

Transition of Slocum Electric Gliders to a Sustained Operational System

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Abstract – In the 1980's Slocum Gliders were a vision of Douglas C. Webb, which Henry Stommel promoted in a science fiction article published in *Oceanography* in 1989. In the early 1990's the glider concept was proven and in the late 1990's open water test flights were done at LEO15. In 2002 Rutgers University COOL Group began collaborating with Webb Research Corporation on the development and deployment of the Gliders. Initially the deployments were on the order of hours to a few days with constant human supervision. By the latter half of 2003 Slocum Gliders were routinely flying multiple week missions and calling in to the automated Glider Command Center on Rutgers main campus via satellite phone to provide a status update, download data and receive any new mission commands.

The ability to operate Gliders with minimal human intervention for extended periods of time has allowed Rutgers to integrate them into the New Jersey Shelf Observing System. Since November 2003 a Glider has been occupying the Endurance Line, a 123km track located between the LEO15 nodes and the shelf break, on a monthly basis. The sustained data set being collected permits scientists to go beyond collecting snapshots of information for short-term projects and gather long-term, expanded region data sets that will allow the tracking of trends over multiple years. While the Endurance Line Glider has been flying, additional Gliders have been operating for shorter periods of time on the West Florida Shelf, in the northwestern Mediterranean and in the Hudson River plume. Like the Endurance Line Glider, these Gliders are controlled by the Glider Command Center via satellite phone.

Rutgers will be adding 2 Gliders to its fleet the end of this year bringing the total to 6 electric Gliders. One Glider will be dedicated to the West Florida Shelf Red Tide research program and the second will be used in the Mediterranean to look at the significance of Sahara Desert dust on biological and optical signals. Dedication of the new Gliders to these two research projects will enable Rutgers to have a continual presence in these regions as well as on the shelf of New Jersey.

INTRODUCTION

In the 1980's Douglas C. Webb conceived the idea of the thermal engine. From that concept evolved the vehicle upon which the engine would be used (Fig. 1), the Slocum Glider. Henry Stommel provided encouragement for this project publicizing it in a science fiction article he wrote for *Oceanography* in 1989 [1]. In 1991 the first Glider prototype was tested in Lake Seneca, NY to determine if a Glider could glide. After these successful tests there was a lull in funding and development of the Gliders until the mid



Fig. 1. Slocum Electric Glider

1990's. In July 1998 the first open water field tests of a Slocum Electric Glider were conducted at LEO 15. After a number of short duration flights the month long trial culminated in a continuous 10-day flight. Since the success at LEO 15 in 1998, Glider development, both electric and thermal, has been in full swing.

In the October 2002 Rutgers University took delivery of its first Gliders. Like Webb Research during their sea trials at LEO 15, the Rutgers team started out cautiously. Initial flights, lasting several hours, were done with a research vessel standing by at the test site. Gliders were programmed to surface every 30 minutes. By the spring of 2003 overnight flights were conducted with personnel standing by 24/7, at the Command Center on shore waiting for the Glider to call home during each surfacing. The Glider was still commanded to surface every 30 minutes. Mid-summer 2003 saw Gliders routinely calling in to the automated Glider Command Center at Rutgers University, downloading data and resuming the mission. The time between surfacing intervals was increased to 60 minutes. An e-mail and pager system was put into place that notified scientists each time a Glider surfaced and what the status of the Glider was at that time. The Command Center no longer had to be occupied 24/7 when a Glider was deployed. In August 2003, Rutgers flew 4 Gliders simultaneously at three different sites (one at LEO 15, one off of Martha's Vineyard and two in Buzzards Bay). Control of the Martha's Vineyard and LEO 15 Gliders was maintained at the Rutgers' Glider Control Center while the two in Buzzards Bay were used in an inter-comparison exercise with optical sensors mounted in a cage and were controlled locally. In October 2003 Rutgers began occupying the Endurance Line, a 123 km transect located between the LEO 15 nodes and the

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shelf break, on a monthly basis. Occupation of the Endurance Line marked a significant addition to the type of dataset collected by the Rutgers' Gliders. Until this time scientists had been collecting snapshots of information for short-term projects. Occupation of the Endurance Line is expected to continue for a number of years and this long-term, expanded region data set, will allow scientists to track trends over multiple years. In addition to the Endurance Line Glider, Rutgers is still flying Gliders for shorter periods of time on the West Florida Shelf, in the Hudson River plume and in the northwestern Mediterranean (Fig. 2). All Gliders are now controlled by the Glider Command Center at Rutgers. Currently, Gliders are programmed to surface every 3 to 6 hours.

