The use of remote sensing data for the fire damage assessment in a burnt area in Cyprus

Maria Prodromou[a,b*] , Ioannis Gitas[c], Kyriacos Themistocleous[a,b], Argyro Nisantzi[a,b], Rodanthi-Elisavet Mamouri[a,b], Dragos Ene[a], Chris Danezis[a,b], Johannes Bühl[d], Diofantos Hadjimitsis[a,b]

a Department of Civil Engineering and Geomatics, Cyprus University of Technology, Limassol, Cyprus
b ERATOSTHENES Centre of Excellence, Limassol, Cyprus
c Department of Forestry, Laboratory of Forest Management and Remote Sensing, Aristotle University of Thessaloniki
d Leibniz Institute for Tropospheric Research, Leipzig, Germany

ABSTRACT

Forest ecosystems are among the most important natural resources on the planet and play a key role in the global carbon budget. Despite the enormous importance of forests to the entire planet, these ecosystems are affected by a variety of disturbances. One of the disturbance types is represented by fires. Cyprus is located in Eastern Mediterranean, which is an area where forest fires frequently occur, especially during the summer period. This study is mainly focused on burned area mapping and damage assessment on land surface and air pollutants for the case of the Arakapas fire in Cyprus which occurred on 3rd of July in 2021. For the purposes of this study, the satellite images acquired from Sentinel-2 were used for the burnt area mapping and the fire severity estimation based on the dNBR (difference Normalized Burn Ratio) spectral index, and other ancillary datasets were used for the damage assessment. Furthermore, on the morning of the 5th of July, due to the change of wind direction, the smoke travelled from the centre of the island to the southwest, and it was detected by the multiwavelength Raman lidar, installed in Limassol. Thus, the optical properties of the smoke plume retrieved from the lidar are presented. The PollyXT-CYP lidar system of the ECoE, observed multiple layers between 500 m and 2.5 km originating by the burned area northeast to Limassol. The depolarization ratio of 5-8% and lidar ratio of 45sr indicate mixtures of local soil dust and fresh smoke in the lower troposphere. . Keywords: Damage assessment, burned area, fire severity, air pollution, earth observation, Sentinel-2, Copernicus

1. INTRODUCTION

Forests have a vital role for the Earth, and it is important to determine their status both strategically and tactically. In recent decades, forest monitoring approaches in a wide range such as, timber production, environmental protection, biodiversity conservation, forest fire prevention, post-disturbance monitoring, wilderness, and open spaces etc. have been improving continuously and remote sensing is increasingly used for the forest monitoring[1].On field measurement methods are important sources of information. However, in cases of monitoring critical forest measurements on a larger scale, the use of these methods is limited. Because of this, forest monitoring has progressed to the use of remote sensing (space and airborne) because can provide fast, accurate and in high resolution information about study area. These technologies have favoured forest monitoring in terms of capacity, scale and detail[2] . Some of the most common types of Earth Observation (EO) data include multispectral and synthetic aperture radar (SAR) systems. Apart from that, are considered also the light detection and ranging (LiDAR) technologies, which provide the tools to assess forest characteristics and can be used to monitor and quantify changes in forests over time[3]. Forest disturbances like wildfires, insect outbreaks (e.g Thaumetopoea pityocampa) etc. are key factors that affect the dynamics of forest ecosystems. For example, they affect forest species composition, structure, above- and below-ground carbon storage[4], forest regeneration and successional dynamics[5],as well as cycle of water and energy[6]. Because of this, it is important to have a continuous inventory of forest ecosystems. Wildfires play a key role in the ecology of many ecosystems, and they have the potential to be beneficial and harmful at the same time [7] [8]. Statistically speaking, wildfires occurs over various parts of the world more than one thousand times every year, making them one of the most frequent natural geophysical disasters. According to recent studies, each year the global burned area is estimated based on coarse satellite images at around 3.5-5 million km^2 [9,10]

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The burn severity determines the degree of the environmental changes which are observed after the fire event and depends by the ecological dynamics that constitute the fire [11]. The assessment of a fire severity is essential, especially for the management strategies. These strategies addressed both ~~the~~ forest regeneration and its recovery [12,13]. The degree of environmental disturbance after a fire event can be effectively assessed using multispectral indices. Multispectral indices are derived from different spectral bands. For example, the Normalized Burn Ration (NBR) is computed as the ratio between the difference from reflectance of near-infrared (NIR) and short-wave infrared (SWIR) bands and the sum of the reflection from the NIR and SWIR bands, as expressed in **Error! Reference source not found.** [14,15]. Considering NIR and S WIR spectral regions, these ratios are less sensitive to atmospheric contamination. Furthermore, they measure vegetation removal, charcoal deposition and reduction of canopy moisture and canopy shadow. By comparing to healthy vegetation, such processes result in reduced NIR and higher SWIR post-fire respectively[16].

