# The effects of Mediterranean oscillation on temperature and precipitation data in Turkey

Sezen Cenk and Partal Turgay


## ABSTRACT

Mediterranean Oscillation (MO) is one of the atmospheric teleconnections that influence climatic variables such as rainfall and temperature. The aim of this study is to determine the relationship between Mediterranean Oscillation Index (MOI) and temperature and precipitation characteristics in Turkey. First, the Pearson correlation analysis was carried out between the MOI and climate parameters. Then, the result of correlation analysis was evaluated according to Student's *t*-test. In this regard, the most significant correlations with MOI and the temperature regime were found in the winter season, whereas the most important relationship between precipitation and MOI was obtained in the summer season. Lag correlation analysis showed that winter MOI is influential on the spring temperature in northwestern Turkey and summer MOI could have an impact on the autumn precipitation. In addition, there are significant winter temperature and summer precipitation differences due to the MOI phases. Finally, the relationship between the MO and North Atlantic Oscillation (NAO) was also investigated. Accordingly, it was realized that the NAO and MO could have similar effects in the winter season particularly in the western part of Turkey. As a result, the MO could have a significant relationship to the temperature and precipitation regime of Turkey.


**Key words** | correlation, lag analysis, mediterranean oscillation, precipitation, temperature, turkey

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## INTRODUCTION

The number of studies determining the effects of global atmospheric teleconnections on hydrometeorological parameters has been increasing in recent years. There has been a lot of research in particular about the best known global atmospheric teleconnections, which are North Atlantic Oscillation (NAO) and Southern Oscillation (SO), in the different regions of the world (Halpert & Ropelewski 1992; Trigo *et al.* 2002; Franks 2004; Brönnimann 2007; Abtew *et al.* 2009; Vicente-Serrano *et al.* 2009; Ward *et al.* 2016; Wang *et al.* 2017; Partal & Sezen 2018). Rodó *et al.* (1997) pointed out that the NAO and El Niño-Southern Oscillation affect seasonal precipitation in southern Europe and in the Iberian region, in particular. López-Moreno & Vicente-Serrano (2008) researched the relationship between drought and phases of NAO across Europe. They stated that the positive phase of NAO is influential on the drought especially in the second half of the twentieth century, while the negative phase of NAO has no remarkable effect on the drought compared to the positive phase of NAO for the same period. Brandimarte *et al.* (2011) showed the connection between NAO and winter precipitation, river discharge and temperature in southern Italy and the Nile Delta. Tabari *et al.* (2014) investigated the link between NAO and streamflow in western Iran and they acquired remarkable findings as a result of the lag correlation analysis in particular. The effects of the global atmospheric teleconnections on climate conditions in Turkey have also been investigated in many studies (Kadıoğlu *et al.* 1999; Kahya & Karabörk 2001; Türkeş & Erlat 2003; Karabörk *et al.* 2005; Küçük *et al.* 2009). Türkeş & Erlat (2009) investigated

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the interaction between the NAO and winter temperature pattern in Turkey. They found significant negative correlations between the NAO and winter temperature data. There have been some studies on the other atmospheric teleconnections such as Arctic Oscillation (AO) (Gong *et al.* 2001; Türkeş & Erlat 2008; Choi & Byun 2010). All these studies indicated the remarkable influences of global atmospheric oscillations on climate variables in different parts of the world.

Mediterranean Oscillation (MO) was also shown to be an atmospheric teleconnection which can be influential in the Mediterranean basin (Dünkeloh & Jacobeit 2003). Dünkeloh & Jacobeit (2003) pointed out that the MO is related to northern teleconnections such as the AO and NAO and is particularly seasonal. They also determined seasonal canonical correlation patterns in the Mediterranean basin. They researched the link between canonical correlation patterns and NAO, AO, and MO. Besides, Dünkeloh & Jacobeit (2003) calculated significant negative correlations between MOI and W-CCP2 (one of the winter canonical correlation patterns in their study) that were found to be one of the most influential winter canonical correlation patterns on the precipitation regime in a greater part of the central and eastern Mediterranean basin. They also pointed out that when the positive mode of W-CCP2 is efficient, precipitation increases from the west/southwest within the frontal airflow stream especially in Greece and Turkey. Sušelj & Bergant (2006) remarked that NAO index and MO index have a correlation with each other. Gonzalez-Hidalgo *et al.* (2009) researched the link between NAO, MO, Western Mediterranean Oscillation (WeMO) and the monthly precipitation pattern of the Iberian Peninsula. They obtained remarkable correlations between the MO and precipitation data in certain months, such as December and March. Furthermore, Gonzalez-Hidalgo *et al.* (2009) also revealed that there is a strong relationship between NAO and MO indices. Vicente-Serrano *et al.* (2009) analyzed the relation between the phases of NAO, MO, WeMO and precipitation in the northeast of Spain. Nastos *et al.* (2011) found significant negative correlation coefficients between the MOI and winter temperature in general in Greece. They stated that this was associated with the penetration of the Mediterranean depression. They found higher correlations in western Greece than the northwestern part. Ramadan *et al.* (2012) searched for the relationship between atmospheric teleconnections and the temperature/precipitation regime of Litani Basin in Lebanon. As a result, they indicated that the MOI has significant positive correlations with winter precipitation in general in the Litani Basin. Törnros (2013) investigated the liaison between winter precipitation data and MO index in southern Levant. Within this scope, Törnros (2013) found that the MO index has positive correlations with winter precipitation. Furthermore, he also pointed out that the precipitation amount inclines to be higher when the positive MOI is influential. On the other hand, if negative MOI is efficient, precipitation has a tendency to be below average. Criado-Aldeanueva & Soto-Navarro (2013) searched for the connection between the MO indices and climate parameters such as precipitation and evaporation in the Mediterranean basin. They found negative correlations between precipitation and MO indices. Philandras *et al.* (2015) carried out some studies to calculate the correlation between atmospheric teleconnections such as MO, NAO, NCP (North Sea–Caspian Pattern) and upper air temperature in the eastern Mediterranean region.

As can be seen, there is much less work on the MO in the literature. There has not been any comprehensive study which examines the impacts of MO on climate parameters in general in Turkey. So, the aim of this study is to specify whether the MO has a relationship with the temperature and precipitation regime in seven regions of Turkey. Within this framework, Pearson correlation coefficients were calculated between the MO index and climatic variables (mean temperature and precipitation totals) as annual and seasonal. In this regard, either the MOI introduced by Conte *et al.* (1989) or the MOI as defined by Palutikof (2003) was used. The results of correlation analysis were assessed according to the Student's *t*-test at the significance levels of $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.1$. After then, lag correlation analysis was utilized so as to observe the impacts of the seasonal MO index in other seasons. Finally, seasonal mean temperature and seasonal mean precipitation total differences that are based on the phases of MO indices were calculated. The significance of precipitation difference was evaluated according to the *t*-test.

## DATA AND METHODOLOGY

### Data

In this study, the mean temperature and precipitation total data were provided by the Turkish State Meteorological Service. The data belong to 84 stations which are located in seven regions of Turkey as indicated in Figure 1. By and large, the mean temperature and precipitation total data cover the period of 1960–2014, although data loss exists in some stations. Statistical data for the temperature and precipitation which belong to 84 stations are presented in Table 1. In this regard, the annual winter (December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November) mean temperature and mean precipitation data are illustrated in Table 1. According to Table 1, the mean winter temperature is especially high in the Aegean (7.0 °C) and Mediterranean (8.7 °C) regions as compared with the other regions. This is related to the characteristics of the Mediterranean climate which is influential on the greater part of the Aegean and Mediterranean regions. On the other hand, the winter temperature values are low in central Anatolia (0.5 °C) and eastern Anatolia (−3.7 °C) where the terrestrial climate is influential. In addition, in other seasons, high temperatures in the Mediterranean, Aegean, and southeastern Anatolia regions are remarkable compared to the other parts of the country. As to the mean precipitation totals, it can be shown that the amount of precipitation is high in the Mediterranean (361.7 mm) and Aegean (336.1 mm) regions in the winter season according to Table 1. Annually, the Black Sea (788.1 mm) region in general is the rainiest in Turkey. In other seasons, precipitation patterns exhibit changeable characteristics which mainly depend on the geographical formations and climate characteristics of the region.

MOI data which cover the period of 1960–2014 were acquired from the Climatic Research Unit of the University of East Anglia (Mediterranean Oscillation Index (MOI) 2017).

### Method

Initially, correlation analysis was performed. If a significant relation exists between the variables, it could be understood from the high correlations between them (Bayazıt & Yeğen Oğuz 2005). Accordingly, Pearson

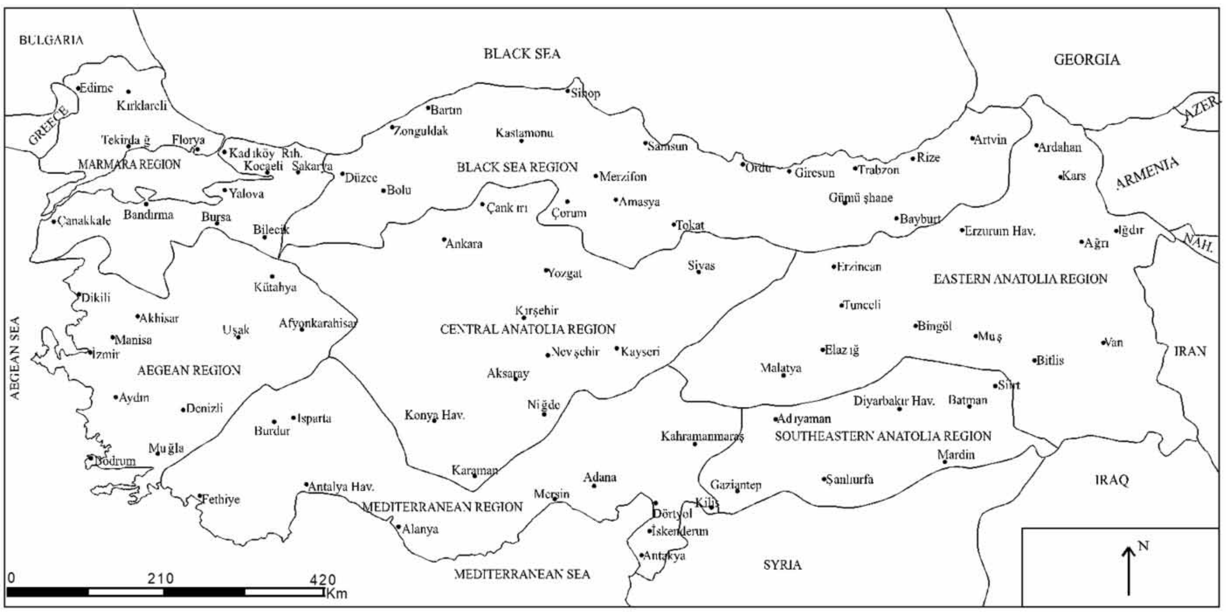



**Figure 1** | Stations throughout Turkey.

**Table 1** | Seasonal and annual mean temperature and total precipitation for the regions of Turkey

| | Mean temperature (°C) | | | | | Mean precipitation totals (mm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Regions** | **Winter** | **Spring** | **Summer** | **Autumn** | **Annual** | **Winter** | **Spring** | **Summer** | **Autumn** | **Annual** |
| Marmara | 5.9 | 12.5 | 23.0 | 15.3 | 14.2 | 238.3 | 153.9 | 85.9 | 181.6 | 660.0 |
| Aegean | 7.0 | 14.2 | 25.2 | 16.6 | 15.8 | 336.1 | 160.2 | 31.4 | 143.8 | 671.6 |
| Mediterranean | 8.7 | 16.0 | 26.3 | 19.1 | 17.6 | 361.7 | 195.3 | 35.6 | 170.9 | 763.5 |
| Central Anatolia | 0.5 | 10.3 | 21.3 | 11.8 | 11.0 | 127.2 | 140.6 | 48.5 | 81.0 | 371.1 |
| Black Sea | 4.0 | 11.0 | 21.0 | 13.7 | 12.5 | 223.5 | 178.9 | 149.4 | 233.0 | 788.1 |
| Eastern Anatolia | −3.7 | 8.6 | 21.9 | 12.2 | 9.6 | 175.2 | 206.9 | 65.9 | 124.8 | 572.8 |
| Southeastern Anatolia | 4.6 | 14.5 | 28.9 | 17.9 | 16.5 | 270.0 | 194.2 | 8.6 | 105.0 | 577.5 |
| **TURKEY** | **3.9** | **12.4** | **23.9** | **15.2** | **13.9** | **247.4** | **175.7** | **60.8** | **148.6** | **629.2** |

correlation coefficients were calculated between MOI and the temperature/precipitation data as annual and seasonal, as indicated in Equation (1).

