Using the Modern Modelling Complex for Operational Forecasting of Oceanographic Conditions in the Ukrainian Part of the Sea of Azov – the Black Sea Basin

Yurii Tuchkovenko [1], Dmytro Kushnir [2]

[1,2] *Odessa State Environmental University, 15 Lvivska Str., Odessa, 65016, Ukraine*

Abstract

This paper addresses one of the most pressing challenges of Ukraine today, namely the establishment of a new cutting-edge automatized system for operational forecasting of oceanographic parameters in the Sea of Azov – the Black Sea basin.

To reestablish a national maritime prediction system of Ukraine, lost after the Russian Federation had annexed the Crimea in 2014, the suite of dynamically coupled numerical models Delft3D-FLOW + Delft3D-WAVE (SWAN) is considered to be applied. This set of coupled numerical models was previously adapted to the conditions of the Black Sea area with employment of meteorological forcing fields from the Global Forecast System (GFS) model.

Results of the model trial runs, which were used to evaluate and predict the marine oceanographic conditions in the North-Western part of the Black Sea near the Odessa Region are presented.

The current version of the automatized modelling complex allows to obtain the following predictive oceanographic data: wind conditions, sea level deviations from the undisturbed state, spatio-temporal variability of the wind waves parameters, water circulation (currents) in the coastal zones with waves taken into consideration.

Embedding the automatized modelling complex 'Delft3D-FLOW + SWAN' into the structure of the intelligent information system for revealing a hydrographic situation in the Black Sea can meet the challenge to operationally forecast the oceanographic conditions in the present (with a hindcast up to 5 days) and in the future (up to 4 days) for the entire Black Sea basin, focusing on its northwestern part and selected coastal areas with the required spatial resolution.

Keywords

The Black Sea, operational forecasting, oceanographic conditions, numerical models, modelling complex

1. Introduction

As a result of the occupation of the Crimean Peninsula by the Russian Federation in 2014, Ukraine lost the national automated maritime forecasting system for the Black and Azov Seas, which was established and operated on the basis of the Marine Hydro-Physical Institute of the National Academy of Sciences of Ukraine (Sevastopol, Crimea) under financial and technical support of the European Union [1, 2]. The cooperation between the Hydro-Meteorological Center of Russian Federation and Ukrainian authorities in terms of providing with the specialized maritime forecasts for the Azov-Black Sea basin was suspended.

Consequently, there is a demanding need for re-establishing the modern national system of operational forecasting of oceanographic parameters in the Ukrainian Azov-Black Sea basin to meet the needs of the maritime complex,

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EMAIL: tuch2001@ukr.net (A. 1); dkush@ukr.net (A. 2)
ORCID: 0000-0003-3275-9065 (A. 1); 0000-0003-4556-0143 (A. 2)

maritime transport infrastructure, and the Naval Forces of Ukraine.

To accomplish this task, an automated software complex, employing modern numerical models, was developed at the Odessa State Ecological University [3]. This modelling complex was integrated into the intelligent information system for revealing the hydrographic situation in the Black Sea [4, 5] and designed for an operational short-term forecasting of spatio-temporal variability of oceanographic characteristics in the Black Sea waters.

This paper presents the description of the structure of automated modelling complex for operational short-term forecasting of the oceanographic conditions in the Black Sea waters, the results of verification and validation of modules, comprising this complex, and discussion of the prospects for future improvements.

2. General description of the structure of automated modelling complex

The automated modelling complex for predicting the variability of oceanographic characteristics in the Azov-Black Sea basin is built around newer generation numerical models, as compared against the ones [1, 2], which are now successfully implemented to address similar forecasting problems in Europe [6, 7], USA [8-10], Australia and New Zealand [11], Asia [12], and designed for predicting the sea waves and water circulation in coastal areas.

The complex is based on the usage of two software modules Delft3D-FLOW and Delft3D-WAVE of the suite of integrated environmental models Delft3D [13], developed by Deltares, the Netherlands. The developer granted free access to the codes of software packages, and their use is governed by the GNU General Public License, version 3 [14].

Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid. It simulates thermal stratification in lakes, seas and reservoirs; stratified and density driven flows; tide and wind-driven currents (i.e. storm surges); fresh-water river discharges in bays; non-hydrostatic flows; transport of dissolved material and pollutants etc.

Delft3D-FLOW solves the Navier-Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumptions. The system of equations consists of the horizontal momentum equations, the continuity equation, the transport equation, and a turbulence closure model [15]. The hydrodynamic equations are solved either on a Cartesian rectangular, orthogonal curvilinear (boundary fitted), or spherical grid in the horizontal direction. In three-dimensional simulations, a boundary fitted (σ-coordinate system) or Cartesian rectangular (Z-model) approach is used for the vertical grid direction. In the σ-coordinate system the shallow water assumption is valid, which means that the vertical momentum equation is reduced to the hydrostatic pressure relation. Delft3D also provides an option to apply the so-called non-hydrostatic pressure model in the Z-model [15].

Delft3D-WAVE is based on the spectral model SWAN (Simulating Waves Nearshore Model) [16] and computes the non-steady propagation of short-crested waves over an uneven bottom, considering wind action, energy dissipation due to bottom friction, wave breaking, refraction (due to bottom topography, water levels and flow fields), shoaling and directional spreading. In SWAN, the waves are described by the discrete spectral action balance equation taking into account the source of energy density, representing the effects of generation, dissipation and non-linear wave-wave interactions. The following processes are accounted for in SWAN: wave generation by wind; dissipation by whitecapping; bottom friction and depth-induced breaking; non-linear wave-wave interaction (quadruplets and triads).

Both modules employ curvilinear computational grids in the horizontal plane and use the ‘telescoping’ technique for the results of calculations.

The modules are coupled by means of a shared interface and interact with each other. The influence of currents on the parameters of wind waves and wave propagation is taken into account in the coupled model. The computation of coastal currents and the intensity of turbulent mixing of waters incorporates wave processes as well.

A correct accounting for the effects of sea waves and currents interaction makes it possible to enhance the quality of calculation of the sea currents, water temperature and salinity in the upper layer of the water column.

The program codes of the Delft3D-FLOW and SWAN are compiled into executable files using the Visual Fortran and C ++ compilers. Both modules use the same set of computational grids and utilize all cores of workstation (or cluster nodes). The Delft3D-FLOW model splits a task for its parallel execution on processor cores (nodes) using the Message Passing Interface (MPI). The SWAN model (WAVE module), by default, uses parallel computations on all processor cores in accordance with the OpenMP (Open Multi-Processing) standard.

The basis of the oceanographic forecast is the data of 10-days meteorological forecast from the global weather forecast numerical model GFS (Global Forecast System). A GFS web-service (National Operational Model Archive and Distribution System – NOMADS) is situated in the United States [17]. Global Forecast System model output is being produced with 0.25-degree resolution in space and 3 hrs. in time.

The US National Weather Service provides free access to the GFS forecast data. Ongoing operational forecasts of meteorological parameters are being read from the NOMADS web resource (Data Transfer: NCEP GFS Forecasts (0.25-degree grid) [18]. In addition, all forecasts made over the past few years within a specified time are stored in the historical archive of GFS forecasts at the corresponding web resource (NCEP GFS 0.25 Degree Global Forecast Grids Historical Archive) [19] of the US National Center for Atmospheric Research (NCAR) and can be downloaded freely. The forecasting products based on the GFS model data are used, in particular, in the operational activities of the Ukrainian Hydrometeorological Center.

The modelling complex Delft3D-FLOW + SWAN is equipped with a service shell, which includes a graphical interface for use by end users. This shell automates the procedure of reading meteorological information from the NOMADS web service, filters these data and prepares it for use in the models, facilitates the procedure of setting up the Delft3D-FLOW and Delft3D-WAVE (SWAN) software modules, performs model calculations on nested grids (NESTING procedure), provides visualization technique for input meteorological data and results of operational forecasting of oceanographic characteristics (using the QUICKPLOT software module).

