Determination of the Computerized Monitoring System Structure of the Small-Scaly Turbulence of the Water Environment Hydrophysical Fields

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Abstract. The algorithm definition of system' optimum structure of monitoring hydrophysical fields of the water environment inhomogeneities that provides a specified measurement uncertainty with the minimum cost of the equipment and the experiment is proposed. The algorithm uses the object-evolutionary model of the information-measuring system and the vertical arrangement model of small-scale turbulence layers.

1. The relevance monitoring small-scaly turbulence of hydrophysical parameters the aquatic environment

The research of the active layer structure water spaces: oceans, seas, lakes, reservoirs, rivers and ponds – has recently become particularly relevant. This is due to the fact that the active layer of the aquatic environment is a zone of the most active physical processes and forms the main sphere of life various living organisms. Modeling its structure is of direct interest for ocean fishing, underwater swimming, exploration of the shelves, hydroacoustics, and so on. The research of the characteristics boundary layer of the water environment is one of the most important stages in the construction of the model atmosphere circulation necessary for mathematical methods of weather forecasting. Numerical long-term weather forecasts are now at such a stage that their further improvement is possible only taking into account the impact on the atmosphere of the aquatic environment as a powerful inertial heat accumulator. Thus, the regularity of the study of processes in the aquatic environment, and especially in its upper active layer, becomes extremely important.

Numerical measurements of the profiles basic thermodynamic characteristics of water spaces show that the ocean is almost universally a finely stratified medium in which there are relatively homogeneous layers with thickness ranging from tens meters to tens centimeters, separated from each other by thin boundary layers with significant changes in thermodynamic characteristics [1]. Given the many parametric and changeful nature of physical processes occurring in the ocean, modern hydrophysical experiment requires a comprehensive approach, as a rule. In modern oceanography, the main means of research are automated systems for collecting, transmitting, processing and storing the results of observations. [2]. The input of such systems receives information about the various hydrophysical values measured by the sensors. The output information is data about both the directly
observed fields and calculated with the equations on the basis data of the previous observations. This information can be generated in the form of arrays, tables and graphs.

Currently, oceanographers and hydrophysicists have a large arsenal of various types probing, towed [3] and autonomous multichannel measuring hydrophysical systems [4, 5]. By the methods application of the system are divided into vertically-probing, horizontally-probing and located on submarines, buoys. For the most part, they are necessarily equipped with channels measurement of basic hydrophysical parameters - temperature, specific or relative electrical conductivity, hydrophysical pressure and velocity. However, the existing vertical probing systems do not allow purposefully to obtain data on small-scaly turbulence and parameters of the layered structure aquatic environment with the necessary metrological characteristics. In this connection, the problem arises of the development hardware and software that provide measurements of the parameters turbulent layers with sufficient discretion on depth for recover information about hydrophysical fields with an error not exceeding the set one.

As a result of the analysis of the principles of monitoring the basic parameters [6] it is established when developing monitoring systems for the fine structure of hydrophysical fields of the aquatic environment the plan of experiments should be taken into account. The conducted analysis showed the necessity development of structural-algorithmic organization monitoring system of inhomogeneities of hydrophysical fields aquatic environment, including models, methods and algorithms for determination characteristics of distribution small-scaly turbulence by depth, on the basis of which experimental research with minimal economic costs is planned.

In [7], an object-evolutionary model of information-measuring systems is proposed and an algorithm for simulating process of vertical probing is developed based on it. The use of a model and an algorithm to determine the structure monitoring system of hydrophysical fields aquatic environment is considered by means of which it is possible to obtain sufficient not excessive amount of data in a minimum time probing with a given accuracy.

2. Problem statement

Based on the performed structural-algorithmic analysis of the information-measuring system for monitoring the hydrophysical parameters of the aquatic environment, taking into account the heterogeneity of the studied fields, and the proposed functional scheme of the monitoring system [8, 9] it is necessary:

- to develop a method and algorithm for determining parameters of the configuration system monitoring the heterogeneities of hydrophysical fields aquatic environment, which allow to choose the structure of the system that satisfies the proposed criterion of its efficiency functioning;
- to carry out research of the proposed structural and algorithmic organization of the system monitoring the inhomogeneities of hydrophysical fields aquatic environment on different test data sets and using the probing plan using the quasi-homogeneous layer depth model [6].

Purpose of the article: determination of parameters structural elements of computerized system for monitoring of heterogeneities of hydrophysical fields, which satisfies the given criterion of efficiency.