This study is mainly focused on burned area mapping and damage assessment on land surface and atmosphere for the case of the Arakapas fire in Cyprus which occurred on 3^{rd} of July 2021. More specifically, this study aims i) to estimate the total burned area and the burn severity based on the dNBR spectral index using Sentinel-2 satellite data, ii) to investigate the affected buildings, and iii) to estimate the affected vegetation types and iv) to estimate the effects on air quality using the Raman lidar system of the Eratosthenes Centre of Excellence (ECoE).

2. METHODOLOGY

2.1 Study Area

Cyprus is located in the Eastern Mediterranean, an area where forest fires frequently occur, especially during the summer period as shown in Figure 1 **Error! Reference source not found.**. The reason for this is represented by the high temperatures, prolonged drought periods, strong winds, the configuration of the ground and extremely flammable vegetation. Forest fires are considered a major and persistent threat to the forests of Cyprus.

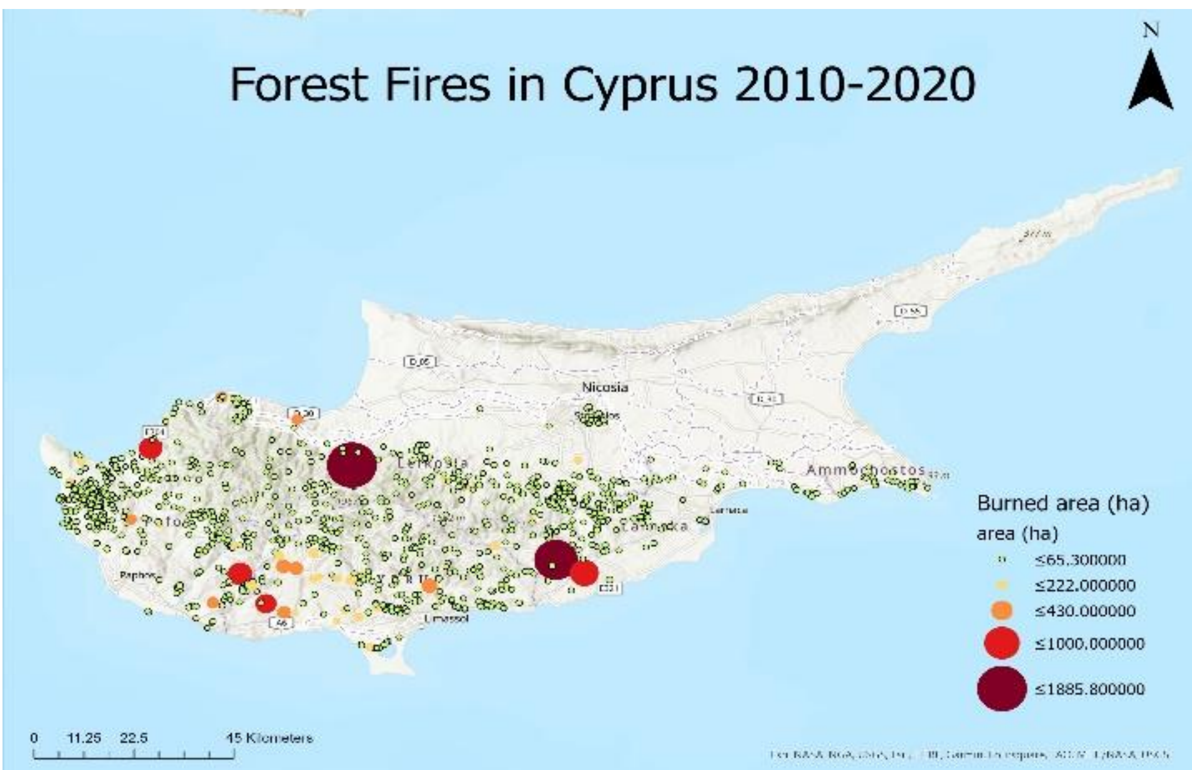

Figure 1 Fire events recorded by the Forest Department of Cyprus from 2010-2020. The size of each point is according to the total burned area per fire event.

The fire event near to the Arakapas village in Cyprus (the central coordinates: 35°N, 33°E). The burned area is situated at altitude range between 351-1194 m as shown in the map in Figure 2, which is derived from EU-DEM. This product is a hybrid one, based on SRTM and ASTER GDEM data fused by a weighted averaging approach. Based on Prodromou et al.2023 [17] in a radius of 3 km there are 22 cultural heritage sites within a 3-kilometer radius sites and is designated as a special aesthetic value of the Troodos Mountain range to the Southwest Shores, and is included in the Troodos UNESCO global geo-park, which characterizes it as a natural heritage landscape.

