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A backseat driver system for Slocum gliders operated under ice

Yaomei Wang, Ben Allsup, Alexander B Phillips, Georgios Salavasidis

Marine Autonomous and Robotic Systems (MARS), National Oceanography Centre, European Way, Southampton, SO14 3ZH, United Kingdom

Introduction

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❑ Experience

- Autosubs over 30 missions under sea ice and ice shelves, over two decades experience

Figure 1. Autosub Long Rang under ice exploration.

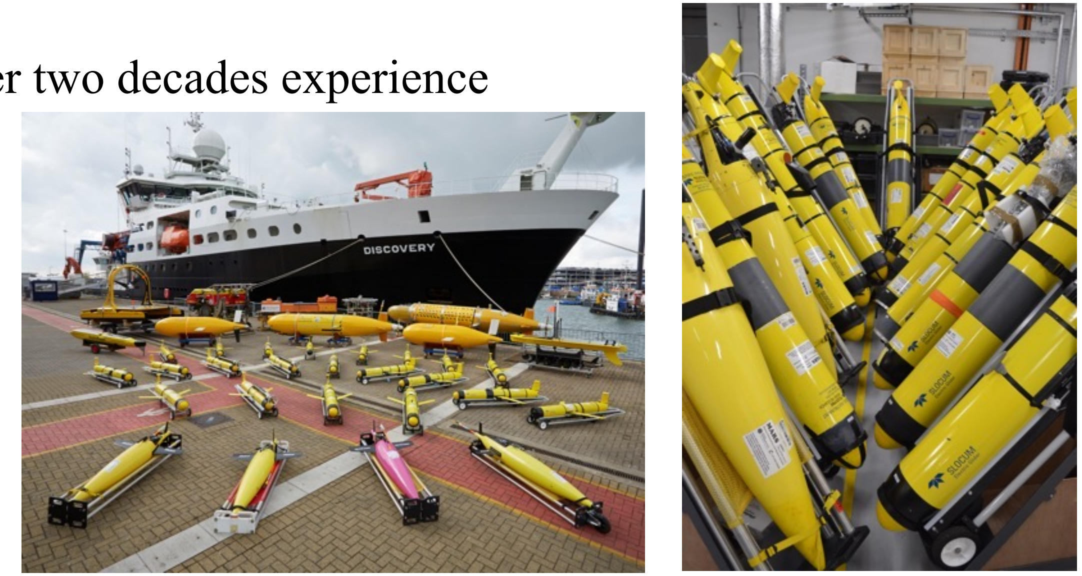

Figure 2. Some vehicles owned by the National Marine Equipment Pool.

❑ Project requirement

- BIOPOLE: Biogeochemical processes and ecosystem function in changing polar systems and their global impacts
- PycnoGen: Generation of the global ocean internal pycnocline in the ice-covered Southern Ocean
- DEFIANT: Drivers and Effects of Fluctuations in sea Ice in the ANTarctic
- …

❑ Why Slocum gliders

- Under ice shelf: planned before deployment. Equip new capabilities for our glider fleet

Technical description

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❑ Standard control system

- Ice coping behaviours, not for deliberate under ice missions

❑ A high-level architecture

- A backseat driver control system
- An upward-looking altimeter

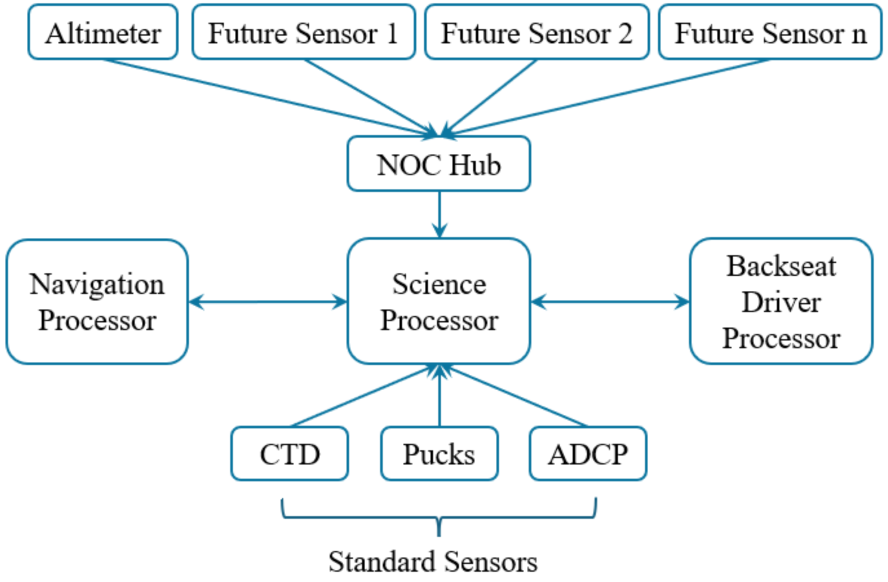

Figure 3. Backseat driver microprocessor and NOC Hub prototype glider integration.

