EMODnet Thematic Lot n°0 – *Bathymetry –High Resolution Seabed Mapping (HRSM2)*

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Satellite Derived coastlines for Europe

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Summary

EMODnet Bathymetry, started in 2009, aims to provide overview and access to available bathymetric datasets and to a harmonised digital bathymetry (DTM) for Europe's sea basins. The EMODnet Bathymetry - High Resolution Seabed Mapping (HRSM2) project is part of the overall EMODnet Bathymetry project and has produced an updated version of a product that was introduced in 2018: a set of coastlines derived from optical satellite images. This has resulted in three coastlines and a dataset that delineates the inter-tidal areas of Europe. The coastlines are given for the three most commonly used levels, i.e. Lowest Astronomical Tide (LAT), Mean Sea Level (MSL) and Mean High Water (MHW). The inter-tidal area is derived as the area between the coastlines at MHW and LAT. These coastlines and inter-tidal areas have been added as an extra layer in the Bathymetry Viewing and Download service (https://portal.emodnet-bathymetry.eu/) which allows users to view these and also to download these as digital files in shape format. The layer has also been included in the WMS – WFS service. Since, the first version of the satellite derived coastline, released in 2018, the updated version now adds coastlines also for the areas at high latitudes, where poor lighting conditions and snow and ice make detection of the coastline hard. In addition, many corrections have been made, such as the addition of Jan Mayen and Madeira. The second version now covers the entire coastline of Europe.

Disclaimer

The EMODnet satellite derived coastline is a high-resolution geography data set (polyline) that must be considered as an estimate of the location of the coastline generated from a methodology involving optical satellite data and tidal modeling. Although the generation of the product has been done with the utmost care, both elements of the methodology might locally generate imprecise results leading to an inaccurate positioning of the resulting coastline.

In consequences as user of this product, you agree that:

- EMODnet Bathymetry does not provide warranties of any kind express or implied, about the completeness, accuracy, reliability, suitability or availability with respect to the information, products, services, or related graphics for any purpose. Any reliance you place on such information is therefore strictly at your own risk.

- In no event will EMODnet Bathymetry be liable for any loss or damage of any sorts arising from the use of this data and derivatives.

- The provided coastlines datasets do not serve as replacement of official coastlines as produced by the responsible national authorities. They should not be used where official coastlines are required.

Introduction

A coastline is a delineation materialised by a curve that separates the land from the sea. Since, the sea-level changes over time through tides and the weather, the instantaneous coastline also changes continuously. For many applications it is more practical to use the coastline at high-water, since this quantity is more stable and it reflects roughly what many people intuitively would consider the coastline. There are many different definitions of high-water, but is common practice to use Mean High Water for this purpose. On the other hand, for territorial claims, it is more common to base these on low water. For this purpose, it is common to use Lowest Astronomical Tides (LAT) (United Nations Convention on the Law of the Sea, 1994). To stay close to common practice, this report and the derived products will use these commonly used definitions. This will also facilitate the comparison to other datasets. It should be noted that the term coastlines often is used in a specific context where there are legal implications, in this context one implicitly refers to the official datasets as produced by the authorities. The datasets described here should not be used for this purpose. On the other hand, the satellite derived coastline described in this report uses a single methodology everywhere, ensuring a uniform generation of this product across Europe and thus can be used to compare with other coastline data. In addition, it can be useful where no other high-resolution coastline is available. Moreover, this methodology benefits from the fact that satellites revisit the same area frequently (e.g. Sentinel 2 has a revisit frequency of 5 days) allowing for frequent updates (in case of coastal erosion or anthropic effects) and for detection of tidal influences.

This document describes the work related to satellite derived coastline that has been carried out within the EMODnet-HRSM and EMODnet HRSM2 projects. The first part of the document describes the methodology for coastline retrieval. The following section presents the tidal correction methodology. Finally, the results and the conclusions are presented.

Note: The EMODnet Bathymetry - High Resolution Seabed Mapping (HRSM2) project is part of the overall EMODnet Bathymetry project which started in 2009.

Methods

The identification of a “coastline” involves two general stages: the first requires the selection and definition of a coastline indicator feature, and the second is the detection of the chosen coastline feature within the available data source. To date, there are different techniques and algorithms for coastline detection. Recent photogrammetry, topographic data collection, and digital image-processing techniques now make it possible for the coastal investigator to use objective coastline detection methods. Some of the methods to be explored further are presented below.

Surface water detection from multispectral images

Existing methods for surface water detection from multispectral satellite data use the fact that water significantly absorbs most radiation at near-infrared wavelengths and beyond. This fact makes it easy to detect clear water employing spectral indices, such as the Normalized Difference Water Index (NDWI), McFeeters (1996).

$$NDWI = \frac{\rho_{green} - \rho_{nir}}{\rho_{green} + \rho_{nir}}$$

where ρ_{green} and ρ_{nir} correspond to the spectral reflectance of green and near-infrared bands. By design, the index values (similar to normalized difference vegetation index (Rouse Jr et al. (1974)) vary between -1 and 1, with water appearing mostly when the index value is greater than zero.

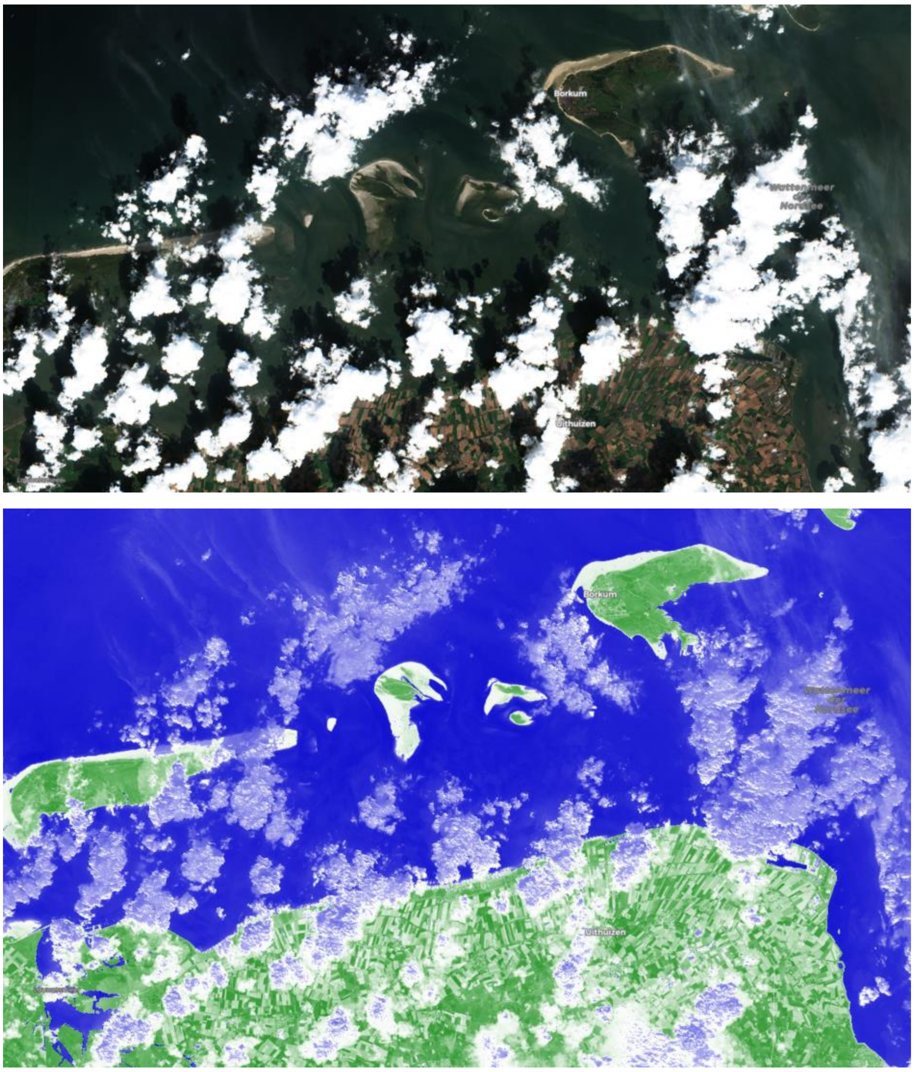

Figure 1 Level 2 True color and NDWI images from Sentinel 2 on August 18 2020 for Wadden Islands around Borkum

NDWI has been used to distinguish between land and water (Bayram et al, 2008; Kuleli et al, 2011; Almonacid-Caballer et al, 2016) and, hence, detect the coastline from satellite images. This technique was used for example in Donchyts et al. (2016) to study changes in land cover worldwide. The availability of Landsat satellite imagery allows us to study these coastlines from 1984 until now with a pixel resolution down to 15m. The recent Sentinel-2 satellite mission (ESA, 2016) even go up to a pixel resolution of 10m. Based on these images historic trends in coastal erosion can be detected. Recent work to assess the accuracy of satellite derived coastline trends compared to survey data has shown very promising results for a case study of the Sand Engine mega nourishment in the Netherlands. Similar analysis can be made to derive other coastal parameters such as vegetation (FAST, 2017), sand and human infrastructure.

