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Annual cycle of sea surface temperature along the east Adriatic coast

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Time series of sea surface temperature (SST), measured over some 20-year interval at 21 stations along the east Adriatic coast, are analysed. By means of the Fourier analysis the average annual cycle of temperature is documented and the year-to-year variability of various SST-related parameters is described. It is shown that amplitudes of the first harmonic of the annual cycle are decreasing and its phases increasing in an offshore direction. The amplitudes range from 5.4 to 8.0 °C, the phases vary from 7.2 to 7.5 months (implying maximal time lag of nine days). The variability is mostly controlled by the autumn/winter cooling process. Amplitude of the first harmonic is anomalously low at Senj, whereas the corresponding phase does not depart from the typical coastal values. The finding is due to the exceptionally low summer SSTs that occur in the vicinity of Senj. At the Sv. Ivan station (near Rovinj) the spring/summer heating is significantly faster than the autumn/winter cooling. This can be ascribed to the influence of the Po River waters, which spread over the open Adriatic in spring/summer, but are mostly confined to the western coast in autumn/winter. The year-to-year changes of all the parameters considered are found to be much smaller than the multi-year average values, and in some cases prove to be small even if compared with the spatial variations of the long-term averages.

Sezonska promjenjivost površinske temperature mora duž istočne obale Jadrana

U radu su analizirani vremenski nizovi površinske temperature mora, prikupljeni tijekom dvadesetak godina na 21 postaji duž istočne obale Jadrana. Primjenom Fourierove analize istražena je srednja sezonska promjenjivost temperature kao i višegodišnje promjene različitih pripadnih parametara. Pokazalo se da amplitude prvog harmonika opadaju, a faze rastu, u smjeru od obale. Amplitude se mijenjaju od 5,4 do 8,0 °C, faze variraju od 7,2 do 7,5 mjeseci (što znači da maksimalni vremenski pomak iznosi devet dana). Ova je promjenjivost uglavnom uvjetovana jesensko/zimskim procesom hlađenja. Amplituda prvog harmonika izuzetno je niska u Senju, dok se pripadna faza ne razlikuje bitno od tipičnih obalnih vrijednosti. To je povezano s niskim temperaturama koje se u ovom području javljaju ljeti. Na postaji Sv. Ivan (u blizini Rovinja) proljetno/ljetno zagrijavanje znatno je brže od jesensko/zimskog hlađenja. Pojava se može pripisati utjecaju rijeke Po, čije vode se razlijevaju otvorenim Jadranom u proljeće i ljeto, dočim su uglavnom zbijene uz zapadnu obalu tijekom jeseni i zime. Utvrđeno je da su višegodišnje promjene svih razmatranih parametara znatno manje od pripadnih dugogodišnjih srednjaka, a u nekim slučajevima male su čak i u usporedbi s prostornim promjenama tih srednjaka.

1. Introduction

Temperature of the Adriatic Sea has been the subject of intensive investigations ever since the early study carried out by Lorenz (1863). A part of the work concentrated on the open Adriatic, being based on shipborne measurements which are usually performed over large portions of the sea with, however, rather poor time sampling intervals. Results deduced from the offshore oceanographic data have been summarized by Buljan and Zore-Armanda (1976). Complementary investigations utilized shore-based measurements, which are restricted to the surface level of stations distributed along the Adriatic coast, but provide time series of daily, or even hourly mean values. A number of coastal stations has been covered in the literature: Trieste (Polli, 1940; Picotti, 1955), Rovinj (Vatova, 1948), Koper (Bernot, 1960), Split/Marjan (Buljan, 1961; Zore-Armanda et al., 1991), Fano (Scaccini-Cicatelli, 1975, and earlier references by the same author), and Hvar (Stipaničić, 1975). Moreover, on several occasions an intercomparison of data taken at different coastal stations has been performed. Bernot (1965) analysed five-year time series collected at Koper and Trieste, Zore-Armanda (1969) discussed data collected over a six-year interval at 14 stations along the east Adriatic coast, whereas Stipaničić (1977) compared measurements originating from Senj, Split and Dubrovnik (without specifying time interval during which the data were registered).

A pronounced signal in time series of the sea temperature is, of course, the annual one. Hann (1901), inspired by a data set originating from the Adriatic Sea, pioneered the use of the Fourier analysis to describe the annual cycle. Later on, the method was applied to temperature data collected in the European shelf waters (Dietrich, 1953), and was used to investigate annual thermal variability of the world oceans (see Levitus, 1987, and references cited therein). Following Hann, several authors submitted the Adriatic shipborne measurements to the Fourier analysis with the aim of extracting the annual signal (Mosetti, 1964; Škrivanić, 1975; Stravisi, 1983). Furthermore, Buljan (1961) used five years of temperatures, registered daily at Split/Marjan, to compute the amplitude and phase of the first harmonic of the annual cycle.

Recently, some twenty-year long time series of sea surface temperature (SST), measured on a daily basis at 21 stations along the east Adriatic coast, became available. The data have been subjected to the Fourier analysis. Results obtained are described in this paper. In the second section the data and methods of their analysis are described. The third section focuses on average annual cycle of SST. The fourth section describes the year-to-year variability. In the final, fifth section the results for the east Adriatic coast are summarized, and are compared with the western coast measurements and remotely sensed data.

2. Data and methods

As already mentioned, SST data base for this investigation consisted of measurements performed at 21 stations distributed along the east Adriatic coast (Figure 1). Measurement intervals for which the data were available are indicated in Figure 2. All the data except those of Split/Marjan were provided by the Maritime Meteorological Center (Split), whereas the Split/Marjan data were supplied by the Institute of Oceanography and Fisheries (Split). Primary data control and quality checks were carried out by the two institutions.

SST was measured at a 30 cm depth, in a water column at least 5 m deep, using standard bucket thermometers. Precision of such measurements is es-

