CLIMATE AND ENVIRONMENTAL MONITORING OF THE BALTIC SEA: GENERAL PRINCIPLES AND APPROACHES

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Abstract

The environment of the Baltic Sea is heavily influenced by human activities. In addition, the region is undergoing significant changes in the face of global climate change. Therefore, it is necessary to assess the state of the environment and greenhouse gas emissions in the region. In 2022, the Programme for the development of the system of climate and environmental monitoring of the Russian seas was launched. For the Baltic Sea, the spatial and temporal scheme of the regional monitoring module has been designed to carry out long-term, regular, and large-scale surveys. The satellite monitoring is based on the analysis of radiometer data and includes analyses of the spatial and temporal variability of suspended particulate matter and chlorophyll a concentrations, as well as sea surface temperature. The shipboard monitoring consists of seasonal and monthly surveys. The coastal monitoring is based on data from sensors installed on a 57-m met tower as a permanent climate and environmental monitoring station located on the coast of the south-eastern part of the Baltic Sea (Kaliningrad Oblast, Russia).

Keywords: shipboard monitoring, satellite monitoring, permanent monitoring station, meteorological tower, carbon dioxide and methane fluxes, primary productivity, oceanographic properties

I. Introduction

The imbalance of the global climate system, the inability to accurately predict the climate changes and the following feedbacks, as well a great influence of those changes on the social and economic spheres determine the global climate agenda for the next decades. To bind an international treaty on climate change, the Paris Agreement was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on December 12, 2015 [15]. Since Russia signed the Paris Agreement, it has committed to take action to reduce greenhouse gas (GHG) emission and develop a long-term low GHG emission strategy. From this time, a low-carbon transformation of Russia started and several legislative documents have been approved in order to achieve carbon neutrality by 2060.

According to the Decree of the Government of the Russian Federation No. 3183-r [4], the National Action Plan for the First Phase of Adaptation to Climate Change was approved on December 25, 2019 for the period up to 2022. The main aim of the first Stage of the Plan was to develop a regulatory and guidance documentation, as well as a legal framework for carrying out adaptation measures at the national, regional, and sectoral levels. This will help reduce the vulnerability of society and the economy to the negative effects of climate change, and take advantage of the opportunities that climate change presents.

In 2020, the Decree of the President of the Russian Federation No. 666 "On the reduction of greenhouse gas emissions" was approved [6]. The Decree mandates: a) to ensure that greenhouse gas emissions are reduced to 70 percent of the 1990 level by 2030, taking into account the maximum possible absorption capacity of forests and other ecosystems and subject to the sustainable and balanced socio-economic development of the Russian Federation; b) to develop and adopt a strategy for the socio-economic development of the Russian Federation with a low level of greenhouse gas emissions by 2050, taking into account the specificities of economic sectors; c) to ensure the creation of conditions for the implementation of measures to reduce and prevent greenhouse gas emissions and to increase the absorption of such gases.

Since 2021, several regulatory instruments were developed and approved. After approval of the Order of the Ministry of Science and Higher Education of the Russian Federation No. 74 "About supersites for the development and testing the carbon balance control technologies" [14], the Carbon Supersites Programme was launched. The Programme implies designation of the reference sites (the carbon supersites) for comprehensive GHG studies within the National Action Plan for Adaptation to Climate Change. On February 8, the Decree of the President of the Russian Federation No. 76 "On Measures to Implement the State Scientific and Technical Policy in the Field of Environmental Development of the Russian Federation and Climate Change" [7] was approved. The document committed to develop the Federal Science and Technology Programme of the Russian Federation in the areas of environmental improvement and climate change for 2021–2030 within six months.

The Federal Law No. 296-FZ "On Limiting Greenhouse Gas Emissions" (2021, July, [9]) and the Decree of the Government of the Russian Federation No. 3052-r "On approval of the Strategy for the socio-economic development of the Russian Federation with low greenhouse gas emissions until 2050" (2021, October, [3]) define measures to ensure the reduction of GHG emissions, taking into account the maximum possible absorption capacity of forests and other ecosystems and subject to the sustainable and balanced socio-economic development of the Russian Federation.

