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January 2023: An Extremely Warm Winter Month in Thessaloniki, Greece †

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Abstract: During the last few years, extremely high temperatures have been recorded in many Greek regions and, in some cases, have been rather abnormal for each season. These extreme events appear to be persistent in duration and are occurring at a disconcerting frequency. The main objective of this study is to examine the exceptionally high temperatures that were recorded during January 2023 in Thessaloniki, Greece. The entire month was characterized by minimum and maximum temperatures that exceeded the climatological mean (1961–2000) by about 4.2 °C on average. Additionally, the average deviation for the mean maximum temperature of the month was calculated at 3.5 °C. In an attempt to classify the intensity of this possible extreme event compared to a future intermediate emission scenario (RCP4.5), a comparison of the observational data with the corresponding data from two future projections (2041–2060 and 2081–2100) of a high-resolution regional climate model was carried out. The spatial resolution of the simulations was 10 × 10 km and they were the result of the dynamical downscaling of the RegCM regional climate model after nesting a 25 km simulation of the model for the initial and boundary conditions. Finally, through this study, the contribution of the synoptic-scale atmospheric conditions of this event was examined.

Keywords: January; high temperatures; winter; Thessaloniki; Greece; RegCM4; future projections

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1. Introduction

The Greek Mediterranean climate is characterized by drought and high temperatures during the summer season, and excessive precipitation with low temperatures during winter. In some cases, long-lasting extreme events with very high temperatures are recorded during summer (heat waves), with unusually low temperatures seen during winter (frost) [1]. However, during the last years, many Greek regions have been characterized by extremely high temperatures that, in some cases, have been rather abnormal for each season [2,3]. The occurrence of these extreme events is becoming more frequent at a disconcerting rate, and the events also appear to be becoming more persistent.

According to the network of 53 meteorological stations of the National Observatory of Athens, the 2022–2023 winter was remarkably warm (the warmest for Northern Greece and 3rd warmest for the other regions). More than 60 days with higher maximum temperatures than the mean value of the time period 2010–2019 were recorded in every geographic region of Greece (65/90 winter days for Thessaloniki) [4].

The main objective of this study is to examine the exceptionally high temperatures that were recorded during January 2023 in the second largest city of Greece, Thessaloniki. Additionally, an attempt is made to classify the intensity of this possible extreme event compared to a future intermediate emission scenario (RCP4.5) by the end of the 21st century. Finally, the contribution of the synoptic-scale atmospheric conditions that are associated with this event is examined.

2. Materials and Methods

Daily minimum and maximum temperature data covering the time period 1961–2023 were utilized in this study. The dataset is derived from the meteorological station of the Aristotle University of Thessaloniki (32 m height) and is a long time series of homogenized data with no missing values.

Additionally, for the purposes of this study, the corresponding data (minimum and maximum temperature) derived from two future simulations performed using the RegCM4 regional climate model were also used. Regional climate model RegCM4 is a hydrostatic and compressible model with sigma-p vertical coordinates [5–7]. The development of the model was originally performed at the National Center for Atmospheric Research (NCAR). Its dynamical core is comparable to that of the hydrostatic version of Mesoscale Model version 5 (MM5) [8]. The two simulations cover the time periods 2041–2060 and 2081–2100. The combination of the model's configurations was evaluated as being the most optimal to simulate climate in the Mediterranean region [9–11]. The horizontal resolution of the simulations is 10 × 10 km, as they are the product of the dynamical downscaling of the model (nested from 25 × 25 km with HadGEM2 as driving global climate model under the RCP4.5 emission scenario) [9]. The RCP4.5 is an intermediate representative concentration pathway that displays no exceedance of radiative forcing at a stabilization level of ~4.5 W/m^2 until 2100. In this research, the closest land grid point (121 m height) to the AUTh meteorological station was used. No correction of model data was performed as they were evaluated previously [9].

In order to achieve the purposes of this study, the daily data from the AUTh meteorological station were statistically analyzed, both daily and monthly. Additionally, the simulated data were used to compare the observational data of 2023 and the period 1961–2022 with two future projections (middle and end of the 21st century). As a result, the 25th and 75th percentile of the simulated data were computed. Finally, in order to study the atmospheric conditions that are associated with this extreme event, the mean geopotential height at 500 hPa and the mean temperature at 850 hPa for January 2023 were compared with the corresponding fields for the long-term period 1961–2022. For this purpose, the monthly NCEP/NCAR reanalysis data for the aforementioned fields were utilized [12,13].

