Coastal Imaging Spectroscopy

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LONG-TERM GOALS

The hope of coastal HyperSpectral Imaging (HSI) data is that it will provide the necessary data stream to simultaneously describe the atmospheric and water column optical properties. However, this goal is contingent sensitive and well calibrated instrumentation. Building upon the progress achieved in the calibration of PHILLS II hyperspectral instrument, we hypothesize that this data stream will provide the spectral and spatial resolution necessary to invert the calibrated remote sensing reflectance and water-leaving radiance to depth-distributed IOP's and optical constituents.

OBJECTIVES

1) Analysis and application of different atmospheric correction techniques on the PHILLS II calibrated spectral remote sensing data.

2) Development of optimization algorithm to derive depth-dependent optical properties.

3) Evaluation of optimization and look-up-table algorithms for real-time, or near real-time processing capabilities.

APPROACH

The emergence of hyperspectral remote sensing as an oceanographic tool carries with it the promise of being able to efficiently map optically complex coastal environments. Hyperspectral remote sensing data, with its numerous, narrow, contiguous wavebands, approximate the true electromagnetic signature of its target. With this new information, mathematical techniques originally developed in laboratory spectroscopy could be applied to this new data set in an attempt to characterize the imagery. There have been some recent efforts to use high spectral data in the mapping of the coastal zone (Kohler, 2001; Lee et al., 1998; Lee et al., 1999). However, the data these studies are based on are limited in temporal coverage and suffers from sensitivity and calibration problems. These limitations require an on-site, vicarious calibration of the data to be useful in these environments, which reduces the applicability of these tools and techniques to other coastal areas. The efforts to derive coastal

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14. ABSTRACT
The hope of coastal HyperSpectral Imaging (HSI) data is that it will provide the necessary data stream to simultaneously describe the atmospheric and water column optical properties. However, this goal is contingent sensitive and well calibrated instrumentation. Building upon the progress achieved in the calibration of PHILLS II hyperspectral instrument, we hypothesize that this data stream will provide the spectral and spatial resolution necessary to invert the calibrated remote sensing reflectance and water-leaving radiance to depth-distributed IOP???s and optical constituents.

15. SUBJECT TERMS

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remote sensing algorithms to separate the depth dependent IOPs have been hampered by the lack of calibrated, high resolution spectral and spatial remote sensing data.

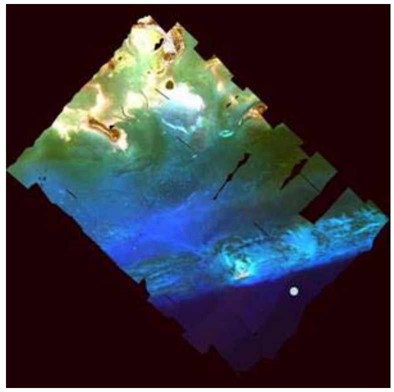

Figure 1: A PHILLS II, three band mosaic of the Looe Key site. Location of ground truth is denoted with the blue dot

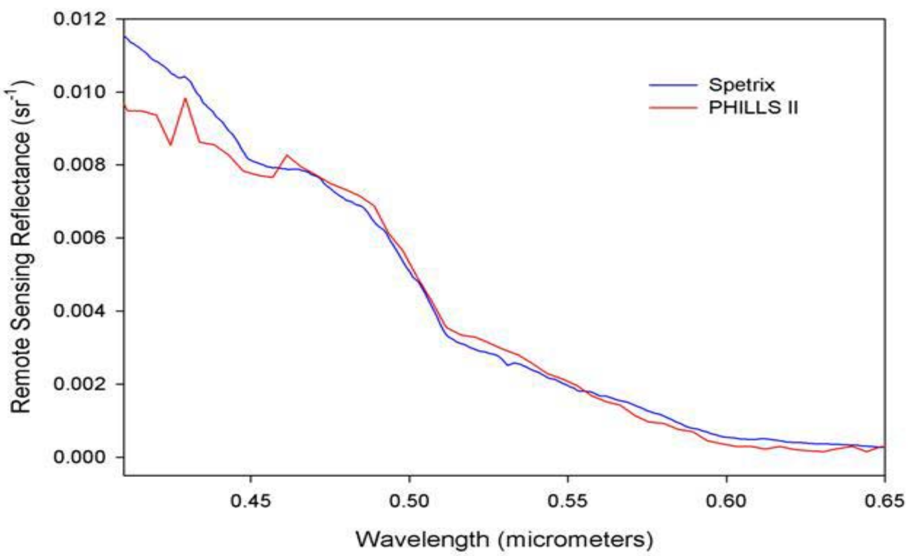

Figure 2: The comparison of the best GA TAFKAA corrected PHILLS II data and the ground truth data.