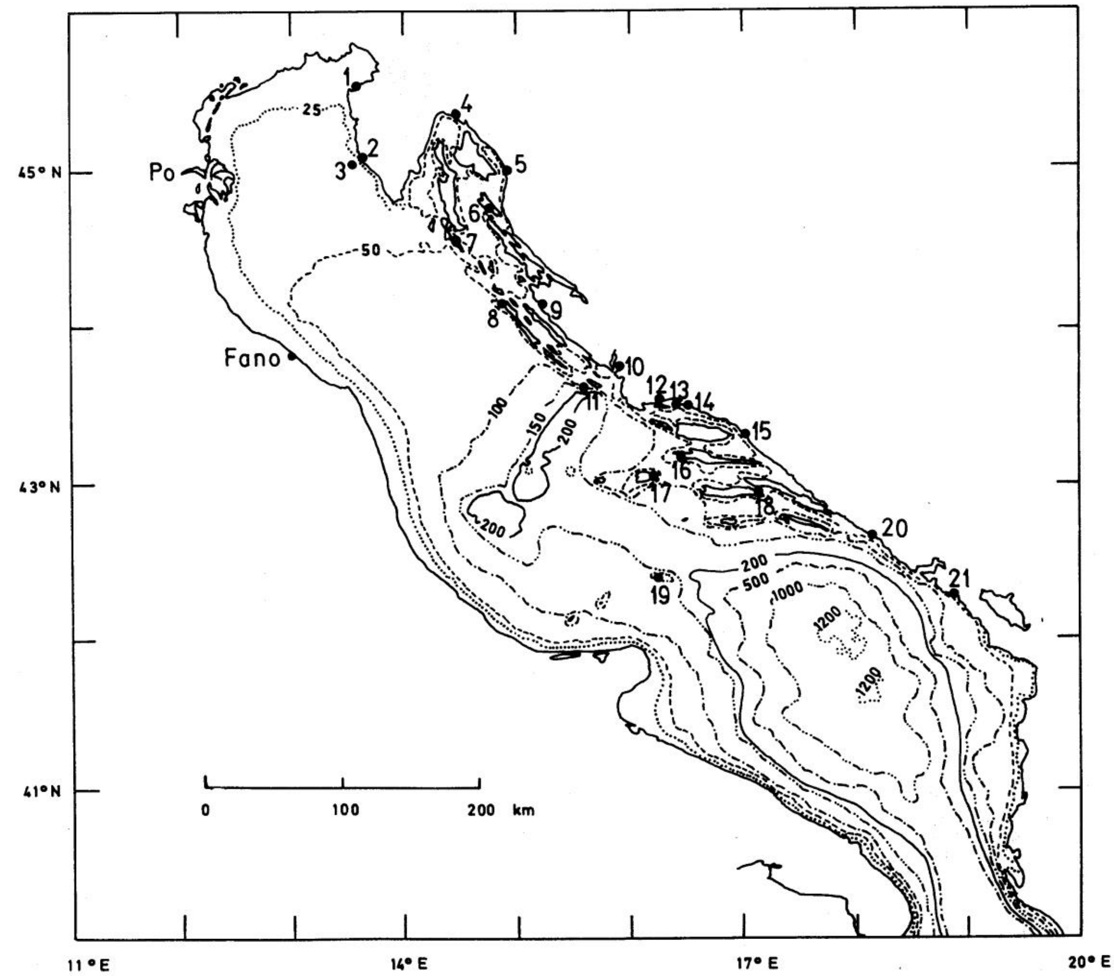

Figure 1. Topography of the Adriatic Sea and position of sampling points (1–21). The station names are given in Figure 2. Also depicted are the Po River mouth and the Fano station.

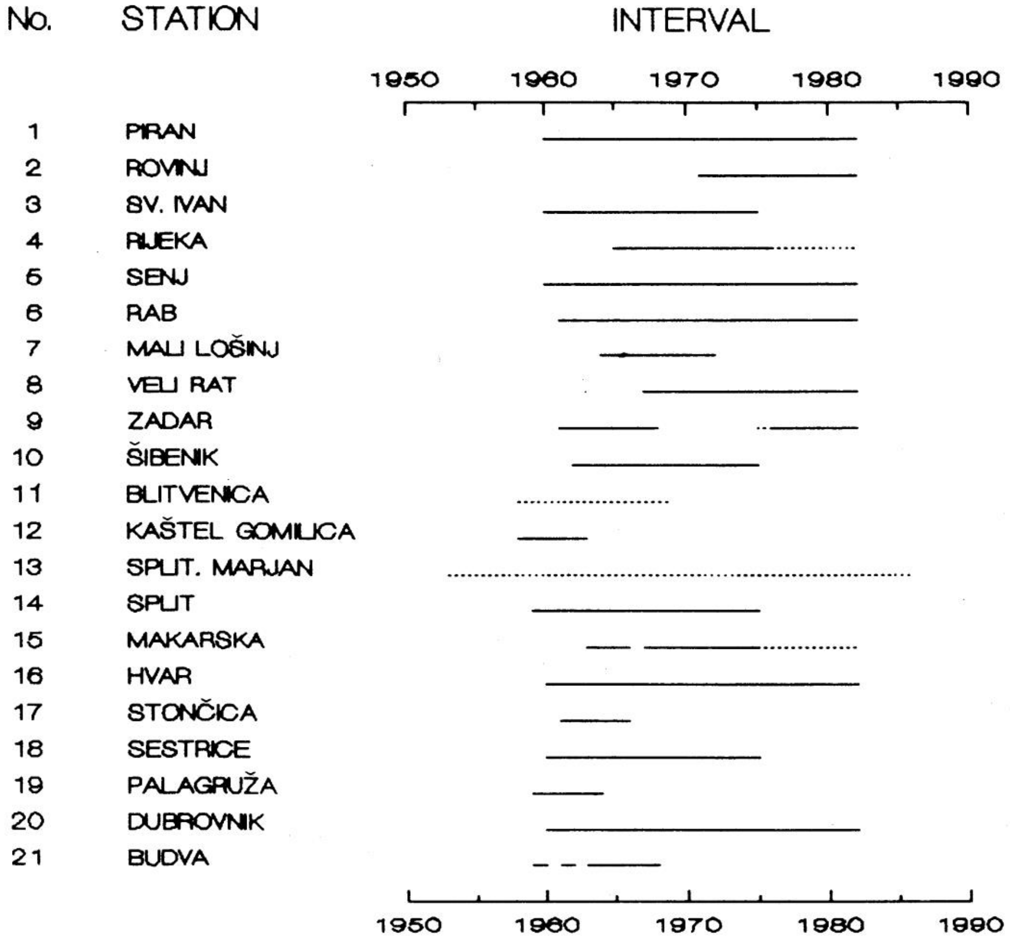

Figure 2. Intervals for which data were available at stations indicated in Figure 1. Solid lines represent intervals over which measurements were performed three times a day, dotted lines mark intervals with only two readings made per day.

timated at ±0.1 °C. Station locations were selected so as to avoid areas influenced by pronounced currents and strong freshwater inflows. At most stations measurements were performed three times a day, at 7, 14 and 21 h EMT. Exceptions are Blitvenica and Split/Marjan, and partially Rijeka and Makarska, where readings were made at 7 and 14 h EMT only (Figure 2).

The two measurement strategies do not yield daily mean values which would be completely comparable. Assuming daily SST change that amounts to 2 °C, with the minimum occurring at 4 h and maximum at 16 h EMT (Zore-Armanda, 1978), daily mean value computed from three measurements would surpass mean obtained from two measurements by 0.06 °C. Consequently, we refrained from pooling all the data together.

From daily mean values monthly means were computed and used as input data for further analysis. This comprised developing in the Fourier series the annual cycles averaged for a number of selected stations, as well as those obtained for each particular station/year. A function of the form

$$T(t) = A_o + A_1 \sin\left(\frac{2\pi}{12} t - \varphi_1\right) + A_2 \sin\left(2\frac{2\pi}{12} t - \varphi_2\right) \quad (1)$$

was least-squares fitted to twelve monthly means/averages T_i (i = 1, 2...12). Here, T denotes temperature, t is time counted from the beginning of the year (in months), and the meaning of other symbols is obvious.

Henceforth, phases will be defined via the moment at which a harmonic reaches its maximum:

$$M_k = \left(\frac{\pi}{2} + \varphi_k\right)\frac{6}{k\pi}, \qquad k = 1, 2. \quad (2)$$

Analogously to time, this value is expressed in months and is counted from the beginning of the year (e. g. M_1 = 7.0 months implies that the maximum in the first harmonic occurs on 1 August). Percent variance contribution of a particular harmonic to the annual cycle will also be computed, according to:

$$P_k = \frac{600\, A_k^2}{\sum_{i=1}^{12} (T_i - A_o)^2}, \qquad k = 1, 2. \quad (3)$$

Exclusiveness of the first harmonic implies that the heating and cooling processes are symmetrical, whereas significant contribution from the second harmonic – characterized by a proper phase – would signify that one process is being speeded up, the other slowed down.

3. Average annual variations

In order to analyse typical annual cycle of SST, we have averaged monthly mean values over two time intervals. The first interval is thirteen years long (1962–1974) but covers data for nine stations only. The second interval is much shorter (1970–1974), yet it comprises data from twelve stations altogether.

For the first time interval, average annual cycles and their representation by the first harmonic are shown in Figure 3. The variance contribution of the first harmonic is extremely high, over 98 % at all the stations considered (Table 1). The greatest contribution of the second harmonic is found at the Sv. Ivan station, where heating is significantly faster than cooling.

The second time interval is more suitable for an analysis of spatial distribution of SST-related parameters. Monthly averages for the 1970–74 interval are given in Table 2. Minimal SSTs occur in February or in March, whereas maximal values occur in August at all the stations. Spatial distributions of average SST in February and August are shown in Figure 4. In winter there are pro-

Table 1. Mean annual temperatures (A_o, °C), amplitudes (A_1 and A_2, °C), phases (M_1 and M_2, months) and percent variances (P_1 and P_2, %) of the first and second harmonic of the annual cycle, averaged over the 1962—74 interval.

