Different Climate Changes at Two Locations on a Small Karst Island Korčula (Adriatic Sea, Croatia)

Različite klimatske promjene na dvjema lokacijama na malom krškom otoku Korčuli (Jadransko m ore, Hrvatska)

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Summary

The article analyses the series of annual, monthly and daily air temperatures and annual and monthly rainfall at two meteorological stations in Vela Luka and Korčula on the island of Korčula (Croatia), for which there are long time series of observations. Today's locations of meteorological stations are only 33.5 km apart. The average annual air temperature at the Vela Luka station is on average 1°C lower than that measured at the Korčula station. A significant upward trend in mean annual and mean monthly air temperatures was observed at both stations, with the increase being much milder at the Vela Luka station. Warming processes are significantly faster at the Korčula station than at the Vela Luka station. Significantly different values of air temperatures, and in particular the fact of different reactions of air temperatures to climate change at two stations, can be explained by their local position in relation to the open sea and orography of the surrounding terrain. While the Vela Luka station is exposed to the open sea and away from the mainland, at Korčula station the impact of the sea is less significant because the sea is located in a narrow channel between the island of Korčula and the Pelješac peninsula. The distance of the Korčula meteorological station from the Pelješac peninsula and the mainland is significantly smaller, which affects the faster trend of rising air temperatures at this station than at the Vela Luka station, where the influence of the sea mitigates the effect of global warming. Orography and proximity to land affect significantly higher rainfall occurrences at Korčula station. Average annual rainfall at this station is 231 mm or 27.5% higher than at Vela Luka station. Both stations show a trend of decreasing annual rainfall.

KEY WORDS

air temperature
precipitation
climate change
small island
island of Korčula (Croatia)

Sažetak

U članku analizira se niz podataka o temperaturama zraka izmjerenima godišnje, mjesečno ili dnevno te o godišnjim i mjesečnim količinama oborina na dvjema meteorološkim postajama u Veloj Luci i Korčuli na otoku Korčuli (Hrvatska), koji su se prikupljali u dužem razdoblju. Današnje lokacije meteoroloških postaja međusobno su udaljene svega 33,5 kilometara. Prosječna temperatura zraka u godini izmjerena na postaji Vela Luka u prosjeku je 1 °C niža od one izmjerene na postaji Korčula. Na objema postajama vidljiv je značajan trend rasta srednjih temperatura zraka godišnje i mjesečno, s time da je rast znatno umjereniji na postaji Vela Luka. Na postaji Korčula zabilježen je znatno brži proces rasta temperature nego na postaji Vela Luka. Uočljive razlike u vrijednostima temperature zraka, posebice činjenica da su klimatske promjene različito utjecale na temperature zraka na ovim dvjema postajama, mogu se protumačiti s obzirom na njihov položaj u odnosu na otvoreno more i orografiju okolnog terena. Dok je Vela Luka izložena otvorenome moru i daleko je od kopna, na postaji Korčula utjecaj mora manje je značajan jer je ono u uskom kanalu između otoka Korčule i poluotoka Pelješca. Udaljenost meteorološke postaje Korčula od poluotoka Pelješca i kopna bitno je manja, a to utječe na brži trend rasta temperatura zraka na ovoj postaji nego na postaji Vela Luka, gdje utjecaj mora ublažava učinak globalnoga zagrijavanja. Orografija i blizina kopna značajno utječu na veću količinu oborina na postaji Korčula. Na ovoj postaji prosječna količina oborina u godini iznosi 231 mm ili 27,5% više nego na postaji Vela Luka. Na objema postajama uočava se trend smanjenja godišnje količine oborina.

KLJUČNE RIJEČI

temperatura zraka
oborine
klimatska promjena
mali otok
otok Korčula (Hrvatska)

1. INTRODUCTION / *Uvod*

An island is defined as a land mass on all sides surrounded by water. As a consequence of being separated from the continental land mass, each island represents a climatologically and hydrologically restricted unit with exclusively local water balance. According to the UNESCO definition, in the hydrological sense, small islands are smaller than 1000 km^2, while very small ones are those whose area is less than 100 km^2 (Diaz Arenas and Febrillet Huertas 1986).

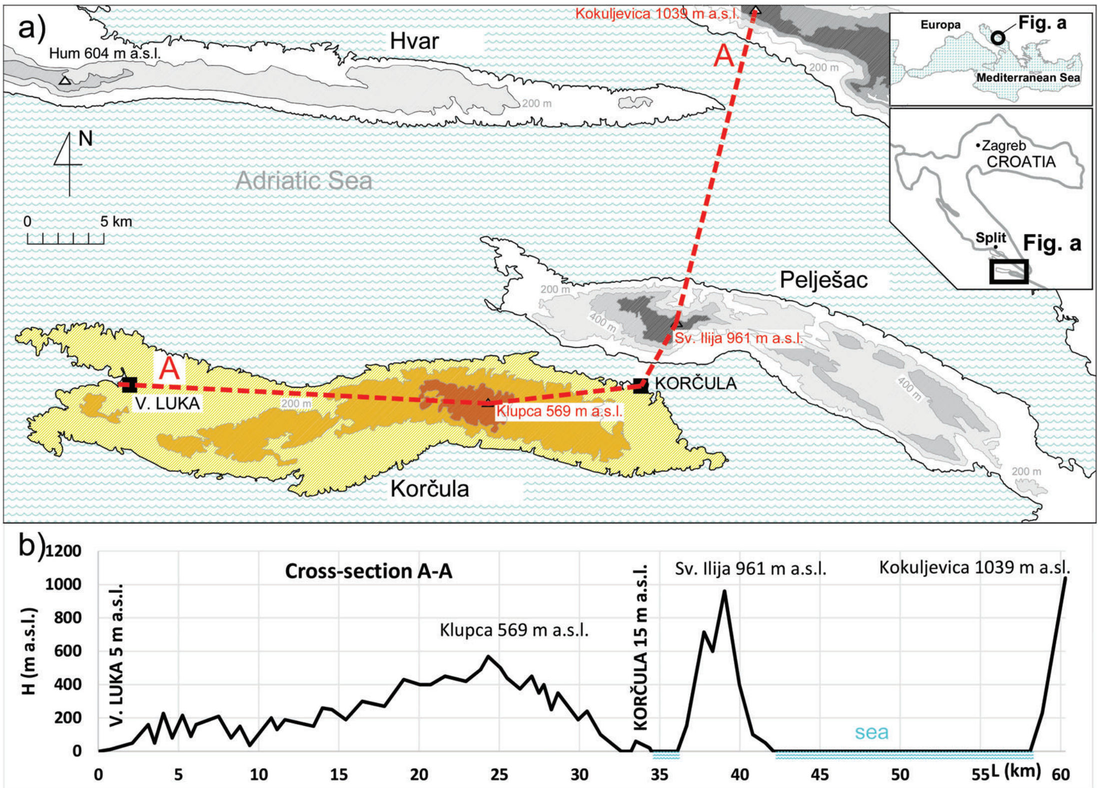

Figure 1 Map of the Korčula Island: (a) locations of meteorological stations; (b) section A-A passing through the location of two meteorological stations (Vela Luka and Korčula) and then through the mountain peaks of Sv. Ilija (961 m a.s.l.) on the Pelješac peninsula and Kokuljevica (1,039 m a.s.l.) on land

Slika 1. Karta otoka Korčule: (a) lokacije meteoroloških postaja; (b) sekcija A-A koja prolazi kroz lokaciju dviju meteoroloških postaja (Vela Luka i Korčula), a zatim kroz vrhove planine Sv. Ilija (961 m nadmorske visine) na poluotoku Pelješac i Kokuljevica (1.039 m nadmorske visine) na kopnu

Figure 1a shows the situation of the island of Korčula from which it can be observed that its eastern part, on which the station of Korčula is located, is only about 1,200 m away from the Pelješac peninsula, while the western part where the Vela Luka meteorological station is oriented towards the open sea. These facts certainly have a significant impact on the microclimate of these two weather stations. Figure 1b shows a section A-A, which passes through the location of two meteorological stations (Vela Luka and Korčula) and then through the mountain peaks of Sv. Ilija (961 m a.s.l.) on Pelješac and Kokuljevica (1,039 m a.s.l.) on land.

Bonacci et al. (2012) have pointed out the significantly different behaviour of rising air temperatures over time as well as the large differences between precipitations that fall on these two stations. They found that there were very different trends of rising air temperatures on them. Obviously, each station responds very differently to the existing climate change. The paper tried to find reasons for such behaviour. The phenomenon of climate change, which is most clearly manifested as global warming, is one of the most intriguing and, therefore, often discussed topics in contemporary science. It is interesting and important to try to study in more detail the dimensions and reasons for the different climatic behaviours at two stations located on a small inhabited island. This is the main goal of the analyses performed in this paper. Such cases have been relatively rarely reported in the literature and the findings presented may be of interest to the wider scientific community.

