Initial Investigation of the North East Pacific Salmon Feeding Waters with Slocum Gliders

John S. Bird
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6
Canada
Email: jbird@sfu.ca

Peter Gross
William McNea
Heather Judd
Haida Salmon Restoration Corporation
Vancouver, BC, Canada
Email: peter.hsrc@gmail.com

***Abstract*—With the decline in the number of salmon returning to the West Coast of Canada despite efforts to improve land-based habitat and increase hatchery releases, attention is turning to the condition of salmon ocean habitat for a reason. The offshore ocean habitat of salmon is complex and needs to be monitored continuously to facilitate an understanding of the dynamics. In preparation for long term monitoring an initial investigation was conducted to explore the suitability of ocean gliders for such a task. Three specific glider missions were executed with Slocum gliders: a long-range transit mission, a water property change mission, and a plankton bloom mission. The gliders were remotely navigated through the three missions using real-time satellite data. The long-range transit mission demonstrated successful near shore launch and recovery coupled with an extended deep sea mission. The water property change mission explored the water properties of a second year Haida Eddy. The plankton bloom mission tested the glider's ability to collect data associated with biological productivity by navigating the glider inside a second year Haida Eddy that was fertilized with iron to stimulate a plankton bloom. The data collected on the three missions is discussed in the context of images of temperature, salinity, sound velocity, water density, CDOM, and chlorophyll. These three missions demonstrated a glider's ability to collect high quality data that is requisite for understanding the dynamics of ocean waters and for developing effective management protocols for ocean salmon habitat.**

I. Introduction

Juvenile salmon emerge from rivers and streams of the West Coast of British Columbia to feed and mature in the North East Pacific Ocean. Although every year more salmon fry from hatcheries are released, fewer and fewer mature fish are returning to spawn [1]. The reasons for the poor returns are under investigation and may be linked to the health of their feeding waters in the North East Pacific Ocean. The physical characteristics of these waters (temperature, salinity, dissolved oxygen, pH, nutrients, etc.) directly influence salmon distribution through preferences [2], and indirectly through food production [3].

In the North East Pacific large eddies called Haida Eddies play a significant role in determining the quality of fish habitat. As described in [4] and associated references, these eddies form in late winter off the west coast of Haida Gwaii and then migrate westward. They range in size from about 150 to 300 km in diameter and have surface heights of up to 40 cm. The rotational speeds of these anticylonic eddies can be more than 30 cm/s. They are warm core eddies with the core waters bearing distinctive coastal water signatures. The surface waters tend to be more horizontally driven and therefore take on the characteristics of surrounding surface waters. These eddies have a distinctive satellite height signature for about two years, but the core properties, although weakened, can persist even longer.

Haida Eddies appear to significantly influence the biological activity of the area as well as serving as a transportation mechanism. In their birth year they supply nutrients and iron to the surface waters spawning plankton blooms. Second year plankton blooms are not so common and the water is described as being largely HNLC (high nitrate, low chlorophyll).

The physical and biological dynamics of the North East Pacific Ocean are intimately connected to the wellbeing of Pacific Salmon, whose spawning rivers are not only those along the West Coast of Canada and Alaska but also Japan, Korea, and Russia [1],[5]. In an effort to understand these complex dynamics it is proposed that a fleet of gliders be commissioned to collect data on a year round basis. In preparation for such a deployment an initial investigation was conducted to explore both first and second year Haida Eddies using Slocum gliders [6], Argo ocean drifters and ship-base instrumentation. This paper describes the glider portion of this initial investigation.

The initial investigation was launched in the summer of 2012 and consisted of three specific glider missions. The first was a long-range transit mission in which a glider was launched off the West Coast of Vancouver Island, navigated through a first-year Haida Eddy, and then recovered off the West Coast of Haida Gwaii. On the second mission the glider transited from inside a second-year Haida Eddy to the edge and then back inside again. The third mission consisted of a glider transiting inside a second-year Haida Eddy that was fertilized with iron to stimulate a plankton bloom. Satellite data was employed to monitor ocean surface elevation, surface currents, chlorophyll, and to adaptively navigate the gliders [7].

The paper begins with this introduction followed by a description of the gliders, their instrumentation and typical mission dynamics. Then the three missions along with exam-

978-0-933957-40-4 ©2013 MTS

Fig. 1. Solcum glider being prepared for launch.

ples of results are described and conclusion drawn. Finally, recommendations are made for future work with regard to a permanent glider presence in the North East Pacific.

II. Slocum Gliders, Instrumentation and Mission Dynamics

Fig. 1 shows one of the Slocum gliders used on the project being prepared for a mission. Slocum gliders alter their density and thereby descend or ascend in the water column. This vertical motion is converted into horizontal motion by wings. Hence the overall motion is described as a saw-tooth pattern oscillating from a minimum depth to a maximum depth. This efficient means of motion conserves battery life allowing extended ocean missions. The saw-tooth path of the vehicle through the water column makes it suitable for measuring ocean parameters that vary sharply in the vertical direction and moderately in the horizontal.

Two Slocum gliders were employed in the project, each having a maximum depth capability of 200 m. The gliders were provided by the Canadian Center for Ocean Gliders. The gliders were equipped with a Wetlabs BBFLslo custom 3-parameter fluorescence/scattering optical sensor, an Aanderaa Optode 3835 oxygen sensor, and a CTD41CP Seabird CTD (SBE-41) conductivity, temperature, depth sensor.

Typically the gliders were programmed to surface every two hours to upload data and to receive instructions. Otherwise the gliders were programmed to perform a saw-tooth pattern with a minimum depth of 4 m to a maximum depth of 186 m. Fig. 2 shows a typical series of yo's versus the distance covered between surfacing. A yo consists of a transit from minimum depth to maximum depth and then back to the minimum depth again. Each yo covered approximately 0.5 linear km depending on currents.