Parameter Name	Range	Selection
Water Column Vapor	[.5, 3.0]	1.980
Ozone	[.246, .248]	0.247
Aerosol Optical Thickness (Tau 550)	[.05, 1.5]	0.05
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	98%
Aerosol Model	• [urban, maritime, coastal, coastal-a, tropospheric]	tropospheric

Table 1: The parameters for the Looe Key, FL (October 31st 2002) derived using the genetic algorithm coupled with NRL's atmospheric correction program, TAFKAA

As part of an ONR Environmental Optics program, NRL program (Code 7212), and NOAA NOS Remote Sensing Division program, we have developed the tools, techniques, and collaborations to calibrate and deploy a hyperspectral imaging spectrometer (Ocean PHILLS II, Davis et al., 2002) that produces hyperspectral remote sensing data at the signal-to-noise level necessary for coastal ocean imaging spectroscopy (Kohler et al., 2002). This effort has led to a radiometric calibration technique that does not require the use of subjective tuning parameters to retrieve upwelling radiance at the sensor from raw digital count data.

Our original ONR funded proposal (Coupling simulated ocean reflectance to the atmospheric correction of hyperspectral images, N00014-00-1-0514) dealt with the collection and atmospheric correction of PHILLS II hyperspectral data in support of the ONR sponsored Hyperspectral Coastal Ocean Dynamics Experiment (HyCODE) field studies. Our studies demonstrated that instrument design, as well as calibration and deployment techniques did not address some previously unforeseen problems that significantly degraded the spectral quality of the data. The importance of radiometric calibration cannot be over-emphasized. The ocean is a dark target, whose spectral reflectance must propagate through a bright atmosphere. At high altitudes, the radiance at the sensor is mostly reflected by the atmosphere (90-99%) (Morel, 1980). The application of atmospheric correction techniques to retrieve the water-leaving radiance requires an imaging spectrometer with a very high signal-to-noise that is very well calibrated and characterized. Thus, we focused our efforts on evaluating the existing calibration and subsequently developing a new robust method to replace it.

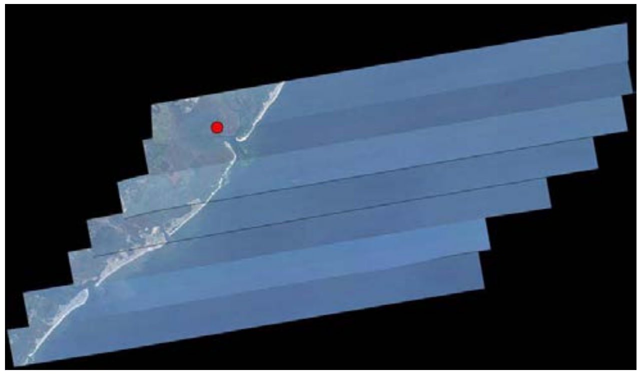

Figure 3: A PHILLS II, three band mosaic of the LEO 15 site in Tuckerton NJ. Location of ground truth is denoted with the red dot.

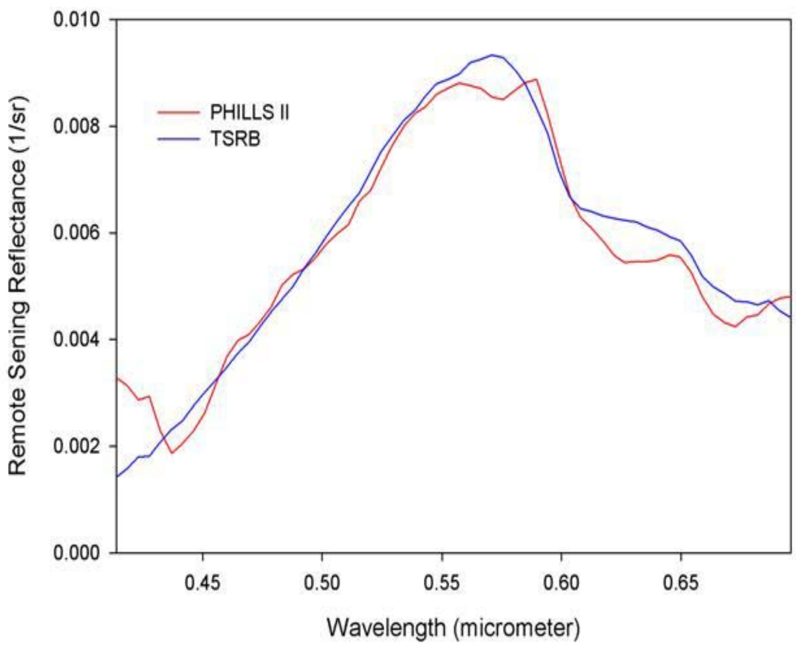

Figure 4: The comparison of the best GA TAFKAA corrected PHILLS II data and the ground truth data.

