The BASE-platform project: Deriving the bathymetry from combined satellite data

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SUMMARY

The project "BAthymetry SErvice platform" (BASE-platform) addresses the lack of available up-to-date, high resolution bathymetry data in many areas of the world. With the increasing number of earth observation satellites, e.g. by the ongoing deployment of ESAs Sentinel fleet, remote sensing data of the oceans is widely available. BASE-platform's ambition is to use this data for creating bathymetric maps and supply them to end users.

Three sources of satellite information are combined in BASE-platform: optical, Synthetic Aperture Radar (SAR) and altimetry data. From optical satellite images, the water depth can be obtained by analysing the spectral changes of the seafloor. This method works in optically shallow waters only, where the seafloor contributes a detectable part of the measured signal. Farther from the coast, SAR bathymetry is used which detects changes of wave lengths in the ocean, indicating changes of the underlying bathymetry due to the shoaling effect. Information about deeper areas is then acquired from altimetry data. Altimetry satellites use radar signals to determine the height of the ocean surface below them. Changes in the bathymetry cause gravimetric distortions which influence the height of the sea surface; this allows a reproduction of underlying bathymetric features.

Additional input is gathered from crowd sourced data, providing depth information from a large number of ships and small craft along their regular tracks. These in-situ measurements are also used for the calibration of EO data. With tidal modelling, all data are corrected for the tides during their respective acquisition time. By combining all these sources, a merged bathymetry product can then be created.

A major point of BASE-platform is the distribution to the user by a bathymetry data portal, where data will be available off-the-shelf as well as on demand. Adequate metadata will be provided along with the bathymetry so usability by the end user is ensured.

1. INTRODUCTION

Bathymetry is the measurement of the topography underwater. While the topography of land is rather well-know and was only recently determined world-wide in high resolution with the TanDEM-X radar satellite mission (Krieger et al., 2007), there is currently no possibility to measure the bathymetry worldwide with a single remote sensing instrument. However, with the ongoing expenses of the offshore industry, e.g. the construction of offshore wind parks, there is an increasing demand for accurate bathymetric data. In-situ measurements performed by ships equipped with echo sounders can produce very high resolution bathymetric data, but their high operational costs make them economically unsuitable for covering larger areas. A coarse bathymetry with a resolution of about 900m is offered on platforms like Gebco for free, but resolution and possibly actuality are not sufficient for commercial usage.

The BASE-platform project fills this gap by combining different data sources that are all available worldwide: three types of satellite data: optical, Synthetic Aperture Radar (SAR), altimetry. This is enhanced by crowd-sourced echo sounding data and sea level modelling to correct variances in water levels. While all these existed individually before, BASE-platform merges these technologies, allowing for a wide coverage and highly accurate data. Within the project, existing data generation processes are automated to become part of a processing chain that requires minimal human interaction. Via the BASE-platform data portal, end user can then obtain a cost effective bathymetry product with a high resolution.

2. DATA SOURCES

This section describes the different sources of data used in BASE-platform. Figure 1 provides an overview on their respective applicable depths.

