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Effects of the wildfires of August 2021 in the air quality of Athens through a numerical simulation

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Abstract

Air quality is significantly deteriorated during wildfire events, which poses a risk for the human health of affected populations. The Mediterranean Basin was strongly impacted by wildfires in the 2021 fire-season, particularly Athens whose numerous inhabitants experienced dangerous levels of air-quality for consecutive days. It is predicted that climate change will lead to a higher frequency of this type of situations over the coming decades.

The numerical modelling system WRF-APIFLAME-CHIMERE, which comprises a meteorological model, a smoke emission model and a chemical transport model, was applied to estimate the impact of 2021 August wildfires in the air quality of Athens. The obtained concentration results were compared with data from air quality monitoring stations with a good agreement between model and measured data. Calculated values indicate concerning levels of air pollution during the days with wildfires close to the city.

1. Introduction

The fire activity around the Mediterranean basin has been increasing over the past years and the burned area in some countries is expected to increase on average by 10% a decade in some countries because of climate change (Dupuy et al., 2021). Allied to this are the lack of adequate forest management, which led during the last decades to the conversion of native oak forests into non-native tree plantations, increasing the risk of large-scale forest fires, and the abandonment of rural areas which may render the situation even worse as fields and forests are left untended, posing a significant fire risk (Corona et al., 2015).

The effects of wildfires are not limited to massive economic and human losses that are caused directly through the action of the flames. Much harm is also done by the unhealthy levels of air-pollutants released in the process such as particulate matter (PM) and carbon monoxide. A study of firefighter health parameters showed how exposure to high levels of air-pollutants released from fires, even for a short term, may lead to dangerous conditions (Miranda et al., 2012).

Greece alongside with other countries around the Mediterranean suffered unusually high levels of fire-activity during the 2021 fire-season. Reports in the media of impressive levels of smoke and ashes are supported by measurements of atmospheric pollutants during that period (Smith, 2021; EEA, 2021). Athens was especially impacted since the city and surrounding urban areas, inhabited by 4 mio people, were surrounded by two large fires in its vicinity during the first week of August.

Previous studies of extreme wildfire events have successfully employed Chemical Transport Models (CTM) and satellite data information to achieve high spatiotemporal resolution fields of species concentrations. This method was used by Péré et al. (2014) in a case-study of an event near Moscow in 2010. They used the Weather Research and Forecasting (WRF) meteorology model coupled with the CHIMERE CTM fed with emissions derived from the Global Fire Assimilation System. The latter uses the satellite derived Fire Radiative Power (FRP) and vegetation maps to estimate emissions. The authors observed a good agreement between satellite observations of Aerosol Optical Depth (AOD) and the model results, whose bias ranged from –40% to 30%. More recently Turquety et al. (2020) used the WRF-CHIMERE system coupled with APIFLAME. This system showed good results in a case-study of Portugal in the 2016 fire season for which 5% of bias in AOD were estimated. The authors showed how the state-of-the art plume-rise model as well as the detection of small fires were important factors that allowed the reduction of the modelling biases.

This study aims at a better understanding of the emission and dispersion of smoke during extreme wildfire events, including their impacts on air quality (AQ), using the events surrounding Athens as a case study. For this, the biomass burning emissions are estimated based on a top-down methodology (using APIFLAME), and their impact on AQ is assessed based on a modelling approach. The WRF model is used to obtain high spatiotemporal meteorological conditions while CHIMERE simulates the chemical and physical processes that pollutants undergo within the atmosphere.

The validation of the chosen model parameterization and input data was done by comparing results with measurements from AQ monitoring stations from Greece.

In the following chapter the case-study is described followed by a detailed explanation of the model and its parameterization. In section 3 the model results are presented, validated and discussed. The last section deals with the conclusions of this work.

2. Methodology

The APIFLAME model was used for estimating biomass burning emissions, while other emissions, meteorology and chemical transport phenomena were handled by the WRF-CHIMERE model. The system was applied to the case study of Athens during the fires in the beginning of August 2021.