Station	A_o	A_1	M_1	P_1	A_2	M_2	P_2
Piran	15.7	8.2	7.2	99.5	0.5	0.1	0.4
Sv. Ivan	15.8	7.2	7.5	98.4	0.9	0.7	1.5
Senj	14.9	5.4	7.5	98.1	0.6	0.4	1.4
Rab	16.4	6.8	7.2	98.7	0.8	0.5	1.2
Šibenik	17.5	5.6	7.4	98.9	0.5	0.2	0.8
Split	17.3	6.1	7.4	99.0	0.6	0.5	0.9
Hvar	17.8	5.6	7.6	99.6	0.3	0.2	0.3
Sestrice	17.6	5.4	7.6	99.4	0.4	0.0	0.5
Dubrovnik	17.9	5.7	7.3	99.5	0.2	0.7	0.1

Table 2. Monthly averages of sea surface temperature recorded between 1970 and 1974 (°C).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Piran	9.0	8.7	9.0	11.9	16.8	21.6	23.4	24.4	21.7	17.3	13.9	10.9
Sv. Ivan	10.1	9.7	9.7	11.1	14.8	19.7	23.2	24.1	22.0	17.8	14.5	12.1
Rijeka	11.2	10.3	10.1	11.7	15.2	19.6	24.0	24.5	20.0	16.7	14.2	12.2
Senj	10.5	10.4	10.2	11.3	14.9	19.1	19.8	20.9	18.4	15.9	14.0	12.2
Rab	10.8	10.6	11.0	12.9	16.7	21.4	23.0	24.0	21.3	17.4	14.5	12.2
Veli Rat	13.1	12.4	12.0	13.5	16.3	20.5	22.9	24.0	22.3	19.0	16.5	14.4
Šibenik	12.8	12.7	12.7	14.2	17.4	21.2	22.6	23.5	21.8	18.7	16.3	14.5
Split	12.1	11.8	12.0	13.6	17.0	21.0	22.8	23.6	21.5	18.6	15.6	13.1
Makarska	12.2	11.8	12.1	13.5	17.1	20.4	22.8	24.1	21.7	18.6	16.2	13.5
Hvar	13.3	12.7	12.7	14.2	16.8	20.4	22.4	23.6	22.5	19.8	17.2	14.8
Sestrice	13.3	12.5	12.5	14.0	16.8	20.5	22.4	23.2	22.0	19.7	17.1	14.8
Dubrovnik	13.3	13.0	13.2	14.6	17.2	21.0	22.9	23.6	22.4	18.9	16.3	14.3

nounced differences between the north and south: over the North Adriatic SST rapidly increases in a southward direction, to become almost uniform over the Middle Adriatic. The minimum occurs at Piran (8.7 °C), the maximum at Dubrovnik (13.0 °C). Close to the coast SST is somewhat lower than farther offshore (compare values found at the coastal station Split and the offshore station Hvar). The summer SSTs show a more uniform distribution. They are slightly higher in the north (Rijeka, 24.5 °C) than in the south (Sestrice, 23.2 °C). There is a pronounced singularity in the vicinity of Senj, where average August SST is as low as 20.9 °C.

Results of the Fourier analysis for the 1970–74 interval are given in Table 3. At all the stations the variance contribution of the first harmonic is somewhat lower than for the long time interval (see Table 1). It ranges between 92.6 %

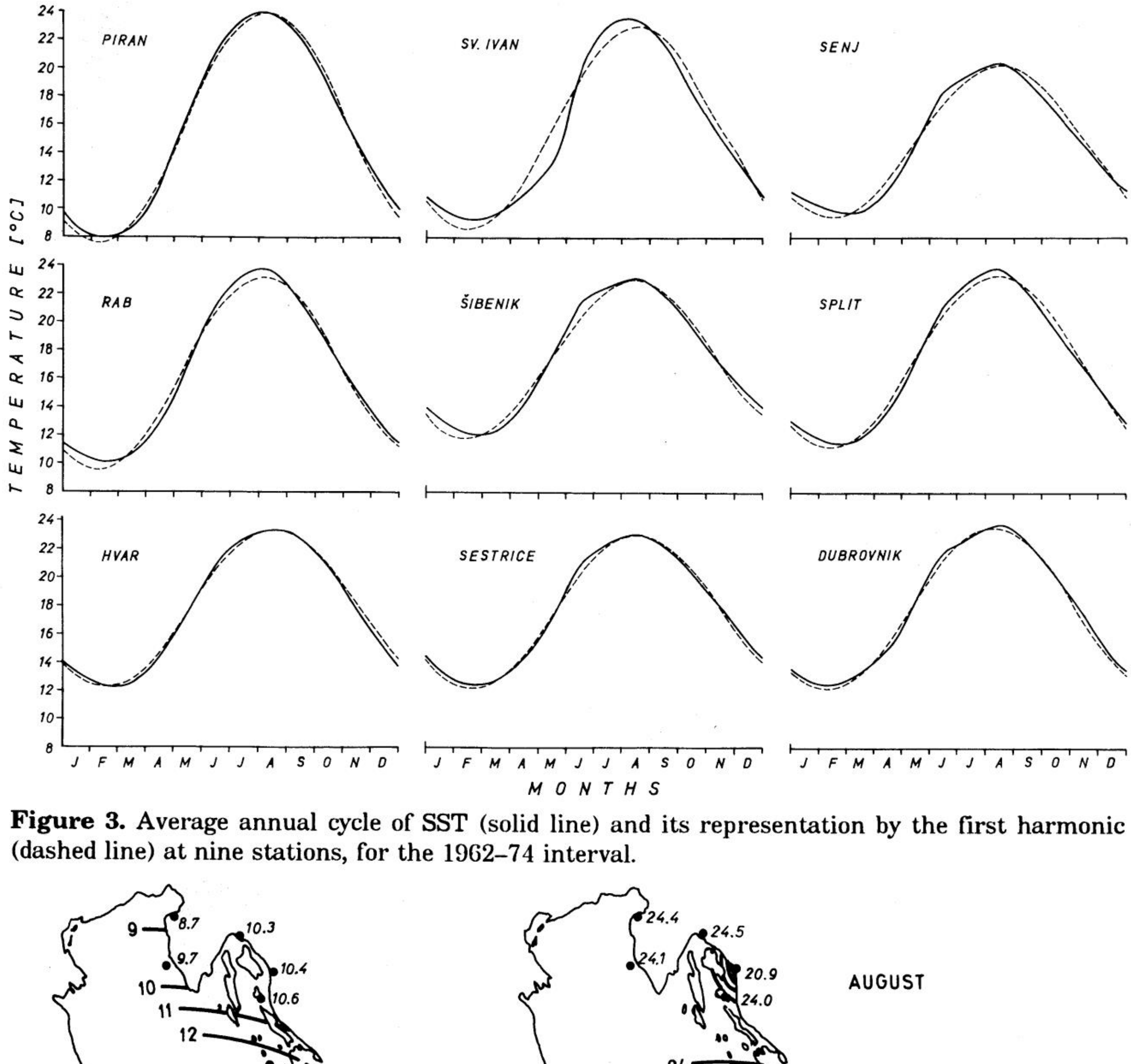

Figure 3. Average annual cycle of SST (solid line) and its representation by the first harmonic (dashed line) at nine stations, for the 1962–74 interval.