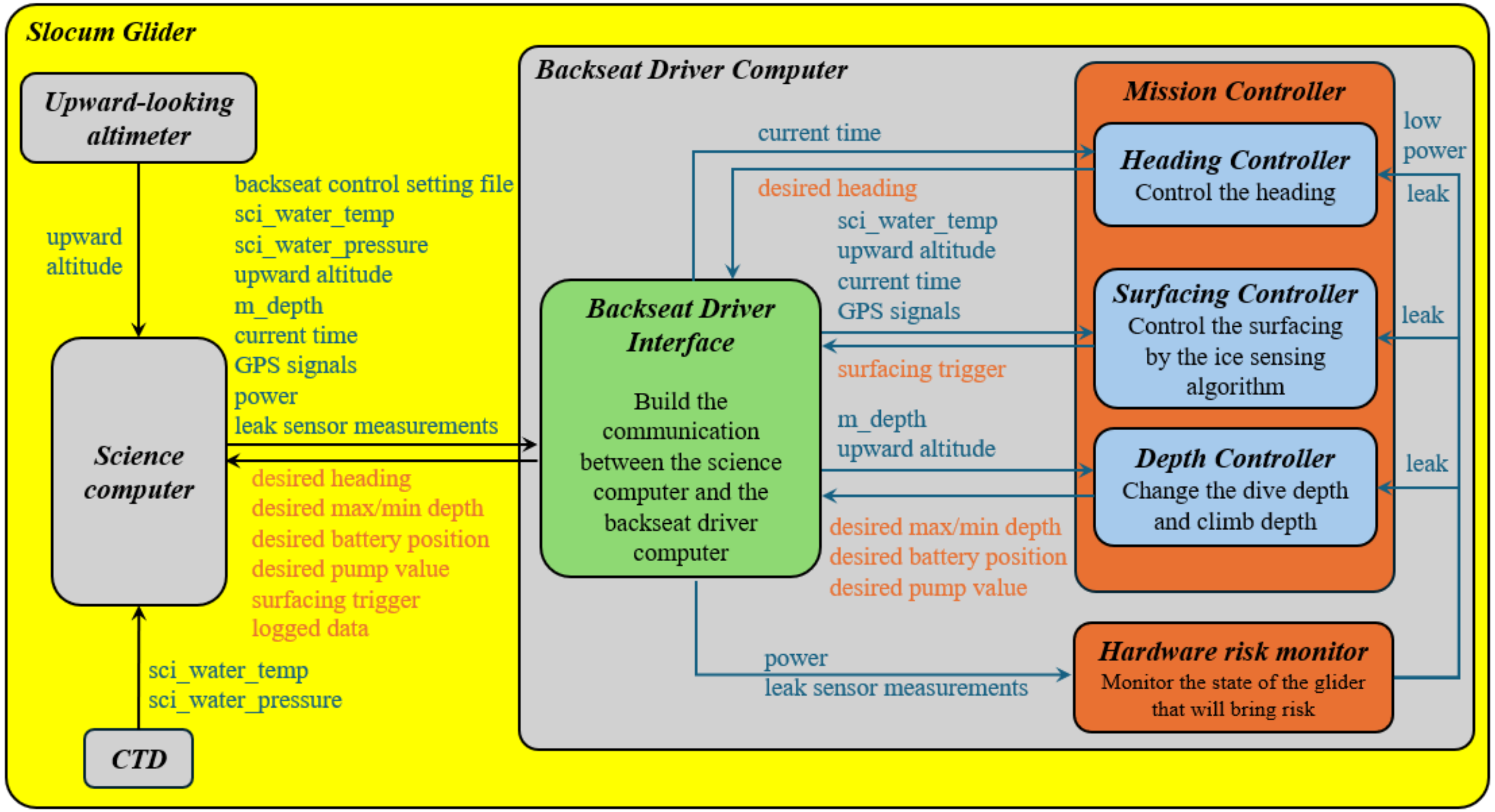

Figure 4. The control architecture of the first-generation backseat driver for Slocum gliders under sea ice missions.

Backseat driver (BSD) control system

- ❑ **Backseat driver interface**
  - A standard module
  - BSD reads glider states and sci sensors measurements
  - BSD performs changes to glider
  - BSD sends log data to glider
  - Remote pilots send files to BSD
- ❑ **Mission controller**
  - Heading controller
  - Depth controller
  - **Surfacing controller**
- ❑ **Hardware risk monitor**
  - Low power
  - Leak

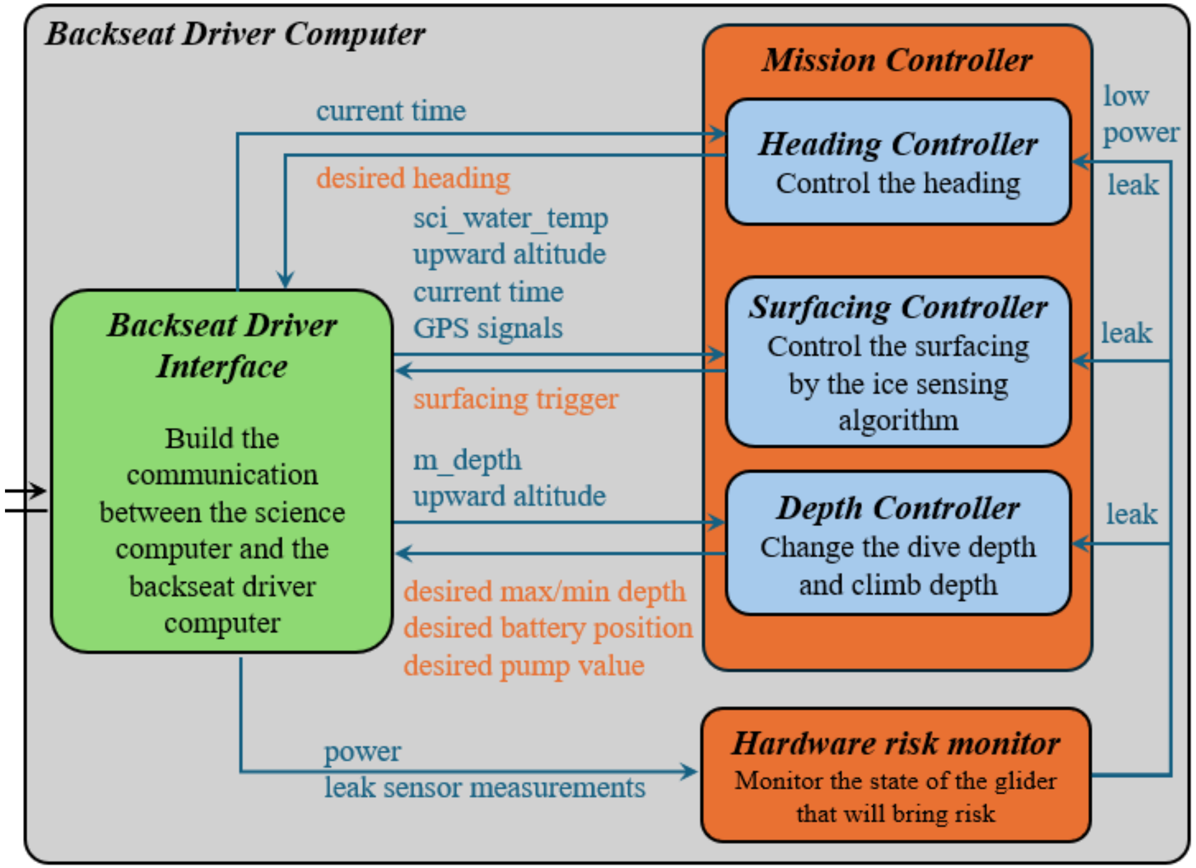

Figure 5. The first-generation backseat driver for Slocum gliders under sea ice missions.

