4.8 Glaciology@NM – Quasi-Long-Term Observatory

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Outline

This project provides long-term time series of glaciological observables at *Neumayer Station III* and its hinterland. In consists of three sub-projects, which will be described in the following order in chapters Objectives and Fieldwork:

The sub-project “MIMO-EIS (Monitoring melt where Ice Meets Ocean – Continuous observation of ice-shelf basal melt on Ekström Ice Shelf, Antarctica)” monitors the temporal variation of the basal melt in the centre of the Ekströmisen on sub-daily times scales. In addition, it investigates spatial variations of annually averaged basal melt rates.

In the sub-project “NM surface mass balance”, surface accumulation and surface layer density were regularly observed at the two stake farms Pegelfeld Süd and Pegelfeld Spuso as part of the airchemistry observatory or the *Neumayer Station III*. Results are described in Chapter 4.2 Part II of this volume.

As part of the conventional density observations, the sub-project “GNSS–RR (Global Navigation Satellite System – Reflecto/Refractometry)” aims at developing a methodology deriving automated and continuous specific surface mass balance time series for fast moving parts of ice sheets and shelves (>10m/a).

The sub-project “Kottaspegel” investigates the spatio-temporal variation of the snow accumulation along the traverse route between *Neumayer Station III* and Kottas camp, if possible, also to *Kohnen Station*, as done in 2023/24. Snow accumulation is determined from reading of snow height at bamboo stakes in annual to bi-annual intervals, which is relevant to provide ground-truth measurement for satellite and regional climate modelling approaches.

Objectives

Antarctic mass balance is mainly controlled at the surface and the edges, where the interaction of ice shelves with the ocean water underneath is one of the key processes for the future development. Especially for the Antarctic ice sheet, mass loss through ice shelves is the dominant component of loss in the mass budget. The quasi-longterm observatory Glaciology@NM provides continuous monitoring system of surface mass balance and basal melting of the Ekström Ice Shelf (EIS) as well as its inflowing part of the grounded ice sheet.

Regarding the ice–ocean interaction of EIS we determine the interannual and seasonal variability of basal melt rates to improve our understanding of the processes of ice-ocean interaction along the DML coast. To this end, an Autonomous phase-sensitive Radio-Echo Sounding (ApRES) was deployed in the center of EIS in 2020, at the flank of the main bathymetric trough, as part of the sub-project MIMO-EIS. Data is retrieved annually and is used as validating constraints in numerical ocean-modelling runs as well as satellite-based analyses. The project will extend a chain of already available and ongoing ApRES observations on other ice shelves in the Dronning Maud Land Region, like Roi Baudouin and Fimbul, and thus increase our

observational and potentially monitoring capabilities in this region. The continuous system has been extended with discrete repeat measurements as well as a second pilot system next to the grounding line of EIS.

The second component concerns the surface mass balance. Apart from weekly and bi-weekly snow height readings at several stake farms since 1990, providing a temporally resolved variation on snow accumulation, a continuous line with a distance of 500 m or 1000 m has been operated on an annual to tri-annual basis along the traverse route to the Kottas mountains and further to *Kohnen Station* (Kottaspegel). Those readings provide the spatial variation of multi-annual surface accumulation.

The third component concerns the determination of density, required to convert snow accumulation to mass. While conventional measurements in snow pits are carried out at *Neumayer Station III* as well as along the Kottaspegel traverse route, the implementation of a GNSS-RR near *Neumayer Station III* enables us to obtain a continuous time series of density. After a successful initial two-year pilot study (Steiner et al., 2023), the system is now in operational use as part of the Neumayer Meteorological Observatory (chapter 4.1 of this volume).

All components together provide an essential understanding of the processes determining the basal and surface mass balance around EIS and towards the polar plateau. These provide unique ground-truthing observations to calibrate, e.g., regional climate models, as well as observations derived from satellite remote sensing. At the same time the time series capture the changing climate conditions in this part of Antarctica, as continuous observations serve as an early warning system (compare Part II of chapter 4.2 of this volume).

Fieldwork

After arrival at *Neumayer Station III* on 8 November 2023 the traverse equipment for Kottaspegel and maintenance of MIMO-EIS was prepared.

