Regional analysis of climate variability in Greece based on six temperature variability indicators – A cluster analysis

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Abstract. In this paper, a comparative analysis of climate variability between different regions of Greece based on some temperature variability indicators, is performed, in order to find out which areas have similar climate variability over time in the context of climate change. For this purpose, temperature variability, based on six temperature variability indices for 20 different stations, is calculated and, then, a K-Means clustering method is applied between the stations for each indicator. The results show that most of the regions of central and northern Greece have a high number of days where mean and minimum temperatures increase. In addition, most of these areas also have a high number of days with a continuous increase in daily mean temperature. As a result, a higher warming pace is observed in these areas than in the rest of the areas. This work is intended to serve as a reference for further scientific research on climate variability in Greece.

1 Introduction

Climate change is one of the biggest environmental issues that concern the scientific community during last decades [1]. As average global temperature increases due to climate change, it also certain that extreme temperature events are becoming more frequent. However, it is not entirely clear, if these changes in extremes are attributed to changes in the mean or changes in variability [2]. Therefore, there is increasing research interest in the variability of climate, which is also associated with numerous impacts on humans and ecosystems [3,4].

The use of appropriate indices is an effective way to understand climate variability. Some previous studies have focused on the quantification of temperature variability. Kalyvas et al. [5] proposed the TEVY index (TEVY=temperature difference within a year) which is based on the difference between the recorded daily mean temperature values and those derived using the Fourier harmonic analysis. This index was applied to different stations in Greece and the results showed a quantitative estimate of the temperature variability within a year. Moreover, Zacharaki et al. [6,7] introduced a new set of indicators for the quantification of climate variability. These indicators mainly refer to the increases and decreases of three typical values of daily temperature (mean, maximum, minimum) and examine temperature variability on an annual, seasonal and monthly basis.

However, those indicators have been applied only in a limited number of meteorological stations in Greece. In this work, we aim to extend our knowledge of climate variability for the entire country. Therefore, we apply some of those indicators [6,7] to more stations and we perform a cluster analysis in order to group regions with similar climate variability in the same cluster. We use the K-Means clustering method which is widely used to identify similarities in climate variables between different regions [8,9].

2 Data and Methods

2.1 Data

Primary temperature data were obtained from 20 stations of the National Meteorological Service (NMS) of Greece and cover all regional departments (13 in total) of Greece. In addition, the longitude and the latitude of each station were retrieved from the NMS (Table 1).

2.2 Temperature variability indicators

In this paper, six temperature variability indicators were used based on daily mean temperature (T_{mean}) and minimum temperature (T_{min}). For each year of the dataset (1955-2021), the following indicators were calculated:

1. The maximum number of days with a continuous decrease in daily mean temperature.
2. The maximum number of days with a continuous increase in daily mean temperature.
3. The total number of days where:

$$\Delta T_{mean} = T_i - T_{i-1} < 0 \quad (1)$$

4. The total number of days where:

$$\Delta T_{mean} = T_i - T_{i-1} > 0 \quad (2)$$

5. The total number of days where:

$$\Delta T_{min} = T_i - T_{i-1} < 0 \quad (3)$$

6. The total number of days where:

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$$\Delta T_{min} = T_i - T_{i-1} > 0 \quad (4)$$

where T_i= the current day and T_{i-1}= the previous day.

Table 1. Latitude and longitude of stations.

Station	Latitude	Longitude
Agrinio	38 37N	21 23E
Alexandroupoli	40 51N	25 56E
Araxos	38 08N	21 25E
Filadelfia	38 03N	23 40E
Florina	40 48N	21 25E
Ioannina	39 40N	20 51E
Heraklion	35 20N	25 11E
Kalamata	37 04N	22 06E
Kerkyra	39 37N	19 55E
Kozani	40 17N	21 47E
Kythira	36 08N	23 08E
Larisa	39 39N	22 26E
Mikra	40 31N	22 58E
Mytilini	39 04N	26 36E
Naxos	37 06N	25 23E
Rodos	36 24N	28 05E
Tanagra	38 19N	23 33E
Tatoi	38 06N	23 47E
Tripoli	37 32N	22 24E
Tymbaki	35 03N	24 46E

