Hydrographic Surveying using High Resolution Satellite Images

Petra PHILIPSON and Frida ANDERSSON, Sweden

Key words: remote sensing, high resolution, hydrographic survey, depth estimation.

SUMMARY

The Swedish Maritime Administration (SMA) distributes official nautical charts and publications in Swedish waters and different methods and techniques are used to collect the relevant data. Remote sensing is one of the techniques that has only been used to a very limited extent so far but that has the potential, especially in shallow areas, of improving the contents of nautical charts. The Swedish Armed Forces (FM), the SMA and the Geological Survey of Sweden (SGU) are the only bodies authorized to perform hydrographic surveys, without seeking specific permission, according to the law regarding the protection of landscape information. We have evaluated the possibility of using high resolution satellite data to collect information on islets and rocks (location, size and depth), to what extent lights and beacons can be identified in the images, if the shoreline could be mapped/updated where necessary, and finally, and most importantly, to analyse the possibility of estimating depth from high resolution optical satellites.

In this geographic area, the depth penetration is rather limited due to dark, humic, waters but in clearer water the depth estimation possibility is increased.

The preliminary results show a potential to use high resolution satellite data for mapping of maritime objects. In areas where detailed information in the SMA database is limited the potential to improve the information content using high resolution satellite data is obvious. With respect to depth estimations, the analysis performed so far has indicated the possibility to identify objects down to 3-4 meters depth in this region. The images show a clear difference in intensity between objects/areas located at different depths and the possibility to derive depth estimations based on these differences will be presented.

Hydrographic Surveying using High Resolution Satellite Images

Petra PHILIPSON and Frida ANDERSSON, Sweden

1. INTRODUCTION

SMA distributes official nautical charts and publications in Swedish waters. A large effort is made to collect all necessary information within a specific area. The SMA is working continously with hydrographic surveying, primarily in fairways, and with positioning of objects that are of importance for navigation. Different methods and techniques are used to collect the information and the SMA is a high-tech organisation with a proven capability to adopt and combine new techniques. Remote sensing is one of the techniques that has only been used to a very limited extent so far, but that has the potential to be a good alternative to the exisiting techniques and improve the contents of the nautical charts, especially in shallow areas. The possibility to use remote sensing as a complimentary technique for mapping of maritime objects is presently being evaluated and we will continue the analysis during 2008 and 2009. The preliminary results accomplished so far are presented in this paper.

2. GOAL

During 2007, the general goal was to evaluate the possibility of using high-resolution satellite data to collect information about a number of objects of interest. The first task was to evaluate if this type of imagery could be used to map (size and location) small islets and rocks in the Swedish archipelago. The outer archipelago is of specific interest, due to its inaccessibility. The second task was to evaluate if rocks located under the surface also could be mapped and to make an estimation of maximum depth. The third issue was to investigate to what extent lights and beacons could be identified in the images and if the geometric accuracy of the image is enough for the SMA's purposes. Finally, the SMA would like to make a comparison between the existing shoreline, based on aerial photo interpretations, and the shoreline that could be mapped from high resolution satellite imagery.

During 2008 and 2009 the goal of the investigation is to analyse to what extent the information collection process could be automated, to develop a strategy to include the satellite derived data in the existing nautical database at the SMA and to test the developed strategy in a pilot production. Additionally, and most important, a more exhaustive analysis regarding the possibility to estimate depth from high-resolution optical satellites will be performed.

3. METHODS

3.1 Area of investigation

The investigation is based on four QuickBird images. Three are collected in the county of Östergötland, east of Arkö-Gränsö during 2006 and one over the archipelago southeast of Nämdö, Stockholm in 2002. Both areas are located in the Baltic Sea on the east coast of Sweden, and are displayed in the image data presented in Figure 3-1 below. The water in the Baltic Sea is of "Case-II" character and dominated by high concentrations of yellow substance (coloured dissolved organic matter). This means that the water has a high absorption of blue light and that the best depth penetration possibilities can be found in the green band. The costal area depicted near Arkö-Gränsö is highly influenced by river discharge from e.g. Bråviken and the water is relatively turbid from time to time. One of the advantages with that area is that the boat traffic is relatively busy and that the image therefore contains several lights and beacons that have been used in the analysis. The image outside Nämdö depicts a part of the outer archipelago and the water here is much clearer, which increases the depth penetration possibilities. This area does not contain any fairways, it is a popular area for private boats during the summer season. There were no navigational marks in this area, which could be useful in the analysis, but a large number of rocks, islets and shallow subsurface areas are evident.

