Spatial and Seasonal Variability of Absorption Properties and Water Color Parameters in Hudson Bay

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Abstract

We present an analysis of *in-situ* bio-optical measurements collected in Hudson Bay that shows a strong spatial variability of absorption properties. A cluster analysis shows that Hudson Bay can be partitioned into coastal and offshore regions having different water color parameters signatures that could be used to better process satellite remote sensing data. Seasonal variability of optical properties is also shown to be important with higher phytoplankton biomass in the fall period.

Introduction

Hudson Bay is a large inland sea (10^6 km^2) located in central Canada. To study the impact of climate change on Hudson Bay primary production, it is necessary to use remote sensing data. However, there is a massive influx of freshwater providing Hudson Bay with estuarine characteristics. This leads to complex optical properties limiting the use of satellite ocean color data. Even though many observations have been made recently in different coastal and inland waters of the world not enough is known about the absorption spectra by all the components in optically complex waters to draw general conclusions about their variation and trends. Previous studies discussed the dissolved organic matter and chlorophyll a absorption characteristics and distribution within the Bay with limited information about seasonal variability. This study aims at improving our understanding on the complexity of Hudson Bay optical properties using *in-situ* bio-optical parameters measured both in the fall 2005 and the summer 2010. By discussing the optical parameters spatial and seasonal variability in relation to the absorption properties and classifying the water types in Hudson Bay, this study could help improve the water color estimation from remote sensing data.

Objectives

- **Determine the relationships between absorption coefficients and water color parameters (WCPs);**
- **Investigate the spatial and seasonal variability of absorption and WCPs;**
- **Classify the water types in Hudson Bay by cluster analysis.**

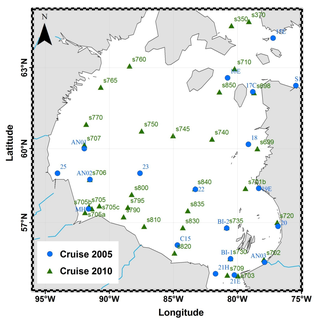

Figure 1. Study area and sampling stations.

Methods

In-situ data (surface) and measurement methods used for both cruises

Parameters	Measuring method
Chl-a (μg l^{-1})	HPLC
TSM (mg l^{-1})	Gravimetry
ISM (mg l^{-1})	Gravimetry, re-weighted after burning
OSM (mg l^{-1})	TSM – ISM
a_p (m^{-1})	Spectrophotometer using Transmittance-Reflectance (T-R) method of Tassan and Ferrari (1995, 2002)
a_d (m^{-1})	Spectrophotometer using T-R method after depigmentation.
a_{ph} (m^{-1})	$a_p - a_d$
a_g (m^{-1})	Spectrophotometer
Salinity	CTD

Important formulas and relationships

Spectral slopes of a_d: $a_d(\lambda) = a_d(\lambda_0)\exp\{-S_d(\lambda-\lambda_0)\}$ (1)

Spectral slopes of a_g: $a_g(\lambda) = a_g(\lambda_0)\exp\{-S_g(\lambda-\lambda_0)\}$ (2)

Table 1. Variability of WCPs (Chl-a in μg l^{-1}, TSM in mg l^{-1}, ISM/TSM ratio, CDOM (a_g(440)) in m^{-1}) in Hudson Bay in 2005 and 2010.

Cruise	WCPs	Mean	Max	Min	S.D.	Variation coefficient %	Number of stations
Fall 2005	Chl-a	0.616	1.480	0.160	0.355	57.6	21
	TSM	0.735	2.484	0.220	0.529	72.0	21
	ISM/TSM	0.312	0.757	0.023	0.205	65.7	15
	CDOM	0.155	0.469	0.032	0.133	85.8	21
Summer 2010	Chl-a	0.184	0.441	0.077	0.081	44.0	33
	TSM	0.546	1.841	0.118	0.349	63.9	33
	ISM/TSM	0.358	0.787	0.040	0.182	50.8	26
	CDOM	0.145	0.528	0.014	0.120	82.8	33

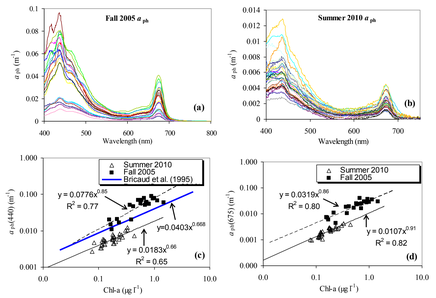

Figure 3. (a) Fall 2005 a_{ph} spectra, (b) summer 2010 a_{ph} spectra, (c) scatterplots of a_{ph}(440) vs Chl-a, and (d) scatterplots of a_{ph}(675) vs Chl-a, dashed line (2005) and solid line (2010). Note the different vertical scales for both years.

