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Satellite-Derived Bathymetry for the Islands of South-Eastern Crete

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***Abstract* – The study presents a semi-authomated model of bathymetry derivation from various satellite imageries (Pleiades, PlanetScope, and Sentinel 2-A) with different spatial resolutions, for two islands of the south-eastern Crete coast (Chrisi and Koufonisi) whose marine cultural heritage attributes remain undocumented. The workflow of the model is based on the empirical, band ratio approach and carried out within ESRI's ArcMap application. The highest accuracy that was achieved was an RMSE of 1.1 m for the bathymetry model from the PlanetScope image for Chrisi island. A low level of turbidity (low NDTI), high amount and reliability of depth training points, specific spectral characteristic (such as narrower bandwidths) and high spatial resolution provide a more precise bathymetry model for the studied islands. The resultsdemonstrate a time-efficient and geographically broad investigatory technique having the potential to form an initial step in the identification and hazard management of coastal cultural heritage sites.**

I. INTRODUCTION

Recent advances in remote sensing techniques and higher availability of satellite sensors has increased their applicability to several scientifc sectors, including marine research. Satellite-derived bathymetry (SDB) exemplifies this trend, with recent developments seeing nearshore bathymetry derived from multispectral, high-spatial-resolution satellite imagery being investigated for various applications . One such application , pertaining to coastal cultural heritage (CH) management, is to provide an additional means of discovering large archaeological features or identifying risks to CH sites through mapping the local maritime geomorphological layout [1]. In both environments, the benefit is a relatievly cost-effective way to survey vast areas before committing valuable time and resources to undertaking targeted, ground-based investigations.

However, the two major traditional approaches to investigating bathymetry via optical imagery, empirical and analytical, each have obstacles to their implementation [2]. Respectively, examples are: investments of time and money in gathering data via field campaigns and; usage of complicated algorithms or software which may impede practitioners with expertise in different areas.

This work therefore aims to overcome both obstacles mentioned above by simplifying the required stages of bathymetry derivation within a semi-automated method, contained within ESRI's ArcMap application. It is easily-adaptable to other sites and avoids the need for sourcing empirical data from field campaigns. The method is theoretically rooted in Stumpf et al.'s 3] band ratio approach, using high-spatial-resolution satellite imagery. The method is additionally applied and compared between imagery generated from three satellite sensors of different spatial resolution: Pleiades 1-A (0.5 m spatial resolution), PlanetScope (3 m), and Sentinel 2-A (10 m), which demonstrates the model's utility and level of accuracy with both commercial and open-source imagery sources

The method has been applied to Koufonisi and Chrisi islands off the coast of south-eastern Crete in southern Greece. The islands' waters have not yet been investigated for their potential value to CH in the area, despite their proximity to the relatively archaeologically rich island of Crete. This paper therefore aims to test the viability of this method in attaining accuracies sufficient to identifying marine CH assets and the geomorphological character of their surrounding environment.

II. METHODS

A semi-automated model was created via ArcGIS's native 'ModelBuilder' tool which carries out several steps required for converting a multiband image into the final bathymetry product via the use of an empirical approach for the respective satellite datasets (Table 1):

(1) Initial processing steps are first undertaken, including: separating the multiband images into single, rasterized bands; then ensuring that the rasterized band layers are not subject to a loss of precision by storing each layer in a file format providing a suitable radiometric resolution. Optionally, sun-glint removal or other pre-processing can easily be integrated into the model and included between Step 1 and 2 when necessary.

(2) Land masking is performed using McFeeter's NDWI index [4]. Its calculation is facilitated by Arc's 'Raster Calculator' tool. NDWI is usually calculated as the quotient of: the difference of the green and NIR bands (wavelengths for each listed in Table 1) and; the sum of the green and NIR bands:

$$NDWI = (band_{green} - band_{NIR}) \div (band_{green} - band_{NIR}) \quad (1)$$

Optimal masking thresholds (NDWI values), for separating land from sea, have previously been suggested to lie between 0.16 – 0.34 [5], though this work found 0.2 to be optimal for the local study areas. The mask is applied to each band individually in the ModelBuilder workflow, with values lower than 0.2 being set as null.

