SHALLOW BATHYMETRY FROM PLÉIADES DATA: THE CASE STUDY OF THE GRINDAVIK VOLCANIC CRISIS.

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ABSTRACT

On November 10, 2023, the town of Grindavik on the Reykjanes peninsula (Iceland) was evacuated due to the propagation of a shallow magmatic fissure near the town. We programmed Pléiades images on the area via the CIEST² initiative. Due to the vicinity of the affected area to the ocean, the lava flow might reach the water modifying submarine topography. Our goal is to test a new space-based method to measure shallow bathymetry and possible submarine lava flow volume in shallow water.

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Index Terms— coastal bathymetry, space, Pléiades, CIEST²

1. INTRODUCTION

On November 10, 2023, the town of Grindavik on the Reykjanes peninsula (Iceland) has been evacuated. This decision has been taken following the identification of the propagation of a shallow magmatic fissure near the town. Due to the probable imminence of an eruption in the area, we programmed Pléiades images for 11 consecutive days via the CIEST² initiative, a scientific exploitation channel fostered by CNES (French Space Agency) and the French national center for solid Earth (Form@ter). The conditions of low solar illumination due to the entry into the winter period in Iceland made the task uneasy. Nonetheless, two Pléiades images could provide good visibility of the area affected by the magmatic intrusion, on land and ocean (figure 1). Due to the vicinity of the affected area to the ocean, the lava flow might reach the water modifying submarine topography. The mapping of lava flows in shallow water environments represents a pivotal aspect of understanding lava volume emissions and their consequential impact on underwater geomorphology. In this study, our goal was to test a new space based method to measure shallow bathymetry and possible submarine lava flow volume in shallow water.

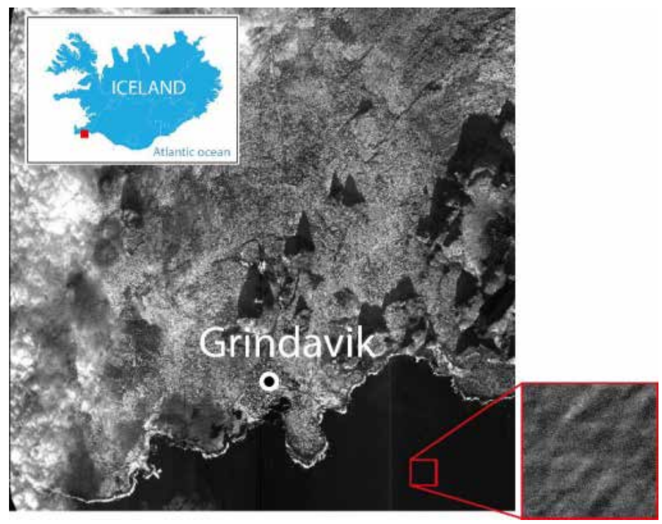

Figure 1. The study area in Iceland. Grindavik area from Pléiades image acquired on 19 of November 2023. The red rectangle in the Atlantic Ocean represents a histogram-stretched zoom on the swell. Image Pléiades © CNES (2023), distribution by Airbus DS.

2. METHODS

Here, the method is based on the joint measurement of ocean wave celerity (c), as presented in [1], and wavelength (λ), both from space. We adapted the method called BathySent [2] to Pléiades images, to retrieve shallow bathymetry from space.
This method is based on the linear dispersion law [3], which relates water depth to ocean wave celerity and wavelength: when the water depth is less than about half the dominant wavelength, the wave celerity and wavelength decreased due to decreasing water depth (h) as the waves propagated towards the coast, as in equation (1):

$$h=\lambda/2\pi \, . \, \tanh^{-1}(2\pi c^2 / g\lambda) \quad (1)$$

where h is the water depth and g is the standard acceleration due to gravity on Earth, equal to 9.81 m/s. Equation (1) was first used in a practical sense during the Second World War [3], and works either with two sequential images acquired within a short time interval, like in our case (i.e., shorter than the wave period), or with one image but with additional in situ measurements.

The idea behind the method is that the CCDs on a push broom sensor can not physically co-exist on the same spot on the focal plane. Therefore, there exist a time lag between the acquisitions of the different spectral bands, as the sensor travels at the speed of 7 km/s, depending on the sensor. This time lag can be used as a crucial variable for the measurement of ocean wave celerities [1]. In a recent past, we developed the method to work with Sentinel 2 data, exploiting the time lag between two Sentinel 2 spectral bands, acquired quasi-simultaneously, from a single satellite dataset [2]. Here, we adapted the method to be used with Pléiades data, acquired during the Grindavik eruptive crisis, via the activation of the CIEST² initiative. The Pléiades satellites are a constellation of optical Earth observation platforms, developed through a cooperation between CNES and Airbus Defence and Space. Operating at a sun-synchronous orbit around 700 kilometers above the Earth's surface, these satellites employ cutting-edge optical instruments to capture high-resolution imagery with exceptional precision. With a maximum ground resolution of 70 centimeters (panchromatic) and 2 meters (multispectral), the Pléiades satellites allows rapid repositioning and imaging of specific targets with stereoscopic view. In disaster management scenarios, the Pléiades satellites play a pivotal role by swiftly delivering pre and post-event images, enabling timely support to emergency response efforts. In our study, Pléiades dataset is acquired on 19 November 2023. The time lag between the acquisition of the panchromatic band and the blue band of Pléiades satellite is 0.16 seconds (CNES, pers. Comm.). Our idea is to calculate shallow bathymetry before and after the eruption to measure volume changes due to underwater lava flows. Here, we show an attempt to measure the pre-eruptive coastal bathymetry from space, before winter in Iceland.