3. Results

3.1. Statistical Analysis of Observational Data

The analysis of the observational data showed that January was characterized by minimum (Tmin) and maximum (Tmax) temperatures that exceeded the climatological mean (1961–2000) by about 4.2 °C on average. Regarding the available time period 1961–2022, the mean Tmin and Tmax values for January were calculated as 2.8 °C and 10.1 °C respectively, while the corresponding values during January 2023 were 6.4 °C (Tmin) and 13.7 °C (Tmax) (Table 1). This is a rise of 3.6 °C in Tmax and in the case of Tmin this rise is more than double the value of the long-term mean (1961–2022). Additionally, the absolute maximum values of Tmin (15.9 °C) and Tmax (19.8 °C) for 2023 were recorded on 19th January. In the long-term period, the corresponding absolute maximum values were recorded on 2nd January 1995, with the Tmax (22.5 °C) being the highest recorded during the period of study. However, 2023 presented the highest Tmin temperature of the study period as the absolute maximum Tmin value of the long-term period is about 3 °C lower.

Table 1. Mean and highest value of minimum and maximum temperatures of January for the time period 1961–2022 and the year 2023.

	Mean Value (°C)	Highest Value (°C)
Tmin (1961–2022)	2.8	13 (2 January 1995)
Tmin (2023)	6.4	15.9 (19 January 2023)
Tmax (1961–2022)	10.1	22.5 (2 January 1995)
Tmax (2023)	13.7	19.8 (19 January 2023)

The comparison of the daily Tmin and Tmax values of January 2023 with the mean daily Tmin and Tmax values for January of the available period (1961–2022) led to the conclusion that January 2023 was the hottest for Thessaloniki. The minimum temperature values for January 2023 exceeded the mean Tmin values for January of the long-term period 1961–2022 (Figure 1). The results are similar for the maximum temperature values in the majority of the month. More specifically, Tmax values during January 2023 were higher than the mean Tmax values for January of the period 1961–2022, except for the last week of the month (Figure 2). In January 2023, the highest values for Tmin were recorded between the 18th and 23rd of the month, while the highest values for Tmax were assessed during the first and the third week of the month.

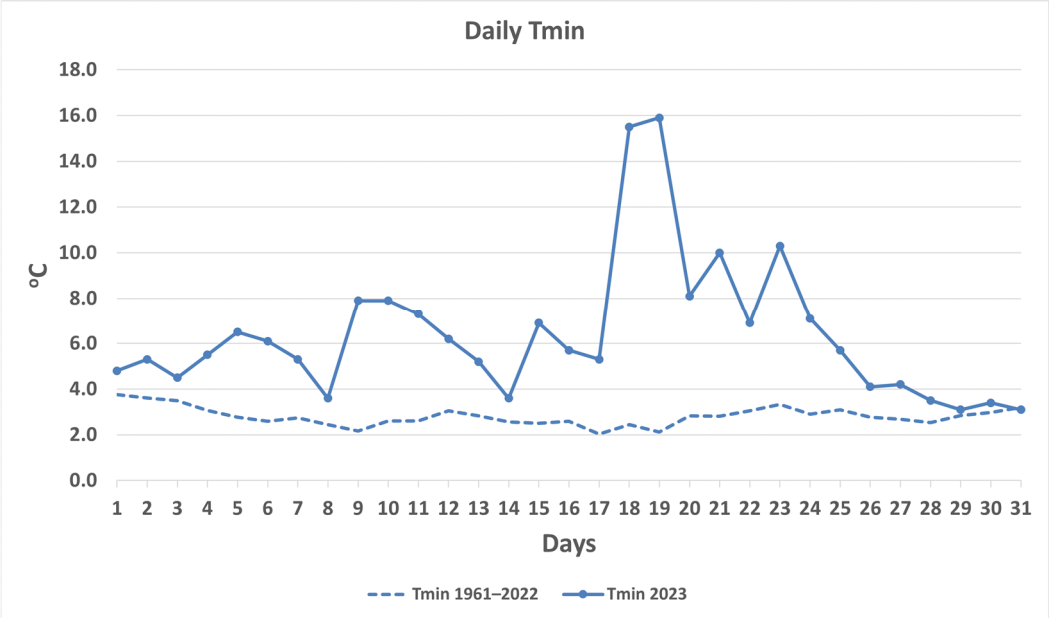

Figure 1. Daily minimum temperatures for January of 1961–2022 (dashed line) and 2023 (solid line).