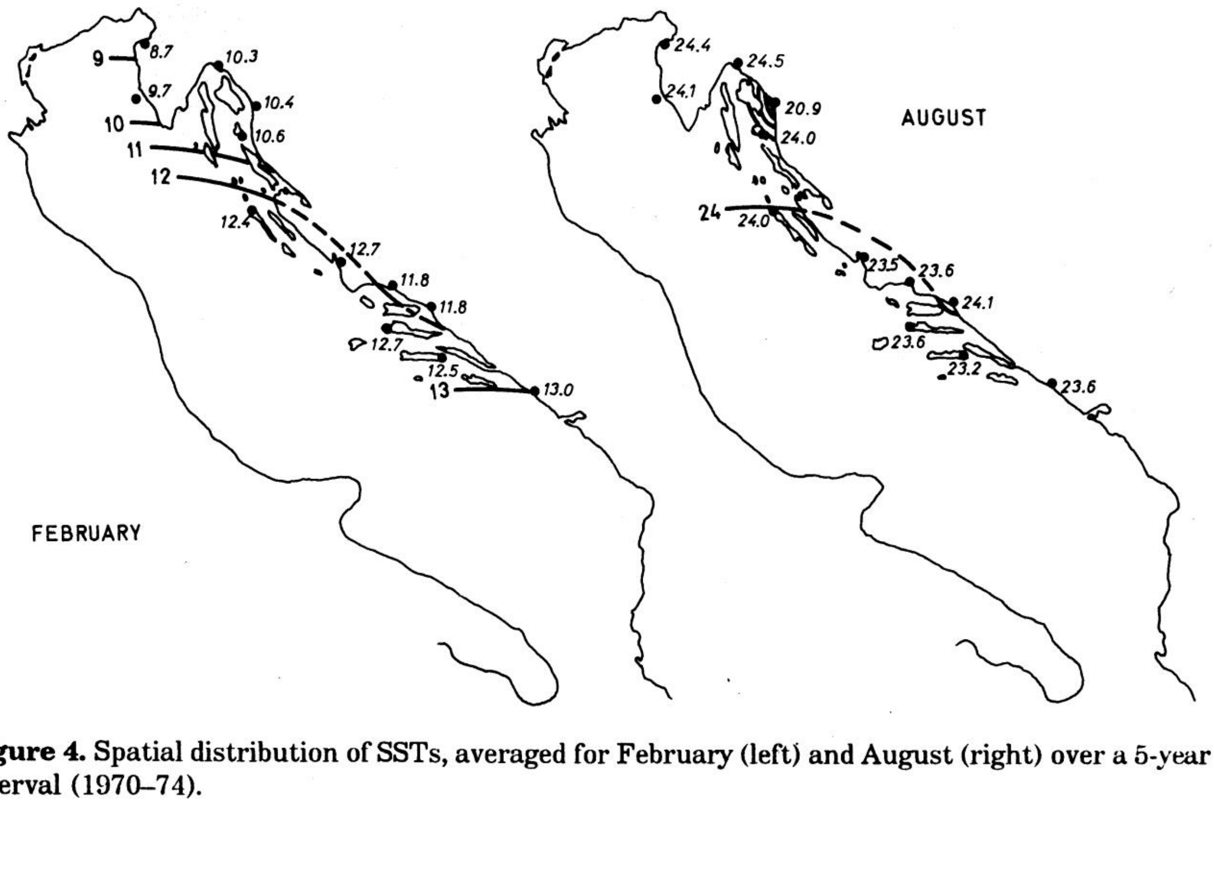

Figure 4. Spatial distribution of SSTs, averaged for February (left) and August (right) over a 5-year interval (1970–74).

Table 3. Mean annual temperatures (A_o, °C), amplitudes (A_1 and A_2, °C), phases (M_1 and M_2, months) and percent variances (P_1 and P_2, %) of the first and second harmonic of the annual cycle, averaged over the 1970—74 interval.

Station	A_o	A_1	M_1	P_1	A_2	M_2	P_2
Piran	15.7	8.0	7.2	98.5	0.9	0.6	1.2
Sv. Ivan	15.7	7.3	7.4	96.9	1.3	1.0	3.0
Rijeka	15.8	6.7	7.3	92.6	1.8	0.8	6.7
Senj	14.8	5.3	7.3	95.9	0.9	0.5	3.1
Rab	16.3	6.7	7.2	97.4	1.0	0.8	2.2
Veli Rat	17.2	5.8	7.5	96.8	1.0	0.9	3.0
Šibenik	17.4	5.5	7.3	97.8	0.7	0.7	1.8
Split	16.9	6.0	7.2	97.8	0.8	0.9	2.0
Makarska	17.0	6.0	7.3	97.9	0.8	0.9	1.7
Hvar	17.5	5.5	7.5	98.8	0.6	1.1	1.1
Sestrice	17.4	5.4	7.5	98.8	0.6	0.7	1.1
Dubrovnik	17.6	5.4	7.3	97.4	0.8	1.1	2.3

(Rijeka) and 98.8 % (Hvar and Sestrice). The sum of the percent variances of the first and second harmonic is close to 100 % everywhere. Mean annual temperature is generally increasing from the north to the south, with the minimum found at Senj (14.8 °C). The maximal value at Dubrovnik (17.6 °C) is about 2 °C higher than the mean annual temperature at Piran, the northernmost station.

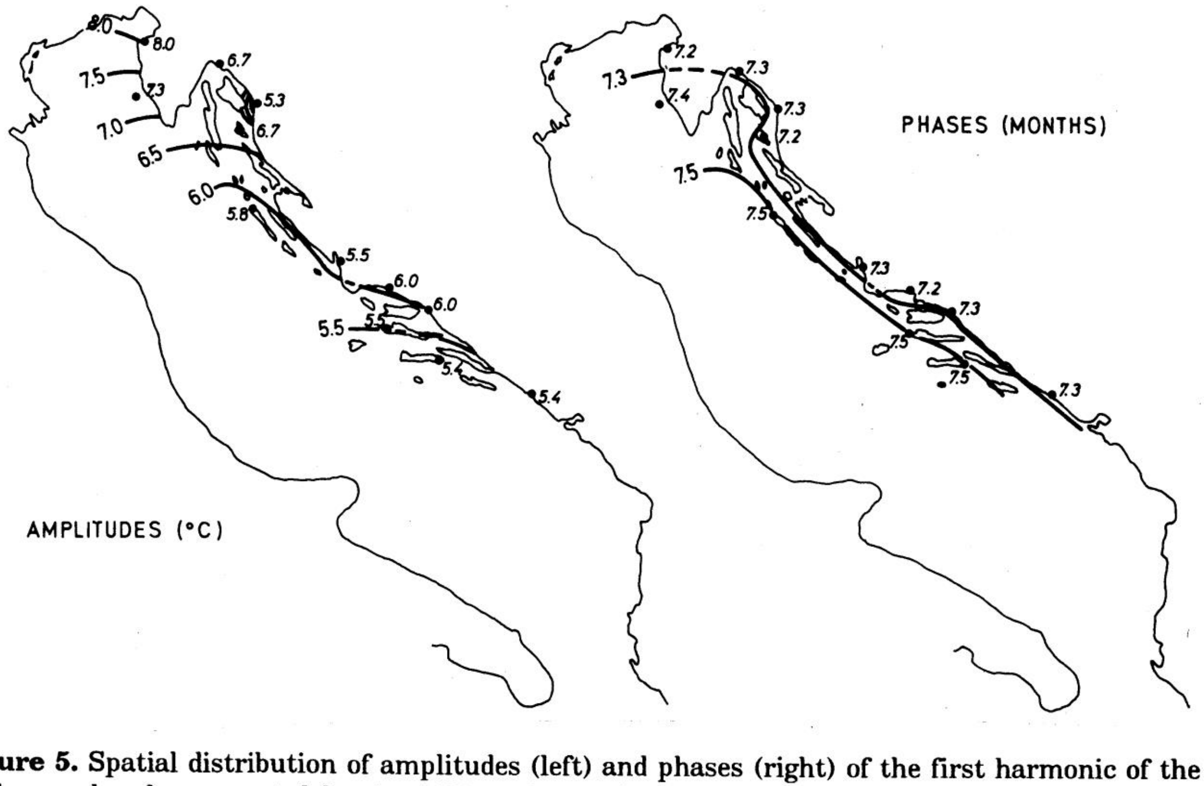

Figure 5. Spatial distribution of amplitudes (left) and phases (right) of the first harmonic of the SST annual cycle, computed for the 1970–74 interval.

