Chapter 15

Plumes and Blooms: Modeling the Case II Waters of the Santa Barbara Channel

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15.1 INTRODUCTION

The goal of the Plumes and Blooms (PnB) project is to develop, validate and apply to imagery state-of-the-art ocean color algorithms for quantifying sediment *plumes* and phytoplankton *blooms* for the Case II environment of the Santa Barbara Channel. We conduct monthly to twice-monthly transect observations across the Santa Barbara Channel to develop an algorithm development and product validation data set. The PnB field program started in the summer of 1996. At each of the 7 PnB stations, a complete verification bio-geo-optical data set is collected. Included are redundant measures of apparent optical properties (remote sensing reflectance and diffuse attenuation spectra), as well as *in situ* profiles of spectral absorption, beam attenuation and backscattering coefficients. Water samples are analyzed for component *in vivo* absorption spectra, fluorometric chlorophyll, phytoplankton pigment (by the SDSU CHORS laboratory), and inorganic nutrient concentrations (Table 15.1). A primary goal is to use the PnB field data set to objectively tune semi-analytical models of ocean color for this site and apply them using available satellite imagery (SeaWiFS and MODIS). In support of this goal, we have also been addressing SeaWiFS ocean color and AVHRR SST imagery (Otero and Siegel, 2003). We also are using the PnB data set to address time/space variability of water masses in the Santa Barbara Channel and its relationship to the 1997/1998 El Niño. However, the comparison between PnB field observations and satellite estimates of primary products has been disappointing. We find that field estimates of water-leaving radiance, $L_{wN}(\lambda)$, correspond poorly to satellite estimates for both SeaWiFS and MODIS local area coverage imagery. We believe this is due to poor atmospheric correction due to complex mixtures of aerosol types found in these near-coastal regions. Last, we remain active in outreach activities.

15.2 RESEARCH ACTIVITIES

We have conducted 12 one-day cruises since November 2002 and anticipate conducting two more before the end of the contract. To date combination, we have completed 70 stations (up to 14 more by the end of the project) comprised of CTD/rosette casts, spectroradiometer profiles and in situ IOP determinations (AC9 & hydroscat). All available processed data has been submitted to the SeaBASS system and we will complete this task by November 1, 2003.

In January of 2003, the Channel Islands National Marine Sanctuary (CINMS) received delivery of its new research vessel, the *R/V Shearwater*. This finally has given us consistent platform to work from since the loss of the *R/V Ballena* in 2001. However, it hasn't come easy. We have experienced several aborted cruises early this year due to "new ship issues". This has been frustrating but we are now finally over the top. We have worked with CINMS and NOAA/NOS staff throughout this process and I think we finally have a stable field observation configuration for PnB cruises. We have continued our acquisition and analysis of satellite ocean color (SeaWiFS) and thermal imagery (AVHRR) from the UCSB HRPT ground station (HUSC). The UCSB ground station presently supported by SIMBIOS and NOAA/NESDIS.

The PnB project has an extensive education and outreach component. Typically, two undergraduate students volunteer on each one day cruise and the PnB data is presently being used in the theses and dissertations of three graduate students at UCSB. We also participated in the California Fish & Game workshops on monitoring the status of no-take marine protected areas around the CINMS. Satellite and field data supported by SIMBIOS are being used in this public process.

