Where have you been, Polarstern?

The most likely position for each moment in a long traveller's life

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We have investigated the quality of position data of one of the longest continuously documented history of an individual research vessel: The impressing track record of the German icebreaking research vessel Polarstern started the 9th of December 1982 and continues up to date. The ship has travelled 1 639 449 nautical miles (until the end of 2016) during the last 35 years and yields thus a huge amount of global position data gathered using different systems. The data quality and frequency was continuously updated and improved. Here, we present an approach to represent the whole track record at respective maximum achievable accuracy in a unified format. This data set, the so-called ›Master Track‹ represents the most likely position during all of Polarstern's voyages.

Polarstern | track record | positioning | antenna position | motion data

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1 Introduction

Today, the real-time positioning of almost every moving platform is a matter of course. Everyone is expecting the route planner's positions to be ›true‹. GPS-measurements are nowadays embedded not only in statutory systems (such as AIS), but in almost any system moving around – from air planes to pet collars. Apart from scientific site investigations and/or hydrographic measurements, one seldom thinks about reliability and accuracy of this all-times available information. Common error correction and filter algorithms optimising the high-frequency data are well engineered and usually sufficiently accurate.

However, from time to time, discrepancies may occur from various error sources, such as wrong reference ellipsoids or projections during search of reported objects at the seafloor, changed configurations of reference points, reduced availability of satellites, reduced reception due to shadowing of the antenna, misguiding through erroneous INS-corrections, etc.

Of course, for high-precision hydrographic measurements (bathymetry and sub-bottom profiling) exact locations as well as correct motion information (pitch, roll and yaw) are obligatory during the survey and on research vessels, it is essential to know the exact location of taken samples or the exposure point of a certain device. During multidisciplinary cruises, the positions for different measurements on the same research vessel may have been logged by different people using different systems with different reference points and/or ellipsoids. Erroneous data may have one or several sources of the above combined making it difficult to find the ›true‹ or even ›most probable‹ location of a certain measurement.

Apparently, historic data is more affected by these problems than positions measured today, because some systems (such as differential or even raw GPS/GLONASS) are only available for about 25 years and in the earlier days of satellite navigation, the data quality was much less accurate. During pre-GPS times, systems such as ARGOS or Transit allowed a position fix every now and then only during the respective overflights of the satellites.

Much effort has been spent to compile the whole track record of Polarstern position-wise because not only the positioning methods have changed during time, but also the logging systems. The first electronic navigation and data acquisition system on board Polarstern, INDAS, was in operation from 1982 to 1993. The continuous recording of navigation position data finally started during the cruise ARK-II/2 in 1984. Since 2000, not only navigational and individual antenna position data is saved, but also motion data from the vessels inertial motion unit, thus allowing correction for pitch/roll and heading.

2 History of Polarstern position data

From 01.12.1982, the satellite navigation system Transit (also known as NNSS or NAVSAT) was used to determine the position of the vessel. Getting satellite fix GPS positions was only possible during satellite passes by using the Doppler shift and the accuracy of the position was between 300 and 1000 metres. Between the overflights, the positions were extrapolated using course and speed (measured by gyro and Doppler log). The longer the satellite fix was dated back, the worse the position determination is. That means that for devices that had to be recovered again (like moorings, etc.), only the times near satellite fix points could be used. All other positions were too inaccurate.

The continuous storage of these data started on 13.06.1984. Fig. 1 nicely shows the jumps in the track caused by misrouted position extrapolation between satellite position fixes.

From 06.07.1989, the accuracy of the positioning was improved a lot. Actual GPS measurements (T-Set) were routed to the software VENUS which extrapolated the positions by using the actual set and drift values between the satellite fixes. The combination with the GPS data lead to a much higher accuracy between the satellite passes. The jumps between the positions when a new satellite fix is taken almost completely disappeared.

