science
& technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

NRF
National
Research
Foundation

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

Winter 2017 Cruise Report

S.A. Agulhas II

VOYAGE 25

Edited by Marcello Vichi
(Marine Research Institute, Department of Oceanography, UCT)
with contributions from the cruise participants

Table of Contents

Figure 1 The team of participants of the Winter 2017 cruise

1 Introduction and aims

The Winter 2017 cruise (Voyage 25) of the S.A. Agulhas II was funded by DST/NRF and took place from 28 June to 13 July 2017. The cruise consisted of 3 legs with several national and international participants and an intense interdisciplinary programme. Details on the framework in which this voyage originated are illustrated in the final Chapter 15.

The major goal of the cruise was to capture the winter recharge conditions in the Atlantic-Indian Ocean sector of the Southern Ocean, from open ocean conditions to the marginal ice zone (MIZ), with a special emphasis on documenting the variability of the MIZ. The voyage was also endorsed by GEOTRACES as a process study and it covered the sampling of the WOCE I06 transect. The cruise participants are listed in the table below and portrayed in Figure 1 on their way back to Cape Town. There were 11 scientific teams on board (Chapters 3-13), with the addition of an artist that made an alternative documentation record of the cruise that brought art and science together (Chapter 14).

Captain Knowledge Bengu was the master of S.A. Agulhas II during the voyage. The officers and crew on the cruise were a real integral part of the scientific expedition and they contributed much beyond their duties. The Chief Scientist and all the scientific participants are extremely grateful for their commitment and dedication; they made this difficult voyage in the winter Southern Ocean an experience to remember and a real scientific success. Special acknowledgments are included in the various scientific sections.

The main scientific aims of the cruise were multiple:

- To train South African students on sea ice research, polar oceanography and engineering, trace elements, atmospheric deposition, nitrogen and carbon cycling, plankton characterization (Resp: all PIs)
- To document sea ice growth processes, physical properties (temperature, porosity, salinity, solid-fluid-gas volume fractions), and the mechanical properties (strength, stiffness, fracture toughness, viscous-elasticity) of sea ice (Resp: MacHutchon, UCT)
- To collect unprecedented data set of met-ocean data in the Southern Ocean, including inside the MIZ during extreme winter conditions; understanding the complex wave physics of the Southern Ocean and the interaction process between waves and sea ice; and upgrading and validating new physics in wave and sea ice model (Resp: Joubert, SAWS; Eayrs, NYUAD; Toffoli, UniMelb)
- To develop computational sea-ice modelling based on observed and measured data to study and predict the break-up and fracture evolution of sea-ice during the Antarctic spring; advance understanding of the complex material behaviour of sea-ice in terms of its liquid and gas-filled porous structural composition; elucidate the mechanisms of biogeochemical exchanges with the underlying ocean and the brine expulsion (Resp: Skatulla UCT, Ricken UniD-E, Bertrand TUD)
- To characterize the phytoplankton community composition and biomass across the marginal ice zone in association with the physical properties of ice (Walker, CPUT)
- To characterize the phytoplankton community composition and biomass along the WOCE I06 line. These will be a repeat of studies carried out in 1993, 1996 and by RV Roger Revelle in 2008, and will therefore lend itself greatly to assessing decade-scale changes (Walker, CPUT, Fawcett, UCT)
- The sampling of the I06 WOCE transect will collect data that can be compared with the previous cruises in the 90’s and 2008 in order to address the changes in the Indian Ocean water masses and to contribute to the activity of the International Indian Ocean Expedition II.
- To investigate the surface ocean and lower atmosphere nitrogen (N) cycle in the Southern Ocean to test the hypothesis that surface ocean biology can be a significant source of NH_x (NH_3 + NH_4^+) to the marine atmosphere (Altieri, UCT)
- To conduct the N transformation and kinetic experiments for NH_4^+ and organic N uptake, NH_4^+ and NO_2^- oxidation, and where appropriate, NO_3^- uptake (Fawcett, UCT)
- To measure soluble, colloidal and dissolved fraction of trace metals in the water column (Fe, Mn, Cu, Zn, Cd, Co, Ni, Pb, Mo, Hg, REEs) according to GEOTRACES protocols, as well as the particulate speciation of Fe, Cu and Zn in colloidal and nano- particles (Roychoudhury, SUN) and trace metals in aerosol (Fietz, SUN; Altieri, UCT)
- To measure stable Isotopes of Fe, Cu, Zn, Ni and Si (Roychoudhury, SUN) as well as nitrate and water isotopes ($\delta^{15}N$ and $\delta^{18}O$, Fawcett, UCT).

- To collect nutrient and nitrogen isotope data from sea ice cores to evaluate the sea ice nitrogen cycle and role of sea ice nutrient cycling in CO_2 cycling (unknown for this sector), and track atmospheric deposition to the ice in this "pristine" region (Fawcett, UCT)
- To evaluate the balance of the various meteorological processes acting on seawater (e.g., evaporation, precipitation, ice formation) using water isotopes ($\delta^{18}O$ and δD). (Fawcett, UCT and Roychoudhury, SUN)
- to assess the importance of the southern African dust for ocean fertilization or inhibition (due to potentially carriage of toxic compounds of anthropogenic origin). We aim to collect aerosol particles within the major dust emitting season and along the major dust plume pathways (i.e. towards the Indian Ocean) and study the main physical (e.g., grain size affecting kinetics of dissolution), and chemical (e.g., content and speciation of macro- and micronutrients) properties (Fietz, SUN, Altieri, UCT). To support this work, concurrent samples for phytoplankton biomass (as chlorophyll a) and community composition will be taken (Walker, CPUT)
- To obtain high quality vibration and human response data on the SA Agulhas II as a result of wave slamming using wave observations and measurements through meticulous rigid body motion measurements. Further data will be collected on shaft-line responses as a result of ice impacts as recent findings have shown that the most critical ice loadings can occur in water with lower ice concentration when propeller blades impact isolated ice floes at high speed (Annie Bekker, SUN)
- To collect data from acoustic (euphausiids), oceanographic, bathymetry and predators (whales and seabirds), To determine the long term response of krill to climate change and environmental variability (Fannie Shabangu, DAFF);
- To contribute to the inventory of distribution and abundance of seabirds related to oceanographic properties for the Atlas of Seabirds at Sea (AS@S, Taryn Morris, BirdlifeSA)
- To conduct observations on distribution and abundances of marine mammals and their linkages to environmental (oceanographic and biological) parameters (DEA)

Team	Name	Affiliation	Gender	Role
CS	A/Prof Marcello Vichi	UCT	Male	Chief Sci
MET	Dr Warren Joubert	SAWS	Male	PI (deputy CS)
MET	Ms Mardene Chrissie De Villiers	SAWS	Female	Scientist
OCE	Ms Tahlia Trish Henry	UCT	Female	Technical chief
OCE	Mr Ayanda Mpalweni	UCT	Male	MSc
OCE	Mr Tumelo Maja	UCT	Male	Hons
OCE	Mr Kirodh Boodraj	CSIR	Male	MSc
OCE	Ms Waajidah Arends	STS	Female	STS tech
SEAICE	Dr Keith Robert MacHutchon	UCT	Male	PI
SEAICE	Dr Sebastian Skatulla	UCT	Male	co-PI
SEAICE	Ms Ehlke de Jong	UCT	Female	MSc
SEAICE	Mr Wade Matthew de Kock	UCT	Male	MSc
SEAICE	Mr Emmanuel Omatuku Ngongo	UCT	Male	MSc
SEAICE	Ms Riesna Audh	UCT	Female	Hons
SEAICE	Mr Rutger Marquart	UCT	Male	PhD
SEAICE	Mr Benjamin Andrew Hall	UCT	Male	MSc
SEAICE	Dr Fleurianne Herveline Cecile Bertrand	UniD-E	Female	INT PI
SEAICE	Prof Tim Ricken	TUDort	Male	INT PI
SEAICE	Ms Carla Henning	TUDort	Female	INT PhD
SEAICE	Mr Marcel Moldenhauer	UniD-E	Male	INT PhD
SEAICE	Mrs Carolin Birgitta Mehlmann	UniD-E	Female	INT PhD
SEAICE	Mr Andre Mielke	TUDort	Male	INT PhD
WAVE1	A/Prof Alessandro Toffoli	UniMelb	Male	INT PI
WAVE1	Dr Miguel Onorato	UniTurin	Male	INT PI
WAVE1	Dr Alberto Giovanni Alberello	UniMelb	Male	INT PI
WAVE2	Dr Clare Eayrs	NYUAD	Female	INT PI
WAVE2	Dr Jhon Fredi Mojica Moncada	NYUAD	Male	INT PI
N cycle	Dr Sarah Fawcett	UCT	Female	PI
N cycle	Mr Mhlangabezi Mdutyana	UCT	Male	PhD
N cycle	Mr Jeremy Kravitz	UCT	Male	MSc
N cycle	Ms Jessica Burger	UCT	Female	MSc
N cycle	Mr Matthew Austen Bone	UCT/UEA	Male	INT PhD
AtmDep	Ms Mishka Rawatlal	UCT	Female	MSc
AtmDep	Ms Shantelle Smith	UCT	Female	Hons
AtmDep	Mr Kurt Spence	UCT	Male	Hons
Ornit	Mr John Daniel IV Kinghorn	AS@S	Male	Birder
Ornit	Ms Ilana Engelbrecht	Birdlife	Female	MSc
Ornit	Ms Nasreen Khan	AS@S	Female	Birder
Ornit	Mr Makhudu Masotla	AS@S	Male	Birder
Ornit	Ms Vanessa Cherry Stephen	AS@S	Female	Birder

Team	**Name**	**Affiliation**	**Gender**	**Role**
Ornit	Mr Niall Perrins	AS@S	Male	Birder
Plankton	Dr David Walker	CPUT	Male	PI
Plankton	Ms Nicole du Rand	CPUT	Female	MTech
Plankton	Mr Kyle Maurer	CPUT	Male	MTech
Plankton	Mr Sedick Gallie	CPUT	Male	BTech
Plankton	Ms Lauren Briant	CPUT	Female	MTech
Plankton	Ms Tayla Hadwen	CPUT	Female	BTech
Plankton	Mr Michael Hart-Davis	CPUT	Male	BTech
Plankton	Ms Roxanne Megan Oliver	CPUT	Female	Btech
Plankton	Ms Jennifer Mohale	CPUT	Female	BTech
Plankton	Ms Melissa Nel	CPUT	Female	BTech
TraceEx	Dr Susanne Sabine Fietz	SUN	Female	PI
TraceEx	Dr Thato Nicholas Mtshali	CSIR	Male	PI
TraceEx	Dr James Richard Lloyd	SUN	Male	co-PI
TraceEx	Mr Bjorn Phillip von der Heyden	SUN	Male	Lecturer
TraceEx	Ms Natasha Renè van Horsten	CSIR	Female	PhD
TraceEx	Mr Jean Christian Loock	SUN	Male	PhD
TraceEx	Mr Ryan Cloete	SUN	Male	PhD
TraceEx	Mr Kaukurawee Kangueehi	SUN	Male	MSc
TraceEx	Mr Ian J Weir	SUN	Male	MSc
TraceEx	Mr Johannes Jacobus Viljoen	SUN	Male	MSc
TraceEx	Ms Jodie Alice Pieterse	SUN	Female	4th yr BSc
TraceEx	Mr Andile Mkandla	SUN	Male	underg
Vibeng	Mr Clinton Frederick Wood Saunders	SUN	Male	PI
Vibeng	Mr Brendon Mark Nickerson	SUN	Male	MSc
Vibeng	Mr Christof Moolman van Zijl	SUN	Male	MSc
Vibeng	Mr Butteur Mulumba Ntamba Ntamba	CPUT	Male	PhD
Vibeng	Mr Frederic Francois Anderson Cloete	SUN	Male	MSc
Artist	Katrine Claassens	UCT	Female	MSc

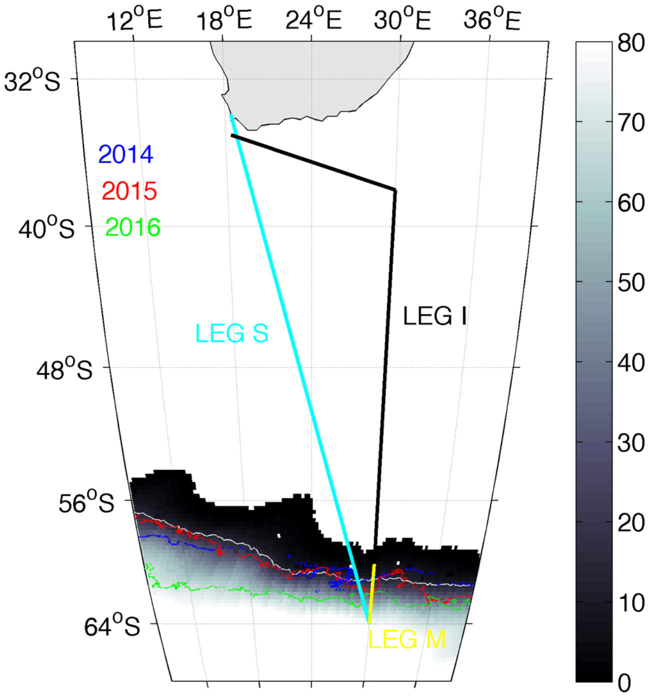


Figure 2 Planned cruise track. The sea ice 80% concentration in July 2014, 2015 and 2016 is shown together with the sea ice climatology from the SSMI sensor data (NSIDC).

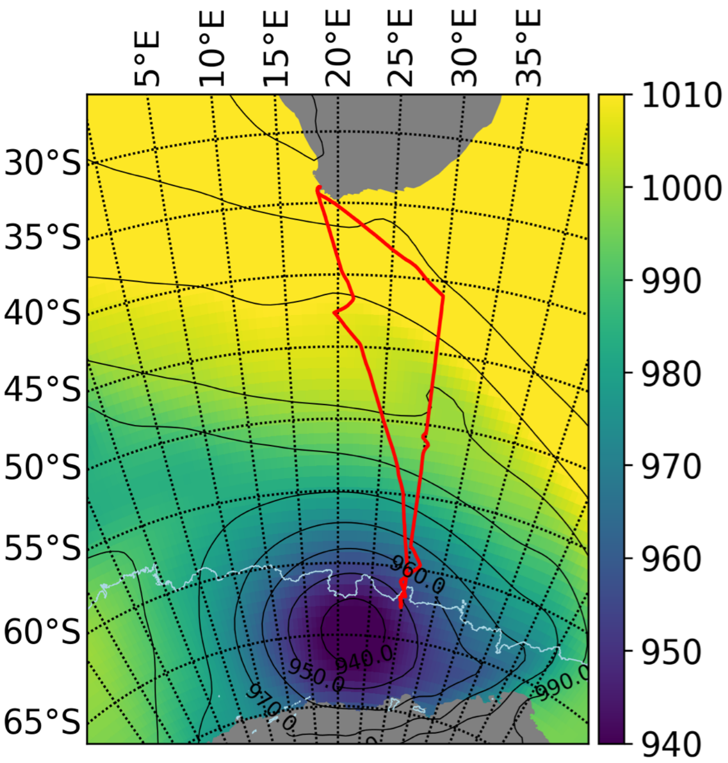


Figure 3 Cruise track of the Winter 2017 expedition (red line) overlain to the 04/07/2017 mean sea level pressure from ERA-Interim reanalyses (shading and contours) and 15% sea ice concentration from AMSR2 (light blue line).
The ship was at the southernmost location on that day.

2 Itinerary, stations and narrative of the cruise

The pre-departure operations started on the day before and some international and non-local scientific members spent the night on board in order to be ready for an early departure. The departure from Cape Town was in the afternoon of the 28th June after completion of all passenger procedures. The planned cruise track is shown in Figure 2 and the actual track in Figure 3. The first station was planned at approximately 40 °S, therefore it was expected after a couple of days of navigation. Leg S was mostly a steaming leg, with only the preparative stations for the GEOTRACES process studies (soaking, reference and testing of the bottles). The underway measurements (Chap. 3, 4, 5 and 6) and the other observational activities for seabird, waves and ship vibrations (Chap. 7, 8 and 9) continued throughout the entire cruise.

The first storm was encountered on the afternoon of the 29th with wind of about 30 m/s and a substantial North-westerly swell. Unfortunately, the ship does not have a wave radar that allowed to estimate the significant wave height. An attempt was made to carry out station S01 at 16:00 GMT. The wind was still above 20 m/s and the automatic positioning system did not allow safe operation conditions due to the different direction of the swell. The station was called off. During the manoeuvre, the ship experienced a big stern slamming and a wave entered from the main stern door on Deck 3 inundating the Environmental Hangar. The scientists on the stern close to the iron lab containers were soaked and a pair of spectacles was lost. During the night, the bad weather persisted and the ship experienced some vigorous slamming. The navigation speed was reduced to appx. 12 knots though maintaining the planned heading.

In the morning of the 30th the wind decreased and the ship headed W to avoid the swell. The preparation for the first station started in the early afternoon. The complexity of the operations for trace metal measurements required the involvement of other members of the science team beyond TraceEx. In particular, due to the positioning of the iron lab on the stern of Deck 3, it was necessary to have people walking with the GoFlo bottles back and forth from the Environmental Hangar. S01 started regularly at about 42° 41’ S at 16:00 GMT (Figure 4).

The ocean conditions impacted hard on the health on board. Many science team members were seasick and the few standing had to work longer shifts to carry out the underway sampling operations and the on-deck incubations. Despite this, the morale was high and every night after dinner the science teams met in the auditorium for a seminar series illustrating the work being done by everyone. It turned out to be such an interesting event that there was not enough time to accommodate all the interested speakers.

Given the delay due to bad weather and the very short amount of time available to reach the MIZ (planned for the 3rd -4th July) and to allow enough time for the stations on Leg I, on the 1st of July the Captain suggested to increase the speed of the ship turning the engine into “ice mode”. Speed was increased to 17 knots and the drop keel was raised, which implied the loss of information on currents through the ADCP. This was a necessary choice taken by the Chief Scientist. The ADCP was planned to be deployed in correspondence of all the stations, but the frosted water when transiting the MIZ and the metocen conditions throughout the cruise impeded this operation. ADCP data are therefore available only for the Leg S stations.

During the next 2 days, the operations on board mostly consisted in underway sampling and preparation for sea-ice observations, buoys deployment and ice coring (Chapters 5, 6). Sea-ice satellite data were downloaded daily to establish the best location for the MIZ stations. They indicated the advancement of the MIZ and a steady increase of the concentration in the target zone. On the 2nd July, the team for sea-ice observations started the training. The majority of members had no prior experience in sea ice observations. Leg M consisted of minimum 3 stations but several kind of sampling according to the following table:

NAME	**DEPTH**	**DESCRIPTION**	**TYPE**	**LON**	**LAT**	**COMMENTS**
M01	50 m (hand)	Baskets on consolidated ice; CTD Niskin Deployment of 3 trackers on stands	hoists + cranes Shift 0: exploration (corer, auger and saw) Shift 1-3: coring, sampling and deployment	30˚E	62˚S	Latitude of station depending on presence of consolidated ice for sampling and deployment
M02	50 m (hand)	Baskets on close drift ice; CTD Niskin; Deployment of 2 trackers + 2 buoys	Shift 1-2: coring, sampling and deployment Pancake lifting: 4	30˚E	61˚S	(station M02 or M03 depending on Ice conditions)
M03	50 m (hand)	Open drift ice; CTD Niskin (SEAICE). Platform for deployment of (SEAICE, WAVE1)	Pancake lifting: 6	30˚E	62˚S	Deployment of the prototype Spotter wave buoy in open waters within the MIZ

The last Leg S station S03 was done on the 3rd July. It involved the testing of the McLane pump operated from the aft deck (TracEx team) and therefore the timing of operations had to be carefully controlled in order to allow the sequential involvement of the crew members. This testing was very helpful as it allowed to prevent further issues on Leg I and smooth operations. Given the very limited time for performing the samples, this turned out to be a very good investment of time.

Weather forecasts from SAWS indicated a large frontal system approaching the area of sea ice operation on the 4th of July (Figure 8). A large swell from North-West had been experienced since the past 2 days and there was hope that sea ice was going to dampen the waves and allow safe sampling operations. The initial planning (see table above) of ice coring and buoy deployment operations had to be revisited in order to deal with rough conditions. It was determined to use the ship hoists operated from the front cranes and to have 2 teams working on the same large ice floe. All the crew members and the Bosun were very instrumental in this phase.

Remote sensing data from the AMSR-2 sensor put the MIZ at approximately 61°S (Figure 5), although there was a large discrepancy between different sensors and algorithms. It was decided to start the observation shifts at 21:00 GMT in order to capture any occurrence. Safety lamps were turned on approximately at midnight. Until 4am of the 4th July there was no sign of sea ice but sea surface temperature started dropping below zero. The first hints of sea ice brush were seen at 4.45am GMT and eventually the ship entered a large field of pancake ice with floes smaller than 3 m, on average 40 – 60 cm thick. Long waves with estimated periods of more than 10 s were still high and were felt by the ship that was however proceeding at sustained speed (16-17 knots). After a few hours of navigation, the ship entered an area of open drift. Based on the satellite map from the day before, it was estimated that the ship passed the ice tongue and we headed SW towards the area where more consolidated ice was expected. This turned out to be the wrong choice because the ship moved out of the open drift region into full open ocean. Visibility was limited due to the storm and snow was falling heavily (wind speed reached 30 m/s with stronger gusts) but sea ice concentration seemed to increase in the SE direction.

After the change of heading, the pancake floes started to become larger in size, even if none of them was large enough to allow safe coring operations and a proper deployment of the buoys. Due to time constraints, it was decided to continue until 64S with the hope to find consolidated conditions. It was clear that the ice surface detected by the satellite was 100%, although the structure and composition was far from being consolidated, with estimated significant wave height of more than 5 m (they were measured to be 7 m, see Sec. 9.1). Pancakes became large enough for buoy deployment and it was decided to change the initial science plan and measure floe movement at smaller scales. Station M01 was split in 2 stations with the deployment of 1 wave buoy and 1 tracker each, at a distance of approximately 2 km apart (M01 and M02 became the two most southernmost stations of Leg M and the ship headed north after them). On the way back North ice conditions changed very quickly and the ice surface was very mobile. The conditions encountered on the way South to M01 were not encountered and the ship had to move erratically to find the desired sea ice features for the other sampling operations.

Figure 4 shows the location and time of the stations in the MIZ. Chapters 9 and 10 illustrates all the deployment operations and some of the preliminary results. Station M03 was therefore the first station with water measurements and the metal basket with 3 scientists and the hand-held CTD and Niskin bottle was used. This operation resulted very time consuming and not much efficient, reducing the amount of time for pancake lifting. The lifting was also quite unsuccessful because of the excessive ship movement due to the high waves and their direction that was changing. Ice floes continued to hit the hull and made the lifting operations with the basket very difficult. Only one pancake was collected and after that the frame holding the basket to the hook bent. The station was closed to allow time to prepare another basket.

The reason for using the handheld CTD was to allow water sampling from the same ice floes that were cored. Since coring was cancelled, M04 was turned into a CTD station with the use of the rosette from the ship side. This allowed to dedicate more time to pancake lifting that was rather successful with the new system designed by the engineers. During the operation, several big waves caused slams that interrupted the work of the ice team. The weather conditions were very rough but unfortunately the time constraints forced a continuation of the operations at the limit of safety (see Chap. 15 for some additional remarks). A very large pancake was taken on board and secured to the portside on Deck 3 for coring the next day, with hopefully calmer conditions. After the closing of Station M04, the ship continued to head NW in order to face the swell and the wind that was always larger than 20 m/s. The sea ice team was hoping to have another station at the very ice margin to collect more smaller pancakes, but in a few hours of navigation the ship entered open waters with big waves. The conditions became less rough at about 5am on the 5th of July, when it was possible to have the last deployment of the open ocean wave buoy (Sec. 9.3; it operated for only one day reporting intense wave field of 7 m height and 14 s period at deployment).

The storm decreased in the morning of the 5th and allowed to check the conditions on the decks. It was found that several big floes were washed on deck (a large one on Deck 3 that was used to collect ice cores for material property studies, Figure 49); one of them also damaged a mast on the ship's bow that had to be taken down. The new set of satellite images allowed to understand what happened on the day before. The whole pancake field moved South as the ship was on it, indicating a substantial influence of the storm on the marginal ice zone movement. A briefing was held with the Captain and the team PIs to illustrate the events of the day before.

The sampling of Leg I started on the 6th July in the early morning with I01. This was the first station with full sampling operations (GoFlo, Niskin and McLane pump) and it took more than 5 hours. I02 started on the same day throughout the night. The teams demonstrated perfect synchronization in handling the various aspects of the sampling. The timing improved after every station and all members were punctual and accurate in carrying out all duties. Given the need to return to Cape Town on a fixed date, this

On the 7th of July the ship hit another storm and the Captain had to reduce speed with a delay of about 3 hors in reaching the I03 location. The ship struggled to keep the position on the station: The GoFlo sampling was cancelled and the Niskin cast was reduced to only 300 m to shorten the operation time. The same bad weather conditions persisted on July 8th for Station I04 (located on a hydrothermal vent), when the ship had to bear away from the wind several times to get to the station position. The situation was further complicated by large changes in bathymetry and the random reset of the echo sounder. It was thus decided to shift the location South in order to be on the safer meridional flank of the sea mount with a depth of 3500 m. All the sampling operations went fine and on time for a full station. The timing of McLane pump operations decreased to approximately 1.5 hours and it was done in between the two CTD casts to gain further time.

The weather improved on the 9th of July and the station I05 was reached on time. Echo sounder was still problematic with frequent reset and a final reading of 5147 m at the opening of the station. I06 occurred on the same day during the night. These tight conditions were of extreme fatigue for the team members and especially for the people working in the iron lab that had very few hours of sleep between the collection of the samples and the preparation of the bottles for the next station. For Station I07 on the 10th it was decided to swap the GoFlo cast with the Niskin in order to give more resting time for the TracEx people. This however reduced the amount of time to the next station that opened at 8pm on the same day. A briefing with the Captain indicated that in order to have the ETA to Cape Town in the morning of the 13th it was necessary to cut off the stations and to head back from the location of I08.

The ship continued to sail in “ice mode' at an average speed of 15-16 knots headed to Cape Town (Figure 3). A final station with GEOTRACES measurements was planned in the Agulhas, but given the high sailing speed and the need for the team to have some hours of rest, the ship turned out to be already in the Agulhas bank when everything was ready for another station.

The ship arrived at the entrance of the harbour at about 4am local time. However, it was not allowed to moor at the East Pier dock due to some safety issues and material that needed to be moved away. This operation required the whole morning and the teams were allowed off the ship only in the mid of the afternoon.

Table 1 List of stations with indication of GEOTRACES (TM) and Niskin (IO) casts. Cruise Number: AGU0254. SA Agulhas II Voyage 25. Source: T Henry (OCE)

	Date	Station ID	Station description	Latitude	Longitude	Progressive Number
LEG S	30/06/2017	S01	Geo Soak	42° 40.86 S	20° 04.43 E	AM00650
	01/07/2017	S02	Geo Test	47° 05.21 S	23° 29.41 E	AM00651
	03/07/2017	S03	Geo Ref	55° 30.45 S	28° 18.65 E	AM00652
LEG M	04/07/2017	M01	Buoy1	62° 46.733 S	29° 48.626 E	AM00653
	04/07/2017	M02	Buoy2	62° 46.684 S	29° 51.229 E	AM00654
	04/07/2017	M03	Buoy3+ Hand	61° 58.036 S	30° 08.918 E	AM00655
	04/07/2017	M04	CTD Ice+ Pancake	61° 58.16 S	30° 09.44 E	AM00656
	04/07/2017	M05	Drifter	61° 58.403 S	30° 09.715 E	AM00657
LEG I	06/07/2017	I01	TM1 IO1	58° 30.05 S	30° 00.00 E	AM00658
	06/07/2017	I02	TM2 IO2	56° 00.11 S	30° 00.02 E	AM00659
	07/07/2017	I03	IO3	53° 30.097	29° 59.988	AM00660
	08/07/2017	I04	TM4 IO4	50° 35.281'S	29° 59.708'E	AM00661
	09/07/2017	I05	TM5 IO5	47° 59.973'S	30° 00.052'E	AM00662
	09/07/2017	I06	TM6 IO6	45° 29.995 S	30° 00.022 E	AM00663
	10/07/2017	I07	TM7 IO7	42° 59.654 S	29° 59.851 E	AM00664
	10/07/2017	I08	TM8	41° 00.016' S	29° 59.989' E	AM00665

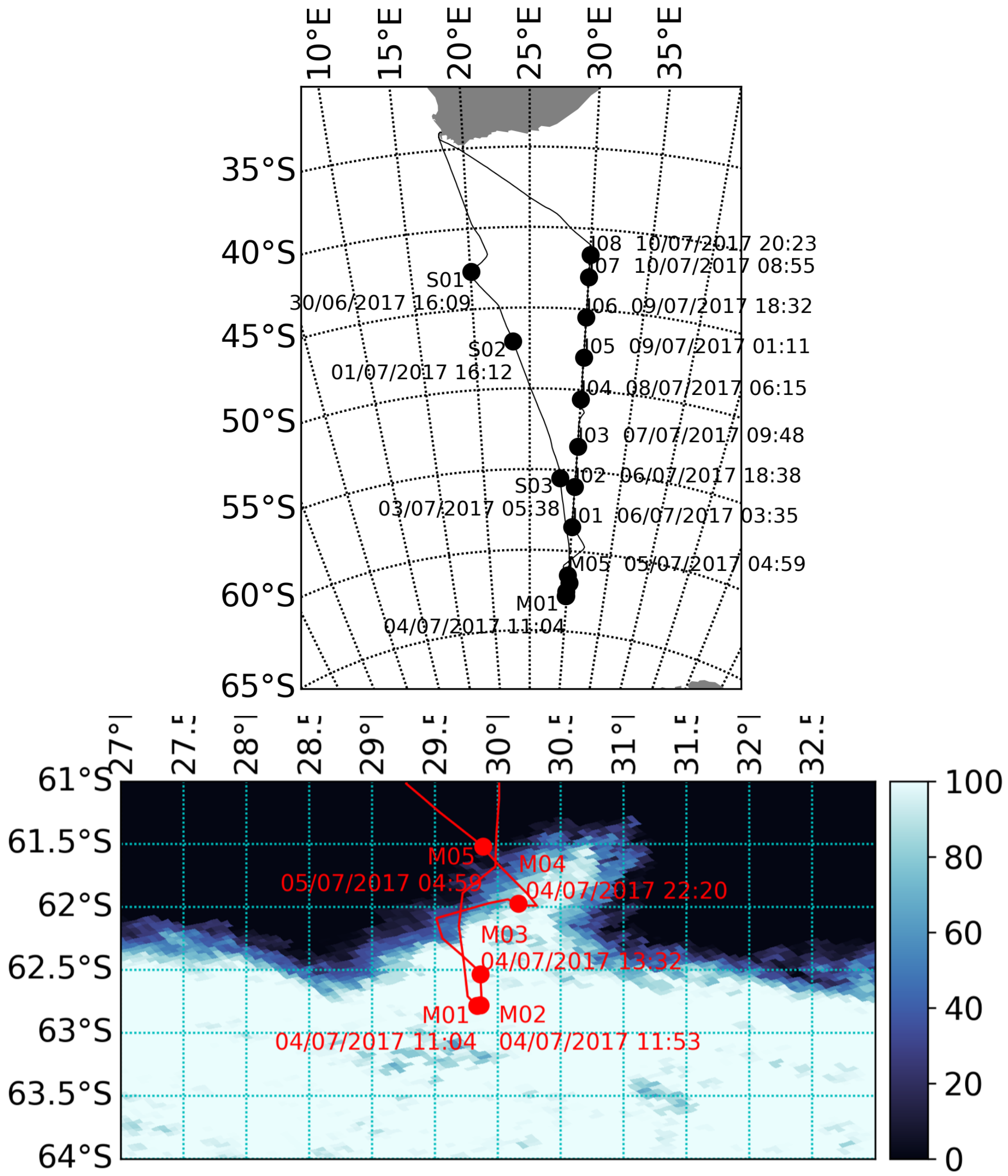


Figure 4 Top panel: Location and dates of the Winter 2017 stations (time is GMT and corresponds to the time of starting of the station activities; see Table 2 for details). Bottom panel: zoom on the location of sea-ice stations M01-05. Daily sea-ice concentration from ASI-AMSR2 (Uni Hamburg).

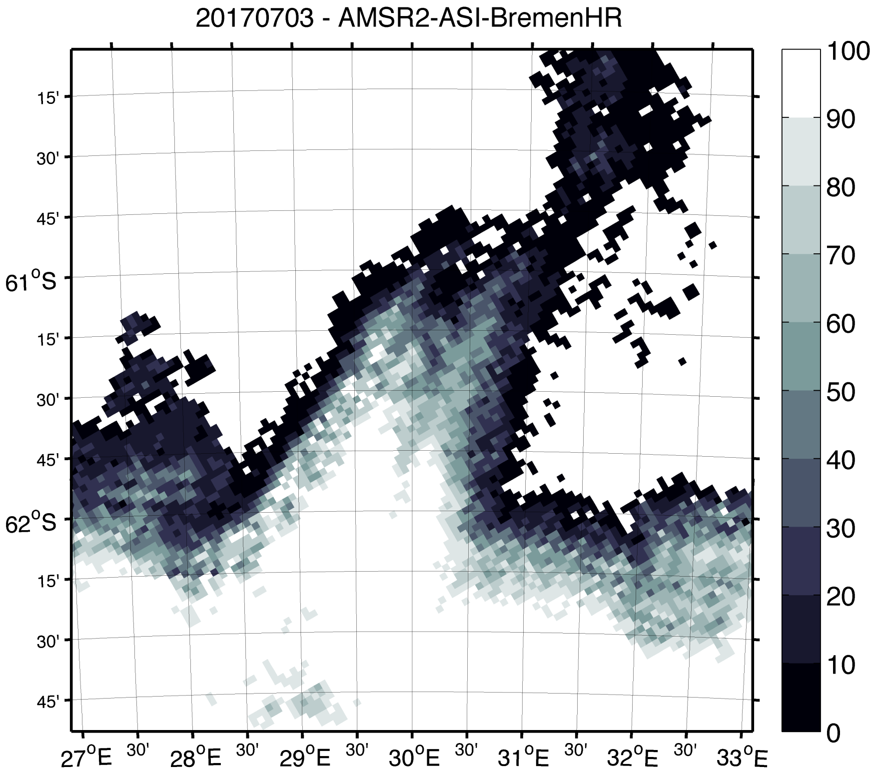


Figure 5 AMSR2-ASI sea ice concentration data downloaded on the ship at midnight of the 03/07/2017.

