Coupling Simulated Ocean Reflectance to the Atmospheric Correction of Hyperspectral Images

W. Paul Bissett
Florida Environmental Research Institute
4807 Bayshore Blvd.
Suite 101
Tampa, FL 33611

Award Number: N00014-00-1-0514

phone: (813) 837-3374 x102   fax: (813) 902-9758 email: pbissett@flenvironmental.org

http://www.flenvironmental.org

LONG-TERM GOALS

Aircraft and satellite Remote Sensing (RS) platforms provide spatial and temporal coverage of oceanic water conditions that are unobtainable by any other cost effective means. The hope of HyperSpectral Imagery (HSI) data is that it will provide the necessary data stream to simultaneously describe the atmospheric and water column optical properties. The goal of these hyperspectral programs is to develop the instruments, platforms, and data analysis techniques to achieve the depth-dependent description of atmospheric and water column Inherent Optical Properties (IOPs).

OBJECTIVES

1) Collection of HSI data on the West Florida Shelf (WFS) and New Jersey Bight (NJB). Process data and make it available to HyCODE team members.

2) Calibration of Ocean PHILLS-2 data.

3) Begin atmospheric data correction of HSI data.

4) Research the feasibility of placing a hyperspectral imager on a High Altitude/Long Endurance (HALE) Unmanned Aerial Vehicle (UAV).

APPROACH

Traditional optical RS algorithms for ocean color products have used empirical formulations between water-leaving radiance, $L_w(\lambda)$, and proxies for phytoplankton, e.g. chlorophyll (Gordon et al., 1983), or Apparent Optical Properties (AOPs), e.g. diffuse attenuation coefficients (Austin and Petzold, 1981), for depth-integrated data products. These algorithms use a limited number of radiance bands, and are generally limited to water conditions where the data was collected to derive the empirical relationships. HSI data provides continuous information across the visible spectrum, and as such, provides a far larger number of degrees of freedom by which to derive data products. This larger number of degrees of freedom allows for numerical techniques, such as spectral matching and linear optimization schemes (Arnone and Gould, 1998), which may provide depth-dependent water column IOP information.

Report Documentation Page	Form Approved OMB No. 0704-0188

1. REPORT DATE **30 SEP 2003**	2. REPORT TYPE	3. DATES COVERED **00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE **Coupling Simulated Ocean Reflectance to the Atmospheric Correction of Hyperspectral Images**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Environmental Research Institute,,4807 Bayshore Blvd.,Suite 101,,Tampa,,FL, 33611**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Aircraft and satellite Remote Sensing (RS) platforms provide spatial and temporal coverage of oceanic water conditions that are unobtainable by any other cost effective means. The hope of HyperSpectral Imagery (HSI) data is that it will provide the necessary data stream to simultaneously describe the atmospheric and water column optical properties. The goal of these hyperspectral programs is to develop the instruments, platforms, and data analysis techniques to achieve the depth-dependent description of atmospheric and water column Inherent Optical Properties (IOPs).

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**11**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Unfortunately, these types of numerical schemes require a "first-guess", or some other means to constrain their solution, requiring either in situ measurements or another methodology of providing this information. We hypothesize that simulated IOPs from nowcast/forecast systems could provide this constraining data stream, and allow for the development of true hyperspectral ocean color algorithms that use the entire collected spectra.

In addition, atmospheric correction of the HSI data has difficulty delineating blue absorbing aerosols from the water-leaving radiance signal, as most correction schemes only use the visible red or near-infrared data to remove atmospheric effects from the data. The obvious solution is to use blue wavelengths in the correction algorithms; unfortunately, these are impacted by the water signal. Schemes to use the blue signal are being developed (H. Gordon, RSMAS) but rely upon simple phytoplankton chlorophyll models to address the water-leaving radiance signal. Prediction of the water-leaving signal from a nowcast/forecast system would appear to offer advantages over simplified chlorophyll models in coastal regions where the optical signal may not co-vary with chlorophyll.