2.3 K-Means clustering

K-Means is a non-hierarchical clustering algorithm that groups multivariate observations into k clusters, where each observation belongs to the cluster with the closest mean [10]. The optimal number of clusters (k) can be determined using the elbow graphical method [11] . The elbow graph shows the Within-Cluster-Sum-of-Square (WCSS) values on the y-axis corresponding to the different values of k (on the x-axis). The optimal k value is the point at which the graph forms an elbow.

In our analysis, the K-Means cluster analysis was performed in the R programming language and the visualization of the clusters is shown on a Google's map of Greece. For the cluster analysis, we calculated the mean values of each indicator for three time periods: 1955-1976, 1977-1998 and 1999-2021. Moreover, we used the elbow method and we found that the optimal number of clusters was three (k=3).

3 Results

3.1 Maximum number of days with a continuous decrease in Mean Temperature Index

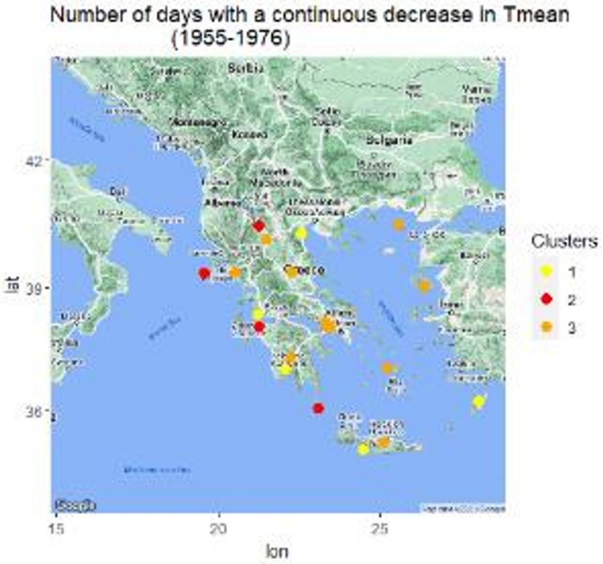
Figs. 1a-c show that the stations are divided into three clusters for each of the periods 1955-1976, 1977-1998 and 1999-2021 respectively. In each of the following figures, the stations with the highest index value are included in the red cluster, while the stations with the lowest index value are included in the yellow cluster. In Fig. 1a most of the stations belong to the orange cluster, so these stations have a similar number of days with a continuous decrease in daily mean temperature. However, a high spatial heterogeneity is observed between the stations, with many stations in the same cluster distributed throughout Greece (e.g., stations in the yellow cluster). During the period 1977-1998 (Fig. 1b), most stations in central Greece belong to the red cluster and have a similar high index value, while only three stations (Tripoli, Kalamata and Heraklion) in the south belong to the yellow cluster and have a lower number of days with a continuous decrease in mean temperature. After 1998 (Fig. 3c), some regions in central and northern Greece (Mikra, Kozani and Larisa) and some eastern islands (Naxos and Mytilini) moved from the red to the orange or yellow cluster and showed a decreasing trend in the number of days with a continuous decrease in T_{mean}.

3.2 Maximum number of days with a continuous increase in Mean Temperature Index

Fig. 2a shows that most of the stations belong to the yellow cluster and have the lowest index value. More specifically, all the eastern regions belong to the same cluster (yellow) and have a smaller number of days with a continuous increase in T_{mean} than the regions in central and western Greece. Fig. 2b-c show that, over time, only a few regions belong to the yellow cluster, indicating that the number of days with a continuous increase in T_{mean} is increasing, especially in coastal areas such as Kerkyra, Alexandroupoli, Mytilini, Rodos and Heraklion, which is due to the warming of climate.