Together with a new generation of computers, the data acquisition system PODEV was installed on Polarstern during 1992 together with a new GPS-system. This system consisted of three two-frequency GPS receivers (Ashtech/COMPASS) which were installed as a triangle with three metre baselines. However, since the navigation system did not support GPS data, this information was used to further improve the set and drift measurements and thus, enhance position prediction between the satellite fixes.

In May 1993, the INDAS system on board of RV Polarstern was replaced by a new navigation system ANP2000 which was capable to process the information from the three GPS receivers. This marks the start of true GPS navigation. Also, a new data acquisition system (PODEV) was installed independently of the navigation system and the original GPS data as well as the navigation data were logged continuously. In October 1994, an increase of position accuracy was achieved by using Wide Area Differential GPS (WADGPS) corrections from Skyfix. However, the position data and subsequent filtering through the navigation system still could be misrouted as can be seen in Fig. 2. In this example, the ship approaches the station from North-East and departs in the same direction after station completion. The red dots (original Ashtech GPS positions) are not as smooth and continuous but describe the factual track correctly. The filtered positions (green dots) are nicely smoothed out and continuous but during station time, the filter algorithms obviously failed and produced some ›ghost tracks‹ far off the factual route.

This setup was used until September 2000 when PODEV was replaced by the real-time data acquisition system PODAS/DSHIP. Additionally, an improvement of positioning occurred due to the switch-off of the Selective Availability (SA) on May the 2nd 2000.

In the fall of 2000, an inertial platform, MINS, was installed on board Polarstern which allowed a better prediction and enhancement of the position data. However, as the MINS is a commercial system optimised for lower latitudes, some new artefacts occurred in the data. The positions have been filtered by the MINS in UTM coordinates which resulted in erroneous predictions, especially in high latitudes. Fig. 3 shows the obvious misguiding of the filtered positions near the North Pole during ARK-XVII/2.

As a big improvement, the new system PODAS/DSHIP allowed a time synchronous acquisition and storage of all GPS receivers on board of RV

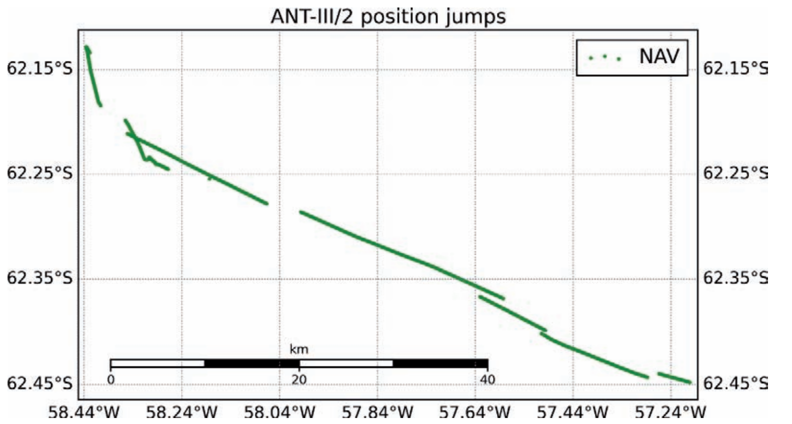


Fig. 1: Position data from ANT-III/2 (15.11. to 09.12.1984). Each jump corresponds to a Transit satellite fix. Due to the high latitude and corresponding high availability of Transit overflights, new fixes were available every 40 to 90 minutes