The pursuit of these goals requires that we collect the RS data at sites where we are building nowcast/forecast systems. There are two sites as part of ONR's Hyperspectral Coastal Ocean Dynamics Experiment (HyCODE), off the coast of New Jersey at the Rutgers University Long-Term Ecological Observatory at 15 meters (LEO-15) and the West Florida Shelf. Readers are directed to the HyCODE web site (http://www.opl.ucsb.edu/hycode.html) for further information on this program. The instrument development, calibration, and data analysis are being accomplished in collaboration with C. Davis at the Naval Research Laboratory (Award N0001400-WX-2-0690).

WORK COMPLETED and RESULTS

With regards to the July 2001 PHILLS II data collect in support of the LEO HyCODE experiment, our focus over the last year can be broken in to three parts: calibration, atmospheric correction, and distribution. As have been outlined last year in our annual ONR report, we have encountered numerous flaws when calibrating this data set. These complications have impeded the efficiency in which we have been able to distribute the data sets. The continuation of systematically addressing these errors has been the focus of this year's efforts (Kohler et al., 2002).

One of the major concerns addressed last year was the effects of stray light within the sensor (see FY2002). We had developed a system of laboratory measurements that utilized a series of filters in order to characterize the amount of stray light present within the PHILLS II instrument. The result of this procedure was a probability distribution function that described the required redistribution of photons to address the stray light issue. Although this procedure produced admirable results, it was a long, tedious, subjective process. To address this, we have put in the effort to develop an objective, automated procedure that will not only quickly create the probability distribution, but also fully automate the entire calibration process. Not only does this save time, but it eliminates much of the possibility of human induced errors corrupting the calibration.

In the process of automating the calibration, we also developed a procedure that characterized the spectral smile of the instrument (see Figure 1 and 2). The spectral shift map determined by this procedure is used to warp all laboratory and field data captured by the instrument to a standard wavelength vector. The standardizing of the PHILLS' wavelength vector has proven valuable when applying the TAFKAA model (Gao et al., 2000; Montes et al., 2001), NRL's atmospheric correction

program. This has resulted in a reduction in both the degree and occurrences of PHILLS – TAFKA spectral mismatches.
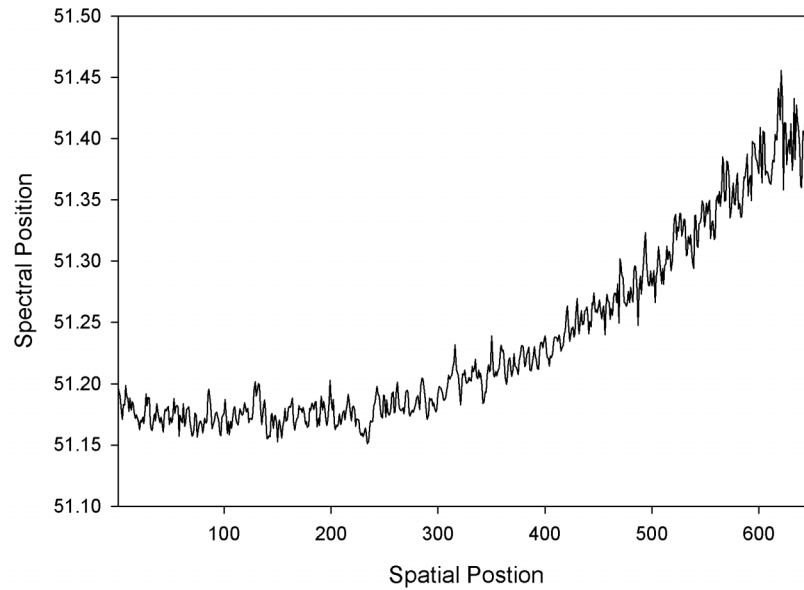

