Changes in precipitation and river flow in northeast Turkey: associations with the North Atlantic Oscillation

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Abstract This paper explores the relationships between the North Atlantic Oscillation (NAO) index and precipitation and river flow over northeast Turkey. Precipitation totals and maximum, mean and minimum river flow are analysed at the seasonal scale for 12 and 10 stations, respectively. Pearson's and Mann-Kendall correlation tests are applied to assess relationships between the NAO index and precipitation and river flow metrics, and to detect trends in time-series. Autumn precipitation totals display significant increasing trends, especially for coastal stations, while inland stations show significant increasing trends for spring precipitation. Minimum and maximum river flow decreases significantly for spring and summer. This tendency implies varying conditions towards a drier regime. Seasonal precipitation patterns show a negative association with the NAO for December–January–February (DJF), March–April–May (MAM) and September–October–November (SON) for some stations. Positive associations between the NAO and winter-extended winter (December–March) river flows are detected for some stations in northeast Turkey.

Key words rainfall; runoff; time-series; trends; hydroclimatology; NAO; northeast Turkey

INTRODUCTION

The North Atlantic Oscillation (NAO) is the leading mode of atmospheric circulation influencing seasonal to interdecadal climate variability in the North Atlantic region. The NAO characterises a large-scale atmospheric pressure dipole between the subtropical anticyclone (near the Azores) and the subpolar low pressure system (near Iceland). It is recognised as the most important climate teleconnection or anomaly pattern affecting western Europe, where it is most pronounced in winter (Wanner *et al*., 2001). Recently, it has been suggested that the NAO may have a noticeable influence further east of the Mediterranean region. Xoplaki *et al.* (2006) and Krichak & Alpert (2005) found that the NAO plays an important role in interannual, decadal and centennial low frequency variability of wet season precipitation across the Mediterranean.

For Turkey, Türkeş and Erlat (2003) analysed the relationships between the NAO index (NAOI) and precipitation and found a negative relationship that is strongest in winter and autumn. Annual, winter, spring, and autumn precipitation means are wetter than the long-term average during the negative NAOI phase, whereas positive NAOI phases are drier than the long-term average (Türkeş & Erlat, 2003). Spatially coherent, statistically significant shifts in precipitation amounts during extreme NAOI phases are apparent in the western and central regions of Turkey (Türkeş & Erlat, 2006). Cullen & deMenocal (2000) studied the association of the Tigris–Euphrates streamflow changes with the NAO, by developing indices of Turkish winter temperature and precipitation, which capture interannual–decadal climate variability in the headwaters. These indices are correlated significantly with the NAO, accounting for 27% of the variance in precipitation. Karabörk *et al.* (2005) documented the influences of the NAO on Turkish hydroclimatic variables (i.e. precipitation, streamflow, and maximum and minimum temperatures) and found that the NAO influences precipitation and streamflow in winter. Kalayci & Kahya (2006) defined the systematic modes of spatial and temporal variation in monthly streamflow in Turkey using principal components (PC) analysis. Seasonal correlation between the PC scores and the NAOI suggest sensitivity of Turkish streamflow to variations of the NAOI.

These previous Turkish studies have evaluated the influence of the NAO on precipitation and river flow variability at broad scales. However, it is important to disentangle NAO-precipitation-flow associations at the regional to basin scale. This study addresses this research gap and aims to explore linkages between seasonal NAOI anomalies, precipitation and river flow in the northeast region of Turkey. To achieve this aim: (a) monthly precipitation and river flow time-series are evaluated to define hydroclimatic characteristics over the study area; (b) seasonal trends in time-series are detected; and (c) associations between the NAOI, precipitation and river flow are analysed to evaluate the influence of large-scale teleconnection patterns on surface hydroclimatology in northeast Turkey.

DATA AND METHODS

Study area

Northeast Turkey has a coastal border with the Black Sea. The highest part of the North Anatolian Mountains is located here. Two major river basins are located in this region: the East Black Sea basin (on the northern face of the mountains) and the Çoruh River basin (on the southern side of the mountains). Two important air masses (mP and cP) prevail in the region, which have a pronounced seasonal effect on surface meteorological conditions. The positions of the jet streams and jet maxima are important in determining surface pressure and rainfall patterns; but these relationships are highly complex. The high mountainous terrain of northeastern Turkey has an important physical influence on regional atmospheric circulation and so yields complex rain and snowfall patterns (Akçar *et al*., 2007).

