GEO4520

Monitoring shelling activity in eastern Ukraine using MODIS Thermal Anomalies & Fire data

Romain Corseri

November 30, 2023

1 Introduction

Remote-sensing of land surface temperature is actively used for global fire detection, the latter accounting for 25% of global emission of greenhouse gases (Kaufman et al., 1998). On-board NASA's Terra and Aqua polar-orbiting satellites, the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors provide daily Thermal Anomaly and Fire detection product at a ∼1km resolution. Aside the scientific questions related to climate science, the MODIS Fire products have recently been used to monitor violence in war-torn Darfur (Sudan) in 2003 (Bromley, 2010). Artillery shelling, air strikes, violence and looting of populated areas often triggers fires and leave burned scars which are readily detectable in satellite data. Therefore MODIS Fire products could be crucial to monitor violence on civilian population and document war crimes. In this work, we use MODIS Thermal Anomaly and Fire product to try and document shelling activities in two active areas of the front line in eastern Ukraine (Figure 1). Those two areas were subject to different type of war fares: conventional artillery shelling in area 1 and white phosphorus incendiary ammunition in area 2.

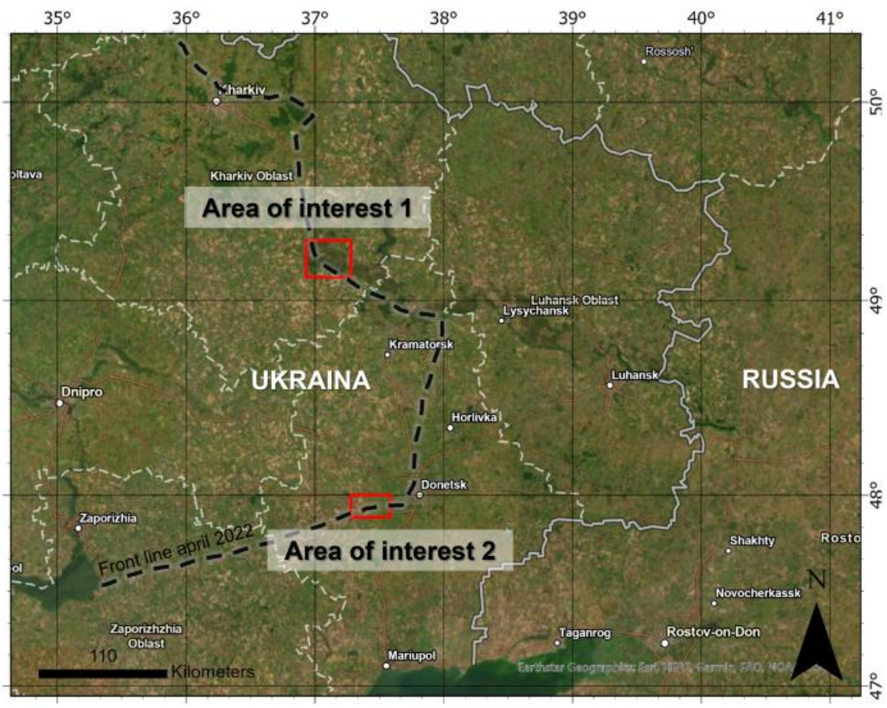

Figure 1: Satellite image of the study area in eastern Ukraine showing the two area of interests (red rectangles) along the front line as per april 2022 (top). Satellite images of a forested area around Izium (Kharkiv Oblast; area of interest 1) and the settlement of Mariinka (Donetsk Oblast; area of interest 2)

This study tackles two main questions: (1) Can the signatures of shelling be detected in MODIS Fire products in eastern Ukraine? (2) Is it possible to distinguish between different type of ammunition with MODIS Fire data? First, we describe the basics of the Fire detection algorithm and introduce the datasets. Then, we analyse the Fire detection data and try to validate them with optical images from Sentinel-2. Finally, we discuss source of errors and the ability of MODIS Fire Radiative Power (FRP) to detect potential use of white phosphorus incendiary ammunition, a prohibited weapon in populated areas under international treaties.