Figure 1: The observed PHILLS II spectral position of a 0.6328 micrometer laser across the full spatial range of the CCD. Note that one spectral position is approximately 4.6 nanometers.
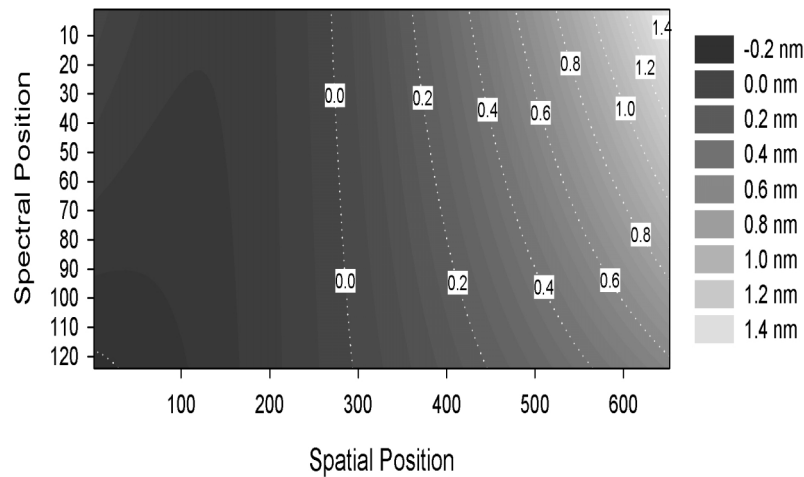

Figure 2: A spectral smile map of the CCD illustrates the difference in nanometers between the spectral regression per spatial position and spectral regression at spatial position 280.

Proper atmospheric correction is crucial to the usefulness of remotely sensed data. It is especially critical over the relatively dark ocean and coastal scenes. The atmosphere can account from 80-100% of the retrieved signal in these areas(Morel, 1980), and thus, inaccuracies in the removal of the

atmosphere can have dramatic impacts on the final product. We have made major strides in the correction of the July 2001 LEO data; however, it still remains an area of active research.

One of the issues relating to TAFKAA, outlined in the FY 2002 report was TAFKAA's limited ability to handle changing sensor and solar geometries over a flight line. Due to the length and subsequent time needed to cover a flight line by the PHILLS II at the LEO study site, this became an issue. Collaborations with Marcos Montes (NRL-DC) helped outline the issue and led to the release of an improved version of TAFKAA in early 2003.

One of the attractive features of TAFKAA model is its ability to automatically select parameters based upon the scene itself. It accomplishes this by using the "black pixel" assumption (Siegel et al., 2000). The assumption states that passive optical returns in the infrared section of the spectrum should be due solely to the atmosphere since water is highly absorbing this region. However, the LEO site is a coastal area. Sediment resuspension and terrestrial sediment laden outflows and their characteristically high infrared returns eliminate "black pixel" model as an acceptable atmospheric correction strategy.

If the model is not run in the optimization mode ("black pixel"), TAFFKA requires six atmospheric/environmental parameters to be defined. The parameters that TAFKAA utilizes are: ozone concentration, aerosol optical thickness, water vapor, wind speed, aerosol model, and relative humidity. There were instruments deployed at LEO that directly measured these parameters. Ideally, these instruments could help in the selection of the parameters. However, calibration and model issues connected to these instruments postponed there inclusion into the process.

