

## ***Underwater Gliders for Ocean Climate Observations***

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Long range underwater gliders have recently become operational technology for oceanography. They have made the transition from fantasy to reality, generating considerable community enthusiasm to apply them to a wide range of problems. As with any observational technique, gliders have both promise and limitations. Their most promising role for ocean climate observations is to make high spatial resolution sections repeatedly, autonomously, and at very low cost compared to conventional methods involving ships or moorings. While they provide profiles, as ARGO floats do, the time and location of glider observations is remotely controllable. Gliders can collect repeat observations on a prescribed spatial grid tailored provide a description of how the ocean evolves in space and time on relevant scales. They provide a means for monitoring boundary currents, of particular importance to ocean climate.

The seminal attribute of existing gliders is that they are inexpensive tools with which to sample the upper ocean. They cost the equivalent of a few days of ship time to purchase and a couple more to operate for several-month missions. They relay data ashore within hours of collection and can be controlled globally via the internet.

Three underwater gliders currently are operational and available for purchase: Spray, Slocum, and Seaglider, developed by Scripps Institution of Oceanography and the Woods Hole Oceanographic Institution, Webb Research Corporation, and the University of Washington, respectively. All three are roughly the same size (mass ~ 50 kg), hence easily handled manually by two people. Descriptions and further references can be found in Rudnick *et. al.* (2004).

Underwater gliders are buoyancy-powered devices that glide slowly (~0.5 kt) along saw-tooth path trajectories through the ocean. They trade speed for range and endurance: halving speed doubles range and quadruples endurance, a result of the quadratic drag law. They lose their ability to navigate when they travel at speeds near or below the speed of currents through which they travel. Their wings provide propulsion by converting buoyancy generated by vehicle displacement volume variations to forward motion. In contrast to typical aeronautical gliders, ocean gliders were designed to fly along paths steeply sloped compared to environmental property surfaces.

Gliders have held the records for autonomous underwater vehicle (AUV) mission endurance and range throughout the current millennium. The longest mission to date lasted over 7 months and covered 3750 km, accomplished by a Seaglider in the Labrador Sea. Longer range missions are planned for gliders with improved endurance due to more and better batteries. Primary lithium cells provide the longest range and endurance. One year glider missions will soon be possible. Current developments include thermally powered, under-ice, and full-ocean depth models.

Gliders are versatile. They can be commanded to visit a sequence of waypoints, stay in one location, or steer a constant heading, interchangeably on the same mission. Where, when, and how they sample can be adjusted each time they communicate at the sea surface. They can 'hold station' as well as a moored surface buoy in deep water. They measure temperature, conductivity, dissolved oxygen, several bio-optical parameters, and currents. Sensor payload requirements are small size, low power, and low hydrodynamic drag.

They typically collect profiles with depth resolution comparable to shipboard CTD casts, but with much higher horizontal resolution. Gliders are thrifty enough to be able to repeat a survey several times in a mission. Persistence is one their most endearing and rewarding qualities.

Gliders have operated through the most severe seas and across the mightiest currents the ocean has to offer. They have worked through Labrador Sea winters and a western Pacific typhoon. They have crossed the Gulf Stream and Kuroshio, and crossed the Alaska Stream, the California Current system, the Labrador Current, and several other boundary currents many times. They have worked in deep water and over the continental shelf and from the tropics to the Arctic Circle. Glider tracks executed between July 2003 and February 2006 are drawn in Figure 1.

As the tracks in Figure 1 attest, glider speeds limit how well they can be controlled in regions of strong current. Since currents are typically surface intensified, deep dives tend to mitigate this limitation. Other constraints faced by gliders are sensor suites limited by power, size, and hydrodynamic smoothness. Their lithium batteries pose special challenges for air transport. Along with other self-navigating AUVs, export of gliders from the U.S. is regulated for national security and anti-terrorism reasons.

An example of how gliders can be used to observe both the spatial structure of oceanic features and the temporal structure of their variability on seasonal and longer scales is given in Figure 2. It shows the temperature anomaly at 100 m depth from the space-time mean on a pair of transects normal to the coast, extending seaward 220-240 km from the continental shelf edge. The continuing repeat survey, started in August 2003, is indicated by the V-shaped pink curves with an apex at 47°N, 128°W offshore western North America in Figure 1. Each leg of the V-shaped pattern across the NE Pacific boundary current system takes about 2 weeks to complete, with dives every 8 hr to 1 km depth along glide slopes of about 1:3 (vertical to horizontal). Individual missions last as long as 5 months with vehicles being launched and recovered from small boats on day trips from shore. Both a prominent annual signal that propagates offshore with a wavelength near 350 km and an interannual warming trend are evident over the 32 month sequence of sections to date. These signals are evident despite the presence of eddies and internal waves in the anomaly field plotted, showing how sampling by a comparatively slow moving vehicle can be effective in resolving spatial structure associated with seasonal and lower frequency oceanic variability.

