Monthly and Seasonal Variation of the Tropopause Pressure on the Middle East

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Abstract. Tropopause is the natural boundary between two different atmospheric layers, that is, stratosphere and troposphere. However, both of these layers (stratosphere and troposphere) differs significantly in terms of various dynamical and chemical parameters (for example, temperature, pressure, water vapors, etc.). It is therefore necessary to study the tropopause in order to better understand the static and dynamic conditions of aforementioned atmospheric parameters. This study therefore highlights the monthly and seasonal variation of tropopause pressure over the Middle East region. For this, reanalysis data set of tropopause pressure over Middle-East through the period from 1948 to 2006 are acquired from National Centers for Environmental Prediction (NCEP). Average of monthly and seasonal tropopause pressure distribution over the study region are estimated and discussed. The results of the study show that the summer seasons and the first month of autumn season have similar tropopause pressure distribution over the study region. The results of the study also show that the distribution of tropopause pressure for summer season started as a short wave at the end of spring season. In addition, northern part of the study region has zonal distribution of tropopause pressure with the exception of summer season as well as for the first month of autumn season.

Keywords: Troposphere, Stratosphere, Tropopause, NCEP.

1. Introduction

The enhancement of greenhouse gases in the atmosphere has been conclusively proved by scientists (Degorska et al., 1996; Hsua et al., 2013; Mashat et al., 2016; Cho et al., 2016). In this context, the phenomena of global warming is real that forced us to study the climatic changes in respect of meteorological parameters (for example, precipitation, temperature, pressure). Several studies have been conducted taking into account of annual rainfall (for example, Sen and Prasad, 1991; Srivastava and Sinha, 1994; Srivastava et al., 1992, 1994; Subramaniam et al., 1992; Sinha and Srivastava, 2000), and maximum and minimum temperature trends (Sinha Ray et al.; 1997; De and Rajeevan, 1997; Srivastava, et al., 2000) over different parts of the world. In addition, several studies have also been conducted examining monthly and seasonal variations in temperature and height (for example, Shastry and Narasimham, 1966; Sharma, 1966; Sivaramakrishnan, 1986). However, very little research has been done considering tropopause characteristics in the atmosphere (Desikan et al., 1994; Schubert and Munteanu, 1988). This study focuses monthly and seasonal variations in tropopause pressure over the Middle East with the main emphasis over Kingdom of Saudi Arabia.

Atmosphere constitutes from five layers (troposphere, stratosphere, mesosphere, thermosphere, and exosphere) that further consists of different gasses (for example,
78% nitrogen, 21% oxygen, 0.9% argon, and 0.03% carbon dioxide) and water vapours which surrounds the earth. These layers have been apportioned with respect to temperature and pressure variations in the atmosphere. The lowest layer from the surface of the earth is troposphere that extends from 0 to 16 km, the stratosphere extends from 16 to 50 km, the mesosphere extends from 50 to 80 km, the thermosphere extends from 80 to 640 km, and the exosphere extends from 640 to 10000 km. The role of the atmosphere is to drive air at different pressure systems and thereby controlling the weather system on earth (Angell, 1981; Bojkov and Fioletov; 1997, Gaffin et al., 2000; Hoinka, 1998, 1999). These atmospheric systems also have very interesting temperature variations. For example, in the troposphere, there is a positive lapse rate (temperature decrease with height) on the average whilst in the stratosphere, the temperature is nearly constant up to about 20 km and then increases with height (Sellers and Wen, 1988). It is the troposphere that contains nearly all the weather as we understand it, namely clouds, precipitation, and wind (Ramamurthy, 1976). On the other hand, stratosphere due to its stability is ideal for the smooth aircraft flying. However, the boundary surface between the two layers (troposphere and stratosphere) which is called tropopause represented the top of the layer acts as a layer that is suitable for mixing and heat transport due to convection. Thus, the temperature variations, as well as the pressure system governed in the tropopause, are very important in understanding the weather system. It is therefore important to discuss briefly tropopause region of the atmosphere particularly in the context of pressure.

