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Decadal Climate Variability and Change in the Mediterranean Region

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ABSTRACT

The Mediterranean region is among the "Hot Spots" projected to experience major climatic changes in the twenty-first century as a result of the global increase in greenhouse gas (GHG) concentrations. However the way in which these changes may initially become manifest in the Mediterranean will also depend on internal decadal variability and its impacts on climate in this region. Here, we present an analysis of the main decadal climate variations that have influenced past climatic conditions in the Mediterranean/South Europe region since the mid-nineteenth century. Decadal variability is discussed in the context of forced climatic changes from increased GHG.

Results point to significant connections between Mediterranean climate and decadal and multi-decadal variability in the Atlantic. Namely, a significant influence of the North Atlantic Oscillation on Mediterranean precipitation and a relationship between regional temperatures and the Atlantic Multi-decadal Oscillation which may imply a certain degree of decadal regional predictability. CMIP3 projections indicate that in the longer term "forced" regional climatic changes from GHG increases would bring significantly drier conditions over land and major changes in Mediterranean Sea water cycle.

1. Observed twentieth century changes

An analysis of observed twentieth century long-term changes in the water cycle of Mediterranean land areas is presented by Mariotti et al. (2008) (see Figure 1). A weak albeit significant long-term negative precipitation trend is found over Mediterranean land areas. The Palmer Drought Severity Index (PDSI), which reflects the combined effects of precipitation and surface temperature changes, shows a progressive and substantial drying of Mediterranean land surface since 1900 consistent with a decrease in precipitation and an increase in surface temperature. The inter-decadal PDSI fluctuations are similar to those of precipitation, with wetter 1960s compared to the drier 1940s.

Consistently with PDSI behaviour, a number of Mediterranean rivers for which long-time series are available also show long-term decreases in discharge during the

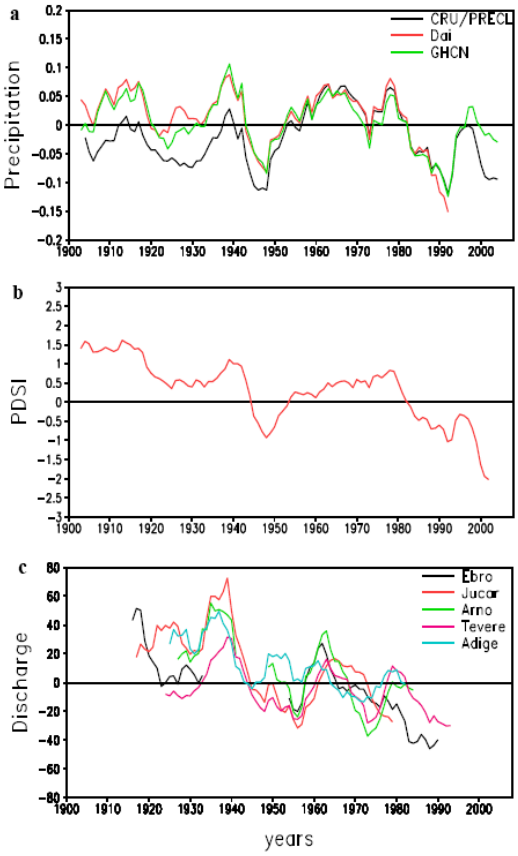

Fig. 1 Mediterranean water cycle changes observed during the 20th century relative to the period 1950-2000. Area-averaged annual mean precipitation anomalies (six-years running means) from various datasets (panel a; mm/d) and PDSI (panel b; a.u.); discharge anomalies (units are % of climatology) for various Mediterranean rivers (panel c). Due to data availability, discharge anomalies are relative to the 1960-1980 period. From [Mariotti *et al*., 2008].

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twentieth century. Such river discharge decreases are likely in part due to intensified water use.

2. Role of the North Atlantic Oscillation

The linkages between decadal variability of seasonal precipitation (DVSP) anomalies over the Mediterranean and the NAO are explored in Figure 2 (see Mariotti and Dell'Aquila, 2011). In DJF, Mediterranean-mean DVSP anomalies evoke a SLP correlation pattern clearly reminiscent of the NAO, a well known major influence on Mediterranean precipitation during winter (i.e. a positive NAO tends to correspond to drier conditions in the Mediterranean and vice-versa). This connection at decadal time-scales is confirmed by the spatial correlation of the NAO index with DJF precipitation in the Mediterranean domain. Based on this map, the NAO explains over 25% - 30% of decadal DJF precipitation variance in a region spanning parts of Spain, Marocco, Southern France, Italy and the Balkans. The NAO has been shown to affect Mediterranean precipitation by modulating SLP directly over the Mediterranean and by reorganizing large-scale moisture fluxes into the region [Mariotti and Arkin, 2007]. Drier (wetter) decades in the Mediterranean largely correspond to higher (lower) than usual regional SLP and to a positive (negative) NAO phase. The correlation of decadal variability of JJA precipitation anomalies in the Mediterranean with the Summer North Atlantic Oscillation (SNAO) of [Folland *et al.*, 2009] is also shown in Fig.2. The SNAO has significant positive correlation with JJA precipitation in Italy and parts of the Balkans, explaining up to 25% - 30% of decadal precipitation variability in these regions.