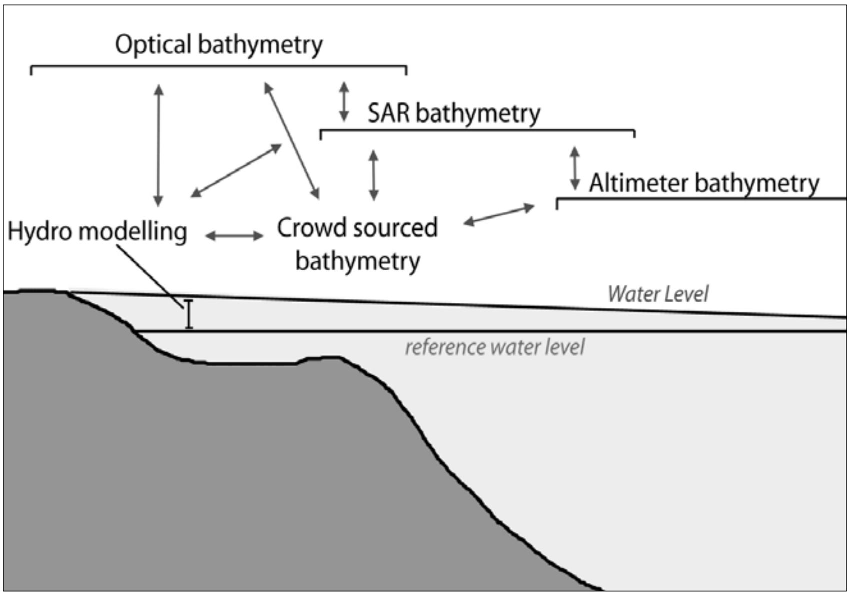

Figure 1: Depth ranges of the different techniques combined in BASE-platform. For remote sensing, optical bathymetry can cover shallow waters, followed by SAR bathymetry for medium depths, while Altimeter bathymetry covers the deepest areas. Crowd sourced bathymetry can be applied everywhere where ships can go, although sensor range generally does not extend 2000m depth. Corrections from hydrodynamic modelling are not limited to depth ranges, but their effect will usually be strongest near the coast.

2.1. Optical Satellite Data

For the successful use of optical bathymetry, the sea bottom must contribute a detectable part to the signal measured by the satellite sensor (Heege et al., 2008). The depth of these so called optical shallow waters varies from <10m in regions like the North Sea to about 30m, e.g. in Caribbean waters. The environmental conditions of the recording strongly vary over time, hence, sophisticated correction algorithms have to be applied. These will remove, e.g., atmospheric effects, adjacency effects when land is nearby, sun glint on the sea surface or water refraction. An example of optical bathymetry is given in Fig. 2.

Multiple satellites are used for data acquisition, including ESAs Sentinel-2 and Landsat 8.

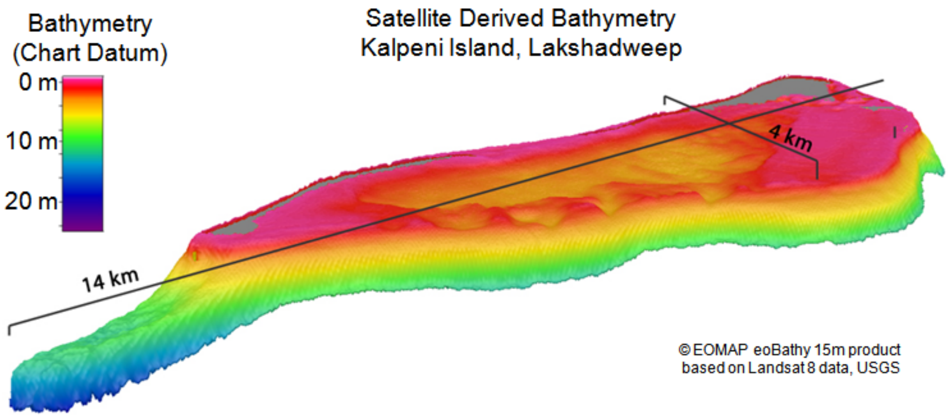

Figure 2: Example of a satellite derived bathymetry product based on Landsat 8 imagery for the Kalpeni Island, Lakshadweep region, India.

2.2. Synthetic Aperture Radar Satellite Data

While radar beams cannot penetrate the ocean surface to directly determine the underlying bathymetry, the bathymetry causes the so called shoaling effects which changes wave parameters at the sea surface (Alpers and Hennings, 1983). This shoaling effects makes waves become shorter and steeper when approaching shallower waters, hence, a direct relation between changes in wavelength and depth exists. With SAR, the ocean waves can be depicted independent of sunlight or weather conditions. The wavelengths are then determined using the Fast Fourier Transform (FFT) on small subsections of the acquired radar image (Pleskachevsky et al., 2011). The algorithm for SAR bathymetry is sketched in Fig. 3.
Due to recent improvements, artefacts like ships, sand banks or wave breaking zones can be filtered out, allowing an automatic and consistent analysis of the scenes.

The data used are primarily acquired by DLRs TerraSAR-X mission and ESAs Sentinel-1 mission, but data from other satellites can also be used for this method.

