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Seasonal Correlation Between the Atlantic Multiple Oscillation (AMO) and Mediterranean Temperature

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ABSTRACT

Numerous studies on the surface of the planet have focused on the role that oceans play in the increase in temperatures brought on by climatic changes. This study has primarily emphasized the long-term warming of the Atlantic Ocean and how it affects the seasonal temperature changes of the Mediterranean Sea as a whole as well as its constituent western, central, and eastern areas. In the fall and summer, a substantial positive connection of roughly (Pearson correlation r= 0.69) and (r=0.65), respectively, between the entire Mediterranean Sea and the AMO is evident, but this correlation declines in the spring and winter.

Positive correlation increases in the western portion of the Mediterranean and diminishes in some areas as we move closer to the eastern Mediterranean; it reaches a maximum of (r=0.61) to (r=0.57) in the fall and summer seasons, respectively, and declines in the spring and winter. According to the findings, there is a noticeable increase in water temperature in the fall and summer, particularly in the western Mediterranean, which is influenced by AMO.

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الارتباط الموسمي بين التذبذب الأطلسي المتعدد (AMO) ودرجة حرارة البحر الأبيض المتوسط

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ملخص: ركزت العديد من الدراسات التي أجريت على سطح الأرض على الدور الذي تلعبه المحيطات في زيادة درجات الحرارة الناجمة عن التغيرات المناخية. ركزت هذه الدراسة في المقام الأول على ارتفاع درجة حرارة المحيط الأطلسي على المدى الطويل وكيفية تأثيره على التغيرات الموسمية في درجات الحرارة للبحر الأبيض المتوسط ككل وكذلك المناطق الغربية والوسطى والشرقية المكونة له. في الخريف والصيف، هناك علاقة إيجابية كبيرة تقريبًا (ارتباط بيرسون 0.69 = r) و (0.65 = r)، على التوالي، بين البحر الأبيض المتوسط بأكمله و AMO، لكن هذا الارتباط يتناقص في الربيع والشتاء. يزداد الارتباط الإيجابي في الجزء الغربي من البحر الأبيض المتوسط ويتضاءل في بعض المناطق مع اقترابنا من شرق البحر الأبيض المتوسط. ويصل حدها الأقصى (r=0.61) إلى (r=0.57) في فصلي الخريف والصيف على التوالي، وينخفض في فصلي الربيع والشتاء. ووفقا للنتائج، هناك ارتفاع ملحوظ في درجة حرارة المياه في الخريف والصيف، وخاصة في غرب البحر الأبيض المتوسط، والذي يتأثر بـ AMO.

1. Introduction

The Mediterranean climate, which is found on the west side of continents between approximately 30° and 40° latitude, is characterized by moderate, wet winters and warm to hot, dry summers [1]. Temperatures in the Mediterranean region have risen more quickly than the average global rate in recent decades [2]. Due to its great susceptibility to the negative effects of climate change and its high intensity of drought events, the Eastern Mediterranean is one of the world's most significant climate change hotspots [3, 4, 5]. Future scenarios show the significant and increasing threats that the basin will face in the ensuing decades as a result of the atmosphere's quick change [6]. The studies indicate a 0.3–4.8 C° increase in global average surface temperature up to 2100, and not only the terrestrial ecosystem but also the aquatic ecosystem have been strongly influenced by climate change since the beginning of the industrial era [7]. Sea surface temperature (SST) is an essential climate variable that plays a significant role in energy, momentum, humidity, and gas exchanges between the ocean and the atmosphere, all of which are essential for controlling the climate [8]. According to the IPCC report, the Earth has experienced considerable warming, especially at higher latitudes [9]. The majority of research on climate has focused on employing atmosphere-ocean general circulation models to simulate the climate system using basic physical, chemical, and biological processes [10]. Anomalies large-scale temperature changes over the North Atlantic are convoluted with global climate change induced by an increase in greenhouse gases [11]. Indeed, the combined effects of anthropogenic climate change and the positive phase of the AMO since 1990 may have caused more rapid warming in the North Atlantic than would be expected from climate change alone [12, 13].

