Coastal protection:
New techniques in capturing and modelling of morphological data

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SUMMARY

Schleswig-Holstein, the most northern state of Germany, is placed between the Baltic Sea at the east side and the North Sea at the west side of the state.

Due to the fact that the Schleswig-Holstein parts of these water bodies are mainly shallow water areas, the conditions for surveying the coastal areas from the coastal protection structures down to the seafloor are difficult at both seas.

Since 2014 the techniques of LIDAR bathymetry have been used for capturing morphological data. The green light of the bathymetric LIDAR is able to penetrate into the water. The reachable depths depend on the turbidity of the waterbody. Therefore the power of the systems is described as a factor of Secchi-depths. The local turbidity value multiplied with this factor allows estimating the reachable depth. In Schleswig-Holstein round 2000 km² have already been surveyed with this techniques. Bathymetric LIDAR provides the results that are expected in depths as well as in accuracy.

Using these techniques, data gaps only occur locally in tide ways or low-lying areas, which are needed to be filled by hydrographic surveys. But compared with the bathymetric LIDAR, these surveys have a substantially lower density of points. Hence it is difficult to merge these data to a morphological model. As a consequence it is necessary to densify the hydrographic data to create a homogeneous model. The mathematic method of Gordon-Coons-patches is suitable for this purpose. The gaps inside the area of hydrographic survey are filled with data points in desired density. The bathymetric information is then calculated using bilinear interpolation.

As a result a dataset which has a similar point density as the bathymetric LIDAR is created. After the preparation a homogeneous morphological model can be generated by triangulation, based on bathymetric LIDAR on the one hand and hydrographic surveys on the other hand.

1. INTRODUCTION

Schleswig-Holstein, the most northern state of Germany, is called "the land between the seas" because it is placed between the Baltic Sea with a coastline of approx. 640 kilometers at the east side and the North Sea with a coastline of approx. 550 kilometers at the west side of the state.

This location between the seas justifies that coastal protection is a main task. Without buildings of coastal protection, 25% of the area and 12% of the inhabitants of Schleswig-Holstein would be threatened of storm surge and floods.

Fig 1: The state Schleswig-Holstein

For coastal protection knowledge about the development of the morphology of the coastal areas is necessary. Therefore an area-wide survey above and below the mean sea level and an analyse of these data has been done.

2. PREVIOUS SURVEY

Both seas have different conditions which are considered by implementing a survey.
The Baltic Sea is stamped by the last ice-age with fjords and shallow shore areas. A nearly constant waterlevel in the hight of the mean sea level is dominate. Variations are only in the

impact of the wind. The North Sea is stamped after the last ice-age by the growth of the Wadden Sea offshore the coastline which is daily formed by two tides.The waterlevel variates between round three meters from the high tide to the low tide.

Both coastal regions are shallow water areas. On focus of coastal protection are the areas between the coastline and seawards the depth line of ten meters below the mean sea level. Because of these natural conditions an area-wide survey is seen to be difficult.

The region of the North Sea including the Wadden Sea until now have been primarily surveyed by ships using the high tide completed by airborne lidarscanning at the low tide.

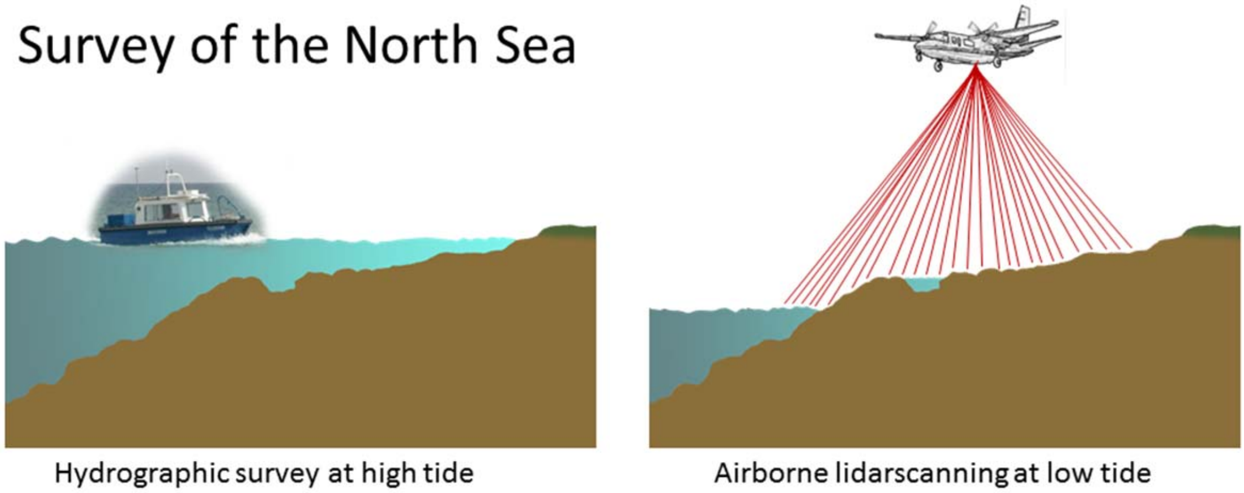

Fig 2: The method of survey the North Sea

The region of the Baltic Sea until now has been primarily surveyed by ships and boats with a small draught following by terrestrial survey on feet up to the waterline and then completed by airborne lidarscanning.