3.2 Satellite data, nautical charts and laser data

Satellite images from the QuickBird sensor have been analysed with respect to the goals described in chapter 2 above. QuickBird generates images with a spatial resolution of 0.6 meters in panchromatic mode ("black and white") and 2.4 meters in multispectral mode (blue, green, red and near infrared). The spectral characteristics are defined in Table 3-1 below. The radiometric resolution is 11-bits, which means that each colour can be represented in 2048 gradients.

Table 3-1: Spectral characteristics of QuickBird.

Bands	Panchromatic	Blue	Green	Red	Near IR
	450 to 900-nm	450 to 520-nm	520 to 600-nm	630 to 690-nm	760 to 900-nm

The QuickBird data from Arkö/Gränsö was collected on the 16th of May, 9th of September in 2006 and on the 18th of October 2007. The image collected in September can be seen in Figure 3-1 below. The main land area is the two islands Arkö and Gränsö, which are separated by a small channel. A number of lights and beacons are located in the main fairway southwest of these islands. The QuickBird data depicting the archipelago south-east of Nämdö was collected on the 29th of May 2002 (Figure 3-1). The water is relatively clear and the traffic less busy compared to Arkö/Gränsö. In this area, both detailed nautical charts and LIDAR data were available for the project developments.

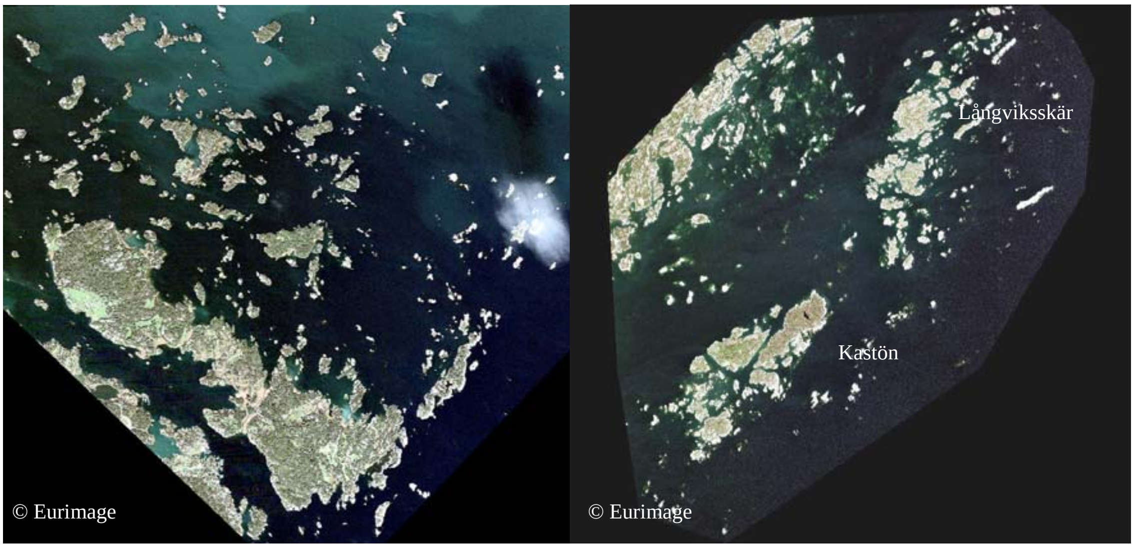

Figure 3-1: The QuickBird images depicting the archipelago outside Arkö/Gränsö and southeast of Nämdö.

