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SATBAŁTYK SYSTEM – SATELLITES FOR THE SAFETY OF THE BALTIC SEA

Abstract: The *SatBałtyk system* is a satellite-based platform for monitoring the Baltic Sea environment in near real-time. Since 2015, it has been providing reliable information supporting the protection and management of the ecosystem and marine resources. Such information is of a wide range of applications including many safety-related, not always obvious. Some of them were briefly presented in the paper. Providing valuable support in threats prevention, rescue operations and decision-making processes, the *SatBałtyk System* can be of great importance for improving the safety of people, the environment and infrastructure related to the sea.

Keywords: *SatBałtyk System*, Satellite monitoring of the Baltic Sea, Remote sensing, Protecting and management of the marine environment, Safety of offshore infrastructure

INTRODUCTION

The exploration and exploitation of the seas and oceans by humans has a long history and star observation has always been an invaluable help in this. For a long time in the past, stars were the sailor's close friends. The only possibility to reach the destination and return home safely was celestial navigation. Today, the development of knowledge and technology allows us to send satellites – our new stars with a wide range of sensors – into orbits around the Earth. Such new stars send explorers the information they need in order to reach their destination safely and fast (efficiently), and it must be borne in mind that the role of the sea in our everyday life and economy has increased. The usage of satellite observation in the exploitation of seas and oceans begins in the 1970s. It has been a relatively short

time since then, but satellites systematically monitor large areas and they are an ideal platform for observing the seas and oceans. It is safe to say, that the surge in application of space technologies started a new era in many areas of human activity related to the sea.

The development of technology makes it possible to place on board advanced sensors recording with high resolution subtle changes of various characteristics describing phenomena occurring in the surface layer of the seas. The operators of publicly funded satellite missions undertake a number of activities to facilitate the access and interpretation of satellite data. Among the possibilities of using satellite techniques the most important are associated with broadly understood safety issues. Safe navigation, rescue missions saving human life, safety of offshore investments, are all very important and topical issues. But the most important for our future is the safety of the seas and oceans themselves. The seas are used more and more intensively. More and more people inhabit coastal areas, the industry is developing and infrastructure is being built, industrial and agricultural pollution flows down the rivers. Marine ecosystems are functioning under increasing pressure from human activity. In the long term, this could degrade the marine environment and, consequently, adversely affect living conditions throughout the biosphere. If we want to ensure safety for the next generations, we must focus on ecological safety of the seas and oceans. This is particularly evident in coastal regions and inland seas where changes caused by anthropological impact are the fastest.

THE *SATBAŁTYK SYSTEM*

An example of such an ecosystem, changing under the influence of various factors related to the development of civilization, is the Baltic Sea, surrounded by countries with highly developed industry and agriculture. Reliable impact assessment of these human activities requires deep knowledge of the processes taking place in the sea and appropriate tools to track changes in it. A good example of such a modern and innovative tool is the *SatBałtyk System*.

The *SatBałtyk System* is a satellite-based platform for monitoring the Baltic Sea in various time and spatial scales. It was launched in 2015 under the European Funds (Innovative Economy Program) as a response from the scientific community to the growing demand for access to reliable and up-to-date information on the Baltic Sea environment. The scientific foundations of the *SatBałtyk System* have been developed as a result of many years of cooperation of a large group of scientists from the institutions associated with the SatBałtyk Scientific Consortium[1]. This team of experienced scientists used the knowledge accumula-

[1] Scientific Consortium SatBałtyk with leading role of IO PAN was founded in 2010 by Institute of Oceanology Polish Academy of Sciences (IO PAN), Gdańsk University (UG), Szczecin

ted over the years about the processes taking place in the Baltic Sea environment combined with many years of analysis of the relationships between the optical properties of waters and the content of substances that shape these properties, as well as many innovative proprietary solutions and advanced research methods. Suffice it to say, that work on the development of the algorithms used in the *SatBałtyk System* has been going on in Poland for the last 20 or even 30 years[2].