In EMODnet-HRSM, NDWI algorithm is used to derive coastlines for the European waters, this in combination with a tidal model allows, to retrieved coastlines at different vertical datum (e.g. MSL, MHW, LAT).

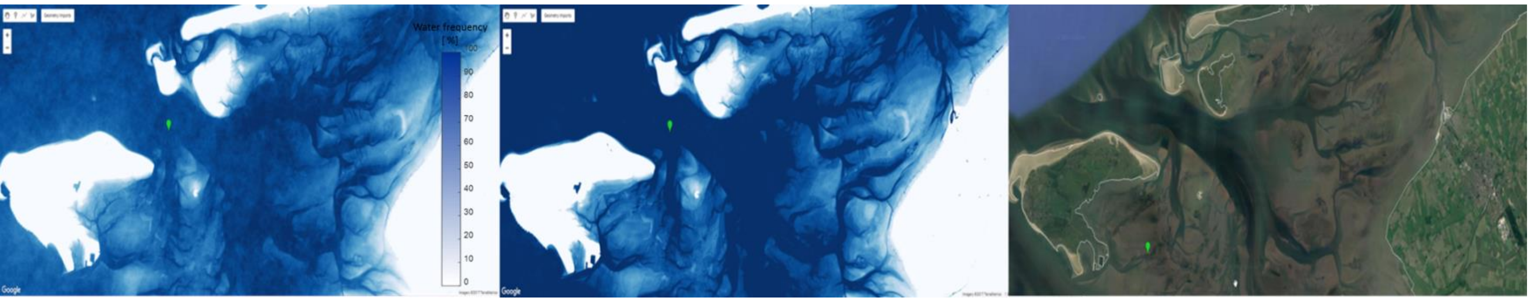

Figure 2 Water occurrence estimated from Landsat 8 and Sentinel-2 images around Wadden Island Borkum (Germany), the first image shows the water occurrence computed as a simple mean NDWI value from all images, the second image shows water occurrence estimate using statistical cloud removal method, and the third image the MHW coastline retrieved from water occurrence.

Method for the coastline estimation from optical satellite images

While a single satellite image can be used to detect coastline geometry, a much more robust approach is to combine multiple satellites. This allows capturing not only coastline geometry, but also variations in the coastline geometry due to tidal water level changes. A number of methods were proposed recently to capture this variation in order to derive inter-tidal bathymetry (Sagar, 2017).

Processing of satellite images at large spatio-temporal scales is a challenging task, due to large volumes of satellite data to be processed, but also, due to variety in the satellite data radiometric properties and formats. In this project, we have used Google Earth Engine platform (Gorelick, 2018) to overcome some of these challenges. The platform allows parallel processing of huge volumes of satellite data in reasonable time and also harmonizes satellite data acquired by different satellite missions performed by NASA and ESA. In this project, we have used a mixture of top-of-atmosphere reflectance satellite images from NASA/USGS Landsat 8 and ESA Sentinel-2 satellite missions, acquired during 2013-2020.

Automated detection of surface water from multispectral satellite images using passive sensor has received significant attention in recent years, Donchyts, 2016 (a), (b)., Pekel, 2016. A number of algorithms were developed to make surface water detection fully automatic. The main sources of noise for optical images are:

a) Clouds and cloud shadows

b) Shadows due to topographic effects

c) Atmospheric effects (scattering, aerosols)

d) Urban areas (complex spectral signal resulting in false-positive surface water)

e) Snow and ice

f) Systematic errors (georeferencing and georectification, sensor hardware of software errors, limited radiometric resolution)

g) Variable thresholds for land/water discrimination when using classical NDWI spectral index

h) Coastline with a very dynamic morphological changes

To address most of these challenges, we have used statistical methods to process and combine a large number of satellite images. In particular, instead of detecting surface water from satellite images using fixed NDWI threshold, the images were processed to represent a probability of land/water boundary, a values close to 1 indicates that a particular pixel is always "wet", therefore almost sure that location is water. The algorithm shown in 3 was used to process most images from Landsat 8 and Sentinel-2 missions covering EMODnet project area.

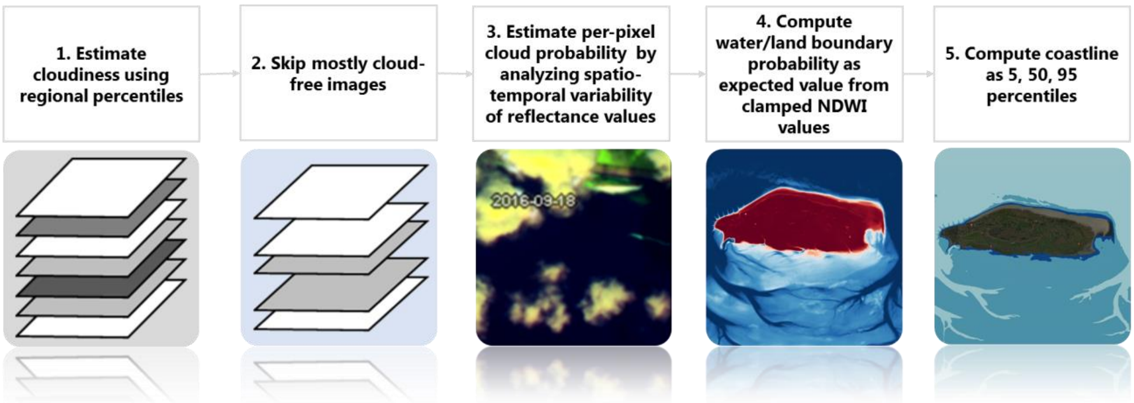

Figure 3 Processing pipeline for coastline detection from optical satellite images, capturing intertidal water level changes

Instead of performing a direct cloud masking for every image, our algorithm fist "learns" the overall distribution of reflectance values within observed over every pixel as the first step. Then, a cloudiness metric is introduced for every image covering the area where potential coastline boundary is expected to be located. This metric is then used to filter-out images mostly covered by clouds. Then, a more robust per-pixel cloudiness probability is computed by comparing its values with the spatio-temporal distribution with a small neighbourhood around every pixel. The resulting cloudiness probability is used to estimate the final water occurrence, computed as the weighted average, using cloudiness as weights. The final water occurrence is used to estimate the coastline geometries.

After assigning cloudiness metric for every image (patch/tile), the algorithm uses mean cloud frequency estimated by Wilson, 2016 to determine the number of images to skip, significantly reducing noise in the resulting time series, 4. For northern regions (The Netherlands, UK, Germany, Sweden, Finland), the mean cloud frequency is relatively high (~60-80%), resulting in only a fraction of satellite images can be used for processing. While this can be an issue for the analysis covering short periods, we were able to overcome it by using all of the available images acquired during 2013-2017.

