Ανασχεδιασμός Δικτύου Περιβαλλοντικού Ελέγχου
Redesign of Environmental Monitoring Network

Παρουσίαση Διπλωματικής Εργασίας

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ΜΠΣ: Διαχείριση Ενέργειας & Περιβάλλοντος

- The re-design/optimization of an existing **Air Quality Monitoring Network (AQMN)** by excluding or relocating monitoring stations with specified methods and criteria is a complicated procedure.
- The present work attempts to examine and define some of these criteria together with an evaluation model developed using the method of multiple linear regression.

Two air pollution episodes are going to be studied

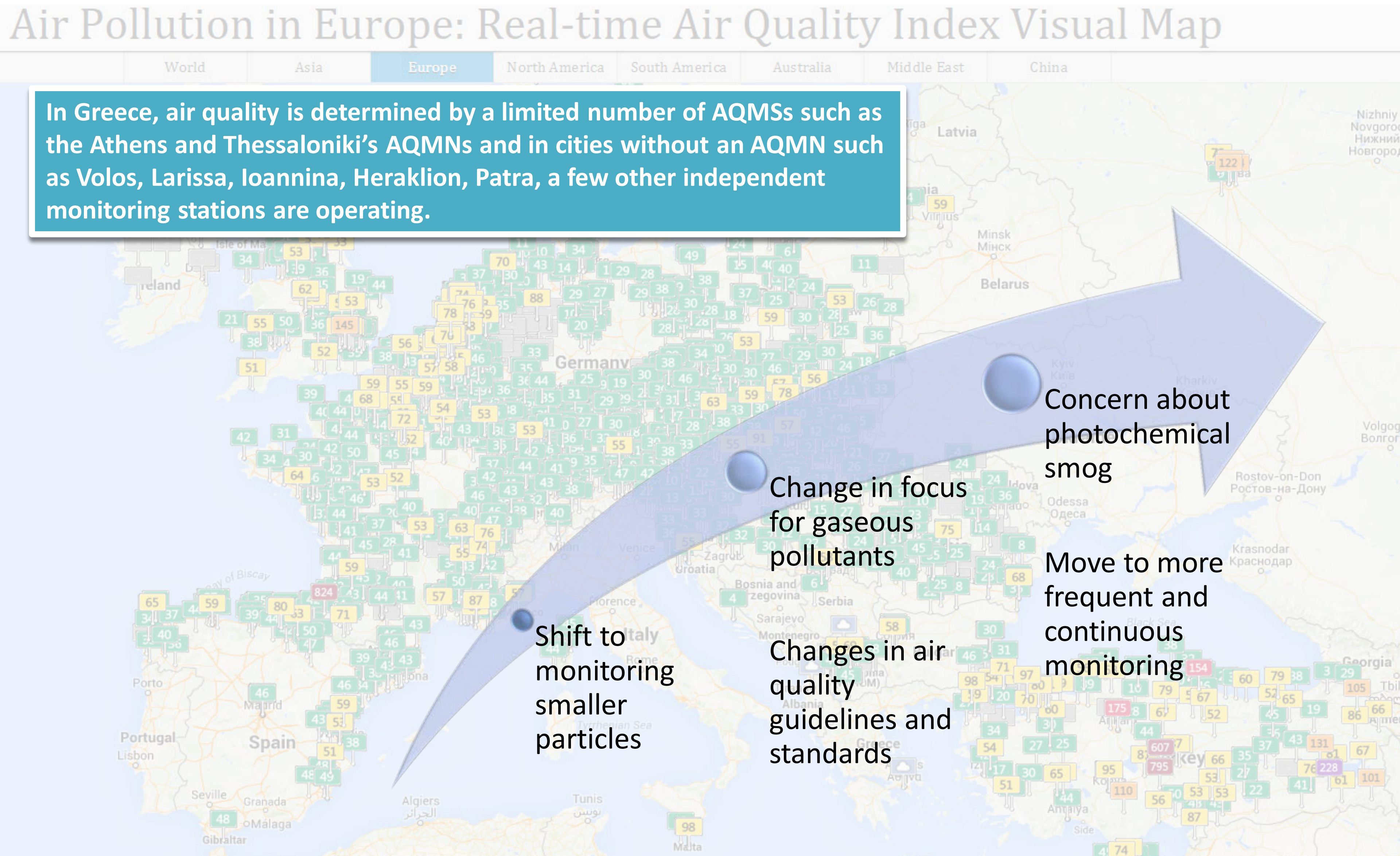
photochemical ozone episode in the city of Athens - unique particularity of the **classical Antiquities** scattered in the center of the city and the suburbs

a Particulate Matter smog episode in the city of Istanbul - largest city in the European territory with **serious environmental problems** due to heavy air pollution since the beginning of industrialization of the area. A very densely populated city without methodically arranged spatial planning

The objectives of a new Air Quality Monitoring Station (AQMS) setup

Objectives

- Categorization of proposed Macro and Micro scale siting criteria for relocating an Air Quality monitoring network (AQMS) - useful for a possible exclusion/elimination from the network of an AQMS in operation.
- Evaluation of the initial **classification of monitoring sites** which was done from the governmental authorities. **A deficient classification or "a not further updated one" through the years reflects a poor representative site**
- Recommend a monitoring station as the most representative of the network as a **"pilot" indication of a potentially evolving air pollution (PM_{10}) episode.**
- The assessment of **how representative (for a specific pollutant)** is a part of an active monitoring network (although it is difficult to assess using monitoring data only) in certain areas