GLIDER GENERAL BACKGROUND

The Slocum Electric Glider is a 1.5 m long, 23.2 cm diameter, 52 kg, torpedo shaped vehicle that travels in a saw-tooth pattern by changing its buoyancy. The saw-tooth pattern is optimal for both vertical and horizontal observations in the water column. Its average forward velocity is 25 cm/sec. The Glider is designed to operate in 4-200 m of water to maximize its capabilities in the littoral region. It operates on C-cell alkaline batteries. Sampling rate of the Glider is dependent upon the scientific payload. The minimum sampling rate is 0.5 Hz. Contents of the scientific payload are limited only by the size of the payload bay, (23.2 cm diameter, 25 cm long), the power requirements of the package and the imagination of the scientist designing the payload. Communication with a Glider can be done with line of site RF modems, by satellite modem or for recovery by ARGOS. All communication antennas are located in the Glider's tailfin. Glider navigation is done using GPS, internal dead reckoning and an altimeter. An emergency abort system has been built into the Glider in the event that a critical system on the Glider fails and it cannot surface on its own [3].

GLIDER MISSION CONTROL CENTER

Construction of a Mission Control Center at Rutgers University to guide the Glider fleet in its data collection is underway. The software being written to run Mission Control is called GRCS (Glider Remote Control System). The project has been divided into phases. Phase one, which was completed last summer, involved the implementation of the basic communication between the Glider and the shore station. The goal for this phase was for the shore station, using standard modem communication commands, to answer the phone when the glider called in, command the Glider to send the short binary data (sbd) file to the command computer and tell the Glider to resume its mission (Fig. 3). A sbd file rather than the full data set collected by the Glider during a leg is sent during a surfacing because of the slow data transfer rate 80-160 bytes/sec) over Iridium. If the Glider was to transfer the entire data set it would be on the surface for an hour or more at a time rather than 20 minutes.

The second phase, completed last fall, was to notify Glider team members via e-mail and pagers of the condition of the Glider when it last surfaced. Included in the e-mail and page is the name of the Glider, reason it surfaced, when it surfaced, its location, battery voltage, leak detector voltage, vacuum and surface temperature and conductivity values and what waypoint (latitude/longitude) it is heading to (Fig. 4).

Phase three involved the construction of a web accessible gui, that showed the most recently downloaded information from the Glider including plots of the temperature, salinity and optical data and Glider health (battery voltage, vacuum and leak detect) (Fig. 5). This phase was completed in spring 2004.

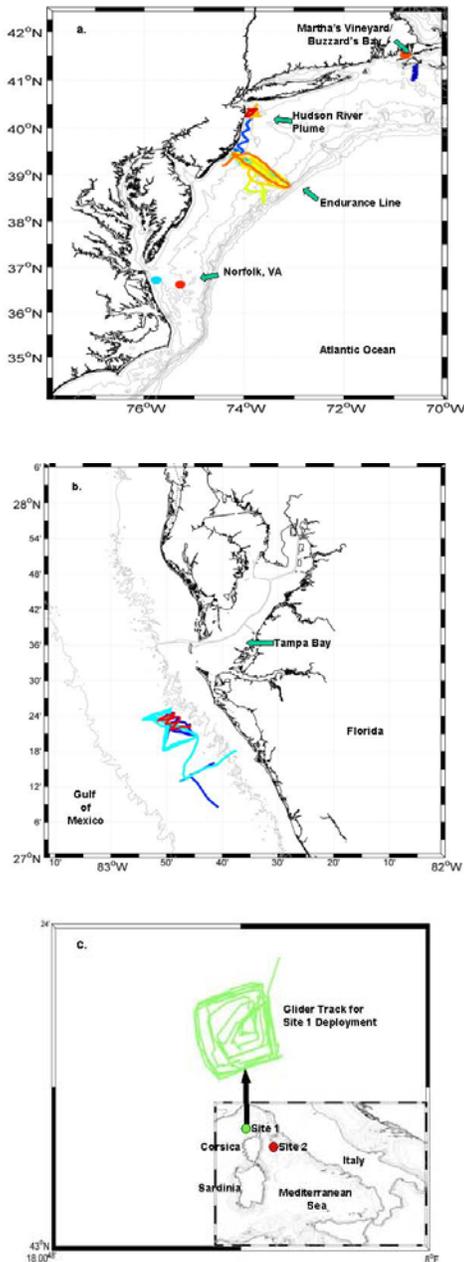


Fig. 2. Maps of Glider Deployment Locations and Transect Paths for the Past Year. a) U.S. East Coast b) U.S. Gulf Coast c) Mediterranean

