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Operational numerical wind-wave model for the Black Sea

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Abstract

In this paper the discrete spectral shallow water wave model named VAGBUHL1 is presented. This model is used for real-time Black Sea state forecasting. The model was verified against satellite ERS-2 altimeter wave height data.

Keywords: Wind-waves, Wave model, Forecast, Black Sea.

Introduction

The considerable increase in the requirements for Black sea forecasts in the recent years has led to the development of a numerical wave forecasting system at the Bulgarian National Institute of Meteorology and Hydrology (NIMH).

The wave model used in this study is the shallow water discrete spectral wave prediction model VAGBULH1. This is a shallow water extension to the METEO-FRANCE wave model (named from the French word for ocean wave "vague") (GOLDING 1983; GUILLAUME, 1990), implemented for the Black Sea. The shallow water effects are included by representation of a shoaling refraction and a bottom friction.

The numerical wave model VAGBULH1 has been in operational use in the Forecast department of the NIMH since December 1996 to provide wave forecasts for the Black Sea.

General characteristics of the VAGBULH1 wave model

The wave model used in this study has been derived from the deep water VAG wave model that is operational at the French meteorological office - Meteo-France for the North Atlantic and the Western Mediterranean marine forecast. The shallow water modification of the VAG model was done in the department of marine forecast of METEO-FRANCE for the North Sea (KABIDI, 1995.), an adaptation was done for the Black Sea area (KORTCHEVA, 1996). Full description of the VAG wave model is given in (GUILLAUME, 1990).

The numerical wave model VAGBULH1 has been formulated in terms of the basic transport equation for two-dimensional wave spectrum. The evolution of the two-dimensional ocean wave spectrum E (f,□,□,□,t) with respect to the frequency f and the direction □ as a function of the latitude □ and the longitude □ on a spherical earth is governed by the transport equation:

$$\frac{\partial E}{\partial t}+\frac{1}{\cos\varphi}\frac{\partial}{\partial\varphi}\left(\frac{d\varphi}{dt}\cdot\cos\varphi\cdot E\right)+\frac{\partial}{\partial\lambda}\left(\frac{d\lambda}{dt}E\right)+\frac{\partial}{\partial\theta}\left(\frac{d\theta}{dt}E\right)=S \qquad (2.1)$$

Where S is the net source/sink term: S =Sin+Sds+Sbf+Snl.

Sin is the energy input from the wind, Sds is the dissipation term due to the white capping, Sbf is the bottom friction term and Snl is the non-linear interaction term.

The energy input Sin, is represented by linear growth term given by (GOLDING, 1983),

$$\begin{cases} Slin(f,\theta)=3.18.10^{-6}\frac{2}{\pi}\cos^2(\theta-\theta_w);\ f=f_{max},\ |\theta-\theta_w|<90^\circ \\ 0-otherwise \end{cases} \qquad (2.2)$$

- and an exponential growth term given by (Snyder et, al., 1981)

$$\begin{cases} S\exp(f,\theta)=0.054.2\pi f\frac{\rho_a}{\rho_W}\left[\frac{U\cos(\theta-\theta_W)}{c}-1\right]* \\ F(f,\theta);if.\frac{U\cos(\theta-\theta_W)}{c}>1 \\ 0-otherwise \end{cases} \qquad (2.3)$$

where: fmax is the maximum frequency in the model

U is the wind speed

□ is the direction of wave propagation

□ is the direction of the wind

□ and □w are the densities of air and water respectively

c is the phase velocity of the spectral component.

- a dissipation term given by (GOLDING, 1983):

$$Sds(f,\theta)=4.10^{-4}f^2E^{0.25}F(f,\theta) \qquad (2.4)$$

- an additional bottom friction term Sbf was taken in the model for shallow water conditions:

$$Sbf=-\frac{\Gamma}{g^2}\frac{\omega^2}{\sinh^2(kh)}E(f,\theta) \qquad (2.5)$$

Where □ is a constant, h is the depth.

