

Article

Analyses of Climate Variations at Four Meteorological Stations on Remote Islands in the Croatian Part of the Adriatic Sea

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Abstract: The Mediterranean region is one of the regions in the world that is most vulnerable to the impact of imminent climate change. In particular, climate change has an adverse effect on both the ecosystem and socioeconomic system, influencing water availability for both human and environmental purposes. The most endangered water resources are along the coasts and on islands since they have relatively small volumes and are intensively exploited. We analyzed the time series of air temperature and precipitation measured at four meteorological stations (Komiža, Palagruža, Lastovo, and Biševo) located on small islands in the Croatian part of the Adriatic Sea in this study. The investigated time series extends from the 1950s to the present, being contemporaneous for approximately 50 years. Despite possessing discontinuity, they can be considered as representative for assessing climate change and variability in the scattered environment of the Croatian islands. The results showed increasing trends in the annual air temperature, while the annual cumulative precipitation did not show significant variations. In addition, the analyses of the monthly air temperature showed that statistically significant increasing trends occurred from April to August, suggesting a more severe impact during these months. These results are in accordance with regional and local studies and climate models. Although the climate variability during the analyzed period can be considered as moderate, the impact on water resources could be severe due to the combined effect of the increase in air temperature during warm periods and the intensive exploitation for tourism purposes.

Keywords: air temperature; precipitation; global warming; Mediterranean; Adriatic Sea

1. Introduction

Climate change continues to draw attention in the scientific community and the general public. The air temperature increase is the most common effect of global warming and this causes negative effects on local and regional economies and the social system, as well as environmental issues. Climate variability is a natural feature of a climate system and it is a consequence of the inherent variabilities of both the atmosphere and the oceans [1–3]. Human activities could add to this natural variability leading to climate change. The investigation of the climate and its modifications in a specific region require detailed local-scale analyses since the forces driving these modifications and their magnitudes could change during the year and at nearby locations. The results of these investigations can be used by stakeholders to implement appropriate, site-specific measures that could mitigate the impact of climate change on both natural and socioeconomic systems. Modifications of the climate can be

considered as climate change when significant variations in the statistical distribution of climate parameters occur over a relatively long period (a standard reference period generally longer than 30 years). Among climate parameters, air temperature and precipitation are used to analyze variations and changes in climate [2,4] since they are generally measured over a dense network of monitoring stations for a long time.

With more than 5000 islands of various sizes, the Mediterranean region is considered as one of the most diverse regions in the world from the geographical, geological, and biological points of view [5,6]. The population of this area is approximately 480 million, with one-third living along the coasts and approximately 10 million people on islands [7]. The Mediterranean region is recognized as one of the hotspots of climate change [8]. Rađa et al. [9] estimated that 20% of the Mediterranean population lives under permanent water stress. This peculiar condition is both natural, due to the water scarcity and the high intrinsic vulnerability of the water resources, and anthropogenic, due to the high population density and the sudden increases in water demand during the peaks of the touristic season. The most important source of fresh water is represented by groundwater, and precipitation is generally the sole source of recharge [10]. Islands of the Mediterranean region have limited fresh water resources that are more and more affected by droughts as a consequence of an increase in air temperature and changes in precipitation.

The Croatian coast comprises 79 islands, 525 islets, and 642 rocks and reefs [11,12]. Merely a few Croatian islands have favorable hydrological or hydrogeological conditions for a sufficient local water supply [11]. Numerous archaeological sites have been discovered in this area testifying to its important position and historical role [13,14]. Climate change will severely affect the Croatian coastal region during the 21st century. Climate models [2,15,16] predict an increase of the mean air temperature up to 5.5 °C and a slight decrease of precipitation but also the occurrence of more and more frequent extreme events, such as flash floods and droughts. These modifications of climate conditions could represent a serious threat to the population of Croatian islands that is highly scattered and relies on local fresh water resources.

This study aims to assess the occurrence of climate variability and change in remote islands with scarce fresh water resources. Time series of the annual and monthly air temperature and precipitation measured at four meteorological stations on remote islands of the Croatian coast are analyzed. First, we will describe the study area and the temperature and precipitation datasets. The results of the exploratory statistical analysis will be shown, and the annual and monthly trends will be described. The results will be used to assess the possible occurrence of climate change in this scattered part of the Adriatic coast providing an effective tool for more efficient water management of the local water resources through the rising challenge of climate change.

2. Study Area

The study area is located in the central part of the Adriatic Sea to the west of the southern Croatian mainland (Figure 1). This part of the Croatian coast is characterized by several islands with different sizes showing a predominant W–E or WSW–ENE direction. The analyzed meteorological stations are situated on small and very small islands (Vis, Biševo, Lastovo, and Palagruža) that are 43 to 54 km away from the mainland (Figure 1).



Figure 1. Map of the study area showing the locations of the four meteorological stations whose data were analyzed in this work.

The study area is part of the Outer Dinaric range, an area characterized by very deep and irregular karstification [9]. The investigated islands are mostly composed of Mesozoic carbonate rocks that are intensely fractured and karstified. Karst aquifers have a heterogeneous distribution of the hydrogeological properties influenced by the regional and local fracture networks and karstic conduits. Due to their peculiar hydrogeological settings, the groundwater resources in karst aquifers are irregularly distributed and highly vulnerable to seawater intrusion.

According to the Köppen climate classification, the study area is characterized by the Csa climate type [17]. It is a semiarid variety of Mediterranean climate, sometimes referred to as the “olive” climate, characterized by mild, humid, and rainy winters with dry and hot summers. Although temperature extremes (i.e., summer heating and winter frosty days) are mitigated, extreme precipitation events alternated with long periods of drought are common. Alpert et al. [18] demonstrated the paradoxical behavior of precipitation in the Mediterranean region showing both a decrease of the total rainfall but an increase in the extreme daily rainfall.

Vis Island is located 43 km from the mainland. The meteorological station on Vis is in the city of Komiža, in the western part of the island (Figure 1). As a result of favorable geological and hydrogeological conditions, Vis has a water supply from its own karst aquifer. Due to its distance from other islands as well as from the mainland, Vis and its archipelago are exposed to stronger winds than other islands in southern Croatia. Biševo Island is part of the Vis archipelago, and Biševo is located 5 km SW from Vis. The Biševo meteorological station is in the northern part of the island. On Biševo Island, the fresh water is obtained from rainwater harvesting.

The Lastovo archipelago is composed of 44 islands, islets, and rocky reefs covering 53 and 143 km² of land and sea surface area, respectively. The meteorological station is located in the town of Lastovo, in the northern part of the island. Lastovo has a distance from the mainland similar to Vis (Table 1). Part of the drinking water on Lastovo is obtained by desalination of brackish water from wells [11] and part is delivered through a regional water supply network from the mainland.

Table 1. Characteristics of the investigated islands and their meteorological stations.

	Lastovo	Komiža	Biševo	Palagruža
Type of Station	AMS and MMS	AMS and MMS	PS	AMS
A (km ²)	40.81	90.03	5.91	0.3
L (km)	48.5	43.5	53.69	51.69 (IT) 113.96 (HR)
H _{max} (m a.s.l.)	417	587	239	103
Latitude	42°46′06″	43°02′55″	42°59′13″	42°23′33″
Longitude	16°54′00″	16°05′13″	16°00′30″	16°15′20″
H _{station} (m a.s.l.)	186	20	65	98

Note: AMS—automatic meteorological station; MMS—main meteorological station; PS—precipitation station; A—*island area*; L—*island’s minimum distance from the mainland*; H_{max}—*the maximum altitude of the island*.

