TIDAL DYNAMICS IN THE GULF OF TRIESTE - NORTHERN ADRIATIC

Vlado Malacic [1] and Dino Viezzoli [2]*

[1] National Institute of Biology, Marine Station Piran, 6330 Piran, Slovenia

[2] Osservatorio Geofisico Sperimentale, P.O. Box 2011, 340160 Opicina, Trieste, Italy

Abstract

Detailed analyses using numerical modelling of Northern Adriatic Sea examined the tidal dynamics in the Gulf of Trieste during two different tidal regimes. Within the Gulf of Trieste, double tidal ellipses are described by rotating transport velocities moving in a clockwise sense. The southern part of the gulf has elongated ellipses oriented along the gulf axis, while in the northern part the ellipses are broader (smaller eccentricity).

Key-words: Currents, Models, Coastal Waters, Adriatic Sea

Introduction

Seven tidal components (four semidiurnal, three diurnal) have a significant contribution to the tidal sea-surface elevation (SSE) in the Adriatic Sea (1). Mediterranean tides are strongest in the northern part of the Adriatic Sea (the Gulf of Trieste). This is with the exception of straits however, where throughflows amplify the tides. Numerical simulations previously made of the tidal dynamics of the small (12 miles x 15.6 miles), semi-enclosed, shallow (depth 20 m) gulf mainly dealt with analysis of the leading M2 tidal component (2, and 3). In (4) the dynamics of the gulf was numericaly simulated with imposed winds of steady direction, where the SSE's were taken from mareographic records. All these models adapted SSE and transport velocity boundary conditions at the gulf's entrance (more than 12 miles long). In order to achieve better understanding of the boundary conditions, the models should have simulated the tidal dynamics of the entire northern Adriatic basin.

The model

The aim of the numerical model was to evaluate the tidal transport of water mass within the Gulf of Trieste during two different tidal situations: one on 8 September 1994 in the south when the tidal rage was of about 100 cm in the port of Trieste and only the semidiurnal components were prevalent, and the other on 15 June 1995 near the Isonzo River mouth (north) when both the semidiurnal and the diurnal constituents were important. On 15 June 1995, the tidal range of the SSE over the gulf was smaller (by about 50%) than the range during 8 September 1994. The numerical model of tides had to simulate the dynamics of all seven major tidal components (M2, S2, N2, K2, K1, O1, and P1). To avoid the open-boundary problem along the western opening of the gulf, a 2D model of tidal dynamics to the entire northern Adriatic area was applied - an area expanding northward of the boundary line connecting two mareographic stations: Pesaro in Italy and Pula in Croatia (5). The tidal dynamics was numerically simulated using the 2D TRIM model (6). This is a non-linear, semi-implicit model which is unconditionally stable. The staggered-grid depth integrated model has a space resolution of 0.3 miles which is sufficient for Lagrangian tracking of "depth-averaged" particles, and for local SSE and Eulerian velocity studies. Values of amplitude and phase, for each of the seven tidal components in the cells along the open-boundary line, were found from a polynomial least-square fit, using points of intersection of co-range and co-tidal lines with the open boundary line (68 miles in length). The co-range and co-tidal isolines were obtained from tidal charts (7). The parameter of implicitness (8) and the depth dependent Chezy-Manning coefficient were adjusted for the port of Trieste, in a way such that the difference between the model and mareographic values of amplitude and phase of the M2 tidal constituent was at a minimum. Adjustments ceased once the difference in amplitude was below 1 cm, and the difference in phase was less than 2° (the M2 component in Trieste has an amplitude of 26.6 cm, and phase g = 277°). Further calibration procedures were performed, which involved modification of the initial least-square fit of SSE along the open boundary line, for each of the seven tidal constituents. This was necessary in order to obtain satisfactory matching of the model and mareographic constants, at the four ports situated along the northern Adriatic coast (Rovinj, Trieste, Malamocco (Venice), and Porto Corsini). The results obtained for the Gulf of Trieste were therefore of reasonable accuracy.

