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Map of Darkness: How Nighttime Lights Trace the Impact of War in Ukraine

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Abstract:

Nighttime light observations from the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite's Day-Night Band (DNB) sensor were employed for the period 2012-2024 to study light intensity changes in Ukraine and its neighboring countries. The study area was 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 pinpoint the locations of pre-war artificial light sources, the annual VIIRS Nighttime Lights (NTL) product[1] for the year 2021 was utilized. DNB radiances, center coordinates, cloud, and lunar conditions for all pixels in nighttime satellite images, located in the vicinity of artificial lights in the time period from April 1, 2012 until now, were compiled into a spatio-temporal database and subsequently reprojected onto a latitude-longitude raster map with a grid step of 0.01°, ensuring compatibility with the 750-meter footprint of the raw DNB image pixels. This process allowed for the generation of time series data, capturing observed nighttime radiances and cloud/moonlight condition for every satellite overpass and each grid cell identified with artificial light presence in 2021, one year prior the war.

To analyze changes in light intensity over time, we employed a segmentation of the time series data for each grid cell. This method assumes consistent radiance of artificial lights between identified points of change. The machine learning algorithm estimated a number of change points within each grid cell, the dates of change, and the radiance of lights within each segment between by these change points. For instance, in the city center of Kharkiv in Eastern Ukraine with population estimate in 2018 of 1,410,515[2], several change points were observed prior to the war, likely attributed to seasonal variations in cloud cover and changes in surface reflectance due to snow cover. Notably, the most recent change point occurred on February 24th, 2022, coinciding with the first day of the war. Following this change point, a significant and consistent decrease in radiance was observed, with the average value dropping from 80 to 2 nW/sr/cm².

To quantify the magnitude of change in the radiance of nighttime lights time series during the war, we propose the following comparative index called the Dimming Lights Ratio (DLR):

$$Dimming\_lights\_ratio = Mean\_radiance\ (Date - 1\ year)\ /\ Mean\_radiance\ (Date)$$

This ratio stands for the relative changes in radiance taking in consideration the seasonal variations in surface reflectance. Here we assume that vegetation, cloud and snow cover exhibit similar seasonality patterns before and after beginning of the war, contrary to the artificial lights. To calculate the DLR for 2023 and 2024, the reference pre-war date in the denominator would need to be shifted back two or three years instead of one.The DLR was estimated daily for all grid cells within the geographic boundaries of Ukraine and its neighboring countries, encompassing the period from January 1, 2024, to the present. By iterating this calculation across various dates, a time series of light variation maps was constructed. This process yielded thousands of raster images depicting the spatial distribution of dimming across the region.

This animated time series of images depicting daily changes in light intensity offers the potential to visualize and quantify the evolving socio-economic conditions during the war, including changes in population and regional domestic product. Furthermore, it enables comparisons with external regions not directly involved in the conflict.

[1] Elvidge, Christopher D., et al. "Annual time series of global VIIRS nighttime lights derived from monthly averages: 2012 to 2019." Remote Sensing 13.5 (2021): 922.
[2] "Table 8 - Population of capital cities and cities of 100,000 or more inhabitants", Demographic Yearbook – 2020, United Nations

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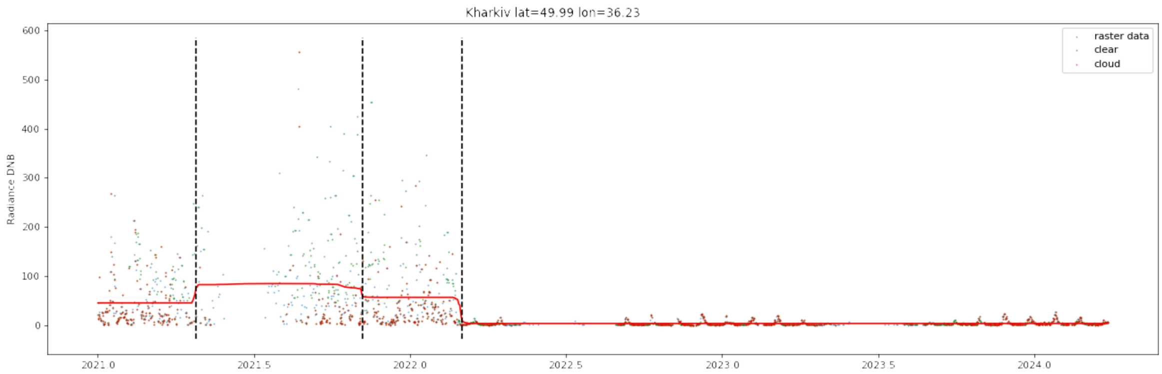

Figure 1. Brightness of nighttime lights in the city center of Kharkiv. Instant cloud-free radiances are shown with blue, cloudy observations in red. The most recent change was detected on February 24th, 2022, on the first day of war.

