Development of a regional model based on adapted WAVEWATCH III and WRF models for the prediction of surface wind waves on the reservoir and wind

A Kuznetsova\textsuperscript{1, 2}, G Baydakov\textsuperscript{1}, D Sergeev\textsuperscript{1, 2}, Yu Troitskaya\textsuperscript{1, 2}

\textsuperscript{1}Institute of Applied Physics of the Russian Academy of Sciences, 46 Ulyanov st, 603950, Nizhny Novgorod, Russian Federation
\textsuperscript{2}Nizhny Novgorod State University, 23 Gagarina av, 603950, Nizhny Novgorod, Russian Federation

alexandra@ipfran.ru

Abstract. A regional model for the prediction of surface wind waves on the Gorky Reservoir and of the wind over the water area is proposed. The wind was calculated in the WRF model with and without Large Eddy Simulation block. The WRF model wind calculation results were used as wind forcing of the WAVEWATCH model. A comparison of the mean wave parameters with the measured in the experiment at the Gorky Reservoir was made.

1. Introduction

The fundamental need to create a software package for high-quality weather and waves prediction on the inland water body is caused by the fact that today the wave forecast in inland waters is calculated very approximately and rarely corresponds to reality. In this paper, we propose a regional model that uses the adapted to the conditions of middle-sized water body global wave model WAVEWATCH III (WW3) \cite{1}, initially tuned to the conditions of the seas and oceans, and then simultaneously uses the adapted atmospheric model WRF \cite{2} as input data for WW3 wind forcing \cite{3}. The simultaneous use of models is undertaken, since the correct setting of the wind provides a more accurate prediction of the parameters of waves in the reservoir, taking into account changes in wind distribution and its heterogeneity over the water area. Thus, the present work demonstrates the first stages of creating a regional model. The next stage in the development of the regional model will be automation of the process of data exchange between the WW3 and WRF models, the implementation is assumed to perform within the OASIS model \cite{4}.

The regional model was developed for the water area of the Gorky Reservoir. Gorky Reservoir is an artificial lake in the central part of the Volga River formed by a hydroelectric dam of Gorky Hydroelectric Station between the towns of Gorodets and Zavolzhye. Its lake part extends for \~100 km, \~40 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 results of the field experiment is presented in \cite{5}.

2. Simulation

The third generation numerical models are adapted to the ocean conditions. However, the wave models such as WW3, SWAN \cite{6}, WAM \cite{7} are used successfully on large lakes \cite{8, 9, 10}. We have chosen WAVEWATCH III model for the simulation of surface waves on the middle-sized reservoirs, because this model considers the largest number of interactions available in the current model versions. Still for the WAVEWATCH III application to the conditions of the middle-sized reservoir, the tuning of the model is required. Reasons and steps of tuning are the following. It should be carried out in two steps: the adjusting of the wind input source term and the adjusting of the "collision
integral”. This adjusting is caused by the specific characteristics of the waves at small fetches the middle-sized reservoir: the wind input, which is proportional to the relation of the friction velocity (or 10 m wind speed) to the phase velocity [1] is more intense, as well as a stronger non-linearity is caused by steeper waves. The dissipation due to wave breaking remains unchanged.

In this paper, we use the adapted to the conditions of middle-sized reservoir WAVEWATCH III model [11]. Briefly, there are the following edits: the minimum value of a significant wave height $H_s$ is adjusted in the Fortran code; then the topographic grid of the Gorky Reservoir with dimensions $72 \times 108$ and increments of 0.00833° is used for the reservoir description. The grid is taken from the NOAA data “Global Land One-kilometer Base Elevation (GLOBE)” (figure 2 a). The approximation of deep water is considered. The frequency range is changed to 0.2-4 Hz in accordance with the experimentally observed range, which is splitted in 31 frequencies in the simulation and is modeled by a logarithmic formula for the frequency growth $\sigma_f = (\delta)^{N-1} \sigma_1$, where the growth rate is \( \delta = 1.1 \) in accordance with the recommendations of [1]; 30 angular directions of the wave field are considered. The waves in the reservoir are simulated for a given Gaussian initial seeding for different wind input parameterizations using the specified topographic data, wind speed and direction, and water-air temperature difference. These parameters can be obtained from the reanalysis data but they are too coarse for our needs. So wind input for the regional model we are working on goes from the WRF simulation. Thus the developing model for regional forecasting takes into account the spatial variability of the wind field using the wind forcing from the atmospheric model WRF.

