ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

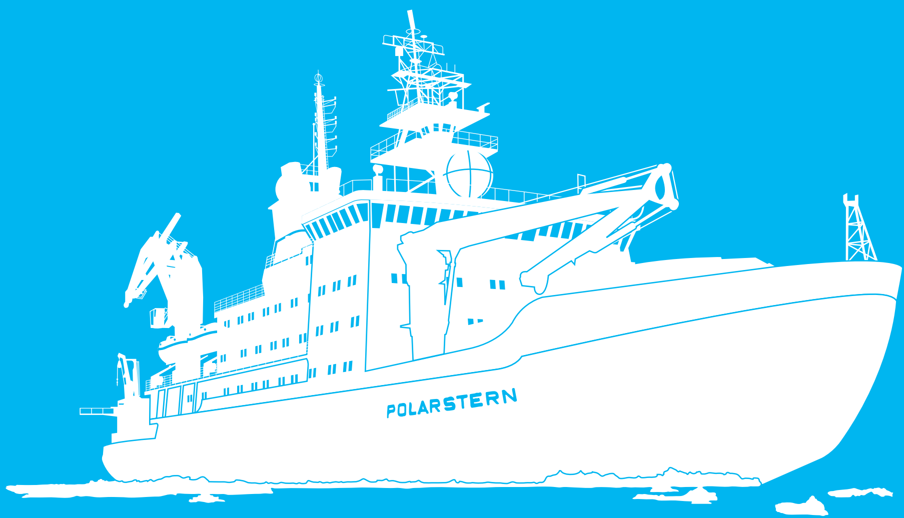
EXPEDITION PROGRAMME PS141

Polarstern

PS141
Hobart - Walvis Bay
06 February 2024 - 14 April 2024

Coordinator: Ingo Schewe

Chief Scientist: Sebastian Krastel



HELMHOLTZ

Bremerhaven, January 2024

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The Expedition Programme *Polarstern* is issued by
the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven, Germany.

The Programme provides information about the planned goals and scientific work programmes of expeditions of the German research vessel *Polarstern*.
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PS141

6 February 2024 – 14 April 2024

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EASI 3
East Antarctic Ice Sheet Instability and its interaction with changes in Southern Ocean circulation – Part 3

Chief scientist
Sebastian Krastel

Coordinator
Ingo Schewe

Contents

1. ÜBERBLICK UND EXPEDITIONSVERLAUF

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Die Expedition PS141 unter dem Titel „East Antarctic Ice Sheet Instability and its interaction with changes in Southern Ocean circulation – Part 3“ ist die dritte der EASI Expeditionen, die das Ziel haben, Eisschildveränderungen der Ostantarktis in verschiedenen Zeiten der Vergangenheit zu untersuchen. Eisschildfluktuationen in der Ostantarktis haben direkten Einfluss auf den globalen Meeresspiegel und wirken sich auf die globale Energiebilanz sowie die Umweltbedingungen im und über dem Südozean aus. Untersuchungen zur Variabilität von Eisschilden auf verschiedenen Zeitskalen haben sich bisher auf den Westantarktischen Eisschild (WAIS) konzentriert. Im Gegensatz zum WAIS ist nur wenig über die Reaktion des Ostantarktischen Eisschilds (EAIS) auf Klimaänderungen bekannt, insbesondere an der Grenze Kontinent-Ozean. Wir beabsichtigen neue geologische und geophysikalische Daten und Proben zu gewinnen, um zum verbesserten Verständnis der Wechselwirkungen zwischen dem EAIS und den Klimabedingungen während des Neogens beizutragen, einerseits mit einem Schwerpunkt der Paläoumweltrekonstruktionen auf dem letzten Glazial-Interglazial-Übergang, und andererseits über Zeitskalen, die die relevanten Warmzeiten des Pliozäns, Miozäns und Oligozäns umfassen. Zielregion ist der kontinentale Schelf zwischen 85°E und 115°E, vor dem Eisrand von Wilhelm II bis Wilkes Land. Unser Forschungsansatz ist multidisziplinär und beinhaltet sowohl marine als auch landbasierte Untersuchungen. Auf der Grundlage von bathymetrischen und flachseismischen Messungen sollen Sedimentarchive vom kontinentalen Schelf sowie aus küstennahen Lagunen und Seen gewonnen werden. Daraus soll die laterale und zeitliche Ausdehnung von Eisschildvorstößen und -rückzügen im Kontext mit gleichzeitig ablaufenden Veränderungen der Ozeanographie, der Meereis- und Seeeisbedeckung, sowie der Limnologie rekonstruiert werden. Aus GPS-Messungen und Daten über lokale relative Meeresspiegelstände sollen Massenänderungen des EAIS während des Spätpleistozäns abgeleitet werden. Seismische Vermessungen der tieferen Sedimentfolgen und deren glazialtektonische Strukturen über den Schelf und oberen Kontinentalhang sollen die EAIS Variabilität seit dem Beginn der Eozän/Oligozän Vereisung bis in das Spätquartär erfassen.

Die Expedition beginnt am 06. Februar 2024 in Hobart (Australien). Auf dem Weg in die Ostantarktis sollen acht Stationen im offenen Ozean für spätquartäre paläozeanographische Rekonstruktionen entlang eines Transekts beprobt werden. Im Hauptarbeitsgebiet auf dem Schelf und oberen Kontinentalhang zwischen 85°E und 115°E findet der Großteil der wissenschaftlichen Arbeiten statt. In diesem Gebiet werden Landgruppen für geologische und limnologische Arbeiten in die Bunger Oase und die Windmill Islands sowie für geodätische Arbeiten zum Gaußberg ausgeflogen. Die Expedition endet am 14. April in Walvis Bay (Namibia).

Die Expedition trägt zu den Zielen des Forschungsprogramms „Erde im Wandel – Unsere Zukunft sichern“ bei. Es ist Teil der programmorientierten Förderung (PoF IV) der Helmholtz-Gemeinschaft. Die meisten Forschungsaktivitäten beziehen sich direkt auf die Ziele von Thema 2 (Ozean und Kryosphäre im Klimawandel) mit einem Fokus auf die Unterthemen 2.1 (Erwärmung des Klimas) und 2.3 (Meeresspiegeländerung). Für die CAU liefern die Expeditionen wichtige Impulse für die Forschung innerhalb des universitären Forschungsschwerpunktes Kiel Marine Science (KMS).

SUMMARY AND ITINERARY

Expedition PS141, entitled "East Antarctic Ice Sheet Instability and its interaction with changes in Southern Ocean circulation - Part 3", is the third of the EASI expeditions that aim to investigate ice sheet changes in East Antarctica at different times in the past. Ice sheet fluctuations in East Antarctica have a direct impact on global sea level and affect the global energy balance and environmental conditions both in and north of the Southern Ocean. Studies on the variability of ice sheets on different time scales have so far concentrated on the West Antarctic Ice Sheet (WAIS). In contrast to the WAIS, little is known about the response of the East Antarctic Ice Sheet (EAIS) to climate change, especially at the continent-ocean boundary. We intend to acquire new geological and geophysical data and samples to contribute to an improved understanding of the interactions between the EAIS and climate conditions during the Neogene; on the one hand with a focus on paleoenvironmental reconstructions on the last glacial-interglacial transition, and on the other hand over time scales spanning the relevant Pliocene, Miocene and Oligocene warmer-than-present periods. The target region is the continental shelf between 85°E and 115°E, off the ice margin from Wilhelm II to Wilkes Land. Our research approach is multidisciplinary and includes both marine and land-based investigations. Based on bathymetric and shallow seismic measurements, sediment archives will be collected from the continental shelf as well as from coastal lagoons and lakes. This will be used to reconstruct the lateral and temporal extent of ice sheet advances and retreats in the context of concurrent changes in oceanography, sea ice and lake ice cover, and limnology. Changes in the mass of the EAIS during the Late Pleistocene will be derived from GPS measurements and data on local relative sea levels. Seismic surveys of the deeper sedimentary sequences and their glacial-tectonic structures across the shelf and upper continental slope will record the EAIS variability from the beginning of the Eocene/Oligocene glaciation to the Late Quaternary.

The expedition starts on February 06, 2024 in Hobart (Australia). On the way to East Antarctica, eight stations in the open ocean will be sampled along a transect for Late Quaternary paleoceanographic reconstructions. Most of the scientific work will take place on the shelf and upper continental slope between 85°E and 115°E. In this area, land groups will set up camps in the Bunger Oasis and the Windmill Islands for geological and limnological work and at the Gaußberg for geodetic work. The expedition ends on April 14 in Walvis Bay (Namibia).

The expedition contributes to the objectives of the research program ‘Changing Earth – Sustaining our Future’. It is part of the Helmholtz Association's program-oriented funding (PoF IV). Most of the research activities are directly related to the objectives of Theme 2 (Ocean and Cryosphere in Climate) with a focus on subtopics 2.1 (Warming Climate) and 2.3 (Sea Level Change). For the CAU, the expedition integrates important themes for research within the university's research focus Kiel Marine Science (KMS).

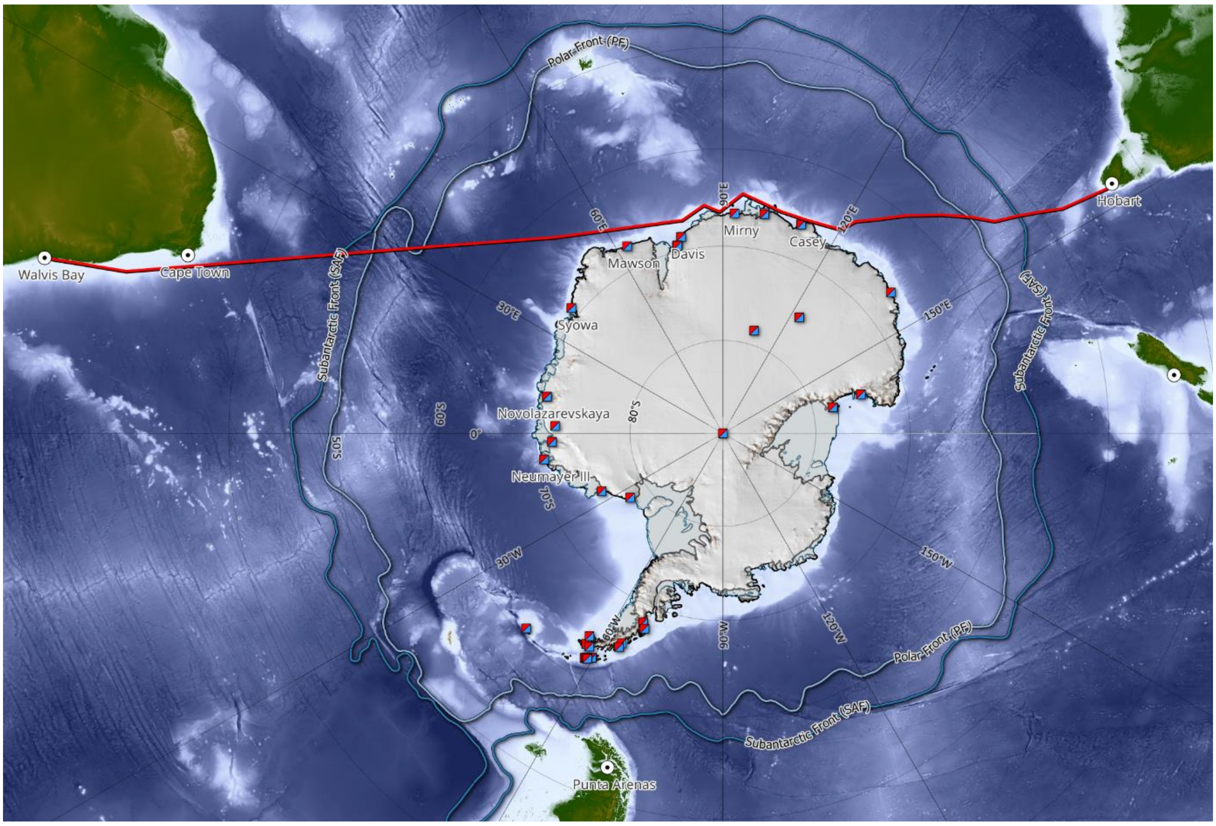

Abb. 1.1: Geplante Fahrtroute der Polarstern-Expedition PS141. Auf dem Weg von Hobart In die Ostantarktis sollen acht Stationen im offenen Ozean beprobt werden. Das Hauptarbeitsgebiet liegt auf dem Schelf zwischen 85°E und 115°E.

