7 Years & 11,000 km Later: Slocum Coastal Electric Gliders are Central to ANY Operational Ocean Observatory

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WEBB RESEARCH CORPORATION

THE RUCOOL SLOCUM GLIDER FLEET

INTRODUCTION

Beginning in August 2003, command and control of the New Jersey Shelf Observing System's (NJSOS) SLOCUM coastal electric glider fleet (Figures 1 & 2) was switched over from a line-of-sight RF communication link to a satellite (IRIDIUM) communication link. This enabled multiple gliders to be deployed anywhere in the world. Real-time data acquisition, processing and glider re-tasking was moved from a local control center within line of sight to the global glider control center at the Institute of Marine & Coastal Sciences (IMCS) in New Brunswick, New Jersey. The integration of a new generation of miniaturized physical and bio-optical sensors with low power requirements provides continuous, real-time vertical sections of the physical and bio-optical properties of the continental shelves.

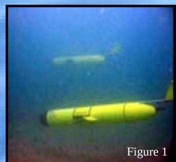


Figure 1

THE SLOCUM VEHICLE

The Slocum glider, designed and built by Webb Research Corporation, is an autonomous underwater gliding vehicle (**AUGV**) that is configured to operate in the coastal ocean in water depths ranging from 4 – 200m. It travels in a saw-tooth pattern to a predetermined set of waypoints by adjusting its buoyancy. This motion results in a low cost, mobile, and highly adaptable instrument platform with very low power consumption. The range of operation is 1500 km and mission duration can reach 30 days assuming a typical sensor payload.

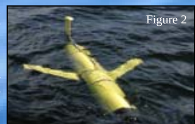


Figure 2

While the majority of the glider is reserved for glider mechanics, battery storage and communication equipment (Fig 3A), a section is devoted exclusively to scientific sensors. Gliders can be configured with a suite of miniaturized physical and bio-optical instrumentation to measure *in situ* water properties. These instruments, combined with the mobility and long range communication capabilities of the glider, will provide continuous, near real time information on ocean physics and biology. To date, a HobiLABS hydroscat-2 backscatter meter (Fig. 3C), WETLabs Scattering Attenuation Meter (SAM) (Fig. 3B) and Mote Marine Laboratory hyperspectral spectrophotometer (Fig. 3D) have been successfully integrated into the payload bay.

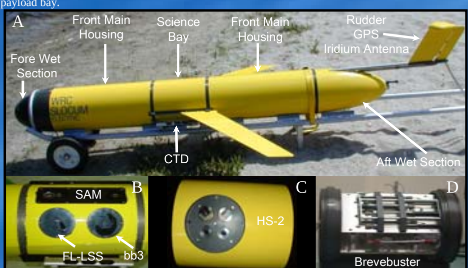


Figure 3

GLIDER COMMAND & CONTROL

The global glider command and control center is located at the Coastal Ocean Observation Laboratory (Figure 4) at Rutgers University. Command and control of the gliders is handled by Dockserver, a server-side application developed using Sun Microsystems Java Virtual Machine and developed by Webb Research Corporation. Glider satellite phone calls are received on one of eight dedicated phone lines via a US Robotics modem bank and are routed to a Dell Systems server (OS: Red Hat Linux). Dockserver handles glider phone calls, automatically receiving data files from the gliders as well as sending new mission parameter files to the gliders for retasking. Users can interact with the glider in real-time via a client-side web interface and can manually take control of the glider from a remote terminal (Fig 5A).

Figure 4

REALTIME DATA ANALYSIS & DISTRIBUTION

Glider progress is monitored via a Matlab-based Graphical User Interface (Fig 5B), allowing for realtime tracking of the vehicle as well as viewing of data. Once data files are transferred onshore via satellite phone, the data is processed in realtime and displayed over the internet at http://marine.rutgers.edu/~kerfoot/auv_data (Fig 5C).

AUTOMATED CONTROL

Autonomous Agent Oriented software (Stanford's Java Agent Template) for self- aware and self-controlled robots is used to automate decision making for glider control. When the glider surfaces, it transfers data and checks it email for new prioritized directions. Mailbox 1 is reserved for direct human intervention. Mailbox 2 is reserved for Level 1 Reactive agent commands that make critical but simpler yes/no decisions, such as turning around when the water depth is too shallow, or when you have flown out of the river plume. Mailbox 3 is reserved for Level 4 Planning Agent commands such as how to optimize a course based on the current conditions. Autonomous rerouting decisions now can be based on location, water depth or environmental conditions.

