Synergy between different earth observation platforms towards the estimation of the intra-urban population exposure to wintertime air pollution of Athens

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APCG National Observatory of Athens – Atmospheric Physics and Chemistry Group

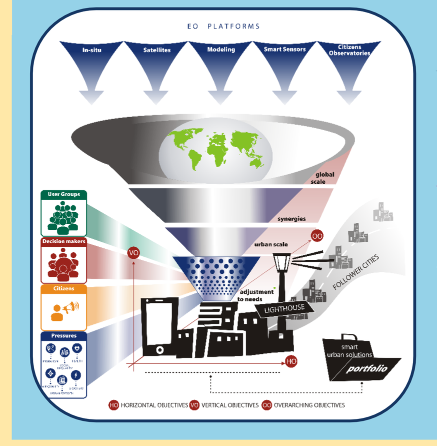
SMURBS ERA-PLANET

Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research

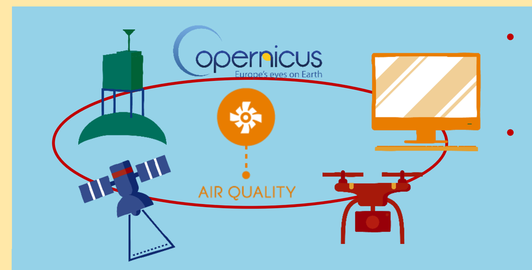
Background | Motivation

The percentage of population residing in urban areas in Europe continues to increase from 74.9% in 2019, and it is expected to reach 77.5% (83.7%) by 2030 (2050) [1,2]. This in turn will increase the urban population exposed to air pollutants and the consequent health impacts.

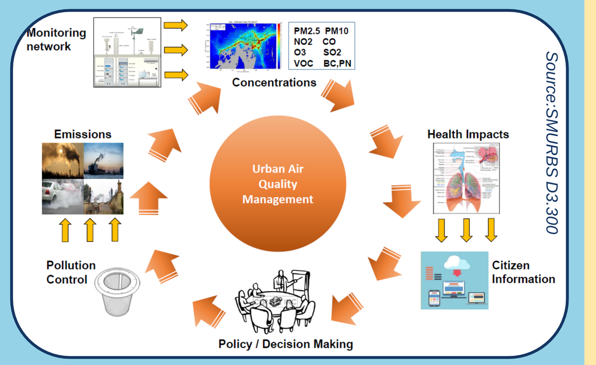
Source: ESA



The "SMart URBan Solutions for air quality, disasters and city growth" (SMURBS/ERA-PLANET) H2020 project (GA: 689443) https://smurbs.eu/ revisited the smart city concept via the exploitation and synergy of different, state-of-the-art earth observation platforms, towards enhancing environmental and societal resilience to air pollution, and other, collectively selected, urban pressures.



- Cross-validated EO information and synergies between different platforms/services for city scale applications *(Objective of SMURBS/ERA-PLANET)*
- Higher spatial resolution -at least in monitoring basic air pollutants- and new pollutants, with potentially high health risks *(from the Key Messages of User Needs of SMURBS)*
- Exploitation of Copernicus data and core services *(Objective of SMURBS/ERA-PLANET)*
- Integration of still-fragmented EO, into information and decision making tools for individuals and local governments *(Objective of SMURBS/ERA-PLANET)*
- Urban air quality management with integrated health assessment, dissemination to the public and city authority decision making process for pollution control *(from D3.3 of SMURBS)*



