GNSS Based Hydrographic Surveying: clear advantages and hidden obstacles

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Abstract:
To fulfill its task of publishing accurate and up-to-date nautical charts, the Hydrographic Service of the Royal Netherlands Navy employs two survey vessels worldwide: HNLMS Snellius and Luymes. In 2013, these vessels have been fitted with new Trimble DGNSS receivers in combination with the Fugro Marinestar SBAS service. The advantages are clear: accurate, reliable, and highly available 3D positioning in a realization of the International Terrestrial Reference System (ITRS), wherever the civilian and military hydrographic duties of the moment take place.

As is widely discussed in literature, the advantages are especially prominent for vertical referencing of the vessel, and thereby for the measured depth values. The signal contains several corrections: water level, heave, draught, and squat, fully independent of the traditional sensors. This redundancy provides opportunities for quality control, efficiency improvement, and easy deployment out-of-area. Moreover, vertical referencing directly to the GRS80 ellipsoid of ITRS enables innovative data processing and storage independent of any realization of a tidal datum. This results in less ambiguous references, in historical and international contexts.

Yet, there are some obstacles to usage for vertical referencing. They only appear after closer examination of the system. We will present the main obstacles that we found. We believe these are universal, and cause the limited operational use of ellipsoidally referenced surveying.
The obstacles that have to be overcome are:
1. The vertical uncertainty of DGNSS systems in combination with a commercial SBAS is still rather large in relation to the IHO S-44 guidelines for survey uncertainty in shallow water. The higher the contribution of the vertical referencing component to the error budget, the lower the allowed uncertainties for other sensors are, translating into a smaller swath width of the multibeam echo sounder and eventually into more parallel survey tracks to fully ensonify an area.
2. Separation models between the ellipsoid and the required vertical datum (LAT, MSL, the geoid, or another chart datum) are still under development, mostly on the national level. As a consequence, there is no basin-wide standard, and uncertainties are strongly variable among and within separation models.
3. The implementation details of separation models in GNSS receivers are unclear and sometimes erroneous. This forces hydrographic offices to work with ellipsoidally referenced data until further into the processing chain. Although this is no disadvantage in itself, it hinders the gradual introduction of GNSS-based vertical referencing.
4. Although the SBAS signal may be highly available, the GNSS signals are weak, i.e. prone to be disturbed. Signal loss could happen due to common operations, like interference with communication devices.
5. In case the SBAS signal does get lost, the GNSS receiver switches to differential mode, introducing a change in horizontal reference frame to ETRS89 (for Europe). This implies an apparent shift in the ship track of about 60cm for the Southern North Sea.

Based on these obstacles, we conclude that GNSS-based hydrographic surveying is a valuable additional tool, rather than a single system that would replace current sensors and procedures.

BIOGRAPHIES

Thijs Ligteringen is a Dutch Geodetic Engineer from the Delft University of Technology. He joined the Ministry of Defence as a navigation consultant. Curently, he is employed within the Department of Geodesy & Tides at the Netherlands Hydrographic Service. His main interests are navigation systems and the Law of the Sea (UNCLOS).

John Loog is a Cat. A Hydrographic Surveyor with a special interest in navigation technology. He currently is Head of Plans & Operations at the Netherlands Hydrographic Service. His past assignments include commanding officer of HNLMS Snellius and project officer at Skydec. John holds an MSc from Nottingham University in Navigation Technology.

Leendert Dorst just started as Deputy Hydrographer of the Royal Netherlands Navy. Until recently, he was Head of the Geodesy & Tides department. He earned his MSc degree in Geodetic Engineering from Delft University of Technology, and his PhD in Water Engineering & Management from the University of Twente. Leendert is an editor for Hydro International. His areas of expertise are maritime boundary delimitation processes, horizontal and vertical references at sea, methods for accurate water level forecasting, and the dynamics of rhythmic seabed patterns.

1 INTRODUCTION

To fulfill its task of publishing accurate and up-to-date nautical charts, the Hydrographic Service of the Royal Netherlands Navy employs two survey vessels worldwide: HNLMS Snellius and Luymes. In 2013, these vessels have been fitted with new Trimble DGNSS receivers in combination with the Fugro Marinestar SBAS service. The advantages are clear: accurate, reliable, and highly available 3D positioning in a realization of the International Terrestrial Reference System (ITRS), wherever the civilian and military hydrographic duties of the moment take place.

For years the vertical solution of GPS, and differential GPS was not accurate enough to be used for vertical calculations in hydrographic appliances (Brouwer, 2009). An exemption was using Real Time Kinematic (RTK) techniques; this gave a good horizontal and vertical solution up to centimeter accuracy. However further away from shore, RTK is not available because of the reception of the base station is limited to the line of sight.
In hydrography, historically the calculations on vertical and horizontal (positioning) solutions have always been separated. The horizontal positioning solution referred to a horizontal datum and the vertical referred to a vertical datum initially based on Mean Sea Level. With the introduction of Fugro Marinestar SBAS services in the Hydrographic Service of the Royal Netherlands Navy a range of applications became available, referred to a vertical datum based on the GRS ellipsoid (FIG Commission 4, 2006; Dodd & Mills, 2012). Although SBAS is not providing cm accuracy (yet?), the dm accuracy that is available is a big improvement on the DGPS solutions used until then.