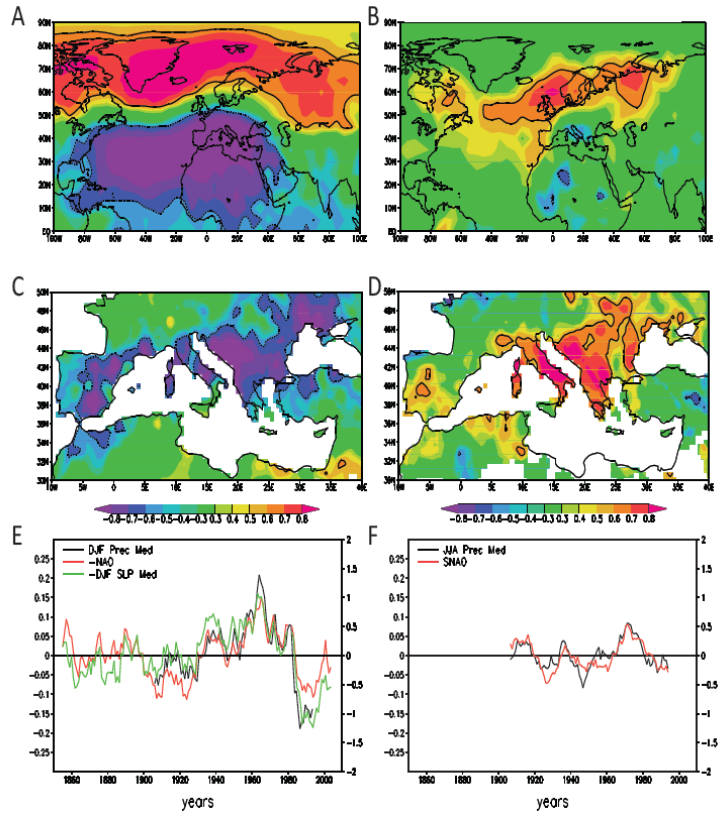

Fig. 2 Influence of large-scale decadal climate modes on Mediterranean precipitation over the period 1850-2009. A)-B) Correlation of Mediterranean-mean DVSP anomalies with SLP anomalies in the Euro-Atlantic sector over the period 1901-2000 for DJF (panel A) and JJA (panel B). C)-D) Correlation of DVSP anomalies in the Mediterranean region with various climatic indices: DJF precipitation and NAO (panel C); JJA precipitation and SNAO (panel D). E)-F) Decadal variation of Mediterranean-mean seasonal anomalies of precipitation, SLP and various climatic indices: DJF precipitation, SLP and NAO (panel E; note the sign of the NAO index is reversed); JJA precipitation and SNAO (panel F). In all, anomalies, relative to 1901-2000, are de-trended and time-filtered using 10-year running mean. In panels A-D, a black contour encloses areas where the correlation is above the 95%.

3. Linkages with the Atlantic Multi-decadal oscillation

An analysis of the linkages between decadal variability of surface air temperature (Ta) anomalies in the Mediterranean and in surrounding regions is shown in Figure 3. In JJA Mediterranean-mean Ta presents a coherent pattern of positive correlation with surface air temperature in the North Atlantic, with highest values in the eastern North Atlantic off the North African and European coasts. The correlation of Ta over the North Atlantic/European sector with the Atlantic Multidecadal Oscillation index shows that in JJA the AMO/Ta pattern over the Atlantic extends to parts of western Europe and the Mediterranean. This is in stark contrast with what is found in DJF, when the AMO correlation pattern is confined to the North Atlantic with no significant correlation with Ta over Europe, nor the Mediterranean (compare Fig. 3 C-D). The analysis of

Mediterranean-mean decadal variability of Ta anomalies also shows contrasting characteristics in JJA and DJF: multi-decadal AMO-like Ta variations in JJA (Mediterranean-mean Ta/AMO index correlation is 0.77 over the period 1850-2009); decadal variation of the anomalies, with no-AMO correlation in DJF (compare Fig. 3 E-F). Interestingly, Mediterranean SST significantly correlate with AMO variability throughout the year.