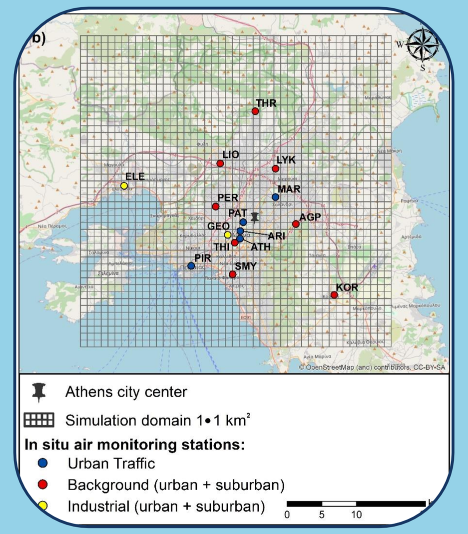
Source: SMURBS D3.300

Model | Experimental Data

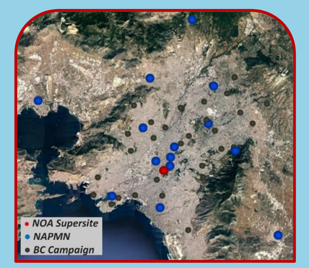
Name (version)	EPISODE-CityChem (v1.2r)
Short description	A Chemistry Transport Model to enable chemistry/transport simulations of reactive pollutants on the city scale. EPISODE is a Eulerian dispersion model developed at the Norwegian Institute for Air Research (NILU) appropriate for air quality studies at the local scale. The CityChem extension, developed at Helmholtz-Zentrum Geesthacht (HZG) is designed for treating complex atmospheric chemistry in urban areas and improved representation of the near-field dispersion.
Reference(s)	Karl et al., 2019 [13]; Hamer et al., 2019 [43]
Availability	The EPISODE model and the CityChem extension are open source code subject to the Reciprocal Public License ("RPL") Version 1.5, https://opensource.org/licenses/RPL-1.5. Zenodo. http://doi.org/10.5281/zenodo.1116173.
Important mechanisms	Gaseous chemistry: EmChem09-mod, including 70 chemical species, 67 thermal reactions and 25 photolysis reactions (Karl et al., 2019 [13]). Aerosol treatment: $PM_{2.5}$ and PM_{10} are treated as passive tracers. Dry deposition of particles due to Brownian diffusion, impaction, interception and gravitational settling, as well as wet scavenging (Simpson et al., 2003 [45]) Street canyon dispersion: Simplified street canyon model (SSCM) based on the Operational Street Pollution Model (OSPM; Berkowicz et al., 1997 [44]) using generic canyon classifications. Gaussian sub-grid dispersion: Line source dispersion (HIWAY2) coupled to SSCM. Point source dispersion by segmented plume model (SEGPLU). Local photochemistry (EP10-Plume; Karl et al., 2019 [13]) is applied in the receptor points of the receptor grid (100 × 100 m^2).
Boundary AQ conditions	CAMS reanalysis hourly AQ data (http://www.regional.atmosphere.copernicus.eu)
Air pollution emissions	Anthropogenic emission rates from CAMS-REG-APv1.3 (Denier van der Gon et al., 2010 ; Kuenen et al., 2011, 2014 [18,42]) **spatially disaggregated by The UrbEm approach (Ramacher et al., 2021): Oral presentation by N. Kakouri, 29/9 15.00 EET, ORAL SESSION Air quality I, COMECAP 2021**
Meteorological fields	The Air Pollution Model (TAPM) [41], fed by synoptic-scale meteorological reanalysis ensemble means (ECMWF ERA 5) .
Outputs	Hourly mean mass concentration values (μg m^{-3}) for O_3, NO, NO_X, H_2O_2, N_2O_5, HNO_3, SO_2, H2SO4, CO, $PM_{2.5}$, PM_{10}, NMVOCs (10 individual species)
Vertical grid	24 levels (from surface to ca. 3.7 km; first layer is 17.5 m thick)
Horizontal domain	SW corner 23.4E°, 37.8N° (45×45 cells of 1×1km^2, with an embedded receptor grid 100×100m^2) *See gridded domain on the right*
Simulation period	1-31 December, 2018
Scenarios	CAMS_noproxy: original emissions database, no proxies used for the downscaling UrbEm: high resolution emissions, based on CAMS, disaggregated through selected proxies

The validation of the city-scale modelling results for the key regulated pollutants (O_3, NO_2, $PM_{2.5}$, PM_{10}, CO) was performed using concentration data from the National Air Pollution Monitoring Network (NAPMN) and the NOA super-site at Thissio in the center of Athens.

14 NAPMN stations are operated by the Ministry of Environment and Energy inside the modelling domain, at locations with varying characteristics (5 traffic, 8 urban/suburban background and 1 industrial site).



Black carbon (BC) concentrations and their spatial distribution were indirectly calculated by the model, taking into account the strong linear interdependence between BC and CO in the urban setting (Baumgardner et al., 2002).



