# Technicalities

## Exploring the Labrador Sea with Autonomous Vehicles

by Brad deYoung, Eleanor Frajka-Williams, Nicolai von Oppeln-Bronikowski, and Stephen Woodward

**Intro and Rationale**

The Labrador Sea is a fascinating and difficult environment in which to work. In the winter, wind speeds can gust upwards of 200 km/hr, while 10-m wave heights and below freezing temperatures (-20°C) are not unheard off, making it an inhospitable area for field work. Indeed, few ships are present in the Labrador Sea during the winter. However, the same harsh conditions have made the Labrador Sea a key region for Earth's climate, with the wintertime conditions resulting in localized deep mixing of waters and carbon to great depths (2 km) in the ocean [Lazier, 1980; Pickart, 1997]. As a consequence, in-situ observations in the Labrador Sea are critical to advancing scientific knowledge on past and future climate change scenarios. Previous attempts to use ships for wintertime work required long expeditions at sea, but often with little data collected due to unworkable conditions. Autonomous marine vehicles provide an obvious solution to collecting in-situ data in the wintertime, as they can operate in extreme conditions yet still give us the flexibility to adapt our sampling during the mission [deYoung et al., 2018; Testor et al., 2019].

The goal of our mission to the Labrador Sea was to make measurements of the oceanic and atmospheric conditions in the central deep waters offshore Labrador during the fall-winter period 2019-2020. We have been planning this research for several years, working to improve our instruments, develop new operational techniques, and form new partnerships. We are interested in the Labrador Sea because of its regional and global importance as a source of deep water – through a process called deep ocean convection [Marshall and Schott, 1999]. Convection occurs when strong atmospheric cooling densifies the surface waters, resulting in sinking to the deep ocean, while the atmospheric forcing also causes intense air-sea gas exchange pumping carbon into the sinking waters [Steinfeldt et al., 2009]. We chose two different vehicles for this work – ocean gliders (Slocum from Teledyne Webb, Falmouth, M.A., and Seagliders from Kongsberg Marine, Seattle, W.A.) and a surface craft (Sailbuoy, from Offshore Sensing AS, Bergen, Norway).

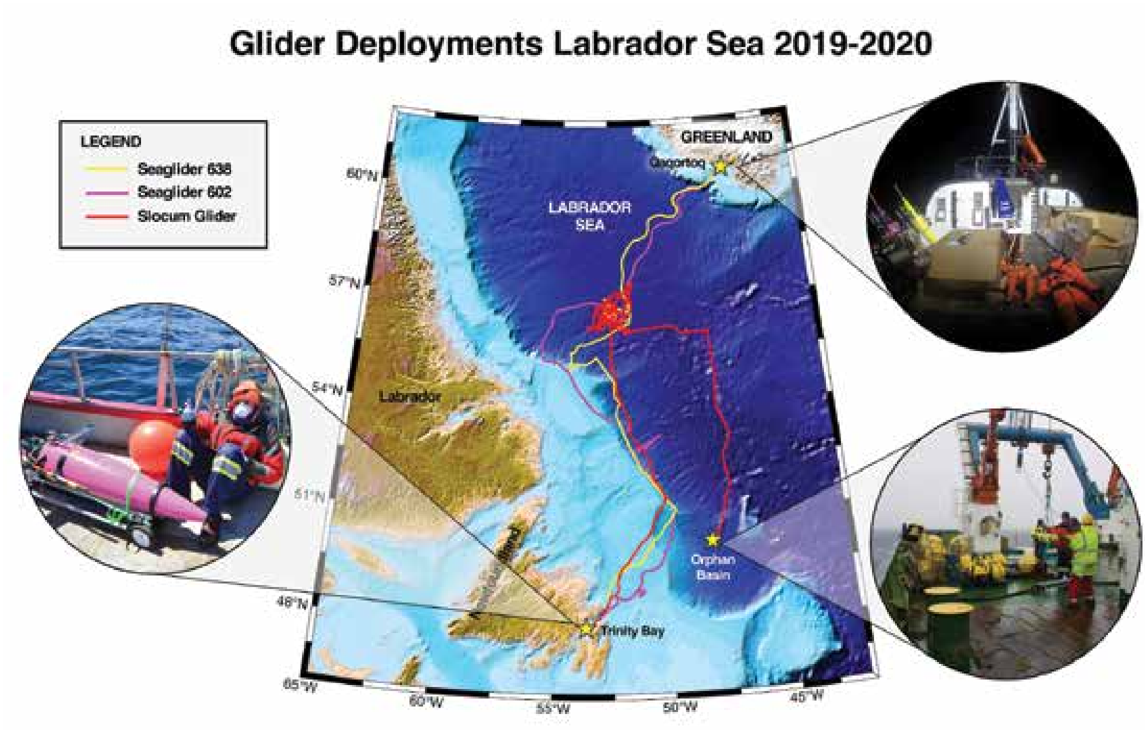


Figure 1: Map shows glider activities in the Labrador Sea during the period from December 2019 to June 2020, including deployment of two Seagliders (magenta and yellow) and a Slocum Glider (red). All gliders returned to Trinity Bay, Newfoundland, at the end of the mission. Photo Insets: (Top right) On route to launch Seagliders near Qaqortoq, Greenland, from the *Adolf Jensen.* (Bottom right) Launching MUN Slocum glider "Pearldiver" in the Orphan Basin from the RSS *James Cook.* (Middle left) Seaglider 602 "Scappa" successfully recovered off Newfoundland.

