An IoT based approach to ultra high resolution air quality mapping through field calibrated monitoring devices

Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

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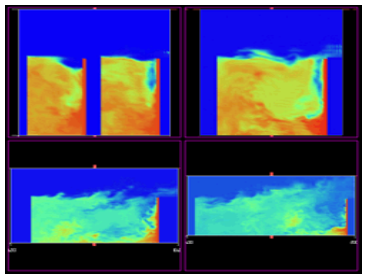
The starting point: Naples Metropolitan area AQ network



- Regulatory AQM network in Naples metropolitan area.
- 8 Stations are currently used for AQ monitoring in the Naples urban area (117Km2, 955k inhabitants).
- **Roughly, that accounts for one station for each 15Km2 and/or one station each 120k inhabitants!**
- It is worth to note that this is one of the most dense network in Europe and it is perfectly in line with the regulating EC directive.
- **As a results small towns have limited knowledge of what happens at their urban scale.**

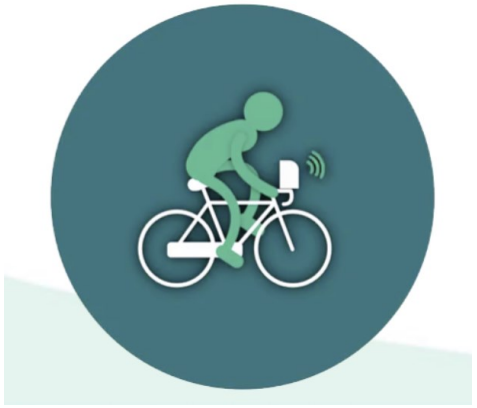
A relatively dense regulatory grade monitoring network which leaves many densely inhabitated area with limited knowledge on local scale AQ

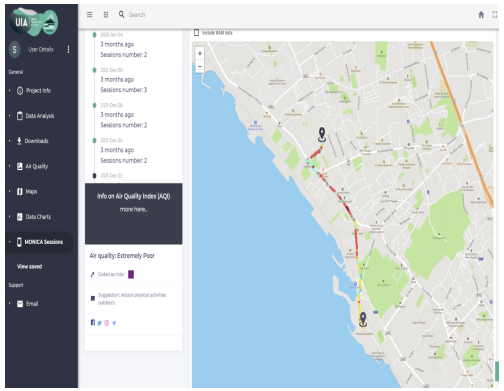
From sparse to dense, hierarchical AQ Monitoring

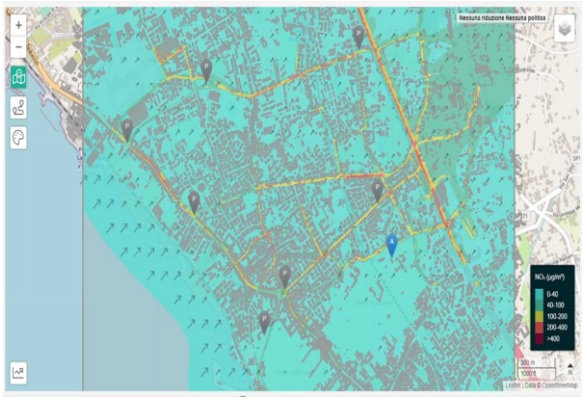
- Advances in IoT and chemical sensors calibration technologies have led to the proposal of **Hierarchical air quality monitoring networks**.

- These relies on sensing nodes which differs from size, cost, accuracy, technology, maintenance needs while having the potential to empower smart cities and communiities with increased knowledge on the highly spatiotemporal variance Air Quality phenomenon.

Successful Citizen Science for AQ: AirHeritage project Pillars







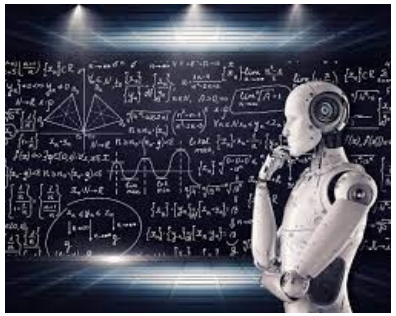
Community based approach:

Monitoring & Sustainable hyperlocal mobility experience:
Volunteers from associations will implement “pedibus” mobility for schools students. Moving back and forth from schools, pedibus users will monitor air quality and produce high spatial and temporal density opportunistic AQ data.

Enhanced Awareness:
Opportunistic Data, Regulatory and fixed monitoring stations Data have been communicated along with data assimilation based air quality mapping model predictions . Hi-res nowcasting and forecasting maps have been returned to citizens.

Traffic Car regulation:
Maps and traffic simulations are at the basis of a DSS that will help MUA to develop participated traffic regulation strategies to improve AQ.

