

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYYY) 31-03-2004		2. REPORT DATE FINAL		3. DATES COVERED (From - To) APR 2000 - DEC 2003	
4. TITLE AND SUBTITLE COUPLING SIMULATED OCEAN REFLECTANCE TO THE ATMOSPHERIC CORRECTION OF HYPERSPECTRAL IMAGES				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER N00014-00-1-0514	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) BISSETT, W. PAUL III				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, STE 101 TAMPA, FL 33611				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) OFFICE OF NAVAL RESEARCH BALLSTON CENTRE TOWER ONE 800 NORTH QUINCY STREET ARLINGTON, VA 22217-5660				10. SPONSOR/MONITOR'S ACRONYM(S) ONR	
				11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE, DISTRIBUTION IS UNLIMITED					
13. SUPPLEMENTARY NOTES N/A					
14. ABSTRACT SEE ATTACHED					
15. SUBJECT TERMS REMOTE SENSING, HYPERSPECTRAL, AIRCRAFT REMOTE SENSING, OPTICAL INSTRUMENT CALIBRATION					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 2	19a. NAME OF RESPONSIBLE PERSON, BEVERLY S. WALTERS
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code) 813-837-3374 X101

## **Coupling Simulated Ocean Reflectance to the Atmospheric Correction of Hyperspectral Images**

### **Summary**

Ocean hyperspectral remote sensing is more difficult than terrestrial hyperspectral remote sensing. The difficulties stem from two major differences between oceanic and terrestrial systems. The first is in the "darkness" of the ocean target versus the terrestrial target. The second is in the spectral differences in the reflectance, particularly in the near infrared (NIR). While these factors were known qualitatively, this program focused on the quantification of the importance of these factors in the characterization, calibration, deployment, atmospheric correction, product generation, and product delivery of coastal ocean hyperspectral information. Specific highlights include –

- 1) The ocean target typically has remote sensing reflectances  $>1\%$  versus terrestrial targets that are  $>30-40\%$ . This requires a very sensitive sensor, with very low noise. In addition, because the best use of these sensors is in the coastal zone, these sensors must have a very high dynamic range. This project yielded the sensor requirements for the next generation low-power hyperspectral sensors. These requirements were incorporated into a funded Phase I ONR STTR.
- 2) The extreme calibration requirements on product generation from an oceanic signal dominated by atmospheric interference yielded the development of a novel calibration technique which is applicable to a wide range of hyperspectral sensors. This calibration technique has led to the delivery of robust ocean reflectance data in physical units of radiance or remote sensing reflectance. The delivery of such data is required before the development of more robust hyperspectral inversion algorithms.

# **Coupling Simulated Ocean Reflectance to the Atmospheric Correction of Hyperspectral Images**

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## **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.

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).

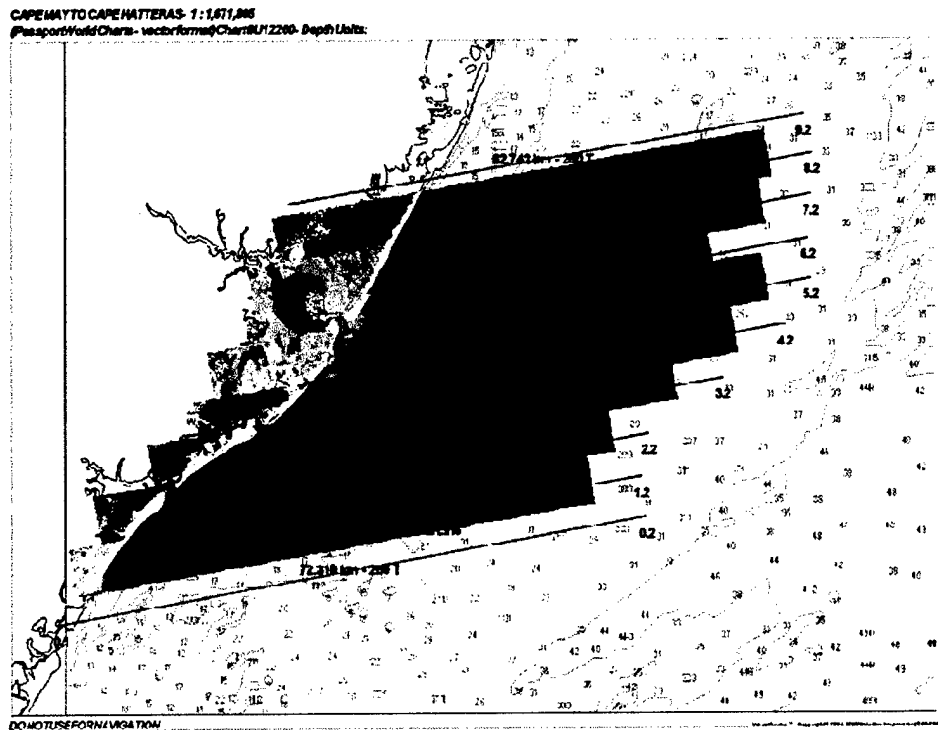
### **WORK COMPLETED-Year 1**

We have flown three missions over the last year with both the Ocean PHILLS-1 (November 2000, WFS) and the Ocean PHILLS-2 (April 2001, WFS, and July 2001, NJB). Ocean PHILLS-1 refers to the PHILLS system with a 1024 x 1024 PixelVision CCD camera and an Agilent (formerly American Holographics) VS15-model 2 spectrometer. The Ocean PHILLS-2 system refers to the system with a PixelVision 494 x 652 CCD camera and an Agilent (formerly American Holographics) VS15-model 1 spectrometer. Both of these systems have a Boeing C-MIGITS IMU system for post-processing geo-rectification attached to the data collection system. These missions were flown on the NOAA Aircraft Operation Center's [AOC] Cessna Citation at 30,000 feet providing synoptic hyperspectral remote sensing data over approximately 5000 square kilometers over multiple days during each mission. These high altitude missions provide HS data at oceanographic spatial scales that can be used to create composite images that will resemble those collected by a future (hopefully) HS satellite (Figure Y1-1 and 2).