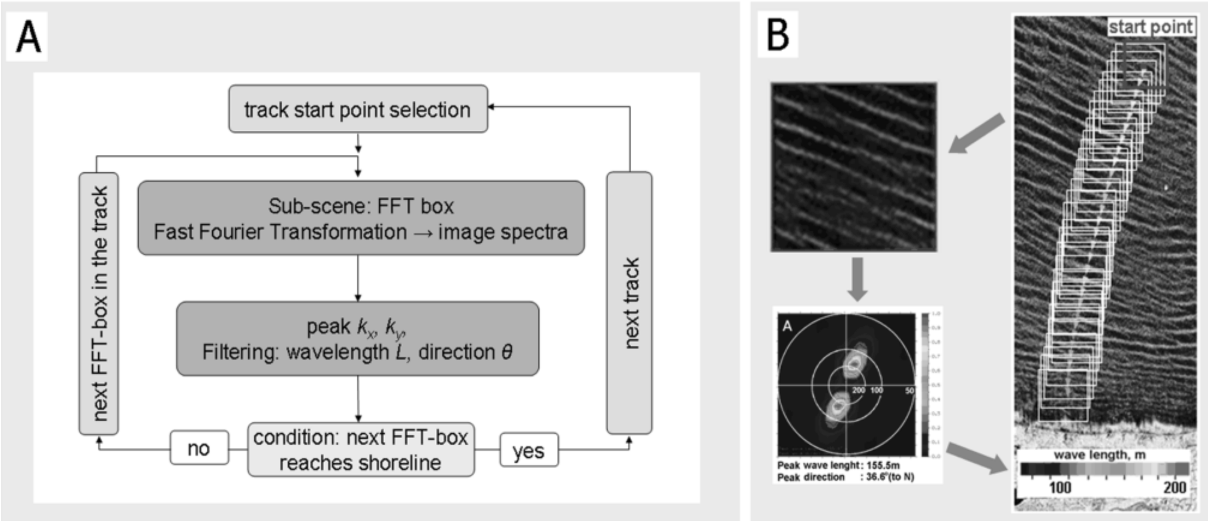

Figure 3: Algorithm for tracking wave rays: by computing the Fast Fourier Transformation (FFT) for a sub-image, a 2D image spectrum is retrieved in wave number space indicating wavelength and wave direction. Starting in open waters, the box for the FFT is moved in the wave direction, and a new FFT is computed. Data filtering is taken into account for the wave direction (cross sea) and wavelength (wind sea and wind streaks). The procedure is repeated until the corner points of the FFT box reach the shoreline (A); an example of one wave ray (B).

2.3. Altimetry Satellite Data

Space altimetry also employs radar waves, but use a very different procedure than the SAR approach described above. The altimetry method relies on the fact that topography on the seafloor creates gravity anomalies that tilt the ocean surface in ways that are measureable with a radar altimeter (Dixon et al., 1983). From these, the underlying changes in bathymetry can be derived.

The estimation of gravity anomalies starts with a smooth version of the geoid (egm08) that can be used to apply the remove-compute-restore procedure widely used in geodesy. This allows the calculation of the rugosity over the smooth geoid model in a flat approach from altimetry data. Afterwards the residual heights are converted to slopes and interpolated into a grid. From the above surfaces the high resolution component of gravity anomalies can be estimated from the east and north vertical deflection by solving the Laplace equation in the Fourier domain. Finally the estimation of gravity anomalies is the sum between the recovered smoothed model (egm08) and the high resolution component.

The gravity anomalies principle is applicable for topographic variations reaching from about 10km (smaller variations create too little influence on the ocean surface) up to several hundred kilometres (larger variations are isostatically compensated and do not produce gravity variations).

