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Book of abstracts

Development of a low-power wet-pluggable interface for easy integration of analog sensors to autonomous platforms

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This study describes an interface module developed in order to facilitate the integration of several analog florescence and backscatter sensors into the deep (2400 m) and ultra-deep (6000 m) SeaExplorers under development as part of the H2020 project BRIDGES (Bringing Research and Industry together for the Development of Glider Environmental Services). This extremely small, light and low-power module is embedded in the cable connecting the sensor and the glider and its firmware provides a simple user-calibration procedure along with several modes of operation depending on the need. By some modifications in the device firmware and attaching the appropriate connectors, this interface can be used to connect any commercial analog sensor to autonomous platforms requiring digital input. Since with most current gliders there is no easy plug-and-play solution for a new sensor integration, this device can be used to avoid the cost and delays of either developing a sensor specific interface or shipping the glider back to the manufacturer. Moreover, with the PUCK protocol included in the firmware, any sensor can comply to the Sensor Web Enablement standardization and therefore provide a more harmonized access to the sensor metadata. Power consumption, and functional examples will be presented for the prototype system. A deep-water (6000 m) version will be produced and pressure tested in the next development phase.

Session: New developments in glider and sensor technology

Examples of autonomous fleet optimisation

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We present a software based framework for the automated optimal control of both cosmopolitan and diversely cosmopolitan fleets of autonomous marine vehicles. We present how a model environment, fast vehicle simulation, and an autopilot mimicking both autonomic and somatic nervous system analogies can be interfaced directly with the proprietary vehicle control firmware. We will demonstrate simulation of both a complex mapping of oceanographic features and behavioural tracking. Currently our framework is in go-live mode for a simpler oceanographic glider monitoring program in the western Mediterranean, and we will also demonstrate the first results of this.
Autonomous marine vehicles are now in a stage of mature development and evolution. However, their control is still largely pilot based. Our objective was to implement optimal and adaptive sampling based around a cost function related to the vehicle mission objectives. This is largely the somatic, or voluntary, part of the vehicle control framework. The autonomic component of the control system is that which passes vehicle emergency flags, AIS warnings, bathymetry alerts etc. Some of these go directly to the pilot operator, others can be dealt with automatically by the somatic system through adaptive re-optimisation.
In this abstract , adaptive describes a system that responds to changes in the environment, to changes in scientific requirement, and to changes in fleet configuration (including failed vehicles or sensors). Cosmopolitan, refers to largely similar vehicles with different detailed characteristics and capabilities. Diversely cosmopolitan refers to a fleet of similar and dissimilar vehicles with differing detailed and gross characteristics and capabilities. Open source software based, we believe we have a highly cost effective solution to the problem of controlling multiple autonomous assets in a manner that maximises quality and quantity of data collection whilst minimising expert labour costs and intervention.

Session: Sampling strategies for single vehicles and networks

Ocean Gliders Applications as an alternative technology to conventional oceanography (analytical) techniques in the Bight of Bonny, Nigeria

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Coastal pollution is characteristically significant in the south Atlantic coastal waters due to enhanced level of contaminants emanating from oil discharges from offshore/onshore production activities, domestic sewage, industrial effluents, fluvial/surface runoff, maritime transportation and intentional dumping at sea. Contaminant inputs of nutrients, toxic metals, hydrocarbons and pesticides from these sources have been exacerbated by climate change scourge in the tropics. Water quality alterations and effects on biota and beaches are of immediate concern. For decades, the quantification, assessment and monitoring of contaminants using conventional oceanography (analytical) techniques aimed at identifying pollutant levels and the corresponding sources. The application of AUVs as an alternative technology will enhance the scientific capability of monitoring coastal and shelf sea ecosystem functioning and assess the potential environmental status over a full seasonal cycle.

Session: The role of gliders in Ocean Observing Systems

Information from data: the use of submarine gliders by the UK MOD

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Submarine gliders have been used to date in the UK principally for academic research purposes. However, the environmental information that they collect may be of significant benefit to the Royal Navy, allowing military systems to be operated more effectively. There are some significant differences between how gliders are operated for academic purposes compared to how they might be used in military operations.
The Royal Navy are interested in having an understanding of the ocean properties and structure throughout the whole of the operating environment, and so wish to use gliders in a routine survey mode. Gliders have the potential to provide near real-time information that can either be used to underpin models or be used directly in military systems; however, there are a number of complexities that have yet to be fully resolved. Data need to be acquired from the correct location, at the correct time, quality assured, down-selected, converted into something that has military relevance and turned into an information product that military personnel can understand and use, in near real-time, ideally with minimal human interaction. In addition, the manner of piloting is likely to be different when supporting military operations compared to during academic use.
This presentation will discuss how some of the concepts have been developed over the last year, in collaboration between Defence Science and Technology Laboratory, the Royal Navy and the National Oceanography Centre. It will also identify how the approaches are being incorporated into Unmanned Warrior, the Royal Navy demonstration of autonomous maritime technologies that will be ongoing at the time of the conference.

Session: Glider operations: piloting, infrastructure, data management and legal issues

PLOCAN Glider School: The hands-on ocean glider technology and training forum

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The PLOCAN Glider School (www.gliderschool.eu) is a yearly international pioneer initiative that edition upon edition consolidates its position as reference training and networking event addressed to public and private sector interested to learn on a clearly emerging technology sector as is underwater robotics, and more specifically the one that refers to ocean gliders as autonomous and unmanned vehicles for ocean monitoring applications.
The Glider School lasts for six intense training days with theoretical and practical contents performed in both lab and open waters, and takes place at the Oceanic Platform of the Canary Islands (PLOCAN) headquarters in Telde, Gran Canaria. The main goal of the school is to provide the opportunity to a selected group of the attendees, to start in some cases and expand in others their knowledge related to ocean glider technology.
Leading companies from marine technology sector like ocean glider and related sensor payload manufacturers, as well as international institutions as reference end-users of such technology, are all directly involved with the school, teaching some didactical contents and support sea operations.
Technological development linked to ocean monitoring through the latest and most innovative technology available, as well as their applications within the different socioeconomic sectors are part of PLOCANs strategic goals which include to become an international gliderport facility reference.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Improving in-situ ocean observations in the Macaronesia region with gliders

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The Macaronesia is a vast area playing a key role in the North-Atlantic ocean-circulation system. Despite a significant and varied scientific and research activity in terms of ocean monitoring in several oceanographic disciplines for decades by key EU research-groups through the use of a wide range of observing systems and methodologies, the area is still undersampled, mainly due access and coverage constrains, as well as the observation sustainability.
Ocean gliders offer a new approach in terms of capacity and sustainability, allowing undertake ocean monitoring in spatiotemporal scales hitherto unavailable. The present work shows preliminary results from a joint-initiative between IH, OOM and PLOCAN whose main goal focuses on strengthening glider endurance lines between Madeira and the Canary Islands, as part of the global observation strategy conducted by the Marine&Maritime Network (R3M) aligned and as contributing party of the international efforts in the East-Central North Atlantic region through initiatives and projects like AtlantOS, AORA-CSA, among others.

Session: The role of gliders in Ocean Observing Systems

Frontiers: Piloting Gliders in Highly Dynamic and Ice-Covered Environments

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During the 2016 ice edge retreat in Baffin Bay (Arctic Ocean), the GreenEdge project carried out a 3-D survey of physical and biogeochemical properties of ice-edge phytoplankton blooms using two Slocum G2 gliders. In particular, we collected bio-optical data from glider-based transects into the highly dynamic marginal ice zone (MIZ). The main challenges were that a) this is a highly dynamic zone where the wind- and current-driven edge of the MIZ (nominally, ice concentration $> 80\%$) can change $pm20$ km in less than 24 h and b) there is a non-zero probability of surfacing under the ice. To address the challenges of a highly dynamic zone, we designed a glider mission that included an under-ice portion to be completed without surfacing for 8-15 hours. During this time, the glider is subject to local currents and has no means to correct its heading based on a comparison of dead reckoned and GPS locations. Our approach was to define navigation geometry tolerant of large heading errors. To do this, rather than navigating to a specific waypoint with a small range circle, we created distant waypoints with very large radius range circles (e.g., 50 km). In the local context of the mission, these larger radius range circles create frontiers to achieve, in this case almost straight line boundaries. When the boundary is reached, the waypoint is achieved and the next step in the mission (heading change, behavior change, etc.) commences. To address the remaining possibility that the glider still might be in the MIZ despite our best efforts to exit, both Takuvik gliders were loaded with special Under Ice mission software from the manufacturer (Teledyne Webb Research) that contained specific special abort behaviours to address being trapped in the ice (i.e., not able to move vertically) or surfacing in an ice covered region. We will present specific examples of mission geometry and actual results of under-ice missions in Baffin Bay. Our navigation approach should be applicable to glider mission planning in other highly dynamic environment.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Pitfalls and Possible Solutions for using Glider Data to Constrain Ocean Models

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Autonomous ocean gliders are rapidly becoming one of the main observational assets of ocean observing systems, but there are important differences in their measurement capabilities compared to more traditional assets of these systems. While gliders can sample relatively rapidly in time, their movements in space are too slow to synoptically measure mesoscale spatial sections as can be done by ship observations. Their measurements are neither Lagrangian like drifters nor Eulerian like moorings, further complicating data interpretation and application. Conventional data assimilation methods typically utilize covariance scales and other assumptions that might not be well suited to make full use of the information gliders can provide. As an example, in the Recognized Environmental Picture 2011 (REP11) experiment several gliders were assimilated using a 3D-Var methodology into the Navy Coastal Ocean Model, but this assimilation failed to correct a substantial bias in the pycnocline depth despite this bias being well observed by the gliders. We are now exploring new local assimilation techniques using 4D-Var techniques to better match the high temporal resolution of glider data and new glider strategies to maximize impact for assimilation. Our goal is to introduce these new techniques into ocean prediction systems and demonstrate improved performance as a result of this on-going work.

Session: The role of gliders in Ocean Observing Systems

Understanding the oceanic variability in the Lofoten basin: an overview of the glider activity of the ProVoLo project

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Located in the northern Norwegian Sea at high latitude between 68°N and 73°N, the Lofoten basin is one of the world's most energetic area regarding the ocean dynamics. It hosts the largest and deepest pool of warm Atlantic Waters, thus leading to very intense air-sea energy fluxes and deep convection in winter. Understanding the physical processes involved in the water masses transformation of this very productive area is thus of crucial interest in a climate perspective, as well as for the fishery economics.
The ProVoLo project aims at quantifying the energy pathways from the large-scale circulation to the (sub-)mesoscale and eventually the dissipation scale. To this end, the project is largely devoted to in situ observations and involves R/V cruises (CTD, LADCP, microstructure), mooring lines, gliders (CTD and microstructure) and RAFOS floats. In particular, two gliders have been in operation since May 2016. We here present a synthetic view of the ongoing glider deployments and describe the key features of the Lofoten basin circulation. In particular, we focus on the Lofoten vortex - a very intense subsurface anticyclone characterized by intense (>0.7 m/s) and a small radius (∼15 km) - and the frontal region situated over the Mohn ridge characterized by a narrow (∼15 km) and intense (>0.5m/s) baroclinic jet.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

The POSEIDON system: A new Glider component and future applications

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The POSEIDON System, the operational monitoring, forecasting and information system for the Greek Seas was initially established in 1999 using as its observing component a network of moored buoys equipped with meteorological and oceanographic sensors. Currently, the POSEIDON systems monitoring module is relying on an integrated observatory, which includes a number of monitoring technologies that have been implemented into its observing component over the past years. A Ferry Box system is in operation since 2012 in the Piraeus Crete route, an HF Radar system has been installed in 2009 through a collaboration with the Department of Marine Science, Aegean University at the northeastern part of the Aegean Sea for the monitoring of Black Sea Waters outflow from the Dardanelles straits. Furthermore, the Greek Argo infrastructure started in 2010 has funded the deployment of several autonomous profiling floats in the Aegean and Ionian Seas, as the Greek contribution to EuroArgo ERIC.
Two SeaExplorer gliders were recently added to the monitoring platforms of the Poseidon system. The two gliders will be gradually integrated to the operational network of the system with the ultimate objective of establishing at least two endurance lines in the Aegean and Ionian Sea. In the southern part of the Aegean, the Cretan Sea, the continuous monitoring through an endurance line is expecting to contribute to the further knowledge of the seasonal variability of the flow field, collecting also evidences of the intermediate or deep water formation events that are known to occur in the area. On the other hand, the tracking of the low salinity Black Sea Water path in the North Aegean is an important feature to be studied through a glider endurance line, even if this line is expected to be much more complex to be established due to the existing circulation pattern and the geographical characteristics of the region. In the short term planning and in the framework of the EU funded JERICO Next project, focused missions will be designed with the priority of gathering data to be assimilated in the POSEIDON circulation forecasting models.

Session: The role of gliders in Ocean Observing Systems

Quantifying West Antarctic turbulent mixing from underwater gliders

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Turbulent mixing on the west Antarctic Peninsula shelf is a highly important process, being responsible both for delivering ocean heat to the melting glaciers of the region, and for supplying nutrients to the biologically productive surface layers. Despite this, literature estimates of the turbulent diffusivity and the associated heat fluxes vary by up to an order of magnitude, and direct estimates of mixing are extremely sparse.
In this talk, we document and discuss two separate pieces of fieldwork aimed at understanding both the magnitude of mixing at the Rothera Time Series (RaTS) site, and its controlling processes. Whilst overall heat fluxes through the pycnocline at the site are relatively modest ($\sim$1 W m^{-2}), shear instabilities in the water column arise by different mechanisms during periods when fast ice is absent or present. Whilst the diurnal tides are important in generating velocity shear year-round, a significant input of wind-driven near-inertial energy into the ocean during the fast-ice-free months is responsible for generating significant turbulent motions. We will also discuss the most recent microstructure estimates of turbulent diffusivity obtained in February 2016 from Ryder Bay from both a Slocum glider and from a microstructure profiler, and discuss how these results compare to finestructure-based estimates of turbulent dissipation.

Session: Gliders in polar oceans: science and technological challenges

Coupled physical and phytoplankton dynamics in Antarctic coastal seas

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There is a high spatial and temporal variability in the biophysical processes regulating primary productivity in submarine canyons in Antarctic coastal seas, with Amundsen Sea, Ross Sea and West Antarctic Peninsula canyons being reported as important features for regional primary production. Canyon heads in the West Antarctic Peninsula (WAP) are considered biological hotspots by providing predictable food resource and driving penguin foraging locations, however the physiology and composition of the phytoplankton blooms and the physical mechanisms driving them arent well understood. Using autonomous underwater gliders equipped with CTD, chlorophyll and backscatter pucks, over 30,000 water column profiles in Antarctic coastal seas have been analyzed with the goal of characterizing physically and biologically the upper 100 m of the water column. The mixed layer depth (MLD), determined by the maximum of the buoyancy frequency criteria, was found to be the MLD definition with the highest ecological relevance. The strongest signal found in the glider data was the seasonal cycle. The shoaling of the MLD in early January results in increased chlorophyll a concentrations and as MLD deepens in mid season due to wind forcing, phytoplankton concentrations decrease, likely due to decreased light availability. A steady warming and increase in salinity of the MLD is seen throughout the season. Spatial variability was evaluated by analyzing glider vertical profiles in the context of surface currents maps provided by High Frequency radars (HF radars). Taking advantage of the high resolution glider data we examined the impact of different source water delivered across the canyon on the vertical structure of the water column and observed phytoplankton biomass. To further evaluate the biological responses to physical forcing, the glider was equipped with a PAR sensor and integrated with a prototype Fluorescence induction and Relaxation (FIRe) sensor. This allowed the continuous and high resolution mapping in depth of the phytoplankton physiological responses to light stress using fluorescence kinetics, as no nutrient limitation was observed. Diel cycles collected show a clear daily cycle dependent on the magnitude of incident radiation, with both Fm (proxy for chlorophyll) and Fv/Fm (indicator of photosynthetic efficiency) showing reduced values only in the upper 15 meters at the highest daily irradiance. With decreasing sea ice trends reported for some Antarctic coastal regions, especially the WAP, the increased phytoplankton exposure to increased irradiance may result in significant ecological and biogeochemical implications, such as the decrease efficiency of atmospheric carbon sequestration.

Session: Observing biogeochemical processes with autonomous vehicles

Autonomous measurements of coastal turbidity using glider mounted ADCP (MATUGLI project)

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Turbidity is a key parameter in coastal areas, to estimate the concentration, the characteristics and the quality of suspended particles, and to monitor its transfer from source (continent) to sink (sea). There are few recurrent turbidity observations in the coastal waters, none dealing with the entire water column at large spatio-temporal scales. We investigate the use of glider mounted optical turbidity sensors and Acoustic Doppler Current Profiler, to monitor the suspended particles transport through the Gulf of Lions water column and shelf. While optical based tubidity sensors are more sensitive to fine particles, acoustic sensors are more sensitive to larger particles. Their association will allow to better characterize the whole size spectrum of marine particles. An experiment have been conducted in front of the Tt river mouth, on the Roussillon coast, where the POEM buoy is operated by CEFREM, giving real time observation of temperature, salinity, and optical backscatter at both the subsurface, and the bottom (28m). Additional sensors were moored in the area, such as a 600kHz ADCP, CTD and LISST. The S/V NEREIS was used for water samples and CTD profiles collection. The major goal was to prove the ability for a Slocum shallow glider, carrying an ADCP and optical backscatter sensors at multiple frequencies, to provide full vertical turbidity profiles on the entire water column. We focused on the acoustic signal processing calibration with the optical sensors, to reach a consistent turbidity measurement, merged from both sensors, from the surface to the bottom. As a byproduct of this experiment, we tested the opportunity of current velocity profiling using a glider in shallow waters, using Bottom Track data to correct the unknown underwater glider movements. Once validated, these measurements methods will be used in the MATUGLI project experiments, to monitor the sediment inputs from the Rhne and Tt rivers and their behavior in the Gulf of Lions, under various conditions.

