Title: Monitoring the motion of the land-fast ice in Lützow-Holm bay, Antarctica

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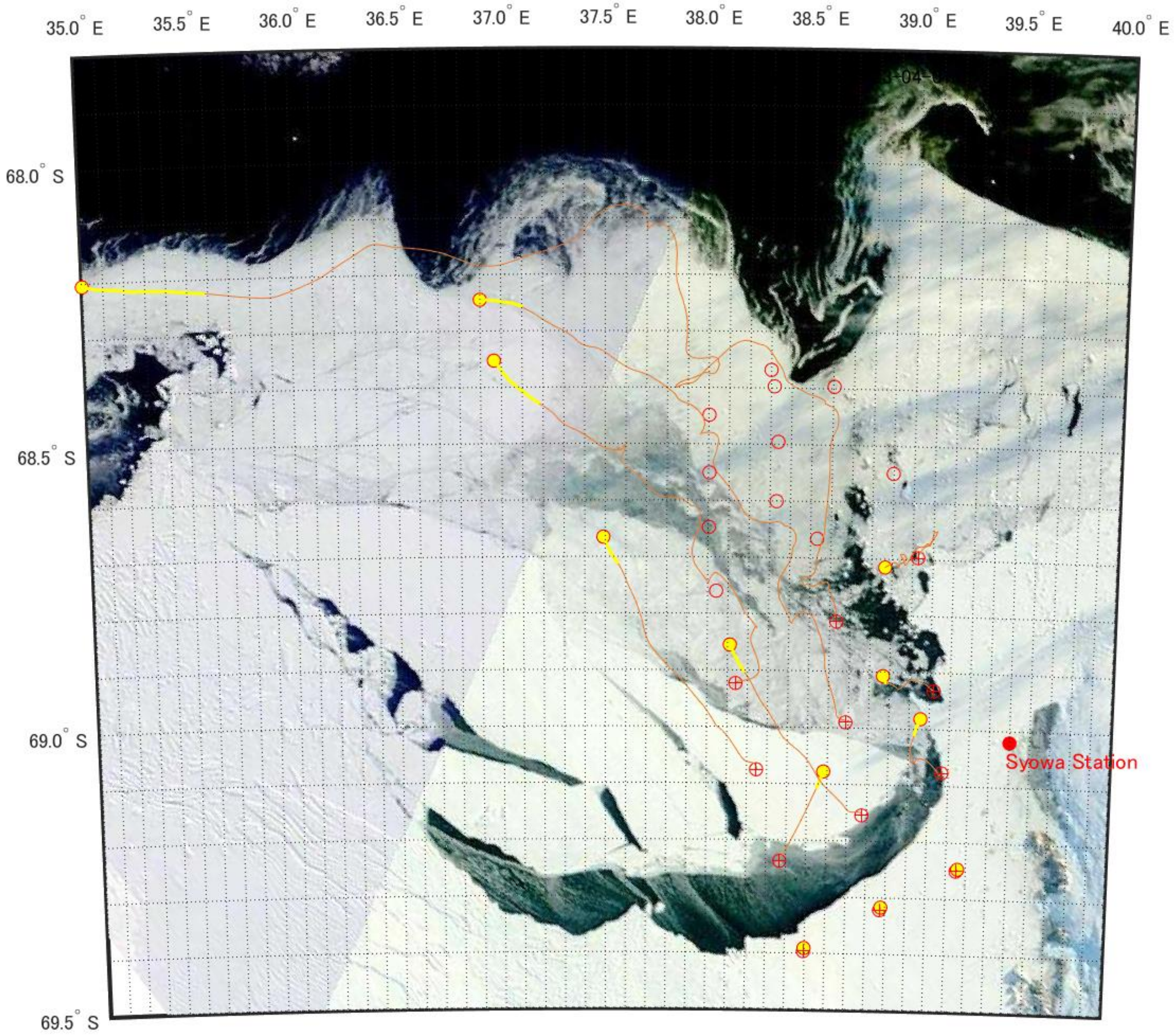
[1]The University of Tokyo, [2]Kitami Institute of Technology, [3]National Institute of Polar Research, [4]Hokkaido University, [5]Met. Norway, [6]Alfred-Wegener-Institut



2023.4.1 Breakup of the Land-fast Ice

APPLIED PHYSICAL
OCEANOGRAPHY

Syowa station & Japanese Antarctic Research Expedition (JARE)

Syowa station

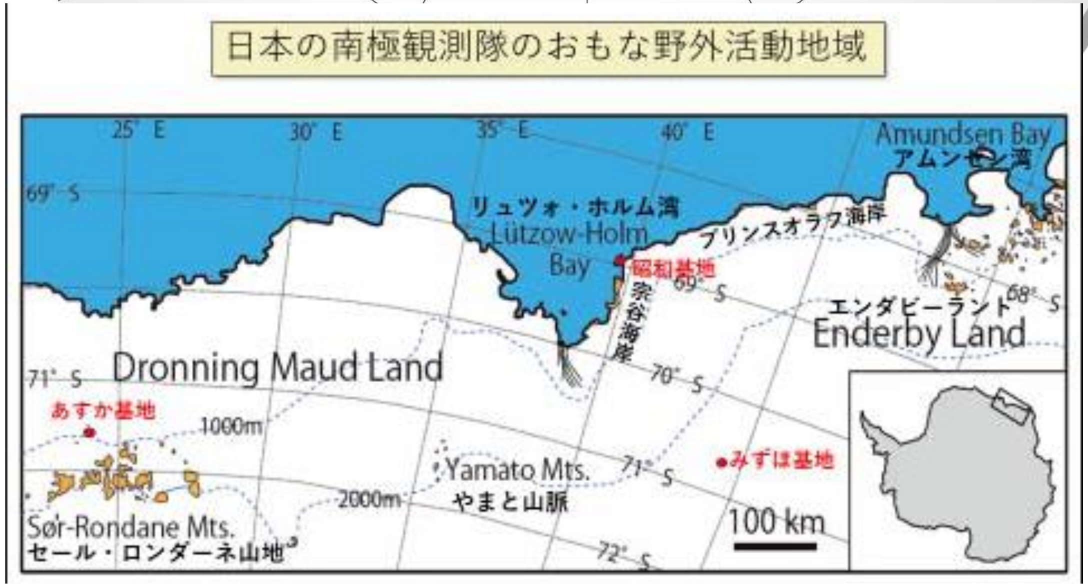
- ☐ Located on East Ongul Island in Lützow-Holm bay
- ☐ Built-in 1957

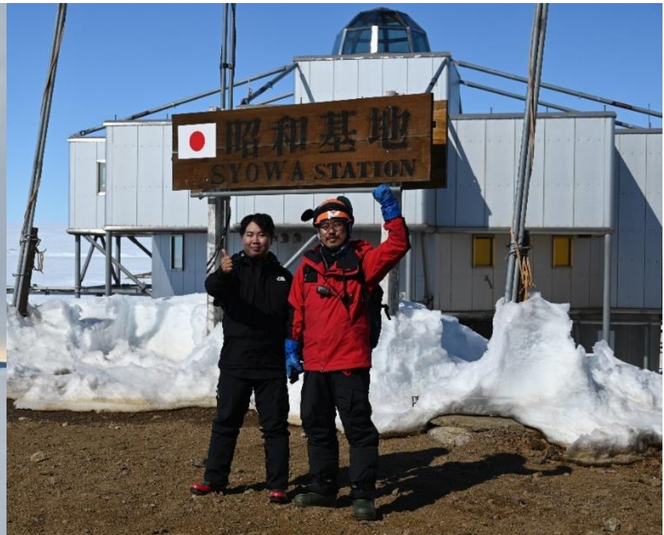
JARE

- ☐ 64 expeditions since 1957 (JARE1 to JARE64)

Shirase

- ☐ Icebreaker, 20,000t, L138m, B28m, D9.2m
- ☐ Capable of continuous ice-breaking up to 1.5 m ice thickness
- ☐ Ramming ice breaking over 2.0 m total ice thickness

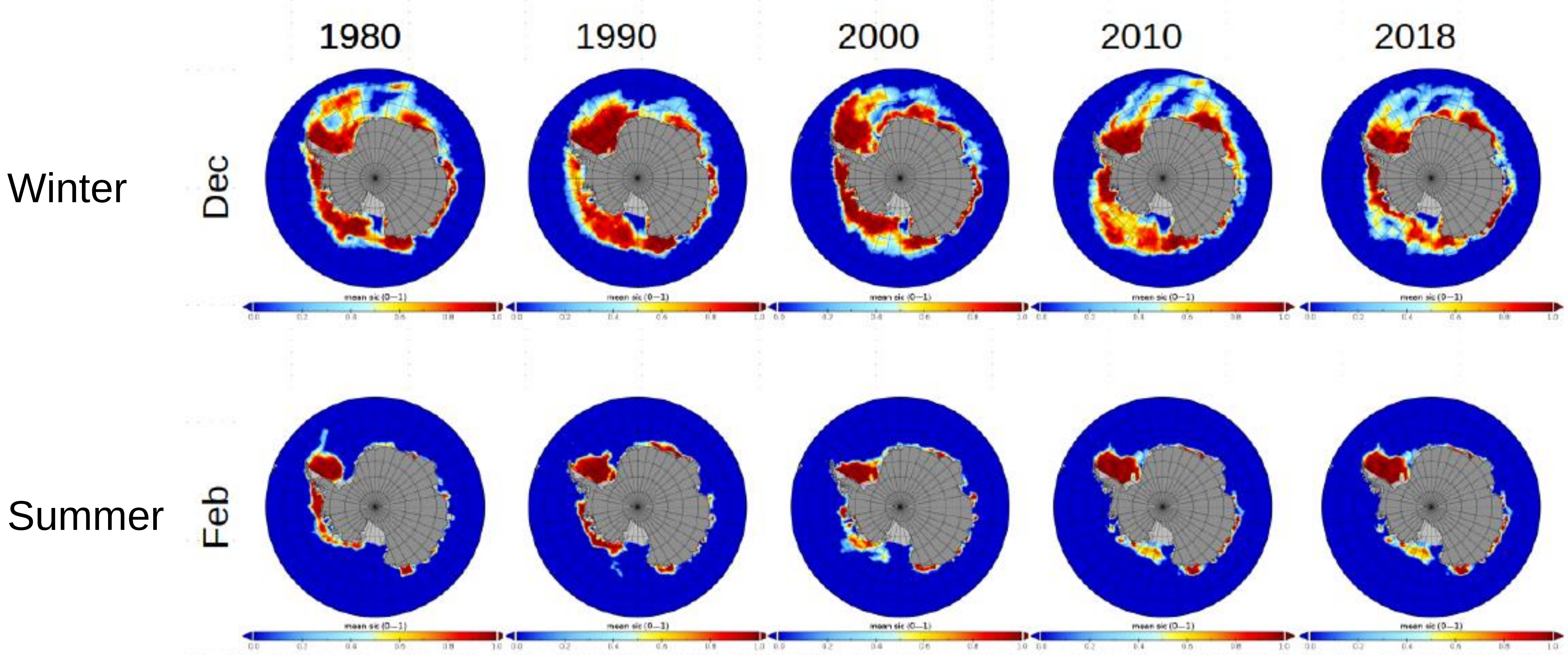




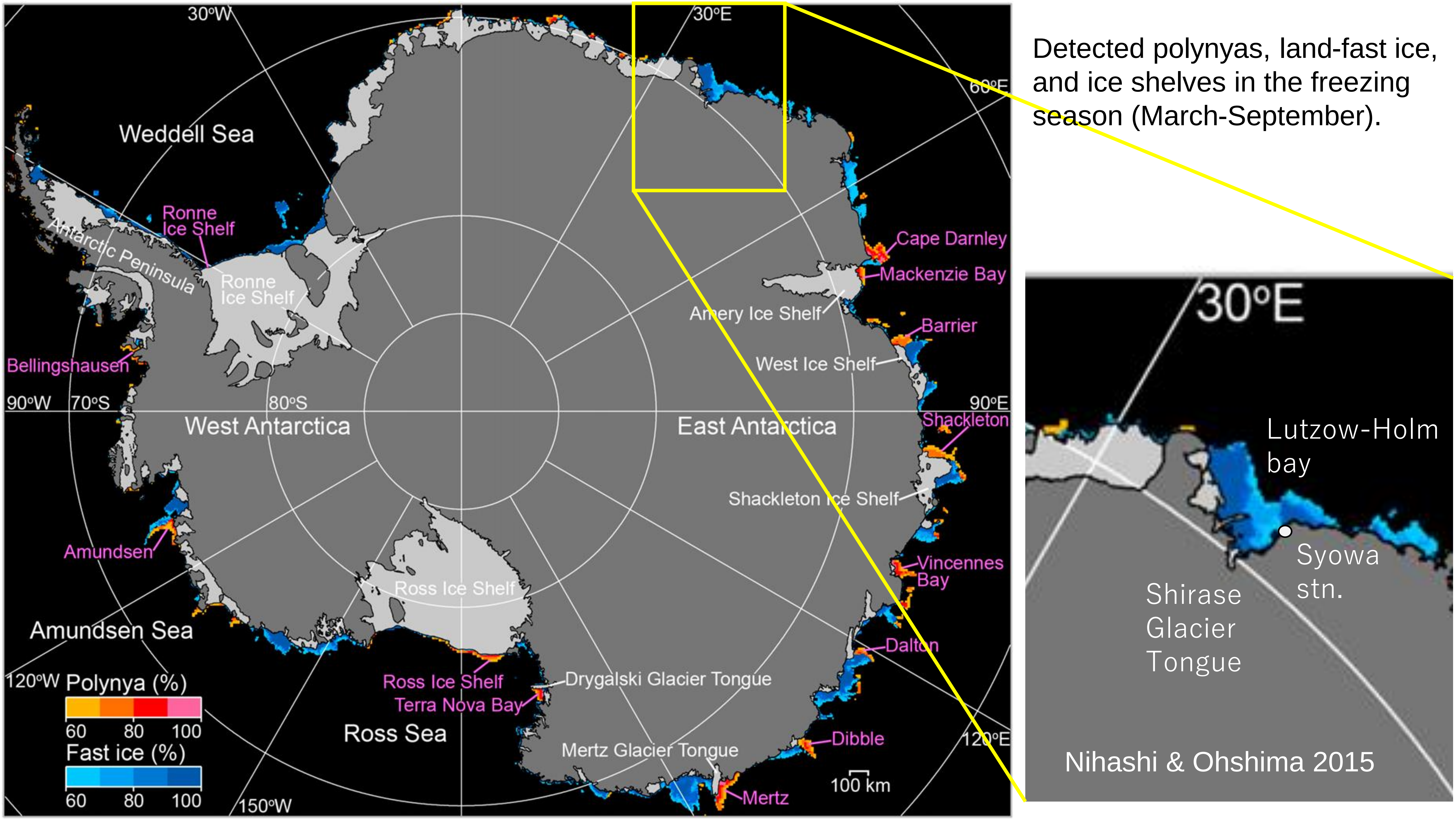
JARE64 Dec. 2022

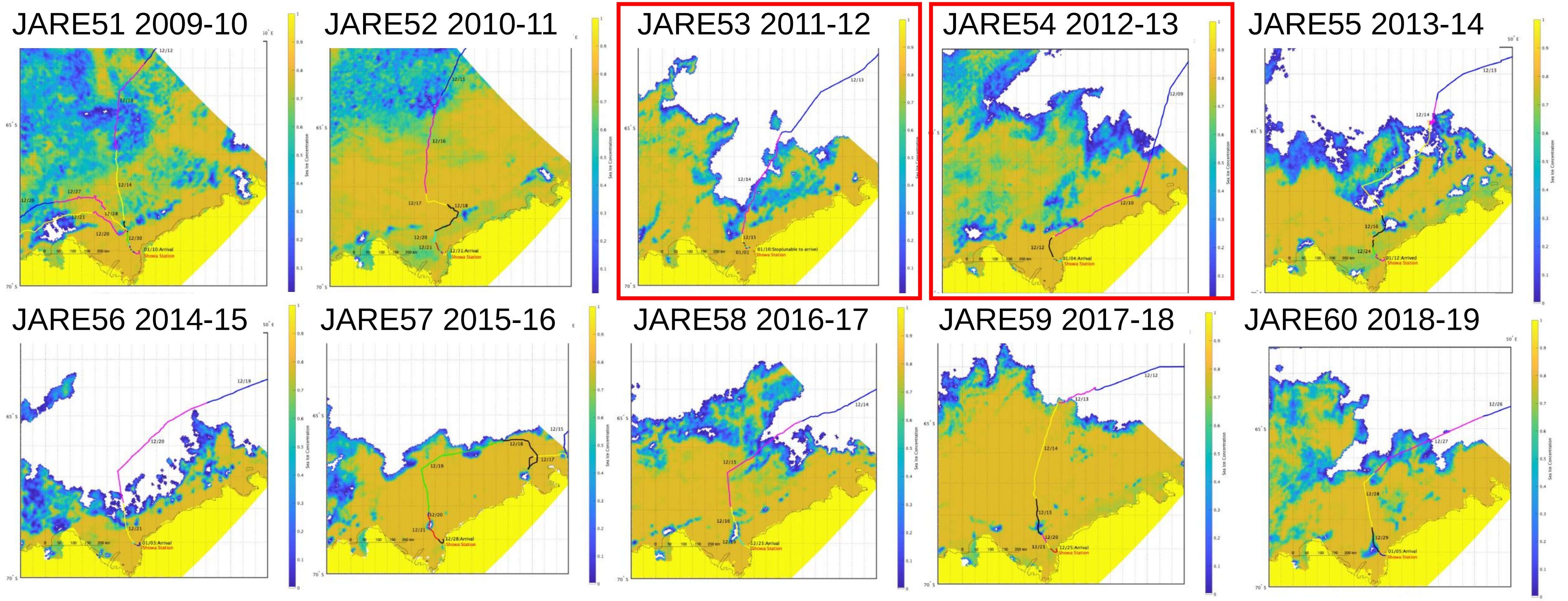
The Southern Ocean sea ice conditions

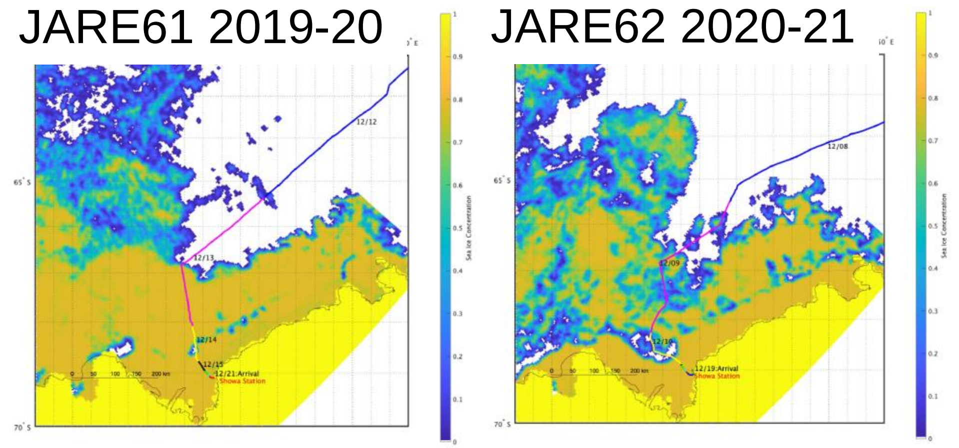
Mean SIC in austral summer months during Shirase outbound (to Syowa) (Dec) and homebound (Feb) legs.



Detected polynyas, land-fast ice, and ice shelves in the freezing season (March-September).





