Physical oceanography in Croatia, 1995 – 1998

Report submitted to the International Association for the Physical Sciences of the Ocean of the International Union of Geodesy and Geophysics

Between 1995 and 1998 the physical oceanographic research in Croatia has been carried out mainly in the following institutions: Institute of Oceanography and Fisheries, Split; State Hydrographic Institute, Split; Center for Marine Research, Rudjer Bošković Institute, Rovinj and Zagreb; and Andrija Mohorovičić Geophysical Institute, Faculty of Science, University of Zagreb.

Altogether, 19 investigators (9 PhD's, 9 MSc's and 1 BSc), supported by a modest technical staff, were involved in the research. Three research vessels (*Bios*, *Hidra*, *Vila Velebita*) were used in the field work, *RV Andrija Mohorovičić* being employed for other purposes. The oceanographic equipment included several CTD probes and thermistor chains, a number of current meters, wave and tide gauges. Most institutions had a local computer network with a mainframe computer and/or a series of personal computers, connected to INTERNET through CARNET (Croatian Academic Research Network). MEDAS (Marine Environmental Database of the Adriatic Sea), a GIS system based on ORACLE RDBMS and ARC/INFO software tools, was used at Split to store various oceanographic data. At Rovinj, a hydrographic data bank, based on the PARADOX 8 program package, was regularly updated.

During the four-year interval considered some previously established measurement programs were maintained and some new were started. Thus, hydrographic data were collected on a monthly or seasonal basis all along the eastern Adriatic coast, as well as along some cross-shore transects (Rovinj-Po, Split-Gargano). This work was intensified somewhat in the mid 1998, when a national project "Adriatic" was launched. Current measurements were performed, mostly on the short-term basis, in the framework of various research (Velebit Channel) and hydrotechnical programs (Pelješac Channel, Brač and Split Channels, Šibenik Archipelago, Zadar Archipelago). Tide-gauge measurements were continued at a network of six permanent stations (Rovinj, Bakar, Zadar, Split-Marjan, Split-Harbour, Dubrovnik). Sea surface temperature was measured daily at a number of coastal stations. Moreover, automatic meteo-oceanographic station, comprising the air and sea temperature, salinity, air pressure, wind, humidity, precipitation and global radiation sensors, was installed at Split-Marjan towards the end of 1998.

Over the preceding four years Croatian institutions participated in several national programs and projects, in bilateral programs (with the Italian and American partners), and in a few projects supported by international organizations (UNEP, IGCP). Croatian physical oceanographers also took part in the IOC assemblies, GOOS and GODAR meetings, as well as in a number of scientific conferences and workshops.

The work done is documented in the publications the list of which is attached to this report. The list contains scientific papers, conference communications published *in extenso*, books and theses. More attention than before was paid to fluxes

across the air-sea interface. Grbec and Beg-Paklar (1995) and Grbec et al. (1997) estimated evaporation for Trieste, using three different bulk formulae. Results were compared to evaporation measured at Trieste, and the most suitable formula was used to calculate long-term fluctuations and trends for several stations distributed along the Adriatic coast. Discussing seasonal cycle of surface heat flux computed on the basis of a 6-year time series of monthly means of meteorological and SST data, Supić et al. (1997) documented the small-scale spatial variability in air-sea heat flux over the northeastern Adriatic. Using a more extensive data set (27-year time series of monthly means) and performing a detailed error analysis Supić and Orlić (1999) reexamined the finding and discussed long-term changes (1966–1992) in surface heat, water and buoyancy fluxes in the region. Pasarić and Orlić (1998) considered momentum transfer across the sea surface. They found that the relationship between smoothed wind stress calculated from hourly wind data and the wind stress calculated from smoothed winds is linear, and proposed a method of estimation of smoothed stress based on the linear regression.

