

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 RS [HRS] 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 HRS 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 HRS 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. HRS 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 (Gould and Arnone, 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

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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 RS [HRS] 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].				
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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 HRS 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

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 1 and 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 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 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 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 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 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 presence 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 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 8). With the FWHM adjusted for, the spectra's spikiness was diminished (Figure 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.

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 HRS data should yield simultaneous solutions for atmospheric optical properties. This program is devoted to collecting the HRS data and developing these new algorithms.

TRANSITIONS

The hyperspectral flight data collected on April 2001 (WFS) and July 2001 (NJB) has been distributed to multiple HyCODE investigators in DVD sets.

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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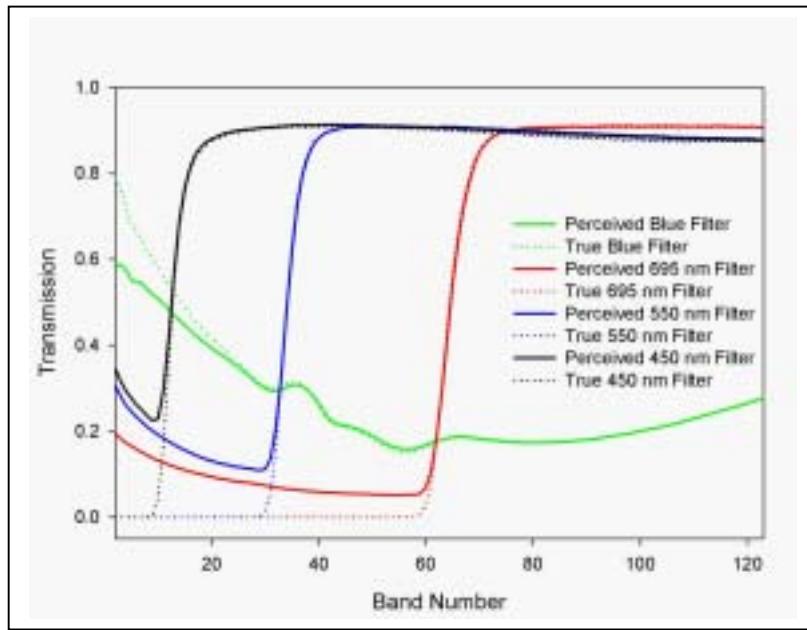


Figure 1: The original perceived filter and true filter responses for three cutoff filters and a blue balancing filter. Differences between perceived and true filter responses revealed that a significant amount of undiffracted light was present (zero order effect). The perceived filter values were calculated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

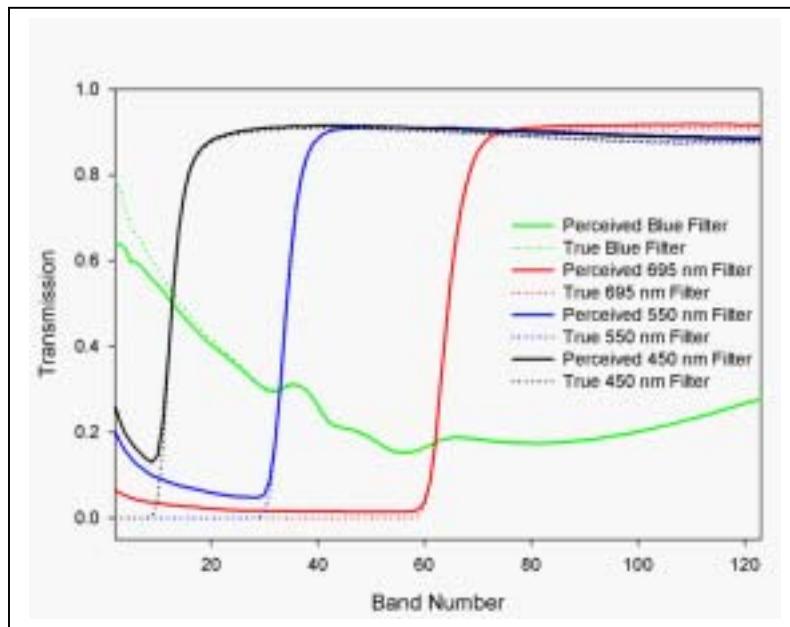


Figure 2: The post mask perceived filter and true filter responses for three cutoff filters and a blue balancing filter displaying a decreased effects of stray light on the CCD camera after the application of the mask to the PHILLS sensor.

