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Water Colour in Inshore Areas

by

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Introduction

The possibility of obtaining extensive coverage of the oceans by satellite surveillance is of potential interest to many marine-orientated sciences, managements and industries. Both ocean colour and sea surface temperature are being monitored in 1981 by satellite systems, and represent parameters of potential interest to fisheries.

Ocean colour is recorded by the Coastal Zone Colour Scanner (CZCS) carried on board the Nimbus-7 satellite launched in October 1978. The scanner records upwelling light from the ocean in five spectral bands and considerable scientific attention has been given to developing algorithms relating sensor signals to parameters such as chlorophyll and suspended solids.

Water colour ratios have been used in attempts to quantify surface chlorophyll in ocean waters (Clark et al., 1980; Smith and Baker, 1978). Various blue-green ratios have been suggested to explain chlorophyll concentrations and the disagreements between various algorithms has been highlighted by Højerslev (1981). The greatest disagreement occurs for coastal waters where concentrations of dissolved organics can mask the chlorophyll signal, river outflows can produce high suspended sediments and tidal mixing can induce resuspension of bottom material. The diversity of factors influencing water colour in these cases requires sea colour algorithms to depend on the water mass in question (Højerslev, 1981).

If coastal water masses require special consideration in algorithm development, it is first necessary to define and identify these particular

SYMPOSIUM ON REMOTE SENSING

For each spectrum, a water sample was taken at 1 metre depth and later analysed for the following parameters: suspended solids, chlorophyll, phaeophytin, dissolved organic carbon, particulate organic carbon and salinity. Both the sampling procedure and analysis for these parameters are described in detail in Keizer and Gordon (1981). Suspended solid estimates represent the dry weight per volume of all material retained by a 0.4 micron nucleapore filter irrespective of the composition of the suspended material. Hence, for this survey different samples and, in particular, different ranges of suspended solid concentrations may relate to different types of material. In clear, low concentration water masses, depth samples were taken to detect possible stratification effects on sample values.

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Coastal Spectra and Sediment Load

Figure 2 gives normalised upwelling quantum irradiance spectra taken at 1 metre depth for concentrations of suspended solids from approximately 1 mg/l to 43 mg/l. The position of four CZCS wavebands are included in the diagram. Figure 2 shows that the relative signal level at 670 nm (CZCS band 4) increases directly with increasing suspended solid concentration. Bukata et al. (1980) have shown, for suspended solid concentrations less than 10 mg/l, that the magnitude of reflected irradiance at 670 nm is directly related to suspended solid concentrations. For the suspended solids concentration range 1-10 mg/l (Fig. 2), the wavelength of the spectral maxima changed by less than 10 nm but signal levels between 450 nm and 550 nm decreased as signal levels between 600nm and 700 nm increased. For further increases in the suspended load, the spectral maximum shifts further towards the long (red) wavelengths. The signal levels at 443 nm (CZCS band 1) were small and often hidden in the instrumentation noise level.

The upwelling quantum irradiance spectra for coastal waters was found to be dominated by the suspended solid load for concentrations in excess of 5 mg/l and still highly influenced for concentrations from 1-5 mg/l. For these cases, sediment load has a primary effect on the spectra and all other substances, chlorophyll, dissolved organics, etc., have a secondary or masked role.

Coastal Spectra and Dissolved Organics

Coastal waters are often typified by the presence of yellow substance (Jerlov, 1978: Højerslev, 1981) which can itself be approximated on a local scale, by the level of freshwater input (salinity) or dissolved organic carbon. Coastal waters, however, also contain variable quantities of other material such as organic sediments, inorganic sediments, chlorophyll and phaeophytin. Identifying the influence of just one of these substances alone can therefore be a difficult task. Figure 3a gives normalised upwelling spectra for concentrations of suspended solids of 1.26 mg/l and 7.92 mg/l with corresponding dissolved organic carbon concentrations of 4.04 μ gC/1 and 2.19 μ gC/1 respectively. In this particular instance, a water mass with high dissolved organic carbon content and low suspended solid concentrations has produced approximately the same spectral profile and hence similar spectral ratios as a water mass with a lower dissolved organic carbon content but a high suspended load. The effect of dissolved organic carbon content on the short wavelength portion of the spectrum of upwelling irradiance is variable and may not even be observed once the suspended load has reached a certain level. Figure 3b gives normalised quantum irradiance spectra for sediment loads of 3.50 mg/l, 3.59 mg/l and 3.37 mg/l with dissolved organic concentrations of 10.33 μ gC/l, 7.23 μ gC/l and 1.85 μ gC/1 respectively; none of the spectra exhibit any marked additional decrease at short wavelengths over that already produced by the sediment load. At 670 nm the spectra showed variations consistent with but larger than increasing sediment loads indicating the possible influence of still another water quality parameter.

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The spectra given in Figures 3a and 3b tend to exhibit features consistent with sediment-laden waters, that is a larger signal at 670 nm than at 443 nm and a spectral maxima at wavelengths greater than 550 nm.

Coastal Spectra and Chlorophyll

The upwelling spectrum in coastal waters appears to be dominated by the suspended load. In order to examine any interrelationship between chlorophyll and water colour for coastal areas, only spectra for suspended solid concentrations less than 1 mg/l were selected. Figure 4 gives three such spectra with the associated concentration levels given in Table 2. Spectrum B was obtained off Yarmouth, Nova Scotia, in early June in a known biologically productive area. The spectrum exhibits a small secondary peak around 670 nm which can be identified with the known fluorescent peak of chlorophyll-a. Spectra A and C were taken in water masses with much lower concentrations of chlorophyll but similar levels of both phaeophytin and suspended solids. The low chlorophyll spectra are not unsimilar (except for the fluorescent peak) to the high chlorophyll profile. All three spectra exhibit features that are consistent with the oceanic spectra measured by Clark et al. (1980), that is low signal levels at 670 nm (except for fluorescent effects), small variations at 520 and 550 nm and clear (above noise level) signals at 443 nm. The spectra obtained for suspended concentrations below 1 mg/l therefore most nearly approach oceanic measurements.