We found that the Ocean PHILLS-1 data from July 2000 and November 2000 was extremely difficult to use due to the inability to effectively calibrate the data. Thus, we spent a tremendous amount of time in the NRL calibration laboratory during the past year trying to characterize the PHILLS-2. This exercise became our dominant work during the period, in addition to the actual data collection. We also found the geo-rectification routines originally developed for the PHILLS data stream were not working properly. Thus, trying to geo-rectify the data has also become a major time sink.

In order to help facilitate with the calibration, we elicited the help of K. Carder at USF to both help with the direct calibration of the PHILLS, as well as to collect atmospheric data during the field experiments. We covered the cost of travel for his technical support staff (Robert Steward), but the

personnel time has been covered by USF. Dr. Carder's efforts have been invaluable to our efforts and the atmospheric data he collected during the 2001 HyCODE experiment in the NJB will be critical to our atmospheric correction of the HS data.



**Figure Y1-1. RGB Mosaic of July 21, 2001 Ocean PHILLS-2 Data from the 2001 HyCODE field experiment.**

The NOAA Citation provided us a high altitude data stream at a fraction of the cost of HALE UAV's, nearly an order of magnitude less (~50K v. ~500K) for each of our experiments. It was decided that we should focus on the development of a radiometrically-calibrated sensor prior to attempting UAV flights, and use the Citation as the development vehicle. At such point that the sensor is robust in geo-location and radiometric calibration we will re-focus on the UAV flight vehicles.

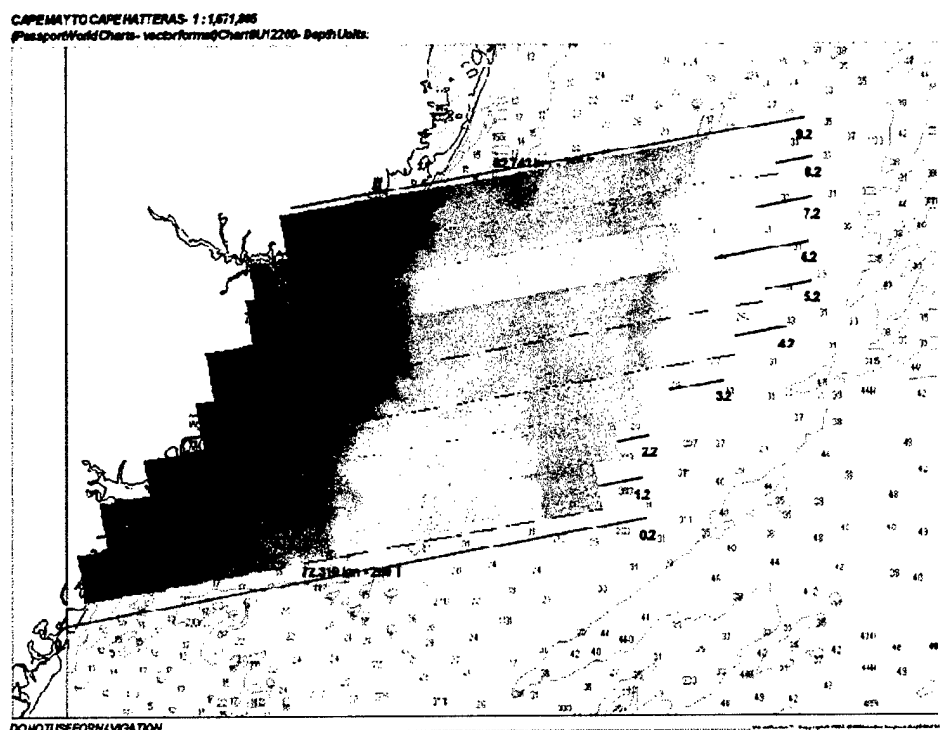
## **RESULTS-Year 1**

Examples of our flight data are shown in Figures Y1-1 and Y1-2. The full data suite can be found on our web site. This data is available for the ONR HS community on a request basis. We are currently working on making the data available in an FTP format, however, each experiment is on order of ~125 GB of data, thus we are developing a system that will allow the user to select smaller spatial and spectral subsets of the entire data suite. This system should be online within the next two months.

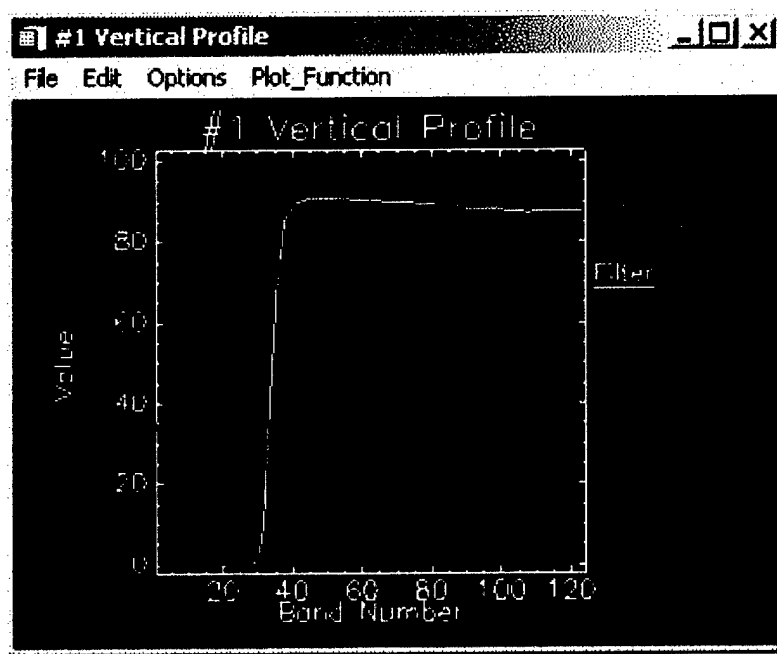
The calibration of the PHILLS data has been frustrating in that the robustness of the instrument design did not meet our expectations. In particular, the design (originally completed by a group of engineers that have since left NRL) did not baffle or mask the zero order light (that light which is directly reflected on the holographic grating) in the spectrometer. This light is much greater than the individual wavelength bands and is projected near the blue wavelengths on the CCD array. Its effects can be seen in Figure Y1-3 where a long-pass cutoff filter has been placed in front of the PHILLS in the calibration

laboratory. In an attempt to rectify this problem NRL designed a mask to block the zero order light from entering the camera. This stopped a large fraction of the zero order light (Figure Y1-4), but it also appears that there is still a lot for which we are not accounting. This zero order effect does appear to be proportionally related to intensity, so it may be that we can correct this in a post processing of the data.