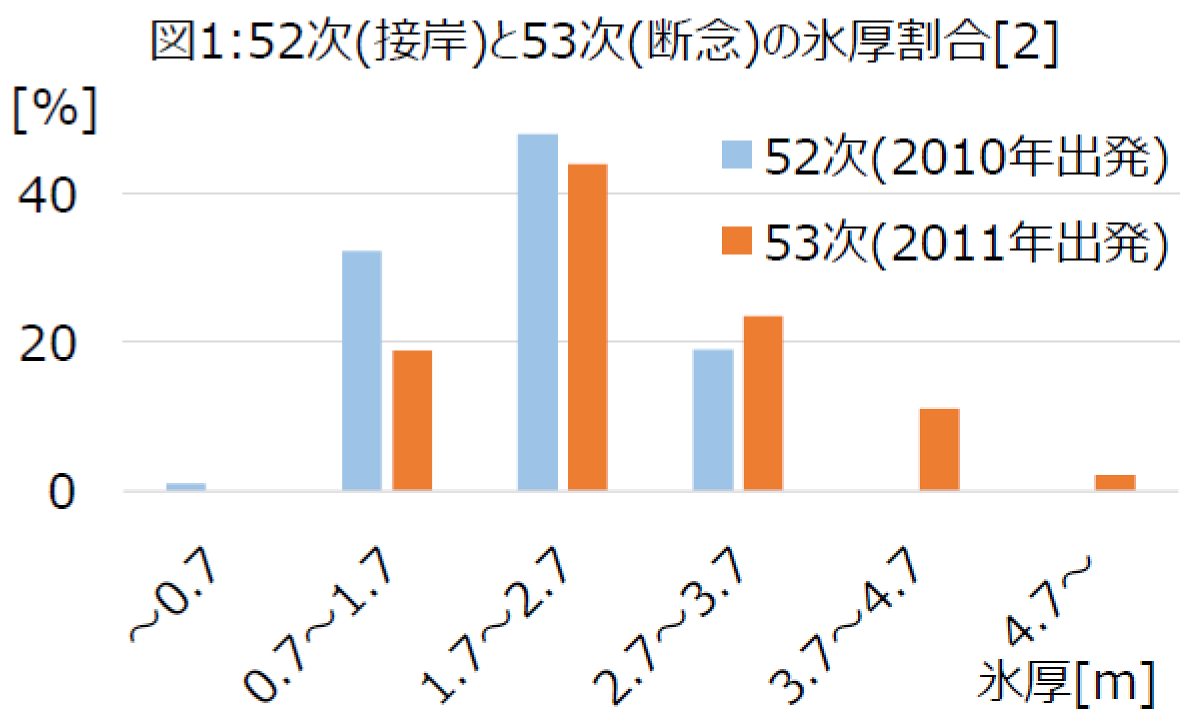


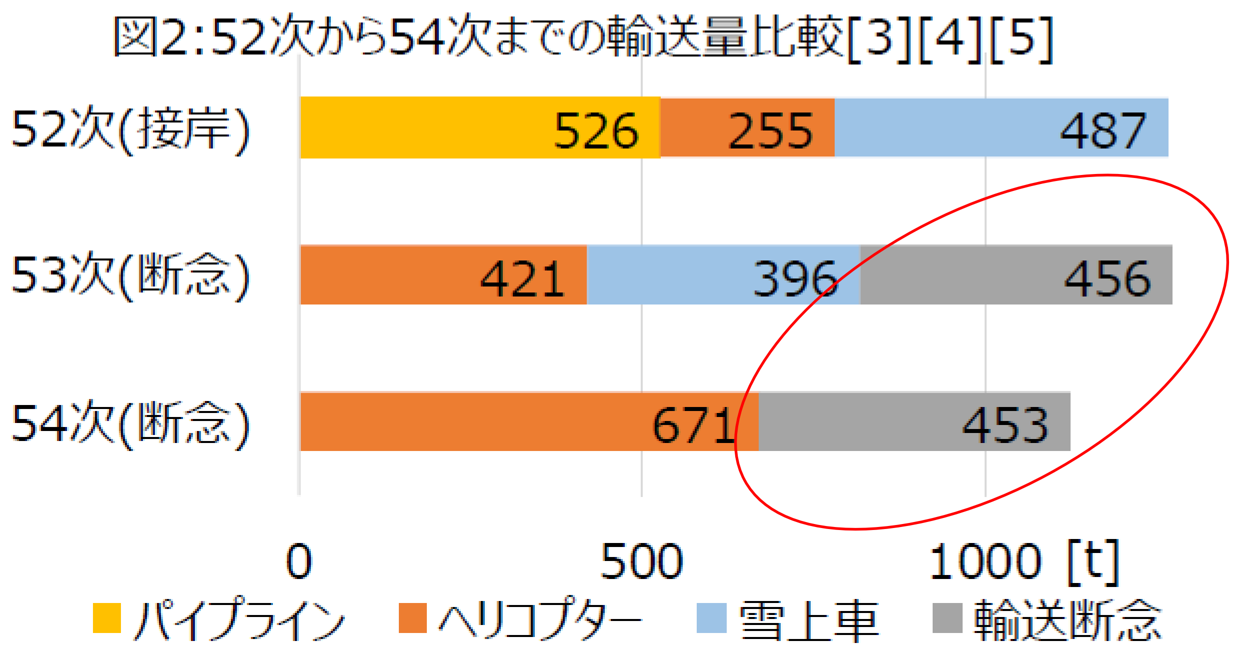
Shirase's ship route and Sea Ice Concentration (AMSR2) since JARE 51

Sea ice condition changes year by year.
The difficulty of navigating through the ice changes accordingly.
Particularly the JARE53 & 54

Ishiyama, bachelor's thesis 2023, UTokyo

Motivation:
Consequence of a failure to berth close enough to Syowa station

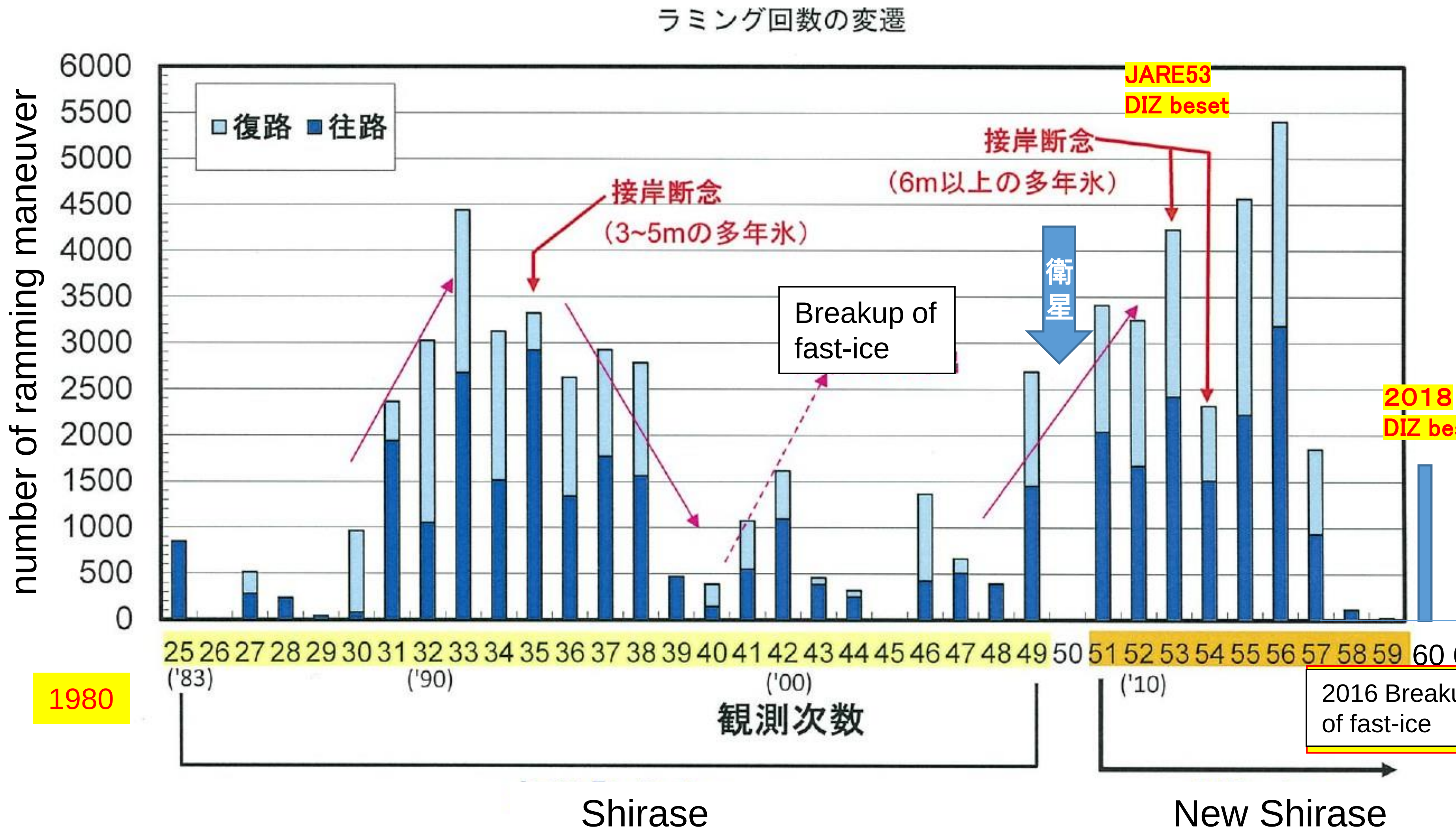




The thicker the ice, the more difficult to navigate through the ice.

A huge amount of goods are undelivered.

Inter-annual variability of the number of ramming maneuver



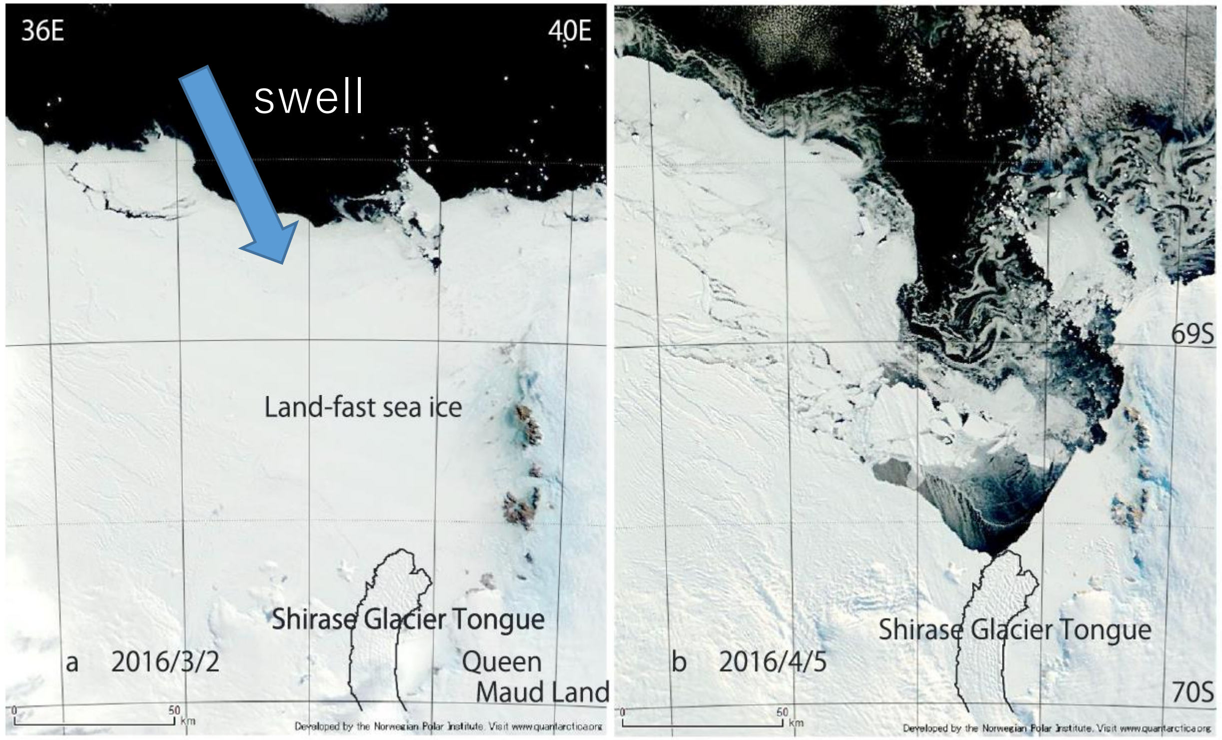
Ramming: to break the ice, back up a few hundred meters, and then charge onto the ice to break the ice by its own weight.

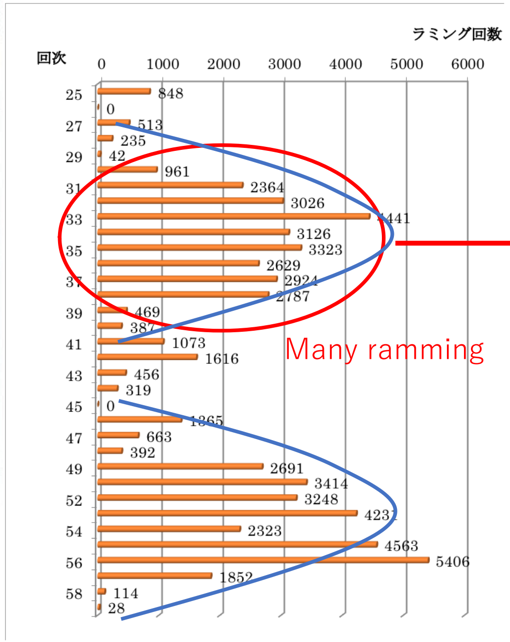
JARE64
Total 562 rammings
Outbound 492
(drift ice zone beset)

Sea Ice thickness of the Lützow-Holm Bay is changing quasi-periodically（Ushio 2003）

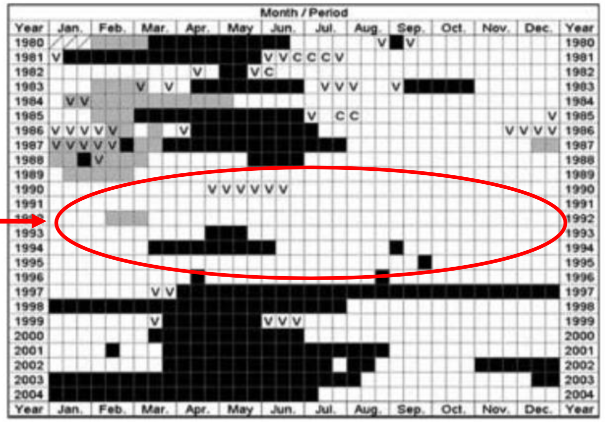
2016 Fast ice break-up in Lützow-holm bay

Possible cause of inter-annual variability





Many ramming



Few breakups

Cyclic change of the ice condition?

牛尾2003

Snow-ice hypothesis (Ushio & Toyota): As the ratio of the snow-ice increases, the sea ice loses its material strength and becomes easier for the propagating swells to break the ice.

Optimum routing for Shirase and the mechanism of MIZ, PIZ, and fast-ice variability

JARE64 – 69 (Xth term of JARE) (PI: Waseda)

- The objective is to monitor the waves propagating into the sea ice and to monitor the motion of the sea ice.

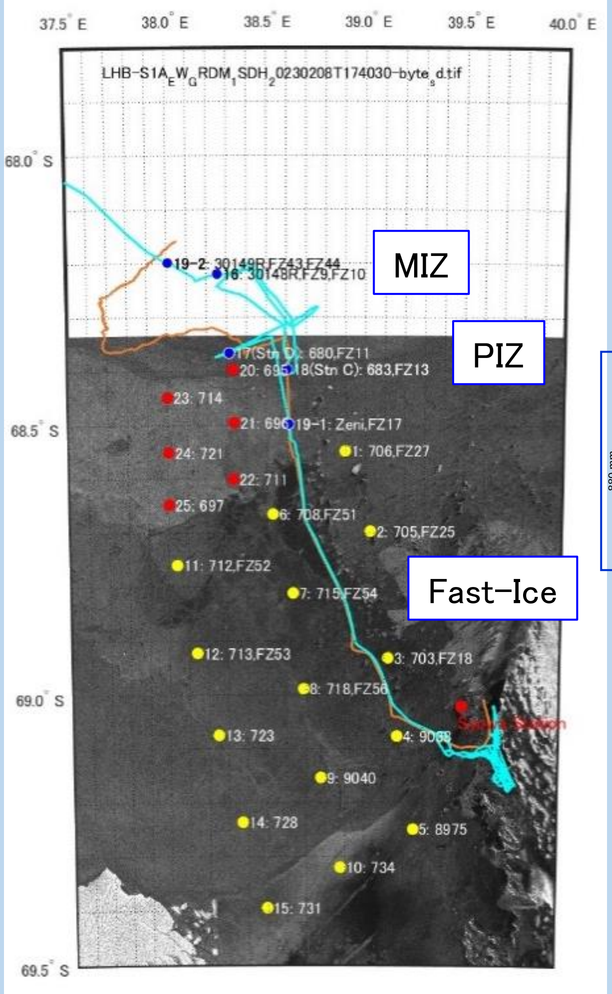
- The Marginal Ice Zone and the Packed Ice Zone prevent the waves to propagate into the fast ice.
  - Propagation and attenuation of waves in the MIZ and PIZ

- The breakup of fast ice
  - Causes: wind, current, and wave
  - Fracture vs. fatigue

- Long-term trend: climate variation, storm

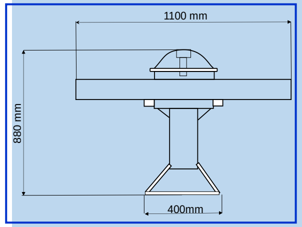
In-house buoys:
Kodaira, T., et al.. OCEANS 2022, CEJ (2023)
Rabault, J., et al. Sci. Data 10, 251 (2023)
Nose, T. (2023). Polar Research, CEJ

JARE64（33 buoys）

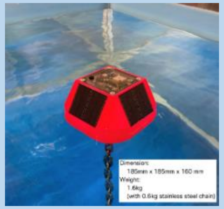


Land-fast Ice
CH 15 buoys

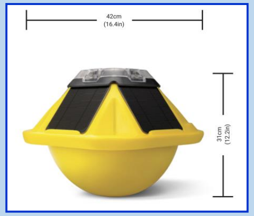
PIZ CH 6 buoys
Crane (Obs) 1 buoy
No.4 Crane 1 buoy



PIZ
Rope/hand 1 buoy



PIZ・MIZ
Rope/hand 7 buoys



MIZ
Rope/hand 2 buoys

JARE64: Waseda, Tateyama, Uchiyama

Key technology: Sensor development – a community effort

geosciences

Article

OpenMetBuoy-v2021: An Easy-to-Build, Affordable, Customizable, Open-Source Instrument for Oceanographic Measurements of Drift and Waves in Sea Ice and the Open Ocean

Jean Rabault [1,*], Takehiko Nose [2], Gaute Hope [1], Malte Müller [1,3], Øyvind Breivik [1], Joey Voermans [4], Lars Robert Hole [1], Patrik Bohlinger [1], Takuji Waseda [2,5], Tsubasa Kodaira [2], Tomotaka Katsuno [2], Mark Johnson [6], Graig Sutherland [7], Malin Johansson [8], Kai Haakon Christensen [1], Adam Garbo [9], Atle Jensen [3], Olav Gundersen [3], Aleksey Marchenko [10] and Alexander Babanin [4]

Table 2. A representative list of components needed to build an instrument monitoring drift (GNSS) and wave activity (9-dof sensor). The assembly time for a single instrument, when assembling a series of 10 instruments in bulk, is about 0.5 h once the user is familiar with the design.

