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Satellite Surveillance of the Sea

Prof. Mirosława Ostrowska from the Institute of Oceanology of the Polish Academy of Sciences, Vice President of the Academy, discusses how satellites are being used to study phenomena occurring in seas and oceans.

You got your first degree in engineering from a technical university, yet now you work in oceanography. How did you transition to such a seemingly distant field?

MIROSŁAWA OSTROWSKA: It's not as distant as it might seem. In the Tri-City area on Poland's Baltic coast, anything related to the sea is not so exotic, more commonplace. My master's degree was in telecommunications, with a specialization in hydroacoustics. This background prepared me to design hydroacoustic equipment and analyze the research data it generated. Therefore, joining the Institute of Oceanology of the Polish Academy of Sciences felt like a natural progression.

The topic of my master's thesis was a scale linearization system for side-scan sonar. After completing my defense, I took up a position as a technical staff member in the Department of Sea Physics at the PAS Institute of Oceanology. My duties involved maintaining and developing the research equipment. I should point out that back then, most of the devices used for studying the marine environment were prototypes, originally developed by scientists. I closely engaged in collaboration with colleagues from the Laboratory of Marine Biophysics, led by Bogdan Woźniak. I consider myself very lucky; as a young graduate, I found myself not only among colleagues who were very supportive but also in a wonderful environment that was both fulfilling and enlightening. My fascination with my work and the marine environment grew so much that I eventually transitioned from a technical support role to more of a scientific one.

You now specialize in marine optics. What does this field study, and why is it important for ocean research?

Marine optics is the science of studying how sunlight interacts with the marine environment. As soon as solar radiation strikes the sea surface, it undergoes various transformations. It may be reflected off the surface or penetrate into the water column, where it can either be absorbed or scattered in different directions (upwards, sideways, backwards) depending on the substances it encounters. The physical properties of these various substances, suspended or dissolved in water, significantly influence how they interact with light. This field is expansive and complex, continually evolving, and there's no doubt that future researchers will unveil many more secrets about these processes. One particularly fascinating element of seawater is phytoplankton. These tiny, microscopic plant organisms utilize sunlight for photosynthesis – and in so doing, they in fact release as much oxygen into the atmosphere as all land-based plants combined.


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The team I lead, the Marine Biophysics Laboratory within the Department of Sea Physics at the PAS Institute of Oceanology, is dedicated to researching and modeling the energy dynamics of marine ecosystems. This extensive research program employs a variety of measurement techniques, tailored to the scale and nature of the processes being analyzed. The complexity of these processes and the significant variability of the environmental factors affecting them mean that our research tools include not only instruments used aboard ships to measure parameters directly in the water column but also sophisticated equipment in laboratories and sensors carried by satellites.

How has satellite technology enhanced research capabilities in oceanology?
The advent of satellite technology in the latter half of the twentieth century revolutionized our ability to observe and analyze oceanic phenomena. Satellites allow us to monitor vast marine areas, on a scale unattainable with traditional research methods like ship-based observations and measurements. Traditionally, these methods might involve, in a colloquial sense, analyzing a bucket of water collected from the ship's particular location. However, that only provides data about that specific spot; extending these observations to broader areas would require a dense network of such measurement points. Given that oceans cover 70 percent of the Earth's surface, it's impractical to perform traditional measurements on such a scale. Satellites offer the ability to collect data for analyzing and monitoring phenomena on both local and global scales.

The process of analyzing satellite data seems highly complex. What challenges are involved?
There's a whole set of instruments carried aboard satellites that capture the *ocean color*, in other words, how the sea reflects light in various spectral ranges. This data carries a wealth of information about what's going on in that particular water body and the dominant substances present in the water. Anyone who has observed the sea knows that its color changes dramatically; it's not always the clear blue typical of oceanic waters devoid of substances. The Baltic Sea, for instance, might sometimes appear blue, but it is often greenish or even brown, depending on the substances predominating in the water at any given time, such as mineral suspensions, dissolved substances, or phytoplankton. By comparing precise information about all the components found in a sample of seawater with satellite measurements taken for the same location and time, we can develop algorithms that quantitatively calibrate these very different research methods. However, this is far from a simple task, as we must find a way to reconcile the vast array of interacting substances present in the sea with only a limited number of direct measurements.