Conversion factors were determined from comparisons (during December 2018) of in-situ measured CO (NDIR – Horiba APMA 360) and BC (Magee AE33 7-λ Aethalometer) at the Thissio supersite and at traffic locations in the greater area of Athens. Hence, it was possible to apply separate conversion factors at urban/suburban background and traffic-impacted grid cells. The linear associations between BC-CO were characterized by r^2 values in the range of 0.92-0.93. The precision of these BC estimates was tested against measured daytime (10:00-18:00 LST) BC concentrations (using a portable Aethlabs AE51 micro-aethalometer) at 50 locations around the Athens Basin during December 2018 (Grivas et al., 2019).

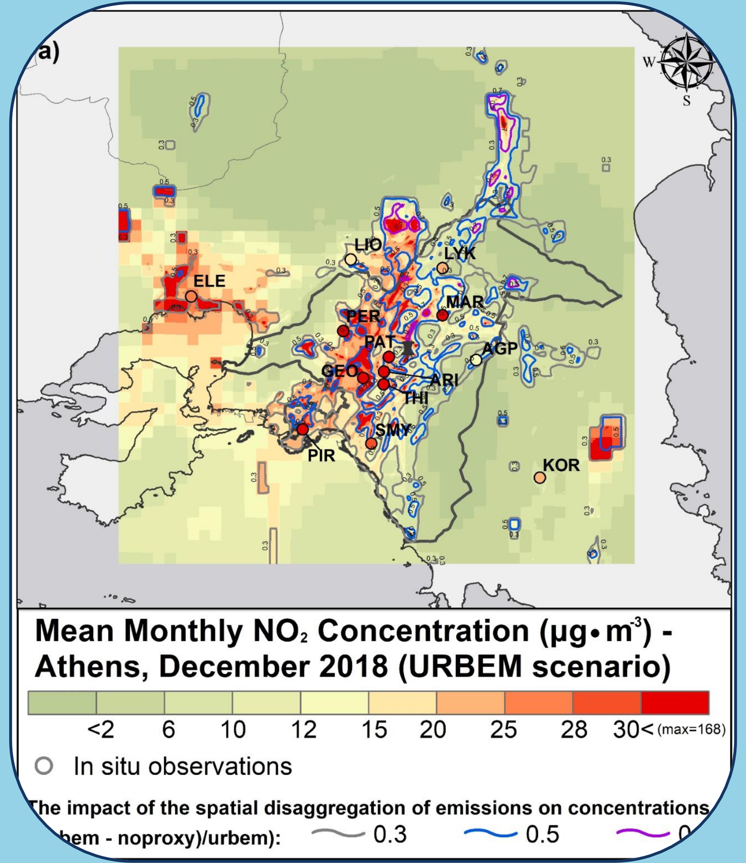
City-scale Model evaluation

The detailed spatial representation of air pollution levels necessitates high resolution emission inventories. The comparison of current predictions (down to 100 m resolution) with available observations shows an effective reduction of model underestimations, when emissions are spatially disaggregated through the UrbEm approach **(Oral presentation by N. Kakouri, 29/9 15.00 EET, ORAL SESSION Air quality I, COMECAP 2021).**

The ability of UrbEm to create line sources for emissions from road transport is of particular value for the selected urban scale model, which explicitly treats line sources, street canyons, and sub-grid photochemistry. The effectiveness of the particular model system is reflected in the performance for NO_2 over the traffic urban areas.

