A NEW TOOL FOR THE EVALUATION OF THE EFFECTIVENESS OF TRAFFIC REDUCTION MEASURES

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ABSTRACT

The performance of the Atmospheric Stability Index, a recently developed tool for the interpretation of atmospheric pollution episodes, is discussed. This Index, based on natural radioactivity measurements, demonstrates to be able to describe the mixing properties of the lower atmosphere and to uncouple the role of emissions and that of meteorology in the build up of pollution. The Index is thus very useful in assessing the real impact of traffic reduction measures on pollutant concentrations. The application of the Atmospheric Stability Indexes to some pollution episodes in the area of Rome (both primary pollutants and PM_{10}) and to the assessment of the effects of traffic restriction measures taken by the Municipality of Rome during the winter of 2004 is discussed .

INTRODUCTION

Traffic reduction measures are one of the means widely used to reduce atmospheric pollution, as required by the European legislation in case the limit values are exceeded. These measures, as well as any other emission reduction measure, act, at a variable extent, on the amount of pollutants injected into the atmosphere. The air concentration of a pollutant, however, depends not only on the emission rate (and, in case of secondary compounds, on the physico-chemical transformations occurring in the atmosphere) but also on the mixing properties of the lower atmosphere, which determine the possible fast dilution or, conversely, the rapid accumulation of the emitted species in the boundary layer. The knowledge of this parameter is crucial for assessing the effectiveness of reduction measures, whose action can be easily masked by variations in the height of the mixed layer (has the concentration decreased as a consequence of the emission reduction or it has decreased as a consequence of the increased mixing of the atmosphere?).

We may obtain useful information about the dilution potential of the planetary boundary layer, which is not directly measured by any standard meteorological procedure, by monitoring a ground emitted and chemically stable compound whose emission rate can be considered to be constant in the space and time scale of our observations. This is the case of Radon and of its short-lived decay products (Radon progeny), as the variation in the emanation rate of Radon from the soil can be considered to be negligible in a time scale of some days and a space scale of some kilometres [1]. It follows that Radon concentration in the air only depends on the dilution factor and that Radon progeny can be considered as a good natural tracer of the mixing properties of the lower boundary layer. Natural radioactivity can be measured by means of an automatic monitor that consists of a particulate matter sampler equipped with a Geiger–Muller counter for determining the total beta activity of the short-lived radon progeny over an integration time of 2 hours.

On the basis of Radon progeny measurements, two Atmospheric Stability Indexes (ASI), one specific to primary pollutants [2] and the other one specific to particulate matter, have been developed. On the basis of the Indexes, each day of the period under study is classified in terms of pollutants dispersion and thus in terms of intensity of a potential pollution event, allowing an easy distinction between the two main contributions that determine the atmospheric concentration of a pollutant: the emission factor and the dilution factor. This procedure makes it possible to assess the real impact of traffic reduction on atmospheric pollution. Successful applications of the ASI method to the study of pollution events in the urban area of Rome and to the evaluation of the effectiveness of traffic restriction measures taken by the Municipality are described.

RESULTS AND DISCUSSION

The ability of natural radioactivity measurements to describe the mixing properties of the lower boundary layer is well shown in the graphs of figure 1, which refer to typical summer and winter periods, respectively. During the warm months, which in Italy are generally characterised by large-scale high-pressure systems, natural radioactivity shows a well-defined and modulated temporal pattern. The pattern shows minimum values during daytime hours (convective mixing of the lower atmosphere that dissipates the inversion layer) that alternates to maximum values during the night (nocturnal atmospheric stability); the mixing period starts very early in the morning and lasts until the late evening.

