Sustained oceanographic observations around Australia using autonomous ocean gliders

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Abstract - **Ocean gliders are autonomous sensor platforms designed to operate in water depths of up to 1000m. By varying their buoyancy, gliders are able to efficiently ascend and descend through the water column. The Australian National Facility for Ocean Gliders (ANFOG) has been established as part of the Australian Integrated Marine Observing system to develop and operate a fleet of ocean gliders in shelf and shelf slope waters around Australia. In this paper several glider operations around Australia will be discussed including deployments at the mouth of the Spencer Gulf in South Australia, the continental shelf and shelf slope off Western Australia and the shelf, and East Australian Current eddies off New South Wales. Discussion will focus on WA deployments which represent the first sustained measurements taken in the Southern Hemisphere using ocean gliders.**

I. Introduction

Traditionally, oceanographic sampling has been undertaken from ships; however due to the significant costs of operating an ocean research vessel (of the order of $50,000 per day) and limitations of working in poor weather conditions this has resulted in difficulties in data collection, particularly where sustained, long term, observations are required to examine long term variability. Ocean gliders, autonomous instrument platforms designed to efficiently operate throughout the water column in water depths of up to 1000m, provide an excellent alternative measurement tool. Due to their relatively low cost and extended deployment durations, gliders will allow for the collection of sustained long term observations, even during periods of extreme weather conditions. The resulting long term data sets will enable researchers to better document the variability of the ocean and of coastal ecosystems.

Gliders descend and ascend through the water column by changing their volume and hence their buoyancy; this momentum is converted to forward motion by wings resulting in an average horizontal velocity of 0.25 - 0.40ms^{-1}. Dive pitch is controlled by moving an internal mass (battery pack) and steering is achieved through the use of an active rudder (Slocum) or by the rotation of an off-centre internal mass (Seaglider). Using GPS, internal dead reckoning and altimeter measurements the glider autonomously navigates its way to a series of waypoints. Near real-time data can be uploaded to a base computer via two way Iridium satellite communication, which also allows for remote updating of glider control parameters and waypoints.

The Australian National Facility for Ocean Gliders (ANFOG) has been established as a facility within the Australian Integrated Marine Observation System (IMOS) to develop and operate a fleet of gliders and to provide a near real-time data stream from the continental shelf and slope waters of Australia.

TABLE I
Glider Specifications

	Slocum glider	**Seaglider**
Type	Coastal	Open ocean
Depth Range	20-200m	75-1000m
Length	1.8m (2.15m inc antenna)	1.8m (2.8m inc antenna)
Mass	52 kg	52 kg
Batteries	230 Alkaline C-cells Energy: 8MJ Mass: 18kg	81 Lithium D-cells Energy: 10 MJ Mass: 9.4kg
Max. Volume Change	460 cc	840 cc
Communications	Iridium GPS Navigation Freewave RF-modem ARGOS Transmitter	Iridium GPS Navigation
Steering	Active Rudder	Rotating internal mass
Endurance	30 days	6 months
Range	500 km	4600 km
Speed	40 cm s^{-1}	25 cm s^{-1}

Currently the ANFOG glider fleet consists of 3 Slocum gliders and 5 Seagliders with another 3 Slocum gliders and 6 Seagliders on order. Slocum gliders, manufactured by Teledyne Webb Research are designed to operate to a maximum depth of 200m and have a maximum endurance of 30 days while Seagliders are made by University of Washington and iRobot; these operate to 1000m and have maximum duration of 6 months (Table 1).

All ANFOG gliders have a similar suite of sensors to measure temperature, conductivity, dissolved oxygen (DO), turbidity, coloured dissolved organic matter (CDOM) and chlorophyll-a fluorescence. Currently both Slocum gliders and Seagliders are equipped with a Seabird-CTD & WETLabs BBFL2S three parameter optical sensor (measuring chlorophyll-a fluorescence, CDOM fluorescence and optical backscatter at 660nm). Slocum gliders are equipped with an Aanderra Oxygen optode to measure DO while Seagliders have a Seabird oxygen sensor.

Over the period November 2008 to March 2010 ANFOG has completed 19 successful Slocum glider deployments (Table 2). During this time the Slocum gliders traversed more than 9,000 km and collected over 55,000 vertical profiles of oceanographic data.

