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COMPARING URBAN AIR QUALITY IN EUROPE IN REAL TIME
A REVIEW OF EXISTING AIR QUALITY INDICES AND THE PROPOSAL OF A COMMON ALTERNATIVE

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ABSTRACT

The EU directives on air quality force member states to inform the public on the status of the ambient air quality. The internet is commonly used for this purpose and often air quality is being presented as an index ranging from good to bad. A review of existing websites and air quality indices shows that the way air quality is interpreted differs considerably.

The paper presents a new air quality index. The index is part of a project to develop a website dedicated to comparing air quality in European cities. The common air quality index (CAQI) is not aimed at replacing existing local indices. The CAQI is a set of two indices: one for roadside monitoring sites and one for average city background conditions. Differentiating between roadside and general city conditions is a first step in assuring consistence in the parameters that are being compared.

Key Words: urban air quality, air quality indices, public communication

1. INTRODUCTION

The Framework directive and associated daughter directives on air quality in the European Union not only force member states to monitor and report on their air quality but also to actively inform the public on the status of the ambient air quality (EU1, www). The Aarhus convention (ratified by the EU in 2005) further enforces the concept that citizens have the right to be informed on the environmental conditions they live and work in (EU2, www). Over the past years a good number of cities and countries have started to display monitored or modelled air quality data on the internet. For most of the monitoring organisations, the internet is the easiest way to meet the dissemination of information requirements of the European (and/or national) legislation. The fact that so much air quality information is available on the internet makes it tempting to compare different cities in different countries. This proves particularly difficult. Apart from the European Environmental Agency's ozone website there are no possibilities to compare cities/countries side by side

(EEA, www). Even if one surfs from one site to the other, comparison is not easy: air quality is presented in different ways using different interpretation criteria and a different typology of stations, which is usually not clearly explained.

The most widespread way to interpret air quality on the internet is the use of an index ranging from good to bad to make the detailed measurements in micrograms more understandable for the general public. A review of existing websites and the associated air quality indexes shows that the way air quality is interpreted differs considerably across the world. More surprisingly, even amongst the EU member states who share common legislation, the indices used do vary. There are a number of reasons to explain these differences. Some of them are historical and conceptual: the index existed before the EU regulations came into force and the index was based on health and exposure criteria, e.g. the UK index (DEFRA, www). The fact that air quality problems (sources, meteorological conditions, etc.) tend to differ is also one of the reasons. The indices tend to be calibrated to the local situation to make sure that there is some variation in the index from day to day (to make it entice repeated visits to a website) and that the typical range of pollutant conditions occurring locally is being covered.

To facilitate the international comparison of near real time air quality the CITEAIR project[1] is developing a common operational website (COW) where cities can display their air quality information side by side. The project aims at making air quality comparable across Europe and the COW will be open for any city to join. The COW is planned to be available by the end of 2006. The common website needs a common air quality index (CAQI). The CAQI is *not* aimed at replacing existing local indices. This would be an unrealistic ambition as in many cities the public has got used to the local, tailor-made index, and the CAQI will be, by the nature of the fact that is common, a non-specific compromise. CITEAIR envisages that there is room for two sources of air quality information on the internet: a local website, in the national language with a dedicated presentation (using a well established and known local index relying on more detailed air quality information); and a common website aimed at comparing - in near real time - the air quality in your own city to the air quality in other European cities. For this website a specific index had to be developed.

