Satellite Views of the Baltic

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Routine methods for monitoring the seas and oceans are costly and unreliable. Researchers are placing their hopes in a new method: remote satellite sensing

Oceans and seas support numerous ongoing natural processes essential for ensuring humanity's survival on the planet. Photosynthesis occurring in marine environments has a powerful effect on determining oxygen and carbon dioxide concentrations in the atmosphere. This means that the oceans are responsible for shaping the Earth's climate and stabilizing the greenhouse effect. The movement of vast amounts of heat in ocean waters also has a major effect on climate, and controls moisture in the atmosphere. Depending on the condition of water in a given region, the seas may purify or contaminate the atmosphere, provide healthy or unhealthy food, supply raw materials, affect the safety of navigation, attract crowds of tourists to seashores, or discourage visitors from enjoying seaside recreation and endanger human health.

On the World Ocean scale, these conditions mainly result from geographical variety in exposure to solar energy, the interactions of the ocean with the atmosphere, and global circulation of warm and cold masses of water. However, even on such a great scale, the impact of human civilization on the environment, including pollution of rivers and the atmosphere, has a negative effect on human life and contributes to global changes that need to be monitored and forecast to allow humankind to survive. This means that teams of experts from international organizations such as the United Nations, the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the International Council for the Exploration of the Sea continue to urge ongoing monitoring of marine environments and the development of numerous international programs and conventions (e.g. the Helsinki Convention) for coastal countries.

As an inland sea surrounded by heavily populated countries, with many tributaries and effluents, major ports and extensive industry, the Baltic is at particularly high risk of powerful anthropogenic factors: pollutants and fertilizers running off fields and meadows, toxic industrial waste, oil, sulfur, engine exhausts, and so on. Poland is the largest supplier of nitrogen and phosphorus into the Baltic, running down with the Vistula and Oder rivers. It is essential to keep tabs on the impact of these pollutants and the adverse effects of excessive eutrophication of the Baltic in order to be able to prevent them more effectively and to facilitate rational planning and optimal utilization of the sea's space and resources.

Ocean monitoring

The condition of Baltic water has been monitored for many years using traditional methods from onboard ships, with Poland's share of the work carried out by the Institute of Meteorology and Water Management. Such traditional methods mainly involve collecting samples of seawater and subjecting them to physical, chemical, biological and other laboratory testing. Some of these methods will always be necessary, but using them for the purposes of routinely monitoring the environment is imperfect and expensive. The samples collected by research ships, crews, and scien-

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tific teams can only cover a limited number of spatial points in this highly changeable marine environment, in a limited space of time. As an alternative, we can take advantage of the fact that a change in the color of a given sea region visible in daylight from a distance (viewed by a satellite) reflects specific environmental changes. For example, a particular color change of seawater may indicate increased algae growth, which in turn is a result and indicator of an increased supply of biogenic substances (such as phosphorus and nitrogen compounds), leading to eutrophication of the body of water. These and other relationships between the spectrum of light reflected by the sea as a result of its dispersion and reflection by the water (in other words, the color of the sea) and the concentration of various substances contained in the seawater can be established on the basis of numerous empirical studies and are increasingly being used to conduct remote monitoring of the levels of these substances.