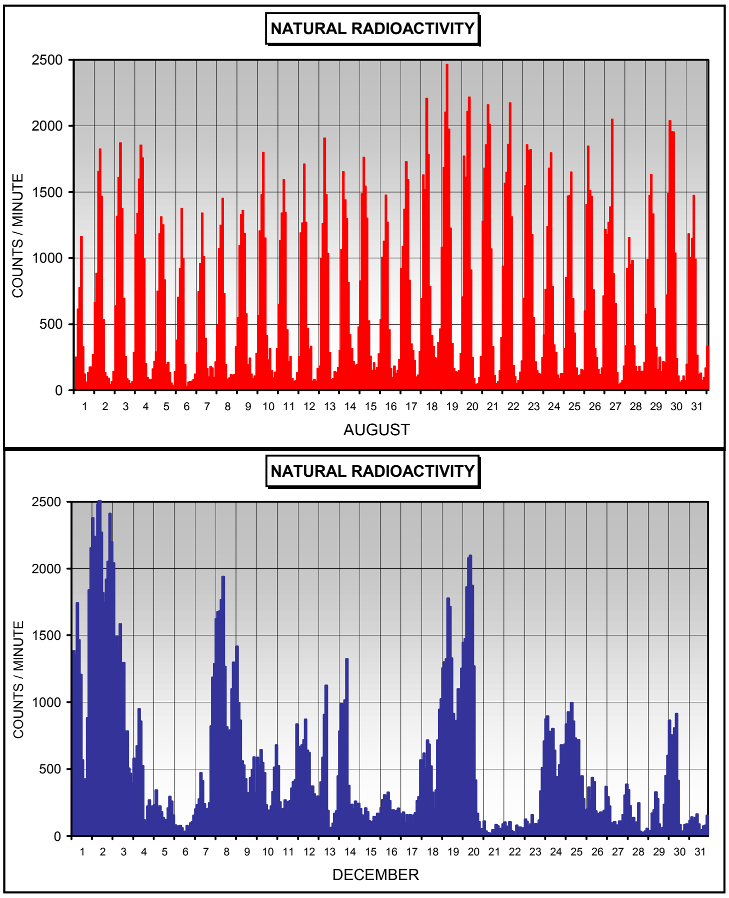

Figure 1: Typical pattern of natural radioactivity during a summer period and a winter period.

During cold months, instead, long high-pressure periods are sporadic, and advection periods alternate to short periods when atmospheric stability persists also during daytime hours. During advection, natural radioactivity always shows very low values (e.g. 5–6, 15, 21–22, 28 and 31 December); during stability, instead, the nocturnal inversion only slackens during the day hours and natural radioactivity exhibits high values also during the day (e.g. 2, 8, 19, 24 December). During the winter period, the diurnal mixing is not only weak but also of limited duration, since it generally stays for a few hours, from the late morning to the early afternoon.

In order to make the information contained in the pattern of natural radioactivity more easily perceived and interpreted, an Atmospheric Stability Index (ASIp) able to characterise each day in terms of meteorological predisposition to the occurrence of a primary pollution event has been developed. The Index is a proper combination of natural radioactivity values and of their time derivatives during the times of the day which favour the occurrence of primary pollution (early morning and evening).

The very good agreement between the ASIp values and the average concentration of a primary non-reactive pollutant such as benzene, reported in Figure 2 for the year 1999-2000, shows that the mixing of the lower atmospheric layer, well described by the ASIp, is of primary relevance in determining the average concentration of non-reactive primary pollutants in the urban area of Rome. The satisfactory values of the correlation coefficient (R=0.89) indicate that the ASIp is a good tool for the interpretation of primary pollution events. A better correlation between ASIp and pollution values is, nevertheless, not expected, since the ASIp takes into account only one of the two driving forces that determine pollutant concentration, that is the meteorological factor, while it does not take into account the day-to-day variations in the emission fluxes. In other words, the two data sets should coincide only if the emission fluxes were constant in time. The study of the differences between the two data sets, anyway, can be useful to identify situations when atmospheric pollution is heavier than predictable on the only basis of the meteorological situation (e.g. in case of heavy traffic episodes) or lighter (e.g. in case of traffic restriction measures or of holidays). For example, a lower correlation is expected during August, when the emission flux is distinctly lower than during the rest of the year, due to summer holidays (see Figure 2).