Phase 4, which is presently being implemented, involves the automatic re-tasking of a Glider based upon data that the Glider itself or other systems (CODAR, satellites or other Gliders) have collected. The initial re-tasking software was designed to check for fronts in the Glider data. Testing of this software was done during LaTTE, an NSF funded project studying the Hudson River Plume. The goal was to have a Glider fly the full width of the plume without going too far into the more saline waters outside of the plume. The plume water was known to be less than 29 PSU at the surface. Therefore, when the Glider surfaced and called the Command Center the first piece of information received on shore, the surface dialog, was parsed and the conductivity, temperature and pressure used to calculate salinity. If the salinity was greater than 29 PSU, new flight coordinates were sent to the Glider immediately after the sbd file had been transferred to shore and the Glider mission was restarted with the new coordinates. If the salinity was less than 29 PSU, then after downloading the sbd file the automated Command Center instructed the Glider to resume its mission with no coordinate changes.

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Glider ru01 at surface
Because timeout expired [behavior surface_7_start_when = 9 0]
MissionName:ALINBB6HMI MissionNum:ru01-2004-229-4-15 (0482.0015)
Vehicle Name: ru01
Curr Time: Thu Aug 19 09:26:42 2004 MT: 152653
DR Location: 3911.722 N -7349.169 E measured 1060.69 secs ago
GPS TooFar: 3923.978 N -7409.874 E measured 127508 secs ago
GPS Invalid: 3911.773 N -7350.141 E measured 1145.8 secs ago
GPS Location: 3911.722 N -7349.169 E measured 1061.76 secs ago
sensor.m_battery(volts)=13.8502762328944 50.057 secs ago
sensor.m_vacuum(mnHg)=8.94481206187606 111.031 secs ago
sensor.m_leakdetect_voltage(volts)=2.49865689873695 47.952 secs ago
sensor.sci_water_cond(S/m)=4.58165 2.423 secs ago
sensor.sci_water_temp(degC)=22.0886 2.506 secs ago
devices(tmi/s) ems: 0/ 0/ 0 warn: 3/ 3/ 1 odd: 337/ 334/ 63

Waypoint: (3647.7800,-7304.6800) Range: 78015m, Bearing: 137deg, Age: 42:21h:m

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Fig. 4. Phase 2, the e-mail and pager notification sent by Rutgers automated Command Center to the Glider team each time a Glider surfaces.

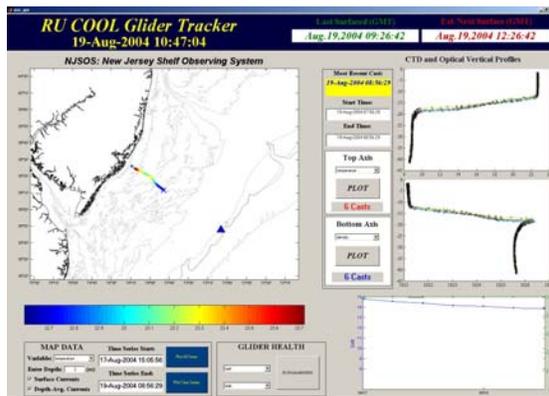


Fig. 5. Phase 3, the Glider GUI. The upper left plot is the track of the Glider color coded temperature. Upper right plot is individual overlaid temperature casts from the last leg. Middle right plot is individual overlaid salinity casts from the last leg. Lower right plot is battery voltage levels since deployment.

This software code is currently being enhanced to include re-tasking for fronts based upon any combination of scientific parameters collected by the Glider. Software that will allow re-tasking based upon clines (temperature, salinity, optical, etc.) seen by the Glider will be developed this winter and tested on the Endurance Line.

After the programming that involves re-tasking a Glider based upon the data that the Glider itself has collected, GRCS will be expanded to include the re-tasking of a Glider based upon information provided by other Gliders flying in the area, CODAR and satellites. This work is planned for 2005.

