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Trend of the Caspian Sea surface temperature changes

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Abstract

The interaction between sea and atmosphere has profound effects on the regions climate. Meanwhile, the sea surface temperature is considered as one of the most effective components of water bodies, and the controller of many atmospheric behaviors. Because of the importance of sea surface temperatures effects on atmospheric elements and also given the role of global warming on land and sea surface temperature rise, in this study, using water temperature data from AHVRR sensor of NOAA weather satellite, the climatic data bank was prepared for 718 sites across the Caspian Sea for a period of 30 years. Then, the trend of sea surface temperature change was studied for four points in Caspian Sea. The results showed that the temperature has changed because of the short-term climate fluctuations type and has a trend that can be seen in some monthly and yearly series. It was concluded from studying the behavior of U and U' components changes related to the average temperatures of four points on an annual basis, a significant mutation with a positive trend was seen and confluence point of the two sequences from 1995 to 2000 is considered as the change point. In conclusion of studying the trend of Caspian SST, it can be said that some parts of this sea is going through the trend of temperature rise and partial warming, that it is consistent with the results of many studies in which the findings are consistent with warming and changes in sea surface temperatures of aqueous areas.

Keywords

Caspian Sea, climate change, sea surface temperature, unsustainable Mann-Kendall test.

1. Introduction

Global warming and hence climate change, in terms of the nature of matter and the effects that has on different parts of the Earth's climate system, is the subject of various studies. The effect of different parts of large climate system covers stratosphere, hydrosphere, biosphere (UNESCO, 2007), and cryosphere (UNEP, 2007). With regard to the specific effects of climate

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change on these systems, especially its role in increasing the intensity of extreme phenomena and increasing the frequency of natural hazards occurrence, nowadays, many studies investigate the dimensions of these effects on the aspects of these systems' response to global warming as well as their direct impact on the biosphere and human life in particular. Sea surface temperature plays a crucial role in the Earth's climate (Guan et al., 2007; Zhou et al., 2008). Sea surface temperature also plays an important role on the global climate through the creation and distribution of heat and moisture. Along with the changes in sea surface temperature, the changes in average global temperature, changes in seas and atmosphere circulation patterns on a global scale, sea level, extreme temperature and precipitation and the extent of ice in seas has been observed (Ashfaq et al., 2010). Sea surface temperature (SST) is one of the most important sources of uncertainty in future climate change (Good et al., 2007). Climate models revealed that most of the variability observed in the average temperature of the global land during the years 2007-1880 had been due to the changes in global water surface temperature (Heorling, 2008). Hence in addition that knowledge of global warming event is important due to climate parameters, in some cases, by studying the phenomena caused by the drivers of water zones and according to features such as periodic frequency and the intensity of these phenomena, one can become aware of possible effects of climate change on different parts of the earth's systems. For example, each 0.6°C increase in sea surface temperature increases the maximum wind speed of hurricanes to 5 knots (Ahrens, 2009). The year 2005 had a historical record in the terms of occurrence of Hurricane in the Atlantic Ocean during 156 year. Before Hurricane season, sea surface temperature in the tropical regions of Atlantic was significant more than normal. The trend of lake snow precipitation of quintet lakes in United States shows an increase in lake snow during the twentieth century (Burnett et al., 2003). This feature was attributed to the warmer waters of the Great Lakes and reduced ice cover which coincides with an incremental warming trend in temperature of the Northern Hemisphere due to global warming. Good et al. (2007), in a study using data from satellite AVHRR to identify the trend of sea surface temperatures calculated linear trends of 0.18 ± 0.04 and 0.17 ± 0.05°C per decade, respectively, in data of night and day. Cook et al. (2008) in a study titled as the effect of dust and sea surface temperature forcing of the 1930s "Dust bowl" drought, considered drought of Central America areas to affect by the changes in sea surface temperatures in the eastern and tropical part of the Pacific Ocean. Water temperature alone affects the America drought and the abnormal precipitation of South America, with less intensity. Diaz et al. (1997) found a very good correlation between abnormal precipitation in Uruguay and south of Brazil and the sea surface temperatures in the Pacific and Atlantic oceans. Ting and Wang (1997) showed that there is a high correlation between precipitation and temperature fluctuations of surface waters in the North Pacific. Such relation is accepted by Mutai et al. (1997) in the Indian Ocean, Enfield (1996), Nobre and Shukla (1996), Paegle et al. (2001) in summer precipitation of South America, Nicholls (1989) in Australia's winter precipitation and water temperature of the Indian Ocean and tropical Pacific Ocean, Shukla and Misra (1977) for the precipitation of western and central parts of India, Aldarin et al. (2003) for precipitation of Indonesia and temperature of the Indian and Pacific Ocean, and Haylock et al. (2005) for winter precipitation in the United States.

