Seasonal Variability of the Inertial Signal in the Northern Adriatic

Valter KRAJCAR and Mirko ORLIC*

Ruder Boskovic Institute, Center for Marine Research, ROVINJ (**Croatia**)
*Andrija Mohorovicic Geophysical Institute, Faculty of Science, University of ZAGREB (**Croatia**)

Previous investigations of the inertia-period oscillations in the Northern Adriatic were mostly related to the individual summer events. They were based on measurements carried at various stations over short time intervals (30-60 days). The object of the present investigation was to document seasonal variability of the inertial signal and its decay time. The investigation was made possible by the year-long time series, recently collected in the Northern Adriatic.

We had at our disposal data taken by Aanderaa RCM-4 current meters at two stations in the Northern Adriatic in the period 1988-1990, as well as density measured traditionally at the same stations in the period 1966-1991. Station A was located about 15 NM west of Rovinj (bottom depth -37 m), Station B 15 NM west of Pula (43 m). Current meters were suspended from the subsurface moorings, at the 5, 20 and 30 m depth (station A), and the 5 and 37 m depth (station B). Density was measured at conventional depths.

To isolate the inertia contents of the current-vector time series, seven principal tidal components were synthesized and eliminated. Thereafter, the inertial signal was extracted, by applying a band-pass filter around the local inertial frequency (1/17 cph). The amplitudes thus obtained for different years were pooled in a single year, and were averaged over successive 15-day intervals. Finally, a polynomial was fitted to the data recorded at each particular station/depth.

The resulting curves for the three depths of Station A are shown in Fig. 1. A similar result was obtained for Station B. Maximum surface amplitude (about 10 cm/s) occurs in summer, minimum (< 2 cm/s) in winter. Ratio of amplitudes at the 20 and 5 m depth is minimal (about 0.15) at the beginning of March, and reaches maximum (over 1) in September. This property can be explained using a two-layer fluid model (CSANADY,1973; ORLIC, 1987). In the model the ratio of vertically averaged baroclinic velocities in the surface and bottom layer is equal to the bottom-to-surface ratio of thickness of the two layers. Density data show that stratification is negligible between November and the end of February. During March it begins to develop, with an average pycnocline depth of about 5 m. From March to October the pycnocline deepens to 20 m, which favours an intensification of bottom currents as related to the surface ones.

In order to determine the decay time of the inertia-period oscillations, exponential curves were fitted to the descending segments of the band-passed time series. Only episodes in which amplitudes exceeded 3 cm/s were considered. Decay times were averaged throughout the depth and over the successive 15-day intervals. Results were similar for the two stations: The greatest decay times were obtained for June and July.

The problem of damping of the inertia-period oscillations by bottom friction had been solved using the two-layer model (ORLIC, 1984). Here, the model was extended by introducing interface friction. It was found that the decay time depends on depths of the surface and bottom layers, on the proportionate density defect of the surface layer, as well as on the coefficients of interface (K) and bottom (k) friction. Empirical decay times and density data allowed the model to be inverted in order to determine the two coefficients. This exercise gave $K=0.14\cdot10^{-7}$ m/s and $k=0.73\cdot10^{-3}$ m/s. The contribution of interface friction to damping was found to be about 20 % in March and April. It decreases to about 10 % in June, due to stabilization of the water column. From July to October the contribution decreases further (to less then 5%) because the pycnocline then deepens and bottom friction gains in importance.

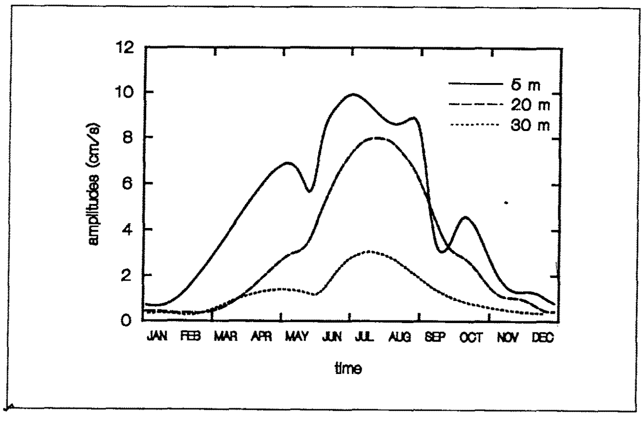

Figure 1. Annual cycle of amplitude of the inertia-period oscillations registered at Station A.

Acknowledgement

Long-term current measurements were organized by Dr J. BRANA. Density data were furnished by the Centre for Marine Research (Rovinj).

REFERENCES

CSANADY G.T., 1973.- Transverse Internal Seiches in Large Oblong Lakes and Marginal Seas. *Journal of Physical Oceanography*, 3, 439-447.

ORLIC M., 1984.- The Influence of Bottom Friction on Transverse Internal Seiches in Rotating Rectangular Channels. *Archives for Meteorology, Geophysics and Bioclimatology*, A33, 175-185.

ORLIC M., 1987.- Oscillations of the Inertia Period on the Adriatic Sea Shelf. *Continental Shelf Research*, 7 (6), 577-598.

