Climate variability of the Eastern Mediterranean and Black Sea based on empirical orthogonal functions (EOFs) analysis

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Abstract- Climate data on surface atmospheric variables, and air-sea fluxes are analyzed to describe comparative surface climatologies of the Eastern Mediterranean and Black Seas and to investigate their interannual and interdecadal variability. Based on these analyses, differences and similarities between climates of these basins and their relationships to other global systems are identified. Empirical Orthogonal Function (EOF) Analysis is used to study spatial and temporal variability of surface climate data and air-sea flux components in the region of interest. The modes which account for the dominant parts of the variance are identified and the temporal and spatial features of these modes are examined. Linkages with other regional climates are examined through correlation analysis of principal components against climate indices characterizing North Atlantic Oscillation (NAO), El-Nino Southern Oscillation (ENSO), Sahel and Indian Monsoon regimes. The result of EOF analysis shows the relative influence of investigated climate patterns over the study region. While NAO is the dominant pattern for the Black Sea, Sahel Monsoon is the dominant pattern for the eastern Mediterranean. These results confirm the influence of the North Atlantic Oscillation (NAO) and tropical dynamics on the climate of the Black Sea-Mediterranean region.

Keywords- Eastern Mediterranean, Black Sea, EOFs, NAO, Sahel Monsoon.

Introduction

A number of studies have investigated the influence of atmospheric teleconnection patterns on the climate variability of the Euro-Asian region. Among these patterns, the North Atlantic Oscillation (NAO) is found to be largely responsible for rainfall, temperature and moisture variability in the Euro-Mediterranean region (Hurrell 1995). Mariotti et al. (2001) have found significant correlation between Mediterranean winter precipitation and NAO. Ben-Gai et al. (2001) have shown statistically significant correlation between smoothed (5 year running mean) cool season temperature and surface pressure anomalies in Israel and the NAO. Good correlation was found between the Tigris-Euphrates stream flow in Turkey and NAO (Cullen and deMenocal 2000). Using optimally interpolated data from five Middle Eastern rivers, Cullen et al., (2002) showed that first principal component of winter (December through March) stream flow reflects

changes in the NAO. Stanev et al., (2001), find clear evidence of anti-correlation between river runoff and NAO with short-term exception, concluding that the dramatic decrease of NAO index in mid 1990s is the main reason for sea level rise in the Black Sea in recent years. NAO has also been linked to Danube river runoff, with directly influencing on Black Sea hydrology

Although the influence of ENSO is not clear, various studies have investigated its effect on the region. Mariotti et al. (2002) have shown that the interannual variability of rainfall in the Euro-Mediterranean sector is significantly influenced by ENSO, depending on the season, Kadıoğlu (1999) using Turkish monthly precipitation between 1931 and 1990 have found spatially coherent and statistically significant precipitation response to El Nino in some regions of Turkey, Rodo (1997) has found significant ENSO signal over southern Europe based on seventeen rainfall stations. There is correlation between the heavy rain and snow in Israel during the last 100 years and ENSO (Alpert and Reisin, 1996). Arpe et al. (2000) have investigated the Caspian Sea Level (CSL) changes and have found a complex relationship with ENSO. On the other hand, Rodinov (1994) has discussed possible impacts of NAO on Caspian Sea level variability.

Rodo et. al. (1997) using records from rainfall stations spanning the Iberian Peninsula, Balearic Islands and North Africa, have concluded that both ENSO and NAO influence rainfall in Iberia, coexisting at different temporal and spatial scales. Two distinct, yet related zones are reported for these phenomena, the NAO-zone extending from the southwest to the northwest in winter (DJF) and the ENSO-zone, covering the east, from south to north in spring (MAM) and autumn (SON). NAO impacts have remained constant throughout this century, whereas ENSO influence has intensified in the second half virtually covering the whole peninsula, which would seem to indicate climatic changes. Kahya and Karabork (2001) examining the relationships between the stream flows in Turkey and El Nino, La-Nina signals found them not to be statistically significant. Price et al. (1998), analyzing various data sets (seasonal rainfall, stream flow, snowfall and lake level data) related to precipitation in Israel, have found connection between El-Nino events and rainfall, stream flow, lake level since the mid-1970s. The connections were statistically significant for the past 20-25 years; however, the relation appeared to vanish for the earlier period.