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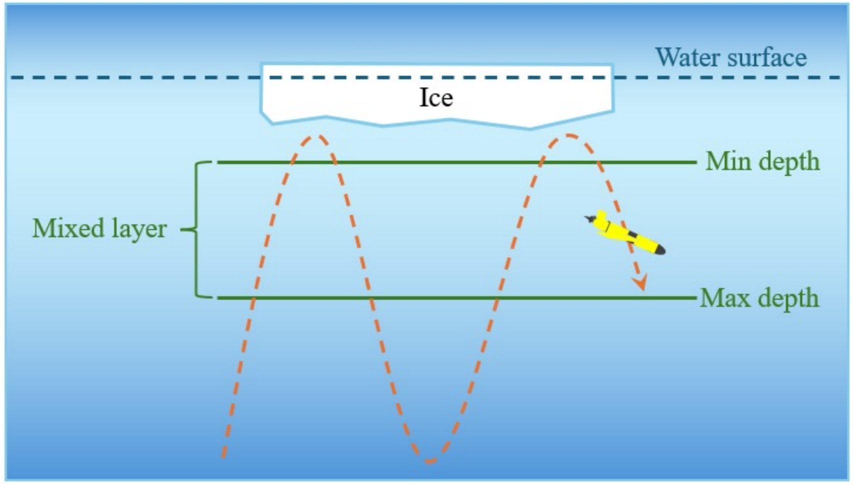
Surfacing control

❑ Ice sensing strategies

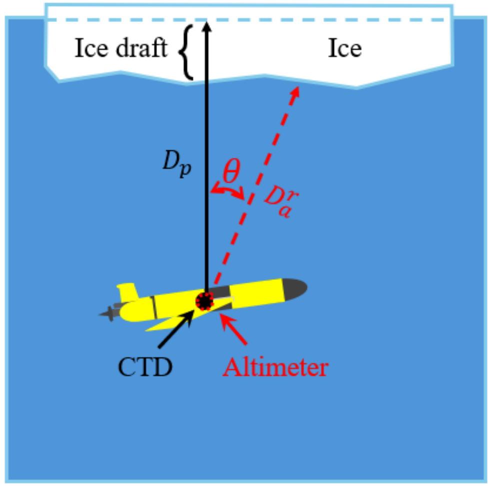
• Median temperature



$$\begin{cases} Ice: & Median\ temp < Thresh\ temp \\ No\ ice: & Median\ temp > Thresh\ temp \end{cases}$$

Figure 6. Measuring the median temperature of mixed layer.

• Ice draft



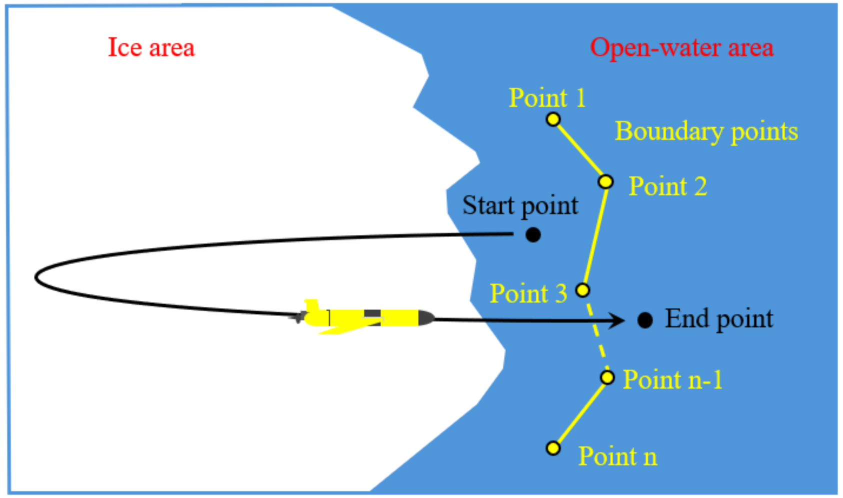
The ice draft D_i is

$$D_i = D_p - D_a * \cos(\theta) \in \begin{cases} (-\infty, b), uncertainty \\ (b, +\infty), \quad ice\ area \end{cases}$$

D_p: CTD depth
D_a: Upward-looking altitude
θ: Angle of the upward-looking altimeter
b: The minimum detectable ice draft

Figure 7. Ice draft which is the difference between CTD depth and upward-looking altitude.