3. Selection of methods for determining the optimal structure monitoring system

An algorithm is proposed in which a bust possible variants of parameters structural elements of a system that affect its functioning and, consequently, the value efficiency criterion is performed. As a criterion efficiency of functioning information-measuring monitoring system the function of experiment’s cost which arguments are speed of sounding V and poll's interval of sensors Δt is chosen:

\[ S = f(V, \Delta t) \rightarrow \min \]  

when limiting the error of the system:

\[ \sigma \leq \sigma_{sp} \]  

(1)

(2)
where \( \sigma_{sp} \) - error that is specified.

A simulation of the sensing process by measuring system with a given set of parameters implemented on the basis of a test set of vertical profiles of hydrophysical parameters for a specific ocean area, which are obtained from previous sensing of environmental. As a result, the time of the experiment, the amount of information received, the measurement error and the cost of the system are determined.

From all possible variants information-measuring system, the configurations are selected that allow you to perform measurements with a given error, that is, satisfy the restriction (2). Then the configuration with the minimum cost of the equipment is determined, which implementing measurements in minimum time.

4. Decision of tasks

As the parameters, the iterate over values of which is implemented in the algorithm, used: the inertially of the temperature sensors, the number of inertial sensors, the distance between the same inertial sensors on the comb, the minimum velocity of the engine, the discreteness of velocity regulating.

If 10 different values are used for each measurement parameter, then the full iterate over of variants is 105. For each variant it is necessary to perform a simulation of the process vertical sensing of the aquatic environment to obtain data on various hydrophysical parameters. Typically, the modeling process requires somewhere between 40-60 implementations to produce some average characteristics. That is, it is necessary to perform the simulation of the sensing process for different vertical profiles (from 40 to 60 pcs.). It is desirable to divide them into groups by ocean areas, seasons and time of day. Thus, to obtain data on the monitoring system with one set of parameters, it is necessary to simulate the process of sensing different profiles hydrophysical parameters 120-180 times. One modeling takes about 0.4 seconds to complete. 120 implementations take 48 seconds. That means a full iterate over of 105 variants will be performed within 55 days. With a significant increase in the values of each parameter, which vary, the duration of the simulation will be of the essence longer.

Reducing the simulation time is possible by determining significant and interacting parameters. For this purpose, the factor plan method was used, which allows to determine which of the parameters structural assumptions have the greatest influence on the performance indicators, as well as which set of parameters the measuring system elements will allow to obtain the optimal characteristics of the system (cost, time of experiment, amount of information, measurement error).

According to the Type 2k Factor Plan strategy, the following values are selected as the levels for each factor:

- inertia of the temperature sensors iner: 0.3 s 0.8 s
- number of inertial sensors K: 3 7
- distance between the sensors on the comb dr: 5 cm 20 cm
- minimum velocity of the engine Vmin: 0.5 m/s 1 m/s
- discreteness of velocity regulating dV: 0 0.1 m/s.

The lower level denote -1, the top is +1.

As the simulation results are: the cost of the equipment Sob, the sounding time T, the error c, and the cost considering the payment of the experiment S.

Table 1 shows the results of simulation of the functioning of the various configurations of the monitoring system the field of temperature for the Black sea, in the month of August using the factorial plan of the type 2k. In the columns Sob and S per unit accepted the minimum cost of the equipment, the remaining values presented relative to the minimum. Value indicators is very relative, as their values is influenced by such factors as competition, markets, wholesale purchase, etc.

Analysis of the main effects leads to the conclusion that the change in the distance between the sensors absolutely does not affect the cost of the equipment, but significantly affects the time of...
sensing (with increasing distance increases the time of the experiment) and the measurement error, because there is skip of turbulent splashes, which is not taken into account in the measurement process.