The Palagruža meteorological station, located on Velika Palagruža Island, is situated in the vicinity of the largest lighthouse in the Adriatic Sea, built in 1875. The Palagruža archipelago lies 51 km NE from the Italian coast and 113 km from the Croatian mainland. The archipelago consists of several very small islands and a dozen islets and rocky reefs [19–22]. The relatively low relief and exposure to the open sea result in the lowest amount of precipitation of the Dalmatian coast. The local meteorological conditions on Palagruža have been thoroughly investigated [23–25]. Fresh water is delivered to Palagruža with water carrier ships.

Vis and Lastovo islands are covered with dense Mediterranean vegetation. Biševo was covered with dense pine forest before it was devastated by fire in 1936. Although the vegetation recovered, it was again devastated by fire in 1994 and 2003. Palagruža is barren. The vegetation cover likely influences the climate variations, primarily air temperature, at stations analyzed within this study.

The main geographical characteristics of the investigated islands and the meteorological stations used in this study are summarized in Table 1.

3. Materials and Methods

3.1. Data Collection and Quality of Data

Data availability: The data used within this study are the property of the Croatian Meteorological and Hydrological Service (DHMZ). Terms of use, data availability, and contact can be found at: https://klima.hr/razno/katalog_i_cjenikDHMZ.pdf

The temperature and precipitation data used in this study were provided by the Croatian Meteorological and Hydrological Service (DHMZ). Meteorological data were collected at main meteorological stations (MMS, Table 1) and on the precipitation station (PS). At MMS, the temperature data is measured hourly, while the precipitation is measured once a day at 7 h (also at PS). MMS are equipped with minimum and maximum thermometers, and the absolute minimum and maximum temperature are measured once a day. In addition, most of the analyzed stations are equipped with automatic monitoring and recording systems (AMS). Due to the complexity of the automatic measurements of meteorological phenomena and gradual modernization of the meteorological network, many AMS still have human operators. At AMS, the time resolution of measurements is 10 min. The mean daily air temperature is given as:

$$t_{\text{mean,daily}} = \frac{t_7 + t_{14} + 2t_{21}}{4} \quad (1)$$

where t_7 , t_{14} , and t_{21} are the air temperature values measured at 7, 14, and 21 h (local time), respectively [26]. The daily air temperature data (i.e., minimum, mean, and maximum values) are usually processed by DHMZ to obtain the monthly statistics (i.e., the minimum, mean, and maximum values of daily temperature during a month, hereafter referred to as the minimum, mean, and maximum monthly air temperature, respectively). The monthly data were processed in the scope of this work to

calculate the annual statistics (i.e., the minimum, mean, and maximum values during a year, hereafter referred to as the minimum, mean, and maximum annual air temperature). Similarly to the temperature, monthly cumulative precipitation data were provided by DHMZ, while annual values were calculated.

Table 2 shows the time series recorded by the meteorological stations. The time series shows several interruptions, and the only station with continuous measurements was Lastovo. Missing data were excluded from the statistical analyses in this study. The temperature time series were considered as contemporaneous from 1958 to 2018 (missing 1964–1965, 1975, 1982–1985, 1993–1997, and 2011), while the precipitation time series were considered as contemporaneous from 1963 to 2018 (missing 1971, 1982–1986, 1990–1998, 2000–2001, and 2006). During the investigated period, external influences or modifications in the data collection (i.e., relocation of the station, change of sensors, and changes in observation rules) did not occur.

Table 2. Available time series of data used within this study.

		Minimum Temperature	Mean Temperature	Maximum Temperature	Precipitation
Lastovo	<i>Investigated period</i>	1/1949–12/2018	1/1948–12/2018	1/1948–12/2018	1/1949–12/2018
	<i>Missing data</i>	-	-	-	-
Komiža	<i>Investigated period</i>	1/1956–12/2018	1/1956–12/2018	2/1956–12/2018	1/1956–12/2018
	<i>Missing data</i>	3/1957–8/1957; 6/1982–2/1983; 7/1983–6/1984; 7/1985	3/1957–8/1957; 6/1982–2/1983; 7/1985	3/1957–8/1957; 6/1982–2/1983; 7/1985	3/1957–8/1957; 6/1982–2/1983; 7/1985
Biševo	<i>Investigated period</i>	-	-	-	2/1955–12/2018
	<i>Missing data</i>	-	-	-	3/1956–7/1957; 1/1991–2/1991
Palagruža	<i>Investigated period</i>	7/1949–12/2018	1/1950–12/2018.	2/1949–12/2018	1/1949–12/2018
	<i>Missing data</i>	11/1949; 9/1950–10/1950; 7/1954; 5/1956–6/1956; 1/1964–8/1964; 2/1965–8/1965; 1/1992; 3/1993–8/1995; 10/1995–2/1996; 5/1996–8/1996; 10/1996; 12/2011	9/1950–10/1950; 7/1954; 5/1956–6/1956; 8/1975–12/1975; 1/1993–8/1995; 5/1996–1/1997	11/1949; 9/1950–10/1950; 7/1954; 5/1955–6/1955; 10/1959–6/1960; 1/1992; 3/1993–7/1996	11/1949; 10/1950–11/1950; 1/1971–4/1971; 2/1982–3/1982; 7/1982–12/1982; 1/1983–4/1983; 6/1984–8/1985; 1/1986; 5/1992–7/1992; 10/1992; 12/1992; 3/1993–7/1994; 10/1994–9/1996; 12/1997–1/1998; 11/1998; 1/2000; 1/2001; 1/2006

3.2. Methods

The annual and monthly air temperature and precipitation were investigated in this study to assess their variations from the 1950s to the present and to highlight the modifications of their distributions within the different years. We employed different statistical methods. First, exploratory data analysis was performed to summarize the main statistical characteristics of the dataset. Afterward, regression analyses were used to detect the trends in the variables (air temperature or precipitation, respectively). Both linear and quadratic regressions were performed, and the correlation coefficients r

and R for the linear and quadratic regressions, respectively, were calculated. When the coefficients were comparable, the linear regression was preferred. To validate the observed trends and to assess their statistical significance, the Spearman Rank Order Correlation (SROC) nonparametric test was used. This test evaluates the monotonic relationship between two variables, thus providing a more general assessment of their correlation than the linear correlation coefficient. This approach was profitably used to investigate the existence of long-term trends in a hydrological time series [27]. Additionally, a significance test for assessing the statistical significance of the SROC coefficient was performed. The null hypothesis was that there was no monotonic association between the two variables.

The trend variations within the times series were also analyzed using the Rescaled Adjusted Partial Sums method (RAPS) [28–30]. This method can be applied to continuous time series detecting (i) subperiods with similar characteristics, (ii) a larger number of trends, (iii) sudden peaks or declines in values, (iv) irregular fluctuations, and (v) periodicity. RAPS is defined as:

$$RAPS_k = \sum_{t=1}^k \frac{Y_t - \bar{Y}}{S_y} \tag{2}$$

where Y_t = the value of the observed parameter at time t ; \bar{Y} = the mean value of the observed time series; S_y = the standard deviation of the observed time series and k = the number of observations. The visualization of the RAPS results over time allows the overcoming of small systematic changes in the records and the variability of data values [29,30].

In addition to their trends, the correlations among the time series were investigated. The differences of their statistical parameters were evaluated using the F-test and the t -test, while their correlations were assessed by calculating their linear correlation coefficient. In particular, the F-test of equality of variances was used to compare the variances of two populations, and its null hypothesis was that two normal populations have the same variance. The t -test was used to determine if there was a significant difference between the means of two groups, and its null hypothesis was that two normal populations have the same mean value.

