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AIR TEMPERATURE AND PRECIPITATION ANALYSES ON A SMALL MEDITERRANEAN ISLAND: THE CASE OF THE REMOTE ISLAND OF LASTOVO (ADRIATIC SEA, CROATIA)

ANALIZE TEMPERATUR ZRAKA IN PADAVIN NA MAJHNEM SREDOZEMSKEM OTOKU: PRIMER ODDALJENEGA OTOKA LASTOVO (JADRANSKO MORJE, HRVAŠKA)

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Abstract

The paper analyses a series of annual, monthly, and daily air temperatures, and annual and monthly precipitation at the Lastovo meteorological station on the island of Lastovo (Croatia) during the 1948-2018 period. The small carbonate Adriatic island of Lastovo is the most remote inhabited island in the Croatian part of the Adriatic Sea. The absolute minimum annual air temperatures range between -6.8 °C (recorded in 1963) and 4.0 °C (recorded in 1974), with an average value of -1.2 °C. The Mean annual air temperatures range between 14.7 °C (recorded in 1980) and 17.4 °C (recorded in 2018), with an average value of 15.8 °C. The absolute maximum annual air temperatures range between 31.7 °C (recorded in 1959) and 38.3 °C (recorded in 1998), with an average value of 34.8 °C. A strong jump in the minimum annual temperatures started in 1972. The mean annual temperature jump began nine years later in 1981, while the maximum annual temperature jump occurred in 1992. The values of the t-test for all three analysed annual temperature indices (ATI) substantiate the conclusion that the average values in two subperiods defined by the RAPS method are statistically significant at the level $p<<0.01$. The increasing trend of air temperatures is significantly higher for the time series of the average maximum temperature T_{max} than for the time series of the average minimum temperature T_{min}. The most prominent increasing trend occurs in June and July. The number of warm and hot days in Lastovo has continuously increased over the analysed period. The increasing trends for both indices are statistically significant at the level $p<0.01$. The day-to-day (DTD) method established a decrease in the night-time to night-time variability, and an increase in the day-time to day-time temperature variability. The number of frost days is steadily decreasing. The average annual precipitation in the 1948-2018 period was 666 mm, while the minimum and the maximum precipitation was 368 mm and 1089 mm, respectively. No trends have been established for the annual and the monthly precipitation time-series during the 1948-2018 period, though a statistically insignificant drop in annual precipitation is found after 1982.

Keywords: climate change, Mediterranean island, temperature change, SROC, day-to-day temperature variability, Island of Lastovo, Croatia.

Izvleček

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Članek podaja analizo časovnih vrst letnih, mesečnih in dnevnih temperatur zraka ter letnih in mesečnih padavin na meteorološki postaji Lastovo na otoku Lastovo (Hrvaška) v obdobju 1948–2018. Majhen kraški jadranski otok Lastovo je najbolj oddaljen poseljen otok v hrvaškem delu Jadranskega morja. Absolutne minimalne letne temperature zraka so med -6,8 ºC (zabeleženo leta 1963) in 4,0 ºC (leta 1974), s povprečno vrednostjo -1,2 ºC. Srednje letne temperature zraka so med 14,7 ºC (zabeleženo leta 1980) in 17,4 ºC (leta 2018), s povprečno vrednostjo 15,8 ºC. Absolutne maksimalne letne temperature zraka so med 31,7 ºC (zabeleženo leta 1959) in 38,3 ºC (leta 1998), s povprečno vrednostjo 34,8 ºC. Visok porast v minimalnih letnih temperaturah se je začel leta 1972. Temperaturni skok srednje letne temperature se je začel devet let pozneje, leta 1981, do velika porasta maksimalne letne temperature pa je prišlo leta 1992. Vrednosti t-testa za vse tri obravnavane letne temperaturne indekse podpirajo ugotovitev, da so povprečne vrednosti v dveh podobdobjih, opredeljenih z metodo umerjenih delnih vsot (RAPS), statistično značilne na ravni $p<<0,01$. Trend povečanja temperatur zraka je znatno višji za časovne vrste povprečnih maksimalnih temperatur T_{max} kot za časovne vrste povprečnih minimalnih temperatur T_{min}. Najizrazitejši trend naraščanja opažamo junija in julija. Število toplih in vročih dni na Lastovu se je v obravnavanem obdobju nenehno povečevalo. Naraščanje obeh indeksov je statistično značilno na ravni $p<0,01$. Z metodo DTD (angl. day-to-day) smo ugotovili zmanjšanje v nočni temperaturni variabilnosti in povečanje v dnevni temperaturni variabilnosti. Število dni zmrzali se vztrajno manjša. Srednja letna količina padavin v obdobju 1948–2018 je bila 666 mm, minimalna količina padavin je bila 368 mm in maksimalna 1089 mm. Za obdobje 1948–2018 nismo ugotovili trendov glede letnih in mesečnih padavin. Statistično neznačilen padec letnih padavin beležimo po letu 1982.

Ključne besede: podnebne spremembe, sredozemski otok, temperaturne spremembe, Spearmanov koeficient korelacije rangov, dnevna temperaturna variabilnost, otok Lastovo, Hrvaška.

1. Introduction

With about 10,000 islands and islets (approx. 250 of which are inhabited), the Mediterranean Sea can be considered one of the largest archipelagos in the world (Moatti and Thiébault, 2016). These landmasses comprise a kaleidoscope of landscape, environmental, hydrogeological, climatological, geographical, socioeconomic, historical, and biotic conditions. Most islands and islets belong to the Greek archipelago, with 7,581 in the Aegean Sea and ca. 300 in the Ionian Sea (Triantis and Mylonas, 2009). Croatia is the second country in terms of the number of islands, with a total of 1246 recorded islands. Within Croatia's territorial waters, there are 79 islands, 525 islets, and 642 rocks, and rocks awash. The Croatian Adriatic Sea islands, islets and rocks awash cover the area of 3195.71 km^2, 62.41 km^2, and 1.44 km^2, respectively (Duplančić-Leder et al., 2004).

The rich and vulnerable ecosystems of the Mediterranean islands, as well as their socioeconomic structure, are under the strong influence of the Mediterranean climate. The social stability and the ecosystem sustainability of the Mediterranean islands are faced with global change. The most imminent and the most dangerous threats may be imposed by the climate change, especially global warming.

Médail (2016) emphasised the following: "*The Mediterranean climate, in particular the drastic and sometimes unpredictable nature of climatic patterns and resource availability, puts severe and contrasted stress on species and communities. The impacts of climate change in the 20th century are less well documented than direct human impacts, but the situation is now changing rapidly and severe impacts on island ecosystems and biodiversity are expected.*"

The availability of water resources and food remain the critical concerns within the local island communities. Tourism is a major economic sector on many small islands, but the problem is that it too may be vulnerable to potential impacts of the climate change (Wall, 1996). On all Croatian small islands, the number of visitors during the holiday season (May-September) substantially exceeds the number of local residents. Since the water resources and agriculture are climate-dependent, it is expected that these sectors will also be adversely affected by future climate and sea-level changes.

