

NASA's Coastal and Ocean Airborne Science Testbed (COAST)

L. Guild^{a*}, J. Dungan^a, M. Edwards^a, P. Russell^a, S. Hooker^b, J. Myers^c, J. Morrow^d, S. Dunagan^a,
P. Zell^a, R. Berthold^a, and C. Smith^a

^aNASA Ames Research Center, Moffett Field, CA 94035, USA - (liane.s.guild, jennifer.l.dungan, maryland.r.edwards, philip.b.russell, stephen.e.dunagan, peter.t.zell, claire.smith-1)@nasa.gov

^bNASA Goddard Space Flight Center, MD 20771 USA – stanford.b.hooker@nasa.gov

^cUniversity of California, Santa Cruz/NASA Ames Research Center, Moffett Field, CA 94035, USA – jeffrey.s.myers@nasa.gov

^dBiospherical Instruments Inc., San Diego, CA 92110, USA – morrow@biospherical.com

Abstract - The Coastal and Ocean Airborne Science Testbed (COAST) Project is a NASA Earth-science flight project that will advance coastal ecosystems research by providing a unique airborne payload optimized for remote sensing in the optically complex coastal zone. The COAST instrument suite combines a customized imaging spectrometer, sunphotometer system, and new bio-optical radiometer instruments to obtain ocean/coastal/atmosphere data simultaneously. The imaging spectrometer is optimized in the blue region of the spectrum to emphasize remote sensing of marine and freshwater ecosystems. Simultaneous measurements for empirical characterization of the atmospheric column will be accomplished using the Ames Airborne Tracking Sunphotometer (AATS-14). Based on optical detectors called microradiometers, the NASA Ocean Biology and Biogeochemistry Calibration and Validation Office team has deployed advanced commercial off-the-shelf instrumentation that provides *in situ* measurements of the apparent optical properties at the land/ocean boundary including optically shallow aquatic ecosystems (e.g., lakes, estuaries, coral reefs). A replicate microradiometer instrument package, optimized for use above water will be deployed for the first time with the airborne instrument suite. This new capability will be tested using the airborne instrument suite in an airborne campaign over Monterey Bay planned for late 2011.

Key words: Airborne remote sensing, coastal zone, bio-optical properties, water column correction, atmospheric correction.

1. INTRODUCTION

Current ocean color satellites such as SeaWiFS, MODIS, and the planned NPOESS VIIRS system are optimally designed for open ocean imagery, calibrated for low radiances and producing coarse spatial and spectral resolution. The coastal ocean, in contrast, is one of the most difficult places to accurately retrieve ocean color and benthic ecosystem reflectance (Dierssen *et al.*, 2006; Dunagan *et al.*, 2009; Guild *et al.*, 2009 a, b). Visible radiance signal magnitude is highly variable, ranging from very dark values in clear, deep water to very bright values at water's edge. Signals are also highly variable in space and time due to many dynamic processes. Aerosol plumes from continental sources complicate the task of atmospheric

correction. The spatial (~1 km) and temporal (~daily) coverage from the satellite instruments normally used for the open ocean is of marginal use in coastal waters. Water-leaving radiance in the blue, critical for discriminating pigments from colored dissolved material, exhibit low signals, which often become negative using standard reprocessing methods for MODIS and SeaWiFS. Additionally, the lack of mid-range spectral bands on most existing sensors makes it difficult or impossible to detect events such as "red tides" (Dierssen *et al.*, 2006), one of the main targets for coastal remote sensing. There is a clear need for high temporal, spatial, and spectral resolution data to meet these challenges; for the foreseeable future, this will require airborne instrumentation (Davis *et al.*, 2007).

The science goal of this project is to develop and fly a portable airborne sensor suite for NASA science missions addressing the challenges of an optically complex coastal ocean zone in support of research areas such as water quality, ocean productivity and biogeochemistry, coastal landscape alteration, coastal and estuarine ecosystem productivity, atmospheric correction, and regional climate variability.

More specifically, this project will enable measurements of several properties of biological interest in the optically complex coastal ocean, especially apparent optical properties (AOPs). Further, AOP measurements from an airborne platform will advance the state of the art to allow rapid surveys capturing the heterogeneity and dynamic range of the near-shore landscape. These properties are key to characterizing estuaries, river plumes, kelp beds, coral reefs, and phytoplankton, including harmful algal blooms.

2. METHODS

2.1 Mission Implementation

The COAST project is integrating an instrument suite on board a trade-study-selected platform that will be flown over a trade-study-selected location. Examining these trade spaces will provide key training opportunities for the team reflecting typical NASA flight mission early-phase activities. A successful mission will yield three main science deliverables:

1) Development and integration of the first end-to-end package for simultaneous measurements of ocean color (modified imaging spectrometer), aerosol optical depth and

water vapor column content (sunphotometer), and water bio-optical measurements (microradiometer-based multiwavelength radiometer package) all of which can be flown on a variety of airborne vehicles (e.g., Twin Otter, P-3B) using inputs from an associated precision navigation system. The imaging spectrometer and microradiometer packages could also be flown on next-generation unmanned aircraft systems (UASs) and a modified sunphotometer or its successor also has UAS potential.