The tropopause is the boundary surface between the troposphere and the stratosphere in the atmosphere. It is not horizontally constant and is lower (about 6km) over the poles and high (approximately 18km) over the equator (Wege and Claude, 1997). In addition, its height also varies with the season, in middle latitudes especially. For example, its height is lower in winter than in summer. The tropopause is the atmospheric zone where the rate of the lapse rate changes from the positive it behaves in the troposphere layer and then moves to the negative lapse rate in the stratosphere. Tropopause layer is characterized by a constant temperature in the entire layer. Jet streams (usually separates colder and warmer air masses) that play an important role in determining the weather, occur in the upper troposphere, just below the tropopause. In addition, the gradients that exist between centres of high and low pressure (anticyclones and cyclones respectively) and the modifying factor known as the Coriolis Effect also has major impacts on winds and thereby weather system. High jet stream wave amplitude is called meridional flow. Troughs with low pressure and ridges with high pressure characterize meridional flow, which increases the mixing of warm and cold air masses. Using the zonal component of the wind at pressure level 250hPa, Athanasiadis et al., (2010) found that there are two continuous jet streams stretch zonally and spiral slightly toward the pole. Awad and Almazroui (2016) in their study have classified the outermost effect of the Red Sea Trough (RST) into three classes, western, central and eastern RST classes. They found that the core of the maximum wind at the 250 hPa pressure level for the western RST was located over northern Libya and Egypt. For the central RST, the core of the maximum wind shifted eastward (in comparing with the position of the western RST) and was located over the northern Red Sea. Whilst for the eastern RST, the core of the maximum wind was located over the northern Arabian Peninsula. Therefore, generally, the maximum wind at the 250 hPa level affected the northern Red Sea in all situations, and the highest wind followed the oscillation of the RST near the Red Sea. Mashat and Awad (2015)
analyzed the widespread dust cases influenced the northern Arabian Peninsula and found four main patterns: western, eastern, northern and southern. They found that the maximum wind speed at the 250 hPa level, accompany the western pattern, occurred over northern Africa (Libya and Egypt), over the northern Arabian Peninsula. This wind forming a trough over the Red Sea as well as forming a ridge over the Arabian Peninsula along with a trough over Iran. They also stated that for the eastern pattern, the wind speedcore was located over the northern Arabian Peninsula, Libya and Egypt. For the northern pattern, the maximum wind core occurred over Libya and Egypt as well as over the north Arabian Peninsula. For the southern pattern, the core of the maximum wind located over Libya and Egypt. A very little research has been done to investigate tropopause relationship with meteorological parameters (Sivaramakrishnan et al., 1972, Steinbrecht et al., 1998). For example, Srivastava et al., (2002) studied the seasonal variations and trends in the tropopause height over Indian stations. Their study confirmed significant linear association ship between tropopause height over Indian stations and sea surface temperature anomalies of east Pacific Ocean with sea surface leading by one year (Verma, 1980).

2. Materials and Methods

The data used in this study is retrieved from National Centers for Environmental Prediction/National Center for Atmospheric Research - NCEP/NCAR reanalysis project (Kalnay et al., 1996) for the period from 1948 to 2006. One of the main advantages of this reanalysis data is that model parameterizations and resolution are unchanged for the entire time period (frozen system) (Kalnay et al., 1996; Kistler et al., 2001). Thus, both, the reanalysis data of the past and the Climate Data Assimilation System for the future are using the same frozen system. Such an arrangement are very helpful for the researchers as it eliminates perceived climate jumps associated with changes in the data assimilation system. Another advantage of reanalysis data as compared with observational data is that it can deliver a complete gridded state estimate that for all variables at all grid points where observational data is not available (Namias and Clapp, 1951; Kistler et al., 2001). The spatial and temporal resolution of the girded data used in the current study is 2.5°x2.5° available for the period 0000, 0600, 1200, and 1800 GMT.

In the present study, the average of the annual tropopause pressure for the period from 1948 to 2006 is calculated at each grid point. In addition, the average of tropopause pressure for each month of the year is also estimated for the entire data sets. The difference between the tropopause pressure for each month and the annual mean tropopause pressure is also calculated in this study.

The main objective of this study is to draw the features of tropopause pressure for different months as well as for different seasons of the year. In current research, the mean tropopause pressure iso-bar lines are drawn at intervals 98, 100, 102, 104, 108, 112, 116, 120, 130, 150, 180 hPa, while the annual mean intervals are drawn at intervals 102, 104, 108, 112, 116, 120, 130, 150, 180 hPa. Similarly, iso-lines of tropopause difference pressure (difference between the tropopause pressure for each month and the annual mean tropopause pressure) are drawn at intervals -50, -40, -30, -20, -18, -14, -10, -6, -2, 0, 2, 4, 6, 10, 15, 20, 30, 40 hPa.

3. Results

The distribution and the characteristics of annual mean, seasonal, and mean monthly tropopause pressure distribution over study area from the year 1948 to 2006 are discussed in this section. In addition, the percentage of deviation of each month with respect to annual mean is also discussed.
3.1 Mean Tropopause Pressure

The annual mean distribution of tropopause pressure is shown in Fig. 1. It is evident from Fig. 1 that there are two prominent areas for annual mean distribution of tropopause pressure. The first area north of 22°N where the tropopause pressure distributed on zonal feature with a small north shift of iso-lines on the east. The second area is south of 22°N where the tropopause pressure distributed on the circular feature, for example, the isobaric line 102 hPa are noticeable. It is also evident from Fig. 1 that the tropopause pressure magnitude and gradient increase towards the north. For simplicity, if pressure is interpreted as height then it is clear that the tropopause height decreases toward the north.

