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

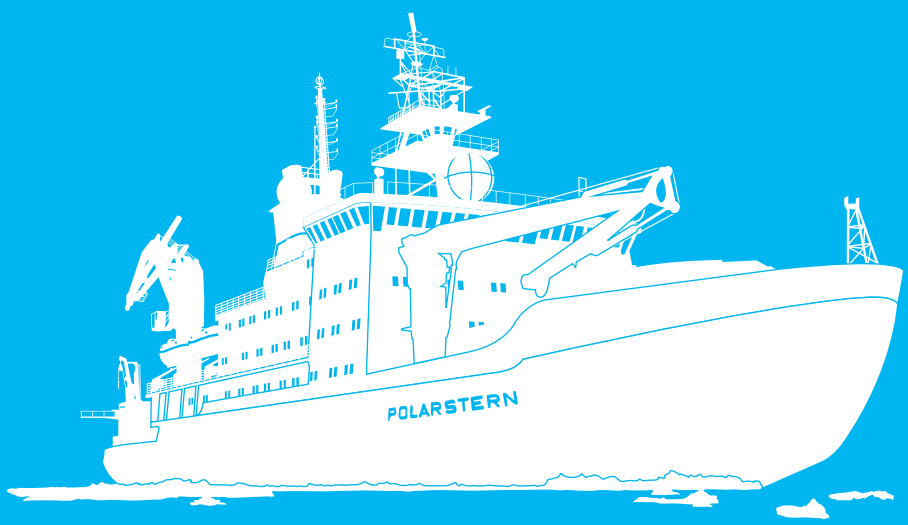
EXPEDITION PROGRAMME PS134

Polarstern

PS134
Cape Town – Punta Arenas
22 December 2022 – 06 March 2023

Coordinator: Ingo Schewe

Chief Scientist: Karsten Gohl



HELMHOLTZ

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PS134

22 December 2022 – 06 March 2023

Cape Town – Punta Arenas

WAIS-BELL
West Antarctic Ice Sheet history and Processes in the Bellingshausen Sea Sector

Chief scientist
Karsten Gohl

Coordinator
Ingo Schewe

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1. ÜBERBLICK UND FAHRTVERLAUF

Karsten Gohl DE.AWI

Die Expedition PS134 unter dem Titel „West Antarctic Ice Sheet history and processes in the Bellingshausen Sea (WAIS-BELL)“ hat primär zum Ziel, die Eisschildveränderungen der Westantarktis in verschiedenen Zeiten der Vergangenheit zu untersuchen. Die Eisschilde der Westantarktis und der Antarktischen Halbinsel haben in ihrer Entwicklungsgeschichte vermutlich sehr dynamisch auf klimatische Veränderungen reagiert, da ein Großteil der Basis des westantarktischen Eisschildes unter dem Meeresspiegel aufliegt und das Eis der Antarktischen Halbinsel einer Oberflächenerwärmung ausgesetzt ist. Beiträge dieser Eisschilde zu Meeresspiegeländerungen in Zeiten, in denen Klimabedingungen ähnlich denen einer sich gegenwärtig erwärmenden Erde zu erwarten sind, erfordert eine Rekonstruktion der glazialen Vor- und Rückzüge in Relation zu den bathymetrischen, topographischen und ozeanographischen Bedingungen. Mittels Daten und Proben, die auf dieser Expedition erhoben werden, sollen Prozesse der Paläoumwelt des südlichen Bellingshausenmeeres und des südöstlichen Amundsenmeeres entschlüsselt werden, da gerade diese Regionen gegenwärtig einen dramatischen Eisschildrückzug erleben. Hypothesen besagen, dass diese Regionen schon immer am sensitivsten mit ersten Eisschildrückzügen der Antarktis am Ende der Glazialepochen reagierte. Daten von reflexionsseismischen Messprofilen, geothermischen Wärmeflussmessungen und Fächersonaraufnahmen des Meeresbodens dienen der Identifikation den Untersuchungen der Transport-, Ablagerungs- und Erosionsprozesse von glazialen Schelfsedimenten und dem strukturellen Aufbau von sedimentären Driftkörpern auf dem Kontinentalfuß. Thermochronologische Daten und Analysen kosmogener Nuklide von Gesteinsproben des küstennahen Festlandes liefern Daten über Hebungsprozesse der Erdkruste sowie über die Rückzugsgeschichte des Eisschildes. Die Beprobung von antarktischen Quallen im Rahmen eines biologischen Programmes soll Aufschluss über deren Diversität, Verbreitung und trophische Rolle im Südozean liefern.

Die Projekte der Expedition tragen direkt dazu bei, die Forschungsziele des Topic 2 “Ocean and Cryosphere in Climate” und seine Subtopics 2.1 “Warming Climates” and 2.3 “Sea Level Change” sowie Topic 6 “Marine and Polar Life: Sustaining Biodiversity, Biotic Interactions and Biochemical Functions“ und seine Subtopics 6.1 “Future Ecosystem Functionality“ und 6.2 “Adaptation of Marine Life: From Genes to Ecosystems“ im Helmholtz-Forschungsprogramm “Changing Earth – Sustaining our Future“ zu erreichen, und unterstützen darüber hinaus nationale und internationale Kooperationen mit Universitäten in diesem Forschungsgebiet.

Die Expedition beginnt am 22. Dezember 2022 in Kapstadt (Südafrika) und wird nach dem Transit über den atlantischen Südozean und der Bergung einiger ozeanographischer Verankerungen zuerst die *Neumayer-Station III* im westlichen Dronning-Maud-Land der Ostantarktis Anfang Januar versorgen. Nach dem Transit über das Weddellmeer und entlang der westlichen antarktischen Halbinsel wird das Hauptarbeitsgebiet im Bellingshausen- und Amundsenmeer erreicht. Dort findet der Großteil der wissenschaftlichen Arbeiten statt, bevor die Rückreise nach Punta Arenas (Chile) angetreten wird, wo die Expedition am 6. März 2023 endet.

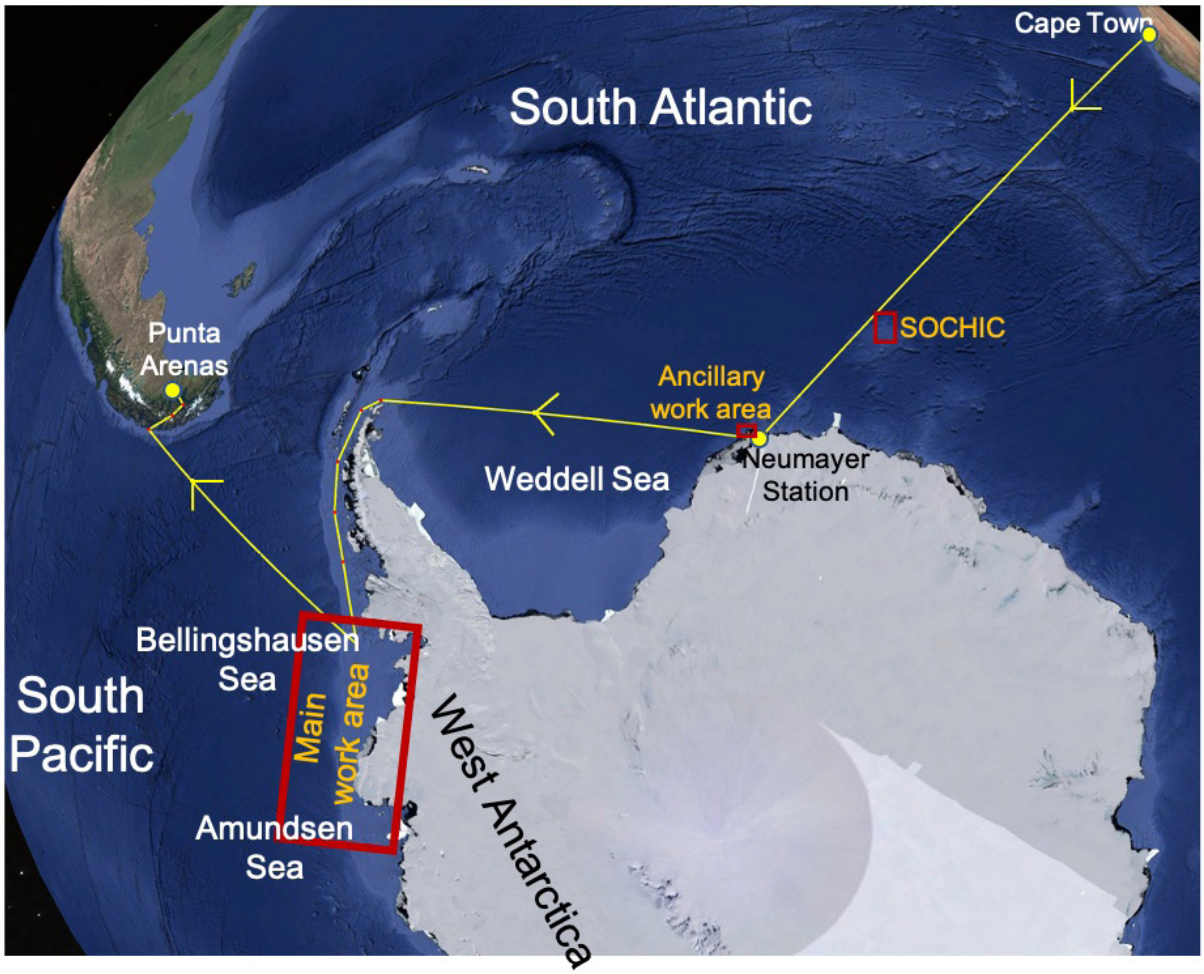

Abb. 1.1: Die Fahrtroute (gelbe Linien) und Untersuchungsgebiete (rote Kästchen) der Polarstern-Expedition PS134

Fig. 1.1: Ship track (yellow lines) and study areas (red boxes) of Polarstern expedition PS134

