EMODnet Bathymetry

Producing Satellite Derived Bathymetry (SDB) data sets for EMODnet Bathymetry

Technical Report

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Prepared by: EOMAP

The European Marine Observation and Data Network (EMODnet) is financed by the European Union under Regulation (EU) 2021/1139 of the European Parliament and of the Council of 7 July 2021 establishing the European Maritime, Fisheries and Aquaculture Fund and its predecessor, Regulation (EU) No. 508/2014 of the European Parliament and of the Council of 15 May 2014 on the European Maritime and Fisheries Fund.

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1 Objective

EOMAP will provide Satellite-Derived Bathymetry data for all the overseas territories of European countries in the Caribbean where shallow water data gaps exist or are not accessible to the EMODnet Bathymetry project.

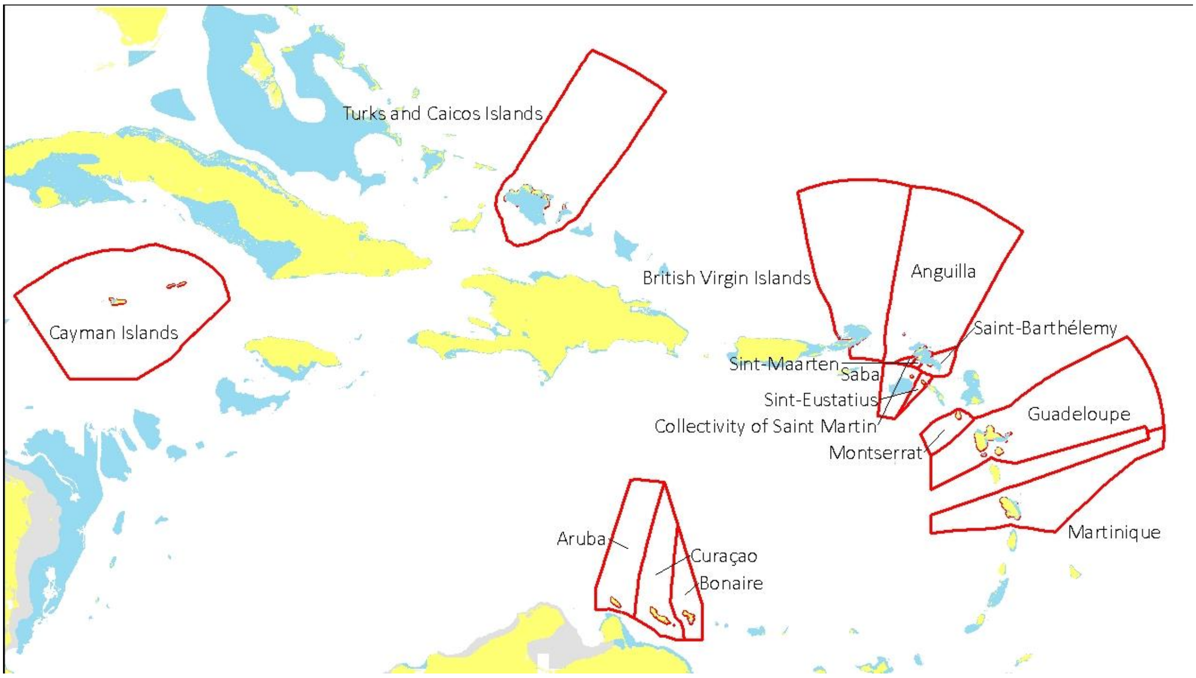

Figure 1: Map of UK, NL and FR Caribbean oversea territories (red) and identification of potential shallow waters (light blue).

The work was structure into a (1) the identification on those oversea territories where survey data exist by other entities which contribute or might be able to contribute those to the project and (2) the analysis of Satellite-Derived Bathymetry for those sites, where shallow water bathymetric data do not exist or are not shared to the EMODnet project.

2 Identification of shallow water bathymetric data for European oversea territories.

The **French** oversea territories were recorded my recent and high resolution Airborne Lidar Topo-Bathy data. Data will be shared with EMODnet. Thus, no data gaps and therefore no need for SDB activities exist.