In the twentieth century, the Mediterranean regional and global temperatures became warmer at a similar rate until the 1980s (Lionello and Scarascia, 2018). The Mediterranean islands are hotspots of global biodiversity, situated in an area among the most susceptible to climate change in the world (Vogiatzakis et al., 2016). This poses a considerable challenge for any conservation strategy. Climate change will impact the extent and distribution of the Mediterranean climate, posing a threat to the survival of many species (Lal et al., 2002; Klausmeyer and Shaw, 2009).

Le Houérou (1990) concluded that, with an expected temperature increase of 3 °C to 5 °C in the Mediterranean throughout the 21st century, potential evapotranspiration is expected to reach an average of 200 mm annually, which is equivalent to a loss of 50 mm in annual rainfall.

Wildfires are an integral part of the Mediterranean ecosystems (Pausas and Fernández-Muño, 2012). It is realistic to expect that the increase in temperature will likely cause more and more destructive wildfires.

The Mediterranean region is one of the “hottest” biodiversity hotspots on the planet (Blondel et al., 2010). Lange and Donta (2006) warned that the smaller the Mediterranean island, the more vulnerable its biodiversity is to climate change. The biological and cultural heritage and abundance of the Mediterranean islands, along with their socioeconomic stability, are now at real risk. As a result, there is an increasing concern for the conservation, adaptive management and restoration of the unique and characteristic natural ecosystems and their cultural landscapes. In order to tackle this urgent and extremely complex and important task, the first step is to gain a better insight into the influence of recent climate changes, first and foremost global warming processes. It should be noted that each island has different climate changes, which differently influence their landscape and socioeconomic structure (Méheux et al., 2007; Walshe and Stancioff, 2018).

This paper examines the temperature and precipitation development in the 1948-2018 period on the island of Lastovo. The coordinates of the small Adriatic island of Lastovo are 42° 45' N and 16° 52' E. It is the most remote inhabited island in the Croatian part of the Adriatic Sea (Duplančić-Leder et al., 2004). With a surface area of 40.82 km^2, coastline of 48,969 m, and the highest point Hum at 417 m above sea level (m a.s.l.) (Fig. 1), Lastovo is the fifteenth-largest and eighteenth-most populated island in the Croatian part of the Adriatic Sea. It is 10 km long and 5.8 km wide. According to the 2011 census, the population of Lastovo was 792. During the summer season, about 9,000 tourists visit the island.

The paper will analyse the series of characteristic (minimum, mean, and maximum) annual, monthly, and daily air temperatures, and annual and monthly precipitation measured at the main meteorological station Lastovo (Fig. 2) of the DHMZ (Croatian Meteorological and Hydrological Service). The Lastovo meteorological station was commissioned in January 1948. Its altitude is 186 m a.s.l. and its coordinates are 42º 46' 06" N and 16º 54' 0" E.

The island’s small surface area and karstic landscape create a very vulnerable environment in terms of water management. Small, inhabited Mediterranean islands with scarce water resources and overpopulation during the summer are particularly vulnerable to even small changes in air temperatures, and especially in precipitation amounts and distribution.

In Croatia and most Northern European countries, the following equation is used to calculate the mean daily air temperature T_{mean}:

$$T_{mean} = (T_7 + T_{14} + 2 \times T_{21})/4 \qquad (1)$$

where, T_7, T_{14}, and, T_{21}, are the air temperatures measured at 7h, 14h, and 21h, respectively. The hours refer to the mean local time. Minimum and maximum daily temperatures are measured by minimum and maximum thermometers.

2. Analysis of annual air temperature indices

By analysing the long-lasting annual air temperature time-series, we try to explain the various changes of ATI (minimum, mean, and maximum). The study's aim is to gain a better insight into the effect of global warming on the increasing trend of air temperatures. Air temperature plays a crucial role in practically all hydrological processes. Its most important influences are on: (1) evapotranspiration as the main element of the water budget; (2) water temperature in rivers and lakes, which affects other physical properties and influences the chemical and biological reactions in its lotic system; (3) soil moisture content; (4) snow and ice melt contributions to floods, etc. Variations in air temperature resulting from climate change are an important driving force behind changing hydrologic processes in any watershed ecosystems (Bonacci and Roje-Bonacci, 2018).

Three time-series of the annual absolute minimum (1949-2018, blue), mean daily (1948-2018, black), and absolute maximum (1949-2018, red) air temperatures measured at the Lastovo meteorological station are presented in Fig. 3. For the mean annual air temperature, the time-series cover the 1948-2018 period. For the minimum and maximum annual temperature, the time-series cover the 1949-2018 period. The minimum annual air temperature ranges between -6.8 °C (1963) and 4.0 °C (1974), with an average value of -1.2 °C. The mean annual air temperature ranges between 14.7 °C (1980) and 17.4 °C (2018), with an average value of 15.8 °C. The maximum annual air temperature ranges between 31.7 °C (1959) and 38.3 °C (1998), with an average value of 34.8 °C.

Figure 3 depicts the linear trend lines with the coefficient of linear correlation *r*. The SROC (Spearman Rank Order Correlation) nonparametric test was used in order to detect the statistical significance of the linear trend (McGhee, 1985; Adeloye and Montasari, 2002). In all three analysed time-series, an increasing trend is detected. The linear correlation coefficients for the series of mean annual and maximum annual data are statistically significant at the level $p<0.01$. The increasing trend in time-series of minimum annual data is not statistically significant.

The Rescaled Adjusted Partial Sums (RAPS) method (Garbrecht and Fernandez, 1994) was used in order to detect and quantify the trends and fluctuations in three analysed time-series. The RAPS visualisation highlights trends, shifts, data clustering, irregular fluctuations, and periodicities in the record. A visualisation approach based on RAPS overcomes small systematic changes in the records and the variability of data values (Bonacci, 2010; 2012).

Fig. 4 depicts three RAPS time-series of ATI: (1) minimum (1949-2018, blue); (2) mean daily (1948-2018, black); (3) maximum (1949-2018, red). Based on the graphic presentations presented in this figure, the annual minimum time-series was divided into two following time-subseries: (1) 1949-1971; (2) 1972-2018. The annual mean daily time-series is divided into next two time-subseries: (1) 1948-1991; (2) 1992-2018. The time-series of annual maximum temperatures is divided into the following time-subseries: (1) 1948-1980; (2) 1981-2018. Table 1 presents the matrix of results for three ATI average values: $T_{average}$, *F-test*, and *t-test*, for two subseries of mean annual air temperatures observed at two subperiods defined by the RAPS method. The values of the t-test for all three analysed ATI values substantiate the conclusion that average values in two subperiods defined by the RAPS method are statistically significant at the level $p<<0.01$. A strong jump in minimum annual temperatures started in 1972. The mean annual temperature jump began nine years later in 1981, while the maximum annual temperature jump occurred in 1992.

The differences in behaviour (jump) of the annual mean daily time-series during the 71-year-long period (1948-2018) are observed in the illustration given in Fig. 5, where two subseries of annual mean daily data are presented. In Fig. 5, linear trend lines, the coefficient of linear correlation *r*, and the average air temperatures in each subseries are noted. In the first subperiod (1948-1991), the decreasing trend is not statistically significant. A strong jump got underway in 1991, and the temperature has continuously increased over the past three decades. A similar trend is observed in many series of mean daily annual temperatures in the Western Balkans, western USA, and in many other regions (Levi, 2008; Bonacci, 2012).