Datasets

Monthly precipitation totals for 12 Turkish State Meteorological Service stations were used (Fig. 1). Kruskal-Wallis (K-W) homogeneity tests were applied to screen for time-series inhomogeneties (Sneyers, 1990). The test result verified homogeneity of the data against any non-climatic changes. The period of record varies between stations from 32 to 78 years, with all records ending in 2007.

River flows were obtained from the Electrical Power Resources Survey and Development Administration of Turkey. The number of gauging stations with long-term data is limited. Ten gauges were selected for analysis on the basis of record lengths and to provide good river network

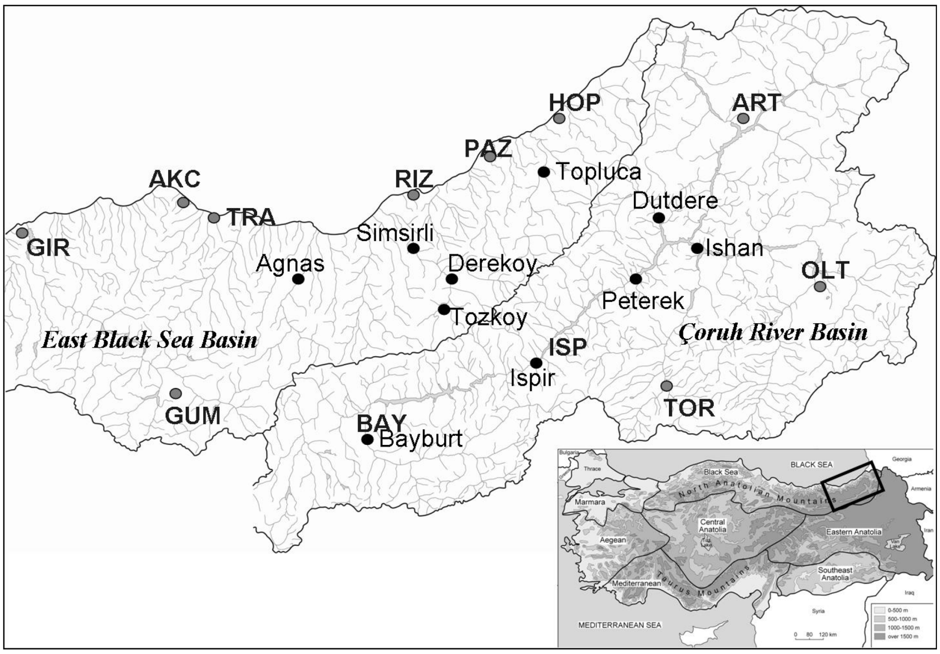

Fig. 1 River network map of the study area with location map inset. Black (grey) dots show the river gauging (meteorological) stations.

coverage (Fig. 1). The K-W test was performed for the monthly mean, maximum and minimum flows. The test results did not identify any significant inhomegeneity in time-series. River flow stations have continuous data up to and including 2005, and span between 28 and 44 years. The daily precipitation and flow records (and metadata) were inspected for any abrupt data shifts.

The precipitation and flow time series were divided into seasons prior to analysis: December, January and February (DJF) as winter; March, April and May (MAM) as spring; June, July and August (JJA) as summer; September, October and November (SON) as autumn. The DJFM (December–March) extended winter period was also evaluated. Time-series were standardized to reduce potential effects of high year-to-year variability.

The NAOI used herein is that provided by the Climate Analysis Section, NCAR, Boulder, USA (Hurrel, 1995). Seasonal (DJF, MAM, JJA, SON) indices of the NAO were derived based on the difference in normalized sea level pressure (SLP) between Ponta Delgada (Azores) and Stykkisholmur/Reykjavik (Iceland). An extended winter (DJFM) NAOI was estimated based on the difference of SLP between Lisbon (Portugal) and Stykkisholmur/ Reykjavik (Iceland).

Since time-series differ in data period, analyses are performed on a 28 year common period (1976–2003) for winter (DJF), and 27 year period (1976–2003) for the other seasons. The analysis for extended winter (DJFM) is carried out for 1976–2005 (30 years).