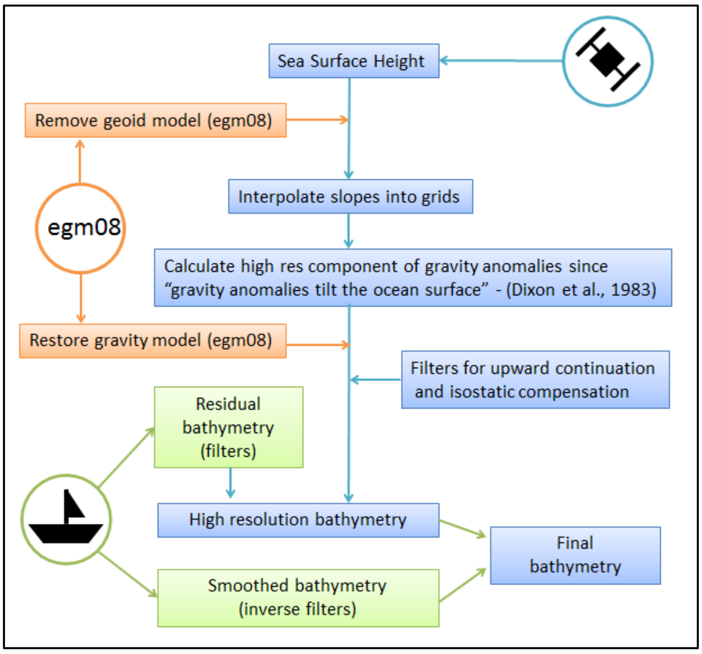

Figure 4: Bathymetry from satellite altimeter workflow. Three inputs are combined during the workflow, sea surface height from satellite altimeter, the EGM08 model and ship soundings.

Adding bathymetric ship soundings to the procedure improves the results in two different ways. On one hand a smoothed version of the bathymetric surface (isostatically compensated component) can be estimated by filtering an interpolated surface from the soundings. On the other hand, gravity to bathymetry ratio grids can be estimated. This avoids defining the unknown seafloor density variations which have great influence in gravity anomalies.

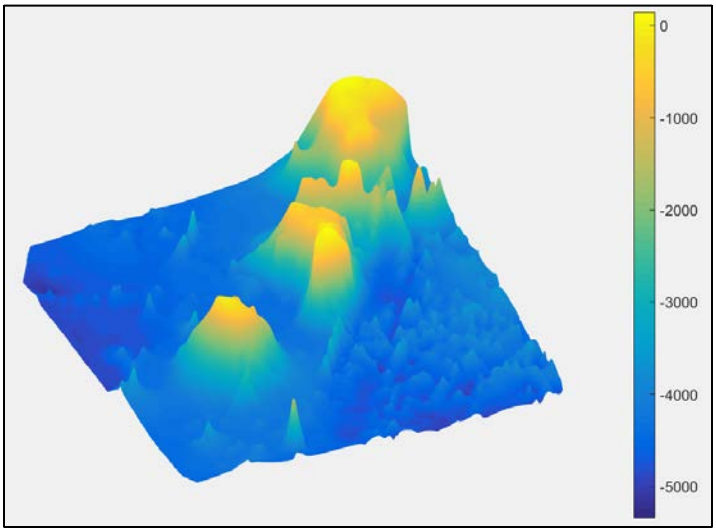

Figure 5: Bathymetry from satellite altimeter in Mauritius Islands

For this methodology, data from Cryosat-2 along with ancillary data from other satellites is used.

2.4. Crowd Sourced Bathymetry Data

While regular seafloor mapping campaigns are expensive, crowd source bathymetry (CSB) asks vessels to log position and depth data while they about their normal activities. The gathered data are periodically uploaded to generate a bathymetric data product. Many vessels were already gathered for the TeamSurv platform during the previous CoSuDEC project, now reaching about 300 vessels plus other vessels like research ships. For BASE-platform, CSB data are used as in-situ measurements and offer a way of calibrating the results obtained via remote sensing.

2.5. Sea level modelling

All of the methods previously described measure the distance between the sea surface and the sea floor at their respective time of measurement. However, this water depth is strongly influenced by tidal and meteorological variations. Tidal amplitudes are often amplified near the coast, which may reach several meters of tidal range, even up to 14.5m in the Bay of Fundy.

As permanently installed tidal gauges are mostly too scarce for global tidal interpolation, numerical hydrodynamic models are applied. Observations from tide gauges and satellite altimetry are included in these models to improve accuracy. For the BASE-platform project, this modelling allows to calculate the correct chart datum. According to the standard of the International Hydrographic Organization (IHO), this is based on the Lowest Astronomical Tide (LAT), and conversions to other reference systems like Mean Sea Level (MSL) and geoids are also possible with these hydrodynamic models.

