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Quantile machine learning models for predicting European-wide, high resolution fine-mode Aerosol Optical Depth (AOD) based on ground-based AERONET and satellite AOD data

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Air pollution is a major environmental risk factor for human health. Among the different air pollutants, Particulate Matter (PM) arises as the most prominent one, with increasing health effects over the last decades. According to the Global Burden of Disease, PM contributed to 4.14 million premature deaths globally in 2019, over twice as much as in 1990 (2.04 million). With these numbers in mind, the assessment of ambient PM exposure becomes a key issue in environmental epidemiology. However, the limited number of ground-level sites measuring daily PM values is a major constraint for the development of large-scale, high-resolution epidemiological studies.

In the last five years, there has been a growing number of initiatives estimating ground-level PM concentrations based on satellite Aerosol Optical Depth (AOD) data, representing a low-cost alternative with higher spatial coverage compared to ground-level measurements. At present, the most popular AOD product is NASA's MODIS (Moderate Resolution Imaging Spectroradiometer), but the data that it provides is restricted to Total Aerosol Optical Depth (TAOD). Compared with TAOD, Fine-mode Aerosol Optical Depth (FAOD) better describes the distribution of small-diameter particles (e.g. PM10 and PM2.5), which are generally those associated with anthropogenic activity. Complementarily, AERONET (AErosol RObotic NETwork, which is the network of ground-based sun photometers), additionally provide Fine- and Coarse-mode Aerosol Optical Depth (FAOD and CAOD) products based on Spectral Deconvolution Algorithms (SDA).

Within the framework of the ERC project EARLY-ADAPT (https://early-adapt.eu/), which aims to disentangle the association between human health, climate variability and air pollution to better estimate the early adaptation response to climate change, here we develop quantile machine learning models to further advance in the association between AERONET FAOD and satellite AOD over Europe during the last two decades. Due to large missing data form satellite estimations, we also included the AOD estimates from ECMWF's Copernicus Atmosphere Monitoring Service Global Reanalysis (CAMSRA) and NASA's Modern-Era Retrospective Analysis for Research and Applications v2 (MERRA-2), together with atmosphere, land and ocean variables such as boundary layer height,

downward UV radiation and cloud cover from ECMWF's ERA5-Land.

The models were thoroughly validated with spatial cross-validation. Preliminary results show that the R^2 of the three AOD estimates (TAOD, FAOD and CAOD) predicted with quantile machine learning models range between 0.61 and 0.78, and the RMSE between 0.02 and 0.03. For the Pearson correlation with ground-level $PM_{2.5}$, the predicted FAOD is highest (0.38), while 0.18, 0.11 and 0.09 are for Satellite, MERRA-2, CAMSRA AOD, respectively. This study provides three useful indicators for further estimating PM, which could improve our understanding of air pollution in Europe and open new avenues for large-scale, high-resolution environmental epidemiology studies.