Development of the Total Ozone Column Model Prediction based on Stratospheric Zonal Wind and Temperature over the Maritime Equatorial Region

Putri Wulandari*, H Halide and Paharuddin

Physics Departement, Geophysics Study Program, Hasanuddin University, Jl. Perintis Kemerdekaan Km. 10, Makassar 90245, Indonesia

*wulandarip14h@student.unhas.ac.id

Abstract. As one of the constituent gases which plays an important role in protecting the earth from UV radiation, the characteristics of ozone important to be studied and even modeled. This study mainly concerned to the temporal analysis of the ozone concentration which is total ozone column (TOZ) in the atmosphere by using zonal wind and temperature in the stratospheric layer. Spectral techniques applying to find out the predominant peak oscillation and investigate anomalous at each layer that varies from 100 – 10 hPa layers. The result showed that TOZ anomaly over the maritime equatorial region has a similar pattern with the zonal wind which related to the Quasi-Biennial Oscillation (QBO) phenomena and stratospheric temperature anomaly, especially at 30 hPa layer. Then, we developed a model prediction for TOZ by using multiple linear regression and validate for 7 lead ahead using statistical approach; Pearson correlation, RMSE, and Euclidean distance. Moreover, our developed model then compared with the persistence model. Finally, we found a significant result with statistical correlation, r = 0.92 at lead 1.

Keywords: Equatorial TOZ, Model Prediction, Stratospheric Temperature, Zonal Wind

1. Introduction
In the recent decade, at least there have been two main atmospheric phenomena impacted the general public life, well-known as climate change and ozone depletion. Consequently, massive destruction of the catalytic ozone cycle by chlorine and bromine that resulting from the photodissociation of chlorofluorocarbon (CFC) compounds emitted at the surface [1]. About 90% of ozone concentration located at the altitude of 15 to 30 km in the stratospheric layer [2]. The higher the latitude, the lower down the ozone. Near the equatorial region, the highest concentration lies within an altitude of 25 km [2]. The total ozone column (TOZ) which referred to column density mostly used to specify the amount of ozone in the atmosphere above specific region. This quantity expressed in Dobson unit.

Generally, ozone (O₃) produced by the photochemical processes that occur in the tropical and subtropical stratosphere, where the sunshine almost intense throughout the year. At the first, ozone formation obtained from photolysis of molecular oxygen (O₂) at wavelengths less than 240 nm, which produces two oxygen atoms in their electronic ground states (3P). This atom then recombines with another molecular oxygen to form ozone by interfering of molecule M, mostly nitrogen or oxygen. At the same time of the ozone-forming, conversely, it is destroyed again by the photolysis of O₃ at wavelengths less than 300 nm and by reaction with an oxygen atom [2].

Stratospheric ozone is an essential parameter that controls UV radiation on the surface since ozone will be the only filter remain when the cloudiness and atmospheric conditions are clean. The ozone in
the stratospheric layer that so-called ozone layer filters a large portion of UV radiation emitted by the sun (about 100 - 380 nm). Among three types of UV radiation, the emission of solar UV-B radiation extremely danger for plants, animals, and humans. Accordingly, increases in UV-B radiation particularly impacting on photosynthesis, skin cancer, and weaken the immune system [2]. Therefore, the role of ozone being necessary for protecting life on the earth.

Chemical processes in the stratosphere affect the thickness of the ozone layer, but it is important to note that physical and dynamic processes also play a significant role. As one of the atmospheric trace gases, ozone transported over long distances by the stratospheric wind system, which affects global ozone distribution [1]. Furthermore, the characteristic of ozone that absorbs solar UV radiation causes the temperature of stratosphere increases with altitude. Consequently, affect the vertical distribution of the stratospheric temperature [1]. Many chemical reactions in the atmosphere depend on the prevailing temperature. The main ozone depletion cycles in the middle and upper stratosphere (brought about by the catalysts HOx, NOx, CIOy, and BrOy) slow down with decreasing temperature, which results in higher ozone concentrations [3]. Fluctuations of the ozone thickness both in the short and long-term possibly explained by the interaction of the entire process. This knowledge is necessary to comprehend the future estimate of the ozone layer. In this present study, we mainly concerned to develop a model prediction of TOZ by including stratospheric wind parameter that represented by zonal wind and temperature in the stratospheric layer, especially at 30 hPa.

