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Evaluations of the Characteristics of the Tropo-Strato-Mesopause Height and Temperature Variability over Bahir Dar, Ethiopia (11.60 N, 37.30 E) Using SABER

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ABSTRACT

The height profile of atmospheric temperature data between 12 km and 100 km was obtained from SABER/TIMED satellite instruments during the year 2016 and used to characterize the three atmospheric pauses temporal variability of height and temperature over Bahir Dar, Ethiopia (11.6° N, 37.3° E). The daily, monthly, and frequency distributions of tropopause-stratopause-mesopause height and temperature are investigated. From the frequency distribution, we had found that of the tropopause-stratopause-mesopause height 17 km, 48 km, and 98 km with the corresponding temperature 192 K, 268 K, and 148 K. The decrement (cooling) trend lines of tropopause height 0.7 K/year and its corresponding tropopause increment temperature has been ~1.5 K/year. The stratopause and mesopause trend lines of height are insignificant and the corresponding decrement (cooling) temperatures are ~3 K/year and ~13 K/year respectively. The mean monthly maximum heights of tropopause 19 km in May with a corresponding maximum temperature of 201 K in September. The maximum stratopause height 49.5 km in February and July and its temperature 268 K and 267 K in February and April respectively. The maximum mesopause height 98 km, 95 km, 97 km in March, Jun, and November respectively, and its maximum temperature 196 K and 198 K in January and July respectively.

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1. Introduction

The Earth's atmospheric layers of transitional height and temperature structures vary through temporal and spatial aspects. The atmosphere is classified in terms of regions based on the vertical structure of the temperature are troposphere (up to 8-19 km), stratosphere (up to ~50 km), mesosphere (up to ~100 km), and thermosphere. Some known physical and chemical characteristics that distinguish these layers by transitional regions are called tropopause (~16 km at low latitudes, ~12 km at mid-latitudes, and ~8 km at high latitude), stratopause (~48 km), and mesopause (~100 km) respectively. The tropopause region is the boundary between convective (turbulent) and non-convective (stable) regions, the stratopause region is joining the stable to turbulent region, and Mesopause also a transition region between the homosphere and heterospheric regions.

The transitional regions of the atmosphere are very important to study as every region is coupled with different regions^[1]. The height and temperature profiles of these pauses are a crucial investigation of the various processes^[2]. The stratosphere and mesosphere region of atmospheric temperature also offers a valuable means to study a variety of chemical and dynamical phenomena that are occurring in it^[3]. The tropopause is a changeover region between the convective dominated troposphere and the non-convective (stable) stratosphere. Recently, the tropopause layer has received large attention due to the stratospheric-tropospheric exchange of mass, water, and other chemical constituents between the two layers. The weather and climate conditions in the troposphere have their influence on the pauses' temperature and height fluctuation. The tropopause height and temperature variability play an important role in the transport between the troposphere and stratosphere. So, it is crucial to properly quantify the pause's height and temperature in the tropical, subtropical, middle-latitude, and over the Polar Regions which are having different processes and constituent characteristics.^[4] Presented a very exhaustive review of the features of dynamical, chemical, and radiative coupling in the troposphere and stratosphere. All over the first three pause features have been studied extensively over the globe, used to explore the dynamical circulations of the troposphere, stratosphere, and mesosphere and have been observed using ground-based instruments, MST radars, LIDAR's, satellites, etc. Exploration of stratopause and mesopause regions is difficult to observe from ground-based observations as balloons are limited

by height coverage, MST radars are blind in this region, and the Rockets are limited to coastal coverage and are very sparse. Ground-based LIDAR instruments are good observers in the middle atmosphere, but these are also limited to night-time clear weather condition observations. The investigation of the vertical structure of temperature in the mesosphere and lower thermosphere region is important, but rather difficult based on ground-based instruments. Exploration of the Mesopause region is rather more difficult due to dynamic characteristics and studies on it using optical, radio, Lidar, and certain satellite observations. On the contrary, satellites measured vertical temperatures from the troposphere to the lower thermosphere during the day and night around the globe. SABER satellite observations of middle atmospheric temperature are a crucial investigation of various processes taking place in the atmosphere^[2]. The Space-borne SABER/TIMED satellite are used to be able to provide good global observations. There are studies based on the SABER observations of instability structures and characterization in the mesosphere, lower thermosphere, and the Mesopause region covering the height range approximately 80-100 km^[5]. Further, they found that the Mesopause temperature is decreasing with a rate of 0.72 ± 0.05 K/year by analyzing SABER data during (2002-2008).

