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Representing teleconnection patterns over Europe: A comparison of SOM and PCA methods

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ABSTRACT

The main goal of this study is a comparison of two different methods of pattern recognition. The first, Principal Component Analysis (PCA), is a method frequently used in climatology. The second, Self Organizing Maps (SOM), is a relatively new and efficient method based on Artificial Neural Networks (ANN).

In order to compare the two methodologies, two teleconnection patterns were chosen, the North Atlantic Oscillation (NAO), which mostly affects the climate of Western Europe, and the North Sea–Caspian Pattern (NCP), mainly affecting eastern Mediterranean and the Balkan Peninsula. The teleconnection patterns are studied for winter 500 hPa geopotential height anomalies over the broader Europe area.

The secondary objective of the study is to evaluate the ECHAM5/MPI General Circulation Model (GCM) in representing the two teleconnection patterns for a reference (1971–2000) and a future (2071–2100) period. The evaluation of the reference period is done comparing the simulated data to the NCEP/NCAR reanalysis data. The future period is studied to examine whether the current dominant circulation patterns change or not during the last 30 years of the 21st century.

According to the results, both PCA and SOM methodologies capture the main variability mode over the study area, represented by the NAO pattern, but SOM is capable of capturing even less pronounced patterns, such as the NCP. In the future simulations, the atmospheric circulation during winter seems to be more pronounced with stronger NAO and NCP teleconnection patterns.

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1. Introduction

Earth climate variability has long been considered to be strongly governed by variability in atmospheric circulation. A usual approach of studying atmospheric circulation is the identification and definition of certain atmospheric patterns or cycles, such as atmospheric teleconnections.

Climate dynamic research has revealed the existence of several atmospheric teleconnection patterns affecting the broader European region: the North Atlantic Oscillation (NAO) in the lower troposphere (Walker, 1924; Wallace and Gutzler, 1981; Rogers, 1984; Barnston and Livezey, 1987; Hurrell, 1995; Jones et al., 1997), the Eastern Atlantic (EA) pattern as the upper manifestation of the NAO (Wallace and Gutzler, 1981; Esbensen, 1984; Barnston and Livezey, 1987), the Eastern Atlantic–West Russia (EAWR) pattern (Barnston and Livezey, 1987; Jones et al., 1997; Krichak and Alpert, 2005) and the Scandinavian Pattern (SCAND) at the 700 hPa level (Barnston and Livezey, 1987; Bueh and Nakamura, 2007), and the North Sea–Caspian Pattern (NCP) at 500 hPa (Kutiel and Benaroch, 2002). Some more local patterns affecting mainly the Mediterranean and southern Europe, are the Southern Europe–North Atlantic (SENA) pattern at 700 hPa (Kutiel and Kay, 1992), the Mediterranean Oscillation (MO) at 500 hPa (Conté et al., 1989) and the Eastern Mediterranean Pattern (EMP, Hatzaki et al., 2007) at 500 hPa and 300 hPa.

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In this study, NAO and NCP patterns were chosen to study the atmospheric circulation at the 500 hPa geopotential height anomaly field in winter. These two patterns are helping the purpose of the study since one of them, NAO, is a well-documented teleconnection pattern, representing the basic mode of variability over North Atlantic and Europe, and the other one, NCP, is a less pronounced manifestation of atmospheric variability over the study area. Therefore, the present paper attempts to find how two different methodologies, RPCA and SOM, operate on a very basic variability mode and on a less pronounced one.

More specifically, NAO is one of the most used teleconnection patterns and it has long been recognized as strongly connected to the climate variability of the Northern Hemisphere and especially that of eastern America and Western Europe (Walker, 1924). It can also be viewed as the regional expression of the Arctic Oscillation (AO) in the Atlantic sector (Thompson and Wallace, 2000). In particular, the NAO is a measure of the contrast in the strength of the Icelandic Low and the Azores High (Givati and Rosenfeld, 2013) and it is defined as the seesaw pattern of the geopotential heights, or the sea level pressure, between the North Atlantic Ocean and a zonal region at around 35°–40° in the Atlantic. Two main poles are taken under consideration, one over Iceland and one over the Azores Islands (Rogers, 1984) or over an eastern location, such as Lisbon (Hurrell, 1995) or Gibraltar (Jones et al., 1997). NAO presents two phases, a positive and a negative one. The positive phase is characterized by low pressure anomalies over the Icelandic region and throughout the Arctic combined with high-pressure anomalies across the subtropical Atlantic. This pattern is associated with stronger-than-average westerly winds across mid-latitudes. Consequently, this phase of the oscillation is associated with cold conditions over the northwest Atlantic and warm weather over Europe, as well as wet conditions from Iceland through Scandinavia and dry conditions over southern Europe. During the negative NAO phase, a weak subtropical high and a weak Icelandic low prevail. The reduced pressure gradient results in fewer and weaker winter storms with a more west–east trajectory, while moist air is brought into the Mediterranean and cold air into northern Europe (Hurrell et al., 2003).

