2 Campaign log

2.1 Team

The campaign took place from 21-25 May 2025. We were based in Longyearbyen, Svalbard. The NORCE field team included the following personnel:

- **Robert Ricker – RR** (NORCE, Science Lead)
- **Andre Kjellstrup – AK** (NORCE, UAV Pilot and Engineer)
- **Oyvind Kasberg Dahl – OKD** (NORCE, Engineer)
- **Jean Charles Sausserau – JCS** (iTech, UAV Pilot)
- **Matteo Baronio – MB** (iTech, Engineer)
- **Eero Rinne – ER** (UNIS, Associate Professor)
- **Jani Suolinna JS** (UNIS, Field Support)
- **Laura Orgambide LO** (UNIS, Field Support)

In addition, we received home support from:

- **Rolf-Ole Jenssen – ROJ** (NORCE, radar scientist)
- **Torbjörn Kagel – TK** (University of Utrecht/NORCE, Student)
- **Loic Richard – LR** (iTech)
- **Henriette Skourup – SK** (DTU, St3TART-FO Sea Ice PI)

2.2 Field Sites

UAV surveys were conducted at two field sites:

- Adventdalen: Test flights over terrestrial snow, and coincident measurements with AWI IceBird
- Agardhbukta: Flights along Sentinel-3B orbit 369.

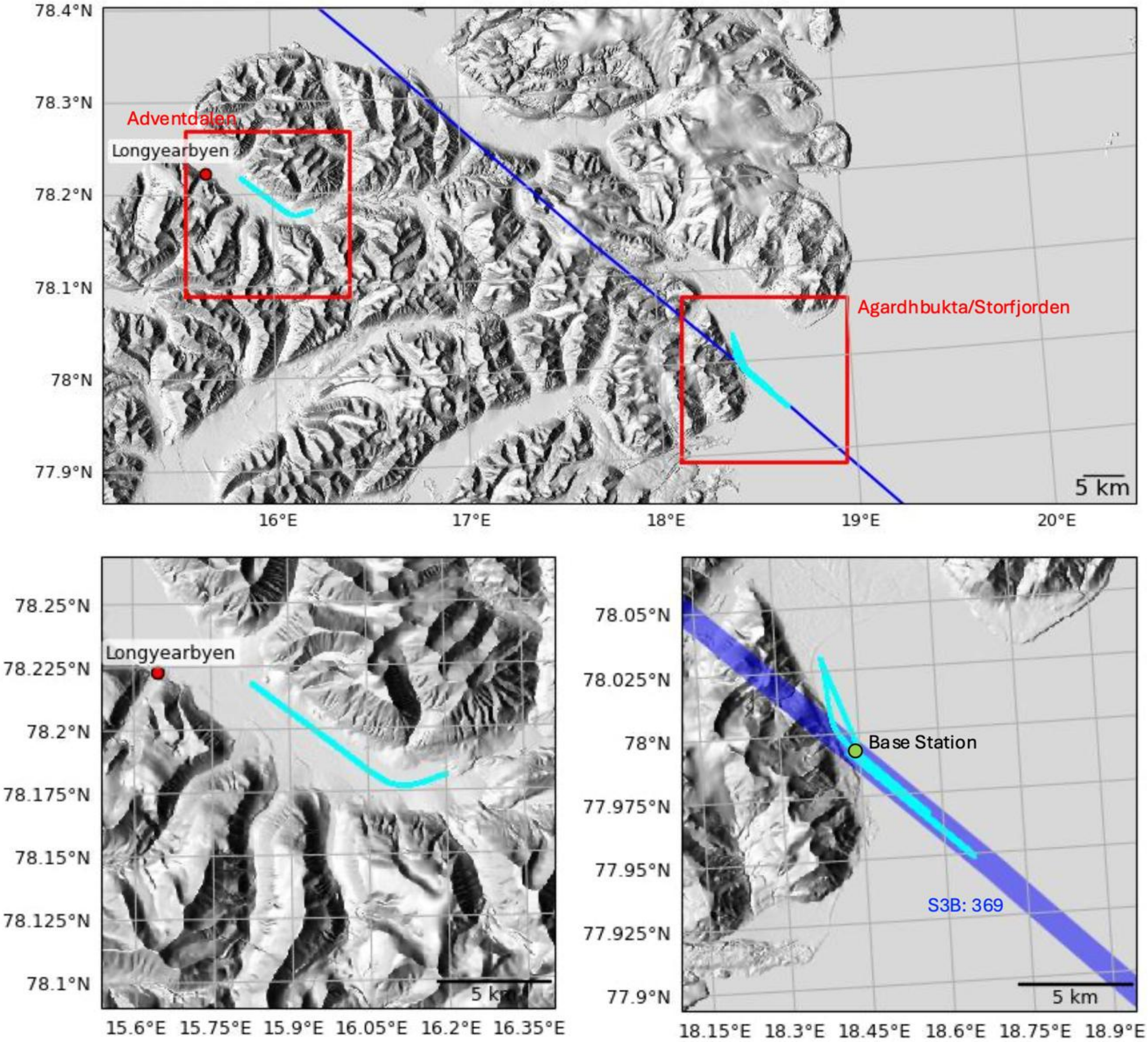

Figure 1: Overview map showing the two sites, where UAV measurements were conducted. UAV flight tracks are shown in cyan.