The Atlantic Multidecadal Oscillation (AMO), which affects North Atlantic Sea surface temperatures for the period 1856–1999, has a 65–80-year cycle with a 0.4 C° range. AMO warm phases occurred during 1860–1880 and 1940–1960, and cool phases occurred during 1905–1925 and 1970–1990 [14]. An investigation of temperature anomalies associated with weather patterns during the previous 60 years shows that the frequency distributions of the seasonal weather patterns have changed as a result of the AMO-driven climatic variability in Europe and the Mediterranean over the past 140 years [15].

1.1. Climatological analysis of Mediterranean temperatures

By using NOAA data to examine the average temperature in the Mediterranean for each of the four seasons from 1948 to 2022 (taking into consideration the reference period from 1961-1990), it can be seen that the Mediterranean region tends to suffer an increase in temperature, much like the rest of the world. In the winter, it can be seen in figure (1, a) that the rise in the west reaches 0.25 C°, while it only reaches 0.06 C° in the middle Mediterranean and roughly -0.21 C° in the east. As shown in figure (1, b), it is noticeable that the temperature value in the west is around 0.247 C° during the spring, while it is 0.07 C° in the center and -0.17 C° in the east. As illustrated by figure (1, c), the substantial increase in temperature during the summer is around 0.37 C° in the west, 0.26 C° in the middle, and 0.135 C° in the east. Autumn is depicted in Figure (1, d), with values of approximately 0.35 C° to the west, 0.24 C° to the middle, and -0.04 C° to the east. The overall average for this time period reveals that the western Mediterranean is seeing a rise starting in its east through figure (1, e).