Fig. 1.1 Planned cruise track of the Polarstern expedition PS141. Eight stations in the open ocean are to be sampled on the way from Hobart to East Antarctica. The main working area is on the shelf between 85°E and 115°E.

2. MARINE GEOPHYSICS

Rachel Barrett[1], Karsten Gohl[2], Sebastian Krastel[1], Patrick Schwarzbach[2], Estella Weigelt[2]

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Grant-No. AWI_PS141_01, AWI_PS141_03

Objectives and outline

The ice sheets of Antarctica have been losing ice mass for the last several decades. This is mainly driven by warm ocean deep-water coming into contact with the ice-water interface of ice shelves and grounding zones, which results in acceleration of glacier flows depending on the bed topography. The long-standing perception that – in addition to the Greenland Ice Sheet – only the marine-based West Antarctic Ice Sheet (WAIS) is vulnerable to currently progressing climate change into the next centuries, while the East Antarctic Ice Sheet (EAIS) will remain relatively stable, has turned into a controversial debate. Recently improved data on sub-glacial topography along the margins of Antarctica show deep glacial troughs adjacent to stabilizing ridges below current sea-level at several locations. These deep glacial troughs potentially connect warm ocean deep-water with the grounding zones and bed-ice interface on bed slopes that are inclined towards deep-seated basins of the continental interior. The Denman and Totten glaciers of the Davis Sea and Mawson Sea sectors of East Antarctica are two such ice stream systems that drain ice from the large marine-based Wilkes and Aurora basins. The detailed shelf and margin morphology of this region, however, remains poorly known. Geophysical data allow the imaging of glacial structures, from which the dynamics of past ice sheets can be reconstructed. Therefore, we plan to intensively collect seismic, sediment echo-sounder and bathymetric data during expedition PS141. Details are described in sub-chapters 2.1 to 2.3.

2.1 Seismic Profiling

Rachel Barrett[1], Karsten Gohl[2], Sebastian Krastel[1], Adalbert Pfeiffer[2], Chiara Tobisch[1], Timo Krause[2], Lenya Baumann[1], Katharina Hochmuth[3], Alejandro Cammareri[4], Ursula Pena Gonzalez[4], Andres Alejandro Scrigna[4]

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Grant-No. AWI_PS141_01

Objectives

The behaviour of polar ice sheets in relation to climatic changes and their contribution to global sea-level change is poorly understood. The reports of the Intergovernmental Panel for Climate Change (IPCC) (e.g., IPCC, 2021) explicitly flag this deficiency in knowledge. In contrast to most of the West Antarctic Ice Sheet and the Antarctic Peninsula Ice sheet, which have been shown to exhibit very dynamic activity both at present and during their history, the East Antarctic Ice Sheet (EAIS) has long been assumed to be relatively dormant during past and present initial phases of climate change. However, this paradigm has been challenged by recent data that show that ice mass loss due to incursions of warm deep-water onto the continental shelves and into sub-ice shelf cavities occurs in parts of the East Antarctic margin, such as off Wilkes Land Subglacial Basin, at Sabrina Coast off Totten Glacier and – in its earlier stage – off Denman Glacier. This led to Hypothesis 1 in the ship-time proposal for PS141: "*The marine-based EAIS sectors reacted with rapid and extended phases of retreat to climatic conditions in all relevant warm phases since early glaciation.*"

The Shackleton Ice Shelf off Princess Elisabeth, Wilhelm II and Queen Mary Lands (Davis Sea sector) and the continental shelf near Petersen Bank (Mawson Sea sector) are fed by major glacier systems: the Denman Glacier and a branch of Totten Glacier that form one of the largest ice catchment and drainage areas of East Antarctica (Fig. 2.1.1). Denman and Totten Glaciers, as well as most of the coastal glaciers in the Davis Sea and Mawson Sea, are marine-based, making them inherently unstable and thus vulnerable to potential warm-water incursions. The deep submarine basin beneath Denman Glacier is currently blocked for potential warm-water incursions by only a very narrow coastal basement ridge (Morlighem et al., 2020). In the hinterland, both glaciers are connected to the vast submarine Wilkes Land and Aurora Subglacial Basins. Earlier studies suggested a relatively stable EAIS since early glaciation, but recent results from the shelf off Totten Glacier show that at least the marine-based sectors of the EAIS behaved very dynamically throughout the Oligocene to Pliocene. Ice advanced across the coast and retreated at least 11 times during the Oligocene and Miocene (e.g., Gulick et al., 2017). In particular, conditions during the Mid-Miocene Climatic Optimum and warm periods of the Pliocene are analogous to the present and the near future, which necessitates quantification of ice sheet behaviour during these time periods.

Geophysical surveying of shelf areas and adjacent slopes, combined with coring of outcropping older strata at appropriate locations, will provide data for assessing EAIS dynamics, in terms of advance/retreat behaviour and extent in warmer-than-present time periods, from early Antarctic glaciations in the Eocene-Oligocene to the Pleistocene. Detailed seismic imaging will reveal the sedimentary architecture of the shelves and will illustrate periods of major progradation during glacier advances, as well as aggradation deposition during prolonged warmer-than-present periods, such as the mid to late Eocene, middle Oligocene, early to middle Miocene, and early/middle Pliocene. Glacial maxima characterized by major advances of grounded ice onto and across the shelf are indicated by truncational unconformities on the inner to middle shelf, as well as progradational sequences on the outer shelf to slope (e.g., Hochmuth and Gohl, 2019). Such seismic characteristics have been successfully investigated on both the Ross Sea shelf (De Santis et al., 1999) and the Amundsen Sea shelf (Gohl et al., 2013, 2021). Integrating the scientific drill records from the East Antarctic margin with a stratigraphic model of the continental rise along that margin (Leitchenkov et al., 2007) will enable the correlation of seismic horizons and units with the shelf sequences, and provide age control for major seismic units and unconformities. In addition, the recently dated sediment core and seismic records of outcropping Eocene to Pliocene strata at steep flanks of glacial troughs off Totten Glacier (Gulick et al., 2017) provide another link to our planned seismic network.

The mismatch between model results and field evidence of EAIS behaviour in the Late Quaternary requires investigation of past ice-sheet configurations in East Antarctica. Knowledge of paleo-ice sheet geometries can support future projections of ice sheet behaviour, either through direct evidence or by providing past examples that can be used to test ice-sheet models. Accordingly, Late Quaternary dynamics of vulnerable marine-based EAIS portions on the continental shelf will be evaluated using an integrated approach incorporating swath bathymetric mapping, shallow seismic surveying, and sediment coring to test Hypothesis 2 "*The palaeo-Denman and Totten Glaciers extended towards the shelf edge during the LGM and reacted very sensitively to past warm-water incursions and sea-level fluctuations*". Integrating seismic and hydroacoustic mapping with sediment coring will provide new evidence for ice expansion, paleo-flow pathways and stillstands in grounding-line retreats. In combining multibeam swath bathymetric mapping, shallow high-resolution seismic surveying and sediment coring, we aim to decipher past ice-flow trajectories and ice-retreat patterns by mapping sub- and proglacial landforms such as mega-scale glacial lineations (MSGLs), grounding-zone wedges (GZWs), drumlin and moraine features, as well as subsurface depositional systems and glaciogenic fault tectonics.

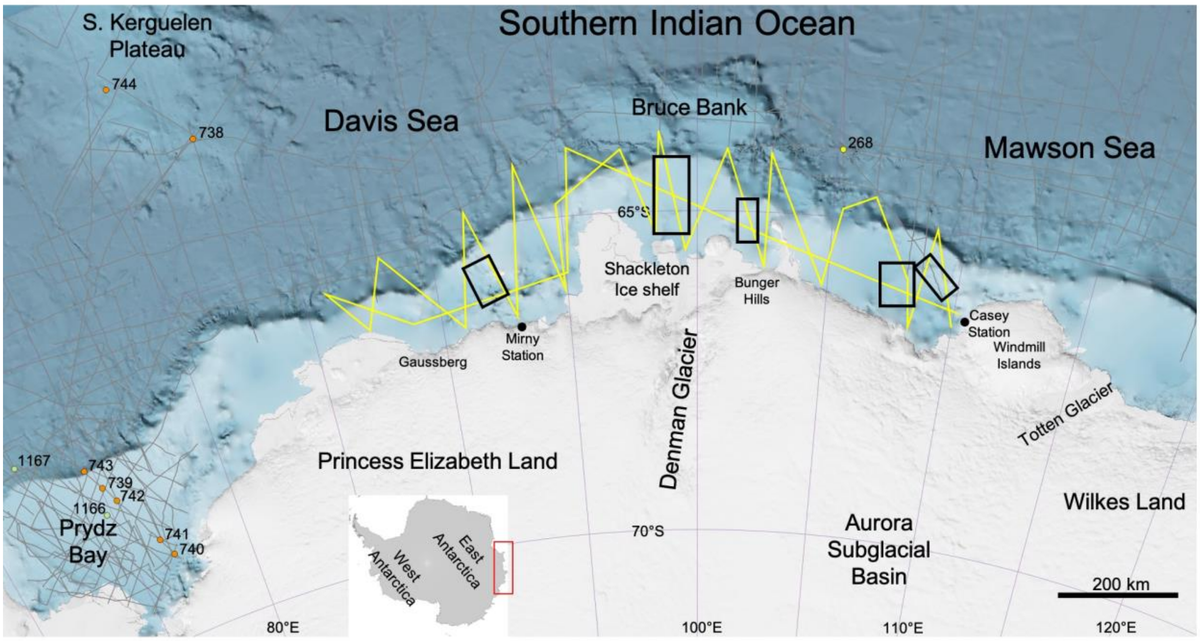

Fig. 2.1.1: Map of the working area for seismic surveys in Davis Sea and Mawson Sea offshore East Antarctica showing planned seismic profiles on the continental shelf and rise. Yellow lines show deep-penetration profiles, black boxes indicate areas of interest for high-resolution profiles. Thin grey lines mark pre-existing seismic profiles. The map also shows the locations of DSDP Leg 28 (Mawson Sea), ODP Leg 119 (Prydz Bay and Kerguelen Plateau) and ODP Leg 188 (Prydz Bay) with their site numbers. IODP Exp. 318 drill sites are off the map to the east.

Work at sea

A dense network of seismic reflection lines will be acquired across the continental shelf and slope of the eastern Davis Sea and western Mawson Sea between 85°E and 115°E, and connected to the existing seismic network across the continental rise (Fig. 2.1.1). As sea-ice cover during the survey cannot be predicted, the planned network outline shows a maximum extent of up to 2,500 nm (4,600 km) profiling (max. 25 days, including deployment and recovery of the seismic equipment and circumnavigation of massive sea ice). This line extent will, however, need to be adjusted based on the sea-ice situation. A 600 m-long seismic hydrophone streamer and a seismic source consisting of a cluster of 4 GI-Guns (Type 150, operating in True GI-Mode) will be used to image the architecture of entire sedimentary sequences down to the top of basement at relatively high vertical and horizontal resolution. A 200 m-long seismic streamer with a single GI-Gun will serve to generate high-resolution images of glacial morphological features on the shelf, including grounding zone wedges and moraines. The seismic network will be linked to pre-existing seismic profiles on the continental rise, as well as scientific drill sites such as those of ODP Legs 119 and 188 in Prydz Bay, and drill sites of IODP Expedition 318 and DSDP Leg 28 (Site 268) offshore western Wilkes Land, to establish a seismic stratigraphy for the shelf. Seismic profiling will be interrupted for geological sampling and to service land operations. The two seismic surveys: (i) deep-penetrating, and (ii) high-resolution, shallow sub-surface imaging of selected glacio-morphological shelf features, are highly complementary and will be closely coordinated.

The seismic surveys will be accompanied by an extensive marine mammal mitigation program to avoid potential risks. This will include permanent visual observation of the ship's surroundings by professional marine mammal observers (MMOs) aided by additional trained observers, operation of an infrared camera system, a softstart procedure for the airguns at the start of surveys, and immediate shutdown of airgun operations when marine mammals are sighted within the exclusion zone.

Preliminary (expected) results

It can be expected that the marine seismic profiles collected during EASI3 will provide images of glacially-transported and deposited sedimentary sequences on the continental shelf and slope of the Davis Sea and Mawson Sea sectors. Through connecting these new seismic data with existing seismic profiles from the continental rise and deep sea, as well as with scientific drill sites of ODP Legs 119 and 188 in Prydz Bay, and IODP Expedition 318 and DSDP Leg 28 (Site 268) offshore western Wilkes Land, we expect to decipher dominant phases of past EAIS advances and retreats in these sectors, in particular from the shelf offshore the Denman Glacier and Shackleton Ice Shelf, from early glaciation to more recent Quaternary ice sheet dynamics.

