



Annual report

Year 4: March 2025-February 2026

Troll Observing Network infrastructure project



Troll Observing Network

Troll Observing Network partner consortium

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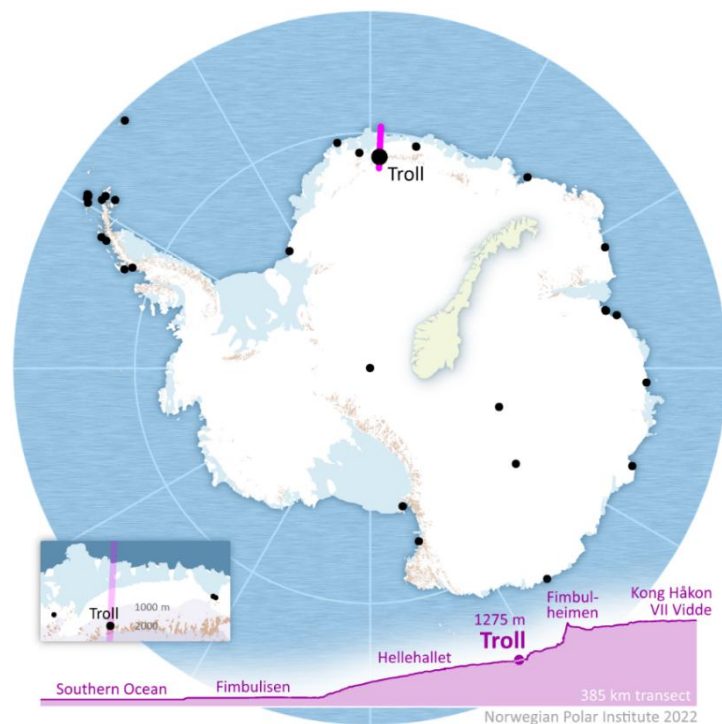
Photo front page: Establishing the TONE seismic- and infrasound array at Armlenet. Photo by NORSAR.

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1. Introduction

The Troll Observing Network (TONE), under the leadership of the Norwegian Polar Institute (NPI), has now completed its fourth year of development. What began as a coordinated effort to strengthen Norway's long-term observational capacity in Dronning Maud Land, Antarctica, has matured into a comprehensive, multi-disciplinary observing system that delivers high-quality data from one of the least monitored regions on Earth. Centred around the Troll Research Station, TONE provides year-round observations that are essential for understanding processes in the atmosphere, cryosphere, ocean, solid Earth, and Antarctic ecosystems.

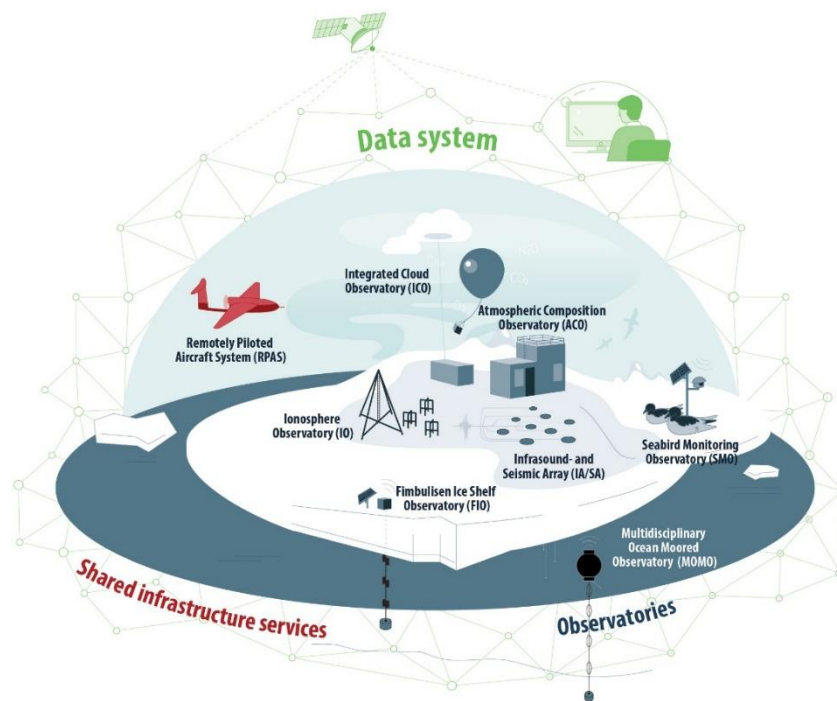


The Troll Observing Network delivers long-term observations across all major components of the Earth system in one of the most data-poor regions of the continent. Troll Research Station holds a unique position among Antarctic stations: located on the continental slope, it sits far from the coast yet not on the high inland plateau offering a rare vantage point for scientific monitoring.

TONE consists of eight observatories together with a long-range drone service designed to extend observational coverage across the wider region:

- The Ionosphere Observatory (IO) – ionospheric plasma and space weather observations
- The Atmosphere Composition Observatory (ACO) – greenhouse gases, aerosols, and trace gases observations to complement NILUs existing monitoring efforts at Trollhaugen.
- The Integrated Cloud Observatory (ICO) – cloud structure, atmospheric profiles, and radiosonde observations
- The Seismic Array (SA) and Infrasound Array (IA) – solid Earth and atmospheric wave observations

- The Fimbulisen Ice-shelf Observatory (FIO) – under-ice oceanography and melt processes observations
- The Multidisciplinary Ocean Moored Observatory (MOMO) – ocean circulation and biogeochemistry observations
- The Seabird Monitoring Observatory (SMO) – autonomous observations of seabird populations and demography
- The RPAS Service – long-range drone operations supporting regional data collection



TONE consists of three components: the eight observatories, the shared drone infrastructure service, and the data management system.

Each observatory contributes with unique datasets. A core principle of TONE is open access to these data sets. All data collected through the infrastructure are made freely available to the national and international research communities. Combined, this infrastructure represents a major strengthening of Norway’s long-term scientific presence in Antarctica and provides a foundation for future research, monitoring, and international collaboration.

This report summarises activities and progress for TONE year 4 highlighting key achievements across the observatories, advances in data management and infrastructure, and the growing scientific and operational impact of TONE. Section 2 provides a summary of the achievements, while details on the scientific and technical work are presented in Section 3, outreach activities are described in Section 4, and Section 5 contains the reference list.

2. Progress and Key Activities in TONe Year 4

Year 4 – March 2025 to February 2026 – marked a transition for the Troll Observing Network from infrastructure establishment to system consolidation. With most observatories installed, the focus shifted from implementation towards validating performance, strengthening dataflow routines, and ensuring that TONe functions as a coherent, integrated observing system.

Across the consortium, activities during Year 4 concentrated on four main areas:

1. Consolidation of the observing infrastructures

Two of the observatories delivered their first full year of continuous measurements (the Ionospheric Observatory and the Integrated Cloud Observatory), while others completed major installation milestones (Seismic and infrasound arrays and the long-range RPAS service).

2. Improved operational routines and data management

Dataflow pipelines matured significantly, with multiple observatories achieving stable near-real-time transmission to international databases.

3. Maintenance, validation, and troubleshooting

The 2025-26 austral summer season was essential for validating instrument performance, resolving technical issues, and performing routine servicing across the network. These efforts strengthened the reliability of the infrastructures and prepared them for long-term operation beyond the project period.

4. Increased scientific engagement and visibility

TONe partners presented results and infrastructure updates at major national and international meetings. Several observatories contributed data to global research initiatives, and new collaborations and funding opportunities emerged as the various infrastructures became more widely known.

Highlights from each of the observatories and RPAS service this year:

- IO: The ionosonde operated continuously throughout 2025, with successful maintenance during the austral summer of 2025-26. Establishment of direct data flow to GIRO database, making Troll a fully integrated part of the global GIRO ionosonde network.
- ICO: First year-round measurements with cloud radar and lidar from East Antarctica, and first radiosonde measurements from the Antarctic Slope region, and successful real-time data flow from Antarctica to the outside world.
- ACO: All three TONe instruments at the Atmospheric Observatory at Trollhaugen were fully installed and in stable operation, with data flowing into database. The annual maintenance and training was successfully completed.
- SA/IA: The old seismic station at Troll was known for its low seismic noise level. With just some weeks of data collection from the new seismic array at Armlenet, it has become clear that the new location and new configuration provide better quality data with an even lower noise level.
- FIO: By the end of 2025, 15 years of oceanographic mooring data from below Fimbulisen were obtained, rendering the world's longest time series of continuous data below an ice

shelf cavity. With the new observatory, the first proof of concept of remotely controllable sound source deployment for under-ice navigation underneath several hundred meters of glacier ice was obtained.

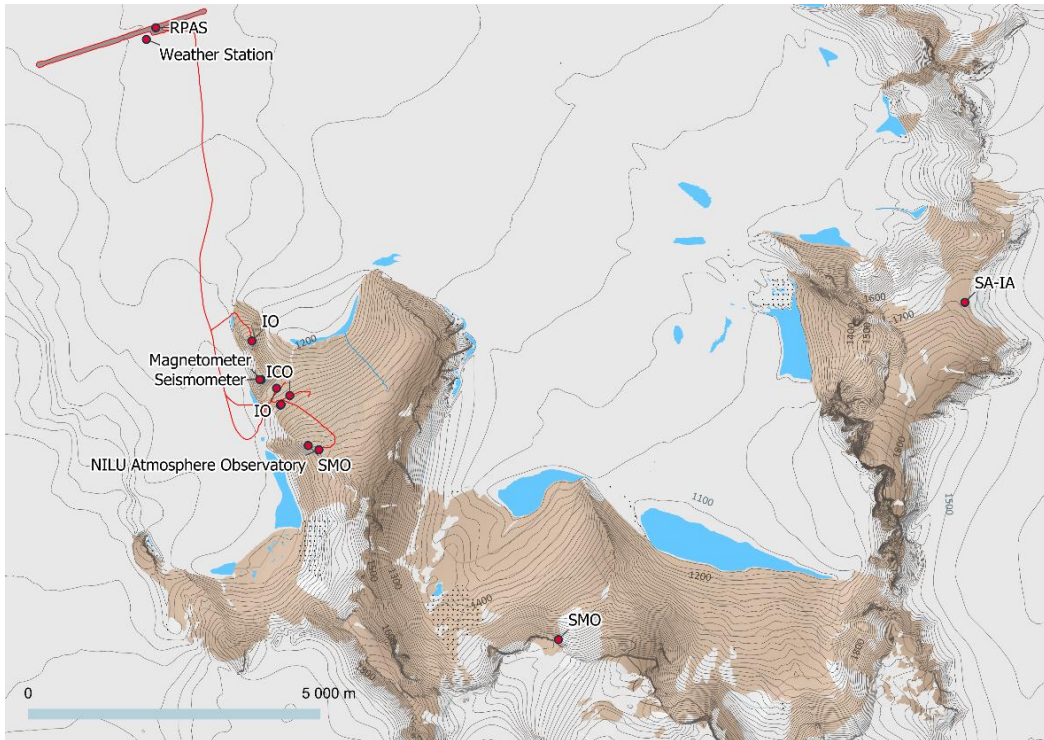
- MOMO: Five years of novel ocean mooring data are now available. In addition, historical NPI CTD data have been published on Norwegian Polar Data Centre (NPDC) and incorporated in pan-Antarctic ocean- and ice climatology.
- SMO: The observatory continued to gain important insights into how the automatic monitoring system should be designed and implemented as the SMO concept remains under development.
- RPAS: The TONe drone Windracer service successfully advanced toward operational readiness this year, with key progress in crew training, aircraft payload integration, permitting, and system testing, positioning the platform for its first full pilot season at Troll in the austral summer of 2026–2027.

