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

EXPEDITION PROGRAMME PS100

Polarstern

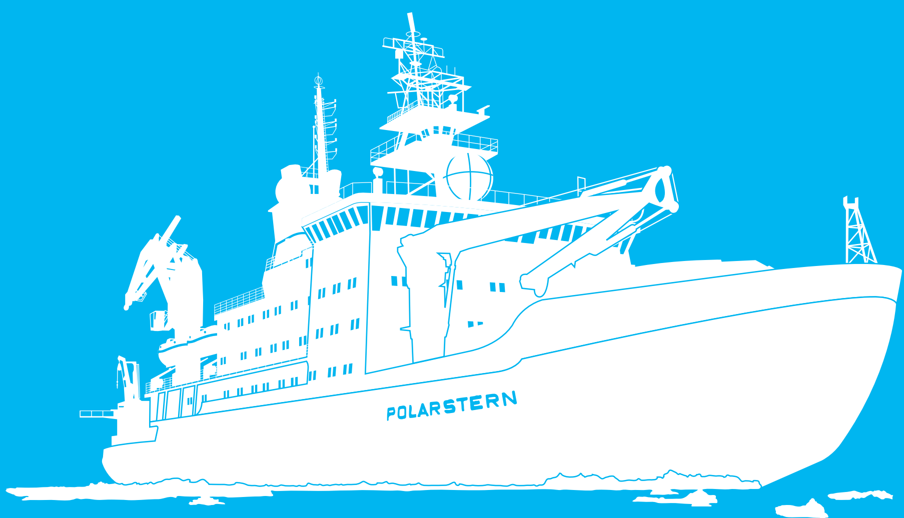
PS100

Tromsø - Tromsø

18 July 2016 - 6 September 2016

Coordinator: Rainer Knust

Chief Scientist: Torsten Kanzow



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Tromsø to Tromsø

Greenland Ice Sheet/
Ocean Interaction and Fram Strait Fluxes
(GRIFF)

Coordinator
Rainer Knust

Chief scientist
Torsten Kanzow

Content

1. ÜBERBLICK UND FAHRTVERLAUF

Torsten Kanzow (AWI)

Die Expedition "Greenland ice sheet/ocean interaction and Fram Strait fluxes" (GRIFF) kombiniert Untersuchungen der ozeanischen Flüsse durch die Framstraße und der Wechselwirkung zwischen dem grönländischen Eisschild und dem Europäischen Nordmeer. Starker Temperaturanstieg in der arktischen Atmosphäre und im Ozean und drastische Veränderungen des arktischen ozeanischen Süßwasserhaushalts in den vergangenen Jahren bei gleichzeitigem Rückgang des grönländischen Eisschilds sowie Änderungen der Ozeanzirkulation stehen in enger Wechselwirkung miteinander. Die Framstraße bildet den einzigen tiefen Zugang des Arktischen Ozeans zum Weltozean, durch den warmes, salzreiches Atlantikwasser nach Norden und auf der anderen Seite ein Teil des arktischen Süßwasserüberschusses, zum Teil als Meereis, in den Atlantik transportiert werden. In größeren Tiefen werden die durch polare Prozesse ventilierten Tiefen- und Bodenwasser aus der Arktis exportiert und in die meridionale Umwälzzirkulation des Atlantiks eingespeist. Gleichzeitig mündet mit dem NEGIS (North East Greenland Ice Stream) einer der mächtigsten grönländischen Eisströme in die westliche Framstraße, der auf dem nordostgrönländischen Schelf in Kontakt mit warmem Ozeanwasser steht. Das nordwärts strömende und damit auch das vor Ostgrönland rezirkulierende Atlantikwasser hat sich in den letzten Dekaden deutlich erwärmt und Klimamodelle skizzieren eine weitere Erwärmung. Es ist davon auszugehen, dass dies Auswirkungen auf den Massenverlust des NEGIS hat.

Zur Erforschung des komplexen Systems wird die Expedition Arbeiten aus den Bereichen Ozeanzirkulation, Geochemie, Glaziologie, Geodäsie, Geologie, Geophysik, Schiffsmechanik, Biologie und Biochemie kombinieren. Die ozeanischen Volumen- und Wärmeflüsse durch die Framstraße werden durch die Fortsetzung eines Langzeitverankerungs- und Hydrographieprogramms quantifiziert. Der Hydrographieschnitt wird die volle Suite des Spurenstoffprogramms von GEOTRACES enthalten. Das dient zum einen dazu, in Kombination mit den ozeanographischen Transportmessungen und mit einem in 2015 ausgeführten arktisweiten GEOTRACES-Programm (u.a. Polarsternantrag TransArc II 2015) den Beitrag des Arktischen Ozeans zum globalen Spurenstoffbudgets abzuschätzen. Zum anderen dienen die Spurenstoffe dazu, Ursprünge verschiedener Wassermassentransporte, unter anderem von Gletscherschmelze, zu identifizieren. Das ozeanographische Verankerungsarray und die hydrographische und Spurenstoff-Aufnahme werden erstmalig durch einen Meridionalschnitt in der Framstraße ergänzt, um die Rezirkulation von Atlantik-Wasser zu untersuchen. Das Verankerungsarray wird zudem auch auf den ostgrönländischen Schelf ausgedehnt, um zum einen die Zufuhr von warmem Zwischenwasser bis zur Mündung des NEGIS zu verfolgen und zum anderen den Schmelzwassereintrag des Gletschers zu quantifizieren. Letzteres wird durch Beobachtungen von stabilen Edelgasisotopen erfolgen.

Die Expedition wird darüber hinaus Messungen der terrestrischen und der Gletscherdynamik zum Ziel haben. Sensoren zur Messung von geodätischen und glaziologischen Parametern werden entlang der Küste von Nordostgrönland und auf dem 79°N Gletscher aufgestellt werden. Das glaziologische Programm wird Gletscherschmelzraten und die Dynamik des Eisstroms erfassen. Das geodätische Programm konzentriert sich auf Wiederholungsmessungen an Langzeitstationen, um die Deformationsraten der Erdkruste zu bestimmen, welche Informationen über postglazialen isostatischen Ausgleich liefern.

Um die neueren Beobachtungen bei Grönland in eine Langzeitperspektive einzuordnen, wird das geologische Programm die Historie des NEGIS nach dem letzten eiszeitlichen

Maximum untersuchen. Ein wichtiges Ziel ist es, den Eisstrom, die Ausdehnung sowie die Dicke des Eisschelfs zu dokumentieren, um die Zyklen des Rückzugs und des Wiederanwachsens durch Sedimentbohrungen und akustische Untersuchungen des Meeresbodens an Schlüsselstellen des Kontinentalschelfs von Nordostgrönland zu bestimmen. Die Zyklen der historischen Eisschelfentwicklung sollen dann im Zusammenhang mit den ozeanographischen und atmosphärischen Bedingungen sowie den Veränderungen des Meeresspiegels interpretiert werden.

Die physikalischen Arbeiten werden durch biogeochemische und biologische Programme ergänzt. Die biogeochemische Arbeit konzentriert sich auf die Charakterisierung von Nährstoffen in der Wassersäule sowie auf Nährstoffquellen in der Framstraße und auf dem Schelf in Nordostgrönland. Die hierbei erhaltenen Wasserproben werden des Weiteren dazu genutzt, das Nährstoffmesssystem von FS *Polarstern* zu validieren. Das biologische Programm konzentriert sich auf die Eisrandzone der Framstraße und soll die Produktivität, die Biomasse, die Biodiversität, die Produktion von ökologisch wichtigen Bestandteilen und die wichtigsten der marinen Artengemeinschaften dokumentieren. Die Biomasse und die Produktion aller wichtigen Bestandteile der Nahrungskette, angefangen von der Eisalge und Phytoplankton über Zooplankton bis zu den wichtigsten Räubern wie Seevögel und Meeressäuger werden synoptisch bestimmt. Wegen des komplexen Strömungssystems in der westlichen Framstraße wird dies eine Herausforderung sein.

Zusätzlich wird eine geophysikalische Studie bezüglich Spreizungsprozessen an einem sich extrem langsam spreizenden ozeanischen Rückensystem durchgeführt werden. Das Ziel ist es herauszufinden, wie Schmelzcharakteristika auf Segmentskalen entlang der Achse von sich extrem langsam spreizenden Rückensystemen propagieren und durch die mächtige Lithosphäre aufsteigen. Um diese Aufgabe zu erfüllen, wird zum ersten Mal ein gesamtes Segment einer ‚ultraslow spreading rigde' über 180 km mit Seismometern am Ozeanboden bestückt, die die Erdbebenaktivität des Knipovich Rückens vermessen sollen.

Außerdem soll noch die dynamische Reaktion des mechanischen Aufbaus von FS *Polarstern* auf Einwirkungen der komplexer Eisstruktur und Ozeanwellen während der Fahrtbetriebs untersucht werden. Dafür werden während der gesamten Reise Vibrationsmessungen auf voller Skala durchgeführt werden.

FS Polarstern wird am 18. Juli von Tromsö auslaufen. Die Hauptarbeitsgebiete sind die Framstraße, der nordostgrönländische Schelf und der Knipovich Rücken südlich der Framstraße (Abb. 1.1). Da wir in der Zeit von Juli bis in den frühen August hinein mit schwierigen Eisverhältnissen im Bereich des nordostgrönländischen Schelfs rechnen, werden wir aller Voraussicht nach mit den Arbeiten in der Framstraße beginnen. Hier werden wir die Verankerungen entlang des 79°N Schnitts warten und ein intensives Wassersäulenprogramm durchführen (Hydrographie, Spurenstoffe, Biogeochemie). Letzteres soll mit dem biologischen „Box-Ansatz" in der Eisrandzone der westlichen Framstraße verschmolzen werden. Während der ersten Hälfte der Expedition werden wir ebenfalls beginnen, die geophysikalischen Ozeanbodenseismometer entlang des Knipovich Rückens auszulegen. In der zweiten Hälfte der Expedition sollten uns dann die Meereisbedingungen gestatten, unsere Arbeiten bezüglich der Ozean-Schelfeis Wechselwirkung auf dem Schelf von Nordostgrönland durchzuführen. Hier werden abermals Verankerungen gewartet und ein Wassersäulenprogramm durchgeführt werden. Dies wird durch das geologische Arbeitsprogramm (Sedimentkerne, Echolot gestützte Bathymetrievermessung) ergänzt werden. Auch werden hier Helikopter gestützte Arbeiten entlang der Küste sowie die glaziologischen und geodätischen Programme auf dem 79°N Gletscher durchgeführt werden. Auf dem Rückweg nach Tromsö, wo die Expedition am 6.

September enden wird, werden abschließend noch die geophysikalischen Arbeiten am Knipovich Rücken beendet werden.

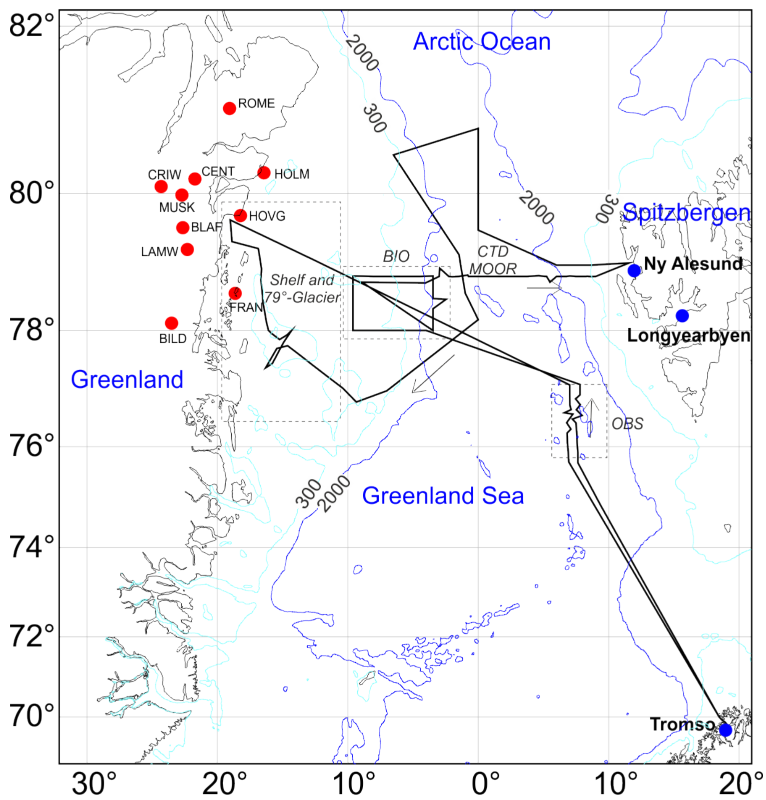

Fig. 1.1: Preliminary track of R/V Polarstern cruise PS100 starting in Tromsö on July 18 and returning to Tromsö on 6 September. The cruise will have 3 main work areas, namely i Fram Strait, ii. the shelf of Northeast Greenland and iii. Knipovich Ridge south of Fram Strait.

Abb. 1.1: Vorläufige Fahrtroute der FS Polarstern Expedition PS100, die am 18. Juli in Tromsö beginnen und ebendort am 6. September enden wird. Während der Expedition werden Forschungstätigkeiten in drei Arbeitsgebieten stattfinden, nämlich in der Framstraße, auf dem Schelf von Nordostgrönland und am Knipovich Rücken südlich der Framstraße.

SUMMERY AND ITINERARY

The cruise "Greenland ice sheet/ocean interaction and Fram Strait fluxes" (GRIFF) combines investigations of the oceanic fluxes through Fram Strait with those of the interaction between the Greenland ice sheet and the Nordic Seas. Strong temperature increase of the Arctic atmosphere and ocean and considerable changes of the Arctic fresh water budget during the past years, and in the same time the retreat of the Greenland ice sheet as well as changes in the ocean circulation are linked via complex interactions. Fram Strait constitutes the only deep gateway between the Arctic and the global ocean through which warm saline Atlantic waters flow northwards and at the same time a substantial part of the huge Arctic fresh water excess is carried southward towards the Atlantic, partly as as liquid water and partly a sea ice. In the Nordic Seas, this fresh water flux is augmented by runoff (and ice bergs) from Greenland. In deeper layers of Fram Strait, deep and bottom waters that are ventilated by polar processes exit the Arctic to be eventually incorporated in the Atlantic meridional overturning circulation. At the same time, one of the mightiest Greenland ice streams, the NEGIS (North East Greenland Ice Stream), drains into the western Fram Strait where its outlet glacier, the 79°N Glacier, is in direct contact with warm Atlantic water recirculating in Fram Strait. The Atlantic water in Fram Strait has been warming considerably during the last decades and climate models propose further warming with possible consequences for the stability of the NEGIS.

The proposed cruise will combine work on ocean circulation, geochemistry, glaciology, geodesy, geology, geophysics, mechanical engineering, biology and biochemistry of this complex system. The volume and heat fluxes through Fram Strait will be quantified by a continuation of the long-term mooring and hydrography programs. The hydrographic section work will involve the whole suite of the trace elements run by the GEOTRACES programme. In combination with the oceanographic transport measurements and with the pan-Arctic GEOTRACES programme carried out in 2015 (*Polarstern* TransArc II cruise completed 2015) this will enable us to estimate the Arctic contribution to the global trace element cycle. On the other hand, the trace elements help identifying the sources of the various water masses flowing through Fram Strait, including contributions from basal glacial melting. The oceanographic mooring array and the hydrographic and trace element surveys will be complemented for the first time by i. a meridional section in Fram Strait to investigate the recirculation of Atlantic Water and ii stations on the East Greenland shelf in order to track the flow of warm Atlantic intermediate water towards the cavity of the 79°N glacier. We will also identify melt water and quantify rates. The latter will be constrained by observations of stable noble gas isotopes.

The cruise will further support measurements of the glacial / terrestrial dynamics. Devices for glaciological and geodetic observations will be installed along the coast of Northeast Greenland and on the 79°N glacier. The glaciological programme will capture the melt rates and dynamics of the ice flow. The geodetic programme focuses on a re-occupation of a long-term sites to capture deformation rates of the earth crust, which will provide information of the glacial isostatic adjustment.

In order to put the modern observations near Greenland into a long-term perspective, the geology programme will study the history of Northeast Greenland Ice Stream after the last glacial maximum. A particular aim is to constrain both the ice stream and ice shelf extents and thicknesses in order to determine rates of retreats and re-advances by sediment coring and acoustic seafloor surveys at key locations on the Northeast Greenland continental shelf. The ice sheet retreat cycles will then be interpreted in the context of oceanic and atmospheric conditions as well as sea level change.

