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SYNOPTIC ANALYSIS OF EXTREME COLD DAYS IN IRAN

Seyed Abolfazl Masoodian[1] and Mohammad Darand[2]

[1]Department of Climatology
University of Isfahan, Iran
e-mail: porcista@yahoo.ie

[2]Department of Climatology
University of Kurdistan, Iran
e-mail: m.darand@uok.ac.ir

Abstract

The aim of this study is to determine the influence of atmospheric circulation on the extreme cold days in Iran. The mean daily air temperature data from 663 weather stations in Iran during 21/03/1961 to 19/03/2004 are processed and interpolated through Kriging method for 18 $*$ 18 Km pixels. A matrix is obtained as a result (15705 $*$ 5214). Data of sea level pressure were collected from NCEP/NCAR, affiliates of National Centers for Environmental Prediction and The National Center for Atmospheric Research of the United States of America. In this study, an extreme cold temperature event is defined by Normalized Temperature Deviation (NTD) index. The data were ordered according to the magnitude and extremeness of cold events. First 500 coldest and the most pervasive days were selected as the sample by which the anomaly of sea level pressure was calculated. The coldest and the most pervasive cold occurrences in Iran are accompanying with four patterns of sea level pressure anomaly.

Keywords and phrases: sea level pressure anomaly, temperature, extreme colds, Iran.

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1. Introduction

One of the anticipated effects of climate change is the possible increase in both the frequency and intensity of extreme weather events such as extreme temperature [9, 12]. Extreme weather and climate events have significant impacts and are among the most serious challenges to that the society has to face [2]. Temperature extremes exert considerable influences not only on processes in nature but also on different aspects of socio-economic activities. The certainty has increased with respect to the extremes that would become more frequent, more widespread and/or more intense during the 21st century [10]; as a result, the demand for information services on weather and climate extremes is growing. Temperature extremes occur as a result of the interaction between large-scale atmospheric circulation and the characteristics of the locality (for example, topographical features and altitude).To better understand the underlying causes for the occurrence of temperature extreme events, it is important to identify the circulation patterns associated with these events [6]. Konrad [13] showed that planetary-scale circulation anomalies are found to be strongly related to the intensity of cold-air outbreaks than the synoptic-scale anomalies. The results of the studies conducted by Prieto et al [17] showed that a non-linear association between extreme cold days and the North Atlantic Oscillation (NAO) has been identified by using log-linear models. Mock et al. [15] by using a subjective classification methodology on January and July sea level pressure, and July 500 hPa height anomaly patterns in, identified 13 major atmospheric circulation patterns (26 pairs consisting of 13 synoptic: temperature and 13 synoptic: precipitation comparisons) that occur over Beringia. The composite anomaly maps of circulation, temperature and precipitation describe the spatial variability of surface climatic responses to circulation. Bonsal et al. [1] conducted an analysis on the spatial and temporal variability of the extreme temperature over Canada for the period of 1950-1998 and found great regional and seasonal differences. Kutiel et al. [14] analyzed the impacts of North Sea Caspian Pattern on the temperature and precipitation regimes in the Balkans, the Anatolian Peninsula and the Middle East. Rusticucci and Barrucand [19] studied the observed trends and changes in temperature extremes over Argentina. The results showed that negative trends were obtained in the number of cold nights and warm days per summer, while the number of warm nights and cold days increased at certain locations. The summer mean temperature is more sensitive to extremes than that of the winter one. Hassanean [7] studied the wintertime surface temperature over Egypt in relation to the associated atmospheric circulation and the results showed that a statistically significant negative relationship existed between winter temperature and winter NAO index can be observed. The extreme temperature of Iran has been described previously, but most of this work is focused on the description of general temperature characteristics [18] or temperature and circulation characteristics at larger spatial scales only [4, 5]. The synoptic and regional extreme temperature over Iran regarding to both the larger and smaller-scale, spatial variations and their correlation to atmospheric circulation, needs to be studied in depth. The purpose of this study is to identify and analyze the synoptic condition in extreme cold days in Iran.