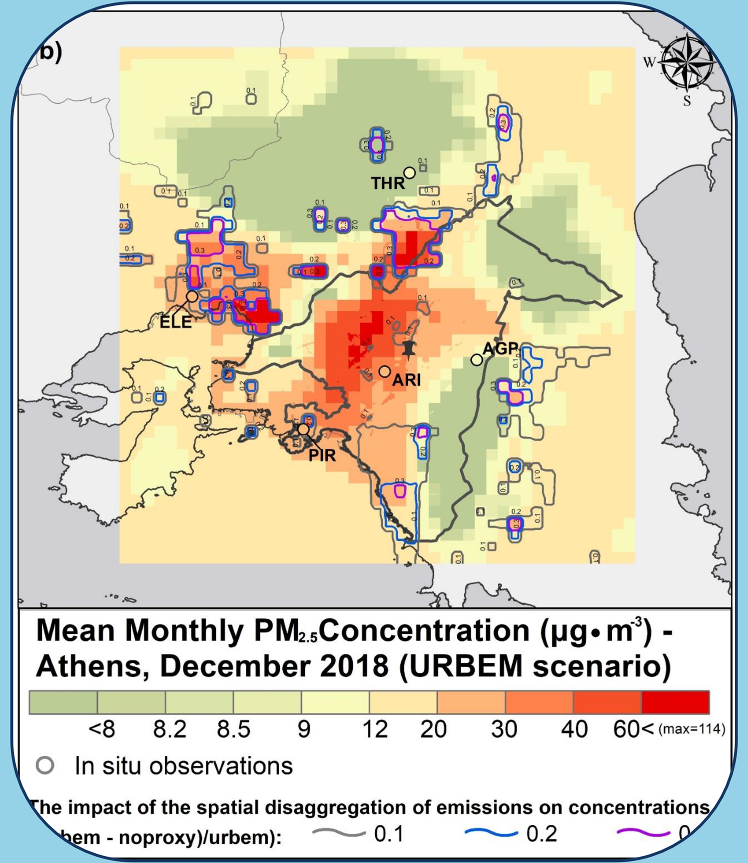
The effect of high resolution emissions (i.e. the UrbEm approach) is less pronounced for $PM_{2.5}$, because 1) traffic has a smaller footprint on $PM_{2.5}$ and hence on its spatial disaggregation and 2) $PM_{2.5}$ shows less spatial variability, due to its governing atmospheric processes, including the role of secondary inorganic and organic formation of atmospheric aerosols.

pollutant	type	scenario	n	FAC2	NMB	RMSE	r	IOA	mean_mod	mean_obs	SD_mod	SD_obs
NO_x	urban background	CAMS_noproxy	4131	0,29	-0,61	22,31	0,28	0,41	8,60	22,83	9,42	17,59
	urban background	UrbEm	4131	0,32	-0,52	21,43	0,33	0,43	10,44	22,83	12,14	17,59
	urban industrial	CAMS_noproxy	1166	0,47	-0,32	22,58	0,09	0,32	19,68	31,46	13,43	15,89
	urban industrial	UrbEm	1166	0,73	-0,04	20,27	0,43	0,45	30,71	31,46	20,91	15,89
	urban traffic	CAMS_noproxy	3620	0,17	-0,74	39,47	0,34	0,20	10,92	42,92	7,99	24,64
	urban traffic	UrbEm	3620	0,45	-0,47	29,89	0,50	0,42	22,51	42,92	17,48	24,64
$PM_{2.5}$	urban background	CAMS_noproxy	1352	0,40	-0,53	8,33	-0,01	0,09	4,92	10,82	3,45	4,83
	urban background	UrbEm	1352	0,36	-0,59	8,97	-0,04	0,00	4,22	10,82	3,74	4,83
	urban industrial	CAMS_noproxy	162	0,65	0,31	19,85	0,57	0,51	25,78	23,01	16,68	22,04
	urban industrial	UrbEm	162	0,59	0,57	26,13	0,60	0,37	29,14	23,01	21,46	22,04
	urban traffic	CAMS_noproxy	1482	0,73	0,06	23,59	0,42	0,56	26,89	25,41	19,35	24,03



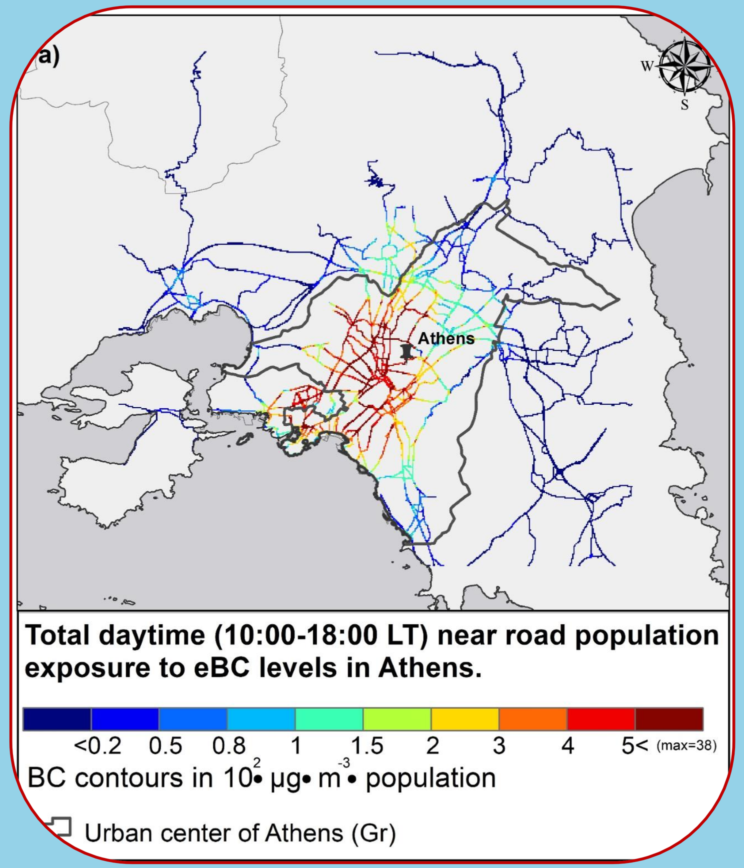
The spatial optimization of coarse emissions over the complex area of Athens during a highly polluted winter month contributes more than 30% and up to 70% to the modeled NO_X concentrations over most of the urban area, and other polluted areas outside the urban center.
Indicatively, over the sites of model-measurement mean monthly inter-comparison (e.g., PIR, ELE, PER, LIO) the UrbEm approach improves model results by 30-50%, when compared to the CAMS_noproxy scenario.