These studies were based on traditional research methods. They include measurements of many hydrological, optical, biological and geo-chemical parameters carried out directly in the water and laboratory analyzes of research material in collected samples. Naturally, the data collected in this way mainly describe a small section of the sea surface limited to the area and time in which the measurements were conducted. Analyses of such data must take into account the inaccuracies associated with the natural variability of the marine environment at different time and spatial scales. There is no doubt that satellite observations that can cover large sea area in a single instant could be a perfect tool to study the marine environment. But it is also indisputable that the quality of this data largely depends on proper verification. The main assumption during the development of the system of satellite monitoring of the Baltic Sea environment was that it can only be reliable and credible if it uses multiple sources of information. Figure 1 shows schematically the main elements of the complex infrastructure of the *SatBałtyk System* and the data sources, based on which the characteristics describing the Baltic Sea ecosystem are determined.

To ensure the accuracy and credibility of provided parameters a very complex information flow system has been organized. The satellite data are used for the day-to-day monitoring of large sea areas. Simultaneously, an important role is played by *in situ* measurements from continuous monitoring systems (buoys, fixed platforms, shore stations and others) and research vessels. At the stage of developing the *SatBałtyk System*, *in situ* data was necessary to develop models and algorithms for the determination of actual physical, chemical and biological characteristics of seawater from satellite data; now they are mainly used to validate and verify the accuracy of the environmental characteristics provided by the *SatBałtyk System*. Last but not least, the system contributed to the advancement

University (US) and Pomeranian Academy in Słupsk (APS) for developed and launched a system of a near real-time monitoring of the Baltic Sea environment within the project funded by the European Union through European Regional Development Fund, (contract No. POIG.01.01.02-22-011/09.

[2] For more details see: B. Woźniak, A. Krężel, M. Darecki, S.B. Woźniak, R. Majchrowski, M. Ostrowska, Ł. Kozłowski, D. Ficek, J. Olszewski, J. Dera, Algorithm for the remote sensing of the Baltic ecosystem (DESAMBEM). Part 1: Mathematical apparatus. Oceanologia 50 (4) 2008, pp. 451–508; M. Darecki, D. Ficek, A. Krężel, M. Ostrowska, R. Majchrowski, S.B. Woźniak, K. Bradtke, J. Dera, B. Woźniak, Algorithms for the remote sensing of the Baltic ecosystem (DESAMBEM). Part 2: Empirical validation. Oceanologia 50(4) 2008, pp. 509–538, and the works cited therein.

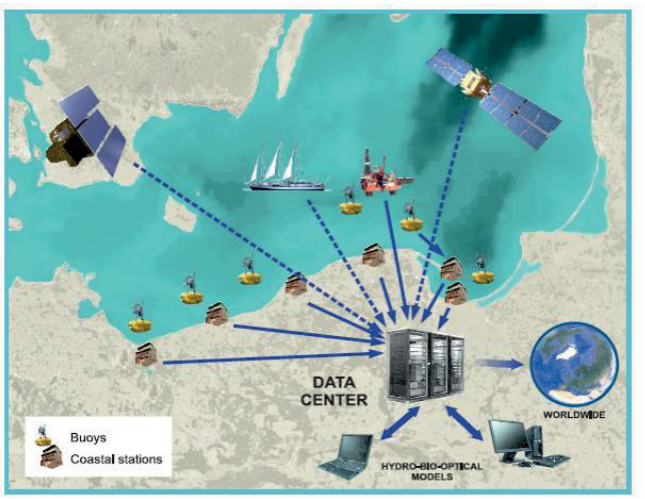

Figure 1. Scheme of the *SatBałtyk System* infrastructure

of knowledge, as a result of which new algorithms are still being developed by the team of researchers from institutions within the Consortium.

