environmental sciences proceedings

Proceedings

Pléiades Neo-derived bathymetry in coastal temperate waters: the case study of bay of Saint-Malo †

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† Presented at The 5th International Electronic Conference on Remote Sensing, online, 7-21 November 2023.

Abstract: Satellite-derived bathymetry is increasingly attracting stakeholders' attention tasked with remote and/or shallow depths given its affordability compared to airborne lidar and waterborne sonar surveys. The 6-band 1.2-m Pléiades Neo (PNEO) multispectral imagery has not yet been evaluated for such a purpose. The contribution of the novel PNEO bands to the depth retrieval was assessed over unclear coastal seawaters (0.2 m^{-1} of vertical light attenuation in bay of Saint-Malo, France). The relevance of the radiometric level was also tested: top-of-atmosphere (TOA) digital number (DN), TOA radiance, TOA reflectance, bottom-of-atmosphere (BOA) maritime-modelled reflectance, and BOA tropospheric-modelled reflectance. The lidar response, ranging from 0 to 20 m depth, was stratified by 90 random samples per bathymetric slice of 1 m. The model was based on an easy-to-transfer neural network (one hidden layer and three neurons). The best predictions, reaching R^2_{test} of 0.81, were equally obtained for the full PNEO dataset at TOA DN, radiance and reflectance. For both BOA full-dataset products, the results were slightly less satisfactory: R^2_{test} of 0.75 (maritime) and 0.76 (tropospheric).

Keywords: very high resolution; satellite; neural networks

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

Published: date

1. Introduction

Despite the growing interest in seabed mapping in the context of sea level rise and storm intensification, only 25% of the global bathymetry has been surveyed using reliable technologies, such as sonar or lidar [1]. This considerable gap is primarily driven by the high cost of associated waterborne and airborne campaigns [2]. Consequently, satellite-derived bathymetry has thrived in recent decades, given its affordability enhanced by its ongoing gain in radiometric, spatial, spectral and temporal resolutions [3,4].

Very high spatial resolution (VHSR) sensors provided with multispectral imagery have raised interest from coastal scientists and managers given the successful bathymetry retrieval down to 30 m in very clear waters (South Pacific) using WorldView-2 imagery [5], or to 10 m in chlorophyll-laden temperate waters (Channel Sea) using WorldView-3 imagery [6]. As a new flagship of VHSR spaceborne sensor, the Pléiades Neo (PNEO) sensor leverages 6 bands : 1 deep blue, 3 visible, 1 red edge, and 1 infrared, provided with 1.2 m pixel size. This new sensor thus outperforms the Pléiades-1 multispectral imagery endowed with 4 bands (3 visible and 1 infrared) at 2 m pixel size.

This study aims to innovatively quantify the contribution of the novel bands of the PNEO to the bathymetry retrieval over optically-challenging coastal seawaters (Channel Sea, 0.2 m^{-1} of vertical light attenuation) in the bay of Saint-Malo [7]. The importance of the level of the radiometric correction was tested based on the lidar bathymetry predicted by a shallow neural network (one hidden layer and three neurons).

2. Methodology

2.1. Study Site

The study site is located within the bay of Saint-Malo (48°40′N 2°4′10′′W; Brittany, France) featured with a diversity of depths (ranging from the 0-m shoreline to the 20-m channel) and benthic albedos (mud, sand, gravel, pebble, boulder, rock) bathed by a megatidal regime (Figure 1).

