

The Coastal Ocean Imaging Spectrometer (COIS) and Coastal Ocean Remote Sensing

Curtiss O. Davis
College of Oceanic and Atmospheric Sciences
104 COAS Admin, Bldg.
Corvallis, OR 97331
phone: (541) 737-4432 fax: (541) 737-2064 email: cdavis@coas.oregonstate.edu

Award Number: N000140610237

LONG-TERM GOALS

The Navy has a requirement to rapidly and covertly characterize the coastal environment in support of Joint Strike Initiatives. Over the past decade we have demonstrated that spaceborne hyperspectral remote sensing is the best approach to covertly acquire data on shallow water bathymetry, bottom types, hazards to navigation, water clarity and beach and shore trafficability to meet those requirements. The long term goal of this work is to put a hyperspectral imager capable of making the appropriate measurements in space to demonstrate this capability.

OBJECTIVES

The proposed activities are designed to move us closer to flying a hyperspectral imager similar to the Coastal Ocean Imaging Spectrometer (COIS; Davis and Carder, 1997; Wilson and Davis, 1999) in space to demonstrate the spaceborne capability to covertly characterize the coastal ocean. Specific activities are to document the history and development of hyperspectral imaging for the coastal ocean, to advance methods of processing and analyzing hyperspectral data of the coastal ocean and to enhance community awareness of the need for hyperspectral imaging of the coastal ocean. This includes continued analysis of data and publication of results from the NRL Hyperspectral Remote Sensing Technology (HRST) program and the ONR Hyperspectral Coastal Ocean Dynamics Experiment (HyCODE).

APPROACH

I proposed work in three areas to be completed during the two year period of this project:

1. Complete a series of publications on the *in situ* and Portable hyperspectral Imager for Low Light Spectroscopy (PHILLS; Davis 2002) airborne hyperspectral data from the LEO-15, New Jersey, Mobile Bay, Alabama and Monterey Bay, California experiments that were conducted as part of the NRL Hyperspectral Remote Sensing Technology (HRST) program and the ONR Hyperspectral Coastal Ocean Dynamics (HyCODE) program and related programs. Articles focus on the development of hyperspectral imaging for the coastal ocean. This will include articles on the in-situ optical data from the three sites, articles on new algorithms for processing hyperspectral data for coastal environments, articles on scaling of hyperspectral data to resolve coastal features using the LEO-15 data and on a comparison of the three sites using the PHILLS data.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 2006		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE The Coastal Ocean Imaging Spectrometer (COIS) and Coastal Ocean Remote Sensing				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) College of Oceanic and Atmospheric Sciences 104 COAS Admin, Bldg. Corvallis, OR 97331				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 The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

2. I will continue my active support for flying a hyperspectral imager in space. There are currently two opportunities; to fly the Hyperspectral Imager for the Coastal Ocean (HICO) on the International Space station and to fly COIS on the NPOESS spacecraft. It is critical to get this technology in space to demonstrate its full utility for Naval applications. I have been asked by Mike Corson who is now the Principal Investigator for both HICO and COIS to continue to be Project Scientist for both HICO and COIS.

3. I have been asked to host an IOCCG workshop on Requirements for Ocean Color Remote Sensing of the Coastal Ocean. I view this workshop as an opportunity to get a broad international review and, hopefully, endorsement for the concepts and approach behind PHILLS, HICO and COIS and the remote sensing algorithms that have been developed through the NRL HRST program and the ONR CoBOP and HyCODE programs.

WORK COMPLETED

Work to date focused on the review and publication of the hyperspectral remote sensing of the coastal ocean data and algorithms developed over the past decade in the HRST, HyCODE and CoBOP programs. On the occasion of the retirement of Alex Goetz, the inventor of hyperspectral imaging I was invited to write a paper on the development of hyperspectral imaging for the ocean (Davis, et al., 2006) and to collaborate on papers on the development of atmospheric correction for hyperspectral data (Gao, et. al., 2006) and on future directions in hyperspectral imaging (Schaeppman, et.al., 2006). The papers were presented at a day long session in honor of Dr. Goetz at the 2006 International Geoscience and Remote Sensing Symposium in Denver CO. These four page proceedings papers were published in November 2006 and are now being expanded into reviewed papers for the journal Remote Sensing of the Environment. The Gao et. al. Paper has been submitted, and the Davis et. al. paper is almost complete and will be submitted in October.

