# BathySent - An Innovative Method to Retrieve Global Coastal Bathymetry from Sentinel-2

## Executive summary report

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**Objectives of the project**

We have proposed to develop an automated method for mapping coastal bathymetry (water depths) based on Copernicus Sentinel-2 mission and assess its performances. The interest of using Sentinel-2 data lies on the capacity to cover large areas (National and European scale targeted), while benefiting from the short repeat cycle (5 days) of the mission. The systematic acquisition plan of Sentinel-2 is of major interest for studying and monitoring coastal morphodynamics. The proposed methodology avoids limitation of exiting techniques in terms of dependency on water turbidity and requirement for field calibration.

**Algorithm development**

In this project, we propose to extract bathymetry from a single Sentinel-2 dataset, exploiting the time lag that exists between two bands on the focal plane of the Sentinel-2 sensor. To tackle the issue of estimating bathymetry using two Sentinel-2 bands acquired quasi simultaneously, we developed a method based on cross-correlation analysis that exploits the spatial and temporal characteristics of the Sentinel-2 dataset to jointly extract both ocean swell celerity (c) and wavelengths λ.
We wrote the code in Python (V3) in reason of its portability and for facilitating the implementation on platforms.

**Synthetic test**

To estimate the quality of our method, we proceed on a simulated dataset where we control all the waves' parameters. We use a model able to simulate each individual wave on complex bathymetries and consider complex morphological site, from 0 to 14 meters depth. The model is based on known bathymetries. Results are in good agreement with the initial bathymetry (de Michele et al., in review, 2020). This test made us confident about the outcome of the Python code and its application to Sentinel-2 data.

**Implemetation on CREODIAS**

Assisted by Cloudferro, we accessed the CREODIAS platform www.creodias.eu. There, we could find the whole offer for Computing&Cloud and EO collection database. They provide cloud computing (virtual machines, operating systems) and storage (standard HDD and fast – SSD) services. Our Python code is now implemented there, in an encrypted environment. It runs close to the Sentinel archive. We used this configuration for the wide area processing. So, there is potential to upscale in the future.

**Validation and Performance assessment**

The main objective of the validation activity is to specify the uncertainty of the derived coastal bathymetry results as extracted by the proposed novel approach using the Sentinel-2 mission. We produced data packages on Kos Island, Kasos island and Crete island, Greece. Ultra-resolution swath bathymetry data were acquired by HCMR onboard R/V Alcyon (HCMR) during a 4-day cruise realized from 8$^{th}$ to 12$^{th}$ of October 2019, in the frame of BathySent project. In addition, bathymetric data were collected at very shallow waters (1-10 m) by the use of a single-beam echo sounder. A comparison with the « linear ratio model » multispectral method is also performed here.

The absolute differences between conventional EO-based bathymetry retrieval approaches (linear ratio model) and the proposed innovative solution using Sentinel-2 data are mainly lower than 2m. According to the outcomes of the evaluation analysis, both models were considered to give results that are more reliable within the depth zone of 5-25m.

**Wide area processing**

The code is successfully run on the South Western coast of Portugal, on 4 Sentinel 2 frames with more than 80 images per frame. We found depth up to 40 meters.

## Conclusions

Today an operator can extract shallow bathymetries in selected areas exploiting the short revisit time and the full S2 archive. A supervisor need to check/filter the results. We calculated bathymetric values using a window of 64x64 pixels (640x640 meters), every 16 pixels (160 meters). Therefore, BathySent can produce Bathymetric maps with 160 meters grid, but the real spatial resolution need to be assessed.

Synthetic tests showed that BathySent could restitute bathymetry in the range 5-14 meters depth, with 2 meters standard deviation with respect to « sonar based » bathymetry. Validation in the Mediterranean shows that results are very good, in the range 5-25 meters depth: precision decreases with depth (as expected) ranging from 10% to 30% from 5 to 25 meters depth. The wide area processing, in the ocean coasts of Portugal, showed that BathySent could measure deeper

bathymetry, at least up to 40 m depth. Precision and accuracy need to be assessed on the Wide Area dataset, in a future step.

The method based on “ratio model” saturates around 25 meters depth and need ground calibration. The bathysent method provides bathymetry at lower spatial resolution with respect to the “ratio model” but :

1) Bathysent does not need « in situ » calibration
2) Bathysent can go deeper than 25 meters

The access to the full archive of S2 is a key aspect for a successful retrieval: there is the need to combine multiple S2 acquisitions.

Cloud processing is as fast as 25 minutes per S2 frame, using a virtual machine with 4 cores and 8 Gb of RAM. Wide area processing on large dataset can be performed in reasonable time (few days). Human driven post processing is still needed (filtering, selecting the best results).

The strict condition for the method to work is the presence of ocean/sea swell. Although global retrieval of shallow bathymetry is feasible, the estimation at higher depths depends actually on local conditions.

## Recommendations for future developments

Wind generated waves or currents can hamper the correct bathymetric estimation with BathySent. Therefore, work on pre-post processing is needed: algorithm development on how to automatically select the « good » bathymetries.

The spatial resolution of the results needs to be improved as the FFT window approaches the shallower bathymetries. Therefore, we highlight the need to improve the algorithm to address this issue e.g. by adaptive window sizes in a proper iteration scheme.

To improve the precision of the bathymetric retrieval, we might need to combine multiple sensors, multiple pixel resolutions, and multiple swell regimes e.g. combination of Landsat 8, Planet Labs and Sentinel-2.

We could add the post-processing functions to the Python code on CREODIAS; on what would be the evolution of the code already implemented. The processing can be further automated: a « user guide » can be developed.

Bathysent could be used to calibrate the conventional « ratio techniques », especially where there cannot be in-situ measurements.

There is the will to contribute to current developments implementing such services on cloud resources.

The Bathysent consortium could contribute to the pole of research institutes dealing with bathymetry from space, in France (pole ODATIS, led by CNES).

This document can lead to the preparation of a White Paper on requirements for bathymetry retrieval from EO and future missions.

BRGM is interested in an agreement for further exploitation of the code, together with CloudFerro on CREODIAS platform, after BathySent project.

BRGM will continue the methodological developments and will search for additional partial funding.