A year's radon measurements in Milan and at EMEP station in Ispra (Lake Maggiore, Italy)

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Abstract

Two radon stations operated for one year (1997) in Lombardy: one was sited in the town of Milan, the second was housed in the EMEP station in the Joint Research Centre at Ispra on Lake Maggiore, north of Milan.
The radon concentration was measured hour by hour in both stations.
The measurements are obtained by means of a high-volume alpha particle detector which directly gives radon concentration. The radon detector is described.
The results of the campaign over the whole year are reported and discussed.
The measurements of radon concentration in the atmosphere allow to study the behaviour and the structure of PBL. In particular radon evidences the presence of temperature inversion such as the formation of the Nocturnal Stable Layer and gives information on the vertical thermal turbulence and the motion of air masses.

Introduction

Atmospheric levels of radon 222, a natural radioactive tracer, can be used to characterize the conditions of turbulence and stability of the lower layers of the atmosphere, to investigate the structure of the PBL, and in some cases, to observe the movement of air masses.(Guedalia et al.[1], Sesana et al.[2])

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The Physics Institute of the Università degli Studi di Milano has for some years been taking radon measurements in Milan as well as in other sites on the Lombard plain and in the prealps. From 1/11/96 to 31/12/97, measurements were carried out at the EMEP station in Ispra (Lake Maggiore, Italy). Ispra is on the shores of Lago Maggiore, 60 km north of Milan.

Measurements: method

Radon concentrations were measured by means of a continuously functioning apparatus which detects the alpha particles emitted by radon as it decays. The apparatus samples air at a height of 3m from the ground. A filter at the air intake captures atmospheric aerosols, to which almost all the decay products of radon 222 and 220 are bound. Radon 222 is measured in a decay chamber with a volume of about 10 l, where a scintillation detector counts the α particles. The system is calibrated using air with a known radon concentration, and a baseline count is established by running air free of radon through the system.

Measurements: results

a) Milan station
Figs 1, 2 and 3 show examples of the trends in hourly radon concentration for the months of March, April and December.
A frequently encountered daily pattern is that characterized by accumulation of radon at night and until the early hours of the morning, followed by a decrease. This pattern was typically observed on sunny days, when the sky was clear both by day and by night, and there was little ventilation.
On such days, as illustrated in figures, the radon concentration was low in the afternoon (a few Bq/m^3), and began to increase in the evening, reaching levels of up to 15-30 Bq/m^3. Nocturnal accumulation of radon occurs under stable atmospheric conditions as the result of the formation of a ground-based temperature inversion. When the sun rises in the morning and heats the ground the inversion is destroyed and remixing of radon takes place in increasingly higher layers.
The radon concentration changes only slightly or not at all:

- on cloudy and rainy days when there is little sunlight,
- on days when there is a strong wind; here the radon disperses over a large area and at height.

b) Ispra station
Figures 4, 5 and 6 show the trends in radon concentration measured at the EMEP station in Ispra for the same periods shown for Milan. It can be seen that nocturnal radon accumulation is far more frequent than in Milan, indicating greater atmospheric stability. There is also a wider excursion in the radon oscillation for Ispra than for Milan.
The minimum values for Milan and Ispra are similar.

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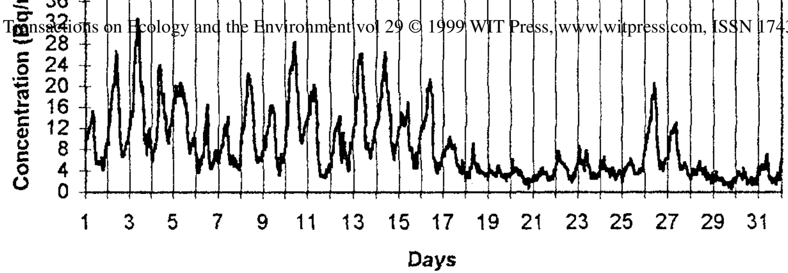