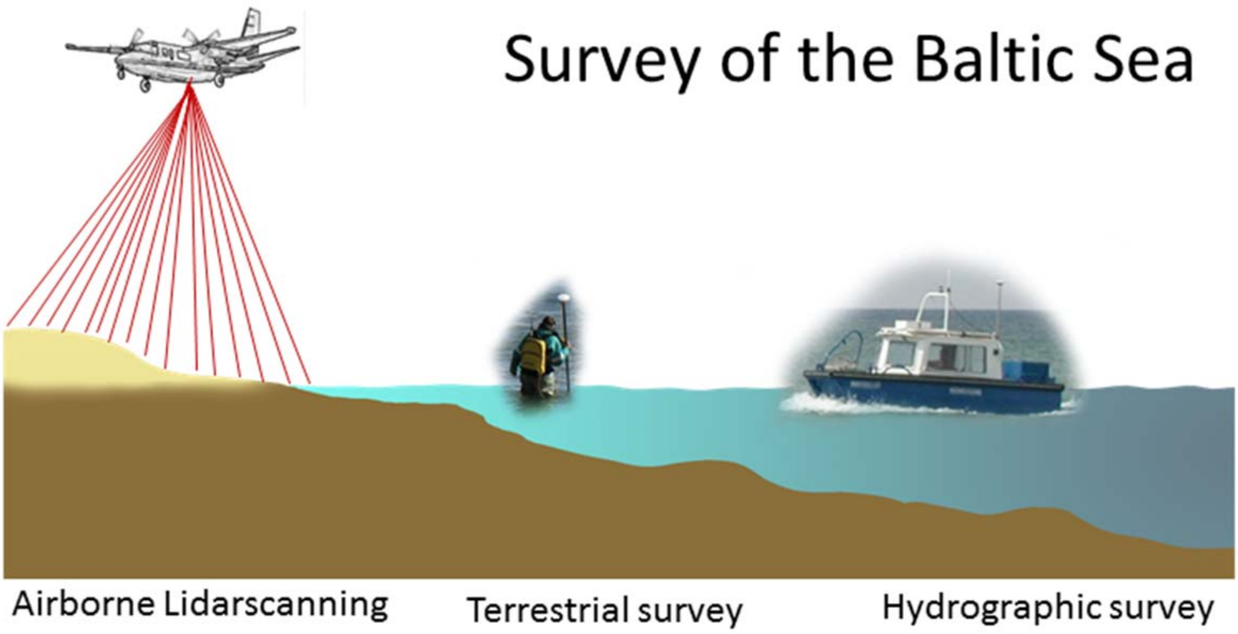

Fig 3: The method of survey the Baltic Sea

3. LIDAR BATHYMETRY AS A NEW METHOD OF SURVEY

Since 2014 the LKN.SH has used the method of LIDAR bathymetry for the survey of the coastal regions above and below the mean sea level. Only lower areas are additionally hydrographical surveyed by ships.

The known method of airborne lidarscanning applies red lidarlight which is able to capture terrain and water surfaces. The technique of LIDAR bathymetry uses aditional green lidar light which is able to penetrate into the water body and capture the seafloor.

