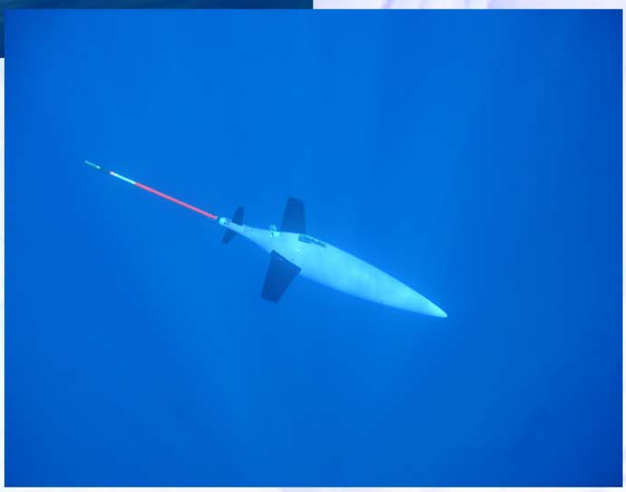
EGO 2009

4th EGO Meeting and Glider School

16 - 20 November
Larnaca, Cyprus



Everyone's
Gliding
Observatories

Schedule for EGO 2009—Meeting Portion

	Monday, 16 November, 2009
0800	**Registration**
0900	**Welcome:** Constantinos Christofides, Vice Rector of Academic Affairs, University of Cyprus
	Topic I: Technology of Gliders and Sensors
0920	**Eriksen and Osse:** Deeper, Longer, Farther and Faster with Deepglider
0940	**Arshad et al.:** System Design of an Underwater Glider for Shallow Water Application
1000	**Claus and Bachmayer:** Hybrid Glider Performance Characterization
1020	**COFFEE**
1100	**Kerfoot et al.:** Correction and Comparison of Pumped and Non-Pumped CTD sensors on the Slocum Glider
1120	**Eriksen**: Salinity Estimation Using an Un-Pumped Conductivity Cell on an Autonomous Underwater Glider
1140	**Hussain et al.:** Modeling and System Identification of an Underwater Glider for Shallow Water Application
1200	**Esser:** Advanced CO2 and Methane Sensor Systems in Future Autonomous Applications
1220	**LUNCH**
1400	**Hudson:** Extending the Operational Range and Application of commercial Gliders
1420	**Hine et al.:** The Wave Glider, a Persistent Platform for Ocean Science
1440	**Jones:** Slocum Glider—Extending the Capabilities
1500	**Bennett:** Sea-Bird Electronics Role in Glider Technology
1520	**COFFEE**
1600	***Round Table Discussion—Manufacturers*** a. User product feedback b. User requests for services/products c. Manufacturer requests for information
1900	**WELCOME COCKTAIL**

	Tuesday, 17 November, 2009
	Topic II—Gliders and Operational Systems
0900	**Fralick and Manley:** DART Wave Glider Advanced Technology Demonstration Results
0920	**Barrera et al.:** Trans-Atlantic Glider Technology School (TAGTS): Engaging Students in Long Duration Underwater Glider Missions Through a Trans-Atlantic Partnership
0940	**Hollings et al.:** The Australian National Facility for Ocean Gliders (ANFOG) – the First 12 Months
1000	**Hayes et al.:** Operational Glider Transects in the Levantine Sea: First Results and Comparisons
1020	**Beszczynska-Möller et al.**: Fram Strait Observatory—Recent Glider Activities and Future Plans
1040	**COFFEE**
1120	**Carval et al.:** The Argo Data Management System and Possible Implementation for Gliders
1140	**Pascual et al.:** Multi-sensor Approach Towards Coastal Ocean Processes Monitoring
1200	**Smeed et al.:** Validation of an Ocean Model Using Glider Data
1220	**Dobricic et al.:** Data Assimilation of Glider Observations in the Ionian Sea (Eastern Mediterranean): A Study of the Path of the Atlantic Ionian Stream
1240	**Desaubies:** International Coordination, JCOMMOPS, Argo and Gliders
1300	**LUNCH**
1415	***Discussion—Data Management Practices*** d. Formats—existing, in use, and future—BRING EXAMPLES e. Metadata—how much? f. Sharing—possible ways to centralize, obstacles
1530	**COFFEE**
1600	***Discussion—Piloting Strategies*** a. Coordination among groups—exchange of resources, expertise, online? b. Coordination among gliders (fleet)—automated? Expert advice? c. Coordination among platforms—glider, float, profiler, ship: expert advice?
2000	**CONFERENCE DINNER**

	Wednesday, 18 November, 2009
	Topic III—Gliders and Process Studies
0900	**Eriksen and Emerson:** Upper Ocean Property Budgets at Ocean Station P from fortnightly glider Repeat Surveys Over 15 Months (and counting)
0920	**Bourrin et al.:** Seasonal Variability of Physical and Biogeochemical Coupling at Submesoscale Across the Ligurian current, NW, Mediterranean
0940	**Fan:** Using Gliders and Moorings to Characterize North Atlantic Eddies
1000	**Søiland et al.:** Investigating Fronts in the Norwegian and Barents Sea using Gliders
1020	**COFFEE**
1100	**Pietri et al.:** Geostrophic Transport Variability and Vertical Secondary Circulations Associated with the Upwelling Front off Pisco (Peru, 14°S) from Glider Data
1120	**Gourdeau et al.:** The Solomon Sea Observed by Glider and Altimetry
1140	**Ruiz et al.:** Combining Glider and Altimetry Data to Diagnose Vertical Velocities in the Upper Ocean
1200	**Merckelbach et al.:** Vertical Velocity Spectra Measured by Gliders During and Around Convective Events
1220	**Mauri et al.:** Glider Measurements Around the Vercelli Seamount (Tyrrhenian Sea) in May 2009
1240	**LUNCH**
1400	***Discussion—Future Plans*** d. EGO community goals and action items e. Globalizing the gliding observatory f. Sustaining the activities: funding opportunities, COST proposal g. Next year's meeting
1530	**COFFEE**
1600	***Discussion (continued)***

Schedule for EGO 20009—School Portion

	Thursday, 19 November, 2009			Friday, 20 November, 2009		
0900	Group 1--Intro	Group 2--Field	Group 3--Data	Group 2--Intro	Group 3--Field	Group 1--Data
1030	COFFEE			COFFEE		
1100	Group 2+3--Ballast	Group 1--Field		Group 1+3--Ballast	Option--Field	
1230	LUNCH			LUNCH		
1330	Group 3--Intro	Group 2--Data				
1500	COFFEE			COFFEE		

Introduction: Expert users present history, general operating and design principles, and past uses of each glider type.

