The BASE-platform project

Deriving the bathymetry from combined satellite data

An article by STEFAN WIEHLE, BERNAT MARTINEZ, KNUT HARTMANN, MARTIN VERLAAN, TIM THORNTON, SIMON LEWIS and DICK SCHAAP

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 ESA's Sentinel fleet, remote sensing data of the oceans are widely available. Three sources of satellite information are combined in BASE-platform: optical, synthetic aperture radar (SAR) and altimetry data. BASE-platform's ambition is to use these data for creating bathymetric maps and supply them to end users via 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.

Remote sensing | Earth observation | Oceanography | Bathymetry | Data fusion

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1 Introduction

Bathymetry is the measurement of the topography underwater. While the topography of land is rather well-known and was only recently determined worldwide 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 900 m 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 crowdsourced 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 users 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. Fig. 1 provides an overview on their respective applicable depths.

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 wavelengths in the ocean, indicating changes of the underlying bathymetry due to the shoaling effect. Information about deeper areas is then ac-

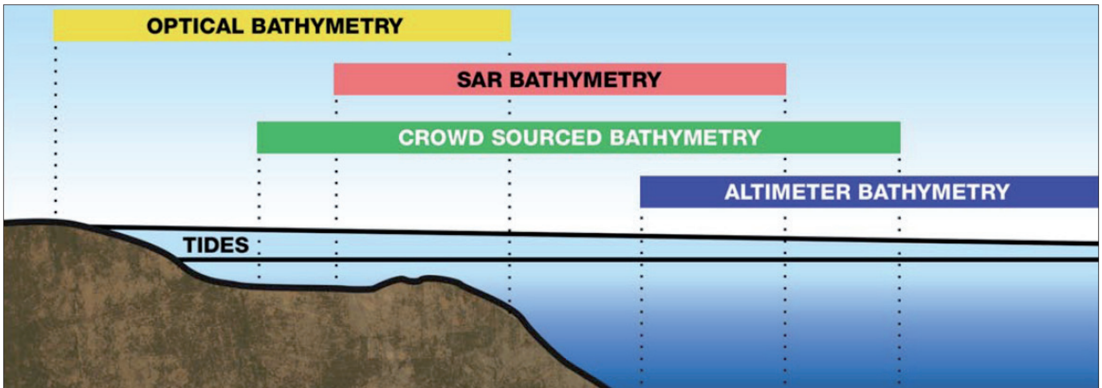

Fig 1: Depth ranges of the different techniques combined in BASE-platform. For remote sensing, optical bathymetry can cover shallow waters, followed by SAR bathymetry for medium depths, while altimeter bathymetry covers the deepest areas. Crowdsourced bathymetry can be applied everywhere where ships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

quired 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 crowdsourced 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 earth observation 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.

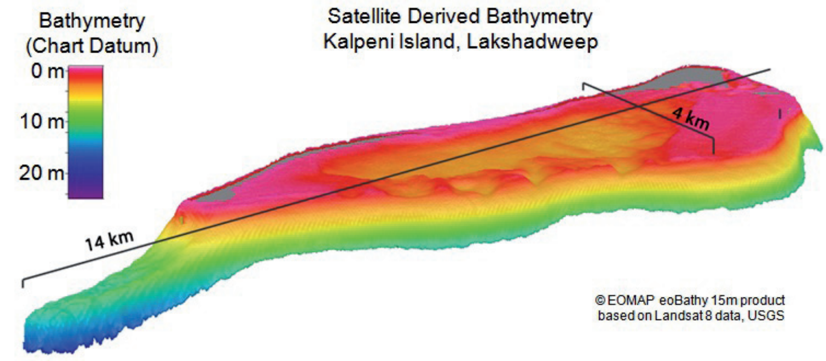

Fig 2: Example of a satellite-derived bathymetry product based on Landsat 8 imagery for the Kalpeni Island, Lakshadweep region, India

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 <10 m in regions like the North Sea to about 30 m, 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, sunglint 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 ESA's Sentinel-2 and Landsat 8.

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 effect which changes wave parameters at the sea surface. This shoaling effect 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). Due to recent improvements, artefacts like ships, sandbanks or wave breaking zones can be filtered out, allowing an automatic and consistent analysis of the scenes. The algorithm for SAR bathymetry is sketched in Fig. 3, an example result is shown in Fig. 4. The data used are primarily acquired by DLR's TerraSAR-X mission and ESA's Sentinel-1 mission, but data from other satellites can also be used for this method.