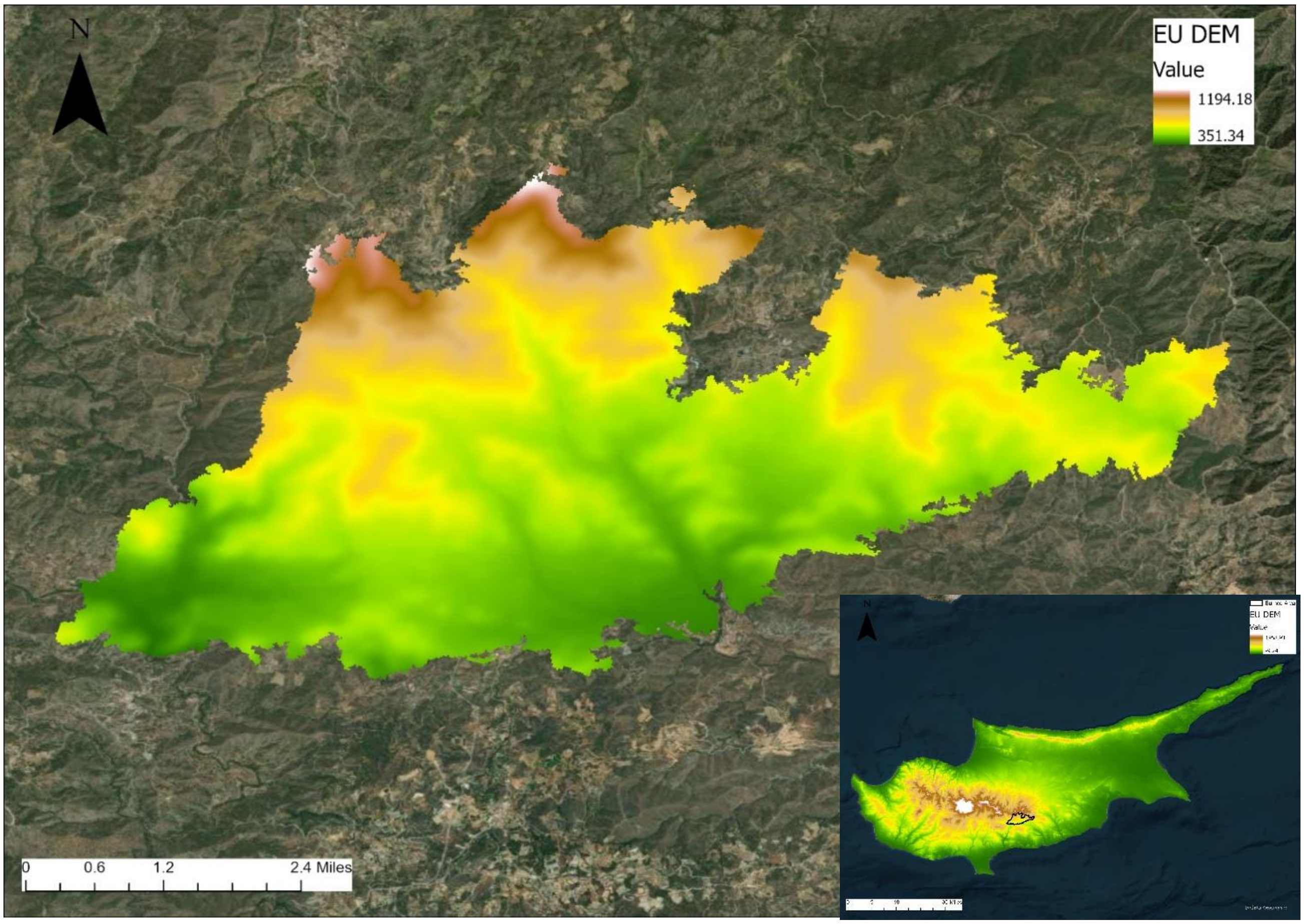

Figure 2 European Union Digital Elevation Model (EU-DEM) v1.1, a hybrid Shuttle Radar Topography Mission digital elevation model (SRTM), and ASTER Global Digital Elevation Map (ASTER GDEM) data fused by a weighted averaging approach over the area of interest.

2.2 Material and Methods

The methodology used in this study is featured in Figure 3 and explained in detail below.

