ISSN: 0001-5113
AADRAY

ACTA ADRIAT.,
42 (1): 23-34, 2001

UDC: 551.502 (497.5 Split)
"1999/2000"
Preliminary report

The first year of the Automatic Metocean Station Split Marjan-Cape - Preliminary results

Branka GRBEC, Vlado DADIĆ, Damir IVANKOVIĆ,
Mira MOROVIĆ and Frano MATIĆ

Institute of Oceanography and Fisheries, P.O.Box 500, 21000 Split, Croatia

The equipment, measured data and retrieved parameters from the Automatic Metocean Station Split (AMOS) are described in details. Based on the one year data output (March, 1999 - February, 2000) from this station, basic statistics of various meteorological and oceanographic parameters (air humidity, air pressure, air temperature, precipitation, salinity, sea temperature, solar and net radiation, wind speed and direction) have been calculated.

In addition, the measured data were used for estimating the long-wave radiation, sensible and latent heat, using the bulk method. Errors due to undersampling of the calculated parameters were determined for different sampling intervals.

Key words: Automatic Metocean Station Split, Adriatic Sea, undersampling error

INTRODUCTION

Meteorological data, necessary for the exchange of properties above the sea, are different from those above the land. The characteristics of turbulence in the maritime area are determined by the temperature difference between the sea and air, wind speed and specific humidity. There are several meteorological stations on the coast in the Kaštela Bay, the most important are the Split Marjan and Split Airport. These stations are a part of the Meteorological and Hydrological Service of Croatia. However, these stations are situated on the land, and the acquired data are not representative for the mentioned boundary layer.

Therefore the data from the station situated above the sea, have a special meaning for studying the processes in the Bay, especially for defining boundary conditions for the dynamic model initialisation. The Institute of Oceanography and Fisheries has intention to maintain the station, named Coastal Oceanographic station Split Marjan-Cape, which has been operating since fifties. The data have been published in the Acta Adriatica series (BULJAN and ZORE-ARMANDA, 1966, 1976; ZORE-ARMANDA *et al.*, 1991). The data set has become long enough for studying the climatic variability, especially when assembled with other long-term data sets (ZORE-ARMANDA, 1972; MARASOVIĆ *et al.*, 1995; DULČIĆ and GRBEC, 2000). Long-term data set from our permanent station consisted of discrete measurements, acquired by the classical oceanographic and meteorological instrumentation and observations. In the framework of the UNESCO's Intergovernmental Oceanographic Commission (IOC) program GOOS (Global Ocean Observing System) automatic recording of oceanographic and meteorological measurements has become obligatory. Trying to keep up with the recent needs, advanced measurement techniques and data transmission methods have been introduced in addition to the classical metocean measurements.

Coastal oceanographic station Split Marjan-Cape

The Institute of Oceanography and Fisheries established the coastal oceanographic station Split Marjan-Cape, in 1946. It operates continuously since 1950, comprising the classical tide-gauge KEPMEN with 1:5 reductions. Sea temperature measurements are performed at 0 m and 2 m, with classic thermometer in first two climatological terms: at 7h and 14h local time. At the same time the state of the sea, current speed and direction, wind speed and direction are observed. Samples for the salinity determination are taken twice weekly. Meteorological station[1], established in 1951 (fixed meteorological screen and rain-gauge) is located 25 m inland form the sea at 12 m altitude. The thermograph (SIAP) measures continuously, while minimal, maximal and actual temperatures are recorded at 7h (local time), as well as daily precipitation sum. This station can be considered as a quasi-climatological station with respect to the WMO classification.

The Automatic Metocean Station Split Marjan-Cape

Based on the General Purpose Data Acquisition System, developed ten years ago (DADIĆ *et. al.*, 1990), the real-time data transmission has been realized in March 1999, through the Internet, from the experimental Automatic Metocean Station (AMOS). Station was mounted at the Split Marjan-Cape ("Punta Jurana"[2]), in front of the main building of the Institute of Oceanography and Fisheries, at the entrance of the Kaštela Bay (Fig.1).

AMOS is a station installed to measure conditions in the air and in the sea, so it has both types of sensors. Meteorological sensors measure temperature, air humidity, precipitation, air pressure, solar and net radiation, wind direction, wind speed and gusts. The wind speed and