In summary, year 4 demonstrated that TONe is evolving into a robust, multi-disciplinary observing system capable of delivering high-quality, year-round data from Dronning Maud Land. The foundations are now in place for the final project year to focus on full commissioning, scientific exploitation, and preparing the various infrastructures for long-term operation and national and international use.

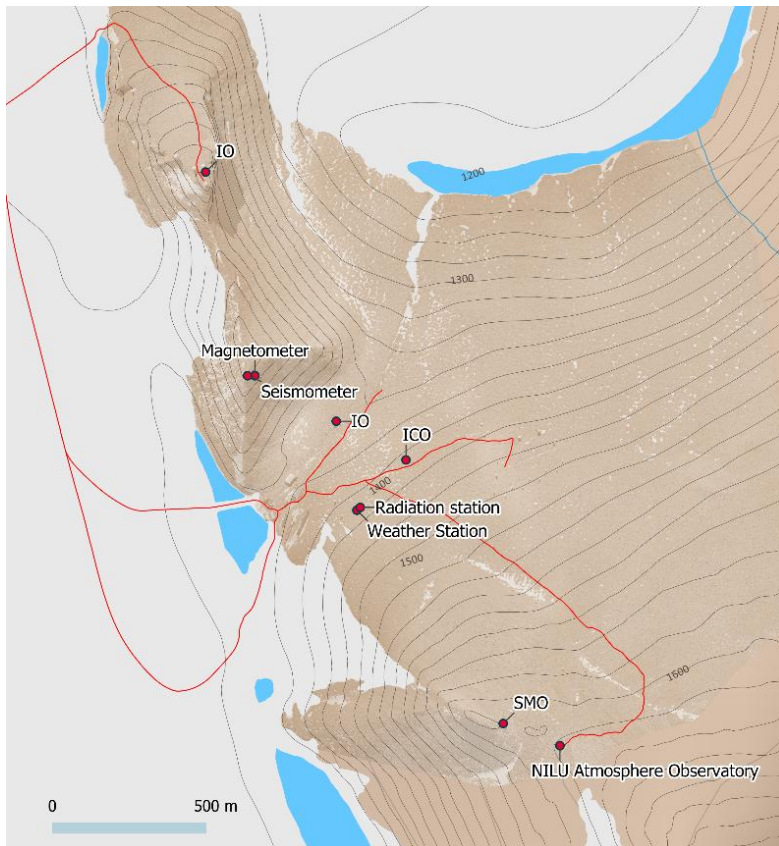
3. Work and Progress for the TONe Infrastructure

Year 4 marked a decisive phase in the development of the Troll Observing Network, with all eight observatories now either fully operational or in the final stages of commissioning. This chapter summarises the status, progress, and key achievements of each observatory during Year 4. It highlights installation and maintenance activities, data collection and validation, operational challenges, and scientific or technical milestones. The chapter also outlines the plans for the final project year.

The significant achievements of the past year are a result of thorough planning, dedicated work, and a consistently positive and solution-oriented attitude from everyone involved in overcoming the challenges encountered. This collective effort spans scientific personnel, technical staff, and the operational team at Troll, supported by the expertise and equipment provided by KSAT. The extensive tasks undertaken during the short summer season at Troll would not have been possible without the commitment and on-site presence of the dedicated team.



Overview of the TONE infrastructures in Jutulsessen. Research infrastructures established before TONE are also included. Map by Even Birkeland, NPI.



Overview of the TONE infrastructures zoomed in on Troll Research Station. Map by Even Birkeland, NPI.

3.1 The Ionospheric Observatory (owned by University of Oslo (UiO))

The Ionospheric Observatory (IO) allows for studies of processes in the upper polar atmosphere, with the focus on its ionised part, the ionosphere. Within TONe, a digital ionosonde (digisonde) has been deployed at the Troll Research Station. The digisonde is an ionospheric radar that sends radio waves to the ionosphere and analyses the reflected signal. Reflection from the ionospheric layer depends on the wave frequency and ionospheric electron density. Thus, scanning through frequencies, the radar allows for studying and monitoring the ionisation profiles in the ionosphere, which is related to geomagnetic activity but also to forcing from below. Digisonde data are valuable for studying atmospheric gravity waves, which modulate the ionospheric density. The digisonde also allows for monitoring of the convection of variations in ionospheric plasma (electrons and ions) in the horizontal direction. This allows studies of the dynamics of ionospheric irregularities and state of the ionosphere over the station. Together with other instruments within the IO and at neighbouring stations this allows for detailed studies of space weather phenomena and space weather effects over Dronning Maud Land. IO provides an insight into processes related to variability of the upper atmosphere, ionospheric plasma, geomagnetic activity and aurora, and how they contribute to space weather effects.

The main instrument, the digisonde radar, consists of an 18 meters tall antenna mast designed specifically for this location, as well as four receiving antennas and an instrument container. The whole system was installed in the austral summer of 2024-25, with the support of NPI and KSAT personnel. During the second half of February 2025 the instrument was prepared for the coming winter season. Initial tests were successful, and no major problems were detected.



Part of the ionosonde system – the transmitter antenna and one of the receivers antennas - at Troll Research Station in December 2025. Photo: W. Miloch, University of Oslo.

During 2025, the ionosonde was operated continuously, and its performance was monitored. The UiO team worked on establishing a direct flow of data to local and international ionosonde databases to provide near-real time data from Troll. During the austral summer of 2025-26, maintenance of the

ionosonde was carried out. The antennas, cables and all outdoor installations were inspected, including all parts of the mast and transmitting antenna. Minor repairs were carried out. No major problems with the system were detected in the first validation season.



The transmitting antenna and one of the receiving antennas during inspection in December 2025. Photos: W. Miloch, University of Oslo.

The ionosonde data are provided directly to the Global Ionosonde Research Observatory (GIRO) and are available online: <https://giro.uml.edu/>. Data are collected at 7.5 minutes interval. Troll ionosonde data are now part of the worldwide digital ionosonde network (with International Union for Radio Science (URSI) code TROP2). Data include daily digital ionograms and drift measurements. Examples of data from the GIRO database are shown in Fig. 1.

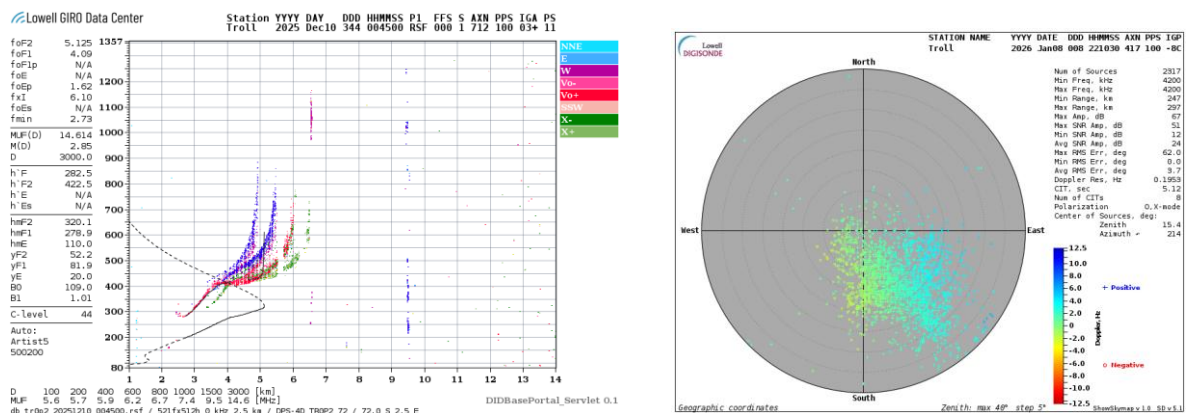


Fig. 1: Example of ionogram (vertical electron profile, left panel) and drift velocity (right panel) measurements from the digisonde at Troll Research Station.

The next year, the system will continue to collect data and the team at UiO will continue the work to establish a robust direct dataflow between the infrastructure at Troll and the local database at UiO. Focus will also be on facilitating access to data for the users. During the austral summer season of 2026-27, a visit to Troll is planned to maintain the installations, test routines on the site, calibrate the digisonde, and run a campaign with different setups of the digisonde. The 2026-27 visit will conclude commissioning of the digisonde. UiO will continue to collect data with regularly maintenance work every year/every other year by personnel from UiO.

With raw data now available, the UiO team will start working on scientific exploitation of data. As only a handful of ionosondes exist in Antarctica, and only one digisonde in this part of Antarctica, IO provides a unique dataset. This is of importance for space weather monitoring and forecasting services. UiO aims to coordinate the efforts with other relevant, complementary datasets from Dronning Maud Land for scientific research.

Publication related to the Ionospheric Observatory for the last year is listed in Sec. 5.

3.2 The Atmosphere Composition Observatory (owned by NILU)

Trollhaugen Atmospheric Observatory is a year-round background monitoring observatory about one km from Troll Research Station (1553 m a.s.l.). Established in 2007 and relocated to an undisturbed site in 2014, it measures greenhouse and reactive gases, aerosols, UV radiation and ozone, halogenated compounds, Persistent Organic Pollutants, mercury, Non-Methane Hydrocarbons, and meteorology. Continuous air and archive sampling support retrospective analyses. Trollhaugen is one of four Global Atmosphere Watch (GAW) global stations in Antarctica. As part of TONE, NILU has been able to add three instruments to the observatory at Trollhaugen. All three have been installed and are in operation:

A CO₂, CH₄, and CO monitor from Picarro was installed in December 2021, and data have been available since then (see Fig. 2). The instrument has operated stably, and quality-controlled data are subsequently submitted to the WMO World Data Centre for Greenhouse Gases and are also available through the database EBAS.

An aerosol particle sizer (APS), which measures aerosols in different size fractions, was installed at the beginning of 2023. The instrument has experienced several issues with the laser beam used to count particles, resulting in extended periods without measurements. In January 2026, the instrument was replaced with a new APS. Data are available from the WMO World Data Centre for Aerosols (WDCA), hosted by NILU (EBAS).

