CHAPTER 40

THE WAMS MODEL APPLIED TO THE MEDITERRANEAN SEA

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Summary

The application of an advanced third generation wave model to the Mediterranean Sea is described. The model is based on the physical description of the wind wave evolution, avoiding any shortcoming in the estimate of the single terms that contribute to the energy budget. The capability of the model to respond to any meteorological situation is illustrated by applying it to a severe storm occurred in January 1987. The results show that the crucial point for the final accuracy lies in the correct evaluation of the wind field.

Introduction

The SWAMP study (SWAMP, 1985), intercomparing the results of ten different wave models for some well defined tests, made clear that, for any drastic improvement in the field to arise, a completely new approach to the problem was to be taken. In particular any shortcoming in the description of the wind wave evolution had to be released, and the problem had to be

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approached only on a physical basis. Being beyond the capability of any single group, the task was faced by a whole team of modellers. The result is the so-called "third generation WAM wave model" (WAMDI-Group, 1988).

While most of the WAM group interest was in the large oceans, we have focused our attention on the Mediterranean Sea. This is a quite interesting basin, with a rather complicated meteorology. Occasional very heavy storms are present, which, from the point of view of a modeller aiming at a detailed study, have the advantage of being free of any distant swell eventually affecting the local results. In the following sections we give a brief description of the model, of its implementation in the basin, and we discuss the implications of the results.

The WAM Model

The WAM model, or WAMS, in its shallow water version used for the Mediterranean Sea, is based on the numerical integration of the energy balance equation. It is assumed that wave conditions at a given time t and location ϕ and λ (ϕ =latitude, λ =longitude) are represented by the two-dimensional spectrum $F(f, \theta, \phi, \lambda, t)$, f and θ being the frequency and direction that characterize the single wave component. The evolution of F() on the spherical earth is governed by the transport equation

$$(1) \quad \frac{\partial F}{\partial t} + (\cos\phi)^{-1}\frac{\partial}{\partial \phi}(\dot{\phi}\cos\phi\, F) + \frac{\partial}{\partial \lambda}(\dot{\lambda} F) + \frac{\partial}{\partial \theta}(\dot{\theta} F) = S$$

where S represents the local source function and the dots represent derivatives with respect to time.

Specifically

$$(2) \quad \dot{\phi} = v R^{-1} \cos\theta$$

(3) $$\dot{\lambda} = v \sin\theta \, (R \cos\phi)^{-1}$$

(4) $$\dot{\theta} = v \sin\theta \, \tan\phi \, R^{-1}$$

Here v is the group velocity and R is the radius of the earth.

The left side of the energy balance equation represents the kinematics of wind waves, i.e. the advection, and its solution is purely a mathematical problem. The physics of waves, the dynamics of the problem, is on the right side term S that is considered as composed of three parts

(5) $$S = S_{in} + S_{nl} + (S_{bn} + S_{bf})_{dis}$$

S_{in} represents the input of energy from the wind based on the Miles process,

$$S_{in} = \beta F$$

where the expression for β is adopted from Snyder et al. (1981). With respect to the original expression the model uses a slightly modified version of β based on the friction velocity U_* . It is given by Komen et al. (1984) as

(6) $$\beta = \max\left(0.,\ 0.25 \frac{\rho_a}{\rho_w}\left(28 \frac{U_*}{c} \cos\theta_w - 1\right)\right) \cdot \sigma$$

($\sigma = 2\pi f$, ρ_a , ρ_w = air and water density, c = water

phase velocity, Θ_w = angle between wind and wave direction).

S_{nl} represents the nonlinear conservative energy exchanges between all the possible quadruplets of wave components that satisfy given resonance conditions. Requiring enormous computer power for its evaluation, the evaluation of S_{nl} has been brought within the actual operational capabilities by the discrete interaction operator parametrization proposed by Hasselmann et al. (1985).

The accuracy of the procedure has been proved by direct comparison against the full calculation results done for different spectral shapes. In shallow water the nonlinear exchanges are corrected by a scaling factor evaluated according to Harterich and Hasselmann (1980). The involved approximation is within acceptably small limits in the range $kd > 0.8$ (k is wave number, d is depth).

S_{dis} represents the dissipation processes, and it can be conveniently split into whitecapping and bottom interaction processes. Whitecapping or breaking is the only relevant dissipation term in deep water. For its evaluation the model uses a modified version of the expression proposed by Komen et al. (1984) given as

$$S_{br} = -2.33 \cdot 10^{-5} \tilde{\omega} \left(\frac{\omega}{\tilde{\omega}} \right)^2 \left(\frac{\tilde{\alpha}}{\tilde{\alpha}_{PM}} \right)^2 F \tag{7}$$

The tilde represents a slight appproximation to the exact values as, for stability reasons, mean circular frequency $\tilde{\omega}$ is obtained as the inverse of the mean period. Specifically

$$\tilde{\alpha} = E \omega^4 / g^2 \tag{8}$$

(9) $$\hat{\alpha}_{PM} = 3.02 \cdot 10^{-3}$$

E is the overall energy, g the acceleration of gravity.