2. Materials and Methods

In order to study the synoptic patterns of days with extreme cold, the mean daily temperature data of 663 synoptic and climatic stations during 21/03/1961 to 19/03/2004 were used. These data were obtained from Meteorological organization of Iran. The data were interpolated applying Kriging method based on $18 * 18$ kilometer pixels. Data of sea level pressure during the same period for 0 to 120°E longitude and 0 to 80°N latitude were obtained from NCEP/NCAR.

Extreme events are rare events that are outside the expected range of conditions and that are large with respect to some relevant norm. There is no single definition of what constitutes an extreme event. Some factors that may be taken into consideration in defining an extreme event include its magnitude, which involves the notion of exceeding a threshold, its meteorological uniqueness that involves the notion of the frequency of occurrence, and its environmental or economic impact or the death toll. The most general and simple, and so more widely used method for defining an extreme event of temperature is based on the definition of frequency of occurrence of the event. For example, according to definition of third assessment report of the intergovernmental panel on climate change [9] and many other studies on extreme events [11, 8], extreme event is one that is as rare as the 5-10% or the 90-95% quantile of a particular distribution. In this study, an extreme cold temperature event is defined by Normalized Temperature Deviation (NTD) index. This index is defined by Fujibe Fumiaki et al. [3]. First, the 43-year average temperature on each calendar day is calculated by

$$\overline{T_*(i,\ j)} = \sum_{n=1961}^{2004} T_*(i,\ j,\ n) \div N,$$

where i represents the day, j month and n the year. As mentioned earlier, the study period was 21/03/1961 to 19/03/2004, that is, 15705 days. The long-term mean temperature of each calendar day is calculated using the values of temperature for each specific calendar day of 43 years. Then nine-day running average is applied three times in order to filter out day-to-day irregularities. The departure from the climatic mean is given by

$$\Delta T_*(i,\ j,\ n) = T_*(i,\ j,\ n) - \overline{T_*(i,\ j)}.$$

The intensity of ΔT_* depends on the day-to-day changes of temperature, and based on season and area it will vary. Since on every specific geographical point the range of temperature variation may differ from day-to-day, the absolute value of temperature deviation from the long term mean of each day ΔT_* cannot be good reprehensive of the importance of extreme temperature. The same is true for identifying the importance of absolute values of temperature deviation from the long-term mean that is calculated for different geographical points. For instance, a +5 degree temperature deviation at points located in the southern parts of the country where the temperature variations are very trifling may be considered as a big event in comparison with the same temperature deviation at the points located in dry lands of central Iran, where the variations of temperature is great. Therefore, in order to compare the temperature deviation values of different times in a geographical point or different places at a certain time together, it is required to standardize the absolute values of temperature deviation with the help of temperature variance. As an index of day-to-day variability, the variance of ΔT_* in the 31 days centered on each calendar day is calculated as

$$\overline{\sigma^2(i,\ j)} = \sum_{n=1961}^{2004} \sum_{j'=j-15}^{j+15} [\Delta T_*(i,\ j',\ n) - \overline{\Delta T(i,\ j')}]^2 \div 31N,$$

$$\overline{\Delta T_*(i,\ j)} = \sum_{1961}^{2004} \sum_{j'=j-15}^{j+15} \Delta T_*(i,\ j',\ n) \div 31N,$$

and then nine-day running average is applied three times to $\overline{\sigma^2 * (i,\ j)}$, as made for the calculation of $\overline{T_*(i,\ j)}$. The normalized temperature deviation is defined by $x_*(i,\ j,\ n) = \Delta T_*(i,\ j,\ n) \div \overline{\sigma_*(i,\ j)}$ where $\overline{\sigma_*(i,\ j)} = \sqrt{\overline{\sigma^2 * (i,\ j)}}$. After calculating

Normalized Temperature Deviation (NTD) index, the data were ordered according to the magnitude and extremeness of cold events and first 500 coldest and the most pervasive days were selected as the sample. Composite maps of the sea-level pressure anomaly related to the 500 days were drawn using the gridded pressure anomaly values in order to illustrate the average atmospheric circulation patterns associated with extreme cold.