The non-linear interactions Snl are treated after growth and dissipation. The total energy is not modified, but the windsea spectrum is separated from the full spectrum at each time step. In this spectrum the energy redistributes following a JONSWAP spectrum (HASSELMAN, 1973).

An important aspect of the wave model is its modular structure. Namely, two main tasks: integration for the advection term and for the source term are isolated. A first order "upstream" propagation scheme was implemented for the integration of the advection term. For the integration of the source term, a first order explicit scheme was implemented.

A spherical (latitude/longitude) grid with a 0.25° spatial resolution including 730 sea grid points was used.

The propagation time step is set at 15 minutes, within the stability limits of the first order, upwind advection scheme and for the integration of the source terms.

The wave energy spectra is divided into 22 frequency bands ranging from 0.04 Hz to 0.42 Hz and 18 regularly spaced direction bands of propagation (□□=20°).

Six hourly forecasts of the surface wind components at 10 m from the operational atmospheric model EUROPE of RSMC-Offenbach are used to force the wave model. The wind fields are available with a 0.5° space resolution and have been then linearly interpolated on the 0.25° resolution grid of the VAGBUL1 wave model.

The output from the numerical VAGBUL1 wave model gives the significant wave height, the mean direction of wave propagation and the mean period, all these for the windsea and for the swell every 6 hours.

The wave model is run in forecast mode, twice per day, starting from 0000 UTC and 1200 UTC, out to 3 days.

Wave products are converted to the binary GRIB code and distributed through a telecommunication network from Sofia to the local meteorological branch in Varna.

Verification of VAGBULH1 wave model

The wave model evaluation for the Black Sea is a difficult task because of lack of conventional wave data from buoys and weather ships. Recent advances in satellite technology have created a possibility to use remotely sensed wave data for wave model validation.

The ERS-2 altimeter data

The second European Remote Sensing Satellite ERS-2 of the European Space Agency was launched in July 1995. Two devices were mounted on the ERS-2, which have been providing information on the wind and waves: the altimeter and the Synthetic Aperture Radar (SAR). The altimeter provides measurements of the Significant Wave Height (SWH) along the satellite track with a good accuracy (QUEFFEULOU, 1996; KORTCHEVA, 1998).

The altimeter SWH was collocated with the VAGBULH1 model results using classical criteria, i.e. a distance between model grid point and footprint of the satellite instruments less than and in time difference less than 1 hour.

Only valid ERS-2 altimeter SWH was considered for the verification. The ERS-2 altimeter data are discarded when SWH standard deviation is equal to zero. A second quality control has been performed in order to reduce the amount of spurious data that had not been detected by the quality flags. The standard deviation of SWH calculated in each box is regarded as an indicator of the spatial homogeneity of the measurements: the average value is rejected, if the standard deviation is too large (higher than 0.25% of the mean value). Observations deviating by more than 3 standard deviations from the mean in each box were also rejected.

To correct the ERS-2 underestimated of the SWH in range from 1 to 10 m the relationship obtained in (OUEFFEULOU, 1996) was used:

$$SWH_{cor.} = 1.09 \cdot SWH_{ers-2} - 0.12 \qquad (3.1)$$

Comparison between model and ERS-2 data

A wave model in operational use will usually be forced by **forecast** winds to produce **wave forecasts**. However, the wave model may also be driven by **analysed** winds pertaining to past events, such as the storm situations. In such cases the wave field is called **hindcast** wave field.

For operational forcing of the VAG model are used wind fields from Offenbach. But for the hindcast study were used wind fields analysis from the ARPEGE model, because only these wind fields were available during that study (KORTCHEVA, 1996). The wind fields used to drive VAGBULH1 wave model were 10-m wind speeds analyses from the French numerical weather prediction model ARPEGE (COURTIER *et al.,* 1991). The model data are available every 6 hours at four standard meteorological times 00,06,12 and 18 UTC, on a regular latitude-longitude grid with a 0.5°x 0.5° mesh size.