Session: New developments in glider and sensor technology

LOGMEC16: a long term glider deployment in the Ligurian Sea

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This work will detail the experimental setup of the LOGMEC16 (Long-term Glider Mission for Environmental Characterization) Sea Trial, that has the objective of studying the variability and the predictability of the acoustical and oceanographic environment in the Eastern Ligurian Sea. The oceanographic data collection was mainly performed by two deep Teledyne Webb Research (TWR) Slocum gliders, deployed in the period from May 3rd to June 28th 2016. To meet the endurance requirement, the gliders were equipped with an extended payload section with additional lithium batteries. In addition to the oceanographic gliders, two shallow water TWR Slocum glider equipped with the CMRE acoustic payload have been deployed for a short period of time in May and June to perform acoustic measurements together with fixed acoustic moorings.

The real time oceanographic Gliders data downloaded at the CMRE glider Mission Support Center was automatically processed to derive additional variables like sea water salinity, density and sound speed profile. The data then went through a quality control and re-formatting to meet users needs. In parallel with the internal data flow, the raw Glider data was submitted to the CORIOLIS Data Assembly Center (IFREMER, FRA) and subsequently integrated into CMEMS (Copernicus) in situ real time observations. A comparison of processing and quality control performances of the two systems will be conducted in the near future. The automated real time quality control system implemented for LOGMEC16 is based on data comparison against thresholds defined from climatology and human expert review at the beginning of the deployment; after some time the thresholds were reviewed, considering the statistics of the collected data and the human expert analysis. The data glider data was then provided in real time to CMRE scientists running operational oceanographic models for assimilation. Two models were active during the experiment: NEMO 3D VAR and ROMS EnKF (Ensemble Kalman Filter). Several days of the oceanographic Gliders campaign were planned for in situ data collection along satellite altimetry tracks measuring sea level anomalies, in order to provide inputs to study how satellite altimetry can be better extended to estimate sub-surface ocean states. As such, the resulting track plans and water space management, due to operational and physical constraints, were quite complex and the level of effort in piloting was demanding. Furthermore, the Ligurian East Sea is characterized by a relatively high ship density. Because of these conditions, the level of automation in data download and piloting operation was decreased, keeping the human pilot in the loop to evaluate the risk to stay in the surface for the time needed for the download. A trade-off between the safety of the instrument, navigation and the requirements for the need of real-time observations was achieved. However, the contact with one of the deep gliders was lost on Sat 11 June while crossing a ship lane. The operational oceanographic models running at CMRE were used to generate drift forecasts

assuming the lost vehicle was drifting at the surface and a small aircraft was used twice to survey the identified areas, in the hope to recover the missing glider but without success.

As a lessons learned for the way ahead, CMRE plan to increase the safety of gliders and of navigation extending gliders sensing capability and by implementing algorithms in the Mission Support Center that could crash dive the glider in the case of close vicinity situations.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Autonomous Glider System Planning for Optimal Sampling

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In the AAOSN SBRI project SOFA a consortium led by the University of Exeter showed that it was possible for a completely autonomous surface vehicle to track ocean features, such as bottom topography, with no human intervention. The framework used communicates immediate waypoint/heading guidance commands to the autonomous vehicle for optimal sampling of the feature. These commands are calculated based only on the specific measurements taken at the previous location of vehicle. Hence, the feedback guidance minimises the requirements for a-priori knowledge of the feature and allows the vehicle to be truly autonomous. Conventional pre-planned guidance typically requires significant a-priori knowledge of the feature. In the absence of such information, pre-planning typically requires exhaustive search in an area (for example lawnmower behaviour). In contrast, our feedback guidance approach maximises the useful information (such as tracking of a constant depth seabed feature) gathered as a mission progresses. Although our sea trials have used water depth simulations have demonstrated that the algorithm can be used with a wide variety of ocean features, e.g. mapping thermal fronts or tracer releases.

We now propose to extend this work to gliders. Conventionally, gliders are piloted by an operator who provides a series of waypoints, which the vehicle attempts to follow. Following the success of the autonomous seabed topography mapping we are extending our framework to the subsurface marine environment. Autonomously changing the glider trajectory according to environmental conditions sensed on-board allows faster and more accurate assessment of the features below the surface. Typically, most sub-sea gliders for data gathering receive a trajectory provided and pre-programmed by a human operator, transmitted from a command centre. We propose an on-board system that will remove the human operator, and will instead allow the vehicle to use measured data collected during the mission to direct itself to achieve a pre-set goal. This will add intelligence to the system and is based on the algorithm used to track bottom topography with a surface vehicle in the AAOSN SBRI project led by the University of Exeter. In that case the algorithm was on a shore based computer. This is impracticable for a glider and since the computational load is small the required calculations can be carried out on the glider itself. A typical mission would be for the glider to map a particular contour (or surface). This could be something directly measured such as temperature, salinity or chlorophyll or a derived quantity such as density. By following the required contour as closely as possible, subject to the hydrodynamic constraints of glider operation, a much more efficient mission can be achieved. Because of the difficulty of communicating between gliders sub-surface the algorithms will be designed for single gliders.

Several gliders can be operated together but any co-ordination could only be carried out when the gliders surface so only gross information can be transferred between vehicles. We discuss how useful this could be for sampling ocean features.

Session: Sampling strategies for single vehicles and networks

Underwater Glider Observations of Hurricane Passages near Bermuda in 2014 and 2015

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In October 2014, Hurricanes Fay and Gonzalo hit Bermuda within a single week. BIOS deployed a deep Slocum glider (Anna) within 2 days of Fays passage and it was positioned directly under the eye of Gonzalo, a category 3 hurricane, as it passed overhead. The glider recorded the evolution of the cold wake created by the two storms, including a 4 deg C surface temperature drop, deepening of the mixed layer, and development of strong inertial currents (> 2 kts), large amplitude (>50 m) internal waves and turbulent mixing at the base of the mixed layer. The dataset is a show-stopper. A year later, Hurricane Joaquin passed about 60 miles to the west of the island as a Category 1 storm, with 2 gliders operating as virtual moorings profiling before, during and after the event. Collectively, these glider measurements provide remarkable and rare views of ocean dynamics associated with a range of high intensity atmospheric forcing. As a consequence of these experiences, a storm strategy for operating gliders in severe conditions has been developed and tested in multiple events.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Radically improved observations of physical and biogechemical dynamics at time series sites using gliders

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With the inception of the Mid Atlantic Glider Initiative and Collaboraton (MAGIC) program at BIOS in 2014, Slocum gliders have been deployed at the Bermuda Atlantic Timeseries Study site for >500 days of the last two years. Of several sampling schemes tested, operating the AUVs as virtual moorings steering continuously around a 0.5 km box has proven to be the most effective. Sampling ∼8 profiles per day to 950 meters the dataset resolves variability of physical properties at near-inertial frequencies and enables estimates of daily biogeochemical inventories (e.g. chlorophyll, dissolved oxygen, nitrate). This greatly enhanced sampling frequency contrasts sharply with bi-weekly and/or monthly profiles obtained by the BATS shipboard program, however the latter provides invaluable data for calibration and validation of the glider sensors.
The quality of glider observations and their resolution of small timescales (< 1day) suggests that these measurements will surmount long-standing hurdles to balancing budgets of physical and biogeochemical properties, substantially boosting efforts to understand carbon and nutrient cycling and their impacts on net community production in the ocean.

Session: Observing biogeochemical processes with autonomous vehicles

Dissolved organic matter dynamics in the NW Mediterranean from a new glider optical sensor

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The spatial and seasonal dynamics of dissolved organic matter (DOM) in the NW Mediterranean is addressed here using a new optical sensor, the MiniFluo-UV, which is now fully operational on the SeaExplorer glider. Data presented here were obtained in the Northwestern Mediterranean Sea during two campaigns (Fall 2015 and Spring 2016) where multiple transects were realized across the frontal zone created by the Northern Current. The two optical pathways of the Minifluo were set to target measurements of tryptophan-like and phenanthrene-like compounds (hereinafter referred to as tryptophan and phenanthrene, respectively). It is shown that when combined to other standard physical and biogeochemical measurements commonly carried out by gliders (temperature, salinity, Chlorophyll-a, Colored-DOM, turbidity, etc.), Minifluo measurements highlight new features of DOM dynamics in the region. For example, the tryptophan, an amino-acid traditionally used as a tracer for waste waters, is found here closely related to open sea Chl-a fluorescence, but with some notable differences that may be indicative of vertical or seasonal changes in microbial communities. The study also highlights the presence of phenanthrene (a hydrocarbon) in the surface waters of the Mediterranean, with a gradual accumulation near the pycnocline by the end of the year. Implications of these finding will be put in the context of the Mediterranean Sea DOM dynamics, but also in the context of the ocean carbon cycle from which the Dissolved Organic Carbon (DOC) remains largely under-sampled ($\sim$75% of the molecules composing the DOC are unknown), although it is by far the largest reservoir (DOC represent $\sim$95% of ocean organic carbon).

Session: Observing biogeochemical processes with autonomous vehicles

The Importance of Glider Observations for the Forecast Skill of the Santos Basin Ocean Observing System (Brazil)

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In line with the concept of Blue Economy, a partnership between private companies and a University made possible the creation of the first Ocean Observing System of Brazil in the Southwestern Brazilian Basin. Also known as Azul Project (dos Santos et al., 2015), this initiative funded by an Oil&Gas operator, BG Brasil/Shell and executed by an oceanography technology-based company, PROOCEANO and a research laboratory of Federal University of Rio de Janeiro, LAMCE, is based on the regular deployment of drifters and profiling floats, as well as the use of gliders to systematically sample Santos Basin. This region recently became the most important Oil&Gas province in Brazil and, therefore many offshore activities are taking place. Since March 2013, 90 drifters and 37 profilers have been deployed and more than 8000 gliders dives were accomplished. As well as yielding precious information on the ocean dynamics of this region, those measurents allowed that operational ocean current forecasts, that are now underway, could be achieved through a data assimilation regional ocean modeling system.
The ocean current forecasts are based on a 4DVAR Data Assimilation System applied to the ROMS regional model for the Southwest Basin of Brazil, in which a highly unstable baroclinic current system occurs, with several meanders and eddies being formed and displaced throughout its path. Features related to the intense mesoscale activity represent a challenge to ocean forecasting since its space-time variability adds a higher degree of complexity in local circulation. ROMS is configured between 15oS to 30oS with 1/12o horizontal resolutionand 40 vertical levels. The observations used in the assimilation cycles include: 1-day gridded, 0.1o resolution SST from POES AVHRR; 1-day gridded, 0.3o composite of the MDT SSH from AVISO; Surface and sub-surface hydrographic measurements of temperature and salinity collected with gliders and profilers from Project Azul.
The assimilative model results were already compared to forward model results and independent observations, both from remote sensing and in situ sources and described in Fragoso et al. (2016). The results clearly show an improvement on the skill of ocean nowcast and short-range forecast for the region. Now, the present work investigates the importance of glider observations for the forecast skill through a series of twin experiments focused mainly in mesoscale eddies that are regularly shed in the area and affects activities of exploration and production of Oil&Gas. Those experiments consist on hindcasts performed during periods in which eddies were shed and observed through satellite imagery, drifters and profilers measurements. The model was run with three different assimilation configurations, namely: assimilating all available data, assimilating all data except for gliders and with no assimilation.
The comparisons of the experiments results show clearly that the capacity of gliders in sampling those mesoscale features up to 1000m depth is essential for the system

to be able to reproduce and forecast those sporadic features in the correct time and space. Therefore, despite being greatly outnumbered by satellite data, glider measurements are of utmost importance for the accuracy of the forecasting system, especially concerning the ability to reproduce mesoscale eddies of this region as it will be demonstrated in this presentation.
Observation Impacts of all measurements regarding different metrics, such as Brazil Current System Transport and Eddy Kinetic Energy will be the next step in the investigations carried out on this Ocean Observing System.

Session: The role of gliders in Ocean Observing Systems

OTN/MEOPAR Glider Operations in Canadian Waters

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The Ocean Tracking Network (OTN) and the Marine Environmental Observation Prediction and Response Network (MEOPAR) jointly operate autonomous vehicles in Canadian waters in support of a variety of projects. These vehicles operate independently at sea from weeks to months, collecting data and reporting back to shore via satellite. Gliders can measure water conditions, detect tagged animals, listen for whales and offload data from acoustic receivers. Data from the glider group have been used to extend federal monitoring programs on the Scotian Shelf, including the monitoring of persistent subsurface chlorophll layers not visible by satellite; relate ocean conditions to salmon migration; validate models of ocean temperature and salinity; aid in environmental assessments of the effects of the Maritime Link on snow crab behavior; and hunt for feeding grounds of marine mammals on the east and west coast of Canada.

Session: The role of gliders in Ocean Observing Systems

Determining Iceberg Characteristics Using an Underwater Glider, Autonomous Surface Craft and Aerial Drone

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We present results from iceberg surveys conducted in Newfoundland in June 2017. We characterized four different icebergs using three different vehicles: a Slocum glider, an autonomous surface craft SeaDragon and an aerial drone. We determined the above and underwater shape of the icebergs using a combination of sonar, radar, Lidar and photographic techniques. Water characteristics around the iceberg were determined using a SeaBird CTD and an RDI ADCP. Each iceberg was surveyed multiple times enabling us to demonstrate the influence of oceanographic conditions on the melt and deterioration of icebergs in coastal waters over a ten day period. We review the effectiveness of the different platforms and sensors for iceberg characterization and attempt to asses the melt rate of icebergs in the relatively warm Newfoundland waters (5 o C).

Session: Gliders in polar oceans: science and technological challenges

Hurricane Gonzalo (2014): upper-ocean processes and hurricane intensity forecast using hurricane underwater gliders data

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In July 2014, an array of underwater gliders was deployed off Puerto Rico by the NOAA Atlantic and Oceanographic Laboratory (AOML) and by the Caribbean Coastal Ocean Observing System (CariCOOS) as part of a multi-institutional effort. The goal of this work is to enhance our knowledge on the role of the ocean on the intensification of Tropical Cyclones (TC) in the Atlantic Ocean. Sustained and targeted upper-ocean profile observations from underwater gliders are carried out to assess the upper ocean response to hurricane force winds and to evaluate the impact of these observations on TC intensity forecasts. In the July 2014 mission, two gliders were piloted along predetermined tracks in the Caribbean Sea and in the North Atlantic Ocean, where hurricanes very often travel and intensify. During July through November 2014, both gliders continuously provided temperature and salinity profile data to 1000m and depth-averaged and surface current velocities. On October 12, 2014, TC Gonzalo developed in the tropical North Atlantic. As Gonzalo travelled $\sim$85 km northeast of the location of the glider, it intensified from a cat-2 Hurricane into a cat-3, providing a unique data set of upper-ocean profile observations under hurricane wind conditions. Observations collected before, during, and after the passage of this hurricane were analyzed to improve our understanding of the upper-ocean response to hurricane winds. These observations were also assimilated in a coupled ocean-atmosphere hurricane model to assess the impact of underwater glider observations on hurricane forecasts.

The main finding from the analysis of the dataset is that a barrier layer characterized by the low salinity in the upper 20 meters, potentially played an important role on changes observed in the upper-ocean, likely suppressed the hurricane-induced upper-ocean cooling, providing favorable conditions for further intensification. Post-storm observations also revealed a partial recovery of the ocean to pre-storm conditions 11 days after the passage of the hurricane.

