**HICO Data User's Proposal**

Using spatial coherence in HICO Data to characterize turbidity events and develop water transparency parameterizations for remote areas with highly variable turbidity

**Principal Investigator**

Karen Fisher Favret
Département de sciences biologiques
Université de Montréal
C.P. 6128, succ. Centre-ville
Montréal Québec H3C 3J7
CANADA
1-514-378-8887 phone
1-514-343-2293 fax
karen.fisher@umontreal.ca

**Co- Investigator**

Eric C. Milbrandt
Sanibel-Captiva Conservation Foundation
900A Tarpon Bay Rd.
Sanibel, FL 33957
1-239-395-4617 phone
1-239-395-4616 fax
emilbran@sccf.org

**ABSTRACT:** The goal of this research is to gain a better understanding of how turbidity events visible in remote-sensing data affect water properties, ultimately to provide better parameterization for optical models. Using the River Estuary Coastal Observing Network (RECON) of seven Satlantic LOBO (Land/Ocean Biogeochemical Observatory) sensors in place since January 2008, and available ocean color and HICO data, we will 1) identify and characterize turbidity events in the *in situ* record; 2) characterize the local coherence structure of relevant wavelengths in the remote sensing data during all phases of turbidity events using a semi-discrete wavelet transform developed at Los Alamos National Laboratory (LANL) [1]; and 3) compare the local coherence structure among wavelengths during phases. Comparing the local coherence structure of physically and biologically dominated wavelengths, we expect to obtain a useful parameterization of turbidity that can be utilized in optical models for remote areas where *in situ* data are not available. HICO data has an exceptional potential for yielding parameterizations that can be used in operational models due to its spatial and spectral resolution. We plan to leverage the insight gained from analysis of HICO data to find workable strategies for other sensors with less resolution as well as providing a novel approach for hyper-spectral processing.

**GOALS:** The goal of this research is to characterize three parameters over relevant spatial and temporal scales for optical models: chlorophyll, suspended sediment, and CDOM. Given the highly episodic nature of events that cause dramatic shifts in these parameters, the ability to effectively use determine the dominant scales of the physical forcings, and the dynamic range of the variables of interest that result, using stand-alone remote-sensing data is necessary in order to improve both academic and operational models.

**STATEMENT OF WORK:** We propose to use the considerable in situ data compiled by the Sanibel-Captiva Conservation Foundation (SCCF) to determine the feasibility of extracting usable characterizations for chlorophyll, suspended sediment, and CDOM in three phases. The first phase is to characterize the historical and ongoing *in situ* SCCF network record on seasonal and event-based scales. The second phase is to examine the contemporaneous ocean color data for past events, and then inter-compare ocean color and HICO data in future high and low turbidity phases. The third phase is to apply our wavelet-based analysis to characterization of our study region and several remote regions. If successful, our analysis of the study region where we can validate the technique can be used to provide guidance on how to characterize chlorophyll, suspended sediment, and CDOM based on HICO alone, and if warranted, other ocean color sensors. Ultimately we hope to assess the feasibility and accuracy of using our method on hyper-spectral data alone to characterize chlorophyll, suspended sediment, and CDOM, and provide a quantitative comparison to making the same characterizations using multi-spectral platforms alone. We plan to use HICO data to gain enough insight to develop usable characterizations from other ocean color sensors, as well as to develop methods specific to HICO that can allow us to more fully exploit hyper-spectral data for operational models in the future.

Given the inherent difficulties in gaining access to reliable *in situ* data in many areas of interest, extracting useful characterizations after deploying wavelet analysis on a variety of multi and hyperspectral remote-sensing data has some advantages. Wavelet analysis: 1) can be used in "exploratory" mode, indicating the existence of patterns and anomalies not known beforehand; 2) is localized in scale, and in sample space, so that rare events and abrupt gradients can be detected and characterized; 3) is flexible enough to be tailored to patterns of interest once they are determined, so templates can be built for certain types of patches, and 4) links to fractal and multi-fractal analysis for statistical characterizations of patchiness, for detection of anomalies, and for realistic construction of fields for inputs to models.

**BACKGROUND:** The wavelet transform provides a microscope localized in space (or time) and in scale. For data analysis purposes, the LANL *LDRD-DR Physics-based analysis of dynamic experimentation and simulation* team developed the semi-discrete wavelet transform (continuous in space but analyzed at discrete scales of interest dictated by the resolution and extent of the observations) into a workhorse for local characterization of features [1]. The LDRD applied these methods to experiments and simulations of: fragments (pRad data), shock fronts, (laser ablation, shock tube), and geophysical fields (MODIS observations). Wavelets filters change in scale and convolve every point of the data series or image, ranging from simple (modified Haar wavelet, [-0.5 1 –0.5] in 1D at scale 1) to complex (a 2-D Kelvin-Helmholz instability template). After convolution of the data with the filter, a scale specific map of the transform values is obtained for each point in the data series. The square of the wavelet transform gives values akin to the power at each scale, at each point. A fractal series has a power-law dependence of power-spectral density on scale (as an FFT would on frequency).