Ballast: Present philosophy and demonstrate techniques used for determination and application of proper vehicle buoyancy of each glider type.

Field: Present and demonstrate piloting principles and techniques and field launch and recovery procedures for each glider type.

Data: Present and demonstrate stages of data processing from format received from glider to visualization, to standard formats with basic and advanced quality control.

DEEPER, LONGER, FARTHER AND FASTER WITH DEEPGLIDER

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Deepglider extends underwater glider range from the upper (1 km) to full open ocean depth (6 km). The goal is to be able to survey the entire water column autonomously under remote control at a cost of a few Euros per km of survey track in missions lasting more than one year.

Deepglider design employs many elements of the successful Seaglider design, while significantly enhancing performance. The prototype Deepglider employed a carbon fiber hull in the shape of the Seaglider fairings. Unfortunately, the tapered shape with tapering wall thickness could not be reliably fabricated and was beyond the state of the art of aerospace composite manufacture. This prototype was operated to 2714 m depth offshore Washington, but fell short of achieving the goal of being able to operate to 6 km depth. A revised design uses a simpler shape which not only provides sufficient strength to withstand sea floor pressure, but also makes it easier to assemble and service, and provides increased hydrodynamic performance. The pressure hull consists of a carbon fiber cylinder sealed by aluminum end caps. Three hulls have been pressure tested to over 6400 dbar in multiple cycles, where strain measurements indicated incipient buckling instability. Fairings are appended to the end caps to produce low hydrodynamic drag and provide flooded enclosures for instrumentation.

Scale model tests indicate that the simpler Deepglider shape has ~10-20% less drag than Seaglider. Deepglider sea trials in a fjord confirmed reduced drag. Sustained speeds in excess of 0.6 m/s were attained, about 50% more than available to Seaglider, due both to lower drag and larger available buoyancy change.

Deepglider benefits substantially from the use of a novel combined 'compressee/expansee' to compensate for buoyancy induced by the difference between the vehicle response to pressure and temperature changes and that of seawater. Bags of a fluid with both high compressibility and high thermal expansion coefficient are packed within flooded spaces to minimize pumping energy required for propulsion. Use of the compressee/expansee is more effective on a per mass basis than batteries in extending vehicle range and endurance. Projected single mission range and endurance are 10,000 km and 18 months in continuous dives to 6 km depth at 0.3 m/s speed.

Data from the first offshore mission, with dives to as deep as 2563 m, will be discussed.

SYSTEM DESIGN OF AN UNDERWATER GLIDER FOR SHALLOW WATER APPLICATION

Nur Afande Ali Hussain[1], Mohd Rizal Arshad[1*] and Ting Ming Chung[2]

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This paper presents the design and development of USM's underwater glider for shallow water application. This preliminary vehicle design has been done using Solidworks – CAD software, while the vehicle design analysis using a Computational Fluid Dynamics (CFD) software and MATLAB Simulink. Once the final design has been verified via the CFD analysis, the parts fabrication and sub-system development are done. The next stage is for system integration and testing. The vehicle dynamic model and control strategy are being formulated concurrently. The completed platform will enable performance comparison between actual, simulated and desired condition. The shallow water application for this prototype presents a serious challenge to the manoeuvrability and suitability of the design. At the same time the glider system is also being envisaged as the main platform for fleet gliding applications. This paper will share some of the results that were used for the final vehicle parameter specifications and also simulation results for the CFD analysis.

HYBRID GLIDER PERFORMANCE CHARACTERIZATION

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The hybrid glider augments the conventional buoyancy drive of a 200m Slocum electric glider with a low power propeller driven propulsion system. The propeller based propulsion module has been optimized for high efficiency operation at typical glider speeds of about 0.35m/s. To achieve the high efficiency at these low power levels the entire drive train from motor controller to propeller was considered. The mechanical design utilizes a dual stage planetary gear box, low friction ceramic bearings and a magnetic coupling to eliminate friction losses to shaft seals. Special consideration has been given to match the motor, gearbox and propeller peak operating efficiencies. A brushed motor operating at a fixed point was selected to remove motor controller losses. The motor and gearbox combination was selected using the OpenPVL matlab propeller analysis program to locate an optimal operational range. Since the propeller propulsion is not in use at all times the parasitic drag of the propeller is minimized by using a folding propeller design. A series of small blade area ratio folding propellers were tested using only the propulsion module in a flume tank for advance velocities on the order of 30 to 60cm/s. From these tests the propeller with the peak system efficiency was selected for use. The system performance of the hybrid glider with the propeller propulsion module was tested in a larger flume tank. For these tests, drag measurements were performed for advance velocities on the order of 30 to 100cm/s at zero angle of attack with the hybrid propulsion module turned on at varying speeds and compared to the glider only performance. The results of these tests allowed us to determine the basic parameters of a ded-reckoning algorithm for glider navigation when driven by the propeller module. In addition the power consumption was monitored during these tests. Preliminary data shows that the propeller based propulsion is able to exceed the propulsive efficiency of the buoyancy driven mode for the 200m SLOCUM glider. Work is currently focusing on developing the navigational behaviors and field testing.

CORRECTION AND COMPARISON OF PUMPED AND NON-PUMPED CTD SENSORS ON THE SLOCUM GLIDER

John Kerfoot[1], Scott Glenn[1], Oscar Schofield[1], Dave Aragon[1], Chip Haldeman[1], Clayton Jones[2], Dave Pingal[2]

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A key feature of the Slocum Glider is modularity. Driven by the rapidly expanding user community, development of small, power conscious sensors is currently underway. Energy and space are central criteria in the selection of a CTD. CT sensor alignment and thermal inertia corrections of conductivity are dependent on glider velocity, which can be highly variable. As many other in situ measurements require corrections for temperature and salinity, accurate CTD profiles are critical.