The nautical charts, laser batymetry data and the national shoreline (NSL) data corresponding to the investigated area were made available to the project by SMA during the investigations.
This area has during past years been surveyed several times. Therefore the depths are collected by a variety of methods. Multibeam surveying was perfomed in early 21th century, but as mentioned earlier, the survey seldom reaches shoals located between sea surface and 6 meters. The nautical charts in the area are produced at 1:25 000 and 1:50 000 and the smaller scale is more generalized than the larger. NSL is, since 2004, surveyed and digitized by the Swedish National Land Survey. The shoreline is digitized in at scale 1:10 000 by using aerial photographs in a 3D environment. The laser survey was performed by the airborned laser bathymetry system Hawkeye in may 2000. The Hawkeye system was operating at a flight altitude of 200m and with a laser spot spacing of 4 m. Positioning of the survey has been made by DGPS.

Additional nautical charts, produced by Hydrographica (Granath, 2008), have been purchased and used for comparison and evaluation. Hydrographica has specialised in production of charts for the private sector. They have permission from the FM and the SMA to produce large scale charts within the popular parts of the outer archipelagos around the Swedish coast, which might be difficult to navigate based on the official nautical charts. These charts are produced in scale 1:10 000 and based on manual interpretation of aerial images over the mapped area and complementary field investigations. For example, an additional 2 meter depth curve has been interpreted and adjusted to the need of the private boat sector.

RESULTS

3.3 Islets, rocks, subsurface rocks

Masking and classification techniques have been tested to identify islets and rocks and a comparison has been made using the available nautical charts in the area. A number of issues have been addressed: Are there rocks and islets in the image that do not exist in the nautical chart? Are there rocks and islets in the nautical chart that do not appear in the image? Is it mainly very small islets and rock that are missing in one or the other of the base materials?

Figure 4-1 to 4-6 below shows an example of the nautical charts and image data used in the comparison and evaluation of the high resolution (HR) QuickBird (QB) data. Looking at the nautical charts (1:50 000) distributed by the SMA (Figure 4-1) the information content is of course incomplete and much more generalised compared to the other nautical charts and image data. In areas were detailed nautical charts (detailed information in the SMA database) are missing, the potential to improve the information content using HR satellite data is therefore large. The detailed nautical chart from the SMA contains much more information with respect to objects and the number of objects are more or less the same as the ones found in the very detailed charts produced by Hydrographica (Granath, 2008). The charts from hydrographica are superior in the depth area representation. The three meter depth isoline is much more detailed and an additional two meter depth isoline has been interpreted and added.

All objects, except two or three, represented in the detaild charts (Figure 4-2 and 4-3) could be indentified in the HR-QB data in the evaluated areas. In Figure 4-6 green stars correspond to objects idetified both in HR-QB and detailed nautical charts. Red stars corresponds to objects identfied in HR-QB, missing in detailed nautical charts. The yellow star corresponds to a deep subsurface rock that could not be identified in HR-QB.

Several areas has been evaluated and in general, an additional 10-20% number of objects could be identified in HR-QB data, showing the potential object discrimination possibilites in this type of data. A number of the objects missing in the charts can of course be an effect of generalisation in the charts, but the possibility to identyfy objects in HR data is obvious.

The investigation regarding the possibility and limitations in automating the analysis and object identification is presently the main focus of the work and will continue.

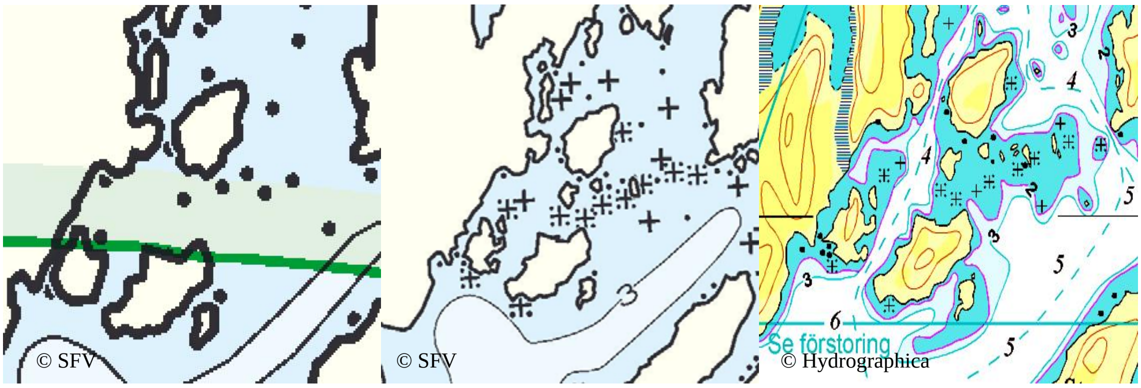

Figure 4-1 to 4-3: SMA 1:50 000, SMA 1:25 000 and nautical chart produced by Hydrographica.

