Tidal Correction Using GPS - Determination of the Chart Datum

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Key words: Hydrographic surveying, chart datum, tide correction

SUMMARY

Tidal corrections in Germany are normally made using the "Wasserstandserrechnungskarte" (tidal correction chart), which is similar to the co-tidal co-range chart, and tide gauge measurement data. This method may produce major errors under unfavourable weather conditions.

The precision and reliability of tide corrections can be improved considerably by using PDGPS for height measurements. This method is independent of tide gauge readings and does not require a conversion of actual water levels at the tide gauge to the survey location. However, GPS measurements relate heights to an ellipsoid, according to the reference service used. They do not provide data relative to the chart datum, which is the information that is crucial to chart users.

This paper deals with a project of Bundesamt für Seeschifffahrt und Hydrographie, the Federal Maritime and Hydrographic Agency of Germany (BSH). The result of the project is a seamless chart datum surface referred to the ETRF89 ellipsoid, which is the same ellipsoid that is used by the German Satellitenpositionierungsdienst SAPOS. The surface is computed by using the results of numerical hydrodynamic models and a tide gauge levelling campaign.

ZUSAMMENFASSUNG

Üblicherweise wird die Gezeitenbeschickung mit Hilfe von Pegelablesungen und der Wasserstandserrechnungskarte durchgeführt. Gelegentlich führt dieses Verfahren jedoch zu erheblichen Fehlern, wenn die Wetterlage ungünstig ist.

Höhenmessungen mit Hilfe von PDGPS können zu deutlich genaueren und zuverlässigeren Beschickungswerten führen. Dadurch ist man unabhängig von Wasserstandsmessungen am Pegelort und der Übertragung der gemessenen Wasserstände auf den Lotungsort. Allerdings beziehen sich die GPS-Messungen auf ein Ellipsoid, je nach Korrekturdienst genutzt wird. Damit fehlt der Bezug zum Seekartennull, der für den Nutzer einer Seekarte unabdingbar ist.

Der Vortrag behandelt ein Projekt des deutschen Hydrographischen Dienstes, dem Bundesamt für Seeschifffahrt und Hydrographie. Das Ergebnis dieses Projektes ist eine Fläche, die das Seekartennull beschreibt, bezogen auf das Ellipsoid des ETRF89, das vom Deutschen Satellitenpositionierungsdienst SAPOS genutzt wird. Die Fläche wurde aus hydrodynamischen Modellen und Pegelnullpunktshöhen, bezogen auf ETRF89 bestimmt.

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1. THE TRADITIONAL WAY OF TIDE CORRECTION

Hydrographic surveying in Germany covers two fundamentally different sea areas, the North Sea and the Baltic Sea, cf. Fig. 1:

- The North Sea is a tidally influenced area. The region close to the coast is very shallow and is characterized by heavy tidal currents. This leads to very frequent changes in its topography, which requires resurveying at intervals from one year to three years, as a minimum. Only sea areas farther from the islands are more stable due to their depths of up to 60 m, which allows larger resurveying intervals.
- The Baltic Sea is almost free of tides, with a tidal height of less than 30 cm on the German coasts. Currents are less intense, and the topography of the sea bottom thus changes much more slowly. Nevertheless, to reduce accident risks, HELCOM decided to resurvey the main shipping routes regularly. The IHO Baltic Sea Hydrographic Commission agreed to carry out the resurvey according to S-44 order I.