For the analysis in this paper the yo's were divided into ascending and descending legs and the data for each leg was analyzed and plotted separately. The separate ascending and descending images serve as one check for consistency in the data. As a result of the transit time for the yo's, the ascending and descending images have horizontal data point densities of approximately 2 per km. The images for the data shown later

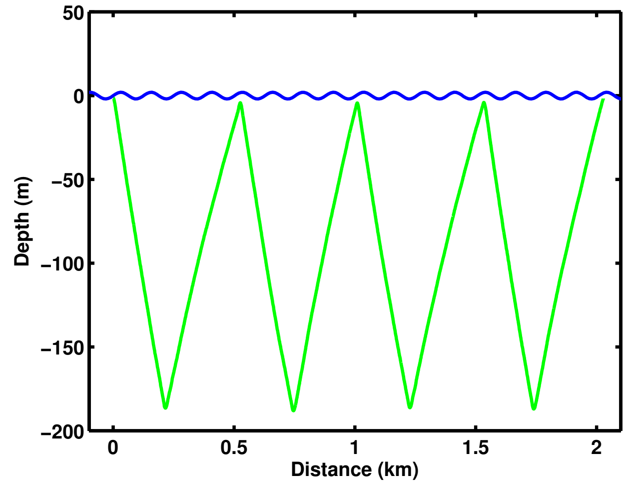

Fig. 2. Series of glider yo's versus distance traveled. Data taken from the long-range transit mission.

in the paper have a pixel resolution of 0.5 km in the horizontal and 1 m in the vertical.

III. Glider Missions

Three glider missions were conducted to investigate the potential for gliders to provide information related to the wellbeing of the salmon feeding waters off the West Coast of Canada. The first mission demonstrates a near coast launch and recovery with an extensive adaptive ocean transit between launch and recovery points. The second mission records differences in water properties as the glider transits from inside a second year Haida Eddy to the edge and then back inside again. The third mission focuses on measurements within a plankton bloom that was spawned by enriching the surface waters with iron.

A. Long-Range Transit Mission

The long range transit mission shown in Fig. 3 was designed to demonstrate near coast launch and recovery along with an extensive adaptive transit between launch and recovery sites. The glider was launched just off the Northern Coast of Vancouver Island, transiting in a northerly direction until it came close to a first year Haida Eddy as determined by real-time satellite ocean surface elevation data. The glider was turned to cross the center of the eddy and then complete its transit to the central coast of Haida Gwaii for recovery.

The mission began at 2343 on June 20, 2012 and ended at 1547 on July 12, 2012 for a duration of just under 20 days. The contours in Fig 3 represent the surface height at determined by historical satellite data with warmer colors indicating higher surface height. The arrows represent surface currents. The glider's path is shown in black with a red section and a green section for reference later in the discussion about the sensor data. It should be noted that although the real-time satellite data shows the glider transiting the center of the Haida Eddy,

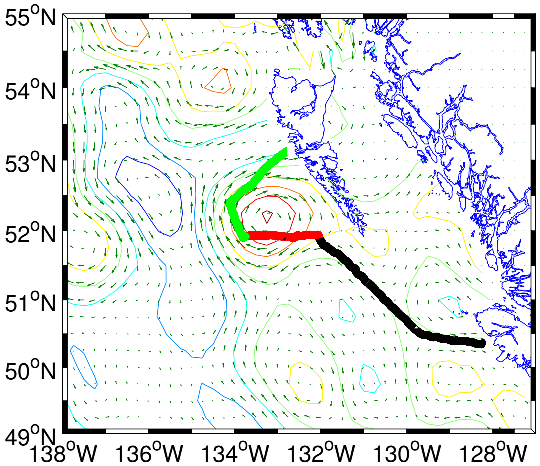

Fig. 3. Long-range transit mission. Contours show ocean elevation with warm colors indicating higher elevation. Blue arrows represent surface currents. The thick solid line, shown in black, red and green, is the glider path.

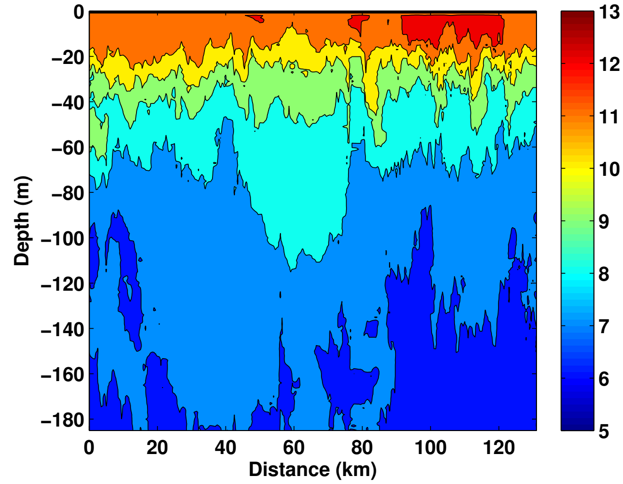

Fig. 4. Dive temperature (C^o) for the red portion of the long-range glider path.

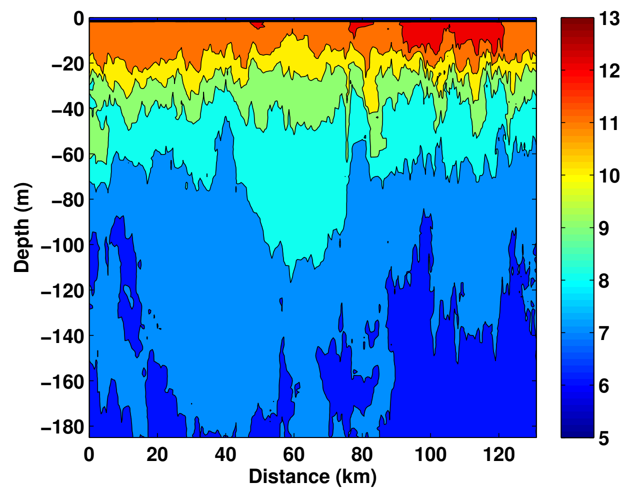

Fig. 5. Ascend temperature (C^o) for the red portion of the long-range glider path.

the historical (supposedly more accurate) satellite data shows the glider just South of the eddy center.

For the interesting portion of the glider path shown in red that goes through the eddy, detailed temperature and salinity data are presented for both the ascend and diving portions of the glider's vertical yo's to establish consistency between these independent data sets. Thereafter, only ascend data sets are shown. Also, it should be noted that the optical sensor used to determine chlorophyll and CDOM, the oxygen sensor, and the CTD are completely independent sensors.

