Glider Measurements of the Solomon Sea

A pilot project to monitor western boundary transport to the equatorial Pacific

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1. Abstract

The Solomon Sea Glider Project has two principle objectives: first, to demonstrate newly-developed glider technology as a sustainable means of measuring swift and narrow western boundary currents, and second, to use this new instrument to monitor the inflow towards the equator from the South Pacific, which is thought to contribute to the variability of El Niño and longer-term climate fluctuations. Gliders are deployed 3-4 times/year to cross the Solomon Sea western boundary current system, measuring vector currents, temperature and salinity.

2. Project Summary

Ocean gliders are small autonomous vehicles based on Argo float technology (see http://www-argo.ucsd.edu/FrAbout_Argo.html/), whose only propulsion is to pump oil in and out of an external bladder (Fig.1a). This makes the glider sink and rise in the water, and with its wings it slowly glides forward. It typically dives to 700m depth every 3-4 hours, gliding 20-25 kilometers per day, while reporting its data and receiving instructions by satellite each time it surfaces (Fig.1b). Although the glider moves slowly, it uses very little power and operates autonomously for 4 to 6 months, so it covers a substantial distance (typically 2500km). It measures profiles of temperature and salinity, and current velocity is inferred from the glider's motion. The glider has three important advantages over previous technology: it can be deployed and recovered entirely by small boats near shore, making the operations much cheaper and more flexible than a research ship; it makes continuous observations for much longer periods than is

practical for a research ship; and it makes densely-spaced profiles right up to the coast. For these reasons, ocean gliders are likely to play a large role in climate monitoring of the ocean, especially for sampling narrow coastal currents. This project tests that concept while also providing the first time series of western inflow to the equatorial Pacific. The Spray glider used in this project is designed and built by the Instrument Development Group at the Scripps Institution of Oceanography, funded by NOAA's Ocean Climate Observation program as a new tool for the climate observing system. All aspects of the program are a collaboration among scientists and engineers at NOAA/PMEL, Scripps, and the French laboratory IRD in Noumea, New Caledonia.

The Pacific Ocean circulation encompasses a great overturning cell in which cool, salty water sinks in the subtropics, flows at depth towards the equator, and upwells back to the surface in the eastern equatorial Pacific. Variations of the cell produce slow changes in the temperature of equatorial water, which can then influence the occurrence and strength of El Niño events and longer-term climate fluctuations. Because El Niños affect weather of the entire Pacific and beyond, changes of the overturning cell play a major role in the year-to-year and decade-to-decade variations in climate.

Observations show that perhaps 70% of equatorial upwelling due to the overturning cell originates from the South Pacific, with a large fraction arriving via the narrow boundary currents in the Solomon Sea (Fig.2). (Such powerful western boundary currents are analogous to the Gulf Stream, but flow towards the equator in the tropics). However, measuring these currents has lagged other elements of the circulation because the region is remote and difficult to work in, with strong narrow filaments of current flowing among a complex network of islands and reefs; as a result there have been only sparse measurements that have barely outlined the circulation. These currents are too narrow and too close to coastlines to be measured by the broadscale observing network (satellites and large-scale in situ programs), and their representation in models has therefore been unchecked. Producing a time series of this system is recognized as one of the most important challenges in gaining a full picture of the climate of the Pacific.

The Solomon Sea glider project began in mid-2007, and has conducted seven deployment cycles (as of October 2009) in continuous rotation since then (Fig.3). Each round-trip mission lasts 3-4 months, crossing the Solomon Sea to within 5km of the coast on each side. The program has demonstrated first, that gliders are capable of sustained sampling of this piece of the climate system dependably and cheaply, and second, that the Solomon Sea boundary current system supports dramatic variability, seen especially associated with the La Niña cold event of early 2008, and the developing El Niño warm event in late 2009.

During FY 2010, we propose to continue deployments, pointed towards establishing an ongoing operational monitoring capability, to conduct sampling experiments to allow a careful estimate of the errors of this measurement technique, and to use the accumulating glider data to diagnose the circulation in connection with climate model simulations.

3. Scientific Accomplishments

Work done during FY2009 was aimed at solidifying the local Solomon Islands infrastructure for longterm operations in this remote situation, building a firm basis to support ongoing monitoring. We are also testing sampling strategies and estimating the errors associated with glider sampling. While the previous work provided proof of concept that the instrument itself could survive and make useful measurements in this challenging environment, the task now is to make the operations routine and the data credible.

We had started from scratch in the first year (FY08), making many mistakes out of ignorance of local conditions, but have now made the operations run fairly straightforwardly. The port of Gizo, Solomon Islands, was chosen for operations since it offers the shortest crossing of the Solomon Sea, allowing extra battery life for repeated surveys of the boundary current within a single mission. Lab space and safe, dependable boat charter in Gizo are now assured. Regular liaison with local authorities, especially the Solomon Islands Meteorological Service, is maintained. (Working in the Solomon Islands is always an adventure, however). Shipping to Gizo is still a problem, with delays due both to infrequent ship schedules and to arbitrary actions of local officials, that require substantial lead time.