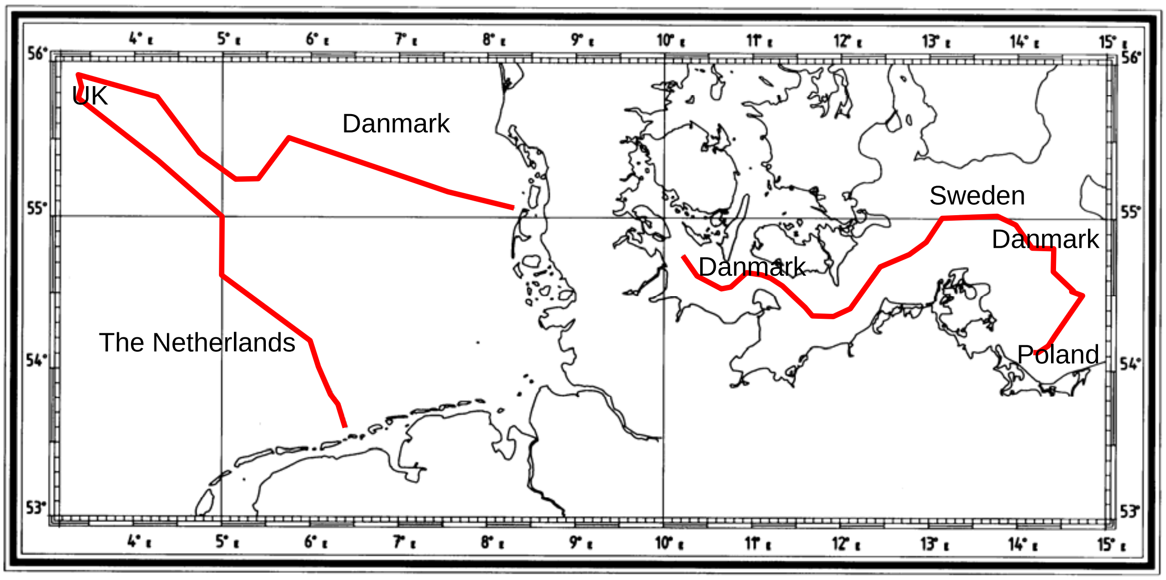

Fig. 1: The area covered by German hydrographic surveying

Tide corrections have been made traditionally on the basis of tide gauge readings taken at the gauge station that is most representative of the particular area surveyed. The method used by Bundesamt für Seeschifffahrt und Hydrographie (BSH) combines the position, the sounding, and the tide correction in a post processing step, cf. Fig. 2. After post-processing, the contour lines are developed and the analogue and digital products are derived.

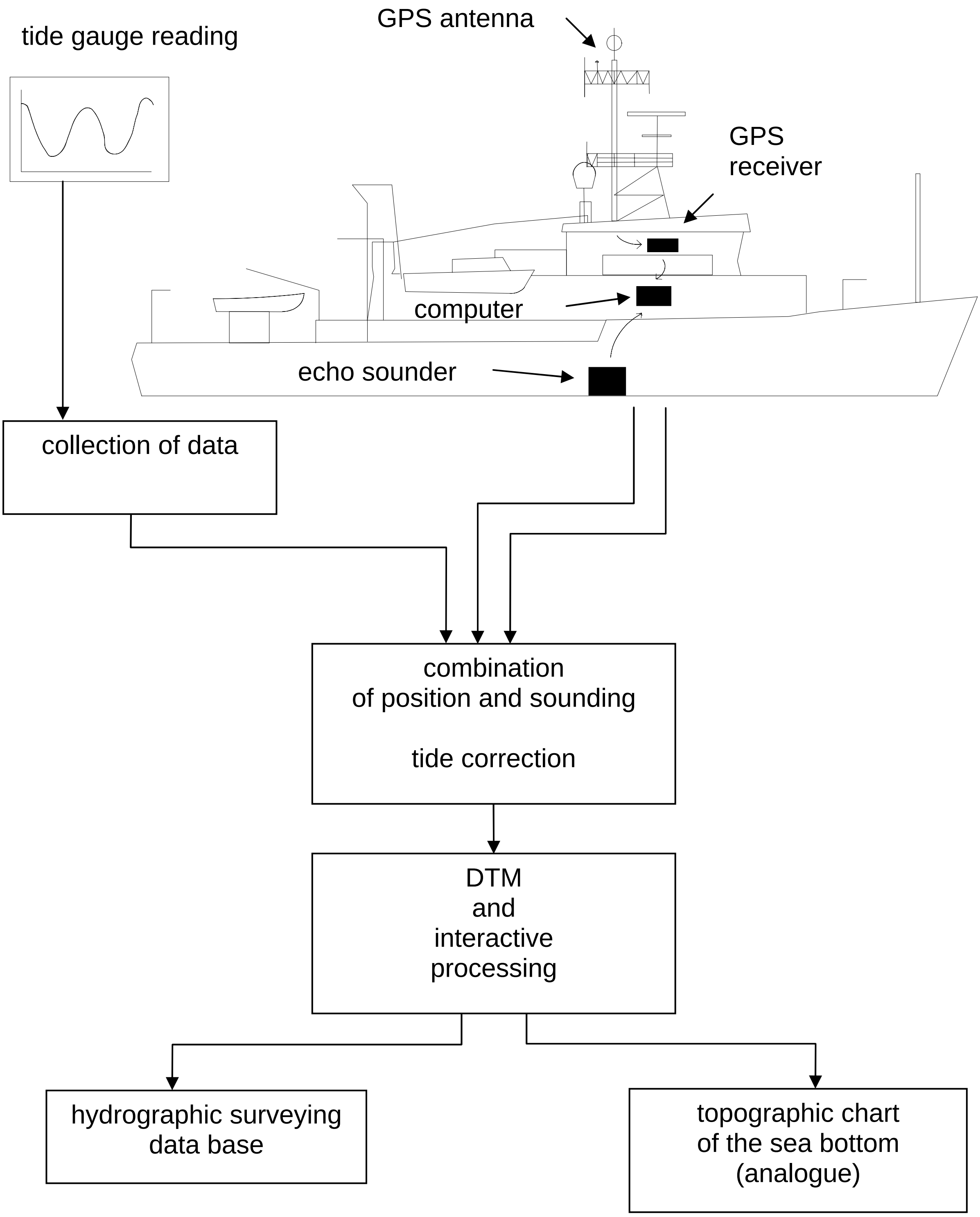

Fig. 2: Processing of the data

The tide correction is carried out using the so-called "Wasserstandserrechnungskarte (WEK)" (tidal correction chart), cf. Fig 3. It is similar to the co-tidal co-range chart. Two values are obtained for each sounding location:

- The time interval between the location of sounding and the tide gauge: this interval indicates the time it takes the tidal wave to travel between these two locations.
- The difference of the tidal range at the two locations: if the tidal range at the location of the sounding is greater than that at the location of the tide gauge, the height of the tide has to be increased proportionally.