2. MATERIALS AND METHODS / *Materijali i metode*

The small Adriatic island of Korčula is situated between 42° 53′ and 42° 59′ north latitude and 16° 38′ and 17° 12′ east longitude. It extends in an east-west direction. It is 46.8 km long, while its width varies from 5.3 km to 7.8 km. With an area of 271.47 km2, Korčula is the sixth largest island and the second in population in the Croatian part of the Adriatic (Duplančić Leder et al. 2004). According to the 2011 census, there were 16,182 inhabitants. During the summer months more than 150,000 tourists visit the island.

The climate conditions prevailing in Korčula are very favourable for living and economic activities. A number of papers have been published on the natural resources of the island of Korčula with a focus on water resources (Terzić 2006; Ljubenkov et al. 2010; Krklec et al. 2011; Ljubenkov and Bonacci 2011; Bonacci et al. 2012; Ljubenkov 2012; Terzić et al. 2012). The island and coastal area of Dalmatia, as well as the island of Korčula, have a Mediterranean climate with mild winters and dry and hot summers. According to the Köppen-Geiger climate classification, the climate type is Csa (Šegota and Filipčić 2003). This means hot-summer Mediterranean climate, coldest month averaging above 0°C (or −3°C), at least one month›s average temperature above 22°C, and at least four months averaging above 10°C. At least three times as much precipitation in the wettest winter month as in the driest summer month, and the driest summer month receives less than 30 mm (Geiger, 1954).

The paper will analyse the series of air temperatures and precipitation measured at the two main meteorological stations of the DHMZ (Croatian Meteorological and Hydrological Service) (Vela Luka and Korčula), which are monitored daily at 7, 14 and 21 o'clock in local time. The basic characteristics of these stations are given in Table 1. The Vela Luka station started operating as a rain gauge in November 1948 and as a meteorological station in February 1951. The Korčula meteorological station started operating in February 1948. The analyses performed in this paper include all available observations up to and including the end of 2018. In

Table 1 The main characteristics of two analysed climatological stations
Tablica 1. Glavne karakteristike dviju promatranih klimatoloških postaja

Station name	Vela Luka	Korčula
Geographical coordinates	42° 57′ 33″; 16° 43′ 14″	42° 57′ 39″; 17° 07′ 57″
Elevation (m a.s.l.)	14	17
Distance from the sea (m)	365	40
Analysed period	XI 1948-XII 2018	I 1948-XII 2018
Missing data for T	XI 1948 - I 1951; VII 1976; X 1986 - IV 1988	I,VIII-X 1948; VIII 1961-VII 1964; VII 1966; I,V-VII 1968; IX 1994-IV 1995
Missing data for P	VII 1976; X 1986-IV 1988	I-XII 1968; IX 1994-III 1995

the period covered by this analysis, there were certain outages that are listed in Table 1.

For each of the two analysed time series of mean annual air temperatures, linear and nonlinear (second order curve) trends were calculated. The term for a linear trend is:

$$T = (a \times t) + b \qquad (1)$$

while the nonlinear trend equation, the second-order curves are:

$$T = (c \times t^2) + (d \times t) + e \qquad (2)$$

where, *T*, is the mean annual air temperature in the year, *t*, while, *a*, *b*, are the linear regression coefficients, *c*, *d*, *e*, are the second-order curve coefficients. They are all defined using the least squares method. It should be emphasized that the coefficient, *a*, represents the slope of the regression line whose dimension is °C/year. As such, it indicates the average annual intensity of rising or decreasing air temperature at a particular station.

Air temperature measurements began at the Vela Luka station in February 1951 and at the Korčula station in February 1948. The Vela Luka station has 63 full years in the period 1951-2018 (missing 1951, 1976, 1986-1988). In the period 1948-2018 Korčula station has 62 full years (missing 1948, 1961-1964, 1966, 1968, 1994-1995).

Among several statistical tests to determine the statistical significance of the linear trend, the SROC (Spearman Rank Order Correlation) nonparametric test was used in this paper (McGhee 1985; Adeloye and Montasari 2002). If there is a statistically significant linear trend, then the coefficient of linear regression, *a*, from expression (1) must be statistically different from zero (Adeloye and Montasari 2002).

The F-test and t-test were used to calculate the statistical significance of the differences between variances and averages of two annual air temperature time sub-series. These two tests helped us quantitatively compare whether the two air temperature time sub-series have a statistically significant difference in the variances (F-test) and average values (t-test).

3. RESULTS / *Rezultati*

3.1. Air Temperature / *Temperatura zraka*

3.1.1. Mean Annual Values Analysis / *Analiza godišnjih srednjih vrijednosti*

The average values of the mean annual air temperatures in the available common period of 55 years 1952-2018 (missing 1961-1964, 1966, 1968, 1976, 1986-1988, 1994-1995) were 15.7°C for Vela Luka and 16.7°C for Korčula. The minimum average annual air temperature at the Vela Luka station was measured in 1980 at 14.5°C. At Korčula station the same year the minimum annual average air temperature of 15.3°C was measured. The maximum average annual temperature of 16.8°C was measured in 2018 at the Vela Luka station, while the maximum annual average air temperature of 18.1°C was measured in 2015 at Korčula. In the mentioned period of 55 years of joint work, the coefficient of linear correlation between the mean annual temperatures of the two stations is, $r = 0.786$.

Figure 2 shows the series of mean annual air temperatures observed at the Vela Luka and Korčula meteorological stations over a 55-year period for which common measurements exist

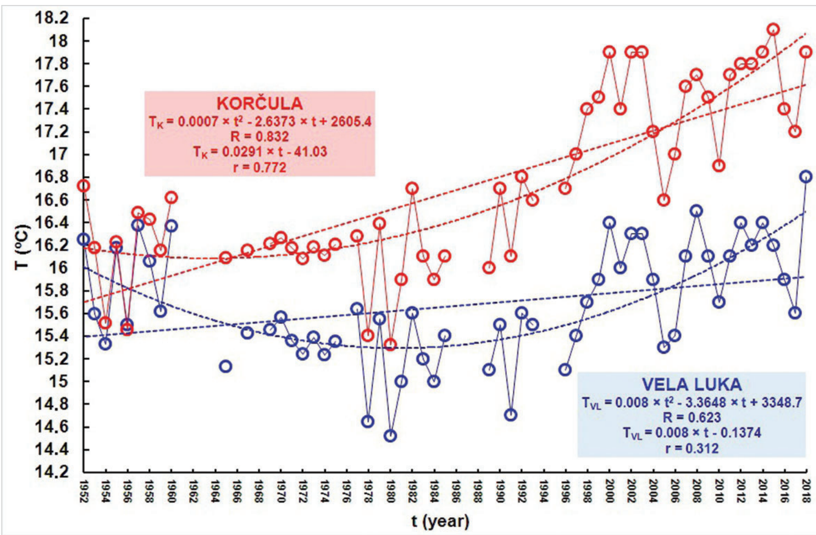

Figure 2 Series of mean annual air temperatures measured at meteorological stations Vela Luka and Korčula in the period 1952-2018 (missing 1961-1964, 1966, 1968, 1976, 1986-1988, 1994-1995) with regression lines, associated linear correlation coefficients, *r*, and second-order curves with associated nonlinear correlation index, *R*

Slika 2. Niz godišnjih srednjih temperatura zraka izmjerenih na meteorološkim postajama Vela Luka i Korčula u razdoblju 1952. – 2018. (nedostaju 1961. – 1964., 1966., 1968., 1976., 1986. – 1988., 1994. – 1995.) s regresijskim linijama, pripadajućim koeficijentima linearne korelacije, r, i krivuljama drugog reda s pripadajućim indeksom nelinearne korelacije, R

Table 2 Matrix of the average annual air temperature values, T_{av}, and results of, *F-test*, and, *t-test*, for the two subperiods of common work at Vela Luka and Korčula

Tablica 2. Matrica prosječnih godišnjih temperatura zraka, T_{av}, te rezultata F-testa i t-testa za dva podrazdoblja u Veloj Luci i Korčuli

station	subperiod	T_{av} (ºC)	F-test	t-test
VELA LUKA	1952-1993	15.45	0.820	***4.41E-05***
	1996-2018	15.99		
KORČULA	1952-1993	16.17	0.519	***7.82E-17***
	1996-2018	17.48		

throughout the year from 1952 to 2018 (missing 1961-1964, 1966, 1968, 1976, 1986-1988 1994-1995). The regression lines are plotted with the associated linear correlation coefficients, *r*, and the second order curve with the associated nonlinear correlation index, *R*. The linear correlation coefficients for the series of mean annual data measured at the Vela Luka station are statistically significantly different from zero at the level, $p<0.02$, while at the Korčula station they differ at the level, $p<0.01$.