The underwater glider data collected during Hurricane Gonzalo was assimilated into the high resolution Hurricane Weather and Research Forecast (HWRF)-Hybrid Coordinate ocean model (HYCOM) coupled forecast system. Three data assimilation experiments were designed to examine the impact of assimilating underwater glider temperature and salinity data and of other conventional ocean observations: one with no data assimilation (NODA), one with only glider data assimilated (GLID), and one including assimilation of all ocean data available. The main finding is that assimilation of glider observations significantly improves the characterization of temperature and salinity fields within HYCOM in the upper 150 m of the ocean. Results show that a realistic model representation of the oceanic barrier layer, as was observed in the region, may be only achieved when glider observations are assimilated. In addition, the assimilation of glider data showed a positive impact on the forecast of Hurricane Gonzalo, despite the limited spatial coverage of the glider

dataset. Results also showed that the assimilation of all available ocean observations significantly improved the intensity forecast. This analysis emphasizes the value of integrating different components of the ocean observing system to enhance the forecast of extreme weather events, such as Tropical Cyclones.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

SPRAY glider for altimetric cal/val activities in the South-Western Pacific: the case example of the East Caledonian Current

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We present an assessment of SARAL/AltiKa Ka-band satellite altimeter for the monitoring of a tropical western boundary current in the south-western Pacific Ocean: the East Caledonian Current. The current has a width of about 200 km, and flows along the north-eastern flank of New Caledonia archipelago. It is one of the major currents of the south-western tropical Pacific, with 10 to 15sv transported over the upper 1000 m. The experiment relies on repeated BLUEFIN/SPRAY glider transects along SARAL ground tracks, supplemented by deep-ocean current-meters moorings deployed in the core of the coastal current. We compare surface geostrophic current estimates obtained from two versions of AltiKa along-track sea level height (1 Hz and 40 Hz) with co-located in situ estimates. The glider provides two independent estimates of the surface current. First one is the classical absolute geostrophic current (obtained by combining the glider CTD profiles and its dead-reckoned underwater trajectory). Second one is simply deduced from the glider drift inferred from its GPS fixes during the few-minutes long period spent idle at sea surface after each descent/ascent cycle. It is concluded that AltiKa-derived current successfully captures the velocity of the boundary current, with a standard error of 11 cm/s with respect to the in situ data (SPRAY glider estimates or current-meter moorings). This level of accuracy is commensurate with previous estimates of SARAL/AltiKa accuracy obtained in the Med Sea. The present study illustrates the benefit of the reliable, low-cost monitoring operated by the SPRAY glider. However we emphasize the need to complement the glider operations with synergetic in situ systems because of the lack of synopticity of the glider sampling in occasions of adverse current conditions.

Session: Sampling strategies for single vehicles and networks

Vertical Structure of Mesoscale Features Observed by Deepglider

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Full water column temperature and salinity profiles and estimates of average current collected with Deepgliders were used to analyze vertical structure of mesoscale features in the western North Atlantic. Fortnightly repeat surveys over a 58 km by 58 km region centered at the Bermuda Atlantic Time Series (BATS) site southeast of Bermuda were carried out for 3 and 9 months in successive years. In addition, a section from Bermuda along Line W across the Gulf Stream to the New England Continental Slope and a pair of sections from Bermuda to the Bahamas were carried out.

Absolute geostrophic current estimates constructed from these measurements and projected upon flat bottom resting ocean dynamic modes for the regions. These indicate nearly equal kinetic energy in the barotropic mode and first baroclinic mode along with decay of energy in higher modes proportional to mode number cubed, a result predicted for geostrophic turbulence. An empirical orthogonal mode decomposition of dynamic mode amplitudes demonstrates strong coupling of the barotropic and first baroclinic modes, while higher baroclinic modes are largely independent of one another.

On two occasions, submesoscale anticyclones were detected at BATS whose vertical structure closely resembled the second baroclinic mode. Anomalously cold and fresh water within their cores (by as much as 3.5°C and 0.5 in salinity) suggests they were of subpolar (likely Labrador Sea) origin.

Estimates of volume transport across the sections were aliased by their non-synoptic nature in the presence of strong mesoscale eddy variability.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Deepglider Characteristics and Capabilities

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Deepgliders have demonstrated the ability to collect full depth profiles in the open deep ocean on missions several months in duration in energetic oceanic environments. They can dive to as deep as 6 km depth hundreds of times in a single mission and relay profiles of temperature, salinity, and dissolved oxygen in near real time. Buoyancy driven full depth operation is achieved by using a carbon fiber pressure hull. Average power consumption of ~1/3 W is enabled by the use of a liquid compressee/expansee with which vehicles can be trimmed to be neutrally buoyant throughout the water column to within ~2% of the in situ range of seawater density variation. To achieve high endurance, Deepgliders are operated at slow speeds (~0.2 m/s horizontally, 0.06 m/s vertically) by limiting thrust to about 0.2% of vehicle mass. To achieve the higher speed necessary to cross the Gulf Stream (~0.45 m/s), thrust was tripled and energy consumption quintupled. Estimated annual operational costs are equivalent to the cost of a single day of research vessel operation. The cost per unit length of survey is ~US$6/km.

Session: New developments in glider and sensor technology

Conductivity Cell Thermal Inertia Correction on Seagliders

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Accurate correction of salinity profiles collected by Seagliders over regions with strong temperature stratification is achieved using the geometry of Seabird cell to calculate the normal modes thermal response of a composite hollow cylinder (potted jacket enclosing a hollow glass cylindrical cell) to flow both within it and past its exterior. Each mode describes exponential decay in time to step temperature forcing and their sum describes the response of the inner wall of the cell. For the necessarily modest flow within the cell induced by vehicle motion, a truncated sum is required to model thermal response within the conductivity cell sample volume. Thermal response due to slow changes in vehicle speed are modeled physically consistently by estimating boundary layer thickness and resulting radial heat flux through Nusselt number scaling. The method applies to pumped as well as un-pumped cell configurations and is generally applicable to all CTD systems using the standard Seabird cell.

Session: New developments in glider and sensor technology

Automated Glider Piloting in a Subsurface Submesoscale Eddy

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Two or more gliders were guided by a Kalman filter routine to simultaneously survey a subsurface submesoscale anticyclone in the California Current (a Cuddy) offshore Washington and Vancouver Island as it moved and changed its radial-vertical structure over the course of 4 months of surveillance. The guidance software ran ashore and produced predictions of eddy strength, lateral and vertical scale, location, and translation velocity based on the observation history of the glider missions. The routine effectively chose new vehicle targets each time a glider surfaced and transmitted data from which density profiles and depth averaged current estimates were constructed. These were assimilated by the Kalman filter to produce an updated estimate of eddy state and project its evolution from which updated target locations were provided automatically to each glider when it surfaced. The targets were chosen by the algorithm to guide gliders across the eddy through its center along independent (nearly orthogonal, in the case of two gliders) tracks.

Session: Sampling strategies for single vehicles and networks

Gliders for mesoscale and mixing in the Bahamas (MerMEED)

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The MerMEED project (Mechanisms responsible for Mesoscale Eddy Energy Dissipation) is planned for the 2017-2018 period, to make measurements of the structure and energy in mesoscale eddies at the western boundary of the Atlantic at 26N. Mesoscale eddies are ubiquitous in the worlds oceans, travelling slowly westward, until they reach the western boundaries of ocean basins and there disappear from satellite measurements of sea surface height. In this project, we propose to use moored observations, Seagliders and microstructure and velocity profiles to determine levels of mixing associated with eddies at the western boundary. The overall aim is to quantify dissipation, and identify the processes associated with mixing (including bottom friction, lee waves over rough topography, and hydraulic effects associated with boundary waves). Here, gliders will be used to document the evolving structure of the eddies at the boundary, and also to estimate turbulent dissipation using vertical velocity variance. Turbulence estimates will be compared against estimates from moored velocity and fast temperature, and in situ profiles from a microstructure profiler.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Is it a seal, no it's a glider: Antarctic krill react to gliders

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Underwater gliders are quiet, have small visual cross-sections, and are slow-moving, thus generating minimal pressure waves. As such, gliders could be thought to have a negligible impact on animal behaviour. We used an echo-sounder mounted on a glider to investigate the distribution of Antarctic krill at the Antarctic Peninsula. We were surprised to observe a noticeable avoidance behaviour in krill as the glider descended over a swarm.

Deployments of calibrated echo-sounders integrated into gliders have demonstrated both their capacity to record mean volume backscatter from pelagic species and the role that such systems will play in future marine observations networks. In January 2015 a Slocum glider, with a 120 kHz echo-sounder, was deployed in Marguerite Bay, Western Antarctic Peninsula. For two months, the glider recorded down-ward facing acoustic data during downcasts at the continental shelf and during passage to Rothera Research Station. Antarctic krill, a species of particular importance in the Antarctic ecosystem, were identified within the data by the morphology of swarm backscatter.

Krill swarms were detected within the water column from the surface to depths of 800 m, with the majority observed within the top 100 m. However no krill swarms were detected within 5 m range of the glider. Instead we found a statistically significant reduction in backscatter attributed to krill at ranges proximate to the AUV, which may extend up to 30 m from the vehicle. This indicates an avoidance reaction. The cause of avoidance is unknown but it is likely to be a visual stimulus with the glider potentially casting a shadow similar to that of a seal or other predator. It could also result from flashing lights of optodes carried by the glider, triggering the response. This reaction, and its influence on acoustic target detection and conversion into biomass, will have to be accounted for when gliders are used to undertake ecosystem assessments.

Session: Gliders in polar oceans: science and technological challenges

A low-cost method for quality controlling SLOCUM temperature and conductivity sensors

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Temperature and conductivity sensors mounted on gliders should be calibrated before and after each mission, as any other ship-handled or moored CTD package. This quality aspect is critical, especially for long-term observations focused on climatic trends of intermediate and deep waters.
In practice, implementing this virtuous routine for gliders is a tricky challenge. On TWR SLOCUM gliders, the Seabird CT sensors are fixed rigidly to the science bay hull. The whole bay has to be shipped to the factory where the sensors are first disassembled, sent for a round-trip to Seabird for re-calibration and finally re-assembled. The whole process, which includes high-pressure re-testing of the hull, is very expensive in both time (weeks to months) and money (∼4 kE for European operators).
Inter-comparisons with (pseudo-)simultaneous CTD casts and/or moored instruments are a lesser evil for assessing sensor drifts in the field from a few samples. This approach may lead to doubtful results because of the high frequency natural variability of seawater characteristics between the platforms, as close as they can be in time and space. It also assumes that the reference in situ instruments biases are perfectly known, which may be utopian, especially for moored conductivity cells. Most of the time, such comparisons are simply not possible due to the lack of concomitant shipborne or mooring measurements.
The CNRS / DT-INSU group has developed a reliable, easy and low-cost method for evaluating routinely the drifts of SLOCUM CT sensors between two factory calibrations. It consists in comparing the glider CT probes with a dedicated reference SBE37 in a controlled, permanently mixed bath, without dismounting the sensors from the science bay hull. This is allowed by bypassing the glider electronics and communicating directly with the CT sensors. Sealed by 2 caps, the bay is powered externally and CT data are sampled simultaneously with the SBE37 at a constant configurable rate. Realistic temperature ranges are achieved in the bath by asymptotic heating from cooled water to ambient temperature, while conductivity steps are controlled by successive dilutions from natural seawater.
The method was first validated by testing CT sensors coming back from factory calibration, with differences found less than 1.10-3 °C and 1.10-3 °C S/m (∼0.002 PSU) over the [12°-20°C] and [2-4 S/m] ranges. A series of tests have been subsequently conducted for defining the most suitable conditions in the bath, especially regarding homogeneity and natural heating rate with respect to the thermal mass and sensors response time.
The protocol is now systematically applied for any mission committed to our group. We detail the method and present the results that are pivotal for glider data quality.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Stratified Coastal Ocean Processes in Landfalling Hurricanes and Typhoons

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An integrated ocean observing system operating during Hurricane Irene (2011) revealed widespread and significant ahead-of-eye cooling (at least $5^{c}irc$C and up to $11^{c}irc$C) as the storm crossed the seasonally stratified continental shelf of the Mid-Atlantic Bight of North America. Buoys and gliders deployed in the storm allow the detailed evolution of the surface temperature to be examined at select points, revealing 76%-94% of the total cooling occurs before eye passage. A range of ocean models were used to diagnose the processes responsible for the observed cooling. In Irene, 1D vertical mixing models generate only 17% of the total cooling ahead of eye, while deepwater 3-D models forced by Irenes nearly symmetrical offshore windfield produce an approximately 50-50 split in the cooling between the front and back side. A 3-D coastal ocean model (ROMS) generates a wind-forced two-layer circulation in the stratified Mid-Atlantic that was validated by the observing system but was not present in the 1-D and 3-D deepwater models. The resultant shear-induced mixing more accurately reproduces both the magnitude and timing of the ocean surface cooling with respect to eye passage. Atmospheric simulations establish that this ocean cooling was the missing contribution required to reproduce Irenes accelerated reduction in intensity over the Mid Atlantic Bight.
Historical buoys from 1985 to present show that ahead-of-eye cooling occurred beneath all 11 tropical cyclones that traversed along the Mid Atlantic Bight continental shelf during stratified summer conditions. The buoys also reveal that an average of about 75% of the cooling in these 11 hurricanes occurs ahead of eye, indicating a robust process in the Mid Atlantic. Similar to the Mid Atlantic Bight, the Yellow Sea has had 26 typhoons cross its shallow highly stratified waters in summer before making landfall in China or Korea. Typhoon Muifa (2011), whose intensity was also overpredicted, generated significant SST cooling (up to 7C) in the Yellow Sea, and a Yellow Sea buoy array similarly revealed 85% of the cooling was ahead of eye. These findings establish that including realistic 3D coastal ocean processes in forecasts of landfalling storm intensity and impacts will be increasingly critical to mid-latitude population centers as sea levels rise and tropical cyclone maximum intensities migrate poleward.

Session: The role of gliders in Ocean Observing Systems

NOAA/AOML CariCOOS Hurricane Underwater Glider Operations

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A network of underwater gliders was implemented in 2014 by the NOAA Atlantic and Oceanographic Laboratory (AOML), the Caribbean Coastal Ocean Observing System (CariCOOS), the NOAA National Data Buoy Center (NDBC), the NOAA Integrated Ocean Observing System (IOOS), and the University of Miami Cooperative Institute for Marine and Atmospheric Studies (UM/CIMAS)as part of a multi-institutional project. The goal of this work is to enhance our knowledge on the role that the ocean plays in the intensification of Tropical Cyclones (TC) in the Atlantic Ocean. In order to accomplish this, sustained and targeted upper-ocean profile observations from underwater gliders are carried out to assess the upper ocean response to hurricane force winds and to evaluate the impact of these observations on TC intensity forecasts. In this presentation, an overview of the past, present, and future of NOAA/AOML CariCOOS Hurricane Underwater Glider Operations will be provided. Starting in July 2014, two underwater gliders were deployed and piloted along predetermined tracks in the Caribbean Sea and in the North Atlantic Ocean, where hurricanes very often travel and intensify. During the first two years of this project, four glider missions were successfully completed, and approximately 10,000 temperature and salinity profiles observations were collected in areas that were previously poorly sampled. The fifth underwater glider mission, that will start during the 2016 Atlantic hurricane season will include the deployment of four gliders, two in the Caribbean Sea and two in the tropical Atlantic Ocean. Glider observations collected by this effort are transmitted in real-time to the Global Telecommunication System (GTS) by NOAA/NDBC, and distributed through AOML and IOOS Glider Data Assembly Center webpages. Datasets include unique temperature and salinity observations under tropical cyclone wind conditions for: (1) Tropical Storm Bertha (August 2014), (2) Hurricane Gonzalo (October, 2014), and (3) Tropical Storm Erika (August, 2015).

Session: The role of gliders in Ocean Observing Systems

The mystery disappearance and reappearance of Glider 416 during a mission in The Great Barrier Reef

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During January 2016 Glider 416 was 7 hours into a 2 week mission when all comms was lost, 6 days later ARGOS location was received. What happened?

Session: Glider operations: piloting, infrastructure, data management and legal issues

A glider observes chlorophyll dynamics during a transition from winter mixing to summer stratification across a subsurface eddy

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In 2013, the Seaglider Pheidippides (SG149), operated by the Oceanography Center of the University of Cyprus, conducted mission EL08 in the Levantine Sea, Eastern Mediterranean. The mission lasted 163 days beginning on 22 February and ending on 5 August, and covered the transition period from winter mixing conditions to summer stratification. The 520 dives performed by the glider repeatedly intersected the anticyclonic (warm-core) sub-surface Cyprus eddy, providing useful synoptic distributions of key physical and biogeochemical properties that are otherwise untenable. The data illustrate the onset of stratification in April and the full development of a warm and salty surface layer by June. During the same period, chlorophyll distribution with depth shifted from a broad surface mixed-layer diffuse signal to a sharp deep chlorophyll maximum. Specifically, the chlorophyll maximum descended from 80 m in February to 140 m in August, while the maximum chlorophyll signal exhibited a step-increase of 50 % in April. Oxygen percent saturation and AOU reflect this development through contemporaneous detectable localized maxima above the chlorophyll maximum. A moving average of chlorophyll inventories integrated over the 0-250 m depth layer did not vary during the mission, suggesting a gradual concentration of the primary producer standing stock in a deeper and narrower layer. However, obvious positive excursions of chlorophyll inventories coincided with passes of the glider across the eddy boundary, and are indicative of the presence of a core-ward convergence (wine-glass) effect in association with the Cyprus Eddy. As shown elsewhere, such an effect may accelerate the removal rate of particles and important bioelements from the euphotic zone and, in this case, it may contribute significantly to the characteristic low nutrient concentrations and productivity of the Levantine Sea region.

Session: Observing biogeochemical processes with autonomous vehicles

The Norwegian Glider Observatory

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The North Atlantic Current Observatory (NACO) became operational as a national Norwegian glider infrastructure project in 2012. Since then our gliders have travelled a distance through water equivalent of a circumnavigation of the Earth (40000km) in the Nordic Seas. Both Seagliders and Slocums have been used for missions ranging from endurance sections of several hundred kilometers across the Norwegian Sea for long term monitoring to process oriented turbulence and shallow water research projects. We will report results and experiences from these missions with respect to platform robustness and consider how the operations can be extended into Arctic conditions.