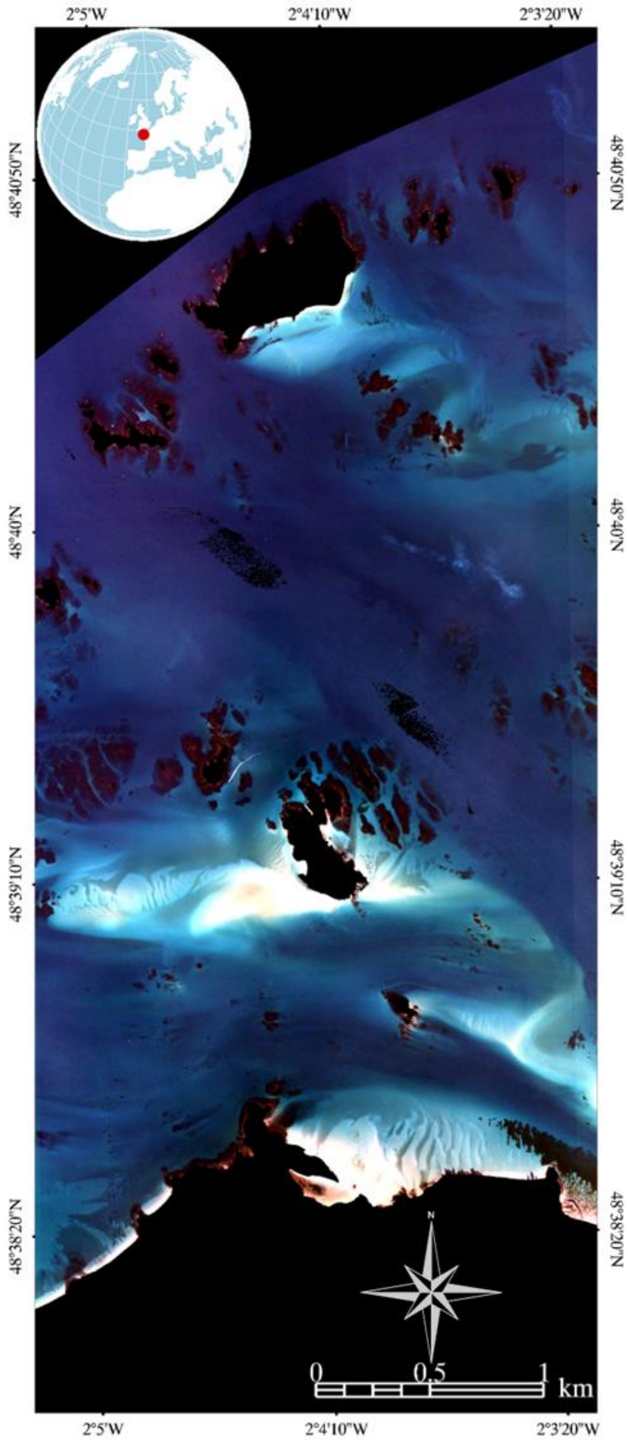

Figure 1. Blue-green-red composite PNEO imagery of the study site and its global location (RGF93 Lambert 93 IGN69; 2 057 × 5 067 pixels; 1.2 m pixel size).

2.2. Satellite Imagery

2.2.1. Pléiades Neo Sensor

The spaceborne mission was ensured by the PNEO 4 sensor that was launched on August 16, 2021 from Kourou (French Guyana). Our imagery was collected from a 620-km orbit on December 7, 2022 at 11h12min48sec UTC time. This sensor collects deep blue (400-450 nm), blue (450-520 nm), green (530-590 nm), red (620-690 nm), red edge (700-750 nm) and near-infrared (770-880 nm) bands at 1.2 m spatial and 12-bit radiometric resolutions (Table 1).

Table 1. Spectral specifications of the Pléiades Neo sensor.

Band names	Lower wavelength	Upper wavelength
Deep blue	400	450
Blue	450	520
Green	530	590
Red	620	690
Red edge	700	750
Near-infrared	770	880

2.2.2. Imagery Processing

The PNEO 4 imagery underwent a series of correction prior to be further analyzed. First, the imagery was orthorectified in the RGF93 datum, projected with Lambert 93 along with the IGN69 vertical reference, based on RPC geometry metadata. Second, the resulting imagery was radiometrically corrected at five various levels using PNEO-4 spectral sensitivity: top-of-atmosphere (TOA) digital number (DN), TOA radiance, TOA reflectance, bottom-of-atmosphere (BOA) maritime reflectance, and BOA tropospheric reflectance (see FLAASH modelling). Third, the by-products were spatially subsetted on a transitional area perpendicular to the shoreline, providing a wide diversity of depths and albedos (Figure 1).

2.3. Lidar Topobathymetry

2.3.1. HawkEye 3

The depth response was derived from an airborne topobathymetric lidar carried out in May-July 2018 over the bay of Saint-Malo by the French Navy (Shom) using a Leica HawkEye 3 system acquiring soundings with a at least 4 points/m^2 until 25-m water depth [7].

2.3.2 Lidar Processing

The WGS84 point cloud was rasterized at 1.2 m in the RGF93 – Lambert 93 – IGN69 geodesy in order to match the PNEO spatial dimensions and resolution (Figure 2).

2.4. Neural Network Modelling

The bathymetry retrieval relied on a neural network modelling, whose the response was embodied by the lidar response and the predictors corresponded to the PNEO spectral bands.

For the sake of transferability, a shallow neural network modeler was developed built from one layer and three neurons using hyperbolic tangent activation functions [8].

The lidar response was sliced at 1-m lag across the 20-m range, then randomly sampled with 90 virtual stations, in order to well balance the statistical modelling. By equally dividing the 90 stations, 30 were randomly used for training, validation and test data.