Calibration Strategy (1)



FIELD CALIBRATION (I.E. BY COLOCATION: MIN 3 WEEKS EACH NODE)

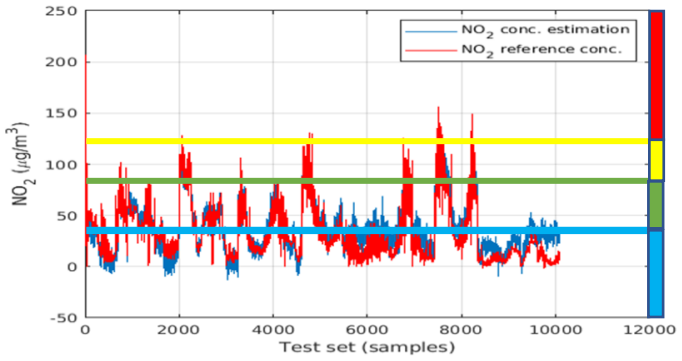
ADDRESSING ROBUSTNESS WITH PERIODICAL (6MONTHS) RE-CALIBRATION

DATA DRIVEN ALGORITHMS (MLR, NN)

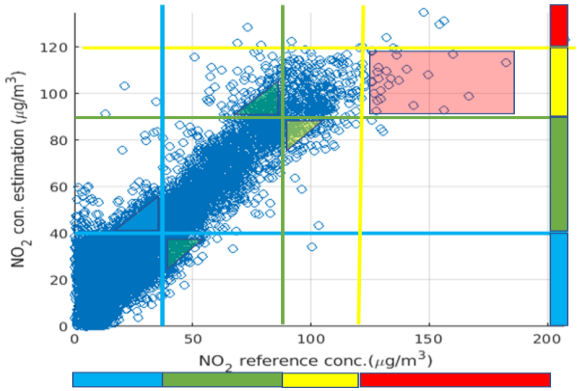
CALIBRATION COEFFICIENTS DOWNLOADED BY MONICA COMPANION APP FOR MOBILE AND OPPORTUNISTIC CITIZEN SCIENCE MONITORING

CALIBRATION COEFFICIENTS IMPLEMENTED IN-CLOUD FOR FIXED STATIONS

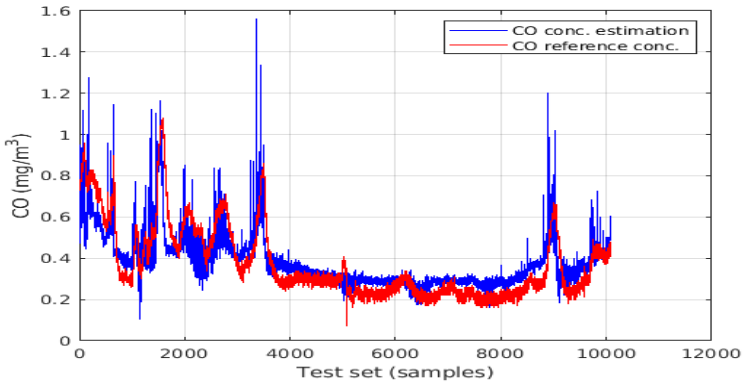
Comparing LCAQMS with Regulatory grade stations



NO2, O3 SENSORS REACT TO THE PROCESS BY FOLLOWING TRUE CONCENTRATIONS NICELY (ON SEPARATE TEST DATA SETS)

