Studying Changes trend on Frequency of days with Pervasive and semi-Pervasive Frosts in Iran

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Abstract

Daily minimum temperature data from 663 synoptic and climatology stations for the period 1962 to 2004 and for the months of October to April from country's meteorological Organization was received. After receiving the data and preparing the database for minimum temperature, the isothermal maps for each day from 1/1/1962 to 31/12/2004 was interpolated for 9116 by Kirging method. In accordance with a spatial principal of frost into three categories: pervasive frost (occurring simultaneously in more than 65% of the total area), semi-pervasive frosts (frost ages occurred simultaneously in 25 to 65 percent of the total area) and the local frost (simultaneous occurrence of frost in an area of less than 25%) were classified. Then, using two methods of linear regression and Sen's Slope Estimator, frequency of days with frost pervasive and semi-pervasive scales at three monthly, quarterly and annually reviewed.

The results showed that the frequency of days with frost pervasive trend in the months of December, January, and annual winter has been a statistically significant decline. But there were plenty of days with frost semi-pervasive trend were significant only in January and it was positive for the changes. It means during the 43 years of the study the number of days with semi-pervasive frosts has increased. So while the number of frost masses has decreased in January the number of part-pervasive frosts is added. The same rule for other measures of monthly, quarterly and annual is also there.

Keywords: Pervasive Frost, Semi-Pervasive Frost, Sen's Slope Estimator, Linear Regression, Iran, Trend

1 Introduction

Changes in extreme climatic events can affect human societies, ecosystems and wildlife in many ways (Parmesan et al., 2000). One of these extreme events has different horrible effects on human activities, plants, and animal life is the nightly below zero degrees Celsius temperatures, which is often referred to as frost days. Surely, the first sector possibly gets affected in future by the extreme events is the agricultural sector; because this sector gets the largest effect of the surroundings and especially the climate (Esmaili et al., 2011). It is expected due to climate change and warming, forest areas lead to the north. So the geography of agriculture in these areas will be affected by climate change (Woodward, 1994). Also studies results of intergovernmental panel on climate change (IPCC) suggest that the most significant consequences of climate change on agriculture will include (Esmaili et al., 2011):

- The climate crisis,
- Higher latitudes, warming up
- Reduced water availability
- Monsoon progress toward the pole.

So studying the changes trend of this climate extreme event and detection of change direction ahead of it can be helpful a lot in policy making of future agriculture sector. Several researchers have been studying the changes trend of this extreme climate event in cast of frosting days, growing season duration, daily minimum temperatures, first and last days of frost replacement, and extreme colds and have reached different results too. So Heino et al.(1999) found evidences about reduction in number of frost days after the 1930s in central and northern Europe, this reduction is in accordance with intensified rise in minimum temperatures of winter in Europe completely (Easterling et al., 2000). Also in Europe from 1959 to 1993 the average of 10.8 days has added to growing season duration (Menzel and Fabian, 1999). Trends of extreme minimum temperatures suggest the increase of 2/5 ° C in China for the period of 1951-1990 in the winter (Zhai et al., 1999). Summer in the country of Estonia has become significantly longer, while winter about 30 days has become shortened (Jaagus and Ahas, 2000). Frequency of cold nights significantly between 10 and 20 days from 1951 to 1996 in various parts of New Zealand has dropped (Salinger and Griffiths, 2001).