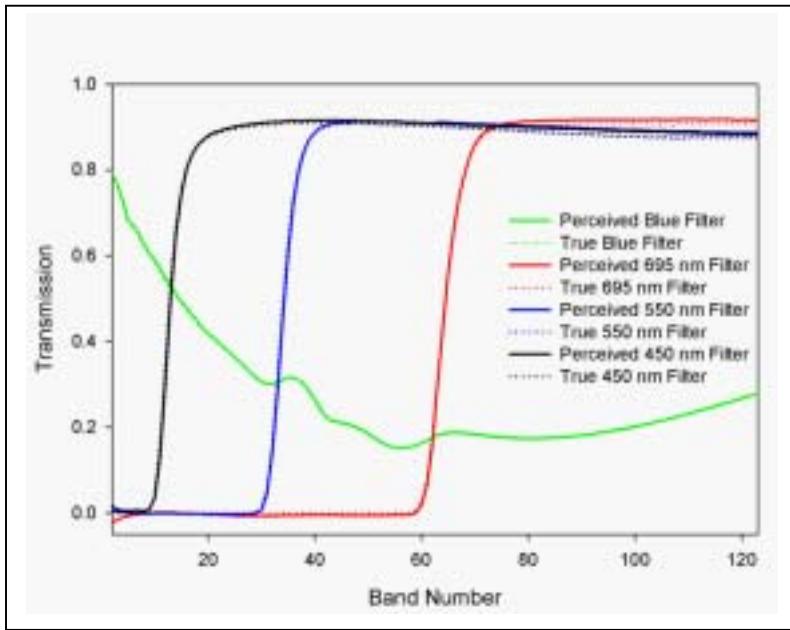


Figure 3: The post out-of-band response perceived filter and true filter responses for three cutoff filters and a blue balancing filter after the application of a genetic algorithm was used to best solve the discrepancies between perceived-filter to true-filter responses and provide a matrix of stray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

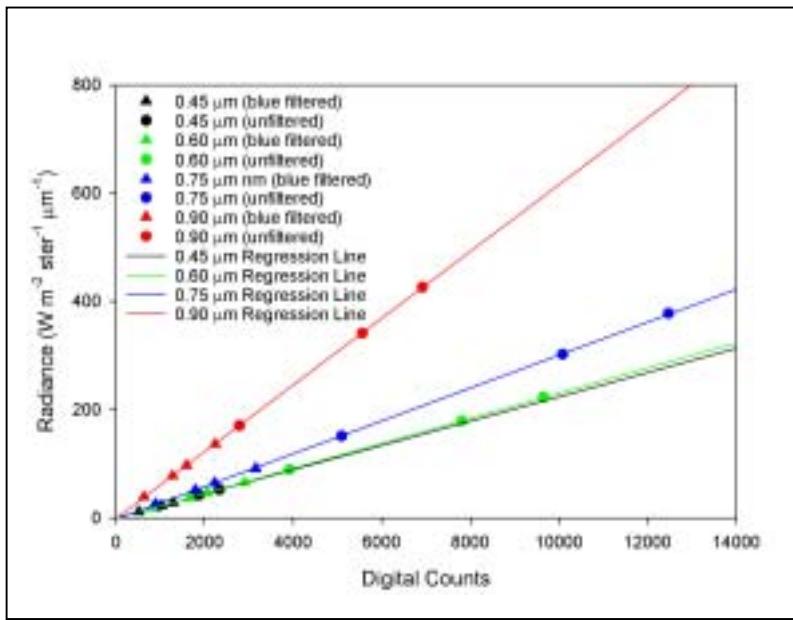
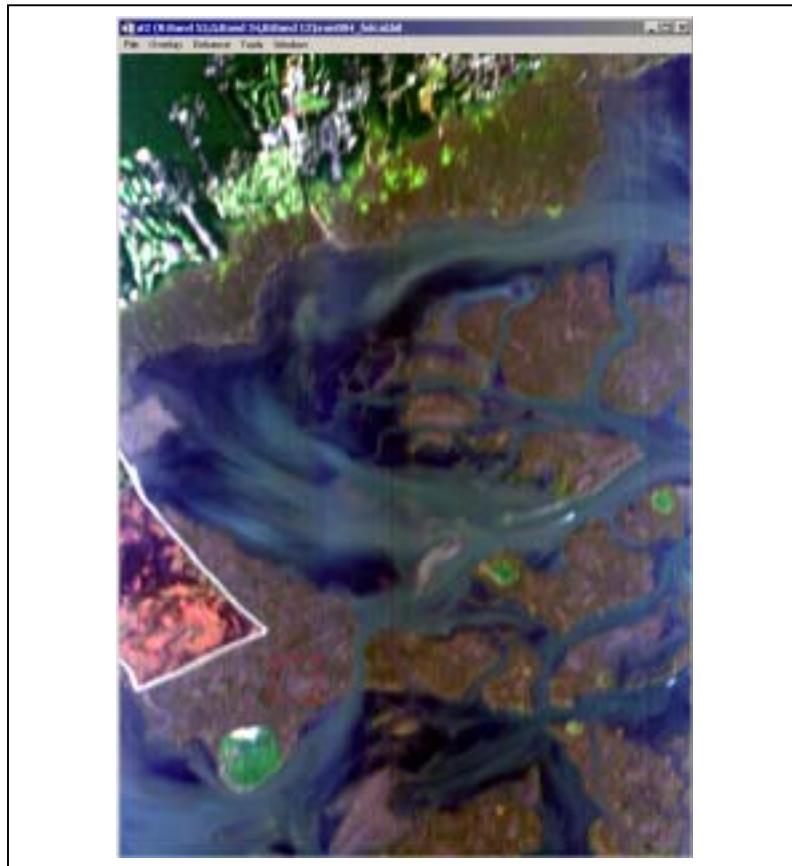