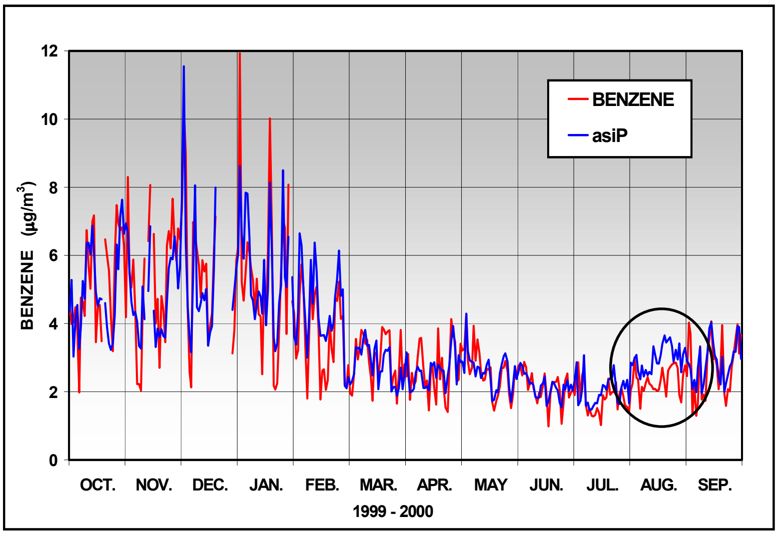

Figure 2: Atmospheric Stability Index for primary pollutants and average daily concentration of benzene in the urban background station of Rome.

A second Atmospheric Stability Index (ASIpm), calculated with a different algorithm, is instead specific to particulate matter pollution. Also in this case (Figure 3), the comparison between the values of the ASIpm and the concentration of atmospheric

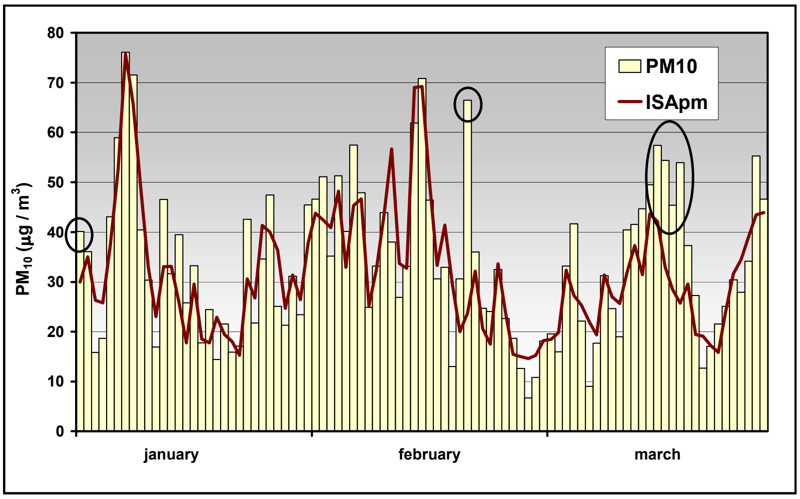

Figure 3: Atmospheric Stability Index for particulate matter and average daily concentration of PM_{10} in the urban background station of Rome (2004). Black circles indicate days when particles of non-urban origin entered the boundary layer.

particles (PM_{10}) is very satisfactory (R=0.88), showing that the mixing of the atmosphere is a driving force also in the build up of a pollutant of heterogeneous composition and origin such as particulate matter. Significant difference between the value of the ASIpm and the experimental value of PM_{10} concentration are recorded on January 1st, February 21st and March 19th and 20th. For all these days, characterised by real PM_{10} concentration higher than the ASIpm value, the increase of PM_{10} was not due to the local meteorological conditions but to the net increase of the amount of particles entering the lower atmosphere, caused by the fireworks on January 1st, and by dust advection from north Africa in the other three cases. Saharian dust advection is easily perceptible in the scatter plot of ASIpm and real PM_{10} concentration, reported in Figure 4 (February dust episode: green squares; March dust episode: green triangles).