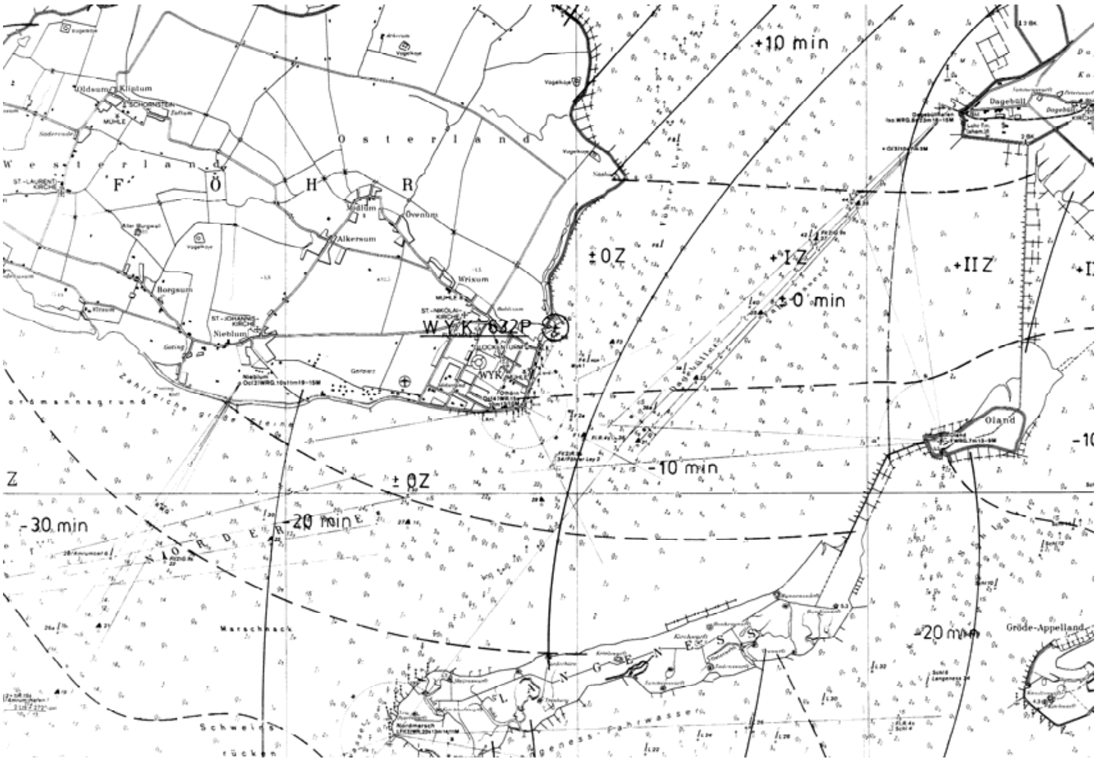

Fig. 3: Wasserstandserrechnungskarte

The advantage of this method is that there are tide gauges throughout the German Bight, and a "Wasserstandserrechnungskarte" exists for each of these tide gauges. This means that the method is suitable for use in the entire area under German authority, i.e. the inland waters, the coastal waters, and the Exclusive Economic Zone.

But there are some important disadvantages:

- Each WEK applies only to the area around a single tide gauge, i.e. in a larger survey area it is necessary to use several WEK.
- The accuracy of this method is limited. The WEK is derived from the basic data, tidal range, and high water interval at several points. A major effort is required to obtain these data, with pressure gauges deployed for at least half a year. Consequently, only few points exist for which such basic data are available and from which a WEK can be

derived. Besides, a sufficient number of tide gauges to increase the accuracy of this method is not available either.
- The reliability of the tide corrections is limited as well. Some systematic errors occur especially when weather conditions change. For example, changes in the wind direction may trigger changes in the travel time of the tidal wave.

In rare cases, soundings of neighbouring survey profiles have been observed to differ by more than 50 cm, even in absolutely flat areas. When conditions are good, the accuracy of this method leads to standard deviations of about 10 to 20 cm.

2. TIDE CORRECTION USING GNSS

In order to improve the accuracy of tide corrections, some developments have been pursued over several years. The basic idea is to use GPS measurements exclusively, not only to locate the sounding but also the height, i.e. to use GPS for tidal reduction. However, two measurements have to be considered which have very different characteristics, cf. Fig. 4:
- The sounding indicates the distance between the sea bottom and the transducer of the echo sounder. Hence the sounding is dependent on the current water level and, particularly, the tide and sea state.
- The GNSS height indicates the distance between the antenna and the centre of the gravity of the Earth, which can be transformed easily into the distance between the antenna and the ellipsoid, which is normally given by the reference system of the differential GNSS used. For example, when the "Satellitenpositionierungsdienst" (SAPOS) of the German State Survey is used, the ellipsoid is that of ETRF89.