(3) The **turbidity** present in the image is then checked via the application of the NDTI. The Raster Calculator is again used with the formula:

$$NDTI = (band_{red} - band_{green}) \div (band_{red} + band_{green}) \quad (1)$$

Lower values represent clearer water and higher values, vice versa [6,7].

(4) Median filtering using a 'low-pass' 3X3 window was applied to remove any outliers as noise from the following steps.

(5) Stumpf et al.'s **band ratio method** using the blue/green ratio is applied to retrieve the relative bathymetry. The following formula is used:

$$ln(n \cdot band_{blue}) \div ln(n \cdot band_{green}) \quad (1)$$

where 'n' is a large, positive constant used to ensure that the result is a positive value (in this case 1000 is used).

(6) Empirical data in this work was sourced from 'EMODnet' (European Marine Observation and Data Network) bathymetric data. EMODnet Digital Bathymetry (DTM) is a multilayer bathymetric product for Europe's seas. It is based upon a collection of bathymetric surveys, Composite DTMs and Satellite Derived Bathymetry bathymetric data. Areas not covered by observations are completed by integrating GEBCO (The General Bathymetric Chart of the Oceans), IBCAO (Gridded bathymetry data for the Arctic Ocean area) and GMRT (Global Multi-Resolution Topography) data sets. The resulting dataset consists of a grid of points with a 115 m spacing.

(7) A **maximum depth** of 15m was used to filter the empirical data, meaning only points with depths shallower than 15m were used to calibrate the points. This rationale is supported by [3] who reported higher correlation coefficients between observed and empirical data in shallower depths when using 'blue' and 'green' spectral areas.

(8) Training points (80% of total data) and **test points** (20% of total data) were then randomly selected from the empirical data to calibrate and test the model respectively. The 80/20 split was selected for its and its successful usage in similar studies [8].

(9) A **log transformation** is applied to the relative bathymetry data calculated with the band ratio method in *Step 5* so that **linear regression analysis** between the observed and empirical data can be performed within ArcMap.

(10) Accuracy is estimated by finding the Root Mean Square Error of the raster cells representing the calibrated bathymetry raster which directly underlie test points extracted from the empirical dataset.

Table 1. Satellite images used in the study.

Sensor	Resolution	Date	Bands Applied
		Chrisi	
Pleiades-1A	0.5 m	16.06.2022	B: 430-550 nm G: 490-610 nm R: 600-720 nm NIR: 750-950 nm
Planet-Scope	3 m	18.06.2022	B: 465-515 nm G: 547-583 nm R: 650-680 nm NIR: 845-885 nm
Sentinel-2A	10 m	06.06.2022	B: 458-523 nm G: 543-578 nm R: 650-680 nm NIR: 785-899 nm
		Koufonisi	
Pleiades-1A	0.5 m	26.04.2022	B: 430-550 nm G: 490-610 nm R: 600-720 nm NIR: 750-950 nm
Planet-Scope	3 m	26.04.2022	B: 465-515 nm G: 547-583 nm R: 650-680 nm

			NIR: 845-885 nm
Sentinel-2A	10 m	07.05.2022	B: 458-523 nm G: 543-578 nm R: 650-680 nm NIR: 785-899 nm

III. RESULTS/DISCUSSION

Applying the technique of SDB via the band ratio approach allowed us to obtain bathymetry models with more or less precise accuracy amounting to between 1-2 m (Table 2, Figues 1-4). Root mean square errors (RMSEs) of validation are lower for Chrisi island compared to Koufonisi. This could be a reflection of the higher amount of control points used and generally lower NDTI values (i.e. lower turbidity) for this area.

Comparing different images, the Sentinel-2A imagery, having significantly poorer resolution and higher NDTI values, provided worse accuracy for the bathymetry models. Notably however, the higher spatial resolution of the image does not necessarily mean better results for SDB. The bathymetry model extracted from the Pleiades imageries, which had the highest spatial resolution available, showed higher RMSEs. That may be related to the broader bandwidths of the Pleiades sensor's spectral bands, hence causing less precise models.