Here, we propose a complementary, rapid, approach to retrieve coastal bathymetry –particularly adapted when the need of the project is to retrieve shallow coastal morphology in the presence of a monochromatic swell.

Our approach stems from the observation that conventional statistical cross-correlation approaches to measure c [1,4] works well in the presence of monochromatic swell. Therefore, instead of utilizing multiple (c,λ) combinations within the same resolution cells, to expedite processing, we implemented a two-step procedure based on the direct measurement of c and the wave period. First, we employed the statistical correlator implemented in the COSI-CORR software [4] to retrieve one value of c within each resolution cell, at each step of a grid. This techniques generates localized, sub-sampled waves offsets and their corresponding waves celerities is calculated by dividing the offset by the time lag that exists between acquisitions in Pléiades bands during a single pass of the satellite.

The wave celerities were computed from smaller sub-images based on a grid defined by the sampling step, which determined the resolution of the final bathymetric map. Then, we measured λ at large by visual inspection. Surely, in a future step, there will be rooms for automating this procedure. Afterwards, for each sub images, we calculated the waves period ($T = \lambda/c$). Finally, we solve the linear dispersion relation as a function of T, for each (c,T) pairs independently, to find h (equation 2, figure 2) :

$$h = cT/2\pi \;.\; \tanh^{-1}(2\pi c \,/\, gT) \quad (2)$$

where λ at large is 78.5; c_{λ} is 11.25 m/s. So $T = (\lambda \,/\, c_{\lambda}) =$ 6.97 sec.

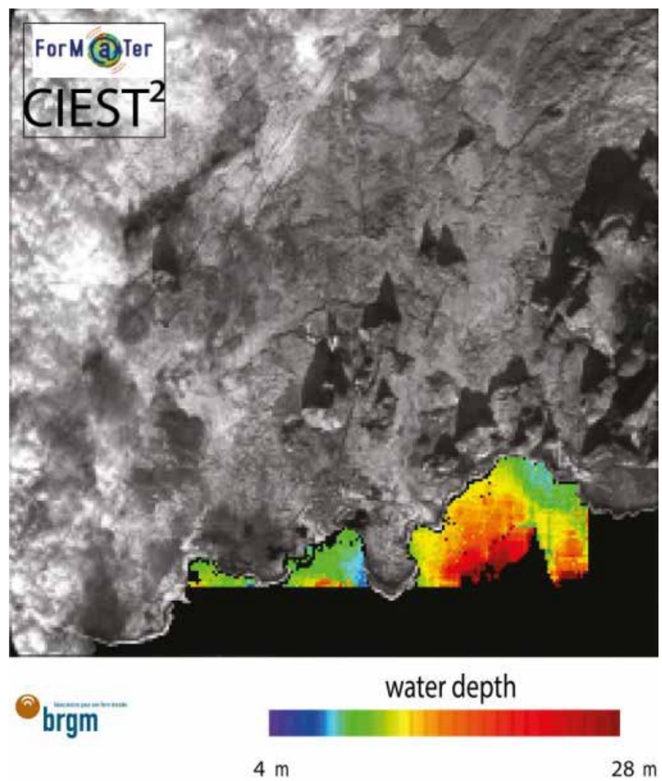

Figure 2. Coastal water depth in the Grindavik area from Pléiades images, 19 November 2023. The color bar is from 4 m depth to 28 m depth. Image Pléiades © CNES (2023), distribution by Airbus DS.

3. RESULTS AND PERSPECTIVES

Our results suggest that the low solar illumination angle, typical for winter time in Iceland, is pretty favorable to image the ocean swell. Therefore, we could calculate a shallow bathymetry map, from 4 to 28 meters depth (figure 2). We found this method stable for fast processing as it does not depend on the square of celerity (c^2) shown in equation (1). Therefore, this method might be suitable for shallow morphology mapping.

This method has high potential for mapping morphological changes of shallow bathymetry, which could be particularly useful in the case of a shallow sub-aerial or shallow submarine volcanic eruption, where the lava delta may extend hundreds of meters beyond the old shoreline. This method might be employed as a bridge in the gap that typically remains between multi-beam bathymetric surveys and the land. We plan to cross-compare our results with future field-based bathymetric surveys. Furthermore, we will be waiting for suitable light conditions in Iceland, next spring, to acquire a new Pléiades dataset.

4. ACKNOWLEDGEMENTS

We thank Emilie Bronner and Claude Boniface (CNES) for providing Pléiades data via the CIEST[2] initiative and the Form@ter center. Pléaides images are distributed by Airbus DS.

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