Another important element of the *SatBałtyk System* infrastructure is a set of hydrodynamic and eco hydrodynamic prognostic models based on the physical and biochemical principles governing the spatial distributions of the relevant parameters. Models included in the set have been expanded or modified during the *SatBałtyk System* development. Their main task is to reconstruct the satellite data when, due to cloud cover, such data couldn't be provided from optical and infrared satellite sensors. The geographical location of the Baltic Sea, frequent cloud cover, specific properties of the Baltic atmosphere and, above all, complex optical properties of its waters, mean that the operational use of satellite remote sensing in the monitoring of the Baltic Sea environment, encounters additional barriers compared to most of the other basins Many applications require constant and reliable monitoring of the sea, and for them any interruptions in the stream of satellite information can be considered as a serious weakness of the system providing data for them. Developed advanced and innovative methodology of merging the satellite and modelled data allows delivering a live and uninterrupted assessment of the current state of the Baltic Sea environment, even when satellite data acquisition could not be performed[3].

The solutions used in the *SatBałtyk System* enable providing in the website http://www.satbaltyk.pl comprehensive, precise and high-quality data describing the Baltic Sea environment. All the parameters are available in the form of maps

[3] These methods are described in detail in M. Konik, M. Kowalewski, K Bradtke, M. Darecki, The operational method of filling information gaps in satellite imagery using numerical models, Int. J. Appl. Earth Obs. Geoinformation, (75) 2019, pp. 68-82, https://doi.org/10.1016/j.jag.2018.09.002

presenting their spatial variability over the entire Baltic or in its selected area (see Fig. 2). System already provides information covering the last 20 years, and this period will still be expended. All parameters are divided into eight categories: 1. Atmosphere, meteorology (e.g. air temperature, atmospheric pressure, cloudiness, wind speed and direction, distribution of solar radiation at the sea surface), 2. Hydrology (e.g. temperature and salinity of the water at different depths, the dynamic state of the sea surface, sea level), 3. Ocean optics (e.g. concentrations of optically active seawater constituents and their absorption coefficients of solar radiation), 4. Radiation budget (e.g. downward and upward flows and doses of long- and short-wave solar radiation, sensible and latent heat), 5. Sea water components (e.g. phytoplankton biomass, the concentration of phytoplankton pigments at different depths in the sea), 6. Phytoplankton, photosynthesis (e.g. spectral distribution of photosynthetically active radiation and energy absorbed by phytoplankton, vertical distribution of the yield of photosynthesis and rate of primary production), 7. Coastal zone (e.g. width of the dry beach, range of beach inundation), 8. Hazards (historical data). What is important, the spatial distributions of these parameters are available to users at different depths, and if necessary, also for different wavelengths of visible light in near real-time. Apart from the common oceanographic parameters of the marine environment, the system determines also advanced parameters, describing a more complex natural processes and characteristics. Many of these characteristics are unique, and their values are not determined operationally by any other comparable system[4]. It enables not only to track long-term changes in the marine environment but also to comprehensively analyze processes taking place in Baltic ecosystems, such as:

- The influx and distribution of the solar radiation energy consumed during various processes in the atmosphere-sea system;
- The radiation balance of the sea surface;
- The optical conditions in which photosynthesis of organic matter takes place and the condition of marine plant communities;
- Distributions of sea surface temperature (SST) and the links between this temperature and various phenomena occurring in the sea;
- Hazards and effects due to storm states in the coastal zone of the sea.

[4] More detailed information on the *SatBałtyk System* is contained in the following works: B. Woźniak, K. Bradtke, M. Darecki, J. Dera, J. Dudzińska-Nowak, L. Dzierzbicka, D. Ficek, K. Furmańczyk, M. Kowalewski, A. Krężel, R. Majchrowski, M. Ostrowska, M. Paszkuta, J. Stoń-Egiert, M. Stramska, T. Zapadka, SatBaltic – A Baltic environmental satellite remote sensing system – an ongoing Project in Poland. Part 2: Practical applicability and preliminary results. Oceanologia 53(4) 2011, pp. 925–958, doi:10.5697/oc.53-4.925; B. Woźniak, K. Bradtke, M. Darecki, J. Dera, L. Dzierzbicka, D. Ficek, K. Furmańczyk, M. Kowalewski, A. Krężel, R. Majchrowski, M. Ostrowska, M. Paszkuta, J. Stoń-Egiert, M. Stramska, T. Zapadka, T., SatBaltic – A Baltic environmental satellite remote sensing system – an ongoing Project in Poland. Part 1: Assumptions, scope and operating range. Oceanologia 53(4) 2011, pp. 897–924. and in the works cited therein