Spatial distribution of amplitudes of the first harmonic is shown in Figure 5 (left). The amplitudes are decreasing from the north towards the south. The maximum occurs at Piran (8.0 °C). At the southernmost stations Sestrice and Dubrovnik the amplitude equals 5.4 °C. The singularity at Senj is again obvious, with the minimal amplitude (5.3 °C) being recorded there. A decrease of amplitudes in an offshore direction is also visible. The amplitude at a coastal station – Split – is 0.5 °C greater than at the nearby insular station Hvar. Although the amplitudes are generally decreasing towards the south, the value found at the northern insular station Veli Rat is smaller than at the Split station. However, there is no difference between the amplitudes recorded at Rijeka, a coastal station in the north, and at the nearby insular station Rab.

Spatial distribution of phases of the first harmonic is also shown in Figure 5 (right). At all the stations the maximum in the first harmonic occurs in the first half of August, the minimum in the first half of February. The phases range between 7.2 and 7.5 months (implying maximal time lag of nine days). There is a pronounced difference between the inshore and offshore stations. Along the eastern Adriatic coast phases do not surpass 7.3 months, irrespective of the geographical latitude. Farther offshore phases increase to 7.4 and 7.5 months, indicating that the open sea lags behind the coastal waters.

By comparing Figures 4 and 5 it may be noticed that spatial distribution of amplitudes of the first harmonic resembles for the most part the winter SST pattern. However, Senj makes an exception: the minimum of the amplitude of the first harmonic is related there to the low summer SST. Monthly averages listed in Table 2 indicate that spatial distribution of phases, shown in Figure 5, is also influenced by the autumn/winter cooling rather than the spring/summer heating.

4. Year-to-year variability

With the aim of investigating the year-to-year variability of the annual cycle, we have subjected monthly mean SSTs for all the station/years to the Fourier analysis. Mean annual values thus obtained for six stations are shown in Figure 6. The most pronounced variations are observed at Dubrovnik, where their range amounts to 2.1 °C. At a nearby insular station, Hvar, minimal variations are found (range – 1.3 °C). In the years 1966 and 1978 extreme values occurred at all the stations considered, in some other years extremes were recorded at a part of stations only. Over the two decades of measurement a cooling trend – more pronounced in the south than in the north – was registered.

Time series of amplitudes of the first harmonic are depicted in Figure 7. The variability is less pronounced at the insular stations (Hvar – 1.4 °C, Rab – 1.8 °C) than at the coastal stations (where the range surpasses 2 °C). The universal 1978 minimum of Figure 6 is also visible here, being obviously caused by an anomalously cold summer. The 1966 maximum of Figure 6 appears here as minimum in the north (warm winter event), maximum in the south (warm

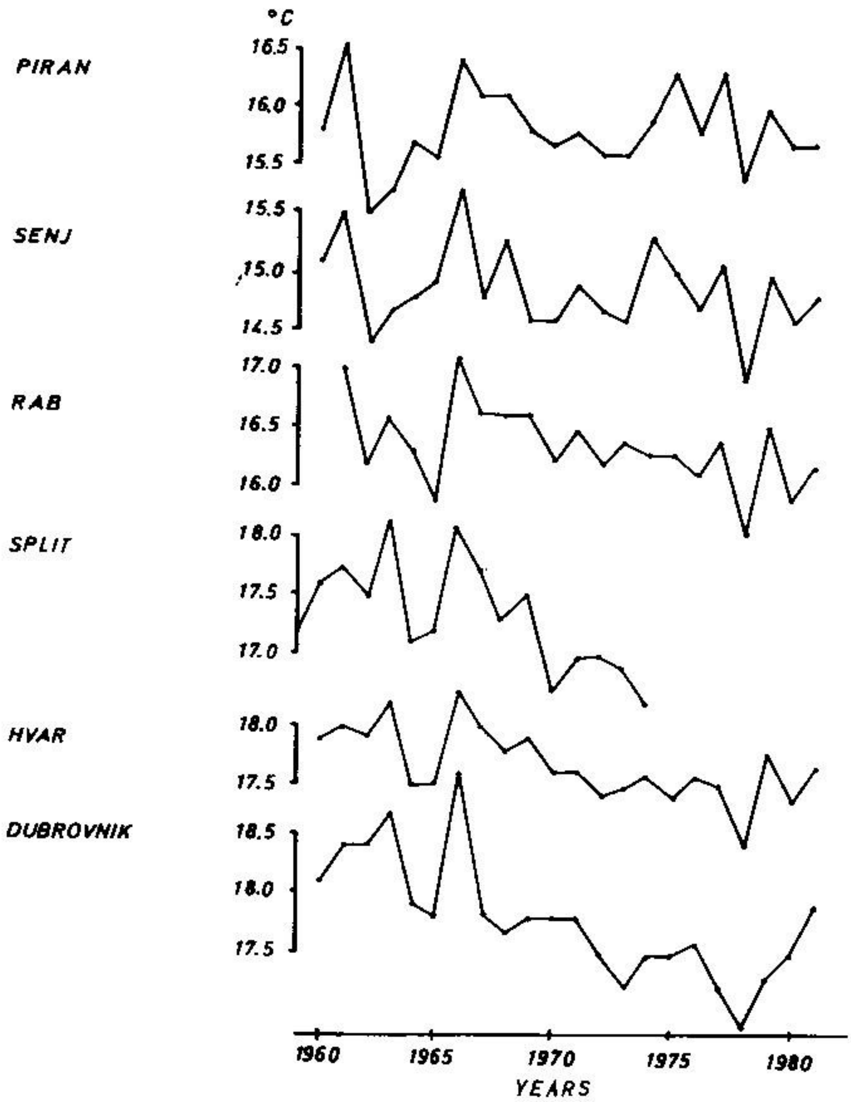

Figure 6. Year-to-year variability of the mean annual SST at six stations.

summer event). Of some interest is also the maximal amplitude of the first harmonic, recorded everywhere in 1963 (Figure 7). Most probably, it was due to the combined warm summer and cold winter events, which might produce minima of the mean annual values recorded in the north, maxima in the south (see Figure 6).

Obviously, an interpretation of time series shown in Figures 6 and 7 requires information on the summer and winter temperatures. These were computed by averaging monthly mean values over three successive months (January, February and March – winter, July, August and September – summer). Results are shown in Figure 8. They support previous interpretation of SST-related parameters obtained for the years 1963, 1966 and 1978. Moreover, they single out as interesting years 1964 (combined cold summer and warm winter in the south), 1965 and 1967 (warm summer and cold winter in the south) and 1972 (cold summer and warm winter in the north).