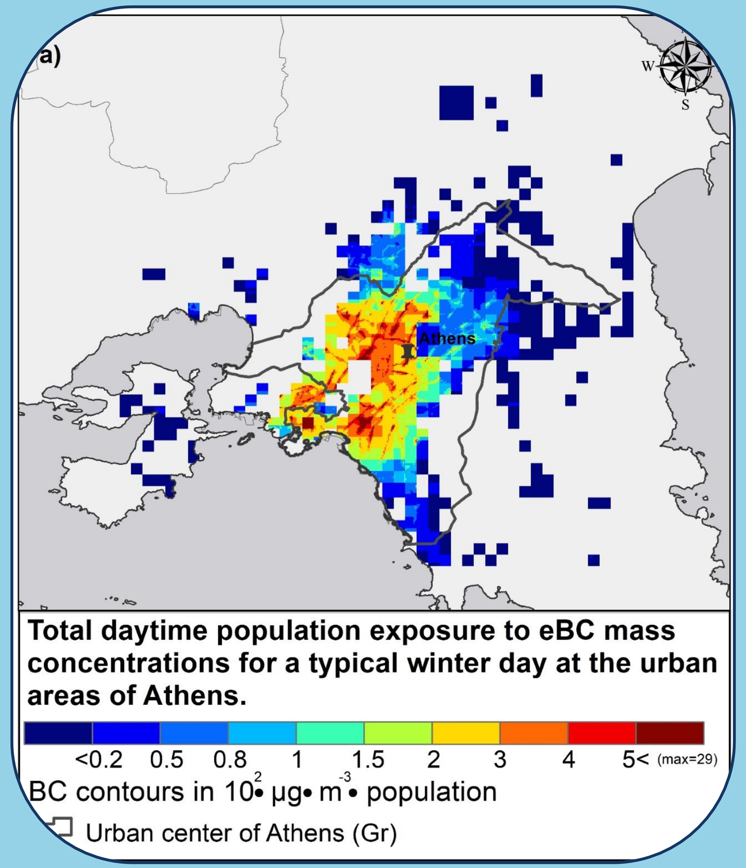
The contribution of UrbEm to the mean monthly $PM_{2.5}$ predictions based on CAMS emissions is lower (up to 30%), and occurs mainly outside the urban center, over the industrial areas and the northern residential suburbs. These maxima of UrbEm effects are related to the spatial optimization of industrial emissions and residential combustion, respectively.
From the 4 measuring sites of $PM_{2.5}$, only the predictions at the urban traffic site at the port (PIR) seem to differentiate around 20%, with the UrbEm approach being consistent with the mean monthly observations.

