Shifting Landscapes: Nighttime Lights and Fires in Confict Zones

Mikhail Zhizhin

Earth Observation Group

Payne Institute for Public Policy

Colorado School of Mines

Golden, Colorado

mzhizhin@mines.edu

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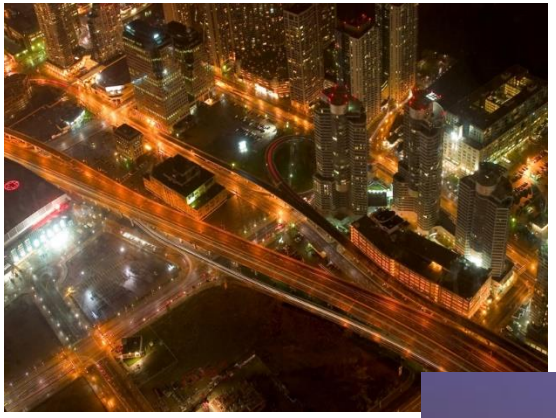
Lights At Night!



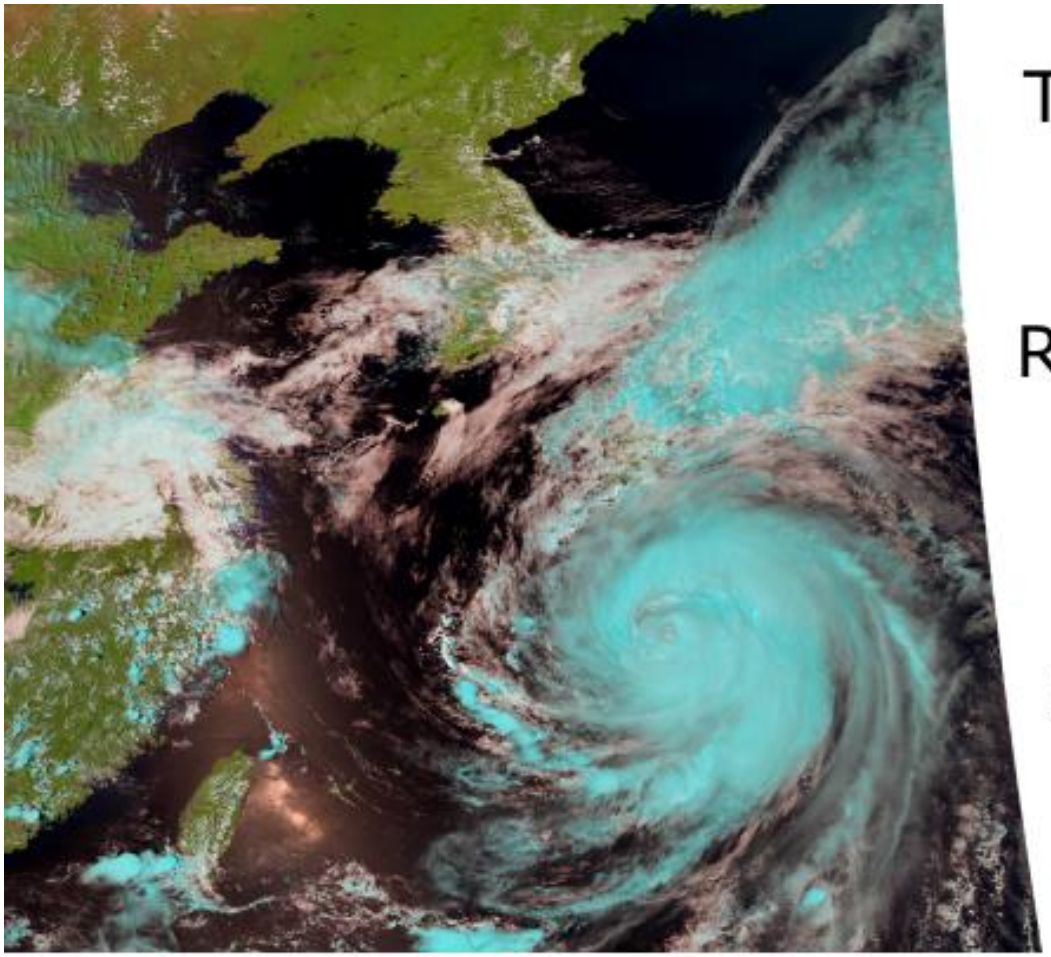
Cities and human settlements

Boats

Industrial Sites

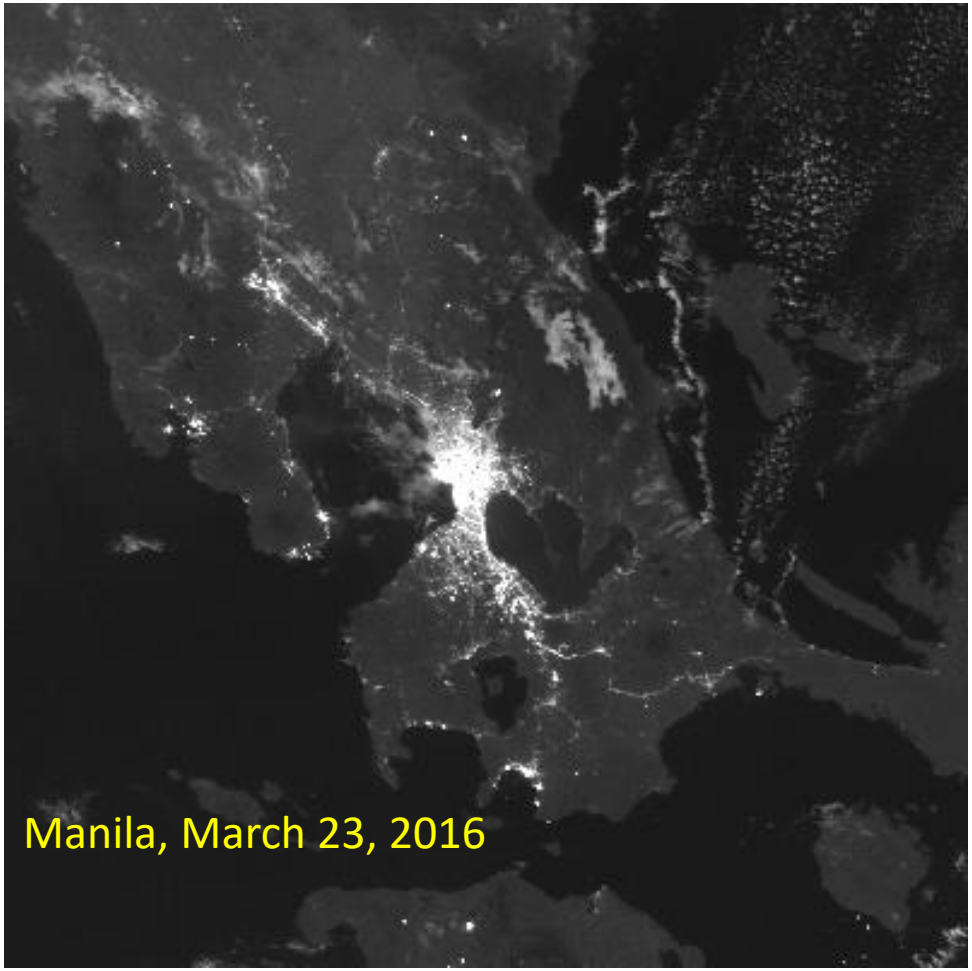
Gas Flares

Fires

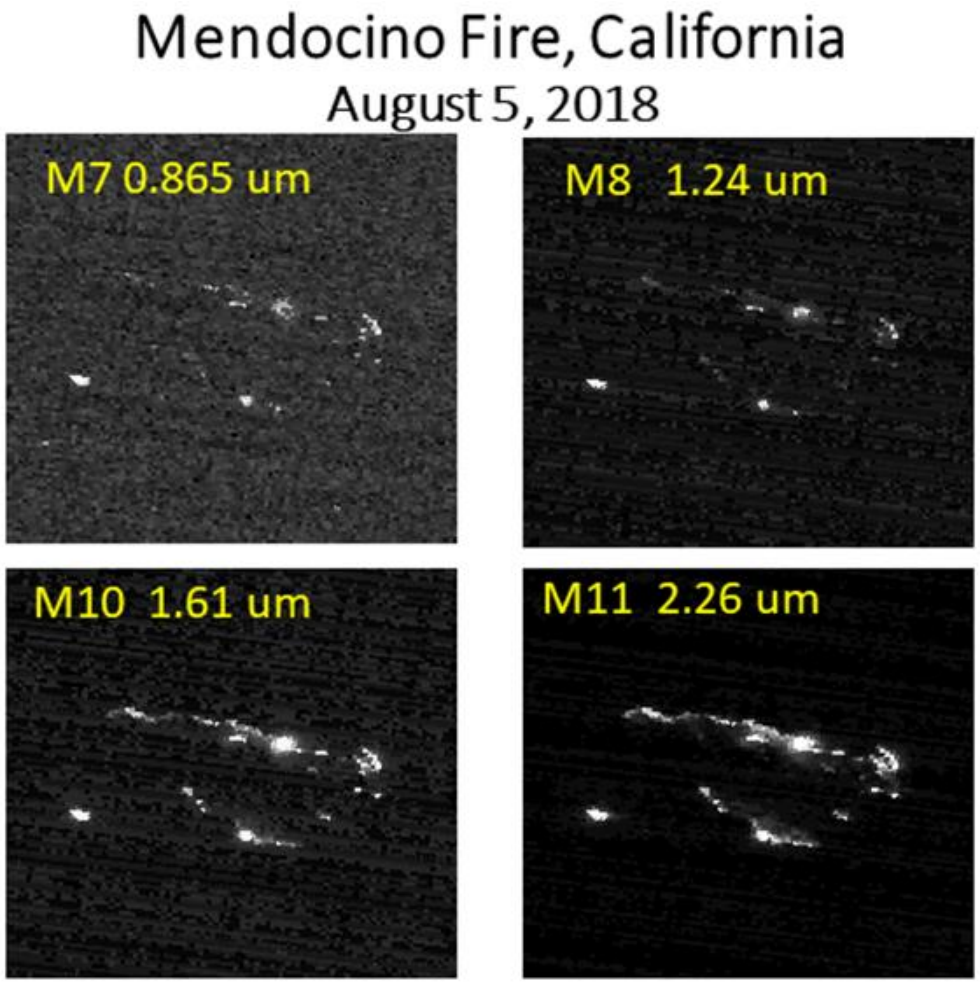


The Visible Infrared Imaging Radiometer Suite (VIIRS) primary mission is weather.

Thank you meteorologists!



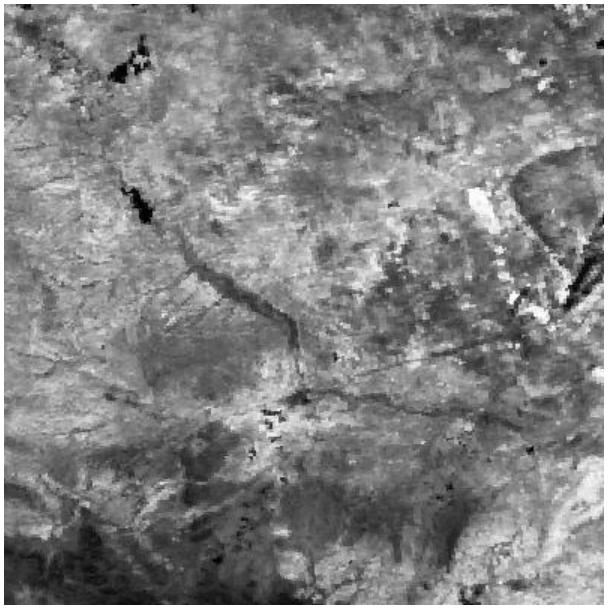
The VIIRS day/night band (DNB) collects low light imaging data in the visible at night to enable detection of moonlit clouds. Electric lighting, fires and flares are also detected.



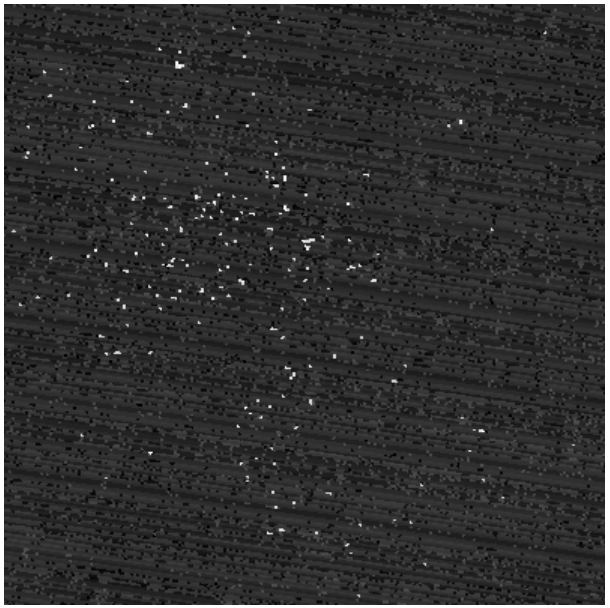
VIIRS collects four other “low-light” imaging channels. Near and shortwave infrared channels designed for daytime imaging. With sunlight eliminated – these serve as “super-detectors” of infrared emitters.

For gas flares – the nighttime is the right time! Bakken Oil Field, North Dakota

Shortwave infrared (1.63 um) day



Same band, same area, next night

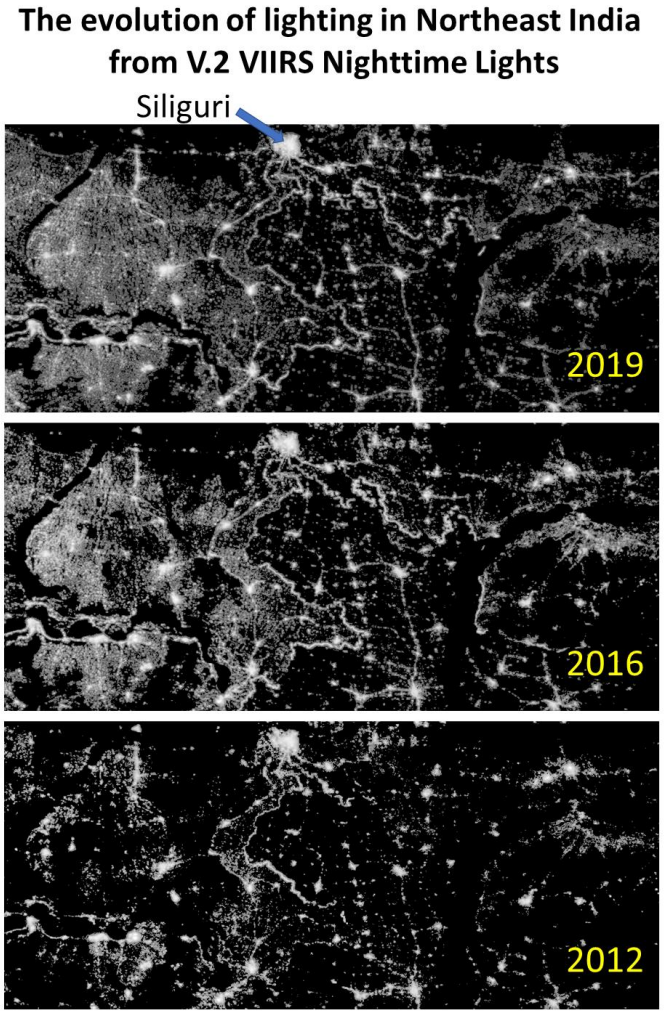


Gas flare peak radiant emissions are near 1.63 micrometers.
The flare radiance is lost during the day due to sunlight.

