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RELATIONSHIP BETWEEN THE SEA SURFACE AND SURFACE AIR TEMPERATURE: A CASE OF THE ISLAND OF HVAR (ADRIATIC SEA, CROATIA)

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Relationship of Sea Surface Temperature (SST) and Surface Air Temperature (SAT) measured at the small island of Hvar (Adriatic Sea) are examined on annual and monthly time scales using data for a period of 55 years (1964-2018). The following three SST and SAT indices were analysed: (1) absolute minimum; (2) mean; (3) absolute maximum. The results highlighted a statistically significant increasing trend for all three SST analysed annual indices. In the case of SAT absolute minimum increasing trend is not statistically significant. For the other two indices the trends are statistically significant at the level, $p<0.01$. Monthly analysis for SST indices almost in all months (except October) have statistically significant increasing trends. In the case of SAT, a statistically significant increasing trend for all analysed indices occurred in summer (July and August). All results point out that the analysed region, especially small Adriatic islands are endangered of climate change, i.e. global warming during the summertime. Using the RAPS method on the minimum annual SST, a statistically significant shift upward was detected in 1988. Ten years later, in 1998, a statistically significant shift upward was detected on the mean and maximum SST and SAT indices. In the case of SAT minimum annual values, a statistically significant shift downward is detected, starting in 1979. In the analysed case of the Island of Hvar, the warming of SST indices is higher than the warming of SAT indices and occur during the whole year (except in October).

KEY WORDS: surface air temperature (SAT), surface sea temperature (SST), Mann-Kendal test, t-test, Island of Hvar (Croatia)

INTRODUCTION

An island represents a landmass surrounded by water on all sides. According to Diaz Arenas and Febrillet Huertas's (1986) classification, small islands are those smaller than 1000 km^2. In this paper the relationship of Sea Surface Temperature (SST) and Surface Air Temperature (SAT) measured at the small island of Hvar (Adriatic Sea-Croatia) are examined on annual and monthly time scales using data for a period of 55 years (1964-2018).

Soil surface heats and cools faster than sea surface. Because of that, the sea mitigates air temperature during the winter and summer. Due to this fact, the mean annual SST is higher than SAT, and the span of SAT is larger than the span of SST. For example, the mean annual SST in Split (37 km from Hvar in a straight line), is 1.2 ºC higher than SAT (PENZAR ET AL., 2001).

SST is a critical factor in the assessment of the climatic structure of a coastal region affected mainly by SAT (VLAHAKIS, POLLATOU, 1993). Quantifying recent time behaviour trends and variability in SST, as well as its relation with SAT, is of fundamental importance to understanding changes in the small island climate. SST plays important role in global lateral energy transport, radiative and turbulent air-sea energy exchange, absorption of anthropogenic greenhouse gases in the ocean, modification of the atmospheric boundary layer, the global water cycle, and many other global and regional processes (BULGIN ET AL,. 2020). The patterns of SST variability on interannual and longer timescales result from a combination of atmospheric and oceanic processes (DESER ET AL., 2010).

The global climate community has produced a wide range of results on the SST-SAT relationship, which are considered an important source in assessing future climate change. In recent decades a number of papers treating climate change influence on SST and SAT, as well as relations between SST and SAT in different regions have been published. S. Yasunaka and K. Hanawa (2011) made an intercomparison of various historical SST datasets. G. A. Theoharatos and I. G. Tselepidaki (1990) study the annual course of the SAT and SST in the Aegean Sea (Greece). They found that the observed delay of the maximum and minimum values of the SST was of the order of one month. Using SST data for the post-war period, A. Bartzokas et al. (1994) divided the Mediterranean Sea into subareas with similar covariances. The scores of the analyses showed clearly that the minimum of the late 1970s and the warming of recent years were somewhat delayed in the eastern Mediterranean. F. Pastor et al. (2001) studied the role of SST in torrential rain development. They concluded that significant improvements in the modelling of peak precipitation could be expected when using SST derived from NOAA satellite data. M. I. R. Tinmaker et al. (2010) disclosed a significant correlation between lightning activity over Peninsular India and SST. M. I. Travasso et al. (2003) analysed relations between SST and crop yields in Argentina, i.e. the role of SST on the drought occurrence.

SST and SAT were measured in situ in Tokyo Bay. The measurements were made with high spatial and temporal resolutions between November 2006 and September 2007. R. Oda and M. Kanda (2009) analysed the impact of the seasonal and diurnal SST on the urban SAT. S. M. Barbosa and O. B. Andersen (2009) analysed trend patterns in global SST. The hydrographic data of 61 years was used to study the regular formation of the SST anomalies and their evaluation in the South- Eastern Mediterranean Sea in front of the northern Egyptian waters (MAIYZA ET AL., 2010). The periods of the cycles fluctuated from 8 to 15 years. The active period of the year was from June to August, and the coastal areas were more active. Y. Tang (2012) described the effect of SST temporal and spatial variability on regional coastal weather forecasts. Climatology and relationship of SST and SAT over the Arabian Sea, Bay of Bengal and the Indian Ocean north of 15ºS were examined on annual and seasonal time scales using the voluntary observing ships data for a period of 40 years (1961-2000) (JASWAL ET AL., 2012). Y. Zheng et al. (2013) analysed the influences of SST gradients and surface roughness changes on the motion of surface oil.

Research in Croatia, regarding the SST and SAT on small islands is scarce. The future eastern Adriatic climate is going to be characterised by warming up to +5 °C towards the end of the twenty-first century (BRANKOVIĆ ET AL., 2013). The UNDP document *A Climate for change* (2008, 78) includes the following statements about sea level rising: “*The Mediterranean, including the Croatian Adriatic coastline, is affected by global sea-level rises caused by thermal expansion of the oceans and melting of the polar ice caps. Areas particularly at risk from sea level rise are low islands such as Krapanj (only 1.5 m above sea level) and river deltas (e.g. the Nereteva river delta, which includes large areas of agricultural land) which are vulnerable to coastal flooding and salinization. Overall, there has been a gradual rise over the past decade, but monitoring stations along the coast gave a wide variety of readings between 1956 and 1991: stations at Rovinj and Split indicate that the local sea level is rising, while those at Bakar and Dubrovnik register falling levels. How much of this is due to local uplift and subsistence is unclear; the Croatian coast is a tectonically active area, which can obscure long-term trends in sea-level changes. This makes it difficult to predict the precise impacts of sea-level rise in the Mediterranean on Croatia.*”

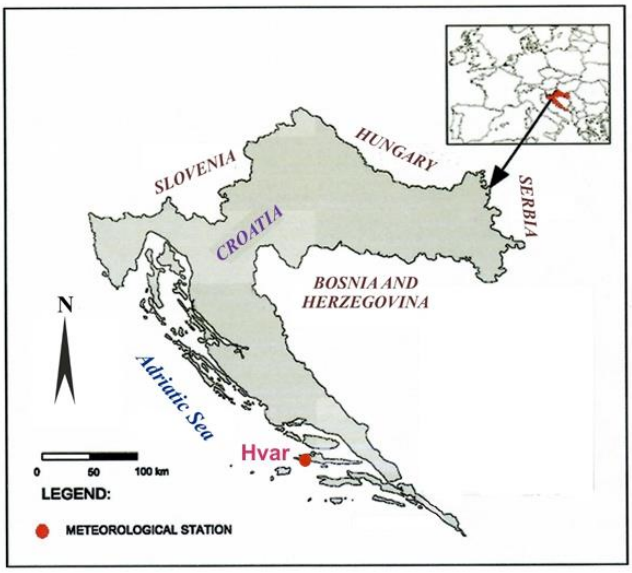
The physical and human characteristics of small islands unravel their potentially high vulnerability to climate change, which can cause fast, drastic, hardly predictable, and dangerous social and environmental changes. The main goal of this paper is to improve the understanding and explain the differences, and interrelations in the annual and monthly behaviour and future development of SST and SAT on a small island in the Mediterranean climate. The study aims to gain a better insight into the effect of global warming on the increasing SST and SAT trends. We wish to initiate detailed interdisciplinary research regarding the changes in SST and SAT on the small islands and coastal zones. Such research can help to prepare better for future climatic uncertainty.

