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# Expeditions to Antarctica: ANT-Land 2020/21 NEUMAYER STATION III, Kohnen Station, Flight Operations and Field Campaigns

Edited by

Tanja Fromm, Constance Oberdieck, Tim Heitland
and Christine Wesche
with contributions of the participants

HELMHOLTZ

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*Titel: Die Geophysiker:innen bestimmen geographisch Nord durch Sternenvermessung, um den Kreiselkompass für das geomagnetische Observatorium zu eichen (Foto: Timo Dornhöfer).*

*Cover: The geophysicists determine geographical north by star observations in order to calibrate the gyro compass for the geomagnetic observatory (Photo: Timo Dornhöfer).*

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# ANT-Land 2020/21

## 19 January 2021 – 19 March 2021

## Neumayer Station III, Kohnen Station, Flight Operations and Field Campaigns

**Field Operation Managers**
**Tim Heitland and Christine Wesche**

**Coordinator**
**Tanja Fromm**

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# 1. ÜBERBLICK UND VERLAUF

Tanja Fromm AWI

Seit Beginn des Jahres 2020 hält die CoV-2 Pandemie die Welt in Atem und so ist auch die Sommersaison 2020/21 von der Pandemie geprägt. Um eine Ausbreitung in die Antarktis zu vermeiden und die Station im Süd-Winter 2021 sicher ohne CoV-2 betreiben zu können, wurden Versorgung, Wartung und wissenschaftliche Nutzung der Station komplett mit *Polarstern* durchgeführt und das Arbeitsprogramm auf das Nötigste reduziert. Dies bedeutete wie bei fast allen anderen Nationen auch, dass viele technische und wissenschaftliche Projekte in die nächste Saison verschoben wurden. Aufgrund einer verlängerten Werftzeit der *Polarstern* war die Saison im Vergleich zu anderen Jahren mit zwei Monaten sehr kurz und liegt im Zeitraum von Januar bis März sehr spät. Das bedeutete erschwerte Wetterbedingungen für die Freilandarbeiten, da Tage mit warmem und mildem Wetter, das für Außenarbeiten geeignet ist, deutlich knapper sind als zu anderen Jahreszeiten (Details in Kapitel 2, Weather conditions). Da wissenschaftliche und logistische Aktivitäten gleichzeitig stattfinden und sich gegenseitig beeinflussen, ist eine sorgfältige Abstimmung und gegenseitige Rücksichtnahme von Wissenschaftlerinnen und Wissenschaftlern, Technikern und Logistikern hinsichtlich der verfügbaren Ressourcen erforderlich. In diesem Expeditionsbericht dokumentieren wir die Aktivitäten des AWI und seiner Kooperationspartner in der Antarktis. Die wichtigsten logistischen Meilensteine und Arbeitsvorgänge werden in Kapitel 3 ausführlich beschrieben, die wissenschaftlichen Projekte in Kapitel 4.

Während der verkürzten Sommersaison ANT-Land 2020/21 gab es 17 wissenschaftliche Projekte an *Neumayer-Station III*. Feldkampagnen außerhalb der Station wurden in diesem Jahr CoV-2-bedingt ausgesetzt. Wann immer möglich, wurden verschiedene wissenschaftliche Projekte kombiniert und gerade in dieser Saison, mit stark eingeschränktem Personal vor Ort, von anderen übernommen. Diese Minimal-Saison bestand aus der Wartung der Observatorien, Langzeit-Projekten, Einarbeitung der neuen Überwinternden und dem Stationsbetrieb.

In den Kapiteln 4.1 bis 4.3 wird die jährliche Wartung der Observatorien beschrieben. Seit einem Jahr ist das Observatorium für Luftchemie durch das Projekt VACCINE erweitert, das auch in diesem Jahr weiter Daten aufzeichnet (Kapitel 4.10). Die Projekte MIMO-EIS und MICA-S sind an das geophysikalische Observatorium angegliedert und werden von diesen Überwinternden mit betreut (4.13 und 4.15). In den Kapiteln 4.4 bis 4.17 geht es um Langzeit-Projekte aus unterschiedlichen Forschungszweigen, z.B. Meereis (AFIN), Tierwelt (PALAOA, SPOT) und medizinische Studien (Neuromayer, CHOICE, P.S.I, HF EDEN). Das wissenschaftliche Gewächshaus EDEN ISS wird in diesem Jahr wieder durch einen eigenen Überwinternden betrieben und entlastet so das restliche Überwinterungsteam (Kapitel 4.11).

# SUMMARY AND ITINERARY

Since the beginning of 2020 the CoV-2 pandemic has kept the world in suspense and the 2020/21 summer season is shaped by the pandemic too. In order to avoid spreading into Antarctica and to be able to operate the station safely without CoV-2 in the southern winter of 2021, the supply, maintenance and scientific use of the station was carried out entirely with *Polarstern* and the work programme was reduced to the bare minimum. This means that, as with almost all other nations, many technical and scientific projects have been postponed until the next season. Due to the extended shipyard period of *Polarstern*, the season is very short with two months compared to other years and very late in the period from January to March. This means more difficult weather conditions for field work, as days with warm and mild weather suitable for outdoor work are much rarer than at other times of the year (details in Chapter 2, Weather conditions). Since scientific and logistical activities take place simultaneously and influence each another, careful coordination and mutual consideration of scientists, technicians and logistic specialists is required with regard to the available resources. In this expedition report we document the activities of the AWI and its cooperation partners in Antarctica. The most important logistical milestones and work processes are described in detail in Chapter 3, the scientific projects report in Chapter 4.

During the shortened ANT-Land 2020/21 summer season there were 17 scientific projects at *Neumayer Station III*. This year field campaigns outside the station are suspended due to CoV-2. Whenever possible, various scientific projects are combined and taken on by others, especially during this season, with severely limited staff on site. This minimal season consists of the observatory maintenance, long-term projects, winterers handover and station operations. Annual observatory maintenance is described in Chapters 4.1 to 4.3.

The air chemistry observatory was expanded last year by the VACCINE project, which continues to record data this year (Chapter 4.10). The MIMO-EIS and MICA-S projects are attached to the geophysical observatory and are supervised by these winterers (4.13 and 4.15). Chapters 4.4 to 4.17 deal with long-term projects from different research areas, e.g. sea ice (AFIN), wildlife (PALAOA, SPOT) and medical studies (Neuromayer, CHOICE, P.S.I, HF EDEN). In the coming year the EDEN ISS scientific greenhouse will be operated again by its own winterer, thus relieving the rest of the wintering team (Chapter 4.11).

# 2. WEATHER CONDITIONS DURING ANT-LAND 2020/21 AT NEUMAYER STATION III

Holger Schmithüsen AWI

The overall weather situation at *Neumayer Station III* during ANT-Land 2020/21 was largely normal in terms of the basic meteorological parameters listed in Table 2.1. The first half of the season until 20 February was rather calm with mostly good working conditions (Fig. 2.1). The second half was dominated by frequent low pressure systems that caused strong winds, frequent precipitation events and almost continuous drifts/snow drifts. In terms of temperature, athmospheric pressure, wind speed, and wihte-out frequency, the monthly averages for the months January 2021 through March 2021 were within two standard deviations of the long-term averages, with one exception.

The average 2 m air temperature in March 2021 reached an all-time high of –8.3° C, slightly warmer than the previous March record of –8.5° C set in 1988. The exceptionally high temperature was associated with a strong advection of moist air, that dominated the weather in March 2021. This is also reflected in the stronger than normal winds (11.3 m/s in 2021 compared to 9.1 m/s long-term average) and the increased white-out frequency (25 % compared to 17 % long-term average).

In contrast to March temperatures, January and February 2021 were colder than normal. Average wind speed recorded in ANT-Land in 2020/21 was above average during all three months. White-out frequency was normal in January and February, while it was well above average in March.

In the first half of ANT-Land 2020/21 there was no relevant event of persistent snow accumulation (Fig. 2.1). On the contrary, there were several such events starting on 20 February. Due to high wind speed there was an increase of snow height of 18 cm from 20 February to 19 March while snow height measurements lack data around 22 February. Compared to earlier years this is well within the expected range (Fig. 2.2).

**Tab. 2.1:** Monthly averages of meteorological parameters at *Neumayer Station III*. In parentheses are the long-term mean values for the time since 1981 (1992 for white-out), together with the standard deviation. All values are calculated from the 3 hourly synoptic observations. Note that at 3 UTC white-out is not observed, which biases the frequency of occurrence to too low values.

| | **Temperature** | **Pressure** | **Wind speed** | **White-out** |
|---|---|---|---|---|
| January 2021 | -6.2° C<br>(-4.1 ± 1.0)° C | 983.8 hPa<br>(989.3 ± 4.0) hPa | 7.5 m/s<br>(6.6 ± 1.2) m/s | 13 %<br>(13± 8) % |
| February 2021 | -10.6° C<br>(-8.1 ± 1.5)° C | 982.4 hPa<br>(987.0 ± 3.7) hPa | 9.5 m/s<br>(7.6 ± 1.5) m/s | 15 %<br>(15±9) % |
| March 2021 | -8.3° C<br>(-13.0 ± 2.1)° C | 985.1 hPa<br>(985.4 +/- 3.9) hPa | 11.3 m/s<br>(9.1 +/- 1.7) m/s | 25 %<br>(17 +/- 9) % |

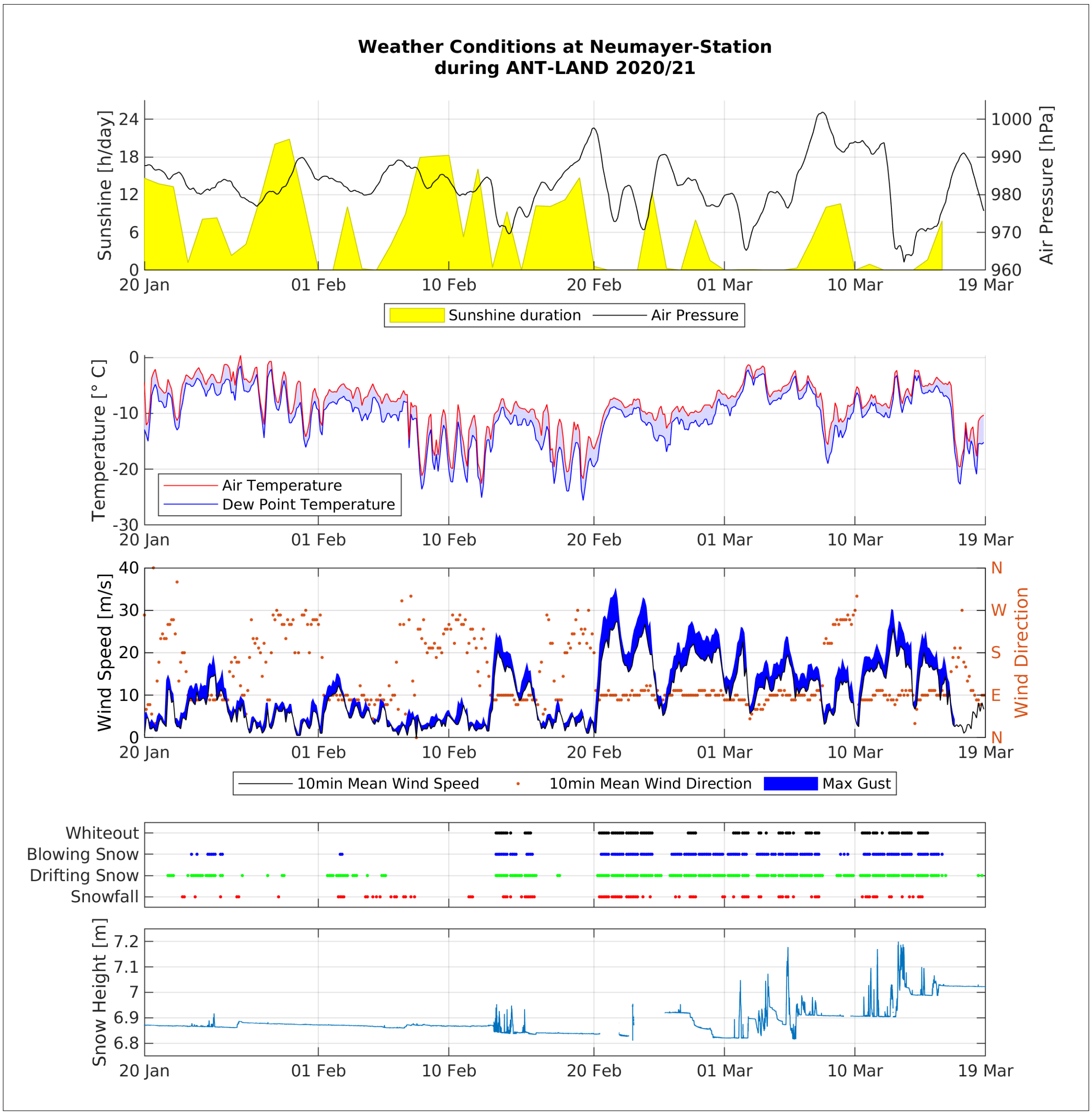

*Fig. 2.1: Weather conditions at Neumayer Station III during ANT-Land 2020/21*

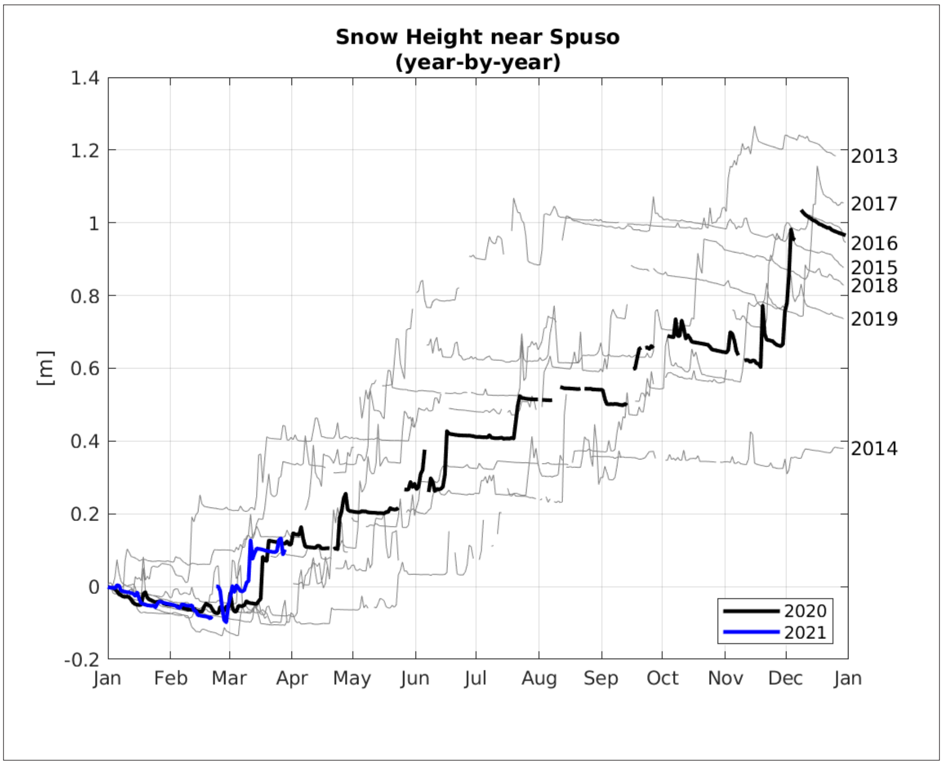

*Fig. 2.2: Snow height measured near Spuso with sensor "Jenoptik SHM30" from 2013 to March 2021; data from ANT-Land 2020/21 are shown in blue, last year in black, earlier years in grey. All data shown are relative to snow height at the beginning of the respective year.*

# 3. STATION OPERATIONS

Tim Heitland AWI

Due to the persisting CoV-2 pandemic, this year's summer seasons logistics needed to be adjusted. In order to prevent in the best possible manner the virus from being introduced to Antarctica, all expedition members as well as the entire crew of *Polarstern* underwent a 9-day hotel quarantine (and two PCR Tests) at Bremerhaven before boarding *Polarstern* for the non-stop passage (PS123) to Atka Bay. Thus, the summer season started significantly later than in the former years and subsequently the amount of time to get the necessary technical and scientific work done was short, the isolation period of the overwintering team prolonged, and the preparation for the cargo operation had to be done by a reduced team.

A storm lasting several days immediately prior to *Polarstern's* arrival in Atka Bay led to a massive snow accumulation and caused even more precarious circumstances and work. Nevertheless, the state of the station and the preparation work that had been done were impressive.

*Polarstern* arrived at Atka Bay on 18 January 2021. With the aforementioned storm pushing the sea against the ice shelf, the preexisting Polynia did close. Due to continuously high wind speed the start of disembarking and cargo operations was put on hold. On 19 January the cargo operation commenced and could be finished as planned without any difficulties on 21 January. On 19 January first evening meeting took place and the new station order was announced and put into effect. *Polarstern* left Atka Bay on 22 January for the Falkland Islands.

The cargo distribution, general organization of goods and stowage followed. The raise of the station started on 26 January. The combined meteorological and geophysical traverse left *Neumayer Station III* on 25 January to Watzmann, AWS Halvfarryggen, Olymp and Sorasen. The party returned on 31 January.

SANAE colleagues visited their summer station by helicopter on 29 January. In accordance with COMNAP protocol, there was no personal contact and the eventual visit of the summer station to introduce the new overwintering team to the use of the E-Base was postponed for two weeks.

At the beginning of February, outside work was difficult due to the stormy weather with compromised contrast and blowing snow. The station construction continued and was finished as planned, on 5 February. The experiment to leave the snow accumulations in the stations surrounding let to enormous northwestern and southwestern hills and subsequently to the need to lift the Radom and made it necessary to put a lot of effort into landscaping. The new overwinterers were continuously trained on the job. SANAP colleagues visited their summer station again on 9 February by helicopter. The station remained closed for another two weeks until 23 February. On 13 February, the next storm reached Atka Bay.

During the second half of February outside work was only possible on 4 out of 14 days due to weather conditions. White-Out was reported on 8 out of 14 days, drifting snow on 12 out of 14 days. Nevertheless 4 panels of the experimental photovoltaic station could be installed on the eastern hull of the station and a lot of landscaping could be done. On 16 January ALCI (Antarctic Logistics Company International) finished the summer season with the last take-off of the Iljuschin 76 from Novo-Airfield. The Basler (BT 67) left the Dronning Maud Land (DML) via the *SANAE IV Station*. On 26 February the last flight departed from the Norwegian *Troll Station*, finishing the flight operations that were planned for this season at DML. On the same day the station was handed over from the 40th to the 41st overwintering team.

The weather stayed stormy in March and, due to this, the work outside stayed challenging and predominantly impossible. Every opportunity was taken to finish the pending projects.

Return cargo was prepared and the shipping papers were sent to *Polarstern* and Bremerhaven. Better weather was predicted for 16 March. According to the original plan *Polarstern* was scheduled to arrive on 20 February, it's departure for the Falkland Islands planned for 22 March.

Due to the weather, cargo operations had to begin on 18 March. All bulk cargo and all but two containers (luggage and waste) were brought on board when increasing ice pressure made it necessary for the ship to leave the ice edge around 16:00 LT.

The further planning had to be adjusted accordingly; the departing expedition members and the content of the luggage container were transferred to *Polarstern* by helicopter. The waste container had to be left behind and will be brought to Germany with next year's return cargo. Incoming freight for *Neumayer Station III* was brought to a kabause by helicopter and stowed there by the crew. It will be retrieved after two weeks of quarantine.

The concentrated, successful and nice summer season 2020/21 ended on 19 March.

The journey home was completed on 3 April after the transfer to the Falkland Islands (arrival on 30 March) and the Flight Mount Pleasant – Munich (departure on 2 April).

## 3.1 Technical operations

As every year the overwintering team had already carried out preparatory work before the first summer guests arrived at the station. Some storage containers from the winter camp on the coast were transported to *Neumayer Station III* to be available for summer operations. The 1,500 m long landing strip made of snow, was reconstructed by the technicians of the overwintering team.

After the technical summer staff arrived, maintenance work was performed on the station. The Summer staff was heavily involved in all ship unloading operations and performed the container stowage work.

Due to the shortened summer season of two months, only the necessary work such as maintenance work on the building and the technical equipment as well as the important technical functional and safety checks of equipment and building were prioritized.

The season was marked by repeated bad weather, which made the outdoor operations difficult, especially at the end of the season when the containers were stowed.

Only one station elevation was made. They started on 25 January and it was completed on 6 February. At the scientific and technical outdoor facilities the Radom (satellite link), the shortwave antenna and the „library in the ice“ were routinely elevated. This was not necessary at the air chemistry observatory and the EDEN greenhouse. The measuring fields of the infrasound array were checked without any technical problem. The exit shafts at the balloon trench were elevated.

In the area of wastewater engineering repair work was carried out on the sewer.

A special labyrinth seal was retrofitted to the hydraulic gates of the balloon filling hall, which were newly installed in the 2019/20 season. In addition, the gate control system was modified.

Various work was performed on the interior and exterior facilities for science.

In addition to other work in the IT area, all active network components were replaced. PCs were replaced at the workplaces. A radio link was established from the station to the air chemistry and magnetic observatory.

In connection with the future refurbishment of the energy supply of the station by using renewable wind and solar energy, the mounting and implementing of a photovoltaics test device with a special data entry function could be placed of the building.

In the vehicle engineering numerous maintenance and repair work on all Pistenbully vehicles, also substantial work on the 300 Polar vehicles, which had been planned, were performed by a Käßbohrer service technician and a technician from RFL as every season. One Pistenbully was sent back to Bremerhaven with *Polarstern* at the end of the season.

Both snow blowers, necessary for the station elevation, were replaced with new ones. Another new snow blower is planned for the *Kohnen Station*.

## 3.2 General flight Operations

All flight movements around *Neumayer Station III* are provided in Table 3.2.1.

**Tab. 3.2.1:** Flight movements at *Neumayer Station III* and Atka Bay during ANT-Land 2020/21

| Date | UTC | Departure Arrival | RWY | Registration | Start | Destination |
|---|---|---|---|---|---|---|
| 12.01.2021 | 11:38 | no landing @NM | – | ZSHND | Sanae | Atka-Bay |
| 12.01.2021 | 12:04 | no landing @NM | – | ZSHND | Atka-Bay | Sanae |
| 18.01.2021 | 18:48 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 18.01.2021 | 18:50 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.01.2021 | 10:38 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.01.2021 | 11:17 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.01.2021 | 12:26 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.01.2021 | 13:19 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.01.2021 | 14:38 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.01.2021 | 15:09 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.01.2021 | 16:02 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.01.2021 | 16:54 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 20.01.2021 | 10:16 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 20.01.2021 | 10.40 | Departure | Helipad | D-HAPS | Neumayer | Forstefjell |
| 20.01.2021 | 11:38 | Arrival | Helipad | D-HAOE | Polarstern | Neumayer |
| 20.01.2021 | 12:31 | Departure | Helipad | D-HAOE | Neumayer | Polarstern |
| 20.01.2021 | 14:16 | Arrival | Helipad | D-HAOE | Polarstern | Neumayer |
| 20.01.2021 | 14:28 | Arrival | Helipad | D-HAPS | Forstefjell | Neumayer |
| 20.01.2021 | 15:03 | Departure | Helipad | D-HAOE | Neumayer | Neumayer |
| 20.01.2021 | 15:19 | Arrival | Helipad | D-HAOE | Neumayer | Neumayer |
| 20.01.2021 | 15:22 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |

| **Date** | **UTC** | **Departure Arrival** | **RWY** | **Registration** | **Start** | **Destination** |
|---|---|---|---|---|---|---|
| 20.01.2021 | 15:56 | Departure | Helipad | D-HAOE | Neumayer | Neumayer |
| 20.01.2021 | 16:13 | Arrival | Helipad | D-HAOE | Neumayer | Neumayer |
| 20.01.2021 | 16:40 | Departure | Helipad | D-HAOE | Neumayer | Polarstern |
| 20.01.2021 | 17:04 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 20.01.2021 | 17:23 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 29.01.2021 | 10:30 | no landing @NM | – | ZSHND | Sanae | E-Base |
| 29.01.2021 | 12:19 | no landing @NM | – | ZSHND | E-Base | Sanae |
| 09.02.2021 | 15:22 | Arrival E-Base<br>no landing @NM | – | ZSHND | Sanae | E-Base |
| 09.02.2021 | 16:06 | Departure E-Base<br>no landing @NM | – | ZSHND | E-Base | Sanae |
| 19.03.2021 | 10:43 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 10:58 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 11:17 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 11:24 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 11:45 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 11:54 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 12:16 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 12:22 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 12:40 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 12:46 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 13:04 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 13:10 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 13:32 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 13:35 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 14:30 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 14:37 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 15:02 | Luggage pickup @NM without landing | Helipad | D-HAPS | Polarstern | Polarstern |
| 19.03.2021 | 15:27 | Luggage pickup @NM without landing | Helipad | D-HAPS | Polarstern | Polarstern |
| 19.03.2021 | 16:34 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 16:54 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |
| 19.03.2021 | 17:20 | Luggage pickup @NM without landing | Helipad | D-HAPS | Polarstern | Polarstern |
| 19.03.2021 | 17:51 | Arrival | Helipad | D-HAPS | Polarstern | Neumayer |
| 19.03.2021 | 17:57 | Departure | Helipad | D-HAPS | Neumayer | Polarstern |

## 3.3 Ship Operations

Two ship calls were performed during the season, both by *Polarstern*, both at the Nordanleger (the northern jetty).

The first ship call took place on 19 January, the cargo operation started immediately and could be finished as planned without any difficulties on 21 January. *Polarstern* left Atka Bay on 22 January for the Falkland Islands.

The second ship call took place on 18 March. All bulk cargo and all but two containers (luggage and waste) were brought on board when the increasing ice pressure made it necessary for the ship to leave the ice edge around 16:00 LT.

# 4. NEUMAYER STATION III

## 4.1 The Air Chemistry Observatory Neumayer

Rolf Weller[1], Linda Martina Ort[1], Julia Loftfield[1], [1]AWI
Silvia Henning[2] (not in field) [2]TROPOS

### Objectives

The atmosphere in Antarctica is the cleanest part of the Earth's troposphere and can be employed as a large clean air laboratory to study natural conditions comparable to atmospheric processes prevailed elsewhere in preindustrial times. Therefore, Antarctica offers an outstanding place to study the background composition and the natural biogeochemical cycling of aerosol. Nowadays, minor anthropogenic emissions arising from fossil fuel combustion during research and tourism activities may be considered as well.

The main task of the *Air Chemistry Observatory Neumayer* is to provide continuous, year-round data records for important gaseous and particulate trace components of the coastal Antarctic troposphere. Such long-term atmospheric observations are mandatory to understand the present Southern Ocean climate system and identify its major drivers. Another aspect of studying atmospheric chemistry in Antarctica is the need to interpret records of archived trace compounds in ice cores. Provided the present atmospheric chemistry and the physical-chemical processes of air to snow transfer are well characterized, we can use such records to derive information about climate, composition and chemistry of the paleo-atmosphere. The *Air Chemistry Observatory Neumayer* is one of only very few comparable clean air laboratories operated in Antarctica partly established since 1983. There is a strong scientific cooperation with the meteorological observatory. Both observatories are part of the GAW (Global Atmosphere Watch) global station network. On site, one of the nine over-winterer, usually an air-chemist or meteorologist is responsible for the observatory.

### Work in field

Due to Corona pandemic, only a restricted summer season was practicable, but we succeeded in completing all necessary work to run the observatory for another year without cutback. Apart from the usual maintenance work in and around the observatory, we re-installed an ozone monitor (O341M, ansyco) and a Condensation Particle Counter (CPC 3775, TSI), both repaired by the manufacturers, and connected a new pump module to the black carbon monitor (MAAP, Thermo). Unfortunately, we have to remove the Aerodynamic Particle Sizer (APS 3321, TSI) for repair by the manufacturer.

Concerning atmospheric chemistry, the project VACCINE (Variation in Antarctic cloud condensation nuclei (CCN) and ice nucleating particle (INP) concentrations at NEumayer station) managed by the Institute for Tropospheric Research (TROPOS, Leipzig; PI: Silvia Henning) in cooperation with the AWI (started in December 2019) will be continued for another over wintering period. We will link these data with regional meteorology and the chemical composition of the sampled aerosol particles for identifying sources of INP and CCN. The scientific background of this project addresses the fact that Polar Regions have a strong global impact on climate conditions but the crucial aerosol-cloud-climate interaction is poorly understood, especially in the Southern Ocean realm. For further information and first, preliminary results, see the separate contribution by Silvia Henning (Chapter 4.10). Finally, on 26 February the operation of the observatory was taken over by the new air chemistry overwinterer Linda Martina Ort.

## Preliminary (expected) results

We completed an in-depth evaluation and validation of the established long-term observations (LTO) in April/May 2021, except the chemical analyses of the aerosol filter samples. Like in previous years, the outcome of this subsequent analysis revealed the high quality of the measured time series comprising

- condensation particle concentration (CPC)
- aerosol size distribution
- black carbon concentration (BC)
- aerosol scattering coefficients
- surface ozone concentration

with generally negligible data gaps, occasionally caused by short temporary instrumental problems, power outage or routine service operations.

On 9 March 2021, we again observed a short extraordinary condensation particle (CP) peak around 5,000 cm$^{-3}$, comparable to the more striking events detected in March 2016 and March 2018 (Fig. 4.1.1). Lasting for several hours, at that time particle concentrations reached values far beyond the usual seasonal maxima around 2,500 cm$^{-3}$.