We worked together as a team from Memorial University (Canada) and the National Oceanography Centre (NOC) (UK), sharing many common goals to improve our understanding of the oceanography of the Labrador Sea, but also with some particular interests. The focus of the Memorial research was on the link between winter convection and the exchange of gas at the surface [Frob et al., 2016]. The focus for the NOC group was on the link between changes in freshwater and convection in the Labrador Sea [Frajka-Williams, 2016]. Combining our resources, complementary interests, and the opportunity to support each other logistically made the partnership both logical and mutually beneficial. Discussion and adaptation were required: from the choice of sensors, to where to deploy, how to sample in the ocean, how to coordinate the mission operations, how to share data, and how to recover the vehicles in the age of COVID-19 when travel and operations were so highly restricted.

**Field Deployment 2019-2020**

The deployments took place in the fall of 2019. Our original plan was to deploy all the instruments from Qaqortoq in southwest Greenland, but it became clear that shipping and transportation costs between Newfoundland and Greenland made it an unfavourable location for the Memorial team. The Memorial team had previously deployed gliders from southern Labrador, but by late fall most of the ports there are frozen up. So the choice was made to deploy the Slocum glider and the SailBuoy in early December from a Fisheries and Oceans Canada research cruise off the Newfoundland shelf on the RRS *James Cook*. The deployment of gliders from small boats can be easier – with low freeboard and increased manoeuvrability – than from large vessels, but small boats are not really an option offshore of Newfoundland in early winter. The glider and the Sailbuoy then had to travel northwards to get to the Labrador Sea, a trip of about a month. The NOC team did its work from Greenland, deploying two Seagliders and a Sailbuoy from the *Adolf Jensen*. The vehicles then took several weeks to transit the Labrador Sea to arrive at the study area.

Given the time it took the gliders to get to the Labrador Sea, either from Greenland or from offshore Newfoundland, the coordinated mission began in early January. Each team operated its vehicles separately, but we regularly shared information about the vehicle progress. As you can see from the vehicle track (Figure 1), we operated the vehicles in a fairly tight region. At times the glider tracks were overlapped to allow intercomparison between the vehicles. In addition, the gliders were piloted near existing long-term underwater moorings [Koelling et al., 2017] to allow intercomparison with mooring data. We also lined up the tracks to extend the reach of our sampling. The Slocum glider was operated farther offshore, while the Seagliders sampled towards the shelf break. Working together meant that the vehicles could sample many hundreds of kilometres, on a regular basis, from the shelf break out into the central Labrador Sea. Throughout the missions, the sensors on the gliders allowed us to measure many key variables. All the gliders carried sensors to measure temperature and salinity. Other sensors measured dissolved oxygen, chlorophyll, and particulate concentrations. All sensors worked well, and we had near-complete data recovery from all the gliders.

The two glider types had differing strengths. The Slocum glider was equipped with an extra battery bay, providing an overall power capacity of 1,000 Ah compared to the Seaglider capacity of 310 Ah. As a consequence, its overall endurance was longer than the Seagliders (roughly 300 days compared to 150 days). In addition, the requirement to pilot the Seagliders for efficient battery use (averaging 1.13 Ah/day) meant that the Seagliders made slower progress (20 km/day) compared to the Slocum speed (30 km/day at an average of 3.1 Ah/day). Both teams had problems with the SailBuoys, each of which failed during strong wind events, over 170 km/hr, and did not survive the mission. There were occasional communication issues, particularly with the Slocum glider whose antenna does not reach as high above the water. This meant that communication during big storms was sometimes limited. Not hearing from the glider for several days can be quite stressful. Operating a vehicle for many months can also reveal new issues that one would not experience in a short mission of just a few weeks: in the case of the Slocum glider, there was an unusual memory leakage issue that was dealt with through occasional remote rebooting of the onboard computer. One of the Seagliders got swept into the fast currents on the partially-ice covered Labrador shelf, taking it downstream and away from the study region. As a consequence, rather than expend battery power to return to the central Labrador Sea, the glider was retasked to occupy the outflow region from the southwest Labrador Sea. None of these issues were critical but they did require ongoing attention and some adjustments to keep the three vehicles operating well together. The original goal of the mission was for all three vehicles to operate through the winter convection period and into the late spring as the stratification redevelops in the Labrador Sea. The Slocum glider achieved this while the lower battery capacity on the Seagliders meant that they had to leave the Labrador Sea somewhat earlier.