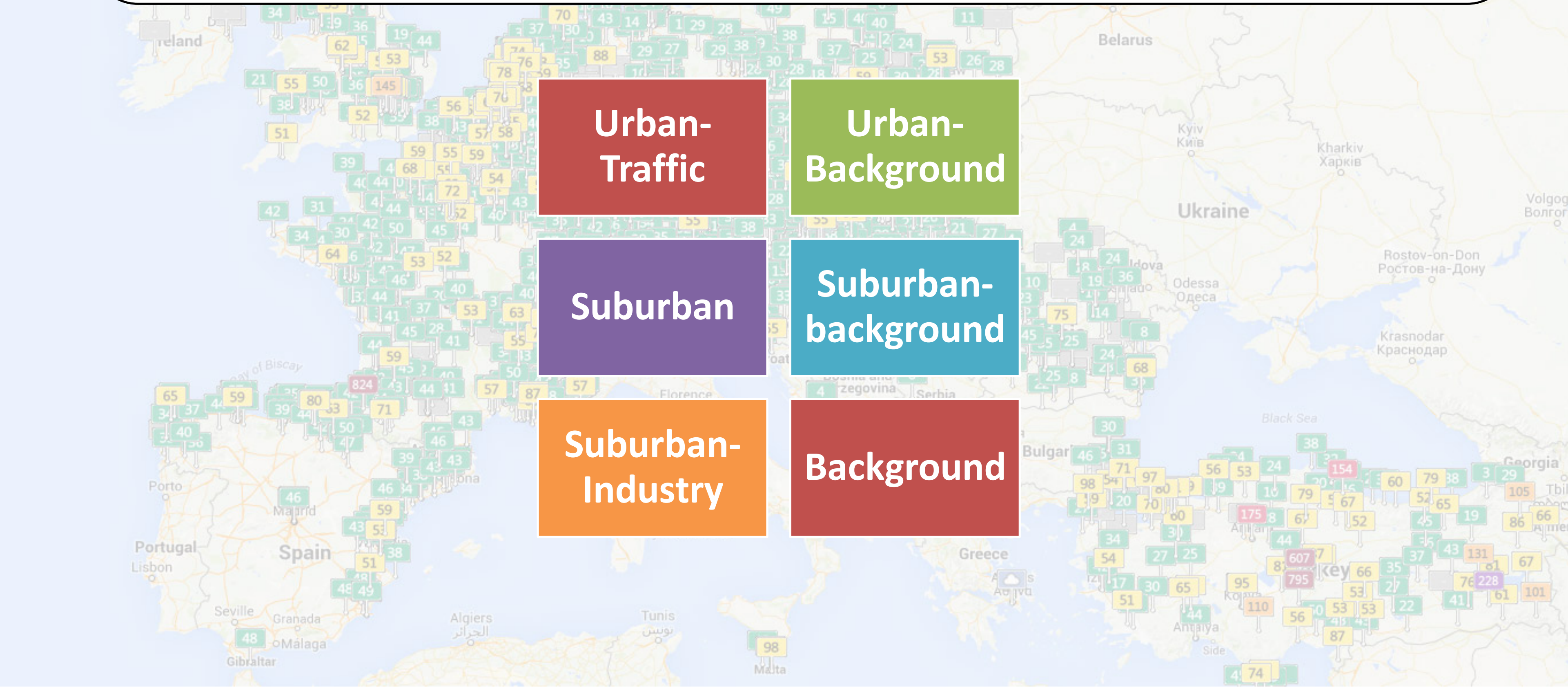


In Greece, air quality is determined by a limited number of AQMSs such as the Athens and Thessaloniki's AQMNs and in cities without an AQMN such as Volos, Larissa, Ioannina, Heraklion, Patra, a few other independent monitoring stations are operating.

- Shift to monitoring smaller particles
- Change in focus for gaseous pollutants
- Changes in air quality guidelines and standards
- Concern about photochemical smog
- Move to more frequent and continuous monitoring

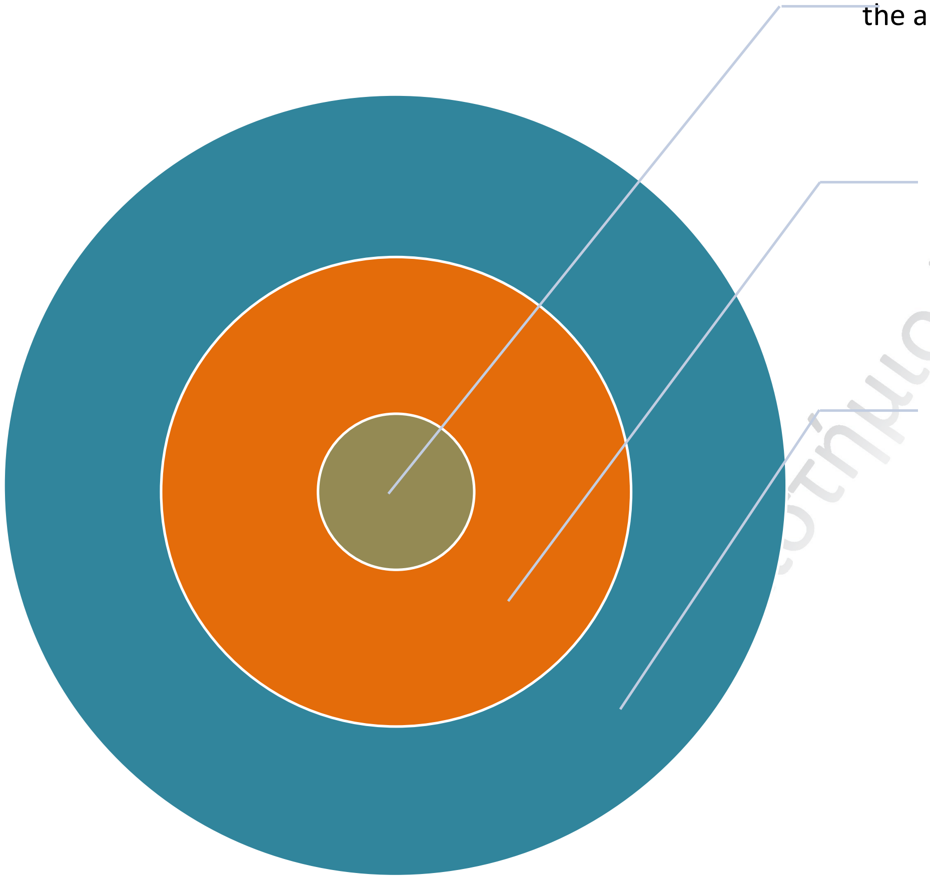
Classification of Monitoring sites

- **Classification** is the grouping of monitoring stations (or in more general terms, geographical locations) according to certain properties of the station which are relevant for the interpretation of the measured data (W. Spangl, 2007).
- The **purpose of each AQMS is different regarding its given classification** and it is an important prerequisite for the assessment and interpretation of AQ data



Urban-Traffic	Urban-Background
Suburban	Suburban-background
Suburban-Industry	Background

Air Quality Monitoring Network (AQMN) - General Requirements site selection (EPA):



The **Air Quality Monitoring Network (AQMN)** consists of several **air quality monitoring stations (AQMS)** which covers a metropolitan area with permanent and some mobile stations.

Each country as a member of the European Union is obliged by National and European Legislation to operate such AQMNs in most of their cities.

Objectives of a new AQMS setup – Macro scale Criteria Categorization

Social Criteria / Population Coverage / Legislation limits/ Sensitive Receptors (Evaluation through GIS interpolation) of a candidate site

Sustainable development factors are balancing social, environmental and economic objectives (which they often come in conflict).

The collected data (environmental, social, economic) of a specific area should provide details of sources and emissions

A **densely populated area** should be selected so the data collected can represent the air quality being exposed by the majority of people in the district

Representativeness

The monitor should be outside the zone of influence of sources located within the designated zone of representation for the monitoring site. The concentration of the pollutant(s) should be representative for the pattern of spatial distribution

"Classification" of air quality monitoring sites is a prerequisite for any interpretation of AQ data. The station should usually be representative of a wider area of at least several square kilometers

Site logistics

Security, electrical supply, installation and maintenance costs, insurance, financial issues, private property permissions, easiness in access and other technical factors

M A C R O

Objectives of a new AQMS setup – Micro scale Criteria Categorization

Contribution to area's network coverage

Protection of Human Health in Low income population areas

Protection of Antiquities

Statistical Representativeness

Contribution to overlap minimization between stations (statistically predicted if possible

AQMS should not overlap each other's area of coverage, so the distance between two of **the same class monitoring stations** should be long enough. If the area is small it may not be worthwhile to maintain a monitoring station on operation. In opposite, such a station is needed to monitor ambient air quality.

Contribution to Network's Redesigning (due to technological progress)

Required quantity and quality of the data.

Correct time scale.

Compatibility with the site design (outdoor or indoor environment).

Compatibility with other equipment, for example: interfacing continuous emissions monitors and meteorological instrumentation with a data acquisition system, new generation data loggers and communication protocols.