MATERIALS AND METHODS

Site descriptions

The small Adriatic island of Hvar (Fig. 1) is situated between 43° 06' 44” and 43° 14' 08” north latitude and 16° 22' 17” and 17° 12' 05” east longitude. It belongs to the Central Dalmatian islands and extends in an east-west direction. The island is largely formed by carbonate rocks from the Mesozoic, which significantly influences its orographic, hydrological, and pedological features (MAMUT, ČIRJAK, 2017). The island is 68 km long and 10.5 km wide at its widest point. With an area of 297.38 km^2, and a coastline length of 270 km Hvar is the fourth largest island in the Croatian part of the Adriatic Sea (DUPLANČIĆ LEDER ET AL., 2004). The highest peak is at the altitude of 628 m above sea level (m a.s.l.). A population of 11,077 inhabitants (according to the 2011 census), makes Hvar the fourth most populated Croatian island. During the summer months, more than 200,000 tourists visit the island.

According to the Köppen-Geiger climate classification, the climate type is Csa (ŠEGOTA, FILIPČIĆ, 2003). The island with Mediterranean climate has mild winters and hot summers.



SLIKA 1. Područje istraživanja

FIGURE 1 Study area

The town of Hvar where the meteorological station Hvar is located (Fig. 2) has a population of 4251 (according to 2011 census). The Hvar meteorological station was commissioned in 1858. Its altitude is 20 m a.s.l. and its coordinates are 43º 10' 16" N and 16º 26' 13" E. This is the main meteorological station of the DHMZ (Croatian Meteorological and Hydrological Service), which are all monitored daily at 7, 14, and 21 o'clock at local time. The paper will analyse the series of SST (location noted as 2 in Fig. 2) and SAT (location noted as

1 in Fig. 2) on annual and monthly time scales using data for a period of 55 years (1964-2018). Aerial distance between these two locations is 100 m.

SLIKA 2. Google karta s označenim lokacijama meteorološke postaje Hvar (1) i položaja s kojeg se mjeri PTM (2)

FIGURE 2 Google map with indicated locations of meteorological station Hvar (1) and position where SST was monitored (2)

This study used the SST and SAT daily indices (absolute minimum, mean, and absolute maximum). SAT is measured at the height of 2 m, monitored at the meteorological shelter of the meteorological station Hvar. SST is measured 30 cm below the sea surface at locations 100 m aerial distance from the meteorological station Hvar. Water depth at this location varies between 1.8 and 2.5 m.

Methods used

In Croatia, the following equation is used to calculate the mean daily SST and SAT, T_{mean}:

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

where, T_7, T_{14}, and, T_{21}, are the air temperatures measured at 7 a.m., 2 p.m., and 9 p.m., respectively.

Linear and nonlinear (second order curve) trends are calculated for time series of three analysed monthly and annual SST and SAT indices. The expression for a linear trend is:

$$T = (a \times t) + b \quad (2)$$

while the nonlinear trend equation, the second-order curve is:

$$T = (c \times t^2) + (d \times t) + e \tag{3}$$

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 all are defined using the least squares method. The coefficient, a, represents the slope of the regression line whose dimension is ºC/year. It indicates the average intensity of rising or decreasing SST or SAT of a particular time series. For linear trends, the coefficient of linear correlation, *r*, and for nonlinear trends, the index of nonlinear correlation, *R*, are both calculated.

Employing pyMannKendall package for Python, trend analyses of SST and SAT time series are performed using a non-parametric Mann-Kendall (M-K) trend test that does not assume the underlying distribution of the data (HUSSAIN SHOUROV, MAHMUD, 2019). This is a rank-based method, which considers the relative magnitudes of a given variable in its time series. The null hypothesis for this test is that there is no monotonic trend in the analysed series, while the alternate hypothesis is that there is a trend. In this study, two levels of significance are used as a criterion of acceptance: (1) $p<0.05$; (2) $p<0.01$.

In order to analyse the effect of SST on SAT, linear regression analysis is used for three indices, in different time scales (year and 12 months) during the 1964-2018 period.

The RAPS method (GARBRECHT, FERNANDEZ 1994; BONACCI ET AL., 2020) helps to overcome random changes, errors, and variability in the analysed time series. The RAPS visualisation effectively highlights shifts (rise as well as drop), data clustering, and periodicities in the analysed time series. The expression for the calculation of $RAPS_k$ is:

$$RAPS_k = \sum_{t=1}^{k} \frac{Y_t - Y_m}{S_y} \tag{4}$$

where: Y_t, is the mean annual temperature in a year, t; Y_m, is the sample mean; S_Y is standard deviation over the entire, n; values in the time series, and (k=1, 2…,n) is the counter limit of the summation for the year k.

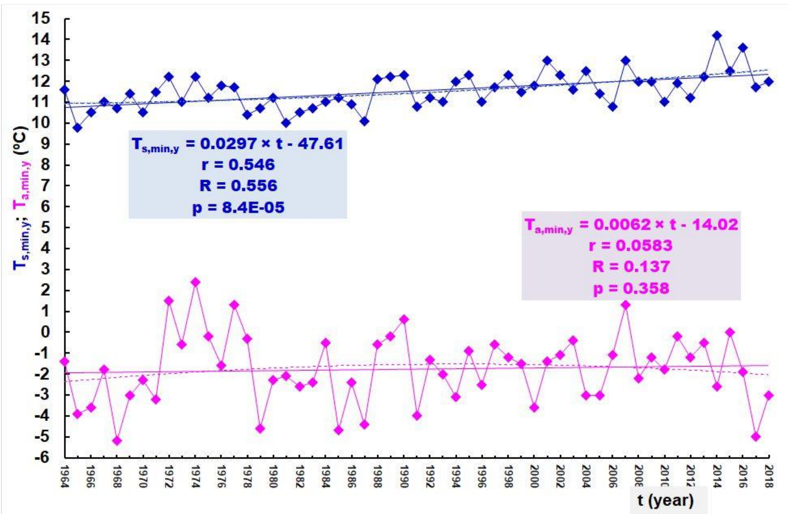
The F-test and t-test are used to calculate how statistically significant the differences are between variances and averages of two annual air temperature time subsequent sub-series defined by RAPS method (MCGHEE, 1985). These two tests helped to compare quantitatively whether the two SST or SAT time sub-series have a statistically significant difference in the variances (F-test) and average values (t-test).

RESULTS AND DISCUSSION

In order to discover efficient integrated measures, which will ensure an efficient answer to climate change challenges and the island`s sustainable development, it is of crucial importance to analyse and understand the similarities and the differences in the behaviour of the relationship between SST and SAT in different time scales. In this paper, two time scales are used: (1) year; (2) 12 month.