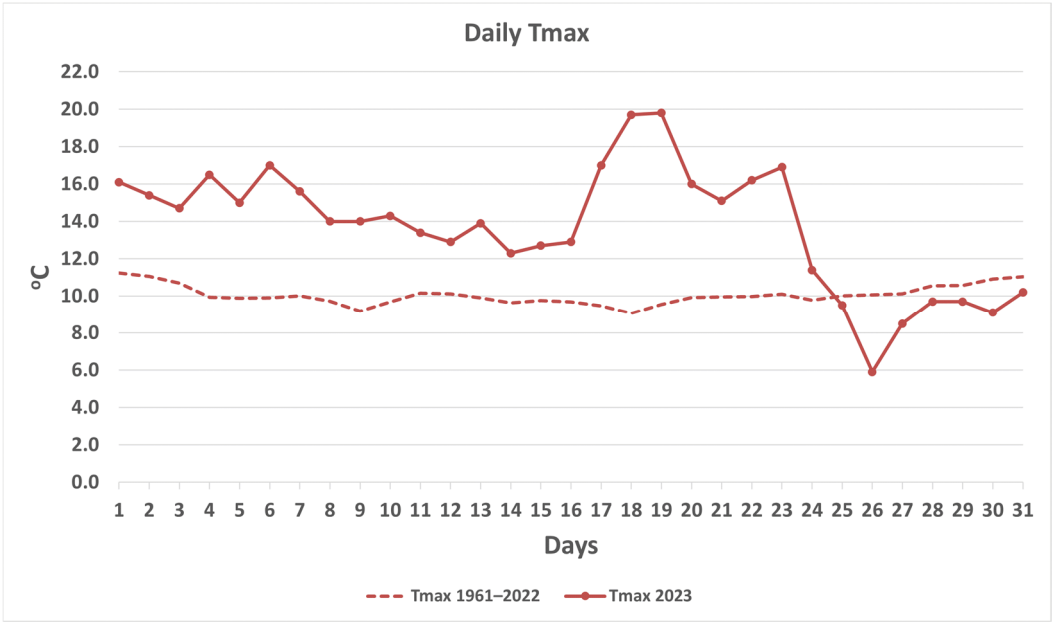

Figure 2. Daily maximum temperatures for January of 1961–2022 (dashed line) and 2023 (solid line).

3.2. Comparison with Future Simulations

The next step of this study was to compare the daily minimum and maximum temperatures of January 2023 and the corresponding mean daily Tmin and Tmax values of 1961–2022 with the projected daily Tmin and Tmax data derived from the RegCM4 regional climate model. As a result, the 25th and 75th percentiles of the two latter datasets were computed for two future periods (2041–2060 and 2081–2100).

Regarding Tmin (Figure 3), the 2023 Tmin values exceed the 25th percentile of the RegCM projections for both future periods. This is mainly during the second and third week of the month. Conversely, Tmin values of the long-term period 1961–2022 are below the 25th percentile of the two future periods. It is worth mentioning that the highest Tmin values of 2023 are rather exceptional as they exceed the 75th percentile of the two future periods according to the RCP4.5 scenario.