Component	Function	Price (USD)	Assembly Steps
Artemis Global Tracker	main board, MCU, GNSS, Iridium	375	ready to use
GNSS + Iridium antenna	passive antenna	65	screw on SMA cable
SMA extension cable 25 cm	extension cable for antenna	5	screw on tracker
Qwiic power switch	power on and off 9-dof	7	disable LED, connect 9-dof and tracker
ISM330DHCX + LIS3MDL	9-dof sensor	18	connect to power switch
Qwiic cables (x2)	connect tracker, 9-dof, switch	3	connect power switch and 9-dof
3.3V Regulator S7V8F3	3.3 V buck converter	10	solder to battery and tracker
2 × D cell holders	house and connect batteries	15	solder to 3.3 V regulator
2 × SAFT LSH20	power supply	35	put in cell holders
reed MDRR-DT-20-35-F	magnetic switch	3	solder between battery and regulator
magnet	turn magnetic switch on/off	1	mount outside housing
housing box	housing, IP68	20	mount the electronics inside
misc: glue, wire	small extras	5	get the design assembled
total	fully functional instrument	562	0.5 h/instruments, producing 10

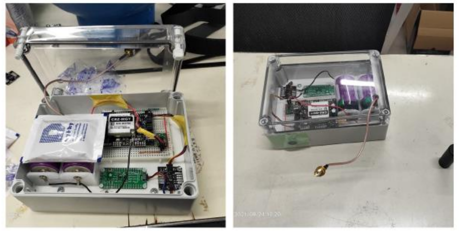
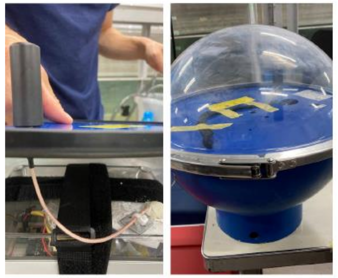
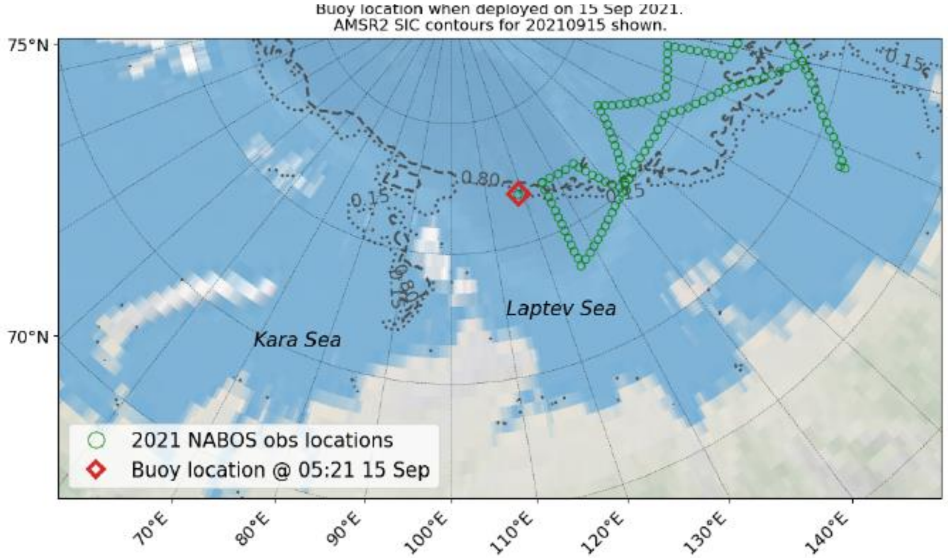
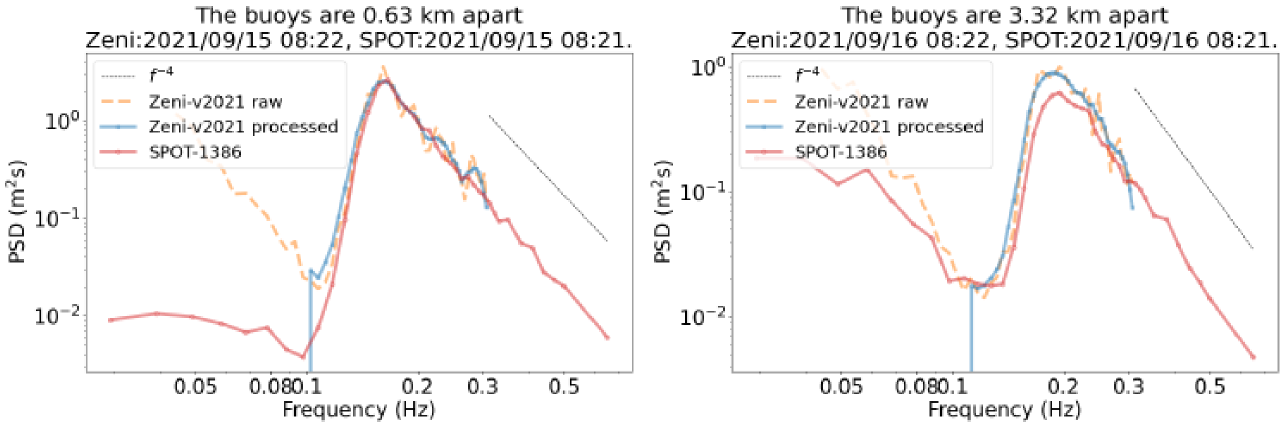



Figure A1. Illustrations of the instrument v2021 electronics components enclosed in a water-resistant Takachi box.



NABOS2021
Drifter type

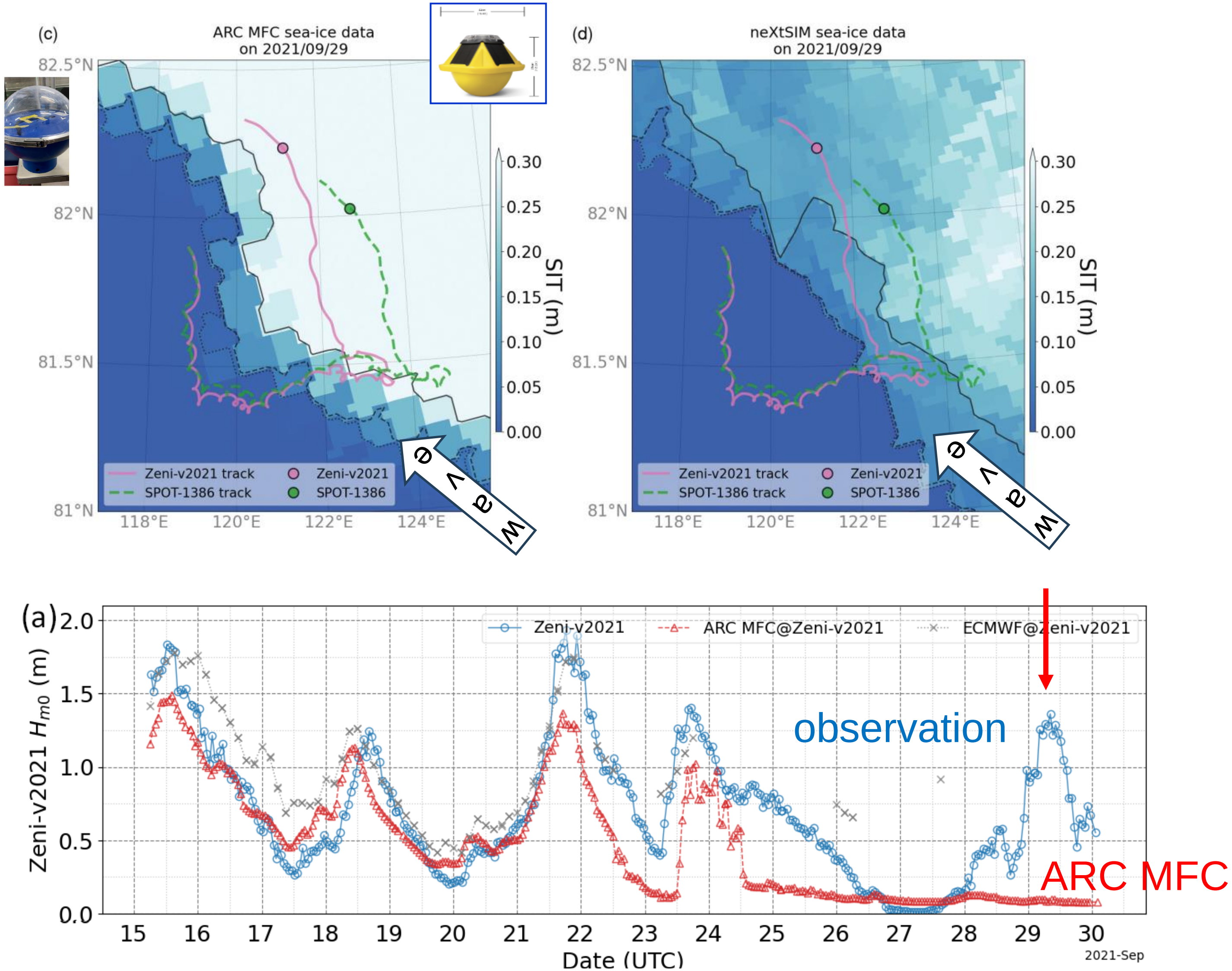
Figure 6. Zeni-v2021 and SPOT-1386 deployment location on 15 September 2021. The 2021 NABOS observation locations also shown in green markers and AMSR2-derived 0.15 and 0.80 Sea Ice Concentration (SIC) contours for the same day are overlaid.



Comparison against commercial product (Spotter)

Findings from the NABOS 2021 cruise and data release

Resolving thin ice; a crucial factor in waves in polar region



Nose et al. 2023 Polar Research: model fails to represent a wave event.

scientific data

Check for updates

OPEN

DATA DESCRIPTOR

A dataset of direct observations of sea ice drift and waves in ice

Jean Rabault[1]✉, Malte Müller[2,3], Joey Voermans[4], Dmitry Brazhnikov[5], Ian Turnbull[6], Aleksey Marchenko[7], Martin Biuw[8], Takehiko Nose[9], Takuji Waseda[9,10], Malin Johansson[11], Øyvind Breivik[12,13], Graig Sutherland[14], Lars Robert Hole[12], Mark Johnson[5], Atle Jensen[15], Olav Gundersen[15], Yngve Kristoffersen[16], Alexander Babanin[4], Paulina Tedesco[1,17], Kai Haakon Christensen[2,3], Martin Kristiansen[8], Gaute Hope[12], Tsubasa Kodaira[9], Victor de Aguiar[11], Catherine Taelman[11], Cornelius P. Quigley[11], Kirill Filchuk[18] & Andrew R Mahoney[19]

Deployment time	location	ice conditions	number & kind of instrument
2017-04	Arctic, Barents Sea, 76.4 N 22.5E	drift ice: 8/10 to 0/10	GPS drifter: 8
2018-03a	Arctic, East Greenland Sea, 73.5 N 15.5E	drift ice: 6/10 to 10/10	GPS drifter: 5
2018-03b	Arctic, Beaufort Sea, 72.3 N 148.4 W	pack ice: 8/10 to 10/10	IWR: 2
2018-04	Arctic, Barents Sea, 75.3 N 19.5E	drift ice: 8/10 to 0/10	GPS drifter: 1
2018-09	Arctic, Barents Sea, 82 N 20E	MIZ: 1/10 to 10/10	v2018: 4
2020-01	Antarctic, outside Davis station, 69 S 76E	landfast ice (breakup)	v2018: 2 + Sofar Spotter: 2
2020-03a	Arctic, Grønfjorden, Svalbard, 78 N 14E	landfast ice (intact)	v2018: 3
2020-03b	Arctic, Beaufort Sea, 71.2 N 141.5 W	pack ice: 8/10 to 10/10	IWR: 2
2020-07	Arctic, Yermak Plateau, Barents Sea, 82 N 15E	MIZ: 3/10 to 10/10	v2018: 6
2020-11	Antarctic, outside Casey station, 66 S 110E	landfast ice (intact)	v2018: 2
2021-02	Arctic, Barents Sea, east Svalbard, 77 N 30E	MIZ: 5/10 to 10/10	v2018: 6 + v2021: 11 (6 with waves)
2021-03	Arctic, Beaufort Sea, 71.5 N 148WE	pack ice: 7/10 to 10/10	IWR: 3
2021-04	Arctic, Utqiagvik, 71.3 N 156.6 W	landfast ice	IWR: 6
2021-09	Arctic, Laptev Sea, 82 N 118E	MIZ: 1/10 to 10/10	v2021: 1 + Sofar Spotter: 1
2022-03	Arctic, East Greenland sea, 70 N 20E	MIZ: 2/10 to 10/10	v2021: 2 + commercial beacon: 5
total nbr tracks			total: 72; with waves: 48

Table 2. Overview of the deployments, their locations and time spans, the sea ice conditions, and the kind and number of instruments deployed.

Waves propagating under ice for a 1000 km (JARE63)

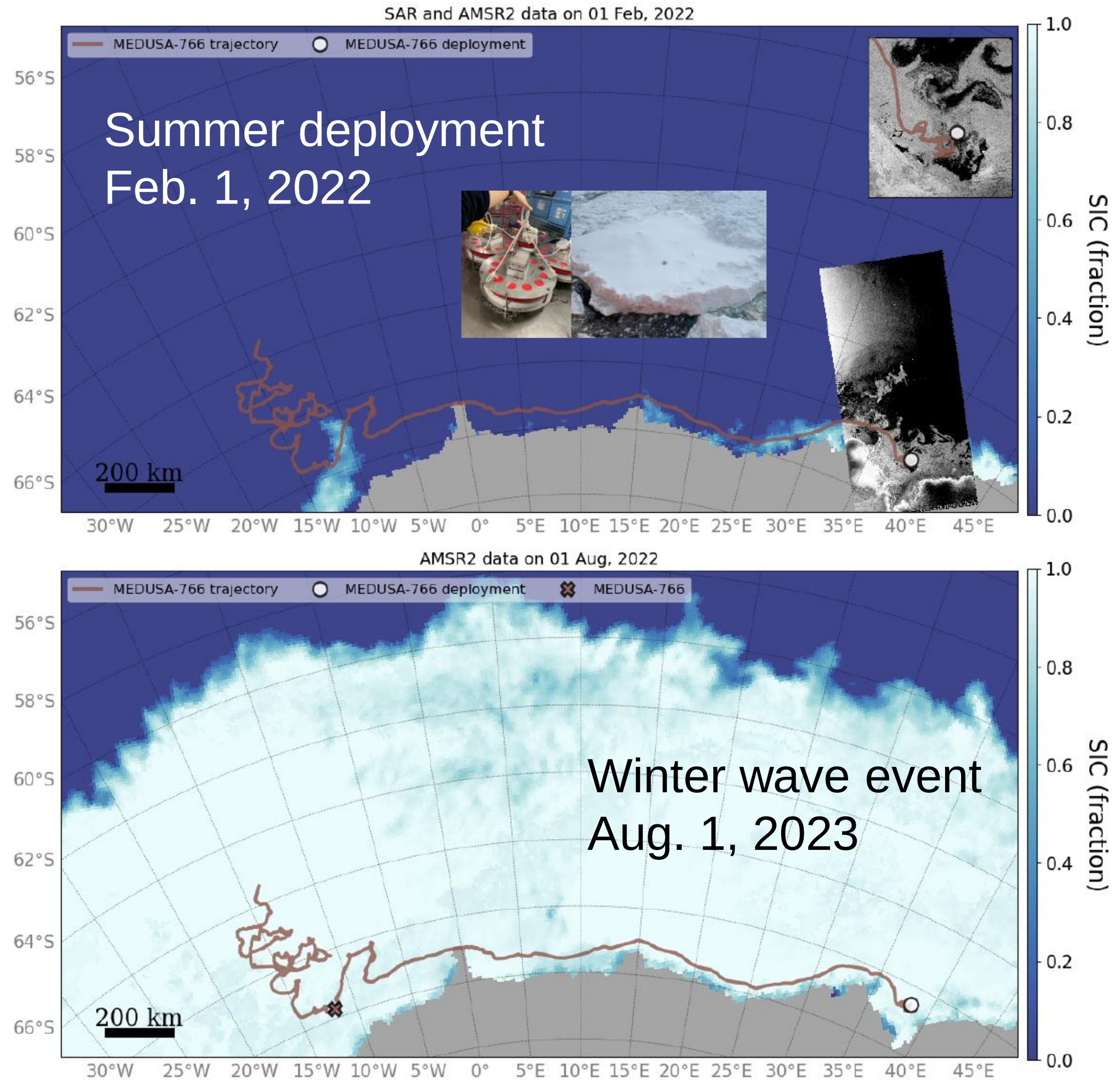
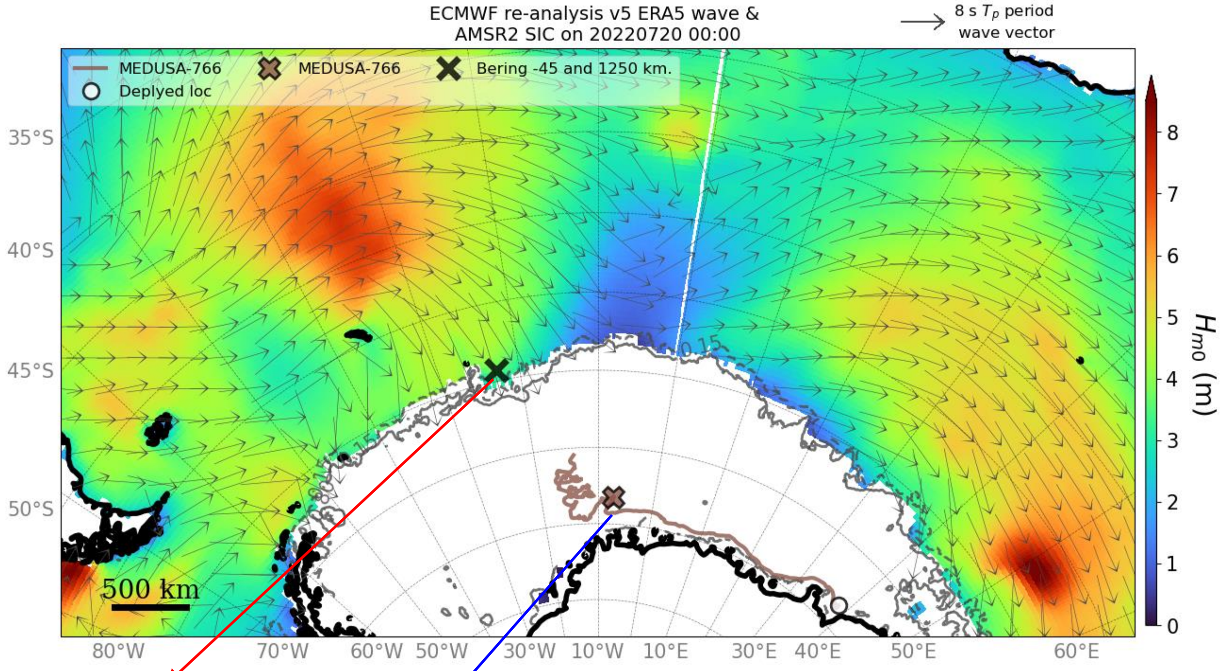
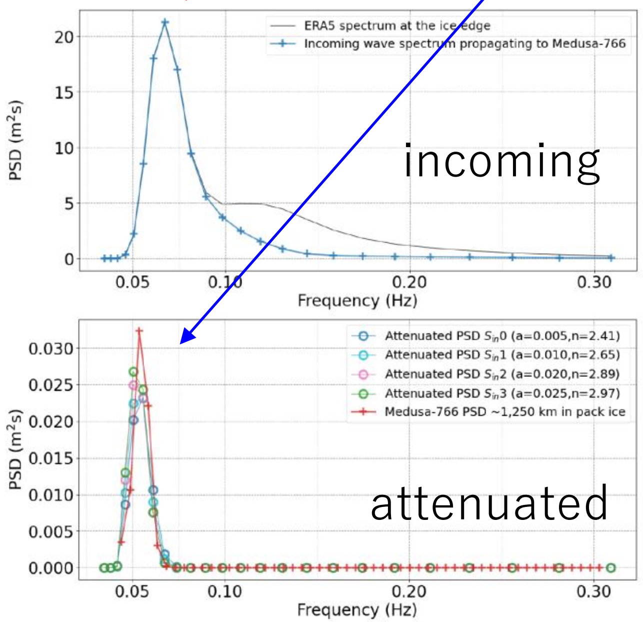


Figure 2.: Medusa-766 trajectory between 4 Feb 2022 and 3 Jan 2023 overlaid on the ADS-AMSR2 SIC on 1 Feb (top) and 1 Aug (bottom) 2022. The brown line is the trajectory, and the brown marker shows its location on the respective dates. SICs are shown in colours. The 1 Feb panel also has Sentinel-1 SAR images overlaid.



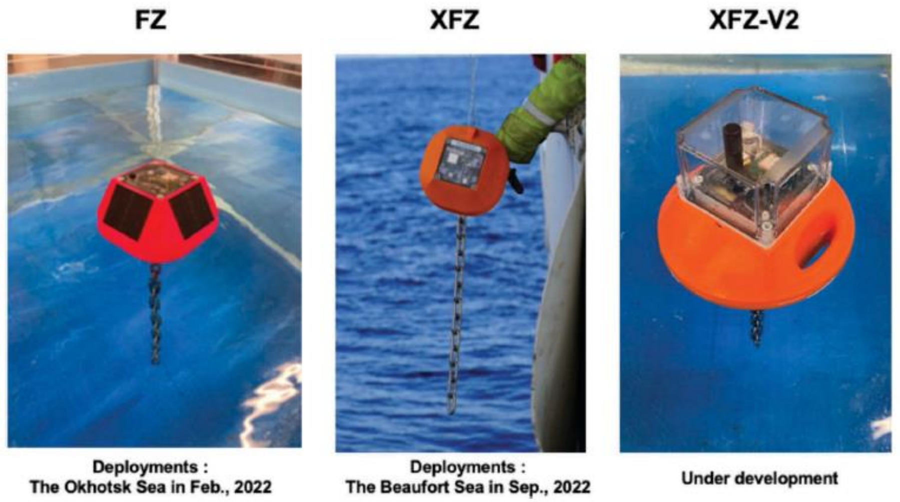


Spectral evolution well explained by frequency dependent attenuation rate.

