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# OPTIMIZATION OF NETWORKS, DATA INTERPRETATION AND EXPERIMENTAL CAMPAIGNS

## Executive Summary

## 5TH SEMINAR ON AIR QUALITY IN SPAIN

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## Introduction.

Due to orographic and meteorological peculiarities, pollution dynamics in Spain, and in southern Europe in general, do not respond exactly to the same spatial-temporal patterns observed in central and northern Europe. Thus, for each EU member state, implementation of the European directives on air-quality evaluation and management (96/62/EC and its derivatives for the different pollutants) and, especially, implementation of the evaluation tools contemplated in these directives, i.e., automatic networks, numerical modelling, experimental campaigns, etc., must serve not only to monitor its particular situation in terms of compliance with the legal norms, but also to increase current knowledge on its air quality and on the degree to which its population and vegetation are exposed to pollutants. In this way, important regional peculiarities can be taken into account in subsequent revisions or amendments of EU legislation in this area.

A decisive step for adapting the available air-quality evaluation strategies and tools to the Spanish scenario would be the design of a zone map and an optimized air-quality station distribution; with these, evaluation results would better reflect the spatial pattern of pollutant concentrations in Spain.

This document recommends zoning and Network-optimization criteria based on the identification of air basins (i.e., a geographic area, defined by its orography, where pollution levels are mainly influenced by the same sources and by the same airmass transport processes from those sources) in which zones with equivalent air quality should be separated. In this way, measurements on representative sites within these zones would provide an accurate knowledge of the air-quality situation throughout the territory.

In this context it is understood that two points have the same air quality when their pollution concentration levels fall within the same interval as defined by EU legislation, i.e., they are above or below the limit and target values for the annual time base corresponding to each evaluation.

One of the underlying issues of zoning criteria is the particular situation of regional-scale pollution in southern Europe in relation to ozone, evidenced in air-quality monitoring networks year after year and reflected in the annual technical reports of the European Environment Agency (EEA). This regional differentiation with respect to ozone levels and the causes producing them has also been recognized by the European Commission in Decision 2004/279/EC on ozone directive application criteria, which is based on scientific evidence obtained in European projects led from Spain: MECAPIP, RECAPMA and SECAP. Thus, more than in central and northern Europe, in

Spain we need to be especially careful when delimiting measurement zones. The areas with elevated ozone levels must be well-defined because, if not, the obligation to take measurements at the points with the highest concentrations in each zone would result in an annual evaluation map showing most zones over the target value.

Moreover, regardless of the zoning map, air quality managers must establish the cause-effect relationships that determine pollutant concentrations in their territory. Without this knowledge it is difficult to design and execute satisfactory measurement plans (the short- and long-term plans considered in Directive 96/62/EC and its derivatives) for progressing towards the quality parameters (limit and target values). To determine these relationships it is necessary to identify the emission sources, air basins, and the usual emission-transport routes within them (determined by the meteorological and orographic peculiarities mentioned above), and to analyse the concentration gradient along these routes. Thus, the knowledge provided by air quality managers on pollution dynamics in their territory should be the starting point in the design of zones and in the distribution of measuring points.

Chapter 1 proposes a **methodology** for network optimization. It is oriented towards optimizing both the distribution of the stations (suitable number and site) and the zoning map, and it is based on the principles already laid out.

To achieve this, the data series provided by the continuous measurement networks must be analysed using tools and procedures that permit a correct **data interpretation**. Chapter 2 presents the most basic aspects to be taken into account for this. Additionally, in some areas the characterization of space-time concentration patterns will require **experimental campaigns** in suitable periods and sites to complete the air-quality analysis (generally, although not always, this is because of deficiencies in the spatial coverage of the automatic monitoring networks). Chapter 3 deals with the use of mobile units and alternative measurement techniques such as passive dosimetry in experimental campaigns.

Finally, it is essential to point out that all these recommendations for evaluation-tool optimization are not feasible in practice without the availability of **other specialized technical and human resources**. This requires both a budget large enough to be able to acquire and maintain the necessary equipment and a consolidated minimum number of technicians trained in data handling and interpretation with the appropriate tools. Nevertheless, the complexity of the air pollution phenomenon, which comprises different fields related to atmospheric physics and chemistry, will in many cases require the assistance of specialists. In this respect, research centres of reference in their respective fields can play an important role in providing support to air quality managers. Chapter 4 deals with all these aspects.

## 1. Optimization of Air Quality Monitoring Networks.

The air quality of a region is determined not only by the geographic distribution of the emission sources, but also by **physical-chemical processes** in the atmosphere that follow characteristic spatial and temporal patterns. In these processes all the spatial-temporal scales overlap, from the local scale to the synoptic scale, passing through the mesoscale, with some prevailing over others at different times of the year and different points in the territory. Moreover, these processes occur in both the horizontal and the vertical dimensions through mechanisms such as the creation of strata aloft and the fumigation and/or recirculation of these strata over the surface, thus contributing significantly to the evolution of the concentrations. Finally, orography has an enormous conditioning effect on air pollution dispersion and transport processes, especially in our latitudes and with an orography as complex as ours.