2. REVIEW OF AIR QUALITY INDICES

There are a substantial number of different ways to interpret air quality in near real time. The most common way to do so is the use of an index, generally based on a number of sub-indices for individual pollutants[2]. There is a wealth of indices and even countries who share the same legislation, or sometimes areas/cities within the same country have different indices. Some of the differences can be explained by the local differences in the nature of the air quality problems. Some other differences are

[1] CITEAIR is an initiative of the cities of Leicester, Paris, Prague, Rome and Rotterdam. Information on CITEAIR is available at http://citeair.rec.org

[2] A version of this paper with a list of indices collected in the course of the development of the CAQI annexed will be available on http://citeair.rec.org

due to fundamentally different approaches. The UK index (and US-EPA) for example is strongly related to perceivable effects. The bands in the index are explained in health terms. This implies that the index covers a very wide range of concentrations and that actual concentrations are very often in the “good” or “moderate” end of the scale. Air quality in Europe, fortunately, is rarely poor enough to cause acute health effects so any index based on health impacts tends to trail at the lower end of the scale for most of the time.[1]

Other indices take a different approach. For example the ATMO index, a countrywide standard in France (Airparif, www) has bands that are somehow linked to values that are also used in the current EU directives. The alert thresholds in the directives tend to define the higher end of the scale. In these cases the top end of the index scale ends somewhere in the middle of the health effect based scales. For example the worst end (very poor) of the NO_2-index in France corresponds to 400 μg/m3. In the UK this is in the lower end of the “moderate” band and in the US it is even considered too low to calculate an index value.

Communication-wise the health-based indices have both a clear advantage and a disadvantage. The advantage is that the index value displayed at the website is easy to interpret: it does or does not cause health effects. The disadvantage is that the index is almost always indicating that air quality is good and pollution is low whereas the limit values for long-term exposure are often exceeded. This leads to an apparent paradox: a citizen regularly checking the local air quality website will always get the message that the air quality is good whereas at the end of the year local government puts out a report that he or she is living in a hotspot area for which an action plan is required. This is the paradox between short- and long-term air quality criteria. The criteria for short-term exposure are often met except for episodes, like for example in the summer of 2003. The criteria for long-term exposure are often not met, in Europe’s urban areas. The ATMO-type of indices provide some differentiation at the lower end of the scale to assure that the air quality is not always “good”. However in this case it is very difficult to attach some kind of health interpretation to the index.

The differences between the two approaches vary from one pollutant to the other. On ozone, the agreement tends to be quite reasonable but for NO_2 and SO_2 the differences are substantial. For PM_{10} the picture is mixed partly because the way PM_{10} affects health and on what timescale this occurs is still subject to a lot of research. This implies that during typical summer episodes the indices tend to agree more or less. On days with less air pollution the interpretation gaps widen.

The long-term ↔ short-term paradox, and the problem to communicate it, typically occurs on the internet. In an annual report the focus is on long term air pollution. On text TV pages dedicated to smog warnings the focus and interpretation is based on health effects. However, internet presentations often serve multiple roles: informing the public, but also making the public aware of air quality issues. In this case the

[1] It should be note that there is increasing evidence indicating that PM_{10} has both short and long-term effects even at moderate concentration levels (WHO, www).

paradox is difficult to resolve: highly variable hourly (or daily) data is being presented to assure an attractive and frequently changing situation that encourages repeated visits. On the other hand, the most challenging limit values appear to be the criteria for the year average so interpreting commonly occurring hourly values in terms of good or bad is fairly arbitrarily. They are not bad from the short-term exposure point of view but might be bad from the long-term exposure point of view. An attempt to overcome this was described by Van den Elshout (2004). For NO_2 and PM_{10} an expected hourly pattern is established for a whole year, based on historic data. This pattern is scaled (up or down) in such a way that it provides a reference pattern that would lead exactly to the limit value. In this way a, be it hypothetical, identification of hourly values that contribute to the exeedance of the year average limit value can be made.

3. COMPARING CITIES ON THE INTERNET

Apart form the fact that the bands differ from one country/city/area to the other, the data behind the index also differ. Whereas most websites have a page explaining how the index is calculated, other methodological aspects are generally not explained. Does the index represent measurements at background stations, traffic stations, a mixture? And in case of PM, how is it monitored, if automated equipment is used is it corrected? In the UK the index for PM depends on the monitoring method (DEFRA, www) but in most cases there is no way of knowing how PM concentrations were established.

CITEAIR aims to provide *one* index and make a difference between background and traffic stations. The potential of having one index will be apparent from the following example in which we try to compare air quality at a given day in four cities. The indices system is described in table 1.

