HIGH RESOLUTION WAVES AND WEATHER FORECASTS USING ADAPTED WAVEWATCH III AND WRF MODELS

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Abstract. High-resolution waves forecast for inland water body was proposed with the use of WAVEWATCH III wave model forced with wind data from WRF atmospheric model. Different surface layer parameterizations and planetary boundary layer parameterizations were tested within WRF. The results were compared with the results of the in-situ measurements.

1. Introduction

High resolution waves forecast is in demand for nearshore areas and for inland water bodies [1]. Nowadays wave models (e.g. WAVEWATCH III) are usually forced with wind field from reanalysis. The disadvantage of the reanalysis is its low resolution which is too big to be used for the considered conditions. To increase the wind input field resolution, the WRF atmospheric model can be used. In this paper, we propose a method of a wave forecast that uses the adapted to the conditions of middle-sized water body global wave model WAVEWATCH III (WW3) [2]. Initially the model was tuned to the conditions of the seas and oceans. The adaptation of WW3 to the conditions of the middle-sized water body and coastal area was discussed in our previous papers [3-5]. Then the atmospheric model WRF [6] is used as input data to force WW3. It takes into account changes in wind distribution and its heterogeneity over the water area so this setting of the wind provides a more precise prediction of the wave parameters in the reservoir.

Comparing to our previous work [7], where WRF v.3.6 was used, new version of WRF model is implemented. WRF v.3.9.1.1 has a number of updates that influence the results of the modeling in the conditions of the area containing a water body. Among them there the most important are the use of new topographical MODIS data with an algorithmically added lake category, better quality of the input reanalysis data and its interpolation method. These solutions helped to make more accurate forecasts presented in this paper.

The PBL and surface layer parameterizations are tested within WRF v.3.9.1. The results are compared with in-situ measurements held by our group in the test days in 2016 and 2017.

2. Simulation

The study is applied to the area containing a middle-sized water body. Gorky Reservoir is considered as a real-case test area. Gorky Reservoir is an artificial lake in the central part of the Volga River formed by a hydroelectric dam of Gorky Hydroelectric Station. Its lake part extends for ~80 km, ~10 km wide. Our group has a huge amount of data from the field experiments carried out in the south part of the Gorky reservoir from the boat. In the course of the experiment, the profiles of wind speed and surface wave spectra were simultaneously measured. The technique of the field experiment is presented in [3]. Test days undertaken in 2016 and 2017 gave the data for the verification of the simulations.
Special attention is paid to the spatial resolution of the modeling because of the small size of the object of the study. The grid resolution used in WW3 wave model is 0.00833°, thus it is expected that the wind forcing obtained from the reanalysis data is too coarse to create accurate forecasts. Today, the modern reanalysis datasets include the ECMWF reanalysis (European Center for Medium-Range Weather Forecasts, UK), NCEP/NCAR reanalysis (National Center for Environmental Prediction, National Center for Atmospheric Research, USA) and JRA-25 reanalysis (Japan Meteorological Agency, Japan). The minimal possible resolution of the reanalysis data is presented by NCEP Climate Forecast System Version 2 (CFSv2) and it is 0.205°. Better spatial and temporal variability may be obtained by the use of the Weather Research and Forecasting (WRF) atmospheric model. It uses reanalysis data to compute fluxes and pressures at different levels and calculates many parameters including 10 m wind speed and its direction. Thus the high resolution wave forecast can be obtained with WRF wind forcing. In this paper, we compare the wave forecasts forced by CFSv2 reanalysis data with 0.205° resolution and by wind field from WRF output.

Each step of the WRF model run is performed by a special module. First, the preprocessing of the data to prepare input to the real program for real-data simulations is realized. The geogrid module interpolates the geographical data for the lakes description «modis_lakes» on 4 nested domains in study area. The minimum cell size of the fourth nested domain is 0.00833°, and the same cell size of the topographical data is used in WW3. Then ungrib module unpacks the loaded meteorological data. CFSv2 with 1° resolution is used as the initial meteorological data. Metgrid module produces a horizontal interpolation of the extracted meteorological data on the domains grid. Then the simulations of real.exe module and wrf.exe module are held in MPI option on the IAP RAS cluster. Different Planetary Boundary Layer (PBL) and surface layer parameterizations are tested in WRF by changing namelist.input for the real.exe and wrf.exe modules, and the chosen option is used for the WRF simulation. The output wind parameters (u10 and v10) are used to force WW3 simulations.

WW3 run is performed by module ww3_grid with GLOBE bathymetry data (0.00833° resolution), ww3_strt with idealized initial conditions, ww3_prnc for the preprocessing of wind forcing (WRF output wind field parameters or reanalysis parameters), ww3_shel for the simulations held in MPI option on the IAP RAS cluster, and ww3_ounf to get the output wave parameters.

