Observational analysis of Mediterranean decadal hydroclimate variability: role of Atlantic-Mediterranean sea surface temperatures

Roberto Suarez-Moreno (1), Richard Seager (1), Yochanan Kushnir (1)

(1) Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York

1. Abstract

We conduct a statistical-observational analysis based on canonical correlation analysis to explore the decadal and long-term drivers of Mediterranean hydroclimate variability for the half-year (October-to-March) wet season. Our results put forward the uneven intraseasonal influence of the decadal NAO, being the leading driver during the winter peak season (December-to-March), while decadal Atlantic-Mediterranean sea surface temperatures (SSTs) act to reinforce the NAO-forced response of precipitation (PCP) and surface air temperatures (TEMP). On the side of long-term trends, the anthropogenic forcing, expressed by global SST warming (GW), is concistently related to increased temperatures. Moreover, we conjecture the GW signal as responsible for a local expansion of the subtropical dry zone over the Mediterranean region, even though this hypothesis is being further explored through experiments with general circulation models (GCMs).

In this presentation we show part of the results collected in:

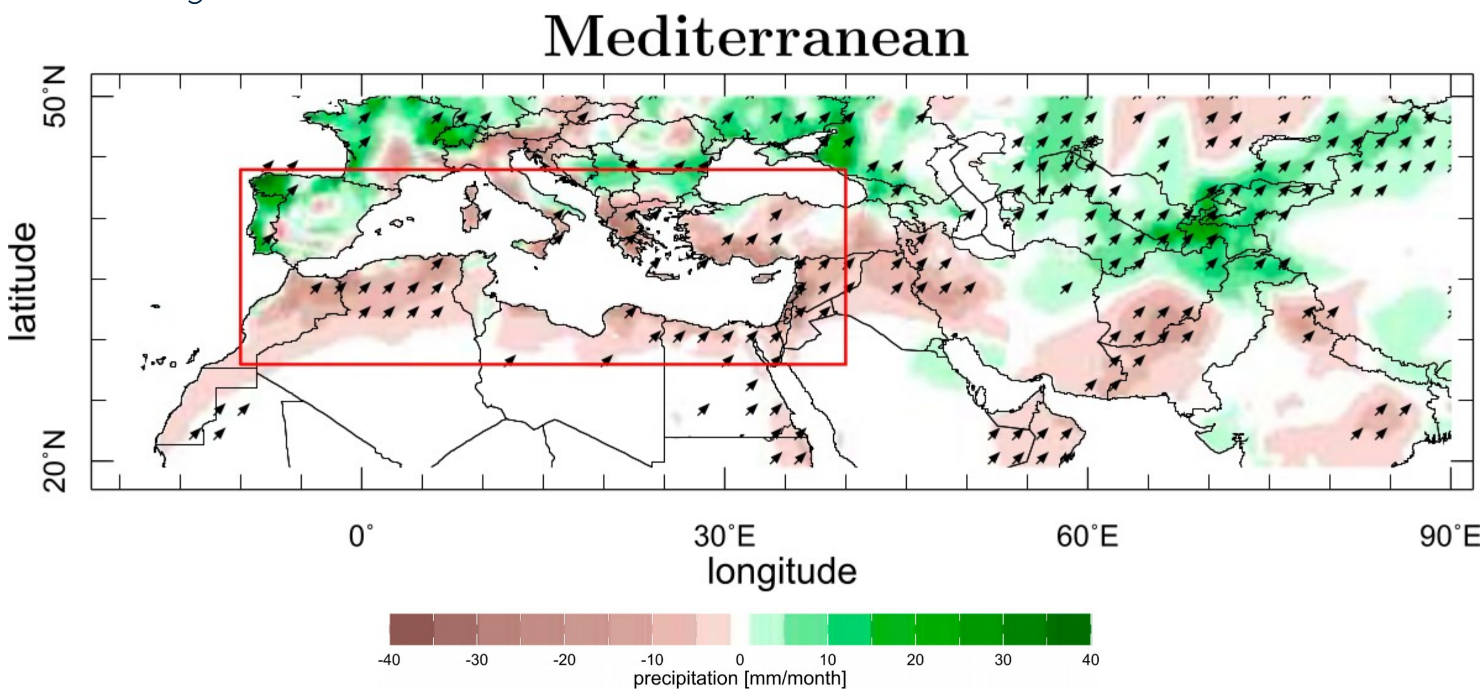
Observational analysis of multidecadal and long-term hydroclimate drivers in the Mediterranean region: role of the ocean-atmosphere system and anthropogenic forcing

(to be submitted to the Climate Dynamics)

Observational analysis of Mediterranean decadal hydroclimate variability: role of Atlantic-Mediterranean sea surface temperatures

2. Introduction

Climate models project a trend towards greater aridification of the Mediterranean region in response to rising greenhouse gases (GHGs). This trend that is detectable in observations and and phase 5 of the Couple Model Intercomparison Project (CMIP5) (e.g., Somot et al. 2007; Seager et al. 2014, 2019; Zappa et al. 2015; Tang et al. 2018).



The linear trend over 1901-2016 for winter precipitation (mm month^{-1}). Stippling denotes significance at the 5% level according to a two-sided *t*-test. Adapted from Seager et al. (2019).

2. Introduction

During the observed record, the decadal NAO (DNAO) has been related to oceanic Atlantic multidecadal variability (AMV) (Li et al. 2013; McCarthy et al. 2015). Often referred to as the Atlantic Multidecadal Oscillation (AMO), the AMV represents decadal-to-multidecadal Atlantic SST variability expressed as basin-wide, spatially-uniform North Atlantic SST anomalies (SSTA) (e.g., Kushnir 1994; Deser et al. 2010). The AMV has been linked to low-frequency hydroclimate variability in Europe (Sutton and Hodson 2005; Knight et al. 2006; Sutton and Dong 2012; Gosh et al. 2017; O'Reilly et al. 2017; Qasmi et al. 2017; Ruprich-Robert et al. 2017; Zampieri et al. 2017; Årthun et al. 2018), albeit its influence on rainfall and temperature is mostly restricted to summer.