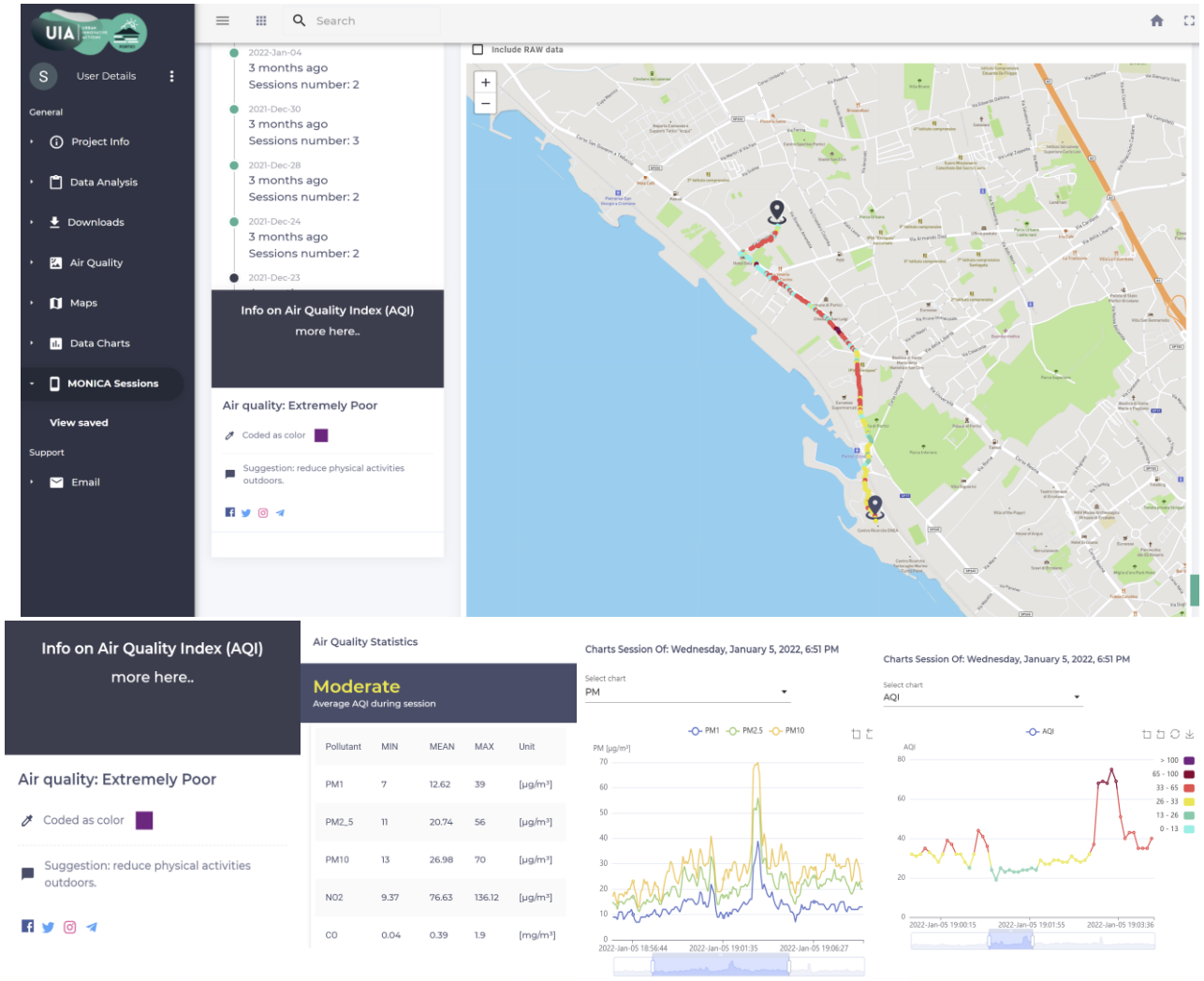


USING SENSORS CONCENTRATION ESTIMATIONS TO EVALUATE EAQI FOR FEEDBACK COMMUNICATION LEADS TO VERY LIMITED ERRORS. THE VAST MAJORITY OF CASE, THE FUNCTION MISCLASSIFY IN THE ADJACENT EAQI CLASS.