MIMO-EIS

The autonomous pRES (ApRES) system at the site MIMO-EIS-8 was dug out by a team of four people (Hameed Moqadam and Fyntan Shaw, assisted by Nora Schoeder, Felix Strobel) over five hours and dismounted on 16 November 2023 and data downloaded. The station was raised to the new level of the surface redeployed by a team of four persons (Hameed Moqadam and Fyntan Shaw, assisted by Holger Zahlauer and Matthias Brehm) and put in operation in the autonomous (ApRES) mode on 21 November 2023 with an antenna separation of 10 m. The system records measurements every hour with data storage in joint files about every 4 h (5 MB limit for file size). Additional pRES re-measurements with different antennae polarizations were performed on 17 November 2023 and 21 November 2023 at seven locations: MIMO-EIS-4 to MIMO-EIS-8 (Fig. 4.8.1), MIMO-EIS-A (formerly also known as site6), MIMO-EIS-B (formerly also known as site7) and at a new position MIMO-EIS-C, which was initialized in November 2021 (Tab. 4.8.1). All polarimetric pRES sites, initially marked with two bamboo poles, were re-marked with two new poles, as the exact positioning of the antennas is key for obtaining useful data (Fig. 4.8.2).

Measurements at all stations were conducted using snowmobiles as vehicles. At the site MIMO-EIS-C the battery short circuited, damaging the interior cables and packaging, which needed to be replaced. The battery remained functional, but the clean-up and repairs delayed work by a couple days.

The ApRES system at the site MIMO-EIS-D (referred to as cApRES_GL in Drews et al., 2022) was serviced as part of the traverse to *Kohnen Station*. It was dug out by a team of four persons (Hameed Moqadam and Fyntan Shaw, assisted by Keno Wind and Bernd Buehler) over five hours and dismounted on 24 November 2023, during the Kottaspegel traverse, and data downloaded. The station was raised to the new level of the surface redeployed by the same team of four persons and put in operation in the autonomous mode on 24 November 2023 with an antenna separation of 10 m. A few days later it was noticed that the initial evaluation of the performance of the station was wrong and that the station was not in operation. It was therefore redeployed by the traverse from *Kohnen Station* on their way back to *Neumayer Station III*.

After repair the system was again deployed on 22 April 2024 at the new site MIMO-EIS-E (position in Tab. 4.8.2). Transfer to and from the site was accomplished using two Hilux vehicle with four people from the overwintering team and took 10 hours in total (transit outbound 3h, deployment 3h, transit inbound 4h). The system has been working since then and regularly sends state of health messages.

Kottaspegel

First density measurements were conducted in the vicinity of *Neumayer Station III*. After a delay caused by bad weather for about a week the measurements along the traverse commenced on 23 November, reaching *Kohnen Station* on 3 December. Measurements along the traverse were performed with the standard setup, i.e., a two-person team on a snowmachine with two Nansen sleds accompanying the traverse train. On some days assistance was provided by the logistic team, Aurelia Hölzer and Matthias Brehm, allowing half-day two-person shifts, with teams swapping over after the lunch break. Aurelia and Matthias helped on 26 and 27November and 1 and 2 December. Aurelia also briefly helped on 30 November. In total, 1,435 stakes readings were obtained at 1,124 locations and 396 new stakes newly deployed. The first South of and including the Kottas mountains, poles were renewed every 1 km, whereas on the plateau (after the Kottas mountains up to *Kohnen Station*) poles were renewed only every 3 km.

At the end of each day, a snow core was drilled to obtain snow density (Tab. 4.8.2). The snow core (diameter: 9 cm, Kovacs ice drill) was weighed with a spring scale. Together with the additionally measured core hole depth, the snow and/or ice density is determined. Snow density is calculated from sample volume and in-field weight measurement using a portable electronic scale.

GNSS-RR

No particular tasks for the sub-project GNSS-RR were carried out in the 2023/24 field season. Any maintenance of the snow height measurement mast (SHM), as part of the meteorological are described in chapter 4.1 of this volume.

Tab. 4.8.1: Position of pRES measurements on Ekströmisen and preliminary values for the long-term average basal melt rates ab. Station MIMO-EIS-D was initialized by the project ReMeltRadar in January 2022 (Drews et al., 2022) and damaged during maintenance. It was thus discontinued and deployed at a new position on 22 April 2024, the new site MIMO-EIS-E.