$$r_{x,y} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{N s_x s_y} \tag{1}$$

In Equation (1), $x_i$ is the seasonal and annual climate parameter (mean temperature and precipitation totals) which belong to the $i$th year, $\bar{x}$ is the mean of climate parameter, $y_i$ is the seasonal and annual MOI, $\bar{y}$ is the mean of MOI, $N$ is the number of data, $s_x$ and $s_y$ are the standard deviations for climatic data and MOI, respectively. The results of correlation analysis were then assessed in accordance with the Student's $t$-test at the significance levels of $\alpha = 0.01$, $\alpha = 0.05$, and $\alpha = 0.1$, respectively. The boundary intervals of the correlation coefficients were calculated using Student $t$ distribution. In relation to that, data length and significance levels were taken into consideration. For example, boundary intervals of correlation coefficients are $r \geq |0.34|$ for $\alpha = 0.01$, $|0.27| \leq r < |0.34|$ for $\alpha = 0.05$, $|0.22| \leq r < |0.27|$ for $\alpha = 0.1$ for the period of 1960–2014.

Secondly, to find out whether a significant relationship between seasonal MO indices and the temperature and precipitation data of other seasons is available, lag correlation analysis was utilized. Accordingly, the correlations between a seasonal MOI and following seasons (e.g. the correlation between winter MOI and spring (lag 1), summer (lag 2), autumn (lag 3) temperature/precipitation data) were calculated.

After the calculation of correlation coefficients, in order to understand winter temperature change depending on the MOI, temperature values were standardized as shown in Equation (2).

$$\mathrm{ST} = (\mathrm{T} - \bar{\mathrm{T}})/\sigma \tag{2}$$

In Equation (2), $ST$ stands for the standardized temperature, $T$ for the winter temperature, $\bar{T}$ for the mean of the winter temperature, and $\sigma$ for the standard deviation of the winter temperature.

Finally, the temperature and precipitation differences that arise from the phases of MOI were determined. Furthermore, the significance of precipitation differences was assessed by taking into account the $t$ test (Bayazıt 1996). It is supposed that $a$ is the cluster of precipitation values, which have an $n$ element, under the effect of extreme MOI and $b$ is the cluster of precipitation values, which have an $m$ element ($m \geq n$), of non-extreme MOI. If $\mathrm{Var}(a) = \mathrm{Var}(b) = s^2$ ($s$ refers the standard deviation) is assumed, $t$ statistics are calculated as shown in Equation (3a)

$$t = \frac{\bar{a} - \bar{b}}{s\sqrt{\frac{1}{n} + \frac{1}{m}}} \tag{3a}$$

Sampling distribution of $t$ statistics in Equation (3a) has a degree of freedom $n + m$–2. In Equation (3a), $s$ is calculated as indicated in Equation (3b)

$$s = \sqrt{\frac{(n-1)s_a^2 + (m-1)s_b^2}{n+m-2}} \tag{3b}$$

If $\mathrm{Var}(a) \neq \mathrm{Var}(b)$, the Equation (4a) is utilized. The degree of freedom is calculated as illustrated in Equation (4b). In Equations (3b), (4a) and (4b), $s_a$ and $s_b$ refer to the standard deviations of $a$ and $b$, respectively,

$$t = \frac{\bar{a} - \bar{b}}{\sqrt{\frac{s_a^2}{n} + \frac{s_b^2}{m}}} \tag{4a}$$

$$\left(\frac{s_a^2}{n} + \frac{s_b^2}{m}\right)^2 \Big/ \left[\frac{(s_a^2/n)^2}{n-1} + \frac{(s_b^2/m)^2}{m-1}\right] \tag{4b}$$

After the calculation of $t$ statistics according to the equations above, the results were evaluated at the significance level of $\alpha = 0.01$, $\alpha = 0.05$ and $\alpha = 0.1$.

### Mediterranean oscillation

MO was introduced as the surface level pressure (SLP) anomalies between the regions of Algiers and Cairo by Conte *et al.* (1989) and Palutikof *et al.* (1996). Later, Palutikof (2003) described the MO by calculating the SLP between the regions of Gibraltar and Lod (Israel). This study benefitted from both MOI data so as to indicate the linkage between MO index and climate variables in Turkey. Hereafter, MOI data which is calculated between Algiers and Cairo will be shown as $\mathrm{MOI}_{AC}$ and MOI data that is calculated between Gibraltar and Lod will be noted as $\mathrm{MOI}_{GL}$. In order to observe the impacts of MOI on climatic variables, it was assumed that if $\mathrm{MOI} \leq -0.5$ that means the negative phase of MOI (MOI (-)) and if $\mathrm{MOI} \geq 0.5$ that means the positive phase of MOI (MOI (+)). The most important reason for preferring these intervals is the MOI data characteristics. In other words, it is thought that the number of data for $\mathrm{MOI} \leq -0.5$ or $\mathrm{MOI} \geq 0.5$ is enough to draw a conclusion for evaluating the temperature differences in the winter season and the precipitation differences in the summer season. Similar evaluations were also adopted to examine the effects of atmospheric teleconnection phases such as NCP (Kutiel & Benaroch 2002; Kutiel *et al.* 2002).

## RESULTS AND DISCUSSION

### Correlation analysis between MO and temperature and precipitation data

In this section, the correlation analysis between MO index and temperature/precipitation data was evaluated as annual and seasonal. In this context, the number of stations where temperature and precipitation data are correlated with $\mathrm{MOI}_{GL}$, $\mathrm{MOI}_{AC}$ at the significance level of $\alpha = 0.1$ are indicated in Table 2. As is seen in Table 2, with 4 stations as annual, 56 stations in the winter season, 12 stations in the spring season, 6 stations in the summer season and 6 stations in the autumn season, the mean temperature has a correlation with $\mathrm{MOI}_{GL}$. It can be understood from this outcome that $\mathrm{MOI}_{GL}$ is influential on the winter temperature as compared with other seasons for the greater part of Turkey. In the spring season, temperature in most stations of eastern Anatolia is negatively correlated with the $\mathrm{MOI}_{GL}$ mostly at the significance level of $\alpha = 0.1$. In the summer and autumn seasons, no significant correlations were observed between the $\mathrm{MOI}_{GL}$ and regional temperature data.

When Figure 2 is taken into consideration, the significant influence of $\mathrm{MOI}_{GL}$ on the winter temperature can be realized in some regions. The correlation coefficients are significant at $\alpha = 0.01$ and $\alpha = 0.05$. In particular, in the majority of stations in the Aegean region, winter temperature is negatively correlated with the $\mathrm{MOI}_{GL}$ at $\alpha = 0.01$. On the other hand, only eastern parts of Marmara region have a connection with the $\mathrm{MOI}_{GL}$ at the significance level of $\alpha = 0.05$. It is also notable that in general stations in Central Anatolia have remarkable correlations with $\mathrm{MOI}_{GL}$ in the winter season. Besides, as is seen in Figure 2, stations in the northeastern part of Turkey (Rize, Artvin, and Ardahan) are significantly correlated with the $\mathrm{MOI}_{GL}$. The winter temperature in the rest of the stations mostly has a correlation with the $\mathrm{MOI}_{GL}$ at the significance level of

**Table 2** | Number of stations according to correlation between $MOI_{GL}$ and $MOI_{AC}$ climate variables (mean temperature and precipitation totals) at significance level $\alpha = 0.1$

| | | Mean temperature (°C) | | | | | Precipitation totals (mm) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Regions | Annual | Winter | Spring | Summer | Autumn | Annual | Winter | Spring | Summer | Autumn |
| $MOI_{GL}$ | Marmara | 0 | 4 | 0 | 0 | 0 | 2 | 0 | 0 | 11 | 3 |
| | Aegean | 0 | 12 | 0 | 2 | 1 | 0 | 0 | 1 | 5 | 1 |
| | Mediterranean | 0 | 9 | 1 | 3 | 1 | 2 | 0 | 1 | 5 | 1 |
| | Central Anatolia | 0 | 11 | 0 | 0 | 1 | 4 | 2 | 0 | 8 | 8 |
| | Black Sea | 1 | 10 | 1 | 0 | 0 | 5 | 0 | 2 | 10 | 6 |
| | Eastern Anatolia | 3 | 7 | 7 | 0 | 2 | 1 | 1 | 3 | 5 | 3 |
| | Southeastern Anatolia | 0 | 3 | 3 | 1 | 1 | 0 | 1 | 1 | 5 | 5 |
| $MOI_{AC}$ | Marmara | 0 | 11 | 10 | 0 | 7 | 5 | 5 | 0 | 11 | 2 |
| | Aegean | 2 | 12 | 9 | 3 | 9 | 0 | 8 | 1 | 6 | 0 |
| | Mediterranean | 6 | 11 | 8 | 6 | 5 | 2 | 2 | 1 | 5 | 0 |
| | Central Anatolia | 10 | 11 | 9 | 1 | 9 | 3 | 2 | 0 | 11 | 0 |
| | Black Sea | 5 | 18 | 15 | 0 | 9 | 4 | 2 | 2 | 11 | 2 |
| | Eastern Anatolia | 10 | 13 | 10 | 3 | 3 | 0 | 1 | 1 | 5 | 0 |
| | Southeastern Anatolia | 0 | 7 | 7 | 5 | 2 | 0 | 0 | 1 | 4 | 0 |

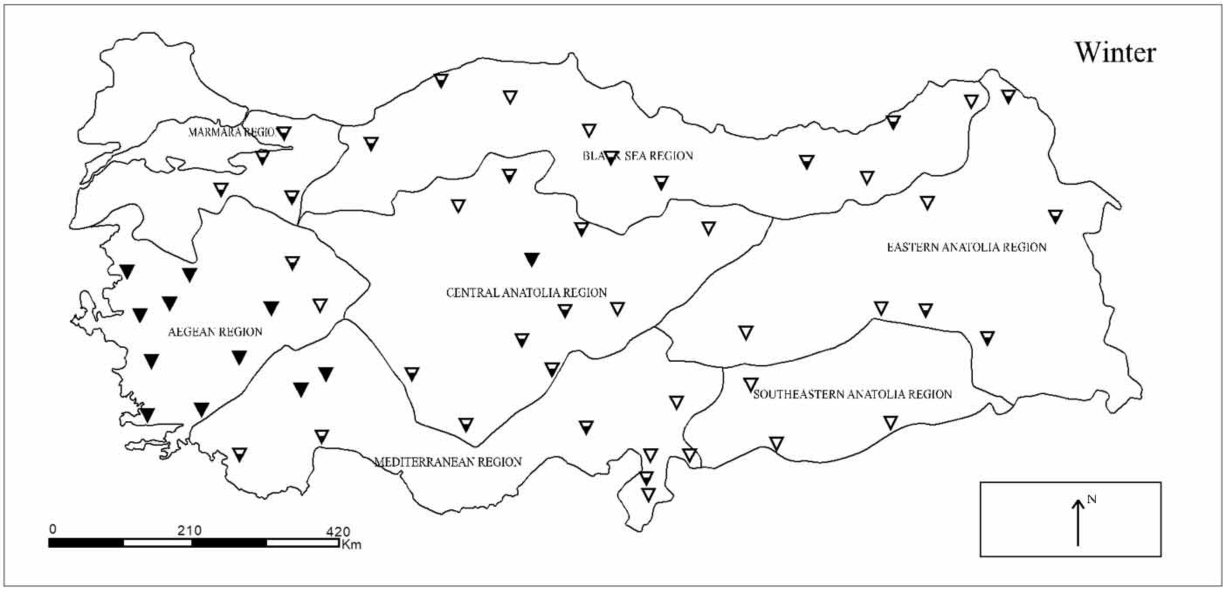



**Figure 2** | Correlation between $MOI_{GL}$ and winter mean temperature. Filled upside down triangle, upside down triangle and half-filled upside down triangle represent the negative correlation coefficients at significance levels of $\alpha = 0.01$, 0.05 and 0.1, respectively. If the correlations are not significant at these levels, they are not illustrated on the figure.

