Influence of fires on atmospheric composition over Greece as seen by TROPOMI S5P

KALOGERAKI E.[1], SFAKIANAKI M.[1], GIALESAKIS N.[1], CHATZIPARASCHOS M.[1], DASKALAKIS N.[2] and KANAKIDOU M.[1,2,3,*]

[1]Environmental Chemical Processes Laboratory, Department of Chemistry, University of Crete, P.O. Box 2208,70013, Heraklion, Greece

[2]Laboratory for Modelling of the Earth System, Institute of Environmental Physics, University of Bremen, Bremen, Germany

[3]CSTACC, ICE-HT, FORTH, Patras, Greece

*corresponding author:
e-mail:mariak@uoc.gr

Abstract The present study uses data from the TROPOspheric Monitoring Instrument (TROPOMI) on board Copernicus Sentinel-5 Precursor satellite to investigate the impact of the forest fires plumes on atmospheric aerosols and gases. For this purpose, the Aerosol Index, nitrogen dioxide (NO_2) and carbon monoxide (CO) Level-2 data have been analyzed. The results show that the fire in Kineta, Attica (in 2018) and the fire in Corinthia (in 2021), enhanced the total CO concentration levels by up to 5.5 times (from $1.5x10^{18}$ to $10x10^{18}$ molecules/cm^2) and up to 4 times from $1.5x10^{18}$ to $6x10^{18}$ molecules/cm^2), respectively. Similarly, the tropospheric NO_2 concentration levels have increased by up to 15 times (from $1x10^{15}$ to $16x10^{15}$ molecules/cm^2) and up to 40 times (from $1x10^{15}$ to $4x10^{16}$ molecules/cm^2), respectively. Fires have also increased the atmospheric load of absorbing aerosol as reflected by the increase of the dimensionless AI by up to 6 times (from 0 to 6 and from -2 to 4 respectively).

Keywords: wildfires, remote sensing, carbon monoxide, nitrogen dioxide, aerosol index, TROPOMI

1. Introduction

Wildfires are recognized as an important environmental issue, affecting the energy balance of the atmosphere, air quality as well as facilitating the recycling of nutrients for the ecosystems. During the last century, biomass burning has significantly increased and is characterized as an important global source of trace gases and aerosols in the atmosphere (Andreae, 2019). Anthropogenic or natural causes, lead to fires of various intensities leading to the destruction of natural ecosystems. Forest Fires and biomass burning can have devastating impacts on the ecosystems and economies and can alter the atmosphere and global climate by producing atmospheric aerosols and trace gases (Reid et al.,1999).

Forest fires are an important environmental issue throughout the Mediterranean area. According to WWF (2004) an area of 600 to 8000 hectares is burnt every year in the Mediterranena region that is comparable to the surface of Crete and almost equal to about 1.5% of the total Mediterranean forests. One of the deadliest fire episodes in the European history took place almost simultaneously in Kineta and Mati in 2018, where over 100 people lost their lives and 150 more were injured. In 2021, a wildfire in Corinthia occurred with many dispersed fronts and has burned over 50,000 acres in the Geraneia Mountains.

Remote sensing has evolved dramatically over the last decades and can be used for the monitoring of fire events (Athanasopoulou et al., 2014; Kaskaoutis et al., 2011). Fires emit trace gases such as carbon monoxide (CO) and nitrogen oxides (NO_x) as well as aerosols, like black and organic carbon. Over the years, nitrogen dioxide (NO_2) and CO columns have been monitored from space by many instruments providing important information and estimates for fire events.

The TROPOspheric Monitoring Instrument (TROPOMI) (Veefkind et al.,2012) was launched on board the Sentinel–5P satellite by the European Space Agency (ESA) in October 2017. TROPOMI provides, with unprecedented spatial coverages, near-global daily measurements of atmospheric trace gases including O_3, NO_2, CO, HCHO, CH_4, SO_2, and aerosol properties such as the Aerosol Index (AI), which is used to track the evolution of episodic aerosol plumes from dust outbreaks but also from biomass burning and volcanic ash. The TROPOMI observations of atmospheric gases and more specifically the observations of CO, NO_2 and AI are instrumental for the evaluation of the impact of wildfires in the atmosphere.