2.3 Instruments

2.3.1 NORCE UAV "SnowDrone"

The SnowDrone consists of two primary components. The Cryocopter FOX is a multirotor platform and carries the UWB radar system. The UAV is based on purchased standard components and proprietary components that are specially adapted to use with radar and antennas. The payload for the multirotor platform is a radar system named UWiBaSS (Ultra-Wideband Snow Sounder). It is a specially designed radar system for snow measurements, with a focus on the ability to penetrate wet snow while retaining high range resolution to image snow stratigraphy.

2.3.2 iTech/vorteX-io UAV DJI Matrice 350 RTK

The Matrice 350 RTK boasts a robust design, powerful propulsion, good protection rating, and excellent flight performance in harsh environments. The aircraft and remote controller feature a four-antenna transceiver system that intelligently selects the two optimal antennas for signal transmission, with all four antennas receiving signals simultaneously. This significantly improves anti-interference capabilities and optimizes transmission stability. The drone and its radio have an IP54 protection rating. The operating temperature range allows for flight in extremely hot or cold environments. It is equipped with the VTX-2 sensor from vorteX-io. This lidar sensor was designed on a DJI development gimbal that allows SDK connection with the drone, allowing full control of the sensor through the drone's control interface. A 2-Day campaign with the two altimeters was executed, and both of the altimeters were used each day to perform several flights.

2.3.3 Snow-Hydro Magnaprobe

We carried out snow depth measurements along UAV transects using the Snow-Hydro Magnaprobe. The Magnaprobe has a data logger that records snow depths and GPS coordinates for each individual measuring point. The typical spacing between measurements is in the range of 2-4 meters. The snow depth is assessed with a moving disk on a pole, which is manually plunged into the snow. The system allows a maximum snow depth of 1.2 m. The precision of the measurement depends on the properties of the air–snow and snow–ice interfaces as well as on ice lenses or crusts within the snowpack. For regular snow conditions (no major internal crusts), the uncertainty does not exceed 0.01 m. The Magnaprobe is standard equipment widely used for terrestrial snow and snow on sea ice. Because of the simple measurement mechanism, Magnaprobe measurements do not require further processing beyond quality control and removal of erroneous data.

2.3.4 Snow Pits

We excavated standard snow pits to collect vertical profiles of snow temperature, hardness, wetness, crystal structure, density, and salinity. The density measurements were collected per layer by 100 cm3 cutters. In Agardhbukta, we found snow densities of 297 kg/m^3 for the bottom snow layer (0-10 cm) and 219 kg/m^3 for the upper snow layer (10-23 cm). The temperatures at different snow layers are summarized in Table 1.

Table 1: Snow temperatures at the base station in Agradhbukta. 0 cm refers to the snow-ice interface.

Snow height (cm)	Temperatures (°C)
0	-4
5	-6
10	-7
15	-8
20	-9
23	-8

2.4 Schedule

The main activities from May 22 to 24 are summarized in Table 2. On May 25, we packed equipment for the return freight. One part of the team left Svalbard on May 25, the other part left May 26.

Table 2: Overview of main activities during the St3TART-FO UAV sea ice campaign.

Date	**2025-04-22**	**2025-04-23**	**2025-04-24**
Location	Longyearbyen	Adventdalen	Agardhbukta
UAV "SnowDrone"	• No flights • Unpacking, testing equipment, and preparing for fieldwork	• Following AWI Polar-6 flight track from the previous day along the valley • 1st flight to the East, 2nd flight to the West, 20 m offset between inbound and outbound flight.	• Two flights, each ca 16 km long (outbound + inbound) • 1st flight: S3B Orbit 369 to the South-East, 100 m offset between outbound and inbound • 2nd flight: Following S3B Orbit 369 to the North-West and then following Polar-6 flight track over fastened sea ice. • 3rd flight: S3B Orbit 369 to the South-East (parallel to the 1st flight)
UAV "iTECH/vortex-io"	• No flights • Unpacking, testing equipment, and preparing for fieldwork	• Following AWI Polar-6 flight track from the previous day along the valley • Flight 1: height 8 meters, speed 6 m/s, North-West direction • Flight 2 height 40 meters, speed 4 m/s, North-West direction • Flight 3 height 40 meters, speed 4 m/s, south-east direction, distance 3.7 km • Flight 3 height 40 meters, speed 4 m/s, south-east direction, distance 4.4 km	• Flight 1and 2: Polar Line 6 Agardh Bukta, height 40 meters, speed 4 m/s, North to South direction, distance 8.5 km • Flight 3: line S3B_369_segment18, height 40 meters, speed 4 m/s, direction North to South, distance 3 km, very strong winds • Flight 4: line S3B_369_segment18, height 30 meters, speed 4 m/s, direction North to South, distance 4 km • Flight 5: intersection between line S3B_369_segment18 and line **Polar6_agardhb**, height 40 meters, speed 3m/s, direction North to South, distance 3.2km •
Magnaprobe	• Testing and preparing for fieldwork	• Ca 1 km validation line along the UAV flight tracks	• Ca 1 km validation line along the UAV flight tracks
Snow pits	• Tested snow pit equipment	• Snow pit at base station	Snow pit at base station