In 2022, the Decree of the Government of the Russian Federation No. 133 "On approval of the Federal Science and Technology Programme of the Russian Federation in the areas of environmental improvement and climate change for 2021–2030 [2] and the Decree of the Government of the Russian Federation No. 3240-r "On approval of the Most Important Innovative Project of National Importance for development of the Unified System for Monitoring Climate-active Substances and an Action Plan ("Road Map") for the implementation of the first stage (2022–2024) of the Project [5] were approved. Several research centers have been established in Russia to address this issue. In order to develop the climate and environmental monitoring systems for the Russian seas, the Consortium No. 2 "Center for Climate and Environmental Monitoring of the World Ocean and Russian Seas (OCEAN: MONITORING AND ADAPTATION)" was founded. As a member of the consortium, Immanuel Kant Baltic Federal University (IKBFU) has launched the two programmes of climate and environmental monitoring of the Baltic Sea in 2022.

The Baltic Sea is a semi-enclosed marginal sea that is undergoing significant transformation in the face of increasing anthropogenic pressures and global climate change [1600]. As a unique basin, it serves as a natural laboratory, so-called ocean in miniature. Here, the response to global processes and their consequences can be traced on a regional scale. The Baltic Sea represents a pronounced maximum of CO_2 sequestration due to extremely high level of water eutrophication and, consequently, high rate of primary bioproduction (photosynthesis). In addition, the largest hydrocarbon fields in the Baltic Sea are being explored off the coast of the Kaliningrad Oblast. Therefore, the assessment of GHG emission to the hydrosphere and atmosphere is also necessary for the region.

Natural changes in ecosystem parameters, in the form of sustained deviations from mean values, can only be observed, and sometimes even predicted, by long-term, regular, and large-scale surveys. This should be taken into account when develop the spatial and temporal scheme of the regional monitoring module. Short-term (episodic) observations can only capture random ecosystem responses, which are extremely difficult to assess and predict. In this context, continuous long-term integrated monitoring of the Baltic Sea ecosystem is of great importance.

II. Current state of monitoring system in the Baltic Sea region

Legislations and commitments regulate the Baltic Sea status assessments [12]. According to ISO 4225:2020, monitoring is repeated measurement to follow changes over a period of time [1]. In Russia, Federal Law No. 7-FZ "On environmental protection" defines environmental monitoring as comprehensive observations of the state of the environment [10]. A unified system of state environmental monitoring shall be established to ensure environmental protection.

The tasks of the unified system of environmental monitoring are: (1) regular monitoring of the state of the environment, including processes, phenomena, and changes in the state of the environment occurring in natural ecological systems; (2) storing, processing (generalization, systematization) information on the state of the environment; (3) analysis of the obtained information for the purpose of early detection of changes in the state of the environment under the influence of natural and (or) anthropogenic factors, assessment and forecasting of these changes; (4) providing state authorities, local government bodies, legal entities, individual entrepreneurs, and citizens with information on the state of the environment. The unified system of environmental monitoring includes the following subsystems: (1) monitoring of the state and pollution of the environment; (2) air quality monitoring; (3) monitoring of the internal sea waters and territorial sea of the Russian Federation; (4) monitoring of the exclusive economic zone of the Russian Federation.

At the international level, current monitoring of the Baltic Sea and assessment activities are guided by the HELCOM Monitoring and Assessment Strategy adopted in 2013. Today there are 12 agreed HELCOM monitoring programmes covering sources and inputs of human pressures and various variables reflecting the state of the environment. HELCOM monitoring programmes are compiled in the HELCOM Monitoring Manual. The latter refers to the existing HELCOM guidelines where more detailed information can be found (https://helcom.fi/action-areas/monitoring-and-assessment/monitoring-guidelines/).

Reckermann et al. [1600] have suggested several state variables of the Earth system of the Baltic Sea region. Environmental state variables include coastal processes, hypoxia, submarine groundwater discharge, marine ecosystems, land use and land cover, non-indigenous species, indirect parameters such as carbon and nutrient cycles, biota and ecosystems. Whereas, climate state variables include climate change, acidification, and direct parameters of the climate system.