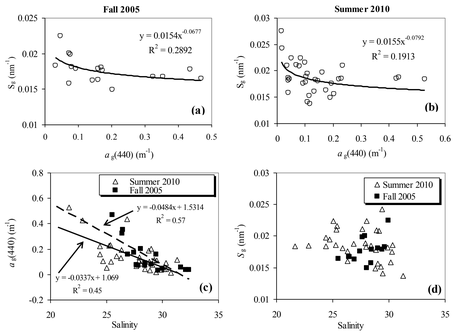

Figure 5. Scatterplots of S_g vs a_g(440) in fall 2005 (a), and in summer 2010 (b), a_g(440) vs salinity with dashed line (2005) and solid line (2010) (c), and S_g vs salinity (d) for both cruises.

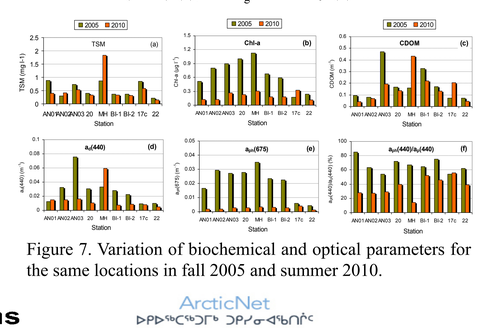

Figure 7. Variation of biochemical and optical parameters for the same locations in fall 2005 and summer 2010.

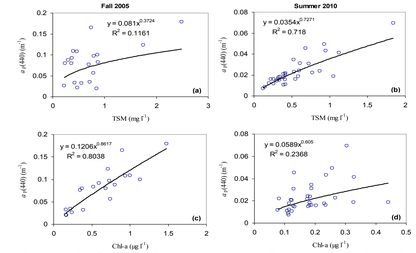

Figure 2. Scatterplots and regression results of a_p(440) vs TSM in fall 2005 (a), and in summer 2010 (b), and a_p (440) vs Chl-*a* in fall 2005 (c) and in summer 2010 (d).

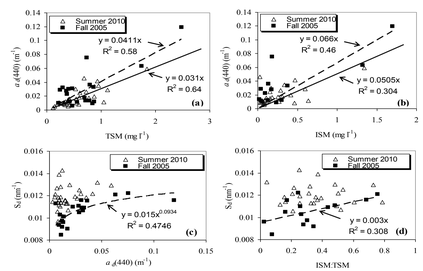

Figure 4. Scatterplots of (a) a_d(440) vs TSM, (b) a_d(440) vs ISM, (c) S_d vs a_d(440) and (d) S_d vs ISM:TSM. Dashed line (2005) and solid line (2010).

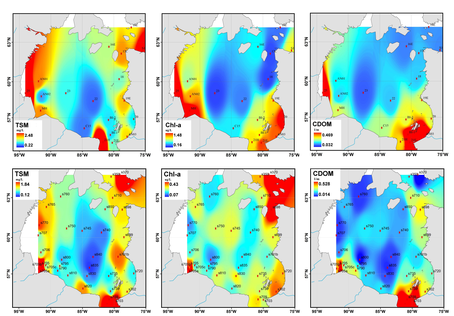

Figure 6. Contour maps of *in-situ* TSM, Chl-a and CDOM in Hudson Bay in fall 2005 (top) and summer 2010 (bottom). Note the different color bar scales.

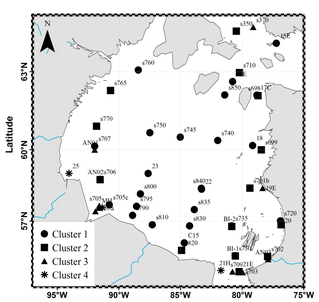

Figure 8. Clustered stations using TSM, Chl-a and CDOM.

Results

WCPs: Table 1 shows the statistical variability of water color parameters for the surface data. Chl-a and TSM concentrations are higher in fall 2005 than summer 2010, while CDOM is relatively stable between the two cruises. The small difference of the ISM:TSM ratio shows that the composition of suspended matter doesn't change much between the seasons. Significant positive correlations exist between Chl-a, TSM and CDOM (not shown).

Variation of the absorption coefficients

Total particulate absorption $a_p(\lambda)$: Fig. 2 shows that a_p(440) is more correlated with phytoplankton in the fall while it is more correlated with TSM in the summer which is consistent with the increased biomass in the fall (Table 1).