The physical work will be complemented by biogeochemical and biological programmes. The biogeochemical work will focus on the characterization of water column nutrients as well as the sources of nutrients both in Fram Strait and on the shelf of Northeast Greenland. The water samples to be obtained will also serve to validate R/V *Polarstern's* underway nutrient measurement system. The biological programme will target the marginal ice zone of Fram Strait. Specifically this involves the quantification of abundance, biomass, biodiversity and production of ecologically important components and key species of the marine communities. Biomass and production of all important components of the food web from ice algae and phytoplankton via zooplankton to top predators such as seabirds and marine mammals will be determined synoptically. This is challenging because of the complex current regime in western Fram Strait.

In addition, a geophysical study of spreading processes at an ultraslow spreading ridge will be conducted. The aim is to find out how melts travel at segment scale along the axis of ultraslow spreading ridges and rise through the thick lithosphere. To accomplish the task, for the first time an entire segment of an ultraslow spreading ridge will be instrumented with a 180 km long network of ocean bottom seismometers in order record the earthquake activity of the ridge.

Finally investigations of R/V *Polarstern's* dynamic responses due to complex ice-structure and fluid-structure interactions will be made. This will require full scale vibration measurements which will be conducted aboard R/V *Polarstern* throughout the cruise.

R/V Polarstern will depart from Tromsö on July 18. The main work areas are Fram Strait, the shelf of Northeast Greenland including the coast, and Knipovich Ridge south of Fram Strait (Fig. 1.1) Since we expect the sea ice conditions to be not particularly favourable for the conduction of research on the East Greenland continental shelf in July and early August, we shall first attempt to conduct the research programmes in Fram Strait. Here moorings will be serviced along the 79°N line and an intense water column sampling programme will be conducted (hydrography, trace elements, biochemistry). This shall be merged with the biological „box“ approach in the marginal ice zone of western Fram Strait. Also we will commence with the deployment of ocean bottom seismometers along Knipovich Ridge in the first half of the cruise. In the second half of the cruise, sea ice conditions should allow us to conduct our work on the ocean – glacier interaction on the shelf of Northeast Greenland. Here both mooring servicing and water column work will be conducted. This will be complemented by the geological workpackage (sediment coring, echosounder-based surveys of the bathymetry). Also the helicopter-based operations will be conducted in order to cover both the geodetic stations on the coast as well as glaciological and oceanographic aspects on the 79°N glacier. On the way back to Tromsö, where the expedition will end on September 6, the geophysical programme at Knipovich Ridge will be completed.

2. FLOW OF ATLANTIC WATER IN FRAM STRAIT AND ON THE EAST GREENLAND SHELF

N. Wilson (MIT-WHOI) ,
not on board: F. Straneo (WHOI) , M. Simon (Greenland Institute of Natural Resources,)

Background and objectives

West Spitsbergen Current

This cruise supports a long-term effort to monitor and quantify the variability of oceanic fluxes through the Fram Strait with a particular emphasis on the physical oceanography.

The Arctic Ocean is a semi-enclosed marginal sea with the Bering Strait, the Canadian Arctic Archipelago, and the Barents Sea being three shallow connections to the world oceans. The Fram Strait is the only deep strait (2,700 m), thereby allowing for the exchange of intermediate and deep waters between the Arctic Ocean and the Nordic Seas, which are in turn a marginal sea of the North Atlantic. Atlantic origin water is cooled throughout the cyclonic boundary current circulation in the Nordic Seas and enters the Arctic through the Barents Sea and the eastern Fram Strait. The temperature and other properties of the inflowing warm and salty Atlantic Water change in response to interannual variability (Beszczynska-Möller et al, 2012), to large scale-, multi-year climate patterns, such as the North Atlantic Oscillation, and to global climate change. The sum of these effects can be measured in the Fram Strait before it enters the Arctic Ocean, where it participates in the formation of the halocline north of Svalbard and forms a mid-depth cyclonic boundary current. Cooling, freezing, sea-ice melt, mixing with Pacific origin water, and the addition of large amounts of river runoff in the Arctic modifies the inflowing water (Rudels et al, 2005) before it exits through the western Fram Strait (de Steur et al, 2014). Thus observations of the outflow from the Arctic make it possible to monitor the effects of many processes in the Arctic Ocean.

The complicated topography in the Fram Strait leads to a horizontal splitting of the inflowing branches of Atlantic Water. Additionally, some of the Atlantic Water participates in a westward flow called the recirculation that then turns southward to exit the Fram Strait back to the Nordic Seas. The southward flowing cold and very fresh East Greenland Current is responsible for a large part of the liquid freshwater export from the Arctic and most of the solid freshwater export in the form of sea-ice. This freshwater has the potential to impact convection in the Nordic Seas and the northern North Atlantic and in turn the meridional overturning circulation.

Since 1997, AWI and the Norwegian Polar Institute have maintained a mooring array across the Fram Strait to monitor the fluxes of volume and heat, and, in the western part of the strait, freshwater into and out of the Arctic Ocean through this gateway.

Atlantic Water Recirculation

The recirculation of Atlantic Water (AW) in Fram Strait controls how much of the warm nutrient rich AW flowing northward in the West Spitsbergen Current enters the Arctic Ocean. This determines the oceanic heat input and therefore the extent of the partially ice-free halocline formation area north of Svalbard (Rudels et al, 2005). The inflow also impacts the light and nutrient distribution in the Arctic and therefore habitat distribution and biogeography in the Arctic Ocean (Metfies et al, 2016) as well as their future evolution.

The part of the AW, that does not enter the Arctic Ocean, follows distinct, but poorly understood, pathways in Fram Strait and is then exported southward in the East Greenland Current. Special to Fram Strait is also that the southward advection of sea-ice and the northward advection of AW balance such that the ice-edge location varies very little. Hence, the region where frontal dynamics associated with the meltwater front at the interface between the two can affect the physics and biology (e.g. Wulff et al, 2016 in review) is confined to a relatively small area. The Polar Water outflow is also located vertically above the AW. While it remains to be explained how that happens, it is clear that the large stratification associated with that transition leads to a similar situation to the halocline of the Arctic Ocean where the vertical nutrient supply to the shallow euphotic zone is inhibited and the primary production has to adapt accordingly. The meridional extent over which the recirculation takes place has not been constrained. A recent numerical model study (Hattermann et al, 2016 in review) has suggested that there are in fact two branches of the recirculation. A southern branch is thought to be comparatively steady, while a northern branch essentially can be considered as an extended region in which eddies are propagating westwards. The recirculation also likely has a baroclinic geostrophic and a barotropic wind-driven component, but it has only been possible to show that both contribute to the recirculation between 78°50'N and 79°0'N (de Steur et al, 2014). It also known that the West Spitsbergen Current is unstable at 78°50'N, especially in winter (von Appen et al, 2016), but it is not known whether there is even more eddy generation further north. The large seasonality in the region (e.g. de Steur et al, 2014, von Appen et al, 2016) also means that an understanding solely based on the summer time situation (calmest season) will inherently be incomplete. The dynamics that lead to the splitting of the AW inflow are essential to other regions of the ocean as well. For example, the Irminger Current splits at Denmark Strait and only some of the warm water flows northward through that strait. The lacking dynamical understanding of the present day recirculation also currently makes it impossible to predict how the recirculation and the processes influenced by it will evolve in the future under changing forcing conditions associated with e.g. climate change.

In order to improve the understanding of the recirculation in Fram Strait, it is crucial to measure several physical and biological parameters over the presumed meridional extension of the recirculation including during the winter months. The temperature and salinity distribution in space and time can be used to track the water of the recirculation and determine its modification and vertical motion reflected in the depth of the temperature maximum. The meridional gradient of the density can be used to elucidate the location of baroclinic geostrophic flows and combination with direct velocity measurements can reveal the full current structure. The short term variability of the currents gives information on the eddy field and its possible contribution to the flow. Vertical velocity shear can highlight the interface between the lighter Polar outflow water and the AW. The horizontal motion of those two layers is likely quite different in some regions and possibly also decoupled from the overlying ice motion. The vertical migration of the interface between the two water masses in response to external factors can be tracked even in the absence of profiling temperature and salinity measurements. The oxygen distribution provides insights on the primary productivity while acoustic backscatter elucidates the presence and migration of zooplankton which possibly responds to the changes physical environment.

The ideal location to measure these properties is along the prime meridian (0°EW). This is outside of the West Spitsbergen Current and the East Greenland Current and what happens there is therefore not due to the boundary currents, but rather due to the recirculation. The prime meridian also avoids the 5,500 m deep Molloy Hole whose likely topographic steering would add an additional level of complexity to this already complex question. The prime meridian also cuts across the ice-edge (near 79°N at 0°EW) such that the influence of the recirculation on the ice-edge can be studied there. Additionally, the small amount of data that exist on the meridional structure of the recirculation is located along the prime meridian (Marnela et al 2013) and it is hence valuable to collect new data at a comparable location. Mooring data will also be used for validation of and assimilation into a numerical model of the region around the Fram Strait.

For these reasons, five equally spaced moorings will be deployed at the following locations along the prime meridian (0°EW): 78°10'N, 78°50'N, 79°30'N, 80°10'N, and 80°50'N which is in water depths between 2,000 m and 3,000 m. Velocity as well as temperature, salinity, and oxygen will be measured in the upper 750 m on the moorings.

East Greenland Shelf Circulation

Mass loss from the Greenland Ice Sheet presently accounts for a third to a quarter of sea-level rise (Milne et al 2009) and the rate of mass loss is increasing (Velicogna 2009). The dominant mechanism is increased mass discharge along the marine margins where numerous major outlet glaciers have undergone a nearly simultaneous retreat, acceleration and thinning (Rignot and Kanagaratnam 2006; Howat et al 2008; Stearns and Hamilton 2007; Dietrich et al 2007). Both data and models indicate that this acceleration was triggered by a change at the tidewater margins of these glaciers (Thomas 2004; Nick et al 2009; Pritchard et al 2009), suggesting that the ocean plays a key role in modulating the ice sheet's mass balance (Vieli and Nick 2011; Straneo et al 2012).

The proposed oceanic trigger is supported by recent studies showing that warm Atlantic waters are present and circulating in Greenland's glacial fjords (Holland et al 2008; Straneo et al 2010; Murray et al 2010; Straneo et al 2011) and by the observation that these waters were warming and accumulating in the subpolar North Atlantic at the same time as the glaciers started to retreat (e.g. Bersch et al 2007).

Greenland's glacier acceleration has been concentrated along the southeastern and western margins terminating in the subpolar North Atlantic. Only recently, Helm et al (2014) observed a general reduction in ice sheet elevation near the margins in the northeast of Greenland. Here, mainly two glaciers Nioghalvfjerdsfjorden glacier and Zachariae Isstrom drain the Northeast Greenland Ice Stream (NEGIS) whose drainage basin contains more than 15 % of the Greenland Ice Sheet area (Rignot and Kanagaratnam 2006). Zachariae Isstrom lost about 5 Gt/yr of its mass since 2003 and was observed to retreat at an accelerated rate since fall 2012, whereas no mass loss but an increased bottom melting was found at Nioghalvfjerdsfjorden glacier (Mouginot et al 2015). Khan et al (2014) observed an acceleration of the ice flow of Nioghalvfjerdsfjorden glacier and a sustained dynamic thinning of NEGIS which they linked to a regional warming. The fact that a warming and thickening of the Atlantic layer has recently been observed in the Nordic Seas (e.g. in Fram Strait; Beszczynska-Möller et al 2012) raises the question of whether the ocean changes may have triggered the fast retreat of Zachariae Isstrom (as suggested by Mouginot et al 2015) and will trigger unstable behavior of Nioghalvfjerdsfjorden glacier.

Warm Atlantic water is carried to the North by the North Atlantic Current - Norwegian Atlantic Current - West Spitsbergen Current system. In Fram Strait a sizable fraction of the Atlantic water recirculates to the south on the East Greenland continental slope. Studies on the eastern Greenland shelf in the 1980s and 1990s found this recirculating Atlantic water (RAW) to penetrate through sea bed troughs onto the East Greenland shelf (e.g. Bourke et al 1987) below the fresh and cold polar waters (PW).

The Atlantic water mass found on the shelf was described by Bourke et al (1987) as Atlantic Intermediate Water (AIW) with temperatures ranging between 0°C and 3°C and salinities between 34.5 and 34.9. Budeus et al (1997) found two distinct types of Atlantic waters in the trough system. They found 1°C warm Atlantic waters with salinities of 34.9 to be present throughout the southern Norske Trough, which cooled and freshened towards 79N glacier, and 0.5°C warm Atlantic waters with salinities of 34.8 in the northern Westwind Trough. An anticyclonic surface circulation on the continental shelf following the trough axis was found based on hydrographic observations (Bourke et al 1987, Schneider and Budeus 1995), moored (Topp and Johnson 1997) and ship based (Johnson and Niebauer 1995) velocity measurements. In addition, Topp and Johnson (1997) proposed an anticyclonic subsurface circulation from moored measurements in Westwind Trough, in contrast to Budeus et al (1997), who proposed that there is no one-directional flushing of the trough system. In the trough area east of the outlet glaciers, i.e. between Westwind and Norske Trough, Budeus and Schneider (1995) suggested a sill depth of 250 m causing the differences in water properties. This part of the shelf has rarely been studied due to a perennially fast sea ice cover (e.g. Schneider and Budeus 1995; Schneider and Budeus 1997), but is of strong interest when studying warm water pathways towards the outlet glaciers.

A survey of Nioghalvfjerdsfjorden glacier in the mid-1990s led to very high estimates of submarine melt rates (about 40 m/yr locally, with a mean basal melt rate of 8 m/yr), which account for the bulk of the ice shelf mass loss (Mayer et al 2000). The melting was attributed to the presence of AIW in the 600 m to 800 m deep subglacial cavity as observed in several conductivity, temperature and depth (CTD) profiles collected at the glacier's margins (Thomsen et al 1997; Mayer et al 2000). A more recent survey conducted in the summer of 2009 (Straneo et al 2012) confirmed that the AIW found under the floating ice tongue still contains large amounts of heat to drive melting. Based on three CTD sections taken north of the main glacier front, Wilson and Straneo (2015) discussed that warm AIW cannot enter the cavity through Dijmphna Sund due to a sill of 170 m depth but needs to pass the eastern pinned glacier front. They proposed that the exchange of warm Atlantic waters between the continental shelf and the cavity through Norske Trough occurs on timescales of less than a year.

Nonetheless these implications are not based on observations towards the east/southeast of Nioghalvfjerdsfjorden glacier, and a direct pathway of warm AIW from the shelf break, through Norske Trough towards Nioghalvfjerdsfjorden glacier is still missing.

Work at sea

Moorings have been deployed in the Fram Strait and on the East Greenland shelf by the Alfred Wegener Institute in 2012 (PS80), 2014 (PS85), and 2015 (PS93.1, HE451.2). Some of the moorings that were deployed in 2012 were recovered during the cruises in 2014 and 2015. It is planned that the 28 moorings currently still in the water (Fig. 2.1) shall be recovered on PS100.

Another large part of the work of the physical oceanography group will be the deployment of 22 moorings (Fig. 2.2). The moorings in the West Spitsbergen Current and in the Atlantic Water recirculation are part of the FRAM infrastructure initiative. The moorings on the East Greenland shelf belong to the physical oceanography section of AWI with the exception of five of the moorings in Belgica Trough which belong to the University of Delaware.

A mooring will be deployed through a rift in the floating ice tongue of the 79N glacier near 79°41'N 20°24'W. This is an area that is covered by sea-ice. Equipment will be moved there by helicopter. The ITM (Ice Tethered Mooring) consists of a surface float, a 600 m long cable, 8 instruments, and an anchor. Gear needed to deploy this system includes a winch, a tripod, sleds to move gear and a generator.

The measurements will be undertaken with a range of instruments, from the ship as well as from the ice. Conductivity-Temperature-Depth (CTD) measurements are carried out with the ship-board SBE 9/11+ CTD system, which is combined with a SBE 32 Carousel Water Sampler (Seabird). The CTD carousel (rosette) will also be equipped with a TRDI Lowered Acoustic Doppler Current Profiler system (LADCP) for recording velocity during the CTD casts. Velocity in the upper water column (200-300 m) is additionally recorded by the vessel mounted 150 kHz ADCP (Teledyne - RDI). Supplementary to CTD measurements we will use expandable CTD sensors (XCTD) launched from the ship or helicopter, as well as AWI's helicopter-borne mobile SBE 16 CTD system (Seabird). An underway (U)-CTD system (by Ocean Science) will be operated from the back of the ship while the ship is transiting through ice-free waters. Fine-scale temperature and shear, needed to infer turbulence, mixing, and heat or nutrient fluxes, will be measured with a MSS90L microstructure profiler (Sea & Sun Technology and ISW Wassermesstechnik), which is equipped with shear- and fast response CTD sensors.

