# OBSERVATIONS AND MODELIZATION OF THE RHONE RIVER PLUME

J.-L. DEVENON and A. BAECKEROOT

Laboratoire de Sondages Electromagnétiques de l'Environnement Terrestre, (LSEET), UA 705 CNRS, Université de Toulon et du Var, BP 132 83957 La Garde Cedex, France

It is often observed that the Rhone river discharge in the Mediterranean sea takes the form of a buoyant surface plume of brackish water spreading horizontally far off-shore over a few tenth of kilometres. In the majority of cases, the river water is found to preserve its individuality on fairly great distances off-shore, and is accordingly confined in a thin layer floating over the underlying sea water. This freshened tongue of brackish water is vertically separated from the ambient marine water by a sharp halocline (thickness of a few metres). It is partially surrounded by an hydrological front with a marked contrast in salinity values on each side, and which is sometimes visible from a boat as a foam line separating the two water masses of different appearance (colour, surface roughness). This front is also a zone of high dynamic horizontal gradients since a frontal convergence of surface currents generally occur there, as evidenced on maps of radial components measured by the VHF radar, or by *in situ* drifter tracking.

The experiments operated by the LSEET laboratory off the Rhone mouth have provided a great amount of current data (one map every half an hour during two months) which could be combined sometimes with in situ observations, and from which a statistical analysis on various typical oceanic and meteorological situations can be well investigated. A morphological insight is provided every times the frontal boundaries of the plume are visible on such maps. Aside of this kind of information, different quantities such as radial acceleration or speeds of displacement of the whole structure can be calculated from one map to another. This gives access to orders of magnitudes for typical scales, both on a temporal and on a spatial point of view. One of the prominent feature is that the response of the system to a wind reversal can be quite fast (few hours), as it is often the case during transient events associated with sea breeze regimes, during while a high temporal variability is likely to occur. Another striking aspect of the phenomenon is its persistance and its approximately well defined location even during events of gusts of winds (Mistral). These are the situations on which we have decided to focus in a first step of a modelization approach.

A reduced-gravity non-linear layer model is developed in order to study river plumes. This stationary model, based on a simpler one found in literature (GARVINE, 1981), considers mass and momentum exchanges in the frontal zone. Interfacial friction has been introduced to take into account the wind and underlying current effects. Supercritical flow is assumed in the outlet channel, so that characteristics method is used for numerical resolution. It provides a variable grid, strongly akin with the flow properties. Finite difference method along characteristic lines and stream lines is used to solve the governing equations. Numerical stability is inherent to the model, as the grid verifies the Courant-Friedrich-Levy stability criterion. For a given accuracy the number of grid points is reduced by several orders of magnitude compared with a fixed orthogonal mesh grid. More over, this grid seems to be optimal for implementing data assimilation because the adjoint model and the direct model possess the same characteristics lines, so only a few additional computational time is needed.

The shape of the river mouth governs the initial expansion of the plume and its orientation. Near the river's mouth, the flow dynamics is mainly a balance between non-linear advective terms and the pressure gradient, whereas far off-shore the model tends towards an Ekman equilibrium. The wind appears as a major forcing term, and the computed flow is comparable with measurements made with the VHF radar of the laboratory near the Rhone's mouth.

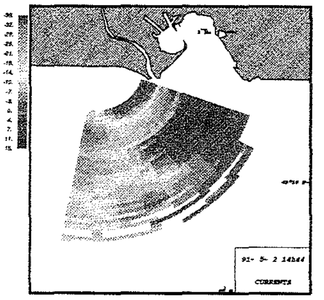


Fig 1: Radial components of sea surface currents (in cm/s) mapped by VHF radar during a Mistral event. Warm colors for currents receeding from the radar.

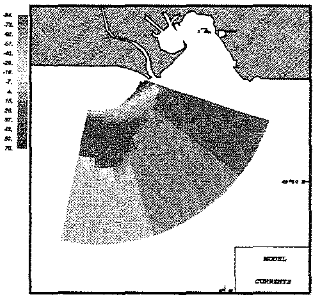


Fig 2: Modelized radial components of inside plume currents.