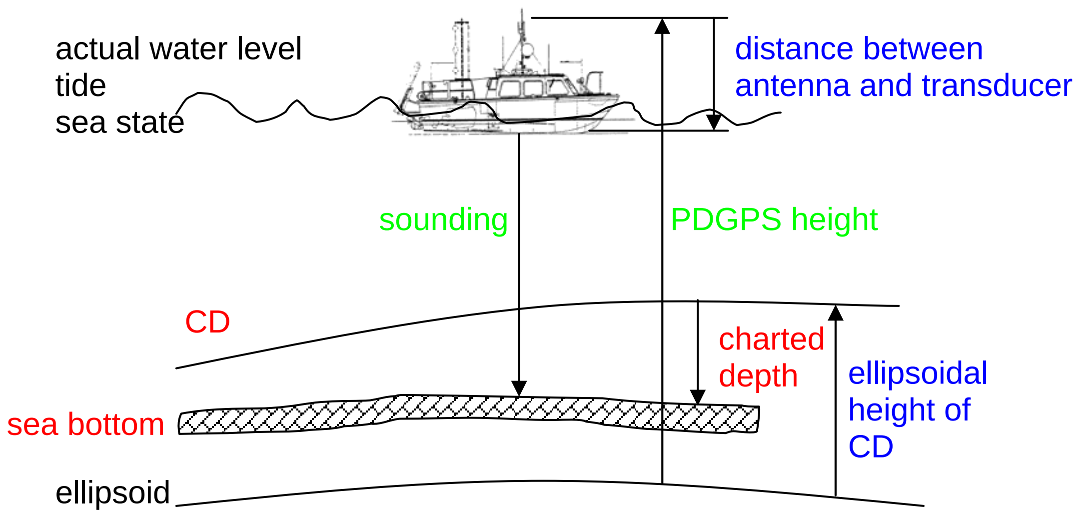

Fig. 4: Quantities to be considered when GNSS is used for tide correction

These measurements have to be connected by
- the antenna correction, which is a purely geometric quantity;

- the height of the chart datum referred to the ellipsoid; this height is comparable to geoid heights in that it constitutes a connection between a geometrical surface - the ellipsoid - and the chart datum, which is a tidal dependent surface.

Thus, two tasks had to be solved to make tide corrections using GNSS:
- firstly, the development of a chart datum surface referred to the ellipsoid, and
- secondly, the production of GNSS height data with at least decimeter accuracy.

The second task is difficult because up to now GPS measurements have been made using code measurements which provide position data with an accuracy of less than one metre. To obtain decimeter accuracy, it is necessary to use phase observations.

3. REALISATION OF THE CHART DATUM

As has been pointed out above, two different chart datums are used in the German waters.

The tidal range in the German Baltic Sea coastal waters is less than 30 cm. Therefore, the chart datum used is the mean sea level linked to the land survey datum. Recently the German State Survey presented a German Combined Geoid 2005 (GCG05). The GCG05 gives the difference between the ellipsoid ETRF89, used by SAPOS, and the new height datum "Normalhöhennull" (NHN) related to normal heights. Its actual version covers land areas only, cf. Fig. 5. This is a disadvantage for surveys but there is much effort to extend the geoid also to sea areas.

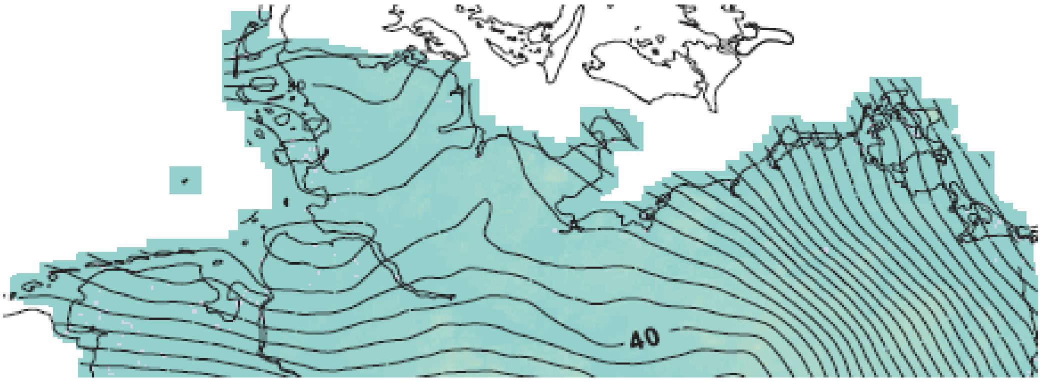

Fig. 5: The area currently covered by the German Combined Geoid 2005 (GCG05)

As the North Sea is under influence of a larger tidal range, the chart datum is defined there by minimal tidal values. Up to January 2005 the Mean Low Water Springs (MLWS) was still in use on German coasts. This datum has been recently referred to the Lowest Astronomical Tide (LAT), now recognized by all adjacent countries and by the IHO. The LAT is about half a meter lower than MLWS.