Table 1: Indices used on the internet in Paris, Leicester, Rome and Rotterdam

ATMO Paris	ozone-1h	PM10-24h	NO2-1h	index	**UK**	ozone-8h	PM10-24h	NO2-1h	index
very good	29	9	29	1	low	32	21	95	1
	54	19	54	2		66	42	190	2
good	79	29	84	3		99	64	286	3
	104	39	109	4	moderate	126	74	381	4
average	129	49	134	5		152	86	477	5
mediocre	149	64	164	6		179	96	572	6
	179	79	199	7	high	239	107	635	7
poor	209	99	274	8		299	118	700	8
	239	124	399	9		359	129	763	9
very poor	>=240	>=125	>=400	10	very high	>=360	>=130	>=764	10

Rome	ozone-1h	PM10-24h	NO2-1h	index	**Rotter-dam***	ozone-1h	PM10-24h	NO2-1h	index
good	90	100	100	50	good		20	100	-
moderate	135	150	150	75	moderate	180	40	200	-
mediocre	180	200	200	100	bad	240	60	400	-
unhealthy	360	400	400	200	very bad	>240	>60	>400	-
very unhealthy	> 360	> 400	> 400	>200					

* Ozone classification from the national smog pages, other classes from a local traffic website.

Three out of four cities have an index, two indices range from 1 to 10, the other from 1 to 200. Two cities have 10 classes, one has 5, one has 4. Two describe air quality in terms of good and bad, one in terms of health and the fourth in terms of pollution levels. The class boundaries are very different. If someone would want to compare these four cities at a given moment he or she would not only have to visit four websites but also be faced with four completely different presentations and qualifications.

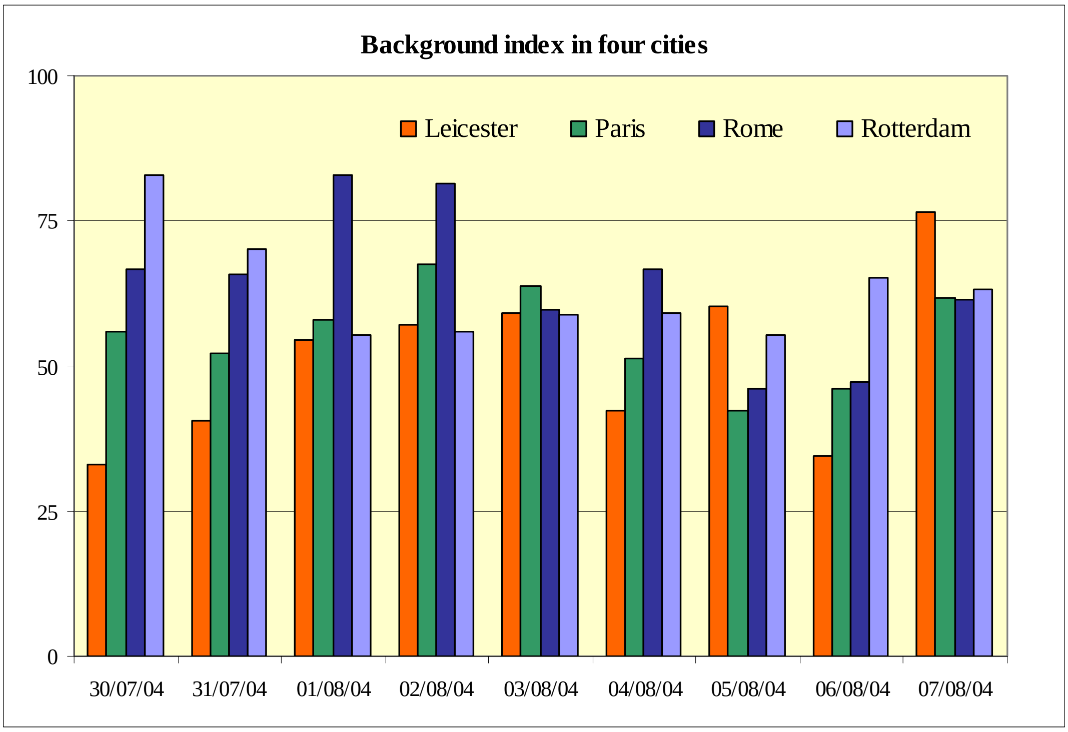

Figure 1: The CAQI applied to background stations in four cities July-August 2004