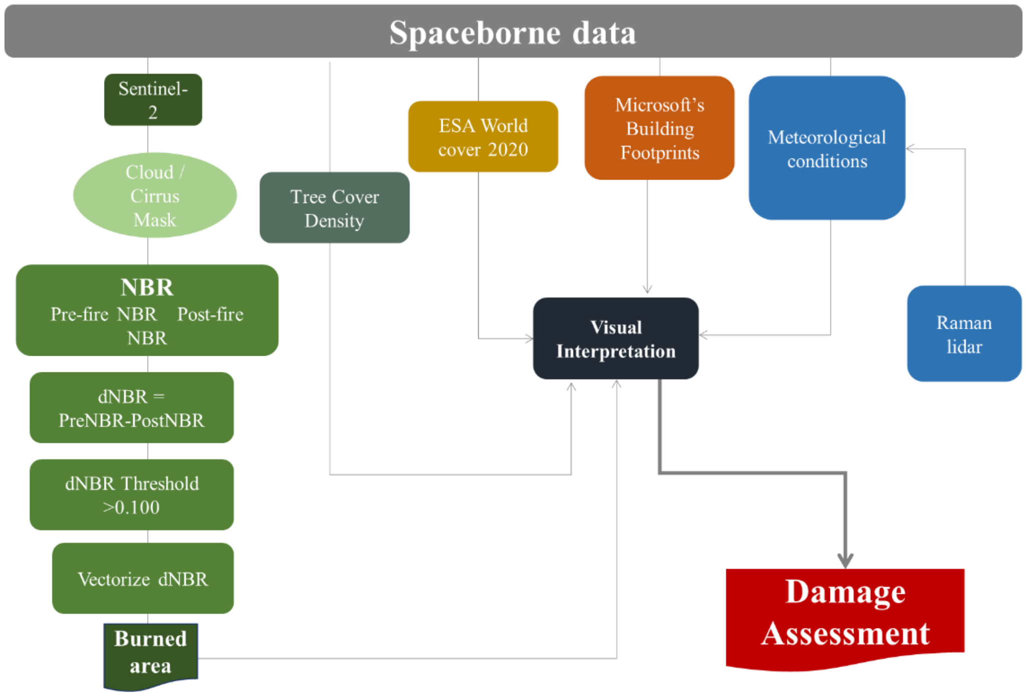

Figure 3 Flowchart of the purposed methodology.

In the study a pair of cloud free Sentinel-2 images were taken before (2/7/2021) and after (27/7/2021) the fire event. The data was used for the development of the dNBR (difference Normalized Burn Ratio). The dNBR spectral index obtained by **Error! Reference source not found.** After the estimation of the dNBR index, the pixel values were classified based o n the thresholding technique according to the severity levels.

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \qquad (1)$$

$$dNBR = NBR_{pre} - NBRpost$$

Table **1** proposed by the United States Geological Survey (USGS) and. The next step involves selecting pixels with dNBR values greater than 0.100 (or 100 - scaled by 1000) to create a mask that isolates the burned area and after that the selected pixels were vectorized in order to estimate the total area of the burned region.

Table 1 Fire severity classes based on USGS thresholds.

Severity level	dNBR range (scaled by 1000)
Enhanced Regrowth, High	-500 to -251
Enhanced Regrowth, Low	-250 to -101
Unburned	-100 to +99
Low	+100 to +269
Moderate-Low	+270 to +439
Moderate-High	+440 to +659
High	+660 to +1300

In order to investigate the effects of fire on vegetation type, the ESA WorldCover for 2020 was used and the area for each land cover type was estimated. ESA WorldCover[18] provides the first global land cover products for 2020 and 2021 at 10 m resolution. These data were developed and validated in near-real time based on Sentinel-1 and Sentinel-2 data. The land cover map contains 11 land cover classes and independently validated with a global overall accuracy of about 75%. Furthermore, the Tree Cover Density data (expressed in the range of 0–100%), obtained from the Copernicus Land Monitoring Service, with a spatial resolution of 10 meters and dated 2018, was used. In addition, Microsoft's Building Footprints were used in order to investigate the number of buildings which were affected by fire and specifically the number of buildings per severity class was also estimated. Microsoft's Building Footprints[19] dataset now contains data on 1.04B buildings around the world from Bing Maps imagery between 2014 and 2022 including Maxar, Airbus, and IGN France imagery. The building footprint data is created by Microsoft by AI detection of buildings from satellite imagery. Due to atmospheric conditions, in the morning of the 5th of July, due to the change of wind direction, the plume from the fires travelled from Arakapas region to the south-west, and reached Limassol. Here, the Cyprus Atmospheric Remote sensing Observatory (CARO) of the Eratosthenes Center of Excellence is placed. The plume was detected using the Raman lidar of CARO, the plume being detected al altitudes of 0.5 – 2.5 km. The PollyXT-CYP lidar system of the Eratosthenes Centre of Excellence was used to measure air pollution resulting from the fire event and ERA5 was used to monitor wind directions.

3. PRELIMINARY RESULTS

3.1 Burn Severity Estimation

The area affected by the fires was identified by the dNBR index. The spatial distribution of the dNBR, is shown in the Figure 4. According to the severity levels
Table **1** proposed by the United States Geological Survey (USGS), a high dNBR value indicates a more severe fire and values near to zero or negative values indicates unburned decreased vegetation productivity subsequent to a fire. The total burnt area was approx. 42 km^2 and the burned area per village is presented in the following chart.