A satisfactory evaluation of air quality requires the availabilty of **monitoring networks** to capture the space-time variability in the concentrations in the area, paying special attention to the zones with greater probability of exceeding the legal values of reference and where continuous measurements are required by the EU Directive. To do this, there must be prior knowledge of the recurrent atmospheric circulations and processes that determine, together with the emissions, the space-time patterns of concentrations.

### 1.1. Methodology for Optimizing Air Quality Networks.

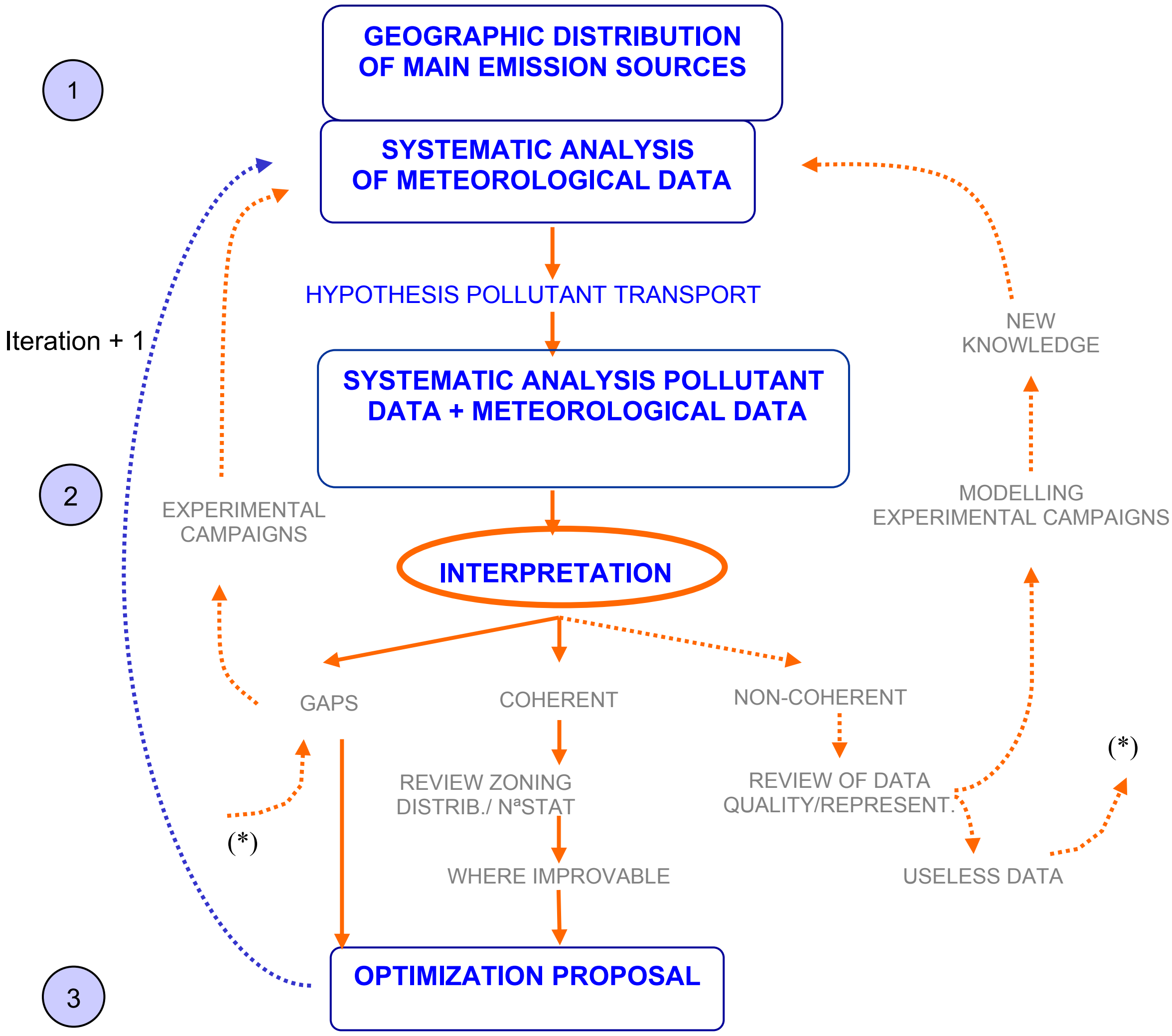
Air quality networks were originally oriented towards monitoring pollution levels around large emission sources, i.e., **urban and industrial areas.** The optimization of these networks must first improve their **spatial coverage**, so that it includes not only the areas where the emissions and population are concentrated, but also the **rest of the territory**, where the highest ozone levels are detected and the objectives of protecting human health and vegetation also need to be applied.