A PANDORA spectrometer measuring the vertical total column of various trace gases (O₃, SO₂, NO₂, and formaldehyde) was installed in January 2023. The instrument is integrated into the Pandora Global Network (PGN) and is used for routine validation of the Sentinel-5P satellite operated by the European Space Agency (ESA). The instrument is stably providing openly accessible data in near real time. A snapshot of this data is shown in Fig. 2.

During the annual maintenance trip from NILU to Trollhaugen in January-February 2026, NPI personnel received training to ensure that the instruments operate in accordance with standard operating procedures. Annual service, maintenance, and calibration of the Picarro instrument were carried out during the trip. In addition, the compressor that will be used to fill standard gas cylinders in the coming years was installed and successfully tested.

Operation and maintenance of the TONE instruments is included in the national monitoring programme funded by the Ministry of Climate and Environment and NILU, with data reported annually to the Norwegian Environmental Agency alongside the other atmospheric monitoring programmes. In addition, there is close cooperation with the European infrastructures ACTRIS and ICOS for quality assurance, data reporting and measurement guidelines.

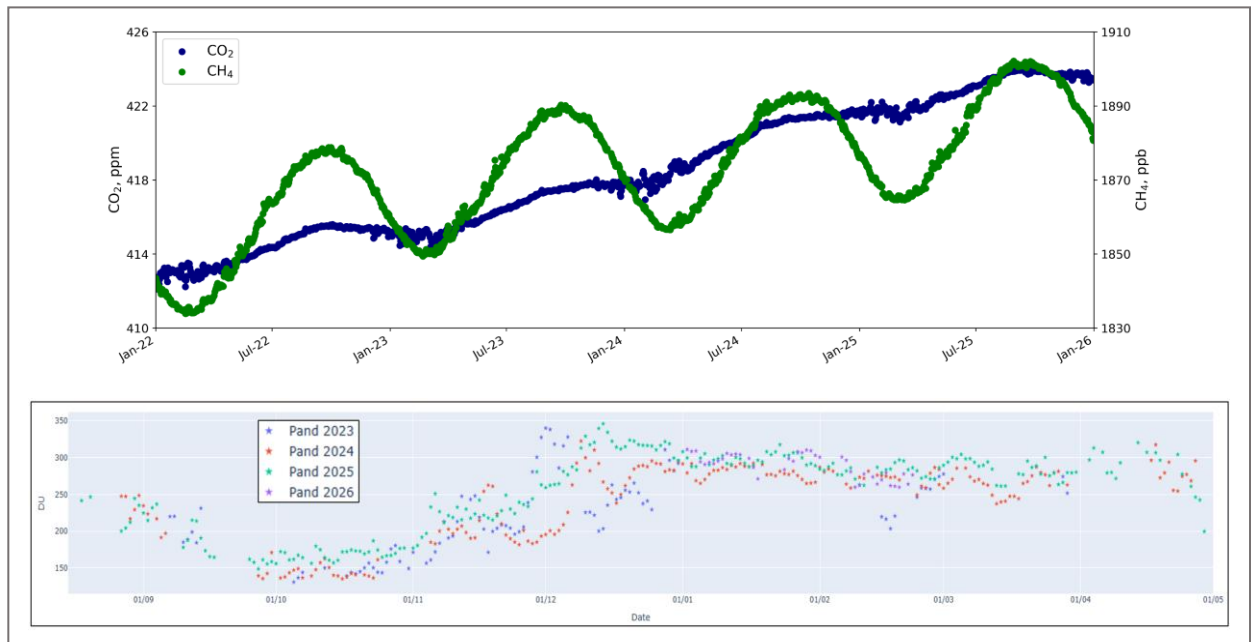


Fig. 2: Daily mean concentration of greenhouse gases (top) and ozone column (bottom) measured at Trollhaugen. Data from 2025 are not finally quality-assured.

3.3 Integrated Cloud Observatory (owned by NPI)

The Integrated Cloud Observatory (ICO) is NPI's new observatory at Troll Research Station. It includes a system of instruments to measure atmospheric and cloud properties. Three instruments make measurements from the ground continuously: a cloud lidar, a microwave radiometer, and a cloud radar. Combined, these give a real-time picture of the temperature and humidity in the atmosphere, cloud heights, thicknesses, and physical properties (liquid, ice or mixed phase as well as particle size).

The lidar sends up a laser beam which is scattered back by clouds and aerosols. It gives good measurements of cloud base height and thickness, if the clouds are not too thick, and has high vertical resolution. Because it measures the polarisation of the returned light it can also distinguish between liquid and ice clouds.

The radar sends out microwave radiation, which can see deeper into thick clouds and is more sensitive to cloud particle sizes. It also measures the doppler shift of the returned light, giving a measure of the particles' motion; if pointed up, this gives fall speed and turbulence measurements, and when pointed in other directions it can measure horizontal winds. The radar can look in any direction and provide spatial information about the clouds in the area, up to about 15 km.

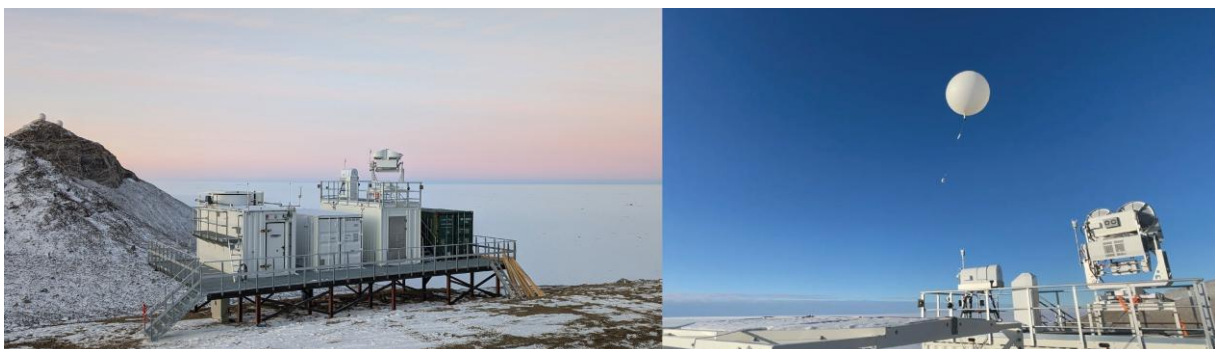
The microwave radiometer measures microwave light emitted by the atmosphere. It can retrieve temperature and humidity profiles and is very good for retrieving the total water vapour in the atmosphere.

A radiosonde programme provides daily in-situ data from weather balloons to help interpret the ground-based data and to help with weather forecasting. They measure temperature, humidity, pressure, and winds up to 30 km above sea level. There are no other stations in Antarctica making similar measurements between the coastal region and the high plateau.

The cloud and atmospheric data will be used to understand the energy and mass balance in the region. Understanding of these clouds' properties will also help improve the representation of them in weather and climate models, which is currently a significant challenge. The radiosonde data are transmitted in real time to global weather forecasting services, and the cloud data are shared with the European network CloudNet.

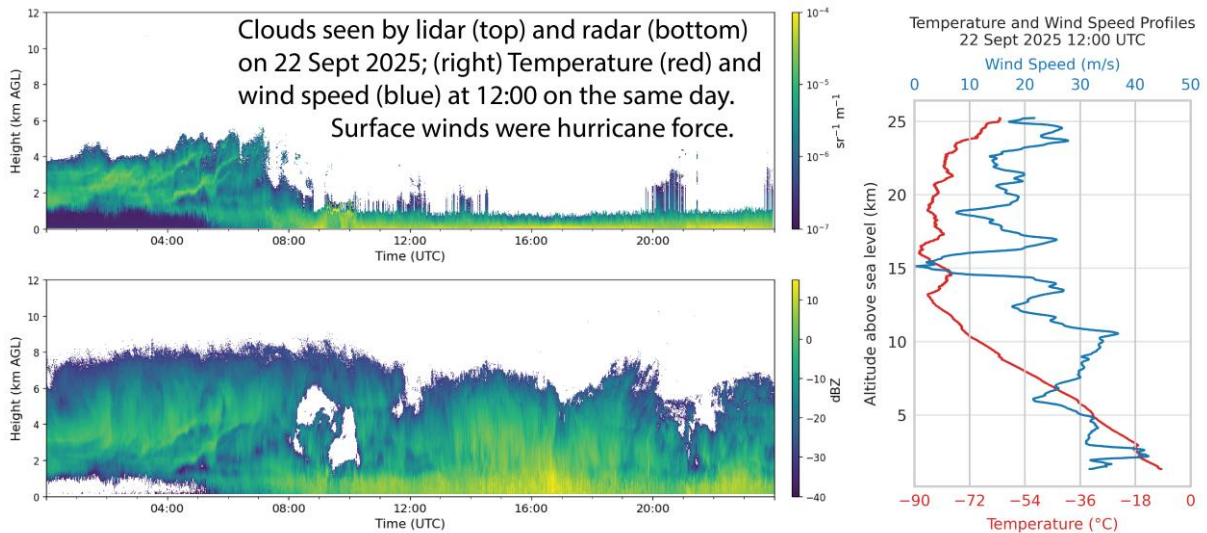
Last year was the first validation year for ICO. Despite some problems, the year was an overall success. The radar and lidar were operational all year, with data losses only due to occasional IT problems. The microwave radiometer suffered an internal instrument failure in April 2025, which required spare parts to be brought in for the austral summer season 2025-26. The radiosonde launcher worked well throughout the year, though some challenges with the hydrogen generator resulted in periods of lost data.

During the first year of data collection, lidar data was transmitted to CloudNet for 319 days and radar data for 325 days. Unfortunately, due to the instrument failure, only about three months of good microwave radiometer data were delivered to CloudNet. Additionally, data from approximately 225 weather balloon soundings were transmitted to the World Meteorological Organization. As this was a validation year, we consider this to be a success.