3 Underway Meteorological Observations

Contributors: Warren R. Joubert and Mardene DeVilliers

South African Weather Service (SAWS)

3.1 Surface Synoptic Observations

Underway meteorological observations were logged continuously every hour on the Automatic Weather Stations (AWS) onboard the SAAgulhas II. Surface synoptic observations were conducted every 3 hours throughout the duration of the voyage. Parameters included:

- Date and Time
- GPS position
- Wind speed and direction
- Swell direction, period and height
- Atmospheric Pressure and tendency
- Air and Sea temperature
- Humidity
- Visibility
- Cloud conditions
- Present and recent weather conditions

Temperature and humidity was measured using a Vaisala Humicap HMP155 probe. Atmospheric Pressure was determined using a Vaisala PTB110 barometer. Wind speed and direction is determined using a Gill Wind Observer II ultrasonic anemometer. The accuracy of sensors (temperature, atmospheric pressure and wind speed) were verified prior to the ships departure. Data is logged using a Campbell Scientific CR1000 logger at 1 hourly intervals. Automated data were transmitted through the FM13 ship message generation system and submitted through the global transmission system (GTS) at 3 hourly intervals and additionally logged manually on a spreadsheet.

Surface air temperature and atmospheric pressure along the cruise track are shown in Figure 5. During the cruise a technical problem was observed with the wind direction measurements, which showed an offset relative to the ships wind data. It is recommended that wind data collected through the ship data system be used for scientific work.

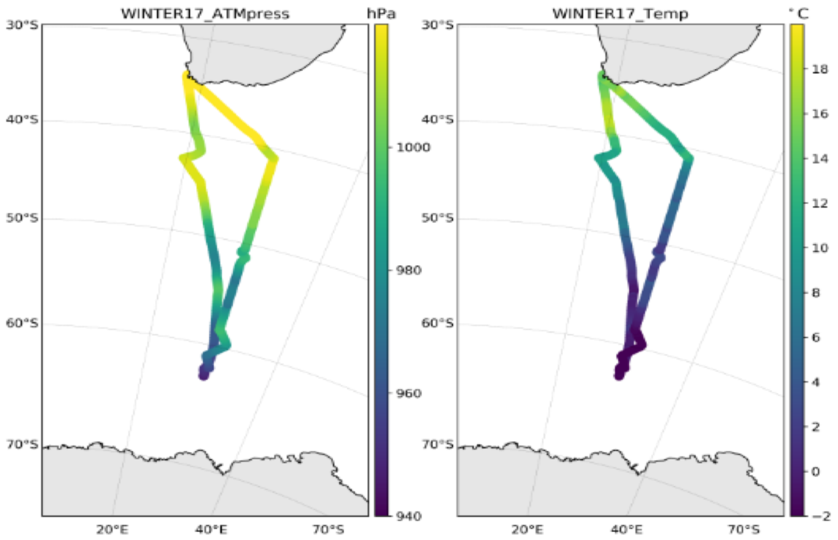


Figure 6 Atmospheric pressure and surface temperature along the transect during Winter 2017

3.2 Upper Air Soundings

Upper air soundings were conducted daily at midnight from beyond 200 nautical miles from South Africa. The radiosondes (Type iMet-2-AA) were deployed from the aft hangar on deck 7. An approximate distance of 25 km of the troposphere was measured for temperature, pressure, humidity and wind speed. Ten successful deployments were completed, while one failed deployment attempt was done on 1 July 2017 during strong wind conditions, which swept the balloon straight into the aft crane of the ship.

3.3 Heat flux observations

A KippZonen pyranometer and pyrgeometer installed on the ship's mast above the bridge collected underway surface solar radiation over the wavelength range 300 – 3000 nm and long wave atmospheric radiation emitted from the earth as infra-red. Several problems were encountered with the observations during the voyage. Electrical problems associated with moisture and the relative inaccessibility of the instrument on the crow's nest inhibited the efficient data collection. Upon inspection of the instrument during the voyage, it was discovered that non-water proof plugs were used in the crow's nest, and it was found that the cabin in the crow's nest was not properly insulated from water. Every visit to the crow's nest showed that some water was present. The water kept shorting the plugs on the electricity distribution board on the bridge. The ships electrician was asked to replace the plugs, however due to the bad weather experienced and the dangers of working at heights, it was only replaced and fixed after 3 days have passed. After the plugs were replaced the data collection commenced on the northbound leg of the voyage.

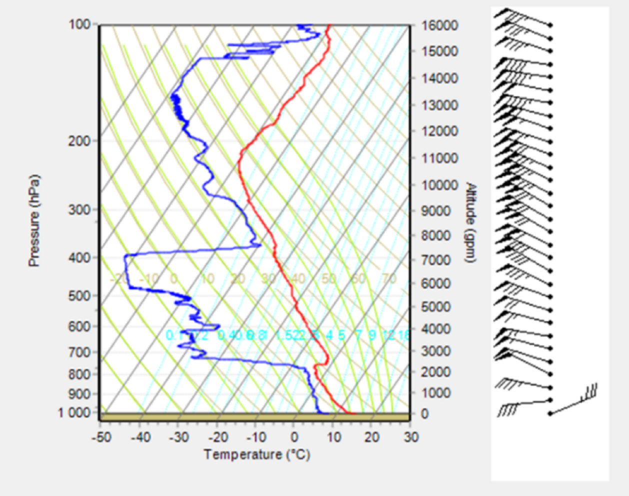


Figure 7 Example of SkewT plot of upper air radiosonde collected on 11 July 2017. It shows temperature (red), dewpoint temperature (blue) and wind speed with altitude.

3.4 Drifting weather buoys

Drifting weather buoys measuring air temperature and atmospheric pressure were deployed at the following locations. The drifters were deployed on leaving the station at these positions.

Buoy ID	678970	**Buoy ID**	770120	**Buoy ID**	773170
WMO ID	1701517	**WMO ID**	1701524	**MMO ID**	1501524
Date	08/07/2017	**Date**	09/07/2017	**Date**	10/07/2017
Time (GMT)	12:42	**Time (GMT)**	23:26	**Time (GMT)**	23:34
Latitude (DD°mm.mm')	50°35.125'S	**Latitude (DD°mm.mm')**	45°29.823'S	**Latitude (DD°mm.mm')**	41°00.292'S
Longitude (DD°mm.mm')	29°59.488'E	**Longitude (DD°mm.mm')**	29°59.926'E	**Longitude (DD°mm.mm')**	29°59.458'E
Air Temp	1.3	**Air Temp**	5.4	**Air Temp**	11.1
Sea Temp	2.1	**Sea Temp**	9.5	**Sea Temp**	18.1
QNH	990.9	**QNH**	1009.2	**QNH**	1014.7

Tab. 2: Drifting buoy deployment information

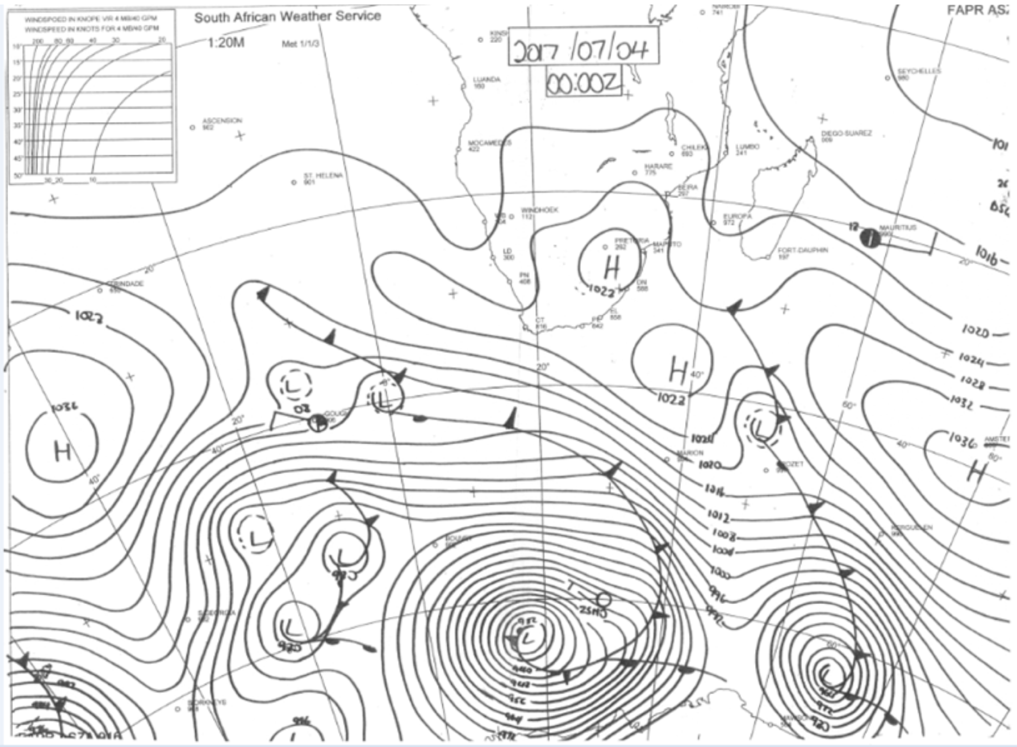


Figure 8 Synoptic chart for 00:00z on 4/07/2017 indicating the frontal systems and pressure isobars of the surface atmosphere.

3.5 Communications

Communication infrastructure during the cruise worked very well. Bandwidth throughout the voyage were always available, so no problems were observed during the voyage. Forecasts (3 days based on the ships anticipated noon positions) and shipping charts (e.g. Figure 8) were received regularly (every 6 - 12 hours) from the SAWS National Forecasting Centre. The forecasts described the synopsis of the atmospheric pressure in the region, along with the wind, weather and sea-state.

An example of the Three day forecast:

Day 1 : Tue 04/07/2017: 62°00 S 030°00 E
Synopsis : Deep frontal low (932 hPa) to the south-west of the area.
Wind : NW 30 to 40, moderating overnight.
Wx : Cloudy with rain, showers and snow.
Sea State : 8.5 to 9.5 m, with NW swell.

Day 2 : Wed 05/07/2017: 58°55 S 029°25 E
Synopsis : Deep frontal low (956 hPa) to the south-west of the area, weakening.
Wind : NW to W 20 to 30, reaching 35 to 40 in the morning.
Wx : Cloudy with rain, showers and snow, mostly in the morning.
Sea State : 6.0 to 6.5 m, with NW swell.

Day 3 : **Thu 06/07/2017:** 53°09 S 026°45 E

Synopsis : High pressure dominating and a cold front approaching from the west.

Wind : NE to 10 to 20, becoming N to NW 15 to 25 in the evening, reaching 30 to 35 overnight.

Wx : Partly cloudy with evening rain.

Sea State : 3.0 to 3.5 m, with W swell.

4 Hydrographic data

Contributors

Tahlia Henry[1,2] (PI), Wade de Kock[1], Ayanda Mpalweni[1,3], Tumelo Maja[1], Kirodh Boodraj[1,3]

1. University of Cape Town (UCT)
2. Nelson Mandela University (NMU)
3. Council for Scientific and Industrial Research (CSIR)

Responsibilities

- CTD operations: Geotrace and Niskin cast
- Winch driver for all over the side operations
- Underway measurements: ADCP (Acoustic Doppler Current Profiler), TSG (thermosalinograph), underway salinity samples
- Salinometer operator
- Post processing of CTD data

4.1 CTD Operations

The CTD rosette used for this cruise was a “clean” frame provided by CSIR in order to fulfil the needs and requirements of a Geotrace CTD. The underwater unit was serviced prior to the voyage and performed flawlessly throughout the cruise. The sample bottles (Niskins and GoFlos) were interchanged between casts therefore the same frame, winch (Kevlar) and underwater unit was used for the duration of the voyage.

Standard protocol was followed for all CTD operations between the ship’s crew, bridge and CTD operators. Additional cleaning procedures of individual Niskin bottles, sensors and frame were implemented once the GoFlos were removed and replaced in order to prevent trace metal contaminates etc. Each cast was run timeously and in accordance with the winch capabilities and sea-state allowance. Minor repairs were performed on the CTD rosette namely the centre firing console due to a piece of latex glove caught in the firing hook. Two Niskin bottles were repaired prior to a cast due to a spring release failure in the one bottle and a snapped leash on the other. All sensors were thoroughly flushed and cleaned after every cast.

The winch used was CTD Kevlar #7, no problems were experienced with the winch control or system software. The compensator was able to handle the light weight of the Geotrace CTD, however rough and unfavourable sea state prolonged the cast duration for certain locations.

4.2 Underway Sampling

Continuous underway salinity samples were taken at four hour intervals throughout the voyage, the samples will be analysed using the on board Salinometer in order to calibrate the TSG system. Results pending… same applies for the CTD salinity samples taken for each cast, these samples will be used to calibrate the salinity sensor on the CTD underwater unit.

The ADCP was switched on: 28/06/2017 – 01/07/2017

On the return leg to Cape Town, the ADCP was not used as the keel was frozen and not operational until the ice had thawed. However, the vessel was operating on "ice mode" therefore the speed exceeded the limit the of operation for the ADCP (no return leg data)

4.3 Salinometer

The Salinometer has recently returned to the vessel after a scheduled calibration and repair. However numerous problems were experienced with the instrument, despite its recent repair. The initial calibration and reference point of the instrument was successfully set and logged but further operation of the instrument was hindered by hardware issues. The cell suction pipes were replaced, a thorough flush of all piping and capillary networks and a rewiring of the intake piping to overflow aided in rectifying the operational issues.

The ice team had collected a number of ice cores which were melted and used as liquid samples for the salinometer. These were successfully analysed and results given to the PIs of the group.

4.4 Conclusion

All CTD data was processed on board and distributed to the various groups. The sensor calibration is pending due to the need to process the salinities and oxygen data obtained during the cruise.

Highlights of the voyage:

- Student training and capacity building was very evident in all science teams on board.
- All physical oceanographic instruments performed at optimal efficiency for the duration of the voyage.
- Despite unfavourable weather conditions, most of the scientific cruise objectives were met

A final thank you to the Captain, officers, crew, engineers and stewards of the SA Agulhas II for their continued professionalism and work ethic. Thank you to our Chief Scientist Dr Marcello Vichi for his thoroughly planning, attention to detail and leadership for all science teams on board. Finally, thank you to the oceanographic students we worked tirelessly and always willing to learn about new physical oceanographic operations and stellar work ethic.

5 Investigation of the Sources of Ammonia in the Remote Marine Atmosphere

Contributors

Shantelle Smith, Kurt Spence, Katye Altieri (PI, land based)
University of Cape Town (UCT)

Ammonia/um (NH_x) are important components of the marine nitrogen cycle, for their influence on productivity as well as for their indication of nitrogen recycling. Cycling of ammonia/um between the surface ocean and the atmospheric boundary layer is also a notable process, with the sea-air flux of these nitrogen species being essential for the formation of particulate ammonium in the atmosphere and so also for the production of cloud condensation nuclei (CCN). The study of the behaviour, structure and formation of CCN are poorly understood and are vital due to their relation to climate regulation.

Anthropogenically-influenced regions of the ocean are thoroughly studied, however, until a baseline of a pre-industrial situation is established, this influence cannot be correctly quantified. The nitrogen cycle is largely influenced by anthropogenic processes such as agriculture but this influence is much smaller in the remote marine region of the Southern Ocean so studies in this region may serve as a suitable proxy for a pre-industrial marine environment. Therefore, significance of the ocean as an ammonia source to the atmosphere can be investigated and quantified and a clearer idea of the anthropogenic influence on these processes can then be constructed. Since the Southern Ocean is a rarely and sparsely studied region, any expansion of the existing dataset and knowledge about this biogeochemically significant portion of the global ocean is valuable to oceanographic research concerned with the region.

5.1 Ammonium sample collection and analysis

The main goal of this cruise was to combine high-resolution underway seawater sampling with the atmospheric aerosol sampling conducted by S. Fietz and the Stellenbosch University group. The underway samples were analysed for chlorophyll concentrations on-ship by D. Walker's group and for ammonium concentrations by our group. Primary productivity experiments were conducted to further characterize the biological activity in the surface ocean to determine which aspects of the surface ocean influence the atmosphere. In addition, we provided ammonium concentration analyses on all CTD casts for all groups on the cruise.

Seawater samples for ammonium analysis were collected from the underway system, from CTD casts, and while in the marginal ice zone. The details from each leg of the cruise are provided below.

5.1.1 Leg S

During Leg S it was anticipated that the constant steaming of the R/V SA *Agulhas II* would lead to clean air for ambient aerosol sampling. As such, this leg was the main focus for the high-resolution underway sampling with the goal of identifying which drives in the surface ocean are influencing the atmospheric aerosols. Samples were collected on station every four hours at 02h00, 06h00, 10h00, 14h00, 18h00, and 22h00 from the ship's underway system. Four aged 50 mL HDPE bottles were filled with seawater to a marked 40 mL line for each sample collection. A total of 31 stations were sampled, where three samples from each were analysed shipboard from stations 1-22 and two samples were analysed shipboard for stations 23-31. Analysis involved a modified version of the Holmes method for ammonium determination [*Holmes et al.*, 1999]. The remainder of the samples were kept frozen as archives to be analysed later at the University of Cape Town Marine Biogeochemistry Laboratory (UCT MBL). A total of 82 samples were analysed shipboard and 38 samples were kept as archives.

5.1.2 Leg M

The second leg occurred in the marginal ice zone and involved sampling of melted ice water and of water between/underneath the pancake ice. At station M01, four samples were taken from a Niskin bottle used to sample surface water (< 10 m deep) between the pancake ice. At station M02, Niskin bottles 1, 2 and 3 from the CTD rosette were sampled in duplicate, where all Niskin bottles were sampled at the surface. Two samples from station M01 and one sample from each of the Niskin bottles from station M02 were analysed shipboard. Samples were also taken in duplicate from each designated piece of pancake ice, which was first melted for easy sampling, and each of these samples were analysed shipboard with no archives kept. The ice was collected in close proximity to the location of the Niskin bottle sampling. A total of 37 samples were analysed shipboard and 60 samples were kept frozen to be analysed at the UCT MBL.

5.1.3 Leg I

The third leg followed the IO6 line and involved eight CTD drops along the line. Samples were taken in duplicate at various depths (10, 25, 50, 75, 100, 150, 200, 300, 400m\, and 500 m) by selecting particular Niskin bottles. One of the two samples collected from each Niskin bottle were analysed shipboard and the remaining samples were kept frozen as archives. A total of 88 samples were analysed shipboard, with the duplicate of each analysed sample kept frozen as an archive.

5.2 Primary Productivity Experiments

Ten primary productivity experiments were conducted, on behalf of the Biogeochemistry Team, during Leg S of the cruise. Two experiments were conducted daily in duplicate from 29 June to 3 July 2017 and each experiment involved the collection of ammonium, other nutrients and chlorophyll samples, in addition to the samples required for the primary productivity experiment. Three ammonium, two nutrient and two chlorophyll samples were collected during each experiment. Once the bottles used in the primary productivity experiment had incubated in the helipad deck incubators for 4-6 hours, the bottles were filtered in two size fractions and the filters were frozen to be analysed at the University of Cape Town Stable Isotope Laboratory in the Department of Archaeology. Filters from both filtered chlorophyll samples of each experiment were also kept frozen for later analysis in the UCT MBL. Two of the ammonium and one of the nutrient samples were analysed shipboard while the remaining samples were kept frozen as archives to be analysed at the UCT MBL.

5.3 Bibliography

Holmes, R. M., A. Aminot, R. Kérouel, B. A. Hooker, and B. J. Peterson (1999), A simple and precise method for measuring ammonium in marine and freshwater ecosystems, *Can. J. Fish. Aquat. Sci.*, *56*(10), 1801–1808, doi:10.1139/f99-128.

6 Quantifying the carbonate system

Contributors

Mishka Rawatlal[1,2], Katye Altieri[1] (PI, land based)

1. University of Cape Town (UCT)
2. Council for Scientific and Industrial Research (CSIR)

The impact of anthropogenic carbon dioxide (CO_2) emissions into the atmosphere is a known driver for climate change on Earth. However, the perturbation CO_2 emissions has a lasting impact on the Earth's oceans, namely, ocean acidification (Zeebe, 2012). As the pH of the ocean decreases (becomes more acidic) the capacity of the ocean to take in CO_2 is diminished, this leads to higher concentrations of atmospheric CO_2, thereby promoting global warming and driving climate change (Zeebe, 2012).

Carbon dioxide is highly soluble in water, allowing the ocean to act as a large sink for anthropogenic CO_2. This means that large amounts of atmospheric CO_2 is dissolved into the ocean. The total dissolved inorganic carbon (DIC) concentration is made up of the four carbonate species present in seawater, in equilibrium:

$$CO_{2(g)} \rightleftharpoons CO_{2(aq)} \rightleftharpoons H_2CO_3 + H_2O \rightleftharpoons HCO_3^{-} + H^{+} \rightleftharpoons CO_3^{2-} + H^{+}$$

Total alkalinity (A_t) is a measure of the charge balance between proton acceptors and proton donors in seawater i.e. the excess in bases over acids in seawater (Emerson and Hedges, 2008).

Ocean acidification is a function of the pH of seawater, which can be calculated by measuring the A_t concentration and the DIC concentration of seawater (Emerson and Hedges, 2008). DIC is measured by coulometric titration of the evolved CO_2 gas from a sample of seawater against a platinium electrode, and A_t is measured by differential potentiometric titration of a sample of seawater with pure HCl.

Characterising seawater samples and contributing to the global database will help researchers gain valuable insight into the changing pH of the oceans, the impact on marine life, and possible drivers that lead climate change.

There were three main goals of this project during the winter cruise, i) determine the total alkalinity (A_t) and total dissolved inorganic carbon (DIC) concentrations, ii) determine the pH, and iii) determine the extent biofouling in the ship's underway system by quantifying total DIC. Samples were analysed using the VINDTA 3C instrument to determine the total alkalinity and DIC concentrations. The A_t concentration is obtained by the differential potentiometric titration of the seawater sample with 0.1 M HCl. The DIC concentration is obtained by coulometric titration of the CO_2 gas evolved from the seawater sample. The calculated alkalinity and DIC were then used to derive the pH of the samples. The

DIC concentration of discrete seawater samples obtained from the niskin bottles along the IO6 transect (Leg I) will be analysed by the VINDTA 3C system and compared to the samples collected from the ship's underway system at the corresponding stations. The difference in these values will be used to correct the measurements obtained from the pCO_2 system which operates continuously off of the ship's underway system.

6.1 Sample collection and analysis

The samples collected on each leg are shown in Table 1.

Table 3 Sample collection for DIC and At

Leg	Sample ID	Number of samples
S	1 – 62	62
M	1A, 1B, 2A, 2B, 2C	5
I	IO1 – IO8	32
Total number of samples		99

Leg S: Samples were collected from the underway system every 4 hours in duplicate.

Leg M: Samples were collected from two hand held niskin bottles at ice station one (M01A and M01B), and 3 niskin bottles at ice station two (M02A, M02B, M02C).

Leg I: Samples were collected in duplicate from niskin bottles and the underway system at each of the WOCE IO6 stations (IO1 – IO8).

Samples were collected in 500 mL glass bottles. A short Tygon tube was used to sample from the underway system as well as the Niskin bottles. The Tygon tube was attached to the underway outlet and sampled from the same flow passing through the pCO_2 system. The tubing was inserted all the way to the bottom of the glass bottle and positioned against the edge of the bottle. The bottle was held at an angle and the tap opened. Water was filled to the brim of the bottle and allowed to overflow for the same duration as it took to fill the bottle. A small portion of the water was decanted from the bottle to allow a headspace sufficient for the expansion of the liquid. The sample was then spiked with 200 μL of saturated mercuric chloride. The bottle was stoppered and stored away. Samples 1-34 were analysed shipboard using the VINDTA 3c system. However, due to the poor functionality of the instrument on board, the remainder of the samples will be analysed on land.

6.2 Instrumentation challenges

6.2.1 VINDTA 3C SYSTEM

Alkalinity titration cell overflow:

The titration cell experienced an overflow problem intermittently. This fault was attributed to a failure of the titration cell sensor. The fault also caused an inadequate rinse of the titration cell with the NaCl solution. According to the method, the titration cell should be rinsed twice with NaCl solution; this rinse should fill the cell with solution while stirring and then decant.

Particle residue in pipettes:

The 100 mL pipette was observed to contain fine particle residue upon being filled with solution. The 20 mL pipette also experienced this intermittently. The pump tubing was seen to contain a build-up of residue. The tubing was replaced to remove this contamination.

Crystallization of inner column of the double junction electrode:

Owing to unreproducible alkalinity readings, both the working and the spare double junction electrode were observed to contain KCl crystals within the inner column. These crystals were dissolved by flushing and soaking the electrode with warm Milli-Q water.

Replacement of the Orion glass electrode:

Once the double junction electrode was serviced and replaced, alkalinity readings were still not reproducible. The Orion glass electrode was replaced – reproducible alkalinity was achieved.

Reproducible DIC readings:

In an attempt to achieve reproducible DIC readings, the coulometer cells were rinsed with concentrated nitric acid, washed with Milli-Q water and left to dry in the oven at ~ 40 °C overnight.

Air bubbles in DIC pipette:

Upon filling the 20 mL pipette, a number of bubbles were seen entering the system and adhering to the walls of the pipette itself. This produced high background readings and irreproducible results. The situation was rectified by replacing all the tubing running from the pipette to the coulometer cell. Bubbles ceased however background readings are still too high to produce viable endpoints.

Gas flow failure:

After the tubing had been replaced, nitrogen flow to the coulometer ceased. Valve 12 gas outlet to the peltier was tightened and the gas flow to the coulometer cell restored.

Pipettes were not calibrated prior to the voyage.

6.2.2 pCO_2 SYSTEM

Inconsistent water flow rate:

The water flow rate during the leg down to the ice was difficult to keep consistent at 3 – 3.5 mL/min due to the extended use of the underway system by researchers. The pCO_2 system was switched off upon arrival in the marginal ice zone. The equilibrator pump mechanism was cleaned of salt residue due to the low flow rate in the equilibrator line. After the pump mechanism had been washed in Milli-Q the flow rate through the equilibrator was restored and maintained throughout the journey.

Build-up of rust from the underway system:

Apparent in the outer jacket of the equilibrator, as well as the walls of the fluorometer cell, is a build-up of rust indicating that the underway lines in the lab where the pCO_2 system is housed need to be epoxied.

Fluorometer cell maintenance:

The fluorometer cell was cleaned prior to departure from Cape Town. The cell was removed from its housing, wiped down with ethanol to remove the build-up of rust along the inner walls, and replaced. The cell and fittings were greased with petroleum jelly as O-ring oil was unavailable at the time.

This process was repeated upon arrival in Cape Town. The fittings and cell were assembled and greased with O-ring oil. It was apparent that the O-rings for the cell holder need to be replaced as they protrude significantly, making it difficult for the cell to slide into the fitting. The use of force to do this will eventually result in the breakage of the fluorometer cell.

6.3 Bibliography

EMERSON, S. & HEDGES, J. 2008. Chemical Oceanography and the Marine Carbon Cycle, Cambridge University Press.

ZEEBE, R. E. 2012. History of Seawater Carbonate Chemistry, Atmospheric CO2, and Ocean Acidification. Annual Review of Earth and Planetary Sciences, 40, 141-165.

7 Full-scale vibration response of the S.A. Agulhas II

Contributors

Clinton Saunders[1], Brendon Nickerson[1], Christof van Zijl[1], Butteur Ntamba Ntamba[2] ,Annie Bekker[1] (PI, land based)

1. Stellenbosch University
2. Cape Peninsula University of Technology

In 2012 STX Finland recognized the sparse high resolution full-scale data spanning across disciplines, and formed an international consortium of research institutions and universities. The aim of the consortium is to create a scientific basis for the design of ice going ships in terms of ship hull, propulsion, power requirements and comfort for passengers and crew on board. The consortium members included Aker Arctic, STX Finland, DNV, Rolls-Royce, Wartsila, The Department of Environmental Affairs (South Africa), African Marine Solutions (AMSOL), Aalto University, the University of Oulu and the University of Stellenbosch (Soal, 2014).

The research on this cruise focuses on the investigation of dynamic ship response, shaft line fatigue, structural fatigue and human comfort. This information is extremely value to ship owners and operators to allow effective and safe vessel operation. The interaction between a vessel and the environment is extremely dynamic and often unpredictable, especially in adverse environmental conditions. Literature reveals that these types of measurements at full-scale are rare. The opportunity to conduct such measurements should not be taken lightly, as it allows for valuable insight and understanding into vessel structural behaviour. This research will feedback into the design of optimal future vessels, with a focus on knowledge and skills transfer to the South African maritime market.

The following sections will look at the successful data collection for the Winter Cruise as well as projects / activities conducted during this voyage. The data collected for these projects was independent of the stations in legs S, M and I as the sampling was continuous throughout the voyage.

The goal of this cruise was to obtain high quality hull vibration, shaft-line response, rigid body motion and human response data. Contributing data was gathered in the form of ice observations, the scientific data system (SDS) output, the ship's forward-facing CCTV camera footage as well as activities and conditions recorded in the ship's logbook. From all of the data collected it is possible to get an overall view of the vessel response and how it is influenced by environmental conditions and other activities taking place on-board.

The daily activities of the team on-board consisted of; checking the measurement systems and troubleshooting problems; downloading data from the measurement PC; converting the data into the correct data format; checking the coherence of the data; observation the ice conditions (when in ice).

7.1 Slamming Investigation

The slamming investigation on board the S.A. Agulhas II has shown in the past that there does exist a positive correlation between the subjective human response as well as the objective measured response of the vessel when slamming is present. The current slamming investigation is seeking to minimize the effort required to identify and categorize slams within the very large data sets. Analysis of the vibration and environmental data will give a better understanding of the interaction mechanisms responsible for the undesired impulsive stern phenomena as well as this phenomena's effect on the structural response. Figure 9 shows an approximate layout of the accelerometers on the vessel. This layout allows for the construction of a rough simulation model as well as the comparison of multiple years of measurements as the locations have remained constant. Figure 10 show the measurement setup's frontend, where all the location's cables come into the data acquisition system on deck 2 of the vessel.

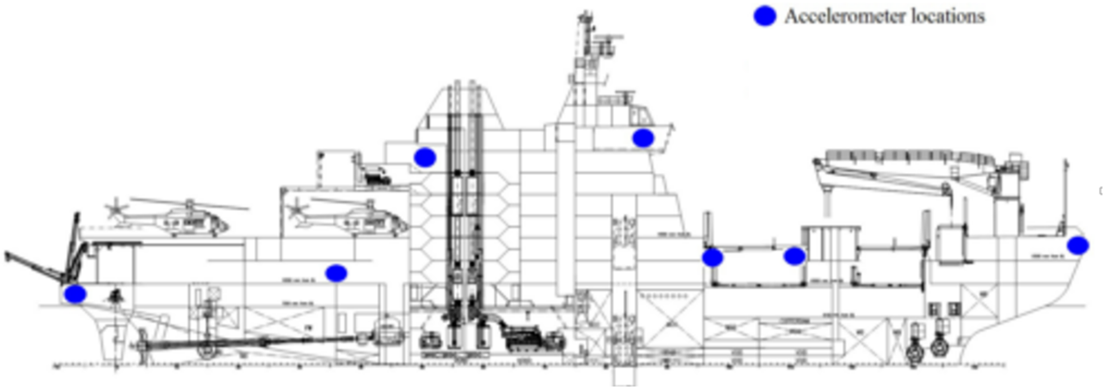


Figure 9: Example of sensor locations

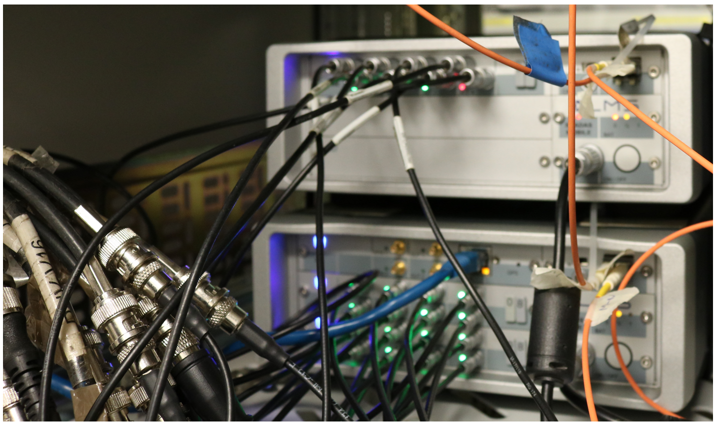


Figure 10: Frontend of the hull vibration measurement setup

Figure 11 shows the crest factor (CF) values of the accelerometers in the bow and stern for the ±20 hours spent in the ice during this voyage. Crest factor is a ratio that shows the signal's peak value over its root mean squared (RMS) value, this gives an indication of the impulsiveness of the signal. The CF was calculated every 60 seconds over this time span. The theory at the moment is that a sharp rise on the graph in Figure 11 correlates to a slam having occurred in that 60 second period. As an example, one can be seen on the graph there was quite a strong presence of impact on the stern during the late night hours towards the end of the graph. This seems to be accurate as the vessel was at a standstill in large swell while picking up pancakes during that time.

