Increases in Night Lights Intensity Reveal Extreme Events: A Case of Study on the Ongoing Conflict in Ukraine

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Abstract

Analyzing night lights images allows identifying and monitoring affected areas during conflicts, as an overall decrease in brightness indicates abandoned or destroyed buildings, curfews, or power shortages. While detecting decrease in lights intensity is an established technique to identify critical areas during conflicts, the causes of appearing bright lights have not been extensively studied. An increase in brightness may be related to extreme events, such as fires resulting from bombing. This paper shows several examples supporting this new use of these images, validated using high-resolution optical earth observation data and ancillary information sources in the frame of the conflict in Ukraine which has been ongoing since February 2022.

1. Introduction

In regions affected by conflict, accurately identifying and monitoring critical areas is essential for effective humanitarian aid efforts, strategic decision-making, and for understanding the dynamics of the events. Traditional assessment methods often face limitations, such as accessibility challenges and risks to personnel on the ground. Remote sensing technologies offer promising solutions to these challenges: in the specific, night lights images may provide valuable insights into critical areas within conflict zones, enabling improved situational awareness and response strategies (Elvidge, 1997). Early sensors, such as the Defense Meteorological Satellite Program's Operational Linescan System (DMSP-OLS), paved the way for capturing night lights on a global scale, indicating human presence, infrastructure development, and socio-economic activity (Roman et al., 2018). Over the decades, advancements in sensor technology and data processing algorithms have significantly improved the quality and resolution of night lights data. An overview of night lights systems is reported in (Levin et al., 2020).

Night lights imagery has been extensively used to monitor conflict areas and assess the consequences of natural disasters. Studies have utilized night lights data to analyze changes in urban areas during conflicts (Li et al., 2018), monitor the effects of power outages in disaster-stricken regions (Sugimoto et al., 2019, Kuffer et al., 2016), and assess the impact of humanitarian crises on nighttime illumination patterns (Oda and et al., 2018). During the 2006 Israel-Lebanon crisis, DMSP-OLS data could reveal damaged and abandoned households in southern Lebanon and around the capital Beirut (De La Cruz et al., 2007). Additionally, night lights data have been employed to detect damage to infrastructure such as roads, bridges, and buildings caused by conflict events (Gao et al., 2017), and to indicate the imposition of curfews or the presence of security measures in conflict-affected regions (Li et al., 2020). By employing high-resolution images, researchers can validate their damage assessment results. In (Aimaiti et al., 2022), WorldView data are used to verify detected changes on the ground in terms of destroyed buildings in a conflict area previously estimated using Copernicus data (Jutz and Milagro-Perez, 2020).

Figure 1. Left: anomalies in brightness increase in night lights from March to April 2022 are depicted in green. In the location corresponding to the blue star, a high resolution WorldView image (right) from Google Earth shows the industrial complex of Rubischne in Ukraine completely destroyed in June 2022 (© 2024 Maxar Technologies).

To the best of our knowledge, the studies taking into account appearing bright lights are usually focused on the appearance of new objects such as buildings and infrastructure (Levin et al., 2020), detection of biomass burning (Wan et al., 2022) and areas occupied by fishing vessels (Li et al., 2022), urban sprawl and local changes in population (Wu et al., 2022), and changing in lighting in urban areas (Xu et al., 2018). This paper focuses instead on the meaning of appearing bright lights in pre- and post-events in conflict areas, namely for the country of Ukraine in the frame of the conflict ongoing since February 2022. It is observed that fires caused by explosions and buildings burning for a long time may be captured by sensors detecting night lights, and that such changes are meaningful enough to be included also in noise-reduced, stray light corrected monthly composites of these data. We report the observed changes for several areas of Ukraine, supporting our observations with multitemporal high-resolution multispectral data and ancillary information from Live Universal Awareness Map (Liveuamap), which provides independent geolocated reports on conflicts, human rights concerns, protests, and natural disasters from various sources (Liveuamap, 2024). Relative rather than absolute changes result in a more accurate location of documented extreme events in the country over a six-month period.

