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GIS-based visualization of numerical wave forecast for the Black Sea

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Abstract. This paper presents an example of an integration of sea state parameters (significant wave height and direction of wave propagation) into the Geographic Information System and a dynamic visualization of the SWAN wave model results in the GIS environment using ArcGIS tools. We discuss the advantages of the ArcGIS technology to present, visualize, animate, analyze and distribute the results of numerical wave forecasts in comparison with the standard Generic Mapping tools. We show how marine geospatial data can contribute to the implementation of the EU Floods Directive and INSPIRE in Bulgaria. We present the examples of a potential application of geospatial wave data.

Keywords: sea state, SWAN, Black Sea, GIS, ArcGIS, MISBS, INSPIRE.

1. INTRODUCTION.

The National Institute of Meteorology and Hydrology, Bulgarian Academy of Sciences (NIMH-BAS) participates in the project "Monitoring and Information system of the Black Sea" (MISBS, 2016). The project coordinator is the Bulgarian Ports Infrastructure Company. One of the main objectives of this project is the establishment of a spatial data infrastructure for monitoring the environment in the Black Sea and the coastal area for the Bulgarian institutions. The system created in Bulgaria is using best practices of the Norwegian Coastal Administration in the development and management of the "BarentsWatch" monitoring and information system (BaretsWatch, 2012). The project MISBS is realized by the Consortium "STEMO-ESRI". An important data hub for the system is the NIMH-BAS. In order to provide the system with geospatial sea state information we have to integrate the SWAN wave model results into the Geographic

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Information System (GIS) environment. The standard static visualization of the SWAN model results has been upgraded using the GIS technology and is displayed in an experimental map solution on the website of the MISBS project.

The MISBS is based on leading modern technologies in the GIS sphere. The unified access to the whole system information is provided by the Center for Special Data, which is the core of the system. It allows the whole environmental data to be used in an efficient and flexible way. Basic GIS software is used for the realization of the Center, including ArcGIS for Server, ArcGIS for Desktop, ArcGIS for INSPIRE, Esri map for Sharepoint, etc. A special Esri application – the ArcGIS Extension GeoEvent – is used for the needs of integration, processing and visualization of data in real time.

The ArcGIS Image Extension for Server is used to accomplish the goal of making large collections of imagery and raster datasets. By accessing imagery and data via focused apps the data can quickly be visualized and analyzed using on-the-fly processing and dynamic mosaicking. This allows users to manage, process, and quickly serve large quantities of raster data for visualization and analysis. The ArcGIS Data Interoperability extension for Desktop is used to handle data with varying resolutions: spectral, spatial, temporal, and radiometric. It enables the integration of data from multiple sources and formats and publishing it with ArcGIS for Server.

A brief description of an operational NIMH-BAS system for real time sea state forecast for the Black Sea and SWAN wave model implementation for the MISBS project is given in section 2. Section 3 describes some of the technical details of the new approach in integrating the numerical wave forecast data sets into the GIS environment. The final section outlines the advantages of ArcGIS technology to visualize and analyze the results form the numerical wave model and presents the examples of potential applications of the geospatial sea state data.

2. METHODS AND DATA

2.1. The operational numerical sea state forecast for the Black Sea

NIMH-BAS issues numerical sea state forecasts for the Black Sea using the SWAN wave model (Booij et al, 1999). The spectral wave model SWAN is used to produce operational 72 h wind waves forecasts for the Black Sea in terms of significant wave height (SWH) and mean direction of wave propagation. The SWAN wave model is implemented on a spherical grid, which is extended from 27 °E to 42°E, and from 40.0°N to 47.0°N and covering the Black Sea area with a spatial resolution of 0.0333° both in latitude and longitude (Galabov et al, 2015). The Limited Area Numerical Weather Prediction Model ALADIN (Bogatchev, 2008) provides the wind input for the operational wave forecast. The SWAN model output is post-processed to produce gridded data sets of SWH and the direction of wave propagation in ACSII format. The forecasted gridded data sets are presented as a series of static snapshots of significant wave height and mean direction of wave propagation using the Generic Mapping Tools (GMT). The GMT (Wessel et al, 2013) are an open source collection of about 60 tools for manipulating geographic and Cartesian data sets and producing Encapsulated PostScript File, which can be converted to the standard image format JPG, GIF, PNG, TIFF and BMP. Fig.1 shows the visualization of SWAN model results representing the modelled SWH and wave direction of propagation during the storm situation in the Black sea on February 8th 2012 at 06.00 UTC.