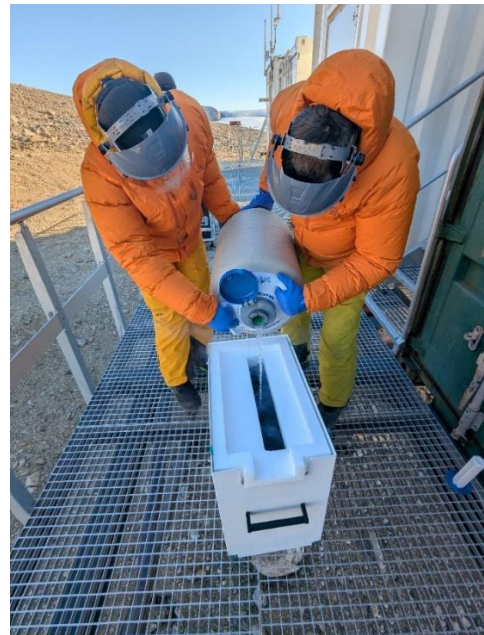
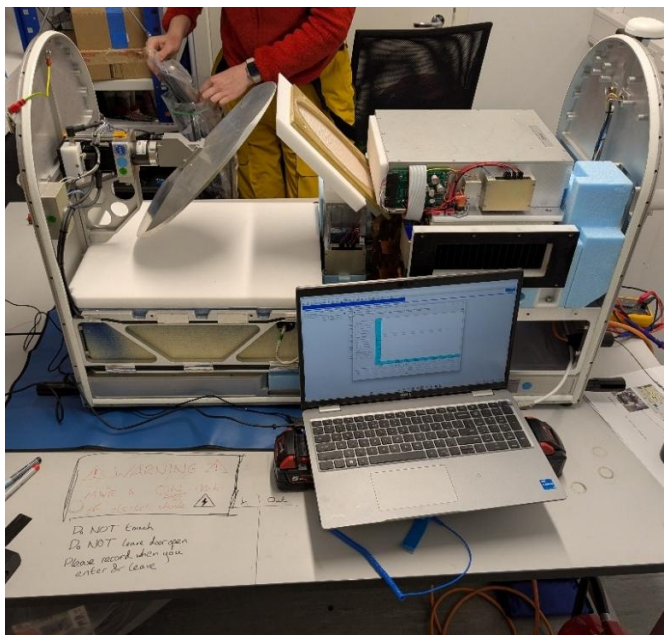


The ICO setup (left) and the radiometer, lidar and radar on the roof (right). Photos: Stephen Hudson, NPI, (left) and Marius Bratrein, NPI (right).

During January-February 2026, maintenance and repair work were carried out on site by the NPI TONe engineer and two PhD students as part of the ICO team, with remote support. The microwave radiometer was successfully repaired and is again transmitting good data to CloudNet. A minor issue with the positioner (scanner) for the radar was repaired. Improvements were made to the hydrogen production unit to hopefully ensure smoother operation through the austral winter of 2026. Routine calibrations on the radar and radiometer were performed, along with routine maintenance to the hydrogen and radiosonde containers. Radiometers were installed to monitor incoming and outgoing solar and infrared radiation. The ICO IT system was rebuilt to make it more robust and easier to maintain.



Examples of data from a stormy day in September 2025. On the left, greens and yellows show dense cloud areas seen by the lidar and radar; the radar sees much deeper into the cloud, but the lidar gives valuable information and exact base height and phase (liquid or ice). On the right, the temperature and wind speed from the surface up to 25 km is shown, as measured by the radiosonde.



Working inside the microwave radiometer to perform necessary repairs in early February 2026 (left). Filling a calibration target with liquid nitrogen for radar and microwave radiometer calibration (right). Photo: NPI/University of Leeds.

The coming year will focus on continued data collection and improvement of routines and documentation. It is also the year the team will actively work with the data to start extracting scientific results. The data flow routines will be fine-tuned and public displays of the data in real time will be developed.

Moving forward, some operations of ICO are expected to be supported as part of NPI's internal monitoring programme, however ICO infrastructure has already sparked external funding and further

interest in collaboration. NERC in the UK recently funded the project SnøTroll to use and extend the ICO observations and to provide funding for two younger researchers to analyse the data. Work is underway on a large NERC grant to fund an aerial campaign and additional surface instruments; Troll was chosen as a target for this work because of ICO. Additional collaboration and funding opportunities are being worked on with partners in Norway, the USA, and Switzerland.

Datasets from ICO are listed in References, part 5.



Reinstalled broadband radiation sensors for monitoring the surface energy budget. Photo: NPI/U Leeds.

3.4 Seismic Array and Infrasond Array (owned by NORSAR)

The TONe Seismic Array (SA) focuses on the dynamics of the ice and solid earth in Dronning Maud Land. The new seismic array will upgrade the existing seismic infrastructure of NORSAR at Troll Research Station into a high-quality seismic observatory, not only compared to other stations in Antarctica, but also in a global context. The array will record signals from all types of seismic events, including earthquakes, icequakes, iceberg calving, explosions, and oceanic swell. The new seismic array will be able to record much weaker signals than the existing single station and additionally measure the propagation directions and velocities of these signals. This additional information will be essential to associate observed seismic and infrasond signals with common sources and to locate them in the dynamic cryosphere.

The co-located infrasond array (IA) measures low-frequency pressure (sound) waves generated by atmospheric events, such as meteors, volcanoes, explosions, and oceanic swell, as well as abrupt ice movements (icequakes). These waves can be used to analyse atmospheric dynamics and vertical coupling between different parts of the atmosphere. The propagation of infrasond waves in the atmosphere is influenced by weather conditions such as wind and temperature. This allows infrasond waves from known sources (such as storm systems, volcanoes, and oceanic swell) to be used for analysing the state of the middle and high atmosphere.

After deciding on the new array location at the end of 2024, all necessary changes for an off-grid installation at Armlenet, ca. 10 km north-east of Troll Research Station, were planned, additional

equipment purchased and sent to Troll by boat in November 2025. Both the seismic and the infrasound arrays were installed at Armlenet in the period December 2025 to February 2026.

In November, the container hosting the Central Registration Facility (CRF) of the arrays, the off-grid power supply, and the data transmission were packed and sent to Troll.

In December, the installation work started with drilling the boreholes for the seismometers with help of NPI and KSAT personell, the cables were laid out and the boxes hosting the electronics and the infrasound sensors at the array sites were dug in the ground. Then, the noise reduction systems for the infrasound sensors were installed at all sites.

During January and February, after arrival of the CRF container together with the additional new equipment for power supply (solar panels, windmills and a diesel generator in case of total windmill failure) and data communication, the installation of all array sensors could be finalised and first instrument tests were performed. On 28 January 2026 the first data from the array transmitted in near real time from Armlenet to NORSAR in Norway.

In February, the installation was finalised. At the end of February, the infrasound array was fully functional with 9 out of 9 array sites in operation. The seismic array was slightly reduced in function. Three of the 10 seismic sensors showed some malfunctions. After working with the manufacturers remotely to troubleshoot the issue, no other solution than to return the three sensors for repair was found. Thus, at the end of the austral summer of 2025-26, 7 out of 10 array elements were in operation. Also, the extreme broadband sensor had to be brought back for repair. At this point it is not possible to conclude if the malfunctions arose from extended long-term storage, due to transport, or malfunctions during installation.



CRF container transport from Troll to Armlenet. Photo: NORSAR.

During the coming year, the focus will be on error diagnostics of the malfunctioning instrumentation by the manufacturer along with repair work and preparations for the maintenance trip planned for the austral 2026-27 summer season. A quality check of all metadata and data channels will be required, together with careful observation of long-term instrument performance. The autonomous power supply, including solar panels, windmills, and backup diesel, will be monitored throughout the coming polar winter, with the potential development of new concepts if needed. The array instrumentation will also be incorporated into the routine State of Health checks performed at

NORSAR for all installations. In addition, the automatic array data processing will be set up and the resulting outputs evaluated.

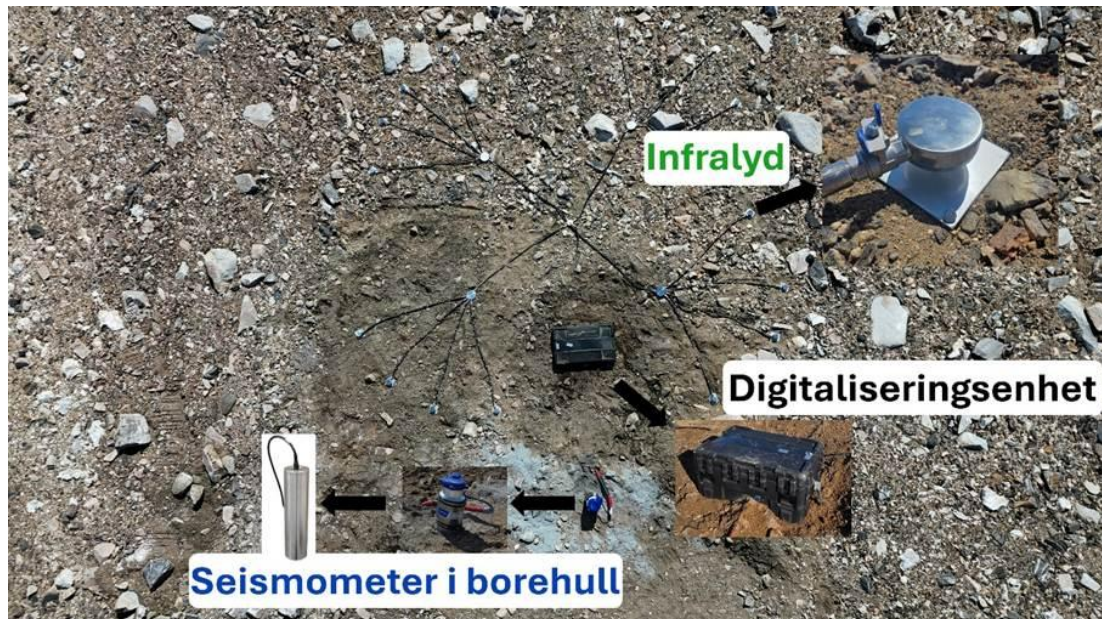


The Central Recording Facility (CFR) installed with windmills, solar panels, and communication antennas at Armlenet. Photo: NORSAR.



Preparation of the borehole casings for hosting the seismic sensors (left). Filling the casings with sand for insulation after installing the seismic sensors (right). Photo: NORSAR.

NORSAR will remain responsible for the infrastructure after the Research Council of Norway's (RCN) funding ends and will cover the operational costs for the two arrays through its base funding. A presentation of the new infrastructure is planned for the SCAR Open Science Conference in Oslo in August 2026, where new collaboration opportunities are expected to emerge through initiatives, institutional support, and projects interested in using the facility.



Drone picture of the array site with information about the installed units. Photo: NORSAR.

NORSAR is operating several arrays (seismic & infrasound) in the European Arctic and is looking forward to combining observations of all infrastructures together. It is also expected that monitoring the cryosphere at both poles will give synergy effects when interpreting the observations.