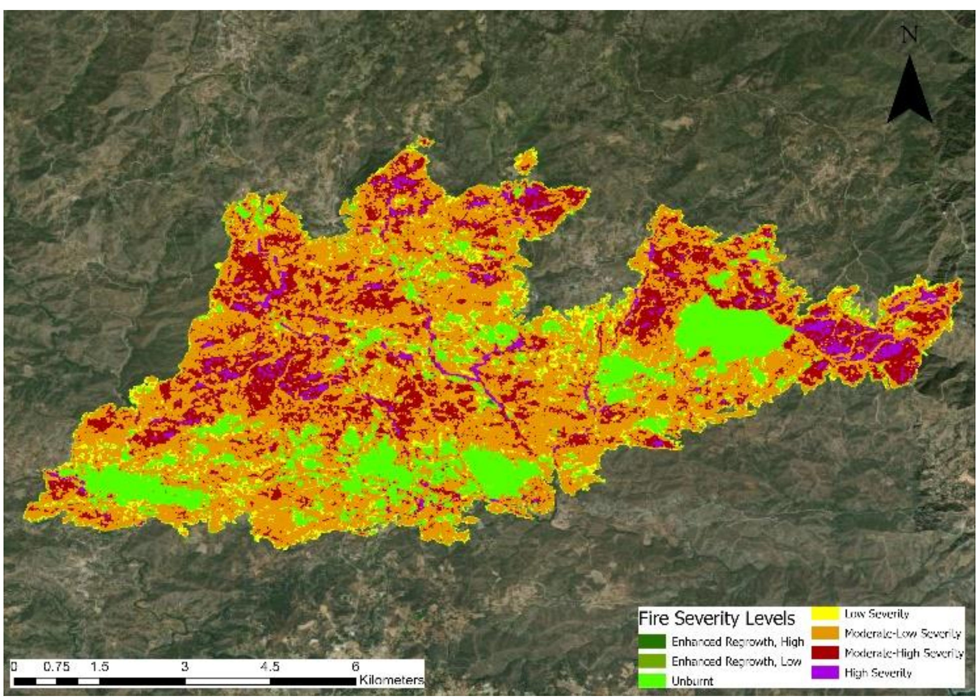

Figure 4 Spatial distribution of the dNBR spectral index based on Sentinel-2 data at 10m resolution.

The land cover map derived from ESA WorldCover contains 11 land cover classes: tree cover, built-up, shrubland, snow and ice, grassland, cropland, bare/sparse vegetation, moss and lichen, herbaceous wetland and mangroves and permanent water bodies. Based on the results derived from ESA WorldCover 2020 dataset in this area, the land cover is characterized mainly by shrublands, grasslands and tress and the built-up areas hold a small percentage Figure 5.

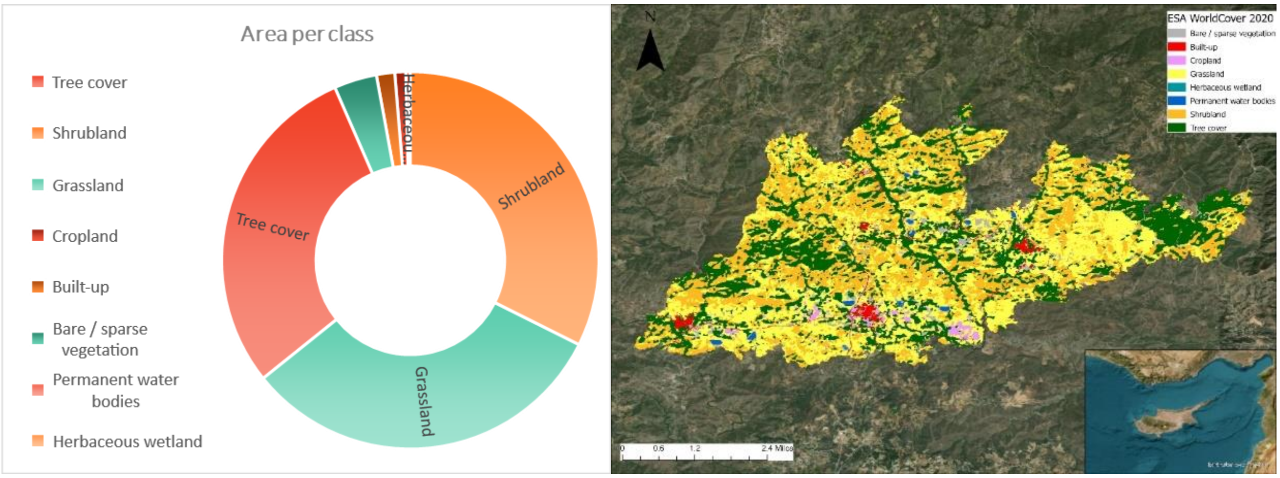

Figure 5 (a) Area per class and (left) Spatial distributions of the land cover types in burned area from ESA World Cover at 10m resolution (right)

The Tree Cover Density 2018 by Copernicus Land Monitoring Service product provides the status layers of the tree cover density level in the range of 0–100%. Based on this data, the results derived from the land cover type were confirmed, where most of the burned area was characterized by shrublands and grasslands. Additionally, based on the tree cover density, the area is mainly characterized by low tree cover density Figure 6.

