A satellite-based spatio-temporal machine learning model to reconstruct daily PM2.5 concentrations across Great Britain

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Epidemiological studies on the health effects of air pollution usually rely on measurements from fixed ground monitors, which provide limited spatio-temporal coverage. Data from satellites, reanalysis, and chemical transport models offer additional information used to reconstruct pollution concentrations at high spatio-temporal resolutions. This study aims to develop a multi-stage satellite-based machine learning model to estimate daily fine particulate matter (PM2.5) levels across Great Britain between 2008-2018. This high-resolution model consists of random forest (RF) algorithms applied in four stages. Stage-1 augments monitor-PM2.5 series using co-located PM10 measures. Stage-2 imputes missing satellite aerosol optical depth observations using atmospheric reanalysis models. Stage-3 integrates the output from previous stages with spatial and spatio-temporal variables to build a prediction model for PM2.5. Stage-4 applies Stage-3 models to estimate daily PM2.5 concentrations over a 1 km grid. The RF architecture performed well in all stages, with results from Stage-3 showing an average cross-validated R2 of 0.767 and minimal bias. The model performed better over the temporal scale when compared to the spatial component, but both presented good accuracy with an R2 of 0.795 and 0.658, respectively. These findings indicate that direct satellite observations must be integrated with other satellite-based products and geospatial variables to derive reliable estimates of air pollution exposure. The high spatio-temporal resolution and the relatively high precision allow these estimates (approximately 950 million points) to be used in epidemiological analyses to assess health risks associated with both short- and long-term exposure to PM2.5.
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