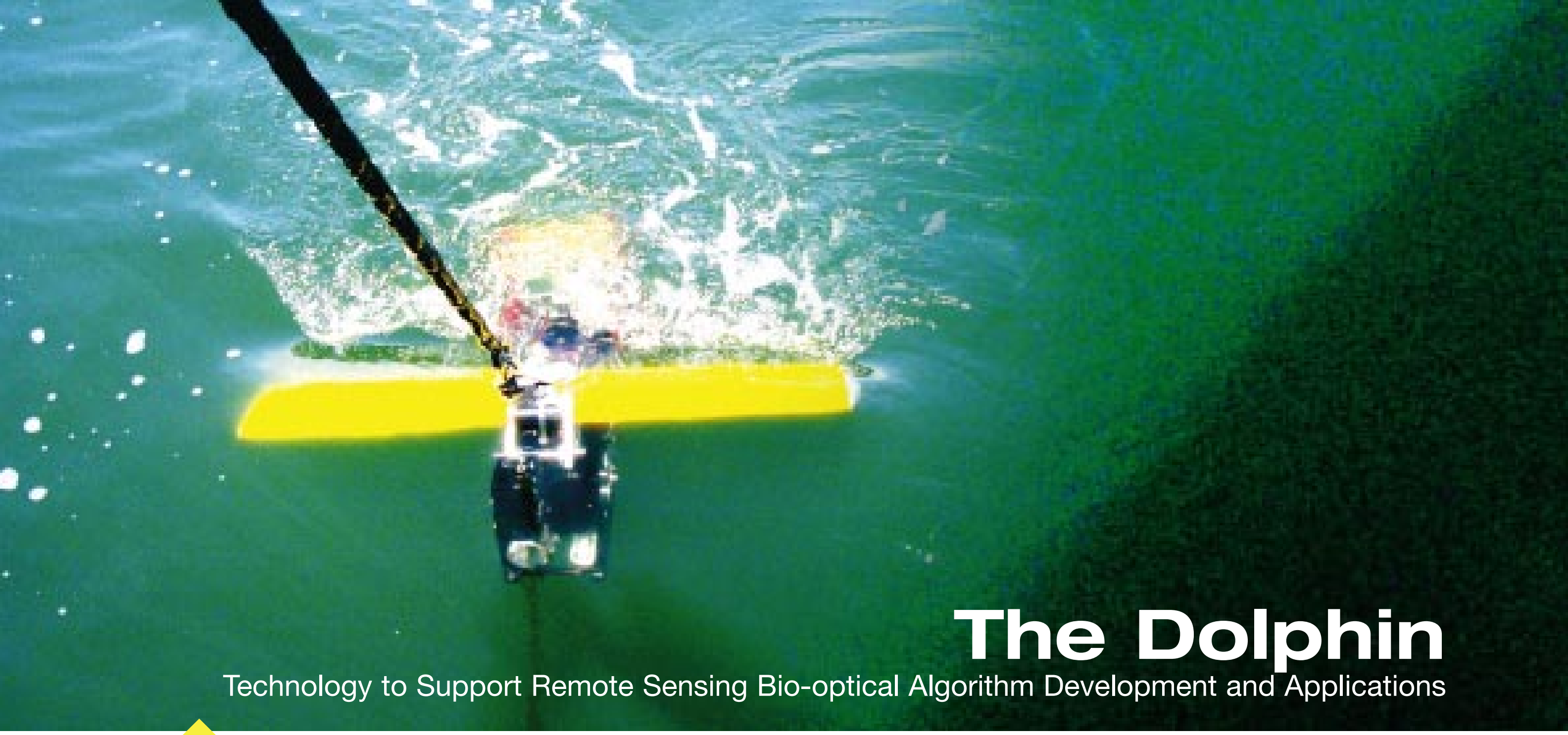

The Dolphin

Technology to Support Remote Sensing Bio-optical Algorithm Development and Applications

Figure 1. *The Dolphin vehicle surfacing after a deployment in Narragansett Bay, RI.*

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A major goal of NASA's Earth Science research and application programs is to develop a clear understanding of the relationship between remotely sensed data and Earth system processes. Components of the Earth system may respond to natural or human-induced changes, or both, and often occur over a broad range of time and space scales. Hence, to achieve this understanding, high quality data are required from space and in the field (i.e.,ground-truthing).