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

Our demonstrated abilities to collect, calibrate, and deliver hyperspectral remote sensing data in a timely manner support the logical progression to the development of algorithms that handle this data stream in an attempt to derive maps of depth dependant IOP's. Preceding the development of these algorithms will be the evaluation, application, and delivery of PHILLS II data using existing atmospheric correction algorithms.

WORK COMPLETED and RESULTS

Remote sensing algorithms assume that the effects of the atmosphere have been properly estimated and removed from the data signal prior to their application. Atmospheric effects account for nearly 90% of the remotely-sensed signal over oceanic waters. The disproportionate influence that atmosphere has on the observed signal dictates that the removal of its effects be handled appropriately. The work to date on this project revolves around the development of atmospheric correction strategies for hyperspectral imagery. This work is an extension of the atmospheric correction work funded under Award N00014-00-1-0514.

The NRL developed atmospheric correction model, TAFKAA, was chosen to process the PHILLS II data stream. TAFKAA is a derivation of ATREM, the standard atmospheric correction model for hyperspectral remote sensing datasets. To increase the efficiency of its application, TAFKAA utilizes sets of predetermined tables. Guided by the solar and sensor geometries and environmental conditions, it returns a solution, which it applies to the dataset. The sensor and solar geometries are directly derived from the data's time stamp and positional information. The environmental conditions, on the other hand, need to be selected by the user. The parameters that TAFKAA utilizes are: ozone concentration, aerosol optical thickness, water vapor, wind speed, aerosol model, and relative humidity. Although there are instruments that measure these parameters, often the instruments or the knowledgeable personnel needed to run them are not available.

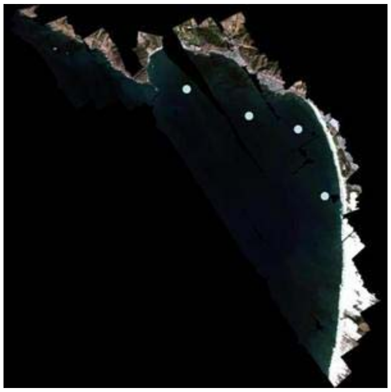

Figure 5: A PHILLS II, three band mosaic of the San Luis Bay, CA site. The locations of ground truth is denoted with the blue dots.