As an example, look at the period end of July - early August 2004 (Figure 1). The background index was quite high in all cities. On the 3rd of August the cities would have had a similar CAQI value. The cause of the elevated background concentrations was different though: PM_{10} in Leicester and Paris, and ozone in Rome and Rotterdam. If someone had looked at the four different websites he or she would have had no possibility of comparing the information. See Table 2. Paris looks worse than Leicester as both seem to have a similar scale (1 to 10); and how to compare the score of 79 of Rome to the others: is it safe to assume that 79 out of 200 equals 4 on a 1 to 10 scale?

Table 2: the CAQI and the local indices on a day with above average concentrations

	CAQI	Pollutant	Own city index	Pollutant	Own city classification
Leicester	59	PM_{10}	4	Ozone	low-moderate
Paris	64	PM_{10}	6	PM_{10}	mediocre
Rome	60	Ozone	79	Ozone	mediocre
Rotterdam	59	Ozone	-	PM_{10}	bad

4. CITEAIR'S COMMON AIR QUALITY INDEX (CAQI)

The CAQI is calculated according the grid in table 3, by linear interpolation between the class borders. The final index is the highest value of the sub-indices for each component. As can be seen there are two CAQI-s: one for traffic monitoring sites and one for urban background sites. The traffic index comprises NO_2 and PM_{10}, with CO as an auxiliary component. The background index obligatory comprises NO_2, PM_{10} and O_3, with CO and SO_2 as auxiliary components. In most cities the auxiliary components will rarely determine the index (that is why they are auxiliary) but in a city with industrial pollution or a seaport SO_2 might occasionally play a role.

Table 3: Proposed pollutants and calculation grid for the CAQI

Index	Class	Traffic			City Background				
		NO_2	PM_{10}	CO	NO_2	PM_{10}	O_3	CO	SO_2
Very low	0 25	0 50	0 25	0 5000	0 50	0 25	0 60	0 5000	0 50
Low	25 50	50 100	25 50	5000 7500	50 100	25 50	60 120	5000 7500	50 100
Medium	50 75	100 200	50 75	7500 10000	100 200	50 75	120 180	7500 10000	100 300
High	75 100	200 400	75 100	10000 20000	200 400	75 100	180 240	10000 20000	300 500
Very High	> 100	> 400	>100	>20000	> 400	>100	>240	>20000	>500

NO_2, O_3, SO_2: hourly value / maximum hourly value in µg/m3
CO 8 hours moving average / maximum 8 hours moving average in µg/m3
PM_{10} hourly value / daily average in µg/m3

Comparing air quality in different cities is a tricky issue: is the air quality being determined in the same way (this mainly applies to particulate matter) and at comparable locations? This is not an issue that we, as the CITEAIR project and the proponents of the QACI, can solve. The website will take for granted whatever a city supplies as input in either category. However, as a first step to improve comparability, the index will be reported both for roadside and city background locations. This is considered an important improvement over city averages: some monitoring networks are designed to monitor, or spot areas of poor air quality (with possibly a high number of roadside stations) whereas others are aimed at providing an average city picture.

The CAQI is used both for a daily index and for an hourly index. In the website the daily index will be shown for the past day (D-1). For the current day, the past 24 values of the hourly index will be available, to be updated every hour. A daily index for today would need forecasting or 'nowcasting' a facility that is not available in each city with a monitoring network, hence the option of an hourly index. The hourly index is also a reasonably dynamic parameter, enticing repeated visits to a website.