2. Data and Method

2.1 Data
To study ozone variations, we used a monthly total ozone columns (TOZ) dataset of a MERRA-2 satellite from 1988 to 2018, obtained from https://disc.gsfc.nasa.gov/datasets/ [4]. Whereas, the zonal wind derived from QBO Singapore's data, available since January 1979 until present. This dataset observed by regularly radiosonde measurement of daily vertical wind profiles at the levels 100 to 10 hPa. Moreover, stratospheric temperature data from NOAA NCEP-NCAR CDAS-1 reanalyses also used. This dataset accessed through the IRI operational website, online data repository and analysis tools. Both zonal wind and stratospheric temperature data on a month-by-month basis.

2.2 Method
In this present study, we apply spectral analysis techniques, hereafter referred to power spectral density and wavelet. Time series data decomposed into time-frequency space, then determine variability dominant modes and variations modes in time as well. Power spectral density function shows the strength each variation (energy) as the function of frequency, mostly used to maintain the magnitude of frequency variations. This method useful to determine a level in which stratospheric zonal wind has similar characteristics with ozone. From here, then we cross-correlate between TOZ dataset with zonal wind and temperature at the stratospheric layer, respectively. By combining significant lags as the result of cross-correlation, we specify a set of predictors in modeling the ozone.

The ozone model was developed to predict the future monthly TOZ by using zonal wind and stratospheric temperature data, especially at 30 hPa. In this case, total ozone column is a single layer property, where an extracted data typically represent the equatorial region in 0° latitude and 100°E longitude. TOZ anomaly obtained by subtracting monthly dataset with the average of TOZ from January 1988 to March 2018 for each month. Regarding the TOZ model with two parameters as mentioned before, the total ozone column model also formed from time series dataset itself. Then, these two models were compared and validate up to 7 lead ahead. Finally, the best model selected based on a statistical approach, which is deterministic skill score.

To assess the prediction skill of an ozone model, we used three skill measures. Two commonly used in a statistical score, which are the Pearson correlation and the RMSE (root-mean-square error). Another skill measure is Euclidean distance, which calculated after performing a 45° rotation for each observation – prediction pair relative to the line of perfect forecast [5]. These measures of skill are defined as follows [6]:

\[
r = \frac{\sum_{m=1}^{n}(p_{m} - \bar{p})(o_{m} - \bar{o})}{\left[\sum_{m=1}^{n}(p_{m} - \bar{p})^2\right]^{1/2} \left[\sum_{m=1}^{n}(o_{m} - \bar{o})^2\right]^{1/2}}
\]
where \( r \) is a Pearson correlation coefficient, \( p_m \) and \( o_m \) are the \( m \)th prediction and observed value, respectively \((m = 1, 2, ..., n)\). While \( \bar{p} \) and \( \bar{o} \) are the mean values of the prediction and observation. Therefore root-mean-squared error and Euclidean distance are defined as:

\[
\text{RMSE} = \left[ \frac{1}{n} \left( \sum_{m=1}^{n} (p_m - o_m)^2 \right) \right]^{1/2}
\]

\[
\text{Euclidean distance} = \left| Y' = \left( \sum_{i=1}^{n} Y_i^2 \right)^{1/2} \right|
\]

3. Result and Discussion

3.1 The characteristics of Ozone, Zonal Wind and Temperature

Figure 1 is showing the PSD of monthly zonal wind data in the stratospheric layer at 100 to 10 hPa for the period of January 1988 – March 2018. From this figure, clearly shown that pre-dominant peak oscillation is about 28 months with the highest spectral energy around \( 12 \times 10^8 \text{ m}^2/\text{s}^2/\text{Hz} \).

![Figure 1. The Power Spectral Density (PSD) of zonal wind for a period of January 1988 - March 2018](image)
Wavelet analysis applied to zonal wind data at all levels of the stratospheric layer. But, only selected layers presented. The results show that zonal wind is an atmospheric phenomenon that oscillates about 28 months. This phenomenon contains a periodically of easterly and westerly phase, which vary from cycle to cycle. In the left panel in Figure 2 above, we can see characteristics of zonal wind oscillation at 25, 30, 50, and 70 hPa since January 1988 - March 2018. A positive value indicates westerly wind, conversely in the negative value. Along with decreasing in altitude, these two phases of wind are quite hard to distinguish caused by atmospheric disturbance. The inconsistency turns up at 50 and 70 hPa which showed an average of the variance in the right panel.

