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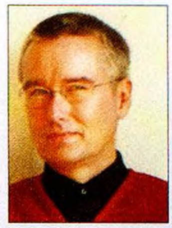

Surveying the 'Jadebusen' As an Example of Hydrographic Surveys for Multiple Uses

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An important user of hydrographic surveys done by Hydrographic Offices traditionally has been nautical cartography. Hydrographic surveys are required for chart production. But the tasks of the Federal Maritime and Hydrographic Agency (BSH) are not limited to navigation. Their scope is wide and continues to expand (e.g. CZM, coastal protection, coastal engineering). More and more different demands are being made by the users. This leads to hydrographic surveys for multiple uses. How to fulfil the needs of different users with just one survey campaign is shown by an example.

In 2001, the 'Jadebusen' had to be surveyed for BSH purposes as well as for special coastal engineering projects. This meant high and quite different demands on accuracy, vertical reference and processing. Multi-beam, single-beam and laserscan data had to be combined. This paper describes the planning, execution and processing of the surveys with a focus on height correction with PDGPS (precise differential GPS using carrier phase corrections) and on the combination of seaborne and airborne data. Problems and solutions are being discussed.

Hydrographic Surveying for Nautical Purposes

Hydrographic surveying traditionally, has been carried out to ensure the safety and ease of navigation. This is apparent from the following definition of Hydrography:

Hydrography is the branch of applied science which deals with the measurement and description of the physical features of the navigable portion of the earth's surface and adjoining coastal areas, with special reference to their use for the purpose of navigation [International Hydrographic Dictionary [HR-2059]].

The same applies to the definition of a hydrographic survey:

A survey having for its principal purpose the determination of data relating to bodies of water. A hydrographic survey may consist of the determination of one or several of the following classes of data: depth of water; configuration and nature of the bottom; directions and force of currents; heights and times of tides and water stages; and location of topographic features and fixed objects for survey and navigation purposes. [International Hydrographic Dictionary [HR-2304]].

The main customer of the survey is nautical cartography. Also the IHO Standards for Hydrographic Surveys have been developed bearing in mind the principal aim as 'to specify minimum standards for hydrographic surveys ... to be safely used by mariners (commercial, military or recreational) as primary users of this information' [IHO Standards, 1998].

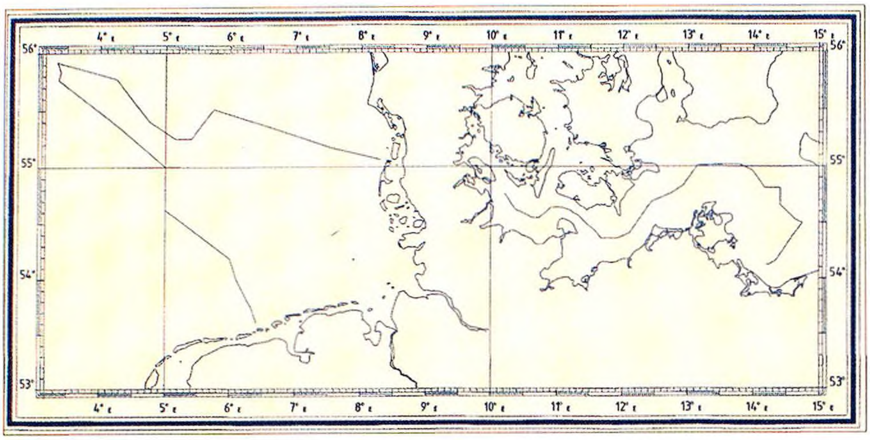

Figure 1: Region to be surveyed by the BSH

Also in Germany, where hydrographic surveying is carried out by the Bundesamt für Seeschifffahrt und Hydrographie (BSH), the standards are accepted in this way. The planning and conduction of the survey is primarily determined by the needs of nautical cartography.

The region to be surveyed comprises mainly the German coastal waters and the EEZ of the North and Baltic Seas, see Figure 1. Especially the near shore area of the North Sea, the Wadden Sea, is characterised by a highly variable sea bed which is shaped by strong tidal streams. To ensure the safety of navigation it is indispensable to resurvey this area quite frequently.