In October 2009, 2 gliders were deployed from the Rutgers University Marine Field Station. One glider was equipped with a standard, non-pumped CTD and the other glider was outfitted with a pumped CTD. The water column was characterized as a highly stratified 2-layer system, separated by one of the most pronounced thermoclines in the world. Using these datasets, and building upon previous methods, we present correction methods for both instruments. Two corrections are applied: 1) short-term sensor (pressure, temperature and conductivity) mismatch and 2) correction of the conductivity signal for thermal inertia effects.

For CT sensor alignment, the non-pumped CTD requires larger temperature and conductivity time shifts relative to pressure compared to the pumped CTD. Calculation of coefficients for correcting thermal inertia effects on the conductivity cell show a dependence on cell flush time, which is moreaccurately quantified in the pumped unit. Time constants between the pumped and non-pumped units are similiar while the magnitude of the effect is reduced in the pumped unit.

Results show that both CTDs produce quality datasets, allowing the end-user to consider price, deployment length, and payload space in the selection of the appropriate unit.

SALINITY ESTIMATION USING AN UN-PUMPED CONDUCTIVITY CELL ON AN AUTONOMOUS UNDERWATER GLIDER

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Salinity is commonly estimated from nearly co-located thermistor and electrode conductivity cell sensors. A pump is often used to regulate thermal exchange between the cell wall and the seawater sample. Unfortunately for gliders, power requirements for the pump can be an appreciable fraction of the overall vehicle power budget. Accordingly, use of un-pumped cells has been standard practice on many gliders. Use of an un-pumped cell requires estimation of cell flushing speed as a function of vehicle speed and a model of cell wall thermal exchange for variable speed.

Since glider speed is not directly measured, it must be inferred from a flight model. A glider's descent or rise rate inferred from pressure includes a normally significant unknown contribution from internal waves. Moreover, glider speed cannot be reliably inferred from pitch and instantaneous relative vertical speed, since vehicle glide slope depends on attack angle. Fortunately, buoyancy changes in glider displacement and variations in thermal environment dominate vehicle buoyancy so flight model verification is insensitive to salinity. Speed through the water can be estimated from glider volume, pitch, temperature, and approximate salinity.

Cell flushing spans the transition between viscous and turbulent pipe flow for SeaBird Electronics conductivity sensors mounted on Seagliders. At low speed, flushing takes the form of Poiseuille flow, driven by the pressure difference between ends of the conductivity cell. The driving pressure arises from flow around the cell's mount and can by parameterized by a drag coefficient. The relationship between external flow past and flushing rate through a SeaBird cell has been determined by laboratory measurements.

The approach of Lueck(1990) to conductivity cell thermal inertia correction can been extended to the case for variable flow and applied to Seaglider data records. A finite difference scheme for thermal inertia response applied to variable flow can be used to correct salinity. An iterative scheme can be used to assure estimated salinity is consistent with glider buoyancy and speed.

Knowledge of glider volume displacement and pitch are crucial, through establishing a flight model, to estimating salinity from an un-pumped conductivity cell. With sufficiently frequent sampling, salinity from an un-pumped conductivity cell aboard Seaglider approaches the accuracy of that from a pumped cell.

MODELING AND SYSTEM IDENTIFICATION OF AN UNDERWATER GLIDER FOR SHALLOW WATER APPLICATION

Nur Afande Ali Hussain[1*], Mohd Rizal Arshad[1] and Rosmiwati Mokhtar[1]

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Underwater glider is an autonomous underwater vehicle that moves by gliding. This gliding motion is achieved by controlling its buoyancy and attitude using an active ballast system and internal actuators. By changing the vehicle's buoyancy intermittently, desired vertical motion can be achieved. The main characteristics of glider motions include upward and downward saw tooth patterns, and gliding in a vertical spiral motion glides without active propulsion. This paper presents the modelling and system identification of an underwater glider system. In order to avoid the complexity of deriving the vehicle model from the first principle, system identification method is utilised. The availability of the glider platform enables this king of approach. System identification technique represents the search for the useful model rather than trying to acquire the true model. It is also a method to understand the behavior of the system, and its properties. System identification utilised on the acquired or observed data from the vehicle, taking an assumption that the observed data follow certain reliable model or structure. For this reason, the observed data can be used to estimate the modelling of the subsystem based on the selected input and output that influence the system behavior. The purpose for this approach is to design the possible control approach for the currently developed underwater glider for shallow water application.

ADVANCED CO2 AND METHANE SENSOR SYSTEMS IN FUTURE AUTUNOMOUS APPLICATIONS

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In light of increasing public awareness of a global climate change and ocean acidification, methane and CO2 are becoming the most important gases in ocean science. Indeed, in many areas of everyday life, the monitoring of methane as well as CO2 has become a necessity. CONTROS therefore has developed and approved the HydroC™ systems. Two similar operating but unique underwater gas sensors, measuring either dissolved CO2 or methane up to 6,000m. These HydroC™ systems were specifically developed to allow fast, realtime and insitu detection of gaseous and dissolved CO2 or methane in the water column under even the harshest environmental conditions. Current applications include greenhouse gas monitoring, ocean acidification, pollution monitoring, seaair exchange, etc. Today buoy systems and other fixed monitoring stations deliver a high temporal resolution of Methane and CO2 concentrations at specific locations. But in order to get an understanding of the special distribution in the oceans, these gasses have to be measured over greater distances and time scales. Therefore the integration on glider or similar systems has to be seen as a future solution.

EXTENDING THE OPERATIONAL RANGE AND APPLICATION OF COMMERCIAL GLIDERS

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Glider technology is entering a new phase, moving from purely research tool to being proliferated commercially and used extensively in civilian, military and industrial applications. As gliders go beyond their early adopters in the research community to applications by a broader set of users, the demands on the technology to be more robust increase. iRobot has analyzed the design of existing gliders and believes there is potential to extend the operating range, operating margins, environmental extents, and ease of deployment and recovery of gliders. This presentation will discuss how the Seaglider buoyancy engine is being enhanced so that it will be efficient over a wider range of density stratifications that are likely to be encountered when the system is deployed in extended environments. Specifically, technical solutions in the design of a single buoyancy engine that can operate efficiently across a very large range of densities will be explored. The benefits of greater buoyancy engine range and efficiency in deployment flexibility, operating safety, and performance in higher currents will be illustrated and prototype tests results presented. Other aspects of adapting to new sensor payloads demanded by the expanding base of users, both software interfaces and physical capacity will be discussed and how gliders will need to stretch their design capacity to accommodate these requirements.