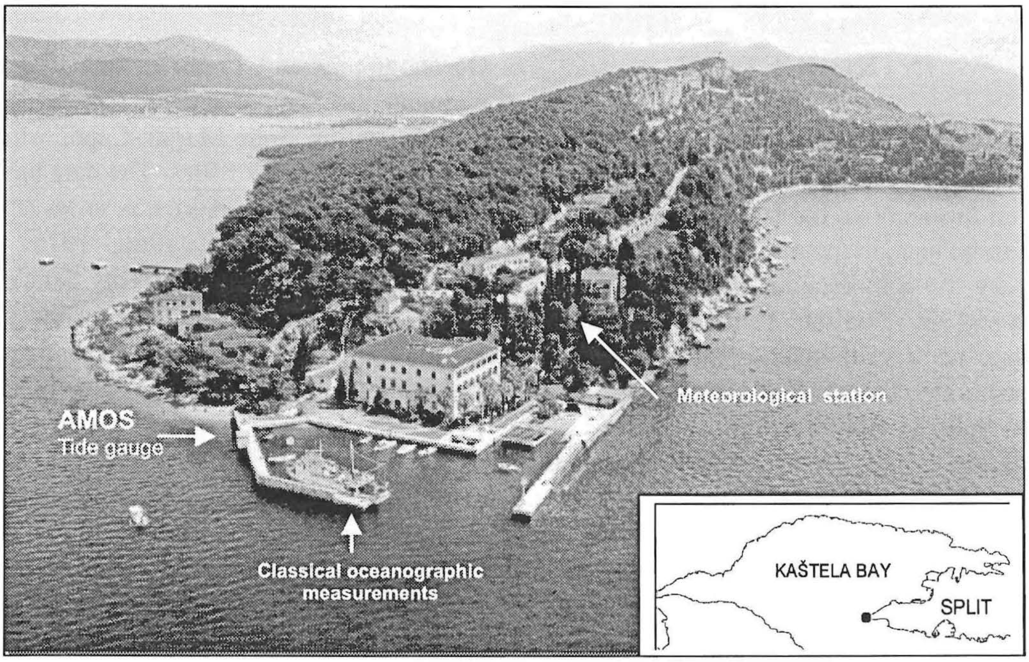

Fig. 1. Location of the station Split Marjan-Cape (fixed meteorological screen and tide gauge) and metocean station AMOS

[1] not according to WMO station classification

[2] "Punta Jurana" – historical name for the location Split Marjan-Cape

direction are measured continuously with respect to the sensors' response, and mean values in 10 min intervals are recorded. The wind gust, as used by the AANDERAA sensor descriptions (www.aanderaa.com) is the maximum speed in the 10 min interval, and not the gust in meteorological terms. All the other meteorological parameters are measured continuously with respect to the sensors response, and recorded every ten minutes. The three sea sensors measure sea temperature, salinity, and sea level. Due to the specific local topographic conditions, wind speed and direction are not always representative for the wider area.

All the sensors are products of the AANDERAA instruments, Norway. Specifications of the used AANDERAA sensors are listed in Table 1.

The station measurements started in January 1999, and since March 1999 the measured data are available 24 hours a day, on the Internet (DADIĆ and IVANKOVIĆ, 1999; IVANKOVIĆ, DADIĆ and SRDELIĆ, 2000). Prior to this station, along the eastern Adriatic coast there were no permanent measurements of global radiation, except in Trieste-Italy, although some sporadic measurements were performed in Hvar and Split (PENZAR and BRATANIĆ, 1979; PENZAR I. and B., 1991). The AMOS measures two radiation parameters: global and net radiation. The sensor for the global radiation measures global radiation (incoming solar and sky radiation) in the wavelength interval 0.3-2.5 μm. The sensor for the net radiation measures the difference between incoming and outgoing radiation, in the wavelength interval 0.3-60.0 μm.

All the measured data are sent in a digital form, directly to the database in the computer. This should enable also transferring data to regional and/or international data centers, from where they would be available to all interested users. Further modernization of the metocean station and the database, as foreseen in the Institute of Oceanography and Fisheries, shall comprise processing and quality control of the data, storing the data and products in the database, and dissemination of data and products (analysis and oceanographic forecasts) via the Internet Web.

The scope of this paper is also to complement the metocean station web site, and provide additional information about the methods for

Table 1. Specifications of the used AANDERAA sensors, mounted at the station Split Marjan-Cape

Sensor	Type[3]	Min. value	Max. value	Accuracy (FS-full scale)	Resolution
Air temperature	3455	-43 °C	+48 °C	±0.1% FS	0.091 °C
Wind direction	3590	0 °	360 °	± 5%	1 °
Wind (speed and gust)	2740	0 m/s	60 m/s	± 2%	20 cm/s
Air humidity	3445	0 %	100 %	± 3%	0.1 %
Participations	3064	0 mm	8mm/min	±0.1 mm	0.02 mm
Air pressure	2810	920 hPa	1080 hPa	±0.2 hPa	0.2 hPa
Net radiation	2811	-2000 W/m2	+2000 W/m2	± 1% FS	0.4 W/m2
Solar radiation	2770	0 W/m2	+2000 W/m2	± 20 W/m2	0.4 W/m2
Sea temperature	3210	-7.5°C	+41 °C	± 0.1 °C	0.05 °C
Salinity	3210	0 ‰	40 ‰	± 0.2 ppt	0.04 ppt
Sea level	3039	-5 m	+5 m	± 0.2 %FS	0.02 m

[3]denotes the original AANDERAA sensor specifications

heat flux calculations. There is a need to adequately study heat fluxes, because of their importance for air-sea interaction and for correct forcing of numerical models, for climatological studies, for inter-annual variability, etc.

MATERIAL AND METHODS

The data analysed in this paper comprise one year data output (March 1999-February 2000) from the Automatic Metocean Station Split Marjan-Cape (AMOS). Sea temperature and salinity were measured at 0.5 m depth and are considered the sea surface measurements. All the other parameters were measured at the 10 m altitude above the sea level. Measurements were acquired in ten minute sampling intervals. The mean hourly values have been calculated for the air temperature, wind speed, humidity, air pressure, precipitation, sea surface temperature and salinity. For all these parameters monthly means and corresponding variances were analyzed. The ten minutes values of relevant parameters were used for the surface heat flux estimation.