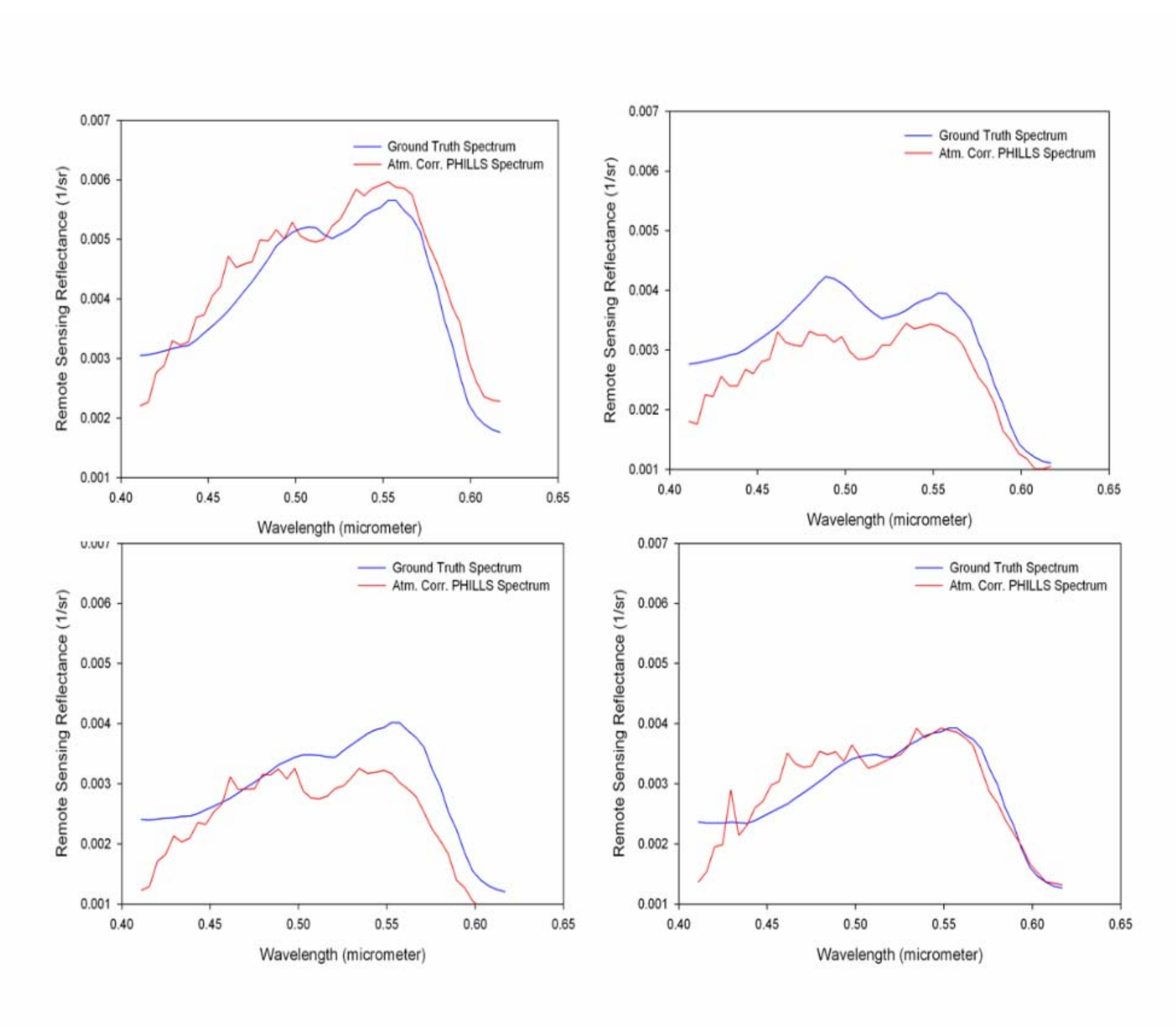

Figure 6: The comparison of the best multi-GA TAFKAA corrected PHILLS II data and the ground truth data.

Parameter Name	Range	Selection
Water Column Vapor	[.5, 3.0]	1.575
Ozone	[.30,.45]	0.3015
Aerosol Optical Thickness (Tau 550)	[.05, 1.5]	0.137
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	80%
Aerosol Model	• [urban, maritime, coastal, coastal-a, tropospheric]	maritime

Table 3: The parameters for the San Luis, CA (October 27th 2002) derived using the genetic algorithm coupled with NRL's atmospheric correction program, TAFKAA.

Rather than making educated guesses at the parameters' values, a genetic algorithm was developed (GA) to aid in the selection. The GA intelligently searched the parameter space by testing different combinations of atmospheric constraints. Prior to starting, a region of interest (ROI) is selected in the radiometrically corrected imagery that corresponds to the location of the ground truth station. The size ROI selected is on the order of 100 pixels. It is important to make the ROI large enough so to reduce the influence of randomly occurring errors. Randomly selected parameter sets are then evaluated by running the ROI through TAFKAA and comparing the spectral mean of its output to ground truth data. Parameter sets that produced results that resembled the ground truth data were maintained and evolved; the remaining sets were eliminated.

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 outcomes. But in doing so it determined a realistic atmospheric model that produced PHILLS II remote sensing reflectance values that closely resembled the ground truth spectra. This approach has been used to determine the parameter selection at two of the PHILLS II deployment sites: LEO 15 Tuckerton, NJ and Looe Key, FL (see Tables 1 and 2 and Figures 1 through 4).

While the fitness between the ground truth spectra and the PHILLS II remote sensing reflectance are in both cases remarkably close, upon examining the history of the rejected parameter sets an issue emerges. There are numerous combinations of parameters that produce acceptable results; however, only one is good enough to make the final selection. This suggests the possibility that sensor or model flaws may play undue influence in developing of the selection. To address this, we have expanded our model to incorporate several ground truth sites at once. In doing so, however, an assumption of a homogeneous atmosphere for a particular day across the study sites had to be made. This approach has been run on the October 17^{th}, 2002 San Luis Bay, CA study site (see Table 3 and Figures 5 and 6).