Comments	• Planning meeting with the field team
	• Coordination between the two UAV teams
	• Safety briefing
		• These flights served as validation for the AWI Polar-6 snow radar and as an exercise for the S3B flights in Agardhbukta	• The surveyed sea ice can be separated into three types:
			  ○ Fast ice
			  ○ Deformed sea ice
			  ○ Open water, newly formed ice

3 Sensor performance analysis

This section is included to ensure compliancy with SOW-REQ-071. Although the sensor performance analysis is not considered relevant for this specific campaign, the section is retained to preserve consistency across reports and ensure alignment with future reporting requirements.

4 Data acquisition and processing report

4.1 Data acquisition

Table 3 provides an overview of conducted flights with the NORCE SnowDrone to measure snow depth.

Table 3: Overview of conducted flights with the NORCE SnowDrone system. The distance covers both, outbound and inbound.

Flight ID	Start time (UTC)	End time (UTC)	Distance (km)	Mission
Adventdalen_1	2025-04-23 11:08:29	2025-04-23 11:51:10	11.85	IceBird/Polar-6 track
Adventdalen_2	2025-04-23 12:28:09	2025-04-23 12:52:55	8.7	IceBird/Polar-6 track
Agardhbukta_1	2025-04-24 11:28:13	2025-04-24 12:08:44	14.47	S3B-369
Agardhbukta_2	2025-04-24 12:47:12	2025-04-24 13:07:31	9.53	S3B-369
Agardhbukta_3	2025-04-24 13:07:52	2025-04-24 13:25:04	8.18	S3B-369

4.2 Processing and Preliminary Results

4.2.1 NORCE UAV

The main processing steps for the NORCE snow radar measurements are:

- Applying match filtering (cross-correlation) to raw radar data during acquisition or post-processing.
- Merge radar and UAV data using synchronized timestamps to create a georeferenced dataset.
- Subtract a reference trace and align time-zero with antenna crosstalk; optionally apply bandpass or SVD filtering.
- Correct the echogram for the UAV altitude
- Identify air-snow and snow-ice interfaces
- Enhance the image using noise reduction (e.g., Wiener filtering) and contrast stretching.
- Convert radar time to depth using snow density data, calibration transects, or advanced inversion methods.
- Export results as point clouds, georeferenced meshes, or radar stratigraphy images for further analysis.

Preliminary results of the echograms from the Agardhbukta/S3B-369 flights are shown in Figure 2. We identified three different snow regimes. Fastened sea ice was present in Agardhbukta, where our base station was located. All UAV flights have been launched from here. The UAV track to the South-East followed the S3B ground track. The snow on the level fast ice appeared to be rather homogenous (Figure 2). After ca 2 km, we found a shear zone with significantly deformed sea ice (Figure 2). Beyond the deformed sea ice, the UAV flew primarily over open water and newly formed, thin sea ice, without snow cover (Figure 2). Figure 3 shows some preliminary snow depth retrieval from the S3B-369 flight, highlighting the three different sea ice and snow regimes. Samples in Figure 2 correspond to the segments shown here.

Currently, the final processing and quality control of the NORCE snow radar is ongoing. The data will be released in the NetCDF format.

