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CLIMATIC CONDITIONS ON THE ISLANDS OF CRES AND LOŠINJ WITHIN THE GLOBAL CLIMATE CHANGES

Klimatski uvjeti na otočju Cres-Lošinj unutar globalnih klimatskih promjena

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Abstract - Most climate models anticipate a surface air temperature rise of several degrees Celsius during the next century supposing carbon dioxide (CO_2) concentration in the atmosphere is going to double. As a consequence of the Earth's surface warming, a sea level rise of several tens of centimeters can be expected in the same period. These changes will not have the same intensity during the whole year, they will depend on the season and the different parts of the world. In this paper, the influence of these changes on the islands of Cres and Lošinj is considered. A higher increase in annual temperature could be expected (up to 5°C) at the end of the 21^{th} century. A significant change in annual precipitation is not very probable. However, a decrease in precipitation during summer and autumn and an increase during winter and spring has been established. A change in other climatic elements can also be expected.

Key word index: Climate changes, Cres-Lošinj archipelago.

Sažetak - Većina klimatskih modela procjenjuje porast površinske temperature zraka u idućem stoljeću, uz pretpostavku udvostručenja koncentracije CO_2. Kao posljedica zagrijavanja površine Zemlje može se očekivati porast morske razine za nekoliko desetaka centimetara u istom razdoblju. Ove promjene neće imati isti intenzitet tijekom godine, dakle ovisit će o godišnjem dobu, kao i o različitim dijelovima svijeta. U radu se razmatra utjecaj navedenih promjena na otočje Cres-Lošinj. Povećan porast godišnje temperature (do 5°C) može se očekivati do kraja 21. stoljeća. Značajnija promjena količine godišnje oborine malo je vjerojatna. Međutim, blaži ljetno-jesenski pad kao i zimsko-proljetni porast oborine ne može se isključiti. Promjena režima ostalih klimatskih elemenata također se može očekivati.

Ključne riječi: Klimatske promjene, otočje Cres-Lošinj.

INTRODUCTION

Recently, there has been a growth in both scientific and public interest (including state authorities) in climatic changes on Earth, especially after the observations of these last decades have been made public. The global surface temperature on Earth has risen by about 0.5 degrees Celsius compared to that of some hundred years ago (Sijerković and Pandžić, 1991). The question is whether this is a usual climatic fluctuation or it is the consequence of human activity resulting in atmospheric pollution produced by industrial development. Theory shows that some gases (carbon dioxide, methane and others), released into the atmosphere by fossil fuel burning, transmit shortwave solar radiation, but not longwave terrestrial radiation. Thus, they retain a part of the solar energy in the Earth-atmosphere system which can cause a temperature rise on Earth. This effect is called the "greenhouse effect" and the gases causing it are called "greenhouse gases". If other climatic factors, which at least partially (e.g. an increase in cloudiness) compensate such influence, are neglected, a rise in global temperature on Earth as a function of the greenhouse gases concentration rise can be estimated. Therefore, most climate models anticipate a temperature rise of several degrees Celsius during the next century supposing carbon dioxide (CO_2) concentration in the atmosphere is going to double. As a consequence of the Earth warming, a sea level rise of several tens of centimeters is also anticipated in the next hundred or so years. This will be brought about by the thermic expansion of the oceans and the melting of the polar ice caps (UNEP, 1992a).

These temperature changes may also cause changes in other climatic elements like air pressure, precipitation, sunshine, wind and other. Further, these changes will not have the same intensity during the whole year which means they will depend on the season. To be able to mitigate, or possibly positively use, the anticipated global climatic changes it is necessary to reduce their effects to local level. To be able to better consider the future state of climatic conditions, the current state of climatic conditions on the Cres-Lošinj archipelago will be presented.

PRESENT CLIMATIC CONDITIONS AND THEIR TREND

As atmospheric pressure, air temperature and precipitation are of the greatest concern in the context of climatic changes, most space in the paper will be dedicated to them. However, wind, sunshine, global radiation and cloudiness characteristics will also be presented. The snow cower will be presented by very short consideration as it is a very rare phenomenon in this area. The same applies to fog and frost, which are also infrequent phenomena on the Cres-Lošinj archipelago. Fog appears, in the average, once on month in the winter half-year, and it usually does not appear in the summer. In winter, frosts are considerably more frequent over the northern part of the islands (an average of up to seven times in a month) compared to the southern part where they usually appear not more than twice in a month. The water balance components, including soil moisture content, also partially influence climatic conditions. According to the results of Pandžić (1985) it can be stated that on the whole eastern Adriatic coast, which includes the islands examined, all the water balance components have a definite seasonal character because they are primarily a function of temperature and precipitation (seasonal wind change is disregarded). This means that evaporation (or evapotranspiration) reaches its maximum in summer and its minimum in winter, while the soil moisture content has an inverse annual cycle.

The results are mostly based on data from the 1961-1990 period, with the exception of the trend for which the time series for the 1891-1990 period were used. Special emphases has been given to the four seasons as the results of the climatic scenario are related to them. Climatic extremes will also be discussed, although, until now, they have mainly not been considered in climatic models.

Atmospheric pressure

A very important generator of atmospheric circulation is the atmospheric pressure distribution, expressed in hectopascals (hPa) in the SI system. The centers of lower atmospheric pressure are called cyclones (or lows) and those of higher anticyclones (or highs). The pressure differences in these centers and their environment cause the occurrence of a pressure gradient force which, balanced by the Coriolis force (the inertial force of the Earth's rotation), supports a circular air streaming (wind) counterclockwise in a low and clockwise in a high. Therefore, if we stand with the wind blowing to our back, then the center of lower pressure is roughly to the left (Buyes-Ballot's rule). Deviations are possible due to friction. The atmospheric pressure distribution changes from year to year. In Figure 1a (a') it may be seen that the atmospheric pressure in winter (January) is lower over the Northern Atlantic (Iceland low) and higher over the European mainland. In summer (July) it is the reverse, the pressure over the Atlantic is higher (Azores high) and it is lower over the continent. This is the consequence of the difference in the warming rate of the sea and the land. This means that the land warms up faster than the sea and it is warmer in summer, but it also cools off faster, so it is cooler than the sea in the winter. Accordingly, the distribution of low centers is also different in winter and in summer (Fig. 1b (b')). There are more low centers in the Mediterranean in winter than in summer. Most highs are distributed over the mainland during winter (Fig. 1c) and over the Atlantic during summer (Fig. 1c'). Areas of low and high pressure in long-term average take the characteristics of centers of action because, as evident from the illustration, they mostly coincide with the areas of high frequency of cyclones and anticyclones. It may be concluded that the Cres-Lošinj area is influenced by low patterns during the cold half-year and by highs during summer. This has a considerable influence on the annual precipitation pattern as well as on the wind pattern which will be discussed later in this paper. It goes without saying that every change in the existing circulation pattern has a significant influence on change in the pattern of these elements.

Temperature

As temperature is a quantitative indicator of the thermal states of the atmosphere, i.e. a measure for thermal energy, which is the agitator of all the processes on Earth, it usually attracts a lot of attention. It changes in space as well as in time. Generally, it is warmer at lower latitudes and in summer and colder at higher latitudes and in winter. It also has a diurnal course, so it reaches its maximum slightly after noon and its minimum after midnight.

The temperature pattern depends on the kind of ground. Areas exposed to the sea have a milder (maritime) climate with smaller daily and annual temperature variations, and areas deeper inland have a more severe (continental) climate with more pronounced daily and seasonal variations. This depends also on orographic characteristics, prevailing air streams, exposition to the Sun and many other microclimatic influences.