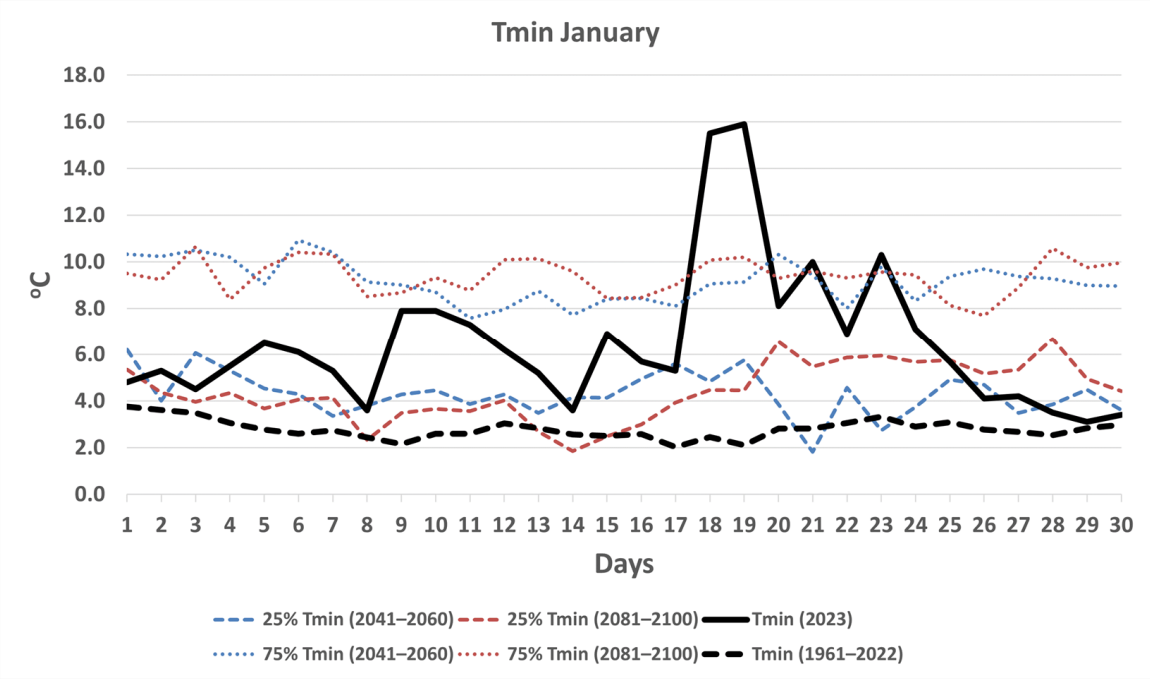

Figure 3. Comparison of daily minimum temperatures for January 2023 (solid line) and daily minimum temperature values for the 25th and 75th percentile (dashed and dotted lines respectively) of the future periods 2041–2060 (blue lines) and 2081–2100 (red lines) for the same month.

The results for Tmax (Figure 4) show a small exceedance of the 25th percentile of the future projections from the Tmax values of the period 1961–2022, mainly in the first two weeks of the month. Conversely, during the second half of the month, the Tmax values are almost equal to the 25th percentile of the second future period (2081–2100). Additionally, the 2023 Tmax values exceed the 75th percentile of the two future periods for the greatest part of the month. This exceedance is greater during the third week of January. It should be noted that, during the last week of January 2023, the Tmax values are below the 25th percentile of the future projections.

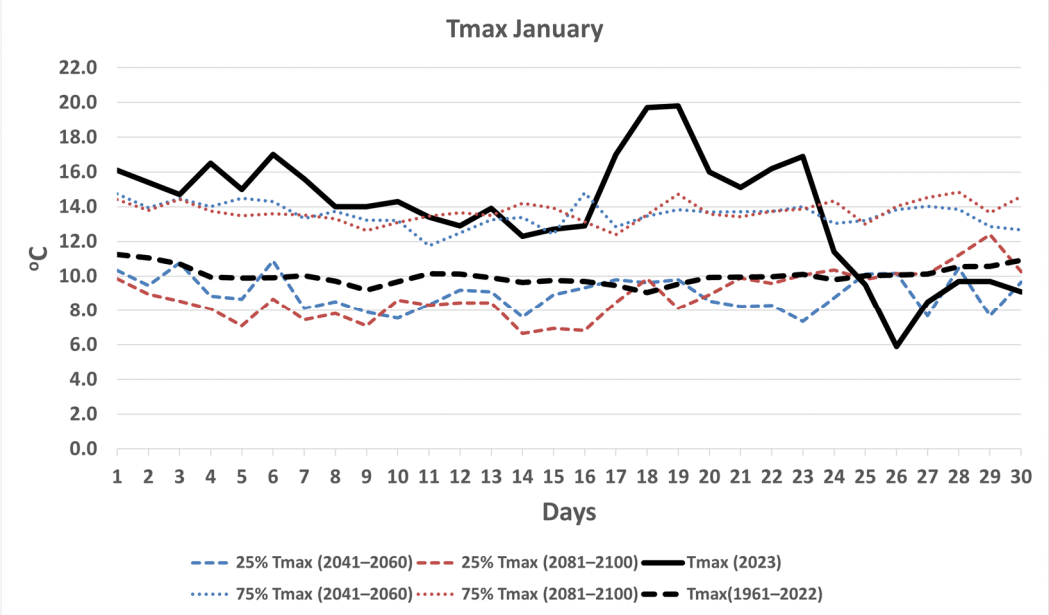

Figure 4. Comparison of daily maximum temperatures for January 2023 (solid line) and daily maximum temperature values for the 25th and 75th percentile (dashed and dotted lines respectively) of the future periods 2041–2060 (blue lines) and 2081–2100 (red lines) for the same month.