2 Data and Method

2.1 Basics of MODIS fire detection algorithm

The algorithm relies on the assumption that the fire Infra-red (IR) temperatures is above the background temperature variability. Based on fire spectral properties, the algorithm utilizes the 4.0 and 11.0 $\mu.m$ brightness temperatures from the corresponding MODIS channels 21,22 and 31 (Giglio et al., 2016; Giglio et al., 2003; Kaufman et al., 1998). In addition, MODIS channels 1,2,7 and 32 are used for cloud, land-water masking and false alarm rejections (Figure 2).

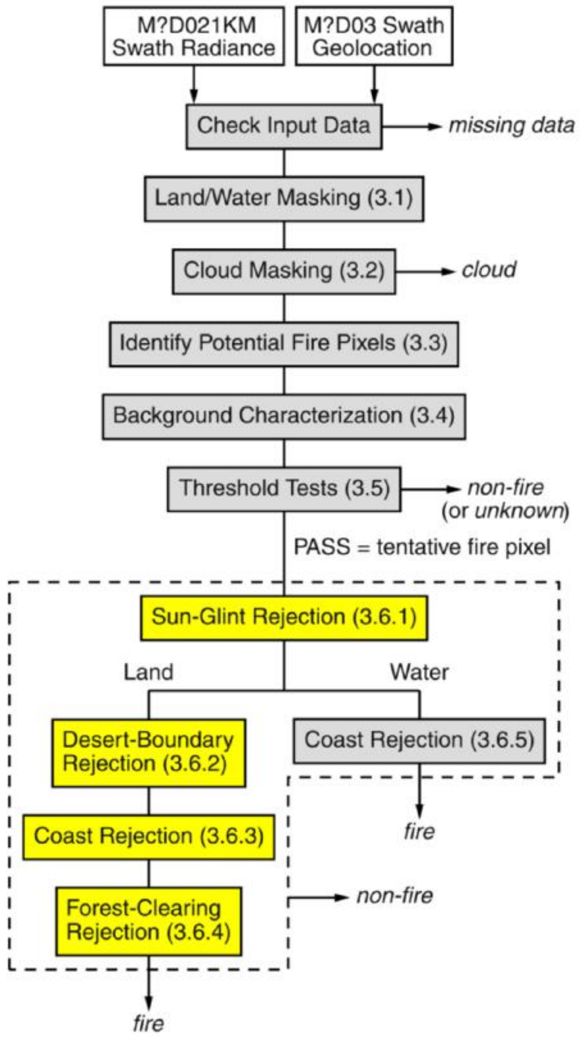

Figure 2: Flowchart depicting the MODIS Fire detection algorithm from Giglio et al. (2016)

Sun-glints are a known source of error for fire detection as they occur at a given satellite-surface-sun geometry. These false alarm tests are performed after the crucial step of the threshold test where the background radiance is statistically evaluated on neighboring pixel using a moving spatial window. The output of the algorithm is the class of the pixel: missing data, water, cloud, non-fire and fire.

For each detected fire pixel, a Fire Radiative Power (FRP) expressed in MW per pixel is computed as

$$FRP \approx (4.34 \times 10^{-19})(T_4^8 - \overline{T_4}^8), \tag{1}$$

where T_4 is the brightness temperatures at 4μm of the fire pixel and $\overline{T_4}$ is the background brightness temperature at 4μm of the non-fire pixel (Kaufman et al., 1998).

2.2 Datasets from Google Earth Engine

The MODIS Fire datasets for area of interest 1 and 2 (Figures 3 and 4) are remotely accessed through Google Earth Engine (GEE) servers. GEE has the advantage of gathering a large amount of open-source remote-sensing data on the cloud, as well as analysis tools accessible through the online Javascript code editor and python libraries. In this work, we use a combination of Javascript codes and Jupyter notebooks to produce and analyse the results. We use the *ee.ImageCollection()* method to extract daily 1km MODIS Thermal anomalies and Fire products for 2022 and Copernicus sentinel-2 optical images for visual validation of the MODIS Fire detection data (Figures 3 and 4).