Session: The role of gliders in Ocean Observing Systems

An Open Software Framework for Adaptive, Autonomous operation of Maritime Autonomous Systems

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SeeByte originally developed a suite of tools to enable command and control of off-board autonomous systems. This includes SeeTrack, a top-side mission tool suit, and Neptune, a multi-vehicle autonomy system. These tools are now being applied to oceanographic and environmental research scenarios, with a particular focus on in-mission adaptive and autonomous behaviors.
This paper will present research results from the Adaptive Autonomous Ocean Sampling Networks (AAOSN) project; a 1.5million project funded by NERC, Dstl and the Technology Strategy Board, to develop new technology solutions for coordinating a suite of marine autonomous systems (MAS). The SeeByte consortium, which includes ASV (a leading marine autonomous systems manufacturer) and the Marine Biological Association of the UK, aims to provide an open software tool-set and user interface that will enable improved use of a wide-range of autonomous systems in gathering data from the ocean over extended periods, while constantly adapting to the environment and mission requirements.
The AAOSN project targeted a range of applications for mixed MAS fleets, including tagged fish tracking, tidal mixing fronts and swath bathymetry mapping. However, a key target of the work was to provide an open tool- set that could be used by third-parties to develop their own autonomy behaviors. In order to accomplish this, ASV undertook to independently develop a Tagged Fish Tracking behavior and to demonstrate this with an extended continuous mission of at least 24-hours.
The major scientific question being addressed is whether the recently introduced (or updated) management zones within the EU Habitats Directive will have detectable effects on important fish species. The UK National Oceanography Centre (NOC) and their scientific partners, including the Marine Biological Association (MBA), have taken part in a number of previous studies to investigate new survey methods to address this question. One new survey approach aims to combine fixed receivers (landers) with mobile platforms (autonomous systems) in monitoring a drip feed of tagged fish over extended durations (> 30 days). The hope was that the autonomous systems could provide the broad area coverage needed to balance the constant data stream being provided by the landers in a statistically reliable way.
Previous work carried out (MASSMO Phase 2) showed the clear potential to use long-endurance autonomous system for monitoring tagged fish but also clearly highlighted the need to make smart use of the mobile platforms to maximize their limited power budget. This paper will present work performed as part of AAOSN that developed adaptive, autonomous behaviors for unmanned surface vehicles to allow them to participate in this new survey method. The behavior developed uses a grid priority scheme to sequence the visits to each grid, and manages a broad exploration strategy to ensure coverage. Periodically, a visit to a sea-bed lander is scheduled to allow for a data harvest from the subsea equipment.
The behavior was developed by ASV, using SeeBytes Neptune autonomy architecture, while the MBA and NOC provided expert input to ensure the behavior

provided the science community with reliable and relevant data. The behavior was tested on-water with the NOC-owned C-Enduro Thomas vehicle for a range of missions, including an overnight mission where the missions was allowed to cycle, simulating its use over an large area, and over an extended period.
The conclusion from the in-water test missions was that the autonomy behavior developed can help ensure high utilization of the autonomous systems while decreasing direct operator piloting. However, the complete system remains to be tested as part of a longer trial that also includes the controlled release of tagged fish in an appropriate water management zone. It is hoped that this will occur within the next 12 months and will prove a significant step forward in survey methods for EU Habitat Directive management zones.

Session: Sampling strategies for single vehicles and networks

Operational assimilation of glider temperature and salinity improves ocean state estimate

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An operational data assimilation system for the Eastern Mediterranean is described and evaluated for a 6-month twin experiment. In the assimilative run, profiles of temperature and salinity from a single glider are assimilated daily into a high resolution ocean forecast. In the control run, the same initial and boundary conditions are used to produce an operational forecast, but without assimilation. While both runs were similar for most of the time and most of the domain, significant differences were found near the region of assimilation, particularly when the glider passed through the anticyclonic Cyprus eddy. Root mean square differences of the misfits between the temperature and salinity observations and the model background field at those locations (before any assimilation) were approximately 15% lower in the assimilative run. Improvements in the forecasting capability of temperature, salinity, and currents were found, and would provide a significant improvement of predictive capacity for applications such as pollutant spreading or offshore operational safety.

Session: The role of gliders in Ocean Observing Systems

Discovery and access of glider data based on the Sensor Web Enablement (SWE) standards: a proposed architecture

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The BRIDGES project aims to develop a new multi-role autonomous underwater vehicle for use by the academic, commercial and government sectors. A key objective of the project is that the data access interfaces are inter-operable with existing and future autonomous infrastructures. The project has reviewed the existing multitude of proprietary standards for different gliders, the fledgling marine domain Everyones Glider Observatories (EGO) international exchange format, and the cross domain Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) standards. The conclusion was to expose metadata using OGC Sensor Model Language (SensorML) which is an element of the OGC SWE framework. Data are to be exposed using a combination of ISO/OGC Observations & Measurements and the EGO format. A new ontology for describing the platform types, platform instances, sensor types and sensor instances is being developed with a global Marine SWE Profile initiative that is coordinated by 52°North (see author list). This common ontology will bring together the range of current and developing SWE implementations both syntactically and semantically. Adoption of the OGC standards will align the output of BRIDGES with on-going international efforts to harmonise data access and formats with the EU Oceans of Tomorrow projects and Ocean Data Interoperability Platform project readily enabling automated machine to machine access and exchange of data. The integrated use of the EGO format aims to maximize utility and uptake of the data by the marine science community.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Progress towards the establishment of an EGO Data Assembly Centre for UK glider data

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The British Oceanographic Data Centre (BODC) is committed to the exposure of UK glider observations through the Everyone's Gliding Observatories (EGO) initiative. Progress towards the setup of the necessary Data Assembly Centre (DAC) infrastructure and workflow is presented.
BODC is the UK's designated National Oceanographic Data Centre (NODC) and has strong collaborations in place with UK glider teams. These include those at the University of East Anglia (UEA), National Oceanography Centre (NOC) and Scottish Association for Marine Science (SAMS). Efforts to date have focused on safeguard and dissemination of interoperable data for long term re-use. Work commenced by BODC under the EU-funded Gliders for Research, Ocean Observation & Management (GROOM) project has been sustained through a number of subsequent small grants, including the Marine Autonomous Systems in Support of Marine Observations (MASSMO) exercises.
In 2016, BODC commenced work on a generic near real-time delivery project that aims to make the near real-time assembly and dissemination of EGO-formatted glider data operational by 2017. Development of the infrastructure is likely to continue through EU Horizons 2020 AtlantOS and recently awarded UK Marine Autonomous Systems funding streams.
UK glider data are predominantly collected as part of Natural Environment Research Council (NERC)-funded process studies. Data arising from such funding typically carry a two year embargo as part of the NERC default data policy. In many cases, further dialogue between BODC and the Principal Investigator sees the relaxation of this standard policy and allows for core physical observations (temperature and salinity measurements) to be channelled by BODC to the Global Telecommunications System (GTS) in near real-time. SAMS have granted open data access to their Extended Ellett Line glider measurements and work is ongoing to convert and submit these data to the EGO Global Data Assembly Centre (GDAC). Further to this, BODC are continuing to work with other Principal Investigators to progress towards the open data goals of EGO.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Glider measurements on the Scotian Shelf

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The Canadian Department of Fisheries and Oceans (DFO) started in 1998 a monitoring program, the Atlantic Zone Monitoring Program (AZMP), to sample physical, biological, and chemical conditions in Atlantic Canada. One component of this program is biannual ship-based transects completed by our region at several locations across the Scotian Shelf. In 2011, the Ocean Tracking Network (OTN) started operating a Slocum glider along one of our transects, the Halifax Line, on an ad hoc basis. We will present some of the results of seasonal and inter-annual variability along this transect. DFO plans to operate a glider along this transect as part of the AZMP.

Session: The role of gliders in Ocean Observing Systems

Nitrate fluxes in the North Atlantic and their relationship with primary production

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We present a depth-resolved year-long time-series of primary production using a novel glider based methodology. We simultaneously calculated vertical nitrate fluxes to the upper ocean resolving several supply processes, including diffusion, advection and convection. These data were collected using an array of moorings deployed at the Porcupine Abyssal Plain Sustained Observatory site in the North East Atlantic (∼49°N) as part of the NERC UK Ocean Surface Mixing, Ocean Sub-mesoscale Interaction Study (OSMOSIS). In comparing the different time-series of nitrate flux with the variability seen in primary production we estimate that nitrate fluxes can support between 75 and 104 % of the observed primary production.

Session: Observing biogeochemical processes with autonomous vehicles

Drivers of variability in water mass exchange at a circulation choke point; a combined observing-modelling approach

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Six years of quasi-continuous glider endurance line observations, undertaken by SOCIB (Balearic Ocean Observing and Forecasting System), have uniquely characterised the high frequency (weekly) variability in the circulation through the Ibiza Channel, an important choke point in the Western Mediterranean Sea. This choke point governs the north/south exchange of different water masses and impacts the basin/sub-basin scale circulation. The resulting multi-scale variability affects the regional shelf and open ocean ecosystems, including the spawning grounds of Atlantic bluefin tuna.
To understand the drivers of this variability we combined high frequency glider data with numerical model simulations (WMOP) and altimetry. The key drivers of this variability are identified as; extreme winter events to the north, which cause the formation of a cold winter mode water (Winter Intermediate Water WIW) and affect the characteristics of the Levantine Intermediate Water (LIW) flowing south out of the Gulf of Lions; and mesoscale activity, linked to the formation of eddies to the north that block the Ibiza Channel in spring and autumn and intermittent vigorous flows of fresher Atlantic waters from the south, through both the Ibiza and Mallorca Channels. The high frequency (weekly) repeat of the glider endurance line transects allows for the identification of specific events, and the evaluation of trends, enabling a multi-level comparison with high-resolution data from models (WMOP and HIRLAM). In combination with satellite altimetry which provides a basin scale view of the surface layer circulation to the north and south of the channels at lower resolution, insight into the drivers of variability at seasonal to inter-annual time scales is gained. When compared to numerical simulations, this enables the characterisation of potential and persistent biases in the northwest Mediterranean ocean models.
In addition, the combining of glider endurance line observations across glider teams in the North West Mediterranean highlights the important contribution of gliders to the monitoring of boundary current systems and significantly enhances our capability to connect ocean processes and their impact on circulation variability in a multi-regional study.

Session: The role of gliders in Ocean Observing Systems

JERICO-NEXT Trans-National Access: Expanding glider monitoring and facilitating external access to the to the glider platform

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Recognising the importance of gliders as a component of a European multi-platform, multi-scale and multi-process monitoring system JERICO made gliders a part of its Trans-National Access (TNA) Program. The primary objective of the TNA Program is to facilitate access for scientists and engineers to costal infrastructures not available in their own countries.
In 2013 2014 the JERICO TNA Program initiated 3 new proto-endurance lines in the Mediterranean, with coordination support through the PERSEUS Project; a Sardinia-Tunisia line, the MUSICS Project operated by CNRS-DT INSU for SAROST, which in a chronically under sampled area showed lenses of fresher water mass related to the meandering of the Algerian Current; a Mallorca-Algerian Basin transect, the ABACUS Project operated by SOCIB for the University of Napoli Parthenope which provided a unique 3D view of an anticyclonic eddy through interactive real-time piloting of the glider, the thermohaline properties of which indicated its origin as a perturbation of the Algerian Current, with differing production levels between Algerian and Mediterranean waters; and a Menorca-Sardinia line, the GABS Project operated by SOCIB for CNR-IAMC, which showed the onset of a bloom after a decrease in wind-driven mixing and the important role played by the frontal-related re-stratification. These missions provided fresh insight into sub seasonal variability in circulation, important characterisation of sub-mesoscale to mesoscale features and their associated physical to biological interactions. These proto-endurance lines are an excellent example of effective, targeted funding and coordination between EU projects, to build capacity and coverage in areas that are traditionally sparsely monitored.
Building on the success of this first program, JERICO-NEXT has increased the number of glider facilities providing access from two to three; the CNRS-DT INSU Glider National Facility, France, the SOCIB (Balearic Islands Coastal Observing and Forecasting System) Glider Facility, Spain, and now the COSYNA (Coastal Observing System for Northern and Arctic Seas) Glider Facility, Germany. We provide insight into the positive impact of the initial 3 JERICO TNA missions in terms of scientific output, increasing European observing system coverage, enhancing cross-national scientific collaboration, and developing glider mission and data skills within teams that would not otherwise have had access to this platform. The next JERICO_NEXT TNA open call will be in May 2017.

Session: The role of gliders in Ocean Observing Systems

Physical drivers of the spring bloom in a temperate shelf sea

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The spring blooming of phytoplankton in high- to mid-latitude oceans makes a significant global contribution to the fixation and export of carbon from surface waters. The biophysical interactions initiating this period of accelerated growth have been topical for many years leading to the development of several hypotheses, each focusing on slightly different mechanisms: light availability and mixed layer depth; predator vs. prey imbalance; horizontal stratification and critical turbulence. Here we take a detailed look at the onset and evolution of the spring bloom on the NW European Shelf, which in contrast to the deep, open ocean environment of the North Atlantic, is a shallow and highly dynamic shelf sea.
Two gliders provided 21 days of high resolution TKE dissipation, temperature, salinity and chlorophyll biomass profiles every 10-15 minutes in the central Celtic Sea. Meteorological variables and near-surface PAR are taken from a nearby mooring array. These observations are then used to drive a Lagrangian particle tracking model from which the displacement of individual cells and their exposure to light and nutrients is tracked. The results provide compelling evidence for the leading order role of vertical turbulent structure in both triggering phytoplankton growth and the subsequent evolution of the bloom. Prior to peak growth rates deep, convective turbulence and weak net surface heat input ensures that the water column is well mixed and cells are circulated between the surface and sea bed. A coincident decrease in wind and tidal stresses allows near surface stratification to become established which subsequently supresses the penetration of wind and wave driven mixing, increasing the residence times of cells near the surface and increasing the average irradiance they receive. There is remarkable agreement between the depth of the active mixing layer and the base of the chlorocline, 10-20 m above the main seasonal thermocline.

Session: Observing biogeochemical processes with autonomous vehicles

Transport Structure and Energetic of the Flow associated to the North Atlantic Current in the Eastern part of the Subpolar Gyre

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We present here the first 2 years of UK-OSNAP glider missions on the Rockall Plateau in the North Atlantic, along the section located at 58°N and between 22°W and 15°W. From July 2014 to August 2016, ∼20 gliders sections were realized on the Rockall Plateau. The depth-averaged current estimated from gliders shows very strong values (up to 45cm s^{-1}) associated with meso-scale variability due particularly to eddies and subpolar mode water formation in winter.
The variability of the flow on the eastern slope of the Iceland basin and on the Rockall Plateau is presented. Meridional absolute geostrophic transports are calculated from the glider data and we will discuss the vertical structure of the absolute meridional transport, especially the part associated to the North Atlantic Current.

Session: The role of gliders in Ocean Observing Systems

Using ocean gliders to determine the physical controls on fluorescence variability in shelf seas

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Shelf seas are vital to biogeochemical cycles. Despite covering ∼8% of the Earths surface, yet accounting for 30% of the oceanic primary production, shelf seas are an important sink for atmospheric CO2 and form a significant part of the air-sea CO2 flux. Phytoplankton photosynthesis plays a key role in carbon sequestration, thus a thorough understanding of what controls phytoplankton distribution is essential for improving the predictive capabilities of global climate change models.
As part of the Shelf Sea Biogeochemistry Programme, four Slocum gliders were deployed to carry out repeat transects between the shelf break and the central Celtic Sea moorings, resulting in a 9-month near-continuous time series from November 2014 to August 2015. Supporting data will include meteorological data, 1D models to determine the tidal cycle and to test the top-down controls on stratification, and Ocean Microstructure Gliders to measure the fine-scale turbulence within the pycnocline over the same region.
Preliminary results show the initial onset of stratification during March; changes in potential density arise from subtle variations in temperature and salinity, with the relative importance appearing to switch between the two. Despite this stratification, chlorophyll fluorescence remains relatively low until the spring bloom in April. Thermal stratification is most prevalent from June to August 2015 where the top to bottom temperature difference exceeds 7°C, and a pronounced subsurface chlorophyll maximum is fully developed and coincides with the depth of the pycnocline. High bands of fluorescence in the bottom mixed layer are indicative of mixing hotspots, potentially formed by local changes in bathymetry and are hypothesised to be a control on seasonal phytoplankton patchiness. Isolated decreases in the potential energy anomaly could be attributed to meteorological conditions, which act to promote vertical mixing. Prolonged periods of anomalous winds or changes in precipitation may explain the surface freshening seen in late March and over the summer, however this has yet to be tested. Although still in its early stages, initial analyses provide an exciting insight into how physical processes impact phytoplankton variability within shelf sea environments.