Figure 5


GLIDER SCIENCE - LONGTERM

NEW JERSEY SHELF ENDURANCE LINE

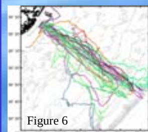


Figure 6

COOL Gliders undertake monthly cross-shelf transects from the Longterm Ecosystem Observatory (LEO) to the edge of the continental shelf (~ 200 kilometers offshore, Figs. 6/7). After our first year, the seasonal cycle shows disruption of late autumn shelf stratification followed by a rapid cooling during the month of December. The winter months (November - April) are associated with a well-mixed water column with the MAB cold pool representing one of the warmer water masses on the shelf. The resuspension of benthic particulate material throughout the water column and is a dramatic feature (Figure 8). Clouds can mask the presence of these events. The shelf begins to stratify in May and the warm upper mixed layer deepens to almost 20 m thick through the summer and autumn. Particle concentrations are high nearshore (< 30 m, Figure 8) 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 (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

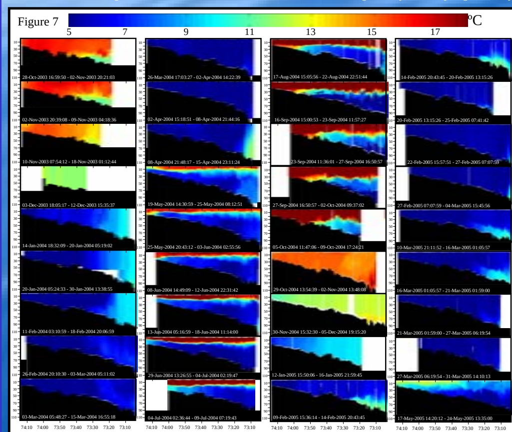
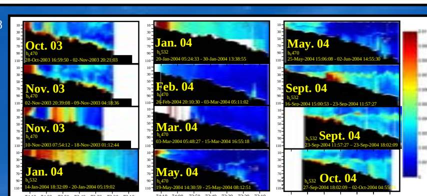
Figure 7


Figure 8


summer, consistent with particle export from productive surface waters (Figure 8). There also appears to be a particle maximum associated in the bottom waters at the outer edge of the MAB cold pool consistentwith 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.

EcoHAB

In partnership with Dr. Gary Kirkpatrick of the Mote Marine Phytoplankton Laboratory, three gliders were deployed on the West Florida Shelf, southwest of Tampa Bay, FL (Fig 9) in November 2003. The study site was chosen based on historical information indicating formation of red tides of the toxic dinoflagellate *Karenia brevis*. Two gliders contained the WETLabs SAM sensors to measure light attenuation (beam c) and the third glider contained a hyper-spectral absorption meter developed by Dr. Kirkpatrick. The gliders remained in the waters off Sarasota, FL for up to 10 days each. All glider communication, re-tasking and data transfer was done via Iridium satellite phone from IMCS in New Brunswick. These plots demonstrate the full-time, high resolution capabilities of the SLOCUM glider. CTD data from glider unit RU02 (Fig. 10A-C) indicate a mixed water column nearshore and south, with slight stratification occurring offshore and north. While some structure is apparent in the CTD data, data collected simultaneously with the WETLabs **S**cattering **A**ttenuation **M**eter (SAM, Fig. 10D-F) reveal an optically homogenous water mass. Higher values of optical backscatter at 532nm, bb(532),indicate the presence of particles near the bottom. The low values of c(532) and c(650) associated with this re-suspension event suggest that these particles are most likely re-suspended sediments. While the gliders were in the water, the R/V Suncoaster was performing hydrographic surveys as part of the Ecology of Harmful Algal Blooms (EcoHAB) experiment. Scientists at IMCS in New Brunswick, NJ were analyzing this data and were in communication with the crew of the Suncoaster, directing them to areas of interest which had been scouted out by the glider fleet, thus optimizing ship research time.