Table 15.1: Plumes and blooms measurements and data products

Direct Measurements:	
$E_d(z,\lambda)$	Downwelling vector irradiance (325, 340, 380, 412, 443, 490, 510, 555, 565, 665 & 683 nm)
$E_d(0^+,\lambda)$	Incident irradiance (325, 340, 380, 412, 443, 490, 510, 555, 565, 665, 683 & 350-1050 nm)
$L_u(z,\lambda)$	Upwelling radiance (325, 340, 380, 412, 443, 490, 510, 555, 565, 665 & 683 nm)
$a(z,\lambda)$	*In situ* absorption spectrum using WetLabs AC-9 (410,440,490,520,565,650,676 & 715 nm)
$c(z,\lambda)$	*In situ* beam attenuation spectrum (same as above)
$b_b(z,\lambda)$	*In situ* backscattering spectrum - HOBI Hydroscat (442,470,510,532, 590 & 671 nm)
$T(z)$ & $S(z)$	SeaBird temperature and conductivity probes
$a_p(z_o,\lambda)$	*In vivo* particulate absorption spectrum by Mitchell (1990)
$a_{det}(z_o,\lambda)$	*In vivo* detrital particle absorption spectrum by MeOH extraction
$a_g(z_o,\lambda)$	*In vivo* colored dissolved absorption spectrum
chl-a(z_o)	Discrete chlorophyll *a* determinations by Turner fluorometry
pigs(z_o)	Discrete phytoplankton pigment sample to be run by HPLC (SDSU CHORS analysis)
nuts(z_o)	Discrete inorganic nutrient concentrations (NO_3, SiO_4, PO_4, NO_2)
$L_{sat}(x,y,\lambda)$	SeaWiFS and AVHRR imagery from the HUSC ground station
Primary Derived Products:	
$R_{rs}(0^-,\lambda)$	In-water remote sensing reflectance from profiling radiometry (see above)
$L_{wN}(\lambda)$	Normalized water leaving radiance calculated from $R_{RS}(0^+,\lambda)$ and $R_{RS}(0^-,\lambda)$
$a_{ph}(z_o,\lambda)$	*In vivo* phytoplankton absorption spectrum (= $a_p(z_o,\lambda)$ - $a_{det}(z_o,\lambda)$)
$K_d(z,\lambda)$	Attenuation coefficient for $E_d(z,\lambda)$ from profiling radiometry (also $K_L(z,\lambda)$)
$b(z,\lambda)$	*In situ* total scattering spectrum (= $c(z,\lambda)$ - $a(z,\lambda)$)
Chl(x,y), etc.	Processed SeaWiFS and AVHRR imagery

15.3 RESEARCH RESULTS

Academic research has gone along two major fronts; 1) the validation and development of satellite data products using the PnB data set (Siegel et al. 2002; 2003a; Otero and Siegel, 2003; Warrick et al. 2003a) and 2) the analyses of field and satellite data to assessment of the time/space variability in the Santa Barbara Channel (Shipe et al. 2002; Siegel et al. 2003b; Otero and Siegel, 2003; Warrick et al. 2003b; 2003c). We have used the PnB data set extensively in validation and development of satellite data products. This includes work related to development and application of global algorithms (Maritorena et al. 2002; Siegel et al. 2002; 2003c) and at the local scale (Warrick et al. 2003a). In particular, we have developed a simple mixing model to estimate suspended sediment concentrations for the Santa Clara River outflow plume (Warrick et al. 2003a). Jon Warrick, a recent PhD graduate from our group, has applied this algorithm to SeaWiFS imagery to examine the fate of river-borne sediment concentrations as they enter the Santa Barbara Channel (Mertes and Warrick, 2001; Warrick et al. 2003b; 2003c). We are still in progress in developing a regional semi-analytical model for this site (following Maritorena et al. 2002) and a new graduate student researcher (Tihomir Kostadinov) has taken this on as his Masters project.

Unfortunately, the hard part about building detailed predictive models of Case II ocean color variability is that matchups between satellite and in situ observations of water-leaving radiance, $L_{wN}(\lambda)$, are often poor and this suggests that significant improvements are required in the assumptions used to drive the atmospheric correction procedure (Siegel et al. 2003a). For example, figure 1 shows that both MODIS and SeaWiFS often, though not always, dramatically underestimate $L_{wN}(\lambda)$, particularly for the violet to blue wavebands. It is premature to make more definitive statements of the comparisons between the two satellite sensors due to the comparatively fewer number of matchup observations found using MODIS (29 as compared with as many as 314 found for SeaWiFS were available when this work was performed). However, these discrepancies are not due to problems with the field data as the satellite retrieved $L_{wN}(412)$ and $L_{wN}(443)$ values shown are much lower than typical values expected (Siegel et al. 2003a). The fact that the retrievals sometimes work and sometimes do not suggests that issues with the satellite's radiometric calibration are also not at fault either. That is, there is no obvious trending the discrepancy with the field observed $L_{wN}(412)$ and $L_{wN}(443)$ values as one would expect with for a static calibration error arising from the difference between two large numbers (measured and modeled top of the atmosphere radiance). Both sensors do a fair job (though clearly not spectacular) predicting $L_{wN}(555)$ and chlorophyll concentrations (r^2 = 0.50 [$L_{wN}(555)$)] & 0.56 [Chl] for SeaWiFS and r^2 = 0.68 & 0.62 for MODIS for the same quantities). This reasonable success gives some confidence in the scientific application of these data to near-coastal regions (see also Otero and Siegel, 2003).