SUMMARY AND ITINERARY

Karsten Gohl DE.AWI

The Expedition PS134 with the title „West Antarctic Ice Sheet history and processes in the Bellingshausen Sea (WAIS-BELL)“ is primarily aimed to assess the development and changes of the ice sheets in West Antarctica in various times of the past. The ice sheets of West Antarctica and the Antarctic Peninsula are likely subject to highly dynamic activities during periods of climate warming as most of the base of the West Antarctic Ice Sheet is grounded below present sea-level, and most of the Antarctic Peninsula Ice Sheet is exposed to surface warming. Knowing their contribution to sea-level during times when climate conditions were similar as expected of a future warming Earth, requires reconstruction of their glacial advance and retreat cycles in relationship to bathymetric, topographic and oceanographic conditions. We intend to decipher the paleo-environmental processes of the southern Bellingshausen Sea and easternmost Amundsen Sea as this region exhibits some of the most dramatic ice mass loss developments in modern times. It is hypothesized that this sector has always been the most vulnerable location in Antarctica for early ice sheet retreat in most deglaciation periods. Data produced by using seismic reflection profiling, geothermal heat flow measurements and swath-bathymetric profiling will be used to study transport, depositional and erosional processes of glacially derived shelf sediments and the structural properties of sediments drifts on the continental rise. Thermochronological data and analyses of cosmogenic isotopes from rock samples of the coastal mainland provide indications on uplift of the Earth's crust as well as the retreat history of the ice sheet. Antarctic jellyfish will be sampled as part of a biological programme to study their diversity, distribution and trophic role in the Southern Ocean.

The projects of the expedition contribute directly to research objectives and challenges of Topic 2 “Ocean and Cryosphere in Climate” and its Subtopics 2.1 “Warming Climates”, 2.3 “Sea Level Change” as well as Topic 6 “Marine and Polar Life: Sustaining Biodiversity, Biotic Interactions and Biochemical Functions” and its Subtopics 6.1 “Future Ecosystem Functionality” and 6.2 “Adaptation of Marine Life: From Genes to Ecosystems” of the Helmholtz Research Programme “Changing Earth – Sustaining our Future”. The projects will also enhance national and international cooperation with universities.

The expedition begins on 22 December 2022 in Cape Town, South Africa, with the transit across the Atlantic Southern Ocean and the recovery of oceanographic moorings before arriving at *Neumayer Station III* in western Dronning Maud Land of East Antarctica for resupply. After the transit across Weddell Sea and along the western Antarctic Peninsula margin, the main work area in the Bellingshausen and Amundsen Sea will be reached. Most of the scientific work projects will take place here, before returning to Punta Arenas, Chile, where the expedition ends on 6 March 2023.

2. MARINE GEOPHYSICS: WEST ANTARCTIC ICE SHEET HISTORY AND PROCESSES IN THE BELLINGSHAUSEN SEA SECTOR (WAIS-BELL)

Gabriele Uenzelmann-Neben[1], Karsten Gohl[1], Estella Weigelt[1], Pascal Daub[1], Thorsten Eggers[1], Marie Gärtner[1], Johanna Gille-Petzoldt[1], Benedikt Haimerl[1,2], Jakob Hamann[1], Sven Hoffmann[1], Ingra Malucelli Barbosa[1,2], Christina Paul[1], Mareen Lösing[3], Caroline Brand[4], Alejandro Cammareri[5], Juan Manuel Salazar[5], Hugo Manuel Santos Lopes[5], Johannes Baltzer[6], Nadya Ramirez-Martinez[6], Luca Schick[6], Klaus Lucke[7], Christopher Stevensen[8], John Newton[8]
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Grant-No. AWI_PS134_01

Objectives

The ice sheets of West Antarctica and the Antarctic Peninsula are likely subject to highly dynamic activities during periods of climate warming as most of the base of the West Antarctic Ice Sheet is grounded below present sea-level, and most of the Antarctic Peninsula Ice Sheet is exposed to surface warming. Knowing their contribution to sea-level during times when climate conditions were similar as expected of a future warming Earth, requires reconstruction of their glacial advance and retreat cycles in relationship to bathymetric, topographic and oceanographic conditions. We intend to decipher the paleo-environmental processes of the southern Bellingshausen Sea and easternmost Amundsen Sea as this region exhibits some of the most dramatic ice mass loss developments in modern times. It is hypothesized that this sector has always been the most vulnerable location in Antarctica for early ice sheet retreat in most deglaciation periods. Data produced by using seismic reflection profiling, multibeam bathymetric surveying, sub-bottom profiling and geothermal heat flow measurements will be used to study transport, depositional and erosional processes of glacially derived shelf sediments and the structural properties of sediments drifts on the continental rise. Details are described in Sub-Chapters 2.1 to 2.4.

This WAIS-BELL project contributes directly to research objectives and challenges of Topic 2 “Ocean and Cryosphere in Climate” and its Subtopics 2.1 “Warming Climates” and 2.3 “Sea Level Change” of the AWI Research Programme, and will enhance cooperation with universities.

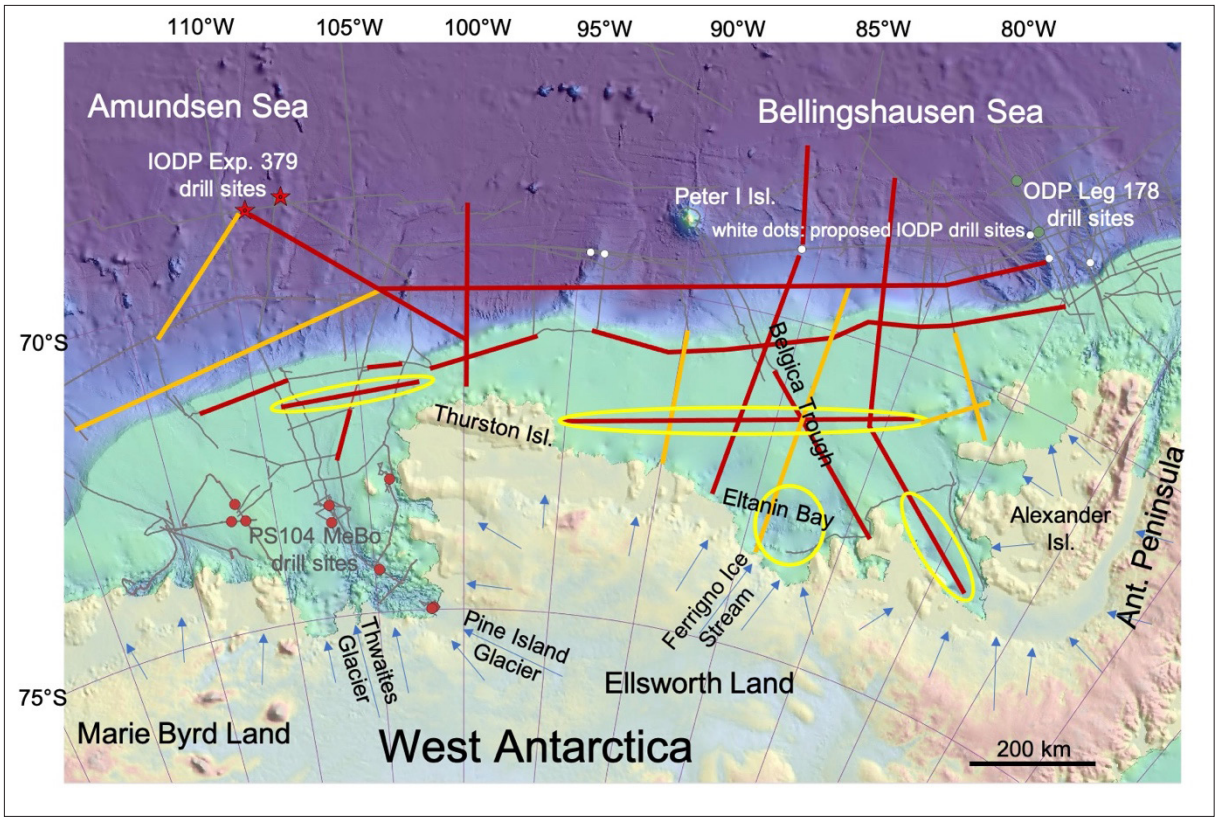

Fig. 2.1: Map of work area for marine geophysical surveys and measurements in the Amundsen Sea and Bellingshausen Sea sector of West Antarctica with planned seismic profiles (red lines for primary profiles, orange lines for secondary profiles) on continental shelf and rise, and areas for geothermal heat flow measurements (yellow ellipses) on the shelf. Thin grey lines mark pre-existing seismic profiles. Blue arrows indicate ice-sheet flow in coastal areas. The map shows also the locations of ODP Leg 178, IODP Expedition 379 and PS104-MeBo drill sites as well as further planned IODP drill sites to which the seismic profiles are linked.