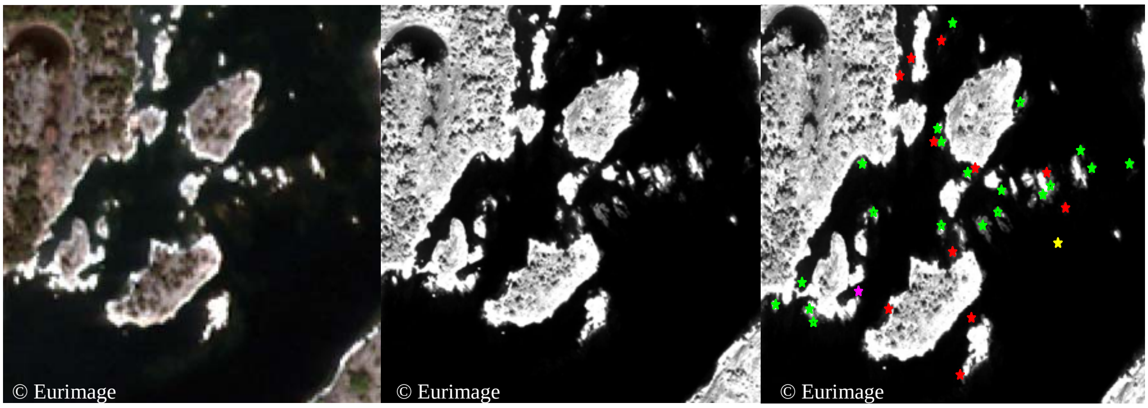

Figure 4-4 to 4-6: Multispectral QB data (2.4 m), panchromatic QB data (0.6 m) and the result of the analysis.

3.4 Navigational marks

There are different types of navigational marks and one of the goals was to define what type of marks that are possible to identify in the high resolution satellite images. A number of navigational marks are available in the existing images from Arkö/Gränsö. The investigation shows that only the lights and one beacon are possible to identify in the image. Smaller marks are not possible to identify, which not only is an effect of the size of the mark, but also due to the poor contrast to the surroundings. Small boat mooring buoys are, for example, visible in the image as they are white and very well separated from the surrounding dark water.

All images used for this part of the investigation, were geometrically corrected before the analysis and the position for each visible navigational mark was extracted. It should be noted however, that the images from Norrköping included beacons that are positioned by SMA, using high precision geodetic equipment, and these were included in the actual geometric correction as a subset of the ground control points used in the process. This makes the analysis a bit circular, but we still believe that the results are indicative as we have managed to achieve the same level of accuracy in the correction without any navigational marks present in the image. The analysis could be improved by excluding these beacons and re do the analysis, by this has not been prioritised so far.

A comparison between coordinates from the different sources (corrected image data and geodetically measured positions) has been made and an estimation of the accuracy that can be derived from image data has been made. Nine lights and beacons were identified and the coordinate differences were calculated. Table 4-1 below shows the mean, min and max difference between coordinate pairs.

Table 4-1: Statisics indicating the difference level in meters between SMA measured coordinates and image derived coordinates.

	Northing	**Easting**
Mean	0.19	0.55
Min	0.05	0.01
Max	0.41	1.13

The results indicate that the accuracy to be obtained based on image data, is equal to the pixel size or better in most cases.

There is one lighthouse in the image that has not been positioned by the SMA using high precision geodetic equipment and the difference between these lower accuracy the SMA coordinates and coordinates derived from the image are 35.0 and 19.5 meters, in northing and easting respectively. This indicates that the position for such lights can be improved based on image data.

It should be noted that this part of the investigation not only indicates the geometrical accuracy with which beacons and other objects could be positioned. The SMA is also interested to find out if the image data could be used to update information about harbours, and with what accuracy different object in the harbours could be positioned.