In relation to Caspian Sea, some studies have also been done on surface water temperature; Javan Samadi (2009) in a study titled as “A statistical analysis of the Caspian Sea surface temperature using water temperature data of MODIS sensor of Aqua satellite” has studied temporal and spatial variations of the Caspian Sea surface temperature. He concluded using a Fourier analysis that almost in all sites, temperature change at different times follows the same pattern; in other words, in all stations the frequency spectrum follows a 12-month period pattern. Also, with the help of Fourier analysis, the Fourier coefficients were calculated and temperatures were predicted for the next year at 24 selected stations. Nazemosadat and Ghasemi (2005) in a study, by investigating the sea surface temperature data obtained from Russia oceanography organization for years 1951 to 1985 evaluated the effect of surface temperature fluctuations of Caspian Sea on the winter and spring rainfalls in northern and southwestern areas of Iran, and the effect of sea surface temperature of Caspian Sea on these areas and came to the conclusion that occurrence of hot conditions in Caspian Sea temperature, generally cause a 20% decrease in winter precipitation over the Caspian Sea Coasts and the northern parts of Fars and

Khuzestan provinces. In warm SST phase in winter, all the studied stations in the coastal zone of the Caspian Sea are associated with an increase in spring precipitation and in contrast, the occurrence of cold SST phase in winter leads to a reduction in spring precipitation at the western area of Caspian Sea. It should be noted that so far, no study has been done in the field of changes trend in surface water temperature of the Caspian Sea.

In this study, due to the important effects of water bodies temperature on atmosphere and also the trend of climate change, which undoubtedly affects the different systems of Earth, the behavior of data will be discussed with respect to the effects of global warming by preparing a relatively long-term databank (30 years) from the Caspian Sea surface temperatures and its statistical analysis.

2. Study area

In this research, the study area is Caspian Sea which is located in geographical location of 36° 33' to 47° 57' of north latitude and 46° 43' to 54° 53' of east longitude (Fig. 1). This lake with an area of 376,345 Km^2 is the world's largest water basin which is located in Eurasia (Alizadeh, 2004). Its greatest depth is 1025 m in the southern Caspian and its average depth is 208 m. This lake considering the expansion of its latitude is divided into three North, Central and South parts (Darvishzadeh, 2001; Alizadeh, 2004). This vast water body has an important role in modulating and changing weather parameter as well as the formation of unique regional climate in its margin (Mofidi et al., 2007; Ghayor, 2011; Mofidi et al, 2012; Janbaz ghobadi, 2011). Lack of meteorological and hydrology data in this geographical zone has caused the meteorological studies in this area to be very low or limited to coastal data or information related to buoy. There are only four buoys in the south of Caspian Sea, which have a statistical gap, lack of proper spatial coverage and lack of corrected data. Therefore, in scientific and administrative resources of the country in the field of Caspian Sea, very low and sporadic information is available.

