# MEASURING MESOSCALE IN SITU OPTICS OF THE CONTINETAL SHELVES WITH AUTONOMOUS WEBB GLIDERS

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**INTRODUCTION**. *"If I were to choose a single phrase to characterize the first century of modern oceanography, it would be a century of under-sampling." Walter Munk 2000* Efforts over the last decade have focused on developing remote sensing approaches because they are capable of providing bio-optical data over ecologically relevant spatial scales. This has revolutionized oceanography; however many of the dominant optical features are found at depth below detection limits of satellites. Advances in long duration autonomous underwater vehicles now offer the potential to maintain a subsurface mesoscale presence over several weeks. To this end our group has focused on developing and deploying optical sensors on Webb Slocum Gliders to map turbid features on continental shelves. This extended abstract will present the scientific questions we are tackling with Webb Gliders and provide examples of recent results. We hope that our results show that Webb Gliders are an operational tool capable of measuring a range of physical (temperature, salinity, waves, currents) and optical parameters (attenuation, backscatter, absorption, and fluorescence). We believe the application of these platforms will open an exciting new era for oceanography.

**METHODS**. Conceived by Douglas C. Webb, Slocum Gliders (named after Joshua Slocum, the first man to single-handedly sail around the world) undulate through the water column by changing their buoyancy (Fig. 1a). The sinking and ascending trajectories allow the Gliders to travel about 25-30 km/day for approximately a month in shallow-water deployments (>200 m). Communication is through satellite Iridium or Freewave radio modems when the Glider is at the surface. This allows Gliders to be controlled remotely anywhere around the Earth. We have deployed Gliders for missions ranging from Northeast United States, the Gulf of Mexico, and the Mediterranean (Fig. 2). From late October 2003 until mid August 2004, we have flown Gliders 200 out of the last 281 days, with these missions covering 4980 kilometers. All our Gliders were controlled from a suite of computers maintained at Rutgers in New Jersey. *Gliders are robust and operational tools and we believe they are ready to be utilized by the wider community.*