4. Results

4.1. Exploratory Analysis of the Data

Table 3 shows a summary of the statistical analysis performed on the annual air temperature and the annual cumulative precipitation values at the analyzed stations, while the results of the analysis for the monthly data are reported in Tables S1 and S2 of the Supplementary Materials for the monthly temperature and precipitation, respectively. In addition, the p -values of the F-test and the t -test for comparing the populations of the time series are reported in Tables S3 and S4 of the Supplementary Materials for the annual air temperature and the annual precipitation, respectively.

Table 3. Statistics (minimum, average, and maximum) of the annual minimum, mean, and maximum air temperature and of the annual cumulative precipitation at the analyzed stations. The range of the annual air temperature was calculated subtracting the minimum annual temperature from the maximum annual temperature. The total dataset includes all available data. The contemporaneous temperature dataset spans from 1958 to 2018 (missing 1964–1965, 1975, 1982–1985, 1993–1997, and 2011), while the contemporaneous precipitation dataset spans from 1963 to 2018 (missing 1971, 1982–1986, 1990–1998, 2000–2001, and 2006).

		Annual Temperature (°C)				Precipitation
		Minimum	Mean	Maximum	Range	(mm)
Lastovo; Total Dataset	Minimum	−6.80	14.66	31.70	29.80	368.00
	Average	−1.30	15.80	34.78	36.08	666.48
	Maximum	4.00	17.41	38.30	42.70	1088.60

Table 3. Cont.

		Annual Temperature (°C)				Precipitation
		Minimum	Mean	Maximum	Range	(mm)
Lastovo; Contemporaneous Dataset	Minimum	−6.80	14.66	31.70	30.00	376.90
	Average	−1.18	15.89	34.94	36.12	690.31
	Maximum	4.00	17.41	38.30	42.70	1008.30
Komiža; Total Dataset	Minimum	−4.50	15.50	32.10	29.50	426.00
	Average	−1.12	16.71	35.01	36.03	792.00
	Maximum	3.00	18.00	38.80	43.20	1269.00
Komiža; Contemporaneous Dataset	Minimum	−4.50	15.50	32.50	30.90	426.00
	Average	−1.09	16.71	35.09	36.17	836.09
	Maximum	3.00	17.90	38.80	43.20	1269.00
Biševo; Total Dataset	Minimum	-	-	-	-	255.10
	Average	-	-	-	-	617.01
	Maximum	-	-	-	-	1045.30
Biševo; Contemporaneous Dataset	Minimum	-	-	-	-	374.00
	Average	-	-	-	-	640.34
	Maximum	-	-	-	-	1045.30
Palagruža; Total Dataset	Minimum	−4.30	15.60	30.00	25.50	109.90
	Average	1.06	16.57	32.64	31.56	314.92
	Maximum	5.60	18.00	36.40	37.80	541.10
Palagruža; Contemporaneous Dataset	Minimum	−2.60	15.60	30.00	26.20	109.90
	Average	1.04	16.61	32.75	31.71	326.34
	Maximum	5.60	18.00	36.40	37.80	541.10

4.2. Analyses of Annual Air Temperature Time Series

Figure 2 shows the time series of all available minimum, mean, and maximum annual air temperature measured at the stations Komiža, Lastovo, and Palagruža.

The minimum temperature ranged from −6.8 °C to 4 °C at Lastovo, from −4.5 °C to 3 °C at Komiža, and from −4.3 °C to 5.6 °C at Palagruža (Table 3). The statistical analyses evidenced (i) similar ranges (Table 3) and variances reflecting the failure to reject the null hypothesis of F-tests (i.e., high *p*-values; Table S3); and (ii) a higher average value in Palagruža than those in Komiža and Lastovo (Table 3) with the rejection of the null hypothesis of the *t*-test for Palagruža versus Komiža and Lastovo (i.e., low *p*-values; Table S3). These differences were corroborated by the linear regression results. All three stations showed an increase in the minimum temperature values, but this was not statistically significant (SROC *p* > 0.05).

The values of the mean annual air temperature were similar for all the stations ranging from approximately 15 °C to 18 °C. The statistical analyses evidenced (i) similar ranges and variances (Table 3) failing to reject the null hypothesis of the F-tests (Table S3); and (ii) similar average values for Komiža and Palagruža and higher than the average values of Lastovo (Table 3) resulting in both the failure to reject the null hypothesis of the *t*-tests for Palagruža versus Komiža and the rejection of the null hypothesis of the *t*-test for the other analyses (Table S3). The linear regressions evidenced increasing trends for all of the time series (Figure 2), which were corroborated by the results of the SROC tests showing statistically significant increasing trends (*p* < 0.01). The quadratic regressions were also tested, obtaining slightly higher R values than the linear correlation coefficient *r* (Figure 2). These regressions evidenced stability or a slight decrease in the mean annual air temperature until the 1970s followed by a gradual increase in the 1980s and a rapid increase from the 1990s.

The maximum annual air temperature was up to 38.3, 38.8, and 36.4 °C at Lastovo, Komiža, and Palagruža, respectively. The statistical analyses evidenced (i) similar ranges (Table 3) and variances and the failure to reject the null hypothesis of the F-tests (Table S3); and (ii) similar average values for

Komiža and Lastovo being 2.4 °C higher than the average value of Lastovo (Table 3) and the failure to reject the null hypothesis of the *t*-tests for Komiža versus Lastovo (Table S3). We performed both linear and quadratic regressions. All three stations showed increasing trends in the maximum annual air temperature, and the SROC test corroborated these results ($p < 0.01$) while quadratic regressions evidenced an increase from the 1980s (Figure 2).