These atmospheric layers contain the composition of different molecules, which are cause for temperature and height variations by absorbing heat from the earth's surface and the source sun. While greenhouse gases heat the lower atmosphere by absorbing radiation, they are also efficient radiators of heat, resulting in cooling the middle and upper atmosphere^[6]. In general, the height and temperature profile from the SABER observation is a crucial investigation of various processes taking place in the atmosphere^[2].

Limited studies are available across tropical regions on the characteristics of stratosphere- mesosphere interactions and exchange. The objective of this study fully understands the height and temperature structures of the tropopause, stratopause, and mesopause in the tropical regions of the northern hemisphere at Bahir Dar, Ethiopia region (11.6° N, 37.3° E) Using one-year SABER observation data. Finally, evaluation of the frequency distribution of the tropopause, stratopause, and mesopause height and temperature variations are determined. This study has shown the extent to which the observed pauses atmospheric layers of height and temperature variability occurred both spatially and temporally.

2. Data Analysis and Methodology

2.1 Data Source

In this study, we have used SABER/TIMED satellite observed temperature data during the year 2016 in the altitude range of 12-100 km over the tropical region, Bahir Dar, Ethiopia (11.6° N, 37.3° E) in the NH. SABER was launched in December 2001 and quality data are available. Since the measurements can be obtained during the day and night time as well as in nearly any meteorological weather conditions. The SABER instrument scans the emissions of photons from 10 up to 153 km vertical altitude.^[7], the time required to make one “up” or “down” scan of the limb is slightly less than one minute.

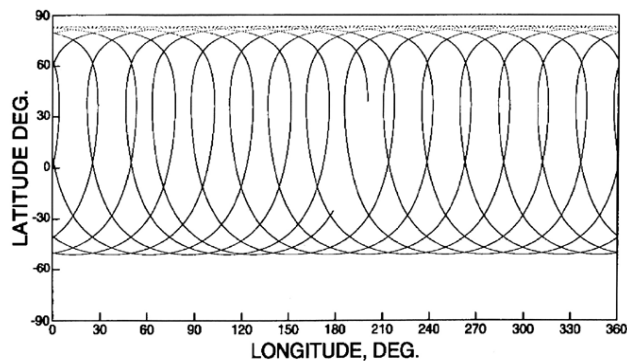


Figure 1. North viewing phase of the TIMED yaw cycle of scanning the atmosphere on the orbit

The SABER vertical temperature profile data downloaded from the website <ftp://saber.gats-inc.com/> at the end utilize this atmospheric height-temperature profile to investigate the pause's temperature and height variability with spatial and temporal aspects.

2.1.1 SABER Instrument Observation System

The SABER (sounding of the atmosphere by Broad-band Emission Radiometry) instrument onboard TIMED (thermosphere ionosphere mesosphere Electrodynamics) satellite has been used for investigating various atmospheric parameters. SABER is one of four experiments on NASA's TIMED mission scheduled to be launched in May 2000 by a Delta II rocket into a $74.1 \pm 0.1^\circ$ inclined, 625 ± 25 km circular orbit. SABER/TIMED satellite is a radiometer, in which retrieves the temperature from the emissions of the radiated waves of a wavelength of about $1.27 \mu\text{m}$ up to $17 \mu\text{m}$ in certain atmospheric species. The limb is scanned vertically by a 10-channel broadband radiometer operating in the near to mid-infrared range

over the altitude range from 400 km to below the Earth's surface. Radiances are measured as a function of tangent height, which is the altitude of the point of closest approach of an emission ray path to the Earth's surface.

