Sea-truthing of MERIS using optical data from the open Baltic Sea

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The marine remote sensing group at Stockholm University is part of the MERIS-ATSR validation and calibration team (MAVT). The objective is to deliver sea-truthing data for the cal/val activities for MERIS derived from an optical station in the open Baltic Sea. We are the only group in Sweden specializing on marine optical offshore applications in relation to remote sensing.

The group has recently received funding from the Swedish Wallenberg foundation for improved optical equipment. The TACCS (Satlantic) is a 7-channel radiometer with the same visible wavebands for upwelling radiance as the SeaWiFS ocean colour sensor on board the Orbview II satellite (Figure 1). The AC9 plus (WETLabs), is the state-of-the-art instrument to measure spectral attenuation and absorption (in nine channels), from which spectral scattering can be derived (Figure 2). It is also fitted with a CTD and an ECO VSF3 (a volume scattering function metre, which is used to derive backscatter). The data from these instruments will be crucial for sea-truthing and for improved optical modelling of the Baltic Sea.

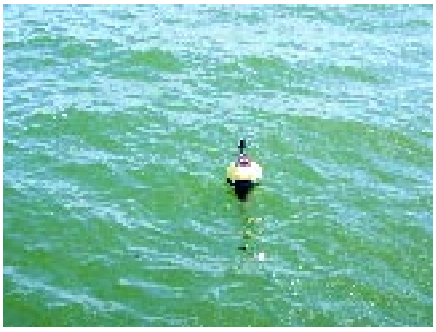

Figure 1. TACCS radiometer (Satlantic).

Figure 2. AC9 plus (WETLabs) on Searcher.

Optically, the open Baltic Sea is dominated by coloured dissolved organic matter (CDOM), also called yellow substance, which consists of a mixture of humic and fulvic acids. Figure 3 shows how the absorption is dominated by CDOM at a station in the open Baltic Sea (Kratzer 2000).

The Baltic Sea is also known for blooms of toxic blue-green algae (filamentous cyanobacteria) during the summer. Surface accumulations of cyanobacteria are visible on AVHRR imagery because of the specific back-scatter properties of filamentous cyanobacteria such as *Nodularia spumigena* (Rud and Kahru, 1994).

The aims of our activities within the MERIS cal/val exercise are:

- To set up appropriate methods and strategies for sea-truthing MERIS in the Baltic Sea region according to international standards (SeaWiFS, MERIS protocols).
- To improve our understanding of the optical properties of coastal waters (optical Case-2 waters) in general, and the Baltic Sea in particular.

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- To combine the knowledge from both remote sensing and sea-truthing to derive optical water quality indicators (such as Secchi depth and chlorophyll *a* concentration).
- In a wider oceanographic and remote sensing context: to work towards basin-wide biomass estimates and bloom prediction.

Specific objectives are:

- To develop offshore, real-time optical methods for improved optical monitoring of water quality using the TACCS instrument (Satlantic) equipped with telemetry. This will provide sea-truthing data for MERIS imagery
- To populate the MERIS data base for calibration and validation of MERIS
- To adapt an optical model (Moore and Kratzer, 2001) for the prediction of water-quality variables from remote sensing imagery to Baltic Sea optical conditions by using Baltic Sea specific parameters, and to test this model using variables from our sea-truthing activities. This model will initially be tested on SeaWiFS, and at a later stage on MERIS imagery.

Sea-truthing and data base development

Over the last two years our sea-truthing activities concentrated on developing methods for validating MERIS imagery. This included adapting our laboratory measurements to the MERIS protocols, and to develop a sound method to validate satellite images using SeaWiFS data. In order to insure international standards we also took part in an intercalibration exercise at Plymouth Marine Laboratory (PML) in August 2001.

For sea-truthing of MERIS on ENVISAT we are planning the deployment of an optical mooring equipped with the TACCS radiometer in the open Baltic Sea. The deployment is currently planned for July/August 2002, but is dependant on the successful launch of ENVISAT. The optical mooring will be deployed by SMHI (Swedish Meteorological and Hydrological Institute) and will be fitted with telemetry (using the Orbcomm satellite system) by JL electronic AB (Oskarshamn) in order to transmit data in near real-time. It will be placed outside Stockholm Archipelago at 58º 56’ 00” N, 19º 11” 00’ E, next to a large oceanographic mooring (OCEANOR buoy), which has been deployed this year by the Swedish Military with help from SMHI. This large oceanographic mooring is equipped with a whole suite of oceanographic instruments fitted with telemetry. Measurements include wind speed, air pressure, air temperature, wave height, wave direction, current speed (at 4 m and 2 m depth), a chlorophyll fluorometer, a transmissometer, 16 CTs, 2 CTDs, and an ADCP at the bottom of the sea. The data from this OCEANOR will provide

