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ORIGINAL RESEARCH ARTICLE

Parameters of wind seas and swell in the Black Sea based on numerical modeling

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Summary The main objective of our work is to estimate the climatic peculiarities of the distribution of wind sea and swell in the Black Sea. The method of our research is numerical modeling. We tuned the spectral wave model DHI MIKE 21 SW for automatic separation of the components of surface waves. We estimated the peculiarities of the spatial distribution of the power of wind seas and swell in the basin of the Black Sea in the last 10 years (2007—2016). We determined the regions of domination of wind seas and swell in the field of mixed waves.

1. Introduction

1.1. General notes

Two main components can be usually distinguished in the structure of surface waves: wind seas and swell. The development of wind seas is immediately related to the local wind field. Swell is related to the waves propagating beyond the zones of their generation, or the phase velocity of these waves exceeds the wind speed (for example, US Army Corps of Engineers, 2002). In the open ocean, swell can propagate over hundreds or even thousands of kilometers. The characteristics of swell in the Black Sea are limited by the geographical size and closeness of the sea basin.

Usually, the characteristics of wave field are presented as a set of integral parameters (significant wave height, mean

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period, general direction of propagation). Such an approach is justified in the case of one-dimensional wave field. If the wave spectrum is formed as a result of interaction between several wave systems it is reasonable to obtain separate wave characteristics for each of these systems.

Besides the fundamental scientific interest to the problem, separation of the wave field into individual components makes it possible to:

- more correctly describe the spatiotemporal structure of surface waves;
- efficiently calculate wave loads on the off- and onshore constructions and forecast hazardous phenomena in closed basins (low-frequency oscillations);
- clarify the schemes of redistribution and transport of bottom sediments;
- improve prognostic estimates of the wave situations for navigation at sea.

Currently, the information about the characteristics of mixed waves and swell is presented within a number of projects of the global reanalysis, for example, European Centre for Medium-Range Weather Forecasts ECMWF (Dee et al., 2011). The results of the recent researches performed on the basis of similar data sets made possible to estimate the climatic peculiarities of the distribution of swell on the oceanic scale (Bitner-Gregersen, 2015; Chong and Chong, 2017; Ewans et al., 2006; Kaiwen et al., 2015; Loffredo et al., 2009; Portilla et al., 2015; Semedo et al., 2011). Application of swell parameters from the database of reanalysis seems incorrect in the Black Sea because the time interval of such data is 3 h. A set of characteristics of storm activity in the Black Sea was investigated in Boukhanovsky and Lopatoukhin (2015). It was shown in particular, that the mean duration of storms is 14—25 h depending on the predefined threshold level. This is the cause that the time interval of the output fields of wind waves is obviously insufficient for the synoptic conditions of the Black Sea.

There are not so many publications on the separate description of surface wave components in the Black Sea. The authors of Bukhanovsky et al. (2000) made an attempt to construct climatic spectra for individual classes of waves in the northeastern part of the Black Sea. The analysis was based on the experimental data published in Kos'yan et al. (1998). The recurrences of climatic spectra for wind seas, swell, and mixed waves were estimated at 43%, 32%, and 25%, respectively. Characteristics of wind seas and swell based on the data of the ECMWF reanalysis in the southern part of the Black Sea in the period from October 1, 2000 to February 28, 2006 with an interval of 12 h were analyzed in the dissertation by Berkün (2007). Such an analysis can be considered only as an estimate due to the cause mentioned above. One of the recent publications is Van Vledder and Akpinar (2016). Unfortunately, by the time our paper has been prepared, this manuscript was available only in the form of a thesis. Therefore it is difficult to make comments.

1.2. Methods of separating of wave components

Calculation of integral wave characteristics with the account for the mixed waves is usually related to the analysis of the power spectra of surface waves or physical conditions of wave propagation.

Several approaches are applied depending on the available data:

- Analysis of one-dimensional frequency spectrum.

Separation frequency f_{sep} is selected in the wave spectrum; it is assumed that the interval of the power spectrum below this frequency corresponds to swell, and the interval of higher frequencies corresponds to wind seas. Then, the curve of spectral density $S(f)$ is integrated and, for example, significant heights of wind seas and swell are determined:

$$H_{s,swell} = 4\sqrt{\int_{f_l}^{f_{sep}} S(f)df}, \quad H_{s,wind} = 4\sqrt{\int_{f_{sep}}^{f_u} S(f)df},$$

where f_l, f_u are the lower and upper integration frequencies.

Frequency f_{sep} can be specified as a constant or function $f_{sep} = 0.8f_{PM}$, where f_{PM} is the frequency of the Pierson—Moskowitz spectrum peak corresponding to the full developed waves (Pierson and Moskowitz, 1964). Frequency f_{PM} is determined by relation $f_{PM} = 0.14g/U_{10}$, where U_{10} is wind velocity at a height of 10 m, g is the acceleration due to gravity. The separation frequency can be also determined from the analysis of wave steepness (Wang and Hwang, 2001) on the basis of the fact that wind seas are steeper than swell and that the maximum steepness is observed in the vicinity of the spectrum maximum.

- Application of the criterion that takes into account the wave age.

The wave component is considered swell if the following condition is satisfied (Bidlot, 2001):

$$\frac{U_{10}}{c}\cos(\theta-\theta_w) < 0.83,$$

where c is the phase velocity of waves, θ, θ_w are the directions of waves and wind, respectively.

- Analysis of two-dimensional frequency-directional spectrum.

The frequency-directional spectrum contains full information about the structure of surface waves. Determination of the main characteristics is performed by integration of individual parts of the two-dimensional spectrum corresponding to the wave systems. We focus attention on publication by Portilla et al. (2009), in which the authors suggested an automatic method of wave separation considering a two-dimensional spectrum as a watershed chart, which makes possible detection of the entire set of the wave systems.

A brief conclusion. If the frequencies of swell and wind seas are quite close, the efficiency of separation using only the frequency spectrum is extremely low. These approaches operate in the case of distinct separation of wave components. Analysis of the frequency-directional spectrum due to its completeness seems a more correct method of separation.