As for climate monitoring in the Baltic Sea region, observational records are too heterogeneous for statistical studies of extremes due to many data gaps. Moreover, a model for the entire Baltic Sea coastal zone is still missing, and the effect of climate change on the coastal filter capacity is still unknown [1300]. The main gaps in the current environmental monitoring of the Baltic Sea are: insufficient monitoring effort, missing/inadequate indicator, missing thematic category, problems with data storage/handling, indicator under development, insufficient monitoring coordination, monitoring costs too high, no specific information on gap type [12].

III. Development of the monitoring system for the Russian sectors of the Baltic Sea

In order to develop a system of climate and environmental monitoring for the Russian sectors of the Baltic Sea, an international approach (HELCOM) and the main principles of the industrial environmental monitoring system of LUKOIL-KLM Ltd. (Kravtsovskoye oilfield – D6) [170], as well as the best practices of long-term research of leading Russian scientific organizations have been applied. The system includes three types of monitoring: satellite, shipboard, and coastal. The monitoring area includes the Russian sectors of the Gulf of Finland and the south-eastern part of the Baltic Sea, as well as the Curonian and Vistula lagoons. The coastal zone is also a subject of monitoring.

3.1. Satellite monitoring

Satellite monitoring is based on the analysis of radiometer data and includes spatial and temporal variability of suspended particulate matter and chlorophyll *a* concentrations, and sea surface temperature. Sea surface temperature is obtained at a spatial resolution of 1 km from the Moderate Resolution Imaging Spectroradiometer (MODIS) infrared radiometers aboard the Aqua and Terra satellites (https://oceancolor.gsfc.nasa.gov). Chlorophyll *a* and suspended particulate matter concentrations are calculated from the Sentinel-3A Ocean and Land Colour Instrument (OLCI) data using a neural network algorithm [11] at a spatial resolution of 300 m (https://coda.eumetsat.int). Satellite images are processed with SeaDAS 8.2.0.

3.2. Shipboard monitoring

Starting in 2022, the following parameters are set for monitoring (Table 1). To cover the diversity of conditions in the monitoring area, monitoring points are located in the open sea and adjacent lagoons (Figures 1 and 2). In the open sea, the seasonal surveys are carried out on board the research vessels of the Ministry of Science and Higher Education of the Russian Federation. In the coastal zone of the south-eastern part of the Baltic Sea and in the shallow lagoons, the monthly surveys are conducted on board small vessels.

Table 1: *The main parameters of the climate and environmental monitoring in the Russian sectors of the Baltic Sea, including the adjacent shallow lagoons*

Climate monitoring	Environmental monitoring
Fluxes of CO_2 at the air/water interface	Elements of the carbonate system (alkalinity and pH values)
Fluxes of CH_4 at the air/water interface	Spatial distribution of chlorophyll *a* in the water column
Fluxes of suspended particulate matter and particulate organic carbon (POC)	Spatial distribution of suspended particulate matter in the water column
Primary productivity of phytoplankton and fixation of carbon and CO_2 from the atmosphere	Planktic and benthic communities
	Bacterial production and degradation of organic matter
	Spatial distribution of total organic and inorganic carbon in the water column
Oceanographic properties	Oceanographic properties
Hydrometeorological factors	Hydrometeorological factors

3.3. Coastal monitoring

The inclusion of regular surveys of key areas of the coastal zone as part of the regional monitoring module is based on the fact that this is where the most active energy and mass exchange takes place. This explains the richness and diversity of shallow marine landscapes [8] Therefore, the zone of maximum ecological sensitivity is adjacent to the coastline.

In addition to shipboard monitoring, a permanent climate and environmental monitoring station has been launched. The 57 meters high met tower Carl C. A/S has been installed on the coast of the Baltic Sea at Scientific and Practical Base of the IKBFU (Kaliningrad Oblast, city of Pionersky, Rybnoe Settlement) (Figure 3).