As from Figure 2, the trends in the mean annual air temperature increase at the two analysed stations can be seen to differ significantly. Much more powerful is the one observed at Korčula station. The linear correlation coefficient of the Vela Luka series, $r=0.312$, is significantly smaller than that for the Korčula series, $r=0.772$. The linear regression coefficient, i.e. the slope parameter of the regression direction, $a=0.0291$ºC, for Korčula is 3.6 times higher than the coefficient, $a=0.008$ºC, for Vela Luka. The t-test indicates a statistically significant difference between the average values of this series of mean annual air temperatures, $p=3.9E\text{-}13$. The F-test indicates that the variance of the two sets is also statistically significant, since its value is, $p=0.003$. Quick look at the temperature data in Figure 2 gives an impression of different behaviour before and after 1994. Because of missing data (1961-1964, 1966, 1968, 1976, 1986-1988, 1994-1995) it is not possible to use Pettitt test or Rescaled Adjusted Partial Sums method for statistical detection of a sudden variation (in this case jump). Due to this fact F-test and t-test are used to determine statistically significant differences between two sub-periods: (1) 1952-1993 (missing 1961-1964, 1966, 1968, 1976, 1986-1988); (2) 1996-2018). Table 2 lists the average annual air temperature values, T_{av}, and results of, *F-test*, and, *t-test*, for the two previously mentioned sub-periods of common work at Vela Luka and Korčula. Italic bold underlined numbers indicate values when the statistical differences are significant at the level, $p<0.01$. In two analysed sub-periods at both stations variances there are no statistically significant differences. The average annual air temperatures in two sub-periods are statistically significant at the level, $p<0.01$.

The upward trends in the analysed time series of mean annual air temperatures over the available period are not linear. From the graphical representation in Figure 2, it can be concluded that average annual air temperatures have only been rising since the mid-1990s, and have stagnated or even fallen slightly until then. This behaviour of air temperatures has been observed at numerous meteorological stations in Croatia (Bonacci 2010; Bonacci and Roje-Bonacci 2018) and in the Western Balkans (Bonacci 2012). It seems that the effects of global warming on the analysed area began to have a significant effect on rising air temperatures only from the mid-1990s.

The average annual air temperatures at the Korčula station have always (except in 1956) been higher than at the 33.5 km distant station of Vela Luka. They are on average 1°C higher and range from a minimum value of -0.04ºC in 1956 up to a maximum value of 1.9ºC in 2015. The foregoing can be explained by the location of the stations in relation to the open sea and the orography of the surrounding terrain. The Vela Luka station is exposed to the open sea and is significantly farther from the mainland than the Korčula station. The influence of the sea on its local climate is less felt because it is smaller water mass located in the narrow channel between the island of Korčula and the Pelješac peninsula.

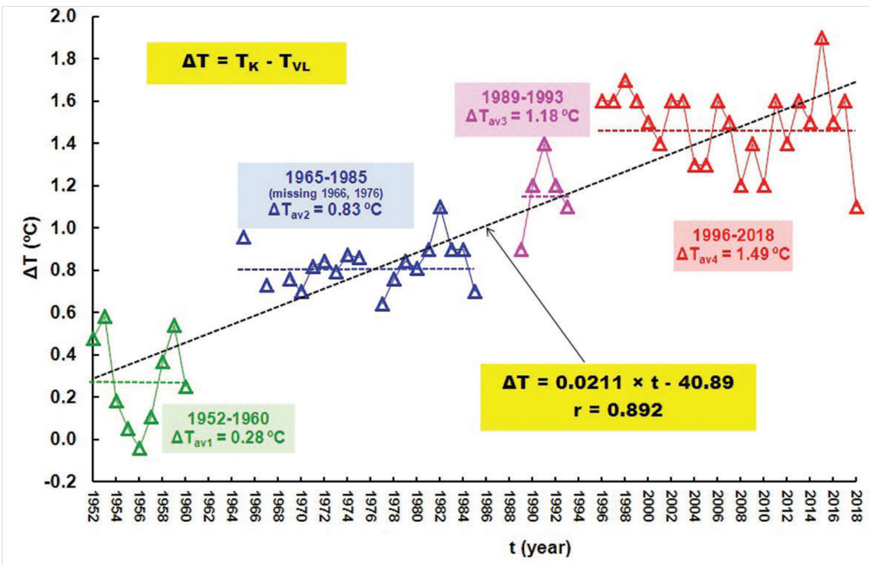

Figure 3 Subset of the difference in mean annual temperatures, $\Delta T=T_K\text{-}T_{VL}$, in the following four sub-periods: (1) 1952-1960; (2) 1965-1985; (3) 1989-1993; (4) 1996-2018 with regression line and linear correlation coefficient, *r*

Slika 3. Podskup razlike u godišnjim srednjim temperaturama, $\Delta T = T_K\text{-}T_{VL}$, u sljedećim četirima podrazdobljima: (1) 1952. – 1960.; (2) 1965. – 1985.; (3) 1989. – 1993.; (4) 1996. – 2018. s regresijskom linijom i koeficijentom linearne korelacije, r

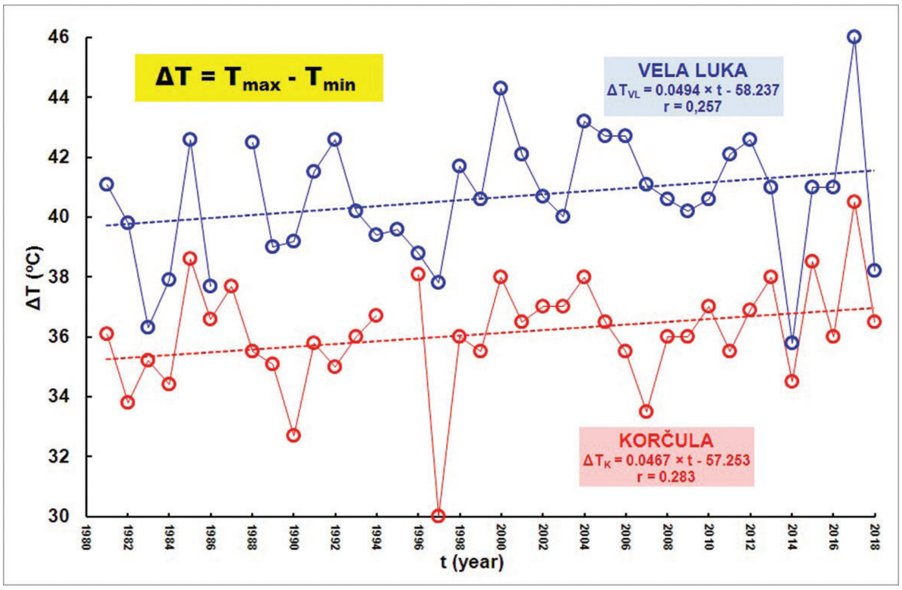

Figure 4 Graphical representation of the series of differences between the maximum and minimum annual air temperature observed in a given year at the Korčula, ΔT_K, and Vela Luka station, ΔT_{VL}, from 1981 to 2018

Slika 4. Grafički prikaz niza razlika između najviše i najniže godišnje temperature zraka zabilježene u danoj godini na postaji Korčula, ΔT_K, i Vela Luka, ΔT_{VL}, od 1981. do 2018.

Analysing the differences between the mean annual air temperatures, $\Delta T = T_K - T_{VL}$, at the two analysed stations, the existence of the following four sub-periods with different average values was determined: (1) 1952-1960; (2) 1965-1985 (missing 1966, 1976); (3) 1989-1993; (4) 1996-2018. Their graphical representation is in Figure 3. The values of the t-tests between adjacent subsets were lower than, $p<0.001$, which is strong evidence that the mean values of the differences, ΔT, differ statistically significantly in the four subperiods.

Figure 3 also shows the regression line (linear trend) for the entire period 1952-2018. There is a statistically significant trend of increasing differences, ΔT, in the analysed period, as evidenced by the high value of the linear correlation coefficient in the amount of, $r=0.892$, statistically significant at the level, $p<0.01$.

Figure 4 shows two series of differences between the maximum and minimum annual air temperatures observed at Korčula, ΔT_K, and Vela Luka, ΔT_{VL}, stations, from 1981 to 2018. From this view, it can be concluded that the temperature ranges during the year at Korčula station, on average, lower by 4.4ºC and range from the minimum value, 0.7ºC, 1996 to the maximum value, 7.8ºC, 1997. There is also a trend of significant increase at, $p<0.05$.

3.1.2. Mean Monthly Values Analysis / *Analiza mjesečnih srednjih vrijednosti*

This chapter will analyse the series of mean monthly air temperatures in each month of the year in the period for which data is available at both stations. Analysing the series of average monthly air temperatures at two stations on the island of Korčula will analyse trends of the average monthly air temperatures during each individual month of the year. Table 3 presents the matrix of characteristic (minimum, average, maximum, range, and standard deviations) mean monthly air temperatures at the two stations analysed. The second row of Table 3 lists the numbers of months, *N*, in the period 1951-2018 in which measurements were made at both stations. That number ranges from 61 to 64. In this table characteristic values (minimum, average, maximum, range and standard deviations) of mean monthly air temperatures at the two analysed stations during the common observation months are given.