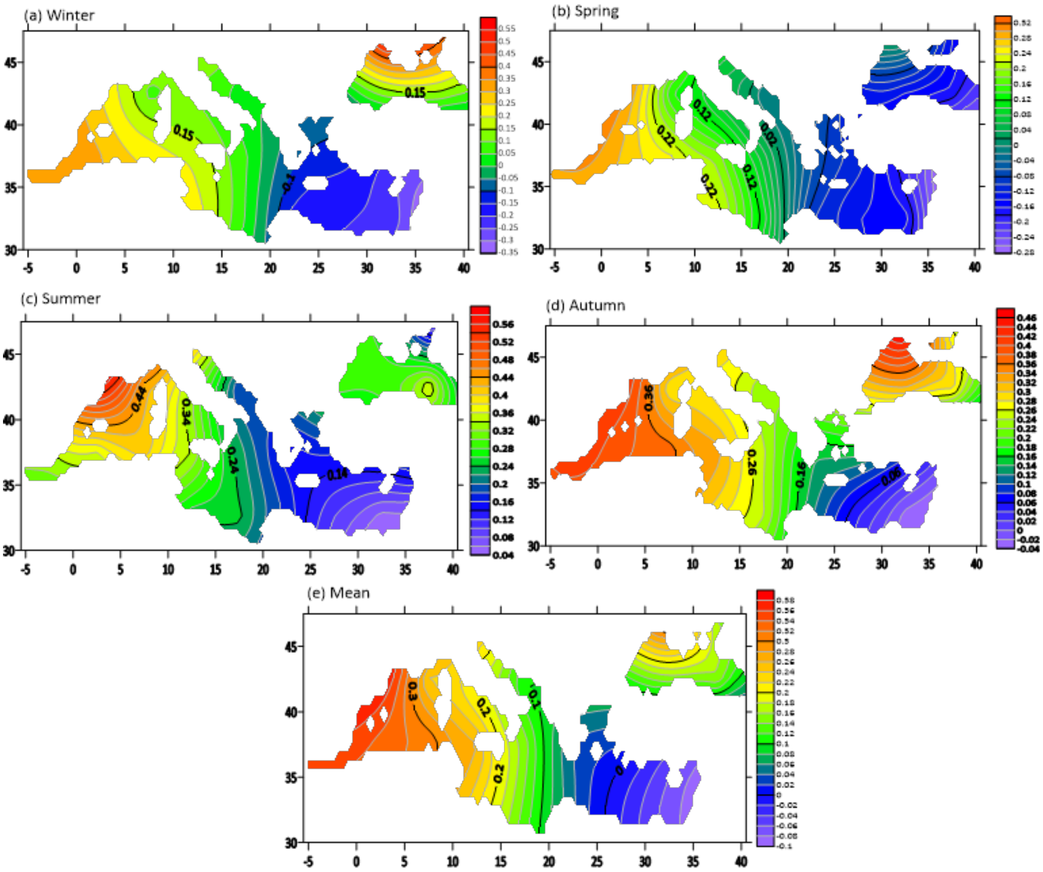

Figure 1: Mean temperatures (C°) over the Mediterranean during the four seasons for the period 1948–2022.

1.2. Research problem

1. The phenomenon of the Atlantic Ocean's long-term warming as a result of climate change and its impact on the Mediterranean Sea's temperature are the main topics of discussion.
2. In the fall, there is a strong correlation between the Atlantic Ocean's heating and an increase in the temperature of the entire Mediterranean Sea, but particularly in its western portion.

1.3. Study objectives

Discusses how the Mediterranean temperature gradient is influenced by the Atlantic Multiple Oscillation (AMO) at the seasonal, regional, and global levels.

2. Materials and Methods

2.1. Study Area

In this study, the entire ocean was examined, with the three Mediterranean zones of west (- 6 W^{o}- 11 E^{o}), center (11–25 E^{o}), and east (25–38 E^{o}). AMO (0-60 N^{o}, 0-80 W^{o}), as shown in Figure 2.

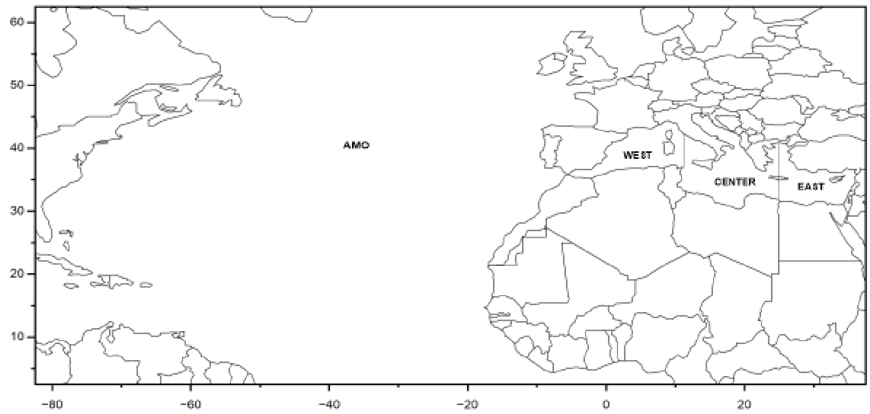

Figure 2: The study area includes the Mediterranean Sea in its three distinct parts and the Atlantic Multiple Oscillation.

2.2. Data and Methods

Climatological data on temperature (C°) over the Mediterranean and the Atlantic Multiple Oscillation were gathered from the National Oceanic and Atmospheric Administration (NOAA) between 1948 and 2022 [16]. The correlation between the entire ocean, specific regions of the Mediterranean Sea, and the Atlantic Multiple Oscillation (AMO) was then calculated using the Pearson correlation coefficient formula:

$$r = \frac{\sum\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\sum\left(x_i - \bar{x}\right)^2 \left(y_i - \bar{y}\right)^2}} \quad \text{...........(1)}$$