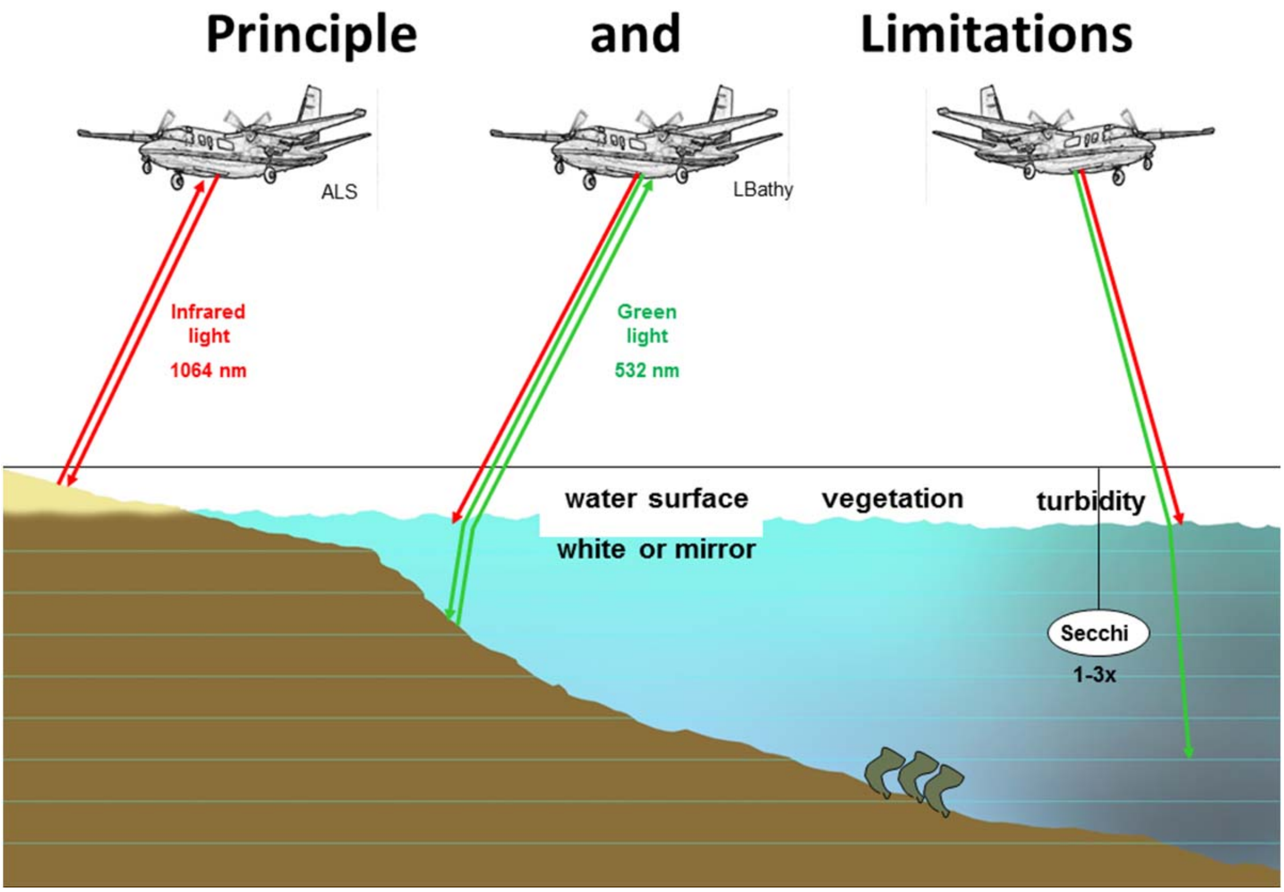

Fig 4: Principle and limitations of LIDAR bathymetry

3.1 Expected depths

For the depth of penetration the turbidity of the water body is deciding. This is declared as Secchi-depth. Also the power of the systems is important which is described as a factor of the Secchi-depth.

At the coast of the Baltic Sea the Secchi-depths variate between three meters at the fjords and five meters at the open sea.

At the coast of the North Sea the values of Secchi-depths variate at the Wadden Sea between nought and one and a half meters and seaside the Wadden Sea nearly three meters.
In spite of the small Secchi-depths the technique of LIDAR bathymetry is very suitable because the ground of all water areas left on the tide land at the low tide are captured.
This is not possible by using airborne lidarscanning. The red lidar light cannot penetrate into the waterbody.

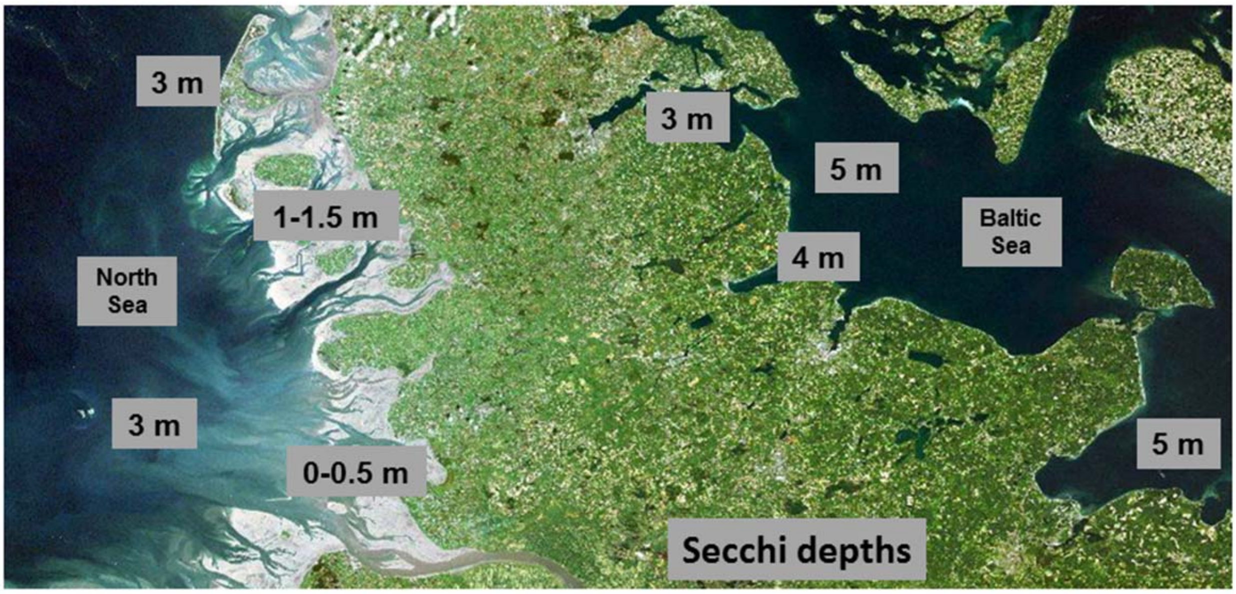

Fig 5: Secchi depths at the North Sea and the Baltic Sea

The systems of LIDAR bathymetry on the market are devided into two catergories. The one systems are able to reach the one to one and an half of the Secchi-depth, the other systems are able to reach the two and a half to three of the Secchi-depth.