The retrieved vertical temperature profile has a vertical resolution of about 0.3 km^[8]. The present study considers SABER temperature data focused on the Bahir Dar, Ethiopia region (11.6° N, 37.3° E) with ± 5 degrees in latitude and longitude discrepancies overpass during the year 2016. The TIMED satellite makes ~ 15 orbits per day with a period of about 1.6 h for each orbit, and it takes to complete 24 h. For every 58 seconds, SABER provides a profile by scanning up and down the Earth's horizon.

The retrieval uncertainties in the kinetic temperature are documented by^[8]. The error is well documented in the temperature retrieval of about 4-5 K in the mesosphere and lower thermosphere about 80-100 Km altitude region. They have also mentioned that the uncertainty is on the order of 1-3 K in the lower stratosphere, ~ 1 K near stratopause. But the main sources of error in SABER were found to be due to inaccuracy in measured radiance, biases in the forward model of CO₂ radiance, errors due to ozone, and uncertainties in retrieving temperature profiles.

2.2 Methods of Data Analysis

The SABER/TIMED satellite observations which measures limb radiance emitted from the terrestrial species in the atmosphere in a selected spectral band from 1.27 to $17 \mu\text{m}$. The SABER instrument uses the new website version 2.0 level 2A data set for analysis of pause characteristics of height and temperature.

The temperature data and its corresponding height are taken from SABER/TIMED satellite for the year 2016 to attain over the Bahir Dar region. An average height profile of temperature is produced for each day, month, and season. The daily and monthly variations of height and temperature pause have been evaluated in the year 2016. For further analysis, the increment or decrement trend of daily temperature and height of the tropopause, stratopause, and mesopause layers of the transition region is based on a linear regression equation for prediction. It is expressed as;

$$Y = mX + b \quad (1)$$

Where X is the explanatory (independent) variable and Y is the dependent variable (response or outcome). The variable m is the slope of the line has been obtained from the linear regression equation, which is the mean temporal and spatial change of temperature or height of pause over one year as a function of altitude and day of the year and b

is the intercept.

Then determine the monthly mean vertical distribution of the pauses height and temperature, in the lower atmosphere at 0.3 km height vertical resolution for every month in the height range of 12 Km up to 100 Km. The mean monthly of height and temperature data analysis using the equation given below;

$$\bar{X} = \frac{\sum_i^N x_i}{N} \quad (2)$$

Where; \bar{X} : = Mean of monthly for height and temperature

x_j = the individual month or seasonal data on height and temperature

N =the total number of months or seasons, height and temperature data through the year.

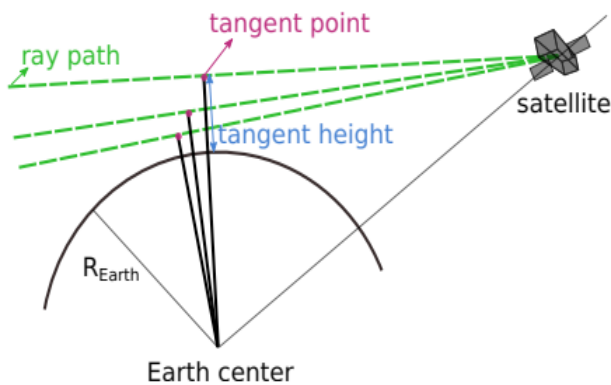


Figure 2. Altitude profiles of the incoming limb radiances can be measured in the geometry of the limb-sounding technique

Finally, evaluation of the frequency distribution of tropopause, stratopause and mesopause height and temperature variations are determined

3. Results and Discussion

3.1 Introduction

The analyzed data and their interpretation in detail which relate to the findings of this work. This study analyzes the characteristics of atmospheric layers of pauses height and temperature variability which are tropopause, stratopause, and mesopause over Bahir Dar. The vertical temperature profile of SABER observation from 12km up to 100km determines the day, and mean monthly variation of pauses height and temperature. Finally, the frequency distributions of tropopause, stratopause, and mesopause height and temperature variations are determined.