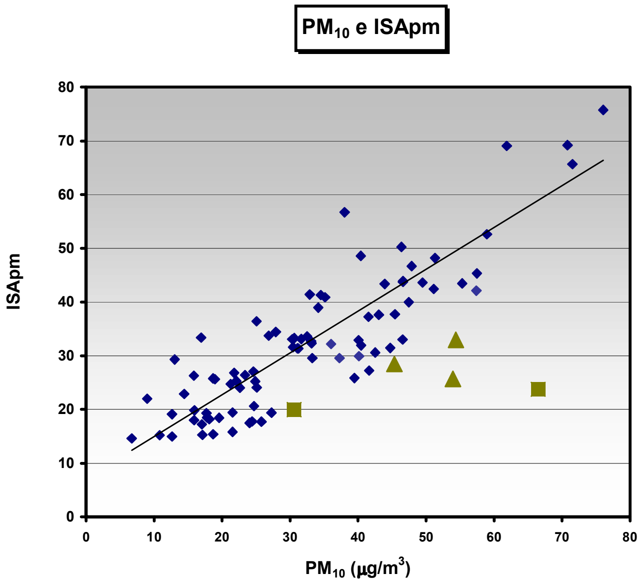

Figure 4: Scatter plot of the ASIpm and real daily PM_{10} in the urban background station of Rome. Green symbols are the dust events.

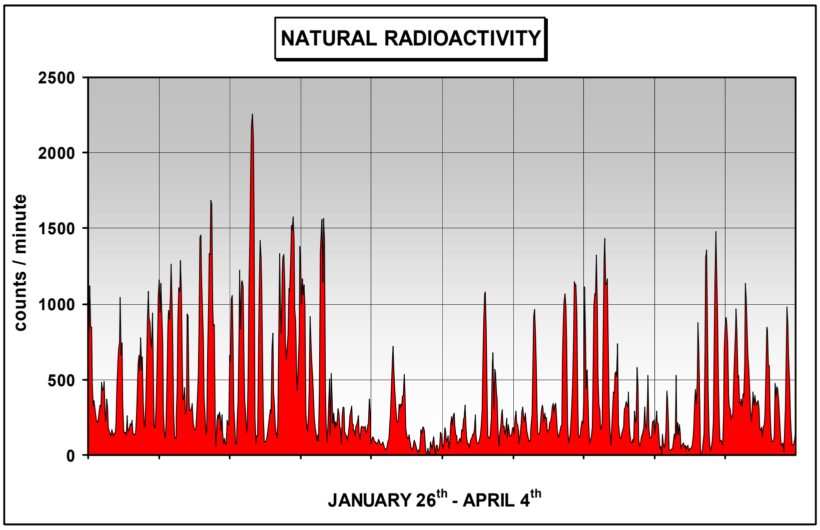

Figure 5: Temporal pattern of natural radioactivity during the 2004 traffic restriction periods in Rome.

Traffic restriction measures taken during the winter of 2004 by the Municipality of Rome consisted in: 1) during ten consecutive Wednesday in the period January 28 - March 31, stop to vehicles having alternatively odd and even plate number from 15:00 to 21:00; 2) on February 8th and March 21st (Sunday) stop to all vehicles from 10:00 to 17:00. The restricted area was 154 Km^2, in the centre of the city.

The temporal pattern of natural radioactivity during the ten restriction weeks, reported in Figure 5, shows that, as expected during the wintertime, a wide range of atmospheric conditions occurred during the period, with alternation of atmospheric stability and advection. As a consequence, a wide modulation of particulate concentration level is also expected.

In these conditions, a decrease in PM_{10} concentration as a result of the traffic restriction measures taken by the Muncipality is expected to be hardly visible, since a decrease in traffic intensity that has been estimated to be of 20 – 25 % is easily masked by the wide concentration variations induced by the meteorology.

With the aid of the Atmospheric Stability Index, instead, the possible effect of the measures is more easily perceptible. The comparison of the value of the ASIpm, that is of the value expected for PM_{10} concentration in the absence of significant variation in the emission flux, and of the results of PM_{10} measurements, reported in Figure 6 for half of the period (red symbols indicate restriction days), suggest the following remarks. During two of the four restriction days (February 25th, March 3rd) the concentration of particles were very close to the expected value, showing no appreciable effect of the restriction measures on the daily average concentration of PM_{10}. During the other two days (February 11th and 18th), a significant decrease of the recorded value with respect to the expected value was observed (of the order of 20%). No variations were instead observed on Sunday 8th (red arrow), when all the cars were stopped between 10:00 and 17:00.

