# Mapping of Dimmed Nighttime Lights in Ukraine During the War

## By Mikhail Zhizhin

This study investigates the impact of the war in Ukraine on nighttime light intensity using satellite data. Nighttime light observations from Suomi NPP satellite (2012-2024) covering Ukraine and surrounding areas were analyzed.

- A segmented regression approach was employed to identify by-day changes and trends in nighttime light intensity over time for each grid cell at a resolution of 0.01 degrees.
- A Dimming Lights Ratio (DLR) was developed to compare relative changes in radiance before and after specific dates, accounting for seasonal variations.
- Daily DLR maps (1095 in total) were created to visualize the spatial distribution of dimming across the region.
- The DLR maps were composited as frames into an animated movie, which can be viewed with any standard media viewer and can be downloaded from https://eogdata.mines.edu/wwwdata/downloads/ukraine_dimming/Ukraine_movie_bounds_colorbar.mp4.

### Key Findings:

1. Significant dimming of lights was observed across most of Ukraine following the war's commencement, likely a direct consequence of the conflict.
2. All large cities in the east of Ukrainian cities (Kharkiv, Sumy, Dnipro) showed a substantial decrease in light intensity compared to the previous year.
3. In contrast, the Russian city of Belgorod exhibited brighter lights, potentially due to increased snow cover in 2022.

This analysis demonstrates the potential of nighttime light satellite data to monitor and track the impact of conflicts on human settlements and infrastructure.

### Data

This study utilizes nighttime light observations from the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite's Day-Night Band (DNB) sensor for the period 2012-2024. The study area encompasses Ukraine and its neighboring countries, defined by a bounding box with latitudes ranging from 44.3°N to 52.5°N and longitudes ranging from 21.5°E to 40.5°E. To establish a reference map for light sources prior to the war, the annual Visible Infrared Imager/Radiometer

Suite (VIIRS) Nighttime Lights (NTL) product for the year 2021 was employed. Nighttime satellite observations were reprojected onto a latitude-longitude raster map with a grid cell size of 0.01°, ensuring comparability with the 750-meter footprint of the DNB image pixels. This process allows for the generation of time series data, capturing observed nighttime radiances for every satellite overpass and each grid cell identified with light presence in 2021, the year before the war.
The variance observed in the NTL time series stems from multiple sources. In mid-latitude regions, short summer nights can lead to partial sunlight contamination within nighttime DNB images. To exclude these pixels, we adopted the established astronomical twilight threshold of 107° solar zenith angle. Natural (non-anthropogenic) variations in nighttime satellite imagery also arise from moonlight reflections on terrain, snow cover, and clouds (causing radiance increases) and cloud transmission blur (causing radiance decreases). Within this study, we opted to retain cloudy and moonlit observations in the time series. Our rationale is that these variations will largely offset each other over the extended observation period. However, to ensure data quality, grid cells with limited coverage (fewer than 350 observations) during the period from 2021-01-01 to 2023-12-31 and a mean DNB radiance below 2 nW/sr/cm² were excluded from further analysis. To mitigate the influence of seasonal variations in reflected radiance from vegetation and snow cover, we employed a comparative analysis. This analysis focuses on corresponding seasons from periods both before and after the war. Given the high observation cadence (1-2 satellite passes per night) within the unfiltered data, this study is positioned to identify precise dates associated with anthropogenic changes.

## Method

To quantify temporal changes in light intensity, we employ a segmented linear regression approach on the time series data for each grid cell. This method assumes constant light emission (radiance) between identified change points. The algorithm estimates the number of change points within each cell, their corresponding dates, and the average radiance for each segment delimited by the change points. Figure 1 illustrates an example of this approach applied to the nighttime light time series for Nyzhin, a small town north of Kyiv with a population of 68,007 (2020 census) situated to the north from Kiev (grid cell coordinates 51.05°N 31.89°E). As depicted, the algorithm identifies a single change point occurring on February 24th, 2022. The average radiance prior to this change point, covering the period January 1st, 2021, to February 24th, 2023, was 7 nW/sr/cm². Following the change point, the average radiance is observed to be 2.5 nW/sr/cm².