The second teleconnection pattern studied here, the NCP, is evident at the 500 hPa level and was identified by Kutiel and Benaroch (2002). It is measured by the index NCPI, which is defined as the geopotential height (at the 500 hPa level) difference between the two poles, North Sea and Caspian Sea. The pattern presents three phases, the positive (NCP+), the negative (NCP−) and the neutral one, when the pattern is not dominant. During NCP−, there is an increased southwesterly anomaly circulation towards the Balkans, western Turkey and the Middle East, causing above normal temperature and below normal precipitation in these regions. The opposite circulation occurs with NCP+ episodes. The NCP is linked to different climatic parameters such as precipitation, temperature and sea-surface temperature regimes in the eastern Mediterranean (Kutiel et al., 2002; Hatzaki et al., 2007; Kostopoulou and Jones, 2007) and in the Balkans (Brown and Petkova, 2007), as well as temperature variability in Europe and Mediterranean (Brunetti and Kutiel, 2011).

Regarding the methods utilized to study teleconnection patterns, correlation analysis is the oldest one. According to this method, the temporal correlation coefficients of a meteorological/climatic parameter between one geographical location and all others in the domain are calculated and the higher coefficients indicate the teleconnection centers (Barnston and Livezey, 1987). However, this method requires considerable time of computation and it is not straightforward to objectively define the most representative set of centers within the domain (Hatzaki et al., 2007). Multivariate statistical techniques, such as PCA, Empirical Orthogonal Functions (EOF) and Singular Value Decomposition (SVD), are also used, with PCA being the most frequently used one. For instance, Horel (1981) and Barnston and Livezey (1987) studied the atmospheric circulation patterns over the Northern Hemisphere using an orthogonally rotated PCA (RPCA) on the geopotential heights of the 500 hPa and 700 hPa levels, respectively. The strongest pattern identified was the NAO, but more patterns were also evident, such as the Pacific–North American pattern (PNA). The authors concluded that the RPCA method provides a physically meaningful, as well as statistically stable product. The understanding of the prevailing variability patterns of the atmosphere, and especially the NAO and the PNA, with the use of PCA, is also highlighted by Corti et al. (1997). Furthermore, NAO was found to be the leading principal component of winter (Robertson et al., 2000) and summer variability (Folland et al., 2009) in Europe. Brunetti and Kutiel (2011) applied the PCA on temperature and their findings indicate that NCP is representative of the atmospheric circulation over Europe and western Asia. Hatzaki et al. (2007) used RPCA to search for possible teleconnection patterns centered over eastern Mediterranean. The Eastern Mediterranean Pattern was identified at 500 and 300 hPa especially during winter, describing a seesaw behavior between northeastern Atlantic and eastern Mediterranean. Finally, Maheras (1984, 1985), Romero et al. (1999), and Quadrelli et al. (2001) used the PCA to investigate atmospheric variability in different Mediterranean regions, such as Greece and Spain.

A relatively new method in synoptic climatology is the Self Organizing Maps (SOM). It is an unsupervised Neural Network methodology that codifies large, multivariate datasets onto a 2-dimensional array, or map, called the SOM, with the aim of discovering patterns in the data (Kohonen, 2001). According to Sheridan and Lee (2011), the SOM can be used in synoptic climatological analysis similarly to most other clustering methods, such as the PCA. However, since the results from a SOM are represented by a two-dimensional array of cluster nodes that "self-organize", the synoptic categories in this array effectively represent a continuum of synoptic situations, compared to the discrete realizations provided by most traditional methods, including PCA. Therefore, a larger number of synoptic patterns can be more readily understood. Also, both basic and transitional patterns are represented in the array. This improved visualization of the results, along with computational advantages of the SOM, has contributed in the growing popularity of the method during the last years (Hewitson and Crane, 2002).

Cavazos (1999) was the first to use the SOM methodology in synoptic climatology, regarding a classification of large-scale circulation anomalies over northeastern Mexico and southeastern Texas. The results were satisfactory since the SOM succeeded in emphasizing the differences of the atmospheric variance. Hewitson and Crane (2002) used a SOM-based approach that allowed a rapid and powerful generalization

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