INFLUENCE OF LARGE SCALE ATMOSPHERIC SYSTEMS ON HYDROLOGY AND ECOLOGY OF TURKISH LAKES

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ABSTRACT

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Impacts of climatic changes on in-land waters of Turkey is a topic that has not been sufficiently investigated yet. In this study, some exploratory work have been performed to form the core of further studies on the subject. EOF (Empirical Orthogonal Function) analysis has been applied to SLP (Sea Level Pressure) field with a wide coverage (20-70N, 50W-70E). The dominant sources of variability in this atmospheric system have been shown to be driven by 3 circulation indices, NAO (North Atlantic Oscillation), EAWR (East Atlantic - West Russia) and EA (East Atlantic) patterns. Linkages between this atmospheric system and the hydro-meteorological properties (data compiled from governmental organizations) of major

Turkish lake ecosystems has been investigated with use of ordinary correlation analysis and CCA (Canonical Correlation Analysis). The results revealed the heavy forcing of large scale SLP field on regional temperature and E–P (evaporation minus precipitation) fields. The 15-year data set of Lake Mogan, as the longest available found, was used to exemplify the approaches and methodologies that can be employed for understanding the influence of climate variability on biological properties of lakes. It was suggested that temperature and salinity, being effective on phytoplankton and zooplankton groups, mediate the climatic impacts in Lake Mogan.

Keywords: Circulation Indices, Multivariate Analysis, Ecosystem

ÖZ

BÜYÜK ÖLÇEKLİ ATMOSFER SİSTEMLERİNİN TÜRKİYE'DEKİ GÖLLERİN HİDROLOJİ VE EKOLOJİSİNE ETKİLERİ

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İklim değişimlerinin Türkiye'deki içsular üzerindeki etkileri, şimdiye kadar yeteri kadar çalşılmamış bir konudur. Bu çalışmada, ileride yapılacak daha kapsamlı çalışmaların çekirdeğini oluşturmak üzere bazı keşif araştırmaları yapılmıştır. Geniş bir alandaki (20-70N, 50W-70E) Deniz Seviyesi Basıncı (DSB) sahası EOF (Empirical Orthogonal Function) analizine tabi tutulmuştur. Bu atmosfer sistemindeki baskın değişkenlik kaynaklarının, 3 dolaşım indeksi; NAO (Kuzey Atlantik Salınımı), EAWR (Doğu Atlantik - Batı Rusya) ve EA (Doğu Atlantik) örümlükleri tarafından yönetildiği gösterilmiştir. Bu atmosfer sistemi ile Türkiyedeki belli başlı göl ekosistemlerinin etrafındaki hidro-meteorolojik koşulların ilişkileri korrelasyon analizi ve

CCA (Canonical Correlation Analysis) ile incelenmiştir. Sonuçlar, DSB'nin sıcaklık ve B–Y (buharlasma – yağıs) sahaları üzerindeki güçlü etkinliğini ortaya çıkarmıştır. Bulunabilen en uzun veri seti olan Mogan gölüne ait 15 senelik (1991-2006) veri seti iklimsel değişimlerin göllerin biyolojik karakterleri üzerindeki etkilerinin anlaşılması için uygulanabilecek analizlere ve yaklaşımlara örnek olarak sunulmuştur. Yapılan analizlerde, iklim değişimlerinin Mogan gölünde sıcaklık ve tuzluluğun fitoplankton ve zooplankton grupları üzerindeki etkileri aracılığıyla etkin olduğu önerilmektedir.

Anahtar Kelimeler: Dolaşım İndisleri, Çok Değişkenli Analiz, Ekosistem

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Dedicated to my family...

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CHAPTER 1

INTRODUCTION

Unlike the non-linearly dynamical weather system, climate, the average state of weather, is a more stable and predictable but still a complex system involving atmosphere, hydrosphere, cryosphere, biosphere and their interactions. Climatic conditions evolve in different time scales with the influence of various natural sources like Milankovitch cycles which are associated with variations of Earth's orbit, changes in sunspot cycles, inter-decadal variations in atmospheric and oceanic circulations, and etc. In recent usage however, the term "climate change" has being used in acronym with "global warming" which addresses the current state of increasing air temperatures mainly attributed to anthropogenic carbon emissions. The fourth Assessment Report of IPCC (AR4) summarizes that, on the global average, an increasing 100-year (1906-2005) trend of 0.74 ± 0.18 °C has been recorded (Figure 1.1) and further increases of 1.1 °C at the best emission scenario (B1 - emphasis on environmental sustainability, globalized world) to 6.4 °C at the worst scenario (A1FI - fossil intensive-rapid economic growth, globalized world (Leggett et al., 1992)) are being projected in 21. century (see Figure 1.2). AR4 also reports that available data show evidence that the tropospheric and upper tropospheric water content generally increased in association with increasing temperatures in the last decades, while precipitation, having a rather variable character both spatially and temporally, shows increasing and decreasing trends in different regions of the world.

Downscaling methodologies, using the Atmosphere-Ocean General Circulation Models (AOGCM) as the input, reveals the finer local features of the projected

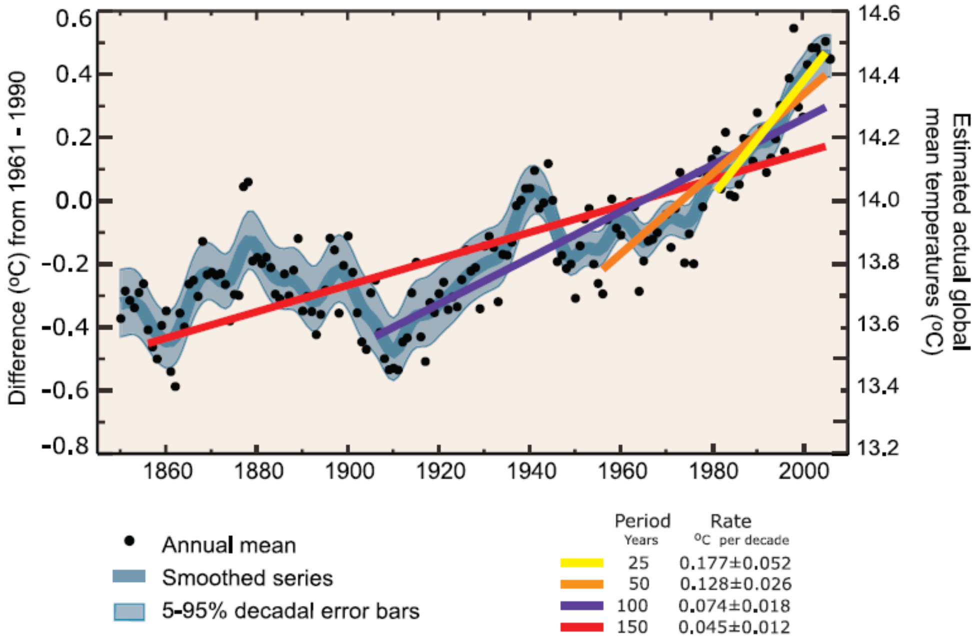


Figure 1.1: Annual global mean temperatures (black dots) with linear fits to the data. The left hand axis shows temperature anomalies relative to the 1961 to 1990 average and the right hand axis shows estimated actual temperatures, both in °C. Linear trends are shown for the last 25 (yellow), 50 (orange), 100 (purple) and 150 years (red). The smooth blue curve shows decadal variations, with the decadal 90% error range shown as a pale blue band about that line (Trenberth et al., 2007)).

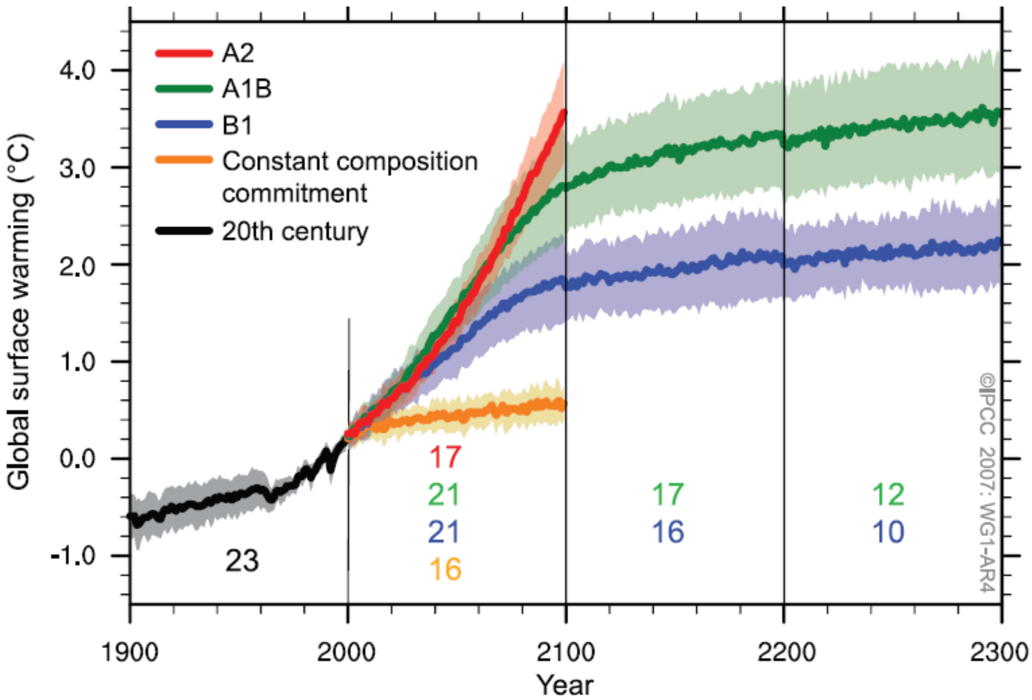


Figure 1.2: Multi-model means of surface warming (compared to the 1980–1999 base period) for the emission scenarios A2 (red), A1B (green) and B1 (blue), shown as continuations of the 20th-century simulation. The latter two scenarios are continued beyond the year 2100 with forcing kept constant. An additional experiment, in which the forcing is kept at the year 2000 level is also shown (orange). Lines show the multi-model means, shading denotes the ±1 standard deviation range. The number of models that have run a given scenario are also indicated (Meehl et al., 2007).

climatic elements. In Europe, annual mean temperatures are likely to increase more than the global mean (Christensen et al., 2007), although spatially highly heterogeneous patterns are expected. More intense warming is expected in Northern Europe in winters while more intense warming in summers are expected in Southern Europe (Figure 1.3). Precipitation even shows a more contrasting pattern with an expected intensification in the northern parts of Europe and weakening in the Southern Europe.

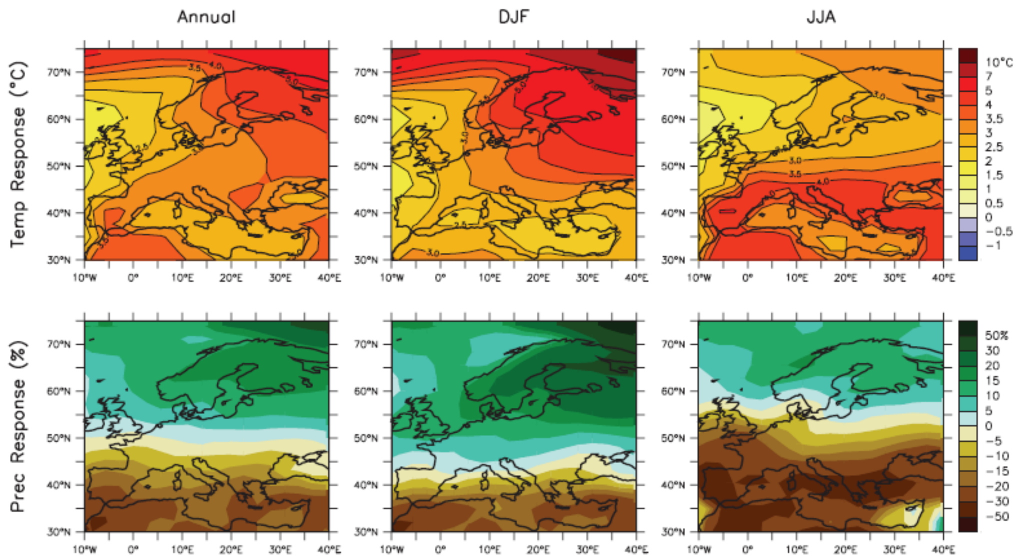


Figure 1.3: Temperature and precipitation changes over Europe from the Multi Model Dataset (MMD)-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation (Christensen et al., 2007).

Being mainly attributed to changes in circulation patterns and thermodynamical factors, the contrasting precipitation projections among Europe also seem to be reflecting the amplification of latitudinal wetness profile (Figure 1.4). This profile mainly reflects the increasing evaporation due to increasing temperature from Polar to Equatorial latitudes, and increasing precipitation due to increasing tropospheric water content as a very natural consequence. However, the saddle on the precipitation profile at the subtropical latitudes is remarkable, but can be easily explained by the fact that, sinking air at this region previously loses its water content when it originally rises and cools down at the equator and at the 60° parallel, following the latitudinal circulation pattern (Kalff, 2001). The net hydrological response of evaporation and precipitation is reflected on the runoff, in which the subtropical saddle is amplified and a sub-polar saddle became apparent.

Turkey, being located between 36°N and 42°N latitudes, lies on a very steep hydrological gradient in which runoff decreases very dramatically (Figure 1.4). This gradient, together with projected dry conditions (Figure 1.3), makes Turkey's inland waters extremely vulnerable to climatic fluctuations, in terms of availability of water, which is manifested by water level fluctuations and even total disappearal of water bodies. While total disappearal of an habitat for many species is on its own a disastrous event, as the involved mechanisms will be considered later, it's been shown that water level fluctuations can also be responsible for dramatic changes in ecosystems. Havens et al. (2007) reported that Lake Okeechobee, a shallow lake in Florida, which is also located in the subtropical zone, experienced a severe zooplankton community structure change, mostly owed to altered predation by fish, in response to vegetation development after a 2-year long historical low-water level period (Figure 1.5).

In this study, detection and identification of possible connections between lake water-level fluctuations and atmospheric circulation patterns as the main drivers of climatic fluctuations in Turkey, was the major concern. In Section 1.1, general information on structures and effects of these patterns associated with climatic indices are given. Propagation of climatic signals through the trophic levels of ecosystems occurs via a complex network of processes, mostly in a non-linear fashion, so detection and understanding of these require very detailed, fine and long-term data sets. Although the best data set that could be found, which is for Lake Mogan, still lacks such qualities, exemplifying some methodologies and approaches to be adopted for understanding climatic impacts on lake ecosystems using this data set constituted the secondary objective of this study, since the topic has not been appreciated and evaluated sufficiently in Turkey. General literature knowledge on mechanisms involved in transmission of climatic signals through

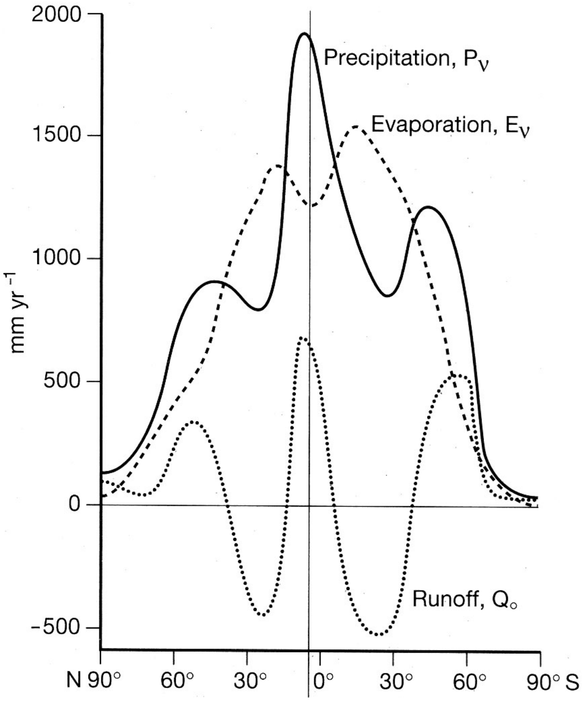


Figure 1.4: Evaporation, precipitation and runoff profiles along latitudes (Straskraba, 1980).

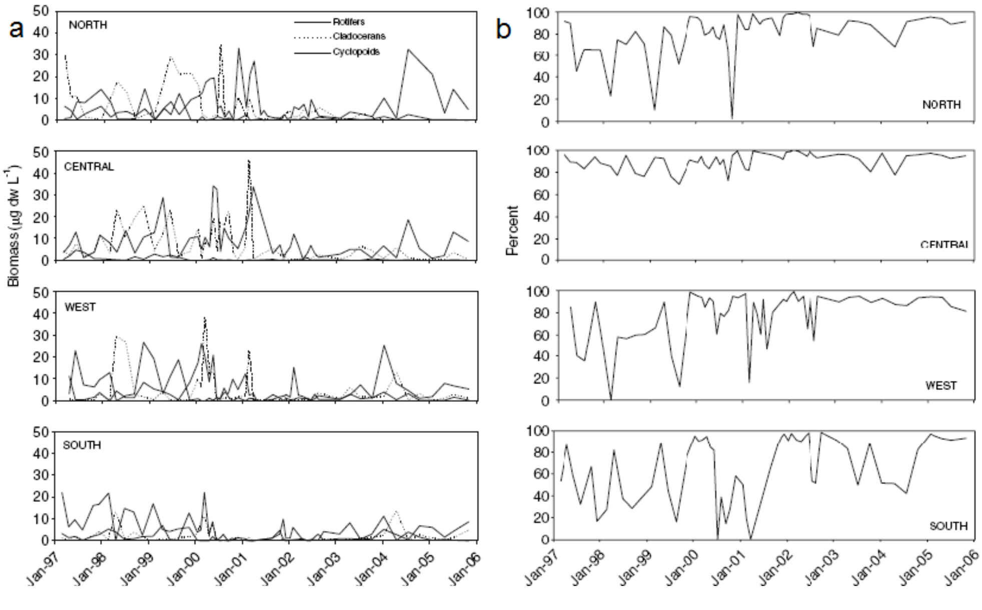


Figure 1.5: a) Biomass of rotifers, cladocerans and cyclopoid copepods; b) Percent of total zooplankton biomass comprised of calanoid copepods; at the four sampling sites in Lake Okeechobee. Note the near-complete loss of other species and transition to community with calanoid copepod dominance after 2001 (Havens et al., 2007).

different components of lake ecosystems is given in Section 1.2.

1.1 Atmospheric Circulation Patterns

Preferred patterns of variability of atmospheric circulation, associated with "teleconnection indices" regulate the regional climatic regimes, by modulating the strength and path of storm tracks, fluxes of heat, moisture and momentum (Trenberth et al., 2007). Although the "teleconnection" concept did not receive much attention firstly when Sir Gilbert Walker noticed the Southern Oscillation (SO) and North Atlantic Oscillation (NAO) back in the 1920's, it's been realized that these simple indices captures important climatic events and are correlated very well with regional weather conditions and have been attracting more and more attention since 1960's (Bridgman and Oliver, 2006). In this section, the circulation indices representing the components of the atmosphere system that surrounds a region involving Turkey, are revieweved with their main characteristics. The other globally important indices which are although not in proximity of this system on focus, are also very briefly mentioned.

1.1.1 The North Atlantic Oscillation (NAO)

NAO index is basically the difference of sea level pressure anomalies of the high pressure system located near the Azores and low pressure system located near Iceland. Different authors selected different meteorological station couples for the high and low pressure systems: Hurrell (1995) used Stykkisholmur (Iceland) - Lisbon (Portugal), Rogers (1997) used Stykkisholmur - Ponta Delgada (the Azores) and Jones et al. (1997) used South Western Iceland and Gibraltar (Portugal). While station based NAO indices can be calculated very easily and they enable going further back in time, they can not capture seasonal and inter-annual spatial variations of pressure centers, so may become imprecise in reflecting the actual atmospheric dynamics. Other than using a "teleconnective" station couple, indices can also be defined by making use of Empirical Orthogonal Functions (EOF). In this approach, the NAO is identified from the eigenvectors of the cross-covariance matrix, computed from the grid point values of a climate variable (Sea Level Pressure (SLP), Sea Surface Temperature (SST), etc.) ((Hurrell et al., 2003), see also Section 2.3). In the Northern Hemisphere, when the pressure fields at certain geopotential heights are analyzed with EOF's, the dominant modes reveal the NAO (Wallace and Gutzler, 1981; Barnston and Livezey, 1987). In Figure 1.6, spatial structure of NAO deriven from EOF analysis of Atlantic Sector Sea Level Pressure (SLP), with it's 3 different station based and 2 different EOF based indices drawn together for comparison purposes are shown (top panel and data for the Hurrel, Rogers and Atlantic Sector NAO are taken from the web page of National Center of Atmospheric Research, Climate Analysis Section (`http://www.cgd.ucar.edu/cas/jhurrell/indices.info.html#naopcdjfm`, `http://www.cgd.ucar.edu/cas/jhurrell/indices.data.html`); data for the Jones NAO is taken from the web page of National Oceanic & Atmospheric Administration, Earth System Research Laboratory, (`http://www.cdc.noaa.gov/Correlation/jonesnao.data`); Data for the Northern Hemisphere EOF NAO is taken from the ftp page of National Oceanic & Atmospheric Administration, Climate Prediction Center (`http://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh`), all last accessed on 04.02.2008). As can be seen in the figure, although some small differences exist, all the station and EOF based indices reflects the same climatic signal.

In Figure 1.6, other from the inter-annual fluctuations, a noticeable feature is that, in some periods, NAO had the tendency to persist its positive or negative phases, forming inter-decadal fluctuations. Hurrell (1995) very effectively argued that these oscillations determined the hydro-meteorological conditions in Europe, and contributed to the exponentially increasing number of studies considering NAO after him (Wanner et al., 2001). Stronger centers of pressure (higher subtropical high and deeper icelandic low) bring the positive phase of NAO while the weaker centers bring the negative NAO. When the NAO index is positive, the flow across the Arctic is enhanced and move the moist and warm maritime air over the Northern Europe, with the contribution of enhanced meridional pressure gradient. The negative NAO index on the contrary, is associated with warmer and wetter conditions in southern

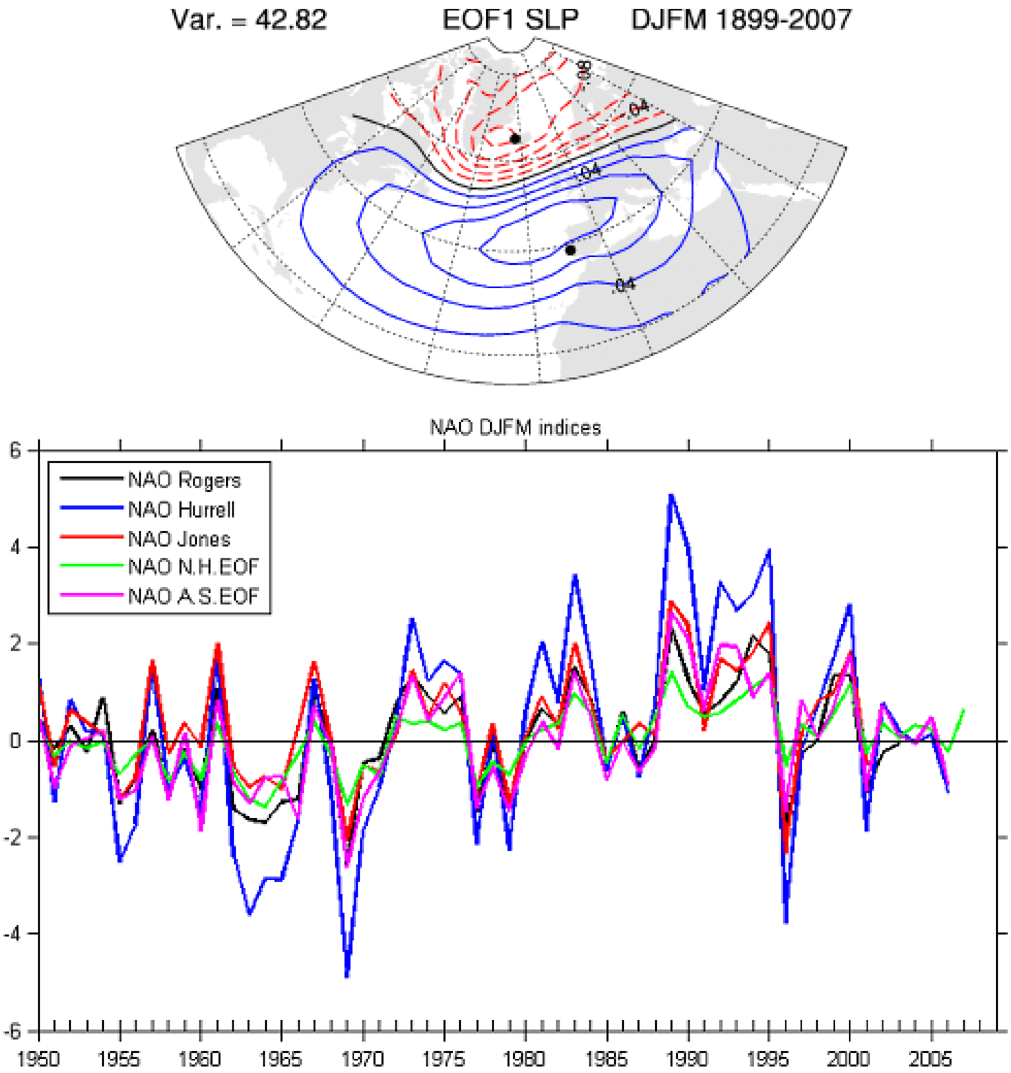


Figure 1.6: Top panel: First EOF mode of Atlantic Sector SLP field, revealing the NAO. Bottom panel: 3 station based (Rogers, Hurrel, Jones) and 2 EOF based (deriven from Northern Hemisphere and Atlantic Sector SLP fields) NAO time series, all for December-January-February-March (DJFM) period

Europe and Eastern Mediterranean and colder and drier conditions in the Northern Europe (Hurrell, 1995; Hurrell et al., 2003).

Influence of NAO on the hydro-climatological conditions in Europe, Mediterranean and Middle East and America were studied and the effects were verified by many researchers (Hurrell and VanLoon, 1997; Krichak and Alpert, 2005b; Pozo-Vazquez et al., 2001; Wanner et al., 2001; Ben-Gai et al., 2001). Ecological effects of NAO, on both terrestrial and marine ecosystems are reported to be occurring through alteration of oceanic circulation, strength of upwelling events, temperature mediated growth and survival rates, phenological cycles, etc. (Ottersen et al., 2001; Stenseth et al., 2004, 2002; Beaugrand et al., 2002; Dippner and Ottersen, 2001; Oschlies, 2001). Influence of NAO on the spot market price of electric energy in Norway, which has a heavy reliance on hydro power, is among the interesting examples of economic impacts of NAO (Hurrell et al., 2003). In Turkey, NAO's influence on precipitation (Turkes and Erlat, 2003, 2005), runoff (Cullen and deMenocal, 2000; Kalayci and Kahya, 2006) and temperature (Karabork et al., 2005) also have been studied and statistically significant results were found, verifying that NAO's impact on climatic elements of Turkey is in consistency with that of Southern Europe. Moreover, Oguz et al. (2006); Oguz and Gilbert (2007) showed that Black Sea Ecosystem is under heavy control of NAO and EAWR (see next section), efficiently coupling with anthropogenic factors like eutrophication and overfishing.

1.1.2 East Atlantic / West Russia (EAWR) Pattern

EAWR, which firstly appeared with the name EU2 (Eurasian Pattern Type 2) in Barnston and Livezey (1987), is a prominent zonal pattern with centers of action on the Caspian Sea and North Sea. Although this index is normally gathered as an emerging dominant component by EOF-analyzing the pressure field covering the region as originally done by Barnston and Livezey (1987), the same dipole pattern was discovered also by Kutiel and Benaroch (2002), in which they have calculated the correlations between each grid point in the 500 hPa geopotential height field.

This system emanates from the interaction of anomalous fluctuations of two pressure systems, one at the Caspian Sea, other at the North Sea (Figure 1.7). When the system is at its positive phase (Figure 1.7 top panel), the negative pressure center at the Caspian causes a counter-clockwise movement and the positive pressure center at the North sea causes a clockwise movement, bringing the cold and dry air over Russia to the Eastern Mediterranean. When the system is at its negative phase (Figure 1.7 bottom panel), opposite conditions push the warm and humid air to the Mediterranean from South. Although the influence of EAWR on the weather conditions in Turkey and Mediterranean have been studied throughly (Kutiel et al., 2002; Kutiel and Turkes, 2005; Krichak and Alpert, 2005a; Hasanean, 2004; Rodriguez-Puebla et al., 2001; Gunduz and Ozsoy, 2005), effects of EAWR on the other close regions is still unknown. Among the ecosystem impacts of EAWR, Oguz et al. (2006) shows that EAWR can be effective on the Black Sea ecosystem, in turn with NAO.

1.1.3 East Atlantic (EA) Pattern

With its meridional dipole centers slightly shifted to South, EA pattern resembles the NAO, although it is a distinct system especially with the subtropical modulation of the southward center (from the web page of National Oceanic & Atmospheric Administration, Climate Prediction Center (`http://www.cpc.noaa.gov/data/teledoc/ea.shtml`), last access: 04.02.2008). While the EA pattern under consideration in this study have its origin in the Barnston and Livezey (1987), it is different than the so-called “the eastern Atlantic Pattern” in Wallace and Gutzler (1981). The EA pattern shows a very strong interdecadal variability being mostly negative between from 1950 to mid-1970’s and mostly positive after mid-1970’s (Figure 1.8).