Standard ocean color atmospheric correction algorithms (e.g. Gordon and Wang, 1996) have assumed that the water leaving radiance at 760 and 865 nm is 0 and that the signal received at the satellite is from atmospheric aerosol scattering. They use these measurements to select an aerosol type and then extrapolate it back into the visible to correct for the aerosol effects in those wavelengths. However, in shallow or turbid coastal waters there is often significant water leaving radiance at 760nm and even at 865 nm in the most turbid waters; and the standard approach overcorrects for the aerosol component leaving low or even negative water leaving radiances in the visible. In particular, this has been a major problem for remote sensing of the shallow waters of the Bahamas Bank which average only a few meters deep. To address this we modified our earlier atmospheric correction for hyperspectral data (Gao, et al. 2000) to work with MODIS data for the Bahamas (Gao et al., 2007). Aerosol models and optical depths are determined by a spectrum-matching technique utilizing channels located at wavelengths longer than 0.86 μm where the ocean surface is dark even over the Banks. The results compared well with hand-held spectrometer measurements over the Bahamas Banks and with the standard MODIS product for deep water.

A second issue for the coastal ocean is that the standard case 1 algorithms used to calculate chlorophyll and other water properties assume that phytoplankton with an associated level of Colored Dissolved Organic Matter (CDOM) and water itself are the only optically active components. In coastal waters high levels of CDOM from rivers and coastal runoff, large phytoplankton blooms, sediments from rivers, or resuspension from the bottom are all significant optical components that need to be

considered as part of the optical signature. As a consequence many researchers are moving away from the case 1 waters assumptions and directly calculating Inherent Optical Properties (IOPs) from remote sensing data (IOCCG, 2006). To develop and validate IOP algorithms for coastal waters it is essential to collect profiles of IOPs and simultaneous water samples for further analysis for phytoplankton, suspended particulates and CDOM. To accomplish this we developed the Profiling Optics and Water Return (POWR) system (Fig. 1, Rhea et al., 2007). POWR is used to measure temperature, salinity and a suite of IOPs of the upper 100 m and collect up to 8 water samples at selected depths. Data is displayed in real-time on the ship and that data can be used to select the depth for water samples.

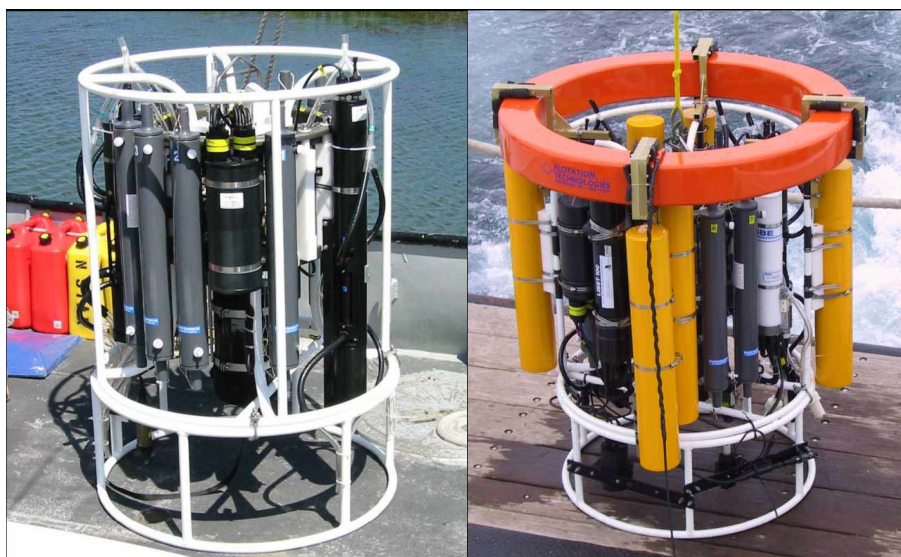


Fig. 1. The POWR system in winch-lowered configuration (left) and free-fall configuration (right) with custom-designed syntactic foam floats (yellow cylinders and orange ring) to limit the sinking rate.

A key goal for the use of POWR was to collect data to validate ocean color products for coastal oceans where using AOP measurements would be difficult. A comparison between POWR data modeled to Remote Sensing Reflectance (R_{rs}) using the Hydrolight radiative transfer program, with above-water measurements using a hand-held Spectrometer and PHILLS hyperspectral imagery collected simultaneously aboard an aircraft flying overhead can be seen in Fig. 2. The modeled data matches the

