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The Eastern Mediterranean Transient in Relation to Atmospheric Circulation Dynamics

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1. Introduction

The Eastern Mediterranean Transient (EMT) is known as a major shift in deep water formation in the eastern part of the Mediterranean region from the southern Adriatic Sea to the Aegean Sea at the beginning of the 1990s. Before that time, deep water formation which is decisive for the whole thermo-haline circulation in ocean basins from continental to regional scales, was thought to be largely restricted within the eastern Mediterranean Sea to the southern Adriatic basin (see e.g. ROBINSON et al. 1992). Several mechanisms for this important event in the ocean circulation of the Mediterranean Sea have been proposed:

- reduced input of freshwater by rivers to the Mediterranean Sea leading to a long-term increase in salinity of the Aegean Sea (BOSCOLO & BRYDEN 2001). However, as shown by JOSEY (2003), the haline component contributes less than 20% of the total density flux in the Aegean Sea which is primarily driven by the thermal component.

- Strong anomalies in regional weather patterns: the winters of 1991/1992 and of 1992/1993 were in fact quite anomalous with mean air temperatures over the southern Aegean Sea about 2°C below the long-term average (THEOCHARIS et al. 1999). However, according to cruise measurements from October 1991, the EMT may already have been operating at this time (MALANOTTE-RIZZOLI et al. 1999) prior to the severe winters just mentioned.

- Long-term trends in major atmospheric circulation regimes: above all, one might think of the distinct rising trend in the winter NAO (North Atlantic Oscillation) from the 1960s to the 1990s (HURRELL 2005, JONES 2005). However, JOSEY (2003) did not get a significant correlation with the net heat flux in the Aegean Sea during this time, and composite fields of anomalous net heat flux for strongly positive NAO winters revealed only a marginal increase in heat loss over the Aegean Sea (JOSEY 2003).

- Impacts of particular atmospheric circulation patterns: for winters with a distinct net heat loss over the Aegean Sea JOSEY (2003) gets a characteristic SLP (sea level pressure) anomaly pattern with above-average pressure over western Europe and the Northeast Atlantic indicating some similarities with the negative phase of the so-called East Atlantic (EA) pattern (NOAA-CPC 2005). It is linked with enhanced northerly winds around the Aegean Sea thus fitting into results of SAMUEL et al. (1999) including increased winter wind stress over this region for the 1988-1993 period compared to 1980-1987.