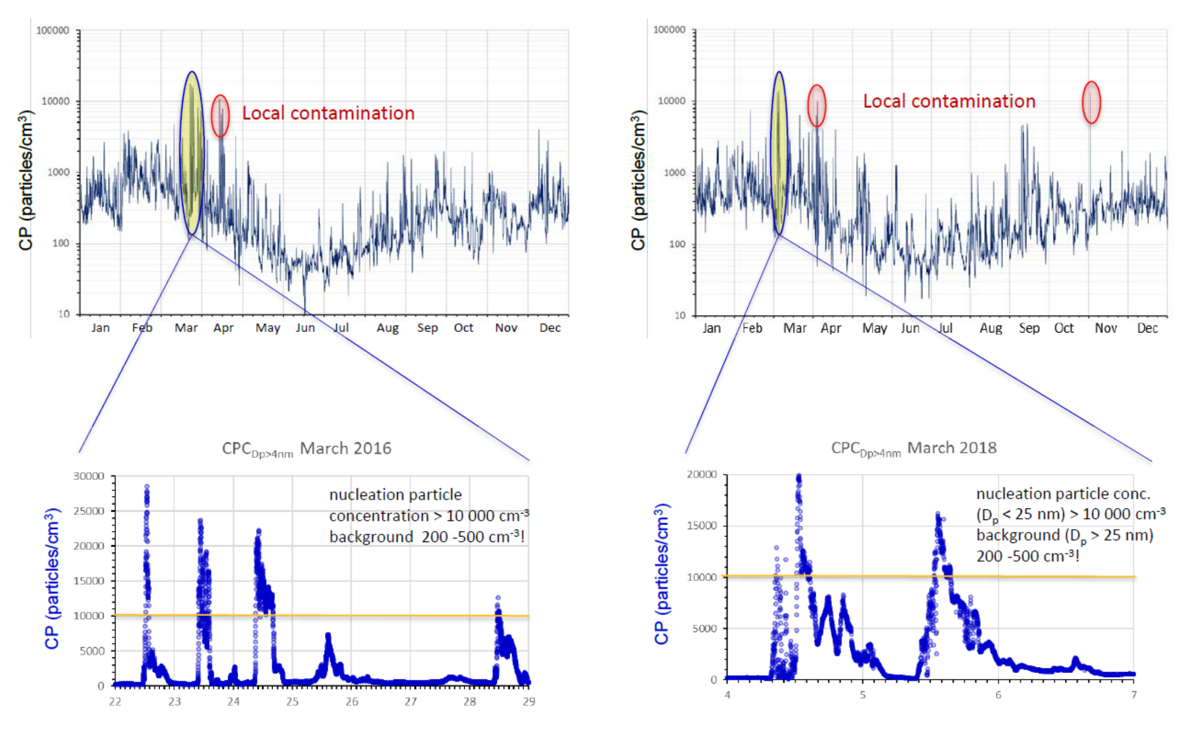

*Fig. 4.1.1: Strikingly high CP concentration events observed in March 2016 and March 2018 (note logarithmic concentration scale on the upper plots). Presented data are one-hour averages based on the data originally taken in 1-minute intervals.*

A more thorough evaluation of the data from 2016 and 2018 revealed that these high CP concentrations were provoked by particle nucleation or new particle formation (NPF) events (Fig. 4.1.2). We observed a high new particle formation rate around 3.5 cm$^{-3}$ s$^{-1}$ but a relatively low particle growth rate between 0.5 nm s$^{-1}$ and 1.0 nm s$^{-1}$. We speculate that the low growth rate of the newly formed particles may be attributed to very low concentrations of a sparse availability of volatile condensable vapors. NPF occurred in the afternoon and correlated with solar radiation, indicating a link to photochemical processes. A comparison with previous NPF events (Weller et al. 2015) and results from contemporaneous long path DOAS measurements (PI: Jan Marcus Nasse, IUP Heidelberg) revealed that photochemistry of marine biogenic dimethylsulfide (DMS) amplified by reactive bromine is the most plausible explanation for the described events.

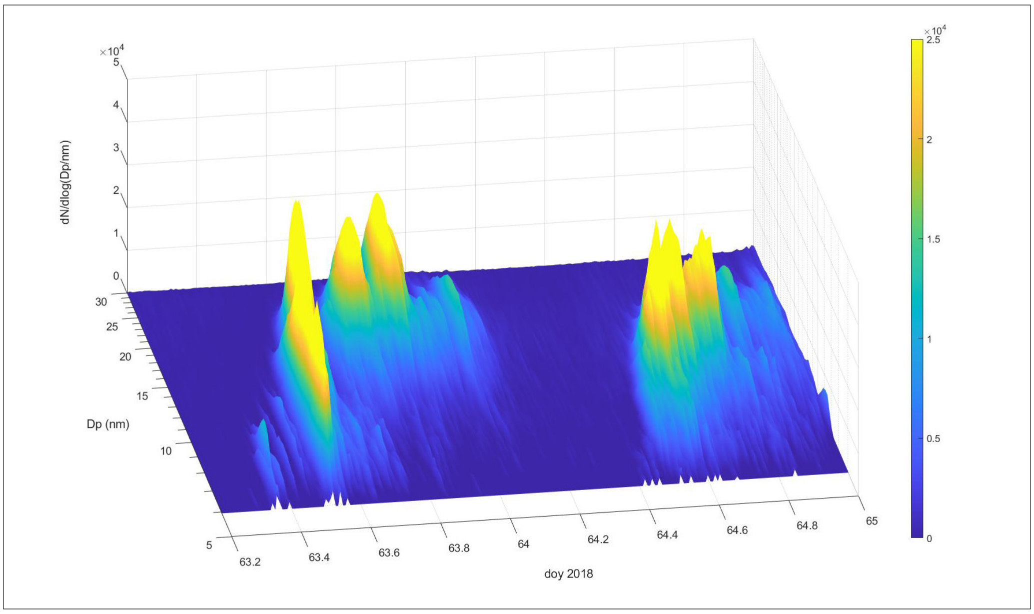

*Fig. 4.1.2: Contour plot of the particle size distribution of two NPF events measured in March 2018, dN/dlogDp (cm$^{-3}$) as z-axis (logarithmic colour scale to the right). The plot shows the observed temporal evolution of the particle size distribution between 5 nm and 30 nm (Dp = particle diameter, measured with a Scanning Mobility Particle Sizer, SMPS). Presented data are one-hour averages based on the data originally taken in 10-minute intervals.*

## Data management

In the meanwhile, we have archived part of the long-term observations after thorough evaluation in the respecting repositories. As mentioned above, the chemical analysis of the aerosol filter samples is ongoing and will be finished during summer this year.

- The entire 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). By default, the CC-BY license will be applied.
- GAW: http://ebas.nilu.no/default.aspx.

In all publications based on this expedition 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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## 4.2 The Geophysical Observatory Neumayer

Tanja Fromm[1], Alfons Eckstaller[1] (not in field),
Jölund Asseng[1] (not in field), Noah Trumpik[1],
Ina Wehner[1], Timo Dornhöfer[1], Lorenz Marten[1],
Jürgen Matzka[2] (not in field)

[1]AWI
[2]GFZ

### Objectives

The Geophysical Observatory at *Neumayer Station III* allows long term observations with different geophysical instruments and contributes to worldwide networks collecting geophysical data for the scientific community. The location at the edge of Antarctica makes the observatory a valuable data point for all networks with sparse data coverage in the southern hemisphere, especially in Antarctica. Distances between two comparable instruments easily become hundreds of kilometers. The closest stations with winter capacities are *SANAE IV* (230 km), *TROLL* (420 km) and *Novolazarevskaya* (750 km). In contrast to project datasets the observatory allows continuous, long time series revealing slow and small changes otherwise undetectable.

The observatory operates instruments covering following disciplines: a) seismology (Fromm et. al 2018; Eckstaller 2006), b) geomagnetism (GFZ 2016) and c) GPS measurements.

*a) Seismology*

The primary objective of the seismographic observations at *Neumayer Station III* is to complement the worldwide network of seismographic monitoring stations in the southern hemisphere. Within Antarctica only eleven broad band seismometers provide data in real time, three of them are operated by AWI. Special interests focus on the detection of local and regional earthquakes within Antarctica. Recently, interest in seismological data from ice covered regions has drastically increased, as seismometers also record cryogenic events giving information about ice dynamic processes (e.g. Aster et al. 2017).

The local seismographic network at *Neumayer Station III* comprises the station VNA1 near *Neumayer Station III* itself and two remote stations VNA2 and VNA3 on the ice rises Halvfar Ryggen and Søråsen, resp. In addition, the seismic broadband station VNA2 features a small aperture array with 15 vertical seismometers placed on three concentric rings in a total diameter of almost 2 km. The temporarily installed network of twelve seismic stations in the vicinity of *Neumayer Station III* completes the number of stations presently operated (see Fig. 4.2.1, inset). These stations, which were set up during the first quarter of 2020 allow further investigations on ice dynamics. Other unattended seismographic broadband stations record data at logistically feasible locations (see Fig. 4.2.1).

*b) Geomagnetism*

The Geomagnetic Observatory at *Neumayer Station III* was built in 2009 and currently hosts a GSM-19 Overhauser proton-magnetometer which records the earth magnetic field’s total intensity, two 3-component fluxgate sensors recording directional changes (FGE and STL) and high frequency induction coils for ionosphere research (MICA-S, see Chapter 4.13). A simple all sky camera once completed the instrumentation for geomagnetic research until it ended its operation in June 2020.

Since 2014 the observatory is a certified member of the Intermagnet organisation guaranteeing quality and standard specifications for measuring, recording and exchanging data. It is one of only nine Intermagnet observatories in Antarctica.

### c) GPS measurements

We continuously record GPS data since the beginning of July 2012 with a dual-band receiver situated on the roof of *Neumayer Station III*. At first we used an Ashtech Z-12 receiver until June 2020. Since February 2020, a Novatel PwrPak7 is installed in combination with the VP6235 VeraPhase Dual band GNSS antenna. GPS data provide valuable information for higher atmospheric research and reveal characteristics of the Ekström Ice Shelf dynamics.

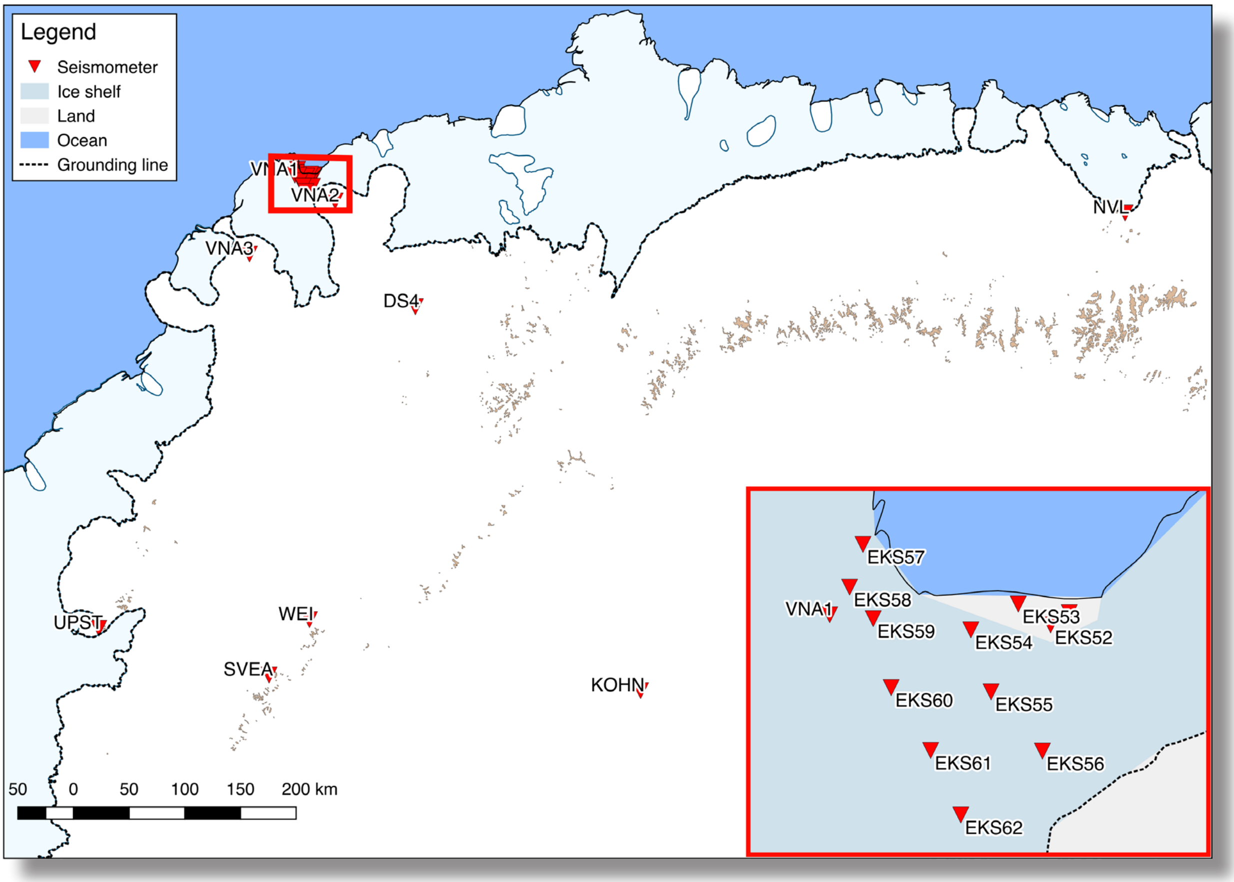

*Fig. 4.2.1: Map showing the active seismometer stations in Dronning Maud Land of the AWI network during 2020 and additional partner stations SNAA and TROLL. The red inset shows the location of the temporary seismometer installation east of Neumayer Station III.*

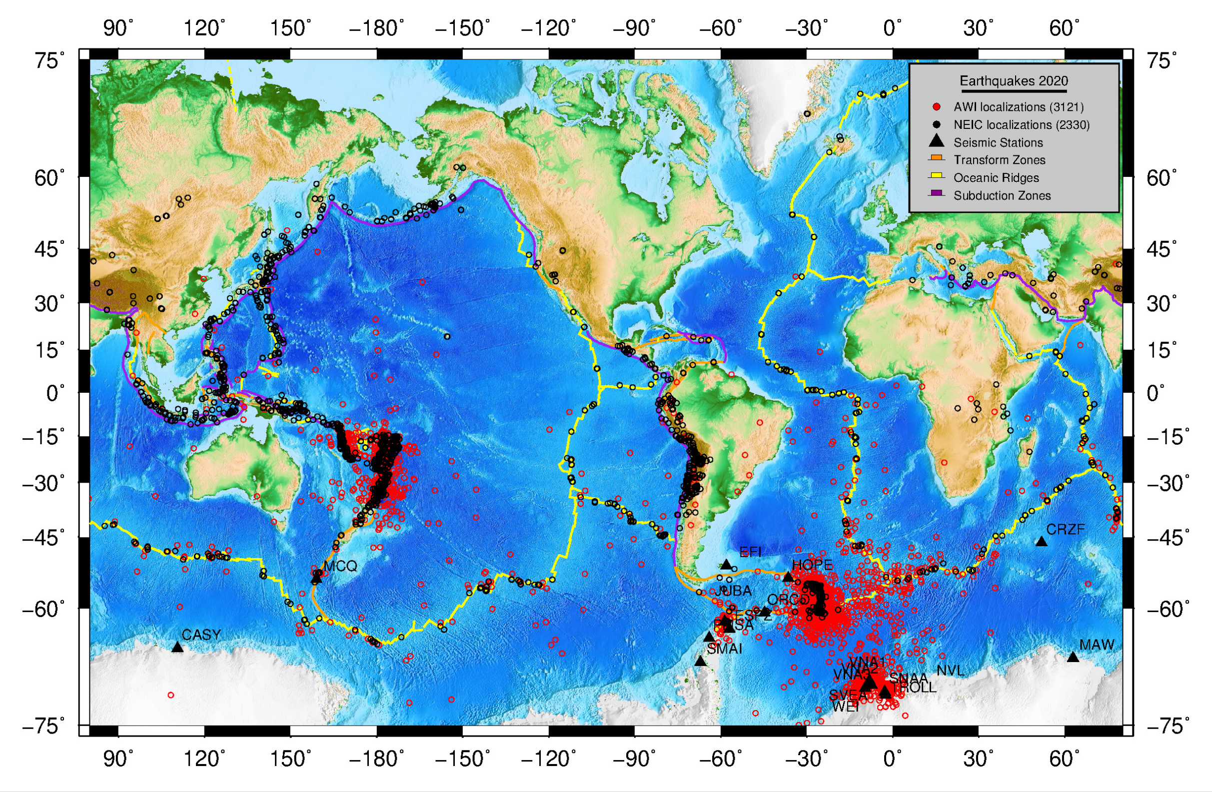

*Fig. 4.2.2: Map showing seismic events recorded at the AWI network in 2020*

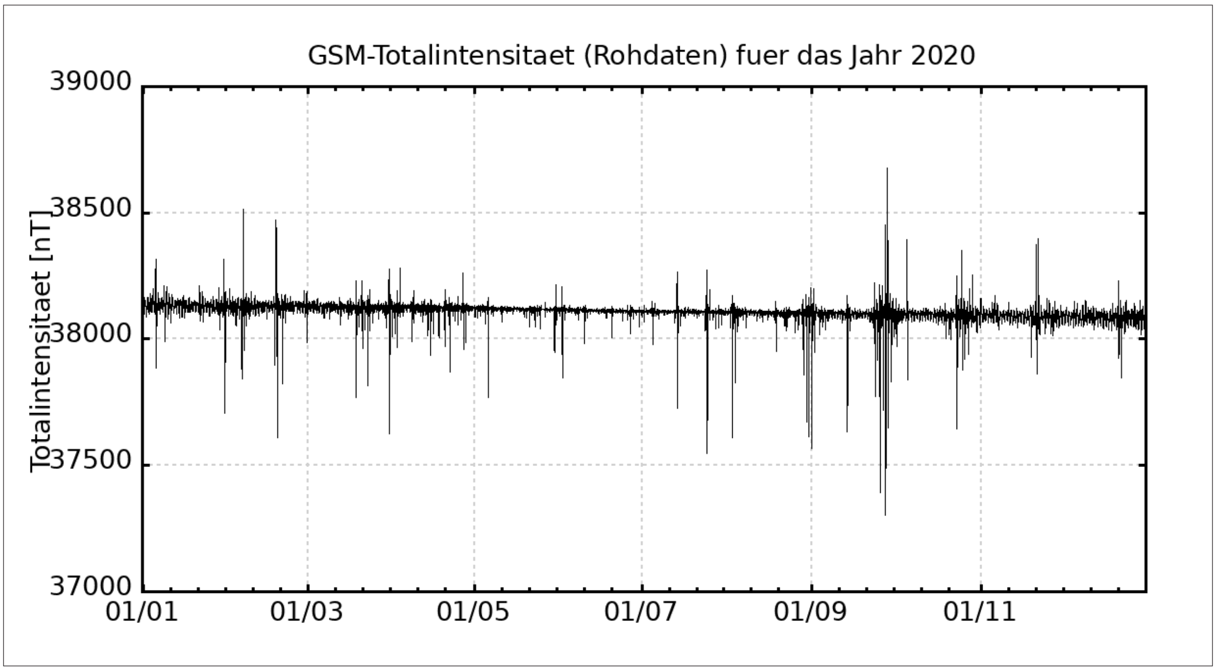

*Fig. 4.2.3: Total Intensity of the geomagnetic field at Neumayer Station III, recorded by the Overhauser GSM-19*

### Fieldwork

During the Antarctic summer season 2020/2021 we serviced the seismometers VNA2 including the 15 single-component array seismometers and VNA3 of the AW network via land based traverses. The seismometers and instrument pits were set up at the new snow level, data downloaded, a quick quality check performed and instruments were upgraded where necessary. Each of the twelve stations of the temporary network “EKS” East of *Neumayer Station III* was checked once in a while during winter. Four stations will have to be set up again in the upcoming summer due to accumulating snow increasing the snow level.

The station DS4 at Forstefjell has been visited by helicopter and data fetched for the year 2020. Stations WEI, SVEA, NVL, KOHN and UPST were not serviced this season.

For the magnetic observatory we calibrated the gyro which gives a reference to North several times in order to correct instrument offsets, using sun observations and GPS measurements.

In addition, the magnetic declination and inclination were measured at the position where the magnetic observatory will be located on 1 January 2023 in order to evaluate the influence of the underlying anomaly on continuous measurements.

### Preliminary results

1. A total of 20,450 arrivals were picked during the year 2020. 3,723 earthquakes were associated with international catalogues, as well as 3,121 regional/local earthquakes located (Fig. 4.2.2).
2. The total magnetic field decreased by 56 nT from a mean of 38,134 nT at 01-01-2020 to a mean of 38,079 nT at 12-31-2020. This decrease includes global weakening of the Earth magnetic field as well as a change of the remanent crustal magnetic field, due to *Neumayer Station III* moving with the ice shelf (Fig. 4.2.3).
3. During 2020 *Neumayer Station III* moved 157.4 metres from (8:16:51.33° W, 70:39:56.46° S) to (8:16:54.40° W, 70:39:51.49° S).

### Data management

- Seismological waveform data can be accessed via Geofon (https://geofon.gfz-potsdam.de/doi/network/AW). Information about arrivals and events can be retrieved from ISC (http://www.isc.ac.uk).
- Data from the geomagnetic observatory can be accessed via INTERMAGNET (https://intermagnet.github.io) and SuperMAG (http://supermag.jhuapl.edu).
- GPS data in Rinex format are available on request.

In all publications based on this expedition 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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Fromm T, Eckstaller A & Asseng J (2018) The AWI Network Antarctica–Alfred-Wegener Institute, Germany. Summary of the Bulletin of the International Seismological Centre, 22-36, 2309-236X, https://doi.org/10.5281/zenodo.1156983.

GFZ German Research Centre for Geosciences (2016) Geomagnetic Observatories. Journal of large-scale research facilities, 2, A83. http://dx.doi.org/10.17815/jlsrf-2-136.

## 4.3 The Meteorological Observatory Neumayer

Holger Schmithüsen AWI

The Meteorological Observatory at *Neumayer Station III* is an ongoing project that is dedicated to climate monitoring. While the observatory is manned all year by a meteorologist, during austral summer major maintenance work is performed.

### Objectives

The meteorological observatory at *Neumayer Station III* is dedicated to monitor essential climate variables in high quality. The station is part of various international networks, such as the Baseline Surface Radiation Network (BSRN), the Network for the Detection of Atmospheric Composition Change (NDACC) and the GCOS Reference Upper Air Network (GRUAN).

In order to guarantee high quality time series, the observatory is serviced once per year by permanent staff. All instrumentation and operating procedures are checked, and the yearly changing new staff is trained on site.

### Fieldwork

Instrumentation and operating procedures of the following atmospheric observations were serviced in the field season 2020/21:

- 3-hourly synoptic observations
- daily upper-air soundings
- weekly ozone soundings
- continuous surface radiation and meteorological mast measurements
- satellite picture reception (HRPT)
- Automatic Weather Station (AWS) Søråsen
- Automatic Weather Station (AWS) Halfvarryggen
- single column precipitation radar

Within the DROMLAN, the meteorological observatory of the *Neumayer Station III* offers detailed and individual weather forecast services for all activities in Dronning Maud Land, especially all aircraft operations. This service is delivered in close cooperation between the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) and the German Weather Service (DWD). Due to the pandemic situation the service was provided predominantly from Hamburg, Germany in terms of aviation forecasting. Weather observations at *Neumayer Station III* for the DROMLAN community were provided as usual.

### Data management

Data of the observatory will be archived, published and disseminated after quality control, first analyses and/or publication according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de). By default, the CC-BY license will be applied. Furthermore, data is supplied to various international networks, mainly those organised within the World Meteorological Organisation (WMO).

In all publications based on this expedition 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.

## 4.4 CTBTO – IS27 Infrasound Station

M. Hoffmann (not in field), T. Grasse (not in field) BGR

### Objectives

According to the Comprehensive Nuclear Test Ban Treaty (CTBT), the IS27 infrasound station is operated at the German *Neumayer Station III* Antarctic Research base as one of 60 global distributed elements of the infrasound network of the International Monitoring System (IMS). Infrasound stations measure micropressure fluctuations in the atmosphere. Therefore, they are mainly focussed on the monitoring of the compliance of the CTBT with respect to atmospheric nuclear explosions. Due to the neighbourhood of the VNA seismic array, seismo-acoustic studies are possible. The IS27 array is located about 3 km southwest of the base of *Neumayer Station III* (Fig. 4.4.1). It consists of nine elements (Fig. 4.4.2) each equipped with a microbarometer and a data acquisition system (Fig. 4.4.3). They are arranged on a spiral at regularly increasing radii from the center point. The aperture of this array is about 2 km. The central array control system is installed in the base of *Neumayer Station III*. IS27 went operational 2003.

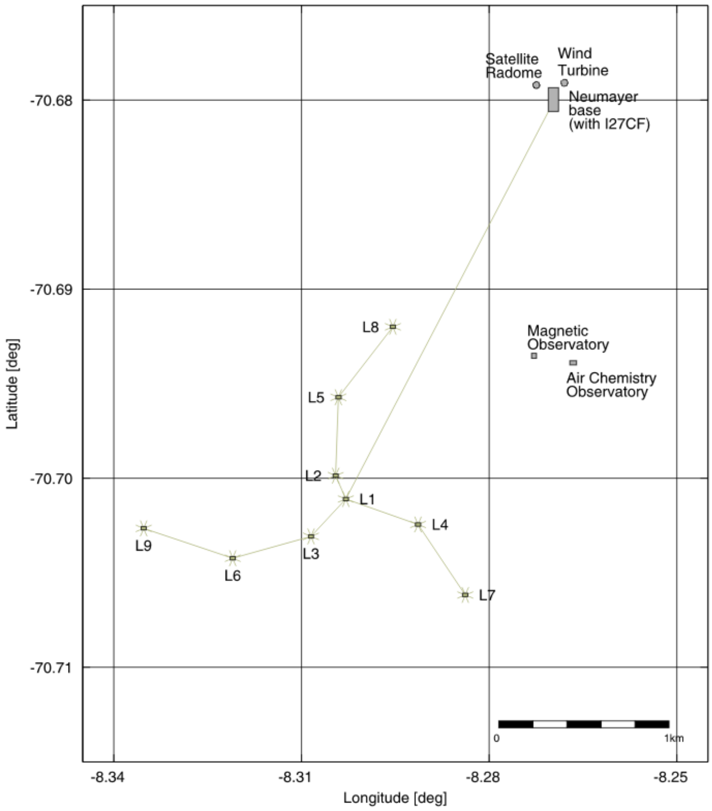

*Fig. 4.4.1: Map showing the location and layout of the Infrasound Array IS27 with reference to Neumayer Station III*

Fig. 4.4.2: One of the nine infrasound elements after recovering from snow. Flagpoles mark the outer positions of the air-pressure inlet-tubes which are part of the wind-noise-reduction-system. In the center, a field-box is buried in the snow. A WiFi-link connects each element with the Neumayer base.

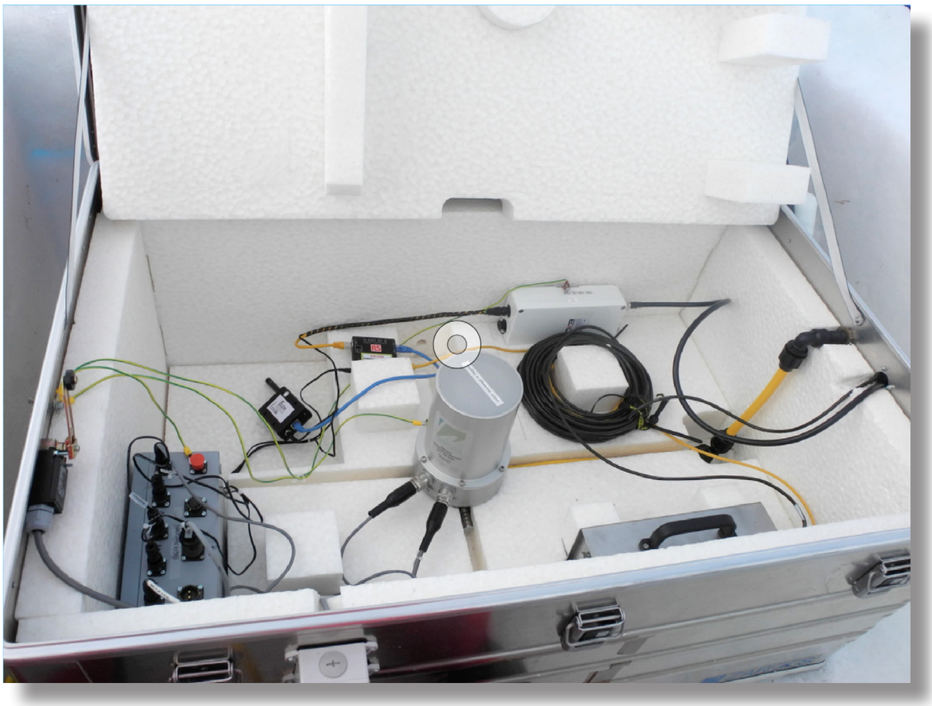

Fig. 4.4.3 The insulated field-box contains the microbarometer (in the middle), data acquisition system as well as the power supply and a communication unit

### Fieldwork

IS27 is to be operated continuously with at least 98 % data availability over a year's time, which is required for an IMS station. Routine maintenance of the array is a prerequisite to ensure the high reliability and is normally carried out every year during the Austral summer between December and February. During this period, the nine array elements have to be recovered from the snow and re-installed on the surface. The condition of the equipment has to be checked, hardware and software upgrades have to be installed.