The survey is performed by five survey vessels:
KOMET: GT 1482, length 64 m, draught 3,8 m, 4 launches
ATAIR: GT 950, length 51 m, draught 3,4 m, 2 launches
WEGA: GT 969, length 52 m, draught 3,4 m, 2 launches
DENEB: GT 969, length 52 m, draught 3,4 m, 2 launches

The vessels ATAIR, WEGA, and DENEB are multipurpose vessels designed for surveying and wreck search as well as for some research tasks.

The result of a hydrographic survey consists of soundings and contours. They are documented in the form of a fair sheet, German: 'Topographische Karte des Seegrundes', see Figure 3. It contains the soundings and contours as well as grids, the grid of the survey and the grid of the nautical chart, some additional information like the coast line, names, and buoys and beacons. Unlike the chart, the fair sheet is considered to be a topographic map. It shows the nature of the sea bottom according to the scale or resolution of the survey.

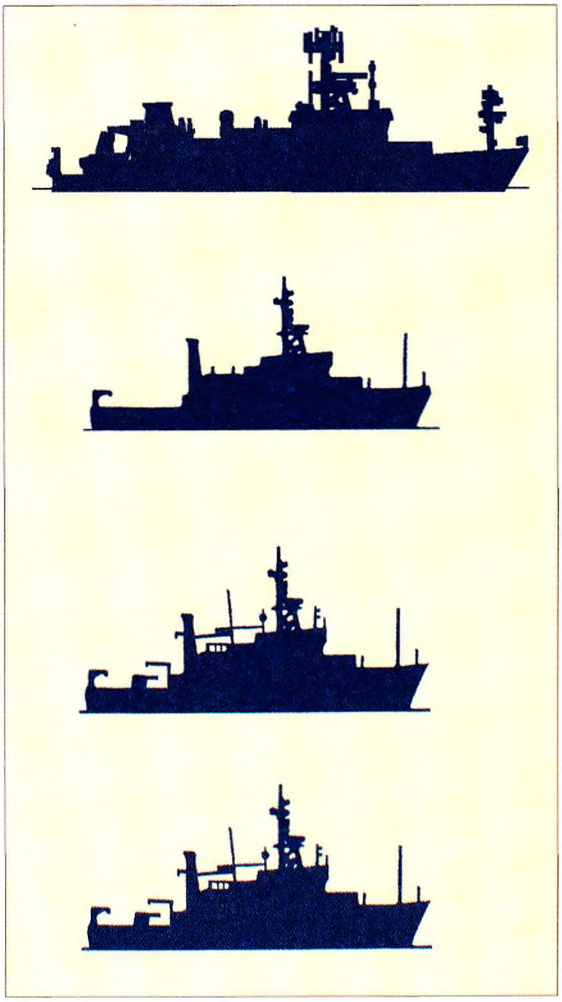

Figure 2: Survey vessels of the BSH

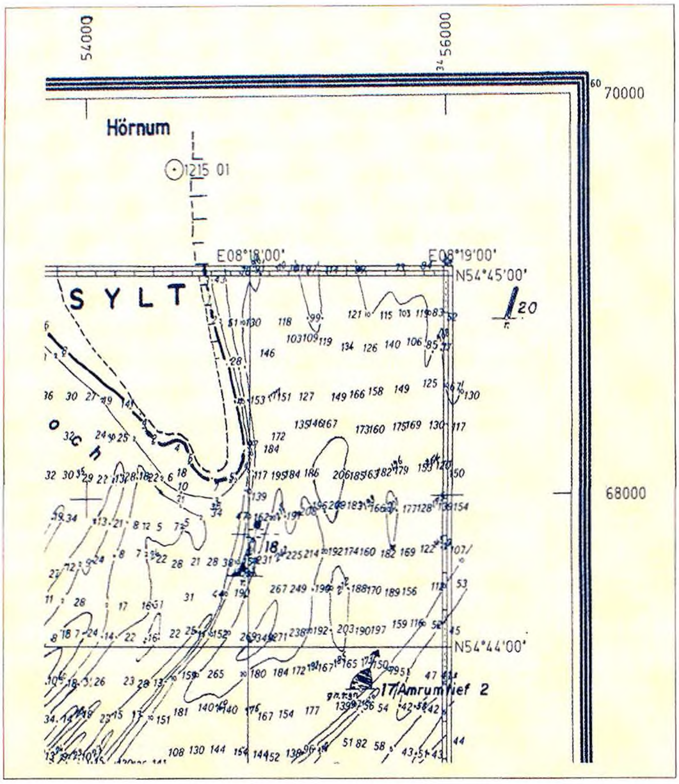

Figure 3: Topographic map

This product is available both in analogue form and in digital form. The digital form is, e.g., a CARIS NTX-file, some other graphical form or just ASCII co-ordinate triples. The fair-sheet is drawn referenced to the system of the survey, traditionally the system of the particular land survey authority. It also contains the grid of the respective chart, normally WGS84. The digital data thus can be delivered in both references, the local datum as well as in WGS84.

The vertical datum is the chart datum. It complies with mean sea level in the Baltic Sea and with mean low water springs in the North Sea. The tidal reduction is done using the so called 'Wasserstandserrechnungskarte (WEK)'. It is very similar to the co-tidal and co-range charts [Rohde, 1989]. It is also possible to get digital data referred to the land survey datum ('Normal-Null'), but only with some reduced accuracy coming from a quite rough transformation.