Measuring system of 11 various sensors is connected to AANDERAA Instruments Sensor Scanning Unit 3010. Sensor Scanning Unit 3010 is compact, electronic device for scanning and reading a set of AANDERAA sensors, and contains a 12 channel multiplexer, (one per parameter) an R-2R network, for analogue to digital conversion, and a digital control system, which includes a microprocessor. The R-2R network converts the sensor signal by successive approximation into raw data words in 10-bit binary code, which are fed to the PDC-4 (Pulse Duration Code of 4 seconds) and RS-232C output receptacles. Sampling intervals can be selected from 0.5 to 180 minutes, or single measurement cycle is performed on reception of remote triggering signal (5V positive pulse). Output signal on RS-232C port is ASCII coded decimals at 1200 baud, eight data bits, no parity and two stop bits. On the other side there is a common IBM compatible personal computer (Fig.2), with serial RS-232 port, connected to the local area network (LAN).

Both, measured and calculated parameters (such as net heat flux and its components) are displayed on the Web site (www.izor.hr).

Heat flux calculations

Total net heat exchange (Q_{TOT}) at the air-sea interface is the sum of irradiative (Q_R) and turbulent (Q_T) fluxes. The irradiative component of the heat flux comprises solar (Q_S) and upward long-wave (Q_L) component. Turbulent heat fluxes are sensible (Q_H) and latent (Q_E) heat flux. The total heat exchange was calculated using hourly values following the procedure found in GILL (1982), keeping in mind that Q_L was cal-

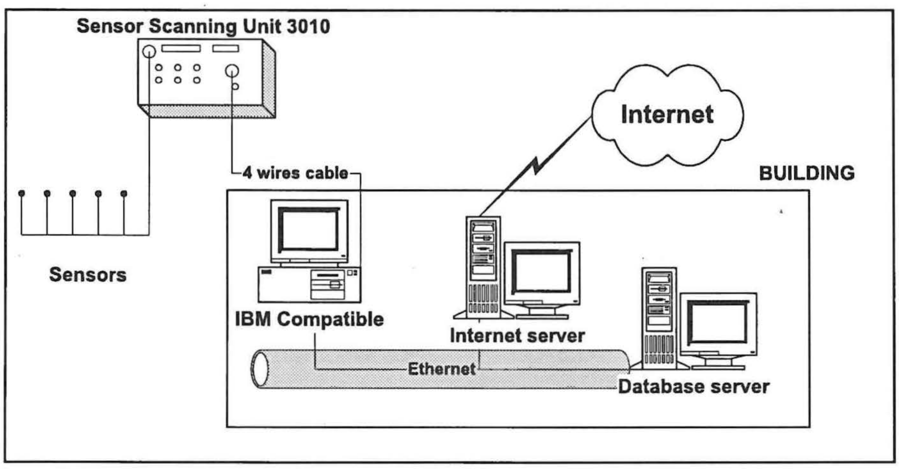

Fig. 2. Scheme of the AANDERAA Instruments Sensor Scanning Unit connection to the local area network (LAN)

culated indirectly using measurement values from the net radiation sensor.

$$Q_{TOT} = Q^R + Q^T \tag{1}$$

$$Q^R \begin{cases} Q_S = Q'_S(1-\alpha) \\ Q_L = -0.985\sigma\, T_w^4(0.39 - 005e^{1/2} \end{cases} \tag{2}$$

$$Q^T \begin{cases} Q_E = -LE \\ Q_H = C_H c_p \rho_a v(T_a - T_w) \end{cases} \tag{3}$$

In eg. 2, Q'_S is incoming short-wave radiation (measured values with sensor for short-wave solar and sky radiation) and = 0.08 is albedo of the sea surface, according to PAYNE (1972). In order to obtain the Q_L value, and because of lack of cloudiness data, instead of the bulk equation (2), measured values of net radiation Q_N were used. This kind of sensor (sensor number 2811) measures the difference between incoming and outgoing radiation at the surface, so the long-wave radiation was obtained as a difference between global (incoming solar and sky radiation) and net radiation; $Q_L = Q'_S - Q_N$ The meaning of other terms in equation (2 and 3) is as follows:

$C_H = 1.5\cdot10^{-3}$ → transfer coefficient

$c_p = 1010$ Jkg^{-1}K^{-1} → specific heat for air

$\rho_a = 1.25$kgm^{-3} → air density

v → wind speed

T_a and T_w → air and sea temperature.

The latent heat radiation (Q_E) represents the amount of energy gain/loss by evaporation. It is calculated using the equation (3), where the rate of evaporation changes is:

$$E = C_L \rho_a v(q_a - q_w) \tag{4}$$

while the q_a, q_w are measured specific and saturation humidity at the air and sea surface temperature, respectively.

Undersampling error

The heat fluxes were calculated in the three ways: $(Q_{TOT})^{10}$ - based on row data (from 10 min intervals); $(Q_{TOT})^d$ - based on daily means; $(Q_{TOT})^m$ - based on monthly means. These are listed in the table 2, together with the amount of error, calculated using the following formula:

$$error^j = \frac{\left|(Q_{TOT})^i - (Q_{TOT})^j\right|}{(Q_{TOT})^i}\cdot 100;$$

$$\begin{cases} i = 10, d \\ j = d, m \end{cases}, \quad i \neq j \tag{5}$$

There were some short measurements interruptions, due to electricity breakdown, or other malfunctions. In spite of occasional gaps and four breaks of measurements longer than a day and malfunctions of some sensors in some shorter intervals, the overall work of the Automatic Station Split Marjan-Cape could be considered successful.