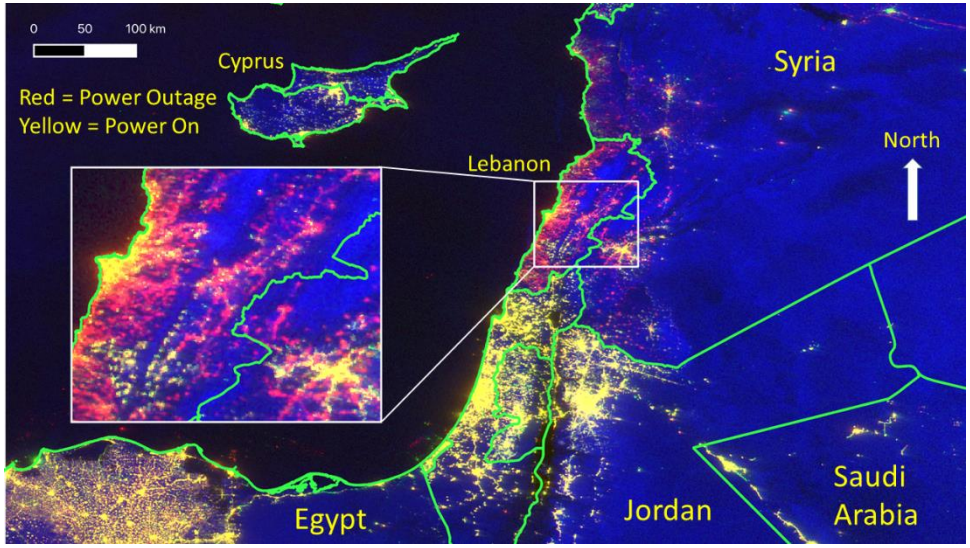
VIIRS Nighttime Lights

EOG's Flagship Product is VIIRS Nighttime Lights

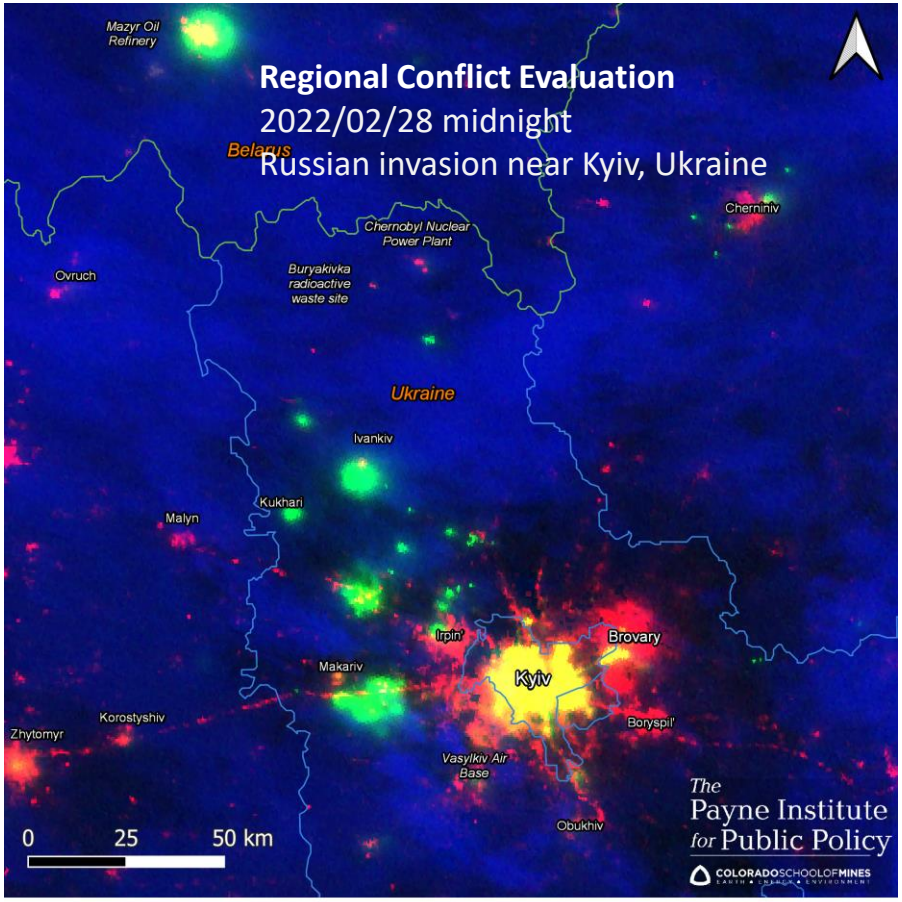
- EOG's most popular dataset
  - ~560TB downloaded in 2021
  - ~42K files downloaded in 2021
- DMSP-OLS (1992-2020)
  - Annual
  - Monthly
- VIIRS (2012-2025)
  - Annual
  - Monthly
  - Nightly profiles in select areas



Power outage detection and recovery tracking

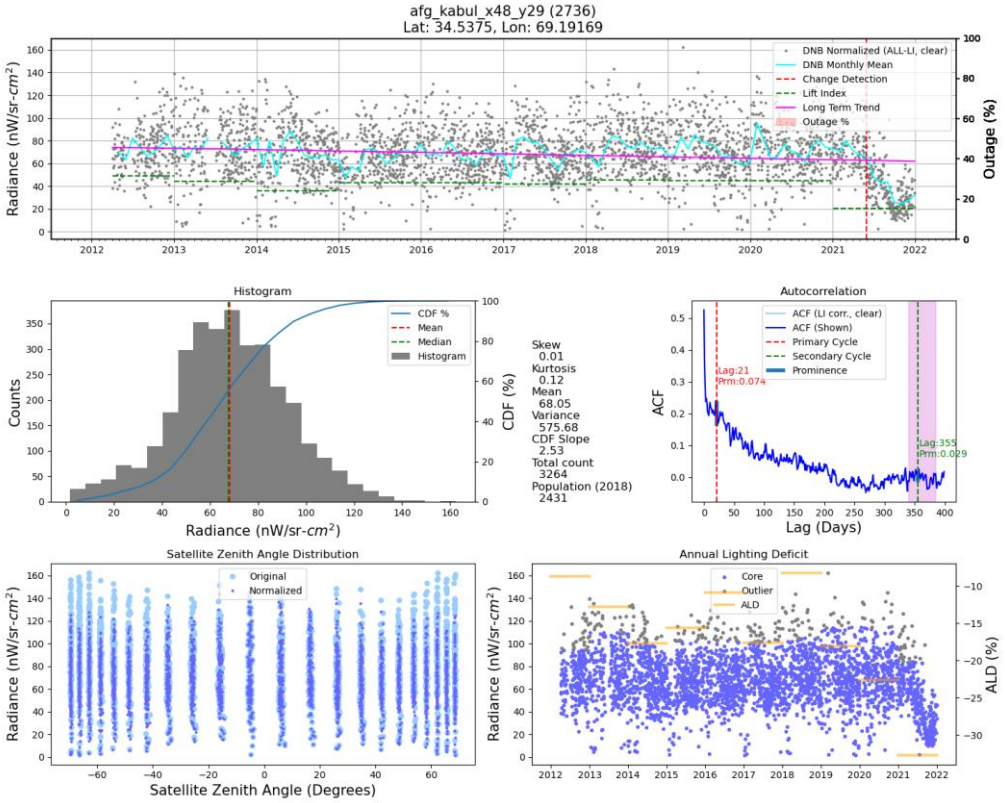


Electricity Supply Event Evaluation
2021/10/09
Power grid failure in Lebanon



Overpass time: 2/28/2022 midnight
Red band JPSS NPP VIIRS-DNB 2022 January monthly cloud free composite
Green band JPSS NPP VIIRS-DNB visible band
Blue band JPSS NPP VIIRS-M15 thermal band

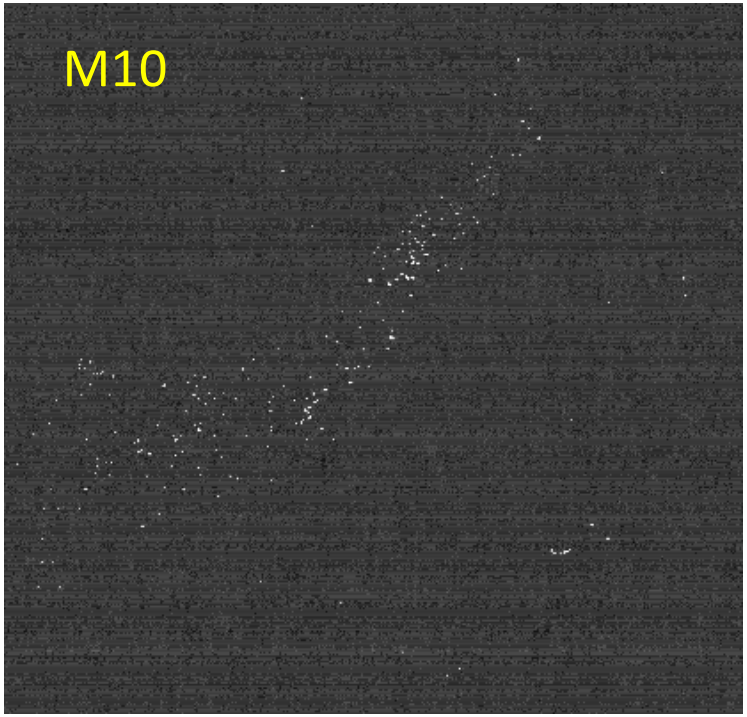
VIIRS Nighttime lights are nightly temporal profiles extending back to 2012

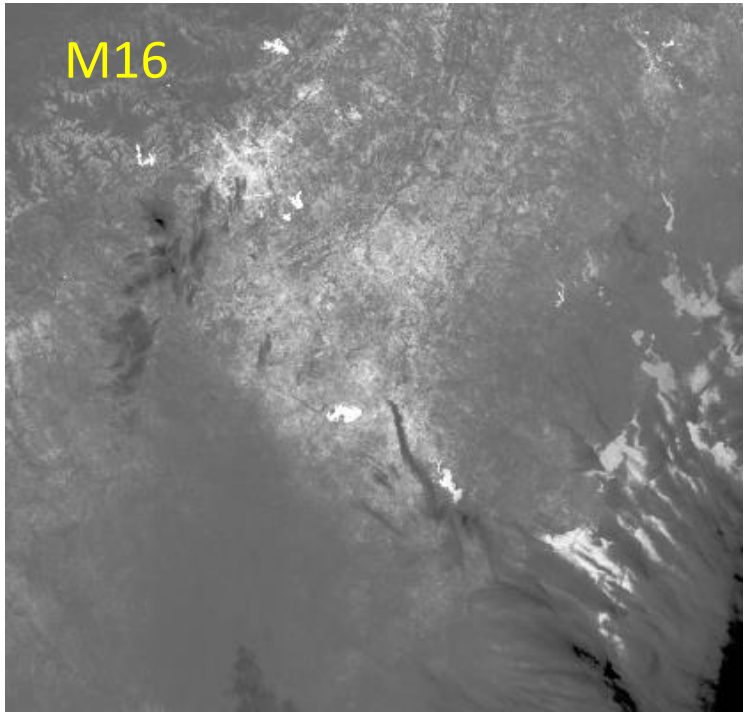


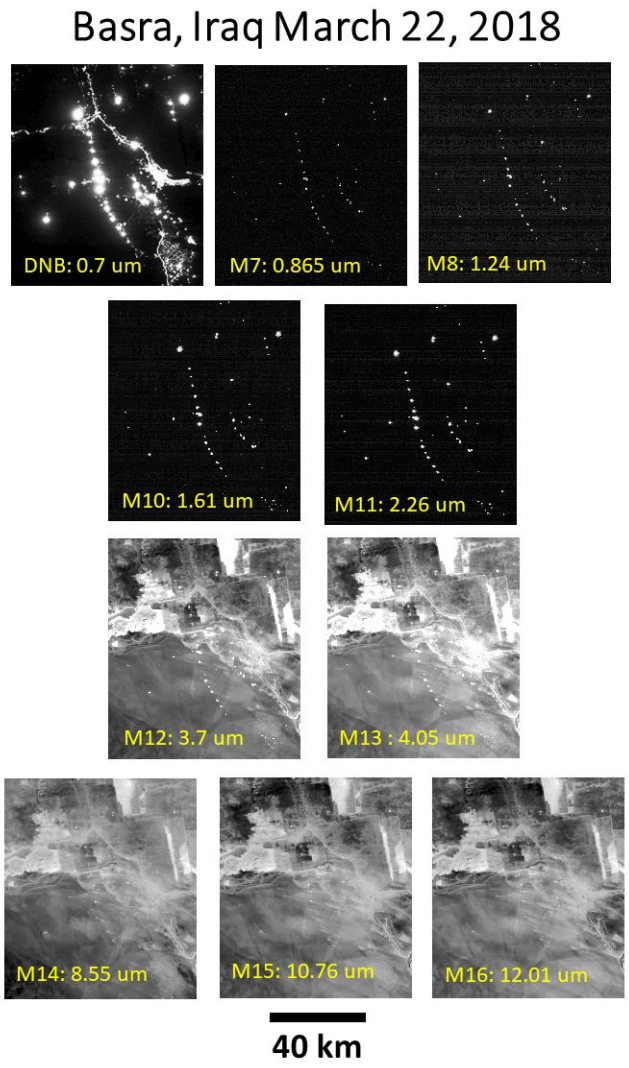
U.S. Embassy, Kabul, Afghanistan VNL v.3 DNB temporal profile showing lights dimmed starting in June 2021. The US withdrawal was in August 2021.