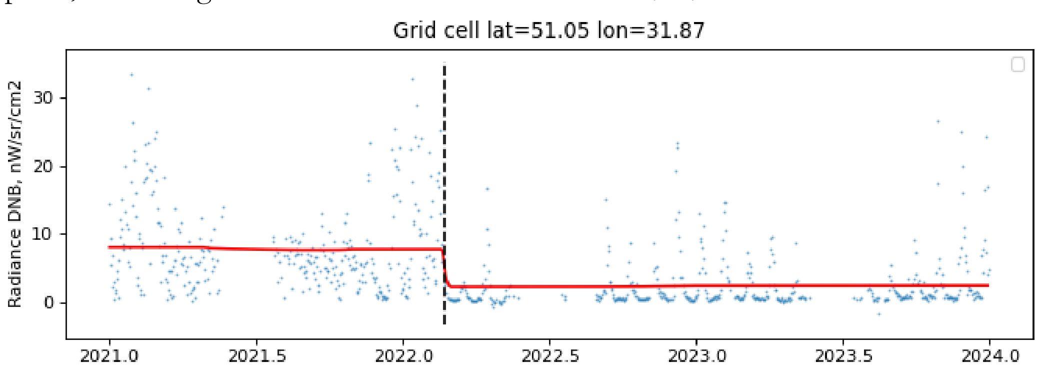



Figure 1. Time series of nighttime lights in a small town Nyzhin to the north from Kiev with the map grid cell coordinates 51.05N 31.89E. Instant radiances are shown with blue. Change detected on February 24th, 2022.

The analysis of nighttime lights in Sumy city center, located east of Kyiv, reveals a more complex pattern. In this case, multiple change points were identified prior to the war, likely corresponding to seasonal variations in lighting and changes in surface reflectance due to snow cover. Notably, the most recent change point occurred on February 26th, 2022, two days after the commencement of hostilities. The average radiance preceding this change point, spanning the period from April 30th, 2021 to February 26th, 2022, was 17.2 nW/sr/cm². Following the change point, a significant decrease in radiance was observed, with the average value dropping to 2.4 nW/sr/cm².

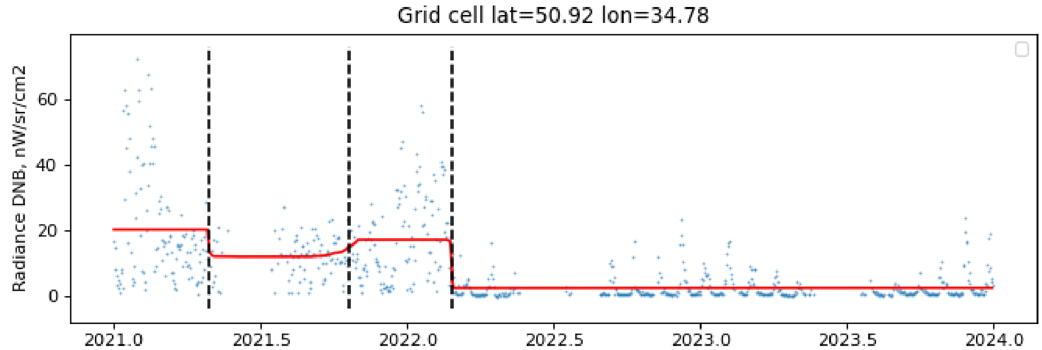



Figure 2. Time series of nighttime lights in the city Sumy to the east from Kiev with the map grid cell coordinates 50.92N 34.78E. Instant radiances are shown with blue. Change detected on February 24th, 2022.

## Dimming Lights Ratio

Building upon the analysis of change patterns in time series of nighttime, we propose the following definition for the comparative Dimming Lights Ratio (DLR):

Dimming_lights_ratio = Mean_radiance(Date – 1 year) / Mean_radiance(Date)

This ratio facilitates the comparison of relative radiance changes before and after specific dates, accounting for seasonal variations in surface reflectance. The underlying assumption is that snow cover and vegetation changes exhibit similar patterns across all years after 2021. To calculate the Dimming Lights Ratio for 2023, the reference date in the denominator would need to be shifted back two years instead of one.

The Dimming Lights Ratio (DLR) was calculated daily for each illuminated grid cell on a specified date for the time period 2021-01-01 to 2023-12-31. Figure 3 presents an example of such a raster image for the vicinity of Nyzhin on March 1, 2022. As evident in the figure, the most significant dimming (DLR = 8.5) is observed in the "downtown" area, which corresponded to the brightest region of the city in 2021. By iterating this calculation across different dates, a time series of light variation maps can be constructed. This computation generates a set of 1,095 raster images depicting the spatial distribution of dimming across Ukraine and its neighboring countries. This image time series has the potential to visualize and to reflect daily changes in the socio-economic situation during the war.