In order to determine the chart datum surface, a project was initiated in 2002 by the German Hydrographic Office (BSH) and is now practically achieved. The aim was to determine both seamless LAT and MLWS surfaces referred to the ETRF89 ellipsoid used by SAPOS.

The input data are:

- ellipsoidal heights measurements of a GPS levelling campaign at about 140 tide gauges all over the German North Sea coast and in rivers under tidal influence. For each tide gauge the height of the chart datum was determined above the ellipsoid. This was necessary to fit absolutely the zero of the corrected tidal model into the chosen reference system, here the ETRF89,
- tidal values computed at these stations using water level observations,
- the heights of the quasigeoid EGG97 used as preliminary reference surface for mean sea level determination,
- results of a tidal analysis at 32000 nodes of a finite element model delivered by the Federal Waterways Engineering and Research Institute (BAW) for the area of the German Bight. The tidal values have been computed at each node using one year hourly tidal simulation. cf. Fig. 6.

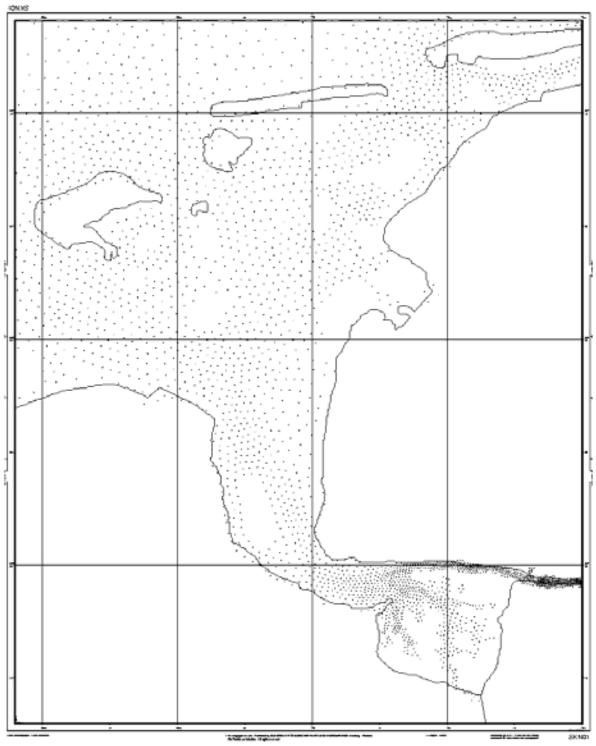

Fig. 6: Part of the finite element model of BAW

Fig. 7 shows the chart datum heights in a section of the German coast.