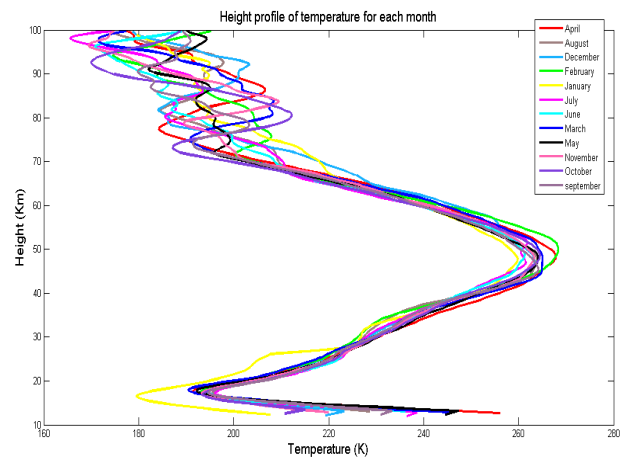


Figure 3. Monthly vertical temperature profiles of SABER observation data from an altitude 12 to 100 km over Bahir Dar, Ethiopian region in 2016

The whole vertical temperature profile data from Fig 3 during the period from January to December 2016 used to characterize tropopause, stratopause, and mesopause height and temperature variation. In the graph, we have shown that the tropopause, stratopause, and Mesopause heights in 17, 48, and 98 km with the corresponding temperature values has been carried out about 192, 268, and 161 K, respectively. [9] reported that the region of the mean stratopause height and temperature have been, 48 km and 271 K, respectively, using Rayleigh Lidar observations over Mt. Abu.

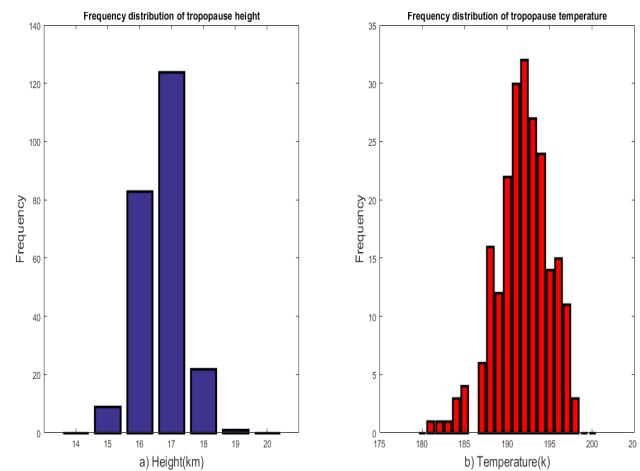


Figure 4. Frequency distribution of tropopause height and temperature

We have shown from the Fig 4, that the tropopause heights in the tropopause region over Bahir Dar at an interval between (15 km - 18 km) and the corresponding tropopause temperature has been existed in an interval between (181 -198) K. The maximum tropopause temperature has been occurring at 192 K and its tropopause

height in Bahir Dar in equatorial region has been carried out about 17 km. The tropopause layer of thickens depicted from the figure has been shown that 3 km. The previous studies by [10] have also reported that the tropical tropopause height occurrence in an interval (16-17) km, in which the troops thickness is found to be consistent with our studies using SABER data.

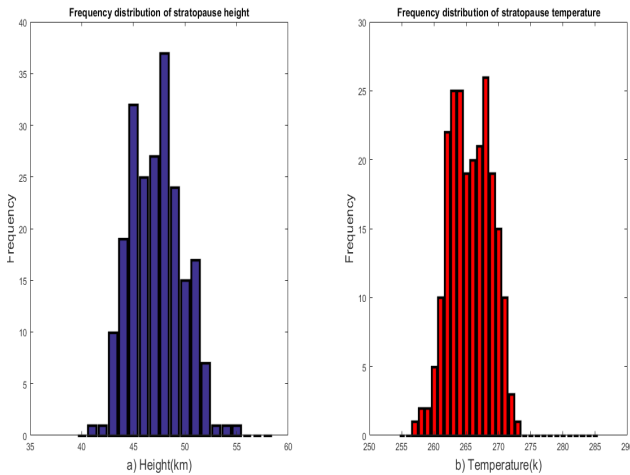


Figure 5. The occurrence of stratopause height and temperature, frequency distribution