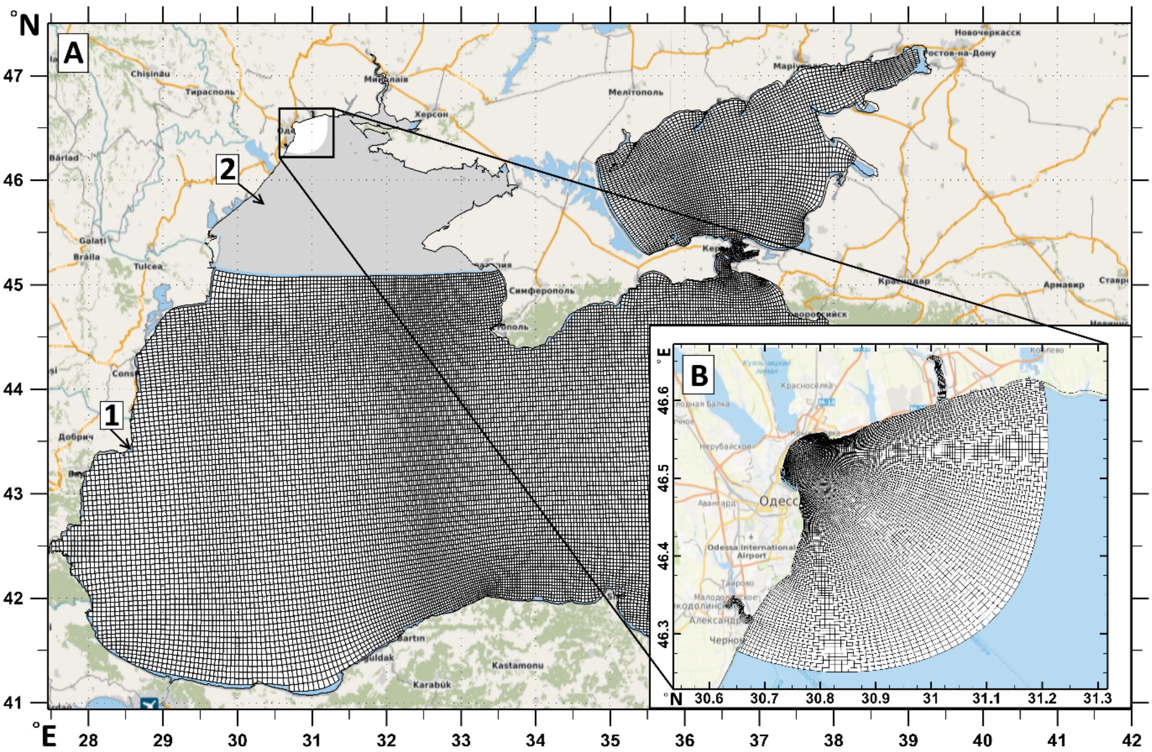

Figure 1: Curvilinear grids for the Azov-Black Sea region: A – basic (1) and detailed (2) computational grids; B – nested grid for water area of the Odessa region at the North-Western parts of the Black Sea

Current version of the automated software complex initially performs the calculations on a generalized grid for the entire Azov-Black Sea basin with a spatial resolution of Δ_{xy} = 2.5-5 km (1 in Fig. 1A). Inside the basic computational grid, the following nested computational grids with higher spatial resolution were generated:

1. Grid for the northwestern part of the Black Sea with Δ_{xy} = 0.8-1.5 km (2 in Fig.1A).
2. Grid for the water area of the Odessa region at the North-Western parts of the Black Sea, where the seaports of Chernomorsk, Odessa, Yuzhny are located (Δ_{xy} = 90-250 m) (Fig. 1B).

Fig. 2 presents a schematic overview of the forecasting procedure, including data processing and interconnections between modules.