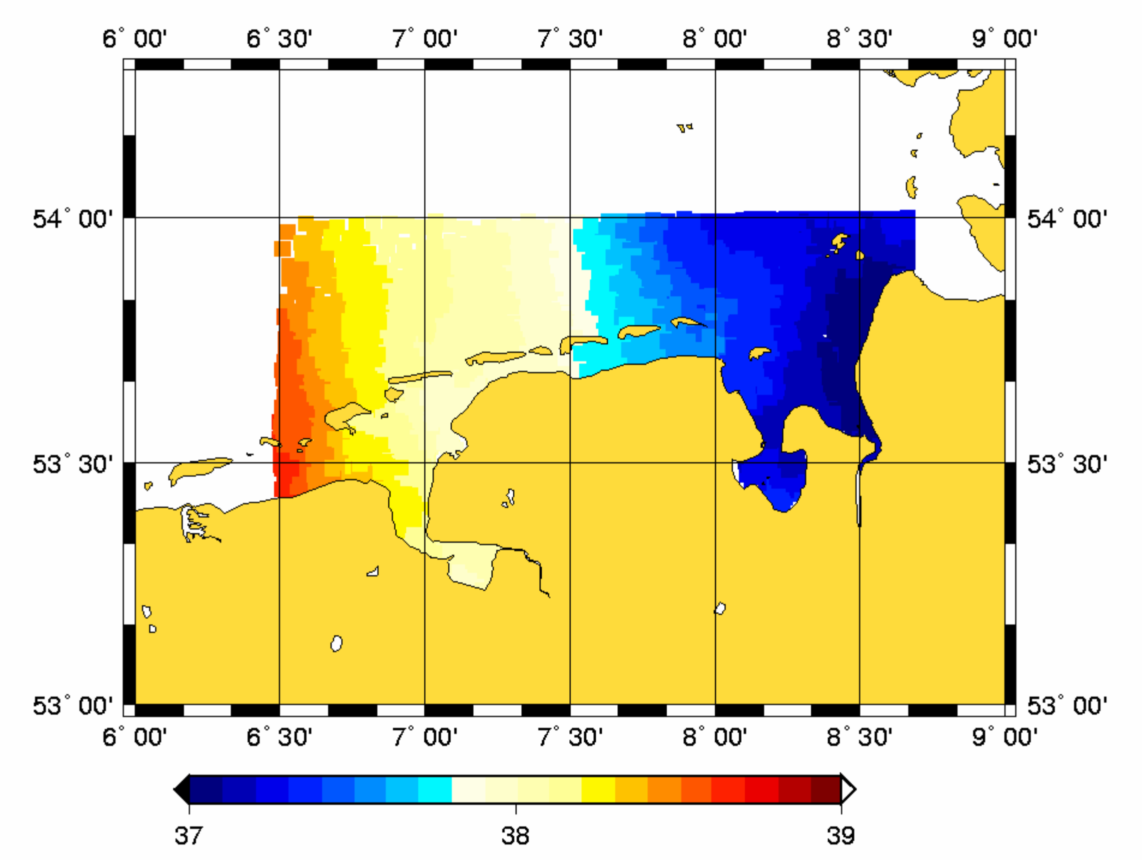

Fig. 7 Chart datum heights above the ETRF89 ellipsoid on the East Frisian coast.

4. USE OF GPS CORRECTION DATA

Three different methods are available to obtain data for the correction of precise differential GPS (PDGPS) measurements using phase observations:

- SAPOS high-precision real-time service distributed by 2 m band transmission
- SAPOS high-precision real-time service distributed by cellular phone (GSM)
- correction data distributed from a special reference station provided by the user.

Fig. 8 shows the positions of reference stations of the German State Survey's "Satellitenpositionierungsdienst" (SAPOS) . Each point represents a reference station of this service. The small circles show the approximate coverage of each 2 m band transmission. Meanwhile, also the station Pellworm is transmitting data on the 2 m band.

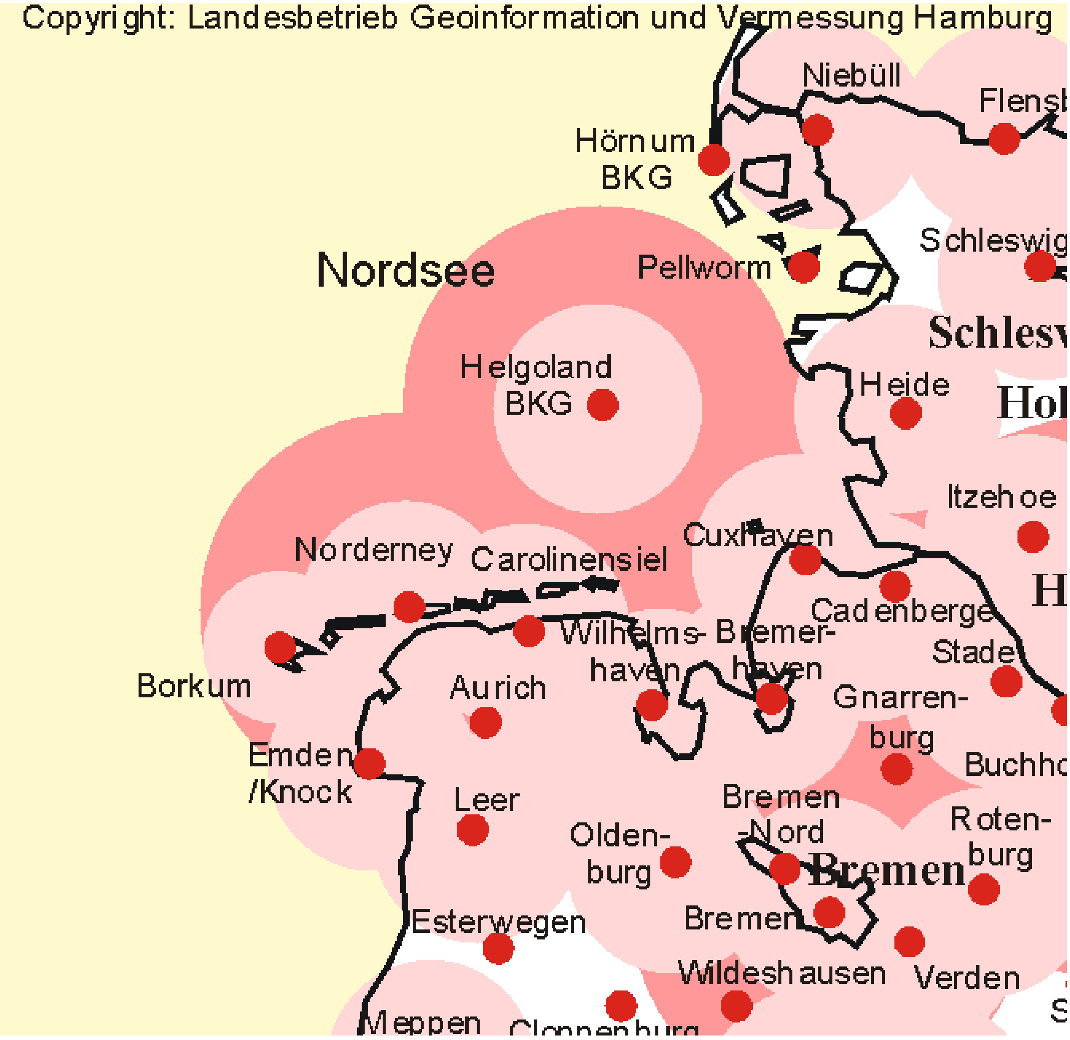

Fig. 8: Positions of reference stations of the "Satellitenpositionierungsdienst"

Transmission of data on the 2 m band is the most economic way of receiving GPS correction data. Only the data as such have to be paid. The reception of the data is free of charge . So this should be the method of choice.

