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Tropospheric temperature climatology and trends observed over the Middle East

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ABSTRACT

In this study, we report for the first time, the upper air temperature climatology, and trends over the Middle East, which seem to be significantly affected by the changes associated with hot summer and low precipitation. Long term (1985–2012) radiosonde data from 12 stations are used to derive the mean temperature climatology and vertical trends. The study was performed by analyzing the data at different latitudes. The vertical profiles of air temperature show distinct behavior in terms of vertical and seasonal variability at different latitudes. The seasonal cycle of temperature at the 100 hPa, however, shows an opposite pattern compared to the 200 hPa levels. The temperature at 100 hPa shows a maximum during winter and minimum in summer. Spectral analysis shows that the annual cycle is dominant in comparison with the semiannual cycle. The time-series of temperature data was analyzed using the Bayesian change point analysis and cumulative sum method to investigate the changes in temperature trends. Temperature shows a clear change point during the year 1999 at all stations. Further, Modified Mann–Kendall test was applied to study the vertical trend, and analysis shows statistically significant lower tropospheric warming and cooling in upper troposphere after the year 1999. In general, the magnitude of the trend decreases with altitude in the troposphere. In all the latitude bands in lower troposphere, significant warming is observed, whereas at higher altitudes cooling is noticed based on 28 years temperature observations over the Middle East.

1. Introduction

Temperature is an important component for measuring the global climate change. It provides evidence of both natural impacts and anthropogenic forcing (Broccoli et al., 2003). Understanding the local changes in temperature is very important in climate research because climate model predictions show highly varying vertical profile trends and have to be adjusted for the region of interest (Thorne et al., 2011). In addition, temperature plays a major role in assessing whether human activity has altered the climate (Lanzante, 2007). Long term variation in the horizontal and vertical temperature structure of the atmosphere plays an important role in the detection and attribution of climate change. With increasing greenhouse gas concentrations, the surface and troposphere are consistently projected to warm, and a higher magnitude is projected in the troposphere (Thorne et al., 2011).

Several studies have investigated temperature trends in the troposphere regionally and globally by using data from different sources, e.g., using radiosonde data for monitoring the tropospheric temperature trends during the past decades (Angell, 1999; Christy and Norris, 2004; Box and Cohen, 2006; Mallik and Lal, 2011; Vinnikov et al., 2006; Christy et al., 2007; Brocard et al., 2013). Satellite based measurements are also used for studying the tropospheric temperature trends, particularly data from a series of microwave sounding units (e.g., Mears et al., 2003; Vinnikov and Grody, 2003). Similar investigations were also carried out using reanalysis data. All these studies show significant warming in the lower troposphere and cooling in the upper troposphere.

Several existing studies on surface temperature variability found significant warming at the surface level over the Middle East (Nasrallah and Balling, 1996; Elagib and Mansell, 2000; Zhang et al., 2005; Elagib, 2010; Elagib and Abdu, 2005; Rehman, 2010; Deniz et al., 2011; Donat et al., 2014). However, studies which analyze tropospheric temperature and trend from past decades are rare. The changes in temperature are not limited to the Earth's surface, but can extend to the troposphere and the stratosphere. The changes in temperature at the surface, in the troposphere, and in the stratosphere are major constituents of climate change. Therefore, the present study focuses on the climatology of temperature from surface to the upper troposphere and analysis of

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trend over the Middle East using radiosonde data from 12 observation stations acquired during the last 28 years.

The first aim is to know the tropospheric temperature characteristics and its climatology over the Middle East, which is not documented well in the literature. The second aim is to identify the sign of the trend in lower and upper troposphere over this region in the past 3 decades. Due to an increasing climate change related studies, this information over this region would be useful in the verification of warming and cooling effects simulated by climate models.

The paper is structured as follows. The next section deals with the brief description of the Middle East climatology. The description of the data used in present study is discussed in Section 3. Section 5 presents the change-point detection and estimation of trends. The temperature variability and its climatology, and trend analysis are discussed in Section 5. Finally, conclusions are presented in Section 6.