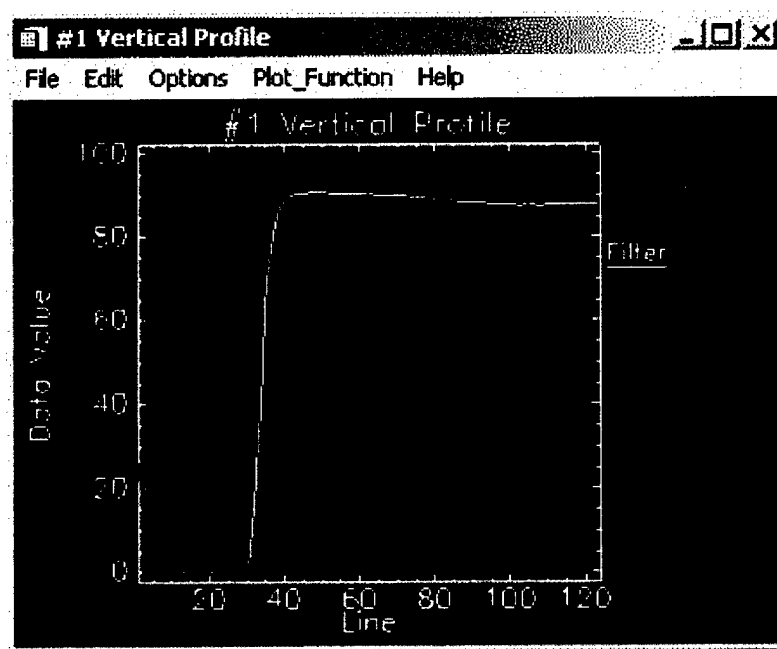
In addition, we discovered calibration difficulties that we did not anticipate to be issues. In particular, it appears that the NIST calibration sphere that we are using is extremely red rich in output spectrum (Figure Y1-5). This provides very little signal in the blue, so we were forced to use a blue filter over the calibration sphere in order to flatten the spectra of the sphere light for calibration. The difficulty is that the PHILLS calibration appears to be linear at high irradiance levels, but non-linear at low irradiance levels (We are not sure of the cause of this effect, and it is a source of calibration woes). At high altitudes over water, we are subjected to high irradiance in the blue, low irradiance in the red, causing problems in that our RS data is not within the range of our calibration series. Extrapolation of the calibration series outside of the radiance range can be problematic. Over the next few months we will begin the post process of the PHILLS-2 data stream in order to provide our best radiometrically-calibrated data to the HyCODE community.



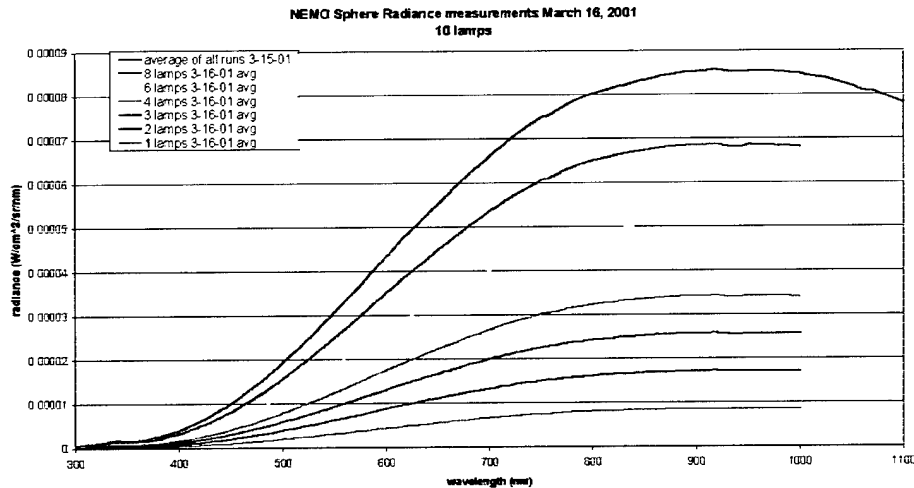
**Figure Y1-2. Ocean PHILLS-2 Ratio Product. Ratio of total upwelling irradiance of 490 to 550 nm ( $L_{490}/L_{550}$ ); used as an indicator of total pigmented particulate material in the water column.**



*Figure Y1-3. The camera response for the 550 long pass filter. The zero order effect can be seen in the blue to green part of the spectrum where the observed filter response differs from the real filter response. Also seen, the observed filter responses match each other – regardless of the lamp setting. This suggests that zero order effect is linear with respect to intensity*



*Figure Y1-4. The camera response for the 550 long pass filter after the application of zero order mask to the CCD camera. The zero order effect is reduced, but has not been eliminated.*



*Figure Y1-5. Spectral Radiance of NIST Calibration Sphere. Note the maximum is near 900 nm.*

## WORK COMPLETED and RESULTS-Year 2

Our focus over this past year has been on the calibration, processing, and distribution of the Ocean PHILLS-2 data sets collected during the previous year (April 2001, WFS, and July 2001, NJB). While working with these datasets, we encountered numerous complications that impeded the efficiency in which we have been able to distribute them. Although we found this initially frustrating, our efforts to systematically address these issues have resulted in an improved and more robust data stream. To date we have been able to deliver to the other HyCODE researchers version 1 of the April 2001 WFS dataset and version 1 and version 2 of the July 2001 NJB data. We are finalizing version 3 of the July 2001 NJB data and hope to be able to distribute it shortly.