Figure 1: *Map of the island of Lastovo.*

Slika 1: *Karta otoka Lastovo.*

Figure 2: *Photograph of the Lastovo meteorological station.*

Slika 2: *Slika meteorološke postaje Lastovo.*

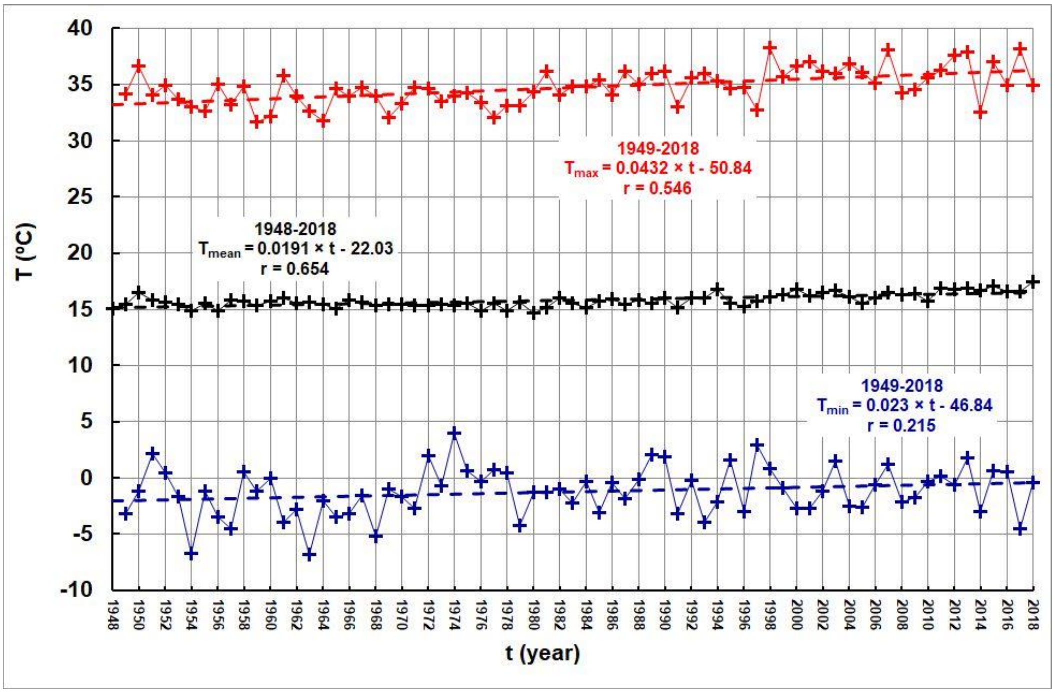

Figure 3: *Three time-series of annual absolute minimum (1949-2018, blue), mean daily (1948-2018, black) and absolute maximum (1949-2018, red) air temperature measured at the Lastovo meteorological station.*

Slika 3: *Tri časovne vrste letnih absolutnih (1949–2018, modra), srednjih dnevnih (1948–2018, črna) in absolutnih maksimalnih (1949–2018, rdeča) temperatur zraka, izmerjenih na meteorološki postaji Lastovo.*

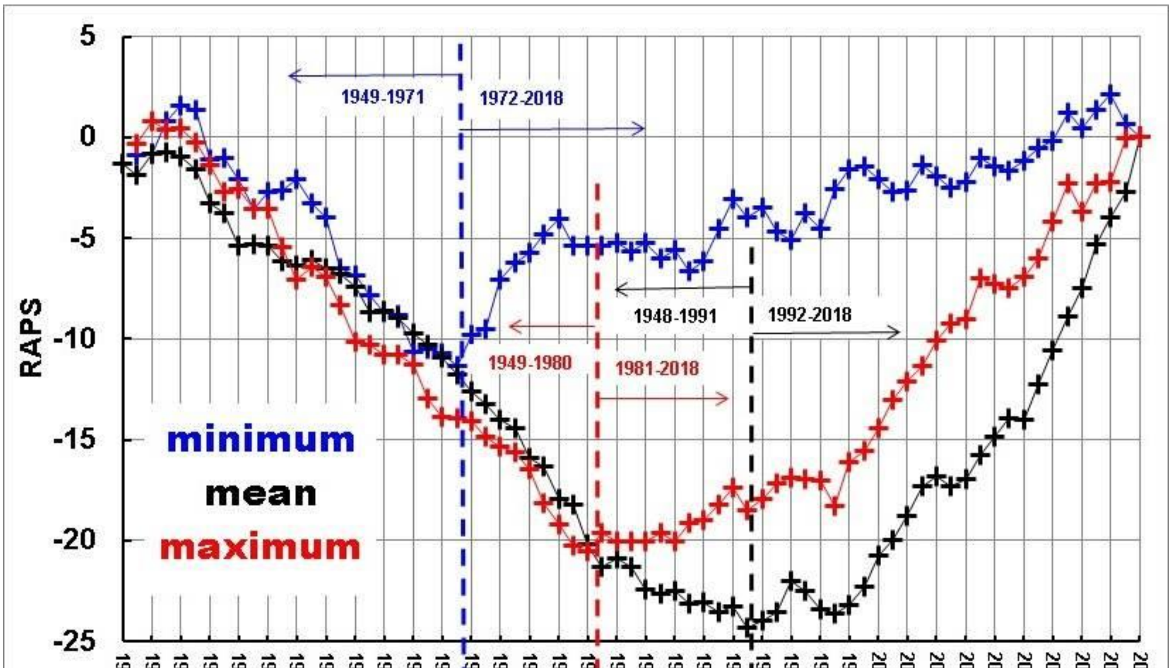

Figure 4: *Three RAPS time-series of characteristic annual air temperatures: (1) absolute minimum (1949-2018, blue); (2) mean daily (1948-2018, black); (3) absolute maximum (1949-2018, red).*

Slika 4: *Tri časovne vrste RAPS značilnih letnih temperatur zraka: (1) absolutni minimum (1949–2018, modra); (2) srednja dnevna vrednost (1948–2018, rdeče); (3) absolutni maksimum (1949–2018, rdeča).*