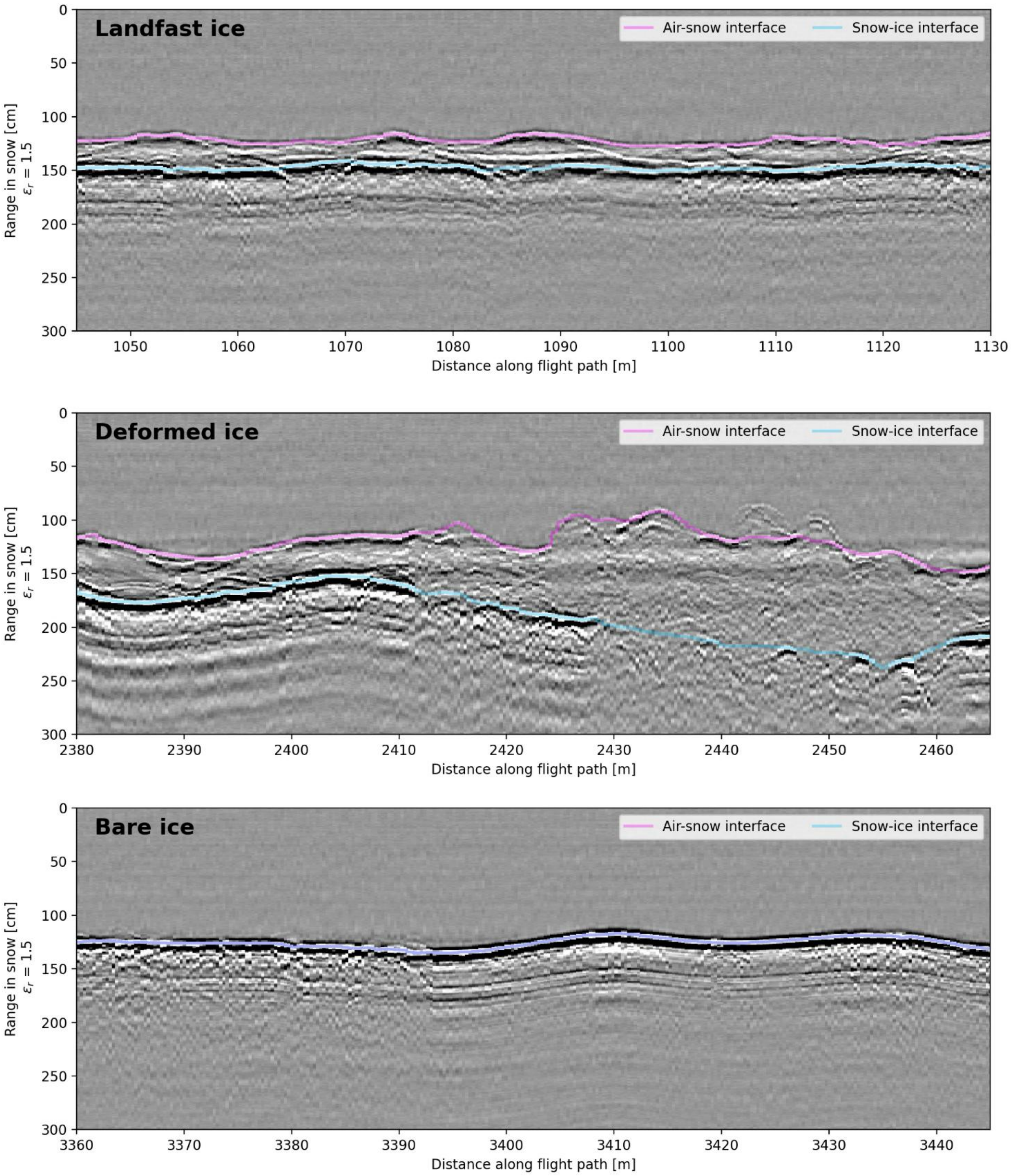

Figure 2: Sample echograms from the NORCE snow radar, showing automatically picked air-snow and snow ice interfaces on three different surface types: 1) Fastened sea ice, 2) deformed sea ice in the shear zone, and 3) newly formed thin ice and open water.

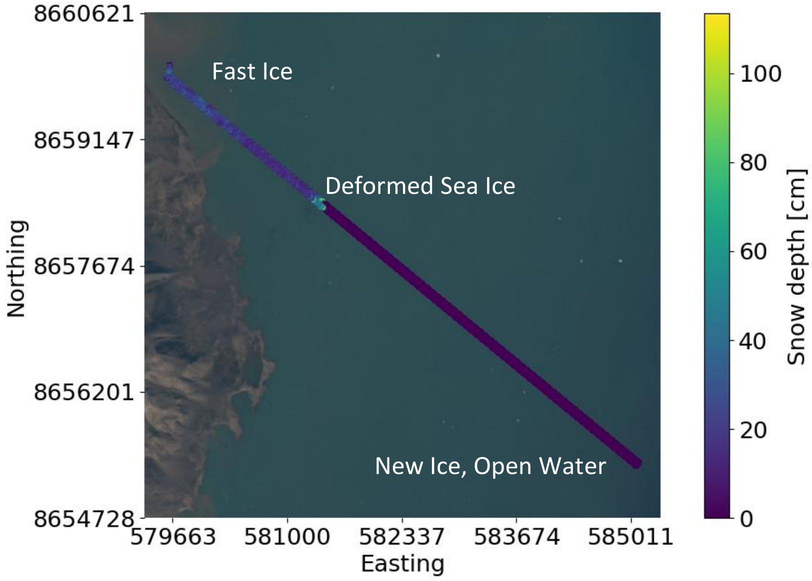

Figure 3: Preliminary snow depth retrieval from the NORCE SnowDrone over sea ice in Agardhbukta and Storfjorden. The three segment annotations correspond to the sample echograms in Figure 2.

4.2.2 vorteX-io / I-TECH UAV

4.2.2.1 Day 1

The base position obtained is excellent, and the number of satellites tracked is very high because there are no possible masks due to buildings or trees, which could have a significant impact on the GNSS processing, in the polar region. The position of the base is excellent with less than 1 mm STD stability (Figure 4).