One of the major concerns addressed last year was the effects of stray light within the sensor. During the pre flight laboratory calibration (see FY2001 report), we demonstrated that there was a significant amount of stray light present within the sensor. We hypothesized that this was the result of reflections within the system's housing of undiffracted light (zero order effect). In an attempt to correct this, a mask was placed within the sensor to shield the charged coupled device (CCD) camera from this flaw. As can be seen in Figures Y2-1 and Y2-2, this greatly reduced the effects of stray light; however, it did not completely eliminate it.

In a continuation of our efforts to calibrate the sensor, we have come up with a novel technique for characterizing and correcting the effects of the residual stray light within the sensor. The diffraction grating of any spectrograph is not 100% efficient, and thus, it distributes photons into CCD elements outside of their desired spectral position. We hypothesized that this "out-of-band" response is the cause for the disagreement between the perceived and true filter transmission curves (Figure Y2-2). However, directly measuring the probability function that would be needed to correct this misdirection of photons is very difficult. The approach we developed uses a genetic algorithm that solves a series of equations that employs sensor data of a stable light source (integrating sphere) at different intensities as viewed through multiple filters. This genetic algorithm generates a probability matrix that best solves the perceived-filter to true-filter transmission comparison (Figure Y2-3). The probability matrix is then used to correct all of the calibration data (as well as, all the field data).

Using this corrected data, a linear regression is performed for every element of the CCD (Figure Y2-4). It is this relationship that relates the digital counts collected by the camera to the physical reality.

After applying the radiometric calibration to the datasets, it became apparent that there was a significant shift in the camera-spectrograph relationship that occurred sometime between the laboratory measurements and the July 2001 NJB experiment (Figure Y2-5). The PHILLS sensor design was developed to take advantage of off-the-shelf components in an effort to make the instrument affordable and easily reproducible. The drawback to this approach is that the system is not completely integrated. This raises the possibility of the occurrence of a physical shift in the spectrograph-camera relationship. A great deal of effort was spent in trying to correct this problem in the data. The correction essentially required the projection of the laboratory calibration to the physical relationship of the spectrograph-camera as seen in the field (Figure Y2-6). Although it is hoped that such a correction will not be needed in the future, the process can also be used to correct the effects of the smile and the keystone, inherent in all spectrographs, in this and future datasets.

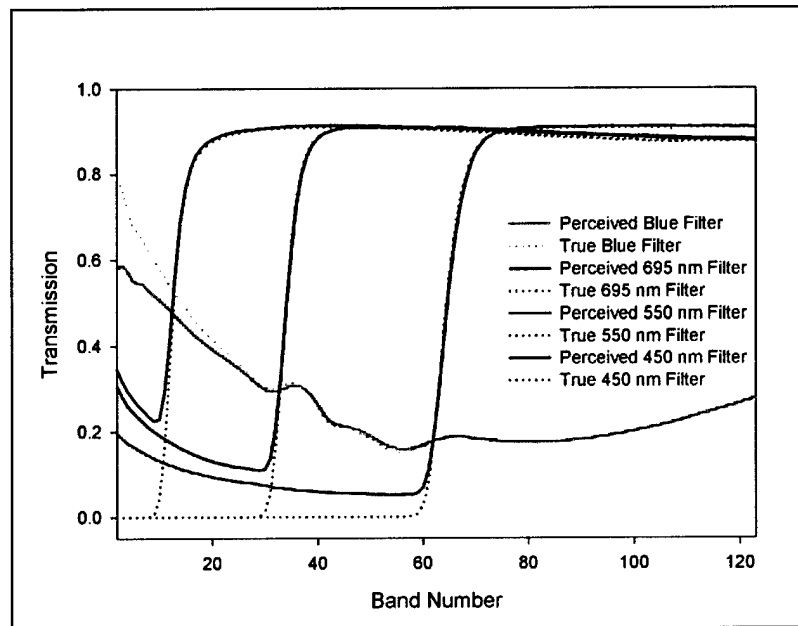
Another issue that was addressed with the data prior to its release dealt with geocorrection. The PHILLS instrument is built around the Windows NT operating system. The Windows family of operating systems do not place time keeping as a high priority. This creates a problem when trying to relate the PHILLS data stream and its Windows generated time stamp with the inertial measurement unit and global positioning system (IMU/GPS) data. The tedious effort of finding multiple ground control points for every line of data flown was necessary to estimate the effect of Windows time lag. With this estimated, the geocorrection could be properly applied. Since these experiments, a GPS timing computer card that takes over Windows timing functions has been purchased, and thus, this complication should no longer be an issue.

The final major issue that we addressed in regards to the PHILLS II data processing was atmospheric correction. Although this is ongoing work for us, we have made some major strides in this area. Our work has focused on the use of an NRL developed atmospheric correction algorithm (TAFKAA). In order to determine the amount and type of atmosphere to remove, TAFKAA evaluates the responses detected at the longer visible and infrared wavelengths. Water has a very low optical signal at these wavelengths, and thus, it is commonly assumed that the majority of the signal here is due to the atmosphere. Unfortunately, the relatively low response of the total signal here also means unaccounted for system noise (dark current) will also be most detectable here. In a response to this, we have developed a mechanism to spatially smooth bands in which the presents of previously unaccounted for noise is measurable. The model is iterated through until the signal to noise level for the band is deemed acceptable at which time TAFKAA is applied.

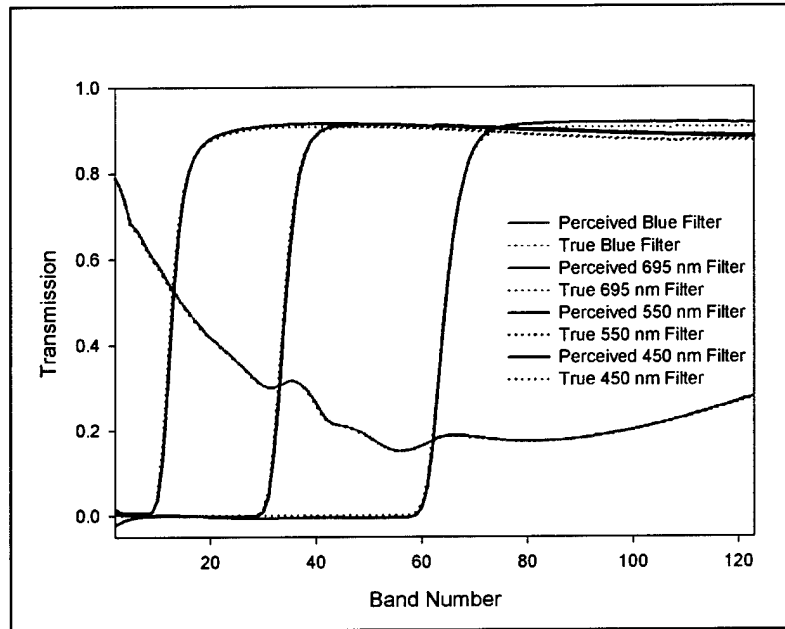
TAFKAA, itself, has several limitations that have become apparent in our analysis. The way TAFKAA deals with both the sun and sensor geometries need to be refined. Also, the wind speed, which is crucial in the determination of the downwelling irradiance, needs to be reevaluated. All of these issues are active research items both here and at NRL.