Data management

Metadata and a short report will be submitted to DOD and PANGAEA. A full cruise report will be made available on PANGAEA within 6 months after the cruise. Seismic data will be submitted to the SCAR Antarctic Seismic Data Library System (SDLS; https://sdls.ogs.trieste.it), which will make them available to interested collaboration partners 2 years after data acquisition and as open access 8 years after acquisition according to the SDLS guidelines. Access for the science community will also be provided according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within three years after the end of the cruise (or after an extended moratorium period). By default, the CC-BY license will be applied.

The research activities are directly related to the objectives of Theme 2 (Ocean and Cryosphere in Climate) with a focus on subtopics 2.1 (Warming Climate), 2.3 (Sea Level Change), and 2.4.

In all publications based on this expedition, the **Grant No. AWI_PS141_01** will be quoted and the following publication will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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2.2 Bathymetry of the East Antarctic Sea

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Grant-No. AWI_PS141_03

Objectives

Accurate knowledge of seafloor topography, hence high-resolution bathymetry data, is key basic information necessary to understand many marine processes. It is of particular importance for the interpretation of scientific data in a spatial context. Bathymetry, and, by extension, geomorphology, is a basic parameter for understanding the general geological setting of an area, as well as geological processes such as erosion, sediment transport and deposition. Furthermore, information on tectonic processes can be inferred from bathymetry.

While global bathymetric maps give the impression of detailed knowledge of worldwide seafloor topography, most of the world's ocean floor remains unmapped by hydroacoustic systems. In these unmapped areas, bathymetry is modelled from satellite altimetry, and has a corresponding low resolution. Satellite-altimetry derived bathymetry therefore lacks the resolution necessary to resolve small- to meso-scale geomorphological features (e.g. sediment waves, glaciogenic features and small seamounts). Ship-borne multibeam data provide bathymetry information at a resolution sufficient to resolve those features and assist in site selection for the other scientific working groups on board.

Glacigenic landforms preserved at the seafloor can form the basis for the reconstruction of the dynamic history of Antarctic Ice Sheets. In particular, these landforms can shed light on ice sheet retreat since their maximum extent during the Last Glacial Maximum. Understanding the processes that led to this retreat in the past can provide important information for predicting future responses of Antarctic Ice Sheets to changing climate conditions and oceanographic settings. Identifying glacigenic landforms requires high-resolution bathymetric data sets. These data are, however, sparse for the study areas of the EASI3 expedition, and detailed bathymetric data will thus be collected in these areas with the ship's hydroacoustic instruments.

Furthermore, the collection of underway data during PS141 will contribute to the bathymetry data archive at the AWI and, thus, to bathymetric world datasets such as GEBCO (General Bathymetric Chart of the Ocean).

Work at sea

Bathymetric data will be recorded with the hull-mounted multibeam echosounder Atlas Hydrosweep DS3. The main task of the bathymetry group is to plan and run bathymetric surveys in the study areas and during transit. The raw bathymetric data will be corrected for sound velocity changes in the water column, and will be further processed and cleaned for erroneous soundings and artefacts. Detailed seabed maps derived from the data will provide information on the general and local topographic setting in the study areas. High-resolution seabed data recorded during the survey will be made available for site selection and cruise planning. During the survey, the acoustic measurements will be carried out by three operators in a 24/7 shift mode (except for periods of stationary work).

Preliminary (expected) results

Expected results consist of high-resolution seabed maps along the cruise track and over target research sites. The bathymetric data will be analyzed to provide geomorphological information of the research area, which will enable better understanding of geological processes active in the research area.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied. Furthermore, bathymetric data will be provided to the Nippon Foundation – GEBCO Seabed 2030 Project.

This expedition will support the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 2, Subtopic 3 Sea Level Change.

In all publications based on this expedition, the **Grant No. AWI_PS141_03** will be quoted and the following publication will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

2.3 Sediment echo-sounding (Parasound) in the Indian Ocean sector of the Southern Ocean and along the Antarctic continental margin (Davis Sea, Mawson Sea)

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Grant-No. AWI_PS141_01

Objectives

Predicting the future response of the East Antarctic Ice Sheet (EASI) to changing climate and oceanographic settings is still restrained by uncertainties. In order to evaluate its contribution to sea-level changes, especially for times when climate conditions were similar to those expected for a future warming Earth, knowledge of changing ice sheet volume and extent, as well as other palaeo-environmental processes are required. These processes leave an imprint in the layering and internal structure of sedimentary strata. In turn, such glacially-formed structures (e.g. moraines) preserved in the sub-bottom can help to reconstruct the dynamic history of the EASI.

In this regard, the sub-bottom profiling system Parasound P70 offers a method to image the upper tens of meters of subsoil to increase understanding of glacial and geological processes such as erosion, sediment transport and deposition, or even tectonic processes that occurred during the more recent past. These data are essential for reconstructing the expansion, extension, and retreat of ice sheets; e.g. by constraining the distribution of Megascal Glacial Lineations, Moraines, or Grounding-zone wedges (e.g., Dowdeswell et al., 2016).

Further, by imaging the upper few tens of meters at high resolution, the sediment echosounder presents an important link between bathymetry (mapping the surface morphology) and reflection seismics (which images structures down to several km depth). The integration of these three datasets is of particular importance for the interpretation of geological data in a spatial context. Moreover, the sediment echosounder survey will provide essential information for geological sampling, enabling the identification of (1) core locations ideally containing undisturbed sediment sequences, and (2) sites with high sediment supply.

Work at sea

Sediment echosounder data will be recorded using the Atlas Teledyne Parasound P70 hull-mounted sub-bottom profiling system. The main task of the sediment echosounder group is to run surveys in the study areas and during transit to provide information for station planning and sediment sampling sites. Profiling will be carried out in a 24/7 shift mode, and the data recorded will be promptly made available for site selection and cruise planning.

Detailed sub-bottom maps derived from the sediment-echosounder data will provide information on glacial-geomorphological features (e.g. grounding zone wedges), erosional structures, and depositional features (e.g. slumps, slides, fans). For the selection of coring locations, the data enable the identification of areas of high and low sedimentation rates and outcrops, and the avoidance of areas of sediment redeposition and erosion.

Preliminary (expected) results

Expected results consist of high-resolution seabed maps along the cruise track and over the target research sites. The sub-bottom data will be analyzed to provide geomorphological information about the uppermost sedimentary sequences of the research area. The expected results will help to achieve the aim of a better understanding of the palaeo-environmental processes that provoke the dynamics of the EASI.

Data management

Sub-bottom profiling data collected during the expedition 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) in accordance to the AWI research data guideline and directive (https://hdl.handle.net/10013/epic.be2ebee5-fb98-4144-9e74-aa1d38378c5e). The data will be made available upon request after a phase of restricted access of 4 years after data acquisition at the latest. By default, the CC-BY license will be applied.

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

This expedition will contribute to the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 2, Subtopic 2.1.

In all publications based on this cruise, the **Grant No. AWI_PS141_01** will be quoted and the following article will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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3. MARINE GEOLOGY AND PALEOCEANOGRAPHY

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Not on board: Ralph R. Schneider[1], Johann P. Klages[2], Oliver Esper[2], Nina Keul[1], Duanne White[3]

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Grant-No. AWI_PS141_02

Objectives

Among Southern Ocean regions, the Indian Ocean sector and its East Antarctic Ice Sheet (EAIS) margin remains one of the least understood areas in terms of its past role in the climate system. However, this region may hold substantial significance for current and future climate and sea-level change. Currently, it is not even known whether the EAIS mass balance is positive or negative, or how it contributes to global and regional sea-level change (The IMBIE Team, 2018), severely limiting precise projections of future climate and ice-sheet evolution. The inherently unstable and likely more dynamic marine-based portions of the EAIS (Cook et al., 2013; Wilson et al., 2018) represent a sea-level equivalent of about 19 m (Fretwell et al. 2013). Recent observations indicate considerable thinning and grounding line retreat of some ice streams draining these basins, resulting in a negative mass balance in their catchments (Shen et al. 2018; Picton et al. 2023). Paleoclimate data indicate a close link between extended Antarctic warmth and ice loss from marine-based sectors of the EAIS during past warm, interglacial intervals (Wilson et al., 2018). This raises concerns for future instability of the EAIS, and its potentially higher vulnerability to climatic and oceanographic forcing than previously thought. The current lack of data, both proximal and distal to the EAIS, prevents better understanding of the dynamic past of marine and shelf-based EAIS sectors, despite them being a critical factor for assessing recent changes and providing long-term geological context.

A major goal of this expedition is to advance our process-oriented understanding of Quaternary climatic and oceanographic processes, and their interaction with the cryosphere on orbital to submillennial time-scales. Our particular focus rests on the Holocene, deglacial warming phases and past warmer-than-present time intervals in the East Antarctic ice-ocean-climate systems. We plan to retrieve marine sediment cores along the continental margins off the Shackleton, Ice Shelf, Vanderford Ice Shelf, prioritising work areas related to basal ice shelf melting resulting from warm Circumpolar Deep Water (CDW) intrusions into sub-ice shelf cavities. Such processes and feedback mechanisms, including freshening and sea ice growth/loss, also directly influence the formation and extent of Antarctic Bottom Water (AABW) sourced from the Ross Sea and Adelie Land coastal regions. Specifically, we want to address the following three key hypotheses with the planned activities:

A) The marine-based EAIS sectors reacted with rapid and extended phases of retreat to climatic conditions in all relevant warm phases since early glaciations. In this regard, the Davis Sea and Mawson Sea shelf areas are both prime recorders of EAIS dynamics. The Denman Glacier and Vanderford Glacier (also referred to as “Totten West”) form one of the largest ice catchment and drainage areas of East Antarctica (Fig. 2.1.1). Both glaciers, as well as most of the coastal Davis and Mawson Sea glaciers, are marine-based, making them inherently unstable and thus vulnerable to potential warm CDW incursions. At present, warm-water incursions into the deep submarine basin beneath Denman Glacier are only blocked by a narrow coastal basement ridge (Morlighem et al., 2020). Both glaciers are connected to the vast submarine Wilkes Land and Aurora Subglacial Basins. Though earlier studies suggested a rather constantly stable EAIS, more recent results from the Totten Glacier shelf show that the marine-based sectors of the EAIS behaved dynamically at least throughout the Oligocene to Pliocene, with repeated ice advances and retreats (e.g. Gulick et al., 2017). Moreover, the impact of past (varying) sea-ice conditions on the stability of ice-shelf fronts (Massom et al., 2018) and the formation of dense shelf water contributing to AABW along the East Antarctic continental margin (Ohshima et al., 2016) remain poorly understood. Sea-ice biomarker analyses (e.g. Lamping et al., 2021) paired with diatom assemblage studies of sediment cores collected along the shelf areas will address this crucial knowledge gap along with other multi-proxy reconstructions.

B) The paleo-Denman, Vanderford-, Bond-, Adams- und Underwood Glacier systems extended towards the shelf edge during the last glacial, reacting sensitively to past warm-water incursions and sea-level fluctuations. Current mismatches of model results and proxy-based data of EAIS reconstructions for the Late Quaternary require more detailed, spatially well-resolved evidence for paleo-ice sheet geometries that, in turn, will constrain projections of future ice sheet behavior. Accordingly, Late Quaternary dynamics of vulnerable marine-based EAIS portions on the continental shelf will be evaluated through a combined approach of swath bathymetry mapping, shallow seismic surveying, and sediment coring (Fig. 3.1) to test this hypothesis. This integration will provide new evidence for ice expansion, paleo-flow pathways, or stillstands in grounding-line retreats to decipher past ice-flow trajectories. Through mapping of sub- and proglacial landforms such as mega-scale glacial lineations, grounding-zone wedges, drumlin and moraine features, as well as subsurface depositional systems and glaciogenic fault tectonics, we aim to define their relative and, if possible, absolute timing throughout the Last Glacial period, including Marine Isotope Stage 3 and the subsequent deglaciation into the Holocene. Such data are still scarce or entirely absent in the working area (Carson et al., 2017; Picton et al., 2023). In combination with time series of environmental proxies from sediment cores, our objective is to establish a four-dimensional reconstruction of ice-sheet advances and retreats for the study area (*cf*. Hillenbrand et al., 2013; Smith et al., 2011, 2014; Klages et al., 2013, 2014, 2015, 2017).

