Circulation Dynamics of Mediterranean Temperature Variability

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Abstract

Coupled circulation-temperature patterns and their time coefficients are derived by Canonical Correlation Analysis (CCA) revealing the main influences of large-scale circulation dynamics on Mediterranean temperature variations and trends. The two most important patterns for winter and summer in the 1948 - 1998 period are discussed. The approach allows the integration of regional temperature anomalies and changes into an overall interrelation between Mediterranean temperature and the large-scale atmospheric circulation.

Introduction

Mediterranean temperature reveals high variability on monthly, interannual and interdecadal time scales. Concerning the last decades, the winter months generally show a warming tendency in the western-central Mediterranean and some cooling in the eastern Mediterranean. During summer most Mediterranean areas are affected by increasing temperatures becoming strongest in the western-central region (e.g. Jacobeit, 2000, Schönwiese & Rapp, 1997). Looking at concomitant changes in the atmospheric circulation, a recent trend towards rising pressure, especially since the 1970s, is well documented for most of the Mediterranean area except in the summer season in the eastern part (e.g. Schönwiese & Rapp, 1997). Only a few studies established circulation-temperature-relationships for the whole Mediterranean area (Corte-Real et al., 1995, Maheras et al., 1999, Xoplaki et al., 2003). In contrast to these studies analyses are extended to the whole seasonal cycle and arrive at the identification of seasonal circulation regimes including seasonal types of coupled variability with Mediterranean temperature. Moreover, the present investigation is based on a highly resolved temperature grid and includes simultaneously near-surface as well as upper-level geopotential heights for representing the large-scale atmospheric circulation.

Data and Methods

1000 and 500 hPa geopotential height fields from the NCEP/NCAR reanalysis dataset (Kalnay et al., 1996, Kistler et al., 2001) are analysed within the North-Atlantic-European area (2.5° x 2.5° resolution). Temperature grids for the Mediterranean land areas are extracted from the highly resolved (0.5° x 0.5°) CRU05 dataset (New et al., 1999, 2000). Both samples cover the period 1948 - 1998 on a monthly scale.

In a first step unrotated Principal Component Analysis (PCA) based on the covariance matrix is separately applied to temperature and geopotential height data in order to reduce dimensions, to get uncorrelated field variables and to eliminate noise. Time series of these principal components explaining 93.0 %/90.6 % of the total variance of the winter/summer geopotential height fields and 87.4 %/83.7 % of the total variance of the winter/summer temperature fields are used in subsequent CCAs. Appropriate backtransformations allow to get patterns in terms of anomalies according to the units of the original variables (von Storch & Zwiers, 1999). The grouping of months for the seasonal CCAs resulted from initial

CCAs for each month allowing to identify three major types throughout the whole year: a 'winter type' (ONDJFM), a 'summer type' (JJAS) and a less distinct 'spring type' (AM).

Results and Discussion

For each season at least five significant (0.001 level) canonical correlation patterns (CCPs) can be derived revealing large parts of coupled variability in Mediterranean temperature and atmospheric circulation. This paper will be confined to winter and summer types focussing on those patterns with the highest canonical correlation coefficients and the highest amounts of explained temperature variance (see Figs. 1, 3).

