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

EXPEDITION PROGRAMME PS89

Polarstern

PS89

Cape Town - Punta Arenas

2 December 2014 - 1 February 2015

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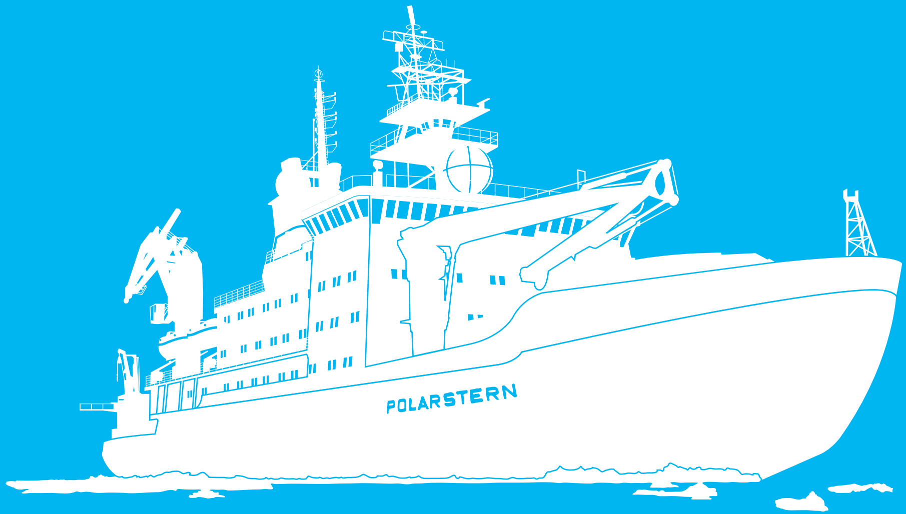

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EXPEDITION PROGRAMME PS89

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1. ÜBERBLICK UND FAHRTVERLAUF

Olaf Boebel
AWI

Am 2. Dezember 2014 wird das Forschungsschiff *Polarstern* von Kapstadt, Südafrika, zur Antarktisreise PS89 (ANT-XXX/2) auslaufen. Zunächst wird der Kurs nach Süd-Südwest führen, um entlang des sogenannten Good-Hope-Schnittes einen Array von ozeanographischen Messgeräten aufzunehmen. Bei etwa 51°S wird *Polarstern* den Meridian von Greenwich erreichen. Von dort werden uns ozeanographische, biologische und meereisphysikalische Arbeiten direkt nach Süden zum antarktischen Kontinentalhang führen. Nach geologischen Probennahmen am Kontinentalhang sollen die Arbeiten auf dem Greenwich Meridian etwa am 23. Dezember abgeschlossen sein, worauf *Polarstern* die deutsche Neumayer-Station anlaufen wird, um diese für die kommende Überwinterung mit Proviant und Treibstoff zu versorgen. Anschließend wird das Weddellmeer auf einem Zick-Zack Kurs bis hin Nordspitze der Antarktischen Halbinsel durchquert, um entlang dieser Strecke weitere wissenschaftliche Arbeiten aus den drei oben genannten Fachgebieten durchzuführen. Am 30. Januar 2013 werden die Arbeiten mit einer Verankerung bei der Elefanteninsel abgeschlossen sein. Die Reise wird am 1. Februar 2015 in Punta Arenas, Chile, enden. Die Fahrtroute ist in Abbildung 1.1 dargestellt.

Ziel des ozeanographischen HAFOS (Hybrid Antarctic Float Observation System) Projektes ist es, die Bedeutung des atlantischen Sektors des Südlichen Ozeans für die großräumigen, klimarelevanten Vorgänge im Ozean besser zu verstehen. Hierzu werden während der gesamten Reise vom fahrenden Schiff aus oberflächennahe Messungen der Temperatur, des Salzgehaltes und der Strömungen des Ozeans erfolgen. Entlang der Kurslinie sollen, vor allem im inneren Weddellmeer, vertikal profilierende eistaugliche Argo Floats ausgelegt werden. Weiter südlich sollen Verankerungen, die Strömungs-, Temperatur- und Leitfähigkeitsmessgeräte, sowie Schallquellen zum Tracking der Argo Floats und passiv akustische Rekorder tragen, aufgenommen und wieder ausgelegt werden. An etwa 100 Stationen sind Messungen mit einem CTD-System (conductivity, temperature, depth) geplant, das mit Wasserschöpfern ausgestattet ist, um Proben zur Bestimmung des Salzgehaltes zu erhalten.

Unsere spanischen Kollegen werden sich dem aktuellen Kohlenstoffhaushalt des Weddellmeeres widmen. Anhand der Wasserproben aus verschiedenen Tiefen werden sie drei wichtige Kenndaten des Kohlenstoffsystems untersuchen: den pH-Wert, die Alkalinität sowie den Gesamtkohlenstoff (DIC). Zusätzlich wird während der gesamten Reise eine kontinuierlich arbeitende xCO_2-Sonde den oberflächennahen CO_2-Partialdruck entlang des Schiffskurses messen.

Das SOCCOM (Southern Ocean Carbon and Climate Observations and Modelling) Projekt unserer amerikanischen Kollegen zielt auf langfristige Beobachtungen des Kohlenstoffzyklus im Südozean ab. Diese sollen mittels 180 bis 200 autonomer profilierender Floats erhoben werden, die, zusätzlich zu den Standard Salzgehalts- und Temperatursensoren, biogeochemische (Sauerstoff, Nitrat, pH) und optische Sensoren tragen. Auf dieser Expedition sollen etwa 15 dieser SOCCOM Floats an den Positionen ausgewählter CTD Stationen ausgelegt werden, um parallel Wasserproben für die Kalibration der Geräte hinsichtlich Sauerstoff, Nährstoffe, pH, Alkalinität und partikulärem Kohlenstoff zu erhalten.

Das übergeordnete wissenschaftliche Ziel der gemeinsam von niederländischen, belgischen und deutschen Kollegen durchgeführten interdisziplinären meereisbiologischen und meereisphysikalischen Untersuchungen, SIPES (Sea Ice Physics and Ecology Study), ist es, ein quantitatives Verständnis der Interaktion von physikalischen Eigenschaften des Meereises und dem pelagische Nahrungsnetz zu entwickeln. Entsprechend wird eine Beprobung von Zooplankton und Nekton mittels pelagischer Schleppnetze und Fischereisonar mit biophysikalischen Messungen unter dem Eis und Eisdickenmessungen kombiniert. Zur Untersuchung der Bedeutung von Eisalgen-Kohlenstoff im pelagischen

Nahrungsnetz werden Organismen für eine Analyse trophischer Eisalgen-Biomarker beprobt. Es sollen bis zu sechs mehrtägige Meereisstationen eingerichtet werden, um die physikalischen und biologischen Eigenschaften des Meereises auf verschiedenen räumlichen Skalen mit einem kabelgebundenen Unterwasserfahrzeug (ROV), Untereis-Sensoren und Eiskernanalysen zu untersuchen. Begleitend sollen verschiedene Meereisbojen eine kontinuierliche Datensammlung gewährleisten. Die Ergebnisse dieser Studie tragen zur Entwicklung gekoppelter biophysikalischer Meereis-Ozean-Modelle bei und helfen damit Vorhersagen von Veränderungen in der Biodiversität, Funktion und Ressourcenverfügbarkeit antarktischer Ökosysteme zu präzisieren.

Die Abhängigkeit der Verbreitung und Häufigkeit von Vögeln und marinen Säugern von hydrologischen Faktoren, wie z.B. Fronten oder Meereis, soll durch die Erhebung von visuellen Sichtungsdaten entlang der *Polarstern* Kurslinie untersucht werden. Dazu werden schiffsbasiert vom Krähennest und fluggestützt vom Helikopter aus gezielte Walerfassungen nach der Distance Sampling Methode durchgeführt. Das Hauptziel der Erfassungen ist die Ermittlung von regionalen Waldichten, insbesondere von antarktischen Zwergwalen *(Balaenoptera bonaerensis),* in Bezug auf Meereiskonzentrationen. Zusätzlich werden Verhaltensbeobachtungen von Walen gegenüber dem Schiff unternommen.

Im Rahmen der biogeologischen Untersuchungen (TRACEMETAL, engl. Spurenmetall) dieser Expedition sollen mit einem „Multiple Corer“ Sedimente aus 1500 m Wassertiefe genommen und in Hochdruck-Aquarien überführt werden. Es werden verschiedene experimentelle Ansätze gewählt, um die in den Sedimenten enthaltenen Foraminiferen bei unterschiedlichen Temperaturen und in Wässern mit unterschiedlicher Karbonatchemie zu kultivieren. Ziel ist die Gewinnung von Spurenmetall-Kalibrationskurven (Mg/Ca, U/Ca, B/Ca) für den tiefen Antarktischen Ozean.

SUMMARY AND ITINERARY

Polarstern will depart from Cape Town, South Africa, on 2nd December 2014 for the 2nd leg of its 30th Antarctic expedition PS89 (ANT-XXX/2). First, she will head south-southwestward along the so called *Good Hope Section* (following the ground track of the Topex/Jason satellite track # 133). Reaching the Greenwich meridian near 51°S, the expedition will continue southwards along the *Greenwich Meridian Section* towards the Antarctic ice shelf, which will be reached near 69°S, just before Christmas. Heading eastwards, a port call at Neumayer Station is scheduled for 25th December 2014, to provide the German overwintering station with provisions. Thereafter, research activities will be continued along a zigzag course across the Weddell Sea, towards the tip of the Antarctic Peninsula (the *Weddell Sea Crossing*). Around 30th January, research activities will come to a close near Elephant Island. The expedition will end in Punta Arenas, Chile, on 1st February 2015. The cruise track is shown in Fig. 1.1.