MiCRO

Athens – Photochemical Episode Summer 2013

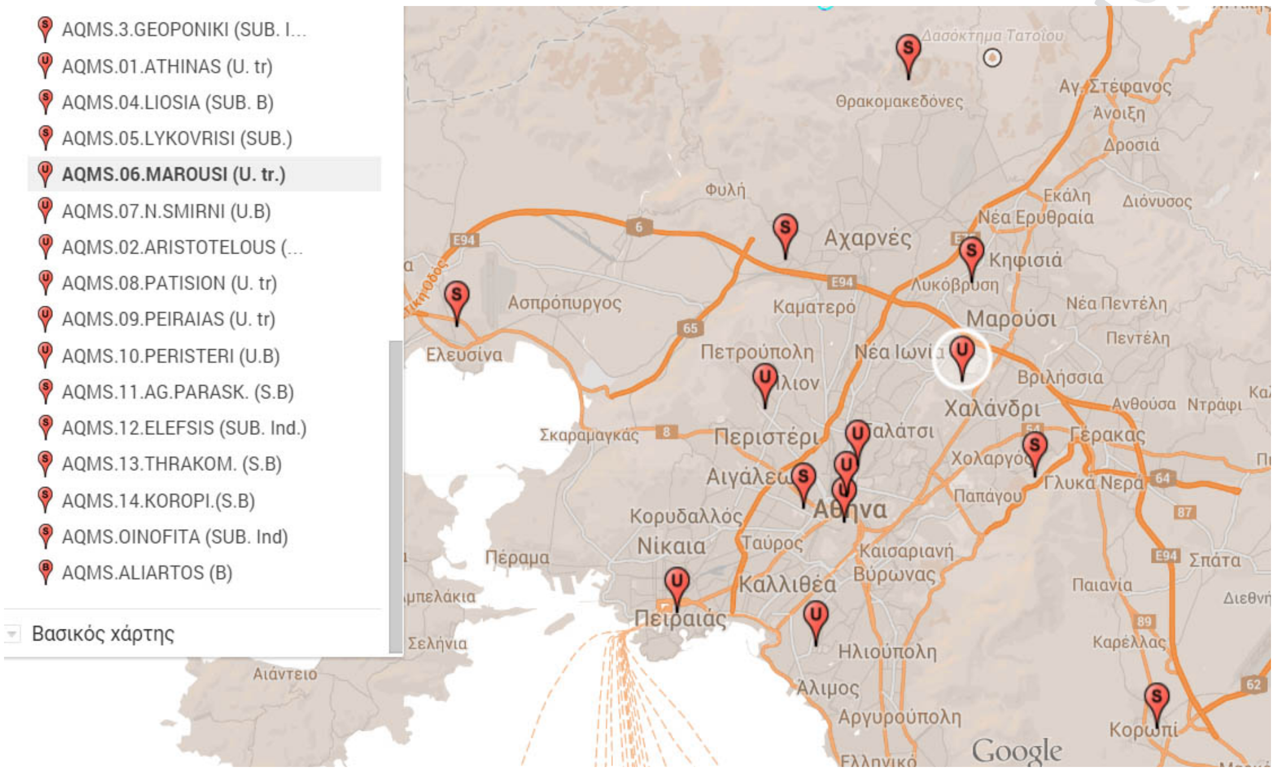
In the present study, we investigated photochemical episodes using concentration time series (covering a monthly period from 15 July to 15 August 2013). We have chosen the most intense episode which was at 30/31 of July 2013 using hourly measured O_3 concentrations from ten AQMSs in a simple multiple regression model.

Air pollutant variables are investigated using data sets obtained from thirteen AQMS in the Athens conurbation, corresponding to the three main monitoring station categories, i.e. urban-traffic, urban-background and suburban background

Long data time-series are available at all thirteen stations, providing the opportunity for an investigation and comparison of the long-term pollutant concentration trends, while on the same time allowing an evaluation of the type/classification of all AQMSs.	**Urban-traffic** stations are located very close to major traffic arteries (roadside or kerbside stations) in order to monitor the direct influence of traffic to air pollution, while **urban-background** stations aim to monitor the background concentrations of pollutants in urban areas, outside the direct influence of major roads	**Suburban-background** stations are set to be representative of the pollution levels observed in the respective suburban background areas. Pollutant concentrations determined from all three types of monitoring stations can therefore be used to explore the spatial and temporal distribution patterns of different pollutants, both primary (e.g. NO) and secondary (e.g. O_3) as well as their interrelation, under varying environmental conditions

Athens – Photochemical Episode Summer 2013

The municipality (City) of Athens had a population of 664,046 (in 2011, 796,442 in 2004)[ELSTAT] within its administrative limits, and a land area of 39 km^2. The urban area of Athens (Greater Athens and Greater Piraeus) extends beyond its administrative municipal city limits, with a population of 3,090,508 (in 2011)[ELSTAT] over an area of 412 km^2



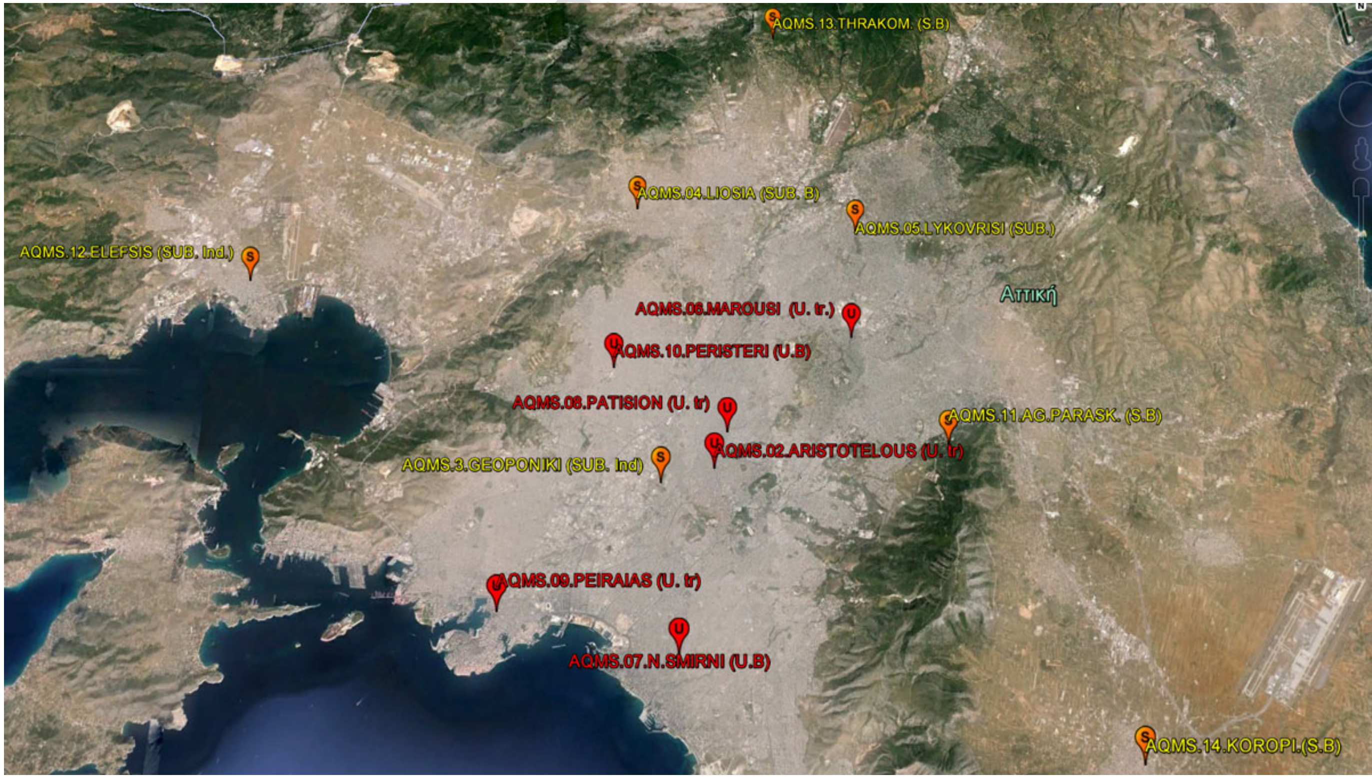
According to HMEECC (Direction of Air Pollution and Noise Control, 2010) these stations are classified as follows: (a) six urban-traffic, (b) two urban-background, (c) four suburban-background, (d) two suburban-industrial, and (e) one suburban

The spatial distribution of the greater Athens area air pollution monitoring network

The Greek ministry of environment has incorporated the upper categories for classifying the AQMSs on the Greater Athens Area (GAA). However the sites cannot be considered as representative of the air quality in the GAA, due to later large construction development and public works which has differentiated the initial topology of the areas in the vicinity of the AQMSs

the AQMN includes fourteen AQMSs and there are also two additional assistant AQMSs for cross-border pollution transfer detection.