3.3 Number of days where ΔT_{mean} <0 index

Fig. 3a shows that only a few regions belong to the yellow cluster, especially in central and northern Greece, which means that in these regions the number of days where the average temperature decreases is lower. On the other hand, in most places, especially in the eastern and western coastal areas, there is higher number of days when the mean temperature decreases. In Fig. 3b-c, a lower number of stations is observed in the yellow cluster and most of the coastal areas are included in the red cluster and have a higher index value. It is important to note that the northern continental areas such as Florina and Kozani, remain in the yellow cluster over time and show the lowest index value and thus a stronger warming trend than the other regions of Greece.



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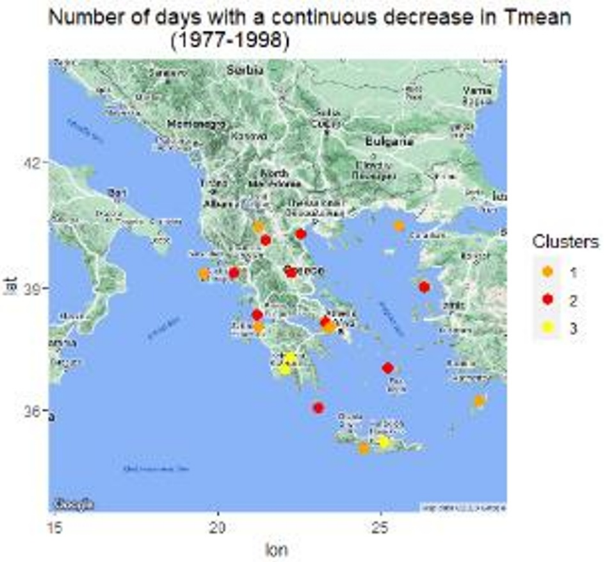

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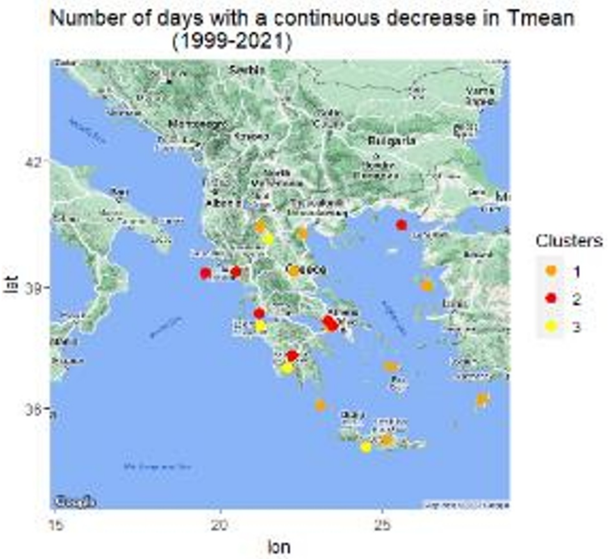
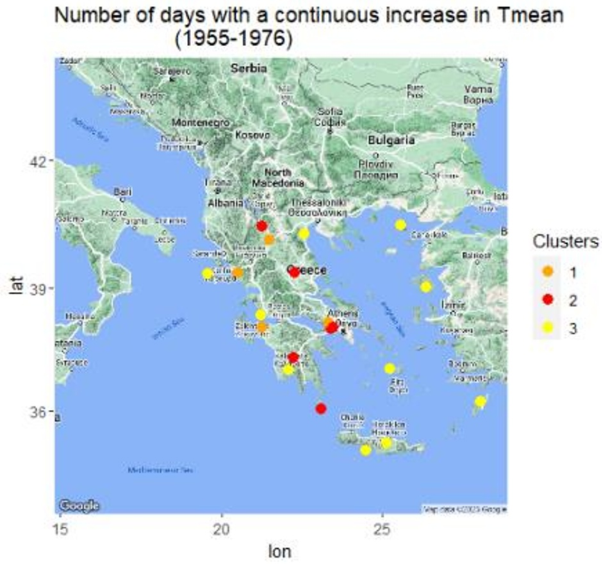


(c)

Fig. 1. Clustering between stations for T_{mean} continuous decrease index (a) 1955-1976 (b) 1977-1998 and (c) 1999-2021. Stations with yellow colour have the lowest index value, while stations with red have the highest value.