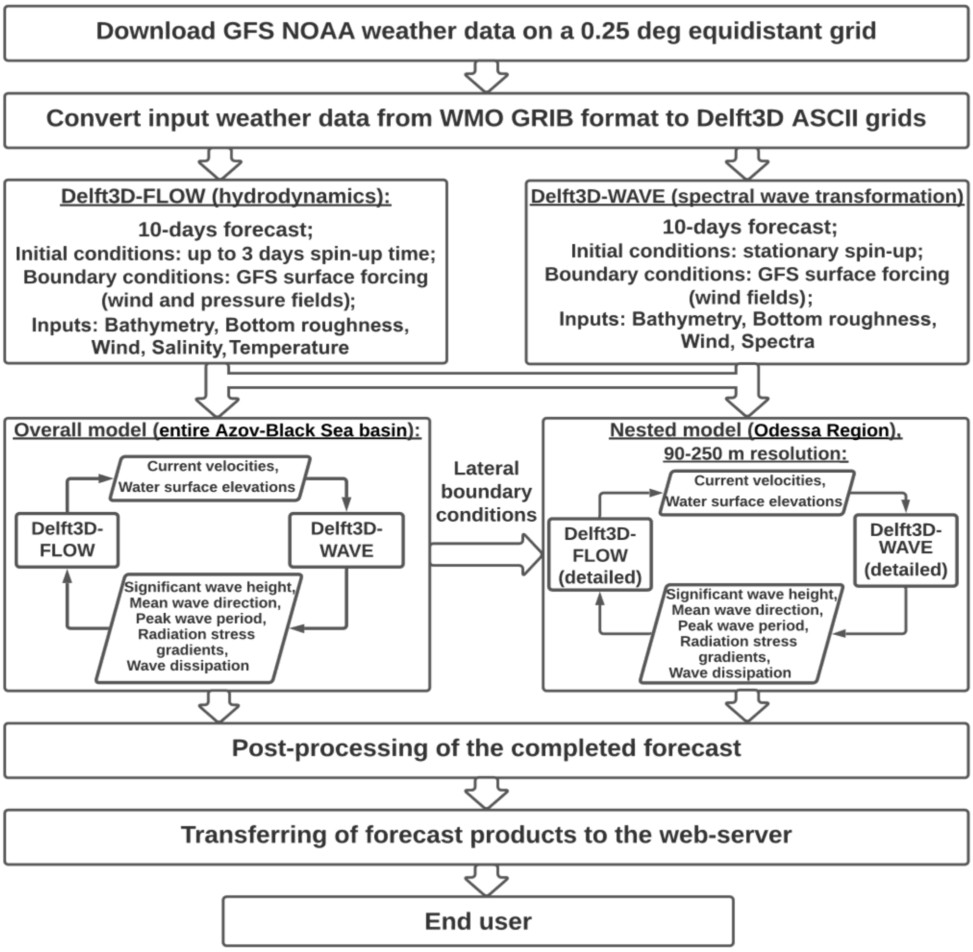

Figure 2: Diagram showing the forecasting flow and the coupling process between FLOW and WAVE (SWAN) modules

3. Results of the forecasting complex trial runs

The task of ensuring the reliable oceanographic forecasts with the use of numerical models involves the implementation of procedures for models' adaptation to the conditions of the studied water areas, their verification and validation.

Verification of the modelling complex was performed by means of comparing the results of simulated water level with observational data from the marine hydrometeorological stations of Hydrometeorological Center of the Black and Azov Seas, located at the Chernomorsk, Odessa and Yuzhny ports. Furthermore, the modelled sea drifting currents and wind wave parameters were compared against in-situ data logged at hydro-meteorological buoy SW Midi-185 (Fugro OCEANOR, Norway) stationed in the Odessa Bay (46.484N, 30.785E) [3].

Fig. 3, 4 present several results of model verification runs for the time periods of 08.10.-18.10.2016 and 16.04.-25.04.2017, under stormy wind conditions. The assimilated meteodata from the GFS global atmospheric model was used as an input to the models.

The verification showed promising potential for employing the software complex of integrated numerical models 'Delft3D-FLOW + SWAN' as a part of the operational forecasting system for predicting the oceanographic parameters of the Ukrainian marine environment.