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TABLE II
SLOCUM GLIDER DEPLOYMENT STATISTICS (MARCH 2010)

#	Node	Deployed	Recovered	Distance (km)	Duration (days)	Raw Casts
1	NSWIMOS	25-Nov-08	11-Dec-08	1002.8	16	1484
2	SAIMOS	15-Jan-09	05-Feb-09	518.39	21	3594
3	WAIMOS	20-Jan-09	10-Feb-09	486.9	21	2937
4	WAIMOS	20-Feb-09	13-Mar-09	445.0	21	3225
5	WAIMOS	13-Mar-09	27-Mar-09	347.6	14	2232
6	NSWIMOS	17-Mar-09	09-Apr-09	705.6	23	1721
7	WAIMOS	02-Apr-09	27-Apr-09	517.28	25	3939
8	WAIMOS	15-May-09	03-Jun-09	380.0	19	4300
9	SAIMOS	28-May-09	24-Jun-09	599.7	27	3721
10	WAIMOS	03-Jun-09	25-Jun-09	459.34	22	3914
11	WAIMOS	29-Jul-09	11-Aug-09	194.8	13	2083
12	WAIMOS	21-Aug-09	31-Aug-09	202.0	10	2015
13	NSWIMOS	02-Oct-09	29-Oct-09	705.4	27	1765
14	NSWIMOS	28-Oct-09	19-Nov-09	659.6	22	1612
15	SAIMOS	04-Nov-09	26-Nov-09	587.8	22	3731
16	WAIMOS	08-Dec-09	24-Dec-09	220.6	16	1980
17	WAIMOS	22-Jan-10	15-Feb-10	396.1	24	4008
18	SAIMOS	10-Feb-10	04-Mar-10	538.5	22	3440
19	WAIMOS	18-Feb-10	09-Mar-10		19	
			TOTAL	**9366**	**384**	**55,665**

**WAIMOS deployments – Perth, WA, SAIMOS deployments – Spencer Gulf, SA, NSWIMOS deployments – NSW mid-coast*

Over the same period 7 Seaglider deployments were completed (Table 3), 3 off Tasmania, 1 off South Australia, 2 off Western Australia and 1 off New South Wales. A total of 9,769 km was covered during 428 days at sea, while collecting over 6548 vertical profiles.

TABLE III
SEAGLIDER DEPLOYMENT STATISTICS (MARCH 2010)

#	Node	Deployed	Recovered	Distance (km)	Duration (days)	Casts
1	BW	13-Feb-09	14-Apr-09	1200	60	860
2	BW	22-Apr-09	24-Jun-09	875	63	1060
3	WAIMOS	20-May-09	08-Jun-09	480	19	1210
4	SAIMOS	26-May-09	07-Aug-09	1860	73	830
5	NSWIMOS	19-Oct-09	12-Jan-10	2382	85	834
6	WAIMOS	11-Nov-09	16-Jan-10	1185	66	914
7	BW	26-Nov-09	27-Jan-10	1787	62	840
			TOTAL	**9769**	**428**	**6548**

***Bluewater (BW) deployments off eastern Tasmania, WAIMOS deployments – Kalbarri, WA, NSWIMOS deployments – NSW mid-coast & SAIMOS Deployment – Portland, VIC*

II. GLIDER DEPLOYMENTS

A. Western Australia

Measurements taken during glider deployments off Perth, WA between January 2009 and February 2010 represent the first set of sustained glider observations in the Southern Hemisphere. Slocum gliders were deployed on monthly intervals on a cross shore transect from Two Rocks, north of Perth.

This region exhibits circulation unlike other western continental margins where the surface flow is usually equatorward and highly productive due to upwelling [8]. Off WA the Leeuwin Current (LC), a shallow (< 300- m-deep), narrow (< 100-km-wide) band of warm, low salinity, nutrient-depleted water of tropical origin, flows poleward from Exmouth to Cape Leeuwin continuing into the Great Australian Bight [7][8]. The LC is accepted to be the longest boundary current in the world with a signature that extends from North West Cape to Tasmania [7].

