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Using wavelet transforms to estimate surface temperature trends and dominant periodicities in Iran based on gridded reanalysis data

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ABSTRACT

In this paper, the discrete wavelet transform (DWT), the Mann–Kendall (MK) trend test, and the sequential Mann–Kendall test are applied to temperature series at different time scales in order to detect the long-term trends (1956–2010) in synoptic-scale surface temperatures in Iran, as well as the dominant time scales affecting these temperature time series. The relevant data was extracted from a gridded data file of the region (44°E to 63.5°E, 25°N to 40°N) and divided into 12 regular zones (of dimensions 5 × 5°), each of which was analyzed as an individual unit. The results of this research show that at the monthly, seasonal and annual time scales, the trends in temperature were significant and positive in all of the study zones. In addition, the 2-month and 4-month components were dominant at the monthly time scale, the 48-month component dominant at the seasonal time scale, and the 8-year and 16-year components dominant at the annual time scale. Also, the temperature trends in the northern, and especially central, regions of the study zones increased from west to east, and these increasing trends in temperature were most prominent for the spring and summer seasons. The methodology applied here is generally applicable and quite useful for studying both trends and the dominant time scales affecting climatic data series and could find significant applications in related fields.

1. Introduction

In recent years, global warming has accelerated; while the past 100 years saw an increase of about 0.75 °C, the rate of temperature increase over the past 25 years has been over 0.18 °C per decade (Grover, 2013). A common method for the assessment of climatic changes is the analysis of historical climatic data, in which trend detection and analysis play important roles (Trenberth et al., 2007; Adamowski et al., 2010). The literature on historic data-based hydro-climatic studies of climate changes is particularly rich, especially in the area of temperature trend analysis; for instance, see Rybski et al. (2006) and Pingale et al. (2014). Sun et al. (2008) analyzed monthly average temperatures in more than 700 stations in China from 1951 to 2001 with the Empirical Mode Decomposition method and showed that in the past 50 years temperatures have followed a significant positive trend in most parts of northern China, while the increase has not been significant in the south. Linear regression approaches and the Mann–Kendall test have also been used to identify trends in surface temperatures in various parts of the globe (for instance, see Makokha and Shisanya (2010), del Río et al. (2011), Marofi et al. (2012), and De Lima et al. (2013)). The Mann–Kendall test has also been used in combination with Sen's slope to analyze temperatures from 22 stations in the state of Florida (Martinez et al., 2012), while Sonali and Nagesh Kumar (2013) applied the sequential Mann–Kendall (MK) test to the analysis of

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temperature trends in India. These analyses, as a whole, have analyzed a wide range of temperature data (monthly averages, maximum and minimum temperatures, diurnal temperature ranges, seasonal and annual temperature patterns) and, for the most part, have indicated rising temperatures over the past several decades.

Temperature trend analysis in Modena, Italy using diurnal temperature range (DTR) showed that minimum temperatures followed a significant positive trend with an increment of 0.9 °C per decade from 1981 to 2010, while maximum temperatures revealed a significant positive trend with an increment of 0.8 °C over the same period (Boccolari and Malmusi, 2013). In Portugal, annual and seasonal temperature analyses for 23 stations from 1941 to 2006 indicated a positive trend in temperature (De Lima et al., 2013). Statistical and paleo-climatological studies in the central Mediterranean region also indicate that the recently observed patterns of warming have also occurred in the past (Diodato et al., 2013). In India, the sequential Mann–Kendall (MK) test revealed that the majority of trends in both minimum and maximum temperatures began after 1970, whether at the annual or seasonal levels (Sonali and Nagesh Kumar, 2013). Trend analysis of maximum and minimum temperatures in 19 synoptic stations in Iran in the period from 1966 to 2005 showed that the majority of trends in these two temperature indices were positive during the last four decades (Tabari and Hosseinzadeh Talaee, 2011). Marofi et al. (2012) used the Mann–Kendall and linear regression trend tests in the Karun–Dez watershed in Iran and found that the maximum temperature and the diurnal temperature range (DTR) followed a decreasing trend, while other temperature parameters followed an increasing trend. In another study in Iran, temperature trend analysis in 35 synoptic stations indicated that there is a significant positive trend in monthly temperature during the summer in the western and eastern parts of the country (Saboohi et al., 2012).