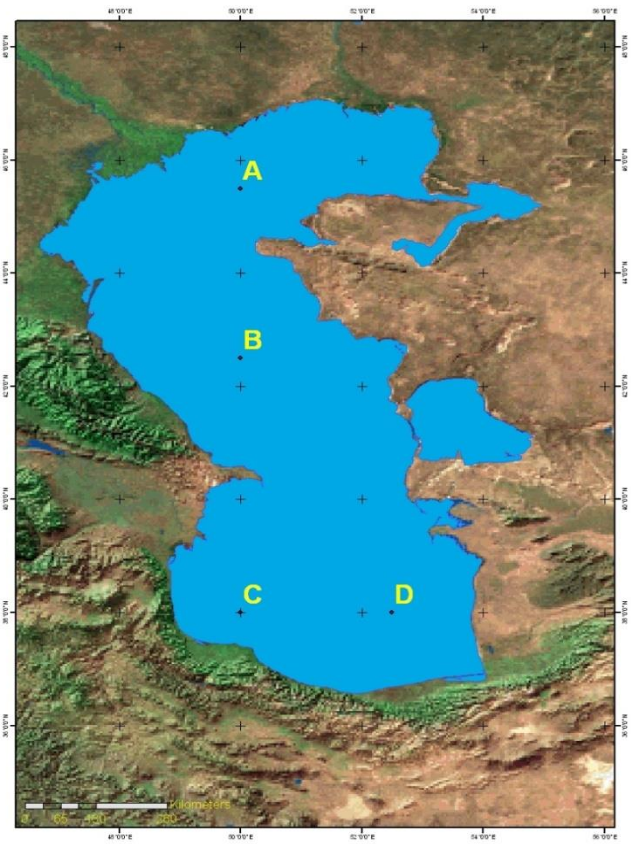

Fig. 1. Location of Caspian Sea and places where the trend of sea surface temperature was calculated for them.

3. Materials and Methods

Nowadays, the existence of satellite data is of a great help in covering the gaps in terrestrial data especially in some zones where access to data is facing the geographical barriers. For example, various studies is done in environmental research using satellites different outputs or for the study of variability in sea surface temperature regime of Caspian Sea and its relationship to phytoplankton, the satellite data were used (Kavak, 2012). Databank of AVHRR sensor has information about daily temperature of world's water areas surface temperature.

The quality of statistical data extracted from this sensor has been approved by some studies such as Jalalzadeh (2006). By examining the relationship between sea surface temperature obtained from data of AVHRR sensor of NOAA satellite and data obtained from field data collection in South Caspian, he measured the surface temperature from satellite data. There was a statistically significant relationship between satellite data and field data. Given that the relative error less than 40% between the two data is acceptable, the results showed that the relative error obtained in this study was a maximum of 21.20% which is acceptable. Also at all stations, measured values by the satellite were always less than the field data that it was consistent with the global results. In this study, the data bank of the world's sea surface temperature daily data was loaded and saved for 30 years since the use of this data was impossible due to their format; according to the model that was written in information system software, the data were called from data bank and their outputs was saved as Raster and Shape format. After this process, a bank with 10950 information layers was obtained in both formats, then with regard to geographical and hydrologic characteristics of the Caspian Sea, four sites were selected and monthly temperature information of Caspian Sea surface temperature were evaluated over a period of 30 years for the four sites.

In this study, the non-parametric Mann-Kendall test method has been approved by the World Meteorological Organization, as well as a large number of studies (Azizi and Roshani, 2003).

One of the conventional methods for analyzing time-series of climatic elements is to investigate the presence or absence of trends in them using statistical tests. Basically, the presence of trend in the time series of climatic elements may be caused by natural gradual changes and climate change or the effect of human activities (Brook et al. quoted by Jahanbakhsh Asl, 1390).

To determine the extent, direction and significance of the trend, Mann-Kendall was used. This method is used to investigate the randomness and determine the trend in the series. In order to ensure the data homogeneity test, a test (Run Test) was applied on sites temperature and by removing the inconsistent sites, eventually four sites were selected. For each of the studied sites, the annual series of temperature were selected. In the case of the presence of trend, data are non-random, and the following test is used to determine randomness of data:

$$T = \frac{4P}{n(n-1)}$$

where T is Mann-Kendall statistic and P is the total number of ranks larger than row n_i which is placed after that and obtained by following equation:

$$P = \sum_{i=1}^{n} n_i$$

And n is the total number of used statistical years. To determine the significance the T statistic is calculated as follows:

$$(T)_t = \pm tg \sqrt{\frac{4n+10}{9n(n-1)}}$$

which tg is equal to normal or standard (z) critical value with the test probability level and is equal to 1.96 with probability level of 95%. In the case of applying this value, $(T)_t$ will be equivalent to ±0.21. According to the critical values obtained for the $(T)_t$, different states will be observed as follows:

If $+(T)_t > T > -(T)_t$ or $+0.21 > T > -0.21$, no significant trend is seen in series and the series are random. Also, if $T < (T)_t$ or $T < -0.21$, it shows a negative trend in the series and if $T > (T)_t$ or $T > +0.21$, there is a positive trend in the series. To determine the direction, type and time of the change trend, there is a need for Kendall graphics test. For this purpose, usually a special table is used. In the mentioned table, first the statistical data are entered with respect to the year (first column) and in the second column the data will receive row number. Then in the third column, the desired parameter values are written and in the fourth column, the third column numerical values are set in ascending order. To complete the table, there is a need to calculate the coefficient t of Kendall test which is derived from the following equation:

$$t_i = \sum_{i=1}^{n} n_i$$

which its distribution function, in conditions of the governance of null hypothesis is asymptotically equal to the following mean and variance and U (t_i) is obtained from the following equation:

$$U(t_i) = \frac{t_i - E(t_i)}{\sqrt{Var(t_t)}}$$

$$E(t_i) = \frac{n(n-1)}{4}$$

$$Var(t_i) = \frac{n(n-1)(2n+5)}{18}$$

The values of U (t_i) are significant when an increase or decrease trend is observed in them and this depends on its value to be larger than zero or less than zero.

To determine the time of the change occurrence, it is necessary to calculate the component U (t'_i), in addition to U (t_i), from the following equation:

$$(t'_i) = \sum_{i=1}^{n} n_i$$

Other required component is the value of u' which is the equivalent of reversed u:

$$u_i' = -u(t'_i)$$

After the above equations and plotting the time graphs which there is a significant trend in the data, u_i and u'_i lines intersect. If mentioned lines intersect within the critical range, symptom of onset is sudden change and if there is no trend, the two sequences will be in parallel or with a few times encounter act in a way that does not lead to their change.

4. Results and Discussion

4.1. The Mann-Kendall test analysis on annual data

The results of Mann-Kendall test to check the yearly and monthly data is in Table 1. Calculations show that according to amount of Mann-Kendall statistic and the p-value in site A, there is a positive trend in all years except 1983, 1984, 1986 and 1991, which no trend does exist. There is a positive trend in sites of C, B and D in all years.

4.2. Mann-Kendall test analysis on monthly data

Based on Table 2, in January, according to the Mann-Kendall statistic in areas of A, B, the trend is exist; in site A there is a negative trend and in site B there is a positive trend, but in sites of D and C no trend is observed. Hence, in the central and northern Caspian, the data have trend, although their tendency is opposite. In February, there is no trend in areas of A, C, and D and it's only existed in area B and is a positive one. There is no trend in site A in March; however, in the central and southern areas of Caspian Sea in areas of B, C, and D, there is a trend and is a positive one. Due to these results, the central area of Caspian is the only area where its data have a trend with positive tendency in all winter. In the southern area of Caspian Sea in January and February, there is no trend and the only existing trend in March has a positive tendency. In April in areas of B, C, and D, there is no trend whereas there is a positive trend in site A. In May, there is a positive trend in A and B sites. But in areas of C and D there is no trend; in June and July, there is no trend in any of these areas. Northern half of Caspian Sea in transition phase of seasons has a warming trend in all months and this issue in summer has also been observed in other regions of Caspian, so that in August and September and October there is a trend in all regions and it is a positive trend; and in November there is a trend in areas of A, B, C, and D which is a positive one. As a result, an increasing trend is seen in the surface temperature of Caspian Sea that can affect the climate of marginal areas of this sea, especially the southern coasts. In December, in B, C, and A areas, there is a trend and in B and C areas it's a positive trend; however, in area A, it is a negative one, and there is no trend in area D.

Table1. Results of Mann-Kendall statistic and P-values for 4 different sites on the annual data

