G. Schernewski & N. Löser (eds.): Managing the Baltic Sea.
***Coastline Reports 2 (2004)**, ISSN 0928-2734*
S. 211 - 218

Towards Operational Monitoring of the Baltic Sea by Remote Sensing

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Abstract

Satellite remote sensing technology allows the assessment of various physical, biological and ecological parameters of water bodies on global and regional scales. Significant research effort was spent during the last years to develop and validate algorithms and processing schemes for operational monitoring applications. The paper reviews available sensors and technologies as well as results for different applications in the Baltic Sea, such as mapping of Phytoplankton and suspended matter, algal blooms by ocean colour or dynamic features using sea surface temperature. In this context it is evident, that automation and standardization of value added product derivation is an important basis to support near real-time request from the users side. A special focus will be put on coastal waters observations.

The BMBF funded "MERIS Application and Regional Products Project" (MAPP) and the "Satellitengestütztes Interpretations- und Bewertungsinstrument für das Küstenmonitoring des Landes Mecklenburg-Vorpommern" (SIBIK) will be discussed as key research activities to develop and promote operational use of satellite data for monitoring and understanding processes in the Baltic Sea. Based on these results planned future activities and perspectives for contributions to operational monitoring systems will be presented.

1 Introduction

Remote sensing from satellites has become a mature technology for a lot of different applications, among them assessment of oceanographic key parameters, such as sea surface temperature (SST), wind and wave fields, ice cover and different water constituents. The technology allows the characterisation of geo-biophysical state as well as the description of dynamic processes on different scales, ranging from local to global in space and from short term (days) to decadal in time. However, most use of remote sensing technology and derived information has been made in environmental sciences, global change and climate research and modelling, not so much in regular environmental monitoring by authorities on local, regional or continental levels. Exceptions are ice mapping and SST as well as demonstrational activities in nationally or EU-funded projects.

There are several reasons for this situation. Partly it is caused by mission constraints, not allowing continuous and regular (i.e. operational) provision of data. A second issue is the availability of validated, reliable data products on regional scale as, for example, water constituents in optically complex (coastal) waters. As a third, necessary data processing and dissemination infrastructure has developed only during recent years realising networking capabilities including research institutes, service providers and value-adding enterprises as well as authorities and other users on different levels. Another topic which has developed rapidly in recent years is the user preparedness to integrate remote sensing information into daily business. Finally, data policy and costs are an issue heavily influencing the acceptance to utilize remote sensing data.

The "remote sensing community", i.e. space agencies, data centres, research institutes and value-adding companies, is aware of the growing needs and demands from the user perspective. This is resulting in a stronger commitment of research and development to the requirements of the user community, aiming to provide remote sensing based information as a regular monitoring tool.

On a European level the joint EU-ESA initiative for "Global Monitoring for Environment and Security" (GMES) has established the corresponding political and financial framework for the next decade. In the following we will introduce results from national German projects with special focus on ocean colour and discuss potential future developments towards operational monitoring.

2 Satellite Capabilities

This paragraph will briefly review the capabilities of satellite remote sensing for oceanographic and coastal applications. Main emphasis will be ocean colour, since the projects discussed in detail below are focussing on this subject.

Passive microwave and active radar measurements allow the mapping of meteo-marine parameters, such as surface wave and wind fields and ice cover independently of cloud cover or weather conditions. The technology has been established during the missions of European Remote Sensing Satellites ERS-1 and -2 and is continued by the European Environmental Satellite ENVISAT. Currently it is integrated as regular information source for weather forecast and hazard warning at several national weather centres and ECMWF. The problem with radar data, however, is a lack of coverage and repetition rate especially on local and regional scales.

A well established service provided by several authorities is the mapping of sea surface temperature, e.g. in Germany by German Aerospace Centre (DLR) or the Federal Maritime and Hydrographic Agency (BSH). Currently derived mainly from thermal infrared data of the NOAA-AVHRR instrument, this will be complemented in future also by European instruments on METOP platforms. For regional and coastal applications limitations apply to SST due to coarse spatial resolution of 1 km. On a short term, cloud coverage may heavily hinder the data availability.