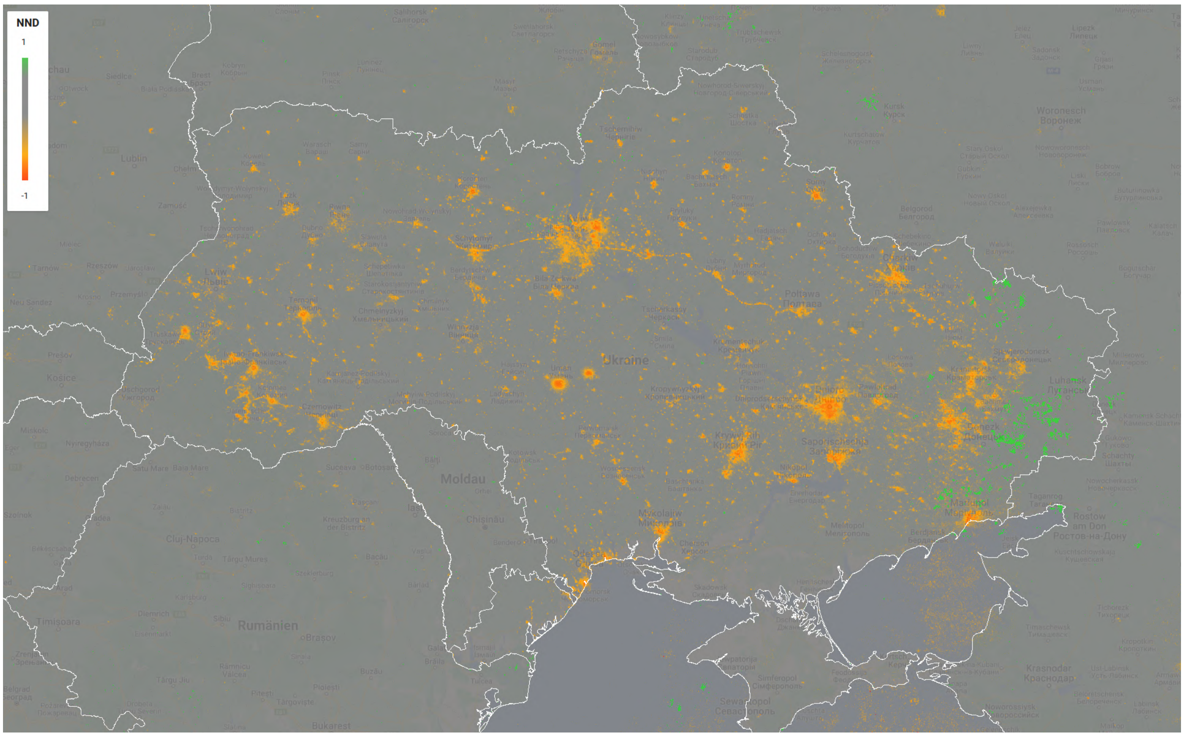


Figure 2. Normalized Night lights Difference (NND) in Ukraine related to the months of March and February 2022. Areas appearing in orange and red exhibit a strong decrease in night lights intensity, while appearing lights are reported in green and are concentrated in the conflict area in the east of the country. Lights appear mostly stable outside of the country borders. Background map © 2024 Google.

An example of the results reported in this paper is depicted in Fig. 1, with further details presented in later sections. Here, an anomalous increase in night lights from March to April 2022 (in green in the image to the left, marked by a star) is observed for the industrial area of Rubizhne, Ukraine, which appears destroyed and surrounded by burned trees in a high-resolution image acquired in June 2022.

The paper is organized as follows. Section 2 introduces the VIIRS datasets used in this work and the derived index of change, along with the high-resolution data and ancillary information used to assess our results. These are reported in Section 3 for several areas in Ukraine affected by the ongoing conflict, where the appearance of bright night lights is correlated to extreme events on the ground. We conclude in Section 4.

2. Data and Methods

This section briefly introduces the night lights and high-resolution validation data used in this paper, and the Normalized Night lights Difference (NND) used to locate areas of change.

2.1 VIIRS

In this paper, we rely on data acquired from the Visible Infrared Imaging Radiometer Suite (VIIRS), developed by NASA and NOAA and launched in 2011 aboard the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. This sensor offers enhanced capabilities for capturing nighttime illumination with higher spatial and spectral resolution than its predecessors (Elvidge et al., 2017). Derived products such as VIIRS Nightfire (Schroeder and et al., 2014) and VIIRS Day/Night Band (DNB) yielded an improvement in spatial resolution and sensitivity to weaker light sources.

