Hyperspectral imaging of river systems

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ABSTRACT

Conventional ocean color imagers are good for characterization of the global ocean, but are of less utility in the coastal ocean. The coastal ocean is more dynamic and more spatially spectrally complex requiring higher frequency of sampling and higher spatial and spectral resolution (Davis et al. 2007). A particular problem has been river systems where it is essential to image the river mouth and estuary which often requires higher spatial resolution than the 1 km sampling of standard ocean color imagers. Furthermore standard processing algorithms do not work when there are high levels of suspended sediments in the river plume causing problems with atmospheric correction and the chlorophyll product algorithms. In September 2009 the NRL Hyperspectral Imager for the Coastal Ocean (HICO) was launched and installed on the International Space Station. HICO has the spatial and spectral resolution required for sampling the coastal ocean. Here we use HICO data and new algorithms for coastal regions to study two river systems, the Columbia River, USA where we have extensive ground truth and can validate algorithms and approaches and we will test our algorithms on the Yangtze River in China.

Statement of Work

We propose two tasks over the two year period:

1. Develop, test and evaluate algorithms for deriving optical properties, chlorophyll, suspended sediments and CDOM for coastal systems including river systems. We will work with HICO data and use the Columbia River system and adjacent coastal waters as a test system for this work.

2. As soon as it is available we will collect HICO data for the Yangtze River and adjacent coastal regions in China. Once we have developed the algorithms and approaches that work for the Columbia River we will test and evaluate those algorithms to the Yangtze. The goal is to validate our algorithms and to further our understanding of this important river and the East China Sea which are rapidly changing due to the development of the Three Gorges Dam and continued urbanization of China.

Background, Objective and Approach

After eleven years at the Naval Research Laboratory in 2005 I moved to a Research Faculty Position at Oregon State University. At NRL I lead the Hyperspectral Remote Sensing Technology (HRST) program to develop hyperspectral remote sensing for Naval applications. The focus was on airborne and spaceborne systems for rapid, covert characterization of the coastal environment. The team grew to 14 people and we developed the airborne Portable Hyperspectral Imager for Low-Light Spectroscopy (PHILLS; Davis, et al., 2002). The PHILLS was used extensively as part of the ONR CoBOP and HyCODE programs (e.g. Carder et al., 2003, Dierssen et al, 2003, Louchard et al, 2003). The work has included the development of algorithms for calibration and atmospheric correction of the data (Gao, et al., 2000), and through collaborations with others algorithms for processing the data to benthic and water column properties (Lee et al., 2005; 2007, Mobley, et al. 2005). This work lead to the development of the Hyperspectral Imager for the Coastal Ocean (HICO; Corson, et al. 2008) and I continue to participate as the HICO project scientist.

HICO is the first spaceborne imaging spectrometer designed specifically to sample the coastal ocean. HICO samples selected coastal regions at approximately 93 m with full spectral coverage (400 to 900 nm sampled at 5.7 nm) and a high signal-to-noise ratio to resolve the complexity of the coastal ocean. HICO was built, calibrated and tested in 16 months by the Naval Research Laboratory. HICO was completed in July 2008 and integrated into the HICO and RAIDS Experimental Payload (HREP) in August 2008. HREP was launched on the Japanese H-2 Transfer Vehicle (HTV) September 10, 2009. The HTV rendezvoused with the ISS on September 17, 2009. HREP was installed on September, 24, 2009 and the first HICO imagery was collected on September 25, 2009. HICO is operating normally and NRL has received over 2000 scenes to date.

In this study our objective is to take advantage of the higher spatial and spectral resolution of HICO data and new algorithms to study the dynamics of major river systems. Our approach is to use the Columbia River and Oregon coastal waters as a model system to test our algorithms and approaches and then apply them to the Yangtze River and East China Sea.

The Columbia River plume is one of the dominant features of the California Current System and it plays a key role in the physical and biogeochemical functioning of that system off the Oregon and Washington Coasts. The traditional picture of the Columbia plume is that it is oriented southwest offshore the Oregon coast in summer and north along the Washington coast in winter. Recent studies by Hickey et al. (2005) have shown that it is more complex and typically bi-directional in the summer with branches both north and south during the summer with the features moving in response to changing wind stress. The physics is now well known and the complex plume dynamics have been modeled in detail (Banas, et al, 2009). Tides, river flow, wind forcing and large scale circulation patters all play a role controlling the size and location of the plume.