The LADCP on the CTD rosette will concurrently record vertical velocity profiles throughout the water column. The horizontal scales of currents in high latitudes are small (~1-10 km) and, hence, for capturing typical boundary current features, a fine station resolution is required. In addition, current measurements of the upper ~200 m along each transect will be collected with the vessel mounted ADCP.

During times when *Polarstern* has to stay in or near one location for at least one day, we will establish small ice camps to measure microstructure. *Polarstern's* vessel-mounted ADCP can record velocity data below 25 m. These data will complement the MSS casts, which will be repeatedly carried out at the beginning of each hour throughout the long-term stations. These sampling methods will generate short (1-2 days) time series of currents and vertical fluxes, and hence valuable physical insights, relevant for biogeochemical processes and for the role of currents and turbulence to oceanic heat fluxes to sea ice as well as between Pacific Water and Atlantic Water and the mixing of the two water masses.

CTD and velocity profiles will be measured in as many locations as possible. In particular, there will be a focus on measuring the flow in the West Spitsbergen Current along 79°N, in the Atlantic Water recirculation along 0°EW, and in the trough system on the East Greenland shelf towards the 79N glacier. The microstructure measurements will be focused on the East Greenland shelf.

Expected results

The planned mooring recoveries will prolong the time series of Atlantic Water temperature and velocity in the West Spitsbergen Current. It is expected that the deployment year 2015-2016 will elucidate some of the impacts of the pan-Arctic air temperature anomaly of January/February 2016. Furthermore, it is expected that the moorings to be recovered in Belgica Trough will provide insights into the along-trough circulation of Atlantic Water and towards 79NG. The CTDs and microstructure measurements will improve the understanding of the interaction of Atlantic Water and Polar Water and how they flow into the Arctic Ocean, towards the Nordic Seas overflows and towards Greenland's glaciers. The data from the deployed moorings will not be available until 2017 or 2018,

but then it will be possible to make assessments of the dynamics of the Atlantic Water recirculation in winter for the very first time.

Data management

The data recorded by the moored instruments that will be recovered on PS100 will be processed after the cruise at AWI and submitted to the PANGAEA data publisher. Some of the moorings that will be deployed on PS100 will be recovered in 2017 and the remaining ones will be recovered in 2018. The data recorded on those instruments will accordingly be processed after recovery and submitted to the PANGAEA data publisher at that time. Likewise, the data collected during PS100 from the different CTDs, the LADCP, and the microstructure profiler will be processed at AWI and afterwards submitted to the PANGAEA data publisher.

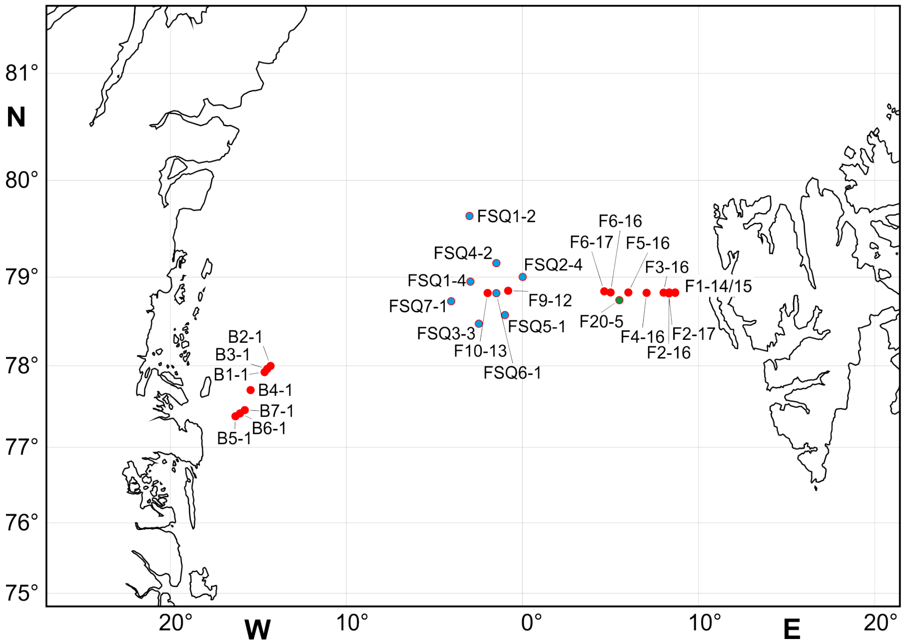

Fig. 2.1: Positions of the moorings to be recovered in Fram Strait and on the East Greenland shelf. Red dots indicate moorings with standard physical oceanographic equipment. Green dot indicates a mooring with an underwater profiling winch. Blue dots indicate sound source moorings.

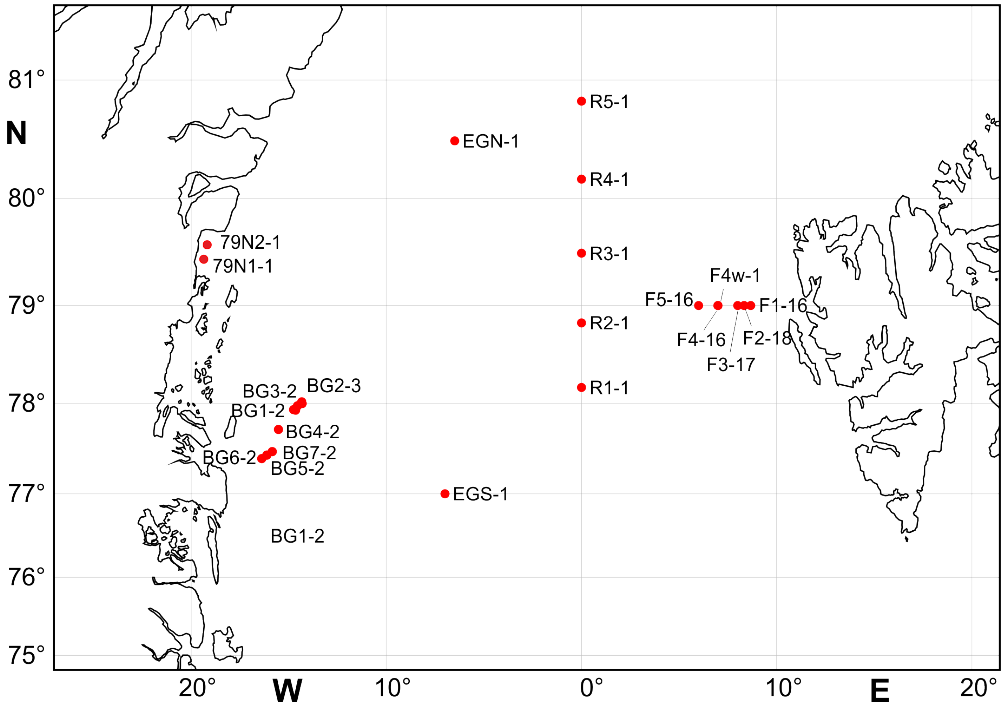

Fig. 2.2: Positions of the moorings to be deployed in Fram Strait and on the East Greenland shelf. The two moorings in front of the 79N glacier (79N1-1, 79N2-1) may be moved slightly depending on the local ice conditions during deployment and may also be of a non-traditional design.

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3. NEGIS: UNDERSTANDING THE MECHANISMS CONTROLLING THE LONG TERM ICE STREAM/SHELF STABILITY OF THE NORTHEAST GREENLAND ICE STREAM.

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Background and objectives

The NEGIS project is supported through the Alfred Wegener Institute (Project N405) via the GRIFF I project and the *Polarstern* programme (Cruise PS100) as well as through UK Natural Environment Research Council (NERC Grant NE/N011228/1).

The incursion of warm Atlantic Water (AW) over the last 15 years to many Greenland glacier margins, as well as increased air temperatures and sea-ice loss, have all been linked to rapid ice margin instability (Straneo et al., 2013; Carr et al., 2013; Khan et al., 2015). However, despite our improved understanding of the forcing mechanisms that have driven recent glacier change, the limited time-span of our observations provide only a short time series with which to understand the complex and non-linear response of ice streams to ocean and atmospheric forcing (Nick et al., 2010). This hinders our ability to understand and forecast how ice sheets will change over longer timescales (Seroussi et al., 2014). What we fundamentally lack is decadal to millennial scale input data with which to calibrate, validate and test the sensitivity of predictive models. One solution to this issue is to distinguish patterns of former rapid ice margin change during periods of warmer climate when the key forcing mechanisms that influence ice sheet stability can be simultaneously reconstructed so their relative importance can be determined.

This project will investigate the dynamics of the Northeast Greenland Ice Stream (NEGIS); the main artery for ice discharge from the NE sector of the Greenland Ice Sheet (GrIS) to the North Atlantic. Unlike other sectors of the GrIS, NEGIS and the ice shelves that front it, have exhibited little response to increased atmospheric and oceanic warming over the last 20 yrs. However, very recent ice shelf loss and grounding line retreat (~ 4km) post 2010 suggest that this sector of the GrIS, and NEGIS in particular, is starting to respond to recent atmospheric/oceanic change (Khan et al., 2014, 2015; Mouginot et al., 2015). Model projections suggest that ocean warming will double by 2100 (Yin et al., 2011) and air temperature will increase significantly in northeast Greenland (AMAP, 2011), so the future evolution of the NEGIS catchment is important not only for understanding changing dynamics in this sector of the GrIS, but also for predicting sea-level rise.

The NEGIS catchment as a whole holds a significant sea-level equivalent (SLE) of 1.1 to 1.4m, but it is the marine-terminating end of the NEGIS system that is particularly vulnerable to marine ice sheet instability because it sits series of interconnected, over-deepened, subglacial troughs; those troughs harbour a SLE of 0.12 - 0.35m. A rapid retreat of this system would therefore have significant consequences for global sea-level rise. Furthermore, the triggering of surface mass balance (SMB) feedback, through dynamic ice loss at the coast and concomitant surface lowering inland (cf. Rignot et al., 2014), could push the entire NEGIS catchment beyond a sustainable SMB threshold (e.g. 0.9 to 2.8°C; Robinson et al. 2012) potentially making a more significant contribution to future sea-level rise.

A critical component of this project is knowledge that one of the NEGIS ice shelves (known as '79N') retreated (possibly collapsed) over 100 km during the mid-Holocene Thermal Maximum (HTM; 8.0 – 5.0 ka BP). 79N is the only large scale ice stream/shelf outlet system in Greenland that has a partially constrained Holocene retreat and re-advance history (Bennike and Weidick, 2001). The HTM was a period when radiative forcing and summer temperatures were up to 2°C higher than present, and analogous to those predicted for the next 100yrs and beyond (Carlson and Winsor, 2012). Hence, increased air temperature could have played a role in ice stream fluctuation and ice shelf collapse, but we presently lack the data to assess the role of different forcing mechanisms (e.g. ocean warming) on ice stream fluctuation which limits our ability to predict the response of NEGIS to future change.

The overall aim of this project is to reconstruct the ice sheet/stream history of the NEGIS from the end of the LGM and through the Holocene. Working both onshore and offshore the project will generate a series of tie points to reconstruct ice sheet thickness, grounding line position, and ice shelf presence/absence. It will also generate a time series of forcing data on ocean and atmospheric temperatures. These datasets will be used to test and model the sensitivity of the ice stream to different forcing mechanisms at 100 - 1000 yr timescales.

The project has three main objectives:

Objective 1: To constrain ice stream/shelf extent/thickness in order to determine rates of retreat/re-advance between 15 – 0 ka BP.

Objective 2: To constrain oceanographic/atmospheric conditions and sea-level change adjacent to NEGIS between 15 – 0 ka BP.

Objective 3: To apply the 3D BISCICLES ice sheet model to test the sensitivity of NEGIS to atmospheric/oceanic /sea-level forcing and to explore feedbacks over 1000 yr timescales.

Work at sea

Objective 1*:* Our onshore and offshore work programme in 2016 and 2017 (GRIFF I + II) aims to reconstruct the geometry (vertical and horizontal) of NEGIS from the end of the LGM through the Holocene. Using the *Polarstern* cruise in 2016 we will target the Norske and Westwind troughs and the Belgica Bank (Fig. 3.1). Exploring the troughs is a critical part of our research strategy as they played a dual role in routing ice offshore and enabling AW incursion on to the shelf at the beginning of the Holocene (Evans et al., 2009; Winklemann et al., 2010). There are several key target areas for geophysical survey and sediment core recovery (Fig. 3.1; sub-areas 1-6). Areas 2, 3 and 4 in particular will be critical for constraining ice sheet/stream configuration at the opening of the Holocene, but areas 1, 5 and 6 will also be essential for constraining LGM ice sheet configuration and early ice sheet deglaciation (both of which are crucial for model spin-up).

Swath bathymetric and sub-bottom profiler data (Atlas Hydrosweep DS-2 and PARASOUND) will be collected to capture seafloor geomorphology and sub-bottom stratigraphic architecture to reconstruct ice stream dynamics and grounding line retreat from the continental shelf edge to the present NEGIS margin (*e.g.* Dowdeswell et al. 2014). Previous work clearly shows submarine moraines, mega-scale glacial lineations and grounding zone wedges occur on the NE Greenland shelf (Evans et al., 2009; Winklemann et al., 2010; Arndt et al., 2015).

Gravity, mulita-core and box core transects will be collected in our target areas along both the Norske and Westwind Troughs. Subglacial to open-marine conditions will be reconstructed on the basis of sedimentology (shear-strength, grain-size, x-radiographs, multi-sensor core logger data) and combined with geomorphological mapping to determine the nature and style of retreat. ^{14}C dating of the contact between subglacial and postglacial sediments at core sites along each transect will allow us to determine the timing and rate of ice retreat (e.g. Ó Cofaigh et al., 2013). Work across the continental shelf (e.g. Belgica Bank) is also essential to establish the configuration of NEGIS at the start of the Holocene and to generate Holocene ocean temperature data.

In order to complement our offshore work the project will work onshore in 2017 and identify/map ice marginal geomorphology (e.g. lateral moraines; ice shelf moraines; deltas; raised beaches) to constrain ice stream thickness and ice shelf extent (e.g. Glasser et al., 2006; Roberts et al., 2013). Work in the 1990's has shown abundant moraines and uplifted marine sediments which mark Holocene thinning, retreat & re-advance of the 79N ice shelf (Bennike and Weidick, 2001). A chronology for ice surface thinning, ice margin retreat, ice shelf collapse and sea-level change will be developed using radiocarbon dating (^{14}C - organic material) and cosmogenic exposure surface dating (^{10}Be). Our aim is to sample ice marginal landforms along a series of vertical transects ('dipsticks') to constrain ice stream and shelf geometry through the Holocene along the 79N, and possibly Zachariae Isstrom, ice shelves (e.g. Roberts et al., 2013).

Objective 2: The sediment cores collected using the *Polarstern* from the continental shelf edge to the current ice shelf margin will provide a record of oceanic conditions from the LGM to the present day. We will use the *Polarstern* gravity and multi-corer systems to recover glacial to modern seafloor sediments and retrieve multiple proxies for quantitative reconstruction of palaeooceanographic & palaeoglaciological conditions (e.g. diatoms, forams, dinocysts & molluscs; Evans et al., 2002; Spielhagen et al., 2011; Muller et al., 2012). Sea surface, shallow surface and bottom water temperatures will be based on proxy datasets (forams, diatoms and dinocysts) and quantified using transfer functions (Ran et al., 2011; Spielhagen et al., 2011). Planktic and benthic foraminiferal stable isotope analyses and sediment geochemistry (total organic carbon (TOC), total nitrogen (TN), C/N) will also be used to support the temperature reconstructions and yield information on water mass characteristics, productivity, sea-ice cover and input of glacier melt water (Lloyd et al. 2007, 2011; Smith et al., 2007; Jennings et al. 2014). Ice-rafted debris will be used to investigate periods of increased iceberg calving linked to episodes of ice margin instability (Andreasen et al., 2011). Contemporary temperature/salinity data collected by the GRIFF project and analysis of the diatoms and stable-isotopes from core tops/surface sediments will also be utilised to aid in the interpretation of down-core (palaeo) sedimentological data.

While working onshore in 2017 we will also recover sediment cores from epishelf lakes along the margin of 79N and from beneath the 79N ice shelf. These will provide a detailed record of grounding line and ice shelf retreat/advance during the Holocene. Epishelf lakes have been shown to harbour detailed records of ice shelf history (presence/retreat), anatomy of collapse (processes and duration) as well as forcing mechanisms (ocean and atmosphere) (Smith et al. 2006; 2007). The sub-ice shelf seafloor sediments will provide a further sedimentary record of Holocene grounding line and ice shelf migration along the fjord (Rebesco et al. 2014). The sub-ice shelf and epishelf cores will also supply data on sub-ice shelf and open water oceanography, specifically AW and fresh water fluxes (Lloyd et al. 2011; Post et al., 2014). Hotwater drilling through the ice shelf and core recovery from the seafloor will be co-ordinated by AWI and BAS.