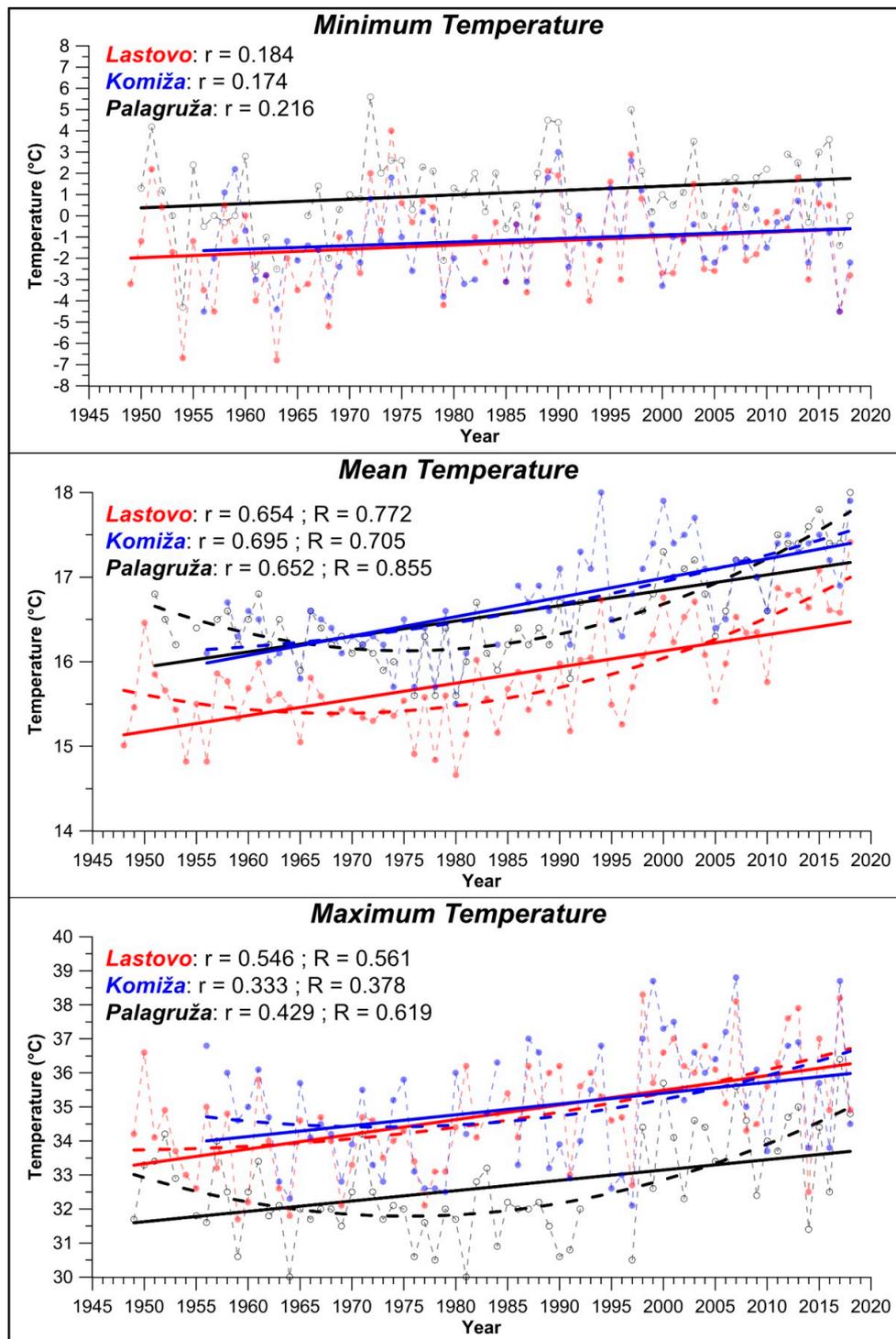


Figure 2. Time series of the minimum, mean, and maximum annual air temperature measured at the Komiža, Lastovo, and Palagruža stations. The *r* and *R* represent the correlation coefficients of the linear and quadratic regressions, respectively.

The annual air temperature ranges (i.e., the maximum annual temperature minus the minimum annual temperature) were investigated (Figure 3; Table 3). They were comparable at Komiža and Lastovo with average values of 36 °C, and these were approximately 4.5 °C higher than at Palagruža. The time series showed slightly increasing values, although the low values of the linear correlation coefficient r and the results of the SROC test pointed to a low significance of the observed variations (SROC $p > 0.05$).

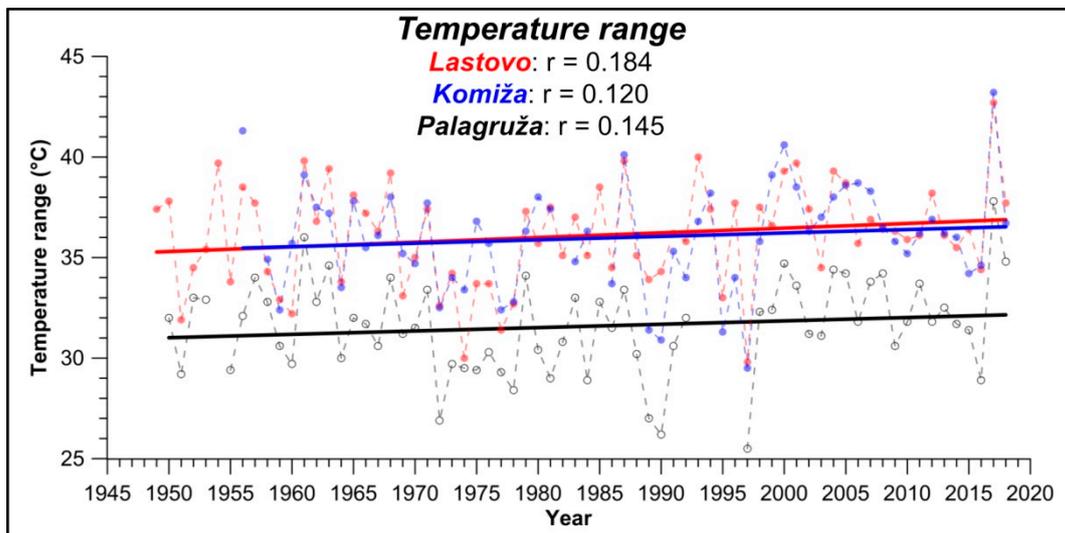


Figure 3. Annual air temperature ranges at Komiža, Lastovo, and Palagruža. The range was calculated subtracting the minimum annual temperature from the maximum annual temperature. r is the linear correlation coefficient.

The RAPS method has been used on the time series of annual air temperature measured at Lastovo (Figure 4) as it was the only station showing a continuous recording (Table 2).

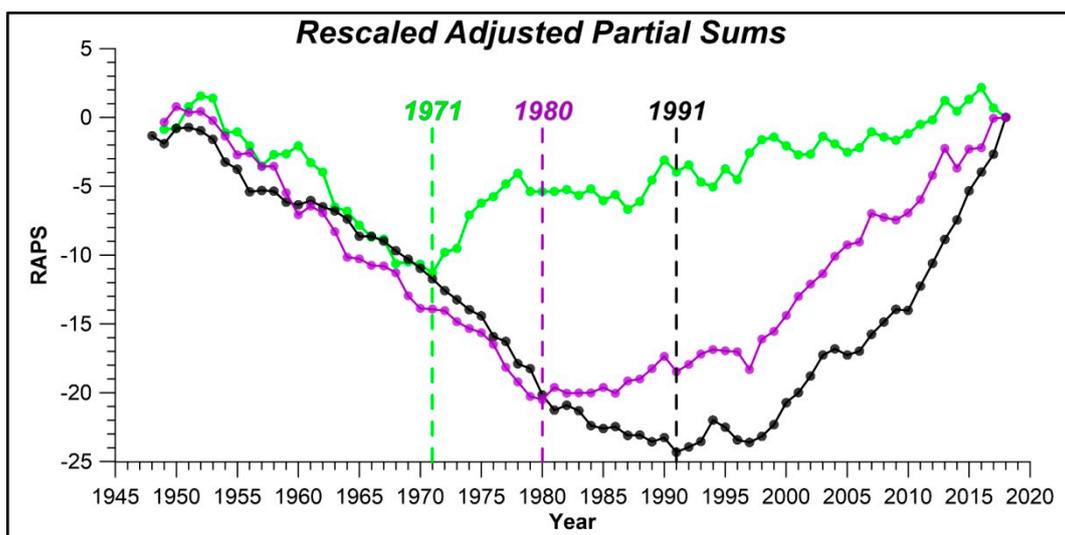


Figure 4. Rescaled Adjusted Partial Sums (RAPS) values for the minimum (green), mean (black), and maximum (purple) annual air temperature measured at the Lastovo station.

The results indicated two different trends in RAPS values. The RAPS of the minimum annual air temperature (green line in Figure 4) showed a sharp decrease until 1971 followed by an initially sharp and subsequently moderate increase. The RAPS of the mean annual air temperature (black line in Figure 4) showed a sharp decrease from the 1950s to the 1970s and a moderate decrease in the 1980s. A moderate increase started in 1992 followed by a sharp increase from the end of the 1990s. The RAPS of the maximum annual air temperature (purple line in Figure 4) showed a sharp decrease until the 1970s followed by a gradual increase in the 1980s–1990s and a sharp increase from the end of the 1990s.

4.3. Analyses of the Characteristic Monthly Air Temperature Time Series

The exploratory data analysis of the minimum, mean, and maximum monthly air temperature measured at the analyzed stations is reported in Table S1 of the Supplementary Materials. Table 4 shows the linear correlation coefficients r calculated for the monthly time series. The results of the SROC test were used to highlight the statistically significant correlations.