A very important characteristic of the fair sheet is the scale. It describes not only the scale of the sheet itself but also the scale of the whole survey. Most fair sheets are made in 1:20,000, but there are also smaller scales farther away from the coast, or larger scales (e.g. 1:5,000) in some special areas. The scale determines some important characteristics of the survey like distance of the profiles, reduction of data along the profile, accuracy of positioning, sounding etc.

The new edition of the IHO Standards for Hydrographic Surveys [IHO Standards, 1998] describes a very important change. The accuracy of the survey is no longer dependent on the scale of the analogue chart. The accuracy as well as the resolution of the survey depend on the type of the area to be surveyed. Harbours have to be surveyed with a very high accuracy and resolution, while offshore areas require less accuracy and a wider line spacing. However, these accuracy classes also correspond to some characteristics of the survey which have to be fixed at the beginning of the survey. Consequently, these characteristics also include the fair sheet scale, or in other words: the resolution of the survey or of the digital terrain model.

The preface of the IHO Standards recognises:

> Hydrographic data is also important for coastal zone management, environment monitoring, resource development, legal and jurisdictional issues, ocean and meteorological modelling, engineering and construction planning and many other uses.

Therefore, and as a consequence of the quality management system, the BSH started interviewing its customers. The questions concern the properties of its products, frequency of surveys, and duration of data processing. Important customers are, of course, the nautical charting group within the BSH, but also the navy and the Federal Waterways and Shipping Administration which is responsible for maintaining the fairways. Other customers are the authorities responsible for coastal protection, research institutions etc. The results of these interviews will influence the redesign of the basic task list from which the yearly list of tasks is to be derived. This basic task list describes particular regions with certain attributes, for example the area to be surveyed, the

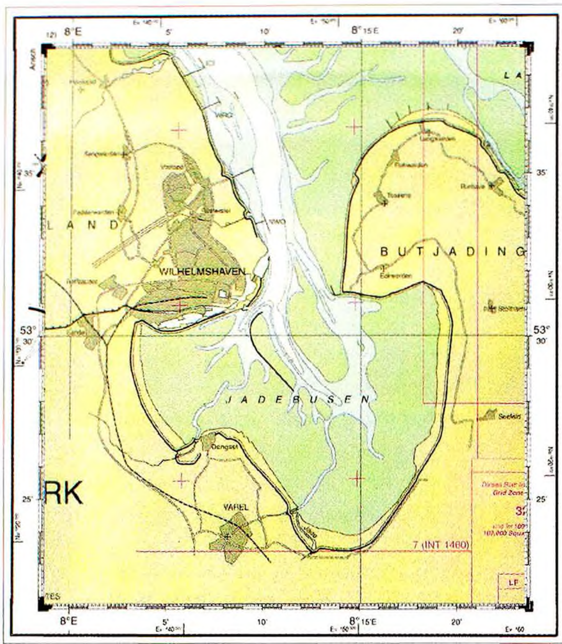

Figure 4: The Jade region

scale or resolution of the survey with the corresponding accuracy, the line spacing, and the frequency of resurvey.