2.1 Seismic Profiling

Gabriele Uenzelmann-Neben[1], Karsten Gohl[1], Estella Weigelt[1], Marie Gärtner[1], Pascal Daub[1], Thorsten Eggers[1], Johanna Gille-Petzoldt[1], Benedikt Haimerl[1,2], Jakob Hamann[1], Sven Hoffmann[1], Ingra Malucelli Barbosa[1,2], Christina Paul[1], Alejandro Cammareri[3], Juan Manuel Salazar[3], Hugo Manuel Santos Lopes[3], Johannes Baltzer[4], Nadya Ramirez-Martinez[4], Luca Schick[4], Klaus Lucke[5], Christopher Stevensen[6], John Newton[6]

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Objectives

The behaviour of the polar ice sheets in relation to climatic changes and their contribution to global sea-level change are poorly understood. The latest Intergovernmental Panel for Climate Change (IPCC) report (IPCC, 2018) explicitly flag this deficiency in knowledge. In contrast to most of the East Antarctic Ice Sheet, the West Antarctic Ice Sheet (WAIS) and the Antarctic Peninsula Ice sheet (APIS) are likely to have been subject of a very dynamic activity during their history. Most of the bases of the WAIS and the southern APIS are grounded below present sea level and incline landward. The APIS is particularly vulnerable, because its relatively northern position exposes it to higher atmospheric temperatures, thus leading to more surface melts in warming climates than at the other Antarctic ice sheets. Thus, the WAIS and APIS are sensitive to changes in global sea level and regional oceanographic conditions as well as atmospheric conditions. Their collapses would result in a global sea-level rise of 3-5 m (Fretwell et al., 2013). Satellite observations of the last decades have shown that the negative ice mass balance of Antarctica is highest along the Pacific margins of West Antarctica and the Antarctic Peninsula, in particular in the Amundsen Sea Embayment (Pine Island, Thwaites, Smith and Pope Glaciers) and Eltanin Bay (Ferrigno Ice Stream) of the Bellingshausen Sea (e.g. Rignot et al., 2019; Schröder et al., 2019). Significant sub-ice shelf melting by relatively warm modified Circumpolar Deep Water (CDW) that spreads across the shelves through deep paleo-ice stream troughs towards the grounding zones of the WAIS and APIS, has been identified as the most likely cause for today's ice sheet retreat (e.g. Rignot et al., 2019).

Largely unknown are the processes of WAIS and APIS dynamics, the oceanographic conditions leading to melting processes and the ice sheet's contribution to sea-level during times with climate conditions similar to today or expected for the near future of a warming Earth. The challenges are (1) to identify the locations of former glacial troughs and paleo-pathways of CDW across the shelves, which have a strong relationship to tectonic features of the basement and pre-glacial consolidated sediments (examples in Gohl et al., 2013a,b; Klages et al., 2014), (2) to identify and quantify the former advance and retreat cycles of the WAIS and APIS across the shelves (e.g. Gohl et al., 2013b; Gohl et al., 2021a) and thus the conditions for their partial and total collapses, and (3) link these ice- and coast-proximal records to more distal deep-sea records of the continental rise and its sediment drifts (e.g. Uenzelmann-Neben & Gohl, 2012, 2014; Lindeque et al., 2016a,b; Uenzelmann-Neben, 2006, 2018; Gohl et al., 2021a,b).

Modified warm CDW, circulating onto the shelves mainly through deeply incised glacial troughs, has been recognized as the main culprit for subglacial melt processes of ice shelves close to the grounding zones. This seems to be at least the modern process along the shelves of Pacific West Antarctica, mainly in the Amundsen Sea Embayment but also on the Bellingshausen Sea shelf. A recent study based on the analysis of a sediment drift patched to the eastern flank

of Pine Island Trough using seismic data showed that inflow of warm deep water slowed the offshore expansion of the WAIS in late Eocene/early Oligocene times (Uenzelmann-Neben et al., 2022). Seismic records from the Pine Island Trough of the Amundsen Sea shelf further show that the location of this trough has been relatively stationary since glacial onset (Gohl et al., 2013) because of constraints by basement flanks along its eastern margin. We speculate that such stationary trough positions are not necessarily the case on the Bellingshausen Sea shelf, for instance for the Belgica Trough.

The planned network of seismic profiles (Fig. 2.1), linked with drill records, will provide a dataset for mapping the extent of former glacial troughs and identifying documents of deep water activity. This will provide the means to analyse past CDW incursions and their possible effects on past subglacial melting mechanisms.

Differences in the dynamics of WAIS evolution between the Amundsen and Bellingshausen Seas have been hypothesized. A west-east trend was inferred with an early Miocene ice advance in the Amundsen Sea, while a glacial advance in the Bellingshausen Sea occurred only post-15 Ma (Uenzelmann-Neben, 2019). At LGM (about 20 ka) grounded ice reached the continental shelf breaks along most Antarctic margins. The Bellingshausen Sea sector shows a dominant anomaly, well constrained by data (Hillenbrand et al., 2010), implying that grounded ice did not reach the shelf break above the Belgica Trough. With warming oceanic conditions, this situation would likely enable a more rapid retreat from the shelf, because major buttressing areas are missing and warm deep water can ‘bite’ into the grounding zones close to the inner shelf already in the early stages of deglaciation periods. It remains to be tested whether this phenomenon existed through the earlier glacial periods back to the Pliocene, thus making the Bellingshausen Sea Embayment a vulnerable spot. Our extensive seismic surveying, linked with the pre-existing seismic lines and recent drill records, will provide a seismostratigraphic record of past glacial advances such as progradational sequences, truncation surfaces and buried grounding zone wedges as seen in parts of the Amundsen Sea shelf sediment sequences by Gohl et al. (2021a).

Work at sea

Up to 5,600 km (ca. 3,000 nm) of seismic profiles are planned to be acquired on the continental shelf and continental rise of the Bellingshausen Sea and eastern Amundsen Sea (Fig. 2.1). This dataset will fill a major data gap in the Bellingshausen Sea sector and missing seismic connections in the Amundsen Sea, and will link to pre-existing seismic profiles as well as scientific drill sites such as those of DSDP Leg 35 (Hollister and Craddock, 1976), ODP Leg 178 (Barker et al., 1999), PS104-MeBo (Gohl et al., 2017), and IODP Expedition 379 (Gohl et al., 2021b). This will require up to 25 days of seismic profiling, incl. deployment and recovery of the seismic equipment and circumnavigation of massive sea ice. A 3,000-m long digital seismic hydrophone streamer will be used to record seismic wave-fields generated by 4 airguns (GI-Guns Type 150 operating in True GI-Mode) at a pulse distance of 25 m at 5 kn ship speed. Previous seismic surveying in Antarctic continental shelf and deep-sea areas has shown that a minimum number of 4 GI-Guns is necessary for the desired depth penetration. Figure 2.1 shows the planned locations of the seismic profiles, but their exact locations will have to be decided upon sea-ice conditions at the time of the expedition.

In addition to the main seismic work programme in the Bellingshausen and Amundsen Sea sectors, we plan to collect 3-4 short seismic profiles (max 100 km = 54 nm in total) on the continental shelf of the Ekström Ice Shelf region in the eastern Weddell Sea, if ice conditions allow. These profiles were originally planned for expedition PS128 (early 2022), but severe ice conditions prevented the collection of these profiles.

The seismic survey programme in the Bellingshausen and Amundsen Sea sectors will be accompanied by extended marine mammal observation and mitigation activities to avoid potential risks to marine mammals from the use of seismic sources. This will include the testing of new observation methods by a hydroacoustic mooring and an air drone.

Expected results

It can be expected that the marine seismic profiles will provide images of glacially transported and deposited sedimentary sequences on the continental shelf and current-influenced deposits in the deep sea area of the Amundsen Sea and Bellingshausen Sea sectors. In connection to pre-existing seismic profiles on the continental shelf, rise and the deep sea with links to drill sites of DSDP Leg 35, ODP Leg 178, PS104-MeBo and IODP Expedition 379, we expect to decipher dominant phases of past WAIS advances and retreats in this sector as well as phases of dominant sediment transport via oceanic currents.

Data management

Metadata and a short report will be submitted to DOD and PANGAEA. A full cruise report will be made available from PANGAEA within 6 months after the cruise. Seismic data will be submitted to the SCAR Antarctic Seismic Data Library System (SDLS) from which they will be made available to interested collaboration partners 2 years after data acquisition and as open access 8 years after data 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.

In all publications based on this expedition, the Grant No. AWI_PS134_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

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Grant-No. AWI_PS134_01

Objectives

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

While world bathymetric maps give the impression of a detailed knowledge of worldwide seafloor topography, most of the world's ocean floor remains unmapped by hydroacoustic systems. In these areas, bathymetry is modelled using satellite altimetry with a corresponding low resolution. Satellite-altimetry derived bathymetry therefore lack 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 bathymetric information at a resolution sufficient to resolve these features and enable 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 its retreat since its maximum extent during the Last Glacial Maximum. Understanding the processes that led to this ice sheet retreat in the past can provide important information for predicting future responses of Antarctic Ice Sheets to changing climate conditions and oceanographic settings. Glacigenic landforms can only be determined in high-resolution bathymetric data sets. It is therefore planned to acquire detailed bathymetric data of these areas with the ship's hydroacoustic instruments.

Furthermore, the collection of underway data during PS134 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

The bathymetric data will be recorded with the Atlas Hydrosweep DS3 hull-mounted multibeam echosounder. The main task of the bathymetry group is to plan and run bathymetric surveys in the study areas and during the transit. The raw bathymetric data will be corrected for sound velocity changes in the water column, 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. The 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 working 24/7 hour shifts (except for periods of stationary work).

Expected results

Expected results will consist of high-resolution seabed maps along the cruise track and from the target research sites. The bathymetric data will be analysed to obtain geomorphological information of the research area. The expected results aim towards a better understanding of the geological processes in the research area.

Data management

Geophysical and oceanographic 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) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Furthermore, the data will be included in regional data compilations such as IBCSO (International Bathymetric Chart of the Southern Ocean) and provided to the Nippon Foundation – GEBCO Seabed 2030 Project.

In all publications based on this expedition, the Grant No. AWI_PS134_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.

2.3 Parasound Sub-Bottom Profiling

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Grant-No. AWI_PS134_01

Objectives

The West Antarctic Ice Sheet (WAIS) and the Antarctic Peninsula Ice Sheet (APIS) exhibit some of the most dramatic ice mass loss developments in modern times (IPCC, 2013). Likely, the grounding of the WAIS's base below present sea level and the exposure of the APIS to surface warming around the Antarctic Peninsula provoked a highly dynamic response of these ice sheets to climate variations.