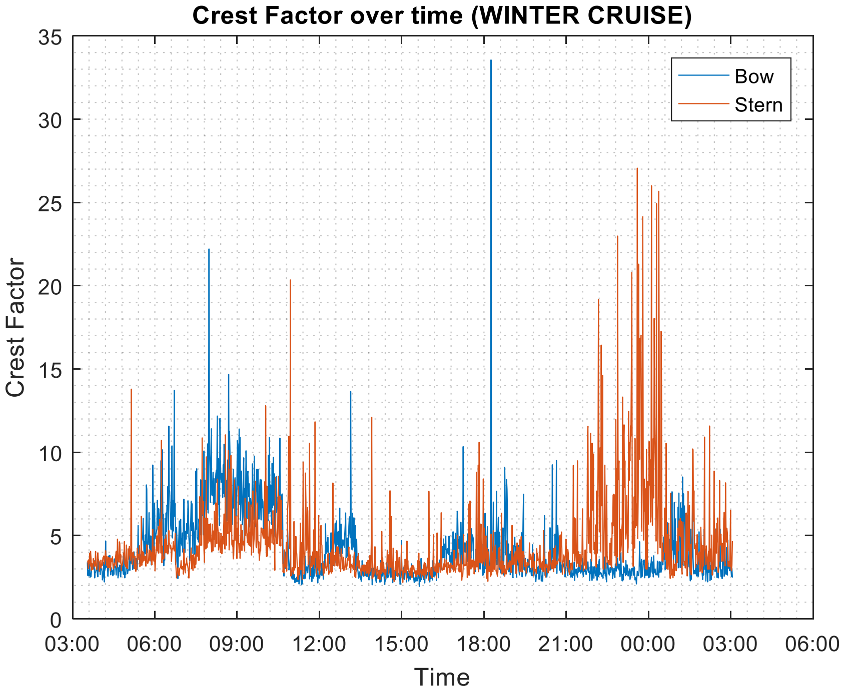


Figure 11: Crest Factor vs. Time (04-07-17 to 05-07-17)

7.2 Full-Scale Measurements of Human Vibration in Accommodation Areas

Full scale vibration measurements were taken on the bridge, deck 8, deck 7 and deck 4. Figure 12 shows the measurement setup in the bridge to capture acceleration in the fore-aft (x), lateral (y) and vertical (z) directions. Similarly, sensors were mounted in accommodation areas to measure lateral and vertical direction. Figure 13 shows sensors located on deck 7. These measurements are currently in the process of being analysed. The results will form part of a final year engineering project looking at the frequency weighting algorithm of measured vibration and human vibration perception.

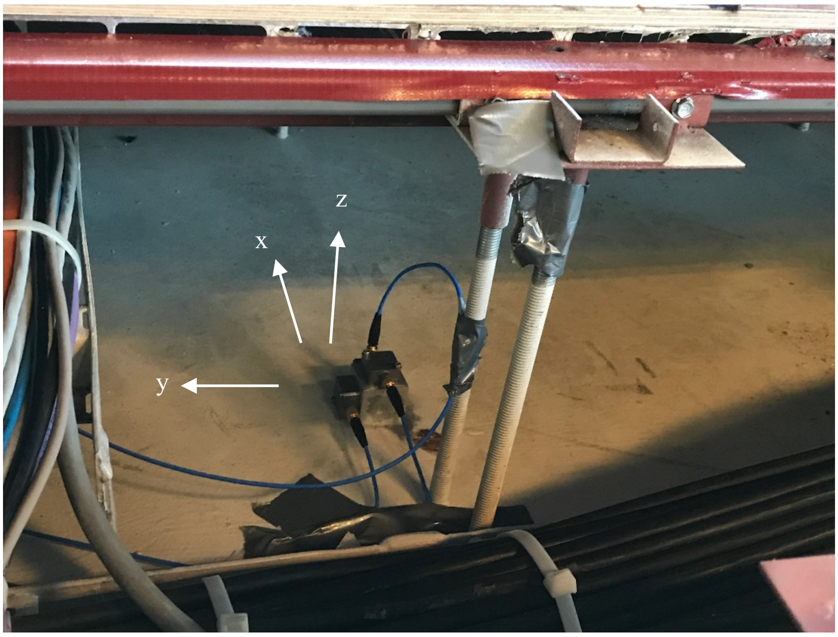
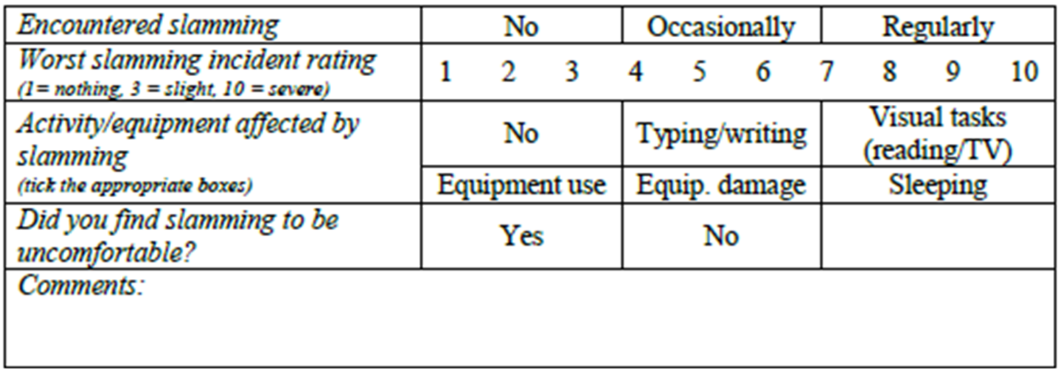


Figure 12: Measurement setup on bridge

Figure 13: Measurement setup on deck 7

7.3 Questionnaires for Human Responses to Slamming Vibration

To correlate the physical slamming vibration measurements with human responses, human response surveys were conducted during the voyage. Figure 14 presents the questions that passengers were required to answer daily. The responses from the questionnaires are currently being entered and catalogued. The response rate from this voyage was ±60% which is a good result compared with previous response rates of as low as 30% on previous cruises. This is more than likely due to the ever-noticeable presences of slamming during this voyage, and the fact that the passenger complement was made up of entirely researchers, who are constantly busy with work on-board and are effected by the harsh conditions. The assistants of all the scientists on board filling out the questionnaires was great appreciated.



Encountered slamming	No	Occasionally	Regularly
Worst slamming incident rating *(1 = nothing, 3 = slight, 10 = severe)*	1 2 3 4 5 6 7 8 9 10		
Activity/equipment affected by slamming *(tick the appropriate boxes)*	No	Typing/writing	Visual tasks (reading/TV)
	Equipment use	Equip. damage	Sleeping
Did you find slamming to be uncomfortable?	Yes	No	
Comments:			

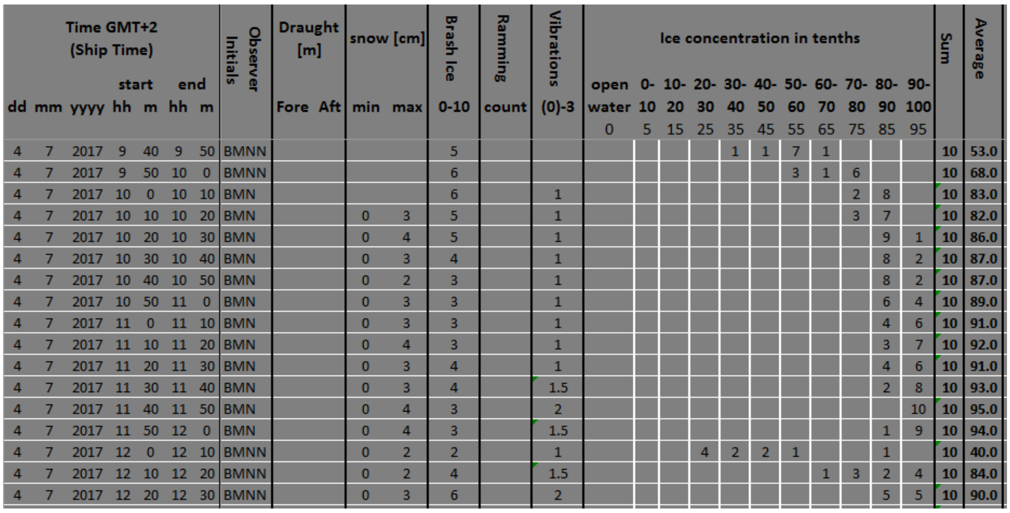
Figure 14: Human response questionnaires

7.4 Ice Observations

Ice observations were performed from the port bridge wing in the marginal ice zone (MIZ) in collaboration with the ice team (see Sec 0). Team members observed in 2 hours shifts continuously during ice navigation. Wave slamming was experienced in icy waters as the vessel moved through large swells (up to 7 m). This proved to be highly interesting as conditions such as this not yet been measured because we expect the seas to be calm in icy waters. Figure 15 presents a photograph of the SA Agulhas II slamming in swells with ice.

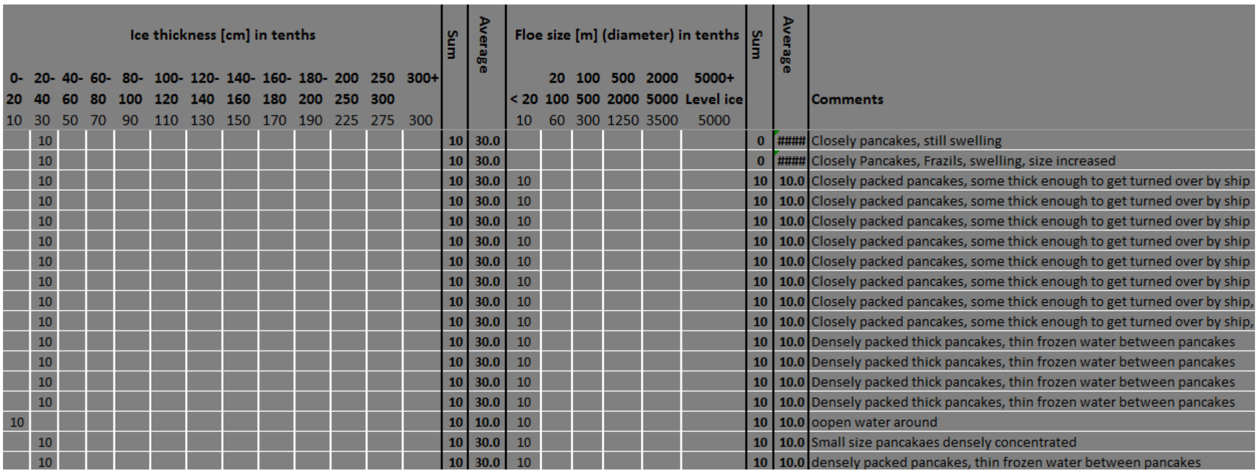
Figure 15: Wave slamming in pancake ice

An example of how ice thickness, ice concentration and floe size are recorded can be seen below. Figure 16 shows the first half of the spreadsheet and Figure 17 shows the second half of the spreadsheet. Ice conditions during this voyage were very light as we stayed in the MIZ were we only expect ice like grease ice, frazil, nilas and pancakes. The thickest ice recorded was no bigger than 40cm thick, with the largest floe size being ±10m (which is typical of pancakes). The concentration however did reach maximum at times (100%) but consisted of closely packed pancakes with frazil or brash in-between.



Time GMT+2 (Ship Time)							Observer Initials	Draught [m]		snow [cm]		Brash Ice	Ramming	Vibrations	Ice concentration in tenths											Sum	Average
			start		end																						
dd	mm	yyyy	hh	m	hh	m		Fore	Aft	min	max	0-10	count	(0)-3	open water	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100		
															0	5	15	25	35	45	55	65	75	85	95		
4	7	2017	9	40	9	50	BMNN					5							1	1	7	1				10	53.0
4	7	2017	9	50	10	0	BMNN					6									3	1	6			10	68.0
4	7	2017	10	0	10	10	BMN					6		1									2	8		10	83.0
4	7	2017	10	10	10	20	BMN			0	3	5		1									3	7		10	82.0
4	7	2017	10	20	10	30	BMN			0	4	5		1										9	1	10	86.0
4	7	2017	10	30	10	40	BMN			0	3	4		1										8	2	10	87.0
4	7	2017	10	40	10	50	BMN			0	2	3		1										8	2	10	87.0
4	7	2017	10	50	11	0	BMN			0	3	3		1										6	4	10	89.0
4	7	2017	11	0	11	10	BMN			0	3	3		1										4	6	10	91.0
4	7	2017	11	10	11	20	BMN			0	4	3		1										3	7	10	92.0
4	7	2017	11	20	11	30	BMN			0	3	4		1										4	6	10	91.0
4	7	2017	11	30	11	40	BMN			0	3	4		1.5										2	8	10	93.0
4	7	2017	11	40	11	50	BMN			0	4	3		2											10	10	95.0
4	7	2017	11	50	12	0	BMN			0	4	3		1.5										1	9	10	94.0
4	7	2017	12	0	12	10	BMNN			0	2	2		1				4	2	2	1			1		10	40.0
4	7	2017	12	10	12	20	BMNN			0	2	4		1.5								1	3	2	4	10	84.0
4	7	2017	12	20	12	30	BMNN			0	3	6		2										5	5	10	90.0

Figure 16: Ice Observation Sheet (part 1)



Ice thickness [cm] in tenths													Sum	Average	Floe size [m] (diameter) in tenths						Sum	Average	
0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	180-200	200 250	250 300	300+			< 20	20 100	100 500	500 2000	2000 5000	5000+ Level ice			Comments
10	30	50	70	90	110	130	150	170	190	225	275	300			10	60	300	1250	3500	5000			
	10												10	30.0							0	####	Closely pancakes, still swelling
	10												10	30.0							0	####	Closely Pancakes, Frazils, swelling, size increased
	10												10	30.0	10						10	10.0	Closely packed pancakes, some thick enough to get turned over by ship
	10												10	30.0	10						10	10.0	Closely packed pancakes, some thick enough to get turned over by ship
	10												10	30.0	10						10	10.0	Closely packed pancakes, some thick enough to get turned over by ship
	10												10	30.0	10						10	10.0	Closely packed pancakes, some thick enough to get turned over by ship
	10												10	30.0	10						10	10.0	Closely packed pancakes, some thick enough to get turned over by ship
	10												10	30.0	10						10	10.0	Closely packed pancakes, some thick enough to get turned over by ship
	10												10	30.0	10						10	10.0	Closely packed pancakes, some thick enough to get turned over by ship,
	10												10	30.0	10						10	10.0	Closely packed pancakes, some thick enough to get turned over by ship,
	10												10	30.0	10						10	10.0	Densely packed thick pancakes, thin frozen water between pancakes
	10												10	30.0	10						10	10.0	Densely packed thick pancakes, thin frozen water between pancakes
	10												10	30.0	10						10	10.0	Densely packed thick pancakes, thin frozen water between pancakes
	10												10	30.0	10						10	10.0	Densely packed thick pancakes, thin frozen water between pancakes
10													10	10.0	10						10	10.0	oopen water around
	10												10	30.0	10						10	10.0	Small size pancakaes densely concentrated
	10												10	30.0	10						10	10.0	densely packed pancakes, thin frozen water between pancakes

Figure 17: Ice Observation Sheet (part 2)

7.5 *Shaft-Line Response*

The goal for this research on the voyage was to test the system previously used for full-scale measurements on the shaft-line and build a familiarity with the processes for data capture and processing. Furthermore, the intent was to build experience on the ship itself. Being a shorter cruise than the year end SANAE voyage, it was advantageous to gather experience and learn from mistakes to insure the success of measurements during the longer voyages. Measurements were conducted on the shaft-line through use of strain gauges and accelerometers. Pre-installed strain gauges were used, one 45-degree rosette and two T-rosettes to measure torque and thrust respectively. The accelerometers were placed to measure multi-directional vibrations at three locations on bearing housings. The data acquisition unit used for these measurements was an HBM Quantum and the software was HBM CatmanEasy. Strain data was measured through a V-Link Microstrain system that was installed on the shaft-line. This device streamed data to a WSDA Base Station connected to the HBM Quantum and a laptop. The measurement system is shown in Figure 18.

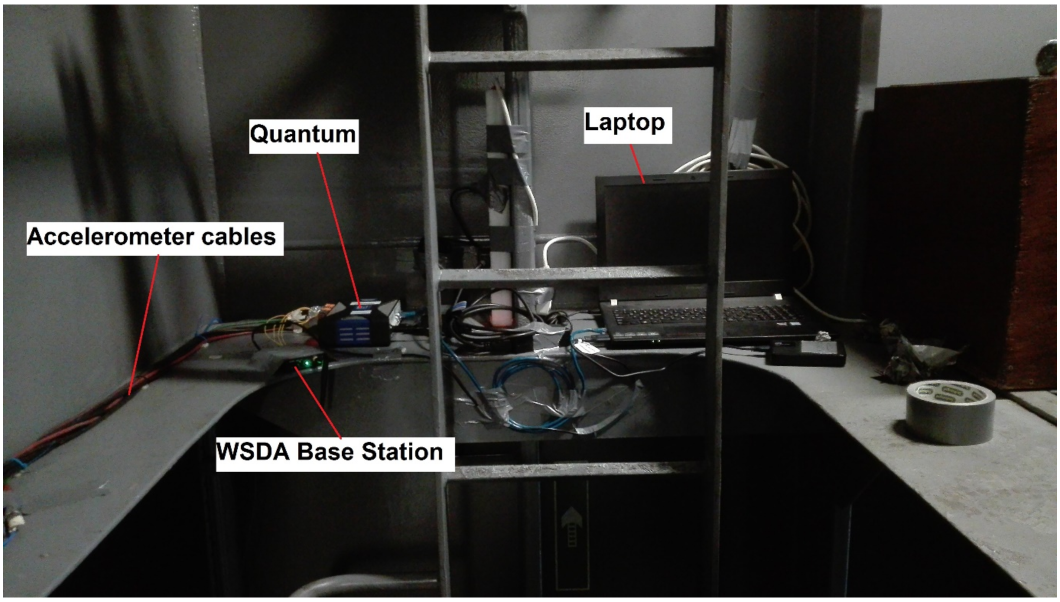


Figure 18: Data Acquisition Setup for Shaft-Line Response Measurement

Previous work (de Waal, 2017) done on this topic revealed that the most critical ice loading can occur in water with lower ice concentration when propeller blades impact isolated ice floes at high speed. It was hoped to see this repeated in the MIZ, but the ice conditions encountered were not favourable for seeing this response. It was later seen from the data that there is a hardware issue with the currently installed torque rosette and that this needs to be replaced. Along with the replacement gauges, further strain gauge installations are planned for future measurements. The thrust and accelerometer data is currently being analysed and will be used to develop propeller thrust loading estimation methods, and check for possible cavitation that occurred during the voyage.

7.6 Determination of Sea State from Rigid Body Motion

Information about sea state is best represented by a power spectrum depending on frequency and direction. It is obviously interesting for meteorological and oceanographic records or even for investigations about climate changes. In nautical practice the watch officer is required to enter the sea state regularly into the ship's log. This is usually done by visual estimation of characteristic height, period and direction. Ship oscillations, in particular roll, are, of course, generated by waves and the avoidance of dangerously high amplitudes is of the utmost importance. Since the reaction of a ship to a particular wave system depends on course and speed, there are decision support systems which rely on the officer's estimate as input. However, the recommendations given by such systems are highly doubtful, as long as the sea state spectrum is reduced to a single point and that depending on the officer's experience.

For this investigation, the S.A. Agulhas II, itself, was used as a sensor to predict the sea state in which she travels. To achieve this, two sensor boxes were placed at different positions on the vessel, to record in real time roll and pitch angles for different course and speed. The first box (Figure 19 (RIGHT)) was

Figure 19 (LEFT) Box on Monkey Island. (RIGHT) Box near the center mass.

placed at the vicinity on the center of mass of the vessel with the second box (Figure 19 (LEFT)) placed on the Monkey Island. Each box has two types of sensors: a 3d acceleration sensor and two gyros for the pitch- and roll axes. The acceleration sensor is used to calculate the angles of roll and pitch from the direction of the gravitational force. Pseudo forces will create an error in this measurement if the device is accelerated with respect to an inertial system. Gyros provide the angular velocity and are not subject to pseudo forces, so in principle the roll- and pitch angle can be determined by integrating the corresponding angular velocity. In practice, the drift of the gyros leads to very unstable results. Therefore, both acceleration and angular velocity data are saved for further processing.

The methodology that is used to estimate sea state parameters using ship motions is called “wave buoy analogy”. It consists of considering the vessel acting as a wave rider buoy. In order to achieve this, the hull shape of the vessel is needed for the vessel’s response to wave response to be computed.

In the process of waiting the hull shape data in order to numerically compute the vessel’s response to wave, a comparison of the angular rate for both roll and pitch recorded from the two different boxes can be seen in Figure 20. Results have shown a perfect fit.

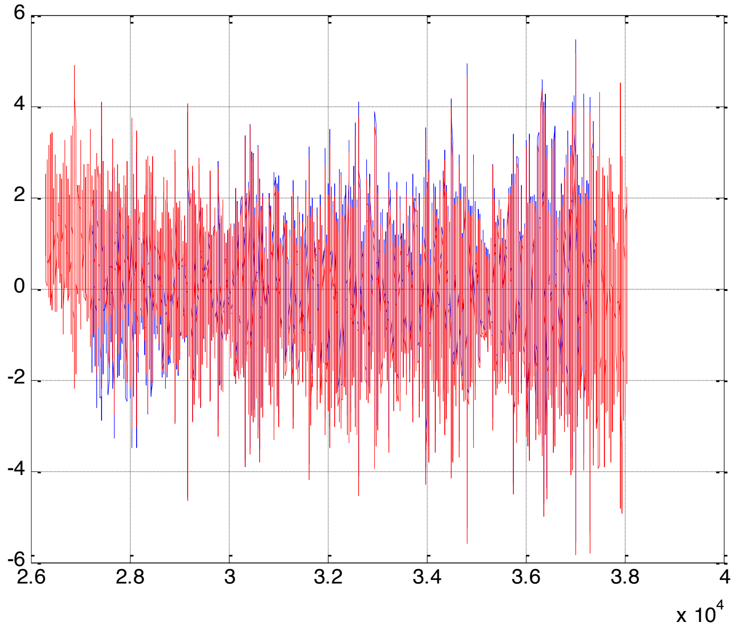


Figure 20: Comparison between roll angle rates of the two sensors.

7.7 Conclusion

The work done on the 2017 Winter Cruise was successful, this time proved valuable in preparing students for future voyages while still being a good opportunity for data collection. It created a platform for training postgraduate students (that had little to no experience at sea) on the use of the measurement equipment and the working conditions on-board. It was also very important to be able to introduce students to the crew of the vessel and help to maintain the relationship, as much of the insight into the vessel behaviour characteristic comes from interactions with the crew. The opportunity to build relationships with fellow scientists also allows for valuable insights that may otherwise have gone unnoticed.

Captain Knowledge and his crew remained as professional as ever and their support and interest in the research goals make it a pleasure to work with them. Thank you to the Chief Scientist, Marcello Vichi, for all of the effort that went into organising and leading the cruise, it was greatly appreciated. The atmosphere between scientists on-board (both local and international) was a positive one, everyone was enthusiastic about one another's areas of research. This is instrumental for the progress of science on-board the S.A. Agulhas II as it breads a culture of collaboration that leads to scientific breakthrough.

The 2017 Winter Cruise was a privilege to be a part of and it is hoped that there will be more dedicated research cruises like it in the future.

7.8 Bibliography

de Waal, R.J.O. (2017). *An investigation of shaft line torsional vibration during ice impacts on PSRVs.* Master's thesis, Stellenbosch University, South Africa.

Soal, K.I. (2014). *Vibration Response of the Polar Supply and Research Vessel the S.A. Agulhas II in Antarctica and the Southern Ocean.* Master’s thesis, Stellenbosch University, South Africa.

8 Atlas of Seabirds at Sea (AS@S)

Contributors
Morris TL (PI, land based), Perrins N, Kinghorn J

In this survey we collected data of the distribution and abundance of seabirds in the southern ocean for the Atlas of Seabirds at Sea (AS@S) project (www.seabirds.saeon.ac.za). This project is a collaborative effort between BirdLife South Africa, the South African Environmental Observation Network (SAEON) and the Department of Environmental Affairs (DEA).

Data from the AS@S project are used to calculate seabird spatial distributions and densities in order to define 'ocean hotspots' – areas where species congregate in relative abundance and with some degree of consistency. Ultimately, these 'hotspots' may be key components in the selection of marine important bird areas (IBAs) for BirdLife International. Furthermore, they could contribute significantly towards the designation of marine protected areas (MPAs) such as special nature reserves on the high seas or no-take zones to protect sensitive species from commercial fishing.

If associated environmental and biological variables are measured concurrently with seabird observations, additional analyses predicting the drivers of seabird abundance and diversity can provide important information as to the underlying factors driving spatial and temporal patterns of pelagic seabirds.

At-sea observations of seabirds were conducted from 28 June 2017 to 12 July 2017 by six AS@S observers: Niall Perrins (group leader), Ilana Engelbrecht, Nasreen Khan, John Kinghorn, Makhudu Masotla, and Vanessa Stephen. Taryn Morris (BirdLife South Africa) was the principle investigator in absentia.

8.1 Methodology

Observations were divided into 10-minute transects from the observation-deck, and were only conducted while the vessel was in consistent, linear motion. Date and time, along with the beginning and end GPS positions of each transect were recorded. The count area was determined using the angle of observation (either 90° or 180°) and distance from the ship (between 50-300m) for each transect. Every bird encountered within each transect, with the exception of 'ship-followers' or birds that appeared to have been attracted to the vessel, was identified and counted. In addition, counts for flying birds, and those sitting on the water were kept separate for each species. Full protocols and explanations can be viewed at www.seabirds.saeon.ac.za

8.2 Preliminary results

Data are freely available at www.seabirds.saeon.ac.za. Throughout the 15 days at sea, 548 ten-minute transects were completed (Fig 1). A total of 14 619 birds were seen of 36 identified species and 3 unidentifiable groups (Table 1). The average number of birds observed per day was 975, per hour was 91, and per ten-minute transect was 27. Prions were the most abundant group of species (11 55 birds), followed by the similar Blue Petrels (707) and thereafter Antarctic (430) and White-chinned Petrels (407).

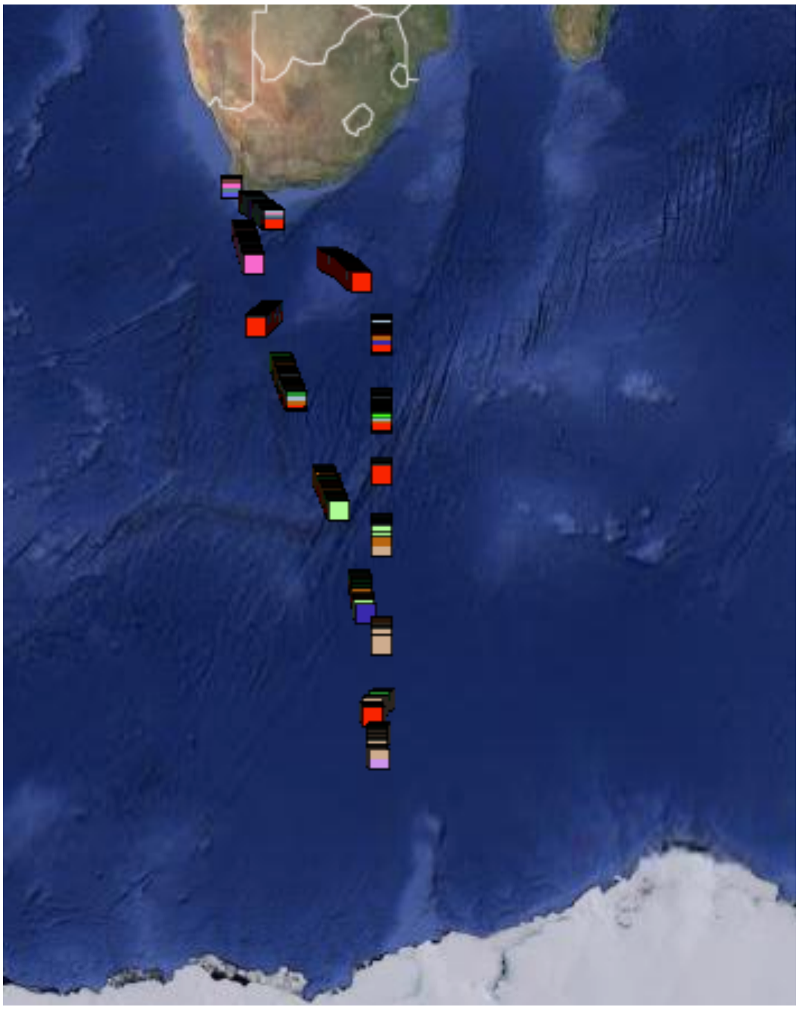
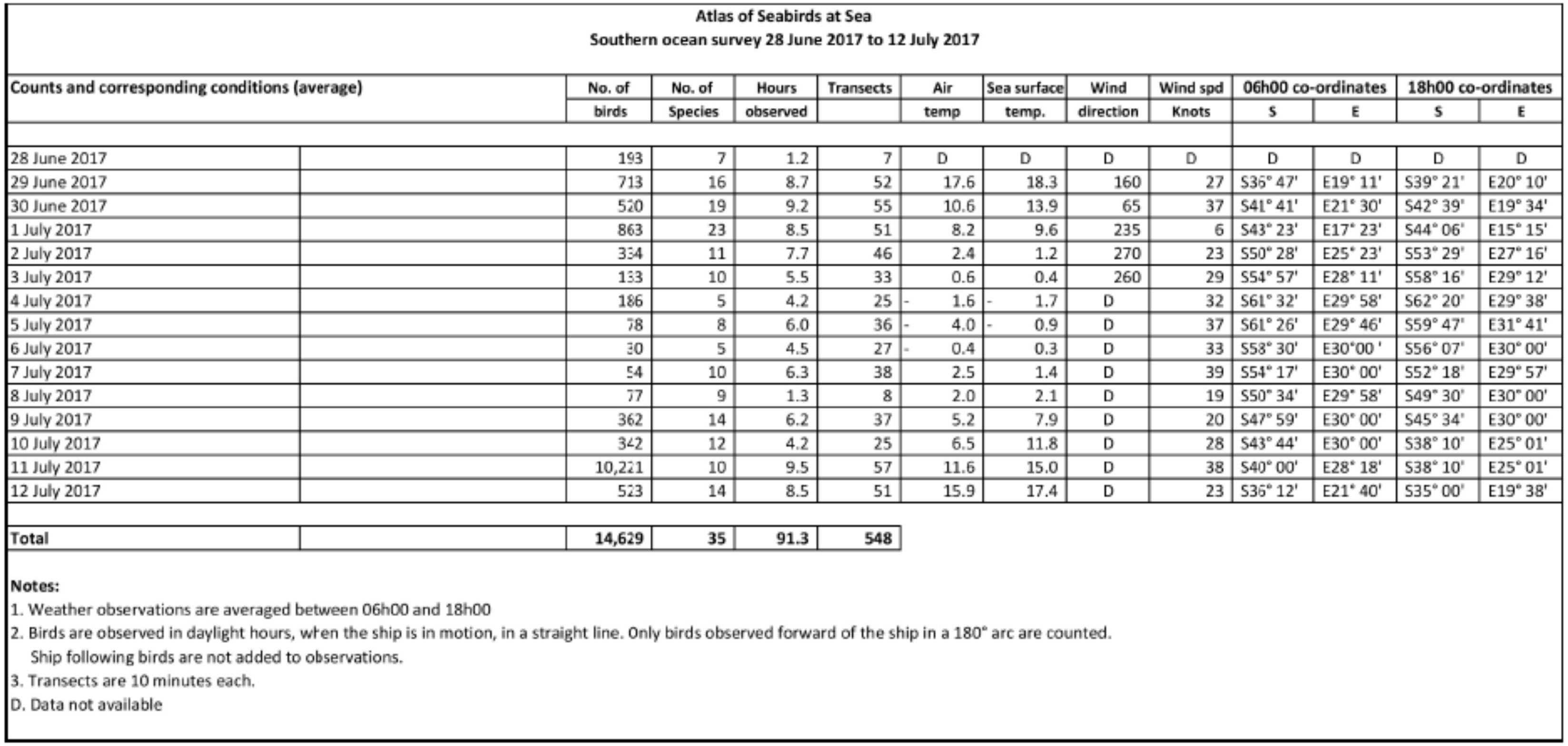


Figure 21 Distribution of ten-minute transects along the voyage during daylight hours when the ship was in motion. A total of 548 transects were completed. Source: www.seabirds.saeon.ac.za

Table 4 Number of birds seen per species throughout the cruise.

Bird Species		**Count**
Albatross	Atlantic Yellow-nosed	1
Albatross	Black-browed	103
Albatross	Grey-headed	118
Albatross	Indian Yellow-nosed	82
Albatross	Light-mantled	7
Albatross	Shy	167
Albatross	Sooty	3
Albatross	Wandering	23
Diving-Petrel	Common	7
Fulmar	Southern	175
Gannet	Cape	46
Penguin	Chinstrap	64
Penguin	King	9
Penguin	Unidentified	3
Petrel	Antarctic	221
Petrel	Atlantic	4
Petrel	Blue	707
Petrel	Great-winged	316
Petrel	Grey	67
Petrel	Kerguelen	32
Petrel	Northern Giant	22
Petrel	Pintado/Cape	140
Petrel	Snow	29
Petrel	Soft-plumaged	47
Petrel	Southern Giant	39
Petrel	Unidentified Giant	1
Petrel	White-chinned	407
Petrel	White-headed	138
Prion	Antarctic	430
Prion	Broad-billed	19
Prion	Fairy	1
Prion	Salvin's	7
Prion	Slender-billed	14
Prion	Unidentified	11084
Shearwater	Little	40
Shearwater	Sooty	17
Shearwater	Subantarctic	24
Skua	Subantarctic (Brown)	4
Storm-Petrel	Wilson's	1
TOTAL		14619

Table 5 Number of birds and species seen per day with associated environmental variables and start and end coordinates.



