Physical oceanography in Croatia, 1991–1994

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

Between 1991 and 1994 physical oceanographic studies in Croatia have been performed mainly by the following institutions: Institute of Oceanography and Fisheries, Split; Hydrographic Institute of the Republic of Croatia, Split; Center for Marine Research, Ruđer Bošković Institute, Rovinj and Zagreb; and Andrija Mohorovičić Geophysical Institute, Faculty of Science, University of Zagreb.

Altogether, 23 investigators (9 PhD's, 12 MSc's and 2 BSc's), 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 confined to a port due to the war restrictions. 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) has been developed at Split as a GIS system based on ORACLE RDBMS and ARC/INFO software tools, and has been used to store various oceanographic data. Independently, a hydrographic data bank has been built at Rovinj, based on the PARADOX 3.0 program package.

Despite the war, 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). Long-term measurements of currents were performed at three stations in the North Adriatic, short-term measurements were carried out at a number of near-shore locations (Lim Channel, Rovinj Archipelago, Vinodol Channel). Tide-gauge measurements were continued at a network of six permanent stations (Rovinj, Bakar, Zadar, Split–Marjan, Split–Harbour, Dubrovnik), with breaks being effected at two of them (Zadar, Dubrovnik) by heavy bombardment. Sea surface temperature was measured daily at some coastal stations (e. g. Split–Marjan). Croatian institutions participated in several international programs, such as POEM (Physical Oceanography of the Eastern Mediterranean) and UNEP projects concerning the Bay of Kaštela and the Cres/Lošinj islands.

Over the past four years Croatian physical oceanographers paid considerable attention to hydrography and current field of the Adriatic Sea. On the

basis of short-term current measurements in the Otranto Strait, Leder et al. (1992) concluded that the pattern of inflow along the east coast and outflow along the west coast may sometimes reverse. Michelato and Kovačević (1991) analyzed long-term current measurements in the same area and found that the average flow is usually less energetic than the wind-driven, inertial and tidal transients. From an analysis of hydrographic data Artegiani et al. (1993) deduced that the intensity of surface outflow from the Adriatic is related to the evaporation–precipitation forcing over the basin. As pointed out by Robinson et al. (1992), deep-layer inflow and outflow in the Otranto Strait may be considered a part of a single vertical thermohaline cell which encompasses the entire Eastern Mediterranean.

Zore-Armanda et al. (1991) published hydrographic data collected in various parts of the Adriatic Sea over a 13-year period, and documented a salinity increase in the Middle Adriatic that has occurred during sixties and seventies – possibly due to the Aswan High Dam construction. In the same area and over a similar interval Morović and Domijan (1991) observed a decrease of transparency, and have related it to an increase of phytoplankton production.

In the North Adriatic, various parts of the current spectrum were investigated empirically: residual circulation, using both Lagrangian (Smirčić et al., 1991) and long-term Eulerian measurements (Brana and Krajcar, 1994), its ten-day variability (Cerovečki et al., 1991), wind-driven currents (Orlić et al., 1994) as well as inertial oscillations (Krajcar and Orlić, 1994). Moreover, a three-dimensional numerical model was applied in order to reproduce observed response of the Adriatic Sea to the bora and sirocco forcing (Orlić et al., 1994). This revealed complex current patterns that Adriatic winds impose on the sea. Within the same dynamical framework the remote sensing techniques have received increased attention of Croatian researchers. Kuzmić (1991, 1993, see also Kuzmić and Orlić, 1991) explored the Adriatic response to bora wind by comparing previous modeling results with the CZCS imagery. Sturm et al. (1992) related coast-hugging and interior-spreading Po River plumes, detected in a number of CZCS scenes, to particular meteorological and hydrographic conditions.

Not only open Adriatic, but also coastal waters attracted attention of Croatian physical oceanographers. Supić and Orlić (1992) Fourier-analyzed 20 years of SST data from 21 coastal stations, and showed that amplitudes of the first harmonic of the annual cycle decrease and its phases increase in an offshore direction. Zore-Armanda and Grbec (1993) related extremely high SST's, which were observed along the east Adriatic coast in summer 1992, to the weakness of winds and unusual absence of the Karachi depression. Several authors addressed processes in the Kaštela Bay: Gačić et al. (1991) wind-driven currents, Leder and Vukojević (1991) stability of the water column, Marasović et al. (1991) and Barić et al. (1992) relation of water dynamics to eutrophication phenomena. During this review period the Krka Estuary

also enjoyed exceptional attention: Legović (1991) presented a method to compute exchange of fresh and marine waters, Legović et al. (1991a, 1991b) empirically considered wind effects and discussed subsurface temperature maximum as high as 31 °C, whereas Orlić et al. (1991) analyzed coupling of surface seiches and internal waves. Also considered were temperature variability in the Trieste Bay (Grbec and Kovačević, 1994), and TS characteristics and currents of the Kumbor Gorge area (Smirčić and Leder, 1992). Dadić and Grbec (1993) used experience gained in the oceanographic work while analyzing temperature and circulation at the Peruča hydroplant, which was heavily damaged during the war.

Several papers addressed sea-level variability in the Adriatic. Beg (1992) considered sources of errors that occurred in tide-gauge measurements at the Split–Marjan station between 1985 and 1989. Leder (1992) performed cross-spectral analysis of air pressure and sea level recorded at Split in winter 1982. Pasarić and Orlić (1992) analyzed coupling of planetary atmospheric disturbances and the Adriatic Sea on the basis of 5-year time series, and attributed anomalously low sea levels that prevailed in winter 1988/89 to a climatic fluctuation. Orlić and Pasarić (1994) extended the work to even lower frequencies, by showing that the Adriatic sea-level rise slowed down over the past 40 or so years.

While most of the work of Croatian researchers concerned the Adriatic Sea, some attempts were made at more general topics as well. Malačič and Orlić (1993) analytically modeled subinertial response of the sea contained in a rotating, rectangular channel of arbitrary width to the air pressure wave traveling at varying directions. They showed that in wide channels sea levels and currents are organized in two coastal waves and a geostrophic current system prevailing in mid-basin, whereas in narrow channels the motion represents a forced Kelvin wave coupled to the atmospheric wave. Orlić (1994) developed a simple model of buoyancy-driven seasonal variability in the oceans. The model makes it obvious that annual sea-level cycle is influenced by the air/sea heat flux, and by both isostatic and non-isostatic water flux effects. Bone (1993) developed a numerical model of non-linear wind-driven dynamics for a shelf area, which incorporates a second-order turbulence closure scheme. Application of the model to the Adriatic Sea showed good agreement with previously obtained numerical results.

Over the past four years several Adriatic-related topics were reviewed by Croatian investigators. Thus, Zore-Armanda (1991) considered relation of water masses and circulation to climatic conditions over the Adriatic. Gačić et al. (1992) analyzed Adriatic in the wider, Mediterranean context, and addressed briefly its possible response to future climatic changes. Orlić et al. (1992) summarized findings published on the Adriatic current variability of various spatial and temporal scales. Finally, Kuzmić and Orlić (1994) overviewed papers dealing up to now with remote sensing and the Adriatic Sea.

To summarize, between 1991 and 1994 Croatian physical oceanographers remained active despite the war: they maintained several measurement programs, organized two data bases, and published or prepared for publication about 40 papers, plus a number of conference presentations and local reports not considered here. Yet, the difficulties of scientific work under wartime conditions are clearly visible: a careful inspection of the list of publications reveals a steady decline of the number of papers published per year. It is to be hoped that conditions will soon improve, and that research of the Adriatic Sea will regain position it merits in Croatia.

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