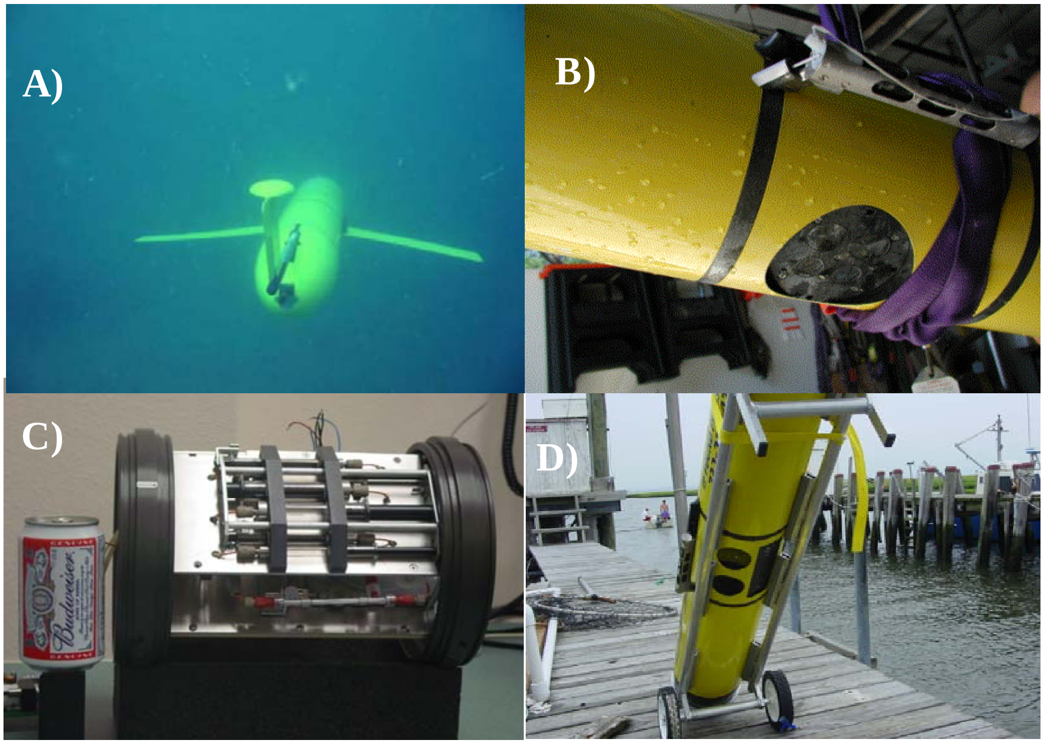


Figure 1. Gliders and sensors used during the 2003-2004 field efforts. 1A). The Webb Glider descending into the primordial depths. The sensor science bay is near the Webb Glider wings. The communication capabilities are facilitated by packages in the tail. 1B). A HOBI Labs HS-2 mounted in the belly of the Glider. 1C). The science payload containing the Breve-buster. As sensors reach the size of a 6-pack or less they become amenable for Webb Gliders. 1D). The WetLabs SAM sensor on a Webb Glider prior to deployment in the field. The rectangular sensor is the attenuation meter. The circular sensors provide backscatter and fluorescence.

*Optical Instruments on Gliders*. The utility of these platforms is their long duration capacity, so developing small compact low power instruments is the key to taking advantage of these systems. We have currently integrated three optical sensors into Webb Gliders. We integrated a HOBI labs HydroScat-2 into the Glider in early 2002 (Fig. 1a). In 2003 we integrated a Wetlabs Scattering-Attenuation System (SAM) which is a small and robust set of sensors capable of measuring backscatter ($b_b$), attenuation (c) and colored dissolved organic fluorescence (fl) (Fig. 1d). In 2003, we miniaturized a capillary waveguide spectrometer (Kirkpatrick et al. 2003) to provide hyperspectral absorption measurements (1.2 nm resolution) (Fig. 1c). The waveguide system, named the Breve-buster, has been deployed in the Mid-Atlantic Bight and in the Gulf of Mexico. Calibration and validation of each of these sensors is an ongoing effort; however initial efforts suggest Glider measurements are accurate (Fig. 3). We are using bio-optical Glider to address a suite of questions world-wide (Fig. 2), but in this paper will focus on examples off the coast of New Jersey.

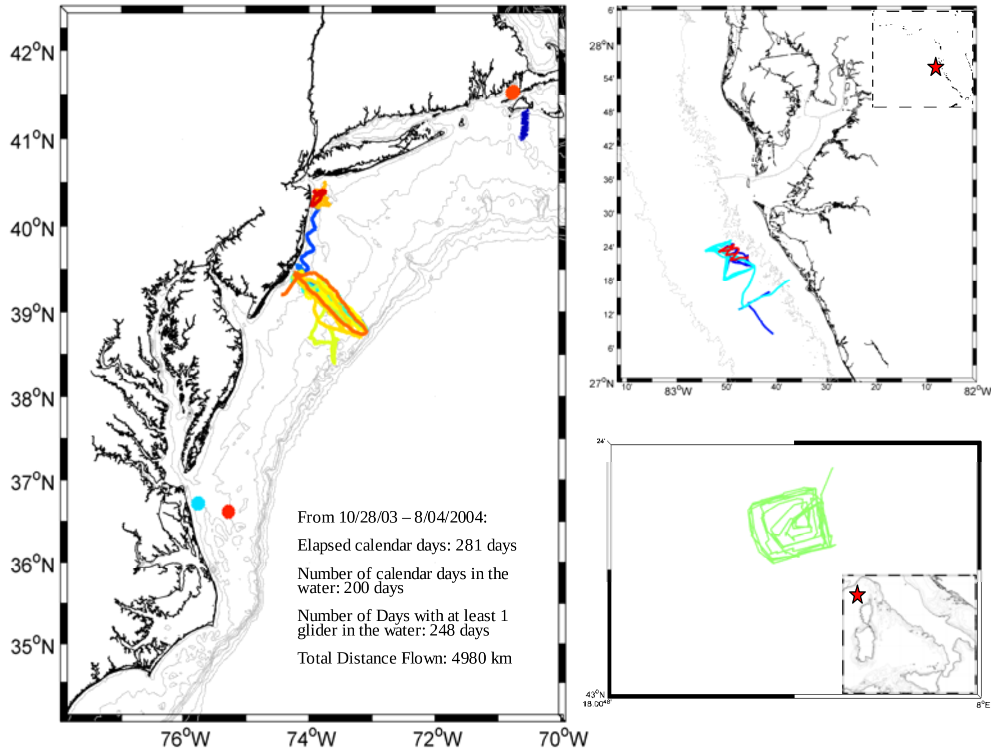


Figure 2. Deployments of Webb Gliders in 2003 and 2004. Gliders are a reliable means for scientists to maintain a subsurface presence in the ocean.