Relationship between annual SST and SAT

Table 1 depicts the main statistical characteristics (absolute minimum, average, absolute maximum, range, and standard deviation) of the annual sea surface, T_s, and air surface, T_a, temperature, and their differences, (T_s-T_a), measured at Hvar during the period 1964-2018. Two time series of annual absolute minimum SST (dark blue), $T_{s,min,y}$, and SAT (purple), $T_{a,min,y}$, are presented in Fig. 3. The regression lines are plotted with the associated linear correlation coefficients, r, and the second order curve with the associated nonlinear correlation index, R. In the analysed 55-year period (1964-2018) the average value for SST is 9.8 ºC, and for SAT it is -5.2 ºC, which is 15.0 ºC less than for SST. The linear increasing trend for the SST (1.6 ºC per 55 years) is statistically significant at the level, p<0.01, while for the SAT is not statistically significant.



SLIKA 3. Dvije vremenske serije godišnjega apsolutnog minimuma PTM-a (tamnoplava) $T_{m,min,y}$, i PTZ-a (ljubičasta), $T_{z\ min,y}$, izmjerena na Hvaru u razdoblju 1964. – 2018.

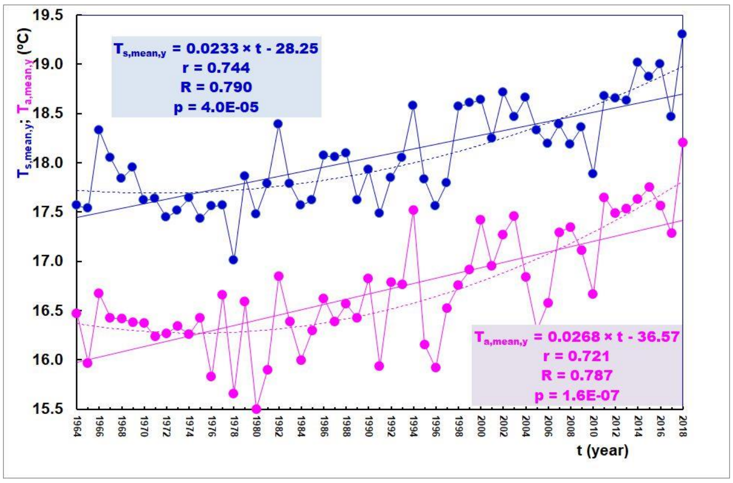
FIGURE 3 Two time series of the annual absolute minimum SST (dark blue), $T_{s,min,y}$, and SAT (purple), $T_{a,min,y}$, measured at Hvar in the period1964-2018

TABLICA 1. Glavne statističke karakteristike godišnje temperature površine mora T_m i površine zraka T_z i njihova razlike ($T_m – T_z$) izmjerena na Hvaru u razdoblju 1964. – 2018.

TABLE 1 The main statistical characteristics of annual sea surface, T_s, and air surface, T_a, temperature and their differences, (T_s-T_a), measured at Hvar during 1964-2018 period

[ºC]		min / min	srednja / mean	maks / max
T_m / T_s	**min / min**	9.8	17.01	24.0
	prosjek / average	11.54	18.07	25.91
	maks / max	14.2	19.30	27.8
	raspon / range	4.4	2.29	3.8
	stdev / stdev	0.871	0.501	0.976
T_z / T_a	**min / min**	-5.2	15.5	32
	prosjek / average	-1.77	16.70	34.48
	maks / max	2.4	18.2	37.5
	raspon / range	7.6	2.7	5.5
	stdev / stdev	1.684	0.594	1.194
$T_m – T_z$ / T_s-T_a	**min / min**	9.8	0.8	-11.4
	prosjek / average	13.31	1.37	-8.57
	maks / max	16.8	2.0	-6.5
	raspon / range	7.0	1.2	4.9
	stdev / stdev	1.575	0.278	1.038

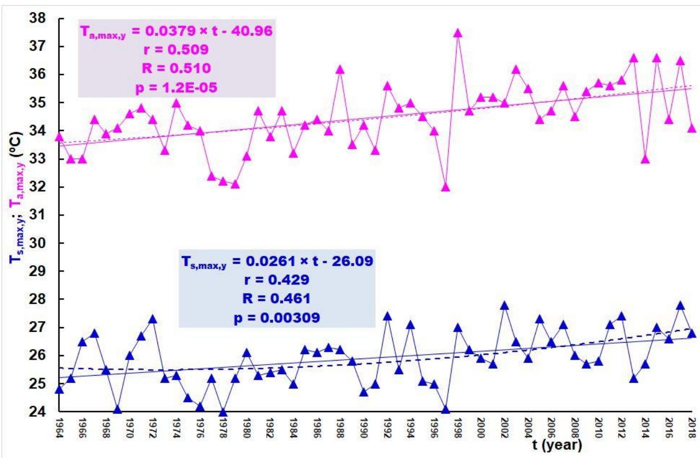
Two time series of annual mean SST (dark blue), $T_{s,mean,y}$, and SAT (purple), $T_{a,mean,y}$, are presented in Fig. 4. The regression lines are plotted with the associated linear correlation coefficients, r, and the second order curve with the associated nonlinear correlation index, R. In the analysed 55-year period (1964-2018) the average value for SST is 17.0 ºC, and for SAT it is 15.5 ºC, which is 1.5 ºC less than for SST. The linear upward trend, for both time series, is statistically significant at the level, $p<0.01$. For SST and SAT, the increases in 55 years are 1.3 ºC, 1.4 ºC, respectively. The upward trends in the two analysed time series over the available period are not linear. From the graphical presentation given in Fig. 4, it can be concluded that the mean annual SST and SAT were only rising since the mid-1990s, but stagnated until then. This behaviour of air temperatures was observed at numerous meteorological stations in the Western Balkans (BONACCI, 2012).



SLIKA 4. Dvije vremenske serije godišnje srednje vrijednosti PTM-a (tamnoplava) $T_{m,srednja,\ y,}$ i PTZ-a (ljubičasta), $T_{z,srednja,\ y,}$ izmjerene na Hvaru u razdoblju 1964. – 2018.

FIGURE 4 Two time series of the mean annual SST (dark blue), $T_{s,mean,y}$, and SAT (purple), $T_{a,mean,y}$, measured at Hvar in the 1964-2018 period

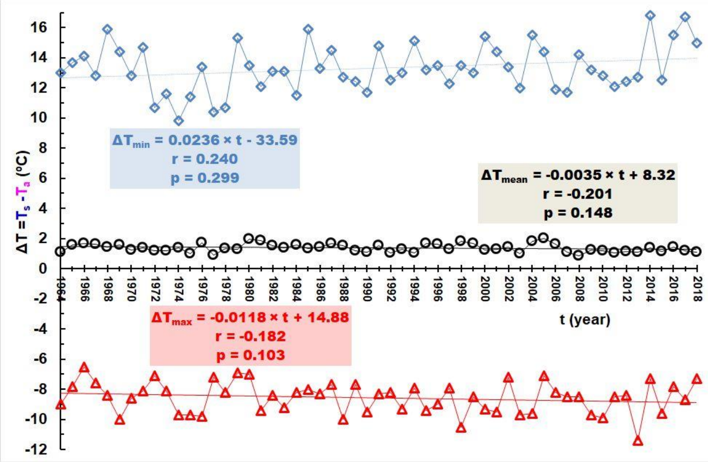
Two time series of annual absolute maximum (dark blue), $T_{s,max},_y$, and SAT (purple), $T_{a,max,y}$, are presented in Fig. 5. The regression lines are plotted with the associated linear correlation coefficients, r, and the second order curve with the associated nonlinear correlation index, R. In the analysed 55-year period (1964-2018) the average value for SST is 24.0 ºC, and for SAT is 32.0 ºC, what is 8.0 ºC more than for SST. The linear upward trends for both time series are statistically significant at the level, p<0.01. As for SST and SAT, the increases in 55 years are 1.4 ºC, and 2.0 ºC, respectively.