In this manner, wavelets are able to distinguish regions of interest in the data. By analyzing the local scaling relationship of every data point to its neighbors (a highly redundant process), these techniques easily distinguish regions that are structured primary by either 2-D or 3-D turbulence from one another in a variety of contexts. In addition, it is sometimes possible to distinguish regions structured primarily by specific biological or physical processes, either with the addition of ancillary data to support the separation, or by analyzing local decorrelations between fields at different frequencies or wavelengths specific to the task [2].

**BENEFITS OF HICO:** Current research is applying these methods to a variety of datasets, including multi-spectral ocean color data (for detection of high turbidity events), high frequency acoustic data (for separation of physically and biologically-driven structures), and hopefully HICO (for further understanding of turbidity events). Turbidity is notoriously difficult to monitor; the influence of turbidity creating events is even harder to predict. While critical for understanding coastal ecosystems, finding *in situ* data even to provide empirical calibrations for most events is not possible. We need to exploit the information in systems like HICO to allow us to provide first order estimates of coastal turbidity. Ultimately, if resources were adequate, it would be of interest to provide global coastal ocean products similar to those provided on the ocean color web based on the spatial entirety of HICO data. Many remote sites of interest are difficult to access. IOP models could benefit from incorporating characterizations from remotely sensed data if our academic understanding of these areas allows us to improve the model parameters, and therefore their outputs.

**PROPOSED USE:** In 2007, the SCCF Marine Laboratory launched the River Estuary Coastal Observing Network (RECON) project to track changes in water quality from Lake Okeechobee to the Gulf of Mexico. The RECON network is composed of moored sensors capturing hourly biogeochemical data, resulting in a fully integrated, portable, real-time water quality monitoring system. Seven of Satlantic's LOBO platforms have been deployed since 2008 at fixed locations, which include the Caloosahatchee River (Moore Haven, Ft. Myers, Shell Point), Pine Island Sound Aquatic Preserve (Redfish and Blind Pass), Tarpon Bay and San Carlos Bay (Gulf of Mexico). Together, these sites have gathered an impressive, nearly uninterrupted record of the turbidity cycles upstream, downstream, and in the Bay. To make full use of this network, we would like to initially request HICO data for the region bounded by: 27.25 N, 25.25 N, 83.5 W, 81.5 W, and the surrounding areas as possible.

**BIOGRAPHICAL SKETCHES:** Karen Fisher Favret is currently a visiting scholar at the University de Montréal. She has an MSc in Biological Oceanography from Dalhousie University, working in the lab of Marlon Lewis and John Cullen. Her masters thesis focussed on estimating global new production using available ocean color and *in situ* data [5]. Her PhD at Cornell University shifted to development of non-linear methods to characterize large datasets, starting with high-frequency acoustic backscatter and associated along-track data (fluorescence, temperature, salinity) over multiple scales [4]. This research led to two post-docs, one at the Romberg Tiburon Center (SFSU) working on historical and ongoing *in situ* USGS data in San Francisco Bay, and another at Los Alamos National Laboratory (LANL) developing non-linear characterizations for a variety of stochastic systems [1, 3]. Following conversion to LANL staff, she worked with the IC in Washington DC for several years before becoming a consultant. Now at the University of Montréal she is a visiting scientist, continuing to pursue the development of improving methods for exploiting large data sets, using multi-scale analysis to maximize insight into stochastic systems when *in situ* calibration is not possible. Favret's personal computer has her Matlab scripts to perform the proposed analysis. The University has additional computational resources that will be leveraged as needed, and the PI is in the process of obtaining an account at Compute Canada.