Rather than making educated guesses at the parameters' values, we built a genetic algorithm (GA) to aid in the selection. The GA intelligently searched the parameter space by testing different combinations of atmospheric constraints. Each set was evaluated by running it through TAFKKA and comparing the output to ground truth data. In doing so, however, an assumption of a homogeneous atmosphere for a particular day across the study sites had to be made. Parameter sets that produced results that resembled the ground truth data were maintained and evolved; the remaining sets were eliminated. A more detailed discussion of this procedure can be found in FY2003 ONR-OP28.
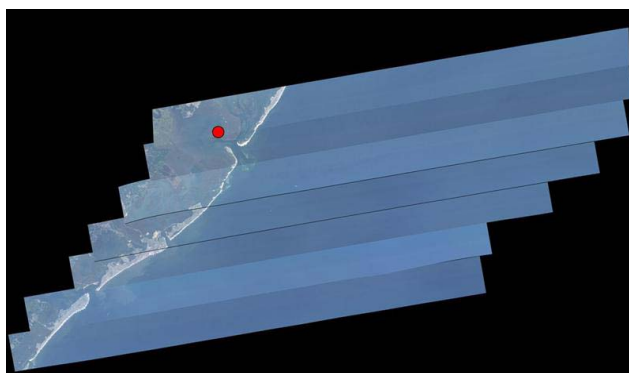

Figure 3: A PHILLS II, three band mosaic of the LEO 15 site in Tuckerton NJ. Location of ground truth is denoted with the red dot.
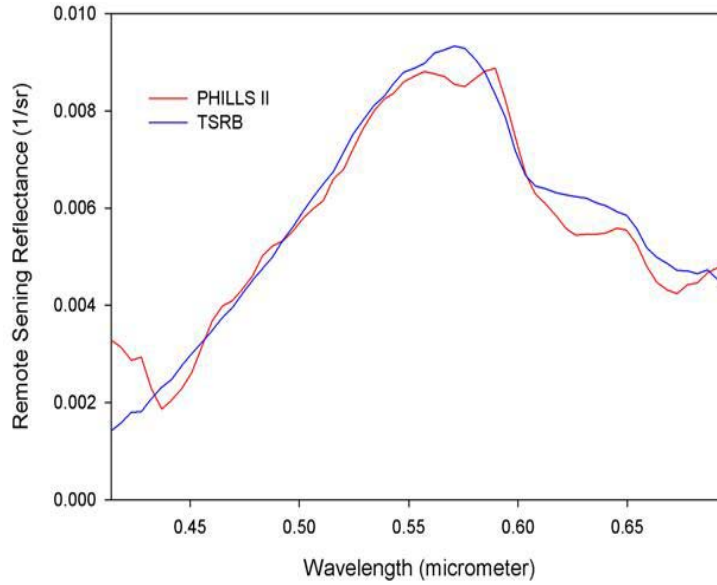
Figure 4: The Comparisons of the best GA TAFKAA corrected PHILLIS II data and the ground truth data.

Parameter Name	Range	Selection
Water Column Vapor	[.5, 3.0]	0.5249
Ozone	[.30,.45]	0.339
Aerosol Optical Thickness (Tau 550)	[.05, 1.5]	0.166
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	70%
Aerosol Model	• [urban, maritime, coastal, coastal-a, tropospheric]	urban

Table 1: The parameters for the LEO -15 Tuckerton, NJ (July 31ˢᵗ 2001) derived using the genetic algorithm coupled with NRL's atmospheric correction program, TAFKAA.

Due to the discretization of the parameter space for the GA, there were nearly 75 million possible solutions to test. Many, however, are unrealistic. The GA tested only about one quarter of one percent of the total possible. But in doing so it determined a realistic atmospheric model that produced PHILLS remote sensing reflectance values that closely resembled the ground truth spectra (see Table 1 and Figure 3).

After applying the parameters in Table 1, there still appeared to be some issues left to address prior to the data set's release. First, a brightening of the data towards the center of the instruments swath has been detected (see Figure 4). As can be seen in Figure 4, the effect becomes more noticeable as a function of the solar angle. We have hypothesized that this is the result of a reflection of light within the plane's cabin reflecting off the inside of the optical flat and corrupting the data. To address this we

developed an iterative flat field procedure that uses neighboring lines which are minimally affected to correct lines whose corruption is noticeable.