SLIKA 5. Dvije vremenske serije godišnje maksimalnog PTM-a (tamnoplava) $T_{m,\ maks,\ y,}$ i PTZ-a (ljubičasta) $T_{z,\ maks,\ y,}$ izmjerene na Hvaru u razdoblju 1964. – 2018.

FIGURE 5 Two time series of the absolute maximum annual SST (dark blue), $T_{s,max,y}$, and SAT (purple), $T_{a,max,y}$, measured at Hvar in the 1964-2018 period

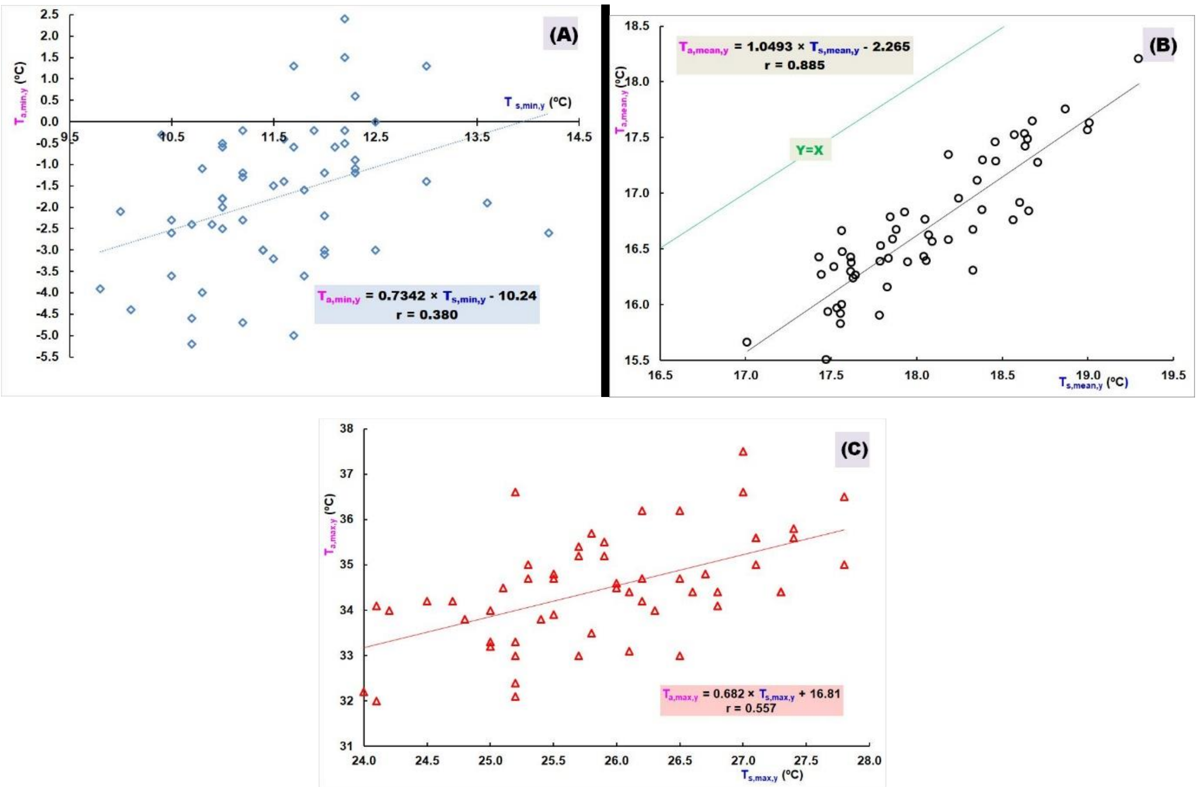
Figure 6 shows three time series of differences, $\Delta T = T_s - T_a$, between the absolute minimum, (blue), mean (black), and absolute maximum (red) annual air temperatures observed at Hvar from 1964 to 2018. In all three analysed series, trends are not statistically significant. Despite this fact, it should be noted that differences between mean and absolute maximum annual temperatures show a slightly decreasing trend, while in the case of differences between absolute minimum annual temperatures, the trend is slightly increasing.



SLIKA 6. Tri vremenske serije razlika između godišnjega apsolutnog minimuma (plavo) $\Delta T_{min,}$ srednje vrijednosti (crno) $\Delta T_{srednja,}$ i apsolutnog maksimuma (crveno) $\Delta T_{maks,}$ PTM, $T_{m,}$ i PTZ, T_z, izmjerene na Hvaru u razdoblju 1964. – 2018.

FIGURE 6 Three time series of differences between the absolute minimum annual (blue), ΔT_{min}, the mean annual (black), ΔT_{mean}, and the annual absolute maximum (red), ΔT_{max}, SST, T_s, and SAT, T_a, measured at Hvar in the period 1964-2018

Figure 7 depicts the ratio of (A) the absolute minimum annual SST, $T_{s,min,y}$, and SAT, $T_{a,min,y}$; (B) the mean annual SST, $T_{s,mean,y}$, and SAT, $T_{a,menn,y}$; and (C) the maximum annual SST, $T_{s,max,y}$, and SAT, $T_{a,max,y}$. The strongest relationship is between mean annual temperatures, with a very high value of correlation coefficient, r=0.885. The weakest relationship is between absolute minimum annual temperatures, with a low value of correlation coefficient r=0.380. Between absolute maximum annual temperatures coefficient of correlation is r=0.557.

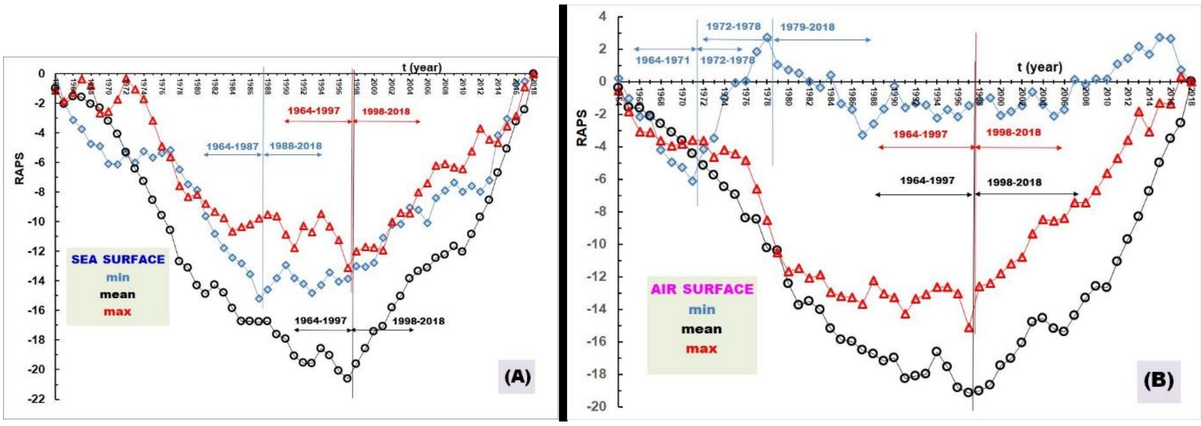


SLIKA 7. Omjer (A) apsolutnih godišnjih minimuma PTM-a, $T_{m,\ min,\ y,}$ i PTZ-a, $T_{z,\ min,\ y}$; (B) srednjih godišnjih PTM-a, $T_{m,\ srednja,\ y,}$ i PTZ-a, $T_{z\ srednja,\ y}$; i (C) apsolutnih godišnjih maksimuma PTM-a, $T_{m,\ maks,\ y}$ i PTZ-a, $T_{z,\ maks,\ y}$