Station	Latitude 2022/23 °	Longitude 2022/23 °	Latitude 2023/24 °	Longitude 2023/24 °	ab m/a	Comments
MIMO-EIS-4	-70.64662	-8.20719	-70.64553	-8.20752	2.63	
MIMO-EIS-5	-70.74422	-8.82184	-70.74210	-8.82374	0.33	
MIMO-EIS-6	-70.80771	-8.62620	-70.80622	-8.62781	0.44	
MIMO-EIS-7	-70.83056	-8.72028	-70.82906	-8.72208	0.44	
MIMO-EIS-8	-70.82139	-8.74583	-70.82006	-8.74226	0.40	
MIMO-EIS-A	-70.76293	-8.87127	-70.76142	-8.87338	0.40	
MIMO-EIS-B	-70.87500	-8.88083	-70.87354	-8.88296	0.57	
MIMO-EIS-C	-70.68314	-8.45211	-70.68173	-8.45302	0.43	
MIMO-EIS-D	-71.6146	-8.4311	-71.6135	-8.4296		Failed after maintenance – discontinued
MIMO-EIS-E	n.a.	n.a.	-71.4264	-8.3302		New site, initialized 22 April 2024 (traverse point KP180)

Tab. 4.8.2: Location of density measurements performed with the snow corer

Date	CoreID	Lat °	Lon °	mean density kg/m³	max. depth cm
22.11.2023		-70.66245	-8.32215	399.80	100
23.11.2023		-71.26076439	-8.40004138	409.98	50
24.11.2023		-71.61093006	-8.4358887	396.85	77
25.11.2023		-72.13255439	-8.83585128	305.58	100
26.11.2023		-73.27866711	-9.69720645	331.04	100
27.11.2023		-74.20532982	-9.75260101	321.34	105
29.11.2023		-74.50067003	-9.21964576	353.83	95
30.11.2023		-74.87010898	-8.30308722	351.15	95
01.12.2023		-75.00219417	-5.25978335	341.76	95
02.12.2023		-75.01531066	-2.1626343	391.26	96
03.12.2023		-75.00833418	-0.02421095	380.59	92

Preliminary (expected) results

MIMO-EIS

Preliminary analysis of the repeated pRES measurement, matching pairs measured at different seasons, and taking into account strain thinning and firn compaction, yield average basal melt rates (Table 4.8.1). Please note that the individual results at each site are a result of multiple measurements at different polarisations. The order of magnitude of tentative results

as published in Eisen et al. (2020) can be confirmed by our preliminary analysis of the re-measurements in previous season.

Since its deployment, the ApRES system operating in unattended mode at MIMO-EIS-8 has been sending state-of-health messages regularly via an Iridium link in its Eulerian frame of reference. Analysis of the continuous ApRES data is ongoing. First results indicate that the temporal variability is very similar in all years 2020 to 2023. It is strongest in month August to November, with melt rate peaks equivalent to up to 2.5 m/a and periodicity of roughly two weeks. Minimum melt rates are always higher than ~0.5 m/a September through November. From December to August, maximum melt rates are below an equivalent of 1 m/a and partly even no melting occurred or was below the detection limit, according to our analysis. A peer-reviewed manuscript is currently in preparation to publish these findings (Zeising et al., in prep.).

As the objectives of MIMO-EIS are strongly overlapping with the those of the project ReMeltRadar, field operations and expertise were joined as much as possible. For instance, the polarimetric ApRES near the grounding line of Ekströmisen as part of ReMeltRadar (Drews et al., 2022) continued the operation as a longer-term station as site MIMO-EIS-D, which was now relocated to MIMO-EIS-E. The added value of such joint operation was already evident during the season: first time series analysis indicates coherence of stronger melting events during winter 2022.

Given our experience from now the several winters of ApRES measurements on Ekströmisen, the operation of the system with a 105 Ah Pb battery, securely stored in a Zarges box, and two 16 GB SD cards (one being the mirror of the other) are sufficient to allow more than one year of unattended operation at 1 h measurement intervals.

Kottaspegel

The compilation and analysis of data regarding actual snow accumulation at each of the measured points has not been completed as of the writing of this report. Table 4.8.2 summarizes the calculated snow core densities along the traverse.