Temperature data from the section in red on the transit (near the center of the eddy and going from right to left) are shown in Fig. 4 for the descending profiles and in Fig. 5 for the ascending profiles. There is not much difference between the ascending and descending images - they both show the same variations and relationships with depth and horizontal distance. This consistency in the images even though the data for each are independent (i.e. samples from different locations horizontally and vertically) speaks to the credibility of the measurements and the variations displayed.

Three features stand out in these temperature images, a general vertical stratification, a bowl shape in the stratification, and the diversity of small scale variations The images show a bowl shaped body of warm water starting at a horizontal distance of 40 km descending from the thermocline to a depth of about 100 m with a horizontal extent of about 30 km. There is also evidence of a broader bowl extending to 180 m depth consisting of cooler water but still warmer than the surrounding water. These bowl shaped warm bodies of water are consistent warm core eddies. The diversity of small scale variations indicates the unique ability of gliders to capture a sense of the horizontal variation of ocean characteristics. However, it should be remembered that the horizontal scale is about 1000 times the vertical scale (i.e. km versus m).

Salinity data for the portion of the glider path shown in red are shown in Figs. 6 and 7 for the diving and ascending profiles respectively. The salinity images were determined from CTD data after a correction was applied for the thermal lag of the conductivity cell [8]. It is again noted that the image obtained from the dive profiles is nearly the same as that obtained from the ascend profiles. The bowl shaped stratification that was evident in the temperature images is also evident in the salinity images. There is also an abundance of small scale variations in the images.

Fig. 8 shows the density of the ocean water along the red path of the glider, and again the bowl shape stratification and small scale variations are evident.

Sound velocity in water is an interesting characteristic that can be calculated from depth, temperature, and salinity. Sound velocity is used to determine the propagation of sound in the ocean for applications of submarine detection, cetacean

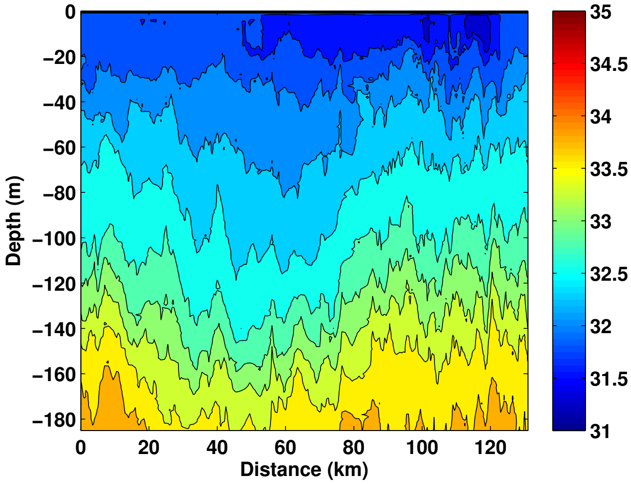

Fig. 6. Dive salinity (PSU) for the red portion of the long-range glider path.

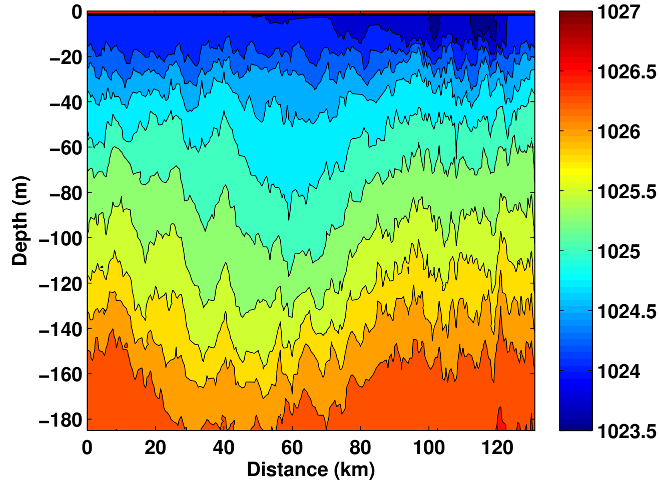

Fig. 8. Ascend density (kg/m^3) for the red portion of the long-range glider path.

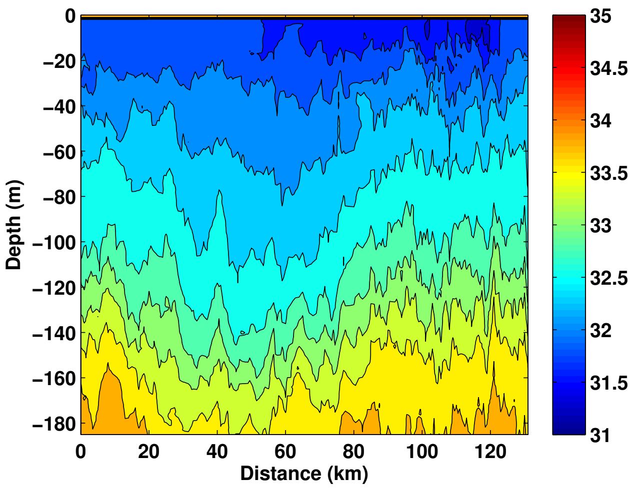

Fig. 7. Ascend salinity (PSU) for the red portion of the long-range glider path.

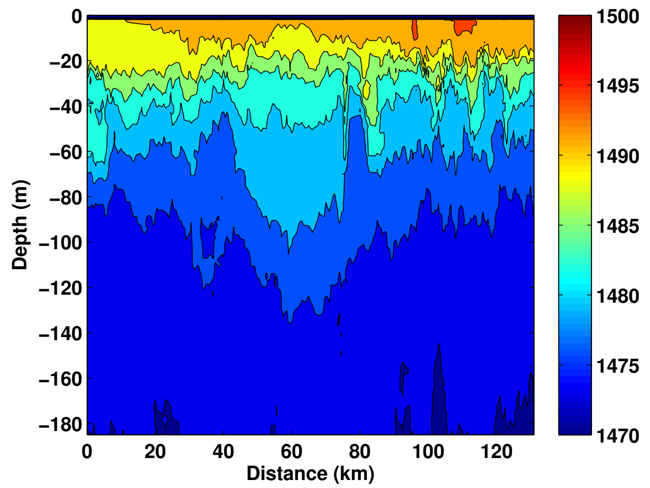

Fig. 9. Ascend sound velocity (m/s) for the red portion of the long-range glider path.

detection and research, ambient noise source identification and detection, etc. Fig. 9 shows the image calculated for sound velocity for the red portion of the glider's path (Leroy's calculation method was used [9]). The sound velocity also shows the characteristic bowl shaped stratification and small scale variation. The stratification is more or less monotonic in this upper part of the water column, from faster water near the surface to slower water at 180 m depth. It would be interesting to study the influence that this kind of complex horizontal and vertical variation of sound velocity has on sound propagation.