Moreover, one of the evaluation criteria established in the current legislation is the use of the **zone** as an air-quality management unit. Zoning is a key element in air-pollution monitoring and control because it conditions both the distribution of the stations and all subsequent air quality management. The current zoning in Spain, carried out independently by each autonomous community, was made on the basis of the monitoring stations available in each community in 1999-2000 (generally without taking into account the natural processes involved in the dispersion of pollutants or the continuity in the transport of the polluted airmass, which frequently crosses administrative borders). As a result, in many cases the zoning maps show basic design flaws generated by network distributions that are inadequate from the current point of view.

Zoning map of Spain ( updated 2004)

Because we are dealing with a pre-existent zoning, the methodology we propose should allow us to check that all the pollutants in each of the current zones are correctly evaluated, so that we can identify the cases in which the zone design (in so far as it does not show the same air quality throughout the area) or the station distribution do not correspond to the evaluation criteria.

The procedure is applied sequentially in three phases, and it will normally require several iterations. Applying an iteration may take from one to several months depending on the available human and technical resources, the amount of information to be analysed, and the geographic extension to be considered. Between one iteration and the next, it is necessary to leave a minimum amount of time (to include at least the season when the pollutant analysed shows the highest concentrations). During this time, the network will provide new data on the space-time patterns of the concentrations in the zone.




- **Phase 1:** *Geographic distribution of emissions, and systematic analysis of meteorological data.*

The methodology is aimed at improving the available network, whatever state it may be in. Its repeated application in a successively improved network will result in a spatial distribution that is more aligned with the evaluation objectives (of course, the initial state of the network will condition the number of iterations needed for this purpose).

In this phase we identify the main emission sources that could affect the zone (a detailed emission inventory is not needed), and we gather all available data from the meteorological towers in the zone of interest as well from those in nearby zones that might show continuity with respect to the most common wind circulations.

We begin by processing the meteorological data to generate **wind roses** in which the seasonal components and the diurnal/nocturnal components are separated in each case. If the met-tower density is sufficient, analysis of these roses will both allow us to estimate wind continuity and provide us with valuable information on the habitual transport routes in the zone and their probable seasonal variations. By subsequently superimposing the orography on these roses, and having at least a minimum knowledge of how orographic forcing can affect these measurements, we can refine these hypotheses.

Next, we analyse the distribution of the main **emission sources** (inside and outside the zone) that may contribute pollutants to the zone, in relation to the wind fields identified in our analysis of wind roses. This will allow us to produce hypotheses on the habitual transport routes of these emissions.

- **Phase 2:** *Joint analysis of meteorological and air quality data.*

In this second phase we add the data on pollutant concentrations. The matching of this data against the hypotheses formulated in the previous phase with regard to prevailing air-mass transport routes in the zone and the spatial variability expected as a result of this dynamics, will allow us to confirm or reject these hypotheses.

Given that the criterion for delimiting a zone is that it shows equivalent air quality throughout, and based on the interpretation presented in the introduction, we now proceed to process the pollutant data in order to calculate any exceedances of limit and target values.

A review of all this information will allow us to make a preliminary evaluation of the suitability of the zone design and the measuring station distribution. Several possibilities can arise from this joint analysis:

1. The analysis of the meteorological and concentration data together with the distribution of the identified emissions is **self-consistent** (i.e., the space-time variability of the concentrations is consistent with the transport dynamics and the emission dispersion identified from the meteorological records) and **complete** (i.e., the results of the analysis apply to all the territory within the zone in every season of the year). In this case we can draw two possible conclusions:

    a. The same level of air quality is present throughout the zone, and the location of the monitoring stations within the zone conforms to the evaluation criteria in that they are representative of the entire zone.

    b. The available concentration data shows that the zone comprises an area with different levels of air quality.

2. The analysis of the meteorological and concentration data together with the distribution of the identified emissions is **self-consistent but not complete** (i.e., the results of the analysis cannot be applied to all the territory included in the zone; there are gaps or significant uncharacterized areas in relation to concentrations).

3. The analysis of the meteorological and concentration data together with the distribution of the identified emissions **is not self-consistent** (i.e., the space-time variability in the concentrations does not coincide with the transport and dispersion dynamics suggested by the meteorological registers).

- **Phase 3:** *Optimization proposal.*

In the best scenario, 1a, an optimization proposal is needed only if redundance is found between different stations. In this case the proposal would consist of "liberating" some of the redundant monitors or stations, which would then become available for covering possible gaps. Case 1b directly implies an optimization proposal to modify the geographic delimitation of the zone analysed, and, if necessary, of the nearby zones.

Case 2 suggests that a gap has been identified in the network spatial coverage. This may lead directly to an optimization proposal such as the installation of a new station in said area or the relocation of a station considered unrepresentative or redundant. When it is not possible to determine the most appropriate monitoring site, complementary information is required and can be provided by measuring campaigns using mobile units at suitable points and periods (see section 3.1.1).

