The Study of the State of the World Ocean Areas Based on Modern Technologies for Processing and Analysing Data

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Abstract. This paper is devoted to the processing of hydrophysical data on the state of marine areas utilizing modern data processing technologies. Author uses Python programming language to process marine data. The results on the processing of the remote sensing data on the Baltic and the Black Seas surface temperature are presented in the study. Daily satellite data for the years 1982–2018 were processed using Python scripts for both water areas. The analysis of the obtained information was conducted with R programming language. This language supports a wide range of statistical and numerical methods and is convenient to use to determine the statistical characteristics of the studied quantities. Data analysis reveals statistically significant positive trend in the sea surface temperature (SST) values in the both studied water areas over the past decades. The paper has also analyzed the spatial variability of the surface temperature within considered areas. The analysis illustrates the temperature variability in certain areas of the sea and identifies areas with the highest rate of temperature increase. Conclusions are made on the usability of the programming languages for various data processing tasks.

1. Introduction
Currently, the development of observational systems for monitoring the state of the environment is being actively developed, and therefore the number of observational data is growing rapidly. At the present time there is much more Earth observation data than we manage to process and analyze. The same applies to the study of the World Ocean. Processing the data of the state of the marine environments, including environmental observations from satellites, buoys and ships, as well as data analysis and reanalysis of numerical models, becomes a challenging task.

Along with an increasing of the amount of data, technologies are being developed for their processing and analysis. The use of modern data processing technologies allows to process information more efficiently.

2. Data and methods
Data provided by Copernicus Marine Service were used in the study (http://marine.copernicus.eu/).

The Copernicus project is an international Earth observation program that provides an opportunity to study, research, and monitor the environment. The Service provides both observational data (remote sensing data, in-situ data) and fields of the main parameters of marine environments, calculated on the basis of numerical models of project participants (reanalysis, forecast etc.). The data observation on the surface temperature of the Black and Baltic Seas are used in the research. The products are stored...
in the Marine service using the NetCDF (network Common Data Form) format (http://www.unidata.ucar.edu/software/netcdf/). The products identifiers are SST_Bal_sst_L4_rep_observations_010_016 for years 1982-2011 and SST_Bal_sst_L4_nrt_observations_010_007_b for years 2011-2018 for the Baltic Sea [1]. The Black Sea data used in the work are SST_BS_sst_L4_rep_observations_010_022_a for the years 1982-2017 and SST_BS_sst_L4_nrt_observations_010_006_a_V2 for 2018 [2, 3].

Two modern programming languages were used to process this data – Python and R. The Python is a high-level, general-purpose, performance-oriented programming language [4]. The language is distinguished by its convenient syntax and ease of use, it allows one to work quickly and integrate different software components into a single system. A set of scripts for receiving data from the Service and converting them into the required formats is implemented using Python. The daily SST data of the Black and Baltic Seas for the years 1982-2018 were processed using the implemented set of scripts. The using of the Python is convenient for solving problems of receiving and processing data as well as for integrating the codes for various applications.

To perform the data analysis programming language R [5] was used. The language has been developed by scientists mainly for statistical data processing and is available free of charge. The R supports a wide range of statistical and numerical methods; its data visualization is implemented conveniently. Using the R allows one to efficiently analyze data, distinguish structures and anomalies in data sets, identify and investigate regularities using statistical methods. Using the capabilities of the R the analysis of observational data on the Black and Baltic SST for 1982–2018 was carried out. To analyze the sea temperature data a simple linear regression was carried out. Linear trend estimation is a statistical technique to aid interpretation of data. When measurements are presented as time series, trend estimation can be used to make and justify statements about tendencies in the data. The linear trend line is represented by a linear function of time $y$ minimally deviating from the observed values $\bar{y}_i$, i.e.

$$\sum_{i=1}^{n} (\bar{y}_i - y)^2 \rightarrow \text{min}.$$  

Another problem addressed by this research is the study of spatial temperature variability. This refers to the changing of the sea heating over time at each point of the considered area since the change in temperature values in the sea is not uniform.

3. Results
The data analysis clearly represents a positive trend in changing of the sea surface temperature values for the Black and Baltic Seas. The graph of the changing surface temperature, averaged over the sea, is presented in Figure 1: (a) for the Baltic Sea and (b) for the Black Sea water area.
Figure 1. Baltic (a) and Black (B) SST for 1982-2018 years, linear trend is indicated by the dotted line, °C.