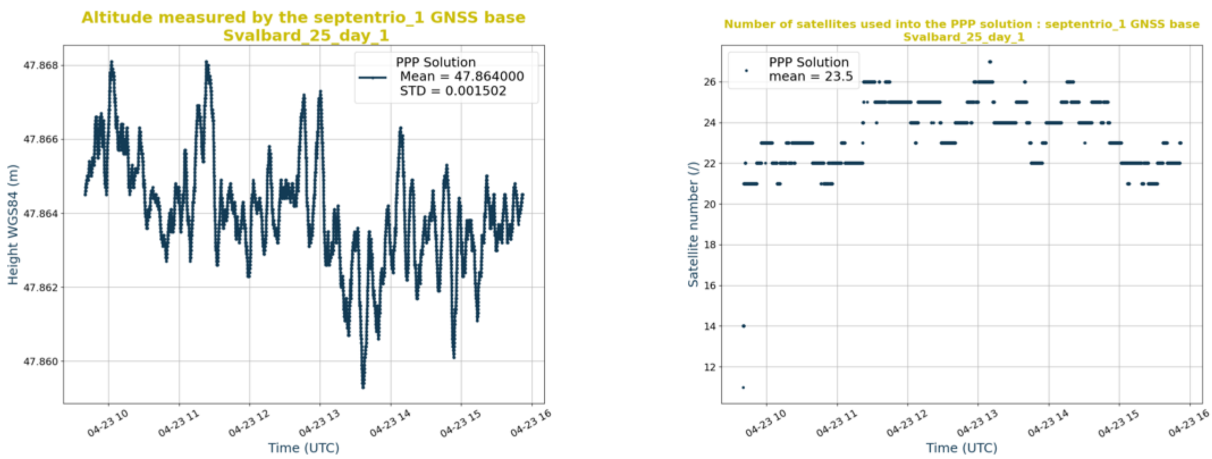

Figure 4: Altitude measured by Septentrio GNSS base (left) and number of satellites used in PPP solution (right) on Day 1.

The first day we performed 2 flights with each altimeter, we present here the positioning results for the first altimeter (Figure 5). For the first altimeter, we have strong confidence in the positioning of the altimeter, as all the ambiguities are fixed for almost the entire flight. The results for the second altimeter cannot be presented as we faced an issue in the acquisition of GNSS data (solved since). The flights performed with the second altimeter cannot be used for this campaign.

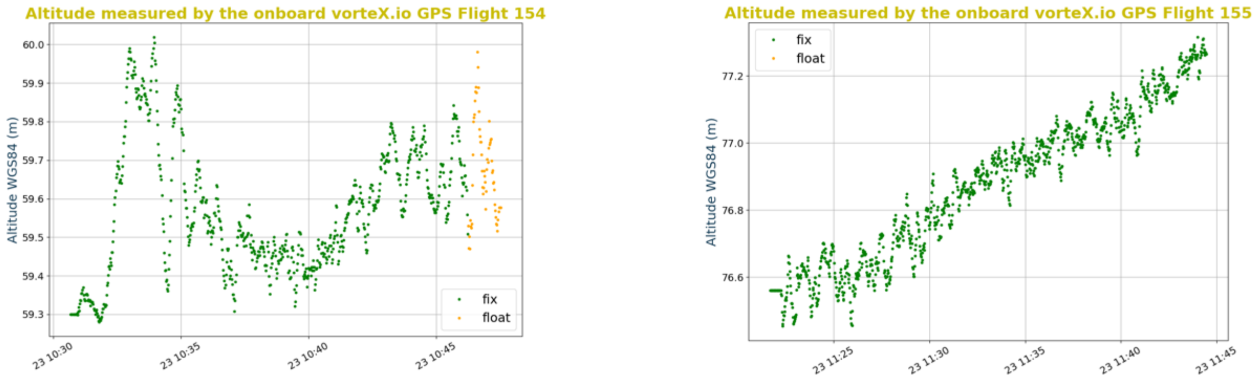

Figure 5: Position processing by the onboard vorteX-io GPS for the altimeter 1 on Day 1.

The quality of the data acquisition is excellent for these two flights. This result was expected; the recent processing of the Hydro campaign showed that the new gimbal gives excellent stabilisation with less than 2° STD on the pitch. We also have a 100% of LiDAR measurement backscattered for all the beams. This result is due to the roughness of the snow/ice. On Hydrology, only the two central beams acquired data as showed on the example on the Marmande super site (Figure 6).