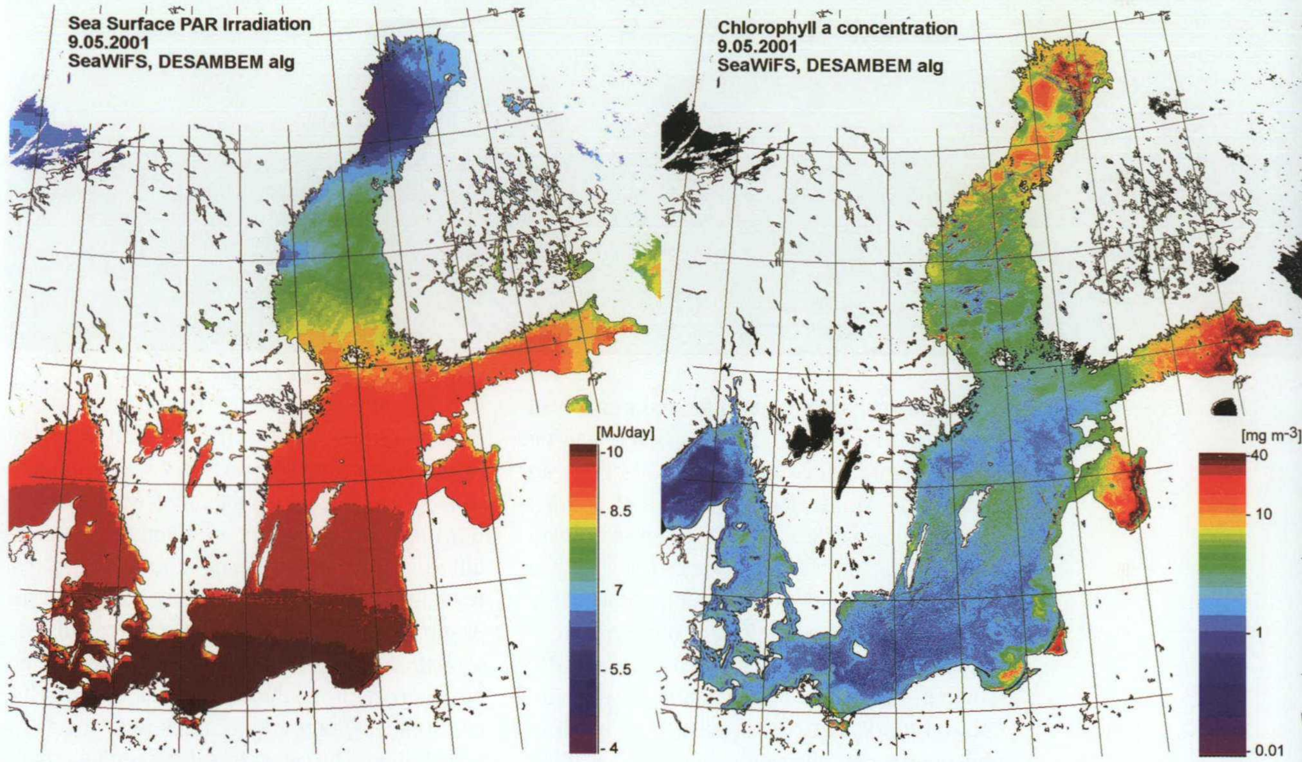
Satellite radiometers register the intensity and spectra of light originating from the sea, and using the right mathematical formulas and models they make it possible to determine the concentration of these substances in subsurface water (such as chlorophyll a). The models correlate these concentrations with light levels (energy supply), surface temperature (also registered by the satellites), water depth, and so on. Satellite data allows researchers to determine various characteristics of the marine environment (including quantum yield of photosynthesis, rate of production of organic matter in a given sea region, or even presence of certain fish). A carefully selected set of several formulas creates an algorithm for calculating the marine characteristics on the basis of data registered by the satellite, including the intensity of electromagnetic waves of various wavelengths (light and others) originating from the sea, and the temperature of sea surface on the basis of its infrared radiation levels. There are several satellites systematically taking such readings, including some in the Baltic region. Different satellites measure different wavelength bands at different spatial resolutions (using pixels covering $1 km^2$, $4 km^2$ or more). Satellite data and specific calculation algorithms make it possible to measure numerous important characteristics of the marine environment, and create maps showing their distribution. The colors on such overview maps express the values of these characteristics in individual sea regions appropriately for the scale of values designated these colors, with detailed information on the characteristics stored digitally. Overview graphic presentations of such maps are also available electronically, making them easy to enlarge; it is also possible to precisely compare colors at any point on the map against the value scale for the given characteristic.

