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Monitoring wildfire smoke dispersion using concentrations of PM10 and PM2.5

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Abstract

Portugal as a member of the European Union (EU) follows the air quality legislation regulated by Directive 2008/50/EC that states that "Member States shall ensure that timely information about actual or predicted exceedances of alert thresholds, and any information threshold is provided to the public". The southern European countries, have biogenic contributions, mainly resulting from the long-distance transport of particulate matter, originating in arid regions, and from large forest fires, whose pollutants loads cannot be imposed limits. These sources lead to an additional contribution of atmospheric pollutants mainly during the spring and summer season. Climate change is increasing the vulnerability of the environment to extreme events, such as those that enhance the likelihood of forest fires. Due to the predicted increase in temperatures, the decrease in precipitation and humidity, an increase in the frequency and intensity of forest fires is expected, namely in regions of the Mediterranean basin, as is the case of Portugal. Monitoring the concentration of particles (PM10 and PM2.5) in the network of air quality stations can be a way of detecting the dispersion of smoke and giving possible alerts to affected populations. The analysis of PM10 and PM2.5 of the air quality network stations, from 2010 to 2020 only for June to October, shows very high concentration values that are associated with to the periods of forest fires. These data were analysed for all seasons by districts, considering a daily average. The daily concentration average was performed by including the observations on the period spanning from two days before and after the registration of a fire with daily burned area larger than 500 ha by district. Trajectory analysis was performed to confirm the origin of the particles observed at the stations. It was verified that, for the period 2010-2020, the daily average value of PM10 concentration is variable and generally increases from the day before to the day of the event by an average percentage of 26%. This variation depends on the proximity of the forest fire, the burned area as an indication of its strength, the stability of the atmosphere and the height of the boundary layer. During the summer season, dust episodes also occur, originating in the Sahara, especially in the southern regions of Portugal, increasing the observed concentration of PM10 and PM2.5 particles. In this way, for the summer period, the days with high values of PM10 and PM2.5 that could have been originated by dust particles, with larger dimensions, were identified and separated from those which referred to smoke particles from forest fires, usually smaller. For this purpose, the relationship between the concentrations of PM2.5 in relation to PM10, in the studied period, was taken in to account. For the large fires of 2017, a more detailed characterization of these features was made, analysing the optical thickness of the aerosols and the Angstrom exponent of the VIIRS radiometer on board the Suomi NPP satellite.

1. Introduction

Climate change is increasing the vulnerability of the environment to extreme events, which happen more frequently, namely those likely to promote forest fires (EEA, 2021). Due to the expected increase in temperatures (Andrade et al., 2014, 2015) and decrease in precipitation and humidity, it is expected an increase in the frequency and intensity of forest fires in certain regions of the Mediterranean basin, considered climatic hotspots, such as Portugal. It is also expected an increase in the duration of the current forest fire season, revealed by the analysis of the last 30 years. Furthermore, the fire regime is expected to change almost everywhere in Europe, southern countries being the ones that concentrate most of the annual burned area (San-Miguel-Ayanz et al, 2018). In 2017 the burnt area in Portugal was 539921 ha, which represented 498% of the average of the previous decennium. Indeed, the wildfires that occurred in 2017 in Portugal, and more recently in 2019 in Australia, have raised awareness towards the need for further studies on the many relevant impacts of wildfires.