Nevertheless, the low power of the signal captured by these sensors, particularly in areas with sparse or dim lighting, can lead to difficulties in characterizing faint sources of light from background noise, affecting the accuracy of the derived products (Ghosh et al., 2010). Stray light, variations in lighting conditions, and atmospheric interference, such as clouds, haze, and aerosols, further complicate the analysis by attenuating or scattering the light signal, resulting in reduced image quality and potential false detections (Liu et al., 2013, Zhang and Seto, 2019).

To mitigate these aspects, we opt to use stray light-corrected monthly composites of VIIRS products in this work, reducing the impact of noise and atmospheric interference (Elvidge et al., 2021). These data are available in platforms such as Google Earth Engine (Tamiminia et al., 2020), which we use for processing the results in this paper. Another way of reducing the impact of fluctuations of absolute brightness values in the detected lights is provided by focusing on relative rather than absolute changes. In this paper, relative differences between nightlights composites from different months are computed through their normalized difference, which we introduce here as Normalized Night lights Difference (NND):

$$NND = \frac{L_{post} - L_{pre}}{L_{post} + L_{pre}}. \quad (1)$$

Here, L_{pre} and L_{post} are the brightness values for the night lights image composites before and after a given point in time, in our case for two consecutive months. In the paper, we consider a change in brightness to be an anomaly if the increase in luminosity with respect to the previous month is approximately tenfold, which translates to a NND value of 0.8 or higher.

2.2 High-Resolution Data

In this paper, we rely on pre- and post-event high-resolution multispectral data to validate the observed changes in nighttime lights imagery and provide context. In the specific, we use satellite images from WorldView-2 and WorldView-3, operated by Maxar Technologies, having spatial resolutions of 0.46 and 0.3 meters in the panchromatic band and pansharpened products, respectively (Maxar, 2022). The satellites have different spectral resolutions, but we use only the RGB bands of their pansharpened products in this work. The WorldView data are systematically corrected, orthorectified, and atmospherically corrected using the processing system Catena (Krauß et al., 2013).

Additionally, we rely on historical imagery from Google Earth, multitemporal high-resolution data typically having spatial resolutions ranging from 0.3 to 10 meters, and on geolocated information from Liveuamap (Liveuamap, 2024). This website serves as an independent global news and information platform and uses maps and symbols to illustrate ongoing events in specific regions. For the conflict in Ukraine, it is possible to see every reported event daily since the beginning of the conflict.

3. Results

In this section, we focus on the validation of the observed increase night lights for selected sites of Ukraine in the frame of the conflict currently ongoing since February 2022. The overview in Fig. 2 shows the NND values (Eq. 1) for the whole country of Ukraine related to the VIIRS night lights monthly composites of February and March 2022. The original image composites are reprojected to a grid having approximately 250 m across-track and 400 m along-track. Areas with severe decrease in nocturnal illumination appear orange and red, while appearing or strongly increasing lights are reported in green. Lights appear stable outside the country, with the exception of some appearing lights across the Russian border which could be related to the deployment of troops and other activities related to the conflict. Within Ukraine, all major cities exhibit a strong decrease in night lights intensity. In the east of the country and to the northwest of Kiev, where most of the conflict took place in its early stages, several areas in green suggest the appearance of bright lights, possibly due to the consequences of war operations.

The remainder of this section analyzes areas exhibiting appearing lights at different times during the first six months of the conflict. In all cases, the starting point was a value above 0.8 for the NND between two consecutive months, considering all night lights composites from February to September 2022. The availability of high-resolution multispectral data and validation from third parties was then verified for the detected changes.

3.1 Hostomel

The Battle of Hostomel (north-west of Kiev), which took place from the 25^{th} of February to the 1^{st} of April 2022, marked the first major battle in the Russian invasion of Ukraine, leading to significant transformations in the landscape and infrastructure of the area. The comparison of night lights images from February 2022, dominated by the situation before the beginning of the conflict, and March 2022 revealed an overall