This year's maintenance work was cancelled due to the corona pandemic. The nine infrasound elements remained deep in the snow and will be raised during the next season. Remote support was available all the time to keep data quality as high as possible.

### Preliminary (expected) results

Data availability and quality for year 2020 met the requirement set by the CTBTO. All data were qualified for data processing at CTBTO.

Waveform-data from IS27 contributed to several recently conducted atmospheric research studies; please refer to the references list.

### Data management

Archived data as well as real-time infrasound data and metadata can be obtained from BGR via FDSN-Webservice (https://eida.bgr.de/info).

In all publications based on this expedition 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.

## 4.5 AFIN – Antarctic Fast Ice Network

Anna-Marie Jörss, Stefanie Arndt (not in field) AWI

### Objectives

Sea ice fastened to coasts, icebergs and ice shelves (fast ice) is of crucial importance for climate and ecosystems. At the same time, it is not represented in climate models and many processes affecting its energy- and mass balance are currently only poorly understood. Near Antarctic ice shelves, this fast ice exhibits two unique characteristics that distinguish it from most other sea ice:

1. Ice platelets form and grow in super cooled water masses, which originate from cavities below the ice shelves. These crystals rise to the surface, where they accumulate beneath the solid sea-ice cover. Through freezing of interstitial water, they are incorporated into the sea ice fabric as platelet ice.
2. A thick and highly stratified snow cover accumulates on the fast ice, altering the response of the surface to remote sensing and affecting sea-ice energy- and mass balance.

At the same time, fast ice is ideal to monitor sea ice and its seasonal evolution, because it may be accessed from nearby stations. In order to improve our understanding of sea-ice processes and mass balance, we perform a continuous measurement programme on the fast ice of Atka Bay, Antarctica. This work contributes to the international Antarctic Fast Ice Network (AFIN), which was initiated as legacy project under the International Polar Year (IPY) and is set out to establish an international network of fast-ice monitoring stations around the Antarctic coastline. The monitoring programme at *Neumayer Station III* started in 2010.

### Work in field

*(1) Manual measurements of sea ice and snow thickness*

Manual measurements of sea ice and platelet-ice thickness, freeboard, and snow depth (drillings and stake measurements) were repeated along a 25-km-long transect across Atka Bay once per month (Fig. 4.5.1). As in the previous years, 6 fixed sampling sites have been revisited monthly between annual formation and break up to obtain the mentioned measurements.

During the season 2020, the sea-ice conditions in Atka Bay have been rather challenging again as ice remained in the bay between the western shelf ice edge and ATKA07 from the previous season (see Fig. 4.5.1).

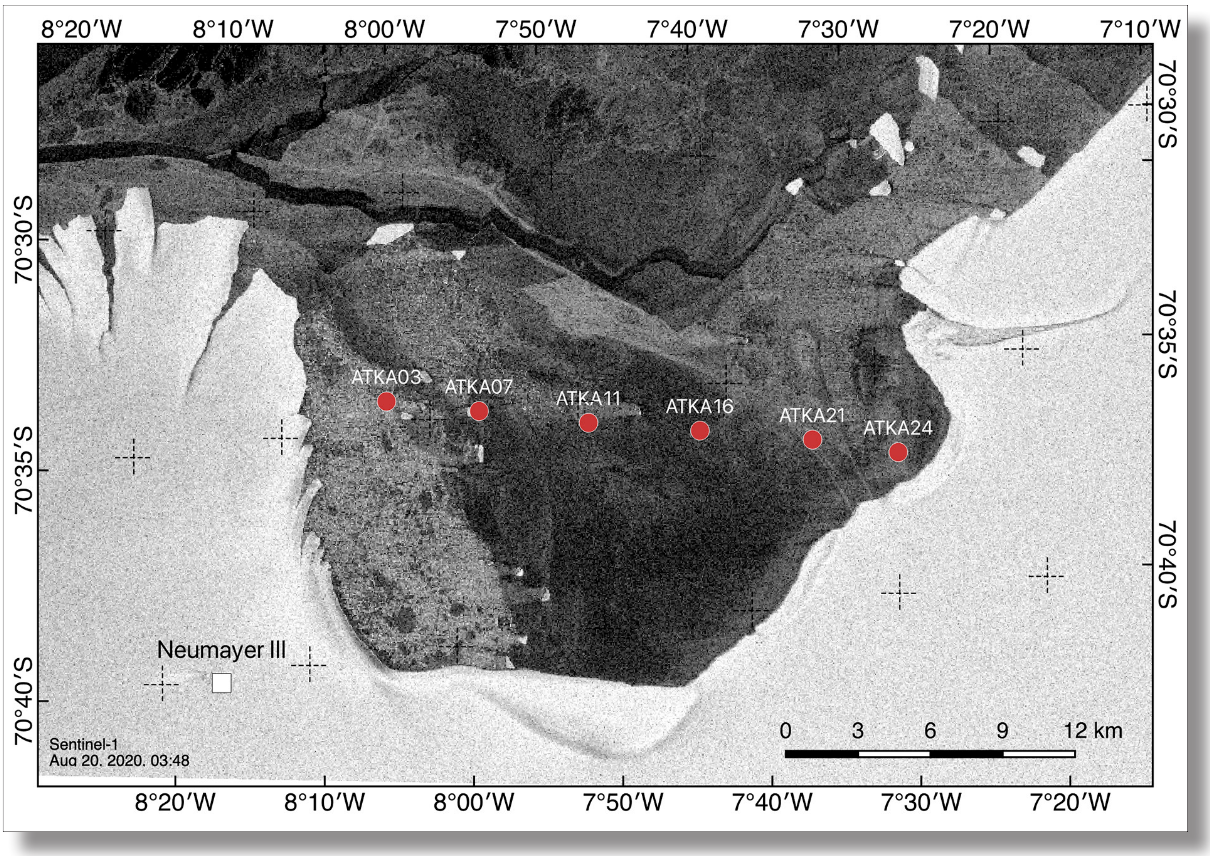

*Fig. 4.5.1: Overview on the measurement sites in Atka Bay for the season 2020. ATKA03-24 denote the routinely measurement sites of AFIN. Numbers (03-24) state the distance to the western (E-W transects). The background of the map shows a Sentinel-1 SAR image recorded on 20 August 2020.*

First sea ice, platelet ice and snow-thickness measurements were carried out on 14 June 2020. In total, 8 series of the entire transect could be conducted. A final measurement was taken between ATKA03 and ATKA11 on 10 January 2021, while access to the remaining bay was already restricted. After that, the entire bay was closed due to crack widening in the southern part. Table 4.5.1 summarizes all mentioned manual measurements.

**Tab. 4.5.1:** Overview of all manual sea ice and snow-thickness measurements along the standard transect. The ATKA sites correspond with the measurement sites in Figure 4.5.1.

| **Datum** | **ATKA03** | **ATKA07** | **ATKA11** | **ATKA16** | **ATKA21** | **ATKA24** |
|---|---|---|---|---|---|---|
| Jun 14, 2020 | X | X | X | X | X | X |
| Jul 15, 2020 | X | X | X | X | X | X |
| Aug 13, 2020 | X | X | X | X | X | X |
| Sep 09, 2020 | X | X | X | X | X | X |
| Oct 05, 2020 | X | X | X | X | X | X |
| Nov 02, 2020 | X | X | X | X | X | X |
| Nov 27, 2020 | X | X | X | X | X | X |
| Dec 21, 2020 | X | X | X | X | X | X |
| Jan 10, 2021 | X | X | X | | | |

### *(2) Electromagnetic sea-ice thickness measurements*

In addition to the manual sea ice and snow-thickness measurements, a ground-based electromagnetic induction device GEM (Geonics Limited, Mississauga, Ontario, Canada) was operated measuring the total sea-ice thickness (sea-ice thickness plus snow depth). Due to technical problems with the GEM at low temperatures in winter, GEM-transect measurements only started in October and then also were conducted once a month. Table 4.5.2 summarizes all conducted GEM measurements.

**Tab. 4.5.2:** *Overview of sea-ice thickness measurements with the electromagnetic induction sounding system (GEM), snow-depth measurements with the MagnaProbe and water profiles with the CTD. The number in brackets indicates the number of down-casts of the CTD.*

| **Date** | **GEM** | **Magna Probe** | **CTD** |
|---|---|---|---|
| Oct 20, 2020 | X | X | X (1) |
| Nov 24, 2020 | X | X | X (2) |
| Dec 25, 2020 | X | X | X (3) |
| Jan 10, 2021 | X | | |

### *(3) Snow-depth measurements with the MagnaProbe*

In addition to the manual snow-depth measurements at the drilling holes, snow depth was derived with a GPS-equipped MagnaProbe (Snow Hydro, Fairbanks, AK, USA). It was operated simultaneously to the GEM transects in order to calculate the actual sea-ice thickness as the difference of total sea-ice thickness and snow depth. Table 4.5.2 therefore also summarizes all MagnaProbe measurements.

### *(4) Deployment of autonomous ice tethered platforms (buoys)*

In order to measure sea ice and snow thickness throughout the seasonal cycle on an hourly basis, two autonomous ice-tethered platforms (buoys) have been deployed on the fast ice in Atka Bay approx. 20 meters north of ATKA16 (see Fig. 4.5.1) on 30 July 2020: One Ice Mass Balance buoy (IMB) deriving the sea-ice growth as well as one Snow Buoy measuring the snow accumulation over the course of the year. Both buoys drifted with the ice into the Weddell Sea after the break up in on 6 February 2021. While the IMB stopped transmitting reliable data from beginning of March onwards, the Snow Buoy is still measuring snow accumulation while drifting through the Weddell Sea (Fig. 4.5.3).

Snow-thickness measurements with the Snow Buoy next to the air-chemistry observatory near *Neumayer Station III* were continued (since January 2013) at the same location. During this period, the Snow Buoy was lifted twice (30 April and 14 December 2020) to avoid a complete coverage in the snow.

### *(5) Vertical water profiling below the fast ice*

In order to measure the water-mass properties in the vertical water column, a Conductivity-Temperature-Depth (CTD) sensor suit was lowered through a drilled hole at ATKA16. All measurements including the number of casts are summarized in Table 4.5.2.

### Preliminary (expected) results

Figure 4.5.2 summarizes all snow, sea ice and platelet-ice thickness measurements as well as the observed freeboard over the season. Although the ice in the west of the bay has not broken out by the end of the previous season, the platelet-ice accumulation under the fast ice was as usual. On average the annual accumulation over the whole bay amounted to 3.57 ± 0.84 m while highest accumulation rates were measured at ATKA21 with 4.60 ± 0.56 m. Also snow thickness showed an annual accumulation of 0.90 ± 0.24 m, despite heavy accumulation in November/December.

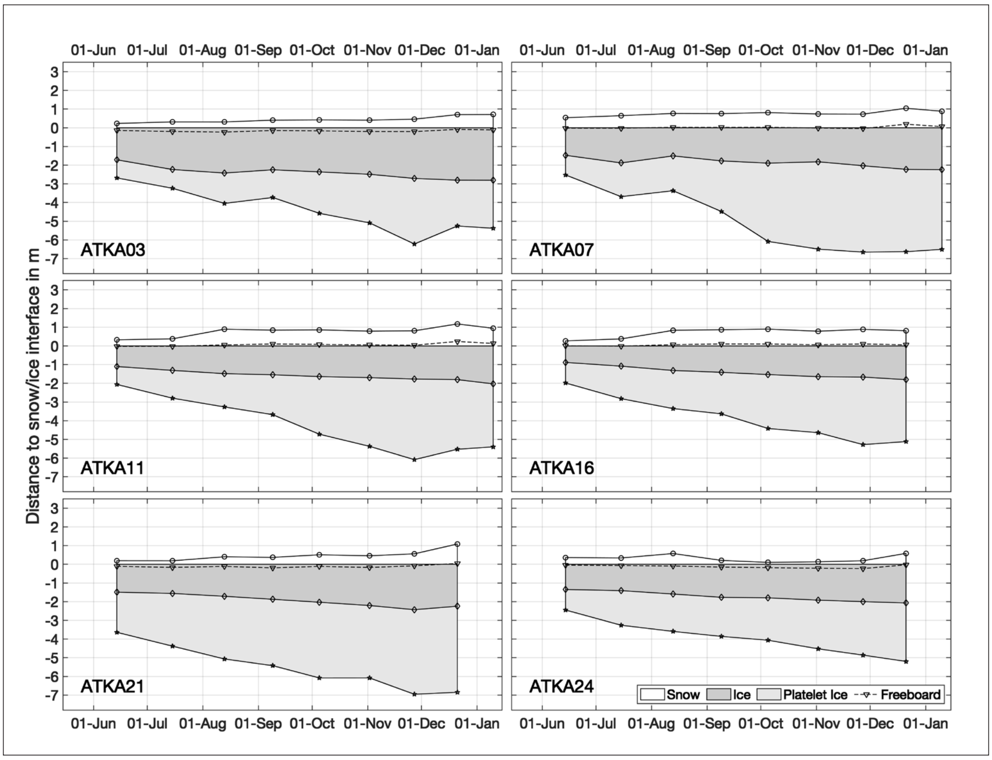

*Fig. 4.5.2: Overview of all manual snow depth, sea ice and platelet-ice thickness as well as freeboard measurements for the 6 ATKA points along the standard W-E transect (Fig. 4.5.1) in 2020.*

Figure 4.5.3 shows the snow accumulation of the deployed Snow Depth Buoy 2020S55 (at ATKA16) for the time period from 30 July 2020 to 10 May 2021. The initial snow depth at the deployment site was approx. 40 cm. A first significant snowfall event with a snow accumulation of additional 20 cm is visible at the end of August. In mid-September, a snow dune with an additional 10 cm in height appears to have formed near the buoy and disappeared less than a week later again. In early December, several successive significant snowstorms ensured that nearly 120 cm of snow accumulated under the Snow Buoy. This snow depth decreased by 20 cm again in the following month due to compaction and presumably slight surface melting caused by temperatures around freezing. Another storm in mid-January caused another snow accumulation of about 10 cm. Since then, the snow depth is rather constant while the buoy drifts through the Weddell Sea.

Sea-ice growth data from the IMB will be only processed at a later stage.

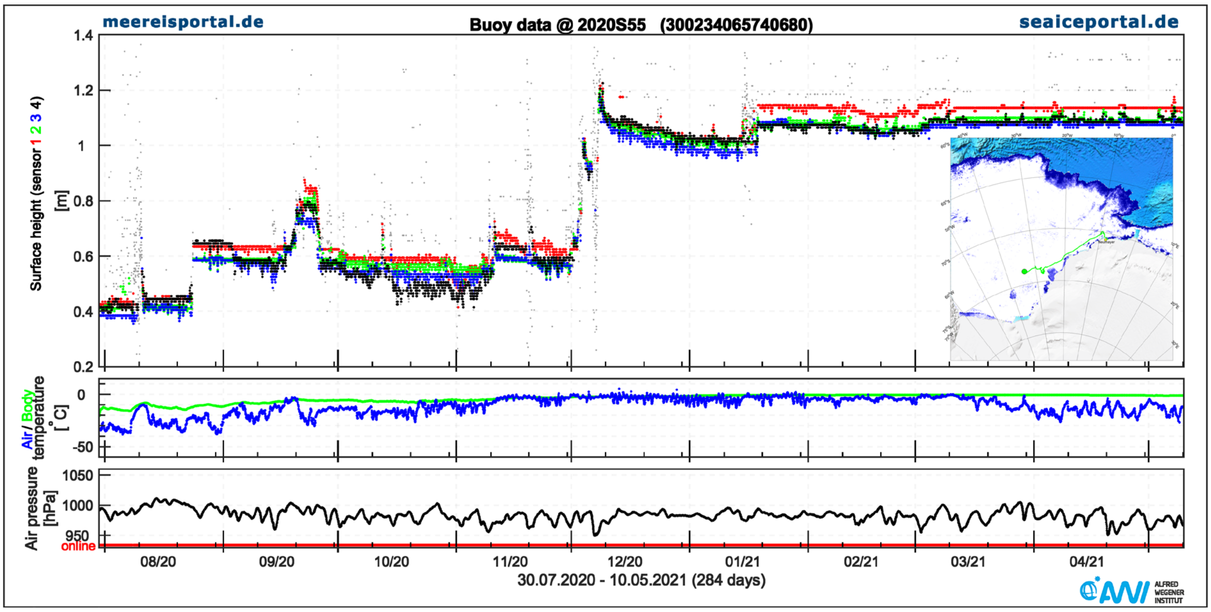

*Fig. 4.5.3: Time series of snow accumulation along with respective meteorological conditions for Snow Buoy 2020S55, deployed on 30 July 2020 at ATKA16 (Fig. 4.5.1). The inset map shows the drift of the Snow Buoy through the Weddell Sea.*

## Data management

All manual drilling measurements are already post-processed and will be archived, published and disseminated after quality control, first analyses and/or publication according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within three months. By default, the CC-BY license will be applied.

The sea-ice thickness data from electromagnetic measurements as well as snow depth data from MagnaProbe measurements will be released following final processing after the field season ANT-Land 2020/2021 or depending on the completion of competing obligations (e.g. PhD projects), upon publication as soon as the data are available and quality-assessed. Data submission will be to the PANGAEA database.

All buoy positions and raw data are available in near real time through the sea-ice portal www.meereisportal.de. At the end of their lifetime (end of transmission of data), all data will be finally processed and made available in PANGAEA. The Snow Buoys report their position and atmospheric pressure directly into the Global Telecommunication System (GTS). Furthermore, all data are exchanged with international partners through the International Programme for Antarctic Buoys (IPAB).

In all publications based on this expedition 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.

## 4.6 SPOT – Single Penguin Observation and Tracking

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(not in field), Céline Le Bohec[3,4] (not in field),
Ben Fabry[1,2] (not in field), Alexander Winterl[1,2]
(not in field)

[1]FAU,
[2]WHOI
[3]CNRS,
[4]CSM

### Objectives

SPOT is a long-term remote controlled observatory to monitor emperor penguins continuously throughout the year for biophysical, ecological and behavioral studies.

Continuous data collection over prolonged time periods is the cornerstone of behavioural and ecological studies. Such data can be used to analyze a large scale of behavioural and ecological problems, from an individual animal to population trends. Time lapse imaging has gained significant interest within the last decade and now is a standard tool due to the large availability of low-cost digital cameras (Kucera & Barrett 1993; Newbery & Southwell 2009; Lynch, Alderman & Hobday 2015) as well as the steadily increasing capability of image processing software (Dell et al. 2014; Gerum et al. 2016). However, in remote and climatically harsh locations such as Antarctica, data acquisition and physical access to the observation system can be challenging. We implemented a remote-controlled and energetically self-sufficient observatory (SPOT, Fig. 4.6.1) specifically designed to operate in Antarctic conditions.

The observatory is designed with the aim to investigate the population and behavioural ecology of emperor penguins (Zitterbart et al. 2011, 2014; Gerum et al. 2013). The challenges in observing emperor penguin colonies are that they are poorly accessible, and their mating and breeding behaviour can only be observed during the coldest and darkest months, with wind speeds up to 150 km/h and temperatures as low as –50° C. Therefore, the observatory needs to be autonomous and remotely controllable, as well as it must require little maintenance. As emperor penguins do not build nests, and incubate their single egg on their feet, the whole colony can move within an area of several km$^2$. To observe such a large area, we installed 7 stationary wide-angle cameras for panoramic overview images, and a steerable 29 megapixel camera mounted on a pan-and-tilt unit as well as a long wave thermal imaging camera. Both, the thermal and the colour camera are equipped with a telephoto lens for either high-resolution images, stitched panoramic images, or video recordings of the colony.

SPOT was deployed in the Austral summer season 2012/2013 at Atka Bay (70°37.0’S, 8°9.4’W), approximately 8 km north of *Neumayer Station III,* on the Ekström shelf ice (Richter et al. 2018). Since 2013, we have been collecting wide-angle overview images at a rate of one frame per minute to determine the colony position, and when visibility conditions permit, daily panoramic images stitched from high-resolution images to count penguins, and on-demand high-resolution video recordings of the colony at 5 frames per second (fps).

### Fieldwork

Due to Covid-19, there was no dedicated field team for SPOT at *Neumayer Station III* during the ANT2020/21 summer field campaign. Nonetheless, with the support from the wintering team the observatory was repositioned during the summer campaign to account for the annual northward drift of the ice shelf, as well as maintenance, such as exchange of cables and the battery bank were conducted.

Data collection throughout the winter 2020 happened without major problems. Overview cameras recording the position and density of the colony were operational at all times and collected a total of 244,907 minutes of data throughout the year (Fig. 4.6.1).

The high-resolution RGB camera was operational throughout the year and recorded images on demand when daylight, the penguin's position were favourable and the SPOT observatory's energy reserves were sufficient. We recorded during 179 days a total of ~8,000 minutes distributed over the whole year. The thermal imaging camera was operated when possible in conjunction with the RGB camera and did not experience fogging due to the automatically closing flap installed in 2019/2020. A total of ~12,247 minutes of thermal imaging data were recorded during 179 days. To count emperor penguins and to study their reorganization processes on a colony scale level, we acquired a total of 323 gigapixel size panoramic images throughout 2020. An example is provided in Figure 4.6.1.

### Preliminary (expected) results

We now have been operating SPOT for 8 breeding seasons with increasing success, which is reflected in annual operation time and data collected. Whilst during the first 2 years we had hardware failure of different components, this has not occurred since the winter of 2015. The operation is conducted completely remotely with support from the Overwinters in case it is needed. Most assistance is required to grease the wind generators every 3 months, as well as to de-ice the overview cameras, which do not have a dedicated heating, especially in autumn when rare freezing fog is possible. Counts throughout the seasons 2018 to 2020 clearly show the arrival pattern as well as the occupation peak of the colony when presumably the whole population is present in May.

### Data management

All data recorded by SPOT is transferred annually to the AWI Data storage repository and stored in the long-term archive.

In all publications based on this expedition 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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Zitterbart DP, Wienecke B, Butler JP. & Fabry B (2011). Coordinated movements prevent jamming in an emperor penguin huddle. PLoS ONE, 6, e20260.

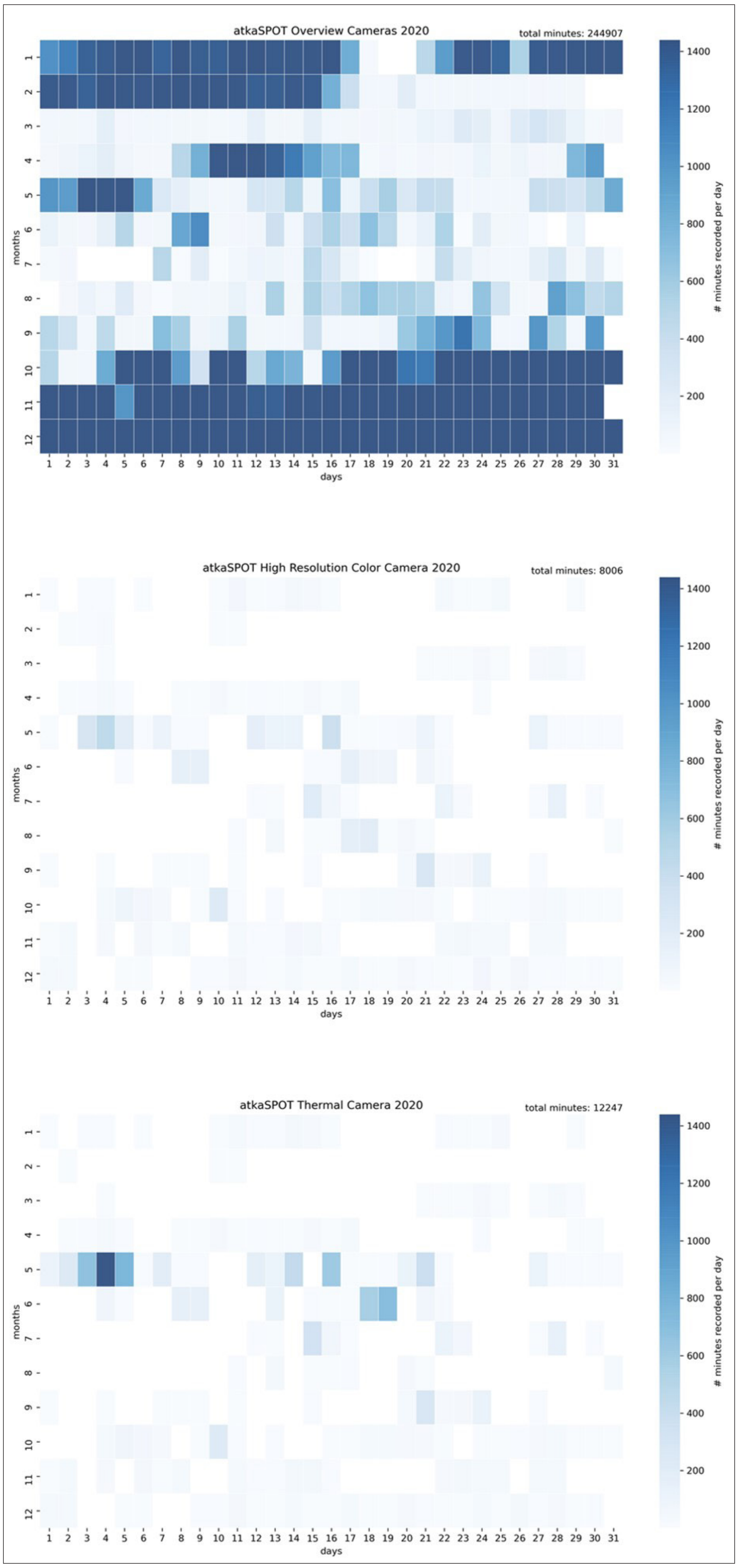

*Fig. 4.6.1: Data collection overview; minutes per day data collected of the respective camera system: Overview cameras (top), high-resolution colour camera (middle), and thermal imaging camera (bottom)*

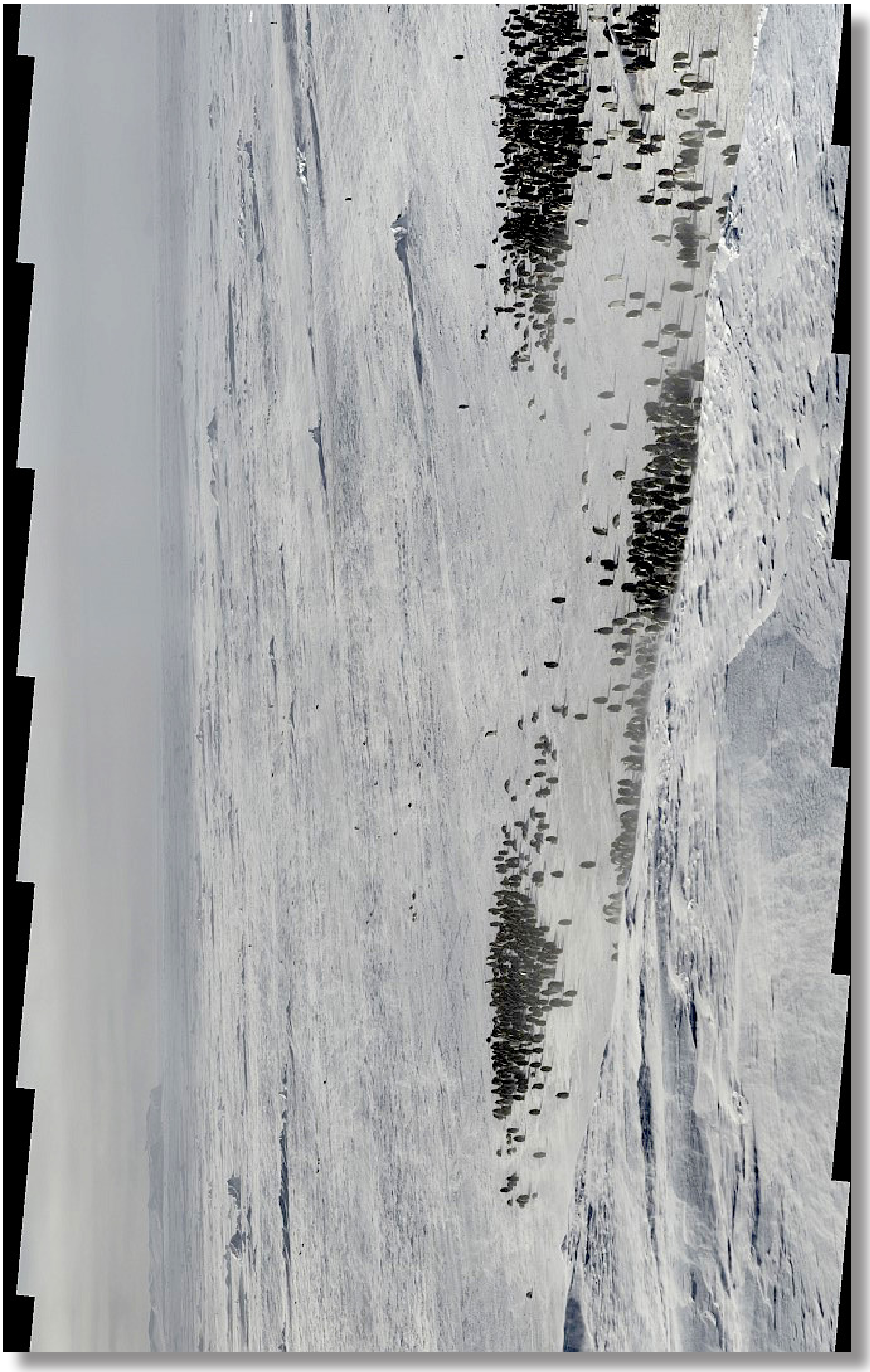

Fig. 4.6.2: High-resolution panoramic images of the whole Atka Bay colony created on 6 October 2020 (top); Cut-out enlargement from the left side of the image (bottom)

## 4.7 PALAOA – Ocean Acoustics

| | |
|---|---|
| Stefanie Spiesecke (not in field), Olaf Boebel (not in field), Elke Burkhardt (not in field), Karolin Thomisch (not in field), Ilse van Opzeeland (not in field) | AWI |

### Objectives

The restricted accessibility of the Southern Ocean throughout most of the year confines our knowledge of the distribution patterns, habitat use and behaviour of marine mammals in this area. Most of the Antarctic marine mammals produce species-specific vocalizations during a variety of behavioural contexts. Hence, passive acoustic monitoring (PAM) offers a valuable tool for research on these species, capable of covering large temporal and spatial scales. Particularly, in remote areas such as the Southern Ocean, moored PAM recorders are the tool of choice, as data can be collected year-round, under poor weather conditions, during darkness and in areas with dense ice cover.