Schwartz and Reiter (2000) concluded that late spring frost events in North America during the twentieth century have been replaced into the early spring. But this move was highly variable and non-linear. Baron et al. (1984) agreed that when in spring, frosts occur late, in Massachusetts frosts will occur in autumn sooner. Making a systematic relationship is the result of a 70-year period study, between beginning and end of the frosting data.
Also, till the peak time of warming in northern hemisphere in 1940, a reduction in number of days of the growing season has been observed in the mid-western of United States (Brown, 1976). Growing season in the U.S. Minnesota state during the early twentieth century due to displacement of the first early frost and the last late frost has been increased. But this increase has been different among the stations of the study (Skagges and Baker, 1985). Brinkmann (1979) showed that during the period between the years 1985-1990 growing season in Wisconsin is increased. Sharatt (1992) also acknowledged that growing season duration in several stations were longer in the twentieth century. Cooter and LeDuc (1995) showed that the frost-free season in the north east of United States, presently starts 11 days earlier than the 1950s. Also, DeGaetano (1996) has obtained significantly trends in decrease of extreme cold days around the same area. In Illinois in the last hundred years the growing season has increased almost a week, which is a result of early spring frosts, while the date of the first frost of autumn practically has been constant and no change is viewed (Robeson, 2002).
In Iran in recent years, extensive studies on the effects on the behavior of long-term climatic changes were undertaken. So most of these studies have acknowledged the trend of minimum temperatures rising (Jahanbakhsh and Torabi, 2004; Rahimzadeh and Asgari, 2004; Mohammadi and Taghavi, 2005; Azizi and Roushani, 2008; Alijani et al., 2011), But it should be pointed out that this increase trend in minimum temperatures wasn't in a size and shape. Furthermore, a shift in the core area of the cold waves has been observed in the west and north west of Iran, as displacement of latitude about 35 degrees has been toward the higher latitudes of 36 degrees (Alijani et al.. 2011). Sedaghat Kerdar and RahimZadeh (2007), also, have investigated the changes in plant growth duration in the second half of the twentieth century for 16 weather stations based on 3 Extreme Indices: the number of frost days, the number of the ice days and the period of growth. The results of this research show that the increase during the growing season, especially in the northern half of the country's most stations so that the three stations of Kermanshah, Mashhad and Tehran, respectively, with an average of approximately 12, 9 and 7 days had the greatest increase. Following the increase in the length of growing season, they trend have also seen a reduction in the number of frost days, 7 days in Tehran, Isfahan, Mashhad and Shiraz 4 days have reported as a reduction in the number of frost days. Esmaili et al. (2010) also used the Statistical downscaling models to examine changes during growth and frost period duration for the last two frost periods (1355-1384) and future (1389-1418) for three stations of Mashhad, Sabzevar increase in growing period duration and Torbat-e-Heidarieh decrease in growing period duration were observed. The research results show that both Mashhad and Sabzevar stations had increase in growing season duration and Torbat station had decline during the growing season.But all three stations during the ice age have had a reduction of 15 to 16 days that the authors conclude that the reasonably result of global warming.
Several statistical methods for analysis of time series trends has been presented that can be categorized in two groups of parametric and nonparametric methods. Nonparametric methods are based on the difference between the observed data so that this method is independent of a statistical distribution, and for those series have much skewness or kurosis is better than parametric methods (Hejam et al., 2008). In this study, using the Mann-Kendal Non-Parametric Methods and Sen's Slope Estimator, changes trend of Pervasive and semi-Pervasive Frosts days as a marker for the detection of changes in Iran's climate will be discussed. So, in part of "materials and methods" the way to separate the pervasive frost days of semi-pervasive frosts will be explained. The results of these two methods will be analyzed.

1.1 Datasets

In this study to identify and detect the frequency changes trend of Pervasive and semi-Pervasive Frosts data related to daily minimum temperatures of 663 synoptic and climatology stations for the period of 1962 to

2004 and for October to April by Iran Meteorological Organization were received. After receiving the data and preparing the database for minimum temperature, the isothermal maps for each day from 1/1/1962 to 31/12/2004 were updated by Kriging Interpolation method for 9116 days. It is noted that the number of stations in each of the years studied were different. So that the number of synoptic and climatology stations in 1962, has been 122 stations (Figure 1), and in 2004, 663 cases (Figure 2), respectively.

