Wave Weather Scenarios Modelling Using Grid Technology

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ABSTRACT

The paper is focused on the description of the most effective approach to the wave climate modelling, based upon development of distributed hardware – software complexes. Such complexes should include a set of physical-mathematical models describing wave climate, including input meteorological data pre-processing and output data post-processing. The technology of distributed calculations, Grid technology, will provide simulation of the complex problems using remote heterogeneous computational resources, simultaneous visualization of the large amount of the scientific data. Distributed data processing and analyses will provide interconnection of the scientific tools with remote computers and data bases.

Keywords: *wave weather scenarios, Grid technology, mathematical modeling , regenerative paradigm, atmospheric parameters*

1. INTRODUCTION

Wave climate is considered as an ensemble of conditions of spatio-temporal wave fields characterized by frequency-directional spectra. Such approach with reference to shipbuilding is caused by expansion of the nomenclature of wave and wind characteristics, which are necessary for engineering offshore structures construction and operation, and ships operation. The use of expanded set of wave and wind characteristics makes it possible to introduce the term “scenario of wave weather” much more correctly and to use it for estimation of navigation safety. There are a lot of methodologies and approaches used for predicting wave and wind characteristics but it is impossible to use most of them for practical purposes in shipbuilding. Nowadays the most perspective approach from the authors point of view is the development of the so-called wave weather scenario, assuming elaboration of the set of united probabilistic-hydrodynamic mathematical models for external forces acting on a ship. General theoretical solution of such approach was presented in the paper (Degtyarev A., 2005). In this paper we focus attention on presentation of some technical issues – specifically the computational component.

Introduction of “climatic spectrum” definition allows to create ensembles of wave weather scenarios and to use them for marine object behaviour simulation. The whole cycle of such simulation should represent hardware-software complex, or virtual testbed, capable to consider: analysis of big files of information coming from measurement systems; identification of extreme situations; determination of CFD characteristics of mathematical models; construction and analysis of scripts of interaction dynamics between marine objects and environment described by a system of spatiotemporal random fields; analysis of alternatives and decision-making in uncertainty conditions. Realization of such complexes requires tremendous computational resources, powerful visualization tools, elaborated high-performance numerical algorithms. The best way to meet all the requirements is to create a distributed computational environment – Grid, capable to offer computational resources, adequate to problem being solved.

2. SCENARIOS OF WAVE WEATHER AS INITIAL DATA IN SEAWORTHINESS PROBLEMS.

Such approach to wave weather evolution presentation in considered water space permits to develop mathematical model of sea waves for long-term periods. The main characteristic of this model is multiscale, i.e. taking into account different time intervals: quasistationarity, synoptic variability, seasonal and year-to-year variability. As a result it is possible to obtain wind wave fields ensemble realizations for any time length.

Thus, introduction of “climatic wave spectrum” and “wave climate” definitions results in expansion of design conditions base of external action for ship’s dynamic problems solution. Now instead of traditional limited set of some integral parameters (significant wave height, spectrum approximation, etc.) we can introduce new concept – wave weather scenario. It can take into account the following items relevant to the problem reviewed (Degtyarev A., 2005):

- peculiarities of wave formation conditions – wind waves, swell, sea properties;
- geographical features of considered region;
- variability of hydrometeorological conditions – features and characteristics of storms evaluation and weather stability;
- scenarios of synoptic variability – alternation of stormy and good weather states;
- characteristics of seasonal variability – features of summer, winter time and off-season for considered navigation regions, special missions carried out by ship, etc.;
- long-term presence of ship in given region or in known exploitation conditions comparable with considered object lifetime.

With the above parameters set, it is possible to propose the following scenarios of wave weather for use in problems of research design, seaworthiness safety estimation and risk assessment for both ships and offshore structures:

- **short-term scenario** – modeling of spatio-temporal wave fields realizations taking into account all the above parameters;
- **“storm” scenario** – wave actions modeling for typical storms in given region and season;
- **“mission” scenario** – variation of wind and wave conditions and external influences on a ship carrying out a specific mission: voyage, rescue operation, ship raising, survey operations, combat mission, etc.;
- **“navigation” scenario** – sequence of ordinary scenarios “mission” covering long period including some seasons such as fishery, long navigation;
- **“lifetime” scenario** - taking into account year-to-year and climatic variability of given region where ships and offshore structures operate. It is primarily related to risk estimation in complicated expansive open-sea objects insurance.