3.3. Synoptic-Scale Conditions

An investigation of the synoptic conditions for January 2023 was conducted. The maps of 500 hPa geopotential height anomaly (Figure 5a) and 850 hPa temperature field anomaly (Figure 5b) for January 2023 compared to the monthly mean of the long-term period (1961–2022) were analyzed (January 2023–January 1961–2022). Regarding the 500 hPa geopotential height anomaly, positive values were detected over E–NE Europe and eastern Mediterranean, with the center being located northeasterly of the Black Sea (anomaly exceeds 120 gpm). This extreme departure from the climatological mean leads to the conclusion that the geopotential heights do not usually reach such high values during January. In the case of the 850 hPa temperature field anomaly, rather high temperatures are observed during January as positive anomalies dominate in the greatest part of Europe and Mediterranean. The center is located NE of Greece and the anomaly exceeds 6 °C.

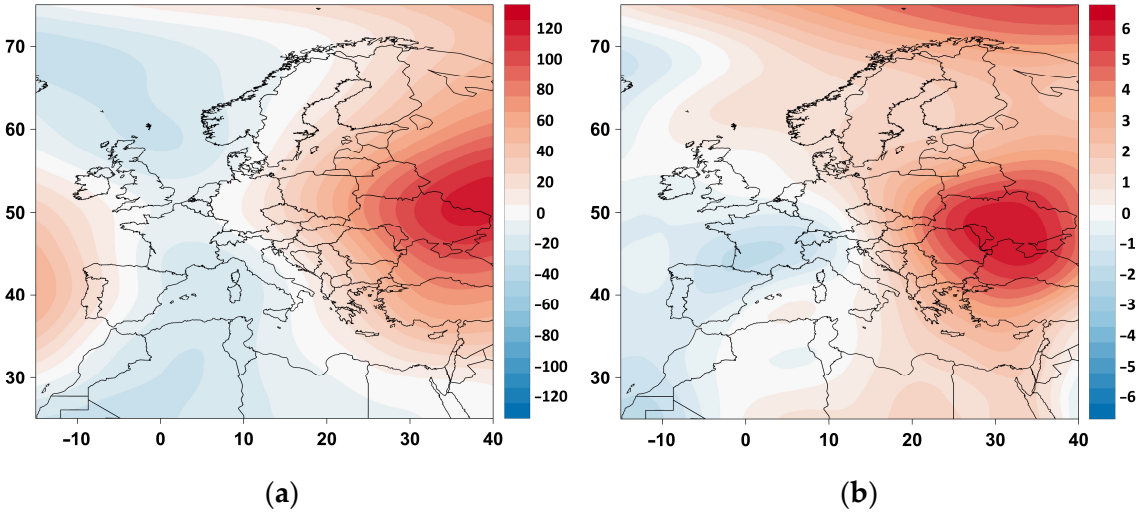

Figure 5. Maps for (**a**) 500 hPa geopotential height anomaly (gpm) and (**b**) 850 hPa temperature field anomaly (°C) for January 2023 compared to the monthly mean of the long-term period 1961–2022.

4. Conclusions

Extremely high temperatures are an increasingly common phenomenon. This is not only true during summer (heat waves) but also during winter months, with severe consequences for nature and humans. In this research, the minimum and maximum temperatures during January 2023 in Thessaloniki, Greece, were examined in order to determine whether this month was an extremely warm winter month for the area of study. The statistical analysis of the AUTh station observational data showed a rather extreme rise in the minimum temperatures during January 2023 (more than double that of the 1961–2022 period mean) throughout the month. These extremely high temperatures are related to the synoptic conditions at the 500 hPa and 850 hPa fields. The appearance of exceptionally warm air masses for the month in the 850 hPa temperature field and the significant increase in the geopotential heights in the 500 hPa field—compared to the long-term mean—contributed to the abnormally high Tmin and Tmax that were recorded in the area of study. Finally, the comparison of the observational data of both 2023 and 1961–2022 period with the corresponding simulated data from two future projections of RegCM4 model led to the conclusion that the occurrence of such Tmin and Tmax values is expected to be more frequent until the end of the 21st century (more than 50% for Tmin and 75% for Tmax).