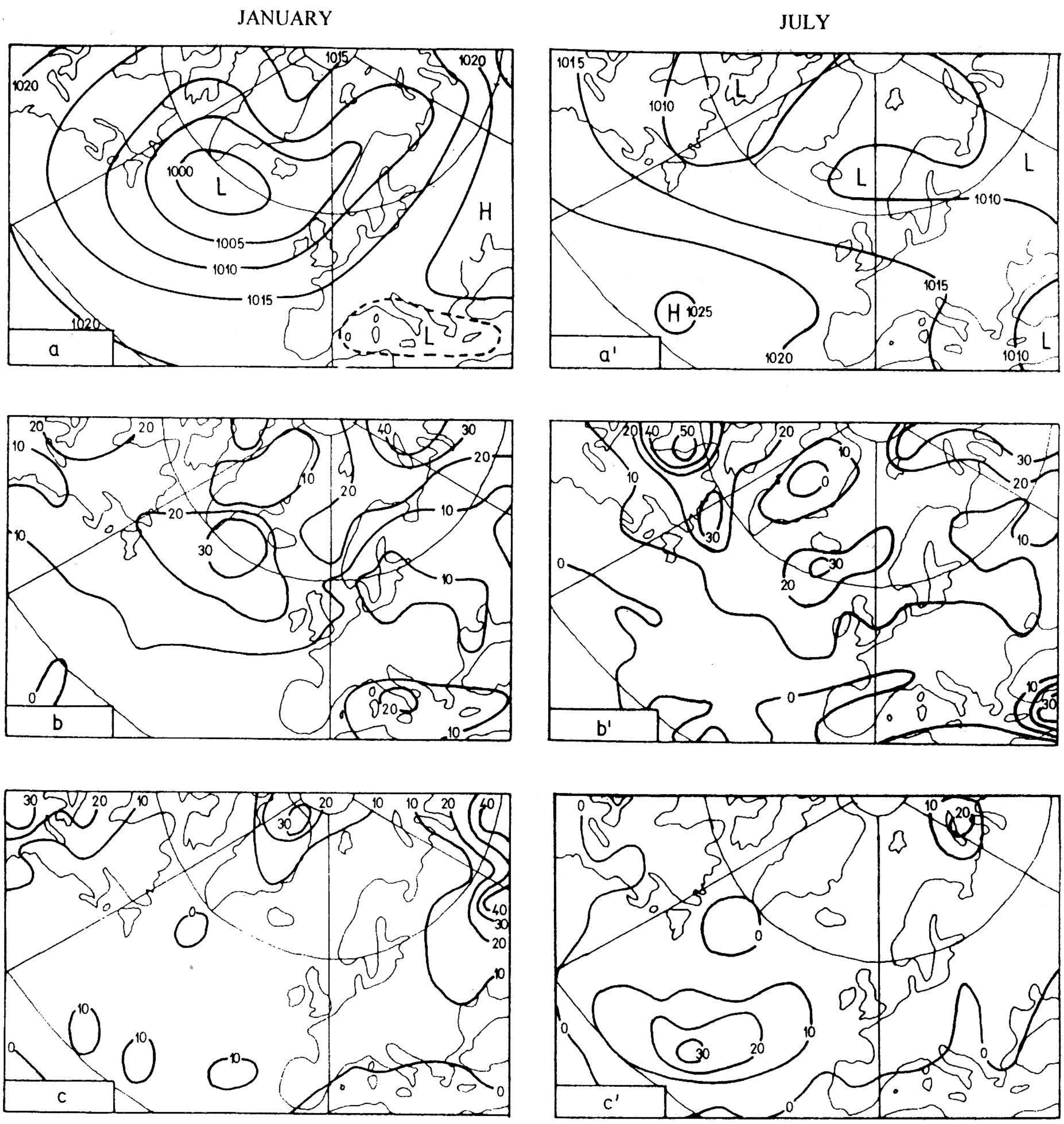


Fig. 1. Centers of action in January and July denoted by: a, a') 20-year (1961 to 1980) mean monthly surface atmospheric pressure reduced to sea level, b, b') occuring frequency of lows and c, c') occuring frequency of highs (After Pandžić et al., 1992)

Slika 1. Centri akcije u siječnju i srpnju označeni s: a, a') razdiobom dvadesetgodišnjih (1961-1980) srednjaka prizemnog atmosferskog tlaka svedenog na morsku razinu, b, b') čestinom pojave centara ciklona i c, c') čestinom pojave centara anticiklona

Because of their characteristics, continuous air temperature measurements take place only at two locations on the Cres-Lošinj archipelago: at Mali Lošinj and at Cres, these being taken as representatives of the whole considered area. The results of a statistical analysis of these two places are presented in Table 1. Looking at this table, it can be noticed that Mali Lošinj, and consequently the southern part of the archipelago, is, in the average, warmer by 1°C than the northern part (the town of Cres). However, this is not the case in all seasons. In summer, some northern parts of the islands are, in average, warmer than the southern parts (as the case is with Mali Lošinj and the town of Cres). This is surely the consequence of a stronger influence of the sea on the southern part and of the surrounding land on the northern part of the islands. It also shows a smaller range of extremes in Mali Lošinj than in Cres. All of this contributes to a still more comfortable climate in

Table 1. Temperature regime characteristics for Mali Lošinj (a) and Cres (b).
Tablica 1. Karakteristike temperaturnog režima za Mali Lošinj (a) i Cres (b).

a) Mali Lošinj	Winter	Spring	Summer	Autumn	Year
Average (°C)	8.1	13.3	22.7	16.3	15.1
Seasonal Max (°C)	11.4	14.7	23.7	17.9	15.9
Return Period (year)	>100	27	22	27	>100
Seasonal Min (°C)	6.7	11.5	21.8	14.6	14.4
Return Period (year)	17	43	17	56	34
Daily Max (°C)	20.4	28.8	35.2	31.7	
Return Period (year)	176	19	32	34	
Daily Min (°C)	-6.7	-3.8	9.7	1.3	
Return Period (year)	74	36	45	21	

b) Cres	Winter	Spring	Summer	Autumn	Year
Average (°C)	6.6	12.9	22.6	15.0	14.3
Seasonal Max (°C)	8.4	14.6	24.5	16.7	15.2
Return Period (year)	56	>100	>100	>100	43
Seasonal Min (°C)	3.4	11.0	21.4	11.6	13.5
Return Period (year)	>100	91	16	>100	43
Daily Max (°C)	20.7	30.1	37.4	32.8	
Return Period (year)	50	17	28	15	
Daily Min (°C)	-9.2	-6.5	7.8	-3.4	
Return Period (year)	47	25	17	27	

Table 2. Precipitation regime characteristics for Mali Lošinj (a) and Cres (b).
Tablica 2. Karakteristike oborinskog režima za Mali Lošinj (a) i Cres (b).

a) Mali Lošinj	Winter	Spring	Summer	Autumn	Year
Average (mm)	259	198	165	313	933
Seasonal Max (mm)	514	291	284	658	1368
Return Period (year)	>100	20	20	>100	43
Seasonal Min (mm)	67	78	67	73	580
Return Period (year)	90	>100	25	90	>100
Daily Max (mm)	58.4	66.0	83.4	156.9	
Return Period (year)	21	77	31	240	

b) Cres	Winter	Spring	Summer	Autumn	Year
Average (mm)	299	234	198	339	1063
Seasonal Max (mm)	612	400	430	573	1419
Return Period (year)	56	>100	91	25	22
Seasonal Min (mm)	59	109	61	124	734
Return Period (year)	>100	91	43	43	24
Daily Max (mm)	87.2	68.1	113.4	104.3	
Return Period (year)	93	34	52	53	

comfortable climate in the southern part of the islands, although the differences are not significant, compared to some parts on the north.

There are also some peculiarities in the temperature conditions on the island tops. If we suppose a temperature decrease with elevation (0.5°C/100 m), then the distribution of the mean annual temperatures can be presented by isolines (Fig. 2). The differences between the coastal and top island zones do not exceed several degrees. It is interesting to search what has happened to the temperature regime during the last hundred years. This trend analysis has been deduced for the 1891 - 1990 period, based on climatological data for Crikvenica, located on the eastern Adriatic coast, about 50 km north-east of the Cres-Lošinj archipelago.

