Section 8

Development of and advances in ocean modelling and data assimilation, sea-ice modelling, wave modelling

A System of Wind Wave Forecasting in the World Ocean and Seas of Russia. The System's Structure and its Main Constituents

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1. Introduction

A system of wind wave forecasting has been developed and put into trial operation mode in the Hydrometcentre of Russia (RHMC). The system is aimed at operational forecasting of wind wave in the World Ocean and seas of Russia.

2. Wind wave models

The computational core of the system consists of wind wave models with open source software: WAVEWATCH III (version 3.14) [3]and SWAN (version 40.81) [2]. Both of them are third-generation models based on finite difference solving of the balance equation of the spectral wave action in the approximation of phase averaging.

Program codes of both the wave models allow one to calculate the development over time of spectral density distribution of the sea surface variance using input data on surface wind speed, surface currents, sea level, and in the WAVEWATCH III also on sea-air temperature difference and sea ice concentration. The derived quantities of practical interest for consumers of marine information such as significant wave height (SWH), mean wave length, mean period, propagation direction, etc. may then be determined from known spectral density. The special feature of the SWAN model, in comparison with WAVEWATCH III, is its ability to simulate more accurately the wave processes in shallow water and coastal zone.

Calculations are executed on a regular latitude-longitude grid over space, a regular directional grid and a logarithmic frequency grid. In the WAVEWATCH III model it is possible to construct multi-grid tasks in order to provide the higher spatial resolution for some parts of a principal marine basin (gulfs, straits, bays, etc.). In the SWAN model it is possible to adopt boundary conditions from the WAVEWATCH III model using its output data.

The WAM4 version of wind generation and energy dissipation with the BAJ set of parameters have been chosen from a variety of parameterization options provided by the WAVEWATCH III model software [3]. The frequency grid is specified by 25 terms of a geometric sequence with a scale factor 1.1 and the first frequency 0.042 Hz. The propagation directions are discretized with a 15º step (24 directions). In the SWAN model the GEN3 Komen AGROW parameterization option is used to provide the possibility of wave generation from calm conditions [2]. The frequency grid is specified by 40 terms of a geometric sequence with a scale factor 1.07 and the first frequency 0.042 Hz. The propagation directions are discretized with a 10º step (36 directions). The calculations for the nested regions (see the Table) are carried out within a single task using the multi-grid technology in the WAVEWATCH III model and as a separate task in the SWAN model with adaptation of boundary conditions.

3. Input data

Bathymetry and the corresponding land-sea mask for each of the basins are constructed using the GEBCO resource (The General Bathymetric Chart of the Oceans), containing the gridded bathymetry data on a global 30 arc-second grid (about 500×900 m in mid-latitudes) [6].

The data used to force the wave models, such as data on wind speed, sea-air temperature difference, sea ice concentration, are taken from output products of several weather forecasting systems: a global Semi-Lagrangian Model (SLM) of RHMC and INM/RAS [4], a Global Forecast System (GFS) of NCEP/NOAA [1], a mesoscale model operating at the Hydrometcentre of Russia (COSMO-RU) [5].

Marine basins, for which the wind wave forecasting is performed, computational grids and sources of prognostic meteorological information used as input are listed in the Table.

4. Initial conditions

Initial conditions for each forecast, consisting of spectral density distribution of sea surface variance at the start time, are generated during the previous forecast cycle. The procedure is also developed for model initialization using the series of wind field analysis over a period preceding the forecast start. The forecast start is referred to one of the main times of meteorological forecasts, and thus the most complete set of daily products can include the wind wave forecasts from 00, 06, 12 and 18 UTC.