FIGURE 7 The ratio of (A) the annual absolute minimum SST, $T_{s,min,y}$, and SAT, $T_{a,min,y}$; (B) the mean annual SST, $T_{s,mean,y}$, and SAT, $T_{a,menn,y}$; and (C) the annual absolute maximum SST, $T_{s,max,y}$, and SAT, $T_{a,max,y}$

Figures 8A and 8B depict RAPS time series, for the minimum (blue), mean (black), and maximum (red) annual: (A) SST and (B) SAT. Based on the graphical presentations given in Fig. 8A the data series of annual absolute minimum SST is divided into two time subseries: (1) 1964-1987; (2) 1988-2018. The data series of mean and absolute maximum annual SST are divided into two time subseries: (1) 1964-1997; (2) 1998-2018. In Fig. 8B the data series of annual absolute minimum SAT is divided into three time subseries: (1) 1964-1971; (2) 1972-1978; (3) 1979-2018. The data series of mean and absolute maximum annual SST are divided into two time subseries: (1) 1964-1997; (2) 1998-2018. In the series of the absolute minimum annual SST, a statistically significant shift upward is detected in 1988. Ten years later, in 1998, a statistically significant shift upward is detected on the mean and absolute maximum SST and

SAT indices. In the case of SAT minimum annual values, a statistically significant shift downward is detected starting from 1979.



SLIKA 8. RAPS vremenske serije za minimalni (plava), srednji (crna) i maksimalni (crvena) godišnji: (A) PTM i (B) PTZ

FIGURE 8 RAPS time series for the minimum (blue), mean (black), and maximum (red) annual: (A) SST and (B) SAT

Table 2 is the matrix of results of average annual values for three indices, $T_{average}$, and probability, p, for F-test, and, t-test, for subseries of minimum, mean and maximum annual sea surface, T_s, and air, T_a, temperatures calculated at subperiods defined by RAPS method (see Figs. 8A and 8B). The values of the t-test between all adjacent analysed subseries substantiate the conclusion that average values in adjacent subperiods are statistically significant at the level $p<0.01$. The values of the F-test confirm that the variances in adjacent subperiods are not statistically significantly different.

TABLICA 2. Matrica rezultata prosječnih godišnjih vrijednosti za tri indeksa, $T_{prosjek}$ i vjerojatnost, p, za F-test, i t-test, za podserije minimalne, srednje i maksimalne godišnje površine mora, $T_{m,}$ i zraka, $T_{z,}$ temperature izračunate u potperiodima definiranim RAPS metodom (vidi Sl. 8.A i 8.B)

TABLE 2 Matrix of results of average annual values, for three indices, $T_{average}$, and probability, p, for F-test, and, t-test, for subseries of minimum, mean and maximum annual sea surface, T_s, and air, T_a, temperatures observed at subperiods defined by RAPS method (see Figs. 8A and 8B)

temperatura / temperature	indeks / indices	potperiod / subperiod	$T_{prosjek}$ (°C) / $T_{average}$ (°C)	p (F-test)	p (t-test)
T_m / T_s	min	1964. – 1987.	10,99	0,331	7,8E-06*

		1988. – 2018.	11,97		
	srednja	1964. – 1997.	17,77	0,933	4,8E-12*
		1998. – 2018.	18,56		
	max	1964. – 1997.	25,54	0,429	1,9E-04*
		1998. – 2018.	26,52		
T_z / T_a	min	1964. – 1971.	-3,05	0,722 0,993	2,4E-04* 5,6E-04*
		1972. – 1978.	0,37		
		1979. – 2018.	-1,88		
	min	1964. – 1997.	16,36	0,439	4,8E-10*
		1998. – 2018.	17,23		
	max	1964. – 1997.	33,95	0,766	5,3E-06*
		1998. – 2018.	35,34		

* p < 0,01

Relationship between monthly SST and SAT

The main statistical characteristics of the monthly sea surface, T_s, and air surface, T_a, temperature time series measured at Hvar during the 1964-2018 period are given in Table 3.

TABLICA 3. Statističke karakteristike mjesečnih temperatura površine mora, T_m, i površine zraka T_z, u vremenskim serijama izmjerene na Hvaru u razdoblju 1964. – 2018.

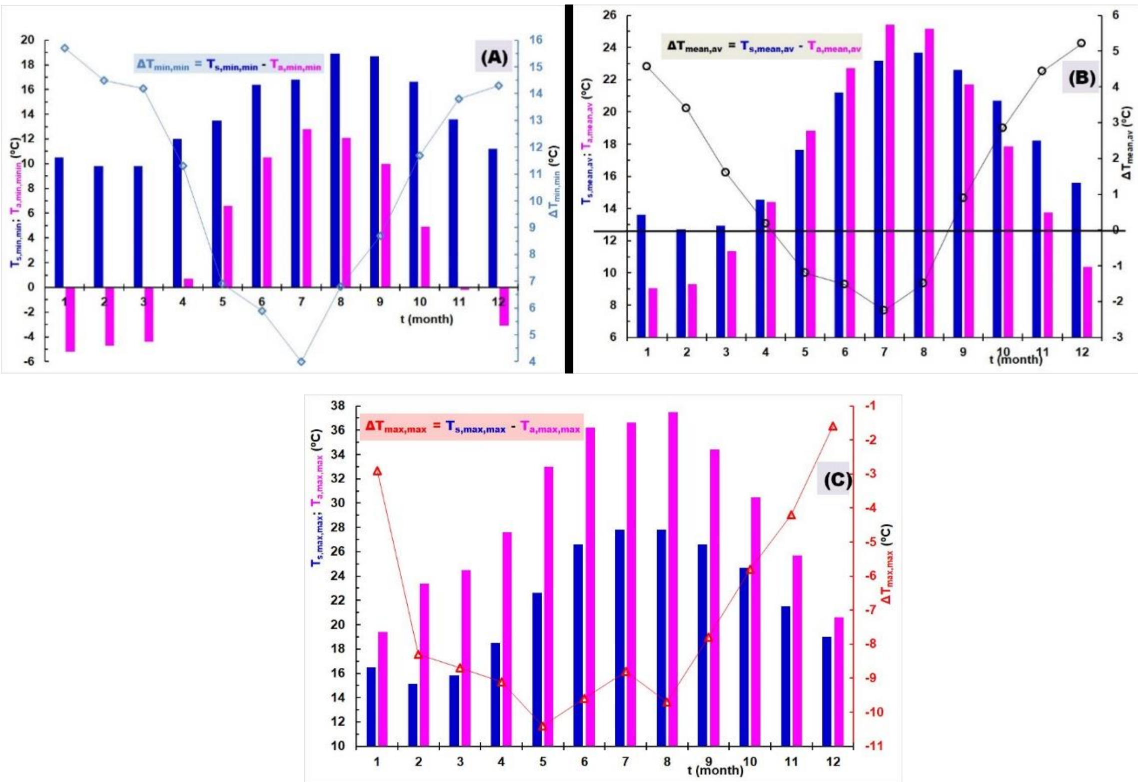
TABLE 3 The main statistical characteristics of monthly sea surface, T_s, and air surface, T_a, temperature time series measured at Hvar during 1964-2018 period