Positive phases of EA pattern causes higher than normal temperatures in Europe while wetter than normal conditions in the Northern parts and drier than normal conditions in the Southern parts. Wibig (1999), in the work in which she showed the relation between the geopotential height field at 500 hPa level and the precipitation records in Europe, a pattern corresponding to EA was related with the precipitation

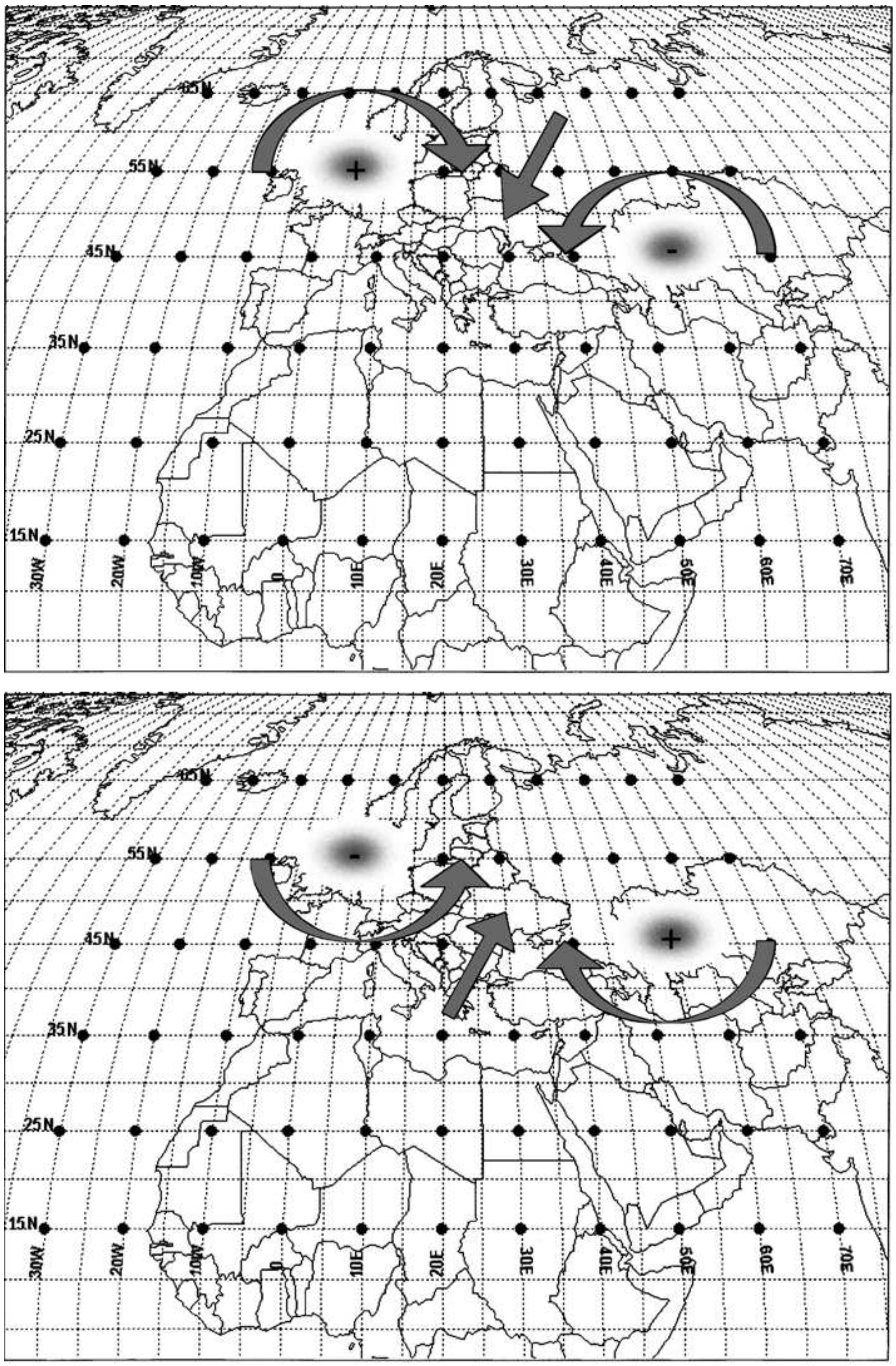


Figure 1.7: East Atlantic/West Russia (EAWR) Pattern (+) (top) and (-) (bottom) phases (Kutiel and Benaroch, 2002)

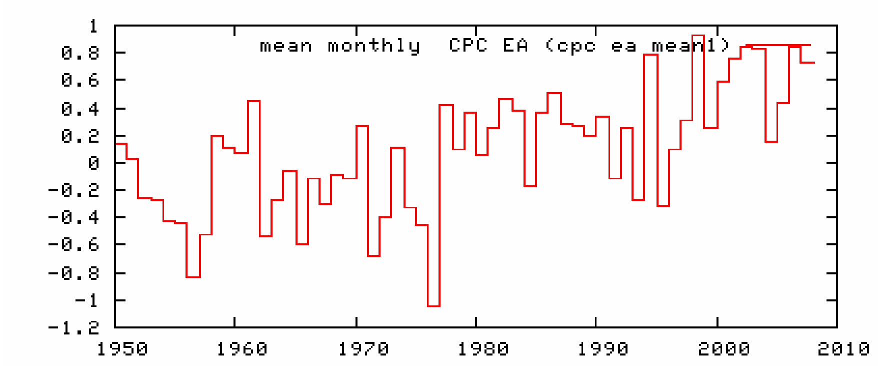


Figure 1.8: East Atlantic Pattern annual mean scores (obtained by making query at `http://climexp.knmi.nl`, last access: 04.02.2008)

in December and March. Precipitation in Spain were shown to be effected by EA although in less amounts than by NAO and EAWR (Rodriguez-Fonseca and Serrano, 2002; Cararmelo and Orgaz, 2007). In the United Kingdom, precipitation regimes were claimed to be affected by the EA pattern, even more than the NAO (Murphy and Washington, 2001). Again in the United Kingdom, a moth specie (*Arctica Caja*), both in abundance and growth rate terms, was shown to be in relation with the EA pattern (Conrad et al., 2003). Moreover, strong relations were found with the sea surface salinity patterns in the East Atlantic (Mignot and Frankignoul, 2004).

1.1.4 Other Important Climatic Indices

Mediterranean Oscillation (MO): Apart from the NAO, which is already known to be effective in the Mediterranean, a smaller scale system, the MO, was claimed to take part in this region (Conte et al., 1989; Palutikof et al., 1996). In the negative phases of this pattern, associated with the low pressure over the western Mediterranean and consequently with intense cyclogenetic activity, wetter than normal conditions occur in most of the region (Suselj and Bergant). Although the MO was originally planned to be considered in the study as a main index, the time series of MO was seen to be highly correlated with NAO, a situation also verified by (Suselj and Bergant). In a study in which a gridded meteorological data set and its linkages with atmospheric patterns are studied with a spatial emphasis, MO could add unique explanation to the discussion. However, as the data sets used in this study are small in number and not gridded, they are far from being able to represent spatial structures, so that discussions were only based on their temporal evolution. Therefore, being highly correlated with NAO, time series of MO was thought to be useless in this study and abandoned.

El-Nino Southern Oscillation (ENSO): ENSO is the most important known source of inter-annual variability in the climate system of the world. ENSO is caused by interacting parts of the climate-ocean circulation system, and was seen to have globe-wide consequences not only on weather but also in especially marine ecosystems and human life. Pressure gradient across the Pacific, with high pressure at eastern coast and low pressure at western coast, being on the equator, cannot be balanced by Coriolis force and directly results with a circulation cell, known as the Walker Circulation. The walker circulation consists of sinking and rising branches at the eastern and western coasts, respectively and countervailing winds flowing to the west at the surface and east at the upper atmosphere. The surface winds dump the warm and moist air collected from the ocean surface to the western coast of Pacific, characterizing the warm, wet weather in the Indonesia and its vicinity. Moreover, the water is warmer in the western coast as the surface warm water is also dragged to west along the ocean. Removal of the surface water in the east, on the contrary, creates the upwelling effect and brings the deep, cold and nutrient rich water to the surface. Being subject to the intensity of high and low pressure centers across the coasts, which is indexed by the Southern Oscillation (SO), weakening of the Walker Circulation together with its effects is referred to as El-nino, while opposite (strengthening of these conditions) referred to as La-nina (From the web pages of Australian government, Bureau of Meteorology, (`http://www.bom.gov.au/climate/enso/`) and Florida State University, Center of Ocean-Atmospheric Prediction Studies, (`http://www.coaps.fsu.edu/lib/biblio/walker-circ.html`), both last accessed on 04.02.2008).

Pacific Decadal Oscillation (PDO): PDO term was firstly coined by a fisheries scientist researching connections between Alaska salmon production cycles and

Pacific climate. Often described as the El-nino like pattern of Pacific climate variability, PDO has 20-30 years long persisting cool or warm episodes in contrast with 6-18 months long El-nino events. Warm phases of the PDO is characterized by warm and dry conditions in the northern North America, cool and wet conditions in the southern North America. Warm episodes also coincide with enhanced coastal biological productivity in Alaska and inhibited production in the southwest coast of United States (Mantua, submitted; , the web pages of Washington University, Joint Institute for the Study of the Atmosphere and Ocean (`http://jisao.washington.edu/pdo/`), last access: 04.02.2008).

Madden-Julian Oscillation (MJO): Known also as the 40-day wave, MJO is a climatic wave occurring primarily in tropics of Indian and Pacific Ocean, characterized by eastward propagation of regions of anomalously high or low rainfall activity, sea surface temperature (SST), ocean surface evaporation, and lower and upper level wind speed. MJO was reported to be modulating the intensity of other climatic events like monsoon systems, ENSO cycles and tropical cyclone activities around the global tropics (From the web page of University of Queensland, Agricultural Production Systems Research Unit (`http://www.apsru.gov.au/mjo/index.asp`) and National Oceanic & Atmospheric Administration, Climate Prediction Center (`http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml#educational%20material`), last access: 04.02.2008).

1.2 Pathways of Climatic Impacts on Lake Ecosystems

In many studies, it was shown that parameters like water temperature, nutrients, chemical properties like alkalinity and pH, ions like silicate and calcium, biological components like chlorophyll-a and zooplankton have consistent fluctuations not only between each other but also with atmospheric circulation indices (Baines et al., 2000; George et al., 2000; Weyhenmeyer, 2004). These consistencies suggest a remote climatic control on lake ecosystems. Generally, these impacts occur through a highly complex network of interacting compartments. However, the least indirect effects can generally be seen on the physical and hydrological characteristics of lakes.

In other words, the physical and hydrological parameters act as an intermediate step carrying the climatic signals to the other compartments of lakes. Therefore, this section, in which the general literature knowledge on climatic impacts on lake ecosystems will be reviewed are organized around main intermediate steps in the following sections.

1.2.1 Climatic Influence on Basin and Lake Hydrology

Precipitation in excess of evaporation on land discharges to springs or lakes as surface or subsurface flow, carrying the materials dismantled from the soil along the catchment. Therefore, depending on the geographical and land use characteristics of the catchment (slope, soil type, forested, agricultural, etc.), discharges directly effect the hydrological properties (water level, retention time, circulation, etc.) and material concentrations of lakes. Quantification of magnitude and composition of subsurface flows is usually not measured but calculated with mass balance equations. Surface flows on the other hand, which are especially important in semi-arid regions characterized by short intense rainfalls, can be accurately measured (Kalff, 2001). Influence of climatic circulation systems on the amount of surface discharges has been studied in various regions of world. Kahya and Dracup (1993) showed that stream flows in the United States are under control of ENSO (1.1.4) while Cullen et al. (2002) showed that of Middle East under control of NAO. Marengo (1995) also showed that South American runoff is heavily effected by the extreme phases of Southern Oscillation. Coulibaly et al. (2000) achieved significant results where he applied recurrent neural networks approach to forecast annual runoffs using ENSO, NAO and PNA (Pacific - North American) as input variables. In Turkey also, Cullen and deMenocal (2000) showed that the Tigris-Euphrates stream flow are negatively correlated with NAO, which is also in relation with temperature and rainfall regimes in the region. Kalayci and Kahya (2006) using 78 stream stations with a reasonable coverage over Turkey, showed that most of the variance in winter averages of stream flows can be explained by NAO.

Export of materials from catchments to lakes occurs especially with the intense rainfall events. In the light rainfall events, dissolved materials have the chance to be re-absorbed by soil when percolating through subsurface layers. However, in the intense rainfall events, this material-rich water reach to lakes as overland flow. George et al. (2004b) showed that dissolved reactive phosphate concentrations in 4 English lakes are affected by NAO via this mechanism. Weyhenmeyer et al. (2004) showed that chemical loadings to a Swedish lake, consequently with the phytoplankton concentrations and turbidity, peaked to the levels ever recorded after an extreme precipitation event. However, in lakes which have different important material sources, like sediment resuspension and atmospheric deposition, increasing discharges may also cause a flushing effect and material concentrations may decrease (Ozen et al., 2005). As another example, phytoplankton, mainly generated within the lake boundaries, was shown to be effected negatively from flushing rates in the 4 English lakes mentioned above George et al. (2004b). Also the concentrations of some ions, especially salinity may increase in response to increasing water residence time (decreasing flushing effect) as a result of increasing proportion of water leaving the system by evaporation (Sanford and Wood, 1991; Verschuren et al., 1999; Zavialov et al., 2003). Beklioglu and Tan (2008) showed the salinity doubled in 2 lakes located in the Anatolian Plateau, following a 4-5 years of drought. Jeppesen et al. (2007) showed that salinity may become a such important factor that it may induce regime shifts in lake ecosystems.

Lake water levels may serve as a good climatic indicator although responses to climatic changes are heavily shaped according to non climatic factors mentioned above. For this reason, different lakes may show different responses to same climatic signals (Magnuson et al., 2005). At this point, it should be noted that human-factors also contribute to water level fluctuations in different extents in different regions of the world, depending on their economical activities (agriculture) as well as the climatic regime in the catchment (Coops et al., 2003). Despite these anthropogenic forcings, climatic effects may become such dominant that they can still manifest themselves in the long-term time series of lake water levels. Mistry and Conway (2003) showed that water level series of Lake Victoria in the eastern Africa were consistent with the Southern Oscillation. Rodionov (1994) detected that the water levels in the "Great Lakes" region were responding to a system like PNA (Pacific-North American) pattern. Arpe et al. (2000) showed the link between water levels of world's biggest lake, Caspian Sea and ENSO. In Turkey, Cengiz (2005) found generally negative correlations between Turkish lake water levels and NAO, especially with a high level of significance with the ones located in the Western Turkey.

The most pronounced effects of water level fluctuations are on vegetation development in the littoral zones. Water level fluctuations act as ecological stress factors and disturbance in these zones, effecting on vegetation community features like species richness and species evenness (Riis and Hawes, 2002; Van Geest et al., 2005). In wetlands and shores of shallow lakes in which water level fluctuations emerge as wet-dry cycles, vegetation species composition reflect both as fluctuations of relative abundance of species and successional elimination and re-appearance of some species (van der Valk, 2005). In Turkey, Beklioglu et al. (2006) showed that water level falls, enhance submerge plant development due to favorable light conditions, being also dependent on the bottom slope and general morphometrical features in 5 Turkish Lakes. Water level fluctuations may have further consequences mediated by vegetation availability, which is an important element in feedback loops especially in shallow lakes. For example, vegetation availability may stabilize the bottom sediment, inhibiting the resuspension of materials (Jeppesen et al., 1997; Meijer et al., 1999; Madsen et al., 2001). Plants may also provide refuge for the large bodied zooplankton against predation by fish (Timss and Moss, 1984; Lauridsen and Lodge, 1996). Moreover, as being further discussed in (1.2.2), as the water level drops, mixing probability of bottom sediment due to wind stress, which decreases exponentially with depth, increases (Scheffer, 1998). Having links with such important feedback loops, water level fluctuations shall also be expected to have important consequences on ecosystem functioning, as been already mentioned with the Lake Okeechobee example (Figure 1.5).

1.2.2 Water Temperature, Ice Cover, Stratification and Mixing

Synchrony between the water temperatures of different lakes, as well as the consistency of these with the atmospheric circulation indices were shown by many researchers (Blenckner and Chen, 2003; George et al., 2000; Gerten and Adrian, 2001; Livingstone and Dokulil, 2001; Livingstone, 2003). However, the same climatic signal may be processed and stored differently according to depth, bathimetry and mixing regimes of lakes. For example deep lakes, due to their higher amount of heat flux for a unit water temperature change, respond less to changes in air temperature (Gerten and Adrian, 2001). However, modulated by their mixing regime, although already being in small magnitudes and further dampened through the water column, the climatic signals captured can be trapped in the deep, non-mixing layers and can be stored for more than a year (Straile et al., 2003b).

Temperature has a positive effect on the rates of many reactions involved in the material cycles in lakes, having consequent effects on biological components. Especially in subtropical regions and in summer months, fish kills are common to observe in relation with oxygen depletion due to high rates of processes like decomposition and mineralization. As another example from temperate lakes, it was argued that low nitrogen levels recorded after mild winters -which can also be tracked by positive phase of NAO- were due to the increased sub-surface assimilation rates taking place in the catchment (George et al., 2004a). Zooplankton species are known to be effected by changes in water temperature depending on their life history traits (Wetzel, 1983). For example, parthenogenetically reproducing cladocerans may respond very quickly to increasing water temperatures, enabling them to double their population size within a short amount of time, when of course the phytoplankton abundance meets the corresponding needs. Copepodes on the other hand, would also respond to the favorable conditions but it would take longer time to show this in terms of overall abundance (Straile, 2004). In many studies, due to its influence on temperature, NAO was shown to be correlating with the abundance of various zooplankton species, with different strengths (Gerten and Adrian, 2000; Straile, 2000; Straile and Adrian, 2000) and depending on the food availability, with different signs (George, 2000). Especially, temperature influence on critical species like *Daphnia* because of its high grazing strength, may also cause alterations in the timing of clear-water phase. Straile et al. (2003b) beautifully summarizes the NAO - clear water timing relationship, which involve several intermediate steps (Figure 1.9). It should, however, be noted that biological consequences may also occur through more unexpected linkages. For example, Winder and Schindler (2004) shows that different adaptation skills of zooplankton species to a long term trend of spring warming may result in a mismatch of trophic linkage with phytoplankton bloom, causing drastic changes in zooplankton community structure. Although a linkage between the phytoplankton and temperature could also be expected, it was found out that there were not much studies focusing on it, probably since nutrient availability is far more important for phytoplankton.

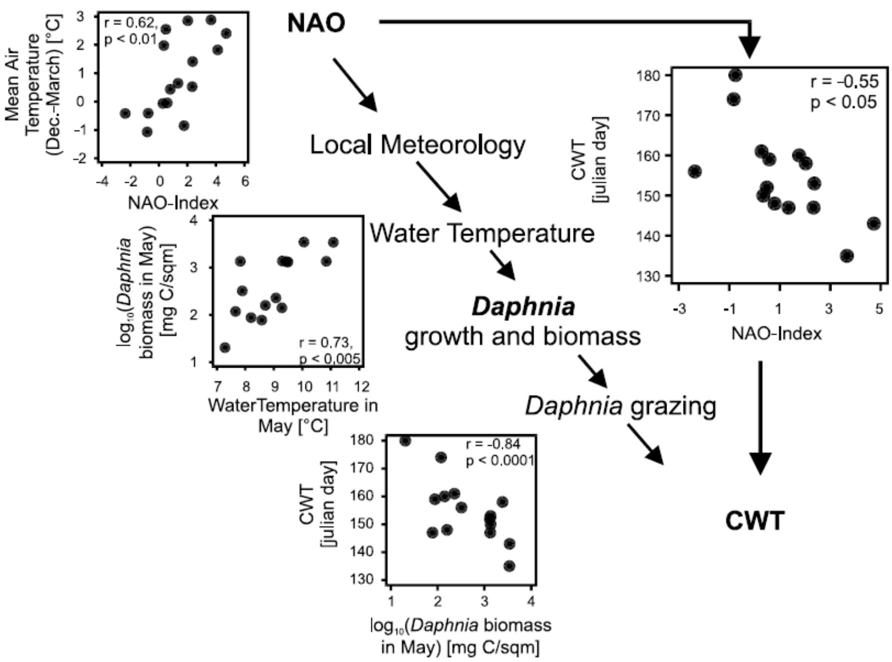


Figure 1.9: NAO influence on timing of clear water phase, taken from (Straile et al., 2003b)

Ice formation and break-up dates were also shown to be related with the air temperatures and the atmospheric circulation indices (Livingstone, 1999; Palecki and Barry, 1986; Yoo and D'Odorico, 2002). Ice phenology, being a naturally-filtered indicator of the winter air temperatures, is an especially important phenomenon which can have dramatic biotic consequences especially in the poleward latitudes. (Magnuson et al., 2000). At spring, due to the sheltering effect of ice, the light availability may become the limiting factor for primary production. Based on this, atmospheric circulation indices were shown to be correlated with spring bloom dates mediated by air temperatures (Weyhenmeyer et al., 1999; Gerten and Adrian, 2000; Blenckner and Chen, 2003). In the northern lakes, anoxic conditions caused by delays of ice break up dates are known to be responsible for fish kills (Greenbank, 1945). This, in turn, is suggested to be decreasing the predation pressure on the zooplankton and pushing the system to clear-water state (Jeppesen et al., 2000, 1998).

Lakes seasonally lose or gain heat mostly from their surface. This heat flux from surface produce a temperature gradient and consequently a density gradient along the water column. Depending on the climatic regime and lake morphometry, this temperature gradient vanishes in difference frequencies throughout the year. The common example is "dimicticity", corresponding to 2 mixing periods occurring due to warming at spring and cooling at fall. Depending on its strength, the density gradient may act as a barrier against mixing and the dense particles may become trapped in the bottom, denser part, in which photosynthetic activity is not much due to light-limited conditions. In large lakes, upwelling of this nutrient-rich water, which may result from several factors like wind induced water movements or sudden cooling and sinking of surface water, may stimulate bottom-up effects cascading through the upper trophic levels in the ecosystem (Heufelder et al., 1982; Haffner et al., 1984; Dunstall et al., 1990). In lake Constance, reduced cooling associated with positive NAO was shown to be responsible for incomplete mixing and limited upward transport of nutrients from the hypolimnion (Straile et al., 2003a).

Wind causes a water movement, called as "wave" at the surface, which propagates downwards through the water column. The shear stress this water movement produces at the bottom depends on the depth, as well as the size of the waves, while the size of the waves depends on the wind strength and the fetch, i.e. the distance over the waves have been allowed to build up (Scheffer, 1998). After a critical threshold determined by the sediment structure (Hamilton and Mitchell, 1997), the shear stress causes mixing of the sediment proportional to its strength (Hamilton and Mitchell, 1996), resuspending the buried materials into water column. In shallow lakes, effects of wind on the concentrations of suspended matter and total phosphorus have been demonstrated many times Degroot (1981); Kristensen et al. (1992); Sondergaard et al. (1992), as well as its further consequences on phytoplankton Carrick et al. (1993); Hamilton and Mitchell (1997) via field measurements, laboratory experiments and mathematical models.

1.2.3 Some Notes

As been mentioned before, same climatic signal may have different, even opposite effects on different lakes. Through the conceptual model he presented, Blenckner (2005) explains that climate driven effects form after passing two filters: a landscape filter, involving geographical position, catchment characteristics and lake morphometry; and an internal lake filter, involving lake history and biotic-abiotic interactions. In this context, when conflicting responses to a similar climatic signal is observed, the features making up the filters should be reviewed carefully before concluding that the relations are coincidental. For example, as been explained in 1.2.1, water level drops may enhance vegetation development which are said to serve as refuges for large-bodied zooplankton against their predators, thus an inverse correlation can be expected with the water levels and zooplankton average body size. However, it was recently shown that this refuge effect was practically not true for the subtropical lakes, in which fish were found in high numbers in the plant beds, contrasting to the situation in temperate lakes (Meerhoff et al., 2006, 2007).

Some processes taking place in ecosystems may occur in a nonlinear fashion and may show hysteresis, mainly due to the existence of feedback mechanisms (May, 1977). For this reason, detection of climatic effects may become nontrivial in some situations. Even worse, this nonlinearity may cause misinterpretations about system behavior which may eventually lead to catastrophic shifts in ecosystems (Scheffer et al., 2001a; Scheffer and Carpenter, 2003). Shallow lakes also, in which several feedback loops exist and have major roles in overall system functioning, commonly show a hysteric behavior with two alternative stable states (Scheffer et al., 1993). Scheffer et al. (2001b) claimed that small temperature changes may become so important that they may determine whether spring clear water phase will occur or not, by using a simple algae-zooplankton model. Although being a controversial one (Jeppesen et al., 2003; Van Donk et al., 2003), this was an important study spotting the possibility of major effects that can be triggered by minor climatic changes.

1.3 Aim and Scope of This Study

Turkey, being located on a strong hydro-climatological gradient from North to South, hosts many endemic and threatened terrestrial and aquatic species. In the face of projected warming and drier than normal conditions in the Mediterranean, investigation and quantification of possible impacts to these ecological resources are required to propose and discuss mitigation measures. However, these topics have not been sufficiently investigated in Turkey. First national communication of Turkey on climate change was published in the first month of 2007 in which also, impacts of climate change was not widely discussed neither in the water resources nor in the ecological contexts (Apak and Ubay, 2007).

In this study, impacts of a large scale atmospheric system, which is the main source of climatic variability superimposed on the long term trends in our region, on the major Turkish lakes were investigated. A secondary objective emerged as identification of the preferred patterns of variability of the large scale atmosphere system, and interdependence of these with the known atmospheric circulation indices. After this atmospheric system was described, reflection of its variability on the physical and hydrological characteristics were analyzed. Lastly, although the best available data set was not sufficient to draw firm conclusions, impacts of climatic variability on further biological components of Lake Mogan was studied, at least to exemplify the methodologies and approaches for such kind of future attempts.

CHAPTER 2

MATERIAL & METHODS

2.1 Data

In the first part of this study, connections between the large scale atmospheric system and the hydro-meteorological conditions around lakes was aimed to be detected. As a first step, Sea Level Pressure (SLP) field, as a proxy to the large scale atmospheric system, in a region (20-70N, 50W-70E, see Figure 2.1) surrounding Turkey as well as known proximal climatic circulation systems was analyzed. For this purpose, NCAR (National Center of Atmospheric Research) SLP dataset (Trenberth and Paolino, 1980), which have a 5°C-5°C monthly resolution was used for the 1899-2006 period. Data was obtained from the web page of National Center of Atmospheric Research, Climate Analysis Section (`http://www.cgd.ucar.edu/cas/guide/Data/trenpaol.html`, last accessed on 04.02.2008).

The second step was centered around detection of linkages between the atmosphere system and physical - hydrological characteristics of lakes, meteorological and water level data was obviously the main requirement. Water level data was obtained from the "Elektrik İşleri Etüd İdaresi Genel Müdürlüğü" (Directorate of State Electricity Works) and "Devlet Su İşleri Genel Müdürlüğü" (Directorate of State Water Works) for 10 major lakes, selected according to the available data length and their geographical positions so that especially the climatic gradient along North to South could be adequately represented (Figure 2.2). Although being quite small lakes, Lakes Eymir and Mogan were also added to the list due to having best

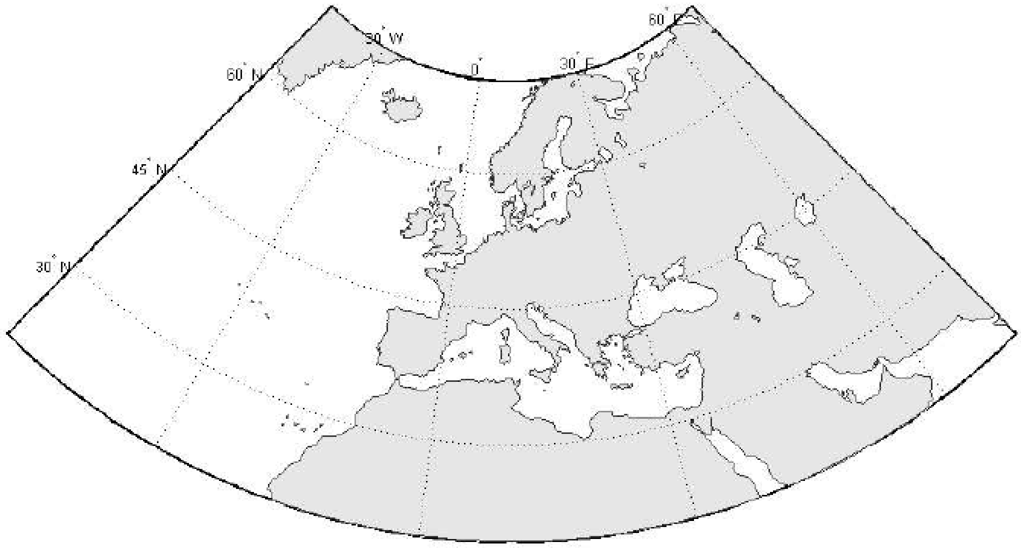


Figure 2.1: Region representing the large scale atmospheric system

data sets available (see below). Data of one example inflow for each lake were also obtained from these two organizations, not for any means of a mass-balance approach but to see if the stream flows of these lakes are also effected by climatic conditions in the same manner as the water levels are effected. Both water levels and inflows were in the form of monthly averages of daily measurements.

Thanks to the extensive coverage of station network of "Devlet Meteoroloji İşleri Genel Müdürlüğü", there were at least one station that could be reasonably reflecting the meteorological conditions occuring in vicinity of selected lakes. Table 2.1 lists the coordinate information both for the lakes themselves and meteorological stations assigned. For Lakes Marmara and Işıklı, data from stations Akhisar and Denizli were used respectively, for a few number of parameters which the original station was lacking. Although more than 50 years of data were available for most of the stations, the data were provided starting from 1975, the period in which the quality control was made by the organization. Data of following parameters were obtained: Monthly average pressure, monthly average wind, monthly total solar radiation, monthly average temperature, monthly minimum temperature, monthly maximum temperature, monthly total evaporation, monthly total precipitation.

