Analysis of Entropy of Temperature and Salinity Distribution in Subsurface Layer of the Kara Sea Water Area by Geomatics Methods

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Abstract. In recent years the nature of the Kara Sea is greatly influenced by human economic activity. It is stipulated mainly by extensive development of the Kara Sea coastline and by huge deposits of hydrocarbons on its shelf. An attempt to estimate the entropy of temperature and salinity distribution in subsurface layer of the Kara Sea water area has been made in this study aided by the newest geoinformational methods of study (Quantum GIS Desktop program complex). The computation and cartographic modeling of this problem show that the greatest values of entropy indices are registered within littoral and shelf regions. It can testify to the high diversity of these water areas and it is necessary that special (nature protection) regimes of nature use should be set up.

1. Introduction

The Kara Sea is considered to be marginal continental sea. It is situated in the Arctic ocean, off the shores of the Siberian lowland. The coast of the Kara Sea is highly indented and has a complex outline. There are numerous fiords here. The largest ones are on the Severny Island of the Novaya Zemlya archipelago. Baidarskaya, Obskaya, Tazovskaya, Gydanskaya inlets as well as Yeniseisky and Pyasinsky bays run deep in land. The area of the Kara Sea is approximately 883 thousand sq.km. Numerous islands are scattered within the Kara Sea water area. Small islands are spread off the shores of Taimyr Peninsula. The largest islands in the Kara Sea water area are Bely, Shmidtta, Vize, Ushakova, Russky, Sverdrup, Uyedineniya, as well as insular archipelagoes – of Arctic institute, Ivvestiy TSTIK, Sergeya Kirova, Shhery Minina and so on [1].

Temperature and salinity of the Kara Sea have been extensively studied for some years [1-8]. The analysis of the references [1, 9-17] has revealed that the Kara Sea is actively polluted that is caused by great deposits of hydrocarbons on the shelf of the Kara sea. So it is expedient that assessing entropy of different physico-geographical and oceanological (thermohaline, hydrochemical and biological)
indices and its geographical distribution in the examined waters should be carried out to determine the most valuable water areas in order to conserve them. In addition, it must be done to create promising reserves and to minimize their economic use. However it should be noted that there are practically no works on entropy of physico-geographical and oceanological (thermohaline, hydrochemical and biological) indices and this problem is almost neglected.

2. Materials and methods

The methods of entropy distribution study of different oceanological (thermohaline, hydrological and biological) indices are based on complete describing all characteristics and defining the regularities of sea functioning as a complex open system. The study of complex systems is possible aided by systematic and synergetic paradigm [18].

The methods of entropy distribution study of different oceanological (thermohaline, hydrochemical and biological) indices can be divided into three main stages: preparatory, studying stage and office studies. During the preparatory stage we’ve collected the primary data about the region studied. This stage includes defining the limits of the object studied, gaining its literary and cartographic information as well.

On the second stage – the data received are processed and analysed. Now it is more expedient to study complex geospatial systems (object of study) using geo-informational technologies provided by the development of cybernetics information and theory and computer technologies. Geographic information systems are the most suitable in geographic studies for these purposes.

There is a great number of geographic information systems (Quantum GIS Desktop, ArcGIS, SAGA (System for Automated Geo-scientific Analysis) GIS, Surfer GIS, Panorama GIS, Map Info GIS and others). But the fact that most Geographic Information systems (ArcGIS, Surfer GIS, Panorama GIS, Map Info GIS and others) are distributed by paid licence makes them difficult to apply in the educational process. However another part of geographical information systems (Quantum GIS Desktop, SAGA (System for Automated Geo-scientific Analysis) GIS and a number of others) are open code programs and distributed free by open licence. Among them Quantum GIS Desktop program is the most functional. This paper analyses the materials of study and makes up cartographic material using Quantum GIS Desktop program.

During office studies the analysis of received information is carried out, new regularities of spatial development of the objects studied are defined.

As it was mentioned above active studies of World ocean seas were done by a lot of researchers, but in our work we’ll be guided by the methods developed by the scientists of physical geography, oceanology and landscape study department of Tavrida Academy in V.I. Vernadsky Crimean Federal University within the framework of scientific school of structural and landscape geography. So, we’ll successively fulfil the following stages [19, 20 with author’s additions] provided by geo-information system – Quantum GIS Desktop 2.18.16:

- Loading and installing Quantum GIS Desktop 2.18.16 program complex.
- Digitizing the boundaries of the sea, the shoreline of the surrounding islands, peninsulas, continents.
- Studying different physico-geographical and oceanological (thermohaline, hydrochemical and biological) indices by, archive, cartographic materials and sources.
- Placement of cartographic material by co-ordinates, which shows a set of basic physico-geographical characteristics.
- Digitizing the main physic-geographical and oceanological (thermohaline, hydrochemical and biological) indices.
- The analysis of basic physico-geographical and oceanological (thermohaline, hydrochemical and biological) indices and natural diversity as a whole.
The estimate of natural diversity is carried out according to the method suggested by Grigori Skrebets and co-authors [19, 20] and was approved for the water areas of the Black and Azov seas. For this purpose the sea water area is divided into squares of one size and a definite number of points is placed in each square. Then the entropy of each square is calculated by Shannon formula [19, 20]. So Shannon proposed to use the formula of absolute entropy $E(A)$:

$$E(A) = \sum \frac{f_i}{\sum f_i} \log_2 \frac{\sum f_i}{f_i}$$

where $f_i$ is the number of points in a definite scope for the square of a given size, $\sum f_i$ is the total number of points in the square of a given size, $i$ is the number of definite scopes for the square of a given size.