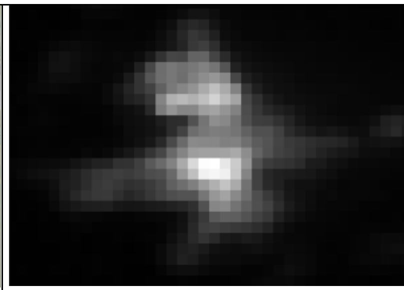
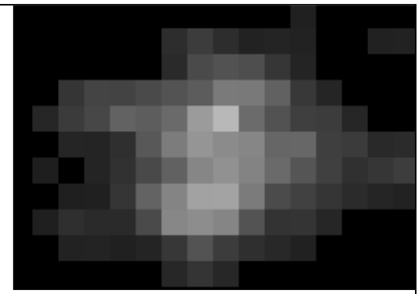
|  |  |  |
|---|---|---|
| Google satellite image | VNL 2021 radiances | Dimming ratio in 2022-03-01 |

Figure 3. Nizhyn city 51.04N 31.29E: Google Earth satellite image (left), maximum DNB radiance in 2021 was 15.5 nW/sr/cm2 (center), maximum dimming ratio in 2022-03-01 was 8.5 (right)

## Visualization

To effectively visualize the daily raster images depicting the spatial distribution of dimming across Ukraine, a customized color palette has been developed. Dark colors represent unlit grid cells, corresponding to areas where no lights were detected in 2021 or where observed radiances in 2022-2023 remained consistently low. White signifies grid cells with no significant change in light intensity (neither dimming nor brightening). Saturation levels of red indicate increasing levels of dimming (corresponding to a decrease in light intensity). Conversely, saturation levels of blue represent areas with brightening lights. Recognizing the predominance of dimming events during the war period, the color palette's saturation is scaled proportionally to the square root of the DLR value. This approach emphasizes areas experiencing the most significant dimming effects. To address the issue of dynamic range within the image, DLR values exceeding a threshold of four are depicted using a single, saturated color. As illustrated in Figure 4, the application of the color palette facilitates the visualization of light intensity changes along the Ukraine-Russia border on March 1, 2022. The image reveals a significant dimming (by a factor of four or more) in the Ukrainian city of Kharkiv with a population of 1.419 million (2017 census, south) compared to the previous year. Conversely, the lights in the Russian city of Belgorod with a population of 339,978 (2021 census, north) appear brighter relative to March 1, 2021.

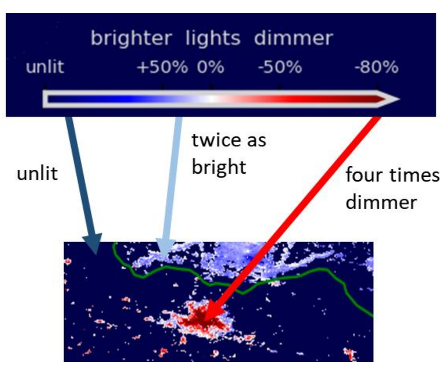



Figure 4. Color palette used to visualize the Dimming Lights Ratio.

Figure 5 presents a comparison of Dimming Lights Ratios (DLR) for two key dates: January 1st, 2022 (two months prior to the war's commencement), and March 1st, 2022 (one week into the conflict). By analyzing these DLR maps, we can formulate a hypothesis regarding the observed brightening of lights in Russia's Belgorod region (eastern border). This brightening may potentially be attributed to increased snow cover compared to 2021. Conversely, the March 2022 DLR map reveals significant dimming across most of Ukraine as a direct consequence of the ongoing military conflict. Political boundaries on the map are provided by the Natural Earth project https://www.naturalearthdata.com/downloads/50m-cultural-vectors/. The state boundaries are shown in yellow. The disputed boundaries are in magenta. The daily DLR maps were composited as frames into an animated movie, which can be viewed with any standard media viewer and downloaded from the Payne Institute website.