With this information of the manufactures and the knowledge of the Secchi-depths of the areas the reachable depths of the survey are estimated.

3.2 Results of LIDAR bathymetry in coastal areas

Between 2014 and 2016 round 2000km² have been covered by LIDAR bathymetry. The whole coastal area of the Baltic Sea with 650km² and approx. 50% of the Wadden Sea with 1350km² have been captured until now.
At all regions the expected depths are nearly reached.
The following examples of the westcoast of the island of Sylt, the Wadden Sea and a coastal area of the Baltic Sea show this.

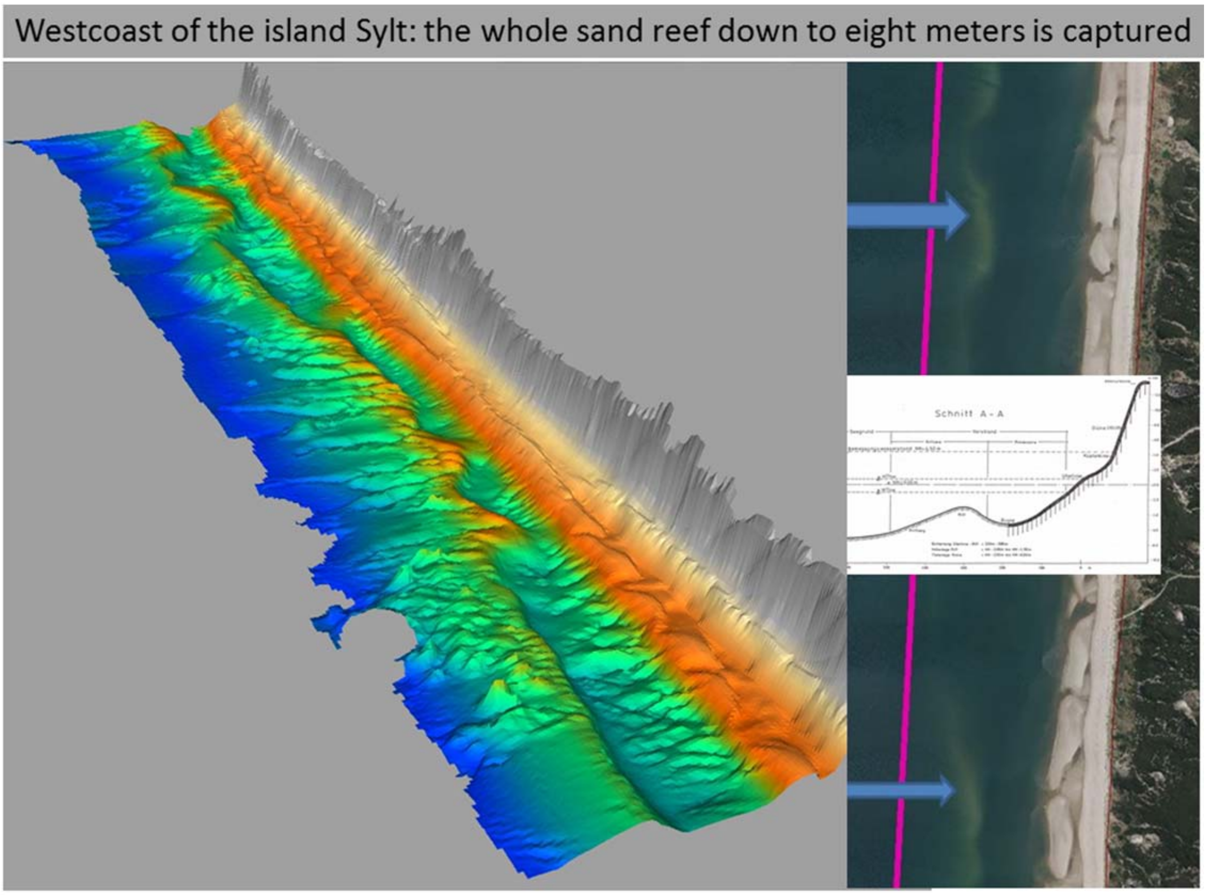

Fig 6: Results of LIDAR bathymetry down to eight meters at the westcoast of the island Sylt