In order to evaluate their contribution to sea-level changes, especially for times when climate conditions were similar as expected for a future warming earth, the knowledge of changing ice sheet volume, variations in ice sheet extension, and any other palaeo-environmental processes are required. These processes left 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 highly dynamic history of the WAIS and APIS.

In this regard, the sub-bottom profiling system Parasound P70 offers a method to image the upper tens of meters of subsoil for understanding glacial and geological processes such as erosion, sediment transport and deposition, or even tectonic processes of the younger past. These data are essential to reconstruct the expansion, extension and retreat of ice sheets e.g. by the distribution of megascale glacial lineations, moraines, or grounding-zone wedges (e.g. Evans et al., 2005; Ó Cofaigh et al., 2008; Graham et al., 2010; Jakobsson et al., 2011; Greenwood et al., 2012; Livingstone et al.,2012; Stolldorf et al., 2012).

Further, imaging the upper few tens of meters, the sediment echography presents an important link between bathymetry (mapping the surface morphology) and reflection seismics (imaging the deep structures down to several km depth). The integration of these three data sets is of particular importance for the interpretation of geological data in a spatial context.

Not at least, the sediment echo-graphical survey is essential as base for geological sampling, to identify (1) core locations ideally containing undisturbed sediment sequences, (2) sites with high sediment supply.

Work at Sea

Sediment echograph data will be recorded using the Atlas Teledyne Parasound P70 hull-mounted sub-bottom profiling system. The main task of the sediment echography 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-hour / 7-day shift mode, and the data recorded will be promptly made available for site selection and cruise planning.

The detailed sub-bottom maps derived from the sediment-echography 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 to identify areas of high and low sedimentation rates, outcrops, and to avoid areas of sediment redeposition and erosion.

Expected results

Expected results will consist of high-resolution seabed maps along the cruise track and from the target research sites. The sub-bottom data will be analyzed to provide geomorphological information about the uppermost sedimentary sequences of the research area. Expected results aim towards a better understanding of the palaeo-environmental processes provoking the highly dynamic ice sheet response in West Antarctica.

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.

In all publications based on this expedition, the Grant No. AWI_PS134_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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Stolldorf T, Schenke H-W, Anderson JB (2012) LGM ice sheet extent in the Weddell Sea: evidence for diachronous behavior of Antarctic Ice Sheets. Quaternary Science Reviews 48: 20-31.

2.4 Geothermal Heat Flow Measurements

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Objectives

The West Antarctic Ice Sheet currently shows increasing retreat dynamics, combined with concerns that it could partially collapse, leading to rapid sea level rise. Glaciers are subject to changes that affect them from the outside. We currently know of three processes that have a significant influence on the stability of the ice sheets: (1) air temperature and solar radiation acting from above, (2) oceanic water acting from below the ice shelves and at the grounding zones, and (3) geothermal heat flow acting from the sub-surface below. This has been the case in the past, with varying effectiveness of the different compartments, as much of the base of the West Antarctic Ice Sheet lies below sea level. We suspect that the ice sheets in the southern Bellingshausen Sea and the southeastern Amundsen Sea sectors have been particularly sensitive in warm times. This marginal region of Antarctica seems to react particularly sensitive to climate changes, especially in interaction with the ocean. Although first studies have indicated regionally high geothermal heat flow in some parts of the Amundsen Sea Embayment sector (Dziadek et al., 2017, 2019, 2021), there is still little known on the effect that geothermal heat flow has had on sliding conditions of grounded ice. Knowledge of geothermal heat flow will contribute to the ice sheet energy budget. Our contributions are focused on processes of two time scales: The identification and long-term effect of the tectonically generated West Antarctic Rift System arms extending onto the Bellingshausen Sea shelf, and the detection of short-term seasonal water mass movements.

Work at sea

Miniature temperature logger (MTL) mounted on either a 6-m long thermal probe or on the gravity corer will measure the water column temperature profile and *in-situ* sediment temperatures for deriving geothermal heat flow values. Target areas (yellow ellipses in Fig. 2.1) are small basins and troughs on the continental shelf where sediments have accumulated and water column temperatures likely show less variations (Dziadek et al., 2017), located near seismic profile lines for knowledge of the structure of the basins and troughs.

Expected results

First temperature gradient values will be read from the MTL recorders shortly after the recovery of the temperature probe. After corrections applied, a first estimate of the geothermal heat flow can be derived for the sites of the deployed probe. This will provide a first overview of the distribution of geothermal heat flow. Corrections such as the influence of bottom water will have to be considered in a later detailed analysis.

Data management

Measured temperature and derived geothermal heat flow 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 cruise at the latest. By default, the CC-BY license will be applied.

In all publications based on this expedition, the **Grant No. AWI_PS134_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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3. MARINE GEOLOGY – ICE SHEET VARIABILITY AND ITS COASTAL RESPONSE IN THE BELLINGSHAUSEN AND AMUNDSEN SEAS (COREBELL)

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Grant-No. AWI_PS134_05

Objectives

The West Antarctic Ice Sheet (WAIS) and the Antarctic Peninsula Ice Sheet (APIS) have undergone major ice loss for decades. In case of the WAIS this mass loss may kick start even faster retreat into subglacial basins in its interior, where ice is grounded as deep as ~2.5 km below sea level. Scenarios of such WAIS collapses are simulated for environmental conditions that are predicted to occur over the next few centuries. Marine geological archives provide valuable insight into both previous configurations of ice sheet and sea ice cover as well as the mechanisms triggering retreat. They, therefore, help to elucidate the significance of recent rapid ice-sheet changes for future mass loss from the WAIS and APIS and resulting global sea-level rise. High-resolution marine geological archives are also required for reliably constraining previous retreat rates of ice sheet margins and sea ice limits. The aims of the marine geological programme are:

- Provide reliable spatiotemporal information about the maximum ice-sheet extent on the Bellingshausen Sea continental shelf and reveal past ice-drainage pathways during the Last Glacial Maximum (LGM)
- Constrain the style and timing of post-LGM grounded ice retreat towards the modern ice front by mapping morphological features that mark ice marginal positions (e.g., grounding-zone wedges, moraines) on the shelf and by developing detailed facies models and reliable age models for sedimentary sequences recovered from these features in cores
- Reconstruct changes in sea-ice cover in the southern Bellingshausen Sea during the Holocene and over the last two centuries using biomarker-based proxies and diatom assemblages
- Deliver detailed information about past and current meltwater dynamics by bathymetric mapping and high-resolution acoustic imaging of inner-shelf channel networks and targeted sampling and detailed analysis of meltwater plumites and channel infill deposits

- Test the hypothesis of a WAIS collapse during the last interglacial by recovering and investigating a record from a selected core site on the outer Amundsen Sea shelf that was not overridden by grounded ice during the last glacial period
- Collate a seafloor surface sediment data set for the further development and evaluation of a range of various palaeoenvironmental proxies (biomarkers, trace metals on calcareous foraminifera, proxies for sediment provenance and meltwater deposition).

Work at sea

Systematic swath bathymetry and sediment echography surveys will be performed in selected areas to characterize the seafloor morphology and structural geometry of pro- and subglacial landforms from the innermost shelf towards the continental shelf edge. These data will form the basis for identifying core locations across the continental shelf. We plan to recover combinations of about 36 gravity/kasten and multiple/box cores (Fig. 3.1; Table 3.1), mainly along major palaeo-ice stream troughs and on inner shelf areas in Eltanin Bay and Ronne Entrance (Fig.3.1). This will provide *in-situ* characteristics of past ice flow, e.g., past ice-sheet bed conditions, and allow to date the (minimum) age of grounding-line retreat from each core location along past ice-stream trajectories. We will further focus on shallower shelf areas adjacent to the troughs above the local Carbonate Compensation Depth (CCD) for recovering sediments that bear calcareous microfossils, a critical requirement not only for reliable dating of post-LGM ice-sheet retreat but also for utilizing trace element and stable carbon and oxygen isotope compositions of fossil calcareous shells to reconstruct past CDW variability and seawater temperatures. At these shallower water depths, it will be especially important to avoid core sites heavily scoured by iceberg keels, which would have resulted in the obliteration of the original geomorphological and geological record.

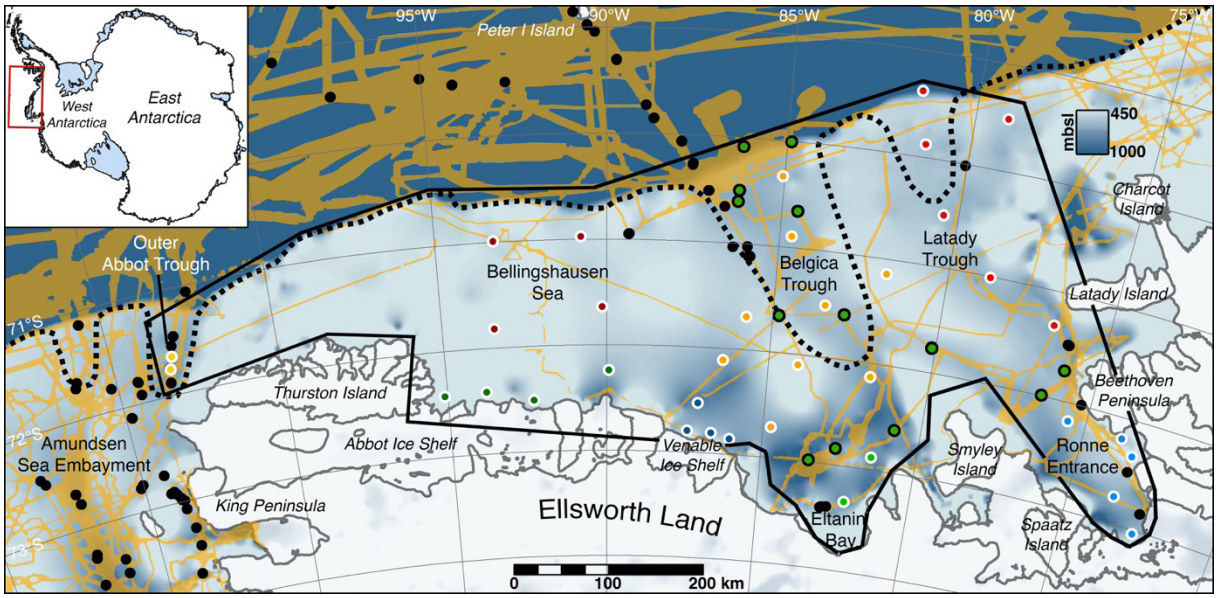

Fig. 3.1: Proposed study area on the Bellingshausen and eastern Amundsen Sea shelves; black dots indicate sites of existing AWI cores, green dots with black circles indicate BAS core sites. Dots of other colors and with white circles mark coring locations proposed for the project, with different colours referring to specific shelf regions (see Table 1); existing multibeam-bathymetry datasets are indicated in yellow (from IBCSO v. 1; Arndt et al., 2013), black dotted line indicates inferred and reconstructed LGM grounding-line position (Larter et al., 2014).

