comparing with other layers. They are 10, 20, 30, 50, and 70 hPa, respectively as showing at figure 4. From this figure, we can see the consistency of 50 hPa and other layers.
Figure 4. As the same as Fig. 1, but for longer data 1987 to 2017.

Then, finally we concentrate to analyze the comparison between QBO and ozone anomalies over Kototabang, West Sumatera, Indonesia started from September 1, 2002 to April 4, 2017 as showing at figure 5. From this figure, we can see an a good pattern both parameters.

Figure 5. The time series ozone anomaly and QBO started from September 1, 2002 to April 4, 2017.
Please note here, this result has already confirmed with Gabis [19] and Fadnavis and Beig [20] when they investigated the ozone behaviour at equatorial stratosphere. Finally, we are showing the scatter plot between ozone anomaly and QBO using Fig. 4 data as showing at figure 6. Although, the coefficient correlation is not too big, but it is enough, since the value is close to 0.5.

![Figure 6. The scatter plot between ozone anomaly and QBO.](image)

**5. Conclusion**

Ozone (O_3) is one of the most important gases at the stratosphere that can be protected the UV light from the sun. Recently, the behavior of ozone concentration especially at the equatorial region is very important to be investigated due to the ozone depletion at this region. Since ozone concentration is related well to the wind speed and direction at the stratosphere, in this present study we investigate the Quasy Biennial Oscillation (QBO). We used the QBO data taken from Singapore that has longer the QBO data. We applied the spectral technique that represented by Power Spectral Density (PSD) and wavelet, respectively. We found the pre-dominant peak oscillation of QBO at around 28 month and located around 50 hPa. Then, we compared with the ozone concentration anomaly for period of September 1, 2002 to April 4, 2017. We found an a good pattern (agreement) between two parameter that represented by coefficient correlation ($R^2$) of about 0.5. Both figures look similar each other. By this reason, we can mention that we can estimate the next of ozone concentration by using the QBO data that produced by the Singapore regularly.

**6. Future Works**

Since, we need to know the next QBO anomaly and their impact on the global and regional climate, especially over the Maritime Continent, we need to make prediction, such as using the ARIMA technique.

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