With regard to Case 3, in order to discard errors in the procedure application, it will first be necessary to review both the data quality and the starting hypotheses on transport routes and emission sources. If this review does not reveal the inconsistencies, other tools and additional data will have to be applied to gain better knowledge of the situation. These include experimental campaigns or meteorological and photochemical modelling exercises.

### 1.2. Site representativeness.

The aim is to determine a station's representativeness, and whether this applies to all the zone in which the station is located or only part of it. At this point we should provide a definition of the concept of *representative area* of a monitoring station in the context of the evaluation criteria stipulated in the directives. Following the criteria for zone delimitation indicated in the introduction, a monitoring station represents a specific area if it meets two conditions:

- Condition 1: The air quality at every point in the area is equivalent in the sense that every point would fall within the same interval of quality parameters established in the legislation. That is to say, below or above the limit/target values, and below, above or between the upper and lower evaluation thresholds.

- Condition 2: The whole area fits within one air basin (understood as a geographic area where pollutant levels are conditioned by the same sources and by the same air-mass transport processes from said sources). This means that the entire area shares identifiable cause-effect relations.

## 2. Interpretation of data from air quality monitoring networks.

In general, the concentration of any pollutant at any point on the surface at any given moment will respond to the balance between the different **processes** of contribution and elimination or destruction of the chemical species involved. These processes occur at all scales, from the microscale, through the local and mesoscale (regional), to the general or synoptic scale. Moreover, these processes overlap one another, with some predominating over others depending on the time of year, the dominant atmospheric conditions, and the geographic situation of the point of interest.

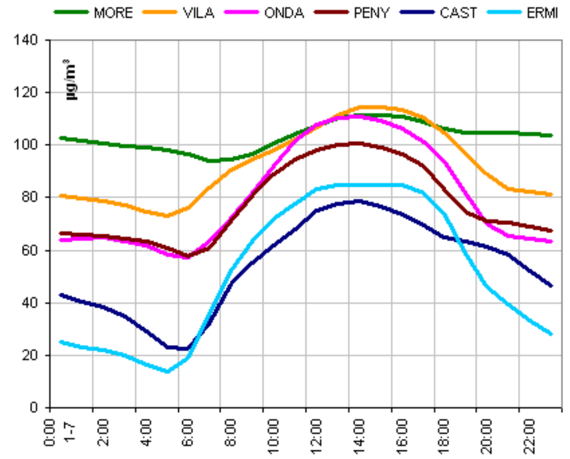
As a result of all the above, pollution concentrations follow **characteristic space-time patterns** that are registered in the air quality monitoring networks. The data series from these networks show **periodic components** (seasonality, weekly cycles, daily cycles), which are manifested regularly, and **non-periodic components**, which are mainly due to transitory periods and/or changing meteorological conditions. When the two coincide, there is an increase or a decrease in the normal levels (understood as mean levels for a geographic point and a day of the year).

In the case of the Iberian Peninsula, and unlike central and northern Europe, the meteorological determinants are strongly marked by **mesoscale** processes, especially during the spring and summer months when anticyclonic conditions favour situations with atmospheric stability and predominance of thermal circulations and show alternating day-night daily cycles such as sea breezes and upslope/valley winds. These circulations drive the air mass transport inside the areas delimited by the orography (air basins), and they are also associated with mechanisms of vertical injection and pollutant strata generation aloft during the day. These strata often end up impacting the surface again the following morning with the recirculation and/or the surface fumigation, affecting the same area or distant points (the latter can occur when light winds in the nocturnal residual layer transport the strata long distance while maintaining their structure). This dynamic implies a spatial limitation on the air mass, which favours the occurrence of pollution accumulation periods lasting several days.