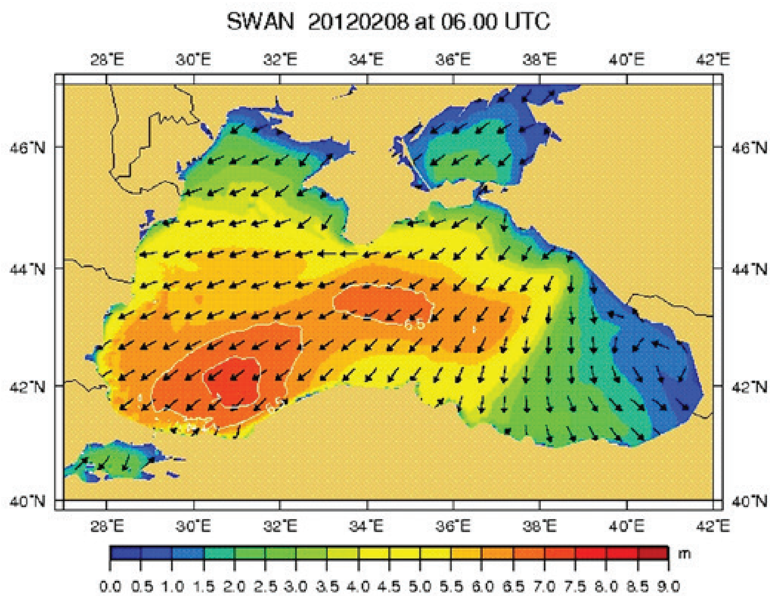

Fig.1. Modelled SWH and wave direction during the storm of February 2012 (SWAN model)

The static maps can be played with respect to time to give an animation effect. The map presented in Fig.1 is the most common map prepared for visualizing the marine data. The colour coded images are important for giving an understanding of the sea state conditions in the Black Sea, however many times it is required to know tabular data at the selected geographical location. In order to obtain this data we have to pre-process the SWAN model output again. (The generation of such data with one-click on the GIS map will be demonstrated in section 3).

It is not possible to implement directly the current version of the operational marine forecast system of NIMH-BAS (Kortcheva et al, 2010) for the MISBS project. Pre- and post-processing procedures of the system were changed in order to satisfy the requirements of MISBS as a GIS system of geospatial data.

2.2 Description of the wave model implementation for the MISBS project

The wave model used in the MISBS is the spectral wave model SWAN implemented for the Black Sea at NIMH-BAS (Galabov et al, 2015). The model runs within the Black Sea area on a space grid with a resolution of 0.0333°. The European Center for Medium-Range Weather Forecasts (ECMWF) global atmospheric model provides 72 hours (from 00.00 UTC) wind at 10m forecast as an atmospheric forcing of the SWAN model. SWAN runs once daily on a LINUX workstation. The directional wave spectra and integrated wave parameters such as significant wave height (SWH) and mean direction of wave propagation are available for each period of 3 hours out of +72 hours (Day 3) from 0600 UTC of Day 1 (current day). This information can be distributed as files in GRIB (Manual WMO-360, 2015) or the Network Common Data Format NetCDF formats. NetCDF has become a standard in Earth System Sciences. The ArcGIS software supports the NetCDF and GRIB formats. The SWAN model output is converted to the NetCDF format and transferred to a NIMH-BAS FTP server (ftp.meteo.bg).

3. USE OF GIS FOR VISUALIZING FORECASTED WAVE DATA.

GIS is a system for handling geospatial information. The Environmental Systems Research Institute (ESRI) is the company that produces the popular ArcGIS software, used in industries, government and academia. ArcGIS is a system that is utilized extensively in the areas that include maps and manipulation of geographic information.

Geospatial data is created, shared, and stored in many different formats. The two primary data types are raster and vector. Vector data is represented as points, lines, or polygons. Discrete data is best represented as vectors. Data that has an exact location, or hard boundaries is typically shown as vector data. Raster data is best suited for continuous data, or information that does not have hard boundaries or locations.

This study implemented a multi-dimensional data approach within ArcGIS that models multi-dimensional gridded data. This new model allows scientists to visualize, analyze, serve multi-dimensional gridded data as well as easily fuse scientific data from different sources in a common coordinate system in a desktop or a web application. This process runs into several steps, as described below in detail.

The ArcGIS framework for supporting multidimensional data and the role of the mosaic dataset is presented in (Xu et al, 2016). ArcGIS currently supports the multidimensional raster types: NetCDF and GRIB. The NetCDF raster files provided by NIMH-BAS are used to add the sea state data to the mosaic datasets directly without extracting any sub-dataset. The original dimension names were copied to the mosaic datasets.