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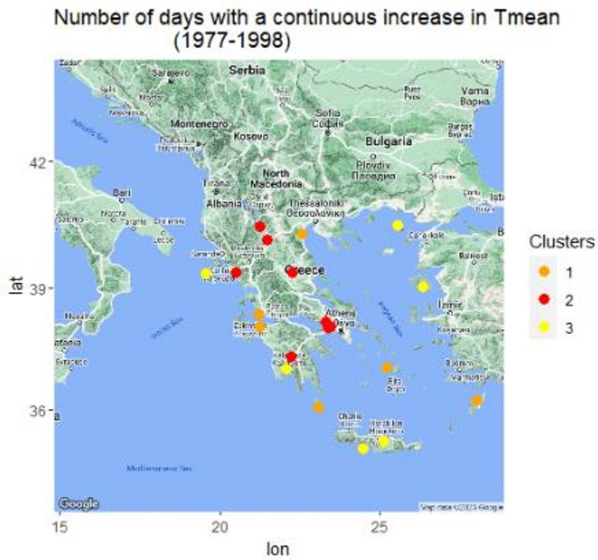

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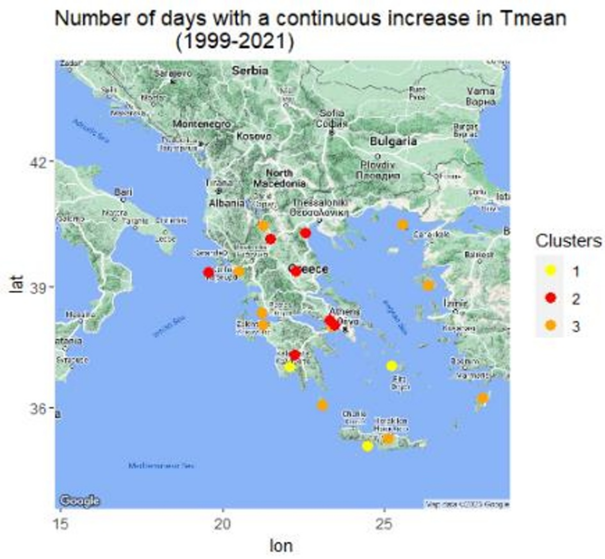

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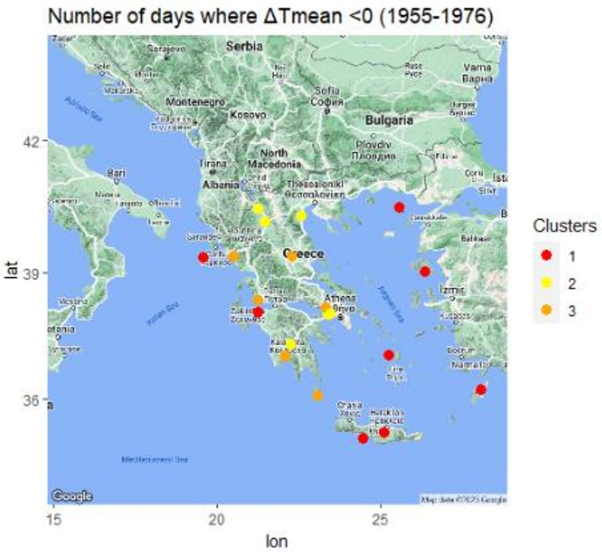
Fig. 2. Clustering between stations for T_{mean} continuous increase index (a) 1955-1976 (b) 1977-1998 and (c) 1999-2021. Stations with yellow colour have the lowest index value, while stations with red have the highest value.