Table 4. The linear correlation coefficient r calculated from the contemporaneous dataset of the minimum, mean, and maximum monthly air temperature. The values in red correspond to the months that showed statistically significant results of the SROC test ($p < 0.01$).

Month	Minimum			Mean			Maximum		
	Komiža	Lastovo	Palagruža	Komiža	Lastovo	Palagruža	Komiža	Lastovo	Palagruža
1	0.165	0.185	0.203	0.272	0.164	0.241	0.075	0.01	−0.057
2	0.166	0.15	0.13	0.132	0.142	0.102	0.224	0.039	0.026
3	0.256	0.245	0.247	0.301	0.307	0.3	0.25	0.291	0.137
4	0.283	0.132	0.212	0.394	0.351	0.361	0.286	0.289	0.224
5	0.534	0.277	0.453	0.354	0.406	0.385	0.261	0.386	0.32
6	0.471	0.298	0.276	0.583	0.513	0.491	0.494	0.521	0.47
7	0.559	0.364	0.225	0.591	0.577	0.518	0.317	0.459	0.429
8	0.415	0.371	0.367	0.454	0.494	0.481	0.33	0.394	0.35
9	0.276	0.033	0.082	0.18	0.144	0.187	0.216	0.156	0.302
10	0.32	0.166	0.206	0.235	0.247	0.279	0.014	0.218	0.01
11	0.311	0.149	0.247	0.208	0.23	0.219	0.22	0.273	0.133
12	0.144	0.02	0.03	0.144	−0.003	0.004	0.135	0.061	0.003

Statistically significant increasing trends for all analyzed variables (high r values; Table 4) were generally observed in the warmer periods of the year (April–August), while the temperature variations were moderate (low positive or negative r values; Table 4) during the colder part of the year (September–March).

The mean monthly air temperature shown in Figure 5 can be considered as representative of the behavior of all monthly variables. For each month, the mean air temperature values calculated for each year of the investigated period (Table 2) are plotted. The spring and summer months showed a moderate to the rapid increase of the air temperature, while random fluctuations with unsystematic spikes were observed during the autumn and winter months. In particular, the most rapidly increasing trends at all analyzed stations occurred in July, as corroborated by the highest r values of the time series for this month (Table 4).

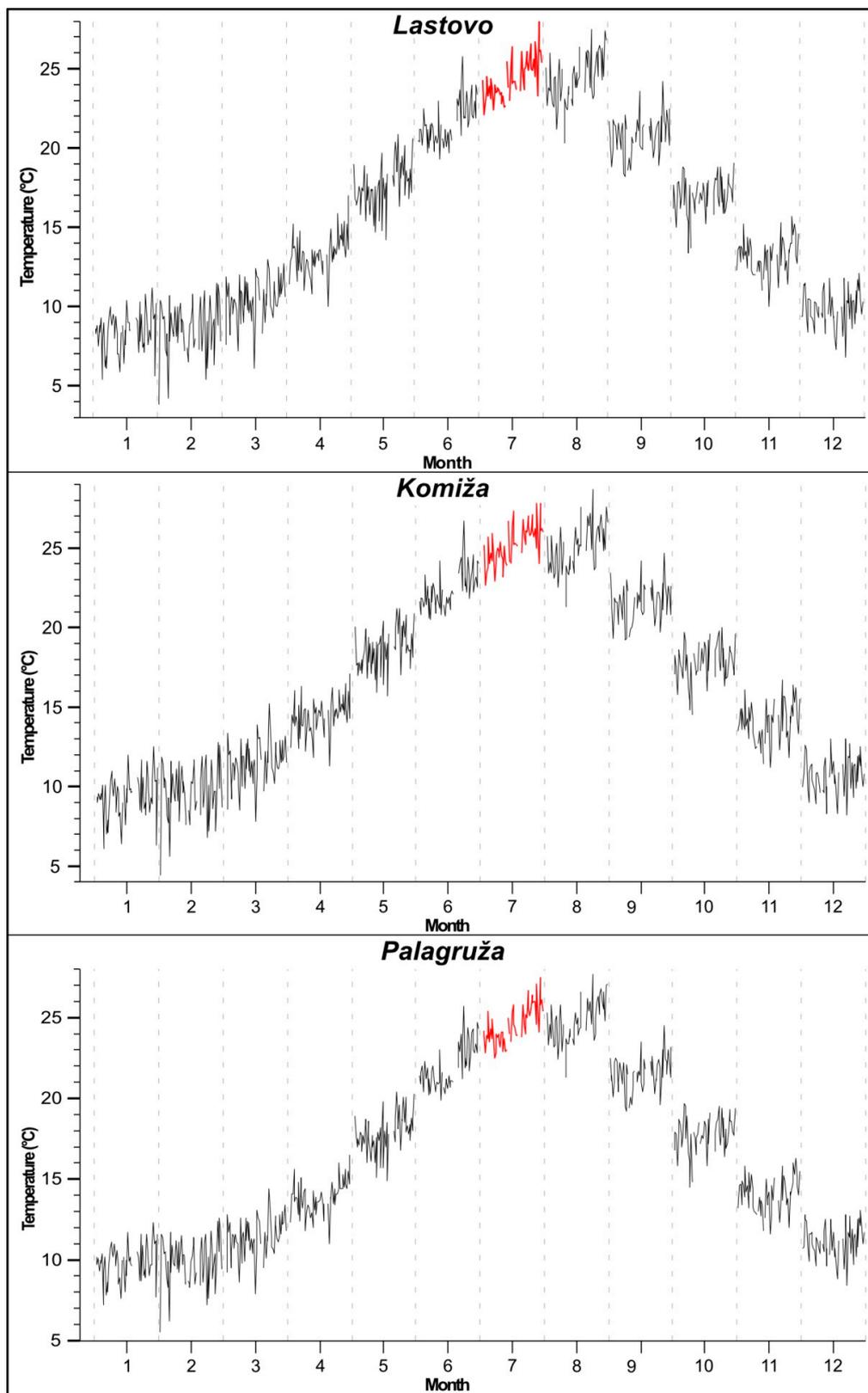


Figure 5. Monthly subseries plot of the mean air temperature at the Lastovo, Komiza, and Palagruža stations. Within a month, the mean monthly values were plotted in chronological order over the period 1958–2018 (Table 2). The time series of July (in red) shows the most prominent increasing trends as suggested by the highest linear correlation coefficient r values (Table 4).

Figure 6 shows the temperature differences of the average monthly minimum, mean, and maximum air temperature between the analyzed stations demonstrating the differences in their temperature regimes. The average monthly minimum air temperature at Palagruža was always higher than at Komiža and Lastovo. Their differences fluctuated throughout the year and were the highest in January, February, and October and the lowest during July.