Session: Observing biogeochemical processes with autonomous vehicles

Slocum Glider - Flight Mission Control

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Slocum Glider Flight Mission Control
"the techniques of graphic displays of data were just emerging from the flat screen of the cathode ray oscilloscope and liquid crystal devices of the late twentieth century. Now, of course, the controller is literally animated. It can be zoomed to any time or space scale..." Henry Stommel, The SLOCUM Mission, 1989.
Henry Stommel's imagination pushed past the boundaries of then available display technology into a future of control and visualization of fleets of gliders and data infrastructure.
Realizing a portion of that dream, Teledyne Webb Research (TWR) presents the features of the newly released Slocum Flight Mission Control (SFMC) tools. Striving to increase the ease of piloting and management to operate either a single glider to fleets of gliders, this latest web-based application provides remote mobile and tablet ready controls. Data hosting features are also reviewed, including available primary and backup services.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Slocum Gliders - Uses and Applications

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"The projects that I have always like best are the once conceived on the spur of the moment by an inquisitive individual... They are generally the most exciting: they evolve in unexpected ways and reveal new dimensions of the unknown about the ocean... And we always have delighted in being of service to scientists with unusual and new ideas that demand examination... 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.
Henry Stommel's futuristic vision was sparked by the opportunity gliders provided to broaden our understanding of the oceans. Slocum glider users continue to find new and novel applications for the platform and with over 600 systems delivered, the community is certainly making an impact on observational methods.
Teledyne Webb Research (TWR) will highlight some of these applications including hypoxia monitoring, under-ice operations, and storm gliders, along with the use of gliders in larger programs.
Also featured are the educational and international outreach impacts that Slocum gliders and data collected are having. On the Challenger front, Rutgers University RU 29 has completed the last leg of the South Africa to Brazil round-trip excursion, and Silbo is back in the water having left Cape Cod and is presently heading towards Europe. We continue to draw together the International Consortium of Ocean Observing Labs (I-COOL) and are beginning to lay a vision for a Magellan Mission.

Session: The role of gliders in Ocean Observing Systems

Slocum Glider - G3 Evolution

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"I walk into our control room, with its panoply of views of the sea. There are the updated global pictures from the remote sensors on satellites, there the evolving maps of subsurface variables, there the charts that show the positions and status of all our Slocum scientific platforms, and I am satisfied that we are looking at the ocean more intensely and more deeply than anyone anywhere else." Henry Stommel, The SLOCUM Mission, 1989.
Once only a fictional piece that Henry Stommel penned based on a glider that Doug Webb, the pioneering ocean engineer in the story, had envisioned. Slocum gliders have become a critical tool for ocean observation and EGO brings us together to share and review the latest capabilities.
Teledyne Webb Research (TWR) will provide an overview of the upcoming Slocum G3 features including reliability improvements, processor upgrade, larger displacement pumps, hybrid 10 Watt thruster, increased external ballasting points, and available rechargeable batteries.
These enhancements continue to increase vehicle capability, allowing Slocum glider users to push boundaries and meet evolving mission requirements.

Session: New developments in glider and sensor technology

Upwelling and isolation in oxygen-depleted anticyclonic modewater eddies and implications for nitrate cycling

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The physical (temperature, salinity, velocity) and biogeochemical (oxygen, nitrate) structure of an oxygen depleted coherent, baroclinic, anticyclonic mode-water eddy (ACME) is investigated using high-resolution autonomous glider and ship data. A distinct core with a diameter of about 70 km is found in the eddy, extending from about 60 to 200 m depth and. The core is occupied by fresh and cold water with low oxygen and high nitrate concentrations, and bordered by local maxima in buoyancy frequency. Velocity and property gradient sections show vertical layering at the flanks and underneath the eddy characteristic for vertical propagation (to several hundred-meters depth) of near inertial internal waves (NIW) and confirmed by direct current measurements. A narrow region exists at the outer edge of the eddy where NIW can propagate downward. The NIW phase speed and the mean flow are of similar magnitude and critical layer formation is expected to occur. Observations indicate upwelling to occur in at the eddy rim, the region where NIW/mean flow induced mixing occurs close to the euphotic zone/mixed layer. Combining nitrate (NO3-) data with the apparent oxygen utilization (AOU) data reveals AOU:NO3- ratios of 16 which are much higher than in the surrounding waters (8.1). A maximum NO3- deficit of 4 to 6 mol kg-1 is estimated for the low oxygen core of the eddy. Denitrification is an unlikely explanation because nitrite is not observed. We introduce here a scheme where the recycling of NO3-, extracted from the eddy core and replenished into the core via the particle export, may quantitatively be more important.

Session: Observing biogeochemical processes with autonomous vehicles

Project CONVERGE: Gliders map local oceanographic processes and features that influence Adélie penguin foraging ecology

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The Palmer Deep submarine canyon on the Western Antarctic Peninsula provides a conduit for upwelling of relatively warm, nutrient rich waters which enhance local primary production and support a food web productive enough to sustain a large top predator biomass. In an analysis of ten years of satellite-tagged penguins, Oliver et al. (2013) showed that circulation features associated with tidal flows may be a key driver of nearshore predator distributions. It is hypothesized that convergent features act to concentrate primary producers and aggregate schools of krill that influence the behavior of predator species. During the austral summer of 2014-2015, project CONVERGE deployed a multi-platform network to sample the Adélie penguin foraging hotspot associated with Palmer Deep Canyon along the Western Antarctic Peninsula. The focus of CONVERGE was to assess the impact of prey-concentrating ocean circulation dynamics on Adélie penguin foraging behavior. Food web links between phytoplankton and zooplankton abundance and penguin behavior were examined to better understand the within-season variability in Adélie foraging ecology. A coordinated fleet of underwater gliders were used in concert with High Frequency Radar surface current maps to sample the hydrography and phytoplankton distributions associated with convergent and divergent features. Three gliders mapped the along and across canyon variability of the hydrography, chlorophyll fluorescence and acoustic backscatter in the context of the observed surface currents and simultaneous penguin tracks. Specific examples will highlight how the vertical structure of the water column beneath the surface features stack the primary and secondary producers relative to observed penguin foraging behavior. The coupling from the physics through the food web as observed by our multi-platform network gives strong evidence for the critical role that distribution patterns of lower trophic levels have on Adélie foraging.

Session: Gliders in polar oceans: science and technological challenges

The use of gliders in a continuous monitoring of the South Adriatic Sea

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The South Adriatic Sea (SA) is the deepest part of the Adriatic Sea (maximum depth $\sim$ 1,200 m) and it is one of the site of deep water convection in the Mediterranean Sea. The Adriatic Dense Water (AdDW) which is formed in the area exits through the Strait of Otranto and flows into the Eastern Mediterranean basin becoming the main component of the Eastern Mediterranean Deep Water (EMDW). This process makes the SA an important site that OGS continuously monitors through several oceanographic platforms, like drifting and mooring buoys, profiling floats, gliders and oceanographic cruises. Since 2013, OGS have performed four glider campaigns in the area whose main target has been the monitoring of the thermohaline properties evolution in the SA. In addition to high resolution data of temperature and salinity (by conductivity), oxygen concentration, chlorophyll fluorescence, colour dissolved organic matter (CDOM) and backscatter have been acquired. Two salinity maxima at the depths of about 100 m and 600 m, were observed in November 2015 and in April 2016. In the first campaign, the salinity maxima were $\sim$38.95 at the shallower level and $\sim$38.85 at the deeper level, while in the second campaign the maxima were $\sim$38.9 and $\sim$38.82 at the shallower and deeper level, respectively. This double salinity maximum is not a permanent feature of the SA. A similar salinity pattern was observed in 1992, 2004, 2005 and 2006, using CTD profiles from research vessels, even if the maxima were characterized by lower salinity values with respect to the ones observed by gliders. Moreover, the difference between the two maxima was about 0.1 during the glider campaigns, while the vessel CTD measurements revealed a difference of about 0.03. The double salinity maximum pattern observed during the glider missions was confirmed by Argo floats that are sampling the SA area on a regular basis since 2010. The use of gliders combined to other platforms, gives the opportunity to deeply investigate this particular salinity pattern and to speculate on its origin.

Session: The role of gliders in Ocean Observing Systems

The glider simulator SIGLID

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SIGLID is a computational tool (Fortran 95) dedicated to the offline calculation of gliders trajectories in the output velocity field of an Ocean General Circulation Model (OGCM). It simulates the flight of the glider – a saw-tooth trajectory deviated by the OGCM current fields, using dead-reckoning to go through the list of waypoints defined by the pilot – and the tracers sampling along its trajectory. SIGLID has the basic fonctionalities of the on-board software implemented on real gliders. The SIGLID application, which is freely put at the whole scientific community's disposal, is developped with a view to being easy to use, and for the sake of high performance and portability. Various uses of the glider simulator are illustrated:
- Observing System Simulation Experiment (OSSE) to validate methodologies to evaluate and quantify physical characteristics of water masses (e.g. volume of deepwater formed during a convection event in the Gulf of Lion) and/or to assess the capabilities of a glider network to sample oceanic processes.
- Glider steering tool : operational forecast of glider trajectories during missions
- Design of glider network deployments for scientific or/and operational purposes

Session: Sampling strategies for single vehicles and networks

Kuroshio Transport and Waterless Modification in the Vicinity of Luzon Stait

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Two years of continuous surveys conducted by long-endurance, autonomous Seagliders characterize Kuroshio variability at five sections near Luzon Strait. Absolute geostrophic velocities estimated from density sections and depth-average currents measured by gliders at 18° 30 N agree well with velocity profiles collected by a collocated mooring array. Immediately south of Luzon Strait, the Kuroshio exhibits a single core extending to 26.6 kg/m3 (400-600m) with a mean transport of 20pm7 Sv, concentrated in the upper 200 m. North of Luzon Strait, the Kuroshio broadens, with a mean transport of 25pm12 Sv. Although mean sections show a well-defined core, individual sections exhibit great variability associated with impinging eddies. The two-year timeseries of Kuroshio transport estimated from glider-based sections at 18° 30 N, offshore of the northern tip of Luzon, correlates with North Equatorial Current Bifurcation Latitude (NECBL) at r=-0.61 (two month lag, -0.83/-0.23 95% confidence limits). Transport at 22° N, off the east coast of Taiwan, shows no significant correlation due to large, eddy-induced variability in the individual sections, though low-passed transports covary with NECBL. All sections exhibit persistent salinity maxima centered at ∼23.5 kg/m3 (∼200 m) associated with North Pacific Tropical Water (NPTW) and salinity minima at 26.5<<27 kg/m3 (∼600 m) associated with North Pacific Intermediate Water (NPIW). Kuroshio waters north of Luzon Strait show clear freshening/cooling of NPTW, consistent with mixing of South China Sea waters during the passage through Luzon Strait. Likewise, the shallowest NPIW waters (carried at the base of the Kuroshio) become slightly warmer and more saline, also consistent with mixing within the South China Sea. Isopycnals associated with these watermasses show elevated temperature and salinity finestructure, indicative of energetic isopycnal stirring.

Session: The role of gliders in Ocean Observing Systems

Upper Ocean Evolution Across the Beaufort Sea Marginal Ice Zone

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The observed reduction of Arctic summertime sea ice extent and expansion of the marginal ice zone (MIZ) have profound impacts on the balance of processes controlling sea ice evolution, including the introduction of several positive feedback mechanisms that may act to accelerate melting. Examples of such feedbacks include increased upper ocean warming though absorption of solar radiation, elevated internal wave energy and mixing that may entrain heat stored in subsurface watermasses (e.g., the relatively warm Pacific Summer and Atlantic waters), and elevated surface wave energy that acts to deform and fracture sea ice. Spatial and temporal variability in ice properties and open water fraction impact these processes.
To investigate how upper ocean structure varies with changing ice cover, how the balance of processes shift as a function of ice fraction and distance from open water, and how these process impact sea ice evolution, a network of autonomous platforms sampled the atmosphere-ice-ocean system in the Beaufort, beginning in spring, well before the start of melt, and ending with the autumn freeze-up. Four long-endurance autonomous Seagliders occupied sections that extended from open water, through the marginal ice zone, deep into the pack during summer 2014 in the Beaufort Sea. Gliders penetrated up to 200 km into the ice pack, under complete ice cover for up to 10 consecutive days. Sections reveal strong fronts where cold, ice-covered waters meet waters that have been exposed to solar warming, and O(10 km) scale eddies near the ice edge. In the pack, Pacific Summer Water and a deep chlorophyll maximum form distinct layers at roughly 60 m and 80 m, respectively, which become increasingly diffuse as they progress through the MIZ and into open water. The isopynal layer between 1023 and 1024 kgm^{-3}, just above the Pacific Summer Water, consistently thickens near the ice edge, likely due to mixing or energetic vertical exchange associated with strong lateral gradients in this region. This presentation will discuss the upper ocean variability, its relationship to sea ice extent, and evolution over the summer to the start of freeze up.

Session: Gliders in polar oceans: science and technological challenges

Combining glider surveys and vertical profilers for process studies in the stratified estuaries (Gulf of Finland, Baltic Sea).

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The Gulf of Finland is a stratified estuary of the non-tidal Baltic Sea. The mesoscale processes, including coastal upwelling and downwelling events, alter the location and strength of the pycnoclines and create horizontal gradients of buoyancy between the coastal and offshore areas. Development and relaxation of coastal upwelling and downwelling events are associated with sub-mesoscale processes, which have to be accounted when estimating the vertical and lateral exchanges of water properties. We present the data of the two campaigns from summer 2015 and spring 2016 when a cross-shore section was repeatedly mapped by an underwater glider in the vicinity of fixed profilers. Such combination of autonomous measurements together with research vessel based sampling has allowed us to detect intra-thermocline sub-mesoscale features, their scales and other properties. Variability at the meso- and sub-mesoscale is analyzed in relation to the varying wind forcing and in connection with the development of the seasonal thermocline in the coastal slope area. We show that the glider surveys provide valuable data better to understand the physical and biogeochemical processes in the pycnoclines.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Quantifying spatial and temporal scales of phytoplankton variability in the Subantarctic Ocean using high-resolution glider data

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Phytoplankton in the Subantarctic Southern Ocean have a distinct seasonal cycle, which is highly variable in both space and time. The seasonal and spatial distribution of chlorophyll-a can be attributed to the complex nature of the physical and biogeochemical factors controlling phytoplankton production. In this study, high-resolution glider data sampled in the Atlantic Subantarctic Zone is used to characterise the scales of phytoplankton variability. Continuous glider data provides a novel way to assess phytoplankton variability at small time and space scales (submeso- to mesoscale), especially in an area that has a lack of continuous measurements, that are necessary for addressing climate related questions. Temporal variability of phytoplankton was investigated using Empirical Mode Decomposition of surface chlorophyll-a concentrations collected from a Seaglider over a period of 5.5 months (25 September 2012 to 15 February 2013). This study found that during spring, chlorophyll-a concentrations oscillate daily around the rising seasonal ramp due to increased light availability when the upper ocean stratifies through seasonal increase in heat flux. The phytoplankton blooms that form in spring do not occur at set temporal frequencies but are rather temporally sporadic. In summer phytoplankton blooms were found to occur at submeso- and mesoscales and modulated by synoptic time scales (4 to 9 days). This variability was found to be driven by storms varying the strength of the wind stress and consequently the mixed layer depth (that alters the nutrient and light environment). Spatial variability was investigated using daily MODIS ocean colour and sea surface temperature data. Spatial variability was characterised by the spatial variance calculated at different length scale. Spatial analysis found that compared to sea surface temperature, phytoplankton were patchier in both spring and summer at both large (266 km) and small (4 km) length scales, though there was greater variance phytoplankton in summer due to greater growth. Further spatial analysis compared satellite spatial variance with glider measurements at the same length scale (70km). This study found that a third of the variability found by the glider was caused by spatial patchiness, while the reminder could be contributed to local growth. These dominant submeso- and mesoscale changes in chlorophyll-a at both temporal and spatial scales, highlights the need to sample phytoplankton at high spatial and temporal frequencies ($<$10 days) in order to accurately reflect phytoplankton seasonal variability and ultimately understand the impact of phytoplankton variability on carbon flux.

Session: Gliders in polar oceans: science and technological challenges

C2 - A command and control Infrastructure for Unmanned Fleets of Vehicles for the UK Community

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Currently, most MAS platforms use their own proprietary control system and are operated by experienced pilots. This makes managing mixed marine autonomous systems fleets extremely complex, time-consuming and expensive, especially during 24/7 operations extending over several weeks. In addition, proprietary control systems are unable to effectively access external data sources (e.g. satellite data, ocean circulation models, predictive tidal models), which would aid efficacious piloting and autonomous sampling. This work presents the design for a National Infrastructure to enhance the data gathering of MAS platforms, improve the piloting and automate the control of them.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Characterization of convective plumes associated with oceanic deep convection from autonomous gliders

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Numerous gliders have been deployed in the Gulf of Lions (Northwestern Mediterranean Sea) and in particular during episodes of open-ocean deep convection in the winter 2012-2013. The data collected represents an unprecedented density of in-situ observations that are analysed in this study to provide a first in situ statistical and 3D characterization of the important mixing agents of the deep convection phenomenon, the so-called plumes. A methodology based on a glider quasi-static flight model was applied to infer the oceanic vertical velocity signal from the glider navigation data. We demonstrate thatduring the active phase of mixing, the gliders underwent significant oceanic vertical velocities (upward and downward, up to 18cm s^{-1}). The gliders move along saw-tooth trajectories between the surface and a maximum depth of 1000m, covering a distance of 2-4km over a period of 2-4 h between two surfacings. They crossed several small scale convective downward plumes with a mean radius of about 400m and distant from each other by about 2km on average, and we estimate that on average the plumes cover 18 % of the convection area. Gliders detected downward velocities with a magnitude twice as big as that of the upward ones on average (-0.061m s^{-1} versus +0.025m s^{-1} on average). Recordings of temperature and salinity as well as biogeochemical properties (dissolved oxygen, fluorescence, turbidity) along tracks alows a characterisation of the water masses properties characterizing the cores of the plumes with respect to the background: the downward signal is of saltier (+0.001psu), colder (-0.005°C) and thus denser waters (0.0015kg.m-3).The plunging waters are also slightly richer in oxygen and less fluorescent but no mean correlation is detected from the turbidity signals despite individual signals in plumes going both directions which compensate on the average.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Assessing the abrupt changes of LIW properties observed in the North-western Mediterranean basin.