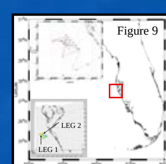


Figure 9

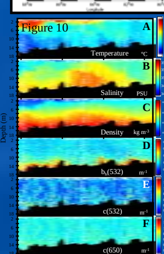


Figure 10

GLIDER SCIENCE PROCESS STUDIES

LATTE

The COOL gliders were deployed as part of the Lagrangian Advection Transport and Transformation Experiment (LATTE). The primary purpose of LATTE is to examine processes that control the fate and transport of nutrients and chemical contaminants in the Hudson River plume, a plume that emanates from one of the nation's most urban estuaries -- the New York/New Jersey Harbor complex. Urban estuarine plumes represent a major pathway for the transport of nutrients and chemical contaminants to the coastal ocean. However, the fate and transport of this material is controlled not only by the plumes dynamics but also by biological and chemical processes that are coupled to the dynamics of the plume. The primary objective of the gliders was to provide near and far field measurements of the physical (CTD) and optical (bb & c) (Figure 16) properties of the buoyant plume.

LATTE – 2004

The local wind vectors measured at Ambrose light house for the duration of LATTE 2004 are plotted in Figure 11. Persistent upwelling winds from April 29 through May 3 caused the Hudson Plume to flow eastward along the coast of Long Island. On May 4, a front resulted in a downwelling favorable wind shift, resulting in a new plume forming a southward flowing coastal current along New Jersey (Figure 12). A glider was deployed to patrol this region in between the 2 plumes, capturing the wind-driven collision of the old plume with the new plume (Figure 13).

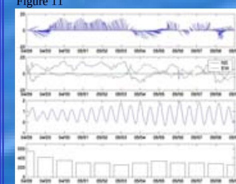
Figure 11


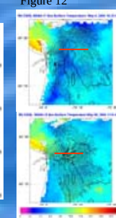
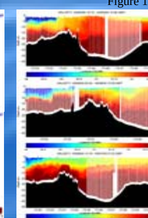
Figure 12


Figure 13


Buoyant plumes are spatially extensive and are associated with both high particle concentrations and Colored Dissolved Organic Matter (CDOM, Fig 14C,E,F). While particle loads are high within the plume, the high absorption of CDOM is a significant proportion of the total attenuation. *The high CDOM concentrations allow buoyant plumes to be differentiated fluorometrically from nepheloid layers.* These 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. Nepheloid layers are optically significant and are almost a universal feature on continental shelves. The maintenance of these nepheloid layers is regulated by the resuspension of material and the relative rates of aggregation and disaggregation. The enhanced concentration of particles is strongly associated with increased light backscatter and attenuation (Fig. 14B). 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).

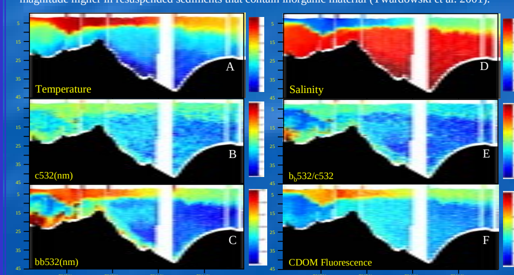


Figure 14

LATTE - 2005

LaTTE 2005 included two dye release studies conducted in April immediately following a series of large rain events. The first dye injection was into an ebb-tide pulse of fresh Hudson water leaving New York Harbor. Instead of propagating down the New Jersey Shelf as a strong coastal current, a recirculation zone formed at the coast just south of the Harbor. Ships surveying the plume found the coastal current to be thin and weak, while satellite imagery and CODAR surface current maps (Figure 15) revealed significant cross-shelf flows along the southern flank of the Hudson Shelf Valley. Because the survey ship could only cover one of these features at a time, a glider was called into play for the second dye release. The glider was deployed outside the Harbor and transited southeast in between the shipping lanes until it reached the southern flank of the shelf valley. During the second dye release, the glider observed significantly more cross-shelf flow of freshwater than the down-coast flow observed by the ship in the coastal current (Figure 16).