Two travelers are usually required for the on-site work. The at-sea glider is steered (remotely) to Gizo and recovered by locally-chartered small boat. It is inspected, dismantled, the internally-stored (engineering) data downloaded, and the instrument prepared for shipping back to the US. The new glider is received from customs, transported to Gizo, assembled and tested, and deployed.

FY09 glider recovery/deployment operations were conducted in November 2008, March 2009, and July 2009 (and the PI has just returned from latest operation in early November 2009). We had one failure, when a voltage regulator (a commercially-purchased part) on a circuit board failed a few days into the March deployment. The glider stopped communicating but remained at the surface and drifted onto a reef about 70km south of Gizo. Thanks to our visibility in the Gizo region (see “Education and Outreach” below), the fishermen who found it about 3 weeks later were able to identify it as ours even though all the markings had been scratched off, and the instrument was returned to be repaired and serve again.

Much of the effort in FY09 has gone toward testing to evaluate and tune the sampling strategy. There are two main issues: short-term variability that is aliased by the months-apart sections, and adequate sampling of the narrow western boundary current. We have used the extra battery life afforded by the shorter crossing from Gizo to make repeat sections: running back and forth over the same section to test the consistency of measurements at 10-20-day intervals. Also, in July 2009, we deployed two gliders at once, with one following the other on the same track about 10 days behind. It is apparent from this testing that there is substantial eddy (short-term) variability, with typical scales of 100-200km and about a month, and we are working to characterize this and to cast it into a framework that will allow evaluating the resulting uncertainty. This effort is complemented by the collaborative model work described below.

We have made sections across the narrow western boundary current at several locations to find a section that is convenient logistically and that also samples the entire current (Fig.3). Flow through the many channels between the islands of Papua New Guinea must not be omitted. Since

the observations have shown that the current is pressed right up to the coast (it is still strong only 5km from the reefline), we have looked for a section where the slope is steep enough that the glider can approach the coast this closely. After some experimentation, we now make the current crossing south of Tagula Island, PNG (Fig.3).

In order to further assess the eddy variability sampled by the glider, we have initiated a collaboration with the Bluelink modeling group at the Bureau of Meteorology (Australia). Bluelink is an advanced ocean model (NOAA/GFDL MOM4 code) run at high resolution (1/10th degree) for the region around Australia, including the Solomon Sea. Comparison with the glider measurements shows that although there are many particular inaccuracies in the model results, Bluelink gives a reasonably good portrayal of the time and space scales of eddy variability. For our purposes this is a valuable resource because it allows evaluating the eddy structures that alias the glider observations: their propagation speed and direction, vertical structure, and origin. Since Bluelink is run in near-real-time, potentially this collaboration could provide a nowcast that could be useful in steering the glider away from strong adverse currents. From the modeling point of view, the glider data is extermely sparse and infrequent, so it is not obvious how to use it for model quality control (unlike, for example, a buoy that gives a continuous time series at one point). The Bluelink group is looking into how to use statistics from the glider measurements for this purpose, which will provide a template for other climate modelers to make use of the data.

The glider has now made coast-to-coast sections across the Solomon Sea since July 2007, thus sampling during the La Niña of 2007-8 and now in the El Niño event that is developing at present. We had expected from theoretical considerations and simple models that La Niña would result in a reduction in equatorward transport and El Niño in an increase. (Indeed, this previously-unmeasured expectation was a major motivation for beginning the project, as it implies that an important fraction of the discharge and recharge of mass and heat from the equatorial Pacific occurs in the narrow western boundary currents that cannot be measured using the existing broadscale observational network). In fact, the transport variations have proved to be larger than expected; transport during the La Niña transport dropped from a mean of about 20Sv to near zero, and the most recent mission suggests that El Niño transport will perhaps double the mean. These observations will prove a powerful challenge to the ocean and climate models, and an important check that an ocean model must meet to be considered accurate.