But up to now this basic task list has been based on the needs of the charting group.

Surveying for Coastal Engineering Purposes

For fairway maintenance tasks and development purposes, the Federal Waterways and Shipping Administration needs very accurate hydrodynamic and morphodynamic models. Especially the Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW) drives such models. The hydrographic data would be not sufficient for these purposes, if they had been collected only according to the requirements of the IHO Standards, i.e. the requirements of nautical charting.

One current project is aimed at the development of the Jade region. It is an important region because the harbour of Wilhelmshaven is to be developed for deep draught container vessels. The region to be surveyed is about 150 km², see Figure 4.

Especially morphodynamic models make high demands on accuracy which far exceed those described in the IHO Standards. The depth accuracy should be on the order of 1 cm referred to an equipotential surface, a requirement that cannot even be met in coastal waters. However, the requirement is that it should be as accurate as possible using state-of-the-art technology. This means that at least the tidal reduction has to be carried out using novel methods.

The coverage of the survey has to be 100 %. This does not make sense in very shallow waters. But it was decided to get 100 % coverage in all fairways and in as many other places as possible.

Last but not least, the survey was requested to be quasi-synoptic. In former times, surveys were usually carried out by different organisations, for different purposes, and according to different standards. The organisations involved decided to carry out their surveys every six years within the time span of one year in order to provide topographic data of different epochs for coastal engineering purposes. However, for the needs of the BAW and for their modelling purposes it was impossible to combine these surveys to a single model topography of sufficient quality. Therefore, they requested a data set from a single organisation. The survey time should be as short as possible, and processing should be done in one step. Only the topography of very shallow areas should be measured using a different method: airborne laser ranging.

The following table shows the different demands made on surveys:

	Survey for nautical purposes	for example order 1 of the IHO Standards (S-44)	Survey for modelling purposes
Horizontal accuracy	S-44	5m+5% of depth	as accurate as possible
Vertical accuracy	S-44	$[0{,}5m^2+(0{,}013*d)^2]^{1/2}$ d=depth	as accurate as possible
Coverage	may be required in selected areas	required in selected areas	100% coverage wherever possible
Duration of the survey	depending on the variability of the bottom		quasi-synoptic

Basic Decisions for the Jade Survey

Sensors

The echo sounders used in hydrographic surveying are mostly single-beam echo sounders. Multi-beam echo sounders are only used for special tasks.

As the survey to be carried out for modelling purposes required 100 % coverage, it was decided to use the survey vessel *KOMET*, see Figure 5. She is equipped with a high resolution shallow water multi-beam system FANSWEEP 20 from STN Atlas Marine Electronics, and has four launches, more than the other survey vessels. Therefore, it is possible to perform surveys within a relatively short period of time. Launch no. 4 is also equipped with a multi-beam echo-sounder FANSWEEP 15, which provides less accuracy and coverage. However, in shallow waters it makes sense to also use this echo sounder. The following table shows some product specifications:

	FANSWEEP 20	FANSWEEP 15
Coverage	12 times the vertical depth	4 times the vertical depth
Beams per sweep	up to 1440 beams	up to 600 beams
Operating frequency	200 kHz	200 kHz
Accuracy (6 times coverage only)	±(0.05 m + 0.2 % depth)	'better than required by IHO standards'

Most shallow water areas have been surveyed using single-beam echo sounders, model CTH from the German company Fahrentholz. In these regions it is almost impossible to achieve 100 % coverage in a reasonable amount of time. This echo sounder is installed in all four launches as well as in the ship itself. So it is very efficient to use them even when the line spacing chosen is very small.

The position has been determined using GPS. As maximum vertical accuracy was required, use of WEK was beyond question. The best method is GPS using phase corrections, precise DGPS or PDGPS. *KOMET* had already been fitted with a PDGPS receiver but the system has not yet been used in routine hydrographic surveying. This was due mainly to the missing link between chart datum and the GPS vertical reference surface, the ellipsoid. However, for modelling purposes, the soundings do not have to be referred to chart datum but to an equipotential surface. The launches had to be fitted with additional receivers. The receivers are type SR530 from Leica which provide 5 positions per second.

