THE UNDERWATER GLIDER SPRAY: OBSERVATIONS AROUND THE WORLD

Daniel Rudnick[1], Russ Davis [1], Mark Ohman [1], William Kessler[2],
Breck Owens[3], Francisco Chavez[4], Uwe Send [1]

[1]Scripps Institution of Oceanography, La Jolla, California 92093, USA
[2]NOAA Pacific Marine Environmental Laboratory, Seattle, Washington 98115, USA
[3]Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA
[4]Monterey Bay Aquarium Research Institute, Moss Landing, California 95039, USA

1. INTRODUCTION

Underwater gliders are autonomous vehicles that profile vertically by changing buoyancy and move horizontally on wings [1, 2]. The Spray glider [3] was developed at Scripps Institution of Oceanography, and has been used at many locations around the world (Fig. 1). At 2 m length, 0.2 m diameter, and 51 kg, Spray is small and light enough to be deployed and recovered from vessels ranging in size from small inflatable boats to global class research vessels. During a typical deployment, Spray dives from the surface to 500-1000 m depth and back, taking 3-6 h to complete the cycle while traveling a horizontal distance of 3-6 km. Spray's speed through the water is thus about 0.25 m/s in the horizontal, and 0.1 m/s in the vertical. While on the surface, Spray communicates using the Iridium satellite system, and navigates using GPS. Endurance depends on the sensors carried, stratification, dive depth, and speed; deployments are usually planned for 3-4 months, covering 2000 km or more. Observed variables have included pressure, temperature, salinity, velocity, chlorophyll fluorescence, and acoustic backscatter. To date, Spray gliders have completed over 60,000 dives, covering over 160,000 km in over 7,500 glider-days.

The purpose of this document is to summarize a few of the scientific programs achieved using Spray. Many of the Spray observational programs are ongoing, having been initiated in the past few years. We are learning that the power of glider observations lies in their sustained presence and fine horizontal resolution. The programs summarized below are just a sampling of what will surely be a growing body of observations from gliders.

2. CALIFORNIA CURRENT

Spray observations of the California Current System (CCS) are a sustained effort to quantify the seasonal and interannual evolution of this important ecosystem. The CCS off southern California consists of the southward flowing, surface intensified California Current, and the