RESULTS AND DISCUSSION

Based on the hourly values, monthly values for all the measured parameters (Fig. 3) were calculated. Relative humidity showed very high variability (Fig. 3a). The highest variability was observed from December 1990 to February 2000. It varied in the range from 25-90 %, while the mean value was 61%. Salinity ranged from 29.82 - 37.51 psu, showing occasionally strong pulses of fresh water in fall and winter months, discharged by the Jadro River into the Kaštela Bay. The longer duration of fresh water intrusions occurred in spring season. During the almost whole 1999, sensor for precipitation was most of the time out of work; so only the data for the period January–November, 2000 were plotted (Fig. 3b). Very high monthly precipitation sum occurred during November 2000 as a result of unusual weather conditions over Europe (SRNEC, 2000).

Output from sea level sensor was compared to the classical tide-gauge showing equivalent response of sea surface elevation (Fig.3c).

The sea surface daily mean temperature, compared to the daily mean air temperature showed that sea surface temperature was higher

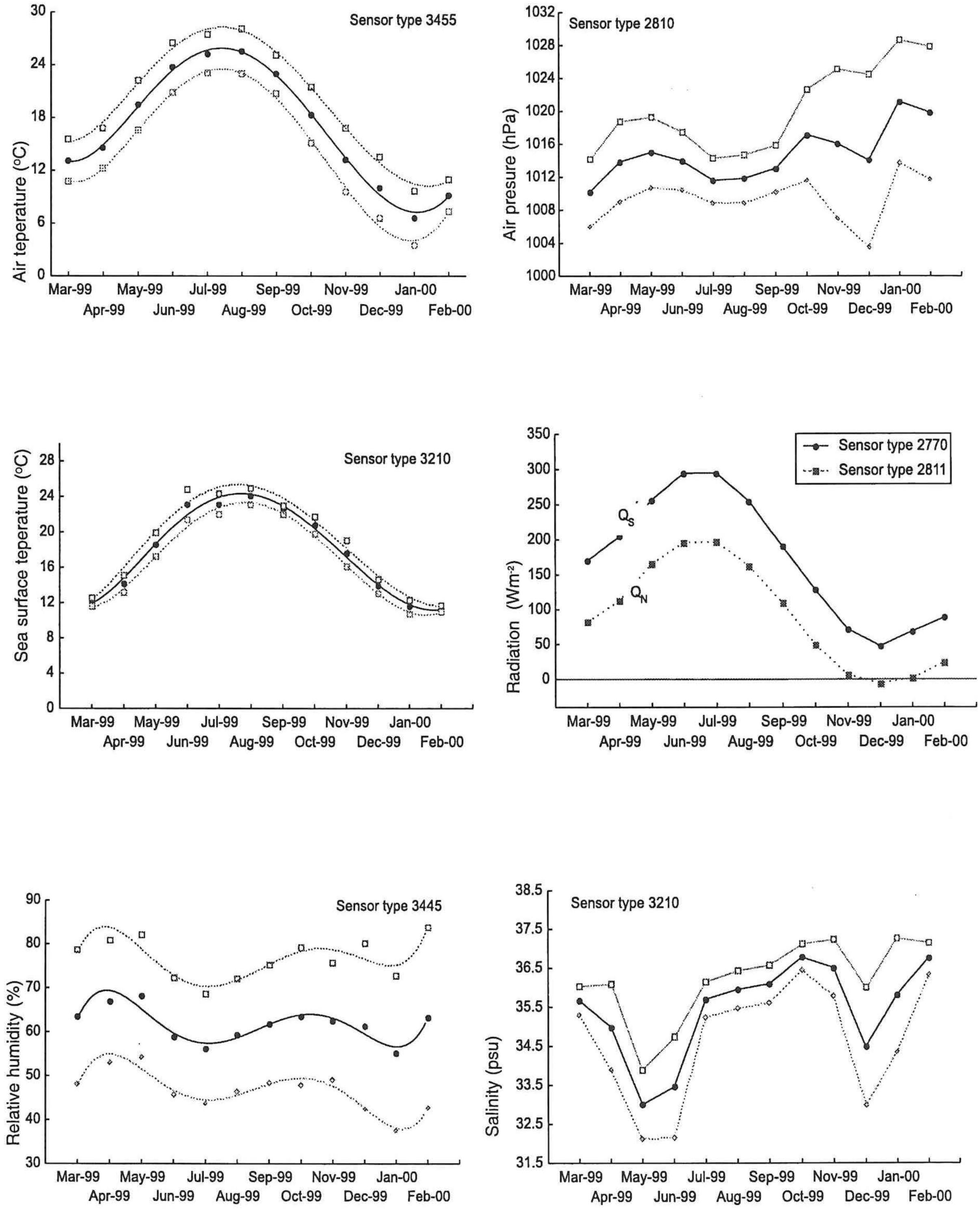

Fig. 3a. Monthly means and monthly variances for all the measured and calculated parameters at the AMOS, for the period March 1999 - February 2000

