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Are Lower Solar Irradiance and Higher Ambient Particulate Pollution Associated with a Higher Incidence of COVID-19? The Case of the Greater Athens Area †

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Abstract: Greece in the period July–August 2021 was affected by two heat waves characterized by very high temperatures. The result was the occurrence of fires in various regions of the country, with Attica being one of the most affected regions of Greece. The atmospheric burden was very high, and the smoke covered the Attica sky at times, affecting the sunshine and by extension the incoming solar radiation. In this study, we examine whether the reduction in solar UV radiation synergistically with the increase in atmospheric particulate pollution was related to the spread of COVID-19 in Attica in the summer of 2021.

Keywords: ultraviolet solar radiation; particles; COVID-19; Athens

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1. Introduction

The disease COVID-19 has caused a global pandemic with enormous implications for public health. Many studies have been conducted on the role of weather conditions, air pollution, solar radiation, wildfires, and airborne dust in the spread and lethality of SARS-CoV-2. The study by Zhu et al. [1] in China showed that a 10 μg/m^3 increase in $PM_{2.5}$ and PM_{10} was associated with a 2.24% increase in cases and 1.76% increase in deaths from COVID-19. Meo et al. [2] observed that after the California wildfires, $PM_{2.5}$ concentrations increased by 220.71% and the number of COVID-19 cases and deaths by 56.9% and 148.2%, respectively.

Particulate pollution from wildfire smoke and from the presence of dust in the atmosphere has been shown to lead to the attenuation of solar radiation and vitamin D levels in the population and consequently to an increase in the risk of infection with COVID-19. Aerosols from the 2020 fires in South America caused an average monthly solar radiation deficit of up to 200 W/m^2 [3]. Also, extreme airborne dust events can lead to the attenuation of Global Horizontal Radiation (GHI) by up to 40–50% and a reduction in Direct Normal Radiation (DNI) by up to 80–90% [4]. On the other hand, studies showed that vitamin D deficiency (<30 nmol/L) in the Chinese population was inversely associated with the incidence of COVID-19 (OR: 2.72; 95% CI: 1.23, 6.01) and disease severity [5], while in the USA, SARS-CoV-2 positivity rates were 40% lower in subjects with sufficiency (>50 ng/mL) of 25-hydroxyvitamin D than in deficient subjects (<20 ng/mL) [6].

The present study aims to investigate: (a) the magnitude of particulate pollution in Attica due to the Varympompi's fire that occurred on 3–4 August 2021, (b) the relationship between particulate pollution and surface solar radiation and whether this relationship affects the spread of the COVID-19 disease, (c) which areas of Attica were most affected by particulate pollution and UVB attenuation, and (d) the impact of these effects on daily cases, ICU admissions of COVID-19, and deaths.

2. Data and Methodology

The datasets were obtained for the period 20 July–10 September 2021, and include (a) the daily number of COVID-19 cases, deaths, and intensive care unit (ICU) admissions in Attica from the National Public Health Organization, (b) daily UV values of solar radiation (UVB) from the measuring station of the Biomedical Research Foundation of the Academy of Athens, and (c) daily values of particulate pollutants (PM_1, $PM_{2.5}$, and PM_{10}) from the particulate matter recording networks PANACEA and ATH-ENVICARE.

More specifically, concentrations of particulate pollution ($\mu g/m^3$) were obtained for the Northern Sector of Attica (ATH-ENVICARE-2), for the Southern Sector of Attica (PANACEA-AirPaP-008), for the Central Sector of Attica (ATH-ENVICARE-0), for the Western Sector of Attica (PANACEA-014), and the Eastern Sector of Attica (PANACEA-AirPaP-014). The present investigation concerns the Regional Units of East Attica, West Attica, Northern Sector of Athens, Western Sector of Athens, Central Sector of Athens, and Southern Sector of Athens. We applied the NOA HYSPLIT model to capture the forward trajectories of the gas masses for 500 m, 1500 m, and 3000 m, starting from Varybombi at 18:00 UTC on 3 August 2021, for the next 96 h.

