COASTAL WATER MONITORING AND REMOTE SENSING PRODUCTS VALIDATION USING FERRYBOX AND ABOVE-WATER RADIOMETRIC MEASUREMENTS

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ABSTRACT

A SeaWiFS Photometer Revision for Incident Surface Measurements (SeaPRISM) has been installed on the Helsinki Light House Tower (HLT) in the Gulf of Finland, Baltic Sea, to determine normalised water leaving radiances at centre-wavelengths of interest for ocean colour applications. Additional *in situ* data are produced twice a week at a distance of 0.5-1 km from the HLT with a ferrybox monitoring system operated on board the MS FINNPARTNER within the framework of the Alg@line project. Ferrybox includes a flow-through system for measuring chlorophyll-a and also for collecting water samples for subsequent laboratory analyses to determine the absorption properties of coloured dissolved organic matter (CDOM), phytoplankton and non-algal particulate matter. The combined use of SeaPRISM and ferrybox measurements is introduced and briefly discussed aiming to show their relevance in assessing remote sensing products of the optically complex coastal waters in the Baltic Sea.

Keywords: Ferrybox, ocean colour data validation, water-leaving radiance.

INTRODUCTION

Satellite instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and Medium Resolution Imaging Spectrometer (MERIS) are widely used for water quality assessment of marine regions with complex optical properties (1). Satellite sensor data, once corrected for the atmospheric perturbations, are applied to determine the normalised water leaving radiance $L_{WN}(\lambda)$ at various centre-wavelengths λ, which carry information on the various optically significant seawater constituents like phytoplankton, dissolved organic and particulate matter (2). However, in coastal waters frequently classified as Case-2, the atmospheric correction process appears challenging and bio-optical algorithms, which are used to quantify the optically significant constituents from $L_{WN}(\lambda)$, are not well established. These shortcomings call for extended field activities to support the development of regional remote sensing products and their successive validation. Aiming at supporting the latter requirement, a measurement programme has been started to combine continuous radiometric measurements at a given site with regular water sampling in the surrounding area.

An autonomous above-water system called SeaWiFS Photometer Revision for Incident Surface Measurements (SeaPRISM) produces L_{WN} data and is designed to support the validation of satellite ocean colour data. Since spring 2006, as a part of AERONET – Ocean Colour network coordinated by NASA (3) (see http://aeronet.gsfc.nasa.gov), the SeaPRISM instrument is operated on the Helsinki Light House Tower (HLT), 10 miles south the city of Helsinki in the Gulf of Finland, (Figure 1).

A ferrybox monitoring system on board the MS FINNPARTNER operates twice a week across the Baltic Proper from Helsinki to Travemünde (Figure 2). The system includes fluorometers for estimating chlorophyll–a and phycocyanin fluorescence as well as turbidity (4). Measurements of absorption properties of coloured dissolved organic matter (CDOM), phytoplankton and non-algal particulate matter are produced using seawater samples automatically collected near HLT site.

The study site is influenced by river discharges and the Neva River is running into the eastern end of the Gulf of Finland, bringing high amounts of allochthonous carbon to the Baltic. The salinity of the seawater on the surface is about 5 psu.

Data collected during summer 2006 are used in this study to assess primary radiometric products (i.e., L_{WN}) from MODIS imagery and additionally to characterise the bio-optical features of the validation site.

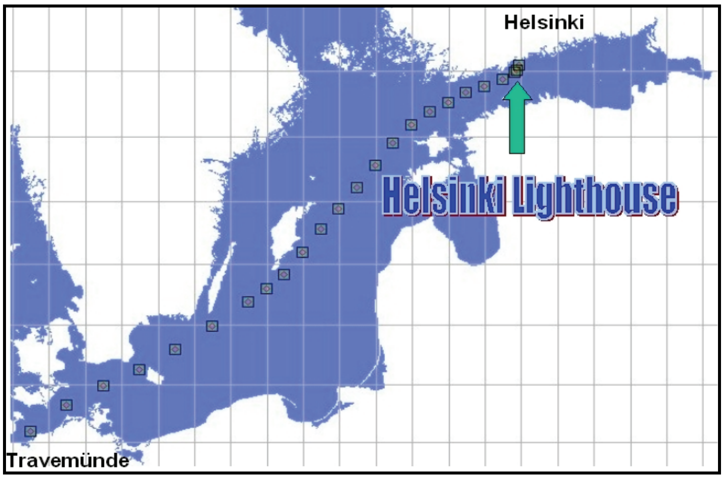

Figure 1: SeaPRISM station on the Helsinki Light House and Alg@line water sampling points by MS FINNPARTNER.

