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VIIRS nighttime thermal anomalies reveal conflict-related events on Black Sea offshore structures and on Snake Island: Ukraine's war at sea

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ABSTRACT

Control of the Black Sea is of critical importance to both Ukraine and Russia, with offshore structures and Snake Island (Zmiinyi Island) playing strategic roles. We demonstrate how nighttime thermal data from the VIIRS satellite constellation can be used to identify and monitor conflict-related events at these sites. Using the VIIRS Nightfire data product, we show that it is possible to pinpoint the exact timing of attacks on offshore structures and to assess associated damage through the duration and affected area of related fire events. Fire types are differentiated by measured temperature, allowing identification of uncontrolled gas fires versus conventional fires. Results are independently validated using Sentinel-2 true-colour and short-wave infrared image composites, including estimation of areas damaged by fire, as well as reports from news sources. Our findings demonstrate that VIIRS nighttime thermal data provide a reliable, low-latency, and independent means of monitoring maritime conflict activities in the Western Black Sea.

1. Introduction

The Russo–Ukrainian conflict already involved the Black Sea even before the 2022 full-scale invasion (Kormych and Malyarenko, 2023). Here, events such as the fighting surrounding Snake Island (known in Ukrainian as Zmiinyi Island; Williams and Kirby, 2022), the sinking of the Russian flagship *Moskva* (Akar, 2022), and the 2022 grain deal (Kormych et al., 2024) have had a substantial impact on the course of the war. Several mobile offshore natural gas structures in the Western Black Sea, occupied by Russia prior to 2022, emerged as vital strategic targets alongside Snake Island. Their central position (see Fig. 1) made them suitable for logistics, as well as for the installation of early warning and air-defence systems, threatening shipping lanes and opening new attack routes. Some newspapers and blogs have tried to reconstruct the events surrounding the attacks on Snake Island and the offshore structures since 2022 using online materials and sporadic high-resolution optical satellite data: Adams (2023) reported that Ukraine had recaptured some of the offshore structures in 2023, while Tucker (2024) and Militarnyi (2025) shed light on an intricate asymmetric warfare campaign fought between the Ukrainian and the Russian navies over control of the remaining structures. However, to our knowledge, a comprehensive system for monitoring these events has not yet been developed, limiting our ability to independently verify and analyse developments in the Western Black Sea.

In this opaque maritime environment, satellite-based night-time thermal remote sensing offers a potential path towards independent verification. Here, the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi-NPP, NOAA-20, and NOAA-21 satellites is well suited. VIIRS provides global, high-frequency coverage (at least three overpasses per night) and can detect both

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visible and thermal emissions (Cao et al., 2017). Thus, the acquired nighttime data can be used not only to detect fires and hot sources, such as those caused by fighting (Dingemanse et al., 2026), but also to estimate their size and temperatures (Elvidge et al., 2019). In addition, the long and consistent image times series acquired on any region of interest on the globe (Liu et al., 2018; Ma et al., 2024) make VIIRS a useful tool for tracking activity surrounding the mentioned offshore structures. The comparatively poor 750 m resolution of VIIRS is less problematic in this context because the structures and the island are isolated by water, making their emissions clearly distinguishable in single VIIRS image elements. VIIRS thermal data has seen use in conflict monitoring (Dingemanse et al., 2026; Yailymov et al., 2023; Tomchenko et al., 2023), but only over land.

Leveraging VIIRS nighttime thermal data, we aim to detect conflict-related events surrounding the Western Black Sea offshore structures and Snake Island. Results are verified using a combination of Sentinel-2 (S2) optical data and non-academic sources such as newspaper reports, blogs and videos. Results deliver, to the best of the authors' knowledge, the first systematic, satellite-based record of conflict activity in the Western Black Sea.

1.1. *Area of study*

The area of study is the Western Black Sea (see Fig. 1), which is surrounded on three sides by Ukraine. This region is strategically important due to its proximity to the major cities of Odesa, Kherson, and Sevastopol. In addition, it borders Crimea (occupied in 2014) and territories south of the Dnieper River, which were occupied in early 2022. Specifically, the scope of this study includes Snake Island and all 13 offshore structures in the region, comprising eight larger platforms and five smaller block conductors (see Fig. 1 and Table A.2 in the Appendix).