Expected results

Our overall goal is to combine the sub-shelf and epishelf cores with the offshore and onshore geomorphologic and sedimentological data to provide a record of grounding line and ice shelf thickening, thinning and migration over a >300 km transect from the opening of the Holocene through to present.

Data management

Sediment cores will be logged and described sedimentologically on broad the *Polarstern*. They will also be sampled for forams and molluscs. Stable isotope analyses and sediment geochemistry (total organic carbon (TOC), total nitrogen (TN), C/N) can be conducted at Durham, as can multi-sensor MSCL core log measurements (*Bulk density, porosity, grain size, P-wave velocities and water content*), XRF and XCT 3D X-ray analysis. Cores will be archived at AWI post analysis. Sample processing for radiocarbon dates (^{14}C) and cosmogenic exposure surface dating (^{10}Be) will be carried out at the NERC Radiocarbon Lab and NERC CIAF, UK. All data will be uploaded to the PANGAEA database. Unrestricted access to the data will be granted after about three years, pending analysis and publication.

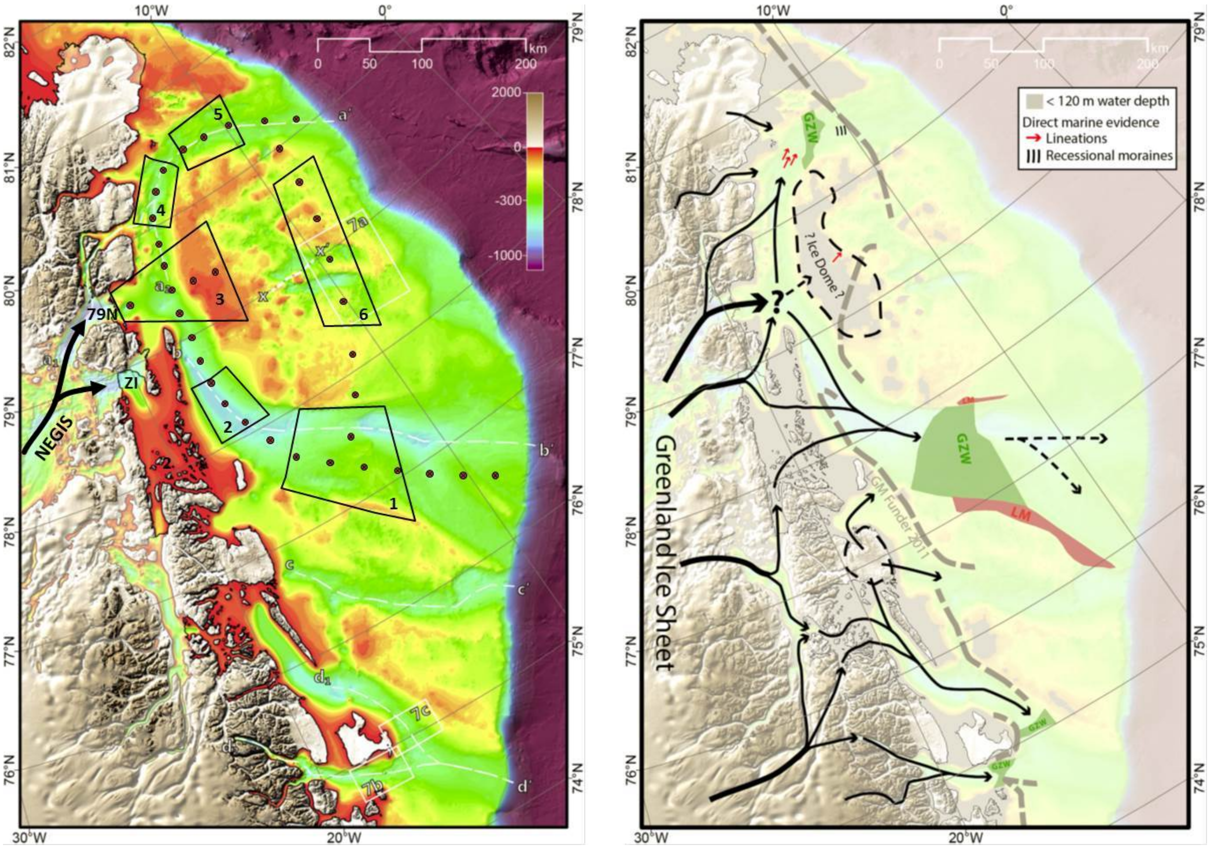

Fig. 3.1. The NE continental shelf of Greenland with the offshore target areas (1-6) for the NEGIS project demarcated. The NEGIS drains the NE sector of the Greenland ice sheet and reaches the ocean via two ice shelves; 79N and ZI. b) Offshore geomorphological mapping suggests that both the Norske and Westwind Troughs routed ice offshore during the LGM but little is known of the flow pathways of NEGIS offshore or its deglacial behaviour. Ice sheet/stream behaviour across the shallow continental shelf areas adjacent to the troughs is also poorly known. Figures derived from Arndt et al., (2015).

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4. OBSERVATION OF OCEANIC TRACE GASES: STABLE NOBLE GAS ISOTOPES (^{3}HE, ^{4}HE, NE) AND TRANSIENT ANTHROPOGENIC TRACERS (CHLOROFLUOROCARBONS, CFCS)

M. Rhein (UHB-UIP, not on board), O. Huhn (UHB-UIP), J. Gerken UHB-UIP), T. Wegehaupt (UHB-UIP)

Objectives and methods

Greenland Ice Sheet (GrIS) basal melting is one of the major contributors to GrIS ice mass loss and thus sea level rise, and accelerating melt rates are caused by intrusions of warm Atlantic water into the glacier terminating fjords. However, estimates of submarine melt rates are usually based on indirect methods (difference between total mass loss from remote sensing methods and surface mass balance or estimated from measurements of ice velocities and ice thickness changes) and are, thus, still highly uncertain. Model results depend strongly for instance on the models ability to simulate the small-scale fjord dynamics and other parameterizations. Large uncertainties also still exist in the processes in the fjords and how the glacial melt is transformed before released into the Greenland boundary current and subsequently into the interior of the adjacent ocean basins. These uncertainties might cause erroneous projections of GrIS mass loss rates and thus sea level for the next centuries. So far, there are no sufficient data available that might allow to trace and quantify the glacial melt water in the ocean.

Here we will use the distributions of measured helium and neon isotopes and transient tracers (CFC and SF_6) in ocean water in the vicinity of one of the major outlet glaciers in northeastern Greenland (79N Glacier) to estimate the basal melt water fraction and inventory in the near- and the far field of the 79N Glacier and how much of the glacial melt water is transported into the Greenland boundary current and the western Fram Strait. From that and from additional data we will estimate how much of the glacial melt water of the GrIS is transferred into the Labrador Sea and the LSW formation region and quantify whether the fractions of glacial melt has increased. We can also provide data to validate high resolution ice-ocean model to analyse how and where and to what amount subsurface melt water is transferred from the Greenland Ice Shelf and the Greenland boundary current into the interior of the adjacent ocean basins, and how an increase in the melt rate changes the regional sea level and by which mechanisms (mass increase, changes in the 3-D thermohaline structure and thus dynamic topography, changes in the large-scale circulation and associated changes in freshwater and heat distribution).

Oceanic measurement of low-solubility and stable noble-gases helium (^{3}He, ^{4}He) and neon (Ne) provide a useful tool to identify and to quantify basal glacial melt water. Atmospheric air with a constant composition of these noble gases is trapped in the ice matrix during formation of the meteoric ice. Due to the enhanced hydrostatic pressure at the base of the floating ice, these gases are completely dissolved, when the ice is melting from below. This leads to an excess of helium and neon in pure glacial melt water (He=1260 %, Ne=890 %). Frontal or surface melt water would equilibrate quickly and not lead to any noble gas excess in the ocean water. With an accuracy of <0.5 % for He and Ne measurements performed at the IUP Bremen, basal glacial melt water fractions of <0.05 % are detectable. Helium has a additional oceanic source (primordial helium from hydrothermal vents with a distinct higher ^{3}He/^{4}He isotope ratio), which neon does not have.

The transient trace gases chlorofluorocarbons (CFC-11 and CFC-12) and sulfur hexafluoride (SF_6) are completely anthropogenic and enter the ocean by gas exchange with the atmosphere. Since the evolution of these transient tracers in the ocean interior is determined on first order by their temporal evolution in the atmosphere and subsequently by advection and dispersion in the ocean interior, they allow estimating the time scales of the renewal and ventilation of inner oceanic deep and bottom water masses. This is often referred to as a "age" of a water mass, i.e. the time elapsed since the water has left the surface.

The combination of the transient tracer based "ages" and the noble gas based melt water inventories allow estimate basal glacial melt rates.

Work at sea

We intend to obtain about 700 water samples for noble gas isotopes from the ship deployed full depth profiling CTD and water sample system. Additionally we plan about 1000 water samples for CFCs and dSF_6 in total, i.e. about 200 water samples of for CFC-12 and SF_6 and further 800 water samples for CFC-12 and CFC-11.

The oceanic water samples for helium isotopes and neon will be stored from the CTD and water bottle system into 50 ml gas tight copper tubes, which will be clamped of at both sides. The noble gas samples are to be analyzed later in the IUP Bremen noble gas mass spectrometry lab. The copper tube water samples will be processed in a first step with an ultra high vacuum gas extraction system. Sample gases are transferred via water vapour into a glass ampoule kept at liquid nitrogen temperature. For analysis of the noble gas isotopes the glass ampoules are connected to a ultra high vacuum mass spectrometric system equipped with a two-stage cryogenic trap system. The system is regularly calibrated with atmospheric air standards (reproducibility better ±0.2 %). Also measurement of blanks and linearity are done.

Water samples for CFC and SF_6 measurements will be stored from the ship deployed water samplers into 200 ml glass ampoules (CFC-12 and SF6) or 100 ml glass ampoules (CFC-12 and CFC-11) and will be sealed off after a CFC and SF_6 free headspace of pure nitrogen has been applied. The samples will be later analyzed in the CFC-laboratory at the IUP Bremen. The determination of CFC and SF_6 concentration is accomplished by purge and trap sample pre-treatment followed by gas chromatographic (GC) separation on a capillary column and electron capture detection (ECD). The amount of CFC and SF_6 degassing into the headspace is accounted for during the measurement procedure in the lab. The system is calibrated by analyzing several different volumes of a known standard gas. Additionally the blank of the system are analyzed regularly.

Expected results

The first noble-gas and the additional CFC measurements close to the 79N glacier and in Fram Strait will provide data to assess the glacial melt water inventory released from the 79N glacier directly in the ocean. The noble-gas data will allow to estimate the basal melt water fraction and inventory in the near- and the far field of the 79N Glacier and how much of the glacial melt water is transported into the Greenland boundary current and the western Fram Strait. They will allow to estimate the actual melt rate of the 79N glacier. We will be able to analyse how and where and to what amount subsurface melt water is transferred from the 79N glacier and the Greenland boundary current into the interior of the adjacent ocean basins.

Data policy and storage

Due to shipping home, the extensive treatment of the samples in the IUP home labs, and an accurate quality control, the results of the measurements are expected for the end of 2016. The data will be made available to our colleagues as soon as possible. Once published, we will store them in the PANGEA data base.

5. GEOTRACES

M. Rutgers van der Loeff (AWI), W. Geibert (AWI) and the GEOTRACES scientific party (the corresponding names of the participating party are listed under the respective articles)

Objectives

GEOTRACES (www.geotraces.org) is an international programme that aims to determine global ocean distributions of selected trace elements and isotopes, including their concentration, chemical speciation and physical form, and to evaluate the sources, sinks and internal cycling of these species. This knowledge is needed to characterize more completely the physical, chemical and biological processes regulating their distributions so that the response of these cycles to global climate change can be predicted, and their impact on the carbon cycle and climate understood (Henderson et al., 2007).

Warming of Arctic terrestrial areas caused increased river discharge which, combined with net loss of the Greenland ice-cap and melting of sea ice, resulted in a freshening of surface waters and increased stratification. These climate induced changes are expected to change the biogeochemical cycling and therefore the distribution of many Trace Elements and Isotopes (TEI's). As part of a pan-Arctic GEOTRACES effort in coordination with Canadian and US initiated research cruises, we have carried out in 2015 a TEI sampling programme in the Arctic Ocean. During these 2015 studies the Bering Strait, the Canadian Archipelago and the Barents Sea Opening could be sampled. In our present expedition we intend to measure all relevant TEI in Fram strait in order to be able to estimate their fluxes through this major gateway between the Arctic and Atlantic Ocean.

Work at sea

We will carry out a sampling programme in Fram Strait as complement to the synoptic programme carried out 2015 in the Arctic Ocean. We will sample and analyse all tracers considered as key TEIs by Henderson et al. (2007).

Expected results

In combination with the results of the synoptic US/ Canadian/ German studies from last year we hope to provide maps of the distribution of TEIs in the Arctic and in all its gateways to the Atlantic and Pacific Ocean. This will allow us to make budgets of trace elements, quantify their cycling within, and their fluxes into and out of the Arctic Ocean.

Data management

Intercalibration results from duplicate sampling will be submitted to the GEOTRACES Standards and Intercalibration Committee for evaluation and approval.

All data and metadata will be submitted to the international GEOTRACES data managementoffice (BODC, www.bodc.ac.uk/geotraces) under the data management scheme agreed upon in the GEOTRACES programme available at http://www.geotraces.org. Most data and metadata will also be submitted to the PANGAEA data base.

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5.1 Nutrients, DOM and POM

K.-U. Ludwichowski (AWI); M. Graeve (AWI)

Objectives

The determination of nutrients and biogeochemical parameters is closely connected with the physical and planktological investigations. The development of phytoplankton blooms is especially dependent on the available nutrients. Nutrients are also well suited as tracers for the identification of water masses. Changes in nutrient concentrations will be followed in the Fram Strait region and across the Greenland shelf and slope. In comparison with similar transects in former years, the seasonal and interannual variability will be determined. In the 1980s and 1990s water masses of Pacific origin usually occurred in the shelf and slope regions of the Fram Strait and further south of the Greenland Sea. The nitrate:phosphate ratios in particular, but also silicate are good tracers to follow the outflow of upper halocline Arctic surface water along the Greenland continental shelf and slope. Water masses may be especially rich in silicate compared to Atlantic waters. The data from this expedition will show whether there are further modifications of the water masses exiting the Arctic Ocean. In addition, dissolved organic matter (DOM) will be sampled at representative stations after consulting the fluorescence profiles on the CTD, in order to follow the outflow of water masses from the central Arctic Ocean to the Fram Strait. DOM samples will be taken for bulk determinations (DOC/DON) and extracted from seawater using PPL sorbent (enrichment of DOM by solid phase extraction). Beside bulk parameter analysis, a detailed chemical DOM characteristic will be carried out using ultrahigh resolution mass spectrometry in the home lab. In addition bulk stable isotopes analysis ($\delta^{13}C$ / $\delta^{15}N$) of particulate material will be carried out. This is a valuable tool to trace the flow of ice-derived matter contributing substantially to the suspended pelagic biomass during the productive season.

Work at sea

From water samples taken with the rosette sampler at different depth, the nutrients phosphate (Murphy & Riley, 1962), silicate (Strickland & Parsons, 1968), nitrite and nitrate (Grasshoff et al., 1983) are determined immediately on board using an auto-analyser-system according to standard methods. DOM samples will be taken for bulk determinations of DOC and DON. Sampling of dissolved organic matter will be decided after consulting the fluorescence profiles on the CTD. Subsequently, representative samples will be extracted on board using solid phase extraction with PPL sorbent (enrichment of DOM by solid phase extraction). Particulate organic matter for bulk stable isotope analysis of ^{13}C and ^{15}N isotopes will be obtained by standard methods after filtration onto precombusted GF/F filters.