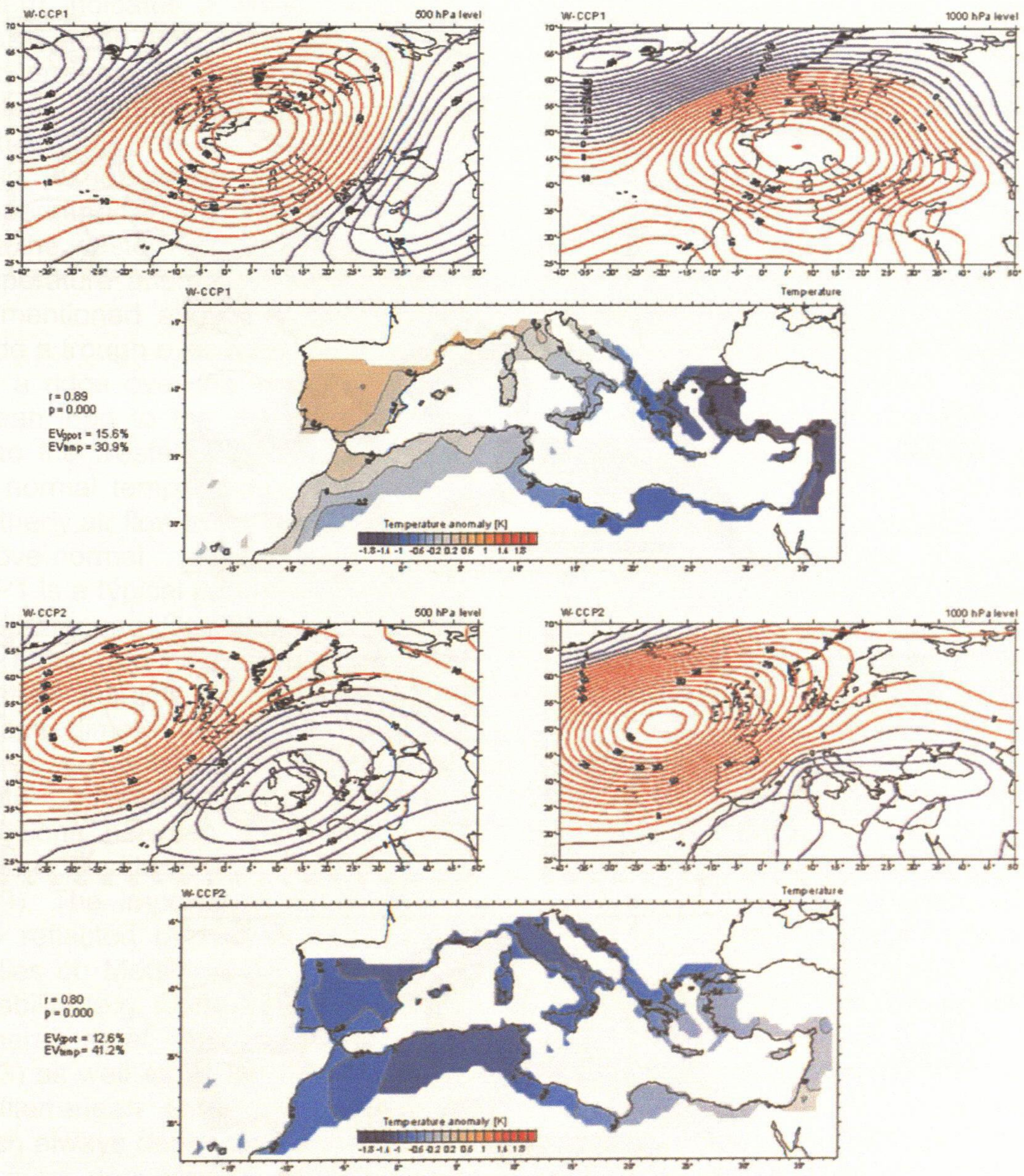

Fig. 1: Canonical correlation patterns for winter (W-CCP) referring to geopotential heights at the 500 and 1000 hPa levels and to Mediterranean temperature (October-March 1948 - 1998). EV_{gpot}: explained variance geopotential heights; EV_{prec}: explained variance temperature; r: canonical correlation coefficient; p: level of significance.

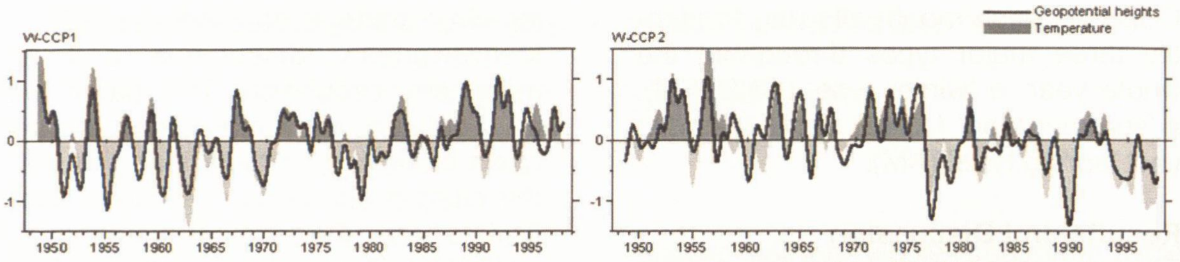

Fig. 2: Smoothed series (Gauss low-pass filter period 10 years) of time coefficients referring to the winter canonical correlation patterns (W-CCP) of Fig. 1.

