

Airborne Hyperspectral Remote Sensing

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Award Number: N0001401WX20684
<http://rsd-www.nrl.navy.mil/7212>

LONG-TERM GOALS

Visible radiation is the only electromagnetic tool that directly probes the water column, and so is key to Naval systems for bathymetry, mine hunting, submarine detection, and submerged hazard detection. Hyperspectral imaging systems show great promise for meeting Naval imaging requirements in the littoral ocean. To support the development of these applications and to test design features for the Coastal Ocean Imaging Spectrometer (COIS) to be flown on the Naval Earth Map Observer (NEMO) spacecraft (Wilson and Davis, 1998, 1999) we have designed and built the Ocean PHILLS instrument. The overall goal is to demonstrate the utility of airborne and spaceborne hyperspectral imaging for the characterization of the littoral zone and to develop algorithms for use with data from NEMO and other future systems.

OBJECTIVES

This task was to collect airborne hyperspectral data during three field campaigns, two on the west Florida shelf and at one at the LEO-15 Site off New Jersey, to demonstrate the utility of hyperspectral data for the characterization of coastal environments. This work is done in collaboration with Paul Bissett at the Florida Environmental Research Institute. The objective is to correlate the hyperspectral imagery with the detailed in-situ measurements and to use the combined data set to develop algorithms for characterization of the coastal ocean using hyperspectral data.

APPROACH

The Ocean Portable Hyperspectral Imager for Low-Light spectroscopy (Ocean PHILLS), is a new hyperspectral imager specifically designed for imaging the coastal ocean (Davis, et al., 1999). It uses a thinned, backside-illuminated CCD for high sensitivity, and a newly designed all-reflective spectrograph with a convex grating in an Offner configuration to produce a distortion free image. It images in 64 or 128 spectral bands over the range 400 to 1000 nm. Data is collected for 1000 pixels across track. The swath width and pixel size are selected to suit the needs of the particular mission.

The data was examined in the field to assure that quality data was collected. The data was calibrated and quick look images were prepared by the following morning to share with the other investigators. Based on the interest expressed in particular data sets, those data sets were further processed to atmospherically corrected data in the field. Careful re-calibration, atmospheric correction and further

processing to test algorithms will be conducted over the next year in collaboration with the other investigators participating in these experiments.

WORK COMPLETED

Two data collections were made November 3-15, 2000 and April 16-26, 2001 on the west Florida shelf as part of the Hyperspectral Coastal Ocean Dynamics Experiment (HyCODE) for optically shallow environments. This was a collaborative effort with Paul Bissett of the Florida Environmental Research Institute (FERI). A new PHILLS (PHILLS-2) was mounted on a NOAA Citation and flown at 300 knots, at 30,000 ft with a wide angle lens. This gave a pixel size of 8 m and a swath width of 5 km which was essential for this large study site. The area imaged was roughly 70 by 70 km. At this site the focus is on the changing optical properties as a function of trichodesmium and red tide dinoflagellate blooms, and the potential of using hyperspectral imaging to track the development of those blooms. For more detail about the West Florida Shelf collections see the annual report by Paul Bissett and the FERI web site <http://www.flenvironmental.org/Projects.htm#IOPs>.

The third data collection was made July 22 to August 2, 2001 at the LEO-15 site offshore from Tuckerton, NJ. This is the HyCODE optically deep study site. We made high spatial resolution measurements using PHILLS-1 on an Antonov AN-2 Soviet-design biplane, operated by Bosch Aerospace (www.boschaero.com). The Antonov AN-2 flew at 90 knots at an altitude of 8,500 ft and produced 1.8 m pixels and a 1.8 km swath. The study site included marsh and river areas as well as the main offshore site for the HyCODE experiment. On two occasions, high-resolution data of the marsh and inland areas were collected at 5,000 ft yielding 1 m pixels and a 1 km swath. At the same time Paul Bissett and co-workers operated the PHILLS-2 on the Citation to collect 8 m data and provide full coverage of the HyCODE study area in 2 hours. The PHILLS-1 quick-look images can be found on the NRL Code 7210 web site (<http://rsd-www.nrl.navy.mil/7212/>). Quick look images of the PHILLS-2 data can be found at the FERI web site listed above. Data were collected on 8 of the 12 available flight days. For most of these flights the weather was exceptionally clear providing high quality hyperspectral remote sensing data. The high spatial resolution marsh images were collected on 27 July and 2 August. The data for 31 July are particularly noteworthy because of the excellent observing conditions and because simultaneous and near-simultaneous data were also collected with other multi- and hyperspectral optical remote sensing sensors. Simultaneous images were obtained with PHILLS-1, PHILLS-2, and AVIRIS sensors flying the same flight lines, while MODIS and SeaWiFS sensors collected data within an hour of the aircraft overflights.