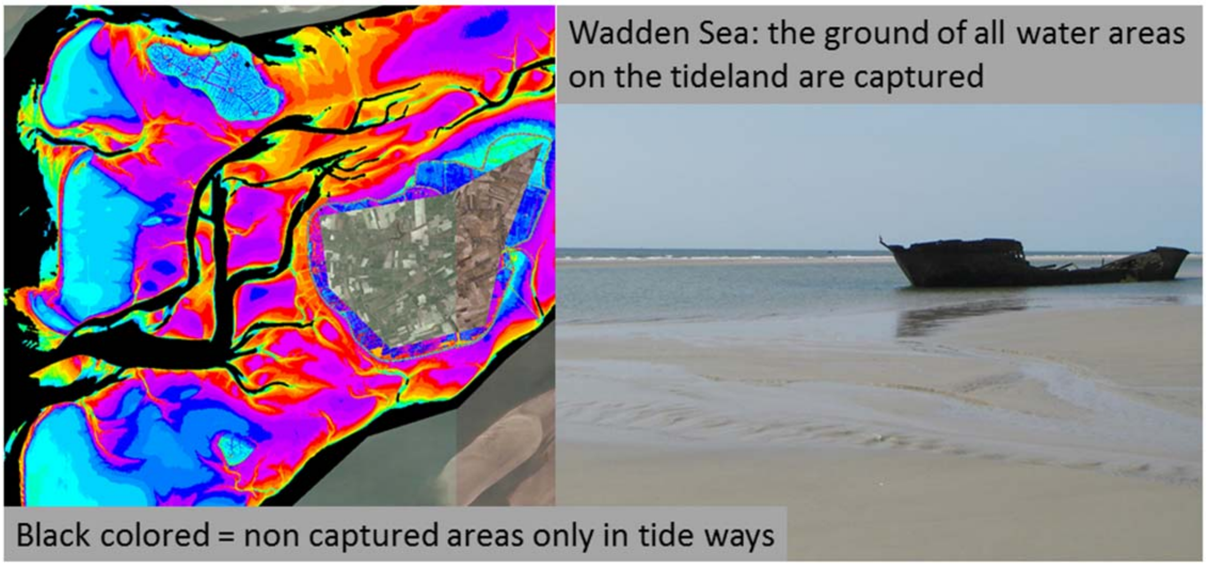

Fig 7: Results of LIDAR bathymetry of the Wadden Sea, the most turbidity area. Only the tide ways are not captured

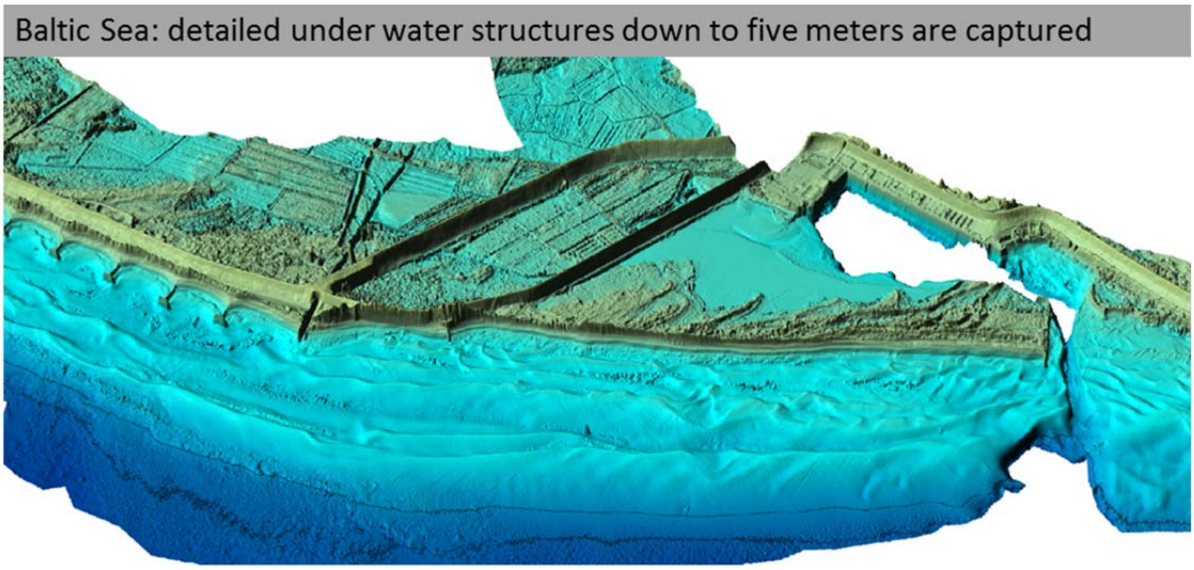

Fig 8: Results of LIDAR bathymetry down to five meters of the Baltic Sea

3.3 Accuracy of data of LIDAR bathymetry

The accuracy of data of LIDAR bathymetry are defined by comparison with terrestical and hydographical surveys realised near the same time. The results are nearly between one and two decimeters in high which conforms with the accuracy of the hydrographic survey as the following examples show.