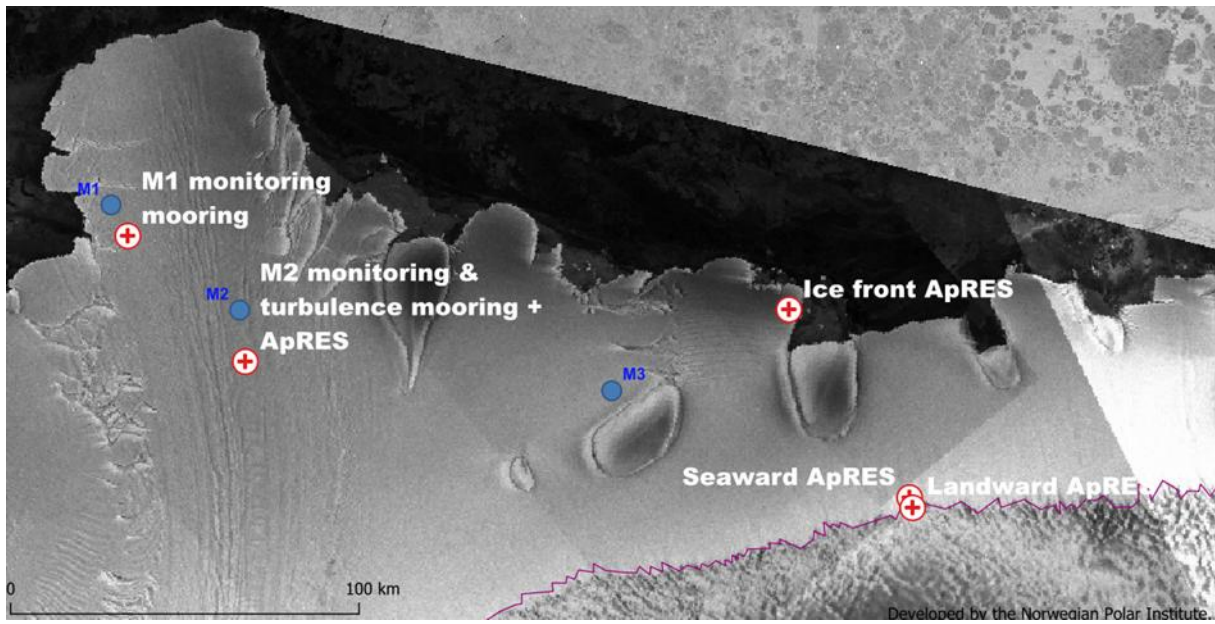
There are already close connections with the Alfred-Wegener Institute in Germany, the operators of the German Antarctica station Neumayer, which is about 400 km away from Troll. Alfred-Wegener Institute operates similar seismic and infrasonic arrays. A common data analysis as well as future cooperative projects are planned.

Presentations from SA/IA are listed in Sec. 4.

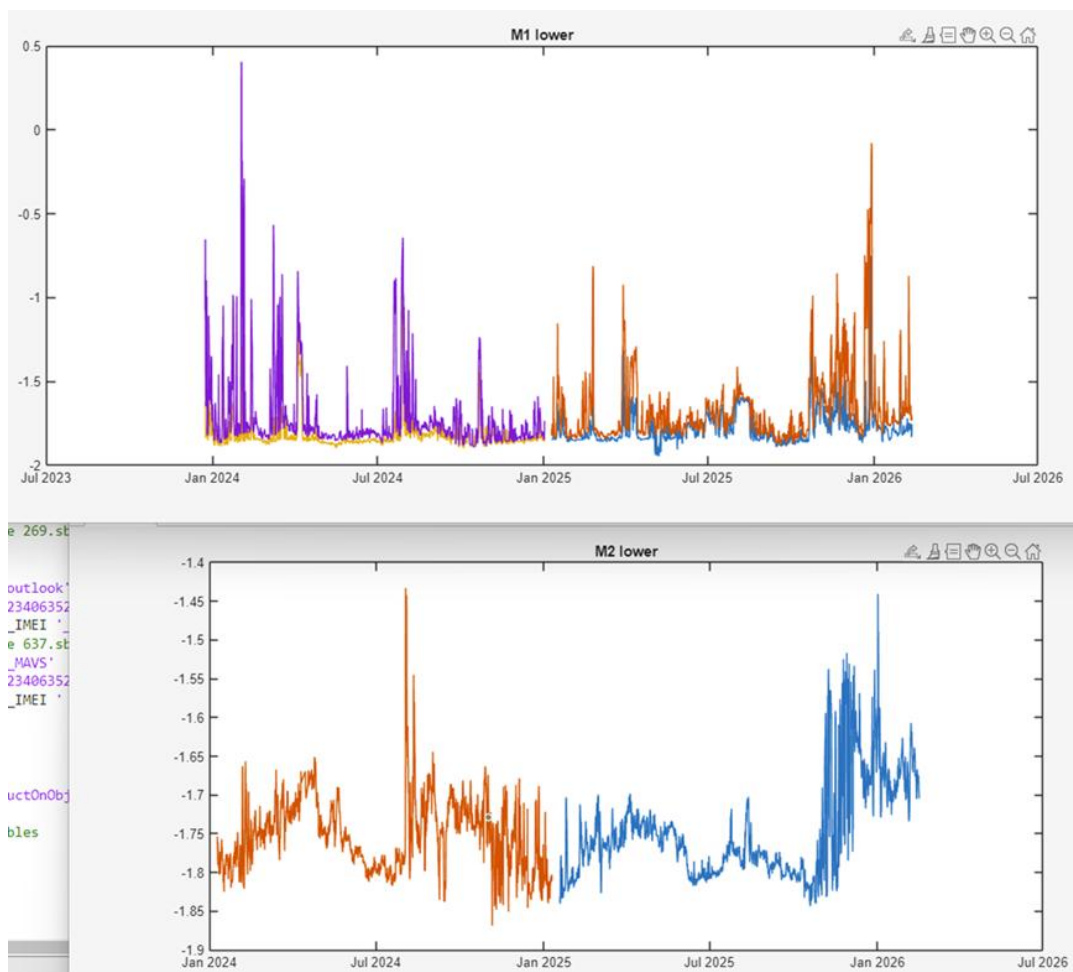
3.5 Fimbulisen Ice-shelf Observatory (owned by NPI)

The Fimbulisen Ice-shelf Observatory (FIO) contributes to understanding the coastal marine environment in the Atlantic sector of East Antarctica, the interactions between ocean currents and ice shelf melting, and the implications for global climate dynamics. The data will help refine global-scale climate models by providing precise measurements of ocean temperature fluctuations, ice shelf melting rates, and long-term environmental changes. Additionally, the observatory includes innovative under-ice acoustic navigation systems, which will support future autonomous glider missions under the ice shelf.

FIO is now in operation, and daily near-real-time data is successfully received from the two under-ice shelf moorings (M1 and M2), as well as data from an autonomous melt rate radar and automatic weather station (M2) on the central Fimbulisen ice shelf.



Overview map, showing the newly established (red) and old (blue) sites that are part of the Fimbulisen Ice Shelf Observatory.



Example of inflow water temperature below Fimbulisen ice shelf from the renewed under-ice shelf moorings, as received from the near-real-time satellite link.

The process-oriented melt rate radar stations that were deployed on the eastern part of the ice shelf during the austral 2024-25 season were successfully recovered during the 2025-26 season.

The plan was to visit the old M1 and M2 sites this last season to recover data to cross-calibrate the long-term temperature records from the old mooring with the new ones, but unfortunately, it was not possible to carry this out. The new plan is to recover data at the old M3 mooring the coming Antarctic summer season. If this visit cannot take place, the old mooring loggers will be covered with snow to such an extent that recovery will no longer be possible.

In relation to NPI's TrollTransect cruise 2026-27, the functionality of the under-ice sound sources at FIO was confirmed by means of a submersible hydrophone that was deployed from the vessel outside the ice shelf cavity.

The near-real-time data are securely archived at NPI Data Centre and automated processing of raw data is being developed, which will leverage data sharing.

An RCN Infrastructure proposal was co-developed for national ocean glider facilities (Norgliders), which, if funded together with the FIO sound sources, will leverage the year-round transect observations from the Fimbulisen cavity across the Antarctic Slope Front and into the deep ocean.

For the next year, an RCN-FRIPRO application is currently being developed to extend the FIO observatory in space by accessing the Jutulstraumen Grounding Zone, and in scope by including biogeochemical and carbon processes, as a collaboration between NPI and UiT under the iC3 Centre of Excellence umbrella. A TONE-drone pilot application was submitted for reconnaissance of the Jutulstraumen Grounding Zone. Scientific collaboration and shared operational support with British Antarctic Survey will be instrumental in this initiative.

Work will continue with completing the observatory description in the form of compiled field reports from the consecutive 2023–2026 seasons. In addition, scientific results and data from the first year of data collection will be published, and a full data pipeline for near-real-time archiving and publication will be established. Further mapping of the soundscape is planned, together with short-term test deployments of underwater gliders equipped with hydrophones that can use the FIO sound sources for acoustic navigation, during the 2027 cruise with R/V *Kronprins Haakon (KPH)* to Kong Håkon VII Hav.

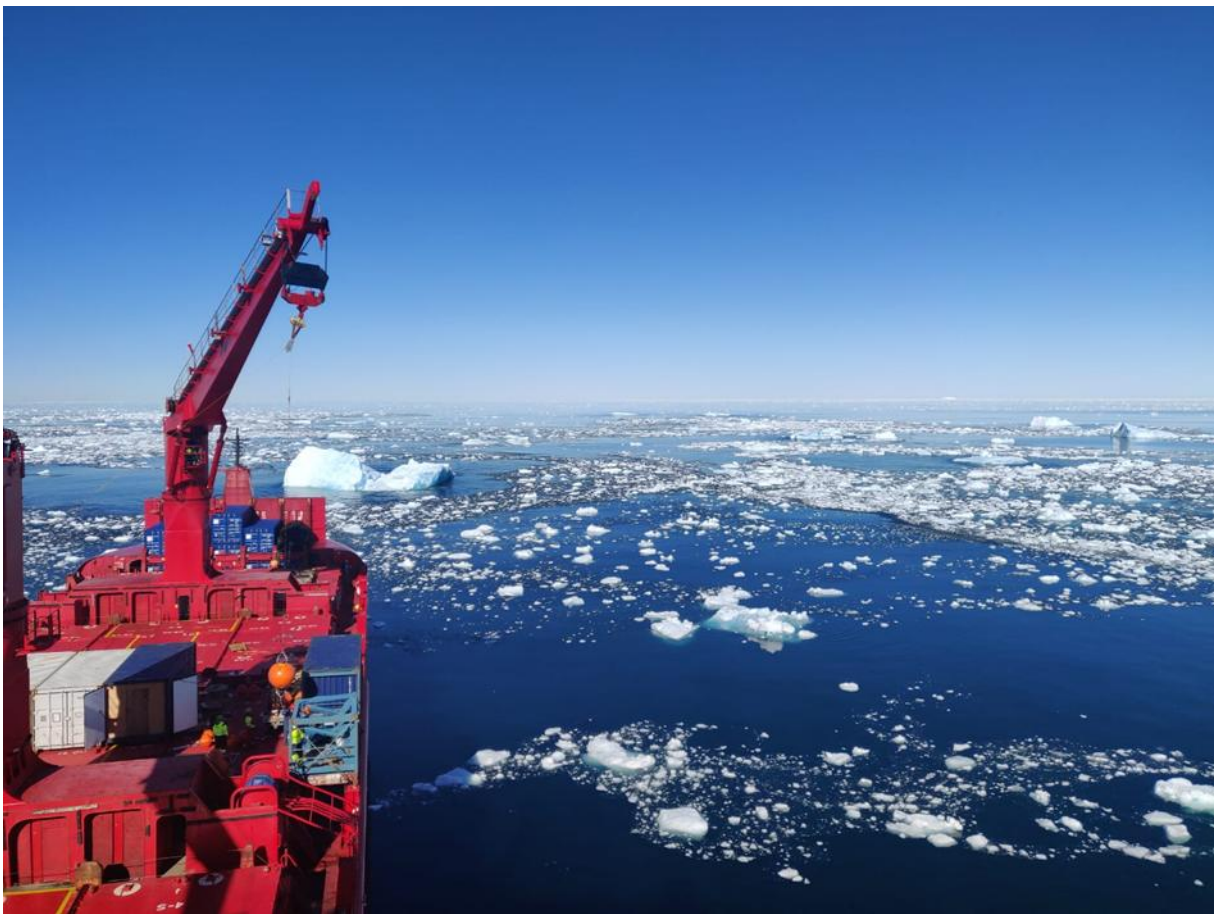
FIO feeds directly into the Antarctica In-Sync activities, where the observatory PI is a co-proponent of the ice-shelf–ocean working group. Ongoing collaborations with Alfred Wegener Institute in Germany focus on coordinating and co-publishing under-ice-shelf observatory data between FIO and the observatory established beneath the Filchner Ice Shelf in 2015/16. FIO also integrates naturally with MOMO, and informal collaboration is underway with University of Hamburg on acoustically navigated glider operations that make use of FIO.