The most promising result was RMSE 1.1 m for the bathymetry model from the PlanetScope image for Chrisi island. It is notable that, for this image, the NDTI values were the lowest. The poorest accuracy (2.2 m) was received from the Sentinel image for the Koufonisi area. This image was probably captured during the period with worse hydrometeorological conditions for bathymetry derivation, as the NDTI values are the highest on this image.

Table 2. Resulting accuracy of SDB from the different sources.

Sensor	Training Points	Equations	Test Points	RMSE (m)
		Chrisi		
Pleiades-1A		y = -31.997x + 31.916		1.2
Planet-Scope	753	y = -22.789x + 22.789	178	1.1
Sentinel-2A		y = -59.519x + 59.620		1.7
		Koufonisi		
Pleiades-1A	522	y = -56.791x + 56.529	131	1.7
Planet-Scope		y = -24.686x + 24.621		1.4
Sentinel-2A		y = -68.762x + 68.901		2.2

Concerning spatial distribution, the most general trend is increasing uncertainty of the extracted bathymetry with depth (Figures 1-4). 30m is a maximum depth at which bathymetry derivation from optical imagery has been reported under ideal conditions within the literature [9]. We tried to use 30 and 15 m thresholds for the bathymetry data from EMODnet to validate our models, and the 15 m one worked the best. Considering this, only the data for depths up to approximately 15 m is generally valid (the errors are about ±1 m). At the higher depths, closer to the boundaries of the images, the error values grow exponentially (up to dozens of m in the Chrisi area, and up to hundreds of m in Koufonisi).

Considering the conclusions of Guzinski et al. [1], who tested SDB with a similar spatial resolution (~0.5m), the scale and accuracy of the resulting bathymetry model here suggests that geomorphologic features at the sites, such as submerged channels/ridges, could be sufficiently discerned. The author notes that only shipwrecks were able to be identified in their study, and that confident identification of finer-scale archaeological structures and artefacts (e.g. settlement walls) are unlikely to be possible at the current image quality. Crucially, in the case of Koufonisi and Chrisi, SDB provides a valuable first-order investigatory tool for identifying or corroborating evidence of potential CH sites where no such information exists yet. Furthermore, if the presence of settlements is confirmed through subsequent investigation, SDB could enable the placement of these settlements within their broader geomorphological contexts and the undertaking of hazard assessments. Finally, in comparison to the aforementioned work, this study's method's simplicity, reproducibility and lack of reliance on field dataprovide further advantages, especially to non-expert practitioners.

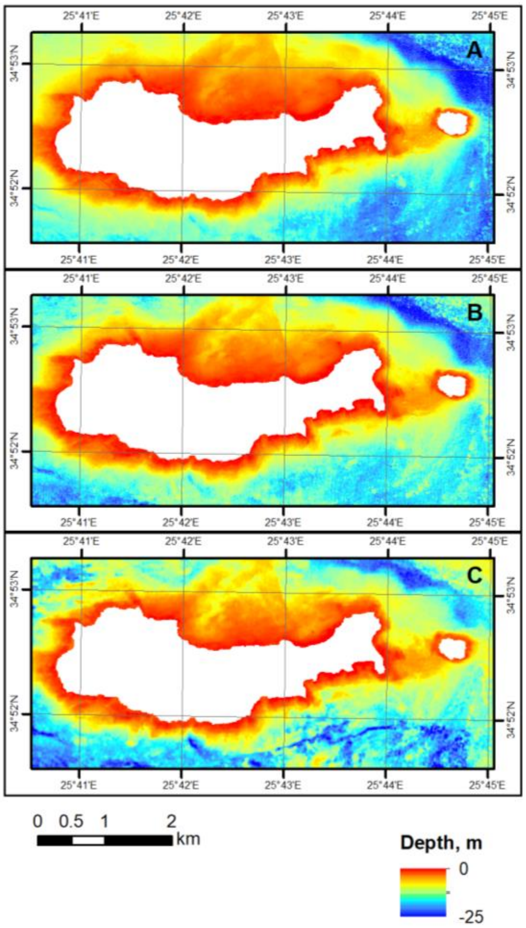

Fig. 1. Bathymetry models for Chrisi island, derived from A) Pliades, B) PlanetScope, C) Sentinel imageries