C) EAIS ice-sheet variations were intimately coupled with circum-Antarctic circulation and biogeochemical cycling in the Indian Ocean sector of the Southern Ocean. We hypothesize that profound marginal EAIS fluctuations during the late Quaternary also had a significant impact on circum-Antarctic oceanic circulation and biogeochemical cycling by controlling the amount of dense shelf-slope brine formation, extension of sea-cover supported by catabatic winds, and via contribution to the biogeochemical nutrient inventory through shelf break organic and inorganic matter plumes introduced by ice-margin dynamics (e.g., Smith et al., 2019). Quantifying changes in the supply of these trace elements and nutrient, and their distribution patterns and pathways in sub-Antarctic waters, are key for constraining changes in past environmental conditions as reconstructed from sediment cores in Southern Ocean frontal zones (Fig. 3.1). Notably for nutrients, the processes that govern the quantity and stoichiometry in the source regions, as well as northward advection of water masses, are insufficiently constrained, making it impossible to predict the consequences of Southern Ocean changes in upwelling or phytoplankton community shifts. While a wealth of knowledge has been gathered on siliceous plankton, surveys for calcifiers, particularly for the ice-sheet margin and shelf water masses, are lacking. While diatoms have high preservation potential in the Southern Ocean Antarctic Margin sediments, and the species distribution patterns provide sufficient information about seawater temperature and trophic conditions (Esper and Gersonde, 2014), calcareous tests of planktic foraminifers and shells of pteropods are sparse in circum-Antarctic sediments. Nonetheless, planktic and benthic foraminifera are preserved in sufficient numbers for paleoenviromental reconstructions at high accumulation sites on the shelf.

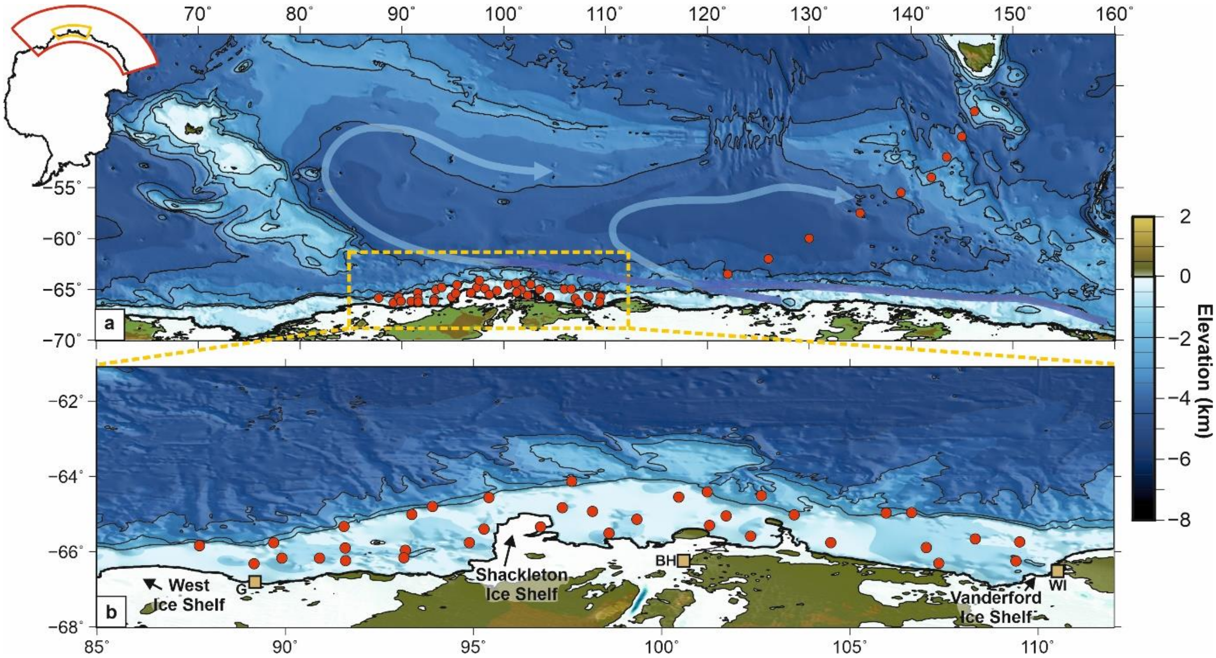

Fig. 3.1: Map of study area depicting a) planned pelagic stations (red dots) for PS141 approach to Antarctica and b) the shallow stations (red dots) along the continental shelf and upper slope of Mawson and Davis Seas off West Ice Shelf, Shackleton Ice Shelf and Vanderford Ice Shelf (field sites of the land campaign are shown by squares: G: Gaußberg, BH: Bunger Hills, WI: Windmill Islands).

Work at sea

The Marine Geology and Paleoceanography work programme comprises of two major, distinct sampling efforts:

(1) The initial pelagic open ocean work area covers a pelagic sub-Antarctic to shelf-based Antarctic transect in the Austral-Indian sector of the Southern Ocean (SO), extending across the major frontal zones and the Antarctic Circumpolar Current (ACC) on the transit towards the Antarctic shelf areas. Due to the need to save time on approach to the Antarctic work areas, the aim is to identify locations of opportunity with underway surveys and relatively limited dedicated mapping for coring stations. We plan to target eight to ten sediment sampling stations, aiming to sample high-resolution Quaternary sedimentary deposits with long piston cores (PC) of up to 25 m (Fig. 3.1a), combined with sediment surface sampling using a Multi-Corer (MUC).

These coring sites are chosen to provide information on changes of the oceanic fronts, ocean circulation, productivity, ocean hydrography and prevailing climate in response to ice sheet variability over the last glacial cycles. The paleoceanographic approach focuses on sediment cores from the Southern Ocean frontal system between Hobart and Antarctica (Fig. 3.1). Pleistocene to Holocene variations in ACC dynamics, near-surface temperatures, salinity and nutrient concentrations will be determined using multi-proxy paleoclimatological reconstructions. Regional changes will enable us to decipher fluctuations in oceanic heat and salt transfer, and will provide information on migrating oceanic fronts and wind fields; while vertical gradients will be used to reconstruct the stratification of the ocean. These changes in stratification form the basis for understanding ocean-atmosphere gas exchange (CO_2), deep-ocean carbon storage and for deciphering past dynamics of bottom-, intermediate- and mode water formation.

(2) The main working area extends along the Antarctic continental margin between 85° E and 110° E, with key areas located along the Wilhelm II, Queen Mary, and Wilkes Land ice rims (Fig. 3.1b), where marine geological fieldwork will focus on the continental shelf and slope off West Ice Shelf, Shackleton Ice Shelf and Vanderford Ice Shelf. We plan to use both previously acquired and new high-resolution hydro-acoustic data from swath bathymetry and sub-bottom profiling surveys to identify subglacial sedimentary features (such as grounding-zone wedges and lineations) at and immediately below the seafloor to target ideal sediment coring sites. Based on these survey results, we plan to collect shorter to medium-length (3–15 m) Gravity Cores (GC) at about 35 marine geological coring stations the shelf and slope (Fig. 3.1b). This sampling will be coupled with sediment surface sampling by Multi-corer (MUC) or Giant Box Corer (GBC) along the major paleo-ice stream troughs on the continental shelf of the study area, west of the Australian Casey Station. We plan to target both sites in shallower outer troughs as well as sediment pockets at inner trough margins in order to ensure sampling of undisturbed sediments and carbonate preservation above local carbonate compensation depths (*cf*. Hillenbrand et al., 2017). Furthermore, we intend to identify shelf areas that potentially remained free of grounded ice during the last glacial cycle (e.g., Domack et al., 1998; Klages et al., 2017), with may thus hold sedimentary evidence for the EAIS state and paleoceanographic conditions during the last interglacial.

Sampling of the MUC, PC, GC or GBC sediment records (in 1 cm slices) into different storage containers will take place onboard immediately after recovery, and will use combusted glass vials (biomarker), KAUTEX bottles (rose Bengal-Ethanol preserved) and Whirlpack sampling bags. Samples designated for biomarker studies and ancient DNA analyses at home laboratories, as well as an archive sample, will to be stored frozen (–20 °C).

We will perform extensive sediment coring in both study areas, with sites distributed in water depths from the shallow shelf down to depths of 4,000 m in the open ocean. This sampling campaign will enable us to reconstruct physical and chemical of water mass characteristics and their influence on EAIS dynamics. At carbonate-bearing stations, we will also use the Kasten Corer (KAC) to ensure that sufficient foraminifers are available for the application of paleoceanographic proxies and AMS ^{14}C dating. Prior to storage, all core sections will be analysed for physical properties of the entire core using a Multi-Sensor-Core-Logger (MSCL-S, Geotek Ltd.). The MSCL-S device provides data of wet-bulk density, porosity, p-wave velocity and magnetic susceptibility at 1 cm depth intervals. Full processing of MSCL raw data will be carried out at sea, so that high resolution records of physical properties are available during the cruise for a preliminary assessment of the sedimentary stratigraphy. Selected sediment cores will be split onboard. Core images, descriptions of sediment properties and smear slide investigations of these cores will allow initial characterization of the sediment. However, some of the sediment cores will remain unsplit until arrival at the home laboratories to allow for high-quality computed tomography scanning.

Preliminary (expected) results

An important initial step in fulfilling our objectives is the development of high-resolution age models. Precise chronostratigraphic information is required to allow comparison with existing high-resolution climate proxy records derived from sediment and ice cores. We will apply a variety of stratigraphical methods, including marine oxygen isotope stratigraphy, ^{14}C-dating techniques; cross-correlation of proxy records to other well dated records; paleomagnetic analysis and tephrachronology. Proxy records from sediment and ice cores may also be correlated by assuming synchronous variability. This could anchor the sediment stratigraphy , e.g., to Antarctic ice core chronologies; provide information to assess characteristics of past ice flow, e.g., past ice-sheet bed conditions; and help to date minimum grounding-line retreats from each core location along past ice-stream trajectories. We will further focus on shelf areas adjacent to the troughs to increase the chance of carbonate preservation, a critical requirement not only for reliably defining an ice-sheet retreat chronology, but also for constraining trace elemental and stable isotopic ratios of calcareous microfossils; e.g., for defining past water temperatures and other ocean parameters.

Two major outcomes from the geological sampling conducted during EASI3 will be (i) a longer-term geological context for more recent ice-sheet dynamic changes in the East Antarctic region; and (ii) a framework for calibrating and improving numerical ice-sheet models – both urgently needed for this largely understudied region. We further aim to constrain the spatial and temporal variability of potential forcing mechanisms leading to past ice-sheet retreat, e.g., incursions of relatively warm deep water onto continental shelves (*cf*. Hillenbrand et al. 2017) via paleo-ice stream pathways (e.g., Klages et al., 2015) towards the grounding line (e.g., Jacobs et al., 2011; Nakayama et al., 2013; Greenbaum et al., 2015). The previously described ocean access to a cavity beneath Totten Glacier suggests increased vulnerability of such glaciers to warm-water incursions, which requires an understanding of variability from initial post-LGM deglaciation to today. In a unique onshore/offshore sampling approach, we will integrate geological samples collected from three coastal areas of Wilkes Land (Windmill Islands, Bunger Hillls and Gaußberg; Fig. 3.1b) with onshore samples collected during EASI3 (see Chapter 6). This suite of samples will be used to determine proximal ice-sheet dynamics over the last ca. 50,000 years in response to climatic changes, oceanic warm-water intrusions, and relative sea level (RSL) fluctuations at key locations along the present-day ice margin. The results will be an essential reference for ice-sheet models to improve projections of future RSL rise.

Lastly, we will gain more robust insights into the distribution of nutrients and certain elemental isotopes in distinct water masses of the Southern Indian Ocean using elemental and stable isotopic compositions of foraminiferal calcite tests and siliceous diatom frustules as proxies to reconstruct past ocean temperature, salinity, nutrient conditions, and sea-ice cover, as well as past intermediate and deep-water mass properties. Measurements will be carried out on the pelagic sediment core transect for comparison to characteristics from the deeper Indian Ocean and its intermediate and deep-water masses, as well as Southern Ocean frontal systems.

Data management

Shipboard data from the expedition will be defined as being acquired by the PS141 Shipboard Geoscience Party and be published as part of the cruise report at the latest six months after the end of the cruise in the AWI open-access series "Reports on Polar and Marine Research". Related meta-data and a short report will be submitted to PANGAEA (https://www.pangaea.de). Sample material retrieved during the cruise will be transferred to shipboard scientists and partners at their respective home institutions according to a jointly agreed sampling plan.

Sample distribution will be recorded, and archive material will be curated and permanently stored at the AWI Polarstern Core and Sample Repository, Bremerhaven. Analytical data and scientific results will be published under open access agreements in peer-reviewed journals. All data will be permanently stored in the PANGAEA data repository as a final data product (open access) with a unique digital object identifier for permanent future reference. Access for the science community will be provided via PANGAEA, once the data are published or at the latest 4 years after the end of the expedition (moratorium period).