Data from the first-year deployment of FIO were presented at the 38th “Forum for Research Into Ice Shelf Processes” in Rovaniemi, Finland, with three oral international workshop presentations. FIO-partners from the Icefin team at Cornell University got research funding for a 2-year post-doc project that will focus on the analysis of the high-resolution under-ice topography and ice ocean interaction processes that were observed during the FIO field campaign in 2023/24.

3.6 Multidisciplinary Ocean Moored Observatory (owned by NPI)

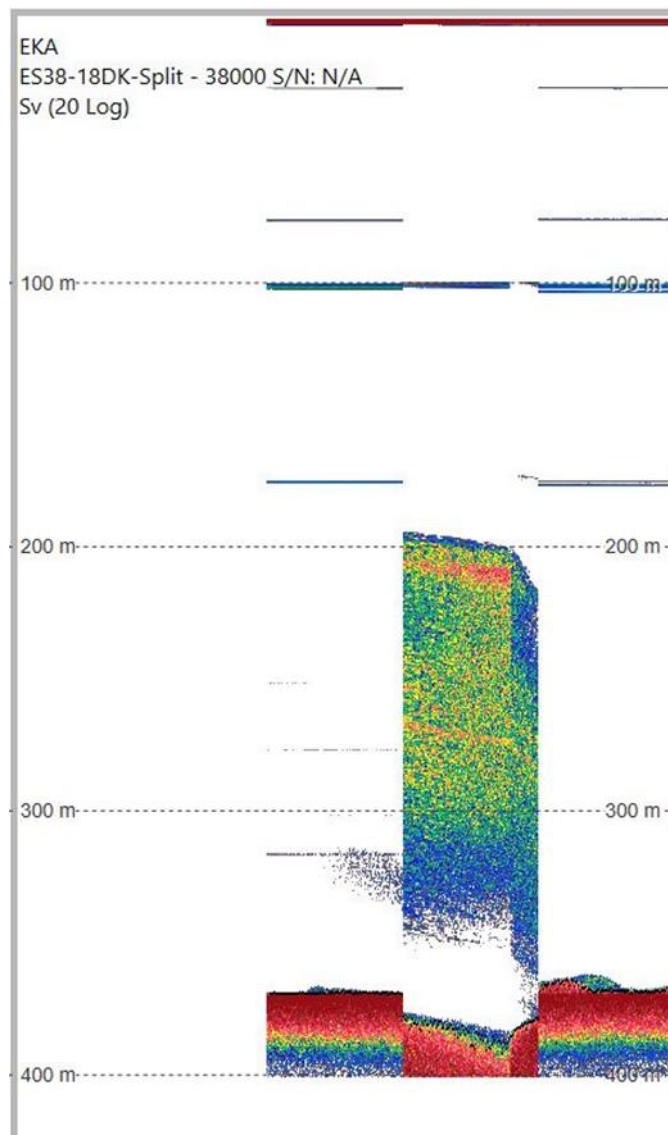
The Multidisciplinary Ocean Moored Observatory (MOMO) aims to monitor oceanographic, biogeochemical, and biological parameters along the Antarctic Slope Front and the seasonal sea ice zone. MOMO will help resolve seasonal and interannual variability in the Weddell Gyre inflow, which plays a fundamental role in climate dynamics and the carbon cycle of the Southern Ocean, and provide long-term time series for insights into the interactions between ocean currents, ice shelves, and biological productivity.

The MOMO observatory is largely operative, although each service has provided further experience and opportunity for optimization of the mooring configuration. The observatory now has provided five years of data for one of the sites and three years of data from the other. The data series are currently being processed and quality controlled for data publication and scientific analysis.



The biennial maintenance service of TONe-MOMO mooring with M/V Silver Mary took place during the TrollTransect cruise in January 2026. Photo: NPI.

In order to ensure sufficient capacity for the comprehensive objectives of the upcoming Antarctic research cruise with *R/V Kronprins Haakon* in the 2026-27 season, the three MOMO moorings were serviced during the Troll Transect 2025-26 cruise. This year, no instruments were lost to icebergs, the upper-ocean weak-link recordings were largely successful, and the setup was further refined during the mooring turnaround. An experimental altimeter for sea ice thickness detection, and a multi-frequency echosounder WBAT were installed during the 2025-26 service and provided a first year of successful data collection.



Example data from the water column echosounder, recording iceberg passage over the mooring during the 2025-2026 deployment period (vertical scale inverted).

MOMO-related data processing has primarily focused on calibration, standardisation, and publication hydrographic (CTD) profile data from NPI-lead Southern Ocean research cruises from 2019 to 2025, as well as historical data from 2001. Several datasets have now been published at data.npolar.no, see the complete list in Sec. 5.

The focus and plans for the next year are as follows; NPI-iC3 post-doc hiring was initialised in late 2025 and shall conclude in early 2026. The successful candidate will work on processing and analysing of data to write up a scientific paper about the established MOMO time series. On the northernmost mooring, an ice-profiling acoustic doppler profiler was installed during the last service, and this will be recovered during the upcoming KPH cruise, potentially providing the first-ever year-round concurrent record of under-ice ocean velocities and ice drift so far south in the seasonal sea ice zone. The opportunistic Rektangelbukta mooring will be recovered and possibly redeployed during the KPH 2027 Southern Ocean cruise.

MOMO data are linked to and directly contributed to the EU-Horizon OCEAN-ICE project. Based on the Troll Transect and MOMO efforts, the NPI was invited to join a large European proposal to support the international Antarctica InSync initiative. The proposal was successfully funded, and NPI will amongst others play a leading role in the development and coordination of pan-Antarctic ocean mooring network as part of InSync.

3.7 Seabird Monitoring Observatory (owned by NPI)

The NPI's Seabird Monitoring Observatory (SMO) aims at providing key information on Antarctic seabird population status and trends. It allows a continuation and expansion of the ongoing seabird monitoring activities NPI has been performing in Dronning Maud Land since 2011. The observatory consists of automatic time-lapse camera systems installed at two of the largest bird colonies in Dronning Maud Land (Svarthamaren and Jutulssessen). A meteorological station has also been deployed at Svarthamaren to record continuously local weather conditions.

The main activities in SMO this year took place in the austral summer season 2025-26. No new development was planned, and the main objective was to consolidate and validate the data (i.e. pictures) obtained by the SMO. Due to unexpected technical issues with half of the cameras this was unfortunately not possible.

At Svarthamaren, the high-resolution Cyclapse cameras had generally functioned, but could no longer be adjusted or serviced and therefore needed replacement. The Hideaway cameras showed mixed performance, with only one working reliably, while the Reconyx units continued to be the most dependable option despite their lower resolution; additional Reconyx cameras can be added next season. The single Browning camera had worked, but was impractical to use and was also set to be replaced.

At Jutulssessen, the Cyclapse cameras had not operated properly and needed to be replaced, while the Reconyx cameras had again proven highly reliable and could be supplemented with more units. The Browning cameras had performed poorly, with one lost and the other failing early in the season. This will be replaced with Reconyx models in the austral summer 2026-27.

The Svarthamaren weather station worked all year round without any issues.

Most of the issues were solved during the field work and visit to the colonies in January-February 2026, but this means that for all these cameras, no usable data, i.e. pictures, were obtained for Year 4. For now, there is still not enough data to validate the SMO as a long term and autonomous monitoring system.

The final field season of the TONe project (Antarctic season 2026-27) will ideally confirm that the cameras work as expected and then be used to validate the manual data collected by SMO. In brief, pictures obtained from the next year should provide information on bird density and breeding success comparable to those obtained by direct observations. The next season shall consolidate the observatory and lead to a smooth transition towards an autonomous system. Additional cameras will be installed in 2026-27 as new units and/or to replace some cameras already in place but not functioning properly.

Data from SMO will consist of pictures downloaded once a year. Existing pictures are only preliminary and do not represent a proper dataset. Data from the Svarthamaren weather station are available online but not yet publicly.

After the RCN funding ends, the SMO will be maintained by the NPI every year or every other year as part of the regular seabird monitoring activities. The maintenance will mostly consist of downloading pictures from all cameras and in some cases change batteries. Should a visit not be possible, the system is designed to be up and running for 2+ years without maintenance.

No publications or datasets have yet been published based on SMO, as SMO is still in the development phase.



Four-week-old chick in front a high-resolution time-lapse camera at Svarthamaren. The chick has started to lose its down and to grow new feathers. Photo: S. Descamps, NPI.

3.8 Remotely Piloted Aircraft System (RPAS) Service (owned by NORCE)

The TONe RPAS (drone) service is set up to support the other observatories at Troll as well as being available as a service to the wider scientific community. The aim is to facilitate data collection in the wider Dronning Maud Land region and contribute to bridge from local to regional scales.

The RPAS service consists of two Windracer Ultra 2 drones with an effective range of up to 800 km under ideal conditions and endurance up to eight hours. In addition, smaller electric multirotor and fixed wing drones will be deployed as part of the service. The drone service is set up to support research projects through data collection with advanced instrumentation that ordinary research projects otherwise would not be able to conduct on their own. This combination of drones allows the TONe drone service to both cover large parts of Dronning Maud Land from Troll Research Station as illustrated in Fig. 3, as well as be as cost efficient and flexible as possible. The operational set up could allow for deployments from the shelf or from other stations in the region in the future.

Drone Specifications

Windracer Ultra 2 drone:

- Endurance: up to 800 km, 8 Hrs
- Payload capacity: 150 kg
- Broadband Satcom: Starlink
- Runway Requirements: 300 m

CW Fox X8

- Cruise speed: 50 kph
- Range: up to 20 km
- Payload capacity: 20 kg

CW Shark VTOL

- Cruise speed: 70 kph
- Range: 100 km
- Payload capacity: 2 kg



The drone service consists of two Windracer Ultra 2 drones and smaller electric multirotor and fixed wing drones.