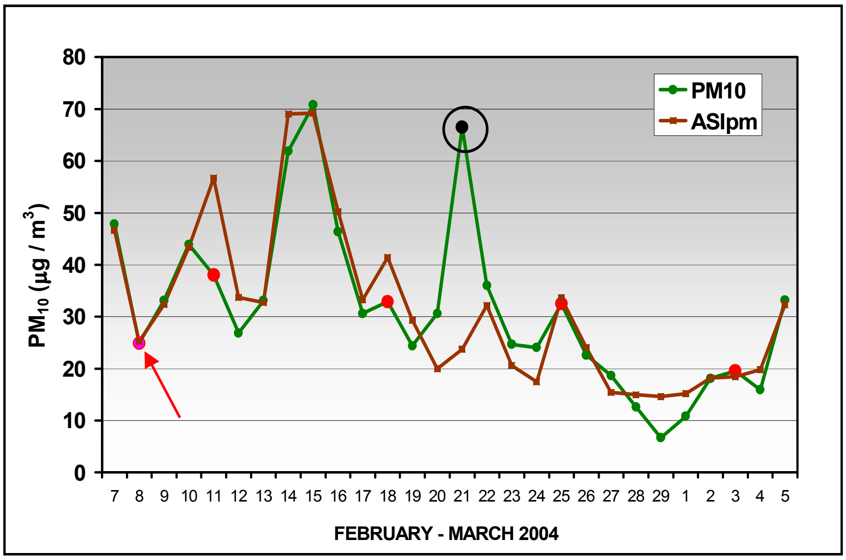

Figure 6: ASIpm and PM_{10} concentration in the urban area of Rome during the period when the traffic restriction measures were applied.

The only case when PM_{10} concentration was higher than the ASIpm value is the already discussed intrusion of air masses from the Sahara desert areas, occurred during the period between February 20th and 22nd, with maximum intensity on the 21st (black circle).

These different results can be explained on the basis of the different mixing properties of the atmosphere and different concentration level expected for PM_{10}. When the atmospheric conditions did not favour the build up of particles (expected concentration below 30-40 µg/m^3) the contribution of the background pollution was predominant with respect to local traffic emission, and the latter was responsible only for a fraction of the particle concentration. In these conditions, the pollution level was insensitive to the applied 20% traffic reduction. When the reduced mixing of the atmosphere favoured the increase of particle concentration, instead (expected concentration higher than 40-50 µg/m^3), traffic emission became the main contributor to the amount of particles in the atmosphere and even a small reduction of traffic intensity could be of help in controlling the increase of particle concentration. During Sunday 8th, the atmospheric conditions were of strong advection (natural radioactivity always below 300 counts/minute) and the concentration of PM_{10} was not higher than 25 µg/m^3; the coincidence between the ASIpm and the PM_{10} value indicates that in these conditions the stop to all cars could not have any effect on the atmospheric pollution in the urban area of Rome.

CONCLUSIONS

The mixing properties of the boundary layer play a main role in the occurrence of both primary pollution and particulate pollution events. The Atmospheric Stability Indexes, calculated on the basis of natural radioactivity data, constitute a valuable and reliable tool for the characterisation, comparison and comprehension of primary pollution events in urban areas. The use of the ASI also allows the environmental managers to evaluate the ability of traffic reduction measure intended to decrease atmospheric pollution, and to distinguish between the real impact of emission reduction and an apparent air quality improvement due to the increase of the dilution potential of the lower atmosphere.

REFERENCES

[1] Porstendorfer, J., Butterweck, G., Reineking, A. (1991). Diurnal variation of the concentrations of radon and its short-lived daughters in the atmosphere near the ground. Atmospheric Environment **25**, 709–713.

[2] Perrino C., Pietrodangelo A. and Febo A. (2001). An atmospheric stability index based on radon progeny measurements for the evaluation of primary urban pollution. Atmospheric Environment **35**, 5235-5244.

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