environmental sciences proceedings

MDPI

Proceeding Paper

Preliminary Results of Satellite-Derived Nearshore Bathymetry †

Ausiàs Roch-Talens *, Josep Eliseu Pardo-Pascual and Jaime Almonacid-Caballer

Grupo de Cartografía GeoAmbiental y Teledetección, Departamento de Ingeniería Cartográfica, Geodesia y Fotogrametría, Universitat Politècnica de València, 46022 València, Spain; jepardo@cgf.upv.es (J.E.P.-P.); jaialca@upvnet.upv.es (J.A.-C.)

* Correspondence: aurocta@upvnet.upv.es

† Presented at the IV Conference on Geomatics Engineering, Madrid, Spain, 6–7 July 2023.

Abstract: This article presents the preliminary results of a study on satellite-derived bathymetry. The purpose of this research is to explore the use of remote sensing and optical imagery for mapping the depth of coastal waters. This study uses empirical models to estimate the water depth based on the optical properties of the water column. To carry this out, it employs atmospheric correction algorithms to remove the influence of atmospheric scattering and absorption on the optical signals. The authors then apply the empirical models to the corrected imagery to obtain the bathymetric maps. The study shows promising results (RMSE ranging between 0.49 and 0.96m using the Lyzenga methodology), with the estimated depths generally consistent with the available ground-truth data. However, the accuracy of the estimated depths varies depending on the water conditions, such as the presence of waves and bottom type. The authors conclude that satellite-derived bathymetry has great potential for coastal applications, such as environmental monitoring and coastal management.

Keywords: remote sensing; satellite-derived bathymetry; atmospheric correction; optical imagery; coastal application; empirical model

Citation: Roch-Talens, A.; Pardo-Pascual, J.E.; Almonacid-Caballer, J. Preliminary Results of Satellite-Derived Nearshore Bathymetry. *Environ. Sci. Proc.* **2023**, *28*, 28. https://doi.org/10.3390/environsciproc2023028028

Academic Editors: María Belén Benito Oterino, José Fernández Torres, Rosa María García Blanco, Jorge Miguel Gaspar Escribano, Miguel Ángel Manso Callejo and Antonio Vázquez Hoehne

Published: 15 February 2024

1. Introduction

An accurate characterization of the near-shore bathymetry is the fundamental basis for making proper decisions related to coastal resources like land development projects, dredging or navigation. In addition, according to the IPCC [1], an increase in the number of natural disasters is expected and is already occurring. These phenomena, along with anthropogenic pressure, have a negative impact on the health of the coasts. This is also why it is necessary to periodically know the state of the coastal bathymetry. Current studies [2–4] have shown that it is possible to relate the attenuation of light when it travels through water and a ground-truth bathymetry to derive a satellite-derived bathymetry (SDB) from medium-resolution satellites. In this paper, we evaluate the capabilities of current empirical models to derive multi-temporal bathymetries. It also assesses possible issues related to high water turbidity or atmospheric corrections. The training of the models needs ground-truth information and it has restricted the geographic availability of study zones. The beach of Son Bou (South Menorca Island, Spain) Figure 1 has been chosen for this study. Sou Bou is a microtidal beach 2.5 km length formed by fine bioclastic sands and oligotrophic waters, although close to shore there are some rocky outcrops and Neptune grass (Posidonia oceanica) meadow patches. The tidal range is lower than 0.2 m and dominated by very soft wave conditions (90% Hs < 1 m). Finally, these computationally efficient techniques have the potential to be automated, which would help in a wide range of coastal issues like emergencies, navigation or coastal research.

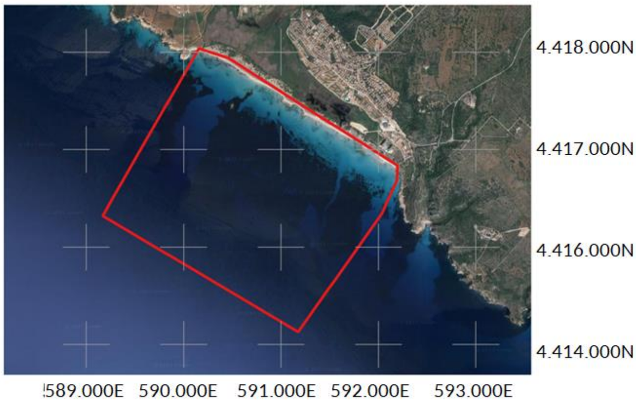

Figure 1. Study area in Son Bou beach with Neptune grass meadows clearly visible. Coordinates in EPSG:25831.

2. Materials and Methods

For this study, visible spectrum bands will be used (blue, 492 nm, and green, 560 nm) which are highly affected by Earth's atmosphere. For this reason, a refined atmospheric correction must be applied to retrieve accurate SDBs. Work has only been carried out on sandy areas and up to a maximum depth of 10m which is the usual limit of SDB according to the current literature [5]. Remember that the models are trained with reference ground-truth bathymetries.

