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A short period rotating seiche of the Ligurian Sea

Ligurian Sea
Rotating seiche
Sea level
Southwesterly wind

Mer Ligure
Seiche rotatoire
Niveau de la mer
Vent de Sud-Ouest

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ABSTRACT

A depth-integrated model of the Ligurian Sea reveals the existence of a rotating seiche motion of the basin with a 1.9 hr period, in association with a SW wind. This seiche has been experimentally identified with variations recorded in sea level data at Savona. The hypothesis of southwesterly wind as the forcing mechanism of this oscillation is formulated.

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RÉSUMÉ

Une seiche rotatoire de courte période en mer Ligure

Un mouvement de seiche rotatoire ayant une période de 1,9 h a été mis en évidence par une méthode H-N. Son existence a été confirmée expérimentalement par des variations du niveau de la mer Ligure à Savone. On suggère qu'un vent de Sud-Ouest associé à cette oscillation en serait à l'origine.

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INTRODUCTION

Recently a depth-integrated hydrodynamical model of the Ligurian Sea has shown the existence of a rotating seiche motion of the basin with a 2.6 hr period triggered by a wind field from the SE. In particular, we have assumed a wind field linearly increasing from zero to a steady value of 20 m sec.$^{-1}$, after a transient time of 30 min. (Fig. 1; Papa, 1981). This computed seiche period was obtained by using an open boundary from

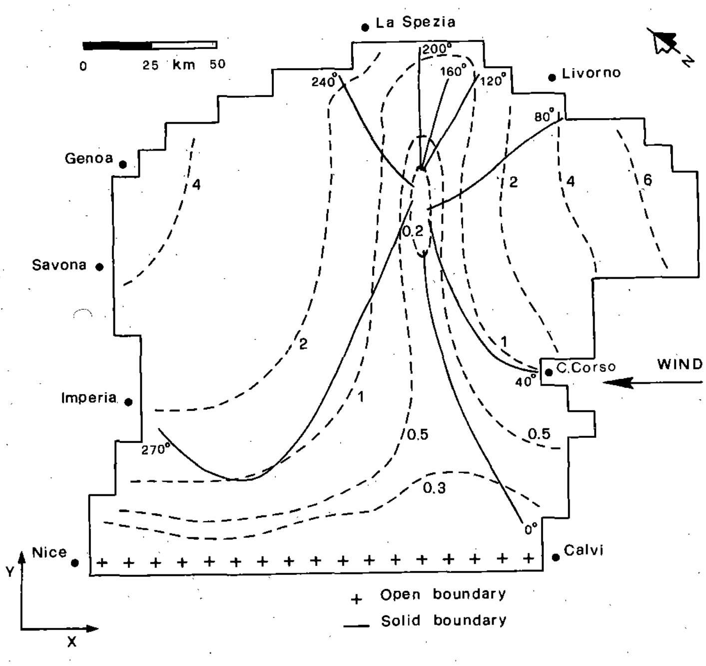

Figure 1
Mean amplitudes (dashed lines, centimetres) and phases (full lines, degrees) of the seiche with 2.6 hr period triggered by a SE wind.

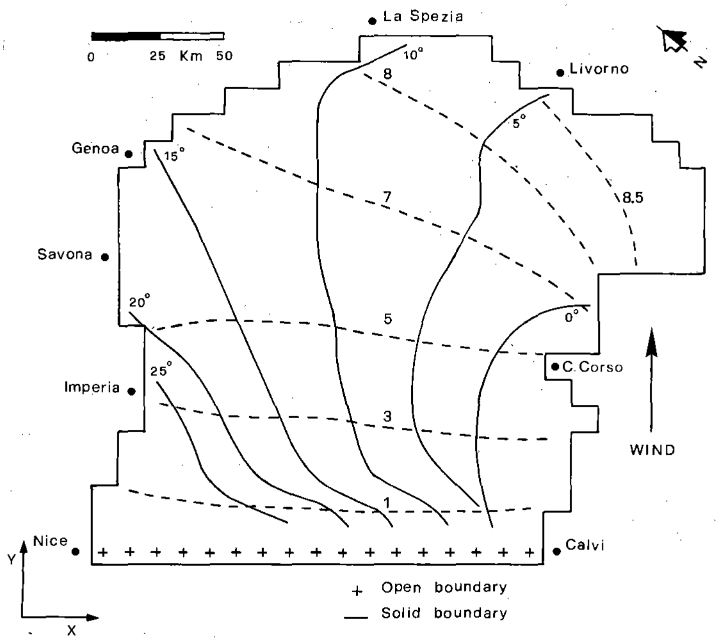

Figure 2
Mean amplitudes (dashed lines, centimetres) and phases (full lines, degrees) of the seiche with 5.8 hr period triggered by a SW wind.