Where values of the x-variable in the data set (AMO), and values of the y-variable in the data set (Temperature of Mediterranean (°C)). The marginal distribution was used to determine the marginal probability density function for both the Atlantic multiple oscillations (X) and the temperatures of the Mediterranean (Y) through the following formulas: The marginal probability density function:

$$f(x,y), \qquad \{a \le x \le b, c \le y \le d\}, \qquad \int_a^b \int_c^d f(x,y)\,dy\,dx \qquad \text{.......(2)}$$

$$Where \qquad \{a \le x \le b\}, \qquad \int_a^b f_X(x)\,dx \qquad \text{...........(3)}$$

$$\{c \le y \le d\}, \qquad \int_c^d f_Y(y)\,dy \qquad \text{...........(4)}$$

The probability density function of X, denoted by $f_X(x)$, is called the marginal probability density

function of X, and the probability density function of Y, denoted by $f_Y(y)$, is called the marginal probability density function of Y [17].
We have the following:

$$f_X(x) = \sum_y f_{X,Y}(x,y) \qquad \text{...............(5)}$$

$$f_Y(y) = \sum_x f_{X,Y}(x,y) \qquad \text{...............(6)}$$

For an ongoing condition:

$$f_X(x) = \int_{-\infty}^{\infty} f_{X,Y}(x,y)dy \qquad \text{............(7)}$$

$$f_Y(y) = \int_{-\infty}^{\infty} f_{X,Y}(x,y)dx \qquad \text{............(8)}$$

3. Rusults and Discussion

By analyzing the time series in figure (3) for the Atlantic multiple oscillation (AMO) and temperature anomalies for the whole Mediterranean Sea and the parts (West, Central, and East) during the four seasons, it was discovered that there was a heating period from 1948 to 1965, a gradual cooling from 1970 to 1995, and then an increase in heating until 2022.
A positive link was found when the Atlantic multiple oscillation and Mediterranean Sea temperatures were compared, and this association is significant throughout the sea as a whole. It is apparent in the summer and fall when it hits 0.65 and 0.69, respectively, while it is at its lowest during the winter when it reaches 0.55 and around 0.46 in the spring.
The high link towards the west is seen when dividing the sea into west, center, and east during the four seasons, particularly in the fall up to 0.61 and in the summer approximately 0.57, while in the spring and winter about 0.57 and 0.42, respectively. Autumn and summer in the central Mediterranean have correlation values of 0.57 and 0.55, respectively, while spring and winter have correlation values of 0.22 and 0.3.

Table 1: Pearson correlation between the anomalous Mediterranean Sea temperature and the Atlantic Multiple Oscillation during the period 1948–2022 (74 years).

Autumn AMO	**Pearson Correlations**	**Summer AMO**	**Pearson Correlations**
Autumn sea	0.69	Summer sea	0.65
Autumn west	0.61	Summer west	0.571
Autumn center	0.57	Summer center	0.55
Autumn east	0.51	Summer east	0.59
Spring AMO	**Pearson Correlations**	**Winter AMO**	**Pearson Correlations**
Spring sea	0.46	Winter sea	0.55
Spring west	0.57	Winter west	0.42
Spring center	0.22	Winter center	0.3
Spring east	0.25	Winter east	0.43

According to Table 1 and the correlation matrix in Figure 4, it reaches 0.59 in the east Mediterranean in the summer, 0.51 in the fall, and 0.25 and 0.43, respectively, in the spring and winter.
In this article, it is clear that the Atlantic Multiple Oscillations (AMO) are responsible for climatic changes that are related to the shifting Mediterranean climate, especially in the fall when the AMO's induced warming causes the hurricane season [18].