HAFOS (Hybrid Antarctic Float Observation System), the physical oceanography core project, intends to investigate the role of the Southern Ocean in the global climate system with focus on the Atlantic sector, including the Weddell Sea. To this end, temperature, salinity and ocean currents will be measured continuously along the cruise track and 28 Argo compatible profiling NEMO (Navigating European Marine Observer) floats shall be deployed at selected locations. Providing the backbone of our long-term Weddell Sea Observatory, totals of 35 and 16 of deep-sea moorings will be recovered and redeployed during the expedition, respectively. These moorings consist of single pressure sensor equipped inverted echosounders (PIES), which are used along *Good Hope Section* and the northern part of the *Greenwich Meridian Section*, or more complex assemblies which contain current meters, temperature and conductivity sensors, sound sources and sound recorders (*Greenwich Meridian Section* and *Weddell Sea Crossing*). Deep water casts using a CTD (Conductivity, Temperature, Depth) probe and rosette sampler will occur at up to 100 hydrographic stations and water samples will be taken to determine the concentrations of salt and oxygen.

The Carbon System of the Weddell Sea project by our Spanish colleagues will use these water samples to determine three variables of the carbonate system at selected depth of the water column: pH, total alkalinity and dissolved inorganic carbon (DIC). Moreover, a continuous underway xCO_2 sensor will measure the partial pressure of CO_2 in the surface water following the ship trajectory.

The SOCCOM (Southern Ocean Carbon and Climate Observations and Modelling) project by our US colleagues aims for sustained observations of the carbon cycle by deploying 180 to 200 autonomous profiling floats with biogeochemical sensors (oxygen, nitrate, pH and optical sensors in addition to temperature/salinity) throughout the Southern Ocean. A total of 15 to 17 SOCCOM floats will be deployed throughout this expedition at locations of CTD/rosette sampling in order to collect water samples (to be analysed for oxygen, nutrients, pH, alkalinity, HPLC, POC) for float profile calibration.

The Sea Ice Physics and Ecology Study (SIPES), a collaboration between Belgian, Dutch and German colleagues, is designed as an inter-disciplinary field study focussing on the inter-connection of sea ice physics, sea ice biology, biological oceanography and top predator ecology. SIPES aims to collect inter-disciplinary data sets from two to three selected areas along the cruise track in order to describe the state of sea ice coverage in the observation area.

One constituent of SIPES, the sea ice project, aims for an improved understanding of how physical properties and processes of sea ice impact sea ice habitats at different spatio-temporal scales. Key elements are airborne measurements of sea ice thickness with the EM-Bird (electromagnetic) system. Surveys with a remotely operated vehicle (ROV) will be used to map sea ice and water properties on floe scales, focusing on the quantification of optical properties of sea ice and finally the amount of sunlight transmitted through the ice. Observation results of different scales will be used to test our ability to interpret and validate satellite data. Furthermore, the combination with SAR data will allow gaining additional knowledge about sea ice deformation and dynamical properties. We complement these observations with ice station work to obtain physical properties of snow and sea ice, deployments of autonomous stations (buoys), and along-track ice observations from the bridge.

A second core objective of SIPES is to investigate the association of under-ice fauna with sea ice properties and other environmental parameters and to quantify the trophic importance of ice algal carbon for these organisms. On transects from open water into closed pack-ice and back, a Surface and Under-Ice Trawl (SUIT) will be used to quantify the distribution of animals in the immediate ice-water interface layer or at the open surface. The SUIT will be equipped with a bio-environmental sensor array allowing real-time measurements of sea ice properties and water column parameters during trawling. A Multiple-opening Rectangular Midwater Trawl (M-RMT) will be used to assess the species and size composition of animals at different depth strata. The distribution of zooplankton and fish in deeper water layers will be monitored *en-route* using *Polarstern's* EK60 echosounder. Last but not least, ice algal samples obtained with corers as well as biological samples taken from the nets and phytoplankton samples will be collected for trophic biomarker analysis. These biomarkers will later allow quantifying the flux of carbon originating from ice algae versus carbon originating from phytoplankton into the pelagic food web. Top-predator censuses will allow quantifying top predator abundance and distribution in direct comparison to prey distribution and abundance as assessed by net catches and acoustics.

Additional dedicated cetacean sighting surveys will be conducted from the ship's crow's nest as well as the helicopters following distance sampling methodology. The surveys aim to contribute to base line data on cetacean occurrence and abundance, especially of Antarctic minke whales *(Balaenoptera bonaerensis)*, with respect to sea-ice concentrations. In addition behavioural observations by means of focal follows shall investigate response behaviour of cetaceans towards vessels in Antarctic waters.

TRACEMETAL will use analyses on trace metal (Mg/Ca, U/Ca, B/Ca) ratios recorded in tests of foraminifers to estimate calcification temperatures, salinity variations, carbonate ion saturation, pH and alkalinity. During this expedition we will retrieve multiple corers from 1,500 m water depth and transfer the retrieved sediments into newly developed high-pressure aquaria in Bremerhaven to establish species-specific trace metal calibration curves for the Antarctic Ocean.

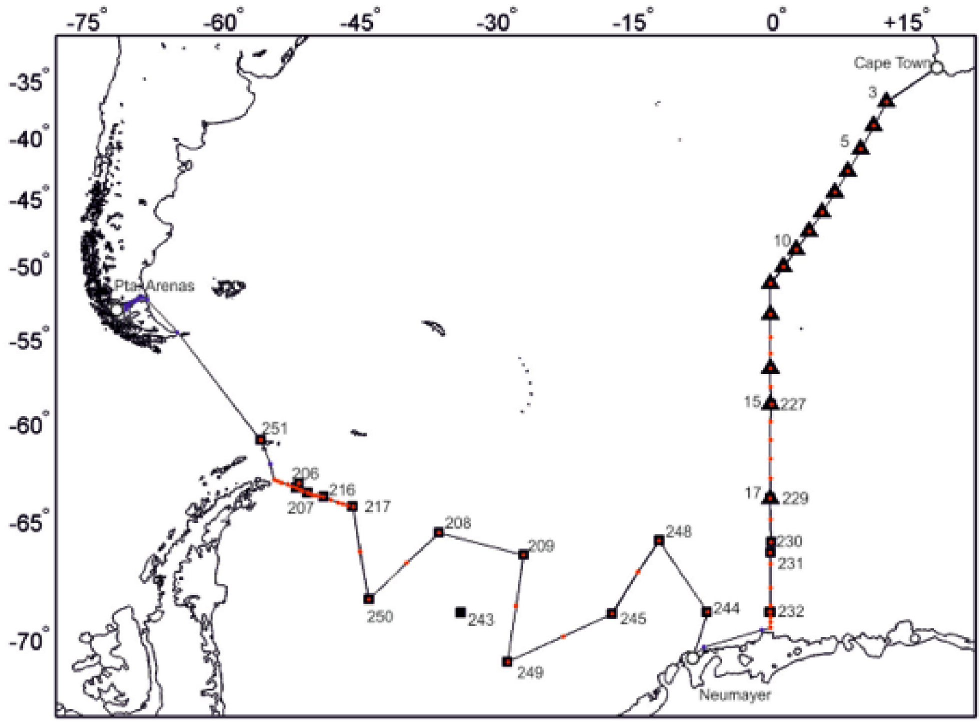

Abb.1.1: Karte des Untersuchungsgebietes und der geplanten Reiseroute der Expedition PS89 (ANT-XXX/2, schwarze Linie). Rote Punkte: CTD/Wasserschöpfer Stationen. Quadrate mit Nummern: Ozeanographische Verankerungen. Dreiecke mit Nummern: Aufnahmeorte von Bodendruckmessgeräten (PIES). Sedimentproben werden am Antarktischen Schelfabhang genommen, die SIPES Eisstationen und Netzfänge werden in geeigneten Regionen je nach Meereislage durchgeführt werden.

Fig. 1.1: Chart of the investigation area and the preliminary cruise track of PS 89 (ANT-XXX/2, black line). Red dots: CTD/water sample station. Squares with numbers: oceanographic moorings. Triangles: PIES (pressure sensor equipped inverted echosounder) recovery sites. Green dots: OBS deployment sites. Sediment samples will be taken in the vicinity of the Antarctic continental shelf break, SIPES ice stations and net catches will be conducted in suitable regions as governed by the sea ice situation.

2. OCEANOGRAPHY

2.1 Implementation of the HAFOS Observation System in the Antarctic

O. Boebel, P. Fischer, R. Graupner, I. Ivanciu, S. Klebe, K. Lefering, P. Lemke, C. Lerchl, T. Meinhardt, M. Monsees, F. Rohardt, G. Rohardt, J. Rohde, S. Spiesecke, K. Thomisch, C. Walcher, M. Warmuth, H. Zanowski, S. Zwicker (AWI)

Objectives

The densest bottom waters of the global oceans originate in the Southern Ocean. Production and export of these dense waters constitute an important component of the global climate system. The formation of dense water in polar areas is controlled by the balance between supplies of fresh water through precipitation, the melt of continental and sea ice and the extraction of freshwater by sea ice formation and evaporation. As deep and bottom waters, these waters of Southern Ocean (SO) origin represent the deepest layer of the global overturning circulation. Their influence can be traced into the Northern Hemisphere, far north of the Antarctic Circumpolar Current (ACC) which delineates the SO to the North. The ACC is the world´s most powerful current system, transporting about 140 Sv (10^6 m^3 s^{-1}) of water at all depths. It connects the Pacific, Atlantic and Indian Ocean and forms a ring around the Antarctic continent. South of the ACC, in the subpolar region, warm and salty water masses are transported by the subpolar gyres towards the continental margins of Antarctica. The most prominent gyres are those of the Weddell and Ross Seas. Therein, water mass modification occurs through ocean-ice-atmosphere interactions and mixing with adjacent water masses. The ACC is dynamically linked to meridional circulation cells, formed by southward ascending flow at intermediate depth and feeding into northward flow above and below. In the deep cell, water sinking near the continental water spreads to the adjacent ocean basins whereas in the shallow cell, the northward flow occurs in the surface layers. Dense waters are produced at several sites near the continental margins of Antarctica. Quantitatively the most important region for dense water formation may well be the Weddell Sea, however other areas provide significant contributions as well.