A number of papers were published on the open Adriatic hydrography and current field variability. Leder et al. (1995a) described seasonal changes in the Otranto Strait by analysing STD and current data collected in 1989 and 1990. An analysis of current-meter records collected in the Palagruža Sill area was performed in the paper by Leder et al. (1996). They found the currents in the surface layer directed westwards, while in the bottom layer a vein of dense water was found leaving the Jabuka Pit and entering the South Adriatic Pit. Temperature and salinity data taken at the Split-Gargano transect over several decades were considered in a series of publications (Grbec, 1996, 1997; Grbec and Morović, 1997; Grbec et al., 1998c, 1998d). Thermohaline fluctuations were described in terms of the principal component scores and, in addition, were compared to the heat and water fluxes at the air-sea interface. Vertical fluxes of heat and salt, compared to the rate of change of heat and salt content, pointed to the season with important advection effects. Vertical exchange prevails in the cold season, whereas horizontal exchange is considerable in the warm period. To describe the advection mechanism additional attention was paid to the pressure field, by analysing frequency of cyclones and anticyclones over a larger area (70W-40E and 20N-80N). Advection mechanism appears to be related to the distribution of the large-scale (extending from Atlantic to Europe) low and high pressure centers. It seems that a northeastward shift of cyclones increases zonal pressure gradients, which enhance salt water advection from the Mediterranean into the Adriatic. Furthermore, Grbec et al. (1998a) studied vertical eddy exchange coefficients in the surface layer in the middle Adriatic using a one-dimensional model (which incorporates Mellor and Yamada Level II closure scheme). Dadić and Grbec (1995) described MEDAS database, and presented some long-term sets of oceanographic parameters stored in it.

A series of papers were published in the framework of an ecological study of gas field in the northern Adriatic (Bone, 1996; Leder and Morović, 1996; Morović et al., 1996a; Zore-Armanda et al., 1996). Seasonal variability of the area was examined using meteorological as well as temperature, salinity, transparency, color and turbidity data collected in the 1911–1986 interval. Moreover, current measurements performed between 1978 and 1986 from a platform positioned in the IVANA and IKA gas fields were statisctically processed and analysed in relation to the various components of circulation. Finally, a non-linear levels model was applied in order

to describe the Bora and Sirocco driven currents in the case of stratified sea. Brana and Krajcar (1995) considered long-term current measurements in the northern Adriatic and showed that at a station off Pula currents are of different direction in late summer and early autumn than during the rest of the year. Brana et al. (1996) analysed sea response to the spatially variable Bora forcing, by comparing the daily averaged time series of direct current measurements performed in the northeastern Adriatic in winter 1992/1993 with the corresponding daily averages of wind speed and air-sea fluxes computed from coastal meteorological data. Seasonal variability of the inertial oscillations and their decay time was investigated and related to seasonal changes in stratification of the water column by Krajcar and Orlić (1995). Supić et al. (1995) described hydrographic conditions in the northern Adriatic in 1994. Suitability of the use of monthly measurements of hydrographic parameters in the northeastern Adriatic while performing an analysis of interannual variability was discussed by Supić and Degobbis (1998).

Coastal oceanography is a discipline that plays a significant role in the investigations. Leder et al. (1998b) showed that in winter a considerable exchange of water occurs between the Rijeka Bay and Vinodol Channel. Leder et al. (1998a) described wind-driven currents in the Zadar and Pašman Channels by analysing both the empirical and theoretical findings. Using the same data set Vilibić (1998a), Vilibić et al. (1998b) and Vilibić and Orlić (1999) analysed surface seiches and internal Kelvin waves, and reproduced the observations analytically and numerically by applying radiation condition in the sound area positioned in the middle of the channel. Current fluctuations in the Mljet Island area were investigated by Leder et al. (1995c). Beg-Paklar and Gačić (1997) analysed the effect of winds on current field of the Kaštela Bay, using data collected during four current measurement experiments between 1982 and 1990 as well as corresponding wind data originating from nearby meteorological station Split-Marjan. Beg-Paklar and Grbec (1995) supplemented the empirical findings with simulations performed with Princeton Ocean Model; the best agreement between measurements and numerical model results was obtained for a station in the bay centre. Smirčić et al. (1995) considered the hydrography of the Baćina Lakes, placed close to the sea and prone to the salt water intrusion. Leder at al. (1995b) and Leder et al. (1997) described the criteria necessary when the bottom sewage outfalls are planned by analysing STD and current data collected along the eastern Adriatic coast. Finally, Smirčić et al. (1998c) described the diffusion experiment performed in the Split harbour and used a simple analytical model to investigate the diffusion.