The proposed study area includes the entire continental shelf area between 75°W and 105°W. Focus areas are the deep inner shelf basins in Ronne Entrance and Eltanin Bay, their seaward bathymetric continuations, i.e., the Latady and Belgica paleo-ice stream troughs, as well as smaller tributary troughs on the inner shelf (Fig. 3.1). Both in these areas and along the shallower trough margins we plan to deploy combinations of multiple-/giant box corers with gravity/kasten corers at about 36 stations. Small grids of bathymetric, high-resolution sidescan sonar data and PARASOUND acoustic subbottom profiles are planned to image (sub-)seafloor structures in as much detail as possible. Final determination of survey areas will strongly depend on local sea-ice conditions. At selected stations, we will additionally deploy a conductivity-temperature-depth (CTD) rosette system for sampling meltwater plume material in the water column. In addition to the CTD rosette, small grids of acoustic Doppler current profiler (ADCP) backscatter transects will be collected to detect potential active meltwater plume flocculation and turbidity gradients in the water column.

Tab. 3.1: Planned marine-geological sampling stations on the continental shelf

No.	Station	Depth (m)	MUC/GBC (min.)	GC/KC (min.)	CTD (min.)	Survey (min.)	Total (hours)
1	RE1	600-900	100	90	80	900	19.5
2	RE2	600-900	100	90	80	-	4.5
3	RE3	600-900	100	90	80	-	4.5
4	RE4	400-700	90	80	70	660	15
5	RE5	400-700	90	80	70	-	4
6	LT1	300-600	80	70	-	900	18.5
7	LT2	300-600	80	70	-	-	3.5
8	LT3	300-600	80	70	-	-	3.5
9	LT4	300-600	80	70	-	-	3.5
10	LT5	300-600	80	70	-	-	3.5
11	LT6	300-600	80	70	-	-	3.5
12	EB1	600-900	100	90	-	780	17.5
13	EB2	600-900	100	90	-	-	4.5
14	BT1	300-600	80	70	-	900	18.5
15	BT2	300-600	80	70	-	-	3.5
16	BT3	300-600	80	70	-	-	3.5
17	BT4	300-600	80	70	-	-	3.5
18	BT5	300-600	80	70	-	-	3.5
19	BT6	300-600	80	70	-	-	3.5
20	BT7	300-600	80	70	-	-	3.5
21	BT8	300-600	80	70	-	-	3.5
22	BT9	300-600	80	70	-	-	3.5
23	VIS1	600-900	100	90	-	660	15.5
24	VIS2	600-900	100	90	-	-	4.5
25	VIS3	600-900	100	90	-	-	4.5
26	VIS4	600-900	100	90	-	-	4.5

No.	Station	Depth (m)	MUC/GBC (min.)	GC/KC (min.)	CTD (min.)	Survey (min.)	Total (hours)
27	WBS1	200-500	70	60	-	660	14
28	WBS2	200-500	70	60	-	-	3
29	WBS3	200-500	70	60	-	-	3
30	WBS4	200-500	70	60	-	-	3
31	AIS1	400-700	90	80	-	660	14
32	AIS2	200-500	70	60	-	-	3
33	AIS3	200-500	70	60	-	-	3
34	AIS4	200-500	70	60	-	-	3
35	AT1	600-900	100	90	-	420	11.5
36	AT2	600-900	100	90	-	-	4.5
						Total	**10 days**

Expected results

We will target selected locations for recovering sedimentary records that will allow us to define past ice-sheet bed conditions, establish the timing of past glacier fluctuations, constrain the mechanisms forcing ice-sheet retreat, reconstruct past sea-ice cover, and identify variability of meltwater discharge and its role for past ice-sheet dynamics. In addition, we will try to sample deposits on the easternmost Amundsen Sea Embayment shelf covering the last interglacial period, which was characterized by atmospheric and ocean temperatures expected for the coming decades and centuries. Together, the knowledge from the geological archives to be retrieved on the Bellingshausen and easternmost Amundsen Sea shelves is urgently needed not only to understand the previous WAIS and APIS dynamics on different time scales, but also to improve models that attempt to accurately predict the future behaviour of these ice sheets.

Data management

National and international partners involved in the expedition will have immediate and preferential access to the cruise report, shipboard data, and retrieved samples. The availability of expedition data and samples will initially remain restricted to these scientists and their collaborators directly involved in the project. After a moratorium period that protects the interests of the project partners, the scientific community will have open access to all data and samples.

In principle, AWI's research data policy follows the principles for the responsible handling of research data, which are based on the recommendations of the Helmholtz Association for guidelines on the management of research data, on the Guidelines of the European Commission on Data Management according to the FAIR principles, and the guidelines of the German Research Foundation (DFG) on handling research data.

AWI aims to publish the primary scientific cruise data as soon as possible. The open-access cruise report will be published shortly after the cruise in the AWI series "Reports on Polar and Marine Research". It will contain detailed descriptions of the fieldwork conducted and initial results obtained along with lists of samples and data collected during the cruise. All data will be archived in a publicly accessible, citable long-term repository two years after collection. The archived data may be under moratorium for a maximum of two additional years. In addition, appropriate moratorium periods will be applied for and recorded in the data management plan. After the embargo periods have expired, the data must be made public immediately and actively using the FAIR principles. All data will be stored in international data bases (e.g., PANGAEA, DOD, SCAR SDLS), preferably in the World Data Center PANGAEA Data Publisher for Earth

& Environmental Science (https://www.pangaea.de) operated as an open-access library by the AWI and the Center for Marine Environmental Sciences, University of Bremen (MARUM) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Sediment samples and cores collected during *Polarstern* expeditions will be archived in the AWI Core Repository, which is operated by the marine geology department since 1983. Cores are stored in sealed D-tubes at 4° C and an air humidity limited at 35 %. The repository is open to the scientific community for sampling but subject to ongoing work at AWI including national and international collaborations.

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 project is supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 2, Subtopic 1 und 3.

In all publications based on this expedition, the Grant No. AWI_PS134_05 will be quoted and the following publication will be cited:

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4. TERRESTRIAL GEOLOGY: TECTONIC AND GLACIAL HISTORY ALONG THE BELLINGSHAUSEN SEA (TEC-GLA-BELL)

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not on board: Cornelia Spiegel[1]

Grant-No. AWI_PS134_09

Objectives

The Bellingshausen Sea sector of West Antarctica is assumed to host the youngest part of the West Antarctic Rift System, although exact timing is still poorly constrained (Granot et al., 2018). Along with the Amundsen Sea sector, the Bellingshausen Sea sector is the area of West Antarctica most affected by glacial mass loss due to dynamic thinning (Smith et al., 2020). Little is known so far on the paleotopography of the Bellingshausen Sea area, and recent paleotopographic reconstructions mostly rely on data from the Amundsen and Ross Sea sectors (e.g., Paxman et al., 2019). Knowledge on past tectonics and geomorphology, however, is important for undstanding the glaciation history of West Antarctica, and is required as boundary condition for correctly modelling ice sheet behaviour. This in turn is required for predicting the future of the West Antarctic Ice Sheet.

A major target of this project is to gain information on timing, location, and extent of tectonic activity along the West Antarctic Rift System, along with information on the paleotopographic evolution of West Antarctica. Furthermore, we plan to obtain information on coastal deglaciation processes in response to past climate change.

For achieving these goals, we will apply (1) low-temperature radiogenic dating methods to rocks collected from onshore exposures as well as to glacially transported clastic sediment deposited in the Bellingshausen Sea. The latter provides age signatures indicative for erosion and exhumation processes integrated over the sediment source area. For better characterizing the subglacial source area, we will (2) additionally study the petrography of lithoclasts and pebbles contained in the sediment as well as the heavy mineral composition. We will (3) collect glacial erratics and / or glacially eroded bedrock from offshore exposures and analyse them for their ^{10}Be contents. The resulting exposure ages provide information since when the sampled areas are free of ice. Data from this part of the project complement the offshore-based work of the Marine Geology group and of other working groups involved in cruise PS134.

Work on land and at sea

Whenever distance to land, the work programme on board of *Polarstern*, and weather conditions allow, we will use the board helicopters to visit coastal nunataks. There, rock specimen will be collected using rock saw, chisel, and / or hammer, in addition to documenting the local geological setting and structural relationships. For some of the outcrops we plan to visit, there is not even information on the basic geology available yet. At sea, we will collect near-shore clastic sediments preferentially close to large glacial outlets, such as Ronne Entrance and

Eltanin Bay (Fig. 1). As we require relatively large amounts of material, we plan to mostly use box corer (or kasten corer), in close cooperation with the Marine Geology group. For the sediments, we will start initial processing (sieving and petrographic inspections) already during the cruise.