$\alpha = 0.1$. In this regard, these significant correlations between the winter temperature and $MOI_{GL}$ demonstrate that the winter temperature has an increasing tendency when $MOI_{GL}$ decreases, in general. When Table 2 is taken into consideration, it is understood that the liaison between $MOI_{AC}$ and temperature data is stronger than the relation of $MOI_{GL}$ with the temperature data. In this regard, it is seen that the correlations between $MOI_{AC}$ and temperature data are very remarkable in the winter, spring, and autumn seasons as well as annual. Even in the summer season there are some correlations, especially in the southern part of Turkey. Furthermore, the effects of $MOI_{AC}$ on the temperature pattern of Turkey can be realized in Figure 3. According to Figure 3, correlations between temperature data and $MOI_{AC}$ are negative and significant at $\alpha = 0.01$ in the winter season in general across Turkey, while in the spring

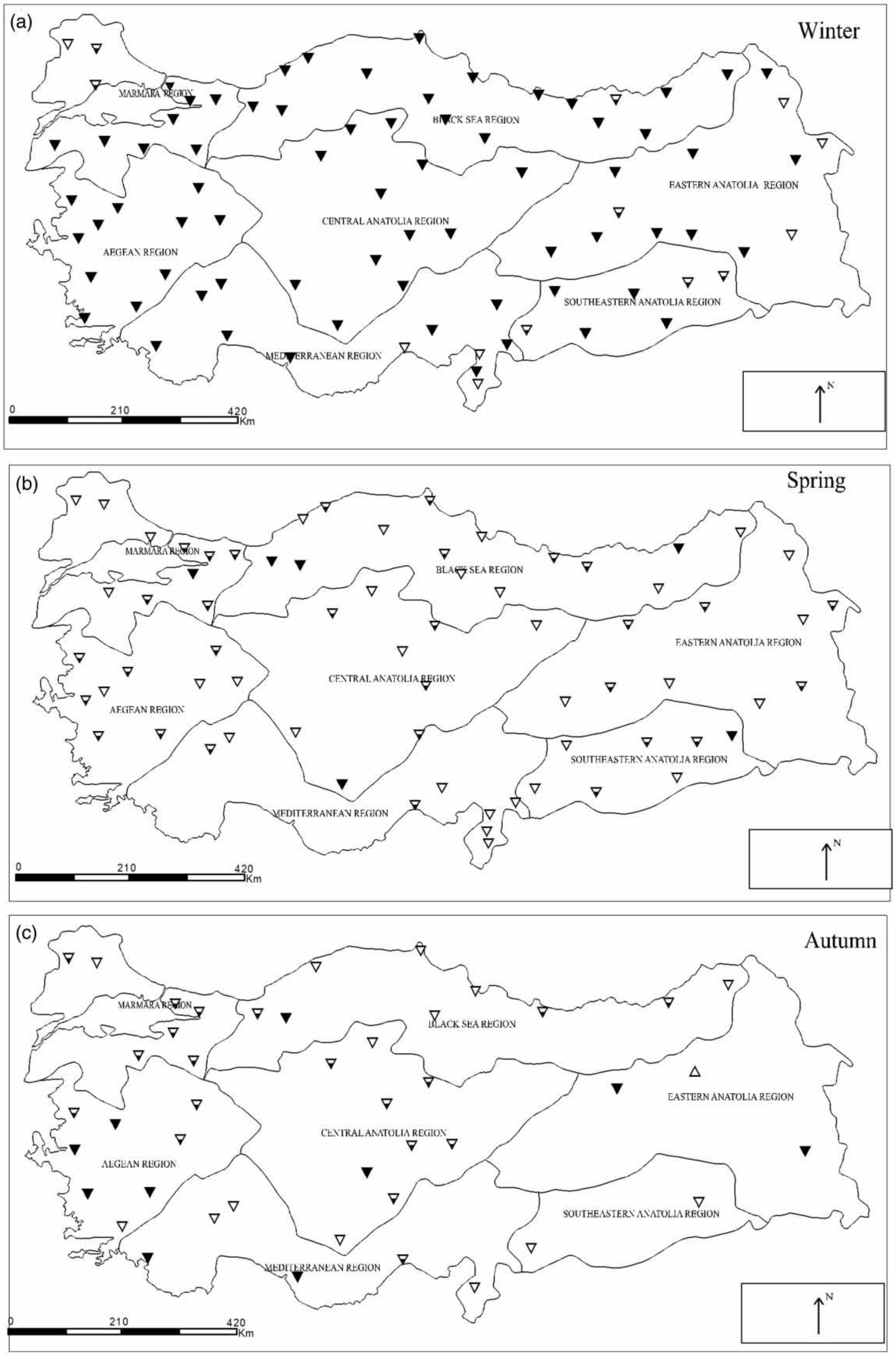



**Figure 3** | Correlation between $MOI_{AC}$ and (a) winter, (b) spring, (c) autumn mean temperature. Filled upside down triangle, upside down triangle and half-filled upside down triangle represent the negative correlation coefficients at significance levels of $\alpha = 0.01$, 0.05 and 0.1, respectively. If the correlations are not significant at these levels, they are not illustrated on the figure.

period most of the correlations seem negative and significant at $\alpha = 0.1$. On the other hand, significant negative correlations were acquired in the central and western part of Turkey during the autumn season, in particular. As to the correlations between the $MOI_{AC}$ and annual mean, the correlations are mostly negatively significant at $\alpha = 0.05$ or $\alpha = 0.1$, except for the western regions, the coasts of the Black Sea and Mediterranean regions as indicated in Figure 4. The negative correlations correspond so that once $MOI_{AC}$ rises, temperature values are inclined to decrease. In this regard, correlations between the MOI and winter temperature data especially for the western part of Turkey coincide with the findings of the study which was carried out by Nastos *et al.* (2011). This is a remarkable finding for the winter temperature regime of the Eastern Mediterranean basin.

In an attempt to observe the link between winter temperature and $MOI_{GL}$, $MOI_{AC}$, the graphs which indicate the winter temperature change according to $MOI_{GL}$ and $MOI_{AC}$ were prepared for eight stations (İzmir, Dikili, Kütahya, Burdur, Muğla, Çankırı, Kırşehir, Muş) as shown in Figures 5 and 6. In Figures 5 and 6, winter temperature values were standardized. When Figure 5 is taken into account, it can be seen that for the lowest value of $MOI_{GL}$ (−1.02) in 2010, high-temperature values were measured in most of the stations. For example, when $MOI_{GL} = -1.02$, the temperatures at the eight stations are: 12 °C at İzmir, 10.8 °C at Dikili, 5.2 °C at Kütahya, 6.1 °C at Burdur, 7.9 °C at Muğla, 1.6 °C at Çankırı, 4.5 °C at Kırşehir, and 1.2 °C at Muş. The temperatures in these stations are quite high compared with their winter temperature mean. Besides, the adverse relationship between $MOI_{GL}$ and winter temperature comes into focus in Figure 5. This referred to the negative correlation between $MOI_{GL}$ and winter temperature. In addition, similar results were also obtained for the relationship between winter temperature and $MOI_{AC}$. For the lowest value of $MOI_{AC}$, maximum winter temperatures were seen in most of the stations which are shown in Figure 6. Likewise, the negative relation between $MOI_{AC}$ with the winter temperature pattern can be observed from Figure 6.

As for the relation between MO index and precipitation data, 14 stations as annual, 4 stations in the winter period, 8 stations in the spring period, 49 stations in the summer period, and 27 stations in the autumn period are correlated with $MOI_{GL}$ at the significance level of $\alpha = 0.1$ as is seen in Table 2. Accordingly, it can be pointed out that $MOI_{GL}$ is influential on the summer and autumn precipitation, in particular. As to the linkage

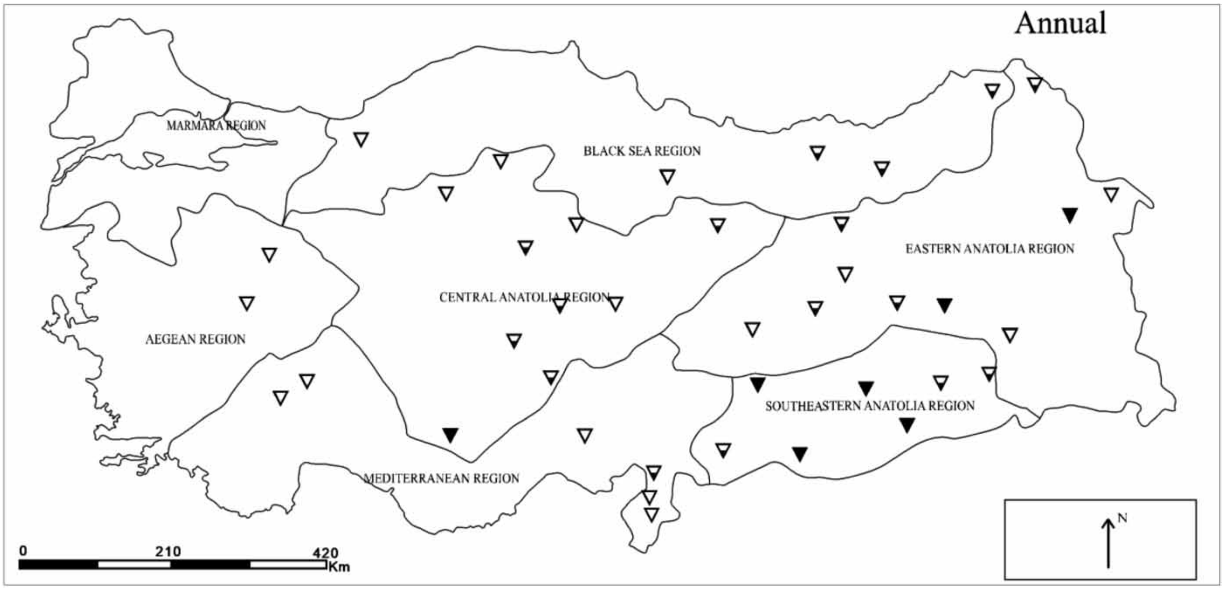



**Figure 4** | Correlation between $MOI_{AC}$ and Annual Mean Temperature. Filled upside down triangle, upside down triangle and half-filled upside down triangle represent the negative correlation coefficients at significance level of $\alpha = 0.01$, 0.05 and 0.1, respectively. If correlations are not significant at these levels, they are not illustrated on the figure.