**SCIENCE FOCUS 1: HYPOXIA/ANOXIA IN THE MID-ATLANTIC BIGHT:** Widespread declines in bottom dissolved oxygen (DO) levels to hypoxic/anoxic conditions are often observed in the MAB and represent a major economic problem. It has been documented that in over 1/3 of the summertime bottom water observations (NOAA surveys from 1977 to 1985) have reduced bottom DO levels concentrated inshore of the 20 m isobath. Low DO off New Jersey, were strongly correlated with deep pycnoclines and strong persistent southerly to southwesterly winds with hypoxic conditions clustered offshore specific estuaries and inlets. The observed spatial distribution led to the hypothesis that the source of organic matter was from the terrestrial ecosystems; however sometimes hypoxic conditions were associated with pristine conditions and some anthropogenically impacted estuaries were not associated with the low DO. This lead us to hypothesize that upwelling might provide the organic matter fueling the low DO zones along New Jersey. Topographic variations associated with ancient river deltas promote upwelled water, which is initially a feature along the entire NJ coast, to evolve into an alongshore line

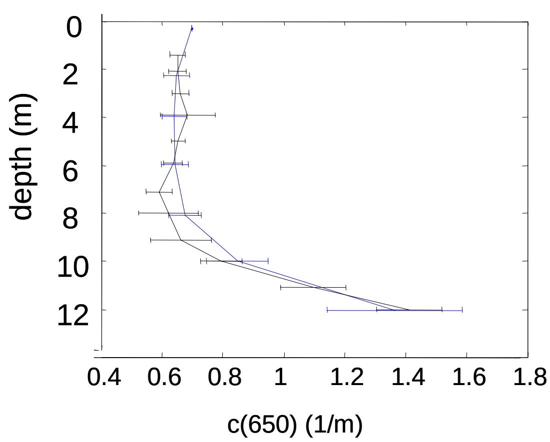


Figure 3. AC-9 (blue) versus SAM Glider measurements of attenuation at 650 nm.

of recurrent upwelling centers that are co-located with historical regions of low dissolved oxygen. The most intense upwelling (size and duration) occurs in summers following colder than usual falls and winters perhaps reflecting the spatial extent of the MAB Cold Pool which ultimately feeds the coastal upwelling (Glenn et al. 2004). Despite the fact that the Cold Pool is a dominant feature on the shelf, first described by Bigelow in 1933, little is known about its interannual variability and its subsequent coupling to coastal upwelling. Therefore we required a spatial perspective over annual time scales to define the biogeochemical state and potential of the MAB for producing hypoxic and anoxic conditions. We are currently using Webb Gliders to understand the subsurface dynamics in the concentration, transport, and transformation of organic material on the MAB. Optical sensors are the key to documenting the particle dynamics.

*Glider shelf-wide time series 2003-2004*: We have initiated a long term time series using bio-optical Gliders to transect at least 2 weeks each month from the nearshore Long term Ecosystem Observatory (LEO) to the edge of the continental shelf (~ 200 kilometers offshore, Fig. 4). After our first year, the seasonal cycle shows the disruption of late autumn shelf stratification followed by a rapid cooling during the month of December. The winter months (November through April) are associated with a well-mixed water