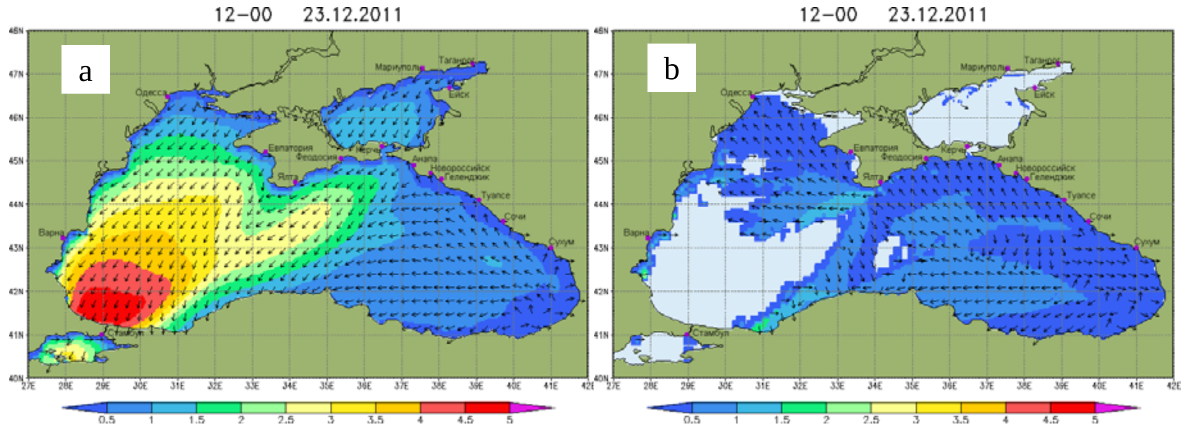
5. Forecast products

The forecasts based on wind wave model computations are disseminated as prognostic charts of common wind wave parameters: SWH, mean propagation directions, mean lengths and periods, mean heights and propagation directions of swell, mean heights and propagation directions of purely wind waves, periods and directions of peak waves. In selected points of marine areas the diagrams of wave energy spectral density in the frequency-direction coordinates are constructed.

The products of the forecasting system functioning in automatic mode are presented as maps at a Web site. An example of the products is shown in the Figure.

Marine basins, computational grids and sources of prognostic meteorological data in the system of wind wave forecasting

Principle basin	Nested regions	Grid	Lead time / output time step (hours)	Source of meteorological data
The World Ocean	Ocean	0.5°× 0.5° (~55 km)	120/3	SLM, GFS
	Arctic	15.0′×6.0′ (~10 km)	120/3	SLM, GFS
Black Sea	Black Sea	6.0′×6.0′ (~10 km)	120/3	GFS
	Sea of Azov	1.2′×1.2′ (~2 km)	120/3, 48/3	GFS, COSMO
	The Kerch Strait	0.3′×0.3′ (~0.5 km)	24/1	COSMO
Caspian Sea	Caspian Sea	3.6′×3.6′ (~6 km)	120/3	GFS
	Northern Caspian	1.2′×1.2′ (~2 km)	120/3, 48/3	GFS, COSMO
Baltic Sea	Baltic Sea	4.8′×2.4′ (~4 km)	120/3	GFS
	Gulf of Finland	2.4′×1.2′ (~2 km)	120/3, 48/3	GFS, COSMO
	Neva Bay	0.24′×0.12′ (~0.2 km)	24/1	COSMO
Barents Sea	Barents Sea	6.0′×2.4′ (~4 km)	120/3	GFS
	The White Sea	3.0′×1.2′ (~2 km)	120/3, 48/3	GFS, COSMO



An example of the output products. Forecast for 36 hours starting from 22/12/2011 of significant wave height (a) and of swell height (b) in the Black and Azov Seas. The arrows indicate the mean directions for all spectral components (a) and for swell (b).

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Verification of the Wind Wave Forecasting System for the Black, Azov and Caspian Seas

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1. Introduction

Since 2010, the Russian Hydrometeorological Centre is gradually putting into operation the components of the system aimed at operational wind wave forecasting in the World Ocean and seas of Russia: the Black, Azov, Caspian, Baltic, Barents, and White. The forecasting is performed through the computations with wind wave spectral models WAVEWATCH III and SWAN. The computations inherently involve the usage of meteorological forecast products [3]. At the first stage of the system exploitation the verification has been performed in appliance to the forecasts for the Black, Azov and Caspian Seas.