The cost of collecting the data shown in Figure 2 is comparable to about 10 days of ship time, or about what it would cost a ship to occupy the pattern twice including transit to and from port.

Gliders feature prominently in plans for the NSF Ocean Research Interactive Observatory Network (ORION) program's Ocean Observatories Initiative (OOI) coastal and global components. While they comprise at most a few percent of the infrastructure costs anticipated by the OOI, they are expected to provide most of the spatial context of ocean circulation observations currently planned in ORION. Multiple continuous repeat transects in the coastal regions of the U.S., particularly off its west coast, are projected for the next 30 years. Continuous glider repeat surveys around OOI global component moorings is expected to provide estimates of advective contributions to observed temporal changes.

Glider observations are also planned for key elements of the ocean's general circulation. Gliders have been used to collect sections across the Gulf Stream and Kuroshio and regular observing programs for such boundary currents are an active subject of discussion. Glider transects along the Iceland-Scotland Ridge to simultaneously observe Atlantic inflow to and deep overflow from the Nordic Seas are scheduled to begin in June 2006. With glider endurance expected soon to exceed one year, missions in remote subpolar regions can be undertaken without the need for field operations in severe sea and weather conditions. An under-ice glider that navigates acoustically via moored RAFOS sound sources is to be deployed in September 2006 to monitor heat and fresh water exchange between Baffin Bay and the Labrador Sea through Davis Strait. The prospect of a full ocean depth glider makes feasible repeat transects across the Antarctic Circumpolar Current on year-long missions. The prospect of a glider that draws power from the ocean's thermal stratification makes feasible multi-year missions in tropical and subtropical regions.

In recent years, the ARGO program has established a network for monitoring large scale climate signals of the ocean interior. Glider technology is poised to make a complementary contribution to knowledge and understanding by resolving the many smaller scale features of which ocean circulation is comprised.

### ***References***

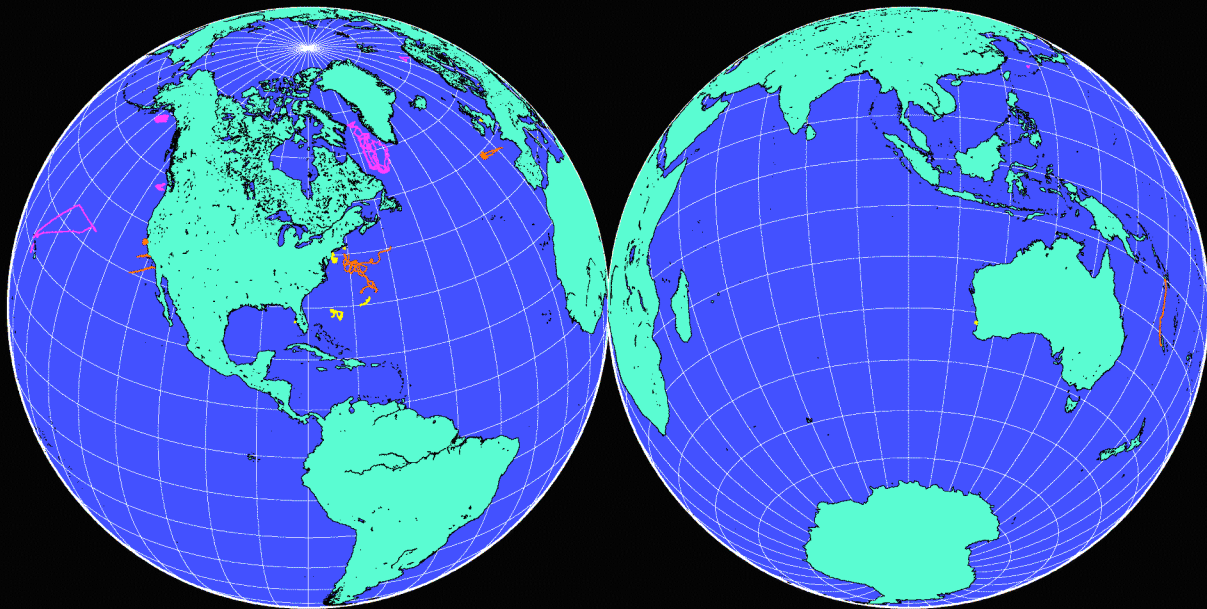
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**Glider Missions July 2003 - February 2006**