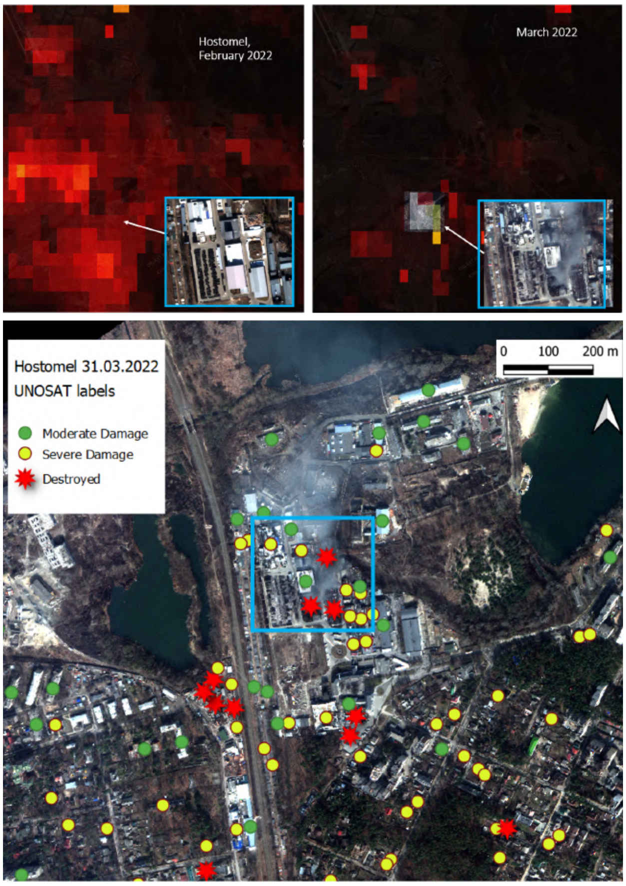


Figure 3. (Top) Night lights composite for the months of February (left, supplied by European Space Imaging © 2022 Maxar Technologies) and March (right, © 2022 European Space Imaging) for Hostomel. While overall night lights intensity decreases, bright lights appear in the area marked by an arrow, where a large industrial complex appears burned down in a WorldView-3 image from 22.03.2022, also reported to the bottom with overlaid damage assessment carried out by UNOSAT.

decrease in brightness, indicative of potential curfews, power shortages, and destroyed or abandoned households during the conflict. This correlation between decreased brightness and disruptions in electricity or damage may be used to identify affected areas in an ongoing conflict and to monitor the expansion of areas affected during conflict situations. Fig. 3 illustrates that, while in general nighttime lights strongly decrease, some bright lights appear, which had a NND above 0.8 in Fig. 2. A closer inspection of high-resolution daytime WorldView-2 and Worldview-3 data, acquired respectively on the 22.02.22 and 22.03.22, suggests that this phenomenon was not linked to the appearance of new structures or man-made sources of illumination, but rather to extreme events. The cause is identified as possibly long-duration fires affecting a large industrial complex in the area, which appears undamaged in the image acquired on the 22.02.22 and completely burned down one month later, in correspondence with the increased brightness observed in night lights data. As additional validation, we report the analysis performed by the United Nations Satellite Centre (UNOSAT), overlaid on the 22.03.2022 WorldView image (UNOSAT, 2022). Several buildings in the satellite image marked as destroyed are still emitting smoke after being burnt down at the time of acquisition.

