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MABEL – Recovery Operation of the first long-term heavy Benthic Laboratory in the Deep Sea of Antarctica

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ABSTRACT

This paper deals with the recovery operation of the bottom station **MABEL** (**Multidisciplinary Antarctic Benthic Laboratory**) with a mass of 1,7 tons in air that has been deployed in December 2005 from the German research vessel Polarstern, by means of a release transponder at a water depth of 1850 m, close to the shelf ice edge near the German polar research station Neumayer. The project is run under the umbrella of the Italian Antarctic programme by the project leader INGV (Istituto Nazionale di Geofisica i Vulcanlogia) /1/. During the cruise ANT XXV-2 of the Polarstern (organized by the German AWI - Alfred-Wegner-Institut) the German partners TFH Berlin and TU Berlin have been participating with their module **MODUS** (**Mobile Docker for Underwater Sciences**) to recover the station from the deep sea.

The special circumstances in the Antarctic sea - the ice coverage of the deployment area and the tight time schedule for the operation - make such an operation quite delicate. This paper describes the special technology used both for the station and the recovery module. The operation itself will be discussed, showing the data of operation using a combined tracking of GPS-data and the underwater positioning system Posidonia of the Polarstern. The special circumstance of the operation was the inadequate data of the position achieved during the deployment, so that a safe search strategy had to be found. The mission ended successfully on December 16th, 2008 with the recovery of the MABEL station. Simulations for the system behaviour will be shown.

KEY WORDS
Deep-Sea Intervention, Sea Ice, Antarctica

INTRODUCTION

The operation in areas of deepwater – or inner space – is technologically both driven by exploration and exploitation activities of the offshore oil and gas industry and marine deep water research that increasingly require high level technical tools. Many tools permit and support these interventions such as Unmanned Underwater Vehicles (UUV) comprising both Autonomous Underwater Vehicles (AUV) and Remotely Operated Vehicles (ROV). Consequently, during the last decades, standard ROV technology evolved into a reliable everyday tool used in all fields of oceanographic engineering /2/. In addition, there are special tools such as MODUS that are able to deploy heavy loads from the sea bottom and recover them after a mission lasting days, months or even years. A scenario for such an operation is illustrated in Fig.1, showing the recovery situation close to the shelf ice edge of Antarctica.

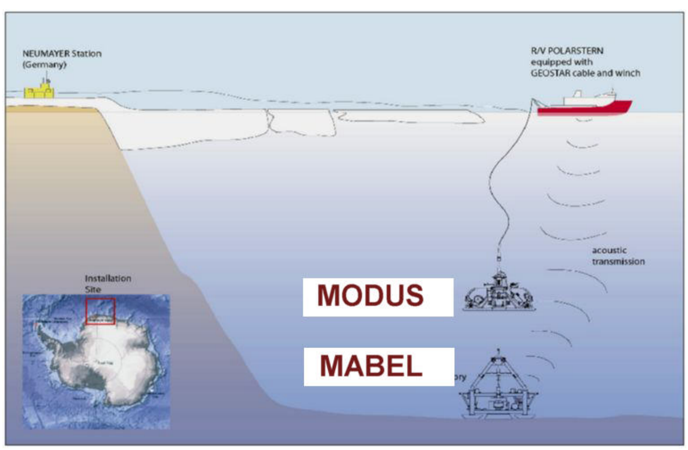


Fig. 1: Scenario of the recovery procedure of the MABEL station. R/V Polarstern as carrier of the docking module MODUS close to the shelf ice edge. Operational depth 1850 m.

MABEL and its technology

The station used for the Italian research project MABEL is derived from the GEOSTAR projects (Geophysical and Oceanographic Station for Abyssal Research - EU-funding; GEOSTAR 1: EU/DG XII Mast III-CT95-0007; GEOSTAR 2: Mast III-CT98-0183). Within this European research project a standard definition of interfaces and operational limitations of the docking module MODUS has been determined, Fig. 5. Main interface is the docking pin on top of the station, which is beared flexible to compensate impacts during the docking procedure due to induced motions by the sea state. The pyramid shaped top area is used as a guidance for the inner cone of MODUS, compensating displacements in case of motions and inaccurate positioning, Fig. 2. The bottom area of the station is dedicated to the scientific purposes. During the last decade a fleet of five different bottom stations of the GEOSTAR type have been built for different purposes, but all fit for long term operations up to one year of autonomous measurements at depths down to 4000 m (based on the starting point in the mid 1990s), /3, 4, 5/. Table 1 provides a rough summary of design specifications of the stations used.