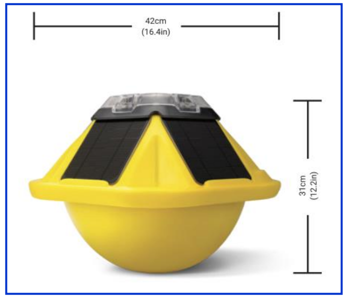
Nose et al. 2023 Coastal Eng. J.

Prototyping the buoys

Drifters: 3D printing + wave sensor (FZ)

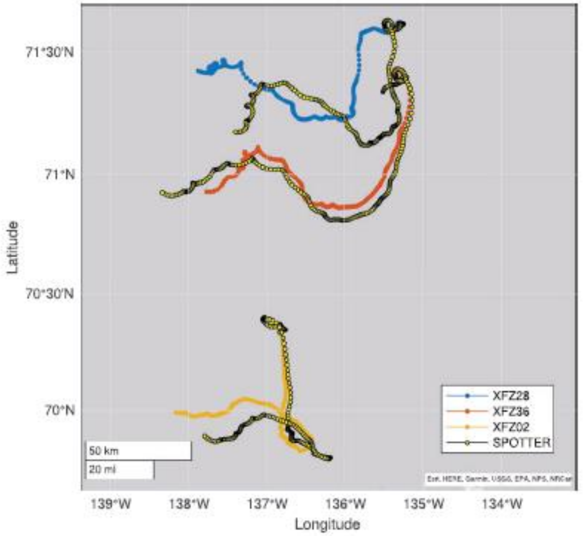


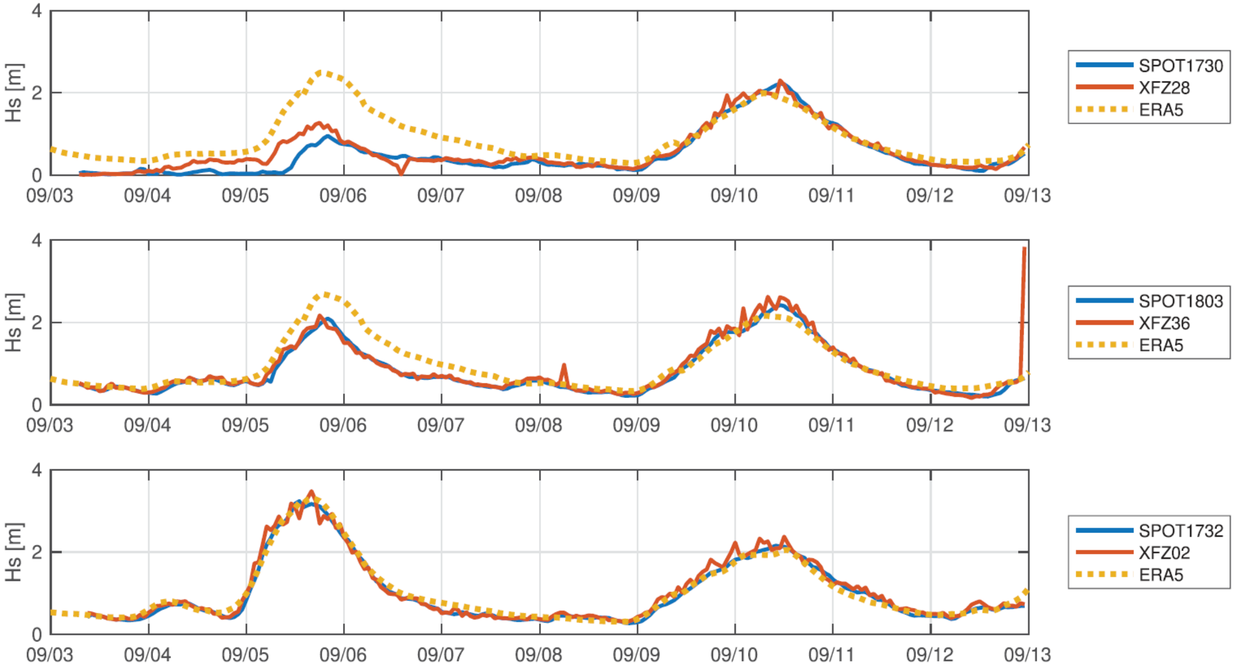
vs.



Buoy on ice: JARE63, 64

Beaufort Sea, Arctic Ocean



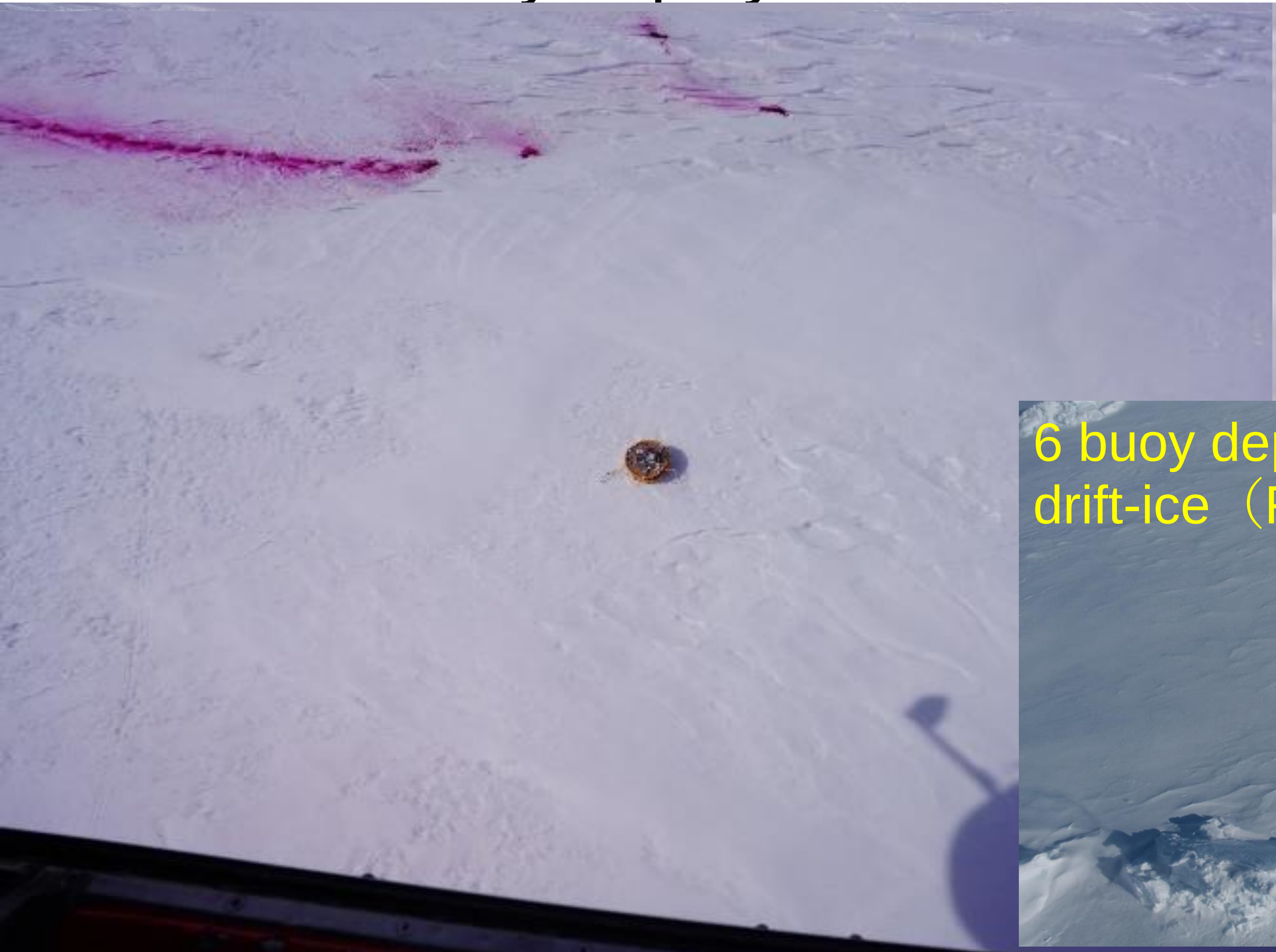


New design for JARE65

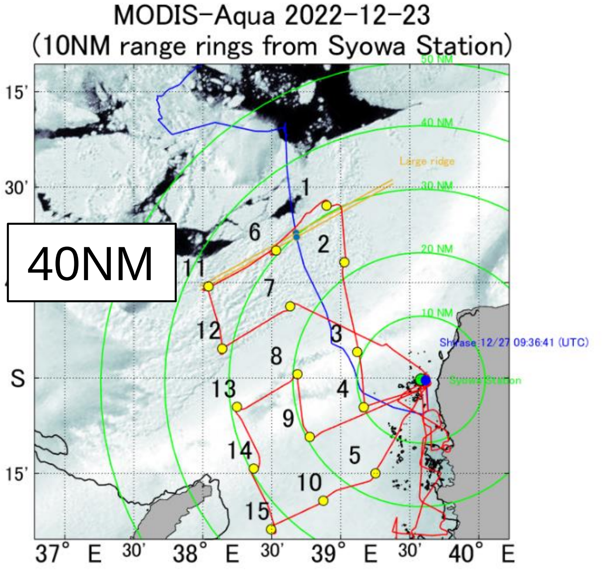
Kodaira et al. 2023 CEJ

JARE64: Buoy deployment on ice from Shirase（Feb. 14, 2023）

JARE64: 15 buoy deployments on Fast-ice（Dec. 26, 2022）



JARE64: Landing on ice：Measuring ice thickness（Feb.7, 2023）

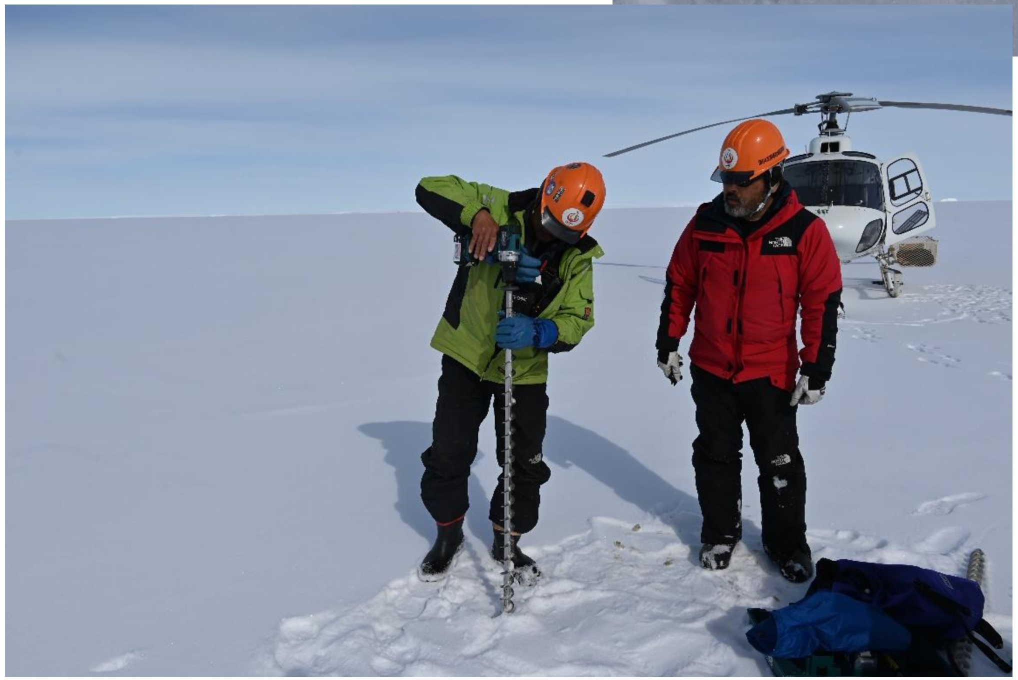


Point 15: Buoy K

Ice thickness　3.61m

Snow depth　1.58m

撮影内山

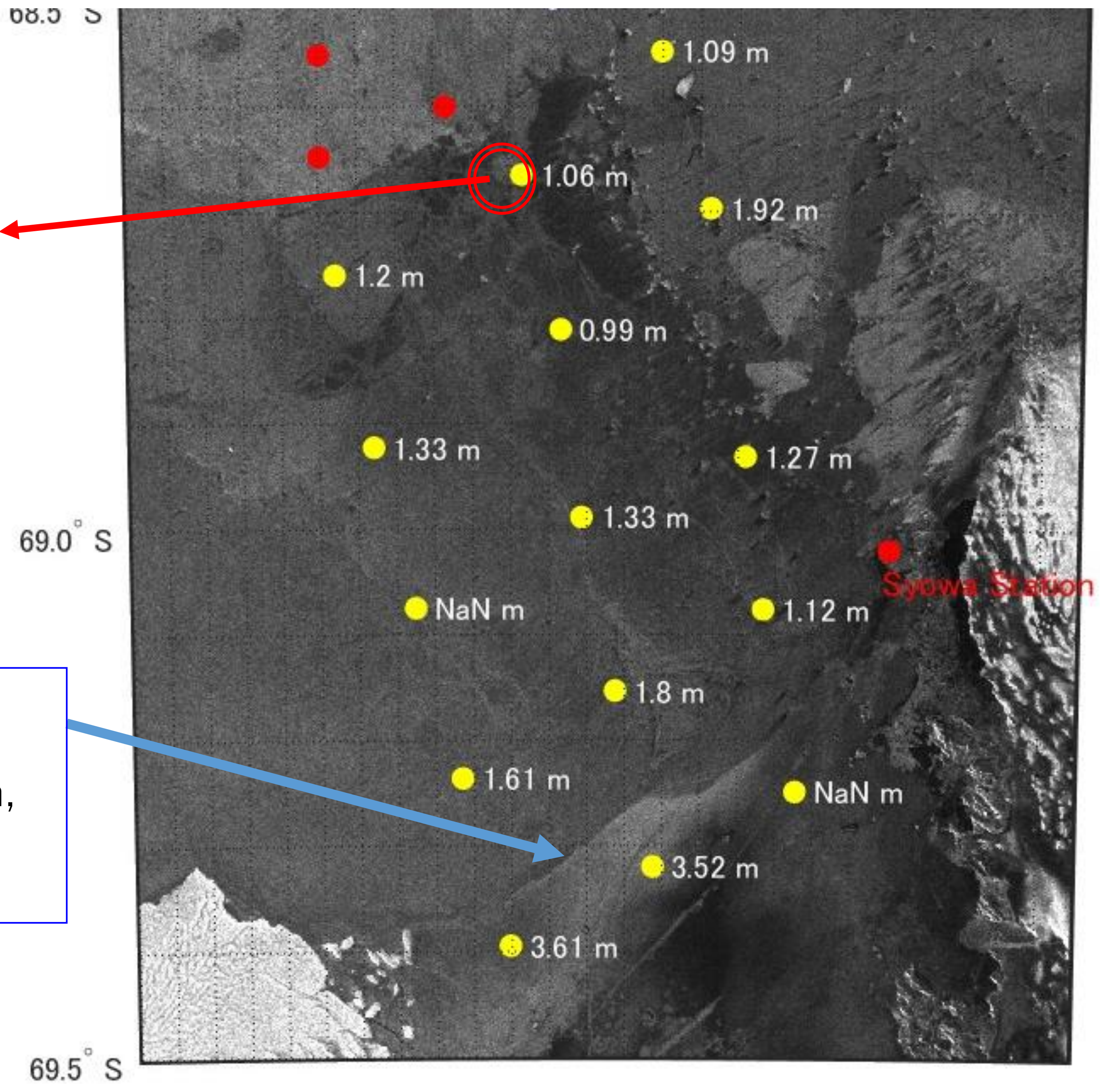


Sea ice thickness
（Jan 3, Feb,7, 2023）

	Ice thickness	Snow depth	Total thickness
1/3	1.06 m	0.36 m	1.42 m
2/7	1.17 m	0.19 m	1.36 m

Landed on 13 points out of 15 buoy positions.
For one point near the PIZ, we landed twice.

The ice edge after the breakup in April 2022. First-year ice in the north, and the multi-year ice in the south.



The motion of the buoys from Dec. 26, 2022 to May 2023

Dec. 26: 15 buoys deployed on fast-ice

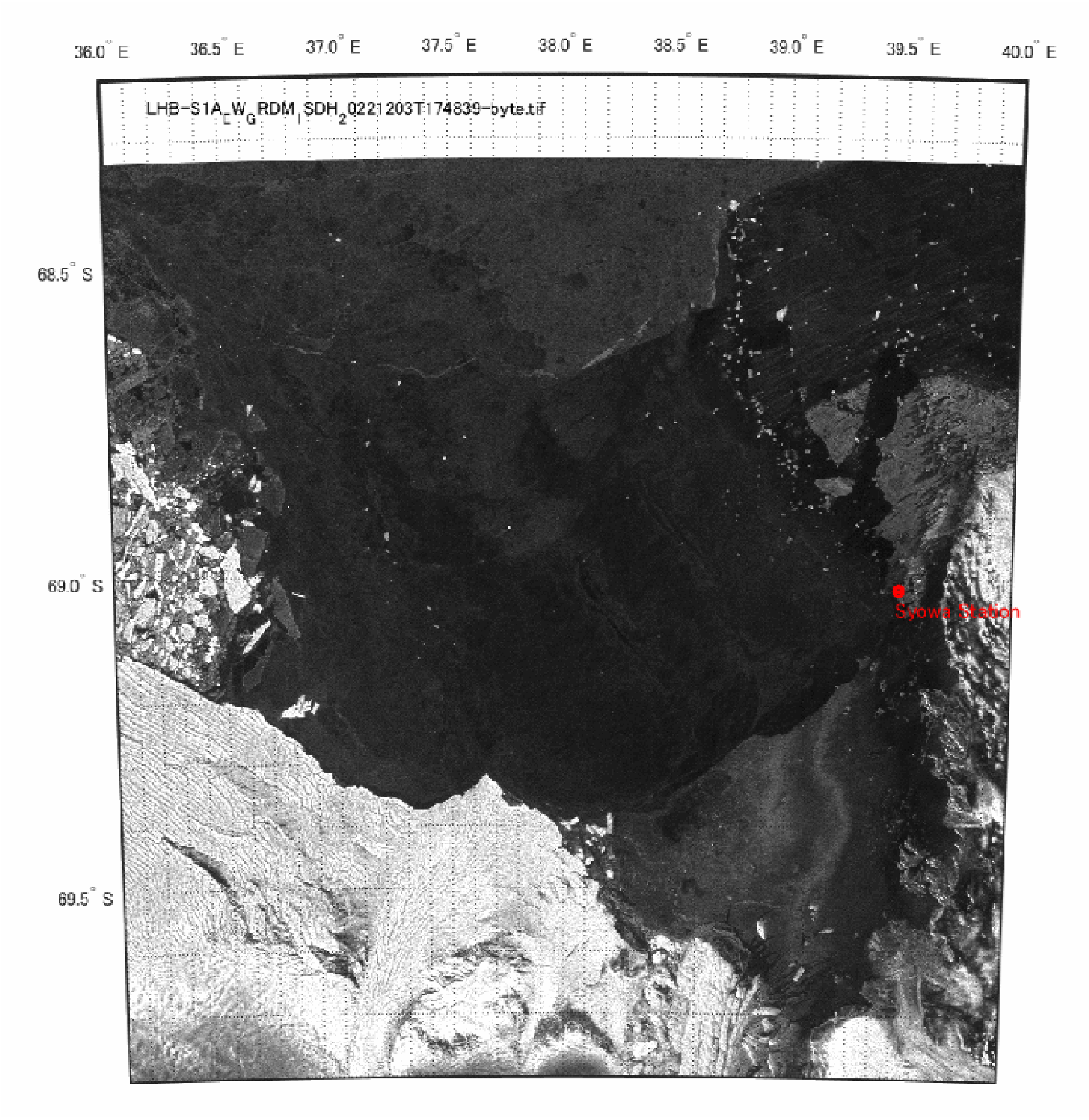
Jan. 3: landed on ice to measure ice thickness