3 Results

3.1 Forest area around Izium (Donestk oblast)

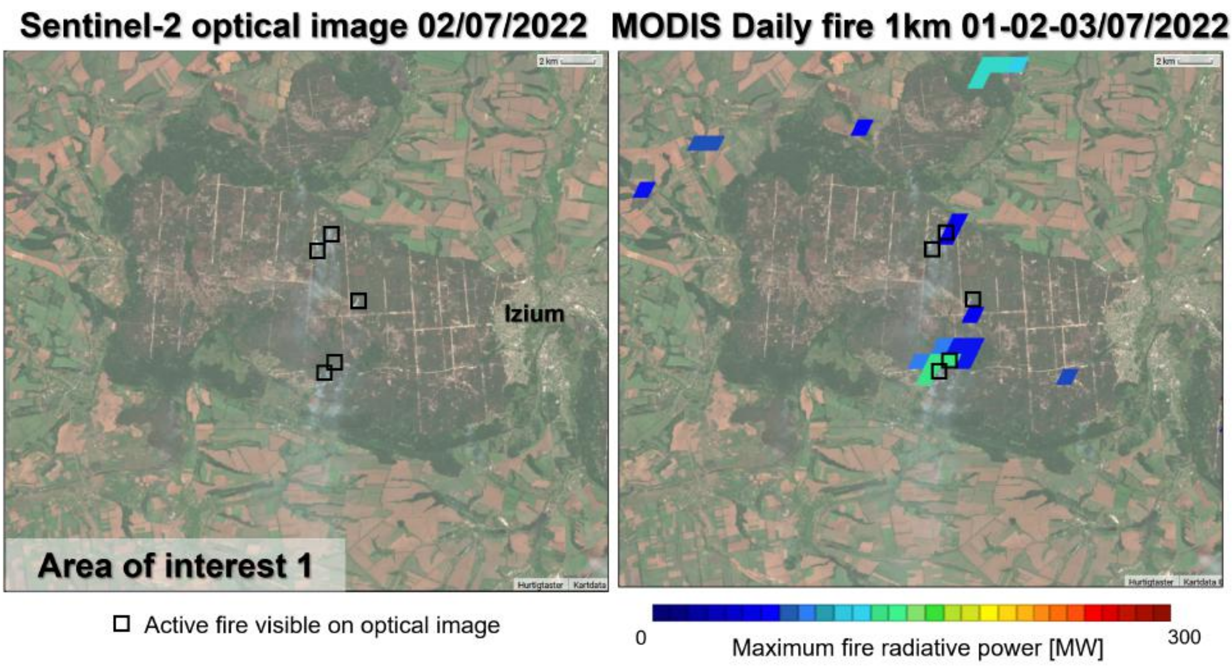

Figure 3: Sentinel-2 optical satellite image taken on 02/07/2022 of area of interest 1 in the Izium area, Karkhiv Oblast (left). MOD14A1.061: Terra Thermal Anomalies & Fire Daily Global 1km level 3 product showing fire radiative power aggregated for 01-02-03/07/2022 in area of interest 1 (right)

On Figure 3, we note that the fire pixels have a diamond shape on the map. The pixel distortion is due to the projection used in MODIS FIRE products. The distortion increases with distance from the Greenwich meridian. Then, we observe that all the visible active fires on the optical images corresponds well to fire pixels detected with MODIS Fire products. However, the exact pixel of the visible fire does not always match with the fire pixel from MODIS but to the neighboring ones. Nine fire pixels that do not match with visible active fires on the 02.07 because they were probably already extinguished on the 01.07 or started on the 03.07. This is confirmed by looking at the number of fire pixel per day in the timeseries (Figure 5). There is a continuous presence of fires on the forest strip from the 30.06 to 11.07 with a peak fire pixel number (29) on the 07.08. This is likely due to intense artillery shelling by the Ukrainian arm forces due to the occupation of the forest trip by the Russian Army from the beginning of June 2022 (https://deepstatemap.live; Figure 5). In the summer 2022, the maximum FRP value (∼70 MW) is observed on the two southernmost active fires on the 02.07. These results shows that forest fires from artillery shells in eastern Ukraine are probably short-lived (not more than a day) and burning at "low" temperature and/or on a limited proportion of the fire pixel surface (details are discussed in the next chapter).