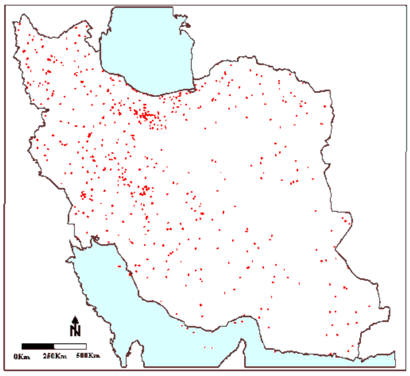

Figure 2 - Location and distribution of synoptic and climatology stations surveyed in 2004 (number of stations 623 stations)

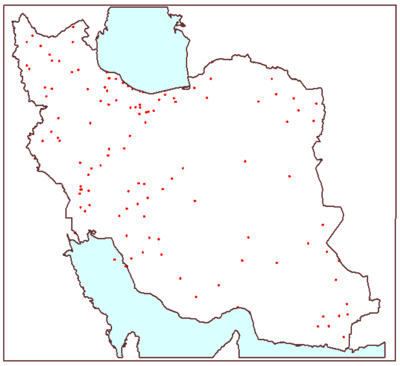

Figure 1 - Location and distribution of synoptic and climatology stations surveyed in 1962 (number of stations 122 stations)

In the following frosts (i.e. the days with temperatures equal to or less than zero degrees Celsius) are divided into three groups: partial frosts, semi-Pervasive Frosts, Pervasive frosts, and each one in one of the following three groups are classified as follow:

- Partial frosts: They are frosts that the percentage of area associated with the frost is equal to or are less than 25 percent of the total area of Iran.
- Semi-pervasive frosts: They are frosts that the percentage of area having frost includes 25 to 65 percent of the total area of Iran.
- Pervasive frosts: They are frosts that the percentage of area having frost includes about 65 percent or more of the total area of Iran.

Figure 3 (a - c) for each of the above groups, for example, to learn a map of business processes is presented.

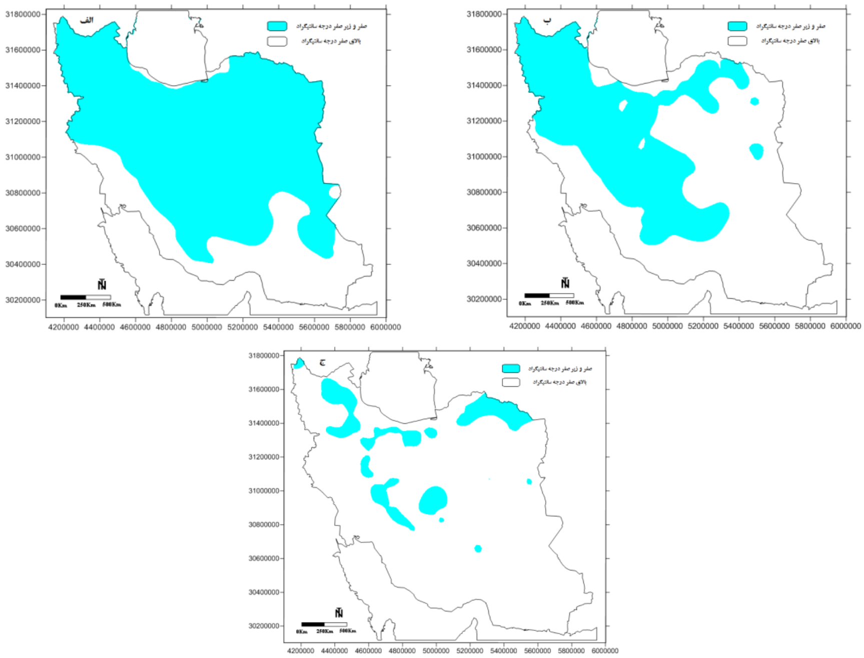

Figure 3 - An example of a map prepared for Iranian triple frost groups A) Pervasive frosts b) semi- Pervasive c) Local Frost

In following, the frequency of monthly, quarterly and annual days with ((semi-pervasive frosts and pervasive frosts)) was counted. Profile of Independent Monthly, quarterly and annual options is as follows:

- Annual (October to April)
- Seasonal (Fall] October and November], winter [December, January and February], and spring [March and April])
- monthly

Finally, in order to detect the changes trend of frequencies of days with semi-pervasive frost and pervasive frosts the Sen's slope estimator as a nonparametric method (Thiel, 1950; Sen, 1968) and the linear regression method as a linear method was used.