Mediterranean decadal SST variability has been also suggested to influence DNAO. A circumglobal teleconnection with remarkable zonal characteristics develops in response to an idealized anomaly of the Mediterranean SST in a GCM that causes a local baroclinic structure (Li 2006; Garcia-Serrano et al. 2013). The teleconnection is found following the subtropical jet-stream across the Asian continent to the North Pacific and North America, appearing as a quasi-barotropic structure in the North Atlantic that weakens the Icelandic Low and induces a prolonged positive DNAO period, which in turn would influence Mediterranean hydroclimate variability, even though evidence of that is tenuous.

2. Introduction

In the Pacific Ocean, decadal SST variability is dominated by the Interdecadal Pacific Oscillation (IPO). The influence of IPO on the Mediterranean ocean-atmosphere system has been limited to a few observational studies. For example, multidecadal variability of winter cyclones in the Mediterranean region was shown to fluctuate according to IPO phases due to changes in the large-scale atmospheric circulation over the North Atlantic (Maslova et al. 2017). In other work, the combined effects of the IPO and El Niño-Southern Oscillation (ENSO) are linked to global hydroclimate variability in general, and Mediterranean wet-dry changes in particular (Wang et al. 2014). Finally, Dong and Dai (2015) use observations, reanalysis products and model simulations to analyze the influence of the IPO on temperature and precipitation worldwide, finding a negative correlation with temperature across the Mediterranean-Middle East.

2. Introduction

We seek observational evidence of the influence of AMV, IPO, Mediterranean decadal SST variability and anthropogenic forcing on the Mediterranean hydroclimate during the half-year wet season. To this aim, we use a robust observational approach based on canonical correlation analysis (CCA) to explore the leading decadal-to-long-term drivers of hydroclimate variability in the Mediterrnean region. This approach is aimed at evaluating the influence of internal atmosphere variability, SST variability and anthropogenic forcing on precipitation and temperature in the Mediterranean region. An association between DNAO and Atlantic-Mediterranean decadal SST variability is found to be strongly associated with TEMP and PCP variability during the winter peak season. On longer time scales, our results suggest that the expansion of the Hadley circulation could be a key factor in the decline of Mediterranean rainfall, whereas anthropogenic forcing is robustly related to widespread increasing TEMP.

3. Data and Methodology

We use rainfall and temperature data from the Climate Research Unit (CRU) Time-Series (TS) version 4.02 of high resolution (0.5o x 0.5o) gridded monthly data, spanning the period 1901-2017 (Harris and Jones 2019).

For SST, we used version 5 of the Extended Reconstructed Sea Surface Temperature (ERSST) dataset from the National Oceanic and Atmospheric Administration (NOAA). The ERSST v5 is derived from the International Comprehensive Ocean-Atmosphere Dataset (ICOADS), being spatially defined on a 2.0o x 2.0o grid with spatial completeness enhanced using statistical methods (Huang et al. 2017).

For the dynamical analysis, we drew upon version 3 of the NOAA-CIRES-DOE Twentieth Century Reanalysis (20CRv3). This reanalysis uses a state-of-the-art data assimilation system based on surface observations of synoptic pressure into NOAA's Global Forecast System, prescribing sea ice distribution and SST. The 20CR uses an ensemble filter data assimilation technique which directly estimates the most likely state of the global atmosphere for each 3-hour period, also estimating uncertainty in the reanalysis.