2) Advanced calibration and validation (cal/val) protocols for ocean color through airborne campaigns of the HIS, AATS-14, and microradiometer package flown in conjunction with satellites and in conjunction with *in situ* cal/val measurements and well as moorings and ships.

3) High spatial resolution (5-10 m), atmospherically corrected and geolocated ocean-color products (calibrated to at-sensor radiance) that will advance understanding of coastal freshwater and marine processes and productivity and improve coastal models. Our primary products will be well-calibrated water-leaving radiances; there are numerous applications for these data to produce biogeochemically meaningful products.

2.2 Instrumentation

The complete flight system includes three main instruments and ancillary devices to support them. The three main instruments include the Headwall Imaging Spectrometer, the Ames Airborne Tracking Sunphotometer (AATS-14), and Biospherical Instruments microradiometers.



Figure 1. The Headwall imaging spectrometer.

The Headwall Imaging Spectrometer (Figure 1) is a concentric push-broom hyperspectral imager of the Offner design, which was especially configured by the manufacturer for low-radiance oceanographic remote sensing. One unique feature of the Offner spectrometer is a curved aberration-corrected diffraction grating that dramatically reduces the spectral distortions (smile and keystone) inherent in standard push-broom systems, which typically use some combination of flat gratings and/or prisms. This system has a very high quality original (as opposed to

replicated) holographic grating, which is designed for optimal efficiency at 440 nm, unlike those intended for terrestrial applications. The Offner design allows for a relatively wide field of view without compromising spectral integrity, which is highly desirable for mapping large areas. This system has a 52.5° field of view that can be varied with interchangeable objective lenses. With the Offner, all spectra are acquired simultaneously, which is especially critical for an airborne system, where small perturbations of the platform would otherwise result in misregistration of the spectral bands. The system is further customized for ocean imaging with a cooled, blue-enhanced silicon detector array. Manufactured by Q-Imaging Inc., the Retiga-2000RV CCD array has 1600 x 800 elements, and is thermo-electrically cooled to -30°C for increased sensitivity and radiometric stability. The sealed detector package also reduces the chance of contamination of the array surface due to condensation or dust. The array can be operated with variable regions-of-interest and binning schemes.

The AATS-14 (Figure 2) measures solar-beam transmission at 14 discrete wavelengths from 354-2139 nm, yielding aerosol optical depth (AOD) at 13 wavelengths and water vapor column content. Azimuth and elevation motors controlled by differential sun sensors rotate the tracking head, keeping the detectors normal to the solar beam. The tracking head mounts outside the aircraft skin to minimize blockage by aircraft structures and also to avoid data contamination by aircraft-window effects. AATS- 14 has been used extensively to test and improve AOD retrievals by MODIS, SeaWiFS, MISR, and many other satellite sensors (e.g., Russell *et al.*, 2007, Redemann *et al.*, 2009). Also, AATS-measured AODs have previously been used in atmospheric correction of images of surface scenes (Spanner *et al.*, 1990; Wrigley *et al.*, 1992).



Figure 2. AATS-14—Ames Airborne Tracking Sunphotometer will make simultaneous measurements for empirical characterization of the atmospheric column.

The Biospherical Instruments microradiometers (Figure 3) design was developed in response to a need for smaller, faster, and potentially less expensive radiometers that could be easily scaled to either more or fewer channels and more easily deployed in coastal waters (Morrow *et al.*, 2010). The

entire assembly, including the photodetector, is located on a single circuit board. Each microradiometer is also equipped with a temperature sensor located close to the photodetector.

Microradiometers are the operational optical sensing units, each with a microprocessor, photodetector, optical filter package, data acquisition system, and communications electronics. Aggregators are used to bundle larger collections of microradiometers and auxiliary sensors (such as temperature) in individual instrument heads. Aggregators control the data flow to and from the microradiometers, they have on-board removable data storage (Micro-SD card) and power control, and have additional sensing roles including tilt angles, input voltage and current, internal humidity and temperature.

The proposed unit includes 19-brass-encased interchangeable individual microradiometers (for different applications) and one aggregator assembly. Included in the band selection are six bands commonly used for ocean color since the onset of the SeaWiFS mission. Wavelengths are also available down to 305 nm, so application-specific sensors such as UV-bands for CDOM or atmospheric correction, bands targeting phycocyanin and phycoerythrin pigments for flights over reservoirs and terrestrial waters (blue-green algae detection), or bands targeting natural fluorescence (for red tide, high sediment load, and primary production applications) could be added. The microradiometer device is sensitive enough to detect moonlight in downward irradiance, yet remain unsaturated when viewing the solar disk in radiance mode.