2.1. Ground-Truth Data

The used ground-truth data were provided by the Balearic Islands Coastal Observing and Forecasting System (SOCIB). Note that these data are not freely accessible and require permission for use. The bathymetric measurements were acquired using a multi-beam echosounder; however, there may be instances where certain areas have missing data. These blank data were complemented with the bathymetries made by the Spanish Government (Ministerio para la Transición Ecológica y el Reto Demográfico) for Menorca Island in 2008. The technical information of the used data is described below:

- Rasterized bathymetry from 2016-04-21, 1 m/pixel.
- Rasterized bathymetry from 2017-05-24, 1 m/pixel.

The bathymetries mentioned above differ by $\pm$75 cm on average. The reference bathymetry might also be affected by the wave conditions at the acquisition time. In consequence, the reference bathymetry might include some noise that affects the modeling.

2.2. Sentinel Imagery

Sentinel-2 was launched by the European Space Agency in 2015 and its sensors include the Multispectral Instrument (MSI), which provides 13 spectral bands and a spatial resolution of 10 to 60 m. It has a temporal repetition of approximately 5 days.

For each reference bathymetry, the two temporally closest and cloud-free images had been chosen. From these images, the used bands where blue and green (10 m/pixel), which have the highest transitivity when they travel through a body of water. However, these bands are highly affected by Earth's atmosphere and accurate atmospheric correction is required.

2.3. Atmospheric Corrections

Both ESAs offer their images with reflectance at the top of atmosphere (TOA) and bottom of atmosphere (BOA). However, given that their atmospheric correction to compute BOA images is focused on in-land applications [4,6,7], an alternative atmospheric correction was performed using ACOLITE [8] (a tool developed by the Royal Belgian Institute of Natural Sciences). ACOLITE is a highly customizable atmospheric correction tool, specifically designed for marine applications. It uses an atmospheric radiative transfer method with ancillary data from NASA models to give an accurate correction. Default settings for ACOLITE have been changed to use black spectrum correction with NASA ancillary data and allow a maximum reflectance of 0.1.

2.4. Satellite-Derived Bathymetry Models

The empirical methods used in this study are based on Bier–Lambert law which describes how light I_0 attenuates exponentially as it passes through a medium of length L with a attenuation coefficient k. It has been assessed the two models that are finding the better results in the literature.

$$I = I_0 \cdot e^{-k \cdot L} \tag{1}$$

Then, the length along the water is linearly proportional to the logarithm of the reflectance, which is the basis for the next methods. In this study, two of the most used empirical methods were applied.

$$L = -log(I/I_0)/k = -log(R)/k \tag{2}$$

2.4.1. Lyzenga Method

The Lyzenga method was one of the first methods widely used to retrieve bathymetries using satellite images [2]. Lyzenga takes the relation between reflectance and depth as Equation (2) which, a priori, can be used with any band. Lyzenga model linearly mixes two or more Bier–Lambert attenuations.

$$SDB = m_1 \cdot ln(\lambda_i) + m_2 \cdot ln(\lambda_j) \cdots + m_n \cdot ln(\lambda_x) + n \tag{3}$$

For a satellite-derived bathymetry, λ_x is a spectral band, usually between ultrablue (443 nm) and red (665 nm). The parameters of the equation m and n can be obtained training with a ground truth bathymetry.For this work, the used bands were blue and green; this is because these bands have a spatial resolution of 10 m and the ultrablue band was discarded because of its coarse geometric resolution (60 m/pixel). Also, a limitation to depths deeper than −10 m was applied to avoid possible errors and also because it is uncommon to expect variations at depths deeper than −10 m.

2.4.2. Stumpf Method

The method developed by Richard Stumpf [3] was the result of an improvement of the Lyzenga method. The Stumpf method, also known as the log-ratio method, is supposed to improve the results when there is more than one seafloor cover. This method is defined as Equation (4) in which the final bathymetry is seen as the ratio of two Bier–Lambert relations over two different bands.

$$pSDB = \frac{ln(n \cdot \pi \cdot R(\lambda_i))}{ln(n \cdot \pi \cdot R(\lambda_j))} \tag{4}$$

n is a fixed number (1000) to avoid negative numbers [4,6], λ_i is usually the blue band, λ_j is the green or red band and $pSDB$ is the pseudo-distance that is adjusted in a linear regression:

$$SDB = m \cdot pSDB - n \tag{5}$$

For this work, the green and blue bands were used, respectively. Also, there was a limitation for depths lower than −10 m.

2.5. Evaluation Methods

It has been considered to use the root mean square error (RMSE) to compare the accuracy of the models. The RMSE has been calculated with the temporally nearest ground-truth bathymetry and the prediction derived by satellite by the showed methods.

Nevertheless, it should be noted that it is important to use more statistical parameters and especially, to analyze the accuracy of the models as a function of depth.

3. Results

The results obtained with the Lyzenga (Table 1) and Stumpf (Table 2) methods were synthesized in a matrix showing the RMSE in meters. The model has been trained on each date using the reference bathymetry closest in time and applied to the other dates. The used bands were blue and green, respectively, and the maximum depth for the ground-truth bathymetry was −10 m. The results shown below correspond to sandy zones not covered by Neptune grass meadows.

