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Short Cruise Report
MARIA S. MERIAN MSM123
Bubble (mediated) exchange in the Labrador Sea (BELS)

Halifax, Canada – St. John's, Canada
23.11.2023 – 27.12.2023
Chief Scientist: Christa Marandino
Captain: Björn Maaß

Objectives

The Labrador Sea is a high latitude region of the ocean where open ocean deep convection and seasonal solubility and biology-driven changes occur faster than air-sea gas exchange can re-establish air-sea equilibrium. It is, consequently, one of the most intense sinks for carbon dioxide (CO_2) and oxygen (O_2) globally. Although it is clear that high-latitude regions are key for ocean-atmosphere transfer and sequestration in the deep ocean, our knowledge of the basic forcing mechanisms at play there remain very uncertain. Gas, momentum, and heat exchange are highly nonlinear functions of wind speed, indicating that mechanisms operating at high winds, such as bubble-mediated transfer, need to be constrained. Global change issues such as increasing temperatures, ocean acidification, and ocean deoxygenation are interlinked and in order to understand the changes in uptake, biogeochemical cycling, and feedback processes of environmentally important gases, mechanisms controlling their air-sea exchange must be understood. Bubble-mediated gas exchange is under-represented in models, in part due to a lack of mechanistic understanding and, thus, limited ability to parameterise its contribution to the overall gas flux. The overarching objective of BELS is to understand and quantify bubble-mediated gas exchange mechanisms. Special attention was given to the forcing and parametrisation of air–sea exchange for the insoluble gas O_2. We employed a range of complementary techniques to tackle the questions posed, including eddy covariance direct fluxes, continuous profiling, tracer release, noble gases, and direct bubble characterization (Figure 1). By combining these techniques, we have the major advantage of connecting bubble process understanding with comprehensive flow, gas saturation and gas flux measurements, and directly observing bubble-mediated gas uptake mechanisms.

We will test currently established air-sea exchange parameterizations and propose new ones if applicable. A secondary goal is to determine budgets of climate-relevant trace gas parameters in the Labrador Sea. Observation-based experiments investigating gas exchange mechanisms in deep mixing regions of the ocean, coupled to wind and wave forcing products and validation are required to reduce uncertainties in the computation of oxygen supply to the deep sea.

Specific questions addressed:

1. How should bubble-mediated gas exchange be parameterized?
a) How are fluxes of different gases with different solubilities partitioned between diffusive and bubble-mediated components?
b) Which existing parameterizations best predict measured and estimated gas fluxes for the conditions in the Labrador Sea?
c) How does the bubble term differ for invasion vs evasion fluxes?
d) What mechanisms (on scales of 0.1-10 meters) drive bubble-mediated gas uptake, and how are they linked to larger-scale flow structures, local gas saturation inhomogeneities and water conditions?
e) What key oceanic and atmospheric conditions determine the appropriateness and utility of parameterizations of the bubble-mediated flux?

2. How much O_2 is supplied to the deep ocean during Labrador Sea deep water formation?
a) Is this supply sensitive to climate change effects (e.g. as a result of freshening in the Labrador Sea)? If so, how sensitive?

3. Do bottom up and top down estimates of APO flux in the Labrador Sea region agree?
a) How do these budgets change on seasonal to interannual timescales?

Narrative

MSM123 BELS started on 24 November 2024, one day later than scheduled due to shipping and customs delays. The scientific crew were from Germany, Canada, the UK, and the USA. Due to the shipping problems, the full eddy covariance system (EC) was not delivered and half of it was reconstructed with spare parts and borrowed items from local collaborators. The underway (UW) systems were set up in port and measured from the beginning of the cruise (included radar, EC, UW seawater carbon dioxide, sea surface temperature, sea surface salinity, dissolved oxygen (DO)). We steamed to the first test site, station 1, and arrived on 26 November 13:00 UTC to test the bubble buoy and autonomous underwater vehicles (AUVs). We then steamed to the second test station, station 2, arriving on 28 November to perform a longer buoy test deployment, along with the moving vessel profiler (MVP) and CTD casts. The CTD casts were the first performed at several moorings of the OSNAP array west, in order to calibrate the DO mooring sensors. In addition, the UW and surface CTD samples were intercompared for dissolved gases. The second AUV test did not occur as planned at station 2, due to weather conditions. Stations 3 and 4 (28 and 29 November) were a continuation of the CTD calibrations for the DO measurements on the OSNAP moorings. At station 4, we added a gas tension device (GTD) to the CTD frame for the first GTD measurements of the campaign.