And second, the assumption of a homogenous atmosphere over the entire LEO study area may be flawed. This assumption was driven by model simplicity and lack of quality ground truth data from different regions within the study area. For our analysis, we have been utilizing the ground truth data collected by the Cornell and NRL-DC teams. The GA atmospheric correction applied was developed using ground truth data found within the bay. However, when we look at the remote sensing return off shore we see negative returns (Figure 4). The flaw seems to be related to an offset - shape appears correct. This issue is still being investigated. Because the flaw looks to be related to an offset, we are hypothesizing that the assumption of a constant wind speed over the study site is at fault. Wind speed is related to surface roughness. And thus, the removal of inappropriate amounts of sun and sky glint as directed by the wind speed parameter may be to blame.
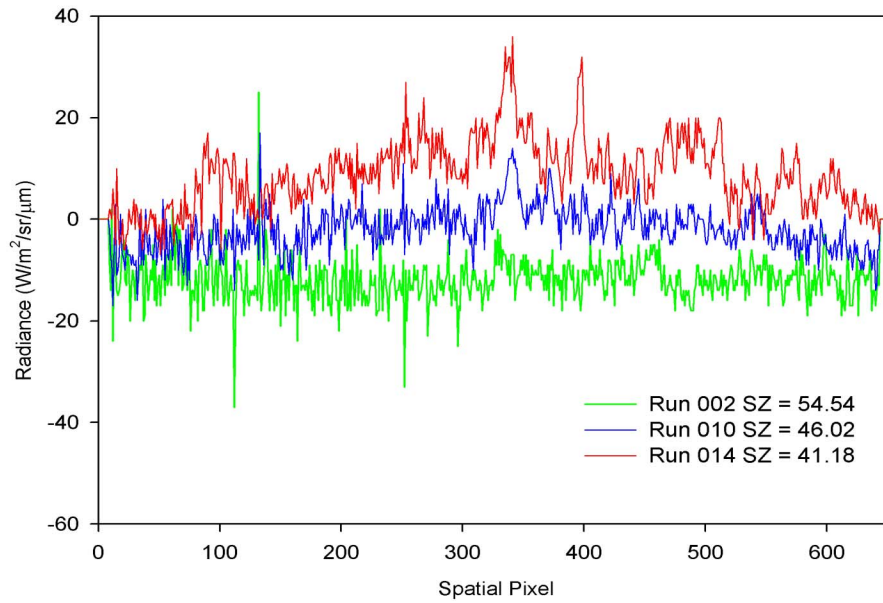

Figure 5: X profiles of homogeneous off-shore waters taken by PHILLS II at the LEO site across different flight lines. The data is taken at spectral band 850nm. As the sun gets higher in the sky, we see a brightening in the center of the image swath.
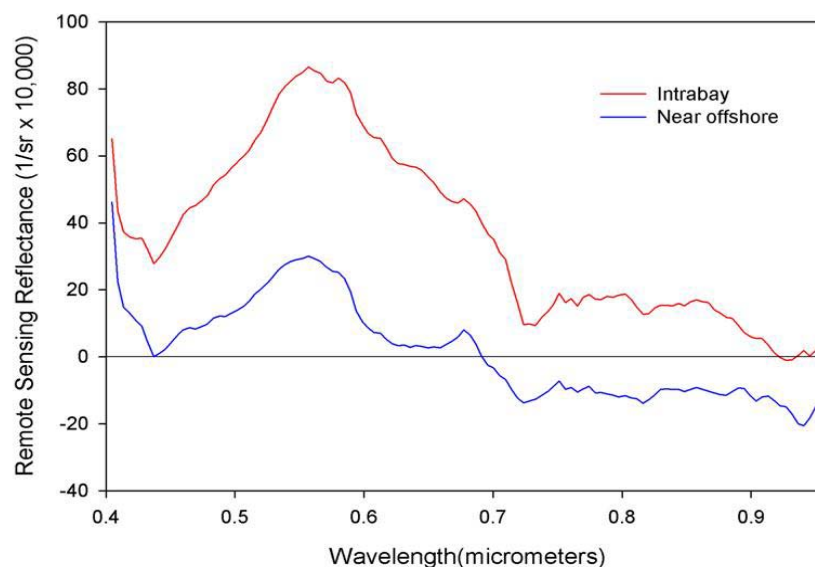
Figure 6: A comparison of PHILLS II atmospherically corrected spectra from within the bay and off shore locations. The atmospheric parameters were trained with data near the intrabay location.