Table 1. RMSE (m) with Lyzenga method.

		Model Trained Dates			
	RMSE (m)	25/4/2016	5/5/2016	10/4/2017	19/6/2017
Model applied dates	25/4/2016	0.74	0.86	0.80	0.96
	5/5/2016	0.75	0.64	0.64	0.73
	10/4/2017	0.65	0.65	0.49	0.74
	19/6/2017	0.74	0.72	0.64	0.51

Table 2. RMSE with Stumpf Method.

		Model Trained Dates			
	RMSE (m)	25/4/2016	5/5/2016	10/4/2017	19/6/2017
Model applied dates	25/4/2016	0.79	1.02	0.81	0.84
	5/5/2016	1.12	0.89	0.95	1.36
	10/4/2017	0.78	0.79	0.67	1.05
	19/6/2017	0.88	1.26	0.97	0.72

4. Discussion

It is predictable that the results on the diagonal of the matrix should be the lowest of each column, that is because the model was trained and validated with its own data should give the lowest RMSE. This is something that can be seen clearly in the year 2017 but not in 2016. On one hand, despite 2016 does not have the best results on the diagonal, on average, it has the lowest RMSE in both methods. On the other hand, on average, 2017 has the worst results. Making a visual observation of the images, they do not have the same atmospheric and water conditions. The 2017 images are clear (the image of 19-06–2017 is exceptionally clear) compared to 2016 images that have algae moving near the coast and swelling that produces higher reflectivity. These differences in the results might be explained due to different water and atmospheric conditions.

In general, despite these differences in errors, the average of the RMSE is 60 cm for the Stumpf method. Considering that data are being analyzed up to a depth of −10 m and that the error remains somewhat constant over time, these error values are considered useful for some applications. Nonetheless, the results show that is possible to apply these methods multitemporally. Future research should be focused on solving problems related to water turbidity, sea rugosity and scale these methodologies to bigger areas and longer periods of time and different water conditions.

Author Contributions: Conceptualization, J.E.P.-P. and J.A.-C.; methodology, A.R.-T., J.A.-C. and J.E.P.-P.; software, A.R.-T.; validation, A.R.-T. and J.A.-C.; formal analysis, A.R.-T.; investigation, A.R.-T.; resources, A.R.-T.; data curation, A.R.-T.; writing—original draft preparation, A.R.-T.; writing—review and editing, A.R.-T., J.A.-C. and J.E.P.-P.; visualization, A.R.-T., J.A.-C. and J.E.P.-P.; supervision, J.E.P.-P.

and J.A.-C.; project administration, J.E.P.-P.; funding acquisition, J.E.P.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was part of the MONOBESAT project (PID2019-111435RB-I00) funded by the Spanish Ministry of Science, Innovation and Universities.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Satellite derived bathymetries that support our results are available upon request. Satellite imagery can be downloaded for free on the Copernicus Dataspace Ecosystem (https://dataspace.copernicus.eu/) and ground truth bathymetry should be requested to SOCIB.

Acknowledgments: Special acknowledgments are given to SOCIB for bathymetric data contribution.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. IPCC. Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2021; pp. 3–32. [CrossRef]
2. Lyzenga, D.R. Passive remote sensing techniques for mapping water depth and bottom features. *Appl. Opt.* **1978**, *17*, 379–383. [CrossRef] [PubMed]
3. Stumpf, R.P.; Holderied, K.; Sinclair, M. Determination of water depth with high-resolution satellite imagery over variable bottom types. *Limnol. Oceanogr.* **2003**, *48*, 547–556. [CrossRef]
4. Caballero, I.; Stumpf, R.P. Retrieval of nearshore bathymetry from Sentinel-2A and 2B satellites in South Florida coastal waters. *Estuar. Coast. Shelf Sci.* **2019**, *226*, 106277. [CrossRef]
5. Yunus, A.P.; Dou, J.; Song, X.; Avtar, R. Improved Bathymetric Mapping of Coastal and Lake Environments Using Sentinel-2 and Landsat-8 Images. *Sensors* **2019**, *19*, 2788. [CrossRef] [PubMed]
6. Caballero, I.; Stumpf, R.P.; Meredith, A. Preliminary Assessment of Turbidity and Chlorophyll Impact on Bathymetry Derived from Sentinel-2A and Sentinel-3A Satellites in South Florida. *Remote. Sens.* **2019**, *11*, 645. [CrossRef]
7. Caballero, I.; Stumpf, R.P. Towards Routine Mapping of Shallow Bathymetry in Environments with Variable Turbidity: Contribution of Sentinel-2A/B Satellites Mission. *Remote. Sens.* **2020**, *12*, 451. [CrossRef]
8. Vanhellmont, Q.; Ruddick, K. Acolite for Sentinel-2: Aquatic Applications of MSI Imagery. In Proceedings of the ESA Living Planet Symposium 2016, Prague, Czech Republic, 9–13 May 2016; Ouwehand, L., Ed.; European Space Agency: Paris, France, 2016; p. 55.