A New World of Velocity Profile

Capabilities for Gliders

by Eric Siegel, General Manager, Nortek USA

Ocean gliders are autonomous underwater vehicles that profile the water column vertically by controlling buoyancy and transit horizontally by gliding on their wings during decent and accent. Initially used by academic institutions primarily for research interests, gliders are now becoming more ubiquitous in military, commercial, and operational oceanographic applications. Gliders can be a cost effective method of collecting oceanographic data over a variety of spatial scales from ocean basins, through mesoscale eddies, to microscale turbulence.

Presently, there are three operational glider manufacturers: Seaglider from University of Washington/iRobot (Eriksen et al., 2001), Slocum from Webb Research Corp (Webb et al., 2001) and Spray from Scripps Institution of Oceanography/BlueFin Robotics Corp (Sherman et al., 2001). The gliders typically descend and ascend through the water with about a 25 degree angle from the horizontal. When gliding, their horizontal speed is roughly 25 cm/s and they move vertically in the water at about 10 cm/s (Rudnick et al., 2004)

Gliders can measure a wide range of oceanographic properties. All gliders measure temperature, salinity, and pressure. Depending on the applications, other commonly measured variables include optical backscatter, chlorophyll fluorescence, and dissolved oxygen. Contour plots of these variables, as a function of depth and time (position), can offer views of biophysical phenomena such as localized mixing, upwelling, phytoplankton blooms, and thin layers. Vertically averaged ocean currents have been inferred by comparing through-water speed and direction with distance made good between surface position updates. But until recently few direct measurements of current velocity from a glider have been made.

There are many reasons for making current velocity measurements on a glider. Simply using profiles of current velocity structure and shear as a reference to interpret contour plots of other physical variables is reason enough for many researchers. Measuring higher velocity in one location compared to another could help explain evidence of upwelling. Observing variance in velocity shear at different locations in the horizontal and vertical could provide insight to the formation and dissipation of phytoplankton thin layers. Further, because gliders do not necessarily need to surface and communicate their location between dive cycles, some geospatial uncertainty about where the measurements are made is introduced. Current velocity may help define the glider path between GPS fixes providing more accurate positioning for other data products.

So why have direct velocity measurements from gliders previously not been included with the standard sampling parameters? Making current velocity measurements from gliders is not trivial. Accurately providing an absolute reference to current velocity data is very difficult due to the glider motion in the horizontal and vertical coordinates. In addition, any sensor added to a glider must be small, light weight, and require very little electrical power. Ultimately, the power budget forces a compromise between mission length, sampling frequency, number of dives, and types of observational sensors.

Since 2005, Nortek has collaborated with leading researchers to develop specialized acoustic Doppler current profilers used to measure current velocity from gliders. The Nortek acoustic Doppler current profilers were well suited to the glider requirement as they are inherently very small and require less power than most other similar Doppler equipment (typically less than 1 W when pinging). Special mechanical configurations, novel acoustic transducer head designs, and high resolution signal processing methods have been developed based on the individual researcher's project goals and requirements. Below, we present case studies of three different applica-

Figure 1
Deployment of a Webb Slocum 200 m glider with self-contained Nortek 1 MHz Aquadopp Profiler. A fleet of similarly-equipped vehicles were used by WHOI researchers to explore relationships between physical and biological fine structure in the ocean.

tions using Nortek acoustic Doppler current profilers on gliders.