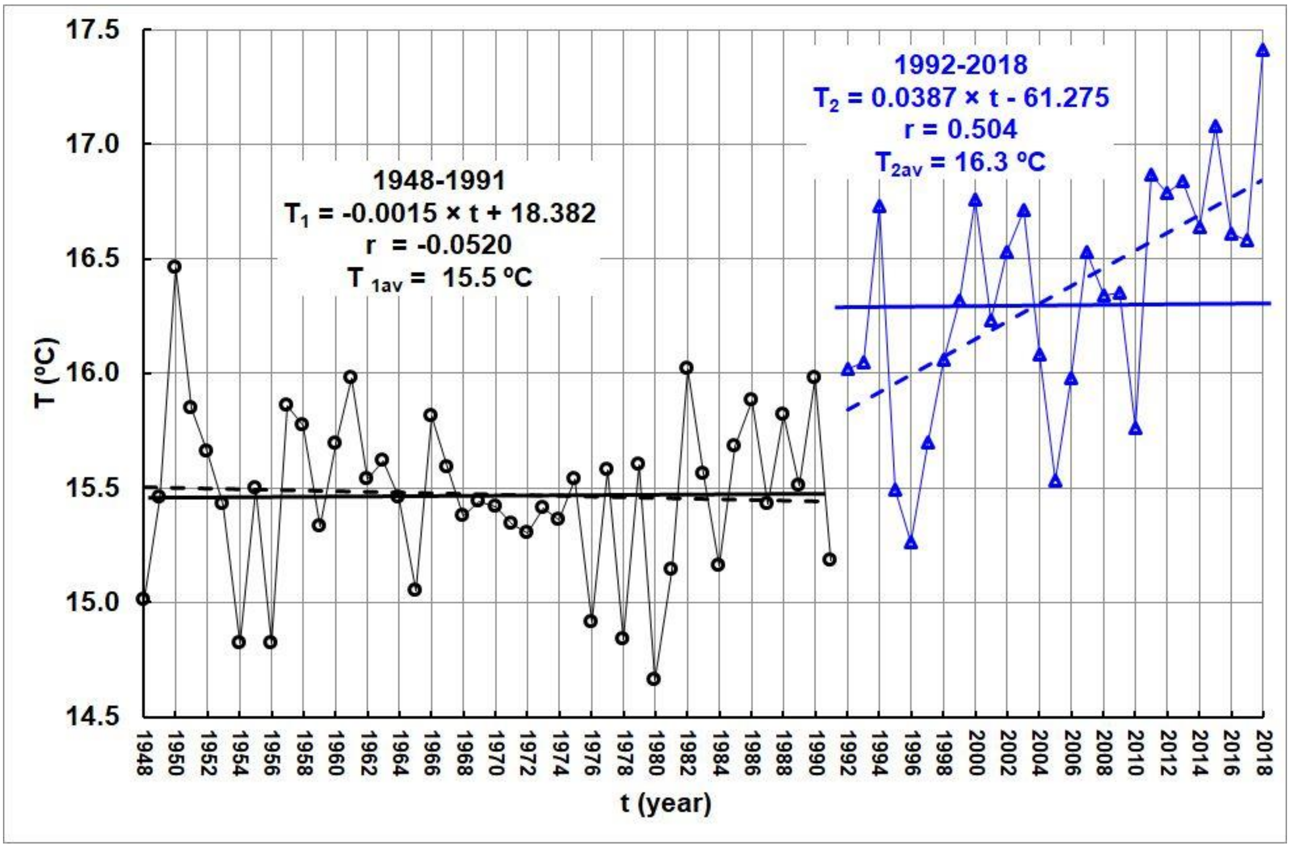

Figure 5: *Time-series of annual mean daily air temperature for two sub-periods: (1) 1948–1919; (2) 1992–2018.*

Slika 5: *Časovne vrste letnih srednjih temperatur zraka za dve podobdobji: (1) 1948–1919; (2) 1992–2018.*

Table 1: *Matrix of results for three indices of average values Taverage, F-test, and, t-test, for two subseries of mean annual air temperatures observed at two subperiods defined by RAPS method.*

Preglednica 1: *Matrika rezultatov za tri indekse povprečne temperature, F-test, in t-test za 2 podvrsti povprečnih letnih temperatur zraka. Podobdobji sta bili določeni na podlagi RAPS metode.*

indices	subperiod	$T_{average}$	F-test	t-test
minimum	1949-1971	-2.37	0.561	**3.5E-03**
	1972-2018	0.78		
mean daily	1948-1991	15.5	0.045	**6.4E-12**
	1992-2018	16.3		
maximum	1949-1980	33.8	0.231	**8.7E-02**
	1981-2018	35.6		

Table 2: *Matrix of characteristic average monthly (minimum Tmin, mean Tmean, maximum Tmax) air temperatures in the 1949-2018 period. In the last three rows, the coefficients of linear correlation r are presented for monthly time-series of characteristic air temperatures in the 70 years long period from 1949 to 2018.*

Preglednica 2: *Matrika mesečnih vrednosti za minimalno, srednjo in maksimalno temperaturo zraka ter vrednosti korelacijskih koeficientov v zadnjih 70 letih (1949-2018).*

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
T_{min}	1.0	1.1	2.8	6.4	10.5	13.7	16.6	16.9	13.7	10.3	5.6	2.4
T_{mean}	8.5	8.5	10.3	13.3	17.6	21.6	24.4	24.3	20.8	17.0	13.1	10.0
T_{max}	14.8	15.3	18.0	21.7	26.7	31.1	33.7	33.7	29.0	24.2	19.6	16.2
r_{Tmin}	0.185	0.150	0.245	0.132	0.277	0.298	**0.364**	**0.371**	0.033	0.166	0.149	0.020
r_{Tmean}	0.164	0.142	0.307	**0.351**	**0.406**	**0.513**	**0.577**	**0.494**	0.144	0.247	0.230	-0.003
r_{Tmax}	0.010	0.039	0.291	0.289	**0.386**	**0.521**	**0.459**	**0.394**	0.156	0.218	0.273	0.061

3. Analysis of monthly air temperature indices

It is crucial to establish the manner in which air temperatures increase, decrease, or jump in different seasons. Temperature behaviour during different months of the year will be analysed in this chapter.

Fig. 6 depicts the histograms of characteristic monthly (minimum, T_{min}; mean, T_{mean}; maximum, T_{max}) air temperatures in the 1949-2018 period. Table 2 presents the matrix of characteristic average monthly (minimum, T_{min}; mean, T_{mean}; maximum, T_{max}) air temperatures in the 1949-2018 period. For all three values, the maximum temperatures are measured in July and August, while the minimum temperature was measured in January. In the last three rows of Table 2, the coefficients of linear correlation *r* are presented for monthly time-series of characteristic air temperatures in the 70-year-long period from 1949 to 2018. An increasing trend is detected in all cases (except in December for average T_{mean}). By using the SROC method, statistically significant trends at the level $p<0.01$ are calculated only in the hot and dry season from May to August. Red bold numbers indicate the values when the increasing trend is significant at the level $p<0.01$. The analysis of the values listed in Table 2 clearly indicates that the increasing trend of air temperatures is significantly higher for the time-series of the average maximum temperature T_{max} than for the time-series of the average minimum temperature T_{min}. The most prominent increasing trend occurs in June and July. It seems that, in the case of Lastovo, the global warming process has a stronger influence on the higher than on the lower temperature. This fact can be explained by the influence of the Adriatic Sea temperature. The reason is that water has a higher heat capacity than land. The air temperature changes more rapidly than water temperature due to thermal inertia, so the times when both are exactly equal are pretty rare.