Beside physical processes imaged by radar or infrared sensors, biological activity and ecological state of ocean and coastal waters are an essential part of environmental research and monitoring. Satellite remote sensing in this field contributes the mapping of different water constituents, such as phytoplankton, suspended and dissolved matter in the water column as well as turbidity and other water quality indicators. Since the first ocean colour satellite CZCS (NASA) in the late 70ies the methodology has become mature and provides operational phytoplankton products for the open ocean, where mainly Chlorophyll and covarying constituents appear (case-1 waters). Currently SeaWiFS and MODIS (both USA) are used to generate these products. Limitations in applicability of these sensors occur in coastal and optically complex water: due to coarse spatial resolution of 1 km on one hand and insufficient spectral resolution on the other.

Optically complex waters (case-2) may be characterised by the fact that several optically active components (water constituents), which may vary independently, are influencing the water colour. Thus, almost all coastal waters may be referred to case-2 waters, also some larger basins with limited exchange to the open ocean, such as the Baltic or the Black Seas. From remote sensing point of view these waters show a multivariate optical behaviour, which requires higher spectral resolution measurements (i.e. more spectral bands) to be able to discriminate and quantify the single constituents by the retrieval algorithms. Better spectral resolution also allows the necessary adaptation of algorithms to regional and seasonal specifies of optical properties.

In 1996 the imaging spectrometer MOS was launched on board the Indian satellite IRS-P3. Developed by DLR, it was the first instrument in space providing higher spectral resolution data at medium spatial resolution (500 m). It was an experimental proof-of-concept mission focusing on the development of case-2 algorithms for coastal waters. However, due to its experimental character the mission did not provide the necessary coverage and repetition rate for monitoring applications.

In May 2002 ESA launched ENVISAT, which carries among a broad variety of instruments the imaging spectrometer MERIS. Also focusing on coastal waters MERIS has similar spectral parameters as MOS. With a large swath and even better spatial resolution of 300 m it realises the spatial and temporal resolution necessary for coastal and monitoring applications (see fig. 1). From the user perspective, however, the uncertainty of continuation after ENVISAT's lifetime seems to be a critical gap. Table 1 summarises currently available ocean colour instruments.

The table above is not ment to be exhaustive, more satellites carrying ocean colour sensors are operated by several agencies, such as from India or China. But due to certain constraints in data availability they are not considered here.

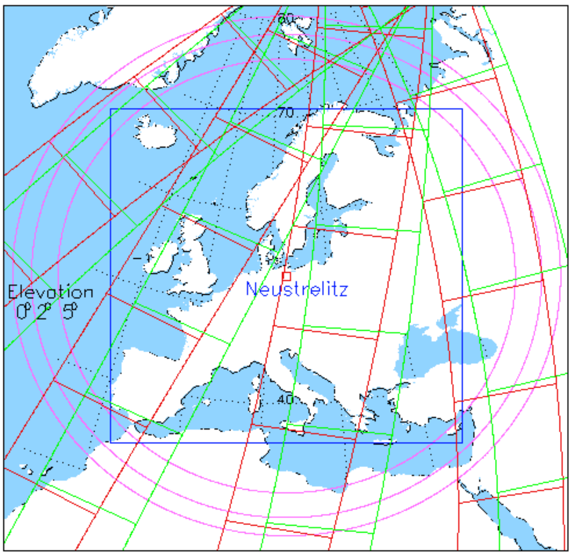

Figure 1: 2-day coverage of MERIS for Neustrelitz ground station.

Instrument/ Satellite	Agency	Launch	No of Bands*	Swath Width (km)	Reso-lution (Nadir)	Repe-tivity	Main Focus	Monitoring
SeaWiFS	NASA	1997	8	2800	1.2 km	2d	open ocean	pre-operational
MODIS/ Terra, Aqua	NASA	1999	9	2330	1 km	2d	open ocean	operational
MOS/IRS-P3	DLR	1996	17	200	500 m	23d	coastal Waters	experimental
MERIS/ ENVISAT	ESA	2002	15	1150	300 m	2d	open ocean coastal waters	pre-operational

Table 1: Overview of Ocean Colour Sensors (*) VIS-NIR spectral range).