Feb. 7: landed on ice to measure ice thickness

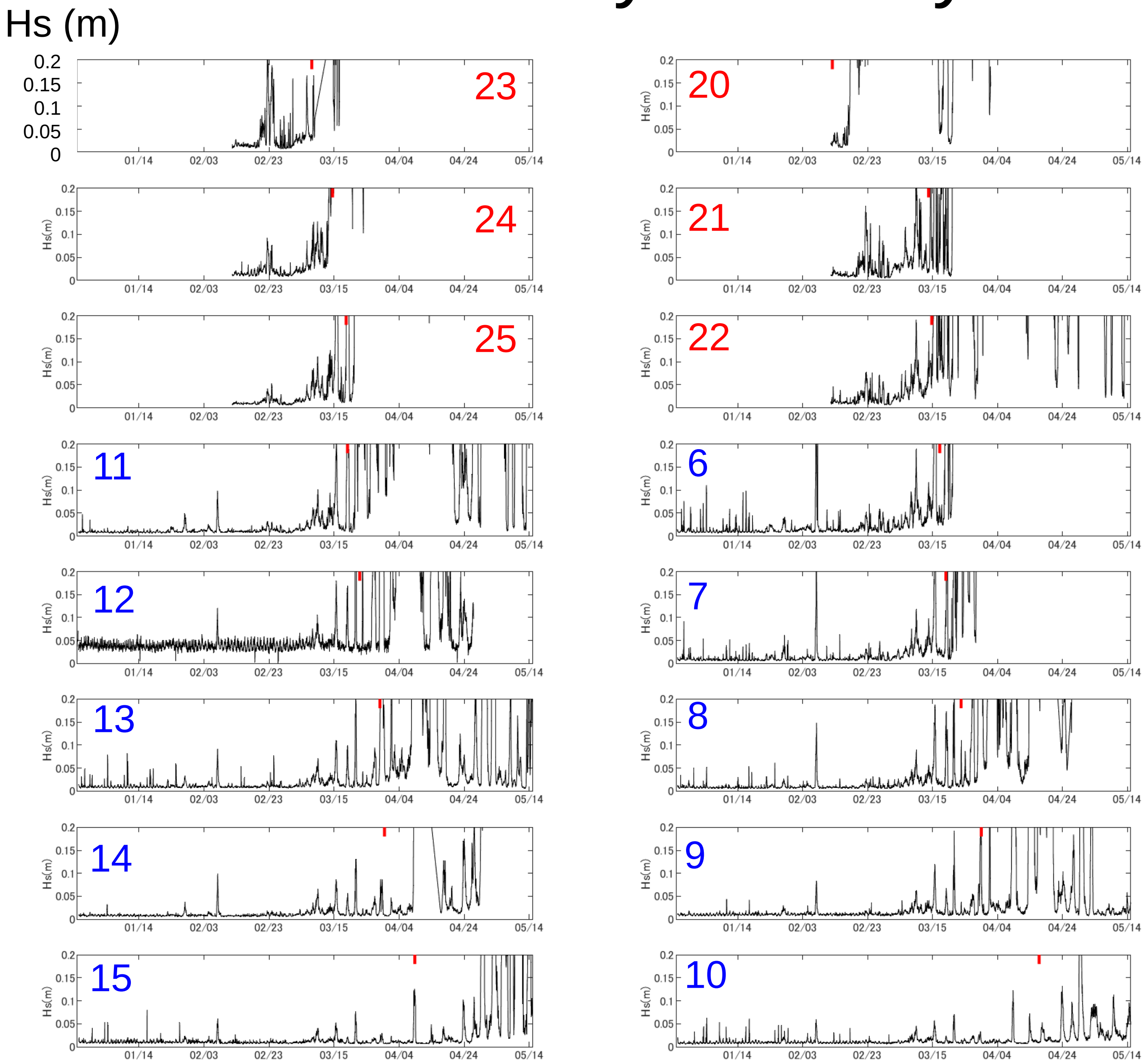
Feb. 11: 6 buoys deployed on drift-ice

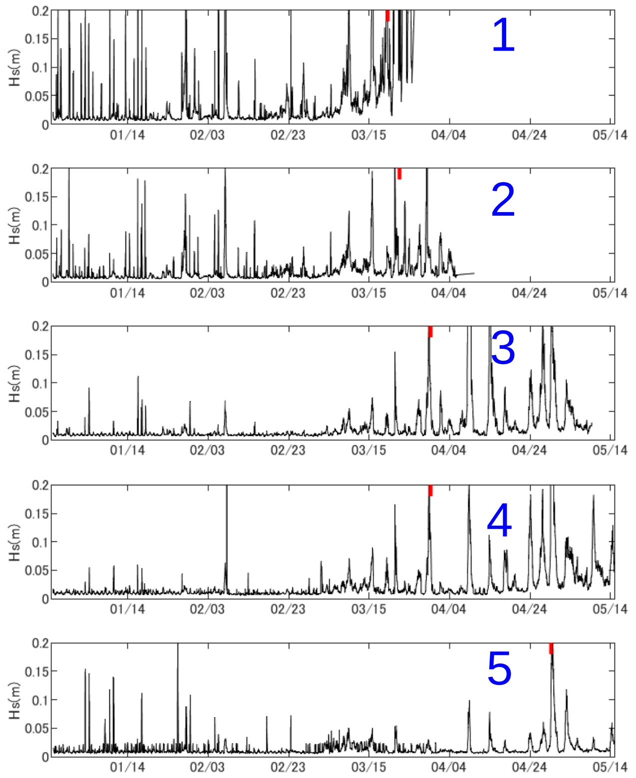
Feb. 12 to Feb. 15 deployed 10 buoys from Shirase

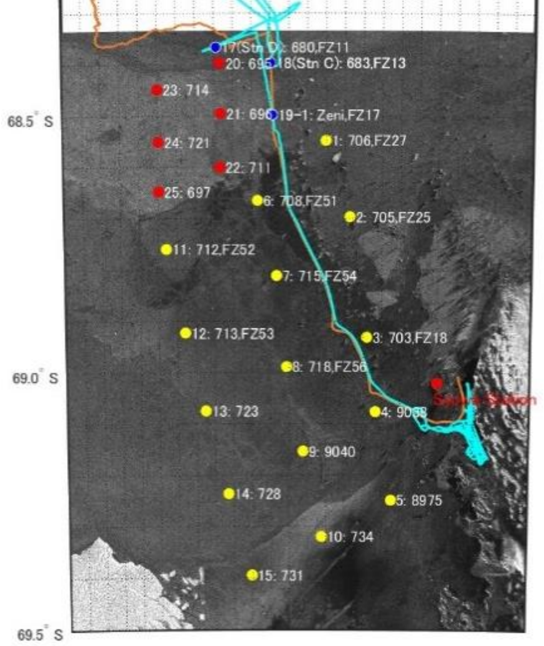
Yellow disk: current location of the buoy
Yellow circle: initial location of the buoy
Orange line: the trajectory of the buoy
Yellow line: a day-long trajectory of the buoy



Waves detected by the buoys

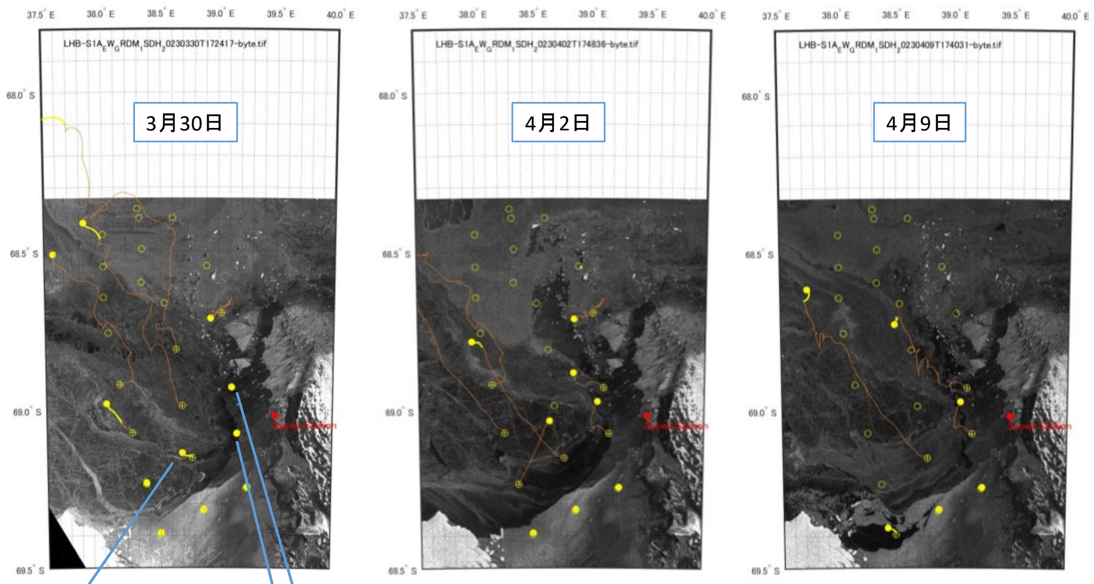


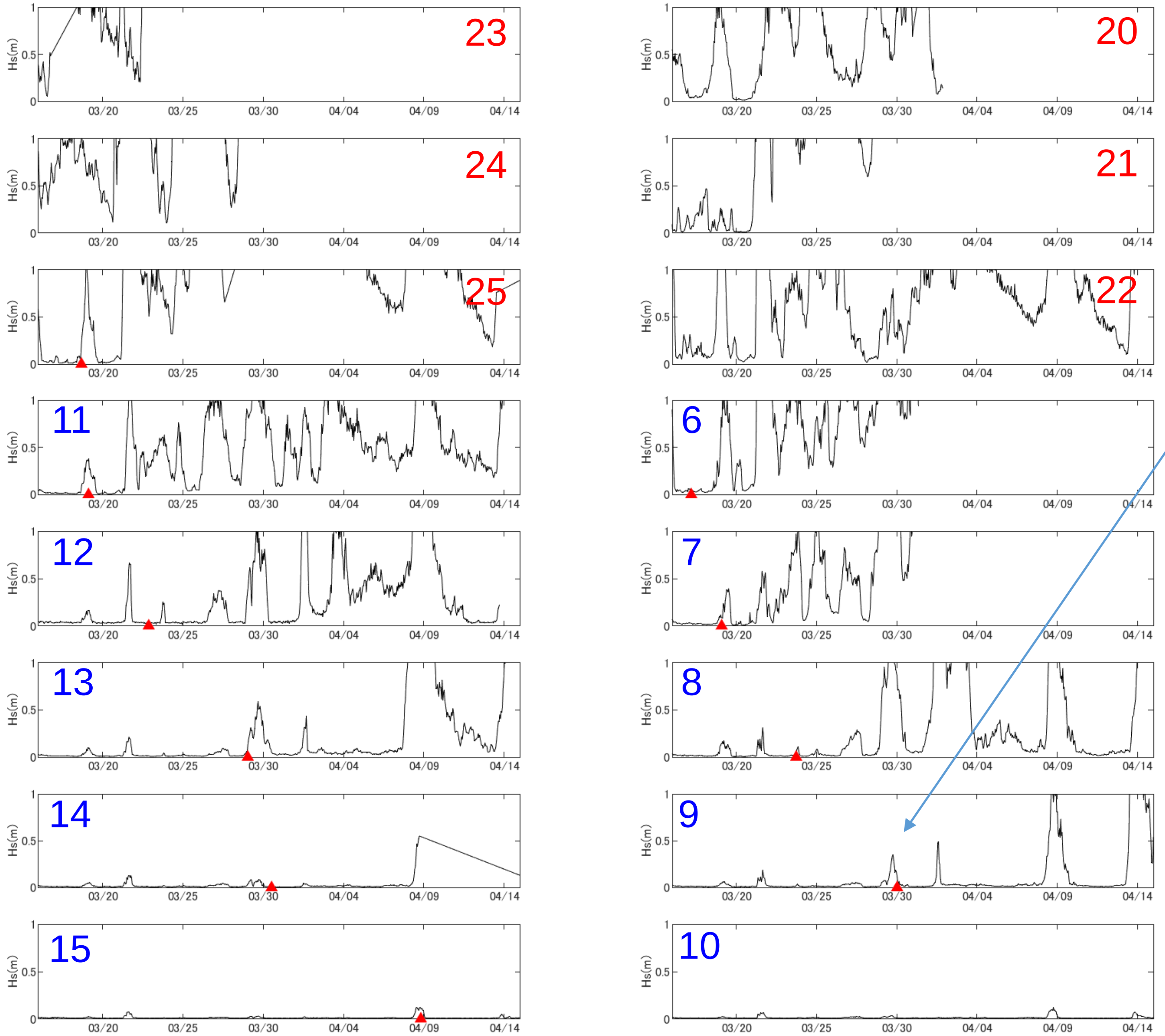


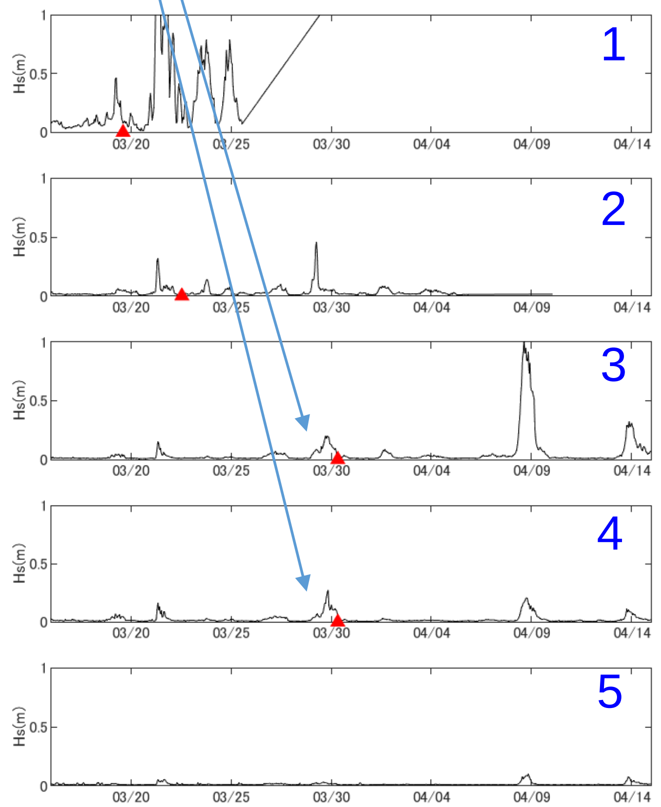


Red marks indicate when the buoy started to drift.

Waves as a precursor to the buoy motion

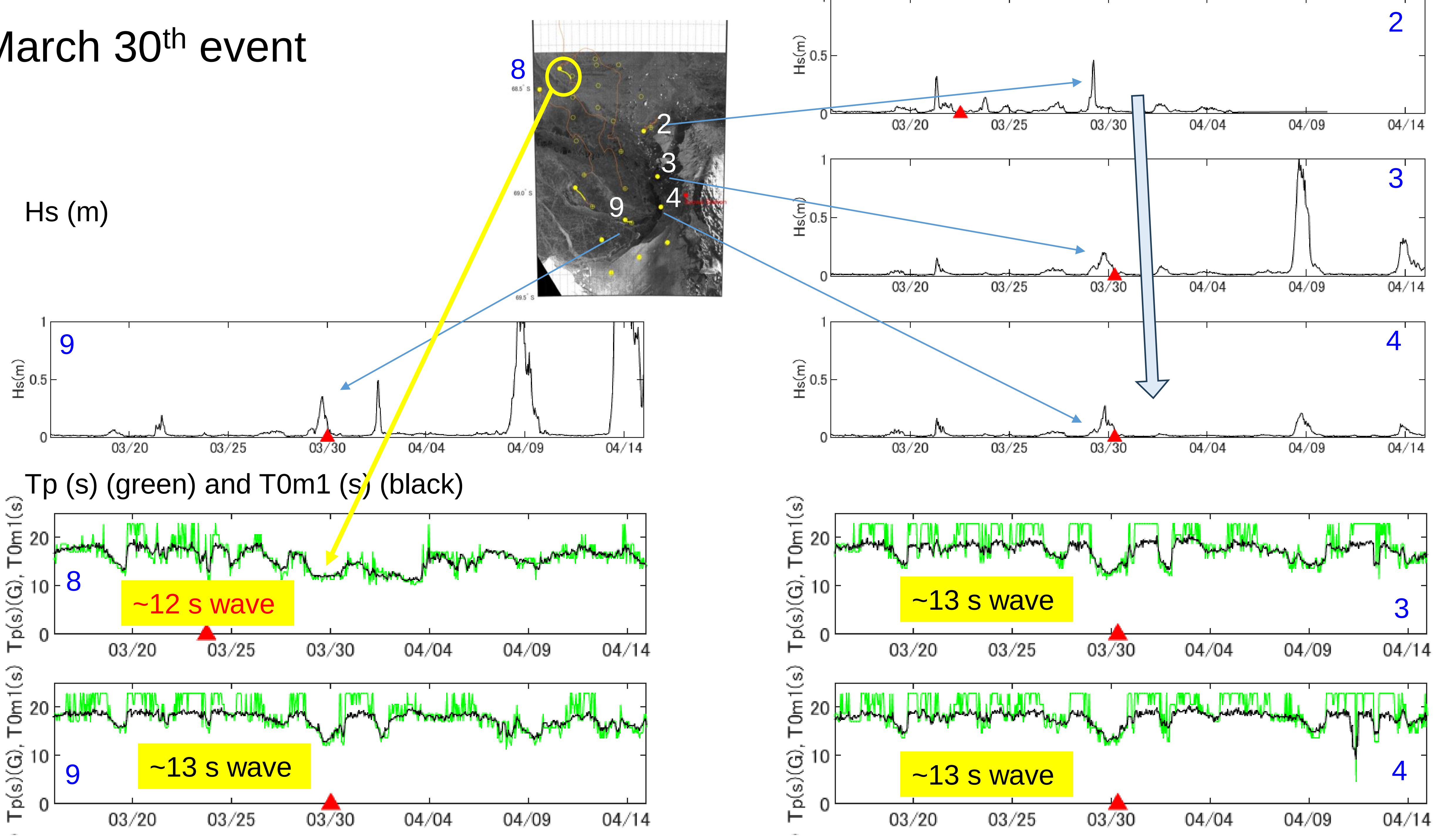




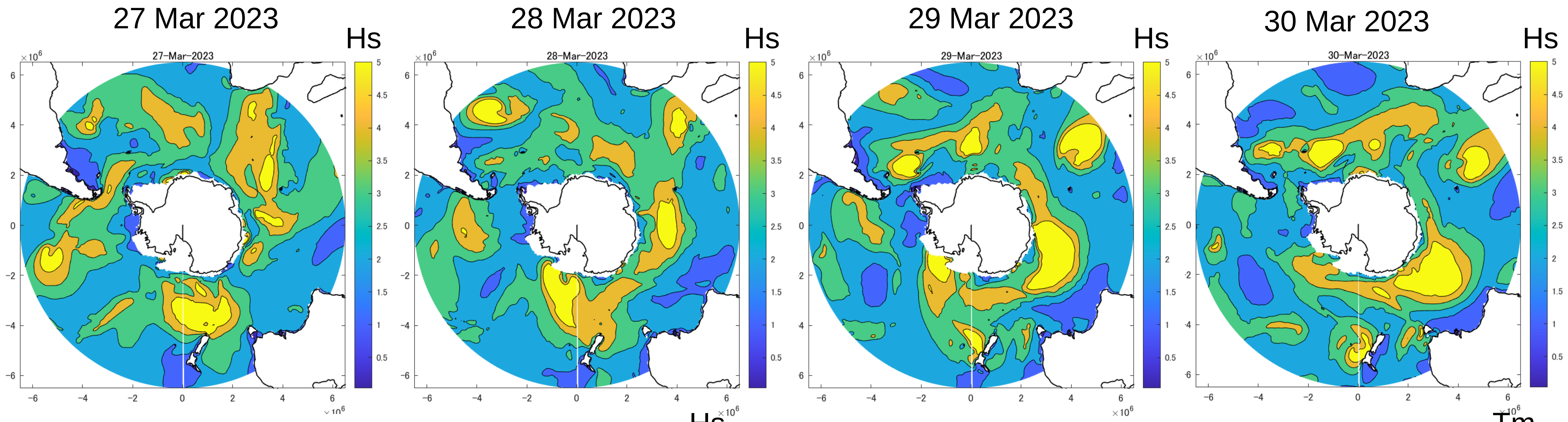


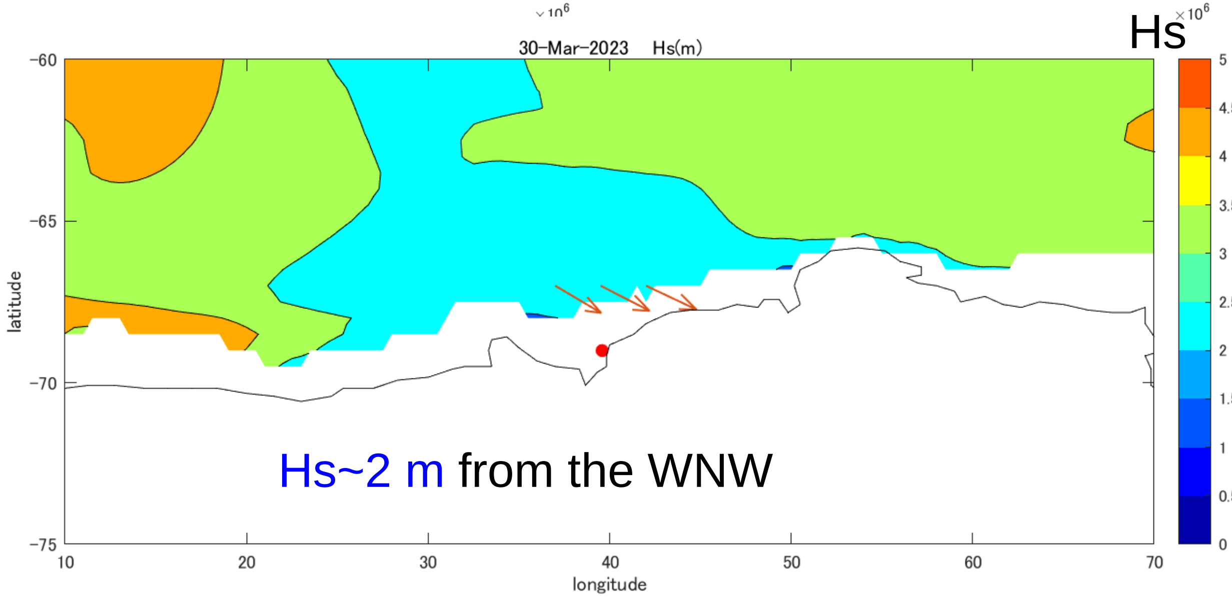
Red marks indicate when the buoy started to drift.