4. Analysis of daily air temperature indices

The graphic presentation of characteristic mean daily minimum, average, and maximum air temperatures measured during the period from 1 Jan. 1949 to 31 Dec. 2018 displays considerable variations between temperatures during one particular day (Fig. 7). The average minimum daily temperature over 70 years was measured on 23 Jan. 1963 (-4.9 °C), while the maximum temperature was measured on 9 Aug. 2017 (32.6 °C). The absolute minimum temperature was measured on 23 Jan. 1963 (-6.9 °C), while the maximum temperature was measured on 3 Aug. 1998 (38.3 °C). The values of air temperature range ΔT on a particular day during the 70 analysed years are marked in purple (Fig. 7). The maximum range value $\Delta T_{max}=17.9$ °C was recorded on 8 March, while the minimum value $\Delta T_{min}=7.6$ °C was recorded on 10 September. The average annual range value is $\Delta T_{av}=12.2$ °C. During the warmer season (especially from the end of May to the mid-October), the ranges between the mean daily minimum and maximum temperatures are slightly lower than in the colder season (from November to February).

Hot days are defined as days on which the highest daily temperature rises above 30 °C. Warm days are defined as days on which the temperature rises above 25 °C. The time-series of hot and warm days *N* measured at the Lastovo station during the 1949-2018 period is presented in Fig. 8. The number of hot and warm days at the Lastovo station has continuously increased during the analysed period. The increasing trends for both indices are statistically significant at the level $p<0.01$. In the second subperiod (1981-2018), the average values of warm and hot days are statistically significantly higher than in the first subperiod (1948-1980).

The days when the temperature falls below 0 °C are referred to as frost days. The number of frost days is steadily decreasing. In the first subperiod (1949-1971), the average number of frost days per year was $N=4.1$. In the second subperiod (1972-2018), it reduced to $N=2.0$ days per year.

5. Day-to-day (DTD) temperature variability

The Day-to-day (DTD) temperature variability is a relatively new method used as an effective metric for the climate changes analysis. The DTD temperature variability framework was first introduced by Karl et al. (1995) and further developed by Gough (2008) and Tam et al. (2015). Gough (2008) used this metric to assess temperature variability. DTD temperature variability better captures the clustering of temperatures perhaps resulting from a number of meteorological and geographic factors that bring order to the local climate (Gough, 2008). By using the DTD method, Tam and Gough (2012) assessed the geographical variation in the climate. Tam et al. (2015) used this method as an alternative metric for quantifying the urban heat island. Gough and Hu (2016) concluded that the DTD temperature variability framework is sensitive to the magnitude of urbanisation and climate type. They found that a subtle difference between the day-time DTD and the night-time DTD, which they referred to as ΔDTD, was a strong indicator of urbanisation with the positive values for urban landscapes and the negative values for rural landscapes. Moberg et al. (2000) investigated the DTD temperature variability trends in 160- to 275-year-long European instrumental records. Their conclusion is that the DTD temperature variability in winter, spring, and autumn in Northern Europe has decreased over the last 200 to 250 years. DTD variability was analysed on the two-century-long daily minimum and maximum temperature series from Switzerland (Rebetez, 2001). The conclusions are that warmer temperatures during the 20th century have been accompanied by a reduction in the DTD variability, particularly for the minimum temperatures and for winter. The trends in the DTD variability were examined on the Chinese daily mean, maximum, and minimum surface air-temperature datasets for 1961-2012 (Li et al., 2017). Different behaviours were found in different Chinese regions.

DTD temperature variation is based on the absolute difference between the temperatures in two adjacent days. The equation for the DTD calculation defined by Karl et al. (1995) is:

$$DTD = \Sigma\, |T_i - T_{i-1}| \,/\, (n-1) \qquad (2)$$

where *n* is the number of data elements, *i* is the counter that marches though the days of the year, *Σ* is the sum of all n-data elements, *T* is the mean daily air temperature, and | | is the mark for the absolute values of the differences.

The other used equation was developed by Gough (2008):

$$\Delta DTD = DTDTmax - DTDTmin \qquad (3)$$

where, *DTDTmax* represents the DTD change in the daily temperature maximum, and *DTDTmin* represents the DTD change in the daily temperature minimum.

A positive value of *ΔDTD* generally indicates a greater day-time to day-time variability, and a negative result generally indicates a greater variability from night-time to night-time (Tam and Gough, 2012).

Fig. 9 depicts four annual time-series values (from 1 Jan. to 31 Dec.) of day-to-day Lastovo temperature variability, namely *DTDTmin*, *DTDTmean*, *DTDTmax*, and *ΔDTD* during the 1949-2018 period, with the designated linear trend lines and the linear correlation coefficients *r*. The time-series of DTDTmean and DTDTmax show an increasing trend, while the time-series of DTDmin shows a decreasing trend. None of them is statistically significant at the level $p<0.01$. The differences between the increasing DTDTmax trend and the decreasing DTDmin trend result in a statistically significant increasing trend of ΔDTD. It can be concluded that, at the Lastovo station, the night-time to night-time variability decreased while day-time to day-time temperature variability increased. This kind of climate behaviour is governed by the temperature of seawater.