Atlas of Seabirds at Sea
Southern ocean survey 28 June 2017 to 12 July 2017

Counts and corresponding conditions (average)	No. of birds	No. of Species	Hours observed	Transects	Air temp	Sea surface temp.	Wind direction	Wind spd Knots	06h00 co-ordinates S	06h00 co-ordinates E	18h00 co-ordinates S	18h00 co-ordinates E
28 June 2017	193	7	1.2	7	D	D	D	D	D	D	D	D
29 June 2017	713	16	8.7	52	17.6	18.3	160	27	S36° 47'	E19° 11'	S39° 21'	E20° 10'
30 June 2017	520	19	9.2	55	10.6	13.9	65	37	S41° 41'	E21° 30'	S42° 39'	E19° 34'
1 July 2017	863	23	8.5	51	8.2	9.6	235	6	S43° 23'	E17° 23'	S44° 06'	E15° 15'
2 July 2017	334	11	7.7	46	2.4	1.2	270	23	S50° 28'	E25° 23'	S53° 29'	E27° 16'
3 July 2017	133	10	5.5	33	0.6	0.4	260	29	S54° 57'	E28° 11'	S58° 16'	E29° 12'
4 July 2017	186	5	4.2	25	- 1.6	- 1.7	D	32	S61° 32'	E29° 58'	S62° 20'	E29° 38'
5 July 2017	78	8	6.0	36	- 4.0	- 0.9	D	37	S61° 26'	E29° 46'	S59° 47'	E31° 41'
6 July 2017	30	5	4.5	27	- 0.4	0.3	D	33	S58° 30'	E30°00 '	S56° 07'	E30° 00'
7 July 2017	54	10	6.3	38	2.5	1.4	D	39	S54° 17'	E30° 00'	S52° 18'	E29° 57'
8 July 2017	77	9	1.3	8	2.0	2.1	D	19	S50° 34'	E29° 58'	S49° 30'	E30° 00'
9 July 2017	362	14	6.2	37	5.2	7.9	D	20	S47° 59'	E30° 00'	S45° 34'	E30° 00'
10 July 2017	342	12	4.2	25	6.5	11.8	D	28	S43° 44'	E30° 00'	S38° 10'	E25° 01'
11 July 2017	10,221	10	9.5	57	11.6	15.0	D	38	S40° 00'	E28° 18'	S38° 10'	E25° 01'
12 July 2017	523	14	8.5	51	15.9	17.4	D	23	S36° 12'	E21° 40'	S35° 00'	E19° 38'
Total	**14,629**	**35**	**91.3**	**548**								

Notes:
1. Weather observations are averaged between 06h00 and 18h00
2. Birds are observed in daylight hours, when the ship is in motion, in a straight line. Only birds observed forward of the ship in a 180° arc are counted.
Ship following birds are not added to observations.
3. Transects are 10 minutes each.
D. Data not available

8.2.1 Notable Bird Highlights

- South African rarities within 200nm range: A single Sooty Albatross and two White-headed Petrels were seen on our second morning in South African waters.
- Atlantic Petrel - three individuals were encountered, between S38° E20° and S26° E23°, somewhat east of the known range.
- Common Diving Petrel - seven individuals were encountered between S46° E22.9°and S46.8° E23.3°
- Snow Petrel - several seen at the pancake ice, where they forage in calmer waters in amongst the ice floes. On our return north a single bird was sighted in 14m swells, +-200km's from the nearest ice.
- Prions - The 11 July was dominated by prions, in such vast numbers that it was almost impossible to reduce them to species level. Count for the day tallied 10,176, probably short of the real number, as there were birds as far as the eye could see. There were the odd identifiable Salvin's, Antarctic, Slender-billed and Broadbilled but the majority are lumped under Unidentified prions.

Snow Petrel *(Pagodroma nivea)* / © John Kinghorn

Figure 22 Snow Petrel (Pagodroma nivea) observed at the pancake ice, with one individual observed more than 200km away from the ice.

8.2.2 Notable Mammal Highlights

- Leopard Seal - four individuals were seen on the pancake ice.
- Antarctic Fur Seal- two seen on the pancake ice.
- Ross Seal- this rare seal, of which little is known, was seen on the pancake ice at S62.5°. Text states that they are more likely to be seen from ice-breakers as they favour the pack ice.
- Cape Fur Seal- regularly encountered within South African waters.
- Antarctic Minke Whale- a single individual briefly showed its head in a gap in the pancake ice
- Humpback Whale- a fair amount of individuals encountered closer to the coast line of South Africa as well as +-4 individuals further out to sea.

Ross Seal *(Ommatophoca rossii)* / © Niall Perrins

Figure 23 Ross Seal (Ommatophoca rossii) observed on the pancake ice at S62.5

9 Metocean properties of the Southern Ocean: Open ocean and marginal ice zone

Contributors

Alberto Alberello[1], Clare Eayrs[2], Keith Machutchon[3], Jhon Mojica[2], Miguel Onorato[4], Alessandro Toffoli[1]

1. The University of Melbourne, Australia
2. New York University, Abu Dhabi, UAE
3. University of Cape Town
4. University of Turin, Italy

Waves in the Southern Ocean are the largest on the planet. At high latitudes, these waves exert extreme stresses on Antarctic sea ice, breaking pack ice and scattering floes. This interaction influences the sea ice concentration and thus reflection of solar heat, which would otherwise be absorbed by the dark ocean it conceals, playing a role in our climate system. The interaction between waves and ice is therefore a key player in our climate system.

As waves penetrate deep into the ice-covered ocean, the pack ice is forced to break into smaller floes and impact the ice cover (Liu and Mollo-Christensen, 1988). Concomitantly, the ice cover attenuates the wave energy over distance, so that wave impacts die out eventually (e.g. Wadhams et al., 1988). The Antarctic ice pack is therefore encircled by a marginal ice zone (MIZ) of broken floes up to hundreds of kilometres in width. Kohout et al., (2014) provide evidence that trends in the contraction and expansion of the Antarctic sea ice edge are correlated to trends in the increase and decrease of the local significant wave height, respectively, over the 1997 to 2009 period. They conjecture wave-induced breakup is responsible for this relationship, and report a breakup event over 300 km into the Antarctic MIZ during the Sea Ice Physics and Ecosystem Experiment 2012 (SIPEX-II), which Kohout et al., (2015) analysed. There is a general lack of field data describing Southern Ocean waves. Therefore, they are still not well understood and poorly modelled, adding uncertainties to the description of the wave-ice interaction processes. In a series of papers Dumont et al. (2011) and Williams et al. (2013a, 2013b) developed a coupled wave attenuation and breakup model, and integrated it into a regional version of the HYCOM ice/ocean model. They show model predictions of breakup are indeed most sensitive to the wave attenuation rate. Uncertainties in waves-in-ice processes consequently mean uncertainties in the sea ice coverage, which in turn affect the thermo-dynamical balance between the ocean and the atmosphere.

At the onset of climate change, there has been an observed southward shift in storm tracks over recent decades (Hartmann et al., 2013) and wave heights are predicted to increase everywhere at the sea ice edge (Dobrynin et al., 2012), with consequent implications for sea ice extent such as a decrease in Antarctica sea ice area (Turner et al., 2017). A proper understanding of waves and waves-in-ice is therefore becoming crucial to properly predict future changes in the Antarctic environment. Activities that took place during this cruise will cast some new light on the dynamics of waves in ice-covered waters and the way they interact with sea ice.

9.1 Waves in Ice Observation Systems (WIIOS)

9.1.1 Equipment and deployment

Two Waves In Ice Observation Systems (WIIOS, Kohout et al., 2015) were deployed in the MIZ to test these buoys for a potential future larger-scale deployment to measure the impact of storms on the winter development of the MIZ. The WIIOS were named NYU 1 and NYU 2, respectively. Each WIIOS consisted of a tri-axis inertial measurement unit (IMU) with 3 degrees of freedom accelerometer, gyrometer and magnetometer, which was located using the Global Position System (Figure 24). The instruments simultaneously recorded wave accelerations for 11 minutes every 15 minutes. This record was filtered and integrated to calculate displacement, and a subsampled fast Fourier transform of the data was returned via the Iridium satellite system.

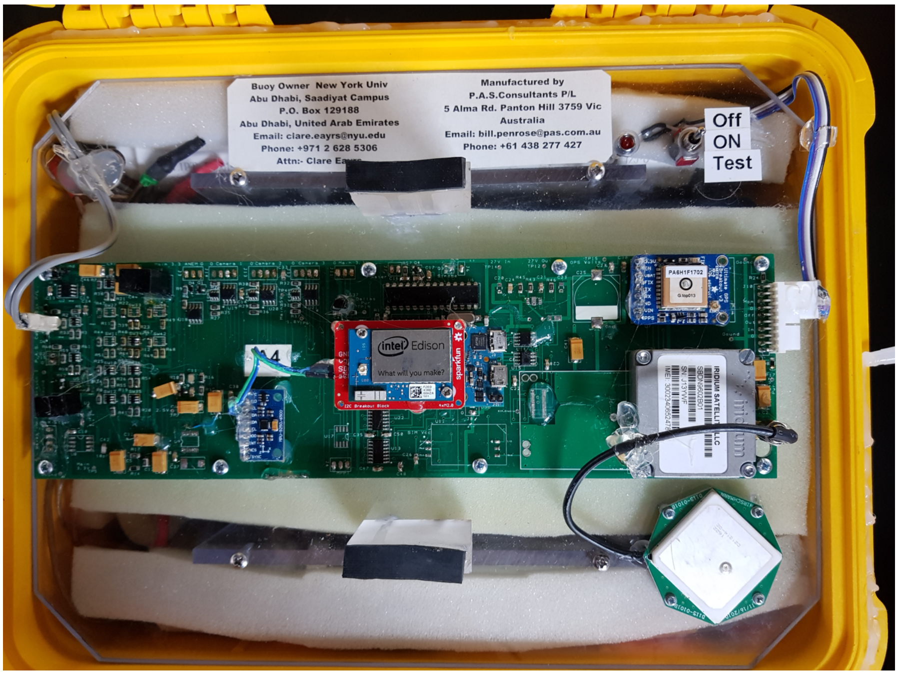


Figure 24 WIIOS components: the batteries, printed circuit board and all components (Edison processor, Atmega328 support processor, 32GB memory card, Intertial Measurement Unit, GPS receiver, Dallas temperature probe and Iridium transceiver) are contained within a Pelican Case #1400.

The two WIIOS were deployed about 1.5 km apart on sea ice close to latitude 62.8º S and longitude 29.8º E on 4th July, 2017 at stations M01(NYU 1) and M02 (NYU 2), respectively. We entered the ice during a storm and much of the ice we first encountered consisted of small pancakes (< 3 m in diameter) that were not large enough to support the instruments. The whole ice field was highly mobile during this storm period. The Antarctic MIZ in the region where the instruments were deployed consisted of first year ice on average 40 – 60 cm thick. The instruments were deployed by hand by 3 people, lowered by crane from the ship to the ice on a basket cradle (Figure 25). NYU 1 was deployed on an ice floe of length 8 m and width 3 m (rectangular shape, see Figure 25, with a thickness of about 40 – 50 cm. NYU 2 was deployed on a triangular floe of length 4 m (see Figure 26) and thickness 40 cm.

9.1.2 Preliminary results

Ice floes have an elastic response to waves and can bend and flex with the propagating waves, allowing the incident wave to propagate without significant interaction with the floe. Using the rule of thumb that floes respond to waves with lengths less than four times their diameter, these floes were small enough to follow the water surface for wavelengths greater than 32 m.

Figure 25 Deployment of NYU 1 from basket cradle.

Figure 26 Rectangular shaped ice floe of length 8 m and width 3 m at Station M01

The survival of the sensors depended on staying fixed to the floe and the battery life. On 12th July, the sampling rate of NYU 2 was reduced from 15 minutes to 2 hourly in order to extend the battery life. Unfortunately, NYU 1 overheated and the battery dropped below the operating voltage on 13th July, 2017 (Figure 27). NYU 2 continued to send back data for another 6 days, but then stopped sending data for an unknown reason on 19th July. There was still plenty of battery (Figure 28) and the temperature inside the box suggests that it did not melt through the flow (Figure 29). Perhaps heavy snow cover prevented the instrument from communicating via iridium. The data set consists of nearly 9 days of 15-minute data from NYU 1 and 15 days of a combination of 15-minute and 2-hourly data from NYU 2.

Figure 27 Triangular shaped ice floe of diameter 4 m at Station M02

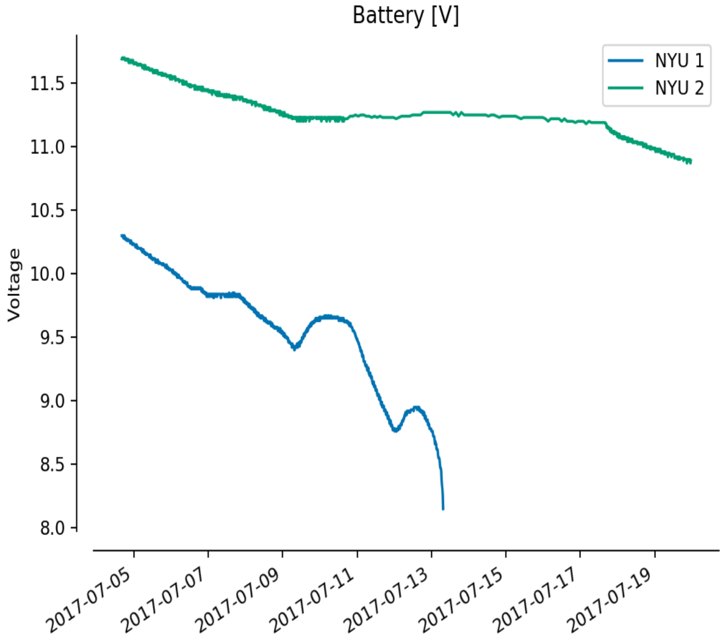


Figure 28 Battery levels [V] for the duration of the deployment

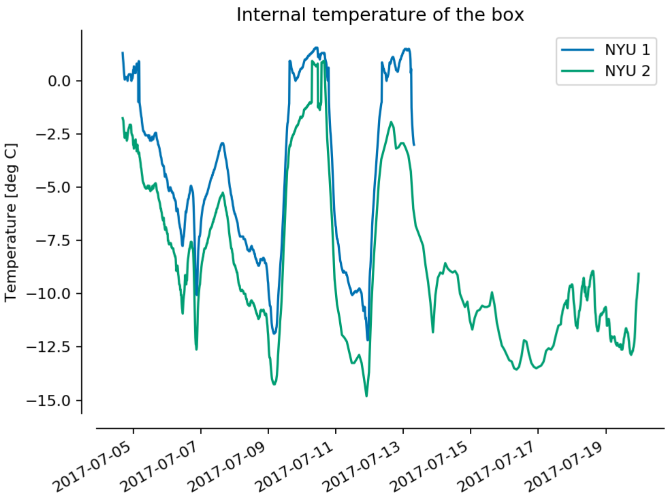


Figure 29 Internal temperature [Celsius] of each box for the duration of the deployment

The ice was highly mobile during the deployment period (Figure 30), with the sensors travelling predominantly back and forth in the east/west direction (NYU 1: 76 km total E/W extent; NYU 2: 104 km total E/W extent). Unexpectedly, they moved back and forth together, rather than drifting in random directions to each other. The ice field moved more coherently than expected, but with large variation in the speed (Figure 31) and direction of movement. In the north/south direction, they mostly travelled northward, covering nearly 70 km N/S. In total, NYU 1 covered 262 km in 9 days and NYU 2 travelled 339 km in 15 days. There was large variability in their distance from the ice edge, due to the complex way in which the ice edge developed.

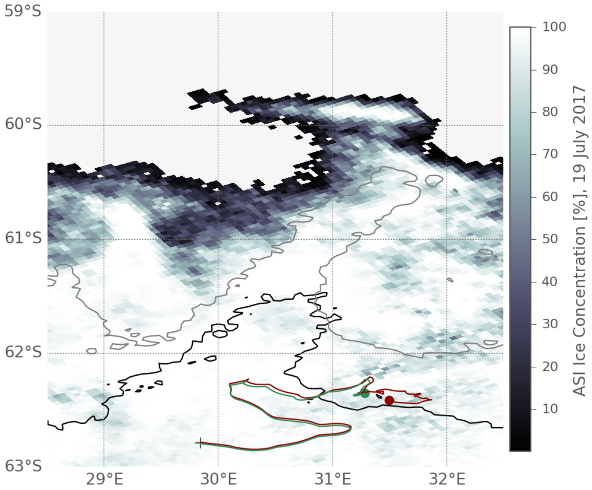


Figure 30 Deployment location and track of each sensor (NYU1 = green; NYU 2 = red). The crosses show the deployment locations and the circles show where each sensor stopped transmitting. The filled contours show the ice concentration on 19th July (when NYU 2 stopped transmitting), the black contour shows the 50 % ice concentration on 4th July (deployment) and the grey contour shows the 50 % ice concentration on 9th July (when NYU 1 stopped transmitting).

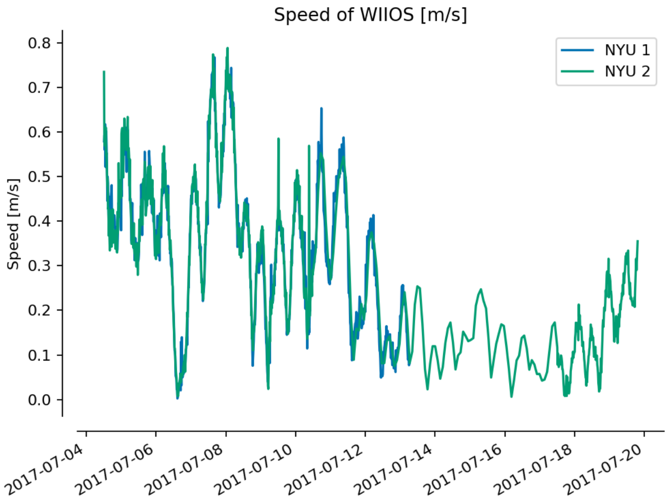


Figure 31 Speed of the WIIOS throughout the deployment period.

The significant wave height is defined to be four times the standard deviation of the surface elevation, ie.,

$$H_s = 4\sqrt{\int_0^\infty S(f)df}$$

and is therefore related to the energy held in the wave spectrum. The peak period is the period of maximum energy in the wave spectrum. Measured wave spectra are unreliable for the very small waves found deep into the MIZ and the reliable limit of the IMU is approximately 0.2 m, so the focus is on large wave events.

The majority of waves measured were less than 0.5 m, with peak periods between 12 and 16 s (Figure 32). Figure 33 also shows that most of the wave energy is contained in the longer periods. Four storm events on the 4th - 5th July, 7th - 8th July, 10th July and 14th July measured wave heights of up to 7 m, 2m and 1 m (Figure 34). During the first event on 4th - 5th July, particularly large waves of up to 7 m were recorded. These events will be examined in terms of alignment with wave direction, ice extent and atmospheric conditions to improve our understanding on how winter storms impact the MIZ.

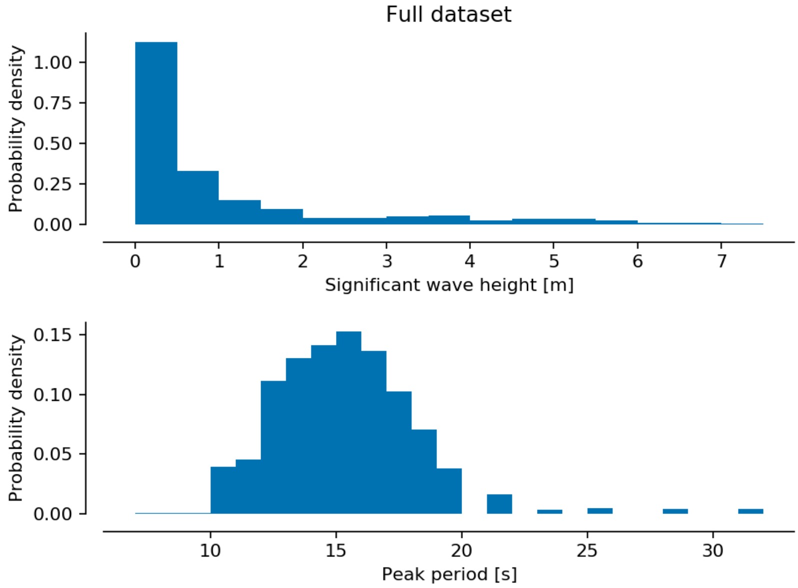


Figure 32 The distribution of significant wave heights [m] and peak periods [s] for the full dataset

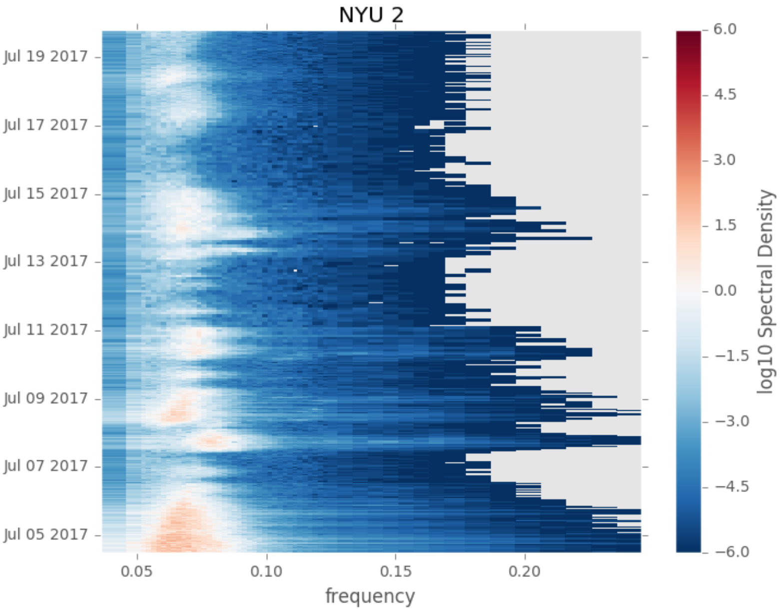


Figure 33 Energy density spectrum [m^2/Hz] for NYU 2 (log taken to improve readability).

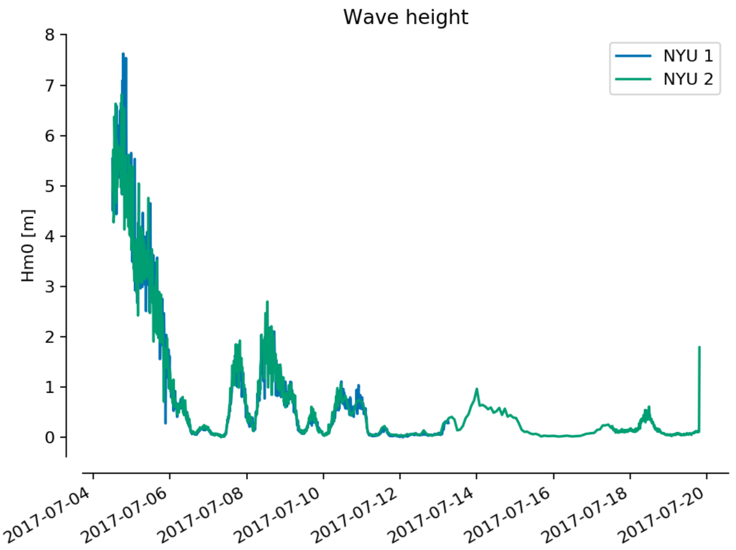


Figure 34 An overview of the significant wave heights [m] for each WIIOS.

9.2 Pancake Ice Drift Tracking Units

9.2.1 Equipment and deployment

In order to monitor the dynamics of MIZ, the University of Cape Town and the University of Melbourne team deployed three pancake ice tracking transceivers (Trident HELIX Ver 4 pcb sensors supplied by Trident Sensors) during the cruise. The first two units were placed in close proximity to the above NYU buoys, but the third unit was placed further north at latitude 62.6° S and longitude 30° E. The transceivers were housed in tubular steel sockets supported on welded steel foundation assemblies as shown in figure 12.

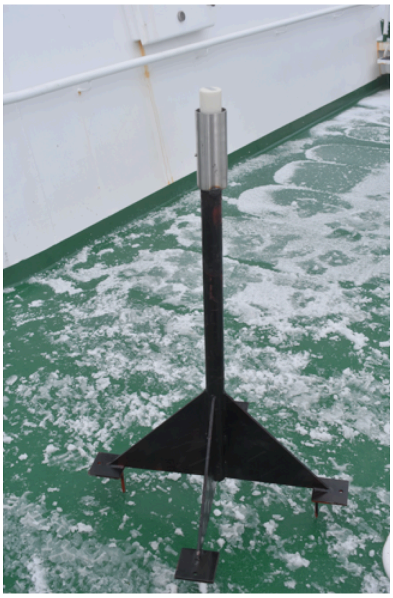


Figure 35 View of a typical tracker transceiver unit fixed into a socket on a foundation assembly.

As shown in Figure 35, the foundation assemblies incorporated steel stabbing pins under the pad footings to ensure that they could be positively located on the surface of the ice. The transceiver units were fixed at the top of the central tubular on a level where they could be kept clear of possible snow build-up. A deployed sensor is shown in Figure 36.

The sensors also included an Iridium 9603N SBD L-Band Transceiver (9603N) with a global positioning system (GPS) receiver and microprocessor. In addition, it was fitted out with a data storage facility, an intelligent power supply module and a clock. Date, time, position, bearing, speed and temperature data were collected by the sensor and transmitted by means of a Short Burst Data (SBD) communications system to the Iridium satellite network every four hours.

Figure 36 View of tracker transceiver unit on the ice

9.2.2 Preliminary results

The locations and tracks of the three sensors have been plotted in figure 37. Units 1 and 2 are situated in more closely packed frazil-pancake ice with a surface concentration of 100% concentration while unit 3 has been tracking in looser pancake ice towards the edge of the ice. Further, it can be noticed that:

- Units 1 and 2 have been following a roughly elliptical track with a major axis in an east-west direction;
- Unit 3 initially followed a similar route to units 1 and 2 but then it broke out from that area and tracked north-eastwards toward the edge of the ice.

Units 1 and 2 have both been tracking at average speeds of 0.24 m/sec and 0.23 m/sec respectively and unit 3 has been drifting at a faster speed of 0.26 m/sec. The individual speeds of the units have ranged from .01 to .74 m/sec. These speeds correlate well with those determined from the NYU buoys above, and by other researchers in the Antarctic where speeds between 22 and 35 cm,/sec were recorded (Doble 2005). Similar average drift speeds for pancake ice, equal to.29 m/sec, have also been found in the Odden Tongue area of Greenland (Wilkinson 2006). The speeds of the trackers since the 5 July 2017 been plotted in Figure 38.

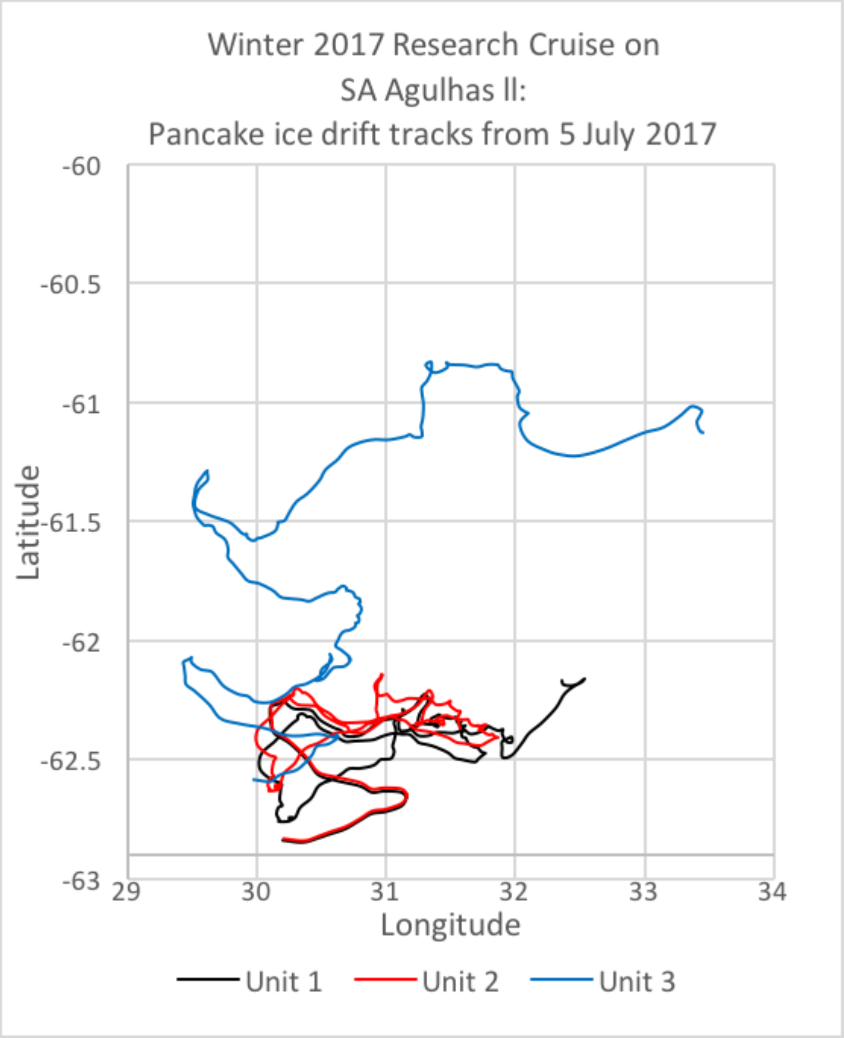


Figure 37 Pancake ice drift racks from the 5 July 2017 to end of August

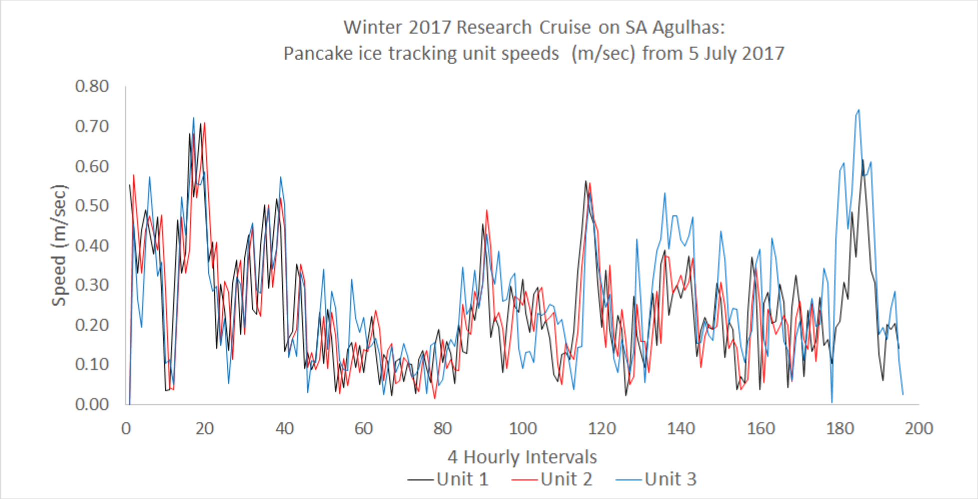


Figure 38 Pancake tracking unit drifting speeds.

9.3 Drift Buoys

9.3.1 Deployment

To complement information from the WIIOS and the drift tracking units, a drift buoy (supplied by Spoondrift) was deployed at 61.5° South and 29.9° East on July 5th, 2017 (Station M05). This device is equipped with an accelerometer for measuring the three-dimensional wave motion on the water surface. The buoy is also equipped with a GPS for retrieving the geographical position and a satellite communication unit for transmitting data in real time onshore. A subscription to Iridium was provided by the supplier and allows receiving averaged parameters such as the significant wave height, the peak and mean periods and mean wave direction every hour; this subscription is for year. The instrument is powered by a battery, which is directly connected to solar panels for automatic recharging (see Figure 39). This peculiar design was thought to ensure a long-term usage of the buoy without recovery for maintenance.

Figure 39 Drift buoy.

It should be noticed that this buoy is specifically designed for operating in open ocean. However, it was never tested in the very harsh environment at high latitude. For this reason, the deployment during this cruise was more for testing the device rather than acquiring quality data. As a matter of fact, the buoy operated normally for approximately 24 hours, after which contact was lost. Water overwashing the buoy and the cold temperature contributed to forming a layer of ice on the top of the device, making the communication with satellite difficult. Log files received before the drop in the connection revealed that the battery drained fast in the attempt to establish a stable connection with the satellite. Due to the limited number of hours of daylight, no significant recharge was possible at the time.

At present, the buoy is probably fully covered by ice (it has probably become a pancake ice itself!). The electronics should be able to withstand the cold temperature (ice cover also works as an natural insulator). We expect that the device will come back to life in spring, when the ice has melt and sufficient daylight has allowed recharging the battery. If this happens, the buoy will provide valuable information on the metocean properties of the Southern Ocean and will be one of the very few buoys operating below 50^{o} South.

9.3.2 Preliminary results

The buoy was deployed just outside the marginal ice zone. The location was ideal to provide vital information on the incoming wave field, to complement data from the other devices (namely the WIIOS and ice trackers). Furthermore, it was expected that pancake ice would have formed at that latitude so that the buoy could have provided valuable data at the edge of the ice cover.