The ship then steamed to the tracer release area to survey for the best location to inject the tracer. However, we could not complete station 5 on 30 November as planned, including the deployment of a BGC Argo float, due to wind and wave conditions. The ship could only sail at minimum speed with the bow turned to the prevailing seas. Station 5 was performed one day later on 1 December. At stations 6 – 11 (until 2 December), we continued surveying the tracer release area, using both the MVP and shallow CTD casts. Late in the day on 2 December, we injected the tracer mixture in the water while the ship moved in a hexagonal pattern. A drifter was released in the center of the patch to assist in locating the patch later. After approximately 8 hours of injection, the ship moved south out of the patch to allow the tracer to mix. Station 12 was performed outside the patch and deployed the CTD, GTD, and for the first time the in-situ pumps and the Slocum glider. The MVP was deployed while waiting to track the tracer, which began at station 14 on 3 December. A BGC Argo float was also deployed at station 14. Normal station work, at least 2 times per day, began with station 15 on 3 December and ended on 21 December with station 41. This included multiple CTD casts for dissolved gases and related parameters and deploying the MVP whenever weather permitted. The general operation at this time was to remain in the tracer patch as best as possible, while performing other operations. The ship received instructions from the tracer team on where and when to direct the ship to follow the patch. At various stations within the tracer patch, different equipment was deployed, but operations were sometimes interrupted by stormy weather conditions:

- AUVs deployed at stations 16, 28, 32
- Waveglider deployed at station 17 and recovered before station 24
- 3 SWIFT buoys deployed at station 18 and recovered before station 42
- Bubble buoy deployed at station 18 and recovered before station, deployed at station 27 and recovered before station 33, and finally deployed at station 37 and recovered before station 42
- In-situ pumps deployed at stations 22, 25, 32, 36
- BGC Argo floats deployed at stations 23, 28
- Homemade drifter deployed at station 24 and recovered before station 42).

Stations 42 to 48 were performed to achieve the last priorities of the campaign, including a final AUV deployment, a final in-situ pump deployment, deep CTD casts, calibration of the MVP, calibration of sensors on board previously deployed BGC Argo floats, and the deployment of the remaining drifters.

Packing started on 24 December, but UW systems were operational until 25/26 December. The campaign ended on 27 December 2024 at approximately 9:00 (in the harbor at St. John's). According to information from the captain, during the campaign, wind forces of 12 Bft and swell heights of 10 m and more occurred several times. For more than 53% of the voyage there was windspeeds higher than 8 Bft. More than 27% of the voyage was in gale force, 9 Bft and higher. Nonetheless, all equipment was recovered in relatively good shape and all tasks were performed, although sometimes for shorter time periods or with less samples than planned.