THE WAVE GLIDER, A PERSISTENT PLATFORM FOR OCEAN SCIENCE

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The Wave Glider autonomous sea-surface vehicle (ASV) is a unique approach to persistent ocean presence. Wave Gliders harvest the abundant energy contained in ocean waves to provide essentially limitless propulsion while solar panels continuously replenish batteries that power the vehicle's control electronics, communications systems, and payloads. Wave Gliders can serve many complementary functions to traditional ocean moorings, buoys and other unmanned vehicles such as buoyancy controlled gliders.

Wave Glider is a hybrid sea-surface and underwater vehicle in that it is composed of a submerged "glider" attached via a tether to a surface float. The vehicle is propelled by the mechanical conversion of ocean wave energy into forward thrust, independent of wave direction. Directing this mobile system to "hold station" results in a watch circle equalling or exceeding conventional moorings with greatly reduced capital and operations costs. WaveGliders have demonstrated long-distance ocean transits as well as long-term loitering.

We will give an overview of the evolution of this unique platform and present results from the extensive engineering sea trials that we have conducted with several generations of the vehicle. The vehicle's performance in a variety of ocean conditions --- varying sea state, wind speed, and surface currents --- is discussed. The vehicle's robustness and capabilities for extended mission durations are also examined.

In addition to the Wave Glider technology we will present results from ongoing scientific demonstrations executed in collaboration with ocean scientists. We look forward to presenting the Wave Glider as a new option for ocean science.

SLOCUM GLIDER
EXTENDING THE CAPABILITIES

Clayton Jones[1*], Tom Altshuler[1], Ben Allsup[1], Scott Glenn[2], Oscar Schofield[2], John Kerfoot[2], Josh Kohut[2], Hugh Roarty[2], David Aragon[2], Chip Haldeman[2], Tina Haskin[2]

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"We have found, over the years, that the payoff in increase of knowledge often is greatest the more unconventional the idea, especially when it conflicts with collective wisdom."
Henry Stommel, The SLOCUM Mission, 1989.

Two decades have passed since Henry popularized Doug Webb's dream of merging environmentally harvested energy with underwater gliders.
In this period of time, Slocum battery powered gliders have become an integral part of the oceanographer's toolbox with surprising rapidity over the last decade. Teledyne Webb Research (TWR) has been involved with autonomous underwater glider design since its inception and continues to push the technology to further the distance travelled, energy balance, sensors integrated, and mission endurance.
Using EGO as a milestone, a year in review highlights some of the latest sensor integrations, available battery solutions, and, in collaboration with the Rutgers University Coastal Ocean Observation Lab (RU-COOL), we review recent endurance flights of battery powered Slocum Gliders – including Trans-Atlantic crossings.
Presented also, is the next generation Slocum glider (G2) architecture, launch and recovery features, and an advanced visualization command and control (C2) toolset.
Recent advances of the originally conceived Slocum Thermal Glider, a long-range endurance glider that harvests its energy from the world ocean's thermal gradients, are detailed in construct and deployments.
The daring objective of deploying fleets of capable, sensor-laden gliders for multi-year transoceanic operation is a goal that we collectively, epitomized in EGO, are in the process of achieving.

THE DART® WAVE GLIDER ADVANCED TECHNOLOGY DEMONSTRATION RESULTS

Charles R. Fralick[1*], Justin Manley[2]

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Over recorded history, large, powerful tsunamis have devastated coastal areas killing hundreds of thousands of people and causing untold billions of dollars in damage. The United States and, increasingly, other countries have deployed detection and verification systems in an effort to provide some warning of these events and improve our understanding of them. The DART® (Deep-ocean Assessment and Reporting of Tsunamis,) system developed by the National Oceanic and Atmospheric Administration (NOAA) consists of a bottom pressure recorder package linked to a buoy on the surface via acoustic modem. The system has proven to be very effective, and its use is expanding to other countries in search of a similar solution. Like any buoy, the surface expression is subject to some failures as a result of mooring line breakage, damage from passing ships, and wave wash-over in high seas. In order to maintain a tight watch circle for acoustic communications, the buoy utilizes a semi-taught mooring. Breakage of the mooring results in the loss of that reporting station as the buoy drifts out of the effective watch circle.

Science Applications International Corporation (SAIC) and Liquid Robotics, Inc., recently undertook a project to test the efficacy of a surrogate surface expression in the form of the Wave Glider™ (Liquid Robotics, Inc.) vehicle. A Wave Glider™ vehicle equipped with an Iridium® (Iridium Satellite LLC) satellite uplink from Iridium Communications, Inc., and acoustic communications equipment could provide NOAA with the ability to quickly replace stations which have suffered surface buoy failures and restore the critical assessment capability DART® provides. Wave Gliders so equipped could provide backup to the buoys, allow fast insertion of systems in unmonitored locations, reduce deployment costs, and possibly offer better bottom-to-surface links due to tighter watch circles.

SAIC and Liquid Robotics successfully tested this concept in August of 2009. Results, which our presentation will cover, were very promising and we intend to carry out a series of further tests and developments of the system. We envision the "DART® Glider" becoming a truly effective component of the DART® system and enhancing its operational availability in protecting the lives of so many people in coastal areas every day.