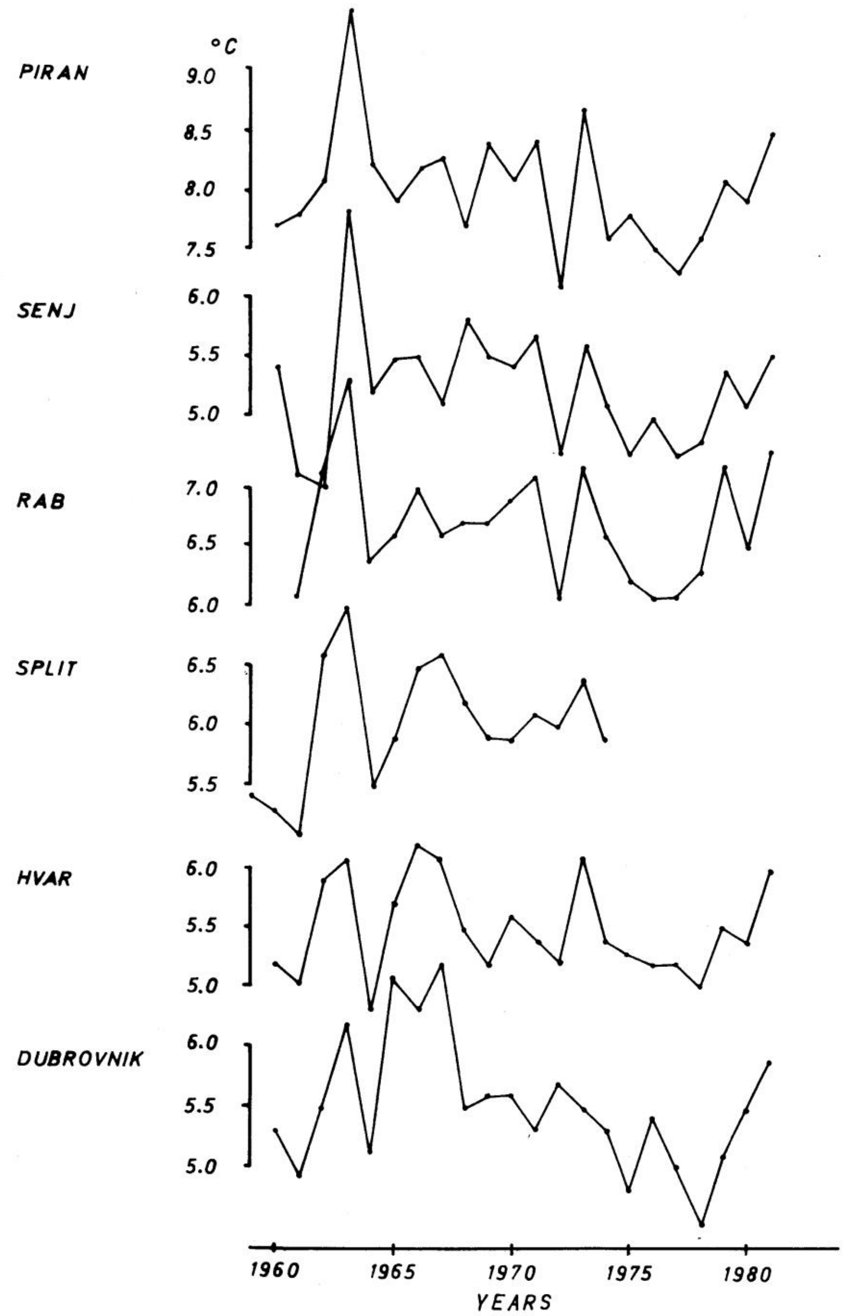

Figure 7. Interannual variability of amplitudes of the first harmonic of the SST annual cycle at six stations.

Year-to-year variability of phases of the first harmonic is documented in Figure 9. The first harmonic peaks in August, with the exception of the years 1972 (Rab and Split) and 1977 (Dubrovnik) when the maximal values appeared at the end of July. The early appearance of the maximum in 1972 is detectable everywhere, as are the late appearances in 1962 and 1967. Results of analysis of the longer time series available for the Split/Marjan station (not shown) indicate that the 1972 event was quite exceptional. Figure 9 shows that variations of phases of the first harmonic are smallest at Piran, where their range equals 15

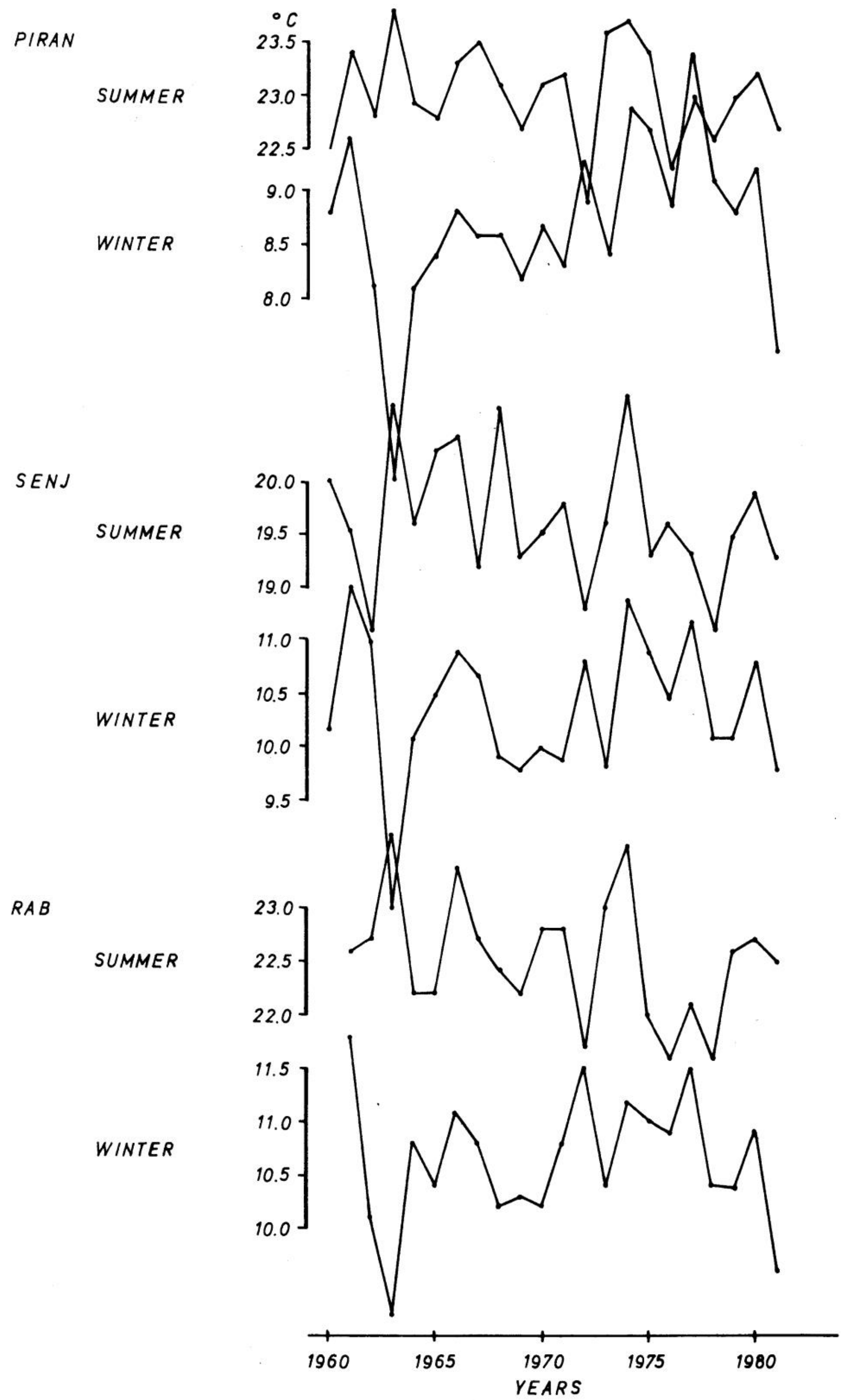

Figure 8a. Time series of the average summer (July, August, September) and winter (January, February, March) temperatures at stations Piran, Senj and Rab.