mjesec / month	**[ºC]**	**T_m / T_s**			**T_z / T_a**		
		min / min	**prosjek / average**	**maks / max**	**min / min**	**prosjek / average**	**maks / max**
S / J	**min / min**	10,5	12,5	13,3	-5,2	5,5	14,4
	srednja / mean	12,50	13,60	14,75	0,04	9,04	16,37
	maks / max	14,6	15,6	16,5	3,5	12,1	19,4
V / F	**min / min**	9,8	11,2	12,5	-4,7	5,3	14,5
	srednja / mean	11,69	12,70	13,36	0,00	9,30	17,27
	maks / max	14,2	14,5	15,1	5,0	12,6	23,4
O / M	**min / min**	9,8	11,6	12,4	-4,4	7,1	16,6

	srednja / mean	11,91	12,93	14,03	2,30	11,34	19,26
	maks / max	14,2	14,8	15,8	6,5	14,4	24,5
T / A	**min / min**	12,0	13,0	14,0	0,7	11,2	19,3
	srednja / mean	13,25	14,56	16,08	6,02	14,39	22,64
	maks / max	15,0	16,2	18,5	9,6	17,3	27,6
S / M	**min / min**	13,5	15,6	16,5	6,6	15,8	23,2
	srednja / mean	15,45	17,62	20,15	10,60	18,83	27,57
	maks / max	19,2	21,2	22,6	13,8	21,6	33
L / J	**min / min**	16,4	19,0	21,6	10,5	20,4	27,7
	srednja / mean	18,65	21,19	23,78	13,91	22,71	31,53
	maks / max	21,7	23,5	26,6	18,8	26,5	36,2
S / J	**min / min**	16,8	20,7	23,2	12,8	23,3	30,8
	srednja / mean	20,66	23,18	25,27	17,35	25,42	33,78
	maks / max	23,0	25,1	27,8	20,5	28,2	36,6
K / A	**min / min**	18,9	21,7	23,2	12,1	21,5	27,9
	srednja / mean	21,46	23,67	25,61	16,90	25,15	33,61
	maks / max	23,9	25,6	27,8	20,8	28,0	37,5
R / S	**min / min**	18,7	20,2	21,2	10,0	18,4	26,0
	srednja / mean	21,28	22,59	24,15	13,38	21,70	30,04
	maks / max	23,7	24,8	26,6	17,7	25,0	34,4
L / O	**min / min**	16,6	18,2	19,8	4,9	14,4	22,1
	srednja / mean	19,25	20,70	22,21	8,96	17,85	26,25
	maks / max	21,9	22,3	24,7	12,6	19,8	30,5
S / N	**min / min**	13,6	16,0	17,0	-0,2	10,6	19,0
	srednja / mean	16,65	18,20	19,70	4,34	13,76	21,83

	maks / max	19,0	19,8	21,5	10,0	16,5	25,7
P / D	**min / min**	11,2	14,2	15,3	-3,1	7,2	14,8
	srednja / mean	14,11	15,58	17,09	1,01	10,73	18,00
	maks / max	16,2	17,2	19,0	5,5	12,2	20,6

Figures 9A, 9B, and 9C as histograms show the series of the average monthly: (A) absolute minimum; (B) mean; (C) absolute maximum SST (dark blue) and SAT (purple) measured at Hvar in the 1964-2018 period. Their differences, $\Delta T=T_s-T_a$, are shown as a line with markers. Between absolute minimum indices, the smallest difference, $\Delta T_{min,min}$, occurs in July with a value of 4 ºC, and the largest in January, with a value of 15.7 ºC (Fig. 9A). In the case of mean indices, SST has lower average values than SAT during the period from May to August (Fig 8B). During the winter months, December and January, the average values of SST are higher 4.6 ºC and 5.2 ºC, respectively (Fig. 9B). Between absolute maximum indices, the smallest difference, $\Delta T_{max,max}$, occurs in December with a value of -1.6 ºC, and the largest in May, with a value of -10.6 ºC (Fig. 9C).

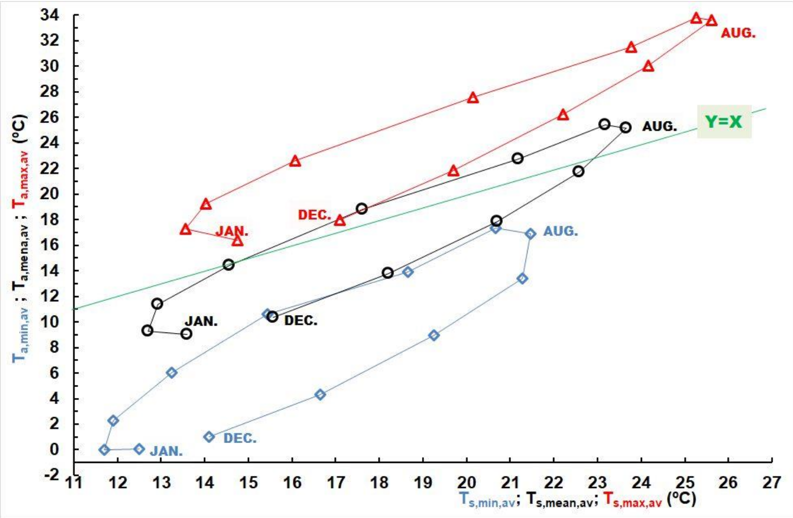


SLIKA 9. Histogrami prosječnoga mjesečnog: (A) apsolutnog minimuma; (B) srednje vrijednosti; (C) apsolutnog maksimuma PTM-a (tamnoplava) i PTZ-a (ljubičasta) izmjerene

na Hvaru u razdoblju 1964. – 2018. Njihove su razlike, $\Delta T = T_m - T_z$ prikazane kao crte s markerima

FIGURE 9 Histograms of the average monthly: (A) absolute minimum; (B) mean; (C) absolute maximum SST (dark blue) and SAT (purple) measured at Hvar in the 1964-2018 period. Their differences, $\Delta T=T_s-T_a$, are shown as a line with markers

The ratio of the average monthly absolute minimum (blue), mean (black), and absolute maximum (red) SAT and SST measured at Hvar in the 1964-2018 period is presented in Fig.10. In all three analysed indices formation of the loop can be noted.



SLIKA 10. Omjer prosječnoga mjesečnog apsolutnog minimuma (plava), srednje vrijednosti (crna) i apsolutnog maksimuma (crvena) PTZ-a i PTM-a izmjerenih na Hvaru u razdoblju 1964. – 2018.