TRANS-ATLANTIC GLIDER TECHNOLOGY SCHOOL (TAGTS): ENGAGING STUDENTS IN LONG-DURATION UNDERWATER GLIDER MISSIONS THROUGH A TRANS-ATLANTIC PARTNERSHIP

C. Barrera[1*], J. Kohut [2], A. Martins[3], M.J. Rueda[1], S. Glenn[2], O. Schofield[2], C. Jones[4] and O. Llinas[1]

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Lead by Rutgers University Coastal Ocean Observation Lab (RU-COOL) and Plataforma Oceanica de Canarias (PLOCAN), the TAGTS concept has a main goal to establish a multidisciplinary-international co-operation across the North-Atlantic Ocean. Through this co-operation scientists, under-graduate students and companies with scientific, technological and socio-economic aims, form relationships to facilitate information exchange, project development, and technological transfer as a whole. In this specific case, TAGTS will focus on the newest ocean-observing technology platform available today: underwater gliders.

In the spirit of TAGST efforts have already begun to form meaningful partnerships. Here we present results from initial exchange between PLOCAN, Rutgers University, and the University of the Azores. All interactions have been within the framework of two trans-Atlantic glider missions. In 2009 two gliders were deployed to cross the Atlantic Ocean from West to East. RU-27 (Electric) deployed in the North Atlantic in April 2009 and DRAKE (thermal) deployed in the South Atlantic in June 2009.

As a start, students from Rutgers University have visited researchers and students at the University of the Azores in Horta. Through this initial trip students were able to meet and talk about ideas surrounding the long glider mission. In the Fall of 2009, students from both PLOCAN and University of Azores have studies at Rutgers. Over the two month visit these students have opportunities to interact with Rutgers students, scientists and engineers on a range of projects from glider mission setup to data analysis. The TAGTS initiative hopes to build on this initial mission a regular programme in the North-Atlantic for routine missions across the basin as a world reference tool for climate/Earth systems studies.

A programme of this scale will only be possible through a strong international partnership from different North Atlantic regions like Açores and Cape Verde (Portugal), Galicia and Canaries (Spain); Puerto Rico, Bahamas and New Jersey (USA).

THE AUSTRALIAN NATIONAL FACILITY FOR OCEAN GLIDERS (ANFOG) - THE FIRST 12 MONTHS

B. Hollings[1*], C. Pattiaratchi[1], M. Woo[1], C. Hanson[1] and M. Baird[2]

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The Australian National Facility for Ocean Gliders (ANFOG) has now been running successfully for 12 months as part of the Integrated Marine Observing System (IMOS). Operating both Slocum Gliders and Seagliders throughout Australia, ANFOG has completed 20 glider deployments providing researchers with near real-time data streams. The primary focus has been monitoring boundary currents, particularly the Leeuwin and the East Australian Currents.

OPERATIONAL GLIDER TRANSECTS IN THE LEVANTINE SEA: FIRST RESULTS AND COMPARISONS

Daniel R. Hayes[1*], Gregory Konnaris[1], Georgios Georgiou[1], George Zodiatis[1], Angelos Hannides[2], Pierre Testor[3]

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Between March and August 2009, two gliders carried out 2150 km and 550 dives of measurements of temperature, salinity, dissolved oxygen, optical backscatter, and fluorescence in the Levantine Sea south of Cyprus. The transects followed a butterfly pattern over the Eratosthenes seamount, extending to a maximum depth of 1000 m. Data were processed and made available from the web site of the Oceanography Center of the University of Cyprus (OC-UCY) in near real time and placed on a free, online graphical database (Bythos 1.0) for user discovery and download. Data indicate the vertical and horizontal placement of the water masses of the region such as the Levantine Surface and Intermediate Water masses sandwiching the Modified Atlantic Water, with the Eastern Mediterranean Deep Water at the deepest observed levels. The transects represent the first in a planned time series for the next several years. The variability of the MAW pathway, the eddy structures, and absolute transport in the region are all to be addressed by the "section series." In this paper, time variability of sections of the above parameters will be illustrated. Comparison will be made with a stationary mooring near a transect and with hydrographic cruise data in the same region from August 2009. Also, comparison with sections from the operational forecast of OC-UCY for the time period will be made.

FRAM STRAIT OBSERVATORY – RECENT GLIDER ACTIVITIES AND FUTURE PLANS

Agnieszka Beszczynska-Möller[1*], Eberhard Fahrbach[1], Harald Rohr[2,] Craig Lee[3]

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Variability of oceanic fluxes through Fram Strait has been monitored since 1997 by the array of 16 moorings and summer hydrographic sections. The main focus is on the inflow of warm Atlantic waters from the Nordic Seas, the only source of heat for the Arctic Ocean, and on the freshwater outflow to the North Atlantic.

Since 2007, in the framework of the EU DAMOCLES and ACOBAR projects, the long-term moored observations in Fram Strait have been complemented with repeated glider sections. During two summer missions, 67 days long in 2008 and 76 days long in 2009, the high resolution data down to 1000 m were collected by Seaglider along the moored array section. Here we report on the preliminary results from gliders measurements and compare them to observations from moorings and ship-borne CTD sections. The special attention is paid to measurements in the West Spitsbergen Current, where gliders have to operate in the strong current regime (occasional events up to 1 m/s).

Future plans to substitute the upper part of moored array with repeated glider sections and to achieve year-round glider operations in the high-latitude, partially sea-ice covered region are presented. Taking advantage of the ice-capable glider technology developed and provided by APL-UW, we aim for deploying the equipped with the RAFOS hardware, acoustically navigated Seaglider, to extend the glider range into the permanently sea-ice covered western Fram Strait and to permit winter missions in its eastern part. For acoustic navigation 260Hz RAFOS sources will be used as well as an array of tomographic sound sources.

MULTI-SENSOR APPROACH TOWARDS COASTAL OCEAN PROCESSES MONITORING

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Dynamics along the continental slopes are difficult to observe given the wide spectrum of temporal and spatial variability of physical processes which occur. Studying such complex dynamics requires the development of synergic approaches through the combined use of observing systems at several spatial/temporal sampling level and quality requirements. Moreover, the development of coastal operational oceanography has to be based on adequate observing systems which can be integrated into coastal circulation models. In those respects, it is necessary to process and validate multi-sensor datasets especially dedicated to coastal ocean studies. This implies to fully understand their physical content in order to really assess their potential complementarities.