Fig. 10 shows oxygen saturation for the red portion of the glider's path. The bowl shape stratification in the deeper water and small scale variations are evident. The oxygen level in the upper 15 to 20 m of the water column is high and relatively constant.

Fig. 11 shows an image of the chlorophyll present during the red portion of the glider's path. These data are displayed without contour lines because the only significant contribution was near the surface. It is noted that there seems to be a weaker chlorophyll signature near the shallower/narrower bowl shaped contours for the temperature data in Figs 4 and 5. The strongest chlorophyll signature (around 90 to 130 km) is from when the glider approaches the far side of the eddy.

Fig. 12 shows an image of CDOM (colored dissolved organic matter) present during the red portion of the glider's path. The scale for CDOM ranges from 0.3 to 375 ppb and the range of the variation in the image is only from about 1 to 3. Therefore, the instrument was working very much at the low end of the scale resulting in a grainy image. Nevertheless, the instrument did show some interesting variation especially in the vicinity of the narrow bowl shaped core of water. Here the CDOM seems to extend down to the level found in the deeper water. It is uncertain what this behavior means but it

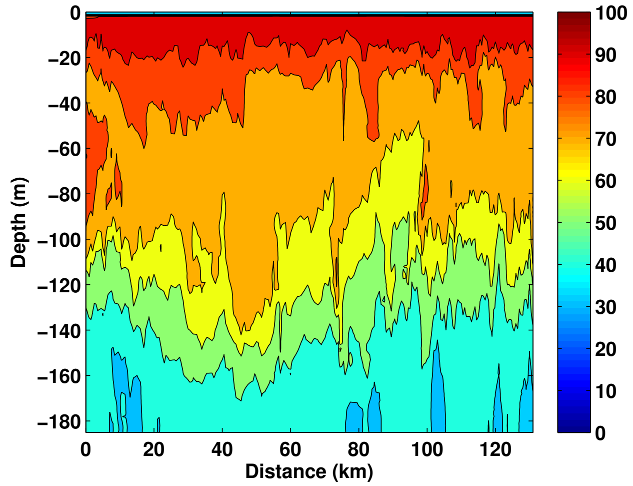

Fig. 10. Ascending oxygen saturation (%) for the red portion of the long-range glider path..

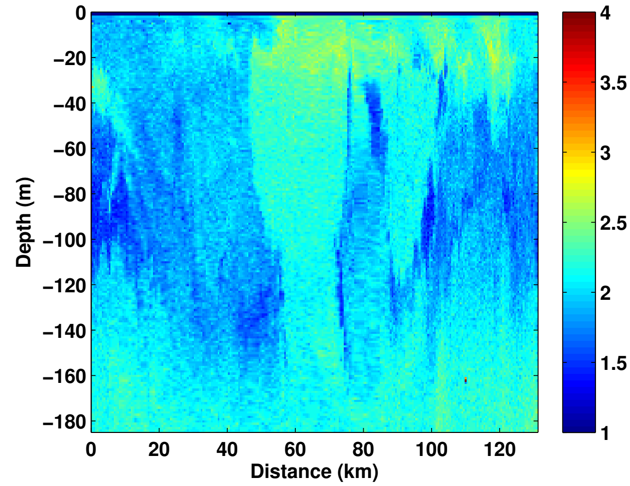

Fig. 12. Ascending CDOM, colored dissolved organic matter, (ppb), for the red portion of the long-range glider path.

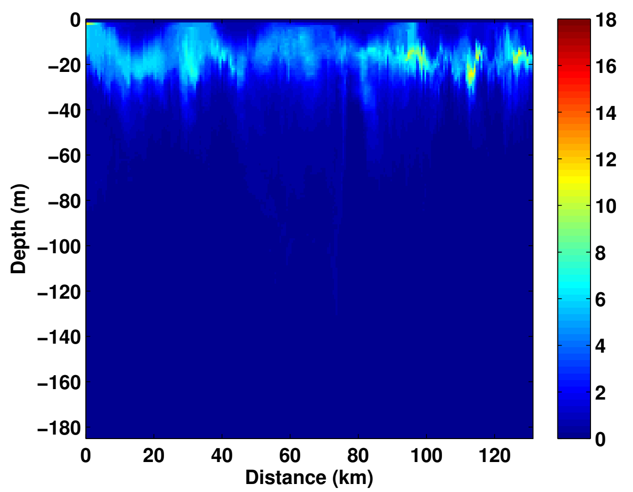

Fig. 11. Ascending chlorophyll (μg/l) for the red portion of the long-range glider path.

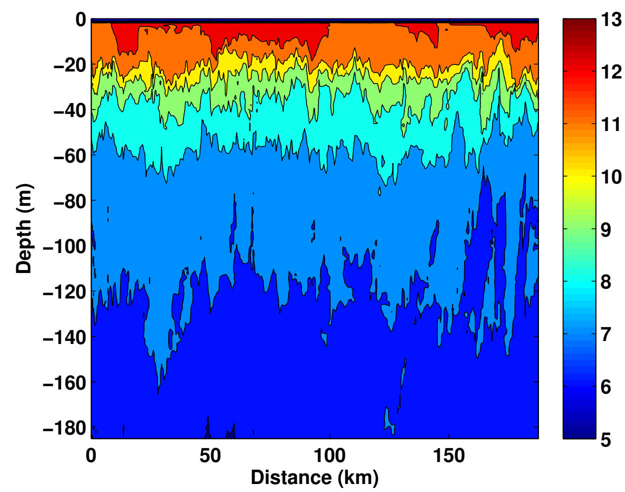

Fig. 13. Ascending temperature (C^o) for the green portion of the long-range glider path.

is interesting.