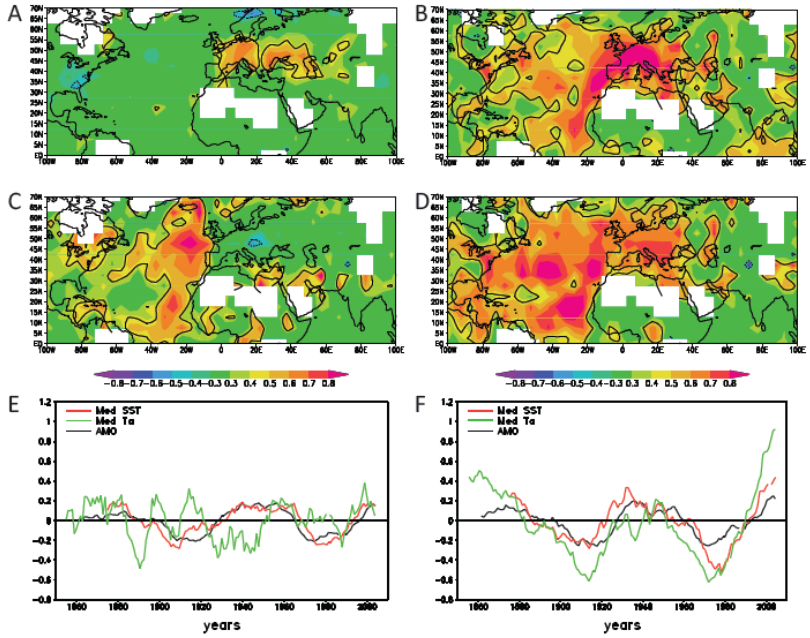

Fig. 3 Influence of large-scale decadal climate modes on Mediterranean surface air-temperature over the period 1850-2009. A)-B) Correlation of decadal Mediterranean-mean land surface air temperature (CRUTEM) anomalies with large-scale surface air temperature anomalies (HadCRU) for DJF (panel A) and JJA (panel B). C)-D) Correlation of decadal surface air temperature anomalies (HadCRU) with the AMO index for DJF (panel C), and JJA (panel D). E)-F) Time series of decadal Mediterranean-mean land surface air temperature (CRUTEM), Mediterranean SST and the AMO index for DJF (panel E) and JJA (panel F). In all, anomalies are relative to 1901-2000; values are detrended and time-filtered using 10-year running mean. In panels A-D, a black contour encloses areas where the correlation is above the 95% significance level. Mariotti and Dell'Aquila, 2011.

4. "Forced" Mediterranean water cycle changes

Mariotti *et al.*, 2008 study Mediterranean water cycle changes associated with modifications in radiative forcing based on an ensemble of multi-model coupled simulations from the WCRP Coupled Model Intercomparison Project Phase 3 (hereafter CMIP3). Twentieth century simulations, using observed radiative forcings (both natural and anthropogenic), give a progressive "forced" decrease in rainfall in the Mediterranean region during this century, somewhat higher than that derived from observational data (see section 1). CMIP3 simulations also show a tendency for Mediterranean Sea evaporation and E-P water budget to increase toward the end of the twentieth century in response to the radiative forcings (see Fig. 4).

Based on an ensemble of CMIP3 twenty-first century SRES-A1B emission scenario simulations, Mariotti *et al.* (2008) show that the above mentioned simulated twentieth century precipitation decrease would be followed by a rapid drying from 2020 onwards. Evapotranspiration would also decrease because of the drier land surface, but, as increased surface temperature favours higher evaporation, the rate would be half that of precipitation. While the "forced" drying found by Mariotti *et al.* (2008) over land is large, projected changes for the Mediterranean Sea are even more dramatic. Unlike the surrounding land region where evaporation decreases, the projected precipitation reduction over the sea is accompanied by a roughly equal increase in evaporation due to increased sea surface temperature (SST) (ultimately due to more energy input from greenhouse warming). The projected increase in the loss of freshwater (E-P) at the sea surface towards the end of the twenty-first century is large, roughly equal to what is typically received in total by the Mediterranean Sea on an annual basis as discharge from neighboring land and as inflow from the Black Sea.