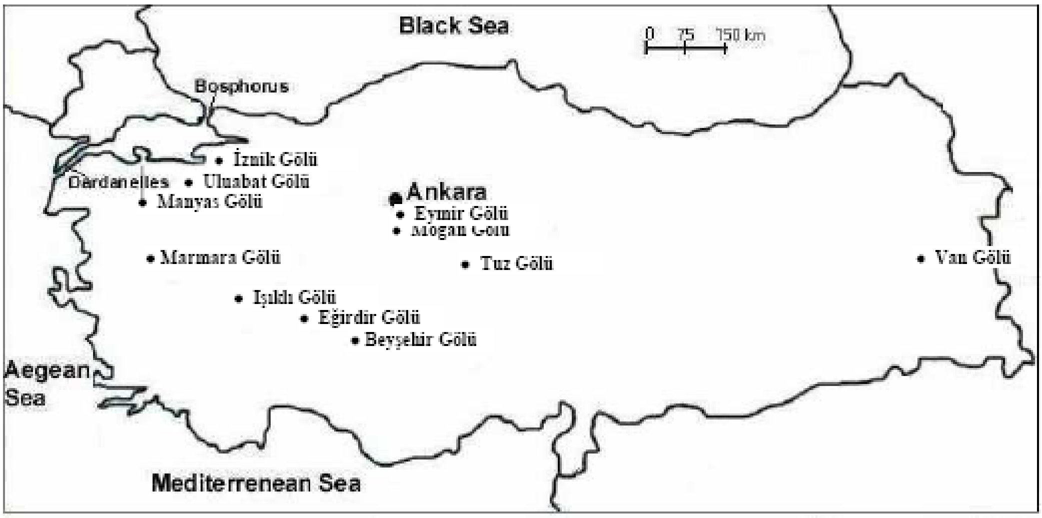


Figure 2.2: Geographical distribution of selected lakes

Table 2.1: Coordinates of the lakes and corresponding meteorological stations

LAKE	COORDINATE		STATION	COORDINATE	
İznik	40° 46' N	29° 31' E	Bursa	40° 11' N	29° 04' E
Manyas	40° 11' N	28° 00' E	Bandırma	40° 21' N	27° 58' E
Uluabat	40° 12' N	28° 40' E			
Eymir	39° 57' N	32° 53' E	Ankara	39° 55' N	32° 51' E
Mogan	39° 46' N	32° 47' E			
Tuz	38° 46' N	33° 20' E	Kulu	39° 05' N	33° 04' E
Van	38° 37' N	42° 57' E	Van	38° 29' N	43° 24' E
Marmara	38° 37' N	28° 05' E	Manisa	38° 37' N	27° 25' E
Işıklı	38° 14' N	29° 55' E	Dinar	38° 04' N	30° 09' E
Eğirdir	38° 02' N	30° 53' E	Eğirdir	37° 51' N	30° 50' E
Beyşehir	37° 45' N	31° 36' E	Beyşehir	37° 41' N	31° 44' E
Burdur	37° 44' N	30° 11' E	Burdur	37° 43' N	30° 17' E

For the impacts of climate on lakes beyond their physical and hydrological characteristics, which can be considered as the second part of the study, data were scarce. The only institutional long-term data sets that could be found for the lakes under consideration were the physical-chemical measurements at the outflows of Lakes Manyas, Uluabat, Işıklı, Eğirdir and Beyşehir. The parameters involved in these data sets, with an emphasis on heavy metals and several ions, reflect that the measurements were undertaken mostly to assess the agricultural or domestic usability of lake waters. Therefore only a few parameters were recognized to be useful: Water temperature, electrical conductivity, ammonium, nitrite, nitrate (last 3 lumped as Dissolved Inorganic Nitrogen (DIN)) and phosphate (PO_4). The frequency of measurements were 3-4 times a year, having an internal consistent cycle within each lake (every March, every August, etc.) but not with different lakes (i.e., Lake Manyas: every March, Lake Eğirdir: every April). Usability of a compilation of biological data from several different published sources (reports, thesis, projects, etc.) was also considered, however it was seen that these would not constitute a continuous, monthly frequented data sets. Moreover, homogeneity (temporal consistency of methodologies and spatial location of measurements) related issues would have additional interference. As can be understood from the examples given in Section 1.2, deciphering of climatic signals in the network of many interacting chemical and biological components needs detailed, consistent, temporally intense long term data sets (see Section 4). As the data sets that could be found for the large lakes do not mostly bear even any of these features, small scaled Lakes Eymir and Mogan, of which moderate level of biological data sets are available, had to be also included in the study.

As most of the lakes under consideration are only subject to discussions regarding their water level fluctuations, information on their biotic features would be pointless. However, in order to represent their differing main characteristics, which would have effect on the water level fluctuations also, are given in Table 2.2.

Time series of the atmospheric circulation indices, namely the NAO, EAWR and EA, used extensively throughout the study, were obtained from a single source for the sake of consistency, CPC (Climate Prediction Center) of the NOAA (National Oceanographic and Atmospheric Administration (`http://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh`), last access: 04.02.2008).

Table 2.2: Main characteristics of the lakes

Lake	Surface Area (ha)	Mean Depth (m)	Max. Depth (m)	Altitude (m)
İznik	~29830	30	65	84
Manyas	~16800	1 - 2	4	15
Uluabat	~20000	2.5	10	8
Eymir	125	3.1	6	967
Mogan	700	2.1	3.5	973
Tuz	<164200	0.5 - 1	2	903
Van	~390000	171	451	1646
Marmara	6800	2.6	4	79
Işıklı	7300	2.4	8	821
Eğirdir	46800	8 - 10	~15	916
Beyşehir	65600	2.1	~10	1125
Burdur	23700	42	100	857

2.2 Data Checking and Processing

Prior to any kind of analysis, all of the available data was checked visually according to some objective criteria like existence of outliers, adequacy of continuity and smoothness, etc. Moreover, in order to set the direction of analysis and assess suitable techniques to entangle the relations, consistency of series within different stations and seasons were also visually checked by constructing composite plots, and evaluated whether if there were visible patterns or if they were totally random. These plots are not given here, however were extensively covered in (Oguz et al., 2007). Available data generally showed consistent behavior and were seen to be in the reasonable ranges. However, some of the data had to be eliminated due to insufficient temporal coverage as mostly seen in the meteorological and hydrological parameters and insufficient frequency, smoothness and continuity as seen only in the physical-chemical data from the outflows. Overall acceptation and rejection results are given in Table 2.3.

Missing data in the remaining accepted data sets were partially reduced by applying linear interpolation. When a missing value was encountered, this value was filled with the average of values for the same month of previous year and following year, if they were both available. On the next round, the remaining missing values were filled with the average of previous and following months of the same year, again if

Table 2.3: Accepted and rejected data. (- indicate that there was no data available)

Lakes	Pres.	Temp.	Prec.	Evap.	Wind	Solar Rad.	Water Level	Inflow	Water Temp.	Elect. Cond.	DIN	PO4
Manyas	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✗
Uluabat	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓
İznik	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-
Eymir	✓	✓	✓	✓	✓	✓	✗	✗	-	-	-	-
Mogan	✓	✓	✓	✓	✓	✓	✗	✗	-	-	-	-
Van	✓	✓	✓	✓	✓	✓	✓	✓	-	-	-	-
Marmara	✓	✓	✓	✓	✓	✓	✓	✗	-	-	-	-
Işıklı	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✗	✓
Burdur	✓	✓	✓	✓	✓	✗	✓	✓	-	-	-	-
Tuz	✓	✓	✓	✓	✓	-	✓	✓	-	-	-	-
Eğirdir	✗	✓	✓	✗	✗	-	✓	✓	✓	✓	✓	✓
Beyşehir	✗	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓

they were both available. By this way, out of 4778 missing fields (total number of fields: 53364, proportion of missing fields: 9%), 815 were filled by the interannual interpolation and 812 were filled by the intermonthly interpolation, making a total of 1627. 3151 (5.9% of total number of fields) could not be filled and left as missing.

When the temperature falls below 0°, the evaporation pans in use freeze and have to be removed. For this reason, the evaporation data was missing in all stations for several months depending on the temperature regime (not ever less than 4 months in Van), which can not be filled by the linear interpolation scheme explained above, because of the systematic missing fields. Evaporation is known to occur also in winter although in small amounts, which could be calculated mechanistically, however, some of the required parameters like relative humidity, aerodynamic resistance were also not available. Therefore, the winter missing values of evaporation were filled with multiple linear regression (See section A.1), using temperature and wind as predictor variables. Although it is known that linearity between evaporation and temperature vanishes dramatically at the low temperatures, this was the only solution that could be employed in the boundaries of practical means. In all stations, this method produced evaporation time series having very highly significant ($p < 0.001$) correlations (Table 2.4) with the original, measured series. In order to check the magnitudinal reasonability of the synthetic data and detect the possible pitfalls in the implementation, the scatter plots and time series plots of observed-calculated pairs were visually inspected. An example is provided in Figure 2.3 for station Bandrma. Note that, not the whole synthetic data set was for the analysis but rather the portions were used in which the measured data was not available. Further note that, when the MLR produced a negative evaporation value for the very low temperature courses, simply the evaporation was assumed to be 0.

Table 2.4: Correlation coefficients between measured and calculated evaporation series

Station	Cor. Coef.		Station	Cor. Coef.
Bursa	0.93		Akhisar	0.97
Bandırma	0.92		Dinar	0.94
Ankara	0.96		Denizli	0.93
Kulu	0.96		Eğirdir	0.98
Van	0.92		Beyşehir	0.95
Manisa	-		Burdur	0.95

2.3 Multivariate Analysis Methods

In this section only some brief knowledge on the aims and literature usage about the used statistical methods is given. Mathematical elaboration are given in the appendix in order not to distract the flow of material by overwhelming the section with numerous equations.

Multiple Linear Regression (MLR) is a standard method used to explain the relationship of a dependent variable with 2 or more independent variables, by fitting a linear model on a set of observations. Area of usage is so wide that attempting to notify some of the usages for literature would be not only pointless but also would be misleading.

Also known as the Principal Component Analysis (PCA), Empirical Orthogonal Function (EOF) analysis is a technique used by a wide scientific community for

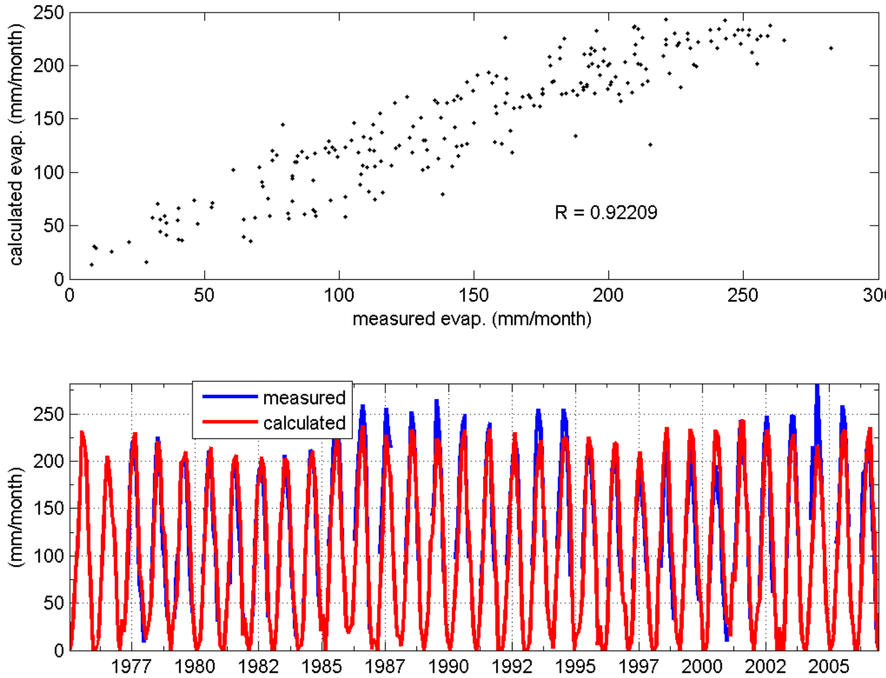


Figure 2.3: Scatter (top) and time series (bottom) plots for the calculated and measured evaporation series for station Bandirma, as a case

discrimination and compression of dominant sources of variability contained in large data sets. Specifically in meteorology and oceanography, EOF is a traditional technique, commonly used to provide a compact description of the temporal and spatial variability, originally found in a set of instantaneous maps of a geophysical field, in terms of independent (orthogonal) functions. Exhaustive surveys on the topic were held in (Barnston and Livezey, 1987; Preisendorfer, 1988; Bretherton et al., 1992). Examples on practical usage of EOF in ocean-atmosphere research are Dai et al. (1997); Zhang et al. (1997); Lionello and Sanna (2005). Although technically the same, the method has also been used in the ecology research. Examples involve Beaugrand et al. (2000); Lim et al. (2001); Michelutti et al. (2002); Hausmann and Pienitz (2007).

Canonical Correlation Analysis (CCA) is a technique used for finding out the linear links between two data fields. Some examples on usage of CCA in atmosphere research can be given as: Wallace et al. (1992); Sirabella et al. (2001); Xoplaki et al. (2003). When the CCA is applied on fields of large spatial dimension compared to temporal dimension (samples), artificially high correlations can be obtained due to contribution of noise variability. However, compressing and filtering the data fields prior to the CCA by using a technique like EOF (A.2) greatly reduces the danger of misinterpreting random correlations as true correlations (Barnett and Preisendorfer, 1987; Bretherton et al., 1992).

Frequently confused with PCA, Factor Analysis (FA) also aims to explain the covariance structure with fewer axes, although with some important differences. First all, only the shared variance is tried to be modeled in FA. In this respect, FA tends to factorize (group) the sources of co-variability while PCA aims to differentiate the sources of variability with components. In PCA, emphasis has been on describing the principal components in terms of original variables while in FA, emphasis has been on rather describing the original variables in terms of factors. Moreover, unlike the PCA, the number of modes have to be explicitly defined in FA (Preisendorfer, 1988; McGarigal et al., 2000). A list of FA usage in ecology research can be given as: Reisenhofer et al. (1995); Romo et al. (1996); Peterson and Peterson (2001).

CHAPTER 3

RESULTS

As been explained in Chapter-1, climatic variations may have effect on different components of lake ecosystems, which also interact with each other. A conceptual model, summarizing the components and their interactions comprised in the signal transmission process is proposed in Figure 3.1. The two main parts of this study can be mapped on this model. In the first part, the patterns making up the large scale atmospheric system were identified and connections of this system with the meteorological (2), hydrological (3) and consequently physical (4,5) and chemical (6) conditions were inquired. In the second part, with the best available data set, which was from Lake Mogan, lower portion of this model which involve more indirect reflections (7-11) of climatic variability were studied.

3.1 The Large Scale Atmospheric System and its Impacts on Local Hydro-Meteorological Conditions

3.1.1 Identification of the Large Scale Atmospheric System

There does not exist any single variable that can represent the behavior of an atmospheric system. Atmospheric circulation indices (namely the NAO, EAWR, etc (see Section 1.1)), which are generally calculated by taking the difference of two pressure centers, although being able to capture some climatic processes, can represent the physical system only partially. There may also exist some important

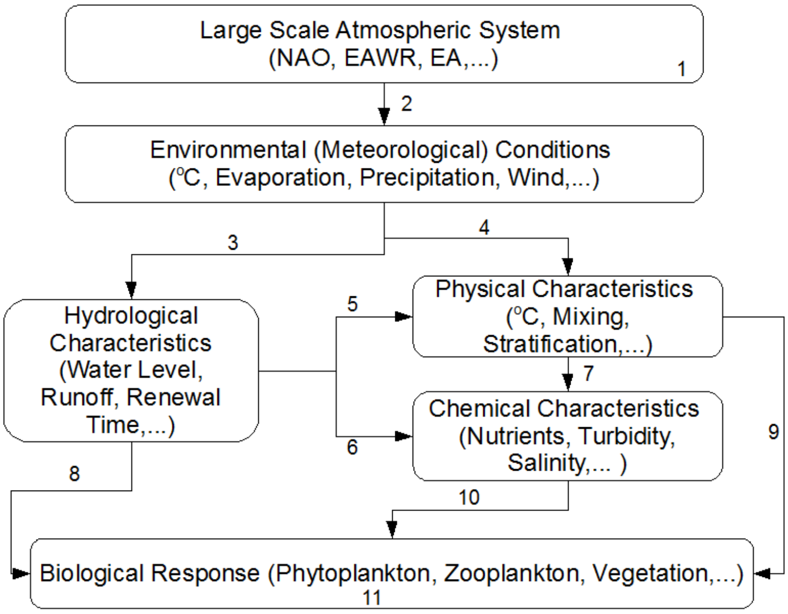


Figure 3.1: The conceptual model summarizing the interactions transmitting the climatic signals

patterns in an atmospheric system which remain undiscovered (or unnamed) yet. Even if discovered and with a greater possibility, as the literature is highly crowded in the field, especially the workers which are not at the core of the teleconnection studies, may not be aware of them. Moreover, it is known that the pressure centers are not spatially stable (Portis et al., 2001), so that the station based indices can not account for the resulting variability. In this study, the variations in the atmospheric system concerning Turkey was materialized by applying EOF analysis on a proximal SLP field (see Section 2.1) covering not only Turkey but also the centers of action of some known prominent circulation indices. Patterns found in this analysis were used in second part of the study as the axes defining the atmospheric variability (Section 3.1.2).

The atmosphere is dynamically most active and perturbations grow to their largest amplitudes during winter (Hurrell et al., 2003). As a result, the influence of circulation indices are greatest at this time of the year. Therefore, the SLP field was analyzed for winter averages at the first place. Dominant modes found in this analysis were compared with selected atmospheric circulation indices. In Table 3.1, for the time series of each of the first 10 modes, levels of significance and sign of the correlations attained with NAO, EAWR and EA are summarized. Also the portion of explained variance by each mode is given. The compression of all significant correlations in first 4 modes, which account for 70% of total variability in the system, suggest that physical processes addressed by these 3 indices constitute the main variability in this system.

Table 3.1: Levels of significance and sign of the correlations observed with NAO, EAWR and EA for each 10 modes of winter SLP. Number of signs show the significance levels; 3: $p < 0.001$, 2: $p < 0.01$, 1: $p < 0.05$

Mode	Expl. Var. (%)	NAO	EAWR	EA
1	33.38	+++	++	
2	14.87	+++	−−	
3	10.95			+++
4	9.29	−−	+++	++
5	6.54			
6	4.03			−
7	3.36			
8	2.49			
9	2.05			
10	1.63			

In order to verify that the listed correlations are not just by coincidence, we need to check the spatial structures of these dominant modes. In Figure 3.2, the principal component loadings of first four modes obtained are shown. A careful inspection of these spatial patterns reveals that these are perfectly consistent with the correlations of their time series. In the first mode, an NAO dipole structure is evident. In the second mode, a coupled NAO-EAWR pattern, with a shared center on the Atlantic also confirms the EAWR correlation attained with its time series listed in Table 3.1. This coupled NAO-EAWR pattern was detected also by Barnston and Livezey (1987) who conducted a similar analysis on the whole Northern Hemisphere. On the third mode, a very clear EA dipole is seen with its positive center slightly out of the region. On the fourth mode, a total of 5 pressure centers observable in the region confirms the complexity one should expect as suggested by the contribution of all 3 indices listed in again Table 3.1. Time series of first 4 modes are also shown in Figure 3.3, Figure 3.4, Figure 3.5 and Figure 3.6, respectively. Each plot is made up of 4 panels. First panel show the series by itself, while in second, third and fourth panels, the series are plotted together with the NAO, EAWR and EA time series, each shown with a dashed line. Time series of further modes are not given for the sake of compactness of information, since it is possible that these further modes reflect mostly the noise signal as been suggested by the suddenly droping explained varience after 4th mode together with no corresponding (persistent) correlations with the indices (Table 3.1).

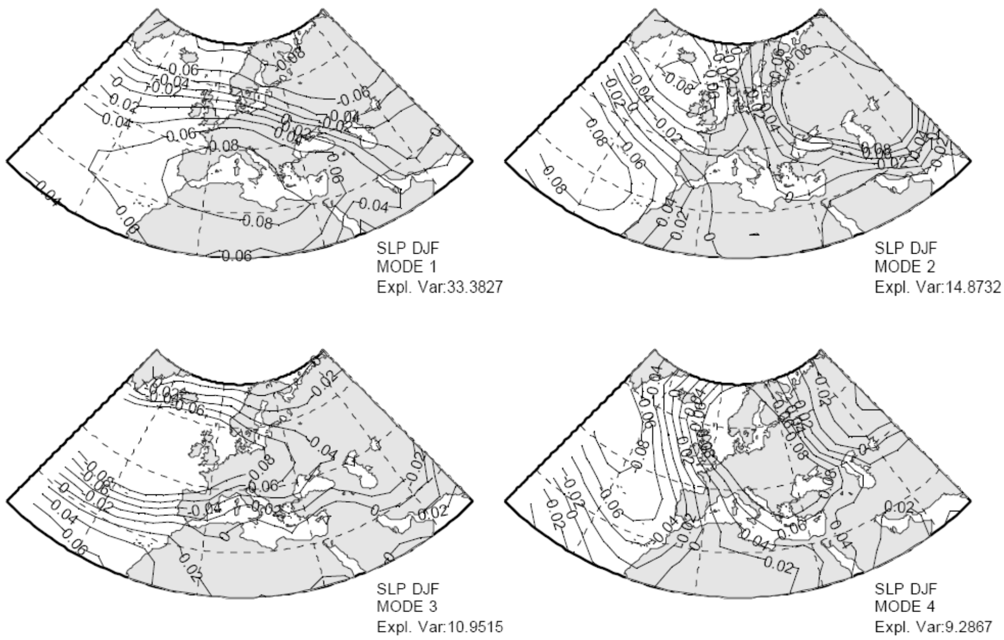


Figure 3.2: The spatial patterns of SLP field obtained with EOF analysis

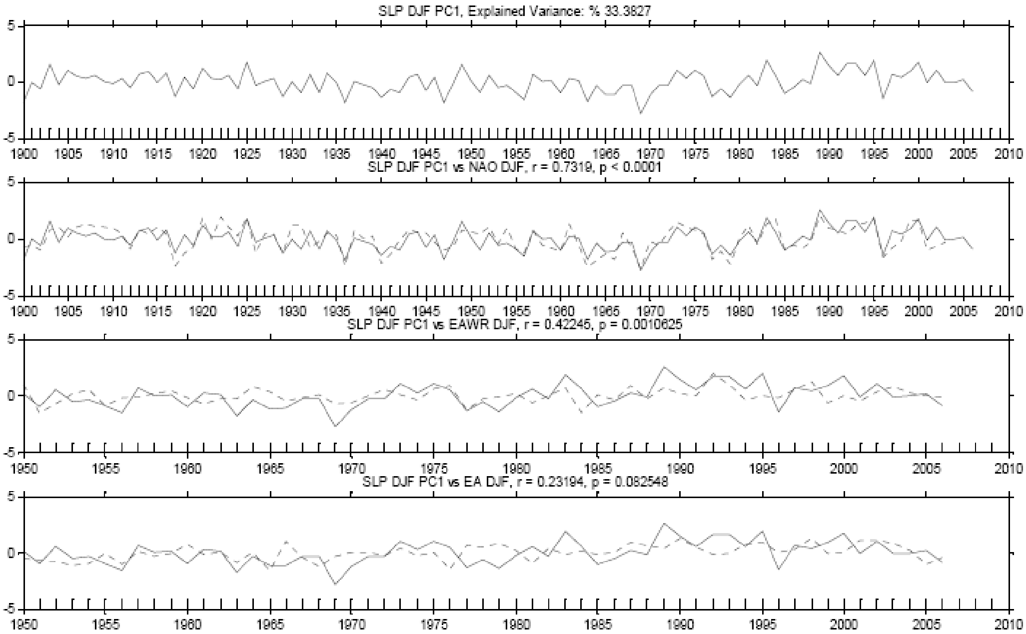


Figure 3.3: Winter SLP mode-1 time series

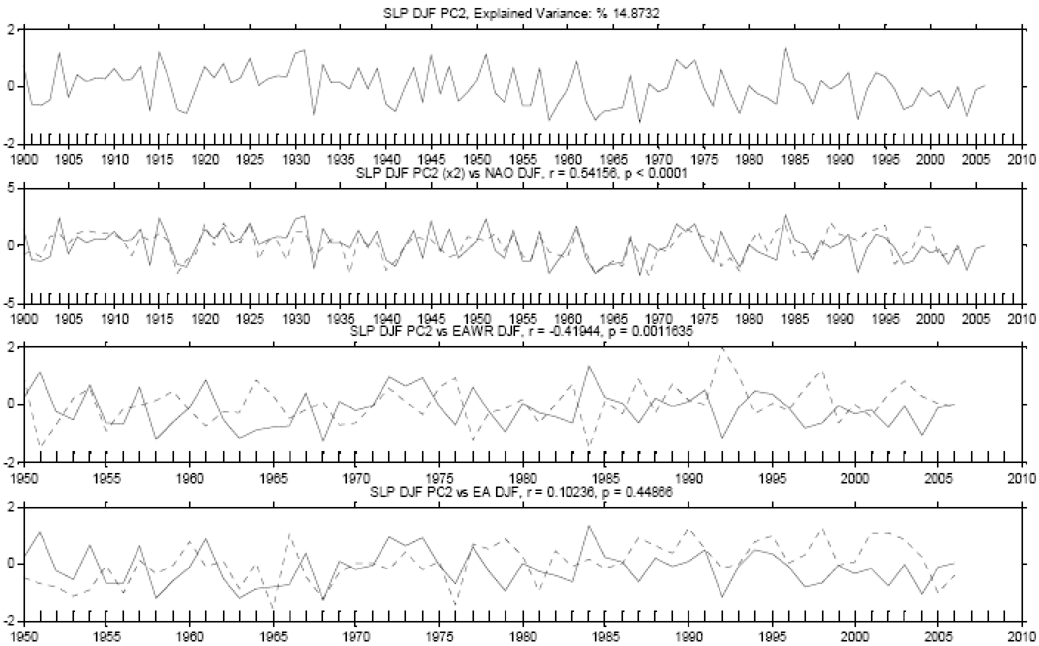


Figure 3.4: Winter SLP mode-2 time series

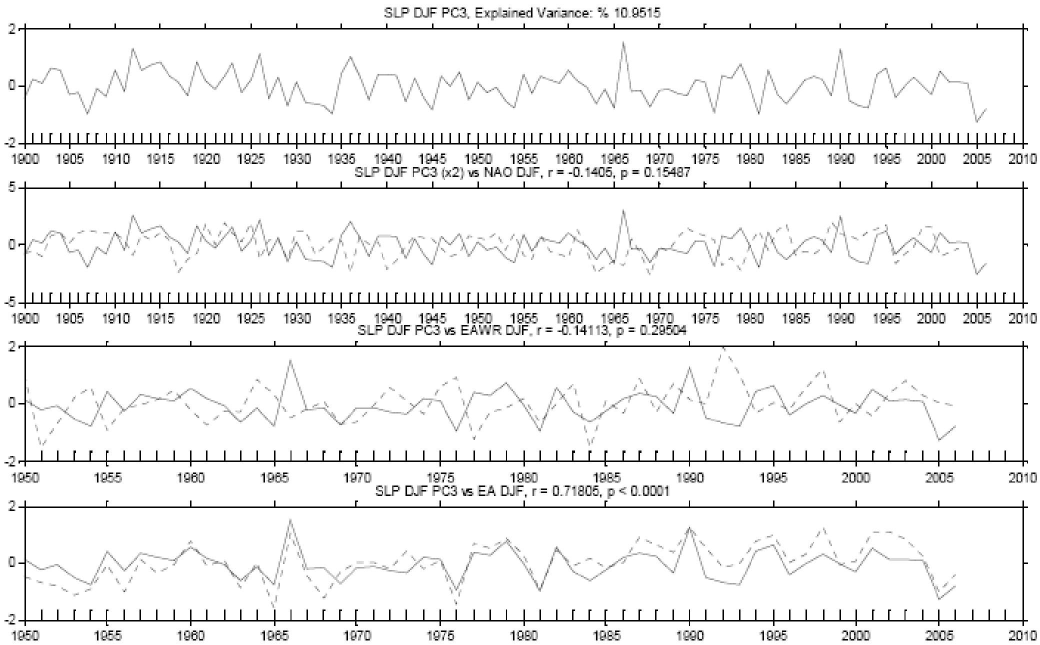


Figure 3.5: Winter SLP mode-3 time series

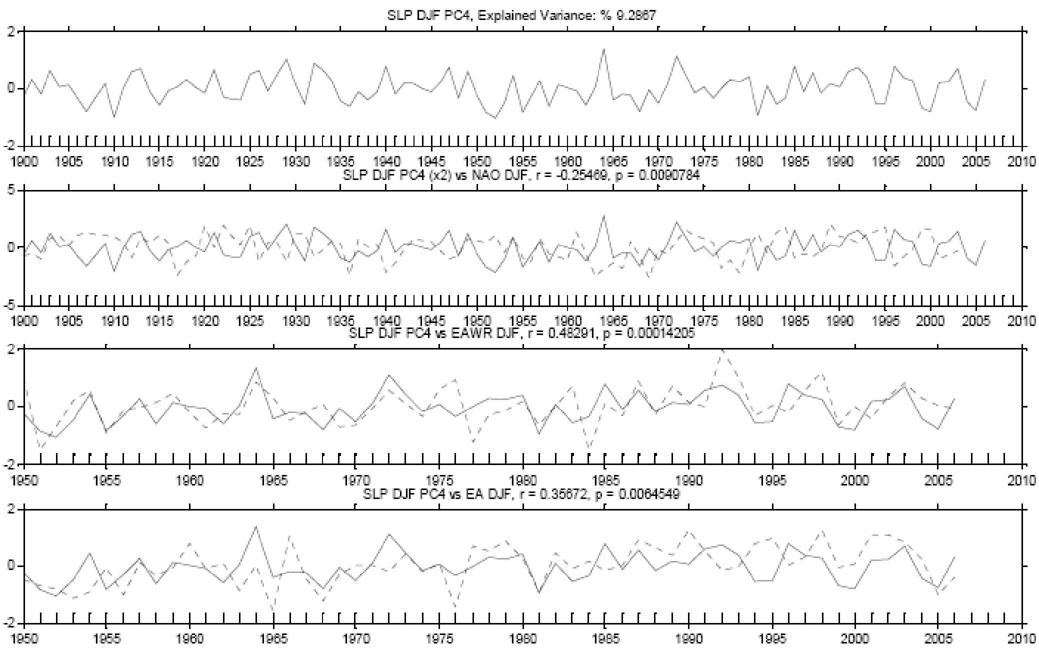


Figure 3.6: Winter SLP mode-4 time series

EOF modes of the SLP field of the interested region was extracted also for the monthly series (i.e., January: Jan 1901, Jan 1902,...,Jan 2006; February: Feb 1901, Feb 1902,..., Feb 2006; ...) to check the seasonal differences. In Table 3.2, correlations attained for time series of first ten modes and the 3 circulation indices, NAO, EAWR and EA are summarized.