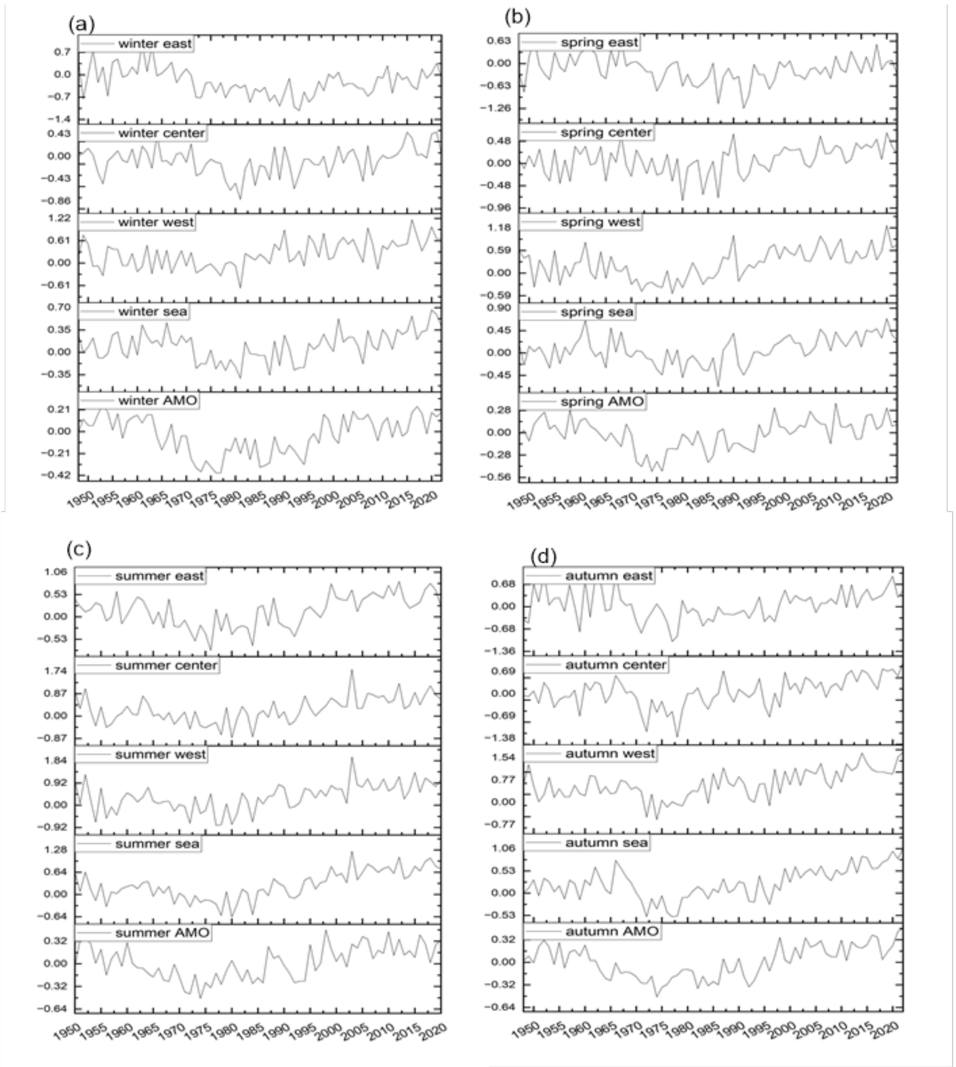

Figure 3: Time series of the total average anomalous temperature of the Mediterranean Sea and of the (west-central-east) and Atlantic Multiple Oscillation (AMO) for the four seasons from 1948 to 2022 (74 years).

Figure 5 shows the marginal distributions between the Atlantic Multiple Oscillation (AMO) and the mean anomalous temperatures of the Mediterranean Sea for the four seasons during the period 1948–2022. On both sides of the figure it shows the normal distribution of the sea and AMO temperatures. It could be noticed that in the fall and summer seasons the curves are spread over depending on their location (east-centre-west) to each other, and are strongly distributed with AMO, while in the winter and spring seasons the curves are spaced apart according to their location (east-centre-west).

Figure 4: The correlation matrix between the anomalous temperatures of the Mediterranean Sea in whole and of the parts (west, central, and east) and the Atlantic Multiple Oscillation (AMO) for the four seasons during the period 1948–2022 (74 years).