Figure 5 shows the series of average monthly mean air temperatures at Vela Luka, T_{VL}, and Korčula, T_K, stations and the differences, $\Delta T = T_K - T_{VL}$, for each individual month of the year during the common observation months. The smallest differences

Table 3 Matrix of number of pairs, *N*, and characteristic values (minimum, average, maximum, range and standard deviations) of mean monthly air temperatures at the two analysed stations

Tablica 3. Matrica broja parova, N, i karakterističnih vrijednosti (minimum, prosječno, maksimum, opseg i standardne devijacije)

month	characteristic	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
	N	60	62	62	62	63	63	61	64	63	62	61	61
Vela Luka	min	3.6	4.2	7.8	10.9	15.3	20.0	23.0	20.5	17.6	13.2	8.2	5.1
	average	7.5	8.1	10.5	13.8	18.4	22.5	25.1	24.5	20.6	16.3	12.2	9.0
	max	11.0	11.3	13.9	15.8	20.8	26.5	27.7	27.1	23.4	18.8	14.9	11.6
	range	7.4	7.1	6.1	4.9	5.5	6.5	4.7	6.6	5.8	5.6	6.7	6.5
	stdev	1.41	1.75	1.23	1.08	1.19	1.26	1.10	1.31	1.12	1.19	1.39	1.41
Korčula	min	5.9	4.4	8.2	11.6	15.7	20.3	22.8	21.5	19.1	14.2	10.0	7.6
	average	9.1	9.3	11.5	14.5	18.9	22.8	25.5	25.2	21.6	17.7	13.6	10.5
	max	11.9	12.7	14.6	17.4	22.2	27.3	28.6	29.0	25.5	19.9	16.5	12.4
	range	6.0	8.3	6.4	5.8	6.5	7.0	5.8	7.5	6.4	5.7	6.5	4.8
	stdev	1.30	1.69	1.32	1.30	1.48	1.45	1.38	1.48	1.20	1.17	1.30	1.16

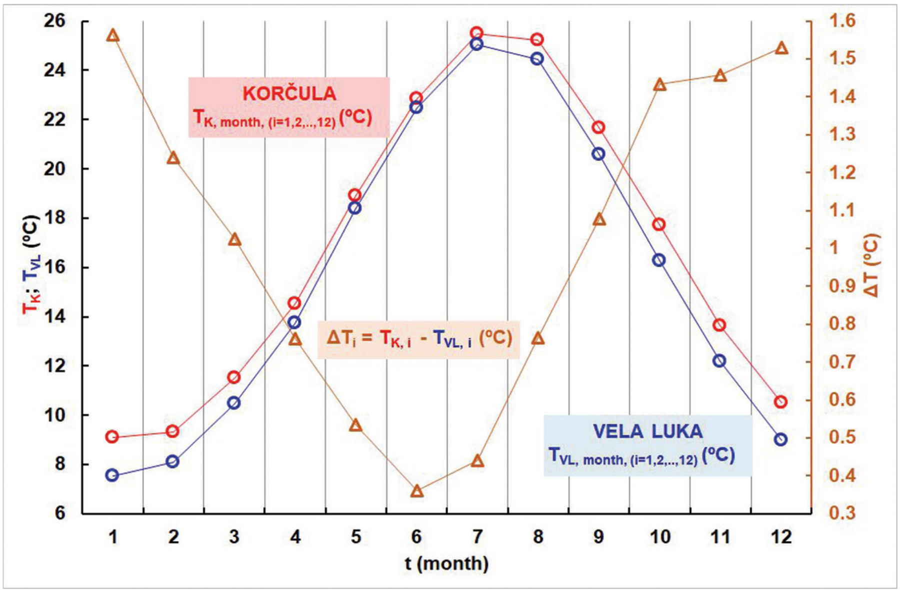

Figure 5 Series of monthly average air temperatures at Vela Luka station, T_{VL}, and Korčula, T_K, and the difference of their average monthly values, $\Delta T=T_K-T_{VL}$, during the common observation months, for each individual month of the year

Slika 5. Niz mjesečnih prosječnih temperatura zraka na postaji Vela Luka, T_{VL}, i Korčula, T_K, te razlika u njihovim prosječnim mjesečnim vrijednostima, $\Delta T = T_K-T_{VL}$, tijekom mjeseci promatranja na objema postajama, za svaki mjesec zasebno

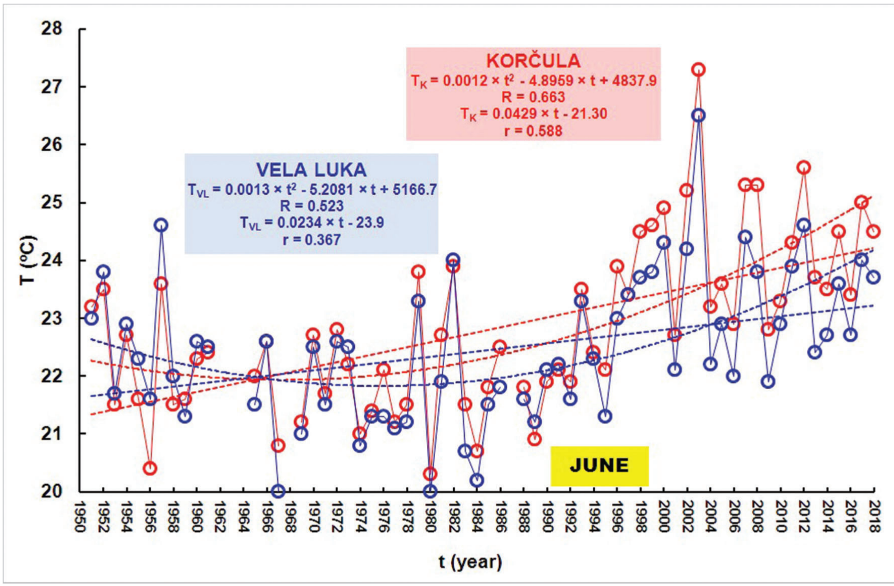

Figure 6 June monthly mean air temperature series measured at Vela Luka and Korčula meteorological stations in the period 1951-2018 (missing 1962-1964, 1968, 1987) with regression lines, associated linear correlation coefficients, *r*, and second-order curves with associated nonlinear correlation index, *R*

Slika 6. Lipanj, niz mjesečnih srednjih temperatura zraka izmjerenih na postajama Vela Luka i Korčula u razdoblju 1951. – 2018. (nedostaju 1962. – 1964., 1968., 1987.) s regresijskim linijama, pripadajućim koeficijentima linearne korelacije, r, i krivuljama drugog reda s pripadajućim indeksom nelinearne korelacije, R

occur during June, $\Delta T=0.36$°C, and the largest in January, $\Delta T=1.56$ °C. Differences from January to June decline, and from June to December they increase.

June monthly mean air temperature series measured at Vela Luka and Korčula meteorological stations in the period 1951-2018 (missing 1962-1964, 1968, 1987) with regression lines plotted, with associated linear correlation coefficients, *r*, and second-order curves with associated nonlinear indices the correlations, *R*, are shown in Figure 6. The time series at both stations show an increasing trend, with the one at the Korčula station is higher. It was statistically significant at the level, $p<0.01$. The upward trend at the Vela Luka station is slightly lower than, $p<0.02$. The slope of the regression direction is 1.8 times higher for the Korčula series than for the Vela Luka station.

Figure 7 shows the series of mean monthly air temperatures in December measured at meteorological stations Vela Luka and Korčula in the period 1951-2018 (missing 1961-1963, 1968, 1986-1987, 1994) with the indicated regression lines with the associated linear correlation coefficients, *r*, and second-order curves with associated nonlinear correlation index, *R*. Time series at both stations show a decreasing trend, with the one at Vela Luka station statistically significant at the level, $p<0.01$, while the decreasing trend at Korčula station is not statistically significant, $p>>0.05$.

Table 4 lists the values of linear regression coefficients, *a*, and linear correlation coefficients, *r*, for the series of mean monthly air temperatures observed at the two analysed stations in the common

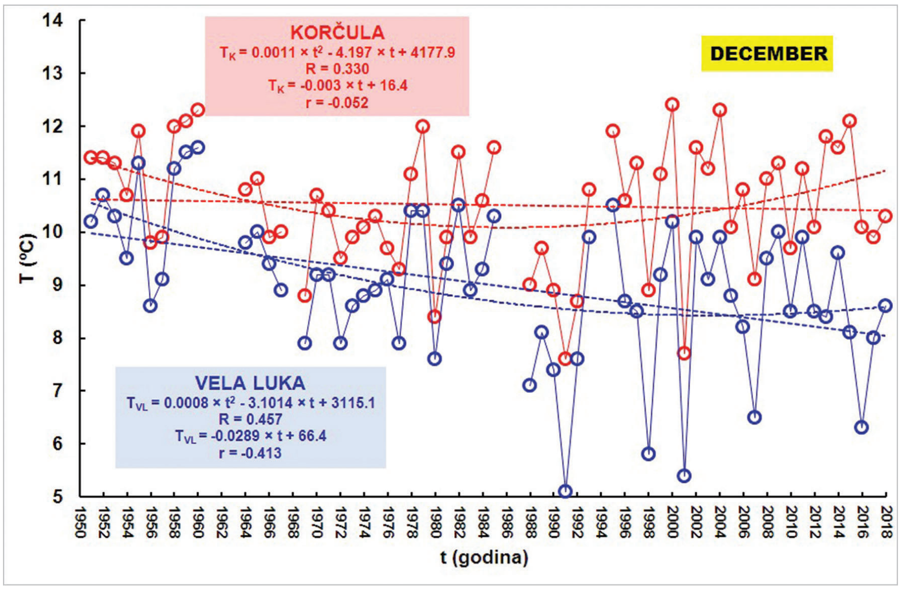

Figure 7 Average monthly air temperature series in December measured at Vela Luka and Korčula meteorological stations in the period 1951-2018 (missing 1961-1963, 1968, 1986-1987, 1994) with regression lines, associated linear correlation coefficients, *r*, and second order curves with associated nonlinear correlation index, *R*