The green portion of the glider's path stays more or less inside the edge of the eddy and hence it is expected that there would not be a bowl shape to the vertical stratification. Fig. 13 shows the temperature image for the green portion of the gliders path and as expected the stratification is relatively flat except for small scale variations.

The chlorophyll signature for the green portion of the glider's path is shown in Fig. 14. It shows a weak chlorophyll signature until near the end of the mission when the vehicle was near the coast of Haida Gwaii. The increased chlorophyll in this region is thought to be due to the nutrient concentration near the coast.

B. Water Property Change Mission

This mission was designed to explore water properties as the glider moved from inside an eddy towards the outside and back again. The reason for moving back again but in a different location gave an opportunity to check if the water properties are the same toward the interior even if that interior is approached from a different direction. Fig. 15 shows the location of the eddy and the path of the glider. This eddy was a second year eddy about 300 km off the coast of Haida Gwaii. The path of the glider was from East to West from inside the eddy to the edge and then back in again in a South East direction.

Fig. 16 shows the image for the temperature for the glider path as it transited to the edge of the eddy and back again. The temperature is well stratified in the upper layers but inside

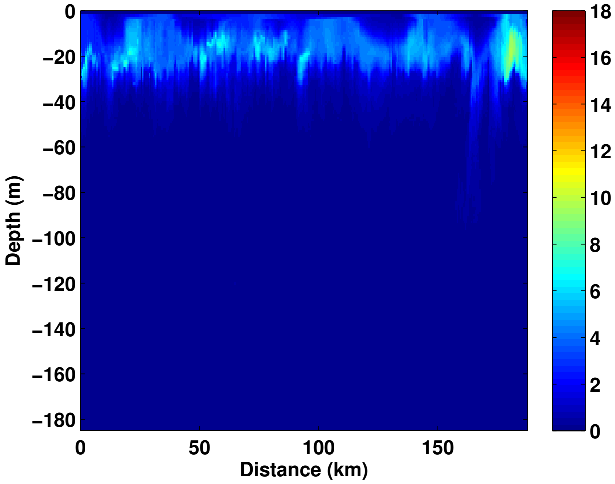

Fig. 14. Ascending chlorophyll (μg/l)for the green portion of the long-range glider path.

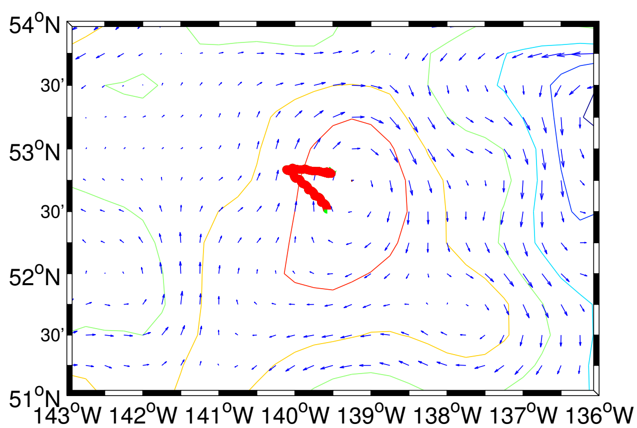

Fig. 15. Path of glider for water property change mission. The glider travels West to the edge of the eddy and then South East back into the eddy.

the eddy there is a layer of cold water sandwiched between a two layers of warmer water. As the edge of the eddy is approached the warmer deeper water disappears and the water is cold down to the maximum depth that the vehicle reached. As the vehicle transited back into the eddy the deeper warm water appears again which is a verification that it was there in the first place.

While it is true that there is a dramatic change in the temperature image from inside to the edge of the eddy, the density image shown in Fig. 17 shows a rather uniform horizontal stratification. The density contours are somewhat wider at the edges for deeper water where the warmer water is located but there is no inversion of density for the cooler water above the warmer water. This stratification indicates that there is not much vertical movement despite the variation in temperature. Hence, within the eddy the bodies of water

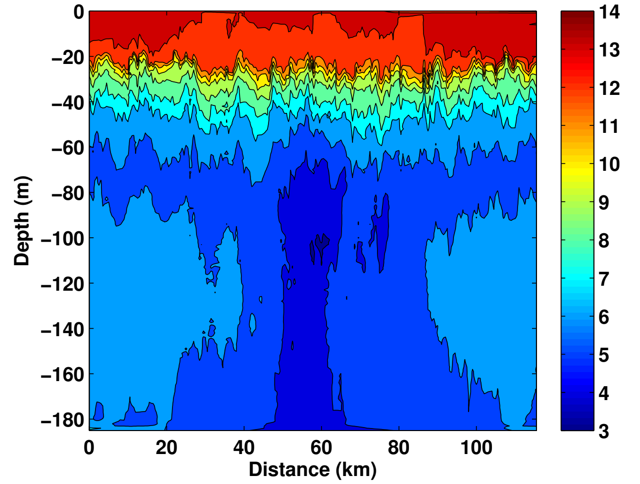

Fig. 16. Ascend temperature (C^o) for water property change mission.

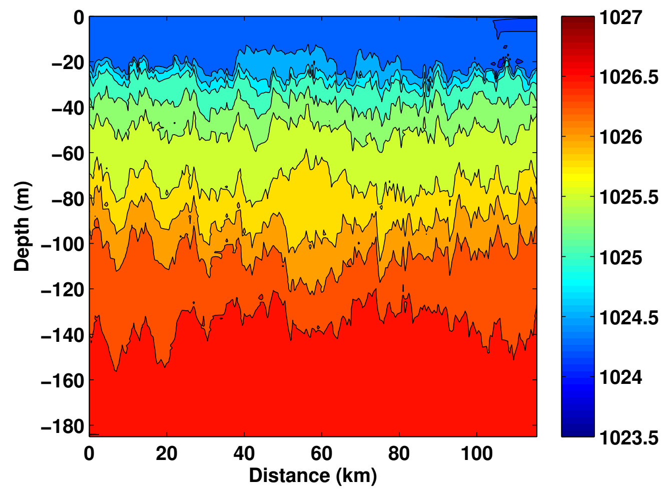

Fig. 17. Ascend density in kg/m^3 for water property change mission.

indicated by the temperature variations appear to have retained properties of their origin and are distributed in the water column according to density with little mixing.