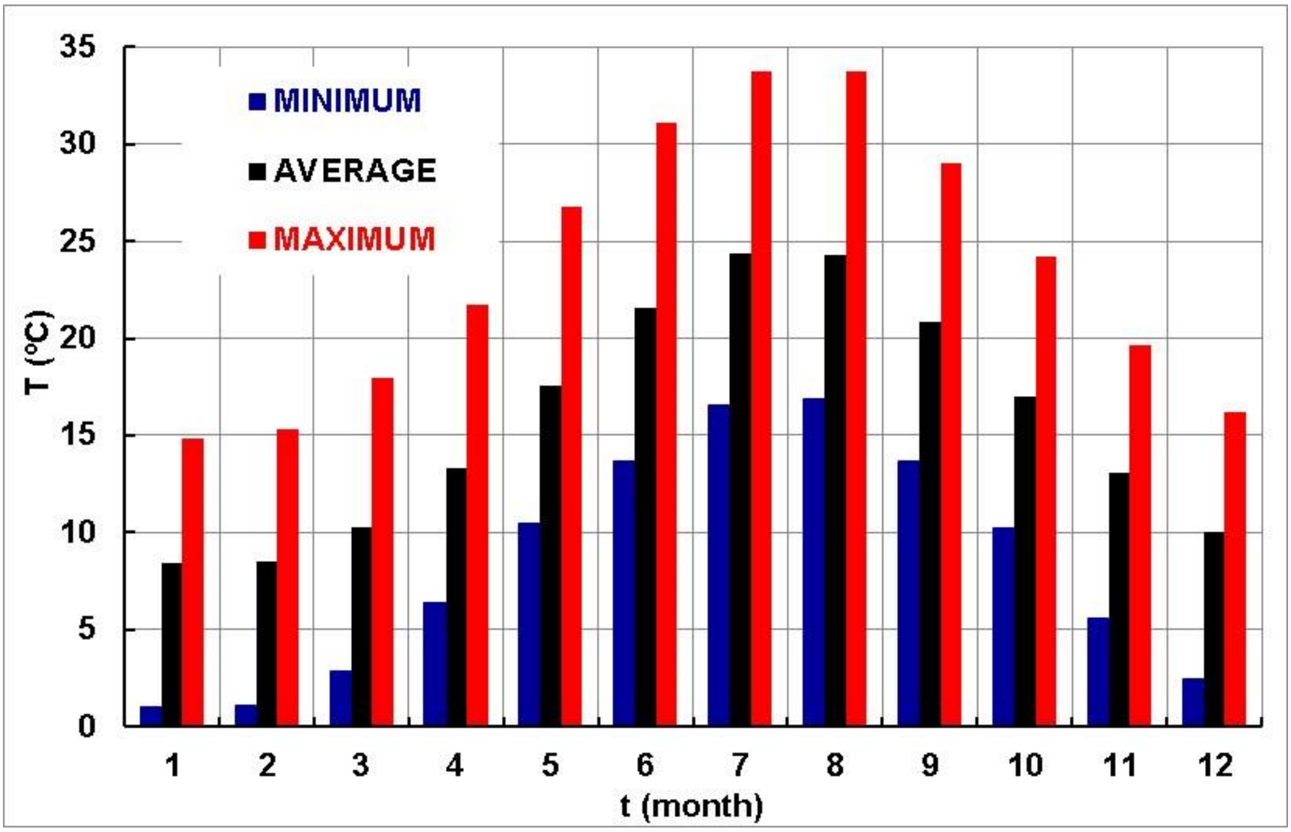

Figure 6: *Histograms of characteristic average monthly (minimum, Tmin; mean, Tmean; maximum, Tmax) air temperatures in the 1949-2018 period.*

Slika 6: *Histogrami značilnih povprečnih mesečnih (minimalna, Tmin; srednja, Tmean; maksimalna, Tmax) temperatur zraka v obdobju 1949–2018.*

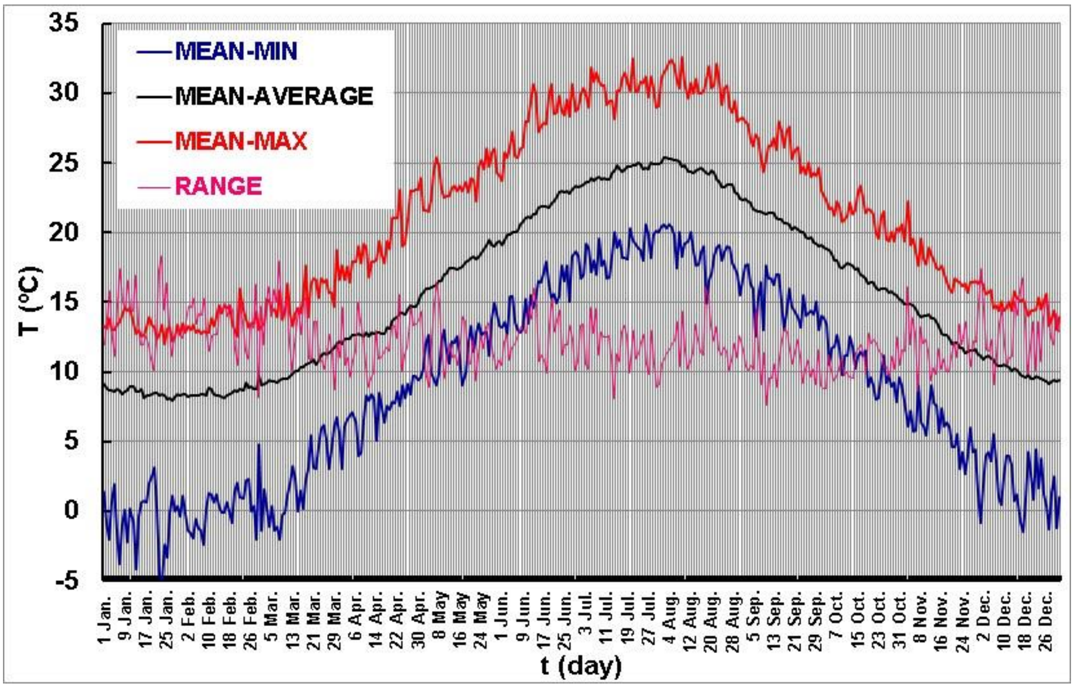

Figure 7: *Four time-series of characteristic mean daily air temperatures for the period from 1 Jan. 1949 to 31 Dec. 2018: (1) minimum mean daily Tmin (blue); (2) average mean daily Tav (black); (3) maximum mean daily Tmax (red); (4) range ΔT=Tmax–Tmin (purple).*

Slika 7: *Štiri časovne vrste značilnih srednjih dnevnih temperatur zraka za obdobje od 1. 1. 1949 do 31. 12. 2018: (1) minimalna srednja dnevna Tmin (modra); (2) povprečna srednja dnevna Tav (črna); (3) maksimalna srednja dnevna Tmax (rdeča); (4) razpon ΔT=Tmax–Tmin (vijolična).*

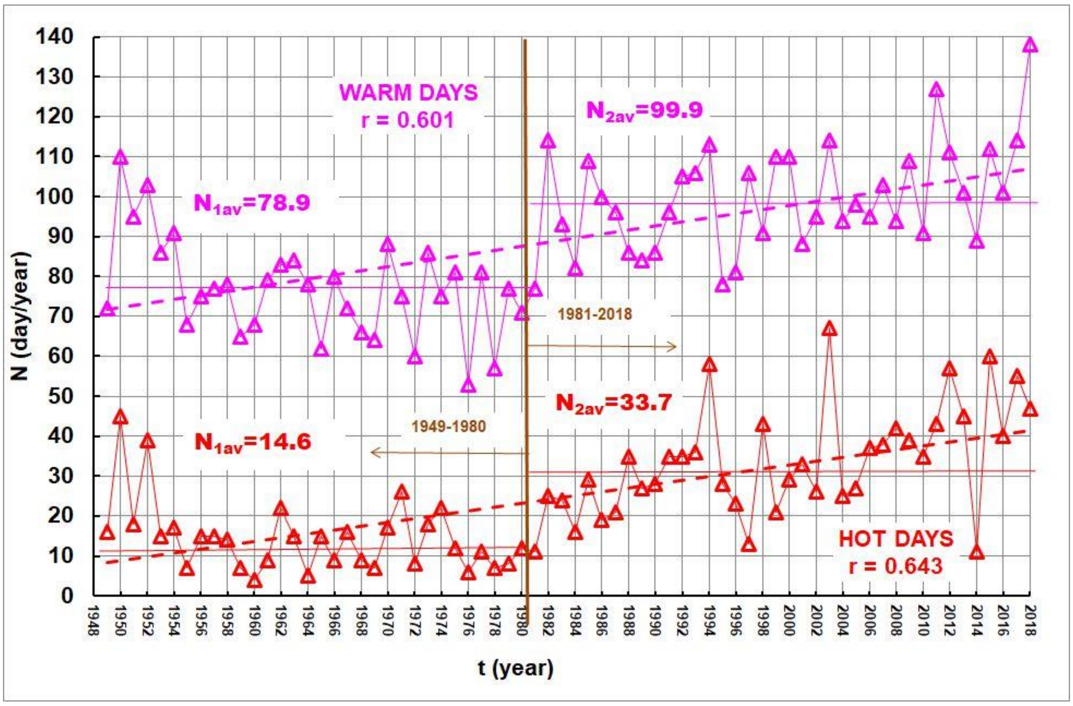

Figure 8: *Time series of hot and warm days N measured at the Lastovo station each year during the 1949-2018 period.*

Slika 8: *Časovna vrsta vročih in toplih dni N, izmerjenih na postaji Lastovo v obdobju 1949–2018.*