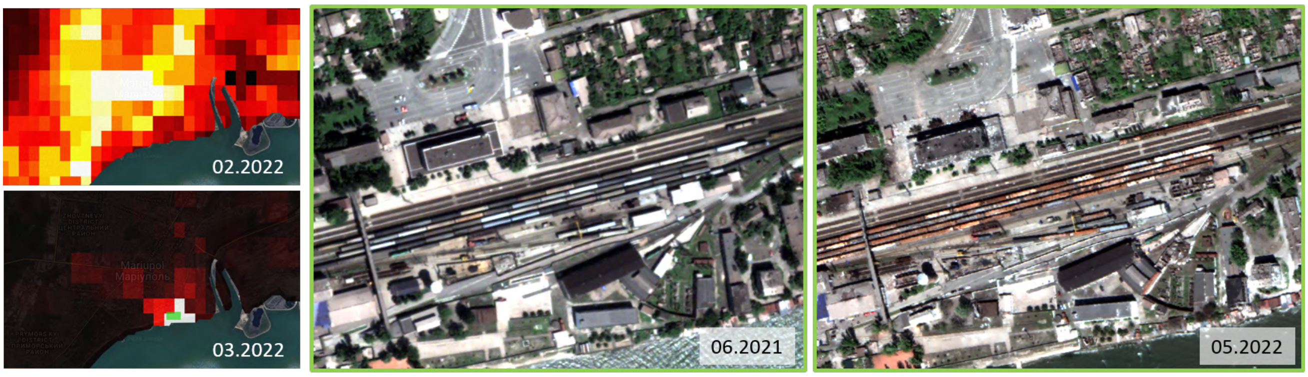


Figure 4. From left to right: night lights image composites for the months of February (top) and March (bottom) 2022 for the center of the city of Mariupol; high-resolution data for the area marked by a green star from WorldView-2 (21.06.2021, © 2021 European Space Imaging) and WorldView-3 (12.05.2022, supplied by European Space Imaging © 2022 Maxar Technologies), respectively.

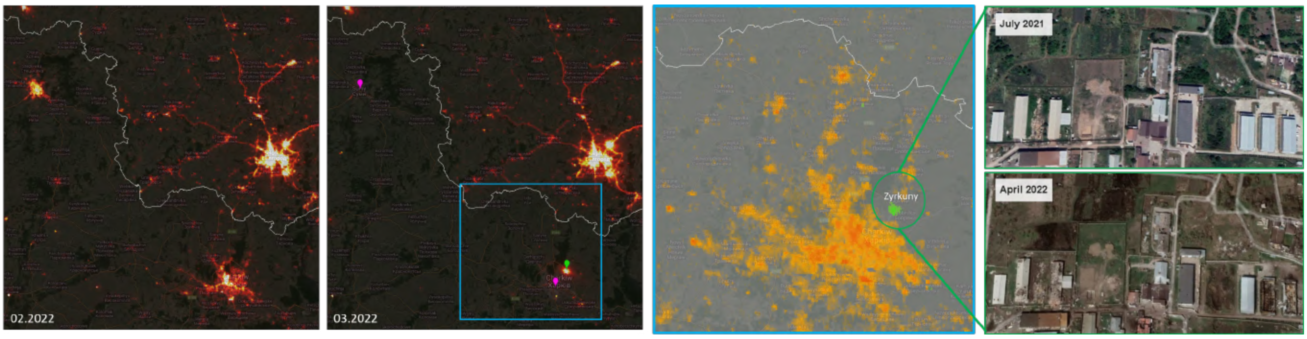


Figure 5. Left: night lights composite for the months of February and March 2022 on the northeast front of the conflict. Lights strongly decrease in the cities of Sumy (north-west) and Kharkiv (south-east), marked by purple pins. Bright lights appear in the neighbourhood of Zyrkuny where the battle started, marked by a green pin. Lights appear stable across the Russian border (in white) to the north-east. Middle: NND values related to March and February 2022 (detail of Fig. 2 for the blue rectangle in the March 2022 night lights composite), with relative decreases shown in red and orange and increases in green. The neighbourhood of Zyrkuny stands out as the main location with increased emissions. Right: high-resolution images from Google Earth (© 2024 Maxar Technologies) showing buildings appearing intact in July 2021 and burnt in April 2022 in Zyrkuny. Background maps © 2024 Google.

3.2 Mariupol

The siege of the city of Mariupol began on the 24^{th} of February 2022 and lasted until the 20^{th} of May. Human Rights Watch reported that approximately 90% of the city was destroyed during the siege (HumanRightsWatch, 2022). Changes detected through NND are analysed in Fig.4 for the city center. Here, lights drastically decrease from February to March 2022, with the exception of bright lights appearing in a small area along the coast. A visual analysis of WorldView-2 and WorldView-3 images, acquired respectively in June 2021 and May 2022, shows the train station north of the train tracks, the trains themselves and other surrounding buildings severely damaged, with photographs acquired on the ground and reported in (Alexandrov and Ermochenko, 2023) showing these sites to be completely burned down.