Our study estimated the effects of air pollution and UV radiation on the spread of COVID-19, disease severity (ICU admissions), and mortality from the Generalized Linear Models (GLM) with Poisson distribution. In the model fitting process, we used dependent variables, the daily values of COVID-19 cases, ICU admissions, and deaths, while as independent covariates we used the daily values of atmospheric particles (PM_1, $PM_{2.5}$, and PM_{10}) and UVB radiation. The Poisson distribution was used to estimate the incidence relative risk (IRR) of atmospheric particles $PM_{1.0}$, $PM_{2.5,}$ $PM_{10.0}$, and UVB radiation in COVID-19 cases and ICU admissions.

3. Discussion and Results

Greece in the period July–August 2021 was affected by two long-lasting heat waves characterized by very high temperatures (38-> 45 °C). According to Masoom et al. [7], the meteorological conditions in Athens at that time were characterized by high temperatures, very dry air, low wind speed (<5 Beaufort), and a lack of rainfall. These conditions were responsible for the existence of highly flammable biomass and the rapid spread of forest fires [8]. The atmospheric burden in Attica from the smoke of the fires was very high, while the high concentrations of African dust over Greece also contributed to the low air quality [7]. On 3 August 2021, the first fire broke out in Ano Varybompi, and on 16 August 2021, two more fires followed, one in Markati of Lavreotiki and the second in the Vilia region of Western Attica which reignited on 23 August 2021 [9].

Applying the NOA HYSPLIT model, we found that after the Varymombi fire, the atmospheric circulation had a southerly direction. Smoke from the fires was carried a great distance from the source of the fire. Air masses at 1500 m and 3000 m reached Africa affecting countries such as Libya and Nigeria, while those at 500 m headed south towards Crete and then moved east towards Cyprus (Figure 1).

The southern, northern, and central regions of Attica were most affected by the particulate pollution caused by the fire because of the southerly direction of the atmospheric circulation. The highest values were recorded on 4 August 2021 in the Southern Sector of Attica (PM_1: 85.40 $\mu g/m^3$, $PM_{2.5}$: 148.64 $\mu g/m^3$, PM_{10}: 168.20 $\mu g/m^3$) followed by the Northern Sector (PM_1: 79.70 $\mu g/m^3$, $PM_{2.5:}$ 119.02 $\mu g/m^3$, PM_{10}: 133.88 $\mu g/m^3$), the Central Sector (PM_1: 76.58 $\mu g/m^3$, $PM_{2.5}$: 118.39 $\mu g/m^3$, PM_{10}: 124.75 $\mu g/m^3$), the Eastern Sector (PM_1: 34.31 $\mu g/m^3$, $PM_{2.5}$: 51.30 $\mu g/m^3$, PM_{10}: 55.82 $\mu g/m^3$), and the Western Sector (PM_1: 26.34 $\mu g/m^3$, $PM_{2.5}$: 37.15 $\mu g/m^3$, PM_{10}: 40.28 $\mu g/m^3$).