The planning for the future is going in two directions. Essential for monitoring applications is the continuity of data from space. Currently only NOAA/NASA seem to have a robust plan to continue MODIS-type observations on the future polar platform program POEM. Unfortunately ESA's plans for MERIS follow-on, may be in the frame of the Earth Watch program, are not settled yet.

A second direction is the development of enhanced instruments, such as spatial high resolution hyperspectral imagers and ocean colour imagers on geostationary platforms, which will add new capabilities to satellite monitoring.

3 Recent Developments and Results

This paragraph will discuss two demonstrators to provide (pre-) operational monitoring tools for water constituents on a regional scale, in particular for the Baltic Sea.

3.1 MOS-Chlorophyll Map of the Baltic Sea

In the period from March 1998 up to October 2003 an operational processing chain for deriving a chlorophyll map of the Baltic Sea on basis of MOS-B data was running at the ground station in Neustrelitz. The maps were produced at the same day as data acquisition. Furthermore, the corresponding quick look product was published via internet. For the years 1996 and 1997 some exemplary data were reprocessed. A statistical overview of available maps is given in Table 2. This long time test clarified the ranges of application of the remote sensing in the context of near-real-time requirements as these would be formulated e.g. by multinational or bilateral environmental agreements to the management of the Baltic Sea. Beside the experimental character of the MOS sensor the maps have given support in studying seasonal and regional variation of the chlorophyll concentration. For example, figure 2 shows an increased concentration within the Bay of Riga.

Especially monitoring and warning systems as basis for the sustainable management of such a damageable ecosystem as the Baltic Sea have to be very stable in their functioning, timely and spatially efficient in their information extraction. These aspects can be only fulfilled, if those systems are physically based, connected with necessary quantitative statements, so that the subjectivity of operator is minimized.

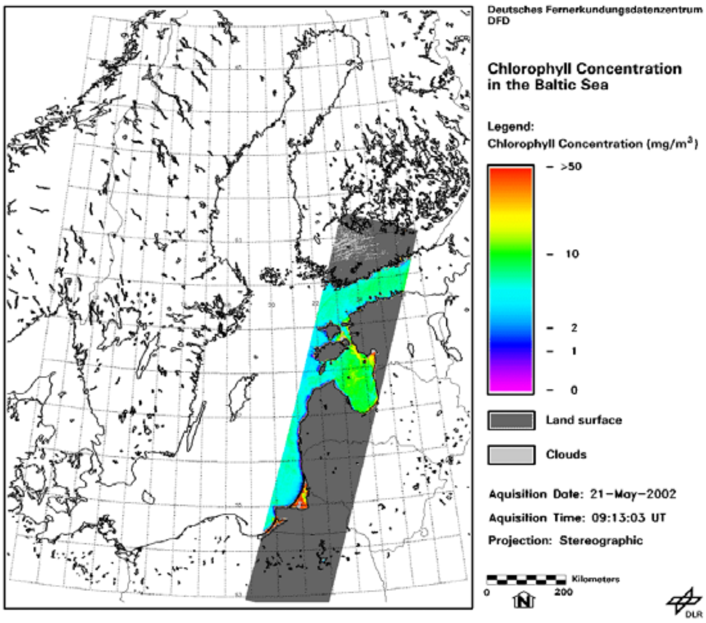

Figure 2: Quick look of a chlorophyll map from MOS, May 21, 2002.

	Feb.	Mar	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Maps total
1998	-	17	14	14	-	-	6	17	21	17	106
*	-	5	4	7	-	-	3	10	8	-	37
1999	-	12	16	24	3	10	-	-	-	-	65
*	-	5	6	18	2	5	-	-	-	-	36
2000	4	20	17	17	-	-	12	12	5	-	87
*	1	5	6	12	-	-	7	7	4	-	42
2001	2	13	9	19	16	17	15	9	7		107
*	-	3	2	12	10	14	8	2	1		52
2002	-	14	16	13	15	16	19	14	4		111
		3	9	8	11	11	15	8	1		66
2003		12	16	16	17	20	11	18	4		114
		6	6	8	15	11	4	11	1		62

Table 2: Statistic overview of available maps per month and year of automatic processing. The lines signed with *) show maps with more than 50 percent cloud free water region after rough evaluation.