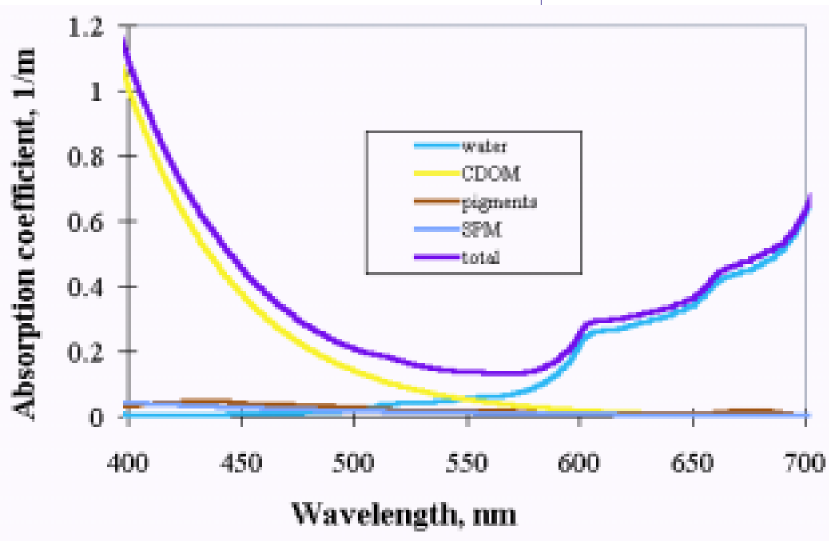

Figure 3. Absorption coefficients from a field station North of Gotland, 5 August 1998, as derived from spectrophotometric measurements of all optical in-water constituents (Kratzer, 2000). Note the strong CDOM absorption in the blue. The absorption spectrum for water was taken from Pope and Fry, 1997.

excellent background information to monitor the development of the seasonal stratification, as well as the onset of toxic algal blooms.

In May 2001 the TACCS instrument with improved spectral resolution was deployed in Gullmar Fjord over a period of one month (Figure 4). The deployment was successful, although there were technical difficulties with the telemetry system, which now have been solved for the OCEANOR mooring.

The optical data collected during our field campaigns will be transferred to the central data storage facility provided by the Norwegian Institute for Air Research (NILU) in Norway. There the data of all MAVT cal/val groups will be used for geophysical validation of the MERIS instruments. Before the field data can be transferred to the NILU database, it needs to be changed into the database format and metadata information has to be added. As MAVT cal/val group we have been involved in the development of metadata guidelines according to the MERIS protocols, which assure a common standard of the validation data submitted by the various groups. In June 2001 we participated in a rehearsal organized by ESA for testing data transfer procedures for the NILU database and the User Service Facility (USF). The objectives of the rehearsal were to test the communication channels and the validation data handling software as well as to generate a test report. Rehearsal tasks included up- and downloading of datasets formatted according to the latest metadata guidelines, navigating within the USF platform and placing product orders. The test report is used by ESA for assessing the performance of these facilities.

Figure 4. Optical mooring deployed during our field campaign in Gullmar Fjord at the Swedish west coast.

Remote sensing and optical methods to improve the monitoring of the Baltic Sea

Due to its spatial and temporal coverage remote sensing provides a powerful tool for improving the monitoring of water quality in the Baltic Sea. The main restrictions for using ocean colour sensor such as SeaWiFS and MERIS for water quality assessment are cloud cover and the fact that they are only sensitive to the upper layer of the sea. Overcoming these restrictions requires the combination of remote sensing with other technique such as *in situ* monitoring and bio-optical modelling. The development of ocean-colour science and technology in combination with advanced automated *in situ* instrumentation, and advances in our ability to model coastal ecosystems, may lead to a revolution in knowledge and management of coastal ecosystems (IOCCG report, 2000).

Most bio-optical work and remote sensing for the estimation of biomass and productivity has concentrated on clear ocean waters (optical Case-1 waters). Coastal waters (optical Case-2 waters), however, tend to be the most productive areas of the world oceans, and it is therefore important to estimate biomass here. However, because of the presence of suspended particulate matter (SPM), and CDOM coastal waters are optically very complicated (Kratzer, 2000), and remote sensing imagery from coastal waters is difficult to interpret.

MERIS with its increased spatial resolution (300 m at high resolution mode) compared to other ocean colour satellites may make it possible to monitor meso scale features commonly found in coastal waters, such as sediment plumes or the occurrence of surface accumulations of cyanobacteria around Stockholm Archipelago.