UK territories are fully (Anquilla) or partly (Cayman, Turks&Caicos, Montserrat, British VI) covered by recent airborne or acoustic survey data. However, discussion with UKHO is ongoing (jointly with Thierry Schmitt) to see if and what kind of data UKHO might or might not contribute. We have decided to include the UK sites in the SDB analytics, but being aware that some of those might be replaced by existing data of UKHO if they are provided in future.

Shallow waters of the **NL** oversea territories are partly covered by acoustic (single beam or MBES) surveys but data gaps exist in the very shallow water zones. For Sint Maarten, new bathymetric airborne Lidar data have been collected but are not accessible at time of writing. Thus, SDB data add value in the coastal/very shallow waters. For Sint Maarten, new bathymetric airborne Lidar data have been collected but are not accessible at time of writing.

See section 4 for a summary of the sites.

3 Current status on Satellite-Derived Bathymetry analytics

3.1 Satellite data selection

For each of the sites we have identified 3 to 10 satellite records from the Sentinel-2, multispectral satellites. We have selected datasets based on the following criteria: (1) atmosphere free of clouds, haze or dust, (2) no floating substances or objects (oil films, floating vegetation), (3) as clear water as possible, (4) the most favourable illumination and recording geometries to ensure radiometric stability and avoid water surface effects (sunglint) and (5) minor or no impact of waves and wave-breaking. The image data were recorded between 2017 to 2021.

3.2 Satellite-Derived Bathymetry (SDB) analytics

EOMAP uses the Modular Inversion and Processing System (MIP) to process imagery and apply a number of relevant pre- and post-processing corrections. Since 1998, a team of physicists, mathematicians and IT experts have systematically developed MIP processors for shallow-water and SDB applications[1] within various research programs[2]. This has continued to evolve since 2006 as proprietary EOMAP technology[3]. Within the MIP, radiative transfer modelling of the coupled atmosphere-water systems is based on the Finite Element-Method (FEM) reference model of EOMAP staff Dr. Kiselev. This has a 30 years development history[4, 5], featuring the state-of-the-art algorithms as listed below. To support efficient production workflows and automated processing, MIP modules and EOMAP pre-/post processors are orchestrated within the EOMAP Workflow System (EWS).

As part of EOMAP's relentless R&D program, this system is continuously being improved. Several years ago, saw the full physical implementation of the atmosphere, water column and seafloor system, in order to map bathymetry independently of any ground truth data availability. Water depth, water constituent's optical properties, as well as sub-surface and seafloor reflectance are derived in a coupled, iterative process, which several correction and algorithms to correct for various recording and environmental specification (details to be provided on request). More recently, multi-image parallel processing (US Patent, 2017) was implemented for MIP, significantly increasing vertical accuracy and the robustness of depth retrievals.

The following figure provides the results for Grand Cayman Island as a showcase of the created bathymetric data.

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[1] a) Heege, T. , Häse, C. , Bogner, A., Pinnel, N. (2003): Airborne Multi-spectral Sensing in Shallow and Deep Waters. Backscatter p. 17-19, 1/2003

b) Heege, T., Bogner, A., Pinnel, N. (2004): Mapping of submerged aquatic vegetation with a physically based process chain. Remote Sensing of the Ocean and Sea Ice 2003. Editors: Charles R. Bostater, Jr. &RosaliaSantoleri. Proc. of SPIE Vol. 5233, ISBN: 0-8194-5116-9 pp. 43-50.

[2] 1998 - 2007, Collaborative research project SFB 454 "Lake Constance Littoral" - research project D3 "Remote sensing of shallow water areas", funded by the DFG (German Research Foundation). Interdisciplinary joint project Univ. Konstanz and DLR. DLR project lead: Dr. T. Heege

2002 - 2005: Development of automated remote sensing tools, supporting management of littoral zones in lakes, part B, BWC21011, supported by BWPLUS. Interdisciplinary joint project DLR and Univ. Hohenheim. DLR lead: Dr. T. Heege

2003 - 2005: High-Tech Offensive Zukunft Bayern project No. 290, Pilot project Waging-Tachinger See, Limnological Station of the Technical University Munich

2016 – 2018: Horizon 2020 project BASE-platform.