Table 1: Main specifications of benthic stations (BS) as load

Main dimensions of bottom stations, full-scale			
Bottom Stations (BS)	Mass m_0 [kg]	Weight in water [N]	L/B/H [m]
GNDT-SN1	1433	8201	3.50 / 3.50 / 2.90
ORION-2	1657	9751	3.50 / 3.50 / 2.90
ORION-1	2771	13479	3.50 / 3.50 / 2.90
MABEL	1730	9900	3.00 / 3.00 / 2.920

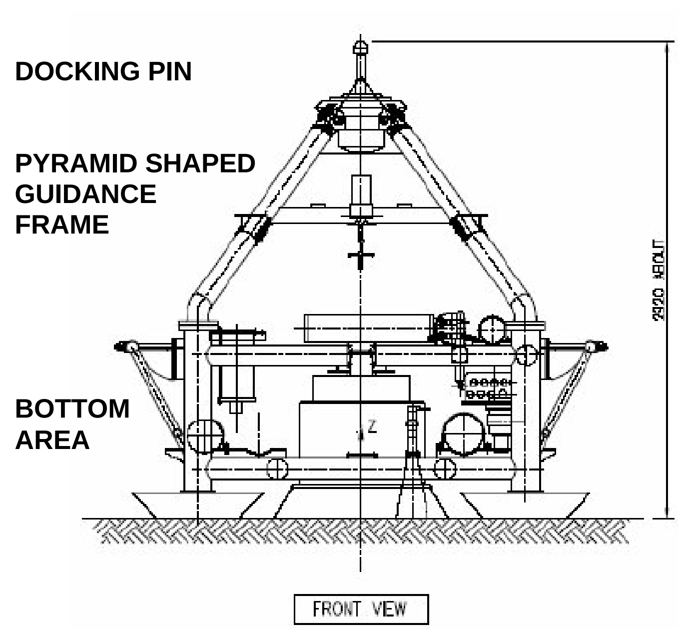


Fig. 2 Bottom Station of MABEL with equipment and docking pin on top – the footprint of the base is 3000 mm x 3000 mm.

The stations have been used in the Mediterranean Sea, the Atlantic Ocean and finally in the Antarctic Ocean within several projects such as GEOSTAR 1 (1995-1998), GEOSTAR 2; 1999-2001), ORION (Ocean Research by Integrated Observatory Networks; 2002-2005 – EU-funding: EVK3-2001-00022), and the ongoing project NEAREST (Near Shore Tsunami Early Warning System; 2005-2009; EU-funding: GOCE 037110), all funded by the European Commission within the Research Framework Programmes /6/. Moreover, this type of station has been used within the Italian earth quake measurement network as SN#1 (Seismic Node No. 1, ongoing since 2001) /7/. This is the first sea based station integrated into the network and is connected to the shore by means of a cable providing power and submitting real time data. Finally, the station design has been used for the seismic and oceanographic station MABEL which operated from 2005 to 2006 in the Weddell Sea of Antarctica.

For this operation the station has been designed to operate for at least one year and to withstand the low water temperatures of about -1.5°C. Fig. 3 gives a view of the layout. The power supply for the scientific sensors and related equipment is given by the battery vessel, including the data acquisition vessel that organizes the power and data storage. Independently from this, an acoustic transmission system (ATS) is installed that allows the communication with the research vessel by means of an underwater acoustic modem operated by a laptop onboard. Table 2 provides the basic data of the ATS. Power for this unit is provided by its own battery vessel. The material used for the vessels is titanium or hard anodized aluminum.

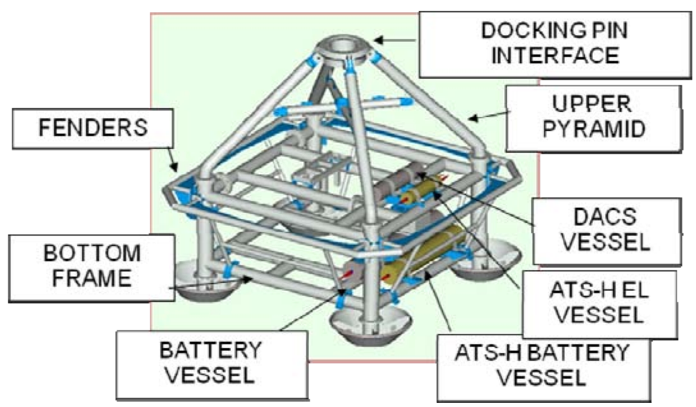


Fig. 3 Supply units of the MABEL station.

The sensors used for the project are:

- Broad Band Seismometer
- CTD
- Transmissometer
- 3-Axial current meter
- pH and Eh analyzer
- Water sampler (HCO, Fe^2, NH4, …).

These sensors are arranged in the core of the lower frame area. Main sensor is the broad band seismometer mounted in the center of the station. After an initial check of all operational modes via the ATS the seismometer is released and drops to the sea floor, thus it is decoupled from the frame. The inducement of vibrations caused by the other equipment (water sampler, hard disk operation) can be reduced to the minimum, Fig. 4. For the veering phase the seismometer is protected by an outer hull,

(Fig. 4 left), after the release it has its own shell to avoid interaction with the water column, (Fig. 4 right): hence, vibrations induced by the water current can be reduced efficiently. In addition the housing protects the seismometer during recovery, which is important because it is hanging 10 m underneath MABEL. As soon as MABEL is recovered and onboard of the vessel, the seismometer might behave like a pendulum and beat against the ship's side. Thus the protection avoids any damage.