3.2 Marïnka settlement (Donetsk oblast)

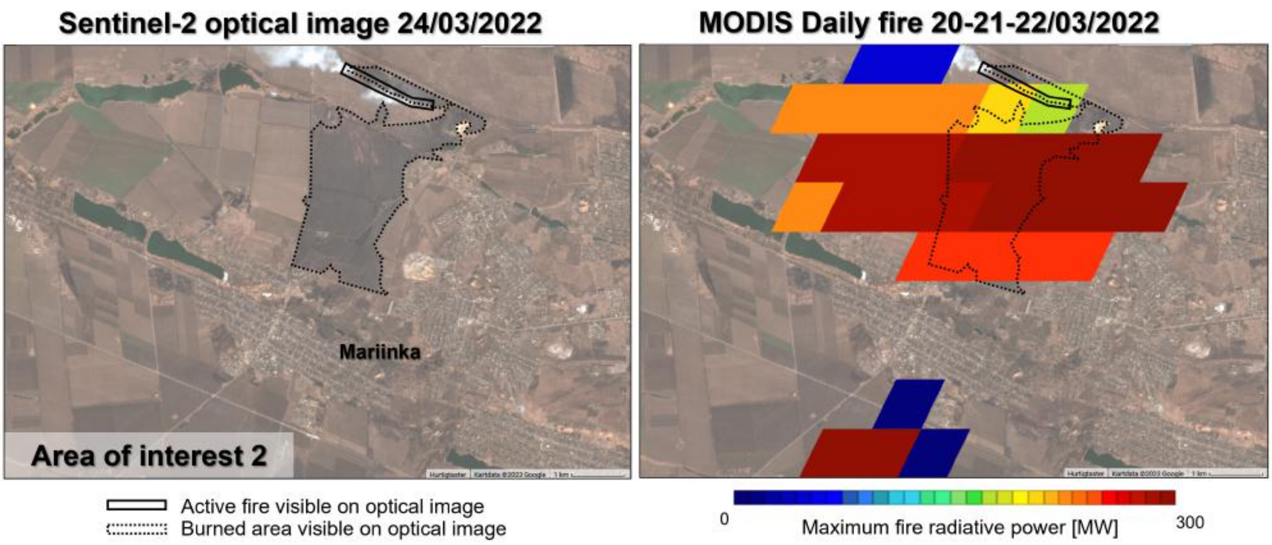

Figure 4: Sentinel-2 optical satellite image taken on 24/03/2022 of area of interest 2 in the Marïnka area, Donetsk Oblast (left). MOD14A1.061: Terra Thermal Anomalies & Fire Daily Global 1km product showing fire radiative power aggregated for 20, 21 and 22.07.2022 in area of interest 2 (right)

In the Marïnka settlement, the number of fire pixels is concentrated on a 5 day period 20.03 - 24.03, with a maximum number 34 fire pixels in surface twice smaller than area 1 (Figures 4 and 5). A visible confirmation is provided by sentinel-2 optical images on the 24.03 showing an active fire front associated with large burned scars on agricultural fields and reaching to the outskirts of the settlement. A maximum FRP of ∼300 MW is observed on 6 fire pixels centered on a large burned crop field to the north of the village. Again, the MODIS Fire product seems to be a relevant tool to monitor intense shelling activities. This period corresponds to advances of the Russian Army at early stages of the invasion and is an evidence of intense fighting in a populated area SW of Donetsk City (https://deepstatemap.live). Interestingly, FRP in Marïnka is 5 times higher than FRP measured in the forest strip in area 1. Furthermore, several reports appeared online on the first use of white phosphorus incendiary ammunition in March 2022 in the russo-ukrainian war.