<u>Response to the four questions on data distribution and archiving:</u>

a. Glider data is not distributed in real time on the Global Telecommunications System.
b. Glider data is maintained and available online in real time at http://spray.ucsd.edu
c. Delayed-mode data is archived and available online at http://spray.ucsd.edu
d. Glider data is archived by mission at http://spray.ucsd.edu

4. Education and Outreach

A requirement for obtaining clearance to operate the Spray gliders in the EEZ waters of the Solomon Islands and Papua New Guinea is that the findings be shared in a form that is relevant to the needs of those countries. To meet this requirement, the PI gives lecture series at secondary

schools and colleges, and meets regularly with planning groups such as weather and climate forecasters, and stakeholders as requested by local government agencies. In FY09, Kessler lectured twice at the University of Papua New Guinea (Port Moresby, PNG), twice at the Solomon Islands College of Higher Education (teachers college for secondary school science teachers) in Honiara, Solomon Islands, twice at secondary schools in Gizo, Solomon Islands, and once to a public meeting in Gizo. These lectures described the glider operations (including inviting students to observe the glider itself), and the climate conditions that the glider monitors. Beyond satisfying national authorities, these activities make us welcome, and build a community that is willing to assist us when needed (e.g., recovering the glider that drifted onto the reef mentioned above).

5. Publications and Reports

5.1. Publications by Principal Investigators

No referreed journal publications have yet described the Solomon Sea glider findings. A manuscript is in progress and will be published in 2010. The PI was co-author of two relevant White Papers for the OceanObs'09 meeting in Venice, Italy (September 2009), one on glider work specifically, and one on various techniques for measuring boundary currents:

Rudnick, D., R. Davis, M. Ohman, W. Kessler, B. Owens, F. Chavez and U. Send, 2009: The underwater glider Spray: Observations around the world. *OceanObs'09 Conference*, Venice, Italy, 21-25 September, 2009.

Send, U., R. Davis, J. Fischer, S. Imawaki, W. Kessler, C. Meinen, B. Owens, D. Roemmich, T. Rossby, D. Rudnick, J. Toole, S. Wijffels and L. Beal, 2009: A global boundary current circulation observing network. *OceanObs'09 Conference*, Venice, Italy, 21-25 September, 2009.

6. Figures

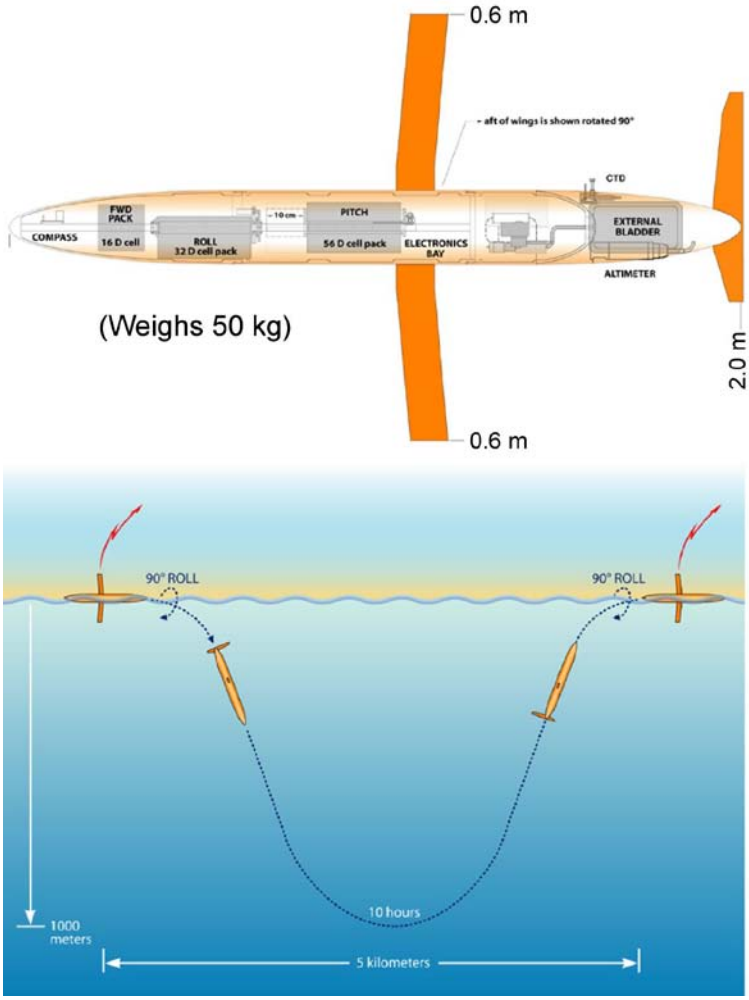

Fig.1a. A schematic diagram of the Spray glider. The instrument is 2 meters long and has a wingspan of 1.2 meters. The external bladder is in a flooded compartment in the rear, inflated and deflated by an oil pump. The dive angle is controlled by moving the internal battery packs forward and aft on a central shaft.

Fig. 1b. A dive of the Spray glider. With antennas in the wings, the glider rolls one wing up to send data and receive instructions each surfacing.