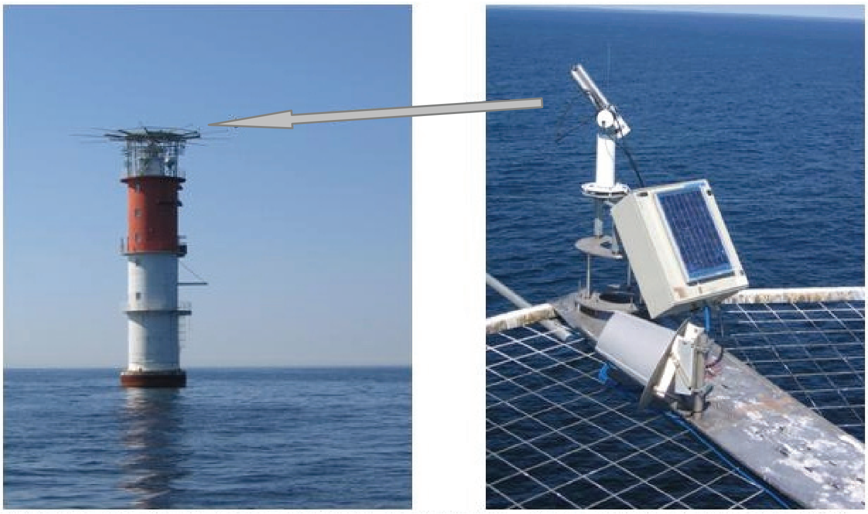

Figure 2: SeaPRISM radiometer on the Helsinki Light House.

METHODS

Radiometric data

The SeaPRISM radiometer has 1.5° full angle field of view and can perform sun, sky and sea observations at the 412, 443, 488, 551, 665, 870 and 1020 nm centre-wavelengths. The sea– and sky–viewing angles together with the related azimuth angle are programmed to satisfy the needs of an assessed measurement protocol requiring successive measurement sequences each comprising 11 sea- and 3 sky-radiance observations per spectral channel, with sea-viewing angle of 40°, sky-viewing angle of 140° and relative azimuth of 90° with respect to the sun. The SeaPRISM is calibrated just before and after each field deployment (generally lasting from spring to early fall). On average, changes of less than 1% have been observed in instrument sensitivity during successive deployments in 2006 and 2007.

Data transmission is made through the METEOSAT meteorological satellite that ensures almost real-time data handling. Collected data are processed and quality- assured at the Goddard Space Flight Center (GSFC) of the National Aeronautics and Space Administration (NASA). $L_{WN}(\lambda)$ is determined by minimising the surface perturbation effects, and removing the viewing angle dependence and the effects resulting from the anisotropy of the marine light field. The expected uncertainty in SeaPRISM $L_{WN}(\lambda)$ is approximately 5% from the blue to the green spectral regions and 12% in the red one.

It is finally recalled that the SeaPRISM measurement sequences also allow for the determination of the aerosol optical thickness AOT at the same centre-wavelengths of $L_{WN}(\lambda)$.

Seawater absorption coefficients

Water samples are collected once a week with an Isco 3700 refrigerated sequential water sampler approximately every 30 nautical miles along the route of MS FINNPARTNER (24 samples total) from Travemünde to Helsinki. One water sample is routinely taken when the ferry passes the Helsinki Light House at a distance of 0.5-1 km on the way back to Helsinki.

The absorption coefficients of seawater components at the HLT site are determined from the water samples. The seawater is filtered through 0.2 µm membrane filters and the CDOM absorption coefficient is determined with spectrophotometry using a Perkin-Elmer Lambda2 photometer. The optical density of CDOM samples is measured using a 10- cm quartz cell and successively converted to absorption. Particulate absorption coefficients are determined with a spectrophotometric technique based on transmittance-reflectance measurements (5). Particles, concentrated onto glass-fibre filters (Whatman GF/F) and stored at -80°C, are analysed using a Shimadzu UV2501PC spectrophotometer equipped with an integrating sphere. Absorption by phytoplankton and non-algal particulate matter is discriminated by applying the NaOCl bleaching technique.