Participating cities are advised to submit average data from the stations they qualify as city background and traffic. The use of average data leads to better representativity and less missing data. However, if a city wants to select (or only has) one station in each category, that data will be used.

The choice of the classes in the CAQI is heavily inspired by the EU legislation and based on a compromise between the participating cities. The dividing line between medium and high is often linked mainly to the values mentioned in the directives: alert thresholds (SO_2, NO_2, O_3) or air quality objectives when available on a daily basis (CO and PM_{10}). Class borders were regularly spaced for the main components. PM_{10} is an exception. To avoid that the CAQI is completely dominated by PM_{10} the value of 50 µg/m3 as a daily average was positioned as the bordering line between low and medium. For the setting of the CO and SO_2 borders additional inspiration was sought from the DAPPS index which aims to define the component sub-indices based on the relative risks attributed to each component (Cairncross and John, 2004).

The CAQI resembles the ATMO index discussed above and it differs substantially from, for example, the UK and US-EPA indices. It therefore shares the drawbacks of the ATMO (no clear link with health effects, fairly arbitrarily quality interpretation for short-term exposure). But it also shares its advantage: frequently changing index values that capture the hour-by-hour changes and make a website dynamic. The latter was of overriding importance as raising awareness is a key objective of the common website.

As cities join the website the exact bands might need reassessment to maintain an attractive comprise. The current classes were derived based on the episodes of august 2003 and a recent year of data (April 2004 - March 2005) for the cities of Leicester, Paris, Rome and Rotterdam.

Table 4: Percentage of hours that a pollutant determines the final index (2004-2005)

Traffic Index	Leicester	Paris	Rome	Rotterdam
NO_2	85	53	31	49
PM_{10}	14	47	69	51
CO	1	0	0	0
	100	100	100	100

City background Index	Leicester		Paris		Rome		Rotterdam	
	main	main + auxiliary	main	main + auxiliary	main	main + auxiliary	main	main + auxiliary
NO_2	30	33	35	35	24	24	21	20
PM_{10}	24	25	27	27	36	35	46	45
O_3	46	42	38	38	40	42	34	26
CO		0		0		0		0
SO_2		0		0		0		9
	100	100	100	100	100	100	100	100

The tables show that in these four cities CO almost never plays a determining role in neither the traffic nor the background index. For the second auxiliary variable SO_2 the situation is slightly different. In Rotterdam, with a seaport and a petrochemical industry, in 9 % of the hours SO_2 would have determined the index[1].

Figure 2 shows the daily indices in the four test cities for a period of twelve months. The Rome background index shows a distinct seasonal pattern. In summer the background index is mainly determined by ozone, in winter by PM_{10} and, to a lesser extent, NO_2. The seasonal pattern is absent in the other cities, though the shift in pollutants determining the index is fairly identical. The winter of 2004/2005 was rather mild so only some days with a higher index can be seen. The winter doesn't show up clearly. The traffic index is significantly higher than the background in Rome and Paris. This was to be expected in large cities with a big vehicle fleet, typical street-canyons, large ring roads, etc. In the much smaller city of Rotterdam the traffic index is only slightly higher than the background index. Leicester provides a mixed picture. With NO_2 being the dominant traffic pollutant in Leicester, the traffic index is relatively low in summer and higher in winter.