The basic mechanism of dense water generation involves upwelling of Circumpolar Deep Water, which is relatively warm and salty, into the surface layer where it comes into contact with the atmosphere and sea ice. The newly formed bottom water is significantly colder and slightly fresher than the initial Circumpolar Deep Water, which indicates heat loss and the addition of freshwater. Since freshwater input in the upper oceanic layers would impede sinking due to increasing stratification of the water column, it has to be compensated by salt gain through fresh water extraction. The upwelled water is freshened by precipitation and melting of glacial and sea ice. Freshwater of glacial origin is supplied from the ice shelves or melting icebergs. Ice shelves melt at their fronts and bases in response to the oceanic circulation in the cavity. Iceberg melting depends highly on the iceberg drift and can supply freshwater to areas distant from the shelves as the Antarctic frontal system. Due to the spatial separation of major sea-ice freezing and melting areas, cooling and salt release during sea-ice formation also help compensating the freshwater gain. Significant parts of salt accumulation occur on the Antarctic shelves in coastal polynyas. With extreme heat losses occurring only over ice free water areas, the polynyas are areas of intense sea ice formation. Offshore winds compress the newly formed sea ice and keep an open sea surface in the polynyas.

The cold and saline water accumulated on the shelves can descend the continental slope and mix with water masses near the shelf edge or it circulates under the vast ice shelves, where it is cooled further, below the surface freezing point, and freshened by melt water from the ice shelf. The resulting Ice Shelf Water spills over the continental slope and mixes with ambient waters to form deep and bottom water. For both mechanisms, relatively small scale processes at the shelf front, topographic features and the nonlinearity of the equation of state of sea water at low temperatures is of particular importance to induce and maintain the sinking motion. The various processes, topographic settings and the atmospheric forcing conditions lead to variable spatial characteristics of the resulting deep and bottom water masses which then spread along a variety of pathways to feed into the global oceanic circulation. Climate models suggest that dense water formation is sensitive to climate change. However, since the relatively small scale formation processes are poorly represented in the models, further improvement is needed.

The properties and volume of the newly formed bottom water underlies significant variability on a wide range of time scales, which are only scarcely explored due to the large efforts needed to obtain measurements in ice covered ocean areas. Seasonal variations of the upper ocean layers are only partially known and normally exceed other scales of variability in intensity. Impacts of longer term variations of the atmosphere-ice-ocean system, such as the Southern Hemispheric Annular Mode and the Antarctic Dipole, are only poorly observed and understood. Their influence on or interaction with oceanic conditions are merely guessed on the basis of models which are only superficially validated due to lack of appropriate measurements.

The extreme regional and temporal variability represents a large source of uncertainty when data sets of different origin are combined. Therefore circumpolar data sets of sufficient spatial and temporal coverage are needed. At present, such data sets can only be acquired by satellite remote sensing. However, to penetrate into the ocean interior and to validate the remotely sensed data, an ocean observing system is required, which combines remotely sensed data of sea ice and surface properties with *in-situ* measurements of atmospheric, sea ice and the ocean interior.

Significant progress towards this goal already occurred in the development of appropriate technology and logistics. Now the *Hybrid Antarctic Float Observing System* (HAFOS) observing system, which shall be maintained during this expedition, aims to capitalize on these advances to investigate the ocean interior in the Atlantic Sector of the Southern Ocean, thereby extending the international *Argo* programme into the Weddell Sea and making an important step towards a *Southern Ocean Observing System* (SOOS).

Work at sea

The oceanographic studies during *Polarstern* cruise ANT-XXX/2 will concentrate on two major areas, the Greenwich Meridian and the Weddell Sea, continuing past *in-situ* observations in the Atlantic sector of the Southern Ocean using moored instruments to provide time series of water mass properties throughout the deep and the surface layers. For this purpose, moorings, which feature current meters, temperature and salinity sensors, sound sources and passive acoustic recorders, will be recovered and redeployed (Tables 2.1 – 2.4). While, during the previous expedition ANT-XXIX/2, the recovery of moorings in ice covered areas had been significantly facilitated by using the ultra-short line positioning system (POSIDONIA), it had not been possible, though, to retrieve 3 moorings due to some extreme ice conditions at that time. For that reason, special equipment had been developed to recover moorings directly from the sea-ice and independent of the ship. If necessary this effort will be assisted by a dedicated team of divers which will participate in this expedition.

To enhance the vertical resolution and to calibrate moored sensors, a total of up to 100 CTD stations will be occupied along the cruise track. The CTD/water sampler consists of a SBE911plus CTD system in combination with a carousel water sampler SBE32 with 24 12-l bottles. To determine the distance to the bottom, an altimeter from Benthos is mounted. A transmissometer from Wetlabs, a SBE43 oxygen sensor from Seabird Electronics and a fluorometer will be incorporated in the sensor package. A portable CTD/winch system is on board to be deployed from ice from ice flows to obtain additional profiles along the routes between the mooring locations in the southern part of the Weddell Basin. However, these airborne CTD deployments are optional and are given second priority to the all other operations. Additionally, two RDI-150 kHz ADCPs, one pointing upward, one pointing downward are attached to the rosette sampler to measure the current velocity profile. The ADCPs occupy two bottle positions, thus only 22 bottles are available for water sampling.

To spread CTD observations horizontally, Argo compatible NEMO floats will be deployed en route. The drift of these NEMO floats will distribute them to sampling sites across the Weddell Gyre. Moorings will contain sound sources, providing RAFOS signals for retrospective under-ice positioning of NEMO floats and passive acoustic recorders to record ambient (biotic and abiotic) sounds. During ANT-XXIX/2, about 30 NEMO floats will be deployed across the ACC and throughout the Weddell Sea.

Tab. 2.1: Moorings and PIES to be recovered between Cape Town and. Asterisks (*) indicate PIESs (bottom landers), rather than full moorings.

Mooring PIES	Latitude Longitude	Water Depth (m)	Date Time (at Depth)	Instrument Type	Serial Number	Instrument Depth (m)
ANT3-3*	37° 05.84’ S 12° 45.23’ E	4904	30.11.2010 06:31	PIES	058	4904
ANT4-3*	39° 13.07’ S 11° 20.04’ E	5122	05.12.2011 12:07	PIES DCS	184 752	5122 5122
ANT5-3*	41° 09.77’ S 09° 55.31’ E	4624	02.12.2010 08:05	PIES	182	4624
ANT6-1*	42° 58.80’ S 08° 30.15’ E	3930	02.12.2010 22:17	PIES	069	3930
ANT7-4*	44° 39.73’ S 07° 05.15’ E	4593	03.12.2010 22:17	PIES DCS	181 750	4593 4593
ANT8-1*	46° 12.97’ S 05° 40.23’ E	4786	04.12.2010 14:55	PIES DCS	183 751	4786 4786
ANT9-3*	47° 39.87’ S 04° 15.22’ E	4541	05.12.2010 10:20	PIES DCS	251 26	4541 4541
ANT10-2*	49° 00.77’ S 02° 50.05’ E	4056	06.12.2010 03:58	PIES DCS	250 31	4056 4056
ANT11-4*	50° 15.45’ S 01° 25.18’ E	3901	07.12.2010 00:13	PIES DCS	249 24	3901 3901
ANT12-1*	51° 25.15’ S 00° 00.24’ E	2713	07.12.2010 10:52	PIES	062	2713
ANT13-3*	53° 31.22’ S 00° 00.13’ E	2642	08.12.2010 11:23	PIES DCS	252 32	2642 2642
ANT14-1*	56° 55.71’ S 00° 00.01’ W	3673	10.12.2010 04:15	PIES	191	3673
ANT15-2*	59° 02.37’ S 00° 05.29’ E	4647	11.12.2010 18:51	PIES	189	4647
AWI227-12	59° 02.57’ S 00° 04.91’ E	4600	11.12.2012 14:41	PAM SBE16	1025 319	1020 4557
AWI229-10	63° 59.66’ S 00° 002.67’ W	5172	14.12.2012 12:34	AVTP SBE37	8050 9835	200 200

Mooring PIES	Latitude Longitude	Water Depth (m)	Date Time (at Depth)	Instrument Type	Serial Number	Instrument Depth (m)
				SBE37	447	250
				SBE37	237	300
				SBE16	240	350
				SBE37	435	400
				SBE37	9838	450
				SBE37	438	500
				SBE37	439	550
				SBE37	2086	600
				SBE37	449	650
				SBE37	245	700
				RCM 11	452	706
				SOSO	0026	807
				PAM	1010	969
				RCM 11	475	1977
				SBE37	9833	5126
				RCM 11	144	5127
ANT17-1*	64° 00.70’ S 00° 02.72’ W	5201	14.12.2010 23:45	PIES	125	5201
AWI230-8	66° 02.12’ S 00° 02.98’ E	3552	15.12.2012 14:39	AVTP	10491	200
				SBE37	2088	200
				SBE37	2090	300
				SBE37	2091	400
				SBE37	2092	500
				SBE37	2093	600
				SBE37	2094	700
				AVT	6856	725
				PAM	1009	949
				AVTP	9213	1657
				SBE37	2095	3508
				AVT	9179	3509
AWI231-10	66° 30.71’ S 00° 01.54’ W	4524	17.12.2010 12:00	AVTP	10541	200
				SBE37	2096	200
				SBE37	2098	250
				SBE37	2099	300
				SBE37	2100	350
				SBE37	2101	400
				SBE37	2385	450
				SBE37	2234	500
				SBE37	2386	550
				SBE37	2389	600
				SBE37	2391	650