PALAOA (Perennial Acoustic Observatory in the Antarctic Ocean), located since 2005 on the Ekström Ice Shelf, collects continuous underwater recordings from a coastal Antarctic environment using a hydrophone deployed at ca. 160 m depths. The recorded data allows an investigation of the temporal patterns in marine mammal biodiversity at Atka Bay.

### Field work

During a previous supply of the *Neumayer Station III* station from 28 December 2014 until 31 December 2014 by *Polarstern*, an aluminium box, containing modified Sonovault electronics, was installed at the position of the former PALAOA container. It was recessed into the snow and was covered with a wooden board and some snow. The box (80 cm x 60 cm x 60 cm) includes a Reson input module EC6073 for the active hydrophone (Reson TC4032) and a SonoVault electronics module, similar to those used in the moored recorders. For the power supply, four 90 Ah, 12 V batteries are included, two connected in row for each, the active hydrophone and the recording electronics. In July 2015, the battery setup was changed to two batteries in a row and those rows in parallel, supplying both, the hydrophone and the recording electronics. Storage capacity is 4.4 TB (35 x 128 GB SDXC). With a sampling rate of 96 kHz at 24 bit and a file size of 600 s the PALAOA system was expected to run up to 6 months. Servicing is provided by the overwintering team of *Neumayer Station III*. Based on the experience of the Neumayer staff, a servicing interval of approx. 3 months was proven to be necessary and was attended to by Neumayer staff since 2018/2019 Antarctic Season. The responsible person at *Neumayer Station III* is the radio officer.

The last on-site visit by the PALAOA project technical staff was during Antarctic Season 2018/2019.

On 10 March 2020, the remaining unused hydrophone cable route of the original 4-hydrophone PALAOA setup was removed from the shelf. A total of 55 poles were excavated during the removal of the cable. The cable was disconnected at a connector close to the entry point into the ice. The part of the cable, which is vertically frozen into the ice and connects to the submerged hydrophone remains in the ice. Its' current position (70.50427°S, 008.20300°W) was marked.

The position of the PALAOA recording box at this time was 70°30.321'S, 008°12.579'W.

During a visit at the PALAOA site in November 2020, Neumayer staff found the poles of the remaining active cable route partially disappearing in the snow cover. They were set straight in the beginning of December 2020.

Batteries and electronics were exchanged on the following dates:

- 16.01.2020
- 10.03.2020
- 12.06.2020
- 22.09.2020 (Recording ends on 07.09.2020 – battery empty < 9 V)
- 28.11.2020
- 11.02.2021

### Preliminary (expected) results

First data screening at the *Neumayer Station III* showed the instruments to be running well during the whole deployment period. Only data from the exchange on 22 September 2020 was partially missing. While examining the recordings it was detected that the electronics ceased to work approx. two weeks earlier on 7 September, probably due to low power. In the instrument's log file, battery voltage was 9 V on 7 September, before recordings ended. It is assumed that the battery capacity was lowered due to extreme cold temperatures during that time (–40° C to –49° C).

The station continues to be in operation with the active hydrophone being located approx. 180 m from the ice shelf edge.

### Data management

Tapes with data from 2020/2021 will arrive in Bremerhaven in May 2021 and will be copied into the OZA project folder on the Isilon Server. An additional backup will made on the OZASRV1. A fix for the WRNO (GPS Week Number Rollover) problem, which occurred in 2019 and is still present in the 2020 data, will be applied. Pre-processing of data and analysis will then be performed.

In all publications based on this expedition 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.

## 4.8 Neuromayer – Neurophysiological Changes in Human Subjects during Long-duration Overwintering Stays at *Neumayer Station III* in Antarctica

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[2]Charité
[3]MPI
[4]Pitt
[5]NASA JSC

### Objectives

The overarching objective of this project is to investigate the effect of long-duration Antarctic stay on crew health and behavior. The research will be performed as part of the NASA sponsored project “NSCOR for Evaluating Risk Factors and Biomarkers for Adaptation and Resilience to Spaceflight: Emotional Valence and Social Processes in ICC/ICE Environments”. The project leverages the NIMH Research Domain Criteria (RDoC) heuristic framework to conduct experimental studies to identify biological domains (molecular, circuitry, physiology) and behavioural domains that relate to individual adaptation and resiliency (as well as behavioral vulnerability) (Maestripieri et al. 2016). RDoC’s emphasis on examining each construct provides an integrative approach that is appropriate for identifying individual differences in vulnerability to multiple stressors in extreme environments. In addition, RDoC’s focus on neural circuits facilitates the examination of observed individual, phenotypic differences and variations in the nature and degree of damage to those circuits, as well as the variations and contributions of a complex interplay of developmental, compensatory, and environmental factors (Morris et al., 2012). We will identify predictive indicators and biomarkers for resilience and adaptation in individuals and teams, to aid in selection and individualised countermeasure development with the goal to maintain and optimise performance capability and behavioural health during long-duration missions. The project will be based on a close cooperation between the Polar Institute for Polar and Marine Research and several international partners, including Charité, Ludwig Maximilian University of Munich, the University of Pennsylvania, Harvard, and NASA.

### Fieldwork

Data has been collected in crew members at *Neumayer Station III* as part of ANT-Land 2018/19, 2019/20 and 2020/21, and will be continued to be collected in 2021/22 and 2022/23. Our primary outcome will be structural and functional brain changes assessed by MRI before and after the winter-over. In addition, we will also assess behaviour and cognitive performance with sensitive but unobtrusive state-of-the-art cognitive and psychosocial measurement tools. These measurements will be performed before, after and during the winter-over. We also propose to draw and subsequently freeze about 25 ml of blood from all experimental subjects before, during and after the campaign, which will later allow for the identification and time course of biological markers of vulnerability to the effects of prolonged exposure to Antarctic overwintering. To parse out the effects of reduced sensory stimulation from other stressors during long duration space missions such as social isolation, crew conflicts, sleep and circadian disorders, as well as reduced physical activity levels (Palinkas & Suedfeld 2008), we will assess additional physiological measures and endpoints, which have already been successfully implemented in previous experiments in Antarctica. The sample rate will vary from continuously to once monthly, and is optimized relative to crew burden/compliance and scientific return. Pre-, in-expedition and post-expedition data collection for the 39th and 40th overwintering have been successfully completed. Pre-mission data collection for the 41th overwintering campaign was accomplished in November 2020. In-mission data collection for this crew is currently ongoing at *Neumayer Station III.*

### Preliminary (expected) results

It is expected that the multiple stressors associated with long-duration overwintering lead to neurobehavioural changes as assessed by structural and functional brain imaging, key neurotrophins and behavior (e.g., mood and cognitive performance). We also expect that resilience will reflect inter-individual differences in sensitivity to the stressors associated with prolonged Antarctic missions. We recently published data on the neurobehavioural effects of overwintering on *Neumayer Station III* in the *New England Journal of Medicine* (Impact Factor: 70.67) (Stahn et al. 2019). These data revealed considerable changes in brain structure, cognitive performance, and neurotrophins that are key to learning, memory formation, and brain plasticity.

As part of the 37th and 38th we therefore investigated the efficacy of an intervention that was hypothesised to mitigate these effects. The proposed intervention combined physical exercise (using a cycle ergometer) with an interactive virtual environment that was expected to augment sensory stimulation, and was termed *Hybrid Training* (HT). This approach took into account (a) key needs that fulfill sensory stimulation, (b) “hedonic adaptation”, i.e., a reduced affective response to stimuli with continued or repeated exposure, (c) delivery schedule, and (d) size, mass and volume requirements. We investigated both immediate and long-term benefits of *Hybrid Training*. Our primary outcomes were neurostructural and neurofunctional changes assessed with fMRI, and cognitive performance assessed with the *Cognition* test battery. We also assessed biochemical markers of stress and neuroplasticity, objective measures of sleep-wake rhythmicity and sleep structure, subjective symptom reports as additional outcomes that provided insights into mechanisms and consequences of the observed structural and functional brain changes, and their reversibility by HT. These data were compared to historic controls from *Neumayer Station III* that had no access to HT (CTRL).

To maximise the effects of HT we encouraged participants to complete three exercise sessions of at least 30 min per week, corresponding to a total of 180 sessions for the 14-month mission. However, as outlined in the proposal we were very well aware of the fact that the delivery schedule of HT had to be flexibly arranged in close cooperation with each individual crewmember, depending on their personal needs, schedules and preferences.

Figure 4.8.1 summarises the exercise sessions for each individual. One must note that the HT system could be operated with or without the virtual sensory stimulation. The amount of exercise that was performed using the HT without sensory stimulation is indicated by the red bars. The clear majority of exercise sessions, i.e., about 90 %, was performed with the sensory stimulation. As indicated in Fig. 4.8.1, there was considerable variation in the number of HT sessions between crew members. Whereas some crew members performed more than 250 sessions, others did not exercise at all. On average, subjects performed a total of 81 sessions with a total exercise time of 44 hours throughout the mission.

As exercise rates were low at the beginning of the 2017 winter-over, we added a financial incentive for performing HT in August 2017. For each ergometer training session of at least 30 minutes duration, each crew member was compensated with €5 up to a maximum of €25 per week. Exercise rates increased after the introduction of this incentive.

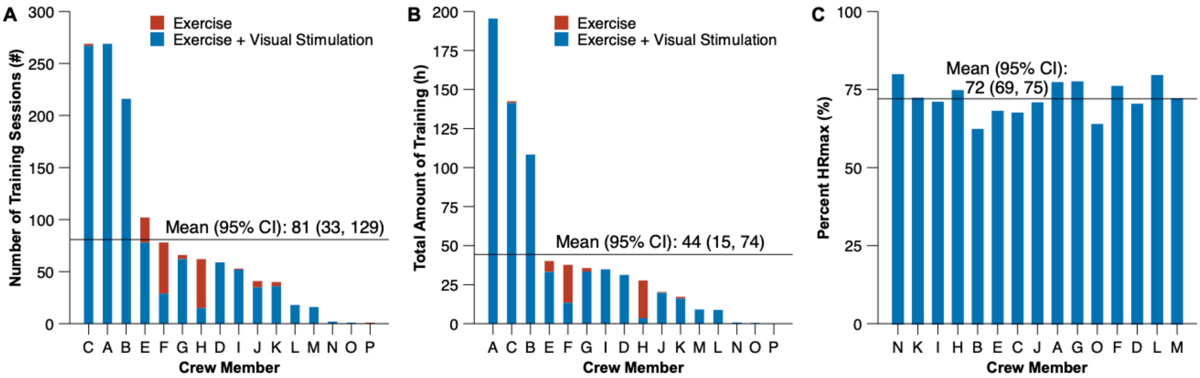

*Fig. 4.8.1.: Summary of Hybrid Training exercise sessions:*
*A: Total number of exercise sessions per subject; B: Total hours of exercise per subject;*
*C: Mean exercise intensity per subject as indicated by mean percentage*
*of maximal heart rate ($HR_{max}$); red colors indicate exercise performed without visual stimulation;*
*blue bars indicate exercise performed in combination with sensory stimulation.*

The specific aims and their primary findings of the effects of HT are summarised below.

**Aim 1: Investigate the effect of Hybrid Training on brain structure and function.**

We observed several differences in brain function and structure that suggest a neuroprotective effect of HT. High-resolution hippocampal imaging revealed some considerable effects of HT on hippocampal subfields. Hippocampal changes strongly predicted tasks assessing working memory. We also observed wide-spread decreases in gray matter in the CTRL group relative to the HT group, including the right medial prefrontal cortex, the left precuneus and left supramarginal gyrus, bilaterally in the parahippocampus and lingual gyrus, the calcarine cortex, and posterior cingulate cortex. Diffusion tensor imaging and tract- based spatial statistics did not detect any differences of changes in white matter integrity between the CTRL and HT group. Functional connectivity analyses showed hyperconnectivity in the CTRL group, characterised by increases in connectivity of the bilateral precuneus in the default mode network (DMN), and between the bilateral hippocampus and areas of the posterior cingulate gyrus and right precuneus. Higher connectivity in the DMN, and lower connectivity between the bilateral hippocampus and the posterior cingulate gyrus and right precuneus were associated with better cognitive performance.

**Aim 2: Investigate the effect of Hybrid Training on cognitive performance.**

We only observed moderate differences between the HT and the CTRL group in cognitive performance at *Neumayer Station III*. The HT group was faster on 9 out of the 10 Cognition tests, statistically significantly for tasks assessing risk-decision making and sensory-motor speed. The HT group was also significantly more accurate on a task targeting spatial orientation. Concentrating on the more relevant performance trajectories over time in mission, cognitive speed across domains increased significantly with time in mission in the HT group only, while cognitive accuracy across domains decreased significantly with time in mission in the CTRL group only. Speed and accuracy on a task requiring complex scanning, visual tracking, and attention, significantly declined in the CTRL group only, while speed significantly increased in the HT group. Also, crewmembers who exercised a lot were able to improve both accuracy and speed with increasing time in mission, while those with low levels of exercise mostly showed a pattern of higher speed at the expense of lower accuracy. Therefore, while the overall changes were small, the results hint to benefits of HT for maintaining high levels of cognitive performance during prolonged stays in isolated, confined and extreme environments.

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**Aim 3a: Investigate the effect of Hybrid Training on biochemical markers of stress and neuroplasticity.**

Neurotrophic factors and neuroprotective cytokines did not change throughout the mission in the Hybrid Training group. In line with our hypothesis, the HT group was characterised by significantly higher BDNF and VEGF levels relative to the controls. Further, there was also a tendency for cortisol to be decreased in Hybrid Training compared to controls.

**Aim 3b: Investigate the effects of Hybrid Training on mood, depression, and subjective assessments of workload, stress, sleep quality, tiredness, sickness, and conflicts.**

Both the HT group and the CTRL group showed healthy survey responses that were relatively stable throughout the *Neumayer* mission. The only significant change with increasing time in mission was observed for increased mental fatigue in the CTRL group only. Survey responses did not differ between the HT group and the CTRL group except for physical exhaustion and tiredness, which were both rated significantly higher in the HT group, with exercise being one possible explanation for this difference.

**Aim 3c: Investigate the effect of Hybrid Training on sleep duration and sleep-wake rhythms using continuously wrist-worn actigraphy.**

The HT crew spent ample amounts in bed (TIB 8.18 ±0.15 h) and sleeping (TST 6.90 ±0.13 h). Most of the sleep was obtained during the nighttime (defined as 9 pm to 9 am). In a comparison between those with high and low levels of HT exercise, sleep time during the nighttime was 0.45 h longer in the low exercise group ($p=0.019$), and it is possible that exercise time cut into sleep time in those with high levels of exercise. 2 Sleep efficiency for the HT crew averaged 84.3 % ±1.0 % and was identical in crew with high and low levels of exercise ($p=0.93$). Spectral analyses of sleep-wake data indicate a main period of ~24 h for all crew members. No other period ±5 h (relative to 24 h) contained significant amounts of power. Moderate and vigorous activity decreased from February to July and then slowly increased again until November. Similarly, light and sedentary activity increased from February to July and then slowly decreased again until November. Average wake activity counts did not differ significantly between the crew with high and low levels of HT exercise.

**Aim 3d: Investigate the effect of Hybrid Training on heart rate, heart rate variability, and sleep structure using monthly 24-h ECG measurements.**

We found some differences in sympatho-vagal balance during the night with increasing mission duration. Separating and analysing the quarters suggest that this effect was particularly prominent in the third quarter. We attribute these changes to increased stress levels associated with prolonged isolation and confinement. It remains to be determined whether heart rate variability could serve as non-invasive biomarker for increased stress levels and neurobehavioural changes.

This report covers the most important analyses. In-depth analyses (including correlations/interactions between the different outcomes) of the extensive data set are still underway and will be published in the scientific literature.

## Data management

Data will be analysed at the PI's laboratory at Charité, MPI, Penn and Pitt. Data will be pseudonymised and stored on a central server that is backed up and managed by the universities' IT programs. Results will be publicly disclosed in a timely manner after completion of the data collection by submission to peer-reviewed journals with authorships that accurately reflects the contributions of those involved. One year after final data collection the data will be submitted to NASA, which will be archived in the NASA Life Sciences Data Archive (LSDA) (http://lsda.jsc.nasa.gov/) for the benefit of the greater research and operational spaceflight community. We will meet all requirements set forth by NASA to share our data with the research community in general and NASA's Life Sciences Data Archive (LSDA). De-identified data will be submitted to the LSDA that can then be made available for internal and external-to-NASA peer-reviewed research studies following a thorough review and approval process by LSDA and after appropriate JSC IRB approval. The de-identified that we will submit to LSDA will include individual data points but any identifying information will be removed. We will carefully attend to any characteristic that might make the data fields identifiable (e.g., campaign, analog, mission length and/or sex).

In all publications based on this expedition 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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## 4.9 WSPR RADIO Beacon at *Neumayer Station III* for Evaluation of Southern Hemisphere Radio Propagation

Michael Hartje[1](not in field), Ulrich Walter[2] (not in field)

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### Objectives

The objective of this project is to gain more knowledge about the propagation of radio waves in the ionosphere at Antarctic latitudes and at frequencies between 100 kHz and 50 MHz. This is achieved bythrough about 1,500 amateur radio stations (also called “ham radios”) spread over the globe. These stations transmit beacon signals or/and receive them from other stations, generating so-called “spots”. These spots are reported into an open web-based database system, also known as “WSPR-Net”. The beacon messages use a standardised format called “propagation reporter protocol”, which was developed and introduced in 2008 by Joe Taylor, amateur radio call sign K1JT, physicist and Nobel Laureate. Because seasonal propagation situations south of the tropic were scarce to date, a WSPR (Weak Signal Propagation Reporter) beacon station was installed at *Neumayer Station III* (Hartje & Walter 2020).

The project was initially intended to last for one year, but has been extended to a full 11-year sunspot cycle until 2030. The project is funded by the two prime investigating institutions as well as by DARC (German Amateur Radio Club) and supported by several private individuals highly dedicated to amateur radio and to research projects. The receivers are operating autonomously with special decoder programmes reporting the relative signal-to-noise ratio (SNR) during receiving intervals.

To transform the SNR values from relative to absolute levels, an additional receiver with a calibrated electrical field sensor was installed on the roof of the “SPUSO”. This offers the opportunity to recalibrate the already existing receiver data from the past and determine the absolute values of noise and signal strength.

The antenna and specially developed electronics were designed and tested by Jörg Logemann, an expert in the field of active antennas.

### Fieldwork

In January 2020, the vertical transmitter antenna was supplemented by an endfed-design longwire with a length of 21 m. Unfortunately, in August 2020 this antenna became unusable because the impedance transformer was defective. The remaining vertical antenna turned out to be highly reliable until the defect components could be replaced in January 2021.

In April and May 2020, several breaks in the wires of the loop antennas at the “SPUSO” were recorded, which was noticed by the staff when inspecting the “SPUSO”. The cause was mechanical stress due to the high wind speeds. The wires were replaced by more stable constructions (steel wire instead of copper braid).

WSPR and FT8 decoder programmes generate reports of the received signal in decibels relative to the measured interference as a signal-to-noise ratio. However, until lately, the absolute levels of noise as signal power in dBm per Hz could not be determined. Therefore, and in order to obtain the desired basis for standardisation, an additional active low-noise receiving antenna was installed on the “SPUSO” roof. The so-called antenna factor, which is the conversion factor from the electric field strength to the voltage at the antenna-output connector, could be calculated by simple and clear arrangements. The mounting of the antenna is shown in Figure 4.9.1.

*Fig. 4.9.1: "SPUSO" with the new active low-noise antenna (red circle) viewpoint from north west*

### Preliminary results

The receiver station at the "SPUSO" was very stable in operation during the reporting period. The loop antennas were damaged by winter storms in April 2020 and later, but could be temporarily repaired by the staff. From January 2020 to the end of March 2021, the receiver reported a total of 2,325,641 spots on both ports with both antennas.

With the old (2018) WSPR receiver, spots were obtained continuously from the day of installation to the day of replacement. Table 4.9.1 shows the comparison of spot numbers received in the two respective months of November and December 2019 compared to 2020, as well as a comparative diagram resolving the hours of the day (Fig. 4.9.2).

**Tab. 4.9.1:** Number of spots during one month in 2019 and 2020

| Month | 2019 | 2020 |
|---|---|---|
| November [n] | 127.346 | 196.949 |
| December [n] | 152.021 | 297.813 |

The data in Table 4.9.1 show that the number of spots received during a calendar month nearly doubled between 2019 and 2020. One reason for this could be the new and very stable receiver. Another factor could be the increasing number of radio amateurs transmitting beacon signals in Europe and North America. In addition, the new receiver is now permanently active on all amateur bands, widening the data basis.

Figure 4.9.2 shows the total number of spots per hour, received on 9 different amateur radio bands. Interestingly, three local maxima can be observed in the October 2020 data at 01:00, 05:00, and 19:00 UTC. These correlate with sunrise and sunset times in Europe, North America East Coast and North America West Coast. These regions of the northern hemisphere are densely populated and accordingly have a high number of radio amateurs. It requires further investigations if this is the only reason for the diagram peaks or not.

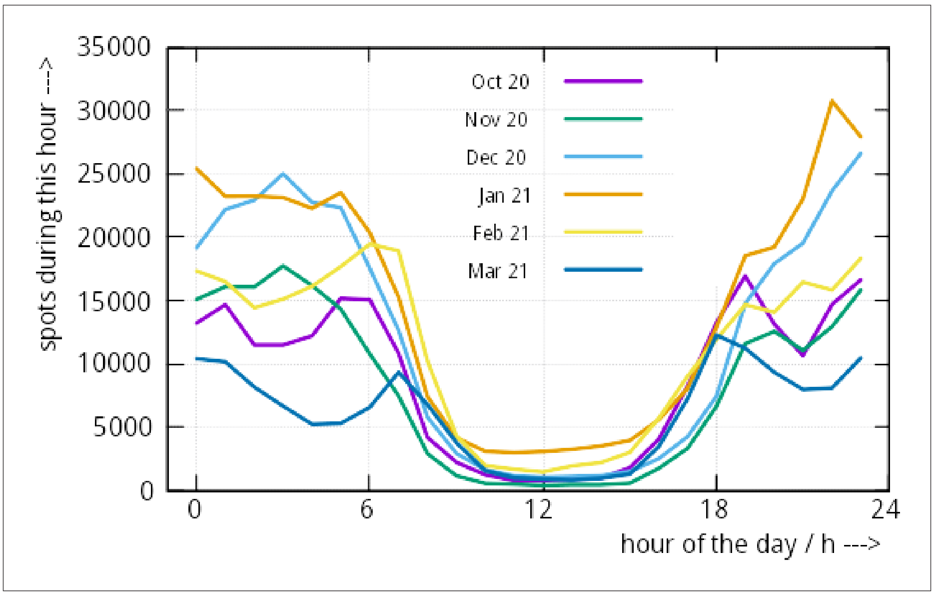

*Fig. 4.9.2: Number of WSPR-spots from October 2020 to March 2021 recorded over hours of the day*

The maximum on January 2021 at 22:00 UTC and the local peak at 05:00 UTC show many spots which may result from a minimal absorption of transmitted signals originating from the northern hemisphere by the D-layer of the ionosphere.

The WSPR and FT8 protocols used generate reports of the received signal in decibels relative to the measured interference as “signal-to-noise ratios”. However, until lately, the absolute levels of the noise as signal power in dBm per Hz could not be determined.

The team designed an additional active low-noise receiving antenna to be installed on the “SPUSO” roof in order to obtain the desired standardisation basis. However, the so-called antenna factor, which is the conversion factor from the electric field strength to the voltage at the antenna output connector (related to a flat ground), was a major obstacle.

The actual position of the mounting point and the surrounding environmental structures result in a deviation of the real antenna values to the previous computer simulations, implying that the calculation of the on-site antenna factor is not simple. The real values can only be measured with calibration equipment, e.g. field strength probes. One approach to solve this problem was to determine an average value of the antenna factor by using a family of simulation calculations, considering the frequency response. In this way, an average value for the real antenna factor could be evaluated.

The simulation model used for the antenna mounted on the container consists of 421 wires and takes into account the mast and the 20 m long support pylons (see Fig. 4.9.3). The antenna is placed at the rear balustrade of the container roof and is marked with a small red dot. The viewpoint is from the upper level of the surrounding ice, heading towards the North.

The simulation was performed with the programme "4nec2". The simulation from 0.5 to 32 MHz was intended to answer the question, of what effective electrical antenna height could be expected at different operating frequencies. The effective antenna height has a major impact on the antenna factor, which is the mathematical relationship between electric field strength and the voltage at the antenna output.

For a small vertical monopole antenna over some electrically short radials (< λ/4), it might be expected that the effective antenna height is half of the antenna pole length plus the mast height. Precondition is that the sum of both values is less than a quarter-wavelength of the highest operating frequency.

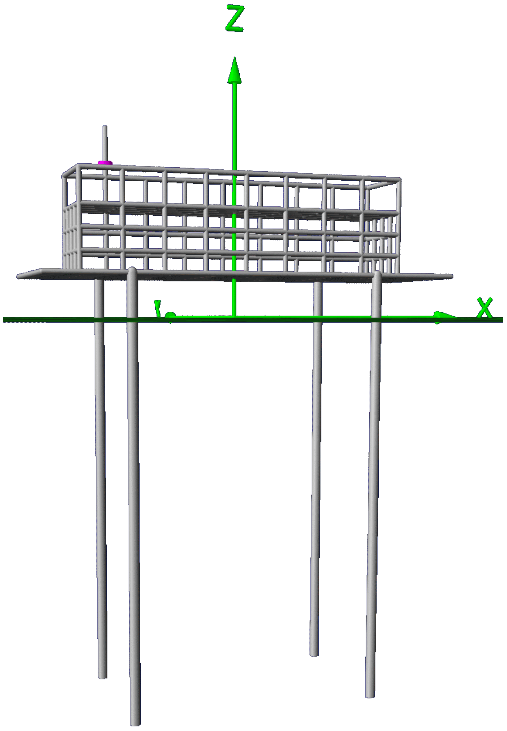

*Fig. 4.9.3:*
*The simulation model assumes 421 wires, including the support pylons in the ice. The view is from south-west to north-east at the height of "0" (upper edge of ice).*

However, the situation at the "SPUSO" differs from standard assumptions used in normal simulations. The most important difference is that there is no effective electrical ground for antennas, the shelf ice is non-conductive. Moreover, the antenna is several meters above the ice level and the impact of the container structure is not contained in the simulation algorithms. One out of 12 simulation results for different frequencies is shown in Figure 4.9.4.

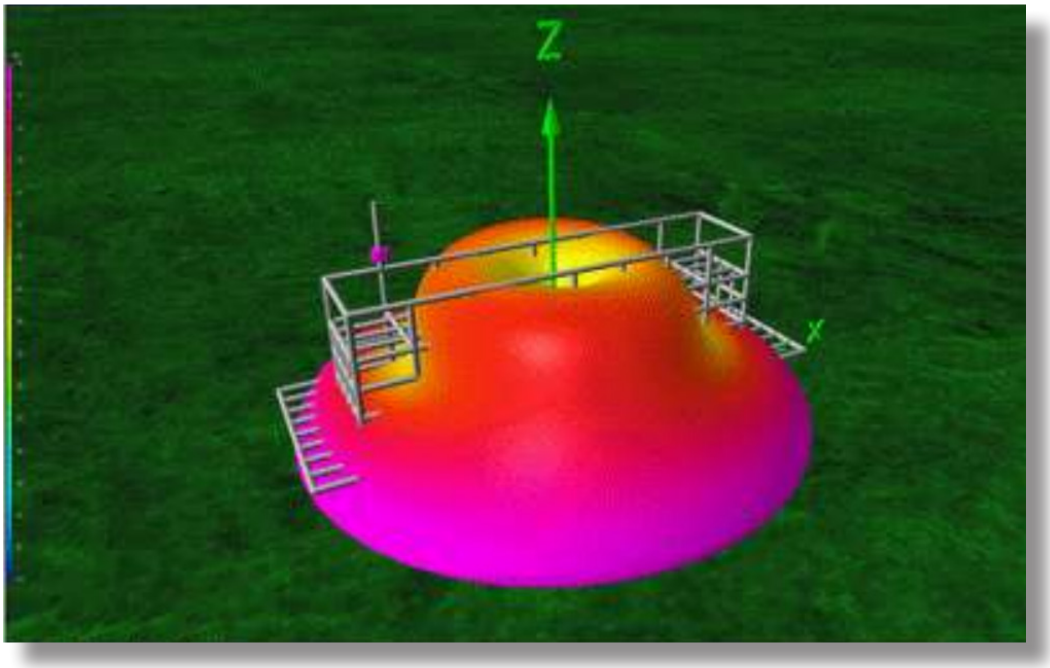

*Fig. 4.9.4: 3-D simulation result of the radiation pattern diagram of the antenna at 0.5 MHz centered at the SPUSO and height "0" (upper edge of the ice)*

The simulation result displayed in the Figure 4.9.4 shows the device under simulation on the left site as a small purple dot and a grey wire. The antenna is mounted at the balustrades as shown in Figs. 4.9.3 and 4.9.4. Due to the electric field distortion of the metallic "SPUSO" container and the supporting pylons, the resulting effective antenna height is reduced to 1.9 m in the frequency range between 0.5 and 10 MHz. The effective antenna height is needed for calculating the antenna factor, i.e. the conversion factor from electrical field strength to voltage at the feed point of the antenna. As shown in Figure 4.9.4, the field distortion of the container structure is negligible for low frequencies, e.g. 0.5 MHz.