Retrospective analysis has been carried out in order to compare results from VAGBULH1 (forced by ARPEGE wind fields) with satellite altimeter data from ERS-2. The wave model has been qualified for various typical meteorological situations during the 1995-1996 (KORTCHEVA, 1996). In that study the comparison between ERS-2 altimeter data with SWH from the shallow versions of the wave model VAGBULH1 is presented. The comparison between the model and the measured values of the mean wave period were not done, because the altimeter and buoy measurements were not available for the examined period.

Statistics of collocated data sets of the ARPEGE wind speeds with satellite measurements are shown in Table 1. Mean differences and standard deviations are in m/s. The collocated data sets contain 13289 collocated points for ERS-2.

Table 1

	Mean (m/s)	Mean Difference	std deviation	correlation
ARPEGE Winds	7.37	-0.03	2.23	0.814
ERS-2 winds	7.40			

Table 2

	Mean (m)	Mean Difference	std deviation	correlation
VAGBUL 1 SWH	2.35	-0.19	0.63	0.873
ERS-2 SWH	2.54			

Statistics of collocated data sets of SWH hincasted by VAGBUL1 wave model forced by the ARPEGE winds and satellite measurements are shown in Table 2. The collocated data sets contain 13289 collocated points for ERS-2.

On the average (Table 2) the model SWH are 0.19m lower than ERS-2. The standard deviation of the differences (0.63 m) is in agreement with the VAG model performances (0.56 m - result from 1-month comparison of VAG hindcast to buoy data [GUILLAUME, 1990]).

Figure 1 shows the VAGHBUL1 model output along with the satellite ERS-2 values of SWH for 29th December 1996 at 20 00.

Conclusions

In this paper it is shown that the second-generation model VAGBUL1 is still a valuable tool for wave prediction for the Black Sea. This model is much simpler to handle than the third generation one because of the treatment of the non-linear term. The second-generation model VAGBUL1 is much easier to implement and uses less computer resources.

The results of statistical analysis of comparing the model SWH with altimeter data from ERS-2 are summarised in Table 2. The model SWH comparison with the ERS-2 SWH (Table 2) indicates a 0.63 m standard

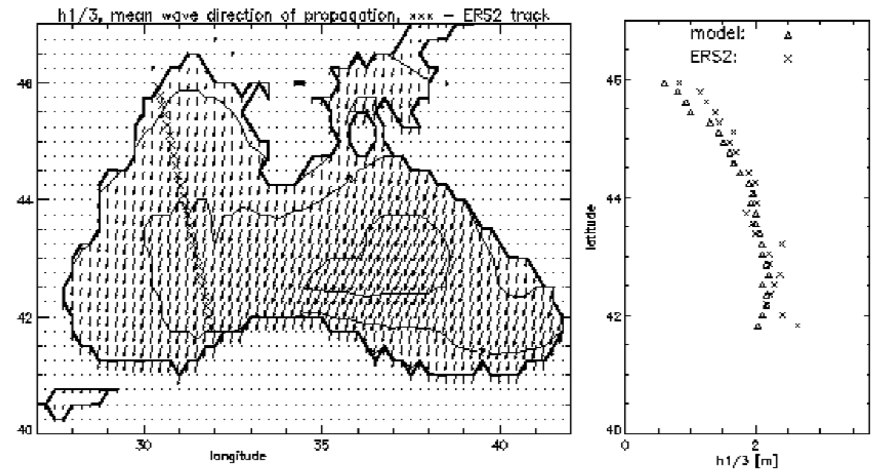

Fig. 1: The VAGHBUL1 model output along with the satellite ERS-2 values of SWH for 29th December at 20:00.

deviation of the error in case of ARPEGE wind input, which agrees with the accuracy of the VAG wave model (0.56 m) (GUILLAUME, 1990).

The computer power in the NIMH is not sufficient for running the third-generation wave model WAM. But after the installation of a new SUN Workstation in NIMH it would be possible to implement the WAN model in order to compare the results obtained from the both models.

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