Most common pollutants which traced by AQMNs are Carbon Monoxide(CO), Ozone(O_3), Oxides of Nitrogen(NO_x), Particulate Matters (PM_{10} and $PM_{2.5}$) and Sulfur dioxide (SO_2). .

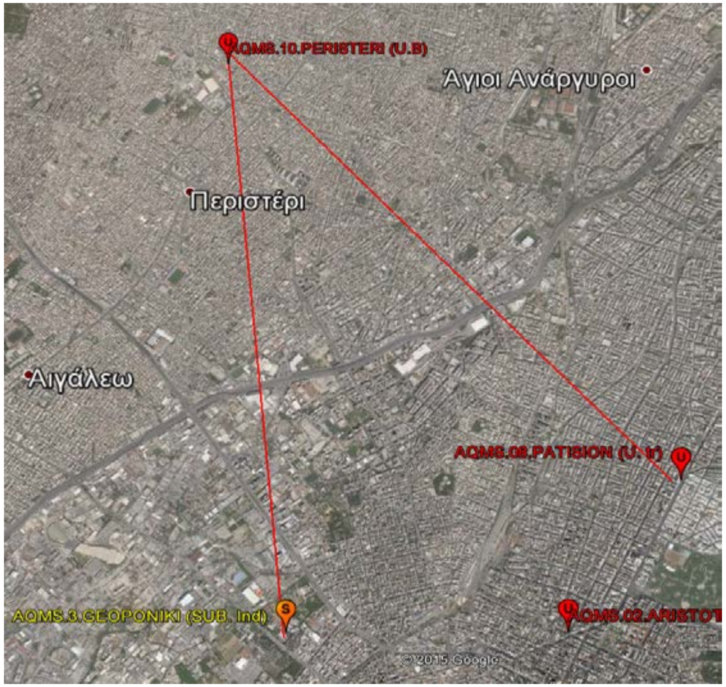


Athens – Photochemical Episode Summer 2013

The AQMS "Peristeri" is selected as our primary dependent variable. The classification of the site is Urban-Background (U.B) and it is located at the western side of the center of Athens, in a suburb inhabited by **low income population**, where high ozone concentrations are also expected

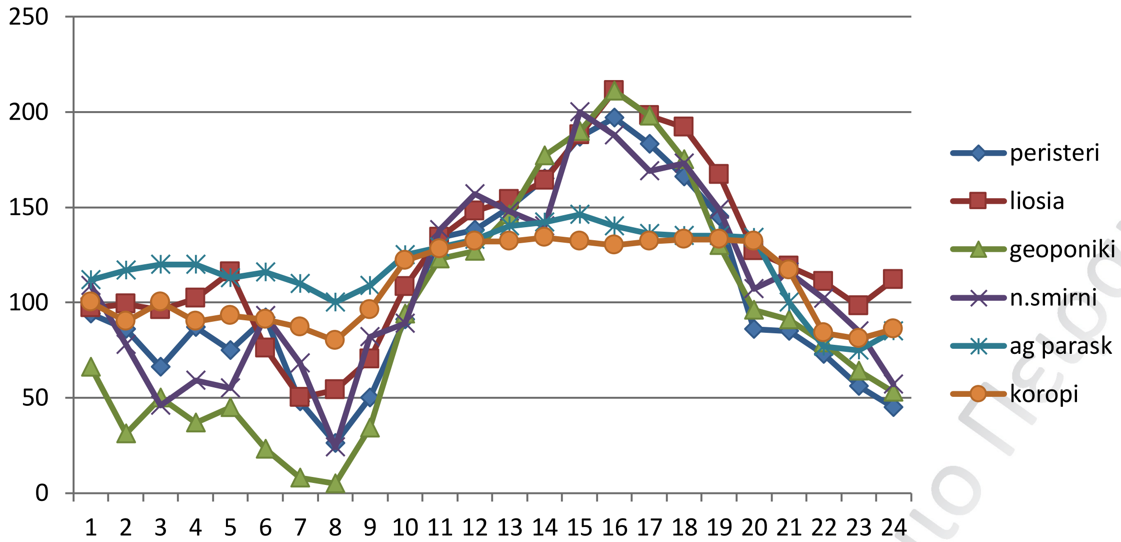
Time	Wind Direction	Wind Speed	PERISTERI
30/7/15		Km/h	Ozone μg/m³
1:00	NNW	9.3	94
2:00	Calm	Calm	86
3:00	Calm	Calm	66
4:00	Calm	Calm	87
5:00	North	7.4	75
6:00	NNW	9.3	92
7:00	Calm	Calm	48
8:00	South	11.1	26
9:00	South	11.1	50
10:00	South	14.8	91
11:00	SSW	18.5	134
12:00	South	16.7	138
13:00	South	16.7	150
14:00	South	20.4	165
15:00	South	14.8	187
16:00	SSW	11.1	197
17:00	South	9.3	183
18:00	Calm	Calm	166
19:00	Calm	Calm	145
20:00	Calm	Calm	86
21:00	NNW	7.4	85
22:00	Calm	Calm	73
23:00	Calm	Calm	56
0:00	NNW	7.4	45

Athens – Photochemical Episode Summer 2013



Southwest of the station, there is an average traffic street, more than 130m away (cyan line) and about 300m (southeast) from another average traffic street (red distance line). In the vicinity of the AQMS there are soccer fields, a park (southwest), a high school (northwest) and low traffic streets with ADT<100 vehicles/day. There is also the municipality’s parking and laundry for garbage trucks at a distance of 330m southwest of the station. During the summer months with high average temperatures and blowing from SSW prevailing winds, it might be a potentially confounding air pollutant source.

