Database of Observations of the Internal Waves in the World Ocean

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Purpose. The purpose of the paper is to describe the permanently updated public database containing the information on observations of the internal waves, as well as the scientific sources on the corresponding themes. The observations are based on the data obtained by remote sensing and direct contact measurements in various areas of the World Ocean and in the inland basins (lakes, water reservoirs).
Methods and Results. The data from 503 literature sources on the observations of internal waves are structured. The structure, format, volume and current content of the database are considered; the stored information is analyzed. Described is the process of adding and viewing the records using the IGWAtlas web application (the online project for working with the database of the observations of internal waves in the oceans and for public access to observations and sources that has an intuitive user interface). Geographical distribution of the recorded observations and their dependence on a season are illustrated. The examples of images of various types of records containing in the database, as well as their distribution according to the types of observations are given. The considered in the paper database is integrated into the IGWResearch software package intended for numerical simulation of propagation and transformation of the internal waves in the World Ocean.
Conclusions. The database contains the materials for 1972–2018 on 2296 recorded manifestations of the internal waves, which correspond to 2465 images, namely device records, satellite images, graphs, maps and tables. The database scope includes geographic information systems, statistical analysis, knowledge bases and web-services for the tasks of the World Ocean research.

Key words: internal waves, database, the World Ocean, IGWAtlas, IGWResearch, the Black Sea.

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Introduction

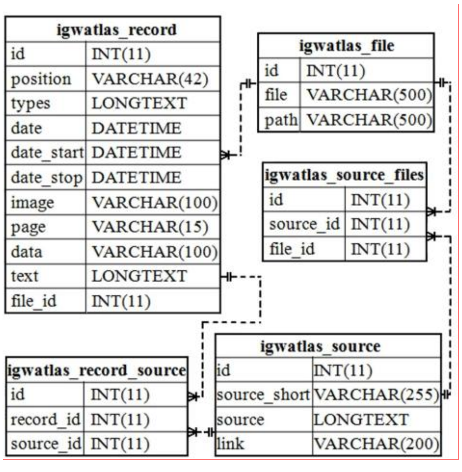
Internal waves appear and propagate inside stratified continuum, including in the aquatic environment due to its vertical inhomogeneity in temperature and salinity and, consequently, density. Intense localized internal waves are of interest for many reasons: they can propagate over hundreds of kilometers and carry out the transfer and redistribution of energy, mass, nutrients, pollution, impurities and bed materials. The shear flows induced by their propagation can lead to a strong mixing and generation of turbulence areas, making a significant contribution to the bottom topography formation and having a significant effect on the ecosystem and underwater parts of hydraulic structures (oil platforms, protective and mooring facilities, navigation locks, ship elevators, etc). It directly affects the human economic activities on the shelf. All of the above confirms the fact that internal waves are the relevant object of research.

Registration of marine internal waves is associated with great difficulties, therefore, despite the fact that it has been performed since the middle of the last century, a limited number of observations have been recorded in various water areas. Until now, there is the only catalog, containing satellite images of internal waves, an *Atlas of Internal Solitary-like Waves and their Properties Waves* [1], published in 2004. The greatest number of observations is contained in papers devoted to areas of the ocean with a high probability of generating internal waves, depending on the intensity of factors such as the power of the barotropic tide and significant bottom slopes [2].

The present paper describes the structure, format and content of a database of observations of internal waves in the oceans, obtained by remote sensing and direct contact measurements in different areas of the oceans, as well as in inland waters (lakes, water reservoirs).

The Database Structure and Format

The database of observations of internal waves in the oceans, has 1.9 GB volume. It is based on the MySQL database management system (DBMS). This is a free relational DBMS that allows several users to access the database simultaneously and centrally store it on the server (Fig. 1).



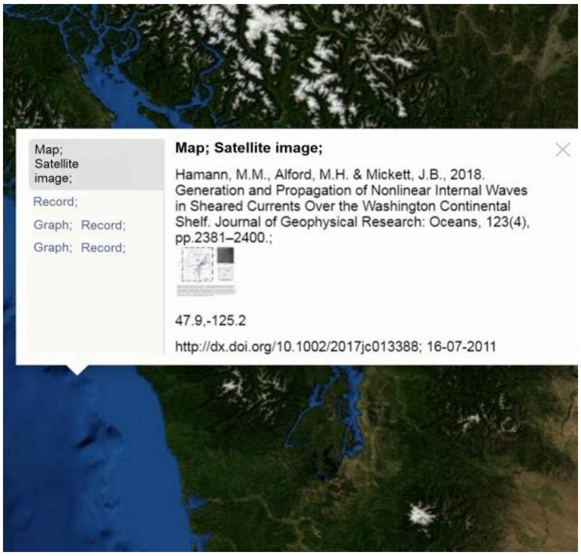
F i g. 1. Database scheme of internal waves in the World Ocean