2.1. Case Study

In the beginning of August 2021 fires were detected in the region around Athens in the Terra/MODIS Fire and Thermal Anomalies satellite product (Giglio et al., 2021). The first detection was on the 4th of August due to a wildfire started 100km to the North of the city in Evia Island. The fire continued to burn for six days resulting in 51000ha of burned area (40% of the total during that fire season in Greece) as estimated by the European Forest Fire Information System Burnt Area satellite product (EFFIS, 2021). According to the same sources a wildfire started directly to the Northeast of Athens, in Attica, on the 5th ending on the 6th of August and burning 8400ha. Other significant fires were detected through their FRP signatures in western Greece and in neighbouring countries. During that period residents reported a strong deposition of ashes inside the city and authorities advised the population to stay indoors or use respiratory masks otherwise (Smith, 2021).

2.2. APIFLAME

Biomass burning emissions of trace gases and aerosols during the 2021 Greece wildfires were calculated using the APIFLAMEv2 model (Turquety et al., 2020). The estimates are based on pre-processed satellite imagery in the form of the MODIS burned scars product (MCD64A1) which uses thermal anomalies from active fires and changes in reflectance due to the charring of the vegetation to detect burned regions. This product has a 500m resolution and is released on a monthly basis indicating the estimated day of burning for each detection. For each fire and associated vegetation type, the consumed fuel was calculated, and the corresponding emissions of 46 trace gases and aerosols were derived using a list of emission factors. The module also uses the fire radiative power (FRP) from the MOD14 satellite product, which processes four daily observations at 1km resolution. This is used in the calculation of the injection height. CHIMERE then re-distributes these emissions in the vertical direction according to a plume rise profile that assigns 20% of the emissions below the injection-height and the remainder around that same height.

2.3. WRF-CHIMERE

The impact of the emissions of wildfires on AQ was quantified based on a modelling approach, using the state-of-the-art CHIMERE model (Menut et al., 2021). This model is an open-source multi-scale Eulerian Chemistry Transport Model, which includes detailed gas-, aerosol- and cloud-phase chemistry. The chosen MELCHIOR2 chemistry mechanism takes 49 species and 120 reactions into account. Additionally, 7 aerosol species are subdivided into 10 size bins, whose chemistry is also considered. CHIMERE can run over a range of spatial scales from the hemispheric to the urban scale (up to 1x1km^2). It has been widely used for operational forecasts in Europe, which has allowed for extensive testing and validation over this study region (Kukkonen et al., 2012).

In addition to biomass burning, the AQ simulations considered anthropogenic, mineral dust, biogenic and sea salt emissions. Anthropogenic emissions from EMEP (EMEP, 2021) were processed to obtain hourly fluxes for the different model species (associated to the selected chemical mechanism) and the specific simulation grids. Available time profiles for specific countries were used, as well as spatial proxies such as land-use, population density, and road networks density. Desert dust, marine aerosols and biogenic emissions were estimated by the model during the simulations, taking static datasets and meteorological data into account.

The boundary conditions for the WRF meteorology driver were taken from the ERA-5 reanalysis dataset (ECMWF, 2022) with a horizontal resolution of 30km and 37 pressure levels between 1000hPa and 1hPa at six-hour intervals. Once these calculations were performed the higher resolution data was passed on directly to CHIMERE.

The whole system was run between 27-07-2021 and 06-08-2021 thus capturing the period with the highest levels of air-pollution around Athens and providing a seven-day spin-up period to stabilize all simulation variables that may be affected by inaccuracies in the initial conditions. The mesh for Greece was nested inside a larger mesh resulting in two computational domains. The coarser mesh captured phenomena at the level of the Mediterranean Basin with 95x69 cells, while the smaller one was positioned around Greece with 106x81 cells as can be seen in Figure1. The structured hexahedral mesh was created over a lambert conformal map of the computational domain with 24 cells between the surface and 200hPa.