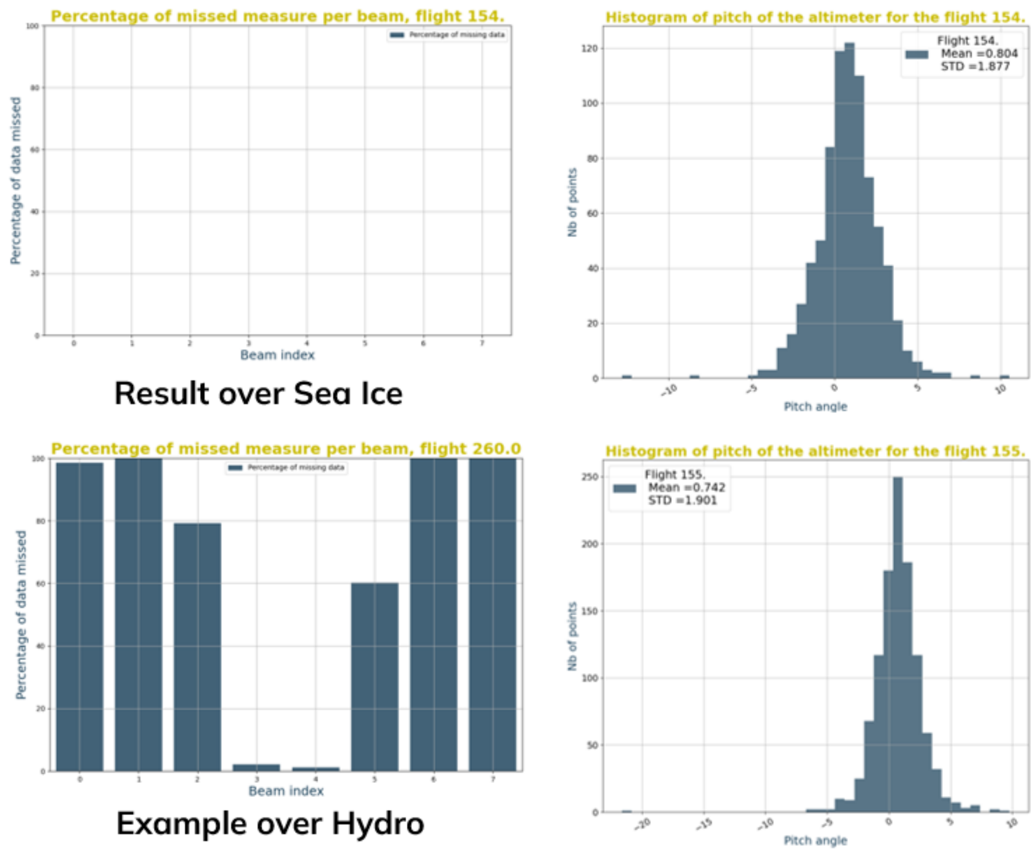

Figure 6: Percentage of missed measurements per beam and pitch of the altimeter on Day 1 and comparison with Hydro results (at the bottom).

The snow/ice topography obtained is coherent with the flight plan; the data are not filtered, and we have a residual instrument noise around 5 cm (**Figure 7**). This result is expected and coherent with the Hydro results.

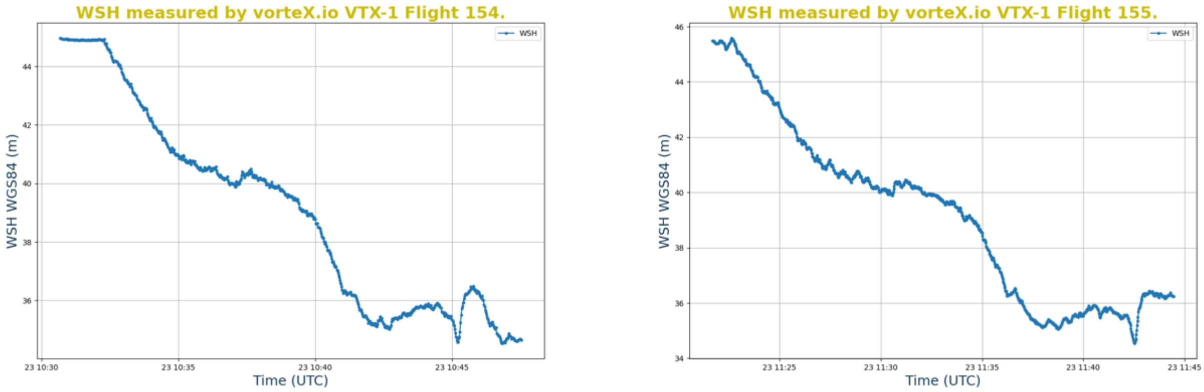

Figure 7: WSH measured on Day 1.

4.2.2.2 Day 2

Similar results were obtained for the second day of the campaign, which allows excellent positioning for the drone altimeter (Figure 8).