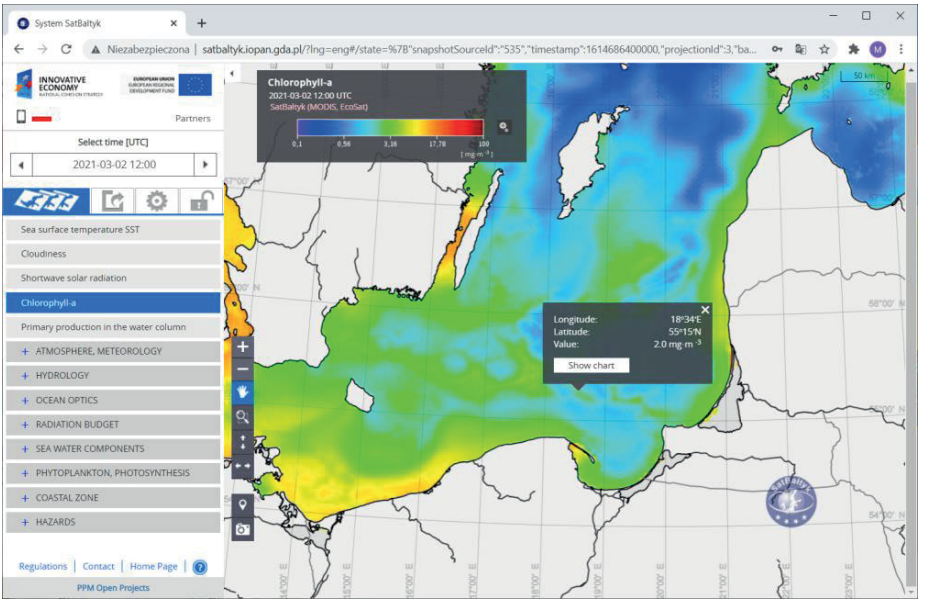

Figure 2. An exemplary map of the distribution of chlorophyll values in a selected area of the Baltic Sea. For each point on the map, you can also read the exact values of the selected parameter. (source: www.satbaltyk.pl).

SAFETY

The holistic information provided by the *SatBałtyk System* describes a sea--coast-atmosphere system as a whole, including, what is important and unique, vertical and spectral variability of physical, chemical and biological parameters. Such information can be essential for protection and management of the marine environment, in particular for the assessment of safety, condition, transformations and the functioning of the Baltic ecosystem, as well as the safety of various aspects of human activity in this environment.

For many years, the Baltic ecosystem has been struggling with eutrophication. It is excessive growth of algae due to the increased availability of nutrients deposited from the many land sources. Due to the progressive eutrophication and many other phenomena indicating the degradation of the Baltic environment, agreements were concluded at the international level to prevent this threat. To restore the Baltic to conditions unaffected by eutrophication by 2021, the Helsinki Commission (HELCOM) issued its Baltic Sea Action Plan (BSAP) in 2007, by which the countries around the Baltic Sea committed themselves to reduce emissions of compounds causing eutrophication[5]. The effects of the im-

[5] Baltic Marine Environment Protection Commission, Baltic Sea Environment Proceedings No. 143, Eutrophication Status of the Baltic Sea 2007-2011, A concise thematic Assessment, HELCOM, Helsinki 2014, p. 7 et seq.