Since our analysis only focused on zonal wind data at 30 hPa, hereafter the complete wavelet results presented. As explained before, the top panel in Figure 3 (a) illustrates the time series data resulting from the normalization of zonal wind data against its standard deviation, while the bottom panel (d) is the average of zonal wind variance after scaling. The wavelet power spectrum of zonal wind (b) displayed in the middle panel. A red color bar indicates the westerly phase of wind, and conversely for blue. From the global wavelet spectrum (c), clearly show that zonal wind still has a periodic oscillation in 28 months, as same as the power spectral density result.
Figure 4. PSD of TOZ, zonal wind, and temperature at 30 hPa from January 1988 - March 2018. Blue, red and orange line represent zonal wind at 30hPa, TOZ and temperature at 30 hPa respectively.

Peak oscillation of TOZ, zonal wind, and temperature at 30 hPa determined after processing the data into anomalies in each month. As shown in Figure 4, our three dataset evidence with the highest spectral energy in 28 months period. This result supported by the plot of TOZ time series on zonal wind and temperature at 30 hPa, respectively (Figure 5). In general, both parameters almost similar to each other, while the negative anomalies in TOZ related to the negative anomalies in zonal wind and temperature at 30 hPa. However, some irregularity still takes account in this case. Please note the similar result also obtained by Hermawan [7] while comparing the QBO and ozone anomalies from AIRS satellite over Kototabang, West Sumatera, Indonesia.

Figure 5. Time series of TOZ, zonal wind, and temperature anomaly for January 1988 - March 2018.

3.2 Development of TOZ Model Prediction
Model prediction of total ozone determines by the significance lag of zonal wind and temperature at 30 hPa layer. Selected monthly TOZ predictions for lead 1, 3, 5 and 7 of MR (purple line) and persistence (yellow line) model presented in Figure 6. Its clearly showed that the longer the lead times,
the smaller the amplitude and shifted at a later time. In other words, lead time influence on expected forecast skill.

Figure 6. Monthly total ozone predictions for lead 1 to 7 of two ozone model (MR-Mod and Persist-Mod) against data from January 2000 - March 2018

In general, our MR model prediction of ozone was successful in predicting the moderate peak and amplitude of TOZ in October 2010, August – September 2013, and August 2015. However, its lack to predict high value on October 2015. If we compare it with a simple persistence model, both of them still have a good result until lead 3. But, the persistence model fails to predict the peak and trough level due to shift time. Therefore, only MR model still be able to follow the TOZ pattern up to lead 7.

3.3 Skill Measures
The scatterplot of both MR and persistence model presented by the figure below. This graph illustrates the distribution of data toward the line of perfect forecast (red-dotted line) only for selected lead 1, 3, 5 and 7.
Figure 7. Scatterplot of ozone model prediction for lead 1, 3, 5, and 7.
As mentioned before that we used a statistical approach, which is deterministic score to assess prediction skill of the model. This method has been used by Halide [6] in predicting ENSO using the SSTA Nino3.4. Figure 8 below present the Pearson correlation score, RMSE, and Euclidean distance of each model, respectively from the left to the right side. Based on this result, we can see that our model developed much better than the comparison model.

**Figure 8.** Skill measure metrics; Pearson correlation, RMSE, and Euclidean distance of the two ozone models. Green line for MR model, whereas Persistence model represented by red line.

4. The Future Works of Ozone Model Prediction

It showed that our model prediction of TOZ produces useful up to 7 monthly leads, with the latter correlation value about 0.88. As the spectral analysis result, we know that TOZ has peak periodic oscillation in 28 months. Therefore, we have questioned the model performed in the long-term trends. Validate for 28 months ahead of expected to fulfill this gap. However, the comparison of our model developed with powerful model either statistical and dynamical probably reliable to predict the future model of total ozone.

5. Conclusion

As one of the atmospheric gases, ozone protecting the life on earth from harmful UV-B radiation. Ozone concentration in the atmosphere influenced by chemical, physical and dynamic processes that interact with each other. Since the equatorial TOZ related well to zonal wind and stratospheric temperature, in this present study we developed the ozone model prediction. The spectral analysis results of PSD and wavelet showed that the predominant peak oscillation of total ozone anomalies, zonal wind and stratospheric temperature at an altitude of 30 hPa was 28 months. Both parameters have almost similar characteristics on time series. Therefore, the development of the TOZ prediction model has been done using these two parameters, where the prediction model equation in lead 1 month is $Y_{t+1} = -0.1754X_{1t} + 0.0431X_{1t-1} + 0.0607X_{1t-2} - 0.0368X_{2t} + 0.7880X_{2t-1} - 0.4838X_{2t-2} - 0.0096X_{2t-3} - 0.0430X_{2t-4} - 0.0029X_{2t-5} - 0.0464Y_{t-1} + 0.7623Y_{t}$. Up to 7 lead months, our MR model still has the best fit on observed data than the persistence ones.

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