From Fig 5 the occurrence of stratopause height, frequency distribution lies within an interval between (41-55 km) which mean its thickness is 14 km and the corresponding frequency distributions of the stratopause temperature has been shown in an interval between (260-271) K. We have concluded from this report that the lower latitude stratopause height is 48 km and the maximum temperature is recorded at about 268 K over Bahir Dar region. [11] Reported that the stratopause thickness is (10 km) and the temperature range over Gadanki at about (260-270) K.

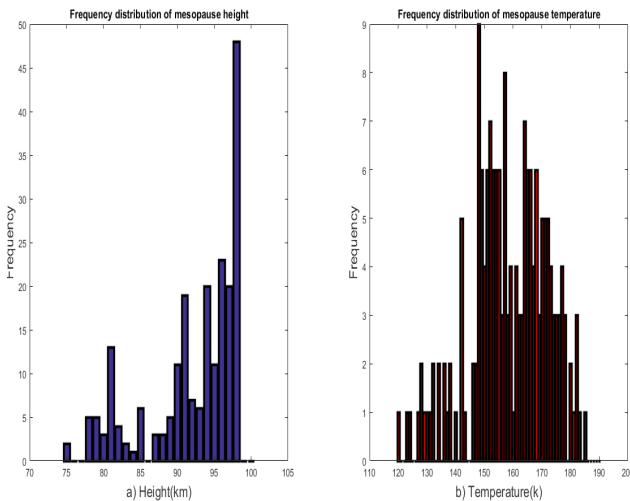


Figure 6. The occurrence of mesopause height and temperature, frequency distribution

The occurrence of equatorial mesopause height over Bahir Dar region lies in an interval between (75-98) km with the corresponding temperature frequency distribution (120-185) K. The most Mesopause height frequencies distribution has been existed in an interval between (94-98) km with corresponding temperature distribution (149-175) K. The mesopause height and temperature with the corresponding occurrence frequency distribution is observed at about 98 km and 148K respectively. The maximum mesopause height and its corresponding temperature occurrence of frequency distribution showed that the Mesopause region is cooler in the NH (North hemisphere) at the lower latitudinal region. [12] Has reported the maximum occurrence frequency distribution of the mesopause height is (~100 km).

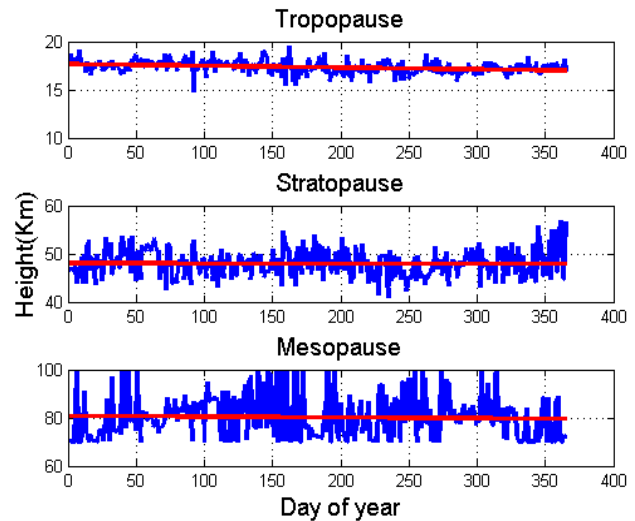


Figure 7. Temporal variation of the tropopause, stratopause, and mesopause height over the Bahir Dar region from January 2016 to December 2016

In Fig 7 daily variation of the tropopause, stratopause, and mesopause height from SABER observation over the Bahir Dar from January to December 2016 are determined. We have deduced that the entire trend lines of linear regression for tropopause, stratopause, and mesopause temporal and spatial variation of heights have shown a very diminutive decreasing trend. These decrement trend lines of tropopause, stratopause, and mesopause height variations has occurred in an interval between (15-19.5) km, (41-58) km, and (75-98) km through the year 2016 respectively. We have seen that the thickness of tropopause, stratopause, and mesopause are 4.5 km, 7 km, and 23 km respectively from the intervals of height variation. In the same kind, previous studies supported by [3, 12] for Indian equatorial regions of stratopause height is located in the range of (43-58) km and (44-52) km respectively.