To apply WRF to the calculation of the wind field over the Gorky reservoir, the following actions are made. In WRF preprocessing system, the preprocessing of the data to prepare input to the real program for real-data simulations is realized. For the geogrid module, the recommended geographical data for the lakes description «modis_lakes» for 4 nested domains in the studied region is used (figure 1).

The minimum cell size of the fourth nested domain is 30 arcseconds (it is equivalent to the cell size of the topographical data used in WAVEWATCH III 0.00833°) (figure 2 b). These data are used to describe the domains and to interpolate the static geographical information for the given grid. To describe the current weather situation, the meteorological data “NCEP Final Analysis (FNL from GFS) (ds083.2)” with 1 degree resolution is loaded. It is updated every 6 hours and is extracted from the GRIB format using the ungrib program. Metgrid program produces a horizontal interpolation of the extracted meteorological data on the domains grid. The simulations are held on the Yellowstone supercomputer [12].
a) Figure 2. Topographical grid of Gorky Reservoir as it appears in a) WAVEWATCH III, b) WRF. Computational cell with a size of 0.00833° is shown.

3. Results of the simulation and discussions

The specified settings of the WRF model, the simulation of the wind field over the water area were performed with switching on the Large Eddy Simulation (LES) block to the WRF model and switching it off. When the LES unit was switched on, the first three domains were calculated within the Yonsei University scheme (YSU) for the planetary boundary layer (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). Without the LES block, all the four domains were calculated using the YSU parameterization. The results obtained in the simulation for the test day 13.06.13 are shown in figure 3. The figure 3 shows the distribution of the wind over the water area of the Gorky reservoir, its value is indicated by color, and its direction is indicated by direction of segment. WRF application to the area containing the Gorky reservoir shows the significant spatial variability of the wind over the water area (figure 3 a).
Figure 3. The distribution of the wind over the water area of the Gorky reservoir in the test day 13.06.13, WRF simulation. a) WRF, b) WRF+LES.

However, the switching on the LES block to the WRF model with the unchanged size of the topographic grid cell resulted in the formation of numerical error, which are planned to be eliminated in subsequent numerical experiments by reducing the cell size. It is expected that with a smaller cell size, the wind speed simulation with WRF + LES will help to create highly accurate forecasts which takes into account the calculation of turbulent flows.

In addition, a comparison of the calculated wind speed at the point of measurement with the measurement data showed a slight underestimation of the calculated data, as well as insufficient tracking of the variability in time (figure 4).

Figure 4. Calculated dependence of wind speed U10 on time: blue line - WRF, black line - WRF + LES, points - experiment.

We associate this inaccuracy of wind prediction in WRF model with several factors. First, with a small amount of data assimilated in the test area. In the considered area, there are two weather stations only (Volzhskaya GMO and Yurievets), and they are located on the coast, where the wind speeds are significantly different from those over the waters of the reservoir. Consequently, the data assimilation from the additional sources (eg, private weather stations) along the perimeter of the pond is needed. Installation of the private weather stations and data assimilation are planned as a part of this study.

Then the wind forcing from WRF is used in the adapted WW3. The verification is made on the basis of the experimental data for the following WAVEWATCH III output: significant wave heights and mean wave periods. Both in the model and in the processing of the experimental results, the calculation of $H_s$ is performed by the formula:

$$H_s = 4\sqrt{E}$$

(1)

The calculation of mean wave period $T_m$ is performed by the formula:
\[ T_m = T_{m0-1} = \left( \int_{f_{\text{min}}}^{f_{\text{max}}} E(f) df \right)^{-1} \int_{f_{\text{min}}}^{f_{\text{max}}} E(f) f^{-1} df. \]  

(2)

All data is obtained at the point corresponding to the point of observations.