IV. CONCLUSIONS

The study presents the initial results of deriving bathymetry, without field-surveyed observations, from satellite images of different spatial resolutions (Pleiades, PlanetScope and Senstinel) for two key areas of the south-eastern Crete coasts (Chrisi and Koufonisi islands). The technique applied was the band ratio approach, which was facilitated entirely through the use of ESRI ArcGIS software.

The accuracy of the bathymetry models obtained is highly dependent on the turbidity conditions of the image (NDTI) and on the reliability and number of depth validation points. The spatial resolution and spectral characteristics of the image play a smaller part in this case.

The bathymetry models generated for Chrisi and Koufonisi provide useful first-order models for their waters where field-surveyed bathymetry is currently nonexistent. The models' scale is currently suitable for understanding the geomorphological context of shallow-water cultural heritage sites, and as inputs to hazard assessments for such sites. Further investigation is necessary to ascertain SDB's utility in directly identifying shallow-water cultural heritage features.In the continuation of the project, it is planned to improve the proposed algorithm using more accurate, field-surveyed bathymetric data for validation. The obtained bathymetry models will become a base for futher detailed mapping and geophysical and geomorphological surveys for the purpose of hazard assessment for the coastal archaeological sites.

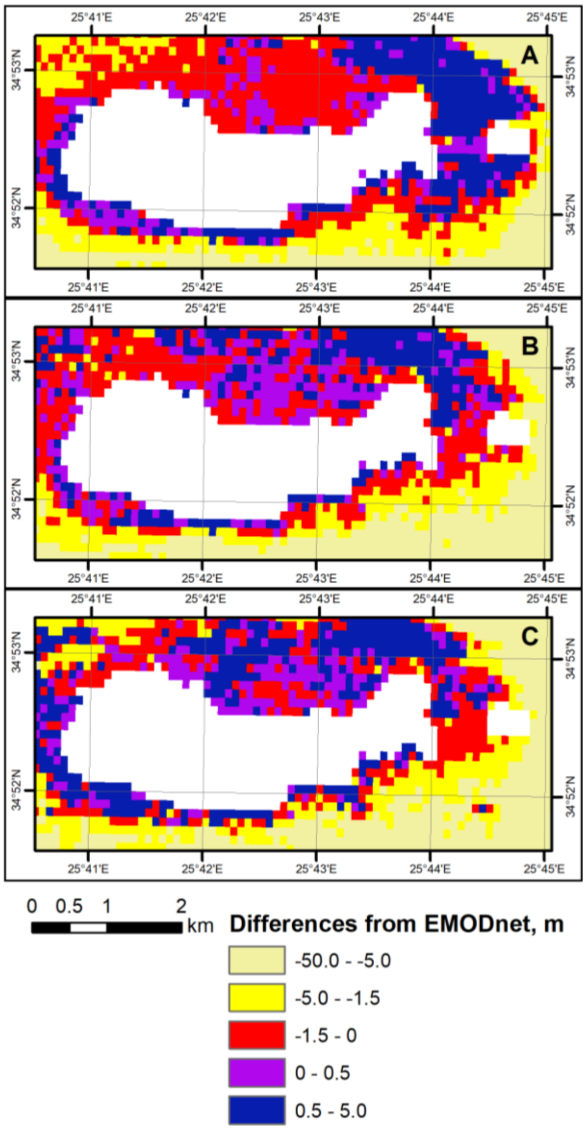

Fig. 2. Differences between the resulting bathymetry models and EMODnet data, for Chrisi island, derived from A) Pliades, B) PlanetScope, C) Sentinel imageries