year	A		B		C		D	
	statistic	p-value	statistic	p-value	statistic	p-value	statistic	p-value
1982	0.242	0.30367	0.303	0.19262	0.242	0.30367	0.242	0.30367
1983	0.198	0.40948	0.26	0.27144	0.229	0.33591	0.321	0.16923
1984	0.185	0.44853	0.4	0.084991	0.369	0.11305	0.369	0.11305
1985	0.273	0.24372	0.364	0.11476	0.303	0.19262	0.364	0.11476
1986	0.168	0.49187	0.321	0.16923	0.321	0.16923	0.351	0.13049
1987	0.229	0.33591	0.29	0.21601	0.26	0.27144	0.321	0.16923
1988	0.212	0.37269	0.303	0.19262	0.303	0.19262	0.364	0.11476
1989	0.242	0.30367	0.333	0.14986	0.364	0.11476	0.424	0.064104
1990	0.242	0.30367	0.364	0.11476	0.364	0.11476	0.394	0.086471
1991	0.168	0.49187	0.351	0.13049	0.29	0.21601	0.351	0.13049
1992	0.212	0.37269	0.364	0.11476	0.333	0.14986	0.394	0.086471
1993	0.242	0.30367	0.333	0.14986	0.303	0.19262	0.333	0.14986
1994	0.242	0.30367	0.394	0.086471	0.364	0.11476	0.455	0.046745
1995	0.212	0.37269	0.333	0.14986	0.394	0.086471	0.394	0.086471
1996	0.26	0.27144	0.351	0.13049	0.351	0.13049	0.321	0.16923
1997	0.212	0.37269	0.364	0.11476	0.273	0.24372	0.364	0.11476
1998	0.212	0.37269	0.333	0.14986	0.333	0.14986	0.364	0.11476
1999	0.273	0.24372	0.394	0.086471	0.424	0.064104	0.424	0.064104
2000	0.273	0.24372	0.364	0.11476	0.303	0.19262	0.303	0.19262
2001	0.242	0.30367	0.333	0.14986	0.303	0.19262	0.333	0.14986
2002	0.212	0.37269	0.364	0.11476	0.394	0.086471	0.424	0.064104
2003	0.242	0.30367	0.333	0.14986	0.394	0.086471	0.394	0.086471
2004	0.242	0.30367	0.455	0.046745	0.364	0.11476	0.424	0.064
2005	0.212	0.37269	0.364	0.11476	0.364	0.11476	0.394	0.086471
2006	0.273	0.24372	0.364	0.11476	0.394	0.086471	0.394	0.086471
2007	0.273	0.24372	0.333	0.14986	0.364	0.11476	0.394	0.086471
2008	0.212	0.37269	0.394	0.086471	0.364	0.11476	0.485	0.033524
2009	0.212	0.37269	0.333	0.14986	0.364	0.11476	0.424	0.064104
2010	0.242	0.30367	0.364	0.11476	0.394	0.086471	0.394	0.086471

Table2. Results of Mann-Kendall statistic and p-values for different sites on a monthly basis

Month	A		B		C		D	
	p-value	statistic	p-value	statistic	p-value	statistic	p-value	statistic
January	0.03245	-0.284	0.013268	0328	0.54826	0.0814	0.38812	0.116
February	0.86594	-0.0246	0.0036	0.384	0.35802	0.123	0.11949	0.207
March	0.27653	0.145	0.0147	0.323	0.0295	0.289	0.022	0.303
April	0.06597	0.244	0.189	0.175	0.67979	0.0567	0.311	0.136
May	0.051	0.259	0.0147	0.323	0.311	0.136	0.523	0.0863
June	0.499	0.0912	0.85	0.027	0.821	0.0321	0.47589	0.0962
July	0.5735	0.0764	0.202	0.17	0.409	0.111	0.348	0.126
August	0.0427	0.269	0.0018	0.412	0.0034	0.387	0.002	0.407
September	0.0018	0.412	0.0011	0.432	0.000556	0.456	0.0018	0.412
October	0.0356	0.279	0.0016	0.417	0.0018	0.412	0.00036	0.471
November	0.0043	0.377	0.00386	0.382	0.0778	0.234	0.006	0.363
December	0.0716	-0.239	0.002	0.407	0.0324	0.284	0.2156	0.165

4.3. Mann-Kendall diagram test analysis to determine the type and time of change

For this, first Mann-Kendall graph is drawn using components of U and U' for all studied elements on an annual and monthly scale. Then, according to Kendall graphical test specification, the type and time of change was found that due to the large number of diagrams, some of them are in Figures 2 and 3. With studies that were performed at four sites on the temperature element at Caspian Sea, it is become clear that they have changed. This change is of the short-term climate fluctuations type and is a trend that can be seen in some monthly and yearly series. By studying the changes behavior of components U and U' related to different sites average temperature in an annual scale (Fig. 2), it is concluded that a significant trend has seen positive, and the confluence of the two series from 1995 to 2010, has been the changes time. By studying the changes behavior of components U and U' related to average monthly temperatures in different sites in Figure 3, there is a negative trend in site A in January during 30 years which from 2000 to 2007, a sudden mutation with the governance of negative trend can be seen. In January, in site B there is a positive trend during 30 years which a sudden mutation from 1998 has started with governance of positive trend. In February, in site B there is a positive trend during 30 years which a sudden mutation from 1995 has started with governance of positive trend. In March, there is a positive trend in site B during 30 years which a positive mutation has started since 1997 and in March, there is a positive trend in sites of C, D during 30 years which a mutation has started since 1999 with the governance of positive trend. In April, there is a positive trend in site A within 30 years which since 1997 to 2003, a mutation with the governance of positive trend can be seen. In May, there is a positive trend in site A within 30 years; a mutation in with governance of positive trend in 2004 and a mutant with the governance of positive trend in site B can be seen in 2002. In August, September, October and November within 30 years there is a positive trend. In December, there is a negative trend in site A during 30 years that a mutation with the governance of negative trend has been seen since 2003, and in December there is a positive trend in areas of B and C during 30 years, which since 1998 a mutation with the governance of positive trend can be seen.