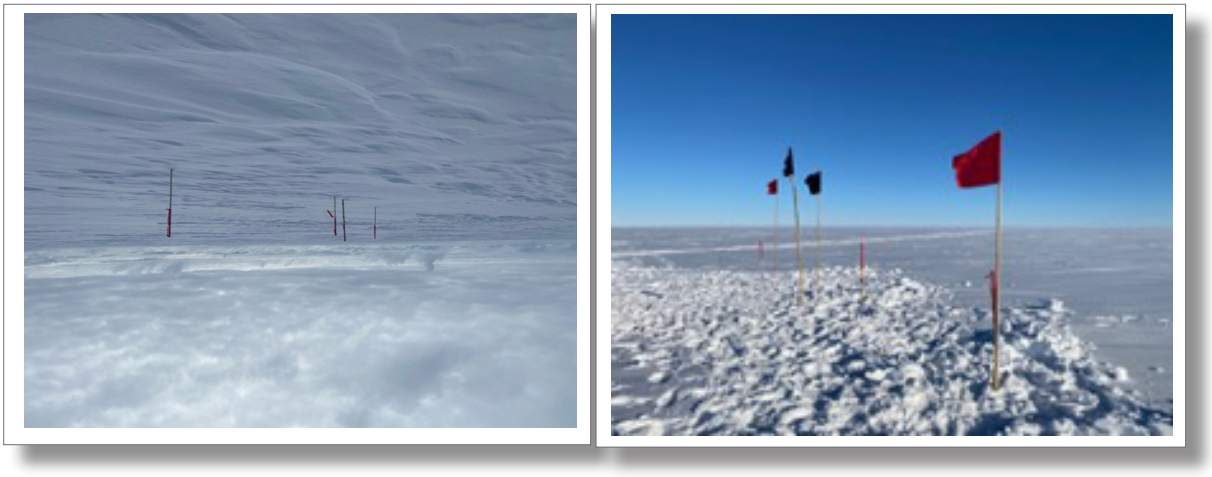

Fig. 4.8.1: Left (a): Photograph of MIMO-EIS-8 before maintenance on 16 November 2023. Right (b): photograph of station MIMO-EIS-8 after deployment on 21 November 2023

Fig. 4.8.2: Accumulation stake measurements: Left (a): Setup of snowmachine train. Right (b): measuring the height of a bamboo stake higher than 2 m with an extension and a wireline device, which automatically records GPS positions.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied. Metadata for MIMO-EIS are already available in registry.o2a-data.de (ID 8403, item: Phase-sensitive Radio Echo Sounding System, event labels NMEIS?_23). Previous results from MIMO-EIS are available in at https://doi.org/10.1594/PANGAEA.962778.

Metadata for density measurement performed during the Kottaspegel traverse and at *Neumayer Station III* for the 2023/24 season are already available in registry.o2a-data.de under IDs 8363 (AWI single tube snowpack sampler) and 5065 (Ice Corer Kovacs Mark II). The already quality checked density data is available in at https://doi.org/10.1594/PANGAEA.963323 .

For the GNSS-RR sub-project, the Python code for preprocessing, processing, analyzing, and visualizing the GNSS-RR data is provided on GitHub https://github.com/lasteine/GNSS_RR.git and archived in Zenodo under https://doi.org/10.5281/zenodo.10135417. Collected and analyzed multifrequency and multisystem GNSS data have been made publicly available at PANGAEA (https://doi.org/10.1594/PANGAEA.958973, Steiner et al., 2023).

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

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In all publications based on this expedition, the **Grant No. AWI_ANT_8** will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung. (2016a). *Neumayer III* and *Kohnen Station* in Antarctica operated by the Alfred Wegener Institute. Journal of large-scale research facilities, 2, A85. http://dx.doi.org/10.17815/jlsrf-2-152

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Drews R et al. (2022) Remelt Radar – Determining Ice Shelf Rheology and Ocean Induced Melting across Timescales. In: Wesche C and Regnery J (eds) Expeditions to Antarctica: ANT-Land 2021/22 Neumayer Station III, Kohnen Station, Flight Operations and Field Campaigns / H. Bornemann and S. Amir Sawadkuhi (editors) , Berichte zur Polar- und Meeresforschung = Reports on polar and marine research, Bremerhaven, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, 127 p. https://doi.org/10.57738/bzpm_0767_2022

Eisen O, Zeising O, Steinhage D, Berger S, Hattermann T, Pattyn F, Trumpik N, Wehner I, Korger E, and Stakemann J (2020) MIMO-EIS – Monitoring melt where Ice Meets Ocean – Continuous observation of ice-shelf basal melt on Ekström Ice Shelf, Antarctica. In: Fromm T, Oberdieck C, Matz T, and Wesche, C. (eds) Expeditions to Antarctica: ANT-Land 2019/20 Neumayer Station III, Kohnen Station, Flight Operations and Field Campaigns. Berichte zur Polar- und Meeresforschung = Reports on polar and marine research, Bremerhaven, Alfred Wegener Institute for Polar and Marine Research 745, 118 p. https://doi.org/10.2312/BzPM_0745_2020

Steiner L, Schmithüsen H, Wickert J, and Eisen O (2023) Combined GNSS reflectometry–refractometry for automated and continuous *in situ* surface mass balance estimation on an Antarctic ice shelf The Cryosphere 17:4903–4916. https://doi.org/10.5194/tc-17-4903-2023