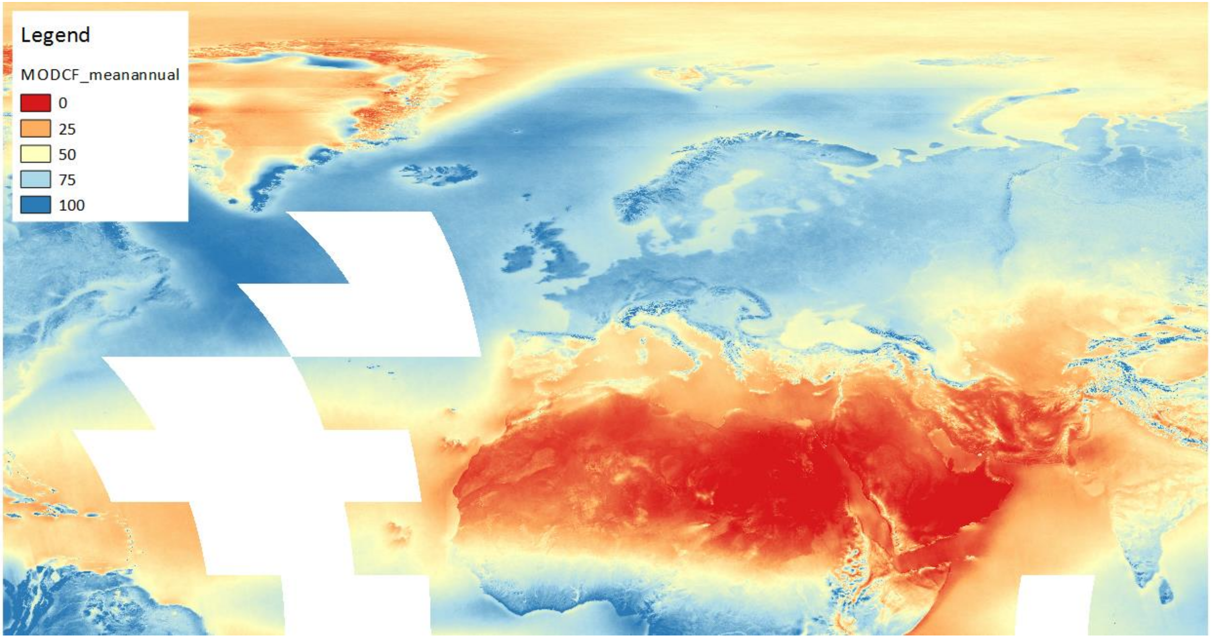

Figure 4 Cloud frequency (0-100) used during step 2 of the algorithm

The Figure 5 shows an example of the final water occurrence estimated using the method outlined above. This spatial resolution of this water occurrence varies between 10m and 30m, depending on the number of Sentinel-2 and Landsat 8 images available for a given area and cloud conditions.

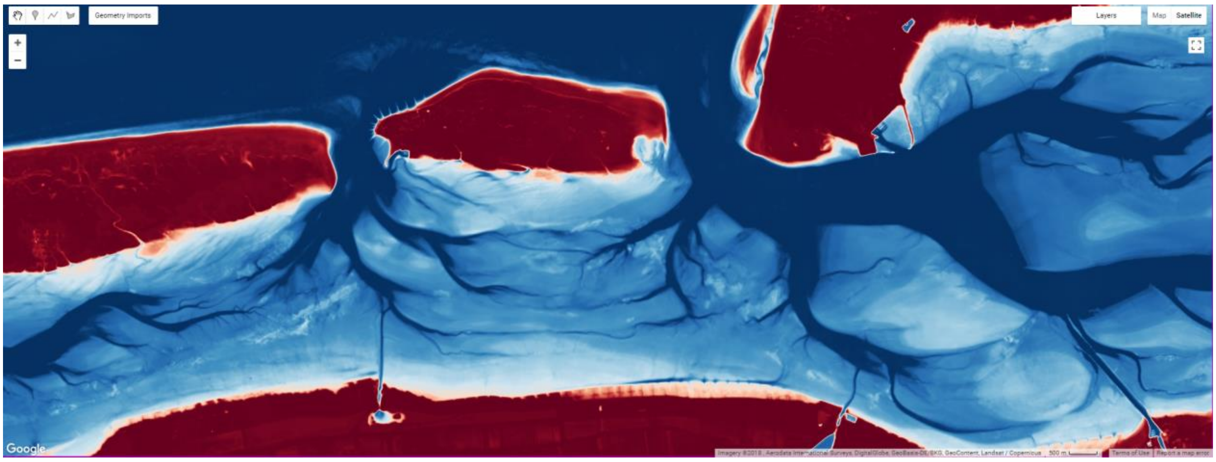

Figure 5 Water occurrence computed as expected value from all NDWI values, using per-pixel cloudiness values as weights (dark blue = permanent water, red = land).

Linking water occurrence to tidal level

In the introduction the coastline was defined as the physical interface between land and water, but this is also the most dynamic part of the coastal zone. Although much of the published literature have studied the problem of coastline position from multispectral images, only a few papers have addressed the problem of mapping the tide coordinated coastline.

Because of the dynamic nature of the ocean waters and of the near coastal lands we introduce the definition of an instantaneous coastline to point out that line position is relative to a given instant of time (Li et al., 2002). Thus, the coastline needs to be defined in a stable vertical datum in order to be used as a reference coastline. If this vertical datum is defined as the linear intersection between the coastal surface and a desired water tidal level, the coastline is called tide-coordinated coastline (Li et al., 2002).

The tidal amplitudes are often amplified near the coast, while at the same time the spatial variability increases because the tidal wave propagation slows down in shallow waters. Tides are small in some regions, but can also reach extremes of 13 meters in the Bristol Channel or 12.3 meters in Bay of the Mont Saint Michel, for example. Traditionally, corrections for local sea level have been computed from local tide gauges or tidal forecasts. On a global scale the number of permanent tide gauges is not sufficient to interpolate to arbitrary locations. At the same time, satellite-based altimeter observations of sea level do not have a sufficient temporal and spatial resolution to be used directly for correction of dynamic variations of the sea-level

In this project, the correction for sea level variation is based on use of the Global Tide and Surge Model (GTSMv3.1), which provides instantaneous water level and tide levels with global coverage. To ensure sufficient resolution near the coast, an unstructured grid model is used (Irazoqui et. al. 2018 and Kernkamp et. al. 2011).

As the accuracy of the coastline position extracted from satellite images depends on the range of tidal height at the satellite overpass time (Yu et al., 2011), it is important to link to the tidal height at the time of image acquisition. The availability of GTSM tidal information allows retrieving water level at any time and location and compute satellite derived coastline to a coordinated tide level. The availability of the conversion between these vertical reference frames makes it possible to connect data-sets using different vertical reference frames, and conversion to a reference frame of choice for the user. The schematization of the vertical datum referencing process is shown in figure 6.

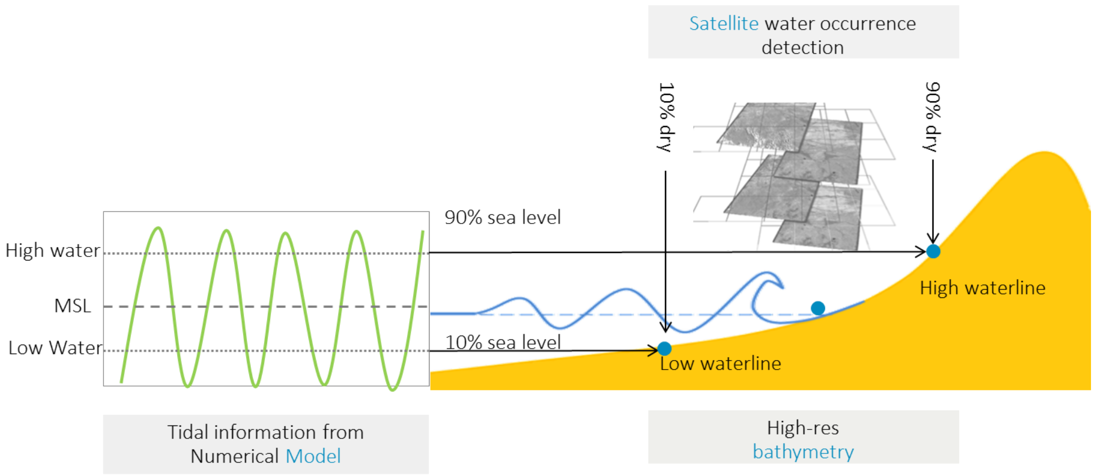

Figure 6 schematization of the vertical datum referencing of satellite derived coastline

Instead of linking to the water level for individual images we used the distribution of water occurrence and the distribution of the local water level to link both. Unfortunately, there was too much noise in the images near the extreme values of the water occurrence distribution, so we had to limit the levels to within the 5% to 95% range. The value of LAT is almost everywhere at a level of more than 95% water occurrence. In the end, it was decided to link LAT to 95%, MSL to 50% and MHW to 95% for the first version of this satellite derived coastline, to describe the maximum tidal range attainable at this time. Future work will aim at more accurate representation of MHW and more extreme levels. The water occurrence grids were contoured on a tile by tile basis.