Mooring PIES	Latitude Longitude	Water Depth (m)	Date Time (at Depth)	Instrument Type	Serial Number	Instrument Depth (m)
				SBE37	3813	700
				AVT	9184	729
				SOSO	0024	830
				RCM 11	509	1812
				SBE37	7726	4413
				AVT	9180	4414
AWI232-10	69° 00.11' S	3370	19.12.2010	ULS	69	150
	00° 00.11' W		10:20	AVTP	8400	250
				AVT	9219	750
				PAM	1003	1250
				RCM 11	212	1800
				POD	403	2000
				SBE37	441	3300
				RCM 11	216	3300
AWI232-11	68° 59.86' S	3319	18.12.2012	AVTP	10925	250
	00° 06.51' W		06:00	RCM 11	469	757
				PAM	1011	958
				RCM 11	512	1765
				SBE37	7727	3265
				AVT	10499	3266

Tab. 2.2: Moorings to be recovered in the central Weddell Sea

Mooring	Latitude Longitude	Water Depth (m)	Date Time (at Depth)	Instrument Type	Serial Number	Instrument Depth (m)
AWI244-3	69° 00.35' S	2900	25.12.2012	SOSO	29	806
	06° 58.97' W		10:27	PAM	0001	998
				SBE16	2419	2857
AWI248-1	65° 58.09' S	5011	27.12.2012	SOSO	0028	839
	12° 15.12' W		08:50	PAM	1013	1081
				SBE37	9841	4968
AWI245-3	69° 03.47' S	4746	28.12.2012	SOSO	16	822
	17° 23.32' W		21:04	PAM	1012	1065
				SBE37	9839	4703
AWI249-1	70° 53.55' S	4364	30.12.2012	SOSO	0030	843
	28° 53.47' W		11:00	PAM	1014	1085
				SBE37	9847	4821
AWI209-7	66° 36.45' S	4830	01.01.2013	SBE16	2420	225
	27° 07.26' W		15:05	PAM	1027	226

Mooring	Latitude Longitude	Water Depth (m)	Date Time (at Depth)	Instrument Type	Serial Number	Instrument Depth (m)
				SOSO	0025	805
				PAM	1028	1007
				PAM	1029	2516
				SBE37	7728	4773
				SBE37	7729	4822
AWI243-1	68° 00.67' S	4443	31.01.2007	SOSO	31	800
	34° 00.15' W		06:15	SBE37	217	4436
AWI208-7	65° 37.23' S	4732	03.01.2013	SBE16	1167	300
	36° 25.32' W		13:4920	SOSO	0029	856
				SBE37	7730	4674
				SBE37	7731	4724
AWI250-1	68° 28.95' S	4100	05.01.2013	SOSO	23	798
	44° 06.67' W		14:53	PAM	1031	1041
				SBE37	9848	4057
AWI217-5	64° 22.94 S	4410	09.01.2013	SOSO	29/34	807
	45° 52.12' W		14:16	PAM	1020	960
				SBE37	9496	4316
				SBE37	9497	4366
				RCM 11	135	4367
AWI216-5	63° 53.61' S	3513	11.01.2013	SBE37	9493	3356
	49° 05.17' W		00:17	SBE37	9494	3406
				SBE37	9495	3456
				RCM 11	215	3457
AWI207-9	63° 42.09' S	2500	12.01.2013	PAM	1032	214
	50° 49.61' W		08:23	AVTP	11888	225
				SBE16	2413	253
				RCM11	474	756
				SOSO	27	807
				PAM	1033	1012
				SBE37	7732	2102
				SBE37	7733	2300
				RCM 11	10530	2308
				SBE37	9492	2489
				PAM	1034	2491
				AVT	10498	2492
AWI207-8	63° 43.20' S	2500	06.01.2011	ULS	63	150
	50° 49.54' W		12:26	RCM 11	294	250
				SBE37	1235	251
				AVT	8405	750
				SOSO	32	850

Mooring	Latitude Longitude	Water Depth (m)	Date Time (at Depth)	Instrument Type	Serial Number	Instrument Depth (m)
				PAM	845	2100
				SBE37	2235	2100
				SBE37	1605	2200
				RCM 11	297	2300
				SBE37	1607	2490
				RCM 11	311	2490
AWI206-7	63° 28.93' S	950	06.01.2011	ULS	65	150
	52° 05.87' W		20:52	AVTP	8417	250
				SBE37	2723	500
				RCM 11	312	501
				SBE16	2418	700
				PAM	844	750
				SBE37	2097	900
				PAM	1006	910
				RCM 11	313	912
AWI206-8	63° 15.51' S	917	14.01.2013	AVTP	11889	276
	51° 49.59' W		05:08	PAM	282LE	277
				SBE16	1975	499
				RCM 11	508	500
				SBE16	1976	706
				PAM	0002	750
				SBE16	1977	908
				RCM 11	100	909
AWI251-1	61° 0.88' S	320	15.01.2013	PAM	231LF	210
	55° 58.53' W		02:13	PAM	1008	212
				ADCP	5848	314
				SBE16	1973	316

Tab. 2.3: Moorings to be deployed along the Greenwich meridian

Mooring	Latitude Longitude	Water Depth (m)	Instrument Type	Instrument Depth (m)
AWI232-12	69° 00.11' S	3370	AVT	250
	00° 00.11' W		AVT	750
			PAM	1250
			RCM 11	1800
			SBE37	3300
			RCM 11	3300
AWI231-11	66° 30.71' S	4524	SBE37	200

Mooring	Latitude Longitude	Water Depth (m)	Instrument Type	Instrument Depth (m)
	00° 01.54’ W		SBE37	300
			SBE37	400
			SBE37	500
			SBE37	600
			SBE37	700
			SOSO	850
			PAM	1000
			SBE37	4500
AWI229-11	63° 59.56’ S	5170	AVTP	200
	00° 002.65’ W		SBE37	200
			SBE37	300
			SBE37	400
			SBE37	500
			SBE37	600
			SBE37	700
			AVT	704
			SOSO	850
			PAM	1000
			SBE37	5150
AWI227-13	59° 02.57’ S	4600	PAM	1000
	00° 04.91’ E		SBE37	4550

Tab. 2.4: Moorings to be deployed in the central Weddell Sea.

Mooring	Latitude Longitude	Water Depth (m)	Instrument Type	Instrument Depth (m)
AWI244-4	69° 00.30’ S	2900	SOSO	800
	06° 58.89’ W		PAM	1000
			SB37	2850
AWI248-2	65° 58.16’ S	5020	SOSO	800
	12° 15.01’ W		PAM	1000
			SB37	4980
AWI245-3	69° 03.52’ S	4740	SOSO	800
	17° 23.05’ W		PAM	1000
			SBE37	4690
AWI249-2	70° 53.67’ S	4360	SOSO	800
	28° 51.99’ W		PAM	1000
			SBE37	4320
AWI209-8	66° 36.70’ S	4830	PAM	200

Mooring	Latitude Longitude	Water Depth (m)	Instrument Type	Instrument Depth (m)
	27° 07.31' W		SBE37	210
			SOSO	800
			SBE37	4775
			SBE37	4825
AWI208-8	65° 37.06' S	4740	SBE37	300
	36° 25.28' W		SOSO	800
			PAM	1000
			SBE37	4680
			SBE37	4730
AWI250-2	68° 29.51' S	4080	SOSO	800
	44° 07.02' W		PAM	1000
			SBE37	4030
AWI217-6	64° 23.88' S	4416	SOSO	810
	45° 51.95' W		SBE37	4320
			SBE37	4370
			RCM 11	4372
AWI216-6	63° 53.66' S	3500	SBE37	3300
	49° 05.20' W		SBE37	3400
			SBE37	3450
			RCM 11	3451
AWI207-10	63° 43.20' S	2500	PAM	200
	50° 49.54' W		RCM 11	250
			SBE37	251
			AVT	750
			SOSO	850
			SBE37	2100
			SBE37	2200
			RCM 11	2300
			SBE37	2490
			PAM	2490
			RCM 11	2490
AWI206-9	63° 28.93' S	950	AVTP	250
	52° 05.87' W		SBE37	500
			RCM 11	501
			SBE16	700
			SBE37	900
			PAM	910
			RCM 11	912
AWI251-2	61° 22.10' S	300	ADCP	250
	56° 00.10' W		PAM	500

Mooring	Latitude Longitude	Water Depth (m)	Instrument Type	Instrument Depth (m)
			SBE37	900

Abbreviations:

ADCP RDI Acoustic Doppler current profiler
AURAL AURAL-Underwater acoustic recorder
AVTCP Aanderaa Current Meter with temperature-, conductivity- and pressure sensor
AVTP Aanderaa Current Meter with temperature- and pressure Sensor
AVT Aanderaa Current Meter with temperature sensor
DCS Aanderaa Doppler current sensor
PAM Passive Acoustic Monitor (Type: AURAL or SONOVAULT)
PIES Pressure inverted echo sounder
RCM 11 Aanderaa Doppler current meter
SBE16 SeaBird Electronics self recording CTD to measure temp., cond. and pressure
SBE37 SeaBird Electronics, Type: MicroCat, to measure temperature and conductivity
SOSO Sound source for SOFAR-Drifter
ULS Upward looking sonar from Christian Michelsen Research Inc. to measure the ice draft

Expected results

We expect to secure data from a large proportion of the instruments currently moored, together with ship-based CTD- and lowered ADCP data.

Data policy

Metadata of recorded data will be made available through the cruise report. Mooring and CTD data will be made available after validation through the PANGAEA database. Float data will be made available through the Argo System. The processing of the lowered ADCP will take several months, but as soon as these data will have been processed and documented they will be made available in PANGAEA, too. Results will be published in international journals.

