Tropopause Estimation from GPS-RO Space-based by Using Covariance Linear Regression Technique

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Abstract —The variation of tropopause height was shown can be lead to changes in weather conditions and also be used as among indicators for climate change activities. Therefore, there are various study was conducted a way to estimate the tropopause location for these purposes through atmospheric profiling from the data collection by various satellite missions. Thus, the recent year shows that the importance of Radio Occultation (RO) data collected by GPS-LEO satellite which has high accuracy data for atmospheric profiling measurement. Furthermore, the RO sounding which are processes from the bending angle profiling using Abel Transform that also correlated with the refractivity profile from the atmosphere layer structure. Due to the sensitivity of RO data towards the atmosphere condition and the different refractivity of atmosphere layer due to the water vapor content, so these studies has been conducted to determine the tropopause location by using the refractivity profile from the space-based station. The vertical resolution data used in this study was collected from 2016 to 2019 from the GRACE and METOPA satellite mission. The tropopause determination using the refractivity profile then has been validated with the current method used such CPT and LRT which define by WMO. The average value of the tropopause distribution has been measured by the latitude zone for both hemisphere and it shows that the good correlation of refractivity profile for tropopause determination with the standard deviation of 0.07951. Thus, from the whole research analysis conducted, the high precision of measurement for tropopause height location at the lower latitude and mid latitude while lower precision measurement in a high latitude >60º due to the double tropopause layer.

Index Terms—GPS-RO, tropopause, refractivity, linear regression

I. Introduction

The troposphere is a layer of the active mixing characterized by intensive vertical motions and it is the densest part of the Earth atmosphere containing almost all water vapor (99%), clouds, and precipitation of atmosphere [1]. Known, that the Tropopause is the boundary layer between the troposphere and the stratosphere and the transmission of water vapor and other trace constituents to the tropical tropopause affects their concentration and distribution in the stratosphere [2], [3]. Therefore, the minor changes in water vapor can drive significant changes in the climate below by modifying the global radiation budget [4], [5]. The location of tropopause in atmosphere layer was varying due to the global temperature variation related to human activities. Hence, the large vertical temperature gradients for above and below tropopause layer act as a strong constraint on the tropopause height variability that can cause such phenomenon like El Nino [6]. It can be defined based on the chemical composition of the atmosphere make use of the fact that the tropopause is associated with sharp gradients in trace gases [7]. While the tropopause also can be defined based on critical values of isentropic potential vorticity (PV) and variation thereof [7].

There are various methods and definition used to identify the variation of tropopause in the recent study. Cold Point Tropopause (CPT) and Lapse Rate Tropopause (LRT) used by World Meteorological Organization (WMO) to measure the tropopause height [8], [5]. The CPT defined as the coldest point of temperature due to the convection activity where the temperature varies with height. It also referred to the cross tropopause flux of water vapor in the tropics and affected by radiative heating of the stratosphere [9], [10]. The transport of water vapor from troposphere to stratosphere layer is a great extent controlled by the temperature at CPT [11]. While the LRT called thermal tropopause from global distributed vertical profiles, which the tropopause height is the lowest level that the lapse rate is less than 2K/km for a depth of at least 2km [12], [9]. This method was not suitable to use for a subtropical and polar region that presence double tropopause [9]. Besides using the temperature as an indicator of tropopause location, the bending angle from an occultation data also can use to determine the tropopause height by using covariance transform method [10].

The data used in the research study of tropopause variation also play an important role in order to get an accurate determination method. Radiosonde data has been used by researchers so many years ago in atmospheric studies. However, this type of data has a weaknesses and limitation which is it have a low vertical resolution of data and also limited radiosonde observations over small populated area such as deserts, north and south poles, seas and oceans and etc. The Radio Occultation (RO) from GPS LEO satellite has recently been used as a remote sensing technique for measuring the earth atmosphere [13]. GPS-RO data provided active limb

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sounding measurements of the Earth's atmosphere with a high

vertical resolution [14], [9] and also have a global distribution for both southern and northern hemisphere. The data varies vertically with altitude from lower level 0.1 to 40 km which is up to stratosphere layer. Long term stability enables data from different missions to be combined without inter-calibration [10]. This RO data provided the atmospheric profile such as refractivity, bending angle, pressure, temperature and also the atmospheric density.