Statistical tests

Long-term trends in seasonal precipitation and river flow are detected by using the widely applied, non-parametric Mann-Kendall (M-K) rank correlation test (WMO, 1966). The M-K test is a distribution-free technique over the series of observations; it is also a nonlinear method. Using a two-tailed test, the null hypothesis of absence of any trend was rejected for large values of $|\tau_t|$ for levels of significance at 0.05 and 0.01. Pearson's correlation is applied to assess the linear relationship (Helsel & Hirsch, 2002) between NAOI and precipitation and river flow. Using a two-tailed test, the correlation coefficient is deemed significant at the 0.05 and 0.01 levels.

RESULTS AND DISCUSSION

Precipitation and river flow characteristics

Northeast Turkey is characterised by mainly coastal and inland precipitation regimes. The western part of the Black Sea coast is characterised by high precipitation in October and December. The eastern part of this coast is characterised by very high rainfall totals in all seasons (except spring), with a clear October peak. Inland, continental regimes characterise the Çoruh River basin, with a wet spring (May peak) but otherwise low precipitation magnitude. The frequency and intensity of the cyclonic systems are hypothesised to be influential on intra-annual precipitation fluctuations and control the seasonality. The Black Sea, together with the mountain ranges that run parallel to the coast, is instrumental in producing high precipitation amounts for these coastal regimes. The local thermal conditions in interior regions serve to accelerate convective activity, which determines the precipitation character of the Çoruh basin.

River flow regimes for the East Black Sea and Çoruh River basins (results not shown due to the page limits) exhibit similarity in timing of discharge with a spring (May) peak and summer low flow season, although flows remain higher in the Çoruh basin from April–June due to snowmelt. There are distinct differences in monthly flow magnitude between the basins, with the Çoruh River basin being markedly higher.

Long-term trends in precipitation and river flows

Autumn and spring precipitation totals display significant trends (Table 1). Spring precipitation totals increase for all continental stations. Conversely, coastal stations exhibit a decreasing trend in spring. Autumn precipitation totals show an increasing tendency that is dominant for the entire study region (apart for the Giresun). The significant increasing trend in autumn precipitation was detected at Hopa and Pazar stations of coastal stations, while Gümüşhane and Ispir represent the strongest positive trend for the inland area. The extended winter precipitation totals for Pazar station display a strong increasing trend (results not shown).

Table 1 Trend analysis for seasonal precipitation totals based on M-K test.

Stations	DJF	MAM	JJA	SON
Akçaabat	0.00	0.14	0.05	0.20
Artvin	0.16	0.22	0.10	0.04
Bayburt	0.00	0.02	–0.06	0.08
Giresun	–0.10	–0.03	–0.09	–0.01
Gümüşhane	–0.06	0.01	–0.08	0.31
Hopa	–0.05	–0.04	–0.10	0.24
Ispir	0.00	0.03	0.04	0.29
Oltu	0.02	0.30	0.19	0.18
Pazar	0.07	–0.02	–0.01	0.28
Rize	–0.11	–0.18	–0.06	0.03
Tortum	0.09	0.09	0.07	0.18
Trabzon	0.04	0.13	0.06	0.12

/ Correlation is significant at the 0.05/0.01 level.

Table 2 Trends for seasonal river flow series based onM-K test.

Basin	Stations	River	Flow	DJF	MAM	JJA	SON
East Black Sea	Ağnas	Kara	Max		–0.26	–0.29	
			Mean		–0.31		
	Dereköy	Çamlık	Max			–0.28	
			Min	0.28		–0.29	
	Şimşirli	İyidere	*No significant result*				
	Topluca	Fırtına	*No significant result*				
	Tozköy	Tozköy	Mean	0.39			
			Min	0.43*		–0.28	
Çoruh River	Bayburt	Çoruh	Max			–0.30	
	Peterek	Çoruh	*No significant result*				
	Ispir	Çoruh	Max			–0.26	
			Min			–0.30	–0.286
	Dutdere	Parhal	*No significant result*				
	Ishan	Oltu	Mean				–0.30
			Mean	0.41			
			Min	0.46			