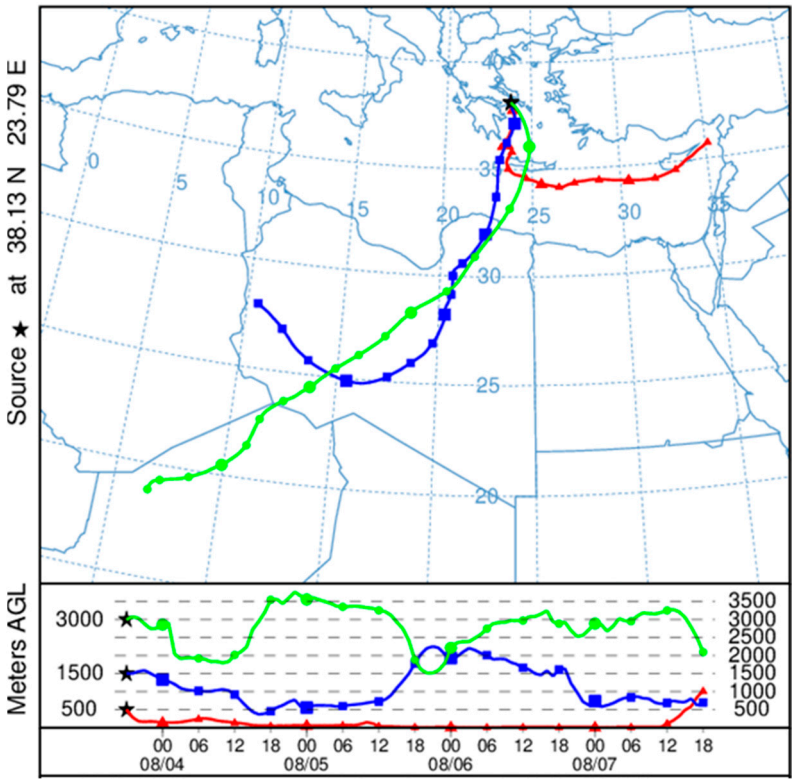

Figure 1. Forward trajectories 96 h at 500, 1500, and 3000 m AGL from NOAA HYSPLIT model starting at Varympompi on 3 August 2021, 18:00 UTC.

Our analysis found an outbreak of the pandemic between 4 and 31 August 2021 in the Southern and Central Sectors of Attica, which were significantly affected by the particulate pollution of the fires. The Southern Sector showed increased ICU admissions for COVID-19, and the Central Sector showed increased ICU admissions and deaths. In the remaining Sectors, no burden of the epidemiological indicators of the COVID-19 pandemic was observed (Figure 2).

In our study, we also examined the effect of smoke on daily integrals of UV-B radiation (Joules/m^2) and CIE erythema (Joules/m^2) acquired by BRFAA. A significant decrease of about 50% during the period of fires compared to previous days has been recorded for both UV-B radiation and CIE erythema. For brevity's sake, only the graphs for the Central Sector are presented, depicting the impact of UV-B radiation and CIE erythema on COVID-19 cases, ICU admissions, and deaths (Figure 3).

The application of GLM with Poisson distribution was performed on our datasets both on the same day and lag days (up to 15 lags in advance). The exponential form of the regression coefficients (i.e., exp(β) for each of the pollutants, UV-B radiation, and CIE erythema), which are reported as the incidence rate ratios (IRRs), along with the corresponding *p*-values to show significance were calculated. On the one hand, the GLM outputs indicated the statistically significant positive influence of particulate matter only on COVID-19 cases (the estimated IRR ($p < 0.05$) was observed at all lags, i.e., an increase of 10 μg/m^3 in mean daily $PM_{2.5}$ (lag7) was significantly associated with an increase of 4% in daily COVID-19 cases). On the other hand, the negative impact of UV-B radiation and CIE erythema on COVID-19, especially in the Central Section of Athens, was estimated, although the results were not statistically significant ($p > 0.05$). This could be attributed to the short period examined in our study.

Figure 2. The effect of particulate pollution from the fires in Attica on the spread (Cases) (**left panel**), severity (Intensive Care Units) (**middle panel**), and mortality (Deaths) (**right panel**) of the pandemic, during the period 20 July–10 September 2021. First row: Southern Sector of Attica; second row: Northern Sector; third row: Central Sector; fourth row: Eastern Sector; fifth row: Western Sector.

The association between reduced solar radiation and vitamin D during the wildfires in Attica was examined by Masoom et al. [7]. It was found that daily levels of vitamin D recorded reductions of 30–50% due to the significant attenuation (>60%) of UV-B radiation by wildfire smoke.