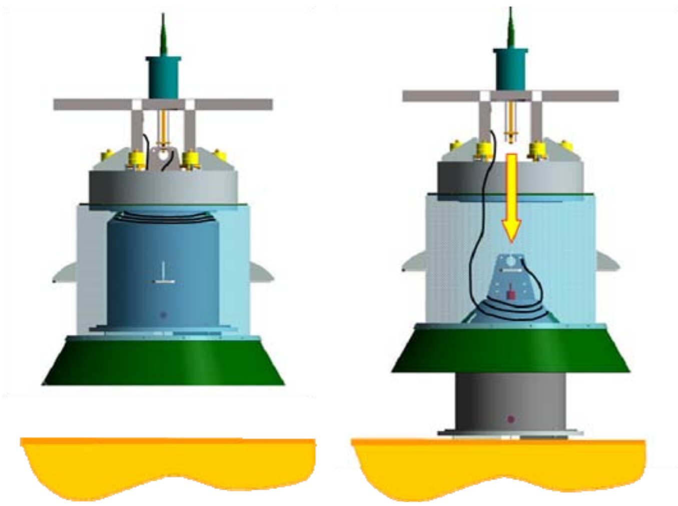


Fig. 4: Cross cut view of the design study of the Seismometer, with the outer shell during deployment (left) and the sea floor operation (right).

Table 2: Main specification of the acoustic transmission system

Implemented modulations	CHIRP –Freq. Hopping MFSK PSK
Frequency Band	9.5 - 13.5 kHz
Digital rate	CHIRP: 20 bit/s. Freq hopping : from 100 to 200 bit/s MFSK hopping 400 bit/s PSK from 600 to 2400 bit/s
Consumption	In emission: 3.0 A / 24 V at 190 dB ref µPa @ 1m. In reception : 90 mA / 24 V. 5 mA / 24 V (idle mode).

MODUS and its technology

The stations described above are carried by MODUS, a recovery and deployment system that has been developed within the projects GEOSTAR 1 and 2. Since then it has operated during more than 20 inner space operation, and has been used also as video monitoring system and sampler carrier in several projects, /7, 8. 9, 10/.

Fig. 5 illustrates the MODUS design. The umbilical with a breaking strength of about 390 kN on the top is mounted, providing: a) the power (30kW via 3~3000 V) transformed in a deck unit on the research vessel, b) the up- and down link of the data via fiber optic lines. The power is transformed in a unit to several voltage levels used for the electronics, the cameras, the sonar, the lighting, and mainly the thrusters that allow a lateral motion of MODUS for accurate positioning. Data for the control of the unit and the management of the sonar and cameras and finally the active coupling unit in the center top under the umbilical are transmitted by a telemetry unit that has its counterpart in the control container from which MODUS is operated. The vertical movement is managed by the winch directly, which limitates the operations at higher sea states, because wave motion is more or less directly transmitted via the umbilical to MODUS.

Fig. 5: Design study of MODUS showing the umbilical connection on top, the transformer at the front, the thruster for positioning, the cameras, and the lighting arrangement. Weight in air 10 kN, in water 7 kN; H 1700 mm, W 2300, L 3200 mm.

This sensitivity to sea state induced motions is the main disadvantage in comparison to ROVs. The advantage, however, is the ability to carry loads up to 3 tons, which is far beyond the capacity of standard ROVs used for marine research. Influences on the dynamic behaviour are illustrated in Fig. 6: sea waves, relative positioning of the vessel, the current of the sea along the water column, flexibility of the umbilical. The horizontal layer shown in Fig. 6 indicates the event horizon meaning the depth of resonance. Simulations have been run using specific sea spectra and the physical specifications of the entire system: sea state, vessel shape, stiffness of the cable, drag of MODUS, added water masses during the operation. WAMIT and tools of the TU Berlin have been used as codes and the partner Tecnomare from Italy has run simulations with the commercial code of Orcaflex. For the configuration of MABEL the results provided data for the operation at around 2000 m water depth, which is close to the operational depth of 1850 m. Fig. 7 top illustrates a series of positions of MODUS close to the sea floor in a distance starting from 2 m (right) going to 10 m (left) during a recovery. Superimposed is a sea state of 2 m double amplitude and a period of 4 s. In the phase of active lowering by the winch a superimposed motion induced by the sea state might lead to vertical motions at critical speeds of more than 1,2 m/s. With deployment speeds exceeding this level, MODUS becomes instable due to vertical drag determined by tumbling motions of the docking cone /11/.