The computation of entropy indices will be fulfilled using Quantum Desktop 2.18.16 and Microsoft Excel 2016 programs. Taking into account that quite different characteristics can be analyzed on the maps, the index of absolute entropy may be replaced by the index of relative entropy – $E(A)_{rel}$ to analyse their distribution and comparison. It can be explained by the fact that values of relative entropy fluctuate between 0 and 1 and are suitable to compare the main physico-geographical and oceanological (thermohaline, hydrochemical and biological) indices which have different dimension quantities.

Thus the study of physico-geographical characteristics of the Kara Sea will be carried out using geo-informational Quantum GIS Desktop 2.18.16 system and this method of study will be applied as a basic one.

3. Results and discussion

According to the methods described above in calculating the entropy index of temperature and salinity distribution in subsurface layer of the Kara Sea water besides the simple characteristics of the main physico-geographical and oceanological (thermohaline, hydrochemical and biological) indices, the following results have been obtained (stated below). They were received by modern geo-informational methods of study.

At first all the cartographic data showing spatial distribution of the main characteristics were digitized in Quantum GIS Desktop 2.18.16 complex program. For this purpose raster pictures were attached to the coordinates in WGS_1984_EPSC_Russia_Polar_Stereographic aided by “Raster Attachment” (see Figure 1).

![Figure 1](image1.png)

**Figure 1.** Digitizing of temperature of subsurface sea water layer for calculating entropy diversity (A map made up by the author using [1]).
Then the basic isolines were digitized and turned into vector format using the “To create a vector layer“ tool. After that the Kara Sea water area was divided into 46 full and incomplete squares, 200*200 sq. km. The area of each full square was 400 sq. km. Each square was given an ordinal number from 0 to 45. All in all 12 full and 34 incomplete squares have been defined. Maximum 100 points are within each square. So all water area of the Kara Sea is covered with a grid of 2417 points according to which the entropy index has been computed.

“Count the points in the range“ tool has helped to compute the number of points in a definite scope of values of the characteristics studied. As a result a set of data necessary for calculating entropy index for each square had been obtained and estimated, natural diversity of the Kara Sea taken into account. The computation of relative entropy index was carried out in Microsoft Excel program. The values of relative entropy have been received – they fluctuate between 0 and 1. A point vector layer using “The points of range center“ was set up and the values of relative entropy for each square were placed in these points. The maps of entropy distribution of temperature and salinity in the subsurface layer of the Kara Sea water were made up using “Interpolation“ tool by points – the centers of range squares (see Figure 3,4).

Figure 2. The square grid on the Kara sea water area.

Figure 3. Entropy of Temperature Distribution in Subsurface Layer of the Kara Sea.

Figure 4. Entropy of Salinity Distribution in Subsurface Layer of the Kara Sea.
4. Conclusion

Entropy distribution of water temperature in the Kara Sea water area in subsurface layer of the sea water is rather complicated. Entropy values of 0.5 prevail in the Kara Sea water area, that testifies to the high diversity of the index studied. The greatest values of entropy are revealed in the western part of the Kara Sea water area in the region of Yugorsky peninsula, Vaigach island, Yuzhny island of Novaya Zemlya archipelago, Yugorsky Shar and Matochkin Shar straits, as well as in the eastern part of the Kara Sea water area – to the east of conventional line of Zhelaniye cape (Severny island of Novaya Zemlya archipelago) – Sterlegov cape on Khariton Laptev shore. The least values the entropy disclose between Zhelaniye cape (Severny island of Novaya Zemlya archipelago) and Kol’zat cape (Grem-Bell island of Zemlya Frantsa- Iosifa archipelago) at the boundary with the Barents Sea, in the region of Severnaya Zemlya archipelago and in most estuary parts. Entropy distribution of water salinity in the Kara Sea subsurface water area can be defined as complex. In the Kara Sea water area the entropy values of more than 0.5 dominate, that testifies to the high diversity of the index studied. The entropy index discloses the highest values in the central part of the Kara Sea water area. But entropy shows the smallest values in the western part of the Kara Sea water area in the region of Yugorsky peninsula, Vaigach island, Yuzhny island of Novaya Zemlya archipelago, Yugorsky Shar and Matochkin Shar straits and the region of Severnaya Zemlya archipelago (in the region of Komsomol’etz, Oktyabr’skaya revolution and Pioneer islands) and run deep towards the west. In estuaries the entropy is increasing while separating from the shore and connecting more with open parts of the sea. The greatest values reveal in the mouths of the large rivers – the Ob’ and Yenisey, but at the same time such regularities are not registered at the mouths of a number of smaller rivers.

5. References

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