• Ice edge



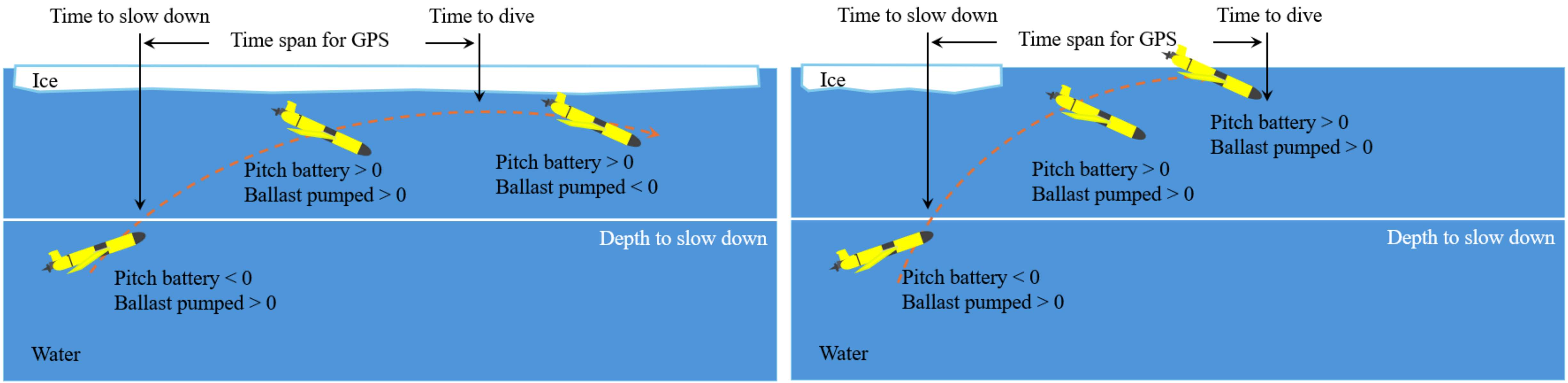
Boundary points location

$$d = f(mission\ time, ice\ edge)$$

Figure 8. Ice edge for defining the boundary points between ice area and open water area.

Surfacing control

- ❑ **Ice sensing strategies**
  - GPS



(1) The surface is covered by ice. (2) The surface is free of ice.

Figure 9. The control of a glider to reach the surface to get GPS signals in an under-ice mission.

Surfacing control

- ❑ Ice sensing strategies
- ❑ Time
- ❑ Hardware risk

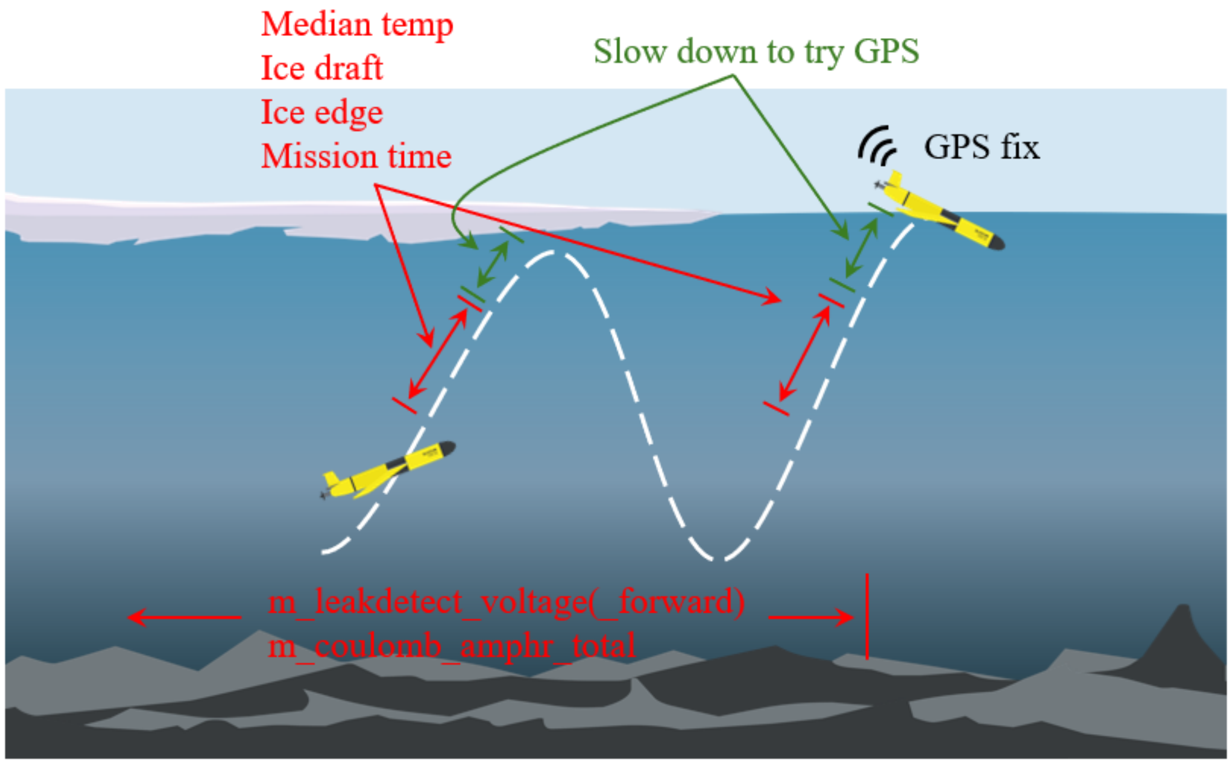


Figure 10. Surfacing control.