plementation of the Plan are assessed based on multi-faceted analyses of a set of several different environmental parameters. One of the commonly used core indicators of the condition of the marine environment is the average chlorophyll-a concentration in the surface water (0 – 10 m) during summer (June – September) annually determined based on *in situ* measurements. This makes it possible to include in the analysis the maximum of this concentration at depth, where the two main limiting factors – the intensity of solar radiation penetrating the water column and the concentration of nutrients in the water – create optimal conditions for photosynthesis. Usually, satellite data can provide information only about the parameters related to the surface of the water. However, thanks to the algorithm used for approximating the vertical distributions of total chlorophyll which took into consideration the principal features of these distributions, specific to the Baltic waters, not only values but also the temporal evolution of the core indicator can be easily calculated and provided from the *SatBałtyk System* (Fig. 3).

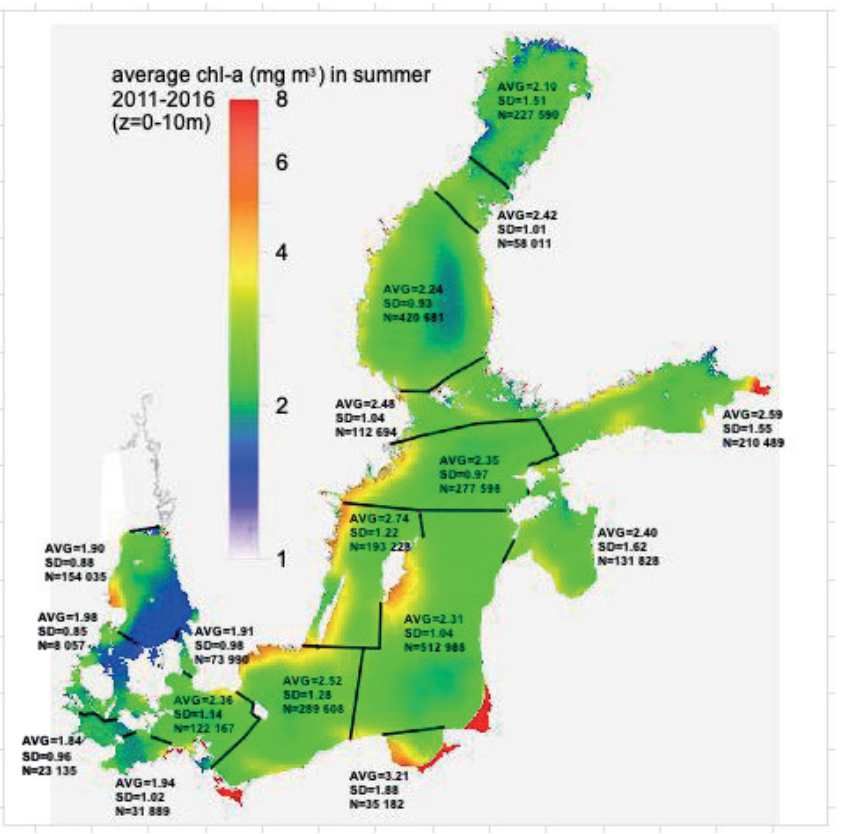

Figure 3. The averaged over the layer 0-10m chlorophyll a concentration for the summer (June – September) in years 2011-2016. The map presents mean values, standard deviations determined based on data from the *SatBałtyk System* for regions used by HELCOM.

At the same time, without a doubt, the values obtained on the basis of daily, verified information available in the *SatBałtyk System,* reflect the variability of the environmental condition of the Baltic Sea much better than single-point measurements. The *SatBałtyk System* also offers information on the development of algae as a result of eutrophication. The analysis of data of primary production enables fast assessment of changes in the last decade without involving significant resources in measurement campaigns. An example of such an assessment is in Figure 4, presenting the annual values of primary production averaged for the entire Baltic Sea for the decade 2010-2019.