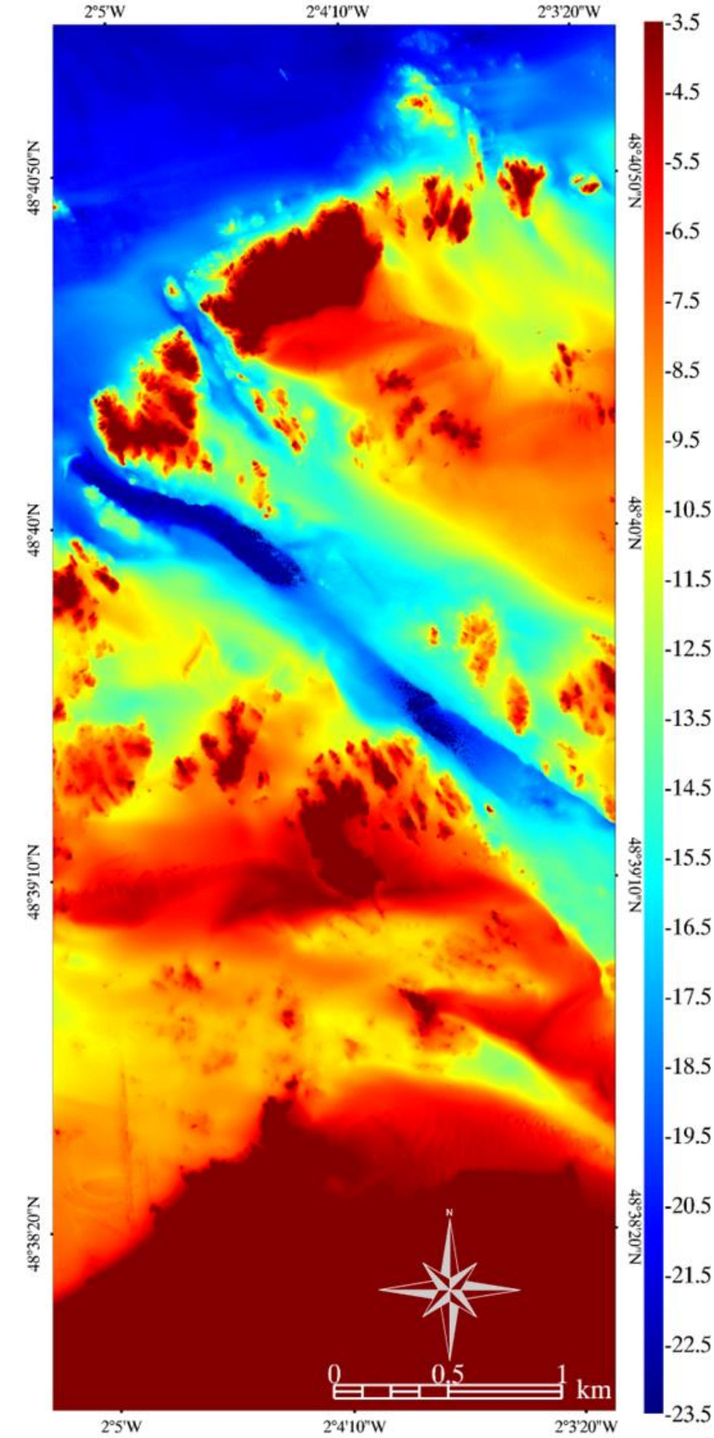

Figure 2. Lidar-derived bathymetry of the study site (RGF93 Lambert 93 IGN69; 2 057 × 5 067 pixels; 1.2 m pixel size).

3. Results and Discussion

3.1. Spectral Contribution

The novel PNEO bands, namely deep blue and red edge, were compared with the reference blue-green-red-near-infrared (BGRIR) findings (R^2_{test}=0.73). Averagely, the blue replacement by the deep blue increased results by 0.01; the addition of the deep blue increased by 0.02; and the addition of the deep blue and red edge increased by 0.06.

3.2. Radiometric Level

The best models were equally found out with the 6 PNEO bands for TOA DN, TOA radiance and TOA reflectance (R^2_{test}=0.81, Figure 3), followed by BOA maritime and BOA tropospheric reflectance (R^2_{test}=0.75 and 0.76, respectively). It is therefore recommended to use TOA radiometric levels, what corroborates bathymetric results stemming from the WorldView-2 sensor [5].