## 2.1. Data analysis and proper representation of time series.

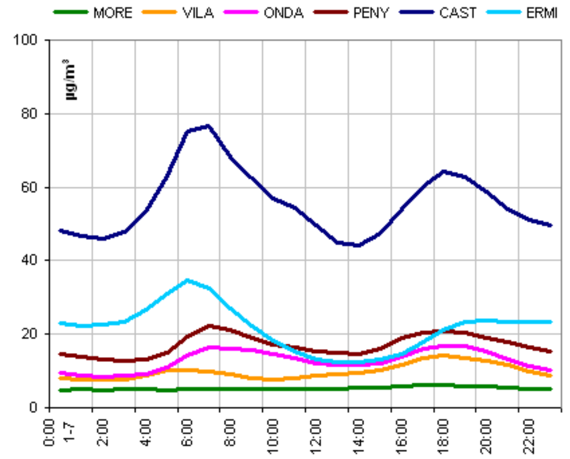
### *a) Daily cycle.*

**$O_3$ Mean Daily Cycle 1999-2005**



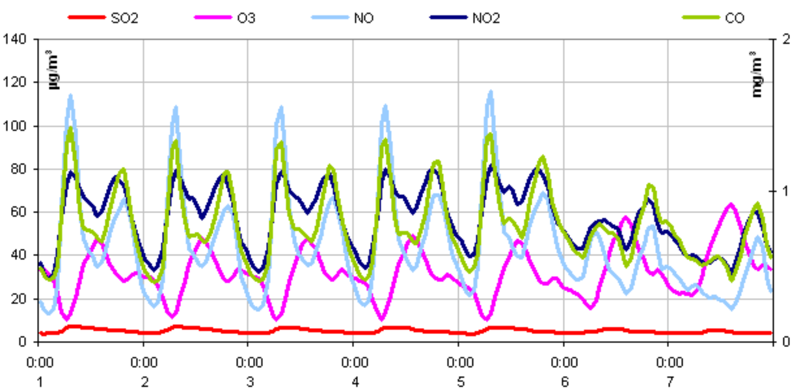

Characteristic ozone cycles in spring-summer at five stations in the Castellón air basin (UTC time values)

**$NO_2$ Mean Daily Cycle 1999-2005**



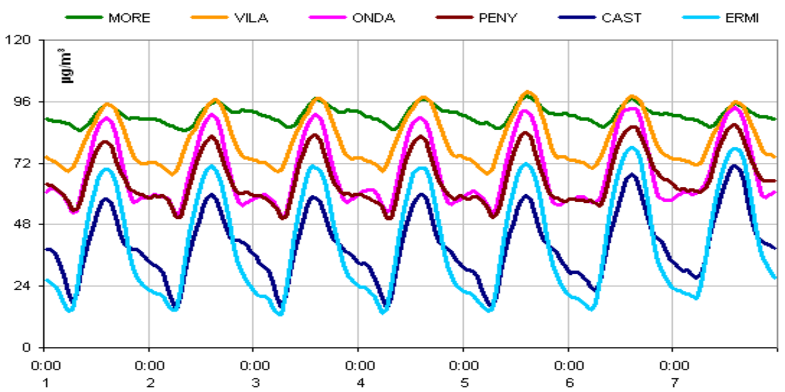

Characteristic nitrogen dioxide cycles in spring-summer at five stations in the Castellón air basin (UTC time values)

### *b) Weekly cycle.*




**Urban Station: mean weekly cycle 1999-2005**

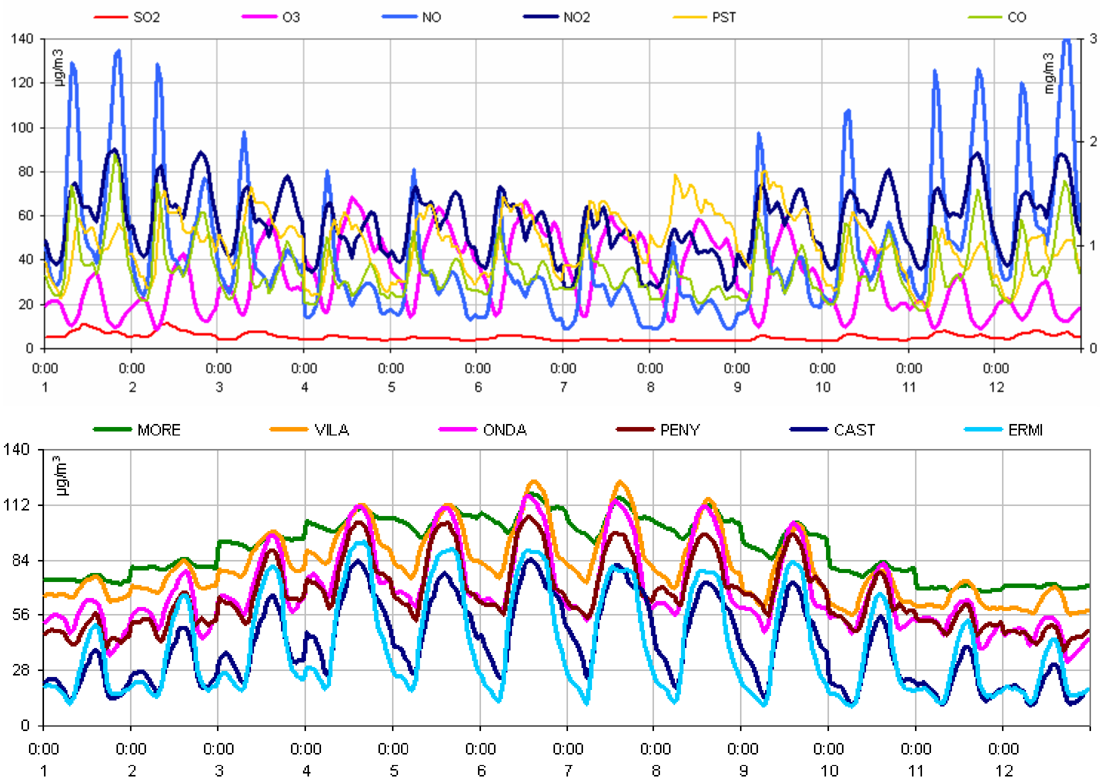
Mean week in the Pista de Silla station in Valencia (hourly values)