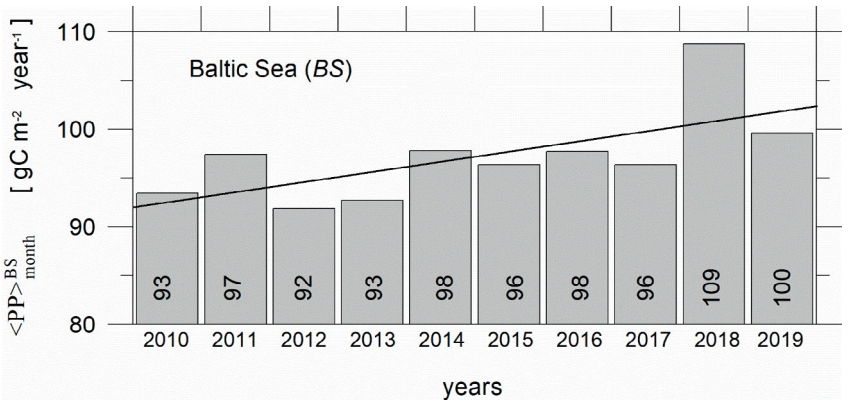

Figure 4. The total yearly primary production and the trend line for the entire Baltic Sea determined using data from the *SatBałtyk System.*

Supporting environmental protection is an obvious task performed by the *SatBałtyk System*. However, this is not the only possibility of using its resources in the context of security. Another issue – human safety and security of various human activities in the marine environment can equally well be assisted by information from the System. In rescue operations, during the search for survivors, information about the direction and speed of movement of objects in the water is extremely important. Owing to the use of hydrodynamic models, in the *SatBałtyk System*, current information and short-term forecasts of the direction of sea currents and waves are available and can be applied. They can prove to be a valuable support for rescue services in situations where time is decisive for the success of a mission. On the other hand, the analysis of historical data provided in the *SatBałtyk System* can significantly increase the probability of planned rescue scenarios in the areas covered by the surveillance and enables the prevention of dangerous events. One such example is the analysis presented in Fig. 5. It shows spatial variability of sea currents in the Polish coastal zone within the period 2011-2016.

Knowledge of the most common directions, average speeds of currents and their stability in this area is important for many safety-related areas. This applies

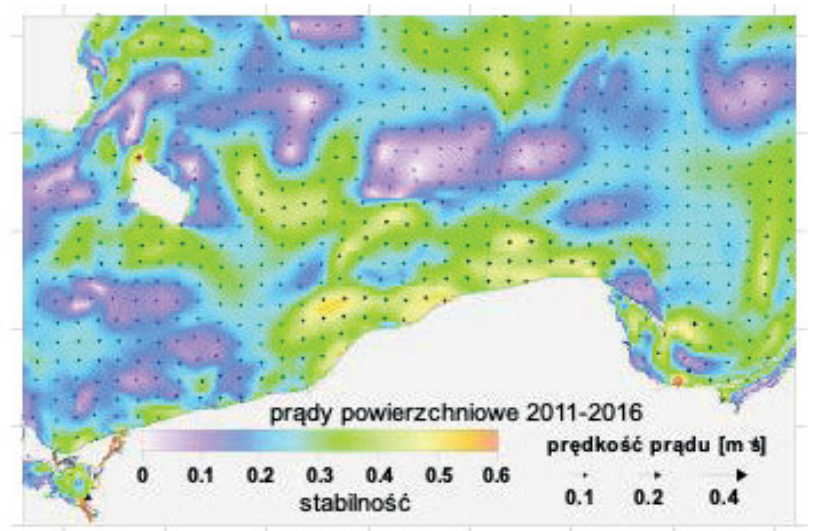

Figure 5. The spatial variability of mean sea current speed and sea current stability at a surface in the area of Polish coastal waters within the period 2011-2016 determined using data from the *SatBałtyk System*.

not only to saving human lives. Preventing and limiting the effects of various types of environmental threats that may affect health and safety of inhabitants of coastal regions or security of investments in coastal areas requires that this type of information be considered already at the planning stage.