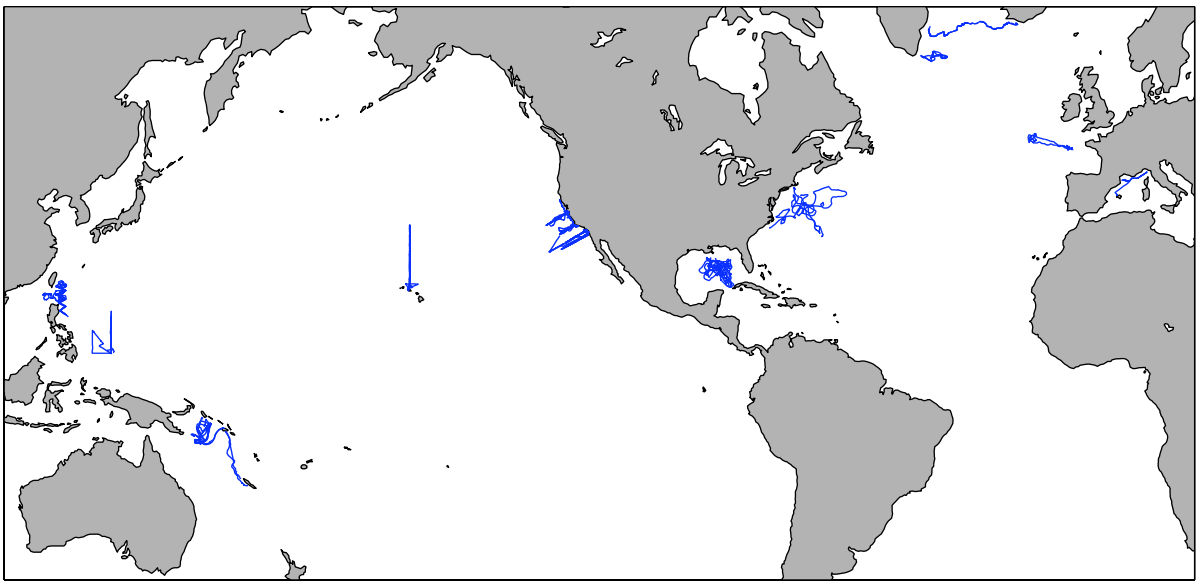

Figure 1. Spray glider deployments around the world. Deployment locations include the Kuroshio off of the Philippines and Taiwan, the North Equatorial Current near Palau, the western boundary current in the Solomon Sea, the Pacific subtropical gyre north of Hawaii, the California Current System off southern and central California, the Loop Current in the Gulf of Mexico, the Gulf Stream off the northeastern US, the Irminger Sea, the Porcupine Abyssal Plain west of Ireland, and the Mediterranean Sea.

northward flowing, subsurface California Undercurrent. Waters from both the south and the north thus affect the SCB, and the resulting mixture of waters has striking effects. The region is populated with mesoscale and submesoscale eddies, with associated strong fronts and vertical fluxes. Stirring the water of different origins creates pronounced thermohaline structure. Wind-driven upwelling occurs along the coast and offshore through wind-stress curl. All of these processes are modulated interannually. The SCB is profoundly influenced by El Niño, with southern influences arriving by advection, coastally trapped waves, and atmospheric teleconnection. The physical features of the SCB make it a remarkably productive area of the world's oceans. The flow structures in the SCB are thought to influence retention of organisms, while the vertical fluxes at meso and submesoscales provide nutrients to the euphotic zone. Wind-driven upwelling has effects felt up the food chain. This seasonal upwelling also causes the intrusion of low-pH waters onto the shelf, a phenomenon that is becoming more intense. With a focus on the ecosystem, the California Sprays have the heaviest payloads, with sensors to measure temperature, salinity, pressure, current, chlorophyll fluorescence, and zooplankton. Anticipated sensor additions include nitrate and dissolved oxygen. Cooperating programs include the California Cooperative Fisheries Investigation (CalCOFI), the California Current Ecosystem Long-Term Ecosystem Research (CCE LTER) program, the Southern California Coastal Ocean Observing System (SCCOOS), the Central and Northern California Ocean Observing System (CeNCOOS), and the Consortium for Ocean's Role in Climate (CORC). Publications from the California work initial results from bight-wide observations [4] and and a study of circulation off Huntington Beach [5].

3. EXPLORING TRANSPORT IN THE SOLOMON SEA

Subsurface equatorward flow through the Solomon Sea is the main source of water for the Equatorial Under Current, which is a major component of the upwelling branch of the shallow overturning circulation in the tropical Pacific. By modulating equatorial surface temperatures, variations in the properties or volume transport of the Solomon Sea flow may affect the timing and intensity of ENSO. To deduce the nature of the flows in the New Guinea Coastal Under Current (NGCUC) and through the interior Solomon Sea, a collaboration between SIO, PMEL, and IRD (Noumea) has begun monitoring flow through the Solomon Sea using Spray gliders crossing between the Solomon Islands and New Guinea. Although the vertically-averaged NGCUC currents are considerably faster than the glider speed, Spray has proved capable of making repeated sections by looping offshore to go upstream. Such a strategy has promise for monitoring other such narrow western boundary current systems.

4. NORTH ATLANTIC WESTERN BOUNDARY MONITORING

It has been demonstrated that Spray gliders can be used to make sections across strong boundary currents in the North Atlantic and the Gulf of Mexico. Transports of properties and volume have been obtained for sections taken across the Gulf Stream downstream from Cape Hatteras, demonstrating that gliders can be used to monitor an important component of the meridional overturning circulation. Similarly, repeated sections across the Loop Current in the Gulf of Mexico have been carried out over a nearly two year long monitoring program. The structure of the detached eddies from the Loop Current have been sampled and used to improve real-time forecasts in support of off-shore oil production.

5. EUROPEAN PROGRAMS

Spray gliders were used in the framework of the European MERSEA project in three different regions – the Mediterranean Sea, the Porcupine Abyssal Plain (PAP) west of Ireland, and the central Irminger Sea (CIS) gyre south of Greenland. There were multiple objectives for these missions. For the operational aspect of MERSEA, the glider sections delivered T and S data for assimilation into the operational forecast models in regions where data were difficult to obtain routinely. A goal was also to explore the potential for providing biogeochemical data on routine sections in the future, in order to force or validate ecosystem models and forecasts. A scientific goal was to study and exploit the synergy between gliders and multidisciplinary timeseries at long-term moorings at CIS, PAP, and in the Northwestern Mediterranean. Thus each glider mission went to and around such MERSEA moorings to collect data complementary to the moorings, in addition to executing oceanographic sections through areas of interest (like the deep convection region in the Gulf of Lions).