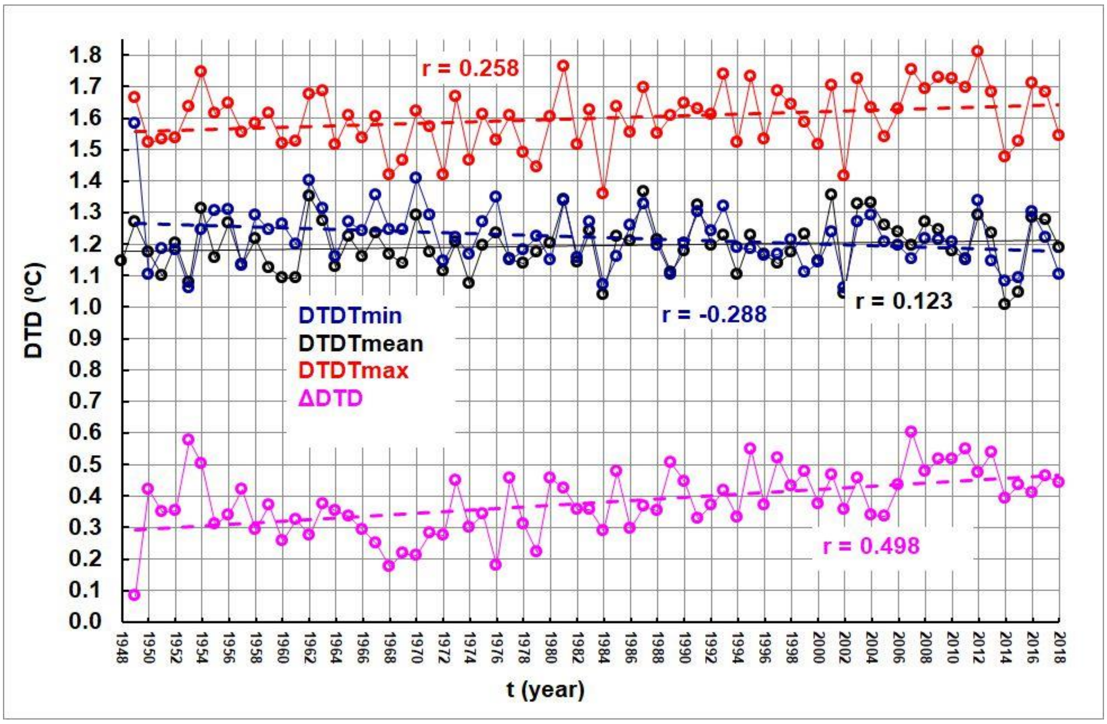

Figure 9: *Four time-series annual values (from 1 Jan. to 31 Dec.) of day-to-day Lastovo temperature variability, DTDTmin, DTDTmean, DTDTmax, ΔDTD, during the 1949-2018 period with designated linear trend lines and linear correlation coefficients r.*

Slika 9: *Štiri časovne vrste letnih vrednosti (od 1. 1. do 31. 12.) dnevne temperaturne variabilnosti na Lastovu DTDTmin, DTDTmean, DTDTmax, ΔDTD, v obdobju 1949–2018 z linearnimi trendnimi črtami in linearnimi korelacijskimi koeficienti r.*

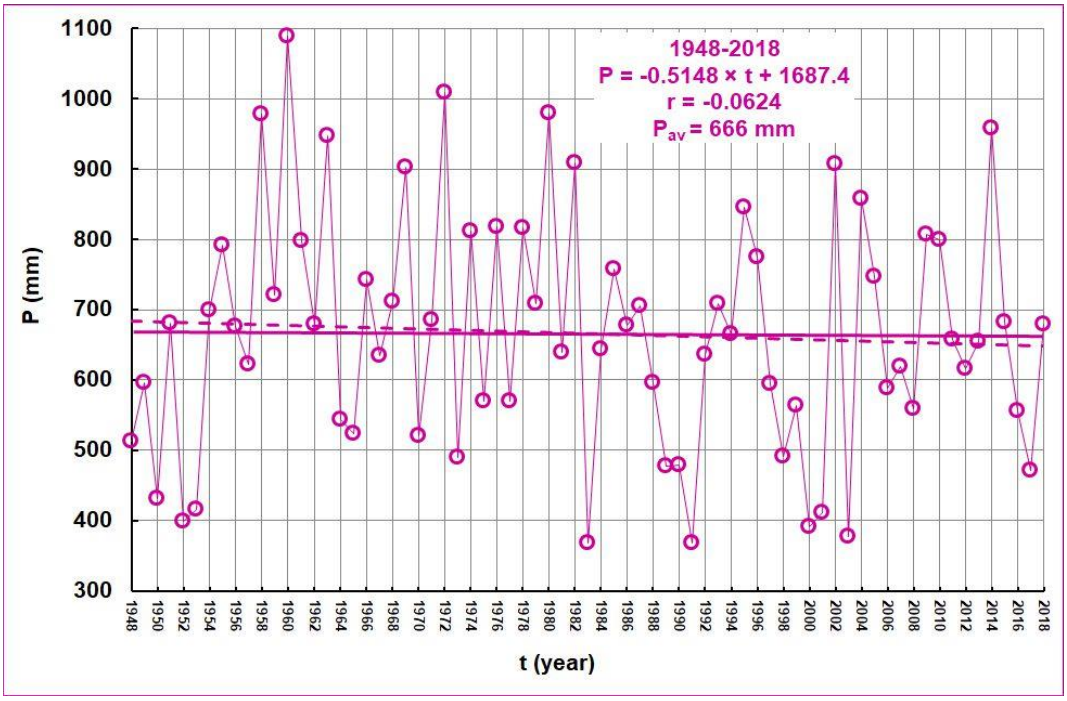

Figure 10: *Time-series of annual precipitation measured at the Lastovo meteorological station in the 1948-2018 period.*

Slika 10: *Časovna vrsta letnih padavin, merjena na meteorološki postaja Lastovo v obdobju 1948–2018.*