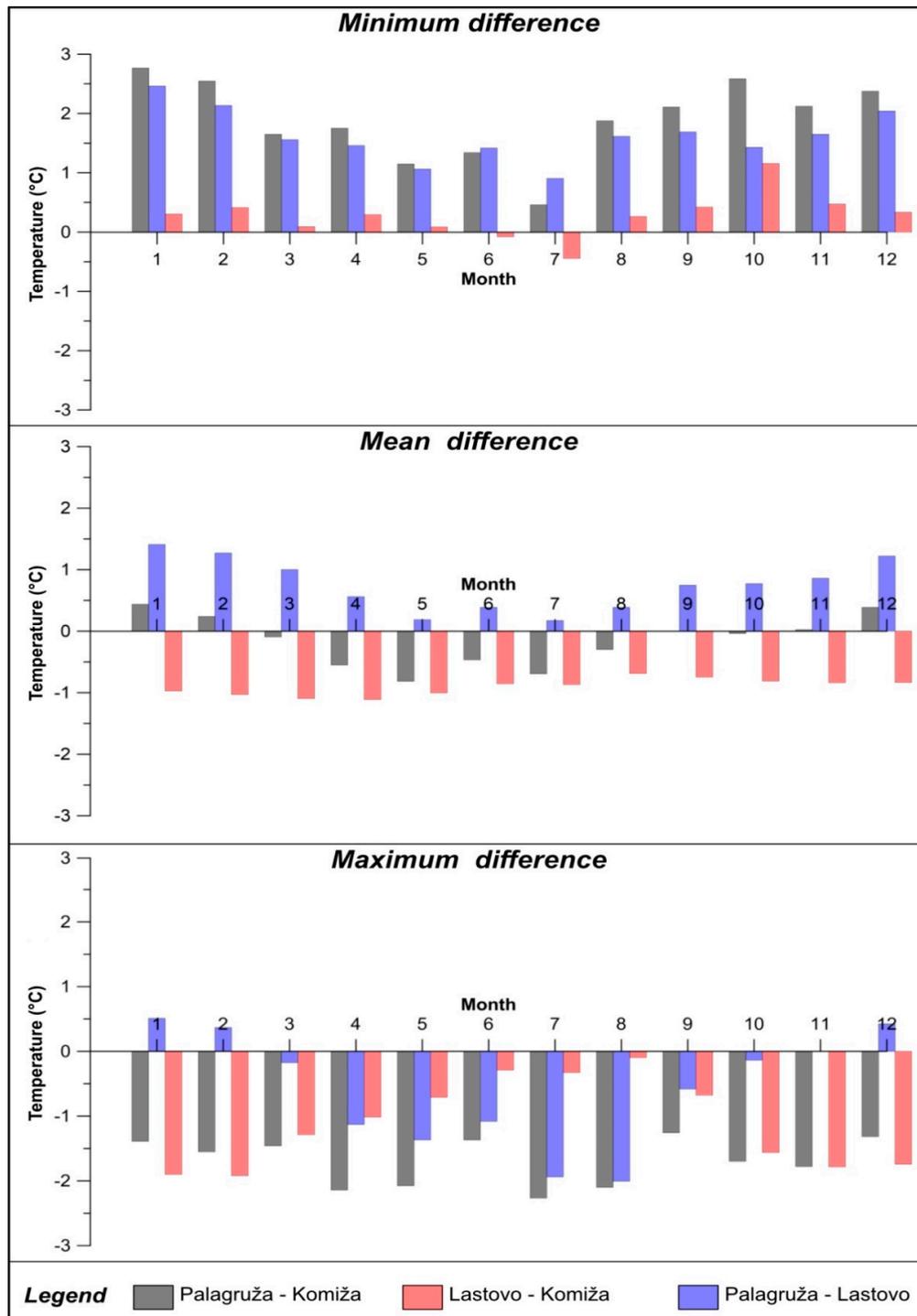


Figure 6. The minimum, mean, and maximum monthly air temperature differences between stations. The differences were calculated based on contemporaneous datasets. Palagruža and Komiža stations (shown in gray), $\Delta T_{P-K} = \text{av} T_P - \text{av} T_K$; Lastovo and Komiža (shown in red), $\Delta T_{L-K} = \text{av} T_L - \text{av} T_K$; and Palagruža and Lastovo (shown in blue), $\Delta T_{P-L} = \text{av} T_P - \text{av} T_L$.

The average monthly mean air temperature at Palagruža was slightly higher than at Komiža during January, February, and December and nearly equal during March, September, October, and November (Figure 6). Palagruža had a higher mean monthly air temperature than Lastovo, and their differences ranged from 0.2 °C to 1.4 °C. The monthly mean air temperature at Lastovo was always lower than at Komiža with a fairly constant difference throughout the year.

The average monthly maximum air temperature at Palagruža was lower than at Komiža in each month and lower than at Lastovo except during the winter period. The maximum temperature at Komiža was always higher than at Lastovo, and their differences ranged from 0.01 °C in August to 1.9 °C in February.

4.4. Analyses of Annual Precipitation Time Series

The annual precipitation was analyzed at four measuring stations (Table 2). During the investigated period, it ranged from 376 to 1008 mm at Lastovo, 426 to 1269 mm at Komiža, 374 to 1045 mm at Biševo, and 109 to 541 mm at Palagruža (Table 3). The statistical analyses evidenced (i) similar ranges and variances for Lastovo, Komiža, and Biševo reflecting the failure to reject the null hypothesis of the F-tests (i.e., high p -values; Table S4), (ii) the lower average value at Palagruža than at Komiža, Lastovo, and Biševo (i.e., low p -values) with the rejection of the null hypothesis of the t -test for Palagruža versus Lastovo, Komiža, and Biševo. (i.e., low p -values; Table S4); and (iii) similar values of cumulative precipitation at Lastovo and Biševo (i.e., high p -values; Table S4). The linear correlation coefficients r close to 0 indicated the lack of a correlation between the precipitation and the time. Random fluctuations around the average values were observed, and systematically lower precipitation only occurred at the beginning of the 1990s and 2000s. The mean value of the cumulative annual precipitation was the highest at Komiža with 836 mm and the lowest at Palagruža with only 326 mm of precipitation (Figure 7). These results suggest that the amount of precipitation decreases with the distance from the mainland (Table 1), but an effect of the station's altitudes cannot be excluded.

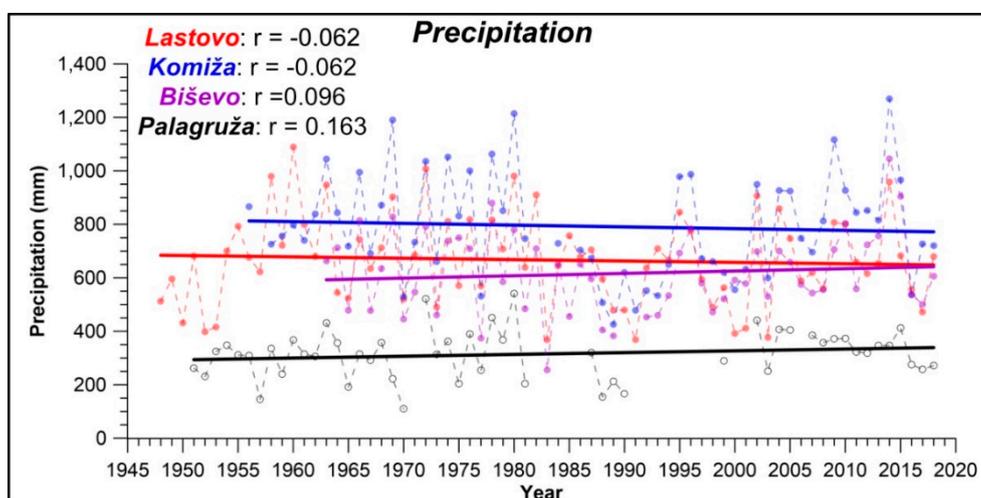


Figure 7. Annual precipitation time series. The linear correlation coefficient r was calculated from the total datasets.

4.5. Analyses of Monthly Precipitation Time Series

The distribution of precipitation through the months of the year is an essential factor that affects all environmental processes. The mean and maximum values of the monthly precipitation were analyzed at four measuring stations (Figure 8).