## Acknowledgment

This study received support from the NASA Land-Cover/Land-Use Change Program

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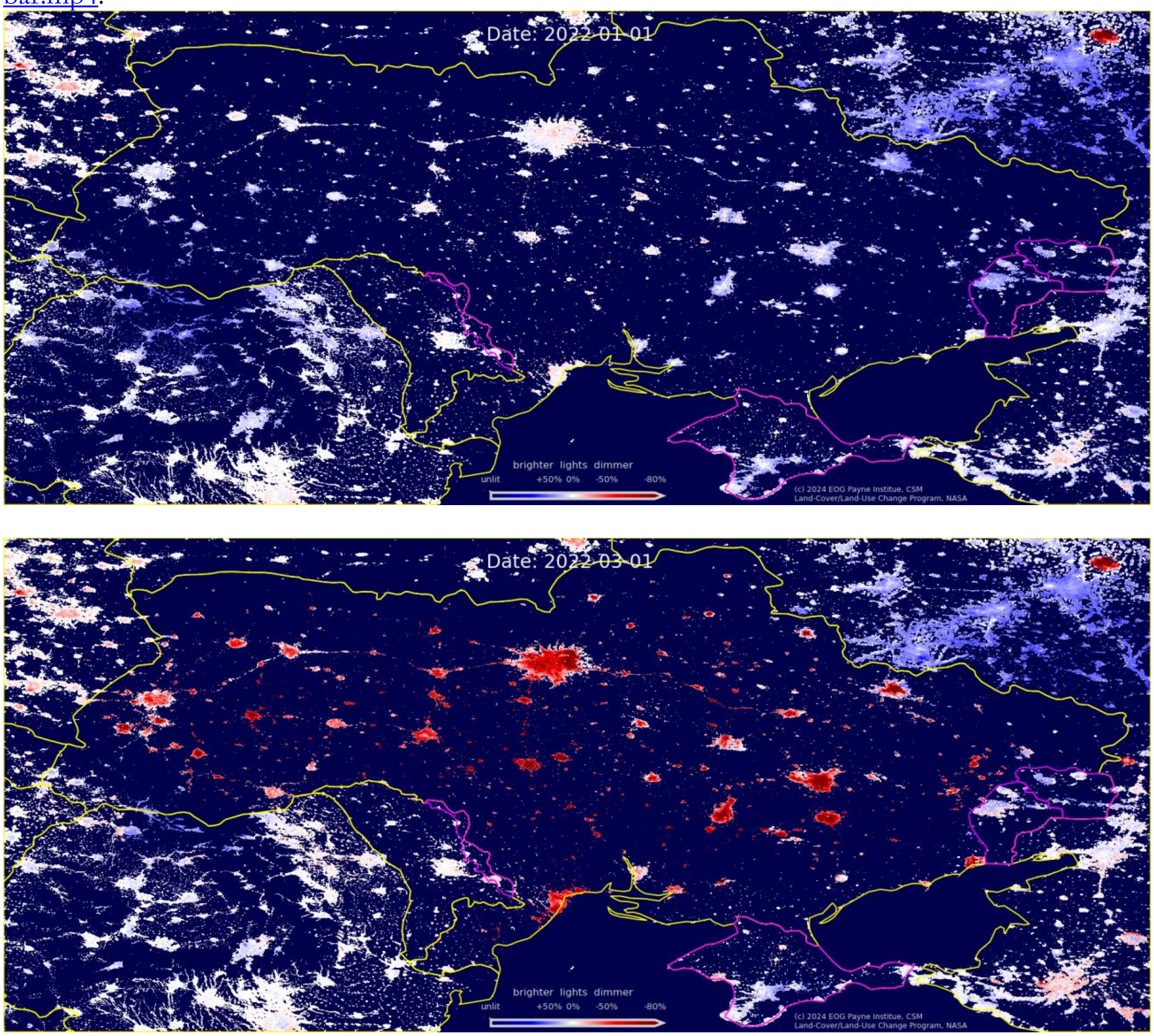


Figure 5. Comparison of Dimming Lights Ratios (DLR) maps for two dates: January 1st, 2022 (upper), and March 1st, 2022 (bottom).

## ABOUT THE AUTHOR

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Mikhail Zhizhin, M.Science in mathematics from the Moscow State University in 1984, Ph.D. in computational seismology and pattern recognition from the Russian Acad. Sci. in 1992. Research positions from 1987 to 2012 in geophysics, space research and nuclear physics at Russian Acad. Sci., later at NOAA and CU Boulder. Currently he is a researcher at the Earth Observation Group at Colorado School of Mines. His applied research fields evolved from high performance computing in seismology, geodynamics, terrestrial and space weather to deep learning in remote sensing. He is developing new machine learning algorithms to better understand the Nature with Big Data.

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