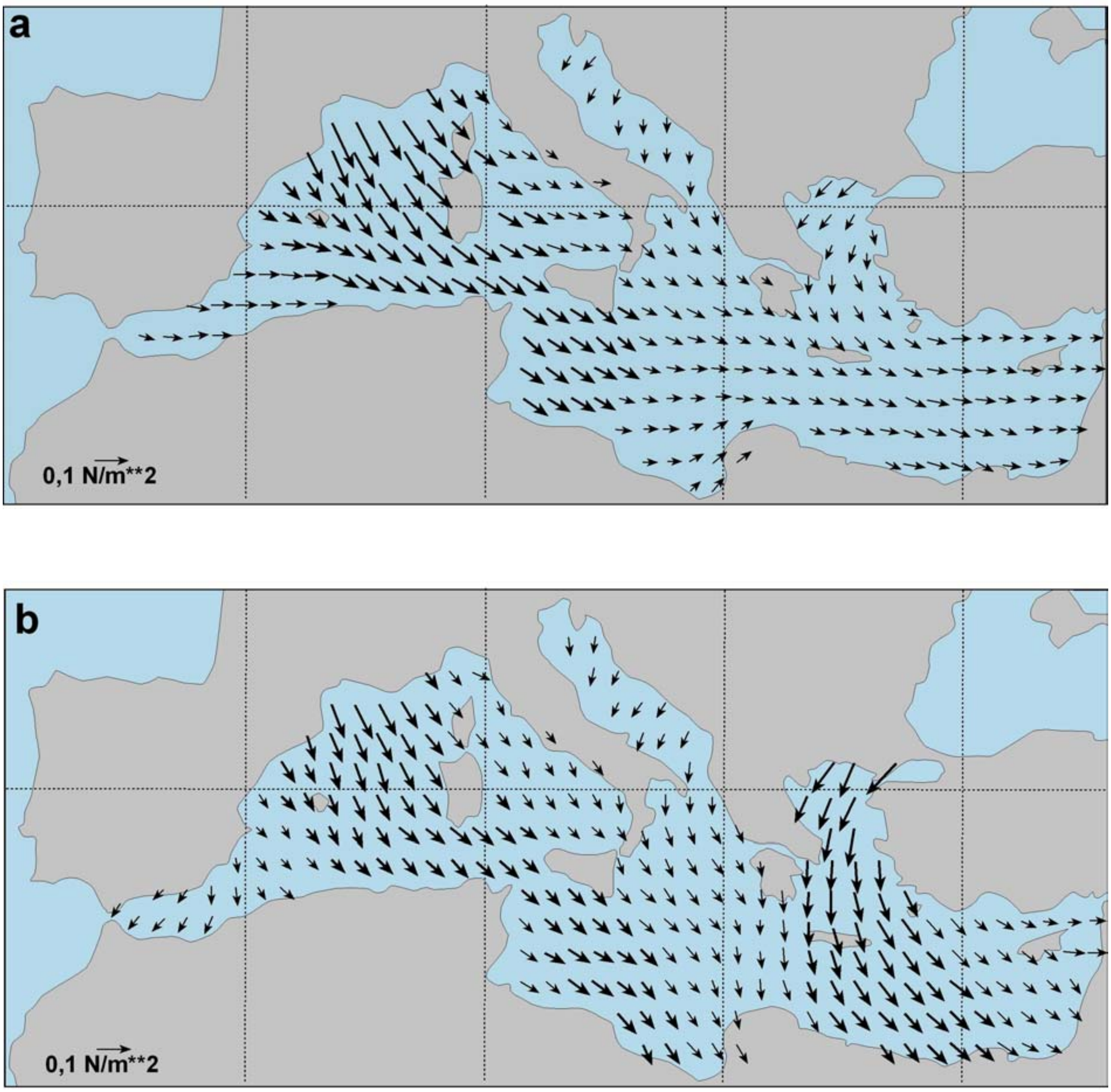

Fig. 1: Wind stress fields from the Southampton Oceanography Centre, averaged over (a) 1980-1987 and (b) 1988-1993 (slightly modified from SAMUEL et al. 1999)

Looking at these wind stress results from SAMUEL et al. (1999) reproduced in Fig. 1, another important phenomenon arises: simultaneously to the increase in northerly wind stress over the eastern Mediterranean there was an opposite change in the western basin (decreasing winter wind stress). This should also be reflected in corresponding pressure patterns if large-scale atmospheric circulation dynamics play a major role in prominent oceanic events like the EMT. Furthermore, opposite changes in different regions like the wind stress results of SAMUEL et al. (1999) might point to rather rapid changes in the preferred mode of some particular circulation patterns as driving forces for such events. In order to examine these potential mechanisms, we refer to a recent study dealing with the determination of main coupled patterns for the large-scale atmospheric circulation and seasonal rainfall in the Mediterranean area (DÜNKELOH & JACOBEIT 2003). These patterns as well as their corresponding time coefficients may give some particular indications on relationships between atmospheric circulation dynamics and the EMT.