2. Methods

The main data source chosen in this study is VIIRS Nightfire (VNF) version 3.0 (Elvidge et al., 2013, 2019). VNF was originally designed to monitor permanent thermal emitters such as gas flares, and enables detection of sub-pixel hot sources using multiple spectral bands. VNF employs two independent methods: one is based on thresholding the M10 (1601 nm) and M11 (2250 nm) short-wave infrared (SWIR) bands, while the other relies on a decorrelation technique on the M12 (3730 nm) and M13 (4066 nm) mid-wave infrared (MIR) bands (Zhizhin et al., 2023). While each detector operates separately, more than one band must yield a detection to estimate the source's temperature and area. These estimates are obtained by separating the source signal from the background Planck radiation curves (Planck, 1901), allowing detection of temperatures from 600 K to 6000 K. The sensitivity of VNF depends on the temperature of the target, with detectable areas ranging from < 1 m^2 for gas flares to > 10 m^2 for forest fires (Elvidge et al., 2019). Here, VNF was chosen over other VIIRS thermal data sets such as the Fire Information and Resource Management System (FIRMS; Schroeder et al., 2025) due to its algorithm being focused on nighttime acquisitions, and to the availability of area and temperature estimates for each detection.

VNF data is provided in CSV format, with one file per sensor and per day, covering the entire globe. We considered only data from the Suomi-NPP and NOAA-20 platforms, as NOAA-21 was launched only after the beginning of the Ukraine war. As an initial data format conversion and pre-processing step, all VIIRS overpasses per night were merged into a single VNF file. Data from all VIIRS sensors covering the period from 2019-01-01 to 2025-11-30 were then transformed into point vector layers, clipped to the area of the Western Black Sea containing all structures and Snake Island, and aggregated into a single consolidated point file. Next, for offshore structure positioning, the precise location of each offshore structure was visually confirmed using Sentinel-1 SAR data. Each confirmed location was subsequently vectorized into a point file and assigned a unique ID ranging from "0" to "12". A buffer zone of 1000 m was then drawn around each structure location. This buffer size was chosen as a spatial trade-off between the need for a sufficiently large area to account for VIIRS' low spatial resolution and variable ground tracks, and the necessity to keep buffer zones distinct given the close proximity of neighbouring offshore structures. A time-series containing the number of VNF detections, their respective temperatures, and their footprint areas was then generated for each offshore structure and for Snake Island. In instances where multiple VNF detections were registered within the same buffer on a single night, the data was aggregated by calculating the mean temperature and the sum of the non-overlapping areas.

Finally, to validate the thermal anomalies detected by VIIRS, a combination of S2 optical data (Gascon et al., 2017), the delta Normalized Burn Ratio (dNBR), and informal sources was utilized. On the offshore structures, S2's SWIR bands were used to confirm active hot sources. On Snake Island, a combination of S2 SWIR composites and the dNBR was additionally used to monitor changes and link VIIRS fire detections to wildfire damage. The NBR is defined for a multispectral image x as:

$$\mathrm{NBR}(x) = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}}, \tag{1}$$

where NIR and SWIR indicate reflectance in these spectral ranges, represented for S2 by bands 08 and 12, respectively. The NBR is particularly sensitive to the changes in the amount of living green vegetation, moisture content, and some soil conditions, which may occur after a fire (Lentile et al., 2006). To derive a change detection based on this index we use the delta NBR (dNBR), since it performs well in capturing the damage severity within fire perimeters (Soverel et al., 2010). The dNBR related to pre- and post-event images, respectively x_{t_0} acquired at time t_0 and x_{t_1} acquired at time t_1, is the delta of the two measurements:

$$\mathrm{dNBR}(x_{t_0}, x_{t_1}) = \mathrm{NBR}(x_{t_0}) - \mathrm{NBR}(x_{t_1}). \tag{2}$$

Using the dNBR allowed for the confirmation of fires on Snake Island even if no cloud-free S2 image was available on the exact day of the VIIRS detection. A complete workflow of the methodology and pre-processing steps is illustrated in the Appendix (Fig. A.4).