Data and Methods

Climate data sources

Among the various sets of data utilized in the analyses, the principal source of information was the NCEP reanalysis data set produced by the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) covering a period of 53 years (1948-2001). This global data set was windowed for the region of interest ($-15^o W, 70^o E, 30^o N, 50^o N$) at 1.9^o grid resolution, and averaged at monthly intervals. Among the climate indices used, the North Atlantic Oscillation (NAO) index is based on the Jones (1997). For Sahel rainfall index, the averaging region is based on the rotated principal component analysis of average June through September African rainfall as presented in Janowiak (1988), using stations within 20-8N, 20W-10E, based on the National Center for Atmospheric Research World Monthly Surface Station Climatology (WMSSC), and retaining 14 stations which had complete or almost complete records for 1950-93. All indices are obtained from Climate Prediction Center (CPC). (http://www.cdc.noaa.gov/ClimateIndices/).

Data Analysis

Data Pre-Processing

The climatic data have dominant annual cycle component which can be eliminated by filtering to investigate interannual variability. A low pass filter with cutoff period at 13 month was used for this purpose. The data at both ends of the time series (half the cutoff period) was eliminated.

After filtering, the data is normalized firstly by subtracting the temporal mean υ_m at each grid point time m,

$$\upsilon_m = \frac{1}{N}\sum_{t=1}^{N}\phi_m(t) \qquad (1)$$

and then dividing each data value by the standard deviation σ_m:

$$\sigma_m = \left[\frac{1}{N-1}\sum_{t=1}^{N}\varphi_m^2(t)\right]^{1/2} \qquad (2)$$

to obtain the normalized data:

$$F_m(t) = \frac{\phi(t) - \upsilon_m}{\sigma_m} \qquad (3)$$

The EOF Method

Climate variability occurs across a spectrum of spatial (global, regional, local) and temporal (interdecadal, interannual, seasonal) scales. The variations on these scales influence land and marine ecosystems. For examining the complex climatic variability of a region one often needs statistical tools such as Empirical Orthogonal Functions (EOF), also known as Principal Component Analysis (PCA) used to extract the major signals in oceanic and atmospheric fields. Using standard EOF technique the spatial and temporal variability of data can be investigated and physical interpretations made based on their information content.

Results

First spatial EOF pattern of precipitation in the Eastern Mediterranean (Fig 1) explains the 47.76 % of the total variance. It shows monopole pattern with positive sign extending over the whole sea with a center around the Crete. Principal Component time series shows strong seasonal variation, but the filtered time series

is correlated with Sahel monsoon with correlation coefficient of 0.73. This shows that first mode of Mediterranean precipitation is under the influence of Sahel monsoon.

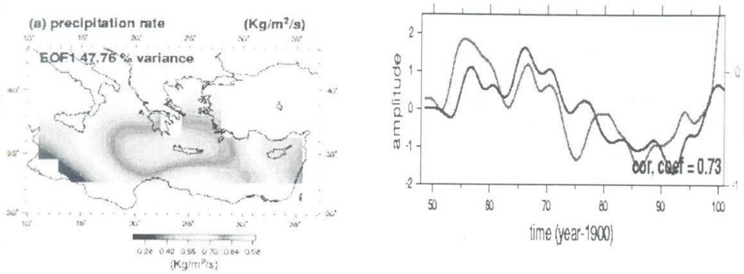

Fig. 1. First spatial and time series of Precipitation for the Eastern Mediterranean

The third mode of precipitation in the Eastern Mediterranean (Fig 2) shows north-south dipole pattern and explains the 9.51 % of variance. A close relationship exists between the third mode time series and NAO index , although there are periods when the amplitudes differ, while the phases of the two signals generally conform to each other.

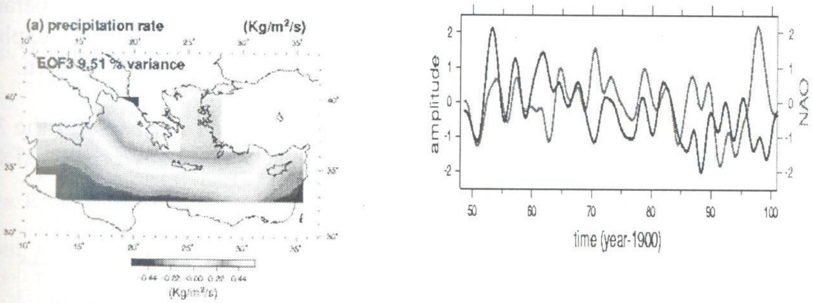

Fig. 2. Third spatial and time series of Precipitation for the Eastern Mediterranean

The dominant tele-connection pattern causing precipitation variability in the Black Sea (Fig 3) is NAO observed in the second mode of precipitation. This mode explains 15.87 % of the total variance and shows east-west dipole pattern, the correlation coefficient between this mode and NAO index is 0.43.