In the next simulation an attempt is made to estimate the extent of field distortion by the SPUSO container. As the container has some corners, the electrical field is expected to become inhomogeneous at these points. Several simulations showed that the container does indeed have an impact on raising of field strength. In addition, there is also an interaction between the orientation of the container and the location of the field source, the far distant transmitters. A simulation is shown in Figure 4.9.5.

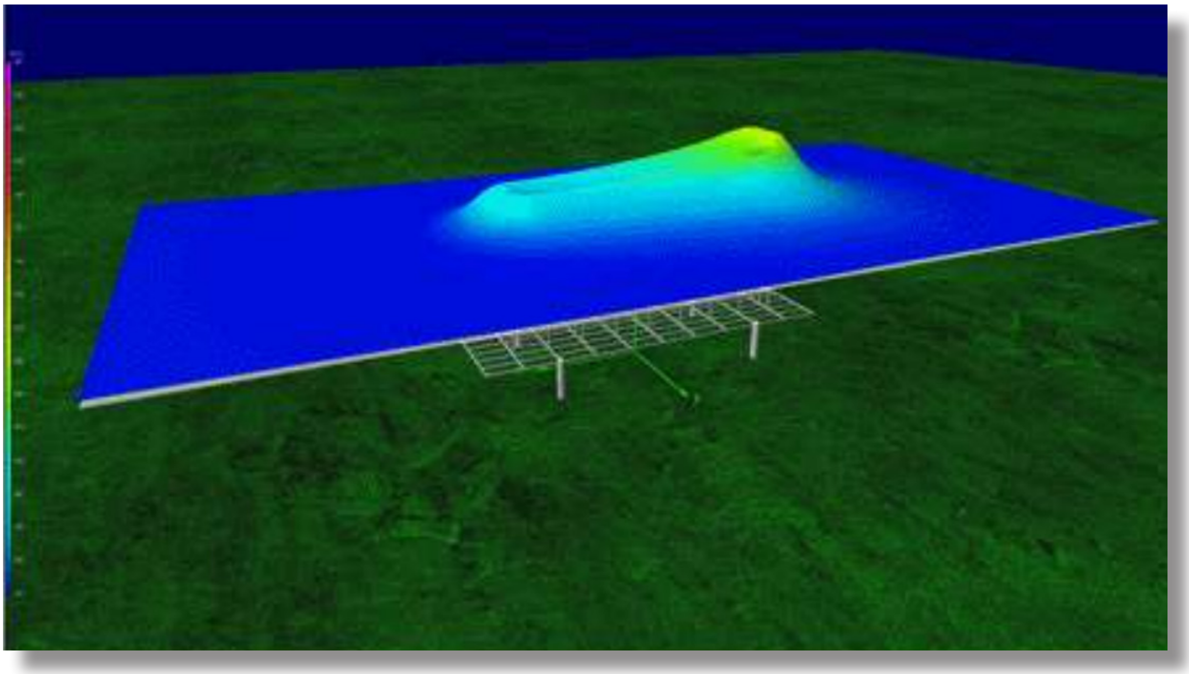

Fig. 4.9.5: 3-D simulation result of the electric field and its distortion by the “SPUSO” container

In Figure 4.9.5, a source with a 0.5 MHz transmitter 2 km west of the “SPUSO” and at a height of 300 m is assumed to simulate a specific elevation angle for a space wave from a far distant transmitter. The blue surrounding area shows the homogenous electrical field strength of about 250 mV/m. The view and orientation of the image is from north-east to south-west. The yellow parts at the western end of the container in Figure 4.9.5 show a level of 510 mV/m, which increases the measured signal by 6 dB, compared to the homogenous case about 10 m next to the container. This leads to a doubling of the measured voltage.

For other frequencies and other transmitter placements around the container and with different heights, the results show more complex figures and increasing factors. All simulations up to 30 MHz should result in a simple antenna factor that could be used for the active antenna at the actual mounting point shown in Figure 4.9.1.

In Antarctica, only very low levels of man-made noise (MMN) are expected (see Figs. 4.9.6 and 4.9.7) and all potentially interfering emissions are from transmitters located at distances of at least 4,500 kilometers away. The receivers in the “SPUSO” generate their own noise, which is mainly thermal in origin, and superimposed by galactic noise and electrostatic discharge resulting from snow drift particles. There is also a low level of man-made noise sources originating from the installations at *Neumayer Station III* itself as well as from some distant broadcast stations in South America or South Africa.

Due to an electrostatically overloaded input port of the “Red Pitaya” FPGA measurement receiver in use, a low-pass filter had to be installed in the active electrical field antenna. This limits the amplified and measurable spectrum to 8 MHz. Higher frequencies can be detected, but with reduced and undefined amplitude.

In Figure 4.9.6, the peak at 3.7 MHz is produced by the WSPR-Transmitter at *Neumayer Station III* about 1.5 km north of the “SPUSO”. Other small peaks at 6 MHz are broadcasting stations outside of Antarctica. As shown in Figure 4.9.6, the noise level amplitude up to 8 MHz is estimated from measurements near the level of “quiet rural” which is defined in the ITU-R P.372. The ITU-R P.372 also defines the term “industrial” noise level.

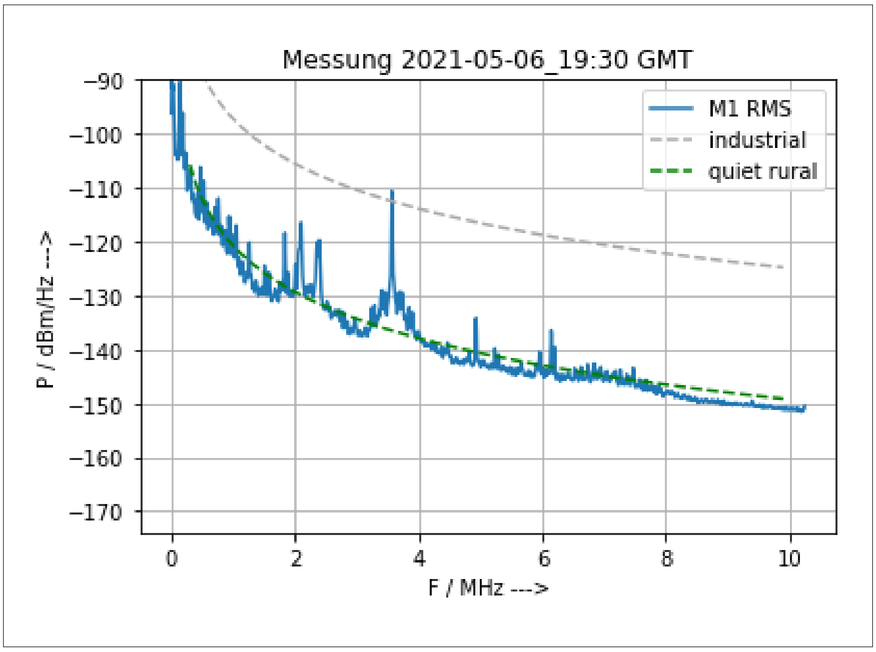

*Fig. 4.9.6: Power density spectrum measured with the new active antenna*

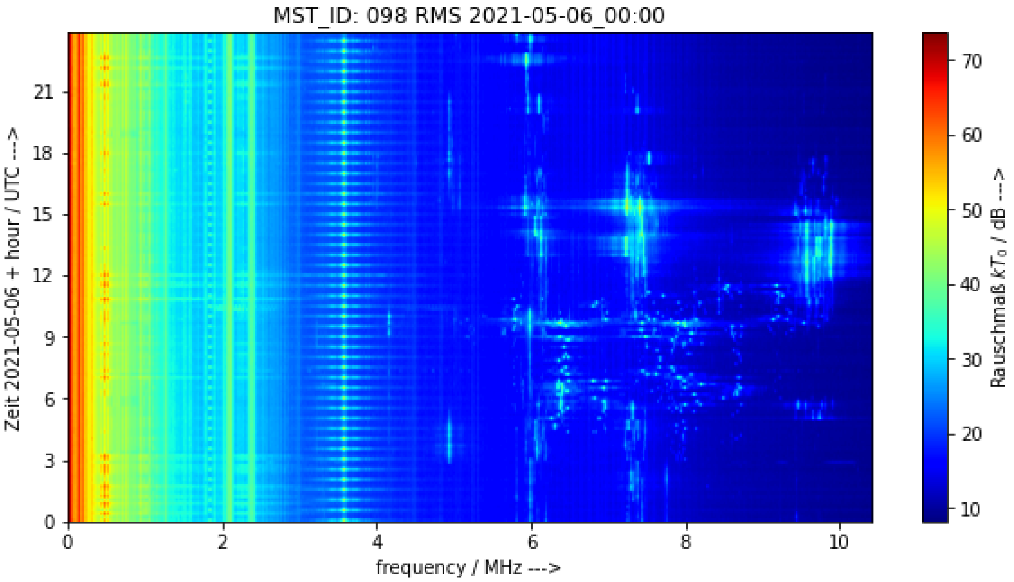

*Fig. 4.9.7: Power density spectrum relative to noise of a 50 Ω resistor*

Figure 4.9.7 shows 144 measurements of the type shown in Figure 4.9.6. These measurements are taken every 10 minutes. In the period from 11 to 17 UTC the broadcasting stations in the 41 m-band at 7.3 MHz and in the 31 m-band at 9.7 MHz reach considerable amplitudes. The measurement of Figure 4.9.6 is an excerpt of this waterfall Figure 4.9.7 at 19:30 UTC.

*Results from experiments with the new transmitter at Neumayer Station III*

In January 2020, the first beacon signal transmitter (version 1) was replaced by a new design. The objective was to enable transmissions on all eleven amateur radio bands the setup was licensed for, between 1.8 and 52 MHz. Previously, only five bands between 7 and 18 MHz could be served. Furthermore, it also should be made possible to transmit a regulated output power of 5 Watts on all bands and to continuously measure and monitor the antenna matching values (e.g. SWR). This makes it easier to compare the reception results. In addition, the new transmitter can be serviced and remotely controlled via the internet.  The new transmitter was a significant expansion of the operating options.

After the commissioning work on-site, the new transmitter (version 2) started operation with the 20 meter end-fed wire antenna on the station's roof. The initial transmission scheme provided a run through all eleven relevant bands within 30 minutes with the frequencies in the middle shortwave range (7 – 18 MHz) being serviced twice. The reason for these parameters is the vast majority of automatic reception reports expected to be in that frequency range based on the current propagation conditions via the ionosphere.

Trouble-free operation was possible until 4 June 2020. Then, through continuous monitoring of the transmission line and antenna matching, a first fault was discovered. Probably due to vibrations of the antenna tower, a connection in the impedance matching transformer became defective during the winter storms.

As a result, electrostatic discharges on the antenna caused by the snow drift could no longer be dissipated directly to the mounting mast. Fortunately, the antenna cable provided a safe galvanic path to the potential equalization ground. However, the high electrostatic voltages that occurred led to further damages to a rectifier diode in the directional coupler.

Subsequently, signals were transmitted by the alternative vertical antenna with reduced power until mid-June 2020. The defective matching transformer could be replaced during the 2020/21 summer season. In addition, its suspension was improved to make sure that no tensile forces could no longer occur at the soldering joints any more, even during violent vibrations of the tower or the antenna. The transmitter was replaced by a new unit (version 3) of the same design. Now, there are two identical beacon transmitters on-site, easing maintenance and upgrades of the hardware.

*First results of measurement campaign with the beacon transmitter*

A total of 66,420 transmission spots were generated and transmitted from March through May 2020. Of these, a total of 42,238 spots were reported from 624 receiving stations. 34 % of the receiving sites (radio amateurs) were located in the Southern Hemisphere, 66 % in the northern hemisphere, most of them in North America and Europe. The signal paths lengths varied from 3,240 km (Falkland Islands) to 18,060 km (Alaska), with an average path length of 11,030 km.

The reception reports covered nine of the eleven frequency bands used. Only for the lowest band (1.8 MHz) and the highest one (50.3 MHz) were there no reports. For 1.8 MHz, this can be explained by high noise levels in this range, which makes it difficult to detect weak signals in densely populated areas. For 50.3 MHz, the reason is the weak ionisation of the ionosphere during the current minimum of the solar activity cycle. For long-distance propagation, 99.95 % of all signal paths require at least two refractions at the earth's ionosphere.

*Analysis of the transmitter spots*

The measurement period was in the lowest phase of the sun's eleven-year-cycle. The estimated activity minimum could be observed in December 2019. The solar flux as the primary measure of solar activity fluctuated between 66 and 72 sfu (solar flux units) and thus hardly above the empirical minimum value of 64 sfu. The ionosphere received extraordinarily low ionising ultraviolet and X-ray radiation from the sun. Accordingly, the highest frequencies still refracted at noon time were usually below 20 MHz.

On the other hand, the low phase of the sun's activity cycle is characterized by few and rather weak perturbations of the earth's magnetic field, which basically supported radio wave propagation at frequencies below 5 MHz and over polar paths.

*Distribution of received spots on frequency bands*

Figure 4.9.8 shows the distribution of spots collected over several 10-day-periods from March to the end of May 2021. These measurement periods cover the transition from Antarctic autumn to winter, roughly from the equinox to the beginning of the polar night.

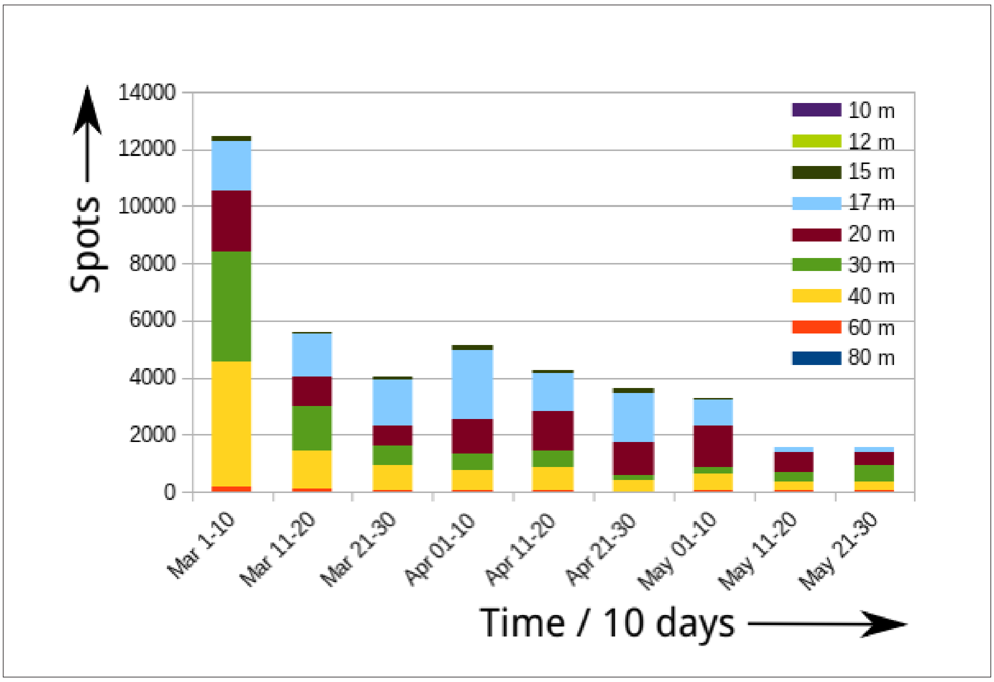

*Fig. 4.9.8: Number of spots from transmitters in 10-day bins for different wavelengths*

The distribution of the number of received spot reports across the frequency bands first indicates a sharp drop in absolute numbers when the Antarctic winter begins. The higher shortwave bands (20 m to 10 m) work particularly well on signal paths that are entirely in daylight, whereas the lower bands (80 m to 30 m) are penetrable for end-to-end night paths. With advancing darkness in Antarctica, the usable time span with reasonable propagation paths on higher bands becomes shorter and shorter, decreasing the absolute numbers and shifting the structure of usable bands.

It should be noted that the majority of spots are reported from stations in the northern hemisphere. On such paths, a radio signal must be refracted several times at the ionosphere. In theory, six “hops” are necessary for the longest distances. At each refraction point, slightly different conditions prevail. In particular, some refraction points are in sunlight, while others are in darkness.

Around the time of the equinox, the daylight/night transition zone runs approximately in the north-south direction. This means that signal paths running along this transition zone, e.g. from Europe to Antarctica, are either completely in the dark or completely in daylight. As a result, at different times of the day, either the higher shortwave band or the lower ones have advantageous propagation conditions, so that a long-range radio operation with Antarctica is possible during many hours of the day.

However, at the time of the solstice, the conditions on long signal paths are reversed. Periods of daylight on one end of the signal path meet nighttime periods on the other. Open paths can only be found along the terminator (day/night border), and that only during a comparatively short period of time.

The distribution depicted in Figure 4.9.8 shows the number of spots received over time as well as their distribution over the various frequency ranges used. A clear decrease of the total number of received spots due to the increasingly shorter propagation windows can be noticed. It also becomes evident that the lower (40 m and below) and upper shortwave bands (17 m and above) are disproportionately affected by the decline. The day/night border in the middle of a signal path interrupts the propagation in these cases.

### *Distribution of received spots on location of the receivers*

The position of the *Neumayer Station III* is at about 62° south magnetic latitude and thus close to the long-term median of the center of the southern auroral oval. Propagation to areas near the auroral zone is strongly restricted even at mid values of planetary indexes ($K < 3$) and almost impossible at high values ($K > 4$). Aurora strongly compromises shortwave propagation due to the outflow of free electrons in the ionosphere.

However, this effect is significantly reduced in northward directions because the first refraction point of northerly paths is further away from the auroral disturbance zone.

From the analysis of the spots and the magnetic activity, no strong correlations could be identified by today.

### *Surface propagation measurements*

At the end of January 2021, *Polarstern* departed for a research cruise into the Weddel Sea. This provided the opportunity for an investigation of propagation via the ground wave, which is of particular interest.

Short waves propagate from the transmitter to the receiver in three different ways:

- The direct wave, when the transmitter and receiver are within the line of sight.
- The ground wave offers signal propagation beyond the optical horizon, the signal following the curvature of the earth’s surface. There are various explanations for this phenomenon, but so far there is no generally accepted one.

- The space wave propagation allows to cover large distances. The radiated signal is reflected by the ionosphere, sending it back to earth, where it is reflected by earth's surface. This process may repeat several times.

The coverage of the surface wave is inversely proportional to the frequency used. Therefore, the lowest frequency available at 1.83 MHz was chosen for the experiment.

The investigations relate to the period from 21 to 26 January 2021. The transmitter was on the vessel *Polarstern* on its way to the Falkland Islands and therefore moved away into a west-north-westerly direction. The permanently installed receivers in the SPUSO were used together with the large loop antenna. Between *Neumayer Station III* and the *Polarstern* there was only the open ocean, apart from the ice shelf between the station and the coast. Transmissions were made with a transmitting power of five watts into a wire antenna onboard the ship.

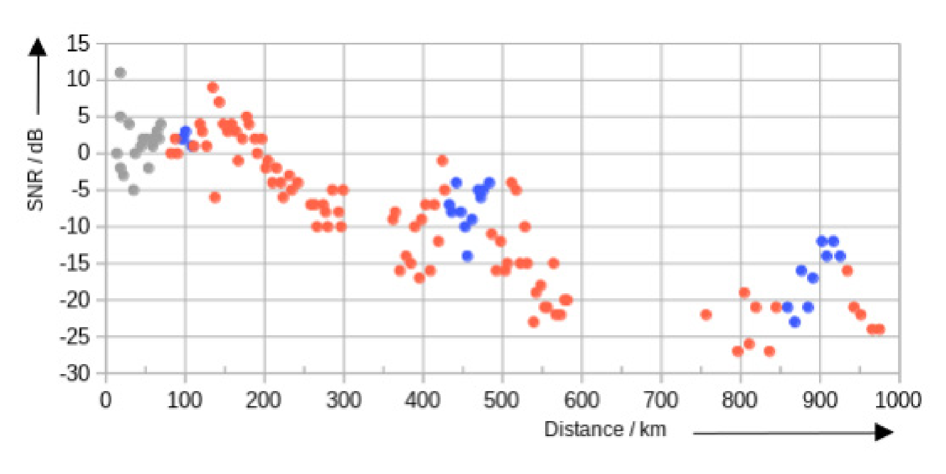

*Fig. 4.9.9: Signal-to-noise-ratio as a function of the distance between the transmitter (Polarstern) and the receiver (SPUSO) and different propagation modes (grey: direct, blue: ionospheric propagation, red: D-layer attenuation, potential ionospheric propagation)*

In Figure 4.9.9 the **grey** dots show the spots while *Polarstern* was still in the range of the direct wave. Due to the height of the receiving and transmitting antennas, this distance is about 80 kms. The **red** dots indicate the spots where there was a potential reflection point of the ionospheric wave at daylight. The attenuating D-region of the ionosphere then prevents propagation via upper layers of the ionosphere. These spots are therefore candidates for surface wave reception. Finally, the **blue** dots indicate the spots where the potential reflection point was at nighttime. The absence of sunlight dissolves the D-Layer, opening propagation to F2 propagation via the ionosphere. In these cases therefore propagation via ionosphere is possible and likely.

However, the appearance and disappearance of space wave propagation cannot be fully determined only by this simple observation; the transition is much more fluid. Therefore, receptions beyond 600 kilometers were certainly all caused by space wave propagation alone.

At sunset, when the irradiation enters the atmosphere at very shallow angles, the D-region begins to vanish even when it is still illuminated by the sun. Especially in the polar regions, the virtual course of the sun intersects the horizon at a shallow angle. It can be assumed that space wave propagation is already possible some time before sunset and also after sunrise.

Based on the results, a range of up to 300 km can be considered as secure for ground wave propagation.

The reception between 360 and 600 km distance cannot be clearly determined from these data. The practically linear decrease in signal strength leads to the assumption that the relevant propagation mode was via the ground wave, while the dropout of the reception between 300 and 360 kms rather indicates that the coverage of the ground wave already ended at 300 kms. A repetition of the experiment should bring more clarity in this respect.

*Conclusion*

With the work done so far, the transmitter and receiver hardware installed on-field was further improved and unforeseeable inadequacies and faulty components caused by the harsh environmental circumstances eliminated. This is an important step in the planned scientific work, as the project involves a long observation and measurement period.

In addition, capacities for the measurement of absolute values of noise power from all relevant sources could be established. This opens the way for interpretation and comparison with data from other locations.

With the newly installed receiver and transmitter systems, it is now possible to concentrate more intensely on the observation process itself and potentially detect new propagation phenomena. It is expected that the new sunspot cycle will begin this year and radio observations can also be extended up to the 50 MHz band as initially planned in this project.

## Data management

The data generated by the beacon receiver are saved locally on a network storage at *Neumayer Station III* as well as on a worldwide database called "wsprnet.org". This offers worldwide access via a web interface. Both offer archive functions as well as basic evaluation functionality.

The wsprnet.org archive collects all spot reports received worldwide since 2008. In May 2021, about 1.5 Million spot reports were stored per day. All spots can be downloaded with free access, compiled on a monthly basis, to a compressed CSV-file. In addition, noise measurement results and locally stored results are available on the server at *Neumayer Station III*.

In all publications based on this expedition 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.

## Acknowledgements

The authors are grateful for the help of many voluntary supporters in this project. Our warm thanks go to the radio amateurs Dipl. Ing. Rainer Englert and IT-Specialist at the DARC Christian Reiber for setting up and tuning the transmitter and receiver hardware, as well as preparing the TX-antenna in Germany. Christian Reiber played a major role in the drafting the report on the work and results about the transmitter. Jörg Logemann developed and prepared the active antenna and set up a simulation programme with great enthusiasm. Dr. Jörg Hofmann enabled the radio experiments with the transmitter on *Polarstern* with great commitment. Special thanks also go to Felix Riess, Andreas Müller, Roman Ackle, Theresa Thoma, and several researchers at *Neumayer Station III*, unknown to us, who set up and repaired the antennas and commissioned the transmitter and receiver systems on-site with untiring commitment.

## References

Hartje M & Walter U (2020) WSPR RADIO beacon at Neumayer Station III for evaluation of southern hemisphere radio propagation. In: https://doi.org/10.2312/BzPM_0745_2020 S. 43-50.

ITU Recommendation ITU-R P.372-14 (08/2019) https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.372-14-201908-I!!PDF-E.pdf.

## 4.10 VACCINE (Variation in Antarctic Cloud Condensation Nuclei (CCN) and Ice Nucleating Particle (INP) Concentrations at *Neumayer Station III*

S. Henning[1] (not in field), R. Weller[2], L. Ort[2], J. Loftfield[2], M. Schumacher[2], F. Stratmann[1] (not in field)

[1]TROPOS
[2]AWI

### Objectives

The Earth's current climate is changing more rapidly than has been predicted in most scientific forecasts, with the Polar Regions being the fastest warming areas on Earth. Polar regions have also a strong global impact on climate conditions and therefore affect lives and livelihoods across the world. Despite the progress polar climate research made, poorly understood processes remain, one of those being the aerosol – cloud – climate interaction, which still cannot be modelled satisfactorily. Clouds and the interactions with the climate system are one of the most difficult components to model, especially in the polar regions. This is, among others, due to difficulties in obtaining high-quality measurements. The availability of high-quality measurements is therefore of crucial importance for understanding processes and for driving and / or evaluating atmospheric models and one of the main objectives of VACCINE. In the ANT-Land 2020/21 season TROPOS continued the *in-situ* Cloud Condensation Nuclei (CCN) and Ice Nucleating Particles (INP) measurements which were launched in the last season at *Neumayer Station III*. The captured data such as number concentrations, hygroscopicity, INP freezing spectra etc. will be linked with meteorological information (e.g. back trajectories) and information on the chemical composition of the prevailing aerosol particles for identifying sources of INP and CCN (secondary *vs*. primary) and transport pathways (local vs. long-range transport) over the full annual cycle. A result of this project will be a deeper understanding which processes dominate the CCN and INP population in high latitudes.

### Fieldwork

Starting with the austral summer season ANT-Land 2019/20 CCN-measurements are carried out at the AWI Air Chemistry Observatory with a commercially available CCN instrument (Roberts and Nenes 2005). With the instrument total CCN number concentrations can be determined as function of supersaturation in the range between 0.1 and about 1 %. The instrument was installed at the observatory in December 2019 (Fig. 4.10.1, left) and has been measuring continuously since then. The remote access to the CCN proofed stable, allowing performance checks of the instrument from TROPOS. The daily / weekly on-site maintenance is being carried out by AWI-staff.

Besides CCN also INP sampling was established, using the low volume filter sampling setup available in the AWI Air Chemistry Observatory (Fig. 4.10.1, right). These activities aim at the number concentrations of INP in the air, active at temperatures above –25° C. Filter samples are collected on polycarbonate filters and immediately frozen for later analysis in the TROPOS laboratories (Wex et al. 2019). The weekly filter change and handling is done by the overwinterer, as well. These samples are the first ever collected for INP analysis at Dronning Maud Land in Antarctica which will span the whole annual cycle. The INP analysis of the first set of filters has just been finished, while the second season of filters just arrived with *Polarstern*.