As our knowledge and technology advance, satellites are being outfitted with increasingly specialized sensors that can measure a growing number of environmental parameters more accurately. Progress in this field consistently opens up new research possibilities and provides us with a vast array of data for analysis.

Will advancements in artificial intelligence affect the future of marine optics research?
Undoubtedly. As I mentioned, we possess vast stores of data collected via satellite techniques, and artificial intelligence is an excellent tool for converting satellite imagery into useful information and refining the accuracy of these interpretations. We expect it to play a significant role in developing sub-satellite algorithms and in discovering previously unseen relationships between data recorded by various measurement instruments on satellites. The number and precision of the products will increase, but most importantly, our understanding of phenomena in the marine environment will also grow.

There is much talk about the unexplored ocean depths. How do you assess our current state of knowledge about them, and what challenges does science face in their exploration?
The depths of the ocean are indeed the least explored regions on our planet – and are likely to remain so for a long time. Exploring them is extremely challenging, especially since studying the deep oceans is more complex even than space research. We have mapped out the surfaces of the Moon and Mars much

better than our own planet's ocean floor. The global ocean, which is essentially a single water body, covers more than 70% of the Earth's surface. It harbors immense biological diversity – it is estimated that the vast majority of Earth's species, over 90%, are marine species, most of which remain undiscovered. They provide us with oxygen, food, and are a massive heat reservoir that stabilizes the climate. Our understanding of life and processes in the depths is limited, but comprehending these processes and phenomena is crucial not just for satisfying our curiosity but also for our very survival.

How do studies in Arctic regions contribute to our understanding of these phenomena?
People often expect that changes in nature occur very slowly and will not be noticeable until several generations pass, but that belief is unfortunately not true. Systematic research in the Arctic over the last 30 years has provided clear evidence to the contrary. Climate change is further confirmed by satellite observations. The extent of sea ice is decreasing, and melting glaciers are releasing not only natural sediments but also pollutants that have been accumulating in the ice cover for centuries. Cold-loving phytoplankton and zooplankton are migrating further northward, which in turn is forcing the birds that feed on them to expend more energy to find them or to move their nesting sites. This results in an absence of natural fertilization in the areas where they previously resided, triggering cascading changes through entire ecosystems. These processes occur slowly but are already visible. Such transformations in the food chain and species shifts are clear indicators of global warming and signal that our planet is indeed changing.

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The theme of this issue of ACADEMIA magazine is "Poland in the World." It seems that Poland ranks quite high in terms of international oceanographic and polar region research?
The Polish oceanographic community is not large, but it is highly recognized in the international marine research community. Our research aligns with global trends, and we are leaders in international consortia implementing projects. Large international oceanographic conferences, such as the International Ocean Data Conference under the auspices of UNESCO, are periodically organized in Poland. We participate in research voyages on scientific ships and host hundreds of foreign researchers on our research vessel, the Oceania, and in our institutions. Our more than 30-year history of research voyages in the Svalbard region earns not only admiration but also envy, even from colleagues in countries with higher levels of science funding. The decision to build that research vessel significantly bolstered the international standing of Polish scientists.

How important is the Oceania for Poland?
While it might not be the most crucial point, it is worth noting that the Oceania is quite simply a beautiful ship that attracts significant interest wherever it docks. It is not a large vessel – about 50 meters in length – but it can navigate almost anywhere, except under extreme ice conditions. As I mentioned, it splits its time between research in the Baltic and the Arctic, spending about 240 days at sea each year. It is a research vessel well-suited to the specific needs of scientists. This has made it an excellent tool for over 35

years. However, it must be acknowledged that the ship is becoming somewhat cramped to be able to accommodate the requirements of modern equipment, and we would really like to build a somewhat larger vessel.

You have participated in many research expeditions at sea. How challenging is such work, what do these expeditions look like?