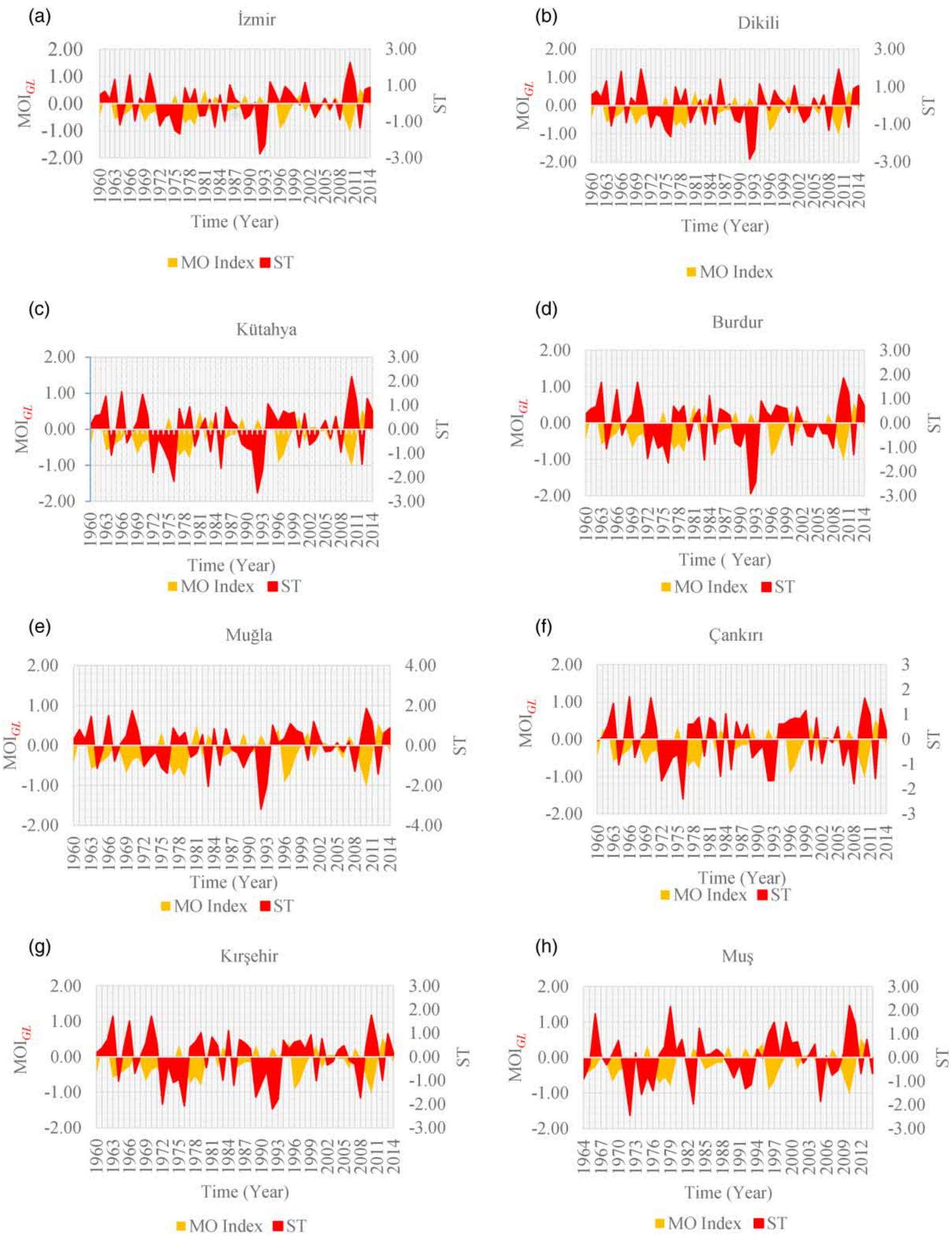



**Figure 5** | Relationship between $MOI_{GL}$ and temperature in winter season for (a) İzmir, (b) Dikili, (c) Kütahya, (d) Burdur, (e) Muğla, (f) Çankırı, (g) Kırşehir, (h) Muş stations.

between $MOI_{AC}$ and the precipitation regime of Turkey, the most significant correlations were acquired in the summer period. Furthermore, there are also some remarkable correlations between the winter precipitation and $MOI_{AC}$ particularly in the western regions of Turkey as seen in Table 2.

As indicated in Figure 7, the summer precipitation of most stations in the Marmara region has a strong negative

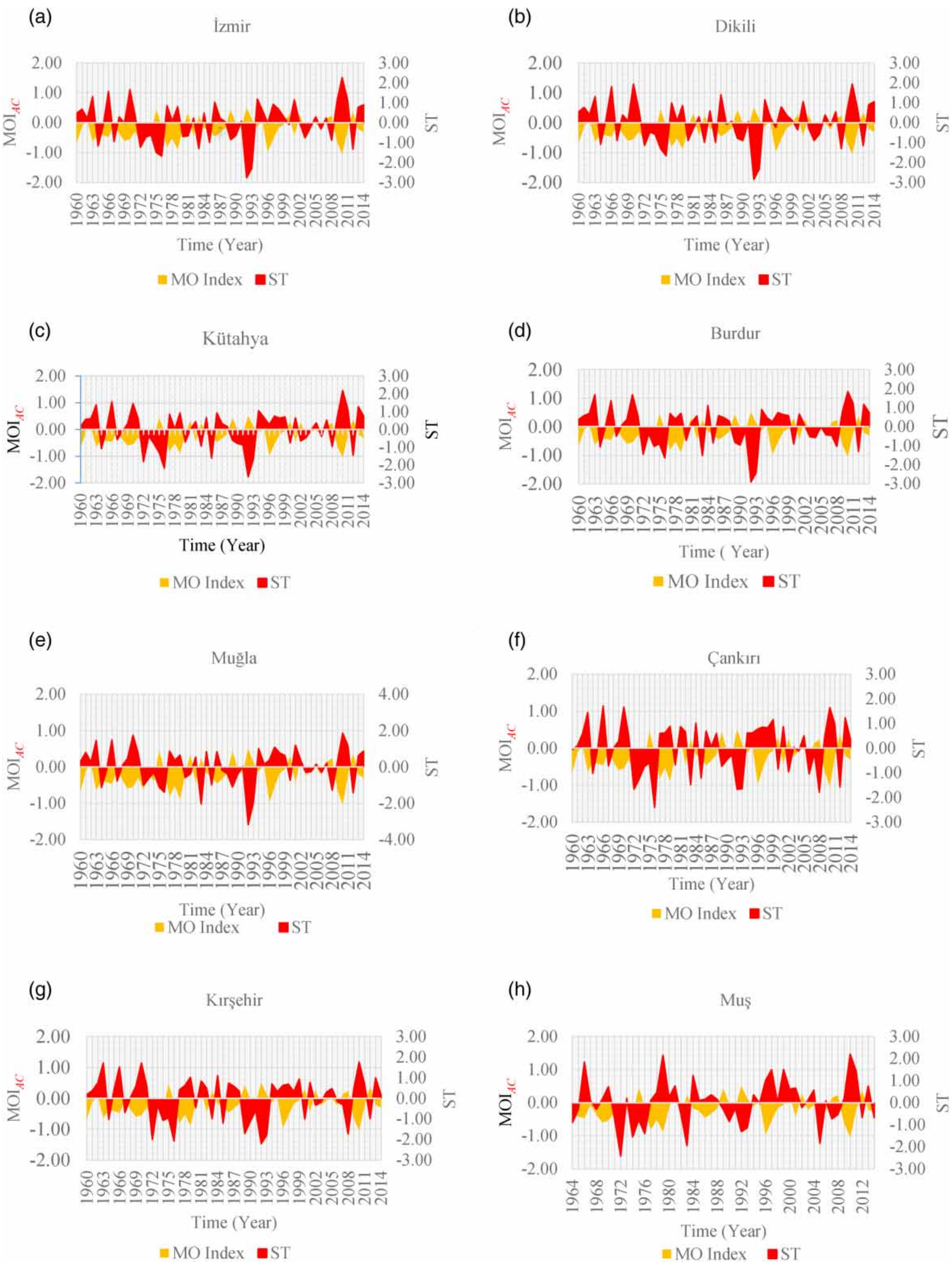



**Figure 6** | Relationship between $MOI_{AC}$ and temperature in winter season for (a) İzmir, (b) Dikili, (c) Kütahya, (d) Burdur, (e) Muğla, (f) Çankırı, (g) Kırşehir, (h) Muş stations.

correlation with the $MOI_{GL}$ at the significance level of $\alpha = 0.01$. Furthermore, in the internal parts of the Black Sea and a greater part of central Anatolia, summer precipitation has a correlation with $MOI_{GL}$ at $\alpha = 0.01$ and $\alpha = 0.05$. Besides, significant correlation coefficients were also obtained in some parts of eastern Anatolia and southeastern Anatolia. With regard to the effect of $MOI_{GL}$ on the autumn precipitation, it can be stated that the autumn precipitation regime of central Anatolia and $MOI_{GL}$ have a correlation at the significance level of $\alpha = 0.05$ and $\alpha = 0.1$ as shown

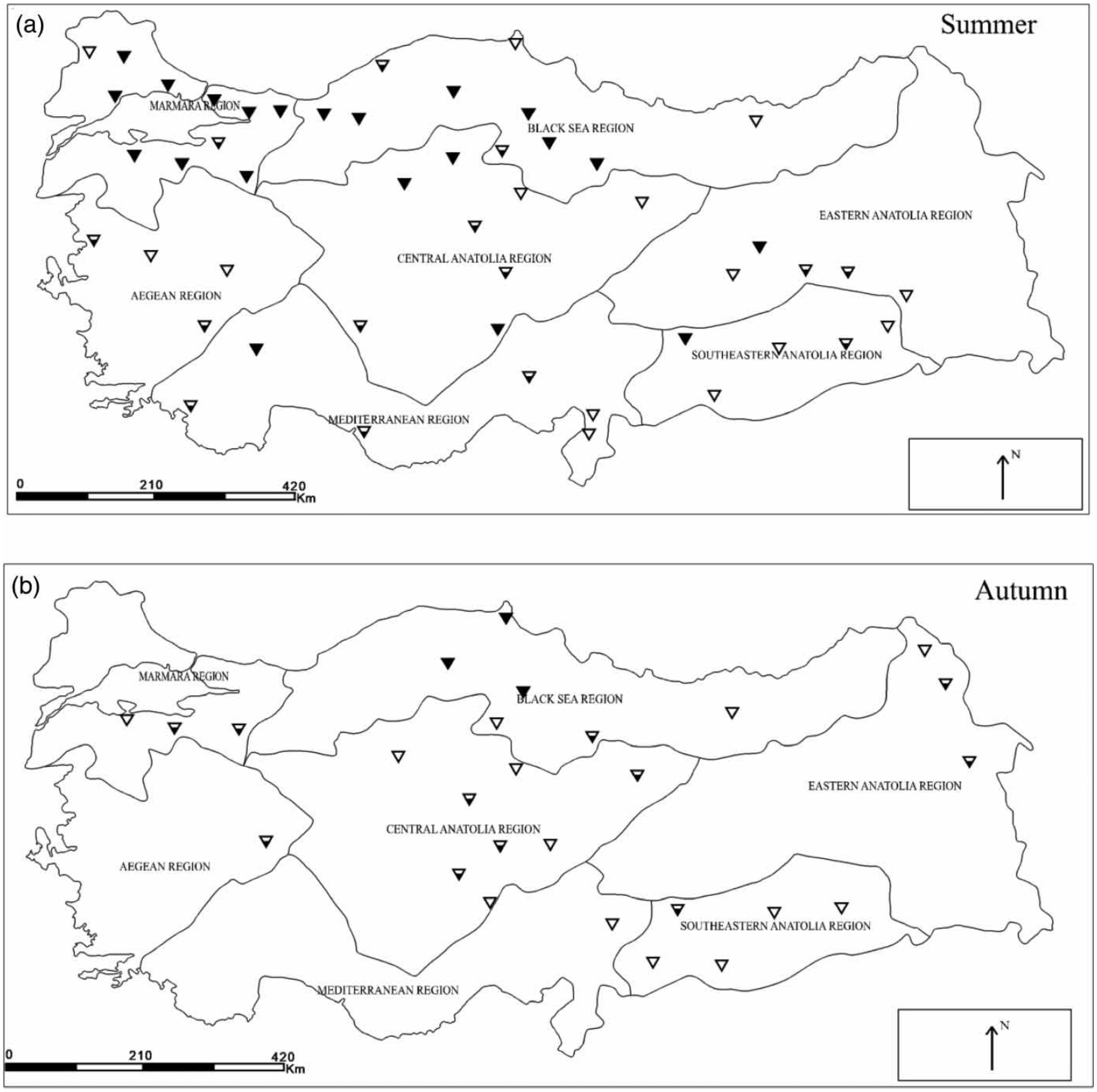



**Figure 7** | Correlation between $MOI_{GL}$ and (a) summer, and (b) autumn precipitation. Filled upside down triangle, upside down triangle and half-filled upside down triangle represent the negative correlation coefficients at significance level of $\alpha = 0.01$, 0.05 and 0.1, respectively. If the correlations are not significant at these levels, they are not illustrated.

in Figure 7. The correlations between $MOI_{GL}$ and autumn precipitation are also significant at the level of $\alpha = 0.1$ in southeastern Anatolia region particularly.