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Data Availability Statement: A publicly archived dataset was analyzed in this study. The climatic dataset from Thessaloniki AUTh meteorological station is available online at https://meteo3.geo.auth.gr/stations/clim_data_2000.htm (accessed on 20 May 2023). The dataset from Regional Climate Model RegCM4 is derived from the author's doctoral thesis. The NCEP-NCAR Reanalysis dataset is publicly available online at https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html (accessed on 20 May 2023).

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Maheras, P.; Tolika, K.; Anagnostopoulou, C.; Velikou, K.; Pytharoulis, I. The thermal budget of 2012. In *Volume in Honour of Professor Apostolos Flokas*; Chelmis, K., Nastos, P., Eds.; Zitis Publications: Thessaloniki, Greece, 2014; pp. 107–116. (In Greek)
2. Bartzokas, A.; Houssos, E.E. Extreme temperature events in NW Greece. In Proceedings of the 10th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Crete, Greece, 17–20 October 2005.
3. Founda, D.; Papadopoulos, K.H.; Petrakis, M.; Giannakopoulos, C.; Good, P. Analysis of mean, maximum, and minimum temperature in Athens from 1897 to 2001 with emphasis on the last decade: Trends, warm events, and cold events. *Glob. Planet. Chang.* **2004**, *44*, 27–38. [CrossRef]
4. National Observatory of Athens—Meteo.gr. Available online: https://www.meteo.gr/article_view.cfm?entryID=2656 (accessed on 5 May 2023).
5. Giorgi, F.; Marinucci, M.R.; Bates, G.T. Development of a second-generation regional climate model (RegCM2). Part I: Boundary-layer and radiative transfer processes. *Mon. Wea. Rev.* **1993**, *121*, 2794–2813. [CrossRef]
6. Giorgi, F.; Marinucci, M.R.; Bates, G.T.; De Canio, G. Development of a second-generation regional climate model (RegCM2). Part II: Convective processes and assimilation of lateral boundary conditions. *Mon. Wea. Rev.* **1993**, *121*, 2814–2832. [CrossRef]
7. Elguindi, N.; Bi, X.; Giorgi, F.; Nagarajan, B.; Pal, J.; Solmon, F.; Rauscher, S.; Zakey, A.; O'Brien, T.; Nogherotto, R.; et al. *Regional Climate Model RegCM User Manual Version 4.4*; International Centre for Theoretical Physics (ICTP): Trieste, Italy, 2013.
8. Grell, G.; Dudhia, J.; Stauffer, D.R. *A Description of the Fifth Generation Penn State/NCAR Mesoscale Model (MM5)*; Technical Note, NCAR/TN-398+STR; University Corporation for Atmospheric Research: Boulder, CO, USA, 1994; p. 121. [CrossRef]

9. Velikou, K. Dynamical Downscaling of Regional Climate Model RegCM for the Greek Region: Statistical Assessment, Dynamical Evaluation, Effects and Future Scenarios. Ph.D. Thesis, Aristotle University of Thessaloniki, Thessaloniki, Greece, 12 February 2021.
10. Velikou, K.; Tolika, K.; Anagnostopoulou, C.; Zanis, P. Sensitivity analysis of RegCM4 model: Present time simulations over the Mediterranean. *Theor. Appl. Climatol.* **2019**, *136*, 1185–1208. [CrossRef]
11. Velikou, K.; Tolika, K. Comparison of two different setups of RegCM4 model over the Mediterranean: Present time simulations. In Proceedings of the 15th International Conference on Meteorology, Climatology and Atmospheric Physics, Ioannina, Greece, 26–29 September 2021.
12. Kalnay, E.; Kanamitsu, M.; Kistler, R.; Collins, W.; Deaven, D.; Gandin, L.; Iredell, M.; Saha, S.; White, G.; Woollen, J.; et al. The NCEP/NCAR 40-year reanalysis project. *Bull. Am. Meteor. Soc.* **1996**, *77*, 437–472. [CrossRef]
13. NCEP-NCAR Reanalysis 1. Available online: https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html (accessed on 20 May 2023).