RESULTS

The primary result of this effort is quality hyperspectral data sets for the three experiments. We are in the process of reviewing and refining the calibration, atmospheric correction and geolocation before producing calibrated data sets for distribution to the other participants. It is anticipated that the majority of the publications from this work will come from collaborations with other participating scientists.

Over the last year a great deal of effort has gone into understanding the optical properties of the PHILLS-1 sensor and the identification and removal of stray light effects. This effort paid off during LEO-15 with the collection of high quality hyperspectral data with little or no systematic effects apparent in most of the data. In Figure 1, we show a reflectance spectra derived from data collected on 31 July. This spectrum was extracted from a single water pixel located within Great Bay near the

position of a ground truth site where simultaneous data was collected for comparison. The red curve represents a simultaneous ASD reflectance measurement collected with the R/V Northstar. The agreement between the measurements is excellent. No special processing of the PHILLS-1 data was required to produce this agreement, and the data shown here represents our normal application of laboratory-derived calibration coefficients followed by our standard atmospheric correction.

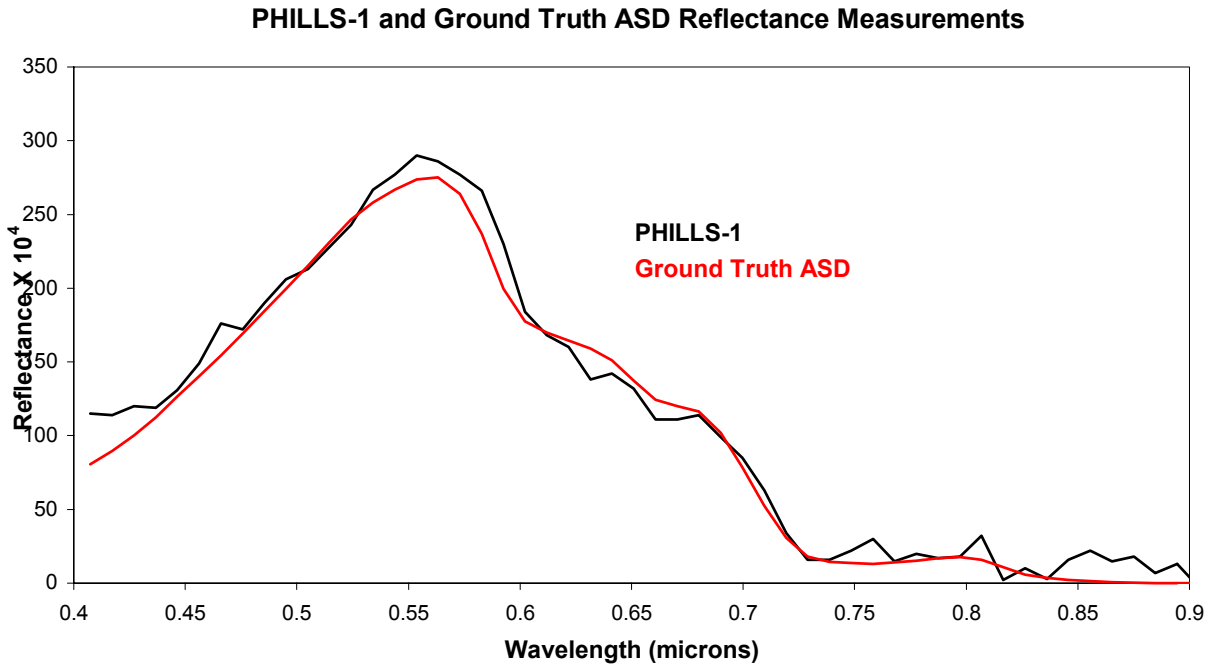
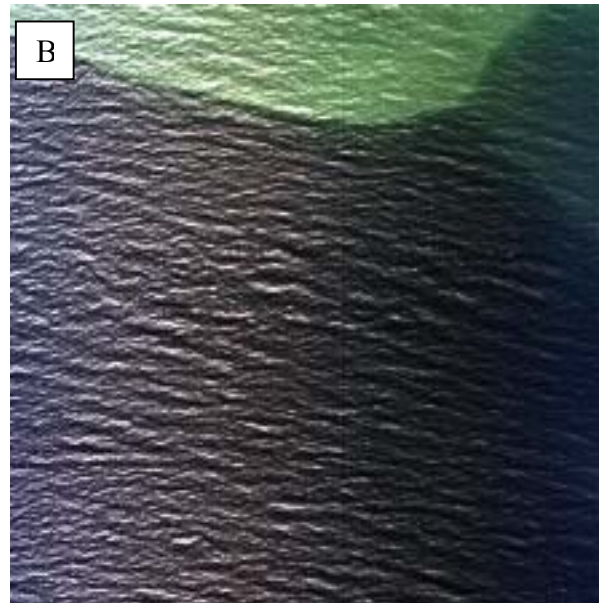
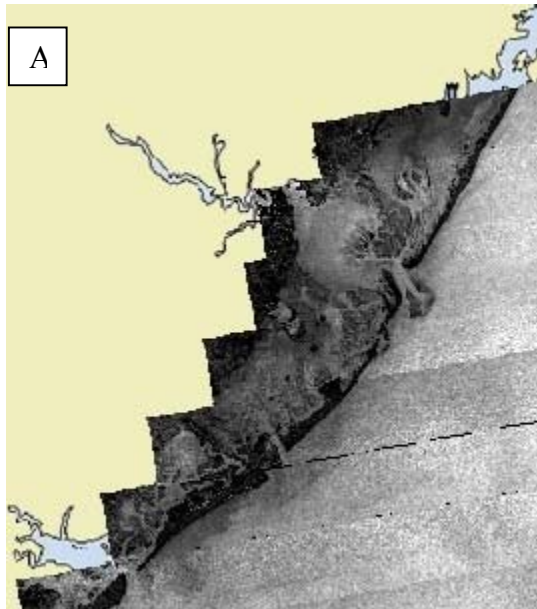