Slika 7. Niz prosječnih mjesečnih temperatura zraka izmjerenih u prosincu na meteorološkim postajama Vela Luka i Korčula u razdoblju 1951. – 2018. (nedostaju 1961. – 1963., 1968., 1986. – 1987., 1994.) s regresijskim linijama, pripadajućim koeficijentima linearne korelacije, r, i krivuljama drugog reda s pripadajućim indeksom nelinearne korelacije, R

Table 4 Matrix of linear regression coefficients, *a*, and linear correlation coefficients, *r*, for the series of mean monthly air temperatures observed at the two analysed stations in the period of common work

Tablica 4. Matrica koeficijenata linearne rgresije, a, i koeficijenata linearne korelacije, r, za niz srednjih mjesečnih temperatura zraka zabilježenih na dvjema promatranim postajama

month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
$a_{Vela\ Luka}$	-0.054	-0.0086	0.0099	0.0127	0.020	0.0234	0.0267	0.0247	-0.0027	0.0021	0.0006	-0.0289
$r_{Vela\ Luka}$	-0.076	-0.099	0.161	*0.235*	*0.334*	*0.367*	*0.485*	*0.372*	-0.048	0.036	0.008	*-0.413*
$a_{Korčula}$	0.0144	0.0148	0.0291	0.0355	0.0418	0.0429	0.0461	0.0461	0.0187	0.0192	0.0208	-0.003
$r_{Korčula}$	0.219	0.176	*0.444*	*0.549*	*0.560*	*0.588*	*0.666*	*0.615*	*0.310*	*0.329*	*0.321*	-0.052

work period. Italic underlined numbers indicate values when the trend of increasing (or decreasing in the case of December at Vela Luka station) is significant at the level, $p<0.01$. Italic underscores with no bold indicate values when the upward trend is significant with the level, $p<0.05$. The black letters indicate the months in which there is no statistically significant trend, i.e. when, $p>0.05$. The analysis of the values listed in Table 4 clearly indicates that the trend of rising air temperatures is significantly higher at the Korčula station, and that temperatures rise significantly faster in the warm part of the year than in the cold part of the year.

Figure 8 shows four series of mean monthly temperature differences, $\Delta T = T_K - T_{VL}$, in June and December during the following four sub-periods: (1) 1951-1961; (2) 1965-1986 (missing 1968); (3) 1988-1993; (4) 1995-2018 with plotted regression lines and entered linear correlation coefficients, *r*. It can be observed that both linear correlation coefficients are high and, according to the SROC test, indicate statistically significant level trends, $p<0.01$. It is important to emphasize that the differences were statistically significant both in June as a representative of the warm part of the year and in December as a representative of the cold part of the year, where the trends of mean monthly temperatures were negative at both stations (see Figure 7). Table 5 lists the values of linear regression coefficients, *a*, and linear correlation coefficients, *r*, for the differences between the series of mean monthly air temperatures, ΔT, observed at the two analysed stations in the common work period. In each of the twelve months of the year, the trend of the regression lines are statistically significant at the level, $p<0.01$. Regardless of whether trends in the average monthly temperature rise or fall occurred in each month, differences between the average monthly temperatures at the two analysed stations increased. It is obvious that the heating processes manifest themselves much faster at the Korčula station than at the Vela Luka station.

Table 6 lists the values of the F-test and t-test results for the series of mean monthly and annual air temperatures observed at Vela Luka and Korčula stations in the period 1951-2018. Italic

Table 5 The matrix of linear regression coefficients, *a*, and linear correlation coefficients, *r*, for the differences, ΔT, between the series of mean monthly air temperatures observed at the two analysed stations in the period of common work.

Tablica 5. Matrica koeficijenata linearne rgresije, a, i koeficijenata linearne korelacije, r, za razlike, ΔT, između serija srednjih mjesečnih temperatura zraka na dvjema promatranim postajama

month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
a	0.0198	0.0234	0.0192	0.0225	0.0218	0.0195	0.0195	0.0212	0.0215	0.0171	0.0203	0.026
r	*0.554*	*0.634*	*0.665*	*0.775*	*0.701*	*0.722*	*0.712*	*0.712*	*0.758*	*0.567*	*0.659*	*0.665*

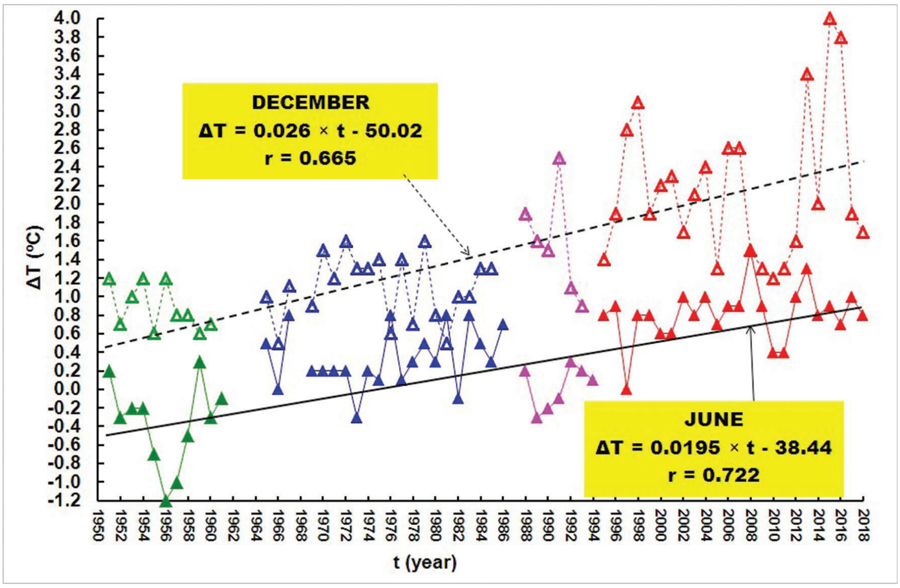

Figure 8 Subset of the differences in mean monthly temperatures, $\Delta T=T_K-T_{VL}$, in June and December over the following four subperiods: (1) 1951-1961; (2) 1965-1986 (missing 1968); (3) 1988-1993; (4) 1995-2018 with regression lines and linear correlation coefficients written, *r*

Slika 8. Podskup razlika u srednjim mjesečnim temperaturama, $\Delta T = T_K-T_{VL}$, u lipnju i prosincu u sljedećim četirima podrazdobljima: (1) 1951. – 1961.; (2) 1965. – 1986. (nedostaje 1968.); (3) 1988. – 1993.; (4) 1995. – 2018. s regresijskom linijom i koeficijentom linearne korelacije, r

Table 6 Matrix of F-test and t-test results for the series of mean monthly and annual air temperatures observed at Vela Luka and Korčula stations in the period 1951-2018

Tablica 6. Matrica rezultata F-testa i t-testa za niz srednjih mjesečnih i godišnjih temperatura zraka promatranih na postajama Vela Luka i Korčula u razdoblju 1951. - 2018.

month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
F-test	0.531	0.788	0.602	0.163	0.089	0.286	0.076	0.336	0.579	0.893	0.593	0.131	*0.003*
t-test	*5.2E-09*	*1.0E-04*	*1.7E-05*	*5.5E-04*	0.027	0.137	0.053	*2.4E-03*	*7.7E-07*	*4.9E-10*	*2.5E-08*	*1.4E-09*	*3.9E-13*

underlined numbers indicate values when the F-test and t-test values are statistically significant at the level, $p<0.01$. It can be concluded that in the warm part of the year the differences between the mean monthly air temperatures between the two stations are smaller than during the cold part of the year.

3.1.3. Daily Values Analysis / *Analiza dnevnih vrijednosti*

Since air temperature a measurement at the two analysed stations are made in three terms (7, 14 and 21 hours), mean daily air temperature, T_{mean}, is calculated by the following expression:

$$T_{mean} = (T_7 + T_{14} + 2\times T_{21})/4 \quad (3)$$

in which, T_7, T_{14}, T_{21}, represent the air temperatures measured at 7, 14 and 21 o'clock. This chapter will analyse the behaviour of air temperatures measured at two stations on the island of Korčula in the three aforementioned terms, as well as the mean daily temperatures calculated by the expression (3).