3.5 NSL shoreline

The SMA has decided to give priority to update the shoreline in the Swedish nautical charts in order to correspond with the shoreline available in the maps of the National Land Survey (NLS). The objectives concerning NSL are included to increace the knowledge about the existing shoreline and its descrepancies from the specifications. There is no plan, as of today, to change the existing shore line based on the results in this project, but the results can serve as a good basis for future discussions and an alternative production method if the shoreline needed to be updated in the future.

The work related to this objective has merely started and will continue during 2008 and 2009. Figure 4-7 and 4-8 below shows an example from one of the initial tests were a possible shoreline has been derived from HR-QB data. These results have not been evaluated and discussed further.

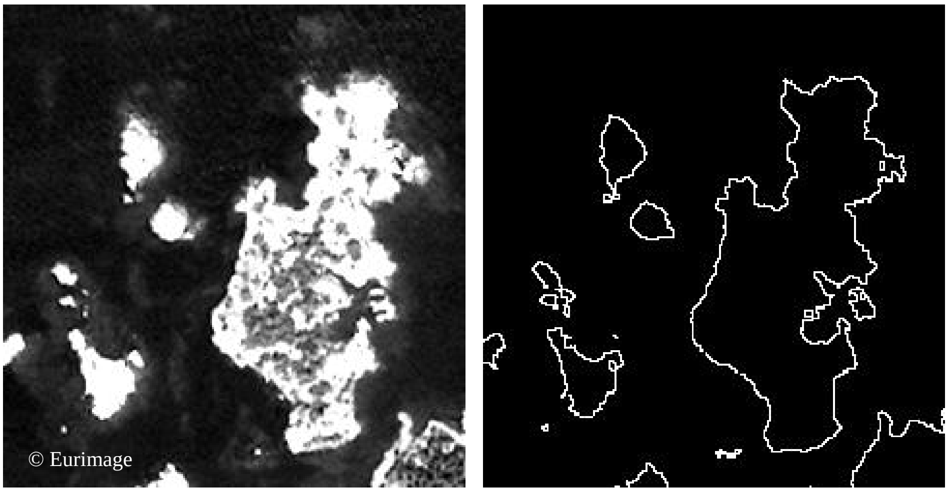

Figure 4-7 and 4-8: Figure 4-7 shows an area in the panchromatic image data and 4-8 the derived shoreline after segmentation and analysis of the image.

3.6 Depth estimation

During the early investigations of possible depths for mapping of subsurface rocks, it was estimated that objects located around 4 meters depth could be identified in the images. The analysis was based on available charts and LASER measurements. Furthermore, the images showed a clear difference in intensity between objects/areas located on different depths. This was the starting point for an increased analysis regarding the possibility of obtaining absolute levels of depth based on the HR-QB data. Initially, the panchromatic, 0.6-meter, data was investigated. The depth penetration possibility in this band is not as good as for the green band, and the deepest objects visualised in the green band could not be identified in the panchromatic band. An example of a depth product that could be derived from panchromatic data is displayed in figure 4-9 to 4-11.