The variation in water properties described above leads to the velocity of sound image shown in Fig. 18. Within the eddy there is a layer of slower water between two layers of faster water which tends to cause a local shallow sound channel.

C. Plankton Bloom Mission

The third glider mission is shown in black in Fig. 19. The mission consisted of a triangular run inside a second year Haida Eddy and then branches out on a NNW run. The Haida Eddy is evident by contour lines showing ocean elevation, with the warmer colors indicating higher elevation. The blue arrows indicate the surface currents as determined from satellite data.

These waters are typically described as HNLC (high nitrate low chlorophyll) [10], however, before the mission began two fertilizations with iron sulphate took place. The ship's

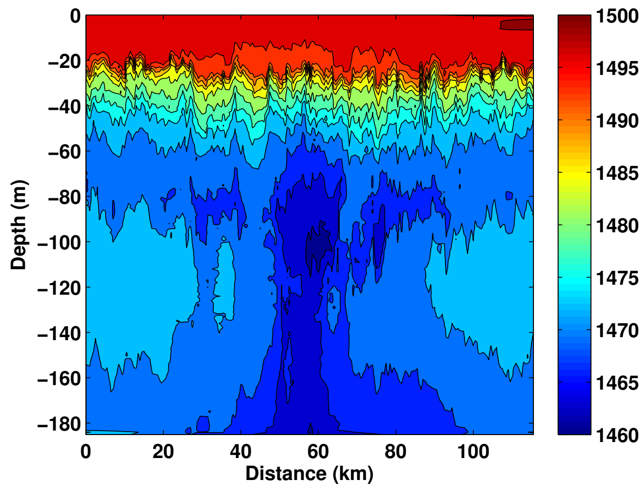

Fig. 18. Ascend sound velocity (m/s) for water property change mission.

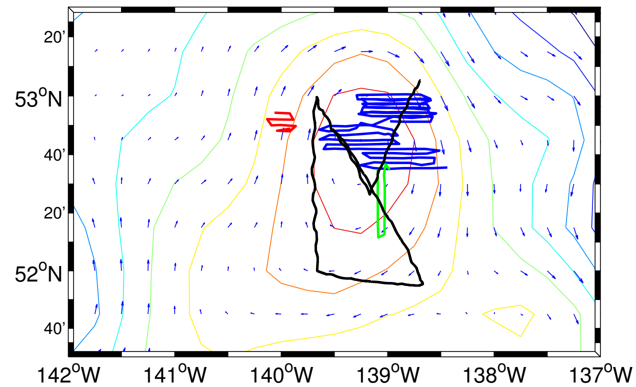

Fig. 19. Plankton bloom mission. The contours show elevation of the ocean with warm colors indicating higher elevation. The blue arrows represent the surface currents. The path of the glider is shown as a black line. The ship's track for first fertilization is shown in blue, the second in red, and the third in green.

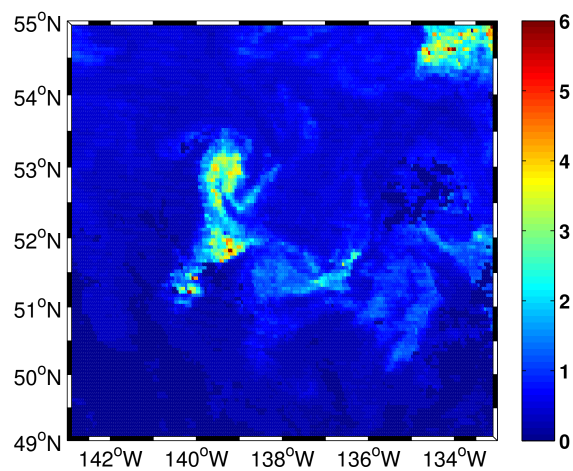

Fig. 20. Large scale composite of plankton bloom (μg/l) generated from satellite data.

tracks for these deployments are marked in blue for the first deployment and red for the second. The first fertilization took place between July 22, 1500 UTC and July 30, 0300 UTC, 2012. This first fertilization consisted of deploying 90 tons of iron sulphate at a rate of 1000 pounds per hour. The fertilization area is roughly 1 degree wide (East/West) at an average latitude of 52.7 degrees North, and 0.5 degrees tall (North/South), which translates into an area of 3,755 km^2. Therefore, the surface concentration of the deployment was approximately 21.7 kg/km^2. The expectation was that this trace amount of iron would be sufficient to stimulate a measurable plankton bloom in these HNLC waters.

The second fertilization (marked in red on Fig. 19) took place between August 16, 1500 UTC and August 17, 0200 UTC, 2012. This second fertilization consisted of deploying 10 tons of iron sulphate. A third fertilization took place after the glider was launched and is marked in green on Fig. 19. This fertilization consisted of deploying 20 tons of iron sulphate between August 18, 1500 UTC and August 19, 0500 UTC, 2012.

This area of the Pacific Ocean is notorious for cloud cover so obtaining good satellite coverage to verify a plankton bloom was difficult because satellites use optical sensors to detect such signatures. However, the cloud cover did break sufficiently on August 25, 29, and 30, 2012 to build a composite picture of the area. This composite picture is shown in Fig. 20. The area of interest is centered around 139.5^{o}W and 52.5^{o}N. The bright colors indicate a plankton bloom. There are also bright colors in the North East corner of the figure but this area is close to the coast of Haida Gwaii where plankton blooms are more frequent. The color scale for the composite satellite chlorophyll image ranges from 0 to 6 μg/l which is different from the color scale used for the chlorophyll images obtained from the glider data which ranges from 0 to 18 μg/l. The reason for the difference is that the satellite image appears quite washed out if a scale of 0 to 18 μg/l is used. Therefore, to gain contrast in the satellite image a different scale was used. Comparisons of the chlorophyll levels are made later in this section.