3.1.2 Local Hydro-meteorological Conditions

Direct Approach: Correlations with Circulation Indices

As been introduced in Section 1.1, several climatic elements over Turkey were shown to be correlated with indices like NAO (Turkes and Erlat, 2003; Karabork et al., 2005) , ENSO (Kahya and Karabork, 2001), and EAWR (Kutiel and Turkes, 2005). In order to check whether these relations hold for the available data sets in this study also, their correlations were inspected with the time series of 3 climatic circulation indices. For the correlations, the raw data of each station were not used, but rather each of leading 3 EOF modes were used, since they represent a less-noisy, compressed form of an important portion of total variability originally represented by several stations. Correlations were systematically calculated between leading 3 EOF modes of each parameter and 3 indices. As well as the meteorological and hydrological data, water temperature, electrical conductivity, dissolved inorganic nitrogen (DIN) and phosphate (PO_4) data gathered from the lake outflows, were also treated in the analysis. Electrical conductivity, which is sometimes used in acronym with salinity, is considered to be able to reflect the changes in hydraulic residence time. DIN and phosphate, on the other hand, to the extend they are able to reflect the in-lake conditions, were shown to be effected by climatic phenomena (Section 1.2). The lake-outflow parameters were handled only on a basis of annual averages, since there were not adequate amount of data to represent the seasonal (e.g., winter) conditions. Moreover, for comparison purposes, meteorological and hydrological parameters were also treated in the annual basis, but also only using the data for 1991-2006 period since the lake-outflow parameters only exist within this period. Table 3.3 summarize the results obtained from this analysis.

Table 3.2: Levels of significance and sign of the correlations observed with NAO, EAWR and EA for each 10 modes of SLP for each month of year. Number of signs show the significance levels; 3: $p < 0.001$, 2: $p < 0.01$, 1: $p < 0.05$

Month	Ind \ Mode	1	2	3	4	5	6	7	8	9	10
1	Exp. Var.	28.85	15.18	13.19	8.73	7.70	4.89	3.96	2.67	2.38	1.59
	NAO	−−−	+++	−−							
	EAWR		−−	+++	+++	++				−	
	EA	−		+++	−−−					++	
2	Exp. Var.	32.00	13.78	11.58	10.04	8.95	4.63	3.27	2.41	1.92	1.73
	NAO	+++	−−−		+++						
	EAWR	++		+++	−−	+++					
	EA	++		−−−	−−						
3	Exp. Var.	29.24	18.10	10.12	8.83	6.47	4.40	3.85	2.71	2.06	1.81
	NAO	+++	−−−	+		−					
	EAWR				++					−−	−
	EA				+++						
4	Exp. Var.	17.61	13.92	10.03	9.10	8.65	5.37	5.01	4.17	4.02	3.24
	NAO	−−−	+++		+	++					
	EAWR					−−−			+		
	EA			+++	−		+	−−−			−
5	Exp. Var.	17.73	13.48	10.08	8.15	7.85	5.79	5.20	3.81	3.21	2.94
	NAO	−−−	−−−								
	EAWR	−		−−−	−−−						
	EA	−−−				−−−	−−	++			
6	Exp. Var.	16.52	14.06	10.57	7.69	7.27	5.57	4.99	4.40	3.64	2.68
	NAO	+++	−−−		+			+			
	EAWR	−			++			−		−−	
	EA					−					
7	Exp. Var.	15.62	11.98	10.24	9.37	7.83	6.06	5.06	3.67	3.21	2.81
	NAO		−−−		++						
	EAWR		+	+++		+++		−	+		
	EA					++	++			++	
8	Exp. Var.	16.14	12.34	10.60	9.55	6.76	5.63	4.72	4.51	3.13	2.74
	NAO	+++		+++	−−−	−					
	EAWR					+				−−−	
	EA			++		−−−					
9	Exp. Var.	14.59	12.67	10.92	10.03	7.59	6.12	5.08	4.40	3.72	2.65
	NAO	−−−	−−−	−	−−						
	EAWR		+++	−	+++					−	
	EA	−−−		−		−−−					
10	Exp. Var.	18.06	15.81	12.03	8.52	7.28	5.63	4.80	4.23	3.01	2.51
	NAO	+++	+++	−							−
	EAWR	−−−		++	+++	−−					
	EA		+++	+		+++					
11	Exp. Var.	21.83	17.09	11.08	10.26	6.24	5.50	3.83	3.53	2.78	2.54
	NAO	+++	−−−			−−−					
	EAWR			−−−		+					
	EA		−−−		−−−	+					
12	Exp. Var.	21.86	18.21	13.04	10.69	7.28	5.26	4.31	2.53	2.09	1.80
	NAO	+++	−−−	−−−	−						
	EAWR	+++	+		+++	+				−	
	EA			+++							

Table 3.3: Correlations between first 3 modes of variables -together with their explained variance in terms of percentages- and circulation indices all in annual and winter (December, January, February) averages. Signs show the nature of correlations (negative or positive) while number of signs show the significance levels; 3: $p < 0.001$, 2: $p < 0.01$, 1: $p < 0.05$

Variable	EOF Mode	1991-2006 Annual Averages				1975-2006 Winter (DJF) Averages			
		Expl. Var.	NAO	EAWR	EA	Expl. Var.	NAO	EAWR	EA
Pressure	1	60.36		+		74.77	−−	−	
	2	16.97				10.85		++	
	3	9.41				7.35			
Wind	1	46.62			++	35.88	+		
	2	22.07				22.98			
	3	11.60				17.36			
Solar Radiation	1	48.79				47.16			
	2	30.68				22.99	+		
	3	14.70	+			16.17			
Temperature	1	86.87		−		85.85		−−−	+
	2	8.39				7.53			
	3	2.40				2.60			
Min. Temperature	1	58.70				33.18			
	2	11.80				24.29		−−−	
	3	8.61				8.87			
Max. Temperature	1	64.85				73.41		−−	+
	2	18.73	−	−−		9.45			
	3	7.77				5.07			
Evaporation	1	49.15				51.17	−−		
	2	15.02				17.45		+	
	3	11.69				13.23			
Precipitation	1	52.56	++			57.78			
	2	14.93				12.67			
	3	8.49				7.89			
E-P	1	48.66	+			50.58			
	2	14.03	+			16.05			
	3	10.60				10.78			
Inflow	1	53.35				39.46			
	2	19.08	−			19.92			
	3	11.81			−	14.47			
Water Level	1	42.25				36.10			
	2	22.93	+			20.08			
	3	12.60				14.38			
Water Temperature	1	35.06				Data not available			
	2	20.89							
	3	17.38							
Electrical Conductivity	1	40.14							
	2	25.02							
	3	20.54							
DIN	1	41.58							
	2	29.91							
	3	22.26							
PO_4	1	45.25		−					
	2	26.39							
	3	23.91							

In order to investigate the seasonal variations in the strength of manifestations of these indices in the meteorological and hydrological parameters, same analysis was conducted for each month also. Lake out-flow parameters were not used in this set of analysis since they are sparse over time and a single measurement is not considered to reflect the monthly average conditions. As been done for the annual and winter averages, linear correlations were calculated between each of the 3 leading modes of each parameter and the 3 circulation indices. Table 3.4 summarizes the correlations attained for each parameter by listing the signs and levels of correlations throughout the year. Furthermore, Figure 3.7 visualizes the seasonal variation of strengths of correlations attained. For each parameter, correlation levels attained by each mode with each index were connected to form lines. For ease of inspection, 3 lines for each mode at 3 different panels for each index was constructed. Moreover, 3 significance levels were marked with 3 different symbols. This way, not only we can see whether the significant correlations are aggregated in a panel corresponding to a relative dominance of an index, but we can also see the changing strength of indices throughout the year.

Table 3.4: Correlations between first 3 modes -together with their explained variance in terms of percentages- of variables and circulation indices for every month of the year. Signs show the nature of correlations (negative or positive) while number of signs show the significance levels; 3: $p < 0.001$, 2: $p < 0.01$, 1: $p < 0.05$

	Variable:	**Pressure**			**Wind**			**Solar Radiation**			**Temperature**			**Min. Temperature**			**Max. Temperature**		
Month	**Mode:**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
1	**Expl. Var.**	84.06	10.12	2.94	39.31	19.95	14.36	53.67	18.85	15.50	86.41	6.98	2.60	37.04	19.56	12.21	64.88	14.39	6.43
	NAO	−			−−					++					+				
	EAWR	−−						−−			−−−			+++			−−		
	EA	−−			−−					++								−	
2	**Expl. Var.**	75.76	13.61	4.47	39.34	19.01	13.04	58.59	20.46	11.35	86.55	7.27	2.86	79.19	6.99	4.18	76.51	8.19	5.41
	NAO	−−−					−	++	−			+							
	EAWR	−	−−								−−			−			−		
	EA							+			+						++		
3	**Expl. Var.**	78.91	9.85	5.86	25.20	23.60	17.16	51.19	24.70	12.00	86.00	6.14	5.35	74.95	9.13	5.74	69.38	14.64	5.55
	NAO	+				−−													
	EAWR																		
	EA	+																	
4	**Expl. Var.**	62.26	16.37	10.40	40.51	16.73	11.87	49.11	25.79	15.83	88.19	5.52	2.84	73.57	10.89	4.97	72.52	9.60	5.98
	NAO																		
	EAWR										+++			+++					
	EA	+									−−−						−−		
5	**Expl. Var.**	58.54	13.62	10.72	30.67	23.28	14.62	63.81	17.90	8.13	75.85	9.63	6.63	62.70	11.47	9.71	71.87	12.31	5.78
	NAO			+													+		
	EAWR				++					−−									−
	EA	+						+											
6	**Expl. Var.**	67.14	14.29	8.06	33.21	24.16	14.34	63.87	18.37	8.23	62.96	16.71	7.10	57.37	14.36	7.37	61.61	16.57	8.11
	NAO					−													
	EAWR														−			−−	
	EA																		
7	**Expl. Var.**	64.24	12.21	10.68	33.41	27.33	10.79	55.73	24.93	10.86	77.19	11.52	4.37	63.46	14.28	6.87	63.29	16.67	8.34
	NAO																−		
	EAWR										+						−−		
	EA					−		++			−−−			++					
8	**Expl. Var.**	62.80	12.57	8.78	34.43	23.04	13.67	51.49	22.47	14.42	79.78	7.78	6.55	58.09	13.77	8.27	72.11	12.62	6.17
	NAO						+		−		−−		−				−−		
	EAWR				−		+												
	EA		−−						++		+++	+		++			+		+
9	**Expl. Var.**	69.51	11.46	7.85	38.04	22.10	11.56	44.68	21.84	16.08	74.53	9.75	8.07	64.52	11.30	8.67	51.73	20.30	7.88
	NAO																		
	EAWR																		
	EA																		
10	**Expl. Var.**	65.96	15.94	8.17	34.21	24.30	12.50	55.06	23.87	10.53	82.96	7.34	4.82	74.49	7.66	5.51	67.91	13.60	8.11
	NAO	−			+						−								
	EAWR																	+	
	EA	−									−						−		
11	**Expl. Var.**	67.45	15.61	6.87	36.31	21.50	16.54	57.50	19.12	12.91	84.23	6.31	4.76	75.83	6.56	6.15	72.72	8.61	7.35
	NAO	−−−			−						+	++							
	EAWR																		
	EA				+									++					
12	**Expl. Var.**	76.48	13.20	5.02	40.07	21.61	14.15	44.03	20.70	16.31	84.62	9.23	2.08	73.44	7.86	5.44	64.26	10.27	8.12
	NAO	−																	
	EAWR		−−−								−−−			−−−			−−−		
	EA															−			

Table 3.4: (Continued) Correlations between first 3 modes -together with their explained variance in terms of percentages- of variables and circulation indices for every month of the year. Signs show the nature of correlations (negative or positive) while number of signs show the significance levels; 3: $p < 0.001$, 2: $p < 0.01$, 1: $p < 0.05$

	Variable:	Evaporation			Precipitation			E-P			Inflow			Water Level		
Month	**Mode:**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	1	2	**3**
1	**Expl. Var.**	58.54	24.15	7.49	66.68	8.53	7.12	63.37	9.29	8.14	30.60	27.19	14.05	35.40	18.41	14.96
	NAO					−			+							
	EAWR															
	EA				+++			+++							+	
2	**Expl. Var.**	64.99	18.35	6.76	60.92	10.52	8.73	59.74	10.96	9.56	36.04	23.02	18.69	34.98	19.01	13.83
	NAO	−−			++											
	EAWR	−−							−							
	EA	++			++			+++								−
3	**Expl. Var.**	73.74	8.79	6.83	54.91	11.92	10.18	64.11	10.07	9.19	39.29	27.41	15.47	34.09	21.66	16.54
	NAO			−−		+			+							
	EAWR								−							
	EA															
4	**Expl. Var.**	48.85	15.31	10.26	56.37	11.29	9.78	64.94	11.08	7.33	39.52	25.00	9.29	33.86	19.40	14.39
	NAO			+		++			+							
	EAWR															
	EA	++					+	+								
5	**Expl. Var.**	44.83	17.86	10.55	47.66	17.52	9.19	52.56	16.00	10.32	30.25	21.09	14.26	35.24	19.01	15.80
	NAO															
	EAWR						+									
	EA							+								
6	**Expl. Var.**	47.22	16.75	12.59	39.30	16.02	12.27	51.39	15.83	8.88	35.44	23.54	14.50	35.99	20.17	16.62
	NAO															
	EAWR								+							
	EA														−−	
7	**Expl. Var.**	37.20	19.90	11.28	34.57	17.16	15.84	36.13	15.97	10.99	28.43	25.04	18.23	33.71	21.10	17.02
	NAO															−
	EAWR															
	EA	−−						−−								
8	**Expl. Var.**	43.87	19.43	9.97	35.08	20.09	13.43	39.21	17.96	13.45	30.72	21.32	13.15	36.16	20.27	16.63
	NAO	++						+								
	EAWR															
	EA	−														
9	**Expl. Var.**	45.43	16.57	12.98	55.19	11.61	8.25	55.02	13.63	9.18	28.63	23.80	13.61	38.41	19.82	16.22
	NAO															
	EAWR									−						
	EA															−
10	**Expl. Var.**	40.36	18.50	8.67	51.31	16.62	10.88	49.71	19.77	8.26	35.63	25.66	14.29	39.96	21.55	14.54
	NAO												+			
	EAWR															++
	EA				−						−		+			
11	**Expl. Var.**	51.36	15.91	8.43	58.11	13.32	7.35	58.88	13.80	7.34	35.89	21.83	13.61	36.15	20.84	14.84
	NAO	+														
	EAWR	+						+								
	EA				−−			−−								
12	**Expl. Var.**	63.97	14.72	11.14	64.42	11.85	7.95	62.01	11.72	9.80	32.83	22.99	17.05	35.40	21.27	14.86
	NAO															
	EAWR	−−−				−				+						+
	EA															

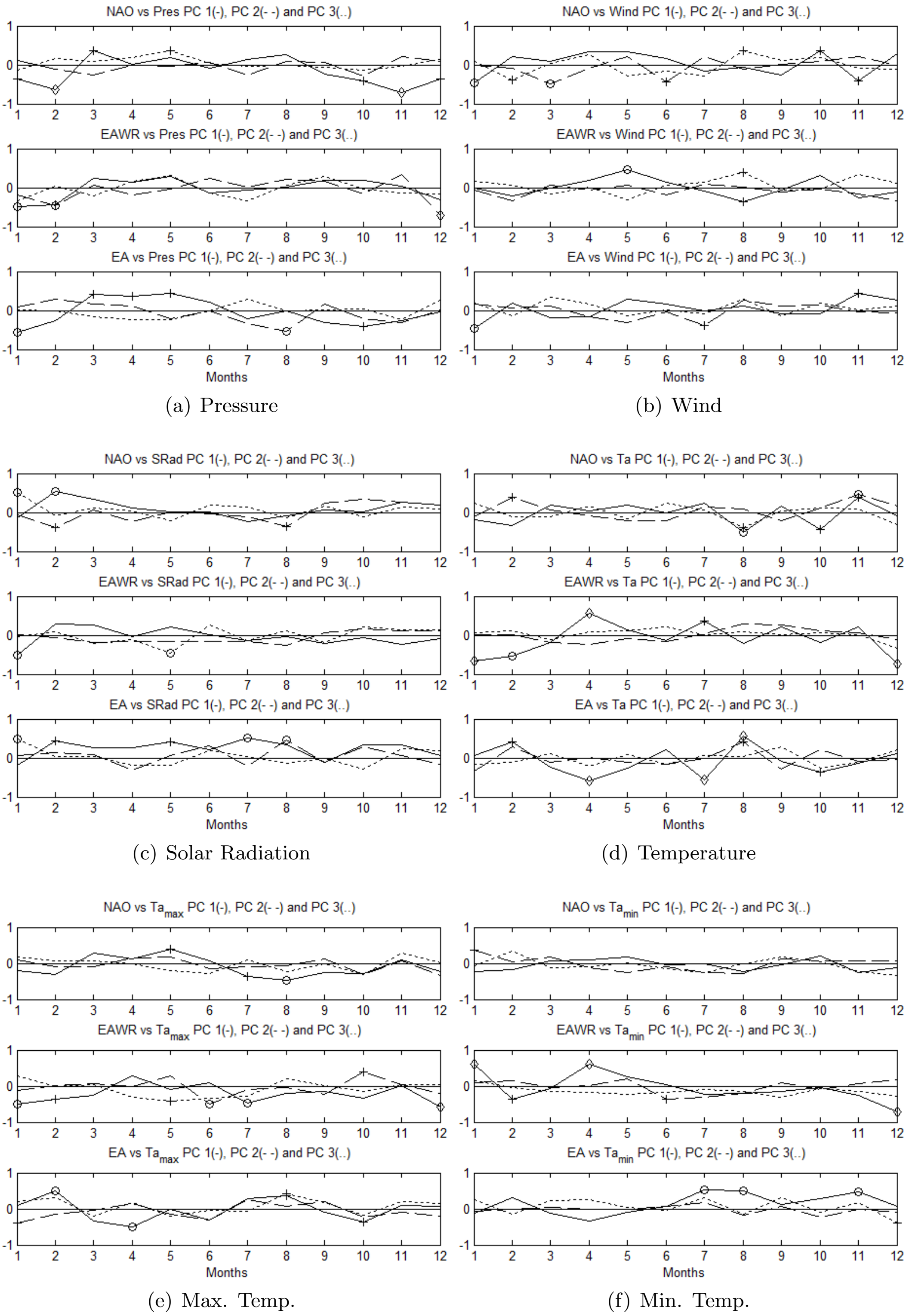
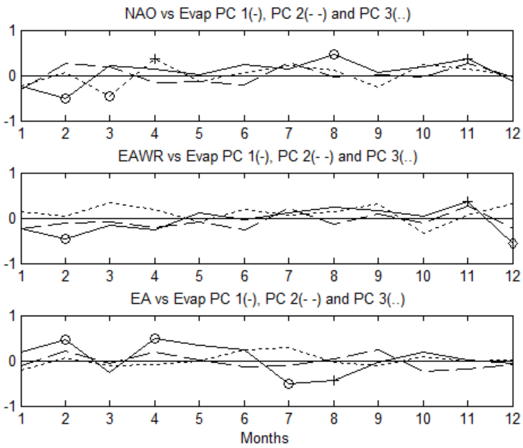
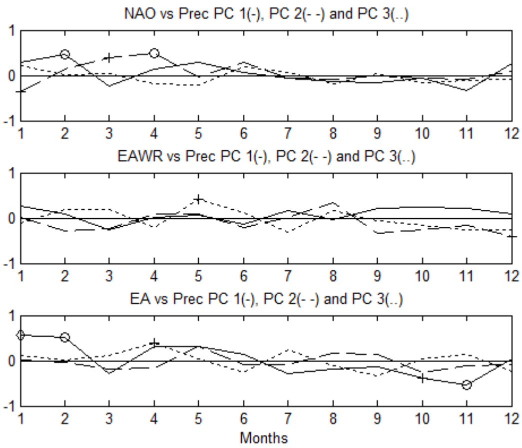


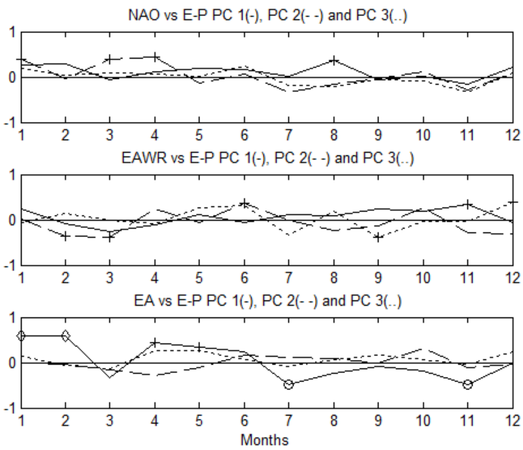
Figure 3.7: Correlation levels between the leading modes of local variables and circulation indices throughout the year. Markers indicate significance levels: 'plus'= :$p < 0.05$, 'circle':$p < 0.01$, 'diamond':$p < 0.001$



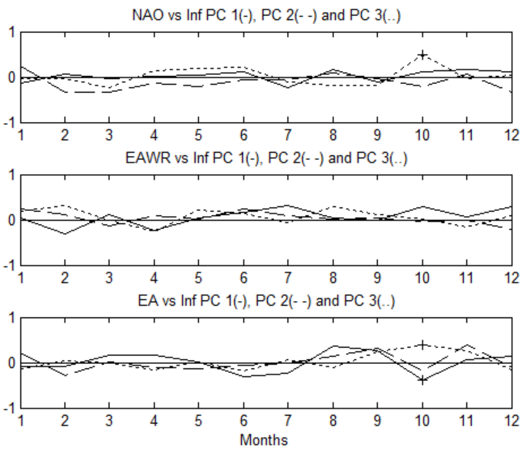
(a) Evaporation



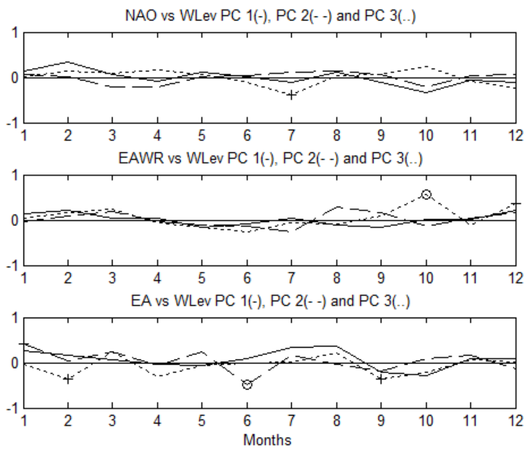
(b) Precipitation



(c) Evap.-Prec.



(d) Inflow



(e) Water Level

Figure 3.7: (Continued) Correlation levels between the leading modes of local variables and circulation indices throughout the year.Markers indicate significance levels: 'plus':$p < 0.05$, 'circle':$p < 0.01$, 'diamond':$p < 0.001$

An Indirect Approach

As mentioned before, an array of indices are not guaranteed to fully represent the atmospheric system being queried. As a more systematic way of detecting the connections, the SLP field, of which's dominant sources of variability were identified in Section 3.1.1, was taken as a proxy to the atmospheric system under question and a Canonical Correlation Analysis (CCA) based technique was applied. Actually the analysis strategy, schematized in Figure 3.8, consists of two main steps: a prefiltering EOF for noise reduction (see Section A.3), and a CCA applied on predictor-predictand variable pairs to find out the linear linkages as expressed by independent (orthogonal) correlation channels. When the significant correlation channels were encountered, to address the responsible physical processes, first the modes of variables contributing to these correlations were tried to be revealed. Then, correlations of these contributing modes with the 3 selected indices, NAO, EAWR and EA were looked to infer if these signals are represented in the modes contributing to correlation channels.

More specifically, relationships of seemingly 2 relatively more important variables for lake ecosystems with the large scale atmospheric system, were focused. The monthly average temperature, for being a direct source of variations in many chemical and biological reactions, as well as being able to alter the relative abundance and fluxes of materials vertically by affecting the stratification cycles. Second one, the water level was also shown to be critical for lake ecosystems especially in our region (Beklioglu et al., 2006), having a direct impact on density and coverage of vegetation in the littoral zone, which have further implications on functioning of ecosystem. However, as an intermediate step between the large scale atmospheric system represented by SLP (see Section3.1.1) and water level, E–P (Evaporation–Precipitation) scores was also considered as a lumped variable. Setting the 4 variables as dependent-independent pairs, relationships of; SLP-Temperature, SLP-(E–P), SLP-(Water Level) and (E–P)-Water Level were analyzed.

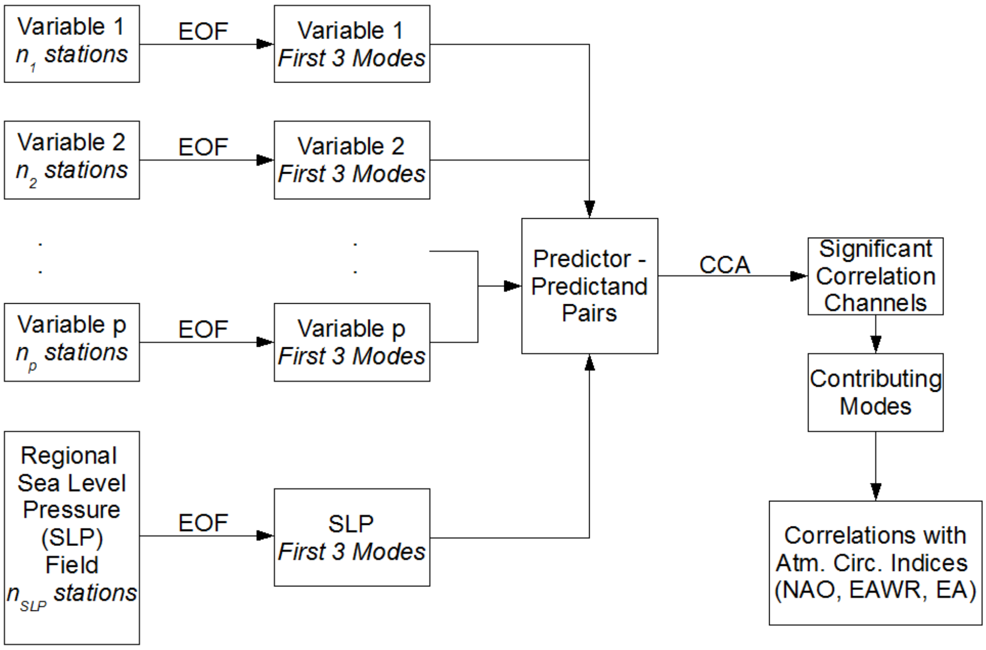


Figure 3.8: Multivariate analysis strategy for finding connections between variable fields

SLP-Temperature Canonical correlations between two fields and correlations between canonical variables and principal components (time series of modes) of each field are given in Table 3.5. The SLP seems to have effect on Temperature from two distinct channels, as represented by 2 correlations of significance levels $p < 0.001$ and $p < 0.05$. Moreover, first principal component of temperature seems to be contributing to first correlation channel and second and third principal components to the second correlation channel, while it seems that SLP contributes with all of its components to the both channels. As been shown in 3.1.1, first 3 modes of SLP was including signals from all 3 indices NAO, EAWR and EA. Temperature, on the other hand, is seen to be carrying EAWR signal ($p < 0.001$) and also EA signal ($p < 0.05$) in its first principal component (Table 3.3) which explains more than 85% of total variance. The plots of principal components which are found to be contributing to the canonical correlations are also given in Figure 3.9, drawn with 3 indices for ease of interpretation. Recall that plots of principal components of the SLP was given in Section 3.1.1 in Figure 3.3 - Figure 3.5.