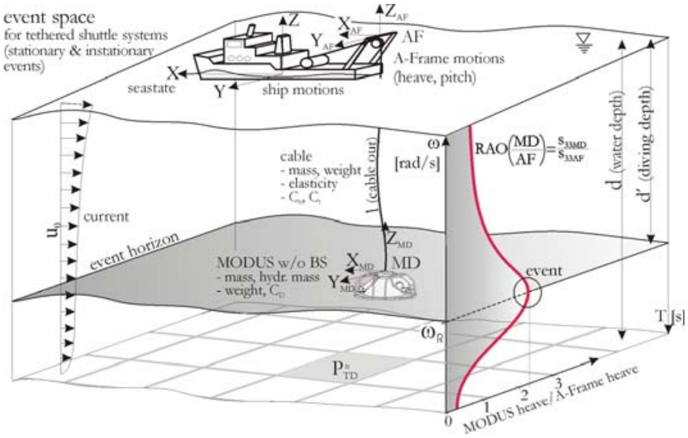


Fig. 6 Event space for tethered shuttle systems: stationary and instationary events. Influences on dynamic behavior of MODUS during sea operation – general terms.

Fig. 7-bottom demonstrates such a critical mode showing the red areas of critical amplitudes that lead to slack cable. Finally Fig. 8 shows a plot of a recovery operation similar to the MABEL cruise. The green line indicates the cable payout at slightly more than 2000 m, the blue line indicates the load in the position of the sheave at the A-frame of the vessel, the red line indicates the load on top of MODUS at the umbilical termination point. It can be clearly seen that the sea state of about 2 m double amplitude and a period of T = 4,5 s induces motion that led to oscillating loads on the A-frame position (blue line). In this case the vertical motions are not on a critical level as no extreme spikes by snap loads are visible. The plateau indicates the situation after docking, with the increase due to the additional load of the bottom station during heaving. The red line illustrates the net load directly on MODUS.

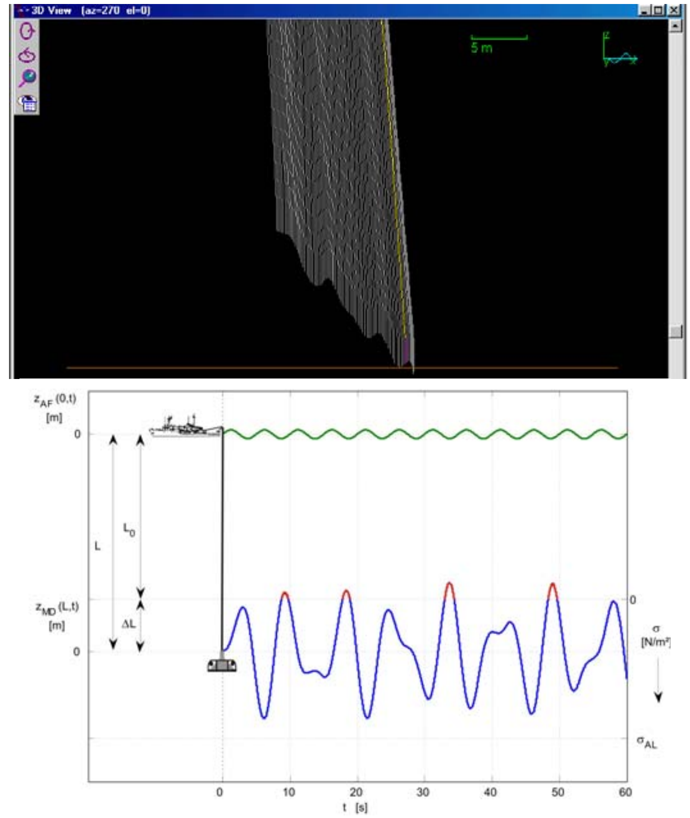


Fig. 7 top: Simulation model of RV and MODUS. Operation close to sea bottom – time line. Results: Orcaflex simulation run by Tecnomare S.p.A.
bottom: Principle of MODUS motion in the event space by wave motion induced from the research vessel (meter of motion vs. time – relative data, non-scaled).

In consequence at high vertical speeds, MODUS is falling freely, which leads to a zero load in the umbilical → slack cable. Shortly after, the entire system is lifted due to a wave crest and dangerous snap loads occur. This has to be avoided as it might damage the umbilical and break the armouring, with the consequence of losing the system.