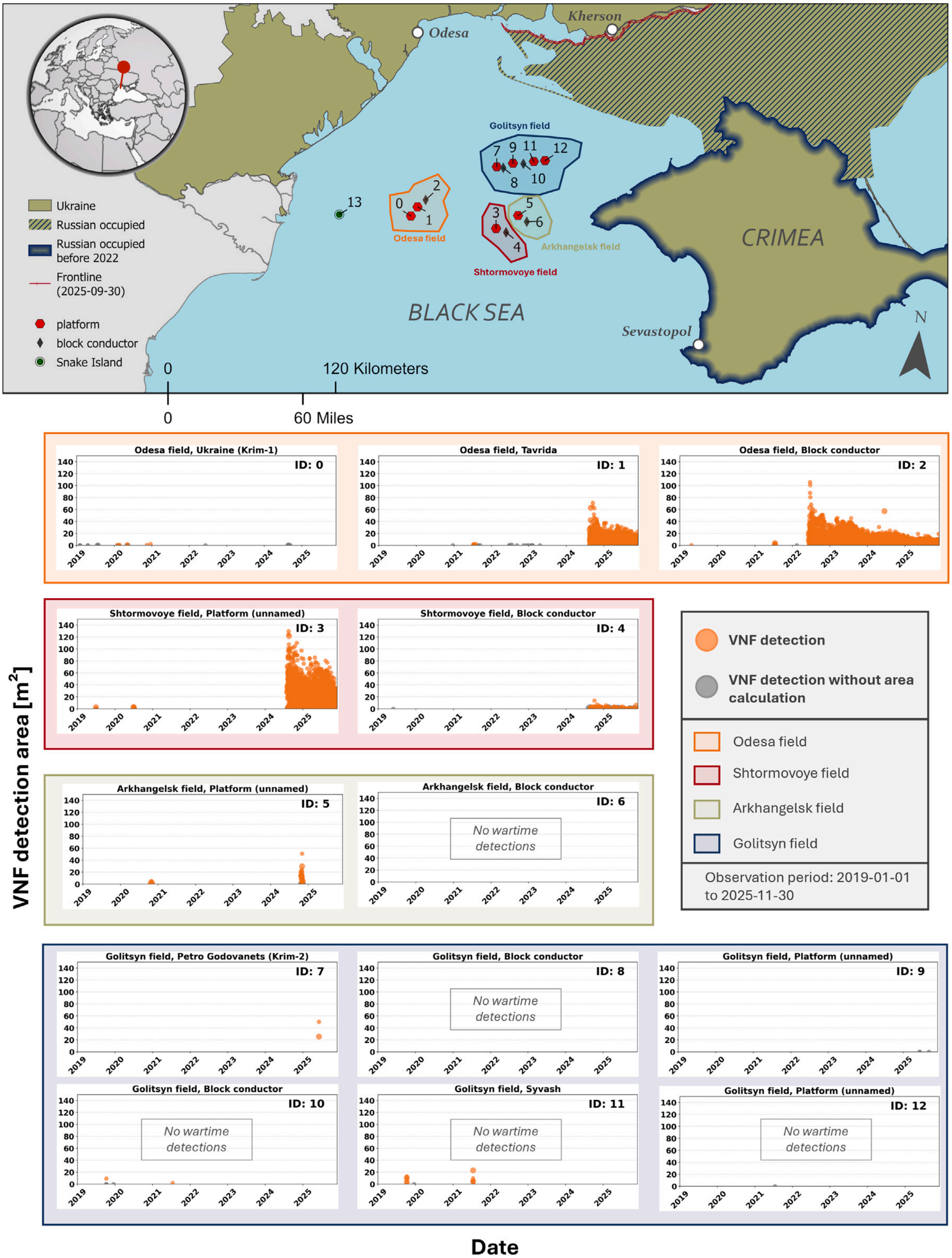

Fig. 1. VIIRS-based monitoring of offshore structures. The top map shows the location of each offshore structure in the Western Black Sea, as well as the status concerning the controlling entity in Ukraine surrounding the Western Black Sea. The plots in the bottom show the number and area of VIIRS VNF-based fire detections per structure, grouped by offshore field (see Table A.2 in the Appendix for further information). VNF detections with and without calculated area data are displayed in orange and grey, respectively. The marker size is related to the number of concurrent detections. Snake Island is discussed in Fig. 3. Data sources: VIIRS Nightfire, OCHA (outlines), liveuamap.com (occupied area data).