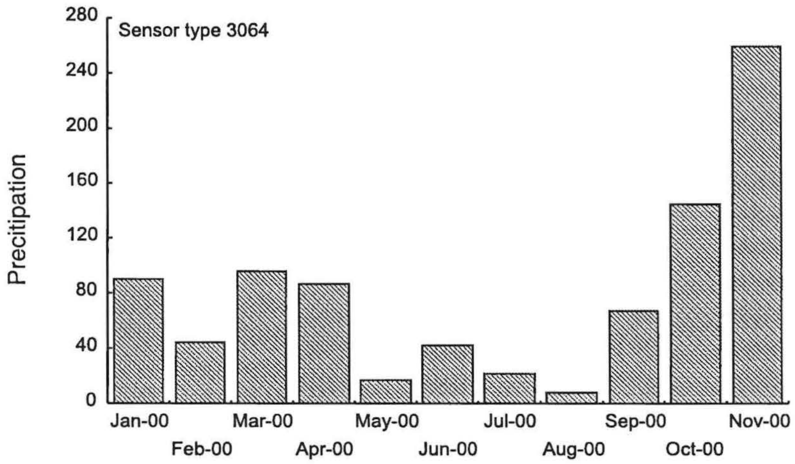

Fig. 3b. Monthly sum of precipitation for the period March 1999-February 2000

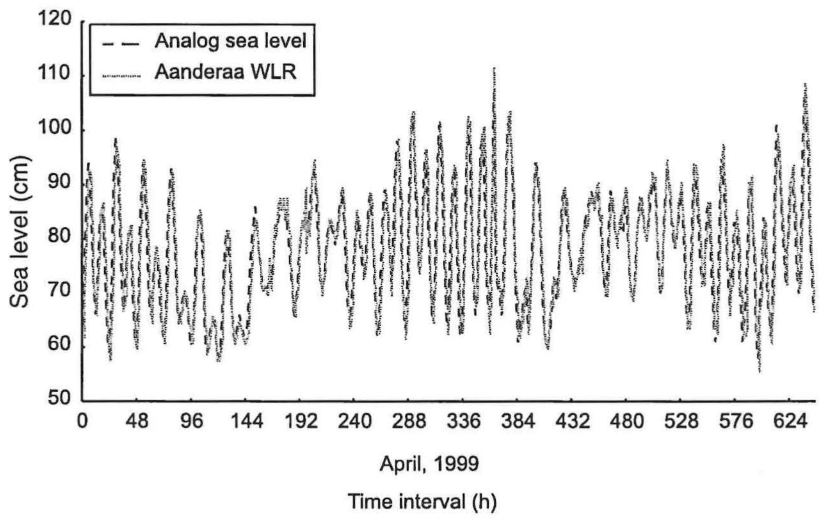

Fig. 3c. Sea level mean hourly values from classical tide gauge and from AANDERAA sea level sensor

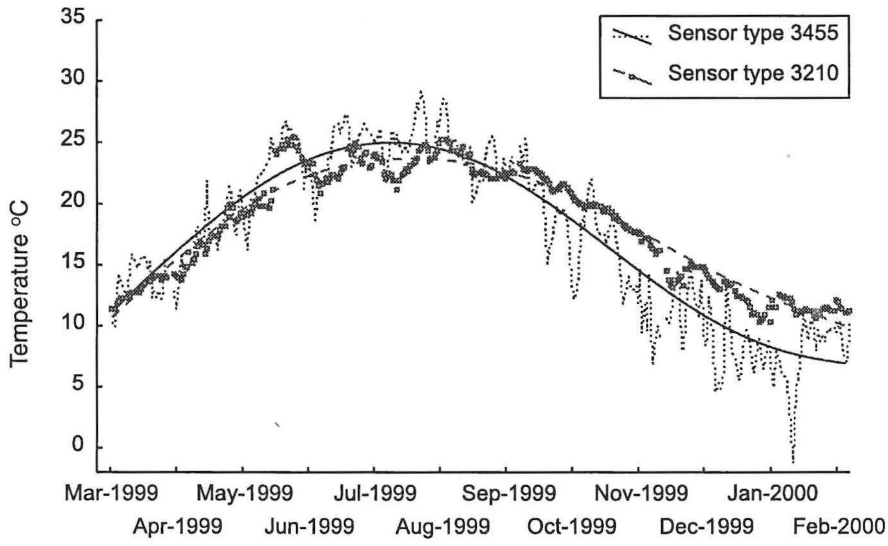

Fig. 4. Sea surface and air temperature daily means at the metocean station AMOS for the period March 1999 - February 2000 and the 3rd order polinomial fit (dashed lines)

from September through March, while air temperature was higher in the rest of the year (Fig. 4).

This reflects seasonal heating/cooling processes. The difference between the two temperatures was the highest in January, when it reached 5 °C. Temperature fluctuations within a month reached about 10 degrees for the air temperature, and not more than 5 degrees for the sea surface temperature.

Seasonal wind roses are shown in Fig. 5. The strongest winds (N and NE) were observed in winter season, however the direction from the north was predominant in all the seasons. It is rather peculiar that characteristic summer winds from W directions were not so energetic. The winds at this station from NE to SE direction can be somewhat reduced, due to the topographic barrier of the nearby Marjan Hill.