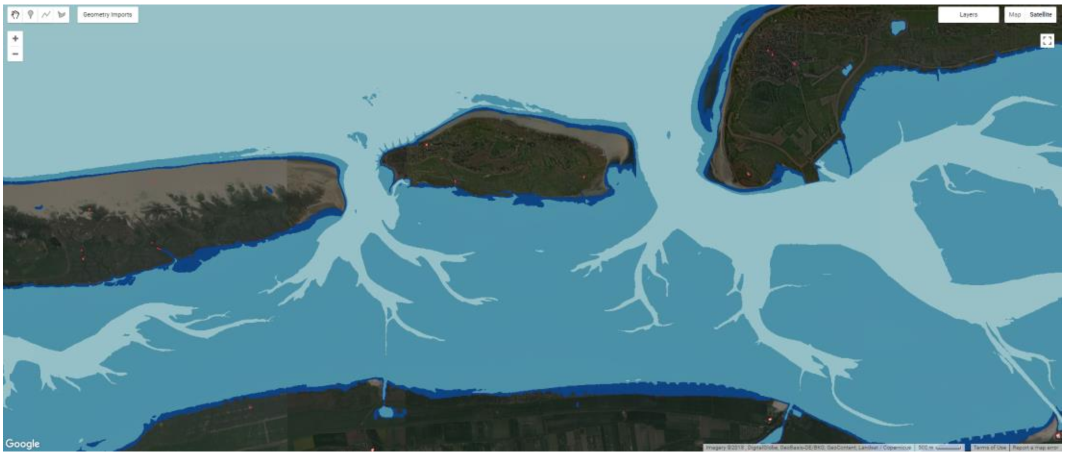

Figure 7 Coastline polygons for MHW, MSL, LAT estimated as 5%, 50%, and 95% percentiles of water occurrence images.

Coastline detection at high latitudes

Deriving coastline for Northern regions such as Greenland and Svalbard can be very challenging due to high cloud cover and the fact that land and water are frequently covered by snow and ice. Furthermore, deriving water/land boundary from optical images in these areas can results in false-positive water detection due to low sun elevation.

However, in recent years there was very little snow and ice end of summer, which makes detection of the coastline easier. In addition, we have used Sentinel 1 radar images to reduce the false positives.

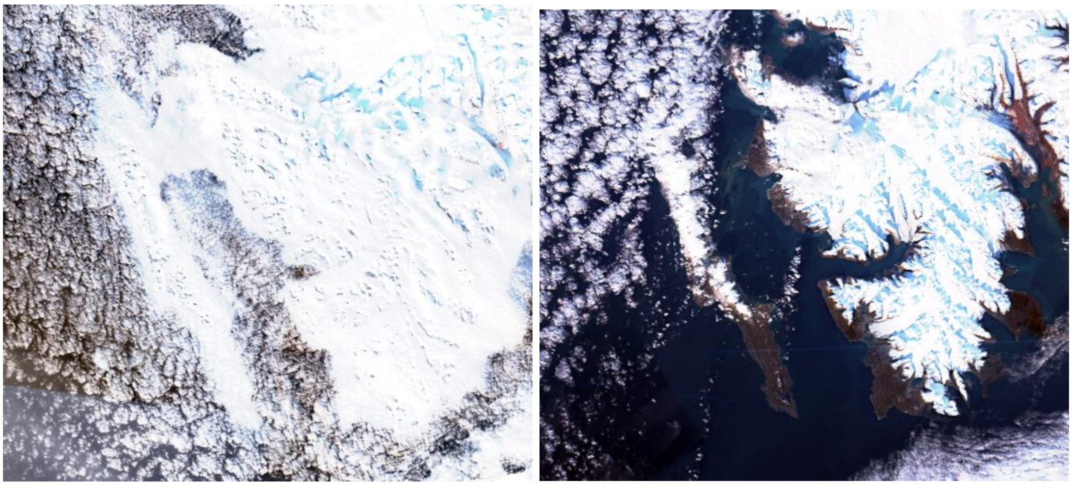

Figure 8 Sentinel 2 optical images of Western Svalbard on March 21 September 25, 2020.

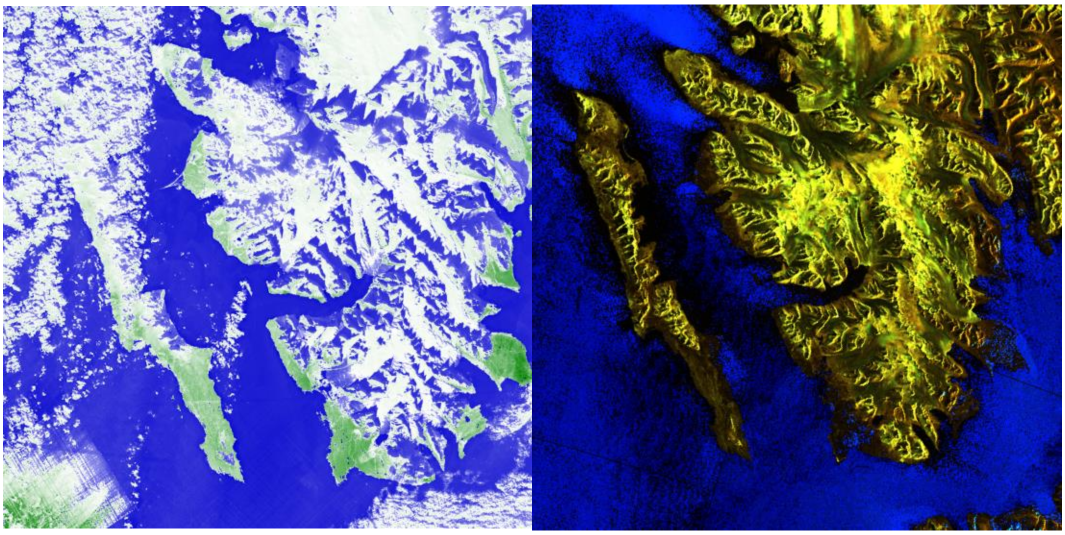

Figure 9 NDWI for Sentinel 2 on September 25 and Sentinel 1 SAR image on September 26, 2020

To overcome these challenges, we have decided to combine optical (Landsat 8) and SAR (Sentinel-1) images acquired only during summer months (June to September). All images acquired during these months are used in processing to generate input features for supervised machine learning algorithm Random Forest (Breiman 2001). The overall algorithm can be outlined in the following steps:

1. For every processing tile, generate input features by combining 100-1000 summer images of Sentinel-1 (HH, HV polarization), use 35% percentile, neighbourhood mean, std as input features
2. For every processing tile, generate input features by combining 100-1000 least-cloudy Landsat 8 images, use 10% percentile, std as input features
3. Generate weak labels using stratified sampling and OpenStreetMap coastline as land use classes, use 1. and 2. as input features
4. Train the first Random Forest classifier with the output = PROBABILITY
5. Remove confusing input samples by analysing probability histogram
6. Train the second Random Forest classifier with the output = CLASS
7. Generate the final coastline