VIIRS Nightfire

The nighttime SWIR bands are vital for flare detection because they cover the peak in radiant emissions. Here is an example of simultaneously acquired nighttime M10 and M16 collected on the Eagle Ford basin in Texas.



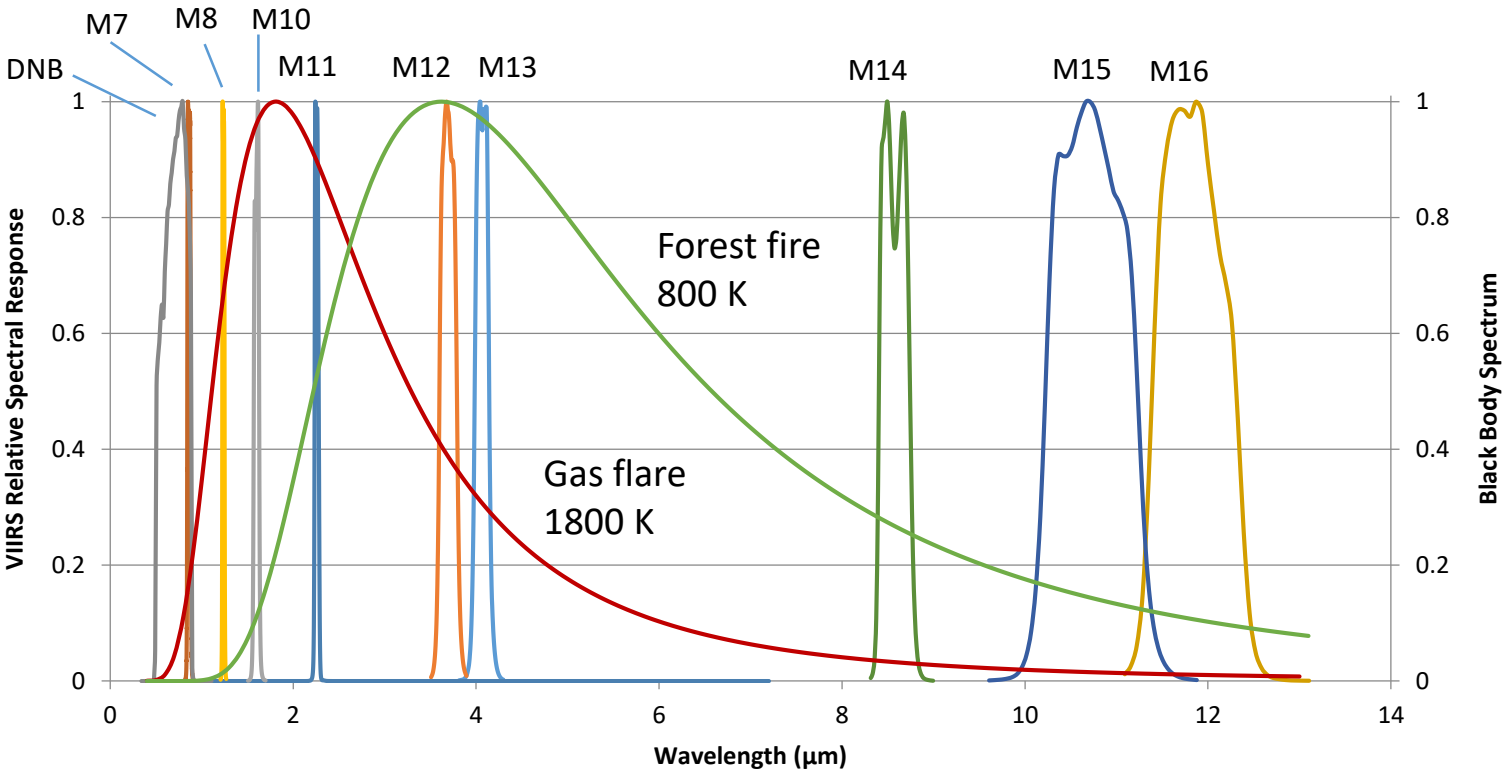




VIIRS collects low light imaging data in five spectral bands at night. The day / night band (DNB) straddles the visible and near infrared and has a million-fold signal amplification. Four daytime channels (two near and shortwave infrared) continue to collect at night. With sunlight eliminated these serve as super-detectors for infrared emitters!

VIIRS Nightfire (VNF)

A global fire product created from nighttime multispectral satellite data

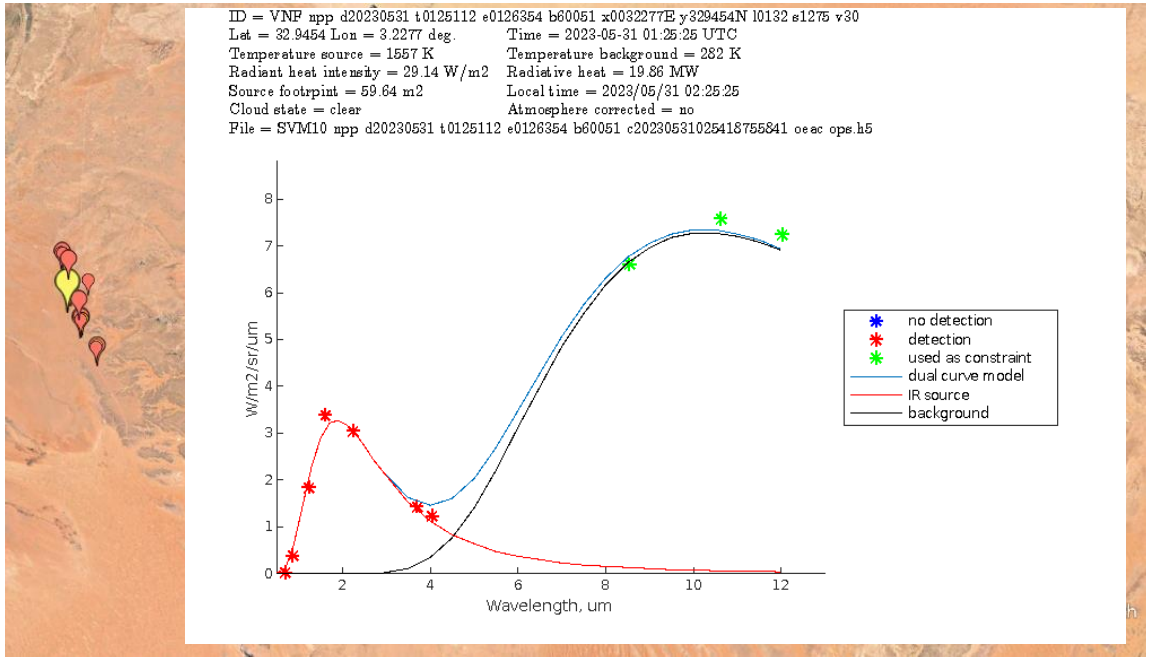


VIIRS M-band spatial resolution is 750m at nadir
Nighttime collection of channel M11 began in Dec 2017

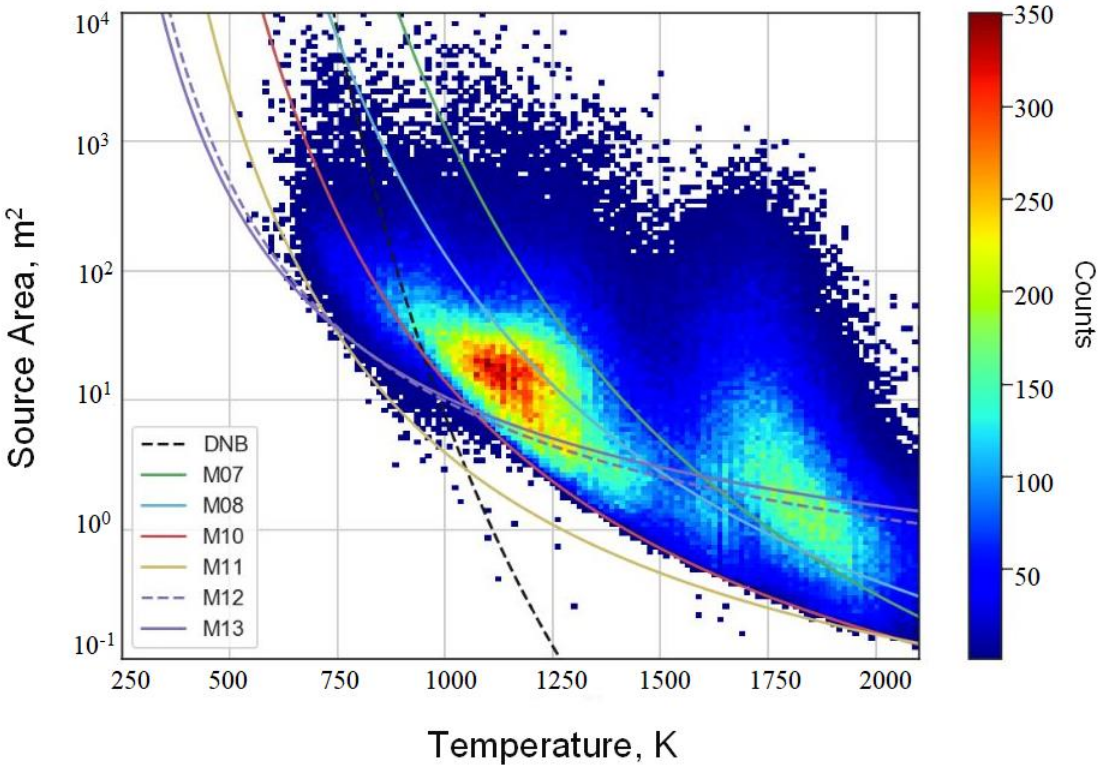
Suomi NPP / VIIRS data is available from March 2012 – present
NOAA-20 (JPSS-1) / VIIRS data collected from June 2018

Physical laws used by VIIRS Nightfire

- Temperature is calculated based on the wavelength of peak radiant emissions using **Wien's Displacement Law**.
- Source area is calculated based on the ratio of the observed Planck curve amplitude versus the Planck for an object at that temperature filling the field of view (**Planck's Law**).
- Heat output (radiant heat) is calculated with temperature and source area via the **Stefan-Boltzmann Law**.



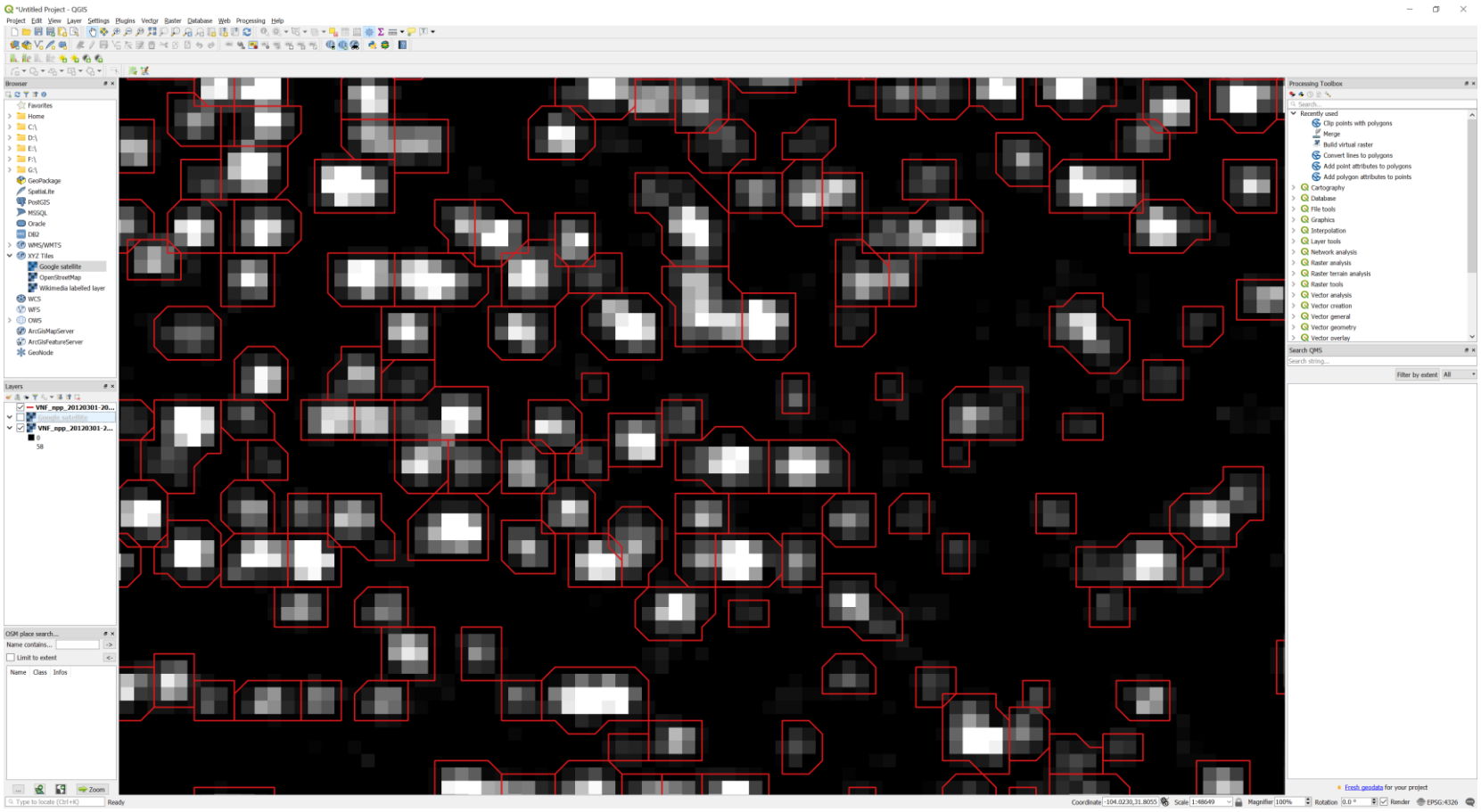
VIIRS Nightfire Detection Limits in Terms of Temperature and Source Area



