Paper 114 – Validation of Actual Depth Measurements by Inland Vessels

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ABSTRACT: COVADEM is a pilot project for collective water depth measurements in which the navigation sector participates. By sharing water depth information it is possible to maximize the loading capacity, to sail more efficiently and to guarantee a reliable ETA. This will save money and increase the profits. In order to optimize the amount of cargo on an inland vessel based on actual measurements of the participating ships, the measured water depth data need to be accurate and reliable. We have investigated the accuracy of underkeel clearances of the COVADEM vessels measured using conventional equipment (GPS meter, echo sounder) by comparing these data to highly accurate and detailed Multibeam bed level data. Our main conclusion is that the results are promising.

1 INTRODUCTION

The just finished Dutch research project "Impulse Dynamic Traffic Management Inland Waterways" (IDVV; De Mol, 2014) aims at realizing a modal shift in favor of inland navigation in order to handle the expected increase of the number of containers due to the "Maasvlakte II" development near the Port of Rotterdam in the Netherlands. One of the spin offs of the IDVV research program is COVADEM, a pilot project for collective water depth measurements in which the navigation sector participates (Van Wirdum et al, 2014; Van der Mark et al, 2014). By sharing water depth information in a clever way it is possible to maximize the loading capacity, to sail more efficiently and to guarantee a reliable ETA (Expected Time of Arrival). This will save money and increase the profits.

As part of the cooperative pilot study COVADEM, about 50 ships are gathering, logging and exporting measured data from the Dutch Rhine River at the moment. During their trips, they measure the depth below the ship (i.e., underkeel clearance, UKC) every second by using conventional echo sounder equipment and the ship's location using a GPS meter. The underkeel clearances are translated into a water depth by correcting for draught, squat and trim. The draught is taken from the logged loading gauge just before the trip starts. The squat and trim is calculated using an empirical model. Input of this model are some characteristic parameters of the vessel (stored in a database for all the 50 participating vessels) and the flow velocity. The flow velocities are derived from a two-dimensional (2DH) numerical model. The position of (a) the GPS meter on the ship and (b) the echo sounder underneath the ship sometimes differs; this is corrected for.

The aim of COVADEM is that the water depths collected by the participating ships will be shared with the navigation sector in a condensed way, such that decisions can be made on the loading capacity and on where/how to sail. This means that the measured water depths should be accurate and reliable. Therefore we have performed a validation study of the measured water depths. This paper describes the validation analysis.

2 FOLLOWED APPROACH FOR VALIDATION

Within the validation study, the focus is on the Dutch Rhine branches Bovenrijn and Waal from Lobith, where the Rhine enters the Netherlands to Werkendam, where the Waal flows into the Rhine-Meuse delta (Figure 1). We have focused on the period from May until August of 2014.

In the COVADEM project, about 50 inland vessels measure UKC during their trips, which is translated into water depth. As mentioned in the introduction, to investigate how accurate and reliable these measurements are, we have compared the COVADEM data to Multibeam data of the Dutch Rijkswaterstaat. Rijkswaterstaat is part of the Dutch Ministry of Infrastructure and the Environment, which is responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands. As the manager of the navigation channel, Rijkswaterstaat measures the bed levels of the navigation channel on a regular basis using Multibeam echo sounder equipment. The most important research question of the comparison was: which accuracy is obtained with the COVADEM data, compared to the Multibeam data?

In short, the followed approach was as follows:

a) COVADEM water depths are translated into bed levels (bed level = water level – water depth; see definition sketch in Figure 2).
b) COVADEM bed levels are compared to Multibeam bed levels.

Aspects that play an important role in the analysis are that both the water levels and the bed levels vary in time and space. Water levels rise and fall by discharge fluctuations. Bed levels change on different time scales due to morphological processes. Bedforms migrate towards downstream on a time scale of meters a day. On a somewhat longer time scale of days to weeks, a flood event may occur. During a flood event, the floodplains may overflow and become part of the river as well. The summer bed of the river will show sedimentation where the water flows into the floodplain and erosion where the water flows back again from the floodplain into the river. After the flood, this sedimentation-erosion pattern will slowly dampen out and migrate towards downstream.