**Mean Weekly Cycle of Ozone 1999-2005**

Weekly evolution in mean daily ozone at an urban station in Castellón and at the five positions characterized on the Spanish east coast

### *c) Seasonal cycle.*

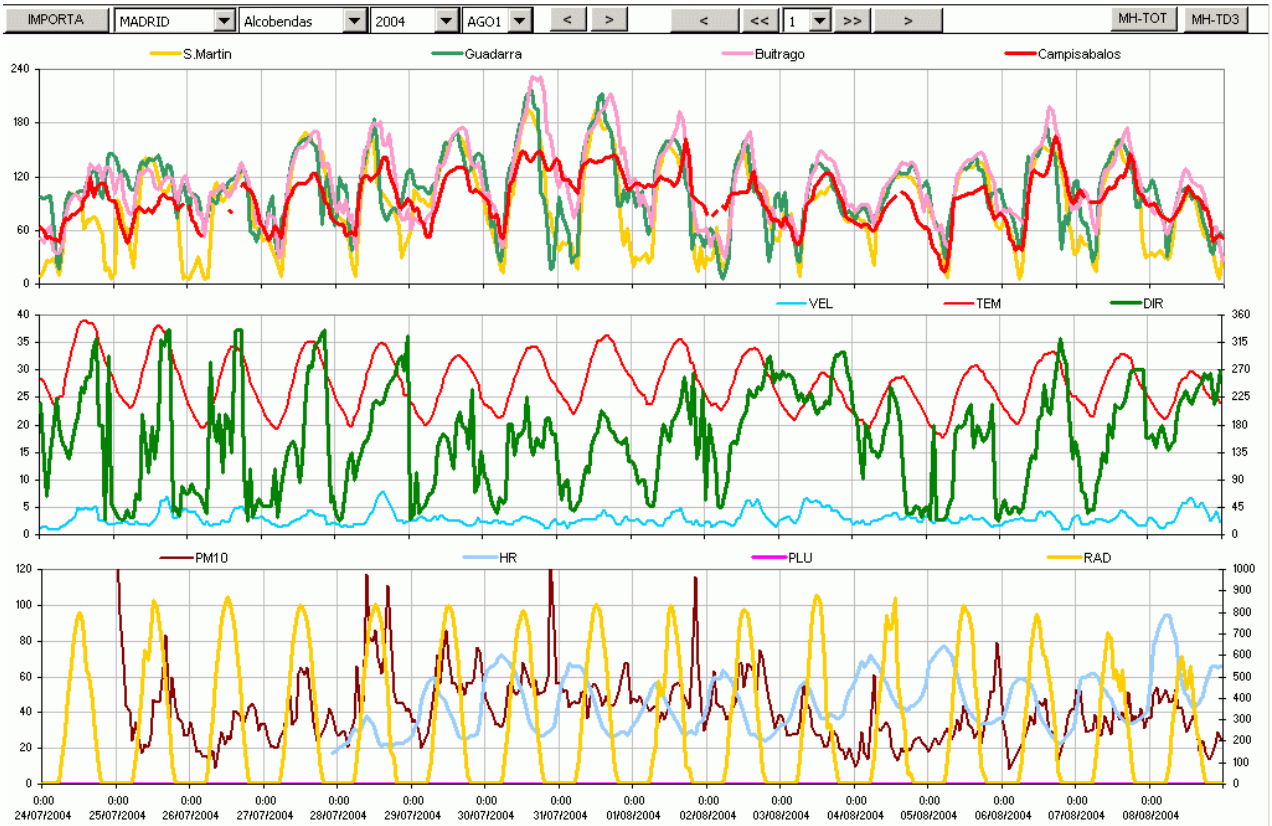



(Top) Annual evolution in mean day at an urban station in Valencia. (Bottom) Annual evolution in mean day of ozone at the five positions characterized on the Spanish east coast

### 2.1.2. Evolution of hourly registers.

At each measuring point, continuous changes in the factors that determine the pollutant concentration evolution (emissions, chemical reactions, and atmospheric-meteorological conditions) result in continuous changes in the inter-related concentrations and meteorological parameters. As a consequence, the correct interpretation of the pollutant concentration evolution requires a joint analysis of the variations in both concentrations and meteorological variables (wind speed and direction, temperature, radiation, relative humidity).

- **Example: Madrid Area.** The Madrid air basin shows a characteristic pollution dynamic that, in the central months of the year, is very conditioned by its orography. In these months the anticyclonic conditions with little synoptic gradient favour the establishment of mesoscale circulations. The general pattern of these circulations tends to become established on a SW-NE axis, with the usual NE nocturnal drainage turning clockwise during the day to SW. As a result of this dynamic, high ozone concentrations are regularly recorded along the whole arc at the north of the city.