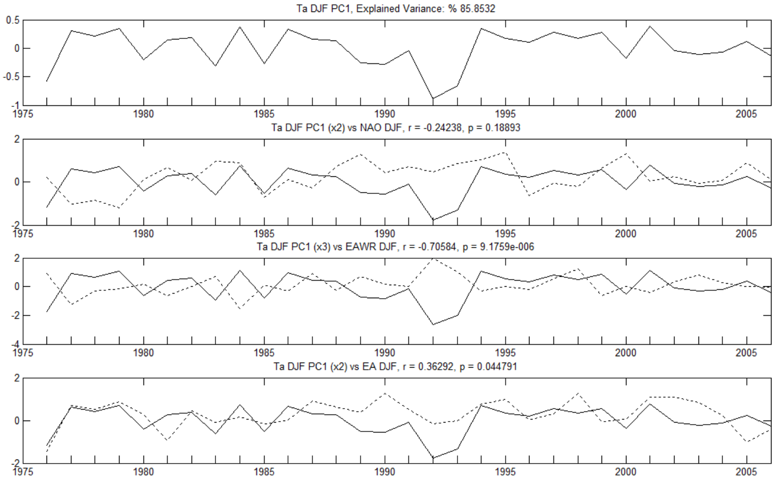
Table 3.5: SLP-Temperature CCA results. All significant correlations are shaded. Notice that only the canonical variables yielding significant correlations were further investigated for contributions by the leading principal components of their original fields (as represented by significant correlations)

	Corr. Coeff.	Significance	Corr. Coeff.	Significance	Corr. Coeff.	Significance
Canonical Correlations (CC)						
	CC 1		CC 2		CC 3	
	0.6525	0.0001	0.3604	0.0464	0.1667	0.3701
Correlations Between Canonical Variables (CV) and Principal Components (PC) of SLP						
	SLP CV 1		SLP CV 2		SLP CV 3	
SLP PC 1	0.5981	0.0004	0.7664	0.0001	-	-
SLP PC 2	-0.5561	0.0012	0.5105	0.0033	-	-
SLP PC 3	-0.6920	0.0001	0.1390	0.4559	-	-
Correlations Between Canonical Variables (CV) and Principal Components (PC) of Temperature						
	Temperature CV 1		Temperature CV 2		Temperature CV 3	
Temperature PC 1	-0.9749	0.0001	-0.2110	0.2546	-	-
Temperature PC 2	-0.1865	0.3151	0.9484	0.0001	-	-
Temperature PC 3	0.1216	0.5145	-0.2368	0.1997	-	-

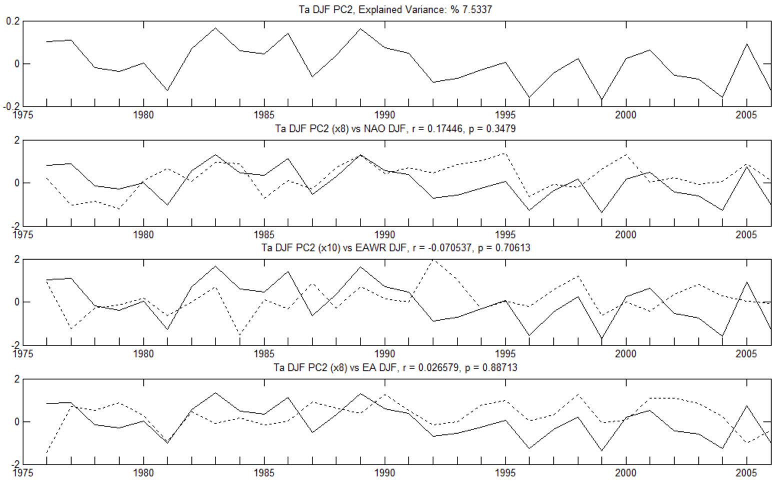
SLP-(E–P) SLP seems to have effect on (E–P) from a single channel as seen from 3.1.2. First 2 components of SLP, corresponding to NAO and EAWR signals contribute to this correlation channel, similar to the situation for the (E–P) side, in which first two components are contributing. These components don't seem to be carrying any signals from indices, as shown in Table 3.3 and Figure 3.10

Table 3.6: SLP-(E–P) CCA results. All significant correlations are shaded. Notice that only the canonical variables yielding significant correlations were further investigated for contributions by the leading principal components of their original fields (as represented by significant correlations)

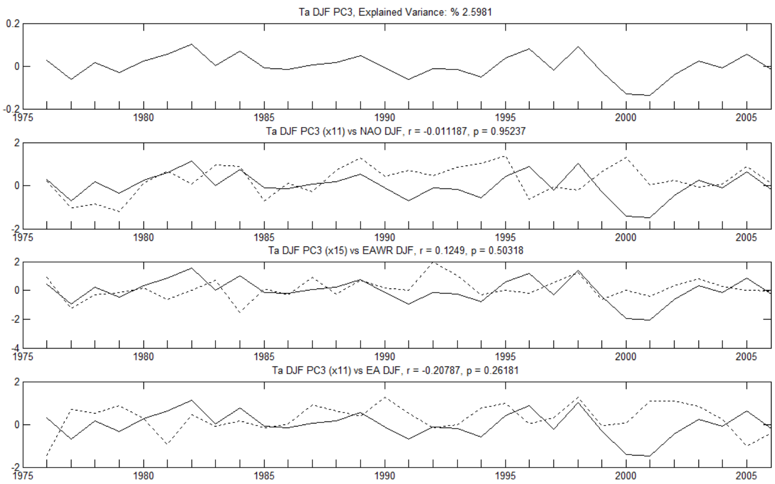
	Corr. Coeff.	Significance	Corr. Coeff.	Significance	Corr. Coeff.	Significance
Canonical Correlations (CC)						
	CC 1		CC 2		CC 3	
	0.4462	0.0119	0.2130	0.2500	0.1370	0.4625
Correlations Between Canonical Variables (CV) and Principal Components (PC) of SLP						
	SLP CV 1		SLP CV 2		SLP CV 3	
SLP PC 1	0.5014	0.0041	-	-	-	-
SLP PC 2	0.8113	0.0001	-	-	-	-
SLP PC 3	-0.0264	0.8877	-	-	-	-
Correlations Between Canonical Variables (CV) and Principal Components (PC) of E-P						
	E-P CV 1		E-P CV 2		E-P CV 3	
E-P PC 1	-0.8306	0.0001	-	-	-	-
E-P PC 2	0.4814	0.0061	-	-	-	-
E-P PC 3	-0.2801	0.1269	-	-	-	-



(a) Principal Component-1

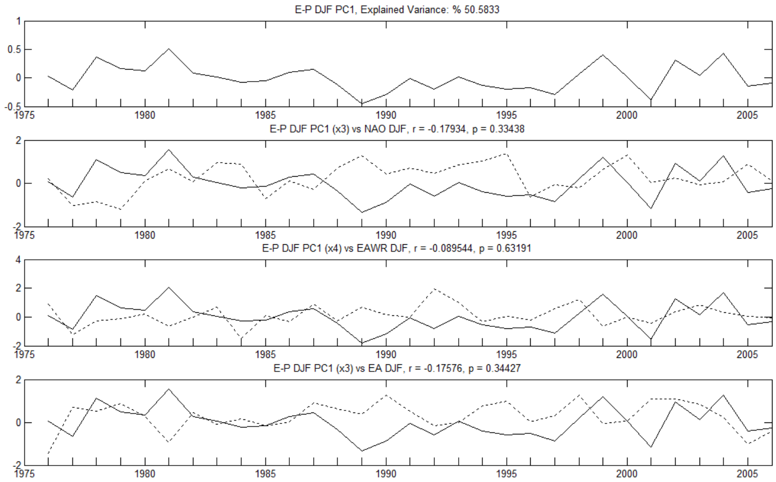


(b) Principal Component-2

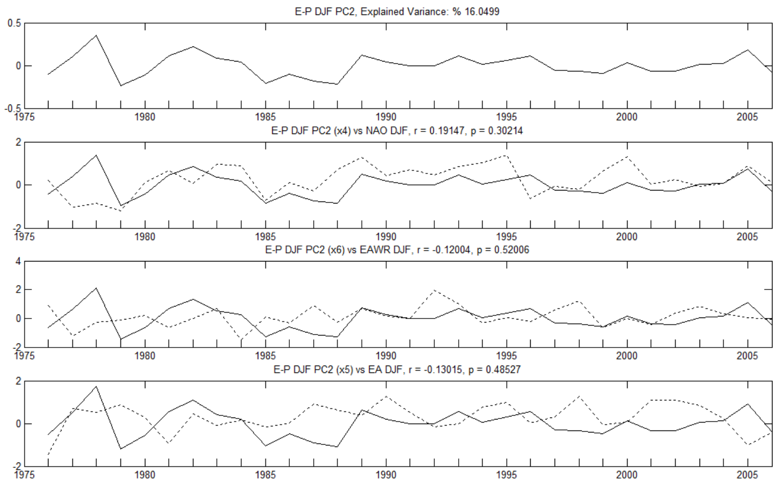


(c) Principal Component-3

Figure 3.9: Principal Components 1,2 and 3 of Temperature. In each sub-figure, the series are drawn on their own in the top panel, with NAO in the second, with EAWR in the third and with EA in the bottom panels



(a) Principal Component-1



(b) Principal Component-2

Figure 3.10: Principal Components 1 and 2 of (E–P). In each sub-figure, the series are drawn on their own in the top panel, with NAO in the second, with EAWR in the third and with EA in the bottom panels

SLP-Water Level From Table 3.7, it is suggested that no direct connections exist between SLP and Water Level. Therefore, there are no correlation channels to look for the contributing principal components.

Table 3.7: SLP-Water Level CCA results

	Corr. Coeff.	Significance	Corr. Coeff.	Significance	Corr. Coeff.	Significance
Canonical Correlations (CC)						
	CC 1		CC 2		CC 3	
	0.3004	0.1067	0.2162	0.2513	0.1121	0.5555

(E–P)-Water Level Above, it was shown that SLP had a one-channel influence on (E–P) but no direct channel between Water Level. If any significant channels between (E–P) could be found, an indirect link between SLP and water level, which can be thought of theoretically, would be statistically supported. Assuming the formerly dependent (E–P) as the independent variable and water level as the depending one, CCA analysis yielded the results shown in Table 3.8. Existence of a very strong channel, represented by a very highly significant correlation is being suggested. Water level contributes to this channel with its 3 principal components, while (E–P) contributes only with its 3rd principal component. Both of the variables were shown to be not carrying any signals from indices (Table 3.3). Plots of these contributing principal components are also given in Figure 3.11 and Figure 3.12.

Table 3.8: (E–P)-Water Level CCA results. All significant correlations are shaded. Notice that only the canonical variables yielding significant correlations were further investigated for contributions by the leading principal components of their original fields (as represented by significant correlations)

	Corr. Coeff.	Significance	Corr. Coeff.	Significance	Corr. Coeff.	Significance
Canonical Correlations (CC)						
	CC 1		CC 2		CC 3	
	0.6592	0.0001	0.1879	0.3201	0.0118	0.9507
Correlations Between Canonical Variables (CV) and Principal Components (PC) of Water Level						
	Water Level CV 1		Water Level CV 2		Water Level CV 3	
Water Level PC 1	0.5106	0.0039	-	-	-	-
Water Level PC 2	0.7733	0.0001	-	-	-	-
Water Level PC 3	0.3759	0.0406	-	-	-	-
Correlations Between Canonical Variables (CV) and Principal Components (PC) of E-P						
	E-P CV 1		E-P CV 2		E-P CV 3	
E-P PC 1	0.1019	0.5922	-	-	-	-
E-P PC 2	-0.0400	0.8337	-	-	-	-
E-P PC 3	-0.9955	0.0001	-	-	-	-

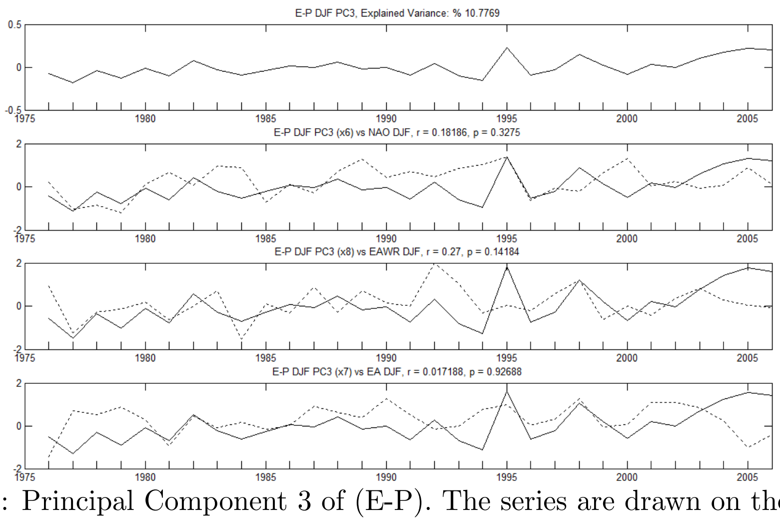
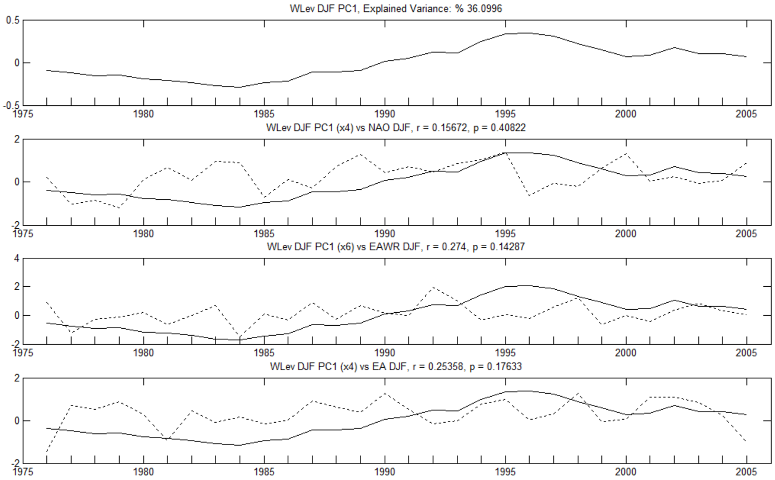
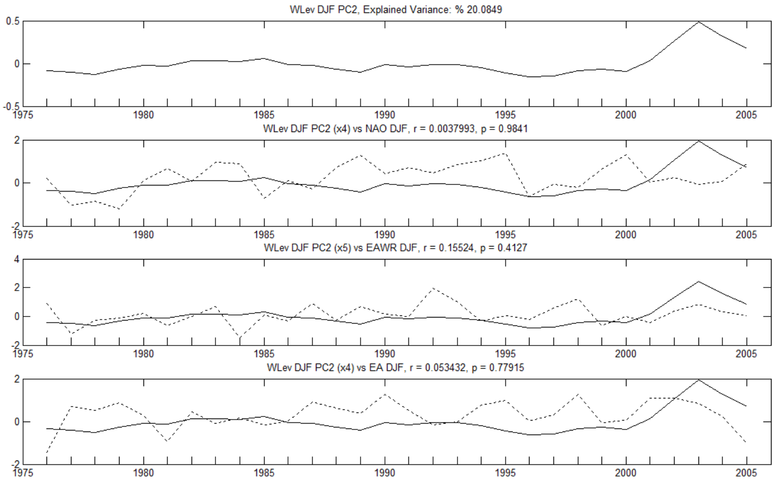


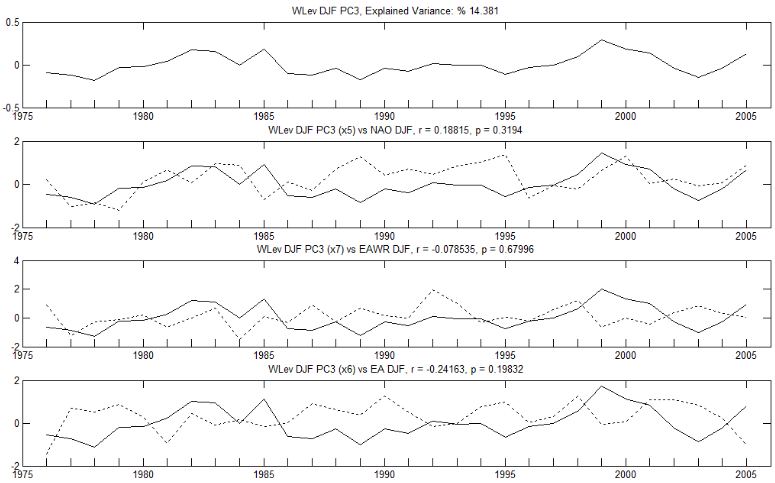
Figure 3.11: Principal Component 3 of (E-P). The series are drawn on their own in the top panel, with NAO in the second, with EAWR in the third and with EA in the bottom panel



(a) Principal Component-1



(b) Principal Component-2



(c) Principal Component-3

Figure 3.12: Principal Components 1,2 and 3 of Water Level. In each sub-figure, the series are drawn on their own in the top panel, with NAO in the second, with EAWR in the third and with EA in the bottom panels

3.2 Impacts of Climatic Variability on Lake Biota: Lake Mogan as a Case

As been mentioned before, entangling the climatic signals from the highly complex network of interactions, require high quality data sets. Continuous and long term biological data could not be found for the lakes considered in the previous part (Section 2.1). Lake Mogan, although its data set is still far from being perfect, was used to demonstrate methodologies and approaches to be adopted for exploring the climatic impacts at the biotic level. As the analyses presented here do not follow a standard flow scheme but rather were designed in an iterative fashion to resolve some mechanisms that were suggested by some preceding analysis or by anonymous knowledge that has to be stated first to justify the need for the following analysis, some discussion had to be also involved in this section. However, in Section 4, these findings are overviewed with their general features and their inter-linkages.

3.2.1 Checking of Connection Between the Circulation Indices and Meteorological Conditions

The connection between the atmospheric system and the meteorological conditions was held in a wider scope as the first part of the study. Assuming that meteorological conditions around Mogan is following those represented guidelines, could cause the further analyses become pointless and conclusions become erroneous. In order to check the situation in a practical sense, temperature and precipitation series from the Ankara station, that was assumed to be representing the conditions at the basin of Lake Mogan, was drawn together with time series of winter NAO and winter EAWR indices. As can be seen in Figure 3.13 for the temperature case, air temperatures in Ankara are showing a nice inverse fit, except 2 exceptions in 1998 and 2003, where they have positive peaks together. At both instances, it is worth to note that NAO have negative peaks, conflicting with EAWR. A more explicit interpretation is as follows: the cold air mass brought from Siberia by positive phase of EAWR is suppressed by the warm air mass brought from Europe by negative phase of the NAO. From this picture, it is also supported that temperature regime is highly under control of NAO and EAWR activities. The precipitation case in which the winter averages were used to avoid high standard deviation that would be encountered at the annual averages, is depicted in Figure 3.14. Similarly, except the common increasing occasions at 1998, 2003 and 2005, and a common decreasing occasion at 2001, the winter precipitation is explainable with the EAWR, which have an inverse relation with precipitation. Again, the common increasing occasions are seemingly due to conflicting NAO modes, although in 2001, we would certainly expect a positive peak since both indices are their negative phases.

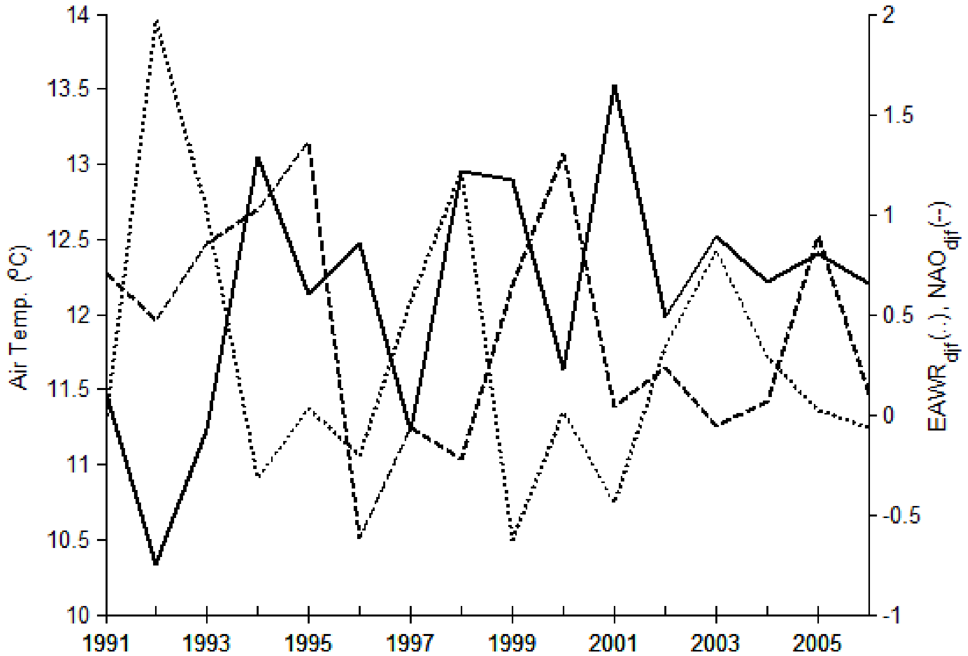


Figure 3.13: Annual average temperature (continuous) vs. winter (D,J,F) average EAWR (dotted) and winter (D,J,F) average NAO (dashed)

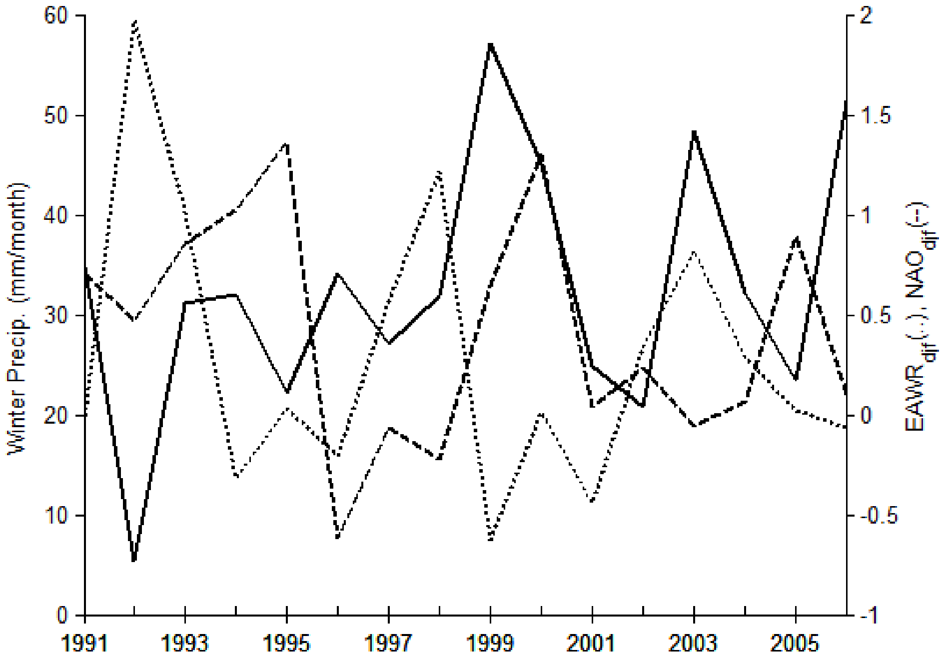


Figure 3.14: Winter (D,J,F) average precipitation (continuous) vs winter (D,J,F) average EAWR (dotted) and winter (D,J,F) average NAO (dashed)

3.2.2 Investigation of Common Sources of Variability by use of Multivariate Statistics

The main objective in applying multivariate statistical methods was to understand whether there exist preferred variable groups that have a tendency to conglomerate (form clusters) with respect to their linear relations, and further to see how these groups are affected from their physical environment. To meet this objective, a 4-step strategy was proposed, which is schematized in Figure 3.15. In the first step, by making use of a Factor Analysis (FA), variables having unique behaviors rather than common were filtered. In the second one, the remaining low-unique variance variables were assorted into 3 factors, standing for the 3 sources of co-variability. In the third step, dominant sources of variability of each factor group were extracted by Principal Component Analysis (same as the method formerly called EOF - Empirical Orthogonal Function analysis. See A.2). Lastly, effects of 2 physical variables, temperature and salinity (as represented by electrical conductivity) on each dominant source (leading 3 modes) were explored, by looking at linear correlations.

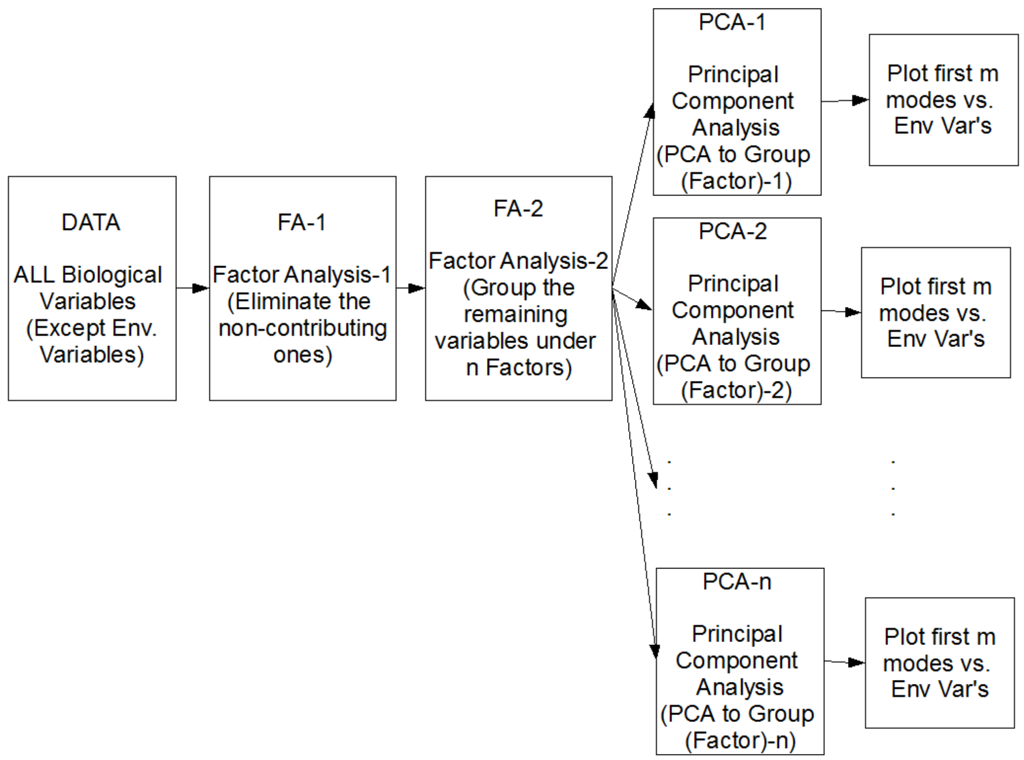


Figure 3.15: Exploratory multivariate analysis strategy for Lake Mogan

In FA, Ψ stands as a measure for the unique (non-shared) variance of a variable (See Appendix-A.4). If every vector in the data set is normalized (by dividing the standard deviation) as in our case, as Ψ of a variable approaches to 1, the uniqueness increase, suggesting that the variable can be eliminated from the view point of 1st step. The point in grouping (factoring) being held at a separate second step is to magnify the interrelations in an intermediate set, which is made up of variables that are more readily factored out. The threshold value for elimination in the first step was taken as 0.75. If Table 3.9 is examined, it can be seen that there lies lots of elements between the 0.70-0.75 while the next larger value occurs to be 0.81 for the variable chlorophyll-a. So this makes 0.75 an unpretentious value which holds conservatively most of the elements in the set. The Ψ values are calculated for a 3 Factor model in this step, as in the second step, since it was seen that 3

Factor most efficiently works. Λ values of the consequent FA step, which only exist for the non-eliminated variables, listed also in Table 3.9 represent the belonging to each factor group (See Appendix-A.4). In a normalized data set, the range of Λ is 0 to 1 and as it approaches to 1, belonging to the corresponding factor increase. The assigning threshold was set to 0.30 so that every variable could be assigned to at least one group. This low level of threshold value also led to fuzzy groups involving shared elements rather than strictly distinct groups. Letting a variable to be involved in more than one group provided a wider source of variability to the consequent PCA. Existence of an element in a factor group would mean a risk of involvement of noise signals in the outputs of PCA, which would be pushed to lower modes, since it is not of great probability that this signal may coincidentally agree with a dominant signal. On the other hand, omission of a necessary element in a group would simply mean that this signal would never be considered in the PCA. The assignment of variables to groups are highlighted in Table 3.9 represented by bold Λ values.

Table 3.9: Results of Factor Analysis (FA). Ψ are for the first FA while Λ for the second FA (See the text). Bold Λ values indicate the assignment status to factors

Variable	Ψ	Λ_1	Λ_2	Λ_3	Variable	Ψ	Λ_1	Λ_2	Λ_3
O_2 surface	0.96				*Euglenophyta*	0.83			
O_2 column	0.94				**TOTAL P.P.**	0.35	-0.29	**0.43**	0.07
Secchi Depth	0.61	**0.40**	0.08	0.03	**# of Phyto. Species**	0.03	0.13	**0.96**	-0.23
pH	0.84				***Arctodiaptomus B.***	0.42	**0.99**	-0.12	-0.04
Silicate	0.92				***Diaphnosoma L.***	0.73	**0.40**	0.05	**0.34**
Chl-a	0.81				*Eucyclops sp.*	0.96			
TP	0.96				*Mesocyclops sp.*	0.99			
SRP	0.91				*Daphnia pulex*	0.85			
DIN	0.98				**Nauplii**	0.71	**0.51**	-0.13	0.11
Diatoms	0.72	-0.01	**0.54**	0.15	**Calanoid C.**	0.05	**0.45**	-0.16	**0.79**
Chlorophyta	0.83				**Cyclopoid C.**	0.36	-0.01	0.00	**0.95**
Dinoflagellates	0.52	-0.10	**0.62**	-0.10	***Ceriodaphnia R.***	0.37	**0.85**	-0.06	**0.31**
Cryptomonads	0.59	0.05	**0.47**	**-0.41**	*Chydorus S.*	0.96			
Cyanobacteria	0.45	-0.21	**0.48**	-0.03	**# of Zoo. Species**	0.75	0.27	-0.02	**0.31**
Chrysophyta	0.66	0.23	**0.43**	-0.06					

In Figure 3.16, the bi-plot shows the distribution of variables remaining from the first FA, in the 3 dimensional space, each dimension addressing a factor. The position of each variable is being calculated by projecting its Λ score onto corresponding factor (dimension). This way, we get a visual representation of groupings, or more specifically, visually see the extend of belonging to each factor. From this figure, we see that the Copopotites, which are known to be not having much function in the ecosystem, are assorted to the 3rd factor and will not be discussed henceforward. In first two factors however, we see that the zooplanktons and phytoplanktons, which have a vital importance for the ecosystem, are grouped in factors 1 and 2, respectively. This distinction was made more clear in Figure 3.17, in which the plane formed by these first two dimensions are viewed from the positive side of the axis perpendicular to it. The situation can be interpreted as, the sources of co-variability (shared variability) in the system, is aggregated around two main axes, standing for the zooplankton and phytoplankton.