Trend evaluation is particularly difficult in non-stationary times series, since the stochastic structure of a time series can lead to trend-like features in the data, causing purely stochastic behavior to appear as a deterministic trend (Fatichi et al., 2009). Also, identifying trends in non-stationary temperature datasets is additionally complicated due to the nature of the data, as climatic changes affecting the temperature trends may occur in a non-monotonic and non-uniform manner; in addition, climate noise can also affect the variability and the trends in the data (Franzke, 2010). Since climatic elements and phenomena (e.g., temperature, precipitation, humidity, and hurricanes) are the results of various complex and often periodic processes in the atmosphere (Barry and Chorley, 2009; Lutgens and Tarbuck, 2013), evaluating the trend and periodic components of hydro-climatic time series separately provides more valuable results than those that can be obtained from direct trend analysis on the raw data. In recent years, signal processing methods have become widely used in the environmental studies field, especially in atmospheric and hydrological sciences; the wavelet transform (WT) is one such method that has been explored in detail over the past ten years (Adamowski et al., 2012, 2013a,b; Adamowski and Chan, 2011; Adamowski and Prokoph, 2013; Belayneh et al., 2014; Campisi-Pinto et al., 2012; Karran et al., 2014; Nalley et al., 2012; Nourani et al., 2013, 2014; Prokoph et al., 2012; Tiwari and Adamowski, 2013, 2014).

WT is a spectral analysis method that has great potential for the analysis of non-stationary (e.g., atmospheric and hydrologic) time series by analyzing both the trend and the dominant time scales affecting the data, which is very useful for interpreting the cyclical patterns in environmental data time series (Percival and Walden, 2000; Pišoft et al., 2004; Rao and Bopardikar, 1998; Sang, 2012; Torrence and Compo, 1998). For instance, Pišoft et al. (2004) used WT on Czech Republic climatic data and discovered that the temperature showed a positive trend from 1930 to 2001 with a dominant periodicity of 8 to 14 years. A different study used the Morlet wavelet to decompose air temperature time series and showed that some regions (e.g., Europe) seem to be under a 30 month-period oscillation, while other areas (e.g., northwestern USA) are under a 43 month-period, both of which are quite similar to large-scale atmospheric–oceanic phenomena, such as the North Atlantic Oscillation (NAO) and the El Niño-Southern Oscillation (ENSO) (Nicolay et al., 2009). In a different example, employing WT for temperature analysis in Adrar (Algeria) revealed that temperature and wind speed co-vary, especially at synoptic scales and intra-seasonal frequencies (Chellali et al., 2010). Nalley et al. (2013) used the discrete WT and the Mann–Kendall test for temperature analysis over the southern parts of Ontario and Quebec (Canada) for the period from 1967 to 2006 and showed that high-frequency components ranging from 2 to 12 months were more prominent in monthly and seasonal trends.

As can be seen, the vast majority of previous trend studies focused only on trends themselves and not on the determination of the dominant time scales affecting the time series and which might provide insights into the causes of patterns in the data. The main purpose of this research is therefore to determine how surface temperature varies spatially and temporally over Iran at a synoptic scale, as well as to assess which dominant time scales are most relevant in these variations and trends. These results will contribute to the elucidation of the interactions and interdependences between atmospheric and oceanic elements and events, as well as to the determination of how climatic parameters and related processes may change in the future. In this paper, we used WT to decompose Iranian temperature data at different time scales [monthly, seasonal (average of every three months), annual and discrete seasons (i.e., multi-year trends in each of spring, summer, fall and winter temperatures)] and then applied the Mann–Kendall trend test to the WT outputs in order to detect both the predominant trends and the dominant time scales affecting the temperature series.

The main source of data for this research was a high-resolution ($0.5 \times 0.5°$) gridded file of monthly surface temperatures in Iran obtained from the National Atmospheric and Oceanic Administration (NOAA). Such gridded files are useful and generally applicable for atmospheric, hydrologic, and other environmental spatial and temporal studies (Lackmann, 2012; Lauritzen et al., 2011; McGuffie and Henderson-Sellers, 2005). Applying WT transforms for the analysis of trends and time scales to a high-resolution temperature gridded file is unique, to the best of the authors' knowledge, and should offer significant advantages over the general practice of using point data from individual weather stations by allowing for a better data resolution for the analysis of trends and their spatiotemporal changes.