Research teams in Sopot, Gdynia, Słupsk and Szczecin have spent many years developing and using optical methods of satellite teledetection for monitoring the Baltic environment. Poland is regarded very highly in this scientific specialty; the PAS Institute of Oceanology coordinates a project devising a system of satellite monitoring of the Baltic environment as part of the SatBałtyk project, initiated by the Institute.

Opportunities and limitations

Open ocean waters are relatively easy to monitor, whereas the Baltic waters pose a significantly more difficult challenge due to their high complexity and changeability.

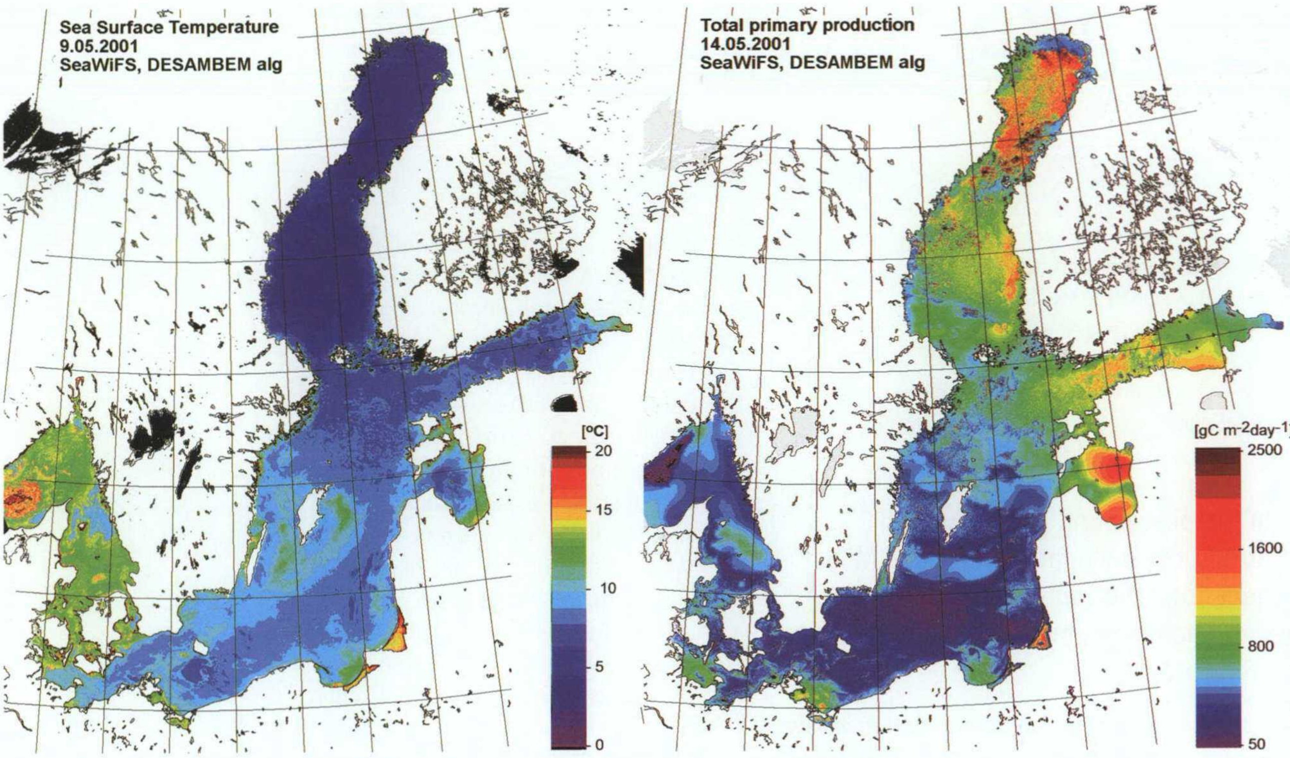
One limitation of satellite technology applications for monitoring the Baltic environment results from the random absorption and dispersion of light by the atmosphere over