Zooplankton Biomass Assessment

Dr. David Fratantoni and his collaborators at the Woods Hole Oceanographic Institute (WHOI) have flown Nortek 1 MHz Aquadopp Profilers on Webb Slocum gliders since 2005. Initially looking to make only velocity measurements from glider mounted acoustic Doppler current profilers, they found the active acoustic instruments very useful for mapping and quantifying zooplankton in both the Pacific and Atlantic oceans. The WHOI scientists began using an off-the-shelf 1 MHz Aquadopp Profiler with a right-angle transducer head mounted piggy-back to the top of the Slocum glider. After several successful missions, Dr. Fratantoni collaborated with Nortek to develop a custom transducer head with transducers angled to point nominally upwards while the glider is at the 25 degree descent angle. The profiler may run autonomously on internal power and memory, or may be connected to the Slocum glider to source external power and/or log data. The 1 MHz Aquadopp Profiler can sample every 30 seconds continuously for 15 days on small internal lithium battery packs. If the profiler is only turned on during the glider descent, the mission can be extended to 30 days. Figure 1 shows the Nortek Aquadopp Profiler with custom transducer head mounted on the Webb Slocum glider.

Figure 2

Time series of temperature, salinity, and backscatter amplitude collected during May 2005 in the Great South Channel east of Cape Cod, MA. Acoustic backscatter at 1 MHz has been shown to be an effective proxy for the vertically-migrating copepod Calanus finmarchicus.