Biomass burning is an important source of gases and particulate matters (PM) that can significantly change local, regional and global atmospheric chemistry, with impact on air quality, which can affect human health (Crutzen & Andreae, 1990). Smoke emissions from forest fires present a highly variable composition between wildfires and with time for the same wildfire, leading to different particle sizes distribution, particle light absorption, and spectral dependence on absorption based on the type of fuel, its amount, burning characteristics, and weather conditions (Dubovik, O et al, 2002; Shi, S. et al, 2019). The released particles and gases can affect the tropospheric chemistry and cause several respiratory and cardiovascular diseases (Cardoso de Mendonça et al., 2006; Reid et al., 2019). Exposure to wildfires pollutants has been associated with an increase in respiratory and cardiovascular hospitalizations (Cardoso de Mendonça et al. 2006; Finlay et al. 2012). Therefore, it is important to monitor the concentration of particles in the ambient air. Monitoring can be done by warnings based on observations of air quality network stations and complemented by observations of the aerosols optical thickness (AOD) for wavelength between 400 to 800 nm, together with the Angstrom exponent, which indicates the particles size distribution in the air column, or with the aerosol index (AI), which gives information on absorbent aerosols. Both aerosols may present high values of AOD (for 500nm), but with large differences in the Angstrom exponent (dust aerosol is characterized by low values, around 0.5, while forest burning aerosols are characterized by high values often higher than 1.5). It is known that the main absorbing aerosols in the atmosphere are dust and aerosols resulting from forest burning. In the great fires of June 17th and October 15th 2017 in Portugal, the coexistence of these two types of aerosols was observed.

2. Material and Methods

2.1. Study Data

In this study, PM_{10} and $PM_{2.5}$(µg/m^3) observational data from surface air quality monitoring stations, was used, from June 2010 to October 2020. These stations are the responsibility of the Portuguese Environment Agency (APA) in coordination with the corresponding Commission for Coordination and Regional Development (CCDR). The data measured continuously at the various stations are reported, in near real time, and made available to the public by QUALAR online database (https://qualar.apambiente.pt/indices).

Back and forward trajectory performed by HYSPLIT Model, (https://www.ready.noaa.gov/hypub-bin/trajtype.pl)

Daily values of burned area in Portugal, by district, were accessed from June to October, 2010 to 2020. The days in which the daily burned area, for each of the districts, exceeded 500 ha were identified.

Optical thickness data from OLCI-SENTINEL3A, with the XBAER algorithm (product C3S from Copernicus) and satellite Angstrom exponent from VIIRS (NOAA) data were used for June 16th to 20th, 2017 and October 14th to 17th, 2017.

Two Doppler weather radars from the IPMA network were accessed to analyze several fire plumes as they were being tracked near ground air quality stations.

2.2. Methods

All PM_{10} and $PM_{2.5}$ concentration values were analyzed for forest fires with a burned area larger than 500ha. For each case, the period spanning from two days before the fire occurrence to two days after the fire suppression was considered. The variation of the daily average of PM_{10} between the days before and after was calculated. For stations where a positive variation was observed, the back trajectory was computed for 24h and 48h in order to verify the origin of the particles in order to confirm the areas they came. In the large fires of 2017, data from AOD 550nm and Angstrom exponent of aerosols were also used, the latter mainly for splitting dust and smoke from forest fires. Data from the IPMA radar network was also used to monitor smoke plumes from the large forest fires that occurred in Portugal in 2017.

One of the radars, Arouca/Pico do Gralheiro (A/PG), is a dual polarization (DP) system located northeast of the observed plumes, with a beam around 1100 m a.m.s.l.(above mean sea level), while the other, Coruche/Cruz do

Leão (C/CL), is a single polarization system located to the southeast of the plumes, with a beam around 200 m a.m.s.l.. Low-level plane position indicators of reflectivity (PPZ) were extracted every 10 min from the A/PG radar and used to identify fire plume patterns in the case of high PM10 values observed at the air quality station Ilhavo (number 2018) from 20UTC of 15th October to 01UTC of 16th October 2017, the radar beam being at approximately 800 m a.g.l. (above ground level). PPZs were also used to identify fire plume patterns in the case of observation of PM_{10} at station Ervedeira (number 2019) and station Montemor-o-Velho (number 2022), but in this case the C/CL radar was used, the beam being at approximately 400 m a.g.l., due to the lower altitude of the radar.