Therefore, the understanding of the tropopause trending is very important in climate change study especially to understand the tropical cyclone activity in future study

II. Methodology

A. GPS Radio Occultation Data

The GPS Radio Occultation (RO) is the technique for sounding Earth's atmosphere that has been demonstrated with the proof of concept by GPS/MET experiment in 1995 to 1997, and continuous observation is available since 2001 till present [15]-[17]. The several mission launched by the Jet Propulsion Laboratory (JPL) [18] proved that the RO concept which sounded the earth has the capability to observe the Earth's atmosphere [16] with the high accuracies of measurement with the vertical resolution is better than 1km [2]. Therefore, in recent years there are much research has been conducted utilizing the RO data collected from the various GPS-RO satellite mission for their research study especially in monitoring and observing the Earth's atmosphere activities. Furthermore, GPS-RO has been proven as a climate change and weather prediction tools with high accuracy, high vertical resolution, full global coverage, suitable for all weather which not affected by cloud, rain and even aerosol and with an independent height and pressure profile [16]. The RO technique is based on the atmospheric refraction phenomenon, which occurs when a GPS/GNSS signal penetrates the Earth's atmosphere and is then received by low-earth orbit (LEO) satellites behind the earth [19]. Table I below shows the satellite GPS-RO mission with a year of mission and the total number of occultation activities.

TABLE I: GPS-RO SATELLITE MISSION

GPS-RO mission	Years	Total atmosphere Occultation
GPS/MET	1995-1997	5002
CHAMP	2001 - 2008	468029
SAC-C	2002 – 2006	353944
GRACE	2002 - 2017	565148
METOP A	20016 - 2021	2942250

GRACE-RO data with a high vertical resolution from 0 to 60km covered troposphere and stratosphere layer has been used in this study. GRACE gravity satellite program was jointly developed by the National Aeronautics and Space Administration (NASA) of the United State and the German Aerospace Centre (DLR) with the objective of providing spatiotemporal variations of the earth gravity field and also the atmosphere and ionosphere environment detection [20], [21]. The measurement of GRACE and Metop A satellite are based on the two carrier phase measurement between two satellites with L1 and L2 frequency respectively [5]. In this study, the radio occultation data from GRACE satellite mission with the second layer data processed that has been extracted from Jet Propulsion Laboratory (JPL) data respository used to measure tropospause height. Fig. 1 below shows the global distribution of space-based station for the year of 2016 to 2017.

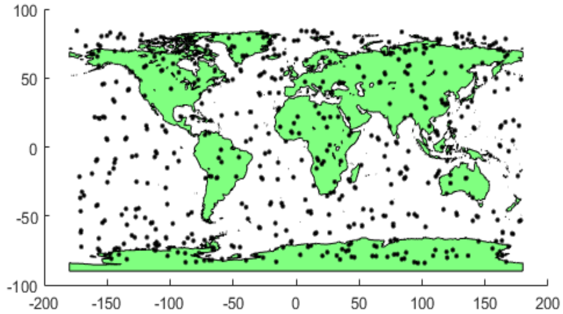

Fig. 1. The global distribution of GRACE –RO data

In this research analysis the set of data from GRACE mission has been used to develop the measurement while Metop A used for validation purposes.