Two methods have been found for correction of the GPS phase data:

- Establishment of an own reference station, which has to be levelled into some vertical datum, and which has to be guarded during the survey
- Use of the reference stations provided by the land survey authorities

Figure 5: The 'KOMET'

The first method was too expensive compared to SAPOS. That is the reference system of the German land survey authorities ('Satellitenpositionierungs-Service'), which provide services on different levels. One level is the high precision real-time positioning service, HEPS ('Hochgenauer Echtzeit-Positionierungs-Service'). On this level one can get phase correction data in the format RTCM 2.3 type 20 and 21 [SAPOS HEPS]. The accuracy is specified to be about 1 to 5 cm. It is provided via FM (2 m band) and via mobile communication (GSM). The next reference station is located in Wilhelmshaven, see Figure 6.

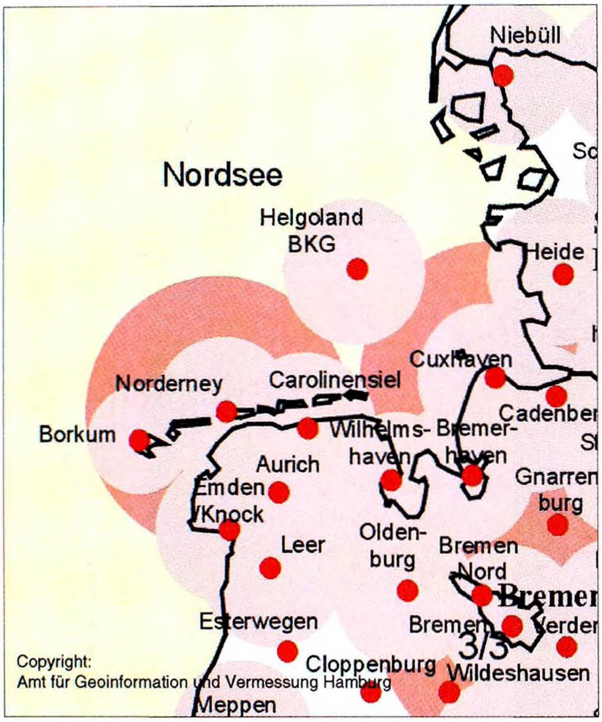

Figure 6: SAPOS reference stations at the German North Sea coast

The motions of the ship and launches are measured using a heave, roll and pitch sensor Dynabase made by STN Atlas. These sensors are necessary for the correction of multi-beam data from the ship and launch no. 4. However, these sensors are also installed in the other launches. It is still difficult to get reliable data from such sensors in small launches like this. Therefore, the sensors are not used routinely in all surveys, especially in the case of surveys in unsheltered areas outside the Jade area.

Reference System

The reference system depends on the positioning system used. Since lateral positioning as well as the reduction of soundings are done using DGPS measurements from SAPOS, the reference system is that of SAPOS, which is the European Terrestrial Reference System, ETRS89 [Differential GPS...].

The vertical reference surface used for modelling should be equipotential. This necessitates a transformation of the heights in order to obtain data for the reduction of the soundings. Normal-Null (NN) is the reference surface of the land survey authorities of the region, see Figure 7. It is almost an equipotential surface. In order to transform the soundings to depth referred to that surface the following steps have to be performed:

- Correction of the ellipsoid based GPS-heights to a quasigeoid
- Correction from the quasigeoid heights to NN
- Correction from the NN based antenna heights to echo sounder

The parameters required for this transformation have been derived from levelling points around the survey area, see Figure 8. The differences between the ETRS89 ellipsoid and the NN surface have been determined. It was to be expected that there existed no linear relation between these two surfaces. Therefore, the difference between the ellipsoid and the quasigeoid EGG97 had to be determined first [Denker, 1998]. From the rest the average was derived at 8 cm ± 1 cm.