CO SENSOR IS FORCED TO WORK CLOSE TO ITS LOD SO SIGNIFICANT RELATIVE ERROR IS EXPECTED AT VERY LOW CONCENTRATIONS

Personal Results @ Airheritage.portici.enea.it

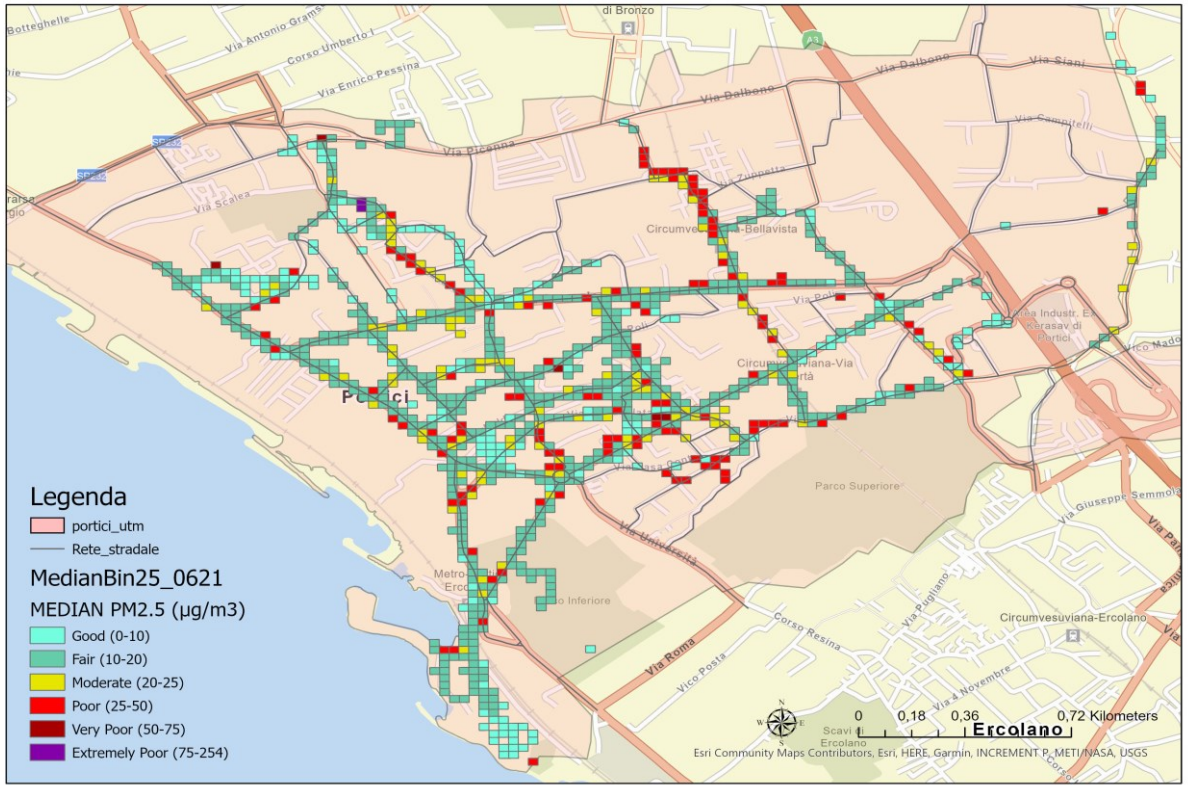


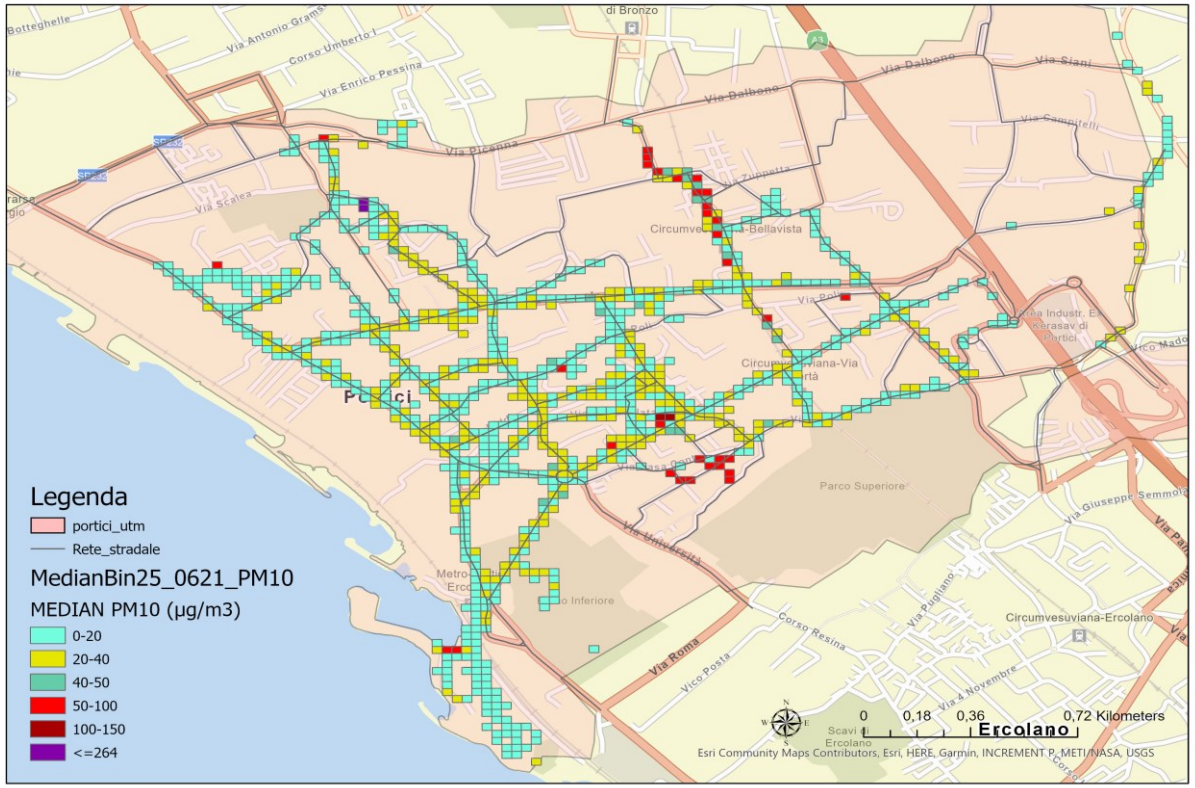
- Personal in city mobility session
- Active Life Feedback (Personal Exposure) based on EAQI estimations
- Simplified Statistics
- Graphical Trends
- Freely downloadable raw and calibrated data

Findable Accessible Interoperable Reusable

{JSON}

Mobile Stations Results





25X25MT SPATIAL BINNING MAPS USING SINGLE SEASON OPPORTUNISTIC DATA RECORDED BY CITIZENS WITH MOBILE DEVICES.