3. Results

The anomaly of the atmospheric circulation in Sea Level Pressure (SLP) is a key factor in better explaining some of the extreme events [16]. The results of cluster analysis on anomaly data of sea level pressure in 500 days indicate that four main sea level circulation anomaly patterns lead to extreme colds in Iran. Each pattern is characterized by two centers represented by positive or negative SLP anomalies. The analysis monthly frequencies of extreme cold days indicate a significant inter-monthly variability. Most extreme cold temperatures occur in the winter especially in January with 30 percent frequency (Figure 1). The least occurrence of extreme cold temperature is in the summer, especially in July with 0.8 percent frequency of the total extreme colds.

The first pattern features two large anomaly areas. A large negative anomaly, indicating below normal SLP values, is located over North Russia with a -11 hPa center. Higher than normal SLP values are found with a +13 hPa center over the North Sea. The positive anomaly associated with a strong high-pressure system over North Sea and Europe. Based on the location, relative magnitude and intensity of the two anomaly centers, this circulation pattern is labeled as the strong dipole of North Sea-North Russia. This circulation pattern is the most frequent in January with 11 percent frequency and does not occur in July. Figure 3 reveals the sea level pressure anomaly in this pattern. In this pattern, the strong pressure gradients resulting in cold air flow from northern Europe to Iran. Figure 4 shows temperature anomaly in Iran, in this pattern. An anticyclone is evident over the North Sea and Europe that extends to northwestward over Iran. The positive anomaly corresponds to a strong cold core in Northwest and Southeast of Iran. About 60 percent of the study area shows temperature anomaly from –4 to –6°C. In general, mean absolute temperature anomaly of Iran is –5.18°C during the occurrence of this SLP pattern.

The composite sea-level pressure anomaly map in the second pattern shows positive anomalies over northern areas of Russia with a +7 hPa center and negative anomalies centered in the North Sea with a –7 hPa center. Based on the location, the relative magnitude and intensity of the two anomaly centers, this circulation pattern is labeled the weak dipole of North Sea-North Russia. The sea-level pressure demonstrates a slight positive anomaly (between +6 and –6 hPa) over a vast area. This circulation pattern is the most frequent in December with frequency 5.4 percent. Almost 24 percent of the extreme colds occur due to the dominance of this pattern. In this pattern, the weak pressure gradients resulting in cold air flow from northern Russia towards Iran (Figure 5). An anticyclone is evident over the Northern Russia that extends northeastward over Iran. The positive anomaly corresponds to a strong cold core in Northeast Iran. However, due to the long distance and weakness of pressure anomaly in this pattern, the effects on temperature anomaly are less than that of the other patterns. Same as the first circulation pattern, the gulf and the Caspian Sea regions of the Iran show little negative temperature anomaly. In general, 57 percent of the country's area shows temperature anomaly from –4 to –6°C in the second pattern (Figure 6).

The composite sea-level pressure map for the third pattern shows two different anomaly areas: one positive anomaly, indicating higher than normal SLP values, that is located over Scandinavia with a +15 hPa center and another one that is negative and is found with a –3 hPa center over the Atlantic. The positive anomaly is in connection with a strong high-pressure system over Scandinavia. This circulation pattern is labeled the dipole of Scandinavia-Atlantic (Figure 7). This pattern has a 19.4 percent frequency of the total extreme colds. This circulation pattern prevails in January with a 5.4 percent frequency and does not occur in April, June, July and August. The temperature anomaly in Iran during the occurrence of this pattern is shown in Figure 8. An anticyclone is evident over the Scandinavia that extends to northeastward over Iran. The positive anomaly corresponds to a strong cold core in Northeast and Southeast Iran. In this pattern, about 37 percent of the study area shows temperature anomaly from –6 to –8°C.