The results, presented in Figure 3, indicate a slight rise in the mean annual temperature (0.34 °C over 100 years) over this area. This warming is mostly visible in autumn (0.70 °C over 100 years) and winter (0.63 °C over 100 years) and less pronounced in summer (0.25 °C over 100 years). At the same time, the spring temperature shows a negative trend (-0.21°C over 100 years). However, these changes are not statistically significant according to the results of the nonparametric Mann-Kendall test for trend (Mitchell et al., 1966). Similar results were achieved also by Arseni-Papadimitrou and Maheras (1991) who used several temperature time series from the Western Mediterranean area. They concluded that the climate of this area has recently been taking more and more over the characteristics of the Atlantic climate with relative mild winters and fresh summers. A monitoring of year temperature trend could indicate such a change which is expected in the next period.

Precipitation

In contrast to temperature, which mainly depends on the length and intensity of sunshine, precipitation primarily depends on the type of air circulation and moisture content. In the cyclonic circulation type the air rises vertically and cools so that water vapour conden-

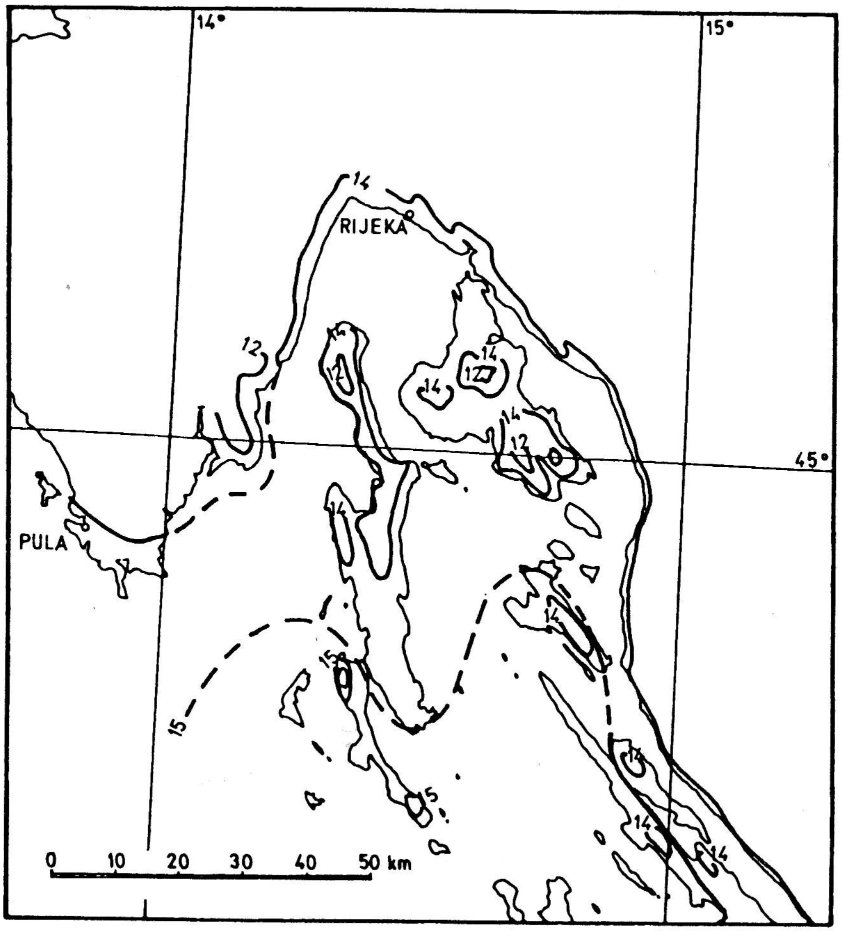
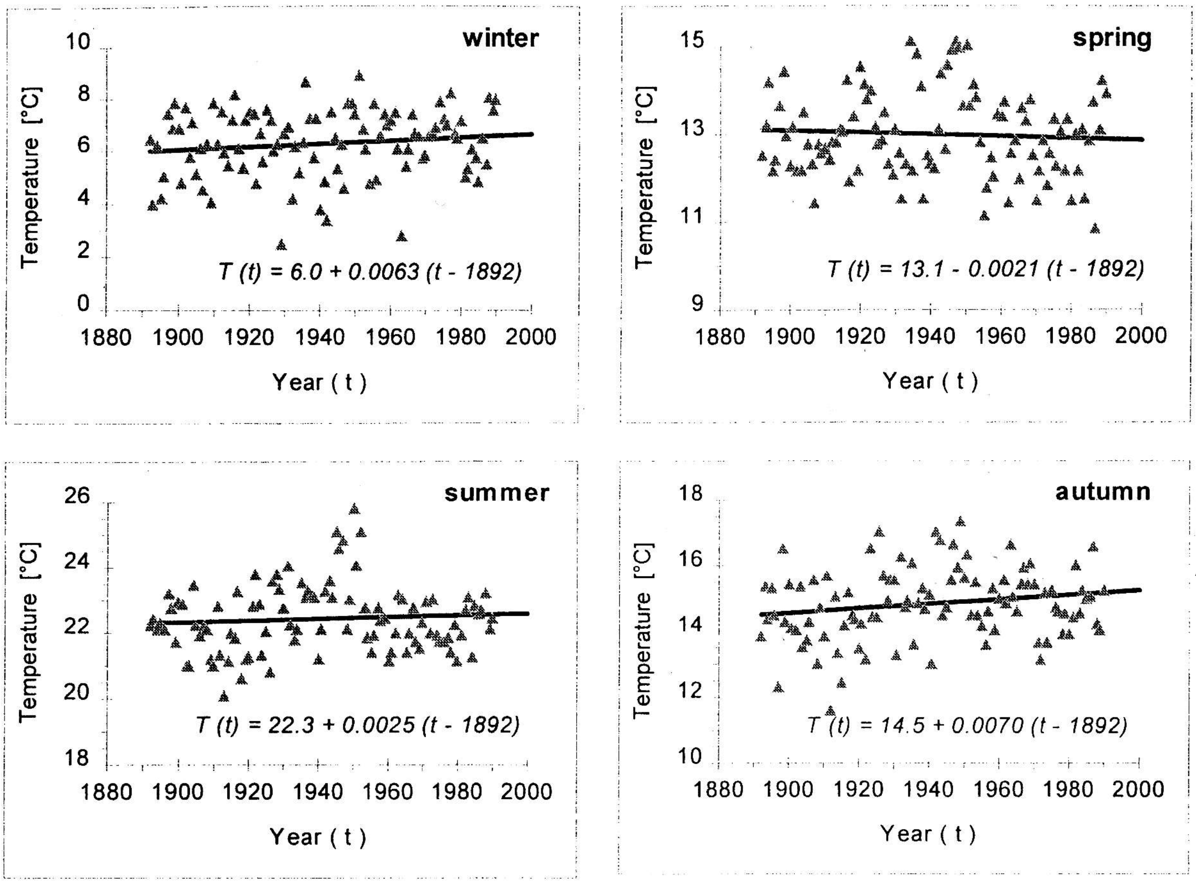


Figure 2. Mean annual temperature distribution for the extended Cres-Lošinj archipelago area (After Penzar and Penzar, 1990)

Slika 2. Razdioba srednje godišnje temperature zraka za šire područje otočja Cres-Lošinj



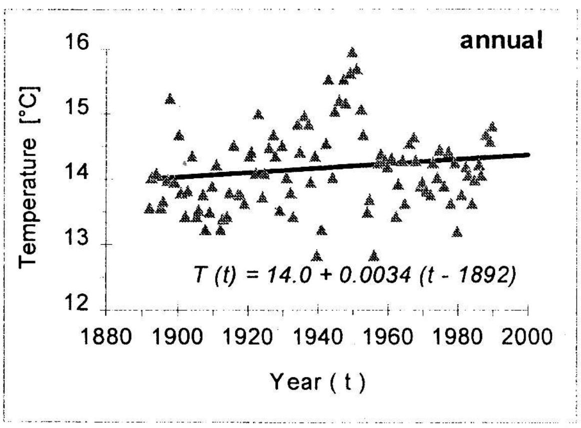


Figure 3. Time series of mean seasonal and annual temperatures with related trends for Crikvenica (1891-1990)

Slika 3. Vremenski nizovi (1891-1990) srednjih sezonskih i godišnjih temperatura za Crikvenicu s pripadnim trendovima

sation, clouds and precipitation formation take place. With the anticyclonic stream type, the air sinks and it warms so that clouds disappear and the sky clears. Besides circulation, orographic influence is essential for the formation of precipitation. During sirocco on the Eastern Adriatic coast, the process of generation (air rising) intensifies and during bora (air sinking) a cloud and precipitation dissolving process exists. Precipitation is also supported by frontal zones (boundaries between cold and warm air masses) as well as by local instabilities caused by a stronger warming of the ground layers of the atmosphere in relation to the upper ones. The result of this process is convective precipitation. All these influences converge to form the precipitation pattern of the Cres-Lošinj archipelago with the cyclonic activity influence and orographic effects prevailing. The first one is reflected on the annual pattern and the second on the space distribution (Tab. 2 and Fig. 4).