These satellite observations will be used here to evaluate the impact of Kineta fire in 2018 and Corinthia fire in 2021 on atmospheric composition of the region. Unfortunately, no sufficient data are available to study the Mati fire impact using TROPOMI observations.

2. Data and Methodology

2.1. Data

AI and column concentrations of CO and NO_2 Level-2 data from TROPOMI, in a spatial resolution of 7x7 km^2 (for 2018) and in km^2 (for 2021) for CO and in 3.5x7 km^2 (for 2018) and 3.5x5.5km^2 (for 2021) for NO_2 and AI and have been acquired. The TROPOMI Level-2 data for NO_2 of May 2021 are near-real-time, which may result in slightly lower quality data compared to those from other periods, or even incomplete.The TROPOMI Level-2 Data for CO were gridded into a 0.2°x0.2° grid using a Fortran program developed by Daskalakis N. and Gialesakis N.

2.2. Study area

Two forest fires in the Attica region and in the nearby part of Corinthia region, Greece, were selected as the study cases. In recent years, Greece is prone to wild fires due to the extreme weather conditions during spring and summer. Long summer droughts, high temperatures and strong winds in combination with low precipitation result in a high fire occurrence. In 2018, two big fires occurred in Attica on the same day, one in Kineta to the west of Athens and one in Mati, northeast of Athens. The Kineta fire burned many houses, while the fire in Mati is one of the deadliest fires in the history of Europe, counting over 100 casualties. In May 2021, a wildfire first broke out in Corinthia and spread eastwards towards Athens, burning houses and densely forested areas.

2.3. Methodology

To investigate the impact of fires on atmospheric composition, we compare the satellite observations during the burning days with a day without fires that is used as a reference day. For this, the Fire Information for Resource Management System (FIRMS) by NASA (firms.modaps.eosdis.nasa.gov/) was used in order to identify a reference day with clear background conditions close to the date of the fire. Images from FIRMS acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra sensor for the reference day and the day where the fires were most intense and satellite observations are available are presented in Fig. 1 for each of the fire events we investigated.

For the two days, identified using FIRMS, AI, NO_2 and CO Level-2 TROPOMI data products were acquired from the Copernicus hub (s5phub.copernicus.eu). In order to examine the impact of fire plumes on the atmospheric composition, the difference in column concentrations of the above-mentioned products between the reference day and the day of the fire event, was derived for each pixel.

3. Results and Discussion

3.1. Kineta's Fire in 2018

The Kineta and Mati fires, in Attica region, took place on the 23rd of July 2018. Pollution from the fire of Kineta has been recorded by TROPOMI observations. The fires lasted from 23rd to 26th of July 2018. As a clean reference day with relatively cloud free conditions, the 7th of July was selected and Fig. 2 shows the impact of this fire event on atmospheric composition.

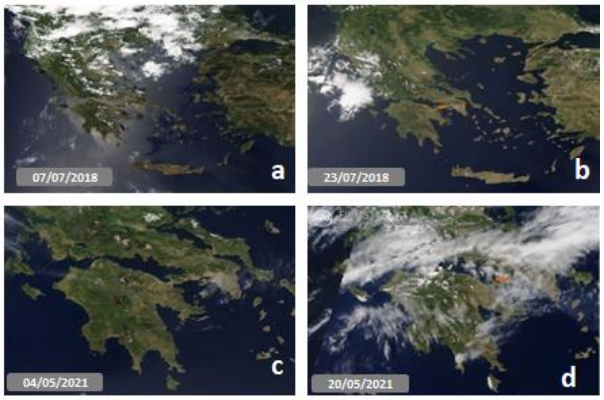

Figure 1. Satellite Images from the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra sensor of a), c) the reference day (left) and of b), d) the day the fire was most intense (right) for the a), b) Kineta and Mati fire, and c), d) Corinthia Fire (https://firms.modaps.eosdis.nasa.gov/).