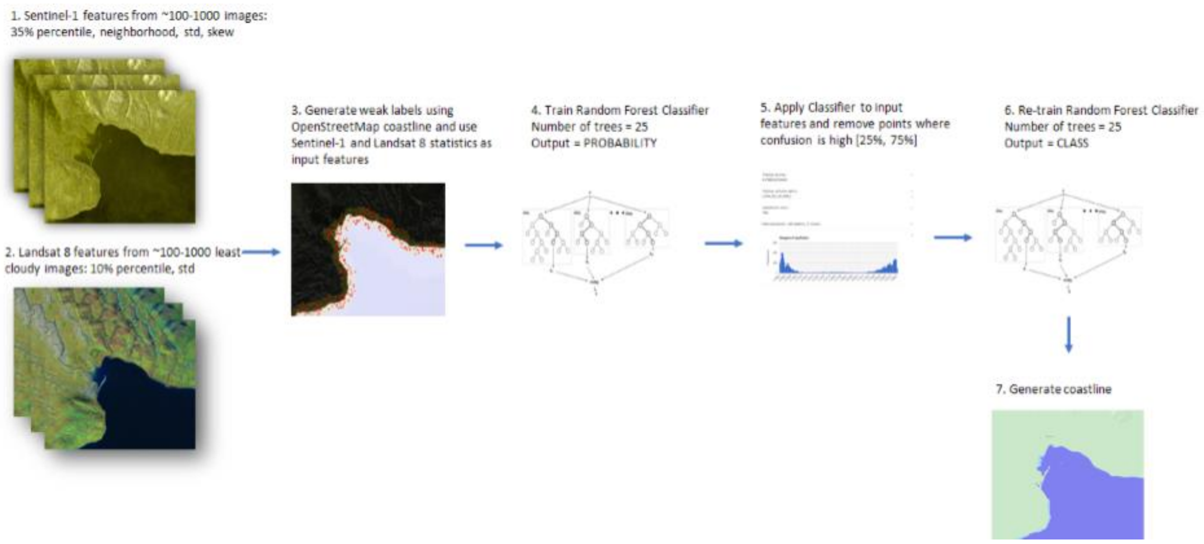

Figure 10 Workflow of the semi-supervised algorithm used to generate the coastline for Greenland, Jan Mayen and Svalbard from Sentinel-1 SAR and Landsat 8 optical data

The resulting coastline shows a very high performance, but still required minimal manual checks to eliminate false land detecting in the areas where number of satellite images is low or where confusion is very high (e.g. water areas always covered by moving ice or very steep hilly areas).

Next the coastline was generated from the raster classification to vector format at 10m resolution. Several additional steps were applied to ensure quality of the results, such as:

- Overriding pixel classes as deep water (EMODnet < -50m), as shown in Fig 11
- Overriding pixel classes as land for high elevation pixels (ALOS DEM > 50m)
- Manual overriding of pixels to be water or land based on visual inspection
- Fallback to OpenStreetMap coastline for the most Northern regions, Figure 12

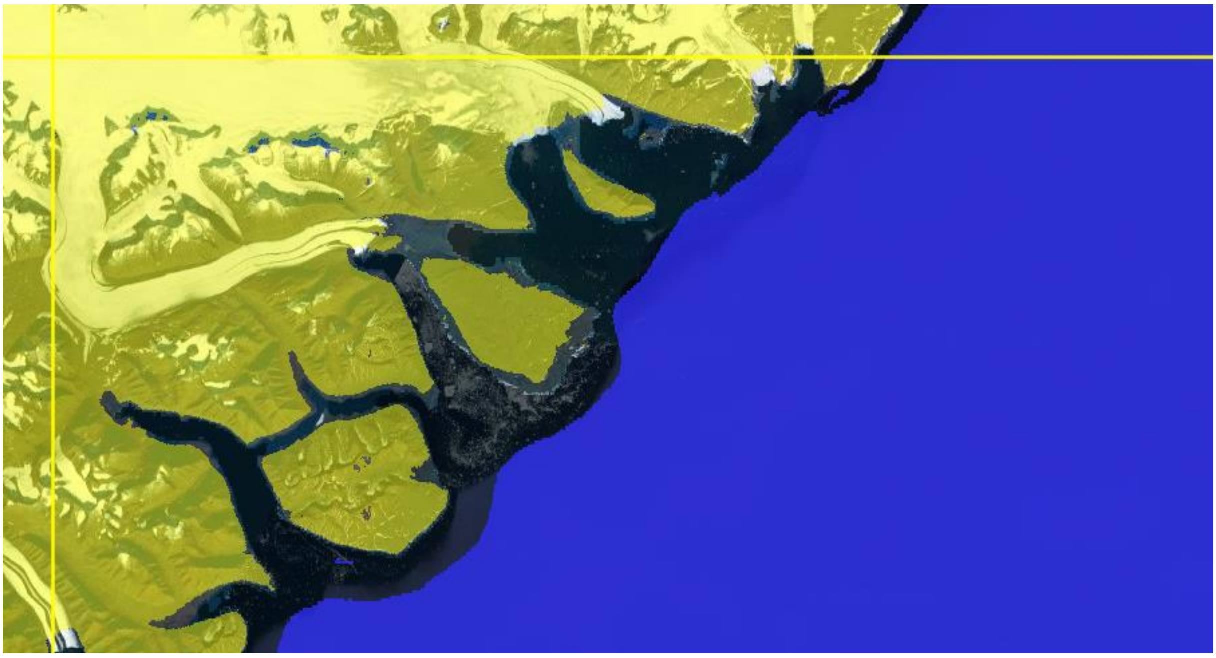

Figure 11 The classified coastline was combined with EMODnet to remove some of off-shore false-positives created by floating ice, all pixels where water depth is < -50m were classified as water. Correspondingly, all pixels where the ALOS DEM was higher than 50m were classified as land.

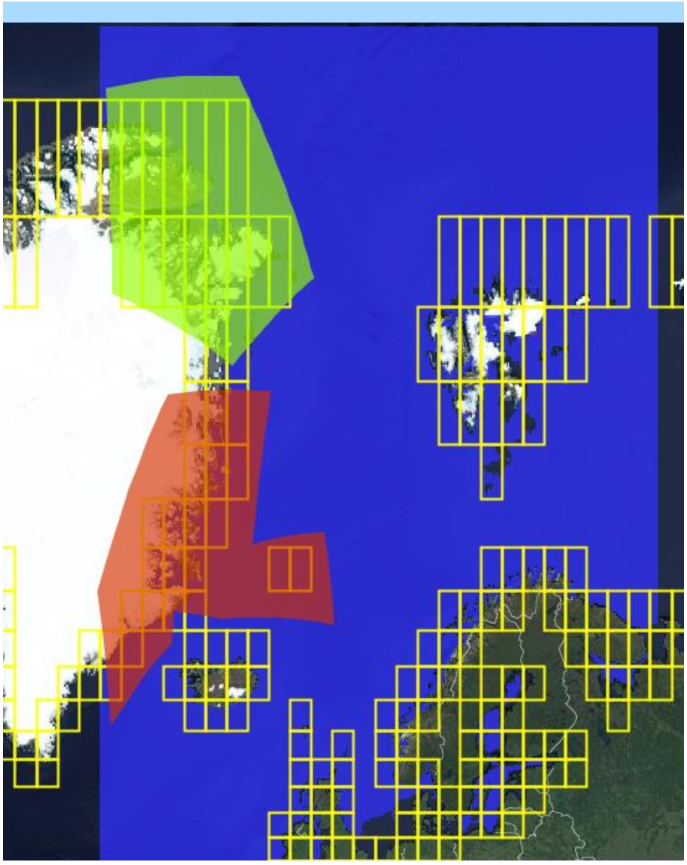

Figure 12 Greenland tiles where OpenStreetMap was used to extract coastline (green) and where Random Forest based algorithm was applied (red)

It's important to note that the Northern regions marked green in Figure 12 are much smaller than they seem, because the area is stretched by the Web Mercator projection used for visualization.

The fallback to the OpenStreetMap coastline was applied only to the tiles where ice was present on almost all optical or SAR images, like shown in Figure 13, where some of the areas are misclassified as land due to permanent ice present in all images. Further improvements may be possible in future versions of the classification scheme, but at the moment too many false islands are generated.

Figure 13 Comparison of Google base map (left), Landsat 8 5% TOA reflectance composite (middle), and reconstructed coastline (right). Some areas with almost always permanent ice present on the sea surface are still classified as land.

For the Arctic regions, we did not derive separate low and high-water coastline, since limiting the images to summer only in combination with the poor lighting and high cloud cover leaves too few images for this type of analysis. Fortunately, much of the coastline in this region shows only a small inter-tidal zone. This implies that in the final coastlines the data for low-, mean- and high-tide will coincide.

Post-processing and generation of final products

After land-water detection and contouring, as described above, there are still several steps needed to produce a final set of products. First the data needs to be exported from the Google Earth Engine (GEE). Next, we need to remove water that was detected, but where we do not consider it to be part of the coastline. Then we compute the inter-tidal area as the area between the low water and high-water. Finally, we need to merge the data, since this is computed and exported in GEE, in many rectangular tiles.