As evident from Table 2 greater amounts of precipitation occur in the winter half-year (autumn, winter) than in summer (spring, summer). This is related to the frequency of passage of lows over considered area (Fig. 1b (b') and Pandžić, 1988).

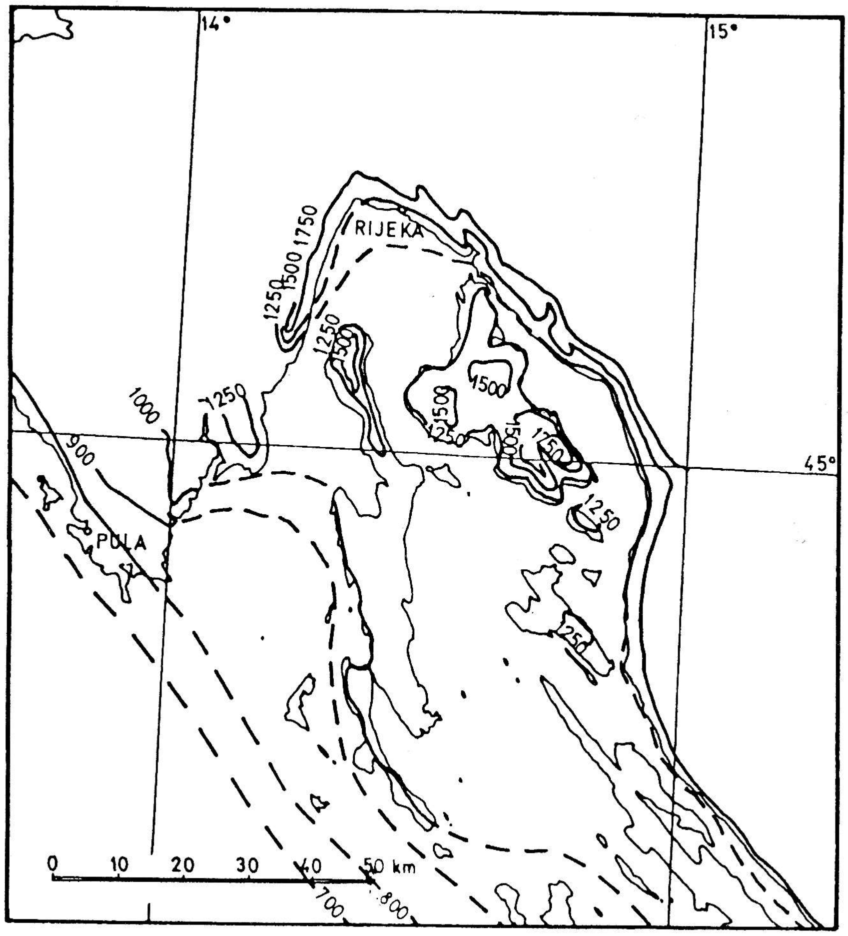


Figure 4. Mean annual precipitation amount distribution for the extended Cres-Lošinj archipelago area (After Penzar and Penzar, 1990)

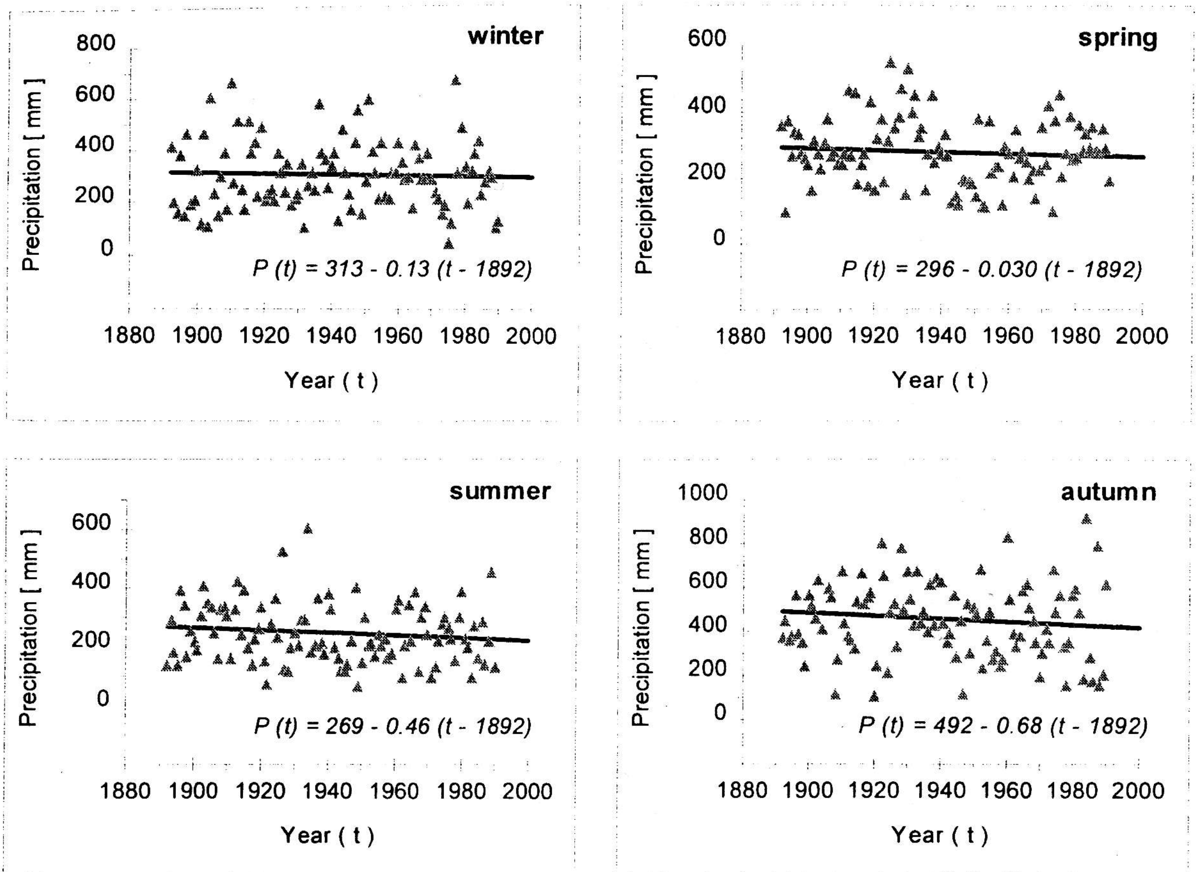
Slika 4. Razdioba srednjih godišnjih količina oborina za šire područje otočja Cres-Lošinj

From Figure 4 (confirmed by Tab. 2), a rise in precipitation toward the north of the islands is evident. This is, in its major part, a consequence of the orographic effect not only of the islands themselves but also of the Kvarner hinterland. The funnelled form of the Rijeka Gulf causes a rising of the air, usually moist, brought about by a southerly wind, not rarely related to cyclonic systems. Therefore, the Kvarner hinterland has the highest amounts of precipitation in Croatia, in the average more than 3500 mm per year which is not often found in Europe (Gajić-Čapka et al., 1985). Crkvice in Boka Kotorska have the highest European annual precipitation amount of 5000 mm.