RESULTS

The MODIS remote sensing raw data (level-1A imagery) have been acquired from GSFC and processed with the SeaWiFS Data Analysis System (SeaDAS) software package (version 5.1.5). The scheme applied in SeaDAS for minimising the atmospheric effects and producing the normalised water leaving radiance from top-of-atmosphere radiance includes corrections for bi-directional effects which make the SeaPRISM and MODIS $L_{WN}(\lambda)$ products directly comparable. For comparison with field observations, MODIS $L_{WN}(\lambda)$ has been extracted for a square of 3×3 image elements centred at the HLT site. A remote sensing record is included in the match-up analysis if at least one field observation is available over a 2-hour time interval centred on the satellite overpass time and if it fulfills the criteria constituting the specific selection protocol for match-ups: i.e., data are not affected by clouds, sun glint, stray light, or an excessive viewing angle (larger than 60°) or sun zenith angle (larger than 70°).

The comparison of MODIS $L_{WN}^{MOD}(\lambda)$ and SeaPRISM $L_{WN}^{PRS}(\lambda)$ normalised water leaving radiances is shown in Figure 3 at the 412, 443, 488, 551, 667 nm centre-wavelengths for 23 match-ups. By contrast, the aerosol optical thickness from MODIS AOT^{MOD} and SeaPRISM AOT^{PRS} is only compared at 869 nm.

Results are presented through the average of relative (signed) percent differences ψ used to indicate biases, and the average of absolute (unsigned) percent differences $|\psi|$ used to indicate typical uncertainties. Results for $L_{WN}(\lambda)$ indicate a relatively good agreement at the 551 nm MODIS centre-wavelength with ψ = -5% and $|\psi|$=15%. The agreement becomes less satisfactory at shorter centre-wavelengths as highlighted by the large scatter affecting the data at 412 and 443 nm and by the significant number of MODIS data exhibiting negative values at 412 nm. However, these apparently poor results have to be evaluated accounting for the relatively low values of $L_{WN}(\lambda)$, when compared to different coastal regions (6).