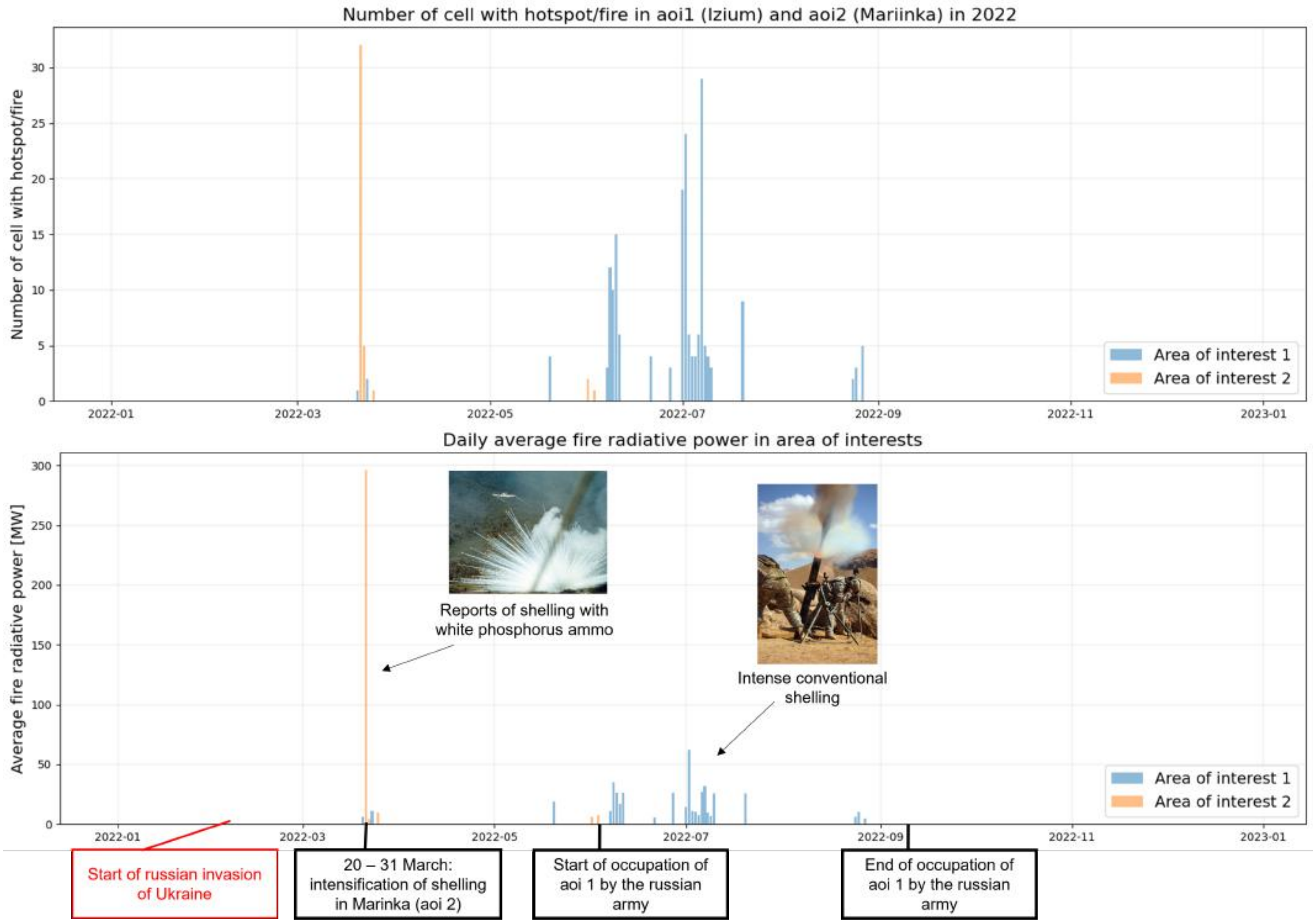

Figure 5: Timeseries showing the daily number of pixel fire in area 1 and area 2 in 2022 (top). Timeseries showing the daily average fire radiative power for area 1 and area 2 in 2022 (bottom)

4 Discussion and conclusion

The results of this study demonstrate that MODIS Fire products can be used to monitor daily shelling activity in the eastern Ukraine front lines. The location of the fires due to shelling in forested and agricultural lands are visually confirmed by Sentinel-2 optical images. We generally find good correspondences between fire pixels and optical images (Figures 3 and 4). However, due to the scanning mode of the MODIS sensors, the fire can be detected on one or two adjacent pixels (Kaufman et al., 1998).

Another source of error could stem from the relatively low brightness temperature saturation of MODIS mid-infrared channels. For example, fires could display little contrast with bright, hot savanna surfaces whose background brightness temperature (Equation (1)) can saturate at mid-infrared wavelengths (Giglio et al., 2003). In our case, neither forest strips in the Ukrainian summer (area 1) nor agricultural fields background temperatures just after snow melts in March (area 2) are likely to saturate MODIS infrareds channels.