Figure 4: The regression lines for four different input spectra at a single spatial position. These regression lines for all elements of the CCD revealed a positive correlation between digital counts and radiance which can then be correlated to physical reality. Prior to the use of the genetic algorithm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



Figure 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 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.*

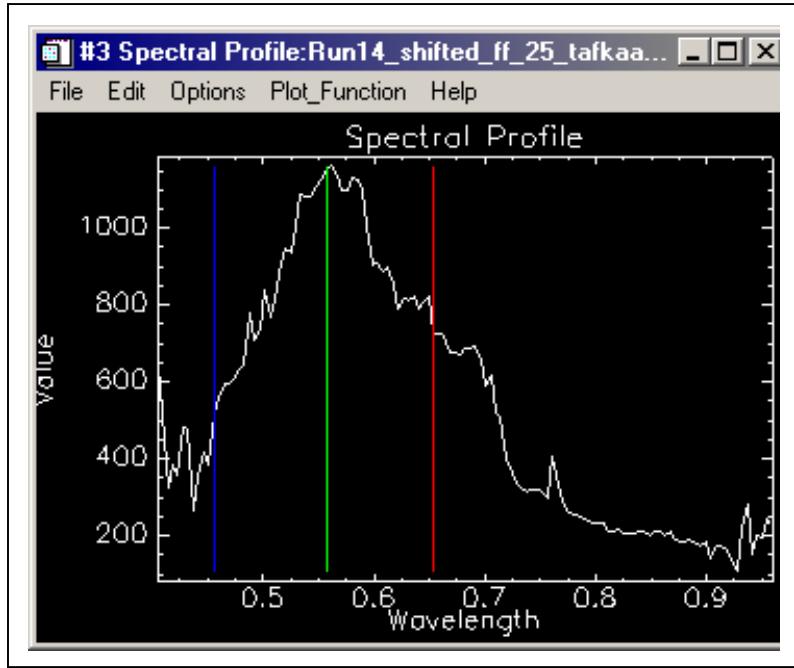


Figure 7: An example of TAFKAA corrected PHILLS II water spectra using the FWHM approximation displaying spikiness in the spectra Rrs profile. Data displays a value of ~ 550 at a wavelength of ~ 0.45, a value of 1200 at a wavelength of ~ 0.55 and a value of 700 at a wavelength of ~ 0.65 (values are Rrs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