Sequence of ozone maxima in the Madrid basin under mesoscale circulations. The San Martín-Guadarrama-Buitrago order is due to the relative position of these points with respect to the capital and the clockwise turn in the wind.

### 2.1.3. Data series interpretation and quality control.

The analysis and interpretation of data series, which we presented in the previous section, has a very important application in the quality control of the networks. Although the measuring equipment generally works correctly, failures do occur with some frequency and result in incorrect measurements which must be filtered out or invalidated from the database. In addition to the routine calculation of statistical parameters (means, maxima, minima, percentages...), which helps to locate the most obvious errors in the data series, the preparation of graphical representations is a useful procedure for detecting invalid data (as well as possible equipment failures).

## 2.2. Unified criteria for data management.

The goal is to provide guidelines so that, starting from the same raw measuring data, the various technicians can arrive at the same processed data (means, number of exceedances, etc), which can then be compared with existing legislation on air quality (strictly respecting the conditions of calculation and minimum data collection stipulated in the legislation).

To do this, we provide several criteria on data storage, aggregation and calculation by reproducing the steps that network managers would take, starting from valid raw measurement data, to obtain the reference values in the legislation and determine the air quality situation in their zone. In problematic cases the reference documents will be, first, relevant national legislation and, in its absence, European legislation.

## 3. Experimental campaigns.

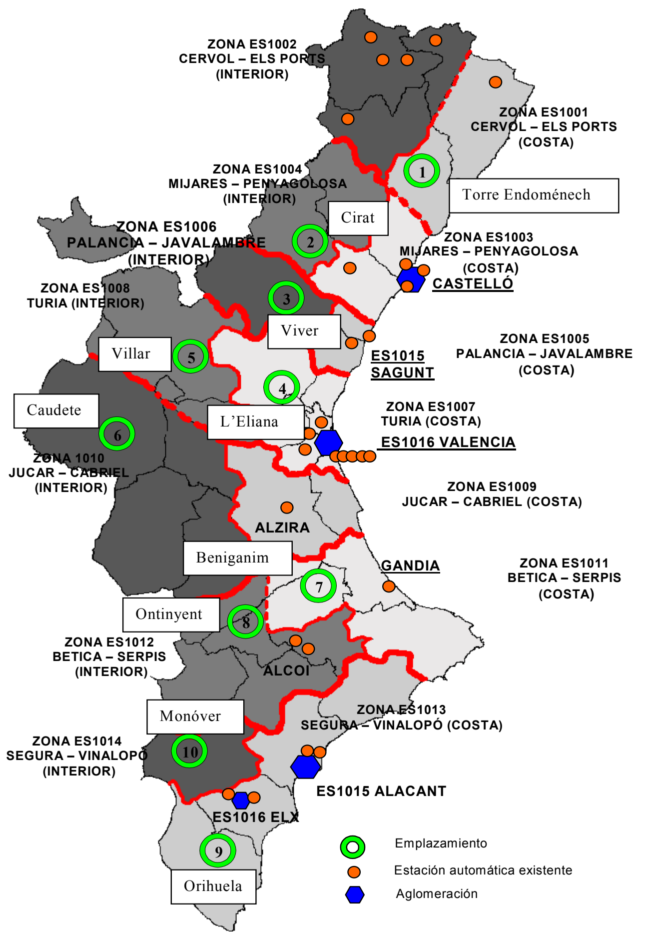
Experimental campaigns play an important role in monitoring air quality. On the one hand, they provide information on areas with no available historical data, and on the other hand, they cover aspects that automatic monitoring stations are unable to detect, such as the processes that drive the vertical transport of pollutants and have a determinant influence on concentrations registered at surface level. The design of the experimental campaigns will depend on the aims pursued. The selection of dates (including the time of year and duration of the campaign), of measuring points (including their number and location), and of field measurement instruments (mobile units with gas monitors and meteorological towers, passive sensors, meteorological soundings, remote sensors of gases, etc.) will be specific to each case.

### 3.1. Using mobile units to optimize networks.

The network optimization procedure laid out in section 1.1 involves carrying out experimental campaigns in areas where the network coverage leaves important gaps, or where there is no prior information on air quality. In these cases the most interesting option for network managers is to carry out measurement campaigns using mobile units at suitable locations within these areas and for periods of time that include at least the season in which the largest pollution concentrations are expected. The data collected during these campaigns will help the managers to decide whether to install continuous measurement systems at these points, or redistribute the existing points in the zone (occasionally they will suggest the modification of the zone map); in the best case scenario, these campaigns will show that it is enough to plan estimation measurements for these areas.

To illustrate this section we show the mobile unit measurement plan carried out in the Valencia Community in the year 2003, after designing the zoning map and evaluating the gaps in the air quality network in relation to this map.