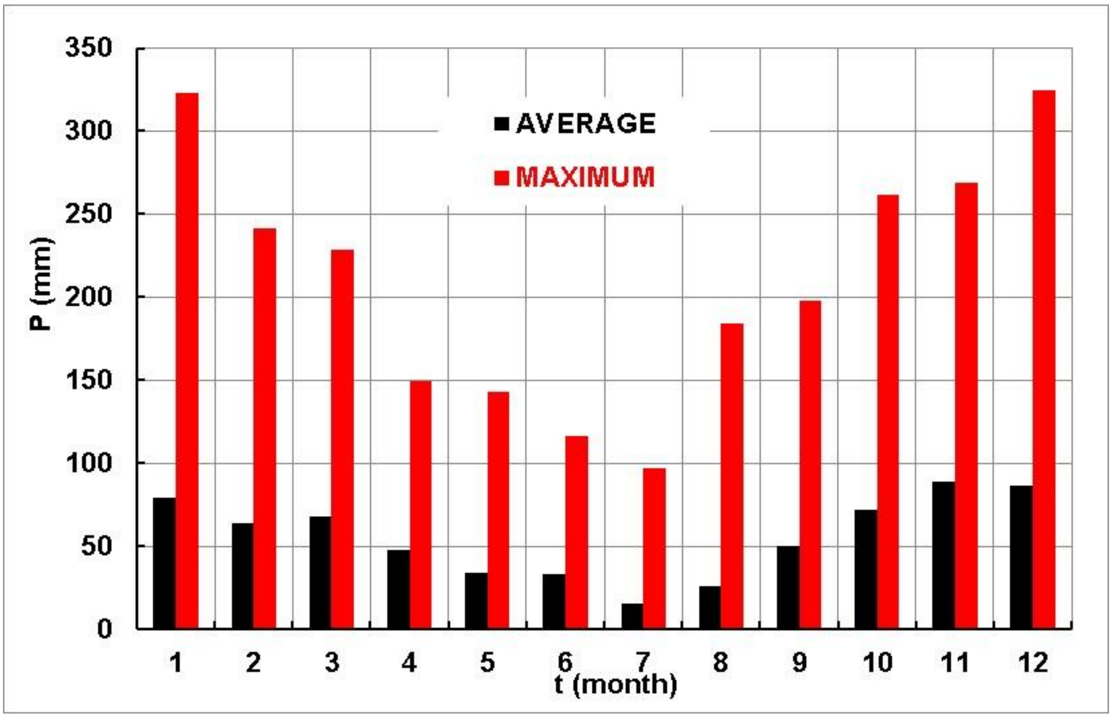

Figure 11: *Histograms of the average and maximum monthly precipitation in the 1948-2018 period.*

Slika 11: *Histogrami povprečnih in maksimalnih mesečnih padavin v obdobju 1948–2018.*

Table 3: *Matrix of characteristic average monthly (minimum P_{min}, mean P_{mean}, maximum P_{max}) precipitation in the 1948-2018 period. In the last row the coefficients of linear correlation r are presented for monthly time-series of precipitation in the 71 years long period from 1948 to 2018.*

Preglednica 3: *Matrika karakterističnih vrednosti mesečnih padavin v obdobju 1948-2018. Zadnji stolpec prikazuje koeficiente linearne korelacije.*

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
P_{min}	2.2	0.7	0	2	0.2	0	0	0	2	0.1	19.1	0
P_{mean}	79.0	64.3	67.7	48.0	34.0	33.6	15.9	26.1	50.5	72.0	88.7	86.7
P_{max}	323	241.1	228.3	149.8	143	116.7	97.1	184.2	198.1	261.4	268.7	324.9
r_P	-0.02	0.01	0.041	0.004	0.042	0.036	-0.12	-0.025	0.005	0.111	-0.046	-0.061

6. Analysis of precipitation

The time-series of annual precipitation measured at the Lastovo meteorological station during the 1948-2018 period is presented in Fig. 10. The decreasing trend is not statistically significant. The average annual value during the 71-year-long period is 666 mm. The variations of annual precipitation are very high. The minimum annual precipitation of $P=368$ *mm* was recorded in 1991, while the maximum annual precipitation of $P=1089$ *mm* was recorded in 1960. Using the RAPS method the annual precipitation time-series was divided into two following time-subseries: (1) 1948-1982; (2) 1983-2018. The average value in the first subperiod is 704 mm, while in the second it is 630. Using the t-test shows that this drop is not statistically significant when $p=0.0682$. A similar conclusion is drawn in the Filipčić et al. (2013) paper.

Fig. 11 depicts the histograms of the average (black) and the maximum (red) monthly precipitation in the 1948-2018 period. The rainy period occurred from

October to March. The maximum precipitation of $P=324.9\ mm$ was recorded in December 2002.

Table 3 presents the matrix of characteristic monthly (minimum, P_{min}; mean, P_{mean}; maximum, P_{max}) precipitation in the 1948-2018 period. The variation of monthly precipitation is extremely high. In the last row of Table 3, the coefficients of linear correlation r are presented for the monthly time-series of precipitation in the 71-year period from 1948 to 2018. There are no statistically significant trends in any of these cases.

7. Conclusion

The paper deals with the specific behaviour of climate change on the small Island of Lastovo during the 1948-2018 period. The presented results show that a strong jump in the minimum annual temperatures began in 1972. The mean annual temperature jump began nine years later in 1981, while the maximum annual temperature jump occurred in 1992. The values of the t-test for all three analysed indices substantiate the conclusion that the average values in the two subperiods defined by the RAPS method are statistically significant at the level $p<<0.01$. The increasing trend of air temperatures is significantly higher for the time-series of average maximum temperatures T_{max} than for the time-series of average minimum temperatures T_{min}. The most prominent increasing trend occurs in June and July. The number of warm and hot days at the Lastovo station has continuously increased during the analysed period. The number of frost days is steadily decreasing.

Based on the results of the DTD method, it is established that the night-time to night-time variability decreased, while the day-time to day-time temperature variability increased. This kind of local climate behaviour is governed by the temperature of seawater. No significant changes in monthly and annual precipitation were discovered. The number of frost days is steadily decreasing. Lastovo's climate changes strongly depend the Adriatic Sea temperature.

The average annual precipitation in the 1948-2018 period was 666 mm, while the minimum and maximum rainfall amounts ranged between 368 mm and 1089 mm, respectively. No trends have been established for the annual and the monthly precipitation time-series during the 1948-2018 period. A connection between the temperature changes and the amount of intra- and inter-annual precipitation distribution was not found.

Small islands account for less than 1% of global greenhouse gas emissions, but they are among the most vulnerable locations to the potential adverse effects of climate change and the sea-level rise. Economic development and the alleviation of poverty constitute the single most critical concern of many small islands. Hence, with limited resources and low adaptive capacity, these islands are faced with the considerable challenge of meeting the social and economic needs of their populations in a sustainable manner (Nurse et al., 2001). The small Mediterranean islands might be especially vulnerable to global change. They will likely be greatly affected by climate change, which is associated with an increase in the frequency and intensity of droughts and hot weather conditions (Lelieveld et al., 2012).

The availability of water resources and food remain critical concerns among island communities. Tourism is a major economic sector on many small islands. In most small island states, the number of visitors substantially exceeds the number of local residents. Since water resources and agriculture are so climate-dependent, it is expected that these sectors will also be adversely affected by future climate and sea-level changes.

Giorgi and Lionello (2008) projected the occurrence of maximum warming in the summer season. The inter-annual variability is expected to increase, especially in summer, which would lead to a greater occurrence of extremely high temperature events. Their conclusions are supported by the previously described analyses in the case of the island of Lastovo.

The limited size of small islands reduces adaptation options to climate change and sea-level rise (Nurse et al., 2002). The limited natural resources of small Mediterranean islands are heavily burdened by unsustainable human activities. The relatively thin and vulnerable aquifers of karstic islands located in the Adriatic Sea are highly sensitive to climate and sea-level changes.

Owing to their social and historical importance, as well as their exceptional biotic authenticity and vulnerability to global change, the Mediterranean islands and islets, particularly the island of Lastovo, require urgent measures of integrated and ambitious conservation planning aimed at the long-term preservation of their outstanding biodiversity, cultural and historical heritage, and socioeconomic stability.

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