In Figure 8, the correlations between precipitation data and $MOI_{AC}$ were illustrated for the winter and summer seasons. Accordingly, it could be seen that winter precipitation and $MOI_{AC}$ have a significant link to western and northwestern Turkey especially. The findings for the relationship between winter precipitation data and $MO_{AC}$ is compatible with the results of previous studies (Dünkeloh & Jacobeit 2003; Criado-Aldeanueva & Soto-Navarro 2013). In this regard, the correlation results, which point out the rise in precipitation amount when $MOI_{AC}$ decreases, is consistent with the findings of Dünkeloh & Jacobeit (2003) particularly for the western part of Turkey. Likewise, Criado-Aldeanueva & Soto-Navaro (2013) also found that $MOI_{AC}$ is negatively

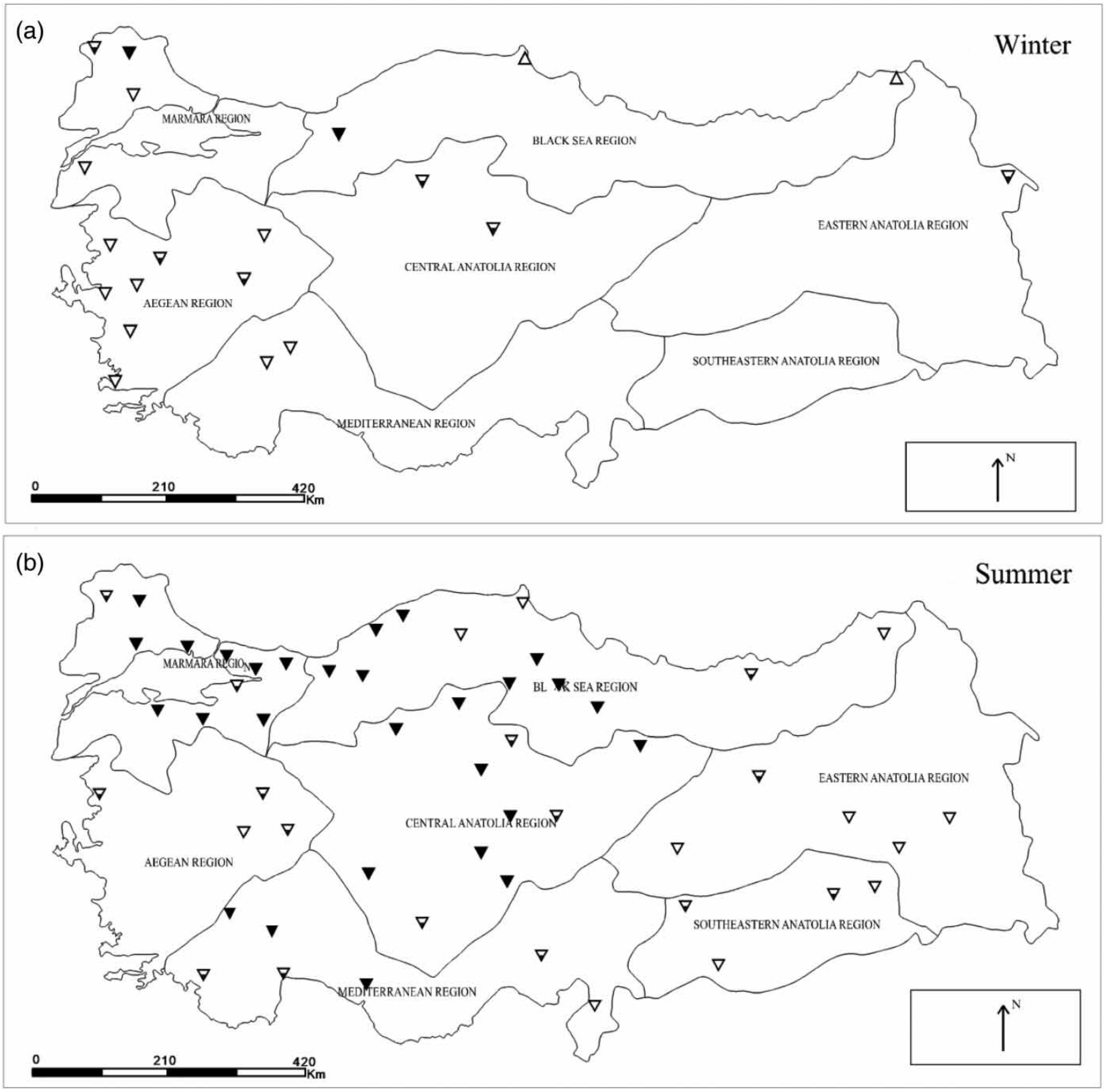



**Figure 8** | Correlation between $MOI_{AC}$ and (a) winter, (b) summer precipitation. Filled upside down triangle, upside down triangle and half-filled upside down triangle represent the negative correlation coefficients at significance level of $\alpha = 0.01$, 0.05 and 0.1, respectively. If the correlations are not significant at these levels, they are not illustrated.

correlated with precipitation data in the majority of the Mediterranean basin during the winter season. Some positive correlations were also observed in some parts of northern coastal Turkey. This may relate to the geographical characteristics of the region or local effects. As for the summer period, it can be understood that the relationship between $MOI_{AC}$ and summer precipitation is very strong in northwestern and northern central Anatolia, in particular. The relationship between $MOI_{AC}$ and summer precipitation is also important for the other parts of Turkey except for northeastern parts, although precipitation characteristics exhibit different patterns from region to region. It can also be noted that $MOI_{AC}$ and $MOI_{GL}$ have similarities with respect to their relation to the precipitation pattern in the summer period. So, the negative correlations between MO indices and precipitation show that the amount of the precipitation could tend to be lower as MOI strengthens. This is a very interesting result since some previous studies put forward that convective and orographic precipitations are dominant during the summer season in Turkey or most of the Mediterranean basin (Türkeş & Erlat 2003; Criado-Aldeanueva & Soto-Navarro 2013). Dünkeloh & Jacobeit (2003) expressed that S-CCP1 (one of the summer canonical correlation patterns in their study) has a link with intense summer precipitation, particularly in the northern Mediterranean. They emphasized that a positive mode of S-CCP1 leads to deviant rainfall patterns in the northern part of the central Mediterranean and northeastern Mediterranean, while negative mode causes drier conditions. In this regard, this pattern could be influential on a wide area from the western Mediterranean to the Black Sea region through the effect of the Mediterranean cyclone path (Alpert *et al.* 1990; Trigo *et al.* 1999; Dünkeloh & Jacobeit 2003). They calculated significant negative correlations between S-CCP1 and either $MOI_{GL}$ or $MOI_{AC}$.

### Lag correlation analysis with regards to temperature and precipitation

In order to observe the relationship between MO indices and temperature/precipitation data in successive seasons, lag correlations were analyzed. In this regard, it was found that the winter $MOI_{GL}$ and spring temperature data (Lag-1) have remarkable positive correlations as seen in Figure 9. In particular, the spring temperature of most stations correlates with winter $MOI_{GL}$ positively at $\alpha = 0.05$ in Marmara region. The spring temperature data of some stations of the north Aegean and coastal Black Sea has a link with winter $MOI_{GL}$ at $\alpha = 0.05$ or $\alpha = 0.1$. After then, the lag analysis was also utilized between seasonal $MOI_{AC}$ and the temperature data. Similarly, the most significant link was found between winter $MOI_{AC}$ and the spring temperature data (Lag-1). As illustrated in Figure 10, remarkable positive correlations were calculated between $MOI_{AC}$ and spring temperature in northwestern Turkey. Within this framework, the significant positive correlations reveal that when the winter MO indices rise, the spring temperature tends to be higher, particularly in the northwestern part of the country.

When the lag analysis was applied for the precipitation, it was found that summer $MOI_{GL}$ could be influential on the autumn precipitation (Lag-1) in the greater part of Turkey. According to Figure 11, summer $MOI_{GL}$ does not have a significant relation with the autumn precipitation in the western parts of Turkey. However, it has remarkable negative correlations with the autumn precipitation in the

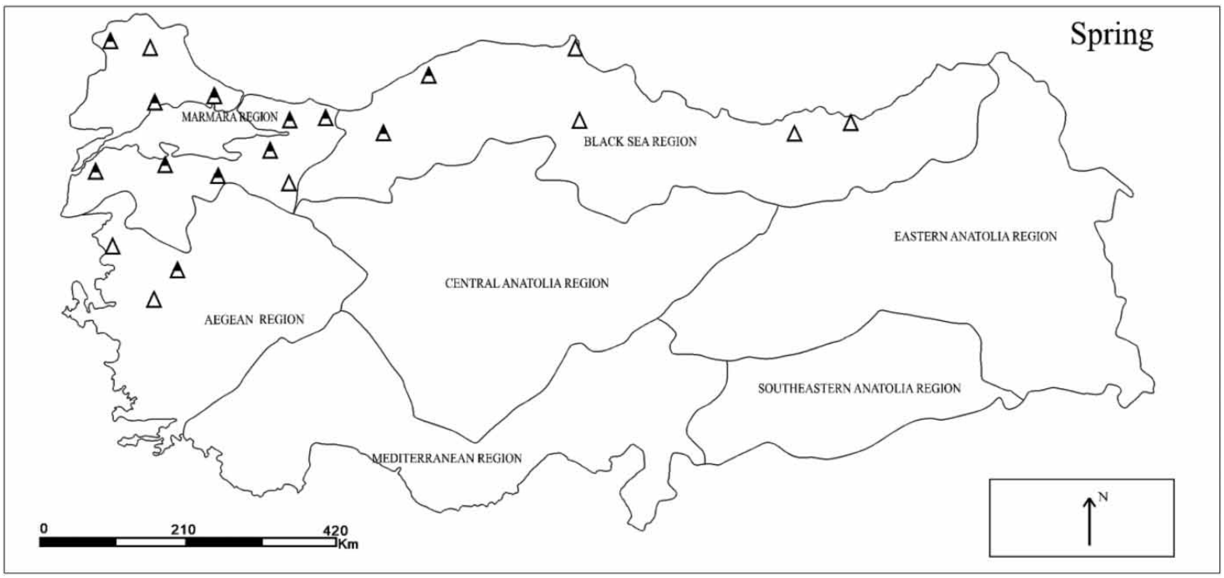



**Figure 9** | Lag correlation analysis between winter $MOI_{GL}$ and spring temperature (Lag-1). Half-filled triangle represents positive correlation coefficients at significance level of $\alpha = 0.05$; hollow triangle represents positive correlation coefficients at significance level of $\alpha = 0.1$. If the correlations are not significant at $\alpha = 0.01$, 0.05 or 0.1 levels, they are not illustrated.