Experience gained while analysing physical phenomena in both the open Adriatic and coastal waters was on several occasions usefully employed in the study of biogeochemical processes. Viličić et al. (1995) described the influence of hydrography and currents on the distribution of phytoplankton in the Strait of Otranto. Marasović et al. (1995) paid particular attention to a sudden and prolonged increase in primary production that started in 1978. This increase was found to be related to the enhanced advection of the Mediterranean waters (richer in nutrients) into the Adriatic, and this in turn could be attributed to global climate changes. Morović (1995) and Morović et al. (1996b) analysed spatial and temporal distribution of surface chlorophyll from the open Adriatic CZCS data. The techniques otherwise used for multifractal analysis of landscapes were applied in the study of scaling properties of the satellite chlorophyll fields. It was concluded

that inconsistency between the satellite and *in situ* chlorophyll, which is partly due to the modest sensor spatial resolution, could be improved in the future by taking the scaling studies into consideration. In the paper by Požar-Domac et al. (1998) the results of the interdisciplinary project, which was launched in order to conserve the Silba area, were presented. Grbec et al. (1998b) considered extremely high (low) sea surface (sea bottom) temperature recorded along the eastern Adriatic coast in summer 1992. Some evidences were found that such thermal conditions had caused the absence of the *Gonyaulax polyedra* red tide bloom.

Sea level also attracted interest of Croatian physical oceanographers over the preceding four years. Vilibić and Leder (1996) examined long-term variations of the Mediterranean sea level by performing spectral analysis on seven longest tide-gauge records as well as on the air pressure and temperature data and by considering the relationship between the atmosphere and sea at the periods greater than two years. In order to explain possible influence of climatic changes on the oceanographic properties of the Adriatic Sea, available historical datasets (sea level and meteorological ones) were studied by Grbec (1997). It was concluded that changes in the air pressure account for a significant part of the low frequency sea-level changes. Orlić (1995) investigated the relative sea-level changes on the basis of monthly mean sea levels registered at Rovinj, Bakar, Split and Dubrovnik over the forty odd years. It was found that three processes are at work in the Adriatic: (a) global sea-level rise, (b) regional sea-level change, and (c) local tectonic movements. Vilibić et al. (1997) examined monthly sea levels recorded at Split between 1955 and 1995 and detected anomalous periods induced predominantly by the air pressure anomalies. Moreover, they determined the trends, mean annual course and significant oscillations of sea level. Variations of annual (Sa) and semi-annual (Ssa) tides and their relation to the air pressure over the 1986–1995 interval were considered by Vilibić (1998b).

Pasarić and Orlić (1998) examined low-frequency ($0.01 \text{ cpd} < f < 0.1 \text{ cpd}$) variability of the air pressure, wind and sea level originating from three locations along the east Adriatic coast. It was found that in the southern, deeper part of the Adriatic the sea-level slope is fully explained by isostatic adjustment to the air pressure gradient, whereas over the shelf it is considerably affected by the action of wind. Vilibić et al. (1996a) analysed the records collected at tide gauges situated in the open middle Adriatic. Furthermore, Vilibić et al. (1998a) investigated simultaneous records originating from nine tide gauges and described the tidal, surge and seiche activity in the Adriatic. A similar study was performed for the Bakar station alone (Vilibić et al., 1998c). Cerovečki et al. (1995, 1997) analysed twelve seiche episodes recorded in the Adriatic between 1963 and 1986, determined their free decay time, and interpreted it in terms of the influence of bottom friction and of energy loss to the Mediterranean. The results of the theory of extremes being applied to the annual maximum and minimum sea levels collected at various tide-gauge stations were documented in the papers by Vučak (1996) and Vilibić et al. (1996b).