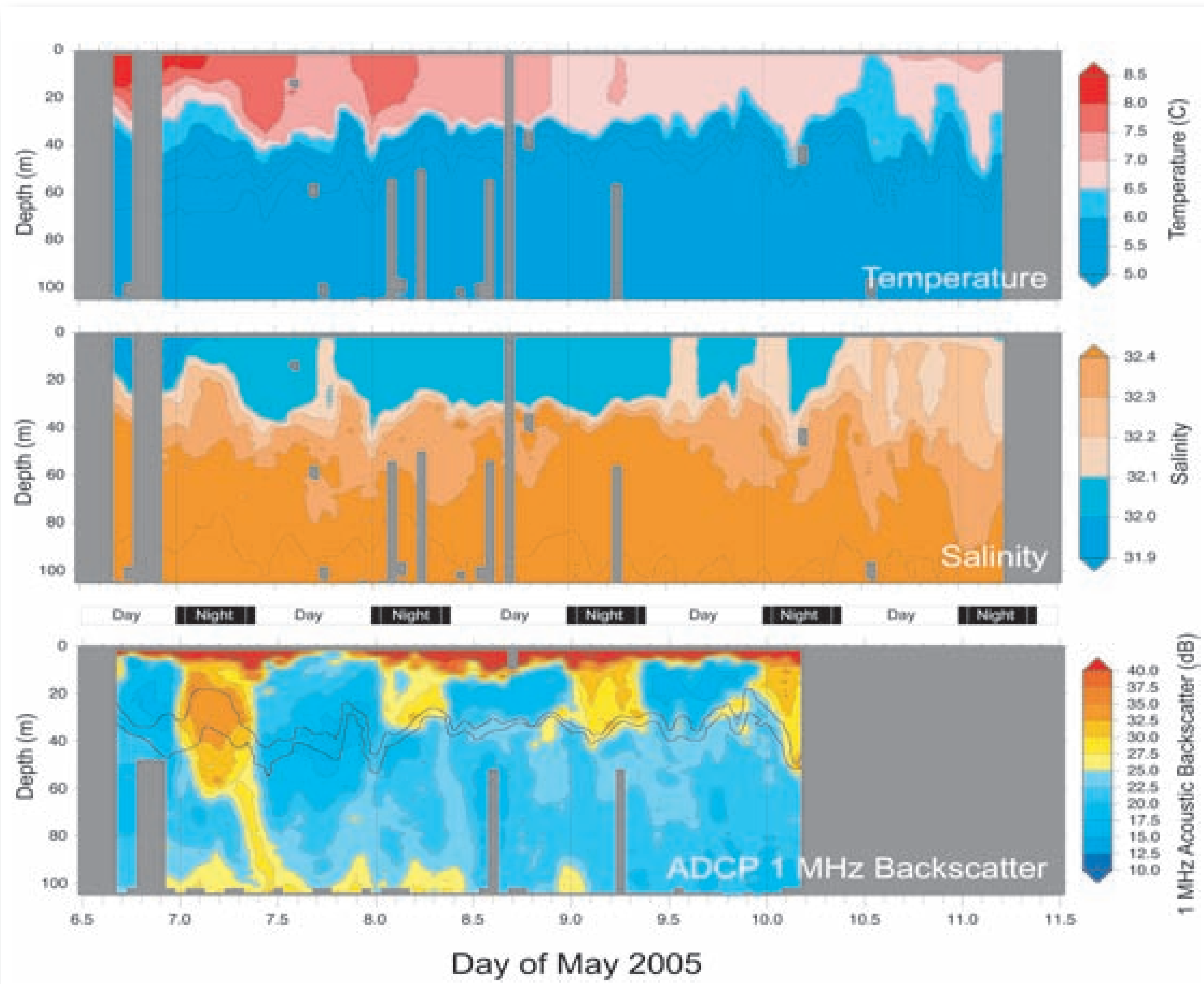

Figure 3
View of 400 kHz Nortek Aquadopp Profiler mounted on the underside of a Webb Slocum glider operated by researchers at Memorial University.

Dr. Fratantoni and his team have flown gliders with the Nortek Aquadopp Profilers in the Pacific and Atlantic oceans on missions to map and quantify zooplankton in an effort to understand zooplankton thin layers and relationship to whale feeding. Acoustic backscatter data from the profiler was corrected for transmission loss and converted into volume backscatter. A calibration of the profiler was conducted using a standard target in a tank facility at WHOI to convert backscatter data from relative magnitudes into absolute magnitudes. Acoustic backscatter at 1 MHz has been shown to be an effective proxy for vertically-migrating copepods. Figure 2 is a time series of temperature, salinity, and backscatter amplitude collected during May 2005 in the Great South Channel east of Cape Cod, MA. The data indicate the abundance of zooplankton is mostly constrained to the surface mixed layer in the upper ~40 m (Baumgartner and Fratantoni, 2008).

Offshore Operations

Dr. Ralf Bachmayer and his collaborators at Memorial University and the National Research Council Canada Institute for Ocean Technology and the Canadian Centre for Ocean Gliders focus on new applications using underwater gliders to support commercial and research projects. Their initial goal of measuring current profiles from gliders was to provide ocean modelers with velocity data to assimilate into their models and to quantify the accuracy of the model predictions. Another aspect of their research was to use velocity measurements in conjunction with an ice profiling sonar mounted on a glider. This combination of glider sensors provides current velocity profiles in close proximity to icebergs and the means to map the submerged part of the iceberg. Providing modelers with this combination of glider-based measurements will help generate better iceberg drift predictions and thus make offshore operations in ice infested waters safer and more manageable.

To support their research requirements, the research team collaborated with Nortek to develop a custom 400 kHz Aquadopp Profiler that is fully integrated in their Webb Slocum glider (Figure 3). The custom 400 kHz transducer head mounts directly to the standard 2.5” ECO Puck port on the underside of the Slocum glider. A fairing is placed around the transducer head to provide better hydrodynamics and additional buoyancy. The profiler electronics board is short enough to fit in the standard electronics bay within the glider. The profiler sources power from the glider and data are logged both to the profiler internal memory as well as the glider science computer. The research team has written the Webb "proglet" to allow the Slocum computer to control the Aquadopp Profiler sampling routine.

The 400 kHz Aquadopp Profiler has a nominal profiling range of about 80 m. For this application, the profiler is configured to point downwards and measures the velocity in the top 80 m of the water column while the glider is resting at the surface between dives. Differential GPS positions will determine the glider drift rate during the current profile and may be used to reference the velocity profile to absolute velocities. If the water is deeper than 80 m, the glider may be able to glide down to the bottom third of the first velocity profile and append another 80 m profile to the bottom, thereby extending the velocity profile to cover most regions with typical continental shelf depths.