SLOCUM GLIDERS vs SAMPLING FROM A RESEARCH VESSEL

Traditional subsurface collection of physical and optical data with a research vessel is labor and boat intensive and weather dependent. On a small UNOLS vessel such as the R/V Connecticut, which requires 4-5 crewmembers to operate and can accommodate 7-8 scientists, the maximum number of days at sea including transit time is 10 with a maximum cruising speed of 11kts. Cost per day for the vessel is \$3800. Weather days, with crew only aboard are \$1900/day. Seasickness will probably strike one or more of the seagoing party at some point during the cruise. The continual grind of sample processing takes its toll on personnel. Tired crews are not as efficient as well rested crews. Tired crews are also more likely to make mistakes than rested crews.

A Glider on the other hand requires 1-2 people to deploy/recover it from a small boat that is chartered by the hour (\$155/hour) for 3-4 hours at a time. Each Glider deployment lasts 20-30 days, depending upon the scientific payload and sampling regime. Gliders, on average, cover 20-24 horizontal kilometers/day. In 100 m deep water Gliders will complete approximately 6 casts/hour or one cast every 150 m. In 15 m deep water Gliders will complete about 20 casts/hour or one cast every 50 m.

A comparison was made between a hypothetical 10 day R/V Connecticut CTD/optical cruise and a Glider mission along the Endurance Line. Transit time for the research vessel from port to the research site is 1 day each way. This leaves 8 days for scientific sample collection – 4 days for the outbound leg of the transect and 4 days for the inbound leg. It was assumed that the vessel would cover 36 km of the transect line per day leaving a half day on both the outbound and inbound legs for equipment failures, poor weather conditions and other problems that usually occur on a cruise. It was also assumed that it would take one hour to transit from one station to the next station on the transect line and collect the necessary samples. Therefore, the ship would be able to collect one set of samples every 1500 m.

Fig. 6 is a comparison of the density of the data collected on the outbound leg of the Endurance Line by the research vessel and the Glider. Note that the research vessel had to complete this leg in under 4 days because the maximum continuous time it can

spend at sea is 10 days while the Glider completed the leg in 5 days. The Glider data is un-interpolated and is approximately 15 times denser than the ship collected data.

As mentioned above bad weather can slow and sometimes temporarily suspend the collection of data on a research cruise. However, Gliders do not get seasick or tired and they are much better able to operate in poor sea conditions than are traditional research vessels. Rutgers personnel have found that, with the vessels generally available to them, work at

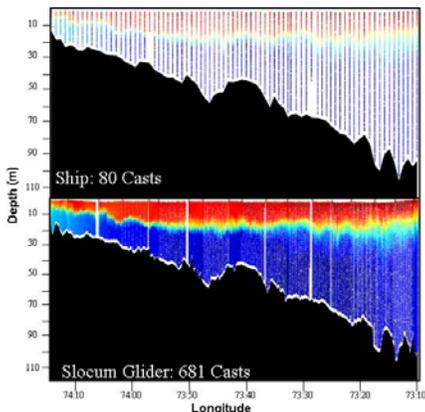


Fig. 6. Comparison of conventional shipboard sampling versus sampling by a Slocum Electric Glider along the Endurance Line transect.

sea can be accomplished if the winds are 20 knots or less and the sea state is less than 1.5 m. However, Rutgers has successfully operated a Glider in 5-meter seas and 35 knot winds. Fig. 7 shows weather conditions in the LEO 15 area from October 28, 2003 – August 19, 2004. Wind data is from Atlantic City, NJ and sea height data is from the Delaware Bay buoy which is located 23 miles southeast of Cape May, NJ. The green line through the wind data is the 20 knot limit and the blue line through the wave height plot is the 1.5 m cutoff height. The shaded blue boxes depict when Gliders were deployed in the Mid-Atlantic Bight (MAB). Gliders were deployed for 195 of the 296 calendar days included in this plot. Wind and sea conditions for 64 of the 195 days, or 33% of the time, that Gliders flew, were considered too rough for small boat operation. During these MAB deployments Gliders covered over 5200 horizontal km.