[3] 2008 - 2010: AUKLASS, Development of operational image classification processors for seafloor mapping applications. AUKLASS IBS-3667a/321/7/-TOU-08080003, supported by the Bavarian Ministry of Economy and Infrastructure

2010 - 2013: EU FP7 FRESHMON Downstream project.

2012 - 2015: Apps4GMES: Development of automated bathymetry processor, supported by the Bavarian Ministry of Economy and Infrastructure.

2015 - 2017: EU H2020 Base-platform: Development of integrated bathymetry services

[4] Kisselev, V.; Bulgarelli, B. (2004). Reflection of light from a rough water surface in numerical methods for solving the radiative transfer equation. Journal of Quantitative Spectroscopy and Radiative Transfer 85, 419-435.

B. Bulgarelli, V. Kisselev, L. Roberti (1999): Radiative Transfer in the Atmosphere Ocean System: The Finite-Element Method. Appl. Opt. 38, pp. 1530-1542

[5] Kisselev, V.B.; Roberti, L.; Perona, G. (1995), Finite-element algorithm for radiative transfer in vertically inhomogeneous media: numerical scheme and applications. Appl. Opt. , 34, 8460-8471.

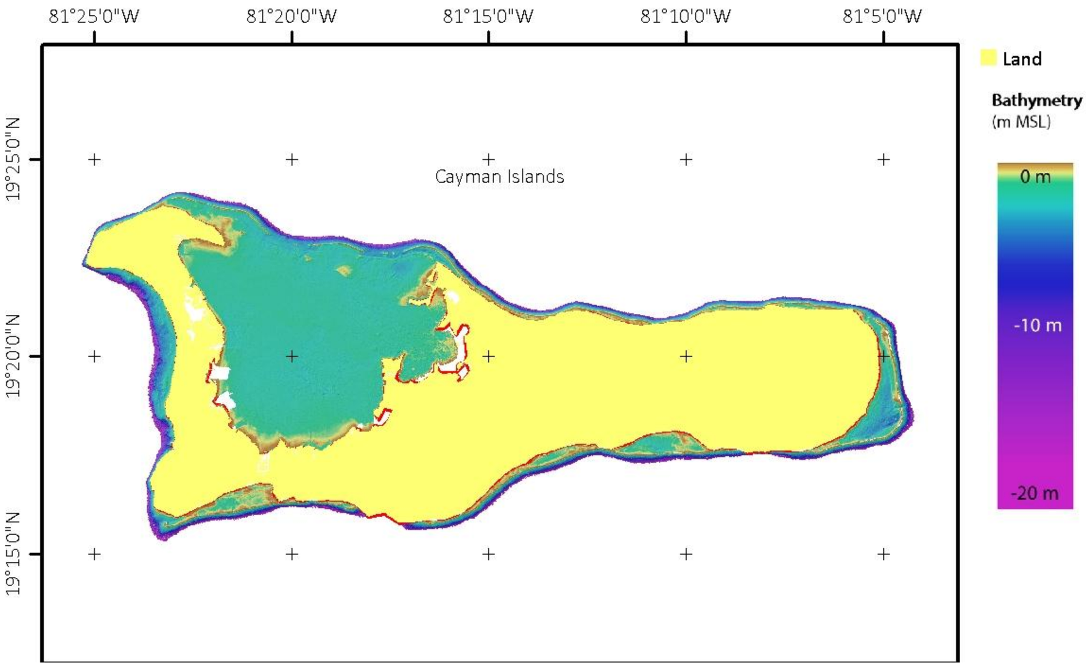


Figure 2: Satellite-Derived Bathymetry (SDB) coverage for Grand Cayman Island.

So far, we have created 6,291 sq km of shallow water bathymetric data – similar to those shown in the previous figure - for the Caribbean oversea territories.