2 Results and Discussions

This study aimed to investigate the detection of changes trend of frequencies of days with semi-pervasive frost and pervasive frosts by Sen's slope estimator as a nonparametric method and linear regression as a linear method was used. The following is the results breakdown of two methods will be provided for semi-pervasive frost and pervasive frosts.

Trend changes frequency for days with pervasive frosts

In this study, days with pervasive frost was defined as a day encompassing area of more than 65 percent of Iran with temperature of zero degrees Celsius and below zero. On monthly scale, it was observed that in the months of April and October, no day with pervasive frost was observed. Therefore, theses two months were removed from the analysis trend of days with pervasive frost. In November, just in three years 1962, 1964 and 1995, respectively, 6, 2 and 2 days with pervasive frost were recorded. And the rest of the year happened to be the day observed with pervasive frost in November. In March, the days with pervasive frost were observed only in 7 years from the 43 years. These years are 1963 with one day, 1966 with one day, 1979 with four days, 1983 with two days, 1985 with six days, 1992 with 2 days 2003 with one day. Considering the very low frequency of days with pervasive frost in these two months and poor distribution of them over 43 years of study period no meaningful trend in their time series was observed .In Table Q.1, trend line slope, Qmin95 and Qmax95, upper and lower limit of the interval confidence as 95% and B is a constant factor. But the most frequency in days with frost is observed in January, February and December. The results of sen's slope estimator method on the time series for these three months showed that changes trend associated with frost pervasive days in Iran in these three months was negatively associated with the number of frost pervasive days has been declining during the last three months. However, this decrease is only significant at level of 95% in two months of December and January, and is not significant for February. Significance of both December and January is marked in yellow color in Table 1. But in seasonal scale, in both spring and autumn seasons because of the very low frequency of occurrence of these two types of frosts and this lowering has caused a lot of zeros in their time series. Therefore, the nonparametric model on time series is not possible. Thus, in Table 1, in the row corresponding to these two chapters no number exists yet. But time series of winter shows a reduction trend in the frequency of days with pervasive frost which in level of 95% this trend was significant. Also, the direction of changes trend of pervasive frosts in annual scale, according to Table 1 is negative, indicating reduction of such frosts in annual scale.

Table 1 –Results of Sen's slope estimator test in probability level of 5% for frequency of days with pervasive frost of Iran

Temporal Scale	Q	Qmin95	Qmax95	B
October	---	---	---	---
November	---	---	---	---
December	-0.071	-0.231	-0.021	4.86
January	-0.200	-0.375	-0.054	13.20
February	-0.043	-0.130	0	3.57
March	---	---	---	---
April	---	---	---	---
Autumn	---	---	---	---
Winter	-0.371	-0.637	-0.147	23.11
Spring	---	---	---	---
Annual	-0.400	-0.790	-0.140	24

The results of the linear regression on the time series of monthly, quarterly and annual frequency of days with pervasive frost was almost similar results of sen's slope estimator , respectively. In the two months of December and January reduction trend of days with pervasive frost is confirmed by the model with the difference that changes the slope of the linear regression for the month of December more sen's slope estimator. Also decreasing trend during winter, with pervasive frost, with decreasing ternd of annual scale is approved by linear regression is confirmed.

Table 2 - Results of linear regression test on 5% probability level for the overall frequency of days with pervasive frost

Temporal Scale		βmin95	βmax95	
October	---	---	---	---
November	---	---	---	---
December	-0.145	-0.276	-0.013	291.670
January	-0.222	-0.382	-0.061	449.762
February	-0.072	-0.196	-0.051	147.855
March	---	---	---	---
April	---	---	---	---
Autumn	---	---	---	---
Winter	0.439	-0.744	-0.134	889.287
Spring	---	---	---	---
Annual	-0.508	-0.816	-0.200	1026.437

The scatter plot in Figure 4 along with the frequency of days with pervasive frost of changes trend relating to the months of December, January, of the winter season is presented annually. The bold red line is the trend line of Sen's slope estimator and a thin black line is related to trend line of linear regression. What these figures show is that both estimates are very close to each other, except that the slope of trend line of linear regression is a bit more than the Sen's slope estimator method.