Expected results

With the help of the nutrient data that will be available approximately within two days after sampling we will have an overview of water masses, biological activity and functioning of the sampling system. Later the nutrient data will be used for many studies related to the cruise to indicate a diversity of physical and biological processes. Detailed analyses of TOC, DOC/DOM will reveal molecular and structural characteristics and its various terrigenous and marine sources throughout the Arctic Ocean. Analysis of $\delta^{13}C/\delta^{15}N$-POM will highlight the interaction between sympagic and pelagic communities

Data management

We sample a large variety of interconnected parameters. Many of the samples (i.e. pigment analyses, particulate matter in the water column, etc.) will be analyzed at AWI within about two years after the cruise. We plan that the full data set will be available about three years after the cruise by the latest. Most of the samples, which will not be analyzed immediately, will be stored at AWI and be available to other colleagues. Data will be made available to the public via PANGAEA after publishing (depending on how many comparisons will be made, long-term study 2 to 5 years after the cruise).

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5.2 CO_2 system and oxygen

E. M. Jones (RUG/NIOZ), Adam Ulfsbo (GOTH)

Objectives

The overarching objective of this study is to further improve our understanding of the carbon system in the rapidly changing Arctic Ocean system and its adjacent sub-regions. More specifically, we aim at improving our understanding of the feedbacks by physical and biogeochemical processes across the boundaries between the Arctic Ocean and the North Atlantic across the Fram Strait and the Greenland-Icelandic-Norwegian Seas with respect to the distribution of the seawater CO_2 system, air-sea CO_2 fluxes, transport of anthropogenic CO_2, and net community production. In addition, apart from hydrography, a thorough knowledge of the carbon system is essential for the understanding of the distribution of trace elements in the ocean in terms of their cycling, sources and sinks, supporting the on board GEOTRACES programme.

Work at sea

Discrete water samples will be taken at the combined hydrographic and biogeochemical stations from the CTD rosette sampler at depths throughout the water column, but with a bias towards the upper layers. Total dissolved inorganic carbon (DIC; also known as TCO2, CT), total alkalinity (TA; also known as AT), and pH are determined in discrete water samples taken from the rosette sampler. Both DIC and TA are sequentially determined according to standard operating procedures (Dickson et al., 2007) with a VINDTA instrument (MARIANDA, Kiel), which combines the two measurements. DIC is determined by a coulometric titration (Johnson et al., 1985; Johnson et al., 1987; Johnson et al., 1993) and TA is determined by potentiometric titration with acid in a semi-closed cell (Dickson, 1981; Dickson et al., 2007). The seawater pH is determined spectrophotometrically (Clayton and Byrne, 1993; Carter et al., 2013) using purified m-cresol purple as indicator (Patsavas et al., 2013). The sampling and analysis work are according to the best practices for ocean CO2 measurements (Dickson et al., 2007). The accuracy is set by internationally recognized and widely used certified reference material (CRM) obtained from Prof. A. Dickson at Scripps Institute of Oceanography (USA). In addition, underway data of surface water partial pressure of CO2 (pCO2) and biological oxygen supersaturation (Δ(O2/Ar)) will be collected from the ship's underway seawater supply . pCO2 is measured with a General Oceanics system (GO 8050) with an infra-red analyzer (LI-COR 7000), both for seawater using an water-air equilibrator and for the atmosphere, the air being pumped from the crow's nest. Biological oxygen supersaturation (Craig and Hayward, 1987; Emerson et al., 1991) is determined using Equilibrator Inlet Mass Spectrometry (Cassar et al., 2009). In addition, the on board analysts will determine dissolved oxygen concentration by Winkler titration to calibrate the oxygen sensors from the CTD.

Expected results

The data obtained will add to the data we collected during TransArc I (PS78/ARK-XXVI/3, 2011) and TRANSARC II (PS94, 2015) and help to quantify air-sea CO_2 fluxes, transport of anthropogenic CO_2, and net community production.

Data management

See GEOTRACES introduction for details on data management.

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5.3 Clean sampling systems for water column and aerosol samples

E. P. Achterberg, M. Frank (GEOMAR; not on board). F. Evers, J. C. Yong, K. Meulenbroek (GEOMAR)

Objective

Sampling for trace elements in oceanic waters requires specialized equipment. Only a handful of institutes in the world have the capacity to undertake trace metal clean water column sampling. On the PS100 cruise GEOMAR will provide and operate a trace metal clean winch, with a dedicated Kevlar coated conducting wire and a clean CTD rosette frame. The winch (LEBUS UK) will be placed on deck and is operated by a GEOMAR technician. The system allows for clean sampling in full depth oceanic waters. Following the CTD casts, the GoFlo bottles will be transferred to the GEOMAR clean container for processing of the samples.

We will also conduct sampling of aerosols and rain on cruise PS100. Two high volume and one low volume aerosol collectors will be placed on the monkey island for collection of trace element, nutrients and organic compounds. The units will be operating full time.

Expected results

We expect to be able to collect uncontaminated water and aerosol samples.

Work at sea

The trace metal clean winch system will be utilized at every station where trace metal sampling is conducted. Aerosol and rain collection will be undertaken continuously whilst at sea.

Data management

See GEOTRACES introduction for details on data management.

5.4 Trace elements
Dissolved Ag, Fe, Mn, Zn, Ni, Cu, Cd, Pb, Co

N. Herzberg, P. Lodeiro, J. Chuen Yong (GEOMAR), M. Rijkenberg (NIOZ, not on board), E. Achterberg (GEOMAR; not on board)

Objective

In contrast to other oceans, the Arctic Ocean has high concentrations of dissolved Fe (DFe) in the surface layers, relative to lower concentrations at depth. These high surface concentrations are due to Siberian and North American rivers giving a strong lateral DFe supply into the stratified surface layers combined with relatively little vertical mixing (Klunder et al., 2012a; 2012b). However, we found in 2015 during TransARCII that the surface values of DFe in Nansen Basin can become sufficiently low that Fe limitation of primary production could exist.

In this cruise we will focus on the full depth distribution of bio-essential and toxic trace metals over Fram Strait and on the shelf systems near Greenland and Svalbard. The objective is to determine the fluxes of trace metals through Fram Strait into and out off the Arctic Ocean and to study shelf processes of trace metals. To reach this objective we will work closely together with Dr. Wilken-Jon von Appen (AWI) (Stöven et al. 2016). The results together with our trace metal data collected in 2015 during TransARC II between Svalbard and Norway will give us an estimate of the transport of trace metals between the Atlantic Ocean via the Greenland-Iceland-Norwegian Seas and the Arctic Ocean. The work will also extend our understanding of trace element cycling on Arctic shelf systems.

We plan to investigate the chemical speciation of Fe by investigating its organic complexation, its presence in colloids and its presence in the total dissolvable fraction. Samples will be taken from different size fractions, a.o. unfiltered samples and filtered by different filter sizes (a.o., 0.2 µm; 0.02 µm). Measurement of the organic complexation of Fe will be performed in close cooperation with Loes Gerringa.

Work at sea

We plan to measure DFe concentrations directly on board by the automated Flow Injection Analysis (FIA) method (Klunder et al., 2011). Filtered and acidified (Seastar© baseline hydrochloric acid; pH 1.7) seawater will be concentrated on a column containing amino-diacetic acid (IDA). Samples will be analysed in triplicate and standard deviations (SD) are given. The consistency of the FIA system over the course of a day will be verified by measuring the same seawater sample several times. Certified SAFe standards (Johnson et al., 2007) for the long term consistency and absolute accuracy will be measured on a regular basis. Samples will be taken for particulate trace metals. Filtered seawater samples will be taken for the measurements of dissolved Ag, Mn, Zn, Ni, Cu, Cd, Pb, Co.

Expected results

In this cruise we will determine the full depth distribution of bio-essential and toxic trace metals over Fram Strait. We expect to be able to determine the fluxes of trace metals through Fram Strait into and out of the Arctic Ocean and to study shelf processes of trace metals.

Data management

See GEOTRACES introduction for details on data management.

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5.5 Mercury in the Arctic Ocean

L.-E. Heimbürger (MIO)

Objectives

Mercury levels in Arctic biota are among the highest in aquatic ecosystems and impact the health of Arctic wildlife and human populations (AMAP 2011). The idea has taken hold that the Arctic is a global mercury sink and that its main entry route is via the atmosphere (AMAP 2011). A recent three-dimensional GEOS-Chem model run by Fisher et al. (2013) puts both ideas into question and argues that the Arctic Ocean is net source and boreal rivers to be the major input (Sonke and Heimbürger 2012). Their findings shift current paradigms of the arctic mercury research that has focused for the past 20 years on atmospheric phenomena and cycling (e.g. atmospheric mercury depletion events). It has been shown for the Arctic (Beattie et al. 2014) and for Antarctica (Cossa et al. 2011) that sea ice, in particular brine formation is a major player in polar Hg budgets. Today, the relative contributions of sea ice dynamics, river inputs, transpolar drift and in/outflow at Fram Strait remain unclear. This is why the following key questions remain to be answered:

- Is the Arctic Ocean a global sink or a source for mercury?
- What is the cause for the high mercury concentrations in Arctic marine biota: anthropogenic Hg emissions or is that a “normal natural” phenomenon?
- What is the impact of boreal rivers: how much of the dissolved and particulate mercury is transported to the central Arctic Ocean?

- How much of the rapidly deposited mercury during atmospheric mercury depletion events is re-emitted to the atmosphere and which portion of it is bioavailable (bio-amplified along the marine food chain)?
- What is the overall impact of warming climate to the Arctic Mercury cycle? Will warming climate shift Hg's biogeochemical cycle and the functioning of the Arctic ecosystems is a way that we should expect even higher methylmercury levels in marine biota?

Our results from the 2011 (Heimbürger et al. 2015) and 2015 Polarstern Arctic cruises show that:

- Methylmercury in the Arctic Ocean are highest in the marginal sea ice zone and just below the halocline (~200 m-depth)
- Methylmercury concentrations are among the highest observed (together with the Mediterranean Sea (Heimbürger et al. 2010) and the Southern Ocean (Cossa et al. 2011)
- Contrary to the North Atlantic and other ocean basins, total mercury concentrations of the Central Arctic Ocean are surface enriched

Work at sea

- High resolution sampling for mercury species: Total Hg (HgT), total methylated Hg (MeHg), MonomethylHg (MMHg), dissolved gaseous Hg(DGM), with particular focus on in/outflow, halocline and gradient along the sea ice edge
- Analysis on board: HgT and DGM
- Analysis at home lab: MeHg, MMHg and inorganic Hg
- Applications of new tracer: mercury stable isotopes to track sources and processes that govern Arctic Mercury cycling (large volumes required at selected stations, 2 or 3)
- I would be interested in having subsamples for sediment, suspended particles (ISP) and plankton
- 2016 GEOTRACES Hg species in sea water intercalibration

Expected results

Alarming rise in Hg levels of Arctic marine biota has been attributed to increased anthropogenic Hg emissions. However, the Hg species that accumulates along the trophic chain is MeHg. MeHg is produced in the oceanic water column during the remineralization of organic matter. This process seems to be independent from atmospheric Hg deposition. The basis of the food web structure determines the amount of MeHg that is produced *in-situ*. We will measure high resolution transect for Hg species at the Fram Strait passage. This is critical to understand marine MeHg production and to predict the impact of ongoing global warming on the Arctic Hg cycles.

- Marine inorganic Hg and MeHg species were included in an Arctic Hg mass balance model (Soerensen et al., 2016), the new data in the central Arctic (PS94) and the in/outflow at Fram Strait will allow to feed a coupled atmosphere-ocean 3D model.
- Study possible temporal changes of North Atlantic inflow vs arctic outflow.
- Exploring the role of the Arctic Ocean in the global mercury cycle.

Data management

See GEOTRACES introduction for details on data management.

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5.6 Radiogenic isotopes and REEs together with stable Ba and Si isotopes

K. Meulenbroek, (GEOMAR), M. Frank (not on board) (GEOMAR)

Objectives and expected results

Tracing water mass mixing and continental inputs within the GEOTRACES programme is enabled through the application of radiogenic isotopes (neodymium, Nd) and Rare Earth Element distributions, which have residence times in seawater similar to the global ocean mixing time. Through weathering inputs, water masses are labelled with radiogenic isotope and REE signatures when they are in contact with the ocean’s boundaries via dust, river inputs, or exchange with the particles of the shelf sediments. Continental rocks have distinctly lower $^{143}Nd/^{144}Nd$ than mantle rocks and young volcanic rocks (e.g. Frank, 2002) and together with REE patterns will allow the geochemical distinction of source waters in the Fram Strait and their mixing. This includes deep and shallow Atlantic and near surface Pacific Waters, as well as freshwaters originating from Siberian rivers and from meltwaters of glaciers supplied via the north-east Greenland Shelf, for which it is planned to establish stable Ba isotopes as a new tracer. The new data will also serve to investigate the water mass variability in the upper 1000 m via Nd isotope distributions based on results obtained during cruises in 2012 (Laukert et al, in prep.) and 2014.

Work at sea

will mainly consist of sampling large volume (20l) water samples for each depth, subsequent filtration (at 0.45 µm), acidification, addition of an $FeCl_3$ solution, coprecipitation of all metals at pH 8 and separation of the precipitate for further treatment in the home laboratory. Separate filtered and acidified samples will be taken for REE, Ba and Si isotope analyses. Focus will be on the upper 1000 m but the entire water column will also be covered at selected locations.

Data management

See GEOTRACES introduction for details on data management.

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5.7 Natural radionuclides

M. Rutgers van der Loeff (AWI), W. Geibert (AWI), O. Valk (AWI), D. Köhler (AWI)

5.7.1 Long lived nuclides

Objectives

The unique conditions in the Arctic of input, removal, and exchange processes in relation to particle composition, particle fluxes, and circulation are acting on trace element and isotope distributions in the Arctic Ocean. These distributions are sensitive to the environmental changes already taking place in the Arctic. The simultaneous analysis of natural radionuclides with the other GEOTRACES key parameters on the same cruise and on the related expeditions in 2015 will provide a solid basis for the evaluation and modelling of biogeochemical processes in the Arctic.

The study of Th isotopes and ^{231}Pa in the water column and particles in the Arctic will provide a baseline of their distributions for the evaluation of expected future changes in this rapidly changing environment.

Hypotheses

1. Widespread ice melt and reducing ice cover allows terrigenous ice-rafted particles to settle out earlier in the central Arctic, enhancing the scavenging removal of ^{230}Th and ^{231}Pa within the Arctic and reducing their export through Fram Strait
2. ^{228}Ra in Fram Strait can be related to its abundance in source waters on the Siberian shelf and used to estimate transit times
3. $^{228}Th/^{228}Ra$ can be used as a tracer for export production with a long integration time

Work at sea

Water column sampling at 16 stations (up to 16 depths per station) for Th isotopes and ^{231}Pa will be realized by direct filtration of seawater from Niskin bottles using AcroPak500 cartridges (0.8/0.45 µm pore size, Supor® pleated membrane). For dissolved isotope samples we require 10-20 L per sample. All samples will be acidified to pH = 3.5 to 2 using 6N ultra-clean hydrochloric or nitric acid. Suspended particles will be sampled from up to 16 depths per station at up to 12 stations using *in-situ* pumps. The filters will be prepared, cut, and stored in plastic sample bags onboard under a laminar flow hood with HEPA filter.

We plan to collect dirty ice (2-30L, depending on particle concentration) using stainless steel tools. The dirty ice will be allowed to melt and we will collect the particles by filtration over the same filter type used for suspended particles (Supor®-0.8µm).

If available, we will also collect surface sediments (1-2g dry weight) for ^{231}Pa/^{230}Th analyses. This can be obtained from multicores if material is left or else using a minicorer under the Rosette.

Expected results

We hope to quantify the net export of ^{230}Th and ^{231}Pa from the Arctic Ocean through Fram Strait. We hope to find out whether average export production on a time scale of approx. a year can be obtained from the ^{228}Th/^{228}Ra ratio.

Data management

See GEOTRACES introduction for details on data management.

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5.7.2 Radium isotopes

Objectives

Four natural isotopes of radium (the radium quartet) occur in the ocean. ^{228}Ra (half life 5.8y) is a known tracer for shelf waters. It is strongly enriched in the Arctic shelves and in the Transpolar Drift waters that originate in the Siberian shelves (Rutgers van der Loeff et al., 1995). ^{223}Ra and ^{224}Ra are short lived (11.4 and 3.7 d half life, respectively). They can trace near-shore processes (Kadko et al., 2005) but can also be used as indirect tracer of the distribution of their parent nuclides, ^{228}Th (Rutgers van der Loeff et al., 2012) and ^{227}Ac (Geibert et al., 2008). The fourth isotope, ^{226}Ra (half life 1600yr), is stable on the time scale of mixing of the Arctic Ocean and can be used as yield tracer for the analysis of other isotopes. Since Pacific and Atlantic source waters have distinct ^{226}Ra activities, the isotope can serves as tracer for the origin of water masses. In previous expeditions we have studied the distribution of the radium quartet in surface waters; during this expedition, as already started last year in the central Arctic, we will include measurements of depth profiles of these isotopes in the water column for the study of exchange rates between shelf/slope and open ocean.