Here, we present the results of an intensive observational programme conducted in the Balearic Sea combining coastal gliders and altimetry data from Envisat radar altimeter. The objectives of this experiment are i) to investigate the limitations and potential improvements of different altimetric datasets in the coastal area, ii) to develop new methods to understand and increase the glider-altimetry synergy and iii) to test the feasibility of new technologies to study coastal dynamics. We focus on one particular mission (April 2008) revealing the appearance of an anomalous anticyclonic eddy detected by altimetry, glider, SST data and model. New methodologies has been developed and tested in order to combine surface glider geostrophic velocities with integrated currents estimated by the glider (GPS locations every 6 hours). This approach proves to be very efficient for reducing the differences between altimetry and glider data. Some hypotheses for the formation of this anomalous structure will be also explored.

VALIDATION OF AN OCEAN MODEL USING GLIDER DATA

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In the winter of 2008 three autonomous underwater gliders were deployed to observe open-ocean convection in the Gulf of Lions. The data gathered by these gliders has been used to assess the performance of the 1/12th degree UK Met Office regional model MED12. Depth profiles were extracted from the model every 6-hours and time-series of temperature, salinity, depth-averaged current, mixed-layer depth and ocean heat content co-located with the glider positions were created. These time series were used to quantify the skill of the model. Integral time and length scales of the model fields and of the glider observations were derived by variogram analysis

The evolution of the model mixed-layer depth is very well simulated and there is a strong correlating with observations. Salinity and potential temperature also have significant correlations with the surface and intermediate waters. However, the Western Mediterranean Deep Water is not well simulated and model profiles are generally smoother than the observations.

The high spatial resolution of glider data enables the calculation of integral length scales though the efficacy of separating spatial and temporal variability is dependent upon the sampling strategy employed. Analysis indicates that the model integral time and length scales are 20% and 50% longer than those of the observations.

DATA ASSIMILATION OF GLIDER OBSERVATIONS IN THE IONIAN SEA (EASTERN MEDITERRANEAN): A STUDY OF THE PATH OF THE ATLANTIC IONIAN STREAM

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Glider observations of temperature and salinity in the Ionian Sea (Eastern Mediterranean Sea), made in the period October 2004 - December 2004, were assimilated into an operational forecasting model together with other in-situ and satellite observations. The impact of glider observations on the estimation of the circulation is studied and it is found that their assimilation locally improves the prediction of the vertical structure of temperature, salinity, velocity and surface elevation fields. The accurate representation of the dynamical structures of the flow field due to assimilation allowed an analysis of the seasonal evolution of the Atlantic Ionian Stream (AIS) in Sicily Strait and the Ionian Sea. The analyses of the Ionian Sea circulation show a large Western Ionian cyclonic Gyre coupled with an anticyclonic gyre in the central Ionian Sea. In both autumn and winter the AIS position follows closely the zero wind stress curl line. During autumn, the AIS is strengthened by the temperature gradient between the warm surface mixed layer and the cold upwelled waters near Sicily. In winter, due to the southward shift of the wind stress curl zero line and the cooling of the surface mixed layer, the AIS flows southward of Malta. An AIS meander is shown for the first time to pinch off an anticyclonic eddy in the Ionian Sea.

UPPER OCEAN PROPERTY BUDGETS AT OCEAN STATION P FROM FORTNIGHTLY GLIDER REPEAT SURVEYS OVER 15 MONTHS (AND COUNTING)

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Continuous glider repeat surveys in the vicinity of Ocean Station P describe the slow evolution of three dimensional upper ocean structure from early summer 2008 through early autumn 2009. Ocean Station Papa (145°W, 50°N) is the site of more than half a century of ship-based and sporadic moored observations of the mid-gyre subpolar northeast Pacific Ocean. Currently, Fisheries and Oceans Canada conducts regular survey cruises along Line P, a transect from the west coast of Canada to Station P, in June, August, and February. Glider surveys repeated twice monthly of a 50 km by 50 km box centered on a NOAA mooring at Station P complement the shipboard observations and provide spatial context for the moored observations.

A Seaglider equipped with dual oxygen sensors (SeaBird 43 and Aanderaa Optode) as well as temperature, salinity, chlorophyll fluorescence, and optical backscatter sensors was deployed at Station P in June 2008. It was recovered and replaced with another in late August 2008, followed by a second recovery and deployment in June 2009. The summer-to-summer mission of more than 9 months is the longest AUV mission to date. The current mission is on track to break that record with one of as long as 11 months. Since no visits to Station P are scheduled between February and June 2010, the plan is to have the Seaglider complete its repeat survey in mid-winter and transit ~1300 km along Line P to the coast.

The surveys around Station P have revealed persistent lateral structure in the upper ocean that evolves on time scales of months. Upper ocean isotherms regularly and repeatably change depth by over 100 m over 50 km, while salinity and density surfaces tilt less dramatically. These contrasts are the result of persistent, isolated temperature inversions embedded in the halocline. Depth-averaged currents in the top 1 km are relatively weak (< 0.02 m/s).

Horizontal advection accounts for much of the time rate of change of density averaged over a single year in the upper ocean near Ocean Station P. The weak currents, slow variation, and modest lateral scales suggest a linear vorticity balance. Using such a balance produces vertical advection that further balances temporal change. Preliminary estimates of vertical diffusivity range from ~1-3 X 10^{-5} m^2/s over 300-1000 m depth to ~1 X 10^{-4} m^2/s above the pycnocline.

SEASONAL VARIABILITY OF PHYSICAL AND BIOGEOCHEMICAL COUPLING AT SUBMESOSCALE ACROSS THE LIGURIAN CURRENT, NW MEDITERRANEAN

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A monthly glider endurance line was started in October 2008 to follow the physical and biogeochemical coupling at submesoscale across a permanent jet-front system located in the NW Mediterranean. Hydrology (CTD) and biogeochemical parameters (oxygen, fluorescence, color dissolved organic matter and backscatter) are measured at high frequency by a bio-optical Slocum glider deployed on a 60km-wide transect through the along-coast ligurian current to a depth of 500m (round-trip in 5 days).