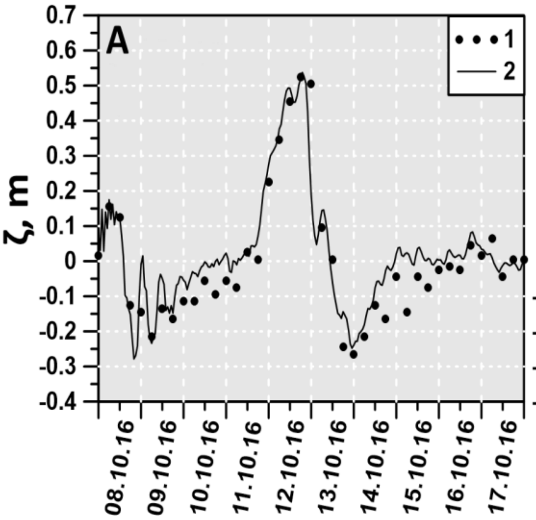

Figure 3: Variability of wind-induced water level oscillations, in m, during the periods of 08.10.-18.10.2016 (A) and 16.04.-25.04.2017 (B) in the port of Chornomorsk (1 – observational data; 2 – model results)

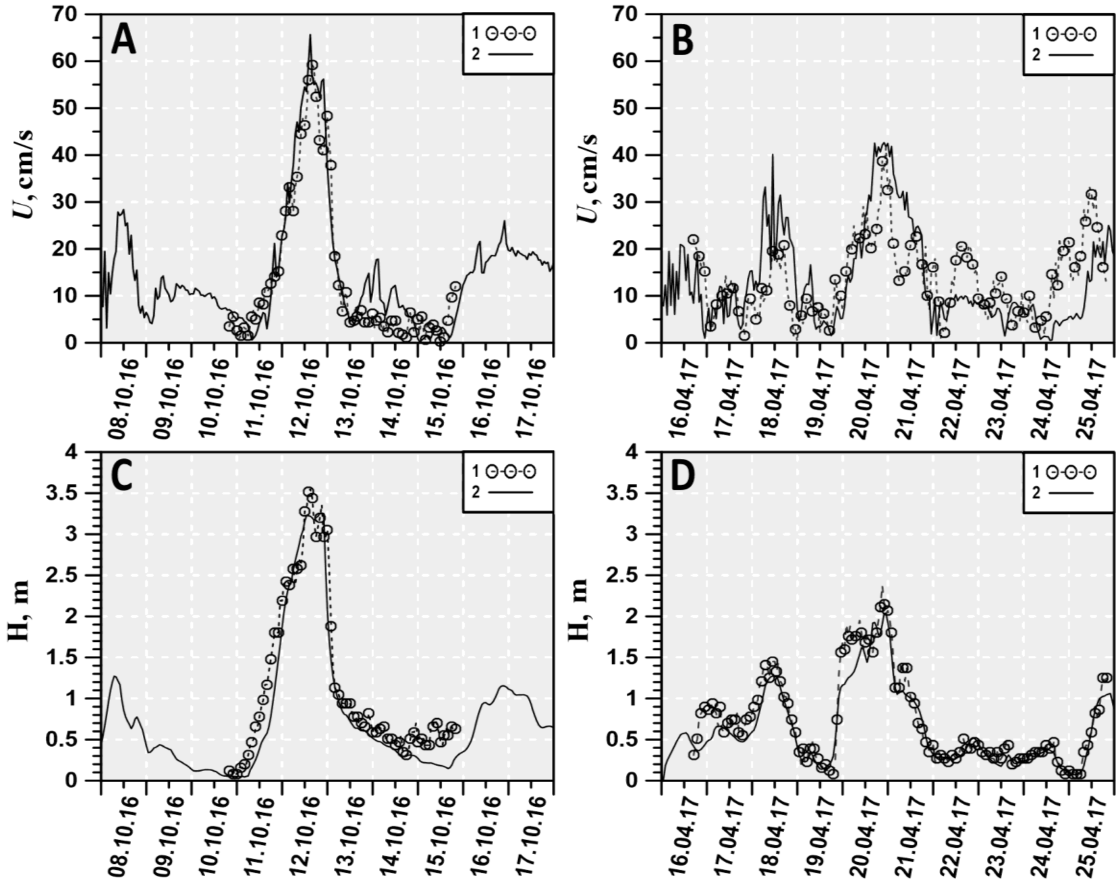

Figure 4: Temporal variability of the drift current velocity (A, B), in cm/s, and significant wave height (C, D), in m, during the periods of 08.10.-18.10.2016 and 16.04.-26.04.2017 (1 – data logged at the hydrometeorological buoy, 2 – model results)

The validation of the model complex was performed by means of making the forecasts with different warning times. The produced 10-days forecasts of storm surges and wind waves in the water area of the Odessa region at the northwestern part of the Black Sea were compared against the observed values.