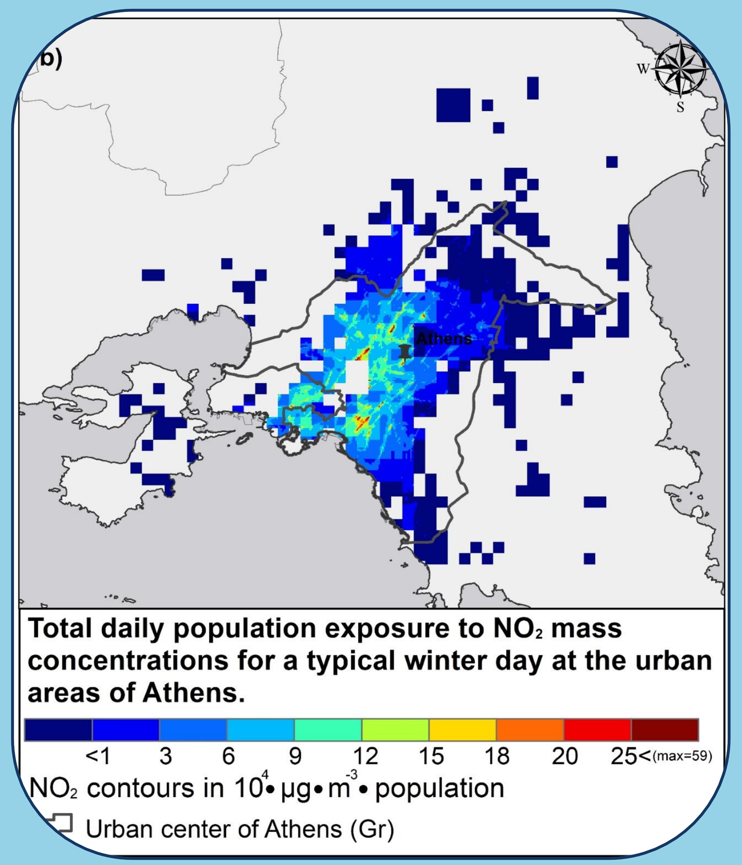


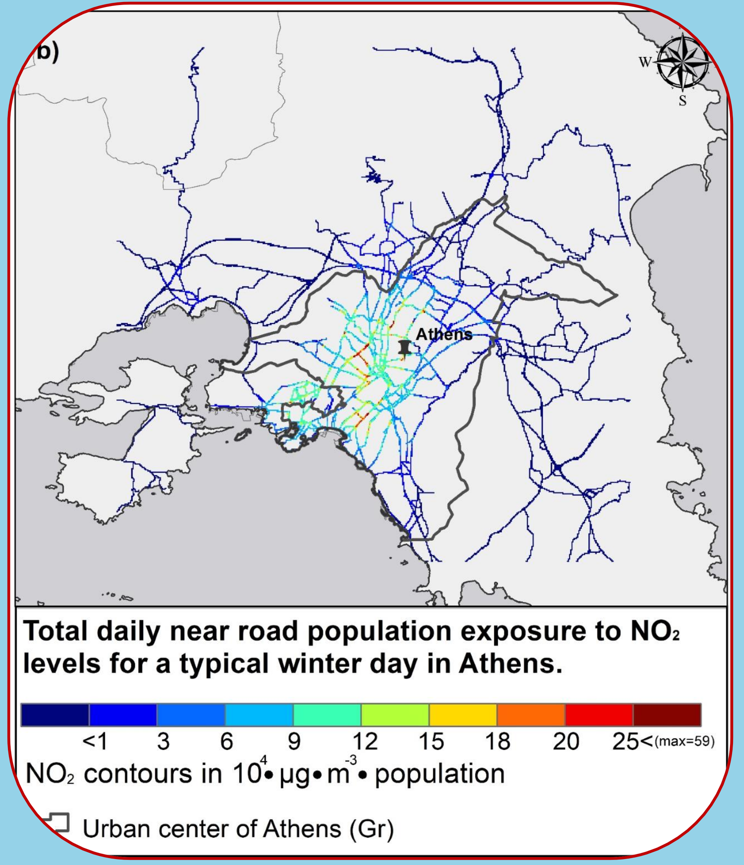
Intra-urban population exposure to air pollution levels

- The synergy with satellite-derived high resolution land type information enabled targeted mapping of population exposure in urban areas and in proximity to the road network.
- The synergy with innovative AQ sensors enabled the derivative maps of population exposed to equivalent BC (eBC) from fossil fuels.
- Road transport is a substantial source of exposure to NO2 and eBC in the Athens urban area.
- The complex topography and emission sources –when incorporated in high resolution AQ modeling- create high gradients in population exposure.









The ability to incorporate fine-scale variability (100m×100m) in air pollution exposure allows for

- the creation of a more nuanced picture of the air pollutants-health association
- the improvement of 'hotspots' representation
- informed and tailored decision making
- regulations and other interventions
- a more direct impact on reducing air pollution inequalities and health-relevant impacts.

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