As is widely discussed in literature (FIG Commission 4, 2006; NSHC Tidal Working Group, 2010; Strykowski et al., 2011; Dodd & Mills, 2012; Slobbe, 2013), the advantages are especially prominent for vertical referencing of the vessel, and thereby for the measured depth values. The signal contains several corrections: water level, heave, draught, and squat, fully independent of the traditional sensors. This redundancy provides opportunities for quality control, efficiency improvement, and easy deployment out-of-area. Moreover, vertical referencing directly to the GRS80 ellipsoid of ITRS enables innovative data processing and storage independent of any realization of a tidal datum. This results in less ambiguous references, in historical and international contexts.

Before we started we did several trials with borrowed GNSS transmitters from the Netherlands Ministry of Transport and the Marinestar SBAS signal from Fugro. The purpose of these trials was to get some experience with these new techniques and to see what practical challenges had to be overcome when integrating the SBAS techniques on the RNLN survey ships.

The project started with static tests on the roof the defense barracks in Den Hague. After that we took the GNSS receiver to HNLMS Snellius for tests on board. The SBAS signal supported both GPS and GLONASS.

2 OBSERVATIONS

2.1 Static tests

As a preparation for on board tests and for getting acquainted with the GNSS equipment measurements were done in The Hague at the reference point of the Hydrographic Service.

Marinestar measurements were compared to plain GPS measurements and NETPOS measurements. NETPOS is an RTK network operated by Kadaster in the Netherlands. Marinestar is a Global SBAS service with different service levels operated by Fugro.
The static time series are not simultaneous.

The results of the comparison between NETPOS and Marinestar for the 2-dimensional situation are displayed in figure 1.

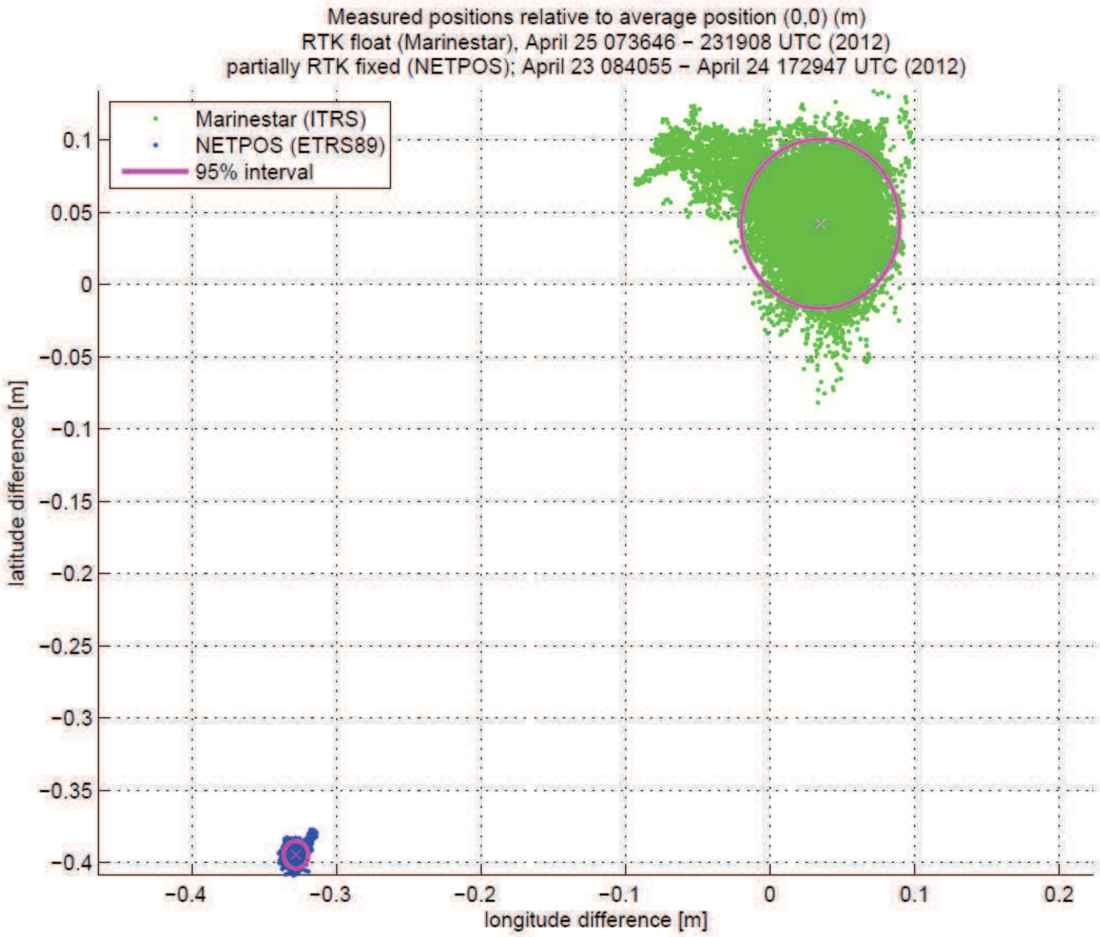

Figure 1: Measured positions relative to average position, comparison between NETPOS and Marinestar results