Adding New Records to the Internal Wave Database and Their View

The database is integrated into the web application *Internal Gravity Waves Atlas* (IGWAtlas) (https://lmnad.nntu.ru/ru/ru/igwatlas/). The Atlas of Internal Gravitational Waves is an online project for working with a database of observations of internal waves in the oceans and for public access to observations and sources. For user interaction with the database the administrator panel was developed. It enables to add, edit, search and delete records – and has an user-friendly interface.

A new record can be added in the following way: at first, the bibliographic data of the literary source containing information on the manifestations of internal waves in the World Ocean are entered in the appropriate fields of the IGWAtlas application. Then the information about the observations described in the source is added. In the absence of coordinates, they can be restored from the published image and manually marked on the map.

An example of an IGWAtlas application web page with the image of the geographical location of the registration of internal waves and an indication of the literature describing these waves is shown in Fig. 2.



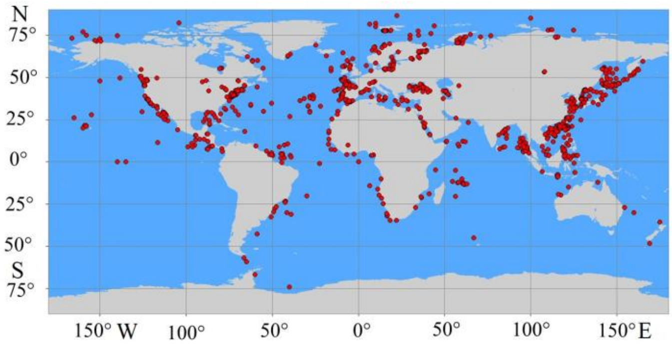
F i g. 2. An example of a web page with visualization of observations of internal waves

Analysis of the Content of the Database of Internal Waves

The created database was originally based on materials from the Atlas of Internal Solitary-like Waves, containing 275 sources and a text description with graphic illustrations of more than 300 examples for 54 different areas of the World Ocean [1]. They are supplemented by information from the following sources: publications in leading Russian and foreign peer-reviewed scientific journals, materials of scientific seminars and conferences, dissertation works, as well as personal communications data. Currently, the base contains 2,296 observations from 503 references, covering the period 1972–2018. Their geographical distribution is shown in Fig. 3.

The largest number of observations recorded in the South China Sea, Yellow and Sea of Japan (441), on the North America and Mexico coasts (297), in the Strait of Gibraltar and on the Iberian Coast (134), in the White Sea (71) and in the Black Sea (59).

Seasonal variability of internal waves in the World Ocean has pronounced manifestations (Fig. 4a). The peak of the number of observations falls on the summer period (764), the minimum values are recorded in the winter (127). In autumn and spring, a commensurate number of data is recorded (376 and 390, respectively).

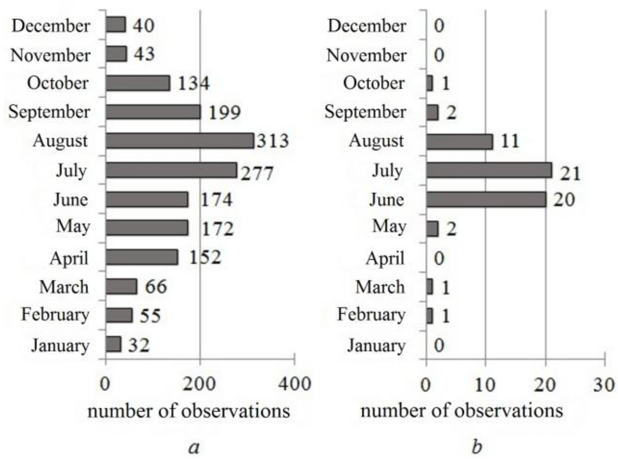


F i g. 3. Geographical distribution of the recorded observations of internal waves in the World Ocean