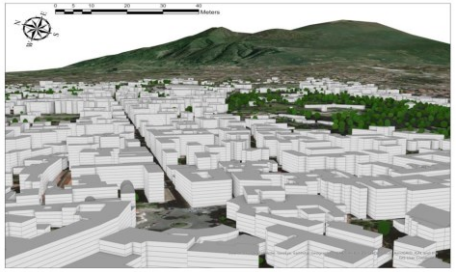
MIN 20 DATA POINTS PER BIN, AVERAGED TO COMPUTE EAQI CORRESPONDING TO SINGLE POLLUTANT

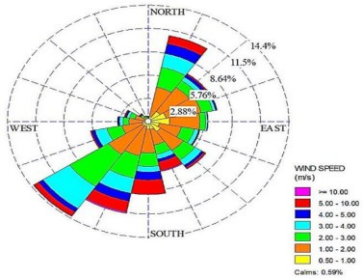
HOTSPOTS CONSISTENTLY DETECTED IN HEAVY TRAFFIC AND CITY CANYONS

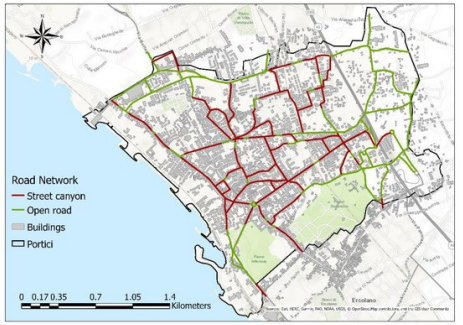
De Vito S. et al., Sensors **2021**, *21*, 5219.

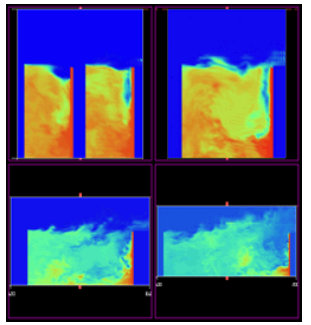
Fattoruso, G.; Nocerino, M.; Toscano, D.; Pariota, L.; Sorrentino, G.; Manna, V.; De Vito, S.; Cartenì, A.; Fabbricino, M.; Di Francia, G. Site Suitability Analysis for Low Cost Sensor Networks for Urban Spatially Dense Air Pollution Monitoring. *Atmosphere* **2020**, *11*, 1215. https://doi.org/10.3390/atmos11111215

Fixed Stations Optimal Deployment (1)

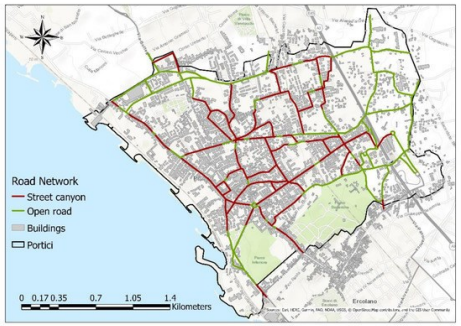


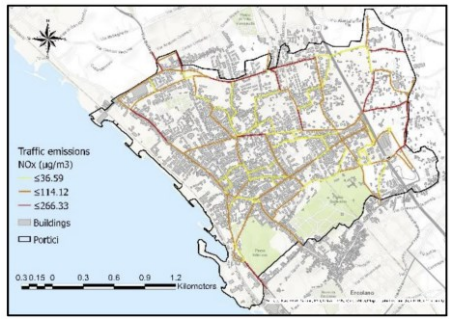


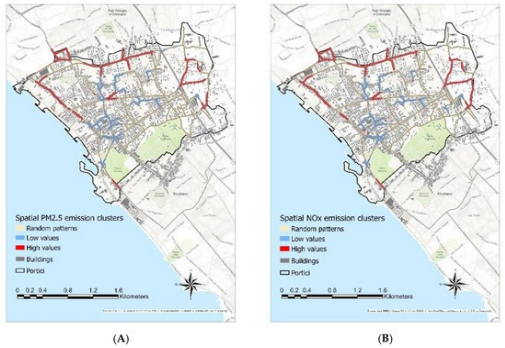




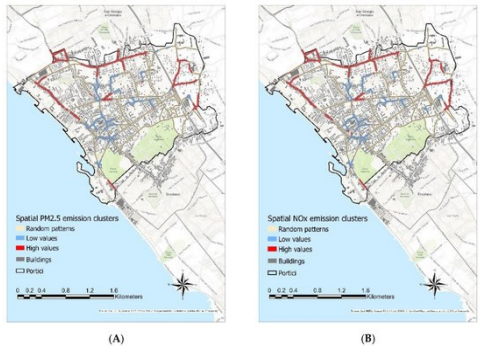
CITY 3D MODEL AND WIND DATA HAVE BEEN EXPLOITED TO DETERMINE POSSIBLE **CANYON EFFECTS AFFECTED ROADS SEGMENTS**