Two multidimensional mosaic datasets were created for storing and visualizing the results of numerical wave forecasts for the Black Sea in the NetCDF format.

1. The first dataset is a mosaic dataset with the Vector Field template for storing the direction and magnitude of the waves. A raster function template for rendering the rasters with vector symbols was created and added to this mosaic dataset.

The Vector Field renderer was used for visualizing wave direction and magnitude. The direction of the raster defines the angles, while the magnitude raster defines the size of the symbol. The Vector Field renderer draws each symbol within a defined tile size, where the tile size controls the density of the displayed vector symbols. The size of the symbol is determined by the tile's magnitude value and the direction of the symbol (arrow) is determined by the tile's direction value. As each tile may contain many pixels, the tile's magnitude and direction values are resampled using a thinning method.

2. The second dataset is a thematic mosaic dataset for storing only the magnitude of the waves. This mosaic dataset was configured to use the classified renderer for visualizing the magnitude of the waves with classes.

Time was enabled on both mosaic datasets, so the Time Slider is an efficient tool to handle the temporal variation of forecasted sea state data. The Time Slider window can be used to navigate through the raster files in the mosaic dataset. Then the mosaic datasets were published and shared as image services. Raster function templates for rendering and visualization were configured on the server to process the raster files on-the-fly (Abdul-Kadar et al, 2016). Fig.2 shows an example of a GIS based visualization of the SWAN wave model results for the storm of February 2012 in the western Black Sea. The process of the creation of GIS maps in this study is completely automatic. Python scripts were scheduled to run daily and load the SWAN wave model results in NetCDF format in the mosaic datasets if new files are available on the NIMH-BAS FTP server.

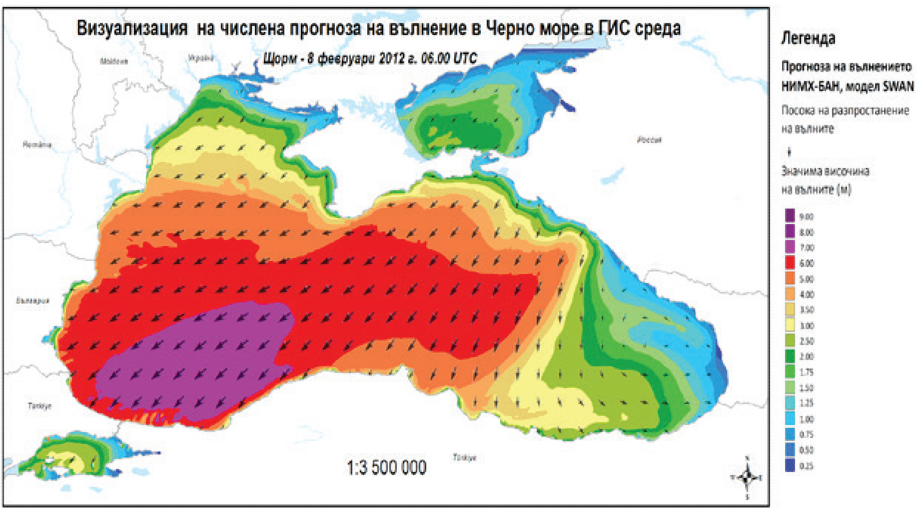

Fig. 2. SWAN modelled SWH and wave direction during the storm of February 2012 (MISBS project)

Fig.3 and Fig.4 demonstrate the basic GIS functionality. The significant wave height at the required location can be retrieved and displayed from the GIS map with a single mouse click on any point of interest.

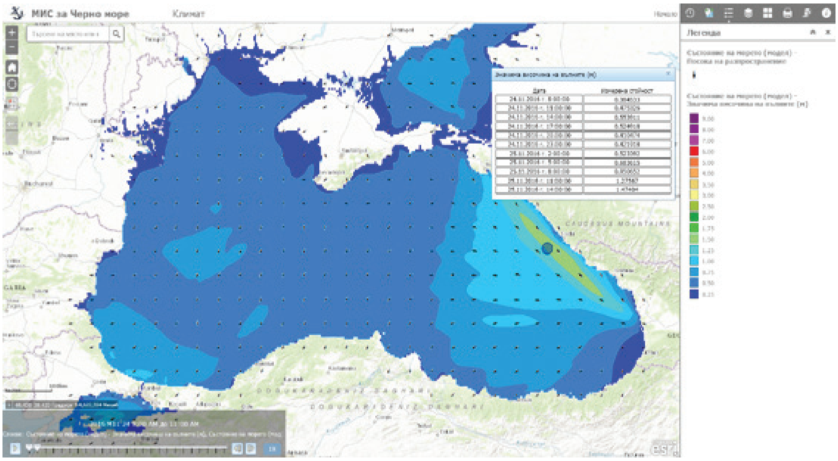

Fig. 3. User interface of web GIS based application in MIBS showing SWAN simulation results for the Black Sea (at the bottom left is the Time Slider window and on the right – table with time evolution of significant wave height at selected point)