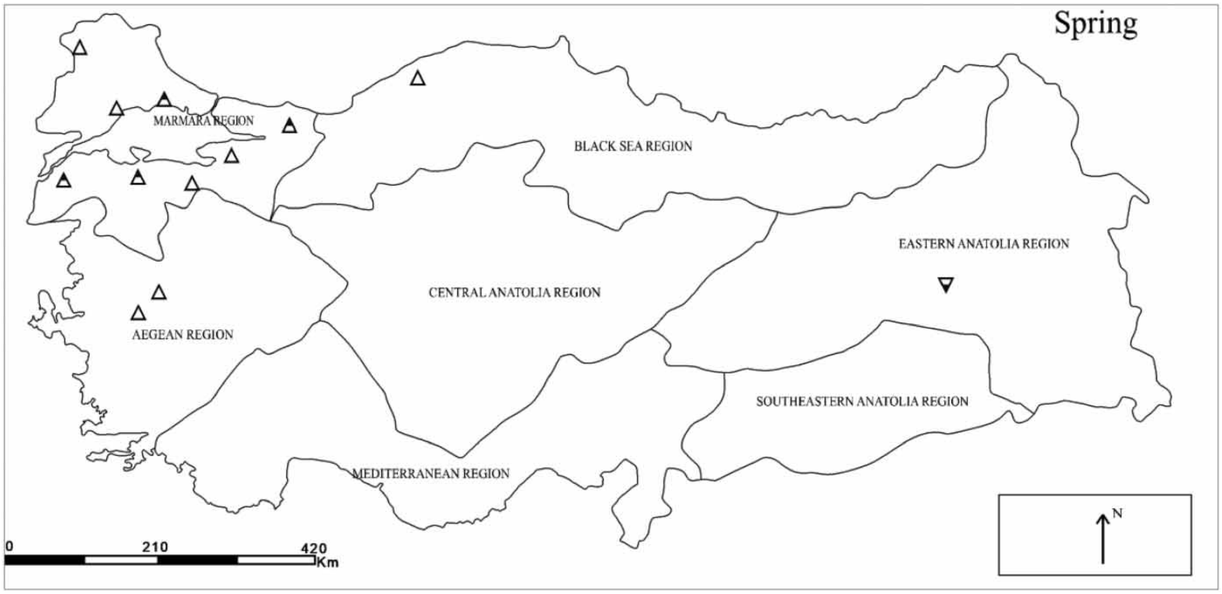



**Figure 10** | Lag correlation analysis between winter $MOI_{AC}$ and spring temperature (Lag-1). Half-filled triangle and hollow triangle represent positive correlation coefficients at significance level of at significance levels of $\alpha = 0.05$ and $\alpha = 0.1$, respectively. Half-filled upside down triangle represents negative correlation coefficients at significance level of $\alpha = 0.05$. If the correlations are not significant at these levels, they are not illustrated.

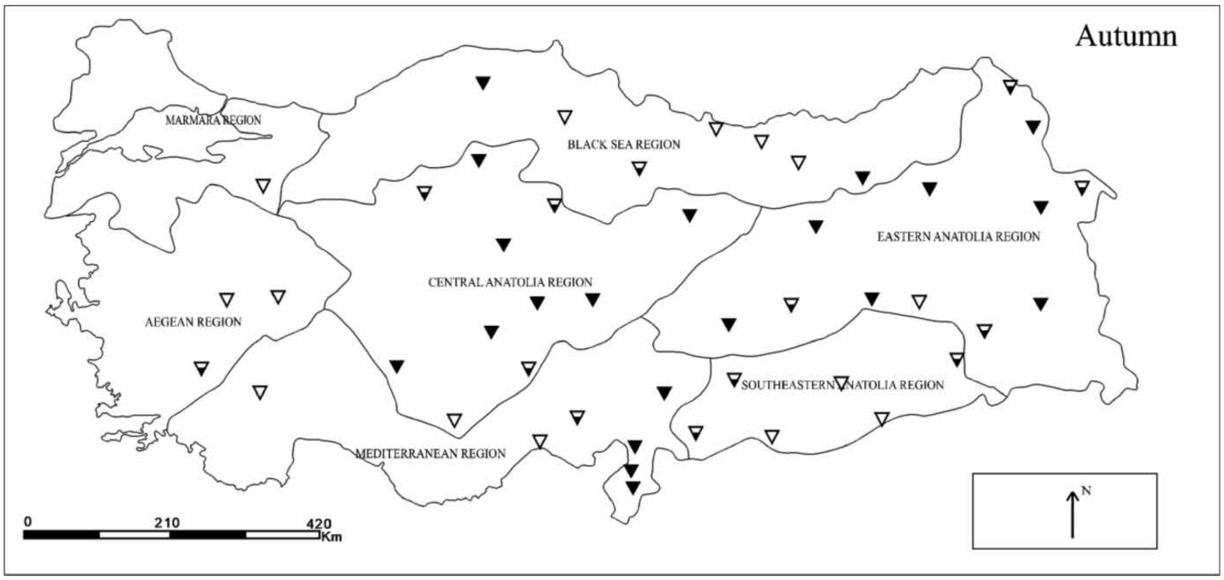



**Figure 11** | Lag correlation analysis between summer $MOI_{GL}$ and autumn precipitation (Lag-1). Filled upside down triangle, upside down triangle and half-filled upside down triangle represent the negative correlation coefficients at significance levels of $\alpha = 0.01$, 0.05 and 0.1, respectively. If the correlations are not significant at these levels, they are not illustrated.

central, eastern and southeastern parts of Turkey. In central Anatolia, significant correlation coefficients were obtained at $\alpha = 0.01$ in the majority of stations. Likewise, correlation coefficients between summer $MOI_{GL}$ and autumn precipitation are negative at $\alpha = 0.01$ in the greater part of eastern Anatolia region. Correlations are negative at the significance level of $\alpha = 0.05$ for the rest of the stations in the region. There are also remarkable correlations in the eastern Mediterranean. Moreover, the autumn precipitation data of most stations in southeastern Anatolia correlates with the summer $MOI_{GL}$, usually at the significance level of $\alpha = 0{,}1$. In other words, the link between summer $MOI_{GL}$ and autumn precipitation is stronger in the terrestrial regions than coastal regions of Turkey. Similar results were also obtained between the summer $MOI_{AC}$ and autumn precipitation data. As is seen in Figure 12, the liaison between the summer $MOI_{AC}$ and autumn precipitation is strong in the continental parts of Turkey, whereas in the western and coastal parts there were, in general, no remarkable correlations.

## Effects of MOI phases on temperature and precipitation data

In this section, it was researched whether or not MO index leads to temperature differences in the winter season and precipitation differences in the summer season. In this context, differences between temperature values which are based on $MOI \leq -0.5$ (negative phase) and temperature values which are based on $MOI > -0.5$ were calculated. First, it was found that winter temperature values for $MOI_{GL} \leq -0.5$ were higher than the winter temperature values for $MOI_{GL} > -0.5$. According to Figure 13, there was no discernable temperature difference in the Thrace part of Marmara, whereas in the other parts of Marmara temperature differences varied between 0.2 °C and 0.9 °C. The winter temperature difference is high and these variations are generally between 0.5 °C and 1.1 °C in the Aegean region. The temperature difference is also remarkable and changes between 1.1 °C and 1.5 °C in the central Anatolia region. Temperature variations are lower throughout the Black Sea coast than the internal parts of the Black Sea region. In the southern regions of Turkey, the temperature difference which arises from $MOI_{GL}$ is usually between 0.4 °C and 0.7 °C. The most significant winter temperature difference was obtained in eastern Anatolia. For instance, the temperature difference is 2.4 °C in Ağrı, 2.2 °C in Muş, 1.9 °C in Erzurum, and 1.8 °C in Ardahan. As can be understood from Figure 13, the winter temperature difference is remarkable in the continental regions in proportion to coastal parts of Turkey. These results point out clearly important decreases in winter temperature as the value of $MOI_{GL}$ increases. Furthermore, this is also compatible with the results of the correlation analysis which was carried out between the winter mean temperature and $MOI_{GL}$. It was obtained that winter temperature for

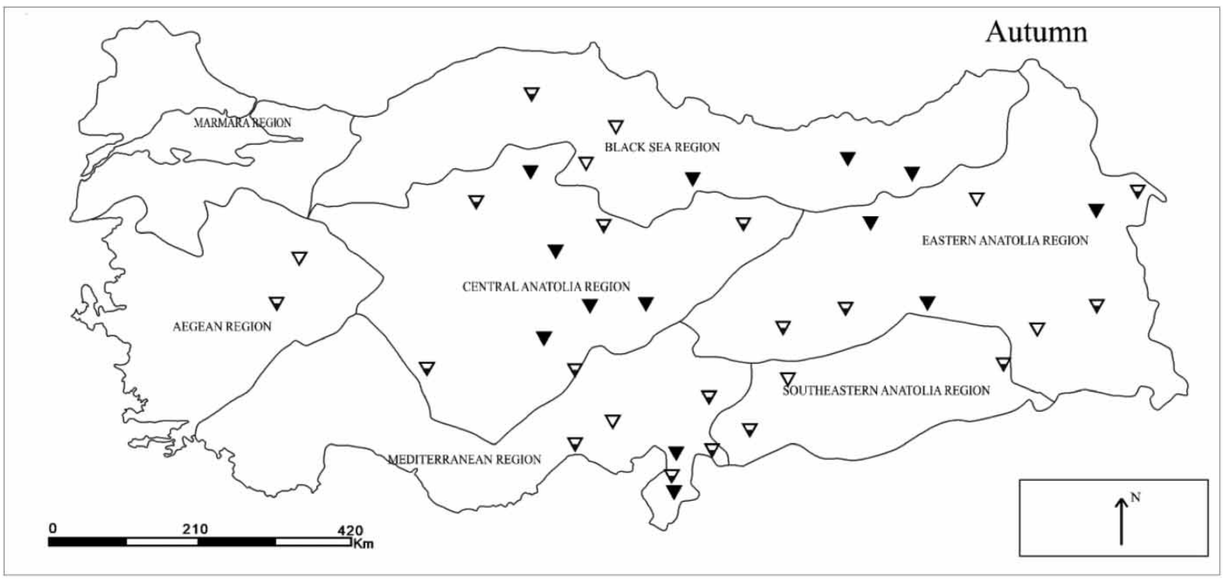



**Figure 12** | Lag correlation analysis between summer $MOI_{AC}$ and autumn precipitation (Lag-1). Filled upside down triangle, upside down triangle and half-filled upside down triangle represent the negative correlation coefficients at significance levels of $\alpha = 0.01$, 0.05 and 0.1, respectively. If the correlations are not significant at these levels, they are not illustrated.