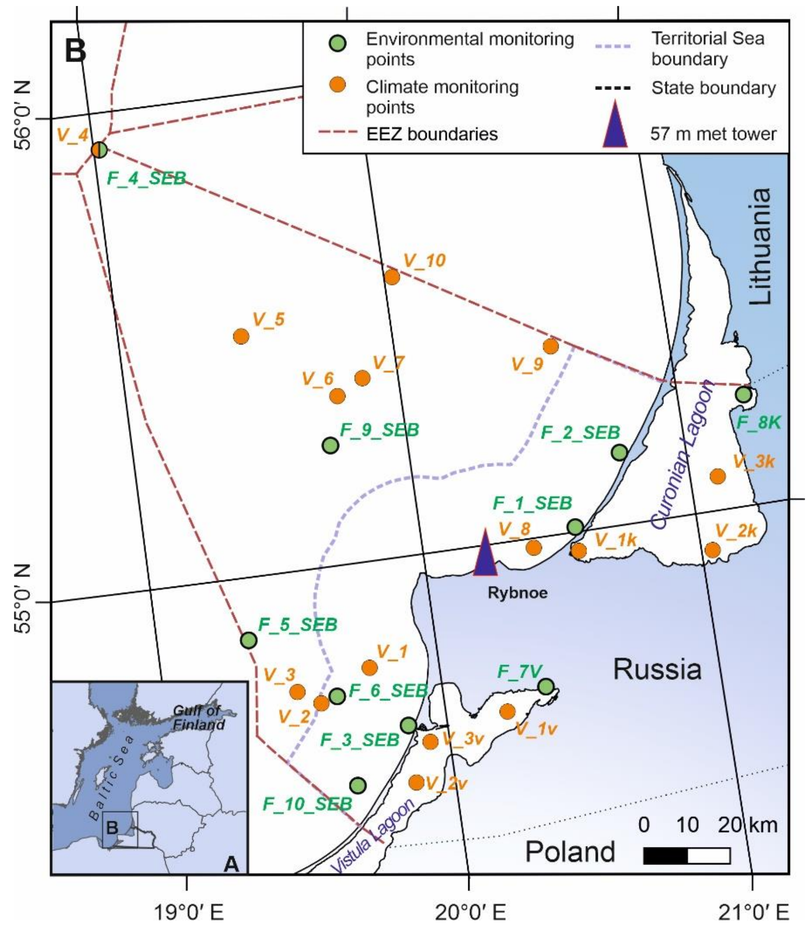


Fig. 1: *Location of climate and environmental monitoring points in the Russian sector of the south-eastern part of the Baltic Sea, including the Curonian and Vistula lagoons*