The following two years were selected for this type of analysis: (1) 1985; (2) 2015. The average annual temperatures in 1985 at Vela Luka station were 15.4ºC and at Korčula station 16.1ºC. It was a year in which the average annual temperatures at both stations were slightly lower than the average values in the whole analysed period. The average annual temperature in 2015 at the Vela Luka station was 16.2ºC. This temperature was higher than average and was in the ten of the hottest mean annual temperatures. At Korčula station 2015 was the warmest year in the whole analysed period and amounted to 18.1ºC. The measurements made in 2015 were selected for further analysis because the difference between the average annual temperatures at the two analysed stations that year was the largest in the available period. It was as high as 1.9ºC. The difference during 1985 was much smaller and amounted to 0.70ºC. Table 7 lists the characteristic (minimum, T_{min}; average, T_{av}; maximum, T_{max}) air temperatures measured at the Vela Luka and Korčula stations in 1985 and 2015 at 7, 14 and 21 o'clock.

In order to analyse the behaviour of air temperatures in more detail at the two analysed stations, the curves of the duration of the air temperature differences of Korčula and Vela Luka, $\Delta T=T_K-T_{VL}$, measured at 7, 14, 21 o'clock during 1985 are plotted in Figure 9, while the same duration curves of air temperature differences for the 2015 are plotted in Figure 10. From these views it is clear that the largest differences occur at 7 A.M., and that the smallest differences occur at 2 P.M. In the evening at 9 P.M. the temperature differences are slightly lower than in the morning.

Table 8 lists the values of characteristic differences in air temperatures (minimum, *min* ΔT; average, *av* ΔT; maximum, *max* ΔT) measured at 7, 14 and 21 o'clock and the average daily measured at Vela Luka and Korčula stations in 1985 and 2015. The last column of the matrix indicates the number of days, N, in each year when the air temperature at the Korčula station was higher than the air temperature at the Vela Luka station.

In the morning (7 A.M.) and evening (9 P.M.), the differences in air temperatures at the two stations are much higher than at 2 P.M. when they are approximately the same. The higher the air temperature in the middle of the day can relatively often be higher at Vela Luka station than at Korčula station. The explanation for this behaviour probably lies in the effect of sea temperature and local winds on air temperature at these

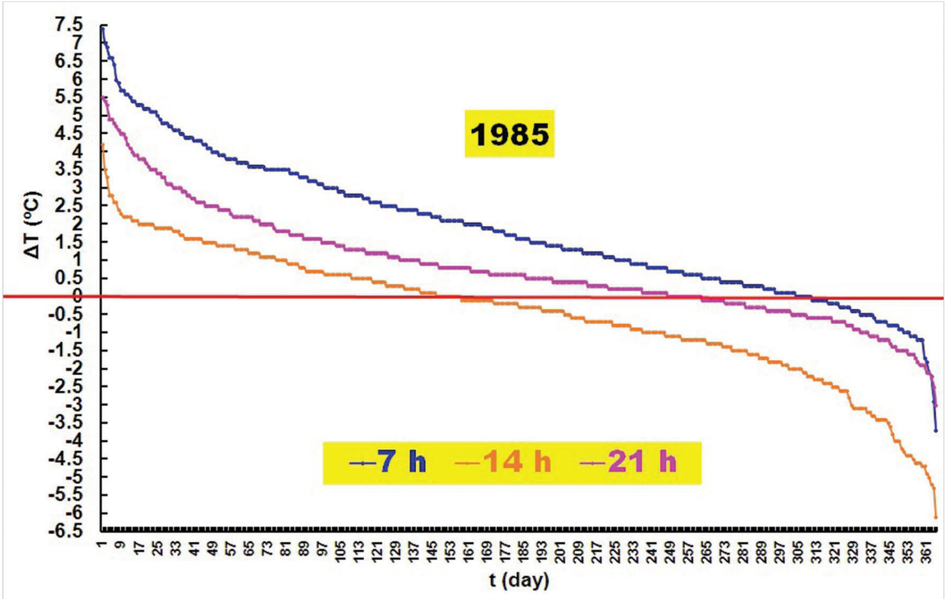

Figure 9 Duration curves of differences between Korčula and Vela Luka air temperature, $\Delta T=T_K-T_{VL}$, measured at 7, 14 and 21 hours during 1985

Slika 9. Krivulja trajanja razlika između temperatura zraka u Korčuli i Veloj Luci, $\Delta T = T_K-T_{VL}$, izmjerenih u 7, 14 i 21 h tijekom 1985.

Table 7 Matrix of characteristic (minimum, T_{min}; average, T_{av}; maximum, T_{max}) air temperatures measured at Vela Luka and Korčula stations in 1985 and 2015 at 7, 14 and 21 o'clock

Tablica 7. Matrica karakterističnih (minimum, T_{min}; prosječno, T_{av}; maksimum, T_{max}) temperatura zraka izmjerenih na postajama Vela Luka i Korčula u 1985. i 2015. u 7, 14 i 21 h

year	station name	hour	T_{min} (°C)	T_{av} (°C)	T_{max} (°C)
1985	Vela Luka	7	-2.6	14.3	30.4
		14	5.6	20.7	35.6
		21	-1.8	14.9	29.2
	Korčula	7	-1.8	15.5	28.7
		14	0.4	18.4	32.1
		21	-0.8	15.4	27.8
2015	Vela Luka	7	-6.4	13.7	27.5
		14	1.2	18.8	34.6
		21	-4.8	14.6	28.6
	Korčula	7	3.0	17.3	32.0
		14	4.8	20.6	37.5
		21	4.5	17.3	31.0

Table 8 The matrix of characteristic differences in air temperatures (minimum, *min ΔT*; average, *av ΔT*; maximum, *max ΔT*) measured at 7, 14 and 21 o'clock and the mean daily measured at Vela Luka and Korčula stations in 1985 and 2015. The last column of the matrix indicates the number of days, *N*, in each year when the air temperature at the Korčula station was higher than the air temperature at the Vela Luka station.

Tablica 8. Matrica karakterističnih razlika u temperaturama zraka (minimum, min ΔT; prosječno, av ΔT; maksimum, max ΔT) izmjerenih u 7, 14 i 21 h te srednjim dnevnim temperaturama izmjerenima na postajama Vela Luka i Korčula u 1985. i 2015. Zadnji stupac u matrici pokazuje broj dana, N, svake godine kad je temperatura zraka na postaji Korčula bila više od temperature zraka na postaji Vela Luka.

year	hour	min ΔT (°C)	av ΔT (°C)	max ΔT (°C)	N (days) $T_K \geq T_{VL}$
1985	7	-3.7	1.85	-3.0	310
	14	-6.1	-0.45	0.8	158
	21	-3.0	4.2	5.5	264
	mean daily	-2.1	0.75	4.2	200
2015	7	-3.0	3.03	10.4	310
	14	-4.5	-0.05	4.2	200
	21	-3.2	2.34	9.4	327
	mean daily	-2.0	2.34	9.4	327

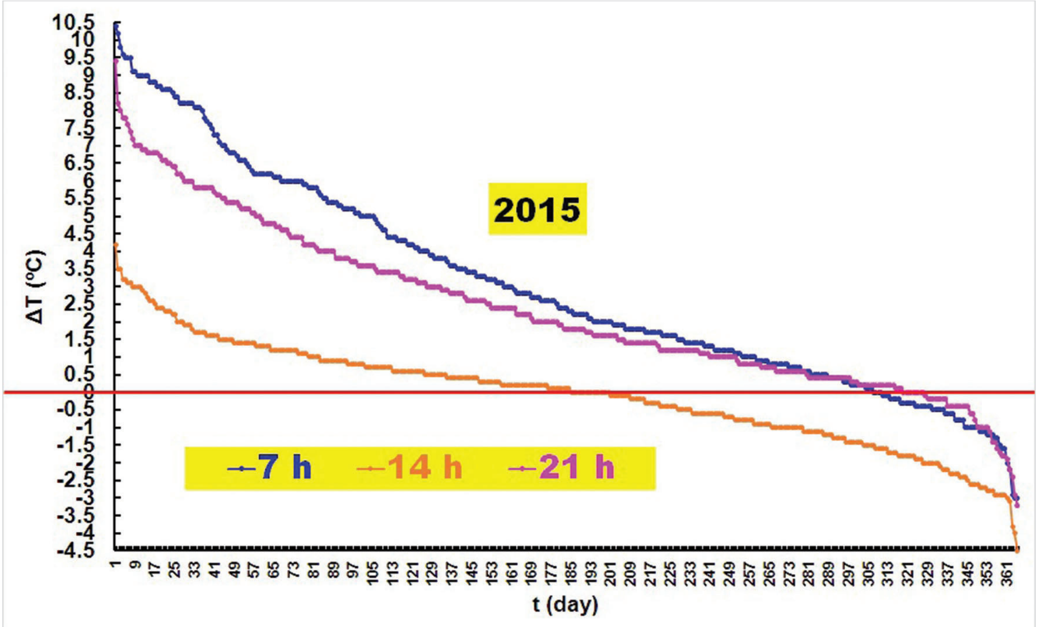

Figure 10 Duration curves of differences between Korčula and Vela Luka air temperature, $\Delta T=T_K-T_{VL}$, measured at 7, 14 and 21 hours during 2015

Slika 10. Krivulja trajanja razlika između temperatura zraka u Korčuli i Veloj Luci, $\Delta T = T_K-T_{VL}$, izmjerenih u 7, 14 i 21 h tijekom 2015.

locations. The temperature of the open seas is subject to greater variations during the day than the sea temperature in the closed Pelješac channel. The range of open sea temperatures as well as local winds during the day, affecting the Vela Luka station, is much higher than the range of sea temperatures affecting the Korčula station. The impact of local air currents from land to sea as well as from land to sea at the two analysed locations, and also the influence of the karst landscape around the stations, must not be neglected. Unfortunately, this aspect of the problem cannot be studied more precisely because there are no more detailed measurements of the various factors.