* Correlation is significant at the 0.01 level

Significant relationships between winter flows and NAO

For river flow, increasing trends are observed in winter (DJF) minimum for the Çamlik and Tozköy rivers of the East Black Sea basin. A decreasing tendency in summer (JJA) flows is detected at stations located in both basins. Trends in winter and spring (MAM) flows are found only for the East Black Sea basin. Significant decreasing trends in autumn (SON) flows are experienced only for the Çoruh basin (Table 2). Significant positive trends are found in the minimum flow series for the DJFM period (results not shown) for some East Black Sea basin stations. Figure 2 illustrates long-term variations in seasonal mean, minimum and maximum river flow for selected stations. An increasing trend is detected for winter minimum flow since 1988 at Çamlik (Dereköy) and Tozköy (Tozköy) rivers (Fig. 2(a) and (b)). For the other seasons, the dominant trend observed is negative, with the downturn most evident after 1994. The first episode of decline in mean and maximum spring flows is observed for the Kara River (Ağnas) around 1985 (Fig. 2(c),(d)), with a steadily decreasing trend over the last decade. Figure 2(e) and (f) shows the decreasing trend in maximum and minimum river flow data for the Çoruh River, detected in the Bayburt and Ispir stations for summer. Minimum and maximum river flows have declined in spring and summer; this trend has become more persistent in recent years. The decreasing tendency in maximum flows is very important, especially when it occurs during the wet season; it implies a shift towards a lower magnitude flow regime.

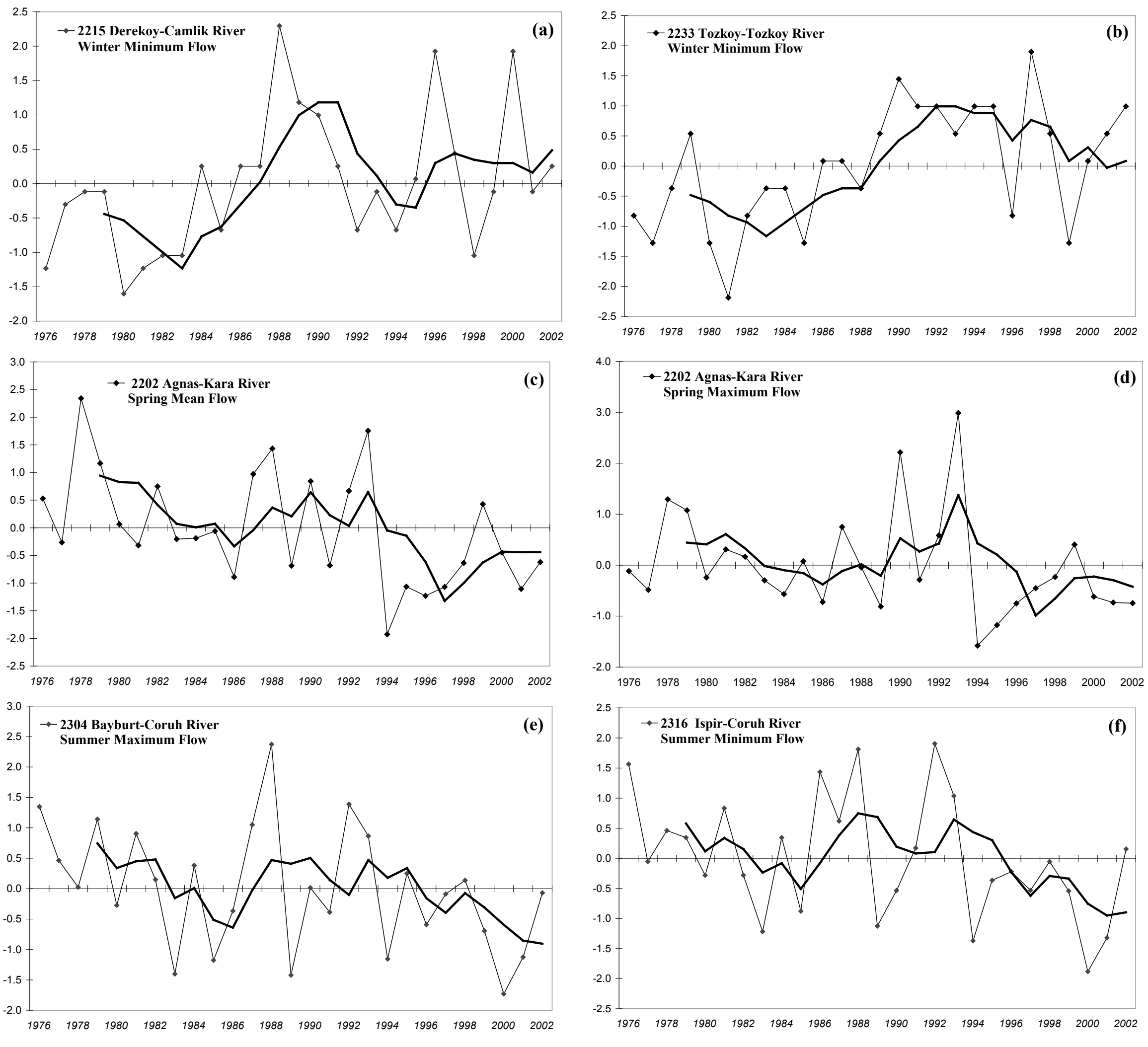

Fig. 2 Interannual variations in standardized seasonal river flow at selected stations (bold line indicates the 4-year moving average).