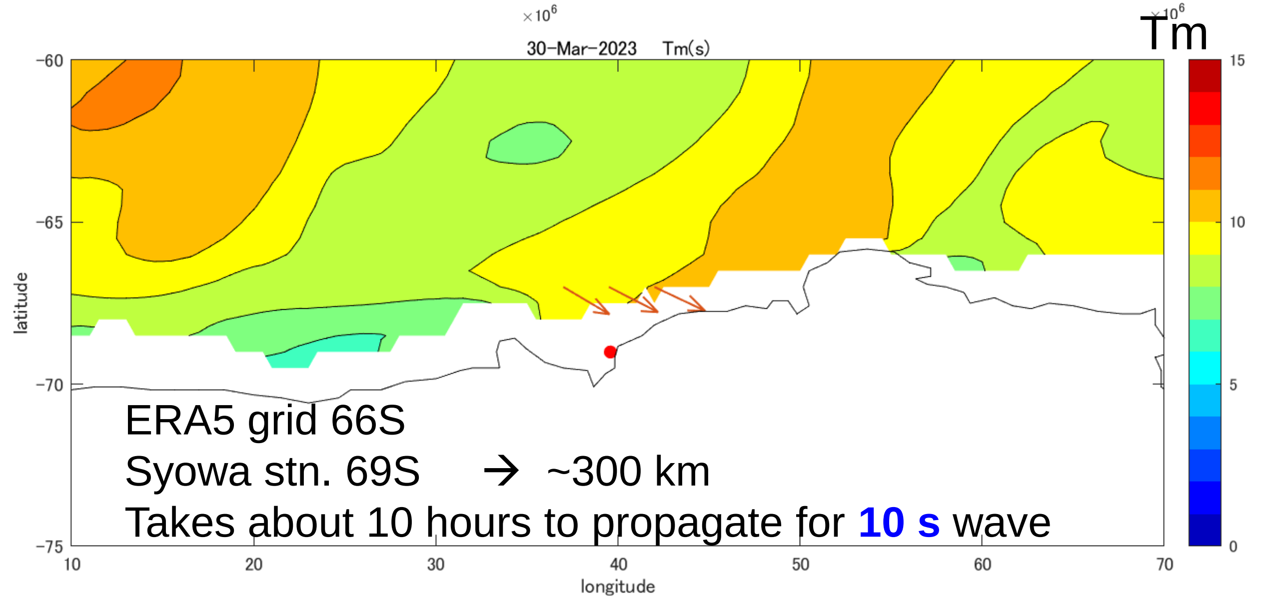
March 30th event



Incoming wave field (ERA5: Significant height of combined wind waves and swell, mean wave direction, mean wave period)

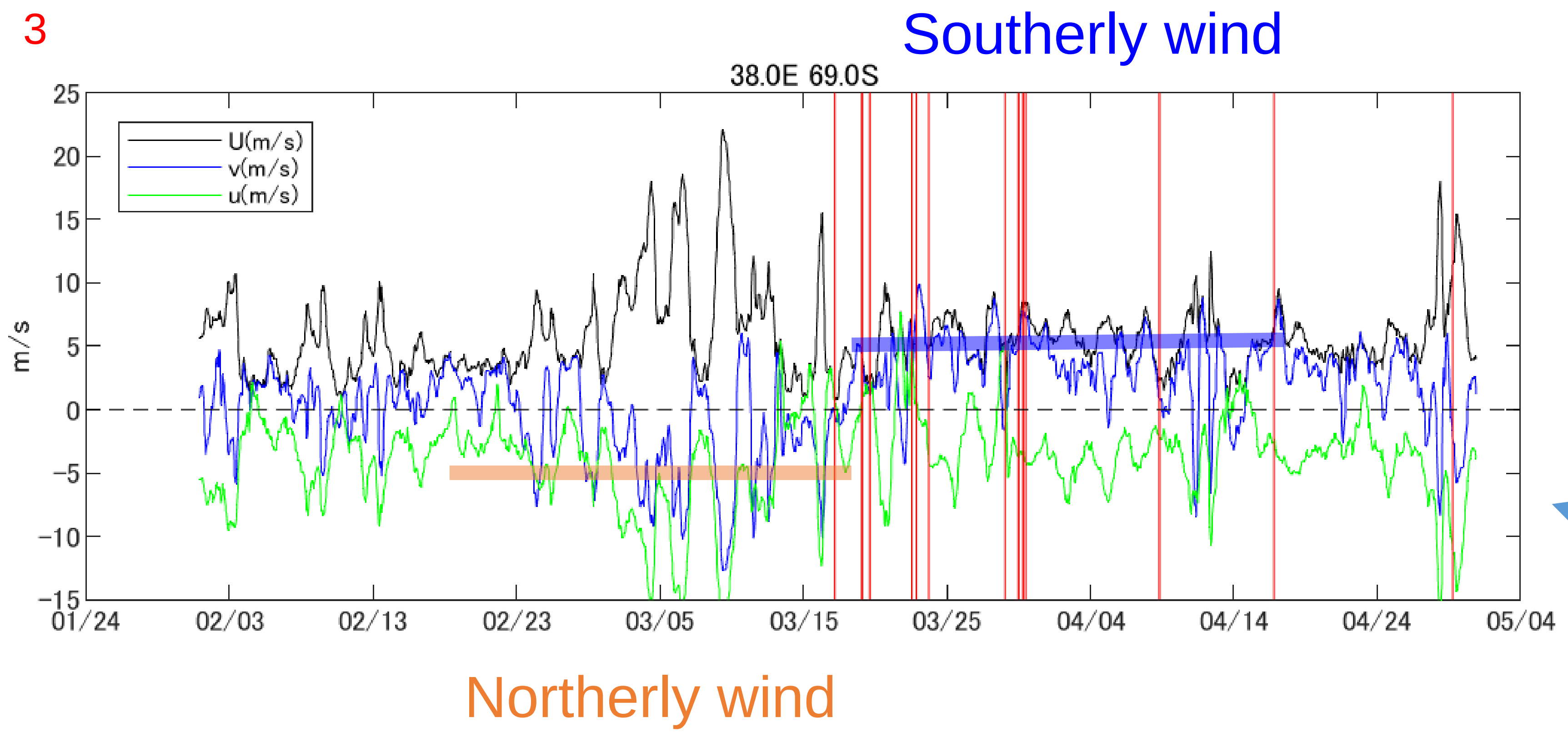


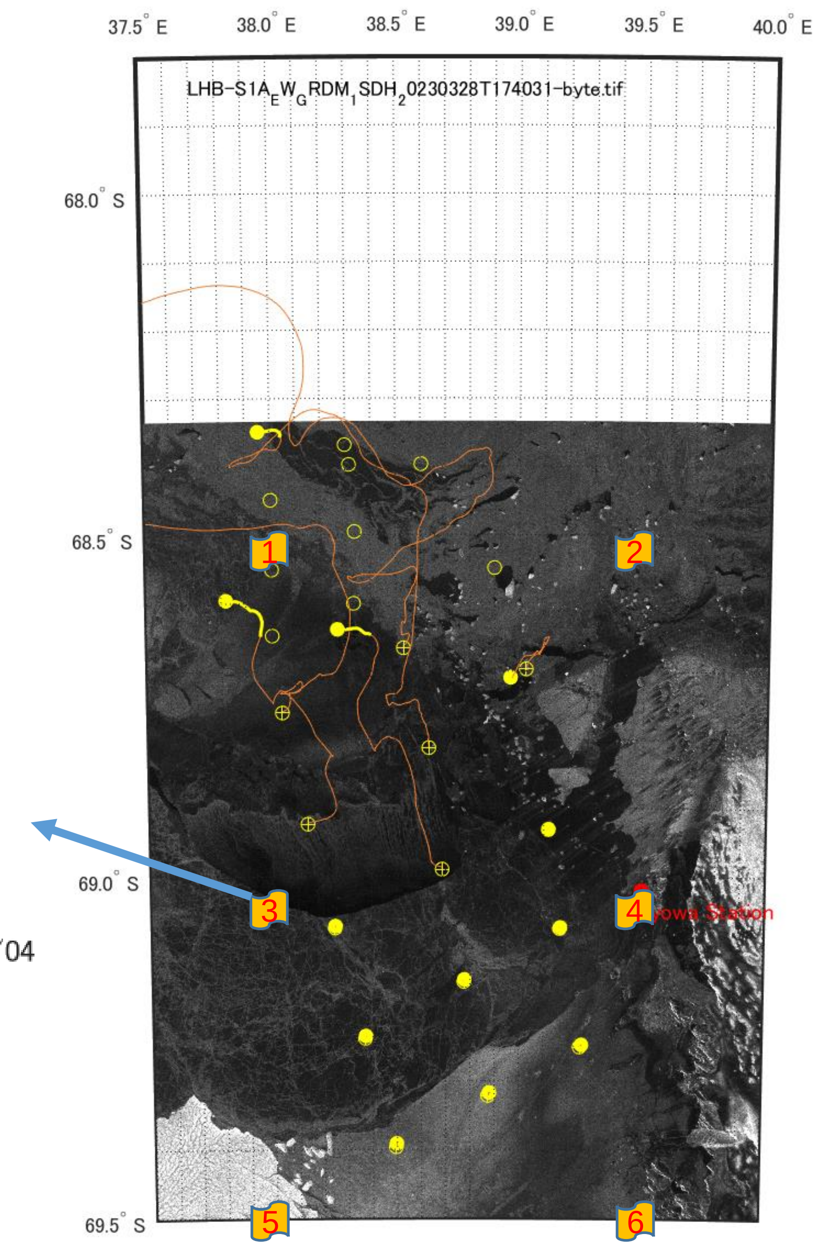




Wind (ERA5) and the timing of drift

3

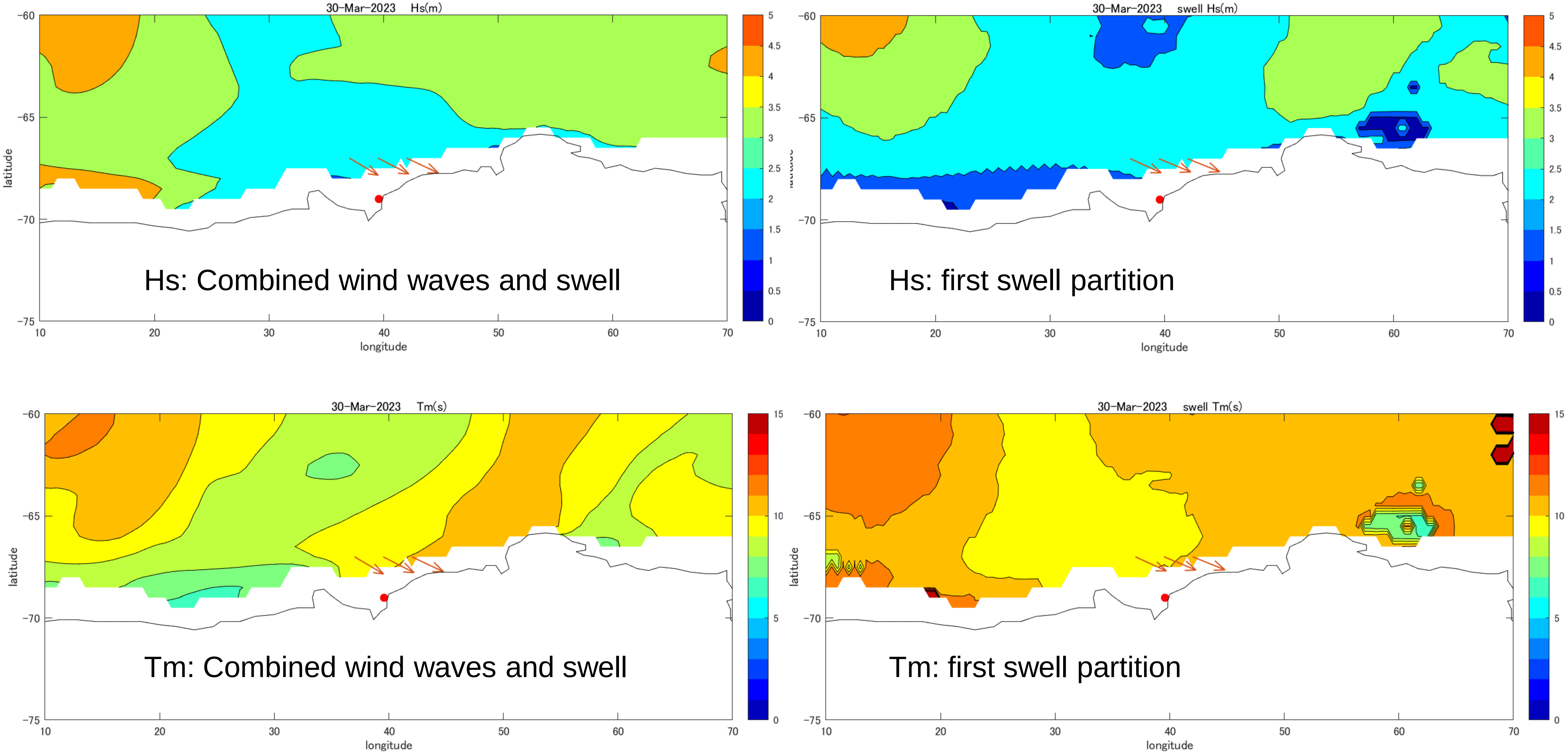




Red vertical lines indicate when the buoy started to drift.

Represents where the wind speeds are sampled.

Trigger of the breakup is the swell propagating into the fast-ice – *the wind is from the south*



Summary

APPLIED PHYSICAL OCEANOGRAPHY

JARE64 observations:

- 23 wave buoys were successfully deployed on the fast-ice and the drift-ice in the Lützow-Holm bay during the JARE64.
- The ice thicknesses of the fast-ice were measured at 13 locations near the deployed buoys.

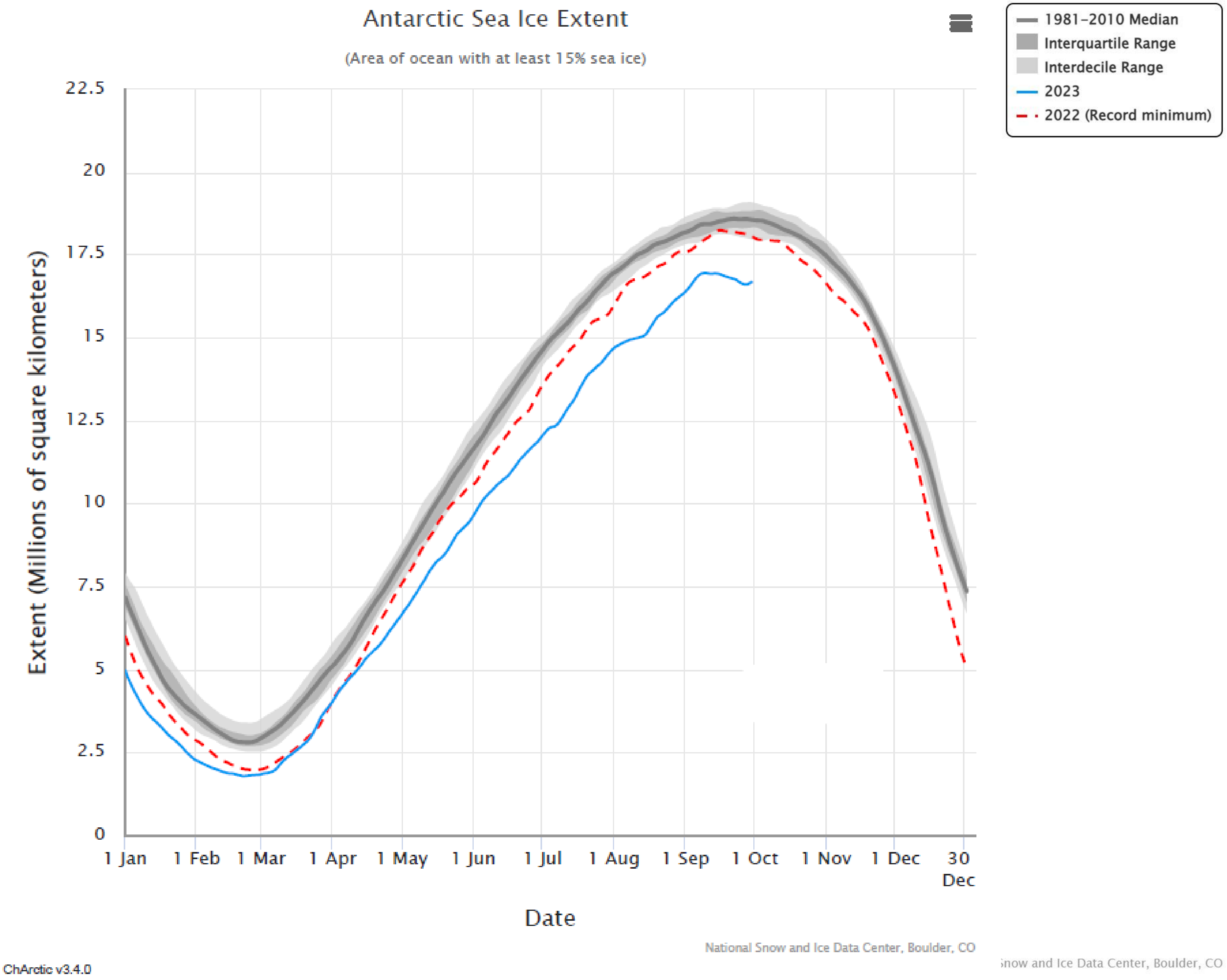
Fast-ice breakup in 2023:

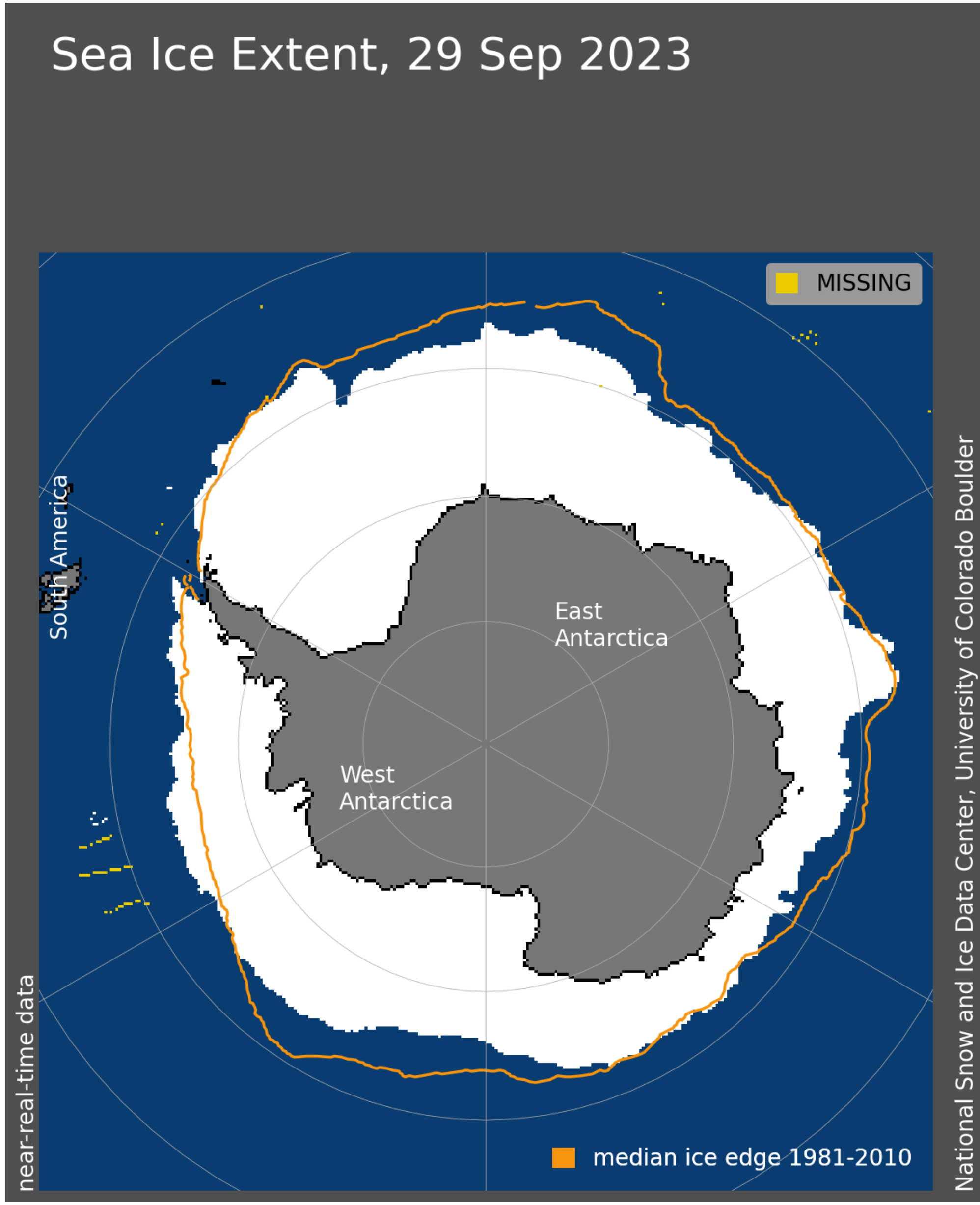
- In March, the fast-ice started to breakup and the breakup continued until the beginning of May when all the buoys drifted out of the bay.
- 3/30 event was triggered by an incoming wave from the WNW.
- The buoys started to drift when the wind changed to southerly

Causes of the breakup

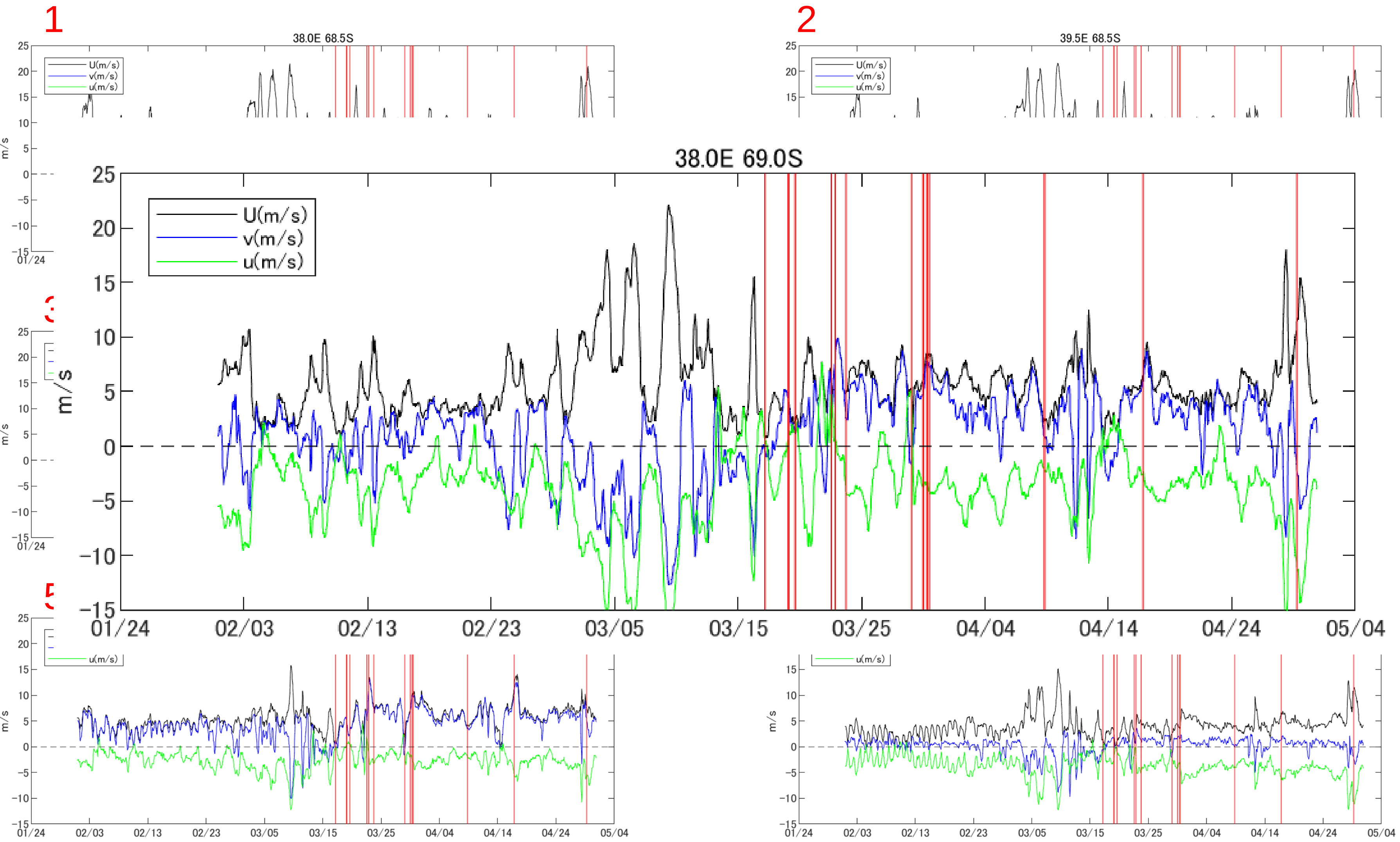
- The analysis of the buoy motion reveals that the combined effect of wave and wind is the precursor to the drift but the direct cause of the breakup and drift may depend on each event.
- There is also a signature of semi-periodic oscillation of the sea-ice likely due to an ocean current field, which possibly relates to a fatigue.

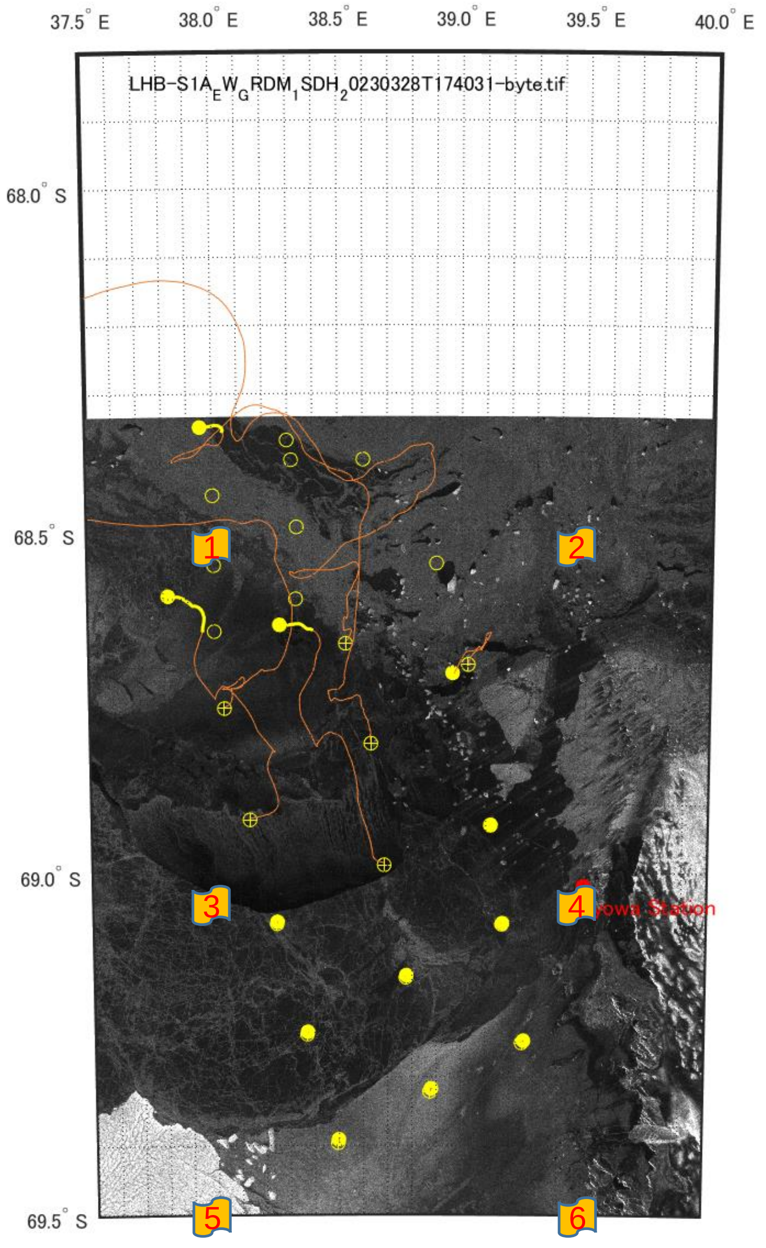
Beginning of the end? 2023 recorded the lowest sea ice extent. Can the multi-year ice in the Lutzow-Holm bay disappear?





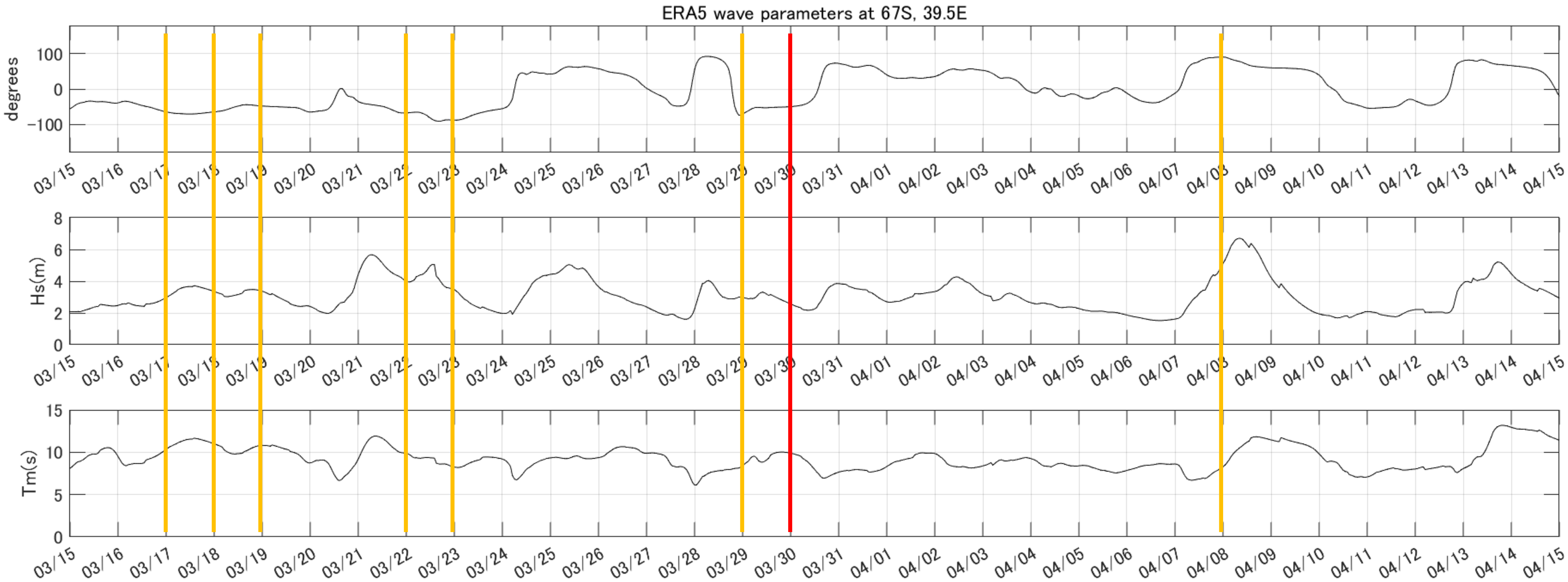
Wind (ERA5) and the timing of drift





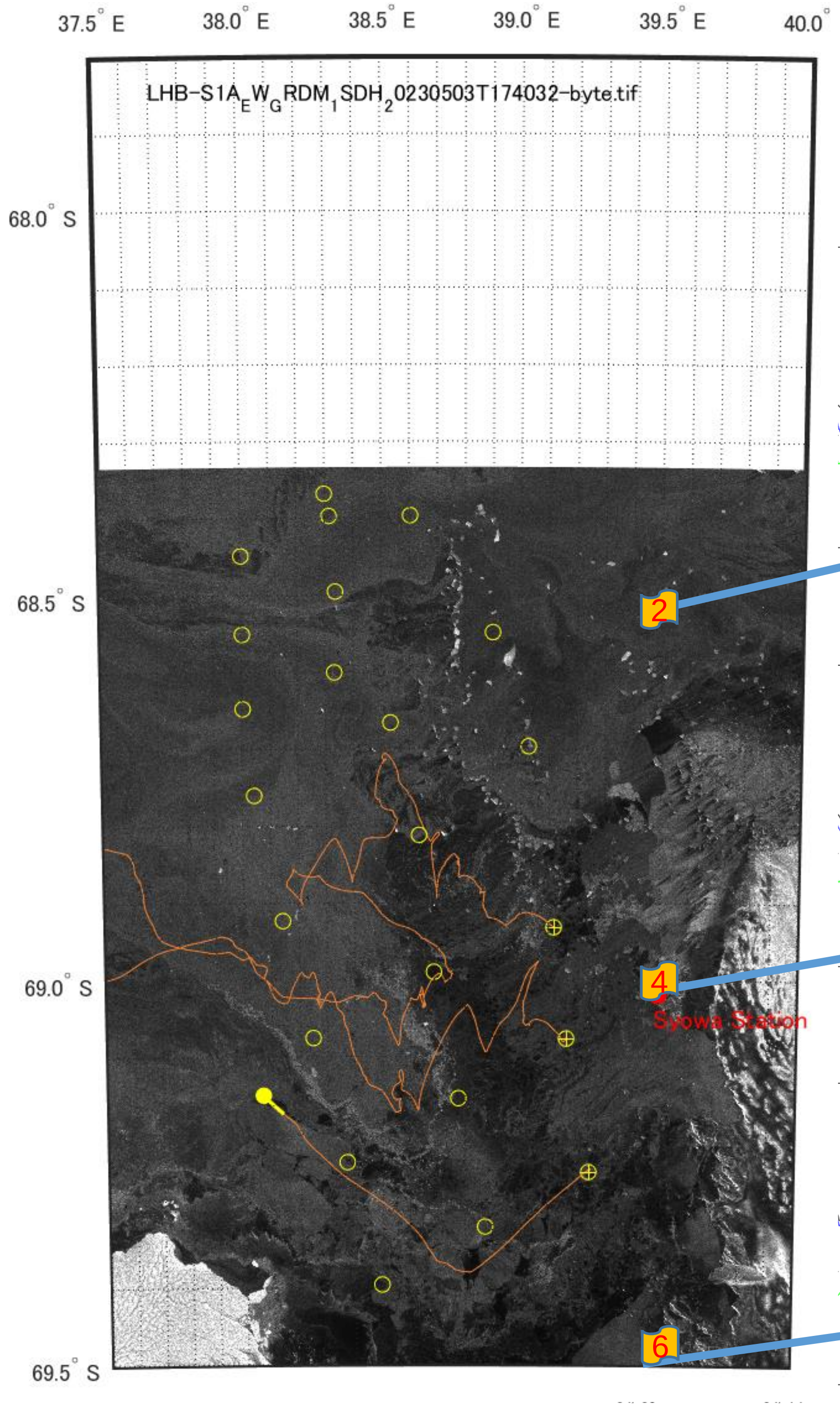
Red vertical lines indicate when the buoy started to drift.

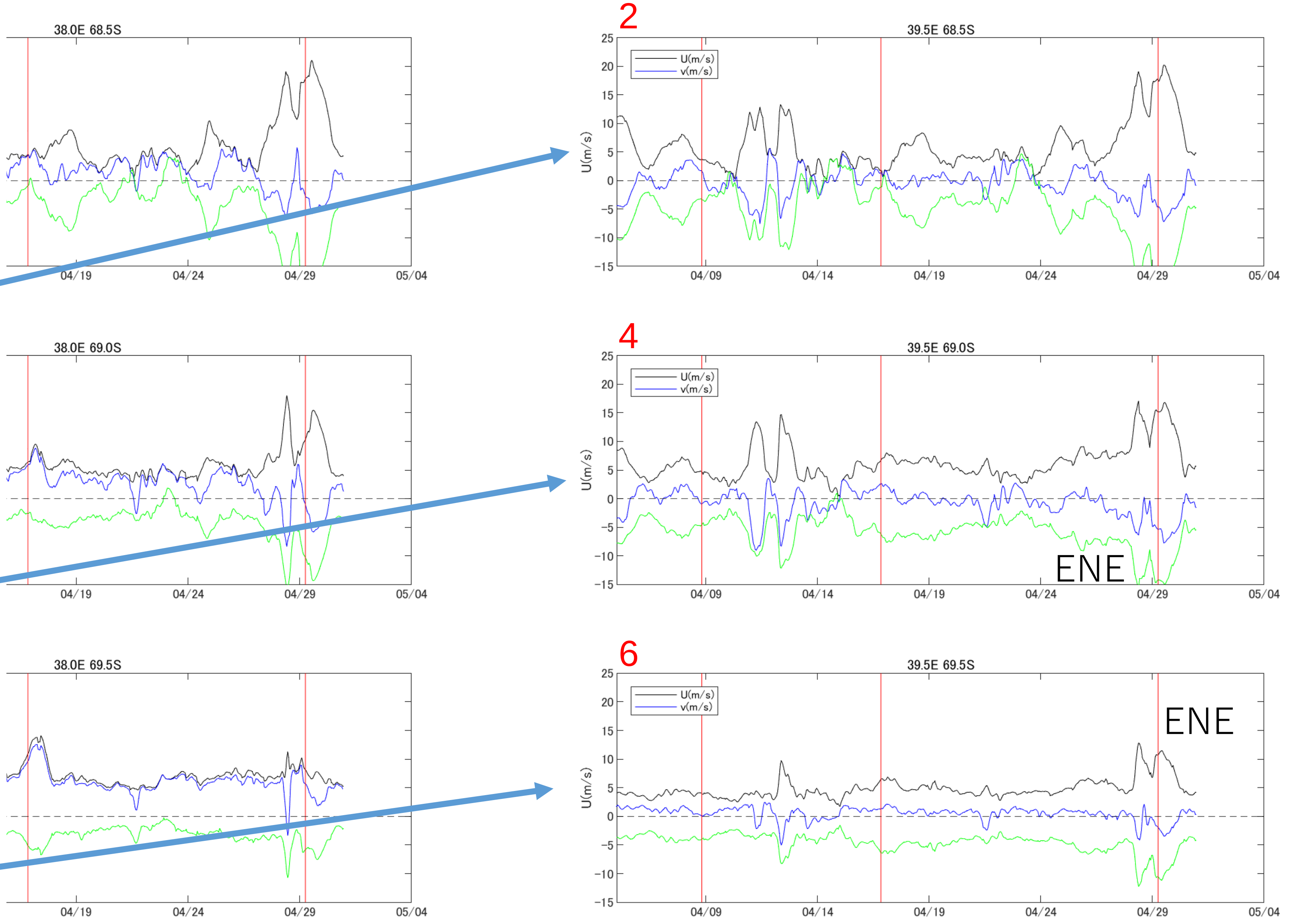
Represent where the wind speeds are sampled.