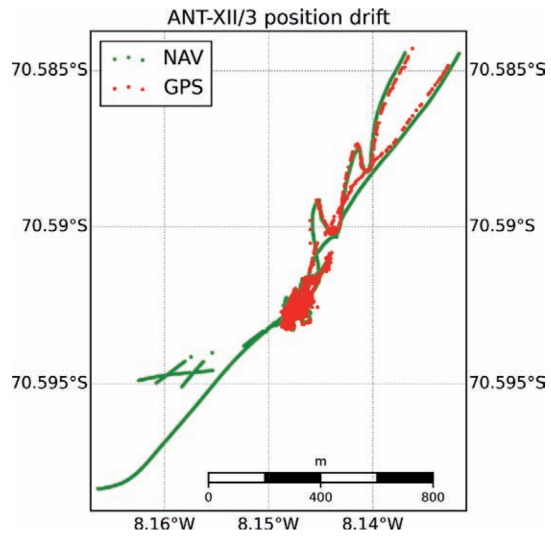


Fig. 2: Position data during ANT-XII/3 (05.01. to 20.03.1995) from the original navigation GPS receiver Ashtech (red dots) and filtered positions from the ship's navigation system ANP2000 (green dots) at a position with station work, i.e. no significant movement. The ship approaches the station from North-East, idles at position and departs towards North-East. Obviously, the filter algorithm is not suited for very small movements and velocities

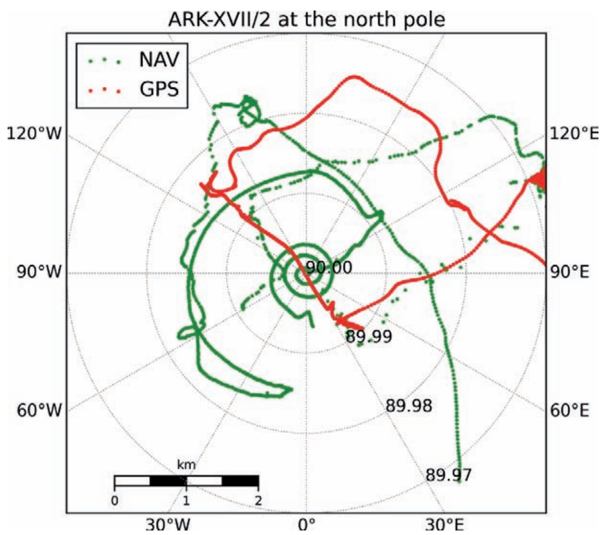


Fig. 3: GPS and filtered MINS positions near the North Pole during ARK-XVII/2 (31.07. to 07.10.2001). The original GPS position (Trimble, red dots) is of high quality and shows the correct route within GPS accuracy. The filtered position (MINS, green dots) are obviously misrouted and erroneous