NAO-precipitation-river flow relationships

Results of correlation analyses indicate a weak connection between the NAO and hydroclimatic variables for northeast Turkey (Table 3). For precipitation, only 15% of the total variance can be explained by the NAO. A general negative relationship is observed for the entire region in the DJF period. The negative correlation is significant at Bayburt and Giresun stations and indicates drier (wetter) conditions in positive (negative) NAO phases (Fig. 3(a) and (b)). The most statistically significant results are detected in MAM, which point to a general negative association. This inverse correlation is significant for all coastal stations, with 42% of variance in spring precipitation explained by the NAOI. In summer, a positive correlation pattern is detected for inland precipitation stations, which is significant for Oltu and Tortum. Autumn precipitation totals exhibit a weak connection to the NAO indices; statistically significant relationships are found for Bayburt and Gümüşhane. For the extended winter season, significant positive and negative correlations are found for Artvin and Giresun stations, respectively (Fig. 3(c) and (d)). Thus broadly, northeast Turkey precipitation data show a negative association with the NAO, with less precipitation received during the positive (negative) NAO years for DJF, MAM and SON. However, the patterns of precipitation variability over the region do not always exhibit a spatial coherency response.

For river flow, only mean and minimum values for Oltu River (Ishan) have significant positive correlation with the NAOI in winter (Table 2). Mean and maximum flows for Şimşirli and Ishan exhibit a strong relationship with the DJFM index of the NAO. Conversely to precipitation, river flow data are positively related with the DJFM index (Fig. 4(a)–(d)). This positive relationship indicates that during strong NAO episodes river flows are above normal. The average flow is higher than normal during the positive NAO years, which includes the periods of 1980–1984, 1988–1995 and 1998–2000. These results show that while flow variability for some sub-basins of northeast Turkey is linked to the NAO. a lack association is observed for other sub-basins in the study area. Further research is required on the role of basin characteristics in modifying climate-flow linkages in order to understand spatially-variable hydroclimatic response.

Table 3 Pearson’s correlation between seasonal NAO index and precipitation series.

Stations	Test	DJF	MAM	JJA	SON
Akcaabat	Pearson's	0.04	–0.43	–0.01	–0.15
	Mann–Kendall	–0.01	–0.35	–0.01	–0.10
Artvin	Pearson's	0.19	–0.12	–0.11	–0.15
	Mann–Kendall	0.11	0.05	–0.10	–0.17
Bayburt	Pearson's	–0.32	–0.36	0.27	–0.42
	Mann–Kendall	–0.27	–0.24	0.24	–0.25
Giresun	Pearson's	–0.27	–0.33	0.07	–0.34
	Mann–Kendall	–0.28	–0.28	0.03	–0.22
Gümüşhane	Pearson's	–0.10	–0.33	0.10	–0.49
	Mann–Kendall	–0.15	–0.22	0.03	–0.37
Hopa	Pearson's	–0.06	–0.34	0.07	–0.28
	Mann–Kendall	–0.12	–0.30	–0.07	–0.25
Ispir	Pearson's	–0.22	–0.12	0.35	–0.28
	Mann–Kendall	–0.16	–0.11	0.26	–0.18
Oltu	Pearson's	–0.15	0.15	0.38	–0.17
	Mann–Kendall	–0.16	0.11	0.21	–0.16
Pazar	Pearson's	–0.15	–0.39	0.06	–0.27
	Mann–Kendall	–0.13	–0.32	0.02	–0.26
Rize	Pearson's	–0.06	–0.41	–0.28	–0.11
	Mann–Kendall	–0.05	–0.22	–0.24	–0.13
Tortum	Pearson's	–0.15	–0.15	0.43	–0.25
	Mann–Kendall	–0.10	–0.13	0.24	–0.21
Trabzon	Pearson's	–0.06	–0.53	–0.07	–0.02
	Mann–Kendall	–0.05	–0.40	–0.08	–0.03