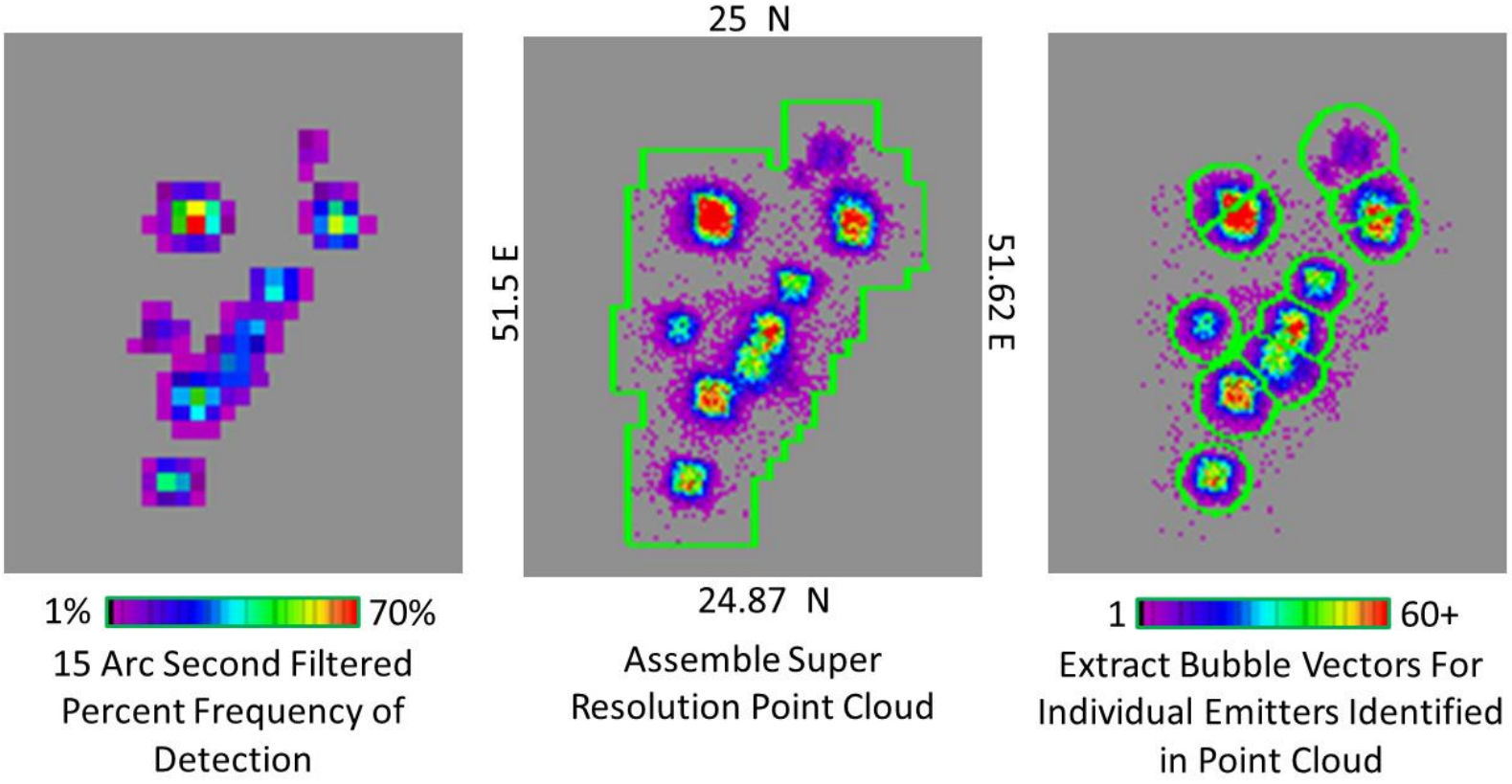
Elvidge, Christopher D., Mikhail Zhizhin, Kimberly Baugh, Feng Chi Hsu, and Tilottama Ghosh. "Extending nighttime combustion source detection limits with short wavelength VIIRS data." Remote Sensing 11, no. 4 (2019): 395.

Persistent IR emitters:
flares, landfills, steel mills, etc.

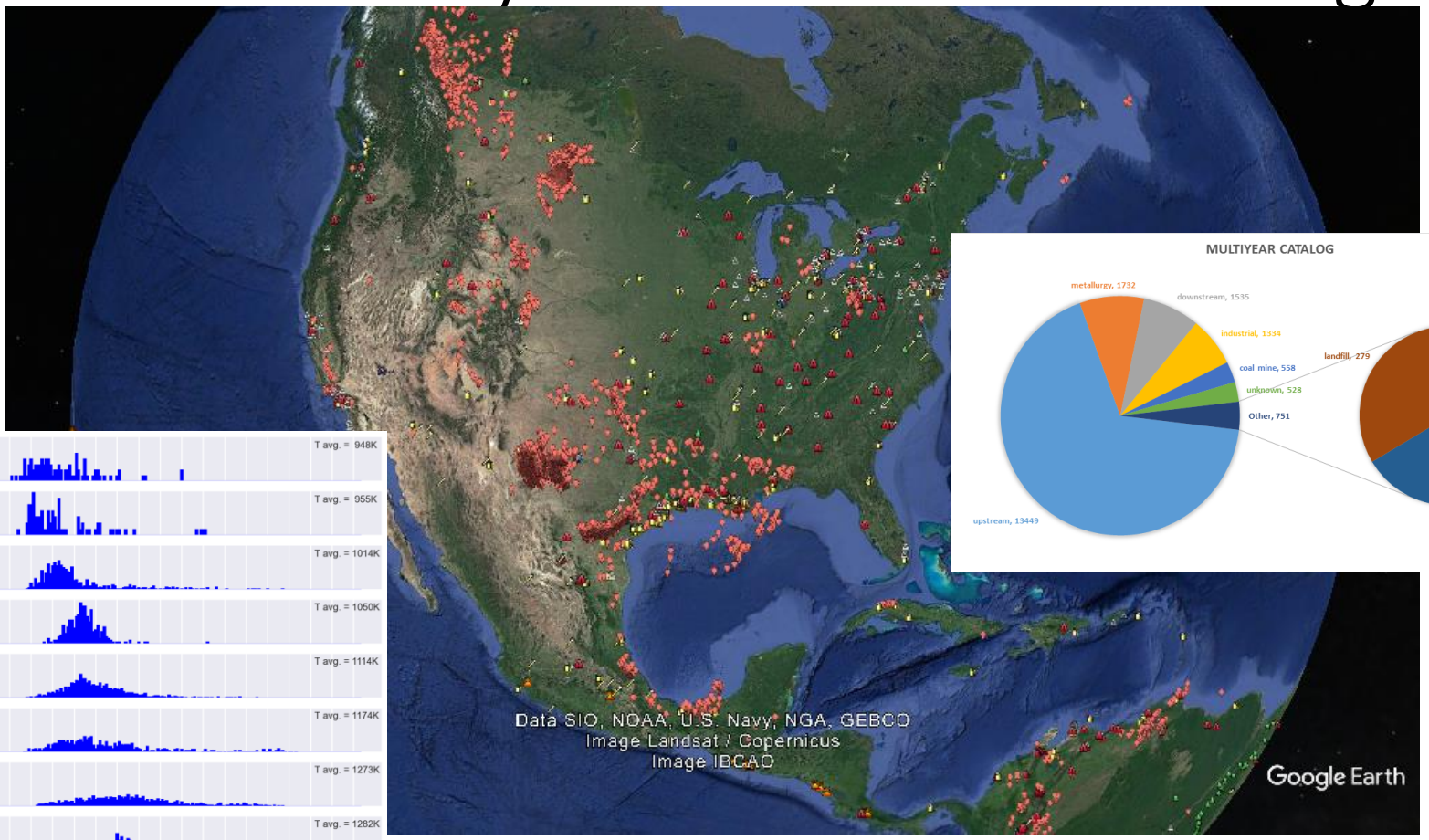
Permian N-detect grid and flare vector boundaries

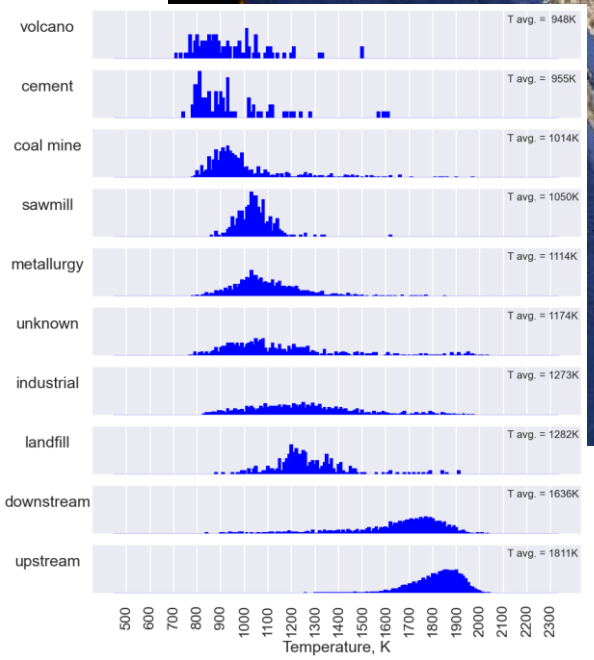


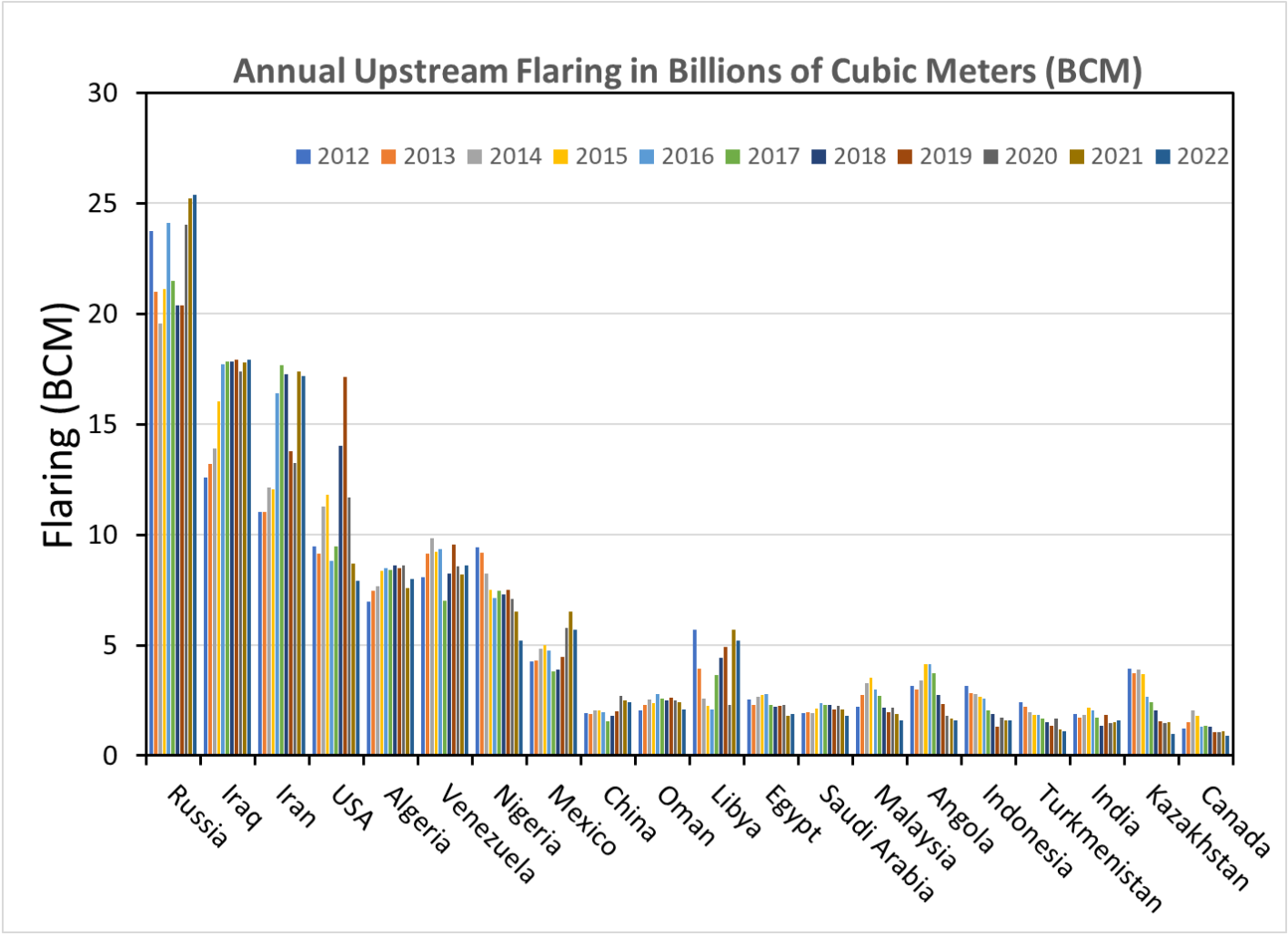
Superresolution method for IR emitters :
1 year temporal averaging = 10-fold spatial resolution