Work at sea

Whenever *in-situ* pumps (ISP) are deployed for the collection of suspended particles, we will mount MnO_2-coated acrylic cartridges in the pumps to collect dissolved radium and thorium isotopes by adsorption on the MnO_2. The activities of ^{223}Ra, ^{224}Ra and ^{228}Th will be determined by repeated counting of the radon emanation of the fibers in a delayed coincidence counting system (RaDeCC; Moore and Arnold, 1996). The $^{228}Ra/^{226}Ra$ ratio will be determined later in the home laboratory using gamma spectrometry, whereas absolute ^{226}Ra will be quantified by coprecipitation of radium in discrete water samples as $BaSO_4$ and subsequent analysis with gamma spectrometry.

Expected results

From the distribution of radium isotopes we hope to derive transit times of surface waters and exchange rates of the shelf and slope with the open ocean at various depths. These exchange rates are needed in models describing the distribution of other tracers like ^{230}Th and ^{231}Pa.

Data management

See GEOTRACES introduction for details on data management.

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5.8 Anthropogenic radionuclides

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Not on board: M. Christl (ETH/LIP), C. Vockenhuber (ETH/LIP)

Artificial radionuclides as tracers of water masses in the Arctic Ocean

Objectives

Artificial radionuclides have been widely used as oceanic tracers to study watermass circulation. Radioactive tracers (^{99}Tc, ^{90}Sr, ^{137}Cs and ^{129}I) dispersed from European nuclear fuel reprocessing plants located at Sellafield (formerly Windscale) in the UK and La Hague in France [*Kershaw and Baxter*, 1995] have proved particularly powerful to that aim. The discharged radioactive waste in coastal waters of northwest Europe has been used to track the water movement through the North Sea [*Kershaw and Baxter*, 1995], the Norwegian Coastal Current [*Alfimov et al.*, 2004b], the Arctic Ocean [*Karcher et al.*, 2012; *Smith et al.*, 1999; *Smith et al.*, 2011] and the Nordic Seas [*Alfimov et al.*, 2004a]. The atmospheric weapon tests performed in the 1950's and 1960's have been another source of artificial radionuclides to the marine environment [*Povinec et al.*, 2005].

Other than ^{137}Cs, ^{90}Sr, ^{99}Tc, ^{129}I, etc., in recent years, several studies have measured the anthropogenic occurrence of ^{236}U ($T_{1/2}$=23 My) in the ocean and pointed out its potential to become a new oceanographic tracer [*Christl et al.*, 2012; *Eigl et al.*, 2013; *Sakaguchi et al.*, 2012; *Steier et al.*, 2008]. Its conservative behavior in seawater and the fact that has it not yet reached steady state in the oceans, together with new developments in Accelerator Mass Spectrometry, proved that the $^{236}U/^{238}U$ atomic ratio can be used as a marker of water masses, particularly in the Arctic and Atlantic Oceans[*Casacuberta et al.*, 2014].

Atom ratios between different artificial radionuclides can be used to identify the sources of radionuclides in the marine environment (i.e. $^{240}Pu/^{239}Pu$ and $^{90}Sr/^{137}Cs$) and track the water masses circulation (i.e. $^{129}I/^{137}Cs$). For example, $^{129}I/^{137}Cs$ tracer measurements are used in simple mixing/advection models to estimate transit times from the North Sea to the Arctic Ocean. Similarly, and due to the different input functions of ^{129}I and ^{236}U from European reprocessing plants, the $^{129}I/^{236}U$ could become a potential tool in tagging the water masses in the North Atlantic and Arctic Oceans [*Christl et al.*, 2015].

The objective of our work during the PS100 cruise is to obtain a comprehensive dataset of artificial radionuclides in the Fram Strait to: i) constrain the sources of artificial radionuclides to the North Atlantic and Arctic Ocean (i.e. global fallout, reprocessing plants, rivers); ii) use the $^{236}U/^{238}U$ atom ratio and $^{129}I/^{236}U$ to identify water masses in the Fram Strait; iii) use the $^{129}I/^{236}U$ atomic ratio to constrain water mass ages; and iv) use them as tracers of the water circulation in the Fram Strait. These results will be put together to the ones in the Arctic Ocean collected during the PS94 expedition in 2015 having a more comprehensive dataset of artificial radionuclides to the Arctic and North Atlantic Oceans.

Work at sea

We plan to collect about 100 water samples to analyze ^{236}U and ^{129}I. Surfaces samples will be collected along the cruise track and 7 depth profiles will be taken in *super stations*. Some samples will be only collected and stored for further analysis, and others will be processed onboard. Volumes of samples, specific treatment onboard as well as the laboratory where samples will be further analyzed are described in Table 1.

Tab. 5.8.1: Description of volume of water, pretreatment onboard and final laboratory of analysis for each of the artificial radionuclides taken during the PS100 cruise.

Radionuclide	**Volume of water (L)**	**Pretreatment onboard**	**Laborator of analysis**
^{236}U	3 L *Surface (0-500 m)* 5 L *Mid depths (500-2000 m)* 10 – 20 L *Deep (>2000 m)*	Acidify, spike and pre-concentrate (with $Fe(OH)_3$).	LIP, ETH Zürich
^{129}I	0.2 L *Surface (0-500 m)* 0.4 L *Mid depths (500-2000 m)* 0.5 L *Deep (>2000 m)*	All radiochemistry based on Michel et al (2007)	LIP, ETH Zürich

Samples for the ^{236}U analysis will be acidified with HNO_3 suprapure and spiked with about 3 pg of a ^{233}U reference material (IRMM-051). After 24 hours of equilibration, U is pre-concentrated by Fe-hydroxide co-precipitation. Precipitates will be stored in 250 ml bottles for further analysis at ETH Zurich.

The ^{129}I samples will be processed based on the method my Michel et al (2007). Briefly, Woodward iodine is added to the pre-weighted sample and all iodine species were oxidized with $Ca(ClO)_2$ to iodate. After 15 minutes, iodate species are reduced with NH_3OHCl and $NaHSO_3$ to iodide. After 45 minutes, pH was raised to 5-6 before going through the separation step. This step consisted in an ion exchange separation using a BioRad ® 1x8 analytical grade resins. Resins are pre-conditioned with 0.5 KNO_3 in order to increase the selectivity of the ion exchange resin. After the sample has gone through the resin, and the ion exchange columns rinsed with 0.5 M KNO_3, the iodine is eluted with concentrated potassium nitrate solution (2.25 M). Finally, iodine is precipitated as AgI, ready for AMS measurement at ETH AMS Tandy.

Expected results

The Fram Strait is the largest gateway to the Arctic Ocean and the only gateway allowing deep water exchange. Atlantic water flows northward in the West Spitsbergen Current while polar water and sea ice is transported southward in the East Greenland Current. Therefore, we expect our results will help constraining the inputs and outputs of artificial radionuclides to the Arctic and Atlantic oceans. This dataset will complement the already existing datasets of ^{236}U and ^{129}I of the past recent years, both in the Arctic and North Atlantic oceans. The quasi-synoptic view of distribution and fate of radionuclides will help constraining the main input sources of anthropogenic radionuclides to the marine environment (i.e. European reprocessing plants and global fallout) and identify other potential sources (e.g. Siberian rivers). Artificial radionuclides results will be coupled together with other anthropogenic tracers such as CFC's, SF_6, etc.

Data management

See GEOTRACES introduction for details on data management.

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5.9 Stable N, O & C isotopes

R. S. Ganeshram, University of Edinburgh (not participating), M. Graeve (AWI)

Stable N & O isotope measurement of nitrate

Objectives

To collect water sample for combined O and N stable isotopes of nitrate and where possible to collect suspended particles for C and N stable isotopes on glass fibre filters (collaboration with others).

Work at sea

Pre-filtered water samples will be collected from Rosette (need not have to be clean Rosette). Duplicates taken at each depth and frozen immediately once all samples are collected from rosette.

Expected results

- The broad scientific aim is to understand what controls N balance in the Arctic and the Arctic through flow. Arctic through flow into the North Atlantic is depleted in N relative to P. This has significant influence on (1) preformed N contents and N:P ratios of North Atlantic Deep water and the excess P also drives N-fixation in the Atlantic. By using stable N and O isotopes of nitrate, nutrient and water mass information I wish to evaluate whether N balance of the Arctic is controlled by (1) Relative proportions of Atlantic and Pacific water masses entering the Arctic; or (2) due to terrestrial nutrients sources to the Artctic : or (3) nutrient recycling processes with in the Arctic Ocean. The specifically the objective is to achieve a spatial sampling coverage if Artcic Inflow and Outflow waters at all depths. We will use isotope data along with nutrients and water mass information in our interpretations.
- We also compare nitrate isotopes data with sediment trap in the Fram Strait (collaboration with Ian Salter) to understand the processes that control isotopic signatures in particle fluxes. The key objective is to sample whenever opportunities exist during these two cruises near the vicinity of the sediment trap mooring sites in the Fram strait.

Data management

See GEOTRACES introduction for details on data management. All data generated will be mutually exchanges with collaborators and relevant data sets will be contributed to the GEOTRACES data products.

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6. FRAM

W. Geibert, D. Köhler (AWI)

Objectives

Naturally occurring radionuclides, especially thorium isotopes, are a powerful diagnostic tool to investigate particle fluxes in the ocean. They have been used to determine the export of organic carbon from the euphotic zone; particle aggregation and disaggregation throughout the water column; removal rates of particle-reactive trace elements; to normalize fluxes intercepted by sediment traps; and to date shelf contact of water masses in the Arctic.

In the context of FRAM, we intend to take advantage of elevated production of ^{228}Th by ^{228}Ra released from the Siberian shelves. ^{228}Th integrates particle export and remineralization over timescales similar to its half-life of 1.8 years. We will link this information to fluxes of main biogenic components and sediment trap fluxes, collected as part of FRAM. In order to achieve this goal, we have to address technological questions as well as questions of ^{228}Th distribution. The main goal of this contribution to the cruise programme is therefore

(1) to evaluate the performance of the trace-element clean processing and detection of ^{228}Th developed as part of FRAM to existing techniques for ^{228}Th measurement (collection and counting on acrylic fibre cartridges; alpha-counting of digested particles) and to ultra-clean trace element sampling performed as part of GEOTRACES.

(2) to establish the distribution of ^{228}Th/^{228}Ra ratios in the Fram strait as a background information for the interpretation of sediment trap data that will be collected as part of the previous cruise leg PS99.

Work at sea

In order to achieve these goals, particulate and dissolved samples of seawater, obtained from the sea water supply and in Niskin bottles (water column profiles) will be collected on 47 mm filters/precipitate and analyzed with the newly developed trace-metal clean ^{228}Th detection system (modified RaDeCC developed as part of FRAM). In addition, splits from filters of in-situ-pumps will be analyzed for ^{228}Th to complete the profiles. These data will be compared to ^{228}Th data and GEORACES trace metal data collected by established alternative techniques.

Expected results

The obtained ^{228}Th profiles will be used to interpret ^{228}Th data collected in sediment traps during PS99, and to study particle remineralization and sinking and associated trace metals in the Arctic.

Data management

See GEOTRACES introduction for details on data management.

7. STRUCTURAL VIBRATION

K. Soal (Stellenbosch U), R. de Waal (Stellenbosch U), A. Bekker (Stellenbosch U, not on board), J. Bienert (TH Ingolstadt, not on board)

Background and objectives

Antarctic research institutes and their scientists rely on polar supply and research vessels (PSRVs) to supply bases and serve as floating laboratories. Increasing interest in the Arctic's Northern Sea Route (Roughead, 2015; Masters, 2013) as well as in Antarctica have resulted in countries such as Germany, China, the USA, Australia and Russia investigating options for new polar vessels (COMNAP, 2014).

Polar research vessels require optimized state-of-the-art design to accommodate ever-emerging research agendas. Advances in the various fields of marine engineering have enabled modern ship designs, which are lighter in weight and offer increased propulsion power. These advances are weighed against structural integrity and fatigue life (i.e. the useful life of the vessel) (Orlowitz and Brandt, 2014). Dynamic structural analyses are therefore of extreme importance during the design and optimization phases of new vessels.

Polar vessels operate in unique environments, and are exposed to complex dynamic loading patterns and vibration responses. The resulting ice-structure and fluid-structure coupled interactions are still not well understood. *Polarstern* was first commissioned on December 9th 1982, and spends almost 310 days a year at sea in some of the harshest environmental conditions on our planet. *Polarstern* has been a tremendous success story and her design has been proven in both ice and open water conditions. With the vessel nearing the end of her operational lifetime, the ability to learn from this proven design, as well as investigate the potential of structural health monitoring for continued safe operation are key goals of the current research.

Structural dynamic analyses will be conducted by instrumenting the vessel in Bremerhaven with 24 accelerometers (see Figure 1) distributed throughout the vessel. These sensors will be connected via 1,800 m of coaxial cable to data acquisition systems (DAQ's).

The measured acceleration signals can be related to the global movement and deflection of the vessel. This information is used to investigate the dynamic response of the structure through a technique called operational modal analysis (OMA). OMA is concerned mainly with the natural frequencies, damping ratios and mode shapes of the structure.

The main scientific questions and objectives include:

1. How do the various fluid-structure and ice-structure interactions occurring during real operation affect the structural dynamic response of the vessel?
2. Are we able to accurately estimate the ice loads on the ship hull from rigid body and elastic motion using a novel inverse technique?
3. Are these data driven structural dynamic models able to improve the fatigue life estimation and design optimization of ships through finite element model (FEM) updating?
4. Are vibration sensors able to accurately monitor the structural health of the vessel based on modal migration?
5. How do the different hull designs of *Polarstern* and the S.A. Agulhas II (South African polar supply vessel) compare in terms of their dynamic response?

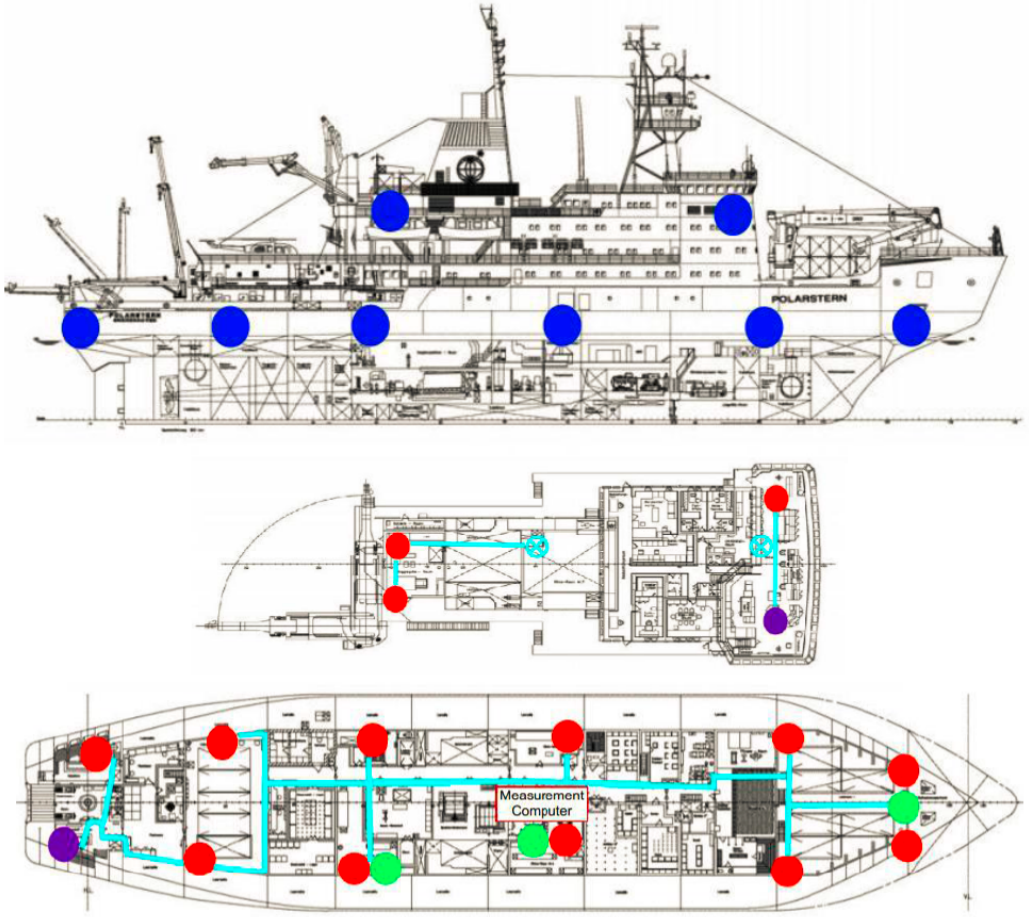

Fig. 7.1 Placement of acceleration sensors on Polarstern.