Obtaining high quality field, or *in situ*, data can be challenging. This challenge may be due in part to the accessibility of measuring the relevant environments, the relevant time and space scales, or to the maturity of select technologies. For example, it is difficult to collect high quality in-water optical and biogeochemical data within a spatially dense field that coincides with the overflight of an ocean color imager. This is particularly important in coastal regions where the optical properties typically show substantial small-scale temporal (< 1 h) and spatial (<10 m) variability due to the effects of tides, winds, bathymetry and river discharge. Conventional profiling optical packages deployed from a ship provide limited horizontal collection points but can be effective in providing data that resolve the vertical structure of the water column. Conversely, underway-shipboard flow-through systems effectively resolve the horizontal dimension, but provide limited resolution with respect to depth. Since the backscattered signals collected by passive and active remote sensing systems are dependent on the vertical structure of optical properties along the flight path, sufficient resolution in both the vertical and horizontal dimensions are needed to develop effective algorithms and remote sensing applications.

One solution to this sampling problem in coastal waters is to use a small undulating towed body equipped with a suite of optical and hydrographic instruments (**Figures 1 and 2**). Following this concept, a system, termed the Dolphin, is being developed by WET Labs, Inc. (*www.wetlabs.com*, Philomath, OR) through a NASA Small Business Innovation Research (SBIR) project sponsored by the Office of Technology Development and Transfer at Stennis Space Center. The Dolphin was designed to provide an easy to deploy, fully integrated system, for the rapid acquisition and analysis of in-water optical and hydrographic data. The primary Dolphin components are a towed optical and hydrographic instrumentation package, a real-time data integration, processing, and visualization network, and a discrete water sampling system designed to continuously pump water from the towed package to the boat for collection and standard analysis (**Table 1**). The in-water system is compact and can be deployed off small boats in shallow waters by a 2-3 person crew (**Figures 3 and 4**). While underway, the towed package can be programmed to

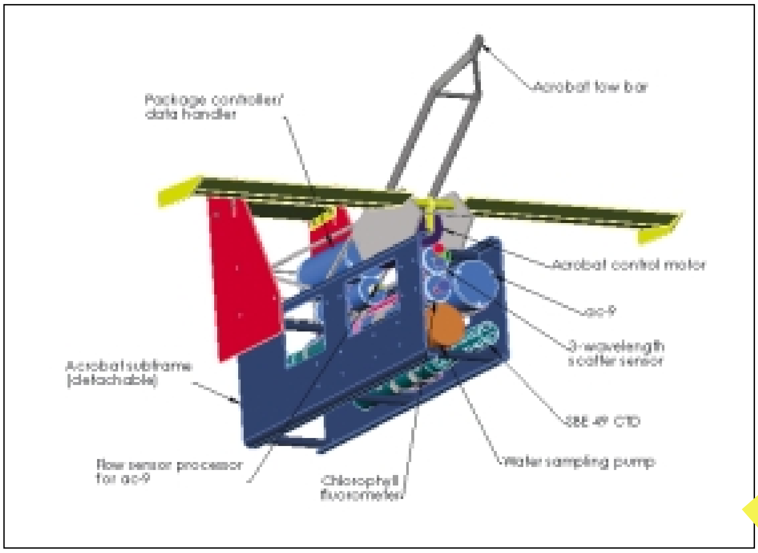

Figure 2. *The Dolphin towed body. The vehicle is a modified Acrobat from Sea Sciences, Inc. The ac-9, scatter sensors, and fluorometer shown are manufactured by WET Labs. The length of the sub-frame is 0.9 m.*

undulate, or move up-and-down, through the water column thus providing data on the horizontal and vertical structure of the environment.

The current Dolphin system is configured to support the development of remote sensing algorithms and applications in coastal waters. Inherent Optical Properties (IOPs) such as backscattering (b_b), absorption (a), and attenuation (c) are measured that provide the link between oceanic biogeochemical properties and the signals collected by remote sensing systems. Samples coinciding with collection of the optical data can also be collected at any time with the pumping system for direct laboratory determinations of these biogeochemical properties. A radiometer mounted to the vessel measuring incident irradiance in air (Satlantic, Inc., OCR-507I) is also logged with the data from the vehicle.