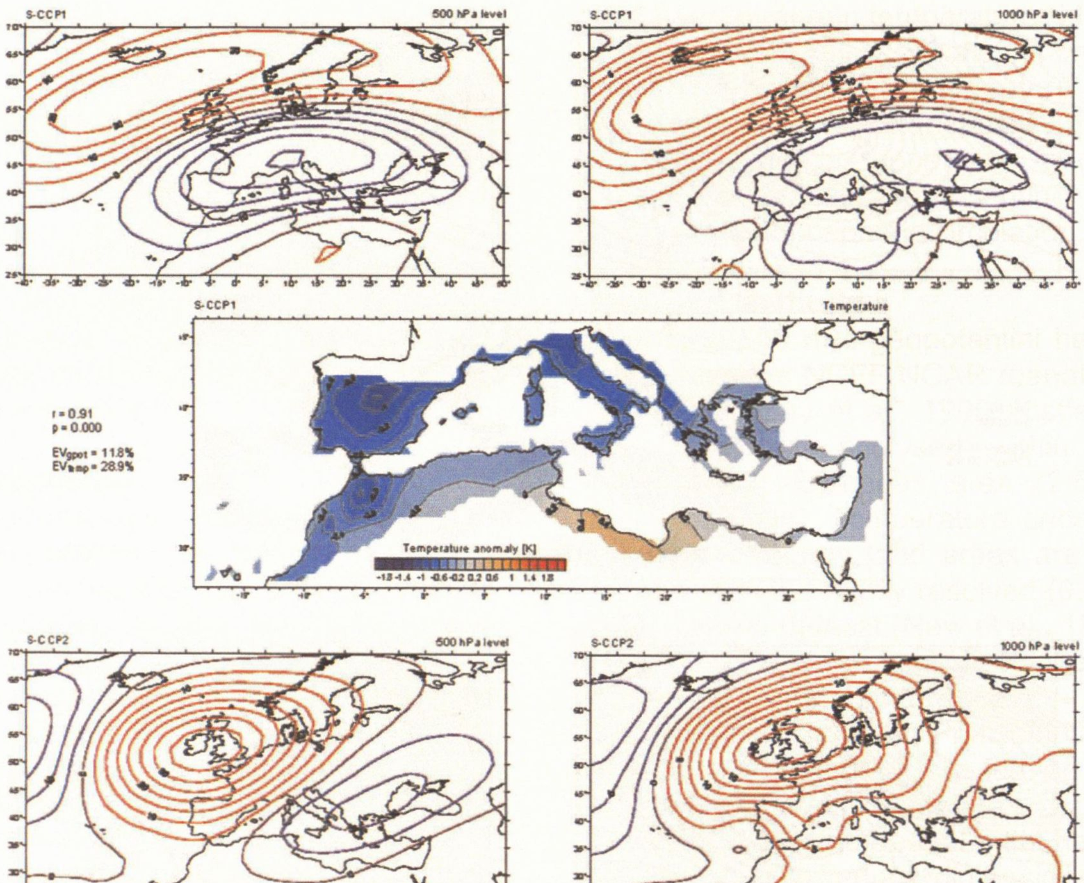

Fig. 3: Canonical correlation patterns for summer (S-CCP) referring to geopotential heights at the 500 and 1000 hPa levels and to Mediterranean temperature (June-September 1948 - 1998). EV_{gpot}: explained variance geopotential heights; EV_{prec}: explained variance temperature; r: canonical correlation coefficient; p: level of significance.