Work at sea

A representative structural dynamic data set requires that the vessel performs her scientific function as described by the various projects in this booklet. This includes the open water crossings in various sea states and swell directions, ice navigation and ramming and scientific stations in open water and ice. During the voyage the measurement system will be checked and maintained daily. Data will be pre-processed during the voyage in order to identify trends or anomalies which could be related to physical observations on board. During ice navigation 24 hour observations of sea ice conditions will be conducted from the bridge of the vessel. This data will be used to correlate with the structural response in ice.

Data management

The results from the data processing will be published in peer-reviewed articles for access to the wider scientific community. There are also plans to publish parts of the, very large, raw data set in order to provide a benchmark full scale case study as a platform to test improvements to existing algorithms as well as new structural dynamic algorithms.

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8. GPS OBSERVATIONS IN NORTH-EAST GREENLAND TO DETERMINE VERTICAL AND HORIZONTAL DEFORMATIONS OF THE EARTH'S CRUST

M. Scheinert (TU Dresden, not on board), B. Ebermann, A. Kraemer (TU Dresden)

Objectives

In Greenland, there still exists the only continental ice sheet outside Antarctica. It plays an important role for the global climate. Despite it contains only 10 % of the global fresh-water storage in comparison to the Antarctic ice sheet, due to its location at high- and sub-polar latitudes it reacts in a very sensitive way to changes in the environmental and climate conditions. Therefore, the Greenland ice sheet has been subject to intensive geophysical and glaciological investigations for almost one century.

Changes of the ice sheet are visible indirectly at deformations of the surface of the Earth. Ice mass changes can be regarded as changing surface loads, which cause – due to the rheological properties of the upper layers of the Earth – long-term visco-elastic and immediate elastic reactions. Hence, in the observable vertical deformation of the Earth's crust we can find the integral effect of all ice-mass changes during glacial history and in present times.

North-East Greenland is characterized by a high variability of the ice edge with regard to its location and mass change as well as of a visco-elastic signal due to glacial history, that – according to model predictions – reaches maximum values for entire Greenland. Additionally, deformations of tectonic origin cannot be excluded, which will be tested analysing the horizontal components.

Satellite-based positioning by means of GPS allows a precise geodetic determination of coordinates and, with repeated observations, the determination of changes for the horizontal as well as for the vertical components with an accuracy in the sub-centimetre level. In order to ensure a high accuracy of repeated measurements, a stable base for the GPS marker has to be chosen. Therefore, the stations are to be set-up at ice-free bedrock locations.

This project is a continuation of research work done during *Polarstern* cruises ARK-XXIII/1+2 (2008) and ARK-XXIV/3 (2009).

Work at sea

The geodetic work to be carried out during this *Polarstern* cruise is a continuation of a project started 2008 during the cruises ARK-XXIII/1+2 (2008) and ARK-XXIV/3 (2009). During these expeditions, 22 locations at bedrock were surveyed, where GPS stations were successfully set up and most of them observed for the first time. The geodetic network configuration realized in this way includes a west-east component (stations at the ice edge and at the coast), and covers a north-south extension from about 74°N to 81.5°N. Due to the logistic conditions of the planned cruise, we will occupy up to 10 stations between 78°N and 81°N again in order to carry out a first re-observation by geodetic GPS positioning (see Table 6.1. and Fig. 6.1.. All locations will be reached by helicopter. The GPS equipment will be set up and remain at each location to observe permanently for 3 days at least.

Preliminary (expected) results

The GNSS observations will be processed at the home institution (so-called post-processing using the Bernese GNSS Software). In the analyses latest standards have to be incorporated used in geodesy (e.g. consistent and precise realization of the reference frame). From the analysis of the repeated GPS observations we will come up with coordinate change rates (especially for the vertical deformation), that serve as an independent source of information for the validation and improvement of models on the glacial history and on the recent ice mass balance of North-East Greenland. While testing the significance of horizontal deformations we will contribute to an improved analysis of the tectonic regime in the working area.

Data management

The geodetic GPS data will be archived in a similar database like the SCAR GNSS Database that is maintained at TU Dresden. The long-term preservation of the data will be maintained also through the close cooperation within the SCAR Scientific Programme SERCE (Solid Earth Responses and Influences on Cryosphere Evolution). A common structure of the data holdings is ensured through the application of the same scientific software package utilized to analyse geodetic GNSS measurements at TU Dresden (i.e., the Bernese GPS Software). Further products and resulting models will be archived in the PANGEA database at AWI.

Tab 8.1: List of GPS stations installed and observed in 2008 and 2009, resp., and to be re-observed during cruise PS100

ID	Longitude	Latitude	Geographical Region
ROME	-19.0617	81.0718	Kronprins Christian Land CN
CENT	-21.7236	80.1913	Centrumsø (Kronprins Christian Land CS)
HOLM	-16.4315	80.2730	Holm Land SE
CRIW	-24.3136	80.0925	Kronprins Christian Land SW
BLAF	-22.6494	79.5329	Kronprins Christian Land S
MUSK	-22.7228	79.9795	Skallingen (Kronprins Christian Land SW)
HOVG	-18.2306	79.7002	Hovgaard Ø

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LAMW    -22.3061    79.2265    Lambert Land W
BILD    -23.5033    78.1164    Bildsøe Nunatakker
FRAN    -18.6273    78.5784    Franske Øer
-------------------------------------------------------------
SW South-West
SE South-East
CS Centre-South
etc.
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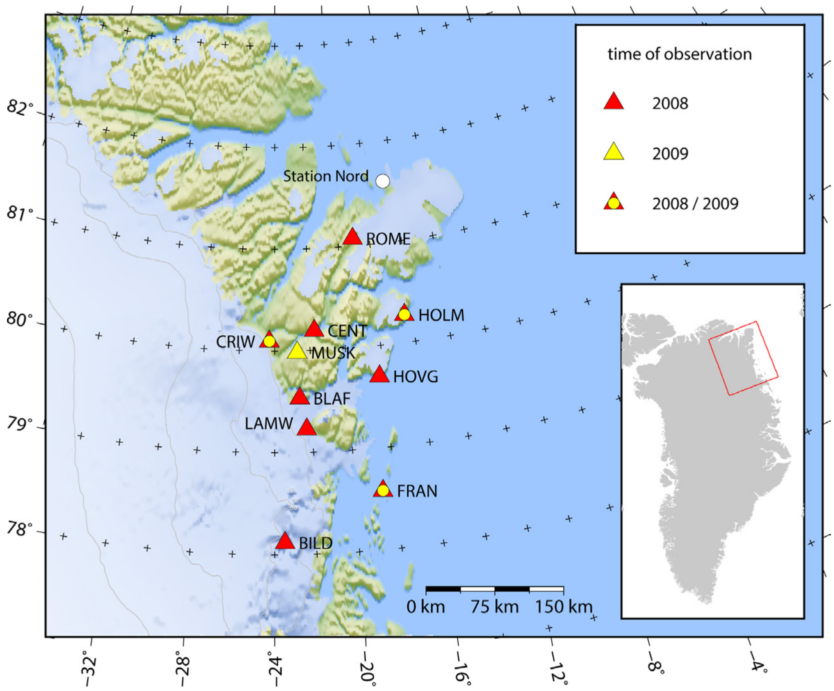

Fig. 8.1.: Overview of the working area with the GPS stations (triangles) that were set up in 2008 and 2009 and shall be re-observed during cruise PS100.

9. AMICA - ARCTIC MARGINAL ICE ZONE COMMUNITY ASSESSMENT: BIODIVERSITY, PRODUCTIVITY & TROPHIC INTERACTIONS IN THE MARGINAL ICE ZONE OF FRAM STRAIT UNDER GLOBAL CHANGE

H. Auel (Uni HB), C. Havermans (Uni HB), R. M. Franco Santos (Uni HB / AWI), N. Prinz (Uni HB), R. Jacinto (CCMAR-UAlg), J. Boavida (CCMAR-UAlg)

Background and objectives

In the framework of AMICA, biodiversity, productivity and trophic interactions within the Arctic marginal ice zone of western Fram Strait will be quantified in order to assess potential impacts of global climate change on marine ecosystems in the Arctic. During recent years, episodes of unexpectedly high water temperatures and an increased inflow of Atlantic water masses via Fram Strait already led to a decline in sea-ice cover and changes in pelagic communities. The relative importance of phytoplankton vs. ice algae for primary production will be quantified and the fate of organic matter during its passage through the food web will be traced. Because of the complex current regime at the East Greenland shelf (East Greenland Current, Return Atlantic Current), advection of organic matter and organisms into and out of the study area will have to be taken into account, too. Field work will be supplemented by experimental approaches determining tolerance thresholds of dominant pelagic species with regard to increasing water temperatures.

The Arctic Ocean is the area most rapidly and intensely affected by global warming and climate change. Models predict a rise in air temperature by 3 to 6°C over the coming 50 years. The temperature increase will be similar throughout the year, but with stronger effects during the summer season, when it will result in a longer and more intense melting period of the sea ice. Multiyear sea ice has declined by ca. 15 % decade^{-1} over the last thirty years. It is expected that the geographical extent of permanent multiyear ice coverage will further decline, while areas with seasonal ice cover and the marginal ice zone will increase.

Field observations in Fram Strait, where sea ice comes into contact with relatively warm Atlantic water masses, show that melting may proceed rather rapidly. The ablation of the ice underside can reach 10-20 cm day^{-1}. Since most of the sea-ice organisms live in the lowermost centimetres of the ice, such a rapid melting would result in the loss of most of the sea-ice community and, hence, a cessation of ice algal primary production.

Studies around Svalbard demonstrated that the marginal ice zone is a very dynamic habitat. During the spring break-up of the pack ice, the ice edge receded northward at a rate of 11 km day^{-1}. An early bloom of *Phaeocystis* in Fram Strait resulted in high new production of ca. 1 g C m^{-2} day^{-1} over a 35 day period. In polar systems, the ratio of new, i.e. nitrate-based, to total primary production is high, resulting in a high potential of these regions for influencing global carbon and nutrient cycles.

Ice-covered polar seas differ from most other oceanic regions due to the fact, that phytoplankton is not the only primary producer. Ice algae, mainly pennate diatoms, greatly contribute to total primary production and may present up to two-thirds of total primary production in ice-covered areas. On average ice algae contribute 57 % of the entire primary production in the central Arctic and 3 % in surrounding regions.

The loss of suitable sea-ice habitats and of the nutritional basis will lead to deleterious effects for endemic sympagic species such as under-ice amphipods and polar cod. On the other hand, seasonal pack-ice areas and the marginal ice zone are highly productive areas. Higher phytoplankton and total primary production in the Arctic may lead to increased zooplankton production and a better food supply for pelagic fish. However, these changes of the Arctic ecosystem are not certain. An early break-up of the ice could initiate a diatom bloom already in March prior to the ascent of copepods in April. This mismatch between the early spring bloom and copepod grazers could result in a pelagic food web dominated by protozooplankton and reduced amounts of organic matter available for higher trophic levels or export from the euphotic zone, despite the increased primary productivity.

In contrast to low-latitude ecosystems, polar seas host high biomasses of relatively large zooplankton organisms, which form an important direct link to top predators, such as seabirds and marine mammals, due to the low abundance or near-absence of small pelagic planktivorous fish in polar marine ecosystems. The long-standing paradox of high Arctic mesozooplankton biomass despite low phytoplankton production can be explained with the additional input of ice algae production, advection of Atlantic water masses and the import of organic matter from the vast Arctic shelves into the central Arctic deep-sea basins. Moreover, physiological adaptations in dominant Arctic zooplankton species, such as diapause, reduce the nutritional demands of the plankton community. Slow growth and long life-spans of Arctic zooplankton species result in rather large individual size despite limited food availability.

Mesozooplankton biomass in the Arctic Ocean and adjacent seas is strongly dominated by calanoid copepods. The three congeners *Calanus finmarchicus*, *C. glacialis* and *C. hyperboreus* together with *Metridia longa* represent two-thirds to three-quarters of total mesozooplankton biomass in the Arctic Ocean during summer. Zooplankton composition is influenced by the inflow of Atlantic water masses with boreal-Atlantic sister species gradually replacing native polar species.

The hyperiid amphipod *Themisto libellula* is very abundant in the entire Arctic region. The species forms dense swarms in the Polar Surface Water, directly beneath the sea ice, in the East Greenland Current and close to the Polar Front. The biomass of *T. libellula* in ice-free waters of the Greenland Sea and northern North Atlantic (65-80°N) has been estimated at 100 million tons with highest concentrations along the ice edge and off Jan Mayen. *Themisto libellula* plays a central role in the Arctic pelagic food web. Due to its epipelagic distribution, the species represents an important and stable resource for Arctic marine vertebrates. *Themisto libellula* is a major diet component of polar cod *Boreogadus saida*, ringed and harp seals as well as seabirds. Little auks (*Alle alle*), which are the most abundant seabirds in the marginal ice zone of Fram Strait almost exclusively feed on this amphipod species and on *Calanus hyperboreus*. Thus, *T. libellula* represents a key link from mesozooplankton secondary production to higher trophic levels.

In contrast to the predominantly herbivorous Antarctic krill, hyperiid amphipods of the genus *Themisto* are predominantly carnivorous preying on a wide spectrum of mesozooplankton including copepods, euphausiids, pteropods and chaetognaths. By means of lipid biomarkers and feeding experiments, *T. libellula* has been shown to extensively feed on *Calanus.* Swarms of *T. libellula* actively preying on copepods accumulate at the ice-water interface at dusk. As compared to congeners of lower latitudes (i.e. the boreal-Atlantic *T. abyssorum*, the Pacific *T. japonica* and the Antarctic *T. gaudichaudii*), the Arctic species *Themisto libellula* shows rather low ingestion rates of 1.9 % day^{-1}. However, low metabolic and consumption rates of high-Arctic *T. libellula* are consistent with low ambient temperature, large body size (up to 60 mm), slow growth and long life span (~2-3 years) of this polar species. Dense swarms of *T. libellula* with concentrations of 25 to more than 100 ind. m^{-3} can effectively control mesozooplankton biomass. Thus, the macrozooplankton species *T. libellula* represents at the same time both, an important predator on mesozooplankton and a major prey item for marine vertebrates, making the amphipod an effective trophic link from zooplankton secondary production to higher trophic levels in the Arctic.

The different species of *Themisto* are known to occur in different water masses. In some places such as the northern Bering Sea and the Gulf of St Lawrence, a southward spreading of *T. libellula* has been observed to these regions, where it was absent before, but now occurs in high densities. Population genetic and gene expression analyses will clarify the role of the different species as potential indicators of climatic variability and predict potential distributional shifts and their implications for the food web.

The sea-ice cover affects living conditions in the pelagic realm beneath the ice in many ways. Besides direct physical effects, such as reduced light intensity and heat flux below the ice and a stabilized stratification due to melt-water discharge in spring, biological exchange processes between the sea-ice community and the pelagic realm, the so-called cryo-pelagic coupling, are essential to understand the productivity of polar oceans. At times and locations where sea ice melts, ice algae and sympagic fauna are released into the water column and present an additional food source for pelagic organisms. However, it is generally believed that strong pulses of released organic matter from melting sea ice supersede the ingestion and remineralization capabilities of epipelagic communities and are exported to deeper water layers and to benthic communities. Especially in areas where large amounts of sea ice melt regularly, for instance in the Greenland Sea, the sedimentation of ice organisms can present an important food source for the deep-sea fauna and contribute to the downward carbon flux.

Cryo-pelagic coupling is not a one-way street for carbon and energy flux from the sea-ice community to the pelagic realm. Both systems mutually affect each other by multiple exchange processes and dynamic recycling of organic matter between both habitats. While pelagic copepods feed on ice algae, under-ice amphipods actively prey on zooplankton, including calanid copepods. Fatty acid biomarkers of ice algae can be traced to higher trophic levels in the pelagic food web, such as the predatory amphipod *Themisto libellula*.

The objectives of AMICA are to quantify the relative contributions of ice algal vs. phytoplankton primary production in the Arctic marginal ice zone and to trace the fate of organic matter throughout the marine food web. The empirical data to be obtained during PS 100 will allow assessing potential impacts of a declining sea-ice cover on Arctic marine ecosystems. The summer situation in Fram Strait where sea ice gets into contact with warm Atlantic waters and rapidly melts can act as a model system for future conditions in high-Arctic regions under scenarios of global climate change.

The specific aims are to ...