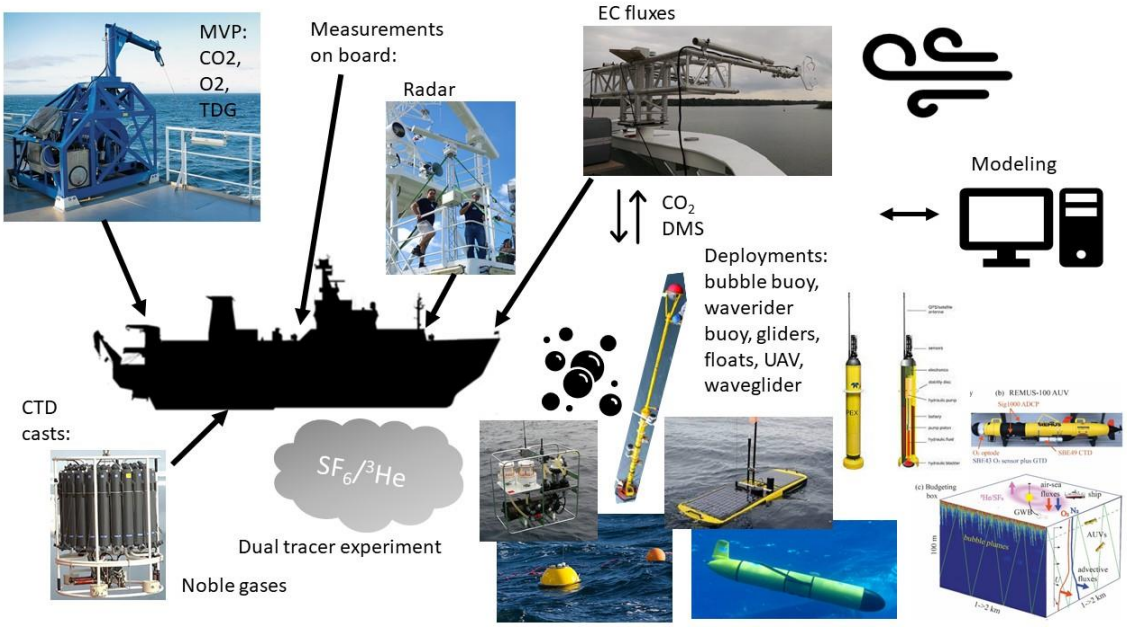

Figure 1. Schematic diagram of the equipment and techniques used on board MSM123 BELS.

Acknowledgements

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Teilnehmerliste

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2.	POSERN, Conny	Eddy covariance/GC-MS	GEOMAR
3.	SCHEIDEREIT, Leonie	Eddy covariance/GC-MS	GEOMAR
4.	STEFFENS, Tim	Eddy covariance/GC-MS	GEOMAR
5.	BROOKS, Ian	Bubbles and waves	Leeds
6.	CZERSKI, Helen	Bubbles and waves	UCL
7.	ATAMANCHUK, Dariia	Dissolved gases	Dalhousie
8.	BECKER, Jeshua	Dissolved gases	Dalhousie
9.	MOLNAR, Meghan	Noble gases	UVic
10.	PARKER, Matthew	Carbon dynamics	LSU
11.	CHASAPIS, Konstantinos	Dual tracer	UCL
12.	DOBASHI, Ryo	Dual tracer	Hawaii
13.	GERKE, Lennart	Dual tracer	GEOMAR
14.	HO, David	Dual tracer	Hawaii
15.	OLBRICHT, Hannah	Dual tracer/MVP	GEOMAR
16.	BYRNE, Tyler	Gliders and floats	Dalhousie/COVE
17.	OSTIGUY, Josiane	Gliders and floats	Dalhousie
18.	STOER, Adam	Gliders and floats	Dalhousie
19.	DANIELS, Robert	UAVs	UW
20.	FONG, Kee Onn	UAVs	UW
21.	LITCHENDORF, Trina	UAVs	UW
22.	MCNEIL, Craig	UAVs	UW