EOG's Multiyear IR Emitter Catalog

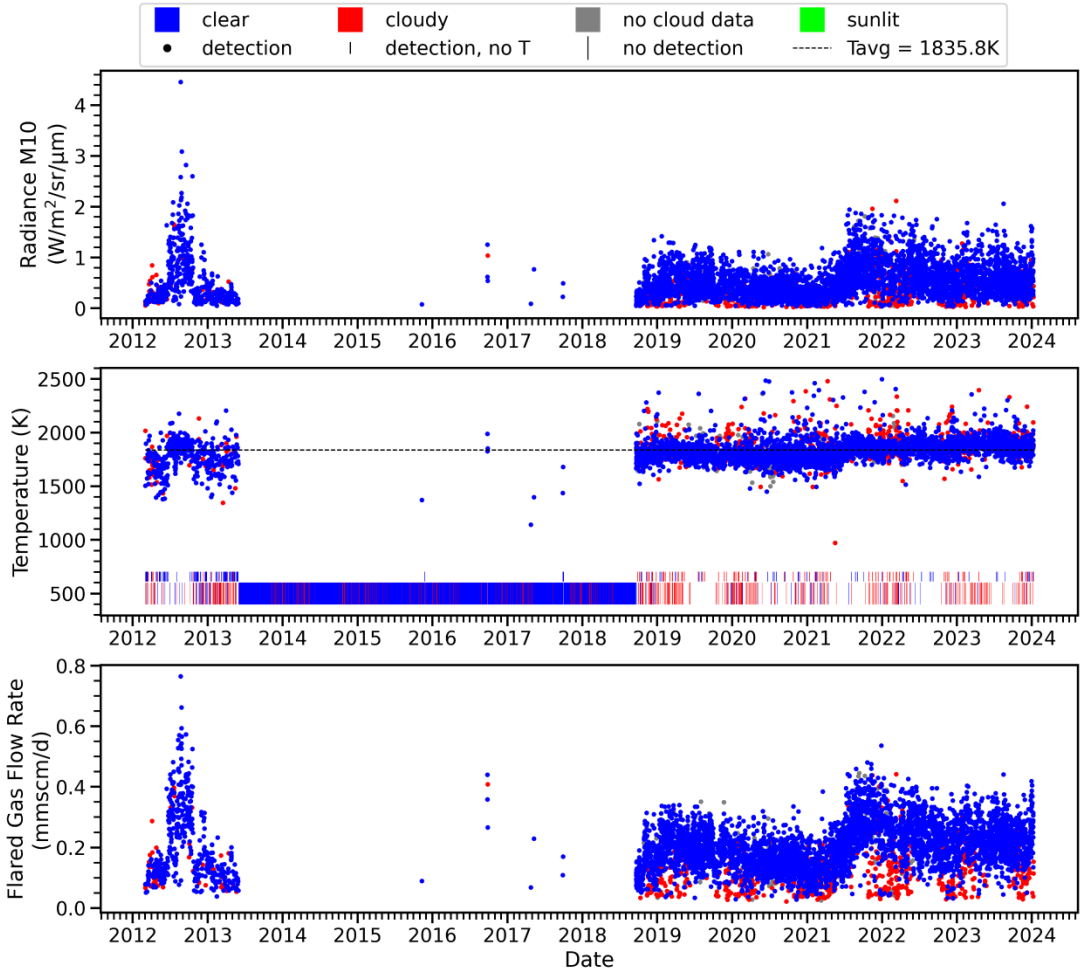






Estimated annual flared gas volumes for the top 20 flaring countries

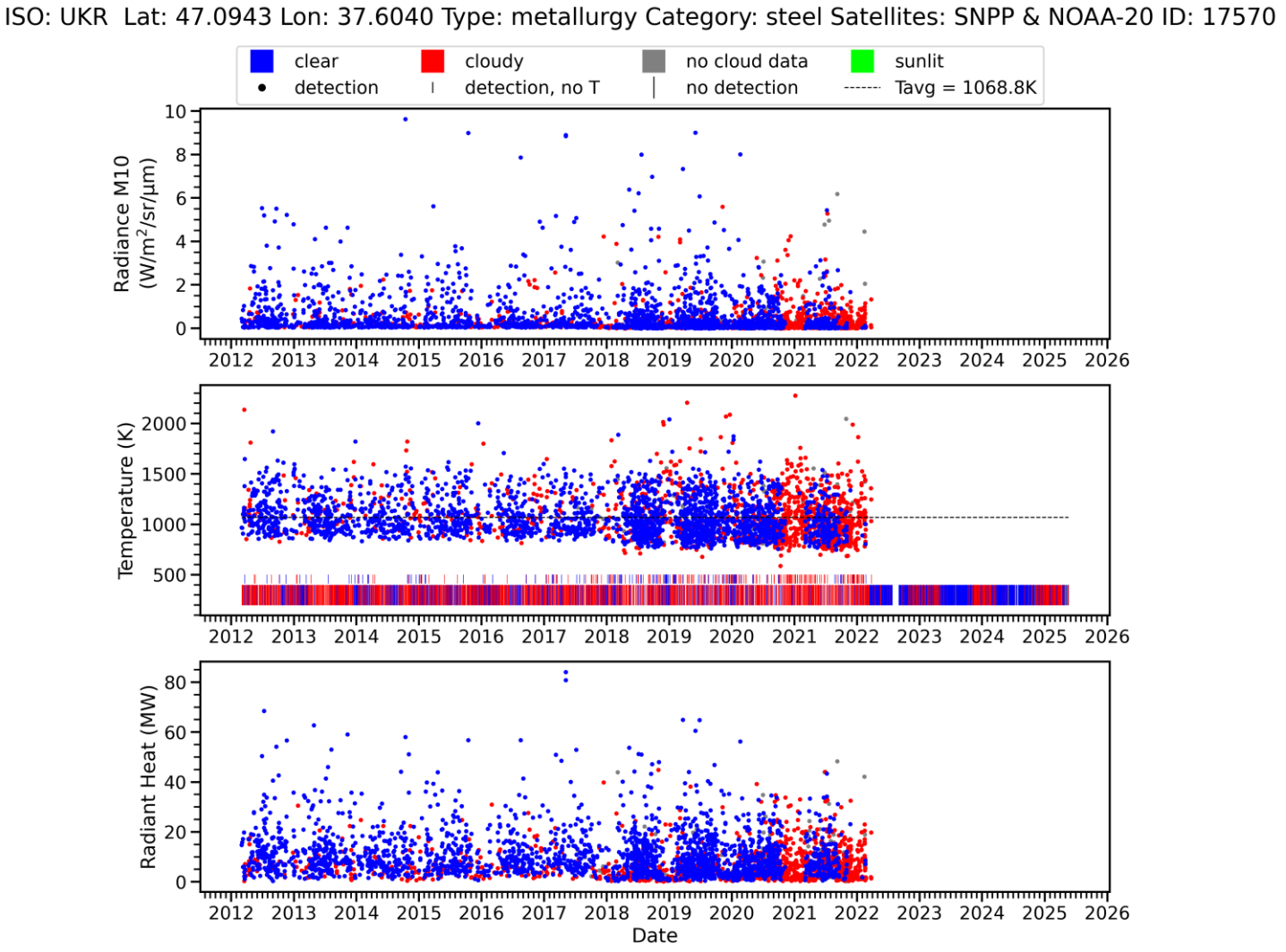
ISO: SYR Lat: 35.3030 Lon: 40.4452 Type: Upstream Flare Category: oil Satellites: SNPP & NOAA-20 ID: 11107



VIIRS Nightfire temporal profile created by the Earth Observation Group, Payne Institute for Public Policy, Colorado School of Mines
Last Updated: 2024-01-09 12:47:19 UTC

Syria Upstream Flare (#11107) Outage Due to Civil War – No Pilot Light Detected

Steel mill in Mariupol seized operations in Mar 2022

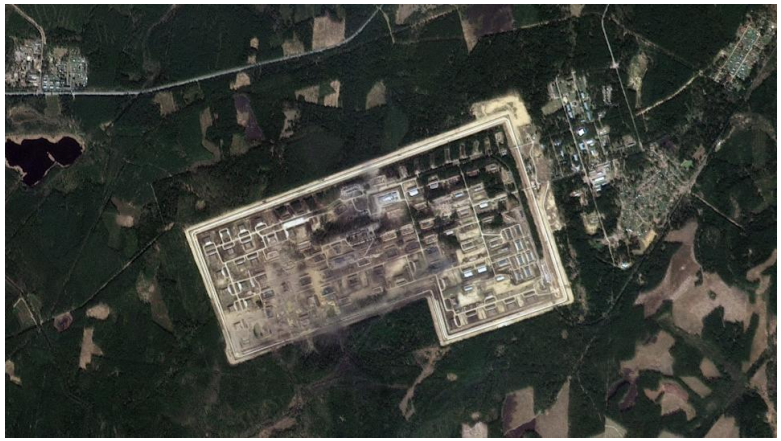


VIIRS Nightfire temporal profile created by the Earth Observation Group, Payne Institute for Public Policy, Colorado School of Mines
Last Updated: 2025-05-19 07:38:42 UTC

Transient IR emitters: fires

Massive fire following Russian arsenal explosion

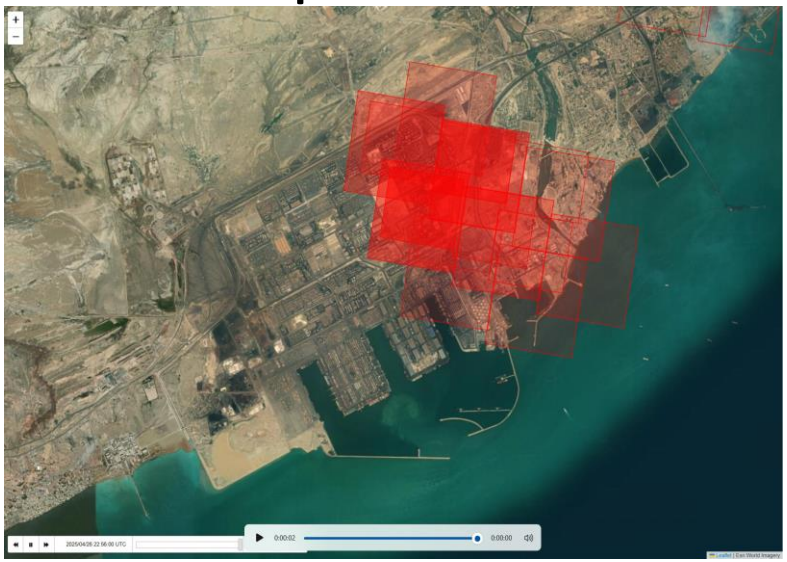
- On April 22, 2025, a significant explosion followed by a large fire appears to have occurred at the 51st Arsenal of the Main Missile and Artillery Directorate near Kirzhach, in Russia's Vladimir Oblast, northeast of Moscow [1].
- Satellite data confirms that an initial blast triggered ongoing secondary detonations throughout the night and into the next day [2].
- The VIIRS Nightfire detected intense thermal anomalies from large fires at the Kirzhach arsenal. The animation displays these detections captured over multiple satellite passes [3].
- In the animation, red rectangular footprints represent individual VIIRS infrared M-band pixel detections, with brighter rectangles signifying greater fire radiative power (heat intensity)
- Daytime images confirm the geolocation of VNF fires [4].



1. https://www.businessinsider.com/blast-rocks-russian-ammo-depot-kremlin-says-explosives-mishandled-2025-4
2. https://payneinstitute.mines.edu/satellite-data-shows-massive-fire-following-russian-arsenal-explosion/
3. https://payneinstitute.mines.edu/wp-content/uploads/sites/149/2025/04/Satellite-Data-Shows-Massive-Fire-Following-Russian-Arsenal-Explosion-Video.mp4
4. https://policy-wire.com/new-satellite-image-shows-tremendous-damage-after-one-of-russias-largest-ammo-depots-exploded/

Tracking a chemical explosion in Iran

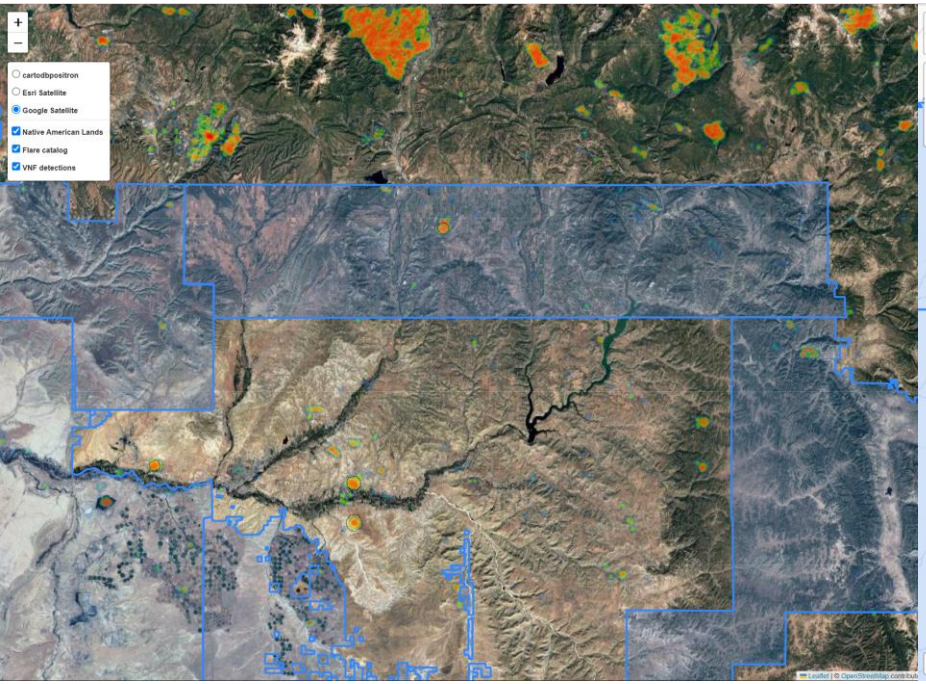
- A massive explosion occurred on Saturday, April 26, 2025, at the Shahid Rajaee port, located near the southern city of Bandar Abbas, Iran [1].
- The explosion resulted in a significant number of casualties. The death toll has risen to at least 40 people, and around 1,000 others have been reported injured [2].
- On the night of April 26th, all three VIIRS satellites detected substantial fires at the Iranian port [3]. Using VNF, we measured these fires at a temperature of roughly 900K, with a maximum fire source area of 2800 m2 and a fire radiative power of 76 MW during that night.