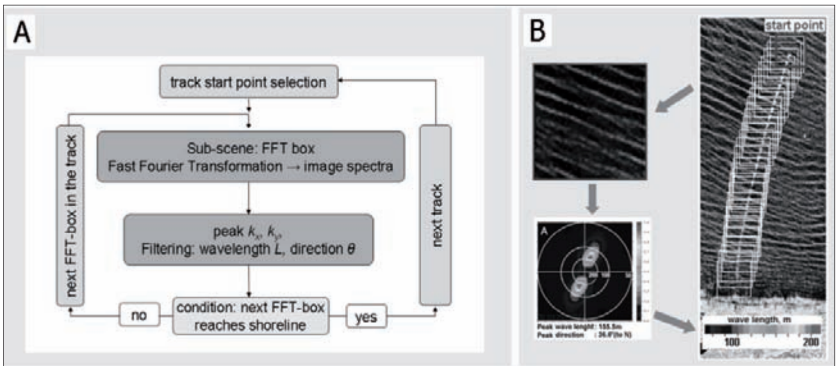

Fig 3: Algorithm for tracking wave rays: by computing the Fast Fourier Transform (FFT) for a sub-image, a 2D image spectrum is retrieved in wave number space indicating wavelength and wave direction. Starting in open waters, the box for the FFT is moved in the wave direction, and a new FFT is computed. 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)

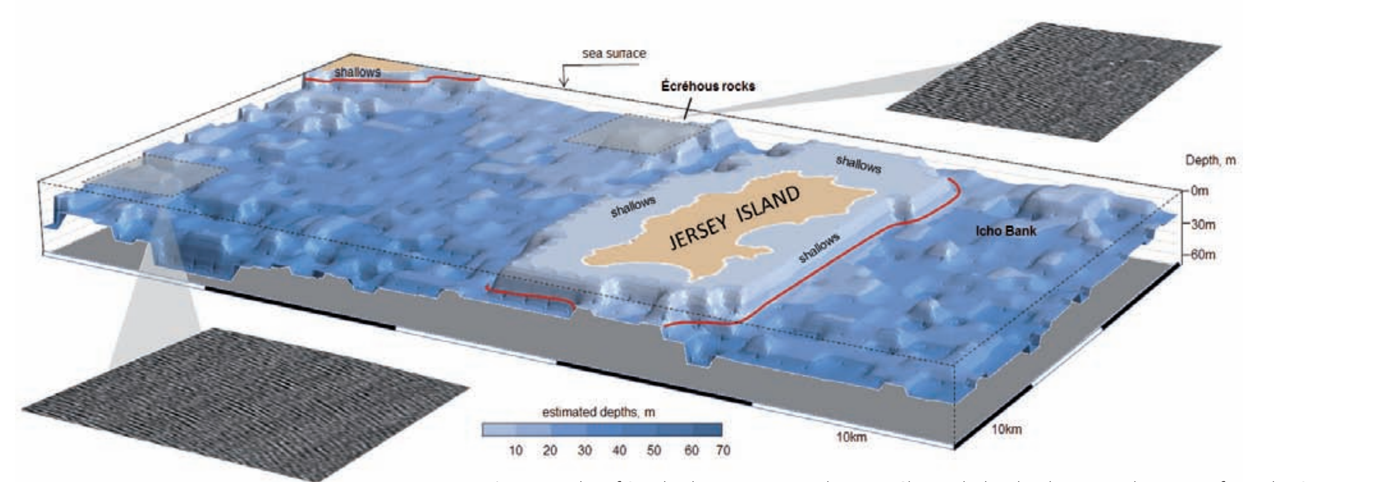

Fig 4: Results of SAR bathymetry around Jersey, Channel Islands. The two sub-images from the SAR scene demonstrate the changes in ocean wavelength resulting from the difference in water depth

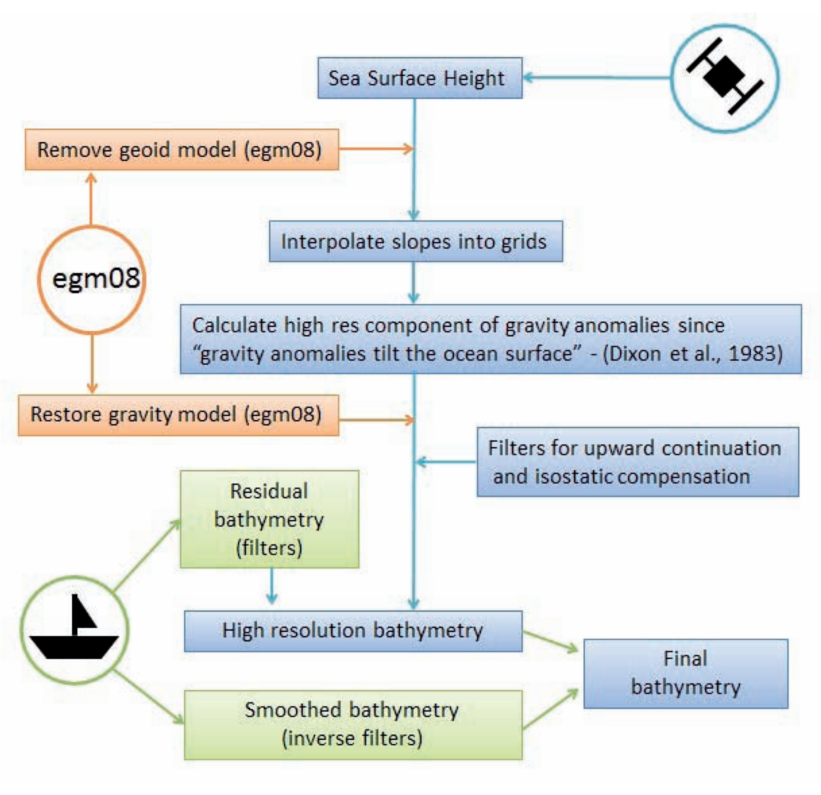

Fig 5: Bathymetry from satellite altimeter workflow. Three inputs are combined during the workflow, sea surface height from satellite altimeter, the EGM08 model and ship soundings

2.3 Altimetry satellite data

Space altimetry also employs radar waves, but uses 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.