Figure 11 shows the duration curves of differences in mean daily air temperatures for Korčula and Vela Luka, $\Delta T=T_K-T_{VL}$, calculated by expression (3), measured in 1985 and 2015. The figure also shows the average values of the differences for each year. It is possible to notice a big difference between the warm 2015 and about the average 1985. The conclusion is that warmer year has greater differences in mean daily temperatures.

3.2. Precipitations / *Oborine*

3.2.1 Mean Annual Values Analysis / *Analiza godišnjih srednjih vrijednosti*

Precipitation measurements at the Vela Luka station began in November 1948. The Vela Luka station has 66 complete years of precipitation measurements in the period 1948-2018 (missing 1948, 1976, 1986-1988). Precipitation measurements at Korčula station began in February 1948. Korčula station has 67 whole years in the period 1948-2018 (missing 1948, 1968, 1994-1995).

This chapter will analyse the series of annual rainfall measured over the 63 years for which data is available at both stations in the period 1949-2018 (missing 1968, 1976, 1986-1988, 1994-1995). In the mentioned period of 63 years, the coefficient of linear

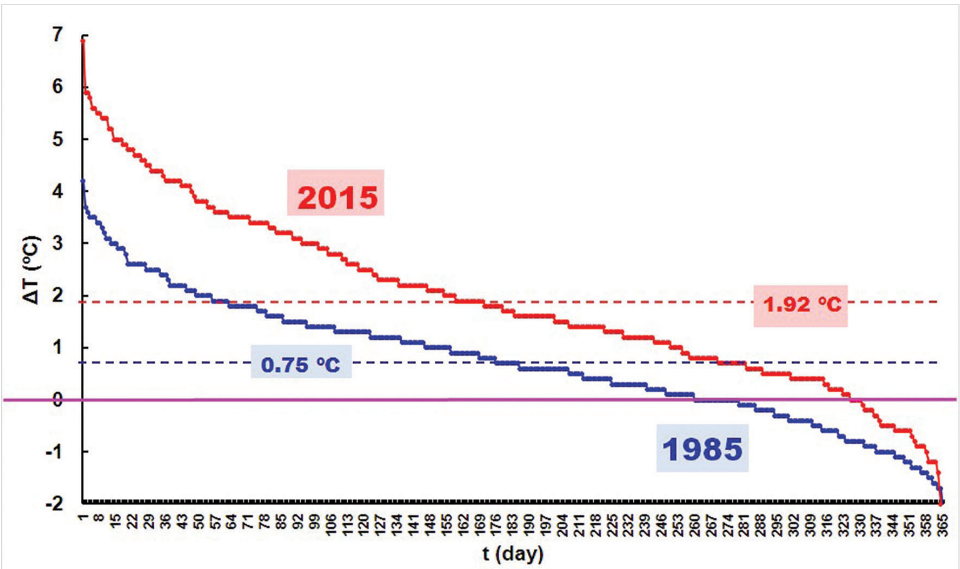

Figure 11 Duration curves of differences of mean daily air temperatures of Korčula and Vela Luka, $\Delta T=T_K-T_{VL}$, measured in 1985 and 2015

Slika 11. Krivulja trajanja razlika između srednjih dnevnih temperatura zraka u Korčuli i Veloj Luci, $\Delta T = T_K-T_{VL}$, izmjerenih u 1985. i 2015.

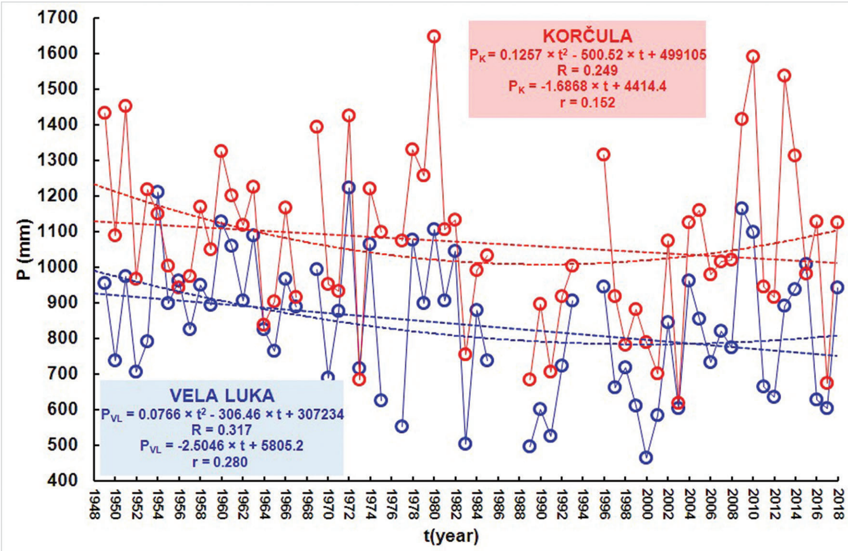

Figure 12 Annual precipitation series measured at Vela Luka and Korčula meteorological stations in the period 1949-2018 (missing 1968, 1976, 1986-1988, 1994-1995) with regression lines, associated linear correlation coefficients, *r*, and second-order curves with associated nonlinear indices correlations, *R*

Slika 12. Niz vrijednosti godišnjih oborina izmjerenih na meteorološkim postajama Vela Luka i Korčula u razdoblju 1949. – 2018. (nedostaju 1968., 1976., 1986. – 1988., 1994. – 1995.) s regresijskim linijama, pripadajućim koeficijentima linearne korelacije, r, i krivuljama drugog reda s pripadajućim indeksima nelinearne korelacije, R

correlation between the annual values of rainfall measured at the two stations was, $r=0.754$. This value indicates the similarity of the precipitation regime at the analysed stations. Figure 12 shows the series of annual rainfall measured at the Vela Luka and Korčula stations over a 63-year period for which common measurements exist throughout the year from 1949 to 2018 (missing 1968, 1976, 1986-1988, 1994-1995). The regression lines are plotted with the associated linear correlation coefficients, *r*, and the second order curve with the associated nonlinear correlation index, *R*.

The average value of annual rainfall during the 63 years of working together at the Vela Luka station was 838 mm. It ranged from a minimum of 464 mm measured in 2000 and a maximum of 1,223 mm measured in 1972. At Korčula station, average annual rainfall was 1,069 mm, which was 231 mm (i.e. 27.1%) higher than average annual rainfall measured at Vela Luka station. The annual precipitation ranged from a minimum of 618 mm measured in 2003 to a maximum of 1,648 mm measured in 1980. Figure 12 clearly shows the trends of declining annual rainfall at both stations. However, in both cases they are not statistically significant because they exceed a value of, $p>0.05$.

The differences in annual precipitation, $\Delta P=P_K-P_{VL}$, between Korčula, P_K, and Vela Luka, P_{VL}, in the period 1949-2018 (missing 1968, 1976, 1986-1988, 1994-1995) are graphically shown in Figure 13. The trend of increasing differences, ΔP, is not statistically significant in the analysed period, which is evidenced by the trend line and the low value of the linear correlation coefficient, $r=0.112$, for which, $p>0.05$. The conclusion is that the differences between the annual rainfalls at the two analysed stations do not change during the analysed period from 1949 to 2018.

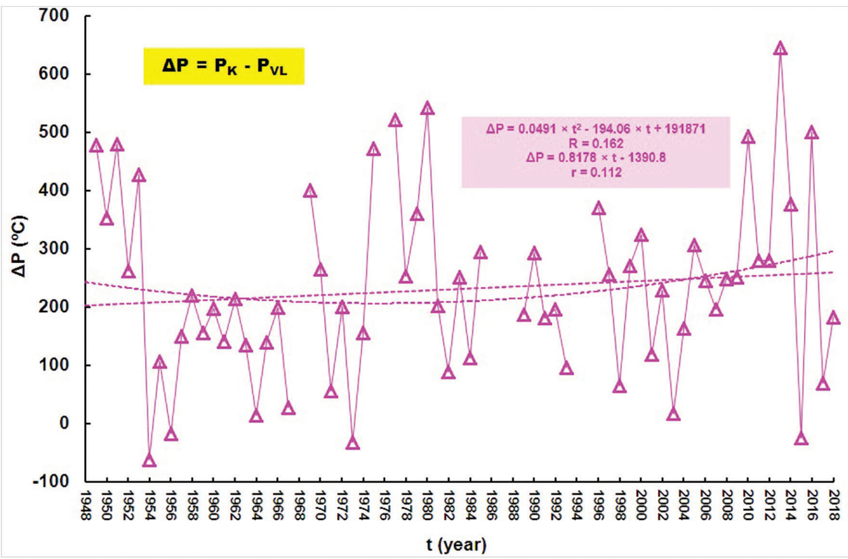

Figure 13 Time series of differences in annual rainfall, $\Delta P=P_K-P_{VL}$, in the period 1949-2018 (missing 1968, 1976, 1986-1988, 1994-1995) with regression line, associated linear correlation coefficient, *r*, and a second order curve with an associated nonlinear index correlations, *R*

Slika 13. Vremenski niz razlika u godišnjim oborinama, $\Delta P=P_K-P_{VL}$, u razdoblju 1949. – 2018. (nedostaju 1968., 1976., 1986. – 1988., 1994. – 1995.) s regresijskom linijom, pripadajućim koeficijentom linearne korelacije, r, i krivuljom drugog reda s pripadajućim indeksom nelinearne korelacije, R

Table 9 Matrix of number of pairs, N, and the characteristic values (minimum, average, maximum, range and standard deviations) of monthly rainfall in mm at two analysed stations.