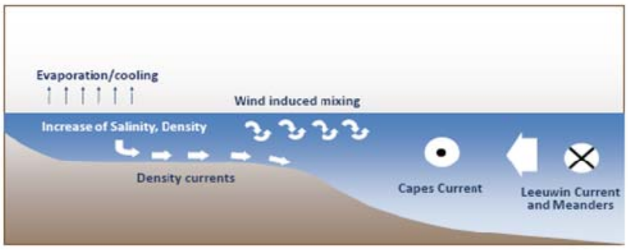

Figure 1. Schematic of circulation off Perth, WA

The continental shelf waters off Perth, WA are influenced by the LC which is generally located along the 200m isobaths and during the summer months by the Capes current (CC), a colder wind driven current, originating between Cape Leeuwin and Cape Naturaliste [6]. The Capes current is generally located inshore of the 50m isobath and has a higher productivity due to upwelling [6]. Previous ship based measurements have shown the existence of a deep chlorophyll maximum off the western Australian coast during the summer months [2]. Data from Slocum deployments has measured the interaction and seasonal variation of the CC and LC.

The south west of Australia experiences a Mediterranean climate with hot dry summers and cool winters. The resultant high evaporation during the summer months causes an increase in the salinity of the inner continental shelf waters. As a result the nearshore waters become more dense that the shelf waters. Slocum glider measurements have shown that in late summer, the higher density water flows off the continental shelf as a gravity current, observed to be up to 20m thick in water depths of 40m (Figure 2 & 3).

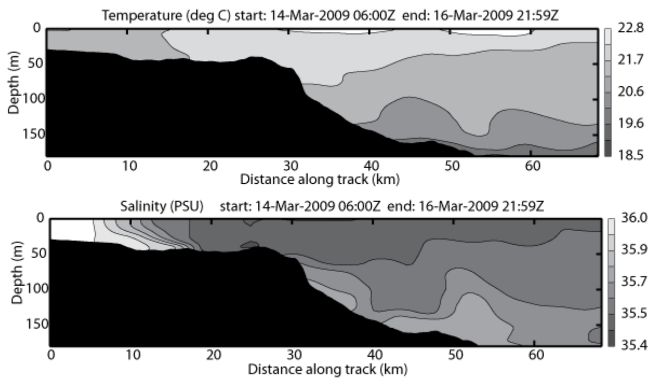

Figure 2. Offshore cross section of Temperature and Salinity off Perth, WA (March 2009)

Subsequent cooling during late autumn and winter results in higher density waters being maintained along the shelf and the dense shelf water cascade (DWSC) persists well into the winter (Figures 4 & 5). In measurements from the end of June 2009 the gravity current appeared to be driven solely by temperature rather than in conjunction with salinity (Figure. 5)

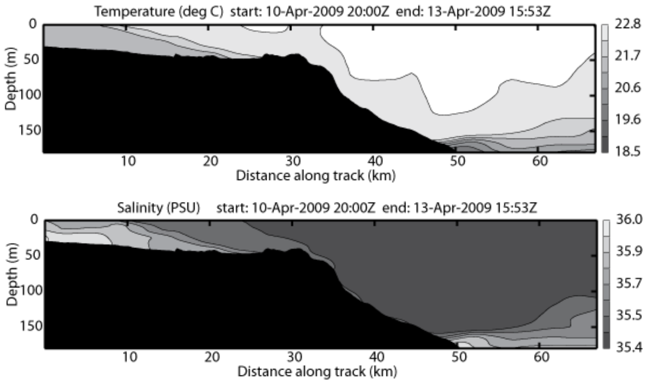

Figure 3. Offshore cross section of Temperature and Salinity off Perth, WA (April 2009)

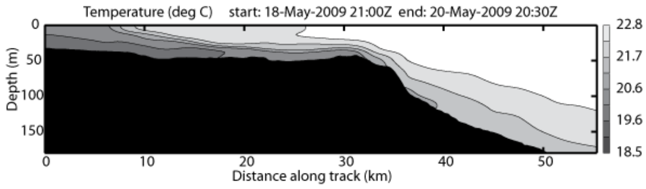

Figure 4. Offshore cross section of Temperature and Salinity off Perth, WA (May 2009)