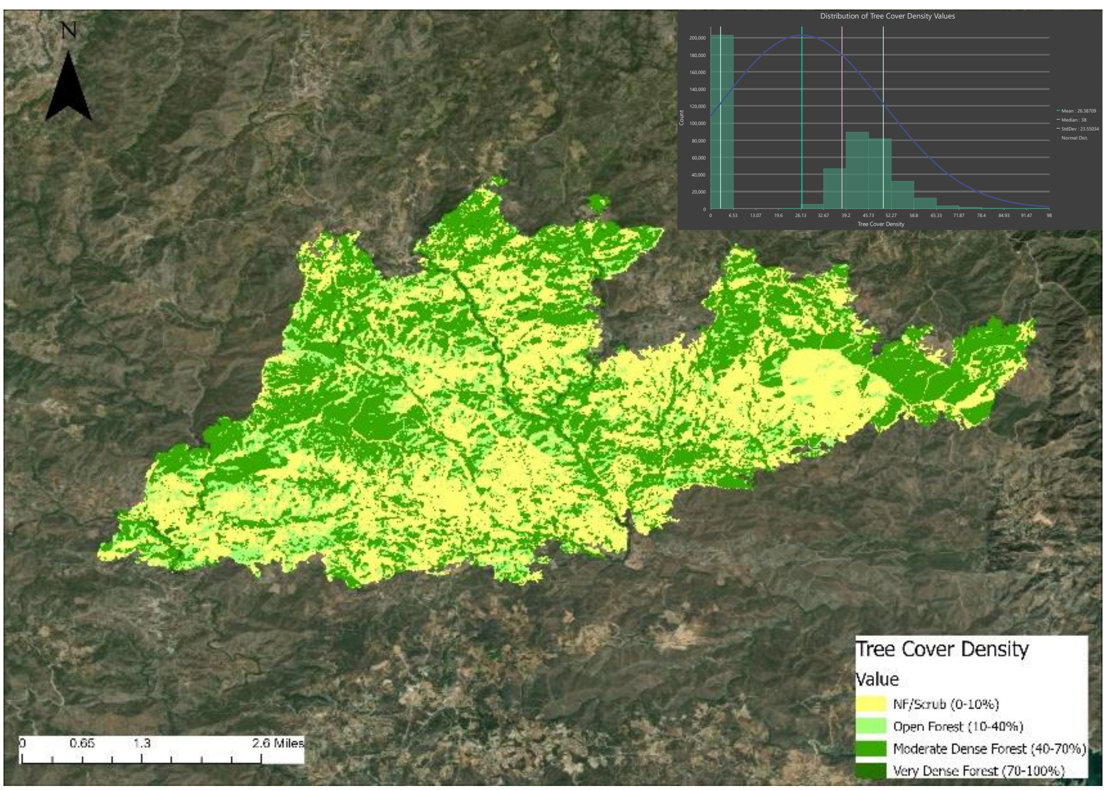

Figure 6 Tree Cover Density 2018 derived from Land Copernicus.

3.2 Buildings

The Global ML Building Footprint can be used to create a low-cost method to assess the number of affected buildings during the fire event. In order to assess the damage on the buildings, two indicators were defined, the number of affected buildings in the total burned area and the number of buildings per class severity Based on this dataset the burned area includes 1954 buildings but comparing with the burned severity classes 699 buildings are distributed in severity classes from low to moderate high. In high severity class there are no buildings. In Figure 7 are presented in detailed the number of buildings in each class.