3. Data and Methodology

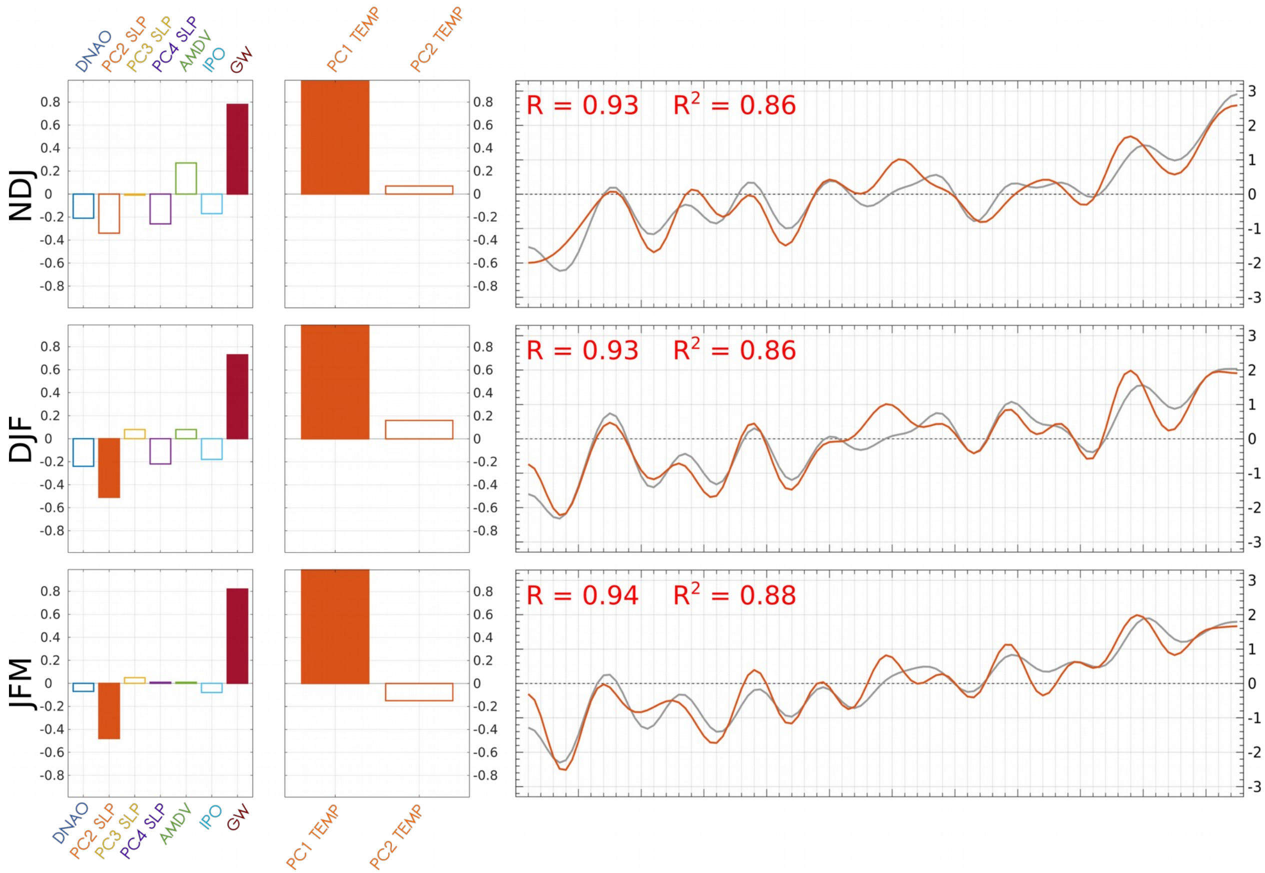
Canonical correlation analysis (CCA) is a widely used statistical analysis procedure intended to identify maximally correlated patterns between two multivariate, random datasets, one identified as the explanatory and the other as the response variables (hereinafter EV and RV respectively). The CCA method represents a powerful tool for multivariate analysis, developing a number of independent canonical modes, also known as canonical modes, that maximize the linear correlation between the EV and the RV (e.g., Green 1978; Green et al. 1978). For extended description and an algebraic representation of the procedure see Barnett and Preisendorfer (1987) and Bretherton et al. (1992) among others.

Individual variables within EV consist of the 4 leading SLP PCs (natural variability) in the North Atlantic-European region along with the AMV, IPO (external SST forcing) and GW indices (anthropogenic forcing).

The RV set is defined for Mediterranean (10W-45E, 30-45N) precipitation (PCP) and surface temperature (TEMP) in terms of time-evolving, overlapping 3-month periods from the summer-to-autumn (August-September-October, ASO) to the winter-to-spring (March-April-May, MAM) transitions. TEMP and PCP RVs consist of 1st to 2th PCs and 1st to 7th PCs respectively to retain high percentages of variance explained in each field (> 70%)

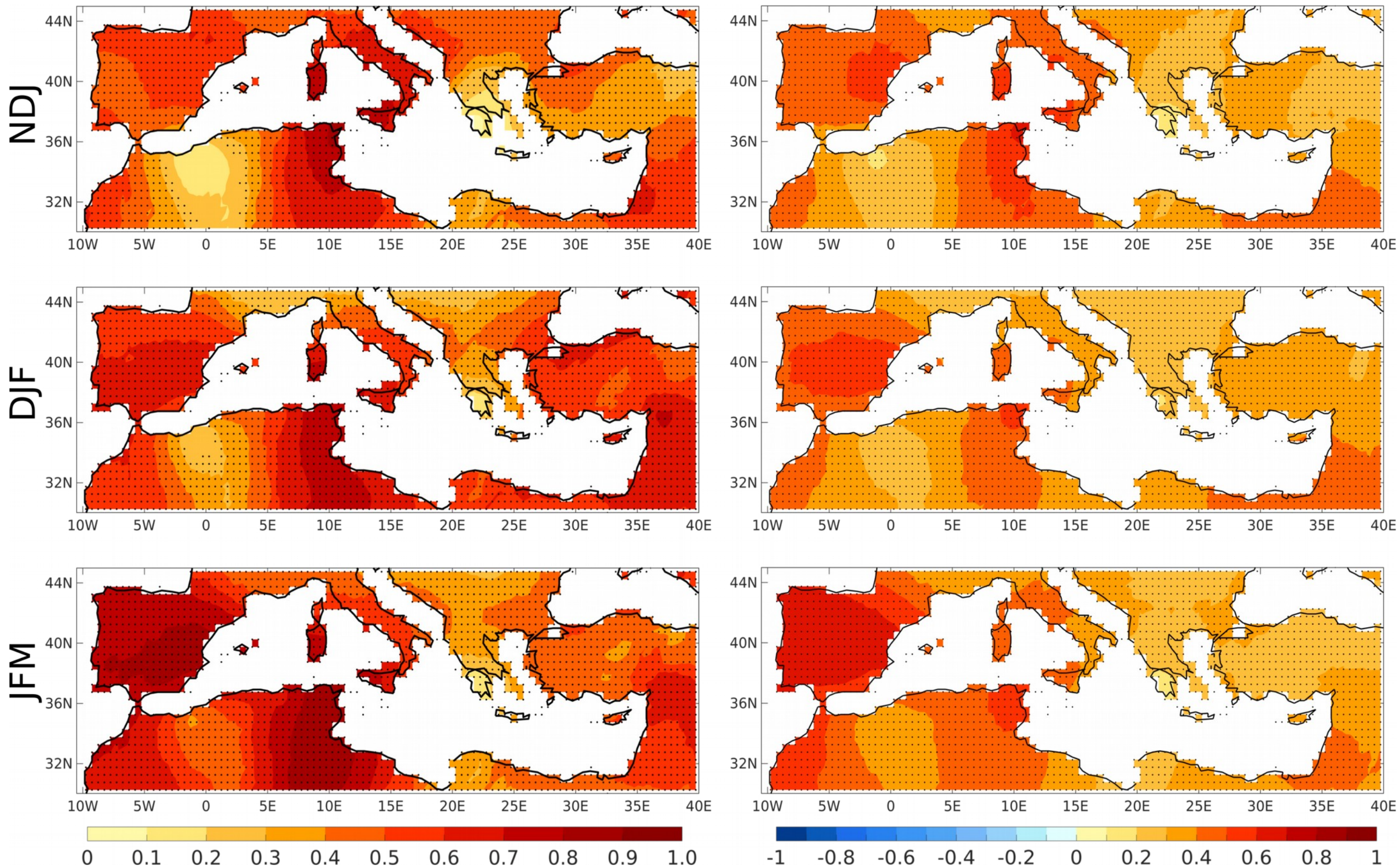
Observational analysis of Mediterranean decadal hydroclimate variability: role of Atlantic-Mediterranean sea surface temperatures