The analysis of time changes in the annual precipitation amounts was made using the data of nearby Crikvenica for the period 1891-1990. The trend analysis indicate that there is a decrease in precipitation in both the annual and the seasonal series (Fig. 5).

The main reason for the decrease in the annual precipitation amounts is a decrease in the autumn and summer amounts. In total, this amounts to 1.62 millimeters per year of which 0.13 during the winter, 0.30 during the spring, 0.46 during the summer and 0.68 during the autumn. Thus, a decreasing tendency in the annual precipitation, in relation to the long-term average, amounts to 0.13 percent, 0.19 in summer, 0.15 in autumn, 0.11 in spring and only 0.04 percent in winter. However, statistical tests show that this trend is not significant (Mitchell et al., 1966; Sneyers, 1990). Also, continuous monitoring of the precipitation trend may signalize possible essential changes in the precipitation amount in this area. Some aspects of the time variation in precipitation for the entire Balkans were observed by Maheras and Kolyva-Machera (1990), and their results agree with those deduced for Croatia. To make statement on statistical basis about likely precipitation or temperature trend in the future some more comprehensive stohastic models should be used (Box and Jenkins, 1970).

There is no much sense in considering solid precipi-



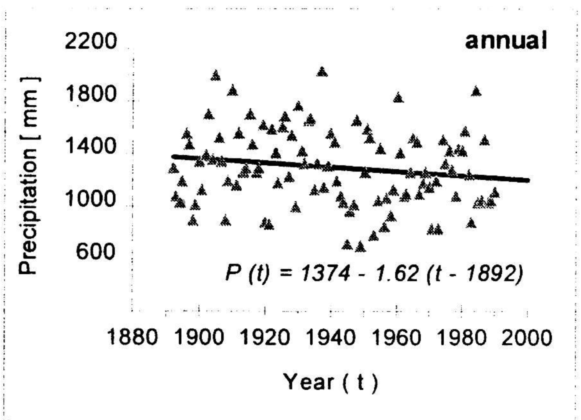


Figure 5. Time series of seasonal and annual precipitation with related trends for Crikvenica (1891-1990).

Slika 5. Vremenski nizovi (1891-1990) sezonskih i godišnjih količina oborina za Crikvenicu s pripadnim trendovima.

tation on the islands because its appearance is relatively rare. In the last 30-year period, snow on the ground was recorded in the area only a few times. The highest was recorded in 1962 at the town of Mali Lošinj with a height of 13 centimeters and a duration of 9 days.

Wind

If there were no wind, the climate on the Earth would be far more unfavourable. Owing to the air stream an exchange of thermal energy between zones at lower and higher latitudes occurs and so the temperature difference between them is being relieved. Wind also brings water vapour, clouds and precipitation from far away oceanic spaces to the land. It pollinates, refreshes the coastal areas during the summer hots etc. However, it has also negative effects: it increases the feeling of cold in winter days, if it is strong it destroys buildings, breaks trees, interferes with traffic etc.

Seasonal winds are characteristic of the Cres-Lošinj area: bora, sirocco and the so called coastal circulation. The first two are more related to the winter and the last to the summer part of the year. Bora is a relatively cold, strong and gusty wind blowing from the north-eastern quadrant perpendicularly to the coast, bringing weather improvement. Scirocco is a kind of antipod to

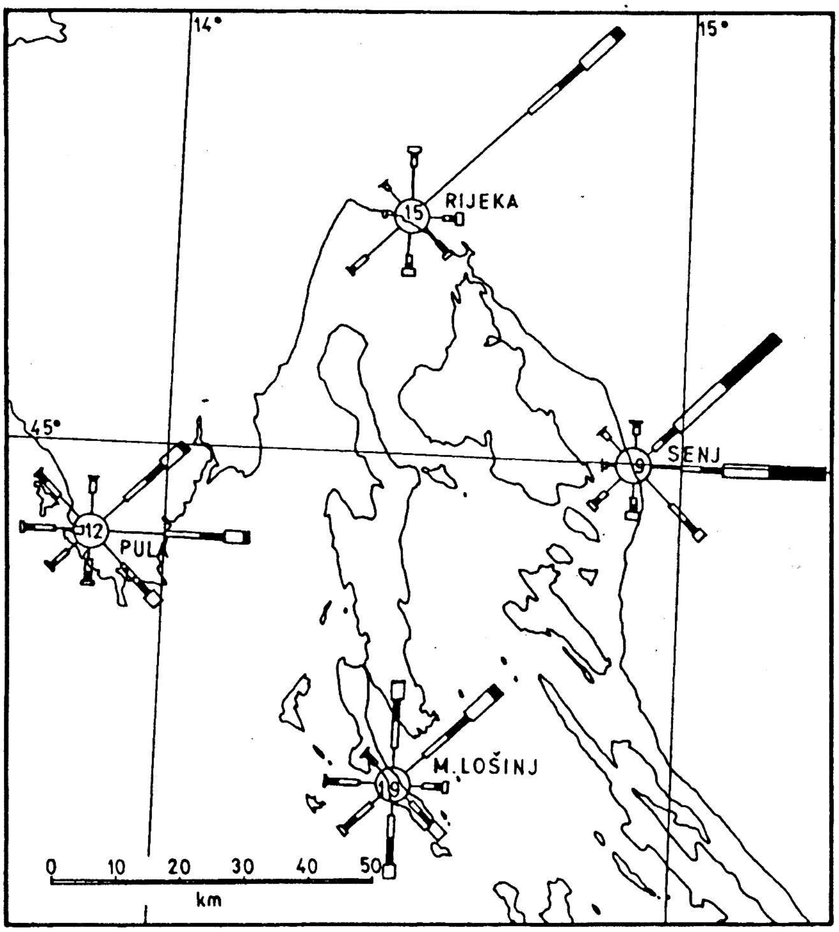


Figure 6. Wind roses for the extended Cres-Lošinj archipelago area. Different widths and shadings in the histograms indicate different wind forces (in the center there is the percentage of calms, the first elements represent one Beaufort, the second two etc.; After Penzar and Penzar, 1990).

Slika 6. Ruže vjetra za prošireno područje otočja Cres-Lošinj. Različite širine i osjenčanost dijelova histograma ukazuju na različite jačine vjetra (u središtu su postoci tišina, prvi element je za jačinu od jednog Beaufort-a, drugi za dva itd.).

the bora. It is a relatively warm and steady wind from the south-eastern quadrant, parallel to the coast, which brings weather deterioration and generates big waves at sea. Coastal circulation is related to days with nice and, on a broader scale, calm weather. It is caused by the uneven warming (cooling) of the land and sea. At night, the land is colder than the sea and the circulation is directed toward the sea ("burin"), while during the day, the sea is colder than the land and a refreshing wind ("maestro") blows toward the land (Lukšić, 1989). The relative annual frequencies of bora and sirocco are presented in Table 3 (Makjanić, 1978).

Besides seasonal variability a space wind variability exists in direction and force. This is illustrated by the annual wind roses presented in Figure 6. It is evident from the drawing that at Mali Lošinj the frequency of strong bora is smaller than at the nearby coastal town of Senj (Lukšić, 1975), while scirocco is stronger at Mali Lošinj than at Senj. On the other hand, a north-eastern quadrant wind (bora) prevails over the whole

Table 3. The relative number of casses (in %) with bora and scirocco at the town of Mali Lošinj.

Tablica 3. Relativni broj slučajeva (u %) s burom i jugom u Malom Lošinju.

	Bora		Scirocco	
	Winter	Summer	Winter	Summer
Mali Lošinj	74	26	74	26

Kvarner.

Maximum gusts of bora and scirocco (Bajić, 1989) can exceed 100km hour^{-1}. However, generally, the frequency of strong bora decreases moving from the north of the Adriatic toward the south, while for scirocco the reverse is valid. Areas with stronger wind are potential, alternative and ecologically pure energy sources.

As wind, in a substantial measure, depends on atmospheric pressure distribution, each change in its distribution will cause a change in the wind pattern and, accordingly, in sea waves as well as in sea streams.