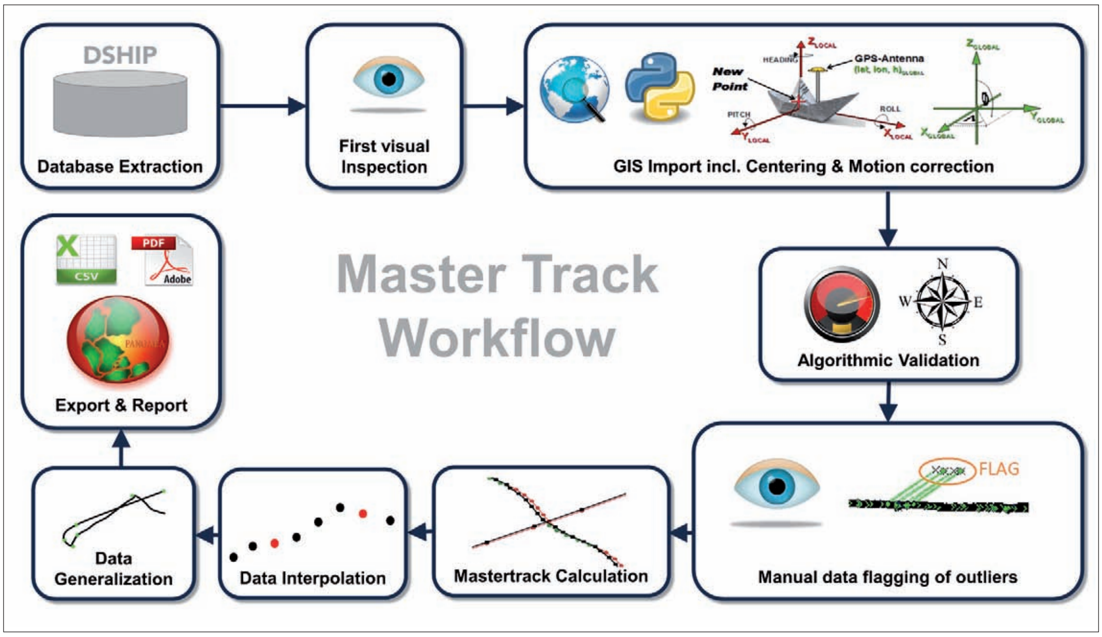


Fig. 4: Processing workflow of the Master Track generation

Polarstern and the temporal resolution changed to one second. All original data as well as motion and filtered data is stored continuously up to date. During 2006, all older data have been converted to common formats and are now available in the state-of-the-art version of DSHIP database (https://dms.awi.de/Polarstern.html).

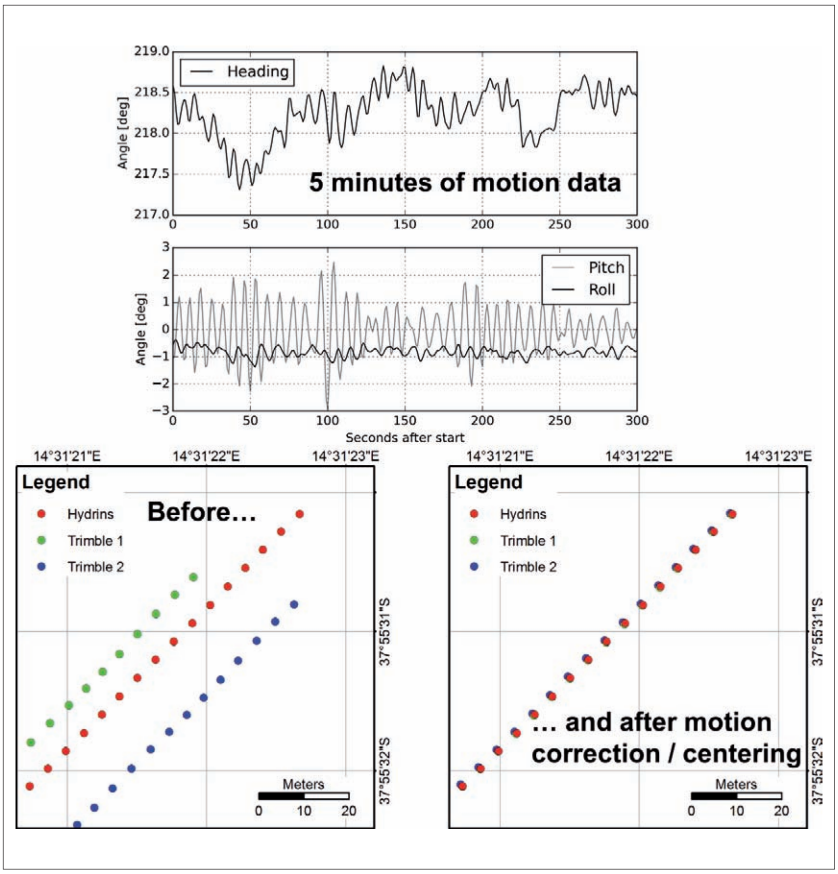
3 The ›true‹ track record of Polarstern

As outlined in the history above, data quality and artefacts have varied through time. Also, the storage and naming of different systems has changed. Several different error sources may have resulted in large deviations of the stored positions and for the standard user, it is very hard to evaluate the database without digging deep into the data and related metadata. In general, the data quality has significantly improved. The temporal resolution increased, the technical developments leaded to more precise positioning and the storage of the raw data in the ship's own databases now enables a long-term storage of relevant information. For some scientific cruises, it was found that different positions of the same sample are published and that its actual position remained unclear. This is caused by the different information distributed concerning the actual locations, i.e. some instruments were fed by raw GPS data and others by filtered navigation. With a length of 118 metres, this can be already critical for a vessel like Polarstern to navigate to distinct small-scaled targets from previous cruises. A good documentation of the GPS antenna positions helps to backtrack the true position where an original measurement was performed or a sample was taken. To be able to do so, the position of the ship (centre of gravity) as well as the orientation of the ship must be known.