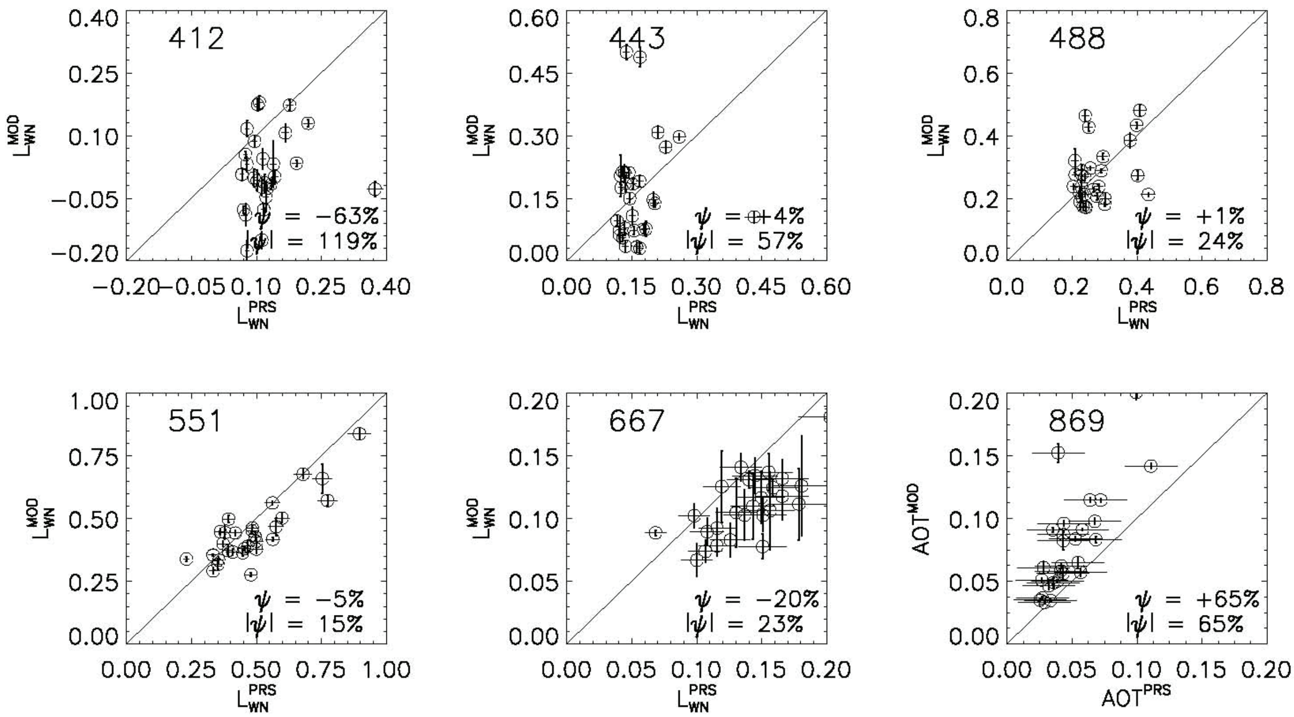

Figure 3: Comparison of normalised water leaving radiances by MODIS $L_{WN}^{MOD}(\lambda)$ versus SeaPRISM $L_{WN}^{PRS}(\lambda)$ at the 412, 443, 488, 551 and 667 nm centre-wavelengths and aerosol optical thickness (AOT) at 869 nm. Percentage differences are indicated in terms of average bias (i.e., ψ) and absolute difference (i.e., $|\psi|$). The horizontal bars indicate the expected SeaPRISM uncertainties, while the vertical bars indicate the standard deviation across the 3x3 MODIS pixels centred at the HLT site.

These relatively low radiance values in the blue spectral region are explained by the high seawater absorption coefficients dominated by CDOM and modulated by phytoplankton and non-pigmented particulate matter, see Figure 4 presenting representative absorption spectra determined from water samples collected at different dates in June and July 2006. This result is highlighted by the ternary plot in Figure 5 showing a comparison of the various absorption coefficients at SeaPRISM centre-wavelengths. Specifically the plot confirms that CDOM dominates the light absorption in the blue part of the spectrum while the contribution of phytoplankton is only notable above 551 nm.

The comparison results for the AOT presented at the 869 nm MODIS centre-wavelength exhibit a systematic overestimate for the satellite derived data with ψ and $|\psi|$, both equal to 65%. A large overestimate was similarly observed for AOT values lower than 0.2 determined with a different processing scheme applied to MODIS data for various oceanic regions (7). This might suggest a specific difficulty of the atmospheric correction code in determining the AOT at 869 nm. A possible explanation is offered by the scheme used for the vicarious calibration of MODIS data. This scheme relies on the assumption that the calibration coefficient at 865 nm does not need any correction. Thus, during the atmospheric correction process, any uncertainty in the calibration coefficient translates into an uncertainty in the derived AOT at 869 nm.

The AOT underestimate at 869 nm might lead to a wrong determination of the Ångström exponent. Actually the comparison of MODIS and SeaPRISM derived Ångström exponents at the HLT site indicate an average underestimate of approximately 20% for the remote sensing derived values (results not shown). This might lead to a wrong determination of the aerosol type at the specific measurement site and consequently to unpredictable uncertainties in the atmospheric correction process, which could explain the overcorrections observed at the 412 and 667 nm centre-wavelengths.