The following table shows the heights of NN and the quasigeoid and the difference between these two surfaces:

Point	difference ellipsoid - NN [m]	difference ellipsoid - EGG97 [m]	Difference EGG97 - NN [m]
551	39,918	40,000	0,082
317	40,009	40,084	0,075
313	40,096	40,161	0,065
007	40,033	40,113	0,080
174	39,879	39,955	0,076
Mean			0,076 ± 0,006

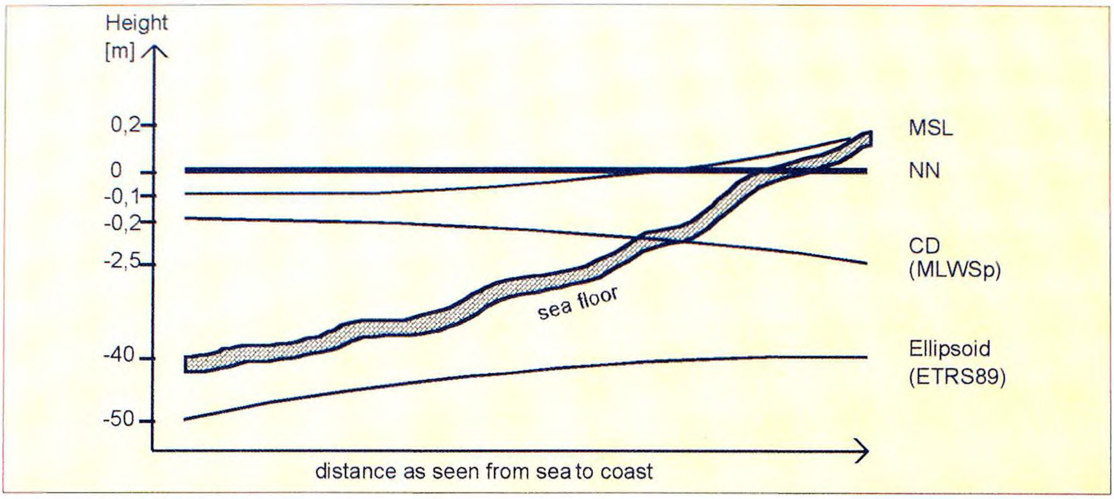

Figure 7: Vertical reference surfaces

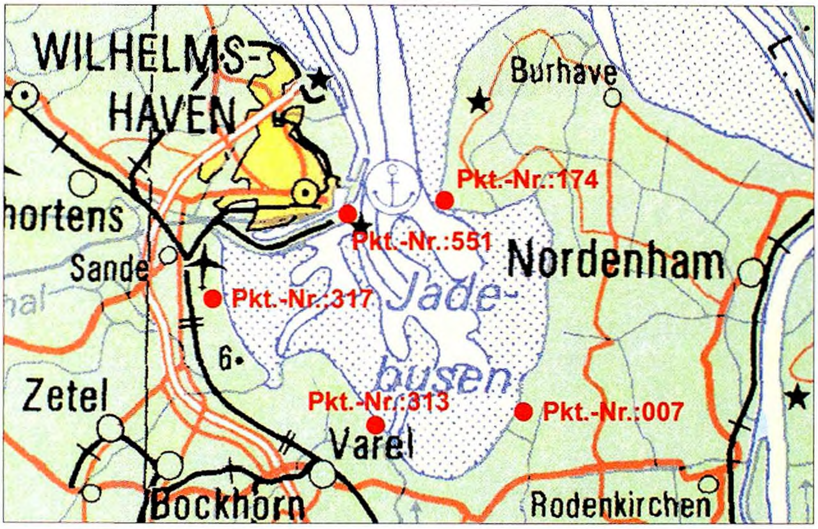

Figure 8: Levelling points for height reduction

So it was possible to reduce the soundings to NN. However, for navigational purposes it is necessary to provide depths with reference to chart datum. These values still have to be determined using the above mentioned WEK (co-tidal and co-range charts). We thus provided very different products from the same survey.

The Jade Project

The surveying project started in spring 2001. To reduce cost to an minimum level, it was decided to carry out the survey with the systems onboard of the vessel *KOMET* without buying any new technology for this project. Only the old GPS-receivers on board of the vessel and the 4 launches were exchanged for new ones which are able to receive the SAPOS-messages.