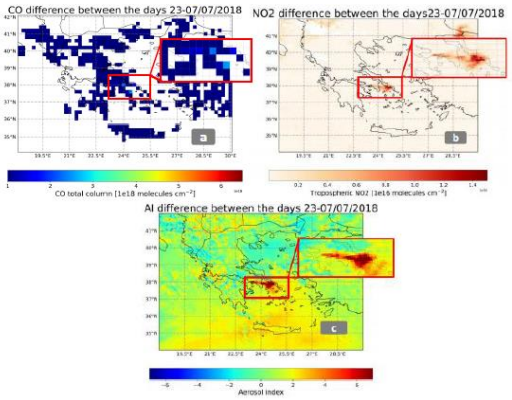

Figure 2. Difference between the 23th and 7st of July 2018 of a) TROPOMI carbon monoxide (CO) column concentration column in 10^{18} molecules/cm^2, b) TROPOMI tropospheric nitrogen dioxide (NO_2) column concentration in 10^{16} molecules/cm^2 and c) the Aerosol Index (dimensionless) over Greece for Kineta fire.

3.1.1. Carbon Monoxide during Kineta's Fire

Fig. 2a illustrates the difference of the TROPOMI CO column concentration levels in molecules/cm^2. The differences between the CO column concentrations

range between $2x10^{18}$ and $2.5x10^{18}$ molecules/cm^2. The Kineta fire affected the atmosphere over and downwind the fire by enhancing the CO total column up to 2.3 times over Kineta.

3.1.2. Nitrogen Dioxide during Kineta's Fire

Fig. 2b shows the increase in tropospheric column concentrations of NO_2 in molecules/cm^2 between the reference day and the day of the fire event as documented by TROPOMI. The differences in concentration range from $0.5x10^{16}$ to $1.75x10^{16}$ molecules/cm^2, while the maximum value in the tropospheric NO_2 column concentration was observed in the outflow of the fire over the north of the Cyclades Islands and not over Kineta.

3.1.3. Aerosol Index during Kineta's Fire

In Fig. 2c, the change in the dimensionless AI as difference between the day of the fire event and the reference day is presented. Similar to NO_2, the plume of the absorbing aerosols has travelled from Kineta to Athens reaching some of the Cyclades islands. The values of the difference in AI ranged between 2 and 6, indicating that the atmosphere was enriched in absorbing aerosols such as smoke and dust-resuspension during the fires. The plumes from the two fire locations (Kineta and Mati) were mixed during transport and travelled as far as the north Aegean Sea.

3.2. Corinthia's Fire in 2021

The fire in Corinthia started in the evening of the 19th of May 2021 and lasted for four days. Over 50,000 acres of land were burnt and many houses and villages were evacuated and burned to the ground. As a reference day with clear background conditions, the 4th of May was selected, while the day where the fire event was intense was the 20th of May.

3.2.1. Carbon Monoxide during Corinthia's fire

In Fig. 3 the TROPOMI CO column concentration in molecules/cm^2 is presented for a) the clear day and b) the day of the fire event. Fig. 3a shows that the levels of CO a real most uniform throughout the area at approximately $1.5x10^{18}$ molecules/cm^2. On the contrary, on the day of the fire (Fig. 3b) the CO column concentrations reach values of $5x10^{18}$ to $6x10^{18}$ molecules/cm^2, over the Corinthia region. The influence of the fire episode on CO column concentrations (maximum increase by about a factor of 4) calculated as the difference between these two days is presented in Fig. 3c.

3.2.2. Nitrogen Dioxide over Corinthia

In Fig. 4 the column concentrations in molecules/cm^2 are provided for the NO_2 over the Attica region for a) the clear day and b) for the reference day as well as c) the difference between the two days to illustrate the impact of this intense fire episode on NO_2 tropospheric column. On the reference day (Fig. 4a) the TROPOMI tropospheric NO_2 concentration levels were low (approximately $0.1x10^{16}$ molecules/cm^2), while during the fire (Fig. 4b) the values over the burnt location were larger varying between $1x10^{16}$ and $4x10^{16}$ molecules/cm^2. The difference between the two days is depicted in Fig. 4c with values that range from $0.1x10^{16}$ to $4x10^{16}$ molecules/cm^2 over the fire location. Therefore, NO_2 levels due to the fire episode have been enhanced by up to about 40 times over the hot spot area.

Monthly average distributions of tropospheric NO_2 columns for April 2019 over Athens and Thessaloniki, two major cities in Greece, based on TROPOMI data (Koukouli et al., 2020) indicate column concentration of NO_2 up to $0.41x10^{16}$ molecules/cm^2 and $0.24x10^{16}$ molecules/cm^2.