Distribution of two selected characteristics of the Baltic ecosystem, collected remotely using satellite technology (9 May 2001, Darecki et al. 2008): a) Daily dose of photosynthetically available radiation (PAR) with wavelength between 400-700nm, expressed as MJ/day, illuminating the Baltic surface. b) Chlorophyll concentration in the surface water layer, expressed as mg/m^3 of water

the sea. The spectra of light carrying information through the atmosphere to the satellite become highly distorted and weakened by aerosols and mists, or frequently cannot penetrate the cloud cover in the first place. Introducing an atmospheric correction to these spectra is a problem that remains unresolved, and tends to generate a high number of errors in charting marine characteristics. Another limitation is the superimposition of light absorption bands caused by various components contained in Baltic seawater, including numerous colored organic substances and different particles entering the sea with rivers. They hinder the identification of substances on the basis of their absorption bands, or - more precisely - on the basis of reflectance, which is the fraction of incident radiation reflected by water surface and detected by the satellite. These problems can be solved to a certain extent by statistical models that harness the results of thousands of previous complex measurements taken *in situ*. For time and space intervals for which there is no satellite data due to overcast conditions, we can interpolate point values for the given characteristic using data calculated from forecasting models.

Yet despite such techniques, errors in the measurements can be significant. For example, the standard deviation of the value averaged within the satellite scanning pixels (1km^2 and more) from the point values measured *in situ* is approximately 23% for the daily dose of solar radiation reaching the sea in the photosyntetically active radiation range (PAR, 400-700nm), and may even exceed 50% for chlorophyll concentration. However, similar errors are found in the method of charting the distribution of these and other values on the basis of precise point analyses usually collected from just a few locations of marine space, not at the same time but over the subsequent days or weeks of a research trip. In terms of chlorophyll, we can assume that a difference of as much as 50% between sampled-point values of its concentration and averaged values derived by satellite techniques is low, considering that the natural fluctuation in chlorophyll levels in Baltic can reach up to 3 orders of magnitude. As such, as satellite techniques continue to be used their algorithms need to be further perfected and verified on the basis of precise *in situ* point measurements performed using survey buoys and research ships.



Darecki i in., 2008

Distribution of surface temperature expressed in Centigrade (a) and total daily production of organic matter Ptot per metric ton of Baltic waters, expressed as grams of carbon assimilated per day in the water column beneath a square meter of the surface [g C/m^{-2} day^{-1}] (b), registered remotely using satellite technology (9 May 2001; Darecki et al. 2008).

SatBałtyk program

Poland's optical marine research dates back 50 years. Between 2001-2005, the PAS Institute of Oceanology, the Institute of Oceanography at the University of Gdańsk, and the Institute of Physics at the Pomeranian University in Słupsk together developed an original, highly complex algorithm for charting numerous characteristics of the Baltic environment using optical data obtained via satellite, known as DESAMBEM (Development of a Satellite Method of the Baltic Ecosystem Monitoring). The algorithm is being used to build a system for satellite monitoring of the Baltic environment. The PAS Institute of Oceanology coordinates the SeaBałtyk project conducted by a scientific consortium including the Institute, the Institute of Oceanography at the University of Gdańsk, the Institute of Physics at the Pomeranian University, and the Institute of Marine Sciences at the University of Szczecin. The project is headed by Prof. Bogdan Woźniak. The main aim of the project is to prepare and initiate a technological base and operational procedures for simple, routine monitoring of the Baltic environment, and to create maps of its structural and functional characteristics, including the supply and characteristics of energy (PAR, UV), temperature distribution, dynamic state of the sea surface, concentration of chlorophyll and other phytoplankton pigments, blooms of poisonous algae, presence of currents bringing water towards the surface ("upwelling"), appearance of spots of pollution including oil spillages, and characteristics of primary organic matter production.

The base will collect information from meteorological and environmental satellites such as TRIOS N/NOAA, MSG Meteosat 9, EOS/AOUA, DMSP, and ENVISAT. It will also use information from mathematical models of the sea and the atmosphere. ■

Further reading:

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