Results

Plots of model SSE values in the port of Trieste against values predicted from tidal tables (9), are shown in Fig. 1. In order that transient effects were unimportant, the model was run fourteen days prior to the days of interest. Since the model simulation of SSE in the port of Trieste was sufficiently accurate, it was believed that the model transport velocities would be representative enough. For each time step in the model, the Lagrangian velocity was calculated using the space interpolation method on the Eulerian velocity components (6). Both transport velocities for the two different tidal regimes are presented in Figs. 2 and 3, respectively. As the 24 hour period of transport velocity evolution is too short, it was analysed using the trigonometric least-square fit composed of just two harmonics: the diurnal and semi-diurnal (full lines in Figs. 2 and 3). The tips of the transport velocities describe double ellipses and move in a clockwise sense. The least-square fit composed of just two trigonometric terms agrees well with the transport velocities of the 2D model, which include the seven

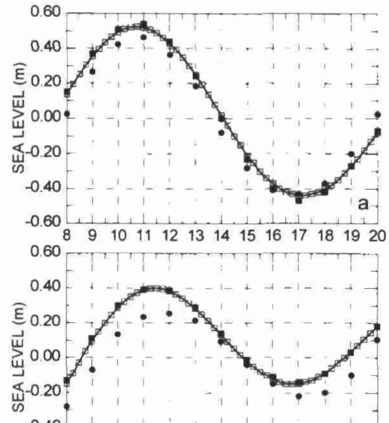

Figure 1 : Sea-surface elevation (SSE) at the port of Trieste (northern Adriatic) during: a) 8 September 1994, b) 15 June 1995. Full rectangles are elevations taken from tidal tables, composed of seven (major) tidal constituents. Empty rectangles are the values of SSE from the 2D model of the northern Adriatic. Circles represent mareographic measurements in the port of Trieste, subtracted by a mean SSE of the displayed period.

tidal constituents. The Eulerian and Lagrangian, semidiurnal and diurnal ellipse parameters show that, in the southern part of the gulf the tidal motion is very elongated and aligned with the coastline. The semidiurnal component of transport velocity, with an amplitude 11.5 cm/s, is of an order of magnitude greater than the amplitude of the diurnal component. In the northern part of the gulf - a few miles southward from the Isonzo river mouth, the semidiurnal tidal component is less elongated, with a speed ranging between 1-4.6 cm/s. The diurnal component is even more circular with a maximum value of 1 cm/s.

The numerically obtained Eulerian tidal transport velocity (Fig. 3 top) is similar to the pseudoellipse of the Eulerian tidal velocity deduced from mooring measurements, at a depth of six meters during the winter period of the 1984 (10). The time series of the Eulerian transport velocity and of the SSE show that, in the southern part of the gulf (8 September 1994) where the depth is around 20 m, the velocity minimum lags behind the local SSE maximum by about 0.5 hours. Surprisingly, this lag is not detectable in the northern part (15 June 1995) where the depth of the water column is about 16 m. However, the starting position of Lagrangian particle of June 15 1995 was much closer to the cotidal line - ending in the port of Trieste, than the starting point of the particle of 8 September 1994. This indicates that the velocity and SSE fields over the gulf are related to fields over the rest of the northern Adriatic Sea.

Finally, although this paper deals mainly with the tide in the Gulf of Trieste it is useful to compare our results for the Northern Adriatic Sea as a whole with results obtained by other authors in the same area. Earlier numerical studies in the Northern Adriatic have concentrated either on the K1 and M2 tidal constituents (11) or on the M2 constituent only (12). The reported results for these constituents are in good agreement with ours despite the lower grid resolution (7.5 km) adopted in those models. Furthermore, our calibration procedure was more severe: the value of the M2 amplitude reported by (11) differed from observed values at Trieste by about 20 % whereas in (12), a comparison of the model results with observed constants for SSE was neglected. Our calibration procedure minimized the error to 2.3 % and 1.3° for the amplitude and phase on the M2 tidal constituent, respectively. The errors in the case of the other six constituents were similar.

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