The figure shows a high accuracy for Marinestar and an even higher accuracy for NETPOS. Another interesting observation in this figure, is the fact that the origins of the error ellipses do not have the same center: this results from the fact that NETPOS uses ETRS89 as the geodetic datum, whereas Marinestar uses ITRS.

The 3-dimensional case in figure 2 shows the difference in horizontal and vertical accuracy. As expected the spreading of height are twice the spreading in the horizontal. The SBAS shows more noise effects that cannot be explained.

During the tests the GNSS receiver was easy to handle with a very user friendly web page controller.

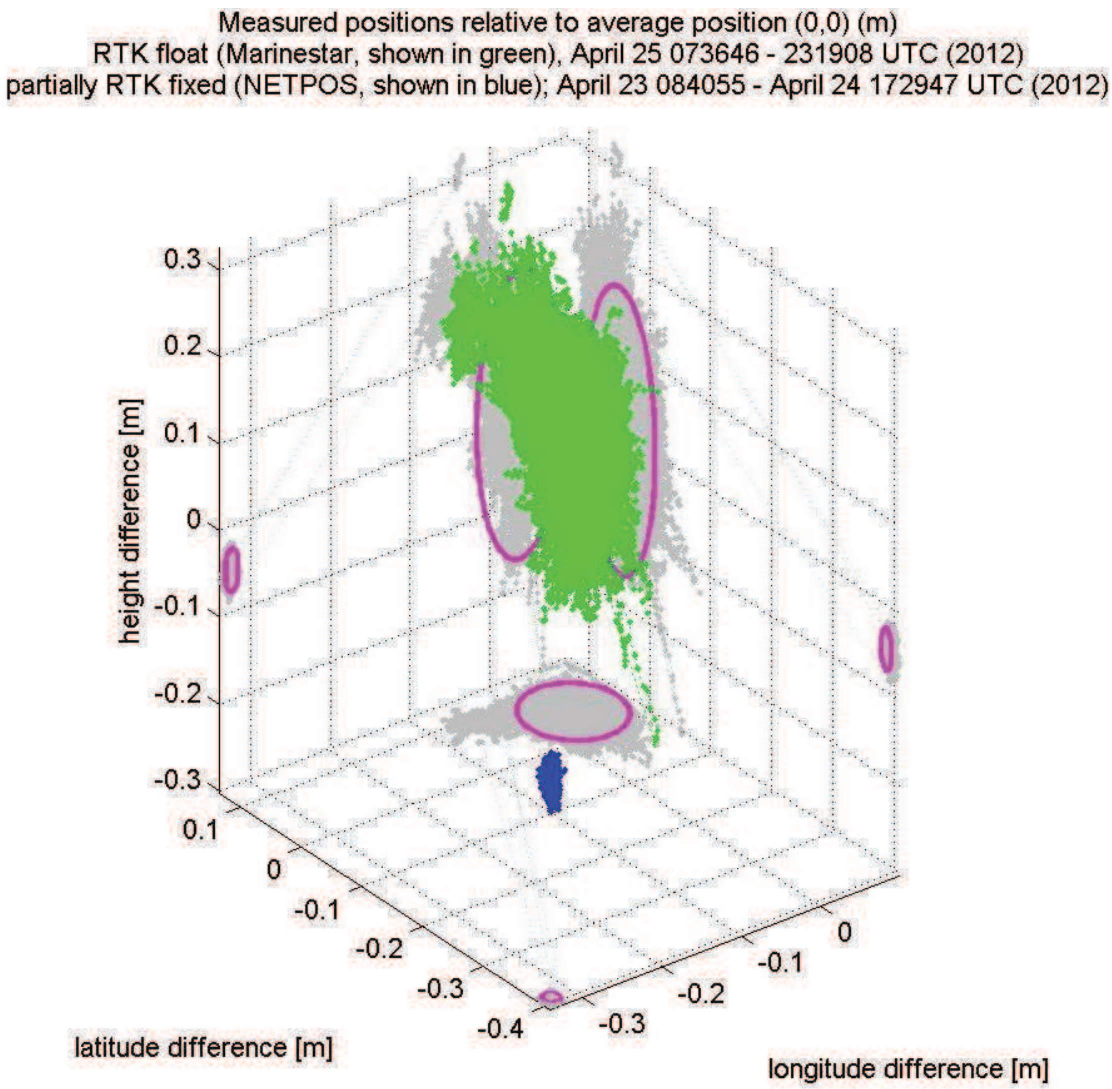

Figure 2: Differences in horizontal and vertical accuracy for NETPOS and Marinestar measurements