Export of polygons per tile

After processing optical satellite data to the level of polygons that together cover the water as detected, we exported the data. Since the GEE computations were organized in small rectangular areas to facilitate parallel computation, this resulted in a large number of files. The figure below gives an overview of the division into tiles. Each tile has an ID, i.e. the number also shown in the figure below. For efficiency, the tiles that consist entirely of land or entirely of water were excluded from the computations in GEE. After the export, we added these back into the dataset.

All gaps in the data that existed in the previous version of the coastline have now been filled. The coastline should cover the entire region shown below.

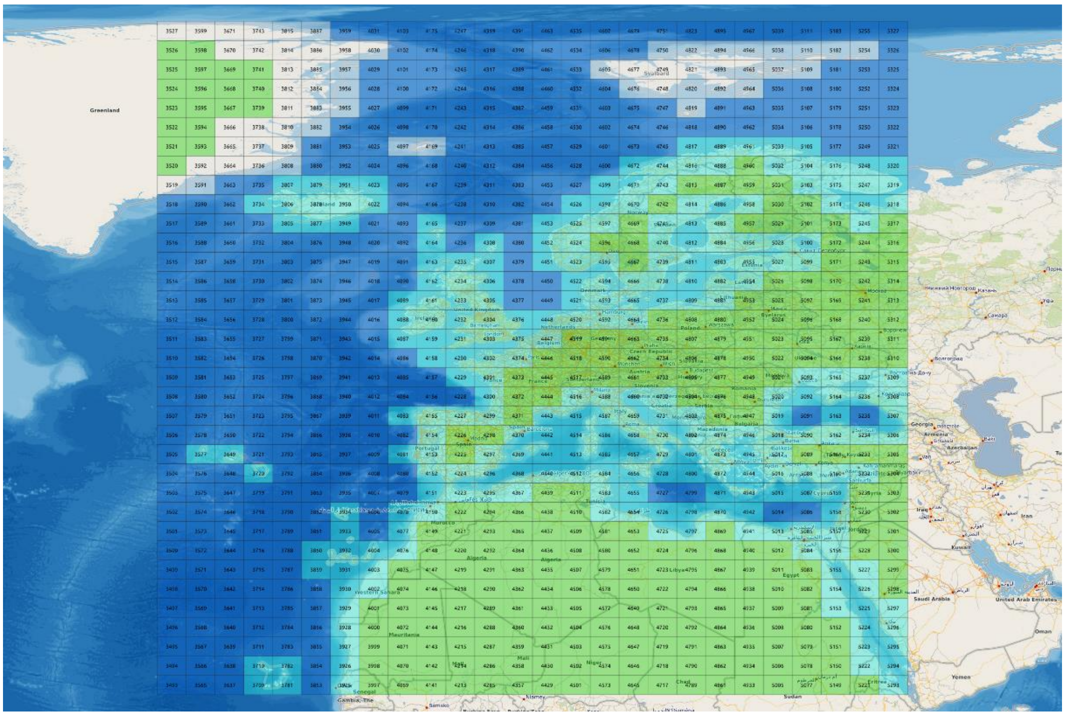

Figure 14 Tiles exported and their status: land only (green), water only (dark blue), part land/part water (light blue), combined optical-sar detection (white)

Filtering lakes

The water detection algorithm does not distinguish between fresh and salt water, resulting in many lakes and other surface water to appear that are not considered to be part of the coastline. It may not be possible to create a clear separation in all cases. The aim of the processing step described here is to eliminate smaller water-bodies that are not connected to open sea. This eliminates many features. We have designed the filtering procedure and threshold to be conservative, i.e. not to delete water-bodies that might be part of the coast line. This implies that the data-set will contain water-land boundaries that we would not consider to be part of the coastline.

The figure below shows part of the Netherlands before and after filtering of small disconnected water-bodies. It can be seen that the North Sea Channel connecting the harbour of Amsterdam to the North Sea is connected to the North Sea in this data-set, but in reality there are sluices near the coast, that separate the water in this channel from the North Sea. Apparently the sluice gates were not detected from the satellite images. In the current version of the satellite derived coastline we have kept these features. In future versions, we may remove the most important internal waters manually.

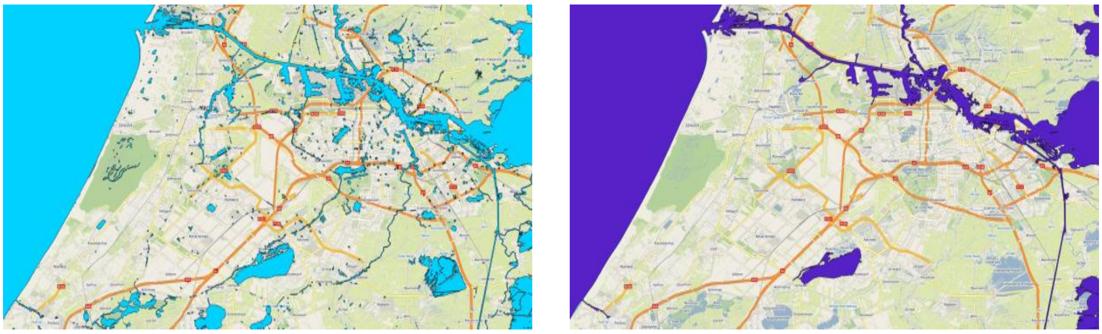

Figure 15 Example of images before (left) and after (right) after filtering water bodies that do not belong to the coastline

Computation of inter-tidal areas

To compute the inter-tidal area we have computed the set-difference of the area covered at high-water minus the area covered at low water. The figure below gives an example for a part of the Wadden Sea (Netherlands). In the final dataset the parts for each of the tiles were merged into one dataset.

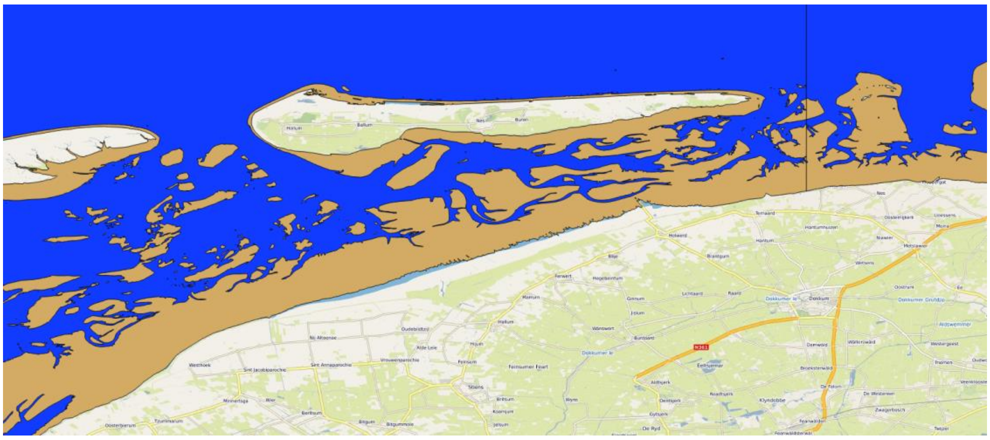

Figure 16 Inter-tidal area (Orange color), computed as set-difference of water at high-water and at low-water

Conversion to Europe wide coastline

Finally, the parts of the coastline per tile were converted from filled-polygons to poly-lines. Figure 17 illustrate the SDC plotted as a line.