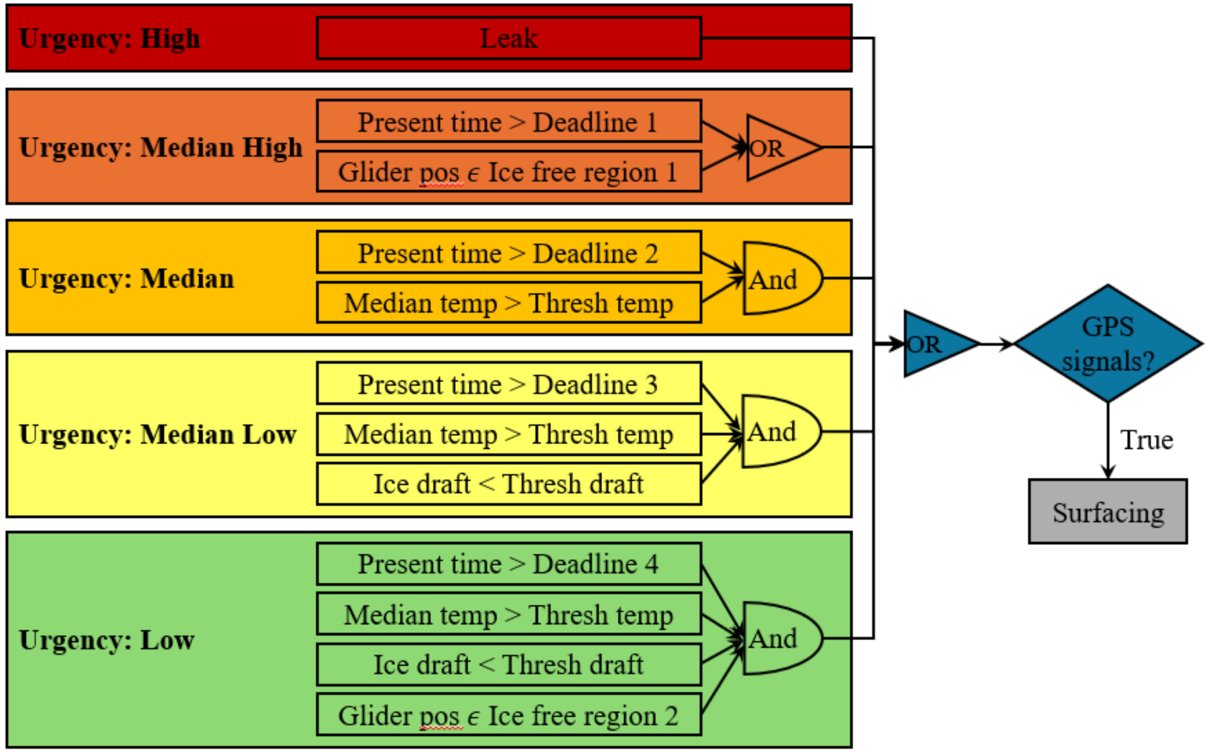


Figure 11. Urgency levels and their control factors which trigger a surfacing behaviour.

Glider test in the open water (DY166)

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No	Mission Statement	Type
1	No backseat driver in proglets. This is a baseline mission with only CTD being used.	Non backseat driver mission
2	ISA500 being running for a majority of time when the gliders have been in the water.	
3	Multiple configurations and settings in mission file (bad.mi). BSD.mi on server can/will be used for BIOPOLE with few changes.	
4	Change bsd_modb.py over iridium.	Backseat driver related mission
5	Modify dive/climb/heading controls using backseat driver.	
6	Modify sampling of upward looking altimeter data.	
7	Glider surfacing controlled by different median temperature threshold.	
8	Glider surfacing controlled by ice draft.	
9	Glider surfacing control by ice boundary.	
10	Glider surfacing controlled by GPS signals.	
11	Glider surfacing controlled by various time urgency level.	
12	Heading changed by backseat driver.	
13	Backseat driver reacts to low battery situation.	
14	Leak response.	
15	Incorrect and correct mount angle setting in the backseat setting file for ISA500.	
16	Multiple day underwater with backseat driver.	
17	Special intial.mi (some modification for BIOPOLE needed).	
18	Special lastgasp.mi (some modification for BIOPOLE needed).	
19	Ice cooping missions in place, but not activated (some modification for BIOPOLE needed).	

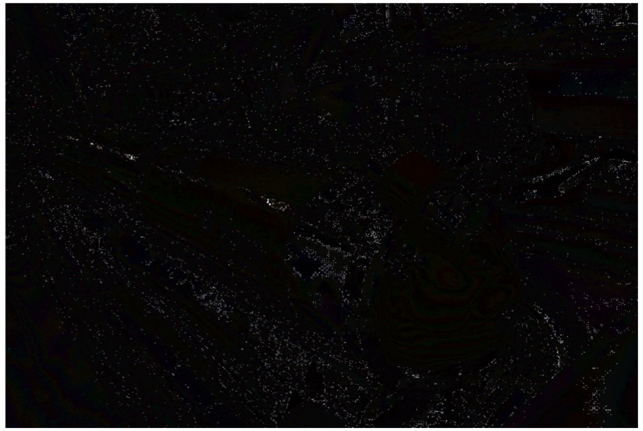

Figure 12. A Slocum glider with an ISA500 altimeter (Photo courtesy of Ben Allsup).

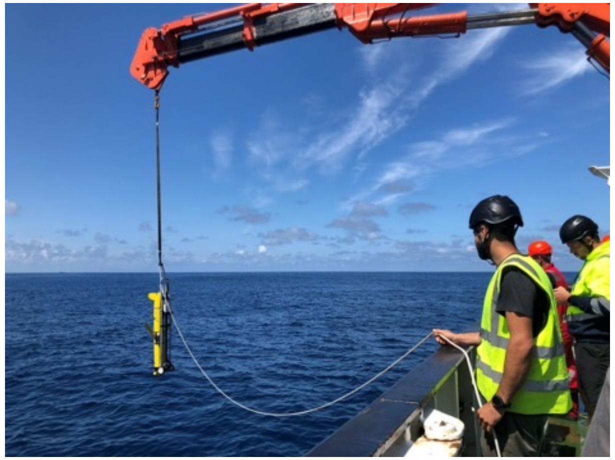

Figure 13. One BSD glider being deployed from RRS Discovery.

BIOPOLE project

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- ❑ **Location: The Weddell Sea**
- ❑ **Time: December 2023 – February 2024**
- ❑ **Three Slocum gliders: Glider 223 (BSD), 438 (BSD), 444**
  - Totals 159 days and 2333 km