2. Forecasts

The forecasts were compiled up to 5 days using the WAVEWATCH III v. 3.14 model giving the output every 15 minutes. The initial conditions were taken from a previous 1 day forecast. The spatial grid resolution was about 10 kilometers in the Black Sea, 2 km in the Azov Sea and 6 km in the Caspian Sea. The model output data were interpolated in time within the 15-minute intervals and in space within a grid cell in order to ensure the temporal and spatial match of predicted and measured data.

3. Data for verification

Forecasting errors were estimated by comparing with satellite altimeter data on Significant Wave Height (SWH) from the Radar Altimeter Database System (RADS) supported by the Delft Institute for Earth-Oriented Space research (DEOS) [1]. The RADS is updated with altimeter data from Earth resources satellites, such as Jason-1, Jason-2, Envisat-1, ERS-2. The network of tracks for three of these satellites over the Black Sea-Caspian region and the spatial SWH data coverage over the Black Sea are shown in Figure 1.

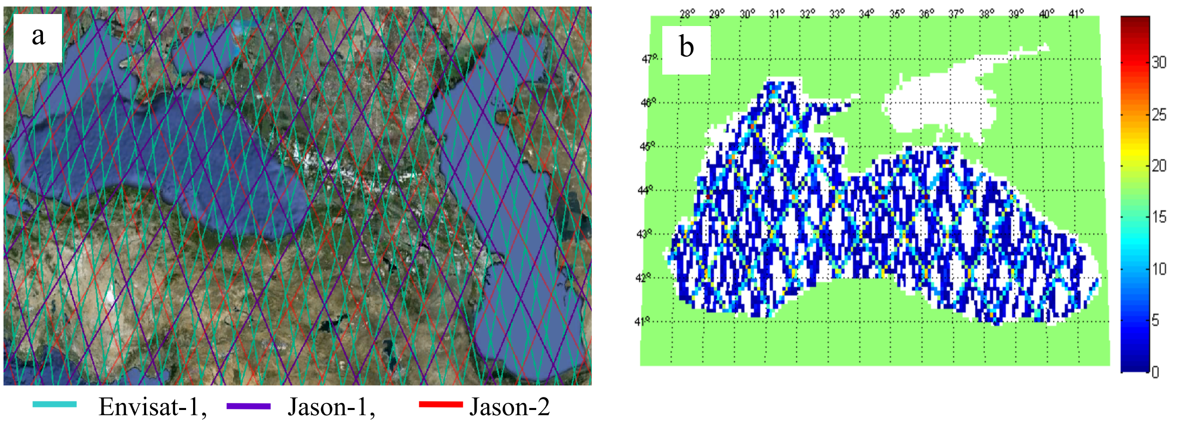

Figure 1. The network of tracks for Envisat-1, Jason-1 and Jason-2 satellites over the Black Sea-Caspian region (a), and the averaged number of data during a day in 1° × 1° cell over the Black Sea (b).

The accuracy of the satellite SWH data itself after bias calibration is max (0.4 m, $0.1\times SWH_{measured}$) [2]. For additional noise filtering, only those data were selected from the original dataset, for which the standard deviation of the signal recorded more than 1700 times per second and then averaged over 1 sec time intervals, didn't exceed 0.1 m. The cases were also excluded, for which model and measured SWH values didn't exceed 0.05 m.

4. Forecast errors

The model and RADS data comparisons were performed through the time period 15.04.2011–30.11.2011.

Mean error (bias), root mean square error (RMSE) and correlation coefficient (CC) between forecasted and measured SWH values were selected as statistical measures of the forecast accuracy.

The absolute values of mean errors were relatively small during the period under consideration, slightly increasing with an increase of lead time from 0.01–0.08 m to 0.09–0.16 m. In most cases the bias has remained negative, indicating some underestimation of wave heights' prediction in comparison with measurements.

An example of scatter plots, giving an idea of the degree of compliance between forecasted and measured SWHs for the second forecast day, are shown in Figure 2, and the dependence of RMSE and CC on the lead time – in Figure 3.