Global radiation (from solar and sky radiation sensor), showed seasonal maximum in June (Fig. 6), which is in accordance with theoretical

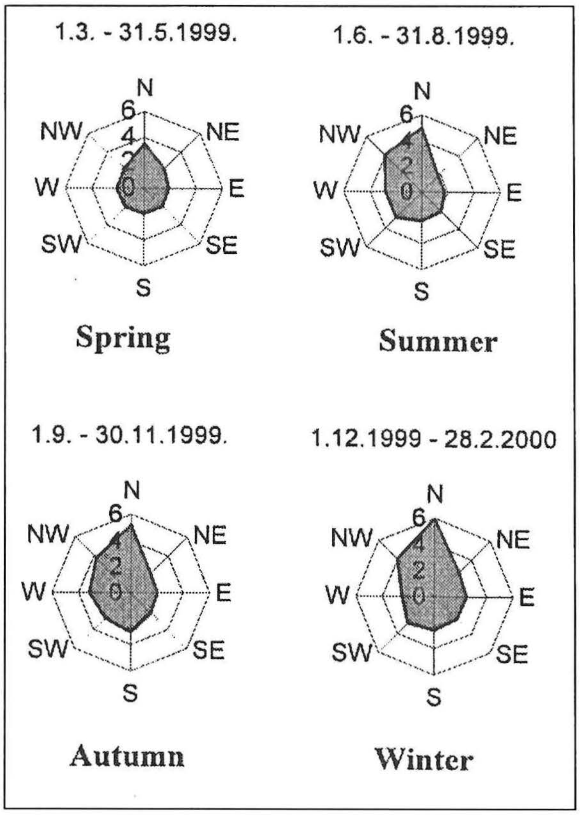

Fig. 5. Seasonal wind roses at the metocean station AMOS for the period March 1999 - February 2000

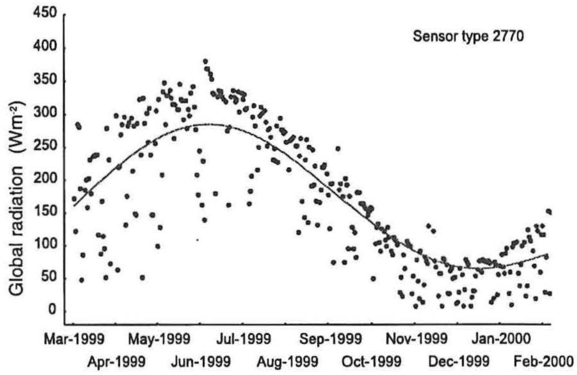

Fig. 6. Global radiation (W m^{-2}) *daily means at the metocean station AMOS for the period March 1999 - February 2000 and the 3rd order polinomial fit (solid line)*

maximum at summer solstice (172nd Julian day). Fluctuations of global radiation from day to day were the largest in the period from March to June. This can be probably connected with the low persistence of cyclonic weather conditions, since generally the persistence of anti-cyclonic weather is longer, because of its physical properties than the persistence of cyclones. The spring months have the lowest persistence of cloudy and cloudless days exchange which has direct consequence to amount of global radiation (GRBEC, 1989).

At this station the sea receives 25.67 W m^{-2} annually, while the annual loss of heat caused by long-wave radiation, evaporation and conduction is 80.44 Wm^{-2}, 61.33 Wm^{-2}, and 3.2 Wm^{-2}, respectively. The sea loses the largest amount of heat in November (102.4 W m^{-2}), and in July it receives maximum. Comparing these data with the data found in literature (PICCO, 1991; SUPIĆ, 1993; GRBEC and MOROVIĆ, 1997), it is evident that for different stations, although from the same geographic area, different heat fluxes were obtained.

For determination of individual components of thermal equilibrium, the selection of formulae is very important and the discrepancies depended upon the selection of formulae used for calculation. Different results obtained using different input values can be also the reason for discrepancies, as a result of undersampling. In order to demonstrate how large can be these differences on the seasonal scale, different input values of heat fluxes, based on 10 min intervals, daily means and monthly means were used. The total heat fluxes calculated using the formule (1-4), together with the amount of error, calculated using the formula (5), are listed in the Table 2.

The fluxes calculated from 10-min intervals, daily means and monthly means are presented in Fig. 7. Heat loss due to evaporation (calculated from daily means or 10min intervals) was higher from March to September, and in January, than in the other months. However, the values were negative, reflecting that the heat loss due to evaporation was present all the season. This shows that, calculating with monthly means, we may overestimate the heat loss due to evaporation, up to 10 % in June, or less in other months. From March to September, sensible

Table 2. Errors (%) according to eq. 5 calculated from 10 minute intervals relative to the daily means *(error)d and, from daily means relative to the monthly means* (error)*m, and heat fluxes (Wm^{2}) calculated using different measurement* intervals: $(Q_{TOT})^{10}$, $(Q_{TOT})^{d}$, *and* $(Q_{TOT})^{m}$