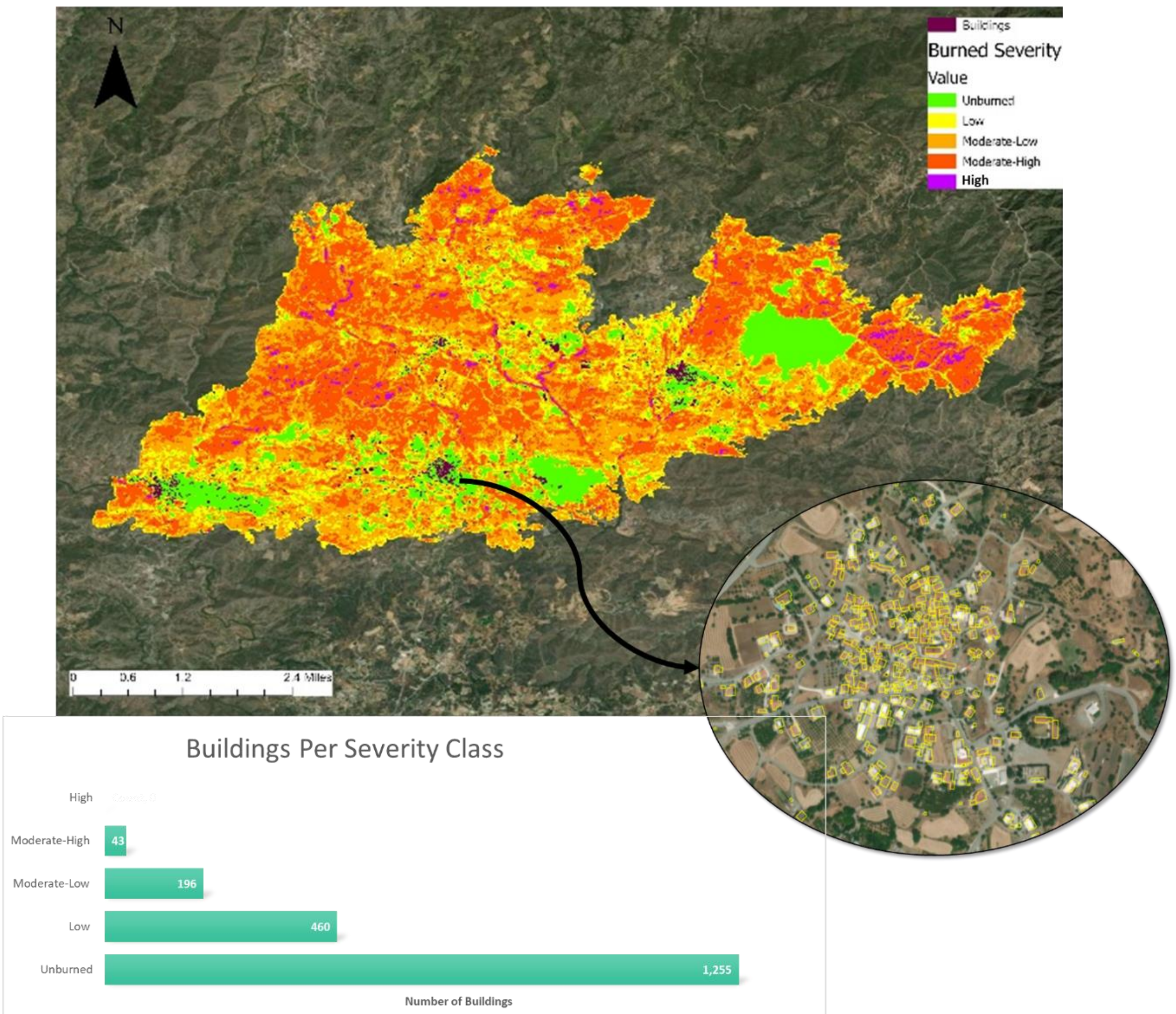

Figure 7 Buildings derived from Global ML Building Footprint per severity class.

3.3 Air Pollution

From ERA5[20] hourly data on single levels, it can be seen that only in the morning of 5 July, between 2-5AM the wind direction was from the north-east to the south-west, meaning the fire plume could travel from Arakapas towards Limassol, where is located the Eratosthenes CoE the PollyXT Raman lidar, and could be detected by it, as is shown in the animation below Figure 8.