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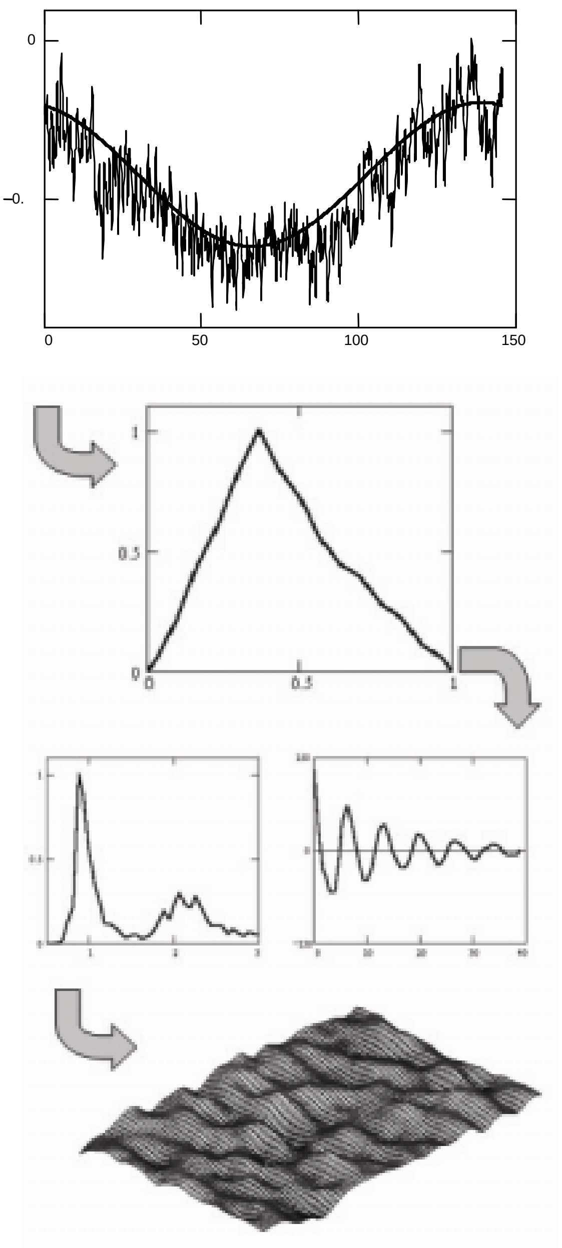

Figure 1. Scheme of wave weather scenario generation (annual variation of average wave height – form of storm – typical wave spectrum – sea surface) (Degtyarev A., 2005)

3. WAVE WEATHER SCENERIES MODELLING

Initial statistical information about wind and wave regime in given region is required for sceneries creation with the help of the methods described above. Obviously it is impossible to obtain such information from measured data only. The most fundamental starting point for derivation of equations governing the wave spectrum evolution is the equation for the conservation of the wave action density N (see, e.g., (Komen,et al., 1994), (Lavrenov, 1998):

$$\frac{\partial N}{\partial t}+\frac{\partial N}{\partial \varphi}\dot{\varphi}+\frac{\partial N}{\partial \theta}\dot{\theta}+\frac{\partial N}{\partial k}\dot{k}+\frac{\partial N}{\partial \beta}\dot{\beta}+\frac{\partial N}{\partial \omega}\dot{\omega}=G \qquad (1)$$

The action N is a function of latitude φ, longitude θ, wavenumber k, angle between the direction of wave propagation and the parallel β, angular frequency ω, and time t. G is net source function. It is represented as the sum of the input G_{in} by the wind, the nonlinear transfer G_{nl} by resonant wave-wave interaction, and the dissipation G_{ds}. There are some other terms of equation (interaction with slowly changing currents, etc.) which are normally small. They are not included in the propagation operator.

Equation (1) describes functional relation between fields of atmosphere pressure, wind and waves. There are many calculation models based on (1) devoted to obtaining time-spatial wave field. The only difference between them is in sources function presentation and computational layout. Present spectral wind wave models based on equation (1) are rather well developed. They incorporate a representation of all significant mechanisms affecting the wave spectrum evolution and are quite sophisticated numerically. Being determined by wind data (or atmospheric pressure), and data on boundary layer stability, the models compute two dimensional (with respect of frequency and direction) spectrum $S(\omega,\beta)$ at nodes r_i of numerical grid at times t_j.

The first wave model which was realized as world-renown software is WAM-model. The theory and methods of numerical simulation are continuously improving. Now we have new results and models WAVEWATCH (Tolman, 1991), PHIDIAS (Van Vledder, et.al, 1994), TOMAWAC (Benoit, 1996), INTERPOL (Lavrenov, 1998) for deep and SWAN (Ris, 1997) for shallow water.

Specifics of computer presentation of hydrometeorological fields information are vast amount of data used and long calculation time. Hence, the use of high performance computers is necessary.