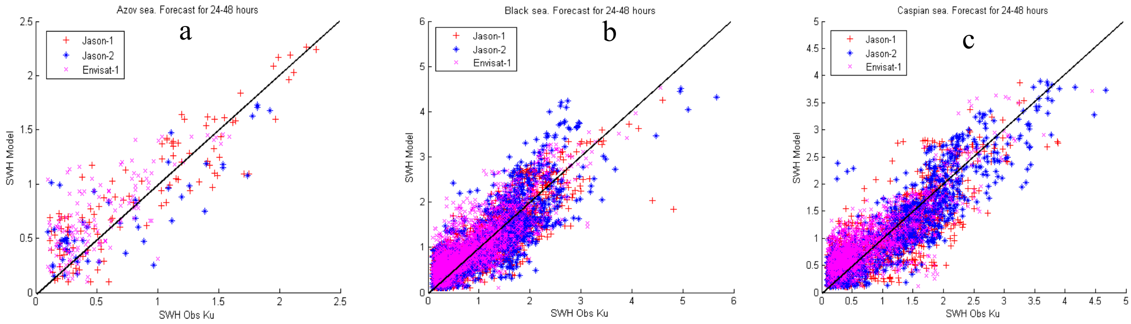

Figure 2. Scatter plots of prognostic and measured SWHs for the second forecast day over the period 15.04.2011–30.11.2011: (a) for the Azov Sea, (b) for the Black Sea, (c) for the Caspian Sea.

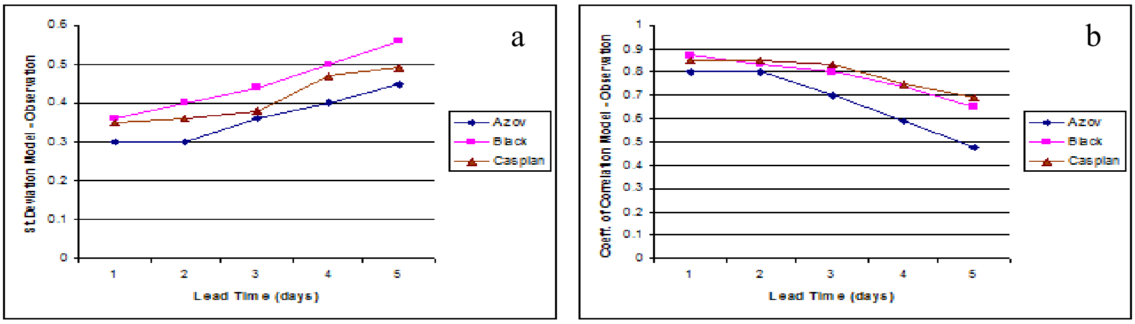

Figure 3. Mean-square difference between forecasted and measured SWHs (a) and correlation coefficient between them (b) for different lead times from 1 to 5 days for each of the Seas.

One can see in the figures that the RMSE of the forecast increases with extending of lead time (LT) from 0.3–0.36 m for the first day up to 0.45–0.56 m for the fifth day. Correlation decreases from 0.80–0.87 for the first day down to 0.48–0.69 for the fifth day.

5. Dependence on wind uncertainties

Deterioration of the forecast quality with LT increase is conditioned to a large extent by the increase of uncertainty of wind speed data used as input in the wave model. The increase of the correlation coefficient between the errors of forecasted SWH and the uncertainties of wind speed data with increasing LT (shown in the Table) makes it evident. The wind speed uncertainties were determined by comparing the wind speed from meteorological forecasting model with satellite wind measurements contained in the RADS database together with SWH data. Thus, we can expect that the accuracy of forecasts for the current version of the wind waves forecasting system will increase with improvement of weather forecasting.

Correlation coefficient between the errors of forecasted SWH and the uncertainties of wind speed data used as input in the wave model for different lead times from 1 to 5 days

Sea	Forecast lead time LT, days				
	1	2	3	4	5
Azov	0.57	0.57	0.69	0.76	0.82
Black	0.48	0.57	0.61	0.67	0.71
Caspian	0.47	0.52	0.54	0.63	0.62

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