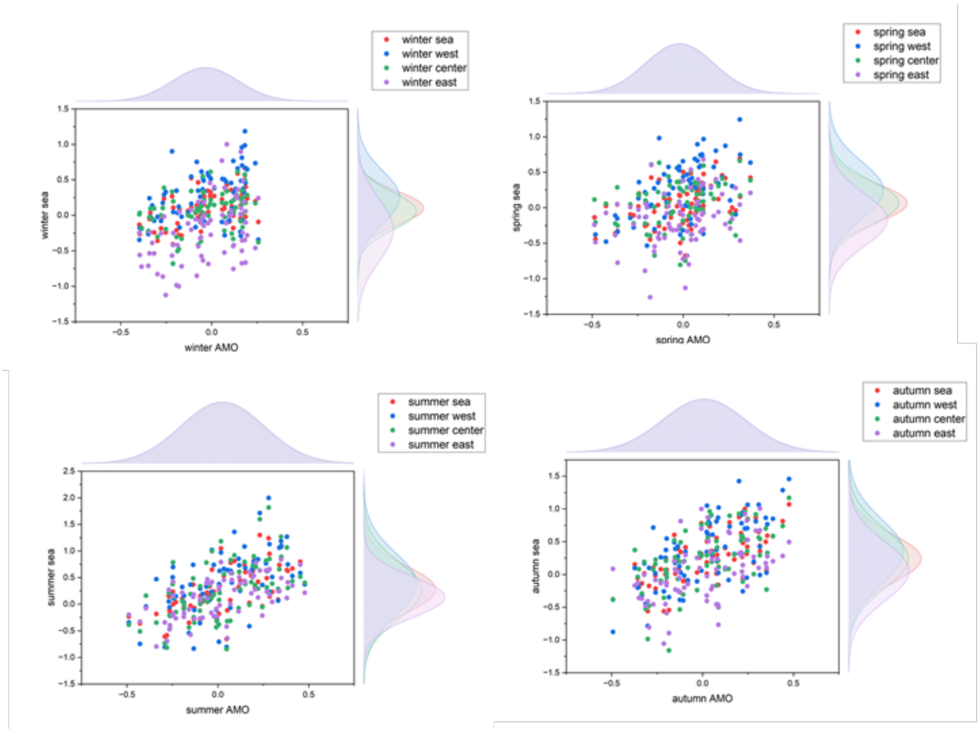

Figure 5: The marginal distributions are shown between the Atlantic Multiple Oscillation and the mean anomalous temperatures of the Mediterranean Sea for the four seasons during the period 1948–2022.

Also, the west curve in all seasons indicate heating and the east curve in all seasons indicate cooling. So, the relationship between AMO and Mediterranean temperatures is most pronounced in the autumn and summer. Recently it has been suggested that anthropogenic aerosols are a prime driver of the AMO using climate model simulations incorporating aerosol indirect effects [19].

4. Conclusion

According to earlier studies, the Atlantic Multiple Oscillation (AMO) has a wide range of consequences, including how the temperature gradient over Libya changes during its hot and cold phases [20]. This study makes the AMO impact on the Mediterranean Sea evident by demonstrating the general positive association in both the whole sea and its constituent portions (west, center, and east). The western Mediterranean is distinguished from the rest of its middle and east by the strongest correlation, especially in the fall until 0.61. The positive correlation is stronger in the summer and autumn with amounts of 0.65 and 0.69, respectively, while it reaches 0.55 and 0.46 for the entire sea in the winter and spring. In addition, when determining the marginal probability density function, the effect was evident in summer and autumn, especially in the western Mediterranean Sea, more than in the central and eastern Mediterranean Seas. This demonstrates that the western Mediterranean has a higher temperature than the central and eastern Mediterranean due to the influence of AMO. Thus, we came to the conclusion that AMO is one of the factors contributing to global climate change, which impacts the average climate of the central Mediterranean.

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Data Availability Statement: "The climatic data used in this research paper obtained from https://psl.noaa.gov/data/gridded/ and https://psl.noaa.gov/data/timeseries/AMO. The study's supporting data and environmental metadata were obtained from freely accessible online sources via the websites of the models".

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Conflicts of Interest: "The authors affirm that they have no known financial or interpersonal conflicts that would have appeared to have an impact on the research presented in this study".

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