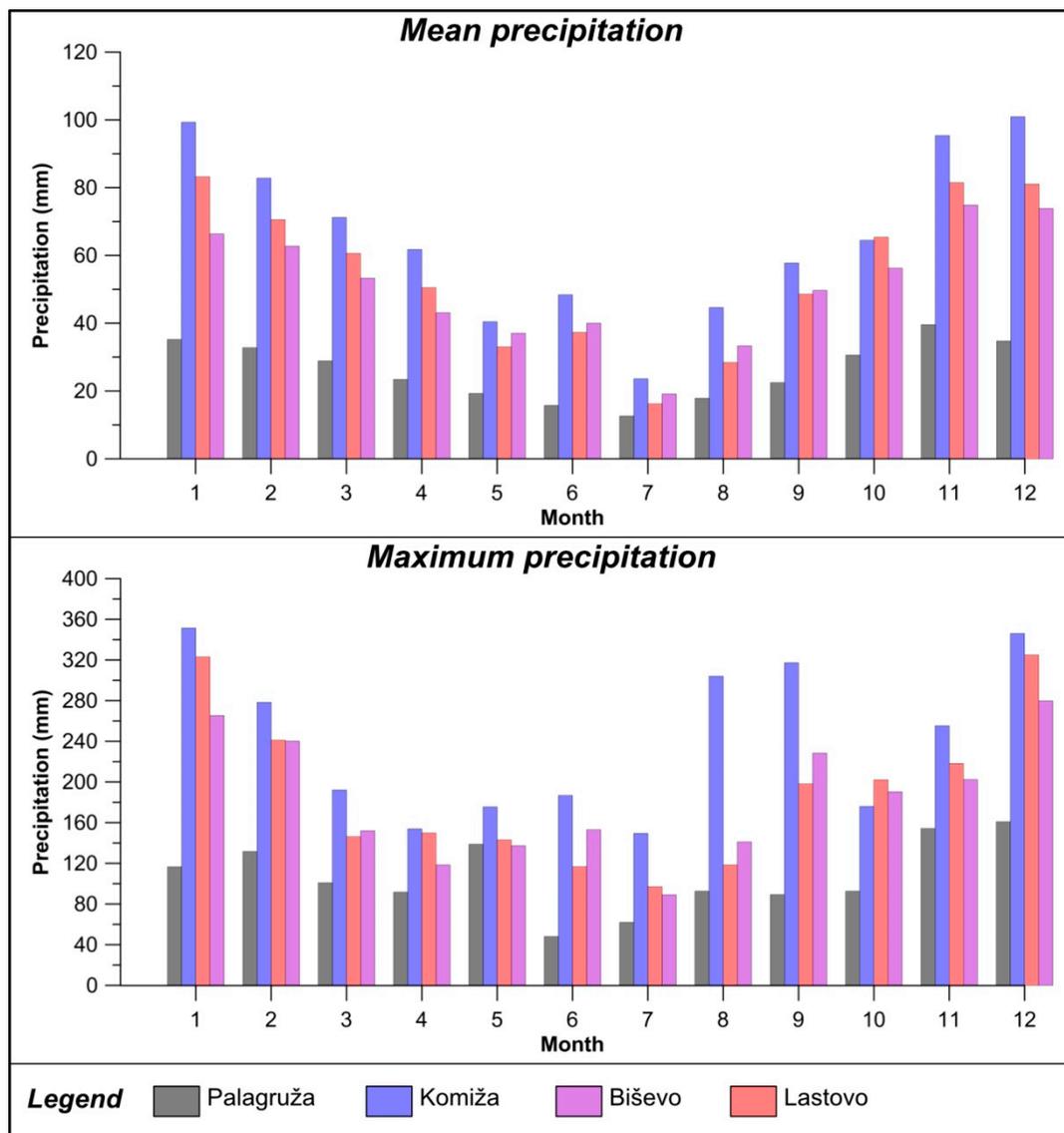


Figure 8. Histograms of the mean and maximum values of the monthly precipitation at the analyzed stations.

The mean values of monthly precipitation ranged from 12 to 39 mm at Palagruža, 23 to 100 mm at Komiža, 19 to 75 mm at Biševo, and 16 to 83 mm at Lastovo (Figure 8). These different ranges reflect the distance of the stations from the mainland as shown by their mean annual values (Tables 1 and 3). The distribution over one year was similar at all stations. The highest precipitation occurred during January, November, and December and the lowest during July and August.

The maximum values of monthly precipitation occurred during January and December at the Komiža, Biševo, and Lastovo stations while, at Palagruža, the maximum precipitation occurred during November and December. The highest monthly precipitation of 351.4 mm was measured at Komiža in January 1978 (Figure 8). During August and October, Komiža had significantly higher values of maximum precipitation than the other stations. The maximum value of monthly precipitation at the Palagruža station was significantly lower than at other stations with only 160 mm in December 2002.

5. Discussion and Conclusions

The annual and monthly air temperature and precipitation data were analyzed from four meteorological stations located on remote islands in the Adriatic Sea (Vis, Biševo, Lastovo, and

Palagruža; Figure 1). Statistical analyses, significance tests, and correlation analyses (i.e., linear and quadratic regressions, Spearman Rank Order Correlation) were performed to investigate the trends of the time series and their relationships. Different trends, as well as trend variations within a time series, were observed. Due to the heterogeneous behavior of the variables, the linear correlation represents the most consistent approach for a comprehensive and homogeneous comparison of the analyzed time series.

Increasing trends in the annual air temperature were observed (Figure 2). During the investigated period, the mean temperature increased by 0.034, 0.029, and 0.018 °C/y at Lastovo, Komiža, and Palagruža, respectively. The mean annual air temperature increased rapidly from the 1990s while the maximum annual air temperature rapidly increased from the 1980s (Figure 2). The RAPS results from the Lastovo time series corroborated these results (Figure 4). In particular, the increases in the mean annual air temperature at Lastovo were 0.004 and 0.053 °C/y from 1948 to 1991 and from 1992 to present, respectively. These results are in accordance with findings in several stations of Croatia and the western Balkan region, where warming started between 1987 and 1997 [29–31]. In particular, the rapid warming started in 1992 at the nearby meteorological stations of Hvar, Korčula, and Split (Figure 1) was in accordance with the RAPS results of Lastovo [30]. These results fit with the acceleration in warming from 1975 observed at a global scale [32]. However, numerous authors reported that the increasing trends in the Mediterranean area were higher than the global values, e.g., [16,32–34]. Increasing trends at Lastovo, Komiža, and Palagruža were consistent with increasing trends in the Adriatic region of 0.07–0.22 for 1951–2010, as well as with 0.29–0.71 °C/decade for 1981–2010 [16]. In addition, a comparison to the Berkeley Earth datasets [34] regarding the mean rate of air temperature change (°C/century) showed similar warming rates of 2.94 ± 0.26 , 3.54 ± 0.33 , and 3.35 ± 0.40 °C/century for Europe, Croatia, and Split, respectively.

Statistically significant increasing trends in the monthly air temperature occurred only in the warmer periods of the year, from April to August (Table 4). The most prominent increasing trends in the mean air temperature were observed in July at all analyzed stations (Figure 5). Hence, we concluded that the effects of global warming on increasing air temperature were higher in the warmer periods of the year at the analyzed stations. Pronounced warming in the summer season was previously reported by several authors, e.g., [16,29].