The final major issue is the distribution of the PHILLS II data. In FY 2002, we made available two different releases of the LEO data sets. While there were many requests for the data, it is not apparent to us that the data has been actively used. And thus, we decided to hold off on another large release until the sensor and atmospheric issues appropriately addressed. The third release is expected shortly.

The cost and time needed by us to make these releases is substantial. To address this, we have developed a password secured web interface (http://www.flenvironmental.org/HyDRO/login.asp) that allows users to geographically select and download PHILLS II data of interest. Additionally, the user is offered the flexibility of selecting band combinations and ground spatial resolutions that better meet their needs. Once a request has been submitted and processed the user is notified by email and directed to an ftp site to download their request. It is hoped that this automation will better serve the research community while helping to alleviating the time and financial costs to FERI associated with distributing these large data sets.

Finally, the experience in the development, deployment, and calibration of the PHILLS II sensor has enabled us to develop a STTR program, which was funded at the Phase I level, for a new UAV Ocean Characterization/MCM sensor. Details of which may be found at the Navy's SBIR/STTR award selection web site for FY2003, Topic Number N03-T018 (http://www.navysbir.com/selections_STTR_03.html).

IMPACT/APPLICATIONS

The field of ocean color science is moving beyond empirical methods of relating water-leaving radiance (from a few wavelengths) to integrated water column pigment concentrations. The focus of new ocean color algorithms will be to invert the RS data to depth-dependent IOPs that will include all optical constituents. These algorithms will be used in visibility and performance prediction models, as well as estimating bathymetry from aircraft or space. In addition to providing depth-dependent estimates of IOPs, these new algorithms using HSI data should yield simultaneous solutions for

atmospheric optical properties. This program is devoted to collecting the HSI data and developing these new algorithms.

TRANSITIONS

The research and development from this project has led to Phase I transition funding under the Navy's SBIR/STTR. Details of the award selection for FY2003, Topic Number N03-T018, may be found at http://www.navysbir.com/selections_STTR_03.html.

RELATED PROJECTS

This project is closely coordinated with the ONR HyCODE (http://www.opl.ucsb.edu/hycode.html) and NRL Spectral Signatures of Optical Processes in the Littoral Zone (Spectral Signatures) programs, as well as the C. Davis's ONR-funded research (N00014-01-WX-20684).

REFERENCES

Arnone, R. and Gould, R.W., 1998. Monitoring the coastal environemnt using ocean color. SeaTechnology, 1998.

Austin, R.W. and Petzold, T.J., 1981. The Determination of the Diffuse Attenuation Coefficient of Sea Water Using the Coastal Zone Color Scanner. Oceanography from Space. Plenum Press, New York, NY, U. S. A., 239-256 pp.
Gao, B.-C., Montes, M.J., Ahmad, Z. and Davis, C.O., 2000. Atmospheric correction algorithm for hyperspectral remote sensing of ocean color from space. Applied Optics, 39(6): 887-896.

Gordon, H.R., Clark, D.K., Brown, J.W., Brown, O.B., Evans, R.H. and Broenkow, W.W., 1983. Phytoplankton pigment concentrations in the Middle Atlantic Bight: comparison of ship determinations and CZCS estimates. Applied Optics, 22(1): 20-36.