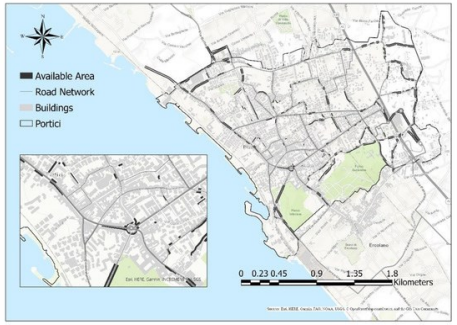


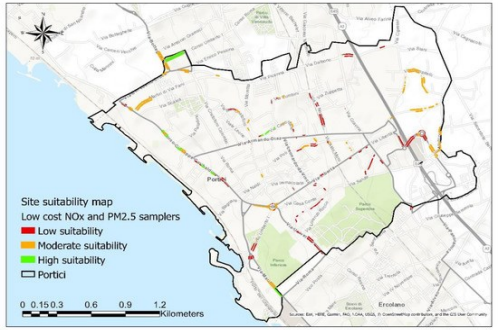




URBAN PLANNING DATA (INBOUND, OUTBOUND MOBILITY, CAR SET AGEING, POPULATION DENSITY,ETC.) HAVE BEEN EXPLOITED TO PREDICT **TRAFFIC AND HOUSE HEATING EMISSIONS** IN THE DIFFERENT URBAN AREAS AND COUPLED WITH URBAN CANYONS DATA







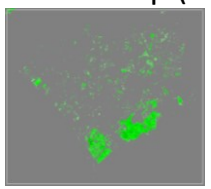
PREDICTED ROAD LEVEL CONCENTRATION MAPS HAVE BEEN JOINED WITH AN AVAILABILITY MAP OBTAINING THE **SUITABILITY MAP** LEADING THE **OPTIMAL DEPLOYMENT** PROCESS (COST VS VARIANCE COVERAGE)

Air Heritage Air Quality Model

INPUTS

- Digital Surface Model (static)

- Vegetation map (static)

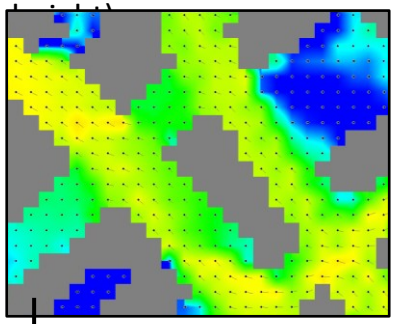


- WARF: mesoscale weather (dynamic)
- Road network (static)

- Traffic flows (dynamic)
- CAMS: background pollution (dynamic)