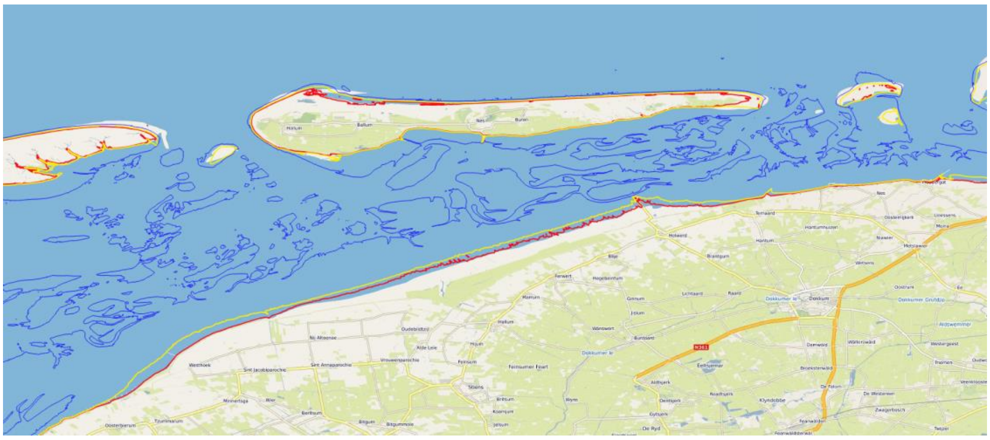

Figure 17 Plotted coastline as poly-line format (Final product delivered)

Coastline comparison

This section presents a visual comparison between the Satellite Derived Coastline (SDC), the coastline derived from Open Street Maps[1] (OSM) and the coastline provided by EMODnet project partners.

The OSM coastline has been derived from Open Street Map ways tagged with `natural=coastline`. This data contains all the detail available in OSM. For small scale maps (small zoom levels) it might be too detailed and therefore slow to use and not well readable. The OSM coastline projection is in WGS84 (EPSG:4326) or web Mercator (EPSG:3857). The coastlines can be obtained as lines and/or land polygons and/or water polygons.

Within the EMODnet-HRSM2 project, one task was to gather official coastlines for the European waters. Information about coastline has been gathered per country, the data comes in different coordinate system and at different spatial resolutions. This data set is also used for the visual comparison and we will refer to it as "Official Coastline".

The visual examination after the retrieval process showed that the SDC coastline is generally in good visual agreement with OSM and the official coastline. The comparison suggests that the discrepancy between the SDC and the other data sets remains within the pixel size in sandy beaches. This comparison therefore bodes well for future attempts to detect coastline changes of larger magnitude than the pixel resolution (10 m).

There are areas where there is a bigger discrepancy between the SDC, OSM and the official coastline. For example, in areas under land reclamation or human intervention the coastline changes rapidly over time. Resolution and accuracy of OSM coastline is variable since it is the result of many contributions by many people and from many sources.in the other hand updates in the official coastline might not be as

[1] Coastline in OSM is defined as the mean high water spring line between the sea and land (with the water on the right side of the way). https://wiki.openstreetmap.org/wiki/Map_Features

fast as the changes due to human interventions. To illustrate this example we present Figure 18. The figure shows Luka Ploce in Croatia, where SDC gives a more detailed contour of the Port in that area.

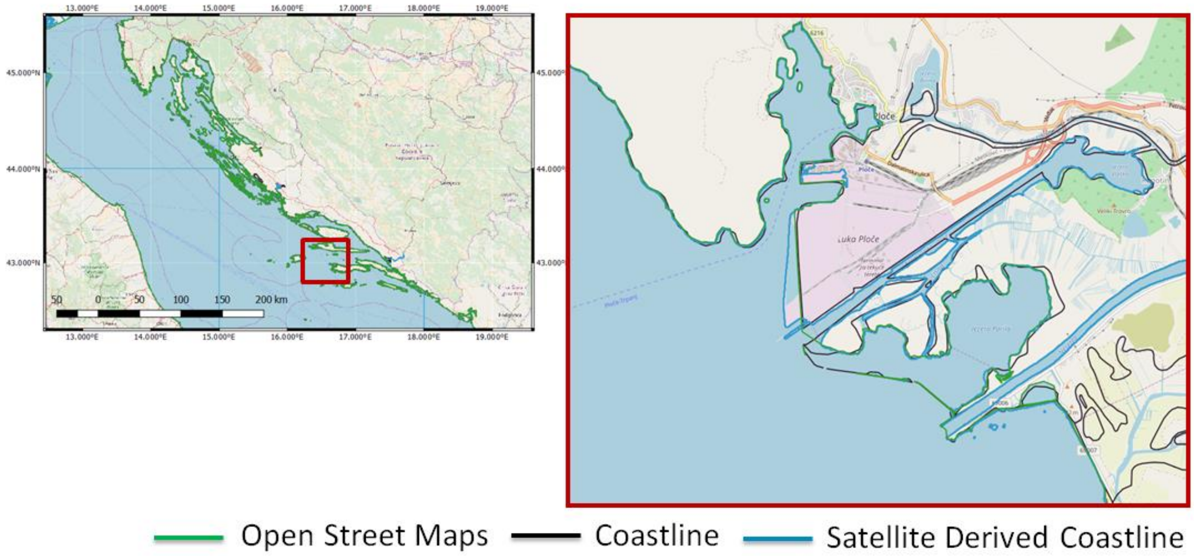

Figure 18 Croatia (Luka Ploce): comparison between SDC (high water), OSM and coastline from official sources

The fact that the biggest discrepancy while comparing the coastlines were consistently observed at intertidal areas, indicates that the current tide level, possible effects of storm surges and the beach slope, play and important role. Figure 19 present the comparison between the different coastlines in an intertidal area. The chosen case is situated in the Netherlands. Terschelling is one of the islands situated in the Wadden Sea. This area is the largest unbroken system of intertidal sand and mud flats in the world. Morph dynamics is very active here, so coastline changes rapidly. The beach is also very flat, so that small differences in approach lead to large spatial differences. The difference between the SDC, the OSM coastline and the official coastline can reach a difference up to 650 meters.

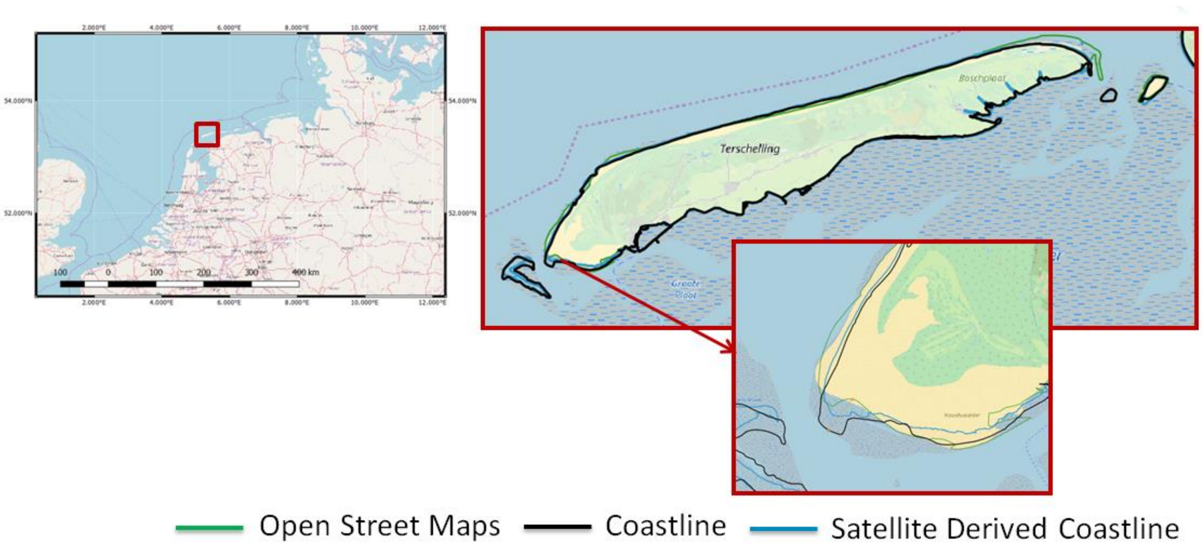

Figure 19 Netherlands (Terschelling): comparison between SDC (high water), OSM and coastline from offical sources

Coastline has been defined as a line that forms the boundary between the land and the ocean. Nevertheless are some regions that line cannot clearly be established. Precisely in those regions, the discrepancy between the SDC, the OSM coastline and the official coastline tend to increase. Figure 20 present a peculiar case in Portugal (Aveiro) where SDC provide more detailed information that OSM and the official coastline.