3.3 Satellite-Lidar Bathymetry (SLB) analytics

EOMAP's Satellite-Lidar Bathymetry (SLB) database holds bathymetric depth points which are derived from the ICESat-2 satellite. NASA's ICESat-2 satellite launched in September 2018 and carries ATLAS, a green photon-counting lidar with a 10kHz pulse repetition rate and nominal 17m diameter footprint. Correction routines are applied to account for the water refraction and recording geometry [6]as well as effects on tides and water heights[7]. A proprietary cluster algorithm separates seafloor photon returns from both the water column and water surface returns (see next figure).

[6] Parrish, C.E.; Magruder, L.A.; Neuenschwander, A.L.; Forfinski-Sarkozi, N.; Alonzo, M.; Jasinski, M. Validation of ICESat-2 ATLAS Bathymetry and Analysis of ATLAS's Bathymetric Mapping Performance. Remote Sens. 2019, 11, 1634. https://doi.org/10.3390/rs11141634

[7] Neumann T., Brenner A., Hancock D., Robbins J., Saba J., Harbeck K.,Gibbons A., Lee J., Luthcke S., Rebold T. 2021. CESat-2 Algorithm Theoretical Basis Document for Global Geolocated Photons (ATL03). Release 004. https://icesat2.gsfc.nasa.gov/sites/default/files/page_files/ICESat2_ATL03_ATBD_r004.pdf

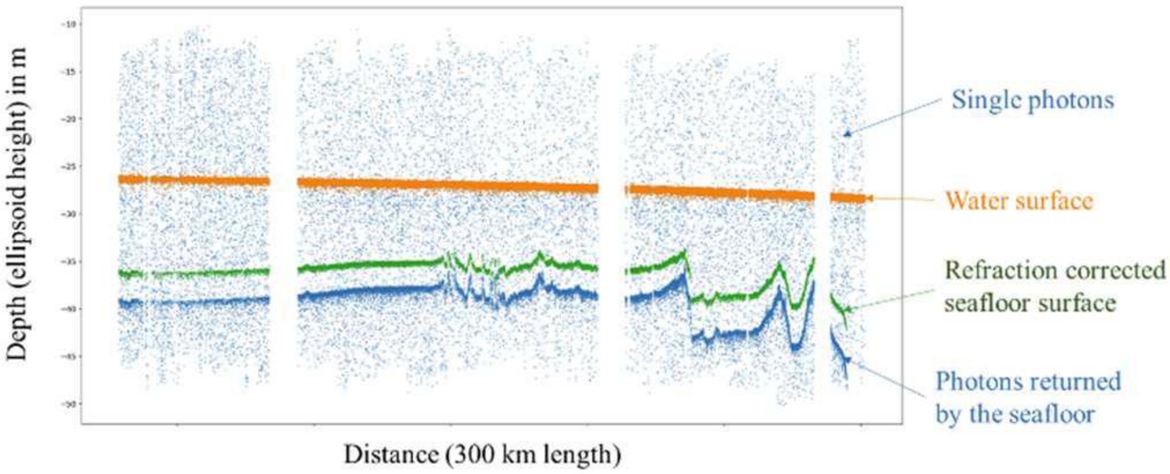


Figure 3: Example of an IceSat-2 Atlas trackline for the Bahamas. The orange line represents single photons which are returned from the water surface, each blue point represents one single photon and the clustered blue dots represent the seafloor returns. Following the correction for the recording geometry and water refraction the blue dots represent the non-tidal corrected depth. Note that the heights are given in ellipsoid and the curvature of the water surface can be seen for this transect of 300 km length.

ATLAS records photon returns in discrete tracklines covering the entire globe, which are capable of measuring bathymetry in a similar procedure to that applied in multispectral imagery. Importantly, ATLAS by itself cannot create a dense spatial grid as each trackline can be up to hundreds of kilometres apart.

We have accessed all ICESat ATLAS tracklines for the study sites and performed the bathymetric data analysis which resulted in 6.7 Million bathymetric depth points in total (see next figure for an example of Grand Cayman Island).