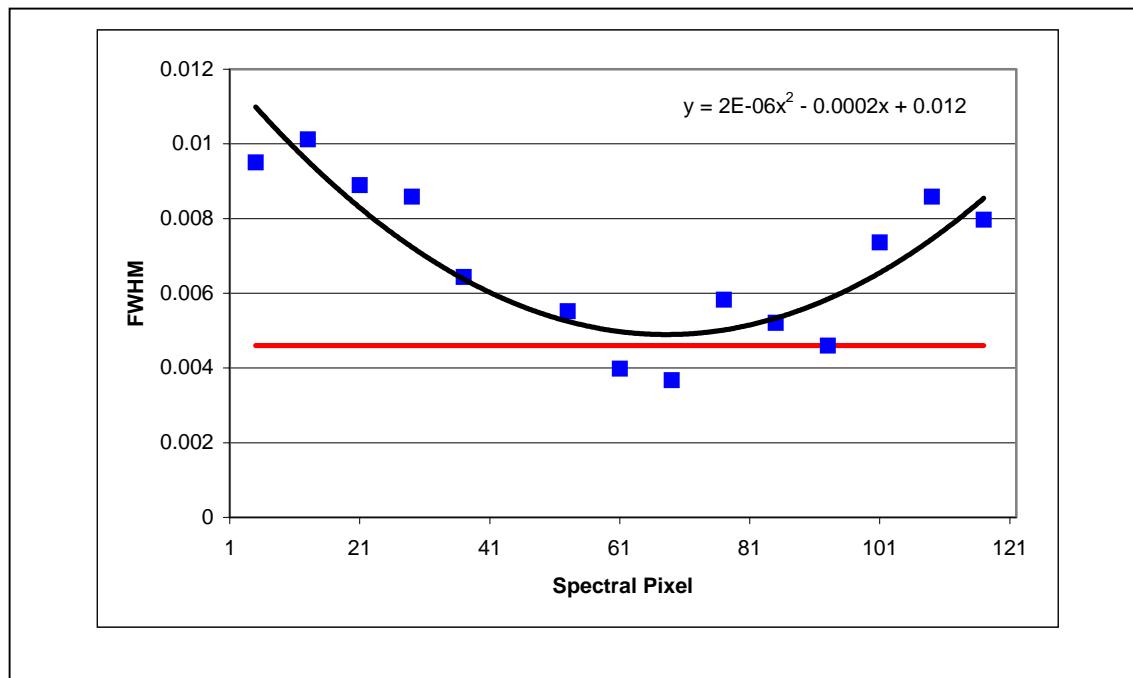
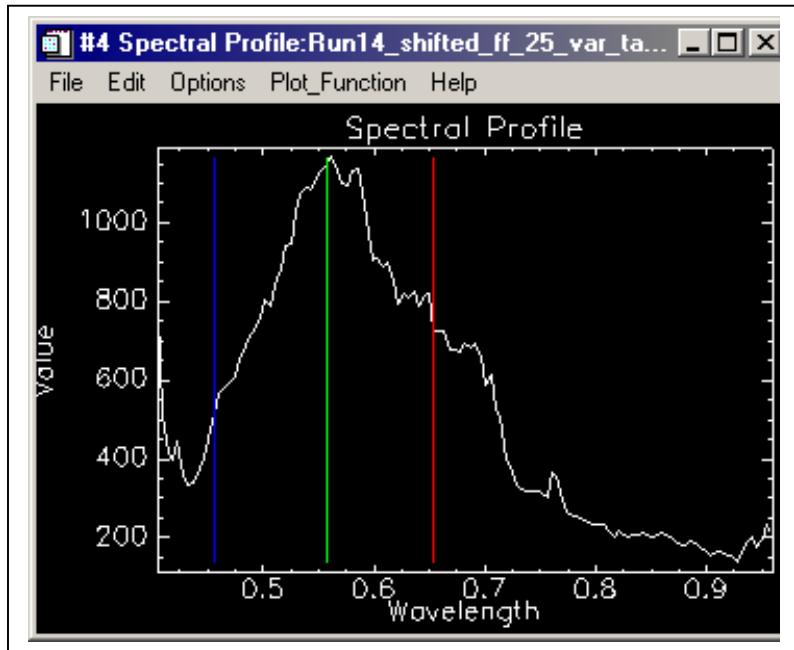


Figure 8: A comparison of the original approximation of the FWHM (red line) ($y \sim 0.0045$) and the indirectly measured FWHM (blue squares and black line) ($y = 2E-6x^2 - 0.0002x + 0.012$). The indirect FWHM was arrived at by running multiple solutions of TAFKAA and varying the FWHM by small increments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



*Figure 9: The same spectra as viewed in Figure 7 except the indirect FWHM measure was utilized generating less spikeness 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).*