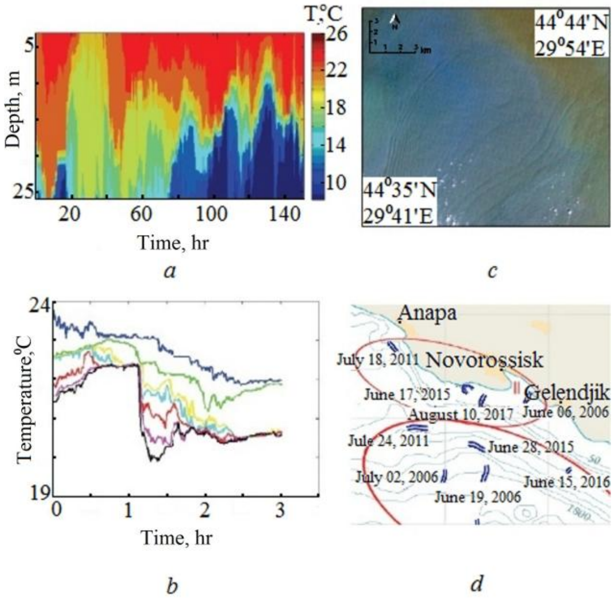
The Black Sea deserves special attention. It is rich in natural resources. There are the largest ports of southern Russia, important hydraulic structures. The communications of international and federal importance are also located in the coastal zone. Therefore, there is no doubt that the study of wave processes in the Black Sea [3–6] is of extremely important ecological, economic and economical importance. The seasonal variability in the number of observations of internal waves in the Black Sea is as follows: in the summer period – 52, in the autumn and spring – 3 each and in the winter – 1 (Fig. 4, *b*).

Except the coordinates, the registration dates of internal waves and data on literary sources, the database contains the following information (types of observations): records from recording devices [7, 9, 10], satellite images [8, 11], several types of graphs [12] , drawings and profiles of stratification parameters, maps [13, 16], showing the observation areas and tables [17, 18] of the parameters of internal waves in different areas of the World Ocean (Fig. 5).

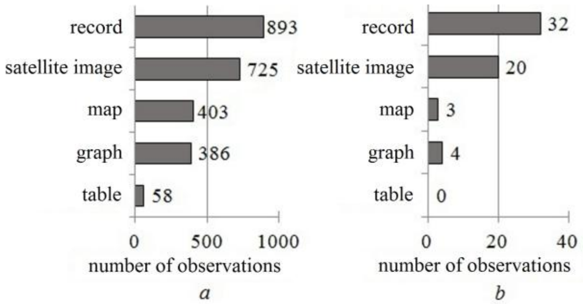
The database is organized in such a way that several types of observations can correspond to each record. The database stores 2,465 different images, including 59 of them across the Black Sea. Quantitative characteristics of the types of observations are shown in Fig. 6.



F i g. 4. Seasonal variability of a number of observations of internal waves: in the World Ocean – *a*, in the Black Sea – *b*



F i g. 5. Types of observations of internal waves: *a* – recording from the devices; *b* – graph [7]; *c* – satellite image; *d* – map [8]



F i g. 6. Distribution of the records by the types of observations in the World Ocean – *a* and in the Black Sea – *b*

Practical Significance

The created database is integrated into the *Internal Gravity Waves Research* (*IGWResearch*) software package for modeling internal waves in the World Ocean. This software complex was developed in a Research Laboratory of Modeling of Natural and Anthropogenic Disasters of Nizhny Novgorod State Technical University n. a. R.E. Alekseev.

In *IGWResearch* computational blocks and algorithms for working with multidimensional data were implemented. They represent physical fields distributed on a geographical grid, algorithms for constructing and preparing data samples for performing mathematical modeling, a number of numerical models (Gardner, Korteweg de Vries, Gardner – Ostrovsky equations) for modeling and transformation of internal waves, algorithms for loading data into a complex, a model for constructing a particle transfer trajectory, as well as a number of software tools for analysis and visualization of the results.

To initialize numerical models, density data obtained from open sources using the equation of seawater state based on the WOA13 (https://www.nodc.noaa.gov/OC5/woa13/) and GDEM [19] hydrological atlases are used. The ETOPO1 bathymetry atlas (https://www.ngdc.noaa.gov/mgg/global/) is used to define the coastline. Details of this complex can be found in [20–22].

Conclusion

The database containing extensive information about the observations of internal waves in the World Ocean was created. It includes 2,296 observations from 503 references for the period 1972–2018. It provides the quick search of data on the confirmed cases of registration of internal waves, described in domestic and foreign literature. The database is of interest for researchers in the field of ecology, hydrobiology, water engineering and oil production. Works on its filling and improving its structure are constantly carried out.

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Artem V. Rybin – development and debugging of a computer program for solving a problem

Tatyana E. Moiseenko – data collection and systematization

Oksana E. Kurkina – formulation of the problem, qualitative and quantitative analysis of the results

Andrey A. Kurkin – scientific leadership, critical analysis and revision of the text

Dmitry Yu. Tyugin – selection and analysis of literature

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