Wind waves were examined in the southern (Smirčić et al., 1998a), middle (Smirčić and Leder, 1996) and northern (Smirčić et al., 1996, 1998b) Adriatic. On the basis of ten-year measurements, these authors found that the maximum measured surface waves occur in the northern Adriatic due to the Sirocco wind which has the longest fetch there. Maximum measured wave height was found to equal 10.8 m,

whereas the extreme wave height for a return period of 100 years was estimated, using the theory of extremes, at approximately 14 m.

While most of the work done by Croatian researchers concerned the Adriatic and Mediterranean Seas, some attempts were made at more general topics as well. Orlić (1996) developed a simple conceptual model of density distribution and currents generated by the surface and coastal buoyancy flux in a land-locked basin. The model predicts cross-shore density gradients, coast-to-surface directed hydraulic flow, and thermohaline circulation characterized by upwelling (downwelling) along the coasts and downwelling (upwelling) prevailing over the greater part of the basin. Due to deflecting influence of the Coriolis force, long-shore currents are generated as well, both barotropic (related to the hydraulic effect) and baroclinic (connected with the thermohaline circulation). Limić and Pasarić (1996, 1997) investigated transport of substance in random velocity field. Velocity fluctuations were defined by means of Gaussian random fields, having covariances that are continuous functions of time and space variables. The obtained transport models generalize the conventional transport model defined by means of the diffusion-advection equation.

Over the past four years several Adriatic-related topics were reviewed by Croatian investigators. Kuzmić and Orlić (1995) considered a decade of classical oceanographic and remote sensing research of the Adriatic. The review demonstrated the researchers bias towards general circulation problems, and lack of mesoscale oriented studies. The analysis of the remote sensing papers revealed prominence of algorithm development and testing work, and again surprising lack of interest in mesoscale dynamics. In a more recent paper Kuzmić (1998) assessed the remote sensing contributions to physical oceanography in general and to Adriatic oceanographic research in particular. Boicourt et al. (1998) made an effort to explore circulation processes of the northern Adriatic and Chesapeake Bay, motivated by a shared environmental concern and the fact that transport processes exert a significant measure of control over marine nutrient cycles. Despite obvious differences between the two systems a closer examination revealed some similarity in the circulation controls and nutrient pathways. The enclosed nature of both basins allows free oscillations and a suite of constrained circulations, whereas in both cases nutrients are delivered from a primary source into an elongated water body whose geometry helps it insulate from the adjacent sea.

Finally, attention was paid to the history of the Adriatic physical oceanography. Zore-Armanda (1996, 1998) overviewed research performed between 1880s and 1980s. She pointed out that between the two world wars oceanography had recessed in Croatia, most probably due to the political and/or military interests interfering with marine investigations. Orlić (1997) paid attention to the important role the early Zagreb scientists had in the development of the Croatian oceanography. One of the results of their activity was operation of tide-gauge station at Bakar for seven decades; the data collected and their use in about forty scientific papers was documented by Orlić and Pasarić (1998). Another result was foundation of the Institute of Oceanography and Fisheries in Split, whose 65th anniversary was marked by appearance of a lavishly illustrated book (Zore-Armanda and Alajbeg, 1995). Last but not least, Zore-Armanda (1997) published her reminiscences of more than forty years spent in physical oceanographic research of the Adriatic and

recollected the empirical work which had evolved from the use of water bottles, reversing thermometers and an Ekman current meter to the predominance of CTD probes and Aanderaa instruments.