	$(Q_{TOT})^{d}$	$(Q_{TOT})^{m}$	$(Q_{TOT})^{10}$	$(\text{error})^{d}$	$\text{error})^{m}$
March	39.14	55.56	54.61	28.33	1.74
April	77.86	80.37	78.12	0.33	2.89
May	131.42	133.13	131.39	0.02	1.33
June	108.03	115.31	108.08	0.05	6.69
July	132.35	133.46	132.37	0.01	0.82
August	98.17	101.18	97.59	0.59	3.68
September	43.83	45.48	43.01	1.89	5.72
October	-27.36	-28.58	-27.36	0.00	4.45
November	-102.37	-101.89	-98.93	3.47	2.98
December	-84.86	-86.84	-84.86	0.00	2.34
January	-80.44	-76.84	-80.44	0.00	4.47
February	-27.72	-26.58	-27.72	0.00	4.12

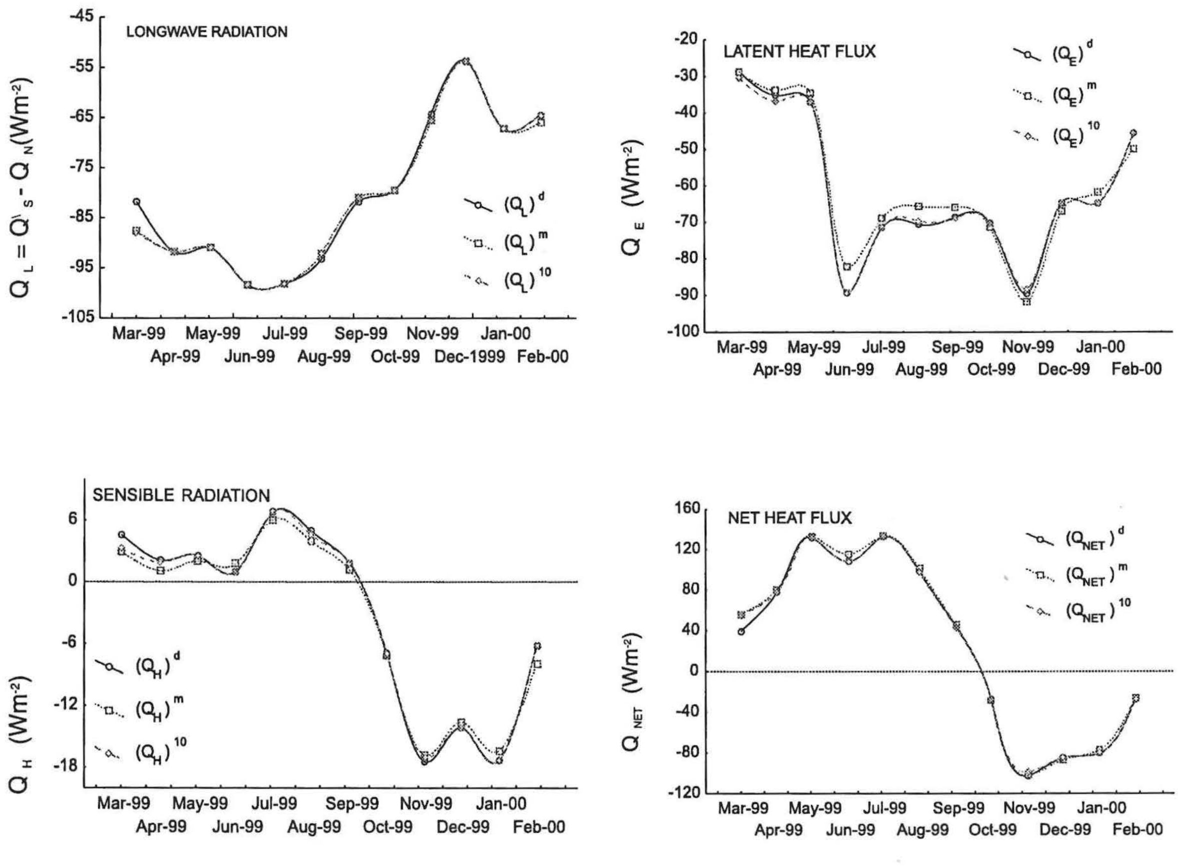

Fig. 7. Monthly mean a) global radiation, net radiation and long wave radiation fluxes, calculated from hourly means; b) monthly mean flux lost/gained by evaporation and conduction calculated from hourly means at the metocean station AMOS for the period March 1999 – February 2000