The fourth pattern features two large anomaly areas (dipole of Iran-Scandinavia). A large negative anomaly, indicating below normal SLP values is located over Scandinavia with a –15 hPa center. A SLP higher than normal values is found with a +7 hPa center over Iran (Figure 9). The positive anomaly is in connection with a strong high-pressure system over Scandinavia. This pattern has a 25 percent frequency of the total extreme colds. This circulation pattern prevails in January with frequency percent and does not occur in June, July, August and

September. An anticyclone is evident over the Scandinavia and towards Northwestward over Iran. The positive anomaly corresponds to a strong cold core in Northwest and West Iran. About 16.8 percent of the study area shows temperature anomaly from –6 to –8°C. In general, the mean absolute temperature anomaly of Iran is –5.04°C during occurrence this SLP pattern. In this pattern, the gulf and Caspian Sea regions of Iran show less temperature anomaly in comparison with other parts.

4. Discussion

In this article, the extreme cold temperatures over Iran are analyzed with respect to circulation patterns based on the mean daily temperature interpolated data set obtained from 663 domestic meteorological stations with use of the Normalized Temperature Deviation (NTD) index. The conclusions of the study are summarized as follows:

The results of cluster analysis on anomaly data of sea level pressure in 500 days revealed that four main sea level circulation anomaly patterns lead to extreme colds in Iran.

Most extreme cold temperatures occur in winter especially in January with a 30 percent frequency. The least occurrence of extreme cold temperature is in summer especially in July.

It was detected that the pattern of positive anomaly of sea level pressure on North Sea-North Russia has the greatest effect on extreme cold temperatures in Iran.

For all circulation patterns, the negative temperature anomaly in the gulf and Caspian Sea regions is trifling due to the atmospheric humidity.

Finally, by analyzing the 500 extreme cold temperature cases, this study suggests an increased practical application of the anomaly in sea-level atmospheric circulation in predicting extreme cold temperature occurrences.

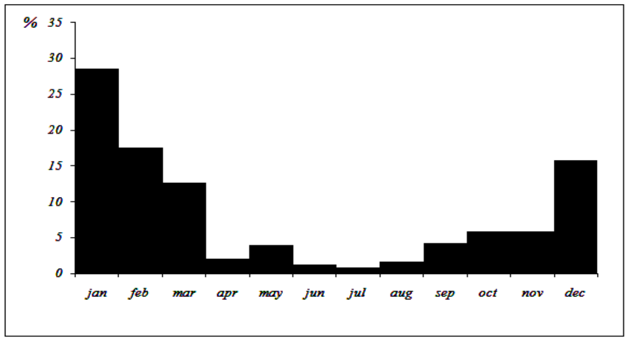

Figure 1. Monthly frequency of extreme cold temperatures during 21/03/1961 to 19/03/2004.

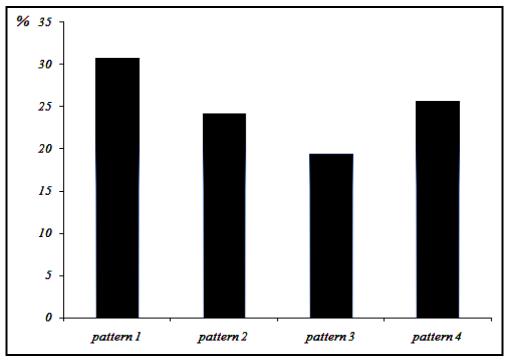

Figure 2. Frequency of each SLP anomaly circulation pattern during 21/03/1961 to 19/03/2004.