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Stationsliste

Station	Date/ Time (UTC)	Lat	Long	Operations
MSM123_1	11/26/2023 13:58	46° 22,199' N	052° 19,204' W	Bubble buoy test 1, AUV test
MSM123_2	11/28/2023 5:43	53° 22,248' N	050° 13,992' W	Bubble buoy test 2, MVP, CTD (2)
MSM123_3	11/28/2023 19:15	53° 07,110' N	050° 52,837' W	CTD
MSM123_4	11/29/2023 18:27	52° 56,459' N	051° 19,331' W	CTD w GTD, CTD
MSM123_5	12/1/2023 11:22	56° 24,866' N	052° 56,058' W	CTD, Argo float
MSM123_6	12/1/2023 14:01	56° 24,162' N	052° 59,889' W	MVP
MSM123_7	12/2/2023 2:36	56° 24,261' N	053° 23,728' W	CTD
MSM123_8	12/2/2023 3:40	56° 24,239' N	053° 32,379' W	CTD
MSM123_9	12/2/2023 6:49	56° 24,471' N	052° 47,602' W	CTD
MSM123_10	12/2/2023 9:32	56° 44,354' N	052° 47,197' W	CTD
MSM123_11	12/2/2023 12:31	56° 25,956' N	052° 48,185' W	CTD, tracer injection, drifter
MSM123_12	12/3/2023 5:08	56° 22,571' N	052° 47,566' W	CTD, In situ pump, Glider, CTD w GTD
MSM123_13	12/3/2023 13:21	56° 23,131' N	052° 48,114' W	MVP
MSM123_14	12/3/2023 23:51	56° 29,201' N	052° 50,169' W	Argo float
MSM123_15	12/4/2023 0:31	56° 30,797' N	052° 50,848' W	CTD
MSM123_16	12/4/2023 10:07	56° 32,076' N	052° 51,140' W	AUV, CTD (2)
MSM123_17	12/4/2023 13:11	56° 33,051' N	052° 50,521' W	AUV, Waveglider, MVP
MSM123_18	12/4/2023 22:15	56° 36,676' N	052° 49,413' W	CTD (2x), SWIFT buoys, Bubble buoy
MSM123_19	12/5/2023 0:09	56° 36,963' N	052° 47,880' W	MVP, CTD (3x)
MSM123_20	12/5/2023 23:17	56° 46,762' N	052° 40,473' W	CTD (2x), MVP
MSM123_21	12/6/2023 10:24	56° 47,531' N	052° 32,142' W	CTD (2x)
MSM123_22	12/6/2023 22:22	56° 48,227' N	052° 27,936' W	CTD (2x), In-situ pump, CTD w GTD, MVP
MSM123_23	12/7/2023 10:35	56° 48,012' N	052° 23,256' W	CTD (2x), CTD w GTD, Argo float
MSM123_24	12/10/2023 14:17	56° 42,858' N	051° 45,203' W	CTD, Drifter, CTD w GTD
MSM123_25	12/11/2023 0:44	56° 41,923' N	051° 41,003' W	CTD
MSM123_26	12/11/2023 10:14	56° 43,331' N	051° 38,647' W	CTD (2x), CTD w GTD
MSM123_27	12/11/2023 21:08	56° 50,922' N	051° 32,011' W	Bubble buoy, CTD, In situ pump, MVP
MSM123_28	12/12/2023 7:59	56° 51,060' N	051° 38,359' W	CTD, AUV, CTD w GTD, Argo float
MSM123_29	12/12/2023 22:25	56° 55,770' N	051° 31,599' W	CTD (2x)
MSM123_30	12/13/2023 10:17	56° 53,796' N	051° 21,850' W	CTD
MSM123_31	12/13/2023 22:46	56° 58,694' N	051° 22,417' W	CTD (2x), CTD w GTD, MVP
MSM123_32	12/14/2023 7:59	56° 59,213' N	051° 17,960' W	CTD (2x), AUV, In situ pump
MSM123_33	12/14/2023 22:36	57° 01,921' N	051° 10,986' W	CTD (2x)
MSM123_34	12/15/2023 4:49	57° 02,490' N	051° 22,838' W	MVP
MSM123_35	12/15/2023 22:58	57° 02,373' N	051° 12,534' W	CTD (2x), CTD w GTD
MSM123_36	12/16/2023 9:53	57° 07,717' N	051° 03,680' W	CTD (2x), in-situ pump, drifter
MSM123_37	12/16/2023 16:56	57° 08,344' N	050° 57,689' W	Bubble buoy
MSM123_38	12/16/2023 22:20	57° 08,860' N	051° 06,618' W	CTD, CTD w GTD
MSM123_39	12/18/2023 16:07	57° 17,023' N	051° 10,030' W	CTD, CTD w GTD
MSM123_40	12/20/2023 17:42	57° 21,837' N	051° 13,034' W	CTD (2x), CTD w GTD, In situ pump
MSM123_41	12/21/2023 7:40	57° 05,439' N	051° 14,414' W	CTD
MSM123_42	12/22/2023 8:33	57° 25,208' N	050° 55,414' W	AUV, CTD w GTD
MSM123_43	12/22/2023 16:07	57° 28,460' N	051° 19,019' W	CTD, CTD w GTD
MSM123_44	12/22/2023 21:35	57° 31,002' N	051° 50,995' W	CTD (2x), In situ pump
MSM123_45	12/23/2023 9:54	56° 52,987' N	052° 08,006' W	CTD

MSM123_46	12/23/2023 14:33	56° 54,645' N	052° 29,665' W	CTD, MVP, Drifter
MSM123_47	12/23/2023 21:13	56° 59,996' N	051° 53,907' W	CTD
MSM123_48	12/24/2023 12:30	55° 38,800' N	054° 28,498' W	CTD, CTD w GTD