Figure 1. PHILLS-1 derived reflectance spectrum compared with simultaneous ASD measurement collected on 31 July 2001 in Great Bay. [The curves show good agreement over the 0.4 to 0.9 micron spectra range with the maximum reflectance value of .025 at .56 microns.]

The R/V Northstar was assigned to NRL during the time PHILLS-1 was at LEO-15. In addition to the ASD measurements, an in-water package containing HiSTAR, filtered and unfiltered AC9, CTD, WETStar Fluorometer and water-collection bottles for filter pad, HPLC, TSS and particle size measurements were also collected. A goal of our deployment was to collect as complete an in-water data set as possible that was *simultaneous* with the aircraft measurements. While this data set is still being reduced, analysis to date indicates that we met our goal.

A major in-water feature present at LEO-15 during our deployment was a strong front separating high chlorophyll coastal water from the shelf water that evolved during the two week time period. This coastal feature is clearly shown in Figure 2a that presents a composite of the PHILLS-2 550/443 nm spectral band ratio observed for 27 July 2001 superimposed on a map of the region. This band ratio highlights chlorophyll features with the darker gray water pixels near the coast defining the frontal region. The RGB image shown in Figure 2b is a portion of this front observed with the PHILLS-1 sensor on 31 July. The front is clearly visible at the top of the image. Note that the front changes color on the right side of the image and becomes a darker green.