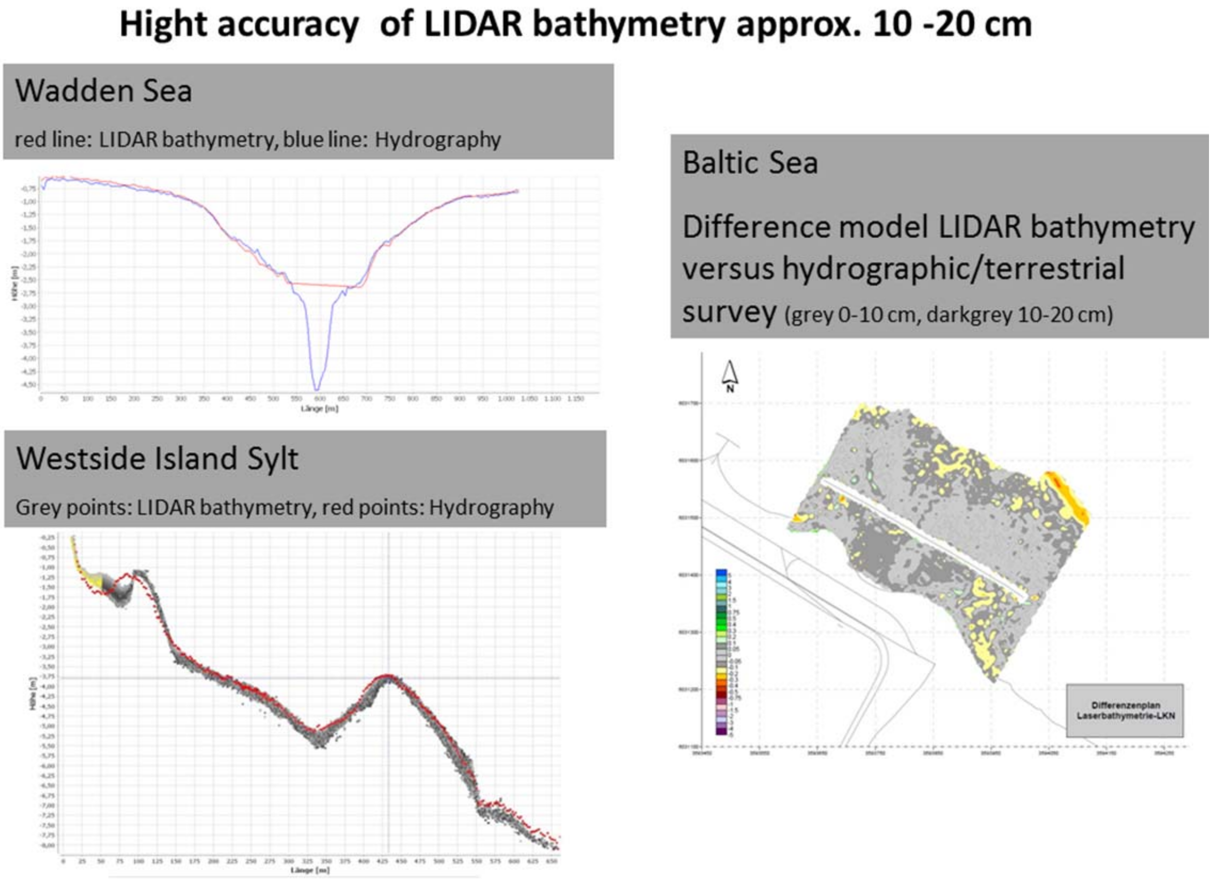

Fig 9:Accuracy of LIDAR bathymetry

4. MODELLING OF LINE BASED SURVEY DATA

After primarily implemented survey by LIDAR bathymetry at the shallow water areas the remaining deeper channels of the tide ways are hydrographical surveyed by using a singlebeam system.

The lidar data is area-wide homogeneous spreaded with at least one point per squaremeter. These data is unproblematically converted into a plausible morphological model.
The line based hydrographical data with an usually line distance of one hundred meters and one datapoint per runnung meter is very problematically converted into a plausible morphological model because of the inhomogeneous data distribution.
Therefore it is a goal of the LKN.SH to create a homogeneous data distribution of line based surveys and to generate a plausible morphological model.
This is possible by using Coons patches.

4.1 Coons patches for higher data density

Especially the car industry needs algorithm to generate free formed surfaces by CAD [1].

Approximation algorithms of Bézier curves and Bézier surfaces are known. These were developed by P. Bézier at Renault.
Steven Anson Coons (1912 – 1979) was a pioneer of developments in computer graphics[1]. He worked among others at Ford [2].

His developed Coons patches are based on an interpolation algorithm [1].
Inside of mostly foursquared polygons a higher data density takes place by bilinear interpolation.

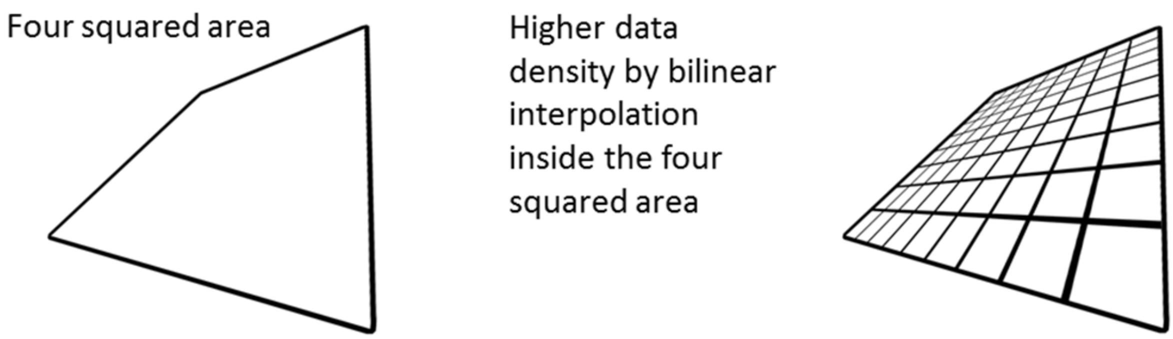

Fig 10: Method of Coons patches

4.2 Transfer to line based survey of channels

At the survey of channels the definition of the measuring lines are perpendicular to the direction of flow.
The hull line composing of the ending points of each measuring line encloses the area which is represented by the inside placed data points.