Fig. 21 shows a close-up of the fertilized area along with the path of the glider. This glider mission began at 1754 on August 17, and ended at 1621 on September 4, 2012. By comparing the location of the glider path with that shown in Fig. 19, the position of the plankton bloom with respect to the location of the eddy and the fertilization is evident. The part of the path shown in red corresponds to the data shown in the next three figures that relate to the beginning of the mission, closer to the time of fertilization. The part of the glider path shown in checkered black and white corresponds to the days that the satellite data was available to build the

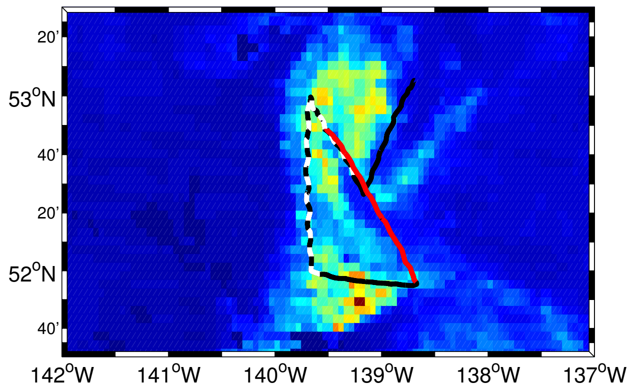

Fig. 21. Small scale composite of plankton bloom (μg/l) generated from satellite data. The glider path is shown as a black, red, and black and white checkered line.

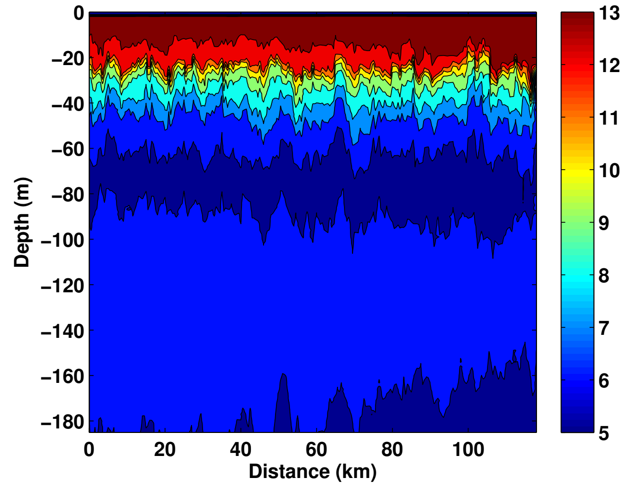

Fig. 22. Ascend temperature (C^o) for red portion of the glider path for the plankton bloom mission.

composite chlorophyll image. It is noted that the latter part of the checkered path is nearly the same as the beginning part of the red path. Therefore, the glider covered the same part of the ocean 14 days later. This overlap will be employed in comparing the chlorophyll data to follow.

Fig. 22 shows the temperature image for the red portion of the glider path shown in Fig. 21. The water is well stratified with respect to temperature with a cold layer at a depth of approximately 60 to 80 m sandwiched between slightly warmer water. This cold layer is consistent with the temperature data for mission 2 shown in Fig. 16 where the lower warmer water gives way to cooler water as the edge of the eddy is approached. The possibility of this giving way is evident in Fig. 22 by the rising and thinning of the warm layer toward the end of this leg of the mission, but the glider did not go far enough to confirm the conclusion.

Fig. 23 shows the chlorophyll signature recorded by the glider on the red portion of the plankton bloom mission. This figure should be compared with Figs. 11 and 14 that show the chlorophyll signatures for the long-range transit mission (mission 1) as the glider transited through a first year Haida Eddy. The chlorophyll signatures for the long-range transit mission are weaker (maximum of 10 to 12 ug/l) and less definite. The maximum levels for the bloom mission are around 18 ug/l and the chlorophyll is much more widely spread although still restricted to the top 40 m of water.

Fig. 24 shows the oxygen saturation image for the portion of the bloom mission marked in red. The oxygen is stratified with the higher saturation levels near the surface. There does not appear to be a variation in oxygen saturation related to the biological activity taking place at the time. The general downward slope of oxygen saturation for the deeper water with increasing distance coincides with a similar trend for the temperature data in Fig. 22

Fig. 25 shows the chlorophyll levels measured by the glider

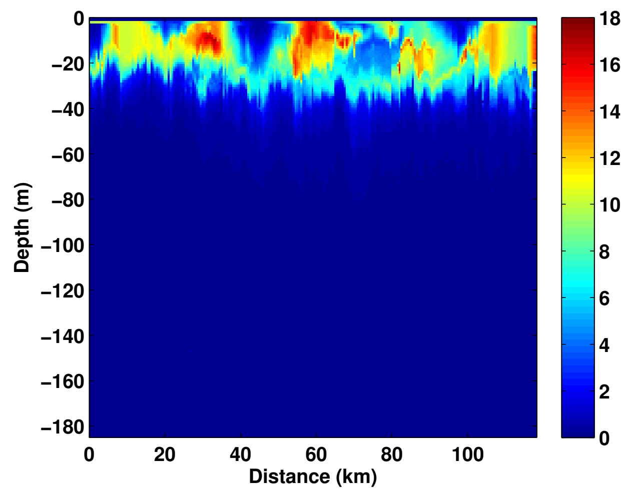

Fig. 23. Ascend chlorophyll (μg/l) for red portion of the glider path for the plankton bloom mission.

during the checkered black and white path shown in Fig. 21. The time span for this portion of the glider path corresponds with the time span for the satellite images that make up the composite satellite image of the plankton bloom. In comparing this chlorophyll image with that for the red portion of the glider path (Fig. 23), it is noted that the overall levels are lower. Specifically, the chlorophyll signature for the part of this image (the last 50 km) that overlaps with the image in Fig. 23 (the first 50 km) is significantly lower. Therefore, after returning to the same location in the ocean 14 days later the chlorophyll levels dropped from an maximum of about 18 to a maximum of about 7 μg/l. The maximum chlorophyll signature from the composite satellite image for the period of time spanned by Fig. 25 (i.e. the black and white checked portion of glider path) is 6 μg/l which is consistent with the signatures shown in Fig. 25.