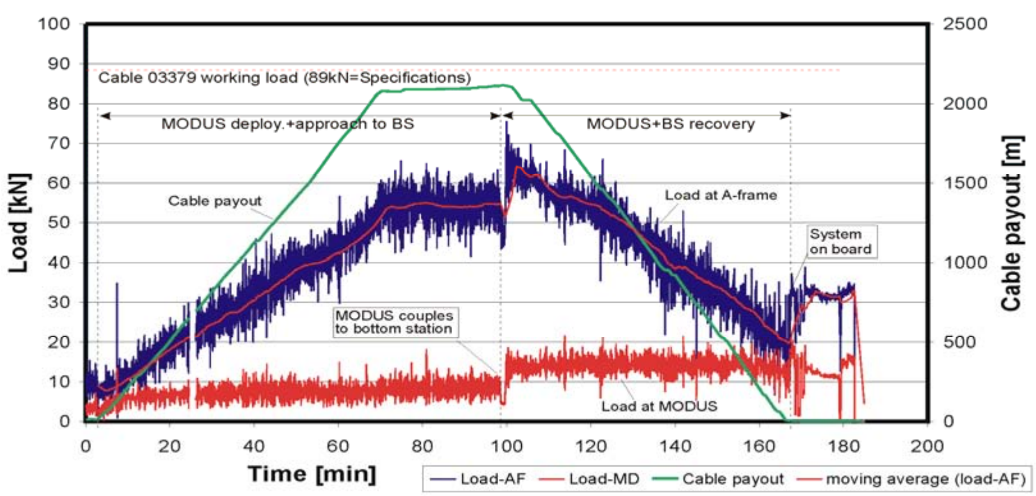


Fig. 8: Profile of load at A-frame (AF) and at MODUS (MD) with cable payout during a complete operations cycle for recovery of a bottom station from 2000 m; (m_0 MD=1090 kg, m_0-BS=1433 kg)

Preparation for Antarctica

Both units, MABEL and MODUS, have been tested under extreme conditions before the deployment cruise was conducted. The Large Ice Tank of the HSVA (Hamburgische Schiffbauversuchsanstalt in Hamburg, Germany) has been used for the environmental test in 2002. Fig. 10 shows the test set-up of MODUS with the station in the water at air temperatures of about -20°C and water temperatures below zero. Both systems were performing well, so that no major changes in the design were required.

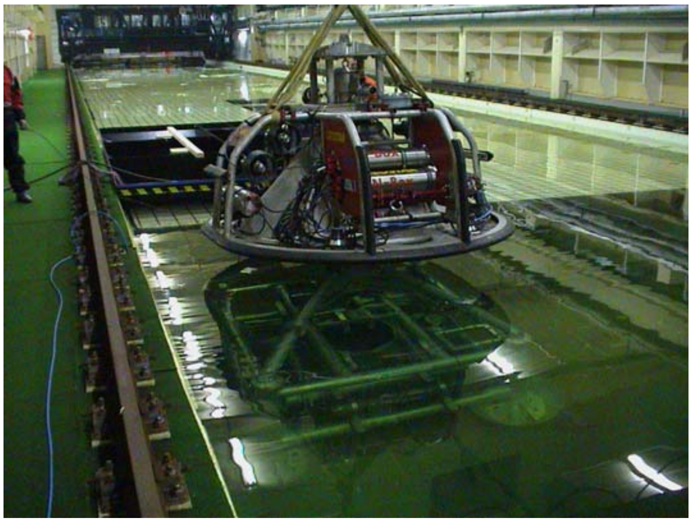


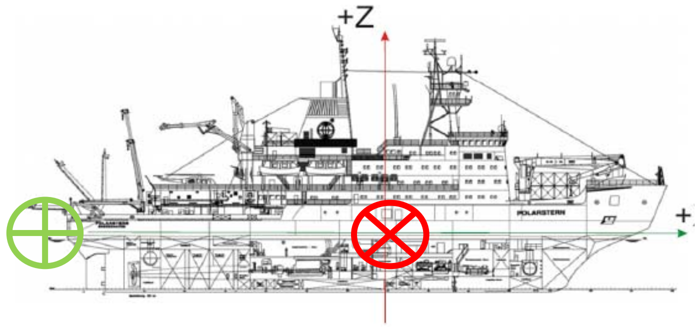
Fig. 9: MODUS and MABEL during the environmental tests in the large ice tank of the HSVA in 2002.

POLARSTERN and deployment

For the operations, both deployment and recovery, the German research vessel Polarstern operated by AWI was used, Fig. 10. Deployment took place during a cruise on December 5th, 2005, by a release transponder and a standard winch without an umbilical. The operation was conducted via the A-frame in the stern of the vessel, lowering the station to the sea floor with continuous ATS-communication, enabling the monitoring of the distance to the sea floor, the settlement of the station, its functionality and the final release at latitude 69° 24,295'S Lon 5° 32,220'W.

Recovery of MABEL

A first recovery attempt took place on February 10th, 2007 during a cruise with Polarstern. The operation failed due to inadequate sea conditions and a deviation in the positioning after a long search of about eight hours. The station could not be located. High swell of more than 4 m double amplitude and T = 9s, illustrated in Fig. 11, led to instable motions of MODUS, Fig. 12. The number of irregular motion events with roll and pitch of more than 90° are listed in Table 3. Finally, these extreme events caused a severe damage of the outer armouring of the umbilical, Fig. 13. Due to the tight schedule a repair could not be conducted on site. However, a system check of the station could be preformed successfully via ATS. The station had stopped its work on December 6th, 2006 as programmed. After this check, the station mode was disabled again, due to the low power status of the batteries after one year of successful operation.