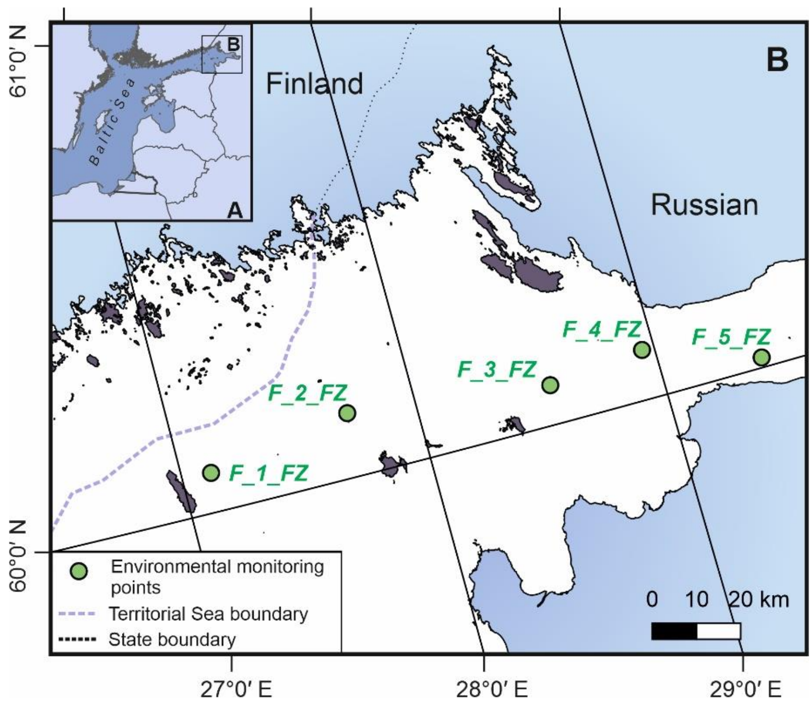
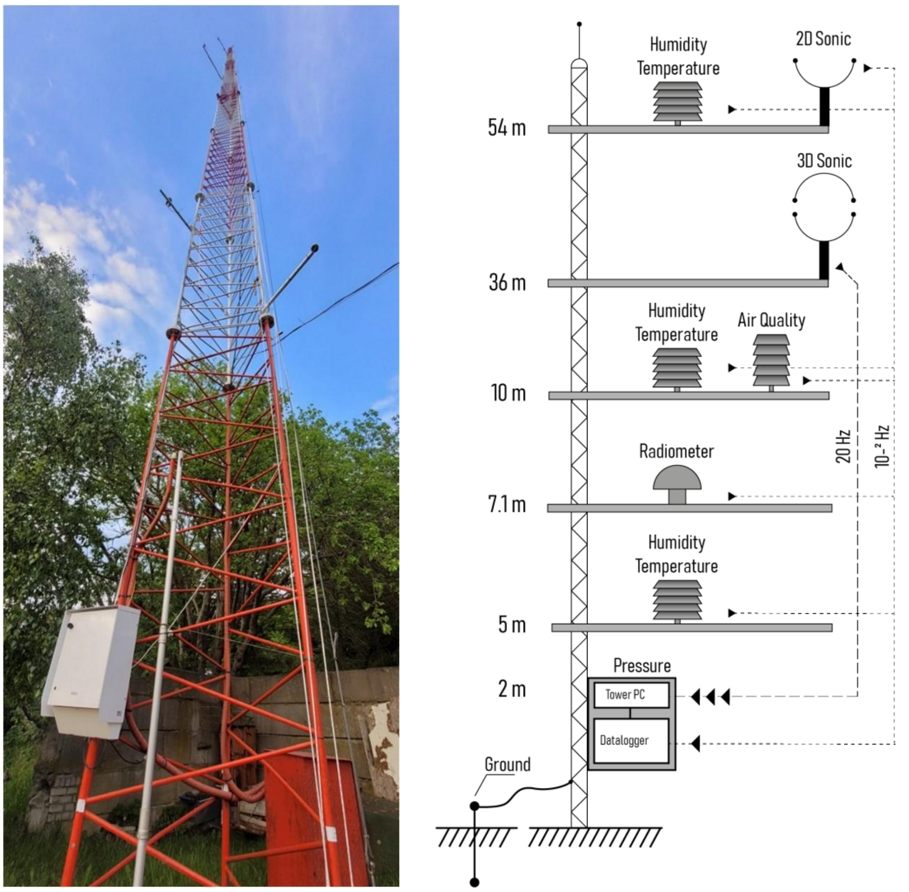


Fig. 2: *Location of environmental monitoring points in the Russian sector of the Gulf of Finland of the Baltic Sea*

The following meteorological equipment is currently installed on the tower:

Level 54.0 m: humidity and temperature probe, acoustic anemometer 2D

Level 36.0 m: acoustic anemometer 3D
Level 30.0 m: Davis VANTAGE Pro2 weather station
Level 10.0 m: humidity and temperature probe, air quality (AQT400 Vaisala: NO_2, SO_2, CO, H_2S)
Level 7.1 m: radiometer
Level 5.0 m: humidity and temperature probe
Level 2.0 m: pressure, datalogger, Vaisala BAROCAP



A B

Fig. 3: *Met tower (A) and a general scheme showing the location of equipment installed on the tower (B)*

The ASUS TinkerBoard minicomputer is responsible for collecting, packaging, and sending data. Moreover, it is responsible for reading data from the MOXA switch via Ethernet protocol. Every 10 minutes, it stacks the read data in .npz format and sends it to the data collection server every 30 minutes. Figure 4 shows a general scheme of operation. The source code of the scripts of the data packaging and sending system is available on the portal: https://github.com/alexavr/tower_parse.