The influence of Sahel monsoon on the air temperature for the eastern Mediterranean (Fig 4) is observed in the second mode of air temperature, explaining 10.76 % of the total variance with an east-west dipole pattern, The correlation coefficient between the second mode time series and Sahel monsoon index is 0.46.

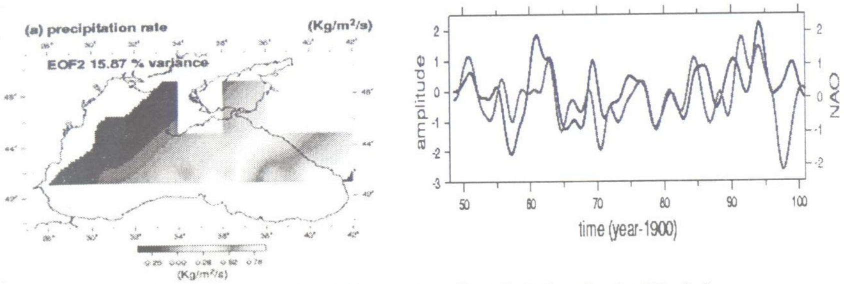

Fig. 3. Second spatial and time series of Precipitation for the Black Sea

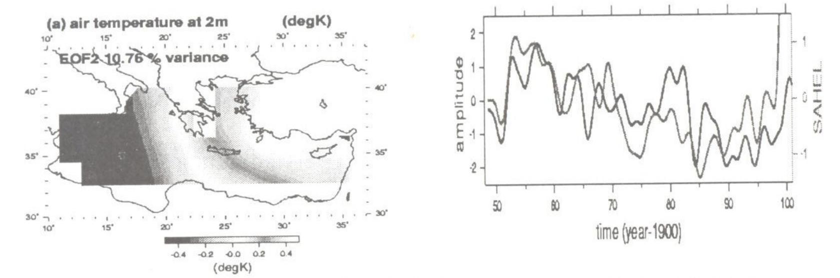

Fig. 4. Second spatial and time series of Air Temperature for the Eastern Mediterranean

After the dominant influence of Sahel monsoon on the air temperature variability, the effect of NAO is seen in the third mode (Fig 5). This mode explains the 1.70 % of the EOF variance and exhibits north-south dipole pattern. The correlation coefficient between third mode and NAO is 0.50.

The second mode of air temperature (Fig 6) in the Black Sea explains the 3.77 % of the total EOF variance, exhibits east-west dipole pattern and correlated with NAO pattern with a correlation coefficient of 0.37.

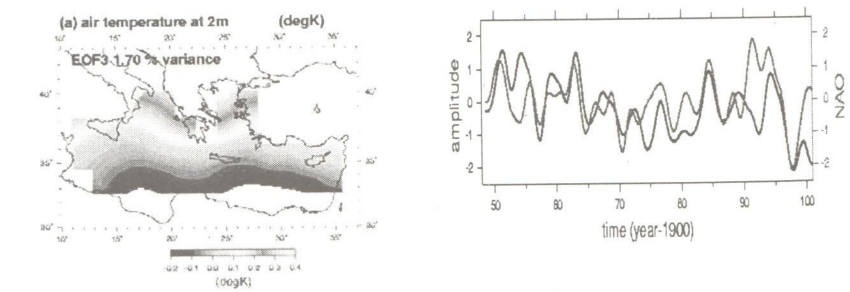

Fig. 5. Third spatial and time series of Air Temperature for the Eastern Mediterranean

In summary, the main tele-connection pattern influencing the Eastern Mediterranean is the Sahel rainfall. After the Sahel regime, NAO is the second

pattern that causes climate variability in the Eastern Mediterranean. NAO is the dominant pattern for the Black sea affecting the precipitation and air temperature.

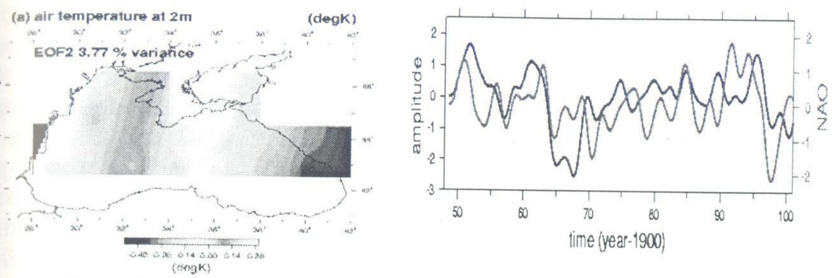

Fig. 6. Second spatial and time series of Air Temperature for the Black Sea

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