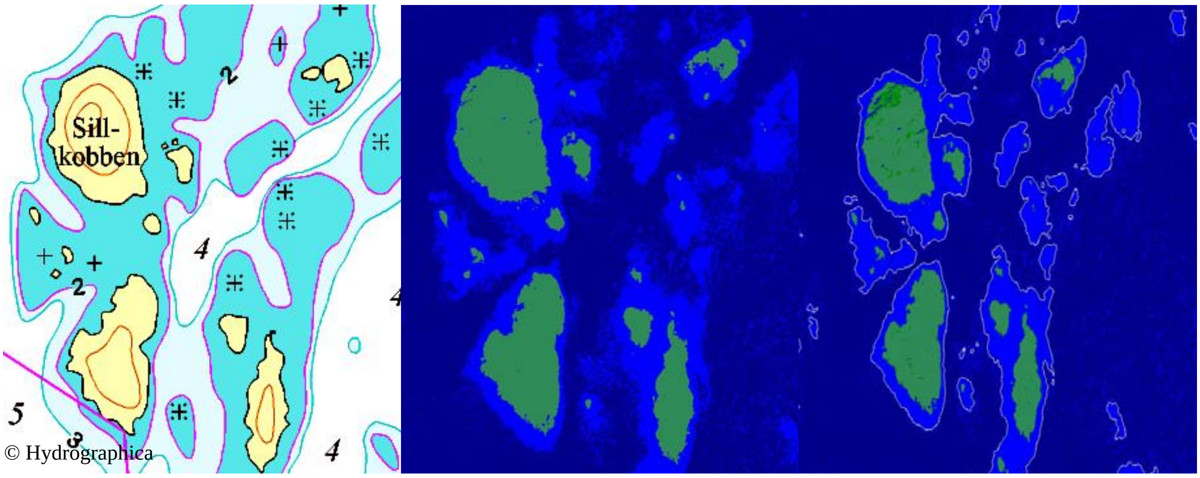

Figure 4-9 to 4-11: Figure 4-9 shows a part of the nautical chart from Hydrographica and 4-10 the corresponding HR-QB area. Figure 4-11 shows a possible 2-meter vector product.

Figure 4-9 shows a part of a nautical chart from Hydrographica. These charts have an additional 2-meters depth isoline and both the 2- and 3-meters depth isoline are more detailed than the one found in the nautical charts produced by SMA. In figure 4-10, we have tried to identify all pixels representing depths between 0-2 meters. The correspondence to the curves in figure 4-9 is relatively good and it should be kept in mind that all chart information is generalised. In figure 4-11, we have converted the raster information to a possible 2-meters depth vector product.

In addition, we have started to investigate the possibility of deriving depth maps based on the green band with 2.4-meter resolution. The analysis, so far, is based on simple segmentation of band 2 intensity levels. Figure 4-12 shows a part of "Femöringarna" in the archipelago of Stockholm. The intensity levels have been segmented into half-meter class intervals, e.g. 1.5-2 meters (orange). The displayed vectors correspond to LASER data for the start of the corresponding depth interval, e.g. orange corresponds to 1.5 meter. Everything located outside the blue vector should be deeper than 3 meters. The same analysis has been made in several areas with promising results and we will now proceed with more sophisticated methods in order to properly evaluate the potential for HR-QB data for this objective.

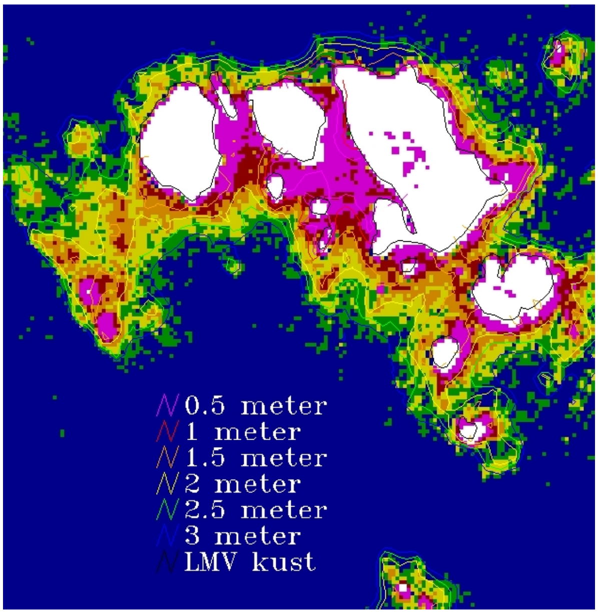

Figure 4-12: Figure 4-12 shows the group of islands called "Femöringarna" in white and the derived depth intervals based on image intensity in band 2. LASER data is overlaid in vector format. The black line is the land contour from NLS.

The work will continue with the application of both empirical and more theoretically based algorithms to derive depth based on the image data. There are several possible methods found in the research literature, but most of them are developed for clear waters. This indicates that we most likely need to make some adjustments and combination of methods in order to get good results in our dark, humic rich, waters.

3.7 Wave correction

Based on the results of the analysis it is clear that if the procedure of identification and mapping of different objects are to be automated, the problems with waves needs to be addressed. Waves/wave crests are spectrally confused with subsurface rocks and shallow areas and the signal is somewhat disrupted by the waves. The waves also blur the representation of the shallow areas. A wave correction algorithm (Hochberg, 2003) has been implemented and tested and improved the appearance of the image data over shallow areas and subsurface rocks. An example is given in Figure 4-13 to 4-15 below. The algorithm cannot be applied to panchromatic data. Wave correction will, if necessary, be included as a preprocessing step in the analysis of image data before the analysis.