3.1.1 Winter season

The distribution of tropopause pressure for the winter months (December, January, and February) are shown in Fig. 2 (a, b, c). It is evident from Fig. 2 (a, b, c) that the general distribution of tropopause pressure for all three winter months is more or less similar. In addition, the general distribution of tropopause pressure for winter months resembled with annual mean distribution with slightly higher gradient and larger range. For example, the winter months ranges between 98 hPa on the south to 180 hPa on the north, while for annual mean distribution it ranges between 102 hPa on the south and 150 hPa on the north. Also, the range increases as winter month advance from the month of December to the month of February. Similarly, the difference of tropopause pressure distribution for the study area is shown in Fig. 3 (a, b, c). The positive and negative difference of tropopause pressure distribution over the area of interest as evident in Fig. 3 (a, b, c) indicates that each month of the winter season (December, January, and February) has higher pressure in the north and relatively lower tropopause pressure in the south of the study area. In addition, the positive value and the gradient in the north area increase as winter months advance. The winter months difference isobars shifted towards relatively south at the eastern region of the interesting area. The wavy shape is clear at south part over the water area of Red Sea and in the interior land of Arabian Peninsula.

3.1.2 Spring season

The distribution of tropopause pressure for the spring months (March, April, and May) are shown in Fig. 4 (a, b, c). It is evident from Fig. 4 (a, b, c) that the horizontal gradient for the spring season is mostly concentrated north of 22° N and is weak in the south of 22° N. It is also evident from Fig. 4 (a, b, c) that the horizontal gradient of the tropopause pressure decreases as the spring months advance from March to May. It can also be noted from Fig. 4 (a, b, c) that the horizontal orientation of the tropopause isobars shifts towards north on the east of the study area as the spring months advances from March to May. Similarly, the minimum value of tropopause pressure during the spring season increases from 98 hPa in March to 102 hPa in May while the maximum value of tropopause pressure during the spring season decreases from 180 hPa to 150 hPa.

Similarly, the difference of tropopause pressure distribution for the spring season over study area is shown in Fig. 5 (a, b, c). The gradient and magnitude of the tropopause pressure during spring months decrease as season month advance from March to May. Also, the wavy shape of the difference of tropopause pressure distribution during the month of March, as evident in Fig. 5a, are changing to circulation shape during the months of April and May especially on the eastern region of the study area. The maximum negative difference of tropopause pressure distribution during the month of May is concentrated at the northeast of the study area.
while during the months of March and April the same pressure is concentrated over the south. The circulation feature of the difference of tropopause pressure distribution during the month of March are much clear in Fig. 5a while the wavy shape of the difference of tropopause pressure distribution which exists in south of study region during the months of March (Fig. 5a) and April (Fig. 5b) are spread away to north during the month of May (Fig. 5c).

![Fig. 1. The average of the annual tropopause pressure over the period from 1948 to 2006.](image1)

![Fig. 2. The mean tropopause pressure in winter months for the period from 1948 to 2006.](image2)
Fig. 3. The difference of mean tropopause pressure in winter months from the average of the annual tropopause pressure for the period from 1948 to 2006.

Fig. 4. The mean tropopause pressure in the spring months for the period from 1948 to 2006.
Fig. 5. The difference of mean tropopause pressure in spring months from the average of the annual tropopause pressure for the period from 1948 to 2006.

3.1.3 Summer season

The distribution of tropopause pressure for the summer months (June, July, and August) are shown in Fig. 6 (a, b, c). It is evident from Fig. 6 (a, b, c) that, in contrast to the winter and spring seasons, the minimum value of the horizontal gradient for the summer season is mostly concentrated at mid-east of the study area. It is also evident from Fig. 6 (a, b, c) that the summer season tropopause pressure distribution has a wavy shape over entire study region which is deeper over the Red Sea area. The minimum tropopause pressure exists for the month of July with the value 98hPa which reaches to 100hPa for the remaining two months (June and August). In contrary to the winter and spring seasons, the horizontal gradient of tropopause pressure increases over the southern region of the study area during summer season. In addition, the horizontal gradient of tropopause pressure decreases from June to August.