Tablica 9. Matrica broja parova, N, i karakterističnih vrijednosti (minimum, prosječno, maksimum, opseg i standardne devijacije) mjesečnih oborina u milimetrima na dvjema promatranim postajama

month	characteristic	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
N		68	68	68	69	70	70	70	70	69	68	69	69
Vela Luka	min	3	1	1	7	1	0	0	0	2	0	28	0
	average	95	81	84	62	46	39	19	35	62	85	122	109
	max	307	275	264	225	218	216	87	184	185	250	343	302
	range	304	274	263	218	217	216	87	184	183	250	315	302
	stdev	64	62	63	39	41	38	22	40	45	58	67	72
Korčula	min	0	0	0	4	1	0	0	0	0	0	22	0
	average	116	104	101	82	55	41	28	48	79	116	156	143
	max	366	326	239	219	227	209	168	276	228	341	420	438
	range	366	326	239	215	226	209	168	276	228	341	398	438
	stdev	73	76	63	44	44	36	36	63	54	79	86	94

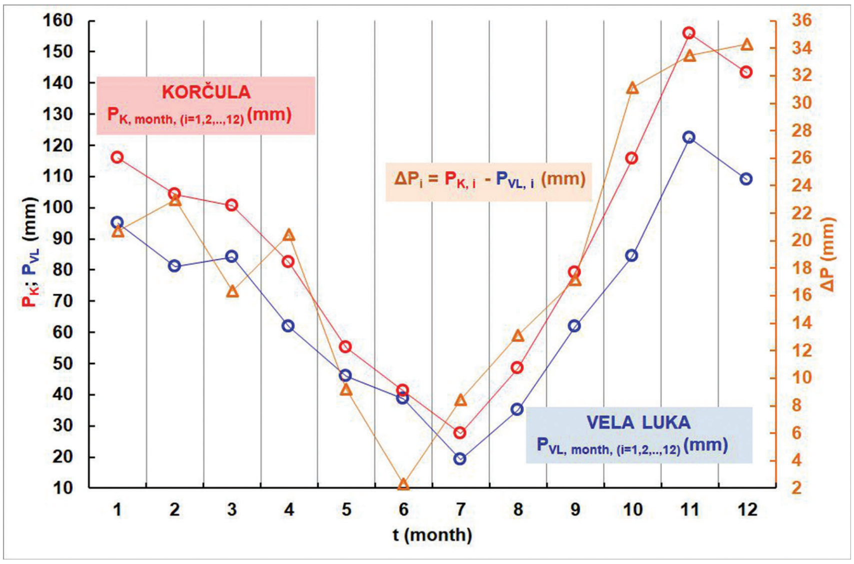

Figure 14 Monthly rainfall time series at Vela Luka, P_{VL}, and Korčula, P_K, and the difference in average monthly values, $\Delta P=P_K-P_{VL}$, during the common observation months, for each month of the year

Slika 14. Vremenski niz mjesečnih oborina na postajama Vela Luka, P_{VL}, i Korčula, P_K, te razlika u prosječnim mjesečnim vrijednostima, $\Delta P = P_K-P_{VL}$, tijekom mjeseci promatranja na objema postajama, za svaki mjesec zasebno

3.2.2. Mean Monthly Values Analysis / *Analiza mjesečnih srednjih vrijednosti*

This chapter will analyse the series of monthly rainfall in each month of the year in the period for which data is available at both stations. Table 9 presents the matrix of characteristic (minimum, average, maximum, range and standard deviations) mean monthly rainfall (in mm) at Vela Luka and Korčula stations. The second row of this table lists the months, *N*, in the period 1948-2018, where measurements were made at both stations. That number ranges from 68 to 70. By far the least rainfall falls in July, while November is the rainiest month of the year. A large range of precipitation should be observed in each month. At both stations, the lowest precipitation is in July. The largest precipitation is in November at Vela Luka station and in December at Korčula station.

Figure 14 shows the series of average monthly rainfall observed at Vela Luka, P_{VL}, and Korčula, P_K, and their differences, $\Delta P=P_K-P_{VL}$, for each month of the year during the common observation months. The smallest differences occur during June when the difference is, $\Delta P=2.3$ *mm,* and the largest in December when it is, $\Delta P=34.3$ *mm*. Differences from January to June generally decrease, and from June to December they increase.

4. CONCLUSIONS / *Zaključci*

Although the locations of two meteorological stations on the small island of Korčula are only 33.5 km apart, their basic climatological indicators, air temperatures and precipitation vary significantly. The average annual air temperature at the Vela Luka station (located in the western part of the island) is on average 1°C lower than that measured at the Korčula station (located in the eastern part of the island). A statistically significant increase in mean annual and mean monthly air temperatures was observed at both stations, although it was significantly higher at Korčula station. Based on the analyses performed in this paper, it is possible to conclude that global warming processes manifest faster at the Korčula station than at the Vela Luka station. The different values of air temperatures, and in particular the fact of the different response of air temperatures to climate change at two stations, can be explained by their local position relative to the open sea and the influence of the topography of the surrounding mostly bare karst terrain. As can be seen from Figure 1, Korčula station is much closer to the high bare mountainous terrain on the Pelješac peninsula and on land. While the climate at the Vela Luka station is exposed to the open sea and away from the mainland, the impact of the sea is less significant at the Korčula station because the sea is located in a narrow channel between the island of Korčula and the Pelješac peninsula. The distance of the Korčula meteorological station from the Pelješac peninsula and the mainland is significantly smaller, which affects the faster trend of rising air temperatures at this station than at the Vela Luka station, where the influence of the sea significantly mitigates the effect of global warming. Local winds at Vela Luka are stronger than at Korčula.

The average value of annual rainfall during the 63 years of working together at the Vela Luka station was 838 mm. At Korčula station it was 1,069 mm that is 27.6% higher than in Vela Luka. Trends in annual rainfall over the period 1949-2018 have been identified, but they are almost identical for both locations. Declining trends are likely caused by global climate change processes, while more annual rainfall at Korčula station is a consequence of the influence of high mountains on Pelješac and on land.

When looking for a reason for the rise in air temperature at these two locations, the potential effect of urbanization should not be neglected. During the period of about 70 years in which temperature measurements were available, the population of neither Vela Luka nor Korčula changed. In 1948 the population in Vela Luka was 4,091, and according to the 2011 census there were 4,137 inhabitants. In Korčula, the population in 1948 was 5,685, while according to the 2011 census it was 5,663. The development of tourism in both settlements influenced their rapid expansion. Urbanized areas have increased significantly. It should be noted that this is not a matter of classic urbanization but of the massive building of houses for holiday. Agricultural land has been almost completely replaced by facilities, roads, parking lots and swimming pools. The built facilities are mainly used as holiday homes, which are not inhabited all year round, but exclusively during the tourist season from May to September. It is estimated that the affected area has increased many times, in Vela Luka and Korčula, compared to the situation in the mid-1950s. In addition to the construction of structures, local streets and coasts were largely covered by asphalt or concrete in this period. In addition, it should be emphasized that the increase in air temperature is more significant during the warm summer period than in the colder winter, which is an indication that the effect of this type of urbanization probably did not significantly affect the increase in air temperature.

The fact is that over the last sixty years, mean annual air temperatures at the Korčula station have increased significantly faster than at the Vela Luka station. It is obvious that the effect of global warming is more strongly felt at the Korčula location than at the Vela Luka site. The extent to which this process is influenced by various factors (local and regional) has yet to be determined by detailed analyses, which cannot be performed at this time because there is not a wealth of key data available. The analyses performed in this paper suggest that the air temperature in the eastern part of the island of Korčula, especially in the part very close to the Pelješac peninsula, will rise significantly faster as a result of global warming than in the eastern part directed towards the open seas.

This paper should serve as an incentive to study in greater detail and more reliably predict the development of rising air temperatures and decreasing annual rainfall on the small island of Korčula, which could be of benefit to many other small islands, especially in the Adriatic and Mediterranean, and possibly beyond. To achieve this goal, it will be necessary to organize much more detailed monitoring of different climatological and environmental parameters.

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