Kohler, D.D., Bissett, W.P., Davis, C.O., Bowles, J., Dye, D., Steward, R.G., Britt, J., Montes, M., Schofield, O. and Moline, M., 2002. High resolution hyperspectral remote sensing over oceanographic scales at the LEO 15 field site, Ocean Optics XVI, Santa Fe, NM.

Montes, M.J., Gao, B.C. and Davis, C.O., 2001. A new algorithm for atmospheric correction of hyperspectral remote sensing data. In: W.E. Roper (Editor), Geo_SPatial Image and Data Exploration II. SPIE, Orlando, FL, pp. 23-30.

Morel, A., 1980. In-water and remote measurement of ocean color. Boundary-Layer Meteorology, 18: 117-201.

Siegel, D., Wang, M., Maritorena, S. and Robinson, W., 2000. Atmospheric corection of satellite ocean color imagery: the black pixel assumption. Applied Optics, 39(21): 3582-3591.

PUBLICATIONS

Bissett, W. P., Arnone, R., DeBra, S., Dye, D., Kirkpatrick, G., Mobley, C., and Schofield, O.M. (2003). The Integration Of Ocean Color Remote Sensing With Coastal Nowcast/Forecast Simulations

Of Harmful Algal Blooms (HABs). UNESCO Monographs on Oceanographic Methodology- Manual on Harmful Marine Microalgae, UNESCO [submitted, refereed].

Bissett, W.P., Arnone, R., DeBra, S., Deterlie, D., Dye, D., Kirkpatrick, G., Schofield, O. and Walsh, J. 2003. Predicting the Inherent Optical Properties and Colored Dissolved Organic Matter Dynamics on the West Florida Shelf. Marine Chemistry, [submitted, refereed].

Chen, R.F., Bissett, W.P., Coble, P., Conmy, R., G. Gardner, B., Moran, M.A., Wang, X., Wells, M.L., Whelan, P. and Zepp, R.G. Chromophoric Dissolved Organic Matter (CDOM) Source Characterization in the Louisiana Bight (2003). Marine Chemistry, [submitted, refereed].

Davis, C. O., Bissett, W. P., Brown, C. (2003). Optical remote sensing of the coastal ocean: Future directions for observing and monitoring, Earth System Monitor, Vol. 13, No. 2, [published].

Oliver, M.J., Kohut, J.T., Irwin, A.J.G., Schofield, O.M., Glenn, S., Moline, M.A., and Bissett, W.P. (2003). Bioinformatic Approaches for Objective Detection of Water Masses. Journal of Geophysical Research, [submitted, refereed].

Schofield, O., Bosch, J., Glenn, S., Kirkpatrick, G., Kerfoot, J., Moline, M., Oliver, M., and Bissett, P. (2003). Harmful Algal Blooms in a Dynamic Environment: How Can Optics Help The Field-Going and Sample-Poor Biologist? UNESCO Monographs on Oceanographic Methodology- Manual on Harmful Marine Microalgae, UNESCO [submitted, refereed].

Schofield, O., Bergmann, T., Oliver, M., Moline, M., and Bissett, P. (2003). Inversion of the Bulk Absorption in the Mid-Atlantic Bight and its Utility for Water Mass Analysis in Optically Complex Coastal Waters. Journal of Geophysical Research, [submitted, refereed].

Schofield, O., Bissett, W. P., Frazer, T.K., Iglesias-Rodriguez, D., Moline, M.A., Glenn, S. (2003). Development of Regional Coastal Ocean Observatories and the Potential Benefits to Marine Sanctuaries, Marine Technology Society Journal, 37 (1): 54-67, [published, refereed].

Shulman, I., Haddock, S.H.D., McGillicuddy, D.J.Jr., D. Paduan, J.D., Bissett, W.P. (2003). Numerical Modeling of Bioluminescence Distributions in the Coastal Ocean. Journal of Atmospheric and Oceanic Technology 20 (7):1060-1068, [published, refereed].