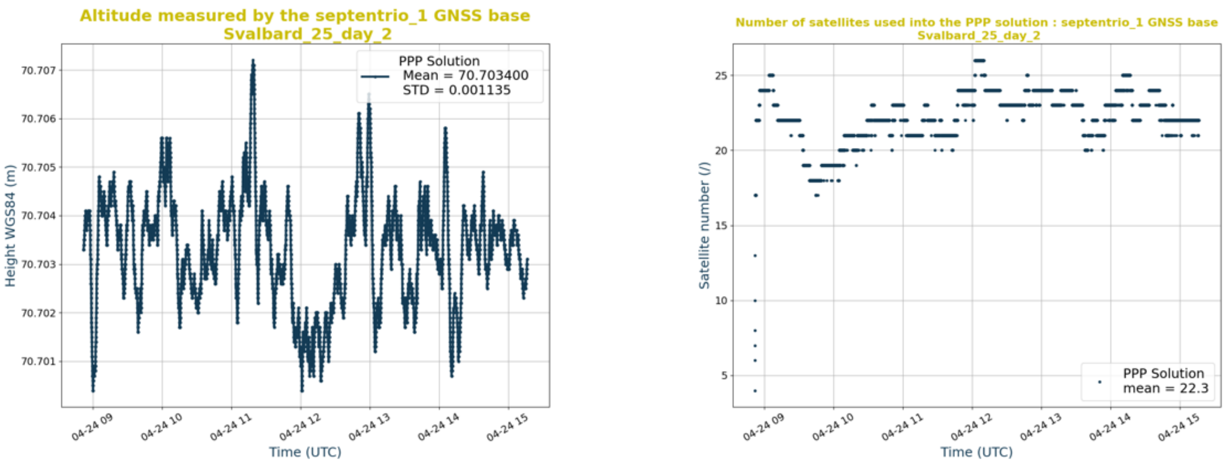

Figure 8: Altitude measured by Septentrio GNSS base (left) and number of satellites used in PPP solution (right) on Day 2.

On the second day, we performed 3 flights with the first altimeter and one flight with the second. Here, we present the positioning results for the first altimeter (Figure 9). The results are poor, showing the same issue observed during the hydro campaign in Italy. For these flights, the ambiguities were not resolved at all, which may introduce a bias in the Z-axis positioning. For flights 158 and 159, the processing created positioning noise. The position time series is highly disturbed, with an amplitude of approximately 50 cm.

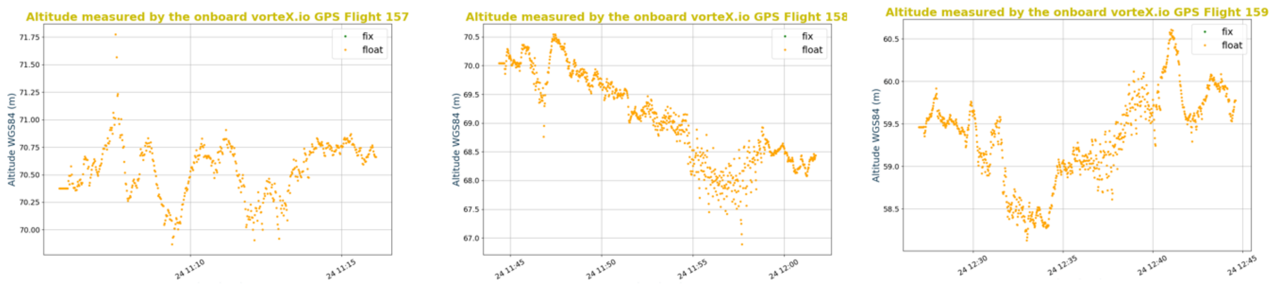

Figure 9: Position processing by the onboard vorteX-io GPS for the altimeter 1 on Day 2.

Analyses of the GNSS observations data (Figure 10) allow us to verify that similar behaviour as in Italy was observed, namely:

- The observations are clean, there are no cycle slips or perturbations,
- The observations of the 2 days are very comparable to each other.

Further investigation is required to better understand the root cause of the issue. The leading hypothesis is an irregular observation frequency.

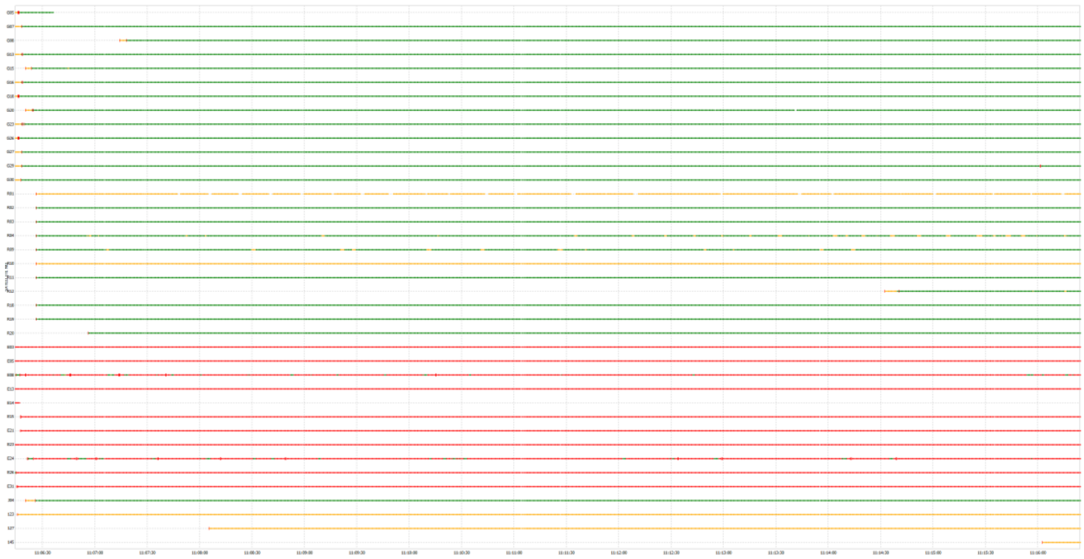

Figure 10: Observed satellites by GNSS antenna with signal quality.