4. Results: long-term drivers of TEMP



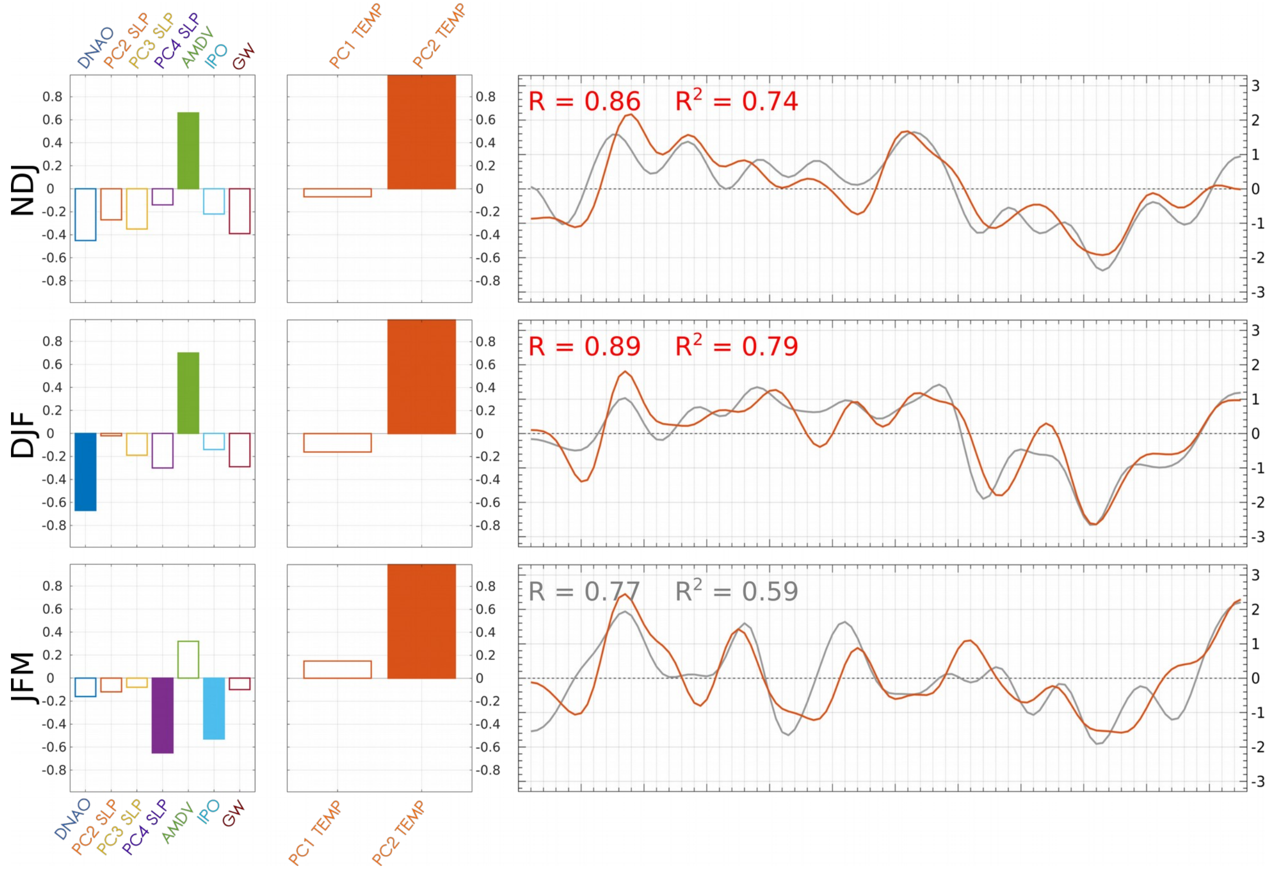
First sequence of canonical modes obtained from canonical correlation analysis (CCA) between the set of explanatory variables (EV) and the set of response variables (RV) for Mediterranean (10W-45E, 30-45N) TEMP. The results correspond to canonical EV cross-loadings (left column; unitless), canonical RV loadings (middle column; unitless) and canonical modes containing pairs of canonical EV-RV variates (right column; std deviation). Red (grey) color for canonical correlation (R) and shaded variances (R^2) indicate significance at the 5% level.