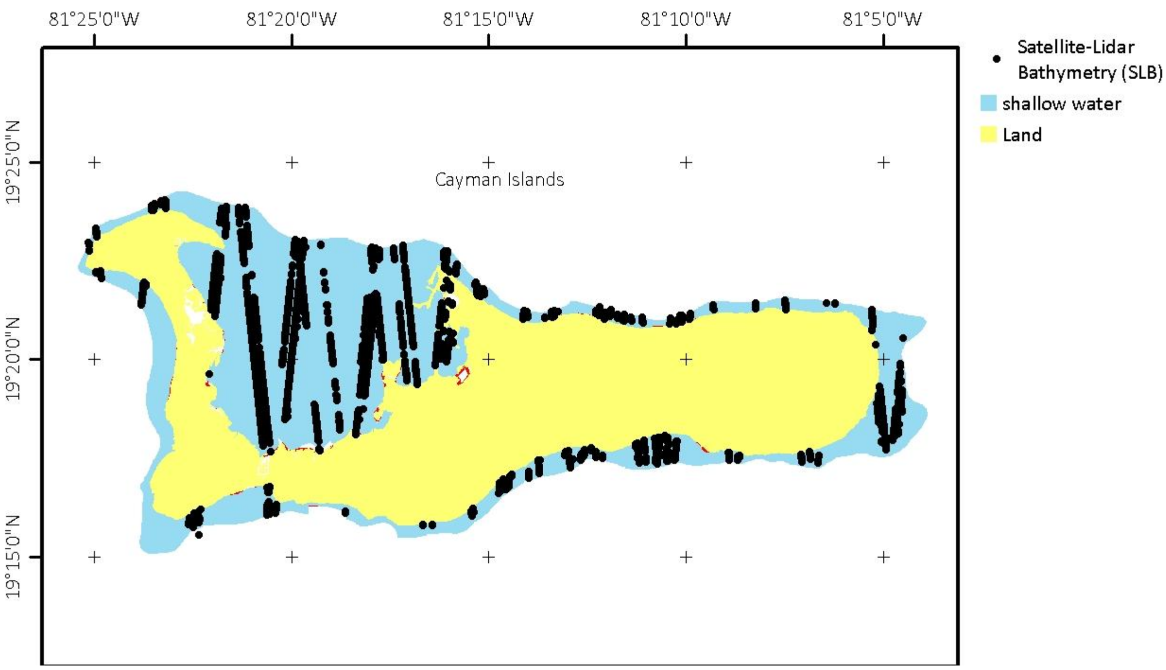
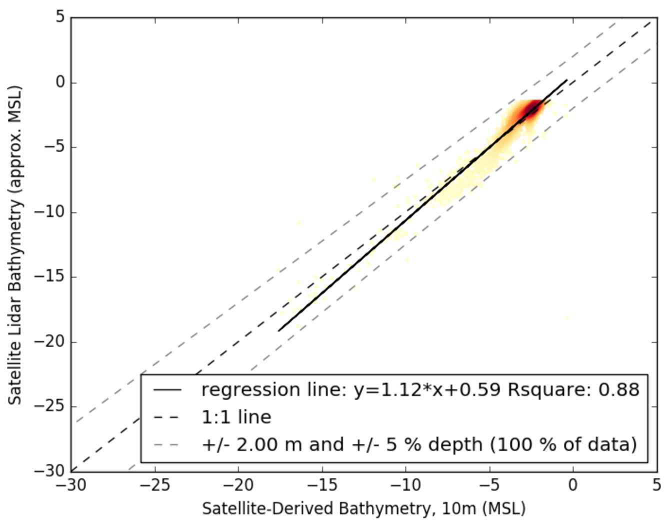


Figure 4: Satellite-Lidar Bathymetry (SLB) coverage for Grand Cayman Island.

3.4 SDB data validation and verification

We have compared the SDB grids against survey data if accessible (mostly accessible for NL territory so far) and against the Satellite-Lidar Bathymetry data (see section 3.3). For each site we created scatterplots, such as shown in the next figure for Grand Cayman Island and statistics on the comparison.