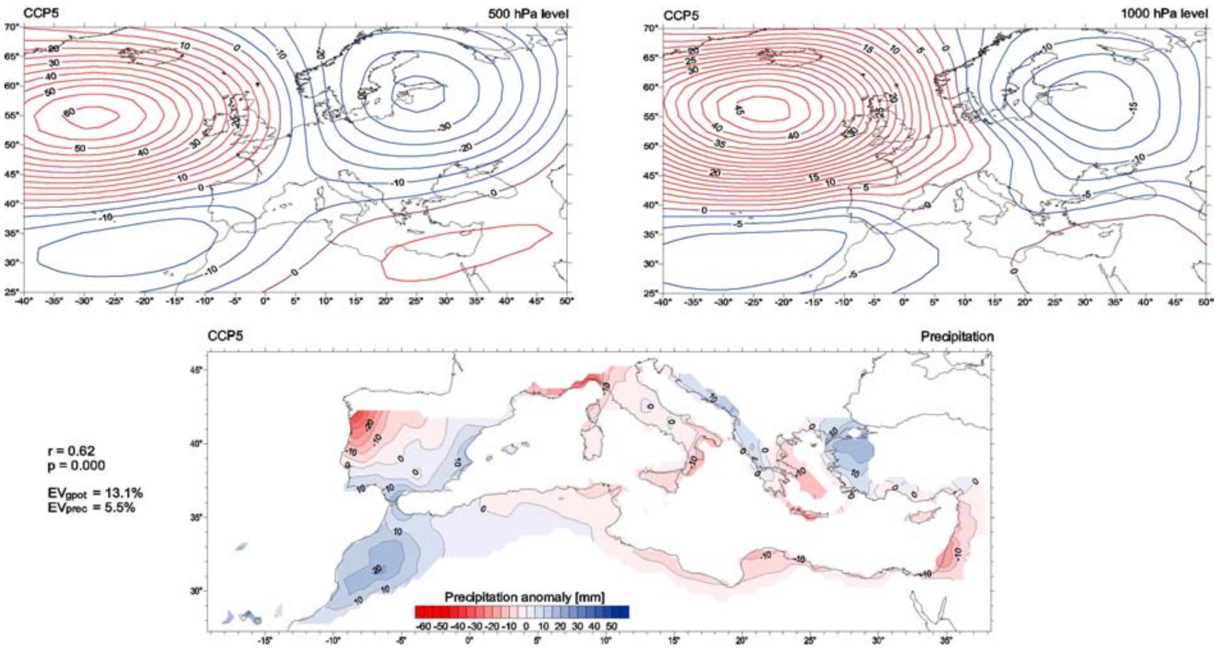

Fig. 2: Negative mode of the fifth canonical correlation pattern (CCP5) referring to geopotential heights at the 500 and 1000 hPa levels and to Mediterranean precipitation (October-March 1948-1998). EV_{gpot}: explained variance, geopotential heights; EV_{prec}: explained variance, precipitation; r: canonical correlation coefficient; p: level of significance.

2. Data and Methods

Monthly geopotential heights (500 and 1000 hPa levels) of the NCEP/NCAR reanalysis data (KALNAY et al. 1996, KISTLER et al. 2001) for the North-Atlantic–European area (2.5°x2.5° resolution) and monthly rainfall grids of the CRU05 dataset (NEW et al. 1999, 2000) for the Mediterranean land areas (0.5°x0.5° resolution) have been analysed for the months October to March during the period 1948-1998.

First an unrotated Principal Component Analysis (PCA) based on the covariance matrix was separately applied to precipitation and geopotential height data in order to reduce dimensions, to get uncorrelated field variables and to eliminate noise. Subsequently the time series of the derived principal components - explaining 95% of the total variance of the geopotential height fields and 71% of the total variance of the precipitation fields - have been submitted to canonical correlation analyses (CCAs) to identify statistical relationships between the two sets of variables. The coupled pairs of spatial patterns are derived from the two sets of variables in such a way that the correlation of their time coefficients is maximized. Thus, each set of coupled patterns represents that part of the variance in both variable groups that is significantly correlated. Owing to the incorporation of two atmospheric levels (1000 and 500 hPa), each resulting mode is spatially represented by a set of three coupled patterns (two for circulation and one for precipitation). Finally appropriate back-transformations allow getting patterns in terms of anomalies according to the units of the original variables (von STORCH & ZWIERS 1999).