Availability of sample material from this expedition will be restricted to PS141 participants and collaborators for a maximum post-cruise moratorium period of 4 years, after which material can be made available to the wider scientific community by enquiry to the curator of the AWI Core and Sample Repository and principal investigators.

The research activities are directly related to the objectives of Theme 2 (Ocean and Cryosphere in Climate) with a focus on subtopics 2.1 (Warming Climate), 2.3 (Sea Level Change), and 2.4 (Advanced Research Technologies for Tomorrow).

In publications based on this cruise, **Grant No. AWI_PS141_02** will be quoted and the respective reference article will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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4. WATER COLUMN SAMPLING

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Grant-No. AWI_PS141_02

Objectives

Global climate change is one of the most pressing challenges our society is facing at the moment. Climate sensitivity due to atmospheric CO_2 doubling will most likely cause global temperatures to increase by 2.0–4.5 °C. Unless we take immediate and large-scale actions to reduce greenhouse gas emissions, it will not even be possible to limit global warming to 1.5 – 2°C (IPCC 2021). While the direct effect of increasing CO_2 is straightforward, the eventual impact of CO_2 rise is uncertain due to various positive and negative feedbacks in the climate system. In combination with temperature reconstructions, accurate atmospheric paleo-CO_2 estimates are necessary to validate models that aim to predict global temperature rise related to CO_2-forcing mechanisms. Reconstructions of atmospheric CO_2 from ice-cores are confined to the last 800 kyr, while reconstruction of atmospheric pCO_2 going further back in time relies on sedimentary archives (e.g., Hönisch et al., 2012). Within the latter, foraminifera play a central role, since the chemical and isotopic composition of their shells reflect the physicochemical properties of the seawater that these organisms grew in.

Currently established, foraminifera-based carbonate system proxies include boron isotopes (pH), B/Ca (CO_3^{2-}) or the reconstruction of total alkalinity via salinity variations. However, none of these proxies allow the reliable construction of the complete carbonate system and thus paleo pCO_2, due to various limitations and uncertainties associated with the different methods used. Despite much excellent work in the field of paleoclimatology aiming at the establishment of new foraminifera-based carbonate system proxies, other calcifiers have not yet been adequately explored for their proxy potential. Yet, without branching out and studying the proxy potential of marine calcifiers, we are left with an inadequate reconstruction of the paleo-carbonate system and thus paleo-atmospheric CO_2. We will remedy this gap by developing new, pteropod-based proxies (e.g., via B isotopes), as well as ground-truth the recently developed pteropod-based proxies for temperature and carbonate ion concentration (Keul et al., 2017), and validate/ improve the calibration of foraminiferal-based proxies. Pteropods are ideal candidates: they are abundant in all major ocean bodies and their physiology is known to be highly sensitive to climate change (see Manno et al., 2017 for a review).

The aims of the water column sampling programme are:

1. Ground-truthing of foraminiferal proxies and establishment of novel pteropod-based proxies: How does the trace elemental and stable isotopic incorporation in pteropods vary with different temperature and CO_2 gradients?

A so-far under-used opportunity to establish new C system proxies is to examine the potential of pteropod shells. Pteropods are ideal candidates: they are abundant in all major ocean bodies, and their physiology is known to be highly sensitive to climate change (Ocean Acidification and Ocean Warming; Lischka et al., 2011). Pteropods are pelagic molluscs, producing shells made out of aragonite, a metastable form of calcium carbonate, which is more soluble than calcite in seawater. This make pteropods an interesting subject in the development of new proxies: since the presence of pteropods in underlying sediments is governed by the corrosiveness of the water column, pteropods can be used as a "double archive" as they offer the unique chance to quantify both the characteristics of the water column at the time of biomineralization (as imprinted in the trace elemental incorporation in the pteropod shell), and the corrosiveness of the water column (through their presence/absence/ fragmentation in the sediment (see also Objective 2 below). We will assess the fractionation of trace elements and stable isotopes in both pteropod and foraminiferal shells, and compare the two groups and the surrounding water masses, which will lead to the establishment of novel proxies for both the carbonate system and temperature. Given the importance of high-latitude areas in the ocean–climate system, there is currently a high need for reliable paleo-proxies of low temperature species.

2. Diversity, abundance and ecology of pteropods along a latitudinal gradient across the Southern Ocean

Pteropods have been shown to be good indicators of ocean acidification (Manno et al., 2017). Their abundance and biogeographical distribution is still poorly known in the study area, even though knowledge of their ecology and biogeography is important in order to predict species-specific sensitivity to a changing ocean. We will examine the abundance and diversity patterns of pteropods along two latitudinal and one longitudinal transect in the Indian Sector of the Southern Ocean. These areas have not yet been widely sampled for pteropods, and we will use samples for molecular analyses to establish species boundaries and population structure. Furthermore, many aspects of the basic ecology of pteropods remain poorly known, which limits our ability to assess their response to climate change. During this cruise, we will learn more about their diel vertical migration patterns, trophic level, diet, and depth habitat (where in the water column do they calcify? where and what do they eat?).

3. Diversity of the zooplankton assemblage

Marine zooplankton are the intermediate trophic levels of pelagic marine food webs, and they play an important role in global biogeochemical cycling, facilitating the movement of carbon, nitrogen and phosphorous from the surface ocean into the deep sea. With representatives from 15 animal phyla and > 7,000 species described worldwide, the taxonomic complexity of the assemblage is high. An additional aim of this cruise is to evaluate the diversity of the assemblage in (sub) Antarctic waters, comparing convential morphological identification of key taxonomic groups with metabarcoding (community amplicon sequencing) approaches.

4. Characterization of the Southern Ocean using trace elements and stable isotopes

Geochemical research to be carried out during PS141 will include seawater sampling for trace metal and isotopic analyses that will not only serve as a reference and calibration for the paleoceanographic proxies and approaches, but will also enhance understanding of Antarctic sub-glacial runoff and nutrient delivery to the Antarctic reaches of the Southern Ocean. Large parts of the Indian sector of the Southern Ocean have not been sampled for contamination-prone trace metals or their isotopic ratios. Conversely, constraining trace metal supply and dispersal in sub-Antarctic waters today is key to developing an accurate reconstruction of past environmental conditions, as well as understanding consequences of ongoing environmental changes. This applies both to effects for the biological pump (trace nutrient limitation) as well as identification of water masses. Moreover, the deep and intermediate Antarctic water masses play a crucial role in supplying nutrients to the lower latitude surface ocean. Notably for the nutrient metals, the processes that govern the quantity and stoichiometry in the source regions and northward-advecting water masses are insufficiently constrained, making it impossible to predict the consequences of Southern Ocean changes in upwelling or phytoplankton community shifts.

Work at sea

Plankton will be collected vertically using a multiple closing plankton net (Hydrobios Kiel, nominal mouth area of 0,25 m^2) with five nets (100 µm mesh size for calcitic plankton), allowing stratified vertical sampling at five depth intervals. A total of 30–40 stations will be sampled: 9 stations during transit ("deep stations", where a full set of water parameters will also be sampled) and the rest of the stations on the shelf ("shelf stations", with limited water sampling). For foraminiferal and pteropod analyses, two tows will be cast at each deep station: a shallow one between 100 m and the surface (standardized intervals 100-80-60-40-20-0 m), and a deep one between 700 or 800 m water depth and the surface. Sampling intervals of the deep net will be chosen according to the water mass distribution at the sampling site and the deep chlorophyll maximum. It has been demonstrated that pteropods dwell in shallower depths at high latitudes, so only one net will be cast at the shelf stations, going to an intermediate depth of 200–400 m. Slacking and hoisting the net will be carried out at 0.5 m/s. The residue of the net cups containing the plankton >100 µm will be immediately observed under the microscope and then diluted with filtered seawater and ethanol (50:50) after each haul. Some of these samples are for K. Peijnenburg and these will be immediately fixed in pure ethanol (96 %) and stored at -20 °C. After 12–24 hours the ethanol will be replaced once. At all multinet stations, a CTD carrying a fluorescence probe to record the fluorescence in the water column (a measure of the chlorophyll concentration) will also be performed at the same location (see below). At as many stations as possible (especially during transit), additional ringnet (200 µm mesh size) samples will be taken to collect larger pteropod species for molecular and ecological research. The tow will take 20–30 min and will gently sample surface waters (50 m - 0 m, hauling speed is 20m/ min). These samples should be immediately preserved in pure ethanol (96%) and stored at -20°C. After 12–24 hours the ethanol should be replaced once.

Living planktic organisms (foraminifers and pteropods) will also be collected in the near-surface water during the cruise using the ship's pump (both in transit and at stations). The surface water will be filtered with a sieve of 63 µm mesh size, which is secured inside a PVC tube of 40 cm in length and 10 cm in diameter to collect the zooplankton safely. To calculate the abundance of the zooplankton, the filtered water volume will be measured with a flow meter attached between the seawater-tap and the filter system. On a typical cruise of comparable length, around 80 – 100 samples can be obtained this way. Samples can be picked wet with a glass pipette after collection for a first overview during the cruise, or preserved in filtered seawater and ethanol (50:50), and stored at 4°C. During the cruise, surface sea temperature, salinity and chlorophyll concentrations will be recorded continuously by the thermosalinograph. Seawater sampling from the ship's pump will be carried out during the same intervals (see below).

Calcifying plankton will be sorted and counted from the sampling bottles (from multinets and underway pumping) after return to the home laboratory (IFG/CAU).

During the PS141 EASI3 cruise, water samples will be collected using Niskin bottles and the ship's pumps during transit. These samples will be analysed to provide information about the carbonate system chemistry (DIC), trace elements (including Mg, Ca, Sr), and stable isotopes (C, O). With the exception of on-board pH-measurements, all samples will be measured upon return to the laboratory. Trace elements will be measured at CAU, DIC and stable isotopes at the AWI. Results will be used together with those from the calcifiers in proxy development and calibration.

Preliminary (expected) results

Expected results for the individual aims are:

1. We expect to establish novel pteropod-based proxies for both the carbonate system and temperature. Furthermore, we expect to be able to groundtruth some of the foraminifera-based proxies.

2. In general, we expect higher species richness in more stratified waters. We furthermore hypothesize that the biogeographical distribution of pteropod assemblages will largely mirror the distribution of Longhurst's biogeochemical provinces (Longhurst et al., 1995). Furthermore, we expect to uncover new pteropod species diversity within the *Limacina* genus with distinct ecologies.

3. We expect to add to reference DNA barcoding libraries (Biodiversity of Life Database: https://www.boldsystems.org/ and MetaZooGene: https://metazoogene.org/mzgdb/), with voucher specimens and DNA stored at Naturalis Biodiversity center.

4. We will enhance the understanding of trace metal supply and dispersal in sub-Antarctic waters, which is key to developing a reference frame for the most accurate reconstruction of past environmental conditions.

Data management

Plankton and water samples retrieved during the cruise will be transferred to CAU and AWI-Bremerhaven. Analytical data obtained on all samples will be published in peer-reviewed journals. Access for the science community will also be provided via the geoscientific database PANGAEA (https://www.pangaea.de), once the data are published or at the latest 4 years after the end of the expedition (moratorium period). Directly after publication, data will be freely accessible. To avoid research overlap, the availability of the sample material from this expedition will be restricted to PS141 EASI-3 participants and collaborators for a period of a maximum of 4 years after the cruise. Afterwards, the material will be available for the wider scientific community.

All data generated in laboratory work by proponents will be permanently stored in the PANGAEA data repository as raw data before peer-reviewed publication (protected with restricted access), and thereafter as a final data product (open access) with a unique digital object identifier for permanent future reference. Data acquired during the project will be archived using the CAU and AWI Cloud Server systems, allowing for immediate exchange of cruise data and preliminary analytical data within the project group. The main proponent and her co-proponent will take care of the data transfers to long-term archives (PANGAEA) in order to ensure external access to the data worldwide and into the future.

The research activities are directly related to the objectives of Theme 2 (Ocean and Cryosphere in Climate) with a focus on subtopics 2.1 (Warming Climate), 2.3 (Sea Level Change), and 2.4 (Advanced Research Technologies for Tomorrow).