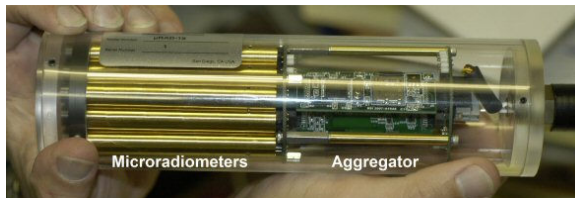


Figure 3. Microradiometer and aggregator boards. The microradiometer is sleeved in brass for support and isolation from electronic noise. The unit has 19 channels and an outside diameter of approximately 7 cm.

2.3 Field Validation Experiment

The field site will have both open ocean and optically complex water masses, so the full dynamic range of the sensor suites and protocols being used in the field can be evaluated.

One field campaign is planned for testing and evaluating the airborne instrument suite. It will consist of flying the HIS, together with the AATS-14 and microradiometers at various altitudes over an instrumented surface (Figure 4). The AATS-14 will provide a simultaneous empirical characterization of the atmospheric column (AOD and water vapor), which will be used for atmospheric correction. The in-water microradiometer system called the Compact-Optical Profiler System (Biospherical Instruments C-OPS, Morrow *et al.*, 2010) that includes an underwater housing

will be deployed from a ship during aircraft overflight and will determine apparent optical properties (AOP) in the shallow water sites. The C-OPS consists of two radiometers: one measuring in-water upwelling radiance, and the other either downward irradiance or upward irradiance. Both radiometers are equipped with 19 wavebands and are mounted on a free-fall frame. The frame can be optimized for either slow descent rates for work in very shallow coastal waters sites, or faster descent rates for observations in the open ocean. The radiometers are a replicate of the aircraft microradiometers and will provide data sets for valid comparison.

It is anticipated that the instrument suite would also eventually participate in the vicarious calibration experiments routinely conducted by other NASA airborne instrument teams, such as AVIRIS and MAS, on a piggy-back basis on other platforms.

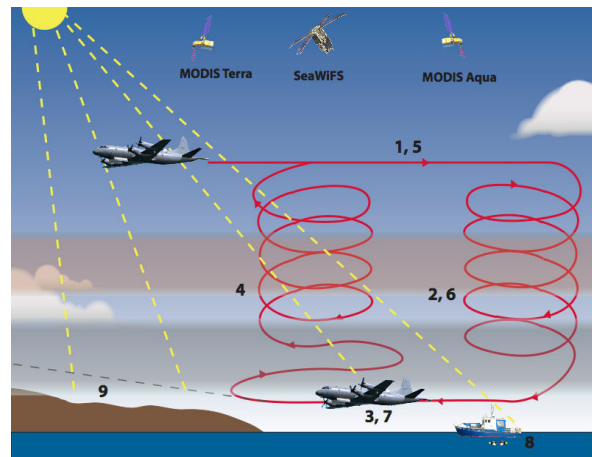


Figure 4. Conceptual illustration of aircraft flight patterns proposed for COAST. 1, 5. Transit to target and high altitude transect. 2, 6. Spiral down to minimum altitude. 3, 7. Minimum altitude transect. 4. Spiral up. 8. Ship-based *in situ* measurements in the water. 9. Exit from the flight sequences.

2.4 Comparisons to Satellite Data

During the field data collections, we will obtain MODIS Aqua, Terra, and SeaWiFS local area coverage (LAC) data corresponding to contemporaneous deployment of the C-OPS microradiometers from a small boat. Satellite observations will be used to compare accuracy of radiance retrievals and derived products versus the HIS, onboard microradiometers, and the *in situ* C-OPS microradiometer measurements. The C-OPS will have identical wavelengths for matchup analysis to the airborne microradiometers and the satellites. We will also use the high resolution atmospheric information to reprocess the MODIS data using regionally tuned atmospheric corrections to determine if the standard MODIS products could be improved with better calibration/validation.

3. DISCUSSION

Scientific outcomes from this project will include:

- 1) A flight-tested instrument suite suitable for cal/val activities for future satellite missions, as well as currently operating and developing missions,
- 2) Advanced payload capabilities for airborne carrier platforms,
- 3) A multi-sensor ocean/atmosphere data set available for improved atmospheric calibration and in-water algorithms,
- 4) Methodologies for empirical atmospheric correction developed for future airborne imagers of this type (e.g., NASA PRISM) when they come online,
- 5) Methods to address the biological properties of important coastal zone ecosystems, and
- 6) Enabling technology for a broad range of research activities in the coastal zone to support the scientific community's research goals and objectives.

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