As aforementioned, the buoy only operated for about 24 hours. An example of the significant wave height and peak wave period retrieved during this time is reported in Figure 40. At deployment, the wave field was intense with approximately 7 m of significant wave height as a severe storm was raging at the time. With the decay of the storm, wave height decayed as well, and it dropped down to about 4m within 18 hours. Interesting to note, waves were quite long (peak period was about 14.5 s) for about 6 hours before dropping to more standard peak wave period for open ocean waves, such as 11-12 s. Such values were consistent with the wave field reported by WIIOS.

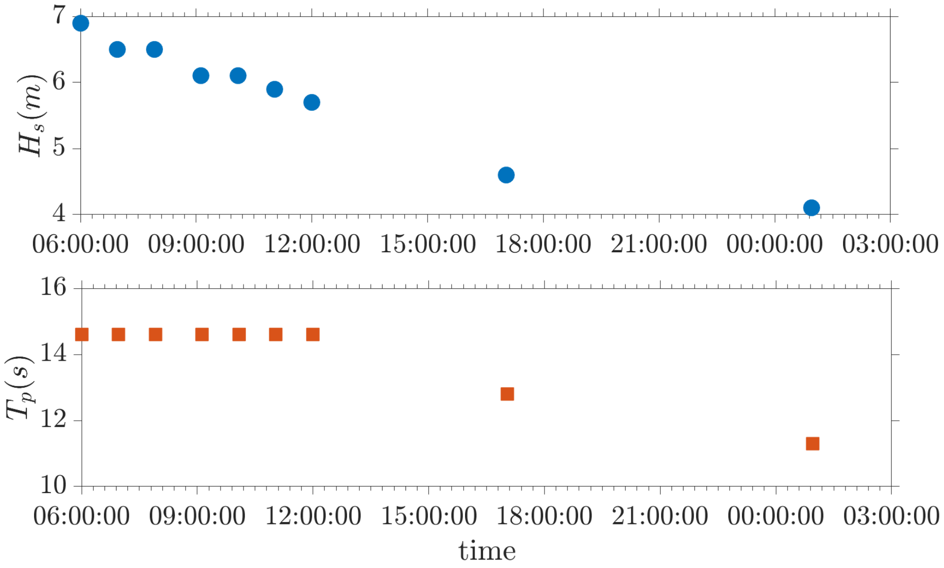


Figure 40 Significant wave height (upper panel) and peak period (lower panel) as measured by the drift buoy.

9.4 Stereo vision camera system for wave detection

9.4.1 Equipment

A stereo video technique recently developed by Benetazzo (2006) was used to measure waves and waves-in-ice during the entire cruise. The method recovers topographic information of a footprint of the sea surface from a sequence of synchronous, overlapping video images by applying binocular stereogrammetry techniques. The method differs from the traditional stereo-photogrammetric analysis of a single stereo-pair, because the use of video allows for a continuous sequence of stereo-images to be digitally sampled and analyzed, providing a spatio-temporal description of the sea surface. Measurements will be used to study the dynamical behavior of waves in the open ocean and the in the marginal ice zone.

Two GigE Monochrome Industrial Camera (2/3" CMOS Global Shutter, 2448 x 2048, 5MP, 3.45 um pixels, 38 fps, Sony IMX264LLR, 8/12 bits) equipped with 5mm F1.8, Cmount, 10MP, 2/3" lens Goyo were installed on the port side of the monkey bridge (see Figure 41). The cameras were mounted at a distance of about 4m from each other. Their longitudinal axes were kept parallel. Both cameras were down-looking the ocean surface at an angle of 25 degrees taken from the horizon. Considering that the height of the monkey bridge is about 35m from the waterline, this particular configuration allowed observation of a footprint of the ocean at a distance of about 140m from the ship. This was enough to capture waves outside the area of disturbance of the ship. An example of the synchronized images taken from the cameras is reported in Figure 42 (upper panels)

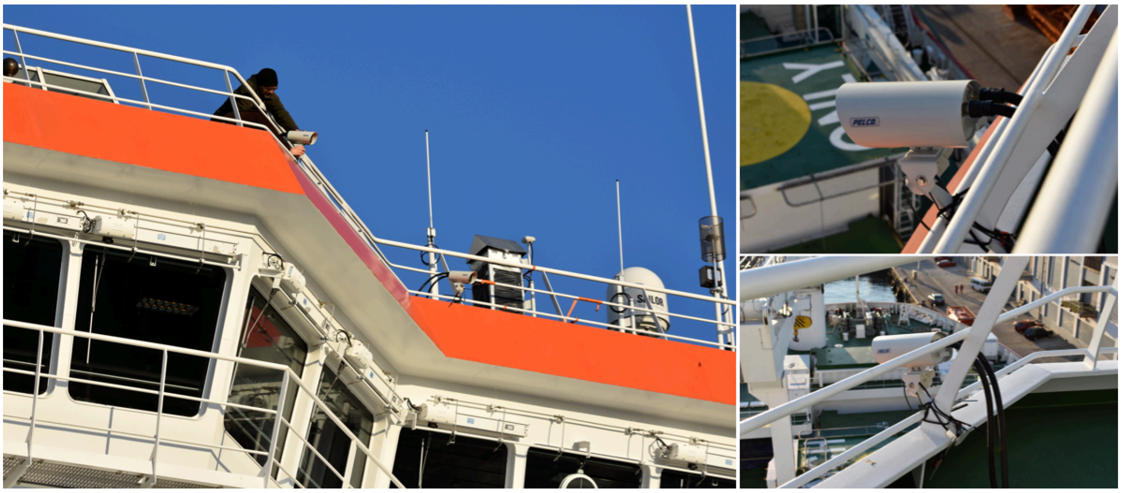


Figure 41 Cameras installed on the monkey bridge

The cameras were controlled by a laptop computer, which was directly connected to the cameras with wires. The acquisition of images occurred during daylight to ensure the pictures were sufficiently bright for post-processing. Photos were taken at a sampling frequency of 2Hz for periods of 30 minutes. This allows the reconstruction of average metocean conditions every 30 minutes, which is a timeframe consistent with standard metocean measurements.

To eliminate the ship motion, a motion sensor unit (IMU) was installed nearby the cameras. In principle, the IMU should have been synchronized with the camera acquisition, but this revealed to be too complicate for the peculiar camera set up adopted for this cruise. The IMU was then operated to a rather high sampling frequency (10Hz), to allow a manual synchronization between the IMU and images (i.e. the photo sequence starts at the image closest to the first available records from the IMU).

9.4.2 Preliminary analysis

Synchronized images are post-processed to reconstruct spatio-temporal information of the sea surface. The reconstruction of a three-dimensional ocean footprint is achieved through standard image processing techniques based on the Fast Fourier Transformation. An example of the reconstructed surface is presented in Figure 42 (lower panel). The three-dimentional water surface is then used to compute the wave energy spectrum, out of which average wave parameters can be extracted. The spatio-temporal evolution of the wave spectrum will also provide valuable information on the dynamical properties of the wave field.

Videos of the ocean surface were also taken in the marginal ice zone. The presence of ice alters somehow the brightness of the pictures and partially masks the water surface elevation, making the analysis of the synchronized images challenging. A preliminary attempt to retrieve the ocean surface, however, provided encouraging results. As shown in Figure 43, the surface elevation can be reconstructed also in ice-covered seas. To the best of these authors knowledge, this is the very first successful attempt to retrieve metocean properties of in the marginal ice zone with remote sensing techniques.

At the time this report is written, a full analysis of the images is not available yet. A proper calibration of the cameras needs to be done in order to ensure the correct dimensions are retrieved from the images. Currently, calibration and image post-processing is ongoing and results are not available yet. For this reason, the values of the water surface elevation in Figure 43 should be disregarded as they have been obtained with dummy calibration coefficients.

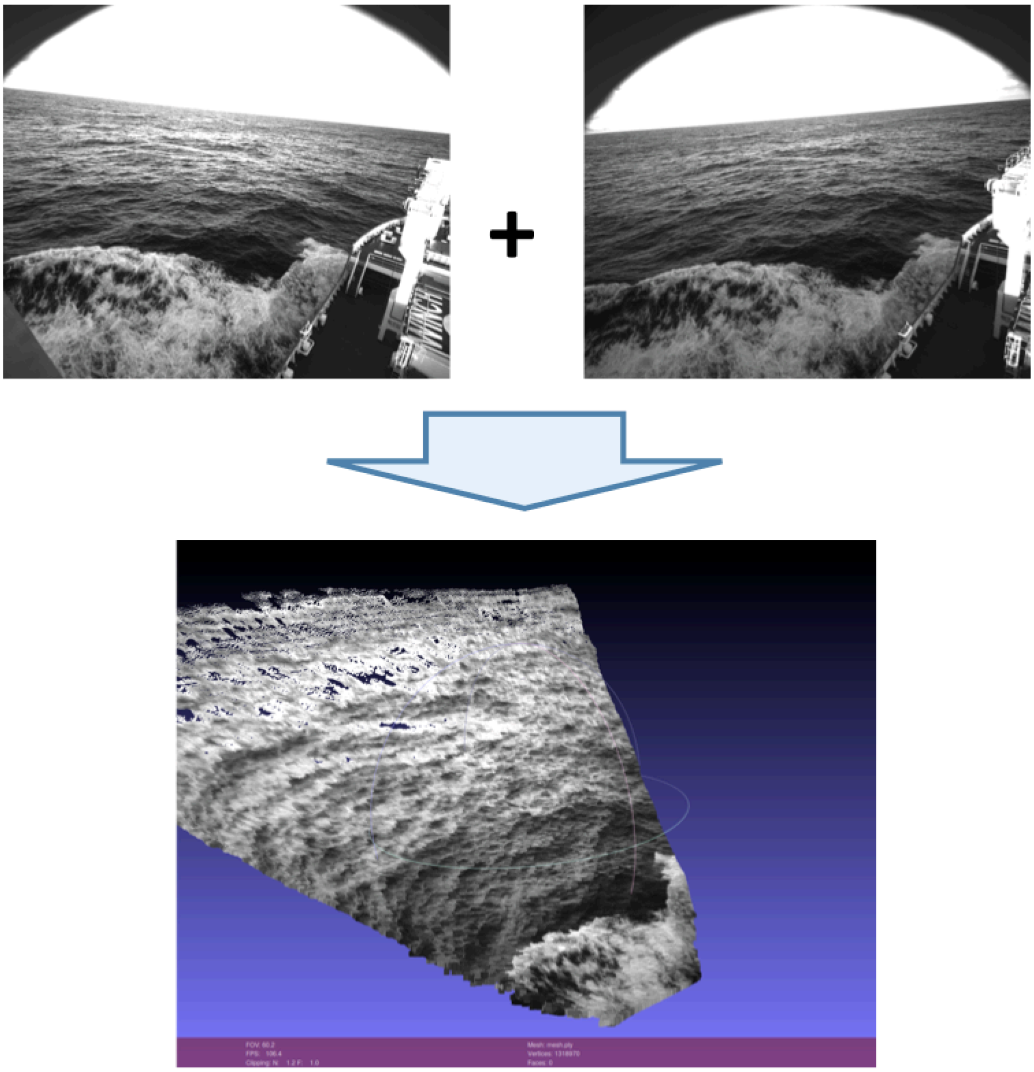


Figure 42 Sample images (upper panels) and reconstructed surface elevation (lower panel)

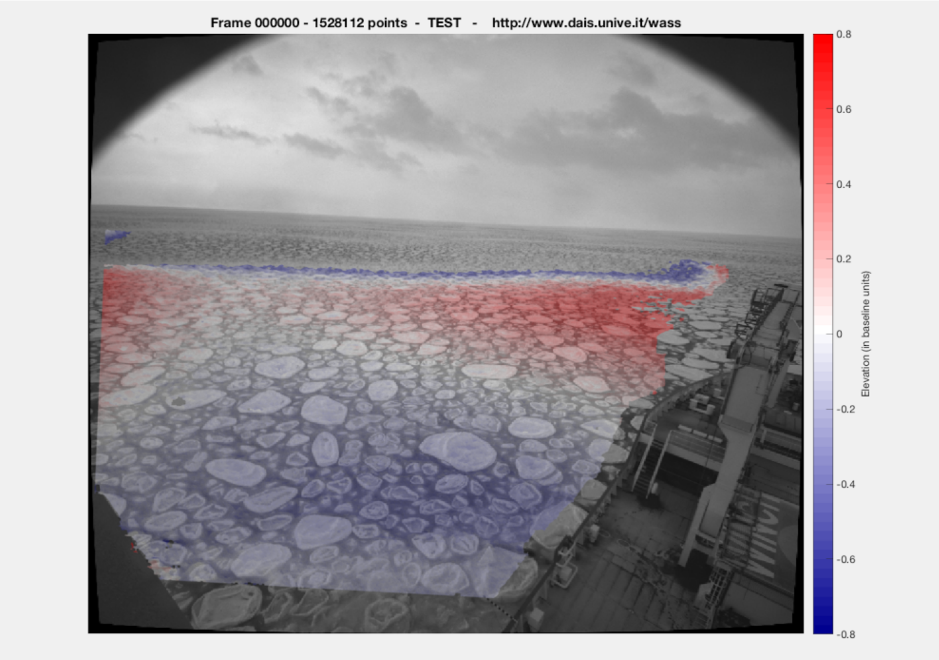


Figure 43 Reconstruction of the three-dimensional ocean surface in the marginal ice zone.

9.5 *Bibliography*

Benetazzo, A. (2006), Measurements of short water waves using stereo matched image sequences. Coastal Engineering, 53, 1013–1032, doi: 10.1016/j.coastaleng.2006.06.012

Dumont, D., A. L. Kohout, and L. Bertino (2011), A wave-based model for the marginal ice zone including a oe breaking parameterization, J. Geophys. Res., 116 (C04001), doi:10.1029/2010JC006682.

Dobrynin, M, Murawski, J. and Yang, S. 2012. "Evolution of the global wind wave climate in CMIP5 experiments. Geopysical Research Letters 39, L18606.

Hartmann, D. L. et al., in Climate Change 2013: The Physical Science Basis (eds Stocker, F. F. et al.) 159 – 254 (Cambridge University Press, 2013).

Kohout, Alison L., Bill Penrose, Scott Penrose, and Michael J M Williams. 2015. "A Device for Measuring Wave-Induced Motion of Ice Floes in the Antarctic Marginal Ice Zone." Annals of Glaciology 56 (69): 415–24. doi:10.3189/2015AoG69A600.

Kohout, A. L., M. J. M. Williams, S. M. Dean, and M. H. Meylan. 2014. "Storm-Induced Sea-Ice Breakup and the Implications for Ice Extent." Nature 509 (7502). Nature Publishing Group: 604–7. doi:10.1038/nature13262.

Kohout, A. L., M. J. M. Williams, T. Toyota, J. Lieser, and J. Hutchings (2015), In situ observations of wave-induced sea ice breakup, Deep Sea Res. Pt. II, doi: http://dx.doi.org/10.1016/j.dsr2.2015.06.010.

Liu, A. K. and E. Mollo-Christensen (1988), Wave propagation in a solid ice pack, J. Phys. Oceanogr., 18(11), 1702-1712.

Turner, J., Phillips, T., Marshall, G. J., Hosking, J. S., Pope, J. O., Bracegirdle, T. J. and Deb, P. 2017 "Unprecedented springtime retreat of Antarctic sea ice in 2016". Geophysical Research Letters. Doi:10.1002/2017GL073656.

Wadhams, P., V. A. Squire, D. J. Goodman, A. M. Cowan, and S. C. Moore (1988), The attenuation rates of ocean waves in the marginal ice zone, J. Geophys. Res., 93 (C6), 395 6799-6818.

Williams, T. D., L. G. Bennetts, D. Dumont, V. A. Squire, and L. Bertino (2013a), Wave-ice interactions in the marginal ice zone. Part 1: Theoretical foundations, Ocean Model., 71, 81-91.

Williams, T. D., L. G. Bennetts, D. Dumont, V. A. Squire, and L. Bertino (2013b), Wave-ice interactions in the marginal ice zone. Part 2: Numerical implementation and sensitivity studies along 1d transects of the ocean surface, Ocean Model., 71, 92-101.

10 Sea ice properties in the Atlantic-Indian marginal ice zone: observations, sampling and testing

Contributors

Keith MacHutchon, Sebastian Skatulla, Benjamin Hall, Rutger Marquart, Emmanuel Omatuku Ngongo, Ehlke de Jong, Marcello Vichi

University of Cape Town

Sea ice is a complex material which is formed by the freezing of sea water. During its formation and growth, the sea ice structure is profoundly modified by the interaction of physical, biological and chemical processes, and becomes a heterogeneous semi-solid matrix in its simplest form (Hunke et al., 2010). These ice processes affect the climate (Light, 2003), ocean mixed layer structure (Morison and Smith, 1981), biological activity in ice and water (Cota, 1985), and the ocean heat flux at the underside of the ice (Maykut and McPhee, 1995). In winter, the Southern Ocean sea ice forms a barrier mediating the exchange of heat and momentum between the atmosphere and the ocean. The gradual ice break-up in spring and summer renders the barrier permeable and influences the ice dynamics in the region (Langhorne et al., 1998).

Current predictive models of Antarctic sea ice and metocean thermodynamics require an accurate knowledge and understanding of the processes of sea ice growth and fracture. However, these models fail to explicitly simulate these processes, due in part to the large computational costs associated with the accurate modelling of ice mechanics. This limits the predictive reliability of these models (Waisman et al, 2009). Additionally, the lack of sufficient data on the physical and mechanical properties of the Antarctic Marginal Ice Zone (MIZ) makes it impossible to accurately calibrate and verify computational models.

It is against this backdrop that the multi-disciplinary Sea Ice Research group was formed in 2016 to study sea ice dynamics and thermodynamics in the Antarctic MIZ. The successful 2016 winter cruise into the MIZ was this group’s first foray into this research. The 2017 cruise activities served to gather additional data on the properties of sea ice in the MIZ with the collected samples undergoing physical testing on board the ship and being stored for further physical and mechanical analysis at the laboratories of the University of Cape Town (UCT).

The gathering of the physical and mechanical properties of the MIZ sea ice will facilitate the development and verification of computational sea ice models. The computational modelling will be twofold: (i) The large-scale model of sea-ice mechanics and fracturing aims to simulate the initiation and propagation of sea ice fracture using the Phase Field Method framework for brittle and ductile behaviour. The framework is currently implemented in the in-house structural analysis software package SESKA. (ii) The small-scale model, which simulates the continuous changes which sea ice undergoes from its early formation to first year sea ice in terms of its main constituents using the Theory of Porous Media.

10.1 In Situ Observational Approach

The performance of passive microwave and in situ sea ice concentration (SIC) analyses in the Antarctic marginal ice zone (MIZ) and at the ice edge attracts ample attention in accuracy assessments. Satellite remote sensing has provided immaculate future potential to study sea ice characteristics and evolution. However, uncertainties remain unresolved. The ice observations conducted during the 2017 Winter MIZ Expedition aimed to collect contemporary, in situ observational data off the *SA Agulhas II* in order to quantify SIC from high-resolution passive microwave (PM) data and develop a comparative analysis. Geographically, the observations were attained on the transect strip on Longitude 30°E from Latitude 61°S to approximately 62.5°S, thus focussing on the Antarctic MIZ and its edge. The sea ice observational data collected shall aid in investigating the satellite spatial resolution. Thus, creating the ability to assess the quality of satellite SIC data with respect to on-board observational SIC estimates, based on the Antarctic Sea Ice Processes and Climate (ASPeCt) protocol. On-board sea ice observations particularly highlight the importance of understanding the small-scale processes that may be key in setting SIC, and need to be considered in future climate models.

The Antarctic MIZ is dynamic and, without accurate in situ observations that can validate satellite estimates, it is unpredictable. The Antarctic continent is surrounded by seasonally-fluctuating sea ice; advancing northward in the Austral winter and retreating in the summer. A marked role on surface ocean dynamics is thus exerted throughout the year. During the winter season, the sea ice extends as far as 2500 km from the Antarctic continent (Petrich and Eicken 2010) covering approximately 18 $10^6 km^2$ of the Southern Ocean, whereas 3 $10^6 km^2$ is covered during summer (Davies, 2015). These fluctuations impact the abiotic and biotic variables within the Southern Ocean as this seasonal ice fluctuation is not constrained by land. In addition, the Antarctic sea ice is contingent upon strong circumpolar winds, producing an outward stress component on the ice (Gloersen et al., 1993). Consequently, the Antarctic sea ice environment is increasingly diverse relative to that of the Arctic.

The aims of on-board sea ice observations are to quantify sea ice concentration from high-resolution passive microwave data and develop a relationship between the seasonal and inter-annual MIZ extension and the sea ice aerial extension. Remote sensing is one way to obtain high resolution images of sea ice surface features, however these need to be validated with direct observations.

The observations were made by six observers operating on the bridge (Figure 43) who were trained on the *SA Agulhas II* 2017 winter expedition. The observers learned standard protocols as well as sea ice observation methodologies. ASPeCt (2016) protocol and definitions were used when sea ice data was collected. The ASPeCt characteristics and definitions included:

- Total concentration: the fraction of the ocean covered by any type of sea ice, estimated to the nearest 10%;
- Categories and concentrations: the dominant ice types present in the pack were divided into primary (most dominant) and secondary (second-most dominant);
- Ice type;

Figure 44 Ice observations conducted from the bridge

- Topography: ridging, rafting, congealing, etc. was noted; and
- Snow type: for example, cold new snow or old melting snow.

Photographic images were captured on the *SA Agulhas II* using TomTom Time lapse footage (Figure 44). Information obtained from these images included time and position, total ice concentration, topography and snow cover of the dominant ice types. Wide angled images provided a 1 km radius for a defined time in space, therefore a single observation conducted from the ship accounts for approximately 1 km.

10.2 Sea ice Sampling and Testing

The Sea Ice Sampling and Testing team formed part of the Marginal Ice Zone (MIZ) Pilot Project. The primary objectives of the team on this cruise were to:

- Deploy pancake ice drift tracking units for metocean studies.
- Collect pancake ice samples.
- Obtain ice cores from consolidated ice and large ice floes.
- Determine the temperature and salinity of some of the obtained ice cores and collected pancakes.
- Store the remaining ice samples for mechanical and additional physical testing in the laboratories of UCT.
- Train students on polar engineering activities such as ice coring and temperature and salinity testing of ice samples.

Figure 45 Location of the TomTom action camera on port side and the relative field of view over sea ice.

The team worked together with other research groups represented by Mr Clinton Frederick Wood Saunders (Principal Investigator, SUN), Ms Tahlia Trish Henry (Technical chief, UCT), Dr Fleurianne Herveline Cecile Bertand (INT PI, UniD-E), Prof Tim Ricken (INT PI, TUDort), Dr Clare Eayrs (INT PI, NYUAD), Dr Jhon Fredi Mojica Moncada (INT PI, NYUAD), Mr Ayanda Mpalweni (MSc, UCT), Mr Tumelo Maja (Hons, UCT), Mr Kirodh Boodraj (MSc, UCT), Mr Wade Matthew de Kock (MSc, UCT), Ms Riesna Audh (Hons, UCT), Ms Carla Henning (INT PhD, TUDort), Mr Marcel Moldenhauer (INT PhD, UniD-E), Mrs Carolin Birgitta Mehlmann (INT PhD, UniD-E), Mr Andre Mielke (INT PhD, TUDort), Mr Jeremy Kravitz (MSc, UCT), Mr Butteur Mulumba Ntamba Ntamba (PhD, CPUT) and the ship crew.

10.3 Deployment of trackers

3 trackers were deployed onto the centre of large pancakes deep inside the MIZ on 04 July 2017. The pancakes were chosen such that the trackers could survive any ice-to-ice collision, wave effects and storm activity. 2 trackers were placed at Stations M01 and M02, about 1.5 km apart, (62.8º S, 29.8º E) and 1 tracker was deployed at Station M03 (62.6 S, 30.0º E). The deployment was carried out using the vessel cranes and hoist platforms. Figure 46 shows the deployment teams being lowered to place the trackers on pancakes.

Figure 46 Deployment of pancake ice drift tracking unit

10.4 Collection of pancake ice

Pancake lifting was briefly attempted at Station M03. However, due to unfavourable sea conditions, high winds and closely packed pancake ice with thick frazil in between, this was not feasible and it was decided to move onto M04 to make better use of the available time. Figure 47 shows the ice conditions at M04.

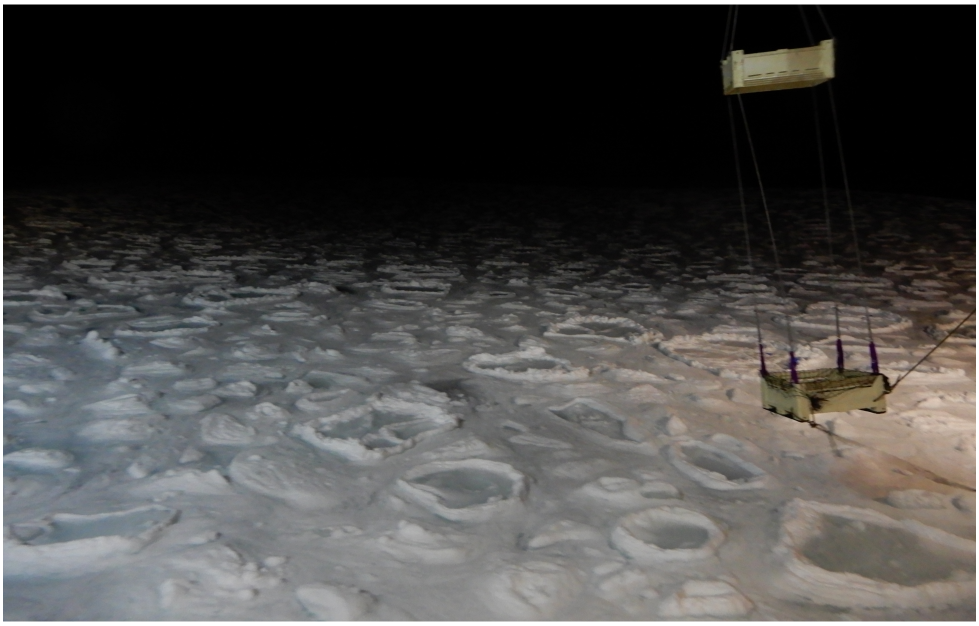


Figure 47 Ice conditions experienced at M04

The conditions at M04 (61° 58.16 S, 30° 09.44 E) were still quite difficult due to strong winds and high seas, but we collected 7 pancakes using the PVC ice lifting basket system and the ship's aft crane during the early hours of 05 July 2017. The collection operations started at 01h00 and lasted about 2 hours. The pancake-lifting baskets were designed using the knowledge and experience of ice conditions acquired during the 2016 winter cruise.

The collection of pancakes was conducted as follows; the lifting baskets were prepared, connected to the vessel aft crane and lowered into the water. After the basket had sunk, it was manoeuvred by the crane operator until it captured a pancake. The basket was then raised and brought back onto deck. Depending on their sizes, pancakes were either unloaded or left on the deck. 3 pancakes of manageable sizes were directly unloaded and analysed on-board, 2 others were directly unloaded and taken to cold storage for subsequent analysis by the biogeochemistry and trace metals research groups, and the remaining 2 were left in their baskets on deck for coring. Figure 48 shows the pancake collection operations in progress.

Figure 48 Lowering the basket into the water, pancake laden basket being brought onboard and collected pancake on deck (Station M04)

In addition to the collection of 7 pancakes, 2 pancakes were washed onto the ship deck by ocean waves. One of these pancakes was analysed for physical properties and the second one, shown in Figure 49, was used to obtain ice cores.

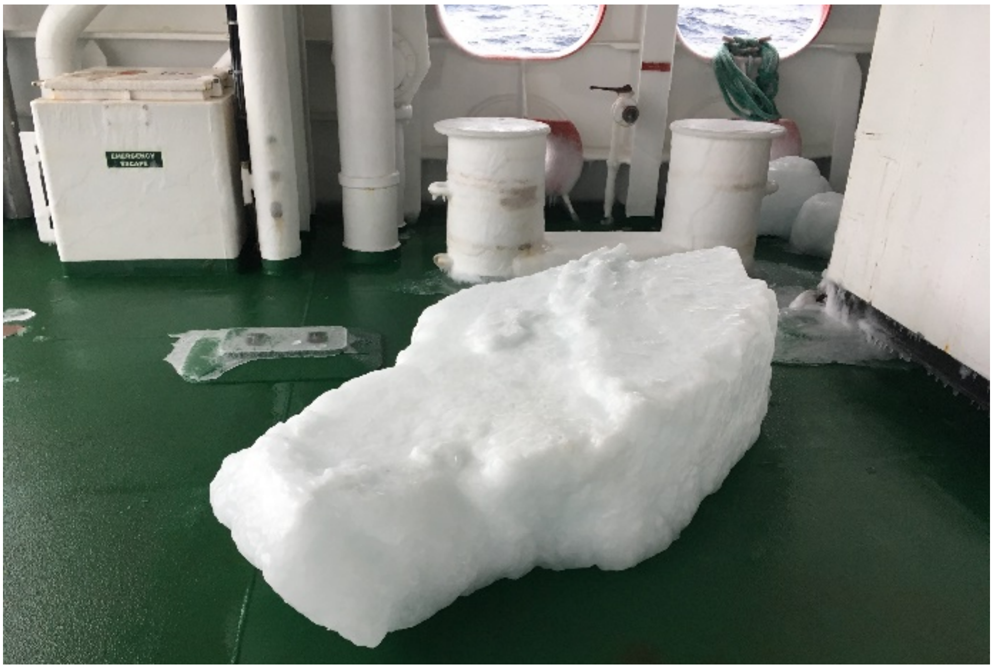


Figure 49 Large pancake washed on ship deck (appx size: 2.5 m x 1 m).

10.5 Coring of pancake samples

One of the main objectives of this cruise was to deploy the coring team on consolidated ice, from where ice cores could be obtained in-situ using the Kovacs Mark II ice corer. The vessel reached the MIZ pancake field at 07h00 on 04 July 2017 in stormy weather conditions. However, as we progressed deeper into the MIZ, it became apparent that the field of consolidated ice had moved from the satellite predicted position. Since we did not have real-time information on the position of sea ice, we kept progressing deeper into the MIZ until 15h00, at which point we gave up on the hope of reaching consolidated ice within the time allocated in the MIZ.

This was unfortunate as coring on consolidated ice would have not only provided valuable data on consolidated sea ice, but also built great experience within the team for ice field-techniques. This blow meant that we had to rethink our coring strategy, as many of the measurements we wanted to perform for later physical and mechanical testing at UCT could best be achieved with ice cores. Therefore, sea ice coring activities shifted focus to collecting large pancakes and coring them from the vessel deck.

With the new coring strategy, 50 cores were obtained from the 3 largest pancakes using the ice corer: 39 vertical and 4 horizontal cores for mechanical testing; 4 cores for biogeochemical testing and 3 cores for temperature and salinity measurements. Figure 50 shows a pancake being cored on board the ship.

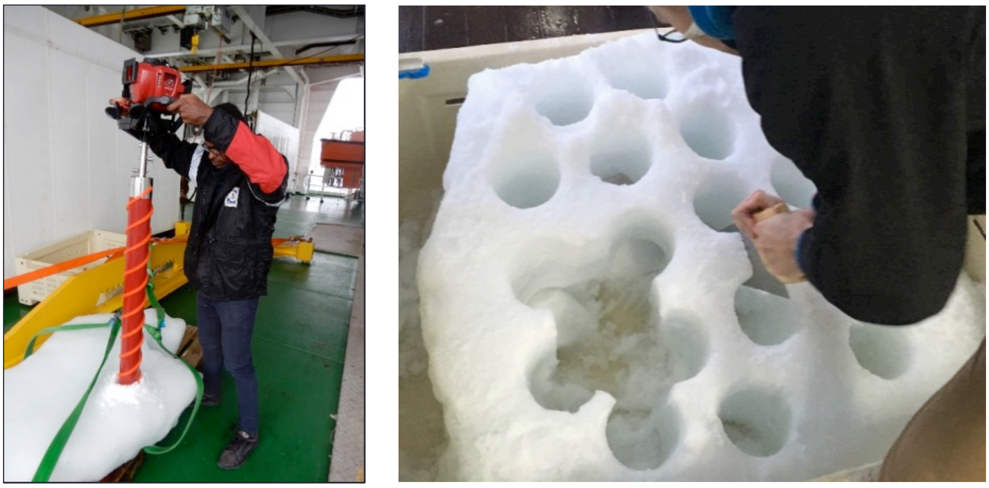


Figure 50 Coring of pancake ice on board the ship

10.6 On-board pancake analysis (Analysis of physical properties of ice samples)

10.6.1 Analysis of pancake samples

Temperature and salinity data were obtained from the collected pancakes while on board the ship. This data is important in that it enables the calculation of the brine volume within the ice, with both temperature and brine volume affecting the strength of the ice. As mentioned in section 2.5, 4 pancakes were directly analysed once they were on the deck. The pancakes were sectioned into 2 lengthwise. One half was taken to cold storage to be used for mechanical testing at the UCT laboratory while the spatial temperature was taken on the open cross-sectional area of the other half using an electronic probe thermometer. This was achieved by scoring of a grid on the ice surface with a probe recording the temperature from the centre of each block. Figure 51 shows the aforementioned grid design, and its implementation onto Pancake 3.