2.2 Dynamic tests

In May 2012, a dynamic test with Marinestar was carried out on HNLMS Snellius one of the Royal Netherlands Navy survey ships. Position loggings were done against the GPS system that was regularly used at that time.
The GPS GGA datastring was logged. This contains: date, time, position North and East in ETRS89, GPS mode, number of satellites, HDOP, height above geoid, height of geoid above ellipsoid.

Measurements on board were done during a period of circa 7 days. During this period, the vessel spent 2 days in the harbour of Den Helder and the rest of the time in different survey areas on the North Sea. The tracks that were sailed are displayed in figure 3. The measurements can be divided in four major parts: two days in Den Helder harbour, several hours in survey area 1, one and a half day in survey area 2, and three days in survey area 3. These numbers are displayed in figure 3 as well.

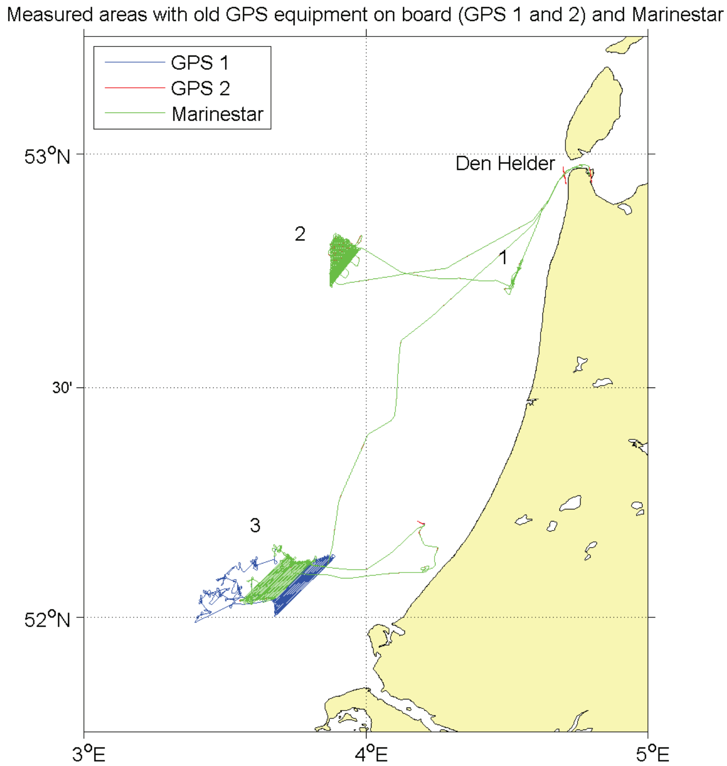

Figure 3: Tracks on the North Sea where Marinestar was tested against current GPS on board.

Availability of Marinestar during the survey was excellent. This is visualised in figure 4.