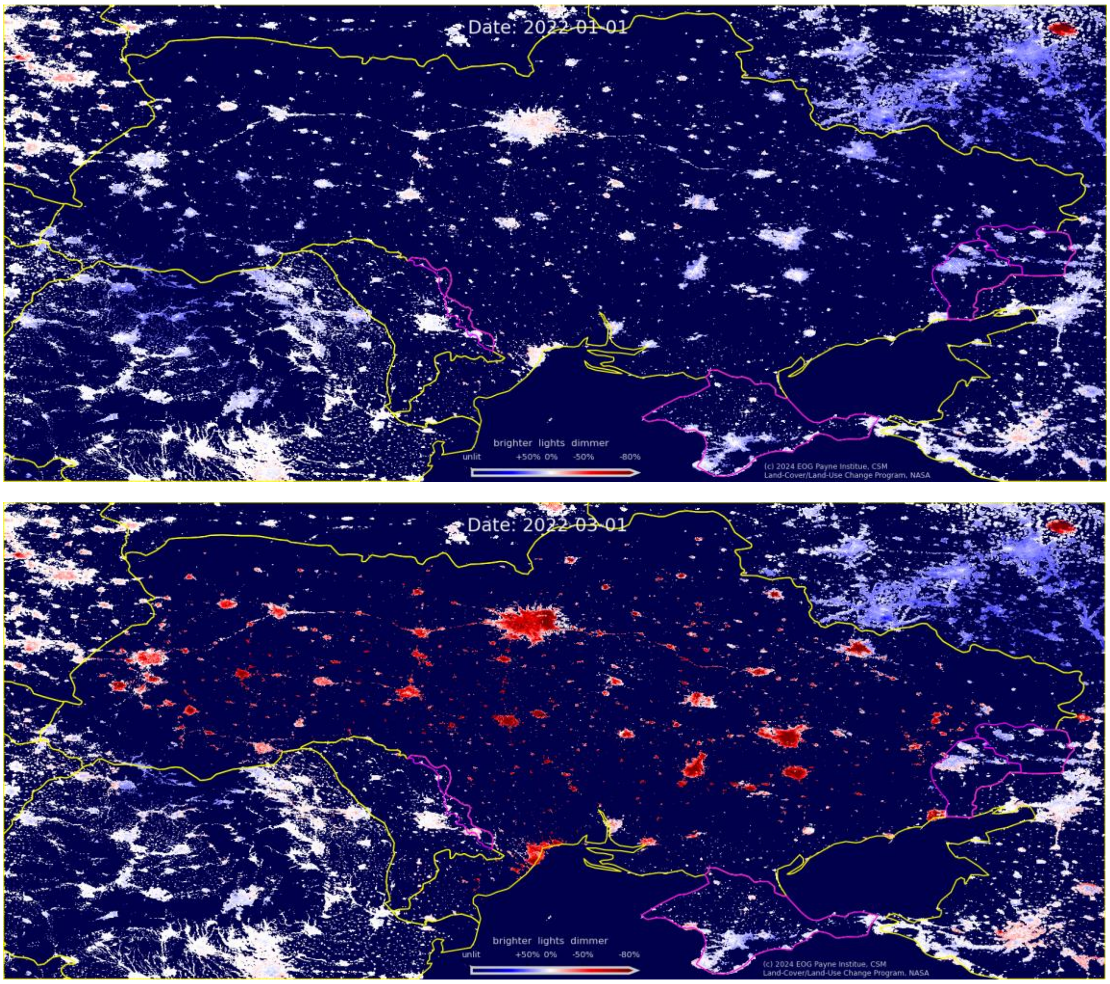

Figure 2. Comparison of Dimming Lights Ratios (DLR) maps for two dates: January 1st, 2022 (upper), and March 1st, 2022 (bottom).

Acknowledgements

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[3] https://repository.mines.edu/bitstream/handle/11124/178850/Payne-Institute-Commentary-Mapping-of-Dimmed-Nighttime-Lights-in-Ukraine-During-the-War.pdf

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