Similarly, the difference of tropopause pressure distribution for the summer season over study area is shown in Fig. 7 (a, b, c). Once again, in contrast to winter and spring seasons, the distribution of negative tropopause difference is over the northern part of the study areas while the distribution of positive tropopause difference is over the southern region of the study area during the summer season. The gradient and magnitude of the tropopause pressure during summer months increase as season months advance from June to August. Also, the wavy shape of the difference of tropopause pressure distribution during the month of August is
changing to circulation shape (as evident in Fig. 7c) and moved to the interior area of the study region.

3.1.4 Autumn season

The distribution of tropopause pressure for the autumn months (September, October, and November) are shown in Fig. 8 (a, b, c). It is evident from Fig. 8 (a, b, c) that, the range of tropopause pressure for the autumn season increases from September (Fig. 8a) to November (Fig. 8c) while the wavy shape of the distribution of tropopause pressure for autumn season decreases from September to November. In addition, the wavy shape is very weak over the northern region of the study area and is concentrated over the south Red Sea and Arabian Gulf. It is also evident from Fig. 8 (a, b, c) that, the distribution of tropopause pressure “at various levels for autumn months” is affected by both, the summer season and winter season. For example, the distribution of tropopause pressure for the first month of autumn season, that is, for September is mainly dominated due to the distribution of tropopause pressure of summer season (Fig. 8a and Fig. 6a, 6b, 6c) while for the remaining two months of autumn season, that is, for the months of October and November the distribution of tropopause pressure is dominated due to the winter season tropopause pressure distribution (Fig. 8b, 8c and Fig. 2a, 2b, 2c). Similarly, the difference of tropopause pressure distribution for the autumn season over study area is shown in Fig. 9 (a, b, c). It is evident from Fig. 9 (a, b, c) that the gradient of the difference of tropopause pressure distribution decreasing from the first month of autumn to the last month, that is, from September to November. In addition, the difference of tropopause pressure distribution is negative at the start of the autumn season, especially at northern part, and ultimately converted into wave shaped and is positive over the entire study region during the month of November.

Fig. 6. The mean tropopause pressure in the summer months for the period from 1948 to 2006.
Fig. 7. The difference of mean tropopause pressure in summer months from the average of the annual tropopause pressure for the period from 1948 to 2006.

Fig. 8. The mean tropopause pressure in autumn months for the period from 1948 to 2006.
4. Discussions

This study highlights the distribution of tropopause pressure over the Middle East from the year 1948 to 2006. In general, the results of the study reveal two distribution features of the tropopause pressure over the study region. The first distribution feature is for June, July, August, (summer season) and September (first month of autumn season) while the second distribution feature is for October, November (last two months of autumn season), December, January, February (winter season), March, April, and May (spring season). The minimum value of the tropopause pressure for the first distribution exists over the mid-eastern region of the study area while for the second distribution it exists over the southern region of the study area for the entire period. Similarly, the maximum value of the tropopause pressure for the first distribution exists over the southern region while for the second part it exists over the northern region of the study area. The results also revealed that the tropopause pressure distribution for the summer season as well as for the first month of autumn is prominent with wavy shape over the whole study area, however, for the second distribution, it becomes wavy only over the southern part of the study area.

The results of the study conclude that the winter season has the highest tropopause pressure range, while the last month of the summer season (July) and the first month of the autumn season (September) has lowest tropopause pressure range over the study region for the entire data set. In addition, the winter season has the strongest tropopause pressure over northern part while the
tropopause pressure for the same season is lowest over the southern region of the study area.

The difference of tropopause pressure distribution for the spring season is affected by both the winter season and summer season. For example, the first two months of the spring features (March and April) are mainly affected by the winter features while the remaining one month (May) is affected by the summer features distribution. The positive value of the difference of tropopause pressure distribution for the summer season as well as for the first month of autumn season exists over the northern part of the study area while the negative values exist over southern part. This is in contrast to the remaining months of the year where positive value exists over southern part while negative value exists over the northern part of the study region.

References


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The troposphere is a thin layer dividing the stratosphere and the troposphere at the Earth's surface. With this, the stratosphere and the troposphere are significantly different in terms of their physical and chemical properties (for example, temperature, pressure, and water vapor). Therefore, it is clear that studying the troposphere is crucial for understanding the behavior of the atmosphere. This study sheds light on the monthly and seasonal variations of tropopause pressure in the Middle East. As a result, a dataset of tropopause pressure over the Middle East during the period from 1948 to 2000 was analyzed. The results show that the summer and the first month of autumn have a similar distribution of tropopause pressure in the study area. Furthermore, the study found that the tropopause pressure for summer begins as a short wave in the late spring. In addition, the northern part of the study area has a distribution pattern of tropopause pressure, except for summer and the first month of autumn. Key words: tropopause, stratosphere, troposphere, Middle East.