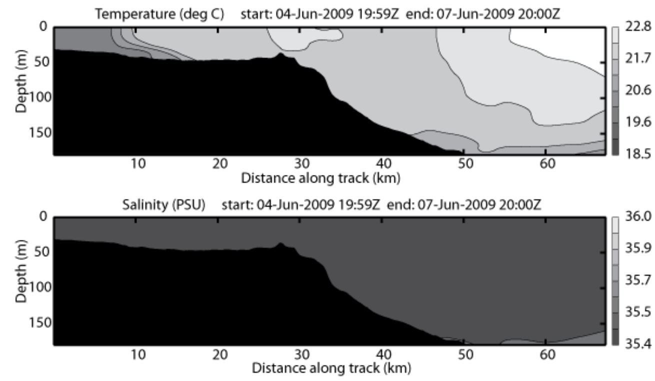

Figure 5. Offshore cross section of Temperature and Salinity off Perth, WA (June 2009)

Increased chlorophyll fluorescence was observed in the frontal region between the CC and LC as well as in the DSWC (Figure 6). The DSWC was found to penetrate up to 150 m water depth and may be an important mechanism for exchange between the shelf and slope waters.

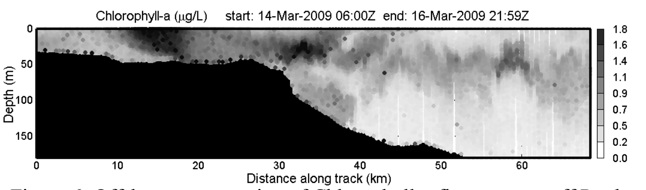

Figure 6. Offshore cross section of Chlorophyll-a fluorescence off Perth, WA (March 2009)

Slocum glider transects are providing the most detailed seasonal oceanographic information to date for the shelf region off Perth, WA.

B. Spencer Gulf

The Spencer Gulf is an inverse estuary located on the south coast of Australia. High evaporation in the Gulf leads to a strong salinity gradient which decreases toward the open boundary [4]. During winter, cooling in the upper reaches of the gulf results the water becoming more dense than the adjacent shelf waters which causes the high salinity water to exit the Gulf as a gravity current [4]. Due to the effects of Coriolis this outflow is concentrated to the eastern side of the gulf and shelf waters flow in to replace it along the western boundary [5]. The outflow is modulated by the spring-neap tidal cycle [3]. Glider deployments in this region aim to monitor seasonal and long term variability in continental shelf – Spencer Gulf exchange.

Glider observations from June 2009 clearly show a cool high salinity water mass on the eastern side of the Gulf entrance characteristic of the winter Gulf-continental shelf exchange (Figure 7).

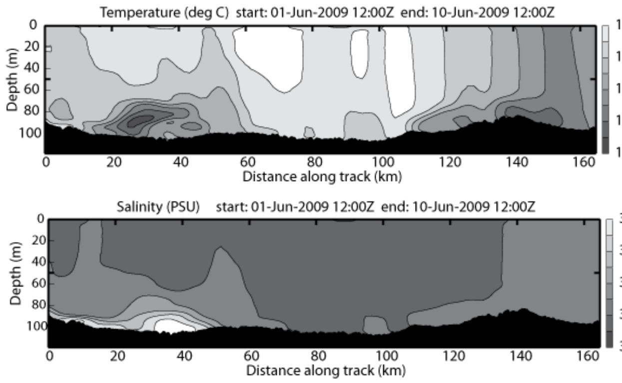

Figure 7. East to west temperature and salinity cross sections across the mouth of the Spencer Gulf, SA (June 2009)

Consistent with past observations, measurements taken during glider deployments during the summer months show strong temperature and salinity stratification across the mouth of the Gulf and do not indicate a near bottom saline outflow (Figure 8).

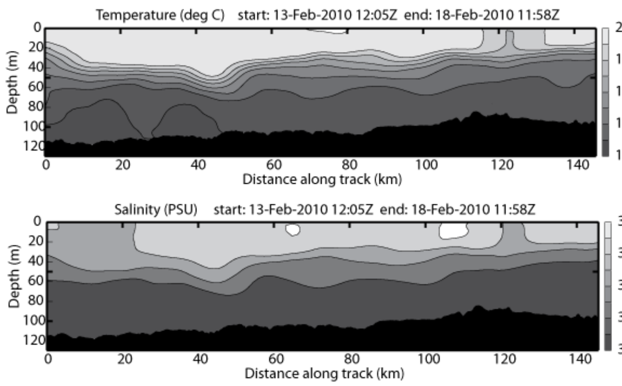

Figure 8. East to west temperature and salinity cross sections across the mouth of the Spencer Gulf, SA (February 2010)