Overall, the level of scientific activity of Croatian physical oceanographers in the 1995–1998 interval seems to be quite similar to that achieved during the four-year interval preceding it and described in the previous report to the International Association for the Physical Sciences of the Ocean*. A novelty is the intensive study of fluxes across the air-sea interface, which proved to be of paramount importance for a proper understanding of physical processes in the Adriatic. Otherwise, the research interests did not change, being constrained by the available research vessels and oceanographic and computing equipment which did not much improve over the last four years.

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List of publications

Beg-Paklar G. and B. Grbec (1995): Numerical model for the wind induced currents in the Kaštela Bay, *Rapports et proces -verbaux des reunions CIESMM*, **34**, 169.

Beg-Paklar G. and M. Gačić (1997): The wind effect on the Kaštela Bay current field, *Acta Adriatica*, **38 (2)**, 31–43.

Boicourt W.C., M. Kuzmić and T.S. Hopkins (1998): The inland sea: Circulation of Chesapeake Bay and Northern Adriatic, In: *Ecosystems at the Land-Sea Margin: Drainage Basin to Coastal Sea* (Eds. T. C. Malone, A. Malej, L. W. Harding, N. Smodlaka and R. E. Turner), Coastal and Estuarine Studies, Volume 55, American Geophysical Union, Washington, pp. 81–130.

Bone M. (1996): Ecological study of gas fields in the northern Adriatic – 5. Numerical modelling of the Bora and Scirocco driven currents, *Acta Adriatica*, **37(1/2)**, 69–83.

Brana J. and V. Krajcar (1995): General circulation of the northern Adriatic – Results of the long-term measurements, *Estuarine, Coastal and Shelf Science*, **40**, 421–434.

Brana J. H., V. Krajcar, D. Morožin and N. Supić (1996): Circulation and heat exchanges of the Northern Adriatic in the winter season 1992/93, *Il Nuovo Cimento C*, **19**, 427–444.

Cerovečki I., M. Orlić and M. C. Hendershott (1995): Adriatic seiche decay and energy loss through Otranto Strait, *Rapports et proces-verbaux des reunions CIESMM*, **34**, 172.

Cerovečki I., M. Orlić and M. C. Hendershott (1997): Adriatic seiche decay and energy loss to the Mediterranean, *Deep-Sea Research I*, **44**, 2007–2029.

Dadić V. and B. Grbec (1995): Marine environmental data base of the Adriatic sea (main results from time series analysis), *Rapports et proces-verbaux des reunions CIESMM*, **34**, 174.

Grbec B. and G. Beg-Paklar (1995): Evaporation problem and long-term variability in the coastal area, *Rapports et proces-verbaux des reunions CIESMM*, **34**, 181.

Grbec B. (1996): *Climatic changes and their influence on oceanographic properties of the Adriatic* (in Croatian), Ph. D. Thesis, Faculty of Science, University of Zagreb, 154 pp.

* M. Orlić (1994): Physical oceanography in Croatia, 1991–1994, *Geofizika*, **11**, XXXIX-XLIV.

Grbec B. (1997): Influence of climatic changes on oceanographic properties of the Adriatic Sea, *Acta Adriatica,* **38 (2)**, 3–29.

Grbec B. and M. Morović (1997): Seasonal thermohaline fluctuations in the middle Adriatic Sea, *Il Nuovo Cimento C*, **20**, 561–576.

Grbec B., G. Beg-Paklar and M. Morović (1997): On the evaporation problem over the Adriatic Sea, *Acta Adriatica,* **38 (2)**, 69–77.

Grbec B., M. Bone, G. Beg-Paklar and V. Dadić (1998a): Experimental and numerical investigation of eddy exchange coefficients in the surface layer of the middle Adriatic Sea, *Rapports et proces-verbaux des reunions CIESMM*, **35**, 146–147.

Grbec B., M. Morović and I. Marasović (1998b): Biological consequences of unusual weather conditions in the Adriatic in summer 1992, *Fresenius Environmental Bulletin*, **7 (1/2)**, 14–17.

Grbec B., M. Morović and M. Zore-Armanda (1998c): Some new observations on the long-term salinity changes in the Adriatic Sea, *Acta Adriatica*, **39 (1)**, 3–12.