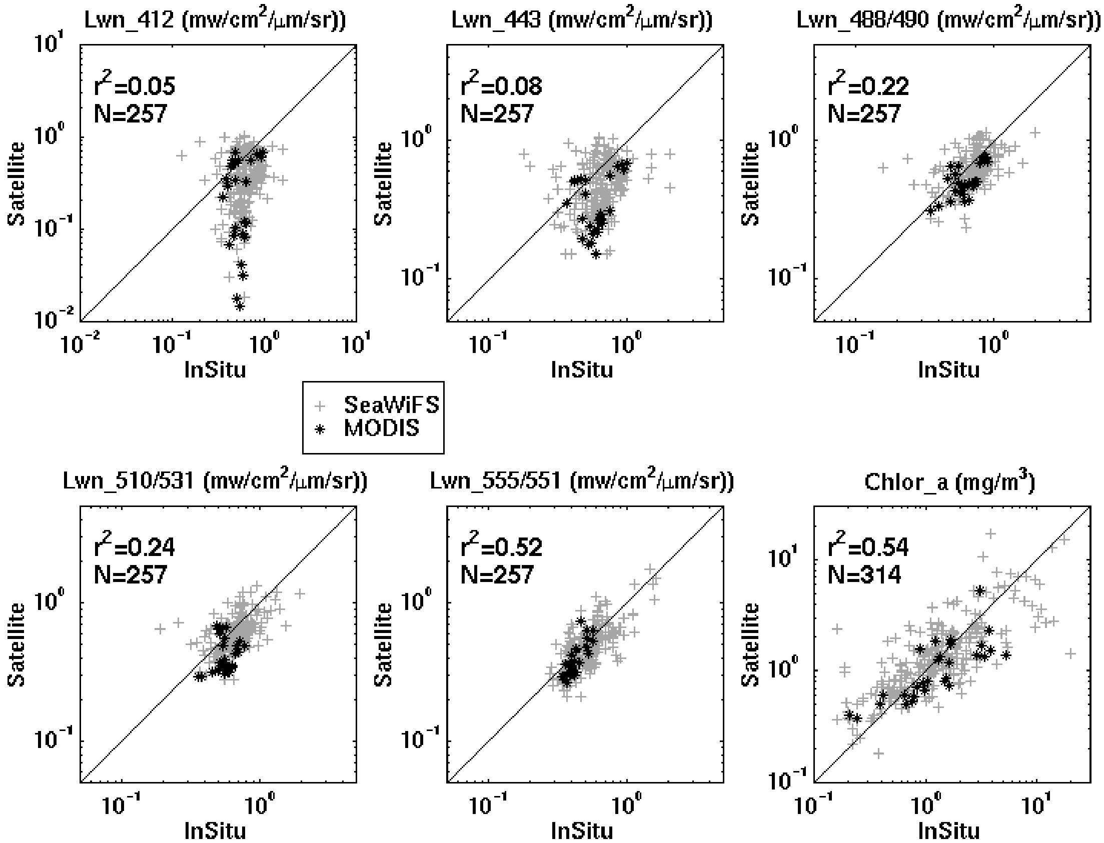

Figure 15.1: Matchup comparisons of satellite vs. field observations for normalized water-leaving radiance and chlorophyll a concentration for both SeaWiFS (+) and MODIS (*). Only MODIS data from Terra are shown and all data pass the quality zero flag. The OC3M chlorophyll estimate for MODIS is shown as there are 29 retrievals with this algorithm vs. 13 available from the MODIS semi-analytical algorithm (failures in the chl_a3 MODIS data product are quality flagged).