Cloudiness, insolation and global radiation

As these three elements have a big influence on the energy state of the Earth-atmosphere system they are physically even more important than the ones formerly described. Thus, their description will be presented in the next sections.

Cloudiness plays an important role in creating the precipitation pattern, radiation balance and it has also an important influence on air traffic. The results presented in Table 4 show that, in the average, cloudiness (expressed in tenths of sky cover) is the highest in the winter and the lowest in the summer months. The number of clear days (cloudiness $<2/10$) is greater in summer and cloudy days (cloudiness $>8/10$) are more numerous in winter. Sunshine (or sunshine duration; measured in hours) is, in a way, complementary to cloudiness. For the Cres-Lošinj archipelago area it is of interest from the aspect of tourism. The maximum number of sunshine hours occur in summer and the minimum in winter (Tab.4). A space comparison for the broader Cres-Lošinj area may be achieved by analyzing Figure 7. According to this picture sunshine is about 200 hours per year longer at Mali Lošinj than in nearby Pula or Rijeka (Poje et al., 1984) and, without any doubt, it contributes to the development of tourism on these islands.

Global radiation has an important role in the radiation balance. As it is related to sunshine and to the Sun elevation it is not difficult to conclude that the maximum amounts are reached in summer and the minimum in winter (Tab.4). The usability of solar energy collectors, which are put on the roofs of buildings and used as alternative energy sources depends on global radiation. It has also its ecological importance because these energy sources, as well as wind, do not pollute the environment and so contribute to diminishing the amount of greenhouse gases and in such a way can indirectly diminish the intensity of the forecasted climate change.

A trend monitoring of three elements, especially on a global scale, is also important, because a small change in one of these elements can cause disturbances in the climate system and may intensify climate changes.

Table 4. Cloudiness (tenth), number of clear and cloudy days, sunshine (hour), relative sunshine (percent) and global radiation (kWh m^{-2}) for Mali Lošinj (a) and Cres (b).

Tablica 4. Naoblaka (desetine), broj vedrih i oblačnih dana, trajanje sijanja sunca (sati), relativno trajanje sijanja sunca (%), globalno zračenje (kWh m^{-2}) za Mali Lošinj (a) i Cres (b).

a) Mali Lošinj

Month	J	F	M	A	M	J	J	A	S	O	N	D	Year
Cloudiness	6	6	5	5	5	4	3	3	4	5	6	6	5
Clear days	6	6	8	8	8	9	16	16	12	9	4	5	107
Cloudy days	12	9	10	7	6	3	1	2	4	7	12	13	85
Sunshine	110	125	168	224	281	314	360	326	245	199	105	79	2540
Rel. sunshine	37	45	46	53	61	65	75	73	63	58	39	34	56
Glob. radiation	1.3	2.0	3.4	5.0	6.2	6.4	6.6	5.8	4.7	3.2	1.7	1.0	47.1

b) Cres

Month	J	F	M	A	M	J	J	A	S	O	N	D	Year
Cloudiness	6	6	6	5	5	4	3	3	4	4	6	6	5
Clear days	7	7	8	8	9	9	16	16	14	10	6	5	116
Cloudy days	11	10	10	7	6	4	3	2	4	7	12	14	90

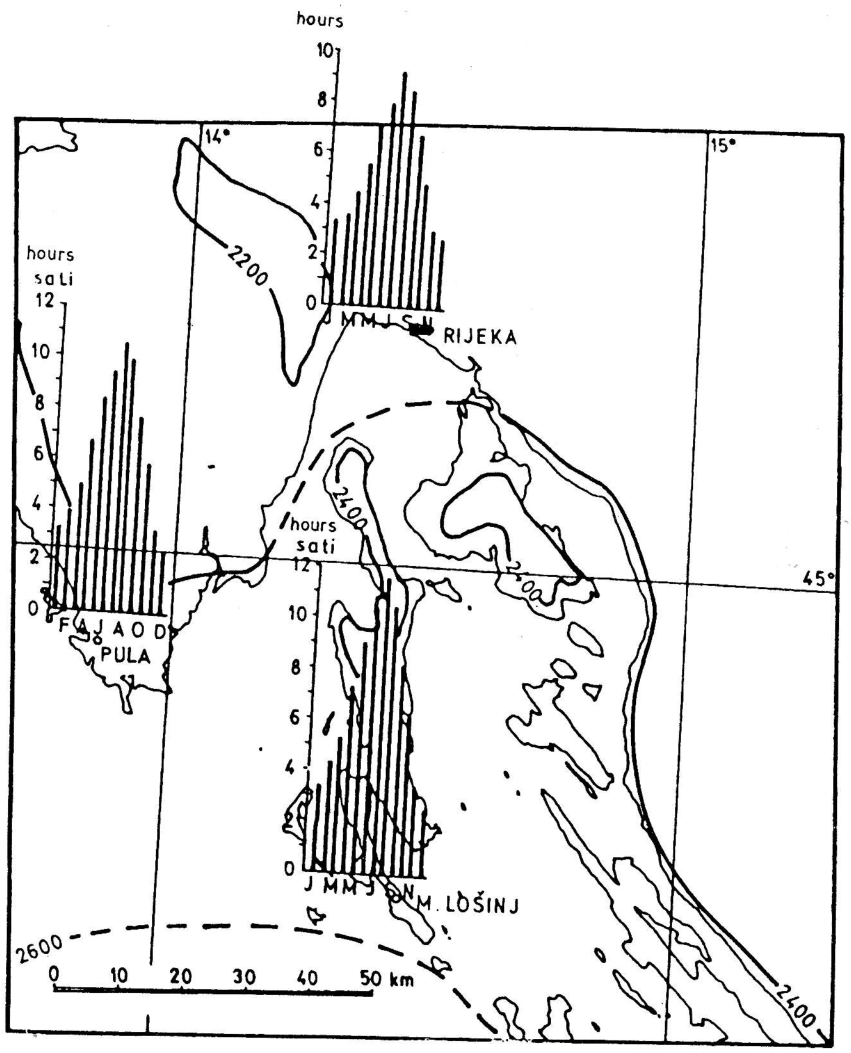


Figure 7. Annual sunshine regime for the extended Cres-Lošinj archipelago area (After Penzar and Penzar, 1990).

Slika 7. Godišnji režim trajanja sijanja sunca na proširenom području otočja Cres-Lošinj.

Bioclimatic conditions

Bioclimatic conditions at Cres and Mali Lošinj were analyzed by means of average 10-year (1981-1990) values of the combined temperature-wind speed-humidity index (TWH in $kJkg^{-1}$; Zaninović, 1992) and the corresponding sensation scale. The TWH index includes temperature, wind speed and humidity in evaluation of thermal comfort, from "extremely cold" to "extremely hot".

The average TWH index values for the Cres-Lošinj archipelago range from "cold" (December-March) to "hot" in summer (Fig. 8). The differences between the TWH index in the coldest (7 AM) and warmest part of the day (2 PM) are higher at Cres than at Mali Lošinj, while the values at 9 PM are similar to the daily mean values at both stations. The distribution of the mean daily TWH index values (Fig. 9) indicate a very rare occurrence of "extremely cold" and "hot" conditions. The distribution for 7 AM would be biased toward the colder part of the scale, and that for 2 PM toward the warmer part of the scale.

CLIMATE CHANGE SCENARIO

Numerical hydrodinamical models are used as the most powerful tool in contemporary weather forecasting. They are based on the initial state of the atmosphere (primarily atmospheric pressure distribution) and calculate the development of this state for more days in advance (successfully up to five or six days). Analogously, climate (average) state of the atmosphere may be also simulated by numerical models.