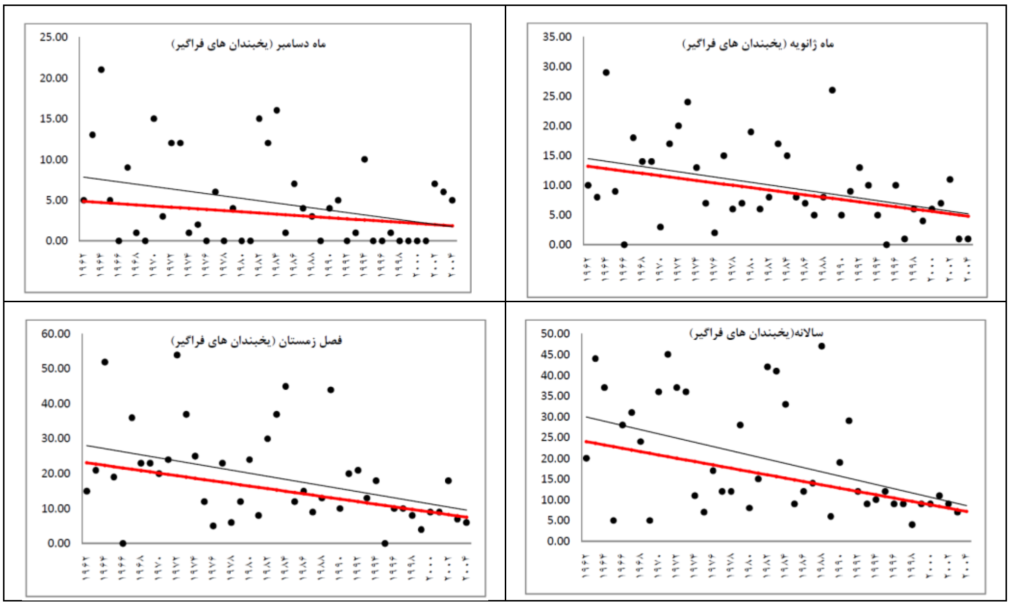

Figure 4, Graph of changes trend of days with pervasive frost. Top left graph: December, right above graph: January, lower left graph: winter and lower right graph: annual. Dark Red Line approximation of Sen's slope estimator and the thin black line is the estimation of linear regression

Changes trend in the frequency of days with semi-pervasive frost

According to the definition provided for semi- pervasive frosts, semi-pervasive frosts are those that cover 25 to 65 percent of country area by zero and below zero Celsius. Based on this, only on threshold of October in the year 1384, two semi-pervasive frosts have been observed and in other years no frost with these features were observed. April is the second month with little semi-pervasive frosts, so in 1965, 1967, 1981, 1997 have had only 1,2,4,1 cases of semi-pervasive frosts, respectively.

Therefore, these two months have been ignored in trend analysis. Then by performing the Sen's slope estimator over longer time series of other remaining months, with seasonal and annual time series, and frequency of days with semi-pervasive frost days was observed that changes trend of November and December months was negative and the other months had positive changes trend.

In seasonal scale, the trend for three seasons of autumn, winter and spring and also, in annual scale the changes trend has been positive. But in terms of statistical significance, only the increasing trend of January at level of 5% has been significant. And in other measures of monthly, quarterly and annual trends was not significant. In Table 3 the results of applying the Sen's slope estimator on the time series of days with semi-pervasive frost is prepared. As can be seen in table, in January the increasing trend has been significant and has been shown in yellow color.