The decrement tropopause trend lines of linear regres-

sion in height through the year 2016 which have 0.7 km/year. But no significant trend line changes are found in stratopause and mesopause during the period 2016. Especially, the stratopause trend lines of height as shown constant throughout the year because the region might behave stable considered to be induced by an increase the concentration of ozone in this region is absorbed more radiation from the sun (source) use as stability of a stratopause region. And a very diminutive decrement trend line of heights in the stratopause and mesopause have been might be due to the effect of greenhouse gas concentration in the tropopause and the depletion of ozone in the stratosphere layer. The previous studies^[13] have been reported that there is a decrement trend in the Mesopause height during 2002-2008 using SABER observations.

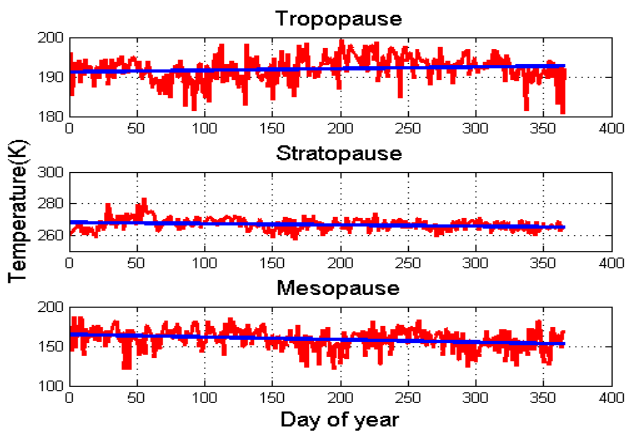


Figure 8. Variations of Tropopause, stratopause, and mesopause temperature retrieved from SABER observation over Bahir Dar from January 2016 to December 2016

From Fig 8 show that the daily variation of the tropopause, stratopause, and mesopause temperature from SABER observation over the Bahir Dar from January to December 2016. The temperature variability of the tropopause, stratopause, and mesopause has been determined in an interval between (180.6-199.4) K, (257.1-283.6) K, and (120.5-186.7) K respectively. In this interval we have shown the increment trend lines of linear regression for tropopause temperature is slightly more warming with the corresponding trend lines of tropopause height. The tropical tropopause temperature is one of the most important factors that control the aridity of air in the stratosphere. These spatial and temporal variations in the tropical tropopause temperature have been intensively investigated by several studies.

From Fig 8 the increment tropopause trend line of linear regression for temperature in the temporal variation through the year has been (~1.5 K/year). This increment of temperature is might be due to the effect of greenhouse gas concentrations in the tropopause and depilation of ozone. The instability of a gravity wave can be attributed mainly to convective instability for the high-frequency components of gravity waves in the tropopause. So, this high frequency of gravity wave is superimposed the jet stream in the tropopause that dissipated the energy to the atmosphere as a cause of thermal heating. We have known that the effect of atmospheric gravity wave propagation upward from the troposphere to the overlying stratosphere and mesospheric region. The maximum and minimum temperature variations have there existed in the region of mesopause and stratopause respectively.