The agreement between the two kinds of results is mainly found on the basis of a morphological comparison. This is partly due to the ability of the model to restitute the frontal boundaries as lines of discontinuities. A quantitative comparison is specifically explored between the mean location of the plume for a given class of quasi identical meteorological forcing conditions and the model restituted location. Another analysis focuses on the comparison of accelerating terms which can be estimated from radar maps, to gain insight on the dynamic balance transcribed by the model equations; physical interpretations are looked for when discrepencies greater than the expected experimental inacurracies are found. Finally a detailed discussion is conducted concerning the parametrisation of the frontal mass and momentum exchange coefficients linked to the (observed) frontal velocity jump, and which will be probably chosen as model controls to be fitted in a future data-assimilation procedure.

**REFERENCES**

DEVENON J.-L., P. BROCHE, J.-C. de MAISTRE, P. FORGET, J. GAGGELLI, G. ROUGIER, 1992. VHF Measurements in the Rhône river plume, preliminary results. Water Pollution Research Reports, 28, Proceedings of 3rd Eros Workshop, Texel, The Netherlands.

FORGET P., J.-L. DEVENON, J.-C. de MAISTRE and P. BROCHE, 1990. VHF remote sensing for mapping river plume circulation, *Geophysical Research Letters,* 17 : 1097-1100.

GARVINE R.W., 1981. Frontal jump conditions for models of shallow buoyant surface layer hydrodynamics. *Tellus*, 33 : 301-312.

GARVINE R.W. 1982. A steady state model for buoyant surface plume hydrodynamics in coastal waters. *Tellus*, 34 : 293-306.

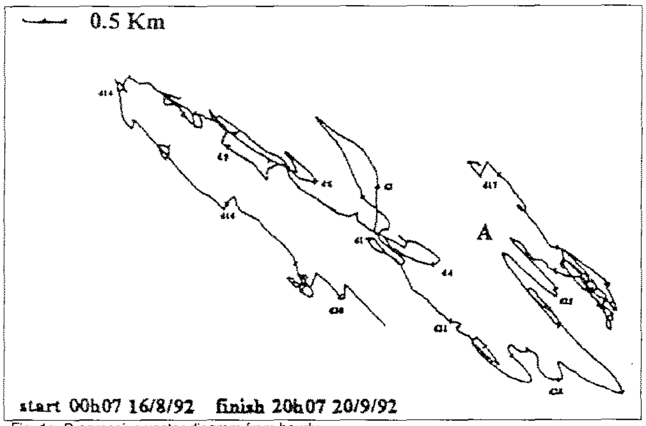
GARVINE R.W., 1987. Estuary Plumes and Fronts in Shelf Waters : A Layer Model. *Journal of physical oceanography*, 17 : 1877-1896.

