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The Impact of the Atlantic Meridional Overturning Circulation (AMOC) Variability on the Mediterranean Climate †

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Abstract: The Atlantic Meridional Overturning Circulation (AMOC) is a major oceanic circulation system in the Atlantic Ocean, which transports heat to the poles and cold saline waters to the tropics. The AMOC mechanism is responsible for many climate and weather systems; however, it is naturally unstable, and it changes in time depending on sea-ice melt, wind patterns, solar radiation variations, etc. At the same time, there are recent indications that the AMOC is in a weaker state than previously thought with impacts more severe than expected. Knowing that the AMOC can impact remote systems, and given the risk the Mediterranean faces with climate change progressing, we focus on the relationship between the AMOC and the Mediterranean climate, based on AMOC indicators and monthly ERA5 fields (sea surface temperature, air temperature and total precipitation) from 1959 to 2021. We find that the two systems exhibit a relationship although it is not homogenous. More specifically, the AMOC is highly correlated with sea and air temperatures of the central and eastern Mediterranean with a time lag of up to 2 years, while strong links are found with the entire Mediterranean's annual total precipitation up to 3 years ahead. The results suggest the possibility of predicting the occurrence of significantly extreme periods in the Mediterranean several months in advance.

Keywords: AMOC; climate variability; Mediterranean climate; ERA5

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1. Introduction

The climate system is highly complicated, with important uncertainties affecting its proper representation. One of the issues the scientific community has come across is the challenge of understanding the Atlantic Meridional Overturning Circulation, or AMOC, and its underlying mechanisms in order to represent its key processes in models [1].

The Atlantic Meridional Overturning Circulation or AMOC is the main overturning system of the Atlantic, transporting warm surface water northwards and cold deep-water southwards as part of the global ocean circulation system. The AMOC influences global ocean heat content and transportation, global anthropogenic carbon uptake, climate sensitivity and sea level change. The AMOC regulates precipitation patterns and moisture transports and can also cause shifts in the ITCZ, Hadley Cell and the Northern Hemisphere westerly jet [2]. In addition, it plays an important role in the energy flux between the top of the atmosphere and the Earth's surface.

The Mediterranean, already a distressed region due to climate change and with a worrying future [3], is at high risk and, thus, needs better future projections to adapt and become resilient to the projected conditions. The AMOC is a widely known driver of global and regional climate, but in order to make proper predictions of how the Mediterranean climate will evolve, a good understanding of all processes that shape the region's climate must be gained. In this study, we investigate how the variability of the AMOC can affect Mediterranean climate features.

2. Data and Methods

For the subsequent analysis regarding the Mediterranean climate, we used ECMWF ERA5 reanalysis monthly datasets provided by the Copernicus Climate Change Service [4]. We specifically used the sea surface temperature (SST), surface air temperature at 2 m (Tair) and total precipitation from 1959 to 2021.

There are several proxies and indicators for representing the AMOC, which can be found in [5]. Here, we used the Caesar AMOC index, which is considered a good indicator of the weakening or the strengthening of the overturning mechanism of the Atlantic. The AMOC index is given in [6] for the period from 1870 to 2016. The index is defined as the difference between the mean SST of the geographic region that is most sensitive to a reduction in the AMOC (the subpolar gyre region) and that of the whole globe. Important to note is that the mean SST does not include all twelve months of the year, but only November to May, as during summer months, a surface mixed layer emerges that is particularly vulnerable to surface forcings and hides the cold patch, i.e., the cold temperature anomaly of ocean surface water.

In order to investigate the relationship between the AMOC index and the Mediterranean climate, correlations maps were created for the three climate variables on both an annual and seasonal basis. When positive correlations are observed on the correlation maps, it means that when the subpolar gyre is cooling and the AMOC is slowing down, the respective Mediterranean variables are decreasing as well. When negative correlations are observed, given that the AMOC index is decreasing, the respective Mediterranean variable is increasing. On all maps, grid points with a p-value lower than 0.05 or the points with the best statistical significance are annotated with a dot.