3.3 Kharkiv and Sumy

One of the most critical areas in the ongoing conflict is the northeastern part of the country, close to the border with Russia. Between the months of February and March 2022, night lights intensity drastically decreased for all cities, while appear stable across the Russian border, as depicted in Fig. 5. Here, the cities of Kharkiv and Sumy become almost completely dark in the image composite for March 2022. On the other hand, one area exhibiting bright light appears to the northeast of Kharkiv, with remarkably high NND values. The area corresponds to the small neighbourhood of Tsirkuny, which was among the first places where the battle of Kharkiv broke out (Schwirtz, 2022). The two inserts, also reported in Fig. 5, are high-resolution images acquired over the southern part of the village from Google Earth (© 2024 Maxar Technologies) from July 2021 and April 2022, within the detected night lights increase, with the latter date showing several burnt buildings.

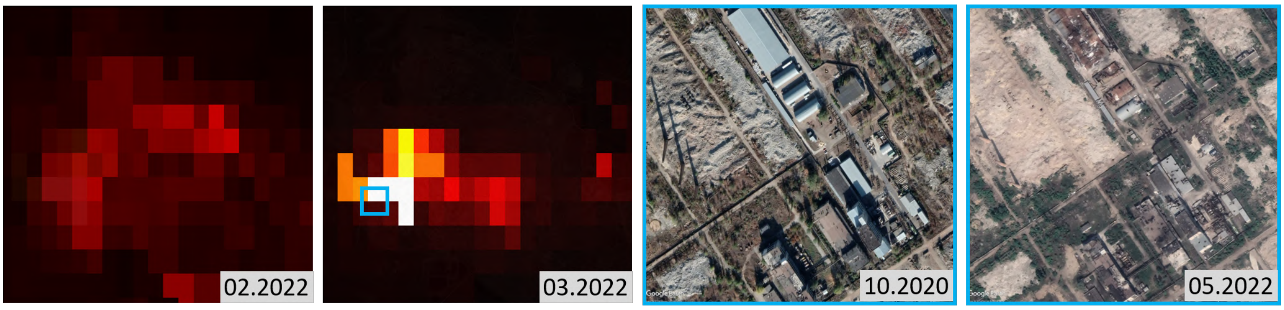
3.4 Luhansk Oblast

In 2022, almost the entire Luhansk region was affected by the Russian invasion. The city of Rubizhne was targeted in the first month of the conflict. A BBC article reported that around 1,500 shells were fired into the city each day (BBC, 2022). During March and April 2022, several appearing night lights could be observed over the city. Figs. 6 (a) and (b) show two sample areas where severe damage and shell craters can be observed in areas of increased night light intensity in high-resolution satellite imagery from Google Earth (© 2024 Maxar Technologies). On Liveuamap (Liveuamap, 2024), several reports of bombings and military actions can be found for the same areas in March and April 2022.

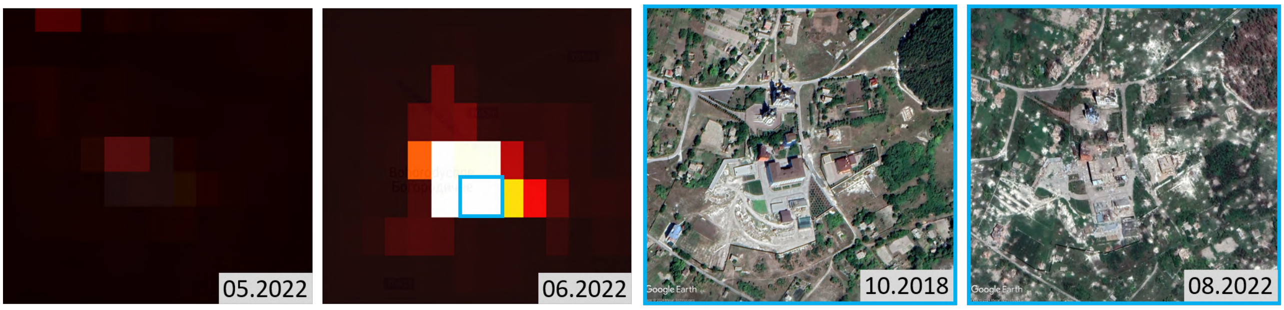
3.5 Donetsk Oblast

Bohorodychne in the very north of Donetsk Oblast used to be a small village with mainly elderly residents. During the war, the