In all publications, based on this cruise, the **Grant No. AWI_PS141_02** will be quoted and the following article will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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5. ANTARCTIC KRILL STUDIED BY CRABEATER SEALS BENEATH THE SEA ICE: SEAL TAGGING

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Objectives

Over the past half century, many climate-induced physical processes have changed the structure and functioning of Antarctic marine ecosystems and the Southern Ocean. The latter is absorbing more and more CO_2 due to the increase in greenhouse gas emissions caused by human activities. The resulting acidification affects calcifying organisms, and also leads to implications for the physiology of crustaceans such as krill (Kawaguchi et al., 2013). Furthermore, increasing ocean temperature, regional and local changes in sea ice thickness and seasonal coverage, and increasing ocean stratification have the potential to profoundly alter marine primary production, its duration and intensity; these changes are already visible in some regions (Meredith et al., 2019). These ongoing changes thus impact the entire local food web, whether it be phytoplankton, zooplankton (krill, primarily), fish, cephalopods, marine mammals and birds, or benthos.

In response to these changes, the distribution of krill in regions of the South Atlantic where the sea ice extent has significantly decreased has, for example, shifted southward over the past 90 years (Atkinson et al., 2019). This can be easily explained by krill's life traits: their larvae use the sea ice area in winter both as a food source (by grazing on algae growing on the submerged side of the pack ice) and as a refuge from predators and surface currents (Meyer, 2012). In doing so, by following the retreat of the sea ice, krill larvae could continue to benefit from refuge areas from their predators. However, it still remains unclear whether or not krill, at the Southern Ocean's scale, will follow their thermal niche southward - under the constraint of climate change - due to the importance of other factors such as depth and amount of primary production. For marine birds and mammals, the degree to which they will be influenced by changes in the Southern Ocean, meanwhile, depends on many factors such as their flexibility to alter their diets, move to alternative foraging areas or resting/breeding habitats for sea-ice-dependent predators, the energy expenditure of longer or more complex foraging trips, or interspecies competition for concentrated or reduced resources (Constable et al., 2014).

Beyond this patchy knowledge, threats to this food web resulting from changes in the Antarctic sea ice remain largely unknown. Mechanistic understanding of the linkages between sea ice, biogeochemical processes, and lower and upper trophic levels remains poor (Ducklow et al., 2007). For example, studies on krill are generally restricted to ice-free waters, as sea ice - when present – hinders both navigation of research icebreakers and satellite visibility of waters beneath the ice. Furthermore, setting up observatories using moorings (fixed buoys equipped with sensors) remains logistically difficult and only allows the collection of information at specific points. The richness, range of opportunities and spatial coverage that polar predator bio-telemetry has provided and will continue to provide in this region are thus essential to study the Antarctic ecosystem. Indeed, krill is very abundant under the sea ice (Brierley, 2002), and many predators feed there. Far from being a homogeneous area, sea ice is a habitat of great heterogeneity that supports very specific biotic and abiotic conditions (Worby et al., 2008; Williams et al., 2014; Meiners et al., 2017). Thus, it is crucial to focus on a mechanistic understanding of the linkages between sea ice and the underlying ecosystem. This is what we propose in this project, focusing on krill, a key link in the Antarctic ecosystem and component of one of the two dominant polar pelagic food webs, as well as its predators.

The objective of our project is to elucidate the mechanisms by which the Antarctic sea ice controls the distribution of krill by studying the functional relationships of krill with their predators. We will study how the functional traits of krill - based on the organization of the swarms they form (e.g. surface area, length, perimeter, average depth, etc.) - influence the functional hunting/foraging/feeding responses of a polar predator - based on its diving behavior (e.g. dive depths and durations, horizontal and vertical travel speeds, 3D acceleration peaks, etc.).

Work at sea

We intend to deploy a total of 15 tags opportunistically during the cruise in near-Antarctic waters in pack ice zones along the ship-track, from February to April 2024 just after the crabeater seal moulting period. The ideal total estimated time within the marginal and pack ice zones is 5h* 15 = 75 hours. We intend to be set out on ice for time slots from 2–8 h, depending on crabeater seal scouting and the number of individuals available. Usually, we observe groups of 1–4 crabeaters, therefore time slots of 5–6 hours would be ideal (this includes helicopter transit times, search times, landing and recovery of staff after the seal deployments) in order to deploy 1–4 tags each time for an ideal total of 15 tags. If several seals are spotted in the same area, 6 time slots of 5 hours each might be sufficient for the 15 tag deployments. The main helicopter time will be dedicated to searching for crabeater seals. In addition to the helicopter operation and in case of bad weather conditions, the seal team can be set out on ice en route along the ship's track if seals are spotted from the bridge and the ship's schedule allows a stop. We plan to have the tags on seals for up to 12 months from the date of deployment after the seals have completed their annual moult in January.

Details:

- Seals will be located by helicopter mainly in the pack ice areas as previously done by Nordøy and Blix (2009), Nachtsheim et al. (2016) and Wege et al. (2021). Once the seals are observed and inspected at close range, and the state of sea ice for landing and moulting has been evaluated, the helicopter will drop the staff on ice. If the animals do not escape and take to the water, they will be immobilized.
- The helicopter will drop 4 persons on an ice floe in the wider vicinity of sighted crabeater seals. All materials and gear will be transported using a pulka or backpacks. Fieldworkers will wear a dry suit and life jacket and will use a sonde to spot holes and cracks within ice floes. AWI and *Polarstern* respectively have long standing experience with seal work on ice (*cf*. Bornemann, 2019, 2017, 2014), and protocols can be applied accordingly.
- Prior to tagging, seals will be immobilized with a combination of 500 mg xylazine, 400 mg ketamine and 50 I.U. hyaluronidase, known as "Hellabrunner Mischung" (HM). Doses of 2–3 ml HM will be supplemented with 2–3 ml ketamine (100 mg ml^{-1}) and injected with a dart-gun directly on the ice floes. Maintenance of narcosis will be ensured by manual follow-up doses of ketamine, and/or xylazine and/or diazepam on demand. The immobilization procedure is described in detail by Bornemann et al. (1998) and Bornemann and Plötz (1993) and dose rates available on PANGAEA (https://doi.pangaea.de/10.1594/PANGAEA.438929). While the seals are immobilized, their standard body length will be measured with the animal lying on its venter. Standardized (blood, whiskers) and opportunistic sampling protocols (scat) complement the procedure. Tags will be attached to the fur on the animal's back with

quick setting loctite glue. These are supposed to fall off during the seals' next annual moult.

- Once the anesthesia and tag deployment are finished, the field team will communicate via radio with the helicopter pilot for retrieval of the team and return to the icebreaker.

Preliminary (expected) results

The continuous monitoring of crabeater seals in East Antarctica using high-resolution accelerometers (SCOUT-DSA, Wildlife Computers) positioned on their heads will provide the opportunity to record acceleration: prey capture attempts; dive depths; and Argos positions. By tracking changes in crabeater seal distribution and behavior, we can uncover seasonal shifts in krill distribution under sea ice — a crucial knowledge gap.Although there is currently no substantial krill fishery in East Antarctica, indications of growing interest necessitate timely monitoring and surveys in the absence of fishing pressure, aligning with CCAMLR CEMP's (Commission for the Conservation of Antarctic Marine Living Resources Ecosystem Monitoring Program) objective of distinguishing environmental changes from resource harvesting impacts on krill-centered ecosystems.

The urgency of our pursuit is heightened by the ongoing decline of Antarctic sea ice. Identifying feeding zones for krill-eating predators across both vertical and horizontal dimensions is vital to unraveling krill distribution patterns and understanding the regional impact of sea ice changes (SC-CAMLR-41 Annex 4, Table 2, section 2 a,e). Our research will offer valuable insights into the distribution of krill beneath the sea ice, their significance for predators, and the dynamic trophic relationships that necessitate monitoring.

This research will serve as a basis for (i) inluding the crabeater seal as a sentinel species in the CCAMLR CEMP monitoring program; and (ii) setting up a long-term monitoring program with annual deployments in East Antarctica. These deployments will utilise international collaboration between Australia, Germany and the French Polar program at *Dumont d'Urville*, and will enable ongoing monitoring of changes in krill distribution and important habitats for krill-dependent predators in relation with changes in sea ice in East Antarctica. There is no significant krill fishery in this region, but an MPA proposal is currently in discussion and includes, particularly for the Dumont d'Urville-Mertz area, a no take zone for krill.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data. This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future".

In all publications based on this expedition, the **Grant No. AWI_PS141_09** will be quoted and the following publication will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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6. CONTINENTAL GEOLOGY AND GEODESY

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Grant-No. AWI_PS141_04, AWI_PS141_05

Outline

Geoscientific research to be carried out on land during expedition PS141 will cover a variety of study areas (Fig. 6.1). The Bunger Hills and the Windmill Islands in Wilkes Land are target areas for terrestrial geological and limnological work. Camps will be set up in order to conduct sediment sampling and geomorphological investigations. The Gaußberg is the main working area for the onshore geophysical-geodetic work. In addition, several sites will be visited for short-term stays in order to maintain existing GNSS sites and install new GNSS sites. Details are given in the sections 6.1 and 6.2.

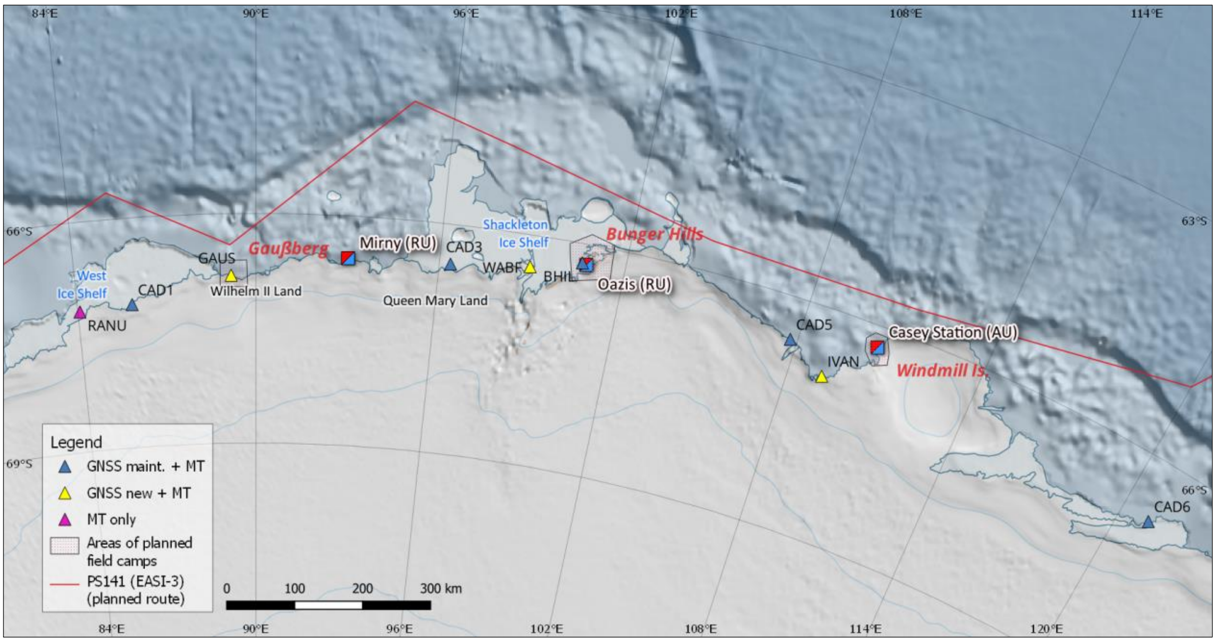

Fig. 6.1: Overview map of the coastal region of East Antarctica with a schematic outline of the planned cruise track of PS141 and the onshore locations to be visited. A field camp at Gaußberg during this project is planned to last about three to four weeks. The other two areas of Bunger Hills and Windmill Is. will be destinations for geology field camps (see Section 6.1). All other sites will be visited for short-term stays (several hours). (GNSS: global navigation satellite system; MT: magnetotelluric measurements; maint.: maintenance)

6.1 Terrestrial Geology and Limnology

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Grant-No. AWI_PS141_04

Objectives

It has long been assumed that the EAIS is stabilised by resting on bedrock above sea level (in contrast to the largely marine-based West Antarctic Ice Sheet). In recent years, however, modelling approaches and field experiments have shown that processes associated with basal melting of ice shelves through the intrusion of relatively warm deep water could also have a destabilising effect on marine-based portions of the EAIS (e.g., Rintoul et al., 2016). Especially in Wilkes Land, where the highest ice mass losses in East Antarctica are observed (Rignot et al., 2019). The possible causes lie not only in the interaction of the ice sheet with the ocean, but are also influenced by the local topography beneath the ice sheet. To better understand the drivers of ice sheet stability/instability in relation to regional features, detailed studies from the presently ice-free regions of Wilkes Land are required. In this regard, the Bunger Hills and Windmill Islands, two ice-free coastal sites, provide a unique opportunity to obtain information on temporal/spatial ice sheet changes at the margins of the major glaciers (Denman/Scott Glacier and Vanderfold/Totten Glacier), which are particularly dynamic under present-day conditions (Rignot et al., 2019). To gain insights into the regional ice sheet history, and the interaction between ocean and ice during the Holocene, we aim to collect geological samples and data at Bunger Hills and Windmill Islands. The new material will provide the basis for a significantly improved spatial and temporal resolution of paleoenvironmental and paleoclimate information in this region.