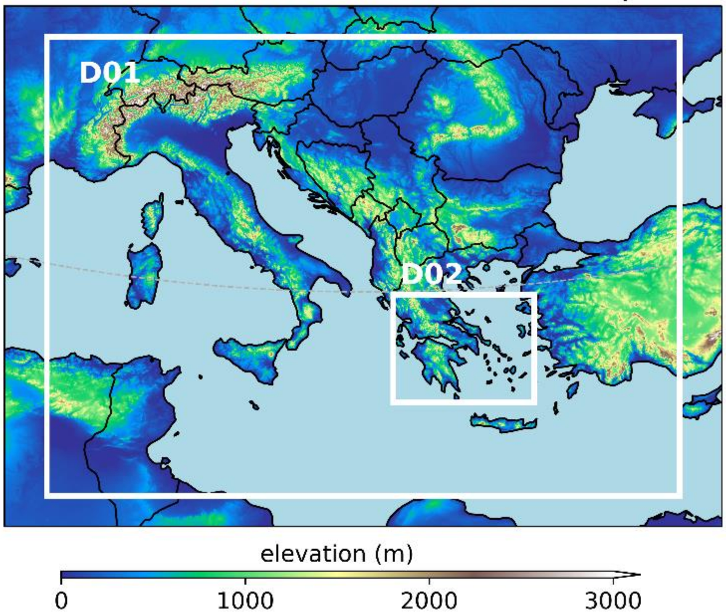


Figure 1 – WRF-CHIMERE nested domains used for the simulations plotted over an elevation map of the Mediterranean Basin. D01: coarse domain with 25km resolution. D02: small domain with 5km resolution.

3. Results

3.1. Validation

The results of the simulations were compared with data from air-quality monitoring stations which were extracted from the AQ database of the European Environmental Agency (EEA, 2021). The goal of this validation is understanding the ability of the system to model smoke emission and dispersion. Since PM and CO are consistently emitted by fires and good tracers of smoke (Schneider, 2021) these two pollutants were considered the most suitable for comparing model results.

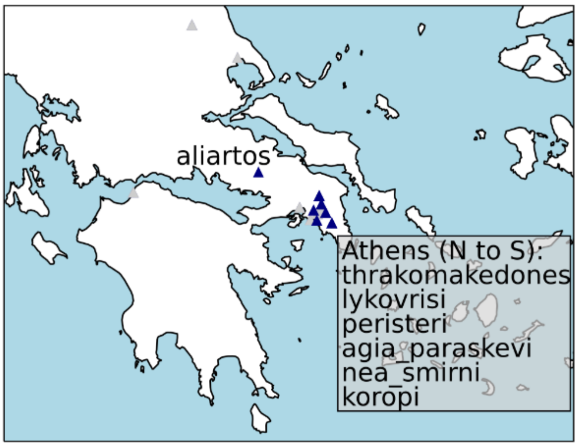


Figure 2 – Location of AQ monitoring stations within D02. Grey locations are not "background" stations and were removed.

Of the 19 available monitoring stations 7 were chosen, with their locations shown in Figure 2. These are classified as "background" stations and are more representative of a larger area around them, as opposed to "traffic" or "industrial" stations which are greatly affected by local phenomena, i.e. sub-grid phenomena for the model.