Athens – Photochemical Episode Summer 2013



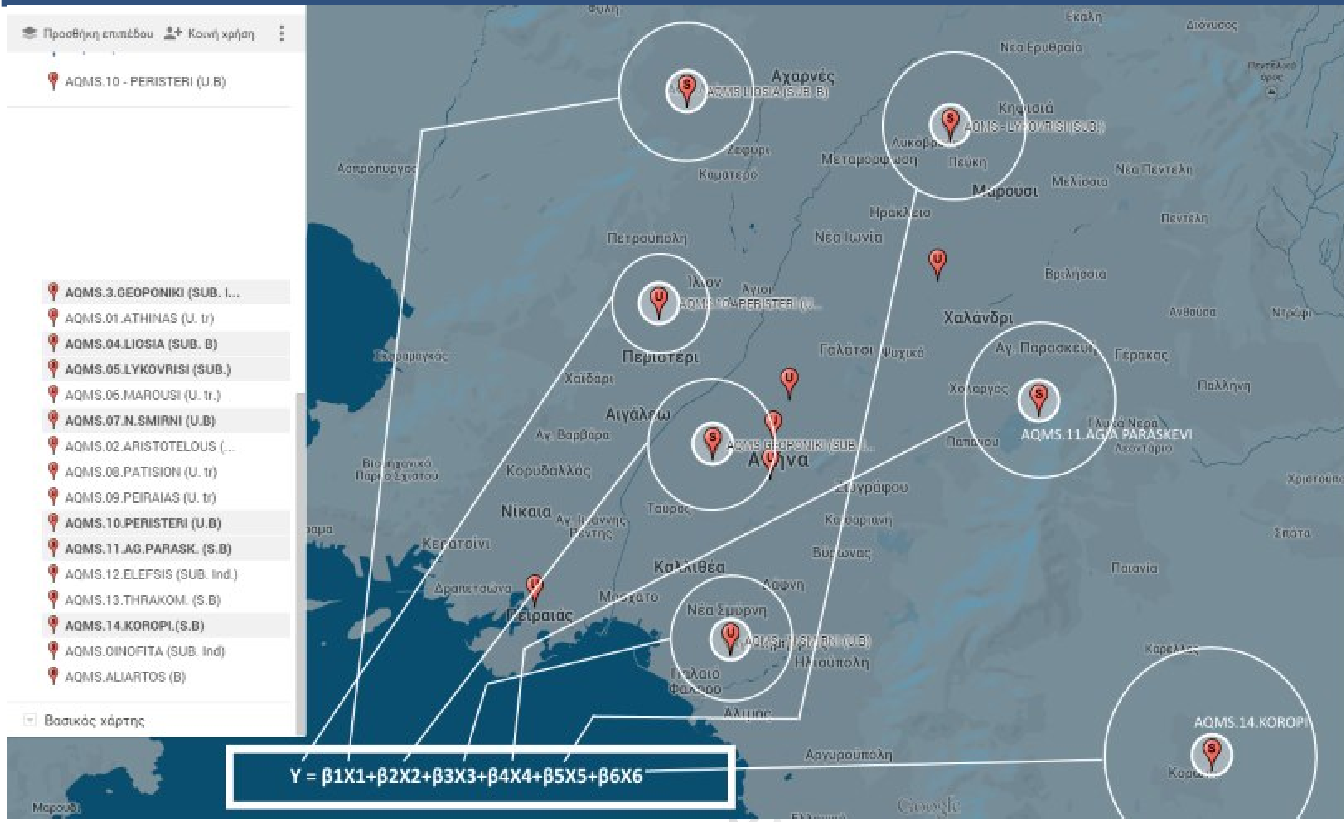
	Lykovrisi	peristeri	marousi	liosia	geoponiki	n.smirni	thrakom	ag parask	eleysina	koropi
Lykovrisi	1									
peristeri	0,885251	1								
marousi	0,869226	0,883752	1							
liosia	0,817284	0,930159	0,895969	1						
geoponiki	0,840924	0,93884	0,93431	0,96338	1					
n.smirni	0,828282	0,932858	0,90548	0,883051	0,923972	1				
thrakom	0,600364	0,684412	0,496998	0,702183	0,660037	0,606632	1			
ag parask	0,857274	0,796448	0,649592	0,655022	0,669532	0,657756	0,505547	1		
eleysina	0,87554	0,902877	0,892904	0,921764	0,941556	0,903707	0,591385	0,687401	1	
koropi	0,850188	0,848209	0,841258	0,821238	0,870298	0,838516	0,498894	0,837237	0,871935	1

Correlation Coefficients for all sites – 30 July 2013

The S.B classified stations of Agia Paraskevi and Koropi have less concentration fluctuation compared to other AQMSs of those who participate on the model and this is something we expected to happen. There is no significant pollutant transportation during the episode from the center of the city (wind direction was opposite) to the direction that the aforementioned AQMSs are located. The correlation coefficient of Agia Paraskevi station is low, compared to all other sites.

All others stations showed a rapid increment of ozone concentration simultaneously at noon hours. It seems that only the general local pollutant sources contributed to this and not a spatial dispersion of the ozone related pollutants

Athens – Photochemical Episode Summer 2013

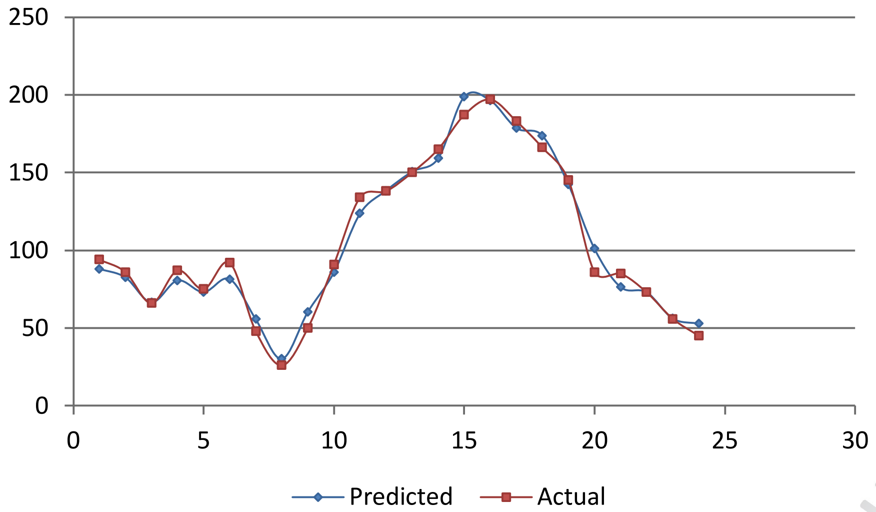


Στατιστικά παλινδρόμησης	
Πολλαπλό R	0,9893
R Τετράγωνο	0,9788
Προσαρμ R Τετράγωνο	0,9729
Τυπικό σφάλμα	8,26
Μέγεθος δείγματος	24

Step 2	Συντελεστές	Τυπικό σφάλμα	t	τιμή-P
Τεταγμένη επί την αρχή	-35,7192	17,61175978	-2,02815	0,057608
X 1	0,2753	0,147554613	1,86617	0,078398
X 2	0,2693	0,138881126	1,939715	0,068249
X 3	0,4478	0,095227117	4,70249	0,000177
X 4	1,1112	0,16349596	6,79662	2,3E-06
X 5	-0,9080	0,237568726	-3,82235	0,001248

Step 3	Συντελεστές	Τυπικό σφάλμα	t	τιμή-P
Τεταγμένη επί την αρχή	-45,9732	19,5672	-2,3495	0,031141
X 1	0,2752	0,1462	1,8828	0,076958
X 2	0,3026	0,1405	2,1530	0,045969
X 3	0,4745	0,0971	4,8858	0,000139
X 4	1,2756	0,2154	5,9216	1,67E-05
X 5	-0,9526	0,2385	-3,9946	0,000938
X 6	-0,0988	0,0854	-1,1577	0,263013