During summer there were made different kinds of tests with the GPS-rovers using the SAPOS-system:

- A long-distance test to check out the service area of SAPOS gave full access to the correction-signals of SAPOS all over the Jade region.
- Some tests for the accuracy of DGPS-signals were made with different results.
- The handshake between GPS-systems and the sounding-systems had to be programmed in a way that allowed to store the time-fixed positions and sounding results in a format for combined processing

The results of the tests gave a maximum reachable vertical accuracy of 5 to 8 cm for the observed ground-high over GRS80-ellpsoid.
From September to December 2001 the vessel *KOMET* and her 4 launches carried out the surveying of the Jade region. The soundings were made every day in a time window 2 hours before to 2 hours after high tide to reach the shallow waters. In very shallow areas the launches surveyed using only single beam echo sounders. The Distances between the lines were selected to survey the morphology of the ground in a most effective way. They changed from 100 m in very flat areas to 25 m in areas with high bottom variability.

The fairways were surveyed by vessel *KOMET* using multi beam echo sounding. 100% coverage was reached using a line space of 80 m.
The airborne laser-scanning was carried out in October 2001 during ebb-tide scanning the dry-fallen sea ground and the coastal area of the Jade region. This guarantees a large overlay zone to the echo soundings which is necessary for evaluation and the fusion of the different data-sets.

Interpretation

The results of the airborne laser-scanning were cleaned from major faults and processed. They were shifted to ETRS89 by using a 7 parameter transformation. This transformation-parameters were fixed on official surveying landmarks in the local area. The reduction to NN follows the way of the soundings described before. The points located in the vegetation or on water surface were cut out as far as possible.
The average vertical accuracy should be better than 5 cm.
The reduction of the single beam soundings on the surveying lines was made by picking up the most important points describing the morphology of the sea ground. Because there was no automatic filter to solve this task, it was a lot of manual work using the Hydromap offline software to reduce the 2700 Kilometer with average point space of 30 cm.
The multi beam soundings were processed with Hydromap Offline System from STN Atlas. The big faults were fixed and the last 10 beams on every sweep were cut out because of low reliability. Nevertheless a complete coverage was reached.
The SAPOS-corrected GPS-positions were collected 5 times per second on the launches. They were shifted from Leica data format to ASCII. For multi beam soundings the positions were collected only 1 time per second, as this is the maximum rate the Hydromap software can process.
The quality of the RTK-PDGPS-positioning was much worse than expected. There were a lot of cycle-slips in the fixed time lines. Using some self-programmed software-tools the data-sets were analysed. Most of the cycle-slips were when the launches turned to a new line, or were in high motion. Fortunately it was possible to determine an observed GPS-position for most of the reduced soundings. Only a few soundings needed to be fixed with interpolated positions, as there were no usable positions due to cycle-slips exceeding 20 cm.
The quality of GPS-positioning should improve on post-processing. For this, the RTK-solutions were the only ones that could be used.
The idea was to replace the heave-information from the motion-sensors with the high-frequency GPS-position, but roll and pitch must be observed to fix the position of the GPS-antenna relative to the sounders. Otherwise the motion of the antenna will decrease the quality of surveying.
The surveys were loaded to a DTM with varying resolution, to describe the morphology of the sea ground with high accuracy and allows to develop different products from the sea chart to an hydrodynamic model. The whole area was split in 16 parts to present the results in fair sheets at a scale of 1:5,000.

The Results

After processing the soundings and laser-scanning there were two independent DTM's surveyed in two different ways with many identical points in the overlaid areas. The comparison of this points is shown in Table 1.

Overall the offset of the two DTM's is 3 cm with a standard deviation of 8 cm. This is considerably better than from BSH and BAW expected. The large maximum errors in sheet JB07 can be attributed to a stray shot, which might be a point on a water surface in the laser-scanning model, perhaps a puddle.
In this project, it was the first time in Germany that sea surveying using conventional techniques were combined with airborne laser-scanning and PDGPS-based results with high quality for different usage.