All this information is made available without any restrictions to any entity interested in using it. Easy access and relatively low cost of data acquisition make satellite data more and more commonly used for various purposes, providing valuable support also in decision-making processes. The number of professional applications of information obtained from satellites is systematically increasing. However, this often requires the introduction of appropriate legal regulations also at the international level, recognizing information obtained from satellite data as a fully acceptable source of information about the marine environment, in many cases even equivalent to data obtained by classical, *in situ* methods. This aspect still requires a lot of activity and initiatives, especially at the national level. When considering satellite data as a source of reliable and useful information in applications related to various security issues, this data should be easily and safely available. That aspect seems to be already more or less solved, and nowadays, many user-oriented systems guarantee such constant access to appropriate and reliable satellite information, among them the Copernicus Marine Environment Monitoring Service (CMEMS) at European level and the *SatBałtyk System*, as a regional solution. This should not be overlooked when discussing the use of satellite techniques in any activities related to various security aspects.

In the case of oceanographic data, growing awareness of the benefits of using data from various sources results in activities that enable the development and

deployment of infrastructure for data management and the provision of FAIR[6] and open access to oceanographic data resources. This is not a trivial problem, it includes secure data storage, its proper description and professional access systems. Polish organizations engaged in research and exploitation of marine resources have been involved in activities targeting harmonization, integration and coordinated provisioning of environmental data resources for many years. In 2018, two consortia gathering most of the organizations involved in marine research and continuous acquisition of oceanographic data: POLMAR[7] and the Scientific Consortium SatBałtyk, both led by IO PAN, joined forces as the eCUDO[8] partnership to organize and deploy the system delivering demanded oceanographic data and products to the users. Deployment of a unified system providing access to data resources managed by key scientific organizations in Poland will give added value for the national economy through the increase of data availability for all stakeholders, with a concurrent decrease of the total cost of data acquisition, management and exchange. The system is open for all stakeholders and ready to aggregate other organizations and data sources, with view to solving the most pressing problem of discovery of all available sources of data, their harmonization, and ensure their safe storage and distribution.

SUMMARY

Easily accessible, verified and up-to-date information is the basis for the effectiveness of all activities not only related to safety. The possibilities of using the *SatBałtyk System* described in a nutshell do not exhaust the possible applications of satellite techniques to increase the safety of people, the environment and infrastructure related to the sea. It is extremely important and strengthening the position of Poland on the international arena, that the Polish science contributes to the construction of an economy based on knowledge and sustainable development, the main feature of which should be an ecosystem-based approach

[6] FAIR data are data which meet principles of Findability, Accessibility, Interoperability, and Reusability. The acronym and principles were defined in Wilkinson, M., Dumontier, M., Aalbersberg, I. *et al.* The FAIR Guiding Principles for scientific data management and stewardship. *Sci Data* 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

[7] POLMAR Scienitific Consortium– with leading role of IO PAN was founded in 2012 by Institute of Oceanology Polish Academy of Sciences (IO PAN), Institute of Meteorology and Water Management National Research Institute (IMGW), Maritime Institute in Gdańsk (IMG), Polish Geological Institute National Research Institute (PIG PIB), National Marine Fisheries Research Institute (MIR PIB) and University of Technology in Gdańsk (PG).

[8] „Elektroniczne Centrum Udostępniania Danych Oceanograficznych eCUDO.pl" (eng. Oceanographic Data and Information System – ODIS) is a Project No POPC.02.03.01-00-0062/18-00 funded within the frame of Operational Programme Digital Poland for 2014-2020, managed by Digital Poland Project Centre (CPPC) with allocated budget 3.5M EUR (84,63% –ERDF, 15,37% national budget).

to the management of living resources and the values of the marine environment. It is high time to use the possibilities offered by satellite techniques not only for scientific research but also for safe exploitation of the Baltic Sea resources, ongoing assessment of the state of its environment and assessment of the effects of undertaken remedial actions. Further development of these applications is only limited by creativity and legal regulations. It is hoped that the legal and administrative regulations will keep pace with the possibilities of wide application of satellite techniques, also in wider security aspects.

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