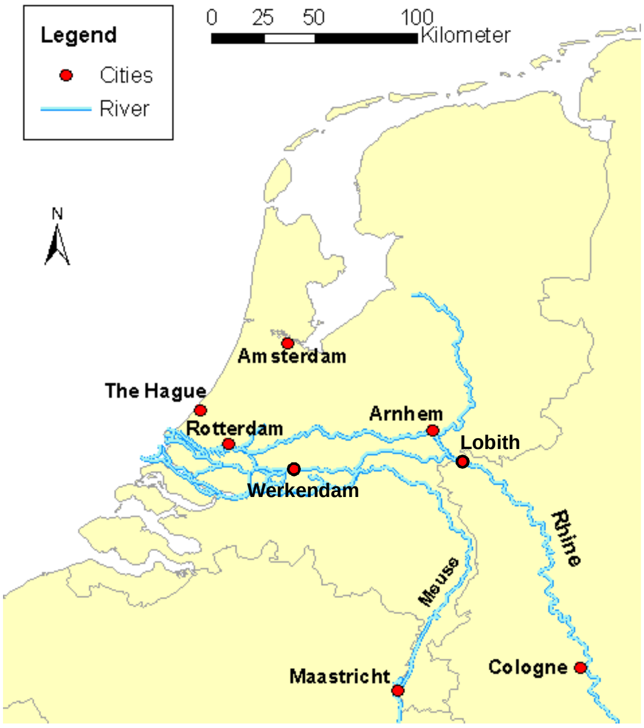

Figure 1: Overview of the Dutch Rhine branches (courtesy Anke Becker).

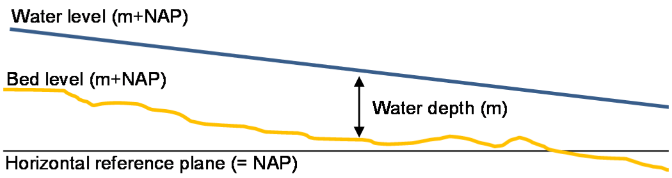

Figure 2: Definition sketch; note that both bed level and water level (and thus water depth) in rivers vary in time and space.

3 PROCESSING OF THE DATA

3.1 Available data

- COVADEM water depth data.
- Highly accurate Multibeam bed level data of 2014 of Bovenrijn and Waal branches on 1 x 1 meter raster, made available by Rijkswaterstaat (example in Figure 3). Each data set is an ASCII raster file, and is measured during a certain period, see the table below:

Number	Begin time	End time
83	22 April	1 May
84	5 May	13 May
85	19 May	28 May
86	2 June	13 June
87	16 June	26 June
89	14 July	24 July
90	28 July	5 August
91	11 August	20 August
92	25 August	3 Sept

- Water level data at 6 measuring stations between Lobith and Werkendam. The water levels along the river are measured every ten minutes.

3.2 Translation COVADEM depths into bed levels

To translate the COVADEM water depth into bed levels, we need to obtain the measured water level both at the same location and at the same moment in time as the water depth. Therefore we interpolated in time and space between the measuring stations.

3.3 Comparison COVADEM bed levels with Multibeam bed levels

The river bed can be very dynamic, since bed patterns migrate through the river. At a certain location, the bed level can be significantly different a few days later. Therefore, it is important that the COVADEM bed levels are compared to Multibeam data at the same location and same moment in time, as much as possible. Same location is easy to realize as X and Y coordinates of both datasets are available. Same location ánd same time step is theoretically impossible, since Rijkswaterstaat does not sail right behind each COVADEM vessel. Therefore, we selected the raster file that was nearest to each COVADEM bed level. This means that the moment in time in the comparison deviated at most about a week. During a week the bed may change because bedforms migrate, which affects the comparison.

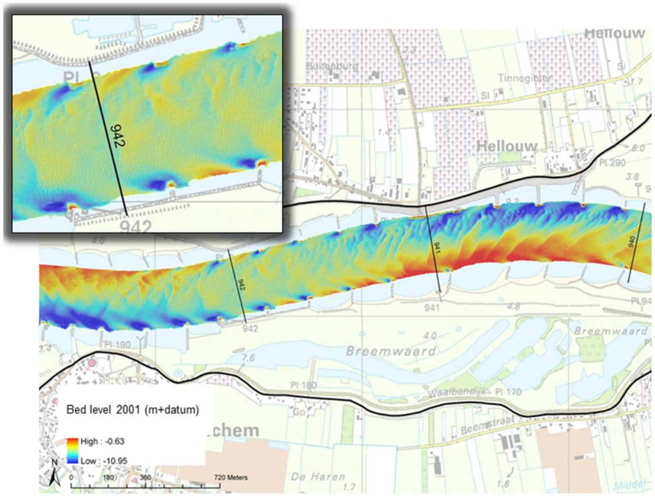

Figure 3: Example of a Rijkswaterstaat Multibeam data set. Morphological bend processes can be seen, as well as bedforms and ripples.

4 VISUALISATION OF RESULTS

For the purpose of visualization and analysis we sorted the resulting data by means of trips of individual ships. A vessel sails from A to B with or without cargo; this is defined as 1 trip. This same ship starts a new trip a couple of days later with a new destination and new cargo.