WIND MODULE

downscaling wind flows at street level (2m



TRAFFIC MODULE calculate emissions

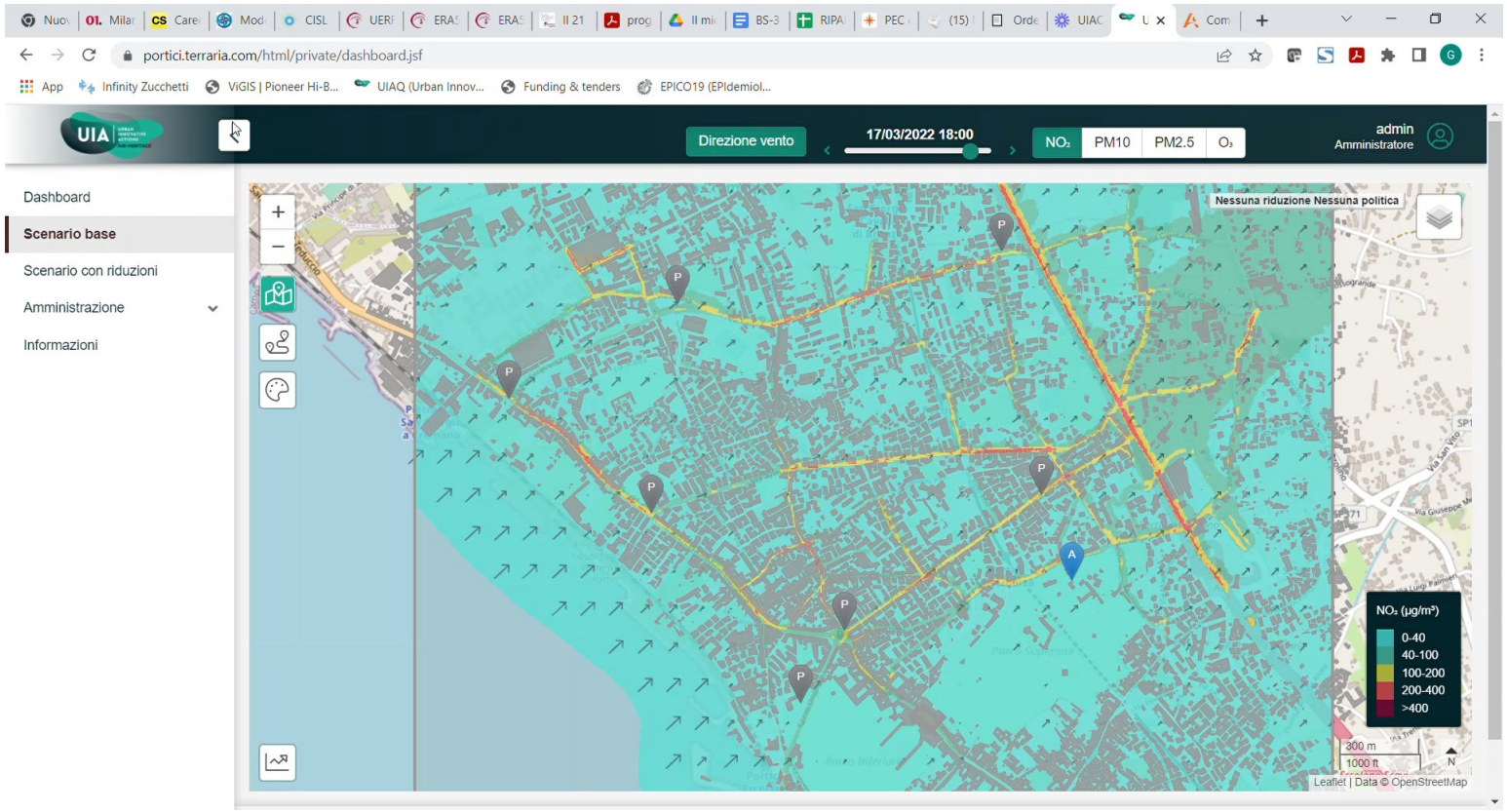
AIR QUALITY MODEL

Partial Differential Equations calculate pollutants concentration in time

- spatial processes (diffusion & advection)
- local processes (wet deposition, dry deposition, sedimentation, chemical transformations)

Initial state and boundary conditions

Air Quality model output and Monitoring Station in UIAQ DSS



Conclusions

- Fixed and Mobile AQMS have been employed in regular and opportunistic campaigns for ultra high resolution AQ assessment
- Several Data sources have been integrated to develop optimal deployment strategies for fixed stations
- Car traffic data, Weather forecasting data, CAMS background data, contributes to AQ model forecasts validated using fixed station data
- An integrated systems allow for personal, city scale real time feedback and AQ forecasts
- Future work will include scalable calibration methods and long term AQ model validation

Thank You for Your Attention!

ALERT: AirHeritage AQ Datalake is available on request!

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Project Scientific Coordinator

Dr. Grazia Fattoruso
Geomatics and AQ Modeling

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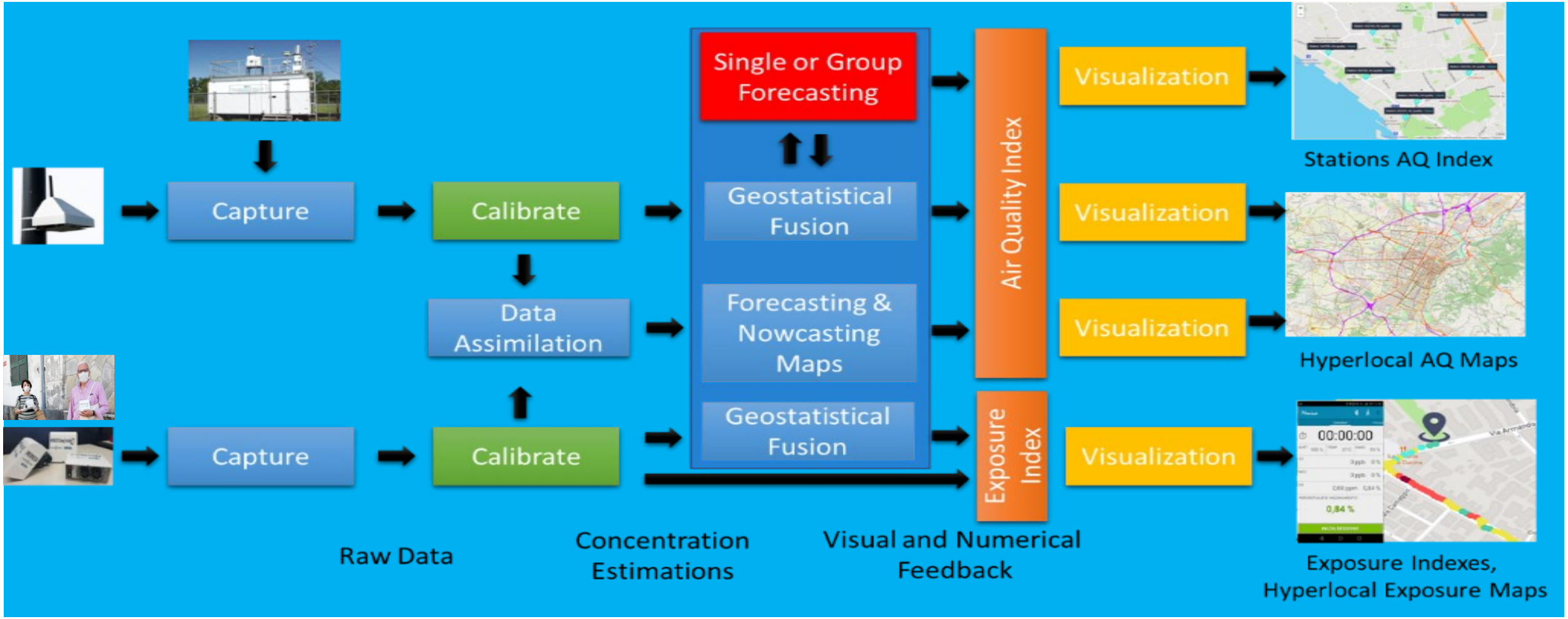
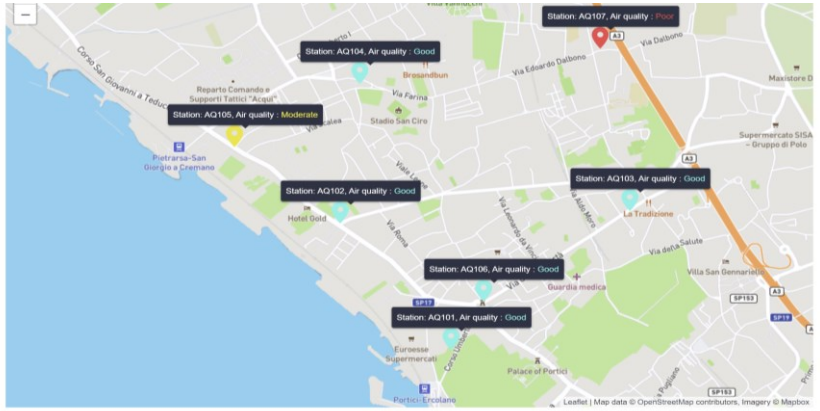
Spare Materials