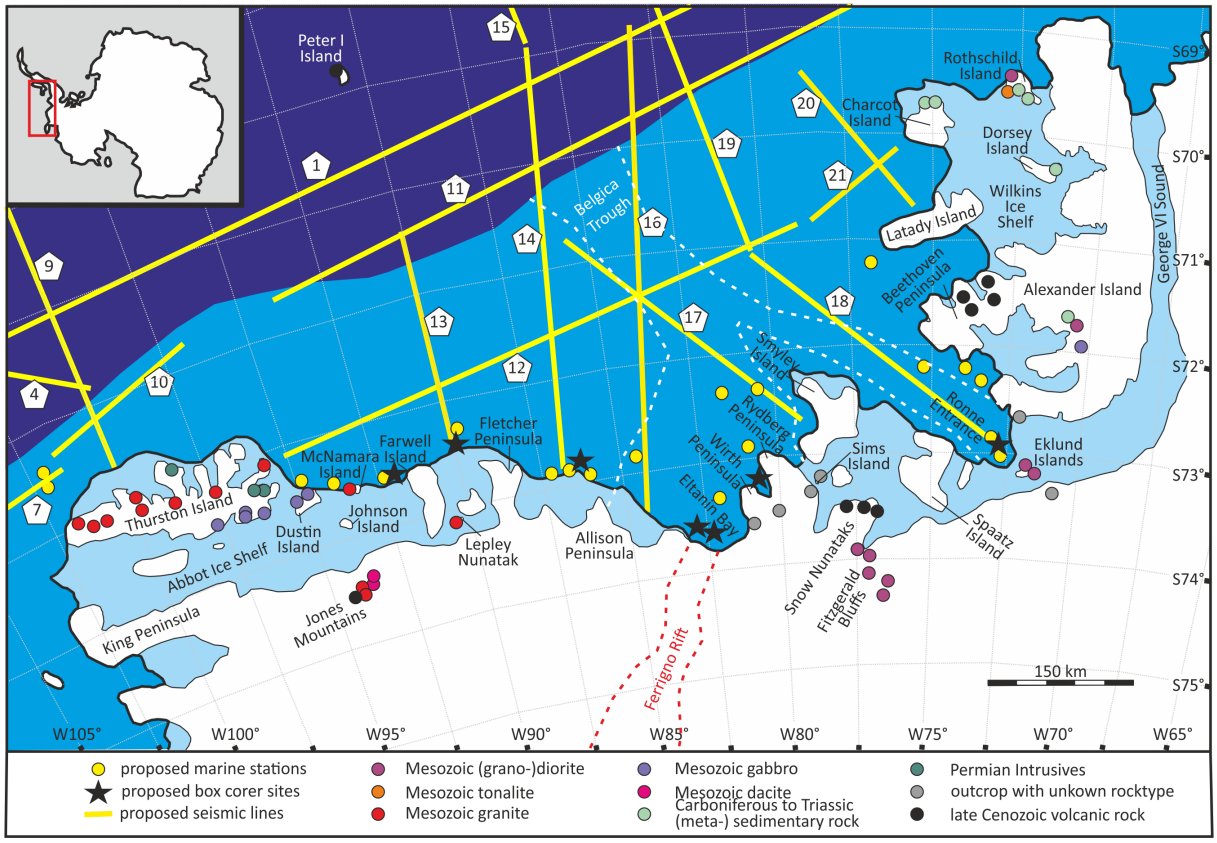

Fig. 4.1: The Bellingshausen Sea sector along with coastal nunataks within maximum flight distance of the board helicopters, colour-coded according the the dominant lithotype; black stars indicate proposed sites for offshore sampling

Expected results

As a direct outcome of PS134, we will have collected a set of rock samples from this rarely visited and hard-to-access area. The sampled material will be processed and analysed in the frame of a DFG-project. The resulting thermochronology and surface exposure dates will provide important new insights in the tectonic evolution and glaciation and de-glaciation history of the Bellingshausen Sea sector of West Antarctica.

Data management

Data generated for this project 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 cruise at the latest. By default, the CC-BY license will be applied.

This project contributes to the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 2, Subtopic 1.

In all publications based on this expedition, the **Grant No. AWI_PS134_04** will be quoted and the following publication will be cited:

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5. MARINE BIOLOGY: CHARACTERIZING JELLYFISH DIVERSITY, DISTRIBUTION AND TROPHIC ROLE ACROSS A LATITUDINAL GRADIENT AND IN UNDEREXPLORED REGIONS OF THE SOUTHERN OCEAN (SO-JELLY)

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Grant-No. AWI_PS134_08

Objectives

Southern Ocean (SO) ecosystems have experienced increasing environmental and anthropogenic changes over the last decades. Measurable consequences are particularly evident in, but not limited to, the Antarctic Peninsula, where some ice shelves have already lost up to 18 % of their thickness in less than 20 years (Paolo et al., 2015). These growing impacts have urged scientists to extensively report on SO marine biodiversity and biogeography (e.g., De Broyer et al., 2014), as well as to investigate how these changes may affect its marine biota, food webs, and ecosystem services (e.g., Constable et al., 2014).

Gelatinous zooplankton (hereafter GZP), jellyfish and allies are a major taxonomically and ecologically diverse group comprising *cnidarians* (i.e., *medusae* and *siphonophores*), *ctenophores*, and *chordates* (e.g., salps, and pyrosomes). Ubiquitous in all oceans, GZP play a key trophic role in planktonic communities (Hays et al., 2018) and have the potential to form large blooms. GZP are also reputed to be climate change winners and are believed to have significantly increased in numbers over recent decades in many marine ecosystems (e.g., Richardson et al., 2009). This paradigm of “ocean jellification” is supported by the growing evidence of negative impacts of GZP aggregations on human enterprises, such as fisheries and hydropower plants (reviewed in Purcell, 2012). Nonetheless, even though evidence is accumulating, the jellification paradigm is still under heavy debate (cf. Pitt et al., 2018). The reason for our inability to confirm recent increases in GZP populations is the critical scarcity of data, and the lack of a reliable baseline (Pauly et al. 2009).

Studies assessing the impact of changing GZP abundance and/or composition in the SO have exclusively been focusing on salps, more easily quantifiable with nets due to their strong tunica, and due to their ongoing range expansion in the most rapidly warming Southwest Atlantic sector of the SO (e.g., Plum et al., 2020). Here, the pelagic realm has undergone an ecological shift from a krill-based to a salp-based ecosystem (Atkinson et al., 2004, 2019). Therefore, strong impacts on higher trophic levels such as marine mammals and seabirds, depending on Antarctic krill (*Euphausia superba*) as their lipid-rich prey (e.g., Trathan & Hill, 2016) are expected. These changes will also have major biogeochemical implications, influencing local productivity and phytoplankton communities (Cavan et al., 2019; Plum et al., 2020). Besides salps, other GZP groups are prone to increase (or decrease) in biomass due to environmental changes, but so far remain unstudied. Periods dominated by krill and/or salps may alternate

regionally with periods dominated by pelagic c*nidarians* and *ctenophores*, e.g., in the Antarctic Polar Frontal Zone near South Georgia (Pàges, 1997).

Data scarcity on GZP is due to two major reasons. The first is because GZP species, especially *ctenophores*, are extremely difficult to chemically fix and preserve. Second, the extreme fragility of these soft-bodied organisms, easily fragmented or destroyed with traditional net sampling (Licandro et al., 2015), has led to the underestimation of their biomass and diversity (e.g., Hosia et al., 2017). The use of alternative methods for GZP studies in the SO, such as environmental DNA (eDNA) studies and optical methods, remained extremely rare or non-existent. eDNA studies, targeting macro-organism DNA in environmental samples (water, sediment), without the animal itself having to be present in the sample, represent a major scientific breakthrough of the last years (Thomsen & Willerslev, 2015). This method has shown high potential to characterize the aquatic diversity of different taxa (e.g., Valentini et al., 2016; Thomsen et al., 2016, Bakker et al., 2019, De Jonge et al., 2021), including GZP (Abato, 2017). It has also been proven to be a promising tool for assessing polar biodiversity, allowing the detection of non-indigenous species and monitoring both open water and under-ice environments (Lacoursière-Roussel et al., 2018). Besides detecting presences and abundances of GZP in the water column, eDNA can also be used in dietary studies. Metabarcoding studies to identify DNA of prey items in predators' stomachs are becoming more cost-effective and, in the case of rapidly digested gelatinous tissues, they provide the only way to detect this otherwise undetectable prey (e.g., Günther et al., 2021). Studies on SO pelagic *Themisto* amphipods have shown that *ctenophores* and other jellies make up an important part of their diet, which was hitherto not recognized with traditional microscopy of stomach contents (Havermans et al., unpublished results). Since a large proportion of the obtained sequences is not available in existing databases, eDNA analyses should be combined with specimen collection and traditional taxonomy.

With the proposed SO-Jelly programme, we aim to establish a baseline knowledge on SO GZP, combining traditional net catches for specimen collection with non-invasive eDNA studies to reliably assess GZP diversity and community composition across a latitudinal gradient in the SO, at each side of the Antarctic Polar Front. We also plan to carry out sampling in regions for which virtually no gelatinous zooplankton studies have been carried out, i.e., the coastal areas and shelves of the Amundsen and Bellingshausen seas (Lindsay et al., 2014).

