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ABSTRACT

The relationship between climate indices and the Caspian Sea Surface Temperature (SST) are investigated, making use of the satellite measured SST during 1985-2005. North Sea Caspian Pattern (NCP) and NINO 3.4 index are shown to have a strong influence on the SST among the studied indices, in the studied February to May period. High correlation of SST with the climate indices suggests prompt response of the surface oceanic variables to the atmospheric forcing. Besides the linear relationships, nonlinear relationships are also studied using the Generalized, Unbiased, Interaction Detection and Estimation (GUIDE) algorithm, the results confirming similar predictions of Caspian Sea SST.

Key words: Caspian Sea, climate indices, North Sea Caspian Pattern, Southern Oscillation Index, Generalized, Unbiased, Interaction Detection and Estimation (GUIDE)

Running Title: Caspian Sea SST vs Climate Indices

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2. INTRODUCTION

Previous studies have investigated the relationship between atmospheric patterns and Caspian Sea variables. For example, [1] showed the effect of the North Atlantic Oscillation (NAO) on the Volga River discharge and consequently on the Caspian Sea level (CSL). The NAO pattern characterizes the motions of mid-tropospheric jet-stream over Europe, and therefore represents the eastward extension and the influence over European-Mediterranean region of the NAO pattern originating in the Atlantic sector. [2] investigated the integrated influence of the Southern Oscillation Index (SOI) on the CSL variability. The SOI is calculated using the pressure differences between Tahiti and Darwin. [3] identified the North Sea Caspian Pattern (NCP), an upper level atmospheric pattern defined by two centers at 500 hPa geopotential height, as another important tele-connection pattern affecting the Euro-Mediterranean and Caspian regions. Their analysis, based on Empirical Orthogonal Functions (EOF), demonstrated that the wind stress and air temperature over the Caspian Sea are strongly affected by NCP. [4] have studied the effects of NCP on the winter temperature in Iran and concluded that the NCP exerts significant influence on air temperature variability.

Understanding the regional response of the Caspian Sea climate to the large-scale atmospheric variability, as defined by climate indices, is important for predicting the future of the sea, including Caspian Sea Level variability, which is a major environmental concern in the region [5].

None of the prior studies have analyzed the effects of these indices on the seasonal variations of SST. This paper seeks to identify links between SST and atmospheric/oceanic indices over the Caspian Sea. Data and methodology are presented in section 2. The results of linear correlations and the Generalized, Unbiased, Interaction Detection and Estimation (GUIDE) algorithm are provided in section 3. Discussion and a summary of major findings are given in section 4.

2. DATA AND METHODS

This study is based on monthly mean SST and climate indices for the years 1985 to 2005. Here, a brief description of each data set is provided. Four climate indices are used: NAO, SOI, Nino 3.4, and NCP. The first three are obtained from [7]. Using the definition and formulation of [6], we recalculate the NCP index to extend its coverage to 2005. NCP is based on monthly mean geopotential height data at 500 hPa, which is available online [8]. The geopotential data are averaged over two centers: the North Sea (0º E, 55º N and 10º E, 55º N), and the North Caspian (50º E, 45º N and 60º E, 45º N). The NCP index is calculated by the normalized difference in mean geopotential between these centers.

The monthly SST data are obtained from the 4~km Advanced Very High Resolution Radiometer (AVHRR) Pathfinder SST version 5 [9]. These monthly SSTs are derived using data only with a quality flag of 7. For the analysis, mean monthly values are removed from climatological SST during 1985-2005. Before analysis of the SST data, a 4-point box-car filter is applied to smooth the SST and climate indices in time.

Linear correlations between climate indices and SST are calculated for different time and domain windows over the 21-year time period.
GUIDE is an algorithm for constructing classification and regression trees [10]. The detailed description of the GUIDE may be found in this web page; [11]. Here, we apply the Generalized, Unbiased, Interaction Detection and Estimation (GUIDE) algorithm by [10]. The goal of this regression tree is to predict or explain the effect of one or more climate indices on SST. GUIDE fits piecewise linear models for SST based on the climate indices. In essence, a regression tree is a piecewise constant or piecewise linear estimate of a regression function, constructed by recursively partitioning the data set and sample space