Nice, France, to Calvi, Corsica, and an artificial solid boundary joining C. Corso to Livorno. These delimitations provided to be reliable also for reproducing a longitudinal seiche with a 5.8 hr period in association with a wind field from the SE and the SW. The southwesterly wind proved to be the primary trigger mechanism of this proper oscillation, as might have been expected because of the longitudinal character of this motion in a SW-NE direction (Fig. 2; Papa, 1983). In the present paper, our aim is to investigate more thoroughly the rotating seiche motions of the basin by using a numerical model and a wind stress excitation from the SW and the SE. Such directions usually characterize the wind field in this area during storm surges in association with frontal systems moving across the Ligurian Sea.

NUMERICAL AND EXPERIMENTAL RESULTS

In the numerical simulations, we first assumed a wind field from the SW linearly increasing from zero to a steady value of 20 m sec.$^{-1}$, after a transient time of 30 min. According to the wind effects in a semiclosed basin, the mean sea level follows the long period components of the driving force and free modes are generally triggered by the jumps of the applied force. A constant wind value after the raising time has been used in order to investigate also the steady state wind-driven circulation. The vertically integrated equations used in the numerical model were the following:

$$\frac{\partial U}{\partial t} - fV = -g\frac{\partial Z}{\partial x} + \frac{\tau_x^w - \tau_x^b}{\rho_0 H},$$
$$\frac{\partial V}{\partial t} + fU = -g\frac{\partial Z}{\partial y} + \frac{\tau_y^w - \tau_y^b}{\rho_0 H}, \qquad (1)$$
$$\frac{\partial (H.U)}{\partial x} + \frac{\partial (H.V)}{\partial y} + \frac{\partial Z}{\partial t} = 0,$$

where U, V are the horizontal components of the mean current, Z is the surface elevation, H is the actual total depth of the water (the equilibrium depth h plus the surface elevation Z), ρ_0 is the mean sea-water density, f is the Coriolis parameter, g is the acceleration due to gravity, τ_x^w, τ_y^w are the components of the wind stress at the sea surface. The wind stress was assumed to be spatially constant over the basin in order to consider the simplest possible scheme. In deriving the above equations the following assumptions have been made:

a) the fluid is homogeneous and incompressible;
b) the pressure is hydrostatic;
c) the Coriolis parameter is constant;
d) internal friction is neglected.

As regards the representation of the bottom stress we adopted a quadratic stress law:

$$\tau_x^b = \rho_0 r U \sqrt{U^2 + V^2};$$
$$\tau_y^b = \rho_0 r V \sqrt{U^2 + V^2}, \qquad (2)$$

where r is an adimensional coefficient set to 3×10^{-3}. Furthermore the components of the wind stress were taken as:

$$\tau_x^w = \rho_a k w_x \sqrt{w_x^2 + w_y^2};$$
$$\tau_y^w = \rho_a k w_y \sqrt{w_x^2 + w_y^2}, \qquad (3)$$

where ρ_a is the air density, W_x, W_y are the components of the wind velocity and k is the adimensional drag coefficient which was set to 2.6×10^{-3}. Due to the staggered grid the equations (1) were solved explicitly using forward differences in time and centered differences in space (Sündermann, 1966; Radach, 1971). A grid of square mesh with size 10 km was employed with a time step of 30 s to satisfy the Courant-Friedrichs-Lewy criterion of numerical stability. The net consists of 24 columns increasing in the positive X direction from Nice, Côte d'Azur, to Calvi, Corsica, at the southwest of the basin towards the western

Mediterranean, and 20 rows increasing in the positive Y direction along the longitudinal axis from the SW to the NE. At the northeastern entrance towards the Tyrrhenian Sea, we adopted an artificial solid boundary joining C. Corso to Elba and the Italian mainland. Recently this delimitation of the basin provided to be reliable for reproducing the rotating seiche with a 2.6 hr period and the longitudinal seiche with a 5.8 hr period, and it this seems to be an "effective boundary" of the Ligurian basin for short time scale phenomena (Papa, 1981; 1983).

ments at Savona, where since January 1983 a pressure sensor has been in operation at about 3 m beneath the mean sea level. A detailed description of the whole apparatus will be given elsewhere; here we merely point out that the signal of the pressure transducer is digitized by an analog-digital converter in the range from 0 to about 4 m level. A microprocessor unit controls data acquisition and transmission through a radio half-duplex link from Savona to Genoa, where the signals are demodulated and analyzed in real time.