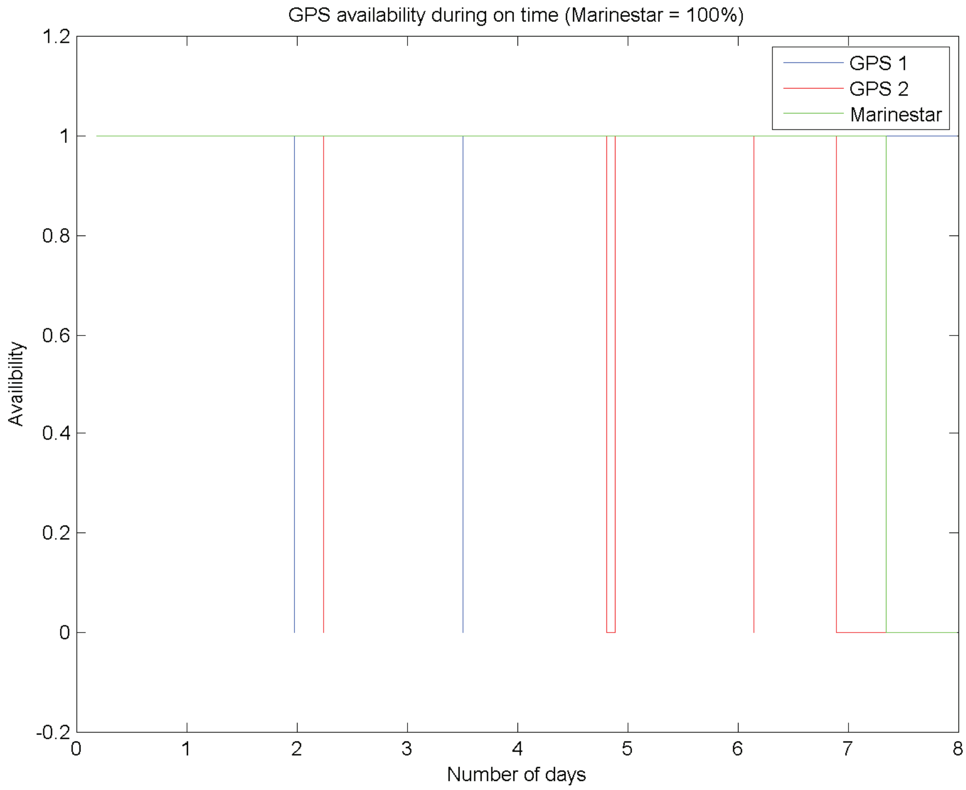

Figure 4: Availability of Marinestar during surveys

The height of the EGM1996 geoid with respect to the ellipsoid is displayed in figure 5. On the horizontal axis, time is displayed (in days), on the vertical axis the height of the geoid with respect to the ellipsoid. The figure shows a clear shift between the two survey areas. This shows the difference in geoid height that exists between the survey areas that were visited. The small noise on the signal is caused by geoid height differences between the two edges of the survey areas.

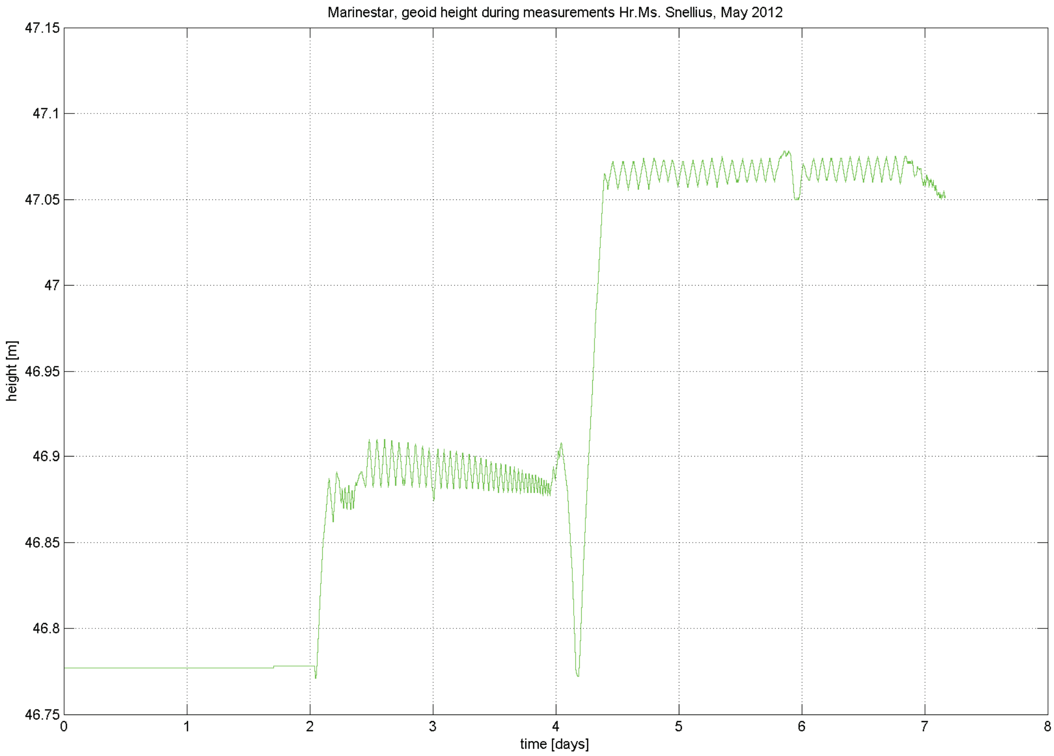

Figure 5: Geoid height during Marinestar measurements.

Figure 6 shows the height of the GPS antenna with respect to the ellipsoid during the measurements.