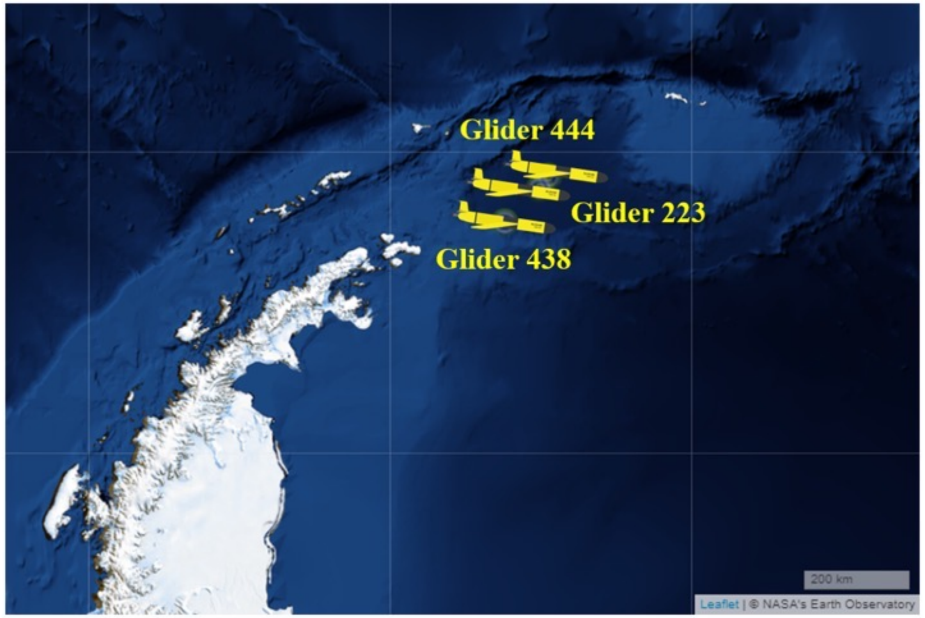

Figure 14. Three gliders being deployed in the Weddell Sea for BIOPOLE project.

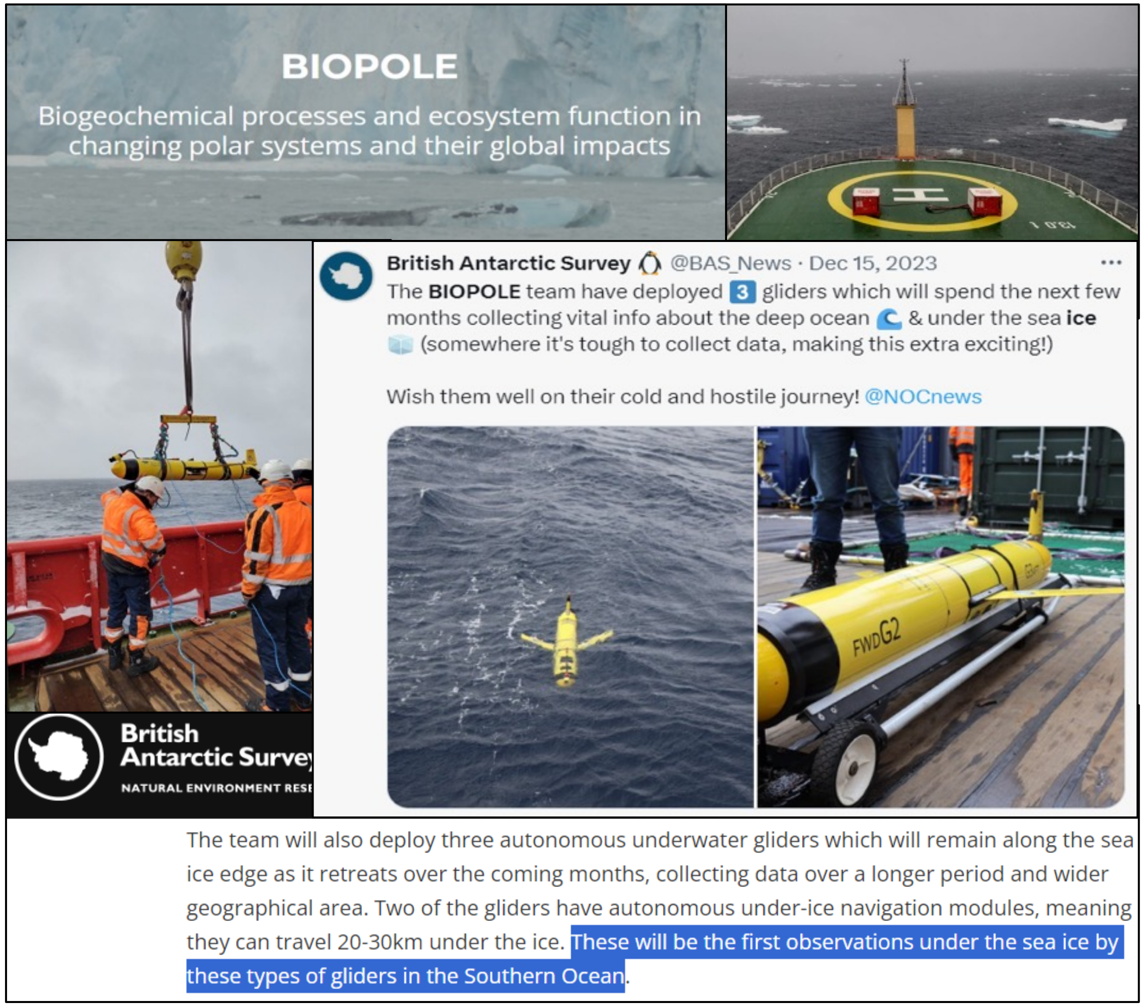

Figure 15. News about BIOPOLE project and the under-ice glider mission.

BSD missions in the Weddell Sea

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Table 1. BSD missions conducted by Glider 223 and Glider 438 in the Weddell Sea.

No.	Mission start	Mission End	Mission type	Glider
1	December 6, 14:12:15, 2023	December 6, 16:36:32, 2023	BSD confirming	223
2	December 6, 17:43:59, 2023	December 7, 02:36:37, 2023	BSD confirming	223
3	December 8, 11:41:09, 2023	December 8, 13:58:44, 2023	BSD confirming	438
4	December 9, 07:31:24, 2023	December 9, 13:37:44, 2023	BSD confirming	438
5	December 9, 18:21:44, 2023	December 11, 21:01:10, 2023	Under sea ice	438
6	December 12, 13:01:26, 2023	December 13, 06:56:09, 2023	Ice approaching	438
7	December 13, 09:41:11, 2023	December 15, 11:09:33, 2023	Under sea ice	438
8	December 16, 14:19:47, 2023	December 17, 06:41:48, 2023	Ice approaching	438
9	December 17, 09:17:29, 2023	December 19, 17:35:02, 2023	Under sea ice	438
10	December 21, 19:20:01, 2023	December 23, 05:27:59, 2023	Under sea ice	223
11	December 27, 10:51:09, 2023	December 28, 10:32:17, 2023	Ice approaching	438
12	December 28, 11:29:58, 2023	December 30, 09:30:05, 2023	Under sea ice	438
13	January 9, 21:04:43, 2024	January 10, 11:22:45, 2024	Ice approaching	438
14	January 10, 12:48:24, 2024	January 11, 09:54:54, 2024	Ice approaching	438
15	January 11, 21:09:39, 2024	January 12, 09:17:20, 2024	Ice approaching	438
16	January 12, 10:05:40, 2024	January 14, 10:33:25, 2024	Under sea ice	438