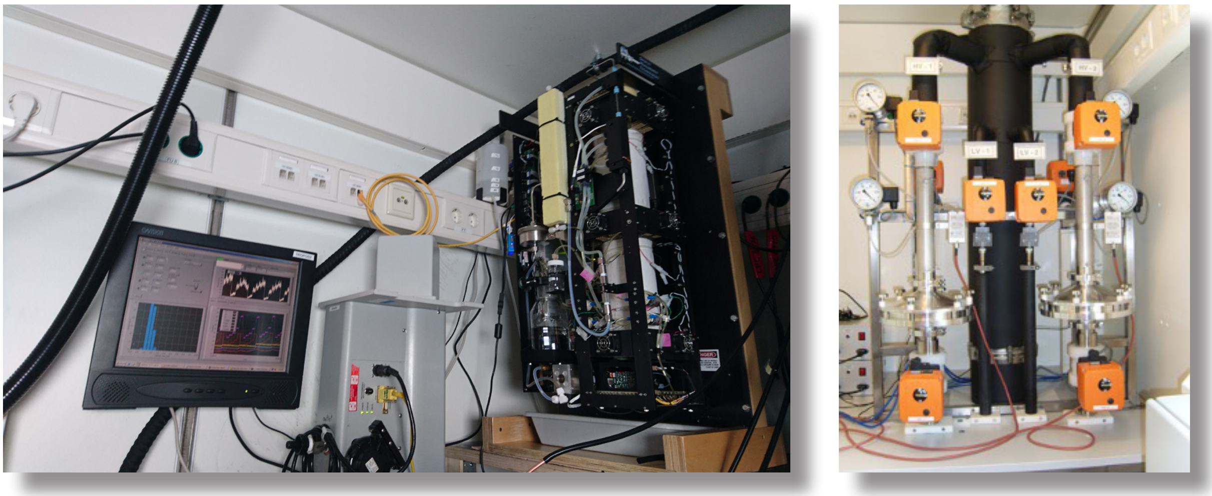

*Fig. 4.10.1: CCN instrument (left) and the LV sample setup (right) as installed in the AWI Air Chemistry Observatory at Neumayer Station III; both units sample at the same whole air inlet as the other aerosol instrumentation, which is situated on top of the measurement container.*

## Preliminary results

The CCN instrument measures CCN number concentrations at 5 different supersaturations. Combined with the particle number size distribution measurements, the particle hygroscopicity can be derived (Petters & Kreidenweis 2006). Running continuously since December 2019, the first full annual cycle of CCN data for *Neumayer Station III* has been gained (Fig. 4.10.2). Number concentrations in general are low and a clear annual cycle is found for CCN as well as for the total particle number (CN). Lowest number concentrations are observed in austral winter months May to August with 10 cm$^{-3}$ at e.g. the supersaturation of 0.1 % (August) and a CN concentration of 60 cm$^{-3}$ (May). In January meanwhile CCN at 0.1 % went up to 90 cm$^{-3}$ and CN to 610 cm$^{-3}$.

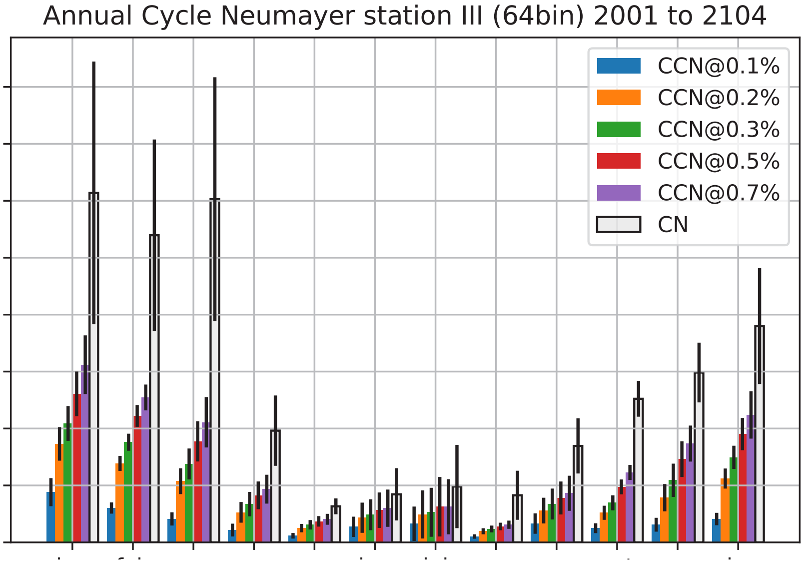

*Fig. 4.10.2: Annual cycle of the number concentration of cloud condensation nuclei between 0.1 % and 1 % supersaturation and the total particle concentration CN. The current data set ranges from December 2019 until April 2021.*

New particle formation events were observed during the summer months. Some of them were followed by particle growth into the CCN diameter range. April is a transition month between summer and winter state. While the ratio between winter and summer concentrations is about 10 for both CCN and CN, for April the ratio to the summer values is only 3 for CN, but 4.5 for CCN. In April new particle formation events do still occur, but might not be followed by particle growth to CCN sizes anymore. Also, the hygroscopicity parameter exhibits an annual cycle, with rather low values ranging in January from 0.3 at 0.7 % to 0.6 at 0.1 % supersaturation suggesting a strong influence of organic material for the smaller particles. In winter the particle hygroscopicity was on average much higher – around 1 – for all supersaturation which might be caused by an increasing influence of long-range transport to the station and thereby aged particles.

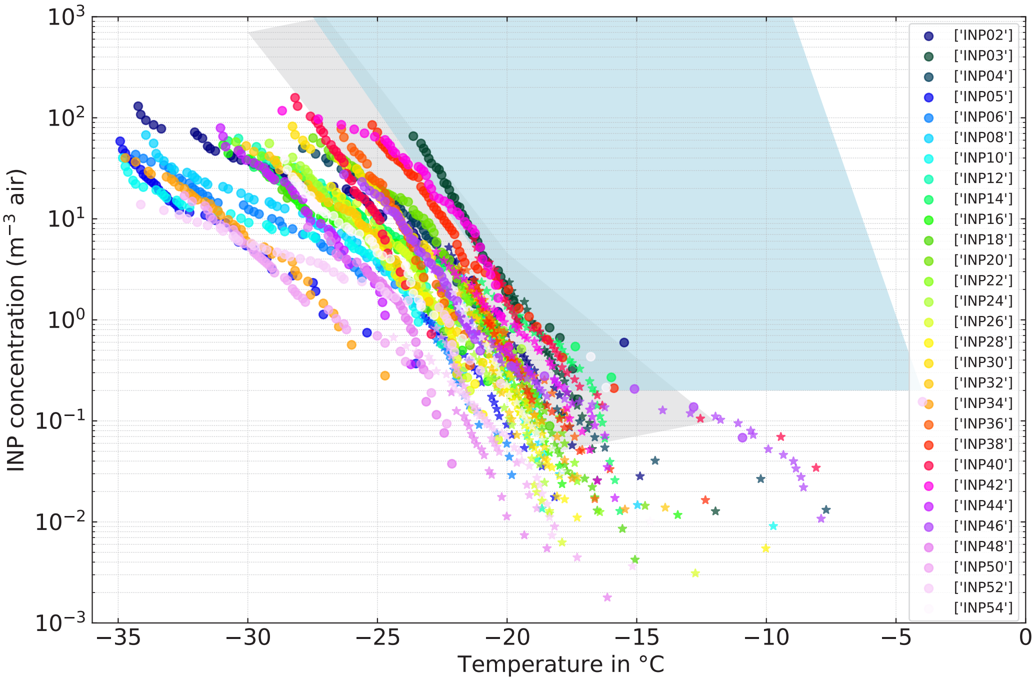

*Fig. 4.10.3: INP freezing spectra (blue area: Welti et al. 2020, grey area: McCluskey et al. 2018); sample period ranges from Feb 2019 until Feb 2020 with weekly to biweekly resolution.*

The off-line analysis of the filter samples for INP freezing spectra for the first season has just been finished recently (Fig. 4.10.3). In general, the INP concentrations are very low even compared to other measurements in the southern hemisphere (blue area: Welti et al. 2020, grey area: McCluskey et al. 2018). As a preliminary result only very few samples are ice active at temperatures warmer than –15° C, which might point towards the absence of biological INP sources in the region. The INP freezing spectra will in the further course of the project be linked with meteorological information and information on the chemical composition of the prevailing aerosol particles for identifying sources of INP and CCN over the full annual cycle.

All results are preliminary and will be followed up by an in-depth analysis including a backward trajectory analysis. A further approach applied for source identification will be the potential source contribution function (PSCF), which is a receptor modelling method that is based on air mass back trajectories. The PSCF (Ashbaugh et al. 1985) has been successfully applied to high-latitude studies in the Antarctic (Dall´Osto et al. 2017). This model is commonly used to identify regions that have the potential to contribute to high values of measured concentrations at a receptor site.

## Data management

CCN raw data are transferred daily from the instrument to the data server at *Neumayer Station III* and from there to the TROPOS server via cronjobs. After their analysis the INP data, will be stored in a long-term archive at TROPOS. Furthermore, the processed CCN and INP data, quality controlled (level 2) data will be archived, published and disseminated after first analyses and/or publication according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de). By default, the CC-BY license will be applied.

In all publications based on this expedition 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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## 4.11 EDEN ISS – Greenhouse in Antarctica

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### Objectives

Sustained human presence in space requires the development of new technologies to maintain environmental control, to manage wastes, to provide water, oxygen, food and to keep astronauts healthy and psychologically fit. Bio-regenerative life support systems, in particular the cultivation of higher plants, are advantageous from this regard due to their ability to be employed for food production, carbon dioxide reduction, oxygen production, water recycling and waste management. Furthermore, fresh crops are not only beneficial for human physiological health, but also have a positive impact on crew psychological well-being.

The EDEN ISS project (Zabel et al. 2015) was a 4.5 M€ European Union Horizon 2020 project (reference number: 636501) supported via the COMPET-07-2014 - Space exploration – Life support subprogramme. It had its official kick-off in March of 2015 and ended in April 2019 after the completion of a year-long Antarctic deployment phase in which the EDEN ISS greenhouse system was installed and operated in the vicinity of the *Neumayer Station III*. The EDEN ISS consortium was comprised of leading European experts (in addition to Canada and the USA) in the domain of human spaceflight and controlled environment agriculture (CEA). The EDEN ISS scientific advisory board consisted of the top scientists in the field of space greenhouses from Russia, USA, Japan, Italy and Germany.

The EDEN ISS greenhouse, or Mobile Test Facility (MTF), has been designed to provide fresh produce for overwintering crews at the *Neumayer Station III* in the Antarctic while at the same time advancing the spaceflight readiness of a number of key plant growth technologies. The greenhouse also serves as a tool to develop operational procedures and select science aims associated with remote plant production. The greenhouse consists of two 20 foot high cube containers, which have been placed on top of an external platform located approximately 400 m south of *Neumayer Station III*. The actual system can be subdivided into three distinct sections:

- Cold porch/airlock: a small room providing storage and a small air buffer to limit the entry of cold air when the main access door of the facility is utilised.
- Service Section (SES): houses the primary control, air management, thermal control, nutrient delivery systems of the MTF as well as the full rack ISPR plant growth demonstrator.
- Future Exploration Greenhouse (FEG): the main plant growth area of the MTF, including multilevel plant growth racks operating in a precisely controlled environment.

The design of the EDEN ISS greenhouse is presented in detail in the following publications Boscheri et al. (2016), Vrakking et al. (2017), and Zabel P et al. (2017).

During the 2018 overwintering period, the EDEN ISS consortium tested essential CEA technologies using an International Standard Payload Rack (ISPR) cultivation system for potential testing on-board the International Space Station (ISS). Furthermore, the FEG was designed with a focus on larger scale bio-regenerative life support systems for planetary surfaces (e.g. Moon, Mars). In addition to technology development and validation, food safety and plant handling procedures were, and will be, developed and tested in Antarctica. These are integral aspects of the interaction between the crew and plants within closed environments.

Due to the necessity of validating key technologies for space greenhouses under mission relevant conditions and with representative mass flows, the EDEN ISS consortium defined six objectives:

1. Manufacturing a space analogue Mobile Test Facility.
2. Integration and test of an International Standard Payload Rack plant cultivation system for future tests on-board ISS and a Future Exploration Greenhouse for planetary habitats.
3. Adaptation, integration, fine-tuning and demonstration of key technologies.
4. Development and demonstration of operational techniques and processes for higher plant cultivation to achieve safe and high-quality food.
5. Study of microbial behaviour and countermeasures within plant cultivation chambers.
6. Actively advancing knowledge related to human spaceflight and transformation of research results into terrestrial applications.
7. Although the project officially ended, the German Aerospace Center (DLR) and the Alfred-Wegener Institute agreed to continue operation of the EDEN ISS facility at the *Neumayer Station III* through 2020 and beyond.

### Fieldwork

*ANT-Land 2019/20 Neumayer Station III summer field season*

A detailed overview of EDEN ISS related activities carried out by members of the German Aerospace Center during the ANT-Land 2019/20 summer season has been documented in the previous year's ANT-Land report (Vrakking et al. 2020).

*Nominal Operations Phase – 2020/21 Neumayer Station III winter season*

For the ANT-Land 2020/21 winter field season, operational activities were carried out by the regular overwintering crew. In the absence of a dedicated operator, scientific activities were reduced throughout the season, in an attempt to limit the required crew effort. Remote support was provided by the consortium partners to assist the overwinterers in the operation of the greenhouse.

The EDEN ISS greenhouse was in operation since 2 January 2020, when the overwinterers, together with the summer season expedition crew members of the German Aerospace Center, carried out the initial sowing operations in the greenhouse. In contrast to previous years this enabled hands-on instruction of the overwinterers with respect to plant cultivation techniques and, furthermore, enabled the first harvests of fresh edible biomass already at the end of January, before the departure of the summer season expedition crew.

Once the summer season had ended, the overwintering crew took over all activities within the greenhouse, in addition to their regular scientific, and station maintenance, work load.

Most of the time needed for operations of the EDEN ISS greenhouse was dedicated to nominal operational and maintenance activities, such as:

- Seeding of various crops,
- Transferring juvenile plants from germination area to cultivation trays,
- Pruning/training of fruiting crops, such as tomatoes and cucumbers,
- Harvesting of various crops, starting with radish on the 25 January 2020,
- Cleaning and desinfection of surfaces, filters and tanks,
- Exchange of consumables (e.g. filters, oxygen tablets, ozone cells),
- Regular (weekly) tele-cons with remote operations team in Bremen,
- Emptying waste water tanks and refilling fresh water tanks,
- Preparation and exchange of nutrient stock solutions,
- Preparation and exchange of acid and base supply,
- Sensor calibration,
- Repair and exchange of thermal control system actuators,
- Cleaning and repair of thermal control system piping leaks,
- Cleaning and exchange of misting nozzles in the aeroponic plant cultivation trays, and
- Repair and exchange of pumps.

In total 324,1 kg of fresh food was produced for the overwintering crew between January and December 2020, with the final harvest occurring on 22 December. Valuable additional knowledge was gained about the operation of the greenhouse with non-specialists and non-scientific personnel. This resulted in improved operation procedures, communication and control software. Furthermore, technical issues were observed that need to be improved in order to optimise the operation of the greenhouse, so that more food can be produced with less resources.

In parallel to the operations on-site at *Neumayer Station III* data evaluation, documentation and publication of the scientific data from the previous winter season were continued by the EDEN ISS partners. Details are provided in a later section.

*ANT-Land 2020/21 Neumayer Station III summer field season*

During the 2020/21 summer season one project member from the German Aerospace Center, along with a dedicated EDEN ISS overwinterer from NASA, travelled to the Antarctic to carry out maintenance and repair work, and to install upgrades to the facility. Although the focus was primarily on routine activities, such as cleaning, sensor calibration, filter exchange and training of the overwinterers, a number of upgrades and changes were implemented as well.

In particular, two of the plant cultivation levels were removed from the Future Exploration Greenhouse to provide more space for tall-growing, fruit-bearing crops such as tomatoes and peppers. Furthermore, special plant cultivation hardware developed by NASA was installed in the Future Exploration Greenhouse (FEG) in order to test its performance throughout the 2021 experiment phase. New filters, developed by the University of Florida, were also installed on the multi-spectral plant imaging cameras as part of ongoing research into plant health monitoring systems.

Due to the CoViD-19 pandemic, the regular flights to the Antarctic were cancelled, and transport of the summer season expedition crew was carried out via ship with *Polarstern*. The EDEN ISS team left Bremerhaven on 20 December 2020 and arrived at the *Neumayer Station III* on 19 January 2021. The summer season expedition crew, along with the 2020 overwintering crew, left *Neumayer Station III* on 19 March 2021. During the two months at *Neumayer Station III*, the following work was carried out with respect to the EDEN ISS project:

- Facility inspection and status documentation,
- Microbial sampling within the facility,
- Cleaning of the facility in preparation of maintenance and repair work,
- Cleaning of the Nutrient Delivery System (NDS) piping with hot water,
- Desinfection of the FEG using the TransMADDs system,
- Exchange of consumables (e.g. $CO_2$ canisters, filters),
- Replacement of the gas concentration measurement system of the EDEN ISS safety system,
- Testing of the EDEN ISS safety system (gas concentration and smoke sensors),
- Preparation of return freight, and documentation, for ship transport to Europe,
- Exchange of multi-spectral imaging camera filters,
- Preparation of nutrient solution for initial plant cultivation,
- Repair of a leak in the Thermal Control System (TCS) piping,
- Refilling of cooling fluid in the TCS piping,
- Preparation of plant scheduling for the summer and winter field seasons,
- Organisation of newly arrived cargo,
- Initial teach-in of the 2020/21 winter field season overwinterers,
- Initial seeding of the FEG,
- Replacement of NDS high pressure pumps,
- Cleaning and reconfiguration of aeroponic plant cultivation trays,
- Replacement of NDS sensors and calibration of new sensors,
- Replacement of tubing and connectors for NDS acid and base supply,
- Inspection and cleaning of the Atmosphere Management System (AMS) cooling coil,
- Replacement of AMS condensate water recovery loop UV lamp,
- Preparation of nutrient salt mixtures for the winter field season,
- Replacement of the AMS cooling coil UV lamp,
- Inventory of consumables and equipment in the MTF, the multi-purpose laboratory and the various storage areas,

- Repair of insulation around the main entrance door
- Backup of data from the previous winter field seasons,
- Preparation of documents for the winter field season (e.g. procedures, task lists),
- Continued training of the winter field season crew,
- Fuse switch exchange in the Power Control and Distribution System with the aid of the AWI electrician, and
- Safety briefings for the winter field season crew.

For the ANT-Land 2020/21 winter field season, operational activities will be carried out by the dedicated EDEN ISS overwinterer from NASA. Remote support will be provided by the consortium partners to assist with EDEN ISS-related activities.

### Preliminary (expected) results

Detailed analysis of the data and samples from the previous operations phases is still ongoing. However, some preliminary results have already been collected and are described below.

Aside from the data which had previously been published, such as the performance of the Plant Health Monitoring system (Zeidler et al. 2019), the impact of plants on crew well-being (Schlacht et al. 2019), crew time measurements (Zabel et al. 2019), biomass production (Zabel et al. 2020), microbiological measurements (Fahrion et al. 2019), and ISPR plant cultivation system performance (Boscheri et al. 2019), a number of new publications have been prepared based on results from the Antarctic operations phases.

General experience gained with respect to the greenhouse operations and the performance of the different technical aspects of the design was used, and will be used in the future, to develop the design concept for a greenhouse for Moon and Mars (Maiwald et al. 2020). With the aim to develop and build an improved greenhouse demonstrator by 2025, the failures and non-optimal design aspects of the EDEN ISS greenhouse will be reviewed and adjustments will be made to the various systems in order to improve performance and reliability, and reduce the amount of crew time needed for nominal and off-nominal operations.

Additional information on the Plant Health Monitoring system, specifically the multi-spectral cameras and the associated image processing, was published (Tucker et al. 2020). Furthermore, new research into the use of machine learning for Controlled Environment Agriculture was initiated. Initial results on image compression and plant classification have been published (Nesteruk et al. 2021). The ultimate goal is to implement an artificial intelligence which can autonomously analyse images taken by the Plant Health Monitoring system, identify the plant type and cultivar in the image and identify the health and age of the plant to then provide instructions to the crew with respect to horticultural activities.

Additional publications regarding crew time, crew work load and energy consumption, among other topics, are in various stages of the publication process.

*Fig. 4.11.1: Germinating plants in the Future Exploration Greenhouse in January 2020*

*Biomass production*

Table 4.11.1 shows the amount of biomass harvested each month during the 2020 operations phase. As mentioned previously, the facility was already put into operational mode at the beginning of January, with first sowing occurring on 2 January. Figure 4.11.1 shows the first germinating plants on 12 January First harvest occurred at the end of January and the last harvest occurred on 22 December. Only part of the available cultivation area of the MTF was used during the months of October and November due to a lack of sufficient nutrient salts, as well as to reduce crew time demand in preparation of the upcoming summer field season. In total, around 324,1 kg of fresh edible biomass was harvested.

**Tab. 4.11.1:** Monthly fresh biomass harvest during the 2020 winter season

| Month | Biomass Yield [kg] |
|---|---|
| January | 2,86 |
| February | 26,00 |
| March | 38,27 |
| April | 41,08 |
| May | 31,96 |
| June | 51,24 |
| July | 20,31 |
| August | 25,86 |
| September | 28,92 |
| October | 31,96 |
| November | 11,57 |
| December | 14,05 |

Based on feedback from the first operations phase in 2018 and 2019, the variety of cultivars available for cultivation in the MTF had been greatly increased for the 2020 winter season. However, for many of these new cultivars no laboratory testing had been done to determine optimal growing conditions and as such some of the new crops did not yield significant edible biomass, thereby reducing the average yield per cultivation area. Additionally, it was found that the germination rate of the seeds, especially those which had been brought to the Antarctic during the first EDEN ISS summer season expedition in December 2017, was significantly lower than the germination rate in previous years. As a result, new seeds as well as a dedicated refrigerator for improved seed storage, were brought to the *Neumayer Station III* during the ANT-Land 2020/21 summer season.

*Crew time and work load*

For the 2020 mission, the overwintering crew of the *Neumayer Station III* was asked to track the amount of time which was spent on activities related to the operation of the MTF. These activities included regular communication with the project team at DLR, nominal operations in the facility such as cleaning, seeding and harvesting, as well as off-nominal activities in case of, for example, component failures. The maximum amount of time needed by the crew per month during the 2020 winter season was 108,5 hours in March. For the other months, the time was 75 hours or less either due to a reduced amount of plant handling activities and/or fewer off-nominal events.

Aside from crew time, members of the 2019 and 2020 winter field season crews were asked to complete an assessment of the work load related to their activities in the EDEN ISS greenhouse. The results of the crew time and work load investigations are currently going through the review process for two separate journal publications. Additional data will be collected during the 2021 winter field season.

*Psychological investigations*

Due to the limited winter crew size of 10 people, the psychological investigations, carried out in 2018, to determine the impact of the greenhouse and fresh produce on crew wellbeing did not yield statistically significant results. Based on anecdotal evidence the general impact of the greenhouse was found to be positive, and in particular the olfactory experience within the greenhouse was explicitly mentioned as a positive aspect.

The ANT-Land 2019/20 winter field season crew participated in a number of psychological and medical investigations and studies. Results from these investigations should add to the data previously collected and allow for more accurate and significant determination of the impact of the EDEN ISS greenhouse on crew wellbeing. For 2021 the questionnaire for the psychological investigations has been reworked to align more closely with the questionnaires used by NASA for astronauts.

## Data management

All data collected and generated by this project will be published in open access journals and/or submitted to a public database (https://zenodo.org/communities/edeniss).

In all publications based on this expedition 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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Boscheri G, et al. (2019) EDEN ISS Rack-like food production unit: results after mission in Antarctica. 49th International Conference on Environmental Systems, Boston, Massachusetts, United States.

Fahrion J, et al. (2019) Microbial Monitoring in the EDEN ISS greenhouse, a mobile test facility in Antarctica. Extreme Microbiology in Frontiers in Microbiology.

Maiwald V, et al. (2020) From ice to space: a greenhouse design for Moon or Mars based on a prototype deployed in Antarctica. CEAS Space Journal, Springer, https://doi.org/10.1007/s12567-020-00318-4, ISSN 1868-2502.

Nesteruk S, et al. (2021) Image Compression and Plants Classification Using Machine Learning in Controlled-Environment Agriculture: Antarctic Station Use Case. IEEE Sensors Journal, 1–1, https://doi.org/10.1109/JSEN.2021.3050084.

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Zeidler C, et al. (2019) The Plant Health Monitoring System of the EDEN ISS Space Greenhouse in Antarctica during the 2018 Experiment Phase. Front. Plant Sci. 10:1457, https://doi.org/10.3389/fpls.2019.01457.

Schlacht I, et al. (2019) Impact of Plants in Isolation: The EDEN-ISS Human Factors Investigation in Antarctica. In: Stanton, N. (eds), Advances in Human Factors of Transportation. AHFE 2019. Advances in Intelligent Systems and Computing, vol. 964, Springer, Cham. https://doi.org/10.1007/978-3-030-20503-4_71.

## 4.12 ISO-ANT – Water Vapour Isotope Research in the Antarctic

Saeid Bagheri Dastgerdi[1] (not in field),
Melanie Behrens[1] (not in field),
Maria Hörhold[1] (not in field),
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[1]AWI

### Objectives

Stable isotopes of water are fundamental for the understanding of the modern hydrological cycle and key parameters for the reconstruction of past climate changes, e. g. from Antarctic ice cores. For several decades, related isotope research projects were focussed on snow and ice samples as end member products of the hydrological cycle only. Vapour measurements in the field were most difficult to perform. Since very recently the isotopic composition of water vapour can be measured with necessary precision by commercially available light-weighted cavity-ring-down spectrometers (CRDS). With the CRDS, the isotope content of the water vapor in the air can be analysed directly under *in-situ* conditions at any place or platform almost autonomously, thus also at remote stations in the Arctic or Antarctic.

The overall goal of the project Iso-Ant, funded by the Helmholtz Climate Initiative Regional Climate Change (REKLIM), is a first-time detailed detection and description of the isotopic composition of water vapour transported to the vicinity of AWI's *Neumayer Station III*. In combination with correspondent isotope measurements on board of *Polarstern* and the well-established long-term isotope measurements of snow samples from *Neumayer Station III*, these new isotope measurements will allow for a unique simultaneous data set of $H_2^{18}O$ and HDO directly above the ocean surface and after transport to the Antarctic continent. Observational data will be paired with complementing climate simulations using atmospheric circulation models enhanced by explicit water isotope diagnostics. Combined analyses of model results and measured data will provide an improved basis to understand Antarctic climate variability and its imprint in firn and ice cores.

### Fieldwork

During the campaign ANT-Land 2016/17 a CRDS instrument was successfully installed at *Neumayer Station III* (Bagheri Dastgerdi et al. 2019). Since the installation of the instrument, automatic, continuous isotope analyses of atmospheric water vapour are conducted at *Neumayer Station III* in Dronning Maud Land, Antarctica. During the field season of ANT-Land 2020/21 necessary maintenance work on the instrument was done. This includes the exchange of spare parts and re-calibration of the instrument to ensure the automatic, continuous isotope analyses of the atmospheric water vapour for at least another 12 months.

### Preliminary (expected) results

Combining the results of isotopic measurements in vapour with meteorological data and climate simulations using two versions of a general circulation model of the atmosphere with explicit isotope diagnostics (ECHAM5-wiso, ECHAM6-wiso) enables a unique quantitative assessment of the isotopic signature of the Antarctic water cycle. First analyses results, which are under review for a scientific publication in the journal The Cryosphere, can be summarised as follows:

A first fully-continuous monitoring of water vapour isotopic composition at *Neumayer Station III*, Antarctica, during the two-year period February 2017 to February 2019 is presented (Fig. 4.12.1).

Seasonal and synoptic-scale variations of both stable water isotopes $H_2{}^{18}O$ and HDO are reported, and their link to variations of key meteorological variables is analysed. Changes in local temperature and humidity are the main drivers for the variability of $\delta^{18}O$ and δD in vapour at *Neumayer Station III*, both on seasonal and shorter time scales. In agreement with previous studies in other regions in Antarctica, in summer, the correlation coefficient between humidity and $\delta^{18}O$ is higher than the one between temperature and $\delta^{18}O$ at *Neumayer Station III*. In contrast to the measured $\delta^{18}O$ and δD variations, no clear seasonal cycle in the Deuterium excess signal *d* in vapour is detected. However, a rather high uncertainty of measured *d* values especially in austral winter limits the confidence in this finding.

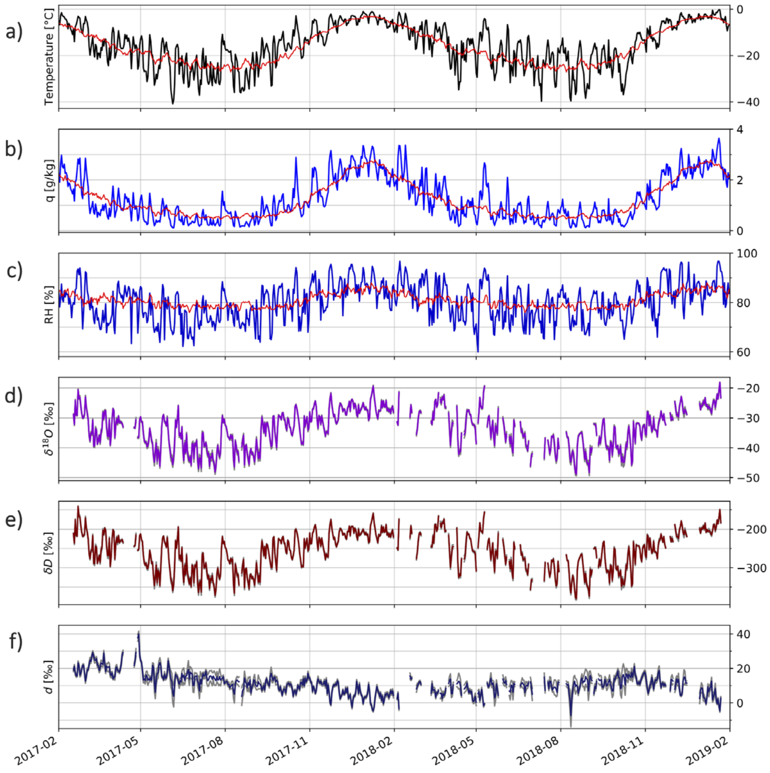

*Fig. 4.12.1. Daily averaged observations at Neumayer Station III from February 2017 to January 2019; downward: a) 2-m temperature (°C); b) specific humidity ( g kg$^{-1}$); c) relative humidity (%); d) $\delta^{18}O$ (‰); e) δD (‰); f) Deuterium excess d (‰). To have a better comparison, the climatology (multi-year daily average temperature, specific humidity, and relative humidity over the 38-year period from 1981 to 2018) is shown with a red line in meteorological observations. The determined uncertainties of the Picarro instrumental data are plotted as grey lines.*

On the diurnal time scale, strong daily cycles in 2-meter temperature, 10-meter temperature, specific humidity, and relative humidity are detected (Fig, 4.12.2). For wind speed, the diurnal cycle is weak and for wind direction no diurnal cycle is detectable. A clear diurnal cycle can be detected for $\delta^{18}O$, δD, and Deuterium excess *d*. A very high correlation coefficient between $\delta^{18}O$ and 2-meter temperature ($r = 0.98$) and 10-meter temperature ($r = 0.99$) suggests that the temperature changes are the main driver of water vapour $\delta^{18}O$ diurnal variations. The Deuterium excess *d* is rather anti-correlated with relative humidity ($r = -0.59$), while it does not show a considerable correlation with temperature and specific humidity. The 2- and 10-meter temperature cycles and consequently $\delta^{18}O$ and δD follow the incoming shortwave radiation with a short delay (about 3 hours) showing the minimum and maximum values at 03:00 UTC (local time) and 15:00 UTC. The relative humidity behaves inversely, showing the minimum value at 15:00 UTC and maximum values between 21:00 UTC and 03:00 UTC. *d* has its daily minimum (maximum) at 00:00 UTC (09:00 UTC).