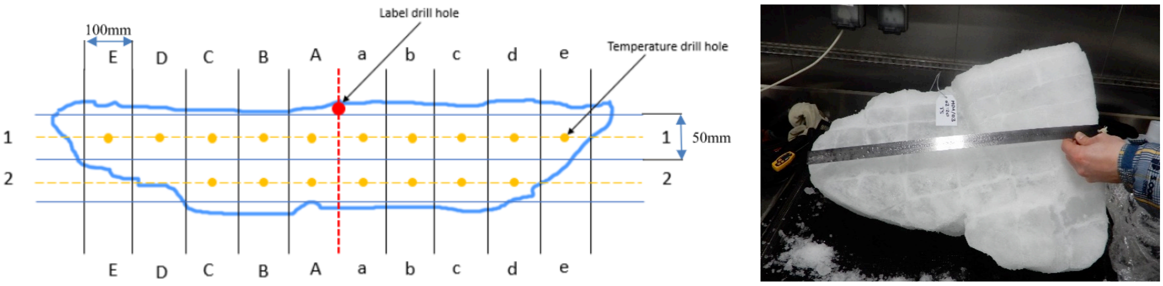


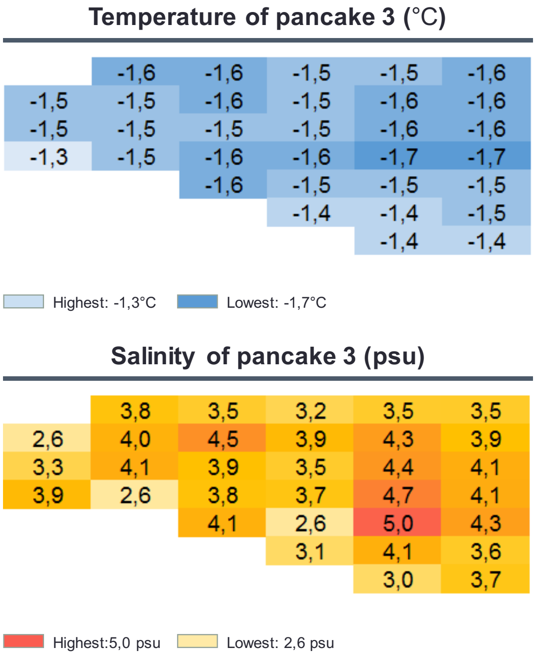
Figure 51 Proposed grid system and implementation onto Pancake 3

After the temperature measurement, the pancake half was then taken to the cold storage room, and this procedure was repeated for all pancakes.

From 06 to 08 July, the pancake halves with spatial temperature were sectioned into pancake blocks of 100 x 100 x 50 mm using a stainless-steel bow-saw and cross-cut saw. The blocks were then put into sealed plastic bags and left to melt as shown in Figure 52 Each melted block was placed into clean bottles and its salinity was measured using an 8410A Portasal salinometer from 08 to 13 July. The remainder of each melted block was then analysed by the biogeochemistry and phytoplankton groups.

Figure 52 Ice blocks in plastic bags for salinity testing

An example of the temperature and salinity results of one pancake can be seen in Figure 53:



Temperature of pancake 3 (°C)

	-1,6	-1,6	-1,5	-1,5	-1,6
-1,5	-1,5	-1,6	-1,5	-1,6	-1,6
-1,5	-1,5	-1,5	-1,5	-1,6	-1,6
-1,3	-1,5	-1,6	-1,6	-1,7	-1,7
		-1,6	-1,5	-1,5	-1,5
			-1,4	-1,4	-1,5
				-1,4	-1,4

🟦 Highest: -1,3°C 🟦 Lowest: -1,7°C

Salinity of pancake 3 (psu)

	3,8	3,5	3,2	3,5	3,5
2,6	4,0	4,5	3,9	4,3	3,9
3,3	4,1	3,9	3,5	4,4	4,1
3,9	2,6	3,8	3,7	4,7	4,1
		4,1	2,6	5,0	4,3
			3,1	4,1	3,6
				3,0	3,7

🟥 Highest:5,0 psu 🟨 Lowest: 2,6 psu

Figure 53 Temperature and salinity results of pancake 3

10.6.2 Analysis of ice cores

Similarly to the analysis of pancakes, 3 cores were used for temperature and salinity measurements. After an ice core was drilled, the core was removed from the corer and placed in a pre-marked gutter. Subsequently, the ice core length was measured and holes were drilled into the core, every 50 mm, using an electric drill. After each hole was drilled, the temperature was immediately taken using a probe thermometer. The core was stored in a pre-marked resealable plastic sample bag and stored in the cold room.

In order to prepare the core samples for salinity analysis, the cores were taken out of the cold room and sectioned into 50 mm long sizes. The core sections were put into sealed plastic bags and left to melt. Each melted block was placed into clean bottles and its salinity was measured using an 8410A Portasal salinometer. **Error! Reference source not found.** shows some of the analysis procedures.

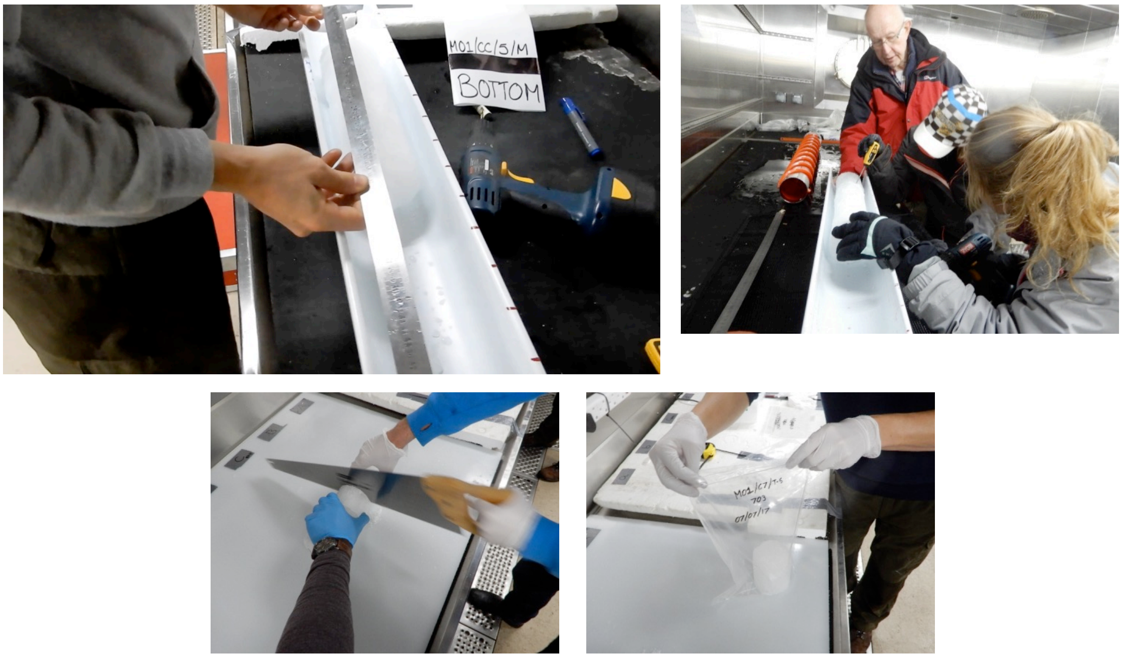
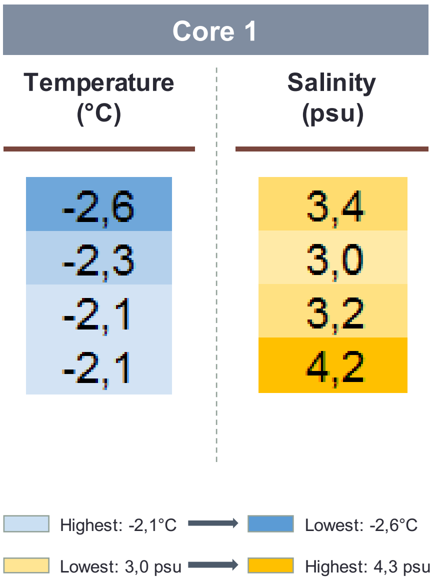


Figure 54 Analysis of ice cores

An example of the temperature and salinity results of one is shown in Figure 55.



Core 1	
Temperature (°C)	Salinity (psu)
-2,6	3,4
-2,3	3,0
-2,1	3,2
-2,1	4,2

Highest: -2,1°C → Lowest: -2,6°C

Lowest: 3,0 psu → Highest: 4,3 psu

Figure 55 Temperature and salinity measurements of core 1

10.7 Multi-disciplinary work and student training

This project has brought together various interested research groups such as trace metals, phytoplankton and biogeochemistry. Ice samples were set aside and given to these groups for analysis. The remainder of the melted ice samples were also tested by the phytoplankton and biogeochemistry groups, and the sea ice team helped with the sectioning and coring of the set-aside samples.

In addition to the multi-disciplinary work, the sea ice team involved students from various disciplines in all the coring and analysis activities in order to share the knowledge and provide an insight into the sea ice work.

10.8 Conclusions and recommendations

Despite the setback due to the stormy weather conditions and unprecedented ice movement, this cruise was a success. Most of the primary objectives were met, and for the few that could not be met an alternative plan was implemented in order to limit the loss of data. For example, the alternative plan to core pancakes on deck replaced the original objective to obtain cores from consolidated ice.

The data gathered on this cruise will be added to the data obtained during the 2016 winter cruise into the MIZ, contributing to the MIZ database. The mechanical properties of the stored ice samples will be analysed at UCT laboratories as well as additional physical properties such as the ice microstructure.

Future research will include:

- The identification of variations in the physical and mechanical properties of the sea ice along the transects into the MIZ.
- The use of observed sea ice properties as a reference for creating artificial ice for analysis in the laboratory, facilitating the testing and recording of changes over time, in a controlled environment.
- The use of observed mechanical properties to model the temporal thermo-mechanical evolution of changes in the aggregate state, i.e. liquid to frozen and vice versa.
- Physical and mechanical variables will be used to develop an understanding of the brine channels within the ice, its porosity and permeability, in order to begin developing Theory of Porous Media (TPM) models of pancake ice.

The unprecedented movement of the ice due to storms was of great interest, and the combination of what was experienced on this trip and the data obtained from the deployed trackers should enable better predictions of ice movement for next time. Satellite images of better resolution and in real time would be of great value for future voyages.

The opportunity to spend a longer time within the MIZ would be of great use in order to obtain more samples from a wider spatial variation. Unlimited time is never realistic though, and we understand the time constraints that are placed on these cruises. However, a time safety cushion to account for the unfavourable conditions experienced during the winter cruises would be advantageous, and allow leeway in situations as experienced during pancake collections at M03 (Section 2.4).

This project was an example of successful multi-disciplinary and international collaboration. Feedback from the other involved parties, including metocean, bioactive trace elements, phytoplankton and nutrient cycle has been that there is a growing interest within each of their fields focussing on the area of the MIZ specifically of that covered by pancake ice, with many questions yet to be answered. A multidisciplinary approach will enable great progress to be made in this field, with collaborative efforts and data sharing leading to a comprehensive understanding of MIZ. Interest and commitment to this collaborative approach has already been shown from the aforementioned involved groups, and we are looking forward to future opportunities to implement this multidisciplinary approach with optimism and great expectation.

10.9 Acknowledgments

This cruise and our participation was only possible through our funders, the Department of Science and Technology through the National Research Fund. Thanks go to the Department of Environmental Affairs for use of the *SA Agulhas II* as well as their facilities. The smoothness of the voyage and the meeting of our objectives would not have been possible without the tireless efforts by the captain and crew of the *SA Agulhas II*. Thank you also to the University of Cape Town for supporting us in the research trip.

10.10 Bibliography

Cota, Glenn F. "Photoadaptation Of High Arctic Ice Algae." Nature 315.6016 (1985): 219-222. Web.

Doble, Martin J., Max D Coon, and Peter Wadhams. "Pancake Ice Formation In The Weddell Sea." Journal of Geophysical Research 108.C7 (2003): n. pag. Web.

Hunke, Elizabeth C., William H. Lipscomb, and Adrian K. Turner. "Sea-Ice Models For Climate Study: Retrospective And New Directions." Journal of Glaciology 56.200 (2010): 1162-1172. Web.

Light, B., G. A. Maykut, and T. C. Grenfell. "Effects Of Temperature On The Microstructure Of First-Year Arctic Sea Ice." Journal of Geophysical Research: Oceans 108.C2 (2003): n/a-n/a. Web.

Maykut, G. A., and Miles G. McPhee. "Solar Heating Of The Arctic Mixed Layer." Journal of Geophysical Research 100.C12 (1995): 24691. Web.

Morison, James, and J. Dungan Smith. "Seasonal Variations In The Upper Arctic Ocean As Observed At T-3." Geophysical Research Letters 8.7 (1981): 753-756. Web

11 The upper Southern Ocean nitrogen cycle: wintertime controls on nitrogen transformation rates and nitrate isotope distributions, with implications for atmospheric CO_2 drawdown

Contributors

Sarah Fawcett, University of Cape Town

The balance between summertime nitrate (NO_3^-) consumption and wintertime NO_3^- recharge is central to the role of the Southern Ocean in setting atmospheric CO_2 (Sarmiento and Toggweiler 1984). It is also the most obvious seasonal signal in the concentration and isotopic composition ($\delta^{15}N$ and $\delta^{18}O$) of NO_3^- in Antarctic surface waters (Sigman et al. 1999; DiFiore et al. 2009; Smart et al. 2015; Kemeny et al., 2016). The focus of this project is to characterise the wintertime "recharge" state of the Southern Ocean in terms of the nitrogen (N) biogeochemistry, as this sets the conditions experienced by phytoplankton in the spring, with important implications for annual CO_2 and nutrient drawdown.

In addition to the recharge-consumption dynamic described above, there is also active cycling of N within the mixed layer that remains poorly understood. Our work to-date using measurements of the dual isotopes of NO_3^- has shown that while NO_3^- assimilation by phytoplankton is the dominant signal in the upper water column of the Antarctic, even in midwinter, nitrification (the oxidation of ammonium (NH_4^+) to nitrite (NO_2^-) and then NO_3^-) is active in the mixed layer in winter but not in summer (Smart et al. 2015; Kemeny et al. 2016; Fawcett et al. in prep). This apparent seasonal separation of important N cycle processes (which have different implications for CO_2 removal) is supported by tracer experiments that reveal high rates of NH_4^+ and NO_2^- oxidation throughout the Antarctic winter mixed layer, while NO_3^- assimilation is low to undetectable (Mdutyana et al., in prep; Figure 56). By contrast, summertime NO_3^- assimilation rates are high and nitrification accounts for <10% of algal NO_3^- consumption. Surprisingly, NH_4^+ uptake appears to be extremely high in winter, which, given the low rates of primary production, we tentatively attribute to heterotrophic bacteria, although more data are required to confirm this.

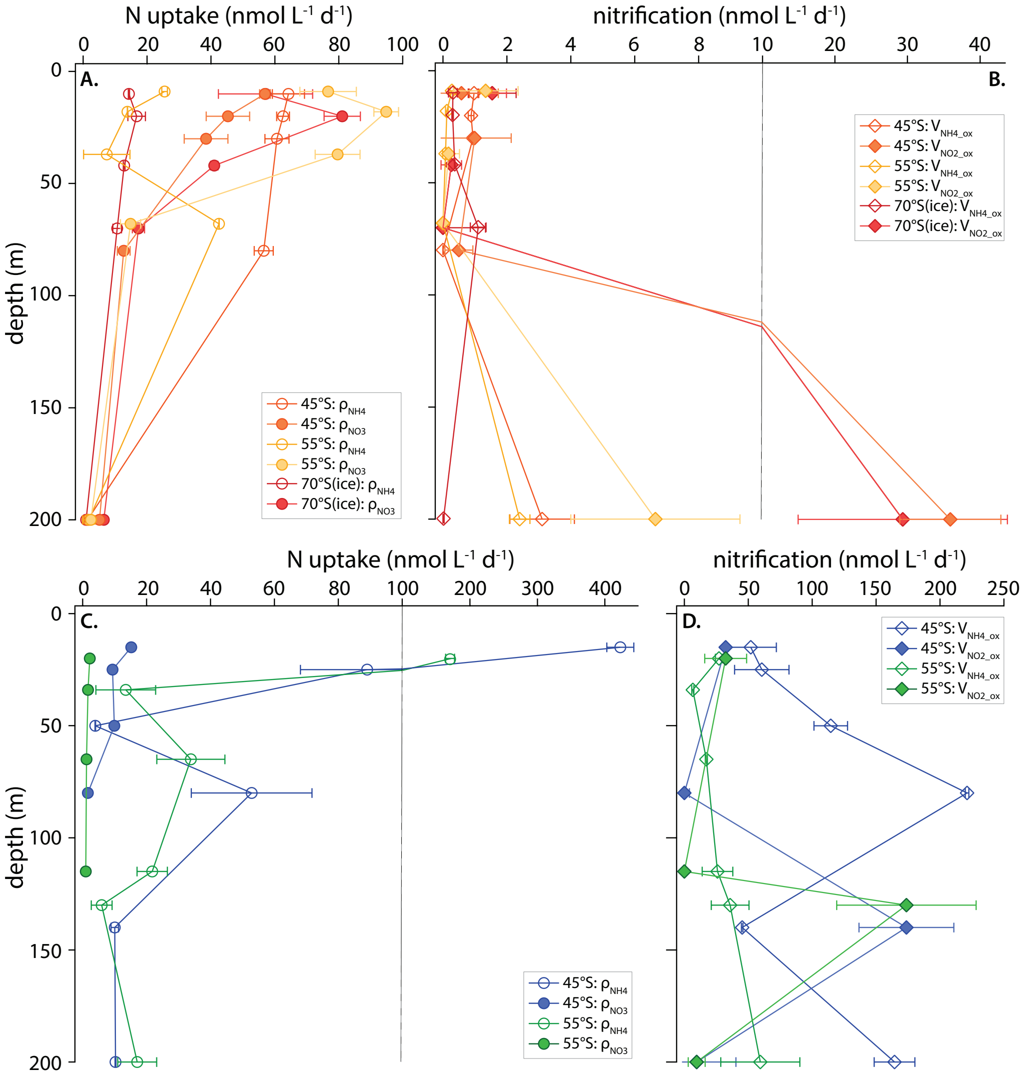


Figure 56 A selection of preliminary data from experiments conducted along the GoodHope Line in summer (warm colours) and winter (cool colours) showing nitrate and ammonium uptake rates (A and C) and ammonia and nitrite oxidation rates (B and D) (Mdutyana et al., in prep).

11.1 Nitrogen uptake and oxidation experiments

To better understand the seasonal controls on the Southern Ocean N cycle and expand our efforts detailed above, we conducted a series of experiments designed to quantify 1) the rates of N uptake (NH_4^+, NO_3^-, and urea) and oxidation (NH_4^+ and NO_2^-), but also the kinetic parameters (i.e., maximum N uptake/oxidation rate (V_{max}); half saturation constants (K_m)) associated with these processes. Such data are necessary for improving biogeochemical and ecosystem models, yet Southern Ocean studies of N cycle kinetics are very limited and there are currently no data for the Subantarctic and Polar Zones of the Atlantic or Indian sectors.

Experiments are detailed in the table below:

Leg	Stn ID	Fawcett lab stn ID	Latitude	Longitude	Parameters sampled
S		UW 1	36 59.147 S	19 16.021 E	Kinetics: NO_3^-, NH_4^+, urea uptake; NH_4^+, NO_2^- oxidation
S		UW 2	41 54.121 S	21 17.340 E	Kinetics: NO_3^-, NH_4^+, urea uptake; NH_4^+, NO_2^- oxidation
S		UW 3	44 50.495 S	22 17.083 E	Kinetics: NO_3^-, NH_4^+, urea uptake; NH_4^+, NO_2^- oxidation
S		UW 4	50 39.666 S	25 31.423 E	Kinetics: NH_4^+, urea uptake; NH_4^+, NO_2^- oxidation
S		UW 5	55 30.425 S	28 18.656 E	Kinetics: NH_4^+ uptake; NH_4^+, NO_2^- oxidation
S		UW 6	57 47.387 S	29 01.979 E	Kinetics: NH_4^+ uptake; NH_4^+, NO_2^- oxidation
M	M03	UW 7	61 58.623 S	30 10.692 E	Kinetics: NH_4^+, NO_2^- oxidation
I	I01	Vertical Stn 1	58 30.050 S	30 00.000 E	Profiles: NPP, NO_3^-, NH_4^+, urea uptake; NH_4^+, NO_2^- oxidation
I	I03	Vertical Stn 2	53 30.097 S	29 59.988 E	Profiles: NPP, NO_3^-, NH_4^+, urea uptake; NH_4^+, NO_2^- oxidation
I	I05	Vertical Stn 3	47 59.980 S	30 00.050 E	Profiles: NPP, NO_3^-, NH_4^+, urea uptake; NH_4^+, NO_2^- oxidation
I	I07	Vertical Stn 4	42 59.654 S	29 59.851 E	Profiles: NPP, NO_3^-, NH_4^+, urea uptake; NH_4^+, NO_2^- oxidation

N uptake samples will be analysed at the Light Stable Isotope Laboratory in the UCT Department of Archaeology; nitrification samples will be analysed using the azide (Peng et al. 2015) and denitrifier (Sigman et al. 2001) methods in the laboratory of Prof. Bess Ward at Princeton University.

11.2 Nutrients and isotopes

Measurements of nutrients and nitrate and particulate organic N (PN) isotopes (bulk and flow cytometrically-sorted) will be used to develop an integrated view of the nutrient recharge state of the wintertime Southern Ocean, shedding light on the relative importance of nitrification and N uptake in the mixed layer over broader time and space scale than the tracer experiments detailed above. Since the winter mixed layer becomes the temperature minimum layer (T_{min}) in summer, which directly underlies the summertime surface mixed layer and exchanges with it throughout the growing season, characterising the winter mixed layer is essential for understanding summertime boundary conditions. Finally, during nitrification, oxygen atoms from water are added to NH_4^+ and NO_2^- to eventually form NO_3^- such that the $\delta^{18}O$ of NO_3^- is directly dependent on the $\delta^{18}O$ of seawater. Using measurements of both the $\delta^{18}O$ of seawater and the $\delta^{18}O$ of NO_3^-, we can compute the quantity of regenerated (vs. preformed) NO_3^- in each water mass, with important implications for atmospheric CO_2.

Nutrients, nitrate, PN, and water isotope samples were collected from the ship's underway intake every four hours during the S leg between 34 10.939 S; 18 13.854 E and 58 52.498 S; 29 28.250 E. Samples were also collected from all CTD stations on the I leg. In total, 32 underway stations (UW01 to UW32) and 8 CTD stations (I01-I08) were sampled (*see sample log in appendix*). Nutrients and nitrate isotope samples were collected from the TM casts in order to sample the full water column depth. At station I03, no TM cast was deployed and nutrients and nitrate isotopes were collected from the Niskin cast (I0_3). The biogeochemical samples described above will be interpreted in the context of co-occurring collections (by other groups) of chlorophyll, salinity, oxygen, phytoplankton, dissolved inorganic carbon and alkalinity.

Nutrient samples will be measured in the Marine Biogeochemistry Laboratory (MBL) at UCT via flow injection analysis for nitrate and silicate and manually for phosphate and nitrite following the Greiss method. Bulk PN isotopes will be measured at the Light Stable Isotope Laboratory in the UCT Department of Archaeology using GC-IRMS. Flow cytometry (Fluorescence Assisted Cell Sorting; FACS) will be conducted in the Flow Cytometry Core Facility on the UCT Medical Campus. Nitrate isotope and flow sorted PN isotope samples will be analysed using the denitrifier-IRMS method (Sigman et al. 2001; Casciotti et al. 2002) in the laboratory of Prof. Daniel Sigman at Princeton University, USA, following persulfate oxidation in the case of the particle samples, which will be undertaken in the UCT MBL.

11.3 Sinking particles

In collaboration with researchers from Stellenbosch University, particle samples >100 µm were collected using Large Volume McLane Pumps from 150 and 250 m at 4 stations. These samples will be measured for bulk PN concentration and isotopes as described above as part of an effort to quantify the wintertime N isotope mass balance. We aim to repeat this sampling in other seasons and to increase its spatial and depth resolution as sinking flux data are required to contrain the annual extent of nutrient consumption in the Southern Ocean, which is directly relevant to CO_2 removal.

11.4 Marginal ice zone sampling

Biogeochemical samples were collected from subsampled sea ice pancakes. Two pancakes were cut in half, and then divided into 3-4 vertical layers. The layers were melted and sampled for nutrients, ammonium, nitrate isotopes, particles, chlorophyll, phytoplankton community composition (*see sample log in appendix*). The Fawcett group will be responsible for the analysis of the ammonium and nutrient concentrations in MBL, and nitrate and particle isotope samples will be run by collaborator Prof. Meredith Hastings at Brown University, USA, following persulfate oxidation in the case of the particle samples, which will be undertaken in the UCT MBL. Chlorophyll and phytoplankton samples will be analyzed by collaborators at Cape Peninsula University of Technology.

11.5 Bibliography

DiFiore, P. J., D. M. Sigman, and R. B. Dunbar. 2009. Upper ocean nitrogen fluxes in the Polar Antarctic Zone: Constraints from the nitrogen and oxygen isotopes of nitrate. *Geochemistry Geophysics Geosystems* **10**: Q11016.

Kemeny, P.K., Weigand, M.A., Zhang, R., Carter, B.R., Karsh, K.L., Fawcett, S.E., Sigman, D.M. 2016. Enzyme-level interconversion of nitrate and nitrite in the fall mixed layer of the Antarctic Ocean. *Global Biogeochemical Cycles* **30**: 1069-1085.

Peng, X., Fuchsman, C.A., Jayakumar, A., Oleynik, S., Martens-Habbena, W., Devol, A., Ward, B.B. 2015. Ammonia and nitrite oxidation in the Eastern Tropical North Pacific. *Global Biogeochemical Cycles* **29**: 2034-2049.

Sarmiento, J. L., and J. R. Toggweiler. 1984. A new model for the role of the oceans in determining atmospheric pCO_2. *Nature* **308**: 621–624.

Sigman, D. M., M. A. Altabet, D. C. McCorkle, R. Francois, and G. Fischer. 1999. The δ^{15}N of nitrate in the Southern Ocean: consumption of nitrate in surface waters. Global Biogeochemical Cycles **13**: 1149–1166.

Sigman, D. M., K. L. Casciotti, M. Andreani, C. Barford, M. Galanter, and J. K. Böhlke. 2001. A bacterial method for the nitrogen isotopic analysis of nitrate in seawater and freshwater. *Analytical Chemistry* **73**: 4145–4153.

Smart, S. M., S. E. Fawcett, S. J. Thomalla, M. A. Weigand, C. J. C. Reason, and D. M. Sigman. 2015. Isotopic evidence for nitrification in the Antarctic winter mixed layer. *Global Biogeochemical Cycles* **29**: 427–445.

12 Winter phytoplankton community composition and biomass in the Southern Ocean marginal ice zone

Contributors

David Walker, Cape Peninsula University of Technology

As part of the effort to understand the dynamics of food webs and carbon transport within the Southern Ocean and marginal ice zone, phytoplankton type and abundance are two of the most critical parameters that require monitoring. A number of surveys of Southern Ocean phytoplankton have been carried out during the austral summer. However, very little information is available on phytoplankton communities in the austral winter in the Southern Ocean generally and the marginal ice zone specifically. The opportunity provided by this winter cruise including ice sampling, is unique in investigating phytoplankton communities during sea-ice formation as opposed to those during sea-ice break up during summer. This project has three main aims:

- To characterize the phytoplankton community composition and biomass across the marginal ice zone. This included sampling of the water column as well as within the ice itself. Investigations of these biological communities are strengthened by the association with the concurrent studies of the physical properties of ice structure by UCT Engineering team led by Dr Keith McKutchon.
- To characterize the phytoplankton community composition and biomass along the WOCE I06 line. These will be a repeat of studies carried out in 1993, 1996 and by RV Roger Revelle in 2008, and will therefore lend itself greatly to assessing decade-scale changes. This work has complemented the proposed research plan by the University of Stellenbosch team of Dr Suzanne Fietz and Prof. Alekendra Roychoudhury. In addition to the routine nutrient measurements, they will be analysing metal concentrations such as iron, and using HPLC to determine phytoplankton pigment characteristics. The envisaged phytoplankton community studies proposed here will greatly enhance our interpretation of the Stellenbosch University team's data. In addition, the data produced on the phytoplankton community composition will also complement the work done by Drs Sarah Fawcett and Katye Altieri of the University of Cape Town (Oceanography Department). Their examination of aerosols, carbon exchange and nitrogen fixation will be aided by the insight we provide on the types of phytoplankton communities present.
- To train and develop capacity in southern ocean oceanographic and Antarctic sciences, with particular emphasis on technological capacity. This is identified as a priority within the Marine and Antarctic Research strategy. Cape Peninsula University of Technology is the only UoT to offer a programme in Marine Sciences which advances technical capacity specifically. The annual summer SANAE cruise is not ideal for this purpose due to its length, timing and space limitations. CPUT participated in the July 2016 sea-ice research cruise, and, under Prof. Marcello Vichi, a similar, but extended programme was implemented on the 2017 cruise.

Sampling took place in 3 phases during the cruise.

1. Underway surface samples. These samples for phytoplankton analyses (microscopic and flow cytometry) as well as for total chlorophyll a were taken every 4 hours from leaving Cape Town until the MIZ using the onboard flow-through system. Chlorophyll a samples were processed on board while phytoplankton microscope and flow cytometry samples were taken back to Cape Town for analysis. Phytoplankton samples have been retained at CPUT for further analysis.
2. Samples as above were taken from ice cores from pancake ice retrieved from the MIZ.
3. Samples as above were taken from CTD stations along the IO line as shown in Table 1 below.

12.1 Chlorophyll a results

12.2 Underway samples

Preliminary chlorophyll a results are shown for the underway stations in the tables below for two different size filters.

CHLOROPHYLL a			Calibration factor - CSIR
30/06/17			Acetone blank assumed to be 0.2
			Volume filtered = 500ml
BLANK	ACETONE	0.19	**Chla conc ug/L**
UW01	0.3µm	880.31	3.05
UW01	2.7µm	579.78	2.01
UW02	0.3µm	273.6	0.95
UW02	0.3µm	238.82	0.83
UW02	2.7µm	170.72	0.59
UW02	2.7µm	170.09	0.59
UW03	0.3µm	190.6	0.66
UW03	0.3µm	195.95	0.68
UW03	2.7µm	142.58	0.49
UW03	2.7µm	149.3	0.52
BLANK	ACETONE	0.17	
UW04	0.3µm	210.56	0.73
UW04	0.3µm	239.74	0.83

UW04	2.7µm	162.7	0.56
UW04	2.7µm	158.13	0.55
UW05	0.3µm	175.25	0.61
UW05	0.3µm	188.06	0.65
UW05	2.7µm	151.83	0.53
UW05	2.7µm	179.08	0.62
UW06	0.3µm	230.47	0.80
UW06	0.3µm	329.49	1.14
BLANK	ACETONE	0.19	
UW06	2.7µm	192.83	0.67
UW06	2.7µm	222.99	0.77
UW07	0.3µm	224.96	0.78
UW07	0.3µm	239.53	0.83
UW07	2.7µm	162.42	0.56
UW07	2.7µm	166.88	0.58
UW08	0.3µm	124.16	0.43
UW08	0.3µm	134.03	0.46
UW08	2.7µm	95.99	0.33
UW08	2.7µm	91.35	0.32
CHLOROPHYLL a			
07-01-2017			
BLANK	ACETONE	0.22	
UW09	0.3µm	212.14	0.73
UW09	0.3µm	160.83	0.56
UW09	2.7µm	148.49	0.51
UW09	2.7µm	146.06	0.51
UW10	0.3µm	200.61	0.69
UW10	0.3µm	123.57	0.43
UW10	2.7µm	204.77	0.71
UW10	2.7µm	133.3	0.46
UW11	0.3µm	164.54	0.57

UW11	0.3µm	141.53	0.49
BLANK	ACETONE	0.25	
UW11	2.7µm	115.91	0.40
UW11	2.7µm	SAMPLE LOST	
UW12	0.3µm	198.71	0.69
UW12	0.3µm	230.86	0.80
UW12	2.7µm	141.33	0.49
UW12	2.7µm	86.24	0.30
UW13	0.3µm	157.09	0.54
UW13	0.3µm	100.23	0.35
UW13	2.7µm	81.94	0.28
UW13	2.7µm	87.18	0.30
BLANK	ACETONE	0.22	
UW14	0.3µm	122.35	0.42
UW14	0.3µm	102.55	0.35
UW14	2.7µm	67.55	0.23
UW14	2.7µm	68.34	0.24
CHLOROPHYLL a			
07-02-2017			
BLANK	ACETONE	0.24	
UW15	0.3µm	99.82	0.35
UW15	0.3µm	122.57	0.42
UW15	2.7µm	67.14	0.23
UW15	2.7µm	65.13	0.23
UW16	0.3µm	125.28	0.43
UW16	0.3µm	96.01	0.33
UW16	2.7µm	93.64	0.32
UW16	2.7µm	72.99	0.25

UW17	0.3µm	103.02	0.36
UW17	0.3µm	105.01	0.36
UW17	2.7µm	97.61	0.34
UW17	2.7µm	114.69	0.40
BLANK	ACETONE	0.23	
UW18	0.3µm	113.81	0.39
UW18	0.3µm	102.33	0.35
UW18	2.7µm	75.6	0.26
UW18	2.7µm	86.66	0.30
UW19	0.3µm	128.95	0.45
UW19	0.3µm	102.43	0.35
UW19	2.7µm	79.15	0.27
UW19	2.7µm	74.01	0.26
BLANK	ACETONE	0.24	
UW20	0.3µm	101.49	0.35
UW20	0.3µm	92.4	0.32
UW20	2.7µm	46.38	0.16
UW20	2.7µm	71.43	0.25
UW21	0.3µm	84.35	0.29
UW21	0.3µm	81.52	0.28
UW21	2.7µm	64.48	0.22
UW21	2.7µm	57.48	0.20
UW22	0.3µm	73.53	0.25
UW22	0.3µm	88.9	0.31
UW22	2.7µm	72.44	0.25
UW22	2.7µm	46.12	0.16
CHLOROPHYLL a			
07-03-2017			
BLANK	ACETONE	0.38	

UW23	0.3µm	85.48	0.30
UW23	0.3µm	66.17	0.23
UW23	2.7µm	45.28	0.16
UW23	2.7µm	36.19	0.12
BLANK	ACETONE	0.36	
UW24	0.3µm	75.33	0.26
UW24	0.3µm	74.22	0.26
UW24	2.7µm	67.51	0.23
UW24	2.7µm	60.49	0.21
UW25	0.3µm	49.41	0.17
UW25	0.3µm	50.44	0.17
UW25	2.7µm	44.63	0.15
UW25	2.7µm	56.42	0.19
BLANK	ACETONE	0.35	
UW26	0.3µm	72.81	0.25
UW26	0.3µm	88.4	0.31
UW26	2.7µm	64.62	0.22
UW26	2.7µm	62.66	0.22
UW27	0.3µm	74.54	0.26
UW27	0.3µm	58.7	0.20
UW27	2.7µm	57.28	0.20
UW27	2.7µm	52.2	0.18

12.3 Marginal Ice Zone chlorophyll a samples:

Chlorophyll a samples from surface waters in the MIZ and from one pancake ice example are shown in Figures 1 and 2 below. It is striking to note the highly enhanced concentration within the ice when compared to the surface waters.