3. RESULTS

Fig. 1.a shows the time series of SST anomalies averaged over the entire Caspian Sea and its sub-basins (i.e. North, Central, and South Caspian Sea regions). Seasonal and inter-annual variations are evident. The whole Caspian Sea and its three sub-basins show similar oscillations during the 21 years period. While the SST anomalies are mostly negative before 1994, positive anomalies are observed after that year with only 2003 having a strong negative anomaly. Fig. 1.b shows the four climate indices (NCP, NAO, SOI and NINO 3.4). The negative correlation between SOI and NINO 3.4 is obvious in this figure. The NAO and NCP show similar behavior during the investigated period. Since the maximum correlation was seen in February to May period (see Table 1 and explanations in later paragraph), Fig. 1.c shows the February to May SST during 1985-2005, and Fig. 1.d shows climate indices for the same period. Positive SST anomalies in all sub-regions of the Caspian Sea are evident in Fig. 1.c during 1995, and there is a negative anomaly in 2003. Inverse of the NCP index is overlaid (green line) in this figure. Except for the 1985-1990 period, the NCP index and Caspian Sea SST (especially with the South Caspian SST) show quasi-synchronous variations. The correlation coefficient between these two time series is 0.5. However after 1990, the correlation increases dramatically and reaches 0.75 (significant at $P < 0.05$). The warm SST periods correspond to the negative NCP index, and cold SST periods correspond to the positive NCP index. During the positive phase of the NCP index, northeasterly winds are dominant and bring cold air to the region, consequently causing a decrease in SST. Similarly, during the negative phase of the NCP index, the winds blow dominantly from a southwesterly direction bringing the warm air of the Sahel region to the Caspian Sea and thereby result in increases in SST.

The correlation coefficients between SST and climate indices at different time intervals are also calculated, while the results are only shown for the NCP index in Table 1. This table shows the correlation coefficients at different lags (the lag number shows the year, the correlations were calculated by setting back the time series) between NCP index and SST averaged over three basins: North Caspian Sea (NCS, 44º N to 47º N), Middle Caspian Sea (MCS, 40º N to 44º N), South Caspian Sea (SCS, 36º N to 40º N). The correlation coefficients have lower values before the year 1990, and therefore we choose to show the correlations only for the more recent time period from 1990-2005. Thus, there are total of 64 points (16 years × four months) on the grid to compute the correlations.

There is no significant correlation between SST and NCP in the NCS. The correlations are higher in the MCS, and the highest correlation amplitude observed in this basin occurs in the February to May period, a correlation coefficient value of -0.68 at lag zero. The non-zero lag correlations are similar to those at lag zero. Correlations are relatively higher in the SCS compared to MCS, with the highest correlation amplitude observed again in the February to May period, a value of -0.70 at lag zero. The correlation coefficients decrease when January months are included in the time series, perhaps due to ice reducing coverage of SST data in winter. There is no significant correlation between SST and NCP index in the other monthly subsets (not shown). Interestingly, there are relatively higher correlations in the May to August (MJJA) period in three basins of the Caspian Sea. The same analyses are also conducted for the other climate indices (not shown), and it is found that the correlations are only significant in the February to May period.

Fig. 2 shows the square of the correlation coefficient (R^2) between SST and climate indices (i.e NCP, NAO, SOI, NINO 3.4) in the time period February to May for 1990-2005 over each grid point in the Caspian Sea. The R^2 values are very weak in the shallow northern part for all of the climate indices. This is probably due to cloud masking and the ice formation in this region. Similar effects are generally evident for the coastal region of the Sea. The R^2 value between SST and NCP increases in the Middle Caspian Sea (Fig. 2.a). Patches of higher correlations are evident in this basin. There is no significant correlation between SST and NAO (Fig. 2.b); SST and SOI (Fig. 2.c). The R^2 has higher values in the SCS for NCP and NINO 3.4 indices (Fig. 2.d), and the maximum R^2 values (~ 0.6) are found in the western part of the basin for NCP and eastern part of the basin for NINO 3.4.

4. DISCUSSION

The impact of climate indices on SST variations is examined based on linear regression. A broader scope considers possible nonlinear relationships between climate indices and SST. In such analysis, combined effects of four climate indices can have different influences on SST. We used a regression tree model to determine the influence of the climate indices in driving the SST variability by year and month..

In the GUIDE analysis as applied to this investigation, we use climatological monthly means of the dependent variable (SST) and four main predictors (NAO, NCP, SOI, and NINO) for the time period from February 1990 to May 2005. There are missing values of SST at some grid points, depending on the time of the year, so they are not used in the analysis.