MAPA DE LOS EMPLAZAMIENTOS ELEGIDOS

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| 23/06/2003 | 21/07/2003 | | | | | |
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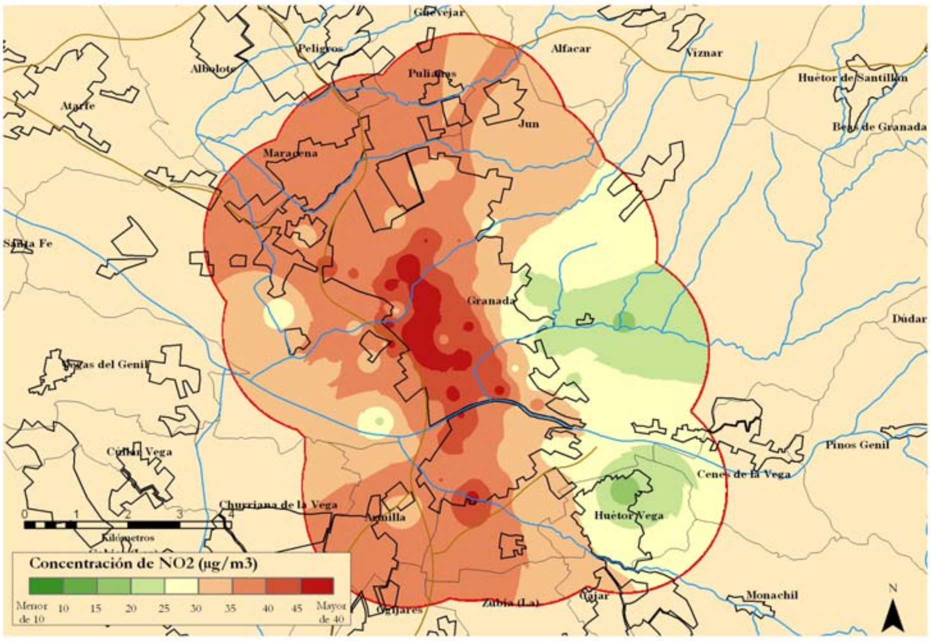
| 05/12/2005 | 02/01/2006 | | | | | |
| 02/01/2006 | 30/01/2006 | | | | | |

Above: Zoning and measurement locations for movile units operation (green circles). Right: Data collection schedule for the two mobile units.

## 3.2. Other complementary measurement techniques.

### 3.2.1. Passive dosimetry campaigns for the study of the spatial distribution of pollutant concentrations.

The passive dosimetry technique offers the advantage of obtaining measurements at a large number of points and at a relatively low cost. In this section we show the use of this tool in a practical case: "*Optimization of monitoring networks in Andalusia by means of campaigns with diffuse detectors*".




NO$_2$ concentrations obtained in Granada City.

### 3.2.2. Obtaining complementary information on parameters that are not routinely measured.

Air quality monitoring networks provide extensive temporal coverage because they operate continuously. Nevertheless, they have important limitations: the lack of measurement of other species or variables that intervene in the chemical processes, a sometimes insufficient spatial coverage, and the fact that the stations register only surface information. With regard to the latter limitation, the lack of knowledge about what is happening in the vertical dimension can lead to an incomplete or incorrect interpretation of the cause-effect relations and the phenomena that influence the observations registered at the station.

In recent years there has been a notable advance in techniques for atmospheric observation and for acquisition, storage and transmission of data on meteorological variables, chemical composition and atmospheric properties. Current techniques can be grouped into two large blocks: direct measurement techniques and remote sensing techniques.

## 4. Other aspects related to network optimization.

### 4.1. Integration of private networks into air quality management systems.

There are many reasons to insist that the companies legally obliged to establish air quality management systems to control the effects of their activity should pay for the maintenance of said systems. The basic legal principle applied is reflected in the saying “he who pollutes must pay”; this can be applied to the obligations of the various Integrated Environmental Authorization plans that are currently being processed, thus permitting its direct and individual application in each company.

There are two models that air quality managers can follow to integrate private networks.

– The stations belong to and are managed by the Administration; this is financed by a specific tax applied to each company.

– The stations belong to the private network, and their maintenance and quality control are the responsibility of the private company as manager of the data reception network.

**4.2. Air quality management systems.**

In the Introduction we pointed out that all the recommendations, procedures, etc. proposed in this document are unfeasible in practice unless air quality managers have access to the necessary human and material resources. On this basis a management system can be developed following two schemes that are not necessarily incompatible:

– Creating Control Centres in the various air quality monitoring networks which would be responsible for managing all the different tasks associated with air quality, or

– Permitting the participation of work groups external to the Administration (universities, research centres, etc.), which have recognized competence in the tasks that need to be performed.

Either of these two alternatives may result in a good management system. In fact, the optimum solution probably involves a combination of the two schemes, by combining their advantages and avoiding their disadvantages.