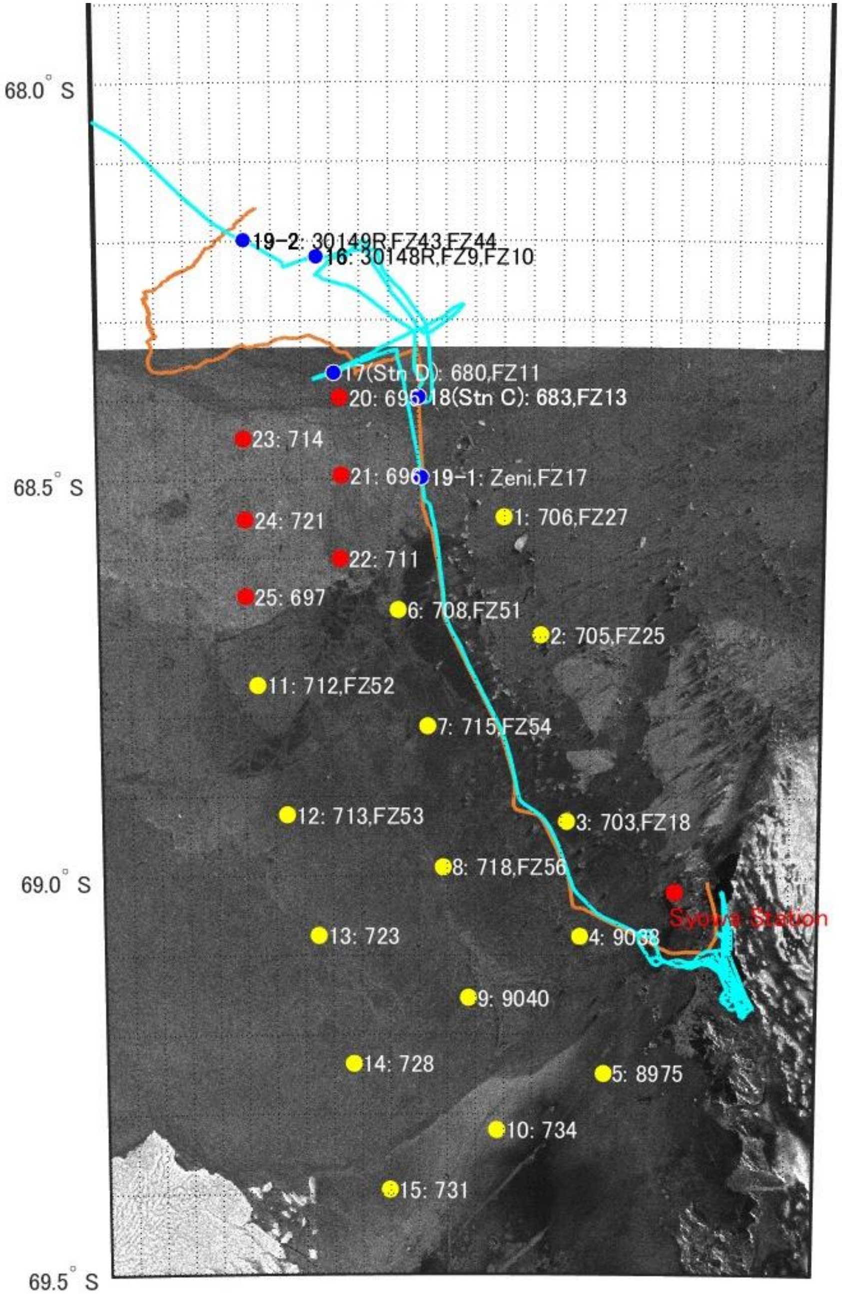
Breakup events are indicated by vertical lines.

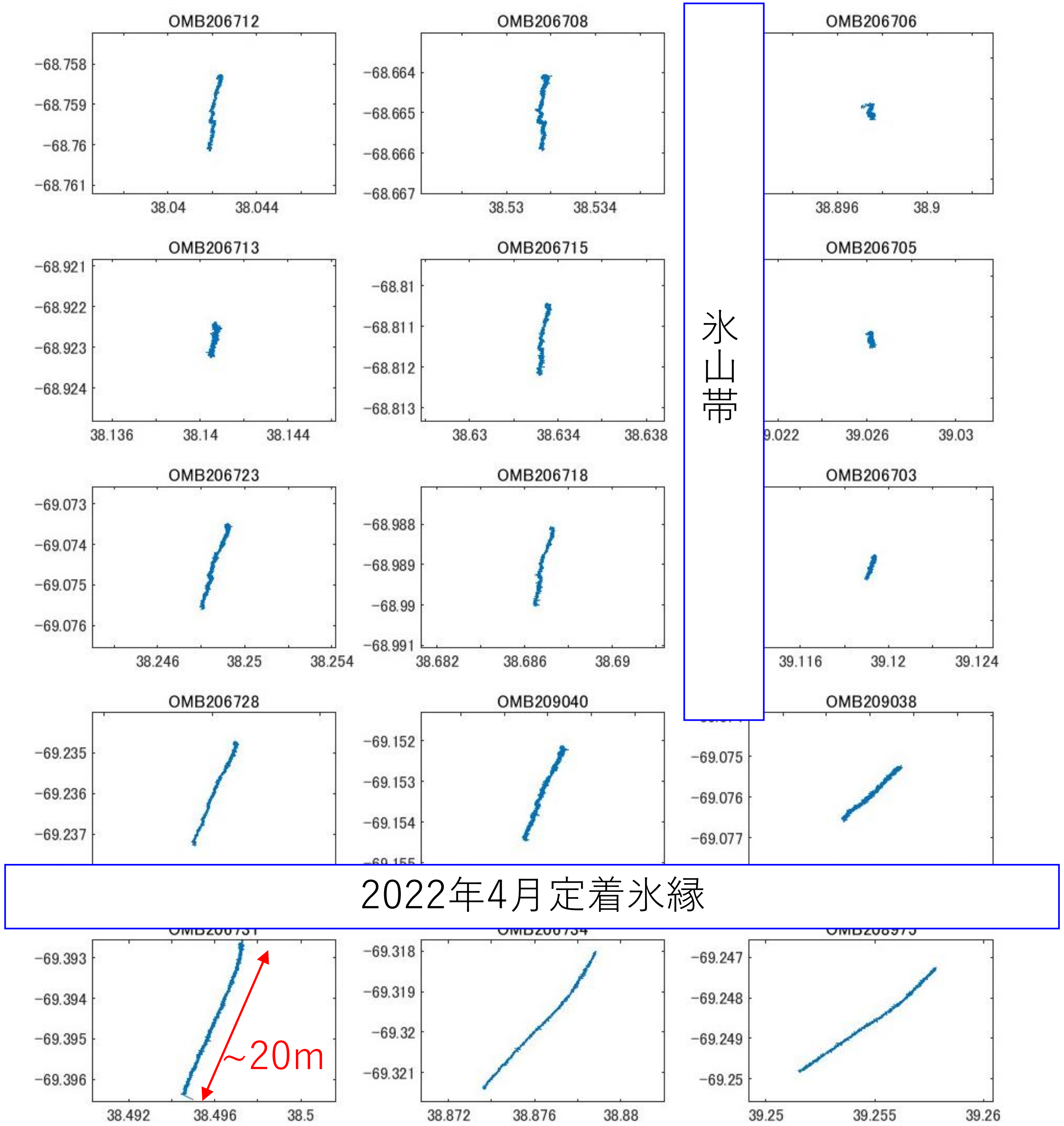
Wind moves the broken ice





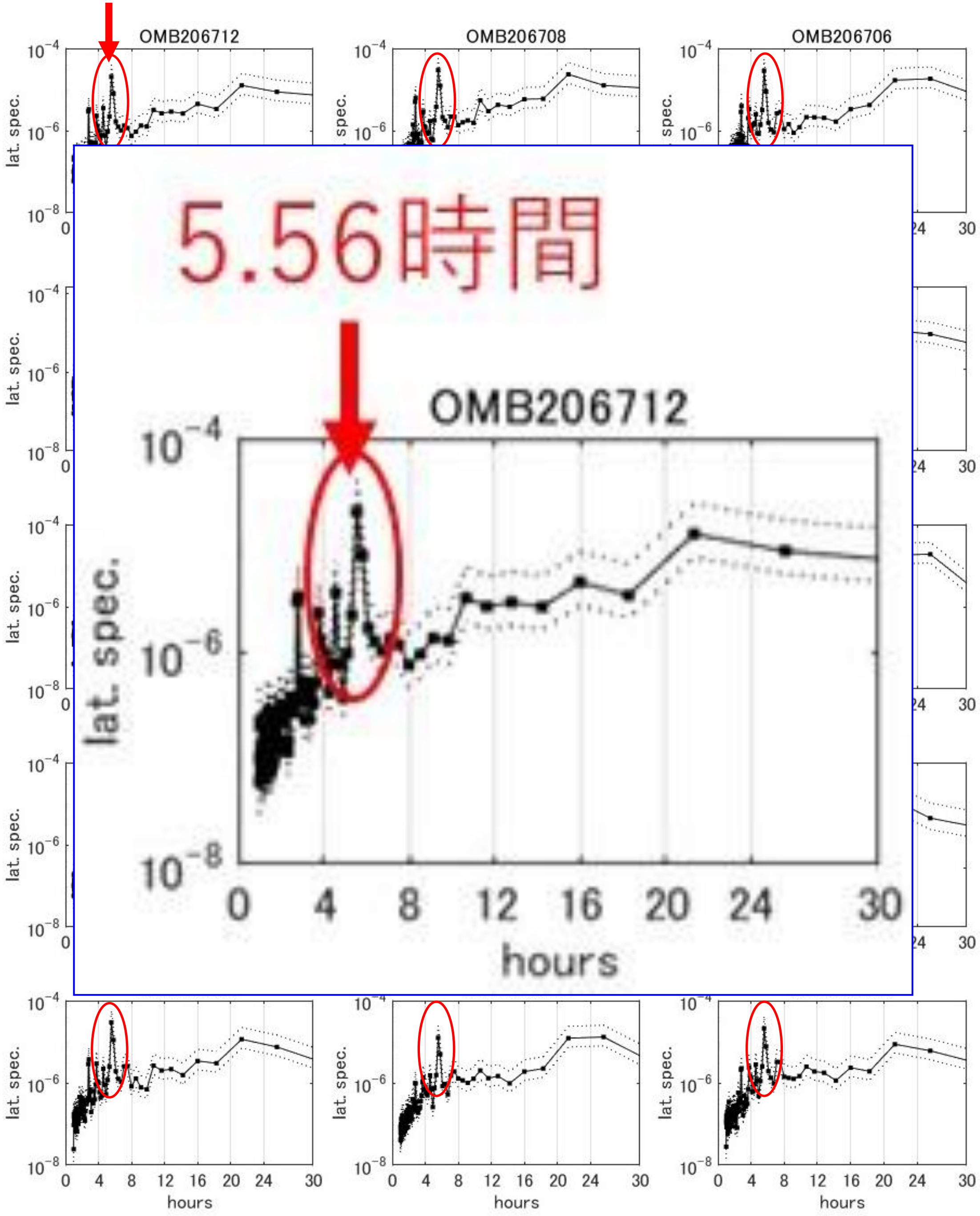
Impact of ocean current





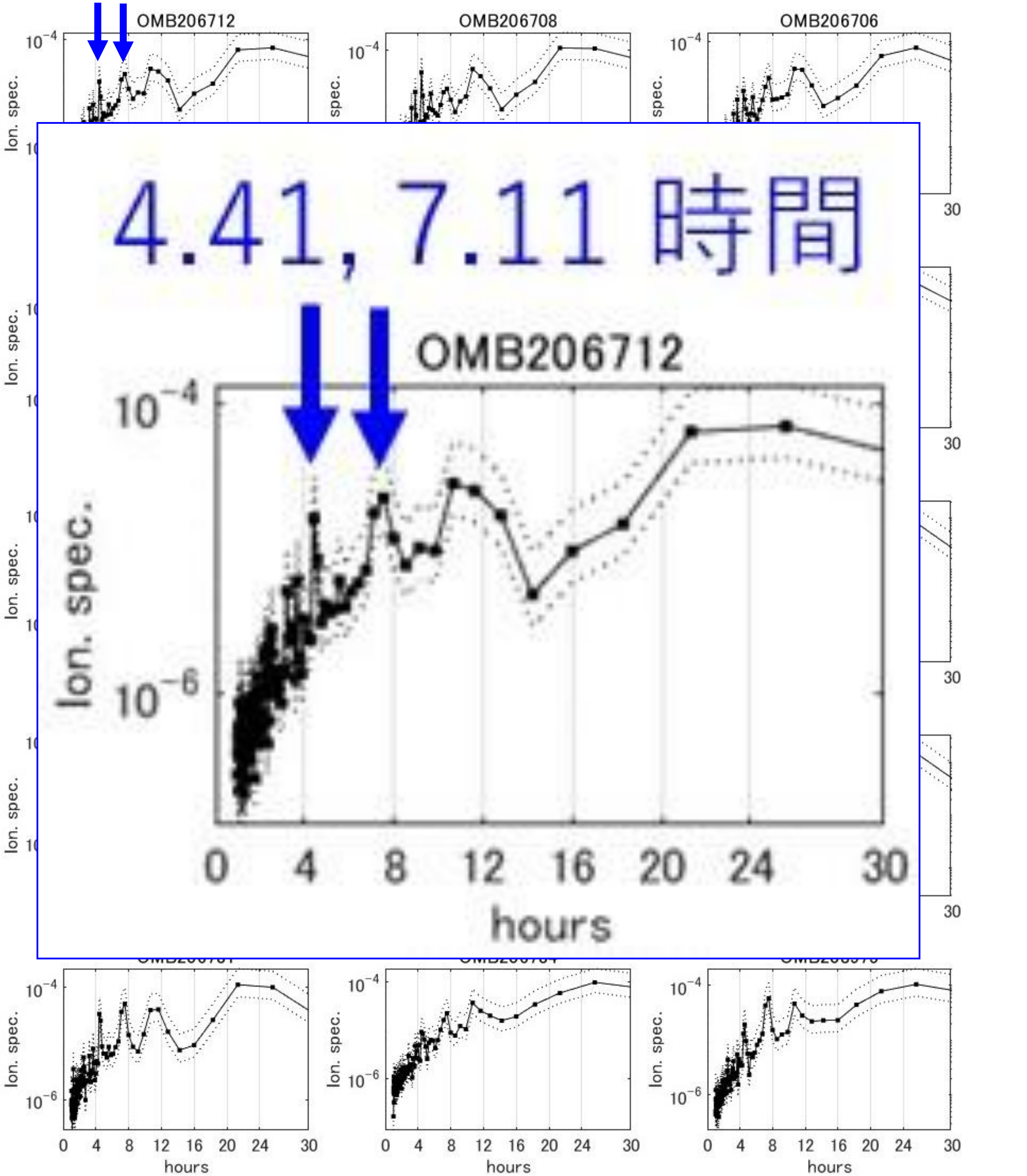
5.56時間

南北の動き

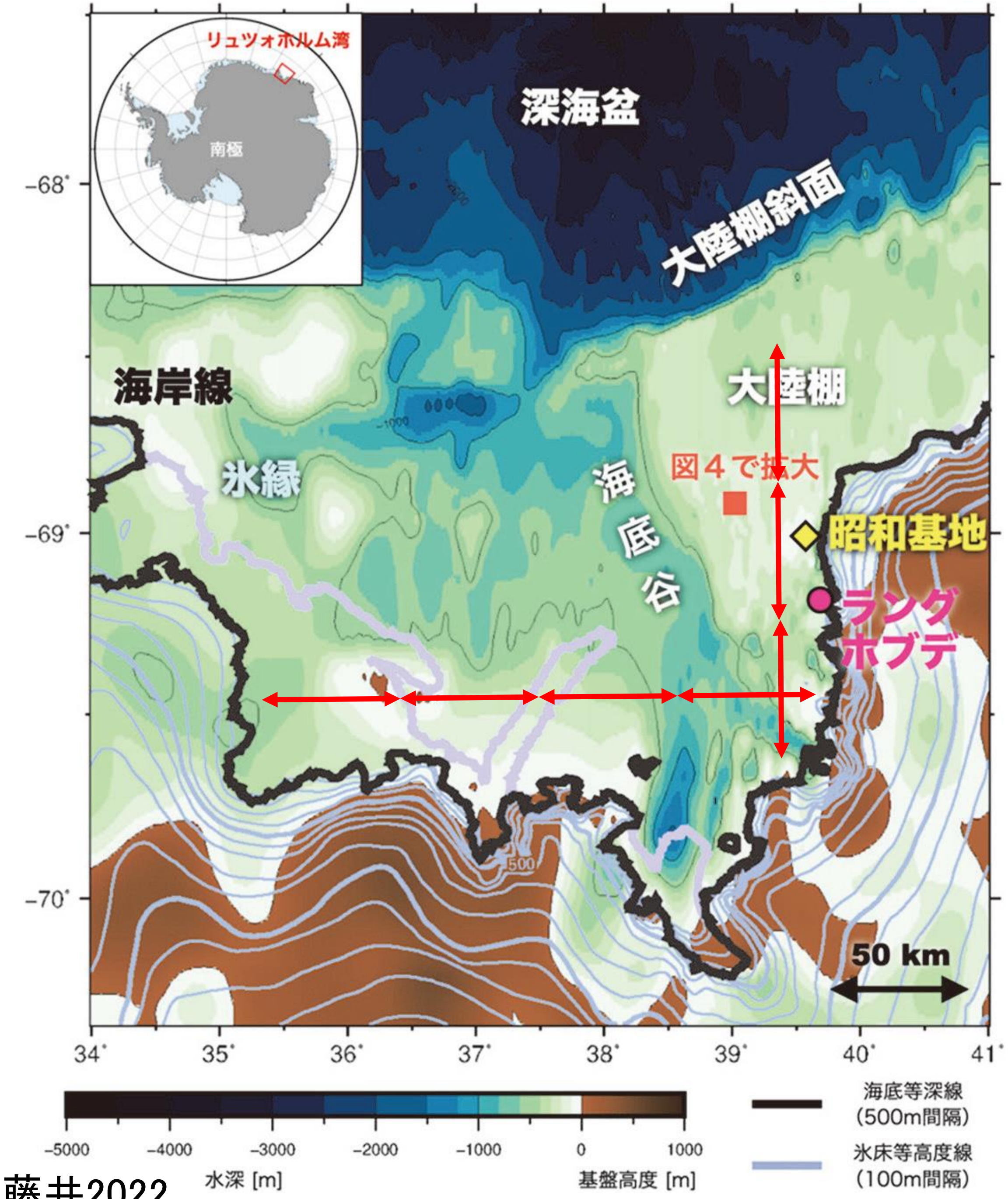


4.41, 7.11 時間

東西の動き



仮説：静振　Seiche



藤井2022

$$L(\text{湾の長さ}) = \lambda(\text{波長}), \frac{\lambda(\text{波長})}{2}, \frac{\lambda(\text{波長})}{4}$$

$$\lambda(\text{波長}) = \sqrt{gH}(\text{位相速度}) \times T(\text{時間})$$

$$H(\text{水深}) = 200 \text{ m}$$

$$\sqrt{gH}(\text{位相速度}) = 44.3 \text{ m/s}$$

	T (hours)	λ (km)	$\lambda/2$ (km)	$\lambda/4$ (km)
南北	5.56	886	443	222
東西	7.11	1,133	567	n/a
	4.41	702	351	n/a

e.g. Nagano, A., Michida, Y., Odamaki, M., Suzuki, K., & Ogata, J. (2010). Seiches in Lützow-Holm Bay, Antarctica. *Polar science*, *4*(1), 34-41.

→ Observed 3.1 hour topographically constrained mode

Appendix: Detecting buoy drift