Modeling of Apparent Hydro-Optical Properties and Retrievals of Water Quality in the Great Lakes for SeaWiFS: a Comparison with In Situ Measurements

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INTRODUCTION

Assessment of water quality parameters from SeaWiFS data proved to be nowadays operational for case I waters, i.e., oceanic and marine open waters [1]. Relatively simple algorithms based on ratios of water-leaving radiance at two or more SeaWiFS wavelengths are successfully used for retrieval of algae pigments in such waters. However, water quality retrieval presents considerable difficulties when processing satellite (e.g., SeaWiFS) data pertinent to case II waters which are generally inland and marine coastal waters. Apart from the atmospheric correction problem for such waters (this issue is discussed in our companion paper), case II water optical complexity necessitates application of sophisticated water quality retrieval algorithms [2] which require *a priori* knowledge of a set of optical characteristics (i.e., usually referred to as a hydro-optical model) appropriate for major optically active constituents indigenous to a targeted water body/water mass.

Since hydro-optical models are being only available for a limited number of case II water bodies, it appears important to investigate translatability of those hydro-optical models developed for specific water bodies to a larger variety of case II waters. Once the extend of this translatability is assessed, the solution to the inverse problem (i.e., retrieval of water constituents abundance) could be attained via application of a suitable bio-optical algorithm/retrieval procedure.

EXPERIMENTAL

Comprehensive field studies on Great Lakes were performed by ERIM in 1997 during July and August. On many occasions, these studies were synchronized with the SeaWiFS overpasses. Having been accompanied by the observations of weather conditions (wind force and direction, waves, nature and degree of cloudiness) as well as the sun zenith (θ_0) and in-water conditions (the abundance of co-existing water components controlling the optical status of the aquatic medium), these radiometric measurements could be used for running closed forward and inverse modeling given the availability of a reliable hydrooptical model of the bay. In the absence of such a model, forward modeling could be, however, attempted making use of some hydrooptical models and combinations of them suggested elsewhere for other temperate lakes.

In this communication we will concentrate on that part of the research that relates to the Saginaw Bay of Lake Huron. Conducted from board a small research vessel, spectrometric measurements (in the SeaWiFS wavelength bands) of the above surface incident irradiation ($E_d(+0,\lambda)$ and subsurface upwelling radiance in the zenithal direction ($L_u(-0,\lambda)$) were complimented with concurrent *in situ* measurement of the phytoplankton chlorophyll concentration (CHL), dissolved organics (DOC) and total suspended matter (TSM).

Lake Huron is dimictic and oligotrophic in the most areas except for Saginaw bay and the restricted waters of Severn Sound in southern Georgian Bay where eutrophic conditions prevail [3]. The lake watershed has extensive glaciolacustrine and morainal deposits, which result in easily eroidable shorelines in some areas.

The Saginaw Bay water quality is largely controlled by run-off, tributary discharge, as well as by the anthropogenic effluents coming from Bay City and the city of Saginaw.

The Lake Huron mean levels of chlorophyll concentrations vary between 0.5 and 1.5 μg/l with the Secchi disk depths averaging 8 m. In Saginaw Bay, the mean concentrations of chlorophyll are 5-10 μg/l with the Secchi disk depths averaging 1-3 m.

The phytoplankton species for the Huron Lake open area are typical of oligotrophic water bodies.

In contrast, the phytoplankton community in Saginaw Bay is representative of typical eutrophic conditions [3].

The morphometric characteristics of Saginaw Bay are such that its area can be conditionally ascribed to the inner and outer parts with the imaginary demarcation line extending

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along its narrowest width (from Sand point to Point Lookout).The bay inner part is shallow with depths mostly less than 7 m. Near the demarcation line the bottom relief forms a kind of threshold beyond which the depths increase fairly rapidly reaching about 30 m in the central part of the outer portion of the bay.

The above indicates that there should be two distinctly different waters masses residing in the outer and inner parts of the Bay which is conducive to a substantial difference in the optical characteristics of both parts of the Bay due to differences in : the phytoplankton abundance and taxonomic composition, mineralogical and microphysical characteristics of suspended minerals (the suspended matter in the inner part should be directly provided by nearby tributaries, run-off and wind/water dynamics driven resuspension whereas in the outer part it is largely the result of filtering due to gravitational settling of the particulate matter generated by *distant* sources).

Similar considerations could be suggested with regard to the dissolved organics (doc): the autochtonic component in the outer part of the bay could be predominant, whereas in the inner part the allochtonic component should most certainly prevail. Evidently, under appropriate conditions, due to wind and current impacts, both types of water masses can invade the counterparts of the bay and mix up with the ambient waters.

FORWARD MODELING

For forward modeling three analytical expressions for the water volume reflectance just beneath the surface $R(z=-0)$ suggested in [4-6] were tested, yielding very close results. The preference was, however, given to the parameterization suggested in [4] since it was developed specifically for the Great Lakes and a wide spectrum of hydro-optical conditions:

- for solar zenith angles in the range ~ (0° - 50°):

$$R(z=-0) = (1/\mu_0)0.319 b_b/a \quad \text{for } 0 \le b_b/a \le 0.25 \tag{1}$$

$$R(z=-0) = (1/\mu_0)[0.013 + 0.267 b_b/a] \quad \text{for } 0.25 \le b_b/a \le 0.50 \tag{2}$$

- for overcast conditions: μ_0 equals 0.858.