Main technical characteristics of R/V Polarstern /12/	
Overall length [m]	118
Breadth [m]	25.0
Draft [m]	11.2
Displacement, max [tons]	17.300

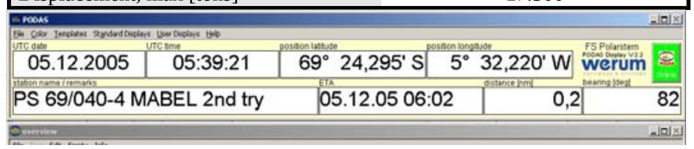


Fig. 10: top: Polarstern, general layout, with GPS reference position (red cross) and the working position at the A-frame of MODUS (green cross), mid: Main characteristics of Polarstern, bottom: operational data of the deployment © AWI, Laeisz.

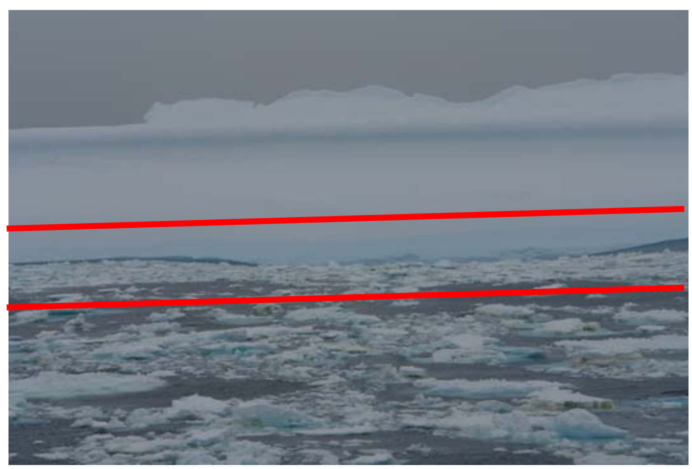


Fig. 11 Visible swell during the operation – drifting iceberg close to the site of operation 2007.

A second attempt was made during the cruise ANT XXV-2 of the AWI, again with Polarstern on December 16th, 2008. The cruise started on December 5th, 2008 in Cape Town, SA and led to the German Antarctic station Neumayer, ending January 5th, 2009 in Cape Town. Fig. 14 illustrates the part of the track approaching Neumayer. The box indicates the site of MABEL.

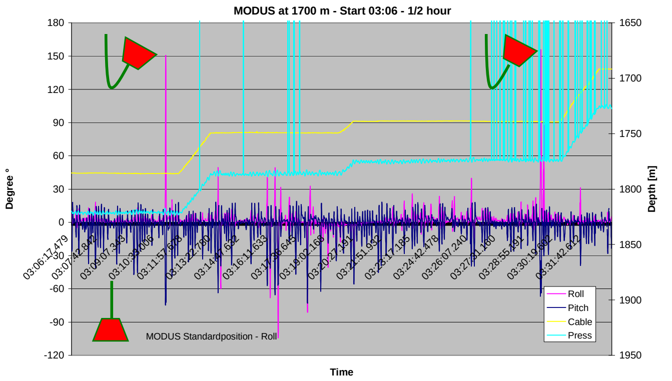


Fig. 12 Last hour of the search operation. Clear indication of extreme events: roll (magenta) and pitch (blue) > 90°. Pitch can be compensated by the flexible bearing of the termination, roll cannot. Operational depth is indicated by cable payout (yellow) and related pressure (cyan). Spikes in pressure indicate transmission failure of the fibre optic line.

Table 3: Number of events (Pitch or Roll > 90°) during the first recover attempt in 2007 for nine data sets of 55 min each. Total time 8h 25 min.

data set (55min)	Pitch	Roll
1	0	4
2	2	12
3	8	9
4	4	13
5	13	8
6	19	14
7	12	17
8	16	11
9	6	9
Events Sum	80	97

Fig. 13 Detail of the umbilical termination after operation. Left: pressure housing connected to the top of MODUS. Right: bending restrictor completely pushed aside due to strong roll and pitch. Mid: umbilical with broken wires of the outer armouring layer.