2.2 Biogeochemical Argo-type floats for SOCCOM (Southern Ocean Carbon and Climate Observations and Modelling)

D. Schuller (SIO-ODF);

not on board: L. Talley, A. Dickson (SIO); S. Riser (U Washington); K. Johnson (MBARI); E. Boss (U Maine); R. A. Feely (NOAA/PMEL); L. Juranek (Oregon State); J. Sarmiento, R. Key (Princeton)

Objectives

The Southern Ocean surrounding Antarctica is the primary window through which the intermediate, deep, and bottom waters of the ocean interact with the surface and thus the atmosphere. In the past 20 years, observational analyses and model simulations have transformed understanding of the Southern Ocean, suggesting that the ocean south of 30°S, occupying just 30% of the total surface ocean area, has a profound influence on the Earth's climate and ecosystems. Prior results suggest that:

- the Southern Ocean accounts for up to half of the annual oceanic uptake of anthropogenic carbon dioxide from the atmosphere;
- vertical exchange in the Southern Ocean supplies nutrients that fertilize up to three-quarters of the biological production in the global ocean north of 30°S;
- the Southern Ocean accounts for about 75% ± 22% of the excess heat that is transferred from the atmosphere into the ocean each year; and
- Southern Ocean winds and buoyancy fluxes are the principal source of energy for driving the global large-scale deep meridional overturning circulation.
- Model studies also project that changes in the Southern Ocean will have profound influence on future climate trends, with corresponding alteration of the ocean carbon cycle, heat uptake, and ecosystems. Projections include:
- due to ocean acidification, the Southern Ocean south of ~60°S will become undersaturated with respect to aragonite (a form of calcium carbonate) by ~2030 with a potentially large impact on calcifying organisms and Antarctic ecosystems; and
- the vertical exchange of deep and surface waters may either increase as winds over the Southern Ocean increase, or decrease as higher rainfall results in more stratification. More vertical exchange would be expected to result in more anthropogenic carbon uptake from the atmosphere, but less storage of carbon through biological cycling, while its impact on heat uptake depends on whether it brings anomalously warm or cold waters to the ocean surface.
-

The SOCCOM (Southern Ocean Carbon and Climate Observations and Modelling) project will implement sustained observations of the carbon cycle, together with mesoscale eddying models linked to the observations. 180 to 200 autonomous profiling floats with biogeochemical sensors (oxygen, nitrate, pH and optical sensors in addition to temperature/salinity) and sea-ice avoidance software will be deployed throughout the Southern Ocean. These will extend current seasonally limited observations of biogeochemical properties into nearly continuous coverage in time, with horizontal spatial coverage over the entire Southern Ocean and vertical coverage to 2,000 m. These float deployments must take place from research ships with CTD/rosette sampling in order to collect water samples (to be analyzed for oxygen, nutrients, pH, alkalinity, HPLC, POC) for float profile calibration. The first set of 6 prototype floats with this configuration of biogeochemical sensors was deployed in the Ross Sea and southern South Pacific in March-April, 2014 from GO-SHIP section P16S on the RV Nathaniel B. Palmer; the floats are operating well, with data reported in near real-time and publicly available from http://www.mbari.org/chemsensor/floatviz.htm (currently the last set of floats listed there). The pH sensor technology, which was developed recently, is proving to be very robust. The T/S data are part of the Argo float data set.

All measurements and calibration measurements, with the exception of the optical measurements, will be funded by the US NSF. Optical measurements included in this plan have been proposed to NASA.

The 15 to 17 floats to be deployed in the Weddell Sea sector from *Polarstern* will be the first large-scale SOCCOM deployment, and will be the first of our international collaborations. These floats will contribute to the international Southern Ocean Observing System (SOOS), and the Argo database.

Work at sea

The 15 to 17 SOCCOM floats will be deployed at dispersed locations along the cruise track, at the location of a subset of the RV *Polarstern* CTD/rosette stations. In the event of exceptionally poor sea conditions/weather that might result in cancellation of a station, the float could be deployed at the next station, but it should always be deployed at the location of a CTD/rosette profile.

Float deployments: The U.W./MBARI Apex-floats, with sensors for oxygen (Aanderaa optode), nitrate (MBARI ISUS), pH (MBARI Deep-Sea Durafet), optical properties (chlorophyll, fluorescence and backscattering at 700 mm, Wetlabs FLBB), and temperature-salinity-pressure (Seabird 43CP CTD), will be shipped to the *Polarstern* in Cape Town. A U.W. engineer will unpack and test them in Cape Town, and then repack them (while still switched on) before loading them on *Polarstern*. At the float deployment location,the float only has to be unpacked and then deploy it as follows: Immediately after finishing the calibration CTD/rosette cast at a deployment location, the ship should relocate to clean water, ~1 km off station, and then proceed at about 1-2 knots in whatever direction offers the most shelter to the deployment. Two marine technicians carry the float to the ship's rail and lower it to the water with a line and then release the line while the ship steams slowly 1-2 knots. If the floats are provided without cardboard cases, the float will first be oriented horizontally and the technicians should watch the float until it tips up vertically. Following deployment the ship should steam in a wide arc back to its steaming direction, ensuring not to pass over the deployment location.

CTD/rosette sampling: At the location of the 15 to 17 float deployments, a CTD/fluorometer station with a 24-place rosette should be occupied. Samples should be collected for oxygen, pH/alkalinity, nutrient analysis by SIO. Sampling order should be gases first (oxygen, pH/alkalinity (single sample), DIC, nutrients, salinity). The nutrient and oxygen analyses will be carried out onboard RV *Polarstern* by SIO's Oceanographic Data Facility (ODF) chemist. The SIO pH/alkalinity samples will be preserved with mercury (II) chloride, sealed, and packed to be shipped back to SIO (Dickson). Approximately 10 % of the samples taken should be duplicates, which usually requires firing two rosette bottles at the same depth. At each float deployment location, the ODF chemist will collect 3 near-surface samples for HPLC and POC, which will be filtered and preserved for shipment by ODF back to the laboratories that will analyze them. HPLC samples must be kept in liquid nitrogen or a -80°C freezer on board the ship after processing.

It is highly desirable to have salinity samples taken from each of the rosette bottles and analyzed onboard *Polarstern* in order to perform quality checks on bottles (tripping and leaking); these would not be run by the ODF chemist. It will also be desirable to have DIC samples run on *Polarstern* from the same bottles as the pH/alkalinity samples that are returned to SIO, in order to merge with the pH, alkalinity and nitrate analyses to obtain the best empirical relationship between all carbon parameters and the measurements that will be made by the floats.

It will be important for the float programme to have the following datasets made available in preliminary form during or shortly after the cruise: CTD T/S/P profile, fluorometer profile, discrete salinity, oxygen (SIO/ODF), nutrients (SIO/ODF). It would also be very useful to have the ULPGC carbon analyses available for comparison.

Tab. 2.5 RV *Polarstern* (ANT-XXX/2) PS89 SOCCOM investigator responsibilities

Investigator	Institution	Responsibility
Lynne Talley	SIO (UCSD)	Observational programme organization; ODF sampling/analyses
Stephen Riser	U. Washington	Apex floats
Ken Johnson	MBARI	Float biogeochemical sensors (pH, nitrate, oxygen)
Emmanuel Boss	U. Maine	Float biogeochemical sensors (optical); Laboratory

		HPLC, POC analyses
Andrew Dickson	SIO (UCSD)	Laboratory pH/alkalinity analyses
Robert Key	Princeton U.	SOCCOM data management, carbon QC
Richard Feely Laurie Juranek	NOAA/PMEL Oregon State U.	Empirical algorithm development
Jorge Sarmiento	Princeton U.	Overall SOCCOM management (director)

Expected results

The profiling float data will be made available immediately following each profile on public websites, including the Argo website (T/S/P data) and MBARI's floatviz website. The floats will have 5 or 10 day cycles and will perform a minimum of 100 profiles. When there is sea ice cover in winter, the floats will only surface after the sea ice has melted and will report all of the profiles collected while under sea ice.

Shipboard data sets that we will provide after onboard analysis: nutrients, oxygen. Shipboard data sets that we will provide after analysis at SIO, NASA and UC Santa Barbara: pH, alkalinity, HPLC, POC.

Data policy

SOCCOM will make all ODF nutrient, oxygen analyses available immediately after collection and onboard quality control, for merging with the other data sets collected on the ship, whether they are collected at float locations or at other stations. We will make all pH/alkalinity data sets available after they are analyzed at SIO.

For profiles at float locations, including all discrete rosette samples and CTD/fluorometer profiles: it is important that these data be available to us for calibration of the floats, in preliminary form and then later with quality control/calibration. SOCCOM can assist with discrete data merging. It would be highly preferable that the data from these stations will be publicly available as soon as possible. SOCCOM would like to post these data on its own website as part of the float programme (R. Key).

For datasets collected at other stations, where floats are not deployed, but where SIO ODF runs oxygen and nutrient analyses, it would be advantageous to us to have access to the profile data for quality control. For stations with full carbon measurements, it would be highly advantageous to collaborate with ULPGC and AWI to extend the SOCCOM empirical algorithm for carbon profiles based on the float data; the algorithm will be developed by SOCCOM (L. Juranek, Oregon State University; R. Feely, NOAA/PMEL). SOCCOM can assist with discrete data merging and quality control. Data release policy will be according to the Chief Scientist (O. Boebel).

2.3 The Carbon system of the Weddell Sea

M. González-Dávila, M. Santana-Casiano (IOCAG); E. Panassa (AWI)

Objectives

The Southern Ocean (SO) remains a key issue in our understanding of the global carbon cycle and how it will respond under predicting future climate change. Recent studies have suggested that SO is uptaking around 30 to 40 % of the anthropogenic excess CO_2 (Cant) followed also by an important and efficient transport of this Cant by intermediate-deep water formation in this area. The uptake and accumulation of Cant is mainly controlled by the ocean circulation and water mass mixing, in particular the deepest penetrations associated with convergence zones. This is why the Southern Ocean is one of the most conspicuous places of the global ocean. The formation of intermediate, deep and bottom water masses together with the upwelling of old waters take place through complex dynamical processes, that will be one of the main objectives of the HAFOS project and this research cruise. North of the polar Front (around 51ºS) the deep winter ventilation that produces the formation of Sub-Antarctic Mode Water (SAMW) and Antarctic Intermediate Water (AIW) inject Cant down to more than 1,000 m depth. To the south, the intrusion of Cant can reach deep and bottom water below 2,000 m during the complex formation of Antarctic Bottom Water (AABW). This cruise will provide a new set of carbon dioxide data for this area that will increase our knowledge of the amount of anthropogenic carbon being incorporated by the different water masses and will be compared with previous results for this area in order to compute anthropogenic carbon inventory, the concentration in deep and bottom layers and its storage and evolution.