3. WORKFLOW

A current hindrance for widely available bathymetric data from satellite measurements is the amount of manual steps involved in the acquisition and high-level preparation of the data. For many satellites, acquisitions must be scheduled several days ahead of time and it cannot be guaranteed that the ordered scenes are useable for the respective algorithms (e.g. cloud cover for optical images, no waves for SAR, etc.). With ESAs Sentinel fleet, this is solved as acquisitions are provided regularly without the need for previous ordering.

The remaining part, optimizing the workflow of the bathymetry data generation and distribution, is a main target of the BASE-platform project. For this, all currently applied algorithms have to be most widely automated. This can include steps like determination of parameters depending on scene location or acquisition time, evaluation of required filters and in which sections of a scene these must be used, or masking land and sea in areas where no land mask is available or the land mask is wrong.

However, most data extracted from an individual acquisition is not directly useable for a user; they need to be corrected for tidal variations and the coordinates and data format must be adapted to fit the user’s needs. This workflow is shown in Fig. 6.

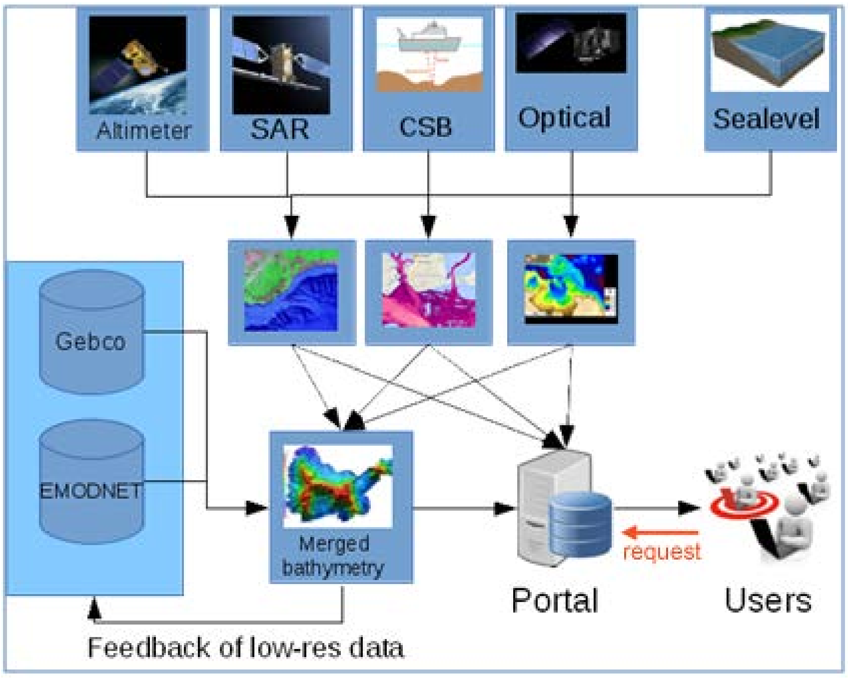

Figure 6: Workflow of BASE-platform. The different data sources are corrected by sea level modelling and are offered on the server individually and as a merged product. Data from Gebco and EMODNET are used for initialization; a feedback of low resolution data is also possible. Users can download off-the-shelf products or request new acquisitions via the BASE web portal.

Furthermore, within the BASE-project a combined bathymetry from all available sources is offered, so different sources must be merged to a single product first. All these steps also need to run as automatically as possible. One aspect therein is the inclusion of the data in a web portal, where users can directly select a region and their desired delivery format, among other parameters. This ensures accessing the data is very simple for any end user.

As sketched in Fig. 6, creating the merged bathymetry may also use freely available data from the Gebco and EMODnet portals. While EMODnet offers a better resolution from a variety of sources with coverage limited to European waters, Gebco offers coarser resolutions with worldwide coverage. As data on these portals may be several years old and, hence, may be found to be imprecise, BASE-platform can deliver low resolution data to these portals.

4. SUMMARY

The BASE-platform project presented in this paper aims to deliver satellite derived bathymetry data to end users. Optical, SAR and altimetry satellite data, which each have their strength in different depths, are included in the project. It builds upon existing algorithms which are automated for easier and faster use. A high quality of the data is achieved by inclusion of sea level modelling and crowd sourced bathymetry data. The delivery of the data is done via a web portal where users can personalize delivery options to have the new data fit into their existing workflow.

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BIOGRAPHICAL NOTES

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