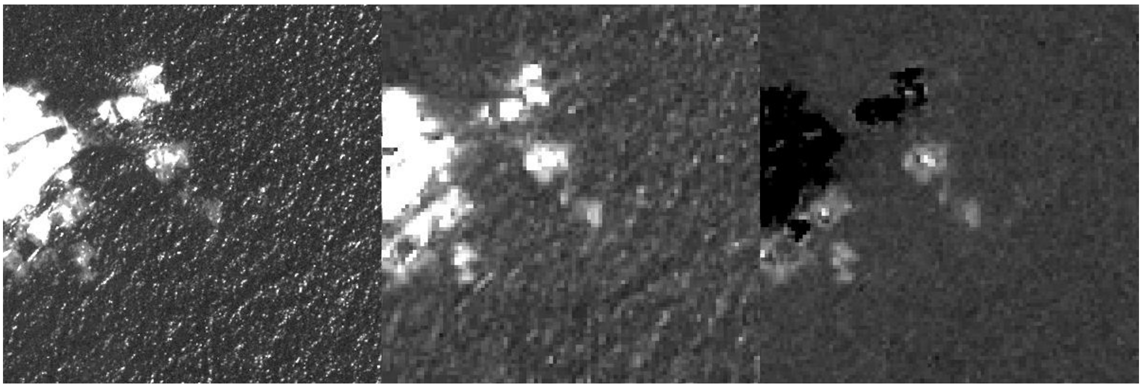

Figure 4-13 to 4-15: Islands and subsurface areas before (4-13: PAN and 4-14: MULTI) and after (4-15: MULTI) the wave correction algorithm has been applied.

4. CONCLUSIONS

The preliminary results show a potential to use high resolution satellite data for mapping of maritime objects as presented in Chapter 4 above. We will continue the analysis and focus on what extent the information collection process could be automated and a more exhaustive analysis regarding the possibility to estimate depth from high-resolution optical satellites.

With respect to the fact that this type of high resolution images can be obtained several times per week, and purchased by anyone and (as a result of these investigations,) the SMA is now investigating the possibility of making depth information public between 0-6 meters in the nautical data base, which presently is classified as secret.

REFERENCES

Granath, L.: www.hydrographica.com, 2008

Hochberg, E.J., Andrefouet, S., Tyler, M.R., 2003: Sea surface correction of high spatial resolution Ikonos images to improve bottom mapping in near-shore environments, IEEE Transactions on Geoscience and Remote Sensing, Volume 41, Issue 7, Page(s): 1724 - 1729

BIOGRAPHICAL NOTES

Dr. Petra Philipson, born in 1974. Graduated in 1996 as Dipl.-Ing. in Mapping and Surveying from University of Gävle, Sweden. Obtaining doctoral degree in 2003 in Aquatic remote sensing from the Centre for Image Analysis, Uppsala University, Sweden. 1996-1998 and 2004 Research and development engineer at the National Land Survey, Sweden. 2004-Present Remote sensing consultant at Vattenfall Power Consultant AB, with main focus on applied projects for aquatic remote sensing.

MSc. Frida Andersson, born in 1981. Graduated in 2005 as MSc. in Geology - Physical Geography from University of Uppsala, Sweden. Carried out thesis at Università di Ferrara, Italy, studying landscape evolution in the PO-delta by using aerial photographs. 2006-2007 teaching in GIS in an Advanced Vocational Education. 2007 – Present working as chart database manager at Swedish Maritime Administration.

CONTACTS

Dr Petra Philipson
Vattenfall Power Consultant AB
P.O. Box 527
SE-162 16 Stockholm
SWEDEN
Tel. +46 8 739 59 33
Fax +46 8 739 53 32
Email: petra.philipson@vattenfall.com
Web site: www.vattenfall.com

MSc Frida Andersson
Swedish Maritime Administration
Östra Promenaden 7
SE – 60178 Norrköping
SWEDEN
Tel. +46 11 19 11 72
Fax +46 11 10 19 49
Email: frida.andersson@sjofartsverket.se
Web site: www.sjofartsverket.se