Innovative Sensors and Models for City-level Air Pollution Exposure Monitoring

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Aims: Space-time resolved estimates of air pollution exposure require information on the movement and location of study subjects together with predictions of air pollution concentration; however, the possibilities are typically limited by the available data. The Dutch city of Eindhoven (90 km^2, 225,000 inhabitants) has two monitoring stations in the LML (Dutch national air quality monitoring system), yielding hourly data. This has been augmented (2013) by 35 "Airboxes" equipped with low-cost sensors for particulate matter (PM), NO2, O3 and ultra-fine particles delivering measurements every 10 minutes, as part of the ILM AiREAS initiative. These data pose new opportunities but raise new challenges, specifically: How should the data be organized? What are their quality and how can this be evaluated automatically? What are the appropriate models to provide spatial-temporal measures of exposure? What spatial and temporal resolutions can be achieved?

Methods: The variability in the PM data was evaluated using descriptive statistics and the variogram (to explore spatial autocorrelation), allowing exploration of different spatial and temporal resolutions. The ILM PM data were validated against the LML data in 2013 and 2015. For analysis we used Bayesian maximum entropy (BME) and space-time dynamic models. Both allowed additional information, for example dispersion model output and weather data, to be incorporated. We used a service oriented architecture (SOA), based on standards from the Open Geospatial Consortium (OGC), to organize the data.

Results: The exploratory analysis showed that the variability in the ILM PM data increased from 10% to 16% (coefficient of variation) between 2013 and 2015 The ILM data tended to

record lower values than the LML data, although the peaks and troughs were still observed. The 10-minute data were typically too noisy to allow the identification of spatial correlation, although this was clear when averaged to 1-hour averages and for longer time periods. Using BME we were able to integrate the dispersion model and ILM data, yielding an RMSE of 1 $\mu g\ m^{-3}$ for daily PM2.5. The SOA was effective to combine different datasets (e.g., ILM and LML) and to implement simple geostatistical models in an automated fashion.

Conclusions: Using low-cost sensors allowed us to identify spatial and temporal patterns that are valuable for spatial prediction at sub-daily time resolutions. These patterns can be identified and modelled using space-time geostatistics e.g., BME. Standards-based tools should be used for organizing, archiving and disseminating data and are essential for future automated analysis.

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