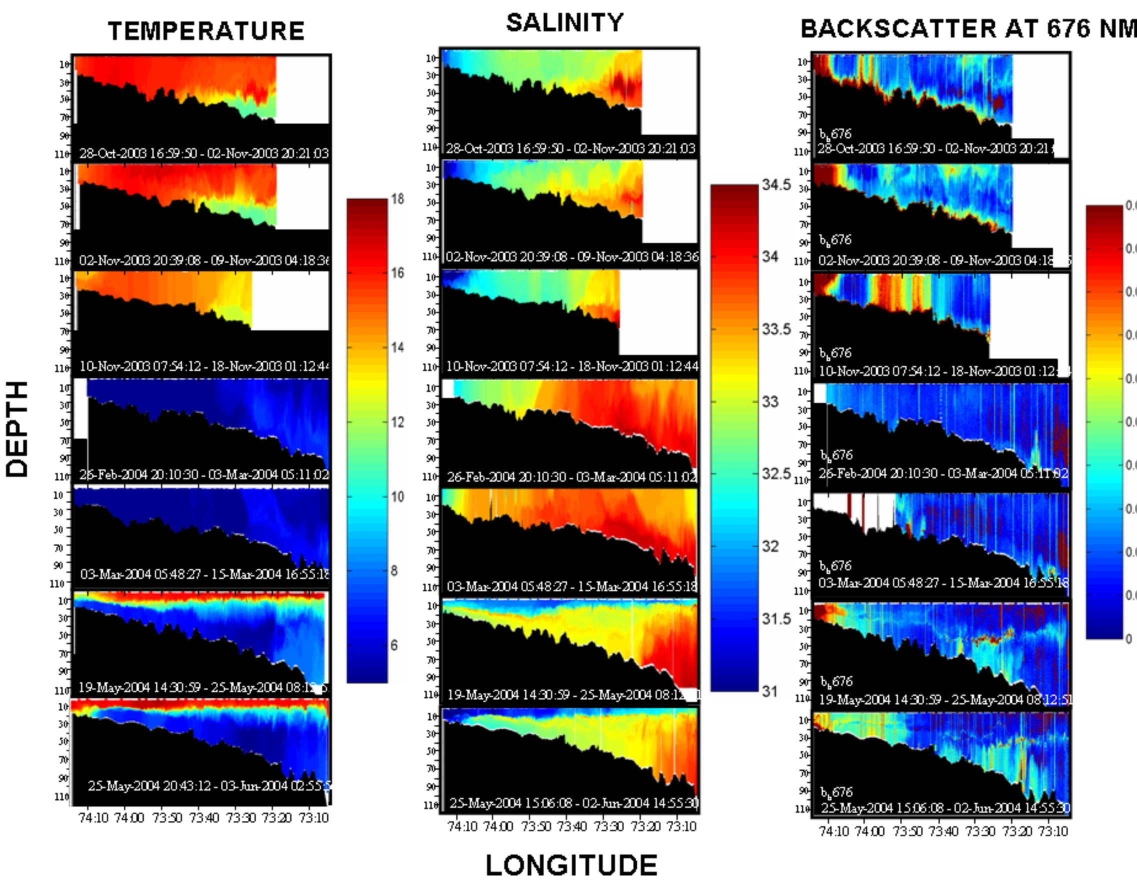


Figure 4. Cross shore transects conducted by a Webb Glider during the autumn, winter and spring. Temperature, salinity, and backscatter data (at 676 nm) is not interpolated illustrating the volume data collected by the Gliders.

column with the MAB cold pool representing one of the warmer water masses on the shelf. Numerous storms keep the water column well-mixed in the winter and associated with these storms is a resuspension benthic particulate material. The resuspension of particles is throughout the watercolumn and is a dramatic feature on the shelf. The near total presence of clouds at these times masks the presence of such large resuspension events. The shelf begins to stratify in the month of May and the warm upper mixed layer deepens to almost 20 m thick through the summer and autumn. Particle concentrations are high in the neashore waters (< 30 m) and the dynamics reflect alternating upwelling and downwelling conditions, storm induced benthic resuspension, and outflow from rivers/estuaries. By summer, a particle maximum is observed with the thermocline in the nearshore waters (<30 m). In offshore waters the particle maximum is found below the thermocline (and below any satellite detection) and is largely associated with MAB cold pool. The particle maximum in these waters is associated with the upper edge MAB cold pool coincident with inner edge of offshore high salinity intrusions that are a dominant feature during the winter months. Particle concentrations increase gradually in late spring and early summer, consistent with particle export from productive surface waters. There also appears to be a particle maximum associated in the bottom waters at the outer edge of the MAB cold pool consistent with detached bottom boundary layer upwelling dynamics. We believe that spatial physical and bio-optical time series will be immensely valuable as recent data suggests interannual-to-decadal scale variability in the water masses entering the MAB and these changes appear to be associated with basin-scale climactic variability.