The GUIDE algorithm is applied to fit several regression tree models for predicting SST using the variables year, month, NAO, NCP, SOI, and NINO. Each GUIDE model partitions the space of the climate indices into many rectangles and then fits a linear model to each partition using stepwise regression. The purpose is to determine which climate index is more related to SST, depending on the time and month of the year. In the analysis, several different combinations of variables were used. The quality of a model can be judged by its R^2 value, which is always between 0 and 1, with 0 being very poor and 1 excellent. Note that R^2 is the proportion of variance explained by the regression model.

The results in Table 2 reveal that the R^2 values are not very high, even when all four variables are included. On the other hand, R^2 does not change appreciably if only one of the four indices is used, with or without year and month. If desired, we can rank the indices by their R^2 values. By this measure, indices NINO and SOI are essentially tied for first place, followed by NCP. It is quite obvious that the NAO index has the least influence on Caspian Sea SST, although its influence is not extremely small relative to the other indices.

Among the four climate indices studied in this paper, there is no significant correlation between SST and the NAO and SOI indices over the Caspian Sea. Relatively high correlations are observed between the SST and the NCP and NINO 3.4 indices. NCP and NINO 3.4 represent the main atmospheric tele-connection pattern affecting the Caspian Sea SST in the February to May period. Although there is no significant correlation between SST and NCP index in the NCS, higher correlations are observed in the MCS and SCS. Similar results are found by GUIDE algorithm for predicting the SST based on the four indices. The GUIDE algorithm results show that there is an integrated, synchronous response of the SST to the four climate indices studied in this paper.

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Table 1 Correlation coefficients between NCP index and area averaged SST time series for different time windows [(a)] and lags for each three basins [(b)] of the Caspian Sea. The higher correlations are statistically significant according to the Student`s t test with significance level 0.05.

Reg.	Lag	JFMA	FMAM	MAMJ	AMJJ	MJJA	JJAS	JASO	ASON	SOND
NCS	3	-0.51	-0.44	-0.37	-0.39	-0.51	-0.38	-0.14	0.26	0.62
	2	-0.51	-0.43	-0.38	-0.41	-0.51	-0.32	-0.09	0.24	0.63
	1	-0.51	-0.43	-0.40	-0.44	-0.51	-0.27	-0.07	0.23	0.65
	0	-0.51	-0.44	-0.43	-0.45	-0.51	-0.27	-0.06	0.21	0.65
MCS	3	-0.59	-0.66	-0.56	-0.48	-0.53	-0.28	-0.06	0.22	0.44
	2	-0.58	-0.66	-0.58	-0.50	-0.54	-0.23	-0.02	0.21	0.47
	1	-0.58	-0.67	-0.59	-0.52	-0.53	-0.18	-0.01	0.19	0.48
	0	-0.58	-0.68	-0.61	-0.53	-0.53	-0.17	-0.03	0.17	0.50
SCS	3	-0.40	-0.67	-0.61	-0.58	-0.63	-0.38	-0.11	0.05	0.01
	2	-0.39	-0.68	-0.62	-0.59	-0.64	-0.33	-0.07	0.05	0.11
	1	-0.39	-0.69	-0.64	-0.61	-0.63	-0.29	-0.04	0.03	0.13
	0	-0.39	-0.70	-0.65	-0.62	-0.62	-0.27	-0.03	0.01	0.15

(a) JFMA: January to April, FMAM: February to May, etc.
(b) NCS: North Caspian Sea, MCS: Middle Caspian Sea, SCS: South Caspian Sea

Table 2 R^2 Values Between SST and Climate Indices based on the GUIDE models.

	With year and month	Without year and month
All four	0.61	0.61
Only NINO	0.61	0.56
Only SOI	0.60	0.58
Only NCP	0.60	0.53
Only NAO	0.59	0.50