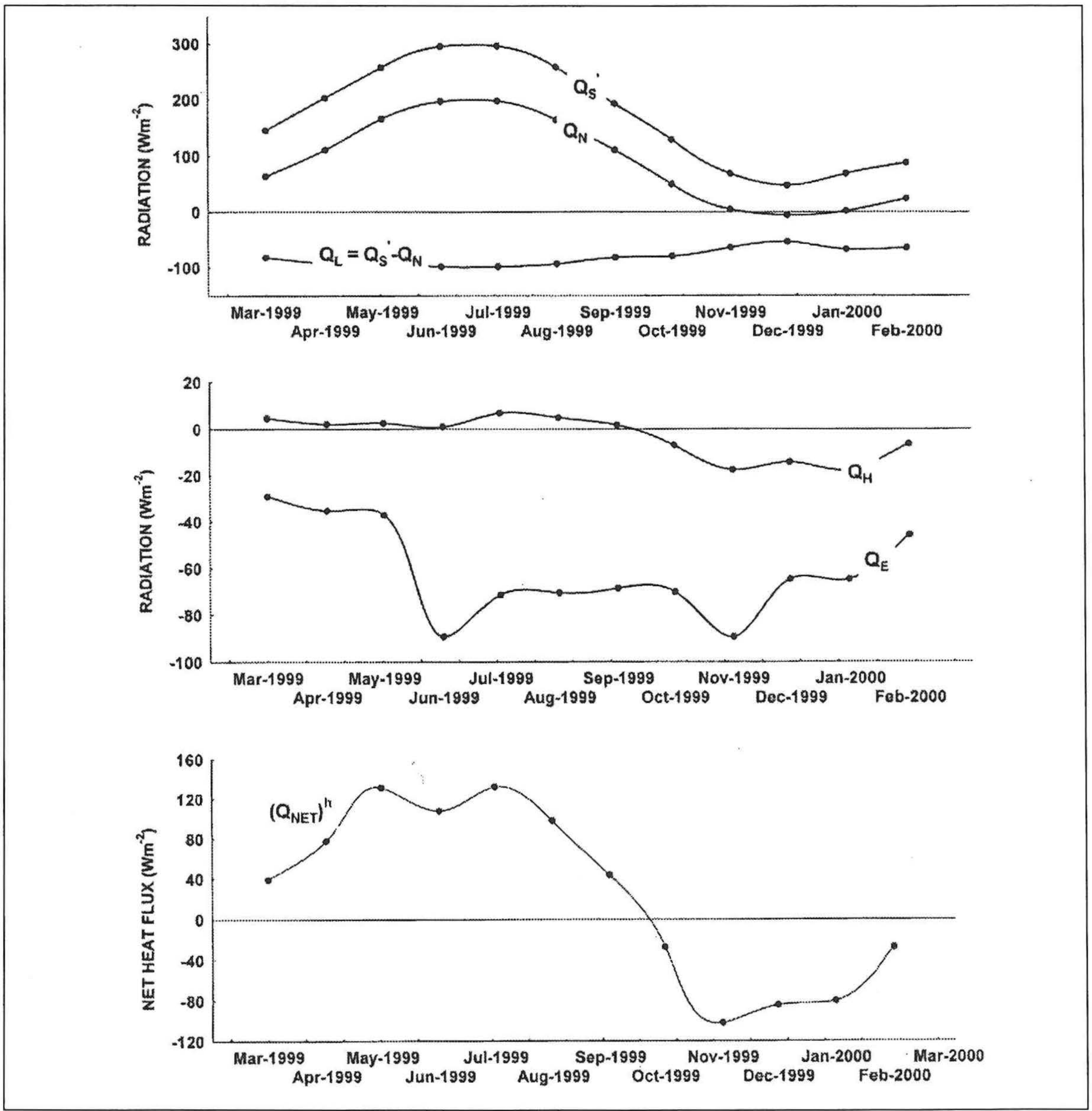

Fig. 8. Monthly mean heat fluxes, calculated from hourly means, at the metocean station AMOS for the period March 1999 - February 2000

heat flux is positive, and the rest of the year negative. Maximum values are reached in July and minimum in November and January. In March, the heat gain due to conduction, calculated from daily means, showed highest departure from the conduction calculated from monthly means, or from 10 min intervals.

Heat loss due to long-wave radiation was highest in June, and lowest in December. Only in March, the difference between the values calculated from daily means and others was considerable, and showed about 10 % difference. Resulting heat budget (Fig. 8) shows that the sea looses heat from October to February and gains heat from March to September. The only considerable departure between the results if different averaging is considered was in March, when daily mean values resulted in lower heat gain. From the climatological point of view, it seems that daily values are good enough for heat flux calculation.

CONCLUSIONS

The statistical analysis, based on hourly values of all parameters, calculated for the first time for a station at the eastern Adriatic coast, matches with previous studies along the eastern Adriatic coast on the monthly scale. Global and net radiations were measured with the error 20 Wm^{-2}, while all other parameters were measured with the error neglectable in respect to those originating from the bulk equations.

The importance of the historical datasets from this station (classical measurements started in 1948), enable investigation of the climatic variability. The station, situated at the entrance at the Kaštela Bay has a special meaning for studying the processes in the Bay.

Since continuous measurements of relevant parameters minimize the undersampling error, which is important for better understanding of dynamical processes, it is essential to establish more automatic stations along the coast and at the open sea.

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Accepted: 23 February 2001

Prva godina rada automatske meteo–oceanografske postaje Split Rt-Marjana - preliminarni rezultati

Branka GRBEC, Vlado DADIĆ, Damir IVANKOVIĆ, Mira MOROVIĆ i Frano MATIĆ

Institut za oceanografiju i ribarstvo, P.P. 500, 21000 Split, Hrvatska

SAŽETAK

U radu su detaljno opisani mjerni instrumenti, mjereni i izračunati parametri s automatske meteorološko-oceanografske (AMOS) postaje smještene na rtu Marjana. Na osnovi podataka nakon prve godine mjerenja (ožujak 1999-veljača 2000) određene su osnovne statističke veličine meteroloških i oceanografskih parametara (relativne vlage, tlaka zraka, temperature zraka, oborina, saliniteta, temperature mora, razine mora, sunčevog i neto zračenja, smjera i brzine vjetra). Osim toga, prikazan je i način izračunavanja komponenata toplinske bilanse. Diskutirana je pogreška izračunatih parametara uzrokovana različitim intervalima mjerenja.