Statistics of the comparison of SDB and SLB*

N	*48220*
Mean Square Error	*0.56cm*
CAT ZOC B (% of data)	*74.7 %*
CAT ZOC C (% of data)	*99.5 %*
R^2	*0.88*

* Note that SLB has it's own vertical uncertainties in the rang of 0.5 to 1m and cannot be compared against modern airborne Lidar surveys.

Figure 5: Comparison of Satellite-Derived Bathymetry grid of 10m spatial resolution (X-axis) and the Satellite-Lidar Bathymetry data (Y-axis) for Grand Cayman Island.

4 Current status in summary

The following table provides a summary of the current status of the SDB data analytics. To summarize, all data have been created and checked, final validation and conversion to the required EMODnet Bathymetry DTM file format need to be done. Sextant metadata have been uploaded.

6.7 Million bathymetric data have been created using the Satellite-Lidar sensor and shallow water bathymetric grids created from Satellite-Derived Bathymetry technique have been create for 6.3 K sq km.

Site name	Status on available bathymetric survey data	SDB action	Satellite-Lidar Bathymetry (SLB) Analytics	Satellite-Derived Bathymetry (SDB), multi-scene analytics	Satellite-Derived Bathymetry (SDB), Validation	Satellite-Derived Bathymetry (SDB), QA/QC	EMODnet Bathymetry delivery package creation	Satellite-Derived Bathymetry (SDB), delivered to project	Total SDB area (sq km)
Sint Maarten (NL)	NL survey data available but data gaps exist	filling data gaps	100%	100%	75%	100%	not yet	not yet	
Saba (NL)	NL survey data available but data gaps exist	filling data gaps	100%	100%	0%	0%	not yet	not yet	
Aruba (NL)	NL survey data available but data gaps exist	filling data gaps	100%	100%	75%	100%	not yet	not yet	
Curacao (NL)	NL survey data available but data gaps exist	filling data gaps	100%	100%	75%	100%	not yet	not yet	
Bonaire (NL)	NL survey data available but data gaps exist	filling data gaps	100%	100%	75%	100%	not yet	not yet	
Caymen, East (UK)	no survey data	SDB data analysis and provision	100%	100%	75%	100%	not yet	not yet	
St. Martin (FR)	SHOM surveyed all shallow waters with high resolution airborne lidar data.	no SDB analysis requried	not relevant	not relevant		not relevant	not relevant	not relevant	
Saint Barthelemy (FR)	SHOM surveyed all shallow waters with high resolution airborne lidar data.	no SDB analysis requried	not relevant	not relevant		not relevant	not relevant	not relevant	
Guadeloupe (FR)	SHOM surveyed all shallow waters with high resolution airborne lidar data.	no SDB analysis requried	not relevant	not relevant		not relevant	not relevant	not relevant	
Martinique (FR)	SHOM surveyed all shallow waters with high resolution airborne lidar data.	no SDB analysis requried	not relevant	not relevant		not relevant	not relevant	not relevant	
Anquilla (UK)	UKHO has full bathymetric coverage but it is not known if data are provided to the project	pending, depending on data contribution of UKHO	100%		75%		not yet	not yet	
Cayman, Grand Cayman (UK)	UKHO has limited survey coverage but it is not known if data are provided to the project	SDB data analysis and provision	100%	100%	75%	100%	100%	not yet	
Caicos Islands (UK)	UKHO has limited survey coverage but it is not known if data are provided to the project	SDB data analysis and provision	100%	100%	75%	100%	not yet	not yet	
Turks Islands (UK)	UKHO has limited survey coverage but it is not known if data are provided to the project	SDB data analysis and provision	100%	100%	75%	100%	not yet	not yet	
Montserrat (UK)	UKHO has limited survey coverage but it is not known if data are provided to the project	SDB data analysis and provision	100%	100%	75%	100%	not yet	not yet	
British Virgin Islands (UK)	UKHO has partly coverage but it is not known if data are provided to the project	SDB data analysis and provision	100%	100%	75%	100%	not yet	not yet	

Table 1: Summary of the current SDB status for EMODnet Bathymetry.