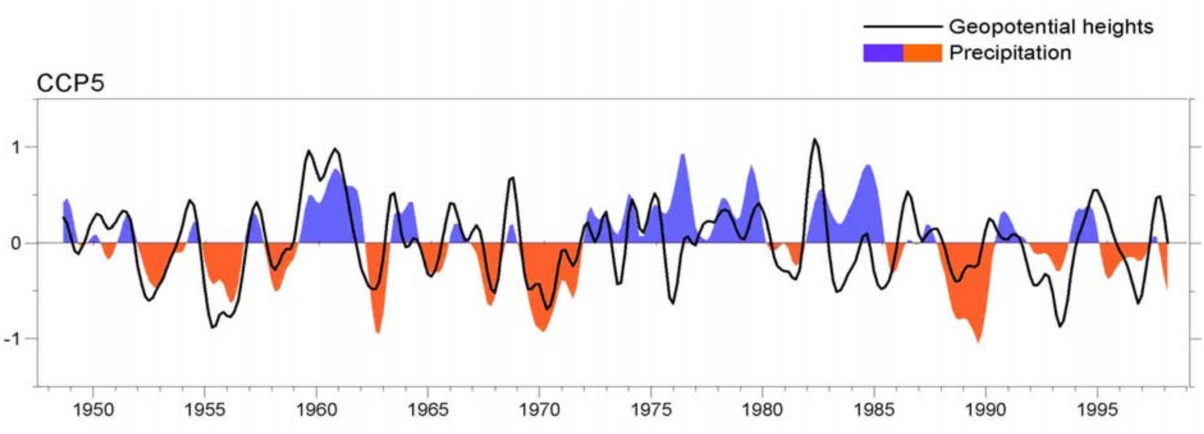

Fig. 3: Smoothed series (Gaussian low-pass filter period 10 years) of time coefficients referring to CCP5 of Fig. 2. Negative time coefficients indicate the negative mode of CCP5 shown in Fig. 2.

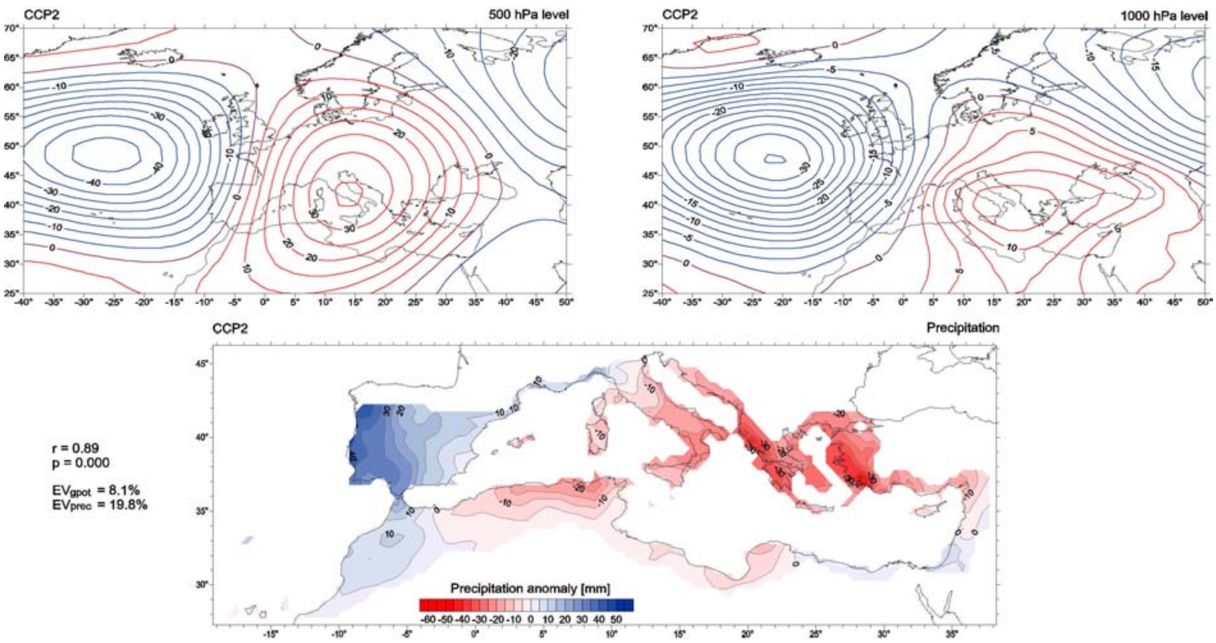

Fig. 4: Negative mode of the second canonical correlation pattern (CCP2) referring to geopotential heights at the 500 and 1000 hPa levels and to Mediterranean precipitation (October-March 1948-1998). EV_{gpot}: explained variance, geopotential heights; EV_{prec}: explained variance, precipitation; r: canonical correlation coefficient; p: level of significance.

3. Results and Discussion

The canonical correlation analysis (CCA) of North-Atlantic-European geopotential heights and Mediterranean precipitation for the winter season from October to March during the period 1948-1998 (DÜNKELOH & JACOBEIT 2003) yielded five significant coupled patterns with two of them implying particular importance for the EMT.