So four squared polygons are produced which allow bilinear interpolation inside. The algorithm of Coons patches are utilized here.

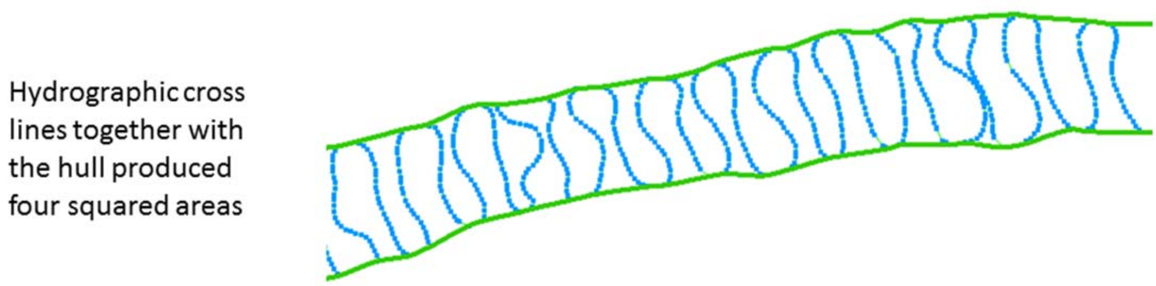

Fig. 11: Structure of hydrographic survey

An improvement of the polygonal partitioning is given by embedding morphological struture lines like the deepest line of the channel bed or lines of change of inclination. These optimize the morphological accuracy of the model.

4.3 Using of Coons patches

As a result virtuell data will be formed with a homogeneous data distribution and assigned high information by bilinear interpolation of the surveyed data.

By using the original data and the Coons data a plausible morphological terrain model is generated as the following examples show.