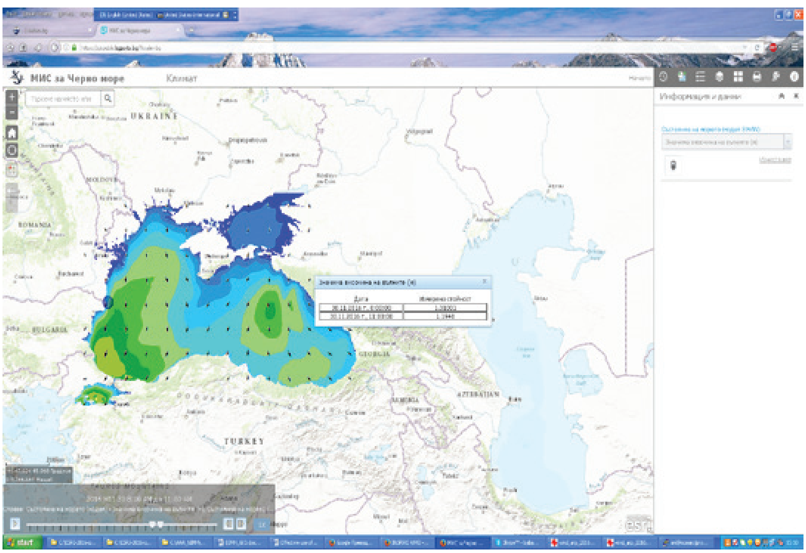

Fig. 4. User interface of web based GIS application in MISBS showing modelled SWH and wave direction for the Black Sea (Demonstration of image zooming capability and generation data at selected point)

4. CONCLUSIONS AND FUTURE WORK

This paper presets an example for the visual expression of the numerical wave forecast data for the Black Sea in the GIS environment, which allows end users to view, analyze and manage the simulation results in a geospatial context. The capabilities of the ArcGIS system for visualization and mapping are illustrated by applications related to numerical wave forecast for the Black Sea area during the storm situation in February 2012 and the wave forecasts in November 2016.

It is an innovation of the numerical wave forecast system that spatial and temporal expression of forecast parameters were dynamically played in time and displayed in space in a GIS environment. A fully automatic process converts the vector data into maps using GIS techniques. An interactive map algorithm allows the user to explore the map at any location to view the model output information in an efficient manner. The GIS platform features visual expression of information and geospatial analysis making it the useful tool for visualization information system for marine forecast. ArcGIS enables forecasters to optimize the delivery of sea state information for the public and the core partners to improve their decision-making.

Future development of this work could be to integrate additional layers such as bathymetric and remote sensing satellite data for the Black sea area into the web based GIS environment, to overlay the wave data with other geospatial data and to express these data together with the wave parameters on the same GIS map.

A few applications of geospatial marine information are listed bellow.

- In coastal search and rescue operation access to geospatial data and information is vital. The geospatial wave data are generally more useful than information in ASCII format for maritime rescue and search operations of Executive Agency Maritime Administration, Maritime Rescue Coordination Centre.
- The new approach in integrating the wave forecast into the GIS platform will be a useful tool for mariners to avoid areas of high waves and to select the optimal ship route.
- The geospatial sea state forecast together with the satellite information can support the European Border and Coast Guard Agency FRONTEX (Malinowski, 2016) in their operations to prevent irregular migration at the external borders in the western part of the Black Sea.
- Local governments and decision makers can not only visualize but also manipulate and integrate the geospatial sea state information necessary for coastal flood hazard and risk assessment (MFHRA, 2013). The new geospatial marine data will help to implement the EU Floods Directive in Bulgaria by the Black Sea Basin Directorate, Ministry of Environment and Water.

The relation between EU INSPIRE Directive (Directive2007/2/EC, 2007; LASD, 2010) and the new approach presented in this paper is obvious, because ArcGIS for Desktop support ISO 19115 (ISO 19115, 2005), which is the main metadata standard of INSPIRE for the establishment and operation of an Infrastructure for Spatial Information in Europe. The geospatial marine data for the Black Sea will support the implementation of INSPIRE Directive (theme Sea Regions) in Bulgaria (Danailova et al 2016, Pashova et al 2013).

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