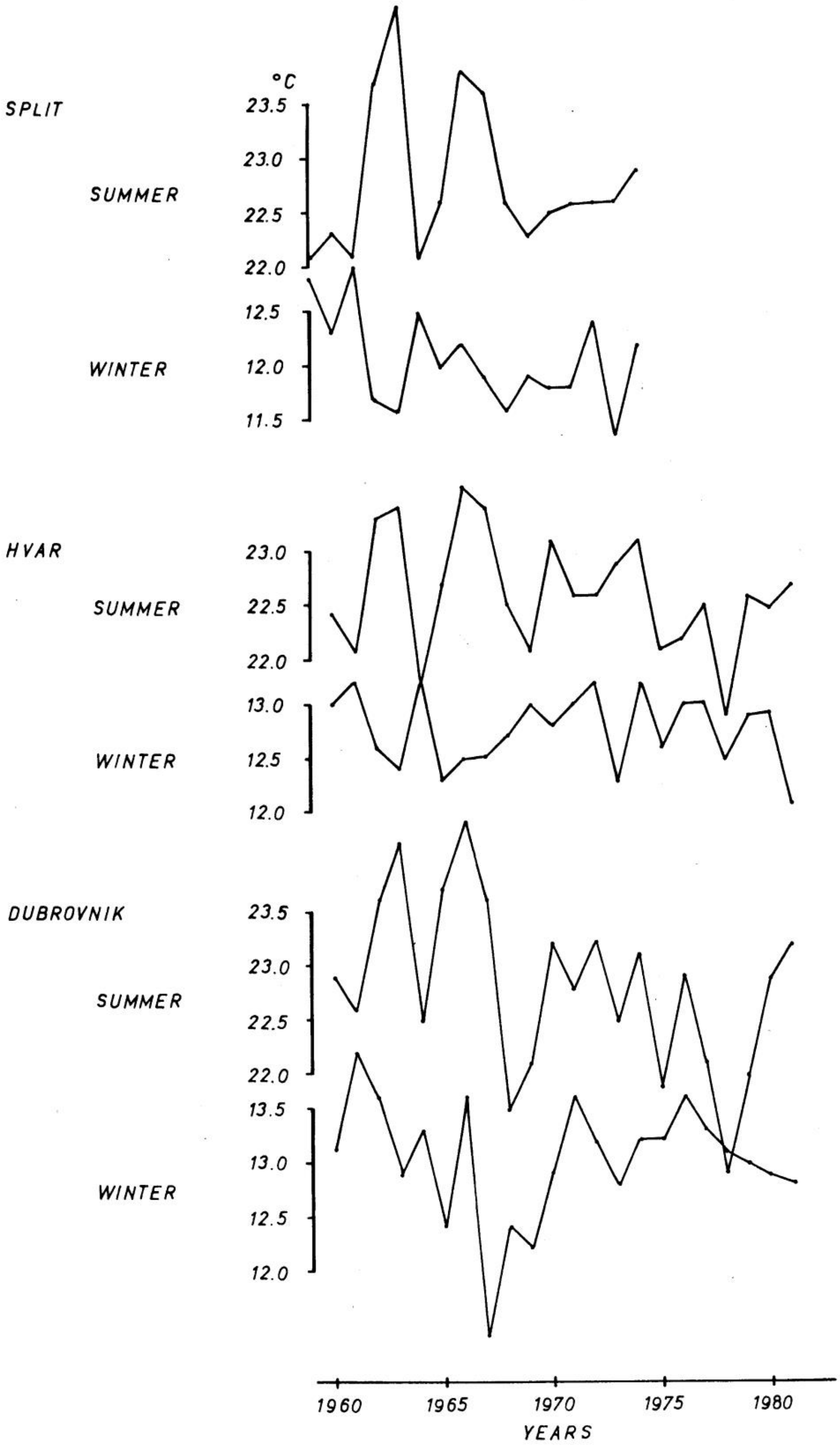

Figure 8b. As in Figure 8a, except for stations Split, Hvar and Dubrovnik.

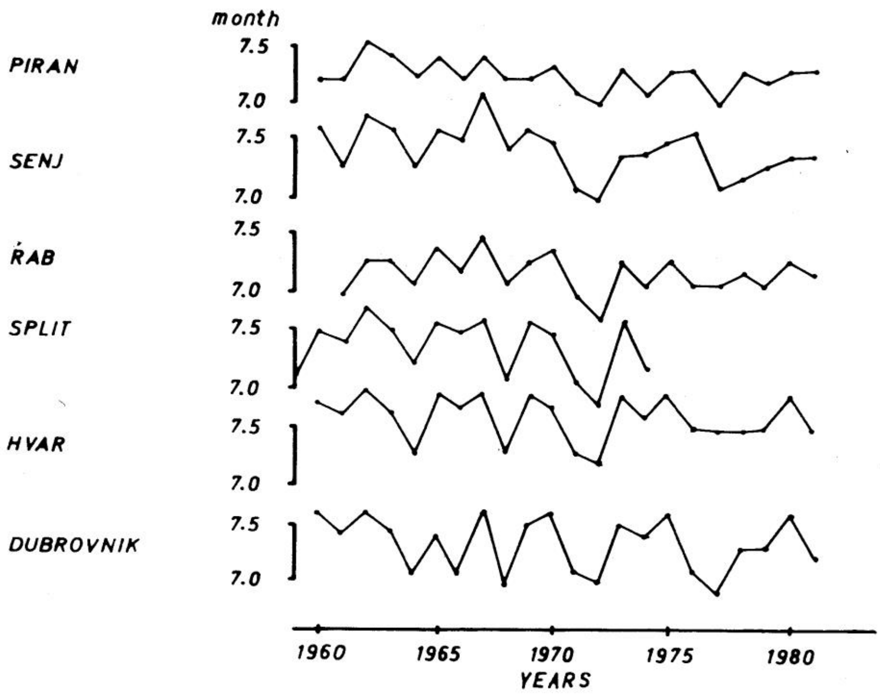

Figure 9. Interannual variability of phases of the first harmonic of the SST annual cycle at six stations.

days. At Hvar the range increases to 18 days, at Rab reaches 21 days, while it is maximal at Senj – 27 days.

The variance contribution of the first harmonic surpasses 91 % for all the station/years (Supić, 1988). The contribution of the second harmonic is shown in Figure 10. The ranges are minimal at Piran (2.5 %) and Hvar (3 %), maximal at Senj (7 %). The values were everywhere close to zero in the years 1966, 1967 and 1975. In 1974 the variance contribution of the second harmonic reached a maximum (2–6 %) at all the stations. The second harmonic peaked in the first half of February and August 1974 (Supić, 1988), reflecting the fact that the symmetry of the annual cycle was preserved.

5. Discussion and conclusion

Interannual variability of SST-related parameters, documented in the previous section, opens the problem of its causes. Why some seasons turn out to be anomalously cold or warm? What lies behind the occasional shifts in thermal cycles? Why the heating/cooling processes are sometimes speeded up or slowed down? In order to answer these questions, one should analyse in some detail year-to-year variability of the air/sea fluxes and the sea dynamics. This, however, is beyond the scope of the present work. What we need here is merely an estimation of interannual variability, providing a background against which the average annual cycles can be discussed.