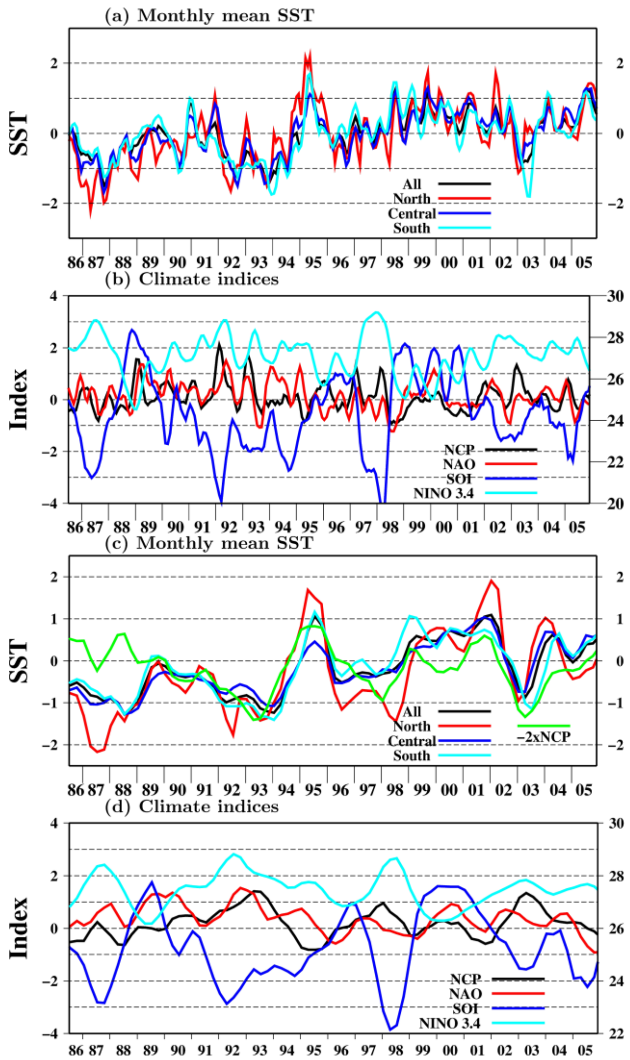

Figure 1 Monthly mean time series from 1985 to 2005 years of (a) SST averaged over different sub-basins (i.e North, Central and South) and whole of the Caspian Sea (b) Climate indices, NİNO 3.4 is on right axis and the rest are on left axis (c) February to May SST overlaid on the NCP index, NİNO 3.4 is on right axis and the rest are on left axis (d) February to May Climate indices. A 4-point box-car filter is applied each data set.

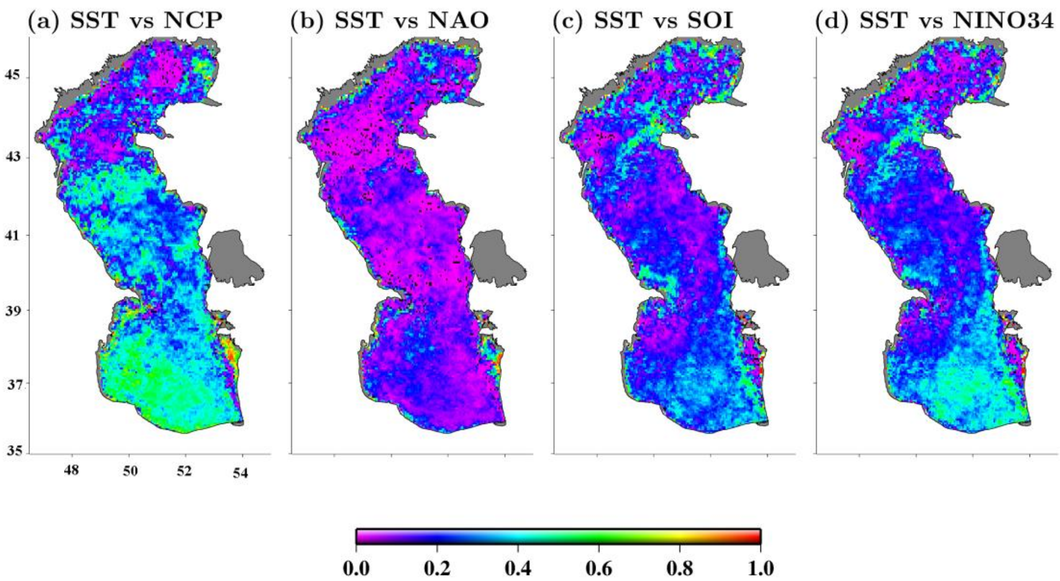

Figure 2 The square of correlation coefficients (R^2) between SST and (a) NCP, (b) NAO, (c) SOI, (d) NINO3.4 indices for the time period from February to May. A 4-point box-car filter is applied to SST and climate indices. R^2 values are calculated for the 1990-2005 time period.