4. Results: long-term drivers of TEMP



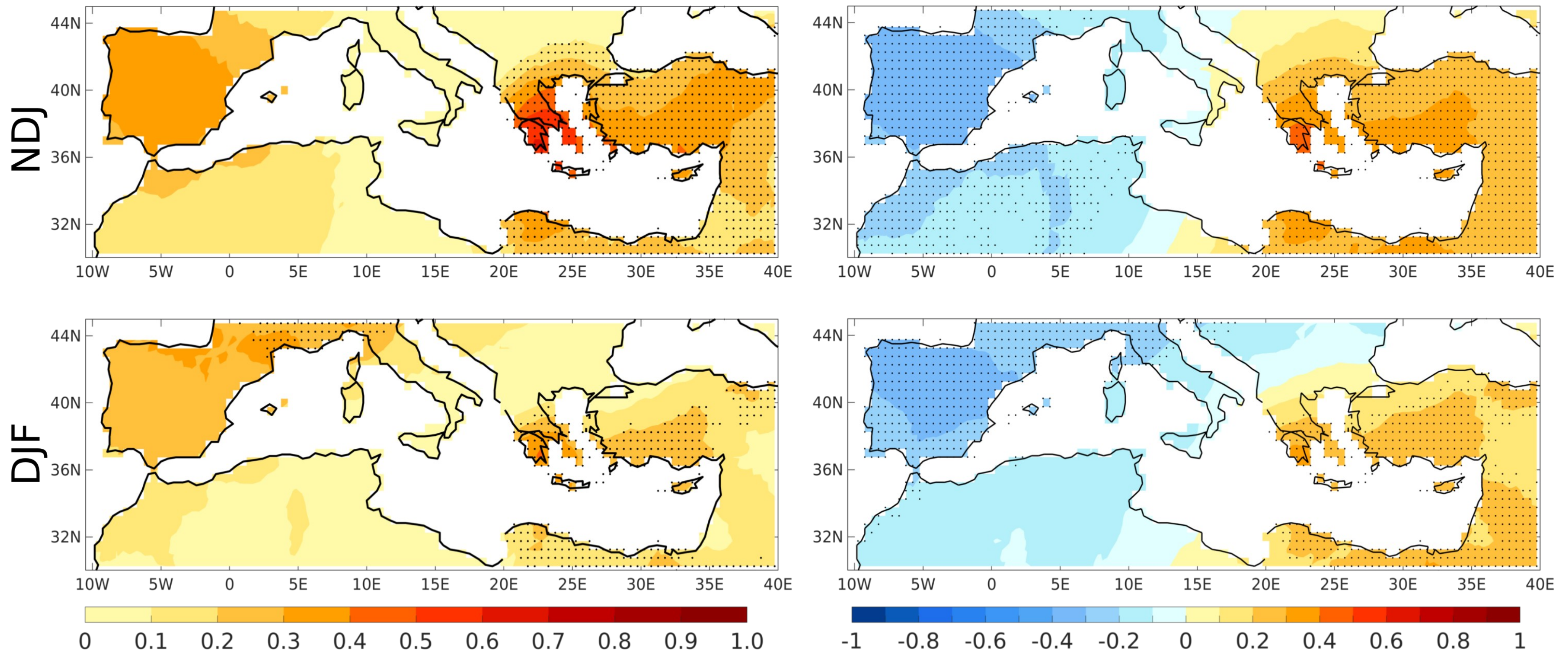
Explained variance (unitless) by the canonical EV variates in the observed TEMP anomalies at each grid point (left column) and spatial patterns of TEMP (K std^{-1}) obtained by regression of canonical EV variates onto observed TEMP anomalies (right column). Stippling denotes statistical significance at the 5% level by applying non-parametric Monte Carlo testing. Results correspond to the first sequence of canonical modes.

4. Results: multidecadal drivers of TEMP



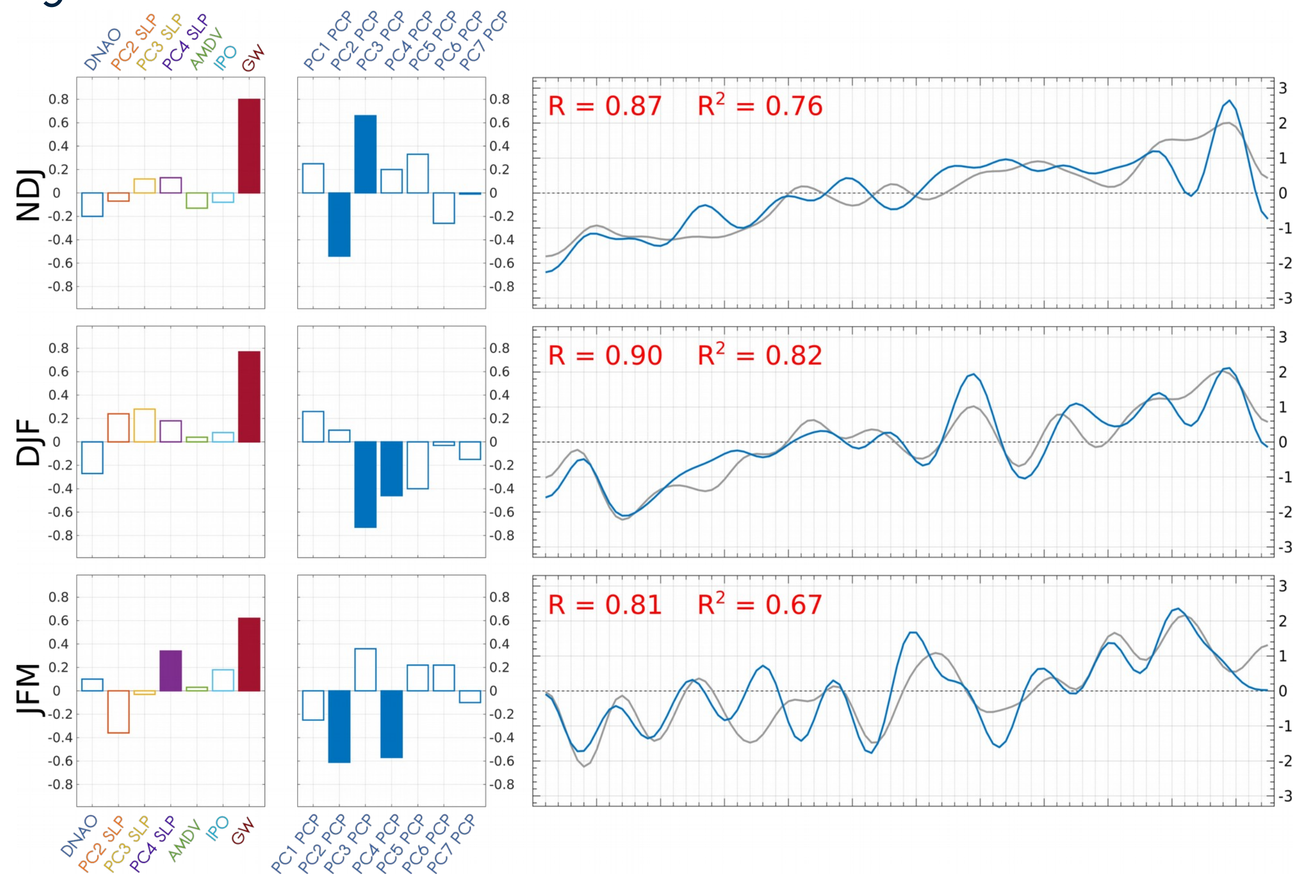
Second sequence of canonical modes obtained from canonical correlation analysis (CCA) between the set of explanatory variables (EV) and the set of response variables (RV) for Mediterranean (10W-45E, 30-45N) TEMP. The results correspond to canonical EV cross-loadings (left column; unitless), canonical RV loadings (middle column; unitless) and canonical modes containing pairs of canonical EV-RV variates (right column; std deviation). Red (grey) color for canonical correlation (R) and shaded variances (R^2) indicate significance at the 5% level.