In order to achieve these objectives, the Marine Chemistry group (QUIMA) from the Instituto de Oceanografía y Cambio Global (IOCAG) at the Universidad de Las Palmas de Granudent assigned to our group and Canaria will measure at all locations for each CTD cast and along the water column three carbon dioxide parameters: the pH in total scale, the total alkalinity (AT) and the total dissolved inorganic carbon concentration (CT), making the value traceable to the highest standards by using Certified Reference Material for CO_2 analyzes. Moreover it is also planned to include a continuous surface monitoring of both pH and partial pressure of CO_2 together with discrete sampling of surface water for both AT and CT. During the cruise, the QUIMA group will also in charge of analyzing the concentration of dissolved oxygen by using the potentiometry WINKLER method.

Work at sea

Three variables of the carbonate system are being measured along the water column on board of the *Polarstern* cruise in order to achieve the highest level of data quality and resolution and to account for the objectives above proposed. Moreover, a continuous underway xCO_2 sensor PRO-CO2™ has been added to measure the partial pressure of CO_2 in the surface water following the ship trajectory. The QUIMA group of ULPGC owns a coulometric determination system for total dissolved inorganic carbon, the VINDTA 3C system (MARIANDATM), and an automatic spectrophotemetric pH system developed by this same group.

pH : The pH is measured in total scale ([H+]T = [H+]F + [HSO4-], where [H+]F is the free proton concentration), pHT at a constant temperature of 15ºC. An automatized system based on the spectrophotometric technique of Clayton and Byrne [1993] with the m-cresol purple as indicator is used [González-Dávila et al., 2003, Santana-Casiano et al., 2007]. A new and compact device has been developed following previous one using ocean optics technology and included in a fully automatic computer controlled system that clean, sample, produce a zero and a blank reading for each sample to be analyzed. Reproducibility of the system is better than 0.002 pH units (after 11 analysis).

- *Total Alkalinity and Dissolved Inorganic Carbon*: A VINDTA 3C system [Mintrop et al., 2000] (www.MARIANDA.com), is used for the titration of the potentiometric total alkalinity and total dissolved inorganic carbon with coulometer determination after phosphoric acid addition, with a system precision of ± 1.0 µmol kg-1. For alkalinity determination, 100 ml of seawater is titrated by adding HCl to the seawater past the carbonic acid end point. For the CT determination, a calibrated pipette of 20 ml of seawater is filled automatically by pumping and the seawater is injected in a scrubber containing 20 drops of phosphoric acid (10% v/v) and the CO_2 released is trapped in a cathodic solution that is titrated coulombimetrically until photometric end point. Each analysis takes about 20 minutes and a titration cell usually is valid for around 60 samples. The titration of CRMs for both parameters is used to test the performance of the equipment after the preparation of each titration cell.

- *Partial pressure of carbon dioxide:* A continuous xCO_2 sensor (PSI CO2-Pro) designed by Pro-Oceanus Systems company in Halifax, Canada will be installed in a continuous clean seawater output onboard the Research vessel *Polarstern* and close to a Seabird thermosalinograph to continuously monitor the molar fraction of CO_2 along the trajectory of the vessel. To maintain accuracy, the detector module has an automatic zero point calibration (AZPC) that compensates for changes in optical cell performance and significant changes in environmental parameters such as gas stream temperature. An AZPC is performed each 1 hour. Accuracy provided by the company is 1 ppm and precision of 0.01 ppm.
- *Sampling procedure:* 500 ml glass bottles are used for the determination of both alkalinity and inorganic carbon. Two-100 ml glass bottles will be used to analyse the pH and dissolved oxygen concentration. The bottles are rinsed twice with seawater and over-filled with seawater. Samples are preserved from the light and analysed between stations. In shallow stations and in case the samples are not possible to be analysed for CT in less than 5 hours after sampling, they are poisoned with $HgCl_2$. Our group will use around 1 liter of seawater for the full procedure.

Expected results

We expect to get 100 % of each carbon dioxide system variables and oxygen data from each CTD cast, and a high resolution data set for surface carbon dioxide variables along the two months ship track.

Data policy

Metadata of recorded data will be made available through the cruise report. CTD sampling data for carbon system variables and oxygen will be made available after validation through the PANGAEA database. Results will be used by a PhD student assigned to our group and published in international journals.

3. SEA ICE PHYSICS

3.1 Sea ice mass and energy budgets in the Weddell Sea

M. Nicolaus, S. Schwegmann, S. Arndt, J. Kainz, T. Hollands, M. Schiller (AWI)

Objectives

The sea ice physics programme during this cruise is a main contribution to the Sea Ice Physics and Ecology Study (SIPES). SIPES is designed as an inter-disciplinary field study focussing on the inter-connection of sea ice physics, sea ice biology, biological oceanography, and top predator ecology. To achieve this, the sea ice physics programme will perform sea ice thickness surveys, under-ice investigations with a remotely operated vehicle, deployments of autonomous stations (buoys), and along-track ice observations from the bridge. In addition we will obtain physical properties of the sea ice and its snow cover during ice stations. Those measurements are supposed to cover different spatial and temporal scales to allow an advanced understanding of the status and importance of Antarctic sea ice, with respect to its interactions in the climate system and the role as a habitat. In addition, the programme continues previous studies of Antarctic sea ice, which have been performed over the last years and decades. Since the area of investigation has a significant overlap with those of the winter experiments in 2013, results will complement to studies of similar kinds, but under very different environmental conditions. The results from our measurements directly contribute to a suite of national, international, and internal projects on the mass- and energy budgets of sea ice in the Weddell Sea. Based on this interdisciplinary approach, there are three main goals for this expedition:

1. We aim to gather an extensive data set for sea ice and snow thicknesses in the northern Weddell Sea in order to describe the state of sea ice coverage in the observation area. Our measurements aim to improve our knowledge concerning the determination of sea ice thicknesses from other methods like autonomous *in-situ* techniques or remote sensing products. Data that will be obtained during the cruise will be additionally useful for the validation of sea ice and snow parameters derived from satellite data (e.g. CryoSat, SMOS) and numerical models (e.g. FESOM), which in turn are used to identify the variability and trends in the sea ice cover.
2. We aim to better quantify relationships between physical properties of sea ice and its associated ecosystem. Therefore, surveys with the remotely operated vehicle (ROV) will be used to map sea ice and water properties on floe scales. A major focus is the quantification of optical properties of sea ice and the amount of sunlight transmitted through the ice. This will allow direct insights into the spatial variability of sea-ice conditions and their relation to ice algal biomass.
3. We aim to improve our ability to interpret SAR data from satellites in order to gain additional knowledge about sea ice deformation and dynamical properties. From the combination of *in-situ* measurements with coordinated satellite data retrievals we aim to directly match both scales of observations.

Deployments of autonomous observatories, groups of drifting buoys that complement each others observations, will enable to extrapolate the findings of the ice station work through time series data from the same floes at least into summer and the next winter.

Work at sea

Helicopter-based EM-Bird (Figure 3.1) surveys are a key element for the *in-situ* sea ice thickness measurements. The EM-Bird measures sea ice thicknesses by electromagnetic induction sounding and will serve, together with surface elevation measurements with a laser altimeter, the regional total (sea ice + snow) thickness distribution next to the cruise track. Additionally included in the EM-Bird system is an air camera from which sea ice concentration and ice class distribution can be visually obtained.

During the planned ice stations, a variety of measurements will be undertaken. In order to find the most representative spots for other measurements as well as to investigate the sea ice thickness distribution at the ice station site, high resolution data will be obtained prior to other activities by using a ground-based Geonics EM-31 or multi-frequency GEM. These devices use electromagnetic induction sounding, like the EM-Bird, and will be carried with a sledge along profiles. Snow depth will be complementary measured with a Magna Probe along the ice thickness transects and over the ROV field. Further observations will include snow pit measurements from which snow properties like density, presence/absence data of flooding (slush) and ice layers within the snow cover will be investigated. One ice station is planned on sea ice in Atka Bay (close to Neumayer III Base) during the station supply, to support and extent monitoring programme (Antarctic Fast Ice Network) there.