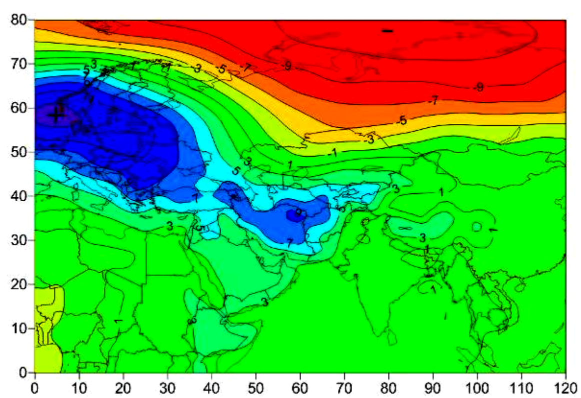

Figure 3. Sea level pressure anomaly, pattern No. 1.

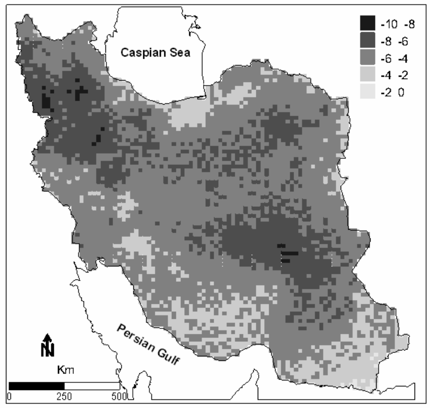

Figure 4. Temperature anomaly over Iran during occurrence of pattern No. 1.

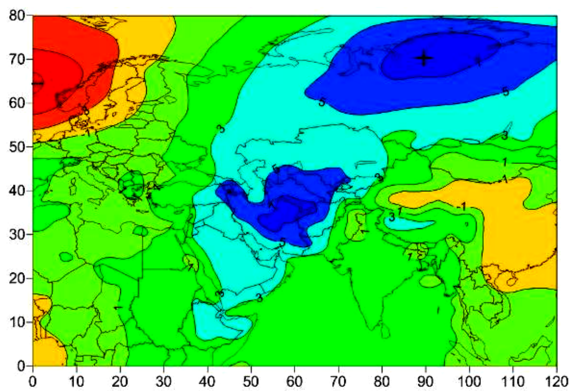

Figure 5. Sea level pressure anomaly, pattern No. 2.

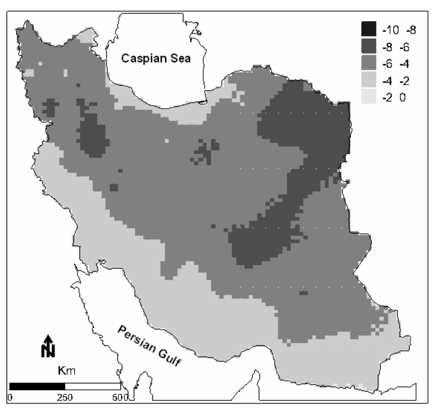

Figure 6. Temperature anomaly over Iran during occurrence of pattern No. 2.

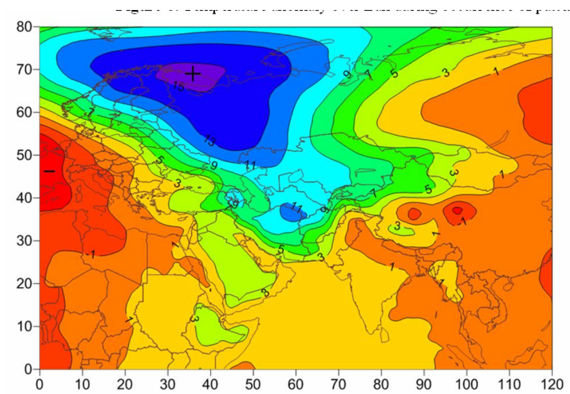

Figure 7. Sea level pressure anomaly, pattern No. 3.