Any hydrodynamic model devoted to wave fields calculation requires initial wind data in meshes of net domain with assigned discretization in time domain. Available information was heterogeneous, fragmentary and discrepant till recently. A significant advance in numerical wave hindcasts resulted from the NCEP/NCAR meteorological reanalysis project (Kalnay, et.al, 1996), which produced global data series of great interest to wave modelling. The use of the reanalysis products to drive the wave model removed many of the inhomogeneities present in earlier data sets.

At the same time it is necessary to note that such technology is rather rough as long as reanalysis information is presented with rough space resolution. It makes it possible to obtain general representation about atmosphere processes evolution. To improve atmosphere parameters it is possible to use special interpolation procedures (Russian Registry of Shipping Publisher, 2003) or to use regional models of atmosphere circulation. There are well-known such models as American model MM5 and European model HIRLAM. These models permit to calculate parameters of atmosphere boundary layer with high spatio-temporal resolution. These parameters include wind speed and direction, pressure, temperature, etc.

Codes of all the models mentioned are open source. It is also possible to obtain detailed manuals for these software.

All these models allow to obtain initial information for statistical generalization, spectra parameterisation, storms classification and scenario wave calculations.

Thus, the general algorithm for data preparation and realization of different scenarios looks as follows (Degtyarev A., 2005):

1. Initial data of pressure fields processing using reanalysis data for considered region or with the help of regional models of atmosphere circulation. Input data are: bathymetrical map, coastline and variation edge of the ice.

2. Verification of prepared data on the basis of comparison with natural observations. If occurrence of interpolation is bad than change of model parameters for recalculation should be made and i.1 should be repeated.

3. Wave fields calculation on the basis of model (1). Computational grid has to cover the considered region entirely. It is necessary for taking influence of distant storms and incoming swell into account. Character of expansion of computational grid is defined by the expert evaluation taking into account geographical conditions of considered region. Time period of calculation depends on purpose of calculation. 20-25 years are necessary for reliable statistical data. For purposes of extremes statistics this period has to be prolonged up to 30-40 years.

4. Verification of wave fields with the help of waves measurements in considered region (if we have long buoy records). Correction of model parameters and recalculation at i.3 if big error of statistical characteristics exists (e.g. see (Russian Registry of Shipping Publisher, 2003)).

5. Assimilation of calculated data and measurements

6. Statistical processing of obtained spatio-temporal wave fields and measurement data

- calculation of trivial statistics;
- determination of statistical parameters characterizing stormy and good weather periods (weather window);
- storms and weather windows classification;
- parameters of storms and weather

windows interchange;

- climatic wave spectra classification;
- extreme statistics calculation;
- calculation parameters related with extreme waves.

7. Data assimilation for models of wave scenarios operation.

8. Using year-to-year rhythmic model for climatic variation of reproducing wave weather in a given region.

9. Superposition of climatic variations and results of probabilistic modeling of annual rhythmic.

10. Superposition of obtained results and results of stochastic modeling of storms and weather windows interchange.

11. Stochastic modeling of climatic spectra sequence corresponding to classes of storms and weather windows.

12. Time variation of frequency-directional spectra reproduction on the basis of obtained realization of average wave height and climatic spectra consecution.

13. Spatio-temporal wave fields generation for each wave spectrum.

14. Subject to solving problem and considered time scale, either reiteration of i.i.8-13 or collecting wave scenario ensembles. The continuity and Navier-Stokes equations are needed

4. POSSIBLE STRUCTURE OF THE DISTRIBUTED HARD-SOFTWARE COMPLEX

The general algorithm for data preparation and realization of different scenarios presented above offers the natural structure of the distributed hard-software complex. The complex should consist of several blocks, the first one should be responsible for the initial data of pressure fields preparation, the second – for wave fields calculation, the third – for the statistical treatment of obtained spatio-temporal wave fields and measurement data, the forth – for wave scenario ensemble collection.

Each block realization requires large volume of calculation conducting with the help of complex mathematical models and tremendous amount of input and output data processing.

Consequently it appears to be very difficult to gather all necessary computational resources and data bases in one place. Very often all the required facilities are distributed over different universities and supercomputer centres. To join them together it is necessary to elaborate distributed calculation environment – calculation Grid.

To make Grid a reality requires new approaches, methods, tools for maintaining large amounts of data and/or computer-intensive calculations. Our approach is to gridify applications: not to develop a generic Grid solution but support specific types of applications by tuning and modifying Grid middleware to fulfil application needs and achieve the best performance.

The applications can be mapped on Grid architecture with the help of solutions for parallelization of specific application types. There are special mathematical techniques, that allow to present traditional numerical procedures in parallel, even if parallelization of sequential code is impossible, with the help of appropriate Grid middleware.