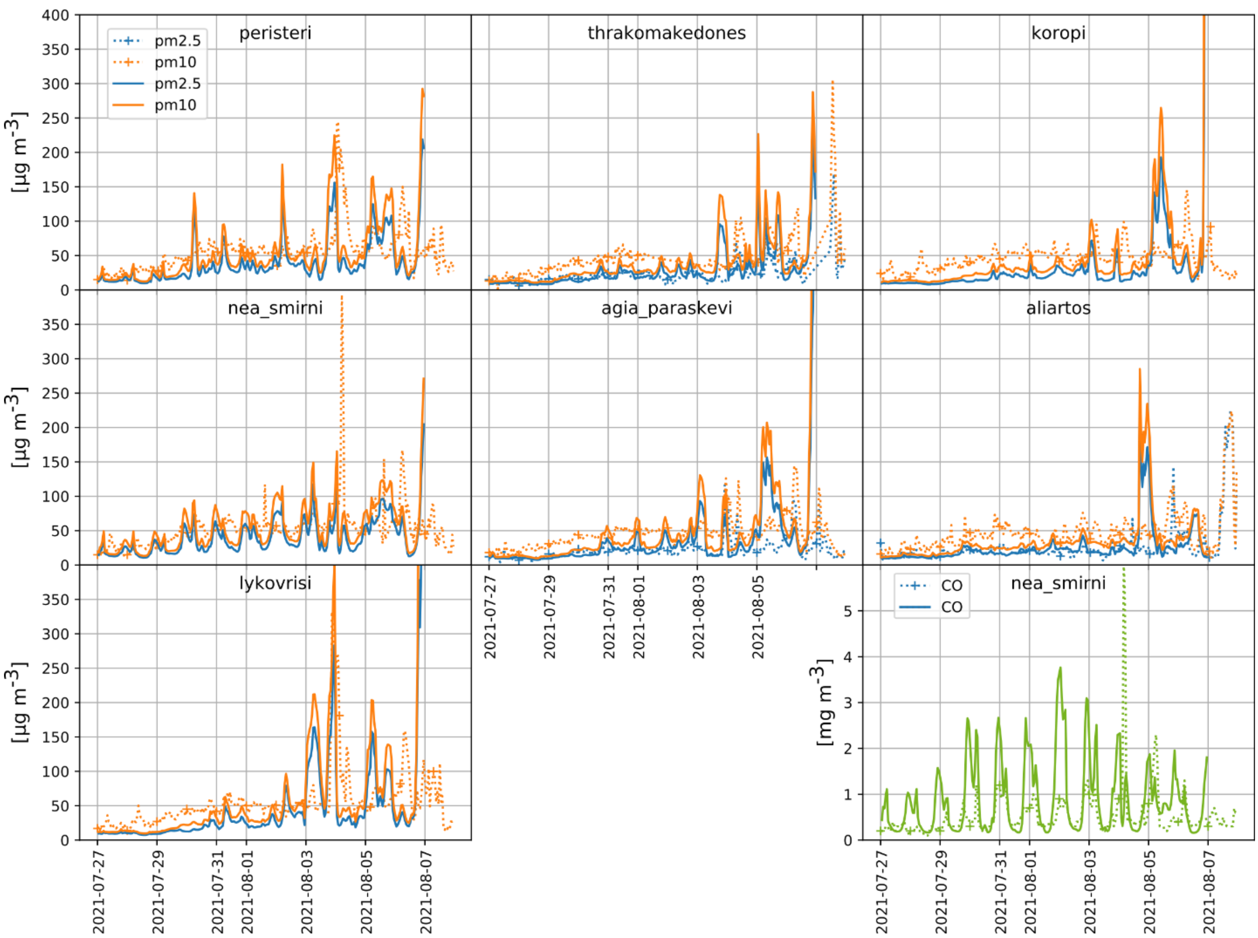


Figure 3 – Measured (dashed) and simulated (continuous) concentrations of CO and PM at the chosen sites.

Once the data was acquired, the AQ monitoring stations were associated to the grid cell of the small domain closest to it and concentration values were compared (Figure 3). Only one station measured CO concentrations, "nea_smirni". The daily fluctuations of this species are slightly underpredicted. PM concentrations, on the other hand, were widely available. Overall, discrepancies become more accentuated during wildfire periods, the station and model concentrations follow the same trends within the same order of magnitude, and the bias is small.

3.2. Emissions

Figure 4 shows the spatial distribution (5×5 km^2) of the atmospheric emissions during the fire events in Greece. It is apparent that the wildfire in Evia Island released the most amount of pollutants, not only due to high emissions by cell, but also the large area. Another four fires in Western Greece evidenced considerable emissions, together with a fire directly East of Athens.

