Forecasting of hazardous marine hydrometeorological phenomena for the regions of oil and gas deposit development on the Sea of Okhotsk Shelf

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Abstract. A brief description of the marine hazard forecast methods and technology for the Sea of Okhotsk developed in the Federal State Budgetary Institution “Far Eastern Regional Hydrometeorological Research Institute (FERHRI)” is presented. These methods and technology provide numerical prognostic products for the following parameters: wave height, period and direction; sea ice concentration, thickness, drift and compression; sea level and storm surges. The successful cases of practical applications of these forecasts demonstrate the effectiveness of the developed forecast methods and technology.

1. Introduction

For the last decades the natural gas and oil field development at the Sea of Okhotsk Shelf has been intensely conducted. To ensure safety and efficiency during production of hydrocarbons using floating drilling rigs, natural gas and oil transportation via tanker fleet or submarine pipelines etc., it is necessary to utilize modern high-quality hydrometeorological forecasts.

Providing the forecasts of marine hazards which pose a threat to human lives and may cause tangible damage and financial loss [1] is of vital importance.

New offshore development requires new facilities to be set up. For such facilities there is a plethora of destructive phenomena such as: “...strong waves, vessel icing, storm surges, intense ice drift, ice compression, formation of ice impassable for vessels and ice icebreakers during navigation...” etc. [1]

It should be noted that for continental shelf it is impossible to develop a statistical model for marine hazard forecast which imply derivation of empirical relations between the parameters of said hazardous events (e.g. time of occurrence vs. event intensity) and factors which cause them. Generally, it follows from two reasons, namely, marine hazards occur relatively rarely, and offshore regions lack continuous monitoring of hydrometeorological parameters.

Hence, the marine hazard forecast methods which are based on numerical hydrodynamic modeling of the processes of interest have been developed in the Federal State Budgetary Institution “Far Eastern Regional Hydrometeorological Research Institute” (FSBI “FERHRI”).
2. Marine hazard forecast methods for the Okhotsk Sea Shelf

Wave forecasts of the Sea of Okhotsk are produced using modern spectral models [2]. These models solve the equation of spectral energy balance of waves. Additionally, they include the energy transfer from wind, the deep-ocean energy dissipation due to bottom depth changes, the wave breaking near shores and the non-linear wave interaction (that characterizes the energy redistribution in the spectrum.) For shallow waters the wave refraction is also solved.

The horizontal grid resolution is $4 \times 4'$ for the open ocean areas, and $250 \times 250$ m for the coastal zones. The users are presented with significant wave height, wave period and direction charts (Figure 1). These forecasts are available at six hour increments out to 120 hours.

![Figure 1. Forecasts of (a) significant wave height, m; (b) wave period, sec, for 2013-11-11 00:00 UTC (72-hours forecast).](image)

The developed numerical models are also used to calculate long-term wave characteristics. Apart from the height, period, and direction of mixed waves, the technology also provides these parameters for wind waves and swell separately, as well as their spectral characteristics. The data analysis using a long (historical) series allows the estimation of characteristics of extreme waves which may occur once in N years, and duration of storms and “weather windows” useful for marine planning. These estimations may be interpreted as “extra-long-term” forecasts of marine hazard intensity in the region of development.

For important coastal regions of marine development in the Sea of Okhotsk (shelves of Magadan and Sakhalin Island, the western coast of the Kamchatka Peninsula) the refined model resolution ($300 \times 300$ m) is used.

The developed forecast technology line allows users to get notifications about the date and area of occurrence of a possible hazardous phenomenon in accordance with the established criteria (wave height exceeding 6 m for open waters, and the wave height exceeding 4 m, for the coastal regions [1]).

The information about upcoming changes in the sea ice cover of the Sea of Okhotsk plays a significant role in safety of the production of hydrocarbons with floating drilling rigs, and their further transportation. The CICE model [3] adjusted to the Sea of Okhotsk conditions produces the information about the ice concentration, the thickness (stage of development), the compressive strength, and drift, as well as an overall ice cover area. This technology provides daily forecast charts of the spatial distribution of all the aforementioned parameters for 9 days forward (see an example in Figure 2). In addition, the method for sea surface temperature forecast has been developed which is then used by the ice model (Figure 2).
To identify the regions of potential vessel icing and its intensity, FSBI “FERHRI” developed a suite of techniques and methods for modeling this process, which use forecasts of wind, air and water temperature, wave height, and water salinity.

The forecast of hazardous sea level in the Sea of Okhotsk with the lead time of 72 hours is conducted with a complex of methods that includes modeling of the storm surges induced by deep cyclones and typhoons (Figure 3), as well as modeling tides, and mean sea level.

![Figure 2](image)

Figure 2. A 5-day forecast of (a) ice concentration, tenths; (b) ice thickness, cm; (c) compressive ice strength, kN/m, and (d) sea surface temperature, degrees Celsius, for 2021-05-05.

These components of the observed sea surface elevation can be predicted directly from a two-dimensional depth-integrated numerical hydrodynamic ocean-ice joint model, which was adjusted in FSBI “FERHRI” to the conditions of the Russian Far East seas [4]. Nevertheless, to save the computation time in operational workflow, another simplified approach has been used. Tidal elevation predictions are calculated using 8 major tidal harmonic constituents that were derived from the results of the previously conducted numerical modeling.

Surges are predicted using the wind speed and direction (at 10 m) and the surface atmospheric pressure reduced to mean sea level. These parameters come from a regional atmospheric model WRF-
ARW. The information about the spatial distribution and concentration of sea ice from the Japan Meteorological Agency (JMA) is also involved in these predictions.

The forecast production line, including the initial data acquisition, calculations, and the forecast product distribution is fully automated. These forecasts are issued twice a day: at 00 and 12 UTC.

The described forecast methods are used during exploration drilling activities at the northern shelf of the Sea of Okhotsk in June-August, 2016 [5]. The results of these dedicated services suggest robustness and efficiency of the methods developed at FSBI “FERHRI”, hence feasibility of their application to other regions of the Sea of Okhotsk Shelf.

![Figure 3](image_url)

**Figure 3.** Predicted storm surge heights for 2014-12-21 18:00 UTC, cm (initial time of the forecast is 2014-12-19 00:00 UTC).

3. Conclusion

Based on the numerical modeling, the forecast methods of hazardous marine phenomena have been developed at FSBI “FERHRI” for the region of the Sea of Okhotsk Shelf including the oil and gas development fields. These methods are successfully used for operational activities of the Russian Federal Service for Hydrometeorology and Environmental Monitoring of Russia (Roshydromet). The forecast products are provided to their users directly, as well as published via the website of FSBI “FERHRI”.

Further development of the forecast technology of marine hazards for the Sea of Okhotsk Shelf should include developing new methods as well as improving the existing ones in order to increase the forecast accuracy and lead time.

References

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