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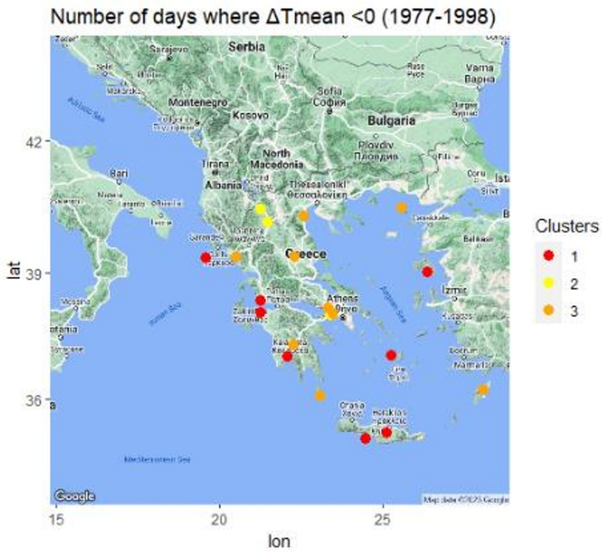

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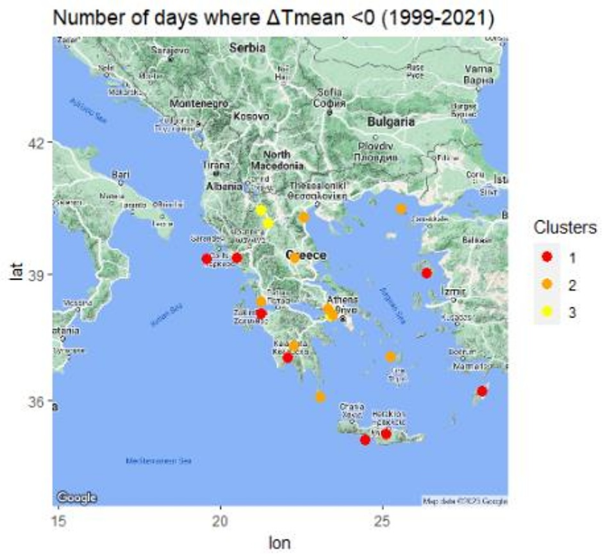


(c)

Fig. 3. Clustering between stations for ΔT_{mean} <0 index (a) 1955-1976 (b) 1977-1998 and (c) 1999-2021. Stations with yellow colour have the lowest index value, while stations with red have the highest value.

3.4 Number of days where ΔT_{mean} >0 index

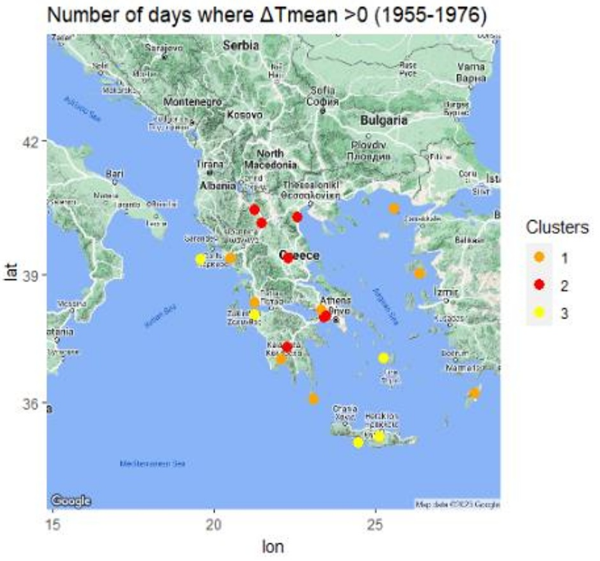
In contrast to Figs. 3a-c, Figs. 4a-c show the opposite pattern, with most central and northern regions included in the red cluster and showing a high number of days where T_{mean} increases, while most of the coastal regions show a lower index value. As a result, a stronger warming rate is observed in central and northern areas that the coastal areas.