Athens – Photochemical Episode Summer 2013

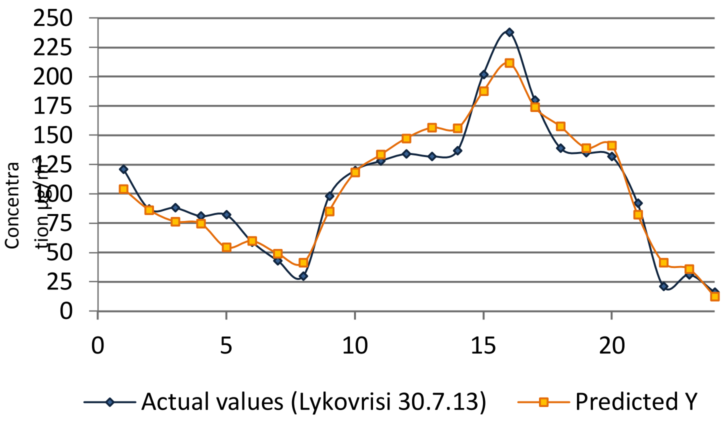


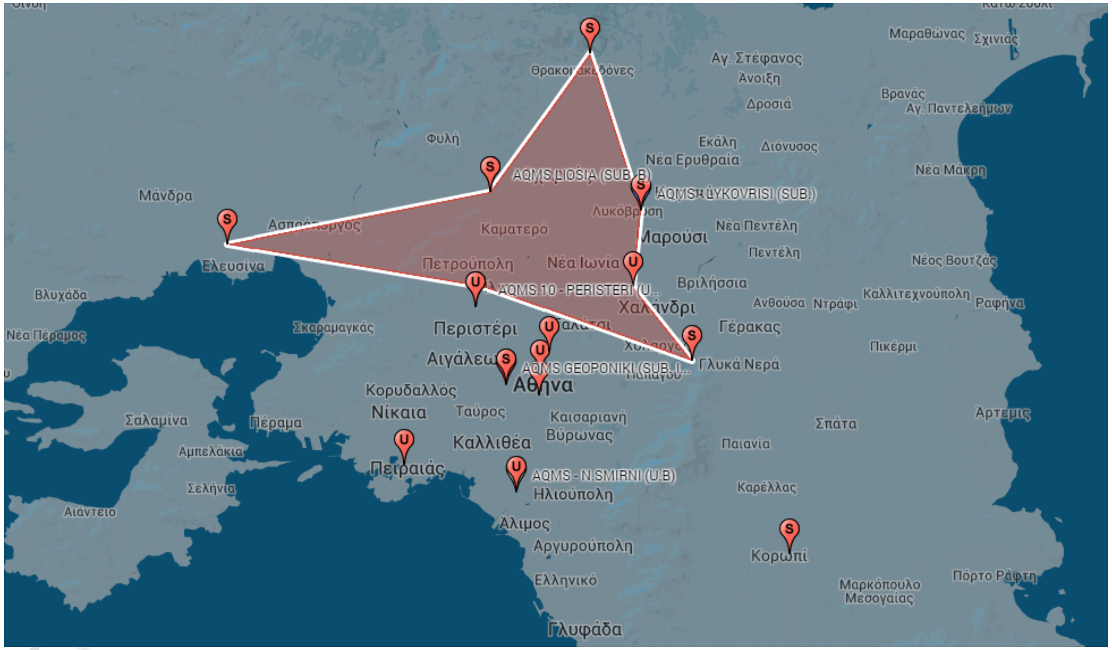
	First"Run"	Second "Run"	Third "Run"
Multiple R	0.9905	0.9893	0.9901
R-squared	0.9811	0.9788	0.9803
Adjusted R-squared	0.9690	0.9729	0.9734
Durbin-Watson test	2.431	2.357	2.377
Explanatory Variables	9	5	6
Statistically significant variables (p-value<0.05)	4/9	4/5	5/6
Observations	24	24	24

Table 7.2e: Model General Statistic Coefficients with AQMS Peristeri as dependent variable

Although the p-value (0.26) of Lykovrisi site is statistically insignificant, the addition of this specific site improved all the other p-values. The **R-squared value** is also improved on the third "run" of the model and **this demonstrates that our data are fitted better in the regression line**. A further addition of an independent variable to the model is not necessary, as this might be a negative influence considering the limit value of adjusted-R^2. **Table 7.2e** presents these results and the Durbin – Watson test. The Durbin Watson test (2.377) result proves no presence of autocorrelation (no relationship between values for the given time lag).

R-squared is a statistical measure of **strength/validity for a parametric linear model**. It is also known as the **coefficient of determination**, or the coefficient of multiple determination for multiple regression.

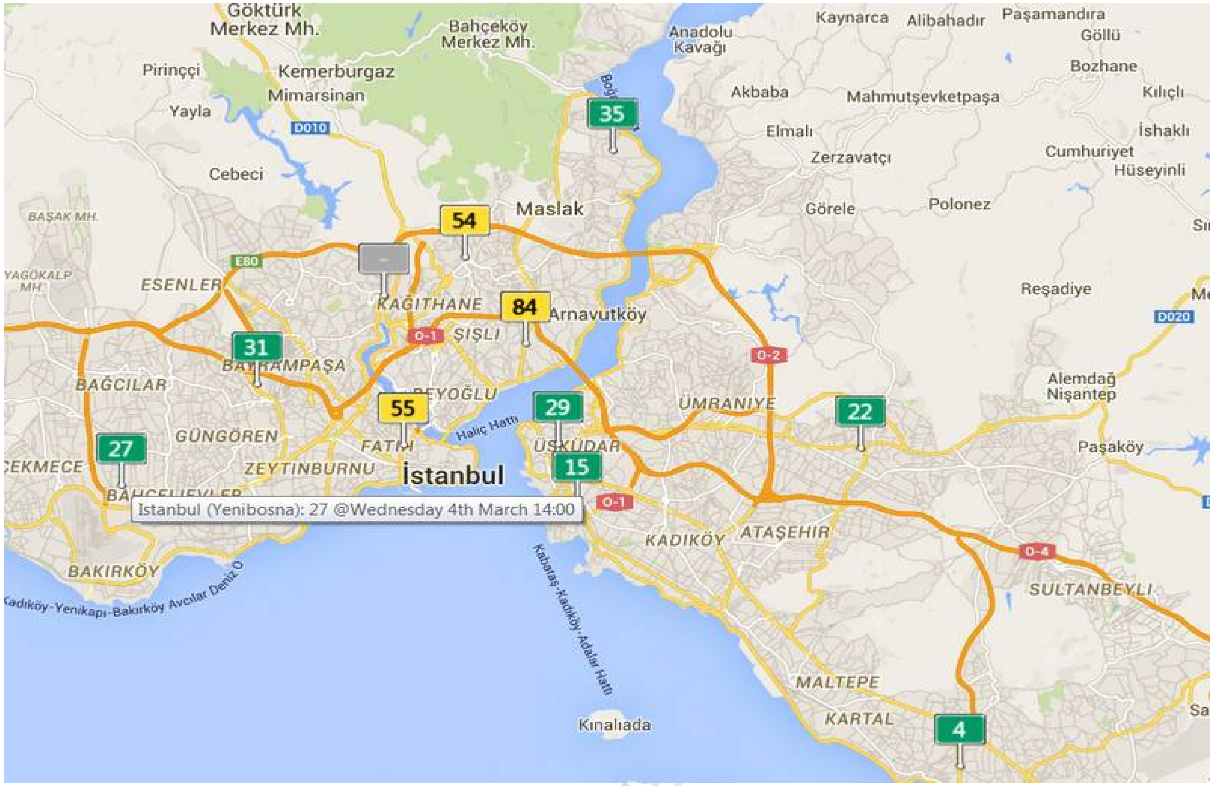




Lykovrisi is the only one AQMS of the network **classified as suburban**. A **classification update should be considered for this site** and/or a **possible exclusion** from the network, too. The site cannot fulfill the macro and micro-scale siting criteria, regarding also the representativeness of the measurements of the area. Other sites nearby might be more representative as “suburban” class sites. **The relocation of the station easterly or north-easterly of its current position** might be a better choice for improved network coverage of the area.

Regression Statistics	
Multiple R	0.9677
R-squared	0.9365
Adjusted R-squared	0.9188
D/W test	1.454