3. Results of the simulation and discussions

Some packages for the calculation of the atmosphere parameters within WRF are intercompared. Among them there are option 1 Yonsei University Scheme (YSU) [8], option 2 Mellor–Yamada–Janjic Scheme (MYJ) [9], option 5 Mellor–Yamada Nakanishi Niino (MYNN) Level 2.5 Scheme [10] and Large Eddy Simulation (LES) option [11, 12].

The LES option let the first three domains to be calculated within the Yonsei University scheme (YSU) for the PBL and within the surface layer scheme based on the Monin-Obukhov similarity theory, taking into account the viscous Carlson-Boland sublayer form. Simulation of the wind speed in the fourth domain were performed with the PBL parameterization turned off, but with taking into account turbulent flows (LES).

The comparison of the behavior of the 10 m wind speed and direction calculated with different parameterizations is shown in the Fig.1. The results are obtained in the simulation for the test day 08.08.17. The comparison shows that the use of the considered WRF parameterizations shows better agreement with the experiment than the direct use of the reanalysis. Among the tested parameterizations, LES package has good both temporal and spatial variability and is chosen for the further simulations.
Figure 1. WRF simulation of wind speed (left) and direction (right) with option 1_1 – MM5 similarity, 2_2 – Eta similarity, 5_5 – MYNN for Nakanishi & Niino, option of WRF LES in comparison with the in-situ measurements in the test day 08.08.2017.

Figure 2 shows trial weather forecasts of the 10 m wind speed distribution obtained within the new version of the WRF v.3.9.1 model. The new version of the model allowed to achieve better spatial and temporal variability comparing with the work [7] both in wind speed and direction. An increase in wind speed over the water surface by a factor of 2-3 is shown comparing with the wind speed over the land. This result favorably emphasizes the use of wind forcing from the atmospheric model instead of the reanalysis data, which do not have spatial variability that is sufficient for the conditions of inland waters and the coastal zone.

Figure 2. The distribution of the wind over the water area of the Gorky reservoir in the test day 08.08.17: night time (left) and day time (right).
The key result is the implementation of wind forcing from the atmospheric model WRF to the wave model WW3. Taking into account the accurate forecast of the state of the atmosphere in the framework of the modern atmospheric model WRF allowed us to obtain qualitative data for calculating the waves parameters, taking into account the heterogeneity of the wind field and the topography of the terrain.

The verification of the wind field calculated in WRF and of then mean wave parameters calculated in the adapted WW3 with WRF forcing is made on the basis of the experimental data. Simulated significant wave heights and mean wave periods are compared with the measured ones. Both in the model and in the processing of the experimental results, the calculation of $H_S$ is performed by the formula:

$$H_S = 4\sqrt{E}.$$  \hspace{1cm} (1)

The calculation of mean wave period $T_m$ is performed by the formula:

$$T_m = T_{m0,1} = \left(\int_{f_{min}}^{f_{max}} E(f) df\right)^{-1} \int_{f_{min}}^{f_{max}} E(f) f^{-1} df. \hspace{1cm} (2)$$

Figure 3. The distribution of the significant wave height on the Gorky reservoir in the test day 08.08.17 a) WRF LES wind forcing, b) CFSv2 reanalysis wind forcing.

Then all simulated data is obtained at the point corresponding to the point of observations.
As a result of the applying of the proposed wave forecast technique, good agreement was obtained between the calculated values of significant wave heights and the experiment. Further improvement of the technique is possible when applying the procedure of coupling. Coupled modeling of WW3 and WRF is based on the automatic exchange of the calculated ocean and atmosphere parameters and can improve the accuracy of the simulations.

4. Conclusion

Technique of a high resolution wave forecast was proposed for inland water bodies. The WRF model was implemented in the area containing a middle-sized water body. The area with Gorky Reservoir was chosen as a control area. WRF simulation was performed for 4 nested domains with min cell size of 1 km. Initial reanalysis was CFSv2 winds. Different surface layer parameterizations and planetary boundary layer parameterizations were tested within WRF: MM5 similarity, Eta similarity, MYNN for Nakanishi & Niino PBL parameterization, and Large Eddy Simulation case. The results were compared with the results of the in-situ measurements held by our group. LES package was chosen for the further simulations.

The WRF model wind calculation results were used as wind forcing of the WW3 wave model. A comparison of the calculated mean wave parameters with the ones measured in the experiment at the Gorky Reservoir was made.

This investigation will be continued with the attempt of coupled modeling based on the automatic exchange of the calculated ocean and atmosphere parameters.

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