This simple matchup analysis suggests that substantial improvements are needed in the procedures used to correct satellite radiance for the complicating effects of the atmosphere. This may be true for global ocean retrievals, but it will be particularly acute for the coastal zone where state-of-the-art ocean color algorithms cannot be used due to the poor performance of present atmospheric correction procedures. We believe these difficulties are algorithmic (due to processing procedures and codes) and NOT to inadequacies in the field observations or in the radiometric calibration of satellite observations. Present techniques used by both SeaWiFS and MODIS to correct for the effects of the atmosphere are based on the initial framework of Gordon and Wang [1994] (see also Gordon and Voss, 1999). The Gordon and Wang (1994) algorithm uses spectral bands in the near infrared (NIR) to assess the aerosol's contribution to the reflectance in the visible. This approach is applicable only for a non- or weakly-absorbing aerosol (Gordon, 1997). When the aerosol is strongly absorbing, associated with soot, pollution, biomass burning, pollen or dust aerosols, the NIR reflectance provides no clue to the path radiance that an atmospheric correction algorithm must correct for. This means that the two-step atmospheric correction process implemented in the retrieval of MODIS ocean color products will fail in the presence of strongly absorbing aerosols. The advantage of the spectral mixing approach of Warrick et al. [2003a] is that anomalies in the atmospheric path radiance due to complex aerosol distributions can be treated in an ad hoc manner enabling the sediment signal to be quantified. Semi-analytical methods (such as Maritorena et al. 2002) will NOT perform well under these conditions. We have ideas (in pending proposals!!) to develop novel correction procedures that simultaneously account for complex atmosphere and ocean interactions following approaches outline by Chomko et al. [2003].

We have continued our analyses of oceanographic processes using the six-year PnB observational record. Of continuing interest is our work assessing the sources and modes of ocean color variability within the Santa Barbara Channel (Toole and Siegel, 2001; Siegel et al. 2003b). The characterization of the substances, processes, and mechanisms that regulate coastal ocean color variability is crucial for the application of ocean color imagery to the management of marine resources. Using an empirical orthogonal function (EOF) analysis, we find that nearly two-thirds of the observed variability in remote sensing reflectance is contained in a backscattering mode. Phytoplankton absorption makes a much smaller contribution to the observed variance in the water-leaving radiance spectrum. Hence, particulate backscattering associated with suspended sediment concentrations is the dominant driver of ocean color variability for this environment. However, sediment plumes appear to play a much smaller role on biological processes. An empirical partitioning of physical, biological and chemical oceanographic parameters suggests that physical oceanographic processes (i.e., upwelling and horizontal advection) have the dominant role in determining phytoplankton pigment biomass for this region. One goal is to use these spectral EOF modes with satellite data to map out where and when blooms occur. Using EOF analysis of the space/time patterns of satellite ocean color imagery, we find a similar partitioning (Otero and Siegel, 2003). This work attempts to differentiate between the role of local (wind-driven upwelling and seasonal heating) vs. non-local (i.e., advection and ENSO) processes in regulating biological distributions in the Santa Barbara Channel (Otero and Siegel, 2003). A similar analysis is looking at the water quality measurements (nutrients, chlorophyll and optical properties, etc.) to address how physical processes are regulating optical variability in the Santa Barbara Channel (Siegel et al. 2003b). Further, a new graduate student supported by the Santa Barbara Coastal-LTER program, Clarissa Anderson, is working with the HPLC pigment data set to look at phytoplankton succession processes and their control by physical oceanographic proceses (Anderson et al. 2003).

On a last technical note, throughout the PnB time series we have noticed that our observations of the specific absorption of phytoplankton at 676 nm [$a^*_{ph}(676)$] often exceed the theoretical maximum of 0.0206 $m^2.mg^{-1}$. We now know that the reason for this overestimate was the use of previously published pathlength amplification factors (β) suggested by Mitchell (1990) from experiments using mixed phytoplankton cultures. To assess this source of bias, we conducted a set of experiments to test the relationship between the optical density in suspension (OD_s) and the optical density of the same sample on a GF/F filter (OD_f) of natural samples from PnB waters enabling us to determine our own β factor for our own spectrophotometer (Guillocheau, 2003). We conducted three independent determinations of the β factor which were consistent with each other (within a factor of 10%). However, the composite PnB β factor is a factor of 1.7 times lower than the Mitchell (1990) coefficients. Procedures used are documented in Guillocheau [2003]. We subsequently corrected all of our filter-pad absorption data and have submitted these to the SeaBASS data set.

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This Research was Supported by the NASA Contract # 00201

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