5. Discussion

Although there is a high degree of inter-model consistency among the CMIP3 models regarding Mediterranean climate projections, uncertainties need to be carefully evaluated. These include general uncertainties associated with CMIP3 projections due to model errors (*e.g.* limited model resolution or the

parameterisation of physical processes), the effects of "internal" variability (from purely atmospheric modes or modes of coupled interactions within the ocean-atmosphere-land system) and uncertainties in future emission paths and natural radiative forcings (*e.g.*, future volcanic eruptions). The uncertainty in emission paths is likely to play a larger role later in the twenty-first century when differences among scenarios become larger. In addition to the above mentioned general uncertainties, there are also region-specific uncertainties, including potential errors and limitations in the CMIP3 models' representation of regional climate variability, Mediterranean Sea circulation and regional climate feedbacks.

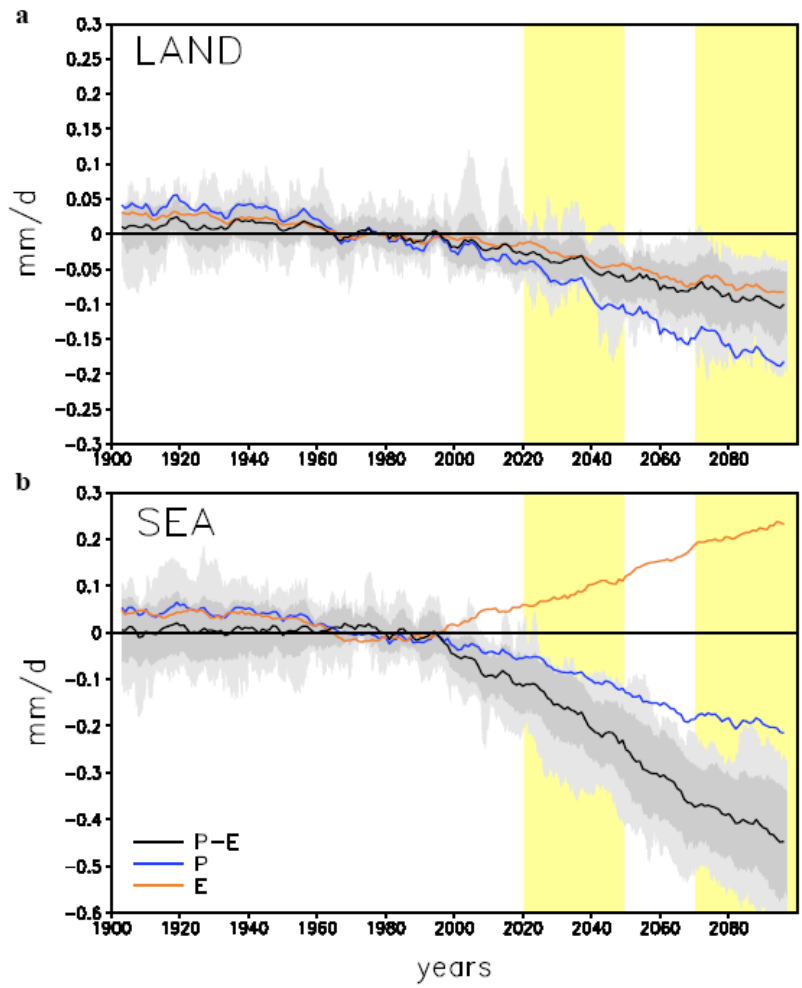

Fig. 4 Mediterranean water cycle anomalies over the period 1900-2100 relative to 1950-2000. Area-averaged evaporation (brown), precipitation (blue) and precipitation minus evaporation (black; P-E) are based on an average of CMIP3 model runs. For P-E, the envelope of individual model anomalies and the 1 standard deviation interval around the ensemble mean are also shown (light grey and dark grey shading respectively). Data are six-years running means of annual mean area-averages over the box of Figure 3 broadly defining the Mediterranean region. (Panel a) Land-only. (Panel b) Sea-only. Focus periods are highlighted (yellow). From [Mariotti *et al*., 2008].

The role of "internal" variability on future water cycle variations can be best understood by looking at past regional water cycle variability and comparing this with the results from the CMIP3 twentieth century simulations. Observational analyses of twentieth century water cycle variability in this region show long-term trends including a tendency for increased surface aridity and increased Mediterranean Sea evaporation. These changes are not inconsistent with the "forced" changes depicted by the CMIP3 simulations as a result of green-house gas concentrations increases during this century. However, observational precipitation and evaporation records also include decadal variations that are larger than the above-mentioned simulated long-term trends (*e.g.* for precipitation, observed decadal anomalies are about two orders of magnitude larger than the simulated trend). As much as both observational errors and model errors can contribute to this discrepancy, this also highlights the important role of "internal" variability in determining observed decadal anomalies. Hence, at least in the short term (roughly 10-30 years out), regional decadal anomalies and any potential for decadal predictability is likely to be critically dependent on the regional impacts of decadal modes of variability "internal" to the climate system.

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