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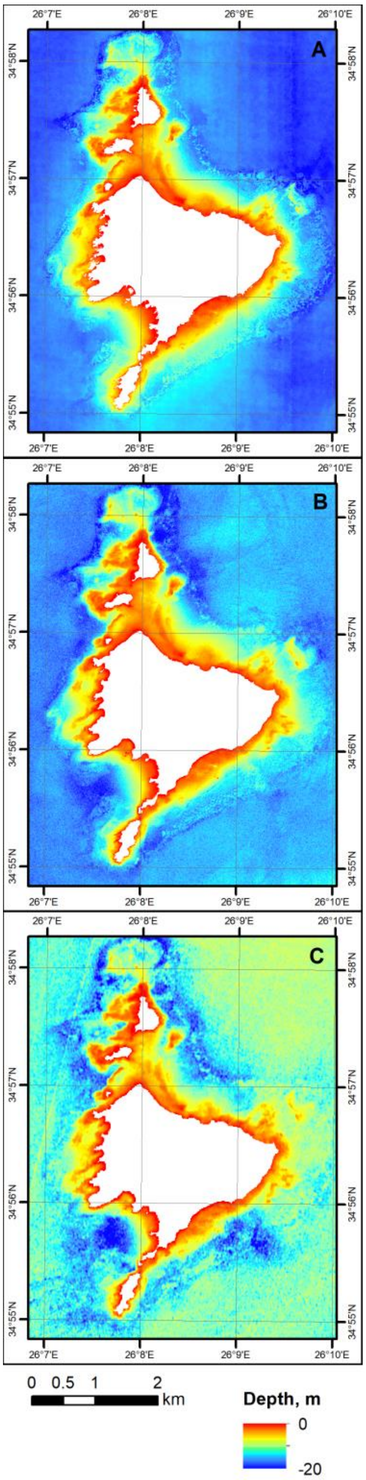

Fig. 3. Bathymetry models for Koufonisi island, derived from A) Pliades, B) PlanetScope, C) Sentinel imageries

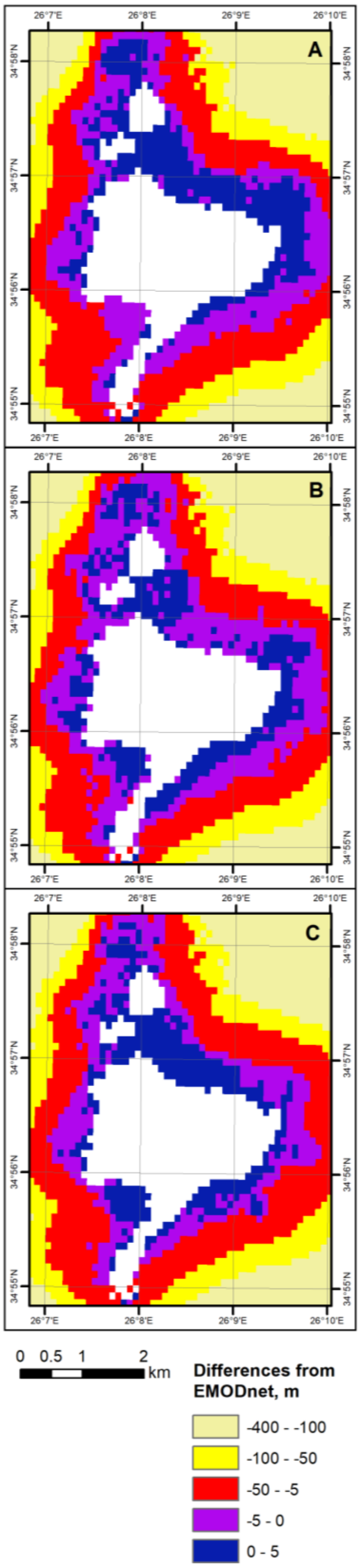

Fig. 4. Differences between the resulting bathymetry models and EMODnet data, for Koufonisi island, derived from A) Pliades, B) PlanetScope, C) Sentinel imageries

VI. REFERENCES

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