Validation results show that the forecast of wind surges and wave heights with warning time up to 5 days are in good agreement with the observation data, provided that there is no significant uncertainty of the meteorological forecast, in particular, wind conditions predicted by the GFS model.

Selected results of approbation of the modelling complex in the forecasting mode using the GFS synoptic forecasts of wind conditions over the Black Sea, are presented at fig. 5.

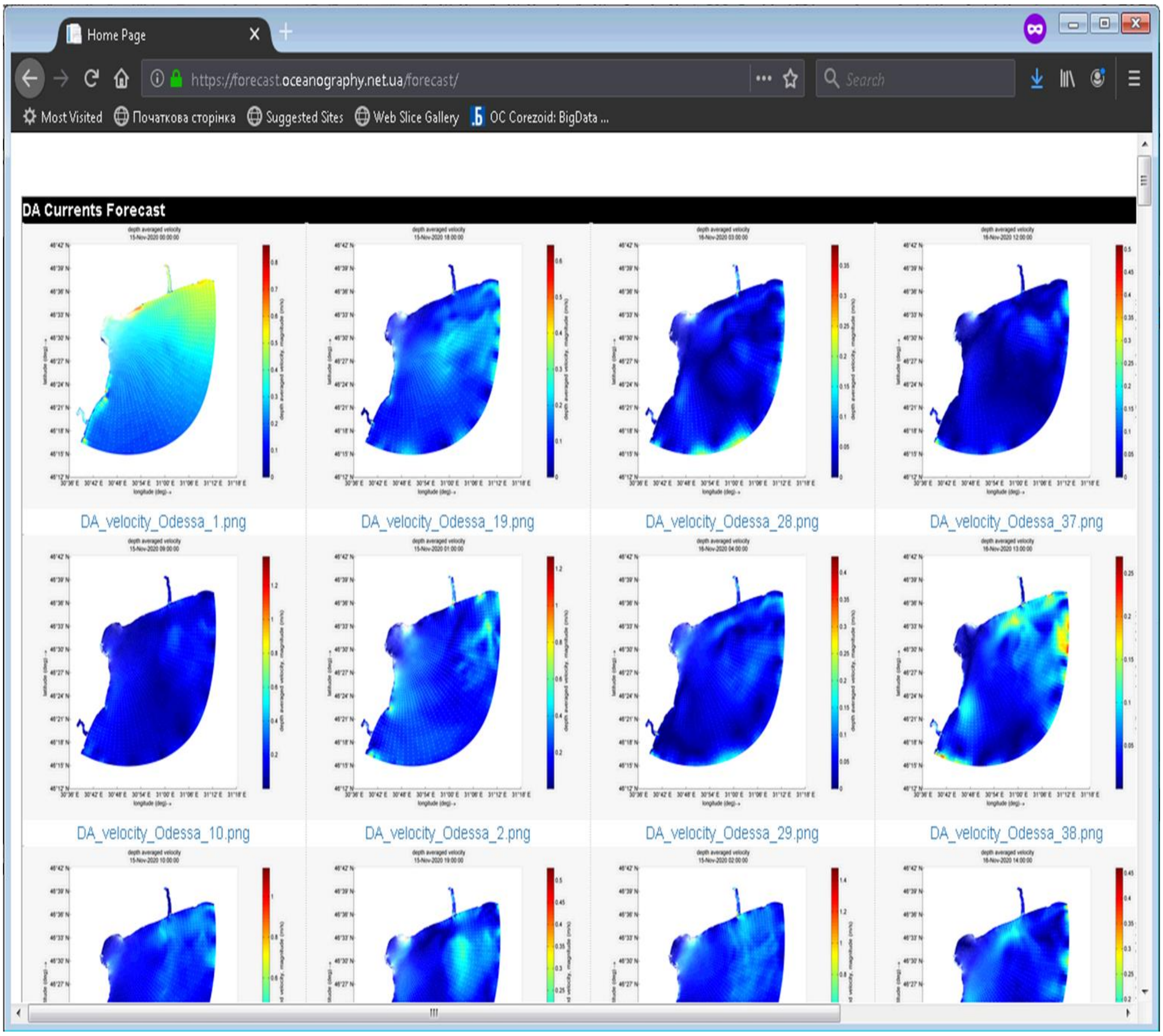

Figure 5: Window for remote access from the Internet to the graphical interface of the Delft3D-FLOW + SWAN modelling complex, showing results of modelled sea water currents with different warning times for water area of the Odessa region at the North-Western parts of the Black Sea

4. Conclusions

The results of the verification and validation of the complex of integrated numerical models ‘Delft3D-FLOW + SWAN’ demonstrate good prospects of using this complex as a part of the system of operational forecast of the variability of oceanographic parameters in the Ukrainian part of the Azov-Black Sea basin with assimilation of predictive meteorological information from the GFS global atmospheric model.

Operational oceanographic information, which can be obtained as a result of the application of the automated software complex ‘Delft3D-FLOW + SWAN’, contributes to the improvement of navigation safety, especially in shallow coastal and estuarine areas of the sea, on the approaches to the sea-ports and other areas of the Azov-Black Sea basin. The application of obtained prognostic information will result in increasing efficiency of the search and rescue operations due to recording the current (operational) and expected hydro-meteorological conditions, and, especially, the pattern of the distribution of currents which determine the movement of objects with different buoyancy, including wind drift.

Integration of the automated modelling complex 'Delft3D-FLOW + SWAN' into the structure of an intelligent information system for revealing the hydrographic situation in the Black Sea will allow to solve the problems of the operational (fast) assessment of the state of the surrounding (marine) environment by providing the information about the oceanographic situation in the present (with a hindcast up to 5 days) and future (up to 4 days) time for the entire Black Sea, its northwestern part and selected areas of the coastal zones with the necessary spatial discretization of data.