An under-ice mission by Glider 438

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Mission start	Mission end	SBD File	BSD file	Heading control	Heading change time
December 17, 09:17:29, 2023	December 19, 17:35:02, 2023	unit_438-2023-350-0-0	12170919.txt	[head_1_2]: [2.59, 5.7]	2023-12-18 09:00:00

Table 2. BSD settings.

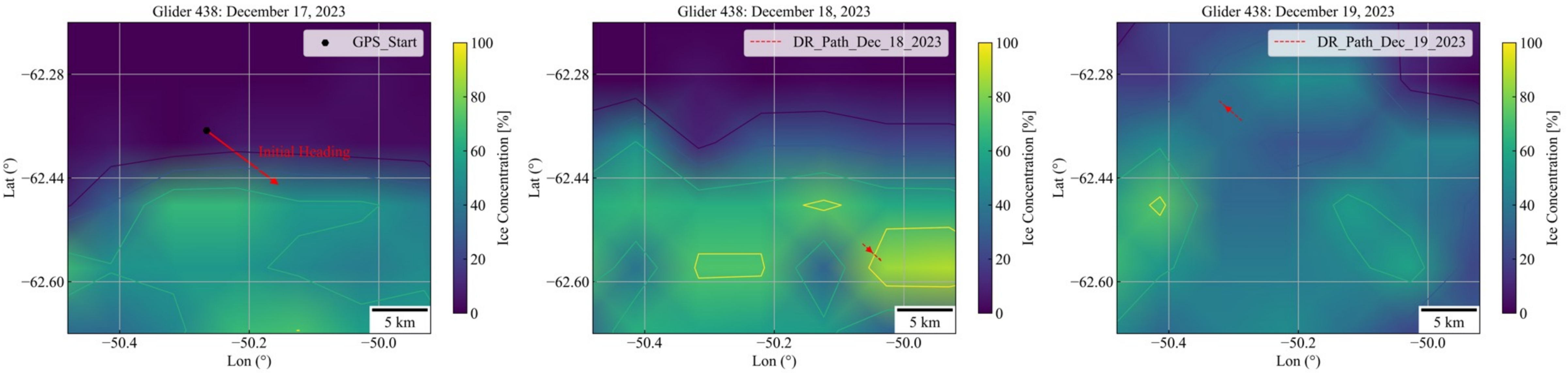
Parameter	Setting	Parameter	Setting
switch_temp	1	expected_time_mission_end	2023-12-19 09:00:00
switch_ice_draft	1	urgency_m_low_time	2023-12-19 12:05:00
switch_boundary	0	urgency_m_time	2023-12-19 15:05:00
switch_time	1	urgency_m_high_time	2023-12-19 18:05:00
switch_GPS	1	dpt_slow_down	10
switch_power	2	pump_battpos_time_GPS	[110, 1.1, 1200]
switch_sim	0	pump_battpos_depth_dive	[-195, 0.51, 990]
min_max_dpt_ml	[20, 50]	pump_battpos_depth_climb	[235, -0.13, 10]
thresh_temp_num	[-1.78, 1]	sensor_log	[7200, 5]
min_thick	5	power_limit/record	[450, 1200]
dpt_ice_draft	60	sound_s_alt/alt_angle	[1500, 0.4712]
head_1_2	[2.59, 5.7]	volt/depth_range/surf_freq/record_leak	[1.8, 25, 1, 20]
time_head_change	2023-12-18 09:00:00	filter_size	3
range_alt_c_t_p	[[0.1, 120], [0, 10], [-5, 45], [0, 200]]		

The glider climbed to the surface to try to receive the GPS signal at both **9:45** and **13: 38** on December 19, 2023. After 20 minutes waiting but no GPS signal received, the glider dived.

An under-ice mission by Glider 438

The glider was controlled to climb to the surface and successfully got the GPS fix at around **17:30**.

Slow down to try GPS and then surface because of:	time_urgency_m_high: [False] loca_urgency_m_high: [Disabled] urgency_m: [True] = urgency_m_time: [True] & median_temp: [True] urgency_m_l: [True] = urgency_m_low_time: [True] & median_temp: [True] & ice_draft: [True] urgency_l: [True] = expected_time_mission_end: [True] & median_temp: [True] & ice_draft: [True] & bndry_pts: [Disabled]



(a) (b) (c)

Figure 16. An under-ice mission conducted by Glider 438 from December 17 to 19, 2023: (a) the GPS location at mission start point and the initial heading of the glider; (b) a portion of the dead-reckoning path on December 18, 2023; (c) a portion of the dead-reckoning path on December 19, 2023.