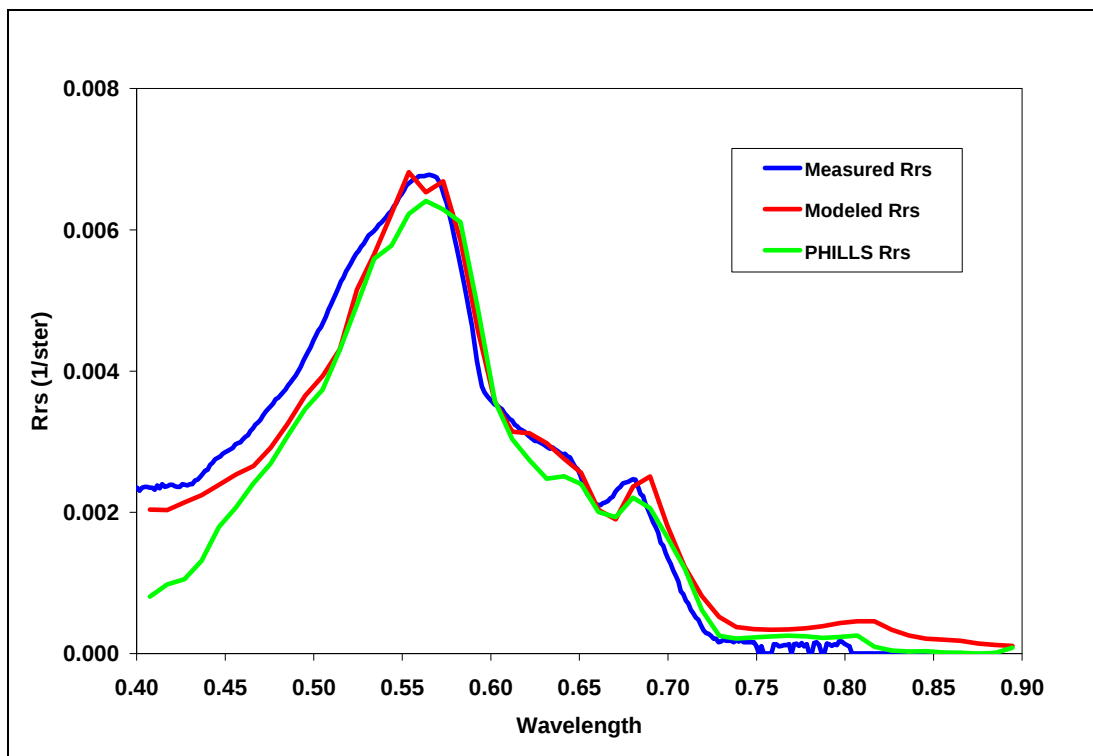


Fig. 2. Example comparison of Rrs spectra modeled from POWR data with spectra from above-water measurements using a hand-held Spectrometer, and with spectra from PHILLS hyperspectral imagery for that location.

handheld spectrometer measurements quite well across the spectrum, while the airborne spectrometer data in this case apparently underestimates Rrs in wavelengths below 450nm, but generally matches the shape of the other spectra.

I continue to support the Naval Research Laboratory in the effort to fly COIS on the NPOESS spacecraft to provide high resolution hyperspectral data for the coastal ocean. On 18 march 2005 COIS was presented as a top priority by the Space Test Board to be carried on the NPOESS spacecraft through the P3I program. STP continued negotiations with the Integrated Program Office (IPO) through fall 2006 when they went into a formal review and reorganization of the NPOESS program. One outcome of that reorganization was that they will not fly any P3I payloads on the first NPOESS spacecraft. The opportunity looked very promising and we look forward to the possibility of resuming those negotiations and to fly COIS if it can be accommodated on a later NPOESS spacecraft.

The Naval Research Laboratory, the University of Hawaii and its partners NovaSol Inc. (UH/NovaSol team led by Dr. Paul Lucey), and Utah State University/Space Dynamics Laboratory (USU/SDL team led by Dr. Byard Wood), formed the Hyperspectral Imager for the Coastal Ocean (HICO) program. Mike Corson at NRL is the Principal Investigator and I am the Project Scientist. The goal of HICO is to develop and launch the first hyperspectral imager optimized for sampling coastal environments, and to develop coastal ocean data products from the images. ONR has provided funding for the HICO program which they see as the first step in the demonstration of maritime hyperspectral imaging for Naval applications.

In January 2007 HICO was selected for flight on the International Space Station. HICO will be integrated and flown under the direction of DoD's Space Test Program. HICO will be combined with another NRL instrument RIADS as the HICO/RAIDS Experiment Payload (HREP). HREP is manifested on the Japanese Experiment Module-Exposed Facility (JEM-EF) on the International Space Station (ISS). It is currently scheduled for launch in August 2009.

There is a recognized need to further identify and define the characteristics of satellite sensor systems that would be optimal for imaging the coastal ocean. Instruments in three categories are deemed essential; continuation of the global time series of 1 km resolution ocean color imagers to build on the time series from SeaWiFS, MODIS and MERIS; flight of a 20 - 40 m resolution hyperspectral imager for characterization of the near coastal ocean, particularly where the bottom is visible, and a 300 m resolution imager to provide the high sampling frequency necessary to resolve coastal ocean dynamics. I am working with the IOCCG to organize a workshop and prepare a report detailing the needs for these systems and detailing the performance requirements. A recent Integrated Global Observing Strategy (IGOS) report (IGOS, 2006) documents the needs for these systems, and the applications they would be used for. Because of that we are reorganizing the planned IOCCG report to focus on the instrument characteristics and performance specifications and the need for calibration, integration of data from the different systems and related issues. I am co-chairing this with Arnold Dekker (CSIRO, Canberra, Australia) and our revised plan was reviewed by the IOCCG in January 2007. We have been asked to put this effort on hold pending the completion of other IOCCG studies.