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Figure 5 gives the blue-green quantum irradiance ratio 440 nm to 550 nm, for data from all locations with less than 1 mg/l concentration of suspended solids, plotted against various concentration values. No consistent relationship can be detected in these plots for irradiance ratio against suspended solids, chlorophyll or dissolved organics. In fact, no relationship could be detected with any absolute concentration level (suspended inorganics, phaeophytin, etc.). A plot of the colour ratio 440 nm to 550 nm against the percentage (by weight) of organic material in the suspended load, Figure 5d, does indicate a trend of lower colour ratio with increasing organic composition. This means that for these data samples the highest ratios (largest blue wavelength signal) occurred in water masses with a low organic component in the suspended load; lowest ratios occurred for waters with the highest organic content in the suspended load.

Summary and Conclusions

The CZCS is being calibrated with in situ data in several geographic areas giving rise to algorithms relating ocean colour ratios to chlorophyll concentrations (Morel and Gordon, 1980). Successful use of any of these algorithms in non-calibrated areas (e.g. the Scotian Shelf) will depend on the optical similarity of the calibrated and non-calibrated areas. It has been seen that areas such as the Bay of Fundy, St. George's Bay, St. Margaret's Bay and Halifax Harbour did not have oceanic optical properties and current CZCS algorithms could not therefore be used for these coastal areas.

It is important to note that not only would the algorithm change for these coastal areas but also the dependent variable would probably change from chlorophyll to suspended solids.

The coastal upwelling spectra presented in this documents have different characteristic features to those associated with oceanic spectra. In particular, the spectra exhibit non-zero contributions at 670 nm which can be related to suspended solid concentrations. As the suspended load increases, the short bluegreen wavelengths are attenuated further but long wavelengths receive additional light from scattering processes. At sufficiently high sediment concentrations, the CZCS band 4 (670 nm) will become the maximum spectral water signal.

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The occurrence of yellow substance in coastal waters causes a strong absorption of ultra-violet light with some accompanying attenuation of short wavelenth, blue, light. Both salinity and dissolved organic carbon concentration can be indicators of ultra-violet absorption in localized situations, but are non-conservative in general cases. A general non-optical parameterization of these optical effects of yellow substances has not been achieved. In this study, optical measurements were made over a wide coastal area, therefore, neither dissolved organic carbon nor salinity measurements provided a consistent explanation of short wavelength attenuation of coastal spectra. Conversely, a CZCS satellite image covering a large coastal, or inshore, area would be unable, with present knowledge, to give a consistent prediction of concentrations of such coastal substances.

Coastal upwelling spectra obtained for low suspended solid concentrations (less than 1 mg/l) exhibited oceanic features for wavelengths greater than 520 nm. For wavelengths less than 520 nm, however, the coastal quanta spectra remains depressed below levels expected for corresponding chlorophyll concentrations in oceanic waters. The colour ratio for the one high chlorophyll station was not inconsistent with ratio predictions from oceanic models. The low chlorophyll stations all gave blue-green ratios much lower than all oceanic model predictions and for several data samples lower than the high chlorophyll data (Fig. 5b). Inclusion of such clear (low concentration) coastal water masses in algorithm calibrations would result in large disagreements with oceanic models and in certain cases, with limited sampling, could even result in inverse or negative relationships being deduced.

Little or no optical information is available for other east coast Canadian waters (e.g. Scotian Shelf and Labrador Sea) to indicate their optical water type and hence similarity to CZCS calibrated areas. CZCS data from these areas could be used for chlorophyll mapping if in situ data were available or if surveys had established the optical characteristics of those areas.

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Site Location	Measured Range of Suspended Solids (mg/l)	
Bay of Fundy: Minas Basin off Digby (N.S.) off Saint John (N.B.) off Yarmouth (N.S.)	$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	
St. Margaret's Bay (N.S.)	0.4 - 3.6	
Bedford Basin and Halifax Harbour (N.S.)	0.4 - 4.9	
St. George's Bay (N.S.)	0.6 - 4.5	

Table 1. Location of Samples with corresponding suspended sediment range.

N.S.: Nova Scotia N.B.: New Brunswick

Table 2. Concentration Levels for Spectra in Figure 4.

Spectrum	Chlorophyll µg/l	Phaeophytin µg/1	Suspended Solids (mg/1)
Α	0.68	0.47	0.72
В	5.99	0.56	0.58
C	1.19	0.41	0.50





1.75 mg/l suspended solids
5.39 mg/l suspended solids

11.66 mg/l suspended solids

43.19 mg/l suspended solids
 Position of CZCS waveband



Figure 3a - Normalised upwelling quantum irradiance at 1 m depth versus

wavelength for differing dissolved organic concentrations and

suspended solids.

4.04 μ gC/1 dissolved organic carbon 2.19 μ gC/1 dissolved organic carbon







• 1.85 µgC/1 dissolved organic carbon

Position of CZCS wavebands



wavelength for suspended solids concentrations less than 1 mg/1.

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Figure 5 - Quantum irradiance colour ratio (440 nm to 550 nm) for profiles

with less than 1 mg/1 suspended solids versus:

a) suspended solids

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d) percentage organic weight of suspended solids

- chlorophyll concentration b)
- c)
- denotes station average for concentration value +
- dissolved organic carbon