For all data analyses, graphs, and statistical computations, R software (version R-4.2.2) was used.

3. Results

By calculating the correlations between the AMOC index and the Mediterranean climate, we aimed to recognize possible relationships between the two. Specifically, here, we present the resulting correlation maps for the Caesar AMOC index (that refers to the subpolar gyre) and the Mediterranean SST, Tair and total precipitation only on an annual basis.

Regarding SST (Figure 1), statistically significant positive correlations were found between the AMOC and the central and eastern Mediterranean regions, mostly for the same year (zero lag), but lasting up to two years later, with correlation coefficients reaching 0.5.

The correlations between the annual mean surface air temperature values and the AMOC index are presented in Figure 2. The strongest correlations are found within the first year, again, similar to the SST, with positive correlations in the eastern Mediterranean and zero to slightly negative in the western Mediterranean, indicating that the AMOC slowing down leads to cooling of the eastern Mediterranean surface air.

Lastly, we investigated the relationship of the AMOC with the total precipitation observed in the Mediterranean region (Figure 3). Strong positive correlations are found at a three-year lag. This time, the positive correlations are not restricted to the east, but extend to the west, as well, covering most of the Mediterranean region. Positive correlations mean dry conditions as the total precipitation decreases along with the decrease in the AMOC index.

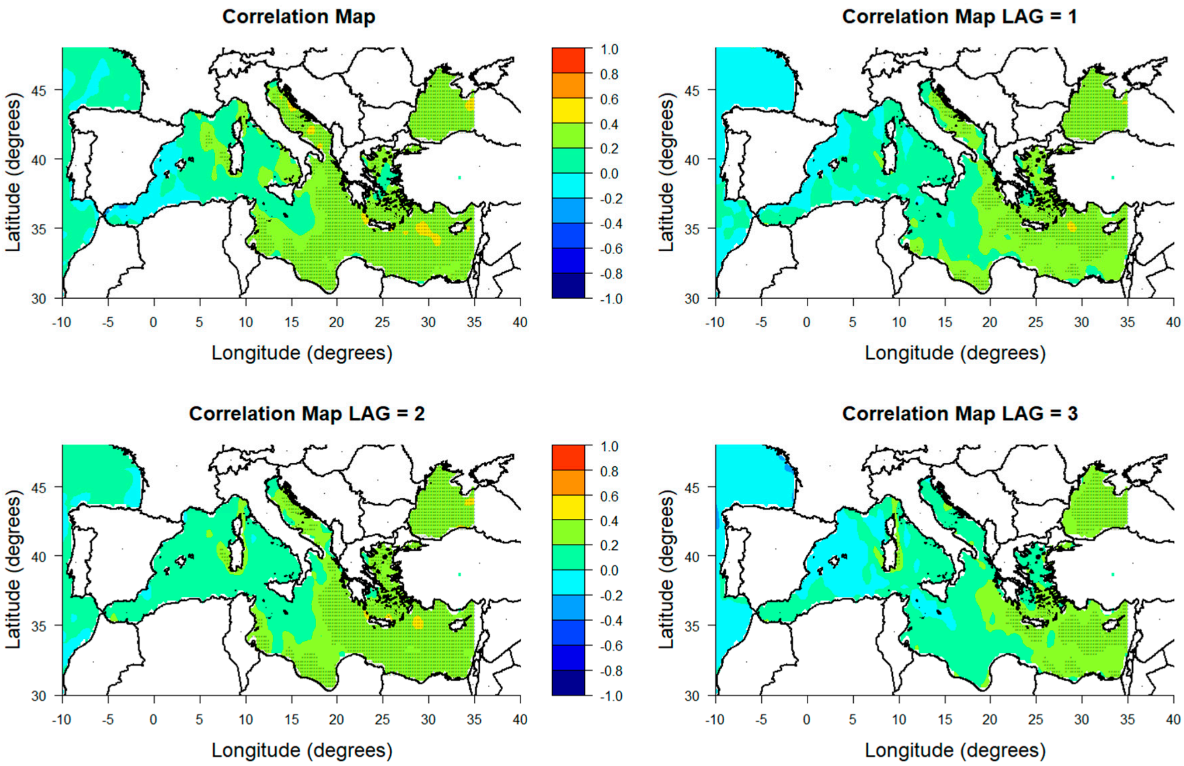

Figure 1. Correlation of AMOC index and Mediterranean mean annual SST with lag of up to 3 years. Shaded areas indicate statistically significant correlation (a = 0.05).

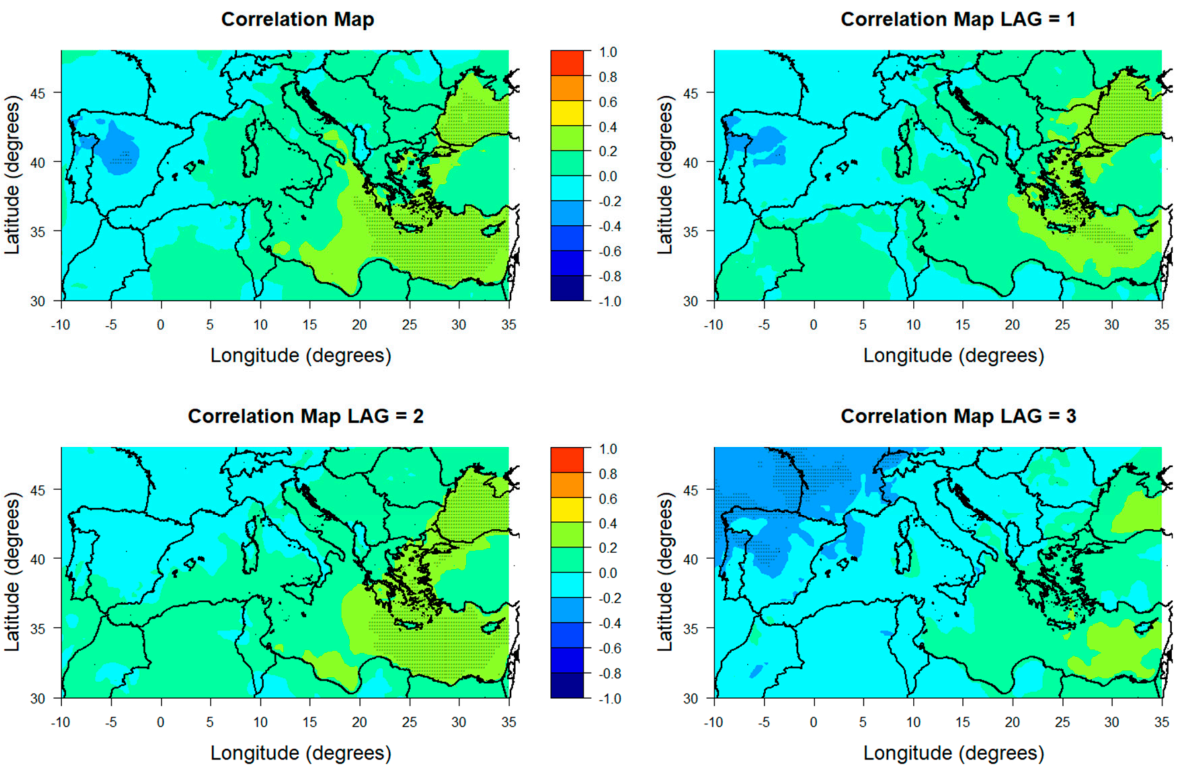

Figure 2. As in Figure 1 but for the Mediterranean mean annual surface air temperature. Shaded areas indicate statistically significant correlation (a = 0.05).