Working at sea is an extraordinary experience, but it comes with its demands. Challenges such as variable weather conditions, limited living space, and the need for close cooperation between scientists and the crew are just a few examples. However, marine expeditions provide a unique opportunity to collect invaluable research material. From the moment we board, our scientific enthusiasm is ignited, and we strive to utilize every possible moment for measurements, often sacrificing sleep. Owning our own vessel is a tremendous advantage and privilege. It allows us the flexibility to choose our research areas and schedules and helps us form a cohesive team with the permanent crew, which is crucial for managing the typically tight scientific agenda. There's a general understanding that seemingly small details, like the ship's orientation relative to the sun or smoking being prohibited on deck when measurements are being taken, are nevertheless important. Thoroughly capturing, quantifying, and analyzing the physical, chemical, and biological processes in the sea requires well-organized teamwork. Oceanography is definitely a team sport, and I've repeatedly seen how important it is for everyone onboard to be familiar with the measurement procedures.

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Does the Oceania spend most of its voyaging days in the Baltic Sea?

Yes, our longer polar voyages occur in the summer, while we spend the remainder of the year in the Baltic. This sea is unique for several reasons: it is relatively young, cold, shallow, low in salinity, and significantly affected by human activity. It attracts marine researchers not only from the Baltic countries. On the Oceania, we have hosted colleagues from Italy, the United States, France, and other distant nations, carrying out numerous international projects and, in the process, creating a unique database from over 30 years of research. This data is extremely valuable, continuously being updated and utilized for analyses, including those related to climate change. For example, the data has enabled us to develop the SatBaltic system, a modern research tool that leverages the satellite techniques I mentioned before.

Could you tell us more about the SatBaltic system and its importance for Baltic research?

The name is an abbreviation for the project that created it, "Satellite Monitoring of the Baltic Sea Environment." SatBaltic is a sophisticated research infrastructure that leverages real-time data from satellite systems, environmental measurements, and mathematical modeling to determine dozens of parameters that describe the state of the Baltic Sea environment.

Since becoming operational in 2015, the system has provided verified data on a scale that was previously unattainable with other research methods. This capability allows for real-time monitoring of the sea and analysis of ongoing changes within it. The SatBaltic platform is accessible not only to scientists but also to other professionals, as well as tourists and hobbyists interested in the Baltic Sea, its coastal areas, or its atmospheric conditions. Users can find up-to-date

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maps that cover the entire sea surface, displaying data such as water temperature, current speeds and directions, concentrations of various sea and atmospheric components, and the amount of organic matter produced by phytoplankton through photosynthesis. The system also offers data analysis tools, such as the ability to track changes over time at any selected point on the map. This consistently delivered and scientifically validated information holds great potential for applications beyond scientific research, supporting decision-making related to the protection, safety, and utilization of marine resources.

How was SatBaltic developed?

It is the product of excellent collaboration among several Polish scientific institutions involved in marine research. Back in the 1990s, even without formal agreements, we teamed up with colleagues from the University of Gdańsk, Pomeranian University in Słupsk, and the Marine Fisheries Institute. Our goal – to put it succinctly – was to develop a mathematical model describing the photosynthesis process in the sea and its dependency on environmental factors. We were also involved in developing algorithms to determine these factors using satellite technology. Launching a system that monitors the Baltic Sea ecosystem in real time now seems like a natural extension of this collaboration. However, back then it was still a very ambitious concept and presented significant scientific, technical, and logistical challenges, particularly because the frequently cloudy Baltic Sea is exceptionally challenging to monitor via satellite, for various reasons. Nonetheless, the project proposal from our SatBaltic Consortium, which the University of Szczecin later joined, was well-received by reviewers and secured funding. Today, the SatBaltic System is supported by our institutions, which have agreed to prolong the consortium agreement indefinitely. We are delighted by the system's growing user base.

What are your plans for the future?

The system is being used extensively for scientific purposes, and we aim to continue developing it and adding new features. Our consortium has also initiated the Electronic Centre for Oceanographic Data Sharing (known by the Polish abbreviation, eCUDO), which aims to collect and share oceanographic data. eCUDO serves as a platform that facilitates easy access to data collected by seven marine research institutions, simplifying information exchange in a machine-to-machine format. This project is in line with calls for increased openness and collaboration in science, helping to enhance understanding and protection of the marine environment. We hope this is a significant step towards establishing a National Oceanographic Data Centre in Poland, which in turn would operate within an international network.

Interview by **Jolanta Iwańczuk, Daniel J. Sax**

Further reading:

www.satbaltyk.pl
(the SatBaltic project)

www.ecudo.pl
(the ECUDO project)