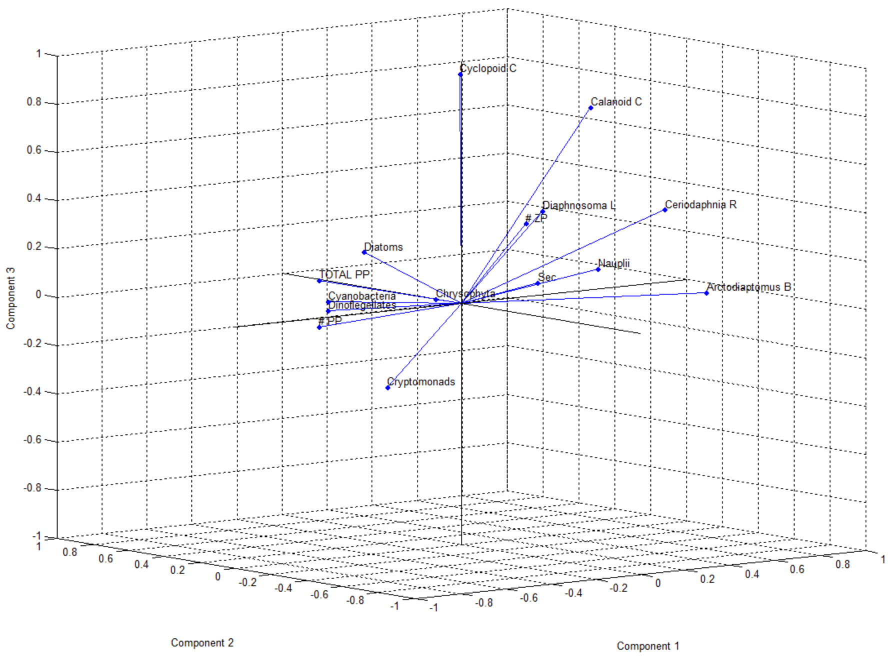


Figure 3.16: Biplot showing the distribution of variables in 3 dimensions

The principal components of each group, extracted by PCA, represents the dominant sources of variability. These sources, although not necessarily, may be driven by some physical processes. In order to check this, linear relationships of the first 3

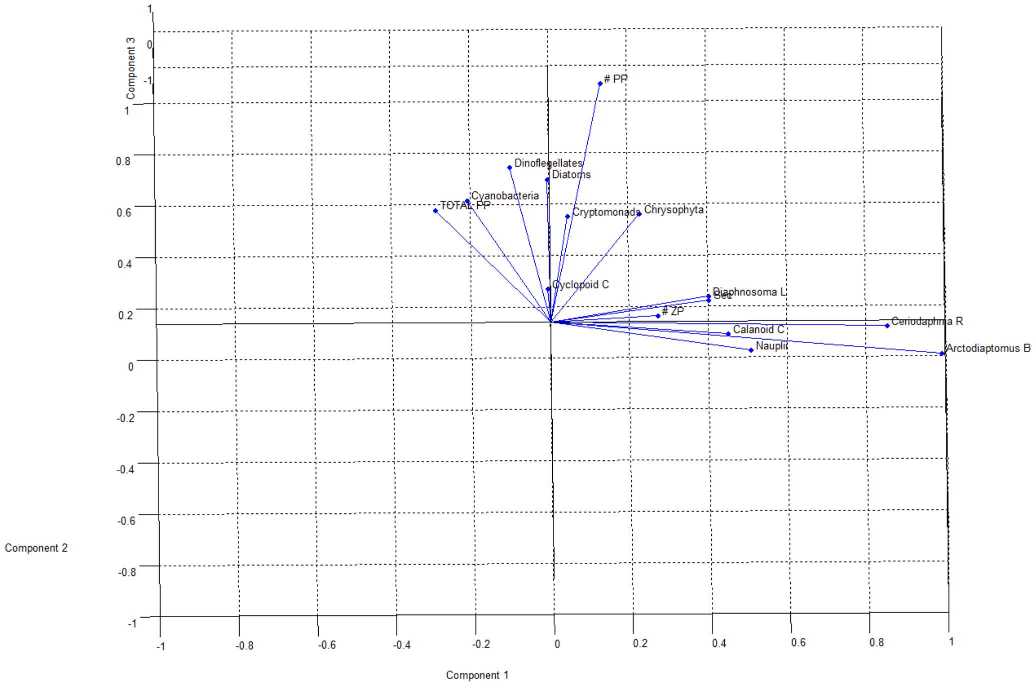


Figure 3.17: Biplot showing the distribution of variables in 2 dimensions: phytoplankton (y-axis) and zooplankton (x-axis)

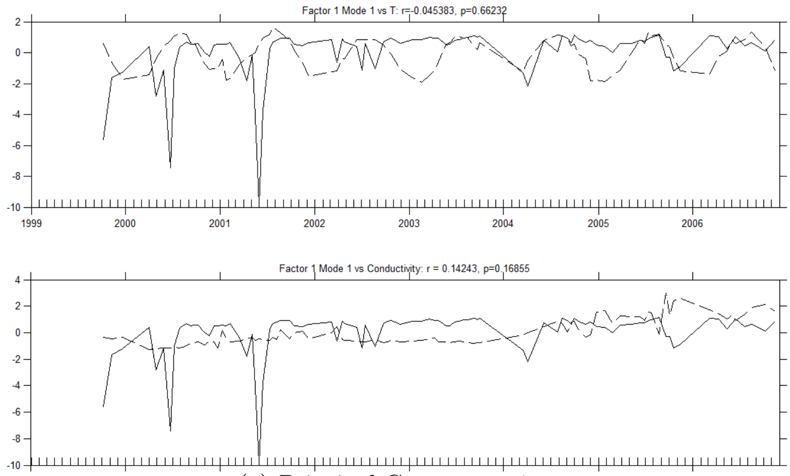
principal component of each group with temperature and salinity (as a proxy for hydrological condition, e.g. high salinity in the drought periods), which are thought to be two important variables for the Lake Mogan Ecosystem was examined by calculating the correlations between them. Table 3.10 shows the results of this analysis, together with the explained variability (in terms of percentege) of each mode. It can be seen that second and third components of zooplankton group and all first 3 components phytoplankton have significant correlations (shaded) both with temperature and electrical conductivity, while none of the principal components of the copepotite group is correlated with any of the selected physical variables. In order to have a closer look to understand the nature of these consistencies, time series of first 3 components are drawn with temperature and electrical conductivity in Figure 3.18 for factor 1 and in Figure 3.19 for factor 2.

For the zooplankton (Figure 3.18), most interesting point is the negative correlation in the second mode, driven by the increasing trend in conductivity and decreasing

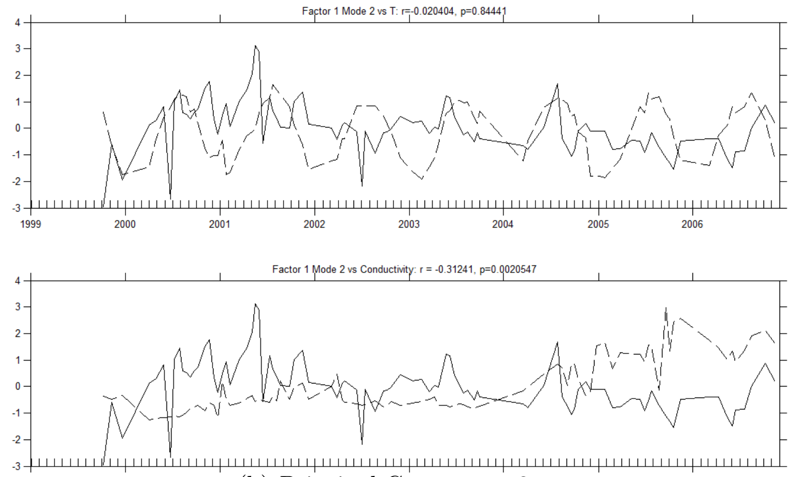
Table 3.10: Correlations between first 3 principal components of 3 factors with temperature and electrical conductivity, together with the explained variability of eac mode

Factor	Mode	Expl. Var	Temperature		Electrical Cond.	
			Corr.	Sign.	Corr.	Sign.
Factor 1 (Zooplankton)	1	50.68	-0.05	0.662	0.14	0.169
	2	16.71	-0.02	0.844	-0.31	0.002
	3	12.45	0.24	0.022	-0.17	0.110
Factor 2 (Phytoplankton)	1	41.68	-0.26	0.012	0.35	<0.001
	2	24.35	-0.39	<0.001	-0.39	<0.001
	3	10.98	0.26	0.011	0.12	0.229
Factor 3 (Zp. Copepotite)	1	53.96	-0.02	0.881	0.13	0.198
	2	16.52	-0.05	0.615	0.10	0.354
	3	14.27	0.19	0.067	0.09	0.385

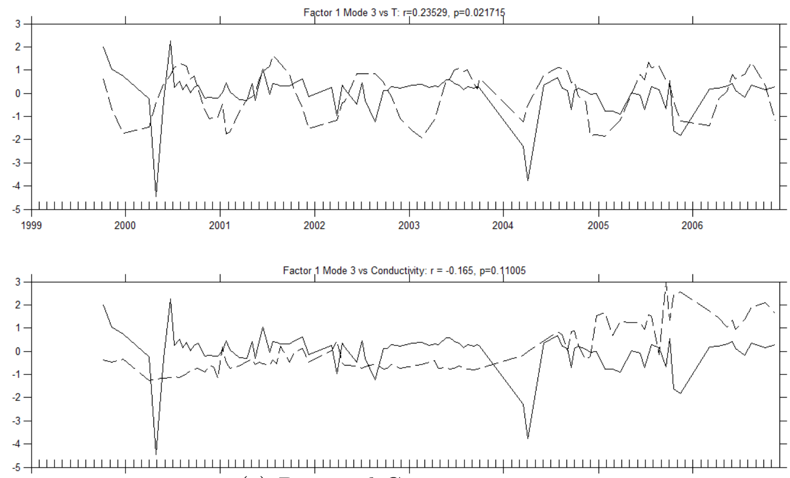
trend in zooplankton. The significant correlation of its 3rd component with the temperature on the other hand, seems to be driven by the seasonality. For the phytoplankton group (Figure 3.19), the correlations of all its components with temperature seem to be also seasonality-driven. In other words, since both temperature and phytoplankton have a strong seasonal cycle, no other kind of signal other than seasonality was strong enough to manifest itself in any of the modes. The correlations of its first and second components with conductivity are also driven by trends as in the case of zooplankton group. However, positive and negative natures of these correlations in first 2 modes may be indicator of different responses of species to salinity.



(a) Principal Component-1

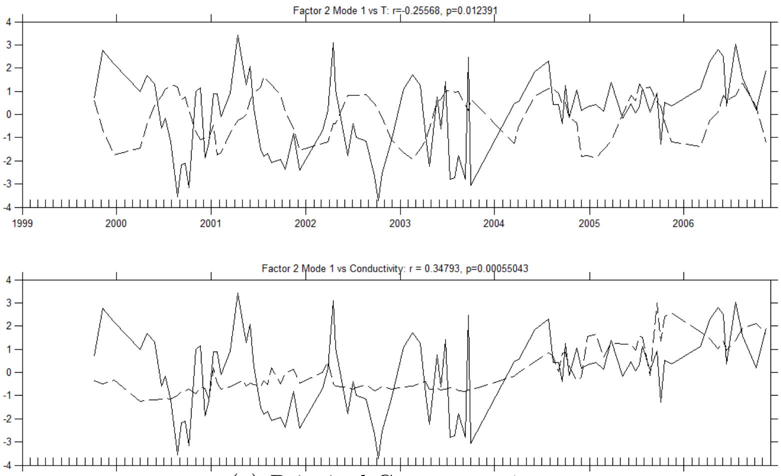


(b) Principal Component-2

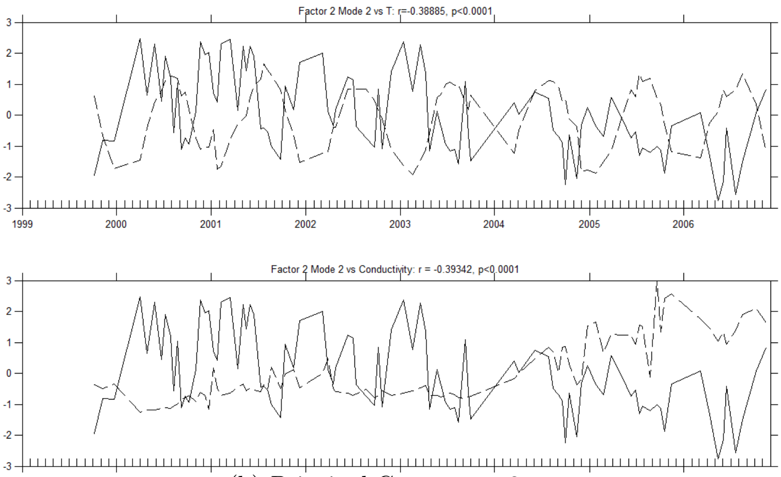


(c) Principal Component-3

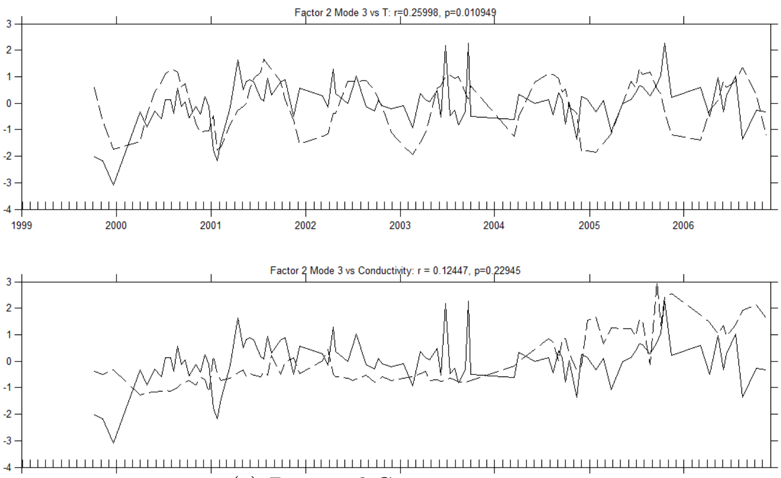
Figure 3.18: Principal Components 1,2 and 3 (continuous line) of Factor-1 (Zooplankton). For each component, time series of temperature and electrical conductivity (dashed line) are also drawn for comparison



(a) Principal Component-1



(b) Principal Component-2



(c) Principal Component-3

Figure 3.19: Principal Components 1,2 and 3 (continuous line) of Factor-2 (Phytoplankton). For each component, time series of temperature and electrical conductivity (dashed line) are also drawn for comparison

3.2.3 Pairwise Comparison of Ecosystem Variables

A common pitfall in using multivariate statistics is to draw firm conclusions in the light of outputs of these analysis. In this case, for example, although it is suggested that phytoplankton is being affected by salinity (as represented by conductivity) positively and zooplankton negatively, these are valuable in the extend reasonable pathways (explanations) can be proposed and further evidence can be shown. From this viewpoint, visual pair-wise comparisons of ecosystem variables are held in this section. To organize the inquiry, variable pairs are formed around the two half of an imaginary line between the phytoplankton and zooplankton trophic levels. The former one represents the climatic effects propagating through the nutrients and phytoplankton, called the bottom-up approach, while the latter represents the effects due to impacts on firstly higher levels like fish and zooplankton.

Bottom-Up Control

As introduced in Section 1.2, variables found in the lower trophic levels of the ecosystem, like nutrients and phytoplankton, can be affected by the climatic conditions. These climatic signals, captured by these low levels, can have cascading effects through the higher levels. Thus, changes and pathways of changes in different compartments of ecosystems stimulated from the lower levels can be regarded as bottom-up control of climatic changes.

In Figure 3.20, affect of winter air temperatures on the Dissolved Inorganic Nitrogen (DIN) on the following spring season (since the DIN data is scarce in winter season) are looked for. As been mentioned in Section 1.2.2, warm winters may coincide with low DIN levels due to enhanced assimilation rates along the soil infiltration. However, no such relations are apparent in Figure 3.20. In Figure 3.21, any possible relations of precipitation on DIN is checked, in an annual average basis. As again listed in the introduction part, precipitation could have positive or negative relations, depending on the catchment characteristics and water budget features of the lake. As in the temperature case, no linear relationships between these parameters are apparent.

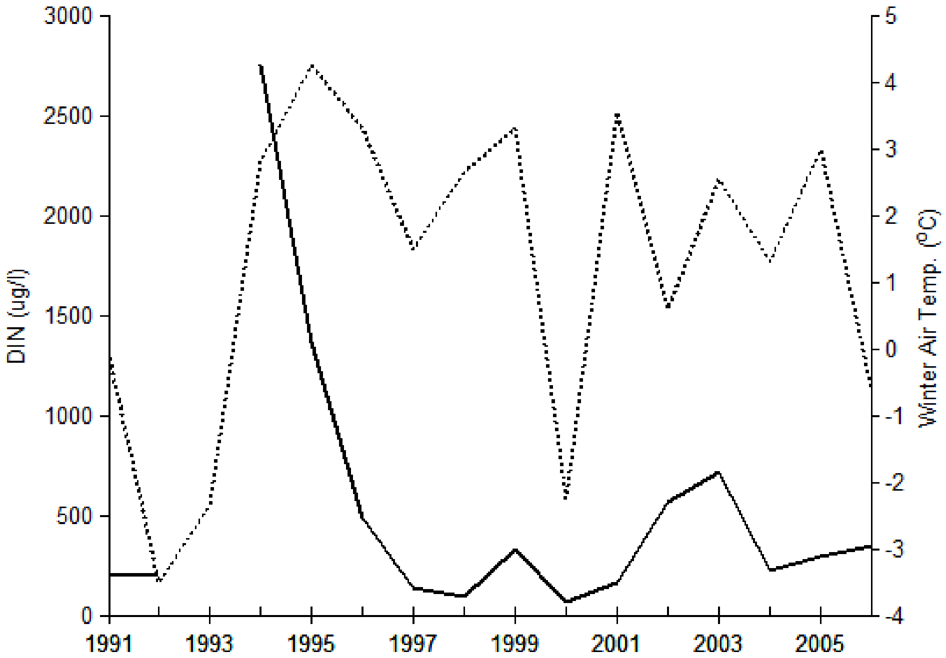


Figure 3.20: Spring (M,A,M) average DIN (continuous) vs. winter (D,J,F) average air temperature (dots)

Figure 3.21: Annual average DIN (continuous) vs. annual average precipitation (dots)

Wind-induced mixing and consequent resuspension of materials from the sediment, which may be enhanced by even lower water levels, is a very common practice in shallow lakes (Section 1.2.2). Effects of wind on Suspended Solids (SS) and Total Phosphorus (TP) were analyzed in Figure 3.22 and Figure 3.23 respectively. For the suspended solids case, it can be suggested that the water level act as a determining variable when the wind is below 2.2 m/s, since the high SS concentrations are found mostly with low water levels. When the wind speeds are above this value, water level seems to lose its determining strength, since the high SS concentrations are both seen for the high and low water levels. For the TP case, in which a positive relationship could be expected, although one can not suggest a such relationship, it may be worth to note that high TP values coincided with low water levels.

Another mechanism affecting phosphorus release from sediment is through the sediment stabilization due to iron-phosphorus binding, which can take place in the availability of oxygen. With high temperatures in summer, due to the increasing reaction rates of oxygen depleting processes like demineralization and organic matter decomposition, the micro-zone just above the sediment may become anoxic and this sediment stabilization mechanism may be disturbed (Liikanen et al., 2002). Therefore, one could expect high TP values when the temperature is high. In Figure 3.24, although a positive relationship between TP and temperature is apparent in the macroscopic scale, disagreements in the microscopic scale hinders claiming this effect loudly.

In order to investigate the phytoplankton response to temperature changes, chlorophyll-a vs. temperature plots are shown in Figure 3.25 and Figure 3.26, respectively for the growth season (March-October) average and for the autumn (September-November) averages, in which the relation is better seen. Comprehensibly, there seems to exist a positive relation although there also are some conflicting years.

Another point of view about these two variables considers the possibility of lower than normal primary production after warm winters, due to lower than normal nutrient abundance left to spring owed to the existence of phytoplankton activity

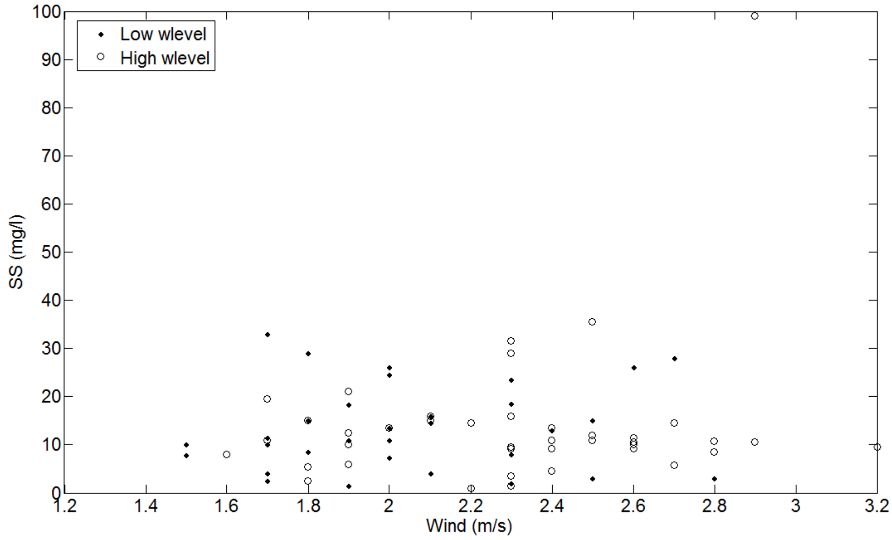


Figure 3.22: Scatter plot of SS (Suspended Solids) (y-axis) vs wind (x-axis). Higher-than-median water level and lower-than-median water level are indicated with circles and dots, respectively. Data covers the period between 2000 to 2006

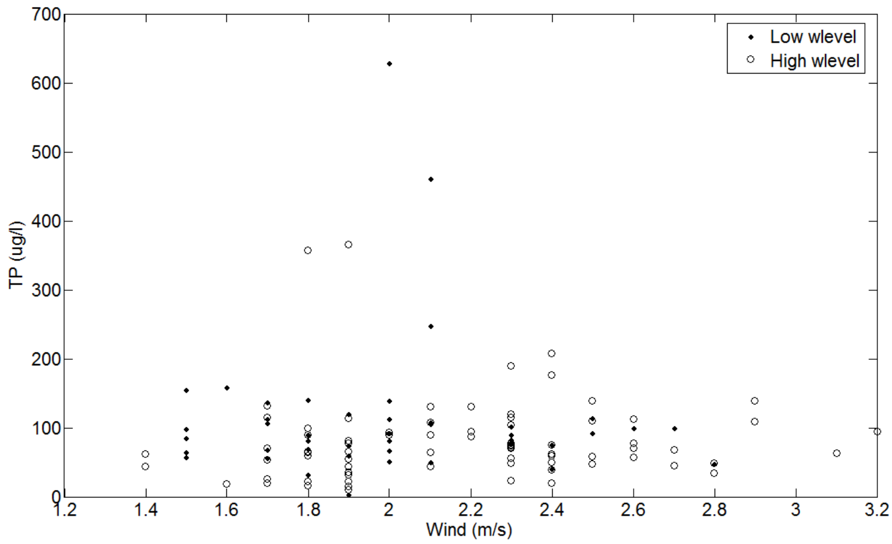


Figure 3.23: Scatter plot of TP (Total Phosphorus) (y-axis) vs wind (x-axis). High water level and low water level are indicated with circles and dots, respectively. Data covers the period between 1996 to 2006

in warm winters. In Figure 3.27, the situation is depicted. Although there is a very clear inverse pattern in the 1998-2004 period, existence of a such relation could be argued in extend the winter phytoplankton activity could be traced with data.

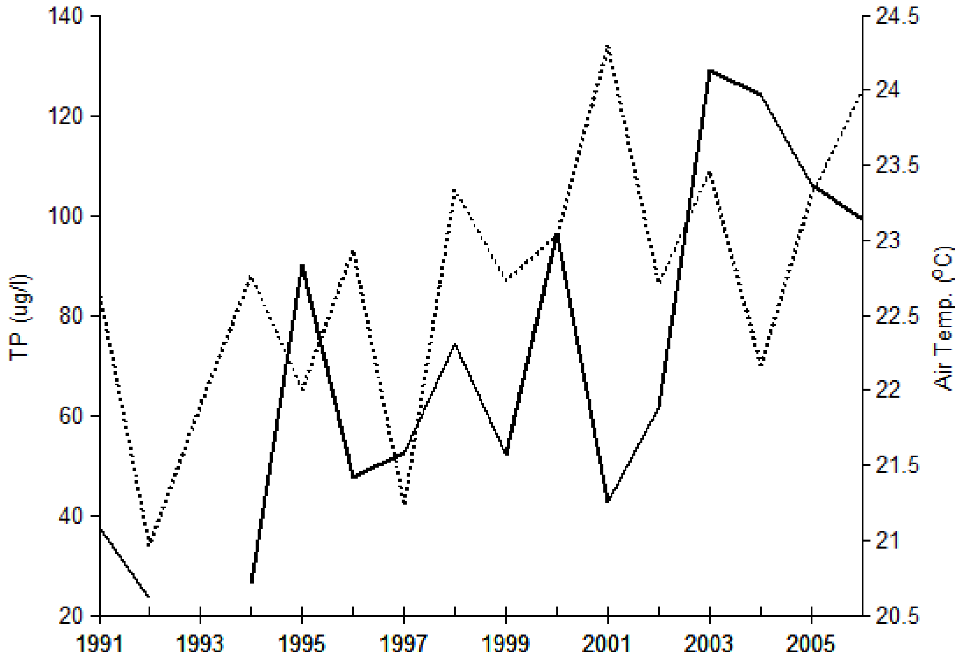


Figure 3.24: Summer (J,J,A) average TP (continuous) vs. summer average air temperature (dots)

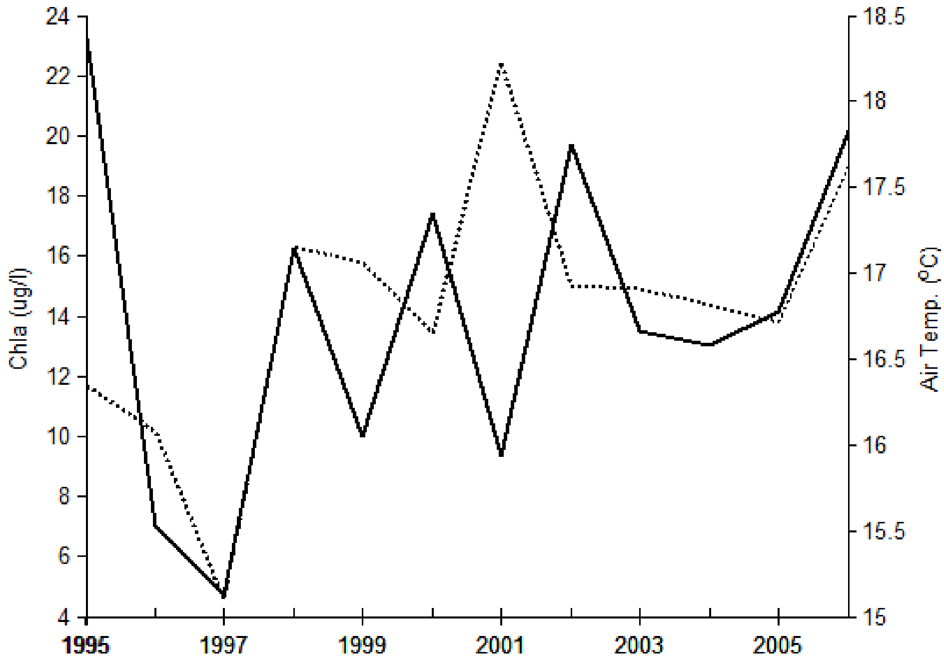


Figure 3.25: Growth season (March-October) average chlorophyll-a (continuous) vs. growth season average air temperature (dots)

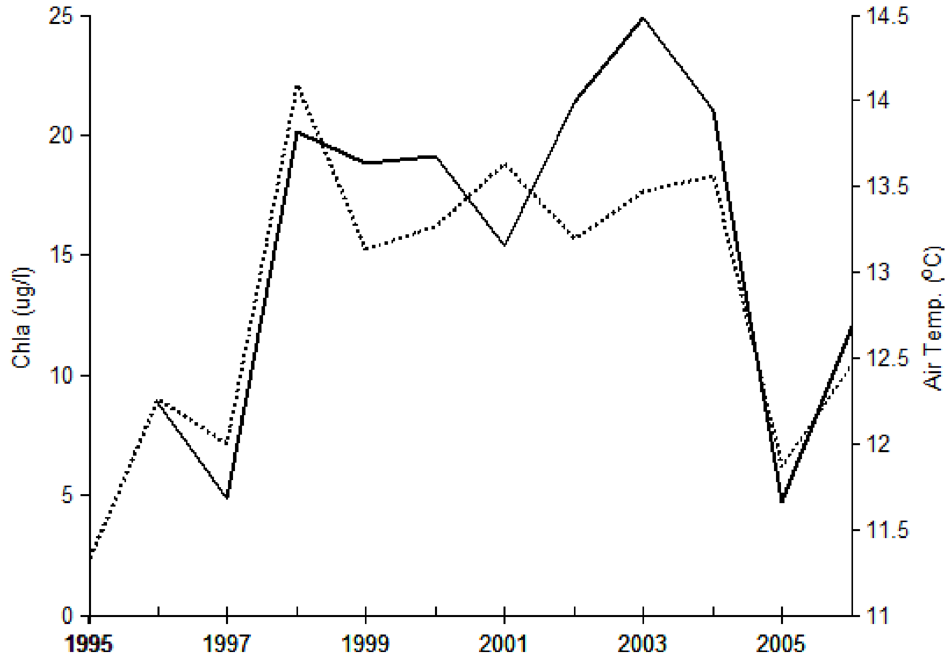


Figure 3.26: Autumn (S,O,N) average chlorophyll-a (continuous) vs. autumn average air temperature (dots)

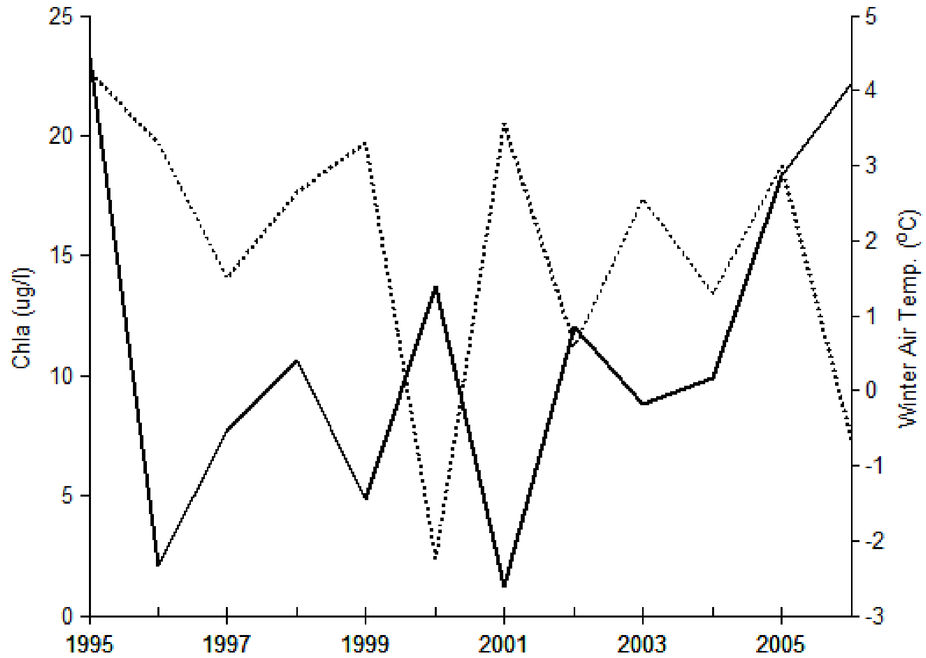


Figure 3.27: Spring (M,A,M) average chlorophyll-a (continuous) vs. winter (D,J,F) average air temperature (dots)

Circulation indices have a direct impact on more than one meteorological variable, which belong to pathways that re-connect at several biological compartments. These distinct pathways possibly may be supporting or suppressing each other for a specific response (increase or decrease of a variable). Therefore, avoiding these intermediate steps and looking for the direct relationships of biological variables and atmospheric indices are worth to check, since they may be more evident. In Figure 3.28 and Figure 3.29, spring (March-May) average chlorophyll-a are shown with NAO and EAWR, respectively. In both, consistencies are noticeable.