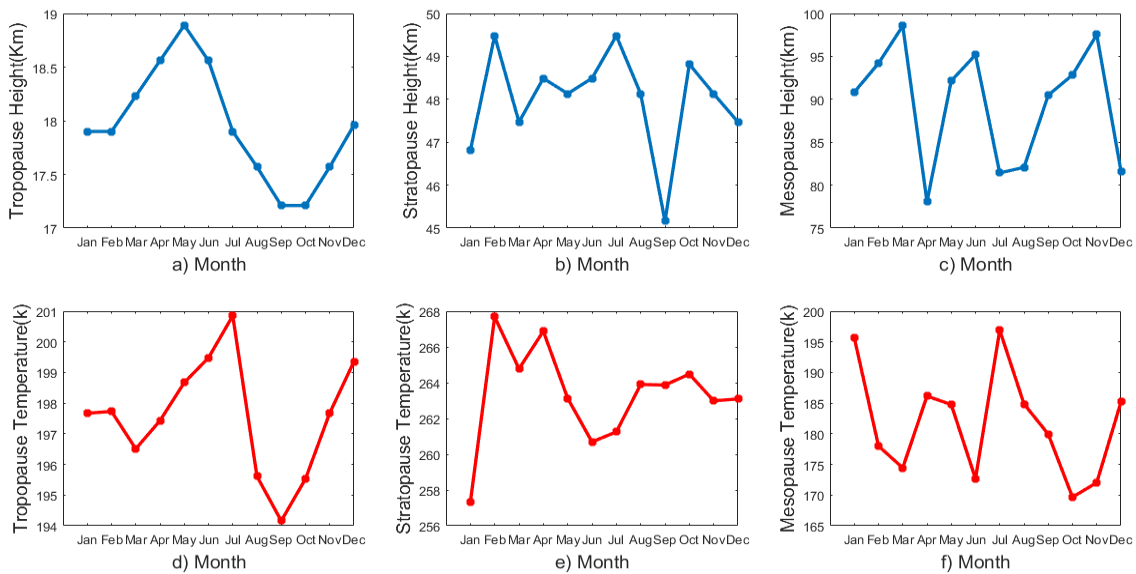


Figure 9. Mean of the monthly tropopause, stratopause, and mesopause temperature and height variation from SABER observation over Bahir Dar during 2016

From our observation, the variations of stratopause temperature trend lines have been decreased by (~3 K/year) from January to December 2016. The stratopause and mesopause decrement (cooling) trend lines of temperature has shown it might be due to the concentrations of greenhouse gases and depletion of ozone. Moreover, we have shown from the figure that the mesopause temperature trend line has been stronger variations in the atmosphere. This cooling trend line of mesopause temperature variation descends by (13 K/year). The negative trend is especially large in the upper stratosphere and the mesosphere, although uncertainties also increase with height. Similarly ^[14] reported that the stratopause temperature trend lines using LIDAR and rocket observations occurred and showed the largest cooling at the rate of ~3 K/decade.

As we have shown from the (Fig 9a, b, c) that the mean monthly tropopause, stratopause, and mesopause height have been demonstrated in an interval between (17.2-18.9) km, (45-49.5) km, and (77-98) km respectively. We have shown from the result the minimum height values (17.2, 45, and 77) km for tropopause, stratopause, and mesopause through the year in September, September, and April respectively. The minimum height of tropopause and stratopause recorded in the month of the September. Whereas the maximum height values (18.9, 49.5, and 98) km for tropopause, stratopause, and mesopause in May, February, and May respectively. The tropopause height in January and February becomes the same value in which 17.9 km. And In the same way, the tropopause minimum height value occurred in September and October. This variation of pauses height around the equator, at this region receives more radiation from the sun (source) and the more radiation reflected back to the atmosphere rise to a certain maximum height from the Earth's surface and atmospheric species. And it might be due to the greenhouse gasses effected, ozone concentrations, and the emission of energetic radiation from the surface of the sun that causes atoms and molecules to ionized and absorbed in the atmosphere.

The tropopause, stratopause, and mesopause, monthly temperature variation through the year in an interval between (194-201) K, (257-268) K, and (170-197) K respectively. Our results more clearly coincide with a similar stratopause previous studies by ^[3] in the Indian equatorial region, be located in the range between (255-270) K. The minimum temperature values are shown from the result (194, 257, and 170) K for tropopause, stratopause, and mesopause through the year in September, January, and October respectively. And in the same way, the maximum temperature values are (201, 268, and 197) K for tropopause, stratopause, and mesopause in July, February, and

July respectively. Those the increase and decrease height and temperature in all pause regions were observed in the warming and cooling effects.

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