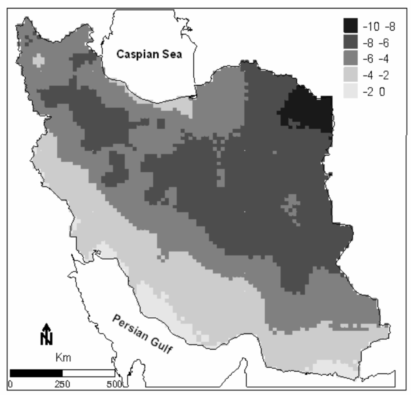

Figure 8. Temperature anomaly over Iran during occurrence of pattern No. 3.

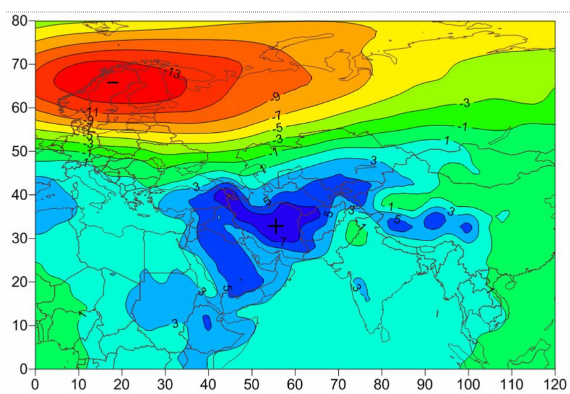

Figure 9. Sea level pressure anomaly, pattern No. 4.

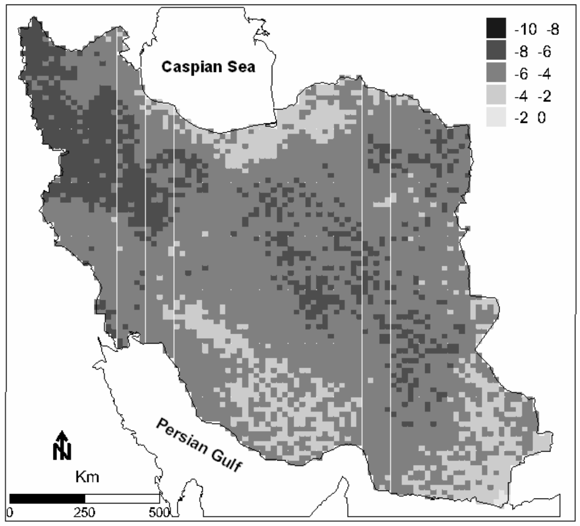

Figure 10. Temperature anomaly over Iran during occurrence of pattern No. 4.

Table 1. Monthly percentage frequency of SLP anomaly circulation patterns during 21/03/1961 to 19/03/2004

	Pattern No. 1	Pattern No. 2	Pattern No. 3	Pattern No. 4
Jan	11	4.2	5.4	8
Feb	5	3.4	4.6	4.6
Mar	4.4	1.8	3	3.4
Apr	0.2	0.8	0	1
May	0.8	2.4	0.4	0.4
Jun	0.2	1	0	0
July	0	0.8	0	0
Aug	1.2	0.4	0	0
Sep	2	1.2	1	0
Oct	0.8	1.6	2	1.4
Nov	1.6	1.2	0.4	2.6
Dec	3.6	5.4	2.6	4.2
	0.30	0.24	0.19	0.25

Table 2. Percentage area of each temperature deviation in Iran during 21/03/1961 to 19/03/2004

	0 to –2	–2 to –4	–4 to –6	–6 to –8	–8 to –10	Iran Mean Normalized temperature
Pattern N0. 1	0.3	15.5	60	23.6	0.6	–5.18
Pattern No. 2	0.1	29	56.4	14.5	0	–4.79
Pattern No. 3	3.8	24	33.2	36.7	2.3	–5.10
Pattern No. 4	0.1	14.4	68.8	16.8	0	–5.04

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