RESULTS

The focus of this effort is on the processing and analysis of existing data sets and the publication of results and new algorithms based on that data and on papers that explain the value and importance of hyperspectral imaging of the coastal ocean. Key results are the presentation and publication of the paper outlining the history of hyperspectral remote sensing of the coastal ocean. Another paper describes the development of a new method for atmospheric correction for data from the Bahamas Banks and other shallow waters. We developed and published a description of an IOP profiling system that provides real-time IOP data and the ability to collect water at selected depths based on that data. We also show progress towards flying HICO on the ISS which would be the first imaging spectrometer in space designed for coastal ocean imaging.

IMPACT/APPLICATIONS

The long term goal of this work is to put a hyperspectral imager capable of making the appropriate measurements in space to demonstrate the capability of this technology for the rapid and covert characterization of the coastal ocean to support Naval operations around the world. The work completed this year is another incremental step towards that goal.

RELATED PROJECTS

I continue to collaborate regularly with colleagues at the NRL Remote Sensing Division (Code 7200) and the NRL Oceanography Division (Code 7300).

REFERENCES

- Davis, C. O., and K. L. Carder. 1997. Requirements Driven Design of an Imaging Spectrometer System for Characterization of the Coastal Environment. *Proceedings of the SPIE, Imaging Spectrometry III*, 3118: 322-329.
- Davis, C. O., et al., 2002, Ocean PHILLS hyperspectral imager: design, characterization, and calibration, *Optics Express*, 10(4): 210-221, 2002.
- Gao, B.-C., M. J. Montes, Z. Ahmad, and C. O. Davis, 2000, An atmospheric correction algorithm for hyperspectral remote sensing of ocean color from space, *Appl. Opt.* 39(6): 887-896.
- Gao, B.-C., M. J. Montes, R-R. Li, H. M. Dierssen, and C. O. Davis, 2007, An atmospheric correction algorithm for remote sensing of bright coastal waters using MODIS land and ocean channels in the solar spectral region, *IEEE Trans. on Geoscience and Remote Sensing*, V. 45(6): 1835-1843.
- Gordon, H.R., and M. Wang, 1994, Retrieval of water leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: a preliminary algorithm, *Appl. Opt.*, 33: 443-452, 1994.
- IOCCG, 2006, Remote sensing of inherent optical properties: Fundamentals, tests of algorithms, and applications. Lee, Z.-P. (ed.), *Reports of the International Ocean-Colour Coordinating Group*, No. 5, IOCCG, Dartmouth, Canada.
- Rhea, W. J., G. M. Lamela and C.O. Davis, 2007, A profiling optics and water return system for validation and calibration of ocean color imagery, *Optics Express*, 15(1): 2-11.
- Wilson, T., and C. O. Davis, 1999, The Naval EarthMap Observer (NEMO) Satellite, *Proceedings of the SPIE*, 3753, 2-11, 1999.

PUBLICATIONS

- Davis, C. O., K. L. Carder, B.-C. Gao, Z.-P. Lee and W. P. Bissett, 2006, The Development of Imaging Spectrometry of the Coastal Ocean, *IEEE Proceedings of the International Geoscience and Remote Sensing Symposium*, V. 4: 1982-1985. [published]
- Gao, B.-C., M. J. Montes, R-R. Li, H. M. Dierssen, and C. O. Davis, 2007, An atmospheric correction algorithm for remote sensing of bright coastal waters using MODIS land and ocean channels in the solar spectral region, *IEEE Trans. on Geoscience and Remote Sensing*, V. 45(6): 1835-1843. [published, refereed]
- Gao, B.-C., C. O. Davis and A. F. H. Goetz, 2006, A review of Atmospheric Correction techniques for Hyperspectral Remote Sensing of Land Surfaces and Ocean Color, *IEEE Proceedings of the International Geoscience and Remote Sensing Symposium*, V. 4: 1979-1981. [published]
- Rhea, W. J., G. M. Lamela and C.O. Davis, 2007, A profiling optics and water return system for validation and calibration of ocean color imagery, *Optics Express*, 15(1): 2-11. [published, refereed]
- Schaepman, E. E., ..., C. O. Davis, et al., 2006, The Future of Imaging Spectroscopy - Prospective Technologies and Applications, *IEEE Proceedings of the International Geoscience and Remote Sensing Symposium*, V. 4: 2005-2009. [published]