The set of oceanographic data that can be obtained with the current version of the automated modelling complex 'Delft3D-FLOW + SWAN' includes: wind conditions, sea level deviations from the undisturbed state under the influence of wind in the coastal zones (which determine the actual depths), spatio-temporal variability of the parameters of wind waves, waters circulation (currents) in the coastal areas of the sea, considering the influence of wind waves.

5. References

[1] Kubryakov A. S., Korotaev G. K., Dorofeev V. L., Ratner Y. B., Palazov A., Valchev N., Malciu V., Matescu R., Oguz T. Black Sea coastal forecasting system. Ocean Sci. 2012. №8. P. 183–196. DOI: https://doi.org/ 10.5194/os-8-183-2012.

[2] Korotaev G. K., Demyshev S. G., Dorofeev V. L. Et al. The architecture and results of the work of the International Black Sea Center for Marine Forecasts, created on the basis of the Marine Hydro-Physical Institute of the National Academy of Sciences of Ukraine within the framework of the European Union project 'My Ocean'. Ecological safety of coastal and shelf zones and comprehensive use of shelf resources: Collected scientific papers. 2013. Issue 27. pp. 128–133.

[3] Kushnir D. V., Tuchkovenko Yu. S., Popov Yu. I. Results of adaptation and verification of the set of coupled numerical models for predicting the variation of oceanographic features in the north-western part of the Black Sea. Ukrainian hydrometeorological journal / Ukr. gìdrometeorol. ž. 2019. Issue 23. pp. 95–108. DOI: https://doi.org/ 10.31481/uhmj.23.2019.09.

[4] Shchyptsov O. A., Shchyptsov O. O. Prospects of the formation of the inter-agency databank for digital oceanographic data for the benefit of navigation and hydrographic support of maritime activities. Marine strategy of the state. Development and realization of the maritime potential of Ukraine: proressing of International. scientific forum. June 20-21, 2018, Kyiv, Ukraine. pp. 19–24.