The aim of this project was to generate a single valid track from all available navigation- and motion sources on the vessel. The basic idea is to use all available information to create the best (or most likely) position for the centre of gravity for every moment of the entire cruise. The related motion and heading data can then be used to reconstruct the most likely location of a certain measurement.

Fig. 4 illustrates the workflow of the Master Track routine. It begins with the download of all available raw data from the web interface of the ship's data acquisition system DSHIP. A first visual inspection of the extracted data is performed mainly to detect missing information and afterwards, all individual GPS positions (i.e. the locations of the GPS

Fig. 5: Data example of the cruise PS103 (16.12.2016 to 03.02.2017)



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antennas) are centred to a distinct location on the vessel. Optimally, this is the location of the motion sensor which is installed close to the vessels centre of gravity. The coordinates are centred or projected using a rotation matrix to take the lever arms and the motion angles into account (Torge 2003; Teunissen and Kleusberg 1998) and finally transformed from the Cartesian coordinate system of the ship to a geodetic system (Heiskanen and Moritz 1967). An example of motion data, as well as positions before and after centring is shown in Fig. 5.

Subsequently, an automatic filtering procedure is applied for the track of every navigation device. Outliers are marked, if their distance to the previous location is too far or the course (calculated after Williams 2012) changes too quickly. For this, thresholds for speed, acceleration and course-change are defined. After this automatic filtering, the whole track is examined visually to detect and manually mark remaining outliers.

Based on the general quality of the navigation devices and the amount of flagged positions for each individual track, the final Master Track is a combination of the best available position for every second of the cruise. Gaps up to a time span of one minute are linearly interpolated.

To evaluate the quality of the created Master Track, but also the quality of the underlying raw data, a score value was calculated for every cruise. The calculation of this value takes into account the completeness of the extracted raw data, the amount of automatically and manually flagged positions, and the number of gaps and interpolated positions in the final Master Track. A score value of 0 means no data, the maximum can be 100 (all data available, nothing flagged and no gaps or interpolations). Fig. 6 shows the development of the scores for the cruises between 1984 and 2013, the improvement of data quality can be seen.

To reduce the amount of data without losing valuable information, the Ramer-Douglas-Peucker algorithm (Ramer 1972; Douglas and Peucker 1973) is used to generate a generalised version of the Master Track. This algorithm only keeps the relevant corner points within a specified distance to the track. The tolerated distance of points off the track was set to 4 arc seconds which is approximately 120 metres.

The resulting Master Track and the generalised Master Track is then published in the data information system PANGAEA together with a processing report.

4 Summary

Since her commissioning in 1982 until December 2016, Polarstern has travelled 262 cruises. It was possible to calculate the Master Track for 240 of these cruises. Up to the cruise ARK-II/1 (which ended on 11.06.1984), the data was not continuously recorded. Thus, for the first 15 cruises, only the positions registered during meteorological observations (from 06:00 a.m. until 9:00 p.m., every 3 hours) are available. For the remaining seven missing cruises, unfortunately no data has been stored in the database.

In Fig. 7, the Master Tracks of all cruises are shown separated for Antarctic-, Transit- and Arctic cruises. ⚓