Here a and b_b are respectively the water absorption and backscattering coefficients, μ_0 being the in-water solar zenith refracted angle .

Several hydro-optical models (i.e., tabulated spectral values of specific values of a and b_b) were explored for forward modeling:

1. a model for mesotrophic waters rich in both phytoplankton and dissolved organic matter [7]; this model was developed for Lake Ladoga (north-western Russia),
2. a model for waters in transition from oligotrophic to mesotrophic conditions [8], this model was established for Lake Ontario,
3. a model suggested for the phytoplankton absorption coefficient residing in waters ranging from strictly oligotrophic to eutrophic [9],
4. a model of the absorption and backscattering coefficients for , presumably, small-sized suspended mineral matter

In addition, several slope parameter (s) values were tested for the dissolved organic matter absorption coefficient $a_{doc}(\lambda)$

$$a_{doc}(\lambda) = a_{doc}(\lambda_0)\exp[-s(\lambda - \lambda_0)], \tag{3}$$

where λ_0 is a reference wavelength.

The choice of the above hydrooptical models was dictated by the following considerations: in the light of a distinct hydrooptical unlikeness of waters in the inner and outer regions of Saginaw Bay, it seemed appropriate to apply different hydrooptical models when modelling R -values: for the inner region - the mesotrophic Lake Ladoga model, for the outer region - either the Lake Ontario model *per se*, or its modifications using options ***3*** and ***4***. . option ***3*** allows the phytoplankton cross sections increase in oligotrophic waters, option ***4*** might be more appropriate for clear waters of the outer part of the Bay. Such combinations were thought to be especially approptiate for some intermediate hydrooptical situations apparently occurring when plumes of inner bay water get into the outer region and vice versa.

Since the field measurement were conducted in a way that downwelling irradiance was measured just above the water/air interface, and subsurface nadir upwelling radiance was measured instead of subsurface upwelling irradiance, the following formula [8] was employed to obtain the water volume reflectance:

$$R(-0,\lambda) = \frac{E_u(-0,\lambda)}{E_d(-0,\lambda)} = \frac{L_u(-0,\lambda)Q(\theta_0,\lambda)}{E_d(+0,\lambda)0.96}, \tag{4}$$

where $E_u(-0,\lambda), E_d(-0,\lambda)$ are respectively the subsurface upwelling and downwelling irradiances, Q is the ratio $E_u(-0,\lambda)/L_u(-0,\lambda)$. The Q values were derived from [9].

INVERSE PROBLEM SOLUTION

Inverse problem solution, i.e., retrieval of the concentration vector from the spectral distribution of $R(-0,\lambda)$ was pursued following [10]. Two approaches were explored:

a)multivariate optimization procedure (the Levenberg-Marquardt algorithm), and b)neural network emulation. Both approaches and the neural network configuration and parameters were discussed in detail elsewhere [11].

RESULTS AND DISCUSSION

The analyses of computational results indicate that the hydrooptical properties of Saginaw Bay are unlikely to be described with a single hydro-optical model. This is illustrated in Figs. 1 and 2. for the above hydrooptical models and their modifications employed in our calculations. As seen from these figures, the Lake Ladoga hydro-optical model proves to be most appropriate for simulating the optical properties of the inner part of the Bay, whereas for the outer part a modified Ontario model (involving options *3* and *4*) appears more adequate. This finding complies with the above background data on the specificity of the inner and outer regions of the bay

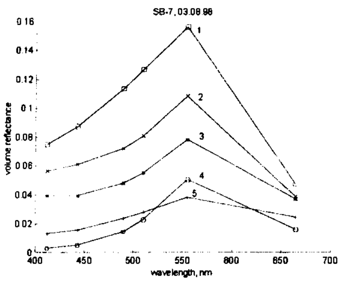

Fig. 1.

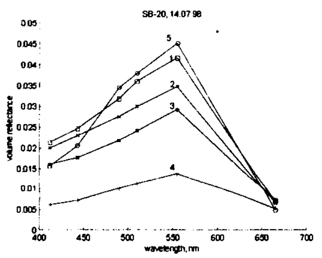

Fig. 2.

Fig.1 (the measured concentrations: CHL– 10.27 μg/l, TSM – 6.6 mg/l and DOC – 2.57 mg/l) and Fig.2 (the measured concentrations: CHL– 1.77 μg/l, TSM – 0.57 mg/l and DOC – 1.19 mg/l) relate respectively to the inner and outer parts of the Bay. The curve labels denote: 1 – option *2* modified with options *3* and *4*; 2 –option *2* modified with option *4*; 3 - option *2*; 4 – option *1*; 5 – actual measurements. θ_0 is 38° (Fig.1) and 34° (Fig.2).

The comparison of results of the concentration vector retrieval obtained via using the Levenberg-Marquardt and neural network procedures indicate that the former assures a somewhat higher retrieval accuracy (ca 20%) whereas the latter, being less accurate (ca 35%) is much more fast and, hence,appropriate for operational use. The major asset of the employed approaches resides in their ability to provide not only the pigment concentration but also the concentrations of suspended minerals and dissolved organics which together with chlorophyll are considered as important parameters-indicators largely determining the trophic status of inland waters.

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