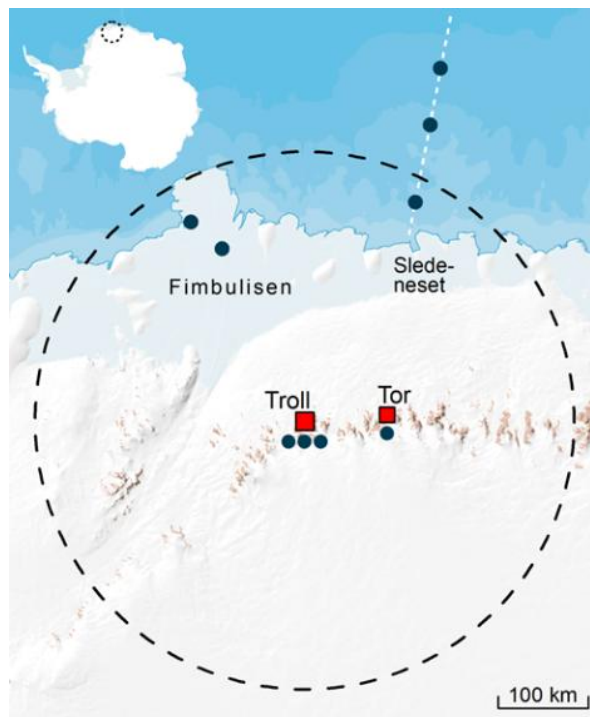


Fig. 3: The Windracer Ultra 2 drones have an effective range of up to 800 km under ideal conditions and endurance up to eight hours, collecting data over large parts of Dronning Maud Land from Troll Research Station.

The Windracer Ultra 2 drones have a range of sensors available:

- VHF radar for bed topography/bounding line mapping/subglacial lakes
- UWB radar (2-6 GHz) for snow stratigraphy mapping
- NEO HySpex VNIR 1800 hyperspectral imager
- High resolution wide swath aerial camera system
- Meteorological sensors TPH
- Broadband radiometers

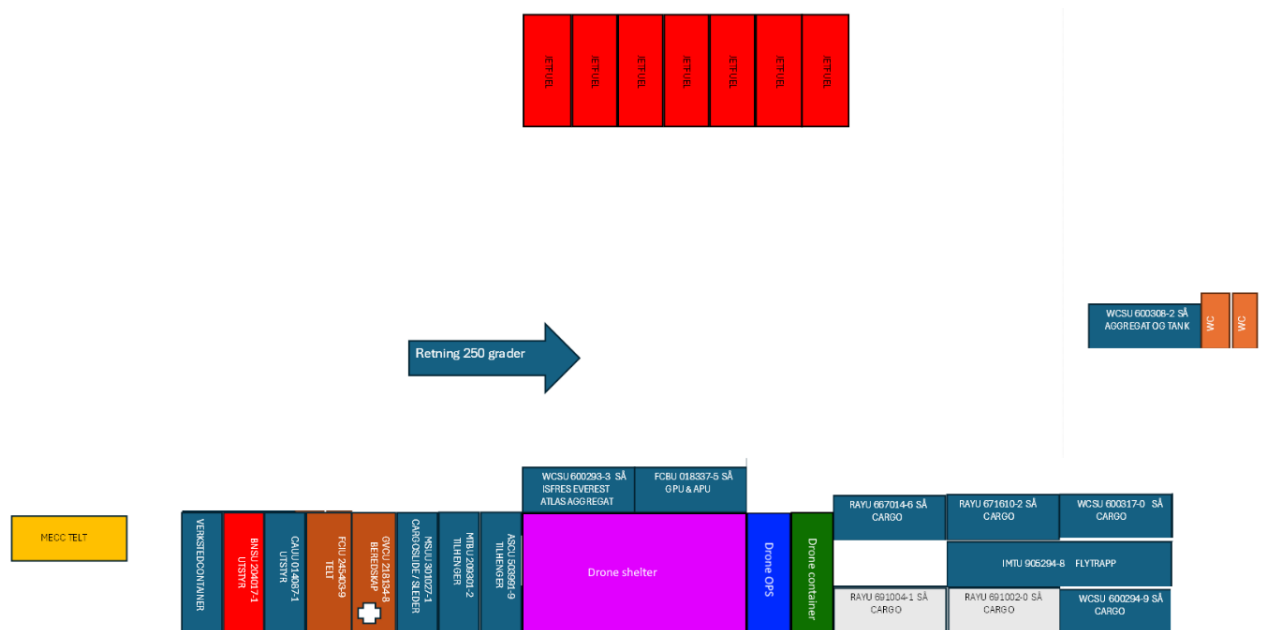
With this configuration, the project anticipated a broad range of application linked to the TONE observatories. Within the cryosphere, the system support measurements of ice thickness, stratigraphy, recent surface mass balance, and snow-water equivalent. In the ocean domain, it enabled observations of sea-ice properties, ice fraction, albedo, primary production, chlorophyll-a, algae, and sea-surface temperature. For the atmosphere, it provided basic meteorological parameters in the boundary layer as well as net radiation, broadband and spectral reflectance, albedo, and heat fluxes. The configuration also support ecosystem studies, including seabird monitoring and marine mammal surveys.

Both aircraft were completed at the Windracer factory in Southampton in the autumn of 2025, including test integration of sensor hardware. Both aircraft were test-flown in the UK and one was shipped to Tromsø in autumn of 2025, where NORCE prepared and shipped it on to Troll Research Station. The second aircraft was successfully test-flown for five days in cold conditions (-24 C) in the vicinity of Rovaniemi in February 2026. Test and training flights in Norway will be conducted in May-June 2026 at Elvenes. The sensors and systems together with control and logging systems were test integrated in the airframe in autumn of 2025 and will be tested on the aircraft in connection with the test and training flights in May-June 2026, while initial training for pilots and engineers on the aircraft will be conducted in England in February (completed) and March 2026.

The drone shelter was shipped to Troll Research Station in fall 2025, and the setup was tested in January 2026. The shelter consists of an insulated container that serves both as an aircraft operations room and a small workshop, while also forming one side of the tent hangar. A second container, used for storing and shipping the aircraft, forms the opposite side wall of the larger tent shelter, which is set up and used as the aircraft hangar during drone operations.



Drone shelter test setup at Troll Airfield in January 2026. Photo: Even Birkeland, NPI



Map of tentative setup at the airport apron, with the drone shelter marked in pink, the drone OPS container in bright blue, and the drone transport container in green. Figure: Even Birkeland, NPI.

During the reporting period, and as a preparation for the coming pilot season in 2026-27, TONE launched its first national Drone Access Call to enable long-range, instrumented drone operations in Dronning Maud Land from Troll Research Station. The pilot campaign – fully financed under the TONE project – will be conducted mid-January to mid-February 2027. Scheduling the pilot after New Year creates intentional overlap with the planned *RV Kronprins Haakon* Southern Ocean cruise to maximise synergies for marine, sea-ice and ecosystem observations. The call attracted strong interest from the Norwegian research community, with proposals spanning cryosphere and geoscience radar surveys, marine and biological observations, atmospheric process studies, and photogrammetric topographic mapping utilising all the available payloads onboard Windracer. Operations will be delivered by NORCE as drone operator, in close coordination with the NPI.

An initial joint review by NPI and NORCE confirms that all submitted projects can be served in principle – but not in full as the available flight hours are limited. To balance scientific breadth and feasibility, flight planning will prioritize (i) near-station transects around Troll, (ii) regional missions at moderate range, and (iii) coastal/ice-shelf and ocean tracks where conditions and endurance permit; the most peripheral targets (e.g., Lazarev Ice Shelf) will be considered with reservations. NORCE will start to prepare a day-by-day flight concept specifying routes and areas, altitude profiles and patterns, and payload per sortie, followed by targeted dialogue with PIs to refine must-have variables, geographic priorities, and timing. As this is the inaugural season, participants acknowledge elevated technical and weather-related risk and potential impacts on capacity and data quality.

As this will be the first drone pilot season under TONE, the strong response to the access call is particularly encouraging. The breadth and quality of the submitted proposals demonstrate a clear demand for drone-based observational capabilities in Dronning Maud Land. This early interest indicates that the drone service is likely to become a valuable and regularly utilised component of the TONE research infrastructure once it enters its operational phase. The high engagement across

disciplines also suggests a solid foundation for an on-demand service model, where research projects can request targeted data collection in future seasons. The pilot campaign will therefore not only test technical and logistical feasibility but also serve as an important indicator of user needs and community uptake as TONE transitions toward full operational status.



The Windracer Ultra 2 near Rovaniemi, Finland, on February 11 2026 during a preflight check. Photo: Katrine Jaklin, NORCE.

The plan for the next year is to develop a detailed and prioritised operation plan for the pilot season, complete the training of the crew who will staff the 2026/2027 pilot season at Troll, and finalise the installation of the payload in the aircraft currently located in Tromsø. Work will also include completing the permitting process and integrating the Windracer Ultra 2 drone into the NORCE operating permit, as well as conducting a test programme of flights at Elvenes airport to verify aircraft and instrument performance. The data-processing lines will be completed and tested prior to deployment, and the pilot season will be carried out at Troll in January–February 2027.

The TONE drone service instruments have high data rates, and all data cannot be transferred from the drone to the base station at Troll Research Station in real time, nor can the data transferred post flight from the drone to the server at Troll be transferred to Norway over the satellite links. Using Starlink, data from the drone will be processed through onboard edge computing and converted into datasets that can be transferred in near-real time to the base station and to scientists elsewhere in the world. This would allow effective quality assurance and make it possible to adjust flight operations in close collaboration with the scientific teams to maximize the scientific value of each mission.

As seen in the data flow chart in Fig. 4 all data collected by the drone are saved in the onboard computers and storage system. A chained database stores all the metadata and links to image- and radar data. This ensures proper coupling between metadata and instrument data allowing for correct timestamping and positioning of the data and the possibility to pull data based on metadata. The chaining of the databases between the drone, the Troll data servers and the data portal allow the flow of data based on bandwidth. Data will be stored at the Troll data servers during the deployment, and data will be carried back on disks at the end of the deployment. When these are verified transferred to the data centre the data can be removed from the Troll data servers. During deployment, data will be transferred after each flight. The instruments and sensor systems will be

taken off the aircraft at the end of the season and shipped back for post calibration and maintenance.