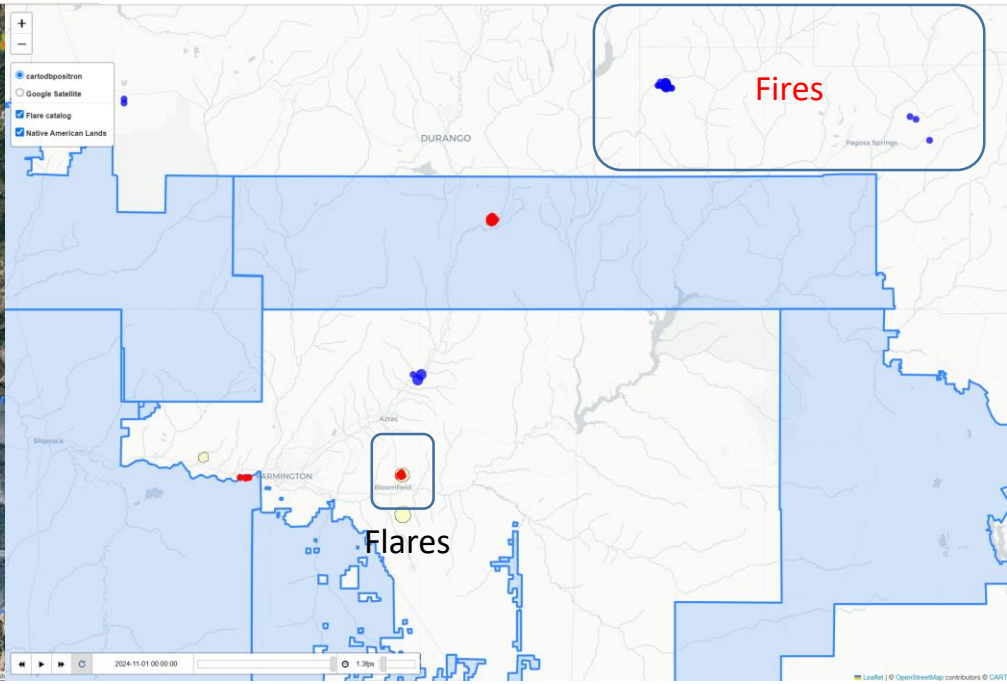
1. https://www.aljazeera.com/news/2025/4/27/irans-president-pezeshkian-visits-injured-site-of-deadly-port-explosion
2. https://apnews.com/article/iran-port-shahid-rajaei-explosion-fire-bandar-abbas-fd31972422ae1612006b1c8005f58440
3. https://payneinstitute.mines.edu/wp-content/uploads/sites/149/2025/04/Tracking-a-Chemical-Explosion-in-Iran-20250426.mp4
4. https://apnews.com/article/iran-port-shahid-rajaei-explosion-fire-bandar-abbas-fd31972422ae1612006b1c8005f58440

Heat sources in Southern Colorado: flares, industry and forest fires

Hot spot detections in 2012-2025

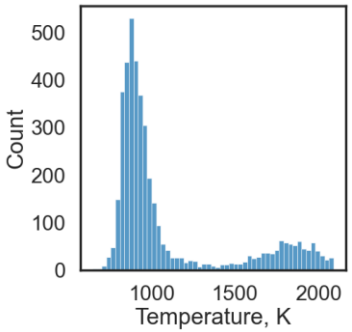


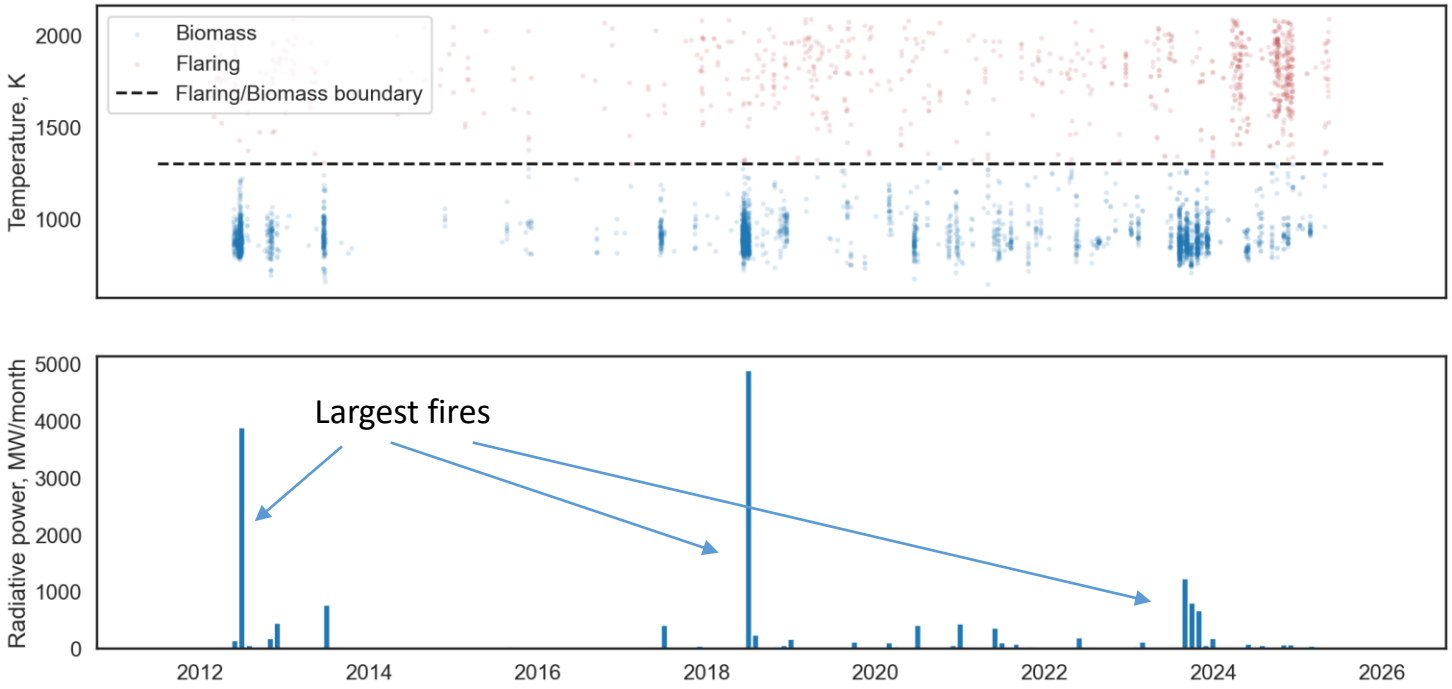
Fires and flares in Nov, 2024



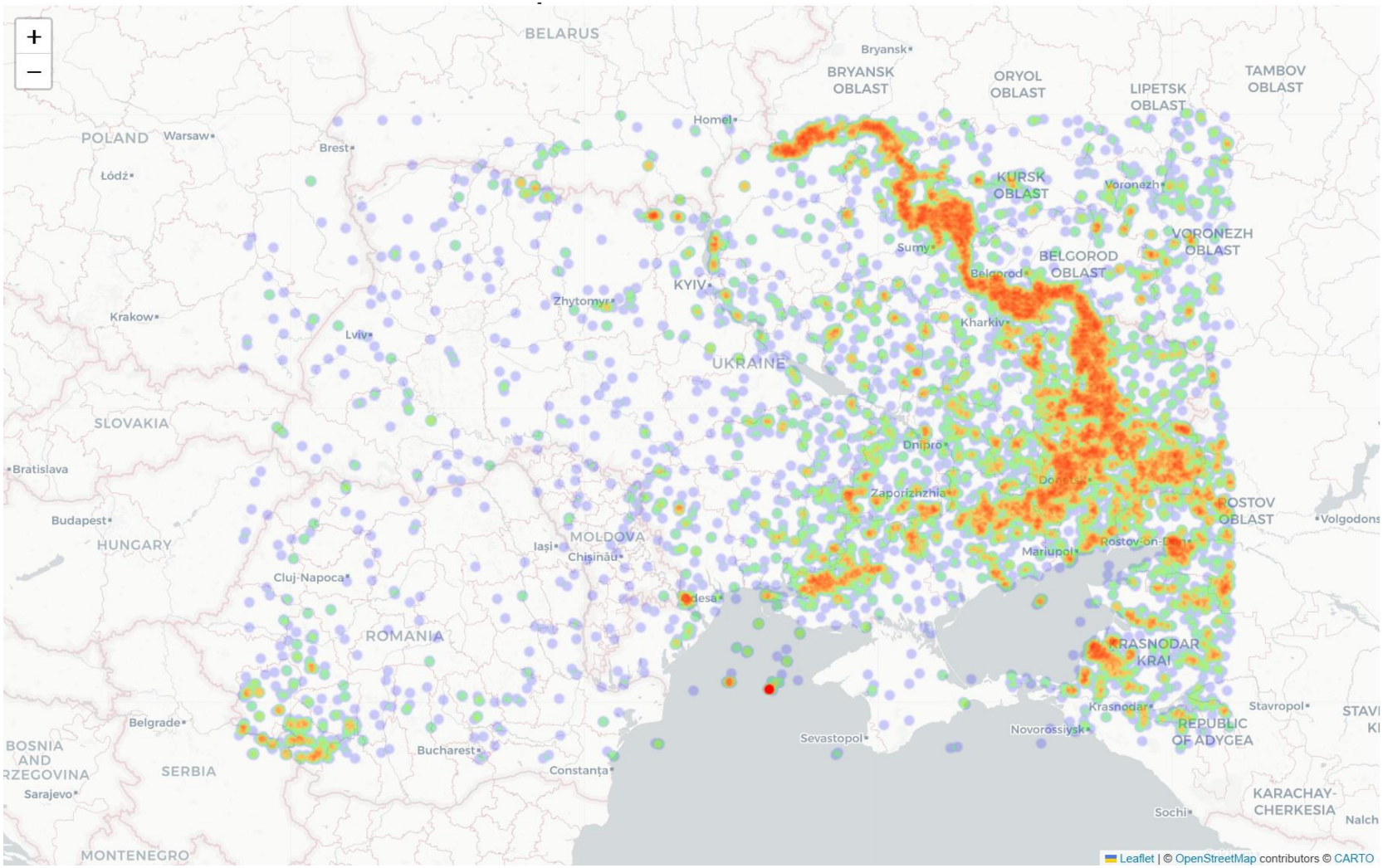
Time history of fires in Southern Colorado