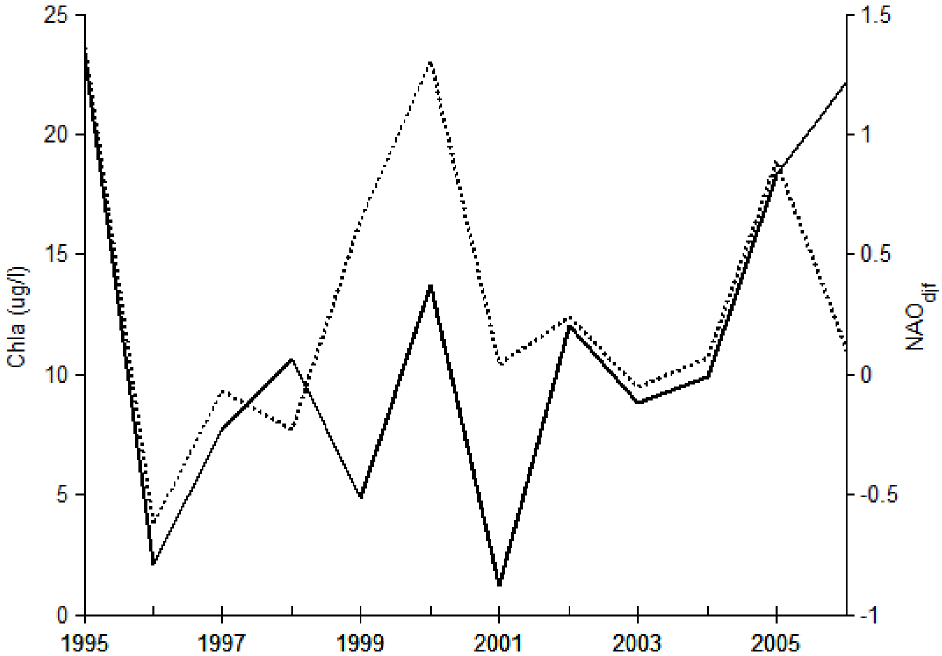


Figure 3.28: Spring (M,A,M) average chlorophyll-a (continuous) vs. winter (D,J,F) average NAO (dots)

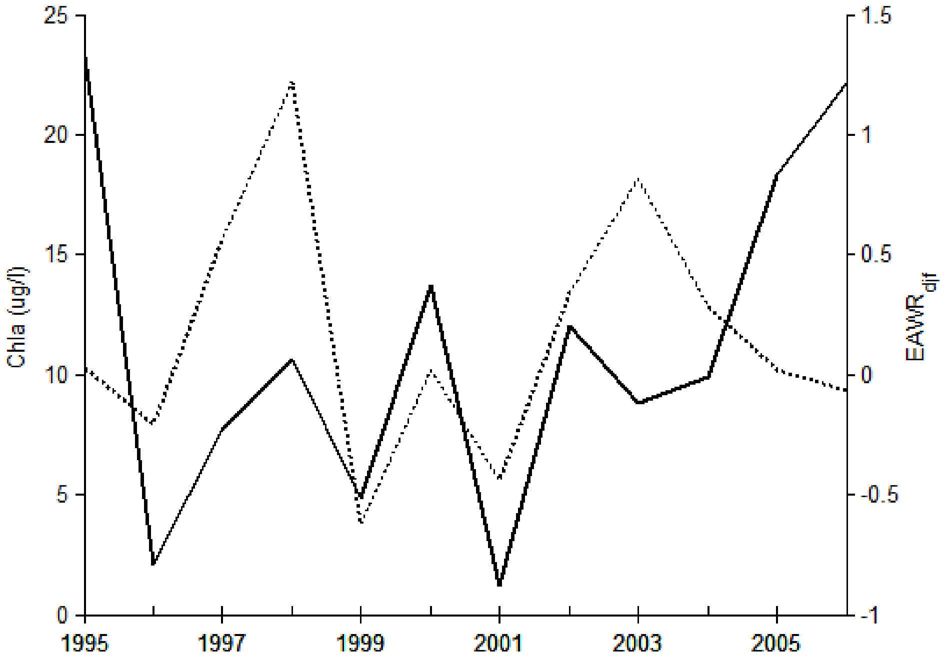


Figure 3.29: Spring (M,A,M) average chlorophyll-a (continuous) vs. winter (D,J,F) average EAWR (dots)

Top-Down Control

Climatic variability may also have direct effects on organisms found in higher trophic levels of the lake ecosystems. As these effects propagate through the lower trophic levels, the effects initiated at the higher trophic levels can be regarded as top-down control of climatic changes.

Salinity induced changes in lake ecosystems, which can be mediated by the loss of key-stone species like *Daphnia*, can be such important that regime shifts may occur (Jeppesen et al., 2007). Multivariate statistics pointed at an inverse relationship between zooplankton and salinity. In order to check whether this can be accounted for by the selective impacts of salinity on different zooplankton species, ratios of *Daphnia* (i.e., *Daphnia magna* and *Daphnia pulex*) to total cladocerans (i.e., *Daphnia magna, Daphnia pulex, Ceriodaphnia reticulata, Bosmina longistris, Chydorus sphaericus, Alona affinis, Diaphnasoma lacustris*), and total cladocerans to total copepodes (*Eucyclops sp., Mesocyclops sp., Megacyclops sp., Arctodiap-*

tomus bacillifer), are drawn together with electrical conductivity in Figure 3.30 and Figure 3.32. It should be noted that the original units of each side of these ratios were in 'individual count per liter', so the 'ratios' come out to be unitless lumped variables. In order to account for possible shortcomings of electrical conductivity measurements, in Figure 3.31 and Figure 3.33, same comparisons are also made with E–P (Evaporation − Precipitation) as a natural index of dryness, which would result in salt accumulation in its positive phases. For the *Daphnia*:total cladoceran ratio, ignoring the details, if the situation can be interpreted as decrease of *Dapnia*:cladoceran ratio and increase of conductivity, then it can be concluded that anticipated higher vulnerability of *Daphnia* to salinity becomes verified. The microscopic scale inverse relations however, was more apparent with the E–P. For the cladoceran:copepode ratio, we can see positive agreements, which is more apparent with the E–P than with the conductivity.

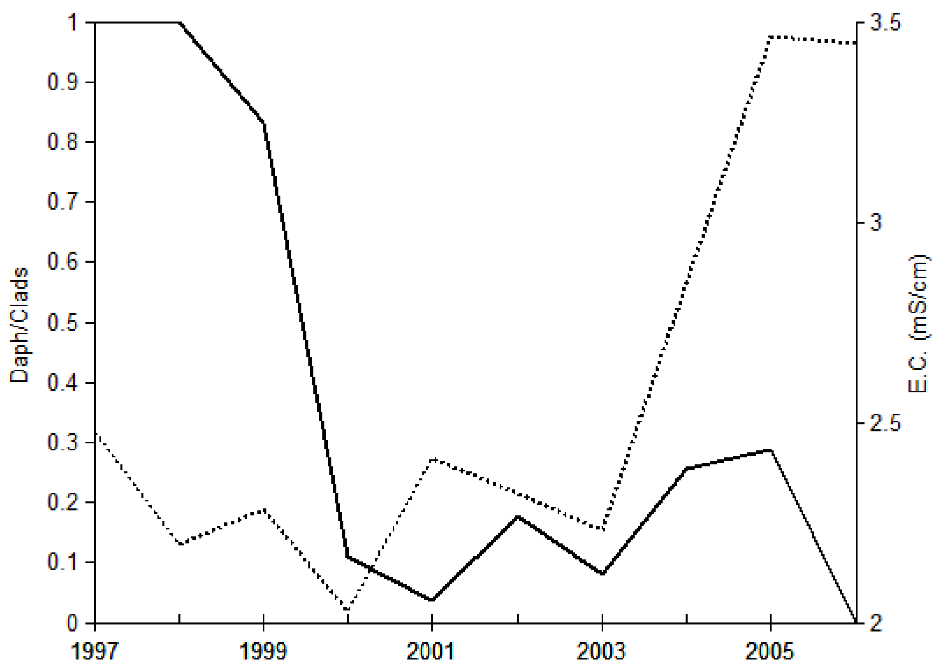


Figure 3.30: Growth season (March-October) average *Daphnia*:total cladocerans ratio (continuous) vs. growth season average electrical conductivity (dots)

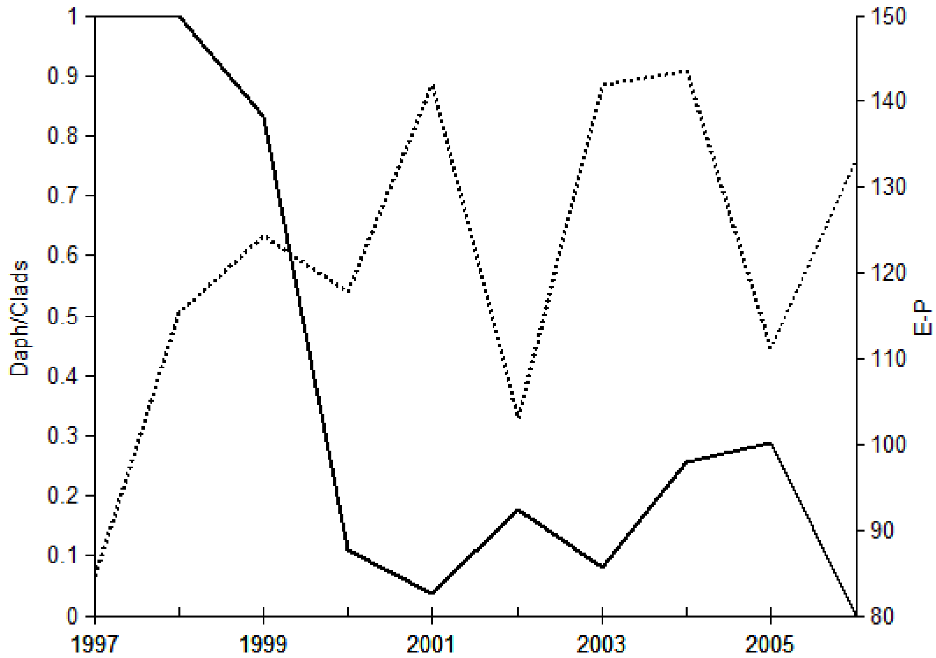


Figure 3.31: Growth season (March-October) average *Daphnia*:total cladocerans ratio (continuous) vs. growth season average E–P (Evaporation-Precipitation) (dots)

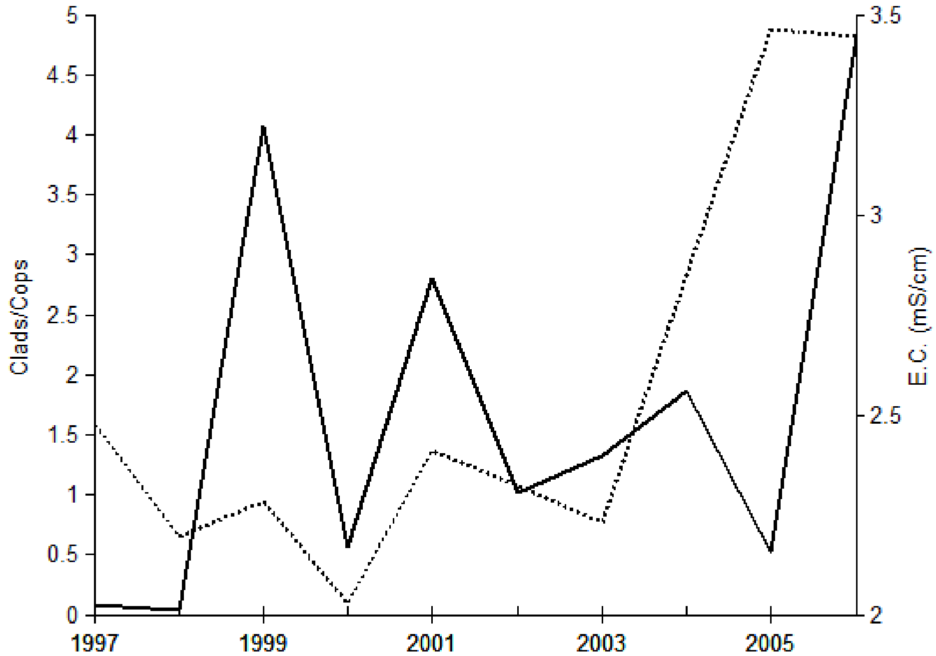


Figure 3.32: Growth season (March-October) average total cladocerans:total copepodes ratio (continuous) vs. growth season average electrical conductivity (dots)

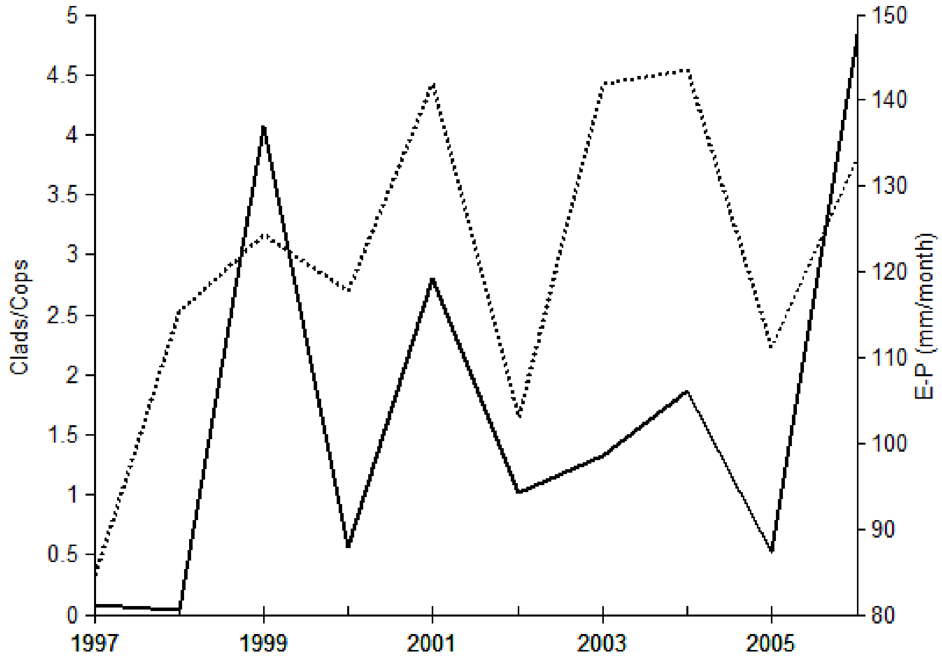


Figure 3.33: Growth season (March-October) average total cladocerans:total copepodes ratio (continuous) vs. growth season average E–P (Evaporation-Precipitation) (dots)

In section 1.2.2, it was mentioned that zooplankton species which have a simpler life cycles may respond to physical changes like temperature increse, much more rapidly. In Figure 3.34, this seems to be verified for Lake Mogan, although some minor disagreements exist.

Since the size of zooplankton species is an important parameter for the predation pressure on them, the ratios of groups can also be used as an indication of predation which is also a function of fish abundance and community structure. As mentioned in the sediment phosphate release case, the oxygen depletion in summer months due to increased rates of oxygen depleting processes, may result in mass fish kills, as a very common practice in sub-tropical climate regimes which was also demonstrated in temperate lakes as well (Jeppesen et al., 1990). Indeed, Figure 3.35 shows that cladoceran:copepode ratio peaks clearly at both 'hot' events, which could experience fish kills, if it is not also the direct metabolic response to temperature. This finding could only be supported by fish data, which unfortunately is unavailable.

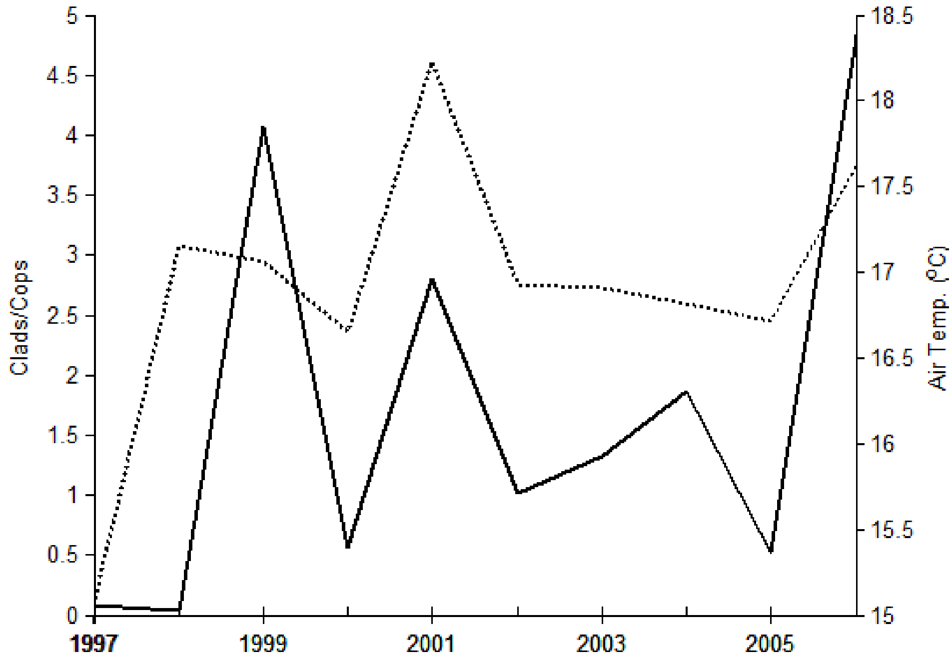


Figure 3.34: Growth season (March-October) average total cladocerans:total copepodes ratio (continuous) vs. growth season average air temperature (dots)

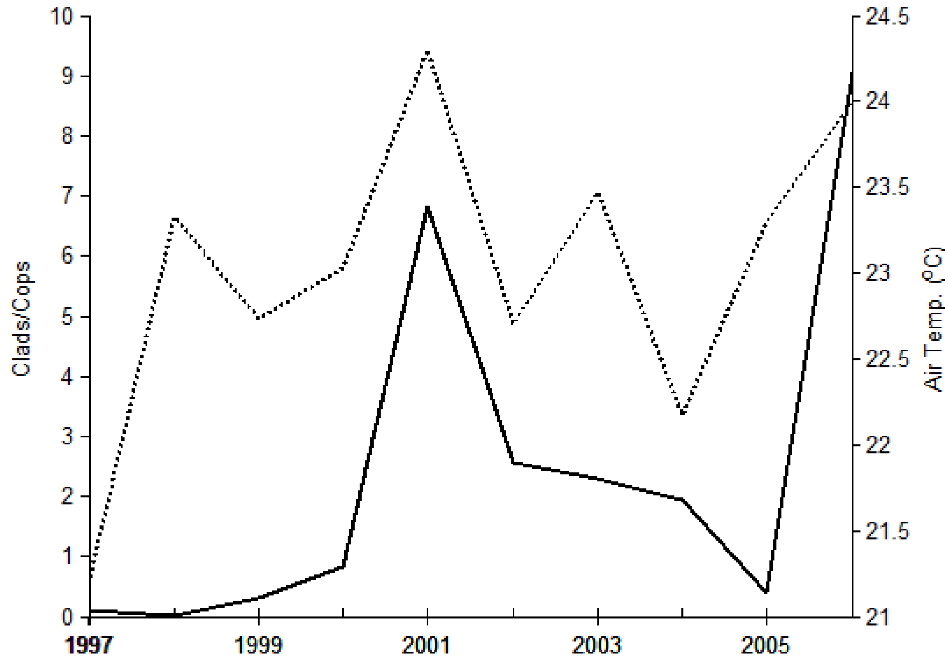


Figure 3.35: Summer (J,J,A) average total cladocerans:total copepodes ratio (continuous) vs. summer average air temperature (dots)

As checked for the phytoplankton, relations between the zooplankton community structure directly with the atmospheric indices were checked, to consider possible suppressing or boosting behavior between different pathways these indices have effect on. Although not as apparent as the phytoplankton case, negative relations between the cladoceran:copepode ratio with the NAO (Figure 3.36) and EAWR (Figure 3.37) are noticeable.

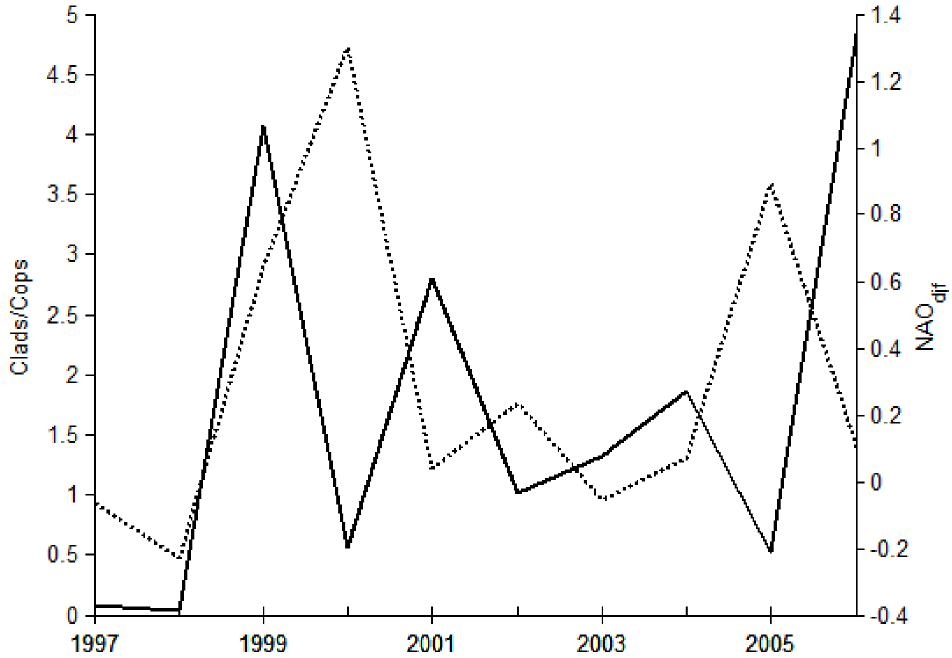


Figure 3.36: Growth season (March-October) average total cladocerans:total copepodes ratio (continuous) vs. winter (D,J,F) average NAO (dots)

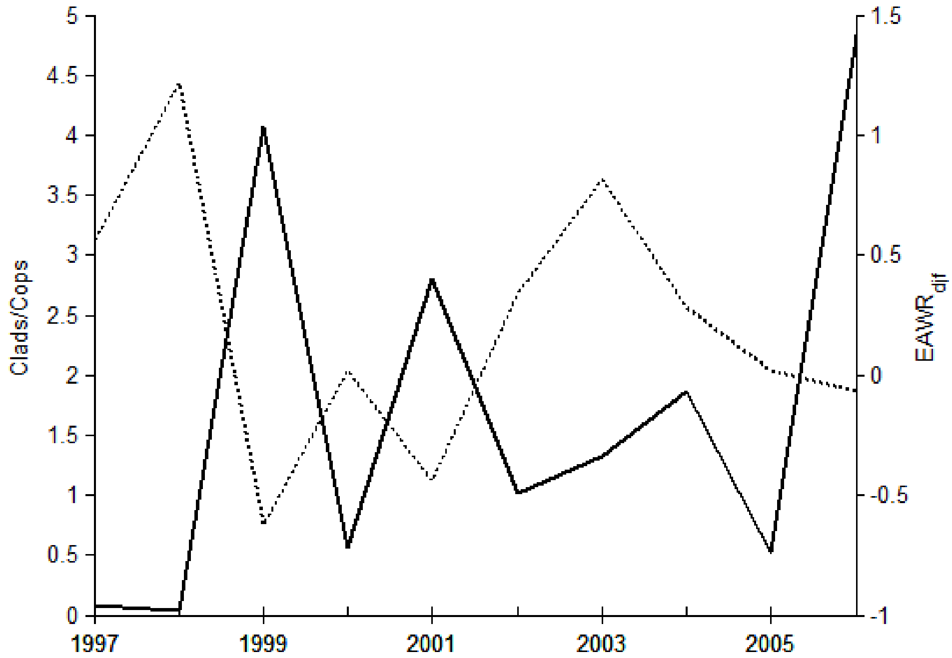


Figure 3.37: Growth season (March-October) average total cladocerans:total copepodes ratio (continuous) vs. winter (D,J,F) average EAWR (dots)

CHAPTER 4

DISCUSSION & CONCLUSION

The 1899-2006 period SLP (Sea Level Pressure) field in a region (20N-70N, 50W-70E) centered around Turkey and covering the pressure centers of 3 selected circulation indices, NAO, EAWR and EA, was analyzed with EOF (Empirical Orthogonal Function) analysis. The analysis made for the winter averages illustrate that the enclosed atmosphere system is mainly composed of and thus can be described by these 3 circulation indices, making up the 70% of total variance in first 4 principal components (modes). More specifically, the variability in the first mode was shown to be driven by positive phases of NAO and EAWR, second mode by positive phase of NAO and negative phase of EAWR, 3rd mode by EA, and 4th mode by contribution of all. These patterns are among extracted dominant (first 10) modes in other studies subjecting the whole Northern Hemisphere (Barnston and Livezey, 1987; Wallace and Gutzler, 1981). To develop an understanding also about the seasonality of these relationships, EOF analysis of the same field was done for the monthly series. One noticeable feature of the overall monthly results (shown in Table 3.2) was that the portion of explained variability by the leading modes are quite high in January, February and March, while moderately high in November and December and weaker in other months. This also is in perfect concordance with the findings of Barnston and Livezey (1987). The interesting point is that the explained variability seemed to be following a smooth pattern along the year, being maximum at winter, suddenly dropping at spring, falling some more through summer and re-establishing itself finally through fall and winter again. This profile may be representing the dynamical avtivity in the atmosphere and amplitude of perturbations, which are largest during winters (Hurrell et al., 2003). There seemed to be a pattern also in distribution of correlations with the circulation indices: as the dominance of leading patterns strengthens, the significant correlations aggregate in the leading modes, and vice versa. In other words, variability was being driven and can be explained with a great extend, by the selected indices in winters in the region. By defining the dominant modes (or at least adressing their sources), it was made possible to consider these 3 indices as embedded signals carried in the atmosphere system in further analysis, in which the connections of the atmosphere system with the hydro-meteorological conditions in Turkey were investigated.

If the atmospheric system is assumed to be represented by several selected circulation indices, than a straightforward analysis strategy for the investigation of possible connections of it with the local climatic variables (temperature, water level, etc.) can be sought of. One was proposed as systematically calculating the correlations between selected circulation indices and extracted dominant sources of information (principal components) of local variables originally found as several stations in different spatial locations. It was observed that although not very intensive, there are some significant correlations in the annual and winter bases (Table 3.3). As the analysis was made for a shorter period (1991-2006) in annual basis in order to provide grounds for comparison with the results for lake outflows -which eventually did not produce any significant correlations- than the period (1975-2006) for the winter basis, it was expectable to encounter weaker correlations. However, no obvious patterns (like weaker correlations in winter basis on the same pairs) were found but rather the correlations were seemingly distributed randomly. This lack of validation ability between two fields raise some suspects about the validity of the correlations. If the inconsistency is with different length of periods, than based on this scheme, we could encounter a completely different picture on a different period, for example 1950-2006, if the data had been available.

In order to consider the possibility that the inconsistency was due to the difference of averaging bases (annual and winter), same analysis was repeated on a monthly basis. Figure 3.7 provides visual means of analyzing the seasonal variability of attained correlations. Pressure and solar radiation were shown to be mostly under influence of NAO and EAWR in winter, while EA seemed to take place in the other months. Wind shows consistency with NAO throughout the year. Monthly average temperature seemed to be under control of EAWR in the winters, EA in summer and NAO at the last part of year. Monthly minimum and maximum temperatures on the other hand, were seemingly in better agreement with EAWR and EA than they are with the NAO. Evaporation and Precipitation were seemingly more affected by EA and NAO than by EAWR. Lastly inflow and water levels failed to show too much response to any of the indices at all. In conclusion, due to the variable nature of relationships in different seasons of a year, it can be suggested that taking the averages, especially on an annual basis, could have led to vanishing of correlations originally found in monthly basis. Consistent negative correlations between temperature and EAWR were in accordance with Kutiel et al. (2002); Kutiel and Turkes (2005). However, correlations for the precipitation were not consistently validating themselves neither in seasonal nor in monthly bases, so that they can not be compared with the documented relations between precipitation and NAO (Turkes and Erlat, 2005; Kalayci and Kahya, 2006) and EAWR (Kutiel et al., 2002; Kutiel and Turkes, 2005). No literature concerning the relations of other parameters with circulation indices in the region could be found.

On a general scale, neither with the analysis on the annual and winter bases nor with the monthly bases, drawing general guidelines for the connections between the large scale atmosphere system and the local variables was not precisely possible, although there are some significant relationships concentrated on some variables particularly. Therefore, this strategy, which attempts to compress the main sources of variability from the data sets involving data from several stations and looks at linear correlations between the indices as proxies for the large scale atmospheric system, can only be considered to be useful as an exploratory study for detection of relations which have to be elaborated by further analysis. In order to enlighten the hydrological pathway between the large scale atmospheric system and lake water levels, a canonical correlation analysis (CCA) based technique was used. In contrast to the previous method which can be said to 'explicitly' tracks the connections between two fields, CCA does it 'implicitly'. As the EOF, it also tries to compress the variability in the leading modes, but with a very important difference: it does it by constraining the construction of modes such that their correlations with the constructed modes of other field is maximized. After obtaining these highly correlated 'canonical variables', which are actually the linear combination of the EOF modes of the data, the role of 3 circulation indices were traced. Very similar data analysis strategies were adopted by Sirabella et al. (2001) and Li and Kafatos (2000).

Although the temporal and spatial features of precipitation regime in Turkey have been investigated extensively (Turkes, 1998; Sen and Habib, 2000; Kadioglu, 2000; Turkes et al., 2002), its connections with a large scale geopotential field has not been investigated to best of our knowledge. Connections of 500-hPa geopotential height field and temperature in Turkey, on the other hand, was investigated and some significant linkages were found (Tatli et al., 2005). There are also a few number of studies concerning the climatic influences on lake water levels, on a single lake basis (Kadioglu et al., 1997). This study is the first one to elaborate the connections of large scale geopotential height field (Sea Level Pressure (SLP) for our case) with meteorological dryness (E–P) and water levels on a general scale. For the temperature, it is expected to contribute to the understanding gained by the analysis of these connections with the 500-hPa height field (Tatli et al., 2005).