**Seaglider**      **Spray**      **Slocum**



*Figure 1. Tracks of Seaglider, Spray, and Slocum missions from July 2003 to February 2006 carried out by the University of Washington, Scripps Institution of Oceanography, the Woods Hole Oceanographic Institution, and Rutgers University.*

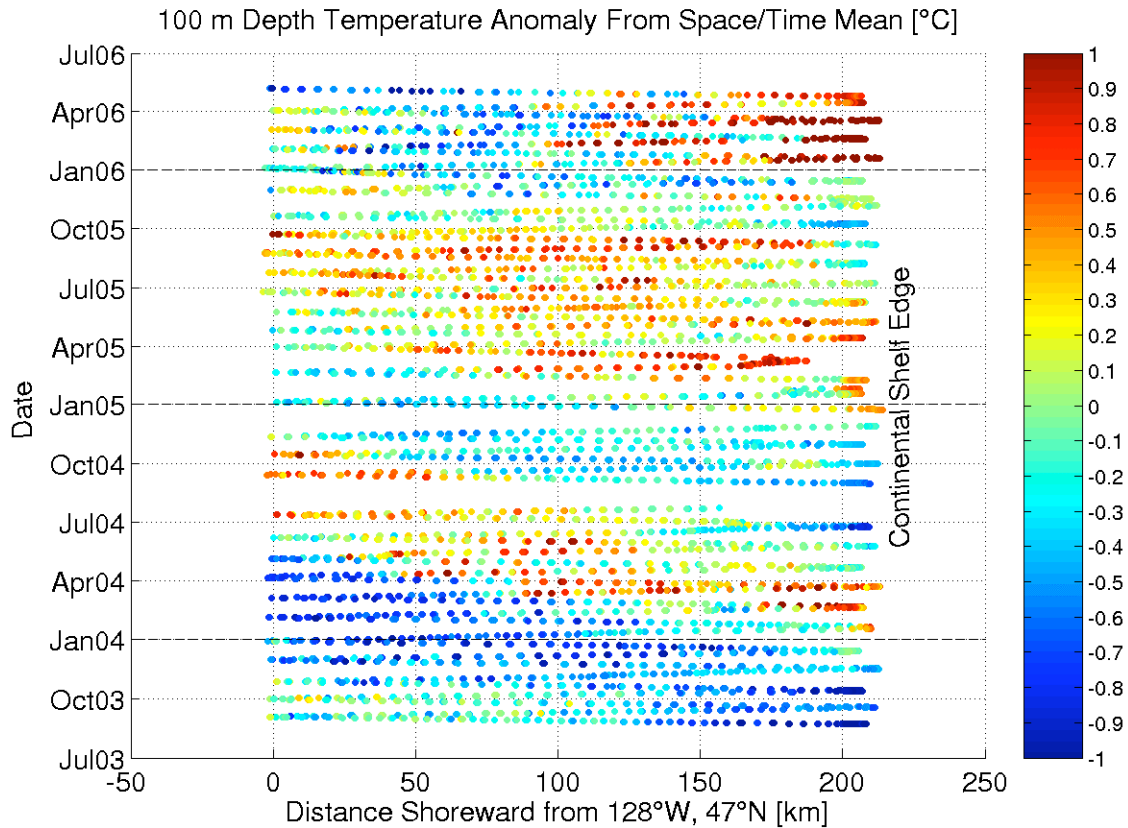


Figure 2. Temperature anomaly [ $^{\circ}\text{C}$  in color] over 32 months from the space-time mean at 100 m depth plotted against date and distance shoreward from  $47^{\circ}\text{N}$ ,  $128^{\circ}\text{W}$  over the continental slope offshore Washington. These data were collected from a sequence of single Seaglider missions following the V-shaped pink track shown in the northeast Pacific in Figure 1. A symbol is drawn for each Seaglider crossing of the chosen depth horizon. Anomalies were calculated from depth interpolation along slanting glide paths without any spatial or temporal filtering to remove eddy or internal wave noise.