Corrected Proof



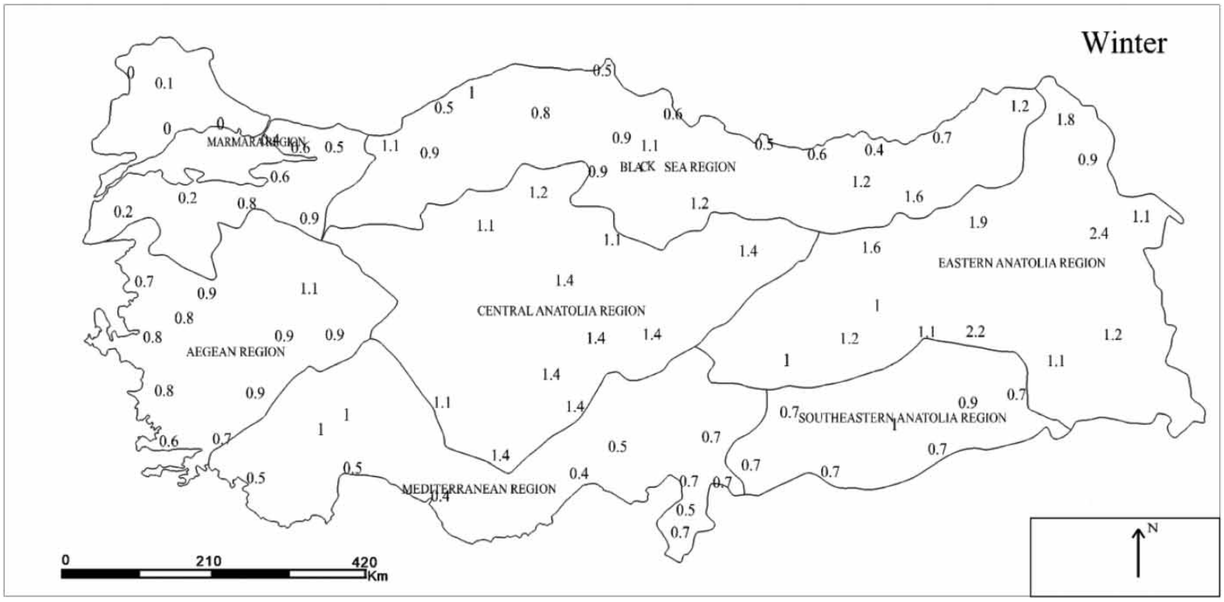



**Figure 13** | Differences between temperature values under the effect of negative $MOI_{GL}$ ($MOI_{GL} \leq -0.5$) and $MOI_{GL} > -0.5$ throughout Turkey for the winter season.

$MOI_{AC} \leq -0.5$ is higher than the winter temperature for $MOI_{AC} > -0.5$. Accordingly, the winter temperature difference is considerable in the terrestrial parts of Turkey in comparison with the coastal regions. Similar to the link between winter temperature and $MOI_{GL}$, the winter temperature difference based on $MOI_{AC}$ is high in central and eastern Anatolia. In these regions, temperature difference approaches 2 °C and even exceeds 2 °C in some parts, as seen in Figure 14.

To examine precipitation differences depending on the phases of MOI, precipitation values for $MOI \geq 0.5$ (positive phase) and $MOI < 0.5$ were compared for the summer

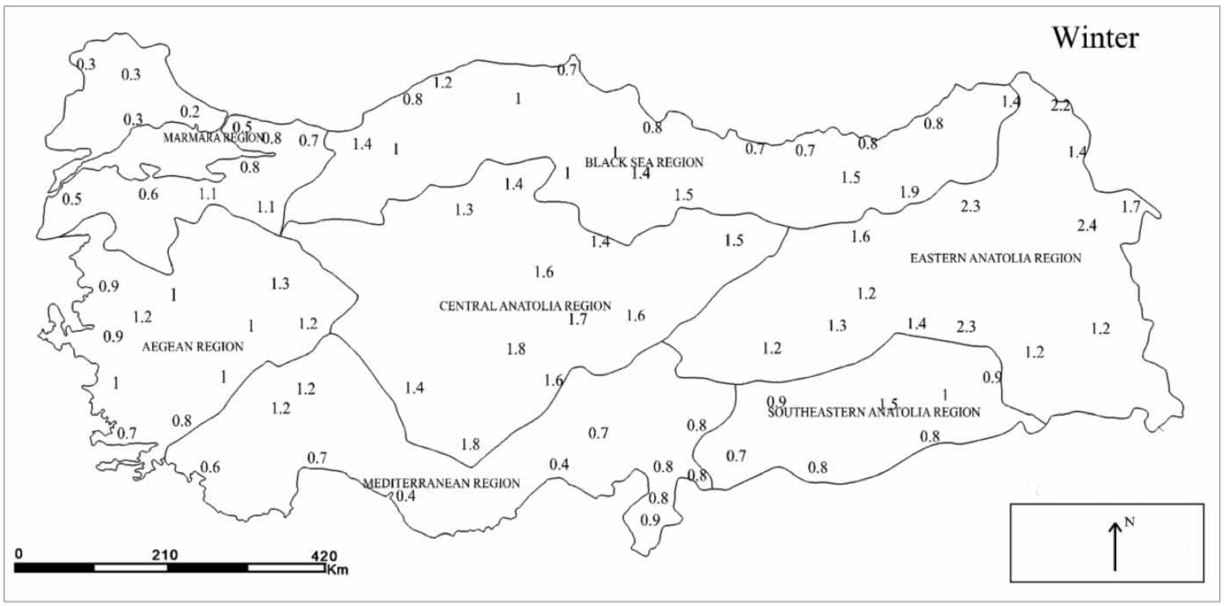
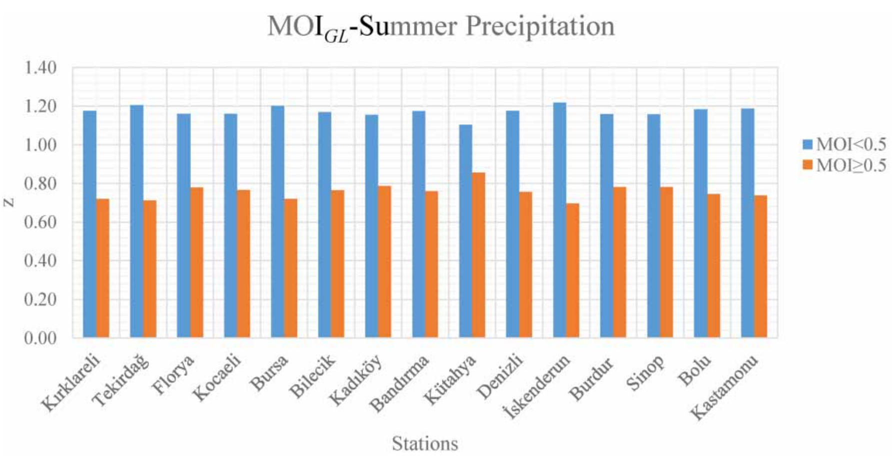



**Figure 14** | Differences between temperature values under the effect of negative $MOI_{AC}$ ($MOI_{AC} \leq -0.5$) and $MOI_{AC} > -0.5$ throughout Turkey for the winter season.

period. In relation to this, precipitation values for both MOI $\geq 0.5$ and MOI $< 0.5$ were broken down to summer mean precipitation totals of respective stations. The obtained values were noted as $z$ and are shown on the $y$-axis in Figures 15 and 16. After that, the significance of precipitation differences was evaluated according to the $t$-test as shown in Tables 3 and 4. In Figures 15 and 16 precipitation differences that belong to 30 stations were given for $MOI_{GL}$ and $MOI_{AC}$, respectively. Even though the rainiest parts of Turkey during the summer season are mostly the northern coastal belt, some stations which belong to the continental regions were also preferred due to significant correlations. As can be seen in Figure 15, the precipitation values for $MOI_{GL} < 0.5$ are higher than the precipitation values for $MOI_{GL} \geq 0.5$ for all the stations. As can be inferred from Table 3, precipitation differences are very significant, particularly in continental parts, at $\alpha = 0.01$, whereas they are significant in coastal areas, mostly at $\alpha = 0.05$ or 0.1. This could be related to the geographical features of Turkey and precipitation patterns which exhibit different characteristics from region to region. Similarly, the precipitation amount for $MOI_{AC} < 0.5$ is higher than the precipitation amount for $MOI_{AC} \geq 0.5$ as seen in Figure 16. According to Table 4 precipitation differences are significant in terrestrial parts of Turkey at $\alpha = 0.01$, generally. Nevertheless, in the majority of stations located in the coastal part of Turkey precipitation differences are largely not statistically significant. These results clearly reveal that significant reductions in summer precipitation could occur as the values of MOI increase. It can also be seen that



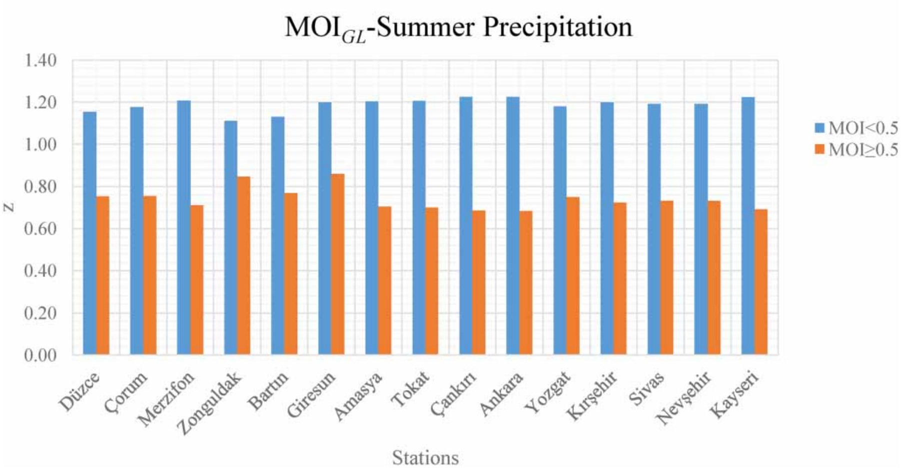




**Figure 15** | Differences between $z$ values under the effect of positive $MOI_{GL}$ ($MOI_{GL} \geq 0.5$) and $MOI_{GL} < 0.5$ throughout Turkey for the summer season.

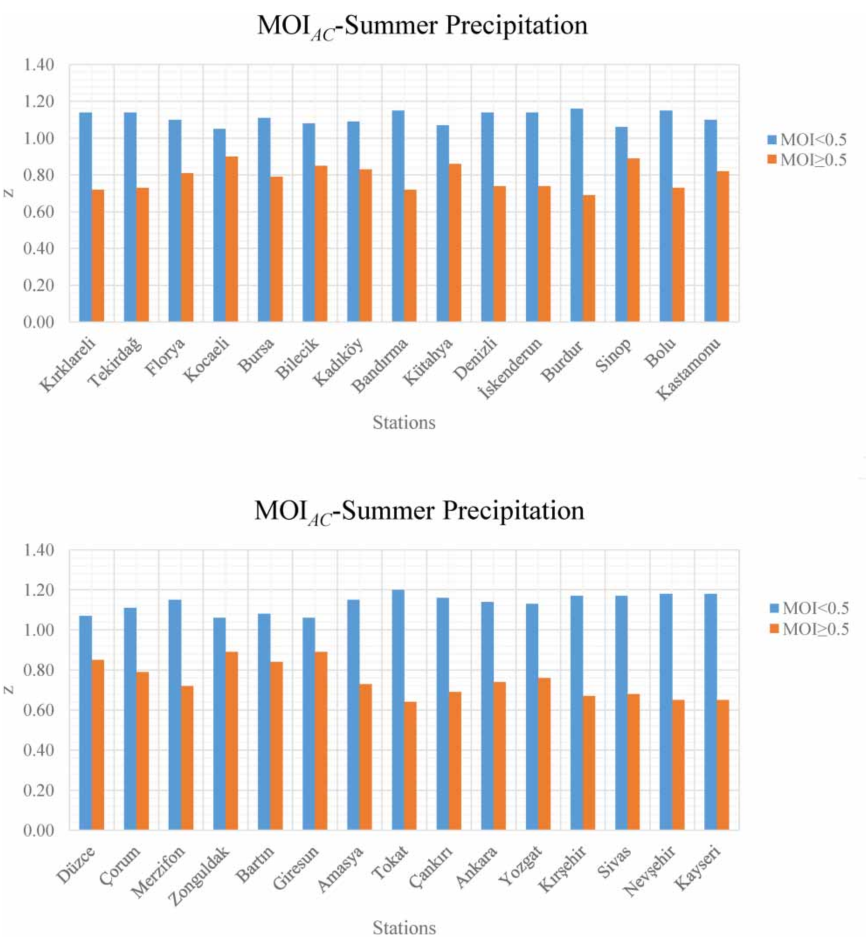



**Figure 16** | Differences between *z* values under the effect of positive MOI$_{AC}$ (MOI$_{AC} \geq 0.5$) and MOI$_{AC} < 0.5$ throughout Turkey for the summer season.

these remarkable precipitation differences in the summer season are in accord with the results of correlation analysis between summer precipitation and MOI.