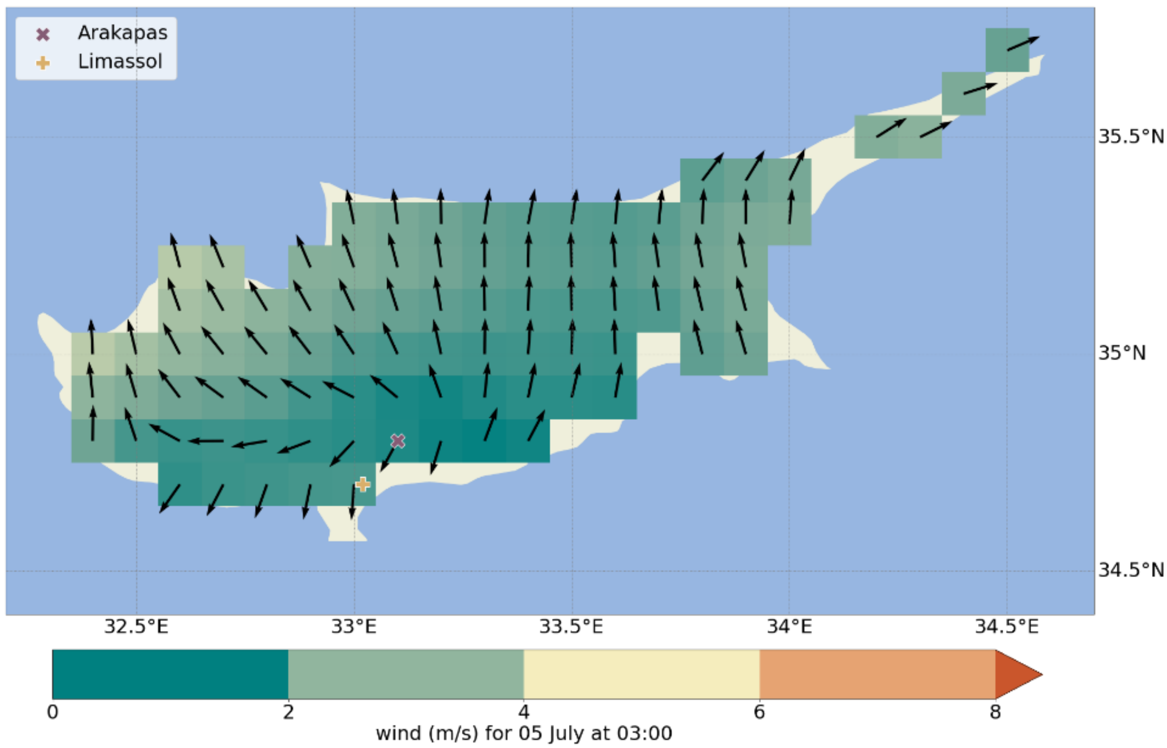

Figure 8 Wind speed and wind direction at 10m derived from ERA5 hourly dataset. Plot for 5 July, 03 UTC. The windspeed is less than 2 m/s, and the arrow shows the wind direction. Arakapas is displayed on the map with a brown "x" marker, and Limassol with a yellow "+" marker [7]

In addition, the multiwavelength depolarization Raman PollyXT-CYP used for the monitoring of the smoke layers evaluation over Limassol. The system observed multiple layers between 0.5 and 3km on 4th and 5th of July 2021. The intensive parameters of the lidar observations such as the extinction-to-backscatter ratio and the depolarization ratio provide information relevant to the aerosol type. The particle depolarization ratio values of 4-6 % for 355nm and 6-9% for 532nm indicated the presence of low depolarizing aerosol in the height range between 1-2.5km. The lidar observations shows that the smoke plume mainly affected the lower atmosphere in a height range below 3kmFigure 9.

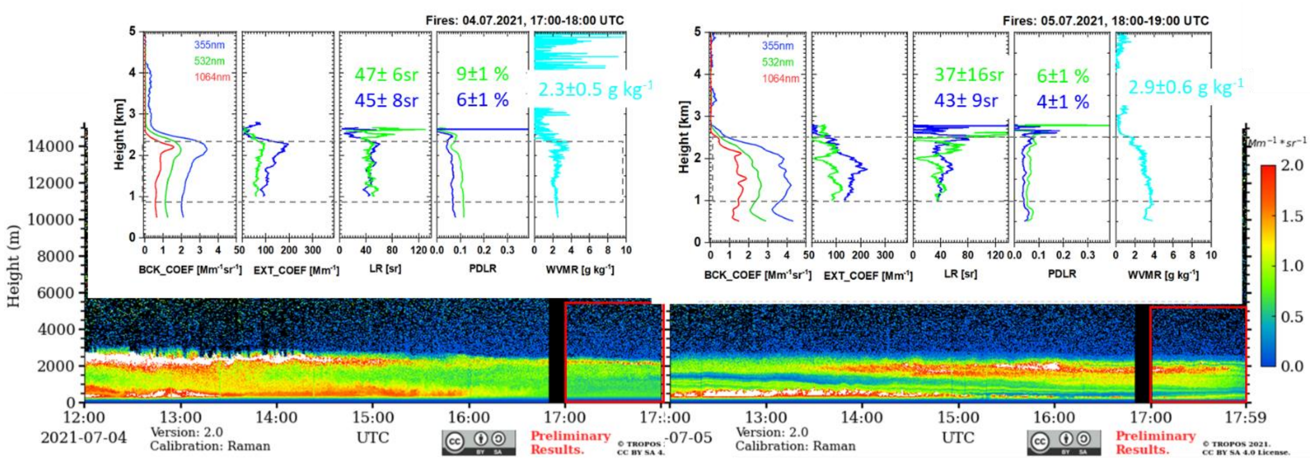

Figure 9 Observations derived from PollyXT-Cyp lidar on 4th and 5th of July 2021

4. CONCLUSIONS

In this study, open-access data from several sources were used.in order to study a wildfire in a natural protected area of Cyprus. The Sentinel-2 satellite data were used for the estimation of the total burned area and the fire severity. Total burned area was 42 km^2 and the part of the burned area was exposed to moderate severity level based on the dNBR map. Based on the ESA WorldCover 2020 the burned area was characterized by shrublands and grasslands, and using the Global ML Building Footprints the affected building were identified. The optical proprieties of the plume were investigated using the Raman lidar in combination with ERA5 wind direction data. The placed in Limassol (distance of ~35 km from Arakapas), since the morning of 5 July, due to proper atmospheric conditions, the plume travels towards southwest. To conclude, the use of open access data for post-fire damage assessment can provide valuable information for emergency response actions and help to mitigate the impact of wildfires on the environment and human health. Future research can include more spaceborne data or ready products for the investigation of air pollution, as well as adding more variables for the holistic damage assessment of the burned area as well the monitoring of the recovery of vegetation in the burned area using time series analysis. Furthermore,a more detailed analysis could provide valuable information about the optical properties of the emitted particles from the burning area with respect to the burning material and the aging processes of the smoke aerosols.

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