Special attention should be paid for parallel processing of extra-large datasets. During the analysis of the problem of processing extra-large multivariate datasets on parallel and distributed (Grid) systems we find that the formal approaches to parallelization fail because of the long-range correlations between data and their non-scalar nature. To overcome those difficulties the new paradigm of the data processing is proposed, based on a statistical modelling of the datasets, which in its turn is realized for different types of data. This paradigm was described in (Bogdanov A., etc., 2004, 2005). The development of the parallel models for problems of considered classes is possible to represent as the next four stages.

Reduction of the dimensionality for the initial data $\Xi(\mathbf{r},\ t) \in H$ in the linear space H. The goal of this stage is the construction of the set of most informative indexes, characterizing the sample variability.

Identification of the model. Previous stages takes possibility to express the dependence between non-scalar components of $\Xi(\mathbf{r},\ t) \in H$ in terms of the system of scalar indexes $Z=\{z_k(t)\}$. For the quantitative description of the temporal (t) and intra-element (k) dependencies of these data the model of linear stochastic dynamic system has been considered (Adomian G., 1983)

$$LZ=RE+BH \qquad (2)$$

Here L, R, B – are the linear differential operators, E – is the multivariate white noise (independent realizations of random value), and H is the set of driving stochastic factors (predictors). The equation (2) is the generalization for different models applied for wave weather scenarios.

Statistical synthesis. The equation (2) could be used as the algorithm for Monte-Carlo simulation of multivariate time series $Z=\{z_k(t)\}$. Hence it is considered as the milestone for the construction of the hierarchy of the stochastic operators of Monte-Carlo procedure

Verification, scenarios and forecast. The procedure of verification is proposed as the technique for qualitative control of the statistical model.

In view of parallel processing, the principal feature of models construction is the intrinsic formalization of the parallel algorithm, using the possibility of the elimination of the correlations between data in computational procedure

All these stages of regenerative paradigm were performed in process of wave weather scenarios construction (Degtyarev A., 2005). For example, reduction of dimensionality was used when random function of climatic wave spectrum was presented as deterministic function with random parameters.

Such basis is related with principles of intrinsic parallelization of proposed algorithms. These principles allow classifying the methods of statistical processing and Monte-Carlo simulation. There were proposed (Bogdanov A., 2004) three principles for such probabilistic models.

Decomposition of the statistical ensemble. This principle reflects the postulate of the independence of sample elements. It allows dividing the sample on the independent fragments and process these data in parallel. The resulting computational algorithm is rather homogenic. The main problem of the ensemble decomposition is the further integration of the estimates, obtained on the different processors.

Decomposition on the base of principle of mixing. This is the modification of statistical ensemble decomposition for the model of time series with local dependence between data. Realization could be divided into the set of non-overlapping fragments. Each fragment is simulated by equation (2) in parallel. After that, the matching of the parallel fragments may be organized as binary tree algorithm

Decomposition of the indexing variable. This principle corresponds to alternative way for dependence elimination in stochastic model. It is important for the multivariate data. The general approach is based on the specific construction of data transformation operators, thus the values of the transformed data for different values of index variable could be computed independently.

This approach shows a very effective scaling and parallelization that allows applying it to Grid.

Special user–friendly interfaces should be developed providing user access to all heterogeneous resources and data bases, enabling the user to monitor application execution and moving the data at user’s request.

5. PROTOTYPE OF THE GRID SEGMENT

As a prototype of the Grid segment for wave weather scenarios modelling let us consider Russian-Dutch High-Performance Grid segment (Bogdanov et.al, 2005), with one of its sites based in the Institute for High-Performance Computing and Information Systems.

Each Grid-site base configuration consists of 5 computer systems minimum: Configuration server, Computing Element (CE), Storage Element (SE), User Interface (UI) and Working Node (WN).

User Interface element provides access to the Grid segment resources. User logs into UI computer in order to choose Grid resources, install the task for execution, get output data and transfer data if necessary.

Configuration server provides semiautomatic installation and configuration (both initial and secondary) of all base control elements.

Computing Element is the main working point on the local site. CE provides common interface for computational resources involved. Among its functions are task launching and task scheduling.

Working nodes provide user task implementation. A site can contain several working nodes. Storage Element provides user universal access to the available databases.

6. CONCLUSIONS

The description of the most effective approach to the wave climate modeling based upon the elaboration of the distributed hardware – software complexes is presented. Possible structure of such complexes based upon Grid technology for distributed calculations is discussed.

7. ACKNOWLEDMENTS

Russian-Dutch High-Performance Grid segment references in the paper was developed in the frame of the NWO-RFBR project N 047.016.007:: "High Performance simulation on the Grid"

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