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In the past 10 years, numerous observation programs in the Mediterranean considerably increased the number of in-situ observations and the data coverage. The glider dataset enables a quasi continuous monitoring of the Western Mediterranean Sea. In this study, we analyse time series built with profile data on interannual scales. Sorting data in regional boxes, we follow the evolution of LIW waters in the basin. In 2014, a rapid change is observed propagating from the Ligurian Sea to the Ibiza channel along the general cyclonic circulation in the absence of intense deep convection events. We then assess the role of deep convection events in these changes with the Nemo-Med12 model.

Session: The role of gliders in Ocean Observing Systems

Trials and Tribulations of operating Slocum Gliders and Seagliders in the highly dynamic waters in the Northern Gulf of Mexico,

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The Gulf of Mexico has a highly diverse physical environment, from the loop current to the influences of the Mississippi River, which have influential affects to many stakeholders from coastal communities to the offshore oil and gas industry. Understanding this physical environment is essential to the health and safety of people working offshore and communities that rely on the gulf for their livelihood. Events such as hurricanes and tropical storms are also influenced by the physical environment and can impact the Gulf residents and businesses. The diverse environment drives scientists to monitor how these features change and interact over time, making gliders the ideal tool for real-time in-situ observations. However, challenges exist for current technology to conquer some of these areas.
The Gulf of Mexico circulation is dominated by the loop current and loop current eddies, which can reach speeds in excess of 3 knots. In the northern Gulf there is substantial freshwater inflow from the Mississippi-Atchafalya River system (the largest freshwater discharge in North America), the rivers emptying into Mobile Bay (the third largest freshwater discharge in the contiguous U.S.), and many smaller rivers. This creates strong density fronts that can develop, sometimes faster than a glider can be navigated away. In addition, the loop current or loop current eddies can propagate north to influence the development of the fresh water plumes. Strong vertical density changes of more than 10 sigma units in less than 5 meters of water, well beyond standard glider buoyancy limits, can be found on the shelf. This combination of strong density fronts and vigorous eddy fields provide significant challenges for operation of buoyancy gliders in the northern Gulf of Mexico. In addition to these physical features, oil rigs, ship traffic, and shrimp trawlers present additional challenges to deployment and piloting.
Despite the diverse environment of the north central Gulf of Mexico, glider research projects in the region have pushed the limits of accepted operating limits and lead to various learning experiences along the way. These experiences using Slocum gliders and Seagliders in this challenging river-dominated environment will be presented along with many solutions and operational adaptations that were used to overcome some of those challenges.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Measuring seawater pCO2 with a Slocum glider

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Obtaining pCO2 profiles with gliders has been difficult given the large energy consumption and size of most commercially-available CO2 sensors. Recently a compact, low-power CO2 optode suitable for use with gliders has been released by Aanderaa. We present the results of a field test of a Slocum glider fitted with this sensor in a deep bay off Newfoundland. While the CO2 optode is found to possess an equilibration time that is too slow for continuous profiling (at around 5 minutes), we demonstrate how this can be overcome using a novel stairstep profiling method of flying gliders. This involves stepping up (down) in a series of hovers with climbs (dives) in between. We find that use of a thruster on the hovers improves depth maintenance over simply drifting. We envisage that carbon gliders using this stairstep profiling method could become a key part of the global CO2 observing system.

Session: New developments in glider and sensor technology

Glider observations and modeling of sediment transport in Hurricane Sandy

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Regional sediment resuspension and transport are examined as Hurricane Sandy made landfall on the Mid-Atlantic Bight (MAB) in October 2012. A Teledyne-Webb Slocum glider, equipped with a Nortek Aquadopp current profiler, was deployed on the continental shelf ahead of the storm, and is used to validate sediment transport routines coupled to the Regional Ocean Modeling System (ROMS). The glider was deployed on 25 October, 5 days before Sandy made landfall in southern New Jersey (NJ) and flew along the 40 m isobath south of the Hudson Shelf Valley. We used optical and acoustic backscatter to compare with two modeled size classes along the glider track, 0.1 and 0.4 mm sand, respectively. Observations and modeling revealed full water column resuspension for both size classes for over 24 h during peak waves and currents, with transport oriented along-shelf toward the southwest. Regional model predictions showed over 3 cm of sediment eroded on the northern portion of the NJ shelf where waves and currents were the highest. As the storm passed and winds reversed from onshore to offshore on the southern portion of the domain waves and subsequently orbital velocities necessary for resuspension were reduced leading to over 3 cm of deposition across the entire shelf, just north of Delaware Bay. This study highlights the utility of gliders as a new asset in support of the development and verification of regional sediment resuspension and transport models, particularly during large tropical and extratropical cyclones when in situ data sets are not readily available.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Large Eddy Simulations of flow around underwater gliders and the impact of flow distortion on sensor measurements

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Large Eddy Simulation (LES) modelling is used to study the flow around underwater gliders. The simulations are used to investigate the extent to which measurements of sensors, including turbulence sensors, are affected by flow distortion around the vehicle body, and the hydrodynamic forces on gliders. Two example simulations have been conducted. In both cases the flow around a Slocum Mk II glider is simulated and the second example includes a MicroRider turbulence package mounted on top of the glider.
Our preliminary results suggest that the usual position of the oxygen sensor on a Slocum glider may be within a separated wake and this could significantly affect the data quality. Flow distortion at the location of the shear probes on the turbulence package is low but could result in a small underestimation of the magnitude of dissipation. Lift and drag forces diagnosed from the simulations were consistent with data from gliders but a more detailed study is needed to assess the quantitative accuracy of these results.

Session: New developments in glider and sensor technology

Navigating New Zealand's Shelf Seas with underwater gliders

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Underwater gliders have revolutionised the way ocean observations are made, particularly in the undersampled Shelf Seas around the world. New Zealands first ocean glider was delivered in 2015, with a second glider arriving in January 2016. The NZ glider facility is very much in its infancy. In the future, subsurface hydrography from regular glider transects will form an essential component of the New Zealand ocean observing system (NZ-OOS). A regular transect has been established in the Taranaki/Cook Strait Shelf Sea region. Tidal currents in this region are some of the strongest in the world and glider navigation in 4 knots of current proved challenging during the first NZ mission. Extending glider deployments to acoustically map mammal distribution was undertaken in March 2016 due to the likely presence of a blue whale foraging ground. This poster will cover aspects of glider operations as well as preliminary analysis of shelf sea biophysics in 2015/16.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Establishing a monitoring Glider program for the investigation of water-mass dynamics in the South-Eastern Mediterranean

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The south-eastern Levantine basin encompasses a variety of mesoscale and submesosclae phenomena such as the north bound jet stream along the eastern continental shelf break, the quasi-permanent Shikmona eddy, coastal water filaments penetrating to deep waters and more. The Generation of the Shikmona eddy, from the meandering jet stream, was recently observed in the summer of 2009 (Gertman et al., 2010) and accentuated the temporal and spatial variability of these structures. Moreover, current studies have shown the thermohaline (and nutrient) dynamics of the region to be multifaceted and interrelated with the Southern Adriatic and North Ionian Seas. Data from Haifa Section Cruises (2002-2014) presented decadal variations in temperature and salinity in the Levantine Intermediate Water mass core which were generally in opposite phase with nutrient levels and integrated chlorophyll variations (Ozer et al. 2016). However the available cruises data allow analysis of variations on inter-annual time scale only and is not sufficient to resolve synoptical, short-term processes which take place in shallower water masses (Levantine Surface Water and Modified Atlantic Water). Under a joint Glider project, the first of its kind in Israeli waters, we have obtained 3 Sea-Explorer gliders of ALSEAMAR with a variety of sensors. This new addition of observational capabilities enables high frequency gliders monitoring program with the aims of investigating meso and submesoscale coherent structures development on the Israeli shelf and the enhancement of observations along the historic Haifa Section.

Session: The role of gliders in Ocean Observing Systems

Understanding turbulent controls on the ocean surface boundary layer with the Ocean Microstructure Glider

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Microstructure measurements made using a buoyancy driven ocean glider are used to investigate the dependency of the turbulence dissipation rate () in the ocean surface boundary layer (OSBL) turbulence on wind, wave and buoyancy forcing on the summer stratified continental shelf. Data from a number of deployments is used to examine OSBL turbulence in non-dimensional space. We observe that the vast majority of OSBL sits within a well developed sea, when wind and wave forcing is in near equilibrium, typified by a turbulent Langmuir number Lat∼0.3. During these periods turbulence is well described by scaling the surface friction velocity (u*3) and the active mixing layer depth, or turbocline (h) and decays exponentially with depth following law-of-the-wall. During wave dominated periods (Lat<0.3) turbulence follows characteristic better described by Stokes drift (uS3) and displays evidence of more efficient transport of turbulence over h, suggesting that Langmuir circulation could play an important role. Using identified scaling arguments we use a simple model to predict the onset of seasonal stratification and compare with observational results.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Korea Underwater Glider Operation Network (KUGON) Project

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The government-funded project named as Korea Underwater Glider Operation Network (KUGON), is to establish integrated glider operation system such as risk management system, glider navigation system, and infrastructures in order to run multiple gliders around Korean Peninsula. Since ship-glider collision, fishing activity, and background ocean current are major concerns to jeopardize glider operations, it is necessary to quantify operational risk and to mitigate the risk by adjusting glider mission parameters. Also, adjustment of glider flight parameters including specific navigation systems could make gliders maintain their planned tracks better, which helps multiple glider operations as well. The navigation systems such as environment-optimized dead-reckoning, DVL-based navigation and RAFOS-based navigation system will be developed in future. In the long run, this project would contribute to supporting coastal shipboard observations on a regular basis being performed by government organizations. In this workshop, the overall KUGON project as a Korean Underwater Glider program will be introduced as well as the results obtained from the first scientific trial of underwater glider operation near Ulleungdo and Dokdo from June 24 to July 15, 2016 will be presented

Session: Glider operations: piloting, infrastructure, data management and legal issues

Kongsberg Seaglider - System Updates and Future Capabilities

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A brief presentation of the Seaglider vehicle updates that have been implemented over the last couple years, including:
- Reliability improvements
- New sensors & functionality
- Available system upgrades
- Planned system improvements

Session: New developments in glider and sensor technology

Glider observations of enhanced deep water upwelling at a shelf break canyon

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Using a pair of underwater gliders, one on the slope and one on the shelf we have identified canyon driven upwelling across the Celtic Sea shelf-break, in the vicinity of Whittard Canyon. The presence of this upwelling appears to be tied to the direction and strength of the local slope current, which is in itself seasonally variable. During typical summer time equatorward flow, an unbalanced pressure gradient force and the resulting breakdown of Taylor-Proudman theorem leads to upwelling along the main axis of two small shelf break canyons. As the slope current reverts to its winter time poleward flow, the upwelling stops and the remnants of the upwelled features are mixed into the local shelf or advected away from the region. The upwelled features are identified by the presence of sub-pycnocline high salinity water on the shelf, and are upwelled from a depth of 300 m on the slope, thus providing a mechanism for the transport of nutrients across the shelf break onto the shelf. The presence of this process over the winter promotes cross-shelf exchange during the season when internal wave driven dynamics, which are primarily thought responsible for exchange in this region, are absent or reduced.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Eddy-mediated habitat compression through changes in the oxycline in the north west Arabian Sea

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Three autonomous underwater gliders were deployed along an 80 km transect extending from Muscat out into the Gulf of Oman during both monsoons and the intermonsoon season as part of a project funded by ONR Global and the UK NERC. The gliders surveyed the top 1000m across the continental shelf, a very steep continental slope, and the open ocean while measuring temperature, salinity, oxygen, chlorophyll a fluorescence, optical backscatter and provided estimates of depth-averaged currents and up/downwelling.
Using a 2km resolution ROMS model of the region and the glider observations, we highlight key regions of Persian Gulf Water (PGW) outflow and describe both the variability of the Gulf of Oman oxygen minimum zone and its importance in defining available habitat space for ecologically and commercially important species. The structure and volume of the outflow was highly variable. During peak outflow, the core extended beyond the glider transects. During periods of minimal flow, it was constrained to 10km beyond the shelf break. PGW was also present in mesoscale eddies beyond the shelf break.
The data show high vertical variability of the boundary to the suboxic zone (< 6 umol.kg-1). Pulses of PGW drive the oxycline down intermittently from 200m to 400m and exhibit oxygen concentrations of around 60-100 umol.kg-1. Further below, observations show a persistent and extensive anoxic zone with concentrations below the detection limit of our sensors down to 900m. The physical drivers of PGW transport therefore double, or reduce by half, the available habitat for macrofauna. Larger predatory fish (ie. tuna) require elevated oxygen concentrations. PGW therefore create a mid-water refugium for the dominant prey species (Myctophid spp.) and other smaller, hypoxia-resilient, organisms.

Session: Observing biogeochemical processes with autonomous vehicles

Long-Term Observations of Upper Ocean Turbulence and of its Impacts on Upper Ocean Variability during the SPURS Campaigns

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Observations collected during the Salinity Processes Upper-ocean Regional Study (SPURS) field campaign in the subtropical Atlantic Ocean are used to identify and quantify the processes responsible for the deepening of the surface mixed layer in winter, and its restratification in spring and summer. An array of autonomous Seagliders, surface drifters, and Argo floats complemented heavily instrumented moorings, allowing us to assess the importance of lateral gradients in the time evolution of the mixed layer and upper 1000 m of the ocean.
Long-term observations of oceanic turbulence are sparse, but essential to understand the processes driving the mixing. Microstructure temperature and shear sensors have been fully integrated onto Seaglider to provide direct estimates of rates turbulent of dissipation in the upper ocean during multi-month deployments. The direct turbulence estimates are used to constraint the evolution of mixed layer properties, and evaluate the impact of mixing due to internal waves and lateral intrusions at the base of the mixed layer.
We also present an overview of the ongoing SPURS-2 campaign in the eastern equatorial Pacific. Together with the mooring and other autonomous components, Seagliders will allow us to resolve the salt storage and its horizontal and vertical advection, and quantify diapycnal mixing of salt by small-scale turbulence around a central air-sea flux mooring. The SPURS-2 campaign provides a direct view of the processes by which the ocean spreads and integrates freshwater from precipitation.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Sustained Measurements of Monsoon-driven Circulation and Watermass Variability in the Northern Indian Ocean

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Monsoon-driven circulation in the Bay of Bengal and Arabian Sea plays a critical role in governing heat and freshwater transport in the northern Indian Ocean. Net evaporation and inflow of high-salinity water masses from the Red Sea and Persian Gulf produce an annual net salt surplus in the Arabian Sea, while large riverine discharge and excess precipitation produce an annual net freshwater surplus in the Bay of Bengal. Seasonal exchanges between the two basins, around the southern tip of the Indian subcontinent, act to maintain the salinity balance in the northern Indian Ocean. A series of autonomous glider and surface drifter deployments have captured watermass variability and circulation in the region around Sri Lanka and along a long, meridional section spanning the Arabian Sea. Observations near Sri Lanka span multiple years (2013 to present) and cover a complete annual cycle, including during the monsoon transitions, while occupation of the Arabian Sea section began in spring, 2016. Both operations are ongoing. Persistent sampling by long-endurance Seagliders characterize surface and sub-surface transport of freshwater out of the Bay of Bengal, and of high-salinity Arabian Sea water into the Bay of Bengal, in the context of monsoon circulation. These direct measurements provide an unprecedented view into the circulation across this important gateway, and allow us to estimate volume, heat, and freshwater transports of the water masses that set the upper ocean properties.

Session: The role of gliders in Ocean Observing Systems

γ-planner : A robust and efficient tool for designing optimal geometrically-based oceanographic missions using fleets of underwater gliders and buoys

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This study describes the γ-planner, a novel planner which can provide optimal sampling mission design to support underwater autonomous vehicles in combination with other observation instruments such as buoys. One of the main targets of marine scientists when designing a sampling mission is how well their measurement systems can cover the area of interest. Most of the time when aiming for coverage of an area the planned mission does not take into account currents due to either highly inaccurate or poorly predicted currents. The introduction of γ-planner addresses the optimization of area coverage by providing sampling strategies of observation networks for exploratory missions where currents are not taken into consideration. A novel optimal geometric criterion is introduced based on the location of the sampling locations and non-sampling locations of the required area of interest. This planning tool has been implemented in MATLAB where a graphical user interface is provided such that the tool can be usable to a wider audience and not just marine scientists specialized in mission planning.