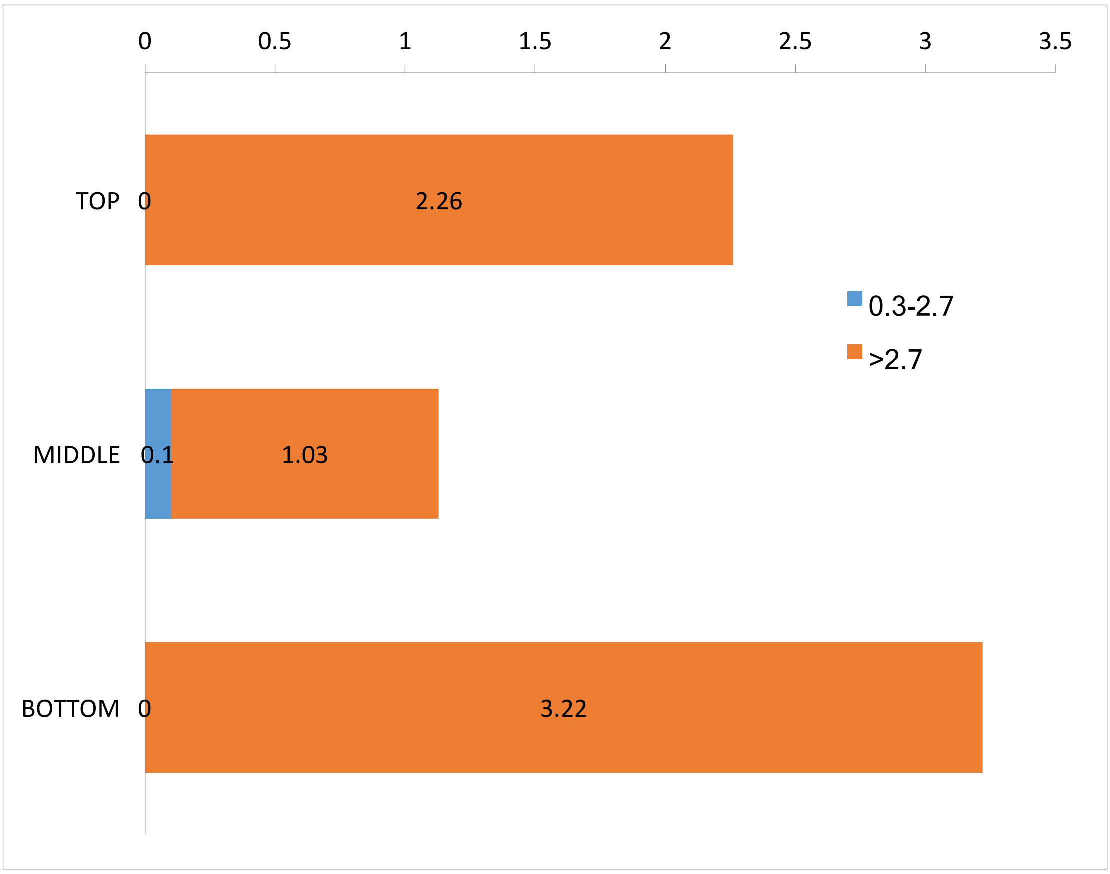


Figure 57 Averaged size fractionated chlorophyll a concentration (µg/L) at three levels of a pancake ice sample

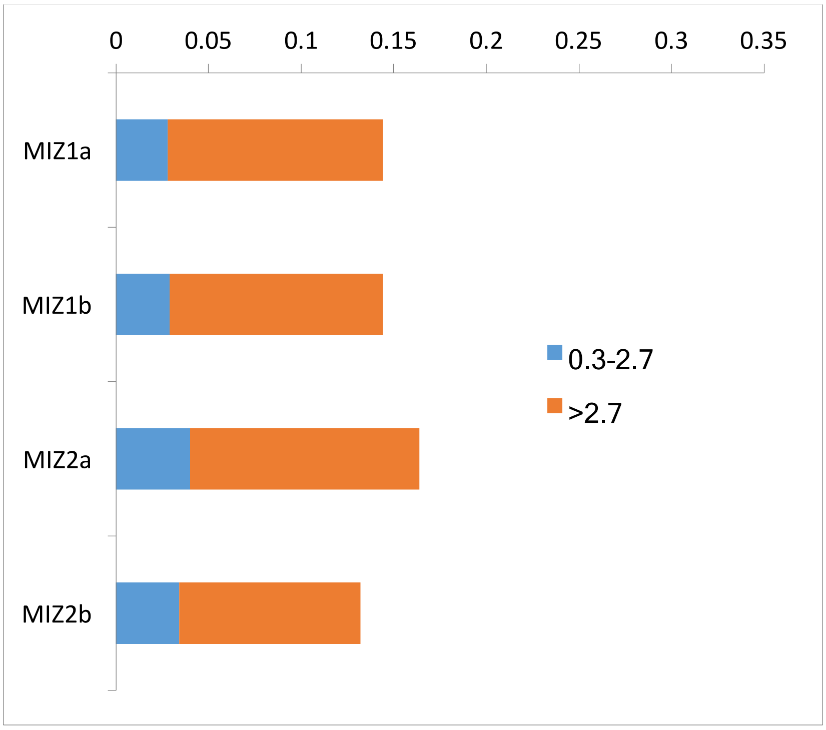


Figure 58 Size fractionated chlorophyll a concentration (µg/L) in surface water at two MIZ stations.

12.4 I leg samples

The raw fluorescence data for the upper layers of the water column for the I leg stations are shown in the next tables. They represent the raw fluorescence values (extracted chlorophyll) from 0.3 µm and 2.7 µm filters from a range of depths in the upper 200 m for CTD stations I01 to I08.

CHLOROPHYLL a				
7/7/2017 (500 ml filtered)				
I01	DEPTH (M)	NISKIN NO.		
BLANK ACETONE				0.3
	10	24	0.3	53.7
	10	24	2.7	36.51
	25	19	0.3	52.88
	25	19	2.7	31.45
	50	16	0.3	53.75
	50	16	2.7	37.41
BLANK ACETONE				0.41
	75	13	0.3	63.49
	75	13	2.7	46.48
	100	9	0.3	58.66
	100	9	2.7	29.17
	150	7	0.3	62.75
	150	7	2.7	37.43

CHLOROPHYLL a				
7/7/2017 (500 ml filtered)				
I02	DEPTH (M)	NISKIN NO.		
BLANK ACETONE				0.23
	10	24	0.3	55.73
	10	24	2.7	49.23
	25	19	0.3	70.65
	25	19	2.7	44.56
	50	16	0.3	66.56
	50	16	2.7	45.22
BLANK ACETONE				0.24
	75	13	0.3	62.07
	75	13	2.7	49.17
	100	9	0.3	68.26
	100	9	2.7	46.78
	150	7	0.3	50.72
	150	7	2.7	42.27

CHLOROPHYLL a				
8/7/2017 (500ml filtered)				
I03	DEPTH (M)	NISKIN NO.		
BLANK ACETONE				0.46
	10	24	0.3	65.29
	10	24	2.7	49.87
	25	19	0.3	106.21
	25	19	2.7	77.43
	50	16	0.3	80.64
	50	16	2.7	56.53
BLANK ACETONE				0.55
	75	13	0.3	75.32
	75	13	2.7	52.01
	100	9	0.3	58.53
	100	9	2.7	29.12
	150	7	0.3	8.09
	150	7	2.7	5.63

CHLOROPHYLL a				
9/7/2017 (500ml filtered)				
I04	DEPTH (M)	NISKIN NO.		
BLANK ACETONE				0.32
	10	24	0.3	91.55
	10	24	2.7	55.64
	25	19	0.3	87.45
	25	19	2.7	60.63
	50	16	0.3	68.13
	50	16	2.7	61.48
BLANK ACETONE				0.34
	75	13	0.3	78.32
	75	13	2.7	56.2
	100	9	0.3	63.44
	100	9	2.7	55.02
	150	7	0.3	9.7
	150	7	2.7	19.13

CHLOROPHYLL a 10/7/2017 (500ml filtered)				
I05	DEPTH (M)	NISKIN NO.		
BLANK ACETONE				0.34
	10	24	0.3	96.45
	10	24	2.7	71.66
	25	19	0.3	92.84
	25	19	2.7	63.68
	50	16	0.3	79.51
	50	16	2.7	68.86
BLANK ACETONE				0.31
	75	13	0.3	91.26
	75	13	2.7	84.31
	100	9	0.3	78.93
	100	9	2.7	55.02
	150	7	0.3	22.98
	150	7	2.7	27.86

CHLOROPHYLL a 11/7/2017 (500ml filtered)				
I06	DEPTH (M)	NISKIN NO.		
BLANK ACETONE				0.41
	10	24	0.3	129.71
	10	24	2.7	89.24
	25	19	0.3	136.86
	25	19	2.7	89.08
	50	16	0.3	135.03
	50	16	2.7	91.32

BLANK ACETONE				0.42
	75	13	0.3	130.75
	75	13	2.7	92.88
	100	9	0.3	100.74
	100	9	2.7	86.28
	150	7	0.3	89.08
	150	7	2.7	56.13

CHLOROPHYLL a				
11/7/2017 (500ml filtered)				
I07	DEPTH (M)	NISKIN NO.		
BLANK ACETONE				0.27
	10	24	0.3	90.18
	10	24	2.7	88.76
	25	19	0.3	77.68
	25	19	2.7	84.24
	50	16	0.3	132.94
	50	16	2.7	81.28
BLANK ACETONE				0.25
	75	13	0.3	114.22
	75	13	2.7	80.73
	100	9	0.3	159.13
	100	9	2.7	96.35
	150	7	0.3	136.59
	150	7	2.7	101.7

CHLOROPHYLL a
12/7/2017 (500ml filtered)

I08	DEPTH (M)	NISKIN NO.		
BLANK ACETONE				0.2
	10	24	0.3	139.1
	10	24	2.7	84.65
	25	19	0.3	175.73
	25	19	2.7	69.57
	50	16	0.3	159.11
	50	16	2.7	87.94
	75	13	0.3	142.93
	75	13	2.7	87.48
	100	9	0.3	141.37
	100	9	2.7	98.67
	150	7	0.3	15.03
	150	7	2.7	16.31

13 Trace element cycling and experimental biogeochemistry

Contributors

Ryan Cloete, Susanne Fietz (PI), Ismael Kangueehi, James Lloyd, Jean Loock, Andile Mkandla, Thato Mtshali, Jodi Pieterse, Alakendra Roychoudhury (PI, land-based), Natasha van Horsten, Johan Viljoen, Bjorn von der Heyden, Ian Weir

Stellenbosch University

Many trace elements are essential for the growth and functioning of marine organisms, e.g. phytoplankton, and therefore influence the functioning of ocean ecosystems and the global carbon cycle. The distribution of trace elements and their isotopes (TEI's) are powerful tools for elucidating the biogeochemical cycling of these micronutrients as they yield important information regarding their sources, sinks, internal cycling and chemical speciation. The past three decades has seen a huge increase in focus, spearheaded by international programs such as GEOTRACES, toward the large scale measurement of trace elements and, more recently, their stable isotopes. Despite this, large spatial gaps remain in the existing database, particularly in the hostile Southern Ocean where few studies have been conducted to date. The 30°E line through the Southern Ocean provides an exciting opportunity to contribute data from a transect never before sampled for some of our parameters. One of the Trace Ex team's major aims is to identify processes and quantify fluxes that control the distributions of key trace elements in the Southern Ocean and establish the sensitivity of these distributions to changing environmental conditions. This attempt is further detailed in section 13.1.

In addition to the dissolved and soluble forms of the trace metals, the team also focussed on the particulate fraction. Whilst the "dissolved" trace metal fraction (<0.2 µm filtrate; see section 13.1) has commonly been designated as the bio-available fraction (Coale 1991; Hassler et al., 2012; Westerlund & Ohman 1991), the presence of nonreactive forms in the surface suggests strong ligand association. It is posited that by way of the releasing of strong complexing agents, and the catalysing of redox reactions, phytoplankton may be able to modify the bio-availability of trace metals (Bowie et al., 2010). Consequently, the properties (speciation, dissolution kinetics, and uptake pathways by biota) of trace metal particles and colloids may further govern the biogeochemical cycling controlling productivity. However, trace metal particulate material and the autotrophic utilization thereof has received little attention. Thus, this investigation into particulate matter geochemistry, speciation and behaviour aims to constrain the understanding of the growth correlated interactions. Details are provided in section 13.4

The team furthermore made use of the rather unique opportunity provided during this cruise of sampling the marginal ice zone in winter. The investigation into the source of trace metal inputs into the Southern Ocean – classically atmospheric, remineralization and hydrothermal – has yet to comprehensively describe the role of annual sea ice melt as an active source pool to Antarctic euphotic waters (Lannuzel et al., 2010). Sea-ice is populated by a range of microorganisms surviving in a diverse "pool" of micro and macro-nutrients, salinity and irradiance. This resident population, posited as a "seed population", and the entrained sea-ice nutrients may provide the crucial framework for seasonal blooms (Grotti et al., 2005). It is probable that trace metal fluxes from melting sea ice may be enhancing or sustaining photosynthetic micro-organism (phytoplankton) productivity in remote seasonally ice-covered regions. Whilst seasonal sea-ice cover inhibits irradiance within the surface mixed layer – accordingly restricting productivity – annual melts play a crucial role in water mass stabilisation and bio-active trace metal inputs favouring the growth of phytoplankton (Grotti et al., 2005). Hence sea-ice may play a significant role in the CO_2 uptake mechanisms of the Southern Ocean and the elucidation of these mechanisms is imperative. Our opportunistic effort to better understand the role of the sea-ice in trace metal distribution is further described in sections 13.3 for trace metals and 13.9 for biological parameters.

Dust represents another, potentially major external source of trace metals for the Southern Ocean. In the open oceans the deposition of external nutrients can increase primary production. The extent of the role that dust plays for ocean primary productivity and thus CO_2 uptake along with dimethyl sulfate (DMS) emissions, depends on a variety of factors such as a) extent of nutrient limitation in the oceanic region, b) timing of the dust deposition in view of phytoplankton seasonal development, c) nutrient load in the deposited dust, and c) solubility of the nutrients, the latter especially considering the micro-nutrients (e.g., trace metals such as Fe, Co, Zn etc). Most studies on aerosol impacts have focused on the Northern Hemisphere. However, numerous small dust plumes were observed in southern Africa (Vickery 2010) that can potentially contribute to surrounding ocean productivity. Nonetheless, little is known about the Air trajectory models have shown that large fractions of dust from southern Africa travels in winter across the southern Indian Ocean. Here we tried to catch some of it over the southern Indian Ocean to analyse the composition with a focus on macro- and micronutrient composition and conducted experiments to better understand its potential to fertilise the marine phytoplankton communities (see section 13.5 for details).

In addition to the investigations of trace metal sources and distributions, the TraceEx team is interested the role the microbes play on the trace metal distribution along with the impact of the trace metal availability on the microbes. This includes the abundances as well as the community structure. For this purpose the team also sampled for photosynthetic pigments used to assess the phytoplankton community structure, as well as for gene analysis for pro- and eukaryotes (sections 13.6, 13.7 and 13.8). Biogeochemical parameters such as particulate organic carbon and biogenic silica concentrations (section 13.11) support this investigation of the ecosystem functioning.

13.1 Trace metals, rare earth elements and isotopes (by Ryan Cloete)

The team’s first key objective was to determine the trace metal (Fe, Cu, Zn, Mn, Ni, Cd, Co and Pb) and Rare Earth Element (lanthanide series, La through Lu) concentrations. Ryan, Natasha, Andile and Thato collected various samples to assess the partitioning of these elements between the total (unfiltered), dissolved (0.2µm), particulate (0.45µm) and soluble (0.02µm) fractions. Natasha, in particular, is interested what influence the ligands have on these interactions. The team will combine these data with measured physical (salinity and temperature) and biological (macronutrients, phytoplankton and bacterial abundance and composition) data to further constrain the biogeochemical cycling of these elements.

Other key objectives consists in determining the distribution and fractionation of the stable isotopes of Cu, Zn, Fe and Si and to quantify the inputs of hydrothermally derived trace elements (specifically Fe, Cu, Zn and REE's) into the deepwaters of the Southern Ocean. We aim to better constrain what are the controlling factors on metal speciation once ejected into the ocean and how does this affect bioavailability.

Sampling strategy and methodology: Three stations were planned for the southward leg (Leg S, Table 1) between Cape Town Harbour and the Marginal Ice Zone (MIZ) at 30°E. These stations included a soak station at 40°S, a test station at 45.5°S and a reference station at 53.5°S. At the soak station, water was collected from a uniform depth of ca. 150 metres for all 24 GoFlo bottles and allowed to soak for more than 24 hours before the test station. At the test station water was collected from a uniform depth of ca. 300 metres. Seawater was sub-sampled in duplicate from each GoFlo bottle with the intention of analysing the seawater, using our on-board Flow Injection Analyser (FIA), for the concentration of dissolved iron (dFe) in order to test for any contamination issues. The reference station was scheduled to collect large volume (20-50L) seawater samples for use as reference material and internal standards needed for the analytical process.

Sampling within the marginal ice zone, during Leg M (Table 1) is described below (see section 13.3). For the northward leg (Leg I, Table 1), nine stations (TM1 – TM9), spaced equally between 58.5°S and 38°S along the 30°E line, were initially planned. The planned stations consisted of five deep stations and four shallow stations. Stations TM3 and TM9 were, however, cancelled due to time constraints. Stations TM1, 2, 4, 5, 6, and 8 were carried out as planned (Table 1), while station TM7 was changed from a deep to shallow station for the same reason. The deep stations, the majority of which were located over the hydrothermal vent complex between roughly 45°S and 55°S, were sampled to a depth of 4250 metres whereas the shallow stations were capped at a maximum depth of 1500 metres. The high resolution of sampling stations ensured we collected water proximal to the various frontal systems as well as from each of the various biogeochemical domains encountered.

A vertical profile sampling method was employed at all sampling stations using the GEOTRACES rosette (Fig. 1). Seawater samples were collected using 24 internally Teflon-coated PVC 12L GoFlo bottles (General Oceanics Inc.) modified with Viton O-rings. The GoFlo bottles were mounted on a Seabird aluminium rosette coated in a trace metal clean polyurethane powder. The rosette housed a Seabird 9+ CTD (conductivity, temperature, depth) recorder. A Kevlar hydrowire with internal signal cables was utilised for transferring of data between the on-board CTD control room as well as triggering the GoFlo bottles at the various depths during the upcast. Directly upon recovery the GoFlo bottles were covered in a plastic wrap in addition to their ends being covered in plastic shower caps, and were transported into a class 100 clean lab for sub-sampling (Fig. 1). Subsampling included trace metals and REE's (total, particulate, dissolved and soluble fractions), isotopes and ligands. Additional subsampling for a range of accompanying chemical and biological parameters from the GoFlo bottles is described below (section 13.2)

Samples to be analysed for their total metals and REE fractions were collected from the GoFlo bottles through polytetrafluoroethylene (PTFE) tubing, unfiltered, in acid-cleaned 125 ml LDPE bottles. All sample bottles and equipment was acid cleaned as per GEOTRACES protocols and sampling conducted as per GEOTRACES protocols. In addition, samples collected for the determination of the dissolved and soluble fractions, ligands (organic fraction) and isotopes were collected after online filtration using a 0.2µm Sartobran filter connected to PTFE tubing and under a pure N2 assisted pressure (99.99% N2) of 2 bar. Samples were collected in acid cleaned 125 ml LDPE bottles however isotope samples were collected in acid cleaned 1L LDPE bottles. Each LDPE sample (with the exception of the samples for soluble and organic fractions) was then acidified to a pH of 1.8 on-board under a laminar flow hood with hydrochloric acid (ultrapur HCL, Merck) and stored in double ziplock bags at ambient temperature in the dark until the samples are analysed in a land based laboratory. The soluble and organic fraction samples were collected un-acidified and frozen at -20°C until land-based analysis. Note that samples for analysis of the soluble fraction will be further filtered through a 0.02µm filter on land before being acidified. All trace metal sampling was done under trace metal clean conditions in the shipboard container labs located on the 3rd level aft deck.

A total of 1340 seawater samples were collected for analysis of various trace metals, REE's and isotopes. Unfortunately, we were unable to analyse dFe samples with our on-board Flow Injection Analyser (FIA). FIA analysis was not possible due to spikes, both negative and positive, in the voltage output of the photomultiplier tube (PMT). It is believed this was due to interruptions of power supply from the ship which occur when there is extreme slamming in bad weather. It is necessary to have an uninterrupted power supply (UPS) for the FIA on the next voyage. The spikes were not present on the last day of the voyage when we were sailing along the coast, in calm weather.

Figure 59. Upper left panel: Water sampling using the GEOTRACES rosette, equipped with Teflon coated frame and GoFlo bottles. Lower panel: Cruise participants queuing to carry GoFlo bottles from the CTD rosette to the clean container laboratory on the aft deck. Upper right panel: Natasha, Thato, Ryan and Andile subsampling from the GoFlo bottles in the trace metal clean container.

13.2 Subsampling for chemical and biological parameters from GoFlo bottles

A number of samples for analysis of chemical and biological parameters other than trace metals and isotopes were sub-sampled from the GoFlo bottles in the clean lab prior to the trace metal and isotope sub-sampling. Samples for $\delta^{18}0$ and δD were collected in 25 mL acid cleaned scintillation vials following GEOTRACES protocol. Samples for NO_3- isotopes (for Dr Sarah Fawcett's team) were collected in 50 ml plastic bottles following GEOTRACES protocol. Bacteria isolate samples were collected in 1 mL Eppendorf vials (see section 13.8). Macronutrient samples were collected in 50 mL Falcon tubes (see section 13.10). At selected stations, seawater for aerosol leaching and dust incubation experiments (see section 13.5) was collected in 1L acid cleaned polycarbonate bottles.

13.3 Trace elements in ice cores (by Jean Loock)

A first aim here was to initiate an investigation developing and testing the protocols required for the collection of uncontaminated trace metals in ice cores from pancake ice kindly provided by the SEAICE team around M. Vichi, S. Skatulla and K. Hutchinson, Departments of Oceanography and Civil Engineering at UCT. It may be that the rapid change in matrix during direct melting induces a break-up of some micro-organisms releasing trace metals stowed intracellularly into the seawater. This may result in the bio-available (dissolved) seawater fraction reading higher than the in-situ reality. Consequently, Jean and Bjorn tested two methods of melting investigating lysed and un-lysed cells: a) Direct Melting (Core 2), and b) Matrix Modification Melting (Core 1).

The second method, involving matrix adjusted melting (4:1; seawater to ice core), sees 0.45µm filtered seawater (TM6 station) added to prevent fragmentation. This method will also require a careful mass balance approach to track the addition of trace metals from the filtered TM6 water. The comparative effort will centre on subsamples of the melted ice cores in the following fractions: a) Total, b) Dissolved 0.2µm filtered, and c) 0.45µm filtered. Analysis will be performed using a multi-element method employing the seaFAST pre-concentration module and ICP-MS as described above (see section 13.1). This should provide an understanding of the concentration of up to 10 trace metals (including Co, Cu, Pb, Fe, Zn, Mn, Cd) in the pancakes.

Sampling strategy and methodology: A single sea-ice pancake was collected by the SEAICE team (station M02) using a plastic crate suspended on the aft deck crane of the ship. The sea-ice pancake block was cored using a Kovacs Mark II corer provided by the Dept. Oceanography and Civil Engineering, UCT. The engine driven (T-handle optional) system consisted of a core barrel made from a light weight filament wound composite approximately 1.15 m long with plastic flighting. The cutting teeth are titanium with a stainless-steel release catch. This system has proven suitable for the collection uncontaminated trace metal cores (Bowie et al., 2010). Samples were cored on the bow of the ship (next to Geology lab) with the pancake covered in rubbish bags – barring the area intended for coring. Cored samples were moved into the geology lab where the work surfaces had been cleaned with ethanol and lined with rubbish bags. Cores were laid out, measured, cut (3 pieces ca. 10cm: Top, Middle, Bottom) and placed in zip-lock bags within 5 minutes. A stainless-steel saw was used to make the initial cut into the core and then it was broken. The bottom of both the trace metal cores did not need to be cut as it had already broken (no contact with stainless steel saw). A ceramic knife was used to scrape down the edges of the ice cores prior to melting to limit transfer. Cores were melted in acid cleaned (0.1M Merck Suprapur) LDPE zip-lock bags. The following three core sub-samples were taken from the pancake: 1) Direct melting (room temperature), 2) Seawater addition melting (melted at 4°C in the walk-in cold room, in the dark), 3) A core for biogeochemical parameters (see section 13.9). Filtrates from the biogeochemical ice core were preserved for measurements of salinity and N-isotopes (Dr. Fawcett's team).

Trace metal sub-samples were collected from the thawed cores for the following fractions: 1) Total - duplicate sub-samples (>60 ml); 2) Dissolved – duplicate sub-samples (>100 ml) for subsequent inline filtration through a 0.2 µm Whatman syringe filter; 3) 0.45 µm – duplicate sub-sample (100 ml) for subsequent inline filtration through 0.45µm filters (25mm diameter) 4) Salinity – single sub-sample (>100ml). Filtration was performed under laminar flow. All samples were stored in acid cleaned

(GEOTRACES protocol) LDPE 125ml bottles and acidified to a pH 1.7 using Merck Ultrapur HCl (2ml/L). Individual samples are described in more detail in Appendix 1).

13.4 Particulate trace metals (by Jean Loock)

The international GEOTRACES program aims to improve the understanding of biogeochemical cycles and large-scale distribution of trace elements and their isotopes. The TracEx research group at Stellenbosch University is privileged to hold collaborative partnership with their focus on expanding the knowledge in the Southern Ocean. A major thrust of the proposed research is to gain a fundamental insight to chemical changes that occur on the mineral-water interface in the presence of organic ligands at nano-meter scales. Once this fundamental understanding is in place we can then expand the understanding in several applied avenues – oceanic productivity and CO_2 exchange being primary beneficiaries. We aim to do this by elucidating on the following controls:

i) Via Scanning Electron Microscopy (SEM) generate textural and morphological data for Cu and Zn particulates in the Southern Ocean. Thereby determine the role that particle morphology plays in governing the trace metals of the biogeochemical system.

ii) Employing the novel picoTrace acid digestion module (DAS) and Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) to generate a chemical characterization of marine particles. This will be linked to an existing dissolved fraction dataset creating an exciting framework to interpret the interplay between fractions and the role this has on phytoplankton productivity.

iii) Evaluate Cu and Zn chemical speciation in marine colloids and nano-particles using Synchrotron Spectroscopic Techniques (e.g. XANES, SXRF). Thereby investigate the spatial differences in Cu, Zn particle chemistry and link them to particle source regions, in situ processing and transformations; and provide insight into their relationship with the ambient marine biota.

Sampling strategy and methodology: Jean and Bjorn performed in-situ collection of trace metal particulates (pTM) at four stations in the Southern Ocean using two WTS-LV McLane pumps (4L/min and 8L/min, McLane Research Laboratories Inc., USA) suspended on a steel cable general purpose winch (Fig. 2). The pumps were fitted with the 142mm diameter vertical intake filter stacks – the 8L/min pump will hereon be referred to as the dual flow. The Whatman Nuclepore (142mm) polycarbonate membrane filters (0.2µm) were used for pTM collection and fitted on the lowest tier of the 4L and DF pump. The Nuclepore filters utilized for pTM collection were soaked in a 0.1M HCl Suprapur (Merck) solution for 20 hours followed by a Milli-Q rinse (3X) and bath (4 hours) prior to each station. A Milli-Q stored 100µm pre-filter mesh was inserted in the top tier of the vertical stack of both pumps to remove any unwanted material on the pTM filter – such as zooplankton.

In addition, the dual flow McLane pump was used to filter large volumes of water for a project on biomarkers used for paleo-reconstructions (see section 13.12). Muffled a Whatman 142mm diameter glass fibre (0.3µm) filters were used for this purpose (see section 13.12). A 0.2µm Nuclepore had to be fitted on the secondary filter head of the dual flow pump to even out preferential flow discrepancies produced when the glass fibre filter for biomarker collection was fitted alone.

The insertion of filters prior to deployment, and their removal upon retrieval, was performed in the trace clean container (ISO class 5) under the laminar flow. Flow heads were kept covered with zip-locks during transport periods. The vertical intake stacks were filled to the top with Milli-Q water prior to deployment. Filters for trace metals were cut upon retrieval using a ceramic knife, stored in acid cleaned petri dishes, placed in Mylar pouches, double zip-locked under nitrogen air, and stored in the -25°C freezer.

Difficulties:

- Given the vacuum created by the pump it is essential that all fittings must be tight and double checked. The 0.2µm filter creates some resistance and the pumps will not pump optimally if the fittings are not secure.
- It is essential to remember that whilst the pumps have stated flow rates (e.g 4L/min) it is unlikely that they will achieve those rates when using a 0.2µm filter – the 4L pump averages ≈ 2.5L/min. Thus, the calculations for timing (pump time) must be adjusted with a safety factor should you require a set volume of water to pass through.
- The DF demonstrates significant preferential flow when the filters, and pores sizes, are not identical. This can be remedied to an extent by placing the smallest pore size filters on both filter heads. When using 0.2µm filters, the DF pump minimum flow rate should be adjusted from its 4L/min default to 3L/min – the lowest allowable for this pump – else the pump will switch off automatically as transpired twice on this cruise. This transpired at station TM1 and again at station TM5. At first it was not clear that the pump had switched off automatically due to minimal flow which is why we removed the 0.2µm for DF FH1 at TM4. This resulted in preferential flow and it took us two stations to understand this and TM7 demonstrates that FH1 and FH2 should have the 0.2µm fitted with amicable, yet still not ideal results.
- The filters should not be fitted below the multi-inlet of the vertical stack. It will impact distribution of the matter and the filter adheres when you remove the multi-inlet of the vertical stack.
- Larger petri-dishes are needed to store the filters. We had to cut them into 6ths using a ceramic knife on the frit. Furthermore, a heat sealer is required to seal the Mylar bags once the nitrogen has been pumped in.
- The general-purpose winch cable used to suspend the McLane pumps was disconcertingly oxidised. To limit contamination risks 20m sections of the cable were wrapped in duct tape and the pumps were attached on these sections. Moreover, we "dunked" the cable 30m past the pump attachment point upon each deployment as a rinse.

Figure 60. Deployment of McLane pumps on the aft deck of R/V SA Agulhas II.

13.5 Dust collection and dust incubation experiments (by Ismael Kangueehi and Susanne Fietz)

Ismael set-up a high-volume dust sampler (Fig. 3) to collect aerosols above the Southern Ocean during all the steaming transects. Additionally, dust incubations and flow-through experiments to assess the leaching of trace nutrients previously conducted in the laboratory with mineral dust and ultrapure (Milli-Q) water were repeated using fresh seawater for comparison.

Sampling strategy and methodology: with 8x10 inch Whatman 41 filter sheets on the Monkey deck (eight deck). However, during the southbound leg (Leg S, Table 1) and most of the northbound leg (Leg I, Table 1), prevailing strong tailwinds of up to 50 knots most likely led to contamination of the filters by the ship smokestack. Three filters from the northbound leg left sampling for ca. 24 hours each are potentially unaffected. These will be subsampled to analyse for carbon and nitrogen in collaboration with Katye Altieri's team as well as for trace metal composition and potential pollutants. Part of the filter will be dedicated to SEM analysis.

Ismael furthermore used fresh seawater collected with the GoFlo bottles at three stations during the return northbound leg to incubate sieved surface soil samples from major southern African dust emitters (Etosha Pan, Magkadigkadi Pan, Omaruru River, Kuiseb River) and measure the concentration of dissolved trace metals after one hour, 24 hours, and one week. These data will be compared to a similar incubation experiment conducted in the laboratory using ultrapure (Milli-Q) water. Sieved soil samples from the same dust emitters and fresh seawater were also used to repeat flow-through leaching experiments previously conducted using ultrapure water in the laboratory.