B. Tropopause

The tropopause can be identifying based on the term of Cold Point Temperature (CPT) and Lapse Rate Temperature (LRT) by World Meteorology Organization (WMO). The LRT can be define as the lowest level at which the lapse-rate decrease to 2°C/km or less, provided that the average lapse-rate between this level and all higher level within 2km does not exceed 2°C/km [3]. Tropopause height was determined which that the lapse rate is calculated as Eq. (1) below [22];

$$\Gamma(p) = -\frac{dT}{dz} = -\frac{dT}{dp^k} \times \frac{dp^k}{dp} \times \frac{dp}{dz} \qquad (1)$$

This common definition of tropopause identification by LRT have weaknesses which the thermal criterion is that leads to ambiguities in the presence of multiple stable layers, which sometime occur in the jet stream region [22], [23]. Thus, the characteristics of tropopause layer as a boundary between troposphere and stratosphere layer which also has chemical constituents such as water vapor, and ozone [24]. It can be taken into account as an indicator for the sensitivity of atmospheric refractivity toward the content of water vapor in this region [25]. The tropopause location also varies depending on the location and latitude. It has a lower tropopause height at the high latitude region while the tropopause altitude will increase near to equatorial zone. the high altitude also occur above the sea compared to the land area due to high content of water vapor in the troposphere layer due to convection proses in the air [24].

C. Method Approach

In this study, the new approaches have been proposed to identify or estimate the tropopause location by using the atmospheric refractivity profile. Therefore, from the curve of refractivity profile, the linear regression technique has been implemented to fine the linear equation of the graph as shows in Fig. 2 below:

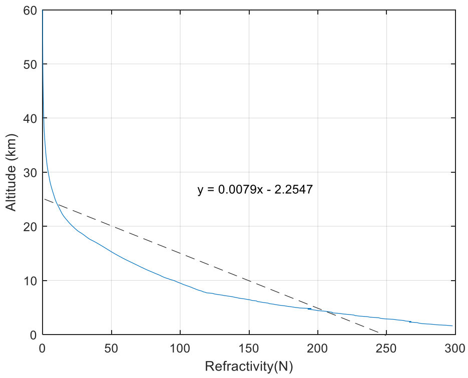

Fig. 2. The linear regression for refractivity profile curve.

The covariance transform technique was able to use to identify the transition of atmospheric boundary layer. [10]. Therefore, the covariance linear transformation has been develop refer to Eq. (2) below:

$$\omega(N) = \left(a\left(\frac{1}{n}\right)\sum_{i=1}^{n}\left(\int_{zd}^{zt} x_i \; dz + b\right)\right) * \phi \qquad (2)$$

where, Z_d and Z_t is the lower and upper limit of data profile which 1km to 60 km respectively. The ɑ and b is a; inear function of data profiling, while n is a gradient function which in this study 37km was used. The Φ parameter was tuning based on the latitude zone vertical scale value which identified from the reflection signal observed [26].

III. Analysis

The vertical resolution data from the GRACE and MetopA mission was used to evaluate the tropopause determination using a refractivity profile. This data distribution divided by three latitude zone which is tropical (0° to 30°), sub-tropical (30° to 60°) and high latitude near polar (60° to 90°) for southern and northern hemisphere respectively. Fig. 3 shows the tropopause height determination for the 47°S, 178°W which the data is on the south pacific ocean surface. With a strong temperature profile distribution, it is easy to determine the tropopause level through the CPT method. However, as reported by NOAA (National Oceanic and Atmospheric Administration) that 2016 is the warmest year compare to the previous resulting of the El Nino phenomenon. The warm surface of the ocean that leads to the convection process that can produce a large amount of water vapor contained in the atmosphere which definitely will affect the refractivity profiling through the atmosphere layer [24]. The result of analysis shows that the identification of tropopause layer by using refractivity profile was consistent with a very small standard deviation value of 0.02.

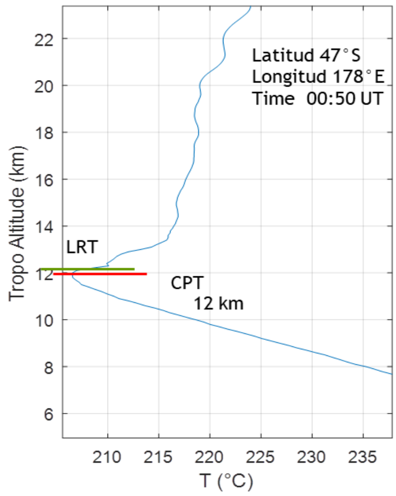

Fig. 3. Tropopause measurement using the CPT and LRT method.