The data network of the Dolphin integrates the signals from the disparate sensors, processes the raw data to the final product with appropriate calibration and corrections, archives the data, and supports scrolling and plotting of the data stream from any instrument in real-time. Several derived data products can also be computed with the Dolphin software, including remote sensing reflectance (RSR), using published bio-optical, semi-analytic algorithms based on bb/a and other optical properties (e.g., Morel and Gentili, 1993; Zaneveld, 1995). With derived RSR and measured downwelling irradiance at the surface (Es), the upwelling radiance measured by a remote imager may be determined from the product of RSR and Es. Biogeochemical properties that can be derived include total suspended matter, chlorophyll concentration, bulk particle refractive index and the log-log slope of the particle size distribution (see Zaneveld et al., 2002 for summary of algorithms).

The Dolphin was deployed on several occasions in 2002. A cruise track from a deployment along the west passage of Narragansett Bay is shown in **Figure 5**. The automated undulation pattern of the Dolphin demonstrates its bottom avoidance capabilities. Optical data from this track show substantial vertical and horizontal variability in the concentration and composition of particles and dissolved material (**Figure 6**). A significant correlation (r2 = 0.58) between b_b/a at 440 nm, a proportionality often assumed proportional to RSR in bio-optical

Figure 3. *Preparing to lower the Dolphin vehicle into waters off the coast of Narragansett Bay, RI. From left, Casey Moore, Richard Miller, and Michael Twardowski.*

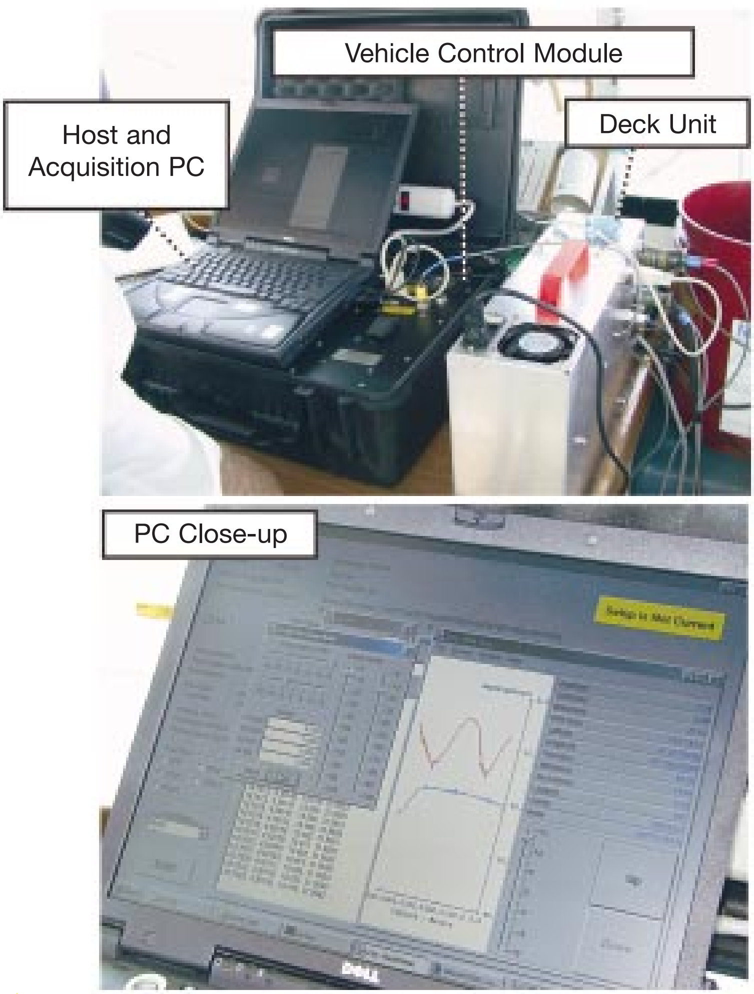

Figure 4. *Dolphin control and acquisition equipment (above) and the GUIs (below) controlling Dolphin data collection, visualization, and Acrobat vehicle flight.*

algorithms, and chlorophyll concentration was observed along this track.

Tests of the Dolphin system have thus far demonstrated the ability to collect optical and hydrographic data sufficiently synoptic in space and time for validation work and algorithm development. Tests are also underway to determine if the Dolphin can be flown sufficiently to the port or starboard side of the bow to collect upwelling radiance and downwelling irradiance without interference from the wake of the boat. A second on-board data handling system has also been integrated to allow time-coordination and data merging with flow-through measurements from bench top instrumentation that use the outflow of the water sampling system.