Table 1. The matrix factorial plan the type $2^k$

| Plan point | K | dr | Factor | Vmin | dV | Sob | T | $\varepsilon$ | S |
|-----------|---|----|--------|------|----|-----|---|-------------|---|
| 1         | -1 | -1 | -1     | -1   | -1 | 14,00 | 200,01 | 2,95 | 309,35     |
| 2         | -1 | -1 | -1     | -1   | 1  | 23,00 | 352,09 | 1,92 | 543,47     |
| 3         | -1 | -1 | -1     | 1    | -1 | 17,00 | 100,00 | 6,33 | 161,34     |
| 4         | -1 | -1 | 1      | -1   | -1 | 53,00 | 352,09 | 1,92 | 563,47     |
| 5         | -1 | -1 | 1      | 1    | -1 | 7,75  | 200,01 | 7,41 | 305,18     |
| 6         | -1 | -1 | 1      | 1    | 1  | 16,75 | 622,04 | 2,08 | 944,22     |
| 7         | -1 | -1 | 1      | 1    | -1 | 10,75 | 100,00 | 19,24 | 157,17     |
| 8         | -1 | -1 | 1      | 1    | 1  | 46,75 | 622,04 | 2,08 | 964,22     |
| 9         | -1 | 1  | -1     | -1   | -1 | 14,00 | 200,01 | 2,97 | 309,35     |
| 10        | -1 | 1  | -1     | -1   | 1  | 23,00 | 352,09 | 2,88 | 543,47     |
| 11        | -1 | 1  | -1     | 1    | -1 | 17,00 | 100,00 | 5,40 | 161,34     |
| 12        | -1 | 1  | -1     | 1    | 1  | 53,00 | 352,09 | 2,88 | 563,47     |
| 13        | -1 | 1  | -1     | 1    | -1 | 7,75  | 200,01 | 5,90 | 305,18     |
| 14        | -1 | 1  | -1     | 1    | 1  | 16,75 | 622,04 | 2,61 | 944,22     |
| 15        | -1 | 1  | 1      | -1   | 1  | 10,75 | 100,00 | 13,27 | 157,17     |
| 16        | -1 | 1  | 1      | 1    | 1  | 46,75 | 622,04 | 2,61 | 964,22     |
| 17        | 1   | -1 | -1     | -1   | -1 | 27,33 | 200,01 | 2,30 | 318,24     |
| 18        | 1   | -1 | -1     | -1   | 1  | 36,33 | 259,12 | 2,03 | 412,90     |
| 19        | 1   | -1 | -1     | 1    | -1 | 30,33 | 100,00 | 2,60 | 170,23     |
| 20        | 1   | -1 | -1     | 1    | 1  | 66,33 | 259,12 | 2,03 | 432,90     |
| 21        | 1   | -1 | 1      | -1   | -1 | 12,75 | 200,01 | 2,57 | 308,51     |
| 22        | 1   | -1 | 1      | -1   | 1  | 21,75 | 375,20 | 2,02 | 577,31     |
| 23        | 1   | -1 | 1      | 1    | -1 | 15,75 | 100,00 | 9,55 | 160,50     |
| 24        | 1   | -1 | 1      | 1    | 1  | 51,75 | 375,20 | 2,02 | 597,31     |
| 25        | 1   | 1  | -1     | -1   | -1 | 27,33 | 200,01 | 11,25 | 318,24     |
| 26        | 1   | 1  | -1     | -1   | 1  | 36,33 | 352,09 | 7,37 | 552,36     |
| 27        | 1   | 1  | -1     | 1    | -1 | 30,33 | 100,00 | 12,43 | 170,23     |
| 28        | 1   | 1  | -1     | 1    | 1  | 66,33 | 352,09 | 9,27 | 572,36     |
| 29        | 1   | 1  | 1      | -1   | -1 | 12,75 | 200,01 | 15,80 | 308,51     |
| 30        | 1   | 1  | 1      | -1   | 1  | 21,75 | 622,04 | 11,23 | 947,55     |
| 31        | 1   | 1  | 1      | 1    | -1 | 15,75 | 100,00 | 16,56 | 160,50     |
| 32        | 1   | 1  | 1      | 1    | 1  | 51,75 | 622,04 | 11,23 | 967,55     |

9,17 0 -10,42 16,5 22,5 At cost of equipment

Main effects -42,48 42,48 115,74 -49,98 294,58 By time
-57,6 63,7 166,7 -64 456,9 According to the total value

The cost of the system and the time of sensing increase when using the motor with the ability to control the speed of sensing. The cost reduction is affected by the use of inertial temperature sensors, but it also leads to an increase in the experiment time and measurement error.

The time of the experiment decreases when using a larger number of sensors or the engine with a higher speed sensing. At the same time, the increase in the second factor leads to a noticeable increase in the measurement error.
The total cost of the experiment according to the table decreases with an increase in the number of inertial sensors, which is explained by a decrease in the sensing time. The same effect has an increase in the speed of sensing. The use of an adjustable motor leads to a significant rise in the cost of the system. The increase in the cost with using sensors of more inertial is the result of the interaction this factor with others.