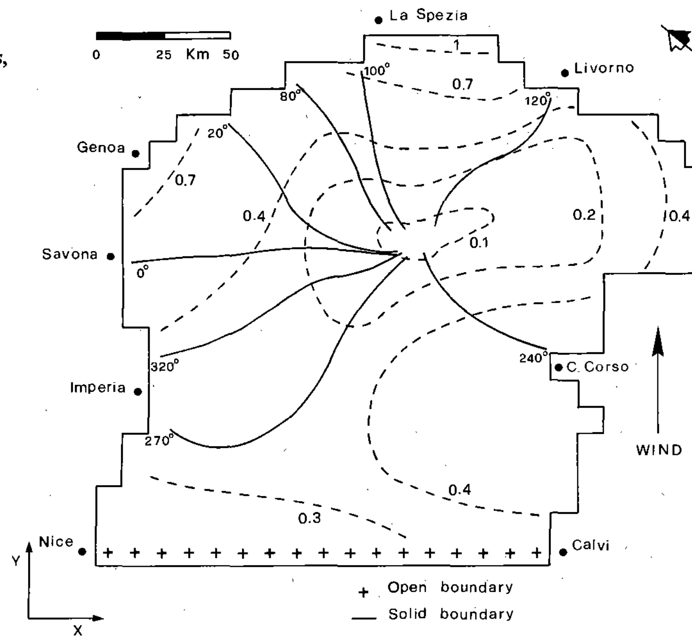

Figure 3
Mean amplitudes (dashed lines, centimetres) and phases (full lines, degrees) of the seiche with 1.9 hr period triggered by a SW wind.

The following boundary conditions were used: a) for coastal solid boundaries: normal components of the mean velocity were always zero; and b) for the open boundary from Côte d'Azur to Corsica the elevations were set equal to zero. The model was run to simulate 560 h of real time computation with regular outputs to magnetic tape at intervals of 12 min to store the elevation fields. We selected 225 special points of the grid (sample points) where we performed spectral analyses in the time interval from 150 to 201.2 hr in order to eliminate completely the transient motion of the model. With the help of the Fast Fourier Transform we computed 225 sample spectra on 256 elevation values, covering frequencies from 0 to 2.5 cph. The result of this investigation was the presence of a well-defined rotating seiche with 1.93 hr period which involves the whole Ligurian basin. The amplitude and phase distribution are shown in Figure 3. A further investigation has been made by computing spectral analyses in the time interval from 508.8 to 560 hr in order to check the seiche amplitude attenuation after a sufficiently long elapsed time from the wind excitation jump. The Fourier spectra carried out at 50 sample points did not show significant peaks at the frequency of 0.52 cph (T = 1.93 hr), in good agreement with the hypothesis of a seiche motion which is completely damped out by bottom friction.

A preliminary experimental verification along the Ligurian coast has been obtained by using sea level measure-

Sampling speed may be programmed at rates varying from 10 to 9 999 seconds. The instrumentation also has the capacity of averaging up to 9 999 samples (sample time is typically 10 milliseconds), in order to cut off the short-period wind waves and to increase the signal to noise ratio. The experimental analysis here described has been computed from a sea level record in the interval January-February 1983 using a 15 min. sampling time. A power spectrum computed following standard techniques (Bendat, Piersol, 1966) provided a significant peak at 0.53 cph (T = 1.9 hr) with a mean amplitude of 0.25 cm, as computed from the frequency band: 0.51-0.55 cph (40° of freedom; Fig. 4). The spectral

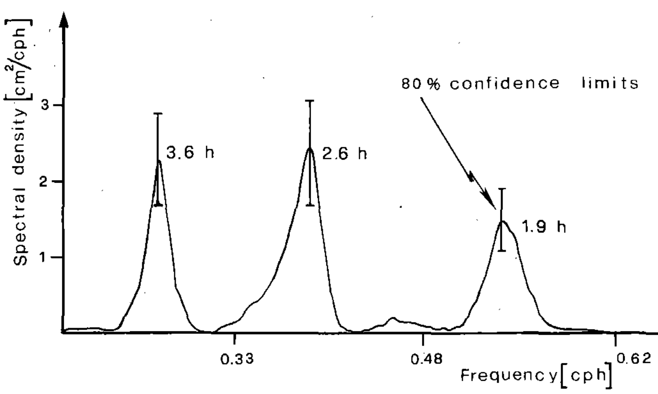

Figure 4
Power spectrum of sea level record at Savona in the interval January-February, 1983 (40° *of freedom*).

peak at 0.27 cph (T = 3.66 hr) represents the longitudinal uninodal seiche of the Ligurian Sea which was previously computed by means of an H-N numerical model (Papa, 1977). The non-astronomical character of the 1.9 hr period wave has been stated by means of six successive 5 day spectra which provided a mean wave period of 1.9 hr with an amplitude fluctuation of ~ 40%. In the light of these results, we advance the hypothesis that this spectral peak could actually represent the rotating seiche motion predicted by the numerical simulation.

A second numerical simulation was carried out using a wind field from the SE, in order to determine the seiche response to this wind direction. As before, a steady value of 20 m $sec.^{-1}$, after a transient time of 30 min., was used in the simulation. Spectral analyses at 50 sample points have shown no alteration in the period of the seiche, the amplitude being less pronounced in comparison with the previous simulation (attenuation factor ~ 0.2). From this result it seems reasonable to conclude that during storm surges an impulsive southwesterly wind is the primary forcing mechanism of this rotating seiche of the Ligurian Sea.

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