3.2 MERIS Value-adding

ESA is providing standardised MERIS products using "global", generic algorithms to derive phytoplankton pigment, suspended matter and dissolved organic material. The data products represent geo-referenced maps of derived parameters in sensor projection on a scene basis (data level 2). The products are provided off-line by ENVISAT processing facilities. Compositing of data for larger areas or computation of time averages (data level 3) has to be done by the user. For a large number of applications, in particular regular monitoring, this situation is unsatisfactory.

In front of this background and to foster the preparedness for MERIS utilisation in Germany the Ministry of Education and Research (BMBF) co-funded the national "MERIS Applications Project" (MAPP) aiming the develop regionally optimised MERIS algorithms and extended products compared to ESA. A second goal was to develop and implement the technical infrastructure for operational processing and product dissemination to users. The project was a cooperative effort of DLR, GKSS Institute of Coastal Research, Free University of Berlin and Brockmann Consult. After algorithm development the MAPP-value-adding (MAPP-VA) processor was implemented and integrated into the data base and management system at DLR Remote Sensing Data Centre DFD. DFD is also realising the reception of MERIS data at its ground station in Neustrelitz. Currently the processor and the algorithms are under evaluation and validation, the goal is to reach operationability by mid 2004. Table 3 lists the MERIS value added products relevant for ocean monitoring. It is planned to deliver for all products daily maps of full overpasses of MERIS for the Baltic and North Seas as well as weekly, monthly and seasonal means at full spatial resolution (300 m) mapped onto a uniform grid.

	Level-2	**Level-3**
Water	• Chlorophyll • Yellow substance • Suspended matter (North Sea, Baltic Sea, Bodensee)	• Baltic Sea- same params, monthly means
Atmosphere	• Aerosol type • Optical thickness in coastal zones • Cloud top height • Cloud optical thickness • Cloud albedo • Water vapour	• same, monthly means • ISCCP cloud types (or extension) • Water vapour in ISCCP cloud categories • Statistics in vertical layers of: - Cloud frequency - Cloud optical thickness - Cloud top height • Water vapour
Land	• NDVI	• NDVI monthly & yearly mean • Land cover classification

Table 3: MAPP-VA data products.

3.3 MERIS Products for the Baltic Sea

The Baltic Sea must be considered more or less completely as case-2 water, mostly characterised by relatively high concentrations of dissolved organic matter (DOM, Gelbstoff) and several point sources of suspended matter (river mouths). An additional phenomenon are strong algal blooms, typically occurring during spring and early summer. Thus, optically the water is complex, very different to other basins and open ocean water. This demands for specific retrieval algorithms adapted to the optical properties of the Baltic Sea.

State-of-the-art inversion schemes are based on physical models describing the multivariate behaviour of the water body. The specifics are introduced by the inherent optical properties of the different constituents under consideration. Radiative transfer models are used to compute simulated spectral radiances representing the satellite measurements depending on water constituents' concentrations, atmospheric turbidity as well as viewing and Sun geometry. These simulated data sets are used to "train" inversion algorithms to compute the concentrations from the spectral radiance measurements. In the case of the Baltic Sea the algorithm is based on a principal component inversion (PCI, KRAWCZYK). The bio-optical model incorporating the specifics of the Baltic Sea was developed in cooperation with H. Siegel of the Baltic Sea Research Institute.

As mentioned above the processing system and the algorithms are currently being tested and validated and it is planned to enter first demonstration phase in May 2004, regular operation is envisaged for mid of the year.