3.5 Number of days where ΔT_{min} <0 index

Fig. 5a shows that only a few stations are included in the yellow cluster (Florina, Kozani and Kythira), indicating that these regions had a lower number of days where minimum temperature decreases during the 1955-1976 period. Over time, more and more stations are included in the yellow cluster (Fig. 5b-c), indicating that the number of days where temperature decreases is lower in more and more regions, thus showing a general warming trend. It is important to note that most of the stations in the yellow cluster are located in central and northern Greece and thus a stronger warming trend is observed in these locations.

3.6 Number of days where ΔT_{min} >0 index

In Fig. 6a, there is a clear seperation between the stations, with the southeastern regions included in the yellow cluster and the central and northwestern stations included in the red cluster, indicating that the number of days on which the minimum temperature increases in the central/northwestern regions is higher than in the eastern regions. In Fig. 6b, some stations have migrated from the yellow cluster to the orange cluster, indicating that there is a higher number of days in these regions where the minimum temperature increases and thus an upward trend in warming is observed. In Fig. 6c, there is a clear seperetation between the stations, with all the western regions belonging to the orange cluster and having a similar number of days where the minimum temperature increases. Moreover, the southeastern regions belong to the yellow cluster and have also a similar average index value, while Larisa, Kozani and Mikra belong to the red cluster and thus have the highest number of days with an increase in minimum temperature.



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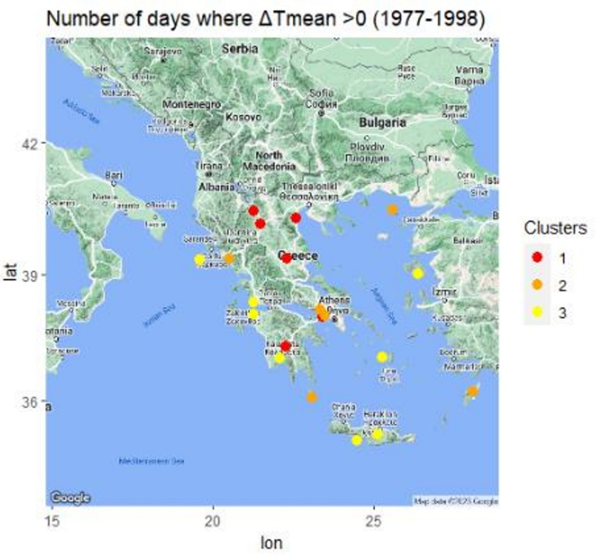

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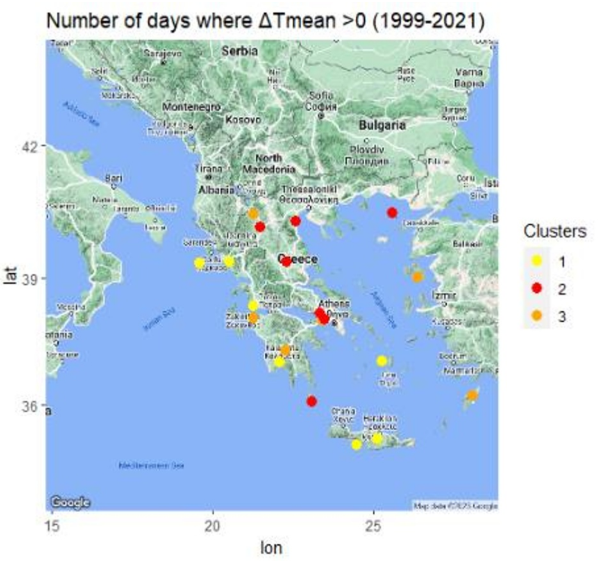
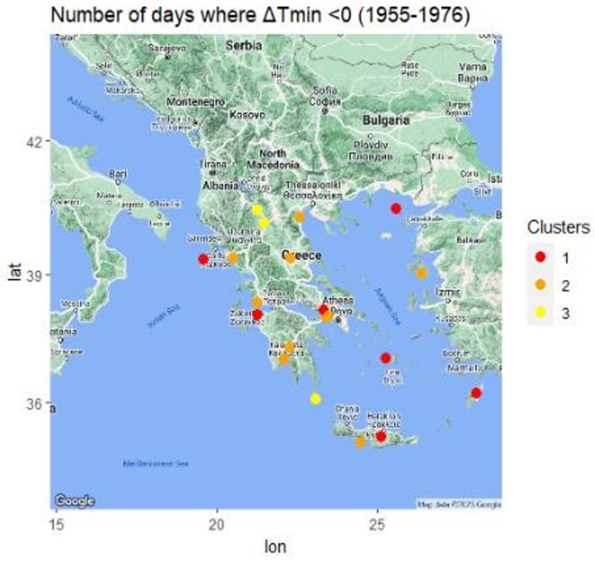