Work at sea and on land

During PS141 we plan to visit the Bunger Hills and the Windmill Islands in Wilkes Land (Fig. 6.1). Camps will be set up at these locations for a period of three to four weeks in total to carry out sediment sampling and geomorphological investigations.

The planned work includes sediment coring on lakes and in marine bays, and sampling of raised beaches and glacial erratics. The material will be used to reconstruct the timing of ice retreat, the development of relative sea level (RSL) and Holocene paleoclimate in the region.

For RSL reconstructions, lakes at different altitudes, which presumably developed from marine bays into lakes in the course of regional isostatic uplift, will be sampled. The timing of the transition from marine to lacustrine conditions (or vice versa) in individual lakes provides constraints for the reconstruction of RSL over time. It is therefore desirable to sample a whole series of these lakes/marine bays to obtain a high-resolution record. For palaeoclimate information, lakes are sampled that were not affected by sea level change and that are at higher elevations (higher than 15 m above sea level at Bunger Hills and 35 m above sea level at Windmill Islands; Goodwin, 1993; Verkulich et al., 2002). Measurements of the height of lake and sea levels as well as georeferencing of sampling sites will be done by geodetic measurements (see also section 6.2).

Glacial erratics indicate previous ice sheet coverage and will be collected to date the ice retreat in the working area by exposure dating (White et al., 2022). In addition to the samples collected during the field camps, erratics will also be collected along the cruise track on nunataks and offshore islands to provide a broader view of the temporal changes and, equally important, ice-thickness changes in the region of the Denman/Scott and Vanderfold/Totten Glaciers. These sites will be approached with helicopter and visited for a few hours each.

Geophysical measurements on land, at the ice sheet margin and in water will be carried out to complement the findings from the sedimentary archives. Ground penetrating radar (GPR) profiles will provide information on the stratigraphy of ancient beach deposits, reflecting past changes in RSL and aiding in selecting suitable sites for sampling beach deposits for age determination. At Windmill Island, GPR will be applied to visualise the internal ice structure at the transition between the ice sheet and land, and to provide information about recent ice movement/dynamics. At marine inlets, hydroacoustic surveys using an Innomar SES 200 compact instrument will be carried out to map the sea floor topography and identify depositional structures, such as moraine deposits, that can inform about past positions of the ice sheet margin and aid in identifying suitable coring locations.

A further focus is the sampling of sub-fossil stomach oil of snow petrels (*Pagodroma nivea*), so-called mumyio deposits. These deposits provide geological evidence for the distribution of snow petrels in the past (e.g., Berg et al., 2019a). The deposits have been used to infer glaciation histories as bird colonisation precludes concurrent ice cover and the deposits can be well dated by radiocarbon dating (e.g., Mackintosh et al., 2011). The purpose of sampling stomach oil deposits here is to use them as an archive for environmental conditions in the coastal ocean, which is the feeding ground of the birds (e.g., Hiller et al., 1988; Ainley et al., 2006; Berg et al., 2019b, 2023). The lipid and isotopic composition of stomach oil deposits can provide evidence for changes in the food composition of the snow petrels (Berg et al., 2023), which is linked to oceanic environmental parameters, such as the sea ice distribution during summer, polynyas and shifts of the southern boundary of the ACC. Stomach oil deposits form in the vicinity of nesting cavities of snow petrels, which are distributed on rocky coastal sites and can also be found on nunataks. The occurrence of snow petrel stomach oil deposits in Bunger Hills and Windmill Islands has been reported in previous studies (Ainley et al., 2006; Berg et al., 2023) and the record from the southern Bunger Hills dates back to the early Holocene (Ainley et al., 2006).

Collection of geological samples will be complemented by sampling for modern environmental and biological studies. We plan to carry out mineral magnetic/biomagnetic investigations on unconsolidated lake sediments from the shorelines and sediment cores of the visited lakes. The focus here is on the concentration and diversity variations of magnetotactic bacteria fossil remains. Magneto fossils are thought to be ubiquitous in aquatic environments and are likely to be an important contributor to magnetic enrichment of aquatic sediments and, thus, to the palaeomagnetic record. However, the study of magneto fossils in Antarctica currently limited to just few studies focused exclusively on marine environments. Therefore, this will be the first study of the abundance and variability of freshwater magneto fossils in Antarctica.

Isotopic and hydrochemical data from lakes provide direct information on the response of the catchment to changing precipitation, evapotranspiration, nutrient cycling, and ecosystem conditions (Meredith et al., 2022). These techniques have rarely been applied to lakes in the high latitudes of the Southern Hemisphere. As part of the planned field work, water samples will be taken from different lakes in the study areas in order to carry out hydrochemical and isotopic studies. These data will be used in a larger study that addresses environmental processes and ecological effects of seasonal, annual and long-term fluctuations.

Biological soil crusts are an important component of Antarctic terrestrial ecosystems. Their microbial biodiversity, however, is not well known. The samples collected here represent an essential contribution to biodiversity research and also provide functional evidence of microbial networks. The samples from the Bunger Hills and Windmill Islands are important contributions to describe the natural composition from which the influence of environmental changes on the ecosystem can be studied.

Preliminary (expected) results

We expect to be able to carry out the sampling necessary to answer the scientific questions described above. The sample material (sediment cores, various sediment samples, mumiyo deposits, soil crusts and water) will be transported to Germany and processed there as part of various ongoing and planned DFG projects. We anticipate to gain important new insights into the glacial and climatic history of the regions visited. In particular, the diversity of sampling targets will allow us to link abiotic environmental conditions and climatic changes with the response of the Antarctic ecosystem.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied. Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data. This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future".

In all publications based on this expedition, the **Grant No. AWI_PS141_04** will be quoted and the following publication will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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6.2 Geodetic-Geophysical Investigations

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Grant-No. AWI_PS141_05

Objectives

The glacial history of the Antarctic Ice Sheet – from the last glacial maximum to present day – directly affects the deformation of Earth. The response of the Earth (its rheology) is, on the other hand, governed by properties of its interior(especially effective elastic thickness of the lithosphere, and viscosity of the upper and lower mantle). The interplay of these parameters – ice-loading history and Earth's rheology – lead to the process of glacial-isostatic adjustment (GIA, e.g. Whitehouse et al., 2019). To model the ice-loading history, geological reconstructions of the climatic and glacial history have to be utilized. These reconstructions will be based on published data and complemented by new findings gained from work onshore and marine geological investigations during cruises PS140 and PS141. To infer and improve models of the Earth's rheology, a number of geophysical observations are used, e.g. seismology and observables of the potential fields (gravimetry, magnetometry). GIA modelling is constrained by geodetic GNSS (global navigation satellite systems) measurements at specially marked points which allow the inference of bedrock displacements (Scheinert et al., 2021).

Our aim is thus to realize a series of permanent geodetic GNSS observations. As a result of the GNSS measurements and consistent post-processing, we will obtain time series of daily coordinates in the vertical and horizontal (north, east) directions. The elastic displacement effect, which is caused by contemporary ice-mass changes, will be separated from the GNSS time series using additional data (especially from satellite altimetry over the Antarctic Ice Sheet, AIS). Using these coordinate time series, coordinate change rates (or velocities) will be inferred. These velocities can then be interpreted in terms of GIA. We expect vertical rates, in particular, to be most sensitive for GIA; however, GIA-induced bedrock displacement of the East AIS is small, such that incorrect treatment of present-day ice-mass change could therefore bias GIA inferences (Koulali et al., 2022; King et al., 2022). Measuring GNSS at multiple sites and integrating our results both onshore and offshore with the other geophysical and geological data collected during EASI3 and previously thus plays a critical role, ensuring that our inferences of GIA are robust. We will also use geophysical observations of seismology and magnetotellurics (MT) to improve models of Earth's rheology (Ramirez et al., 2022). In combination with additional data (especially from seismology, group of T. Stål and A. Reading), these data will help to improve our knowledge of Earth's rheological properties.

Furthermore, we plan to realize a geodetic-geological field campaign at Gaußberg. Gaußberg was discovered in 1902 by the first German South Polar Expedition, which was lead by Eric von Drygalski. Gaußberg, which rises to a height of about 360 m above sea level, is of volcanic origin, and was erupted subglacially about 56 ka B.P. As the most isolated Quaternary volcanic centre in Antarctica, Gaußberg is of great importance for understanding the paleoenvironment (Smellie and Collerson, 2021). In April/May 1902 and in September/October 1902, the Drygalski expedition realized an extensive geodetic survey across Gaußberg; determining horizontal coordinates of points at the mountain and on the ice surface, as well as their heights relative to sea level (Drygalski et al., 1906; Drygalski, 1921). Re-surveying Gaußberg will thus allow us to infer height changes, as well as changes to ice-flow velocity in its direct vicinity over a time span of 120 years. This survey will be accompanied by photogrammetric measurements to generate a high-resolution digital elevation model of the Gaußberg area for further geomorphological-glaciological investigations, as well as to aid the inference of contemporary ice-flow velocity. Geological sampling will also be carried out in order to improve our knowledge of the geologic-vulcanological characteristics of Gaußberg.

Work at sea

The planned work refers to locations on land, at or close to the Antarctic coast. Table 6.2.1 gives an overview of the locations that will be visited and the planned activities (see also Figures 6.1 and 6.2.1).

Geodetic GNSS recordings will be realized in collaboration with the group of M. King (University of Tasmania), who already runs a number of permanent GNSS sites along the East Antarctic coast (King et al., 2022). We will carry out maintenence work at existing GNSS sites. Additionally, three new permanent GNSS installations will be deployed at Gaußberg (GAUS), in the region of the Shackleton Ice Shelf (WABF), and at Ivanoff Head (IVAN). A new campaign GNSS installation that should be set up at Gaußberg during the preceding cruise PS140 will collect data in preparation of the field campaign during PS141. During the field work at Gaußberg, this new campaign site will serve as a reference station for GNSS real-time kinematic (RTK) measurements, and will be picked up after termination of the campaign. Geophysical measurements, especially magnetotelluric observations (MT; Ramirez et al., 2022), will be co-located with the GNSS sites (cooperation with the group of K. Selway). The MT equipment will be primarily set up during the preceding cruise PS140 and retrieved during PS141. If time and weather conditions allow, further MT deployments will also be realized during PS141.

A field campaign of about three to four weeks in length is planned for Gaußberg. The team for this campaign will comprise five persons who will carry out the following work:

- rediscovery and identification of locations at Gaußberg that were marked (by cairns) during the Drygalski expedition in 1902 (Fig. 6.2.2), and short-time measurements with GNSS;
- static and kinematic GNSS measurements at the ice surface close to Gaußberg covering the area of the measurements accomplished by the Drygalski expedition in 1902;
- set-up of a temporary GNSS installation to measure the sea surface at the northern shore of Gaußberg utilizing the method of GNSS reflectometry; measuring for 14 days or more will facilitate the inference of the four main ocean tide constituents;
- static photogrammetric recordings to infer ice-surface geometry and ice-flow velocity, and (supplementing GNSS reflectometry) of the sea surface;
- UAV-based photogrammetric survey to develop a high-resolution digital elevation model of Gaußberg and the ice surface in its vicinity, and to infer ice-flow velocity;
- sampling for geological investigation and climate reconstruction (glacial erratics and bedrock for cosmogenic isotope analyses; beach sediment for optically stimulated luminescence analysis; erratic/xenolith samples for provenance studies; volcanology bedrock samples), and sampling of ‘dirty’ ice for Beryllium analysis.

With the exception of the Gaußberg field campaign, the land study sites will be reached during day visits, where the helicopter will stay on site. These visits will facilitate maintenance of existing GNSS sites and installation of new GNSS sites, and retrieval of MT. These land visits will be complemented wherever possible by cosmogenic rock sampling for exposure dating.

The geodetic measurements collected by this team will also support the geological field work of the land geology group (see Section 6.1), by georeferencing sampling sites and measuring the height of lake and sea levels.

Tab. 6.2.1: List of measurement locations, their coordinates and planned activities.
GNSS: global navigation satellite systems; MT: magnetotelluric measurements (pick up of deployments made during PS140, optionally new deployment); seismo: seismometer; maint.: maintenance. Further geological sampling (cosmogenic rock samples) will be done wherever possible (especially at RANU, CAD1 and IVAN).