Commonly used parameters for water quality in the Baltic Sea are for example Secchi depth, which is an indicator for the transparency of the water, and chlorophyll *a*, as an indicator for phytoplankton blooms. Both Secchi depth and chlorophyll *a* are also used as indicators for eutrophication. Another measure for water transparency is Kd490, the diffuse attenuation coefficient at 490 nm. It is more accurate than the Secchi depth, because it is more independent from the person taking the measurements, as it is a physical measure of the rate of decay of downwelling irradiance with depth.

Commonly used algorithms to predict chlorophyll *a* from ocean colour data use the ratio of water-leaving radiance in the blue to the green wavebands. These standard remote sensing algorithms tend to overestimate the concentration of chlorophyll *a* in the Baltic Sea. This is because the optical properties are dominated by yellow substance. The standard two-band ratio algorithms for chlorophyll are not able to distinguish between chlorophyll *a* and CDOM, and are therefore not valid in the Baltic Sea area. The SeaWiFS sensor includes a channel at 412 nm. This band was originally meant for the distinction between chlorophyll *a* and CDOM. However, the standard atmospheric algorithm developed by NASA tends to give negative irradiances below 490 nm (Land 2001; Mueller, 2000) when applied to Baltic Sea data.

We have developed a method to monitor water quality in the Baltic Sea, using SeaWiFS imagery. A time series of (Kd490) was produced over the Baltic Sea (Ishii 2001). Figure 5 shows an example of what these images look like.

Weekly composites were compared and validated against *in situ* Secchi depth measurements, which showed a significant correlation. The correlation improved when using Secchi readings matching the SeaWiFS overpass in time, and using a higher spatial resolution (1 km instead of 4km). The next step was to compare the Kd490 data derived from the satellite data to Kd490 derived from the TACCS radiometer. This comparison showed a high correlation, but the regression analysis showed that the intercept was significantly different from zero. This may be due to the fact that the algorithm was produced for waters with lower Kd490 values than commonly found in the Baltic Sea (Mueller, 2000). Our plan is to include data from a field campaign in 1999 (Subramaniam *et al.*, 2000) into the data analysis and validation technique, and to derive a correction factor for the Baltic Sea.

Kd490 is not a standard product of the ENVISAT campaign, and it may be desirable to develop a similar algorithm for MERIS as an indicator for the eutrophic state in the Baltic Sea.

Optical modelling

In a previous study data derived from a four-channel radiometer was used to test and improve a semi-empirical optical model to predict reflectance ratios for the Irish Sea (Harker 1997, Kratzer *et al.*, 2000). Subsequently, the model was adjusted to the Baltic Sea using area-specific parameters (Kratzer *et*

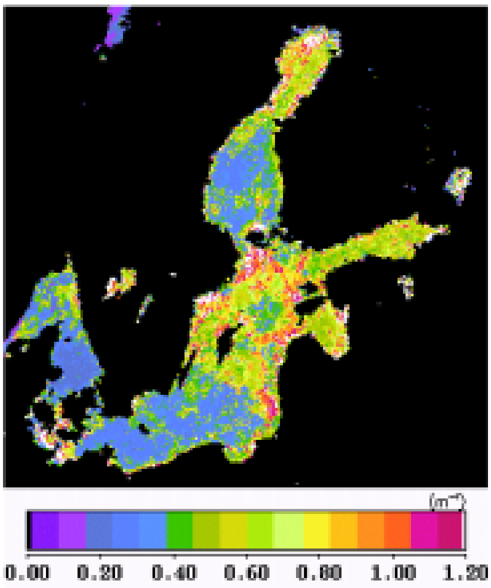

Figure 5. SeaWiFS monthly mean attenuation coefficient (m^{-1}) at 490 nm. Image from July 2000 (Ishii, 2001).

al., 1998). Sensitivity analysis of the model gave a better insight into optical theory, and helped to identify which optical parameters to focus on (i.e. scattering and backscattering processes, Kratzer, 2000).

There is a need to describe these parameters in order to improve semi-empirical optical models, and to improve remote sensing in the Baltic Sea. Currently, a more sophisticated semi-empirical model for the Baltic Sea is developed in collaboration with Plymouth Marine Laboratory (Moore and Kratzer, 2001). The model includes an atmospheric correction and predicts optical water quality parameters using satellite imagery as an input. Work is in progress to test the model on SeaWiFS data using Baltic Sea specific parameters, which have been gathered within our group. The model will subsequently be tested with variables derived during our sea-truthing activities between1998-2001, and will be adapted to MERIS.

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