Satellite remote sensing of phytoplankton pigment distribution in the U.S. northeast coast

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Introduction

- Not only chlorophyll a (Chl_a) but also other phytoplankton pigments play an important role in primary production.
- The pigment constituents, including chlorophyll group (Chl_a, Chl_b, Chl_c), photosynthetic carotenoids (PSC) like fucoxanthin (Fuco), peridin (Perid), and a-carotene (Caro), and photoprective carotenoids (PPC) like alloxanthin (Allo), diadinoxanthin and diatoxanthin (Dia), and zeaxanthin (Zea), vary significantly with season and region in coastal waters due to shifts in abundance of phytoplankton species and light levels.
- In coastal waters, the complicated atmospheric and water conditions such as strong riverine discharge and sedimentary resuspension make it more difficult to develop pigment algorithms from ocean color remote sensing reflectance (R_{rs}).
- Objectives: 1) to develop regional algorithms for phytoplankton pigments;
  2) to validate with SeaWiFS and MODIS-Aqua observations;
  3) to study seasonal and regional variation of pigment distributions that can be related to phytoplankton biodiversity.

Study region and field expeditions

- U. S. northeast coast from Gulf of Maine (GoM) to the Chesapeake Bay Estuary:
  Bio-physical Interactions in Ocean Margin Ecosystems (BIOME 1-4; 2005 - 2006);
  Chesapeake Bay Plume Experiments (CBP 2 - 4; 2005 - 2006);
  Chesapeake Bay Hydrological Survey (CBH; 2004 - 2006);
  Gulf of Maine cruises (GoM 1-4; 2007);
  Ocean Color Validation experiments in Hudson River Estuary (OCV 1-3; 2007-2008).

Empirical algorithms

$$\log[Pigment] = A_0 + A_1 X + A_2 X^2 \qquad (1)$$

Here $X = \log[Rrs(\lambda_1)/Rrs(\lambda_2)]$, and Ai were derived coefficients for each pigment. The selected λ_1 and λ_2 were 490, 5110, 555, or 670 nm for SeaWiFS, and 488, 532, 551, or 667 nm for MODIS-Aqua.

Results and Discussion

- Since diatoms are generally the dominant species in this coastal region, algorithms developed for pigments rich in diatoms (e.g. Chl_a, Chl_c, and Fuco) are typically more robust than other pigments (Fig. 1 and Table 1).
- Complex circulation, such as ebb recirculation in the Hudson River Estuary, may generate relatively low CDOM but high pigment condition (LCHP) as observed in OCV2 (November 2007) cruise (Fig. 1 and Table 1).
- As the biomarker pigment for cyanobacteria, which seldom bloom in relatively cold water (e.g. T_w<15°C),algorithms for Zea are very different for relatively warm (Tw>20°C) and cold (Tw<15°C) water mass (Fig. 1 and Table 1).
- The match-up validations to satellite observations showed reasonable agreement for our pigment algorithms (Fig. 2 and Table 2). Higher deviations were found for MODIS match-ups due to limited data points (N=10 for +/- 3 hour overpass window) and higher portion of data (N=5) from the bay mouth region.
- The application of our algorithms showed reasonable seasonal and regional distribution of pigments from satellite observations (Fig. 3). For example, winter-spring bloom of diatoms as indicated by Chl_a and Fuco distribution is obvious. The significant disappearance of dinoflagellate bloom as indicated by Perid distribution in GoM from May to August, and significant increase of cyanobacteria as indicated by Zea distribution in the summer, are also clearly shown.
- The knowledge of phytoplankton pigment distribution may improve our understanding of algal community composition, water quality, and carbon flux.

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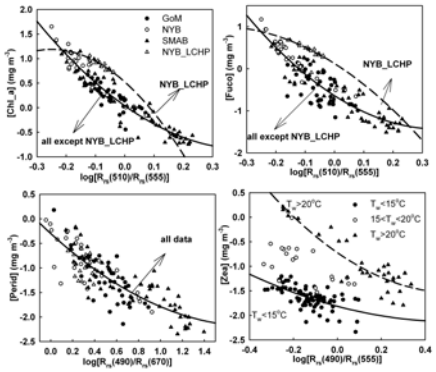

Figure 1. Examples of phytoplankton pigment algorithms derived from field measurements of Rrs band ratios. The data sampled in New York Bight (NYB) during November 2007 was separated from other data set for pigments like Chl_a and Fuco.