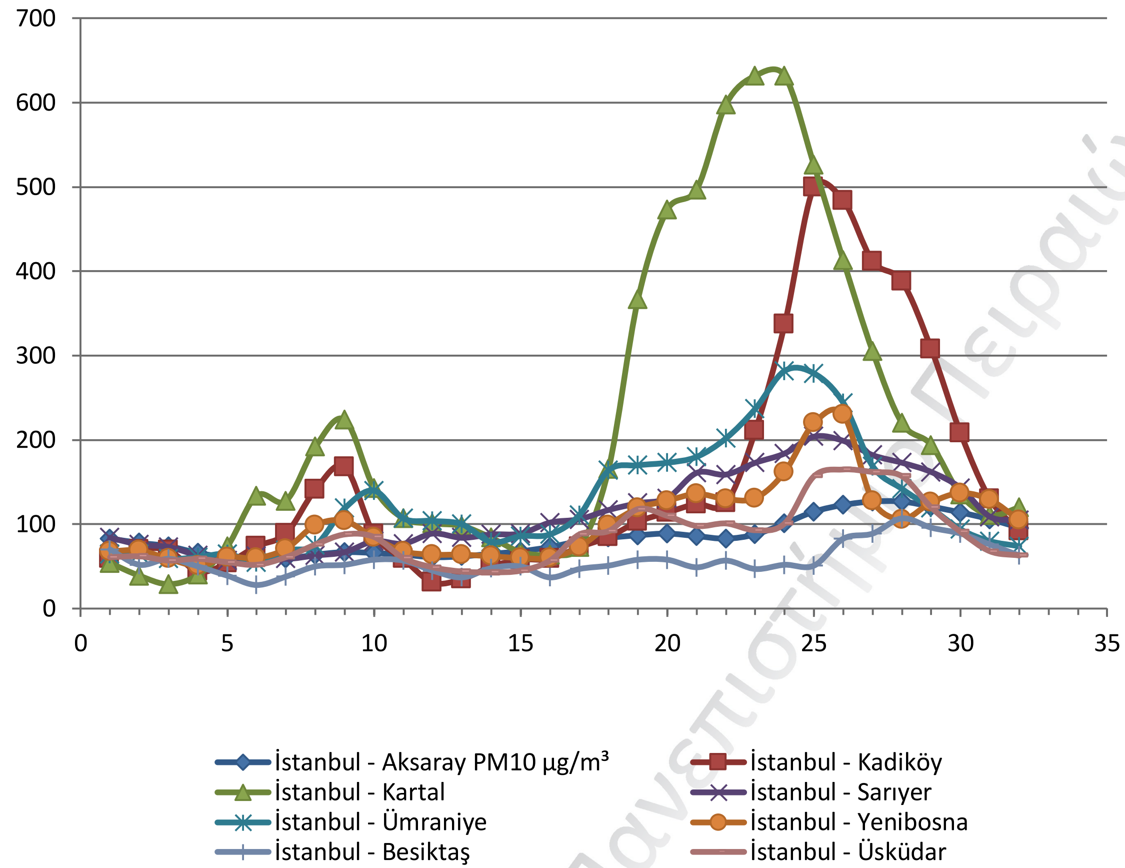
Istanbul – PM_{10} Smog Episode



Air pollution has been monitored since 1995 in İstanbul and **metropolitan network includes fourteen AQMS** with ten of them being active or **PM_{10} certified** and most of them **classified** as urban-traffic/urban/suburban, covering an area of approximately 2040 Km^2

The PM_{10} smog episode (**11-12, Jan 2014**) was evaluated and hourly measured PM_{10} concentrations from **eight AQMS used in a simple multiple regression model**. Initially performing a multiple linear regression model is running mean PM_{10} concentration at Aksaray's AQMS **location** as the **dependent variable** and seven other AQMSs as independent variables

Istanbul – PM_{10} Smog Episode



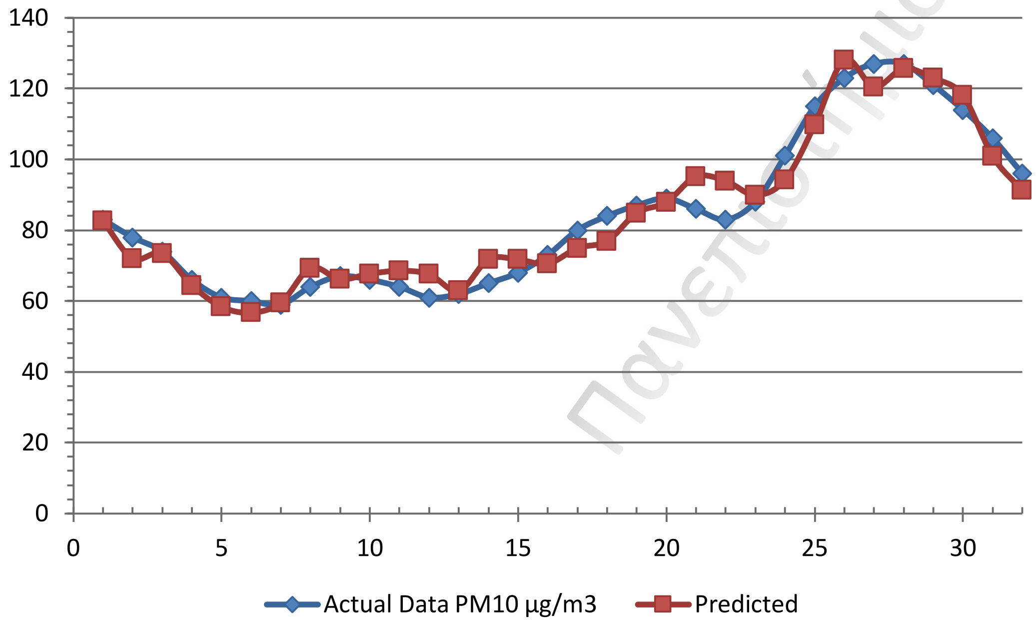
The industrial area of **Kartal** showed a rapidly increment of PM_{10} concentration after 17:00 of 11th January, which cannot be explained for the specific hour. Real-time measurements shows a severe smog episode (PM_{10} mass>400µg/m3) which **indicates a stable concentration of black carbon** in the aerosol. It might be exclusively by **local stream** sources and the same happened to **Kadikoy,** which affected a few hours later, due to pollutant dispersion from variable and WSW wind directions

The correlation coefficients for PM_{10} are quite high except from those AQMSs which they are at the eastern side of the city. It seems that initially the local emission sources contributed only, so the average concentration to be constantly above 50µg/m³. The emission sources from the European side of the city (domestic heating), later affected the Aksaray territory and thus the average concentration increased dramatically during the first morning hours from 01:00 up to 07:00 of 12/1/2014. Later that day the episode faded out. The model worked well for the specific incident and the prediction values are closed to the actual values and it is obvious that the areas of Sariyer, Umraniye, Yenibosna and Besiktas are highly correlated with Aksaray area.

Istanbul – PM_{10} Smog Episode

Regression statistics	First Run	Second Run
Multiple R	0.980542027	0.975393943
R-squared	0.961462666	0.951393343
Adjusted R-squared	0.95022261	0.944192357
D/W test	1.341	1.31
Explanatory Variables	7	4
Statistically significant variables (p-value<0.05)	4/7	4/4
Observations	32	32

Table 7.3f



All the independent variables were statistically significant with p-values far below 0.1%. F-test and T-test gave as expected fine results and although the correlation coefficient and the coefficient of determination were slightly decreased after the exclusion of three independent variables, their values are already high. **The combination of R-squared, adj-R-squared and p-values of the explanatory variables indicates a good fit and validity of the model**

The **modification of the model** by exclusion of Kadikoy, Kartal and Uskudar AQMSs, which they gave us the least correlated data during the incident, improved our model with more accurate predictions. These sites are in the **Asian territory** of the city. Although the initial model performed adequate predictions, additional assistance of the specific meteorological conditions helped for valid measurements during the episode.

The increment of PM_{10} concentration at all locations during the evening hours (Saturday night) indicates a contribution of traffic and the whole residential area due to poor quality of domestic fuels. The contribution of wind speed and wind direction is very significant. During morning hours the PM_{10} concentrations are generally in a stable (but already above the European alert threshold of 51-75μg/m^3) condition with minor exceptions in industrial areas

Istanbul – PM_{10} Smog Episode

During a "normal" day with the same meteorological conditions the correlation coefficients between the AQMNs were generally lower than they were during the episode. The contribution of specific local sources mainly consists of the coarse part of PM_{10}. This reveals that mostly mechanical processes emit dust, such as windblown dust, re-suspension by traffic and handling of dry bulk goods.