Sheet	average error [m]	deviation [m]	max. - error [m]	max. + error [m]
JB06	-0.005	0.052	-0.144	0.224
JB10	-0.072	0.057	-0.274	0.066
JB16	0.053	0.059	-0.128	0.307
JB11	0.106	0.063	-0.122	0.454
JB14	0.072	0.070	-0.275	0.453
JB13	0.003	0.071	-0.239	0.341
JB04	0.091	0.073	-0.161	0.432
JB01	-0.059	0.082	-0.035	0.332
JB09	0.061	0.090	-0.220	0.612
JB02	0.033	0.093	-0.388	0.073
JB12	0.015	0.095	-0.276	0.763
JB05	0.047	0.096	-0.213	0.452
JB03	0.070	0.102	-0.355	0.810
JB07	0.012	0.110	-0.750	1.175
Mean	0.030	0.080	-0.256	0.464

Table 1: Comparison of the overlaid DTM's

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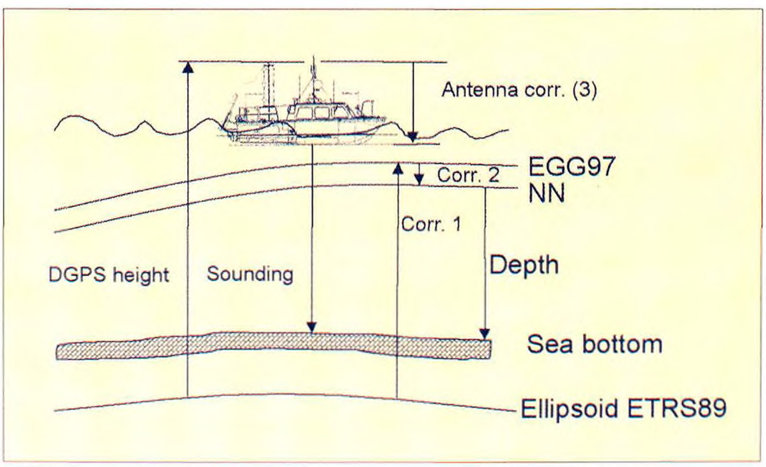

Figure 9: Corrections for obtaining depths referred to NN

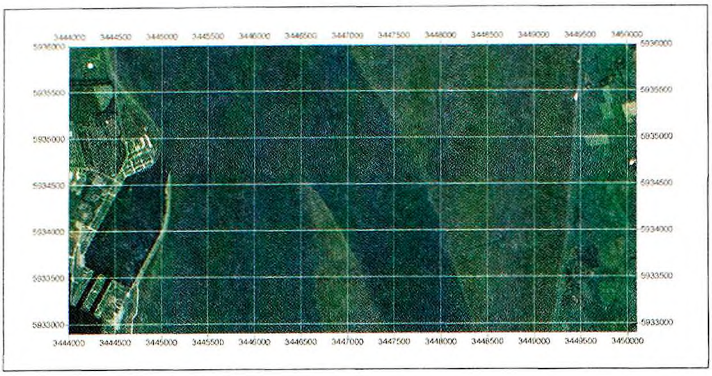

Figure 10: Various sea ground with shallow waters

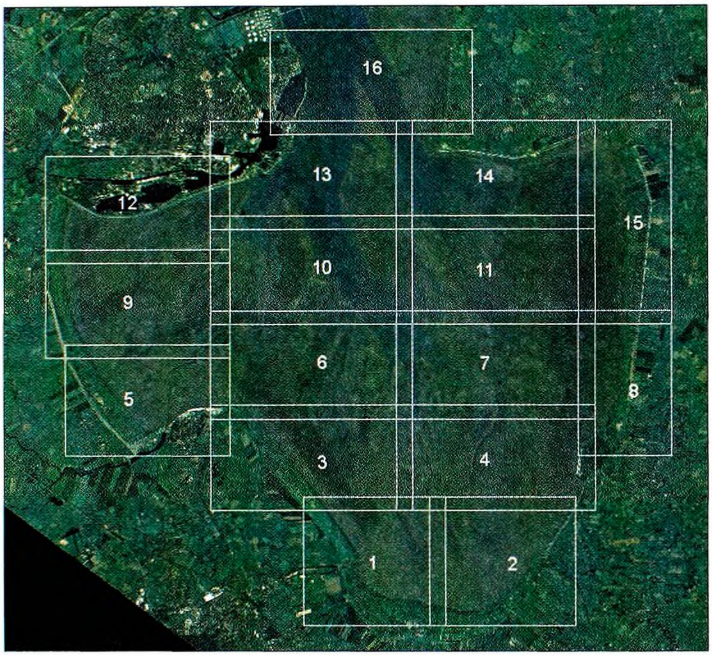

Figure 11: 16 fair sheets from the Jade

Biographies

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