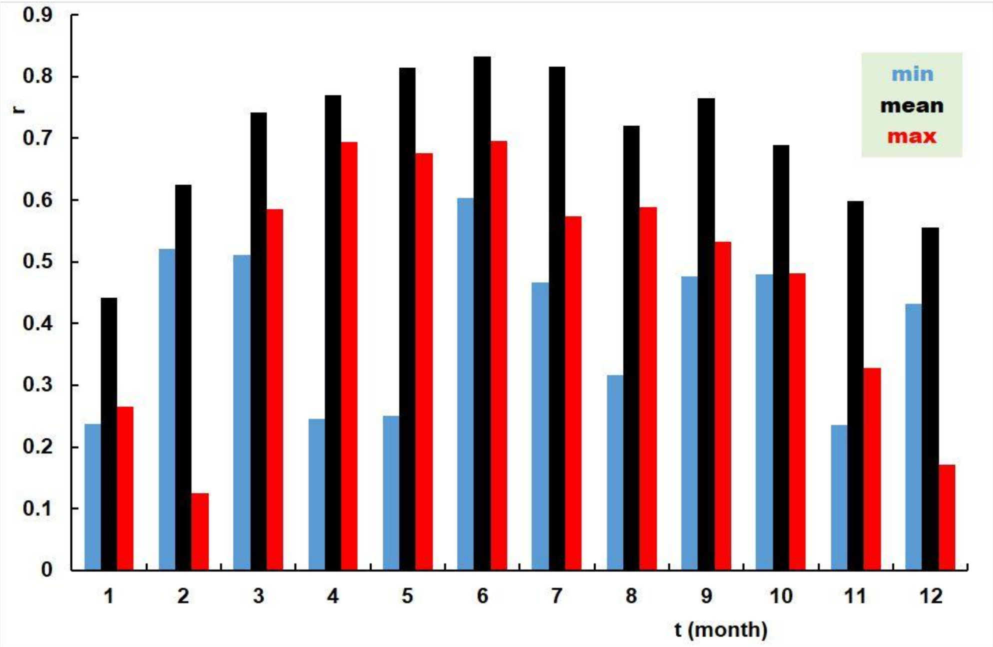
FIGURE 10 The ratio of the average monthly absolute minimum (blue), mean (black), and absolute maximum (red) SAT and SST measured at Hvar in the 1964-2018 period

Table 4 shows values of coefficients of linear correlation, r, between time series of absolute minimum, mean, and absolute maximum monthly sea surface, T_s, and air surface, T_a, temperatures measured at Hvar during the 1964-2018 period. For all three indices the maximum values (designated with a bold red number) of the coefficient of correlation, r, occur in June. The minimum values (designated with a bold dark blue number) occur in cold part of the year, for the absolute minimum in November, for mean in January, and for absolute maximum in February. Figure 11 presents histograms of the coefficients of linear correlation, r, between the average monthly absolute minimum (blue), mean (black), and absolute maximum (red) SST and SAT measured at Hvar in the period 1964-2018.

TABLICA 4. Matrica koeficijenata linearne korelacije, r, između vremenskih serija apsolutnog minimuma, srednje vrijednosti i apsolutnog maksimuma mjesečne temperature površine mora, $T_{m,}$ i površine zraka $T_{z,}$ izmjerenih na Hvaru u razdoblju 1964. – 2018.

TABLE 4 Matrix of coefficients of linear correlation, r, between time series of absolute minimum, mean and absolute maximum monthly sea surface, T_s, and air surface, T_a, temperatures measured at Hvar during the period 1964-2018

r	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
min	0.237	0.520	0.511	0.245	0.250	**0.603**	0.467	0.316	0.476	0.480	**0.236**	0.431
mean	**0.442**	0.624	0.743	0.771	0.814	**0.833**	0.816	0.721	0.766	0.689	0.599	0.555
max	0.265	**0.126**	0.584	0.694	0.676	**0.695**	0574	0.588	0.533	0.481	0.328	0.171



SLIKA 11. Histogrami koeficijenata linearne korelacije, r, između prosječnoga mjesečnog apsolutnog minimuma (plavo), srednje vrijednosti (crno) i apsolutnog maksimuma (crveno) PTM-a i PTZ-a izmjerenih na Hvaru u razdoblju 1964. – 2018. godine

FIGURE 11 Histograms of the coefficients of linear correlation, r, between the average monthly absolute minimum (blue), mean (black), and absolute maximum (red) SST and SAT measured at Hvar in the period 1964-2018

Table 5 is the matrix of values of coefficients of linear correlations, r, and the probability of M-K test, p, for characteristic monthly sea surface, T_s, and air surface, T_a, temperatures time series during the period 1964-2018. They are designated with bold red numbers when M-K test probability is $p<0.01$ and with bold dark blue numbers when M-K test probability is $0.01<p<0.05$. It can be seen that the statistically significant increasing trends for mean SST occur in all months (except in October). The statistically significant increasing trends for mean SAT occur only from April to August.

TABLICA 5. Matrica vrijednosti koeficijenata linearnih korelacija, r, i vjerojatnosti M-K testa, p, za karakterističnu mjesečnu temperaturu površine mora, T_m, i temperaturu zraka, T_z, u vremenskim serijama tijekom razdoblja 1964. – 2018.

TABLE 5 Matrix of values of coefficients of linear correlations, r, and probability of M-K test, p, for characteristic monthly sea surface, T_s, and air surface, T_a, temperatures time series during the period 1964-2018

mjesec / month	**indeks / indices**	**T_m / T_s**		**T_z / T_a**	
		r	**p**	**r**	**p**
S / J	**min / min**	0,541	5,8E-05**	0,040	0,77092
	srednja / mean	0,445	0,00462**	0,162	0,42004
	maks / max	0,220	0,21960	0,339	0,00571**
V / F	**min / min**	0,513	0,00025**	0,182	0,14356
	srednja / mean	0,398	0,00579**	0,075	0,52567
	maks / max	0,210	0,25844	0,039	0,36167
O / M	**min / min**	0,540	8,4E-05**	0,105	0,18889
	srednja / mean	0,455	0,00157**	0,259	0,07923
	maks / max	0,301	0,05015	0,272	0,01290*
T / A	**min / min**	0,425	0,00192**	0,179	0,14128
	srednja / mean	0,515	0,00042**	0,448	0,00022**
	maks / max	0,317	0,02176*	0,415	0,00914**
S / M	**min / min**	0,555	7,2E-05**	0,209	0,18134
	srednja / mean	0,492	0,00184**	0,389	0,01087*
	maks / max	0,415	0,00295**	0,461	0,00357**
L / J	**min / min**	0,542	6,4E-05**	0,288	0,08065
	srednja / mean	0,535	0,00022**	0,578	2,6E-05**
	maks / max	0406	0,00464**	0,492	0,00022**
S / J	**min / min**	0,403	0,00099**	0,629	6,0E-06**
	srednja / mean	0,594	1,0E-05**	0,678	1,1E-06**
	maks / max	0,488	0,00033**	0,373	0,00423**
K / A	**min / min**	0,389	0,00728**	0,562	3,6E-05**
	srednja / mean	0,492	0,00154**	0,633	2,6E-06**
	maks / max	0,346	0,02449*	0,459	0,00062**
R / S	**min / min**	0,297	0,03257*	0,092	0,32425
	srednja / mean	0,307	0,04437*	0,259	0,09007
	maks / max	0,414	0,00556**	0,404	0,00549**
L / O	**min / min**	0,374	0,00764**	0,241	0,22928
	srednja / mean	0,272	0,07064	0,201	0,35047
	maks / max	0,095	0,35428	0,032	0,62208

S / N	**min / min** **srednja / mean** **maks / max**	0,499 0,310 0,224	0,00060** 0,03702* 0,14311	0,261 0,263 0,346	0,13332 0,08573 0,04211*
P / D	**min / min** **srednja / mean** **maks / max**	0,372 0,403 0,322	0,02454* 0,00930** 0,03970*	0,024 0,092 0,039	0,90494 0,38566 0,68103

* 0,01 < p < 0,05

** p < 0,01

TABLICA 6. Matrica vrijednosti koeficijenata linearnih korelacija, r, i vjerojatnosti M-K testa, p, za karakteristične mjesečne razlike, $\Delta T = T_m - T_z$,, vremenskih serija u razdoblju 1964. – 2018.

