Research Highlight

‘Global high-resolution ultrafine particle number concentrations through data fusion and machine learning’

Summary

Global high-resolution ultrafine particle number concentrations through data fusion with machine learning present the first global maps of particle number concentration (PNC) and associated ultrafine particles (UFPs) at 1 km resolution over land for 2010–2019, led by the Climate and Atmosphere Research Center (CARE-C) of The Cyprus Institute in close collaboration with the Computation-based Science and Technology Research Center (CaSToRC) of The Cyprus Institute and the Max Planck Institute for Chemistry (MPIC). The study fuses long-term measurements from 155 ground stations with a rich set of global predictors, including emissions, NO_2 and $PM_{2.5}$ fields, population and built-up volume, road networks, and key meteorological variables, using an XGBoost regression model with conformal prediction for uncertainty quantification. The model attains $R^2 \approx 0.90$ on an independent test set and R^2 of 0.77–0.87 under spatial and temporal cross-validation and indicates that UFPs constitute on average about 91% of total PNC, with annual mean near-surface PNC ranging from a few thousand cm^{-3} in pristine regions to over 40,000 cm^{-3} in polluted urban centres. The resulting open-access NetCDF dataset (2010–2019) provides annual mean PNC, UFP and 95% coverage intervals on a global 1 km grid, enabling direct integration with high-resolution population data for exposure and health impact studies.

Impact

Delivering ultrafine particle number concentrations at 1 km resolution fundamentally changes what can be done in exposure and health-impact assessment. This scale is crucial for UFPs, whose concentrations vary steeply over hundreds of metres near traffic corridors, industrial sites and dense urban canyons; coarser products systematically smooth out these hotspots and underestimate risks to populations that live, work or attend school in immediate proximity to major sources. By resolving these fine-scale gradients on a globally consistent grid, the dataset enables epidemiological studies to link long-term UFP exposure to health outcomes with less spatial misclassification, improving estimates of disease burden and sharpening

Authors’ bios

Dr. Pantelis Georgiades is an Associate Research Scientist at The Cyprus Institute (CyI), holding an M.Sc. in Physics and a Ph.D. in Biological Physics from the University of Manchester. His early career included postdoctoral research in super-resolution microscopy and a role as a Data Scientist applying novel AI methodologies to cybersecurity. Dr. Georgiades later joined CyI, transitioning his expertise into the study of vector-borne diseases, climate science, and environmental health. He actively contributes to climate science by developing AI models for climate and atmospheric modelling, including bias-

the evidence base for UFP-specific guidelines and standards.

Beyond health, the maps can act as a decision-support tool for many sectors by highlighting where UFP exposures are persistently high. They can inform urban and transport planning, air-quality management, infrastructure investment and environmental regulation, especially in rapidly developing regions with sparse monitoring. Their global coverage and quantified uncertainties also make them useful as a benchmark for models and for comparative assessments of UFP exposure across populations.

Reference

Georgiades, P., Kohl, M., Nicolaou, M.A., Christoudias, T., Pozzer, A., Dovrolis, C. & Lelieveld, J. Global high-resolution ultrafine particle number concentrations through data fusion with machine learning. Sci Data 12, 1790 (2025). https://doi.org/10.1038/s41597-025-06055-9

Contact details

Pantelis Georgiades – p.georgiades@cyi.ac.cy

correcting and downscaling air pollutants like NO_2 and $PM_{2.5}$ as well as climate forecasting and projections. Dr. Georgiades's research interests centre on applying advanced AI methodologies to climate, health, and climate change impact assessment.

Prof Jos Lelieveld is Director at the Max Planck Institute for Chemistry in Mainz, and Professor at the Cyprus Institute where he leads the Environmental Prediction Department of CARE-C.