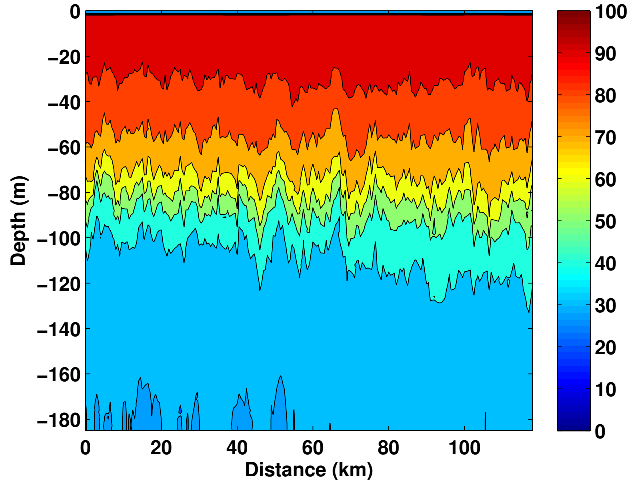

Fig. 24. Ascend oxygen saturation (%) for red portion of the glider path for the plankton bloom mission.

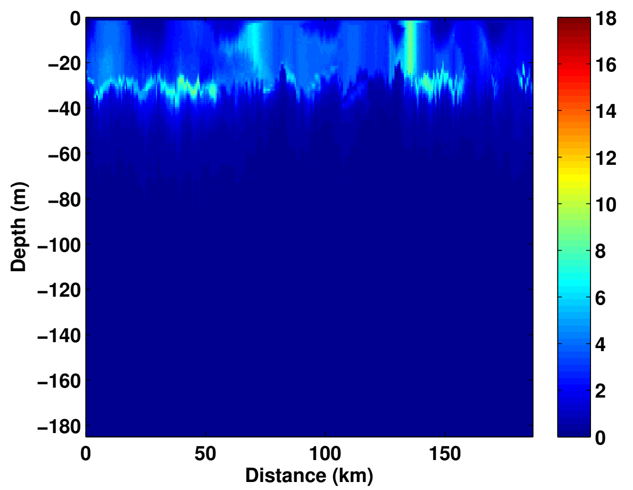

Fig. 25. Ascend chlorophyll (μg/l) for black and white checkered portion of the glider path for the plankton bloom mission.

The plankton bloom glider mission demonstrated the glider's ability to collect data associated with biological productivity.

IV. Conclusion and Recommendations

With the decline in the number of salmon returning to the West Coast of Canada despite efforts to improve land-based habitat and increase hatchery releases, attention is turning to the condition of their ocean habitat for a reason. The offshore ocean habitat of salmon is complex and needs to be monitored continuously to facilitate an understanding of the dynamics for the purpose of developing management protocols. To collect the requisite data, it is proposed that a fleet of gliders operate continuously off the West Coast of Canada. The missions of these gliders would be directed from shore using real-time satellite and glider data.

In preparation for such a deployment an initial investigation was conducted to explore Haida Eddies using Slocum gliders. Three specific glider missions were executed: a long-range transit mission, a water property change mission, and a plankton bloom mission. The long-range transit mission demonstrated successful near shore launch and recovery coupled with an extended deep sea mission. The glider was successfully navigated through a first year Haida Eddy guided by real-time satellite ocean elevation data. Also demonstrated was the glider's ability to collect two sets of consistent independent data, one on descent and one on ascent.

The water property change mission explored the water properties of a second year Haida Eddy. The glider was navigated from inside the eddy to the edge and back inside again. The water properties were observed to change as the edge was approached, and as the glider returned to inside the eddy, the water properties returned to their initial values and distributions. This mission demonstrate the glider's ability to collect consistent data sets in dynamic environments.

The plankton bloom mission was designed to test the glider's ability to collect data associated with biological productivity. The glider was directed on a triangular path inside a second year Haida Eddy that was fertilized with iron to stimulate a plankton bloom. Plankton signatures obtained from the glider indicated the presence of the bloom. Glider chlorophyll levels measured over a period of time when satellite measured chlorophyll levels were available were consistent with the satellite measured levels - important because of the persistent cloud cover in this region.

It is concluded that a fleet of continuously active remotely navigated gliders operating off the West Coast of Canada would provide data requisite for understanding the dynamics of these waters and for developing effective management protocols.

Acknowledgment

The authors would like to thank Mr. Terry Curran for his diligent organization of the glider data and his help in handling the gliders. We would also like to thank Mr. Paul Lacroix (Canadian Centre for Ocean Gliders) for providing the gliders, helping to handle the gliders, and patiently instructing in their use.

References

[1] R.T. Lackey, "Pacific Northwest Salmon: Forecasting Their Status in 2100", *Reviews in Fisheries Science*, 11(1), pp. 35-88, 2003.

[2] K. Echave, M. Eagleton, E. Farley and J. Orsi, "A Refined Description of Essential Fish Habitat for Pacific Salmon Within the U.S. Exclusive Economic Zone in Alaska", NOAA Technical Memorandum NMFS-AFSC-236, June 2012.

[3] R.V. Walker, V.V. Sviridov, S. Urawa and T. Axumaya, "Spatio-Temporal Variation in Vertical Distribution of Pacific Salmon in the Ocean", North Pacific Anadromous Fish Commission, Bulletin No. 4, pp. 193-201, 2007.

[4] L.A. Miller, M. Robertand W.R. Crawford, "The large, westward-propagating Haida Eddies of the Pacific eastern boundary", Editorial, *Deep-Sea Research II*, pp. 845-851, 2005.

[5] M.P. Shepard, A.C. Hartt and T. Yonemori, "Salmon of the North Pacific Ocean - Part VIII", International North Pacific Fisheries Commission, Bulletin Number 25, 1968.

[6] http://www.webbresearch.com/slocumglider.aspx

[7] Colorado Center for Astrodynamics Research, University of Colorado Boulder, http://eddy.colorado.edu/ccar/data_viewer/info

[8] C.M. Bishop, ”Sensor Dynamics of Autonomous Underwater Gliders”, Master of Science Thesis, Environmental Science Program, Memorial Univeristy of Newfoundland, 2008.

[9] C.C. Leroy, ”Development of Simple Equations for Accurate and More Realistic Calculation of the Speed of Sound in Sea Water”, *J. Acoustical Society of America*, Vol. 46, p. 216, 1969.

[10] W.K. Johnson, L.A. Miller, N.E. Sutherland and C.S. Wong, ”Iron transport by mesoscale Haida eddies in the Gulf of Alaska”, *Deep-Sea Research II* 52, pp. 933-953, 2005.