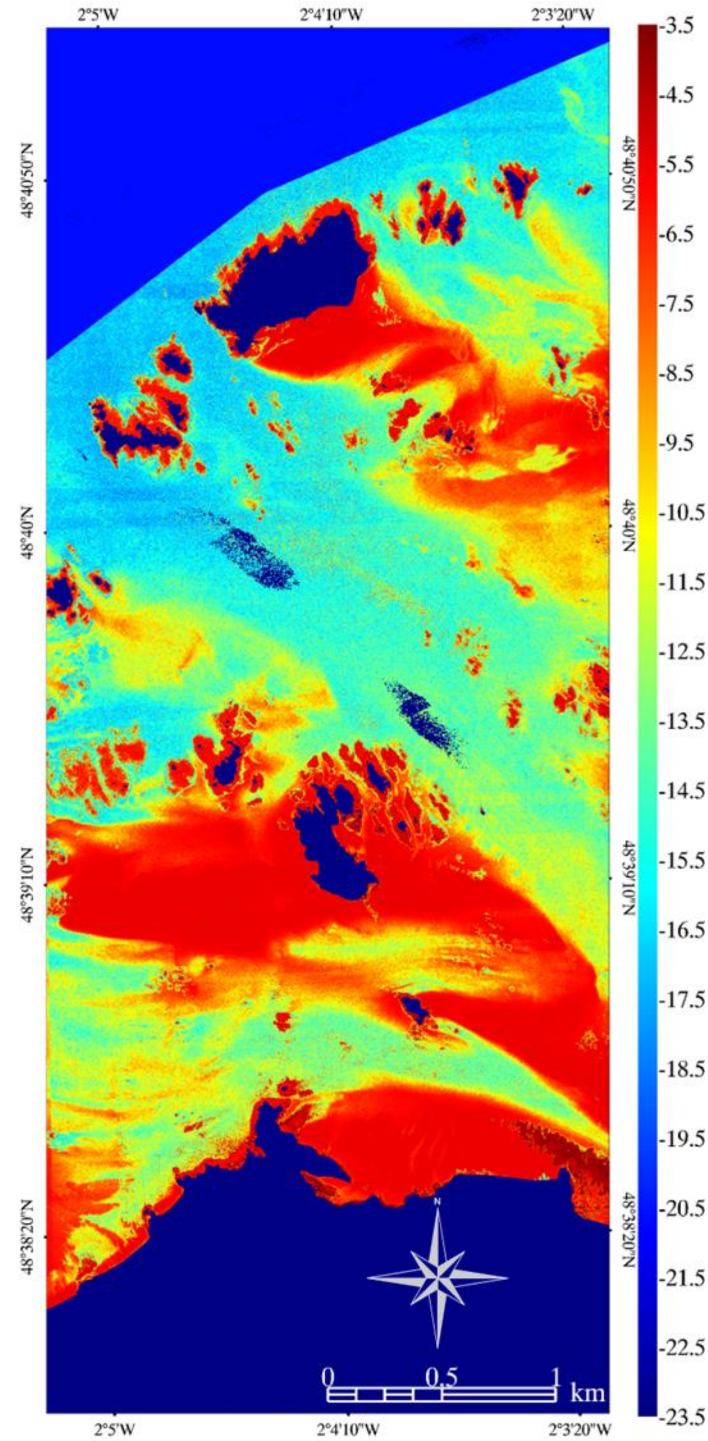

Figure 3. PNEO-derived bathymetry of the study site based on a neural network developed with the 6 PNEO bands at the top-of-atmosphere radiance level (RGF93 Lambert 93 IGN69; 2 057 × 5 067 pixels; 1.2 m pixel size).

4. Conclusions

The capacity of the novel bands associated with the PNEO sensor, compared to Pléiades-1 (BGRIR), to derive bathymetry was estimated over the bay of Saint-Malo (Channel Sea, France) using lidar response and a shallow neural network. Irrespective of the radiometric level, the replacement of the blue by the deep blue increased reference results by 0.01, the addition of the deep blue to the reference gained 0.02, and the use of all 6 bands increased by 0.06, reaching R^2_{test}=0.79. The best radiometric levels were equally TOA DN, TOA radiance and TOA reflectance (R^2_{test}=0.81).

Author Contributions: Conceptualization, A.C, D.J., R.G., E.P. and E.F.; methodology, A.C, D.J., R.G., E.P. and E.F.; software, A.C, D.J., R.G., E.P. and E.F.; validation, A.C, D.J., R.G., E.P. and E.F.; formal analysis, A.C, D.J., R.G., E.P. and E.F.; investigation, A.C, D.J., R.G., E.P. and E.F.; resources, A.C, D.J., R.G., E.P. and E.F.; data curation, A.C, D.J., R.G., E.P. and E.F.; writing—original draft preparation, A.C, D.J., R.G., E.P. and E.F.; writing—review and editing, A.C, D.J., R.G., E.P. and E.F.; visualization, A.C, D.J., R.G., E.P. and E.F.; supervision, A.C, D.J., R.G., E.P. and E.F.; project administration, A.C, D.J., R.G., E.P. and E.F.; funding acquisition, A.C, D.J., R.G., E.P. and E.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data is unavailable due to privacy.

Acknowledgments: Authors are grateful to French Office for Biodiversity for authorizing the UAV flights over natural and semi-natural habitats.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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