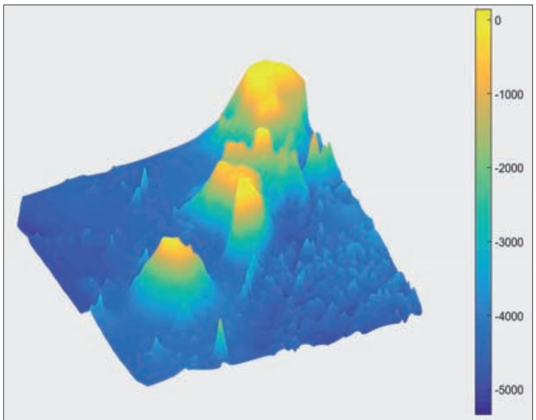

Fig. 6: Bathymetry from satellite altimeter in Mauritius Islands

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 workflow for deriving bathymetry from satellite altimetry data is given in Fig. 5, an example result is shown in Fig. 6.

The gravity anomalies principle is applicable for topographic variations reaching from about 10 km (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).

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

2.4 Crowdsourced bathymetry data

While regular seafloor mapping campaigns are expensive, crowdsourced bathymetry (CSB) asks vessels to log position and depth data while they carry out 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 seafloor 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 metres of tidal range, even up to 14.5 m 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 ESA's Sentinel fleet, this is solved as acquisitions are provided regularly without the need for previous ordering.

The remaining part, optimising 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. 7.

Furthermore, within the BASE-platform 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. 7, 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 crowdsourced bathymetry data. The delivery of the data is done via a web portal where users can personalise delivery options to have the new data fit into their existing workflow. ⚓

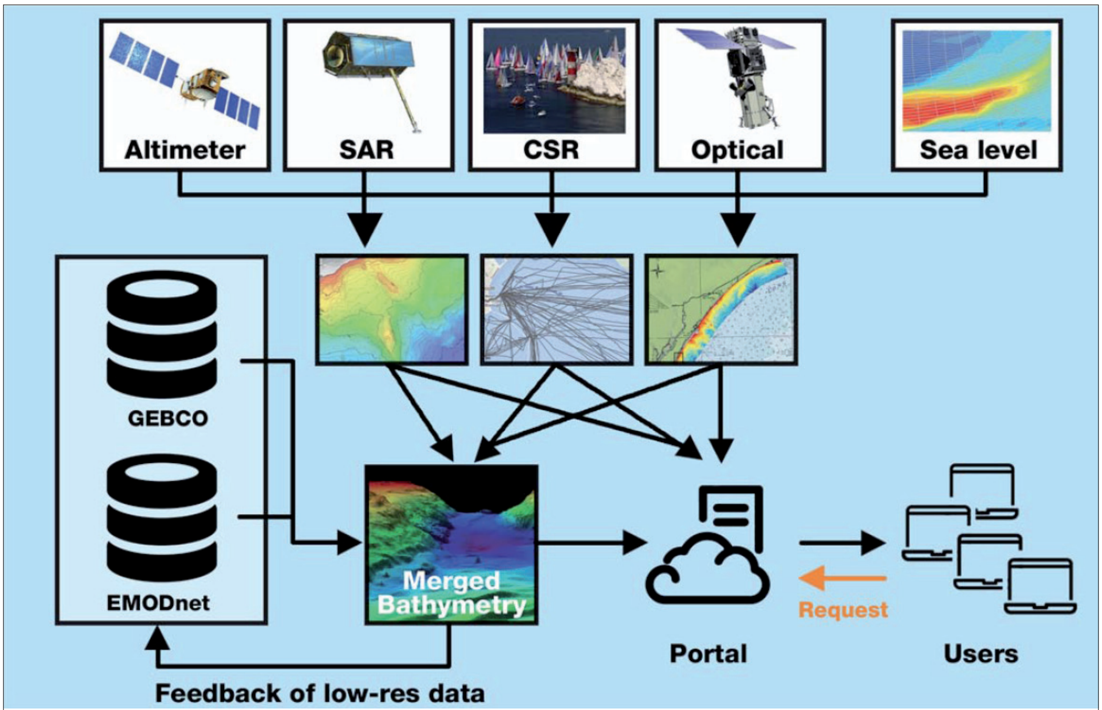

Fig. 7: Workflow of BASE-platform. The different data sources are corrected by sea level modelling and are offered on the server individually and as a merged product. Data from GEBCO and EMODnet are used for initialisation; a feedback of low-resolution data is also possible. Users can download off-the-shelf products or request new acquisitions via the BASE-platform web portal

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