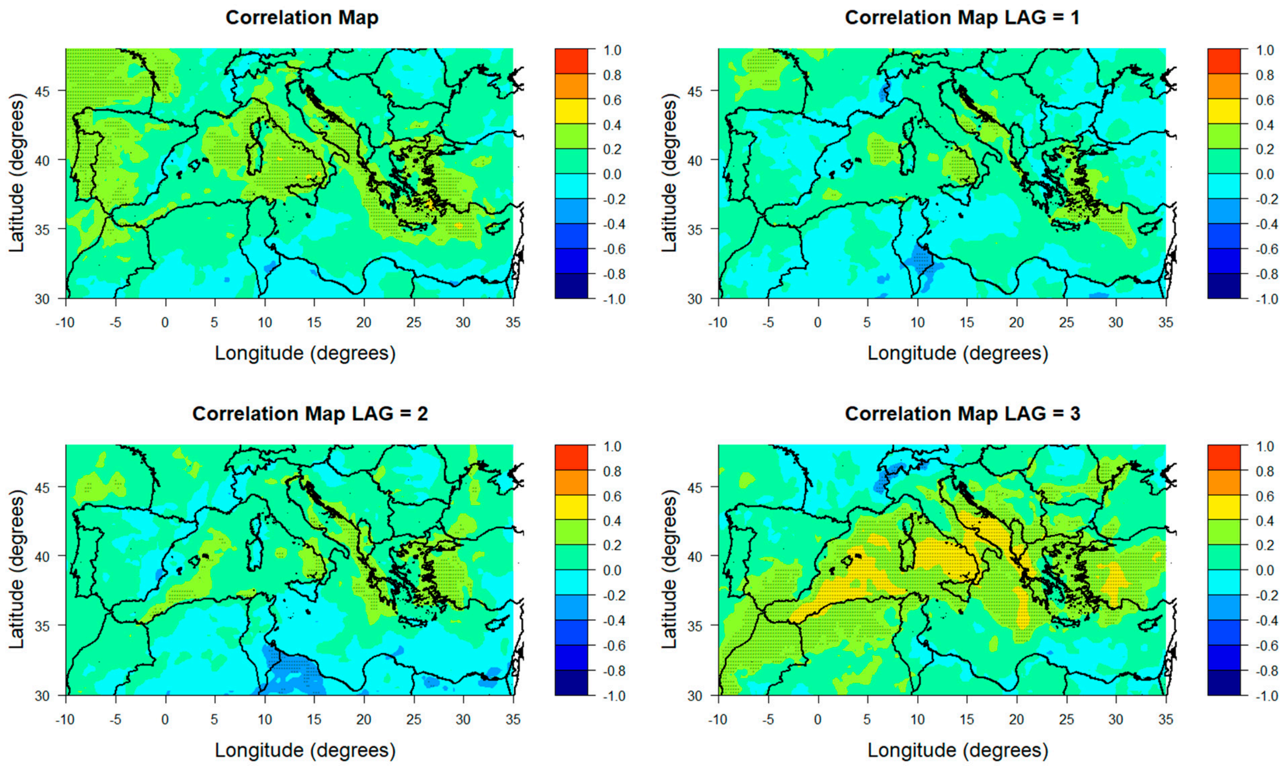

Figure 3. As in Figure 1 but for the Mediterranean annual total precipitation. Shaded areas indicate statistically significant correlation (a = 0.05).

4. Conclusions

We found that there is indeed a connection between the subpolar gyre behavior and the Mediterranean climate. Specifically, we noted that a cooling of the subpolar gyre (connected with a slowing down of the AMOC) leads to cooling of the central and eastern Mediterranean air and sea. This is apparent up to 2 years later and causes drier conditions for the entire Mediterranean even 3 years later.

Further analysis is needed as the Mediterranean responds to multiple atmospheric/oceanic systems and to a complicated morphology. Nonetheless, the results suggest the possibility of predicting the occurrence of significantly extreme climate periods in the Mediterranean several months in advance.

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