Table 1. Derived coefficients for pigment algorithms from equation (1) based on the selected wavelengths (λ_1/λ_2). In the upper section, stations sampled in the Hudson River Estuary during November 2007 (OCV2) were not included for analysis for pigments such as Chl_a, Chl_c, Caro, and Fuco.

		SeaWiFS					MODIS-Aqua				
Pigment	N	λ_1/λ_2	A_0	A_1	A_2	r^2	λ_1/λ_2	A_0	A_1	A_2	r^2
Chl_a	124	510/555	0.0394	-4.229	5.012	0.902	488/551	-0.0444	-3.028	3.422	0.883
Chl_b	139	490/555	-1.120	-2.734	-0.2896	0.717	488/551	-1.129	-2.803	-0.2031	0.714
Chl_c	124	510/555	-0.7466	-3.876	3.813	0.833	532/551	-0.6336	-8.570	13.47	0.819
Caro	124	490/555	-1.363	-2.568	4.289	0.870	488/551	-1.378	-2.615	4.713	0.864
Allo	139	490/670	-0.0154	-1.968	-0.1345	0.802	488/667	-0.0355	-1.749	-0.2806	0.789
Fuco	124	510/555	-0.6413	-4.474	6.306	0.810	532/551	-0.5088	-10.08	24.15	0.799
Perid	139	490/670	-0.2986	-2.038	0.5481	0.710	488/667	-0.2852	-1.971	0.4893	0.709
Dia	139	510/555	-0.9048	-3.702	3.791	0.758	532/551	-0.8278	-8.206	18.64	0.766
Zea (T_w<15)	77	490/555	-1.815	-1.188	1.119	0.401	488/551	-1.821	-1.145	1.655	0.408
Zea (T_w>20)	33	490/555	-0.7234	-3.095	2.926	0.824	488/551	-0.733	-3.131	3.074	0.820
Lut (T_w<15)	77	490/555	-2.200	-1.170	3.041	0.348	488/551	-2.206	-1.150	3.524	0.349
Lut (T_w>20)	33	490/555	-2.014	-3.319	1.246	0.806	488/551	-2.003	-3.381	0.7897	0.813
Neo	139	490/555	-2.023	-2.455	1.943	0.742	488/551	-2.030	-2.514	2.098	0.738
Viola	139	490/555	-1.978	-2.176	2.772	0.655	488/551	-1.986	-2.225	2.991	0.650
Hudson River Estuary under the condition of Low CDOM High Pigment (LCHP)											
Chl_a	15	490/555	0.5292	-3.575	-4.172	0.912	488/551	0.5314	-3.822	-4.886	0.915
Chl_c	15	490/555	-0.2123	-2.815	-1.647	0.887	488/551	-0.2087	-2.988	-1.935	0.886
Caro	15	490/555	-1.018	-3.725	-5.802	0.844	488/551	-1.014	-3.927	-6.471	0.850
Fuco	15	490/555	0.1337	-2.843	-1.189	0.923	488/551	0.1353	-3.055	-1.569	0.923

Table 2. Statistical results for satellite validation. The slope, y-intercept (y-int.), and r2 were based on the linear regression (Model II) of log-transformed field and satellite-estimated pigments.