With about 50 ships participating during May and August 2014, we obtained more than 500 trips. The results for each trip are plotted in 3 different figures:

1. View from above (example in Figure 4).
2. Longitudinal profile of bed levels in which both the COVADEM data and the Multibeam data are plotted, together with a plot of the difference between the two (example in Figure 5).
3. Scatter plot COVADEM bed level versus Multibeam bed level (example in Figure 6).

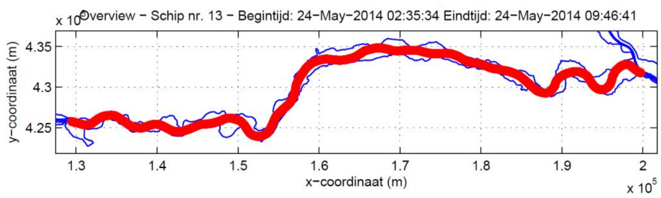

Figure 4: Example of view from above of a COVADEM trip measurement.

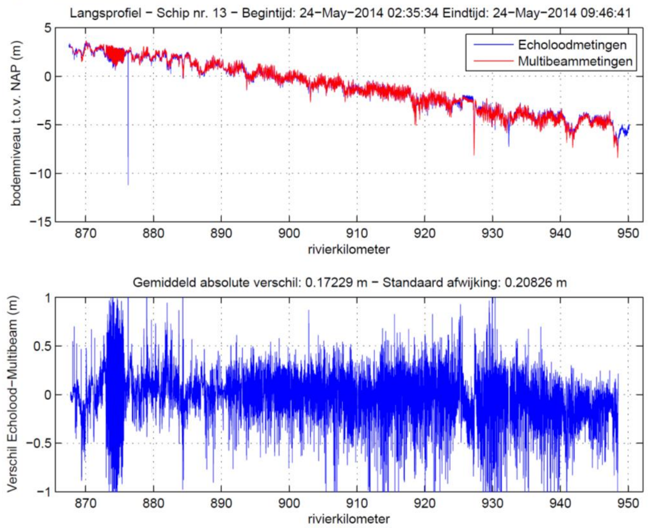

Figure 5: Example of longitudinal profile of measured bed levels; COVADEM bed levels in blue, Multibeam bed levels in red (top), and the difference between these (down).

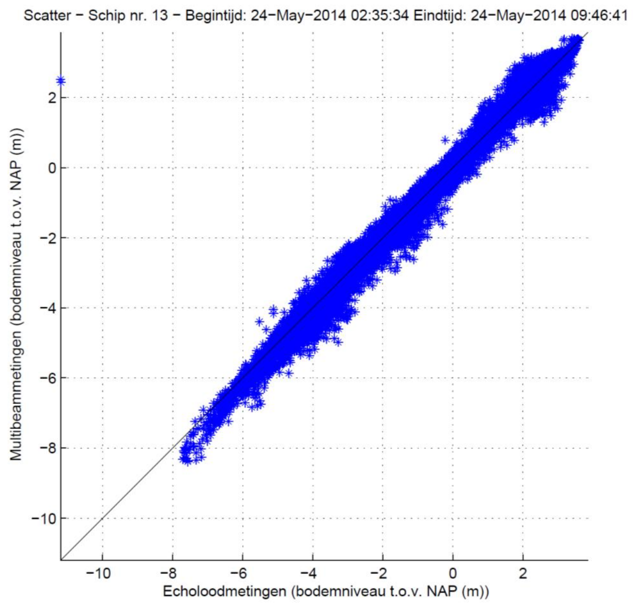

Figure 6: Example of scatter plot of COVADEM bed level versus Multibeam bed level.

5 ANALYSIS

Here general results are presented of our findings after viewing the figures of the more than 500 trips.

For some COVADEM vessels it is immediately clear that something goes wrong either in the measuring or in the data processing. For most vessels there is a good agreement with the Multibeam data. If we consider these good measurements only, we find that the average absolute error is of the order of 20 cm. A “good measurement” follows the bed patterns well and does not show significant horizontal and vertical shift (example in Figure 7).

The error or difference between COVADEM and Multibeam bed levels is caused by a combination of factors. We distinguish three types of errors:

1) Measuring errors
2) Errors caused by translation from UKC to water depth.
3) Errors caused by translation from water depth to bed level:
   a) In space: to determine water level at the exact location of a COVADEM measurement we need to interpolate between measuring stations, and we ignore possible transverse slope effects in the water level at river bends.
   b) In time: we compare a COVADEM measurement for a given time step (exactly known) with a Multibeam measurement for a different time step, taken at some unknown time within a period of about 2 weeks.

A horizontal shift occurs due to a wrong determination of the vessel’s position (error 1), or by comparison at the wrong time step (error 3b). In the latter case, the river bed has changed meaning a bedform has evolved and migrated (is located a couple of meters away).

Many trips show a vertical shift. This may be caused by a wrong determination of the draught of the ship (error 2).