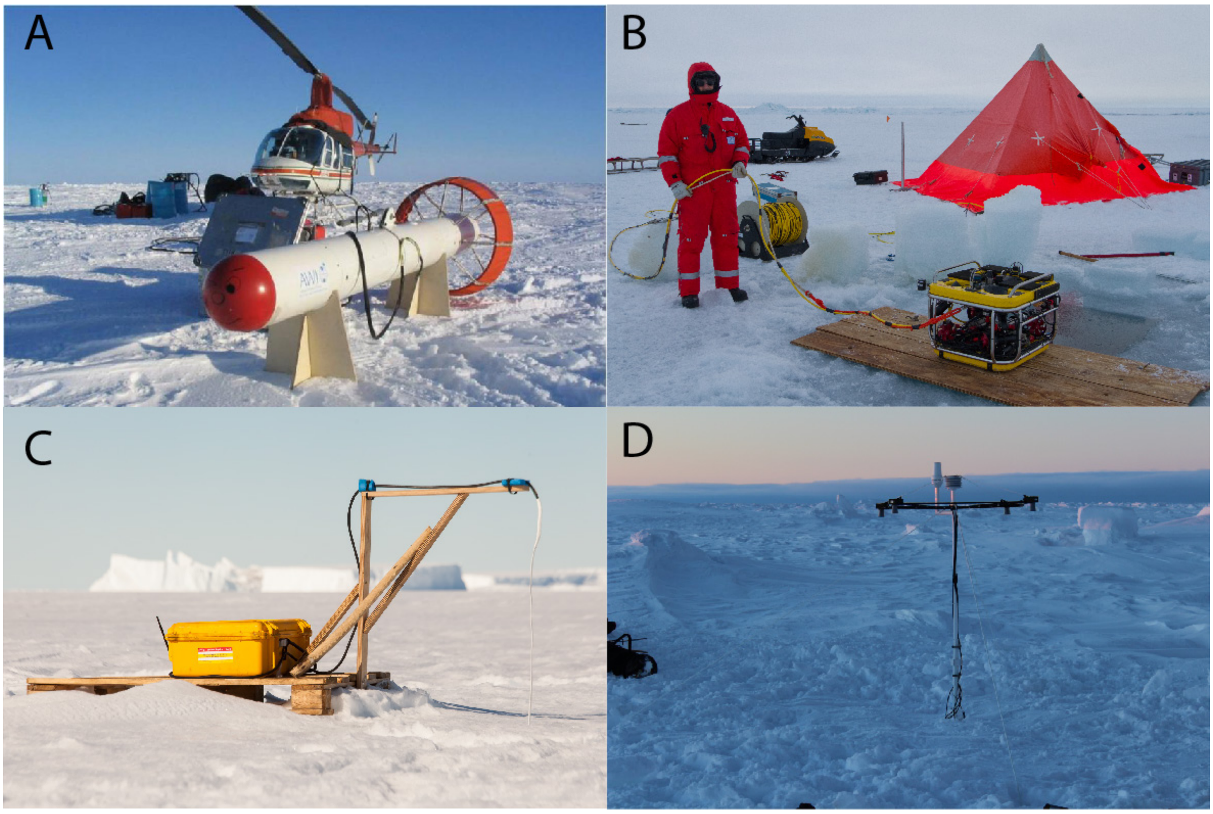

Fig. 3.1: Main instrumentation of the sea ice physics programme A) EM Bird for sea ice thickness measurements, B) Remotely Operated Vehicle (ROV, here on Arctic sea ice), C) Thermistor String Buoy (IMB), D) Snow Depth Buoy.

Another key element of the ice station work are hyperspectral measurements of optical properties of snow, sea ice, and the uppermost ocean. These measurements will be based on above, in, and under-ice radiation measurements using Ramses spectroradiometers ranging from 320 to 950 nm. Two of these radiometers will be mounted on a Remotely Operated Vehicle (ROV) and operated along transects and grids under sea ice while a reference sensor will measure solar irradiance above the ice. The two radiometers on the ROV will measure irradiance for energy budget estimates and radiance in order to characterize different light regimes depending on snow and ice conditions. In addition to the radiometers, the ROV will be equipped with similar sensors as the SUIT (see section 4.1). Such, the ROV measurements will contribute also to the fine-scale description of sea ice habitat properties. This kind of ROV work is planned for each ice station off *Polarstern*, but novel developments might allow helicopter transportation of the equipment to more remote floes, too.

Since sea-ice temperature, salinity, and texture determine most small-scale properties of sea ice, including those relevant as habitats, these parameters will be obtained through ice-core analyses. On each ice station, a set of ice cores will be taken and processed immediately in a freezer lab container (at -20°C) on board *Polarstern*. In addition archive cores will be taken and stored after the cruise. Moreover, ice cores for bio-optical measurements will be taken in cooperation with the sea ice biology group in order to study correlation between spectral optical properties and bio-optical sea ice parameters such as particular absorption.

In order to detect the temporal evolution of the physical state of an ice floe after leaving the ice station, different autonomous systems will be deployed. Spectral radiation stations will be deployed to measure solar irradiance above and under sea ice. These stations also include basic meteorological measurements and serve as key elements of SIPES. Thermistor string buoys (IMB) will help to detect the temporal evolution of snow and sea ice thickness as they measure the sea ice surface and bottom accumulation and melt. Complementary, sensors allow for measurements of air, snow, and sea ice temperature. Snow Depth Buoys will additionally serve small-scale regional variability of snow accumulation. In combination with the deployment of drifting GPS buoys in an array around the station, the evolution of sea ice and snow thickness can also be related to dynamical processes.

The coordinated acquisitions of TerraSAR-X images over the buoy arrays will link the high resolution *in-situ* buoy drift with ice drift retrieved from the satellite image time series. This will help to validate the drift algorithms and contribute to the analysis of sea ice dynamics and deformation for larger areas at high spatial resolution. Complementary, ice conditions (especially with respect to small-scale surface roughness and appearance) will be documented in written and photographical form at the time of satellite overpasses in order to investigate the influence that properties might have on the received satellite signal. Combined with other field work measurements, this will improve our ability to interpret the SAR images acquired during the campaign and might lead to a better understanding of the effects which influence the SAR signal over sea ice.

Complementary information on the physical state of the sea ice including its concentration, the three most dominant ice classes and their respective coverage, ice floe structure and snow thickness will be visually detected hourly from the bridge of *Polarstern* between ice stations. Data will be documented together with the meteorological state and the location within a standardized protocol for such observations. Those data will contribute to the database of the ASPeCt programme, which already compiled data for about three decades, and is used to create and update a sea ice thickness climatology for the Antarctic. In order to support and validate these visual observations, as well as to obtain high resolution sea ice thickness and snow data complementary to those measured at ice stations, suitable floes will be surveyed between ice stations using the helicopter for transportation.

Expected results

The expected results of SIPES will contribute to a statistically sound understanding of the role of sea ice in structuring Antarctic ecosystems, and will enable quantifications of the flux of sea ice-derived carbon through Antarctic food webs. The outcome of this study will serve the development of coupled bio-physical sea ice-ocean models, as well as more precise predictions of future shifts in biodiversity, function of Antarctic ecosystems, and resource availability.

Data policy

Metadata of recoded data will be made available through the cruise report. All data will be published after processing in the PANGAEA database. Buoy data contribute to the International Program on Antarctic Buoys (IPAB) and are available online in real time through www.meereisportal.de, and the ship observations will directly contribute to the Aspect online database (www.aspect.aq). Final results and analyses will be published in international journals.

4. BIOLOGY

4.1. Sea ice ecology, pelagic food web and top predator studies

H. Flores (AWI, UHH); J.A. van Franeker, A. Meijboom, F. Schaafsma (IMARES); A. Van de Putte (RBINS); G. Castellani, M. Vortkamp (AWI); J. Ehrlich (UHH); B. Feij (NIOZ); M. van Dorssen (van Dorssen Metaalbewerking)

Objectives

Sea ice ecology, pelagic food web and top predator studies during PS 89 are a main contribution to the Sea Ice Physics and Ecology Study (SIPES). SIPES is designed as an inter-disciplinary field study focussing on the inter-connection of sea ice physics, sea ice biology, biological oceanography and top predator ecology. Pelagic food webs in the Antarctic sea ice zone can depend significantly on carbon produced by ice-associated microalgae. Future changes in Antarctic sea ice habitats will affect sea ice primary production and habitat structure, with unknown consequences for Antarctic ecosystems. Antarctic krill *Euphausia superba* and other species feeding in the ice-water interface layer may play a key role in transferring carbon from sea ice into the pelagic food web, up to the trophic level of birds and mammals (Flores et al. 2011, 2012). To better understand potential impacts of changing sea ice habitats for Antarctic ecosystems, the HGF Young Investigators Group *Iceflux* in cooperation with IMARES (*Iceflux-NL*), aim to quantify the trophic carbon flux from sea ice into the under-ice community and investigate the importance of sea ice in the support of living resources. This will be achieved by 1) quantitative sampling of the under-ice community and environmental parameters; 2) using molecular and isotopic biomarkers to trace sea ice-derived carbon in pelagic food webs; 3) applying sea ice-ocean models to project the flux of sea ice-derived carbon into the under-ice community in space and time, and 4) studying the diet of sea ice associated organisms.

In the Southern Ocean, the exploitation of marine living resources and the conservation of ecosystem health are tightly linked to each other in the management framework of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). Antarctic krill is important in this context, both as a major fisheries resource, and as a key carbon source for Antarctic fishes, birds, and mammals. Similar to Antarctic krill, several abundant endothermic top predators have been shown to concentrate in pack-ice habitats in spite of low water column productivity (van Franeker et al. 1997). Investigations on the association of krill and other key species with under-ice habitats will be complemented by systematic top predator censuses in order to develop robust statements on the impact of changing sea ice habitats on polar marine resources and conservation objectives.

Work at sea

SUIT sampling

A Surface and Under-Ice Trawl (SUIT: van Franeker et al. 2009) will be used to sample the pelagic fauna down to 2 m under the ice and in open surface waters. During SUIT tows, data from the physical environment will be recorded, e.g. water temperature, salinity, ice thickness, and multi-spectral light transmission. Core SUIT deployments will be conducted along transects from open water into the closed pack-ice and back in a restricted survey area which will be defined based on sea ice conditions and biological indicators. Intermediate SUIT hauls will be conducted during the passage between moorings. At the planned ice stations, SUIT hauls will be conducted on arrival and/or departure to obtain the maximum possible comparability of under-ice species composition and abundance and under-ice sensor data with data collected during the ice stations.

Pelagic sampling

We aim to also investigate deeper-dwelling key species of the pelagic food web, such as euphausiids, amphipods, and myctophids. A Multiple opening Rectangular Midwater Trawl (M-RMT) will be used at many SUIT locations. A new type of dip-net will be tested to sample zooplankton surface swarms from a helicopter, should those be encountered. For biomarker analysis, Particulate Organic Matter (POM) will be collected from filtered seawater obtained from the CTD rosette. Chlorophyll samples will be filtered from melted ice cores and CTD rosette water samples to calibrate fluorometers built in the ship's CTD and the SUIT. In addition, *Polarstern's* EK60 echosounder will be running during steaming to map the distribution of resources in the water column continuously and identify potential hot spots for target hauls for SUIT and M-RMT.