Zhang, X., Lewis, M., Bissett, P. and Johnson, B. (2003) Optical Influence of Ship Wakes. Applied Optics. [submitted, refereed].

Davis, C. O., J. Bowles, R. A. Leathers, D. Korwan, T. V. Downes, W. A. Snyder, W. J. Rhea, W. Chen, J. Fisher, W. P. Bissett and R. A. Reisse (2002). Ocean PHILLS hyperspectral imager: design, characterization, and calibration, Optics Express, 10(4): 210-221, [published, refereed].

Schofield, O., Bergmann, T., Bissett, W. P., Grassle, F., Haidvogel, D., Kohut, J., Moline, M., Glenn, S. (2002). Linking regional coastal observatories to provide the foundation for a national ocean observation network. Journal of Oceanic Engineering, 27(2): 146-154, [published, refereed].

Schofield, O., Glenn, S., Chant, R., Moline, M. A., Bissett, P., Haidvogel, D., and Wilkins, J. (2002). The evolution of a nearshore coastal observatory and the establishment of the New Jersey Shelf Observing System. Oceanology International 2002, [published].

Walsh J.J., Haddad, K.D., Dieterle, D.A., Weisberg, R.H., Li, Z., Yang, H., Muller-Karger, F.E., Heil, C.A., and Bissett, W.P., (2002). A numerical analysis of landfall of the 1979 red tide of Karenia brevis along the west coast of Florida. Continental Shelf Research, 22(1):15-38, [published, refereed].

Bissett, W. P, Schofield, O., Glenn, S., Cullen, J. J., Miller, W. L., Plueddemann, A. J., Mobley, C. D., (2001). Resolving the impacts and feedbacks of ocean optics on upper ocean ecology. Oceanography, 14:30-49, [published, refereed].

Walsh, J.J., B. Penta, D.A. Dieterle, and W. P. Bissett. (2001). Predictive ecological modeling of harmful algal blooms. Human Ecological Risk Assessment, 7:1369-1383, [published, refereed].

Bissett, W.P., Schofield, O., Mobley, C., Crowley, M.F., and Moline, M.A. (2000). Optical Remote Sensing Techniques in Biological Oceanography. Methods in Microbiology, Volume 30: Marine Microbiology (J.H. Paul, ed), Academic Press, London. 519-540, [published, refereed].

Bissett, W. P., J. J. Walsh, D. A. Dieterle and K. L. Carder (1999). Carbon cycling in the upper waters of the Sargasso Sea: I. Numerical simulation of differential carbon and nitrogen fluxes. Deep-Sea Research, 46(2):205-269, [published, refereed].

Bissett, W. P., K. L. Carder, J. J. Walsh and D. A. Dieterle (1999). Carbon cycling in the upper waters of the Sargasso Sea: II. Numerical simulation of apparent and inherent optical properties. Deep-Sea Research, 46(2):271-317, [published, refereed].

Schofield, O., Grzymski, J., Bissett, W.P., Kirkpatrick, G., Millie, D.F., Moline, M., and Roesler, C.S. (1999). Optical monitoring and forecasting systems for harmful algal blooms: possibility or pipe dream? Journal of Phycology, 35, 1477-1496, [published, refereed].

Walsh, J.J., D. A. Dieterle, F. E. Muller-Karger, R. Bohrer, W. P. Bissett, R. J. Varela, R. Aparicio, R. Diaz, R. Thunell, G. T. Taylor, M. I. Scranton, K. A. Fanning, and E. T. Peltzer (1999). Simulation of carbon-nitrogen cycling during spring upwelling in the Cariaco Basin. Journal of Geophysical Research, 104, 7807-7825, [published, refereed].

HONORS/AWARDS/PRIZES

2003 Small Business of the Year, Semi-Finalist, Florida Environmental Research Institute, W. Paul Bissett, Ph.D., Executive Director, Greater Tampa Chamber of Commerce.