The only bottom dissipation process permanently considered in the model is bottom friction. The bottom friction is expressed by

(10) $$S_{bf} = -\frac{\Gamma}{g^2} \frac{\sigma^2}{\sinh^2 kd} F$$

a parametrized expression deduced form the JONSWAP study (Hasselmann et al., 1973, henceforth referred to as J) with the constant Γ =0.038 m s.

Equation (1) includes the long distance refraction of wave train associated with the great circle path. For shallow water this term, given by (4), is augmented to include the refraction due to the variation of water depth.

In the actual version the model considers 25 frequencies in geometric progression (f_1 =0.0418 hz, f_{n+1} =1.1 f_n), and 12 directional bands with 30 degree resolution. Beyond the upper frequency limits (F_{25} =0.4114 hz) the spectrum is completed with a f^{-4} tail.

WAM Implementation in the Mediterranean Sea

Two grids, with different resolution, have been used to represent the geometry of the basin, respectively with 0.25 and 0.50 degree resolution. In this paper we describe the former, applied to the western Mediterranean Sea.

The grid is shown in Fig. 1. It covers the area from Gibraltar till Bengasi at the right end of the Sirte Gulf. The 0.25 degree resolution corresponds to

20-24 km in longitude and 28 km in latitude. This is largely enough to describe with good accuracy the geometry of the coasts. Obviously, if detailed studies were to be carried out at a single location, a nested high resolution model should be used. We point out how this implementation requires almost as many points as the global model at the three degree resolution described by the WAMDI-Group (1988).

The advection and integration time steps have both been fixed at 15 minutes. The outputs are available at 3-hour intervals. All these are optional quantities. In the actual form the model requires 5 minutes of CPU on a CRAY X-MP48 for each day of simulation.

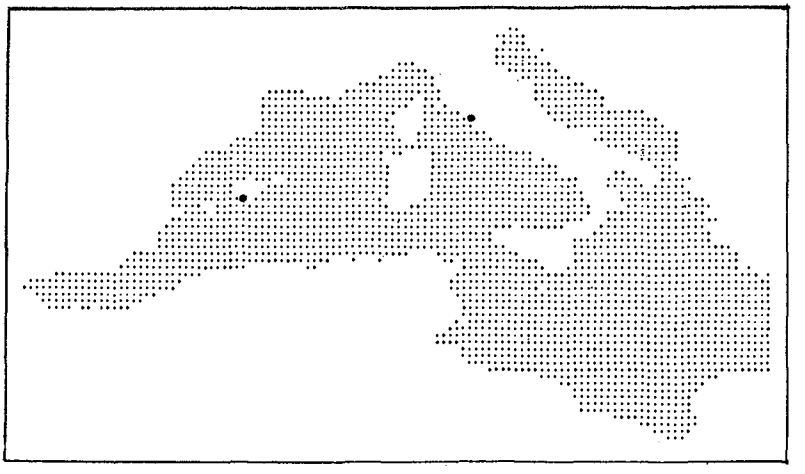

Figure 1. Grid covering the western Mediterranean Sea The resolution is 0.25 degree. Dots indicate wave recording positions.

Wind Fields

Two main sources of wind fields are available for the Mediterranean Sea, the European Centre for Medium Range Weather Forecasts (ECMWF) and the British

Meteorological Office (BMO). the latter has been used for the hindcast here reported.

The BMO runs a global model within which a high resolution nested model is used to describe in detail the wind over Europe. In this area, and in particular over the Mediterranean Sea, the wind is provided at the knots of a geographic grid with 0.9375 degree resolution in longitude and 0.75 degree for latitude. This corresponds to a step size of 70-80 km. The wind is available at 1-hour intervals, and it is linearly interpolated in longitude and latitude to provide the wind fields in correspondence of the WAM grid. At the same time, prior to the use by the wave model, the wind is transformed into wind stress according to the formula

$$U_*^2 = c_D \; U^2$$

where c_D is a friction coefficient that is again a function of U given by (WAMDI-Group, 1988)

$$c_D = \max(1.2875,\ 0.8+0.065\ U)\ 10^{-5}$$

Severe Events of 10-15 January 1987

Several major storms have been hindcasted and compared with measured data. The results show in general the very good performance of the WAM model, even in basins with complicated geometry as the Mediterranean Sea. As an example we report here the results for a period of severe events that took place in the first fortnight of January 1987. Between 10 and 15 January two sequential storms entered the western Mediterranean producing heavy sea conditions twice at a short interval. Fig. 2 reports the wave fields (significant wave height H_S , in meters) for 03 and 21 UT of 11 January.