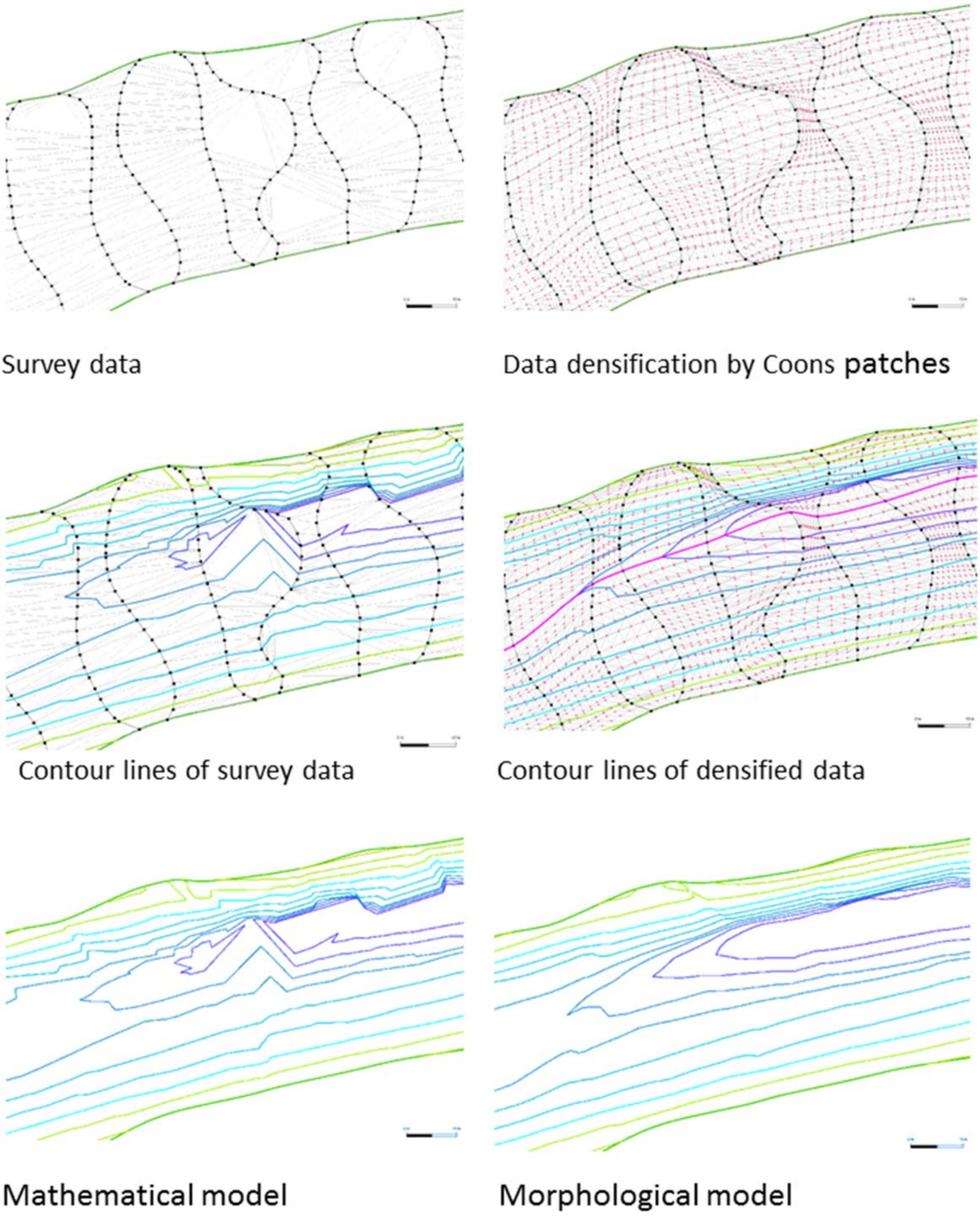

Fig 12: Comparison of the mathematical model with only the survey data and the morphological model additional with the Coons data

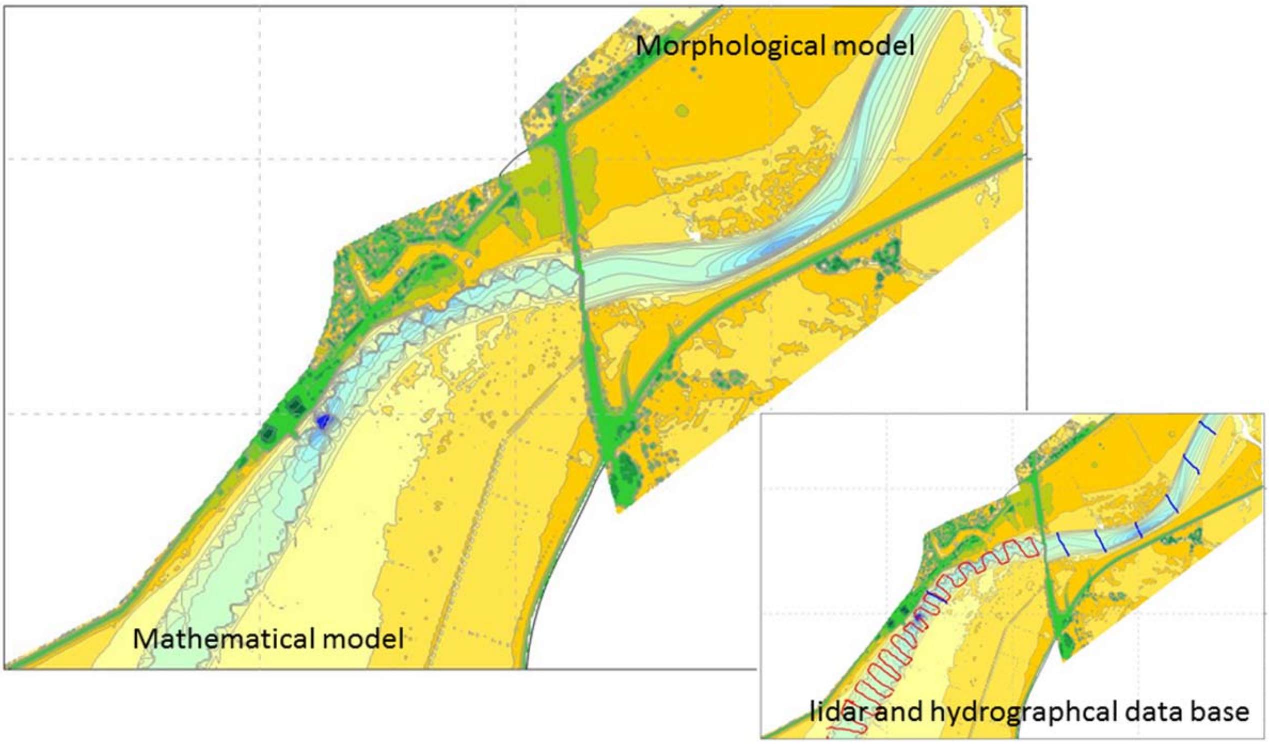

Fig 13: Demonstration of the difference between the mathematical model and the morphological model at a part of the river Eider

5. CONCLUSIONS

For an area-wide survey of shallow water areas along the coast the technique of LIDAR bathymetry is very effectivly usable. This method replaces the difficult realisation of hydrographic survey which is only neccessary as addition in deeper areas.
In a hydrographic survey with single beam technique it is possible to generate a homogeneous data density by using Coons patches. More plausible morphological terrain models are creatable.

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BIOGRAPHICAL NOTES

Lutz Christiansen graduated the Studies of Surveying and Mapping at the University of Applied Sciences in Hamburg in 1987. Since 1990 he has been working as a member of the technical staff of hydrographic survey and morphological analysis at the Administration of coastal defense of the state Schleswig-Holstein in northern Germany. In 2008 he became the Survey Manager at the same Administration. Since 2009 he has been dealing with the technique of LIDAR bathymetry.

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