(light grey) / (dark grey) Correlation is significant at the 0.05/0.01 level

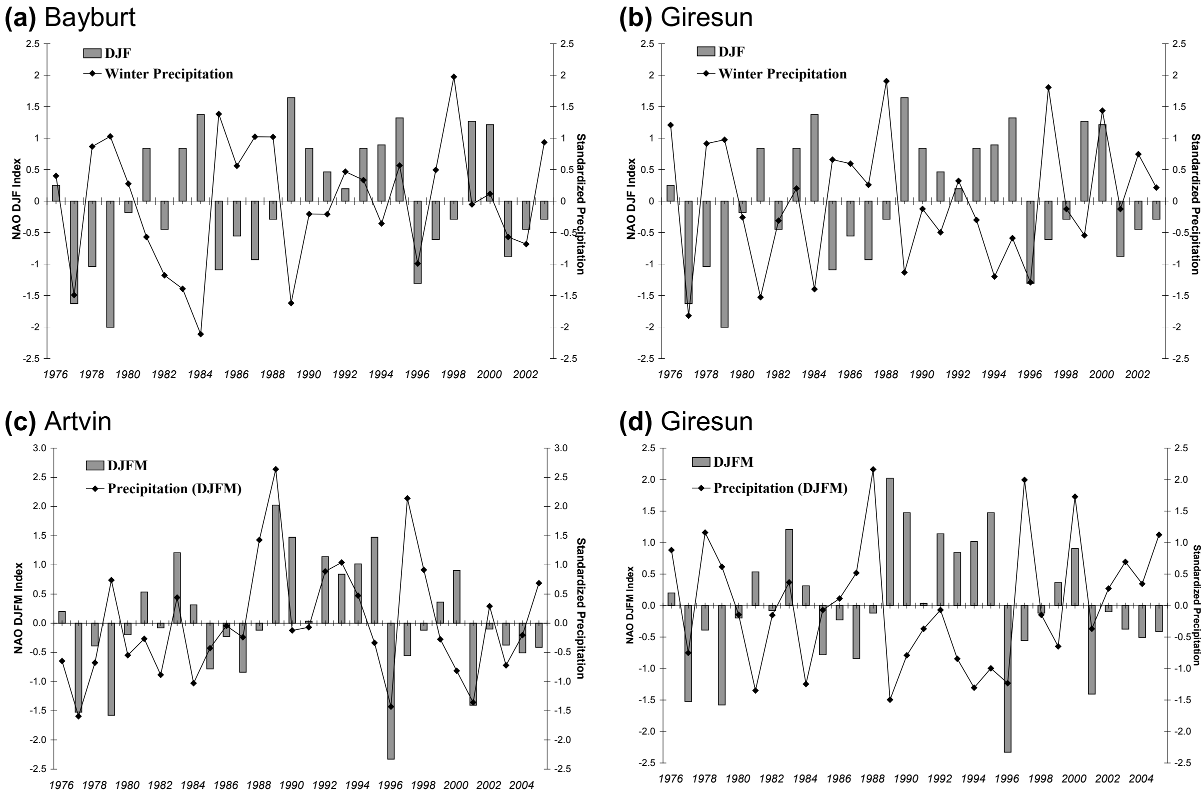

Fig. 3 Interannual variations in standardized NAO indices and precipitation at selected stations.