3. Results

3.1. Offshore structures

The results of this study can be seen in Fig. 1, which shows the location, as well as a time-series for all offshore structures, divided by offshore field. While many of the 13 structures show some VNF detections pre-2022, they are limited in number and area. Only for the Syvash platform (ID: 11), notable detections occur in 2019 and 2021, which cannot be confirmed with S2 data due to a lack of concurrent imagery. Since February 2022, five structures show substantial anomalies, most of them located in the Odesa and Shtormovoye fields (IDs 1–5). Three of these structures exhibit patterns that are consistent with uncontrolled gas fires (IDs 1–3). Each of them show a sudden spike in thermal detections, with calculated hot-source areas reaching up to 150 m^2. After this initial spike, continuous emissions remain visible at average temperatures of about 1760 K (ID 3), 1700 K (ID 2), and 1820 K (ID 1). These values align with the typical temperatures of permanent emitters classified as ‘‘upstream’’ in the VNF permanent emitter database (Elvidge et al., 2019). Over time, the calculated source area for each of these structures decreases but remains well above 20 m^2. Such large areas rule out normal gas flaring, suggesting an uncontrolled gas fire. In contrast, the spike in detections for the platform in the Arkhangelsk field (ID 5) is short-lived and has an average temperature of only 1415 K, suggesting a conventional fire occurred.

The findings presented here are supported by S2 imagery (see Fig. 2) and newspaper reports. All three structures presumed to experience major gas fires display very strong SWIR detections in S2 immediately after the strike. These anomalies remain visible to the data cutoff date, though with reduced intensity. Additionally a missile strike has been reported for each structure at the respective times of ignition (Newdick and Altman, 2025; Afanasiev, 2022, 2024), with the Tavrida platform (ID: 1) reportedly struck more than ten times over the course of the war. The Arkhangelsk platform (see Fig. 2, ID: 5) is seen to burn for at least five days in S2's imagery, although SWIR emissions are notably weaker. The only structure displaying VNF detections without S2 SWIR detections is the block conductor in the Shtormovoye field (ID 4). However, inspection of the raw data suggests that emissions attributed to this structure are likely false alarms. Because of its close proximity to the nearby offshore platform (ID 3) and the intensity of the fire there, the detected signals are most likely originating from that platform instead. Together, these lines of evidence strongly indicate that the observed anomalies reflect genuine conflict-related damage and prolonged offshore fires, proving the utility of VIIRS nighttime thermal data in this regard.

3.2. Snake island

Regarding Snake Island, only a total of four dates with VNF detections are present in the data set. However, due to the island's comparatively large size and vegetation coverage, it becomes possible to validate each of these detections. As reported in Fig. 3, an initial detection on 2022-05-08 can be validated in S2 by large SWIR emissions at the island's harbour, and coincides with Ukraine's recapture of the island as reported by Williams and Kirby (2022). Additionally, the red roofs of the houses in the centre of the island disappear between 2022-05-02 and 2022-05-07, as they are destroyed in a Ukrainian airstrike (BFBS Forces News, 2024). The other three dates can be confirmed using the dNBR based on S2: a VNF detection on 2024-08-24 coincides with several smaller burn scars, as well as a report that Russia attacked the island using cruise missiles (Kravchuk, 2024). One year later, on 2025-08-14, two VNF detections coincide with a very large burn scar covering the entire east of the island, followed by another large burn scar and VNF detection on 2025-09-05. Following the damage classifications established by Key and Benson (2006), values exceeding a dNBR of 0.1 generally indicate low burn damage, and this threshold was applied to the more moderate 2024-08-14 event. However, as this value could yield some false alarms (Guarino et al., 2024), a more robust threshold of 0.16 was selected for the other cases. While the latest two events cannot be conclusively tied to military activity, the alleged loss of a Russian aircraft near Snake Island on 2025-08-14 (Zadorozhnyy, 2025) suggests that the war does not seem over on or near this island. The only VNF detection for which a temperature estimate is available (2024-08-14) indicates a temperature of 1100 K, consistent with that of a typical vegetation fire. While it should be clearly stated that all these events cannot be conclusively attributed to military activities, VIIRS thermal data can nonetheless be seen as a reliable, low-latency source of information regarding activities on the island.