4. Results: multidecadal drivers of TEMP



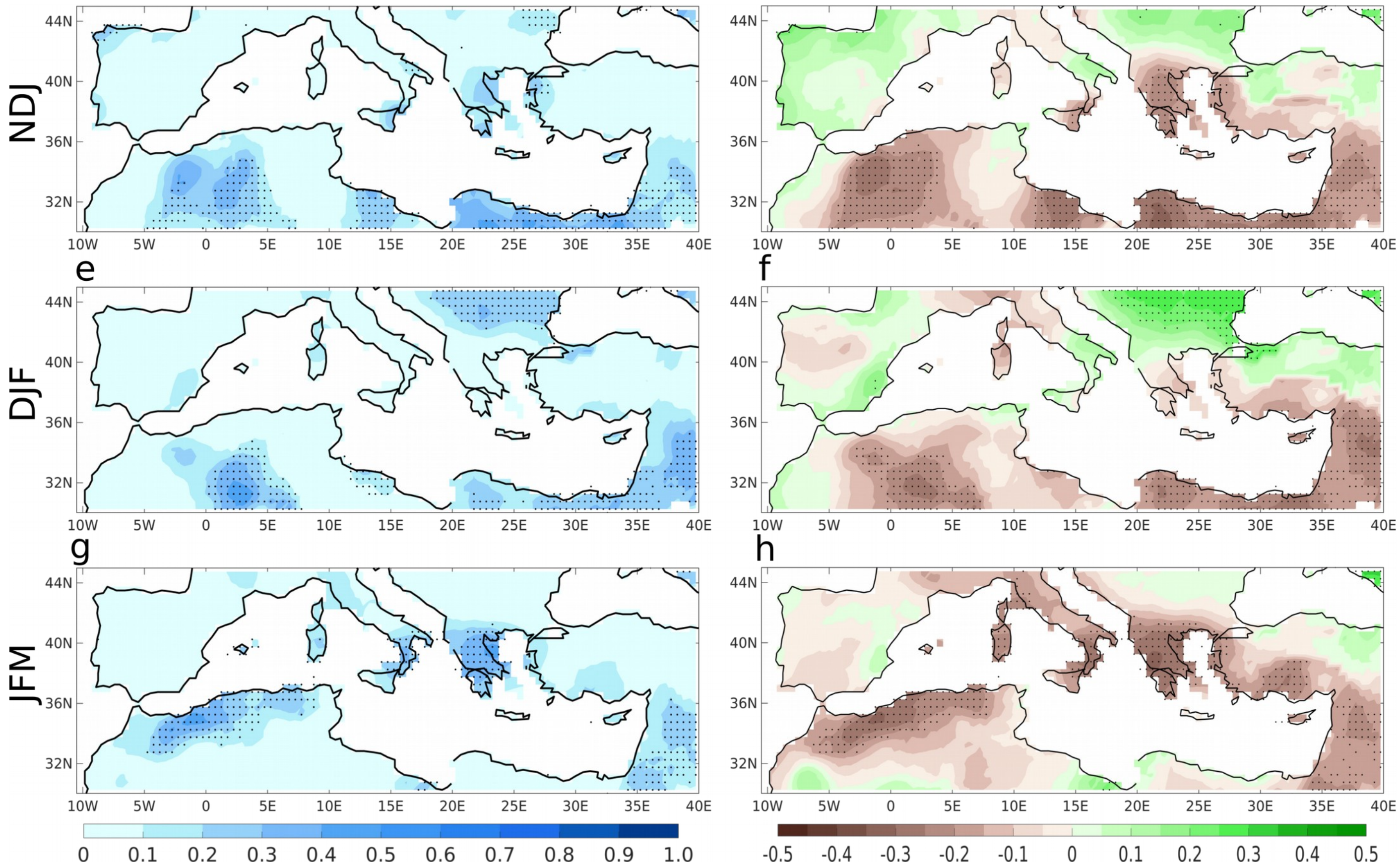
Explained variance (unitless) by the canonical EV variates in the observed TEMP anomalies at each grid point (left column) and spatial patterns of TEMP (K std^{-1}) obtained by regression of canonical EV variates onto observed TEMP anomalies (right column). Stippling denotes statistical significance at the 5% level by applying non-parametric Monte Carlo testing. Results correspond to the second sequence of canonical modes.