Current studies conducted by the Center for Coastal Margin Observation and Prediction (CMOP, www.stccmop.org) have included characterization of the River water properties with sampling extending through the estuary and as much as 100 km up river. The CMOP Science and Technology Research Network (SATURN) includes modeling and an observation network throughout the estuary and into the plume. This network links with the offshore measurements models that are part of ORCOOS (agate.coas.oregonstate.edu). The intensive sampling from these programs and weekly sampling as part of the MILOCO program (Microbial Initiative in Low Oxygen areas off Concepción and Oregon, miloco.coas.oregonstate.edu) provide in situ and model data for the testing and validation of our remote sensing products for this region. We are supplementing those measurements by making profiles with a HyperPRO (Satlantic, Halifax, NS, Canada; Fig. 1) optical profiling system during MILOCO and CMOP cruises. The HyperPRO is a free falling optical profiling system that collects profiles of spectral Lu and Ed and chl fluorescence, backscatter, T and salinity. The system is calibrated by Satlantic and we use the Satlantic software for processing including all of the latest corrections based on NIST calibrations. This system produces high quality measurements of spectral remote sensing reflectance (Rrs) for direct comparison to the HICO data after atmospheric correction. The HyperPRO data together with other data collected on each station including HPLC pigments, productivity, CDOM and suspended sediments will be placed in a data base with web access for each program.

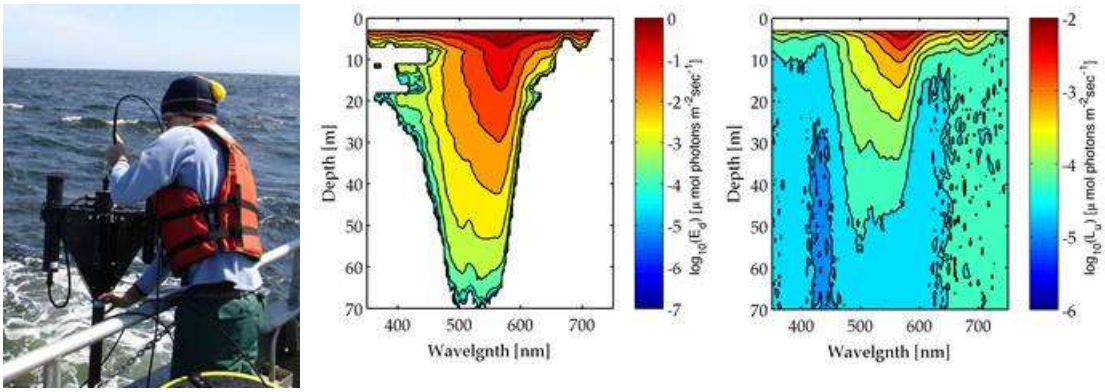

Figure 1. Collecting HyperPRO data and an example data set from the MILOCO cruise off the Oregon coast taken June 4, 2009.

Ocean color remote sensing has been used to establish the extent and seasonal location of the Columbia River plume (Thomas and Weatherbee, 2006). They note that the plume carries a mixture of fine silts, clays, phytoplankton, dissolved organic matter and nutrients into the coastal zone. The plume also affects light levels and stratification further affecting the productivity of the coastal region. Thomas and Weatherbee analyzed six years of SeaWiFS data and identified the plume by enhanced backscatter at 555 nm. They noted that standard algorithms for chlorophyll and other products did not work in the

plume and all of their analyses are relative; they were not able to produce estimates of chlorophyll, suspended sediments or other products. SeaWiFS does not have enough spectral channels to resolve the complex optical signature of the river plume. The also did not analyze the river mouth and estuary which ranges from 3 to 15 km wide extending around 100 km inland from the coast. The SeaWiFS 1 km pixels do not adequately image these features.

We propose overcoming these deficiencies by using HICO data. HICO data has 88 spectral channels and 93 m Ground Sample Distance (GSD) which will allow us to sample the Columbia River including approximately 100 km up the river including the estuary and mixing zone. The HICO data together with the CMOP cruises and the SATURN network we will provide a unique view of this estuary and enable us to use this as a model system for characterizing a major river system.

HICO data became available beginning in October 2009 following launch and system checkout in September. For this study we will use HICO calibrated spectral image cubes with 88 spectral channels of data. Several experimental products will be produced from that data. One approach is to use the Hyperspectral Optimization Process Execution (HOPE) algorithms developed by Zhong-Ping Lee to produce coastal products including bathymetry and bottom type for optically shallow water. These algorithms were developed using Hyperion data (Lee et al, 2007) and we expect them to work well with HICO data that will have much better radiometric quality and 20 times the signal-to-noise ratio of Hyperion data. These algorithms specifically include CDOM, chlorophyll and suspended sediments as well as bathymetry and bottom properties. For this project we will test and evaluate the products from the HOPE algorithms for the Columbia River system.