## The relationship between MO and NAO

MO was compared with other northern hemisphere teleconnections, such as NAO in some studies (Dünkeloh & Jacobeit 2003; Gonzalez-Hidalgo *et al.* 2009). Thus, the link between NAO and MO was investigated statistically and possible physical phenomena behind MO will be mentioned in this section.

First of all, the correlation between NAO and MO indices was calculated as seasonal and annual. Accordingly, the correlation between NAO and MO$_{GL}$ is very high, especially in the winter season as seen in Table 5. Likewise, the same situation was also observed for the relation between NAO and MO$_{AC}$. This shows the link between NAO and MO indices is very strong during the winter season in comparison with the other seasons. Dünkeloh & Jacobeit (2003) stated that the effects of MO indices correspond with the impacts of NAO. In this respect, they inferred that the relationship between MO and NAO is obvious, particularly in the winter season in comparison with the other seasons. They also pointed out that if the positive phase of MOI is influential, the occurrence of high pressure in the southwestern region leads to less winter precipitation in a greater part of the Mediterranean. In addition, Türkeş & Erlat (2003) found significant negative correlations between the winter precipitation and NAO index and important precipitation differences particularly in the western and

**Table 3** | Precipitation values under the effect of $MOI_{GL} < 0.5$ and $MOI_{GL} \geq 0.5$

| | Summer | | | |
|---|---|---|---|---|
| **Stations** | $P_{av}$ (mm) | $P_{MOIGL<0.5}$ (mm) | $P_{MOIGL\geq0.5}$ (mm) | $P_d$ (mm) |
| Kırklareli | 95 | 111.7 | 68.4 | 43.3*** |
| Tekirdağ | 74.7 | 90.1 | 53.2 | 36.9*** |
| Florya | 73.5 | 85.3 | 57.2 | 28.1*** |
| Kocaeli | 133.9 | 155.4 | 102.4 | 53** |
| Bursa | 68.2 | 82 | 49.1 | 32.9*** |
| Bilecik | 68.3 | 79.9 | 52.2 | 27.7*** |
| Kadıköy | 73.6 | 85 | 57.9 | 27.1** |
| Bandırma | 54 | 63.4 | 41 | 22.4** |
| Kütahya | 67.9 | 74.9 | 58.1 | 16.8* |
| Denizli | 46.2 | 54.3 | 34.9 | 19.4** |
| İskenderun | 58.1 | 70.8 | 40.5 | 30.3*** |
| Burdur | 44.2 | 51.2 | 34.5 | 16.7** |
| Sinop | 110.2 | 127.6 | 86.1 | 41.5** |
| Bolu | 109.5 | 129.6 | 81.5 | 48.1*** |
| Kastamonu | 138.5 | 164.5 | 102.3 | 62.2*** |
| Düzce | 153.2 | 176.7 | 115.5 | 61.2*** |
| Çorum | 87.6 | 103.1 | 66.1 | 37*** |
| Merzifon | 80.9 | 97.7 | 57.5 | 40.2*** |
| Zonguldak | 230.2 | 255.7 | 194.7 | 61* |
| Bartın | 210.4 | 237.8 | 161.7 | 76.1** |
| Giresun | 244.6 | 269.3 | 210.2 | 59.1** |
| Amasya | 60.9 | 73.3 | 42.9 | 30.4*** |
| Tokat | 55.4 | 66.8 | 38.8 | 28*** |
| Çankırı | 74.1 | 90.8 | 50.8 | 40*** |
| Ankara | 61.6 | 75.5 | 42.1 | 33.4*** |
| Yozgat | 64.3 | 75.9 | 48.2 | 27.7** |
| Kırşehir | 46.6 | 55.9 | 33.7 | 22.2*** |
| Sivas | 49.6 | 59.1 | 36.4 | 22.7*** |
| Nevşehir | 45.8 | 54.6 | 33.5 | 21.1** |
| Kayseri | 55.5 | 67.9 | 38.4 | 29.5*** |

*Notes:* $P_d$ refers the difference between $P_{MOIGL<0.5}$ (mm) and $P_{MOIGL\geq0.5}$ (mm); $P_{av}$ is the average summer precipitation data for each station; ***significance at $\alpha = 0.01$; **significance at $\alpha = 0.05$; *significance at $\alpha = 0.1$.

**Table 4** | Precipitation values under the effect of $MOI_{AC} < 0.5$ and $MOI_{AC} \geq 0.5$

| | Summer | | | |
|---|---|---|---|---|
| **Stations** | $P_{av}$ (mm) | $P_{MOIAC<0.5}$ (mm) | $P_{MOIAC\geq0.5}$ (mm) | $P_d$ (mm) |
| Kırklareli | 95 | 107.9 | 68.5 | 39.4*** |
| Tekirdağ | 74.7 | 85.4 | 54.3 | 31.1*** |
| Florya | 73.5 | 81 | 59.5 | 21.5** |
| Kocaeli | 133.9 | 140.9 | 120.9 | 20 |
| Bursa | 68.2 | 75.8 | 53.9 | 21.9** |
| Bilecik | 68.3 | 73.9 | 57.8 | 16.1 |
| Kadıköy | 73.6 | 80.2 | 61.3 | 18.9 |
| Bandırma | 54 | 62 | 38.9 | 23.1** |
| Kütahya | 67.9 | 72.9 | 58.4 | 14.5 |
| Denizli | 46.2 | 52.6 | 34.1 | 18.5 |
| İskenderun | 58.1 | 66 | 43.1 | 22.9** |
| Burdur | 44.2 | 51.4 | 30.6 | 20.8*** |
| Sinop | 110.2 | 116.3 | 98.6 | 17.7 |
| Bolu | 109.5 | 125.4 | 79.4 | 46*** |
| Kastamonu | 138.5 | 151.9 | 113.2 | 38.7** |
| Düzce | 153.2 | 164.6 | 129.6 | 35* |
| Çorum | 87.6 | 97.3 | 69.4 | 27.9** |
| Merzifon | 80.9 | 92.9 | 58.2 | 34.7*** |
| Zonguldak | 230.2 | 244 | 204 | 40 |
| Bartın | 210.4 | 226.5 | 176.1 | 50.4 |
| Giresun | 244.6 | 258.8 | 217.6 | 41.2 |
| Amasya | 60.9 | 69.8 | 44.6 | 25.2*** |
| Tokat | 55.4 | 66.3 | 35.4 | 30.9*** |
| Çankırı | 74.1 | 86.1 | 51.2 | 34.9*** |
| Ankara | 61.6 | 70 | 45.6 | 24.4** |
| Yozgat | 64.3 | 72.4 | 49 | 23.4** |
| Kırşehir | 46.6 | 54.7 | 31.3 | 23.4** |
| Sivas | 49.6 | 57.9 | 34 | 23.9*** |
| Nevşehir | 45.8 | 54.1 | 29.9 | 24.2*** |
| Kayseri | 55.5 | 65.7 | 36.3 | 29.4*** |

*Notes:* $P_d$ refers the difference between $P_{MOIAC<0.5}$ (mm) and $P_{MOIAC\geq0.5}$ (mm); $P_{av}$ is the average summer precipitation data for each station; ***significance at $\alpha = 0.01$; **significance at $\alpha = 0.05$; *significance at $\alpha = 0.1$.

central regions of Turkey. This result is compatible with the negative correlations between the $MO_{AC}$ and winter precipitation which were obtained in the western part of the country. Furthermore, Türkeş & Erlat (2009) pointed out there are important negative correlations between the NAO and winter temperature in the southwestern regions and central Anatolia. In relation to this, they stated that when the negative phase of NAO is influential, winter temperature tends to be higher because of the westerly and northwesterly circulations towards Turkey. On the other hand, when the positive phase of NAO is influential, the winter temperature is inclined to be lower due

**Table 5** | Correlation between NAO and MO indices

| | Correlation | | | | |
|---|---|---|---|---|---|
| | **Winter** | **Spring** | **Summer** | **Autumn** | **Annual** |
| NAO-MOI$_{GL}$ | 0.77 | 0.09 | −0.07 | 0.10 | 0.38 |
| NAO-MO$I_{AC}$ | 0.74 | 0.12 | −0.09 | 0.16 | 0.36 |

to the northeasterly circulations. In this context, this is also a remarkable finding in terms of investigating the characteristics of MO indices and NAO index.

## CONCLUSION

In this study, the relationship between MO and the temperature/precipitation regime of Turkey was studied. For this analysis, MO$_{GL}$ and MO$_{AC}$ indices were utilized. According to the correlation analysis for temperature/significance, negative correlations were obtained in the winter season in general for Turkey. Significant negative correlations between the MOI$_{AC}$ and temperature data were also found in the spring and autumn seasons. In general, the relationship between the MOI$_{AC}$ and temperature data is stronger than the relationship between MOI$_{GL}$ and temperature data.

As to the impacts of MOI on the precipitation regime in Turkey, it was observed that both MOI$_{GL}$ and MOI$_{AC}$ have negative correlations with summer precipitation data in general across Turkey. However, the relationship between MOI and precipitation is especially strong in the Marmara region, in the internal parts of the Black Sea region and the vast majority of central Anatolia.

Furthermore, lag correlation analysis for the temperature data indicates that either winter MOI$_{GL}$ or MOI$_{AC}$ could affect the spring temperature regime of the Marmara region positively. On the other hand, lag correlation analysis for precipitation reveals important outcomes. It was found that either summer MOI$_{GL}$ or MO$_{AC}$ are negatively correlated with the autumn precipitation, particularly in the interior part of Turkey.

The effects of extreme MOI phases on the temperature and precipitation data were also examined in general across Turkey. In this regard, winter mean temperature differences which vary according to the magnitude of MOI$_{GL}$ and MOI$_{AC}$ were calculated. Thus, it was realized that the value of winter temperature is high if MOI $\leq -0.5$ in comparison with the winter temperature values when MOI $> -0.5$. In addition, it was found that winter temperature differences are remarkable, especially in the terrestrial regions such as central and eastern Anatolia compared with the coastal parts of Turkey. Moreover, the amount of precipitation is higher for MOI $< 0.5$ than for MOI $\geq 0.5$ during the summer period.

In summary, these results clearly show that significant decreases in winter temperature could be observed as the values of the MO indices increase. Likewise, a remarkable decrease in summer precipitation could occur as the values of the MO indices rise. Finally, the link between MO and NAO was also examined. In this regard, the most significant relationship between them was observed in the winter season.

As a result of this study, it was noticed that MO could have a significant relationship with the temperature and precipitation characteristics in Turkey. In order to examine the effects of MO on climate variables and the relationship with the other teleconnections, further studies and analysis need to be conducted.

## ACKNOWLEDGEMENTS

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