6. ORIGINS OF THE KUROSHIO

The origins of the Kuroshio offshore of the Philippines and Taiwan is a region dominated by mesoscale eddies. Two objectives, one technical and one scientific motivated this project, a collaborative effort between SIO and University of Washington using both Sprays and Seagliders. The primary technical objective was to demonstrate the use of a glider fleet in sampling a strong boundary current where the flow is often stronger than the glider can overcome. The general scientific objective was to quantify the spatial structure and temporal evolution of the southern reaches of the Kuroshio, including its excursions through the Luzon Strait into the South China Sea. Strong internal wave activity is a feature of the South China Sea, caused by tidal flow over the ridges in the Luzon Strait. To observe these internal waves, Spray held station to yield time series, including estimates of vertical velocity from the

fluctuations in glider flight. A recently started program aims to observe the flow in the North Equatorial Current and Mindanao Current using Sprays launched from Palau.

7. MODULATION OF FINE-STRUCTURE IN THE NORTH PACIFIC SUBTROPICAL GYRE

The goal of this project is sustained sampling of upper ocean hydrography to resolve the seasonal-to-interannual modulation of meso- and fine-scale thermohaline structure. Sprays are deployed to make repeated occupations of a 1300-km meridional section northward from Hawaii to 35°N along 158°W. The observations are quantifying the modulation of: (1) the horizontal density ratio in the mixed layer and upper thermocline, (2) spice variability in the thermocline, (3) horizontal variability in mixed-layer depth, (4) horizontal variability in the deep chlorophyll maximum, (5) depth-average velocity and vorticity. Using Spray gliders deployed near the Hawaii Ocean Time-series (HOT) site off Hawaii, the section is being repeated roughly every two months, with nearly 2.5 years of sustained observations to date. In an effort to understand better the sampling characteristics of relatively slow gliders, a cruise was undertaken using the rapidly towed vehicle SeaSoar to make sections for comparison.

ACKNOWLEDGMENTS

Spray development and operation took place through the Instrument Development Group at Scripps Institution of Oceanography. We gratefully acknowledge the support of the Office of Naval Research, the National Science Foundation, the National Oceanic and Atmospheric Administration, the state of California, the Gordon and Betty Moore Foundation, the David and Lucile Packard Foundation, British Petroleum, and the European Commission FP6 project MERSEA. This work would not have been possible without our partners Institut de Recherche pour le Développement (Noumea, New Caledonia), Solomon Islands Meteorological Service (Honiara, Solomon Islands), IFREMER (Brest, France), LOCEAN (Paris, France), IMEDEA (Mallorca, Spain), National Taiwan University (Taipei, Taiwan), National Sun Yat-sen University (Kaohsiung, Taiwan), Coral Reef Research Foundation (Koror, Palau), University of Washington (USA), University of Hawaii (USA).

REFERENCES

1. Davis, R.E., C.C. Eriksen, and C.P. Jones, Autonomous buoyancy-driven underwater gliders, in *Technology and Applications of Autonomous Underwater Vehicles*, G. Griffiths, Editor. 2003, Taylor and Francis: London. p. 37-58.
2. Rudnick, D.L., et al., Underwater gliders for ocean research. *Marine Technology Society Journal*, 2004. **38**(2): p. 73-84.
3. Sherman, J., et al., The autonomous underwater glider "Spray". *IEEE Journal of Oceanic Engineering*, 2001. **26**(4): p. 437-446.
4. Davis, R.E., et al., Glider surveillance of physics and biology in the southern California Current system. *Limnology and Oceanography*, 2008. **53**(5): p. 2151-2168.
5. Todd, R.E., D.L. Rudnick, and R.E. Davis, Monitoring the greater San Pedro Bay region using autonomous underwater gliders during fall of 2006. *Journal of Geophysical Research*, 2009. **114**(C06001).