4. Discussion

While VIIRS' thermal bands can detect emissions through limited cloud cover, the probability of capturing conflict events remains low, as a target must be set on fire, continue burning until the satellite overpass, remain unobscured by clouds, and be sufficiently large to register. An analysis of all S2 datatakes archived in Google Earth Engine for our study area in 2024 and 2025 (n=341) reveals that cloud cover frequency is highly seasonal. While the yearly average of images with under 10% cloud cover is 30%, the monthly average ranges from a peak of 72% in August to just 3% in December (aggregated for 2024 and 2025; see Table 1). As such, these constraints limit the visibility of short-lived events and make detections highly sensitive to VIIRS narrow nighttime acquisition window and the time of year. While the intense gas fires expected on offshore structures are a favourable target in this regard, a lack of VIIRS detection does not indicate an absence of conflict events. This methodological limitation is critical when interpreting thermal data in the Western Black Sea, as under-reporting is highly likely due to environmental and temporal constraints.

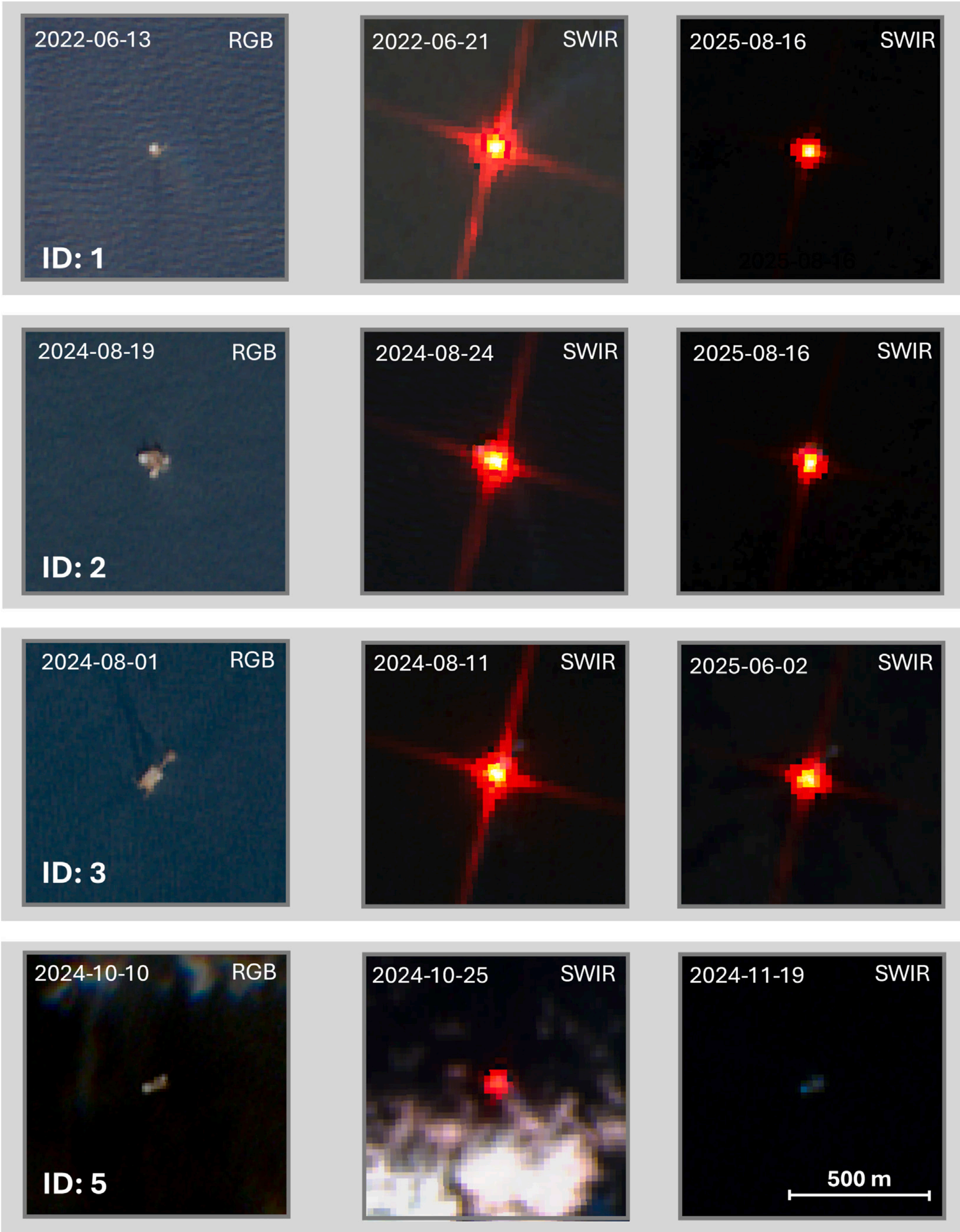

Fig. 2. Sentinel-2 based cross-validation of offshore structure damage for the four structures with the largest VIIRS-based thermal anomalies. The images in each row show from left to right: the structure as a true-colour composite (Red: B04, Green: B03, Blue: B02) before a damage event; a SWIR composite (SWIR: B12, NIR: B08, Red: B04) closest to a VIIRS detected event; ongoing emissions (ID 1–3) or post-event image (ID 5). Observation period: 2022-02-24 to 2025-11-30.
Source: Copernicus Space Data Ecosystem.