We aim to accomplish the following objectives:

- Study GZP species diversity. We will perform an integrative taxonomic study combining morphological and molecular tools. The main outcome includes a reference DNA database covering the molecular diversity of the species encountered in the different water masses, which will serve further eDNA and molecular diet studies. Additionally, the obtained sequences from different regions will allow us to study genetic connectivity of widespread GZP species – plankton net catches, DNA barcoding and phylogeographic analyses;

- Assess distributions and abundances of GZP species and link these to environmental parameters. Species distributions will be assessed vertically from the surface across the midwater zone and along a latitudinal gradient covering different water masses. These data will allow us to study distributional patterns of different species in different regions, by sampling along a latitudinal transect across the Antarctic Front, and sections across the shelf break in the Amundsen and Bellingshausen seas, – plankton net catches, eDNA metabarcoding of water and sediment samples, phylogeographic analyses, 3D ecological niche modelling;

- Study speciation processes and test population connectivity at oceanic scale. For a subset of selected species, we will compare our previously obtained samples from the Arctic and sub-Arctic/boreal regions with the ones we will obtained in the SO. Species delimitation based on Sanger sequencing, and divergence time based on High-Throughput Sequencing will be then overlapped with life cycle history and character evolution to obtain a novel and more complete perspective of the origin and evolutionary consequences of bipolarity – plankton net catches, DNA barcoding, genomics, phylogeographic analyses;
- Elucidate the trophic role of dominant jellies in the SO food webs. The importance of different jelly species as prey for pelagic amphipods will be evaluated – plankton net catches, molecular diet analyses.

This baseline knowledge will pave the way for future studies exploring the consequences of potential increases (or decreases) in jelly biomass and distributional shifts for the rapidly changing SO pelagic ecosystems.

Fig. 5.1: Illustration of the diversity of Southern Ocean gelatinous zooplankton: A. The scyphomedusa Diplulmaris antarctica, B. the ctenophore Callianira cristata, C. the siphonophore Pyrostephos vanhoeffeni, D. the ctenophore Beroe sp., E. the hydromedusa Koelikerina maasi, F. the salp Salpa thompsoni. Photo courtesy A-E: Emiliano Cimoli (Verhaegen et al. 2021), F: Mike Stukkel.

Work at sea

Net sampling

Meso- and macrozooplankton, including GZP, will be collected using net deployments. Stratified vertical hauls with the Midi-Multinet will allow us to obtain information on vertical distribution

patterns and link these with the results of our planned eDNA studies. The Midi-MN has a 0.25 m^2 mouth opening and an opening-closing mechanism with 5 net bags with a 150-335 µm mesh size, and will be hauled vertically at 0.5 m/s. The Bongo net consists of two nets, with a mouth opening of 60 cm diameter, of 300-500 µm mesh size. The nets are equipped with non-filtering cod ends and a V-fin depressor will be attached to the net frame. Oblique tows with the Bongo net will allow us to catch the larger-sized, fast-swimming macrozooplankton (e.g., larger jellies and hyperiid amphipods) and small nekton, and will be towed sideways at a ship's speed of 2 knots. Flowmeters attached to the nets will allow to calculate the volume of water sampled.

Sample preparation for molecular analyses

After retrieving the nets, jelly abundances will be calculated based on the volume of water sampled and the number of jellies counted per number of species and sample (or subsample in case of large trawl catches). Freshly caught individual jellies will be photographed with particular attention to identification features (e.g., gonads, manubrium, umbrellar marginal structures, tentacles and oral arms) depending on the taxonomic group. Specimens will be measured along the oral-aboral axis for ctenophores, and height/diameter of the bell for cnidarians. In case some taxonomically/ecologically interesting specimens damaged during collection (e.g., ctenophores or delicate hydrozoan medusae), short-term maintenance using kreisel aquariums will facilitate regeneration and posterior further characterization and fixation. Several preservation ways of the samples allow us to maximize the usage for a large set of analyses. Ethanol-preserved specimens will be kept for morphological analyses and as reference or voucher specimen for the DNA sequence libraries. A small tissue of these specimens will be removed and preserved in 100 % ethanol or frozen at -80° C for subsequent molecular studies. Hyperiid amphipods will be frozen for molecular diet analyses of their stomach contents.

CTD profiles and in-situ water sampling for eDNA studies

At each station, the CTD rosette cast will be carried out, preceding net sampling. Depth distribution of water masses will be determined based on the vertical profiles of temperature, salinity and fluorescence measurements (as a proxy for chlorophyll-*a* concentration). The rosette will be used to sample water at different depth intervals. Water samples of 2 L will be collected in triplicates, corresponding to the depth layers sampled with the stratified multinet hauls. Water will be immediately filtered on board through Sterivex cellulose filters of 0.2 µm average pore size. An extraction blank will be filtered in the same way after filtration at each station to monitor cross-contamination between samples. Filters containing eDNA will be frozen at -80° C until further analyses (DNA extraction and sequencing) at the AWI home laboratories.

Sediment sampling for eDNA studies

In collaboration with the Marine Geology working group on board, we will sample sediment from the corer deployments. We will take triplicates for eDNA metabarcoding analyses. Sediment samples will be stored at -80° C until further analyses (DNA extraction and sequencing) in the AWI home laboratories.

Expected results

GZP species composition based on net catches

GZP species composition and abundances will be determined for each net haul and linked with oceanographic data identified in the CTD profiles. Vertical distribution and diversity will be assessed based on the depth-stratified Multinet hauls. This will allow us to infer regional and

bathymetric differences in GZP community composition and distributions. These data will also be used to validate the obtained eDNA results on GZP distribution.

Systematics, DNA barcoding and phylogeographic analyses

All samples collected during SO-Jelly will be barcoded for the cytochrome c oxidase subunit I gene (COI), the 16S and 18S ribosomal RNA genes (16S and 18S). Taxonomic revisions or descriptions will be conducted by describing, photographing, and keeping vouchers for relevant specimens, including barcoding information. Based on the barcoding information from the Cape Town – Neumayer transect, the latitudinal variation in GZP communities will be tested through genetic populations and multivariate analyses of community composition. Whether GZP species' populations are connected with gene flow or are, in fact, constituted of differentiated populations or cryptic species, will be tested. Species delimitation methods (using COI, 16S and 18S genes) will allow to determine potential bipolar taxa (i.e., whether or not our case studies represent the same lineage in both poles). Double digest restriction-site associated DNA sequencing (ddRADseq) will be performed on particular taxa to reconstruct the evolutionary history of selected morphological traits and evolutionary origin of the different species, characterized by different life cycle strategies.

eDNA metabarcoding analyses for assessing GZP communities

eDNA metabarcoding analysis can provide detailed and accurate biodiversity assessments of marine zooplankton communities. We will use this method to investigate GZP diversity based on water and sediment samples from different depths of the CTD casts. DNA will be isolated and PCR amplifications will be carried out on technical triplicates per sample using general and GZP group-specific primers. We will target the same genetic markers as used for the reference databases. The general primers include the V4 region (450 bp) of 18S rRNA (Balzano et al., 2015) and a 313-bp fragment of COI (Leray et al., 2013). This variable 18S rRNA V4 region is known to perform well in both community clustering and taxonomic assignments across a very wide taxonomic range of eukaryotes (e.g., Blanco-Bercial, 2020; Questel et al., 2021) whereas the barcode region of mitochondrial COI will provide a finer assay of community diversity and achieve a higher level of taxonomic discrimination (Questel et al., 2021). The Leray COI primers have been proven useful for discriminating a wide range of GZP species across different ctenophores and cnidarian groups (Havermans et al., unpublished results). Jelly-specific primers are currently being developed and tested for Arctic GZP in the context of the HYIG ARJEL project. Reads generated with an Illumina NovaSeq sequencer will be processed and clustered into operational taxonomic units using bioinformatic pipelines. Non-metric multidimensional scaling (nMDS) will be used to evaluate the differences in taxonomic composition as well as regional differences in GZP community structure and species richness.

Molecular diet analyses

Stomach contents of hyperiid amphipods will be studied with DNA metabarcoding in order to assess GZP predation. We will apply a similar combination of general and group-specific jelly primers as for the eDNA analyses to detect the occurrence of jelly DNA reads in predators' stomachs. The workflow is similar to the one described above for eDNA analyses, from DNA extraction to NovaSeq sequencing and taxonomic assignments. Prey compositions will be analysed using multivariate analyses and diversity indexes. MOTU richness will be calculated by rarefying to the number of reads corresponding to the sample with the least reads to allow for statistical comparison among predator species and sampling sites.

Ecological niche modelling

Based on environmental data retrieved from the CTD casts upon collection and from oceanographic GIS (i.e., geographic information system) grids available from the World Ocean Atlas 2018 of NOAA, statistical models (e.g., generalized linear models, ecological niche models, and/or multivariate analyses of community composition) will be performed to define the environmental conditions limiting the distribution of the different species along the latitudinal transect and in the two high Antarctic seas sampled during PS134.

Data management

Zooplankton samples and Sterivex filters for eDNA studies will be archived and stored at the AWI. DNA extracts of jellies and eDNA samples from water column and sediment will be stored at -80° C for up to 10 years after publication of the results (according to the DFG guidelines for good scientific practice). A voucher collection of ethanol preserved jelly specimens, linked to their DNA extracts, will be kept in a repository at the AWI. Geo-referenced environmental data sets such as GZP distribution records and species inventories from net catches 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 cruise at the latest. By default, the CC-BY license will be applied.

Biogeographic datasets will also feed other databases (e.g., OBIS, GBIF). Molecular data (DNA and RNA data) will be archived, published and disseminated within one of the repositories of the International Nucleotide Sequence Data Collaboration (INSDC, www.insdc.org) comprising of EMBL-EBI/ENA, GenBank and DDBJ. Results on eDNA metabarcoding analyses will be published in peer-reviewed journals within three years after the cruise. 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 project is supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 6, Subtopic 6.1 and 6.2.