And finally, TAFKAA relies on a measure of the full width half maximum (FWHM) of the spectral response per wavelength in converting its look up tables to match the sensor's output. Unfortunately, we did not have the equipment necessary to collect these measurements during the calibration, and thus, we relied on an approximation of this metric. However, when evaluating the TAFKAA derived results, it was determined that our approximation was inaccurate. The inaccurate FWHM resulted in spiky spectra (Figure Y2-7). Through an extensive investigation, we were able to derive a FWHM like

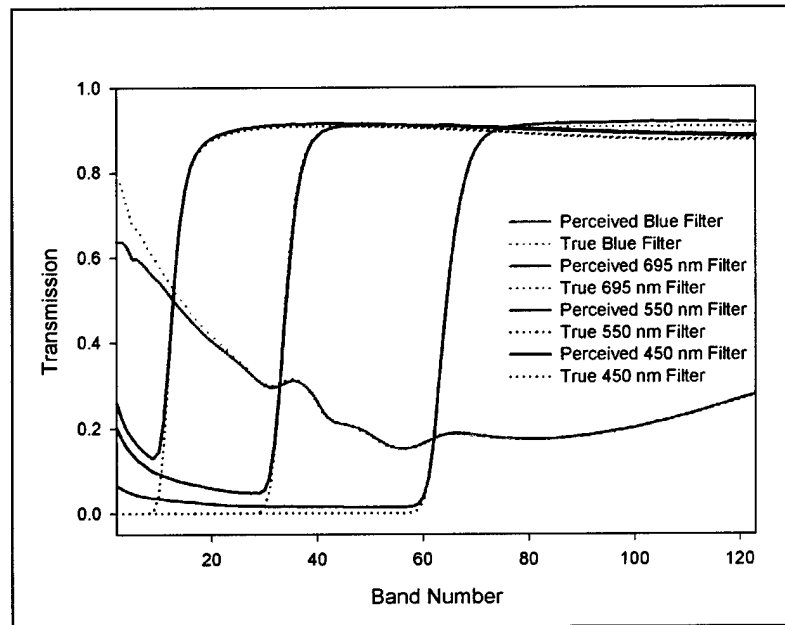
measure. The new measure was both spectrally variant and larger than what we had been using (Figure Y2-8). With the FWHM adjusted for, the spectra's spikiness was diminished (Figure Y2-9). We have now secured a way to make a direct measurement of the FWHM for future calibration. This will hopefully eliminate the need for the estimation procedure developed for this experiment.



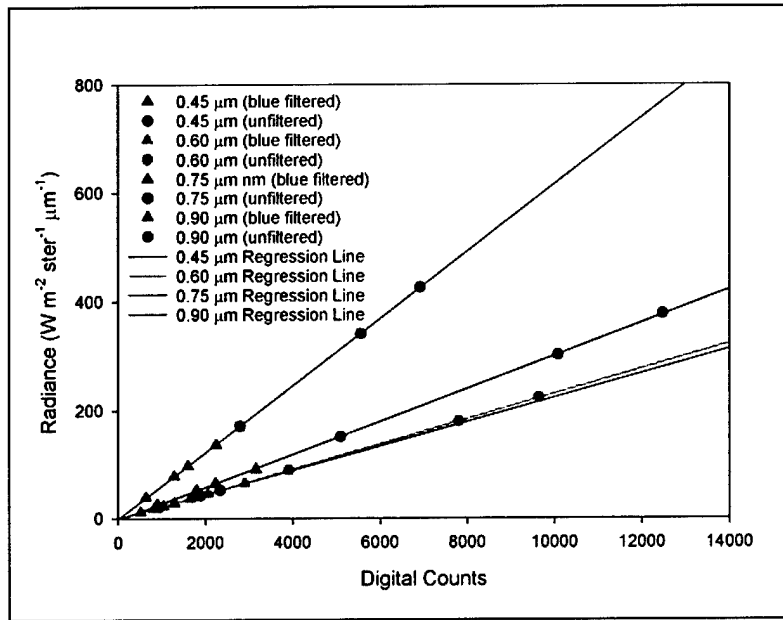
***Figure Y2-1: The original perceived filter and true filter responses for three cutoff filters and a blue balancing filter. Differences between perceived and true filter responses revealed that a significant amount of undiffracted light was present (zero order effect). The perceived filter values were calculated by dividing the light collected by the PHILLS with the filter in front of the sensor by the light collected without the filter.***