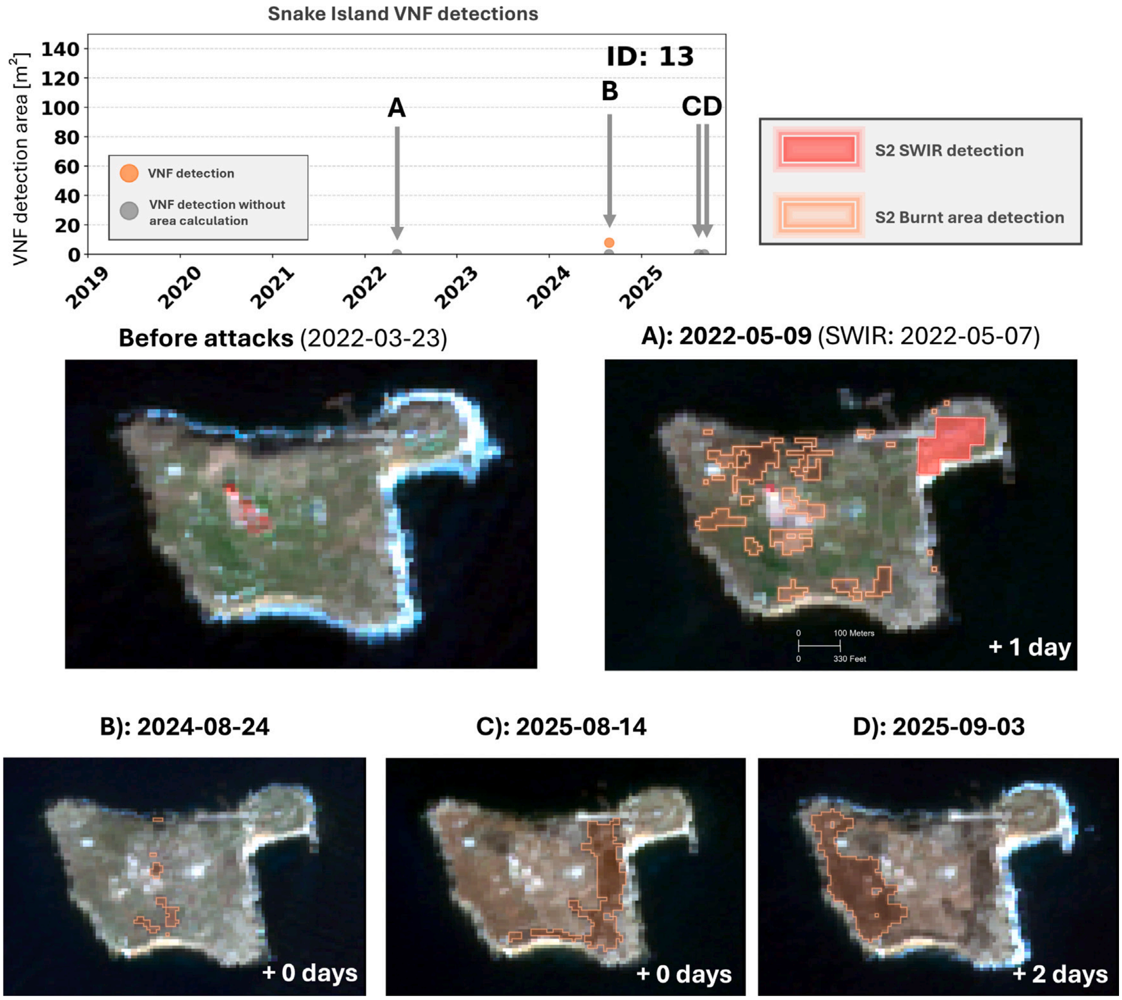

Fig. 3. VIIRS-based monitoring of Snake Island. The top plot shows the number of VNF-based fire detections (labelled A to D) on Snake island as in Fig. 1. The bottom figures shows S2 true-colour composites (Red: B04, Green: B03, Blue: B02) of the island for each VNF detection, with highlighted B12 SWIR detections (highlighted in red), and burnt area detections derived from the dNBR index (highlighted in orange). The time distance between the VNF fire detection and the S2 observation is shown in the bottom right of each image. Observation period: 2022-02-24 to 2025-11-30.
Source: VIIRS Nightfire, Copernicus Space Data Ecosystem.

5. Conclusion

This study set out to detect conflict related events surrounding the Western Black Sea offshore structures and Snake Island using VIIRS nighttime thermal data. Results show that three of the 13 offshore structures exhibit clear signatures of uncontrolled gas fires, and a fourth experienced a major short-lived fire in late 2024. All four cases are independently corroborated by S2 data analysis. Several additional structures display sporadic VIIRS detections, though these could not be verified with S2 and are likely associated with brief, low-intensity events or false alarms caused by nearby large emitters. On Snake Island, all four VIIRS detection dates coincide with observable changes in S2 data, either active SWIR emissions or distinct burn scars, demonstrating that even relatively small or short-duration events can be validated in this environment. Taken together, these observations provide insight into the scale and persistence of damage to both the offshore structures and the island, indicating which structures have likely been rendered unusable during or after the conflict. Overall, the findings highlight the utility of VIIRS nighttime thermal data as a reliable, low-latency, and independent source for monitoring and verifying conflict-related activity in the Western Black Sea.