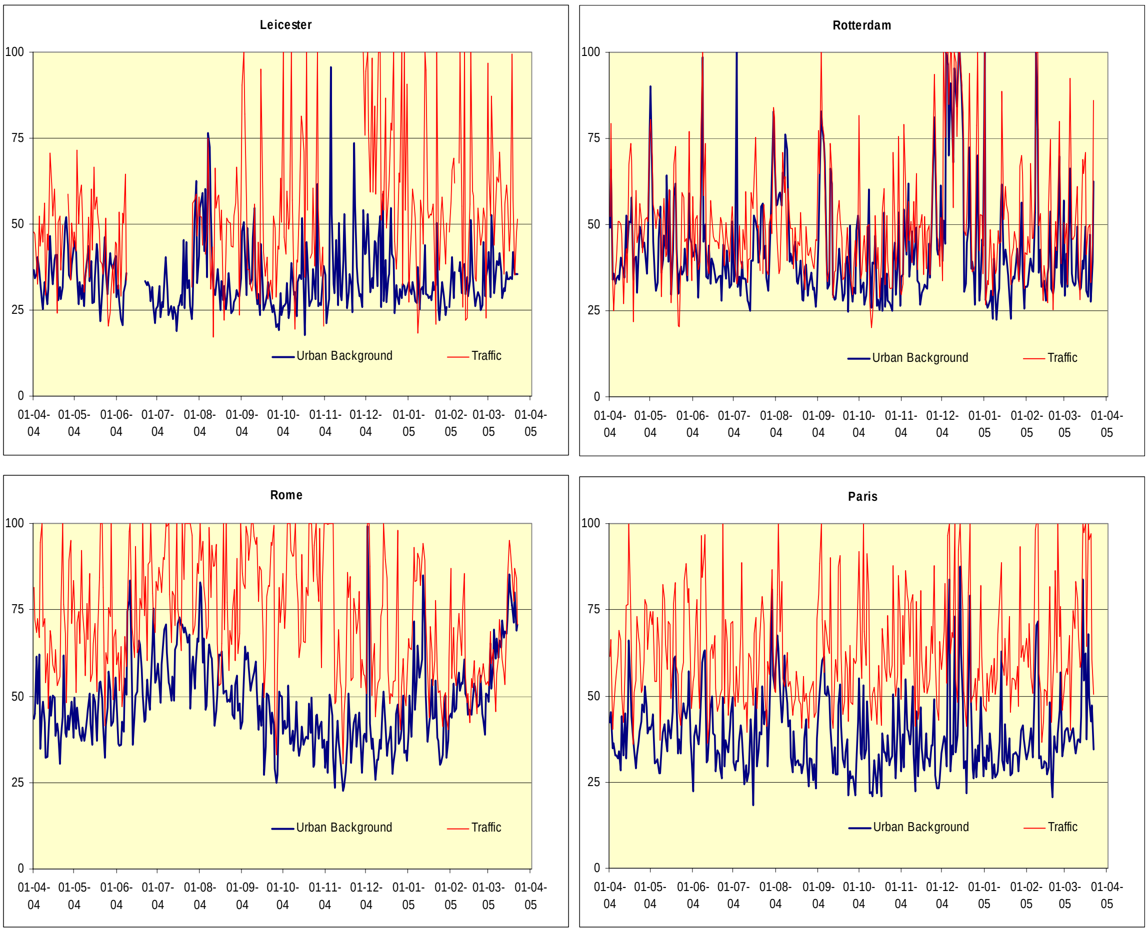

Figure 2: The CAQI (traffic and background) in four cities

[1] In fact even in Rotterdam this is exceptional. SO_2 determined the index in a short period with flares due to unexpected maintenance in a petrochemical plant and otherwise low concentrations.

The usefulness of a separate background and traffic index can be seen from figure 3 showing the daily index in Paris in August 2003. August 2003 was characterised by hot weather and poor dispersion conditions, leading to very high ozone concentrations. Except for a few days at the end of the month the background index was dominated by ozone. The traffic index was mainly determined by nitrogen dioxide with a few days of PM_{10}.

The poor dispersion conditions, combined with a large amount of imported ozone, are evident from the fact that the background index is similar or even higher than the traffic index, whereas normally (e.g. good dispersion conditions) there would be a gap of 15 to 25 index points between traffic and background. From the graph it can be seen that the traffic index drops in weekends (days labelled 6 and 7) whereas the background index rises. In this ozone dominated month, the relative lack of fresh exhaust (NO) emissions, leads to higher ozone concentrations in the weekend. This weekend ozone effect is well known (Lawson, 2003).