2. Region of study

The Middle East is characterized by distinct land mass, typically deserts, mountains and coastal areas. The characteristics of the region are unique with a combination of large scale circulation process which exerts a major influence on weather and climate (Medany, 2008). The climatic conditions vary greatly, depending on the season and the topography. The Middle East spans a large area of extent starting from tropics to mid-latitudes which involves distinct changes in climatic conditions. The climate of this region is characterized by hot and dry summers, droughts, and mild and moderately wet winters (Bolle, 2003; Lionello et al., 2006). The temperature change in this region is found to be most remarkable (IPCC et al., 2014). Large areas of the Middle East experience maximum temperature of over 50 °C (Hasanean, 2004). Recent studies showed the increase in surface temperature over this region (Donat et al., 2014). Several studies focused on the evolution of rainfall and its relation with teleconnections over the UAE (Ouarda et al., 2014; Kumar and Ouarda 2014; Basha et al., 2015; Chandran et al., 2015).

3. Data set

Radiosonde temperature time series contains valuable information for climate change research, because they provide longest record of upper air measurements. The data used in this study comes from routine operational radiosondes, which are launched regularly at 00 and 12 GMT, and are obtained from the U.S. National Climate Data Center Integrated Global Radiosonde Archive (IGRA) (Durre et al., 2006). Radiosonde measures pressure, temperature, relative humidity, and wind speed and wind direction vertically. In this study, only temperature data is used. The Middle East radiosonde stations with background topography are depicted in Fig. 1. The radiosonde stations in this study are selected based on the continuous availability of data without gaps. Large gaps in data are observed before the year 1985. Therefore, for avoiding temporal inhomogeneity, only the data acquired during 1985–2012 are considered. The description of the stations and completeness of data is presented in Table 1. The analysis was carried out by dividing the region based on latitude as a 5° bins i.e. 20°–25°N, 25°–30°N, 31°–35°N, and 36°–40°N. The whole analysis of this article is based on this average of stations' temperature data in the above latitude bands. Stringent quality checks are employed to remove outliers in the radiosonde data (Tsuda et al., 2006). The quality checks include the removal of outliers with more than mean $\pm$ 2 standard deviation. Since the observations are made twice a day, the estimation of trends can be sensitive to the time of observation, i.e. 00 and 12 GMT. To assess this uncertainty, the mean and standard deviation were calculated for each level for the difference of observations at 00 and 12 GMT respectively. For example, the mean and standard deviation at 850 hPa for the difference of the observations at 00 and 12 GMT is 0.2 $\pm$ 0.8 K. If the standard deviation exceeds the mean value, it suggests that biases are random and cancel out (Box and Cohen, 2006). The average daily observations are used in order to study the trends vertically. On an average, 95% of data is available in all stations.

4. Methods used for trend analysis

4.1. Cumulative sum method

The Cumulative Sum method (CUSUM) is a sequential analysis technique used to graphically observe the change points in time series data. For a given time series $x_1, x_2\ldots.. x_{n,}$ the cumulative sum of deviations at time k is given as

$$S_k = \sum_{i=1}^{k} (x_i - \overline{x}) \tag{1}$$

The positive and negative slopes indicate sequences of values above or below the mean value. The intersections of change of slope indicate change points.

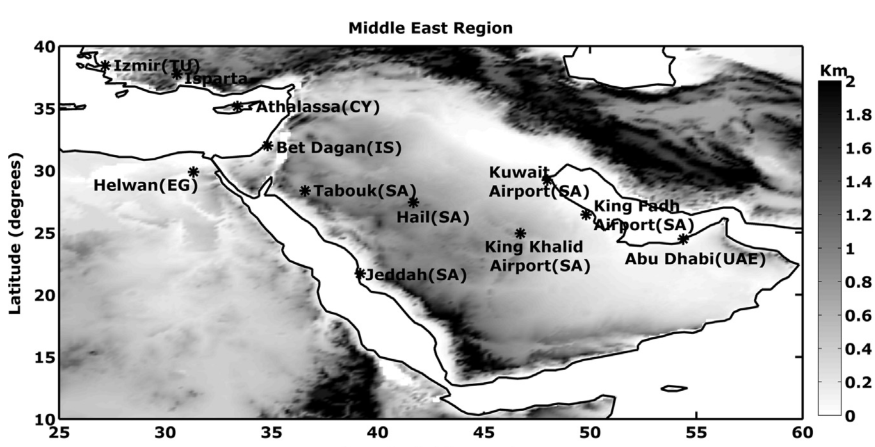

Fig. 1. Topography of Middle East region and locations of all radiosonde stations from which at least 28 years of homogeneous data were available to be included in this study.