	±3 hours					±8 hours				
Pigment	MAPD (SD)	RMSE	Slope	y-int.	r^2	MAPD (SD)	RMSE	Slope	y-int.	r^2
SeaWiFS (N=19 and 34 for ±3 and 8 hours overpass windows, respectively)										
Chl_a	29.0 (19.9)	0.202	0.791	-0.076	0.949	33.0 (20.9)	0.241	0.825	-0.125	0.883
Chl_b	38.6 (19.3)	0.261	0.880	-0.297	0.841	45.6 (27.5)	0.333	0.931	-0.289	0.630
Chl_c	34.8 (15.4)	0.214	0.800	-0.260	0.938	38.3 (18.3)	0.266	0.835	-0.293	0.862
Caro	29.7 (22.0)	0.235	0.769	-0.376	0.874	32.8 (20.9)	0.244	0.817	-0.364	0.844
Allo	44.0 (34.7)	0.435	1.432	0.290	0.560	54.7 (38.3)	0.570	1.810	0.594	0.392
Fuco	40.8 (22.1)	0.311	0.713	-0.317	0.958	42.1 (20.9)	0.311	0.723	-0.331	0.918
Perid	36.6 (35.3)	0.204	0.796	-0.288	0.816	42.4 (33.1)	0.293	0.796	-0.391	0.677
Dia	30.7 (18.5)	0.208	0.948	-0.204	0.907	33.1 (21.5)	0.251	0.921	-0.243	0.814
Zea	60.6 (43.4)	0.408	1.315	0.169	0.645	65.6 (45.2)	0.474	1.400	0.223	0.563
Lut	30.9 (18.1)	0.174	0.926	-0.217	0.828	45.3 (43.2)	0.230	0.861	-0.330	0.637
Neo	38.0 (23.6)	0.260	0.844	-0.439	0.778	42.1 (24.8)	0.329	0.832	-0.530	0.636
Viola	39.9 (22.0)	0.271	0.775	-0.552	0.745	42.0 (20.8)	0.302	0.830	-0.514	0.659
MODIS-Aqua (N=10 and 17 for ±3 and 8 hours overpass windows, respectively)										
Chl_a	47.3 (20.3)	0.362	0.632	-0.133	0.894	40.5 (21.6)	0.312	0.666	-0.123	0.893
Chl_b	51.8 (20.5)	0.394	0.733	-0.533	0.735	47.5 (20.9)	0.357	0.736	-0.499	0.771
Chl_c	58.6 (21.2)	0.543	0.460	-0.646	0.663	51.6 (24.9)	0.470	0.499	-0.590	0.731
Caro	44.3 (16.9)	0.297	0.622	-0.605	0.850	39.4 (19.5)	0.269	0.656	-0.549	0.899
Allo	39.5 (26.1)	0.379	1.135	-0.111	0.716	45.2 (26.8)	0.427	1.491	0.295	0.651
Fuco	64.3 (23.5)	0.659	0.441	-0.638	0.729	60.6 (23.1)	0.586	0.435	-0.586	0.769
Perid	42.6 (41.6)	0.250	0.669	-0.444	0.735	42.2 (37.0)	0.244	0.725	-0.395	0.822
Dia	55.2 (12.9)	0.393	0.684	-0.563	0.727	46.6 (16.1)	0.329	0.667	-0.513	0.771
Zea	54.2 (27.0)	0.488	3.002	2.070	0.045	60.1 (25.8)	0.546	1.542	0.194	0.485
Lut	36.5 (20.0)	0.285	0.546	-1.066	0.529	36.8 (20.9)	0.281	0.448	-1.241	0.551
Neo	52.6 (19.3)	0.389	0.655	-0.890	0.810	48.3 (19.4)	0.354	0.674	-0.826	0.776
Viola	49.7 (19.3)	0.359	0.520	-1.042	0.729	47.7 (16.0)	0.328	0.643	-0.844	0.792

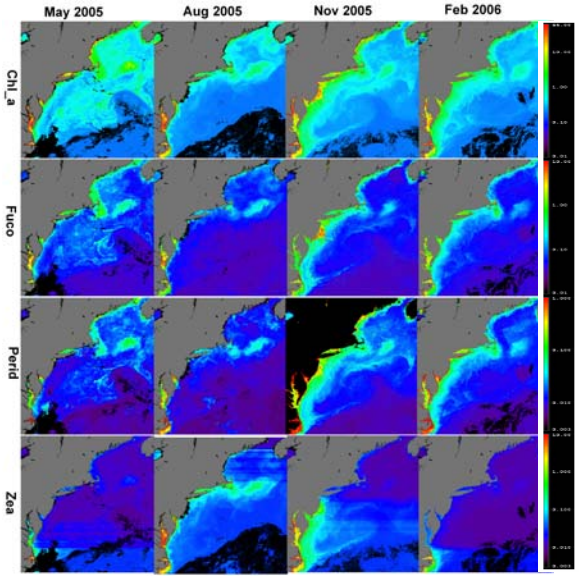

Figure 3. Examples of the distribution of phytoplankton pigments derived from MODIS-Aqua images. Each image represents an 8-day average for Julian days of 133-140 (May 2005), 213-220 (Aug 2005), 302-309 (Nov 2005), and 041-048 (Feb 2006). Latitude: 35 to 45 °N; Longitude: -77 to -65 °W.

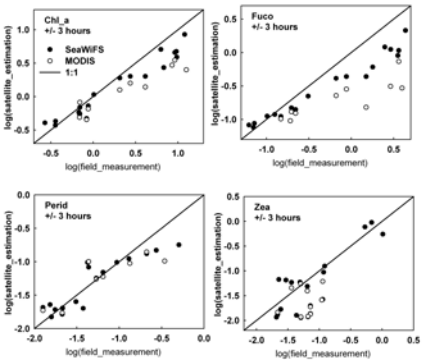

Figure 2. Examples of the comparisons between satellite-derived pigments and field measurements. The match-up procedure is limited to +/- 3 hours between satellite overpass and field measurements.