# SOME PHYSICAL OCEANOGRAPHIC ASPECTS IN THE NW COASTAL AREA OF MALTA

Aldo F. DRAGO

Marine Resources Network, MCST, Valletta, Malta

The Central Mediterranean is an exchange region between the western and eastern basins of the Mediterranean and presents an interesting case in physical oceanography with phenomena that are presently of great interest in current research. The Maltese Islands provide an obstacle to the main SSE vein of Atlantic water moving across the Sicilian Channel, and unpredicted coastal oceanographic aspects that are especially relevant to island systems and covering the full spectrum of temporal and spatial scales have been revealed. The present study is mainly based on the data collected during a survey in August 1992 with support from data acquired successively. Besides the survey undertaken in the subsequent Summer, short 3-day data collection campaigns during 1994 will allow the study of the seasonal variability. An intensive water current measurement programme is also being followed since mid-1993. An ENDECO water level recorder has become operative inside Mellieha Bay since mid-1993. A meteorological station set up at a coastal point in the area of study started data registration since April 1994. Fig. 1 shows the PVD from hourly averaged water currents at Ahrax Station, measured by a taut-wire moored instrument at 6.3 m from the sea bed and in a total depth of 34.9 m. This station is positioned mid-way between the main headland at Ahrax Pt. and the White Bank (see insert) which shoals steeply to the NE, reaching depths as low as 11m. The Eulerian transport follows a SE-NW axial pattern and is dominated by diurnal current fluctuations and reversals that are modulated by longer-period signals. The PVD zoom shows in detail the frequent sharp rotations of the current vector, with both clockwise and anticlockwise changes in flow directions. This characteristic water current pattern is accompanied by an oscillation of the seasonal thermocline, and is found to persist even during the winter months when the near-coast water column has no stratification.



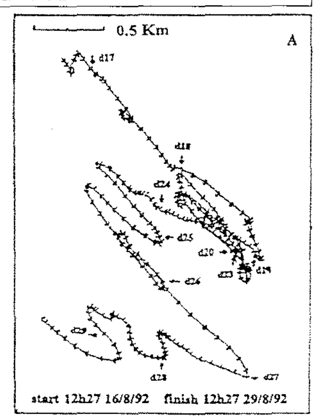




Fig. 1a. Progressive vector diagram from hourly averages current vectores at Ahrax station. Fig.1b (right). PVD zoom of section marked A on fig. 1a.

Towards the higher frequency end of the spectrum the current regime is also affected by a strong seiche which pervades the whole coastal area around the Maltese Islands, often masking completely the small semi-diurnal astronomical tide, and causing water body movements with very short time periods of the order of 20 minutes. Subsurface currents observed by an ENDECO tethered current meter inside Mellieha Bay are found to follow cycles of much the same order, with a rapid reversal of the current vector over a matter of a few minutes. Direct wind forcing is excluded because such currents are present even on very calm days; the magnitudes can often reach 10cms-1 even at points close to the head of the bay and when the seiche is not particularly active. The water column inside the bay is homogeneous throughout the year so that any turbulent origin is also excluded. Such rapid changes in the current vector have been also detected by ADCP profiles. On the spatial dimension it is known, especially from remote-sensed data, that this area of the Mediterranean is very prolific in mesoscale phenomena that give rise to a system of intertwining frontal structures that reach close the islands. Wake-like streaks have been also observed to trail towards east behind the westernmost tip of Gozo, following well-defined swerving paths downcoast, capturing surface garbage and debris along their way. On a smaller scale, data collected in the coastal area of Mellieha Bay and St. Paul's Bay is revealing a complicated circulation in the surface mixed layer, with both the White Bank and the Ahrax headland acting as sources of negative vorticity. The effect of wind forcing on this circulation as well as the relation of its seasonal variability on the presence or eventual erosion of stratification, are all issues of current study. The Maltese archipelago presents itself in an ideal position in the area, acting as a large permanent research vessel in the region; also the advantage of a small tide permits the study of physical oceanographic phenomena that are often masked or contaminated in other areas with dominant tidal streams. Physical oceanography in Malta is still at its birth and the present work in this field of study represents a foundation for future investigations.

**REFERENCES**

ARTALE V., PROVENZALE A. & SANTOLERI R., 1989. Analysis of internal temperature oscillations of tidal period on the Sicilian continental shelf. *Contin. Shelf Res.*, 9, 10 :867-888.

DRAGO A.F., 1992. Long Period Sea Waves in the Grand Harbour, Malta. Marine Sciences Network, Technical Report 1, 1992.

DRAGO A.F., 1993. A Computer Software Application for an Acoustic Doppler Current Profiler. Proceedings Clean Seas Conference '93 (Malta).

GRANCINI G.P. & MICHELATO A., 1987. Current Structure and Variability in the Strait of Sicily and adjacent area. Annls. Geophys., 5B, 1, 75-88.