We explored several different options for recovery, including getting an offshore vessel – possibly a fishing boat – to perform the recovery. Unfortunately, as COVID-19 appeared in early March, there were very few ships in position, and so an offshore recovery was not possible. We were able to take advantage of the deep shelf break current, the core of the Labrador Current, to give the gliders a boost of 20 km/day or so, thereby saving some battery power for the recovery. Indeed, at one point, the Slocum glider achieved a speed record of almost 50 km/day, fast for a glider. As the track shows, we allowed the current at the shelf break to speed the gliders southwards, and then piloted the gliders across the shelf operating in depths as shallow as 200 m. Gliders use more power operating in shallow water, with each cycle of the pump producing less forward motion, unable to take advantage of a long "glide." For the Seagliders in particular, power consumption on the shelf was two to three times higher than in deep water, so we had to allow for increased usage as the gliders returned across the shelf. The two Seagliders were successfully recovered in early May just north of Grates Cove, Newfoundland. One glider had reached the threshold for profiling, and so was recovered while drifting on the surface and occasionally transmitting its position; the other glider had just over 2% battery remaining. As we turned the Slocum glider south for the end of the mission, it got trapped in an eddy that was so energetic we became concerned about the recovery (see circles in the return track, Figure 1: red). For a while, the glider was headed in the wrong direction, going north and not south. It was recovered in June in Trinity Bay, Newfoundland, with 20% of the battery power in reserve.

The recovery required significant planning including much preparation, numerous discussions, and many approvals to get permissions for research technicians to go into the field. Clearly it was impossible for technicians from NOC to travel to Newfoundland and so all the work had to be conducted by technicians from Memorial. The two technicians had to drive in separate cars; there were fittings for face masks – special masks had to be brought for the captain of the ship; and there were significant constraints about travel to and from the ship. We did manage to make it all work, however, and viewed the overall mission as a great success.

The Slocum glider covered more than 4,000 km and made over 2,500 profiles, more than your typical research cruise. Each of the Seagliders transited more than 2,500 km and made over 1,600 profiles. The three vehicles collected an enormous trove of data during the winter giving us an unprecedented view of the Labrador Sea. As important as the numbers themselves are, it is also important to note that through alignment of the tracks, together the three gliders produced a coordinated data set revealing ocean water properties from the shelf break out into the Labrador Sea. We will now explore these data to improve our understanding as to what happens in this region during the wintertime and how that influences climate and the oceanography of the North Atlantic. Plans for our next deployment into the wintertime Labrador Sea are already underway.

**References**

deYoung, B. et al. [2018]. *Glider operations in the Labrador Sea*. Journal of Ocean Technology, Vol. 13, No. 1, pp. 106-120.

Frajka-Williams, E. et al. [2016]. *Greenland melt and the Atlantic Meridional Overturning Circulation*. Oceanography, Vol. 29, pp. 22-23. DOI: 10.5670/oceanog.2016.96.

Frob, F. et al. [2016]. *Irminger Sea deep convection injects oxygen and anthropogenic carbon to the ocean interior*. Nature Communications, Vol. 7, pp. 1322. DOI: 10.1038/ncomms13244.

Koelling, J. et al. [2017]. *Intense oceanic uptake of oxygen during 2014-2015 winter convection in the Labrador Sea*. Geophysical Research Letters, Vol. 44, pp. 7855-7864. DOI: 10.1002/2017GL073933.

Lazier, J. [1980]. *Oceanographic conditions at Ocean Weather Ship*

*Bravo, 1964-1974*. Atmosphere-Ocean, Vol. 18, pp. 227-238. DOI: 10.1080/07055900.1980.9649089.

Marshall, J. and Schott, F. [1999]. *Open-ocean convection: observations, theory and models*. Reviews of Geophysics, Vol. 37, pp. 1-64. DOI: 10.1029/98RG02739.

Pickart [1997]. *Adventure in the Labrador Sea: a wintertime cruise to the North Atlantic*. Oceanus Magazine. Retrieved from: https://www.whoi.edu/oceanus/feature/adventure-in-the-labrador-sea.

Steinfeldt, R. et al. [2009]. *Inventory changes in anthropogenic carbon from 1997-2003 in the Atlantic Ocean between 20S and 65N*. Global Biogeochemical Cycles, Vol. 23, GB3010. DOI: 10.1029/2008GB 003311.

Testor, P. et al. [2019]. *Ocean gliders: a component of the integrated GOOS*. Frontiers in Marine Science, Vol. 6, pp. 442. DOI: 10.3389/fmars. 2019.00422.

Brad deYoung and Nicolai von Oppeln-Bronikowski are with the Physics and Physical Oceanography Department at Memorial University of Newfoundland. Eleanor Frajka-Williams and Stephen Woodward are with the National Oceanography Centre in Southampton, U.K.