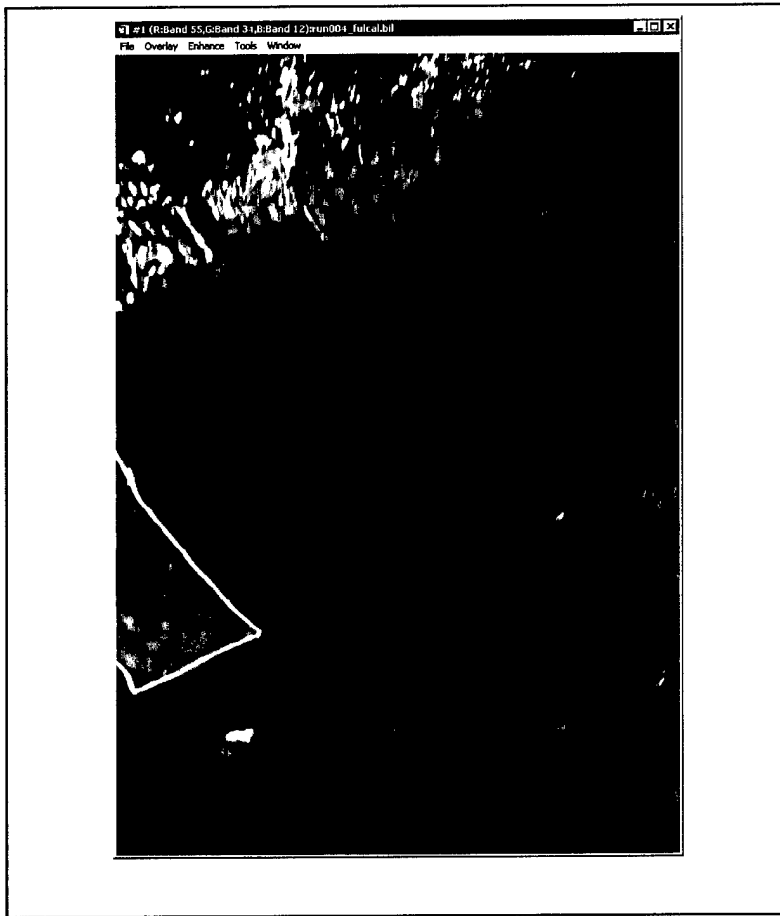
**Figure Y2-2:** The post mask perceived filter and true filter responses for three cutoff filters and a blue balancing filter displaying a decreased effects of stray light on the CCD camera after the application of the mask to the PHILLS sensor.



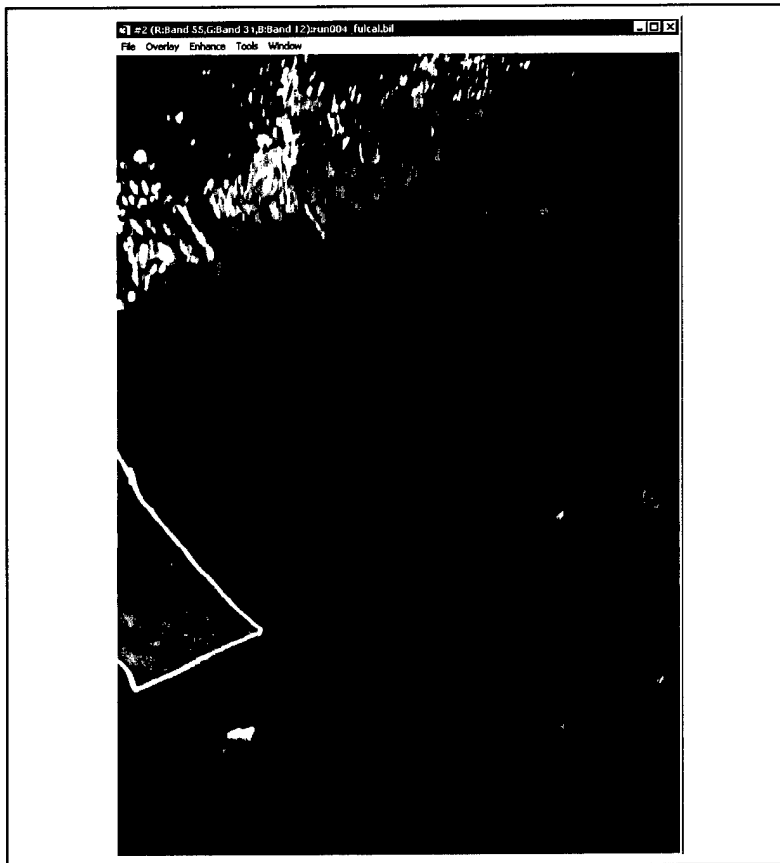
**Figure Y2-3:** The post out-of-band response perceived filter and true filter responses for three cutoff filters and a blue balancing filter after the application of a genetic algorithm was used to best solve the discrepancies between perceived-filter to true-filter responses and provide a matrix of stray light correction factors for every spatial and spectral viewing element in the PHILLS.



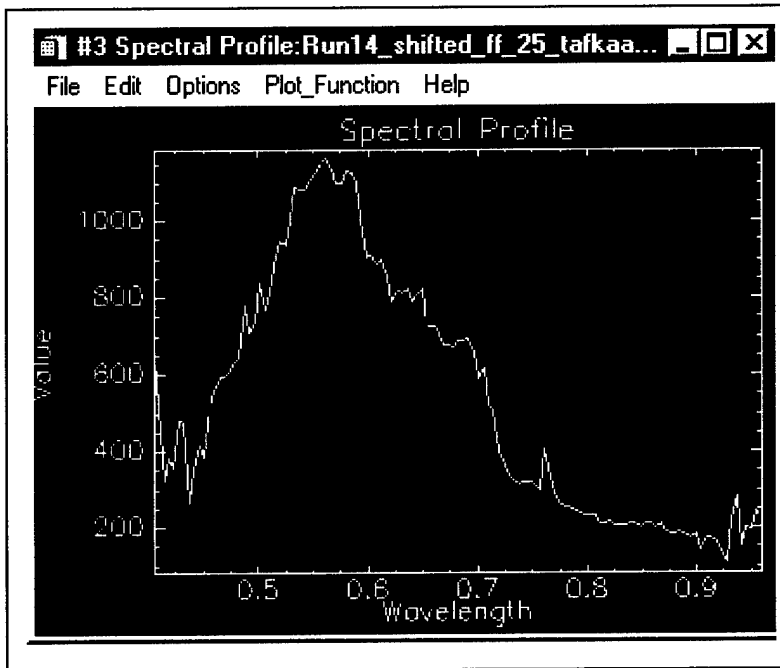
**Figure Y2-4: The regression lines for four different input spectra at a single spatial position. These regression lines for all elements of the CCD revealed a positive correlation between digital counts and radiance which can then be correlated to physical reality. Prior to the use of the genetic algorithm each input spectra would have yielded a different retrieved radiance.**