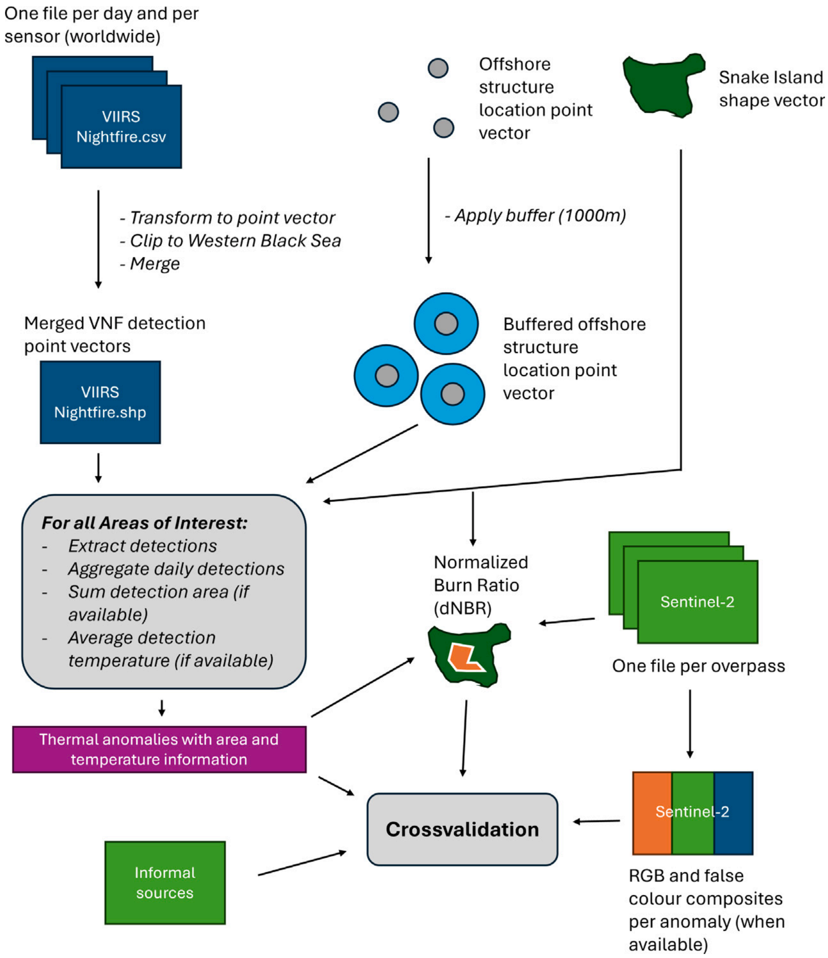

Fig. A.4. Methodology workflow. For more information see "Methods" section.

Table 1
Seasonality of cloud cover over the area of interest. The table shows the number of Sentinel-2 datatakes available over the area of interest for the years 2024 and 2025, aggregated by month, as well as the percentage of datatakes with under 10% cloud cover.

Month	Total images	<10% cloud cover	Percentage
January	23	1	4,3%
February	22	3	13,6%
March	25	7	28,0%
April	29	8	27,6%
May	32	8	25,0%
June	28	16	57,1%
July	30	20	66,7%
August	32	23	71,9%
September	28	9	32,1%
October	29	10	34,5%
November	30	5	16,7%
December	33	1	3,0%
Sum	**341**	**111**	**32,6%**

Table A.2
Lookup table for the areas of interest, including type, field and date ranges of wartime thermal anomalies. the ID column matches those from Fig. 1.

ID	Type	Name	Field	Wartime thermal anomaly dates
0	Offshore platform	Ukraine-1 (Krim-1)	Odesa	2022-06-08, 2024-08-24, 2024-09-11
1	Offshore platform	Tavrida	Odesa	2022-06-26 to 2024-08-23 (intermittent), 2024-08-24 to present
2	Block conductor	–	Odesa	2022-02-12, 2022-06-21 to present
3	Offshore platform	–	Shtormovoye	2024-08-10 to present
4	Block conductor	–	Shtormovoye	2024-08-10 to present
5	Offshore platform	–	Arkhangelsk	2024-10-23 to 2024-11-10
6	Block conductor	–	Arkhangelsk	–
7	Offshore platform	Petro Godovanets (Krim-2)	Golitsyn	2024–06–06
8	Block conductor	–	Golitsyn	–
9	Offshore platform	–	Golitsyn	2025-06-08, 2025-09-06
10	Block conductor	–	Golitsyn	–
11	Offshore platform	–	Golitsyn	–
12	Offshore platform	Syvash	Golitsyn	–
13	Island	Snake Island (Zmiinyi Island)	–	2022-05-08, 2024-08-24, 2025-08-14, 2025-09-05

CRediT authorship contribution statement

Merlijn I. Dingemanse: Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daniele Cerra:** Writing – review & editing, Supervision, Software, Methodology, Investigation.

Ethical statement

This study does not involve human participants, animals, or personal information. Therefore, no ethical approval was required.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used the LLMs Gemini and ChatGPT 3.5/4.0 in order to assist with scripting and to improve readability. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Declaration of competing interest

The Authors declare no conflict of interest.

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All authors have read and agreed to the published version of the manuscript.

Appendix A. Supplementary figures and tables

See Fig. A.4 and Table A.2.

Data availability

Due to data licensing restrictions and the coverage of an ongoing conflict, not all data can be freely redistributed. Data availability is as follows:

• **VIIRS Nightfire data** was used under an academic license from the Colorado School of mines, which does not permit redistribution in any form. However, the data can be licensed free of charge for academic purposes at the Colorado school of mines at https://eogdata.mines.edu/products/vnf/.
• **Sentinel-2 data** is freely available for download at the Copernicus Space Data Ecosystem at https://browser.dataspace.copernicus.eu/.
• **Administrative boundary data** is freely available from OCHA's website at https://www.unocha.org/.
• The **code used for data preparation and analysis** is available upon reasonable request to the authors.

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