High Resolution Shear Measurements

Researchers at the University of Washington Applied Physics Lab (APL-UW) have been using Seaglider autonomous underwater vehicles for many years to study the structure of ocean currents such as the Kuroshio boundary current in the western north Pacific Ocean. The Kuroshio current has characteristically high shear and fine structures at the western edge and lower reach of the current.

As a long endurance (up to nine months), battery powered, buoyancy driven vehicle, low power, size, and weight are all critical considerations when integrating a new sensor onto Seaglider. Developing an instrument to make high resolution current velocity measurements (over the 1000 m operating range) that meet these size and power requirements is a significant challenge.

Seaglider developers at APL-UW collaborated with Nortek to develop a custom solution to meet these difficult requirements. The solution took the form of a 1 MHz (optionally 2 MHz) Nortek Aquadopp Profiler with a custom 4-beam transducer head. The full package, including transducer head, profiler electronics, tilt sensor, compass, and internal memory, is mounted in a very low-profile anodized aluminum housing designed to fit externally on the Seaglider (Figure 4). A small 6-pin connector interfaces with the Seaglider control electronics and provides power to the acoustic profiler. This complete package is rated to the full 1000 m glider operating depth and may be easily installed or removed from any Seaglider.

The novel 4-beam transducer head was designed to work optimally during both the glider descent and ascent. The two "side-looking" beams are used during both descent and ascent. During descent, the forward-looking beam is employed for a 3-beam velocity solution. During ascent, the aft-looking beam is employed.

The 1 MHz (and 2 MHz) Aquadopp Profiler may be used in a High Resolution (HR) pulse-coherent mode that provides extremely high accuracy velocity (and shear) observations over a short range (on the order of 2 m) (Lohrmann and Nylund, 2008). When configured in HR mode, the Aquadopp Profiler may be able to collect a series of high accuracy shear measurements as the glider descends in the water. The shear measurements may then be integrated vertically to create a high resolution profile of shear within the water column. With an absolute velocity reference at the surface or bottom, the relative shear profile may conceptually be corrected for a true velocity profile over the 1000 m operating range.

Summary

Current velocity observations using a variety of acoustic Doppler current profiler configurations are being collected by gliders to address physical oceanographic, fisheries management, and offshore operational interests. Certainly, profiles of current velocity structure and shear may be used as an excellent frame of reference for inter-

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preting the contour plots of other observed variables such as density, fluorescence, and dissolved oxygen. Because gliders do not necessarily need to surface and communicate their location between dive cycles, some geospatial uncertainty in where the measurements are made is introduced. Direct velocity measurements may help to define the glider path between fixes, thus providing more accurate positioning for other data products.

With further research and development additional applications of glider-based velocity measurements will be realized. Adding a Doppler profiler to a glider could allow for depth-dependent velocity profiles used for calculating heat, salt, and chlorophyll fluxes (Rudnick et al., 2004). Gliders are also ideal platforms for measuring ocean turbulence because they move slowly with little vibration or noise. Turbulence measurements can provide invaluable information when researching mixing, air-sea fluxes, sediment suspension, and plankton thin layers. Other measurements of turbulence from Nortek acoustic Doppler current profilers could conceivably be used to search for and/or locate the existence of underwater disturbances caused by submarines or other military installations.

Despite the novel hardware that has been developed to integrate acoustic Doppler current profilers onto gliders, the data processing methods are not yet commercially available off-the-shelf. Data post-processing is complex as the problem is fully three-dimensional and dependent on time and space. Today, experimenting with velocity profilers on gliders is mostly in the realm of research scientists. As the research community continues to gain experience with these velocity data, and applies similar signal processing expertise gained from lowered acoustic Doppler current profiler (LADCP) projects, the applications will expand. Tomorrow is a new world for direct velocity measurements from ocean gliders and the future bright.

Figure 4

Drawing of a 1 MHz Nortek Profiler for the Seaglider. The full package, including the 4-beam transducer head, profiler electronics, tilt sensor, compass and internal memory, is mounted in a low-profile anodized aluminum housing rated for 1000 m.