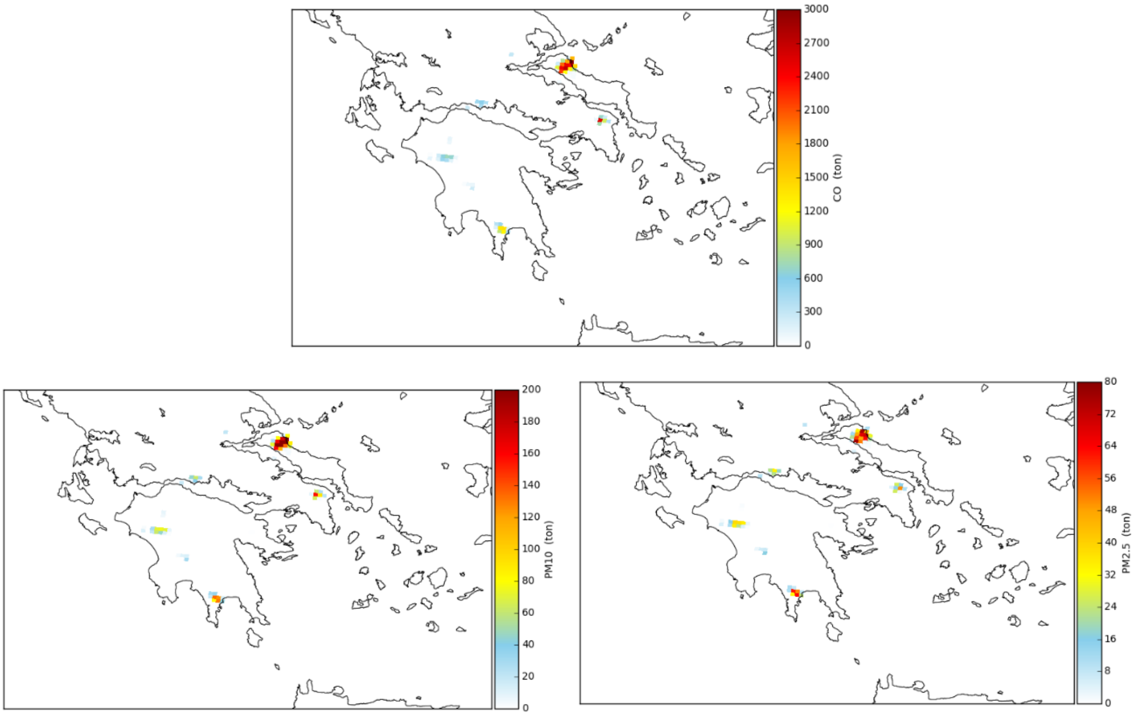
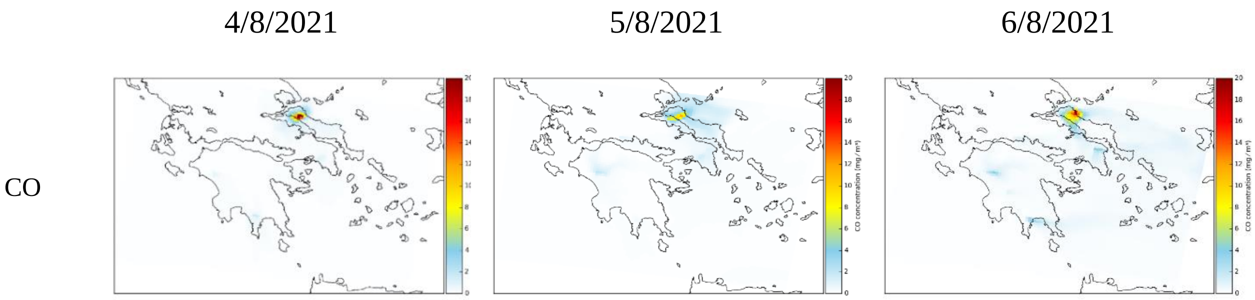


Figure 4 - Spatial distribution of the CO, PM10 and PM2.5 total emissions (ton) between 27th July and 8th August 2021.

3.3. Air Quality

Concentrations of CO and PM at the surface were analyzed through time-series of maps containing the spatial distribution (5×5 km^2) of the atmospheric levels. The daily averages for days 4 to 6 are shown in Figure 5. The European Ambient Air Quality Directive (2008/50/EC) sets limits at 25µg/m^3 for PM2.5 (annual limit) and 50µg/m^3 (daily limit) for PM10 above which considerable health impacts are to be expected.