Double Front Reflectance Spectra

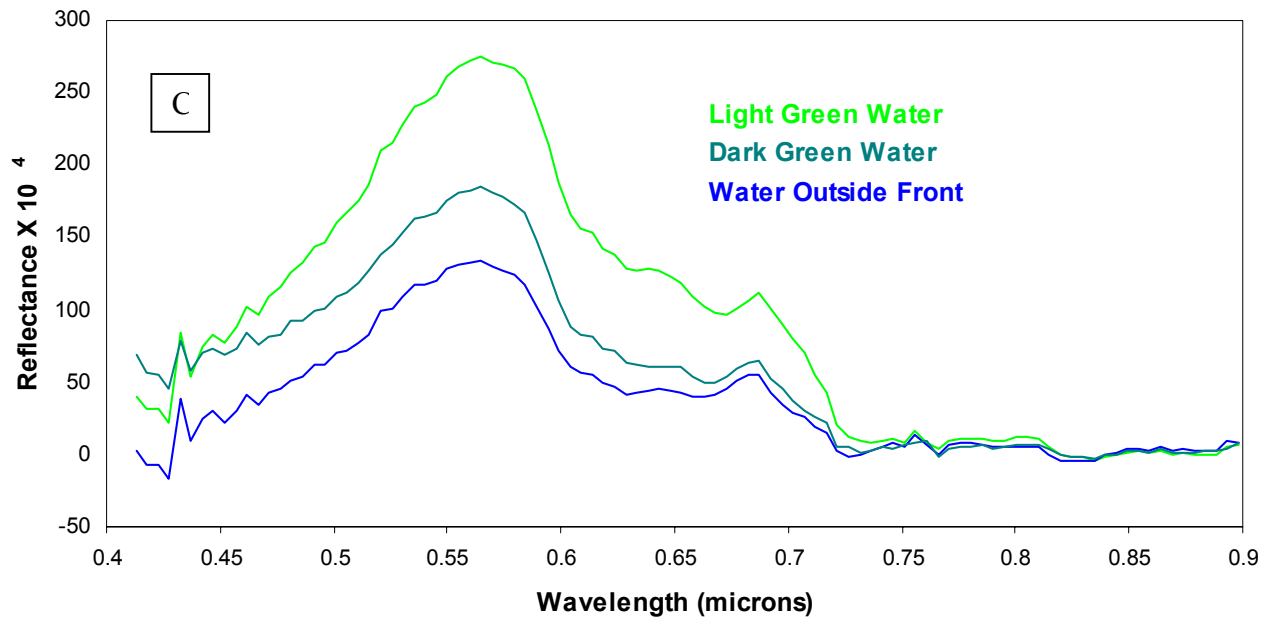


Figure 2. A) 27 July 2001 PHILLS-2 data (band 550/443 ratio) superimposed on a map of the LEO-15 area. Pixel spatial resolution is 8 meters. Data extends an additional 20-30 km offshore to cover the entire HyCODE area. B) A 1.8 km square portion of the front observed on 31 July with PHILLS-1. Pixel resolution is 1.8 meters. C) Reflectance spectra from the image in B. Light green (top center) and dark green (top right) coastal water have higher reflectances over the .45 to .7 micron spectral range compared to the clearer shelf water.

The reflectance spectrum for the bright and dark green coastal front is compared with the clearer ocean water in Figure 2c. These fronts develop as a result of the time variable upwelling that occurs along the New Jersey coast which is a central focus of the ongoing work at the LEO-15 site.

IMPACT/APPLICATIONS

The Ocean PHILLS produces high quality spectral imagery of the coastal ocean. The data has very good sensitivity for ocean scenes as demonstrated in the CoBOP and HyCODE experiments. A key element in this success is the VS-15 spectrograph developed jointly by NRL and American Holographic, Inc. All of the components of the Ocean PHILLS are now commercially available. Six PHILLS like systems have been build to date by commercial companies for DoD and commercial applications. A key to the utilization of this data will be the product algorithms, such as those that will be developed based on the CoBOP and HyCODE data that will be applied for future Naval applications of hyperspectral data.

TRANSITIONS

The Ocean PHILLS data will be shared with the HyCODE participants. When combined with their in-water data we anticipate jointly developing algorithms for shallow water bathymetry, the characterization of bottom types, and water column optical properties. Many of these algorithms will eventually be transitioned through NEMO and other DoD hyperspectral programs.

RELATED PROJECTS

This effort is closely coordinated with the ONR Coastal Benthic Optical Properties (CoBOP) DRI (Mazel, 1998), the ONR Hyperspectral Coastal Ocean Dynamics Experiment (HyCODE) DRI and NRL hyperspectral Characterization of the Coastal Ocean (HCCO) ARI.

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- Davis, C. O., M. Kappus, J. Bowles, J. Fisher, J. Antoniadis, and M. Carney, "Calibration, Characterization and first Results with the Ocean PHILLS Hyperspectral Imager", *Proceedings of the SPIE*, V. **3753**, 160-168, 1999.
- Mazel, Charles H, "Coastal Benthic Optical Properties (CoBOP) Program Overview", *Proceedings of Ocean Optics XIV*, Kailua-Kona HI, November 10-13, 1998, published on CD by the Office of Naval Research Optics Program.
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PUBLICATIONS

- Davis, C. O., M. Kappus, J. Bowles, J. Fisher, J. Antoniadis, and M. Carney, "Calibration, Characterization and first Results with the Ocean PHILLS Hyperspectral Imager", *Proceedings of the SPIE*, V. **3753**, 160-168, 1999.