[5] Shchyptsov O. A. Improving the inter-agency system for collecting and using oceanographic information regarding the situation in the Azov-Black Sea Basin and other parts of the World Ocean. Marine strategy of the state. Development and realization of the maritime potential of Ukraine: proressing of International. scientific forum. May 22-23, 2019, Kyiv, Ukraine. pp. 55–58.

[6] SWEEP (2019). Co-creating Operational and Strategic Modelling Systems to Reduce Economic and Social Impacts on Coastal Hazards: Wave modelling. Project summary. URL: https://sweep.ac.uk/wp-content/ uploads/IP-001-A4-ESummary.pdf

[7] Apecechea M. I., Verlaan M., Zijl F., Le Coz C. & Kernkamp H. (2017). Effects of self-attraction and loading at a regional scale: a test case for the Northwest European Shelf. Ocean Dynamics. , No 67 (6). pp. 729–749. URL: https://link.springer.com/article/ 10.1007/s10236-017-1053-4.

[8] Veeramony J., Orzech M. D., Edwards K. L., Gilligan M., Choi J., Terrill E. and Tony De Paolo. Navy nearshore ocean prediction systems. Oceanography. 2014. Vol. 27. No 3. pp. 80–91.

[9] Veeramony J., Condon A. J., Linzell R. S., & Watson K. (2016). Validation of Delft3D as a Coastal Surge and Inundation Prediction System. Scientific Report. Naval Research Laboratory. Oceanography Division. Stennis Space Center, MS 39529-5004. URL: https:// pdfs.semanticscholar.org/bbf0/18c6db02bcf 8d63a4 8542637d531e788c32a.pdf.

[10] Veeramony J., Condon A., van Ormondt M. Forecasting Storm Surge and Inundation: Model Validation. Weather and Forecasting. 2017. No 32 (6). pp. 2045–2063. DOI: https://doi.org/10.1175/waf-d-17-0015.1.

[11] De Kleermaeker, Simone; Verlaan, Martin; Mortlock, Thomas; Rego, Joao Lima; Apecechea, Maialen Irazoqui; Yan, Kun and Twigt, Daniel (2017). Global-to-local scale storm surge modelling on tropical cyclone affected coasts. In: Australasian Coasts & Ports 2017: Working with Nature. Barton, ACT: Engineers Australia, PIANC Australia and Institute of Professional Engineers New Zealand, 2017: 358-364. ISBN: 9781922107916. URL: https:// search.informit.com.au/documentSummary; dn=934 516484243698; res=IELENG.

[12] Thanathanphon, Watin: Luangdilok, Narongrit: Sisomphon, Piyamarn (2016) Development of an Operational Storm Surge Forecasting System for the Gulf of Thailand. 12th International Conference on Hydroscience & EngineeringHydro-Science & Engineering for Environmental Resilience. November 6– 10, 2016, Tainan, Taiwan. URL: http://mdide.baw.de/ icheArchive/documents/2016/12-0021.pdf.

[13] Delft3D Open Source Community. URL: https://oss.deltares.nl/web/delft3d/home.

[14] Terms of use Delft3D Community. URL: https://oss.deltares.nl/web/delft3d/terms-of-use.

[15] Deltares (2020). Delft3D-FLOW, User Manual: Simulation of multi-dimensional hydrodynamic flow sand transport phenomena, including sediments. 682 p. URL: https://content.oss.deltares.nl/delft3d/ manuals/Delft3DFLOW_User_Manual.pdf.

[16] Deltares (2020). Delft3D-WAVE, User Manual: Simulation of short-crested waves with SWAN. 196 p. URL: https://content.oss.deltares.nl/delft3d/manuals/Delft3D-WAVE_User_Manual.pdf.

[17] NOAA, National Operational Model Archive and Distribution System (NOMADS). URL: https:// nomads.ncep.noaa.gov/.

[18] NOMADS. Data Transfer: NCEP GFS Forecasts (0.25 degree grid). URL: http://nomads.ncep.noaa.gov/cgibin/filter_gfs_0p25.pl.

[19] NCAR. Research Data Archive at the Computational and Information Systems Laboratory. NCEP GFS 0.25 Degree Global Forecast Grids Historical Archive. URL: https://rda.ucar.edu/datasets/ds084.1/.