As fires intensify, heat flux increases combustion and buoyancy, and more pyrometeors are transported upward, according to Jones et al, (2010). Thus, the magnitude of low-level reflectivity observed near the fire site is a good indicator of the overall intensity of strong convective processes caused by fire. A/PG radar was additionally used to verify if the suspected plume patterns were, in fact, originating from fire activity, based in the magnitude of the correlation coefficient that is processed in DP mode (Balakrishnan et al. (1990), Pinto et al. (2022)). Within the range of 100 km, the spatial resolution of the radar observations was 1 km or better. The evolution of plume patterns observed in the low-level PPZ was followed in the vicinity of ground stations as shown on a georeferenced map. A comparison was made between ground station air quality observations and low-level radar observations. Every 10 min, the magnitude of the reflectivity value of the plume that was being observed was estimated, at each moment, in an area of 3 x 3 km^2 (in polar coordinates). The center of this area was selected to be 5 km upstream from the ground station in relation to the identified buoyancy source and for each instant an average reflectivity was derived.

3. Results and Discussion

The variation in PM_{10} concentration between the day before and the day of the forest fire, for the stations whose back trajectory indicated this origin, was on average, 26%, ranging between 22% and 31% for the 2010-2020 period.

The 2017 forest fire season in Portugal was considered as a complex of extreme forest fire events, with two noticeable events, one in June and the other in October, not only because of the amount of total area burned, but because of the high number of casualties (more then 100 in two days). We studied, in detail, the behavior of the air quality stations for these two events. These events were also characterized by having dust events associated.

During the forest fires episodes, the proportion between $PM_{2.5}$ and PM_{10} varies in the sense of increasing the percentage of $PM_{2.5}$, indicating an increase of smaller particles, with greater damage to health. In the case of the large fires in Pedrogão Grande, 17th to 22th of June 2017, Figure 1 shows this ratio for stations 3096-Chamusca, 3089-Mem Martins, 2020-Fundão. By analyzing the back trajectory for the Fundão station (2020) it appears that on the 16th, 20th and 21th, the concentration of PM were due to dust, coinciding with the periods in which the $PM_{2.5}/PM_{10}$ values were lower, while on the 18th and 19th they were due to large fires in the central region of Portugal, with higher values of the $PM_{2.5}/PM_{10}$ ratio, Figure1. In the intermediate periods, a mixing of particles may have occurred, with intermediate values of the ratio. With the same methodology applied to Chamusca (3096, in blue in Figure 1) it was confirmed that the concentration of particles was essentially due to the forest fires in Pedrogão Grande and Góis on the 17th to 19th of June and the variation in the type of particles from the afternoon of the 19th of June.

