Remote sensing of the Baltic Sea ecosystem

Tangled Colors of the Sea

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Seen from orbit, our Blue Marble is a planet of seas. Their colors carry hidden information about the ecosystem. Getting at it is a difficult task that requires measuring hundreds of shades and filtering out tricks played by the atmosphere

Approximately half the area of the European continent is covered by the waters of sea shelfs and semi-enclosed seas. For the countries surrounding a semi-enclosed sea, keeping it clean and healthy is of utmost importance. This is true of the Baltic Sea for the Baltic countries. Due to human activities, the sea's ecosystem is constantly evolving. Eutrophication and pollution, climate change, sea level and water temperature variations, blooms of harmful algae, the decline of marine plant and animal species, the invasion of new species - this evolution has many aspects, which together make the whole picture extremely complicated. Thus, in order to ensure a well-adjusted, sustainable development of the Baltic Sea and its resources, its ecosystem needs to be constantly monitored. While *in situ* measurements and analyses at preselected sites and times are a standard practice, effective monitoring can only be achieved with remote sensing technology. This involves optical remote sensing of the sea color, which in turn makes it possible to calculate pigment concentration, primary production of biomass in seawater, and other properties of the marine ecosystem.

Through a clouded window

The principle behind the remote sensing of chlorophyll concentration is simple, but getting it to work requires complex methods. Some of the sunlight reaching the sea surface enters the water, and is scattered in all directions. Part of this scattered light is absorbed by chlorophyll and other substances in water, while the rest is reflected back into the atmosphere and can be measured by a spectrophotometer on-board a satellite. The properties of the atmosphere calculated from this measured upward irradiance yield the downward irradiance at the sea surface. As a result

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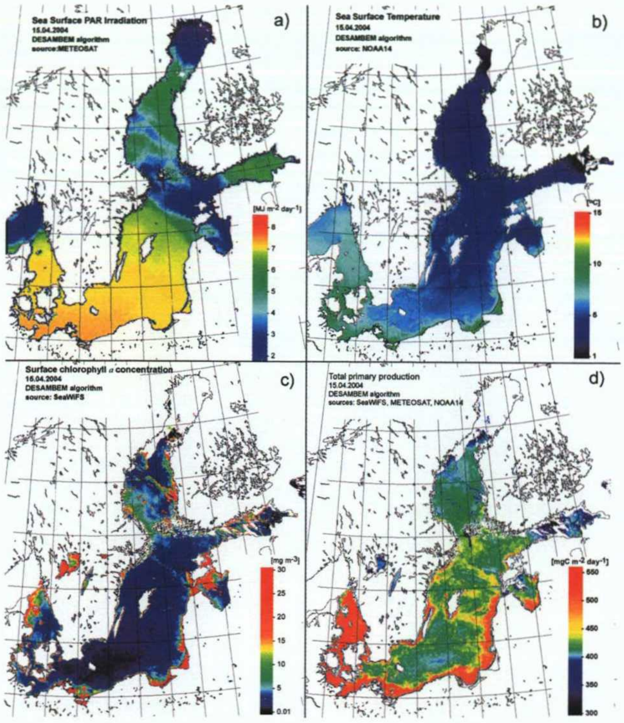
Optical device for *in situ* measurements on board the research vessel *Oceania*



Example maps of the Baltic ecosystem, showing distributions of four parameters obtained from remote sensing on April 15, 2004

of absorption, the spectrum of the light leaving the sea differs from that of the sunlight incident on the water. The differences between these two spectra in various bands allow inferences to be drawn about the concentrations of chlorophyll and other light-absorbing substances present in the sea. The transmission of light in both directions through the atmosphere also has to be taken into account, and this is done with the aid of an optical model of the atmosphere.

In order to determine the total rate of primary production by photosynthesis, three parameters must be known: the chlorophyll concentration, the simultaneously recorded solar irradiance and sea water temperature. This requires the application of a complex bio-optical model describing the absorption of light by phytoplankton and the quantum yield of photosynthesis in the sea. By calculating such primary production, we are determining the quantitative characteristics of the first link in the food chain of marine organisms, through which energy is supplied to the ecosystem.

A very complex algorithm incorporating many different factors is required for proper determination of the primary production. Several research teams in the US, Europe (including our team in Sopot) and elsewhere have been attempting to solve this problem. Algorithms for the open ocean, where the optical properties of water are simpler than in shelf and semi-enclosed seas, are already well developed. Unfortunately, shelf waters (and Baltic waters in particular) differ considerably from open oceans, and in terms of the remote sensing of the ocean's color their properties cannot be parameterized as simply as the properties of ocean waters can. The optical properties of open ocean waters - known as "Case 1" waters - correlate well with chlorophyll concentration, and consequently with the biomass of phytoplankton, because the majority of the optically active matter in the water is formed as a result of the primary production of phytoplankton. In contrast, the waters of semi-enclosed seas like the Baltic - known as "Case 2" waters - in addition to chlorophyll contain large amounts of suspended and dissolved organic matter from rivers, coasts, atmosphere etc., which strongly influence the absorption of light and water color.

Color error

In order to solve the problems arising with the remote sensing of the Baltic ecosystem, a comprehensive national project was launched in summer 2002. Entitled *Development of a satellite method for Baltic ecosystem monitoring* (DESAMBEM) it aims to develop an appropriate mathematical model and algorithm for Baltic sea-color observations. The ultimate goal of the project is to work out a standard methodology for determining the characteristics of the Baltic ecosystem. This would allow routine records to be seamlessly combined into distribution maps of the whole Baltic, showing different parameters, like surface temperature, upwelling currents, phytoplankton blooms, the radiation balance of the upper layers of the atmosphere and the sea surface, photosynthetically available radiation (PAR) energy above and below the sea surface, concentrations of chlorophyll and other pigments, primary production of organic matter and free oxygen, and others.

After years of bio-optical studies, field experiments and theoretical modeling, we have developed preliminary working algorithms and approximate maps of the remotely sensed temperature, PAR, chlorophyll concentration and primary production in the Baltic. The accuracy of the data is still below expectations, however. The difference between deviations of the total primary production determined by remote sensing and measured *in situ* can be as high as 30% at some stations. This error is mostly due to the scattering of light in the atmosphere (on aerosols, clouds), and to the differences in organic matter content across the Baltic waters.

Our current remote-sensing results show that primary production in the Baltic Sea varies by two orders of magnitude over different regions and seasons. As the algorithm is still not perfect, all the remote-sensing data for the Baltic will be normalized against the records of *in situ* measurements obtained from radio-buoys at selected points. ■

Further reading:

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