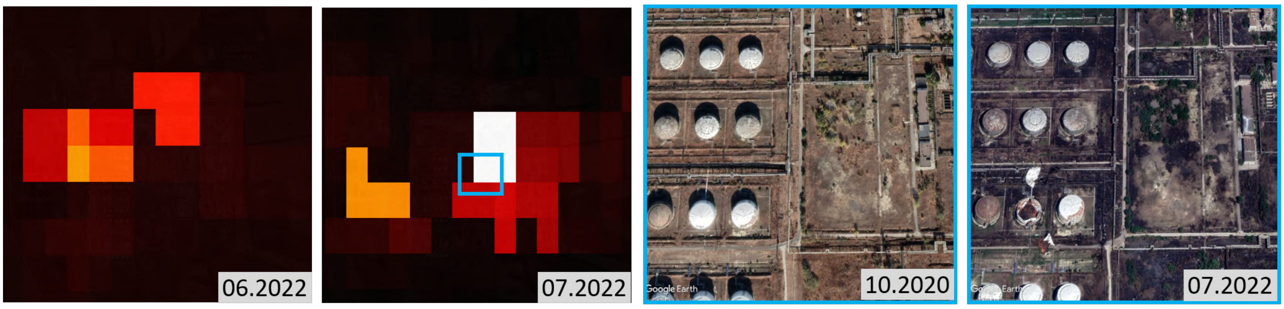
(a) Rubizhne



(b) Rubizhne



(c) Bohorodychne



(d) Verkhn'okam'yans'ke

Figure 6. Four sample areas having $NND > 0.8$ during the first six months of the conflict in Ukraine. From left to right: night lights monthly composites for two consecutive months, and pre- and post-event high-resolution satellite imagery from Google Earth for the areas in the blue rectangles (© 2024 Maxar Technologies). The NND values for subfig. (a) are reported in Fig. 1.

town became a strategic hotspot and a battleground. By destroying the bridge over the Siwerskyi Donets River, the Ukrainians made it difficult for the Russian ground troops to advance further into Oblast Donetsk and into the strategically important city of Sloviansk (Terajima, 2022). The appearance of bright night lights in June and July 2022 bears witness to the fighting and the bombardment, some of the destruction of which can be seen in Fig. 6 (c).

Verkhn'okam'yans'ke is a small town in the northeast of Donetsk Oblast. Between the months of June and July, we could observe a sudden increase in the intensity of night lights over a large refinery located near the town (see Fig. 6 (d)). Reports from Liveuamap confirm this observation with reports of fires over this refinery on 22.6.2022 and Russian artillery and airstrikes over the area between 28.6.2022 and 30.6.2022 (Liveuamap, 2024).

4. Conclusions

The analysis of decreasing night lights as a tool to reveal damage and power shortages in critical areas has been widely used in the past, but a potential use of sudden increased brightness as a source of complementary information has not been yet extensively studied. In this paper, we present a first effort at identifying extreme events in the frame of large scale conflicts by relying on anomalous increases in brightness observed in nighttime remotely sensed optical data. We focus on the ongoing conflict in Ukraine, reporting an overview on the whole country and several examples in which events such as bombings, long-lasting fires, and other phenomena result in a tenfold increase in night lights brightness. The events detected on the ground are then assessed by using high-resolution satellite images, either ordered by the authors or coming from Google Earth's historical archive, photographs acquired on site, and ancillary geolocated information from independent third parties and international organizations such as the United Nations. In the frame of ongoing conflicts, researchers and policymakers can thus gain insights into the spatial and temporal dynamics of the conflict, identifying areas of heightened activity and potential humanitarian crises. Results presented in this paper could be coupled with other sources of information detecting active fires and thermal anomalies, such as hotspots from NASA's Fire Information for Resource Management System (FIRMS) data (Davies et al., 2019), further enhancing the accuracy and comprehensiveness of monitoring efforts. Given the sensitivity with respect to noise and atmospheric effects of night lights imagery, special care should be taken in order to avoid false alarms in the detected changes. Regarding this aspect, we could verify that the increase in night lights intensity, even if not persistent during the event for a whole month, is meaningful enough to appear in monthly night lights composites corrected for stray light, the use of which is preferred in order to reduce the number of false positives. Furthermore, we could observe that the presence of solar power plants may represent an additional source of false alarms, with no clear explanation for this aspect. Future work should investigate these sources of errors and integrate ancillary information in order to mitigate these aspects. The detected anomalies in brightness increase for the first six months of the conflict are available on demand as a Google Earth Engine application.

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