We find that the Multibeam bed levels are often higher than the COVADEM bed levels. We could not really explain this. In fact, lower values instead could be explained by the difference in beam angle for single- and Multibeam echo sounder equipment. Possibly this trend of higher bed levels in the Multibeam data is caused by frequencies or other settings of the equipment.

In several trips it seems that the Multibeam data is tilting with respect to the COVADEM data. Downstream the Multibeam bed levels are lower with respect to the COVADEM bed levels than upstream. This may be explained by the sediment size or composition (finer sand and silt downstream, gravel and sand upstream).

The highly detailed Multibeam data are more scattered than the COVADEM data during the last two months. This has to do with the higher river discharge in these months, resulting in more dynamic river bedforms.

COVADEM vessels with less sophisticated equipment than the Rijkswaterstaat Multibeam vessels have difficulties to measure small-scale features with large gradients, see for instance the bottom vanes at Erlecom (Figure 8; this vessel shows very good results in general, except at Erlecom).

We correct for the distance between GPS meter and echo sounder. However, if a vessel is drifting in a bend, this distance correction is not sufficient. From the resulting data we are not able to conclude whether the effect of drift is significant. The results in bends are not significantly different from the results in straight river reaches.

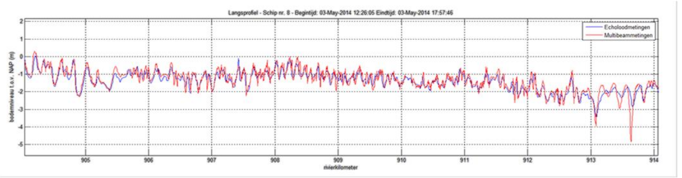

Figure 7: Example of a "good measurement". Axes and legend as in Figure 5; on the horizontal axis distance in km, on the vertical axis bed level in m+NAP.

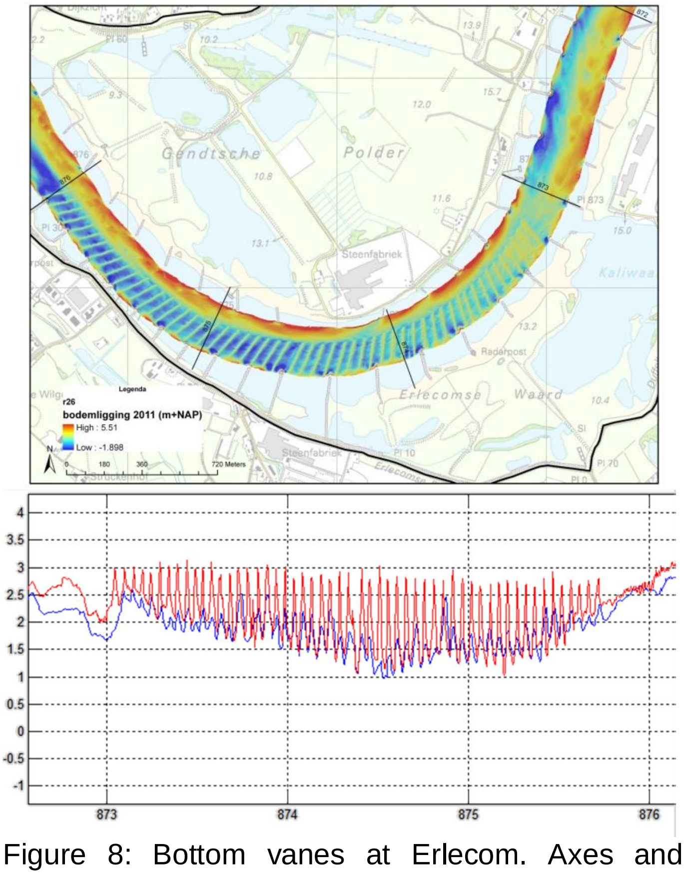

Figure 8: Bottom vanes at Erlecom. Axes and legend as in Figure 5; on the horizontal axis distance in km, on the vertical axis bed level in m+NAP.

6 CONCLUSIONS AND RECOMMENDATIONS

We have investigated the accuracy of underkeel clearances of inland vessels measured using conventional equipment (GPS meter, echo sounder) by comparing these data to highly accurate and detailed Multibeam bed level data.

Our main conclusion is that the results are promising. So far we conclude that the average absolute error is of the order of 20 cm. All the ships measure the same pattern as in the Multibeam data: i.e. shallow and deep parts and bedforms. Often a small systematic horizontal shift was visible, probably caused by the fact that the moment in time for both data sets may deviate a couple of days. Also a small systematic vertical shift was often visible. This may be caused by an incorrect translation from underkeel clearance to water depth.

Vessels that did not perform well (for example had a large vertical shift), are now subject of further inspection. We check among other things characteristics of the ship in the database and the measured draught.

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