The Dolphin is being developed to provide high quality data to support remote sensing algorithm develop and applications. The system's design, data handling and real-time analysis capabilities were developed to address the complexities of coastal optical environments. The NASA Earth Science Applications Directorate at Stennis Space Center will use the system when complete to support national applications within the Earth Science Enterprise.

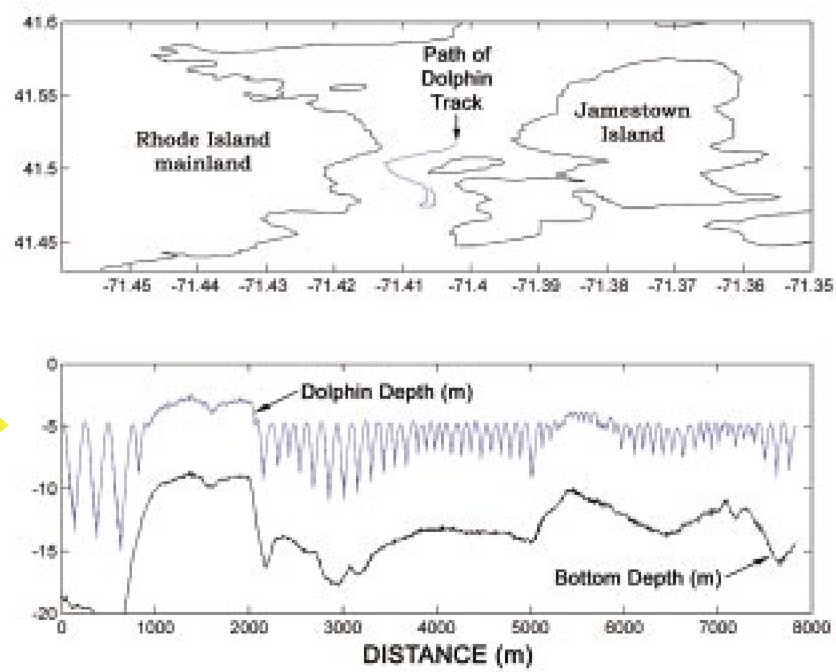

Figure 5. *Map of a Dolphin track (Long-W, Lat-N) in Narragansett Bay, RI and the depths of the vehicle and the bottom. The Dolphin was programmed to automatically undulate within the range of 5 m from the surface and 5 m from the bottom unless the bottom depth shoaled to less than 10 m, in which case the vehicle would ride the bathymetry, keeping the 5 m clearance.*