Fig. 4 shows the global average distribution of tropopause height measurement over the year of 2016 to 2019 using CPT definition and new method. In this study, the double tropopause layer has been eliminated by using the LRT definition which lower LRT has been selected as a reference to identify the tropopause layer. Based on observation through this study, it shows that the significance of assumption with the lower bias. From the analysis, there is no significant difference in tropopause measurement between these two methods with a small rms value of 0.025.

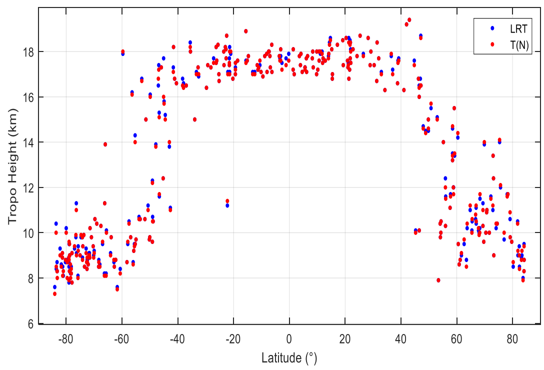

Fig. 4. The tropopause height distribution using LRT and ω(N) measurement

Refer to the Table II, the highest tropopause layer is at 18.8 km above in the middle of the Atlantic ocean with the location coordinate is 25.34°N, 36.4°W while the lowest tropopause height recorded as 7km at the location of 84.18°S 96.68°E which is above the Antarctic.

TABLE II: THE MEASUREMENT OF COMPARISON TROPOPAUSE DETERMINATION BETWEEN THE NEW METHOD AND LRT

T(N)	LRT	x	$x-\bar{x}$	$(x-\bar{x})^2$
7	8	1	0.70833	0.50174
9.8	10.5	0.7	0.40833	0.16674
10.8	10.4	0.4	0.10833	0.01174
10.2	10.1	0.1	-0.19167	0.03674
11	11.5	0.5	0.20833	0.04340
12.1	12.3	0.2	-0.09167	0.00840
16.1	16.2	0.1	-0.19167	0.03674
16.9	17.1	0.2	-0.09167	0.00840
18	18.1	0.1	-0.19167	0.03674
17.8	17.8	0	-0.29167	0.08507
18.8	18.8	0	-0.29167	0.08507
18.1	18	0.1	-0.19167	0.03674
17.2	17.1	0.1	-0.19167	0.03674
12.8	13	0.2	-0.09167	0.00840
16.7	16.8	0.1	-0.19167	0.03674
10.2	10.2	0	-0.29167	0.08507
8.2	7.7	0.5	0.20833	0.04340
12.2	12.1	0.1	-0.19167	0.03674
17.5	17.5	0	-0.29167	0.08507
13	14	1	0.70833	0.50174
12.6	12.8	0.2	-0.09167	0.00840
17	17.2	0.2	-0.09167	0.00840
12.6	12.9	0.3	0.00833	0.00007
9.3	8.4	0.9	0.60833	0.37007

For the evaluation performance of measurement, the error mean bias was calculated from the difference between population mean of measurement toward the reference or true value [27]. Thus, the accuracy also been calculated from the error bias of measurement as shown in Table III.