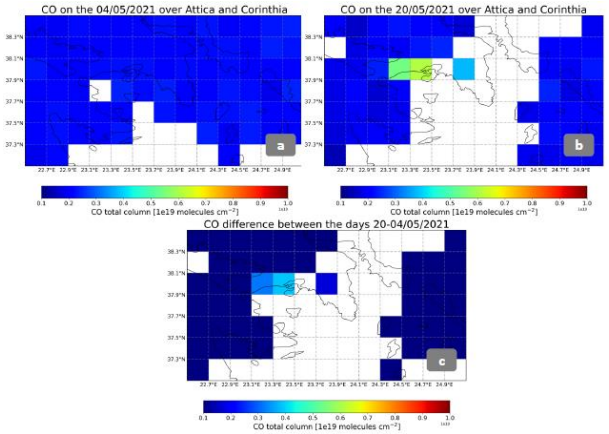

Figure 3. The TROPOMI CO column concentration in molecules/cm^2 over Corinthia and Attica regions of Greece, a) for the reference day (4th of May 2021), b) the day of the fire event in Corinthia (20th of May 2021) and c) the difference between these two distributions.

3.2.3. Aerosol Index during Corinthia's fire

The Aerosol Index is shown in Fig. 5 for the reference clear day and the day of the fire event. The difference between the two days is also shown to illustrate the influence of fire episode on aerosol properties. For the reference day (Fig. 5a) the levels of the Aerosol Index are negative over the Attica region indicating the presence of scattering aerosols. Over the city of Athens, the AI reaches the value of -2. On the day of the fire event the AI over the location of the fire varies between 2 and 4 indicating the presence of smoke, absorbing aerosol, while the plume has moved from the location of the fire to the east of the Attica region. The difference of the AI between the two days is shown in Fig. 5c and indicates that the enrichment of the atmosphere in absorbing aerosol while the AI values range between 2 to 6 over the fire location.

4. Conclusions

Greece has been affected by devastating forest fires throughout the years, with hundreds of people losing

their lives and villages being evacuated and burnt to the ground. This study assessed the impact of the fire in Kineta in 2018 and of the fire in the Corithia region in 2021, in the atmospheric composition using Level-2 satellite-derived products from the TROPOMI instrument onboard Sentinel-5P.

Tropospheric NO_2 column concentrations increased by up to 6 times (from $2x10^{15}$ to $12x10^{15}$ molecules/cm^2) over Kineta fire and up to about 40 times (from $0.1x10^{15}$ to $4x10^{16}$ molecules/cm^2) for Corinthia fire. The results also showed that the fire in Kineta enhanced the total CO concentration levels by up to 6.6 times (from $1.5x10^{18}$ to $10x10^{18}$ molecules/cm^2) and that in Corinthia up to 4 times from $1.5x10^{18}$ to $6x10^{18}$molecules/cm^2) whereas over the European-polluted hot spots, during the year 2019, the column concentration levels of CO are up to $2.4x10^{18}$ molecules/cm^2 (Sannigrahi et al., 2021).

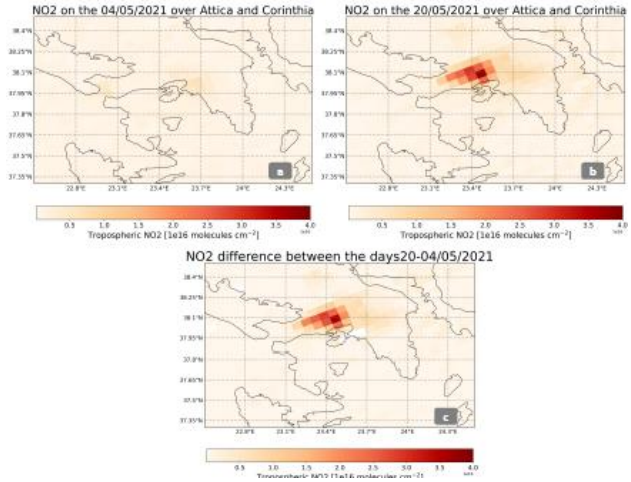

Figure 4. The TROPOMI NO_2 column concentrations in molecules/cm^2 over Corinthia and Attica regions for a) the reference day (4th of May 2021), b) the day of the fire event in Corinthia (20th of May 2021) and c) the difference between these two distributions.