4. Results: long-term drivers of PCP



First sequence of canonical modes obtained from canonical correlation analysis (CCA) between the set of explanatory variables (EV) and the set of response variables (RV) for Mediterranean (10W-45E, 30-45N) PCP. The results correspond to canonical EV cross-loadings (left column; unitless), canonical RV loadings (middle column; unitless) and canonical modes containing pairs of canonical EV-RV variates (right column; std deviation). Red (grey) color for canonical correlation (R) and shaded variances (R^2) indicate significance at the 5% level.

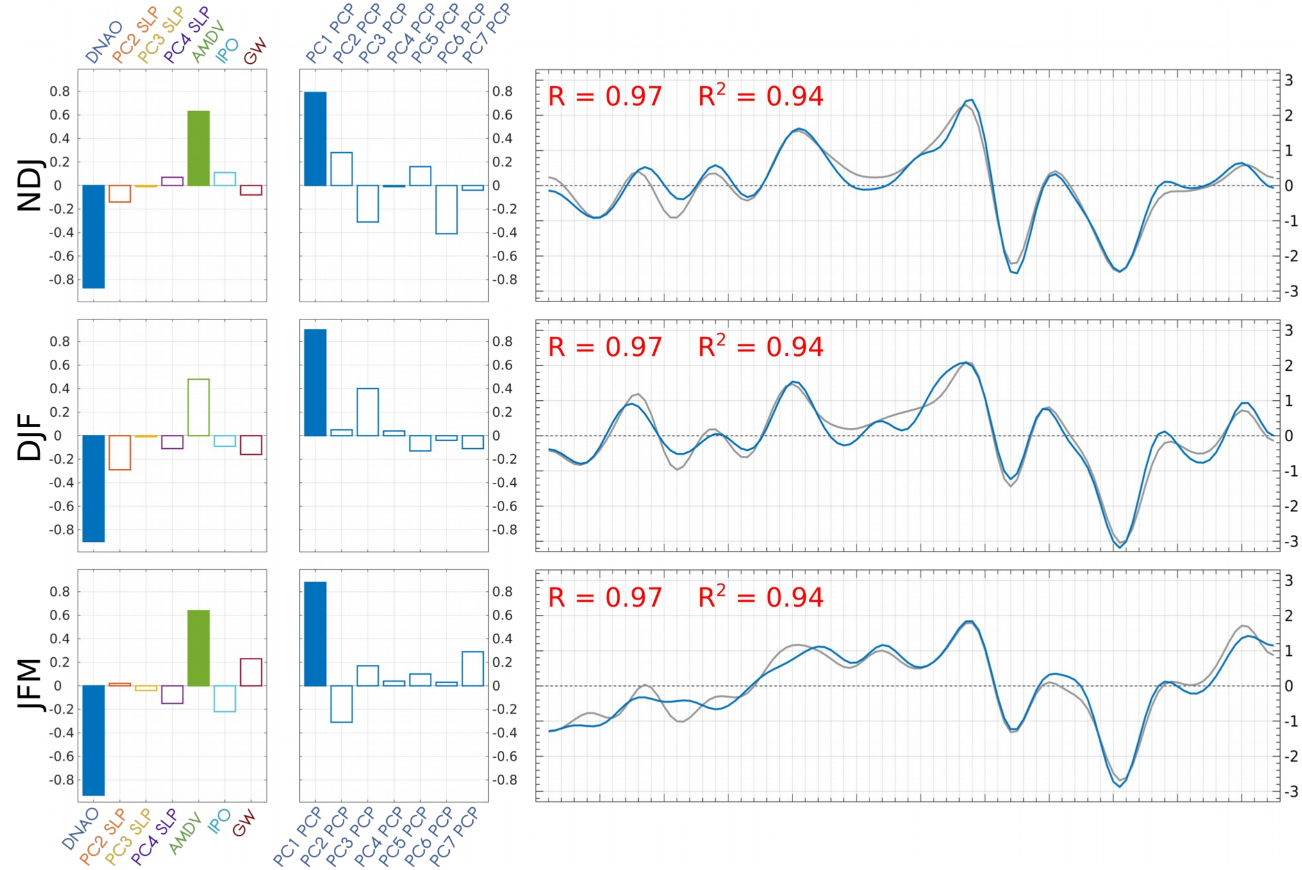
4. Results: long-term drivers of PCP



Explained variance (unitless) by the canonical EV variates in the observed PCP anomalies at each grid point (left column) and spatial patterns of PCP (mm day^{-1} std^{-1}) obtained by regression of canonical EV variates onto observed PCP anomalies (right column). Stippling denotes statistical significance at the 5% level by applying non-parametric Monte Carlo testing. Results correspond to the first sequence of canonical modes.