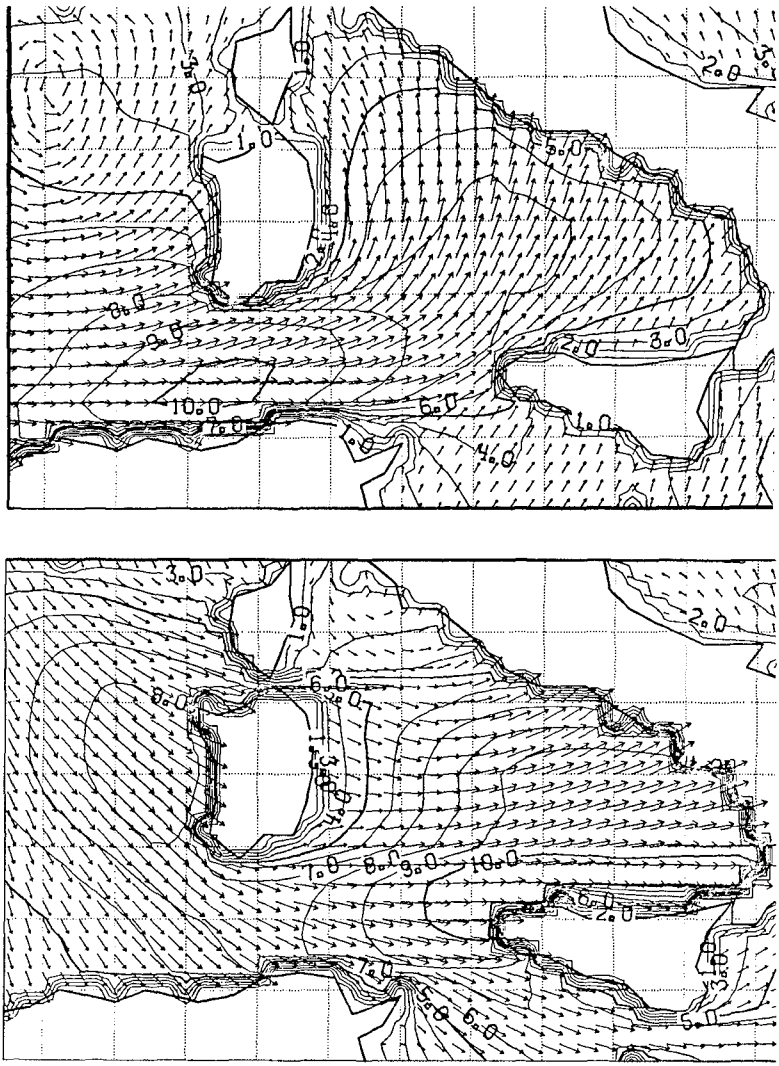

Figure 2. Wave fields for 03 and 21 UT of 11 January 1987.

Several wave measuring stations were active during this period. Anyhow most of them are of little use because of short fetch or secluded locations. The two main sources of information came in this case from Palma de Mallorca, in the Balearic Islands, and Montalto di Castro on the west coast of Italy marked by dots in Fig. 1. At both stations a Waverider buoy was operating, and the records were taken for 20 minutes at 3-hour intervals. Fig. 3 shows the H_s comparison between model and experimental data at Palma for the period 8-15 January. Both the storms are well reproduced, particularly in the growing stage, the decay being anticipated a few hours by the hindcast. This is likely, as from direct inspection of the maps, to be strictly dependent on the input wind fields.

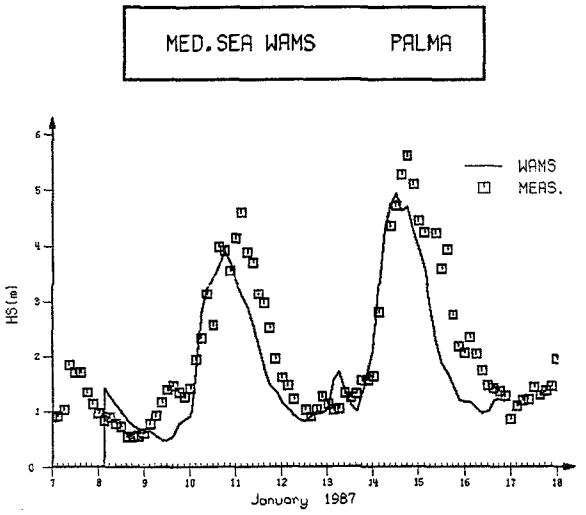

Figure 3. Model results versus experimental data at Palma de Mallorca (see Fig. 1).