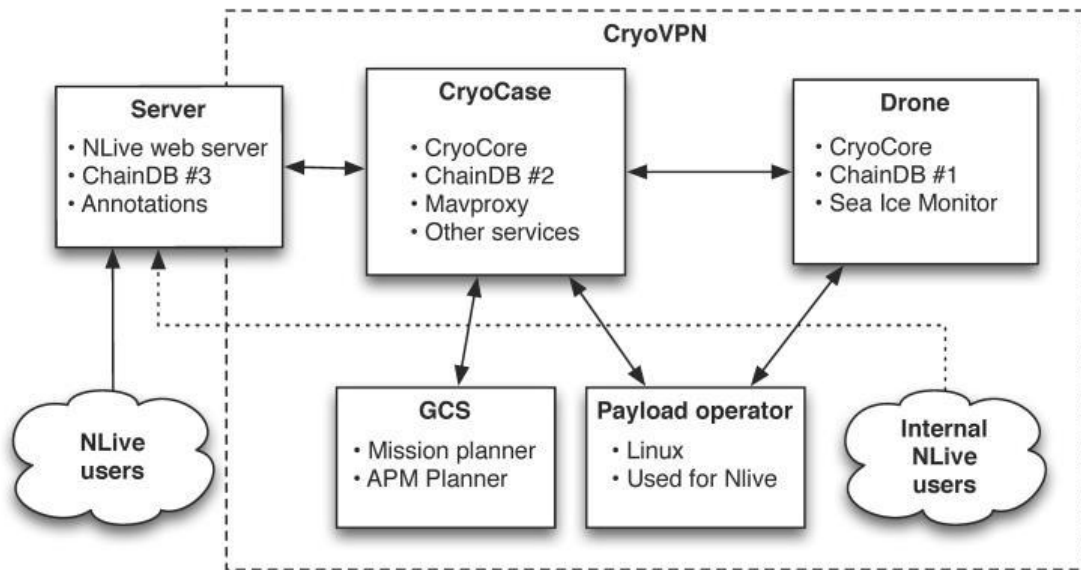


Fig. 4. Data flow chart for the TONe drone service capability, showing how drone platforms, ground control systems, payload operators, servers, and users are connected through CryoVPN for data acquisition, processing, storage, and live data access.

Biennial deployments supporting multiple projects will lower the costs for each individual project and reduce operational risk by relying on professional drone operators with experience in polar environments. NORCE together with NPI are working to set up a financial plan that will enable predictability to the users while keeping limited financial risk. This implies there will be a threshold of planned activities that need to be filled to decide for deployment. In 2025 there were two workshops developing future activities with the TONe drone service, one physical in Tromsø with the SFF IC3 project in the spring and one open national digital workshop in the autumn.



Left: TONe-RPAS under production in Southampton. The VHF radar antennas can be seen under the wings. Right: Radar hardware installation in the fuselage. Photos: Andreas Tøllefsen, NORCE.

British Antarctic Survey (BAS) are also using Windracers drones in the operations out of the Rothera Research Station in Antarctica. They had the first deployment in the austral summer season of 2023-

24, and they are planning new operations. The plan is to collaborate with BAS on instrument- and product development, but it is also possible to conduct coordinated flight campaigns in the future. The University of Alaska Fairbanks has also acquired Windracer Ultra 2 drones. NORCE has a long-standing collaboration with the Alaska-team and will explore future possibilities, similar to those with BAS.

The infrastructure is still under development, so no scientific results or data are yet published.

3.9 Data Management System

The TONe data management system (DMS) is a distributed data storage and publication system with an online data portal for unified access to all TONe data. The DMS comprises local data and application servers at Troll Research Station, permanent data storage and management at the partner data centres in Norway, metadata management by NorDataNet – a national research infrastructure operated by the Norwegian Meteorological Institute, and the new data portal that will be hosted by NPI.

The local data storage and application servers at Troll Research Station are operational as of 2025. Work continues in 2026 to establish individual backup solutions for the observatories offloading data at Troll. Metadata delivery to NorDataNet has been implemented and tested for NPI, while implementation for the other TONe data centres will be done in 2026.

The TONe data search facility, hosted by NPDC (the NPI data centre) and harvesting metadata through NorDataNet, was developed in 2024, with the launch awaiting implementation of the TONe web portal and completion of the metadata pipelines from the external data centres hosting TONe data. A dedicated developer position has been opened at NPI, and development of the web portal with integrated data search and data presentation, will commence in April 2026. The data portal is expected to be operational by the end of the year.

The data management plan for TONe will be fully developed by Q3/2026, based on the principles outlined in the Research Council of Norway's Policy for Open Access to Research Data and the SCAR Data Policy.

4. Outreach and Communication

Effective communication is a core component of the TONe project and follows the framework set out in the project's communication strategy. A key priority for TONe's management is to encourage both national and international researchers to make active use of TONe's data, observatories, and services. At the same time, TONe places strong emphasis on communicating how the Norwegian research community contributes to global understanding of Antarctica, including through public-facing outreach activities.

Information on TONe's observatories, the drone service, and the developing data infrastructure is available on the TONe website (<https://www.npolar.no/en/tone/>). NPI is currently recruiting a web developer who will establish the new TONe web portal, which will become the main access point for researchers seeking to use any part of the TONe infrastructure. This portal will provide consolidated information, data access, user guidance, and updates on ongoing developments.

Strong collaboration and clear communication across the consortium are also key to the success of TONe. The TONe partner group meets digitally each month, maintaining regular dialogue and coordination. The fourth annual in-person partner meeting was held in Tromsø, Norway, in June 2025.

A summary of TONe's communication and outreach activities over the past year is presented below.

4.1 TONe Communication and Outreach Activities Year 4

Information about TONe, at overall project level and through individual observatories, has been widely communicated over the past year, and TONe including its components has been presented at scientific conferences and workshops:

- Poster with first data from TONe-ICO, ESR, WSU and NPI at AMS Polar Met (18th Conference on Polar Meteorology and Oceanography), Denver, Colorado (USA), May 2025
- Invited talk *Ionospheric plasma irregularities, their current understanding, models, and related space weather effects*, W. Miloch and the 4DSpace team at the 11th International Conference, Frontiers in Plasma Physics and Technology, Dubrovnik, Croatia, May 2025
- Presentation *Troll observasjonsnettverk (TONe): Status TONe og koordinert bruk av TONe-dronetjeneste*, C. A. Pedersen, R. Storvold, and the rest of the TONe Team, Online Antarktismiseminar, May 2025
- Presentation *Spatial variability of melt beneath a sub-glacial channel*, E. Darelus et al., FRISP Workshop, <https://frisip.w.uib.no/2024/10/21/frisp-16-18-june-2025-in-rovaniemi-finland/>, Rovaniemi, June 2025
- Presentation *Observing asymptotic suppression of basal melting for increasing ocean forcing*, T. Hattermann et al., FRISP workshop, <https://frisip.w.uib.no/2024/10/21/frisp-16-18-june-2025-in-rovaniemi-finland/>, Rovaniemi, June 2025
- Presentation *Turbulence observations beneath the Fimbul Ice Shelf*, Zheng et al., FRISP workshop, <https://frisip.w.uib.no/2024/10/21/frisp-16-18-june-2025-in-rovaniemi-finland/>, Rovaniemi, June 2025
- Poster *TONe: Plans and Status of the Seismic and Infrasound Arrays*, Oye et al., 56th Nordic Seismology Seminar, Copenhagen, Denmark, June 2025
- UN Ocean Conference side event - Breakfast and conversation aboard the tall ship Statsraad Lehmkuhl, *New observation platforms in the Southern Ocean*, Nice, June 2025
- Presentation *Observations of Polar Clouds and Boundary Layer Processes from the Integrated Cloud Observatory at Troll Station, Antarctica*, M. Town et al, Busan IAMAS-IACS-IAPSO Joint Assembly (BACO-25), Busan, Republic of Korea, July 2025
- Presentation *Ionospheric Plasma Irregularities in the Polar Regions*, W. Miloch et al., URSI Asia-Pacific Radio Science Conference 2025, Sydney, Australia, August 2025
- Presentation *Ionospheric plasma irregularities, their current understanding, models, and related space weather effects*, W. Miloch et al., Asia Oceania Geosciences Society - AOGS Annual Meeting, Singapore, August 2025
- Presentation *Cryoseismology studies for monitoring surface environment in polar regions: A decade progress around the Dronning Maud Land, East Antarctica*, M. Kanao, Y. Hiramatsu, T. Murayama, J. Schweitzer, IAGA / IASPEI Joint Scientific Assembly, Lisbon, Portugal, September 2025

- Poster *Plans and Status for the new Seismic and Infrasound Arrays in Dronning Maud Land, Antarctica*, Schweitzer et al., IAGA / IASPEI Joint Scientific Assembly, Lisbon, Portugal, September 2025
- Presentation *Turbulence observations beneath the Fimbul Ice Shelf, through a hot-water-drilled borehole*, Zheng et al., WAIS, <https://waisworkshop.org/>, Coupeville, Washington, USA, September 2025
- Invited talk *In-situ and remote studies of the polar ionosphere*, W. Miloch, 8th International Symposium on Arctic Research, Tokyo, Japan, October 2025
- Presentation for the Polar Pandora Group on TONe-ACO, A. M. Fjæraa, 3rd PGN workshop, Seoul, Republic of Korea, November 2025
- Invited talk, *Ionospheric irregularities and their influence on radio signals for different solar conditions*, Kotova et al, COSPAR Symposium 2025, Nikosia, Cyprus, November 2025
- Presentation *Ionospheric plasma irregularities in relation to auroral activity in the polar regions*, W. Miloch et al., COSPAR Symposium 2025, Nikosia, Cyprus, November 2025
- Poster *Hydrodynamic Regimes in Kong Håkon VII Hav: Shelf Break Dynamics and Water Mass Transformation in the Divergence Zone of the Eastern Weddell Gyre*, T. Hattermann et al., AGU SOM, <https://www.agu.org/ocean-sciences-meeting>, Glasgow, Scotland, February 2026

In addition, popular science updates on TONe have been published on the Internet and in the media:

- Popular science updates on TONe-ICO were published as news stories on npolar.no and forskning.no, March 2025.
- Blog post from UiO fieldwork at Troll in SCAR Newsletter and social media (Facebook, Bluesky), by W. J. Miloch and J. B. Carlsen.

To communicate our initiative to stakeholders is also part of TONe strategy; among others the TONe drone service was presented to a Norwegian Arctic Parliamentary Delegation in January 2026 and for a delegation from British Antarctic Survey in May 2025.

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5.1 Publications

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Zhou, S., Dutrieux, P., Giulivi, C., Meijers, A., Lee, W. S., Kim, T.-W., Hattermann, T., and Janout, M.: The OCEAN ICE hydrography profiles compilation and climatology, *Earth Syst. Sci. Data Discuss.* [preprint], <https://doi.org/10.5194/essd-2025-727>, in review, 2026.

5.3 Datasets

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Aasen, A. T., Hattermann, T., Moreau, S., Hus, J., & Foss, Ø. (2025). CTD profiles from the TrollTransect2023 cruise to the Kong Håkon VII Hav, Antarctica [Dataset]. Norwegian Polar Institute. <https://doi.org/10.21334/NPOLAR.2025.D5258978>

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