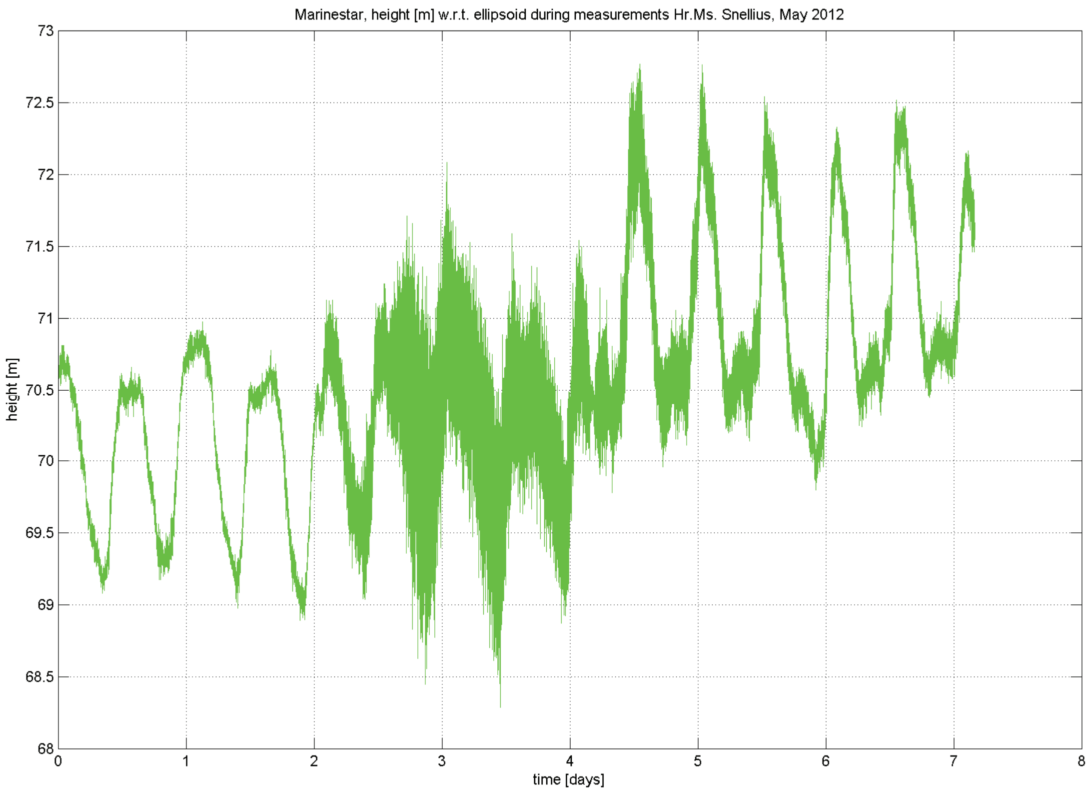

Figure 6: Height with respect to the ellipsoid.

Figure 7 shows the height with respect to the geoid. This is the most interesting graph for hydrographic surveying.

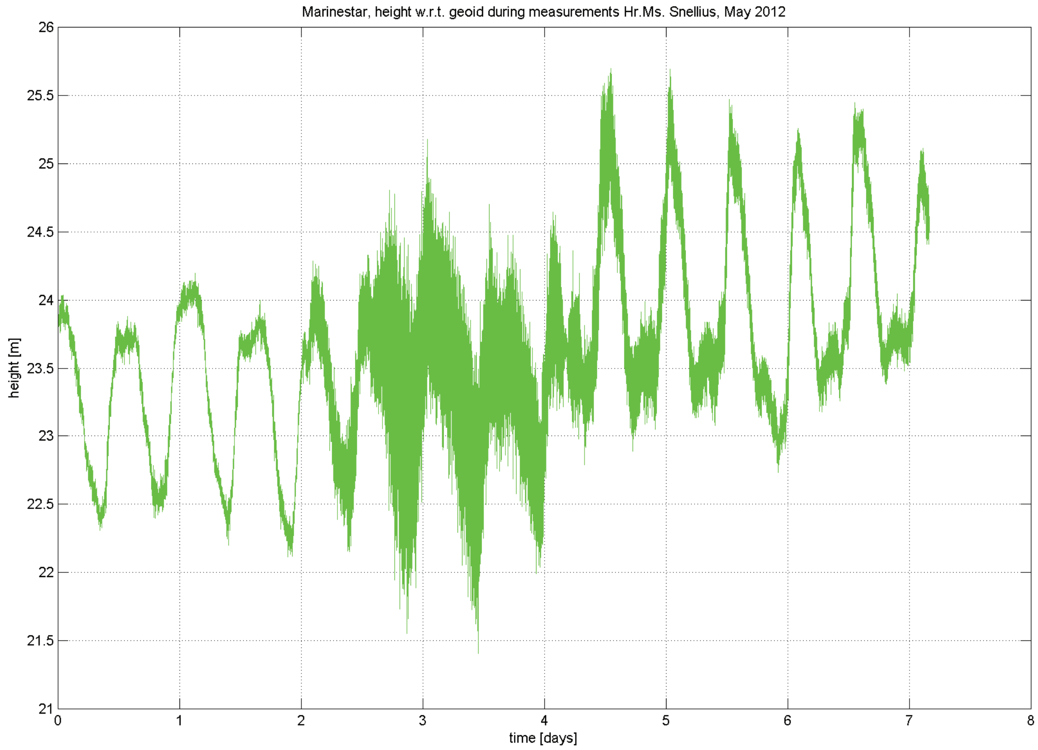

Figure 7: Height with respect to the geoid.