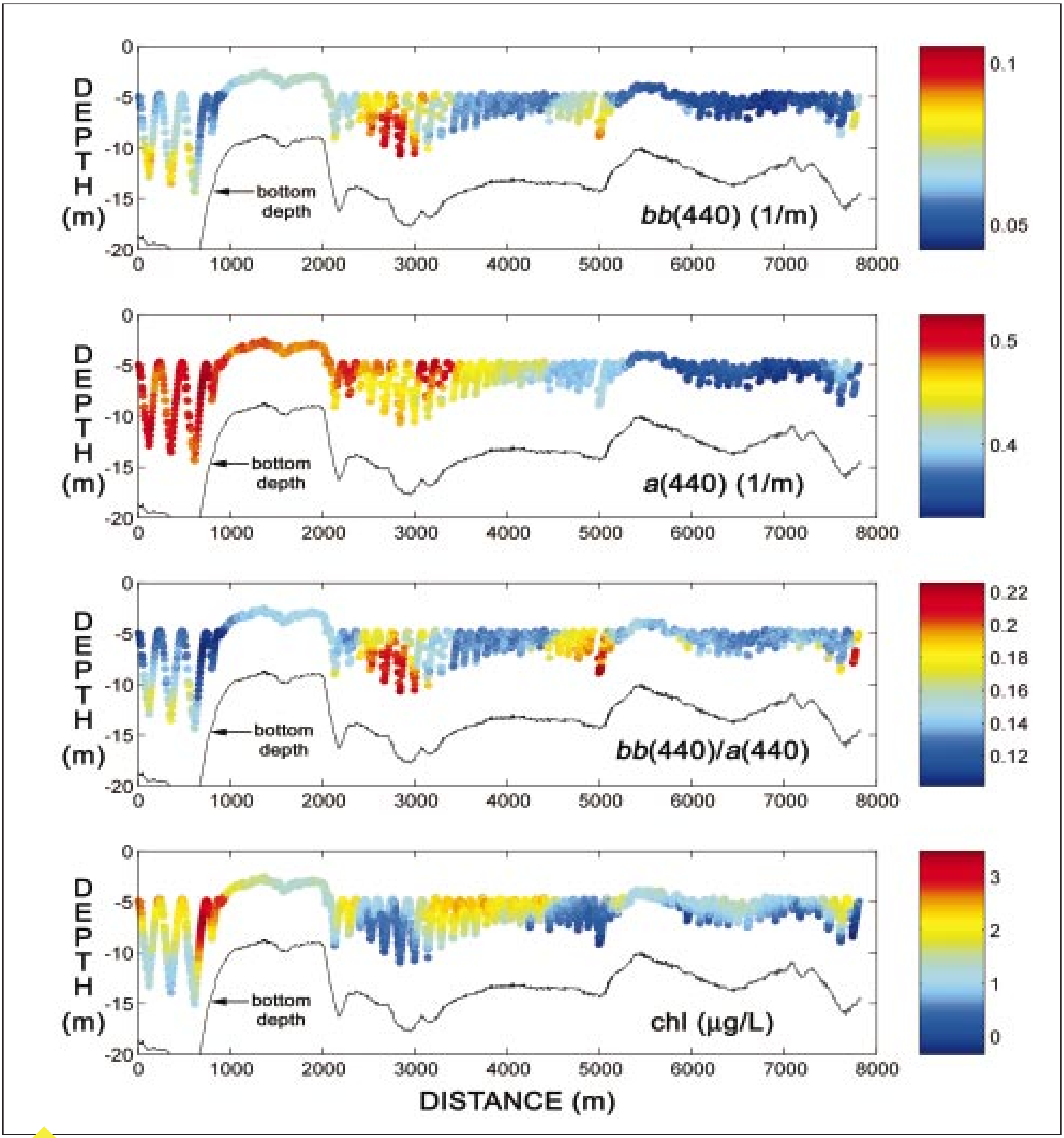

Figure 4. *Dolphin control and acquisition equipment (above) and the GUIs (below) controlling Dolphin data collection, visualization, and Acrobat vehicle flight.*

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CHARACTERISTIC	RESEARCH BENEFIT
Synoptic coverage with rapid (up to 10 knots), along-track surveys	**High data resolution in space and time** The DOLPHIN provides a continuous series of data for validation needs, along the path of the remote sensing platform or any other desired path.
Fully integrated optical and hydrographic measurements	**Relevant data content of high quality** Optical measurements of the needed parameters for remote sensing calibration and validation - including absorption, backscattering, attenuation, total scattering, chlorophyll absorption, and chlorophyll fluorescence – are collected with WET Labs "ECO" sensors and an ac9. The miniaturized SBE49 from SeaBird Electronics, Inc. provides CTD measurements at 16 Hz.
Compactness, enabled by advances in sensor technology which provide high data quality in smaller form factors	**Inland, shallow water capabilities** The DOLPHIN is deployable from small boats (< 10 m) by a 2-3 person crew and has modest power needs. This allows along-track surveys in coastal waters, estuarine, riverine, and lacustrine environments, while still retaining oceanic surveying capabilities.
Automated, real-time multi-level processing and visualization of raw data from multiple instruments with different sampling rates and communication protocols	**Immediate realization of the final data product** Integrating a multi-sensor in-situ optical system typically is a lengthy, expensive, and ongoing process. Processing is also typically a post-cruise activity that takes several months. Considerable resources will be saved by providing a product which automates this process at the time of collection. In addition, "now-time" decision-making can be made in the field with derived parameters such as computed reflectance values from the in-situ measurements.
Continuous water sampling system	**Real-time discrete sampling while underway** Water samples are pumped continuously from the Dolphin fish to the boat through an umbilical hose integrated into the towing cable. Biogeochemical parameters estimated by remote sensing models can be validated directly by laboratory analyses of the discretely collected samples.

Table 1. *Dolphin characteristics and benefits for research in remote sensing validation and the development of bio-optical algorithms.*

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