Dr. Eric Milbrandt began his career in marine science in N. California at Humboldt State University. His first course in InvertebrateZoology at the Telonicher Marine Laboratory in Trinidad helped to inspire a career in marine science. He received an REU fellowship to study marine science using molecular tools at the University of Wisconsin-Milwaukee and the Center for Great Lakes Research with Dr. Chuck Wimpee. The internship led to a directed senior undergraduate research project on rocky intertidal seaweeds under the direction of phycologist, Dr. Frank Shaughnessy. Dr. Milbrandt decided to pursue a graduate degree in marine science. He was accepted at the University of Oregon to study at the Oregon Institute of Marine Biology in Charleston, OR. During his Ph.D., Eric received a Graduate Research Fellowship from the South Slough National Estuarine Research Reserve to study the microbial ecology of the South Slough Estuary. While writing his dissertation, he was offered the position of Research Scientist at SCCF. He returned to OIMB to defend in the spring of 2003 and has been contributing to the SCCF ever since. During his transition to Florida, Dr. Milbrandt established several permanent mangrove forest plots to study the effects of human activities on mangrove reproduction, recruitment and forest structure. He has published numerous peer-reviewed journal articles on the recovery of mangroves after hurricane disturbance and the effect of sea level rise on black mangrove recruitment. He has also led several grant-supported efforts to restore the tidal hydrology to Clam Bayou, then to enhance and restore mangrove shorelines. Part of the effort was in collaboration with Drs. Loren Coen, Steve Geiger and others to build oyster reefs and conduct extensive mapping and monitoring. At SCCF, Dr. Milbrandt has been instrumental in the establishment of RECON (River Estuary Coastal Observing Network) which is providing Real-time information to advance SCCF policies. This tool introduces the Marine Laboratory to difficult socio-economic challenges in the policy arena and helps support the collaborative meetings and influences of the Southwest Florida Stakeholders. RECON also enhances research at the lab including in numerous water quality studies around Sanibel and Captiva Islands and in cooperation with the USFWS in J.N. "Ding" Darling National Wildlife Refuge. In 2011, Dr. Milbrandt was named the third SCCF Marine Laboratory Director. He serves as a reviewer of manuscripts for Estuaries and Coasts, Limnology and Oceanography, Botanica Marina, the Journal of Wetland Ecology and Management, and Hydrobiologia. He is a Graduate Faculty at Florida Gulf Coast University and an affiliate member of the Coastal Watershed Institute.

**AVAILABLE FACILITIES AND ANCILLARY DATA:** The River Estuary Coastal Observing Network (RECON) is composed of seven **Land/Ocean Biogeochemical Observatory (LOBO)** sensors and one mobile unit. Originally developed by Dr. Ken Johnson's team at the **Monterey Bay Aquarium Research Institute**, and now commercially available from **Satlantic**, the Land/Ocean Biogeochemical Observatory was designed to create a real time sensor network for aquatic systems. Land/Ocean Biogeochemical Observatory uses a system of high quality, high temporal resolution in situ sensors to monitor fluxes. Water properties such as salinity, temperature, and current velocity are combined with nutrient measurements to monitor important processes that affect biogeochemistry. Parameters measured by the RECON:

- Physical measurements include **temperature**, **sensor depth**, **salinity**, current profile and **turbidity**.
- Chemical sensors include **colored dissolved organic matter (CDOM)**, **nitrate**, and **dissolved oxygen**.
- Biological measurements include **chlorophyll *a***.

The system uses robust, high accuracy, high stability sensors with integrated antibiofouling systems to maximize deployment time, minimize operational costs and provide high quality data sets. The sensor suite includes the WET Labs **WQM instrument** with an **ECO series** fluorometer and turbidity sensor with integrated bio-wiper™, integrated CTD and dissolved oxygen sensors with a comprehensive antifouling system (including copper cladding, a bleach injection system and a Tributyltin module) all designed to greatly extend deployment times in coastal environments. The system also includes the chemical-free nitrate sensor, which is pumped from the WQM to maximize antifouling capabilities. Water velocity profiles are collected using the **Nortek Aquadopp**.

The SCCF RECON network will provide the ongoing *in situ* data for testing and development of the proposed methods, with hourly data from deployed LOBO systems in the network starting in 2008. These data are quality controlled by the co-investigator and will be available for the duration of the study.

**OUTPUT AND DELIVERABLES:** Over the course of our project, we will:
1) identify and characterize turbidity events in the *in situ* record; 2) characterize the local coherence structure of relevant wavelengths in the remote sensing data during different phases of the turbidity cycle using a semi-discrete wavelet transform developed at Los Alamos National Laboratory (LANL); and 3) compare the local coherence structure between wavelengths to determine these relationships with regard to the turbidity cycle, and 4) exploit any of these relationships with quantitative links to observed chlorophyll, suspended sediment, and CDOM concentrations in the *in situ* data. Assuming we are successful, we will produce seasonal and event-based estimates for turbidity in the SCCF region, and make them available as needed.

**USING HICO TO ADVANCE THE MISSION:** HICO data offers a new approach to exploiting remote sensing data to improve estimates from a first-principles IOP model. We expect that both the spatial and spectral resolution will be instrumental in allowing us to develop the characterizations to a point where they can be operationally useful.

**RETURNS TO HICO PROGRAM:** Any algorithms found to be of benefit to the academic community will be published, and the data produced will be made freely available to the HICO community as directed. Validations will similarly be made available to the HICO community. We also hope to demonstrate effective techniques that can be adapted by the hyper-spectral community for other applications, and for similar applications in other geographic regions, and look forward to interacting with others in the HICO program to develop new avenues of research.

**ANNUAL MEETING:** The investigators will commit to make every effort to attend the annual meeting. We look forward to interacting with the community to develop effective techniques for high resolution hyper-spectral sensors in a variety of applications.

**REFERENCES**

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