***SCIENCE FOCUS 2: NEPHELOID AND BUOYANT LAYERS***. Characterizing *in situ* water turbidity is critical to numerous applied science needs. Often water column turbidity is used to judge water quality and also impacts the efficacy of sensors that use optical measurements for a variety of purposes including laser detection of mines and prediction of the operational detection horizon for bioluminescence. Efforts over the last decade have focused on developing remote sensing approaches capable of providing rapid environmental assessment over operationally relevant spatial scales. Two major layers found in varying extent in almost all coastal waters water masses are bottom nepheloid and surface buoyant plume layers. We are using Gliders to map the spatial extent of these both layers in the coastal waters off New Jersey (Fig. 5 & 6).

Nepheloid layers are optically significant and are almost a universal feature on continental shelves (Fig. 5 & 6). The maintenance of these nepheloid layers is regulated by the resuspension of material and the relative rates of aggregation and disaggregation. Aggregation and disaggregation rates depend on sediment concentration and turbulence in the water column, which in turn are functions of the wave and current shear stresses at the seabed, the distance from the bottom, and the stratification. The enhanced concentration of particles is strongly associated with increased light backscatter and attenuation (Fig. 5). The optical properties of the nepheloid layers depend not only on sediment concentration but also on organic particle composition and size distribution. For example, backscattering will be an order of magnitude higher in resuspended sediments that contain inorganic material (Twardowski et al. 2001). *The nepheloid layers mapped using Webb gliders have enhanced backscatter to attenuation ratios sometimes* *two to three times greater than the turbid buoyant plumes and five times greater then shelf water. This enhanced ratio likely reflects the significant presence of inorganic particles.*

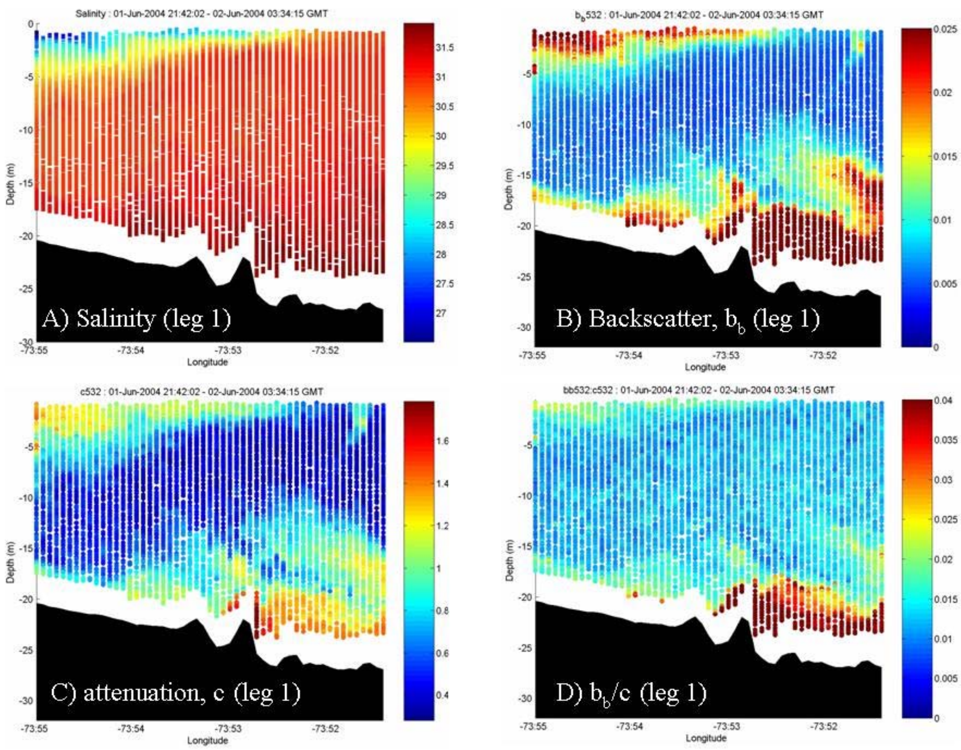


Figure 5. Physical and optical data collected curing Leg 1 (see Figure 3) in June 2004. The data shows a turbid low saline water in the nearshore surface waters, and nepheloid layers offshore. Note that attenuation is greater in the nepheloid layer then in low saline plume.