Data reception by cellular phone (GSM) involves extra charges for the phone, in addition to the charges for the SAPOS data. It is expected that the coverage will not be much better than that of the 2 m band, cf. Fig. 8. It may be possible, though, that there are some places where phone coverage exists but 2 m coverage does not. In such places, the data should be received preferably by phone.

Own reference stations should only be established at locations where the reception of SAPOS data is impossible, provided that a suitable place can be found for the establishment of the station and determination of its position data . The disadvantage is that a survey group has to be sent to that place, often an island. The reference station may have to be supplied with electric power, and it may have to be guarded.

In all of these cases, the coverage will be limited to a region close to the coast because the reference station has to be located in a stable place and the distance between the reference station and the mobile is limited. SAPOS offers a service called "Flächenkorrekturparameter" (FKP), which gives two parameters for each point between three reference stations, one for latitude and one for longitude. Based on these parameters, the mobile station calculates an interpolation of the GPS corrections of the three stations. This makes it possible to solve phase ambiguities at greater distances from reference stations. We hope that ambiguities in the region between the coast and Heligoland can be solved in this way. .

5. FIRST EXPERIENCE

First trials testing the use of GPS measurements in tidal corrections of soundings were carried out at two sites.

In early 2006, the survey vessel CAPELLA operated in the Fehmarnsund waters between Schleswig-Holstein and the island of Fehmarn, cf. Fig. 9. As this region is part of the Baltic Sea, the tide correction could be referred to mean sea level, i.e. the quasigeoid GCG05 was used. That was no problem because the survey area was very close to the coast.

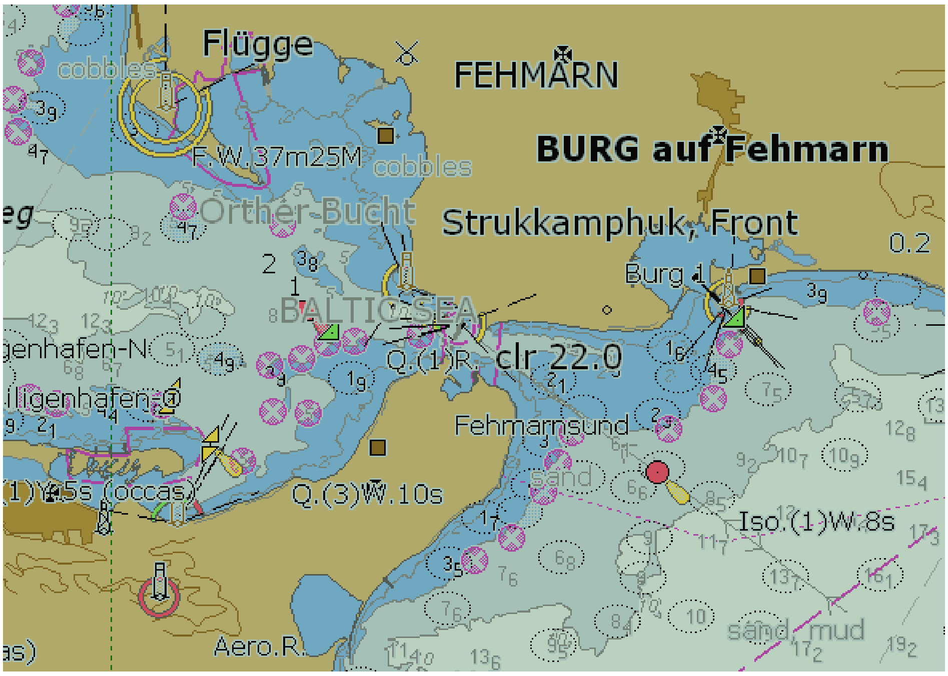

Fig. 9: The Fehmarnsund survey area

No SAPOS signal was received in this area, the area was not covered by 2 m band, and there were no facilities for GSM phone reception. Therefore, we established our own reference station at the Flügge lighthouse, at a height of 39 m. The correction signal was transmitted on the 70 cm band. Phase ambiguities were solved at a distance of 15 NM on board CAPELLA, and at a distance of 8 NM on the launch, cf. Fig 10. Some problems arose while turning the launch at the end of a survey profile. With good weather conditions, the difference between GPS derived tide corrections and those derived from tide gauge observations typically was about 2 dm. However, some unacceptable differences of up to 9 dm were observed as well, which are in need of clarification. Another problem occurred when errors arose due to loss of the ambiguity solution. There was no warning because information about the loss of the solution came too late. In future, the monitoring software will be changed to the NMEA telegram GGQ. This telegram provides a 3D quality information which can be observed, and an alarm is triggered upon reaching a certain value.