2012-2025 detections

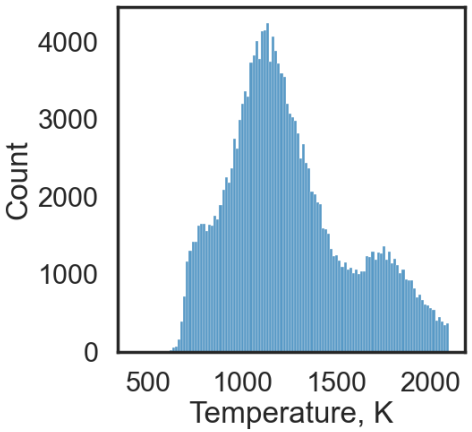


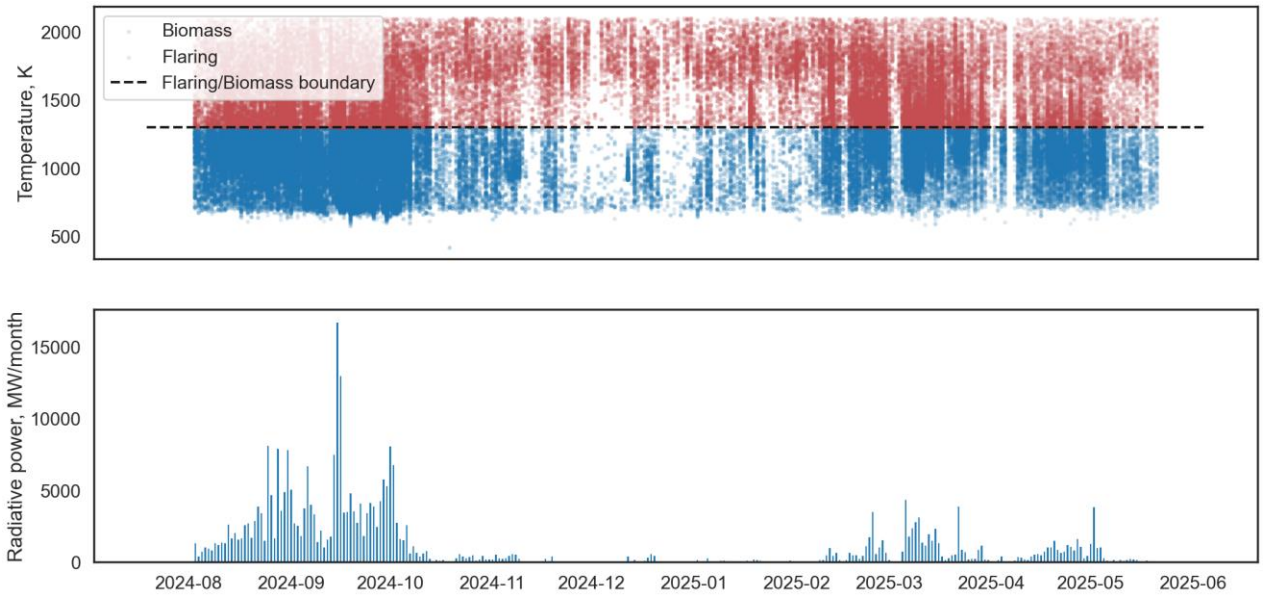


Density map of VNF detections in August 2024 – May 2025

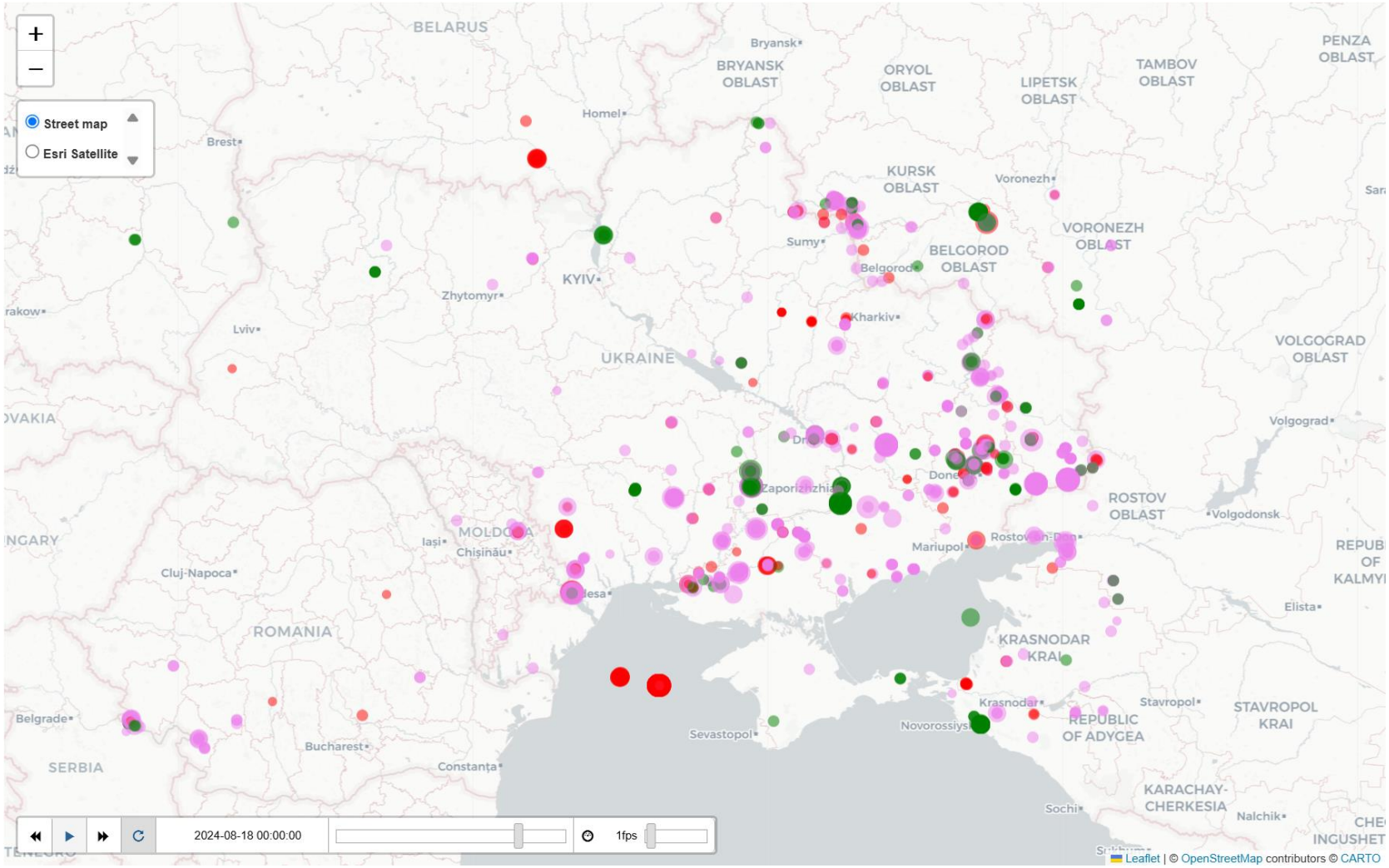


“Untypical” distribution of temperatures in conflict zone





T>1400K red, T>1000K magenta, T > 400K green

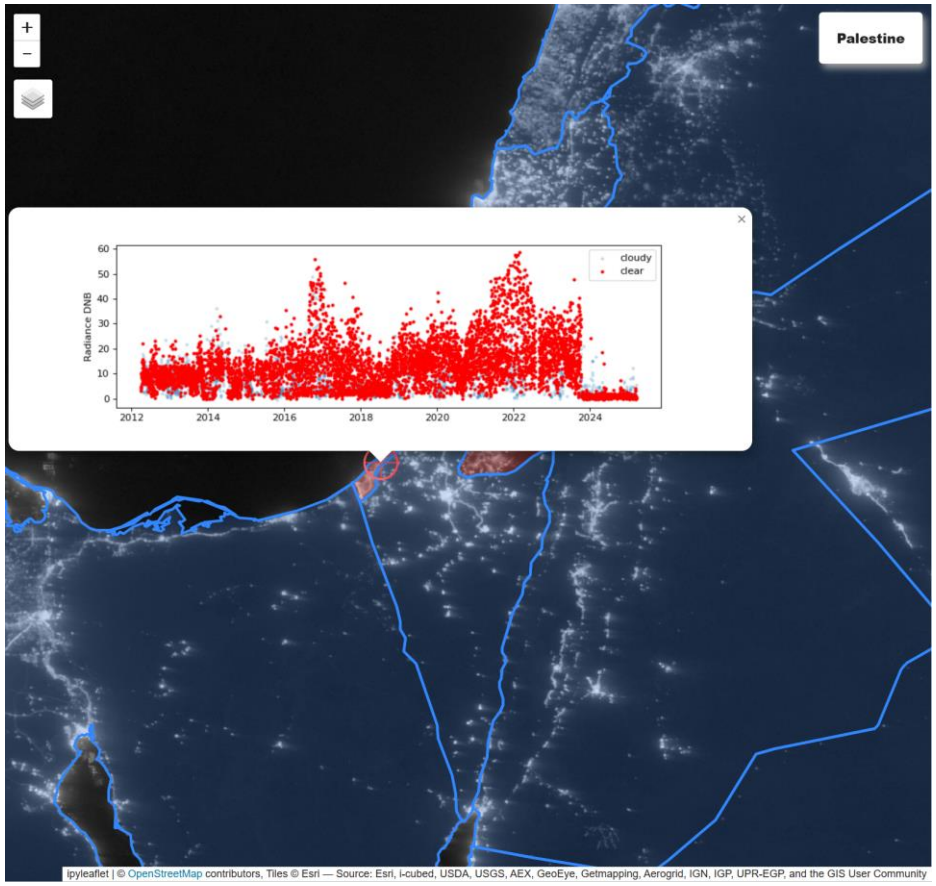


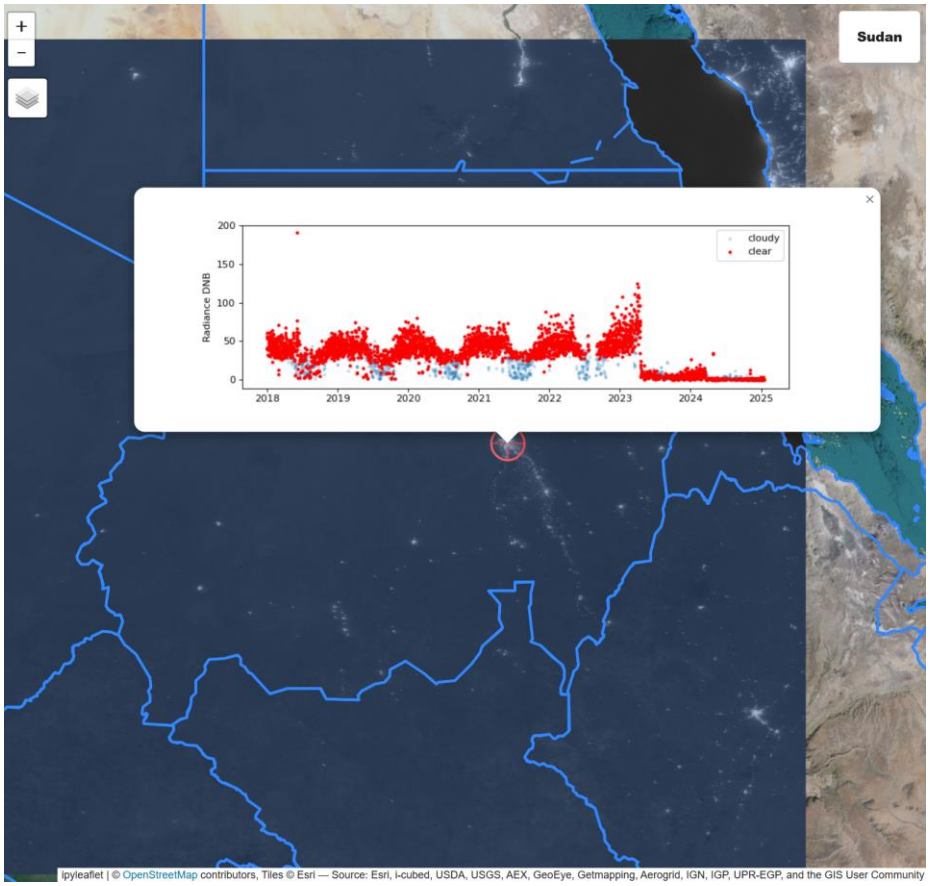
Dimming nighttime lights

Data Acquisition and Processing:

- Nighttime Light Data:
  - The Suomi NPP satellite's DNB sensor was used to collect nighttime light data from 2012 to 2024.
- Pre-War Light Source Identification:
  - The VIIRS Nighttime Lights (NTL) product for 2021 was used to identify pre-war artificial light sources.
- Time Series Data Generation:
  - 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.
- Interactive web tool:
  - To select on the map, visualize and export DNB radiance profiles at any location in Ukraine in the period 2012-2024. The radiances are selected from the spatio-temporal database for all the observed DNB pixels in the vicinity of the cursor location on the map. The time profile can be filtered by cloud state, lunar illuminance, as well as solar and satellite zenith angles.

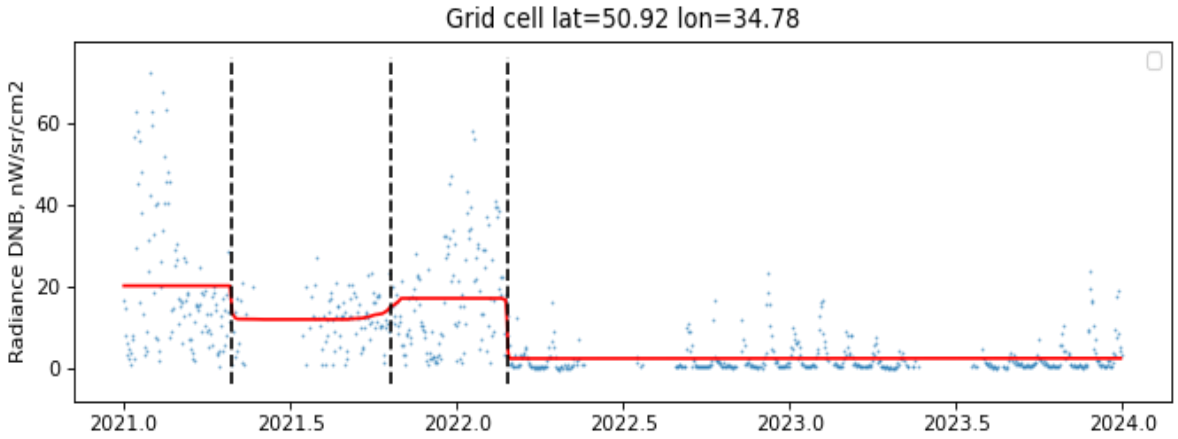
Interactive web tool: street, satellite, NTL maps and DNB profiles

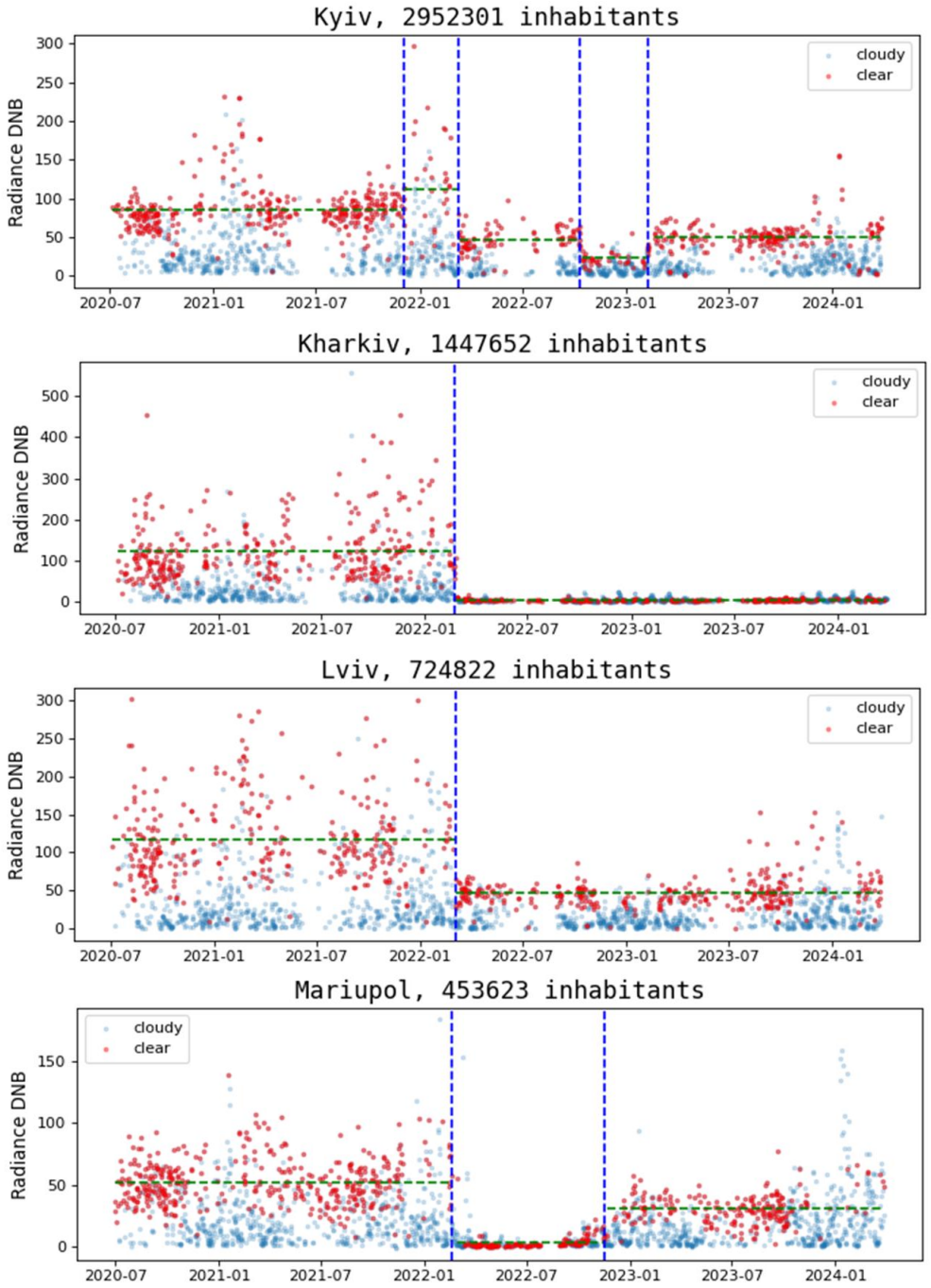




Change point detection and analysis:

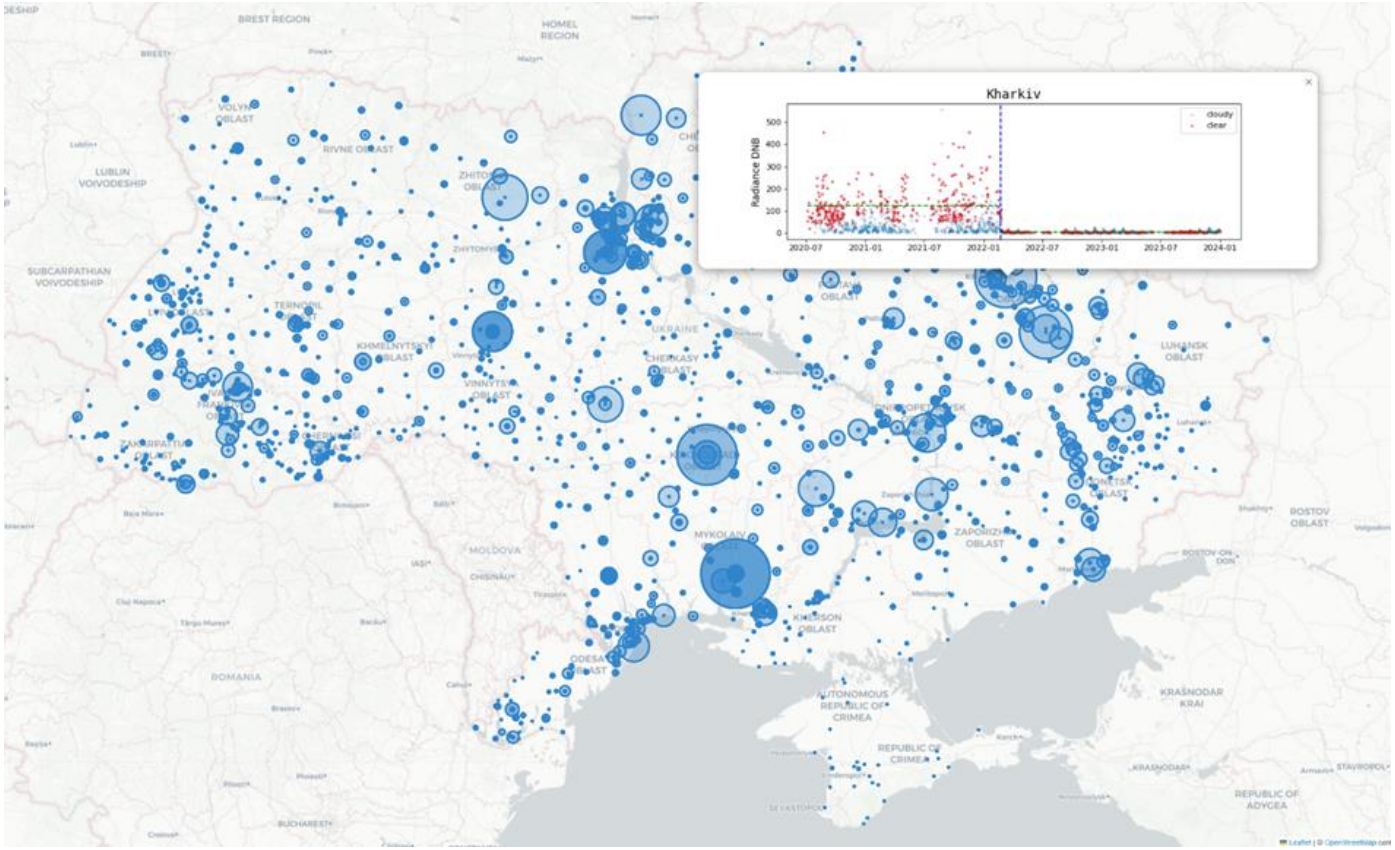
- Time Series Segmentation: To quantify temporal changes in light intensity, the time series data for each grid cell was segmented to identify points of significant change in light intensity.
- Machine Learning Algorithm: We employ a segmented linear regression approach on the time series data for each 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 dates, and the mean radiance for each segment delimited by the change points.
- Example: 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.




Kyiv, 2952301 inhabitants
Kharkiv, 1447652 inhabitants
Lviv, 724822 inhabitants
Mariupol, 453623 inhabitants
Radiance DNB
cloudy
clear
2020-07
2021-01
2021-07
2022-01
2022-07
2023-01
2023-07
2024-01

Interactive web map of all the Ukranian cities with population greater than 10,000 inhabitants.

Radius of the circle centered at city downtown indicates the DLR value. Time history of the city lights with the detected changes are displayed inside the pushpins.



https://eogdata.mines.edu/wwwdata/downloads/ukraine_dimming/Ukraine_city_gt_3k_lights_changes_2021-2023.html

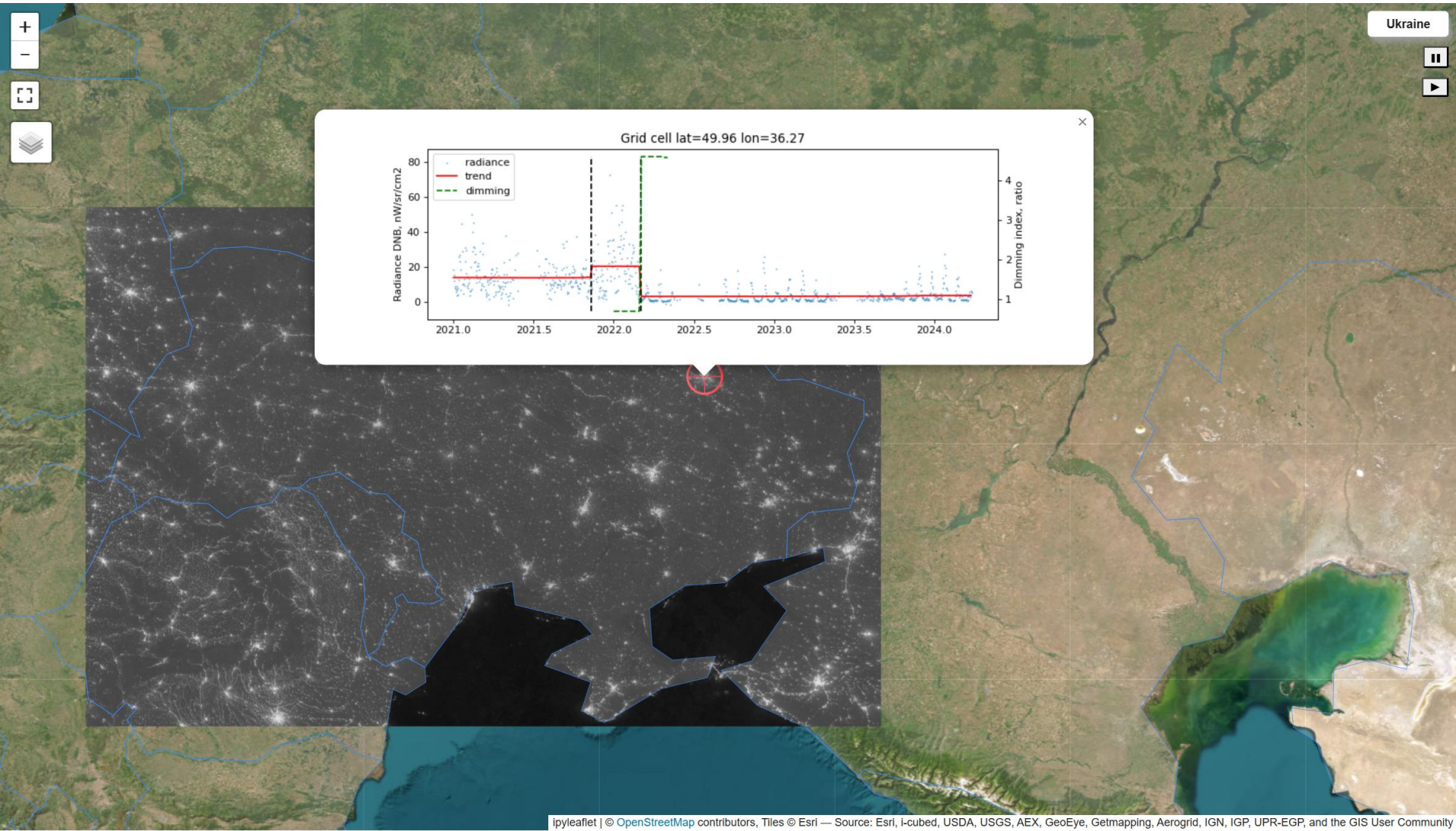
Dimming Lights Ratio (DLR) Calculation:

- 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 DLR is defined as the ratio of mean pre-war radiance to post-war radiance, allowing for the quantification of relative changes in light intensity.

$$DLR(\text{pixel}) = Mean\_Radiance(\text{date} - 1\ \text{year}, \text{pixel}) \,/\, Mean\_Radiance(\text{date}, \text{pixel})$$

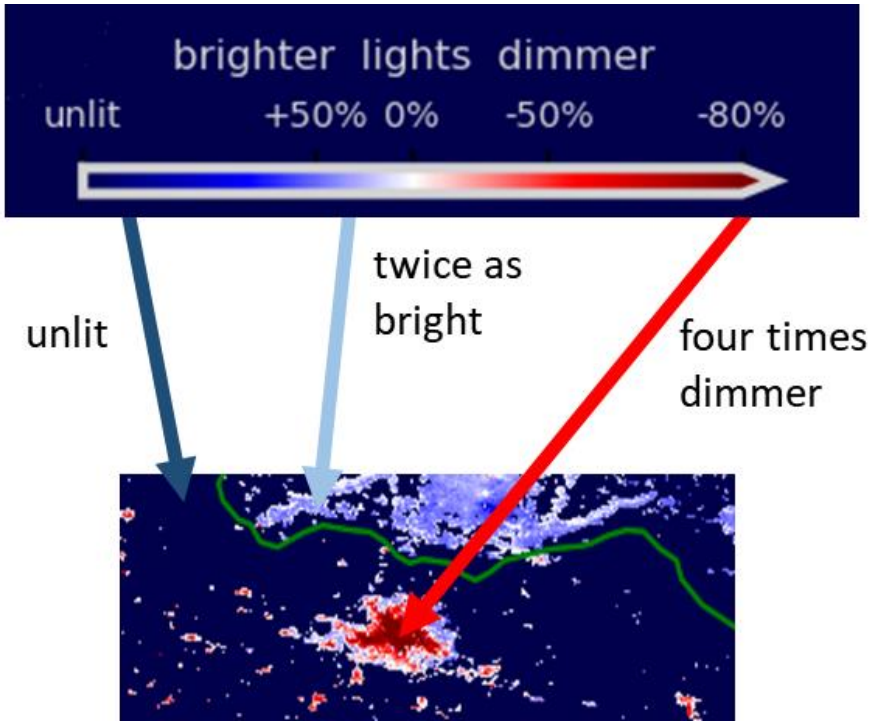
- This ratio facilitates the comparison of relative radiance changes before and after specific dates, accounting for seasonal variations in surface reflectance.
- The underlying assumption is that snow cover and vegetation changes exhibit similar patterns across all years after 2021.
- To calculate the Dimming Lights Ratio for 2023, the reference date in the denominator would need to be shifted back two years instead of one.
- By calculating the DLR daily for each grid cell, a time series of light variation maps was generated (1095 in total).

Dimming Light Ratio profile in Kyiv



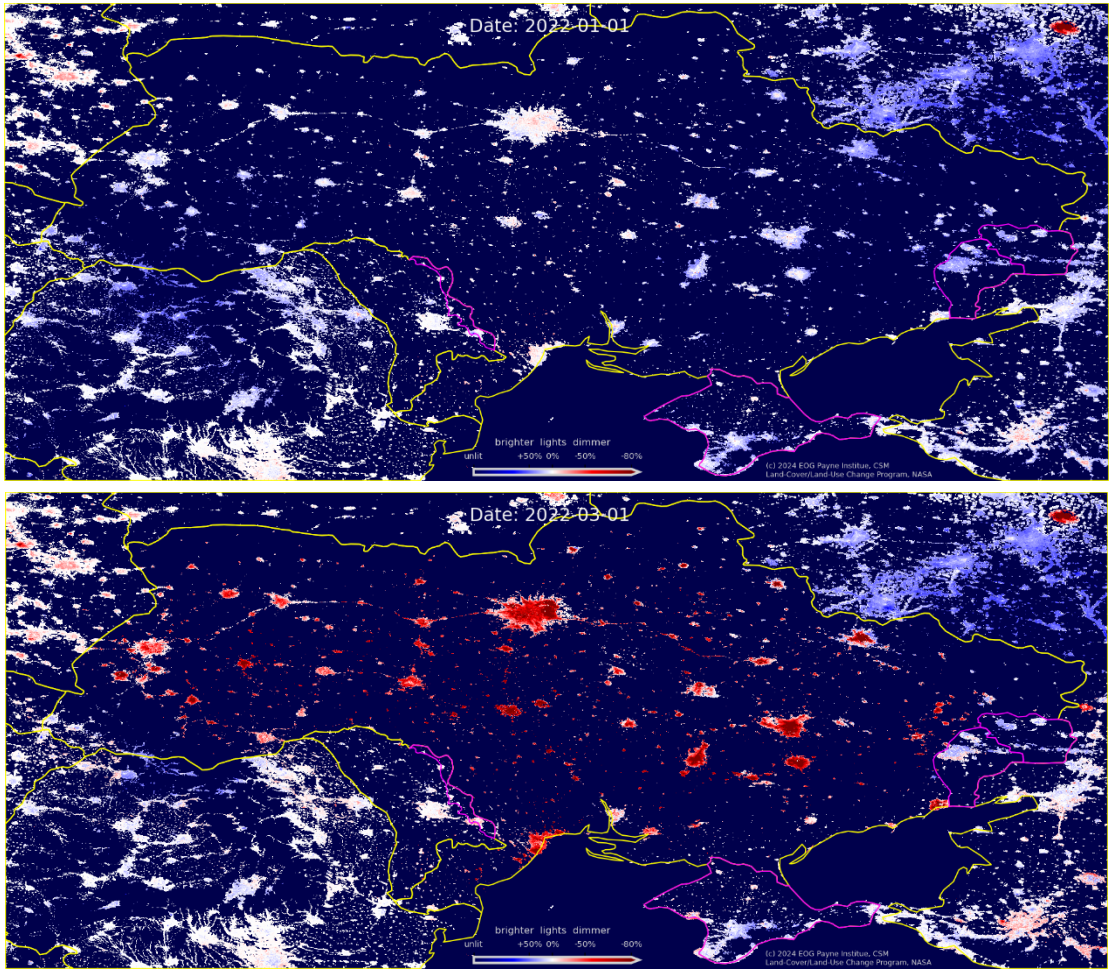
Customized color palette

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.



Dimming Lights Ratio animation:

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



https://eogdata.mines.edu/wwwdata/downloads/ukraine_dimming/Ukraine_movie_bounds_colorbar.mp4

Conclusion

- VIIRS Nightfire (VNF) detections effectively pinpoint significant events (explosions, fires) within conflict zones.
- Temporal profiles of radiative heat and temperature from known infrared emitters clearly indicate changes in industrial activity over time.
- Density maps created from VNF detections vividly illustrate the progression and spatial dynamics of military campaigns.
- Nighttime light observations offer critical insights into the impact of military conflicts on regional infrastructure, economy, and population dynamics.
- The DLR (Dim Light Ratio) metric provides a quantitative assessment of changes in light intensity, enabling robust monitoring and analysis of the evolving conflict situation.
- Future research should investigate correlations between the DLR metric and socioeconomic indicators, such as population displacement and economic shifts, to deepen our understanding of the broader implications of war.