An under-ice mission by Glider 223

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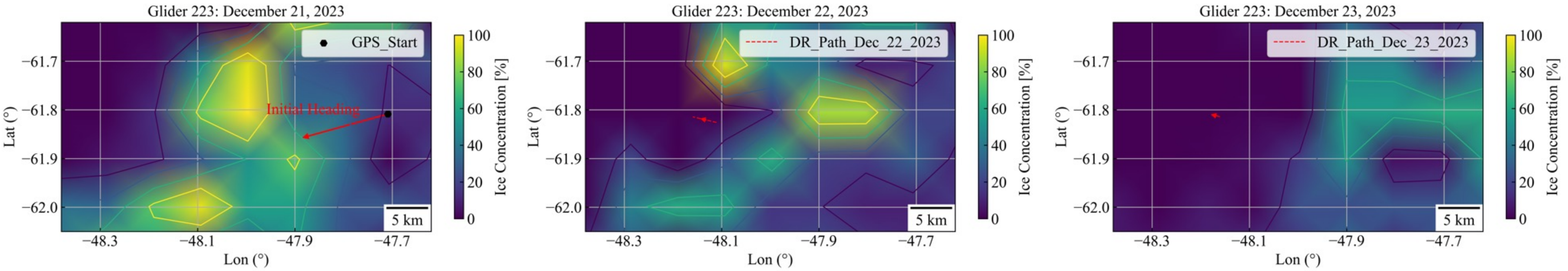
Mission start	Mission end	SBD File	BSD file	Heading control	Heading change time
December 21, 19:20:01, 2023	December 23, 05:27:59, 2023	unit_223-2023-354-0-0.sbd	12211906.txt	[head_1_2]: [4.18, 5.06]	2023-12-22 11:00:00

[switch_temp]: 1 [switch_ice_draft]: 1 [switch_boundary]: 0 [switch_time]: 1 [switch_GPS]: 1



(a) (b) (c)

Figure 17. An under-ice mission conducted by Glider 223 from December 21 to 23, 2023: (a) the GPS location at mission start point and the initial heading of the glider; (b) a portion of the dead-reckoning path on December 22, 2023; (c) a portion of the dead-reckoning path on December 23, 2023.

Conclusions

❑ First generation

- Standard glider + BSD + an upward-looking altimeter
- Heading control + depth control + surfacing control + hardware risk monitor
- Urgency levels for surfacing control

❑ Worked as expected

- Tests in open water
- Application in ice water
- Benefit future projects around ice

Figure 18. BSD Gliders 305 and 330 onboard RRS Discovery before open-water missions.

Future work

- ❑ Features
  - Slocum glider
  - Triangle path
  - RAFOS beacons
  - Under ice for months
- ❑ Challenges
  - Navigation
  - Localization
  - Power consumption
  - Data log
  - Contingency behaviours
  - …

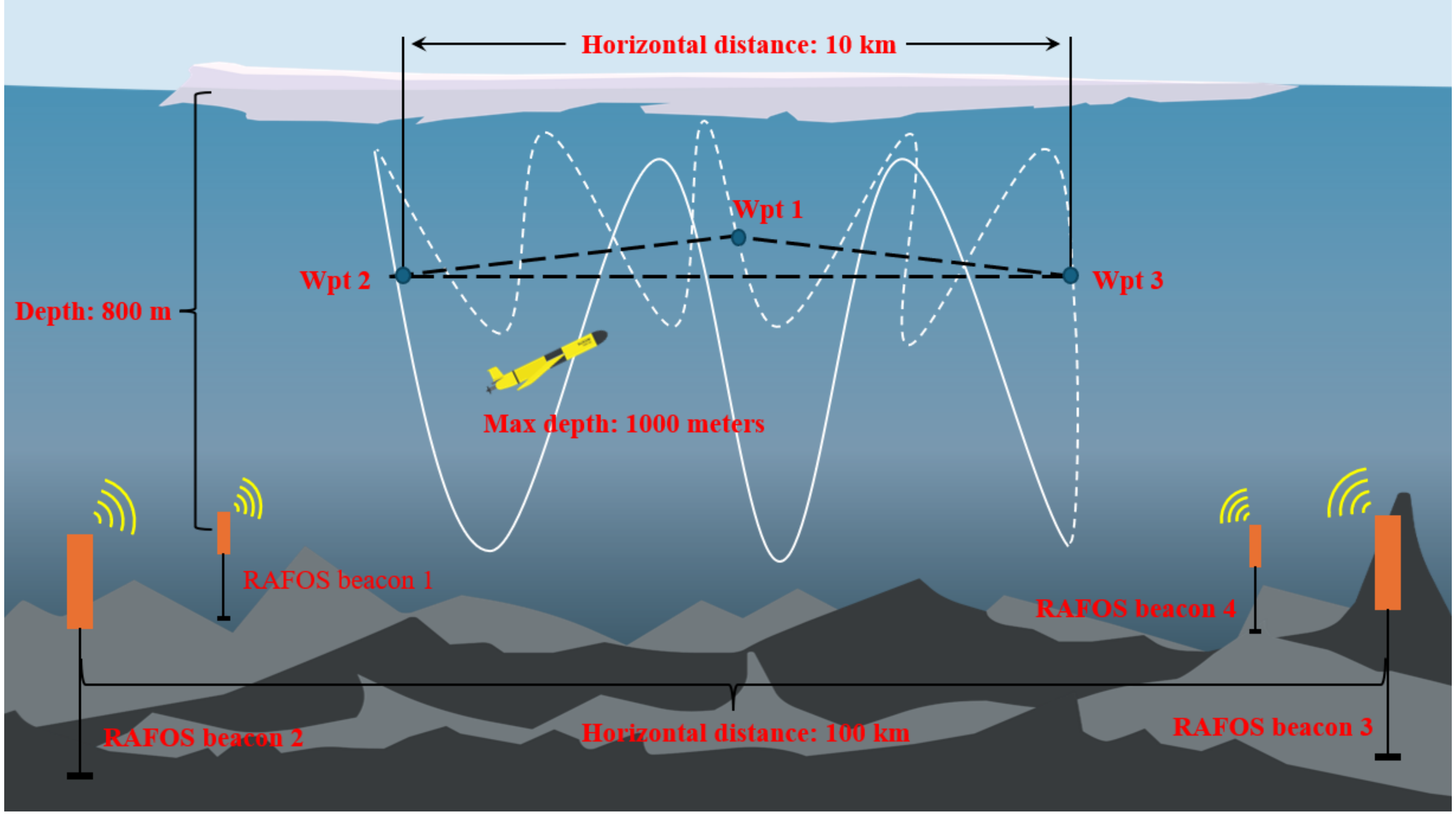


Figure 19. **PycnoGen** project in which a glider navigates along a triangle path, aided by RAFOS beacons under sea ice for months (Project management: Prof. Alberto Naveira Garabato, Prof. Eleanor Frajka-Williams).

Thank you!

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