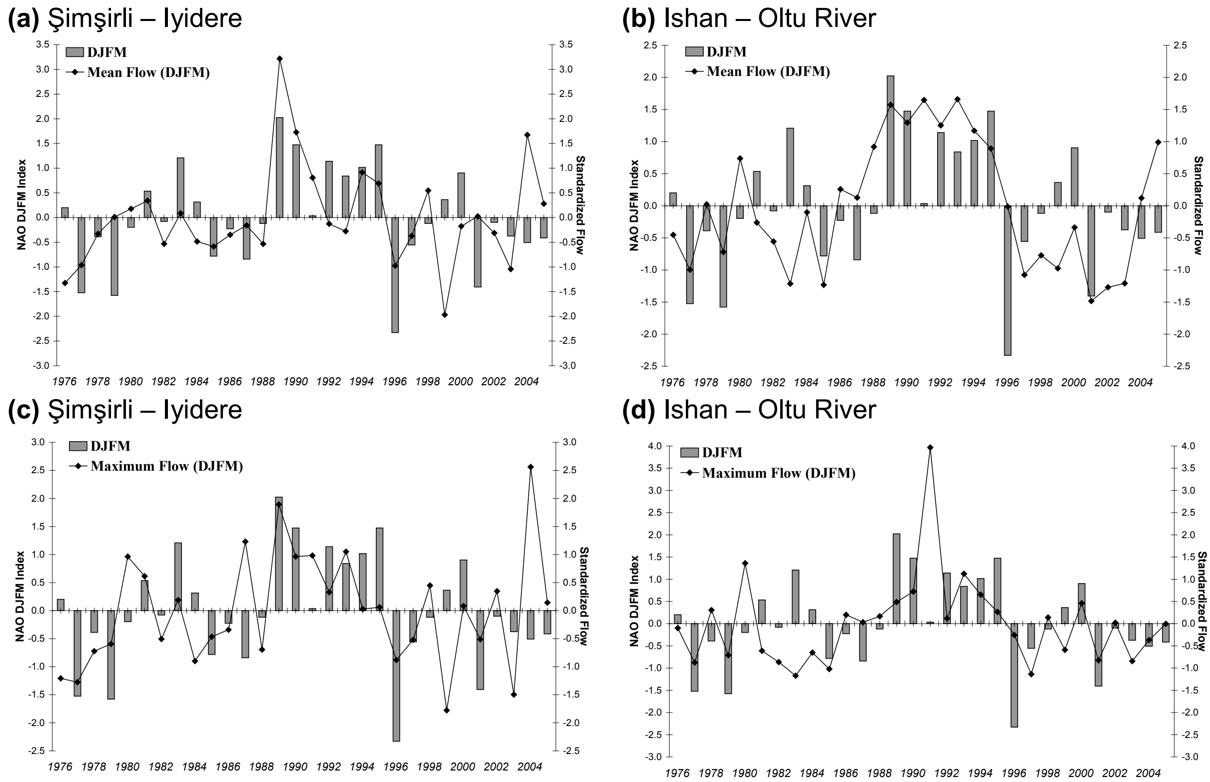

Fig. 4 Interannual variations in standardized NAO index and river flow at selected stations.

CONCLUSION

This paper provides new insight on the role of large-scale climate drivers (North Atlantic Oscillation, NAO) on the surface hydroclimatology of northeast Turkey, specifically precipitation and river flow dynamics. The results allow the following conclusions to be drawn:

– Significant increasing trends are observed for autumn precipitation totals of coastal stations (in the East Black Sea basin), while inland stations (in the Çoruh River basin) have positive trends in spring. For river flow, increasing trends in winter (DJF) minimum flow series are observed for some rivers of the East Black Sea basin. Significant results for the other seasons indicate negative river flow trends, particularly in maximum and minimum flows. A decreasing tendency in summer (JJA) flow is detected for both basins, while changes in spring (MAM) and autumn (SON) flows are found for rivers in the East Black Sea and Çoruh River basins, respectively. In addition, minimum flows for the extended winter (DJFM) period exhibit strong positive trends for rivers in the East Black Sea basin.

– A weak connection between NAO index (NAOI) and precipitation totals is detected for northeast Turkey. A negative correlation is observed in the winter precipitation for Bayburt and Giresun, indicating drier climatic conditions in positive NAO years. A negative relationship between the NAO and spring precipitation is also detected, which is strong and significant for coastal stations. Summer–autumn precipitation exhibit weak positive and negative associations with the NAOI.

– In general, the NAOI and river flow series are not well correlated; however, some significant results are apparent. Mean and minimum flows for the Oltu River have a significant positive correlation with the NAO DJF index. Mean and maximum flows for Şimşirli and Ishan have strong positive relationships with the DJFM NAOI. This positive correlation suggests above normal river flow may occur during the strong positive NAO episode.

The NAO is a dominant circulation pattern influencing climatic conditions in the Northern Hemisphere; but the results of this study do not demonstrate a strong link between the NAOI, precipitation and river flow variability for northeast Turkey. Evaluating only the NAO patterns seems to be inadequate for identifying the hydroclimatological process cascade from large-scale circulation to surface conditions. Other climate system diagnostics (e.g. North Sea-Caspian Pattern) trends may be associated with changes in precipitation and river flow for northeast Turkey. Therefore, further research needs to be done to better understand the sensitivity of surface hydroclimatology to large-scale circulation for this region.

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