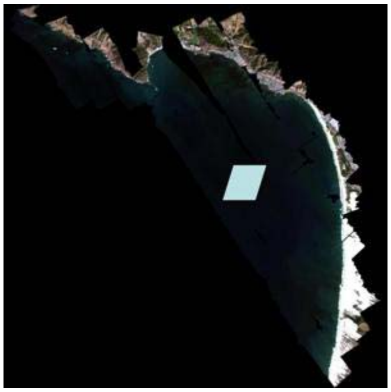

Figure 7: A PHILLS II, three band mosaic of the San Luis Bay, CA site. Location of area in which both water and atmosphere were determined to be invariant.

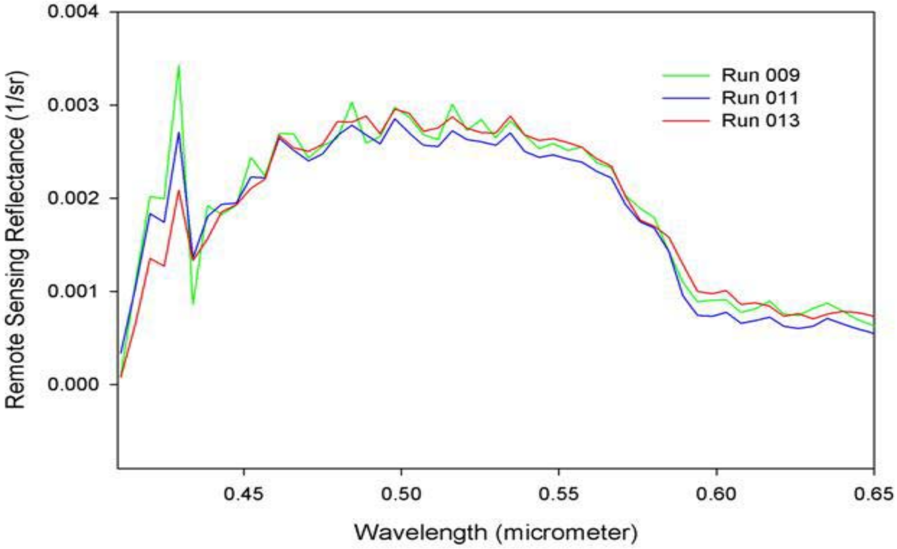

Figure 8: The comparison of the best GA TAFKAA corrected PHILLS II data.

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]	0.1805
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	90%
Aerosol Model	• [urban, maritime, coastal, coastal-a, tropospheric]	urban

Table 4: The parameters for the San Luis, CA (October 27th 2002) derived using the genetic algorithm with no ground support coupled with NRL's atmospheric correction program, TAFKAA.

Although we make every effort to have field support available when the PHILLS II is deployed, sometimes it is either logistically or financially prohibitive. We are currently working on two variations of the atmospheric GA to handle these situations. The first utilizes a "stacking" approach. This strategy requires that the aircraft on which the PHILLS II is deployed to make a gradual, spiral descent over a homogeneous target area (i.e. deep water area). At different altitudes over the same ground ROI, separate data sets would be taken. Once atmospherically corrected, all of these data sets should be identical. Thus, rather than using the spectral difference as a measure of the parameters' fitness within the GA, the minimization of the spectral variation amongst the different data sets is employed. Although this approach has been coded, we do not yet have a data set to test it against. We hope to get one shortly.

The other method is based on the same premise. However rather than varying the altitude and thus atmosphere in which the sensor is exposed to, the time and corresponding solar geometry is allowed to vary. This approach depends on the selection within the collected imagery of a large area in which it is believed that both the atmosphere and water type are each invariant. Assuming this area is large enough to touch several flight lines, ROI's can be selected from each of these flight lines. Again once atmospherically corrected, the return of these ROI assumed to be identical. And thus, as was the case in the "stacking" approach, the GA is run employing a fitness derived from the spectral variation of the different ROIs. Although this approach is still in its developmental stages, it has produced some promising results on the San Luis Bay, CA image (see Table 4 and figures 7 and 8).

IMPACT/APPLICATIONS

Atmospheric correction of coastal hyperspectral remotely sensed data is difficult problem. The subtle yet variable signals found in these areas do not lend themselves to traditional techniques of selecting atmospheric correction parameters. The procedures being investigated within this study not only address how to select these parameters given ground truth data, but also suggest ways in which atmospheric correction can be done completely remotely.

RELATED PROJECTS

This project has grown out of the ONR Award N00014-00-1-0514. As that project was, it is also 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).

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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.