(c)

Fig. 4. Clustering between stations for $\Delta T_{mean} > 0$ index (a) 1955-1976 (b) 1977-1998 and (c) 1999-2021. Stations with yellow colour have the lowest index value, while stations with red have the highest value.



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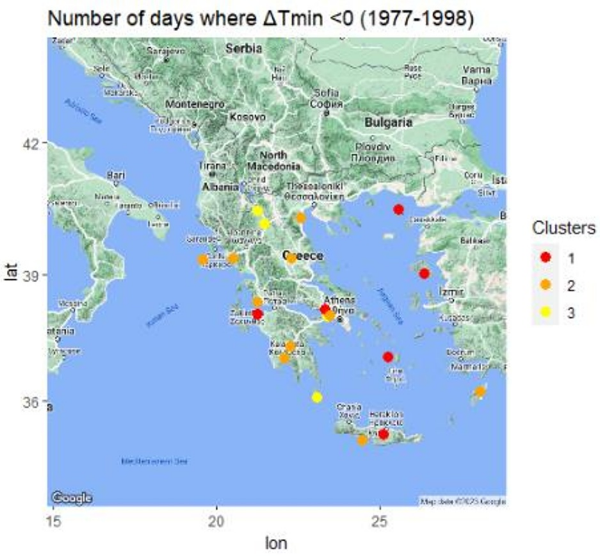

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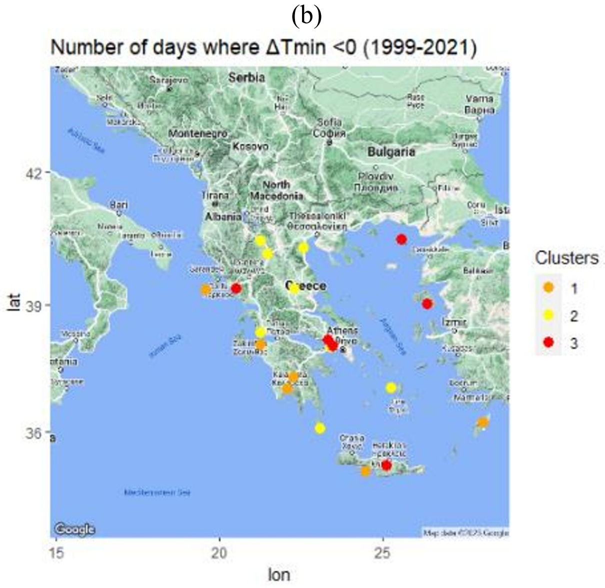