We have also been working with MERIS data for the Oregon Coast. The standard algorithms for MERIS like those for MODIS and SeaWiFS give false high chlorophyll values for the Columbia River plume primarily due to the high suspended sediments in the water which causes problems with both the atmospheric correction and chlorophyll algorithms. However, for European Coastal waters Doerffer and Schiller (2007) have developed case 2 water algorithms using a neural network approach that work well for MERIS data for European coastal waters. Their algorithms include a modified atmospheric correction that works over turbid and other coastal waters and in situ product algorithms including chlorophyll, CDOM and suspended sediments. Their networks are trained on European in situ data. Here we propose applying those algorithms to HICO data for the Columbia River system. We will do this in three steps. First we will apply their standard algorithm to MERIS full resolution data of the Columbia and evaluate those products against the in situ data. Second, we will modify the neural network to include in situ data from the West Coast of the US and specifically the Columbia River and Oregon coastal waters. Third, we will modify the algorithms to work with HICO data taking advantage of the full spectral data. This is a straight forward process as the neural network will include and take advantage of any data you provide it. This work with MERIS data for the Oregon coast is already underway funded by NOAA. We are beginning to collect full resolution MERIS data for the Oregon coast and apply the standard ESA algorithms. Also under NOAA funding Nick Tufillaro, who will conduct this work, has attended a workshop with Rolland Doerffer on the use of the neural network coastal algorithms and how to modify them for our region. Here we propose to apply our experience with MERIS data to modify the algorithms to work with HICO data for the Columbia River and Oregon coast.

Once we have our algorithms developed and tested on the Columbia River we will test them on another important river system. The Yangtze (Changjiang) River is the largest river in China and fifth largest in the world. It inputs a large amount of nutrients and sediments into the East China Sea (ECS) and the Straits of Taiwan which is home to one of the largest and most productive fisheries in the world. Construction and filling of Three Gorges Dam is dramatically reducing the water flow and nutrient input to the ECS affecting this important fishery (Gong et al, 2006).

Schedule and Plans

During the first year we will focus on processing and analysis of HICO data for the Columbia River system and adjacent coastal waters. First, we will test a neural network algorithm for HICO data based on the MERIS coastal algorithms developed by Doerffer and Schiller. Those algorithms are tuned for European coastal waters which include waters with very high sediment and CDOM levels. We will expand them to include the Columbia River and waters off the Oregon coast and then adapt them to HICO full spectral data. Second, we will use the HOPE algorithms (Lee et al., 2007) imbedded in the APS-HICO processing system which take advantage of the continuous spectra in HICO data specifically testing it for the Columbia River system. We will use extensive in situ data for this area from the MIOLCO, CMOP and ORCOOS programs for testing and validation of our products for the Columbia River and the Oregon coast. With this approach we expect to produce the first quantitative estimates of chlorophyll, suspended sediments and CDOM from remote sensing data for the Columbia River system.

During the second year we will focus on publishing algorithm descriptions and the Columbia results. At the same time as soon as it becomes available we will begin to collect HICO data and all available in situ data for the Yangtze River and adjacent waters. Once the algorithms are completed we will then evaluate them using the Yangtze data and focus on processing and analysis of the Yangtze River data and publication of that work.

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Personnel

Curtiss Davis will direct this work and have overall responsibility for its outcome. He will be supported by Nick Tufillaro who will do much of the data processing and algorithm work. This work will be conducted in collaboration with Mike Corson, and others in the Remote Sensing Division of the Naval Research Laboratory, Bob Arnone and others in the Oceanography Division at NRL Stennis Space Center and with Zhong-Ping Lee at U. Southern Mississippi.

Facilities

Adequate facilities are available for this activity. HICO data is processed using the APS software for HICO on a quad processor Dell server with 32GB of memory and 5TB of raid storage. Additional processors and an additional 300TB of storage are available on the COAS 10 Gb local network as needed. Local computers provide additional processing capability including IDL and ENVI software, with the NRL enhancements for Tafkaa atmospheric correction and PHILLS data processing.

A Satlantic HyperPRO optical profiler is available and used routinely on the MILOCO and CMOP cruises in and around the Columbia River plume. The full ORCOOS, CMOP and MILOCO data sets are available on local web servers for use in this study.