TABLE 6 Matrix of values of coefficients of linear correlations, r, and probability of M-K test, p, for characteristic monthly differences, $\Delta T = T_s - T_a$, time series during the period 1964-2018

mjesec / month	**indeks / indices**	**ΔT =T m –Tz / ΔT = $T_s - T_a$**	
		r	**p**
S / J	**min / min** **srednja / mean** **maks / max**	0,161 0,066 -0,172	0,12231 0,41989 0,12686
V / F	**min / min** **srednja / mean** **maks / max**	0,008 0,093 0,036	0,66490 0,62210 0,97616
O / M	**min / min** **srednja / mean** **maks / max**	0,110 -0,030 -0,183	0,60652 0,95827 0,05035
T / A	**min / min** **srednja / mean** **maks / max**	0,006 -0,189 -0,345	0,95832 0,25603 0,06843
S / M	**min / min** **srednja / mean** **maks / max**	0,155 0,022 -0261	0,69792 0,95230 0,06520
L / J	**min / min** **srednja / mean** **maks / max**	0,042 -0,251 -0,339	0,84027 0,11489 0,01062*
S / J	**min / min** **srednja / mean** **maks / max**	-0,308 -0,353 -0,014	0,04458* 0,02397* 0,83437
K / A	**min / min** **srednja / mean** **maks / max**	-0,329 -0,459 -0,311	0,03595* 0,00048** 0,01266*
R / S	**min / min** **srednja / mean** **maks / max**	0,109 -0,037 -0,173	0,62755 0,39022 0,31707
L / O	**min / min**	-0,017	1,00000

	srednja / mean	0,041	0,39843
	maks / max	0,041	0,49216
S / N	**min / min**	-0,014	0,60691
	srednja / mean	-0,067	0,78780
	maks / max	-0,161	0,35807
P / D	**min / min**	0,176	0,33546
	srednja / mean	0,232	0,08965
	maks / max	0,160	0,18150

* 0,01 < p < 0,05

** p < 0,01

Table 6 is the matrix of values of coefficients of linear correlations, r, and the probability of M-K test, p, for characteristic monthly differences, $\Delta T=T_s-T_a$, time series during the period 1964-2018. The coefficients of linear correlations, r, are low, and mostly negative, which can be explained with a slight decrease in differences between SST and SAT. The statistically significant decreasing trend is noticed in the hottest parts of the year, in June (for absolute maximum), July (for absolute minimum and mean), and August (for all three indices).

CONCLUSIONS

The warming of SST indices is more pronounced than the warming of SAT indices and it occurs during the whole year (except in October). The seasonal analysis revealed a much greater increase in summer (June, July, August) and spring (March, April, May) temperatures in respect of autumn and winter. This finding is consistent with the most recent evidence from the Mediterranean region. The results highlighted a statistically significant increasing trend for all three analysed SST annual indices. In the case of SAT, the absolute minimum increasing trend is not statistically significant. For the other two indices, the trends are statistically significant at the level p<0.01. Monthly analysis for SST indices almost in all months (except October) have statistically significant increasing trends. In the case of SAT, a statistically significant increasing trend for all analysed indices occurs in summer (July and August). All results show that the small Adriatic islands are negatively affected by climate change, i.e. global warming, especially during the summertime.

The rich and vulnerable ecosystems of the Mediterranean islands, as well as their socio-economic structure, are under the strong influence of the Mediterranean climate (BONACCI, 2019). The drastic and sometimes unpredictable nature of the Mediterranean climate put severe and contrasted stress on all aspects of small island sustainable development. The role of the Mediterranean Sea in the European summer climate is mostly passive (TOMASSINI, ELIZALIDE, 2012). In winter, when the upper layers of the Mediterranean Sea are well mixed, the record of the Mediterranean Sea surface temperature stretches over longer time scales, which implies a potential for active governing of regional climate characteristics to some extent.

F. Giorgi and P. Lionello (2008) projected that occurrence of warming in the summer would lead to a greater occurrence of extremely high temperature events in the whole Mediterranean region. Using homogenized daily minimum and maximum temperature data set (1955–2007) for the central Mediterranean area of Tuscany (Italy), yearly and seasonal long-term trends of some climatic and extreme climatic indices were studied (BARTOLINI ET AL., 2012). The seasonal analysis revealed a much greater increase in summer (June, July, August) and spring (March, April, May) temperatures in respect of autumn and winter temperatures. This finding is consistent with most recent Mediterranean evidence. All their analyses confirm that the Mediterranean is a region especially responsive and thus very vulnerable to climate change. D. Macias et al. (2013) established that from the 1990s Mediterranean waters have been warming at a rather high rate resulting in scientific and social concern. The warming trend has been observed in satellite data, field data, and model simulations, and affects both surface and deep waters throughout the Mediterranean basin. Based on the regional climate change index calculated from temperature and precipitation projections, the Mediterranean region was revealed to be one of the most prominent hot-spots over the globe (GIORGI, 2006). Definite conclusion in many published scientific papers is that climate change projections for the Mediterranean region indicate substantial warming, especially in the warm season (e.g. GIORGI, LIONELLO, 2008; LÓPEZ GARCÍA, 2014; SHALTOUT, OMSTEDT 2014; MOHAMED ET AL., 2019; PISANO ET AL., 2020). The analyses made in this paper support this statement of A. Pisano et al. (2020): “*The observed change in the Mediterranean Sea affects not only the mean trend but also the amplitude of the Mediterranean seasonal signal, with consistent relative increase and decrease of summer and winter mean values, respectively, over the period considered (1982-2018).*”

The limited size and limited resources of small islands, as well as unsustainable anthropogenic activities (e.g. tourism, land use changes, and urbanisation), reduce islands' adaptation options to climate change. Due to exceptional historical and social importance, biotic authenticity, and vulnerability to global changes, the small Mediterranean islands, particularly the island of Hvar, require urgent and efficient integrated measures, which will ensure their sustainable development. Monitoring, understanding, and explaining the relationship between SST and SAT represent the first and inevitable step in order to achieve this goal.

Like some other Mediterranean countries, Croatia lacks sufficient data to determine climate change at small islands accurately. Different locations on the island, due to various distances from the sea, local position relative to the open sea, orography, and altitude, result in significantly different SAT values (BONACCI, LJUBENKOV, 2020; BONACCI ET AL., 2020). A shortage of accurate climate change representations, first of all, SST and SAT, severely handicaps conservation, adaptation, and mitigation plan efforts, and further hinders appropriate preparedness measures (AL SAYAH ET AL., 2021). The aim of this study is to initiate detailed interdisciplinary research regarding the changes in SST and SAT on the small islands and coastal zones. Such research can help prepare better for future climatic uncertainty.

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