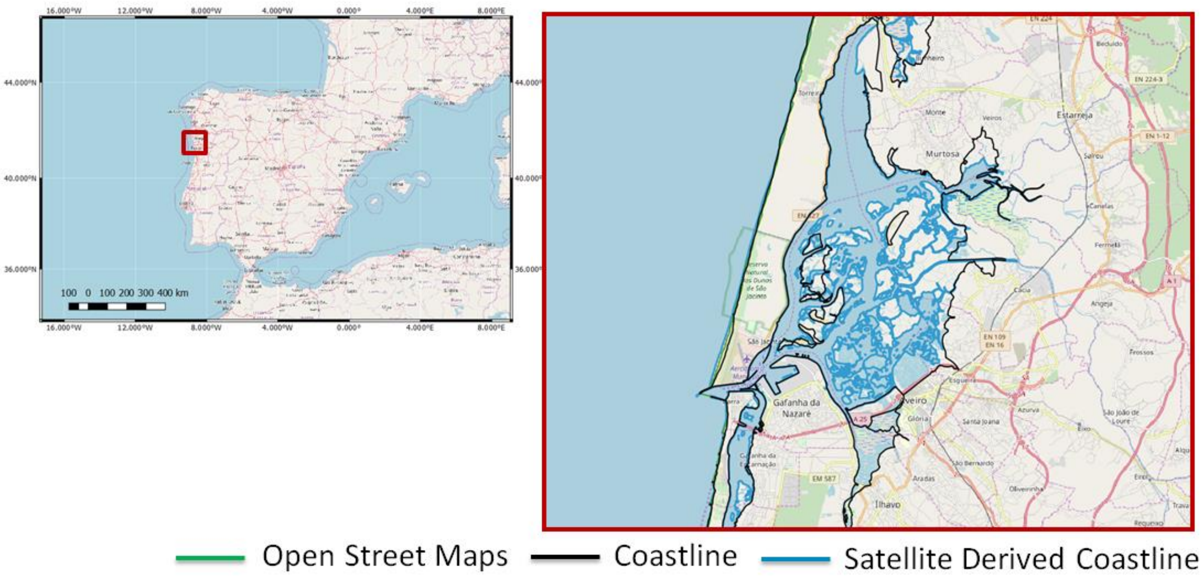

Figure 20 Portugal (Aveiro): comparison between SDC (high water), OSM and coastline from offical sources

At high latitudes the performance of the new detection algorithm is generally good. Difficulties arise in some areas which combine frequent ice and high cloud cover rate. Note also that the edge of glaciers is dynamic and thus depends of the timing of the satellite images used. Meltwater from glaciers also introduces much sediment into the water, which makes detection harder.

The figures below compare the new method (green) against Open StreetMap (OSM red), with a Google satellite image as background.

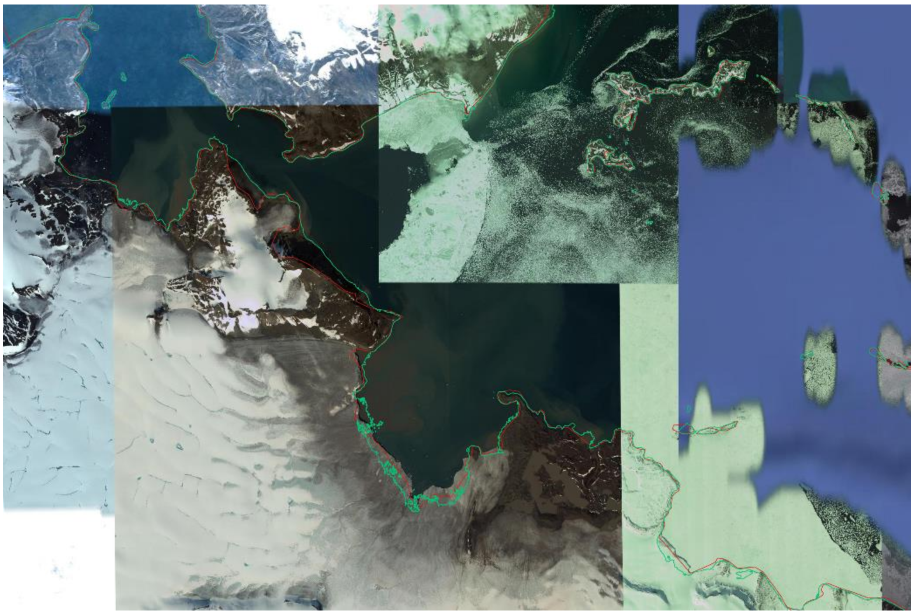

Figure 21 SDC (green) against OSM (red) for eastern Svalbard

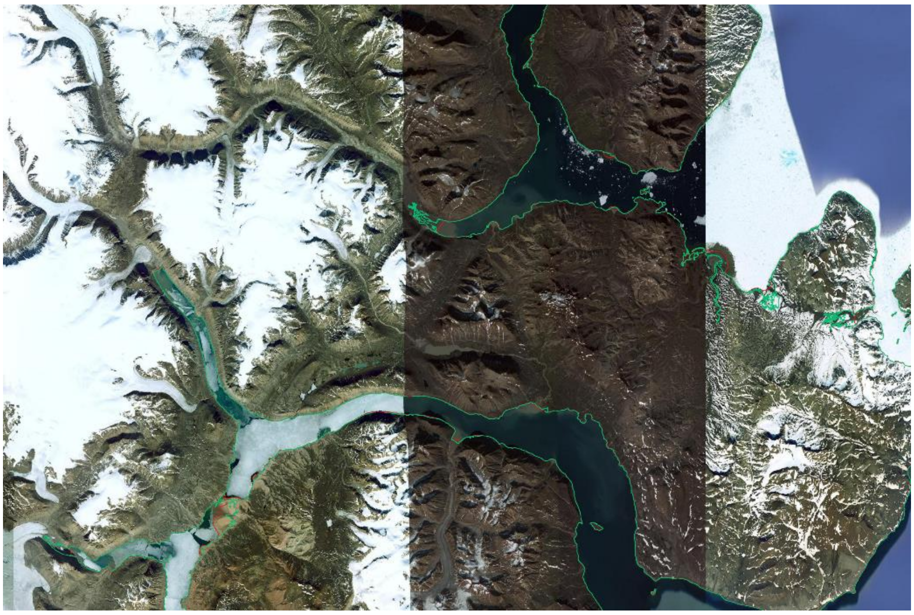

Figure 22 SDC (green) against OSM (red) for eastern Greenland

Conclusions and recommendations

In this report we described the methods used to derive a coastline from optical satellite imagery. In comparison to other sources, the coastline retrieved from satellite images shows good agreement in most areas. It is consistent with the Open Street Map (OSM) and the official coastlines, giving confidence that the interpretation of different positions of SDC shows a real representation of the coastline at different datum.

For the second version, a new detection algorithm has been developed and applied for hight latitudes, where snow and ice, high cloud cover and low sun angle make detection difficult. The method is based on a combination of optical images and Sentinel-1 SAR images. The detection works well, except in the most northern part of Greenland.

Although the quality is generally high, the following aspects could be improved:

- At high latitudes, there are a few areas with too few useful images, resulting in some ice to be classified as small islands. Even with the current quality checks not all were removed. Improvement is desirable in future versions
- We did not succeed so far to detect the coastline at low water for Iceland and the Faroe Islands. Perhaps the very high cloud cover and poor lighting conditions are to blame. This needs further investigation.
- NDWI is not robust for very turbid water. In the future, we wish to extend the analysis to use MNDWI and maybe other indices to improve quality for these regions (in particular, UK) is needed.
- Shadows at steep coasts and spray in the surf zone is sometimes accidentally classified as land.
- A further exploration and improving of the algorithm in urban areas is needed. For example, construction activities during the period of the analysis may lead to misclassification of these areas as inter-tidal.

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Annex – digital satellite derived coastlines and intertidal areas

The satellite derived coastlines and dataset that delineates the inter-tidal areas of Europe as determined and described in this report are available for viewing and for downloading as digital files in shape format. Therefore these coastlines and inter-tidal areas have been added as an extra layer in the Bathymetry Viewing and Download service (https://portal.emodnet-bathymetry.eu/). The coastlines are given for the three most commonly used levels, i.e. Lowest Astronomical Tide (LAT), Mean Sea Level (MSL) and Mean High Water (MHW). The inter-tidal area is derived as the area between the coastlines at MHW and LAT. The extra layer is also included in the WMS-WFS service.