Figure 2a shows the temporal variability of the average annual values of the Baltic SST for the investigated period and a linear trend based on the observed data. The same is presented for the Black SST in Figure 2b.

The trend in changing of the Baltic SST is positive, sea surface temperature rises with change rate $+0.044 \pm 0.008$ °C/year, where ±0.008 is dispersion. Dispersion is a measurement of variation, which is the average square of deviations from the expectation, it expresses the variation of values relative to the mean. To assess the statistical significance of the result obtained, a t-test was carried out, showed...
significant evidence (p-value < 0.001) against the Null-hypothesis that there is no positive trend, therefore it is reasonable to conclude that average temperature does increase over time.

The result confirms the results of a similar study [6] conducted in 2014. The mentioned work on studying the climatic variability of SST and the level of the Baltic Sea showed that the average surface temperature of the Baltic Sea grew at a rate of +0.04 ±0.02 °C/year during the period 1982-2013.

In the paper [6] the Gulf of Finland area has been identified as the region with the highest average SST growth rate for the years 1982 - 2013, which is +0.09 ±0.02°C/year. The analysis of observation data for 1982-2018 described in the present study illustrates that the average growth rate of SST in the Gulf of Finland is no longer so high, about +0.06 °C/year. However, the nature of the SST spatial variability is not uniform, and the growth rate of average annual surface temperature increases from west to east of the Gulf of Finland from +0.045 °C/year to +0.09 °C/year, respectively. The change rate of the average annual Baltic SST is presented in Figure 3a.
Figure 3. Change rate of the average annual values of the Baltic (a) and Black (b) SST for 1982–2018, linear trend is calculated in every point, °C/year.

Thus, the general warming trend of the Baltic Sea SST has been preserved and has not been changed; however, the warming of the Gulf of Finland is no longer so rapid, although it exceeds the average warming rate of the whole sea.

In this paper, a series of calculations were carried out to study the variability of the Black Sea surface temperature. The Black SST data analysis also revealed a positive trend, the surface temperature increase with the speed $0.066 \pm 0.007$ °C/year during the period 1982-2018 (Figure 2b). According to Copernicus Marine Service Ocean State Report [7], global sea surface temperature has increased and SST trend is $0.08 \pm 0.008$ °C/year for the Black Sea water area and $0.03 \pm 0.007$ °C/year for the Baltic Sea (based on data for the period 1993-2016 years). The estimated rate of SST of the present study is less than in the mentioned Report; this is due to a longer period of research. It seems that the surface temperature values have not been changed so quickly in the first ten years of the study period, therefore the average change rate is less than it is indicated in the Report.

The study of the spatial-temporal variability of the Black Sea surface temperature has also been carried out in the present research. Figure 3b shows the change rate of the sea surface temperature, calculated over 1982–2018 for each point of the Black Sea. The northeastern part of the water area, where the sea is connected with the Sea of Azov, heats up faster than the southwestern part, where the sea is connected by a strait to the Marmara and Mediterranean seas.

It should be noted that according to the results of processing and analyzing data of the surface temperature of the Black and Baltic Seas, the coldest year for the study period is 1987 in both water areas. 2018 is the warmest in both areas.

4. Conclusion

The use of modern technologies allows one to efficiently process and analyze data. Using the Python language makes it possible to process the large amounts of data and integrate various programs for specific tasks into a single system. Due to a wide range of built-in statistical methods and great
visualization capabilities, the R allows to perform the analysis of such challenging data as hydrophysical one.

In the research the data on the sea surface temperature for 1982–2018 years were processed for two water areas: the Black Sea and the Baltic Sea. Data analysis revealed a positive trend in changes in the average annual values of SST in the both seas, the result is statistically significant. This fact indicates the overall warming of the considered seas in recent decades. Black Sea surface temperature has been increasing with the growth rate +0.066 ±0.007 °C/year during the period 1982-2018 years. Baltic Sea surface temperature has been rising with the change rate +0.044 ±0.008 °C/year. This study confirms that the positive trend revealed earlier (e.g. [6]) for the whole sea is being preserved. However, for the Gulf of Finland water area, the average rate of changing in average annual surface temperature values decreased from +0.09 °C/year to +0.06 °C/year. The warmest year for the study period for the both water areas was 2018 in accordance with satellite data. The study of spatial and temporal variability allows to identify areas with the highest rate of temperature change in the studied areas and to analyze the changes in certain parts of the water areas.

5. References
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