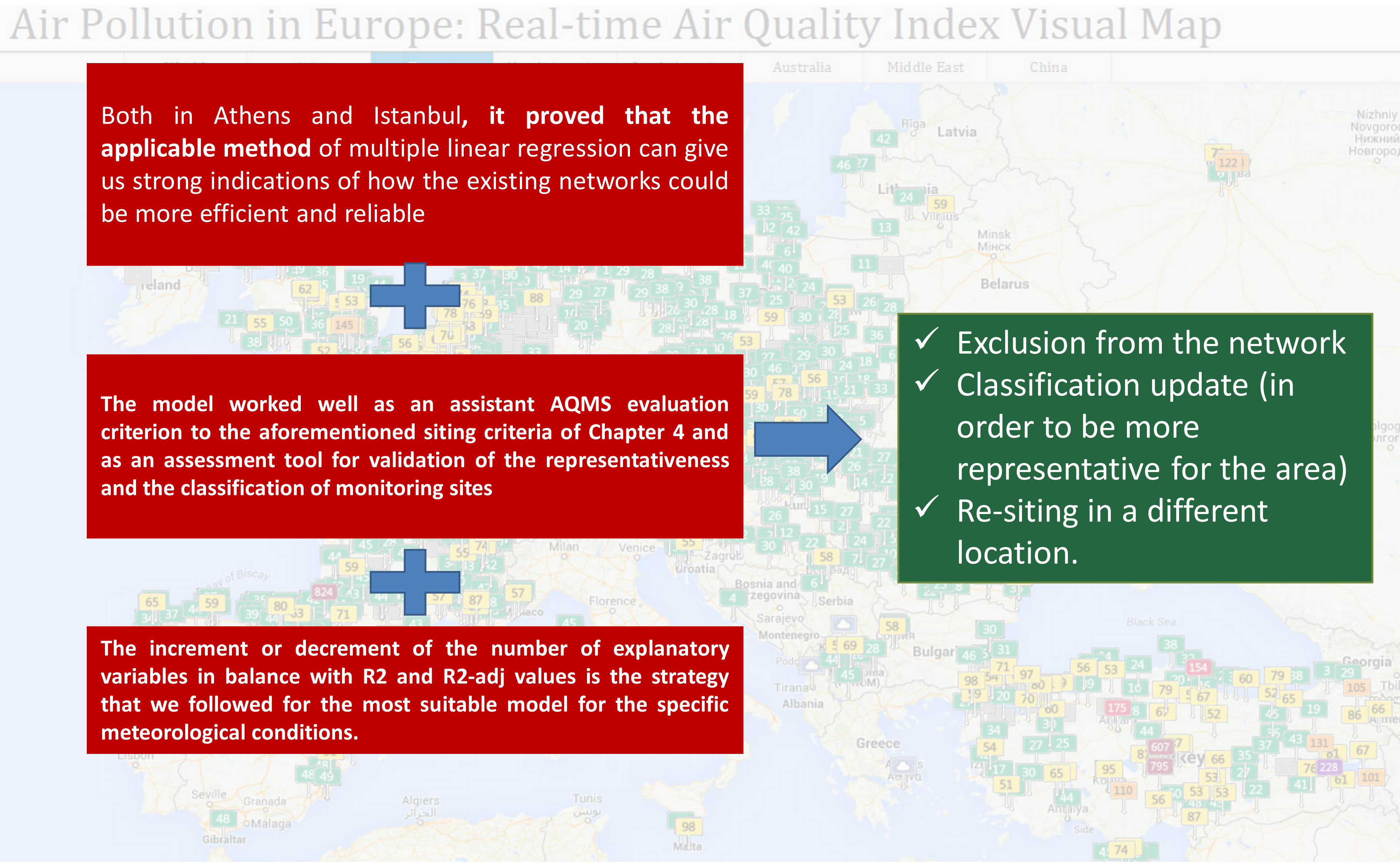
	İstanbul - Aksaray	İstanbul - Alibeyköy	İstanbul - Besiktaş	İstanbul - Esenler	İstanbul - Kadiköy	İstanbul - Kartal	İstanbul - Sarıyer	İstanbul - Ümraniye	İstanbul - Üsküdar	İstanbul - Yenibosna
İstanbul - Aksaray	1									
İstanbul - Alibeyköy	0,2974	1								
İstanbul - Besiktaş	0,079633	0,718301	1							
İstanbul - Esenler	0,675128	0,644295	0,479809	1						
İstanbul - Kadiköy	0,424679	0,78285	0,688799	0,829194	1					
İstanbul - Kartal	0,203481	0,631658	0,401681	0,431818	0,567672	1				
İstanbul - Sarıyer	0,507591	0,724316	0,636382	0,676582	0,756978	0,635487	1			
İstanbul - Ümraniye	0,2974	1	0,718301	0,644295	0,78285	0,631658	0,724316	1		
İstanbul - Üsküdar	0,380772	0,749874	0,734904	0,759294	0,811542	0,617544	0,685432	0,749874	1	
İstanbul - Yenibosna	0,751229	0,289594	0,18187	0,636128	0,62352	0,326102	0,489459	0,289594	0,522078	1

It is proposed, in a possible optimization of the AQMN considering the already heavy polluted inventory of the area, that **no AQMS should be excluded**. Instead a repositioning and re-classification of some AQMSs is necessary. **The siting criteria for redesigning the Istanbul's metropolitan network should be enhanced with these specific local particularities (low income population areas/near industry)** which affect the decision making process

Some AQMSs should be used as "pilots" for an early warning system of a possible pollution episode. In such cases, with an automated process, the sampling frequency of the measured pollutants should be changed in such a rate that the trend of the concentrations should be predictable compared to historical data for the specific site with the assistance of continuous meteorological forecasts. **We propose the AQMS "Kartal" as pilot station for an early warning system** because the site is constantly providing data with intense increment rates in similar episodes and meteorological conditions, compared to other AQMSs of the network

Non episode Correlation Conditions

Conclusions regarding the application of the evaluation model



Both in Athens and Istanbul, **it proved that the applicable method** of multiple linear regression can give us strong indications of how the existing networks could be more efficient and reliable

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The model worked well as an assistant AQMS evaluation criterion to the aforementioned siting criteria of Chapter 4 and as an assessment tool for validation of the representativeness and the classification of monitoring sites

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The increment or decrement of the number of explanatory variables in balance with R2 and R2-adj values is the strategy that we followed for the most suitable model for the specific meteorological conditions.

→

- ✓ Exclusion from the network
- ✓ Classification update (in order to be more representative for the area)
- ✓ Re-siting in a different location.

Conclusions regarding the application of the evaluation model

In the city of Athens we saw that the AQMS of "Agia Paraskevi" (classified as Suburban-Background) is the least correlated site among all the others of the network and this is an evidence that during the episode conditions (low relative humidity, high temperatures, variable wind directions and average wind speed below 7km/h) the AQMS is representative for its location

the AQMS "Lykovrisi" which was the dependent variable on the second attempt to apply the model in Athens' AQMN seems to be less representative as "suburban" class site compared to nearby AQMSs.

We've recommended the relocation of the station in less predictable areas, easterly or north-easterly of its current position, as a better choice for improved network coverage of the area, although a possible update to its classification as an "urban-background" site should be another potential decision for the local authorities.

In **real conditions our evaluation model could be useful**, such as in the case of overlaps between stations. The proximity of three of the same class(Urban-traffic) monitoring stations, ("Patission", "Aristotelous" and "Athinas") in the center of Athens kept are attention

The model verified that the range between urban traffic stations has to be such that should also satisfy a threshold value for the correlation coefficient.

The method that we have followed has also functionality in cases that although the site is representative for some measured pollutants and for its classification, too, but due to high predictability it is an easier choice for elimination from the network and as an aftermath, a decline in operational costs.

The application of the evaluation model in the metropolitan network of Istanbul except from similar conclusions as mentioned above**,** it proved that **some AQMSs should be used as "alarm signals"** of an early warning system for potentially evolving air pollution episodes**.**

the Athens Metropolitan AQMN **is not participating to an early warning system or AQI for the public**. Additionally, the technological obsolescence of the current operating AQMN is obviously an issue that has to be considered regarding the reliability of the provided measurement reports to EEA

Ευχαριστώ…


DNREC - Division of Air Quality
Checking the Air
Because we Care!
Ozone (O_3)
Carbon Monoxide(CO)
Sulfur Dioxide(SO_2)
Nitrogen Dioxide(NO_2)
Particulate Matter
www.dnrec.delaware.gov