Sea ice work

Our sea ice work is conducted in close collaboration with AWI sea ice physics (S. Schwegmann, M. Nicolaus), and I. Peeken (AWI). On-ice work will consist of ice coring, bio-optical measurements, and the deployment of sea ice buoys (see chapter 3.1). Ice coring and bio-optical measurements will be done at multiple sites in order to capture the small-scale variability of ice algal biomass and physical properties. At each coring site, cores will be collected for biomarker analysis; chlorophyll *a* content; salinity; temperature and ice texture. The bio-optical measurements are an important prerequisite for the calibration of hyper-spectral light profiles obtained from SUIT and from the bio-optical ice buoys. They require the deployment of an L-arm under the ice with a mounted spectral radiometer to acquire the spectral light properties of the sea ice and the under-ice environment. At L-arm survey sites, ice cores will be extracted and processed for chlorophyll *a* content in order to determine the relationship of ice algal biomass with the under-ice spectral light properties.

Biomarker analysis

For later biomarker and diet analysis, samples of phytoplankton, zooplankton, sea ice POM and water column POM collected with the CTD rosette, SUIT, other nets and ice corers will be stored in ethanol or frozen at -80°C on board.

Top predator censuses

During steaming, surveys of top predator densities will be conducted mainly from observation posts installed on the flying bridge. Standard band transect methods are used, with snapshot methodology for birds in flight, and line-transect methods for marine mammals. To improve spatial coverage, top predator surveys will be conducted from a helicopter following rigid grid patterns. In addition, heli-surveys will be offered for closer inspection of the surroundings of dive holes built for the recovery of moorings, checking for the presence of Leopards seals.

Expected results

We expect to obtain a comprehensive dataset of the distribution and diversity of pelagic and under-ice fauna in the core survey area as well as along the Weddell Sea cross-section. In conjunction with physical data from our collaborators of the sea ice physics group, our environmental datasets will help to model the relationship of ice-associated biota with their habitat. Data collected by autonomous sea ice buoys will provide a unique dataset of the evolution of bio-optical properties of Antarctic sea ice over the entire season. Biomarker and diet samples will be analysed in the home laboratories and will contribute to a more quantitative understanding of the role of ice algal production and sea ice associated zooplankton in the Antarctic food web. In combination with top predator census data from IMARES and from the whale census group on board, interdependencies of the sea ice ecosystem may be mapped from the level of physical parameters to the distribution of large mammals.

Data policy

Almost all sample processing will be carried out in the home laboratories at AWI and IMARES. This may take up to three years depending on the parameter as well as analytical methods (chemical measurements and species identifications and quantifications). As soon as the data are available they will be accessible to other cruise participants and research partners on request. Depending on the finalization of PhD theses and publications, data will be submitted to PANGAEA and SCAR-MarBIN, and will be open for external use.

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4.2 Cetaceans in ice

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not on board: H. Herr, U. Siebert (ITAW)

Objectives

The main aim of this project is to further our understanding of the contribution of cetaceans to biodiversity within Antarctic sea-ice ecosystems and to develop baseline cetacean data for measuring impacts of climate change and increasing human activities in the Southern Ocean.

Knowledge on the density, distribution and habitat use of cetaceans in the Antarctic is comparably limited. Until today it is unknown to what extent cetaceans use the ice covered waters, though they are thought to play an important role in the sea-ice ecosystem and thus to contribute largely to biodiversity in this habitat. Knowledge on cetacean densities in relation to sea ice concentrations is central for understanding impacts of climate change on the Antarctic marine ecosystem as well as for Southern Ocean ecosystem management, including the conservation and management mandate of the International Whaling Commission (IWC). Especially, but not only, data on Antarctic minke whale *(Balaenoptera bonaerensis)* distribution in ice covered areas of Antarctica are urgently needed and requested by the IWC, as current abundance estimates of cetaceans in Antarctic waters are based on assessments conducted up to the marginal ice zone only. Without surveying for whales across the ice zone it is almost impossible to estimate their entire population sizes (i.e., both inside and outside of the ice) and how changes in climate and increasing human presence around the Antarctic will impact on whale populations in the coming decades.

Aerial surveys are currently the favoured method for obtaining data on cetacean occurrence in pack ice regions. Regional estimates of cetacean densities in selected areas of varying sea ice concentrations may allow to compare bounds and magnitudes of abundances of cetaceans, both inside and outside of the sea ice region and provide valuable information in order to account for potential biases in current abundance estimates.

By means of dedicated cetacean sighting surveys, our project aims to contribute to base line data on cetacean occurrence and abundance, especially of Antarctic minke whales in selected areas of the Antarctic. We will conduct aerial as well as ship-based cetacean sighting surveys following standard line-transect distance sampling methodology to obtain estimates of density for selected cetacean species with a special focus on Antarctic minke whales. In addition behavioural observations shall investigate response behaviour of cetaceans towards vessels in Antarctic waters.

Work at sea

We will conduct shipboard and aerial cetacean sighting surveys whenever sighting and weather conditions permit (i.e. calm seas, good visibility). For the shipboard survey our observation platform will be the crow's nest and we will survey along the cruise track of *Polarstern*. During any shift two observers will collect sighting data according to distance sampling methodology and a third person will enter these data directly into a computer connected to a GPS. The same method will be followed during the aerial surveys, which will be conducted from the helicopters. The track lines for the helicopter surveys will be designed ad-hoc, whenever weather conditions and ship logistics permit a flight. In general, a square shaped track design around the ship will be followed. Priority will be given to the aerial surveys, but given the size of our team, it will be possible to conduct both methods in parallel.

In addition to the distance sampling survey we will conduct a tracking study from the crow's nest, i.e. focal follows of detected (groups of) animals with high-powered binoculars („Big Eyes"), noting down their track (angle and distance to ship) as long as possible. This is a means to evaluate cetacean behaviour, for example movement in response to the ship.

Expected results

We expect to collect aerial as well as ship-based sighting data that can be used for regional density estimation and model-based investigations of cetacean – sea-ice relationships. The tracking data is expected to contribute to a data base used to model cetacean behaviour in response to vessel presence.

Data policy

All recorded data will be stored in the cetacean survey data base of the ITAW. An overview of data obtained during the expedition (effort, sighting numbers, species) will be made available in the cruise report. Results will be published in international journals and made available to the IWC.

5. GEOSCIENCES

5.1. Culture experiments on trace metal incorporation in deep-sea benthic foraminifers from the Southern Ocean

E. Wurz (AWI);
not on board: J. Wollenburg (AWI)

Objectives

The Antarctic Ocean is one of our most important climate amplifiers: First, the production of Antarctic deep water drives the Global Thermohaline Conveyer Belt, thus, climate. Second, the Antarctic deep water during glacial time was/ disputably still is, the largest marine sink of atmospheric CO2. Employment of effective sensitive and in geological sense preserverable proxies to obtain precise information on changes in the polar deep oceans physical to geochemical properties are essential to assess past, modern, and future physical to geochemical changes in bipolar deep-waters. In this respect, analyses on trace metal (Mg/Ca, U/Ca, B/Ca) ratios recorded in tests of foraminifers to estimate calcification temperatures, salinity variations, carbonate ion saturation, pH and alkalinity became common methods. However, for the Southern Ocean deep-sea benthic foraminifera calibration curves constrained by culture experiments are lacking. During this expedition we will retrieve multiple corers from 1,500 m water depth and transfer the retrieved sediments into 15 different aquaria including newly developed high-pressure aquaria. These aquaria will in different experimental set-ups be used to cultivate our most trusted paleodeep-water recorders at different temperatures and in waters with different carbonate chemistries to establish species-specific trace metal calibration curves for the Antarctic Ocean.

Work at sea and expected results

Since our work is focused on epizooic Cibicides-type foraminifers, filter-feeding unilocular animals with maxima abundances in areas of high current activities, we will deploy 2-3 multiple cores at exposed sites with a water depth around 1500m. The retrieved cores will be transferred into a cold laboratory running at a site-alike bottom water temperature during the cruise. During the last day on board the sediments and overlaying water will be transferred into transfer-cores and storage systems. These storage systems will be transferred into special cold boxes ensuring a site-alike temperature during the flight to Bremerhaven. In Bremerhaven the sediments will immediately transferred into the respective aquaria and connected to respective supportive sea-water systems..

Data management

This work is part of a bipolar DFG-project on the incorporation of trace metals in benthic deep-sea foraminifera. The results will be published in international journals within approx. 2 years after the expedition.

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51	Wurz	Eric	AWI	Student
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53	Zwicker	Sarah	AWI	Student

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02.	Spielke, Steffen	1.Offc.
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05.	Stolze, Henrik	2.Offc.
06.	Hering, Igor	2.Offc.
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13.	Ganter, Armin	Electron.
14.	Dimmler, Werner	Electron.
15.	Winter, Andreas	Electron.
16.	Feiertag, Thomas	Electron.
17.	Schröter, Rene	Boatsw.
18.	Neisner,Winfried	Carpenter
19.	Clasen, Nils	A.B.
20.	Burzan, Gerd-Ekkehard	A.B.
21.	Schröder, Norbert	A.B.
22.	NN	A.B.
23.	Hartwig-L., Andreas	A.B.
24.	Kretzschmar, Uwe	A.B.
25.	Müller, Steffen	A.B.
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27.	Sedlak, Andreas	A.B.
28.	Beth, Detlef	Storekeep.
29.	Plehn, Markus	Mot-man
30.	Fritz, Günter	Mot-man
31.	Krösche, Eckard	Mot-man
32.	Dinse, Horst	Mot-man
33	Watzel, Bernhard	Mot-man
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35.	Tupy,Mario	Cooksmate
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