The lower warming intensity during the colder periods of the year is most likely a result of the influence of the sea temperature. The study area is located along the Palagruža sill and between the Mid and the South Adriatic pits, the deepest areas of the Adriatic Sea [35]. In the proximity of these pits, the highest annual mean air temperature at sea level is observed [36] and the sea acts as a temperature buffer resulting in milder summer and warmer autumn and winter. The microclimatic conditions at all stations strongly reflect the maritime influence, which, compared to stations located on the mainland, is apparent through (i) lower summer air temperature, (ii) lower amplitudes of the annual air temperature, (iii) lesser cloud cover, (iv) lesser precipitation, and (v) higher relative humidity.

The distribution of precipitation through the months of the year is an essential factor that affects all environmental processes. Annual precipitation time series showed neither increasing nor decreasing trends at the analyzed stations (Figure 7). The highest value of the cumulative annual precipitation was 1269 mm at Komiža while the lowest was only 109 mm at Palagruža (Table 3). The amount of precipitation decreased with distance from the mainland, but could be also affected by the altitude and the position of the measuring station.

The annual precipitation trends reflect monthly trends in terms of Komiža receiving the highest precipitation and Palagruža the lowest. The highest monthly precipitation occurred during January, November, and December and the lowest during July and August. Statistical analyses of the monthly precipitation trends were performed for Lastovo, as the only station with continuous records from 1948 to 2018. Statistically significant increasing or decreasing trends cannot be seen in the months of the year. Global and regional precipitation patterns showed a mix of increasing and decreasing trends, and most were statistically insignificant, e.g., [16,33,37].

The similarity between the climate regimes in the study area was corroborated by the relation between the island distances and the correlation coefficients of their mean annual air temperature and precipitation (Figure 9). The values of the linear correlation coefficients of air temperature were very high and ranged from at the lowest, $r = 0.894$, for the furthest stations at Komiža and Palagruža, to the highest, $r = 0.977$, for the closest stations at Palagruža and Lastovo. As anticipated, the highest linear correlation coefficient of precipitation, $r = 0.863$, occurred between Komiža and Biševo, as their distance is 9.3 km. Other pairs of stations, having similar distances from each other, ranging from 63.5 to 76.3 km, showed varying linear correlation coefficients from $r = 0.582$ to $r = 0.732$.

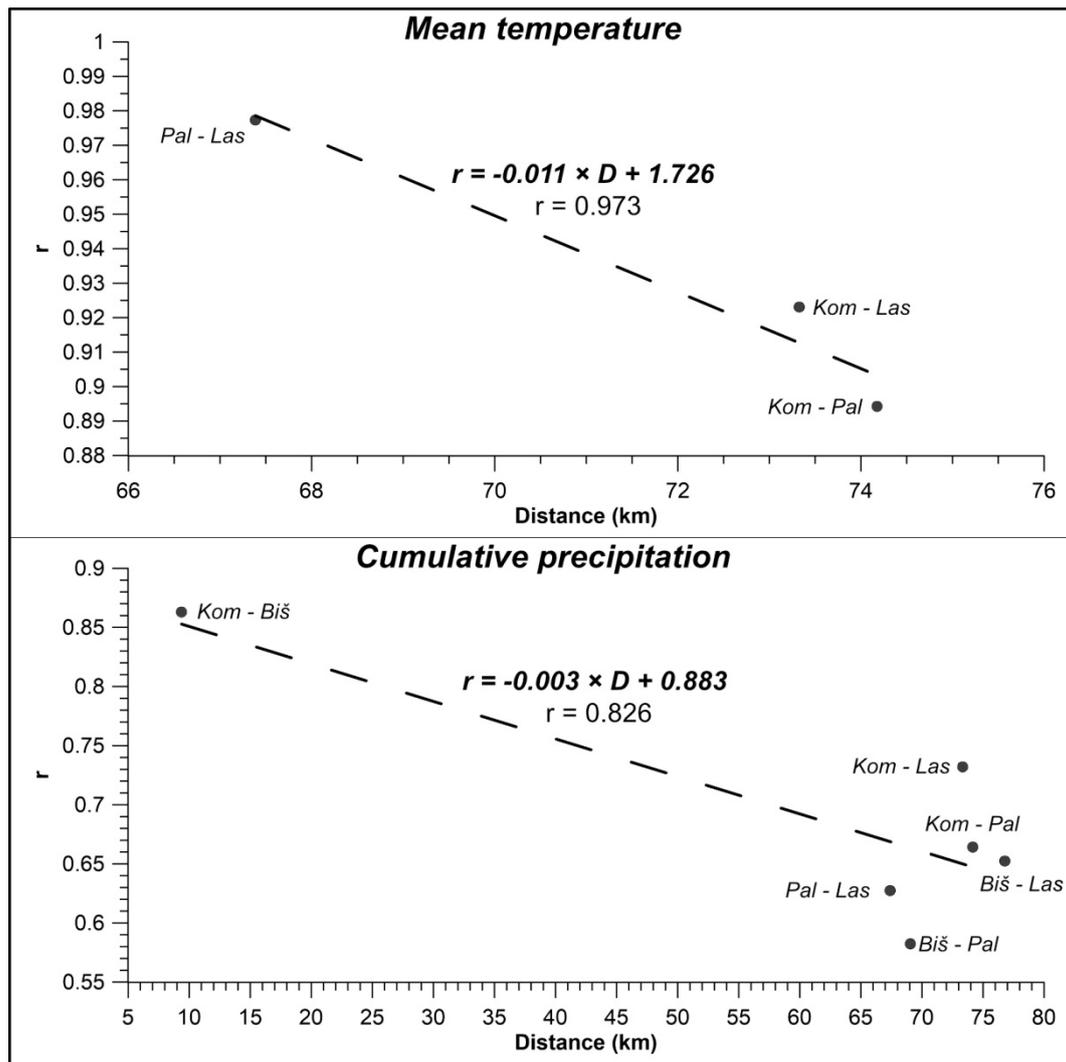


Figure 9. The ratio of the linear correlation coefficient r of the mean annual air temperature (up) and precipitation (down) against the distance between stations, L.

Air temperature is an important factor for explaining and addressing past events and for foreseeing future significant climate modification ascribable to global warming processes [38]. Therefore, it is essential to continue detailed monitoring and predict future trends in air temperature at different locations. Climate models for the Mediterranean region predict a gradual decrease in precipitation and an increase in variability, with a negative influence on the water balance [39]. The main conclusions of this study, namely an increase in air temperature, corroborate the results based on climate models. An increasing trend in air temperature could have a negative effect on the water balance through higher evapotranspiration and decreased recharge.

However, there are insufficient meteorological stations in the investigated area. Another drawback is the lack of data from investigated stations due to the cease of work. Precipitation can significantly differ between nearby locations, especially on remote islands with dynamic topography. Therefore, it is necessary to improve meteorological measurements that would allow for a more detailed investigation of precipitation regimes. Detailed monitoring and investigation of storm events could reveal how the duration, frequency, and intensity of storm events are linked to global warming.

The authors hope that this study initiates more detailed interdisciplinary research regarding the changes in air temperature and precipitation on the islands and coastal zones. Such research will foster better preparation for future climatic uncertainty. Hence, intensive interdisciplinary cooperation based on a detailed and carefully planned network of new meteorological stations will enable this crucial task to be fulfilled.

Supplementary Materials: The following are available online at <http://www.mdpi.com/2073-4433/11/10/1044/s1>. Table S1: Statistics (minimum, average, and maximum) of the monthly minimum, mean, and maximum air temperature at the stations of Lastovo, Komiža, and Palagruža. Table S2: Statistics (minimum, average, and maximum) of the monthly precipitation at the stations of Lastovo, Komiža, Biševo, and Palagruža. Table S3: *p*-values of the F-test and *t*-test for the minimum, mean, and maximum annual air temperature. Table S4: *p*-values of the F-test and *t*-test for the annual precipitation.

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