Previous results based on glider measurements during winter 2006 (Niewiadomska et al., 2007) described the presence of submesoscale features associated with the biogeochemical response to physical forcing into the frontal zone between this coastal current and off-shore waters. Downwelling of slight waters characterized by high concentration of fluorescence and oxygen were measured at unusual depth of 200m. These downwelling waters were balanced with upwelling of denser waters with low concentration of fluorescence/oxygen but high concentrations of color dissolved organic matter (CDOM) which seems to be a proxy of nutrients. The goal of this glider endurance line is to examine the persistence of these structures associated to the frontal system through seasons.

Results from the monthly survey from October 2008 seem to show that downwelling of tongues characterized by high concentration of fluorescence occur principally in winter period when the coastal current is strong enough to provoke secondary circulations into the frontal zone. A higher-frequency glider survey was tested in March 2008 through the frontal zone between the ligurian coastal current and off-shore waters (2 transects per week during one month) and confirm the permanent character of such tongues at anormal depth in winter until 300m. This detailed survey also highlight the importance of the glider sampling strategy to cross the front in the same way through space and time. Indeed, high frequency match-up with satellite data show that the ligurian

current exhibits highly variables meanders and confirm the difficulty to cross the front in the same way with the glider and make comparable sets of data.

Combination of backscatter data at 6 wavelengths and fluorescence also allow to discriminate fine coastal particles to off-shore larger biological particles. Coastal particles are dominated by a high proportion of detritic particles in winter associated to adjacent riverine inputs and are limited seaward by the position of the frontal zone of the ligurian current. In spring, following high riverine inputs of terrestrial matter of the winter period, high concentration of fluorescence were found in surface waters both in coastal waters and off-shore waters.

This glider endurance line is to be continued in order to access to the seasonal variability during the whole year and then to the annual and interannual variability of such submesoscale features. Future plans in NW Mediterranean include the deployment of several judicious glider endurance lines along the basin and particularly in the Gulf of Lions to study in more details the land-to-sea transfer of terrestrial material during extreme events such as cascading, storms and floods, and study how such events can impact deep-sea ecosystems.

USING GLIDERS AND MOORINGS TO CHARACTERIZE NORTH ATLANTIC EDDIES

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The CIS (Central Irminger Sea) and PAP (Porcupine Abyssal Plain) moorings have been in operation since their first deployments in 2002, recording temperature, salinity, pressure, currents and a series of biogeochemical data (chlorophyll fluorescence, nitrate, carbon dioxide, oxygen). It is evident in the long timeseries that numerous eddy-like events pass through these moorings each year, as seen by changes in water properties and turning of currents. The mooring data provide valuable information about the frequency and time scales over which these events change the water properties at a fixed point. However, spatial scales (both horizontal and vertical) are difficult to estimate with mooring data alone. Spray gliders were flown around both the CIS and PAP moorings, with deployments lasting each about 3 months. They profiled up to 1000m depth the temperature, salinity, average currents, and chlorophyll fluorescence in the vicinity of the moorings. Moreover, both glider missions encountered anticyclonic eddies in the region of the moorings, and were made to follow circulations within these eddies. From the glider perspective, one can characterize the structure of these eddies. Their radius, vertical extent, typical rotation speeds, and non-dimensional numbers (Rossby, Burger) are calculated. These calculations are compared to mooring observations and confirmed by AVISO satellite dynamic topography. Since these eddies tend to preserve properties of the water mass in which they were formed, their distinct signatures can be picked out in the mooring observations, and thus a time scale of variability for these features can be estimated. Along with the physical mechanisms of these observed eddies, profiles of chlorophyll fluorescence as seen by the glider are used to characterize the distribution of phytoplankton in the region and within the eddy structure. Because these long-lasting eddies do not easily mix with surrounding water, the dynamics of the phytoplankton community trapped in and advected with these eddies are interesting to examine. These measurements are compared with mooring measurements of fluorescence and its variability during an eddy event. Due to the long and well-sampled (in time) mooring timeseries, mixing and restratification events can be seen, and are discussed within the context of eddy formation and decay. The implications to the phytoplankton field and nutrient variability of the eddy system are discussed from this perspective.

INVESTIGATING FRONTS IN THE NORWEGIAN AND BARENTS SEA USING GLIDERS

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The aims of IPY NESSAR (Norwegian Component of the Ecosystem Studies of Subarctic and Arctic Regions) Project are to examine the physical dynamics, as well as the structure and function of the marine ecosystems, in and around the Arctic Fronts separating Atlantic and Arctic waters in the Norwegian and Barents seas. Field studies during 2007 and 2008 were carried out on the Jan Mayen Front between the Norwegian and Iceland Seas and the Polar Front in the Barents Sea. Measurements included hydrography, turbulence levels and repeated finescale resolution transects with an autonomous glider. Data from the glider at the Jan Mayen Front shows interleaving of Arctic and Atlantic water masses in layers 20-40 m thick that extended for several kilometers in the across front direction. Enhanced mixing is observed in the frontal region due to both current shear and double diffusive processes. Also, the position of the front was observed to move eastward by approximately 7 km during the 10 day duration of the experiment. In the Barents Sea fairly strong tidal currents occur in the vicinity of the Polar Front near Hopen Island and are superimposed on the along front advection. A double frontal structure and small scale variations in salinity and temperature are observed, which may be a result of eddy activity in the area. Relatively low fluorescence was observed at both fronts suggesting the possibility of low primary productivity.

GEOSTROPHIC TRANSPORT VARIABILITY AND VERTICAL SECONDARY CIRCULATIONS ASSOCIATED WITH THE UPWELLING FRONT OFF PISCO (PERU, 14°S) FROM GLIDER DATA

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We present here an analysis of the data from a glider which has been deployed off Pisco (14° S), Peru, from October 3rd to November 24th 2008, in the Humboldt Current System (HCS) which is one of the four major Eastern Boundary Upwelling System (EBUS). The glider completed nine consecutive sections perpendicular to the continental slope from about 10 km to about 100 km from the coast. The glider collected about 1300 profiles, down to 200 m depth and distributed between the nine sections. Once the data are calibrated and validated, physical and biogeochemical parameters can be studied to characterize the high resolution structure and the dynamics of the upwelling front. The nine cross shore sections enable us to evaluate the region's variability on a wide range of scales as well as to compute estimates of the geostrophic currents and transports along shore. We highlight here small scale features (few km horizontally) showing localized vertical motions at the edge of the upwelling area that could be due to ageostrophic secondary circulations and the influence of the wind.