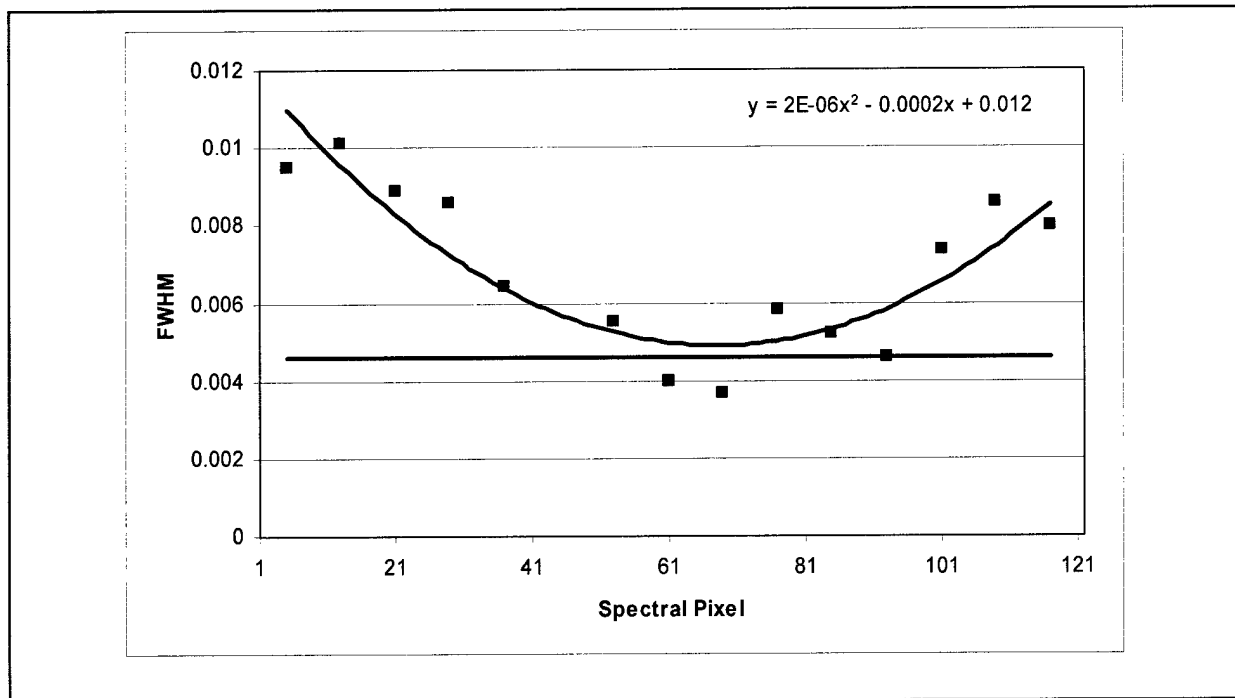
*Figure Y2-5: A subsection of a flight line before the radiometric calibration was applied. The vertical banding present is an indication of a mismatch between the field and laboratory calibration. This mismatch appears to have occurred as a result of a physical shift between the spectrograph and the CCD camera during shipping and loading of the PHILLS onto the NOAA Citation.*



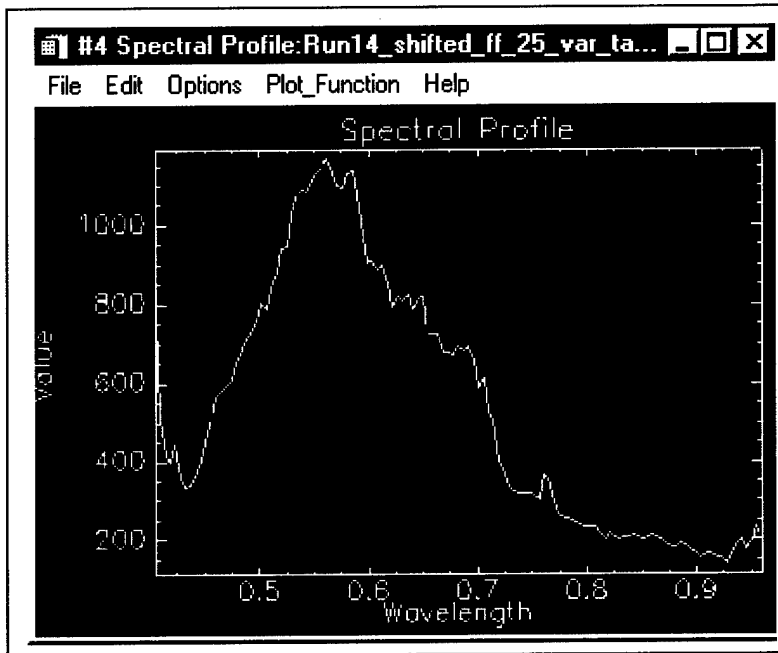
*Figure Y2-6: A subsection of a flight line after the radiometric calibration was applied correcting for the physical shift in the spectrograph-camera. The banding of the previous image has been removed.*



**Figure Y2-7:** An example of TAFKAA corrected PHILLS II water spectra using the FWHM approximation displaying spikeness in the spectra Rrs profile. Data displays a value of ~ 550 at a wavelength of ~ 0.45, a value of 1200 at a wavelength of ~ 0.55 and a value of 700 at a wavelength of ~ 0.65 (values are Rrs \* 10,000).



**Figure Y2-8:** A comparison of the original approximation of the FWHM (red line) ( $y \approx 0.0045$ ) and the indirectly measured FWHM (blue squares and black line) ( $y = 2E-6x^2 - 0.0002x + 0.012$ ). The indirect FWHM was arrived at by running multiple solutions of TAFKAA and varying the FWHM by small increments until the resulting spectral Rrs profile yielded a minimization of band by band changes.