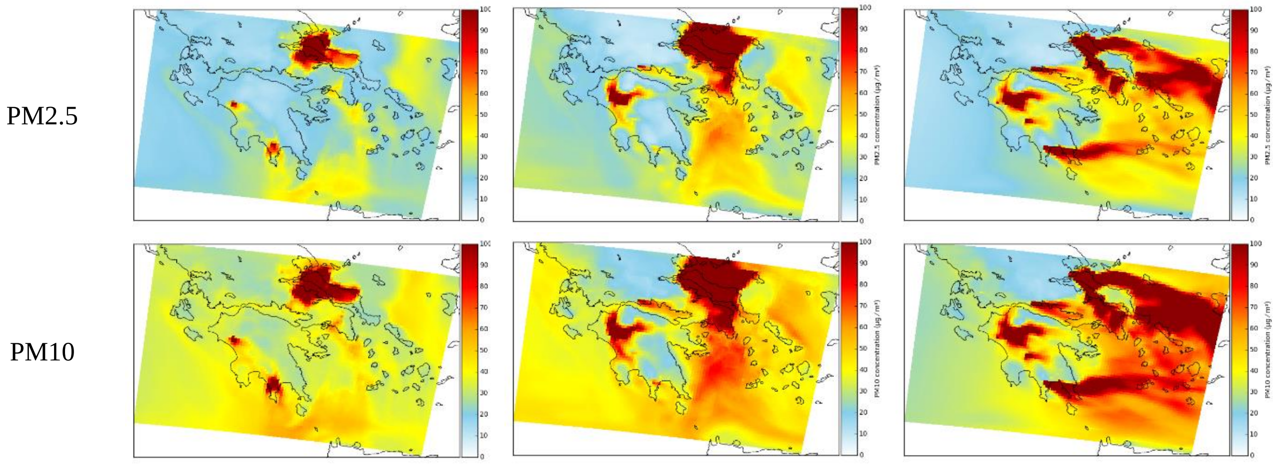


Figure 5 - Spatial distribution of the CO, PM2.5 and PM10 daily mean concentration (µg·m^{-3}) of simulated values at surface level.

On the 4th of August the fire in Evia starts early in the morning and air-pollution in the area increases throughout the day as seen from the plots, however the weak winds near the surface inhibit the dispersion of smoke and Athens is not affected. It is only during the night that PM reach dangerous levels. During the 5th of August PM levels remain high due to the ignition of the fire to the East of Athens. Atmospheric conditions are like the previous day so that PM from Evia is no longer reaching the city. Strong Easterly winds at dusk have a significant impact in cleaning the air-pollutants out of the city. This also advects smoke from fires burning to the East, however the effect on AQ is positive. Throughout the beginning of the 6th of August surface winds remain strong. By veering to the North and loosing much of their strength on the second half of the day, considerable levels of air-pollutants accumulate over Athens.

The simulation results indicate that Athens was experiencing levels of PM above the threshold before the beginning of the fires and days 5 and 6 of August were significantly impacted by the forest-fire smoke. Thus, all three days exceeded the PM thresholds.

4. Conclusions

The high spatiotemporal resolution of the calculated concentrations allowed for a more detailed analysis of the smoke plume dispersion and development, which would be unmanageable with satellite images or local air-quality monitoring stations. The model results showed a good agreement with measurements in general. However, the simulated levels of PM were clearly exaggerated during one of the events of wildfire smoke over Athens. Further analysis of the vertical profiles of the smoke and plume rise models will provide more information on how to improve model predictions during such extreme wildfire events.

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9. Bibliography

Corona, P., Ascoli, D., Barbati, A., Bovio, G., Colangelo, G., Elia, M., Garfì, V., Iovino, F., Lafortezza, R., Leone, V., Lovreglio, R., Marchetti M., Marchi M., Menguzzato G., Nocentini S., Picchio R., Portoghesi L., Puletti N., Sanesi G. and Chianucci F. (2015). Integrated forest management to prevent wildfires under Mediterranean environments. Annals of Silvicultural Research, 39, 1-22. https://doi.org/10.12899/asr-946

Dupuy, J.L., Fargeon, H., Martin-StPaul, N., Pimont, F., Ruffault, J., Guijarro, M., Hernando, C., Madrigal, J. and Fernandes, P. (2020). Climate change impact on future wildfire danger and activity in southern Europe: a review. Annals of Forest Science, 77(2), 1-24. https://doi.org/10.1007/s13595-020-00933-5