For the quality of the data acquisition, we obtain the same results as on the first day. The gimbal stabilization is excellent for all the flights (Figure 11). The LiDAR received all the backscattered signals emitted due to the ice/snow surface roughness.

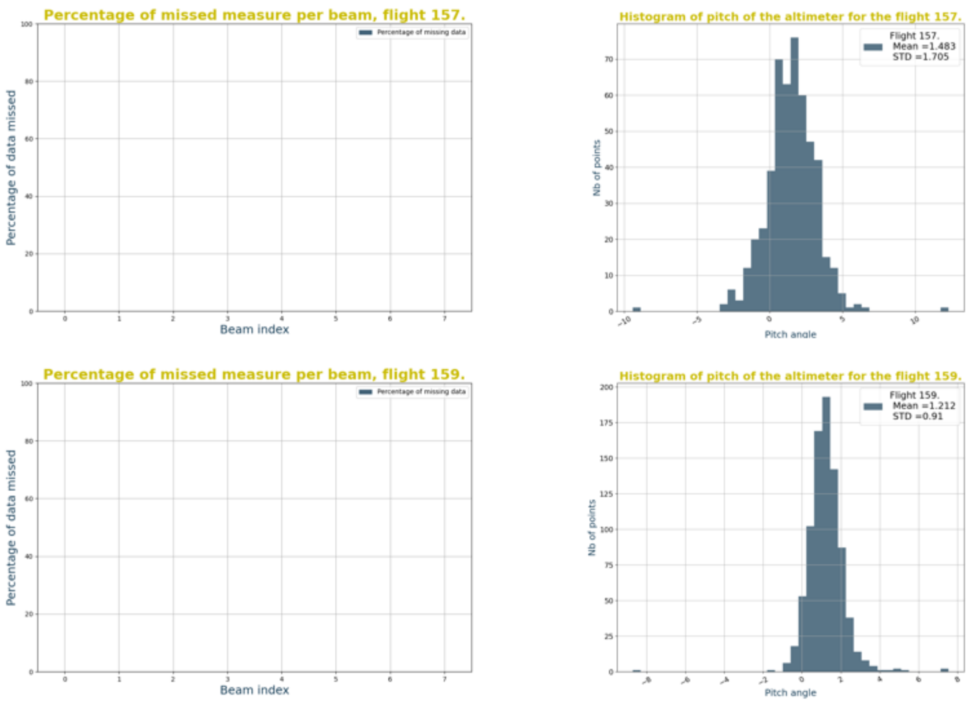

Figure 11: Percentage of missed measurements per beam and pitch of the altimeter on Day 2.

We observe the same behaviour as in Italy, with a high variability in the Sea Ice height measured (Figure 12). This variability is caused by degraded GNSS positioning and the resulting noise, whose amplitude is on the order of 50 cm.

The affected segments of the flight cannot be used for precise sea-ice elevation measurements. In addition, a height bias may be present in the derived positioning, as previously observed during the Italian campaign.

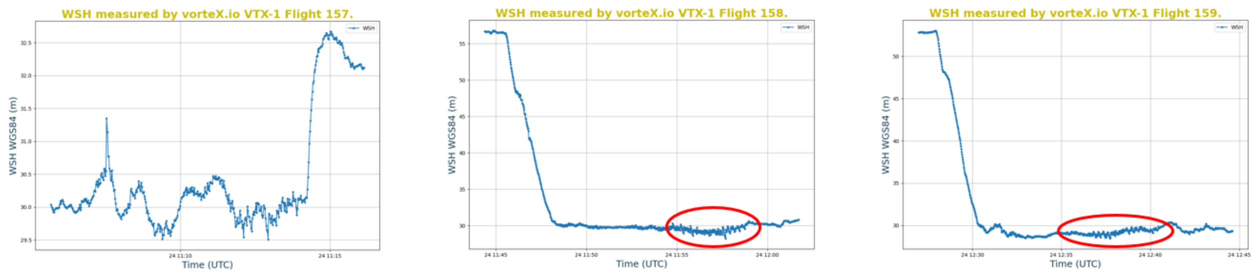

Figure 12: WSH measured on Day 2.

For each flight, we indicate whether the data are fully usable in the next table. When a flight is not exploitable, the issue that caused this is described.

Deployment information	Drone ID / Flight ID	Exploitable flights	Main issue identified
First day of deployment	2-01 / 154	Yes	-
	2-01 / 155	Yes	-
	2-02 / 2033	No	Issue in the acquisition of GNSS files
	2-02 / 2035	No	Issue in the acquisition of GNSS files
Second day of deployment	2-01 / 157	No	GNSS processing issue
	2-01 / 158	No	GNSS processing issue
	2-01 / 159	No	GNSS processing issue
	2-02 / 2036	No	Issue in the acquisition of GNSS files

For this deployment only 2 flights of the first day are usable by the Sea Ice team for validation activities.