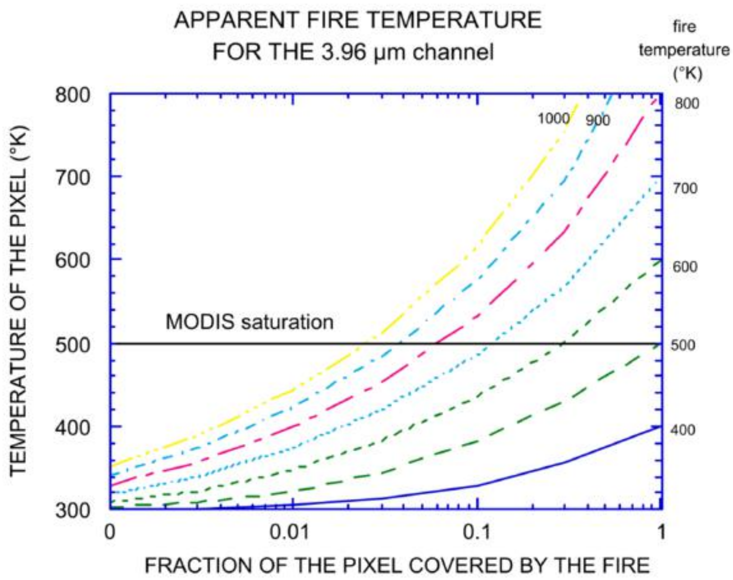

Figure 6: Apparent temperature of the fire pixel for the 4 μm MODIS channel. Figure modified from Kaufman et al. (1998)

Then comes the question of whether MODIS Fire products can be used to distinguish between different types of ammunition, in our case, white phosphorus and conventional shells. Several online articles reported the use of white phosphorus incendiary shells in March 30 to 31 in the Marïnka settlement. It is interesting to note that our observations (Figure 5) indicate that no fire pixels are detected in those two days but rather on march 20 and 21. Here, we find that MODIS Fire products can be used to check and correct for false or inaccurate reports.

Our MODIS Fire data shows a five-fold maximum FRP value increase in Marïnka fire pixels compared to Izium forest fires (Figures 3 to 5). Figure 6 summarizes simulation results from Justice et al. (2006) showing the dependence of the fire pixel brightness temperature to the actual fire temperature and the area of the pixel covered by fire, for the 4 μm MODIS channel. Considering that white phosphorus can burn at very high temperature (up to 2800 K), it is theoretically possible to distinguish between fire pixels from conventional and white phosphorus shells under the saturation temperature of the 4 μm MODIS channel and for an equivalent fire area. In practise, this is much more complicated because the 4 μm MODIS channel is sensitive to both the thermal energy emitted from smoldering and flaming (Ward et al., 1996). The rate of combustion of grassland fires is higher than forest fires, the latter having a much more pronounced smoldering phase (Kaufman et al., 1998). Following this reasoning, it is puzzling that FRP values from the forest fires in area 1 are lower than the ones from Marïnka on agricultural lands. All in all, we cannot decisively conclude that MODIS FIRE products can document the use of white phosphorus ammunition in Marïnka but we foresee that the MODIS products have a great potential in documenting potential war crimes and violence in conflict area. More research and laboratory testing are required to investigate the characteristics of fire due white phosphorus incendiary shells.

References

Bromley, L. (2010). Relating violence to modis fire detections in darfur, sudan. International Journal of Remote Sensing, 31(9), 2277–2292. https://doi.org/10.1080/01431160902953909

Giglio, L., Schroeder, W., & Justice, C. O. (2016). The collection 6 modis active fire detection algorithm and fire products. Remote Sens Environ, 178, 31–41. https://doi.org/10.1016/j.rse.2016.02.054

Giglio, L., Descloitres, J., Justice, C. O., & Kaufman, Y. J. (2003). An enhanced contextual fire detection algorithm for modis. Remote Sensing of Environment, 87(2-3), 273–282. https://doi.org/10.1016/s0034-4257(03)00184-6

Justice, C., Giglio, L., Boschetti, L., Roy, D., Csiszar, I., Morisette, J., & Kaufman, Y. (2006). Modis fire products - algorithm technical background document (Report).

Kaufman, Y. J., Justice, C. O., Flynn, L. P., Kendall, J. D., Prins, E. M., Giglio, L., Ward, D. E., Menzel, W. P., & Setzer, A. W. (1998). Potential global fire monitoring from eos-modis. Journal of Geophysical Research: Atmospheres, 103(D24), 32215–32238. https://doi.org/10.1029/98jd01644

Ward, D. E., Hao, Y.-T., & Susott, R. A. (1996). Effect of fuel composition on combustion efficiency and emission factors for african savanna ecosystem. Journal of Geophysical Research: Atmospheres, 101, 23569–23576. https://doi.org/10.1029/95JD02595