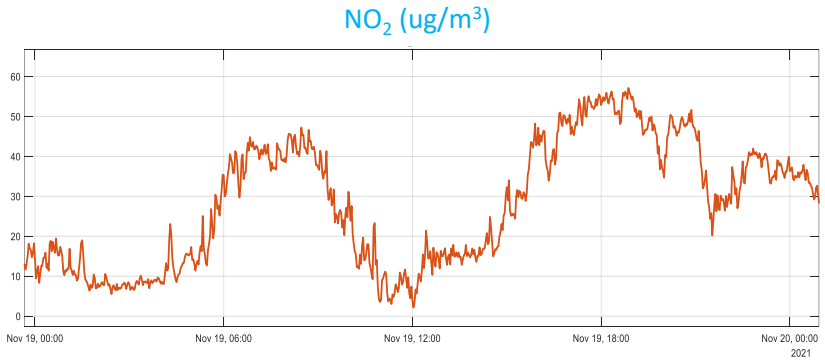
Project Air Heritage: Data pipeline



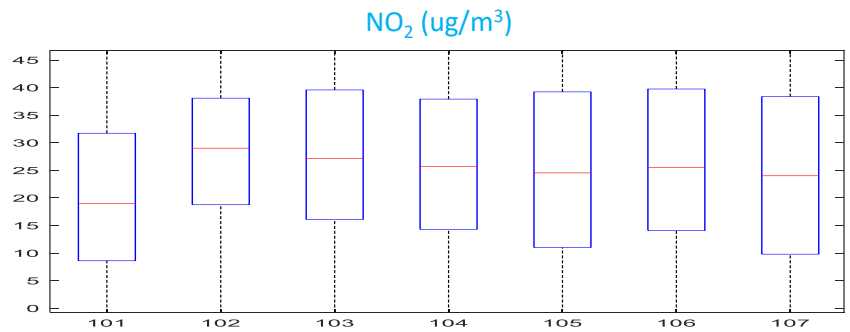
Fixed stations results



7 STATIONS CONTINUOUS MONITORING SERVICE COVERING HOT AND COLD SPOTS



MULTI TIME-SCALE VARIANCE PATTERNS IN SINGLE STATIONS DISCOVERY



ANNUAL AVERAGE SPATIAL PATTERNS HIGHLIGHTING EXPOSURE ENVIRONMENTAL DISPARITIES

Yearly results by using complete calibration set

Results are in line with consolidated literature in the mid term (3 months) or when using both summer and winter time recorded training data

	R^2 (median)	R^2 (mean)	R (mean)	MAE	Err (%)
PM2.5_AVG	**0.40**	**0.39**	**0.67**	**5.88**	**0.13**
PM2.5_STD	0.12	0.10	0.05	1.04	0.05
PM10_AVG	**0.21**	**0.20**	**0.60**	**9.78**	**0.18**
PM10_STD	0.10	0.10	0.05	2.10	0.07

Yearly results by using complete calibration set

Results are in line with consolidated literature in the mid term (3 months) or when using both summer and winter time recorded training data

	R^2 (median)	R^2 (mean)	R (mean)	MAE	Err (%)
NO2_AVG	0.60	0.40	0.81	10.73	0.13
NO2_STD	0.12	0.37	0.04	2.89	0.05
O3_AVG	0.85	0.74	0.94	9.93	0.18
O3_STD	0.05	0.22	0.02	2.86	0.07
CO_AVG	0.16	-0.19	0.44	0.18	0.03
CO_STD	0.21	0.52	0.50	0.07	0.03