ID	**Location**	**Longitude east [°]**	**Latitude south [°]**	**Applied method / planned activities**
RANU	Ravich Nunatak (West Ice Shelf)	84.0689	67.1670	MT pick up
CAD1	Carey Nunatak (West Ice Shelf)	85.8365	67.1306	MT pick up, *GNSS (maint.), seismo (maint.)*
GAUS	Gaußberg	89.1750	66.8043	Field camp (geodesy, photogrammetry, geology) GNSS: new permanent installation pick up of MT and episodic GNSS
CAD3	Gillies Is.	96.3661	66.5195	MT pick up, *GNSS (maint.)*
WABF	Watson Bluff (Shackleton Ice Shelf)	98.9500	66.4167	GNSS: new permanent installation, MT (optional)
BHIL	Bunger Hills	100.5990	66.2510	GNSS (maint.), MT (optional)
CAD5	Snyder Rocks	107.7640	66.5525	GNSS (maint.), MT (optional)
IVAN	Ivanoff Head	109.1291	66.8808	GNSS: new permanent installation, MT (optional)
CAD6	Chick I.	120.9886	66.7894	GNSS (maint.), MT (optional)

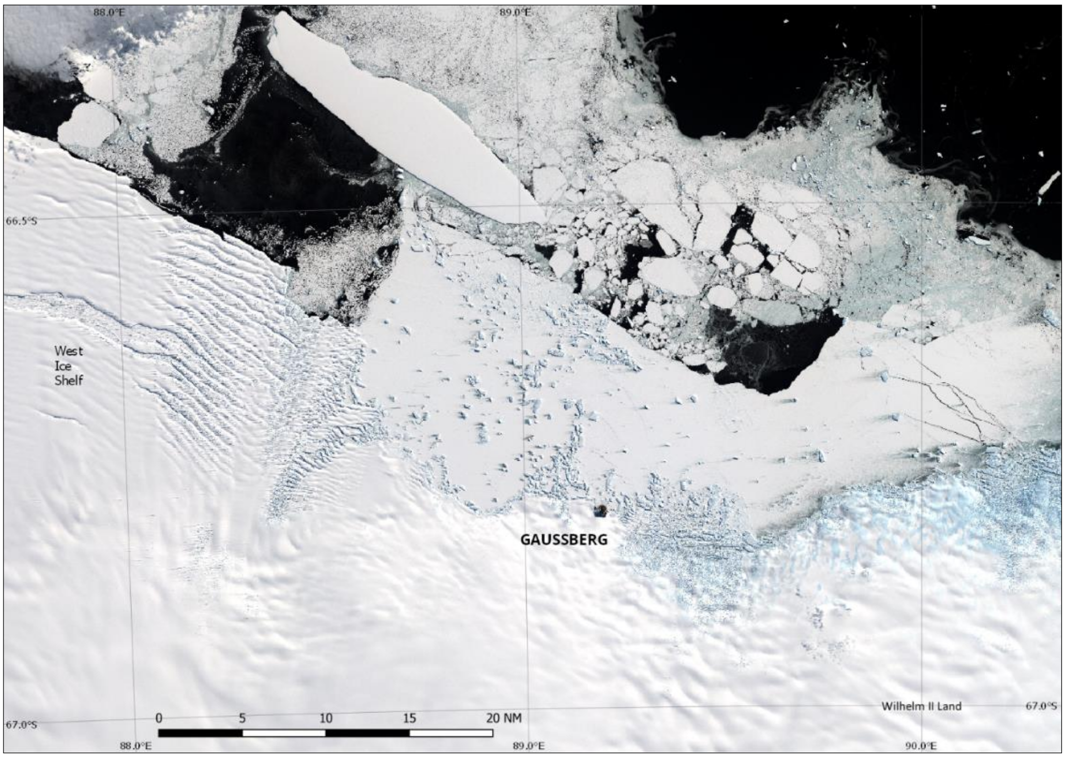

Fig. 6.2.1: Detailed map showing the location of Gaußberg. Satellite image: Sentinel-2 (17-03-2023).

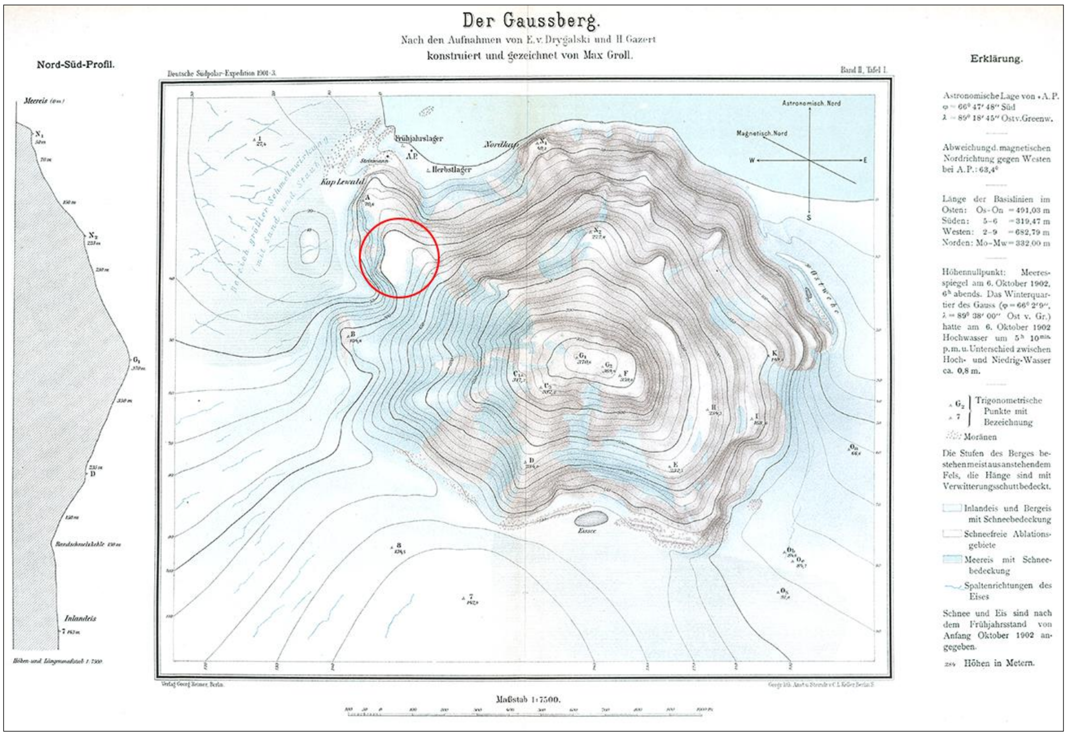

Fig. 6.2.2: Detailed map of Gaußberg (from Drygalski et al. 1906, Band II, Tafel 1). The planned location of the field camp is marked by the red circle. The camps of the Drygalski expedition („Frühjahrslager“ April 1902 and „Herbstlager“ Sept. 1902, respectively) were situated at the shore on the northern hillside of Gaußberg. Measurement points are denoted by letters (mostly at the mountain) and numbers (at the ice surface).

Preliminary (expected) results

All measurements and geologic samples will be analysed at the home institutions. This refers to the GNSS recordings at bedrock sites, as well as those taken during the Gaußberg survey. Post-processing will be carried out using the Bernese GNSS Software v5.4 applying differential GNSS and precise point positioning (PPP). The latest standards used in geodesy have to be incorporated in the analyses (e.g. precise realization of the reference frame; consistent treatment of corrections; and reductions). During the Gaußberg survey, we will calculate transformation parameters to facilitate transformation of the local geodetic system used by Drygalski's team in 1902 to the modern system supported by GNSS. Likewise, the photogrammetric data (from static cameras as well as from the UAV-based survey) will be processed at home. First insights in terms of quality and plausibility of the data will be achieved during the Gaußberg survey. The geological samplings will be shipped home for analysis.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data. This refers especially to GNSS data, where archiving will be carried out in the framework of the SCAR Expert Group "Geodetic Infrastructure in Antarctica" (GIANT).

Geological samples will be stored and analysed at the cooperation partners in Australia (University of Tasmania, Hobart, and University of Canberra).

In all publications based on this expedition, the **Grant No. AWI_PS141_05** will be quoted and the following publication will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

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7. ISOMETHANE: ONBOARD IN SITU ANALYSES OF METHANE CONCENTRATION AND ITS STABLE CARBON ISOTOPIC SIGNATURE ($\delta^{13}C$-CH_4) IN THE LOWER TROPOSPHERE ABOVE THE SOUTHERN OCEAN

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Grant-No. AWI_PS141_11

Objectives

Methane is the secondmost important human-influenced greenhouse gas in terms of climate forcing. For methane, both bottom-up and top-down modelling approaches are subject to large uncertainties, leading to a significant mismatch. We aim to record a time series of methane concentration and its stable carbon isotopic signature in the lower troposphere during the cruise. This time series will contribute to the quantification of methane sources and sinks in the Southern Ocean needed for the improvement of model parameterizations.

Work at sea

The continuous ship-borne measurements of CH_4 concentration and $\delta^{13}C$-CH_4 will be carried out by Cavity Ring-Down Spectroscopy (CRDS) using a Picarro G2132-i isotope analyser (Picarro, Inc., Santa Clara, USA). CRDS is a highly sensitive gas analysis technique that measures the near-infrared absorption spectra of small gas-phase molecules within a high-reflectivity cavity using a laser diode. Air will be sucked from the starboard side of the Peildeck at about 21 m above sea-ice/water surface using a Teflon tube. A constant flow will be generated with a 3KQ Diaphragma pump (Boxer, Ottobeuren, Germany).

Preliminary (expected) results

Variations in CH_4 concentration and $\delta^{13}C$-CH_4 ratios over time will help to understand and validate source and sink capacities. The data evaluation focuses on using backwards airmass trajectories to monitor air masses and to distinguish locally induced signals from signals transported from remote areas. Combined with the time series recorded during MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate 2019–2020), the project aims to study differences in the source-sink balance along a global North-South transect.

Data management

The Picarro G2132 will be calibrated and maintained during the cruise to ensure high data quality. The recorded raw data will be processed with a spike detection code to distinguish the background signal from contamination by local pollution (like pollution from the ship stack). The atmospheric data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental

Science (https://www.pangaea.de) within two years after the end of the expedition at the latest. By default, the CC-BY license will be applied.

This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 1.

In all publications based on this expedition, the **Grant No. AWI_PS140_11** will be quoted and the following publication will be cited: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTES

A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS EXPEDITIONSTEILNEHMER:INNEN / EXPEDITION PARTICIPANTS

A.3 SCHIFFSBESATZUNG / SHIP‘S CREW

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Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
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Xydis	Georgios	DE.GEOMAR	Student (Master)	Biology

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

Name / Last Name	**Vorname / First name**	**Position / Rank**
Wunderlich	Thomas	Master
Langhinrichs	Jacob	C/M
Strauß	Erik	2/M Cargo
Grafe	Jens	C/E
Hering	Igor	2/M
Rathke	Jannik	2/M
Dr. Gößmann-Lange	Petra	Doc
Dr. Hofmann	Jörg	E/E Com.
Brose	Thomas	2/E
Bähler	Staphanie	2/E
Farysch	Tim	2/E
Redmer	Jens	E/E SET
Kliemann	Olaf	E/E Brücke
Hüttebräucker	Olaf	E/E Labor
Pliet	Johannes	E/E Sys
Jäger	Vladimir	E/E Winde
Sedlak	Andreas	Bosun
Neisner	Winfried	Carpenter
Burzan	Gerd-Ekkehard	MPR
Klee	Philipp	MPR
Klähn	Anton	MPR
TBN		MPR
Meier	Jan	MPR
Rhau	Lars-Peter	MPR
Schmidt	Patrick	MPR
TBN		MPR
Schwarz	Uwe	MPR
Klinger	Dana	MPR
Wendt	Meyk	MPR
Münzenberger	Börge	MPR
Peußner	Jörg	Fitter/E
Hofmann	Werner	Cook
Hammelmann	Louisa	2./Cook
Dietrich	Emilia	2./Cook
Pieper	Daniel	C/Stew.

Name / Last Name	**Vorname / First name**	**Position / Rank**
Hinz	Nina	Stew./Nurse
Dibenau	Torsten	2./Stew.
Stocker	Eileen	2./Stew.
Brändli	Monika	2./Stew.
Arendt	Rene	2./Stew.
Cheng	Qi	2./Stew.
Chen	Dansheng	2./Stew.
Klett	Onno	Trainee