Regarding the effect of wildfire smoke on air pollution and deaths from COVID-19, our findings agree with those of Meo et al. [2], who showed a positive correlation between air pollution and COVID-19 deaths. Regarding the effect of wildfire smoke and African dust on UVB solar radiation, the results of our research agree with those of Rosário et al. [3], Kosmopoulos et al. [4], and Masoom et al. [7], which showed that an increase in air pollution and high concentrations of airborne dust led to the weakening of solar radiation.

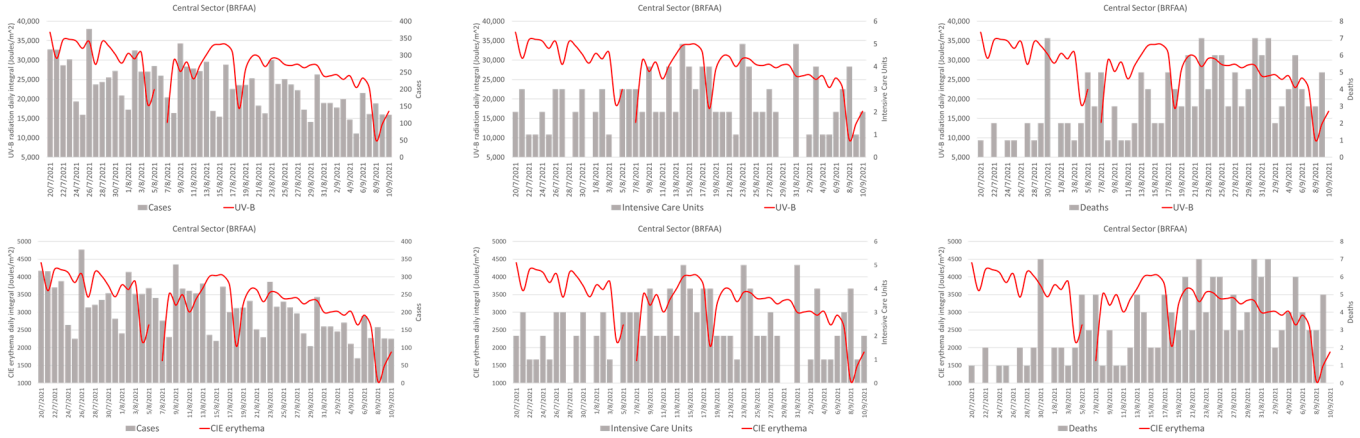

Figure 3. The effect of UV-B radiation daily integral (**upper graphs**) and CIE erythema daily integral (**lower graphs**) from the fires in Attica on the spread (Cases) (**left panel**), severity (Intensive Care Units) (**middle panel**), and mortality (Deaths) (**right panel**) of the pandemic, during the period 20 July–10 September 2021.

Our study has advantages over other studies, but also limitations. Advantages include (a) investigating the synergistic effect of air pollution (from forest fires and airborne dust) and solar radiation on the spread of COVID-19 and (b) recording daily COVID-19 ICU admissions and deaths, data that capture the true picture of the pandemic as opposed to studies based only on the number of daily cases. Limitations of the study concern factors that were not accounted for such as age, gender, and comorbidities of individuals admitted to the ICU with COVID-19, vitamin D levels in the population, public health policies, human behavior, adherence to health measures, mobility, and population density.

4. Conclusions

We detected increased particle pollution in Attica during the fires in the summer of 2021. The sectors most affected were the Southern Sector, followed by the Northern Sector, the Central, the Eastern, and the Western Sector of Attica. The spatial distribution of increased PM_1, $PM_{2.5}$, and PM_{10} concentrations is explained by the southward movement of the atmospheric circulation. An increase in particulate air pollution caused a decrease in solar UV radiation. We hypothesize that the attenuation of solar radiation negatively affected vitamin D levels. In conclusion, the synergistic action of the above factors worsened the severity of COVID-19 cases (increased ICU admissions) and mortality.

Further research is needed to draw firm conclusions about the effect of an extreme episode of particulate pollution, due to a large wildfire, on the spread and mortality of COVID-19.

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