The first set of winter CCPs (W-CCP1) shows opposite temperature anomalies between the western and eastern Mediterranean area connected to a seesaw like pressure pattern with opposite centres over south-west Europe and the eastern Mediterranean (500 hPa level); another major centre is located in the northern sector near Greenland and Iceland. In the positive mode this pattern indicates a ridge over south-west Europe influencing the western Mediterranean and a trough over the eastern Mediterranean with strong northerly air flow towards the eastern basin experiencing strong negative temperature anomalies. At the same time the western region shows positive temperature anomalies due to the ridge mentioned above. In the negative mode a trough over south-west Europe and a ridge over the eastern Mediterranean lead to the inflow of subpolar air to the western Mediterranean (below-normal temperatures) and a more southerly air flow in the eastern domain (above-normal temperatures). W-CCP1 is a typical pattern related to the Mediterranean Oscillation (MO) being the most dominant feature with the greatest influence on Mediterranean surface climate variability. The MO is known as a seesaw like system of opposite pressure and surface climate conditions between the western and eastern Mediterranean (Conte et al., 1989). The importance of the MO is also reflected by results from further studies on Mediterranean temperature variability (e.g. Corte-Real et al., 1995, Maheras et al., 1999, Xoplaki et al., 2003) as well as by results concerning Mediterranean precipitation variability which always depict similar patterns as the most dominant ones (e.g. Corte-Real et al., 1995, Jacobeit & Dünkeloh, 2003, Dünkeloh & Jacobeit, 2003, Hertig et al., 2003). MO patterns are furthermore related to the North Atlantic Oscillation (in this case with r=0.59; significance level 0.01). W-CCP2 (Fig. 1) includes an extended temperature anomaly covering most of the western and central Mediterranean. It is directly correlated to a Central Mediterranean pressure variation centre which is integrated into a seesaw like system with a strong opposite centre over the north-eastern Atlantic Like for W-CCP1 both modes (pos. and neg.) imply synoptic features consistent with the corresponding temperature anomalies. W-CCP2 has also great importance for Mediterranean surface climate variability; its circulation pattern frequently appears in the above-mentioned literature including studies on rainfall variability. In view of a missing technical term Dünkeloh & Jacobeit (2003) proposed to call it the "Mediterranean Meridional Circulation" (MMC) pattern. S-CCP1 (Fig. 3) represents the strongest summer-type patterns of coupled variability consisting of more zonal-symmetrically organised centres of variation in the geopotential height fields. The corresponding temperature pattern shows an anomaly covering most of the Mediterranean area with strongest values in the western-central part. S-CCP2 is somewhat related to the MO as a weakened and northward shifted modification of W-CCP1. Both summer circulation patterns also occur in similar studies referring to precipitation variability (Dünkeloh & Jacobeit, 2003). The normalized time coefficients of the winter CCPs (Fig. 2) reveal distinct connections to the well-known temperature trends of the last decades (see above). This is not likewise true for the summer CCPs (Fig. 4). It rather seems that S-CCP4 and S-CCP5 (not shown) representing increasing pressure and increasing temperature especially in the southern Mediterranean have a particular importance with respect to recent climate change.

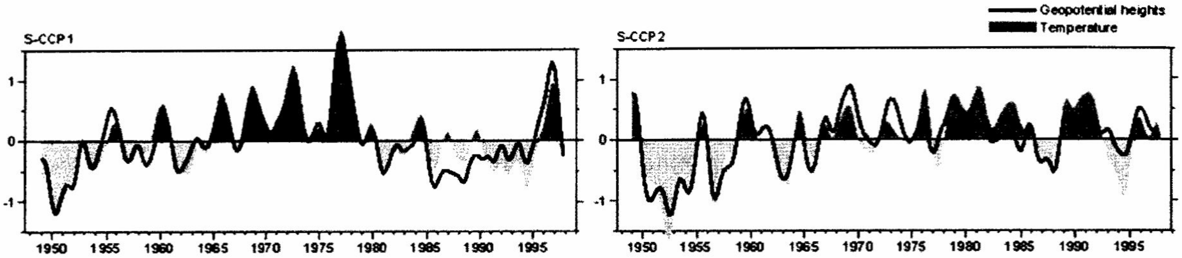

Fig. 4: Smoothed series (Gauss low-pass filter period 10 years) of time coefficients referring to the summer canonical correlation patterns (S-CCP) of Fig. 3.

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