Fig. 10: Survey vessel CAPELLA and the antenna position on her launch.

Another trial was started a short time ago in the area of North Frisia, also using CAPELLA, cf. Fig. 11. A SAPOS reference station was established recently on the island of Pellworm. This station just started transmitting signals on the 2 m band. However, due to an as yet unsolved problem, it is impossible presently to solve ambiguities at a distance of 3 NM. On the other hand, no problems were encountered at a distance of more than 10 NM with a reference station of our own on Amrum .

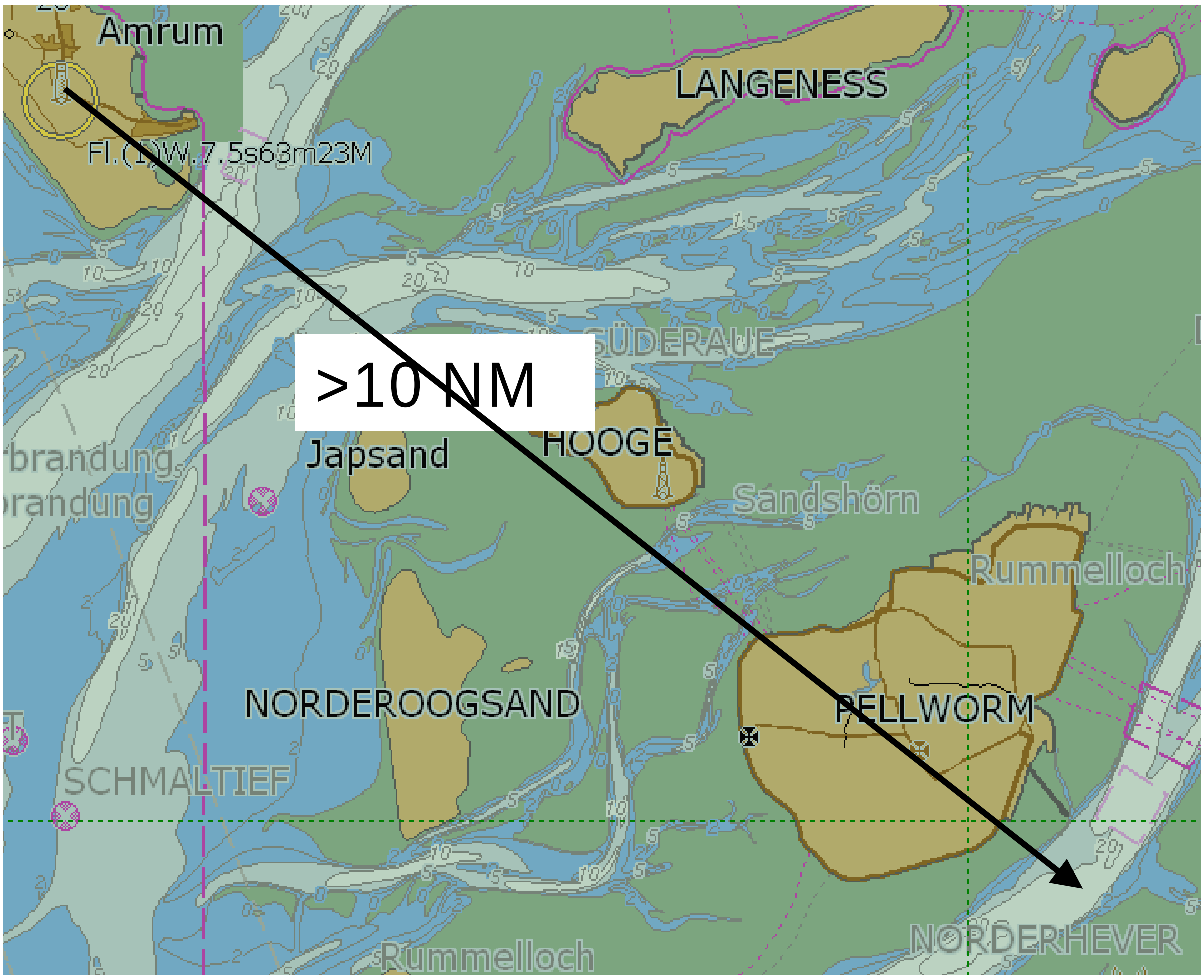

Fig. 11: The North Frisian survey area

6. CONCLUSIONS

The basic problems of tide correction using GPS have already been solved:

- There exists a seamless chart datum surface above the ETRF89 ellipsoid
- Means to receive correction signals for GPS phase measurements (PDGPS) are available.

However, some detail problems remain to be solved. In particular, difficulties have been encountered in solving the phase ambiguities at a larger distance from the reference station. In hydrographic surveying, this is important because many of the survey areas are far from the coast. Besides, there have been some discrepancies while processing the survey data, which will have to be investigated . Nevertheless, the first experience looks promising.

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Information about the "Satellitenpositionierungsdienst" (SAPOS) of the German State Survey can be obtained at http://www.sapos.de/

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