THE SOLOMON SEA OBSERVED BY GLIDER AND ALTIMETRY

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In the South-West tropical Pacific, the Solomon Sea is a key region for the tropical/subtropical connexion and for the feeding of the Equatorial Under Current. Indeed, it exhibits intense western boundary currents like the New Guinea Coastal Current, which have possible effect on the modulation of El Nino – Southern Oscillation (ENSO). The sharp Papua-New Guinea coastline and the Solomon Sea with its narrow straits to the north impose strong topographic constraints on the flow that is little documented so far. Long-term observations in the region are sparse, and so far the ARGO floats array does not sample this enclosed area well. Climatologies are hampered by the sparse data coverage. Gliders are expected to be an important contribution to monitor boundary currents, especially in regions of difficult accessibility. An experimental glider monitoring of the western boundary current of the Solomon Sea is currently tested to understand how the flow is distributed within the southern entrance of the basin. Five glider missions have been operated from August 2007 to January 2009. They show a huge variability of the transports in relation with ENSO conditions and eddy activity. Another information on this variability comes from altimetry where the Solomon Sea exhibits the highest levels of sea level variability of the whole South Equatorial Pacific Ocean. Altimetry-derived surface geostrophic currents, as well as eddy kinetic energy, capture most of the transport variability in the Solomon Sea. The satellite data are useful to replace the glider data in a synoptic context whereas the glider data are useful to assess how the surface altimetric information is representative of the dynamics at depth. The complementarity of both datasets (gliders and altimetry) motivates this study.

COMBINING GLIDER AND ALTIMETRY DATA TO DIAGNOSE VERTICAL VELOCITIES IN THE UPPER OCEAN

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This study represents a first attempt to combine new glider technology data with altimetry measurements to understand the upper ocean dynamics and vertical exchanges in areas with intense horizontal density gradients. In July 2008, just two weeks after Jason-2 altimeter was launched, a glider mission took place along a satellite track in the Alboran Sea (Western Mediterranean). The mission was designed to be almost simultaneous with the satellite passage. Dynamic height from glider reveals a sharp gradient (~15 cm) and corresponds very well with the absolute dynamic topography from Jason-1 & Jason-2 tandem mission ($r > 0.97$, rms differences < 1.6 cm). We blend both data sets (glider and altimetry) to obtain a consistent and reliable 3D dynamic height field. Using quasi-geostrophic dynamics, we diagnose large-scale vertical motions (~1 m day-1) which may provide a local mechanism for the subduction of the chlorophyll tongue observed by the glider.

VERTICAL VELOCITY SPECTRA MEASURED BY GLIDERS DURING AND AROUND CONVECTIVE EVENTS

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During the winter of 2008, three NOC 1000m gliders were deployed in the Gulf of Lions (northwest Mediterranean). The aim of the mission was to observe deep ocean convection with gliders.

Using CTD data and engineering data such as buoyancy drive and measured pitch, vertical water velocities can be measured following a method outlined by Merckelbach et al. (2009). In this contribution we focus on spectra of vertical water velocities measured during the 2008 measurement campaign. As the vertical velocity is measured every 4 seconds, the corresponding frequency spectrum had Nyquist frequency 1/8 Hz. Although the glider is a moving platform (relative to the Earth), the measured spectrum is Eulerian rather than Lagrangian, so that a frequency spectrum can be transformed to a wavenumber spectrum using Taylor’s frozen turbulence hypothesis.

The rate of kinetic energy dissipation is an important parameter characterizing oceanic turbulence and diapycnal mixing. For 3D isotropic turbulence, the spectrum adopts a universal form over the inertial subrange of length scales. The dissipation rate can be estimated by fitting the observed spectrum over the inertial subrange. Unfortunately, noise in the measured vertical velocity signal due to the pressure sensor dominates the spectrum at frequencies higher than about 0.01 Hz. A further complication is the undulating behaviour of the glider, which leads to a spectrum from a signal with depthvarying characteristics. In practice, meaningful spectra can be obtained for the frequency range of $f=[7\cdot10^{-5}, 1\cdot10^{-2}]\ s^{-1}$.

We analyse the spectra from a model glider in a simulated ocean undergoing convection (MITgcm model). We show that the glider derived spectrum is representative for the averaged spectrum of the upper 1000 m, supporting Taylor’s hypothesis.

The glider observed (wavenumber) spectra show a white spectrum for internal waves, corresponding to the GarrettMunk spectrum. For mesoscales the spectral energy is proportional to $k^{5/3}$, where k is the wavenumber.

Recommendations are made with respect to how to increase the information contained in spectra from (future) glider observations.

GLIDER MEASUREMENTS AROUND THE VERCELLI SEAMOUNT (TYRRHENIAN SEA) IN MAY 2009

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Some international projects focus on sea mountains because of their importance on the ecology of the marine environment and of their high level of vulnerability to the global climate change. Hence the Italian Ministry of University and Research (MUR), sensible to this topic, financed the Tyrrhenian Seamounts Ecosystem Project (TySEc) polarizing the attention on the Vercelli Seamount located in the Northern Tyrrhenian Sea, (41°05'00 N / 10°53'00 E), whose summit reaches 55 m below the sea surface.

As part of this integrated study, the Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS) operated a Slocum shallow batterypowered glider around the Vercelli seamount from the 23rd to the 30th of May 2009 to sample the physical and biochemical characteristics of the water column in its vicinity.

The glider "Trieste1" was programmed to cover an area of roughly 750 km^2, above the seamount. It was configured to provide oceanographic data during the ascending phase of the saw tooth path, every 0.75 km. During the entire campaign 300 profiles between 4 and 200 m depth were acquired providing temperature, salinity, oxygen, fluorescence, and turbidity data.

Preliminary results derived from the glider data are presented. In addition to the expected thermal stratification and the subsurface salinity maximum characteristic of the Levantine Intermediate Water, a layer with minimum in salinity and maximum in oxygen concentration is evident near 20 m depth. A subsurface maximum in chlorophyll concentration and turbidity is also seen between 60 and 80m, just below the surface highly oxygenated layer.