TABLE III: THE BIAS MEAN VALUE, µ AND STANDARD DEVIATION (SD) OF MEASURING ERROR BETWEEN TREF AND CPT METHOD FOR AN LATITUDINAL ZONE WITH AN INTERVAL OF 10°

Latitude zones	80N-90N	70N-80N	60N-70N	50N-60N	40N-50N	30N-40N	20N-30N	10N-20N	0-10N
µ	0.03	0.045	0.073	0.061	0.052	0.006	0.04	0.02	0.009
SD	0.008	0.023	0.057	0.033	0.016	0.016	0.004	0.013	0.008
MSE	0.009	0.025	0.063	0.036	0.019	0.016	0.006	0.014	0.015
Latitude zones	80S-90S	70S-80S	60S-70S	50S-60S	40S-50S	30S-40S	20S-30S	10S-20S	0-10S
µ	0.075	0.13	0.09	0.029	0.065	0.0385	0.02	0.006	0.035
SD	0.025	0.034	0.041	0.012	0.013	0.016	0.013	0.008	0.010
MSE	0.031	0.05	0.049	0.013	0.029	0.018	0.013	0.008	0.012

The mean error bias, the standard deviation of data sampling, and mean square error was determined for the each of latitudinal zone with an interval of 10° for the north and south hemisphere respectively as shows in Table III. The lowest mean error bias is 0.006 at the 30N-40N zone, while 0.073 is the highest mean bias at the 60N-70N zone for the northern hemisphere. However, the lowest mean bias for the Southern hemisphere stated that 0.006 at the 10S-20S, and the highest value is 0.13 for the 70S-80S zone area. Definitely, from an observation the highest mean error is located at the higher latitudinal zone which above 60°. Probably it may cause by the double tropopause layer which normally occurs in the subtropical region [9]. Thus, the total mean square error value for the annual distribution of 2016 and 2017 is 0.027 and 0.031 respectively.

Fig. 5 below shows the average tropopause height distribution of the latitudinal zone for the year 2016 to 2019 that was using the refractivity profile. From the distribution trend, it shows that the correlation between the global temperature and tropopause height trend due to the changes in water vapor concentration in the atmosphere layer and the convection activity. The average highest level of tropopause layer for 2018 is 18.41km while 18.4km in 2019, 17.85km in 2016 and 17.34km height in 2017 which all in the equatorial zone. The lowest tropopause layer has been found above the antarctic ice shield which 7.627km in 2017 that slightly higher compared to a year 2016, 2018 and 2019. The average bias between these years is about 0.722.

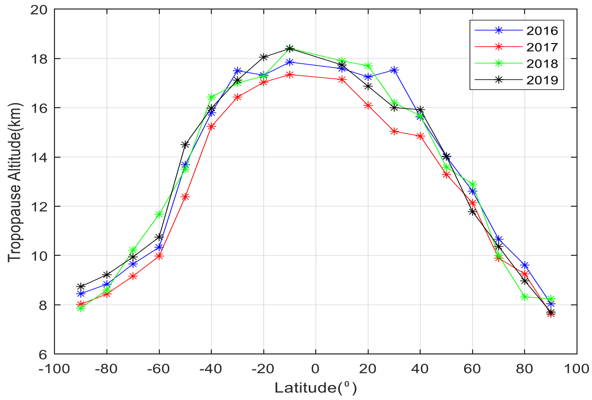

Fig. 5. The average of tropopause height distribution based on the latitudinal variation for 2016 to 2019

IV. CONCLUSION

The Global distribution of tropopause height can be determined by using a refractivity profile from the radio occultation data. The bottom atmosphere structure is formally known as a key indicator of the global climate change activity in which all the air current activity occurs in this troposphere layer. In this study, the evaluation of measurement has been performed by comparing with the existing method use to estimate tropopause by using the CPT. From the analysis, the lower value of mean square error shows that the high accuracy of tropopause identification by using a refractivity profile. This measurement also has an advantage compared to the CPT and LRT to identify the tropopause layer in the subtropic region. Therefore, the data assimilation process has been conducted well and can be used as one of the climate change indicators in the future.

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CONFLICT OF INTEREST

The authors declare there is no conflict of interest.

AUTHOR CONTRIBUTION

Rohaniza M. Zali: Conducted the research, Data collection, Conception of the work, Data analysis and interpretation, drafting the article, Final approval of the version before publishing

Mandeep J. S: Critical revision of the article, Final approval of the version before publishing

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