Another one of the other major optical features present in coastal waters are buoyant plumes. Buoyant coastal currents extend along much of the US east coast and consist of a series of estuarine plumes that are fed by rivers with typical maximum discharge rates on the order of 1000 m3/s. Among these rivers the Hudson's flow rate is typical, yet it may dominate the transport of nutrients and chemical contaminants to the coastal ocean. For well over 100 years it has been the most urbanized estuary in the US. Our efforts are focused on using optics and salinity to map the distribution of the buoyant plume in order to facilitate adaptive sampling. The buoyant plumes are spatially extensive (Fig. 4-7) and are associated with both high particle concentrations and Colored Dissolved Organic Matter (CDOM). *The high CDOM concentrations allow buoyant plumes to be differentiated fluorometrically from nepheloid layers (Fig. 7).* While particle loads are high within the plume, the high absorption of CDOM is a significant proportion of the total attenuation. Results confirm findings of others (Johnsen et al. 2003, Oliver et al. 2004) that CDOM is an effective tool for mapping the Hudson River plume on the MAB.

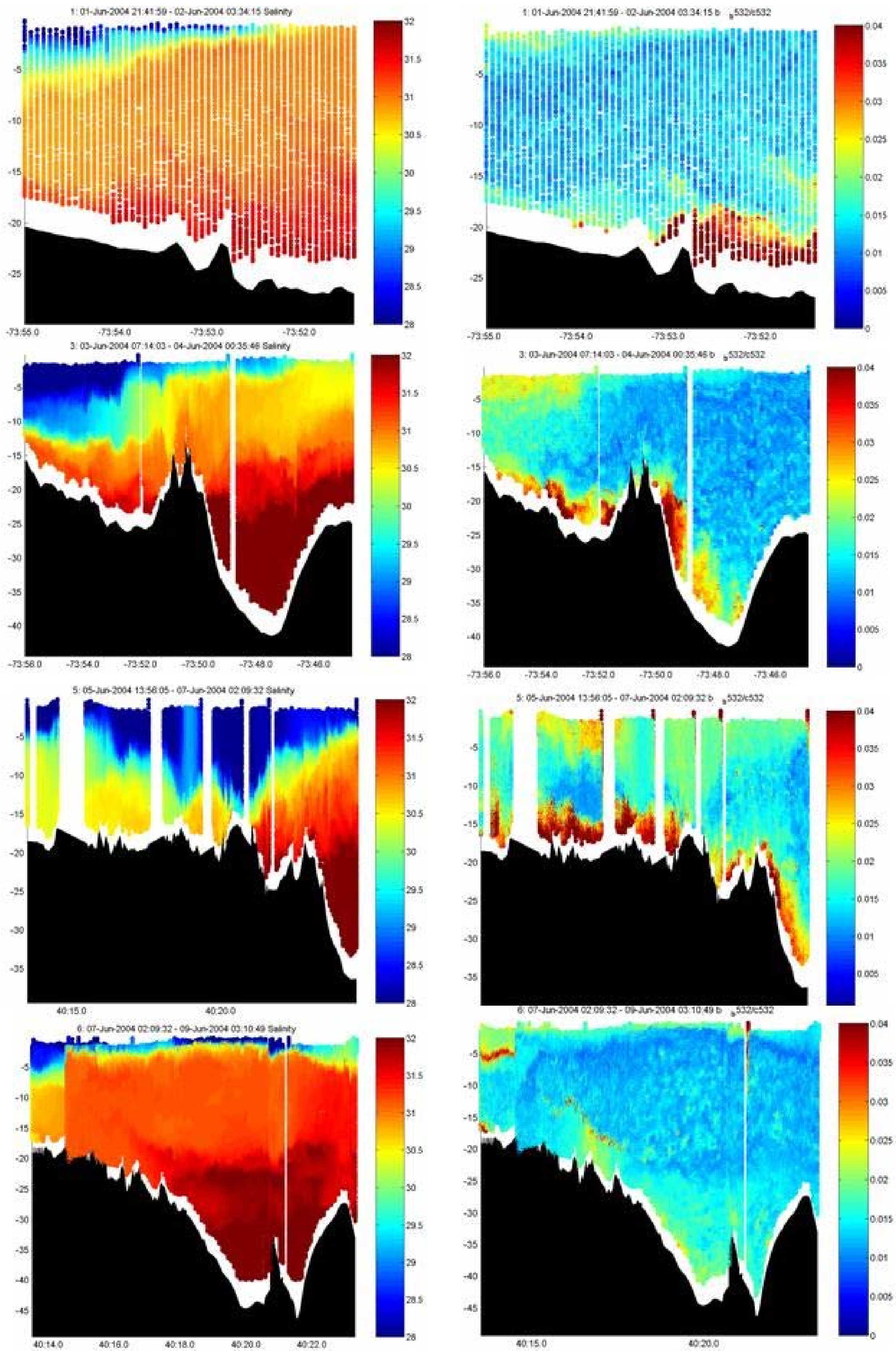


Figure 6. The data collected during 4 transects of a bio-optical glider in June 2004. The right hand panels are salinity. The low saline water of the Hudson River and the high saline water in the Hudson canyon are clearly evident. The left hand panels are the bb/c ratio for 532 nm.