The summer isotope data from *Neumayer Station III* have been compared to similar measurements performed at *Kohnen Station* (Ritter et al., 2016) and *Dumont d'Urville Station* (Bréant et al., 2019). For all three locations, specific humidity is stronger correlated with $\delta^{18}O$ than temperature, but for completely different reasons. Whereas *Dumont d'Urville Station* is strongly influenced by katabatic winds, which advect cold and isotopically depleted air from the continent to the base, *Kohnen Station* is situated on the East Antarctic Plateau in a dry and cold climate very different from conditions at *Neumayer Station III*. While temperature changes play a main role in diurnal cycles at *Neumayer Station III* and *Kohnen Station*, at *Dumont d'Urville Station* katabatic wind is the key control for driving diurnal cycles.

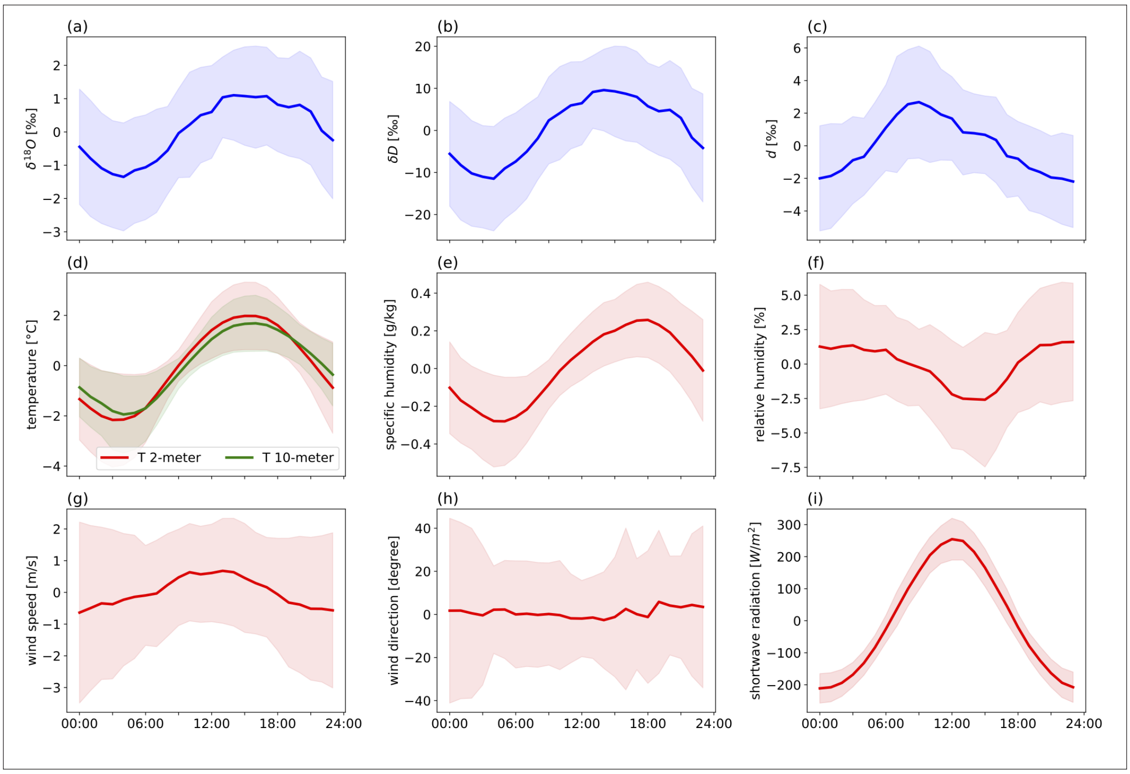

*Fig. 4.12.2: Anomaly diurnal cycles of (a) $\delta^{18}O$ (‰), (b) δD (‰), (c) d (‰), (d) 2-meter temperature and 10-meter temperature (°C), (e) specific humidity (g $kg^{-1}$), (f) relative humidity (%), (g) wind speed (m $s^{-1}$), (h) wind direction (degree), (i) shortwave downward radiation (W $m^{-2}$), and their ±1σ standard deviations for two months of two consecutive summers (December–January of 2017/18 and 2018/19). Blue colour shows the Picarro instrument measurements and red (and green) colour shows meteorological observations at Neumayer Station III. All data are in local time (UTC time zone).*

## Data management

All data will be archived, published and disseminated after quality control, first analyses and/or publication according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de). By default, the CC-BY license will be applied.

In all publications based on this expedition 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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## 4.13 MICA-S – Magnetic Induction Coil Array – South

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[6]GFZ

### Objectives

The objective is to continuously observe geomagnetic pulsations at *Neumayer Station III*. The geomagnetic latitude of *Neumayer Station III* is ideally suited to investigate so-called electromagnetic ion cyclotron (EMIC) waves near the plasmapause by observing these pulsations. EMIC waves are naturally occurring electromagnetic waves in near-Earth space that can cause loss processes for particles in Earth's radiation belts as well as the ring current and are therefore relevant for space radiation processes and risks to spacecraft. They are studied with ground and satellite magnetometers and often in conjunction with each other. Both fluxgate and induction magnetometers can be used, although the latter are preferred. Therefore, the MICA-S induction magnetometer at *Neumayer Station III* is relevant for scientific satellite missions like ESA's Swarm mission, NASA's Van Allen Probes, or JAXA's ARASE (ERG) satellite. Also of great importance is a coordinated ground observation effort at both hemispheres and especially at high latitudes.

### Fieldwork

New snow constantly accumulates on top of the instrument pit, which therefore becomes deeper over time. Once a year, we remove the upper layer of snow from the wooden plates on top of the pit and reinstall the cover at snow surface. Now the coils are approximately 5 m below the surface.

### Preliminary (expected) results

Figure 4.13.1 shows an example of geomagnetic pulsations at *Neumayer Station III* (VNA) and other high latitude stations. It demonstrates both the quality of the data from the instrument installed at *Neumayer Station III* and shows that the signal is to some extent coherent with that at other stations in Antarctica and the Arctic, capturing important wave activities peculiar at certain geomagetic latitudes.

Since its installation in January 2018, results from MICA-S have been published by Salzano et al. (2019), Kim et al. (2019), Kim et al. (2020), and Kim et al. (2021).

### Data management

Data (plots and cdf-files) is currently freely distributed through http://mirl.unh.edu/ulf_status.html. Data will also be curated either at AWI or GFZ and will receive a DOI.

In all publications based on this expedition 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.

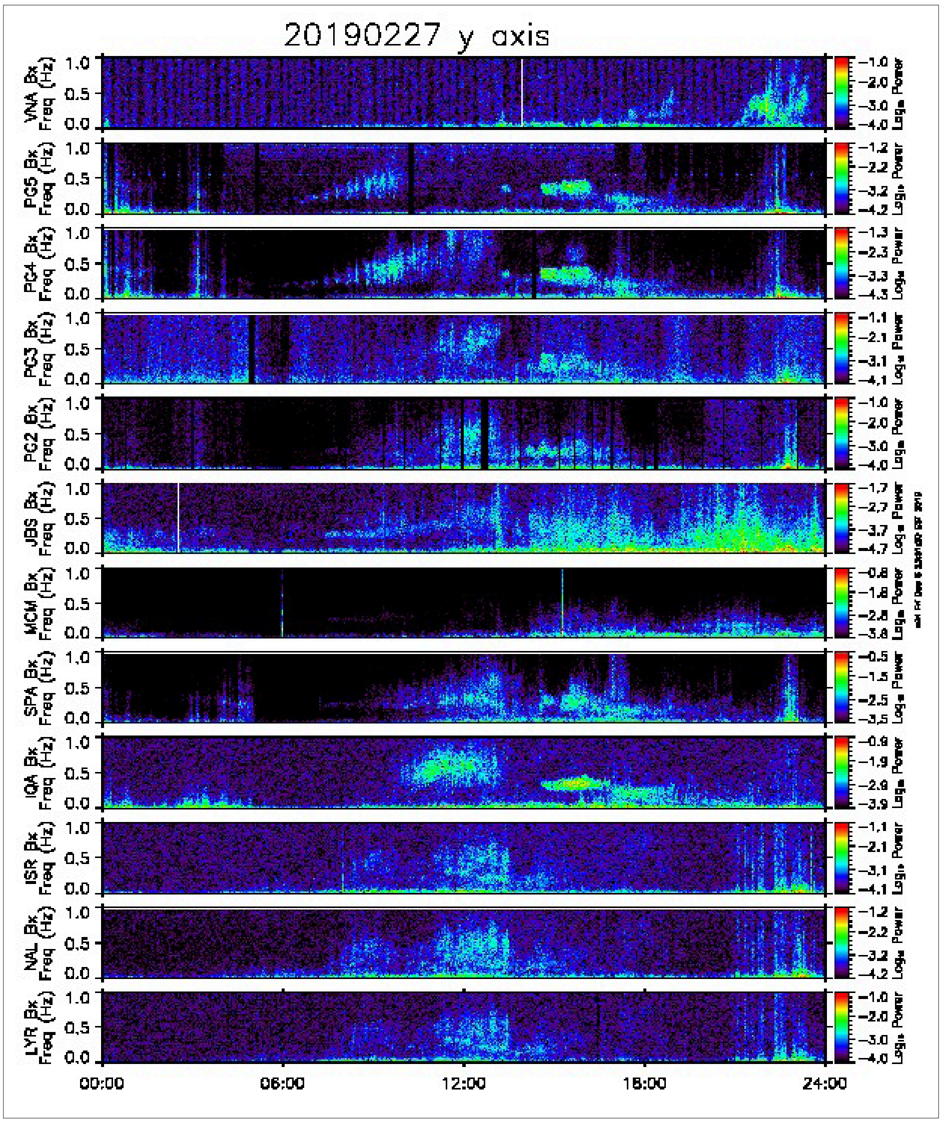

*Fig. 4.13.1: Geomagnetic spectrograms for 27 February 2019,
for 8 Antarctic stations (VNA to SPA) and 4 Arctic stations (IQA to LYR)*

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## 4.14 PSI – Performance and Stress in Isolation

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[3]Università e-campus

### Objectives

Performance and Stress in Isolation (PSI) is a research project that aims to create an instrument for managing stress. The goal of this instrument is to record and prevent the impact of stress during isolation by analysing the communication structure.

The idea is to create a simple instrument for self-monitoring and managing the stress level that can be used autonomously by persons who are in isolation and might not have access to external support and whose reliability could impact the overall system safety.

The instrument is based on an algorithm that correlates the communication structure with the level of perceived and physiological stress without the use of long questionnaires and intrusive blood and saliva analysis.

To create this algorithm, the first step is to collect a statistically relevant number of written communications in isolation. For this reason, an important contribution of written communication was collected during the 2020 Antarctic winter mission at the *Neumayer Station III.* Early detection of stress-related issues by analysing the written production of the crew members in real time could represent an important change, as it could minimize human-related accidents during space missions and other isolation conditions, such as Antarctic winter missions.

In summary, this research aims at the collection of important data for the development of a system that can help people in isolation by autonomously monitoring their level of stress through a software that analyses their communication.

### Fieldwork

In extreme environments, such as outer space, crews of scientists and astronauts live in isolation under very difficult conditions, and the stress factor has a very strong impact on overall performance and safety. The stress level is a key metric that can affect the performance and safety of human's working in complex and dangerous environments. Considering the need of early detection of stress in those contexts, people are subjected to long investigations, questionnaires, and intrusive tests like blood analysis.

A multitude of scientific studies on natural language (Allegrini et al. 2003; Ferrer et al. 2005; Piantadosi 2014) suggests a correlation between changes in the amplitude and frequency of the everyday vocabulary on the one hand and stress levels on the other hand. These studies show that test subjects tend to use a less elaborate and shorter vocabulary in stressful conditions. The connection between vocabulary and stress condition was then used to develop a first algorithm as a diagnostic tool for psychiatric and psychological disorders based on the analysis of written and spoken language (Tausczik et al. 2010).

The fieldwork of this research consists of the creation of an algorithm specifically for self-monitoring stress in isolation using the correlation suggested by these previous studies on natural language. To collect data for creating this algorithm, the written communications – more specifically, the monthly written reports – of one wintering team member were collected during the *Neumayer Station III* mission. Once the algorithm is finalised, the analysis of the stress level will consist of a comparison of text length and the amplitude and frequency of everyday vocabulary used, with the perceived stress as evaluated with the support of the NASA TLX questionnaire. The analysis will be performed by a software called PSI specifically developed for this research.

### Preliminary results

During the 2020 Antarctic mission at the *Neumayer Station III* human factors and psychological investigations provided important information for the development of better living conditions in isolation. The first results of the PSI project carried out on different previous missions (Alcibiade et al. 2018 & 2020) show a clear correlation between the stress level perceived by the crew members during the mission and their communications. Those previous research were based on the data collected from 27 members in isolation during five different short-duration missions. The data collected during the *Neumayer Station III* mission bring an important contribution to the PSI study because is related to the written communications in long-duration missions. The data collected was restricted to the monthly reports. Considering that this was the first written communication composed in a long-duration mission collected from *Neumayer Station III*, it is now planned to collect comparison data from other crew members of long duration mission over the next years.

The result of the research on *Neumayer Station III* will be the implementation of the algorithm of the PSI software with data from a long-duration missions to improve the correlation between stress levels and the vocabulary. Implementing the envisioned tool will enhance the possibility of early detection and management of distressing conditions in isolation (e.g., from space to pandemic isolation).

### Data management

The data management of this experiment was reviewed and created following the ethical guidelines used in Italy for medical research. All data will be archived, published, and disseminated according to the Information Sheet produced following the Italian ethical approach as validated by the ethical commission of “Ospedale di Bergamo”. All the data will be destroyed after the study has been concluded and will be presented without any connection to personal information. No molecular or physical data was collected, only the monthly report of one crew member. The raw data cannot be accessed on-line because this would make it easy to identify the person involved in the study as well as their personal information.

In all publications based on this expedition 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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We strongly thank the *Neumayer Station III* crew member who cordially supported this research and the *Neumayer Station III* scientific team for their support in performing this research and their patience. Finally, we thank the entire team at Universitá di Pisa, Prof. Melchiorre Masali, Prof. Harald Kolrep for their support and advice during the development of this study and the HMKW Berlin University of applied science.

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## 4.15 MIMO-EIS – Monitoring melt where Ice Meets Ocean – Continuous Observation of Ice-Shelf Basal Melt on Ekström Ice Shelf, Antarctica

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### Objectives

On-ice seismic measurement over the last ten years on Ekströmisen resulted in a mapping of its bathymetry to that extent, that it is now the best known of all ice shelves in the Dronning Maud Land region (Eisermann et al. 2020), only topped by those ice shelves in Antarctica where sub-shelf AUV observations from swath sonars are available. It turned out that the bathymetry of Ekströmisen is much more complex than previously assumed and as currently implemented in all tidal and other numerical ocean models (Smith et al. 2020). Instead of a homogeneously flat seafloor, as for instance released in the BEDMAP2 compilation, the bathymetry shows a deep trough in the center of the ice shelf, more than 900 m below the surface of the ice shelf up to 350 m thick. Consequently, it is obvious that all previous ocean model results were not able to consider the correct bathymetry and thus produced results which might be considerably wrong. Coming along with our improved knowledge of the bathymetry, we now have the opportunity to assess the influence of errors and uncertainties in the bathymetry on ocean-modelling results. This would also enable us to predict basal melt rates of Ekströmisen more realistically than previously possible. Such efforts, however, will strongly benefit from direct observations of the basal melt rates on Ekströmisen. In addition, satellite-based estimates of basal melting of ice shelves are highly uncertain (Berger et al. 2020) and widely lack validating/calibrating points. Ground-based measurements of basal melting on Ekström Ice shelf would therefore offer an invaluable asset to constraint satellite-based measurements. The main research questions of this proposal therefore are:

- How variable are basal melt rates over the course of a year underneath Ekströmisen?
- How are temporal changes in melt rates linked to atmospheric, cryospheric or oceanic conditions?
- Can these melt rates reliably be reproduced by a state-of-the-art ocean model when using the new bathymetry?

The method of choice consists of repeatedly measuring the ice thickness with a phase-sensitive radar (pRES). The change of ice thickness over time, under consideration of other effects, basically results in the basal melt rate.

### Fieldwork

The autonomous pRES (ApRES) system at the site EIS-8 was raised to the new level of the surface and data downloaded on 9 and 10 January 2021. Additional pRES remeasurements were performed at seven locations (EIS-4 to EIS-8, site6/A and site7/B) by the overwintering personnel (Tab. 4.15.1).

## Preliminary results

Since its deployment, the ApRES system 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.

Preliminary analysis of the **repeated pRES measurement**, couples measured at two different times, and taking into account strain thinning and firn compaction, yield basal melt rates. 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), which showed melt rates of approximately 0.4 m/a at EIS-5 to EIS-8, and almost 1.9 m/a for site EIS-4 (east of *Neumayer Station III)*, can be confirmed by the preliminary analysis of the re-measurements in the 2020/21 season. Interannual variability at each site (in a Lagrangian frame) are on the order of 1 to 25 cm/a.

The ApRES measurements at site EIS-8/HWD5 show strong temporal variability, ranging from on melt up to 2.5 m/a for a period of several days in the period from August to November and in the range of no melt to 0.5 m/a in the period from December to July. Preliminary spectral analyses of the melt rate do not indicate any strong forcing of tides.

Given the low melt rates and rather short time period for repeated measurements, the remeasurements in the 2020/21 season first have to undergo a thorough analysis to correct for firn compaction and strain thinning before reliable estimates including their uncertainty can be provided.

**Tab 4.15.1:** Position of pRES measurements on Ekströmisen

| **Site (naming 2018/19 season)** | | HWD1 | HWD2 | HWD3 | HWD4 | HWD5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| **Site (naming Sub-EIS-Obs convention)** | | EIS-4 | EIS-5 | EIS-6 | EIS-7 | EIS-8<br>(ApRES) | A | B |
| | **Season** | | | | | | | |
| **Position °lat** | 2018/19 | -70,65157 | -70,75108 | -70,81418 | -70,83701 | -70,82758 | -70,7703 | -70,8824 |
| **Position °lon** | 2018/19 | -8,20515 | -8,81113 | -8,61745 | -8,71078 | -8,73117 | -8,8589 | -8,8709 |
| **Position °lat** | 2020/21 | -70,64902 | -70,74747 | -70,81090 | -70,83362 | -70,82468 | -70,7661 | -70,8783 |
| **Position °lon** | 2020/21 | -8,20630 | -8,81697 | -8,62181 | -8,71543 | -8,73540 | -8,86596 | -8,8758 |

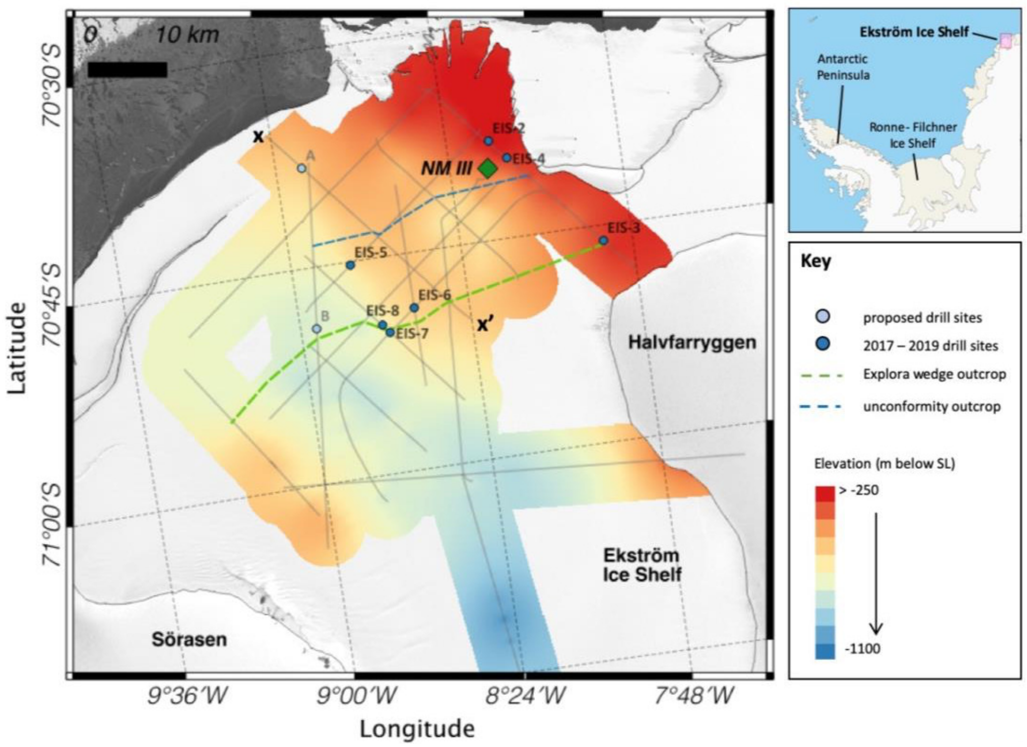

*Fig. 4.15.1: Ekström ice shelf with key features indicated (positions as of seasons 2018/19). Main map: Ekström ice shelf, the survey area of Sub-EIS-Obs campaign (Wilhelms, 2019). Grey lines indicate pre-site seismic vibroseis data lines (Smith et al., 2020). Colored underlay is sea-floor bathymetry (m below sea level) interpolated from seismic lines. Blue circles are sites where sediment cores have been take (light blue are planned core locations). The seismic line shown in Figure 4.15.2 is indicated by X-X'.*

*Small map: Location of Ekström ice shelf*

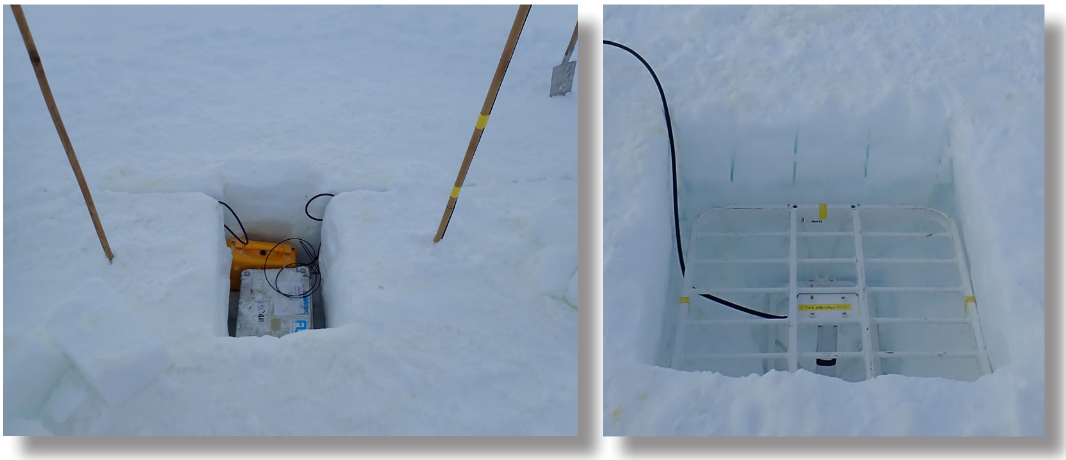

*Fig. 4.15.2: Deployment of the ApRES system controller and power supply (left) and of the ApRES frame antennas (right).*

## Datamanagement

After primary publication, the ApRES and pRES 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). By default, the CC-BY license will be applied.

In all publications based on this expedition 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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## 4.16 CHOICE – Consequences of Longterm-Confinement and Hypobaric HypOxia on Immunity in the Antarctic Environment at the *Concordia* and *Neumayer Station III* (CHO2ICE @ Neumayer)

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[4]University of Heidelberg
[5]Charité

### Objectives

The overarching purpose of this field study (CHOICE@Neumayer) is to determine the interaction between „stress and immune system“ and its impact on the health of overwintering crews at the *Neumayer Station III*, Antarctica. This investigation is closely linked with previous and ongoing scientific studies in Antarctica (Concordia, acronym CHOICE) as well as in Space (ISS, acronym IMMUNO).

The international research team, led by the Ludwig-Maximilians-University Hospital in Munich (Department of Anesthesiology) aims to investigate on *Neumayer Station III* *a)* how immune system responds to an isolation and confinement period for several month and which stress-dependent, neuroendocrine and metabolic changes may occur and *b)* how this may affect the health of the participants.

### Fieldwork

For the season 20/21, after a baseline data collection in the fall of 2019, the examinations of all nine subjects on the station started in February 2020 to run the CHOICE@Neumayer observation in a monthly period over the winter. The study ended by the last time point in May / June 2021 (split as to availabilities) for the post-collection at Charité, Berlin (joint activity with A. Stahn). Blood, saliva, urine, hair and stool samples were collected and questionnaires were also filled in. All subjects participated and only a few time-points could not be assessed due to personal or operational reasons.

### Preliminary (expected) results

Human psychology and physiology are significantly altered by isolation and confinement. In the light of planned exploration class interplanetary missions, the related adverse effects on the human body need to be explored and defined as they have a large impact on a mission‘s success. The terrestrial space analogues in the Antarctic offer an excellent and so far well controlled environment to study some of these stressors without the complex environment of e.g. the International Space Station. Participants subjected to these space analogue conditions can encounter typical symptoms ranging from neurocognitive changes, fatigue, misaligned circadian rhythm, sleep disorders, altered stress hormone levels, and immune modulatory changes. Many of these effects are also seen and reported in historic reports and also case-reports from overwintering crews. Our previous and current research at *Neumayer Station III* (and together with other study environments at Dome C (Concordia)) focuses on both, the psychological and the physiological responses to the effects of winter-over. They have already provided first and important insights into similarities and differences encountered in each environmental setting since Antarctica with its different extreme environments is a challenge for human explorers. The human physiology needs to be understood to best mitigate health problems in Antarctic expedition crews.

To date, its effects on human physiology have mostly and mainly been studied in male cohorts although more and more female expeditioners are being selected and participating. Therefore, **the identification of sex differences** in stress and immune reactions are becoming an even more essential aim to provide a more individualised risk management. For instance, we analysed and compared 10 female and 16 male subjects from three 1-year expeditions to *Neumayer Station III.* Here, blood, saliva, and urine samples were taken 1–2 months prior to departure, subsequently every month during their expedition, and 3–4 months after return from Antarctica. The analyses included measurements of stress-hormones as cortisol, catecholamine and endocannabinoid. Moreover, psychological evaluation; differential blood count; and recall antigen- and mitogen-stimulated cytokine profiles were quantified. Interestingly, the stress hormone cortisol showed significantly higher concentrations in females than males during winter whereas this seemed to be independent of a differentially enhanced psychological stress in both sexes. In contrast, the other stress hormone category, the ctecholamines – its excretion was higher in males than females but never showed significant increases compared to baseline. Independently of the biological sex, the stress mediators endocannabinoids and N-acylethanolamides increased significantly in both sexes and stayed consistently elevated during the confinement as well as the cytokine profiles after in vitro stimulation. White blood cells (the so-called leukocytes) concentrations increased during confinement with a dip for both sexes in winter whereas lymphocytes were significantly elevated in both sexes during the confinement indicating a sex independent immune status change. In conclusions the extreme environment seems to trigger some distinct stress and immune responses but – with the exception of cortisol – without any major relevant sex-specific differences. Stated sex differences were shown to be independent of enhanced psychological stress and seem to be related to the environmental conditions. However, sources and consequences of these sex differences have to be further elucidated and these investigations are underway.