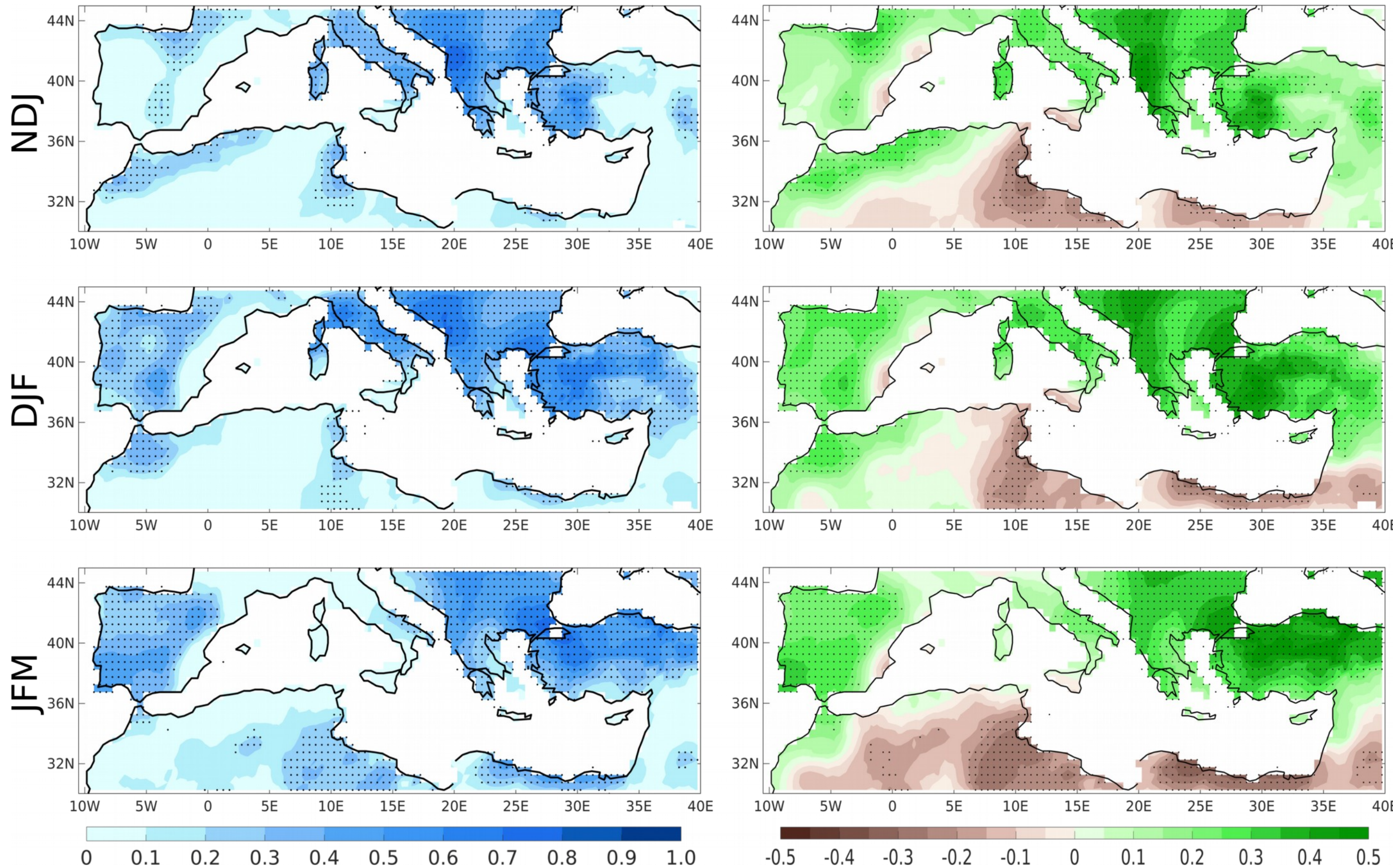
Observational analysis of Mediterranean decadal hydroclimate variability: role of Atlantic-Mediterranean sea surface temperatures

4. Results: multidecadal drivers of PCP



Second sequence of canonical modes obtained from canonical correlation analysis (CCA) between the set of explanatory variables (EV) and the set of response variables (RV) for Mediterranean (10W-45E, 30-45N) PCP. The results correspond to canonical EV cross-loadings (left column; unitless), canonical RV loadings (middle column; unitless) and canonical modes containing pairs of canonical EV-RV variates (right column; std deviation). Red (grey) color for canonical correlation (R) and shaded variances (R^2) indicate significance at the 5% level.

4. Results: multidecadal drivers of PCP



Explained variance (unitless) by the canonical EV variates in the observed PCP anomalies at each grid point (left column) and spatial patterns of PCP (mm day^{-1} std^{-1}) obtained by regression of canonical EV variates onto observed PCP anomalies (right column). Stippling denotes statistical significance at the 5% level by applying non-parametric Monte Carlo testing. Results correspond to the second sequence of canonical modes.

5. Concluding remarks

Based on a robust observational-statistical approach, our results show a DNAO-AMV adjustment to be maximally correlated with multidecadal variability of PCP and TEMP in the Mediterranean region. This hypothesis is based on high and significant canonical correlations prone to physical causation.

The DNAO is found to be the leading driver of multidecadal TEMP and PCP variability, while positive AMV plays a reinforcing role in terms of enhanced low-level moisture budget, which intensifies moisture transport by the westerlies towards the eastern Mediterranean basin. This advection of warm and moist air is partially responsible for the multidecadal TEMP-PCP spatial patterns shown in this study.

The global SST warming, which is a good approximation to anthropogenic forcing (Ting et al. 2009) is shown to modulate mutlidecadal to long-term variability of PCP. Consistently, our results (not shown) suggest anomalies of the global mean meridional circulation calculated in terms of the meridional mass stream function. The descending branch of the northern Hadley cell weakens in winter, while a poleward expansion of a high-pressure system over the Mediterranean region suggest the northward shift of the subtropical dry zone. This hypothesis is being further investigated through the use of GCMs.

As for TEMP, there is a general consensus that increasing concentrations of anthropogenic GHGs are responsible for rising worldwide temperatures due to radiative forcing (e.g., Lashof and Ahuja 1990; Myhre et al 1998; Jain et al. 2000; Collins et al. 2006; Scheutz et al. 2009; Feldman et al. 2015). Our results agree with these works, showing taht this warming is more pronounced in the western and eastern Mediterranean, with maximum values in North Africa and the Iberian Peninsula and secondary maxima in the Middle East. Seasonally, warming is less intense during the boreal winter months, probably due to amplification of GHG-induced warming by land surface feedback in the fall and spring months.