- Quantify abundance, biomass, biodiversity and production of ecologically important components and key species of the marine communities within the Arctic marginal ice zone including phytoplankton, ice algae, zooplankton (copepods, hyperiid amphipods, chaetognaths, gelatinous zooplankton), seabirds and marine mammals (seals, cetaceans);
- Characterize microbial and phytoplankton biodiversity with molecular tools via metabarcoding and metagenomic approaches to be applied to seawater communities from contrasting conditions and to ice algae.
- Quantify import and export of organic matter and organisms (phyto- and zooplankton) into and out of the study area through advection by combining field data on phyto- and zooplankton biomass in different water layers with hydrographic data on water mass exchange and advection in Fram Strait;
- Study trophic interactions, grazing and predator-prey relationships in order to trace the pathways of organic matter through the marine food web in the Arctic marginal ice zone. For this purpose, classic approaches (feeding experiments, morphological

gut content analysis) will be combined with state-of-the-art trophic biomarker studies (fatty acid biomarkers, stable isotopes) and molecular diet analyses.

- Establish species-specific tolerance thresholds for dominant pelagic species with regard to increasing water temperatures.
- 0Establish comparative gene expression responses and transcriptional regulation of polar vs. boreal-Atlantic key zooplankton species under varying thermal regimes. These data will be integrated with physiological responses to temperature to gain insight into phenotypic differentiation in Arctic and boreal-Atlantic species that may be crucial for adaptatio0n under climate change scenarios.
- Study the genetic structure of pelagic amphipods throughout the sampling region, and in a later stage, between the sampling region and other localities in the Arctic and sub-Arctic, in order to clarity their adaptation and spreading potential and interspecific evolutionary relationships.
- Provide the database for food web models of ice-covered Arctic seas with the ultimate goal to develop a predictive capacity for potential impacts of global climate change on Arctic marine ecosystems.

Work at sea

Biomass and production of all important components of the food web from ice algae and phytoplankton via zooplankton to top predators such as seabirds and marine mammals will be determined synoptically by an interdisciplinary research team. Because of the complex current regime in western Fram Strait (East Greenland Current, Return Atlantic Current), advection of organic matter and organisms must be considered, too. Therefore, the AMICA study area will consist of a closed box of 60 x 70 nm, which will be sampled along the outer margin and in the centre. Field studies will be supplemented by experimental approaches on board to establish dietary preferences, feeding rates and species-specific thresholds with regard to rising water temperatures.

The AMICA station grid consists of a closed box in the marginal ice zone of western/central Fram Strait. The exact position will be set according to the actual sea-ice conditions. According to previous experience, the study area could be located between 78 and 79°N and between 4 and 10°W. The box has an East-West extension of approx. 70 nm and a North-South extension of 60 nm. Oceanographic and planktological stations will be spaced at 10 nm along the outer margins of the box and along a diagonal transect. A typical station will consist of a CTD/Rosette cast and a MultiNet haul to sample mesozooplankton. A Bongo net trawl will be conducted to collect macrozooplankton, in particular amphipods and krill. CTD and MultiNet casts will encompass the whole water column. Seawater samples to be taken from contrasting hydrographic regimes (Atlantic vs. polar) and ice algae will be filtered to separate different components of the community, and immediately frozen for molecular analyses.

Zooplankton samples will be sorted alive immediately after the catch in order to collect frozen and ethanol-preserved samples for trophic biomarker studies, ecophysiological and genetic analyses. Specimens of key species (*Calanus* spp., *Paraeuchaeta* spp., *Themisto* spp., *Thysanoessa* spp.) will be incubated for several days on board at increasing temperatures of 0°C, 2°C, 4°C, and 8°C and their metabolic activity measured with optode respirometry in order to establish their response to increasing water temperatures and to identify ecophysiological thresholds and tipping points in native polar vs. boreal-Atlantic sister species. The experimental appraoch will be combined with molecular genetic analyses of gene expression (transcriptomics), for which experimental samples will be rapidly frozen in liquid nitrogen and stored for molecular analyses later on.

Pelagic amphipods will be kept alive in aquaria for feeding experiments and behavioural observations. Prey preference experiments will be carried out in order to elucidate dietary preferences of the different *Themisto* species and their daily ingestion rates. Swimming and sinking speeds of pelagic amphipods will be determined. Video recordings will capture so far undocumented feeding interactions between *Themisto* and potential prey items such as soft-bodied zooplankton as well as phytoplankton aggregates. Migratory behaviour, and possibly feeding interactions, will be observed *in vitro* under bright and dim light conditions, mimicking sun- and moonlight conditions. Ethanol-preserved amphipod samples will be taken for various purposes, including taxonomic, life history, phylogeographic and molecular diet analyses, RNAlater samples will be used for gene expression analyses and frozen samples for biomarker studies and dry weight calculations.

In additional incubation experiments we will study the effects of a changing food regime on the performance of *Calanus* spp.. The energy budget of the copepods will be quantified in relation to food quality in order to tackle the question whether and how late or failed diatom blooms affect growth and reproduction. Moreover, the allocation of dietary components will be studied. Copepods will be continuously fed for at least ten days with a diatom and a heterotrophic dinoflagellate species, both of which we will culture on board. In regular intervals, grazing, faecal pellet and egg production rates will be measured by means of short-term incubations (<24 hrs). Respiration rates will be determined via optodes. Also, algal cells will be enriched with stable isotopes ($\delta^{13}C$) and fed to the copepods. With assimilation, $\delta^{13}C$ will accumulate in the zooplankton organisms - a process that can be followed by compound-specific stable isotope analysis, which will be conducted after the expedition in the laboratories at AWI.

10. BASALT MELT RATES OF THE FLOATING PART OF 79°N GLACIER

A. Humbert (AWI), D. Steinhage (AWI, both not on board), B. Ebermann, A. Kraemer (TU Dresden)

Objectives

The 79°N Glacier is one of three outlet glaciers of the only large ice stream in Greenland, the NEGIS (North-East Greenland Ice Stream). In contrast to other glaciers in Greenland, which are typically tidewater glaciers, the 79°N Glacier forms a floating tongue and is rather comparable to an ice shelf (Fig. 10.1). As the NEGIS drains about 8 % of the ice sheet, the question whether its contribution to sea level change is increasing is coming more into focus. The floating tongue is pinned by ice rises along the ice front, which keeps its lateral extent at the moment stable, however, the ice flow velocities at its grounding line are slightly increasing (Joughin, pers. comm.) and the upstream ice surface elevation has started to decrease in the past few years (Helm et al., 2014). Warm water masses were also already detected to drain underneath the floating tongue and hence the question arises if the warm water increases the basal melt of the floating tongue, causing grounding line retreat and weakening of the tongue itself.

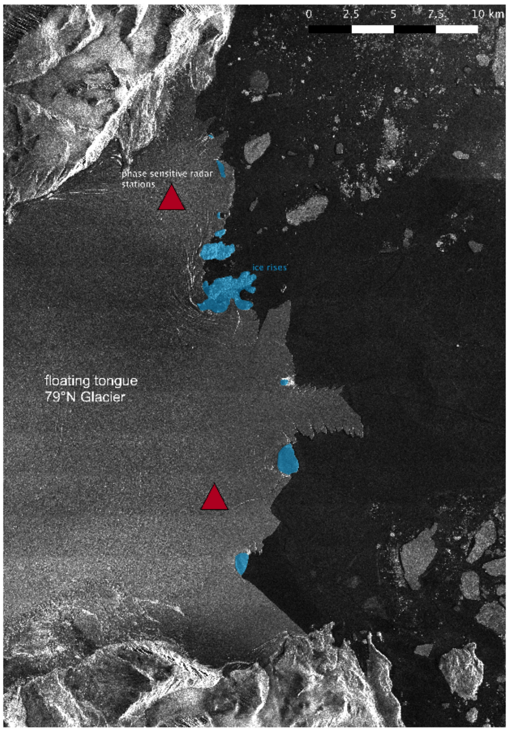

Fig. 10.1.: Overview of the 79NG in the vicinity of the calving front showing potential ApRES sites

Thus aim to measure the seasonal variation of basal melt rates of the 79°N Glacier at two locations on its floating tongue. The melt rates at the ice-ocean transition are measured using a phase sensitive radar (Corr et al., 2002; Jenkins et al., 2006), which measures the change of the distance between internal layers of the glacier. This method can separate the ice thickness change due to stretching of the glacier from the thickness change due to basal melt. As the basal melt over a short period of time is too small to be detected by the amplitude of the radar signal, the phase of the radar signal is used for this purpose. The radar is a multi-frequency radar that sends a burst of radar signals with defined repetition times and gives hence a change of the phase and hence the basal melt rate over time. With this method we can thus detect the penetration of warm water masses underneath the tongue that cause the change of the melt rates.

Work at sea

Using the helicopter a group of 2 persons plus ranger will be flown to the glacier and install autonomous radar stations. The work is expected to take 2-3h for each of the two stations.

Preliminary (expected) results

Time series of basal melt rates at two locations (red triangle in map).

Data management

All data will be uploaded to the PANGAEA database. Unrestricted access to the data will be granted after about three years, pending analysis and publication.

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11. SEISMICITY AND LITHOSPHERE STRUCTURE OF THE ULTRASLOW SPREADING KNIPOVICH RIDGE

V. Schlindwein, H. Kirk (AWI), F. Krüger (not on board, U Potsdam)

Objectives

Ocean basins are formed by seafloor spreading at active mid-ocean ridges. Mantle material is upwelling under the ridges and melts to produce magma, which erupts onto the sea floor and crystallises at depth to produce new oceanic crust. Crustal generation and plate separation rate keep pace over a wide range of spreading rates and produce oceanic crust with a uniform thickness of about 7 km. Yet, models predict that at spreading rates below about 20 mm/y, the mantle loses heat by conduction and only small amounts of melt are produced at large depths (Bown & White, 1994). This melt is distributed very unevenly along the axis of ultraslow-spreading ridges: Isolated volcanoes at distances of about 100 km are separated by long ridge sections that show little or no magmatism and mantle rocks may be exposed directly at the seafloor (Michael *et al.,* 2003). Underneath these volcanic centres, the lithosphere is postulated to be thinner, such that melt can flow along the lithosphere-asthenosphere boundary along the segment towards the volcanoes and rise through a thinned lithosphere. For this geological model (e.g. Standish *et al.,* 2008), we found first geophysical evidence during a short-term deployment of ocean bottom seismometers (OBS) around Logachev Seamount on Knipovich Ridge: The maximum depth of earthquakes marking the thickness of the elastic lithosphere rises from about 20 km depth to less than 8 km depth underneath Logachev Seamount (Schlindwein *et al.,* 2013). At the Southwest Indian Ridge, a long-term deployment of OBS in 2012 (Schlindwein, 2014) allowed to define detail the topography of the lithosphere-asthenosphere boundary along a short ridge section (Schlindwein & Schmid, 2016).

In order to better understand how melts travel at segment scale along the axis of ultraslow spreading ridges and rise through the thick lithosphere, we aim to instrument for the first time an entire segment of an ultraslow spreading ridge with an about 180 km long network of OBS from the DEPAS instrument pool and record the earthquake activity of the ridge. From the seismicity pattern we can derive the thermal structure of the ridge and identify regions of contrasting deformation modes. Mantle rocks altered to serpentinite, for example, show little seismicity, whereas basalt dominated ridge areas break in numerous earthquakes

(Schlindwein & Schmid, 2016). Earthquakes furthermore trace active faults that potentially play a significant role in the oblique spreading of Knipovich Ridge. Around Logachev Seamount, our OBS network will be denser to acquire a dataset that is suitable for seismic tomography to image the internal structure and plumbing system of a volcanic centre.

The OBS will remain for about one year at the seafloor and will be collected during a dedicated cruise with *Maria S. Merian* in 2017. At that time, we will additionally acquire refraction seismic profiles across Logachev Seamount for a high-resolution image of its structure and seismic velocities at depth. Bathymetry mapping in the off-axis direction of Logachev Seamount will then complement our data to look for expressions of phases of tectonic and magmatic activity of Logachev Seamount in former times.

Work at sea

During PS 100, we will install the network of 24 OBS. They will be spaced at distances of about 20 km on each side of the roughly 20 km wide rift valley. Logachev Seamount at 76.6°N 7.25°E will receive additional 6 OBS to reduce the station spacing to about 10 km.

At sea we will first check the OBS acoustic release units. In three rounds, we will lower the releasers in a basket to about 2500 m water depth and test the release mechanism. Afterwards, the OBS will be assembled, programmed, time-synchronized and prepared for the deployment. The large number of OBS will occupy a significant amount of space on deck such that we can prepare only about half of the OBS at a time. We will first instrument the distal ridge sections and later Logachev Seamount itself. As stations there will have to record airgun signals during the recovery cruise in 2017, it is important that their batteries are not exhausted by then. The OBS deployment itself is straightforward and largely independent of weather: We will search for a sufficiently flat area at the seafloor, shortly stop the ship and use the crane to heave the OBS into the water to sink freely to the seafloor.

As further part of our geophysical programme, we will record variations of the Earth's gravitational field along Knipovich Ridge en route with *Polarstern's* onboard gravity meter. The main variations in the gravity field along Knipovich Ridge stem from differences in crustal thickness which are an indicator of magmatic productivity. Gravity measurements are relative, such that we have to tie them to a reference point with known absolute gravity. This is done in the port of Tromsö prior to departure and after arrival with a portable land gravity meter and a measurement next to the ship and at the reference point in town, respectively.

Finally, we aim to use the occasion of glaciology and geodesy measurements on the 79°N glacier to place a broadband seismometer onto the 79°N glacier. These reconnaissance data will give us a first impression of the seismic activity of 79°N glacier, the waveform characteristics and frequency content of its icequakes. This information helps us to dimension suitable seismic networks for a future land campaign on 79°N glacier.

Preliminary (expected) results

During this cruise, we will only deploy OBS. Data cannot be accessed before station retrieval in 2017. Only then we can start to inspect the continuous seismic data, identify and extract earthquakes and start to process them. Gravity data from the cruise will be extracted from the ship's data management system and referenced and corrected later. The seismic activity of the 79°N glacier can be inspected as soon as the station is back on board. We will scan the data, identify different types of events and determine their spectral characteristics.

Data management

Our seismic data will be archived in a common data repository for all data acquired with the OBSs of the DEPAS instrument pool. As data processing of this large data set is very time consuming, we will be make the data publicly available through the GEOFON seismic data request system after 5 years of restricted access.

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A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

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Auel	Holger	UHB-MAR	Scientist	Biological Oceanography
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Evers	Florian	GEOMAR	Technician Winch	Geochemistry
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A.3 SCHIFFSBESATZUNG / SHIP'S CREW

No.	Name	Rank
1.	Schwarze, Stefan	Master
2.	Grundmann,	1.Offc.
3.	Heuck, Hinnerk	Ch. Eng.
4.	Janik, Michael	2. Offc.
5.	Hering, Igor	2.Offc.
6.	Fallei, Holger	2.Offc.
7.	Pohl, Klaus	Doctor
8.	Fröb, Martin	Comm.Offc.
9.	Grafe, Jens 2	.Eng.
10.	Krinfeld, Oleksandr	2.Eng.
11.	Holst, Wolfgang	3. Eng.
12.	Redmer, Jens	Elec.Tech.
13.	Christian, Boris	Electron.
14.	Hüttebr.ucker, Olaf	Electron.
15.	Markert, Winfried	Electron.
16.	Lehnert, Lars	Electron.
17.	Himmel,Frank	Electron
18.	Loidl, Reiner	Boatsw.
19.	Reise, Lutz	Carpenter
20.	Hagemann, Manfred	A.B.
21.	Winkler, Michael	A.B.
22.	Scheel, Sebastian	A.B.
23.	Bäcker, Andreas	A.B.
24.	Brück, Sebastian	A.B.
25.	Wende, Uwe	A.B.
26.	Völker, Frank Rainer	A.B.
27.	Wittek, Sönke, Fritz Ole	A.B./Tr.
28.	Schulz, Fabian	A.B./Tr.
29.	Preußner, Jörg	Storek.
30.	Teichert, Uwe	Mot-man
31.	Rhau, Lars-Peter	Mot-man
32.	Lamm, Gerd	Mot-man
33.	Schünemann,	Mario Mot-man
34.	Pinske, Lutz	Mot-man
35.	Redmer, Klaus-Peter	Cook
36.	Silinski, Frank	Cooksmate
37.	Martens, Michael	Cooksmate
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40.	Dibenau, Torsten	2.Steward
41.	Silinski, Carmen	2.Stwdess
42.	Grigull, Elke	2.Steward
43.	Arendt, Rene	2.Steward
44.	Sun, Yong Shen	2.Steward
45.	Yu, Kwok Yuen	Laundrym.