The data storage server is also responsible for displaying primary information: actual data from all sensors and several parameters of the minicomputer status (CPU temperature, free memory and Internet channel load). This information is available at the open platform: www.tower.ocean.ru. The graphical information is updated every 30 minutes. The data received is converted into the carefully described NetCDF format (once a day). The source code of the data collection and storage system scripts is written in Python Programming Language and is available on the portal: https://github.com/alexavr/tower_collect.

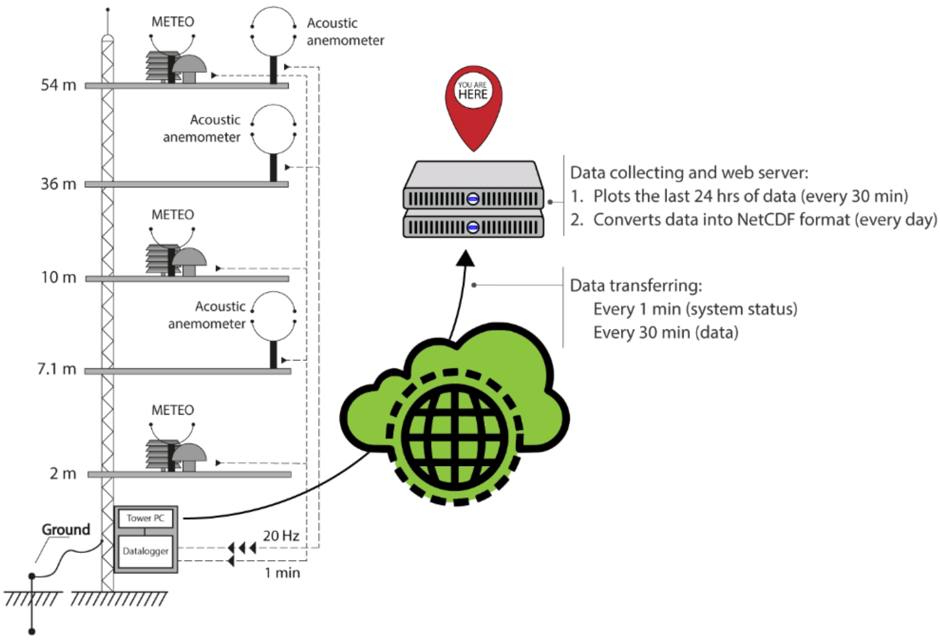


Fig. 4: G*eneral scheme of operation of the data collection and storage system at the met tower*

3.4. Data availability

All data obtained as a result of the implementation of the monitoring will be transferred to the Unified Data Collection and Monitoring Management Center, which will ensure the collection, accumulation and archiving of information, information retrieval and operational analysis of the current environmental situation. Such a database will serve as a basis for the development of a specialized geographic information system. The main forms of information support will be annual bulletins with monitoring results.

IV. Conclusions

In order to contribute to a low-carbon transformation of Russia, a system of climate and environmental monitoring for the Russian sectors of the Baltic Sea has been developed based on the best practices of international and Russian experts. The system includes three types of monitoring as follows: satellite, shipboard, and coastal. The main parameters of the monitoring system have been defined and the spatial and temporal scheme of the regional monitoring module has been designed in order to carry out the long-term, regular, and large-scale surveys at the regional level. The monitoring area includes the Russian sectors of the Gulf of Finland and the south-eastern part of the Baltic Sea, as well as the Curonian and Vistula lagoons and the coastal zone. A high met tower (57 m) has been installed on the coast of the Baltic Sea and a permanent climate and environmental monitoring station has been set up.

All the data will be transmitted to the Unified Data Collection and Monitoring Management Center.

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