EGU24-2097, updated on 27 Jul 2024
https://doi.org/10.5194/egusphere-egu24-2097
EGU General Assembly 2024

Degassing from The Nord Stream Leaks as seen from space : an analog for submarine volcanic eruptions.

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Submarine volcanic activity, constitutes a significant portion of Earth's volcanic events and presents challenges for direct observation due to its predominantly deep-sea occurrence. Despite the rarity of direct observations, insights garnered from shallow eruptions and hydrothermal vents aid in understanding these phenomena. Here, we use the Nord Stream 2 gas leaks in the Baltic Sea region as an analogue to investigate the link between gas emissions at depth and surface manifestations, akin to shallow submarine volcanic degassing. Our study focuses on the mechanical interaction between gas bubbles surfacing from the Nord Stream 2 incident and the resultant sea waves measureable with Sentinel-2 satellite data. We explore the capability of this optical sensor to measure wave celerities and directions generated by the gas plumes impacting the sea surface, inferring gas flow rates at the source. Through a combination of theoretical modeling and satellite-based observations, we measure the kinematic of concentric waves resulting from gas bubble surfacing, presenting a novel method to estimate gas flow rates. Analysis of wave celerities suggests an equilibrium regime, enabling the derivation of gas output rates at depth. Our findings indicate that Sentinel-2 satellite-based measurements can capture and characterize surface waves, offering indirect insights into the dynamics of submarine volcanic gas emissions. We determine a flow rate range of 265 to 400 m^3/h, translating to methane gas emissions of 630 to 950 tons/h if considering a source at 70m depth. Furthermore, the use of high-resolution optical satellite missions extends beyond this particular study, holding promising capabilities of detection and characterization of degassing events associated with submarine volcanic eruptions, such as those observed near Mayotte island. The application of our method offers a broader spectrum of observational tools for studying submarine degassing phenomena and complements strategies recommended by the International Methane Emissions Observatory (IMEO) for methane emission characterization. Our study adds up to the methods that advances our understanding of underwater degassing processes and also holds implications for early volcanic unrest detection and risk assessment.

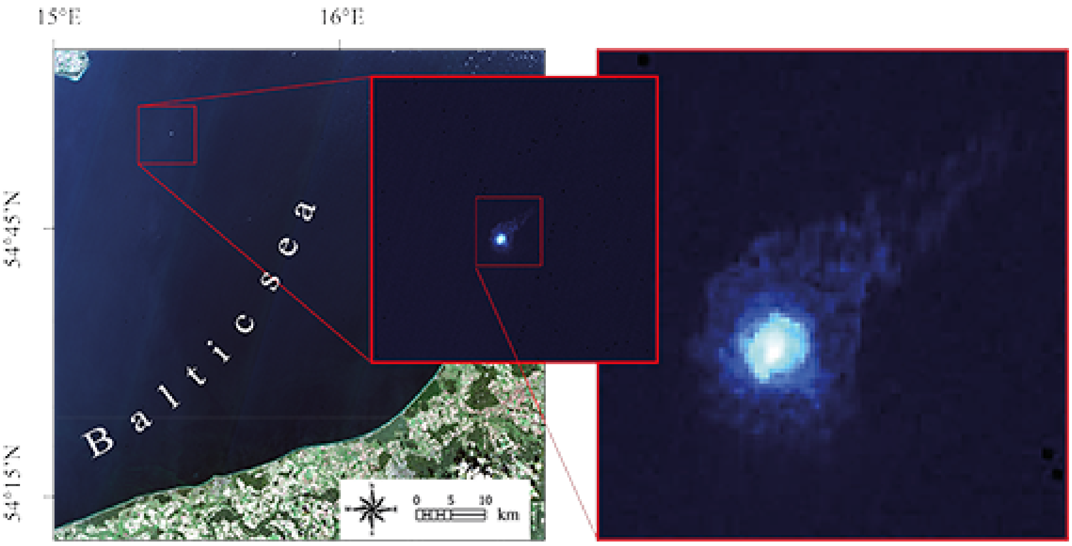

Figure 1. Location of the study area and zooms on the gas leak. Contains modified Sentinel-2 data [2023].