Grbec B., M. Morović, M. Zore-Armanda and N. Leder (1998d): Interannual salinity fluctuations in the middle Adriatic Sea, *Rapports et proces-verbaux des reunions CIESMM*, **35**, 148–149.

Krajcar V. and M. Orlić (1995): Seasonal variability of inertial oscillations in the Northern Adriatic, *Continental Shelf Research*, **15**, 1221–1233.

Kuzmić M. and M. Orlić (1995): Remote sensing of the dynamic patterns in the Adriatic Sea, *Bulletin de l'Institut oceanographique*, **15**, 117–132.

Kuzmić M. (1998): Remote sensing in oceanography (in Croatian), In: *100 Years of Photogrammetry in Croatia* (Ed. V. Kušan), HAZU, Zagreb, 123–130.

Leder N., A. Smirčić and Z. Gržetić (1995a): Seasonal variability of dynamical and thermohaline properties in the Otranto Strait area – 1989/1990, *Rapports et proces-verbaux des reunions CIESMM*, **34**, 187.

Leder N., A. Smirčić and Z. Gržetić (1995b): Investigations of currents and optimum positioning of sewage outfall in the area of Cetina estuary (in Croatian), *Proceedings of "1st Croatian Water Conference"*, Dubrovnik, 487–495.

Leder N., A. Smirčić and Z. Gržetić (1995c): Seasonal current fluctuations in the area of western part of Mljet (in Croatian), *Symposium on "Natural Characteristics and Human Validating of the Island of Mljet", Ekološke monografije 6*, Croatian Ecological Society, Zagreb, 415–436.

Leder N. and M. Morović (1996): Ecological study of gas fields in the northern Adriatic – 2. Climate characteristics, *Acta Adriatica*, **37 (1/2)**, 9–15.

Leder N., A. Smirčić, Z. Gržetić, B. Grbec and I. Vilibić (1996): Dynamic characteristics of the Palagruža Sill area (in Croatian), *Proceedings "Palagruža – The Pearl of the Adriatic"*, Split, 339–343.

Leder N., A. Smirčić and Z. Gržetić (1997): Optimum sewer locations and circulation investigations in closed channel areas of the east Adriatic coast, In: *Water Pollution 97 – Modelling, Measuring and Prediction* (Eds. R. Rajar and C. A. Brebbia), Computational Mechanics Publications, Southamptom, 195–204.

Leder N., G. Beg-Paklar, Z. Gržetić, A. Smirčić and I. Vilibić (1998a): Wind-driven currents in the channel area: an example of the Channels Zadarski kanal and Pašmanski kanal (east Adriatic coast), *Rapports et proces-verbaux des reunions CIESMM*, **35**, 166–167.

Leder N., A. Smirčić and I. Vilibić (1998b): Some characteristics of the current field in the Rijeka Bay (NE part) – Interaction of the Rijeka Bay and the Vinodol Channel across the Tihi Channel (in Croatian), *Proceedings "Natural History Researches of the Rijeka Region"*, Rijeka, 213–221.

Limić N. and Z. Pasarić (1996): On a class of random differential equations and the expectation of its solutions, *Bollettino della Unione Matematica Italiana B*, **10**, 549–568.

Limić N. and Z. Pasarić (1997): The continuity equation with random velocity field and the expectation of its solutions, *Journal of Mathematical Analysis and Applications*, **212**, 209–224.

Marasović I., B. Grbec and M. Morović (1995): Long-term production changes in the Adriatic, *Netherlands Journal of Sea Research*, **34**, 267–273.

Morović M. (1995): Chlorophyll dynamics of the Northern Adriatic studied from satellite data, *Rapports et proces-verbaux des reunions CIESMM*, **34**, 190.

Morović M., Z. Gržetić and N. Leder (1996a): Ecological study of gas fields in the northern Adriatic – 7. Thermohaline and optical properties, *Acta Adriatica*, **37 (1/2)**, 89–108.