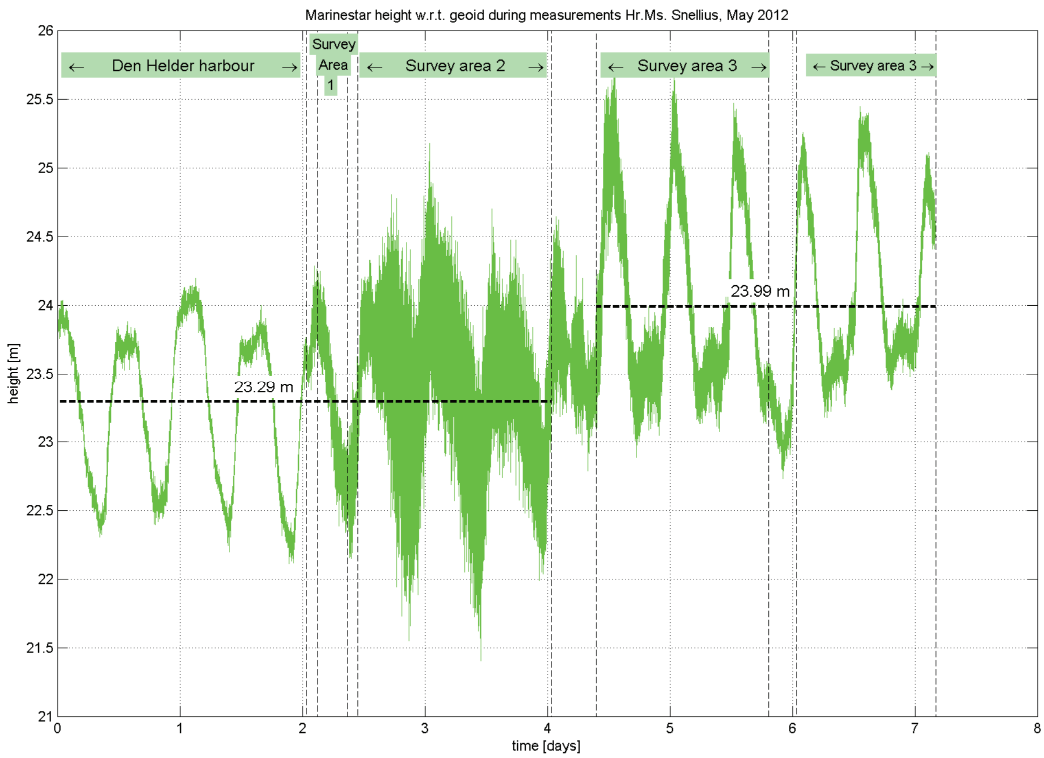

Figure 8: Height with respect to the geoid; different survey areas indicated.

On the vertical axis, figure 8 shows the height, measured with Marinestar, with respect to the geoid. In green, it is shown that during the time frame, several areas were visited: Den Helder harbour and three survey areas on the North Sea. The tide is the most significant component in the height. The “noise” on the graph is the vertical motion of the vessel. In survey area 2, the motion of the vessel was considerably larger than in survey areas 1 and 3.

3 DISCUSSION

The dynamic tests gave us the following insights:

- The availability of the Marinestar was much better than ever experienced before with DGPS.
- When SBAS lock was lost, it took at least 30 minutes to reach full accuracy
- Horizontally the position solution was accurate enough to notice roll and pitch of the ship.
- Vertically the height solution was less accurate than horizontally but accurate enough to match the accuracy of tidal reduction solutions in use, and within the relevant IHO S-44 standards (IHO, 2008).
- The test results of integration with the ship systems were satisfactory for further integration with the ship systems.

Further integration on board and introducing the high accuracy in the hydrographic operations however did not went as smooth as expected. Strangely, instead of an instant big leap forward it introduced practical obstacles that had to be overcome. Each of those will be introduced in the subsections 3.1 to 3.5.

3.1 Vertical uncertainty

In general, the vertical uncertainty of DGNSS systems in combination with a commercial SBAS is still rather large in relation to the IHO S-44 guidelines (IHO, 2008) for survey uncertainty in shallow water. The higher the contribution of the vertical referencing component to the error budget, the lower the allowed uncertainties for other sensors are, translating into a smaller swath width of the multibeam echo sounder and eventually into more parallel survey tracks to fully ensonify an area.

In our case, the vertical accuracy obtained with the SBAS support was beyond expectation. The graph of the antenna heights during the dynamic test shows that the low period tidal movement is visible. The graph shows the antenna height and for determining the tidal height, the own ship vertical movement by roll pitch and heave must be corrected for by use of a motion reference unit. When corrected the tidal height is well within the accuracy of conventional tidal measurements.
Reversed, the availability of a long period vertical level (tide) could improve the relative short period errors in the mean level of the heave measurement.

3.2 Separation model development

Separation models between the ellipsoid and the required vertical datum (LAT, MSL, the geoid, or another chart datum) are still under development (NSHC Tidal Working Group 2010, Strykowski, 2011; Slobbe, 2013), mostly on the national level. As a consequence, there is no basin-wide standard, and uncertainties are strongly variable among and within separation models.