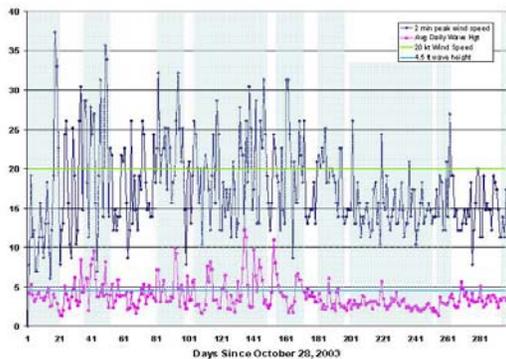


Fig. 7. Wind speed data from Atlantic City, NJ and wave height data from the Delaware Bay buoy.

A cost comparison between the hypothetical R/V Connecticut cruise and a Glider deployment on the Endurance Line is shown in Table 1. Ignoring the purchase price of the research vessel and the Glider and concentrating just on operations costs for each, a 10 day shipboard cruise is \$38,000 plus salary for 7-8 scientists while a 21 day Glider deployment is \$3,820 plus salary for 2 scientists. Combining the information from Fig. 6, Fig. 7 and Table 1 it is shown that Gliders can collect data that is 15 times denser, 2 times longer in duration and for less than 10% of the cost than shipboard data.

Table 1. Cost comparison of a Glider deployment versus a 10 day cruise on the R/V Connecticut

	Glider	R/V Connecticut
Initial Investment	\$85000	\$1000000
Cost/Cruise or Deployment [scientific personnel salaries not included]	3820 [500 battery packs 620 boat time deploy 620 boat time recover 1680 Iridium phone bill [80 min/day for 21 days]]	38000/10 day cruise
Length of Cruise/Deployment	21	10
Scientific Personnel Needed:	7-8	1-2

Fig. 8 is an uninterpolated temperature scatter plot of the data Gliders have been collecting on the Endurance Line for the past 10 months. See Fig. 2a for the location of the Endurance Line. This time series shows the annual winter mixing and cooling and subsequent late spring and summer stratification on the Mid-Atlantic Bight. Conductivity and optical data was also collected simultaneously with the temperature data. Rutgers will complete its first year of occupation

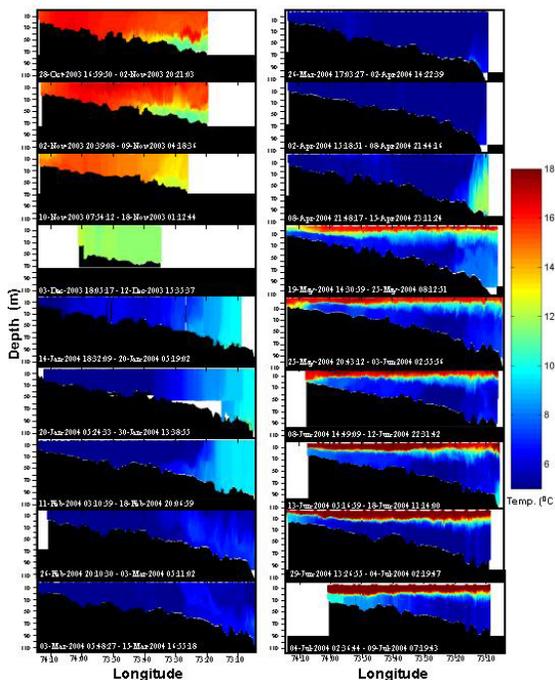


Fig. 8. A time series for the Slocum Electric Gliders crossing the continental shelf spanning from the nearshore (15 m) to 123 km offshore (Endurance Line).

of the Endurance Line the end of October 2004.

In the past year Gliders have moved from the test phase to being a major contributor to scientific data collection. Slocum Electric Gliders are ready to anchor littoral region sampling and provide a mesoscale subsurface context to complement the satellite and CODAR surface maps.

Acknowledgments

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References

- [1] Henry Stommel. "The Stommel Mission," *Oceanography*, 1989.
- [2] Slocum Battery Glider Operations Manual version 1.5, Webb Research Corporation, East Falmouth, MA, June 17, 2004.
- [3] Elizabeth L. Creed, Chhaya Mudgal, Scott M. Glenn, Oscar M. Schofield, Clayton P. Jones and Douglas C. Webb, "Using a Fleet of Slocum Battery Gliders in a Regional Scale Coastal Ocean Observatory," *OCEANS 2002 MTS/IEEE Conference Proceedings*, Biloxi, MS. Vol. 3, IEEE, 2002, pp. 1234-1238.