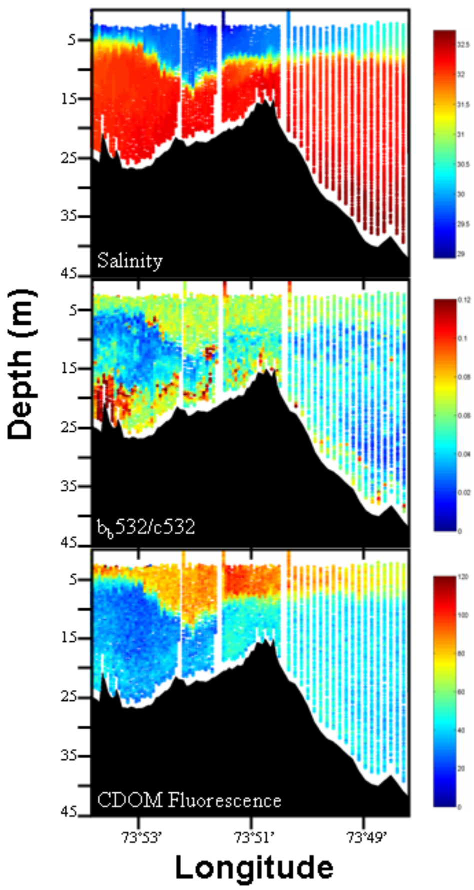


Figure 7. Data collected at the Hudson river plume in April 2004. Note the high CDOM fluorescence associated with the low salinity plume.

*Overall our results demonstrate that buoyant plumes and nepheloid layers can be effectively mapped with Webb Gliders. Enhanced $b_b/c$ values are associated with nepheloid layers and enhanced CDOM fluorescence is associated with low salinity buoyant plumes. Given the ability to collect spatial seasonal data, Webb gliders will provide an effective tool for mapping plumes in coastal waters. The ability to map inherent optical properties and fluorescence will provide an effective means for water mass discrimination in coastal waters.*

**CONCLUSIONS**

● Optical sensors exist and are amenable to autonomous platforms such as Webb Gliders.

● Optical measurements providing backscatter and attenuation allow particle dynamics to be defined over shelf-wide seasonal time scales. The ratio of backscatter to attenuation provides an indicator of the nature of the material present.

● The fluorescence of CDOM is detectable in the coastal ocean with AUV mounted sensors. It is an effective means to map River plumes, and differentiate turbid buoyant layers from turbid benthic nepheloid layers.

● Gliders offer the opportunity for the oceanographer to be at sea all year round. Optics will be one of the KEY approaches making Gliders a community wide asset.

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