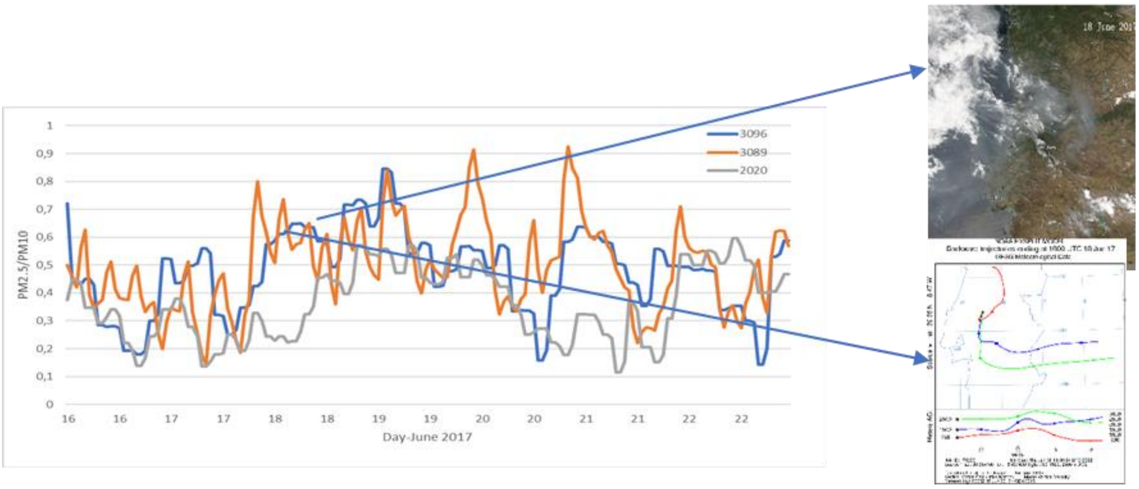

Figure 1- Hourly variation of the ratio between $PM_{2.5}$ and PM_{10} on three air quality monitoring stations (3096-Chamusca, 3089-Mem Martins, 2020-Fundão) the 16^{th} to 22^{th} of June 2017. Satellite image (MODIS/VIIRS) and backtrajectory for Chamusca Station for 18^{th} June 2017.

Optical thicknesses of aerosols at 550nm allow a good identification of regions affected by smoke particles from fires (Figure **2**), when available.

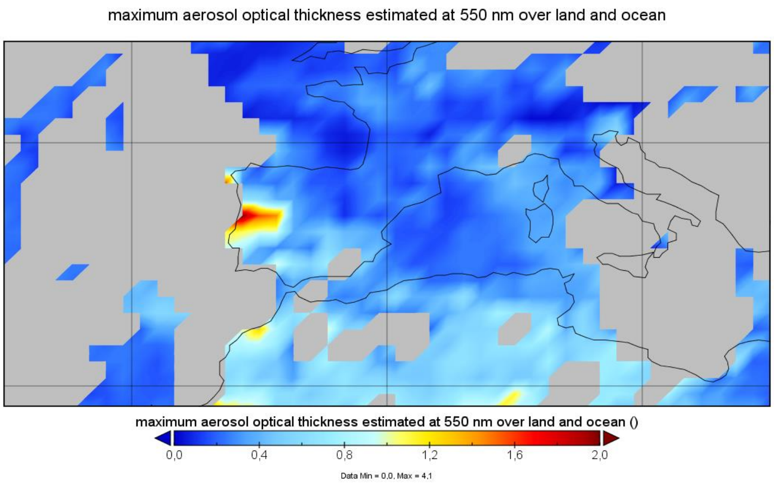

Figure 2- Maximum aerosol optical thickness estimated at 550nm on 18^{th} June 2017(C3S from Copernicus)

Combining the optical thickness of the aerosols and the variation of the PM_{10} concentration (negative, in the direction of decrease, above 50% of variation, and positive with a variation above 50%), monitoring maps are obtained. These maps can allow the monitoring of the most serious episodes.

During the great fires of October, several stations had $PM_{2.5}$ observation´s gaps, especially the stations in the North and Central region of Portugal, where due to the location of forest fires and the predominant south-north flow will have been the most affected

In the wildfire events of October, the stations with PM_{10} observation located in the north and central region of Portugal were analyzed, jointly with the analysis of trajectories, dispersion of the point of fire and mainly with the analysis of smoke by radar observation. In the case of Ilhavo station (number 2018), two rapid increases in PM_{10} concentration were observed, one from 21UTC on the 15^{th} to 2 UTC on the 16^{th} and the other on the 17^{th} of October, Figure 3. For the first PM_{10} observation period, low-level radar observations were analyzed every

10 minutes, monitoring the advection of the smoke plume from the forest fire, Figure 4. In the second period, no smoke was identified by the radar, being observed, by satellite, a mass of dust driven by a strong southerly flow.