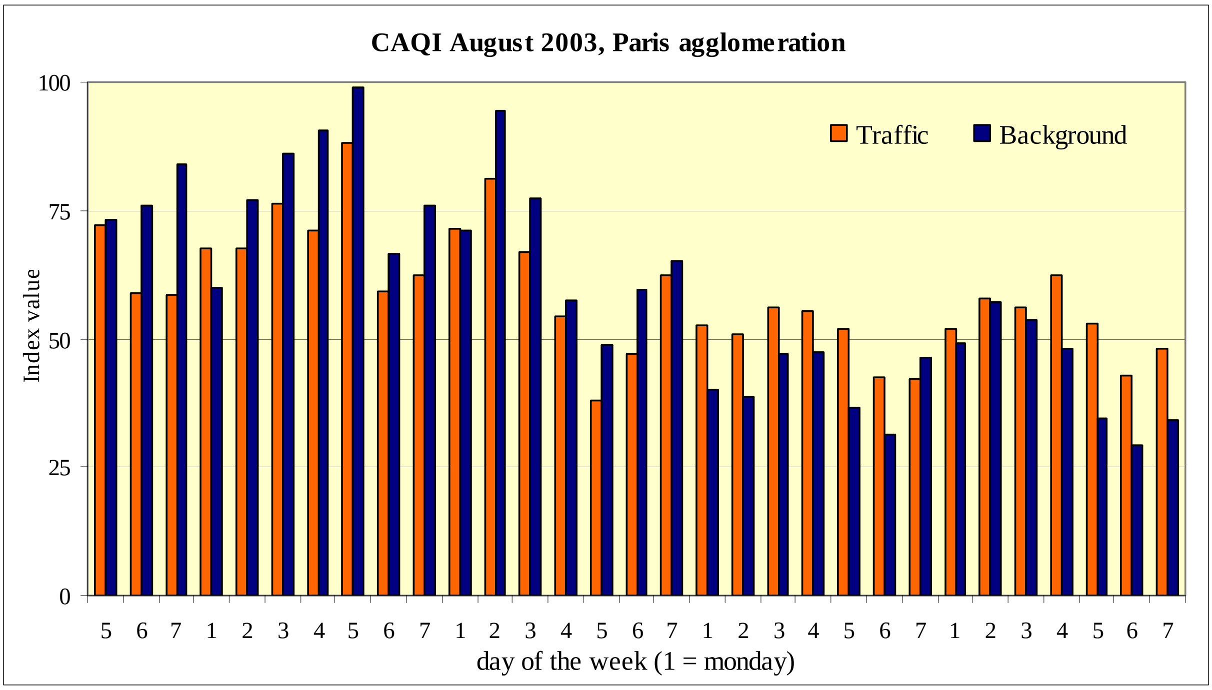

Figure 3: The traffic and background indices during an episode in Paris

5. CITEAIR AND THE COW

The CITEAIR common website (COW) will be launched in 2006, initially with contributions from the CITEAIR partners. Once the site is fully operational other cities will be invited to join and upload their data as well. The COW is meant to be an interesting *complement* to the cities' own websites. The COW and the CAQI are not launched to replace existing websites or indices. For those cities who are not yet on the internet, and/or do not currently use an index, the COW and the CAQI could be their primary platform. It is envisaged that most calculations are done inside the COW. Cities only have to upload their data (through an agreed ftp format).

Cities engage in communication with the public, not only because of legal obligations but often also to raise awareness. This implies that air quality issues have to be presented in an attractive and educational way. The possibility to compare your own local air quality to a number of other European cities could be an asset in this respect. To make the COW attractive and to solicit repeated visits dynamic content such as an hourly updated index will be presented.

However, not every city has its own network or both traffic and background stations, and not everyone is able to deliver data in near real time. If cities want to participate in only one of the indexes, can only deliver data on a daily basis, or even only present year average data, they can still join (the concept of) the COW. Different sections of the website will provide a platform to compare different data (year average, daily, hourly) so participation is not limited to those with their own automated network.

6. ACKNOWLEDGEMENTS

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