Remotely Observing River Discharge on Shelf - A Case of Wind-provoked Extrusion of Po Waters

Milivoj KUZMIC

Center for Marine Research, Rudjer Boskovic Institute, ZAGREB (**Croatia**)

Remote sensing of marine environment offers unsurpassed opportunity of synoptic and frequent assessment of its various properties. Colour of the sea is unique among them in offering, to remote sensing, information from below the surface. Optical properties of near surface waters could be profoundly changed under the influence of river discharges rich in nutrients and/or loaded with dissolved and suspended material. This makes river discharges particularly suitable for remote detection by optical sensors. The fresh water runoff also supplies low salinity waters whose eventual fate is often, to various degree, influenced by prevailing wind regime. MULLER-KARGER *et al.* (1989), for example, have found that the largescale distribution of pigments in the Caribbean Sea seems to be controlled by wind stress, flux of water through the basin and river discharge; the Orinoco river plume dispersal was found tightly coupled to variation in the wind.

The Northern Adriatic into which the Po River discharges offers a case of pronounced river discharge into shallow, coastal waters. Although not nearly comparable to the rivers of previous example (Amazon and Orinoco) Po does supply the largest discharge into the Adriatic. Within the last decade the area was object of several remote-sensing related studies. These studies often dealt with retrieval algorithm development, but remote sensing was also used to aid oceanographic work. BARALE *et al.* (1986), for example, used a time series of Coastal Zone Colour Scanner (CZCS) scenes for the years 1979 and 1980 to study the surface colour field and circulation patterns on monthly and interannual scales, distinguishing coastal and open sea water masses via different pigment levels. It is interesting to note that, on the considered scales, the authors found the wind ineffective regarding the pigment distribution. CLEMENT *et al.* (1987) reported two types of pigment patterns observed on the Adriatic shelf, suggesting also their seasonal behaviour. One type is elongated, trapped along the Italian coastline, and found in winter, whereas the another is wide, irregularly spreading into the basin interior, and appearing in summer. Studying further this dichotomy STURM *et al.* (1992) have recently shown that the two patterns are not necessarily seasonally restricted, i.e. both may occur in summer and winter.

The case of offshore spreading in winter is the one previously reported by KUZMIC (1991) and further considered in present paper. Namely, in winter, as number of papers confirm, the Northern Adriatic is well mixed along vertical and river-affected waters remain confined to the western Adriatic coast. Apparently, this situation can change if certain conditions are met. In particular, is has been suggested and partially empirically verif ied (see e.g. KUZMIC and ORLIC, 1987) that spatially heterogeneous bura wind, known to blow in the area, spins up a cyclonic gyre which carries upwind (towards northeast) the waters from the southwestern coastal strip. Since that is the area into which the Po waters are discharges the gyre could be a mechanism to extrude the turbid and nutrient-rich waters into the basin interior. In order to explore this hypothesis previously developed hydrodynamical model has been augmented with a simple two-dimensional dispersion model. The extension facilitated comparison of model simulations with the remotely sensed data, avoiding at the same time *ab initio* modelling of the near field interactions. Selected CZCS scenes were processed to yield derived field of pigment concentration as well as total suspended matter. Atmospherically uncorrected fields of composite reflectances (the first three CZCS channels) and histogram equalized original channels were also analysed. Rather imperfect infra-red information in channel 6 was consulted when available. The comparison of model-generated and sensor-collected information suggests that the heterogeneous bura wind is indeed capable of provoking Po-water extrusions into the Northern Adriatic interior.

REFERENCES

BARALE V., McCLAIN C.R. & MALANOTTE-RIZZOLI P., 1986.- Space and time variability of the surface colour field in the northern Adriatic Sea. *Journal of Geophysical Research*, 91, 12957-12974.

CLEMENT F., FRANCO P., NYKJAER L. & SCHLITTENHARDT P., 1987.- Northern Adriatic Sea and River Po. In R. Reutner and R. H. Gillot, Eds. Remote Sensing of Pollution of the Sea. *Proceedings of International Colloquium*, Oldenburg, FR Germany, 98-111.

KUZMIC M. and ORLIC M., 1987.- Wind-induced vertical shearing: ALPEX/MEDALPEX data and modelling exercise. *Annales Geophysicae*, 5B, 103-112.

KUZMIC M., 1991.- Exploring the effects of bura over the Northern Adriatic: CZCS imagery and a mathematical model prediction. *International Journal of remote Sensing*, 12, 209-216.

MULLER-KARGER F.E., McCLAIN R., FISHER T.R., ESIAS W.E. & VARELA R., 1989.- Pigment distribution in the Caribbean Sea: Observation from space. *Progress in Oceanography*, 23, 23-64.

STURM B., KUZMIC M. & ORLIC M., 1992.- An evaluation and interpretation of CZCS-derived patterns on the Adriatic shelf. *Oceanologica Acta*, SP 11, 13-23.

Rapp. Comm. int. Mer Médit., **33**, (1992).