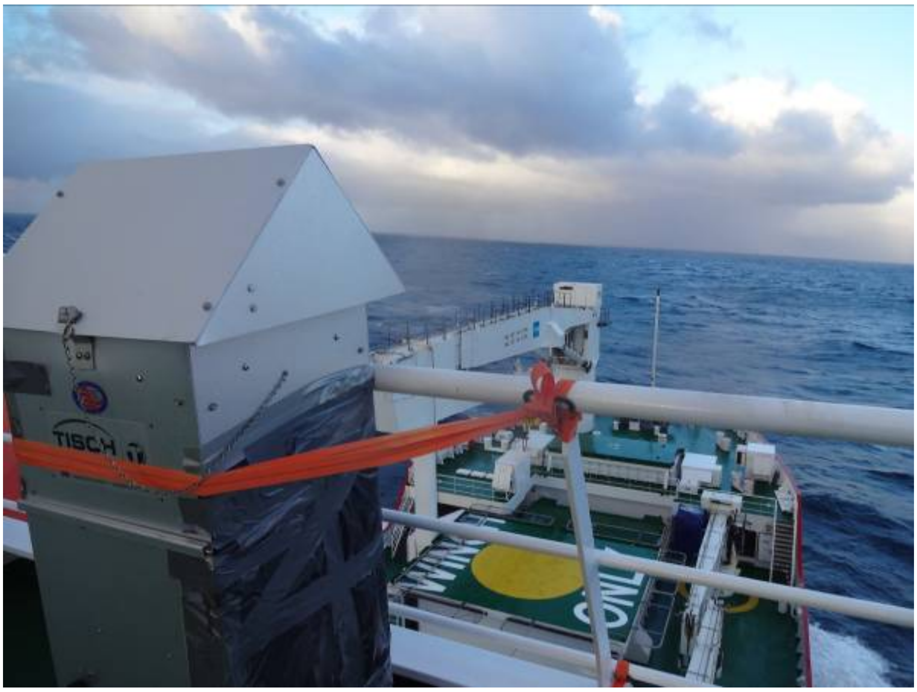


Figure 61. High volume air sampler (TISCH Environmental) on board R/V SA Agulhas II during the Winter Cruise 2017.

13.6 Pigments and particulate organic carbon (POC) (by Johan Viljoen)

The aim of the pigment sampling was to determine the phytoplankton community composition along the cruise transects, including at depth, and how and why they changed and compare these to previous cruises done during different sectors and seasons of the Southern Ocean. All the pigment filters collected will be used to determine the phytoplankton community structure based on characteristic pigment compositions using CHEMTAX software. The POC will be used to support the determination of the total biomass. Pigments and POC data will be furthermore combined with the results from the genomic (pro- and eukaryotic phytoplankton) analysis and microscopic identification and cell counts conducted by David Walker.

Sampling strategy and methodology:

Underway sampling (Leg S): Underway sampling is essentially the sampling of the ocean's surface water by using the ship's underway water supply. The underway water is continuously pumped into two of the ship's labs, except when the ship goes through ice and the water temperature is too low. Johan, Ian and Jodi were mainly sampling for phytoplankton pigments, POC and occasionally macronutrients during the southbound leg (Leg S). POC was subsampled and filtered using a vacuum pump and multi-filtration rack, while pigments were directly filtered from the tap using an in-line filter holder. Both filters were stored in -25˚C and -80˚C freezers respectively. These samples were taken every four hours to fit into the underway sampling schedule of the other teams (i.e. Fawcett, Altieri and Walker teams) on-board. However, additional pigment samples were taken at higher resolution across the frontal zones. In total for the underway, Johan, Ian and Jodi took 38 pigment samples and 32 POC samples by the time they reached the pancake ice. During the southbound underway sampling, the sea surface temperature dropped from a relatively warm 14°C to a freezing -3°C. The appearance of pancake ice marked the end of the southbound underway sampling. Sampling within the marginal ice zone is described in detail below

Depth profiles (Leg I): Unfortunately, the team was only able to complete eight out of the planned nine Niskin CTD stations due to time constraints caused by adverse weather conditions. Following a pre-determined water budget as per the needs of the different teams on board, Johan sampled 6L of water at six depths (10, 25, 50, 75, 100 & 150m) to be filtered for pigments. These were depths that phytoplankton would most likely be present at the euphotic zone. This sampling was done by sub-sampling water from the different Niskin bottles (Fig. 4), representing the various desired depths, into labelled amber PE bottles. For most of the deeper depths the material collected onto filters was low and was usually higher at surface (as expected).

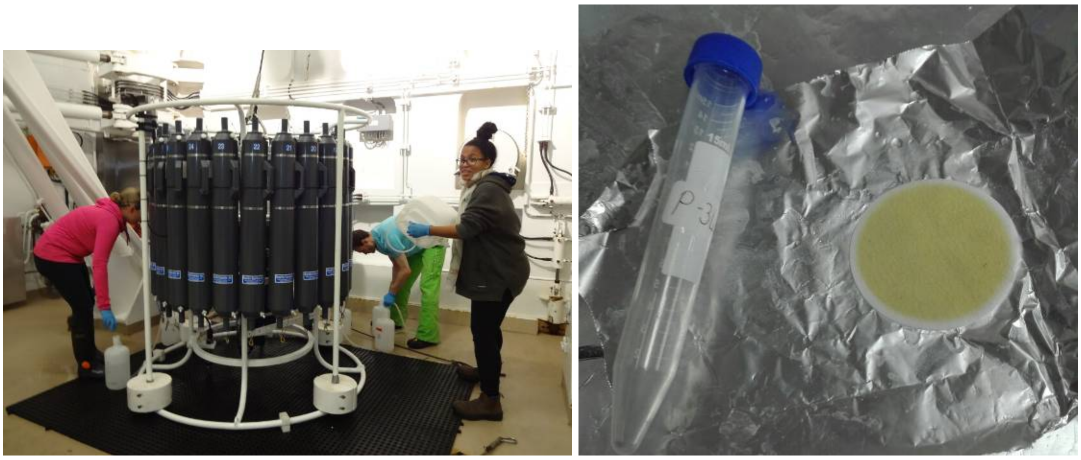


Figure 62. Sampling for biological parameters. Left: subsampling from Niskin bottles. Right: Glass fibre filter loaded with particles, most likely phytoplankton.

13.7 Genomics (by Jodi Pieterse and Susanne Fietz)

The determination of the phytoplankton community composition will be further supported by genomic analysis across the water masses. These samples will be analysed for eukaryotic phytoplankton by our partner laboratory at NTNU Norway, led by Prof Atle Bones. Taking advantage of the filters though, we will also study the prokaryotic community. Phytoplankton and microbial communities are normally studied separately, but it is important to assess their tight interactions. The genomic samples will thus serve the identification of pro- and eukaryotes, and elucidate their roles in the cycling of nutrients.

Sampling strategy and methodology: As mentioned above, the TraceEx team collected genomic filter for the water beneath the ice (station M03, Table 1) and three genomic filters for the pancake ice (M04; ice core “Core 3”, divided into upper, middle and bottom sections). Furthermore, Jodi filtered up to 10L for genomics from 50m water depth at each Niskin cast during the return northbound leg (Leg I, Table

1). Water was subsampled from the Niskin bottles into acid cleaned and rinsed carboys and filtered through an inline filter system and a 47mm diameter, 0.2µm pore size membrane filter using a peristaltic pump. All filters were stored immediately at -80°C.

13.8 Cultivation of microbial isolates (by James Lloyd)

Trace metal availability drives the microbial community, while at the same time the microbial community impacts the trace metal distribution and availability. In future, we aim to conduct experiments on trace metal impact and search for functional genes in isolates. For this purpose, James started isolating and cultivating microbes from all water masses and depths along the return, northbound transect (Leg I).

Sampling strategy and methodology: To isolate pure microbial cultures from water samples on the cruise, James plated water samples from all Geotraces (i.e. GoFlo bottles) casts and at all depths onto artificial seawater enriched actinomycete agar. This consists of approximately 250 plates covering all depths at each sample point. Ca. 1mL were subsampled into sterile Eppendorf vials in the trace metal clean container and spread onto the previously prepared sterile agar plates. In addition, James plated samples taken from a hand lowered Niskin bottle within a marginal sea ice environment (station MO3, Table 1). We have observed microbial growth on many plates taken from all latitudes. Differences in colony morphology indicate that several different species have been isolated.

13.9 Sampling for pigments and genomics in the marginal ice zone

Through inter-institutional collaboration, the TraceEx team was able to procure water samples from just below the ice taken by members of the UCT team and a piece of pancake ice that was hoisted from the ocean by the international ice team and designated members of the UCT team (Fig 5). Jean and Bjorn from the TraceEx team were then able to core ice samples (see section 13.3), some of which were later melted and filtered. In addition to analysing the trace metals in these water samples, the TraceEx team also had a vested interest in the phytoplankton and bacterial community in the water and how they compared to the community within the ice in terms of composition and productivity/biomass. For this reason, the TraceEx team filtered the water from just below the ice to collect samples for pigments, POC and pro- and eukaryotic genomics (station M03, Table 1). Due to a very tight ice core water budget, only pigment and genomics samples could be taken from the melted ice cores. Pigments and genomics were sampled from two different ice cores retrieved from the same pancake as the three ice cores sampled for trace metals (section 13.3). Each ice core was divided into top, middle and bottom sections before melting. Coring and cutting was conducted under as clean conditions as possible (e.g. ethanol cleaned saw and plate for genomics) and placed in clean zip-lock bags within a couple of minutes after coring. Cores were kept covered in clean plastic sheets during coring. The filtrates from the pigment and genomic filters were furthermore stored to be analysed later for macronutrients (section 13.10), salinity and N-isotopes by the UCT team.

Figure 63. Sampling in the marginal ice zone. Left: UCT Oceanography and Civil Engineering teams sampling surface water in pancake ice using a handheld Niskin bottle. Right: typical chunk of pancake ice collected from the marginal ice zone (note the ice displayed on the photo is a spare ice float that was not used for trace metal or biogeochemical subsampling).

13.10 Macronutrients (N, P, Si) (by Ian Weir)

In collaboration with the nutrient sampling conducted by Dr Sarah Fawcett's team, the TraceEx team collected samples for macronutrients from the GoFlo bottles. These samples were collected in conjunction with the trace metal samples following the GEOTRACES protocol. The purpose of this is to reconstruct a high-resolution nutrient distribution along the 30°E transect.

Sampling strategy and methodology: In total 139 macronutrient samples were collected from the GoFlos in duplicate. Nutrient samples, for each depth, were sub-sampled into 50mL falcon tubes in the shipboard trace metal clean laboratory. Sub-sampling in the trace metal clean laboratory took between 30-50 min at each station. The samples were filtered using a 0.2µm pore size syringe filter. The filtered volume was recorded. Filtering sub-samples from each station took between 1-1.5hrs. Once all sub-samples were filtered they were placed in ziplock bags and stored in the -20°C freezer immediately after filtration. One duplicate was used for analysis on board by the Sarah Fawcett, Katye Altieri's and David Walker's teams, the second was kept frozen as archive sample.

13.11 Biogenic silica and cell wall structure (by Ian Weir)

Biogenic silica (bSi) was sampled as diatoms, siliceous phytoplankton, are one of the dominant plankton species responsible for export production from the surface ocean, which contributes to the transport of particulate matter (including carbon) to the deep ocean. The bSi samples were taken in conjunction with the pigment samples from all Niskin CTD casts done on the return northbound leg (Leg I). The bSi samples were also collected from the ice station along with the pigments. The bSi data collected will be coupled with silicon isotopes, phytoplankton community composition (including microscopic identification and quantification by David Walker), and macronutrient distributions to provide information on the incorporation of silicic acid within the photic zone and to make inferences about silica export. Sections of the filters collected for bSi will furthermore be used for scanning electron microscopy (SEM) of the diatom cell walls (frustules).

Sampling strategy and methodology: At each CTD station (IO1 to IO8; Table 1), Ian collected six samples between 150m water depth and the surface. Due to water budget restrictions, ca. 2L were subsampled per depth from the respective Niskin bottles into PE bottles. All samples were filtered within 2 to 4h after collection. Bottles were gently shaken prior to filtration to distribute particulates without breaking the cells. Samples were filtered onto polycarbonate track etch membrane filters with a diameter of 47 mm and 0.8 µm nominal pore size. The filter was placed in a plastic petri dish and dried at 60°C.

13.12 Biomarkers for paleo-reconstruction

The sedimentary layer on the sea floor records climatic and environmental changes over Earth history, with palaeoceanographic reconstructions based on isotopes and biomarkers preserved in deep-sea sediments offering a window into the climate of the past. These records provide clues about regional temperature variability and record changes in global amplifiers of regional signals, such as the greenhouse gas, CO2. Deciphering these records is a challenge, however, and little has been done in the Southern Hemisphere compared to the large international efforts in the Northern Hemisphere. Here, we propose to ground-truthing and calibration of multiple paleo-proxies.

Ground-truthing is necessary for all proxies. The idea behind the molecular palaeo-proxies is a more or less linear relationship of the index value (e.g., the UK37 or TEX86 index values) in core tops (most recently deposited sediment) or suspended particulate matter (from the water column) with temperature (usually derived from satellite data or ship-board measurements). This has been shown, for instance, for the UK'37 derived sea surface temperature relationship (e.g., Sachs et al., 2007) and the TEX86-SST relationship (e.g Kim et al., 2008). However, other studies have highlighted the need for regional caution or new calibrations (e.g., Bendle and Rosell-Mele 2004 for UK'37; Ho et al., 2014 for TEX86 and modifications; Fietz et al., 2013 for hydroxylated GDGTs). A first set of samples from surface and/or deeper waters were collected during the Antarctic relief voyages (SANAE 54 and SANAE 56) and the Winter Cruise 2015. However, all those sample sets were taken along the GoodHope Line, Atlantic Southern Ocean. Here we proposed to shift to new grounds and probe the wintertime Indian sector of the Southern Ocean.

Sampling strategy and methodology: A general problem sampling for paleo-biomarkers is the required amount of water filtered to recover sufficient amount of molecules. We therefore used the newly acquired McLane pumps for in-situ filtration of large volumes (see section 13.4). The 142mm diameter Whatman 0.3µm glass fibre filters utilized for biomarker collection were previously combusted in an oven at 450°C for 4 h and stored in muffled aluminium foil. Placement and retrieval of filters followed the methodology described for particulate trace metals above (section 13.4). Filters were stored frozen upon retrieval in muffled aluminium foil and zip-lock bags. Biomarkers will be extracted and analysed using a UPLC-MS according to the methods described in Becker et al. (2013, 2015). Results will be linked to the genomic analysis of microbes, especially archaea, collected from the Niskin bottles (see section 13.7)

13.13 Bibliography

Bowie, A.R. et al., 2010. Analytica Chimica Acta Modern sampling and analytical methods for the determination of trace elements in marine particulate material using magnetic sector inductively coupled plasma – mass spectrometry. Analytica Chimica Acta, 676(1–2), pp.15–27. Available at: http://dx.doi.org/10.1016/j.aca.2010.07.037.

Coale, K.H., 1991. Effects of iron, manganese, copper, and zinc enrichments on productivity and biomass in the subarctic Pacific. Limonology And Oceanography, 36(8), pp.1851–1864. Available at: http://www.aslo.org/lo/toc/vol_36/issue_8/1851.html.

Grotti, M. et al., 2005. Trace metals distributions in coastal sea ice of Terra Nova Bay , Ross Sea , Antarctica. , 17(2), pp.289–300.

Hassler, C.S. et al., 2012. Exploring the link between micronutrients and phytoplankton in the Southern Ocean during the 2007 austral summer. Frontiers in Microbiology, 3(JUL), pp.1–26.

Lannuzel, D. et al., 2011. Distribution of dissolved and particulate metals in Antarctic sea ice. Marine Chemistry, 124(1–4), pp.134–146. Available at: http://dx.doi.org/10.1016/j.marchem.2011.01.004.

Westerlund, S. & Ohman, P., 1991. Cadmium, Copper, Cobalt, Nickel, Lead, and Zinc in the Water Column of the Weddell Sea, Antarctica. Geochimica Et Cosmochimica Acta, 55(8), pp.2127–2146. Available at: <Go to ISI>://WOS:A1991GC43900003.

Appendix I: Details on individual samples collected from Ice Cores by the TracEx team (compiled by Jean Loock; the reader is also referred to the main text of "Trace Metals in Ice Cores", section 13.3)

1) *Direct melting: core sample 2 (denoted C2; Method 1):*
   a) Sample must be cored outdoors where the drill head fumes will not contaminate the sample (preferably a hand auger should be used).
   b) Once cored, the sample should be evaluated to determine whether mineralogical characteristics can be used infer the top versus bottom of the core. The core should be photographed.
   c) The core is divided into three segments (±10 cm) using a clean stainless-steel saw, packaged in ziplock bags and stored at -5°C (no light) or taken to a clean container for all further processing. Care must be taken that samples are labelled well.
   d) Areas affected by the corer and the saw should be scraped clean using a ceramic knife.
   e) The cleaned core segments should be transferred into acid clean (0.1M HCl Merck Suprapur) ziplock bags for melting at ambient temperature inside the laminar flow hood of the clean laboratory (ISO 5).

   f) As soon as the final piece of ice has completely melted, sampling and filtration should proceed (see below).

2) *Sea-water melting: core sample 1 (denoted C1, Method 2)*
   a) The exact same protocol shall be followed as for the direct melting (points a-d above).
   b) The clean core segments should be placed into clean ziplock bag and to this, 0.45µm filtered seawater should be added to each sample at a ratio of 1:4 (ice:seawater).
   c) The exact volume of the seawater should be included, such that mass balance calculations can be conducted during reconciliation.
   d) The salinity of this added water should also be measured.
   e) Triplicate samples should be collected of the added filtered seawater such that the associated metal concentrations can measured and later subtracted.
   f) The acid cleaned (0.1M HCl Merck Suprapur) ziplock bags must be sealed, doubled bagged into a second ziplock bag and placed in a double layer of black plastic bags (to exclude light).
   g) Samples should be allowed to defrost in a fridge at 4°C, and once completed melted, should be transferred into the clean container (ISO 5) for filtration under laminar flow.

3) Biogeochemistry core sample (denoted C3):
   a) Protocols as per above (points a-d)
   b) Melted at ambient temperature in the Geochem lab of the SA Agulhas 2.

This core is intended for the collection of nutrients, POC, chlorophyll-a, pigments and genomics.

Table 6-Details for the sub-samples collected from the ice-cores taken from the pancake collected at M02. Core C2 using method 1 did not require a mass balance approach hence the omission of volumes for the core. Each X denotes a single sample. 1L of TM6 0.45µm filtered water was added to each core section of C1(Method 2). Subscript TM denotes trace metal sample.

Ice Core	**Section**	**T_{TM}**	**D_{TM}**	**$0.45\mu m_{TM}$**	**Salinity & Spare**	**Total Volume (L)**	**Volume Core (L)**
C1	Bottom	XX	XX	XX	XX	1.756	0.756
	Middle	XX	XX	XX	XX	1.622	0.622
	Top	XX	XX	XX	XX	1.780	0.780
C2	Bottom	XX	XX	XX	X	N/A	N/A
	Middle	XX	XX	XX	X	N/A	N/A
	Top	XX	XX	XX	X	N/A	N/A

Notes:

Core C1 received the following additions from 0.45µm TM6 (4X1L LDPE) filtered seawater:

C1 Bottom: 750ml TM6_1 IC
250ml TM6_2 IC
C1 Middle: 500ml TM6_2 IC
500ml TM6_3 IC
C1 Top: 250ml TM6_3 IC
750ml TM6_4 IC

125 ml LDPE sub-samples were taken for each of the 1L LDPE 0.45µm filtered seawater used in the addition. This will be analysed to determine the concentration of trace metals added to the core. We also kept the 0.45 µm filters to attempt analysis of particulates trapped during the filtration – a long shot.

Appendix II: Details of sampling station for deployment of McLane in-situ pumps (compiled by Jean Loock; the reader is also referred to the main text of “Particulate Trace Metals”, section13.4)

Table 7 – Compilation of samples collected for the two McLane pumps with respective filter descriptions and volumes achieved. The DF clearly experienced some trial and error when it came to filters and pump rates – explained in problems. Superscript a denotes that the stations were taken near known hydrothermal vents over the Indian ridge.

Station	Location	Pump	Filter 1 (µm)	Filter 2 (µm)	Filter 3 (µm)	Depth (m)	Volume (L)
Test (RM_1)	55° 30.453 ’S 28° 18.656 ’E	*DF FH1*	-	-	-	-	-
		DF FH2	-	-	-		-
		4L	-	-	-	-	-
TM1	58° 30.060 ’S 30° 00.003 ’E	*DF FH1*	0.2	0.3	100	300	9.6
		DF FH2	0.2	-	100		14.4
		4L	0.2	-	100	500	77.3
TM4^a	50° 35.261 ’S 29° 59682 ’E	*DF FH1*		0.3	100	300	198
		DF FH2	0.2	-	100		26.4
		4L	0.2	-	100	500	98.25
TM5^a	47° 59.993 ‘S 30° 00.047 ‘E	*DF FH1*	0.2	0.3	100	300	6.6
		DF FH2	0.2	-	100		1.1
		4L	0.2	-	100	500	50.4
TM7	42° 59.654 ‘S 29° 59.852 ‘E	*DF FH1*	0.2	0.3	100	300	53.9
		DF FH2	0.2	-	100		129.9
		4L	0.2	-	100	500	59.2

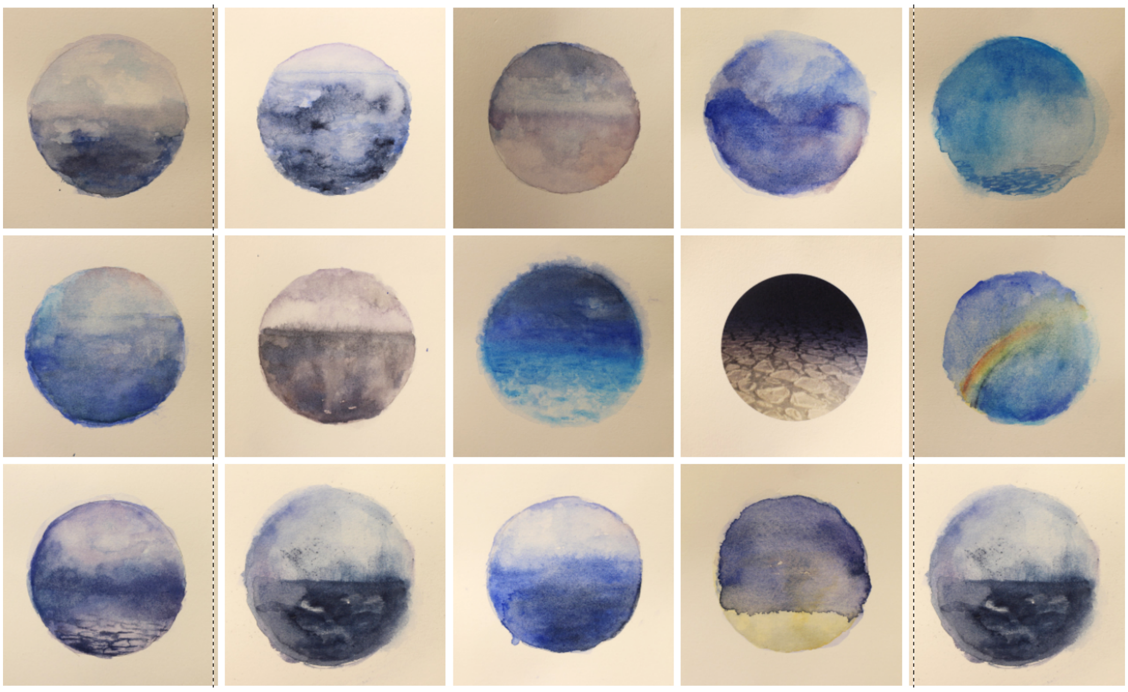
14 Arts and media

Lena Sulik, Curator, 99 Loop Gallery with Katrine Claassens (artist) and Marcello Vichi (PI)

Art can provide insight, context and create awareness about science. The inclusion of an artist and science communicator from the African Climate & Development Initiative (Katrine Claassens) on the winter cruise reflects a growing movement towards science/humanities collaborations and interdisciplinary research.

In the artwork done during and shortly after the voyage, the intention was to compliment the science being done on the ship but to also create a space to remember, to mourn, and most importantly, to empathize with a world being transformed by climate change.

The resulting art formed the exhibition inspired by the cruise, *we came at a time*, at 99 Loop Gallery (Cape Town). The exhibition included four large scale oil paintings, over forty watercolours, three works on silver-leaf and a video piece "One Hand For You, One Hand For the Ship". All the paintings were made using melted Antarctic sea ice collected during cruise. In addition to the art exhibited at the exhibition, Claassens is currently working on an illustrated essay about the cruise. The complete collection of paintings can be seen on the artist's website.



Katrine Claassens, *Impressions of the South Ocean*, (installation detail). Melted Antarctic sea ice and watercolour on fabriano, 10 x 10cm each

Installation views, *we came at a time,* 99 Loop Gallery

Above (l-r) *The Last Hours of Ancient Sunlight; Sea Change* and *Ship Light in The Night* all mixed media (melted Antarctic sea-ice, acrylic and oil) on canvas, dimensions variable.

Press & Media

Scientists Turn To Antarctica For Answers To Global Warming
Interview with Marcello Vichi and Katrine Claassens
Sunday Times: Times Weekly
By Tanya Farber

Interdisciplinary Research Cruise to the Marginal Ice Zone of Antarctica
UCT news
Staff Reporter

SAfm - the Enviro show
Interview with Marcello Vichi and Katrine Claassens
With Nancy Richards

567 CapeTalk
Interview with Katrine Claassens
With Africa Melane

Event: Presentations by Marcello Vichi and Katrine Claassens
5th August 2017
99 Loop Gallery

15 Overall comments, technical issues and recommendations

This cruise was organized by DST/NRF with the central objective to develop and strengthen Southern Ocean and marine research, and to use the research platforms available to the South African research community to build capacity in South Africa, the region and the continent. This set of dedicated research voyages during the austral winter have demonstrated the crucial importance of measuring the winter conditions in the Southern Ocean. In this specific case and for the first time, a complete program involving the science of the cryosphere was carried out in conjunction with a process study endorsed by GEOTRACES.

15.1 Expression of interest, Organization and pre-departure operations

Access to the dedicated winter voyage was determined by way of an expression of interest. Almost all the scientific groups participating in this cruise presented a joint expression of interest, that was sub-divided in different components in order to comply with the individual-based request from the funding agency. The design of the cruise that was discussed before the presentation of the expression of interest was an essential step that brought to the success of this voyage. The small consortium that was constituted during the planning phase demonstrated a degree of maturity, interdisciplinarity and mutual understanding of logistical issues that allowed a proper organization of the scientific program. This cooperative model of concerted voyages is proposed as a way forward for the future oceanographic research in the Southern Ocean, especially in view of a rationalized management of the South African polar infrastructures.

One aspect to be taken into consideration is the duration of these dedicated voyages. There is a clear constraint based on the funding availability. However, it also needs to be considered that oceanographic research in the Southern Ocean is largely determined by met-ocean conditions and the ship costs are based on averages over different kind of navigation modes. The initial duration of the voyage was from 1 June 2017 to 12th July 2017. To maximize the overall return on investment it was requested to extend it, but the return date was fixed to the 13th In the early morning. The number of days for science activities should therefore be counted always considering the departure operations that may take up to one day and can be delayed due to logistic reasons (as in this case the availability of the ship doctor) and the return time that is in the morning. Out of 15 days of cruise made available by DST, this turned out to be a cruise of 13 days without any buffering for bad weather conditions. This implied a continuous balance between the contingent environmental conditions, the need to fulfill the science plan and the relative fuel costs. These choices ultimately sit on the Captain, that takes the decision in consultation with the Chief Scientist. It is recommended that a larger time window and a proper consideration of the science activities would effectively lead to the same costs, because considerable fuel savings could be attained.

15.2 Safety and winter navigation in the Southern Ocean

Navigation in the Southern Ocean is always difficult. Winter conditions, however, takes this to the extreme, and the safety of the ship and personnel is a key issue.

The SA Agulhas II is a polar vessel, which is equipped for this kind of operations, however, given the emphasis on training and exposing cruise activities to the younger generation, it is quite likely that not all the personnel have received a proper training. The ship suffered some damages due to the floes washed on deck by waves during station activities and navigation. A large floe was washed on Deck 3 during the navigation in the MIZ (Figure 49), but also during the pancake lifting the crew and science personnel have been affected by smaller though dangerous ice floes (Figure 64). A specific induction of the personnel on this kind of issues should be done in addition to the standard safety drills. The safety of the navigation would also be improved with the installation of a specialized wave radar that would allow the ship to be informed on the wave field conditions.

Polar operations on sea ice are particularly difficult and the adequate equipment is not available in South Africa. In terms of gears, DEA was very kind to provide some of the equipment used at the SANAE Antarctic base, which is however not suitable for wet operations of deployments on sea ice. Thanks to the intervention of the ship officers, the team was provided with high-quality wetsuits that allowed a safe and successful deployment of the buoys on the ice floes. It is recommended that this specialized equipment be made available in the future with special agreements between the science teams and the ship owner, in order to maximize the investments and reduce the use of science funding to purchase very expensive gears.

Figure 64 Consequences of ship slamming on sea ice during the pancake lifting operations

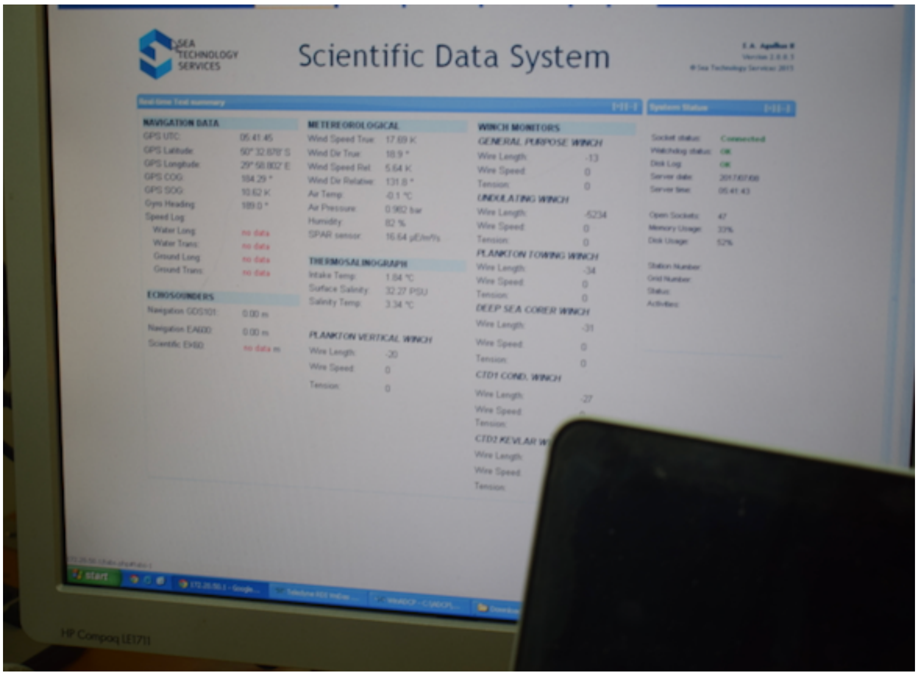
15.3 Communication, instrumentation, data availability

The communication on the ship greatly improved respect to the previous voyages. The ship owner was able to provide a state-of-the art bandwidth, that allowed download of scientific data as well as the control of the deployed instrument. It also allowed all the students on board to enjoy social media, although the more demanding services have been filtered. It may be necessary in the future to further limit the bandwidth in certain decks if more sophisticated real-time operations are required.

The system that requires major intervention is SDS. For the whole duration of the cruise it was not possible to download the data and check for their consistency. The technician on board assured that raw data were stored, but given the uniqueness of these data it is always desirable to back them up during the cruise and check them for drifts. All computers on board do require a refurbishing and renewal, with an update of the operating systems. It is suggested that a more robust operating system (linux) would be used in all the public places, keeping the more delicate windows machine only for the Operation Room for software compatibility.

The science echo sounder also requires some prompt action. As it can be checked on the ship data log, its behaviour was quite erratic and tended to reset at random. This created quite some issues in the proper positioning of the stations closer to the sea mounts. It is also not clear what are the data being stored in the SDS, as there is a bundle of cables in the serial plug (Figure 65).

Finally, and this is a major issue of concern, there is no system in place for a long-term storage of the metadata and data from every single cruise, as well as a proper quality control system in place. Everything relies on post-processing of the data by various people, which does not ensure a proper continuity and reliability of the information. It is recommended that this issue is dealt with in the process of rationalizing the polar infrastructures undertaken by the DST.



Scientific Data System

NAVIGATION DATA
GPS UTC: 05:41:45
GPS Latitude: 60° 32.878' S
GPS Longitude: 29° 58.802' E
GPS COG: 184.29 °
GPS SOG: 10.62 K
Gyro Heading: 189.0 °
Speed Log
Water Long: no data
Water Trans: no data
Ground Long: no data
Ground Trans: no data

ECHOSOUNDERS
Navigation GDS101: 0.00 m
Navigation EA600: 0.00 m
Scientific EK60: no data m

METEREOROLOGICAL
Wind Speed True: 17.69 K
Wind Dir True: 18.9 °
Wind Speed Rel: 5.64 K
Wind Dir Relative: 131.8 °
Air Temp: -0.1 °C
Air Pressure: 0.982 bar
Humidity: 82 %
SPAR sensor: 16.64 µE/m²/s

THERMOSALINOGRAPH
Intake Temp: 1.84 °C
Surface Salinity: 32.27 PSU
Salinity Temp: 3.34 °C

PLANKTON VERTICAL WINCH
Wire Length: -20
Wire Speed: 0
Tension: 0

WINCH MONITORS
GENERAL PURPOSE WINCH
Wire Length: -13
Wire Speed: 0
Tension: 0
UNDULATING WINCH
Wire Length: -5234
Wire Speed: 0
Tension: 0
PLANKTON TOWING WINCH
Wire Length: -34
Wire Speed: 0
Tension: 0
DEEP SEA CORER WINCH
Wire Length: -31
Wire Speed: 0
Tension: 0
CTD1 COND. WINCH
Wire Length: -27
Wire Speed:
Tension:
CTD2 KEVLAR W
Wire Length:
Wire Speed:
Tension:

System Status
Socket status: Connected
Watchdog status: OK
Disk Log: OK
Server date:
Server time: 05:41:43
Open Sockets: 47
Memory Usage: 33%
Disk Usage: 52%
Station Number:
Grid Number:
Status:
Activities:

Figure 65 Top: issues with data transmission from echo sounder to the SDS. Bottom: Cables connecting the SDS system to the various sensors. The echo sounder is connected with the patched red-taped cables.