*Figure Y2-9: The same spectra as viewed in Figure Y2-7 except the indirect FWHM measure was utilized generating less spikiness in the spectra Rrs profile. Data displays a value of ~ 500 at a wavelength of ~ 0.45, a value of 1200 at a wavelength of ~ 0.55 and a value of 725 at a wavelength of ~ 0.65 (values are Rrs\*10,000).*

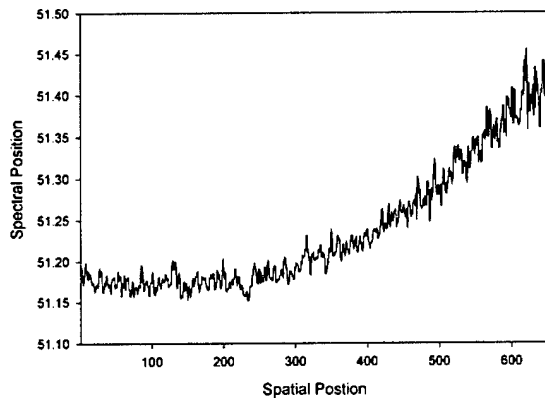
### **WORK COMPLETED and RESULTS-Year 3**

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).

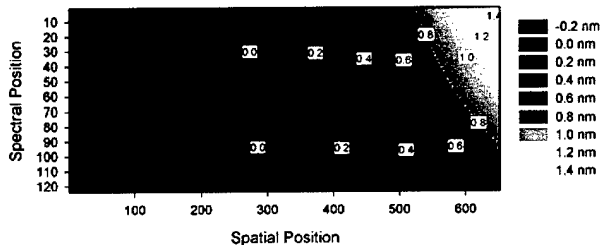
One of the major concerns addressed last year was the effects of stray light within the sensor (see FY2002). We had developed a system of laboratory measurements that utilized a series of filters in order to characterize the amount of stray light present within the PHILLS II instrument. The result of 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 Y3-1 and Y3-2). 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 – TAFKAA spectral mismatches.



**Figure Y3-1: 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 Y3-2: 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.**

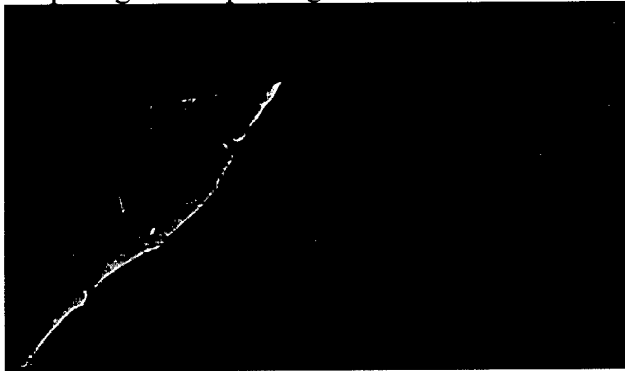
Proper atmospheric correction is crucial to the usefulness of remotely sensed data. It is especially critical over the relatively dark ocean and coastal scenes. The atmosphere can account from 80-100% of the retrieved signal in these areas (Morel, 1980), and thus, inaccuracies in the removal of the atmosphere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

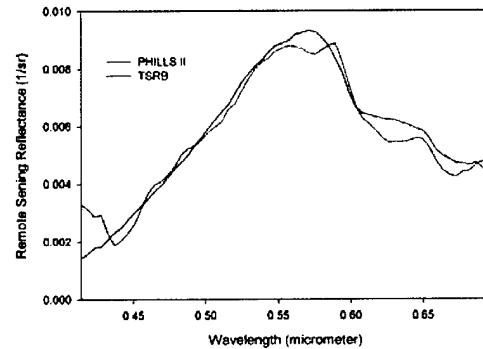
One of the attractive features of TAFKAA model is its ability to automatically select parameters based upon the scene itself. It accomplishes this by using the "black pixel" assumption (Siegel et al., 2000). The assumption states that passive optical returns in the infrared section of the spectrum should 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"), TAFKAA 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 their 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



**Figure Y3-3: 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 Y3-4: The comparison of the best GA TAFKKA 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 1: The parameters for the LEO -15 Tuckerton, NJ (July 31<sup>st</sup> 2001) derived using the genetic algorithm coupled with NRL's atmospheric correction program, TAFKKA.**

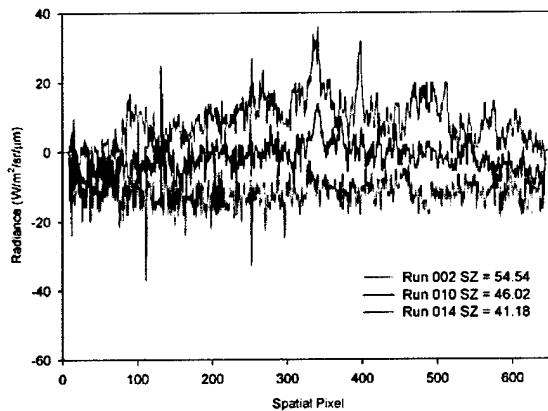
atmosphere for a particular day across the study sites had to be made. Parameter sets that produced results that resembled the ground truth data were maintained and evolved; the remaining sets were eliminated. A more detailed discussion of this procedure can be found in FY2003 ONR-OP28.

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 Y3-3).

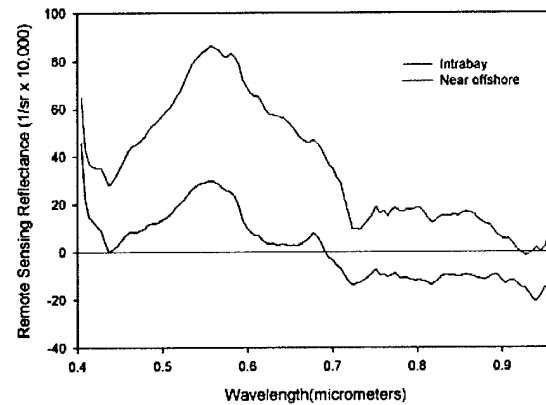
After applying the parameters in Table 1, there still appeared to be some issues left to address prior to the data set's release. First, a brightening of the data towards the center of the instruments swath has been detected (see Figure Y3-4). As can be seen in Figure Y3-4, the effect becomes more noticeable 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 Y3-4). 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



**Figure Y3-5: 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 Y3-6: 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.**

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.

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](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](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).

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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.