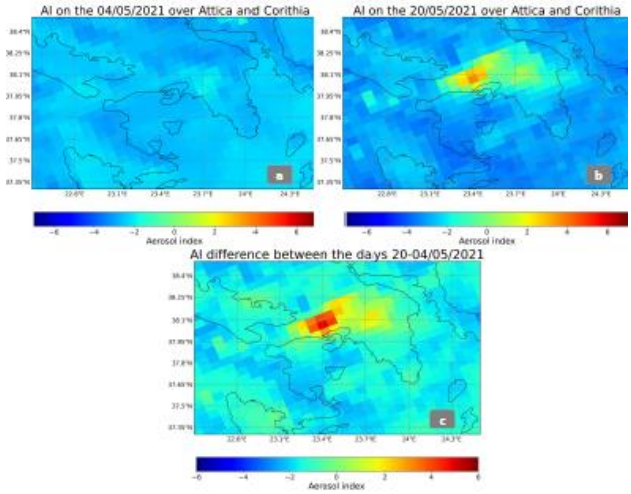

Figure 5. The TROPOMI Aerosol Index dimensionless over Corinthia and Attica regions, for a) the reference day (4th of May 2021), b) the day of the fire event in Corinthia (20th of May 2021) and c) the difference between these two distributions.

Acknowledgments. This work is funded by the Action "National Network on Climate Change and its Impacts (CLIMPACT)" implemented under the project "Infrastructure of national research networks in the fields of Precision Medicine, Quantum Technology and Climate Change", funded by the Public Investment Program of Greece, General Secretary of Research and Technology/Ministry of Development and Investments; and by the Deutsche Forschungs-gemeinschaft (DFG, German Research Foundation) under Germany´s Excellence Strategy (University Allowance, EXC 2077, University of Bremen).

References

Andreae M.O. (2019), Emission of Trace Gases and Aerosols from Biomass Burning – an Updated Assessment, *Atmospheric Chemistry and Physics*, 19.13: 8523-546.

Athanasopoulou E., Rieger D., Walter C., Vogel H., Karali A., Hatzaki M., Gerasopoulos E, Vogel B., Giannakopoulos C., Gratsea M., and Roussos A. (2014), Fire Risk, Atmospheric Chemistry and Radiative Forcing Assessment of Wildfires in Eastern Mediterranean, *Atmospheric Environment*, 95, 113-25.

Kaskaoutis D., Kharol S., Sifakis N., Nastos P., Sharma A., Badarinath K. and Kambezidis H. (2011), Satellite monitoring of the biomass-burning aerosols during the wildfires of August 2007 in Greece: Climate implications. *Atmospheric Environment*, 45(3), pp.716-726.

Koukouli E., Skoulidou I., Karavias A., Parcharidis I., Balis D., Manders A., Seges A., Eskes H., van Geffen J. (2020), Sudden Changes in nitrogen dioxide emissions over Greece due to lockdown after the outbreak of COVID-19, *Atmospheric Chemistry and Physics*, vol. 21, number 3, pp. 1759—1774, doi 10.5194/acp-21-1759-2021.

Reid J.S., Thomas F.E., Sundar A.C., Hobbs P.V. and Holben B. (1999), Use of The Ångstrom Exponent to Estimate the Variability of Optical and Physical Properties of Aging Smoke Particles in Brazil, *Journal of Geophysical Research: Atmospheres*, 104.D22: 27473-7489.

Sannigrahi S., Kumar P., Molter A., Zhang Qi, Basu B., Basu A.-S., Pilla F. (2021), Examining the status of improved air quality in world cities due to COVID-19 led temporary reduction in anthropogenic emissions, *Environmental Research*, Volume 196, 2021, 110927.

Veefkind J.P., Aben E.A.A., Mc Mullan K., Förster H., deVries J., Otter G., Claas J., EskesH., de Haan J., Kleipool Q.,van Weele M., Hasekamp O., Hoogeveen R., Landgraf J., Snel R., Tol P., Ingmann P., Voors R., Kruizinga B., Vink R., Visser H. and Levelt P. (2012) TROPOMI on the ESA Sentinel-5 Precursor: AGMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications, *Remote Sensing of Environment*,120, pp.70-83.

WWF (2004), Forest Fires in the Mediterranean: A burning issue.https://ec.europa.eu/environment/forests/pdf/meeting140504_wwffirstdocument.pdf (last access 5/2021)