Fig. 4 shows four sequential 2-dimensional spectra at Palma out of the model. The arrow in each figure represents the direction of the local and actual wind (the modulus is shown in the lower righthand corner, 1.0 corresponding to about 18 m/s). Ten levels of energy, scaled on the peak value, are shown. The three complete circles are at 0.05, 0.10 and 0.20 hz frequency.

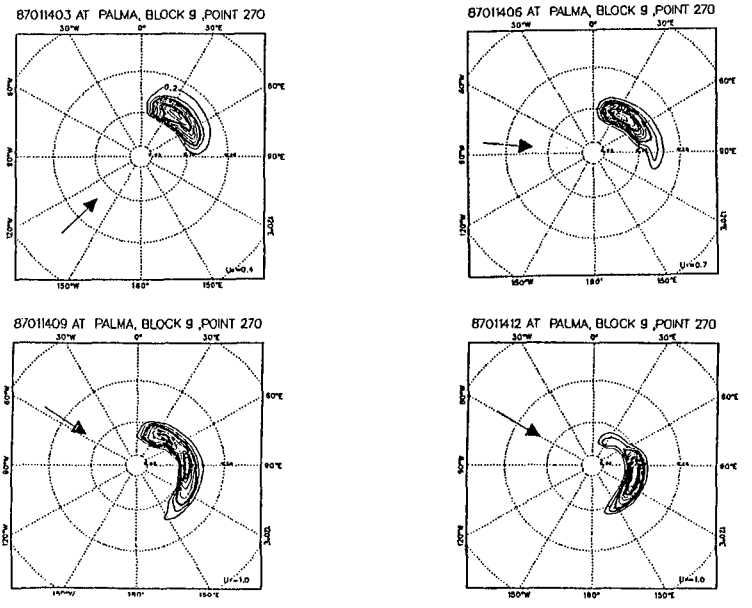

Figure 4. Four sequential 2-dimensional spectra at Palma de Mallorca on 14 January 1987.

The sequence is simultaneous to the passage of the cold front. The wind is firstly from the southwest, ahead of the front, and a well developed 3 meter sea is present in the same direction. While the front is passing (next map of 06 UT) a local wind sea begins to develop in the new wind direction, then quite evident in

the next spectrum of 09 UT. The swell to the northeast is still very strong. A few hours later, at 12 UT, a major storm has developed in the new direction, with H_s up to almost 6 meters, and only a slight swell still propagating to the northeast.

Fig. 5 shows the H_s history at Montalto. On the general trend the storm is well reproduced, but the experimental field showed wild oscillations only partially reproduced in the hindcast. Supported also by evidence of the local wind record, we believe this to be due to oscillations of the wind field largely smoothed by the atmospheric model.

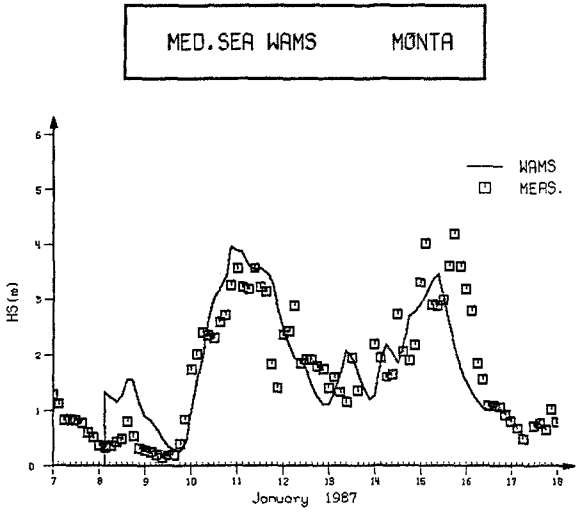

Figure 5. Model results versus experimental data at Montalto di Castro (see Fig. 1).

Conclusion

The main advantage of a physical approach to wind wave description is that the resulting model has no limitation, and it can be reliably applied to any meteorological situation also in basins with very complicated geometry. Together with the ones reported by the WAMDI-Group (1988), the results we have obtained confirm the above statement and the validity of the approach. On the other hand the sensitivity of the results to limited variations of the wind field transfer the problem to the meteorological input. The correct definition of the surface field in the Mediterranean Sea is not an easy task, as proved by detailed tests carried out by Dell'Osso (1984) for the Alpex experiment. It is our feeling that, for the full exploitations of the WAM model capabilities, high resolution local wind models are required to provide correct input in the area of interest.

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