Not only sex differences can trigger or modulate the stress and immune answers to different degrees in isolated and confined conditions, but also some very specific environmental effects, such as the atmospheric pressure per se. There have been reports from MD at the *Kohnen Station* that the higher altitude has led to a higher rate of medical incidences. To analyse these effects in a controlled study and with longer exposition, conditions of the German station *Neumayer Station III* and the French-Italian *Concordia Station* (3,200 m above sea) were compared. This because of several general similarities such as the seasonal shifts of complete daylight (summer) to complete darkness (winter) as well as the group sizes and work flow and occupancies, and therefore **the effects of hypobaric hypoxia** of ~650 hPa – as in effect on the *Concordia Station* – allow to systematically compare to conditions at *Neumayer Station III*. So we studied three expedition crews at *Neumayer Station III* (sea level) (n = 16) and two at *Concordia Station* (high altitude) (n = 15) to determine the effects of hypobaric hypoxia on hormonal/metabolic stress biomarkers [endocannabinoids (ECs), catecholamines, and glucocorticoids] and evaluated the psychological stress over a period of 11 months including winter confinement. At *Neumayer Station III* (sea level) crew, EC and n-acylethanolamide (NAE) concentrations increased significantly already at the beginning of the deployment. In contrast to this, catecholamines and cortisol remained unaffected. Over the year, ECs and NAEs stayed elevated and fluctuated before slowly decreasing until the end of the deployment. By contrast, at *Concordia Station* (high altitude), norepinephrine concentrations increased significantly at the beginning which was paralleled by low EC levels. Prior to the second half of the deployment, norepinephrine declined constantly to end on a low plateau level, whereas the EC concentrations then increased significantly during this second period of the overwintering. Psychometric data showed no significant changes in the crews at either station.

These previous findings and ongoing studies have helped to demonstrate that an exposure of healthy humans to the physically challenging extreme environment of Antarctica is 1.) partly different in women and men, 2.) has a distinct modulating effect on stress responses, and that

3.) high altitude/hypobaric hypoxia triggers a catecholamine release that seems to negatively regulate and hence downregulate the EC response. These results are likely not strongly associated to perceived/documented psychological stress but render the environmental effects to be of high impact. The identification of these and more adverse effects of confinement conditions will not only allow a better preparation of the overwintering crew, but also to design feasible countermeasures that will help to support Antarctic crews as well as space travellers on future exploration class missions.

Samples have not been received yet.

### Data management

All samples and documentation collected along the study timepoints are considered confidential and medical research data that are subject to data protection and have to follow the rules and regulations of the institutional ethical board (Ethikkommission an der Medizinischen Fakultät der LMU). Once the samples are analysed and fully anonymised, data batches can be made available to other researchers upon request and topics of interest can be reconsidered once they are covered by the ethical approval (a re-iteration to the ethical board might be necessary).

In all publications based on this expedition 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.

## 4.17 HF EDEN-ISS – Impact of Plants and Creative Activities on the Wintering Team

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### Objectives

To gain information on the quality of life in isolation, a Human Factors (HF) investigation was carried out during the 2020 mission at *Neumayer Station III* in order to determine the impact of interaction with plants as well as the impact of creative activities in isolation.

The investigation on the impact of plants is called HF EDEN ISS and was performed by the *Neumayer Station III* wintering team (Fig. 4.17.1) to investigate whether having plants in the all-white Antarctic desert could be socially, psychologically, and physiologically beneficial to a crew spending one complete year in isolation without plants. Indeed, to protect the local environment (e.g., from foreign bacteria), plants are prohibited at *Neumayer Station III* which is why the crew members usually neither have fresh food nor the possibility to interact with plants during the winter isolation period. With the high-tech EDEN ISS greenhouse, plants are now allowed to grow (however, the greenhouse is located in a separate environment 500 meters away from the *Neumayer Station III*). One of the aims of this greenhouse is to provide a place to interact with plants as well as to grow fresh food as an important variation from the long-term storable food. This is something very special during 12 months of isolation in an ice desert. The aim of this study was therefore to discover from a human factors perspective, what the weaknesses and potentials of growing plants in isolation – from Antarctica to Space – are. The study started in 2018 and the previous results are now being compared with the current ones.

*Fig. 4.17.1: Wintering team performing the Human Factors investigation during the 12-month isolation mission at Neumayer Station III*

The investigation related to creative activity started in 2010 with a space mission simulation. It aimed to find out whether creative activities and humanities investigations should also have their place among the many scientific activities conducted during isolation missions.

### Fieldwork

The investigation consisted of:

1. Questionnaires on the plants' impact in isolation
2. Post-mission interview (postponed because of Covid-19)
3. Investigation on creative activity

### (1) Questionnaires on the plants' impact on isolation

The wintering team performed the questionnaire on the plants' impact in isolation in two sessions: one in July and one in October 2020. Six members of the wintering team took part in the session in July and nine members in the session in October.

Each session consists of:

- An extraction of the Questionnaire on Food preferences from The Robert Koch Institute
- Dedicate Questionnaire on Plants Interaction developed by Schlacht for the EDEN ISS project
- POMS (Profile of Mood States) short version

The results of the two sessions did not diverge significantly, therefore the mean value of the two sessions is reported in the result (hence the values of 0.5).
Below are the mean values from the questionnaire on the impact of the plants and the greenhouse on the wintering team (for more information see the separate document at the end of the report):

- CREW: Three wintering team members visited the greenhouse weekly, and six members did so less than once a month. The three members who visited the greenhouse weekly (called "greenhouse weekly workers") experienced a clearly stronger impact and interaction with the plants than those who visited once a month or less often.
- GREENHOUSE: The greenhouse was built around 500 meters from the *Neumayer Station III*, so the wintering team needed to confront the extreme polar climate to visit the greenhouse. The impact of the greenhouse, as well the impact of the greenhouse location, was not seen as a constraint, but as a positive feature. Some wintering team members reported that it is good that "you need to go outside" or that it brings a "change in the daily routine". Indeed 8.5 out of 9 members had nothing to improve, apart from two members who commented in July that there was a lot of "unforeseen work in greenhouse maintenance" and an improvement could be the implementation of "instructions for providing plant care".
- PLANTS: The mean value of the level of satisfaction regarding raw food consumption was "extremely satisfied". All nine members of the wintering team who took part in the investigation reported that they enjoyed eating the plants produced by the greenhouse

every day; seven enjoyed it “a lot” and the two “greenhouse weekly workers” reported that they enjoyed it even “extremely”. Eight out of the nine members who took part in this investigation also liked to interact with the plants (five liked growing, and four liked tending; some also interacted by processing, visiting, watching, or storing, especially the greenhouse weekly workers).

- The variety of the harvest was evaluated as good by eight of the nine members. Tomatoes, in particular, were the best-loved plants (8.5 of 9 members), followed by lettuce/rucola (5 of 9 members), cucumbers (4.5 of 9 members), radishes (4 of 9 members) and sweet peppers (3.5 of 9 members); kohlrabi was also mentioned, but was not present in the list. Strawberries were probably not mentioned because the plants did not produce any fruits.
- The consumption of the plants was enjoyed in particular for their taste (5.5 of 9 members), refreshing feeling (5 of 9 members) and smell (3.5 of 9 members).
- MOOD: The mood was also evaluated via a short version of the Profile of Mood States (POMS) Questionnaire, a standard validated psychological test used in research to measure mood and initially developed in 1971. Considering the questionnaire replies, the team seemed to not have any particularly negative mood and gave a mostly positive evaluation for competence and proud feelings.
- IMPACTS: The impacts of the plants on the *Neumayer Station III* wintering team in 2020 were stronger for the team that interacted with the greenhouse weekly (Fig. 4.17.2). In particular, the positive impact of the plants was recoded on:
    - nutritive value,
    - pleasure of eating fresh food,
    - psychological value,
    - improvement of well-being,
    - the health improvement,
    - enjoyment of plants and of eating the plants,
    - satisfaction from eating raw food.

These variables were evaluated with a stronger score compared to the other variables (Fig. 4.17.2). The data analysis shows a clear positive impact of the plants and greenhouse interaction on all nine wintering team members who filled out the questionnaire; it was stronger among the 3 members who interacted weekly with the plants. The positive impact emerged in particular for the variable of pleasure, enjoyment and satisfaction of having fresh food to eat during the isolation in comparison to other variables such as safety improvement.

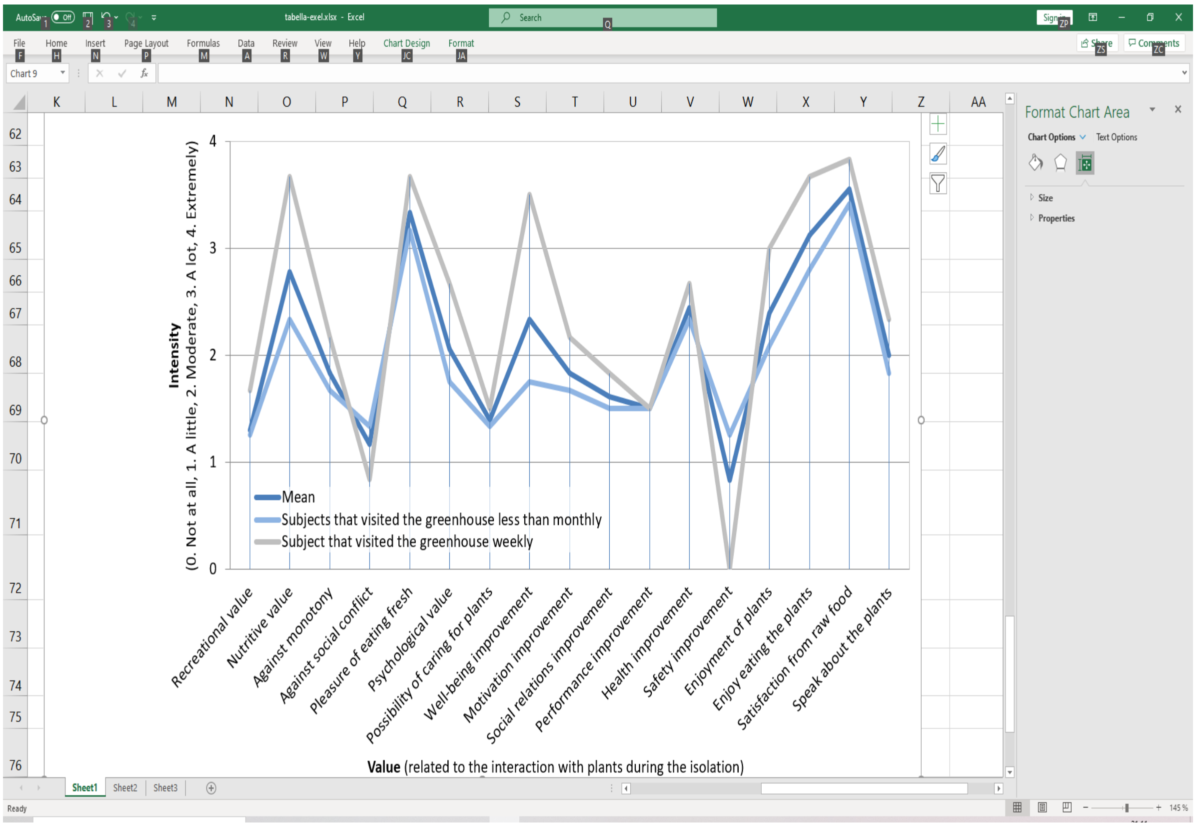

*Fig. 4.17.2: Impact of plants on the 2020 Neumayer Station III wintering team*

## (2) Post-mission interview

The aim of the post-mission interview was to confirm the first data obtained during the mission from the questionnaire on the effect of plants in isolation. In this case, this investigation was postponed due to the Covid-19 pandemic restrictions on meetings.

## (3) Investigation on the impact of creative activity in isolation

On 8 October 2020, four wintering team members performed the investigation on the impact of creative activity in isolation. The investigation methodology consisted of performing a free creative activity followed by a short questionnaire on stress, scientific vs. humanistic discoveries and emotional expression.
The questionnaire results were as follows:

- Stress: All four wintering team members of *Neumayer Station III* who took part in this investigation said that creative activities act as a countermeasure to stress. This wintering team seemed to particularly enjoy musical expression as a creative activity, which is also the most preferred creative activity in isolated environments in Space, where its positive effect against stress has been demonstrated (Schlacht & Ono 2009).
- Humanistic investigations: All four members who took part in this questionnaire agreed that creative activities add a personal human experience to scientific investigation. Humanistic research such as creative activities is also a very important means of communication with the world, while scientific investigation (which always constitutes the majority of investigations performed in these isolated contexts) can be directly interpreted only to a small group of scientists (Schlacht & Ono 2009).

- Emotional expression: Three of the four members who took part in this investigation thought that creative activity supports the expression of emotions. This is very important if we consider that creative expression of emotions could help to prevent violence and conflicts, especially in isolation (Schlacht & Ono 2009).

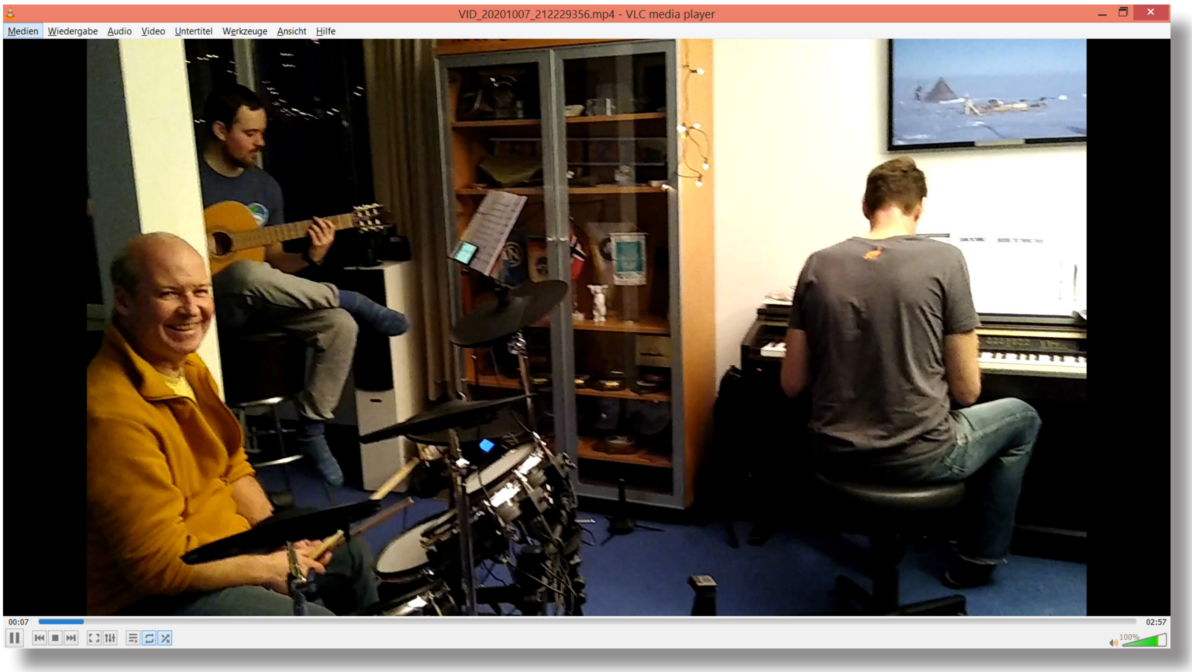

*Fig. 4.17.3: Wintering team members playing music during the 12-month isolation mission at Neumayer Station III*

Comments were reported by three wintering team members:

- Member 1
  **Stress:** Creative activities counteract stress because “expressing yourself with music, hitting the keys” has a “strong release”.

  **Humanistic investigations:** It adds a personal human experience to scientific investigation because “I find personal balance, through music, and am filled with worship”.
  **Emotional expression:** It is important to express emotion; “joy, thankfulness, mourning, anger”.
  **Kind of creative activity:** “Playing music (alone or together) is a strong part of my life and it is a gift to play together here, though it can’t fill me the way worship does.”

- Member 2
  **Creative activity:** It “changes the everyday routine”; it could be a “group activity. I play music with other crew members”.

- Member 3
  **Stress:** Creative activities counteract stress “especially in long duration missions” because “it is good to do something totally different”.

  **Humanistic investigations:** It adds a personal human experience to scientific investigation because “it might change your point of view”.

**Emotional expression**: It is important to express emotion, for example with music you can express emotions “like anger, happiness, sobriety, loneliness”. Kind of creative expression: “We played music with four crew members every Wednesday from 8 to 10 pm and every time it brought a smile to my face”.

- Member 4
  Did not report any extra comments.

In conclusion, based on this data we can hypothesize that creative expression, such as music, was an important element of socialization for the wintering team of the *Neumayer Station III*, both as a group activity and as stress relief, and also proved to be a tool for emotional expression, from joy or happiness to the non-violent expression of anger. Moreover, it adds a personal human experience to scientific investigations, contributing to creating a greater variety of experiences in isolation.

### Preliminary results

During the 2020 Antarctic mission at the *Neumayer Station III* the human factors investigation presented here provided a human-centered overview of the wintering team’s quality of life, as well as important information for the development of better living conditions in isolation.

In particular, three studies were performed:

*(1) Questionnaires on the impact of plants in isolation:*

In 2020, the investigation also confirmed the positive impact of plants not only as fresh food and as an important change from the long-lasting food (e.g., frozen, canned,..), but also as an element that supported satisfaction and enjoyment.

All nine wintering members who participated in the study really enjoyed eating the plants and interacting with the plants. The members reported that they felt a lot of satisfaction from eating raw and fresh food; nutritive value, well-being improvement and health value were also recorded as elements of positive impact. Also, the variety of the harvest was evaluated as good: Tomatoes were the best-loved plants, followed by lettuce/rucola and cucumbers. Taste, refreshing feeling and smell were some of the most pleasant stimuli recorded during interaction with the plants.

Previous results of the same study conducted in 2018 (preliminary study started in 2014) showed that the impact of plants on isolation is recordable and positive, stimulating most of the wintering team socially, psychologically, and physiologically, with positive multisensory experiences (Imhof et al. 2018; Quantius et al. 2014; Schlacht et al. 2019, 2016; Schubert et al. 2018). For example, many members of the 2018 wintering team reported enjoying the fragrant and pleasant smell released when the plants were harvested inside the station (Schlacht et al. 2019).

In 2020, some new results were also obtained. For the 2020 wintering crew, it was observed that the impact of the plants was stronger for those people who visited the greenhouse every week, compared to those who only visited the plants once per month or less often. The mood of the crew was generally positive. Regarding the experiment set-up, the greenhouse location (500 m from the *Neumayer Station III*) was perceived as motivation to experience the external environment and get some variation. The only constraints were the high maintenance workload in the greenhouse; also, “instructions for providing plant care” were requested as an improvement to be implemented.

*(2) Post-mission interview (postponed because of Covid-19)*

The investigation on the plant's impact was also intended to comprise a post-interview, but this could not be conducted due to the restrictions related to the Covid-19 pandemic.

*(3) Investigation on creative activity*

Another result was the positive impact of creative activity in isolation. The research on creative activity was conducted by four members of the wintering team. All four members confirmed the relevance of creative activity as stress relief, as an element of socialization, as a tool for non-violent emotional expression in isolation and as a space to investigate the personal human experience behind the numerous scientific investigations that are restricted to a scientific public. This research contributes to adding a greater variety of research fields studied in isolation missions by also adding artistic expression as a form that can be used to communicate the experience in isolation to a wider audience. The creative activity mainly consisted of music, as in other isolation contexts such as Space missions (Fig. 4.17.3).

These results were all achieved during a 12-month isolation mission in the ice desert of the Antarctic. Similar results have also been gained from other contexts of isolation, like prison and homes for the elderly, among others, which also confirm the positive impacts of plants and creative activity in isolation.

### Data management

The data management of this experiment was reviewed and created following the ethical guidelines used in Germany for psychological research. All data will be archived, published, and disseminated according to the Information Sheet produced following the German ethical approach. All data will be destroyed after the study has been concluded and will be presented without any connection to personal information. No molecular or physical data was collected; only the crew's opinion was collected with questionnaires. The raw data cannot be accessed online because this would make it easy to identify the people of the crew involved in the study.

In all publications based on this expedition 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.

### Acknowledgments

We strongly thank the *Neumayer Station III* wintering team, not only for the support of this experiment but also for the courtesy concession of the use of the images, and the DLR team and the *Neumayer Station III* scientific team for their support in performing this research and their patience during this difficult Covid-19 time. We thank all the people who gave us their kind advice during the DLR meeting in Bremen in 2019. Finally, we thank Prof. Melchiorre Masali, Prof. Harald Kolrep for their support and advice during the development of this study and the HMKW Berlin University of applied science

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## 5. KOHNEN STATION

Kohnen Station was closed during season 2020/21.

# 6. DALLMANN LABORATORY

No activities at Dallmann Laboratory. AWI has resigned from the Dallmann Consortium.

## 7. FLIGHT CAMPAIGNS POLAR 6

Due to the CoV-2 pandemic, no scientific flight campaigns were conducted in season 2020/21.

# 8. OTHER SCIENTIFIC PROJECTS WITH AWI PARTICIPATION

Due to the CoV-2 pandemic, there were no other scientific projects with AWI participation in season 2020/21.

# APPENDIX

**A.1 Teilnehmende Institute / Participating Institutions**

**A.2 Expeditionsteilnehmer / Expedition Participants**

**A.3 Logistische Unterstützung, Überwinterer / Logistics Support, Wintering team**

## A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

| Institution | Address |
|---|---|
| AWI | Alfred-Wegener-Institut<br>Helmholtz-Zentrum für Polar- und Meeresforschung<br>Postfach 120161<br>27515 Bremerhaven<br>Germany |
| BGR | Bundesanstalt für Geowissenschaften und Rohstoffe<br>Stilleweg 2<br>30655 Hannover<br>Germany |
| Charité | Charité – Universitätsmedizin Berlin<br>Zentrum für Weltraummedizin und<br>Extreme Umwelten Berlin<br>CharitéCrossOver (CCO)<br>Charitéplatz 1, Virchowweg 6<br>10117 Berlin<br>Germany |
| CNRS | Institut Pluridisciplinaire Hubert Curien (IPHC)<br>UMR 7178 CNRS-Unistra<br>Département Ecologie, Physiologie et Ethologie (DEPE)<br>23, rue Becquerel<br>67087 Strasbourg Cedex 2<br>France |
| CSM | Centre Scientifique de Monaco<br>Département de Biologie Polaire<br>8, quai Antoine 1er<br>MC 98000<br>Monaco |
| DLR | Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)<br>Institute of Space Systems<br>Robert-Hooke-Str. 7<br>28359 Bremen<br>Germany |

| **Institution** | **Address** |
|---|---|
| FAU | Friedrich-Alexander-Universität Erlangen-Nürnberg<br>Lehrstuhl für Biophysik<br>Henkestraße 91<br>91052 Erlangen<br>Germany |
| GFZ | Helmholtz Centre Potsdam<br>GFZ German Research Centre for Geosciences<br>Potsdam<br>Germany |
| HS Bremen | Hochschule Bremen<br>Fakultät Elektrotechnik und Informatik<br>Neustadtswall 30<br>28199 Bremen<br>Germany |
| ILEWG | International Lunar Exploration Working Group<br>ESTEC<br>2201 AZ Noordwijk<br>The Netherlands |
| KHU | School of Space Research<br>Kyung-Hee University<br>Gyeonggi<br>Korea |
| Klinikum der Universität München | Klinikum der Universität München<br>Marchioninistrasse 15<br>81377 München<br>Germany |
| Klinikum Mannheim der Universität Heidelberg | Klinikum Mannheim der Universität Heidelberg<br>Theodor-Kutzer-Ufer 1<br>68305 Mannheim<br>Germany |
| KOPRI | Division of Polar Climate Sciences<br>Korea Polar Research Institute<br>Incheon<br>Korea |
| LMU | Ludwig-Maximilians-Universität München<br>Geschwister-Scholl-Platz 1<br>80539 München |

| Institution | Address |
|---|---|
| MPI | Max-Planck-Institute for Human Development<br>Lentzeallee 94<br>14195 Berlin<br>Germany |
| NASA JSC | NASA Johson Space Center,<br>Behavioral Health & Performance Laboratory<br>2101 NASA Parkway<br>Houston, TX 77058<br>USA |
| NJIT | Center for Solar-Terrestrial Research<br>New Jersey Institute of Technology<br>New Jersey<br>USA |
| NPI | Norsk Polarinstitutt<br>Framsenteret Hjalmar Johansens gt.14<br>9296 Tromsø<br>Norway |
| Penn | University of Pennsylvania,<br>Perelman School of Medicine,<br>Department of Psychiatry<br>Philadelphia, PA 19004<br>USA |
| Pitt | University of Pittsburgh<br>Department of Sports Medicine and Nutrition<br>3860 South Water Street<br>Pittsburgh, PA 15203<br>USA |
| SCK-CEN | Sck-cen<br>Research Centre Mol<br>Boeretang 200<br>2400 Mol<br>Belgium |
| TROPOS | Leibniz-Institut für Troposphärenforschung e.V. (TROPOS)<br>Permoserstraße 15<br>04318 Leipzig<br>Germany |

| **Institution** | **Address** |
|---|---|
| TU München | Technische Universität München<br>Lehrstuhl für Raumfahrttechnik<br>Boltzmannstr. 15<br>85748 Garching b. München<br>Germany |
| UF | University of Florida, Fifield Hall<br>2550 Hull Road<br>PO Box 110690<br>Gainesville, Florida 32611<br>USA |
| ULB | Université libre de Bruxelles – Faculté des Sciences<br>Laboratoire de Glaciologie<br>Department Geosciences, Environment, Society<br>Av. F.D. Roosevelt 50, CP 160/03<br>B-1050 Brussels<br>Belgium |
| UNH | Space Science Center<br>University of New Hampshire<br>Durham, New Hampshire<br>USA |
| ULB | Université libre de Bruxelles – Faculté des Sciences<br>Laboratoire de Glaciologie<br>Department Geosciences, Environment, Society<br>Av. F.D. Roosevelt 50, CP 160/03<br>B-1050 Brussels<br>Belgium |
| Uni Bremen | Universität Bremen<br>Bibliothekstraße 1<br>28359 Bremen<br>Germany |
| Universitá di Pisa | Università di Pisa<br>Via Lungarno Pacinotti 43<br>56126 Pisa<br>Italy |
| Università di Torino | Università di Torino<br>Via accademia Albertina 13<br>10123 Torino<br>Italy |

| Institution | Address |
|---|---|
| Università e-campus | Università e-campus<br>Via Isimbardi 10<br>22060 Novedrate CO<br>Italy |
| University of Rom<br>“La Sapienza” | University of Rom “La Sapienza”<br>Piazzale Aldo Moro 5<br>00185 Rome<br>Italy |
| Université Paris Saclay | Université Paris Saclay<br>3 rue joliot Curie<br>Bâtiment Breguet<br>91190 Gif-sur Yvette |
| WHOI | Woods Hole Oceanographic Institution<br>266 Woods Hole Rd., MS# 11<br>Woods Hole, MA 02543-1050<br>USA |

## A.2 EXPEDITIONSTEILNEHMER / EXPEDITION PARTICIPANTS

| **Name / Last name** | **Vorname / First name** | **Institut / Institute** | **Beruf / Profession** | **Fachrichtung / Discipline** |
|---|---|---|---|---|
| Fromm | Tanja | AWI | Scientist | Geophysics |
| Preis | Loretta | AWI | Technician | Meteorology |
| Schmithüsen | Holger | AWI | Scientist | Meteorology |
| Vrakking | Vincent | DLR | Scientist | Aerospace Engineering |
| Weller | Rolf | AWI | Scientist | Air Chemistry |

## A.3 LOGISTISCHE UNTERSTÜTZUNG, ÜBERWINTERER / LOGISTICS SUPPORT, WINTERING TEAM

| **Name / Last name** | **Vorname / First name** | **Institut / Institute** | **Beruf / Profession** | **Fachrichtung / Discipline** |
|---|---|---|---|---|
| Ackle | Roman | AWI | Technician | Wintering Team 2020 |
| Baden | Markus | AWI | Technician | Wintering Team 2021 |
| Bähler | Stefanie | RFL | Technician | Logistics |
| Beyer | Mario | AWI | Technician | Wintering Team 2020 |
| Bunchek | Jess | AWI | Scientist | Wintering Team 2021 |
| De Almeida Santos | Wanderson Divino | AWI | Cook | Wintering Team 2020 |
| Dornhöfer | Timo | AWI | Scientist | Wintering Team 2021 |
| Doron | Tanguy | AWI | Cook | Wintering Team 2021 |
| Guba | Klaus | AWI | Physician | Wintering Team 2020 |
| Heitland | Tim | AWI | Physician | Expedition Leader |
| Jörss | Anna-Marie | AWI | Scientist | Wintering Team 2020 |
| Jonczyk | Peter | AWI | Physician | Wintering Team 2021 |
| Koch | Florian | AWI | Technician | Wintering Team 2021 |
| Laubach | Hannes | RFL | Technician | Logistics |
| Lemm | René | RFL | Administration | Housekeeping |
| Loftfield | Julia | AWI | Scientist | Wintering Team 2020 |
| Marten | Lorenz | AWI | Scientist | Wintering Team 2021 |
| Oblender | Andreas | AWI | Technician | Wintering Team 2020 |
| Ockenfuß | Paul | AWI | Scientist | Wintering Team 2021 |
| Ort | Linda | AWI | Scientist | Wintering Team 2021 |

| **Name / Last name** | **Vorname / First name** | **Institut / Institute** | **Beruf / Profession** | **Fachrichtung / Discipline** |
|---|---|---|---|---|
| Riess | Felix | RFL | Technician | Logistics |
| Schütt | Philipp | RFL | Technician | Logistics |
| Sterbenz | Thomas | RFL | Technician | Logistics |
| Thoma | Theresa | AWI | Technician | Wintering Team 2021 |
| Trumpik | Noah | AWI | Scientist | Wintering Team 2020 |
| Wehner | Ina | AWI | Scientist | Wintering Team 2020 |

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