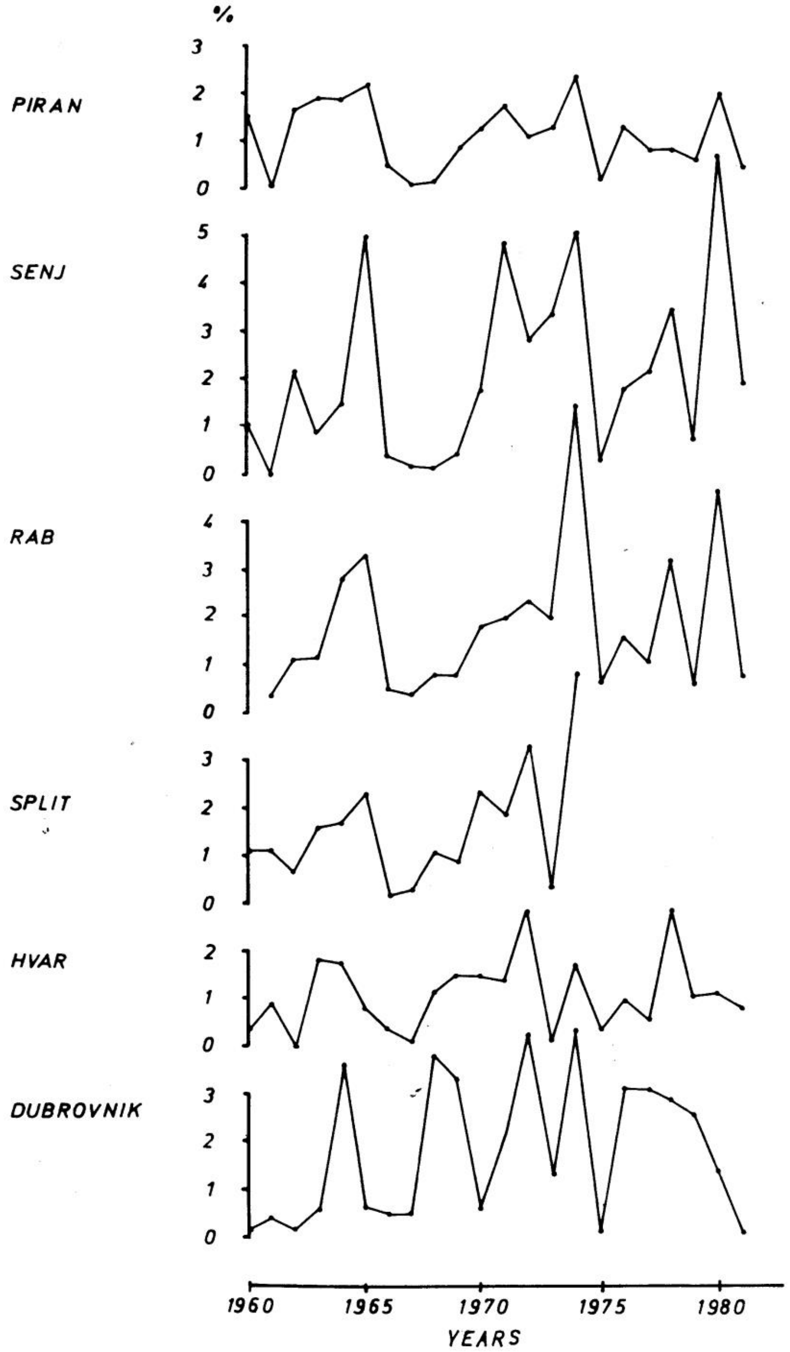

Figure 10. Percent variance contribution of the second harmonic to the SST annual cycle at six stations, between 1960 and 1981.

The year-to-year changes of all the parameters considered are obviously much smaller than the multi-year average values, and in some cases prove to be small even if compared with the spatial variations of the long-term averages. Consequently, careful attention should be paid to the results of the analysis of average annual variability. The most important conclusions can be summarized as follows:

(1) amplitudes of the first harmonic of the annual cycle are decreasing and its phases increasing if moving from the north to the south, from the coastal waters offshore;
(2) amplitude of the first harmonic is anomalously low at Senj, whereas the corresponding phase does not depart from the typical coastal values;
(3) at the Sv. Ivan station the spring/summer heating is significantly faster than the autumn/winter cooling.

In order to interpret these findings, one has to recollect that, in principle, SST depends on the heat fluxes at the air/sea interface, as well as on the advective/convective processes and mixing in the sea. Let us now look more closely at the three conclusions listed.

The spatial variability of the amplitudes and phases of the first harmonic is even more obvious if one compares results obtained here for the Adriatic Sea with those published by Levitus (1987) for the world oceans. Thus, the minimum amplitude in the Adriatic equals 5.4 °C, whereas the maximum amplitude in the open Atlantic is close to 4 °C. The maximum phase in the Adriatic is 7.5 months, i. e. much smaller than the value observed in the Atlantic at mid-latitudes (8 months). The fact that the annual variability of SST is more pronounced in the vicinity of coasts than farther offshore was recognized already by Boguslawski (1884). Krümmel (1907) supplemented this finding by noting that the phases of the annual cycle decrease in an onshore direction. Probably, the most persuasive evidence on the spatial variability of the amplitudes and phases of the SST annual cycle was presented by Dietrich (1953) for the European shelf waters. As for the Adriatic Sea, the differences in range and timing of SST between the coastal and offshore waters were noticed by Ercegović (1934) and Zore-Armanda (1969) in the vicinity of Split. The present results show that the phenomenon is observable all along the east Adriatic coast, and that it is primarily controlled by the autumn/winter cooling process. In part, its occurrence can be explained in terms of onshore-offshore differences in the exchange of heat between the atmosphere and sea (Colacino and Dell'Osso, 1975). However, response of the sea of variable depth to even an uniform forcing would also result in the cross-shore variability of both the amplitudes and phases (M. Orlić, unpublished results). Estimating the relative importance of the two mechanisms is obviously an interesting problem, which we plan to address in a future paper.

The fact that the summer SST is anomalously low close to Senj was already pointed out by Zore-Armanda (1969). She attributed the anomaly to submarine springs (called vrulje), which discharge cold waters originating in the littoral karst area, and are concentrated in the vicinity of Senj (Alfirević, 1969). However, it should be pointed out that the Senj station is anomalous also from the meteorological point of view: bora, cold offshore wind, blows there with the greatest speeds in the whole Adriatic (Yoshino, 1976; Smith, 1987), whereas sea and land breezes are not only rather strong but support an anticlockwise rotation of the wind vector as well (Orlić et al., 1988). Strong winds imply violent mixing, offshore winds support upwelling. Both processes would lead to a decrease of the summer SST in the Senj area. Obviously, a detailed quantitative analysis is needed to estimate the importance of the submarine springs when compared with the wind forcing. Irrespective of the outcome of such an investigation, it may be expected that the anomaly of the sea is reflected in the atmosphere above it. Consequently, Senj emerges as a potentially interesting site for a study of the atmosphere/sea coupling.

The finding that the Sv. Ivan station displays the greatest departure from the symmetry of the heating/cooling processes also deserves a brief comment. We are inclined to attribute it to the fact that Sv. Ivan is the station closest to the Po River mouth (Figure 1). In autumn/winter the Po plume is mostly confined to the western coast, in spring/summer it spreads to the eastern coast as well (e. g. Orlić, 1989). The presence of the Po-affected waters at the Sv. Ivan station would influence the heating process in at least two possible ways. Low-salinity waters in the surface layer would stabilize the water column, leading to a reduction of the amount of heat transferred from the surface to the bottom layer. Moreover, the surface layer would be heated by purely advective processes, because the Po waters are warmer than the ambient sea in spring and summer (Sturm et al., 1992). Both mechanisms would tend to speed up the heating process, more so at the stations which are closer to the Po River mouth.

It is of some interest to compare results obtained here for the eastern coast with the western coast data. We shall concentrate on a high-quality time series collected on a daily basis at Fano (Figure 1). Scaccini-Cicatelli (1975) published the Fano monthly means of SST for the 1970–74 interval, the same that was selected for the analysis of spatial variability along the eastern coast. The minimum SST occurs at Fano in January, i. e. much earlier than along the eastern coast, and is as low as 6.9 °C. Even the February average SST at Fano is lower than the eastern coast minimum (8.0 vs. 8.7 °C, Figure 4). The maximum SST occurs at Fano in August, and is very high (25.4 °C – about 1 °C greater than the simultaneous eastern coast maximum, shown in Figure 4). The differences between the two coasts are similar to those observed from shipborne measurements carried out in various years (e. g. Buljan and Zore-Armanda, 1976). Present results show that the differences represent a stable, climatological feature of the Adriatic Sea. The Fano SSTs appear to depart more from the Middle Adriatic than the North Adriatic values, which is not surprising bearing in mind that the surface circulation of the Adriatic Sea is dominated by a cyclonic meander (e. g. Orlić et al., 1992). Consequently, previously proposed interpretation of the summer and winter variability along the east Adriatic coast is also applicable to the cross-basin changes, with an important exception: the western coast is influenced by the Po River outflow not only in summer but in winter as well. This should help to explain the low winter temperatures recorded close to the western coast and the occurrence of the minimum SST as early as January.

Let us conclude by a few words on the high altitude remote sensing of SST. This technique bridges the gap between the shipborne and shore-based measurements, by providing data which are both space and time intensive. Until now, infrared satellite imagery has been used mostly to analyse particular realizations of the SST field (Philippe and Harang, 1982; Barale et al., 1984; Böhm et al., 1986; Bracalari et al., 1989; Kastanos and Ferentinos, 1991; Sturm et al., 1992; Orlić et al., 1992). The published results fit in the annual cycle of the SST patterns as deduced from *in situ* data, and also reveal some small-scale variability. The time is ripe for a climatological analysis of remotely sensed SSTs, with the aim of determining the annual cycle for the entire Adriatic Sea. When verified against the corresponding *in situ* information, the results should open the way to a more formal interpretation and modelling of the Adriatic temperature field.

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