C. New South Wales

The shelf waters of Sydney are influenced by the East Australian current (EAC), the western boundary current of the South Pacific subtropical gyre that affects the flow along much of the eastern coasts of Australia and New Zealand. Extending from the Coral Sea to the Tasman Sea, the EAC system generates numerous eddies [1]. EAC transport (southward flow) varies between a minimum of 7 Sv in winter (July) to a maximum of 16 Sv in summer [1].

A Slocum glider was used to monitor the physical and biological processes within a warm core eddy in November 2008 and revealed strong physical/biological interaction. After deployment off Port Stephens, the glider was transported by the EAC southwards parallel to the coast before entering the eddy. The glider was then flown into the centre of the eddy, and then back out again while undertaking one rotation of the eddy (Figure 9).

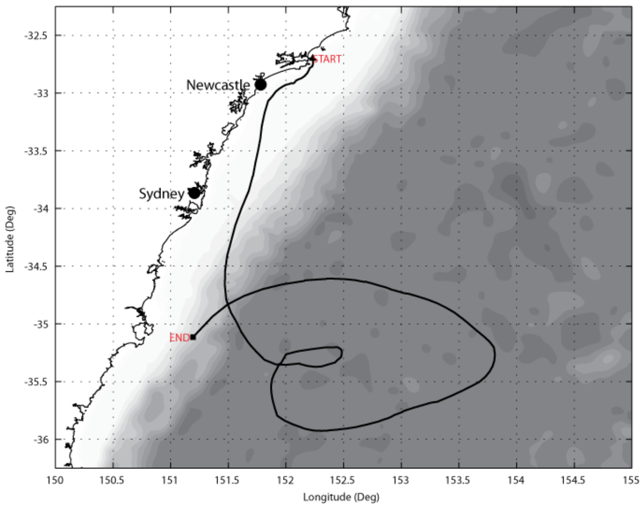

Figure 9. Slocum glider path during deployment (Nov-Dec 2008)

Observations of the eddy showed a complex vertical structure with a well mixed surface layer of 50-70 m depth and a subsurface chlorophyll maximum (SCM) below the thermocline. Chlorophyll fluorescence within the SCM was approximately an order of magnitude greater than observed in the rest of the water column (Figure 10).

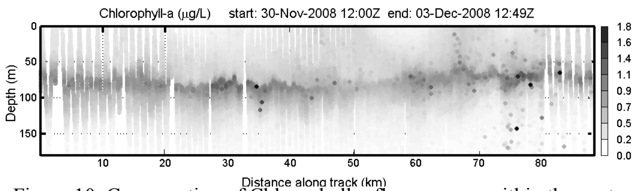

Figure 10. Cross section of Chlorophyll-a fluorescence within the centre of the warm core eddy (Nov-Dec 2009)

D. Tasmania

Three Seaglider deployments have been completed off eastern Tasmania, monitoring the East Australian current in this region. The Seaglider deployments off eastern Tasmania monitored the East Australian current in this region – the glider was entrained into an eddy and revealed very strong currents within the region (Figure 11).

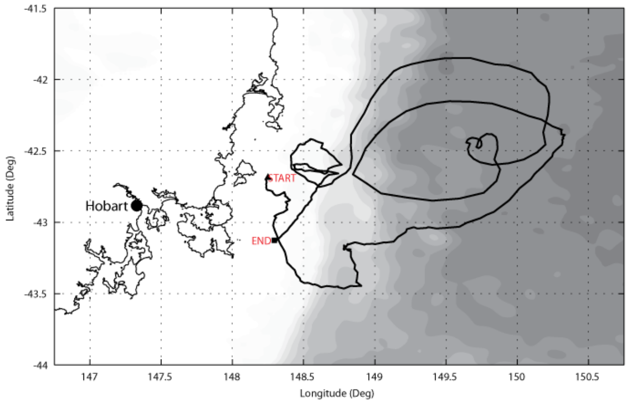

Figure 11. Seaglider glider path during deployment (Feb-Apr 2009)

ACKNOWLEDGMENT

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