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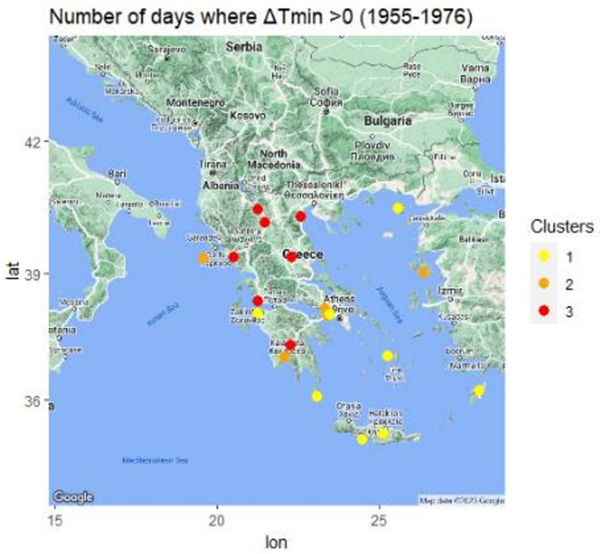
Fig. 5. Clustering between stations for $\Delta T_{min} < 0$ index (a) 1955-1976 (b) 1977-1998 and (c) 1999-2021. Stations with yellow colour have the lowest index value, while stations with red have the highest value.



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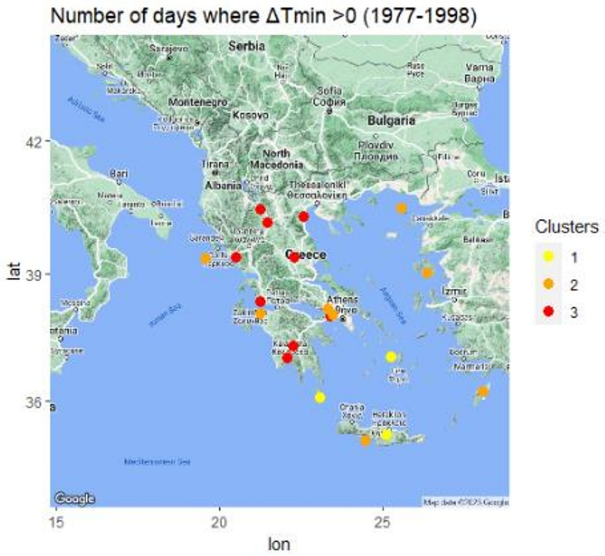

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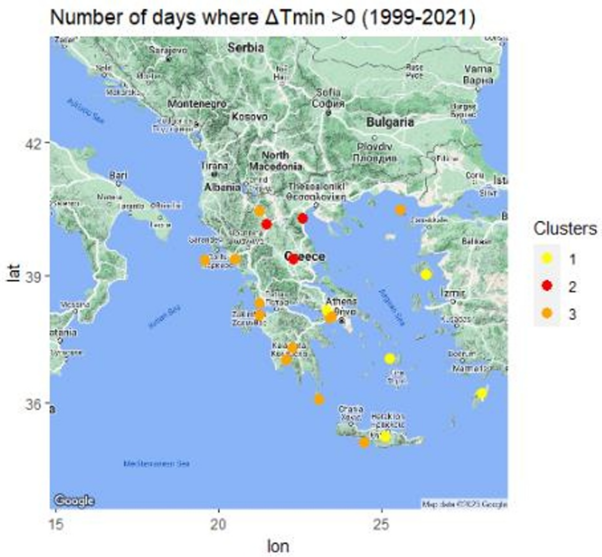

(c)

Fig. 6. Clustering between stations for $\Delta T_{min} > 0$ index (a) 1955-1976 (b) 1977-1998 and (c) 1999-2021. Stations with yellow colour have the lowest index value, while stations with red have the highest value.

4 Conclusions

In conclusion, as for the maximum number of days with a continuous decrease in mean temperature, the K-Means cluster analysis showed that most of the stations belonged to the red cluster during the period 1977-1998, indicating that the index value was similar in these locations, while only three stations belonged to the yellow cluster with the lowest index value. Moreover, the analysis showed that all the eastern regions had a similar number of days with a continuous increase in mean temperature (yellow cluster) and most of the stations in central and western Greece had a similar high index value (red cluster). Regarding the number of days when the mean and minimum temperatures decrease/increase, the cluster analysis showed that the number of days when the mean and minimum temperatures increase is significantly higher in the central and northern continental areas than in the coastal areas. Our work, can serve as a reference for further scientific research on climate variability analysis and comparison between different regions of Greece.

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