Making use of this accuracy in GNSS height almost worldwide gives exciting opportunities. As heights are obtained referenced to the ellipsoid, the tidal height can be obtained referred to the ellipsoid and separate height time series on the same location can be linked to the same level.
For hydrographic purposes this is not enough, depths in navigation charts are not referred to the ellipsoid but to Lowest Astronomical Tide (LAT); the reference level for depths are related to the amplitude of the tidal regime (IHO, 2010).
The next step to real-time tidal reduction using SBAS techniques is determining the separation between the ellipsoid and the LAT level. Studies and measurement are underway this moment to determine this separation in the Netherlands through the NEVREF project of Delft University of Technology.

3.3 Separation model implementation

The implementation details of separation models in GNSS receivers are unclear and sometimes erroneous. This forces hydrographic offices to work with ellipsoidally referenced data until further into the processing chain. Although this is no disadvantage in itself, it hinders the gradual introduction of GNSS-based vertical referencing.

From the GNSS receiver positional information can be extracted. When working with high accuracy it is good to check how this information is calculated. Which ellipsoid is used in the receiver and which geoid is used for calculations of the GNSS height. For full understanding of the system, this kind of information would be very useful when available in the manual.

3.4 GNSS vulnerability

Although the SBAS signal may be highly available, the GNSS signals are weak, i.e. prone to be disturbed. Signal loss could happen due to common operations, like interference with communication devices.

The availability of the SBAS signal was a big improvement. With an availability of more than 99.9 % SBAS proved a more reliable positioning system than when using IALA DGPS. This could be explained with the age of the older DGPS receiver, spikes in the position solution with DGPS however were seen during its total lifetime.

There was one signal that proved lethal for any GNSS reception and that was the mobile Iridium telephone. Using an Iridium telephone on board the NL survey vessels was as effective as using a multi frequency GPS jammer. According to the manufacturer of the GNSS receiver this was a known disadvantage of the GNSS receiver, a distance of at least 70 m was advised to avoid these interferences.

3.5 Horizontal uncertainty and geodetic datum changes

The horizontal accuracy of the SBAS proved well within the provider claimed limits. With the antenna high in the mast (23 meters in this case) the position must be precisely transferred to the ship reference point using motion reference unit information. This way a very reliable ship position can be calculated improving the hydrographic survey data. This directly improves the operational employment of the ship as calibration runs for hydrographic equipment are no longer limited to range of RTK equipment.
Steering the ship on the high accuracy GNSS data proved less successful; the course and speed information from the receiver was very accurate, showing all position changes and accelerations of the mast head. This resulted in a less stable steered course by the auto pilot.

The Output messages for the high precision must support the accuracy. The “normal” NMEA messages in use do not have enough digits to support this. When supplying the longer and accurate NMEA message to the data distribution system several receiving systems did not work as required; the longer format was not recognized and rejected.

Working with cm or dm accuracy makes a good awareness of the geodetic datum important. The assumption that a GPS or GNSS receiver only gives WGS84 datum output proved wrong. When operating with unaugmentated GNSS the datum is WGS84 indeed, augmentation however may change this. When using SBAS the geodetil datum of the corrected position is that of the reference system. It is rather challenging to find this reference datum.
When using DGPS in Europe, ETRS89 is used. When using Marinestar or Omnistar the positions are ITRF08 referenced.
Although the differences are hardly noticeable for the common GNSS user, when using high precision GNSS it matters, the differences between the datums in use are larger than the accuracy of the system. On the Netherlands Continental Shelf this may give shifts up to 60 cm.

The data output port of the GNSS receiver therefore does not always gives WGS84 referenced positions, this depends on the use of an augmentation system and which augmentation station.

As a user, we must be aware that when switching over to another GNSS operating mode, the geodetic datum may also change. This may even be initiated automatically when the receiver is programmed to use the most accurate mode possible. This happens e.g. in case the SBAS signal does get lost, the GNSS receiver switches to differential mode, introducing a change in horizontal reference frame to ETRS89 (for Europe).

4 CONCLUSIONS

From these tests, the following conclusions can be drawn:

- Marinestar turned out to be a high precision survey method, valuable for hydrographic surveying;
- The horizontal accuracy is sufficient for calibration purposes;
- The vertical accuracy is sufficient for tidal measurements;
- The availability is very good (> 99.99 %);
- It is important to switch off Iridium since this causes large disturbances on the reception of GPS and Marinestar signals.
- When using Marinestar, it is important to be aware of the geodetic datum in use.
- Compatibility of new technology with older technology may be weak.
- Better documentation is needed on the position solution. This focuses mainly on the questions which ellipsoid is used and which geoid model is used.

Suggestions for further developments and further research are:

- Improving the height (heave) solution by integration of the SBAS height and the heave measurement of the motion reference unit.
- Real-time water level measurement is possible with the LAT level referenced to the ellipsoid.

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