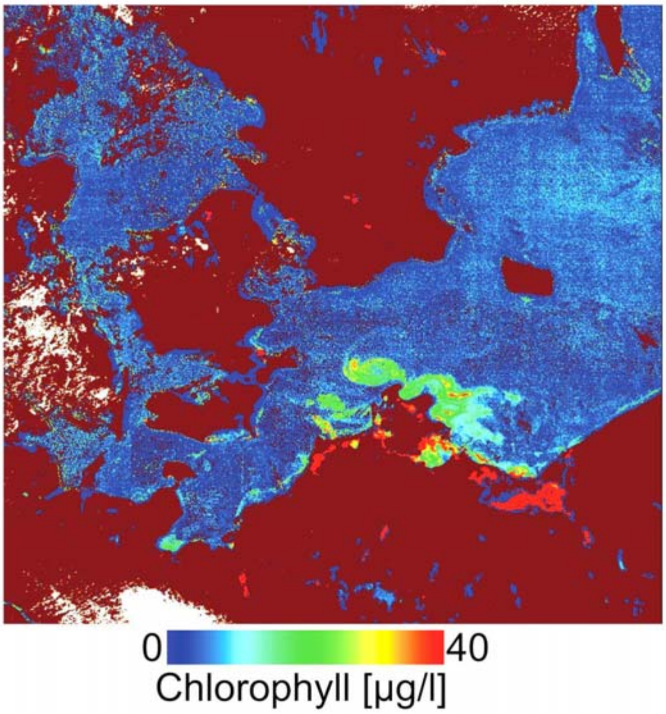

Figure 3: Chlorophyll concentration derived from MERIS full resolution data, August 13, 2003.

Currently additional algorithms are under development, such as for detection and monitoring of harmful algal blooms.

4 Outlook

4.1 Operationalisation

In contrast to temporally limited campaigns with in-situ measurements, automation of remote sensing data interpretation makes it possible to monitor ecosystems over a long time at minimal cost and to detect special phenomena. Furthermore an interactive data interpretation is not applicable to process a large number of data sets, within a time interval acceptable for a user. An additional aspect consists in operator's subjectivity in the data processing. This is complete in conflict to the requirements of objective and transparent monitoring.

Furthermore, the integration of remote sensing in monitoring and warning systems or in environmental models requires beside automation of data processing the standardization of algorithms for deriving information. Especially the last aspect is important for combining different sensor types. Both, automation and standardization of value added product processing are important to support near real-time request of users. For this background, the "Chlorophyll Map of the Baltic Sea" is a pre-cursor demonstration for the stability of a remote sensing monitoring. The processing chain itself is a result of close cooperation between former "Institute of Space Sensor Technology", the "Institute of Baltic Sea Research Warnemuende", and the German Remote Sensing Data Centre. The processing chain is described in more detail in Wolff et al. (1998). After this first successful step the connection of the remote sensing based monitoring to a comprehensive environmental monitoring of the Baltic Sea must be carried out.

The operationalisation of monitoring and warning systems on basis of remote sensing includes both, the technical solution of the system and its implementation into the decision making process of the environmental administrative. The technological aspects are defined by a large number of processing chains, different types of data, and a high level of user service, which require a corresponding environment, as provided by the German Remote Sensing Data Centre in its Data and Information Management System (DIMS). With help of Processing System Management (PSM) software, the different components of a processing chain are controlled, comparable with the production process in a large factory. A strong request by users is the inclusion of mistake analysis, providing the user of a remote sensing product with the range of validity, including the limits of applicability. Guiding principles are necessary for the derivation of a product and its use in legal proceedings.

These aspects are the major preconditions for the implementation of such a system into the decision making process of the environmental administrative. Full-coverage information on the basis of satellite based remote sensing data will gain importance if legally binding statements can be included in data interpretation.

Arguments for such a tendency are given by the international activities for protecting nature and the environment in connection with bilateral and multilateral agreements, for example the EU Water Framework Directive.

4.2 Availability and Access

The MAPP-VA system will provide the data through a web-based user interface called EOWeb (http://eoweb.dlr.de:8000/index.html). According to current data policy the data are provided online (ftp) free of charge, for copies on CD or other media a copy fee will be charged.

According to ESA's policy this approach is allowed for research and demonstration activities. The conditions and pricing for regular, operational monitoring need to be negotiated with ESA. DLR is prepared to go into these discussions together with users once operational state has been demonstrated.

Acknowledgements

The authors of this paper wish to acknowledge the work of Brockmann Consult in Geesthacht, who implemented the operational MAPP-VA processor. We would also like to thank Dr. Herbert Siegel of Baltic Sea Research Institute (IOW) for his collaboration in developing the bio-optical model for Baltic waters.

The work on algorithm development and implementation was supported by funding of the Federal Ministry of Education and research (BMBF) under sign 07 UFE 16/1.

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