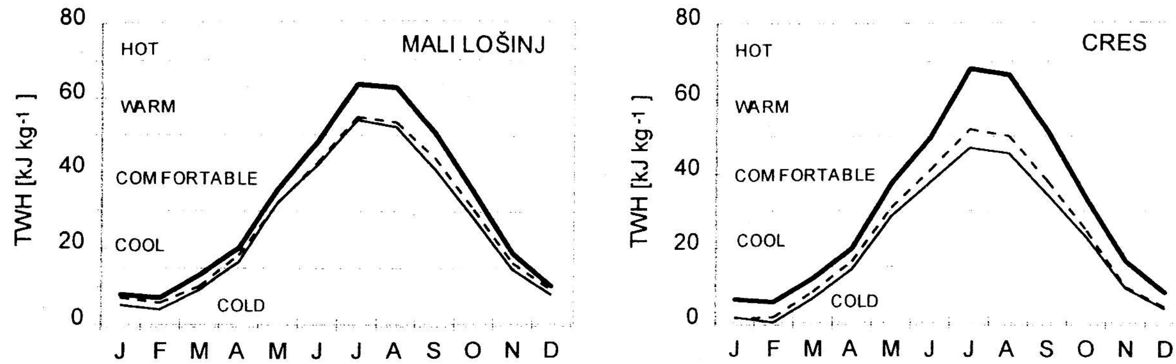


Figure 8. Annual regime of TWH ($kJ\,kg^{-1}$) for: 7 a.m. (thin line), 2 p.m. (thick line) and 9 p.m. (dashed line) in the Cres-Lošinj area.

Slika 8. Godišnji režim TWH ($kJ\,kg^{-1}$) za: 7 (tanka linija), 14 (debela linija) i 21 (crtkana linija) na otočju Cres-Lošinj.

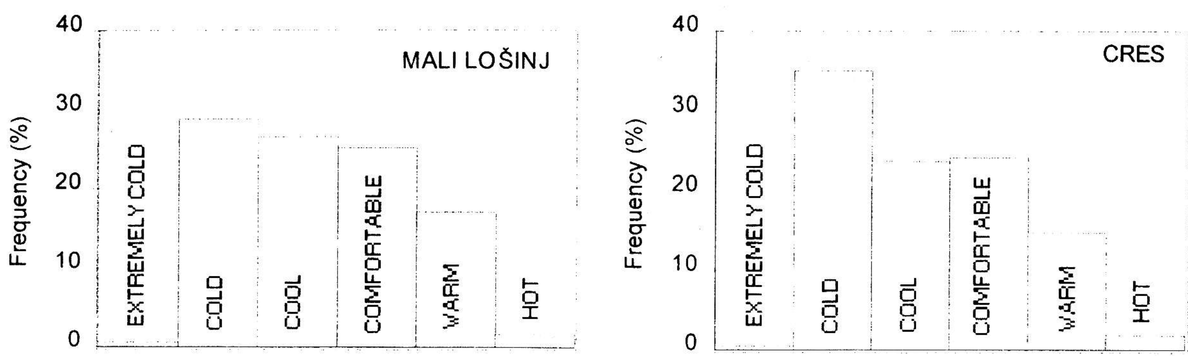


Figure 9. Distribution of the mean daily TWH index values in the Cres-Lošinj area.

Slika 9. Razdioba srednjih dnevnih vrijednosti TWH indeksa na području Cres-Lošinja.

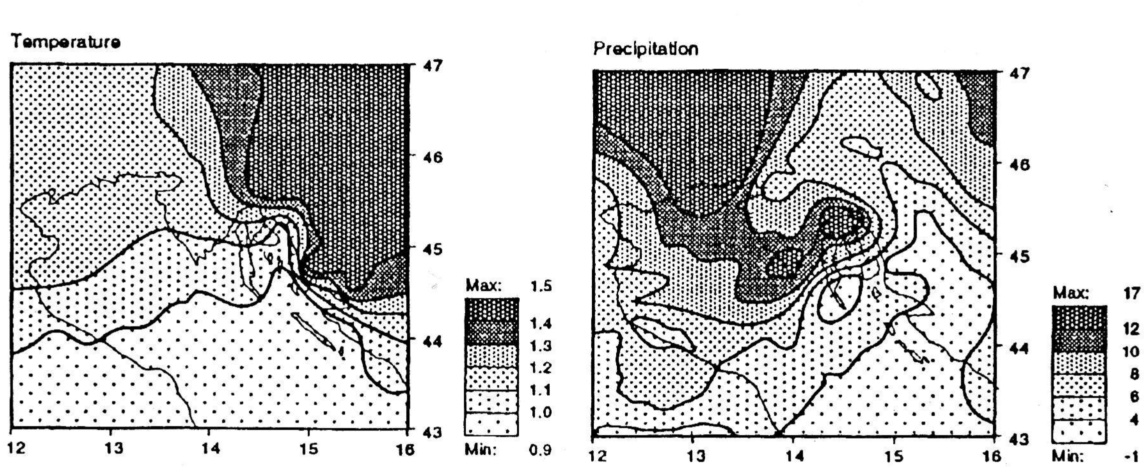


Figure 10. Regional climate scenarios for the northern Adriatic: annual (After Guo et al., 1992).

Slika 10. Regionalni klimatski scenarij za sjeverni Jadran: godišnji (prema Guo et al., 1992).

However, special, so called Global Circulation Models (GCM), have been used here, which take into account a larger number of parameters than the "common" forecasting models (e.g. radiation, cloudiness, ice cover etc.). Atmospheric components like water vapour, aerosols (solid particles), greenhouse gases (e.g. CO_2) are usually introduced into these models. Greenhouse gases, as it was already said, directly influence the radiation balance of the Earth-atmosphere system and the global temperature on the Earth's surface. If their amount is greater, the temperature is also higher.

Consequently, if a larger percentage of these gases is introduced into the mentioned model, a rise of global temperature has to be expected. However, this rise will not be the same at all points of the Earth's globe. Therefore, additional analyses of such obtained results are necessary. Further, a temperature change will cause a change in atmospheric circulation and thus also in cloud amount, wind and precipitation distribution. Available results, however, are limited only to the temperature and precipitation field. Atmospheric pressure is discussed only briefly.

The results of the GMC refer to the $4^{o} \times 5^{o}$ grid points. Thus, they represent areas of several hundreds of kilometers. Because of that, it is not possible to deduce a detailed analysis on a local scale from these results, especially in areas of complex orography. This can be avoided using a conversion of the macroscale results to local ones. To establish a relation between these scales, historical climate data and regression methods were used. The final results were expressed in terms of global temperature change (Guo et al., 1992; UNEP 1991. and Fig. 10).

Air pressure scenario

While temperature and precipitation are influenced by local conditions, this is not the case with pressure. Therefore, the pressure results refer only to the broader Mediterranean area without subregional ones. They indicate a pressure decrease of 0.3 hPa per degree of global warming, which is not a significant change. On the basis of that it is difficult to say anything about changes in the present atmospheric circulation.

Temperature and precipitation scenarios

By applying the method described and the GCM results, the expected changes of temperature and precipitation for the Northern Adriatic area have been obtained (Guo et al., 1992). The corresponding temperature and precipitation ranges for three time horizons: 2030, 2050 and 2100 and two locations: Mali Lošinj and Cres are presented in Table 5 separately for the year and the seasons

a) Annual scenario

According to the Table 5, an increase in temperature of 1-5°C can be expected over the Cres-Lošinj area, depending on the time horizon. If the real values of the present mean annual temperature of 15°C (in the area considered) are taken into consideration, then there is a probability of an increase in the mean annual temperature up to 20°C, which can be alarming.

However, a significant change in the annual precipitation amount is not expected. The border of the zero-change intersects the archipelago considered. Therefore, according to the model results, an increase and decrease of the annual precipitation could be expected on the northern and southern part of the islands, respectively. Thus, as the average annual precipitation for the area ranges from 900-1500 mm, it is not difficult to calculate what changes could be for a particular time horizon.

b) Winter scenario (December, January, February)

The expected temperature increase for the winter season is similar to the annual one. If we take into consideration a winter temperature average of about 8°C then a maximum increase in temperature up to 13°C can be expected, which is the present spring average.