Morović M., A. Marani and V. Barale (1996b): The analysis of the chlorophyll field in the Adriatic with satellite images (in Italian), *Atti del Istituto Venetto di Scienze, Lettere ed Arti, Clase di Scienze Fisiche, Matematiche e Naturali*, **154**, 85–95.

Orlić M. (1995): Adriatic sea level and climate (in Croatian), *Proceedings of "1st Croatian Water Conference"*, Dubrovnik, 553–559.

Orlić M. (1996): An elementary model of density distribution, thermohaline circulation and quasigeostrophic flow in land-locked seas, *Geofizika*, **13**, 1996, 61–80.

Orlić M. (1997): The Zagreb scientists, Josip Goldberg in particular, and research of the Adriatic Sea (in Croatian), *Geofizika*, **14**, 83–117.

Orlić M. and M. Pasarić (1998): Seven decades of tide-gauge measurements at Bakar (in Croatian), *Proceedings "Natural History Researches of the Rijeka Region"*, Rijeka, 201–211.

Pasarić M. and M. Orlić (1998): Response of the Adriatic sea-level slope to the air-pressure gradient and wind forcing at subsynoptic frequencies, *Rapports et proces-verbaux des reunions CIESMM*, **35**, 184–185.

Pasarić Z. and M. Orlić (1998): On the estimation of wind stress from mean wind time series, *Rapports et proces-verbaux des reunions CIESMM*, **35**, 186–187.

Požar-Domac A., T. Bakran-Petricioli, P. Filipić, A. Jaklin, N. Leder, J. Mužinić, G. Olujić, A. Pallaoro, G. Sinovčić, A. Smirčić, I. Šimunović, V. Šojat, S. Vidić, M. Vučetić, V. Vučetić, E. Zahtila, D. Zavodnik and N. Zavodnik (1998): The Silba Marine Park – preliminary research of the main characteristics of the area establishment of specially protected area, and marine park managing organisation, *Periodicum Biologorum*, **100**, 7–18.

Smirčić A., B. Glavaš and M. Švonja (1995): Some hydrological and bathymetric characteristics of the Baćina Lakes (in Croatian), *Proceedings of "1st Croatian Water Conference"*, Dubrovnik, 471–484.

Smirčić A. and N. Leder (1996): Characteristics of the extreme sea states in the area of the Palagruža island (in Croatian), *Proceedings "Palagruža – The Pearl of the Adriatic"*, Split, 345–351.

Smirčić A., M. Gačić and V. Dadić (1996): Ecological study of gas fields in the northern Adriatic – 3. Surface waves, *Acta Adriatica*, **37 (1/2)**, 17–34.

Smirčić A., N. Leder and I. Vilibić (1998a): Surface waves in the southern Adriatic area, *International Symposium on "Water Management and Hydraulic Engineering"*, Dubrovnik, Book 1, 461–471.

Smirčić A., N. Leder and I. Vilibić (1998b): Characteristics of surface wave elements during extreme sea states in the area of northern Adriatic (in Croatian), *SORTA 98*, Zadar, Book 1, 469–479.

Smirčić A., I. Vilibić, N. Leder and Z. Gržetić (1998c): Diffusion experiment in the Split harbour (middle Adriatic Sea), In: *Oil and Hydrocarbon Spills, Modelling, Analysis and Control* (Eds. R. Garcia-Martinez and C. A. Brebbia), Computational Mechanics Publications, Southampton, 267–275.

Supić N., I. Ivančić, Ž. Stipić and D. Degobbis (1995): Hydrographic conditions in the Northern Adriatic Sea during 1994 (in Croatian), *Izvanredne meteorološke i hidrološke prilike u Hrvatskoj*, **18**, 137–142.

Supić N., M. Orlić and D. Degobbis (1997): Small-scale spatial variability of surface heat flux over the northern Adriatic, *Periodicum Biologorum*, **99**, 169–179.