Phytoplankton absorption $a_{ph}(\lambda)$: Fig. 3 (a and b) shows that a_{ph}(λ) in the fall 2005 are much higher than that in summer 2010 which is again consistent with the higher biomass measured (Table 1). Strong power relationship exists between a_{ph}(440) or a_{ph}(675) and Chl-a (Fig. 3 c and d) but different from case 1 waters (blue line in Fig. 3c).

De-pigmented absorption $a_d(\lambda)$: Fig. 4 (a and b) shows that there are good correlations between a_d(440), TSM and ISM. Table 2 shows that there is no significant difference between the spectral slope S_d in the fall 2005 and the summer 2010 meaning particle size distribution is similar in the two seasons. S_d values were higher in near-shore than in offshore waters. Fig. 4 (c and d) shows that fall 2005 S_d has a positive relationship with a_d(440) and ISM:TSM while the relationship is not clear for summer data.

CDOM absorption $a_g(\lambda)$: There is no significant difference between the spectral slope of CDOM (S_g) for both seasons (Table 2). Most higher S_g values were located in the offshore waters. Fig. 5 (a and b) shows an inverse relationship between S_g and a_g(440) for both seasons. Fig. 5c shows that there is an inverse relationship between a_g(440) and salinity within the salinity range of 22 – 32 as often found elsewhere. However, there is no obvious correlation between S_g and salinity (Fig. 5d).

Table 2. Statistics of spectral slopes S_d and S_g in both seasons.

Cruise		Range (nm)	Data points	Max	Min	Mean value	SD	Variation coefficient %
Fall 2005	S_d	480 – 650	33	0.0143	0.0097	0.0118	0.0008	6.8
	S_g	350 – 500	33	0.0276	0.0137	0.0188	0.0029	15.4
Sum. 2010	S_d	480 – 650	20	0.0122	0.0085	0.0105	0.0011	10.5
	S_g	350 – 500	20	0.0225	0.0115	0.0172	0.0021	12.2

Table 3. Mean bio-optical properties for waters in cluster analysis group I and group II. Properties are for the summer 2010 surface observations.

Group	Chl-a	TSM	CDOM	a_d(440)	a_{ph}(675)	Comments
I	0.15	0.30	0.10	0.01	0.002	Offshore waters
II	0.25	0.80	0.20	0.03	0.003	Coastal waters

Spatial and seasonal variation: Fig. 6 shows the contour maps of the three WCPs generated using Kriging for both seasons. Despite differences in magnitude, similar patterns are observed with higher concentrations in near shore waters. Fig.7 provides the comparisons between TSM, Chl-a, CDOM, a_p(440), a_{ph}(675) and a_{ph}(440):a_p(440) for nine stations sampled in both seasons. With a few exceptions, measured values are higher in the fall than in summer, especially for Chl-a and a_{ph}(675).

Cluster analysis: A classification was performed using hierarchical cluster analysis (squared Euclidean distance as similarity measure and average linkage method) using all available data of TSM, Chl-a and CDOM. Fig. 8 shows the spatial distribution of the stations in each of the four major clusters. These four clusters can be aggregated into two major groups with group I containing the stations from cluster 1 and group II is the integration of cluster 2, 3 and 4. Table 3 shows the statistical data of each group for the summer 2010. Applications of ocean color remote sensing are usually problematic in the waters of group II.

Conclusions

Using data gathered during summer and fall, we were able to describe the spatial and seasonal variability of absorption properties and water color parameters in the surface layer of Hudson Bay. Results showed that:

1) Even though the spatial distribution of WCPs was similar for both seasons, concentrations are higher in the fall than in the summer, especially Chl-a. A possible mechanism to explain this is an increased mixing due to stronger winds.

2) The increased phytoplankton biomass in the fall lead to phytoplankton pigments contributing more to particulate absorption than inorganic particles while the inverse happens in the summer. Phytoplankton absorption is always strongly coupled to Chl-a concentrations although differently than in other coastal regions. The slope of the exponential function describing a_d(λ) and a_g(λ) shows little variability for both seasons.

3) The stations were divided into two major groups by cluster analysis based on the *in-situ* WCP. More optically complex waters are confined to a relatively narrow band along the coast meaning that remote sensing data can be used with a higher degree of confidence in the rest of the bay.

These preliminary results helped us understand the basic optical properties of Hudson Bay so that we can now better use remote sensing data for climate studies. Future work will now focus on the vertical variability of the bio-optical properties, determination of the spectral signatures of both coastal and offshore waters using satellite data, and exploration of the source of increased phytoplankton biomass in the fall.

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