The expected precipitation increase ranges from 5-30% over the whole archipelago depending on the time horizon. This increase can not be of great importance because the present winter precipitation is also high. It could only help to increase the water resources of the Vransko lake as evaporation is small during winter.

c) Spring scenario (March, April, May)

The temperature change is near to the annual one. If it is added to the present spring mean (about 13°C), then a picture of temperature conditions in the area can be obtained.

A something smaller increase in precipitation (up to 20%) can be expected on the southern part of the area and up to 30% on the northern part. This could improve agricultural conditions in the area.

d) Summer scenario (June, July, August)

For the summer season, the model again estimates an increase in temperature up to 5°C, similar to the annual one. By adding this value to 30-year average of 23°C, a high temperature of 28°C will be obtained. In this case, the mildness of the archipelago is in question.

The average summer precipitation is 200 mm. An additional decrease of 30 or, somewhere, up to 50 % could seriously destroy the present hydrological conditions.

e) Autumn scenario (September, October, November)

Again, the temperature change does not seriously deviate from the annual average. However, when the mildness of the climate is in question, this autumn

Table 5. Scenario of the climatic change for the Cres-Lošinj islands *

Tablica 5. Scenarij klimatskih promjena na otočju Cres-Lošinj.

Scenario	Time horizon		
	2030	2050	2100
Temperature (°C)			
Annual	+1.6 - +1.8	+1.4 - +2.8	+1.8 - +5.0
Winter	+1.4 - +1.8	+1.2 - +3.0	+1.6 - +5.0
Spring	+1.8 - +2.0	+1.5 - +3.3	+2.0 - +5.5
Summer	+1.8 - +2.0	+1.5 - +3.3	+2.0 - +5.5
Autumn	+1.8 - +2.0	+1.5 - +3.3	+2.0 - +5.5
Precipitation (%)			
Annual	0 - -5	0 - -9	0 - -15
Winter	+5 - +10	+4 - +18	+6 - +30
Spring	-2 - +7	-2 - +12	-2 - +20
Summer	-7 - -13	-6 - -21	-8 - -35
Autumn	0 - +7	0 - +12	0 - +20
b) Cres			
Temperature (°C)			
Annual	+1.8 - +2.0	+1.5 - +3.3	+2.0 - +5.5
Winter	+1.4 - +1.8	+1.2 - +3.0	+1.6 - +5.0
Spring	+1.8 - +2.0	+1.5 - +3.3	+2.0 - +5.5
Summer	+2.0 - +2.3	+1.7 - +3.9	+2.2 - +6.5
Autumn	+2.0 - +2.2	+1.7 - +1.8	+2.2 - +6.0
Precipitation (%)			
Annual	0 - +5	0 - +9	0 - +15
Winter	+5 - +10	+5 - +18	+6 - +30
Spring	+14 - +18	+5 - +18	+6 - +30
Summer	-7 - -13	-12 - -30	-16 - -50
Autumn	0 - -13	0 - -21	0 - -35
Sea level (cm)			
Annual	+18 +/-12	+38 +/-14	+65 +/-35

* Source: University of East Anglia

warming could prolongue "summer" conditions and thus improve comfort.

When discussing precipitation, a discrepancy between the north (a decrease of up to 35%) and the south (an increase of up to 20%) can be observed. This could reduce the difference in precipitation between these subregions.

Bioclimatic condition scenario

Assuming an increase of 3°C in the 10-year mean daily temperature, the TWH index values would also rise (Fig. 11). Taking into consideration the differences between the mean daily TWH index values and those for different parts of the day, an increased occurrence of TWH in the class "hot" and even "extremely warm" would not be unexpected in the warmest part of the day (2 PM).

Possibility of extreme change prediction

As already mentioned, there is a relatively slight possibility of prediction of extreme climatic changes in the area considered. However, some conclusions can be made comparing different weather behaviour during summer and winter. It is a known fact that during summer the weather over the Cres-Lošinj archipelago has subtropical characteristics (warm, precipitation

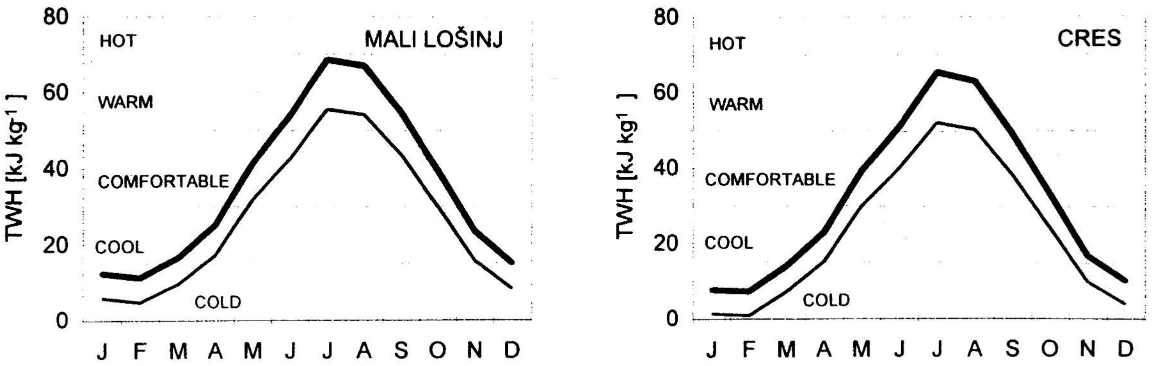


Figure 11 .Comparison of annual regimes of daily average TWH indices: present situation (thin line) and future situation assuming a 3°C temperature increase (thick line)

Slika 11. Usporedba godišnjih režima srednjih dnevnih vrijednosti TWH indeksa: sadašnje stanje (tanka linija) i buduće stanje uz pretpostavku porasta temperature zraka za 3°C (debela linija)

showers, longer drought periods etc.). Thus, through global warming, a tendency toward summer weather can be expected. Further, a stronger temperature contrast between the equator and the poles can causes stronger winds during the first part of the warming period (before the melting of the ice caps). However, later, i.e. after the ice cap melting, a decrease in wind intensity can be expected. This would be valid on a global scale (e.g. for the Northern hemisphere) but not necessarily for the Cres-Lošinj area because of its specific local wind regime.

In connection with warming, a movement toward the north of tropical cyclone paths (typhoons) can be expected. Thus, a possibility of the appearance of these rare but dangerous phenomena could not be excluded. They are also accompanied by destructive wind, strong rainfall, and great waves if they move over water surfaces. Thus, an increase in short-term precipitation extremes can be expected.

A rising of the lower limit of the temperature extremes could also be expected as, after the melting of the ice caps on the poles, the "sources" of very cold air will disappear. However, these hypotheses are rather speculative and they have to be taken with reserve.

CONCLUSION

A mild Mediterranean climate prevails over the Cres-Lošinj archipelago, characterized by warm and rather dry summers and temperate and rainy winter seasons. Snow is a very rare phenomenon. Prevailing winds are bora and sirocco, especially in the winter season. During summer, a refreshing wind from the sea (maestro) prevails. The number of sunny and fair days is the highest during summer which is favourable for tourism in the area.

According to GCM results, a warming is to be expected of 1-5°C over the Cres-Lošinj area, which depends on the time horizon. A higher increase in temperature could be occur in the second half of the 21th century.

The results do not indicate any significant change in air surface pressure over the Mediterranean area and neither over the Cres-Lošinj archipelago. However, a change in the present atmospheric circulation can not be excluded. It has to be expected, because of the global warming, a circulation tendency toward the summer season circulation type.

A significant change in the annual precipitation amount is not very probable. However, for each season separately, a significant change in precipitation can be expected. A decrease in precipitation during summer and autumn as well as an increase during winter and spring was established. A winter increase and summer decrease in precipitation can improve or destroy the islands' hydrological conditions. A contrast between seasons will grow stronger.

It is difficult to say something definite about the other climatic elements and extremes, but it is certain that a temperature change will cause other changes. However, the sign and intensity of those changes is not possible to determine without complex and perhaps prolongued research projects being coordinated at world level. In such a study, a rich climatological data basis as well as global circulation models should be used. In addition, the oceans, as great accumulators of thermal energy, should not be forgotten.

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