Figure 5 shows the value of the wind measured in the experiment and averaged over 15 minutes (dashed black line) and over 60 minutes (black line) for the convenience of the comparison with the wind from WRF, which is also averaged over 60 minutes (red line). The significant wave height and mean wave period are compared with those measured in the Gorky Reservoir experiment. It could be seen that the results of simulation adequately describe the mean wave parameters but underestimate it. Then, there is also insufficient tracking of variability in time.

4. Conclusion
The regional model for the prediction of surface wind waves on the Gorky Reservoir and of the wind over the water area is proposed. The wind was calculated in the WRF model with and without LES. The use of LES in the WRF model with the unchanged cell size of the topographic grid has led to the formation of numerical errors, which are planned to be eliminated in the subsequent numerical experiments by reducing the cell size. It is expected that with a smaller value of the cell size, the wind speed calculation results with WRF + LES will help to create highly accurate forecasts. The WRF model wind calculation results were used as wind forcing of the WW3 model. A comparison of the mean wave parameters with the measured in the experiment at the Gorky Reservoir was made. In general, the results are satisfactory and meet the needs of operational modeling of wind and waves, but there is an underestimation of the calculated data. Further improvement of calculations is planned due to, first, the elaboration of the used topography. Secondly, among the assumptions made in the calculations, the deep water approximation assumption is made. Taking into account the real bathymetry of the Gorky Reservoir, as well as the inclusion of WW3 source terms associated with the transition to shallow water, can make a positive impact on the results. Thirdly, the data assimilation from the additional sources like private weather stations along the perimeter of the pond will be performed.
References

[1] Tolman H and WAVEWATCH III Development Group. User manual and system documentation of WAVEWATCH III version 4.18. //Environmental Modeling Center, Marine Modeling and Analysis Branch. 282 pp. + Appendices. 2014

[2] Skamarock W C, Klemp J B, Dudhia J, Gill D O, Barker D M, Duda M G, Huang X-Y, Wang W, and Powers J G, 2008: A Description of the Advanced Research WRF Version 3. NCAR Tech. Note NCAR/TN-475+STR, 113 pp

[3] Kuznetsova A M, Baydakov G A, Papko V V, Kandaurov A A, Vdovin M I, Sergeev D A, Troitskaya Yu I, // Geography, environment, sustainability, Vol. 9, № 2, 2016, DOI: 10.15356/2071-9388_02v09_2016_02

[4] Craig A, Valcke S, Coquart L, 2017: Development and performance of a new version of the OASIS coupler, OASIS MCT 3.0, Geosci. Model Dev., https://doi.org/10.5194/gmd-2017-64

[5] Kuznetsova A M, Baydakov G A, Papko V V, Kandaurov A A, Vdovin M I, Sergeev D A, Troitskaya Yu I, (2016) // Russian Meteorology and Hydrology, 2016, №2, c.85-97

[6] SWAN team. SWAN – user manual. (2006) //Delft University of technology, Environmental Fluid Mechanics Section. 129 pp.

[7] Gunter H, Hasselmann S, Janssen P A E M (1992) The WAM model cycle 4. Technical report No. 4. //DKRZ WAM Model Documentation. Hamburg. 101 pp

[8] Alves J H G M, Chawla A, Tolman H L, Schwab D, Lang G, Mann G. //Wea. Forecasting, 29, 1473 – 1497. 2014

[9] Lopatoukhin L J, Boukhanovsky A V, Chernyshova E S, Ivanov S V (2004) // Proc. The 8th International Workshop on Waves Hindcasting and Forecasting, Hawaii

[10] Hesser T J, Cialone M A, Anderson M E (2013) // The US Army Research and Development Center (ERDC), 156 pp.

[11] Kuznetsova A M, Baydakov G A, Papko V V, Kandaurov A A, Vdovin M I, Sergeev D A, Troitskaya Yu I, // Hindawi Publishing Corporation, Advances in Meteorology, 2016, vol. 1, article ID 574602, pp. 1-13

[12] Computational and Information Systems Laboratory. (2012) Yellowstone: IBM iDataPlex System (University Community Computing). Boulder, CO: National Center for Atmospheric Research. http://n2t.net/ark:/85065/d7wd3xhr

Acknowledgments

This work is supported by RFBR (17-05-41117, 15-45-02580). The numerical simulation is partially supported by Russian Science Foundation (Agreement No. 15-17-20009).