Supić N. and D. Degobbis (1998): Estimations of errors originating from the assumption that a single measurement represents the monthly mean of temperature and salinity in the northeastern Adriatic, *Rapports et proces-verbaux des reunions CIESMM*, **35**, 198–199.

Supić N. and M. Orlić (1999): Seasonal and interannual variability of the northern Adriatic surface fluxes, *Journal of Marine Systems*, **20**, 205–229.

Vilibić I. and N. Leder (1996): Long-term variations of Mediterranean Sea level calculated by spectral analysis, *Oceanologica Acta*, **19**, 599–607.

Vilibić I., N. Leder and A. Smirčić (1996a): Spectral analysis of the sea level data in the wider region of the island Palagruža (in Croatian), *Proceedings "Palagruža -The Pearl of the Adriatic"*, Split, 353–356.

Vilibić I., A. Smirčić and N. Leder (1996b): Analysis of extreme sea levels along Croatian Adriatic coast in the period 1955–1995 (in Croatian), *Izvanredne meteorološke i hidrološke prilike u Hrvatskoj*, **19**, 125–130.

Vilibić I., N. Leder, A. Smirčić and Z. Gržetić (1997): Sea level long-term changes along the Croatian Adriatic coast (in Croatian), In: *A Millenium of the Fisheries as Documented in Croatia* (Ed. B. Finka), Zagreb, 437–445.

Vilibić I. (1998a): *Surface seiches and internal Kelvin waves of the Zadar and Pašman Channels* (in Croatian), M. Sc. Thesis, Faculty of Science, University of Zagreb, 139 pp.

Vilibić I. (1998b): Variations of the Sa and Ssa tides in the Adriatic Sea, *Acta Adriatica*, **39 (1)**, 53–60.

Vilibić I., N. Leder and A. Smirčić (1998a): Forced and free response of the Adriatic sea level, *Il Nuovo Cimento C*, **41**, 439–451.

Vilibić I., M. Orlić, A. Smirčić and N. Leder (1998b): Surface seiches and internal Kelvin waves observed off Zadar (east Adriatic), *Rapports et proces-verbaux des reunions CIESMM*, **35**, 206–207.

Vilibić I., N. Leder and A. Smirčić (1998c): Some characteristics of sea level changes in the Rijeka Bay (in Croatian), *Proceedings "Natural History Researches of the Rijeka Region"*, Rijeka, 223–232.

Vilibić I. and M. Orlić (1999): Surface seiches and internal Kelvin waves observed off Zadar (east Adriatic), *Estuarine, Coastal and Shelf Science*, **48**, 125–136.

Viličić D., N. Leder, Z. Gržetić and N. Jasprica (1995): Phytoplankton and oceanographic conditions in the Strait of Otranto (Eastern Mediterranean), *Rapports et proces-verbaux des reunions CIESMM*, **34**, 218.

Vučak Z. (1996): Ecological study of gas fields in the northern Adriatic – 6. Tides, *Acta Adriatica*, **37 (1/2)**, 85–87.

Zore-Armanda M. and M. Alajbeg (1995): *65th Anniversary of the Institute of Oceanography and Fisheries* (in Croatian), Institute of Oceanography and Fisheries, Split, 144 pp.

Zore-Armanda M. (1996): The development of oceanographic research in the Palagruža waters (in Croatian), *Proceedings "Palagruža -The Pearl of the Adriatic"*, Split, 317–327.

Zore-Armanda M., M. Bone, V. Dadić, M. Gačić, V. Kovačević and Z. Vučak (1996): Ecological study of gas fields in the northern Adriatic – 4. Circulation, *Acta Adriatica*, **37 (1/2)**, 35–68.

Zore-Armanda M. (1997): *Reminiscences of an Oceanographer* (in Croatian), State Hydrographic Institute, Institute of Oceanography and Fisheries, Split, 137 pp.

Zore-Armanda M. (1998): Development of the Mediterranean oceanography, *Sixth International Congress on the History of Oceanography*, Qiangdao, 129.

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