The γ-planner is used to optimize two actual exploratory missions that took place in 2014(butterfly) and 2016(Crete). In both cases the results are encouraging with the near optimal missions providing a coverage increase of approximately 15% and 11% respectively. The γ-planner is currently used at the Oceanography Center and University of Cyprus in order to investigate potential cost savings (data transmission or battery energy) in relation to potential coverage improvements (depending on the constraint for a particular mission). It is also possible to incorporate other platforms, such as fixed point moorings, into the calculation. Future improvements will also take into account currents so that γ-planner is not only used in exploratory missions.

Session: Sampling strategies for single vehicles and networks

The California Underwater Glider Network

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The overarching goal of the California Underwater Glider Network (CUGN) is to sustain baseline observations of climate variability off the coast of California. The CUGN uses Spray underwater gliders making repeated dives from the surface to 500 m and back, repeating the cycle every 3 hours, and traveling 3 km in the horizontal during that time. The CUGN includes gliders on three of the traditional cross-shore CalCOFI lines: line 66.7 off Monterey Bay, line 80 off Point Conception, and line 90 off Dana Point. The glider missions typically last about 100 days, and cover over 2000 km, thus providing 4-6 sections on lines extending 300-500 km offshore. Since 2005 the CUGN has covered 200,000 km in over 10,000 glider-days, while doing 93,000 dives. The last two years have been unusually warm in the California Current System, starting with the warm anomaly of 2014-2015, and continuing through the El Nio of 2015-2016. The causes of the warming are studied using a climatology of glider data . In particular, the effects of atmospheric forcing and oceanic advection are addressed.

Session: The role of gliders in Ocean Observing Systems

Observational and numerical evidence for ocean frontogenesis inducing submesoscale processes and impacting biochemistry

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We present the results of ALBOREX, a multi-platform and multi-disciplinary experiment completed in May 2014 as a part of PERSEUS EU funded project. This unique process-oriented experiment in the eastern Alboran Sea (Western Mediterranean) examined mesoscale and submesoscale dynamics at an intense front. The field campaign, conducted during 8 days, included 25 drifters, 2 gliders, 3 Argo floats and one ship (66 CTDs and 500 biochemical samples). The drifters followed coherently an anticyclonic gyre. ADCP data showed consistent patterns with currents up to 1 m/s in the southern part of the domain and Rossby numbers up to 1.5 suggesting significant ageostrophic motion.
We show observational evidence for mesoscale frontogenesis produced by the confluence of (fresh) Atlantic Water and the resident (more saline) Mediterranean Water. This confluence resulted in lateral density gradients of the order of 1 kg/m3 in 10 km and associated vertical velocities of about $pm20$ m/day, diagnosed using the QG Omega equation. However, the vertical velocity is likely underestimated due to unresolved submesoscale processes (<10 km), which are induced by intense mesoscale frontogenesis. In order to assess the role of these submesoscale processes in the frontal vertical transport, a high-resolution Process Ocean Model Study is initialized with hydrographic data (0.5-1 km resolution) from underwater gliders. Numerical results show that observed lateral buoyancy gradients are large enough to trigger submesoscale mixed layer instabilities. The coupling between mesoscale and submesoscale phenomena can explain remarkable subduction events of chlorophyll and oxygen captured by ocean gliders, as well as local increases of primary production.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Seagliders capture manifestation of the North Atlantic spring bloom

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The emergence of pronounced spring blooms in the North Atlantic Ocean has important consequences for the ocean carbon uptake and marine ecosystem functioning. The mechanisms that trigger spring blooms have been studied for decades, but still remain uncertain in part due to the lack of data on phytoplankton distribution across winter and spring. In this regard, autonomous underwater gliders represent a powerful platform for studying the spring bloom phenomenon due to their ability to provide a high-resolution, vertically-resolved sampling of the upper ocean over inter-seasonal timescales irrespective of light and weather conditions. To analyse a process of spring bloom manifestation, we invoke a unique year-long glider data set collected in the Northeast Atlantic Ocean. Mechanisms controlling the bloom onset were studied in light of the main competing theories: the critical depth, the critical turbulence, and the dilution-recoupling hypotheses. The bloom onset was consistent with the critical depth hypothesis, if the decoupling between the actively mixing layer and the mixed layer is considered. However, the observed bloom developed slowly and was relatively low in magnitude. Our analysis suggests that meteorological conditions during a winter to spring transition have profound impact on spring blooms development. The frequent passage of storms and periods of convective mixing can significantly decrease mean growth rate for phytoplankton populations affecting the intensity of incipient spring blooms.

Session: Observing biogeochemical processes with autonomous vehicles

Addressing observation continuum between satellite and glider measurements of Chlorophyll a

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Extensive mapping of phytoplankton distribution in upper ocean layer is highly important for accurate assessment of ocean primary production and its contribution to the global carbon cycle. Ocean colour remote sensing provides daily snapshots of Chl a distribution over the global ocean. However, satellite data observations are limited to ocean surface. Autonomous platforms, such as gliders and Bio-Argo floats, are capable of extending satellite ocean colour data to the ocean interior because of their ability to obtain depth-resolved profiles of Chl a fluorescence regardless of external conditions. Satellite and in situ Chl a fluorescence data sets complement one another and if used simultaneously provide a comprehensive picture of phytoplankton distribution in the ocean. However, discontinuity in measuring techniques and calibrations procedures hampers coherent usage of both data sets in observational and modelling studies of phytoplankton variability.
Observation continuum between satellites and autonomous platforms was addressed in the framework of ENVRIplus Horizon 2020 project. ENVRIplus is a European consortium aiming to create a coherent interdisciplinary cluster for future cross-domain environmental studies. Methods of homogenising satellite ocean colour and glider Chl a fluorescence data sets are presented. The methods were validated for the open Northeast Atlantic Ocean, Continental Shelf Seas, and the Mediterranean Sea. Results of the validation aim to assess robustness of the homogenising methods in diverse biological regimes and their applicability in studies of oceanic primary production.

Session: Observing biogeochemical processes with autonomous vehicles

Occurrence and characteristics of mesoscale eddies in the tropical northeast Atlantic Ocean

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Coherent mesoscale features (referred to here as eddies) in the tropical northeastern Atlantic Ocean (between 12-22° N and 15-26° W) are examined and characterized. The eddies surface signatures are investigated using 19 years of satellite-derived sea level anomaly (SLA) data. Two automated detection methods are applied, the geometrical method based on closed streamlines around eddy cores, and the Okubo-Weiss method based on the relation between vorticity and strain. Both methods give similar results. Mean eddy surface signatures of SLA, sea surface temperature (SST) and sea surface salinity (SSS) anomalies are obtained from composites of all snapshots around identified eddy cores. Anticyclones/cyclones are identified by an elevation/depression of SLA and enhanced/reduced SST and SSS in their cores. However, about 20% of all anticyclonically rotating eddies show reduced SST and reduced SSS instead. These kind of eddies are classified as anticyclonic mode-water eddies (ACMEs). About 146 *pm* 4 eddies per year with a minimum lifetime of 7 days are identified (52% cyclones, 39% anticyclones, 9% ACMEs) with rather similar mean radii of about 56*pm*12 km. Based on concurrent in situ temperature and salinity profiles (from Glider, Argo float, shipboard, and mooring data) taken inside of eddies, distinct mean vertical structures of the three eddy types are determined. Most eddies are generated preferentially in boreal summer and along the West African coast at three distinct coastal headland regions and carry South Atlantic Central Water supplied by the northward flow within the Mauretanian coastal current system. Westward eddy propagation (on average about 3.00 *pm* 2.15 km d^{-1}) is confined to distinct zonal corridors with a small meridional deflection dependent on the eddy type (anticyclones equatorward, cyclones poleward, ACMEs no deflection). Heat and salt fluxes out of the coastal region and across the Cape Verde Frontal Zone, which separates the shadow zone from the ventilated subtropical gyre, are calculated.

Session: The role of gliders in Ocean Observing Systems

Tidal and frontal flows in the Fair Isle Current observed using a Seaglider

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The JONSIS line is a 127 km-long hydrographic section in the northern North Sea at 59.28°N that runs from the eastern coast of Orkney (2.23°W) to the central North Sea (0°). The line crosses the path of the main western inflows of Atlantic water. Ten Seaglider occupations were completed between October and December 2013. Data from 1525 dives was recovered. The maximum depth along the line was 140 m, and the majority of dives were to the seabed. The average length of dives was 28 minutes. A strong front is identified in both temperature and salinity distributions. Geostrophic shear is referenced to the glider dive-average current velocity to derive a time series of volume transport associated with the front. Maximum dive-average current speeds were approximately 70 cm/s. A southward barotropic component of the flow is responsible for approximately five times the transport of the depth-varying geostrophic velocity assuming a level-of-no-motion at the sea bed. The addition of the glider-derived barotropic current permits a more accurate estimate of the transport than is possible from long-term hydrographic monitoring, and enables better separation of barotropic and depth-varying components. Tidal ellipses are derived at four points along the section and are compared to current measurements from moored current meters and from a surface-observing high-frequency radar system. All observations were collected as part of the Brahan project, a multi-platform current monitoring study in the north-western North Sea. Calculated tidal currents are used to assess the extent to which the fronts location follows contours of Simpson and Hunters (1974, Nature, volume 250) stratification parameter. The results refine our understanding of where fronts are likely to form in the northern North Sea and of their contribution to shelf sea circulation. An accurate description of Atlantic inflow is crucial for understanding the ecosystem of the northern North Sea, and for modelling contaminant pathways and water quality. We discuss the value that a glider could bring to the ongoing JONSIS ocean monitoring campaign.

Session: The role of gliders in Ocean Observing Systems

A role for gliders in sustained observations on the eastern boundary of the subtropical Atlantic

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The RAPID programme measures the Atlantic Meridional Overturning Circulation (AMOC) in the sub tropical Atlantic using an array of moored instruments. To measure the AMOC accurately it necessary to have measurements close to the boundary so that the signal of the AMOC is not masked by eddy variability. During the last 12 years the RAPID program has made measurements using an array of moored instruments that extend west from the Moroccan shelf and south of the Canaries. This is an area where seasonal upwelling occurs resulting in variable boundary flows and important impacts on the shelf waters. We have made trials using autonomous underwater gliders as a replacement for one or more of the RAPID moorings. Six glider deployments have been made concurrent with mooring deployments. In this presentation data from the moorings and from the gliders are compared, different glider sampling strategies are considered, and the advantages and disadvantages of gliders are discussed.

Session: The role of gliders in Ocean Observing Systems

Tidewater Glacier Measurements from Gliders: Results from the Fjord Ecosystem Experiment on the West Antarctica Peninsula

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Fjords with tidewater glaciers (glacio-marine fjords) occur widely at temperate to polar latitudes, and extensively along the sub-polar Western Antarctic Peninsula (WAP). Glacio-marine fjord ecosystems can be heavily modulated by glacial ice, meltwater and terrigenous sediments, causing ecosystem structure and function to differ from the open continental shelf and to be highly sensitive to climate warming. Arctic Fjord ecosystems have been extensively studied and are strongly influenced by meltwater processes, high turbidity, and burial disturbance, yielding "cold spots" of productivity and biodiversity. Climate warming and glacial retreat in the Arctic is predicted to reduce glacial disturbance of many Arctic fjords, enhancing fjord productivity and biodiversity. In contrast, fjord ecosystem structure and function remain very poorly studied along the WAP, and several lines of evidence suggest that WAP fjords are intense hotspots of pelagic and benthic productivity and biodiversity, providing critical habitat for keystone species including krill and their predators. The high productivity/biodiversity in WAP fjords could be facilitated by existing conditions of weak meltwater and terrigenous-sediment inputs, which appear likely to change with climate warming. In December 2015 and April 2016, a Teledyne Webb Slocum glider was utilized to investigate meltwater and sediment inputs to Andvord Bay, a sub-polar glacio-marine fjord on the WAP. The glider completed several transects near glacier termini, over sills and in the channel entrance. Glacial subsurface plumes were observed near glacier termini, which corresponded to significant increases in backscatter. Our deployments were significantly affected by the presence of large tabular icebergs in the fjord, one of which trapped a glider underwater for over 24 hours. This presentation will focus on the applicability and utility of gliders in seasonally ice covered waters and the need for more advanced under ice navigation and avoidance features.

Session: Gliders in polar oceans: science and technological challenges

Glider observation in the Bussol Strait

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Vigorous vertical mixing in the Kuril Straits is an important physical process for water-mass formation, ocean circulation, biogeochemical processes, and climate in the North Pacific. The spatiotemporal variability of vertical mixing is closely linked to the dynamics of internal tide generated within the Straits. In Jun. 2014, we deployed a slocum glider equipped with a turbulence package and CTD (Conductivity-Temperature-Depth) sensor down to 1000m depth in the vicinity of the Bussol Strait which is the deepest and widest strait in the Kuril Straits, and the largest outflow occurs from the Okhotsk Sea to the North Pacific. Harmonic analysis within a 3-day moving window shows that the semi-diurnal amplitude is enhanced in the upper few hundred meters, while the diurnal amplitude is enhanced in the deeper layer around 700 m depth. This difference is presumably due to the fact that the semi-diurnal frequency is super-inertial at this latitude, and thus the generated internal tide can freely propagate in the interior ocean, while the diurnal frequency is sub-inertial, and the internal tide can only propagate as the topographically trapped waves. We will discuss the linkage between the internal wave dynamics and vertical mixing.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Global Ocean Biogeochemistry Observing System based on Essential Ocean Variables - Focus on Gliders

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The complexity of the marine carbon cycle and its numerous connections to carbons atmospheric and terrestrial pathways mean that a wide range of approaches have to be used in order to establish its qualitative and quantitative role in the global climate system. In addition, an inter-correlation with carbon-related biogeochemical and non-biogeochemical parameters requires a coordinated, comprehensive biogeochemistry observing system that is fit-for-purpose, sustainable in long term and globally feasible.

The International Ocean Carbon Coordination Project (IOCCP) was created in 2005 by the IOC of UNESCO and the Scientific Committee on Oceanic Research. IOCCP provides program-independent, global technical coordination for ocean carbon and biogeochemistry observations and integration with global carbon cycle science programs. The major focus of our work is the development of a global network of ocean carbon and biogeochemistry observations, development of globally acceptable strategies and technical coordination developing methodologies and practices and standards to facilitate the compatibility and comparability of results from individual efforts and development of the ocean carbon and biogeochemistry data products that can be integrated with the terrestrial, atmospheric and human dimensions components of the global carbon cycle.

Over the past 4-5 years IOCCPs long standing experience in coordinating biogeochemical observations and data flows globally, resulted in assuming a leadership role during the design and implementation of the biogeochemistry portion of the Global Ocean Observing System Framework for Ocean Observing (FOO, 2012). Based on current ocean observing requirements, representing the needs of societal and scientific stakeholders, and to optimize and enhance the global ocean observing system, the community developed a set of Essential Ocean Variables (EOVs) each accompanied by a very specific technical description of phenomena to capture, temporal and spatial scales of needed observations, current and future observing platforms and sensor technologies and existing and lacking data flow elements.

Each of the 8 EOV Specification Sheets (available from http://www.ioccp.org/index.php/foo) has many gaps that, as a community, we hope to fill over the coming months and years. Many of these gaps could be filled by the development of coordinated global gliders observing network utilizing the advantages that gliders have over other observing networks such as surface and subsurface ship observations, surface and subsurface moorings, floats, drifters and satellites.

We would like to update the gliders community across disciplines on our efforts and present a short- and long-term strategies for the future. The IOCCP works directly with several formal bodies programmatically connected to GOOS as well as the WMO-IOC JCOMM to integrate ocean carbon and biogeochemistry observation information into the Implementation Plan of the Global Climate Observing System in support of the United Nations Framework Convention on Climate Change, the World Summit on Sustainable Development, the Group on Earth Observations, and other international and intergovernmental strategies. In our opinion, a direct communication and coordination with communities focused on platform types is necessary to fully connect the opportunities arising on the decision and policy-making arena with the technical development occurring globally and regional and global observing system design efforts. IOCCP serves as a platform for exactly that type of communication and coordination.

Session: The role of gliders in Ocean Observing Systems

Observation of 2012-2013 deep convection events in the north-western Mediterranean Sea

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During winter 2012-2013, open-ocean deep convection occurred in the Gulf of Lions (Northwestern Mediterranean Sea) and has been thoroughly documented thanks to the deployment of several gliders at the same time, Argo profiling floats, dedicated ship cruises, and a mooring located within the deep convection area thanks to several national and European projects (GROOM, JERICO, PERSEUS, MOOSE, SOCIB, MERMeX, HyMeX, ASICSMED, REP12, REP13). We show that deep convection reached the bottom in winter early in February 2013 and present results about the three overlapping phases of deep convection: preconditioning, violent mixing and restratification. Thanks to these intense observational efforts we also present quantitative results with estimates of heat and salt contents at the sub-basin scale at different time scales (diurnal to seasonal), through optimal interpolation techniques in particular.