Due to the southerly components from the negative mode of the MMC pattern in the western basin the overall northerly surface wind stress in this region is reduced. In the eastern basin, however, the overall northerly surface wind stress is enhanced by the northerly MMC components leading to changes of the thermohaline circulation: as shown by MYERS et al. (1998) changes in wind stress have significant effects on intermediate water pathways which are crucial in particular for transporting the Levantine intermediate water (LIW) to the deep convection sites in the Mediterranean Sea. According to an ocean general circulation model study by SAMUEL et al. (1999) the LIW pathway to the Adriatic Sea was greatly reduced by the increase of northerly wind stress around 1990 resulting in a collapse of Adriatic deep water formation. In contrast to that, increased exchange of LIW occurred at the Cretan arc straits, and increased cooling over the Aegean Sea induced anomalous deep convection in this region. The latter mechanism constituting the EMT event continued for several seasons with the winters of 1991/92 and 1992/93 showing the strongest net heat losses and net evaporation anomalies of the Aegean Sea (JOSEY 2003). With respect to large-scale atmospheric circulation dynamics these anomalies were enabled by the negative mode of the EA-related pattern, which dominated just at this time (Fig. 3). Also in accordance with the subsequent development of the atmospheric time coefficients (Figs. 3 and 5) conditions get back to normal during the second half of the 1990s with no further deep water formation in the Aegean Sea and renewed deep convection in the southern Adriatic (JOSEY 2003).

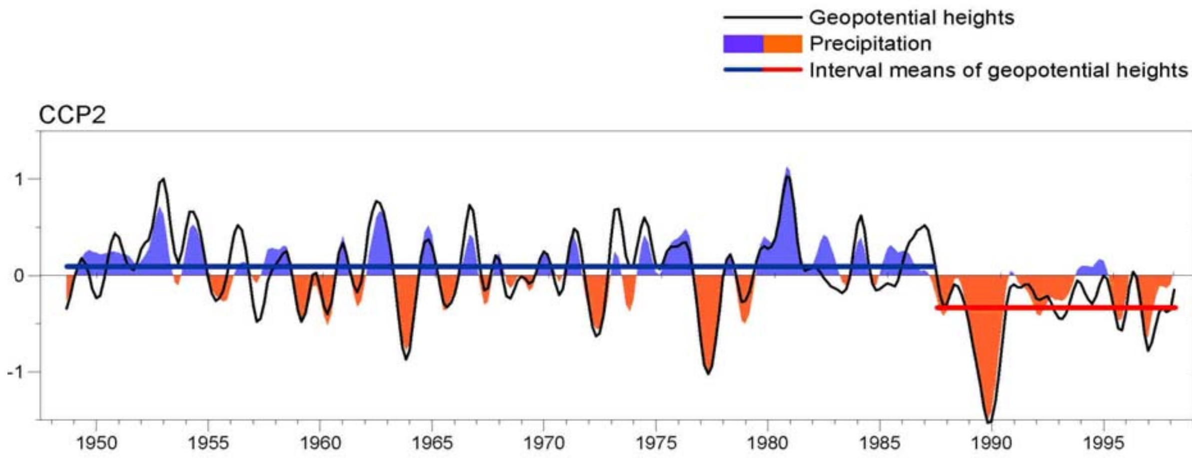

Fig. 5: Smoothed series (Gaussian low-pass filter period 10 years) of time coefficients referring to CCP2 of Fig. 4. Negative time coefficients indicate the negative mode of CCP2 shown in Fig. 4. The coloured lines indicate mean values for particular intervals differing significantly at the 0.1% level (Mann–Whitney test).

4. Conclusion

Results from a canonical correlation analysis (DÜNKELOH & JACOBEIT 2003) have provided strong indications for a link between the EMT and large-scale atmospheric circulation dynamics. This link, however, does not exist in terms of long-term trends in major atmospheric circulation regimes, but rather in terms of rapid shifts in preferred modes of particular circulation patterns. This includes two patterns with special importance for the Mediterranean area: at first the MMC pattern whose strongly negative anomaly around the turn from the 1980s to the 1990s induced an increase in northerly surface wind stress over the Eastern Mediterranean leading to a change in the thermohaline circulation with the result of the EMT initiation; secondly an EA-related pattern whose negative mode during the first half of the 1990s continued the wind stress anomalies and implied net heat losses of the Aegean Sea perpetuating the EMT until the mid-1990s. Thus, dynamical modes in different parts of the climate system – in atmospheric and in thermohaline circulation systems – seem to be particularly linked concerning distinct anomalies as for example the EMT event.

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