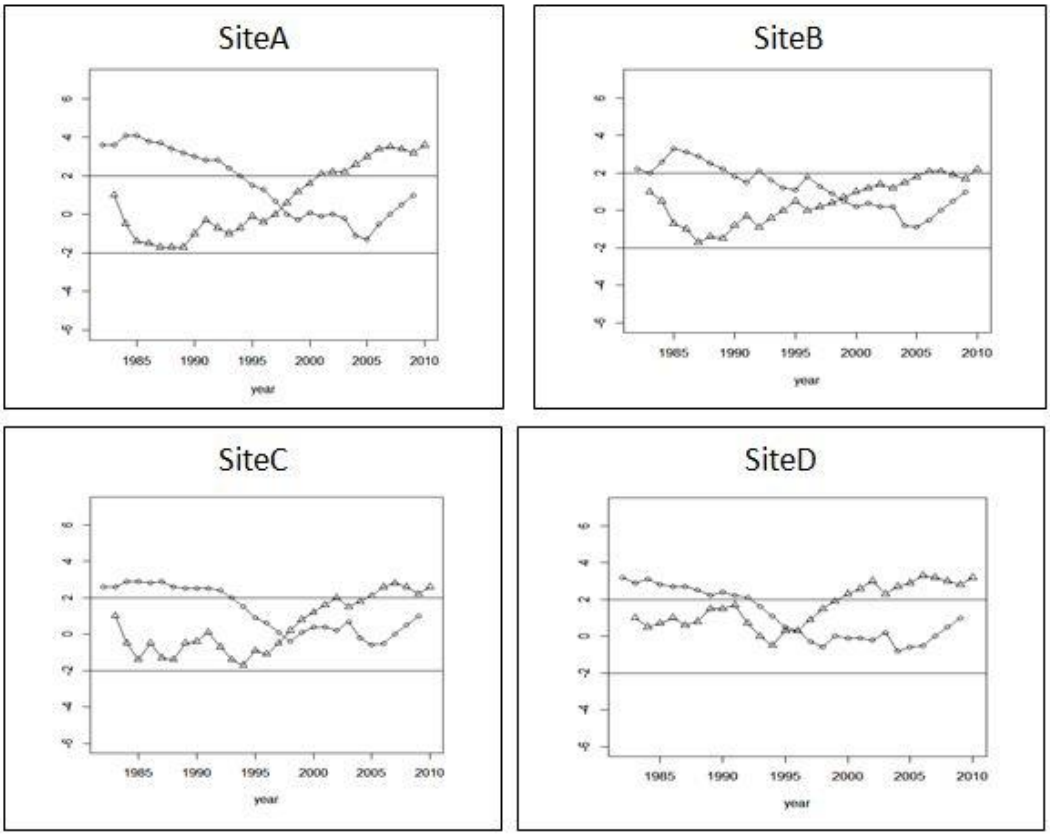

Fig. 2. Changes in u and u' statistics for the average temperature in different sites in an annual scale