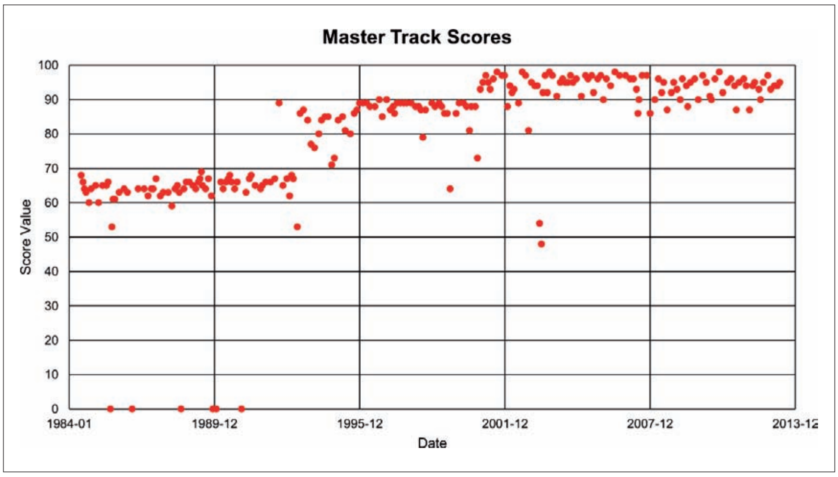

Fig. 6: Development of the score values from 1984 to 2013

Further reading

A complete overview of the Master Tracks calculated for Polarstern is given on the expedition homepage of this vessel on PANGAEA (https://www.pangaea.de/expeditions/cr.php/Polarstern). A detailed description of the method including the algorithmic validation and all errors can be found in the data processing logbook (hdl:10013/epic.45909). This logbook is a living document and updated continuously.

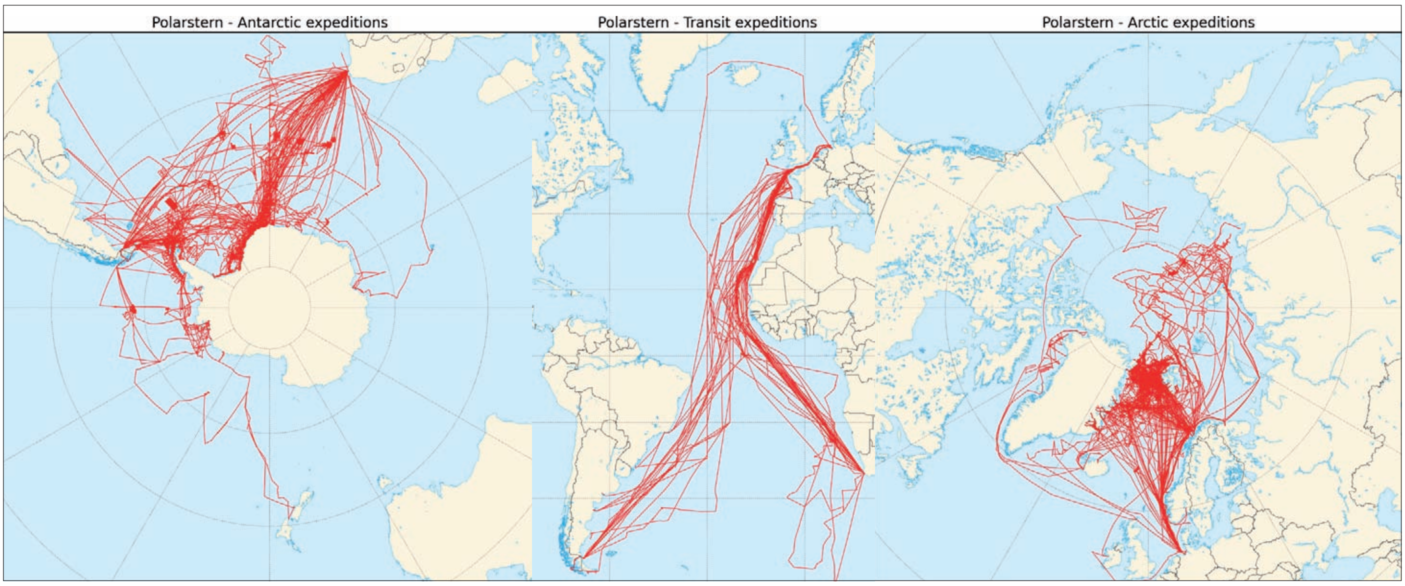

Fig. 7: All available Master Tracks from 1982 to 2016