Interesting is the conclusion about the impact on the results the system increasing the number of inertial sensors. There should have been a decrease in the error, which is not observed by the results of the experiments according to the factor plan. In this regard, a second table of the factor plan was developed to check the increase in the number of inertial sensors from 1 to 3. Also, when using one sensor, the distance between the sensors was 0, and when using 3 sensors, the distance levels was taken to be 3 cm and 20 cm, respectively. The values of the levels of other factors used are the same as in the first table. Analysis the results allows us to conclude that changes in the number sensors from 1 to 3 significantly reduces the measurement error, which can explain a deterioration in the measurement results with further increased number of sensors, or there is a strong interaction this factor at the upper level with other factors. The results of the main effect for the total cost the system have changed dramatically, namely, the increase in the number of inertial sensors or their inertia leads to a rise in the cost the system. If the former is understandable, the latter is the result interaction with other factors. The influence of other factors, except the distance between the sensors, remained the same. The fact that the results of the main effect from the distance factor change are not clear is explained by the fact that this factor was not taken into account for one sensor.

A quantitative assessment the effect of the interaction factors gives additional information that will assess the degree of interaction individual factors (see table. 2). The results of table 2 are based on the data from table 1 and allow us to conclude that factors affect to the cost of the system only in pairs, with the exception of two options: the number of sensors or sensing speed and the number of sensors or distance between them.

This allowed to build the result's surface "Cost" as the function of two arguments. Of all the options for the interaction of factors (arguments) were chosen:

1 variant – the distance between the sensors, the inertia of the sensors;
2 variant – the speed of the engine, the distance between the sensors;
3 variant – the inertia of the sensors, the speed of sensing.

This choice is due to the fact that the interaction these pairs of factors has a positive effect on other responses of system also. Therefore, the surfaces of the total cost of the system as function these very factors were constructed. An examples graphs surface of response is provided in Fig. 1. A construction of the surface on figure 1, the following values parameters was used: 2 inertial sensors, an engine without speed control with an permissible speed of sensing 0.5 m/sec.

Graphs of response surfaces for different pairs of factor values were constructed. For the construction of all the graphs, the simulation was carried out under the condition of using the engine without adjusting the speed of sensing, since this factor is indirectly involved in changing the values minimum permissible speed of the engine. The graphs are divided into groups, in each of which the construction of response surfaces was carried out at different fixed values of some third parameter: for different levels of sensing velocity values using two inertial sensors; for a different number of inertial sensors at a constant speed of sensing; for different levels of inertia sensors, the number of which has not changed and was equal to 2; for a different number of sensors with inertia of 1; for a different number of inertial sensors, which are located at a distance of 3 cm from each other.
Table 2. Quantifying the effects interaction of factors.

| Factor | Interaction effect |
|--------|--------------------|
| K      | dr     | iner | Vmin | dV | Sob | T | ε |
| +      | +      | 0    | 42,48| 4,71|
| +      | 4,17   | -19,23| -0,39|
| +      | 0      | 0    | -0,87|
| +      | -2,81  | -84,61| 1,56|
| +      | -6,53  | -60,4 | -2,05|
| +      | -6,53  | -79,63| -2,59|
| +      | -2,81  | 34,0  | 0,61|
| +      | -6,53  | -79,63| -0,93|
| +      | -2,81  | 73,61 | -2,01|
| +      | 10,69  | 7,87  | -1,62|
| +      | 0      | 19,23 | 0,92|
| +      | 0      | 0    | 0,12|
| +      | 0      | 0    | -0,57|
| +      | -19,23 | 1,14 |
| +      | 0      | 1    | 1,1 |
| +      | 0      | 0    | -0,78|
| +      | 19,23  | 0,63 |
| +      | 0      | 0    | 0,79|
| +      | 0      | 0    | -1,35|
| +      | 0      | 0    | -0,34|
| +      | 19,23  | -0,09|
| +      | 0      | 0    | 0,11|
| +      | 0      | 0    | 0,33|
| +      | 0      | 0    | 0,54|
| +      | 0      | 0    | 0,11|

Figure 1. Response surfaces of the measurement error (a) and system cost (b) from the inertia of the sensor and the distance between the sensors.
On the graph of the response surface of the measurement error, a plane at the level 3% of the error is drawn. Thus the values that lie above this level and do not satisfy the restriction 2 are cut off. According to the requirements of the monitoring system of fine structure of hydrophysical fields of the aquatic environment, the measurement error can not be more than 5%. Since the simulation of the sensing process to analyze the impact of various factors on the system structure was carried out on values of one implementation to reduce the execution time program, this limit was reduced to 3%. The graph shows that the distance between the two sensors should be in the range from 3 to 9 cm, while the inertia of the sensor can not be higher than 0.2 s. On the graph b, a surface is drawn which separates areas that not satisfying the limitation of the measurement error. This allowed us to determine the lower limit of the cost of the system at given values of factors and this value is equal to 210 conditional units.