In all publications based on this expedition, the Grant No. AWI_PS134_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. OCEANOGRAPHY: SOUTHERN OCEAN CARBON AND HEAT IMPACT ON CLIMATE – RECOVERY CRUISE (SO-CHIC-RECOVERY)

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Objectives

The present programme enters within the framework of the wider European project H2020 SO-CHIC (Southern Ocean Carbon and Heat on Climate). The overall objective of SO-CHIC is to understand and quantify variability of heat and carbon budgets in the Southern Ocean through an investigation of the key processes controlling exchanges between the atmosphere, ocean and sea ice. The Southern Ocean regulates the global climate by controlling heat and carbon exchanges between the atmosphere and the ocean. It is responsible for about 60 – 90 % of the excess heat (i.e. associated with anthropogenic climate change) absorbed by the World Oceans each year, and is also recognised to largely control decadal scale variability of Earth carbon budget, with key implications for decision makers and regular global stocktake agreed as part of the Paris agreement. Despite such pivotal climate importance, its representation in global climate model represents one of the main weaknesses of climate simulation and projection. Limitations come both from the lack of observations in this extreme environment and its inherent sensitivity to intermittent small-scale processes that are not captured in current Earth system models.

The present programme aims at recovering three mooring lines deployed in 2021 – 2022 from the *SA Agulhas II* (https://doi.org/10.5281/zenodo.6948850), and to deploy 5 new mooring lines.

Work at sea

The work will consist of recovering three mooring lines (ASFAR, PROPOL, ULS), redeploying one of the three recovered lines after refitting (ASFAR), and deploying 4 new mooring lines (M1 – 4). The first operation will be to recover ASFAR, then we will deploy M1 – 4, then recover PROPOL and ULS, and finally redeploy ASFAR.

Tab. 6.1: List of planned mooring stations

Station #	Station name	Latitude	Longitude	Operation	Depth
1	UK1	63° 34.05‘ S	02° 26.60‘ E	Deployment	4.241 m
2	UK2	63° 39.19‘ S	02° 26.60‘ E	Deployment	3.875 m
3	ASFAR	63° 39.46‘ S	02° 26.60‘ E	Recovery	3.845 m
4	UK3	63° 39.73‘ S	02° 26.60‘ E	Deployment	3.814 m

Station #	Station name	Latitude	Longitude	Operation	Depth
5	UK4	63° 44.86‘ S	02° 26.60‘ E	Deployment	3.185 m
6	ULS	64° 33.07‘ S	03° 12.86‘ E	Recovery	2.092 m
7	PROPOL	64° 31.79‘ S	03° 14.54‘ E	Recovery	2.092 m
8	ASFAR	63° 39.46‘ S	02° 26.60‘ E	Re-Deployment	3,.845 m

Expected results

The collection of measurements obtained with these mooring lines will be rigorously analysed to document and quantify the processes governing open ocean Polynya development. This analysis will entail three complementary stages focussing on classes of processes of distinct scales.

First, the processes preconditioning the emergence of Polynyas via a reduction of ambient stratification over Maud Rise will be assessed. Two types of processes will be targeted here: (i) the generation of a Taylor cap circulation over the Rise, and of slowly-evolving mesoscale meanders around the Rise, by the impingement of the Weddell Gyre’s southern limb on the local topography; and (ii) the generation of small-scale turbulent mixing associated with e.g., the breaking of internal tides radiated from the Rise. To document the contribution of (i) to reducing regional stratification, the measurements of the mesoscale circulation obtained by satellite altimetry, Deep-Argo floats and moorings will be examined concurrently, using proven analytical techniques previously developed and applied by our team. To document the contribution of (ii), the distribution of the turbulent dissipation rate will be quantified, and the finescale motions underpinning turbulence (e.g., internal waves) will be characterised from the mooring measurements.

Second, the impact of intermittent de-stratifying processes (sea ice formation, small-scale turbulent mixing events, and instabilities linked to the nonlinear equation of state of seawater) in reducing upper-ocean stratification and promoting oceanic heat loss and Polynya growth will be assessed, in the context of the evolving atmospheric and sea ice conditions (e.g., storm events and wind-forced sea ice divergence). The atmospheric forcing of de-stratification events will be evaluated from air-sea fluxes of heat, freshwater and momentum provided by a state-of-the-art atmospheric reanalysis (e.g., the ECMWF ERA-Interim product), constrained locally by our observations. Daily satellite measurements of sea ice concentration and motion will be utilised to document the relationship between evolving sea ice conditions and the unfolding of de-stratification events.

Third, the role of re-stratifying processes (specifically, submesoscale instabilities and mesoscale baroclinic instability of the frontal system encircling Maud Rise) in enhancing upper-ocean stratification and arresting Polynya growth will be assessed. This will be achieved by evaluating the occurrence of submesoscale symmetric and baroclinic instabilities in the upper ocean through a potential vorticity-based instability analysis of the glider observations; by calculating the upward buoyancy flux associated with both submesoscale and mesoscale instabilities from the mooring measurements; and by evaluating the mesoscale circulation and atmosphere / sea ice conditions in which each instability occurs, and the impacts of each instability on upper-ocean stratification.

The outcomes of these three lines of analysis will be synthesised and contextualised within a sea ice concentration budget of the Maud Rise region for the period of the experiment. This exercise will enable us to attribute events of significant change in regional sea ice concentration (such as e.g., the opening or closing of a Polynya) to mechanical and thermodynamic drivers. By contrasting this information with our preceding diagnostics of atmospheric forcing and de-

stratifying and re-stratifying processes, the processes governing the Polynya's development will be identified and quantified.

Data management

The present project is part of the wider SO-CHIC project which has an entire work package (and associated budget) dedicated to data handling. In particular, we will enable discovery, open access, view and download of the data generated and collected during the SO-CHIC project. Data management is developed in coordination and collaboration with already existing infrastructures and integrators (e.g. EMODnet, CMEMS, SOOS) to avoid the duplication of effort and to facilitate a fast adoption and availability of the produced data.

During the Targeted Operation Period, the SO-CHIC observations will be provided to the European and international marine and ocean data management infrastructures. For SO-CHIC-Recovery, data will be provided to SISMER (the French national oceanographic data repository): The data will be made publicly available either after the first scientific peer-reviewed publication using the dataset, or after a maximum of 2 years after the end of the expedition. We expect a total data volume of about 50 GB for the SO-CHIC-Recovery cruise, including all raw, postprocessed, and calibrated datasets.

In all publications based on this expedition, the Grant No. AWI_PS134_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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A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Baltzer	Johannes	DE.TIHO	Scientist	Biology
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Brauer	Jens	DE.DRF	Pilot	Helicopter service
Brehmer-Moltmann	Johanna	DE.AWI	Student	Geophysics
Burkhalter-Castro	Rosemary	US.USF	PhD student	Oceanography
Cammareri	Alejandro	AR.MARYBIO	Scientist	Biology
Cardinahl	Lena	DE.AWI	Student	Geology
Daub	Pascal	DE.AWI	Technician	Geophysics
Dorschel	Kolja	DE.AWI	Student	Geophysics
Dreutter	Simon	DE.AWI	Technician	Geophysics
Eggers	Thorsten	DE.AWI	Technician	Geophysics
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Kirkham	James	UK.BAS	PhD student	Glaciology
Klages	Johann	DE.AWI	Scientist	Geology
Larter	Robert	UK.BAS	Scientist	Geophysics
Lensch	Norbert	DE.AWI	Technician	Geology
Lösing	Mareen	DE.UNI-KIEL	Scientist	Geophysics
Lucke	Klaus	AUS.JASCO	Scientist	Biology
Lourenco	Antonio	FR.USORBONNE	Engineer	Oceanography
Malucelli Barbosa	Ingra	DE.AWI	Student	Geophysics
Newton	John	NZL.MAUI63	Engineer	Biology
Panter	Gabriel	DE.NHC	Technician	Helicopter service
Paul	Christina	DE.AWI	Student	Geophysics
Ramirez-Martinez	Nadya	DE.TIHO	Scientist	Biology
Röhnert	Daniela	DE.UNI-BREMEN	Scientist	Geology

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
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Santos Lopes	Hugo Manuel	AR.MARYBIO	Scientist	Biology
Schick	Luca	DE.TIHO	Scientist	Biology
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Stevenson	Christopher	NZL.MAUI63	Pilot	Biology
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Uenzelmann-Neben	Gabriele	DE.AWI	Scientist	Geophysics
Van Coillie	Meltse	BE.MEDIA	Journalist	Media
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Verhaegen	Gerlien	DE.AWI	Scientist	Biology
Weich	Zelna	UK.BAS	PhD student	Geology
Weigelt	Estella	DE.AWI	Scientist	Geophysics

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

Name	Vorname	Master
Langhinrichs	Moritz	Master
Langhinrichs	Jacob	Chiefmate
Ziemann	Olaf	Chiefmate Cargo
TBN		Chief
Fallei		2nd Mate
Peine	Lutz	2nd Mate
Dr. Guba	Klaus	Ships Doc
Dr. Hofmann	Jörg	SET
Ehrke	Tom	2nd. Eng
Krinfeld	Oleksandr	2nd. Eng
Rusch	Torben	2nd. Eng
Pommerencke	Bernd	SET
Frank	Gerhardf	ELO
Schwedka	Thorsten	ELO
Winter	Andreas	ELO
Krüger	Lars	ELO
Brück	Sebastian	Bosun
TBN		Carpen.
Möller	Falko	MP Rat.
Buchholz	Joscha	MP Rat.
Schade	Tom	MP Rat.
Decker	Jens	MP Rat.
TBN		
Weiß	Daniel	MP Rat.
Niebuhr	Tim	MP Rat.
Lutz	Johannes	MP Rat.
TBN		MP Rat.
Thiele	Linus	MP Rat.
TBN		MP Rat.
Clasen	Nils	MP Rat.
Arnold-Becker	André	MP Rat.
Waterstradt	Felix	MP Rat.

Name	**Vorname**	**Master**
Plehn	Marco Markus	Storek.
Schnieder	Sven	Cook
TBN		Cooksm.
TBN		Cooksm.
Witusch	Petra	Chief Stew.
Pommerencke	Kerstin	Nurse
TBN		2nd Stew
Golla	Gerald	2nd Stew
Ilk	Romy	2nd Stew
Shi	Wubo	2nd Stew
Chen	Quan	2nd Stew
Hu	Guo Yong	Laundym