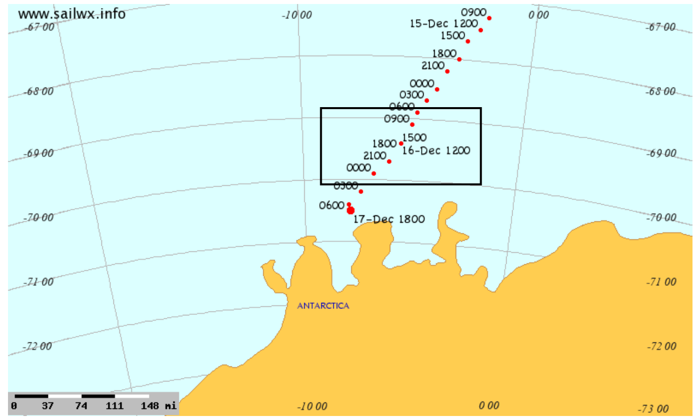


Fig. 14 Part of the cruise track from ANT XXV-2 approaching the shelf ice close to the Neumayer station in the area of the recovery operation. © www.sailwx.info.

In order to minimize the risk of failure, all circumstances and conditions were carefully analyzed: sea ice conditions, general drift of ice on the surface, weather forecast, and a review of the MABEL deployment.

The sea current was analyzed by software provided by AWI monitoring the tidal current on the surface. Usually this is not significant for sea operations, but in the relevant area an ice coverage of more than 50% was predicted, see ice map of the University of Bremen for the day of recovery, Fig. 16. This meant that ice plates of significant size and speed might cover the area of operation. If drifting against the research vessel the forces are extremely high, pushing the ship away from the target position, which could lead to delays of hours or days. Ice around the vessel had to be avoided in any case to protect the umbilical from impacts and damages. Taking this into account, a period for the operation in the afternoon was chosen, as during this period the drift was at a minimum. In addition to this a GPS sensor was deployed on an ice plate one day in advance to verify the forecast data. The measurements confirmed the prediction of the simulation model shown in Fig. 15. Moreover, the weather forecasts were good, meaning low winds and almost no swell or wind waves, due to the damping of the ice on the surface.

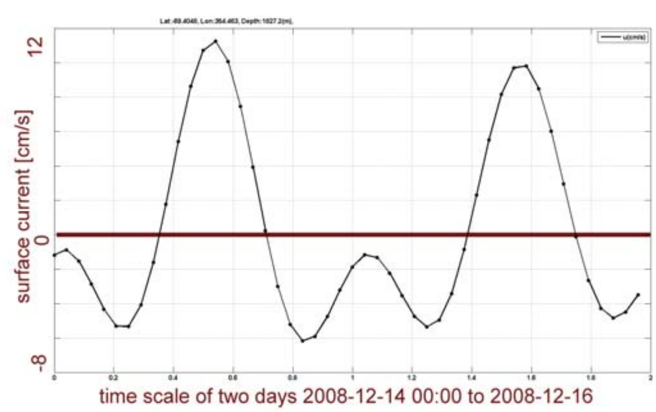


Fig. 15: Tidal current in cm/s on the surface of the operation area on 14 - 16 December, 2008. © AWI.

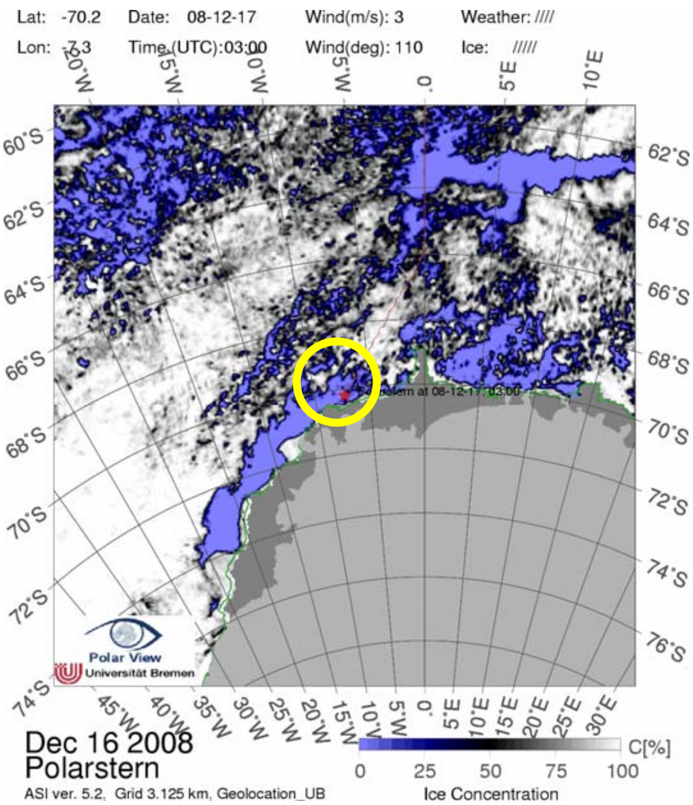


Fig. 16: Ice coverage in the Weddell Sea on December 16th, 2008 and the area of operation (yellow circle). © University of Bremen.

In addition to the meteorological analysis, the possible position of the deployment was discussed as the accurate position of the bottom station was unknown. Fig. 17 shows the tracks (black) of the first unsuccessful recovery attempt in 2007. The center of the track was supposed to be the position of deployment. Because during the entire search no signal of the station on the sonar could be found a search mission was launched around the center spot (radius of about 400 m). Also this search track was not successful until the abort.