ECMWF: European Centre for Medium-Range Weather Forecast (2022) ERA5 hourly data on pressure levels from 1979 to present. Retrieved March 2022. https://doi.org/10.24381/cds.bd0915c6

EEA: European Environmental Agency (2021). Air quality e-reporting. Retrieved January 2022. https://www.eea.europa.eu/data-and-maps/data/aqereporting-2

EFFIS: European Forest Fire Information System (2022, March). Rapid Damage Assessment – MODIS Burnt Areas. Retrieved March 2022. https://effis.jrc.ec.europa.eu/about-effis/technical-background/rapid-damage-assessment

EMEP/Centre on Emission Inventories and Projections database (2021). EMEP gridding 2021/2019. Retrieved March 2022. https://webdab01.umweltbundesamt.at/download/gridding2021/2019/

Giglio, L., Hall, J. V., Schroeder, W., Justice, C. O. (2021, February 11). MODIS/Terra Thermal Anomalies/Fire 5-Min L2 Swath- 1km. Retrieved March 2021. http://doi.org/10.5067/MODIS/MOD14.NRT.061

Kukkonen, J., Olsson, T., Schultz, D. M., Baklanov, A., Klein, T., Miranda, A. I., Monteiro, A., Hirtl, M., Tarvainen, V., Boy, M., Peuch, V.-H., Poupkou, A., Kioutsioukis, I., Finardi, S., Sofiev, M., Sokhi, R., Lehtinen, K. E. J., Karatzas, K. R., San José, Astitha, M., Kallos, G., Schaap, M., Reimer, E., Jakobs, H. and Eben, K. (2012). A review of operational, regional-scale, chemical weather forecasting models in Europe. Atmospheric Chemistry and Physics, 12(1), 1-87. https://doi.org/10.5194/acp-12-1-2012

Menut, L., Bessagnet, B., Briant, R., Cholakian, A., Couvidat, F., Mailler, S., Pennel, R., Siour, G., Tuccella, P., Turquety, S. and Valari, M. (2021). The CHIMERE v2020r1 online chemistry-transport model. Geoscientific Model Development, 14, 6781-6811. https://doi.org/10.5194/gmd-14-6781-2021

Miranda, A. I., Martins, V., Cascão, P., Amorim, J. H., Valente, J., Borrego, C., Ferreira, A.J., Cordeiro, C.R., Viegas, D.X. and Ottmar, R. (2012). Wildland smoke exposure values and exhaled breath indicators in firefighters. Journal of Toxicology and Environmental Health, Part A, 75(13-15), 831-843. https://doi.org/10.1080/15287394.2012.690686

Péré, J.C., Bessagnet, B., Mallet, M., Waquet, F., Chiapello, I., Minvielle, F., Pont, V. and Menut, L. (2014). Direct radiative effect of the Russian wildfires and its impact on air temperature and atmospheric dynamics during August 2010. Atmospheric Chemistry and Physics, 14(4), 1999-2013. https://doi.org/10.5194/acp-14-1999-2014

Schneider, S. R., Lee, K., Santos, G., & Abbatt, J. P. (2021). Air Quality Data Approach for Defining Wildfire Influence: Impacts on PM2.5, NO_2, CO, and O_3 in Western Canadian Cities. Environmental Science & Technology, 55(20), 13709-13717. https://doi.org/10.1021/acs.est.1c04042

Smith, H. (2021). ‘Apocalyptic’ scenes hit Greece as Athens besieged by fire (August 2021), https://www.theguardian.com/world/2021/aug/07, accessed 2021-11-09

Turquety, S., Menut, L., Siour, G., Mailler, S., Hadji-Lazaro, J., George, M., Clerbaux, C., Hurtmans, D. and Coheur, P.F. (2020). APIFLAME v2.0 biomass burning emissions model: impact of refined input parameters on atmospheric concentration in Portugal in summer 2016. Geoscientific Model Development, 13(7), 2981-3009. https://doi.org/10.5194/gmd-13-2981-2020