It was shown that there were two channels of interaction between SLP and local temperature field, while the main driver of relation between two fields was the first channel, with the contribution of first principal component of temperature field which accounts 86% of total variance. The strong negative relationship of this first mode with the EAWR is consistent within winter months as well as with the literature as already been mentioned above. A statistically significant correlation channel was also shown to exist between SLP and (E–P) (Evaporation-Precipitation). However, first and second principal components of (E–P) was also observed to be unrelated with any of the selected indices on the winter average basis. This actually conflicts with the monthly case, in which it was observed that there were signicant correlations especially with EAWR at the 99.9% confidence level, in January and February months (see Table 3.4 and Figure 3.7). As been mentioned previously, taking the winter averages could have severely resulted in vanishing of these correllations for the (E–P), which already has a high variability in temporal and spatial senses due to the chaotic nature of physical processes (e.g. cloud dynamics) effecting both evaporation and precipitation. Although no direct linkage between the SLP and lake water level fields were found, one very strong channel between (E–P) and water level could suggest that (E–P) is acting as an intermediate step between SLP and water level. However, it should be noted that (E–P) was contributing with its first 2 components to the SLP-(E–P) connection (see 3.1.2), however it is contributing to the (E–P)-water level connection with its third component (Table 3.7). Therefore, it was statistically suggested that the connection between (E–P) and water level is not driven by SLP. But before concluding it firmly, modulations of (E–P)-water level connection by catchement characteristics (different topographies, soil types, etc) and lake morphometries should be considered. This actually can be achieved to some extend by evaluating the canonical correlations between (E–P) and a set of water level fields constituted by introducing an array of lags (e.g. 1 month, 3 months, 6 months, 12 months, 24 months). This, however is not a very straightforward task and could constitute an entire setting for a seperate research.

Actually the multivariate strategy scheme held to decipher the connections between the large scale circulation system and local hydro-meteorological variables could be best benefited if the spatial patterns suggested by CCA could be interpretable. That could only be possible if the local variables were also represented by gridded data sets with a more reasonable geographical coverage. In this study, in order to exclude the processes having nothing to do with the lakes, the stations used in these analyses were limited with only the ones in the vicinity of selected lakes. The outcome of analyses suggest that especially the air temperature, which heavily dictates the water temperature in lakes, are strongly driven by the variations of large scale atmospheric system. It was also shown that the dryness (E–P) in vicinity of lakes is also driven by the same system, and although driven by distinct sources, (E–P) and water level fields are connected. However, addressing of physical processes taking place in these connections could not be adequately made as could be done in some other works done in Europe (Wibig, 1999; Xoplaki et al., 2000), because of the uninterpretable spatial outputs of the CCA. Therefore, it is suggested that an exhaustive elaboration of the topic should be made based on gridded data sets of meteorological and hydrological variables in order to develop our understanding on the remote control of these variables by the atmospheric system.

Although shown in a larger scale in the first part of study, it was verified that circulation indices have an important role in determining the meteorological conditions around Lake Mogan also. It was shown that temperature and precipitation has a very strong inverse relation with EAWR, especially on the years in which they are in agreement with NAO. That is, in only a few years, which the precipitation and temperature were seen to be conflicting with the theoretical expectation according to the EAWR, it was seen that NAO was in disagreement with EAWR. Recall that by coincidence (i.e. not owing to similar mechanisms, see Section 1.1), positive modes of both indices were associated with cold and dry conditions in Turkey, and vice versa.

The common sources of variability in Lake Mogan data set mainly consisting of plankton and several chemical variables was investigated using factor analysis (FA). The FA, first attempted method for separation of variables according to their relationships, was considered to be successful by being able to group the variables into mainly 2 functional compartments, the phytoplankton and zooplankton. Therefore, no other methods was tried. However, it was claimed that the interpretation of FA can become tricky when such straightforward results are not achieved (McGarigal et al., 2000). For such cases, other methods (e.g. cluster analysis) shall also be considered. In order to extract the dominant sources of variability in the emerging groups after FA, a principal component analysis (PCA) was conducted. Apart from the seasonality driven significant correlations with temperature, the leading modes of phytoplankton and zooplankton groups were also found to be significantly correlated with salinity having an increasing trend. Different phytoplankton species have evolutionarily developed different levels of adaptation skills for osmotic and ionic regulation (Wetzel, 1983). Different zooplankton species are also known to have different levels of tolerances to salinity (Aladin, 1991). Therefore, these trend driven correlations with salinity may be due to changes in community structures as well as the total abundance of zooplankton and phytoplankton groups.

In order to provide evidence and supporting ideas to the relationships found in multivariate analysis, and to develop further understanding about climatic influence mechanisms that would be taking place, pairwise comparisons of some important parameters were made. To introduce some organization, evaluation of relations taking place in different compartments of the ecosystem were handled under two headlines: The bottom-up control of climatic impacts, corresponding to the climatic impacts initially occurring at the lower trophic levels and propagation of them upwards, and top-down control of climatic impacts for the opposite.

Several works have reported significant relations between meteorological elements (temperature, precipitation, wind) with in-lake nutrient concentrations in Europe (George et al., 2004b; Weyhenmeyer, 2004). These relations could not be displayed robustly for Lake Mogan. Although the absence of strong relations may be simply resulting from control of more dominant non-climatic processes on the nutrients, some other reasons concerning the data quality can be proposed. For example, since the data were not frequent within a year, temporary conditions following internal lake dynamics (e.g. post-spring bloom period) that could be coincided at the time of field surveys can be contributing to the plotted variability. Another obvious problem is that, since the data were not long-term enough, a sense of normal and abnormal meteorological conditions can not be easily developed, which is required to evaluate the response of these variables to extreme conditions. These problems held true for other variable pairs as well.

In accordance with the results of Markensten (2006), annual (without winters) average chlorophyll-a was shown to be in a major scale positive relationship with air temperature, which may be reflecting the increased pigment content of algal cells to compensate the increased light requirement for saturation photosynthesis with increasing temperature (Wetzel, 1983). Conflicts at some years can be explained by two apparent mechanisms. First of them is due to the ongoing activity of phytoplankton in warm winters. As this activity causes the nutrient stocks to decrease, exponential increase of phytoplankton in spring may become limited as been also demonstrated in Figure 3.27 by dampened spring chlorophyll-a concentrations after warm winters. Due to this nonlinear effect, the distribution of primary production throughout the year instead of accumulation in spring may result in lower overall chlorophyll-a values, as represented by an elongated season average (growth season, March-October in our case). A second explanation is related with the grazing pressure on phytoplankton. As also been shown, cladoceran:copepode ratio gives robust responses to the air temperature supposedly due to the higher adaptation skills of the parthenogenetically reproducing cladocerans (Straile, 2004). In Figure 4.1, it can be observed that, chlorophyll-a has an inverse relation with cladoceran:copepode ratio at an inter-annual scale, modulated with a trend-like increase against decreasing *Daphnia*, verifying the effective control of large-bodied zooplankton on phytoplankton (Moss, 1998). Therefore, it can be suggested that the positive relation between cladoceran:copepode ratio and temperature may be also responsible for the yearly conflicts between chlorophyll-a and temperature.

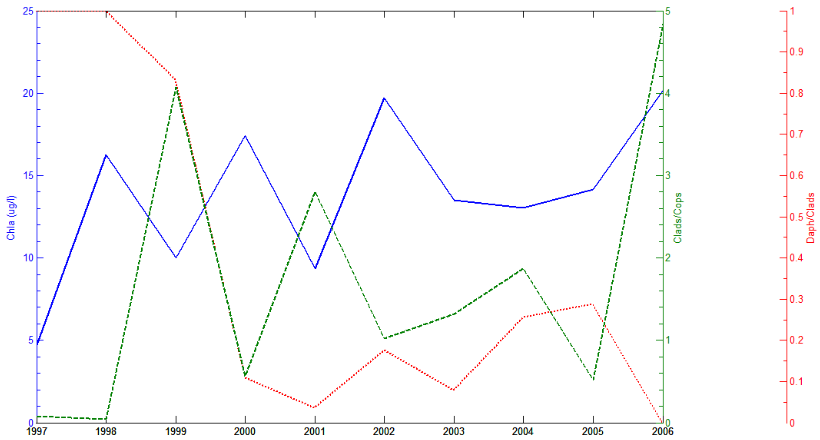


Figure 4.1: Growth season (March-October) average chlorophyll-a (continous) vs. total cladocerans:total copepodes ratio (dashed) and *Daphnia*:total cladocerans ratio(dots)

There exist many studies showing the linkage between NAO and several biotic variables such as chloropyll-a (George et al., 2004b), phytoplankton biovolume (and biomass) (Straile and Adrian, 2000; Noges, 2004) timing of clear water phase (Gerten and Adrian, 2000), and several zooplankton species (*Daphnia, Eudiaptomus, Keratella*) (George and Hewitt, 1999; Straile, 2000; Winder and Schindler, 2004). NAO and EAWR were seen to have positive consistencies with the spring chlorophyll-a in Lake Mogan. A possible explanation for this relation is through temperature: Winter temperature is negatively related with both NAO and EAWR, while spring chlorophyll-a values were lower than normal after mild winters (as represented by a negative relationship), probably because of the ongoing primary production and consequent depletion of nutrients in winter. On the other hand, NAO and EAWR were shown to have inverse relationships with the ratio of total cladocerans to total copepodes. Again recalling the negative relationship between temperature and NAO and EAWR, this can also be explained by the fact that cladocerans respond to temperature changes better than the copepodes as represented by a positive relationship between temperature and Cladoceran:Copepode ratio. However, for being able to argue these links more strongly, other important functional elements (vegetation, fish, etc.) of the ecosystem, as well as the winter values of especially primary production should be considered also.

Daphnia was observed to be negatively effected by salinity (as proxied by the conductivity and E–P (Evaporation–Precipitation)). On the other hand, positive relationship between the total cladocerans:total copepodes and salinity suggests that cladoceran species other than *Daphnia* (*Ceriodaphnia reticulata, Bosmina longistris, Chydorus sphaericus, Alona affinis, Diaphnasoma lacustris*) were favored against copepode species (*Eucyclops sp., Mesocyclops sp., Megacyclops sp., Arctodiaptomus bacillifer*). This result actually is not in concordance with Jeppesen et al. (1994) which documented that cladoceran species were replaced with copepodes with increasing salinity levels. However, the picture could be only completed by considering the predation pressure on zooplankton species which could have also change with climatic impacts (Havens et al., 2007).

The analyses conducted for Lake Mogan, not only demonstrated the methodologies and approaches to be adopted in future studies, but also served to face with problems beforehand and enabled to more precisely specify the features of required data sets for such an attempt. A general list of these features can be given as:

- these data sets firstly need to be long term enough, to cover the extreme events of climatic variability, and to differentiate them from the normal behavior.
- they need to be frequent in time (like at least twice a month), to capture momentary extreme signals that biological parameters may show, like, for example in the blooming periods of phytoplankton and zooplankton.
- they must contain a reasonable spectrum (range) of functional biological parameters, in order for being able to consider the multiplicity of pathways that may possibly be contributing to an investigated response.
- as the compulsory requirement for any data set used in any scientific discipline, the data must be homogeneous (not effected by any artificial source or impacts, i.e. change of methodology, change in the location of sampling site, restoration efforts, etc.) along the samples, or at least, these sources effecting the data quality must be considered. It should be further noted that, in a study aiming to find the climatic connections, other than improper sampling practices, like researcher-independent changes, that are part of non-climatic drivers (e.g., eutrophication) may also confound the homogeneity of data, in a conceptual sense.

Unfortunately, in Turkey, the lakes still can hardly be percepted beyond their value as the freshwater sources for usability. A natural reflection of this attitude is absence of monitoring programs and consequently the long term data, which becomes a major limitation for research. However, lack of research, that could emphasize the need for such programs and data, turns the situation a chicken-and-egg problem. In this study, Lake Mogan, despite the inadequacies in its data set, was used as a case to contribute to the existing limited understanding of climatic impacts on lake ecosystems in Turkey. At this point, it has to be clarified that, although the available data set of Lake Eymir was superior from that of Mogan with respect to first 3 items in the above list, Lake Eymir was strongly violating the 4th item as a lake having experienced sewage effluent diversion (Beklioglu et al., 1999) as well as being host to a biomanipulation study (Beklioglu et al., 2003), and therefore was not used.

Existence of inadequacies in the data set led to a deficiency of producing counter-arguments or introducing new ones to the existing literature knowledge, although verification of literature knowledge with the cases only needing straightforward interpretations would also be a good starting point as one of the few studies (Beklioglu et al., 2006; Cevik et al., 2007) conducted related with the climate related changes in Turkish lakes.

In conclusion;

- The large scale atmospheric system, as represented by the Sea Level Pressure (SLP) field was analyzed. The dominant sources of variability were identified
- Relations of circulation indices with several surface climatic variables were analyzed. Although correlations with a confidence level of 99.9% were encountered, inconsistencies and lack of persistencies hindered drawing firm results
- Connections of the large scale atmospheric system with the temperature, evaporation minus precipitation (E–P) and water levels were analyzed. Temperature and (E–P) was seen to be heavily dominated by this system although it was realized that detection of linkages with water levels needs further analysis considering the lagging effects
- Methods and approaches that can be adopted in understanding the ecosystem responses stimulated by climatic variability were exemplified with Lake Mogan, as a case
- NAO and EAWR were seen to have negative relations with cladoceran:copepode ratio and positive relations with spring chlorophyll-a in Lake Mogan, possibly both relations being mediated by temperature.
- Salinity was also suggested to be effective on the zooplankton community structure in Lake Mogan.

- Experiencing problems regarding the data enabled specifying the requirements of a data set that would be adequate for analyzing climate-related impacts in the ecosystem level, so that future monitoring and sampling practices can be managed accordingly

In the face of global warming and expected dryer conditions in the region, Turkish lakes are likely to be under threat in the close future. Variabilities in the atmospheric circulation in this scene can get even more important as the potential drivers of state shifts or even temporary vanishing of water bodies. Therefore, hydro-meteorological implications of these variabilities are recommended to be extensively elaborated by means of gridded data sets. Moreover, in the data gathering process, it was realized that especially biological data is extremely scarce for Turkish lakes. Monitoring and sampling programs should be initiated immediately to stimulate research on the subject which is currently very insufficient.

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APPENDIX A

MULTIVARIATE METHODS: A TECHNICAL OVERVIEW

A.1 Multiple Linear Regression (MLR)

Let's represent p independent variables with X_i $(i = 1, 2, ..., p)$ and the independent variable with Y. Regression model consists of independent variables X_i multiplied with their parameters β_i, a constant term β_0 and the error term ϵ as in equation (A.1a). Note that the model is not called linear because the response variable Y will be linear along the observations (or independent variables) but rather because the relation of the response to the independent variables is assumed to be a linear function of their parameters. For example, the model shown in equation (A.1b) is still a linear one although Y is not a linear function of X_2.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \epsilon \tag{A.1a}$$

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2^2 + \epsilon \tag{A.1b}$$

There are several ways of solving the MLR problem, i.e. determining suitable estimates for the parameters, β_i. Here, a commonly used method, least square regression is mentioned. If equation (A.1a) is written in matrix form, $y = X \cdot \beta + \epsilon$, the estimated values of the parameters, β can be given as in (A.2) and consequently the error term, ϵ as in (A.3):

$$\widehat{\beta} = (X^T X)^{-1} X^T \vec{y} \tag{A.2}$$

$$\widehat{\vec{\epsilon}} = y - X\widehat{\beta} \tag{A.3}$$

In these notations, hats above β and ϵ indicate that they are estimated. The success of model can be obviously defined by the smallness of the difference of calculated y by the estimated parameters β_i. This intention can be set as a minimization problem by defining an objective function, ESS (Error Sum of Squares) as:

$$ESS = \sum (y_i - \widehat{y}_i)^2 = \vec{y}^T\vec{y} - \widehat{\beta}^T X^T \vec{y} \tag{A.4}$$

Afterwards, this becomes a linear algebra problem, in which the partial derivatives according to each β_i have to be taken and set to 0, which means that at the minima, slope (derivative) should be equal to 0. For MLR, MATLAB 7.1's *regress* function was used. Sources: von Storch and Zwiers (1999); Chapra and Canale (2002)

A.2 Empirical Orthogonal Function (EOF) Analysis

Let's consider a data set consisting of values of a field (e.g. pressure) in M spatial and N temporal locations. This field can be represented by a matrix F, in which columns correspond to the spatial, rows correspond to the temporal locations:

$$F = \begin{bmatrix} F_1(1) & F_2(1) & \cdots & F_M(1) \\ F_1(2) & F_2(2) & \cdots & F_M(2) \\ \vdots & \vdots & \ddots & \vdots \\ F_1(N) & F_2(N) & \cdots & F_M(N) \end{bmatrix} \tag{A.5}$$

Following the classical covariance method, first step is to calculate the spatial covariance matrix, R_{FF} of F, which can be obtained by multiplying the transpose of F (F^T) with F:

$$R_{FF} = F^T \times F = \begin{bmatrix} \langle F_1F_1\rangle & \langle F_1F_2\rangle & \cdots & \langle F_1F_M\rangle \\ \langle F_2F_1\rangle & \langle F_2F_2\rangle & \cdots & \langle F_2F_M\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \langle F_MF_1\rangle & \langle F_MF_2\rangle & \cdots & \langle F_MF_M\rangle \end{bmatrix} \tag{A.6}$$

It should be noted that in equation (A.6), $\langle F_iF_j\rangle$ represents the covariance between time series F_i and F_j respectively at the grid points i and j, which can be explicitly defined as:

$$\langle F_iF_j\rangle = \langle F_jF_i\rangle = \frac{1}{N-1}\sum_{t=1}^{N} F_i(t)F_j(t) \tag{A.7}$$

If the time series in F, are the normalized anomaly values (z-scores), R_{FF} is then rather called correlation matrix. After the R_{FF} is obtained, the following eigenproblem has to be solved:

$$R_{FF} \times E = E \times \lambda \tag{A.8}$$

In equation (A.8), λ is an $M \times M$ matrix involving eigenvalues λ_k, $k = 1, 2, ..., M$ of $R_F F$ in its diagonal elements, and these eigenvalues are sorted in descending order from top-right to bottom-left. Although it has M columns and rows, its effective size is $K \times K$ since only λ_k, $k = 1, 2, ..., K$ ($K \leq$min(N,M)) elements are bigger than 0. This also suggests that only first K elements which also correspond to modes, can be calculated. E on the other hand, is a $M \times M$ matrix which contain eigenvectors of R_{FF}, E^k, each corresponding to a λ_k:

$$E = \begin{bmatrix} E_1^1 & E_1^2 & \cdots & E_1^M \\ E_2^1 & E_2^2 & \cdots & E_2^M \\ \vdots & \vdots & \ddots & \vdots \\ E_M^1 & E_M^2 & \cdots & E_M^M \end{bmatrix} \tag{A.9}$$

Since only first K eigenvectors E^k corresponding to bigger than zero λ_k's, effective size of E also reduces to $M \times K$. E^k vectors, each involving M elements, constitute the spatial EOF pattern of the mode k and are called Empirical Orthogonal Functions (EOF), principal component loadings, principal vectors or just loadings. One important feature of eigenvector matrix E is that it satisfies that $E^T \times E = E \times E^T = I$, where I is the identity matrix. This means that each E^k is orthogonal (independent) to each other.

Temporal variability (along 1. to N'th time steps) of the k'th EOF mode E^k can be represented with the time series $A^k(t)$ which can be obtained by projecting the matrix F ($F_m(t)$) on the eigenvector E^k:

$$A^k(t) = \sum_{m=1}^{k} F_m(t) \tag{A.10}$$

in which $k = 1, 2, ..., K$ corresponds to modes, $m = 1, 2, ..., M$ corresponds to spatial locations and $t = 1, 2, ..., N$ corresponds to temporal locations (time steps). Equation (A.10) can be rewritten with the matrix notation as $A = E^T \times F$. Since sizes of E^T and F are $K \times M$ and $M \times N$ respectively, A emerges from this multiplication with a size of $K \times N$. K rows of matrix A, each corresponding to a mode, contains N elements each corresponding to a time step. Time series $A^k(t)$ are called principal components, time coefficients, eigenvector time series, or simply scores.

Each λ_k is proportional with the explained variance of the field F by mode k and this explained variance can be calculated as:

$$\% \text{ explained variance} = \frac{\lambda_k}{\sum_{i=1}^{K}} \times 100 \tag{A.11}$$

Original data field F can be completely reproduced by multiplying each spatial EOF pattern E^k with the corresponding principal component A^k for all K modes and summing them up:

$$F_m(t) = \sum_{k=1}^{K} E_m^k A^k(t) \tag{A.12}$$

If, however, only H ($H \ll K$)modes are used, which can already explain most of the variance, an approximate, compressed and less noisy estimate $\widehat{F}$ of the original field f can be obtained:

$$\widehat{F}_m(t) = \sum_{k=1}^{H} E_m^k A^k(t) \tag{A.13}$$

This way, still an important portion of variability in the field F can be represented while data size can be dramatically reduced. Although not necessarily, these dominant modes may also correspond to some important physical processes, which can be enlightened by making further analysis (looking at correlations, etc.).

The classical covariance method explained above may quickly become inefficient and cumbersome since the size of the covariance (or correlation) matrix R_FF increases proportionally with the square of M, i.e the number of spatial locations. There exists another method called Singular Value Decomposition (SVD), which can solve the eigenvalue problem in a single step, without requiring any temporary huge matrices like the R_FF. SVD approach is based on the concept that any matrix F of size $M \times N$ can be written as the product of three matrices: matrix U of size

$M \times M$, diagonal Γ matrix of size $M \times N$ consisting of positive or 0 elements and the transpose of matrix V of size $N \times N$:

$$F = U \times \Gamma \times V^T \tag{A.14}$$

The diagonal elements γ_k of Γ are called singular values and they are usually sorted descendingly. γ_k are proportional with the λ_k in the classical covariance method such that $\lambda_k = {\gamma_k}^2$. Columns of U matrix are orthogonal to each other and are equal with the eigenvectors E^k, i.e. they are the spatial EOF patterns, each corresponding to a singular value γ_k of the field F. Rows of the matrix V^T are also orthogonal to each other and they are proportional with the time series A^k, with a constant of proportionality γ_k:

$$A = \Gamma \times V^T \tag{A.15}$$

$$A^k(t) = \gamma_k {V^T}^k(t) \tag{A.16}$$

In this study, principal components were calculated using the SVD method. U, Γ and V matrices were obtained using the “svd” function in MATLAB 7.1.

Source:Venegas (2001)

A.3 Canonical Correlation Analysis (CCA)

CCA is a technique used for finding out the linear links between two data fields. Let two data sets are represented by matrices S and P of sizes $N \times M_S$ and $N \times M_P$ respectively, having M_S and M_P spatial locations in their columns and both N temporal locations in their rows. Their covariance matrices and cross-covariance matrix, R_SS, R_PP and R_SP is calculated as:

$$R_{SS} = S^T \times S \qquad = \begin{bmatrix} \langle S_1S_1\rangle & \langle S_1S_2\rangle & \cdots & \langle S_1S_{M_S}\rangle \\ \langle S_2S_1\rangle & \langle S_2S_2\rangle & \cdots & \langle S_2S_{M_S}\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \langle S_{M_S}S_1\rangle & \langle S_{M_S}S_2\rangle & \cdots & \langle S_{M_S}S_{M_S}\rangle \end{bmatrix} \tag{A.17a}$$

$$R_{PP} = P^T \times P \qquad = \begin{bmatrix} \langle P_1P_1\rangle & \langle P_1P_2\rangle & \cdots & \langle P_1P_{M_P}\rangle \\ \langle P_2P_1\rangle & \langle P_2P_2\rangle & \cdots & \langle P_2P_{M_P}\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \langle P_{M_P}P_1\rangle & \langle P_{M_P}P_2\rangle & \cdots & \langle P_{M_P}P_{M_P}\rangle \end{bmatrix} \tag{A.17b}$$

$$R_{SP} = S^T \times P \qquad = \begin{bmatrix} \langle S_1P_1\rangle & \langle S_1P_2\rangle & \cdots & \langle S_1P_{M_P}\rangle \\ \langle S_2P_1\rangle & \langle S_2P_2\rangle & \cdots & \langle S_2P_{M_P}\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \langle S_{M_S}P_1\rangle & \langle S_{M_S}P_2\rangle & \cdots & \langle S_{M_S}P_{M_P}\rangle \end{bmatrix} \tag{A.17c}$$

Then the combination matrices Q_S and Q_P can be formed as:

$$Q_S = {R_{SS}}^{-1} \times R_{SP} \times {R_{PP}}^{-1} \times {R_{SP}}^T \tag{A.18a}$$

$$Q_P = {R_{PP}}^{-1} \times {R_{SP}}^T \times {R_{SS}}^{-1} \times R_{SP} \tag{A.18b}$$

in which the matrices Q_S and Q_P are of sizes $M_S \times M_S$ and $M_P \times M_SP$, respectively. Then the eigenproblems for these combination matrices Q_S and Q_P have to be solved:

$$Q_S \times \Pi_S = \Pi_S \times \lambda \tag{A.19a}$$

$$Q_P \times \Pi_P = \Pi_P \times \lambda \tag{A.19b}$$

In equations (A.19a) and (A.19b), Λ, in its diagonal elements, carries the eigenvalues λ^k $(k = 1, 2, ..., K)$ corresponding to equal K modes of Q_S and Q_P. Similarly, the matrices Π_S and Π_P having sizes $M_S \times M_S$ and $M_P \times M_P$, carries the eigenvectors of Q_S and Q_P respectively. When the eigenproblems (A.19a) and (A.19b) are solved and eigenvalues and eigenvectors are obtained, E_S, E_P matrices containing spatial "Canonical Correlation Patterns (CCP)" $E_S^k, \quad E_P^k \quad (k = 1, 2, ..., K)$ in their columns can be found according to:

$$E_S = R_{SS} \times \Pi_S \tag{A.20a}$$

$$E_P = R_{PP} \times \Pi_P \tag{A.20b}$$

and A_S, A_P matrices containing temporal "Canonical Correlation Coefficients (CCC)" $A_S^k, \quad A_P^k \quad (k = 1, 2, ..., K)$ in their columns can be found according to:

$$A_S = S \times \Pi_S \tag{A.21a}$$

$$A_P = P \times \Pi_P \tag{A.21b}$$

The CCC ($A_S^k, \quad A_P^k$) are constrained to be temporally uncorrelated while CCP ($E_S^k, \quad E_P^k$) need not to be necessarily orthogonal in space. Furthermore, following requirements hold for the CCC:

- The correlations between A_S^l and A_S^k, A_P^l and A_P^k and A_S^l and A_P^k are zero for all $l \neq k$ where $l, \quad k$ indicate the node
- The correlation between A_S^1 and A_P^1 is the largest and equal to the largest eigenvalue of matrices Q_S and Q_P
- The correlation between A_S^1 and A_P^1 is the second largest and equal to the second largest eigenvalue of matrices Q_S and Q_P, and so on for the further pairs

When the CCA is applied on fields of large spatial dimension compared to temporal dimension (samples), artificially high correlations can be obtained due to contribution of noise variability. However, compressing and filtering the data fields prior to the CCA by using a technique like EOF (A.2) greatly reduces the danger of misinterpreting random correlations as true correlations (Barnett and Preisendorfer, 1987; Bretherton et al., 1992).

Source: Venegas (2001)

A.4 Factor Analysis (FA)

FA actually resembles also MLR (A.1): If the factors were observable at the beginning, an MLR model could be constructed by using factors as the independent variables and the original variables as the dependent variables. However, since the factors are not known, a totally different strategy is needed. The factor model can be described with the matrix notation as follows:

$$Y = \Lambda F + \epsilon \tag{A.22}$$

According to this model, variables Y are percepted as the sum of shared variability represented by $\Lambda \times F$ and and unique variability represented by ϵ. Λ, the parameters of F are also called the "factor loadings". If (A.22) is represented in open form, M pieces of $Y_m \quad (m = 1, 2, ..., M)$ variables are assumed to be linearly related with K pieces of $F^k \quad (k = 1, 2, ..., K)$ latent factors, as in:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_M \end{bmatrix} = \begin{bmatrix} \Lambda_1^1 & \Lambda_1^2 & \cdots & \Lambda_1^K \\ \Lambda_2^1 & \Lambda_2^2 & \cdots & \Lambda_M^K \\ \vdots & \vdots & \ddots & \vdots \\ \Lambda_M^1 & \Lambda_M^2 & \cdots & \Lambda_M^K \end{bmatrix} \times \begin{bmatrix} F_1 \\ F_2 \\ \vdots \\ F_M \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_M \end{bmatrix} \tag{A.23}$$

Concerning the Y, Λ and ϵ in (A.23), if it is assumed that Λ and ϵ are independent (i.e., $\Lambda\epsilon^T = \epsilon\Lambda^T = 0$),the relation between the covariance matrices ($Y^TY = \Sigma, \epsilon^T\epsilon = \Psi, F^TF = \Phi$) follows that

$$Y^TY = (\Lambda F + \epsilon)(\Lambda F + \epsilon)^T \tag{A.24}$$

$$\Sigma = \Lambda\Phi\Lambda^T + \Psi \tag{A.25}$$

Supportingly, it can also be seen that multiplication of equation (A.22) with F^T (Recalling that $\Lambda\epsilon^T = \epsilon\Lambda^T$)

$$YF^T = \Lambda\Phi \tag{A.26}$$

From equation (A.26), it can be observed that all of the relation between the original variables (Y) and Factors (F) can be represented by $\Lambda\Phi$. When the factors are normalized and made orthogonal to each other, i.e. when $\Phi = I$, Λ becomes the single conveyor of this information. The ultimate objective of FA can be formalized as explaining the covariance structure (Σ) of the original variable set by making use of Λ loadings and Psi unique variances with the least possible amount of orthogonal factors F. For the extraction of factors, a wide spectrum of approaches can be utilized like generalized least squares, maximum likelihood estimation, principal axis factoring, etc. (Costello and Osborne, 2005).

Sources: Preisendorfer (1988); McGarigal et al. (2000)