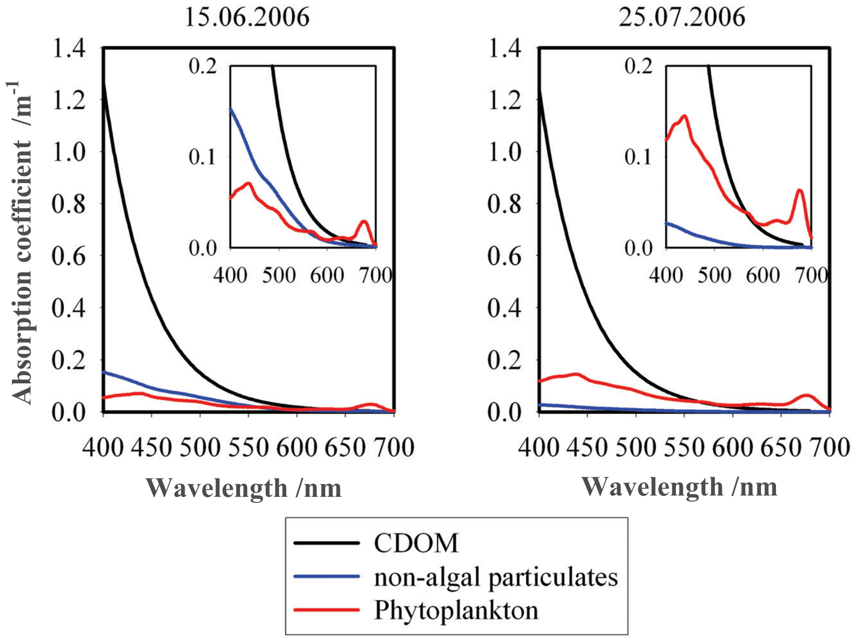

Figure 4: Contribution of coloured dissolved organic material (CDOM), non-algal particulates and phytoplankton to light absorption coefficient in the 400-700 nm spectral range.

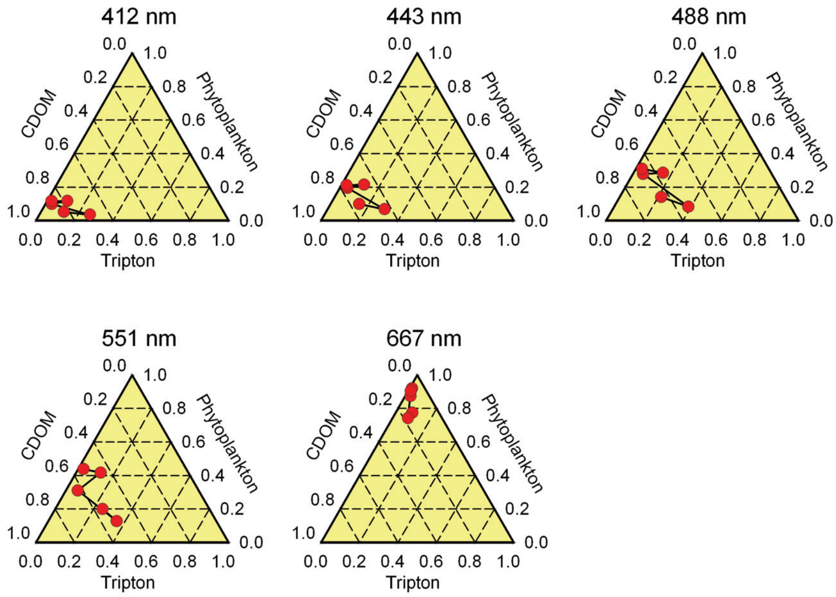

Figure 5: Relative contribution of the absorption components at the SeaPRISM centre-wavelengths determined from water samples collected nearby the HLT during summer 2006.

CONCLUSIONS

Standard algorithms for Chla retrieval are inappropriate for the Baltic Sea and regional algorithms should be developed (8). A field programme has been started to collect *in situ* observations to support the development and assessment of remote sensing products for the optically complex Baltic Sea waters. Field data are collected with an autonomous radiometer operated on the Helsinki Lighthouse Tower to produce L_{WN} at center-wavelengths of interest for ocean colour applications. Additionally, water samples are collected through a ferrybox system as a part of the Alg@line project to determine the chlorophyll-a concentration and absorption coefficients of the optically significant seawater components.

A first analysis of MODIS and SeaPRISM $L_{WN}(\lambda)$ match-ups at the HLT site indicates an underestimate of 63 and 20% for MODIS $L_{WN}(\lambda)$ at 412 and 667 nm, respectively. By contrast, average differences are within ±5% at 443, 488 and 551 nm. An explanation of this result is probably offered by a wrong determination of the aerosol type at the validation site. This is supported by an appreciable overestimate (i.e., 65% on average) of the aerosol optical thickness at 869 nm and an underestimate (i.e., 20% on average) of the Ångström exponent determined from MODIS imagery. Comparable results have been obtained from another SeaPRISM site in the Baltic Sea (9).

The availability of additional match-ups during the following years will enable a more extended analysis of this problem and will be the focus for future validation studies of regional ocean colour products in the Baltic Sea. Additionally, the availability of the chlorophyll-a concentration and, apparent (i.e., L_{WN}) and inherent (i.e, absorption coefficients) properties of seawater at the HLT validation site will provide the possibility of investigating novel regional bio-optical algorithms.

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