The set of measurement error surfaces as a function of the distance between the sensors and their inertia, built for different sensing speeds when using only two sensors and for the sensing speed of 1 m/s at different amounts of inertial sensors, show that the distance between the sensors, regardless of their number, must be selected in the range of 3-8 cm, and the inertia should not exceed 0.1 – 0.2 seconds. The graphs show that the lowest cost of the system, taking into account the payment for the experiment, which meets the requirements for the accuracy of measurements, corresponds to the structure: 2 sensors with an inertia of 0.1 s; the engine with a constant sensing speed of 1 m/sec. In this case, the cost of such a system will be equal to 109 conditional units. These conclusions are confirmed by the analysis other graphs and can significantly reduce the range of variation parameters in the simulation modeling of monitoring systems, namely:

- inertia of the temperature sensors iner: 0,1 с 0,3 с
- number of inertial sensors K: 2 3
- distance between the sensors on the comb dr: 3 см 8 см.

The system uses an engine that performs sensing at a constant speed of 1 m/s, which is typical for modern sensing systems.

5. Examples of using the proposed algorithm
10 different vertical temperature profiles obtained for the black sea water area in August and 10 models of the vertical structure the distribution of turbulent layers in depth [11] were used to simulate the sensing process. The input data were mixed and 100 different results were obtained for each configuration option the monitoring system, on the basis of which the average performance the system was calculated. The simulation results satisfying the limitation for the measurement error are given in table. 3.

6. Conclusions
Based on the results obtained, the systems’s configuration for the monitoring fine structure of water environment hydrophysical fields should consist of three sensors with inertia 0.2 s located on the comb at a distance of 5 cm from each other. However, in this case the measurement error is close to the limit value – 5%. A system with parameters: 3 sensors with inertia 0.1 s, located at a distance of 3 cm from each other allows to get the lowest measurement error of 3.5%. Herewith the rise in price of the system will be insignificant.

The proposed algorithm can be used to determine the structure measurement system of the sensing before the experiments. This will allow to obtain the results of hydrophysical parameters with a given depth resolution, taking into account the presence of turbulent layers.

The obtained results provide a basis to perform similar studies for information-measuring systems using a plan to determine the sensing strategy based on the location model of the quasi-homogeneous layer using test data sets of different ocean areas.
Table 3. Simulation' modeling results of systems's different configurations for monitoring fine structure of water environment hydrophysical fields.

| Number of sensors | Distance between the sensors, sm | Inertia of sensors, s | The measurement error, % | Cost of equipment | Total cost |
|-------------------|----------------------------------|-----------------------|--------------------------|------------------|-----------|
| 2                 | 3                                | 0.1                   | 4.52                     | 27               | 168,00    |
| 2                 | 4                                | 0.1                   | 4.06                     | 27               | 168,00    |
| 2                 | 5                                | 0.1                   | 4.02                     | 27               | 168,00    |
| 2                 | 6                                | 0.1                   | 4.06                     | 27               | 168,00    |
| 2                 | 7                                | 0.1                   | 4.55                     | 27               | 168,00    |
| 3                 | 3                                | 0.1                   | 3.5                      | 37               | 174,67    |
| 3                 | 4                                | 0.1                   | 3.69                     | 37               | 174,67    |
| 3                 | 5                                | 0.1                   | 4.06                     | 37               | 174,67    |
| 3                 | 5                                | 0.2                   | 4.92                     | 22               | 164,67    |
| 3                 | 6                                | 0.1                   | 4.0                      | 37               | 174,67    |
| 3                 | 6                                | 0.2                   | 4.63                     | 22               | 164,67    |
| 3                 | 7                                | 0.1                   | 4.25                     | 37               | 174,67    |
| 3                 | 7                                | 0.2                   | 4.6                      | 22               | 164,67    |
| 3                 | 8                                | 0.1                   | 4.84                     | 37               | 174,67    |

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