Obviously there was an unexpected displacement in the position data. The analysis of the data had been conducted: GPS position, band width of error, ship heading, drift, sea current profile. This led to the planned red tracks in Fig. 17 assuming an westward correction of 100 m. The station itself was not providing any signal after 3 years on the sea floor. Hence, the search was dependent on this passive approach.

An advanced check of the ice conditions by the helicopter crew gave a good prognosis: Fig. 18 shows the ice coverage on the site, Lat 69° 24,295'S Lon 5° 32,220'W. For the monitoring of the surface system a GPS antenna was mounted to the A-frame directly providing the exact position of the umbilical going into the sea. In addition MODUS was equipped with a transponder communicating with the underwater positioning system Posidonia run by Polarstern.

Fig. 17: Track of the first recovery attempt in 2007 (black) and the planned tracks for the search in 2008 (red). Polarstern on the initial spot of deployment heading east. Distance between red tracks about 80 m.

Fig. 18 Ice coverage during the day of the recovery operation at the site: Lat 69° 24,295'S Lon 5° 32,220'W.

The recovery operation started in the early afternoon on December 16th, 2008 with the deployment of MODUS to the full depth of about 1800 m. Polarstern was approaching the middle track, at a speed of 0,5 kn, with MODUS following this track with the same heading controlled by its thrusters. During this operation the area on portside and starboard was scanned by sonar searching for signals indicating the station. The maximum range to receive a significant signal under the operational mode and speed is about 120 m. Midway on the first track we got a clear signal of the station on portside. Everything could have been easy now, but a large ice plate was approaching the vessel position, and a racing duel started. We were able to approach the station position in time, with the vessel parallel to the ice edge. Docking took place at 16:41, and the system was brought back to safety at 17:50, Fig. 19 and 20. Only minutes after the docking the ice plate drifted over the target position.

Fig. 19 MODUS approaching MABEL at a water depth of 1837 m shortly before docking.

Fig. 20 Recovery of MABEL close to the edge of a drifting ice plate.

The final evaluation of the tracking data is given in Fig. 21. Analysing the data, the given position of the station and the final one, had an offset of about 200m, which is outside of the reach of the first search track from 2007. Offset estimation went in the right direction and allowed the detection of the station within a short time.

The first checks of the station showed no significant damage by corrosion or a failure of the sealings of the pressure vessels. The data were recovered and the water samples were prepared for future analysis.

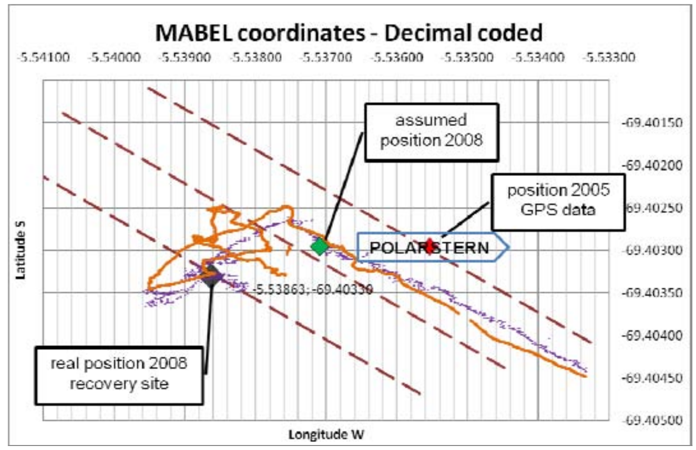


Fig.21 Search tracks December 16th, 2008: Polarstern (orange). MODUS with Posidonia (purple). Red spot: deployment position: Lat 69° 24,295'S Lon 5° 32,220'W. Assumed position of the station (green), real position on the sea floor (deep purple – large spot on the lower track).

CONCLUSIONS

The deployment and recovery of MABEL ended successfully, demonstrating the feasibility of the operation of an Antarctic long term benthic station mission with the technology described in this paper. In the future, redundant positioning transponders on the stations will help to avoid the difficulties of repositioning. The weather will always remain a risk for all sea operations on tight schedules. The data processing of the scientific sensors is still undergoing the post processing in conjunction with data from the land based sensor units on Neumayer.

ACKNOWLEDGEMENTS

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The authors are very grateful for the cooperation with the funding organizations and the partners in these projects mentioned. Moreover, we like to thank Dipl.-Ing. Wilfried Langner as member of the deep sea system group in Berlin for his contribution during the mentioned projects. Paolo Favali (INGV) for the backing from abroad and Massimo Calcara (INGV) for initiating the MABEL project.

Related projects are ORION, GEOSTAR 1 and 2, SN#1, MABEL, NEAREST, ESONET, LIDO. General information is given at /1/.

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