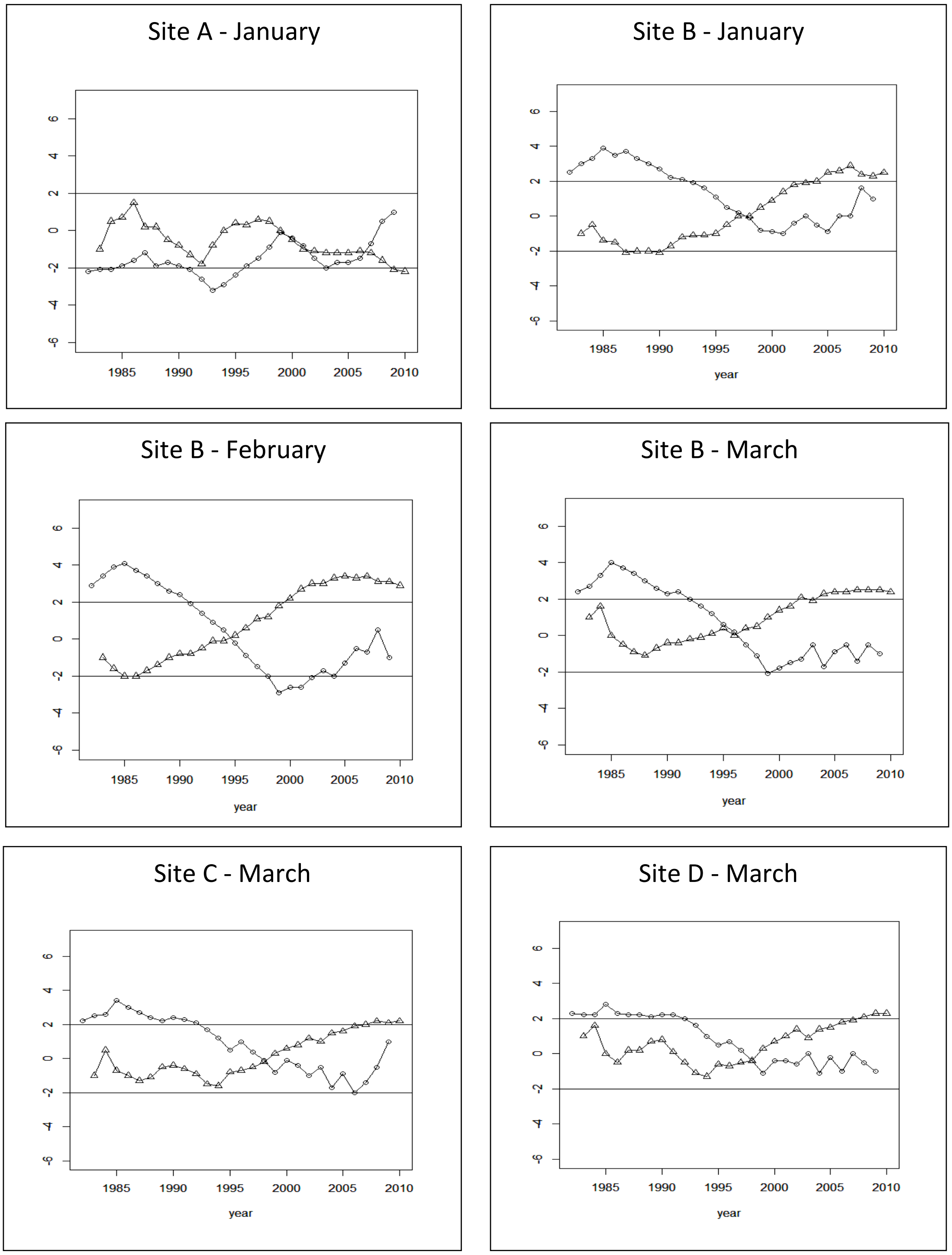

Fig.3. Changes in u and u' statistics for average temperatures in different points in a monthly scale

5. Conclusions

In the annual review of temperature changes trend of Caspian Sea surface, an increasing trend can be seen in all four areas. Also in monthly review it was found that there is a decreasing trend for northern Caspian in the three months of December, January and February and an increasing one for other month. In the middle and southern Caspian in most of the year months the changes trend is positive and increasing; however, months without change in trend in southern part of Caspian are more. In this area, for the first two months of winter, three months of spring and the first month of summer, no trend is observed for surface temperature changes. It seems one can conclude that it is the Middle Caspian in which the surface temperature shows a rising trend in most months of the year. Also, by studying other results of Mann-Kendall test, another significant result was obtained and it was the start of temperature changes mutation for each of the four Caspian areas since 1995 AD.

In conclusion, it can be acknowledged that some parts of the sea spend the temperatures increase and relative warming, in which this issue is in compliance with the results of many studies which their findings are consistent with warming and changes in surface temperatures.

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