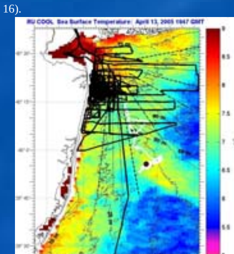


Figure 15

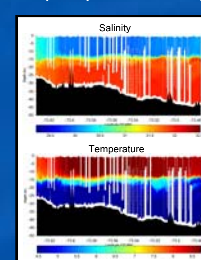


Figure 16

GLIDER APPLICATIONS

SHAREM 2005

The SHip Anti-Submarine Warfare Readiness and Evaluation Measurement exercise measures how well surface ships and aircraft can detect and track submarines. Using an arsenal of shipboard sensors including active sonar, passive sonar, towed arrays, sonobuoys and AUVs, naval vessels gather data, identify tactical problems, and produce tactical guidance/recommendations for the fleet commander. In support of this exercise, the Rutgers COOL group, in partnership with SPAWAR, Alaska Native Technologies and Webb Research Corporation, deployed 5 glider to assist in environmental data collection for assimilation into Naval tactical models. The fleet commander noted 42 separate instances of changes in tactical plans as a direct result of the environmental data collected by the gliders.

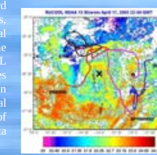


Figure 17

An example of this is displayed in figures 17 & 18. Figure 17 is a satellite sea-surface temperature image. Without the gliders, it is very difficult to model the subsurface temperature vertical structure; however, the gliders were able to map out this vertical structure autonomously, freeing up other naval assets to gather and assimilate environmental data over other locations in the large field area. Figure 18 displays the 3-dimensional subsurface temperature structure in this area of interest. A temperature just below the surface of the water is evident in figure 18, but would not have been evident in the sea-surface temperature imagery used as an input to naval oceanographic models.

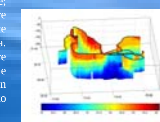
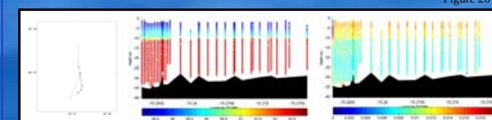


Figure 18

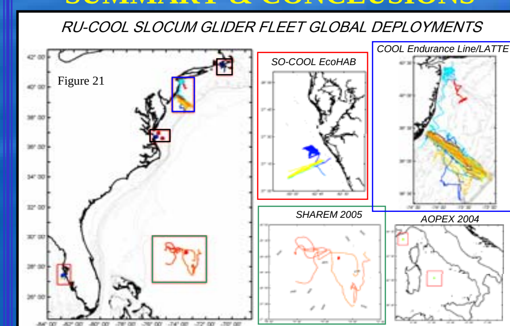
MIREM 2004 & 2005


Figure 19

COOL gliders were deployed in support of the Mine Warfare Readiness and Effectiveness Measuring exercise conducted by the United States Navy and Marine Corps in September 2003 and April 2005. The gliders were deployed in pre-selected areas of interest within coastal mine fields to provide optical and other environmental data in addition to data gathered by mine hunter ships. This real-time data was transmitted via satellite link, processed onshore and fed into environmental (MEDAL) and electro-optic performance models at the Naval Oceanographic Office to assist in the detection of subsurface mines. The glider revealed a highly backscattering particle layer associated with a fresh water surface layer (Figure 20). Based upon environmental data such as this, the fleet commander knew prior to arrival in the battle theatre that a sonar based detection scheme (Figure 19) would have a better probability of detection of subsurface shapes.

Figure 20


SUMMARY & CONCLUSIONS



- The RU-COOL glider fleet has and will continue to maintain a subsurface presence in the world's oceans, collecting physical, optical and biological datasets irregardless of marine conditions. These datasets have provided insights into large scale ocean processes that would have otherwise gone un-detected.

- Since switching over to satellite communications in September 2003, the COOL glider fleet has flown over 11,000 km in the following locations (Figure 21):
  - New York/New Jersey Shelf – USA (Endurance Line, LaTTE)
  - Martha's Vineyard, Massachusetts – USA (CBLAST)
  - West Florida Shelf/Gulf of Mexico – USA (ECOHAB)
  - Norfolk, Virginia – USA (MIREM)
  - Mediterranean Sea – Europe (AOPEX)
  - Sargasso Sea – Atlantic Ocean (SHAREM)

- COOL gliders have logged 522 total glider days in the water and 391 out of a possible 671 calendar days as of June 2, 2005.

- The fleet is maintained by a full-time staff of 2 (one engineer and one software/data analyst) and has moved from an experimental ocean sensing platform to a cost-effective operational asset for both scientific and applied research.