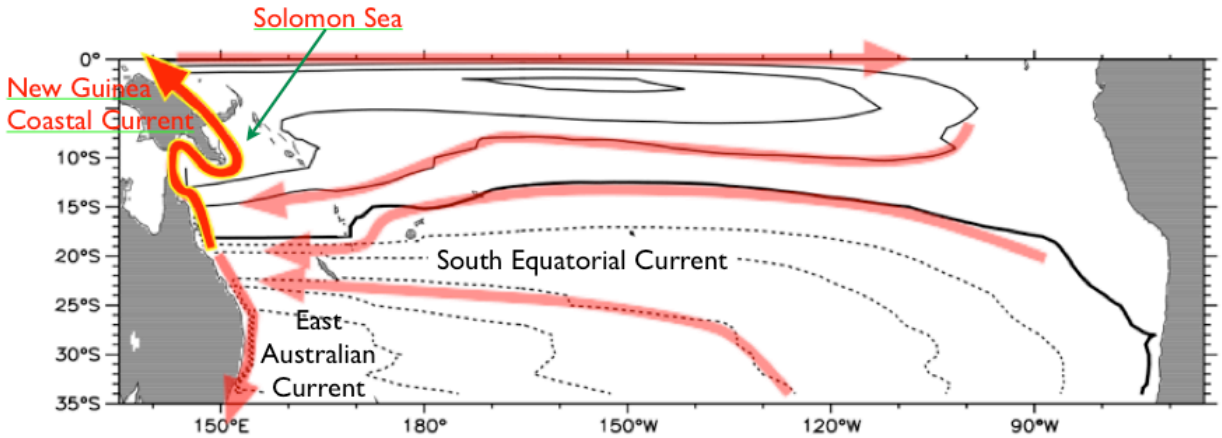

Fig.2. Overview of the South Pacific Ocean circulation, showing the pathway of water going to the equator through the Solomon Sea.

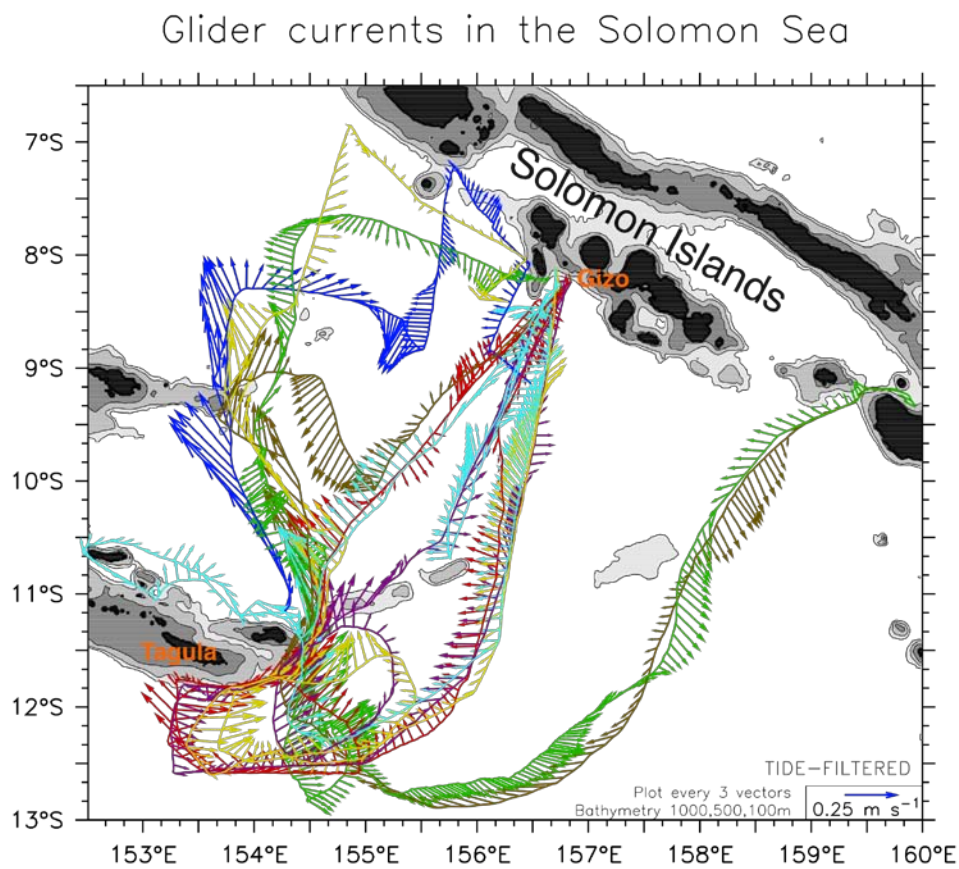

Fig.3. Detail of glider operating area in the Solomon Sea. The vectors show the measured current from each of the 7 missions accomplished to date, each making a coast-to-coast crossing. Black indicates land; increasingly-dark gray-shading shows ocean depths of 1000m, 500m and 100m.