Session: The role of gliders in Ocean Observing Systems

Shallow water glider experiments in the Finnish coastal waters

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The Finnish Meteorological Institute (FMI) has been operating Argo-buoys in the Baltic Sea since 2012. These buoys are part of the operative monitoring of the Baltic Sea. The next step is to use gliders in research to support that monitoring.
FMI was a partner in Gliders for Research Ocean Observation and Management in 2011 - 2014. Within that FMI experimented with the help of PLOCAN, Canary Islands, a glider in two different areas in the Baltic Sea in 2013. As those experiments were successful, FMI purchased a shallow-water Slocum G2 glider in late 2015. The Finnish marine research infrastructure FINMARI co-financed the purchase and thus the new glider is part of FINMARI. The glider is equipped with CTD, oxygen optode, chlorophyll-a, turbidity and DOC sensors enabling multi-scientific operations. In co-operation with SOCIB, Mallorca, the glider was prepared for our first mission that was conducted in the sea area of Tvrminne biological station in the Gulf of Finland in spring 2016. The glider was piloted in a narrow route from the inner archipelago towards the open sea and back. In this first mission we tested the instruments capability in coastal area. Our next mission in the summer 2016 takes place in an inland fresh water lake. After that, in the autumn, a longer mission is devoted to studies of the hydrography of the southern Bothnian Sea in a project on the water exchange between the Gulf of Bothnia and the Baltic Sea Proper.
FMI has got a good start to glider operations because of the close co-operation with GROOM partners and especially with PLOCAN and SOCIB from Spain. It has been vital for us to get experiences and advise including SOCIBs glider software. We have good co-operation with Estonian glider group, too. With similar gliders it is possible that Helsinki Tallinn co-operation can serve as a basis for a glider port for northern Baltic Sea.

Session: The role of gliders in Ocean Observing Systems

New views of the Gulf Stream

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The Gulf Stream plays a major role in the climate system and is a significant forcing agent for the coastal circulation along the US East Coast, yet, in recent years, routine subsurface measurements of Gulf Stream structure have only been collected in the Florida Straits and between New Jersey and Bermuda. Underwater gliders are now being used to repeatedly survey across the Gulf Stream and to provide subsurface Gulf Stream observations to the community in realtime. Spray gliders are deployed on three-month-long missions from Miami, Florida to the New England shelf south of Cape Cod, during which they zigzag back and forth across the Gulf Stream.
Four such missions have been completed so far with a total of more than 30 cross-Gulf Stream transects occupied. These new observations detail the subsurface structure and variability of the Gulf Stream upstream and downstream of its separation from the continental margin; reveal large-amplitude, high-frequency internal waves within the boundary current; and capture thick bottom mixed layers where the Gulf Stream reaches the bottom. Ongoing glider missions in the Gulf Stream promise to provide critical observations for examining inherent Gulf Stream variability, investigating western boundary current influences on coastal circulation, and constraining numerical simulations.

Session: The role of gliders in Ocean Observing Systems

Past, present and future perspectives of SOCIB Glider Facility from a technical point-of-view

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The 7th EGO Conference stands as a potentially fruitful gathering of Glider-focused professionals (providers, operators and users) during which a general picture of the worldwide Glider panorama, and state-of-art, will be jointly constructed and analyzed. In order to contribute to this, SOCIB-Glider-Facility (S-GF) has prepared a presentation focusing on introducing itself from a past, present and future perspective; altogether with remarks on specific aspects which are considered relevant for these three profiles of audience: mission-performance, infrastructures, personnel, development and national/supra-national cooperation. S-GF began to execute science-oriented glider missions in 2011 after an irregular and complicated start-up since 2009. At the end of the period [2011-2015] 49 missions were completed covering 10.912 Nm during 932 days-at-sea. Although the majority of them ended successfully, others were aborted or cancelled mainly due to mechanical and structural glider failures. During that period, many changes occurred with respect to checklists/protocols, personnel, auxiliary vehicles and infrastructures chapters. S-GF consolidated during these years becoming more efficient, robust and sustainable during internal (Balearic-Channels Endurance Line) and external (Jerico-FP7) missions. Presently, S-GF team is formed by 2 full-time engineers and 1 part-time technician (although it benefits from other SOCIB facilities when necessary) managing a fleet of 7 gliders. In 2016, 2 missions have already been completed by covering 914 Nm, during 85 days-at-sea, and collecting 3894 CTD profiles. The estimation is that 220 days-at-sea (split in 5 different missions) will be achieved for both internal (endurance-lines) and external (Competitive-Access and Jerico-Next) initiatives. Although S-GF is at 80-90% of its productive capability, with a maximum of 3 gliders simultaneously deployed, a 10% of the facility's time is dedicated to specific glider-tool development and sensor verification.

The Future of S-GF [2017-2020] is foreseen as a continuation period during which well-established working-lines will be extended and recent ones elevated to an operational state (maximum of 2 endurance-lines and 90 days of external access). Nevertheless, parallel new initiatives could be engaged if resources are available: new sensors for gliders, additional endurance lines and reinforcement of the Mediterranean-Glider-Port concept. The acquisition of 2 new glider units is also in the horizon although it will depend on multiple contextual factors. In conclusion, the ultimate goal will be collecting useful, reliable and high-quality scientific glider-data optimizing costs and efforts while reducing risks and enhancing development, know-how, excellence and partnership.

Session: Glider operations: piloting, infrastructure, data management and legal issues

SeaExplorer Glider: Latest Innovations and Developments

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Ocean gliders have definitely revolutionized underwater missions for ocean data collection as they offer clever and inexpensive methods for large-scale monitoring and exploration. However, back in 2012, although all existing gliders were traditionally using alkaline or primary lithium batteries, ALSEAMAR, was the first glider manufacturer to introduce rechargeable Lithium-ion batteries in its SEAEXPLORER, as an effective, reliable and affordable solution for the market. This green technology meant free reconditioning and low workforce required, thus offering the most cost-effective glider solution.
Since then, scientists have used this innovative platform accross the seven seas and the main advantages of the SEAEXPLORER are now well recognized: 1 liter ballast volume, fully swappable payloads, wingless design, Linux-based CPU, etc. But ALSEAMAR has always given pride of place to innovation and to customers' satisfaction. That is why, taking into account end-users' feedback and fast-evolving needs, our engineers are working relentlessly to enhance the SEAEXPLORER features and capabilities...
We will present here the latest SEAEXPLORER innovations and developments, including new sensing capabilities such as Methane, Hydrocarbon or Turbulence measurements, but also brand new and unique features such as the "bottoming" (seabed anchoring) navigation mode. We like to do things differently but our watchword is always the same: making the life of our customers easier!

Session: New developments in glider and sensor technology

SOCIB Glider toolbox: from sensor to data repository

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SOCIB Glider Toolbox is a complete set of MATLAB/Octave scripts freely available at https://github.com/socib/glider_toolbox. This new toolbox automates glider data processing functions, including thermal lag correction, quality control and graphical outputs. While the scientific value of the glider platform has been proven, the experience for the glider data user is far from perfect or routine. Over the last 10 years, ocean gliders have evolved such that they are now considered as a core component of multi-platform observing systems and multi-disciplinary process studies; the toolbox is a generic processing system that appropriately complements the glider capabilities.

In an ideal world, a simple connection to a glider would provide oceanographic data ready for scientific application in an intuitive, familiar format; the reality has been somewhat different. Up till now users have faced several time-consuming tasks that prevent them from directly and efficiently extracting new oceanographic knowledge from the acquired data. The SOCIB glider toolbox covers all stages of the data management process, including: metadata aggregation, raw data download, data processing, quality control, data correction and the automatic generation of data products and figures.

It is designed to be operated either in real-time or in delayed mode. In addition to the two of the most widely used and commercially exploited glider platforms, Slocum gliders and SeaGliders, contributions from a user allowed us to now also read in and process data generated by the SeaExplorer vehicle.

The SOCIB glider toolbox is ready to accelerate glider data integration and promote oceanographic discovery.

Session: Glider operations: piloting, infrastructure, data management and legal issues

Wintertime glider measurements in the western Iceland Sea

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Wintertime convection in the Iceland Sea is a source of dense water to the lower limb of the Atlantic Meridional Overturning Circulation. The dense water formation is influenced by cold air outbreaks that provide particularly intense atmospheric forcing along the ice edge in the western Iceland Sea. Three Seagliders were operated in the western Iceland Sea from early fall 2015 to late spring 2016 in order to quantify the evolution of the seasonal mixed layer, investigate the impact of cold air outbreaks, and map the extent of the wintertime convection. Preliminary results indicate that convection was most active in the vicinity of the ice edge and that individual high atmospheric forcing events had a substantial impact on the water mass transformation.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Connections between surface and deep variability on the west Antarctic Peninsula shelf

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[1] British Antarctic Survey
[2] Teledyne Webb Research

Slocum gliders have been operated successfully for the last four years from Rothera, the British Antarctic Survey base on the west Antarctic Peninsula. These missions have expanded our understanding of the area from our time series site close to the base, specifically understanding the interaction of the warm Circumpolar Deep Water with the bathymetry as it flows across the shelf. Blocking of the densest water and large overflows of water from intermediate depths to the bottom are observed, with significant mixing and entrainment occurring. The depths affected extend well above the depths of the sills (about 4-600m) to depths shallower than 200m. This produces a route whereby surface heat loss driven by varying winter ice cover can propagate to depth, this being observed at our time series site. Enclosed depressions are also sampled, with benthic biology sampling following at one anomalously cold site.
Operating in the Antarctic has advantages and disadvantages. The advantages include small boat support from base, 300m deep water just offshore and reduced risk from ships and lost fishing gear. The main disadvantage is ice but developments with Teledyne Webb have led to ice coping software that allows the gliders to continue their mission if they surface under either sea ice or an iceberg.

Session: Gliders in polar oceans: science and technological challenges

Using a Lab-on-Chip nutrient sensor in an autonomous glider to measure nitrate in shelf seas

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Seasonally stratified shelf seas act as important carbon sinks, where primary production is controlled by the availability of limiting nutrients such as nitrate. Phytoplankton spring blooms can drastically reduce the surface availability of nitrate to below the limit of detections. Short pulses of nitrate from replete bottom mixed layer water up through the nitricline can replenish the depleted surface mixed layer for short periods of time. These processes can happen on temporal scales from hours to days with current methods unable to sample continuously at the needed high resolutions. Autonomous underwater vehicles (AUV) are becoming key tools in acquiring simultaneous physical and biogeochemical parameters on both spatial scales from meters to kilometers, and temporally, from hours to multiple years. By combining AUV with new microfluidic nutrient sensors, with low resource use, high-resolution sampling on long-term deployments can accurately remove our current data gaps. We describe the use of a novel Lab-on-Chip nutrient sensor (LoC) deployed within a Seaglider (Kongsberg) to collect high-resolution temporal NO3- data during April and July 2015 in the central Celtic Sea, as part of the NERC Shelf Sea Biogeochemistry project. The LoC accurately captured the onset of the spring bloom and drastic drawdown of NO3- concentrations from $\sim$6 M to < 0.15 M in the surface mixed layer. Excellent agreement between the LoC and simultaneous shipboard NO3- measurements was observed (R2 = 0.98 n = 11). During summer, the LoC produced a high-resolution time series of nitrate concentrations that showed the depth of the nitricline varied over time.

Session: Observing biogeochemical processes with autonomous vehicles

How much use can you get out of your gliders?

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When an institute or university has more than just one or two gliders, or more than one science project on the go, management and stakeholders will develop an expectation that all the gliders could and should be used, in the water, 100% of the time. In 2015 the NERC gliders held in NOC were deployed on a large UK-based project (Shelf Seas Biogeochemistry), as well as individual deployments from Iceland by SAMS and the Antarctic with BAS, and around the UK. Using data from this very busy year I will look at the effect that the real world has on our ability to live up to this expectation, and some of the factors that constrain it. This will result in a more realistic target usage, as well as showing some of the costs of improving this target.

Session: Glider operations: piloting, infrastructure, data management and legal issues

An electro-magnetic flow sensor for measuring the axial speed of gliders

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The axial speed, U, of a glider, i.e., its speed in the forward direction, is an important quantity affecting the flight dynamics of the glider, as well as the accuracy of certain oceanographic observations. For example, accurate knowledge of U is required when converting time-rate-of-change signals, $\partial/\partial t$, to spatial derivatives, $\partial/\partial x$. Some turbulence sensors, such as shear probes, require U for proper scaling or measured signal. While U can be estimated from hydrodynamic models, a direct measurement of the axial speed is useful and preferred in many applications.
This presentation introduces a small, low-power sensor module designed for convenient integration on gliders to measure the axial speed U directly. The sensor works on the pricinple of electromagnetic induction. The presentation describes the sensor operating principle, integration and mounting arrangements, and data from test flights.

Session: New developments in glider and sensor technology

Using AUVs to resolve fronts and eddies in the upper circulation of the Central Red Sea

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Mesoscale eddy activity in the central Red Sea is investigated using observations from autonomous underwater gliders, satellite imagery, and reanalysis data. The limited observations that exist and model results confirm the significant role of eddies in the complex circulation of the seas upper layer. Eddies contain and transport kinetic and thermal energy, salt, and chemical and biological properties. Both cyclonic and anticyclonic eddies have been observed in the region. A sustained glider transect coupled with satellite altimetry and reanalysis wind have been used to characterize this region over the course of a year. Winter-time mixing driven by surface cooling and strong winds, contributes nutrients into the upper layer resulting in increased chlorophyll within the upper 100 meters as was detected by ocean color imagery. Localized diel fluctuations in phytoplankton biomass are clearly evident during these well-mixed periods.
High spatial resolution associated with this time series resolves the coupling between phytoplankton distributions and the physical dynamics of the fronts and eddies. While the deep chlorophyll maximum is typically associated with the pycnocline, chlorophyll distributions often penetrate deeper into the water column at these frontal boundaries lying at the interface between cyclonic and anticyclonic eddies. Increased chlorophyll patchiness is usually associated with vertical isopycnal displacements. The horizontal structure of both chlorophyll and CDOM appear to be influenced by mesoscale stirring.
Most of the water column kinetic energy is contained with the eddies Typical velocities are 0.1 0.15 m/s but brief accelerations can be observed. These eddies often have signatures extending to about 250 meters depth.

Session: Observing biogeochemical processes with autonomous vehicles

Mesoscale eddy observed by glider in the Iceland Basin

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The meridional heat flux in the subpolar North Atlantic is vital to modulate the high latitude climate. For the basinwide heat flux across Greenland and Scotland, much of its variability occurs in the Iceland basin, where the North Atlantic Current (NAC) carries relatively warm and salty water northward. As a critical component of the Overturning in the Subpolar North Atlantic Program (OSNAP), WHOI-OUC jointly deployed gliders in the Iceland Basin to continuously monitor the circulation and corresponding heat flux. Based on one year observations, two circulation regimes in the Icealand basin have been identified: a mesoscale eddy like circulation pattern and northward NAC circulation pattern. When a mesoscale eddy is generated, the rotational currents associated with the eddy lead to both northward and southward flow in the Iceland basin. This is quite different from the broad northward flow associated with the NAC when there is no eddy. The transition between the two regimes coupled with the strong temperature front in the Iceland basin can modify the meridional heat flux by the order of 0.3PW, which is the dominant source for the heat flux change in the Iceland Basin and thereby significantly contribute to the meridional heat flux variability between Greenland and Scotland.

Session: Micro-scale to meso-scale physical processes observed with underwater gliders

Preliminary Results of Surface Vehicle Assisted Navigation of a Underwater Glider

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Navigational accuracy for underwater vehicles is critical for high precision mapping tasks, such as bathymetric surveys and iceberg profiling. Conventionally, the gliders position is based on dead-reckoning. The dead reckoned position is derived by integrating the vehicle velocities over time. The vehicle velocity vector is composed of a measured vertical velocity, i.e. depth rate, and the horizontal velocities being derived using a simplified glider model with measured vehicle attitude. As a result of the integration the unknown environmental influences accumulate over the submerged period of the mission, causing a bias between the dead-reckoned position and the actual location. This usually becomes evident when the vehicle surfaces and updates its actual position with the Global Positioning System (GPS). We will present a framework implementing a navigational network between a surface vehicle and a hybrid underwater glider. The framework consists of a transducer integrated into the hybrid glider in conjunction with an Ultra Short Baseline System (USBL) deployed from a small surface vessel. Several deployments were conducted for evaluating the performance of the USBL. During those deployments the surface portion of the USBL was side-mounted on the small vessel at a depth of three meters. The system measured range and bearings of the glider with respect to the USBL transducer. This information combined the GPS location of the vessel and the transducers off-set was used to compute the submerged location of the glider. The comparison between the resolved location from the USBL and gliders dead-reckoning position will be shown and discussed. In the case of level-flight of the hybrid glider, this information was further used to calibrate the dead-reckoning algorithm in level-flight mode. We will further discuss our next steps, making the measured global position available to the underwater glider in order to improve mission execution. Additionally, we are integrating the surface transducer into our Unmanned Surface Vessel SeaDragon, and exploiting collaborative multi-vehicle operations for underwater mapping and monitoring applications.

Session: New developments in glider and sensor technology