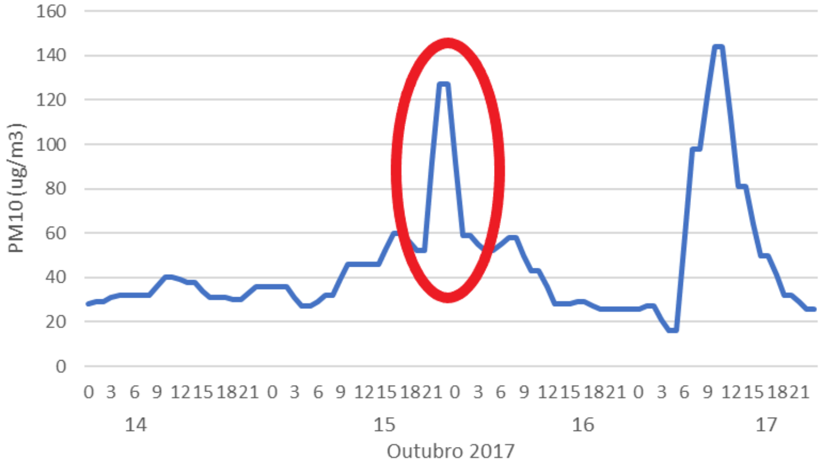

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Figure 3- Hourly variation of PM_{10}, on air quality monitoring station 2018 (Ilhavo), on October 14th to 17th October 2017r

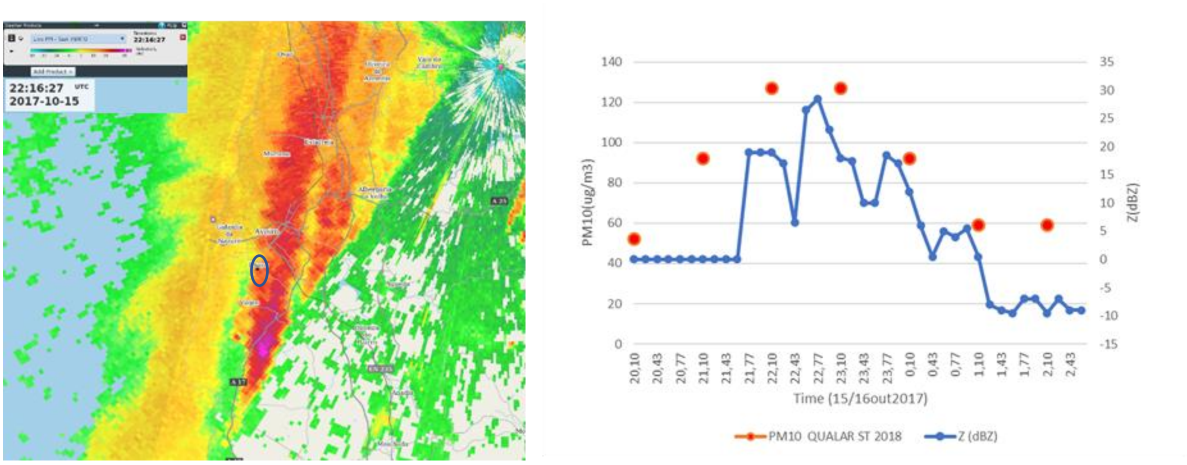

Figure 4- Low-level PPZ radar observation in an area matrix 3X3km² at 22:16 UTC of 15th October. The Ilhavo station is marked with a circle, (right). Hourly variation of PM_{10}, (red), on air quality monitoring station 2018 (Ilhavo), on October 15th at 20:00UTC to 16th at 2:00UTC, 2017, and low-level PPZ radar observation every 10 minutes in an area matrix 3X3km² between 15th at 20:06 UTC and 16th at 2:36 UTC October (blue), (left)

4. Future Work

Combining multiple sources of information (RADAR reflectivity observations; surface air quality observations; AOD from remote sensors observations on board of satellite) we can early warn local authorities for atmospheric pollution events, caused by forest fires, in order to prevent population health issues.

As future work, this study should be extended to other severe forest fire events in Portugal, and it will also be necessary to study how to combine, operationally, all the existing information from observation.

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