Table 3 - Results of sen's slope estimator test on 5% probability level for the overall frequency of days with semi-pervasive frost

Temporal Scale	Q	Qmin95	Qmax95	B
October	---	---	---	---
November	-0.048	-0.177	0.031	5.81
December	-0.048	-0.200	0.105	19.14
January	0.143	0.012	0.294	15
February	0.050	-0.011	0.170	16.35
March	0.034	-0.060	0.143	4.72
April	---	---	---	---
Autumn	0.050	-0.178	0.035	5.90
Winter	0.143	-0.185	0.435	50
Spring	0.031	-0.066	0.143	4.88
Annual	0.077	-0.333	0.580	66.12

By performing linear regression on the time series of monthly, quarterly and semi-annual frequency of days with pervasive frost days, it was observed that the results are similar to results of execution the Sen's slope estimator. By observing table 4 and comparing it with the results presented in table 3. This similarity can be seen clearly. Therefore, parametric method of linear regression such as Sen's slope estimator proves the incremental trend of days with semi-pervasive frosts in January with significantly level of 5 percent. This significance has been specified in Table 4 with darker color.

Table 4 - Results of linear regression for the probability of 5% for frequency of days with semi-pervasive frosts.

Temporal Scale		βmin95	βmax95	
October	---	---	---	---
November	-0.077	-0.196	0.042	158.816
December	-0.061	-0.215	0.094	138.870
January	0.147	0.004	0.289	-272.423
February	0.077	-0.034	0.189	-136.761
March	0.041	-0.066	0.149	-75.423
April	---	---	---	---
Autumn	-0.077	-0.195	0.041	158.263
Winter	0.163	-0.086	0.413	-270.314
Spring	0.031	-0.082	0.143	-53.676
Annual	0.107	-0.275	0.489	-145.192

In Figure 5, the scatter plot of frequency about days with semi-pervasive frosts of Iran along with the trend line of two methods of Sen's slope estimator and linear regression for a single month whose changes trend was significant i.e. January month has been shown . As can be seen, the trend line resulting from the two methods are almost coincided, indicating that the results are identical.

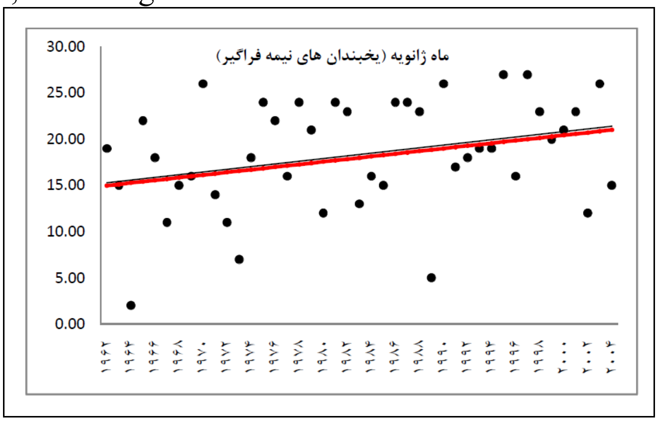

Figure 5 – Diagram of changes trend associated with semi-pervasive frost days of January. Dark Red Line is the approximation of Sen's slope estimator and the thin black line is the approximation of linear regression

Conclusions

Based on a local principle, the days with frost in Iran were classified in three categories: pervasive and semi-pervasive and locally. The frequency of these days were counted on three scales of monthly, seasonal and annual. Then, using statistical methods of Sen's slope estimator and the linear regression the trend changes of pervasive and semi-pervasive was studied in Iran.

The results showed that changes trend of frequencies of days with pervasive frosts of the months of December, January, and winter and annual has statistically significant reduced trend. It means during the 43 cases studied, the frequency of days with pervasive frost has been reduced. And this could be the result of a direct effect of warming, on reducing the number of this feature of frost in Iran. By studying the slope changes was recognized that changes trend respectively, in annual scale is much and in December is very less. But for frequencies of days with semi-pervasive frosts, it was observed that only in January the changes trend has been significant. And the direction of changes has been positive. It purports that during the 43 years of study, the number of semi-pervasive days has increased. So while the number of pervasive frosts of January has decreased, the number of semi-pervasive frosts has been added. For other scales, the same law prevails. Thus the increase in semi-pervasive frosts can be the signs of global warming are on Iran. A comparison of two methods of Sen's slope estimator and linear regression results also showed that the results of these two methods are very close and similar that shows capability of both in detection of changes trend.

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