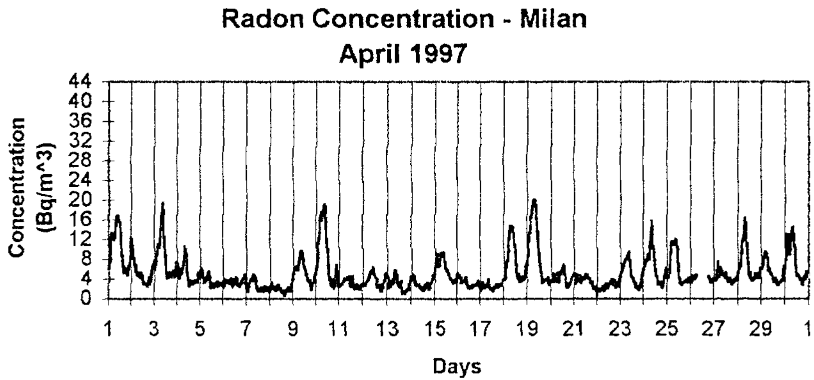

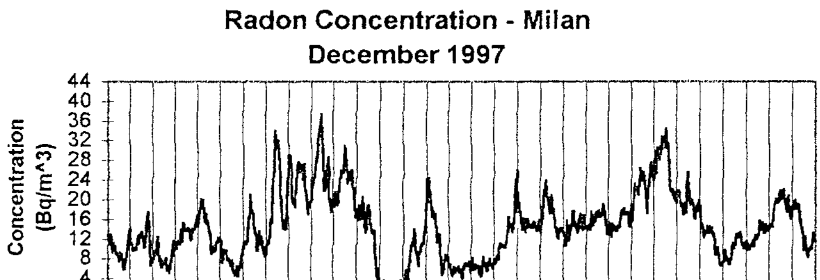

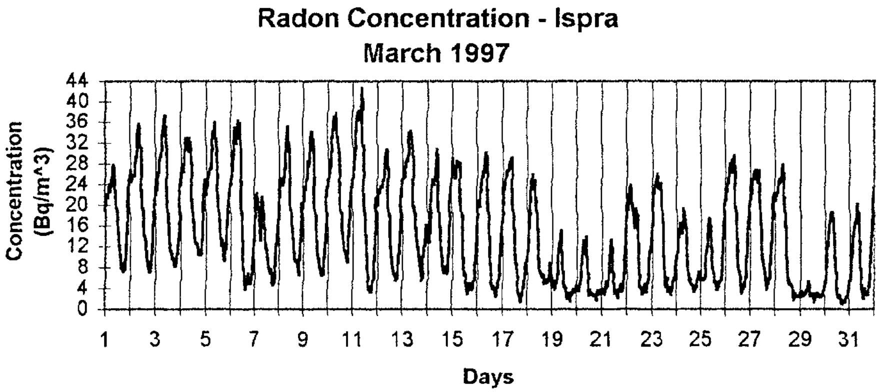

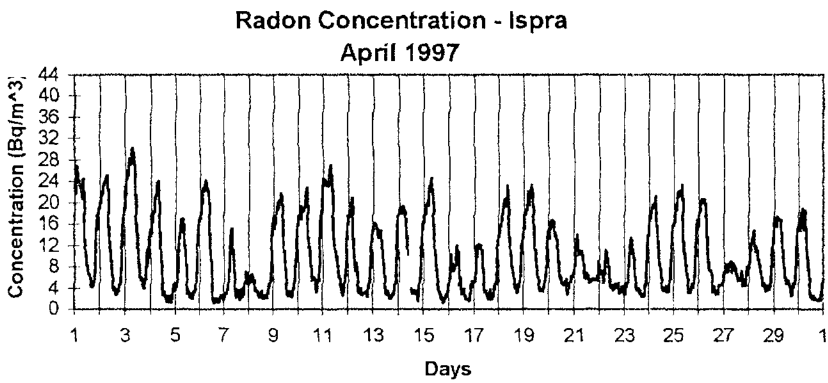

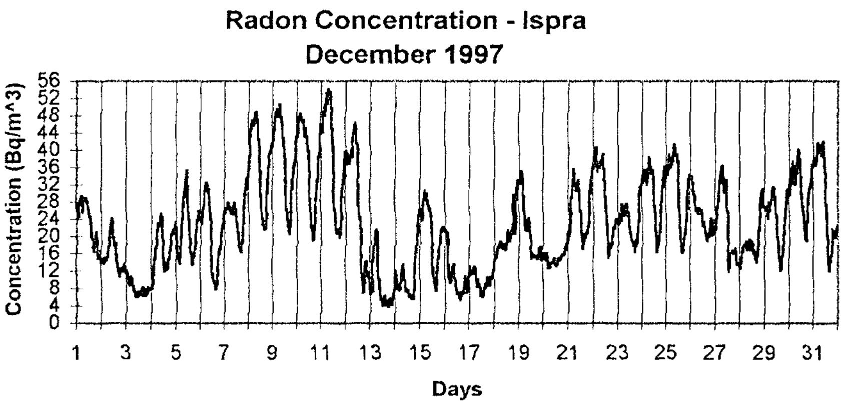

Figs. 4 - 5 - 6

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Interpretation of the results: the box model

Nocturnal stability conditions in Milan are obtained by radiosounding at Linate airport, a few km east of the city. In the example in figure 7 the formation of a ground-based inversion layer is clearly shown.

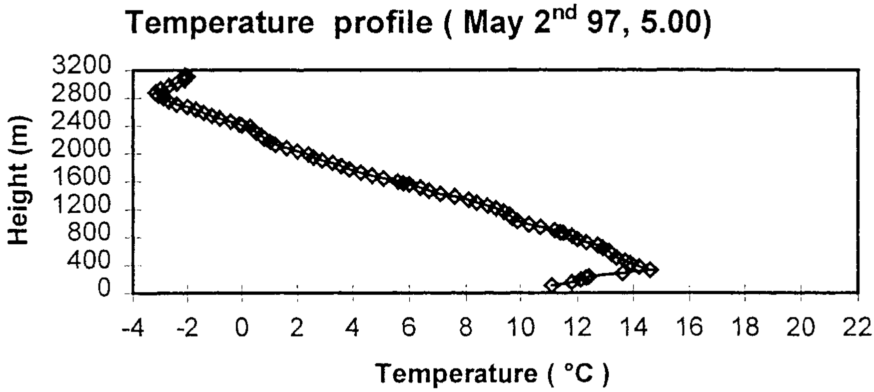

Fig. 7

Again, the nocturnal accumulation of radon indicates the formation of the Nocturnal Stable Layer, where mixing is limited but not completely inhibited. The Equivalent Mixing Height, (EMH, h_e) can be obtained by analysing radon concentrations. In Fontan et al.s' box model (Guedalia et al.[1]), the following assumptions are made:

a) radon is emitted from the ground at a practically constant rate over a large time and area;
b) radon concentration inside the box is uniform;
c) variations in radon concentration are related solely to vertical stability.

The increase in radon concentration within the box is represented by the formula

$$h_e(t)C(t) = h_e(t)C(t_0)e^{-\lambda(t-t_0)} + \frac{\phi}{\lambda}(1 - e^{-\lambda(t-t_0)}) \qquad (1)$$

where C(t) represents radon concentration at time t during the accumulation phase; $C(t_o)$ is the concentration at the beginning of the accumulation phase, at time t_o,; λ is the decay constant for radon 222; and ϕ is the flow of radon from the ground.

Figures 8 and 9 show EMH levels for Milan and Ispra on the same day in May.

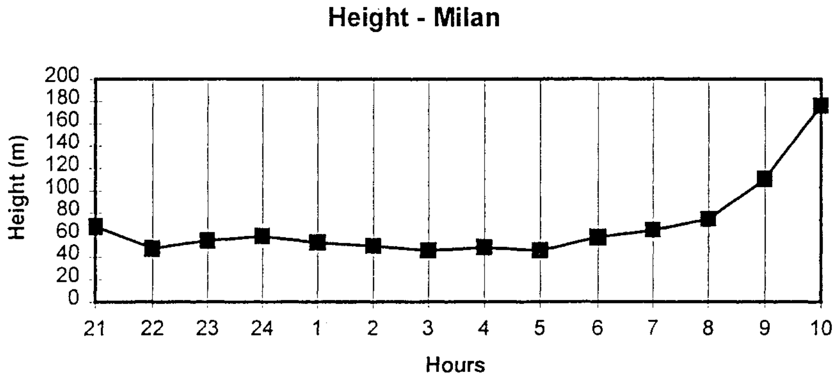

Fig. 8

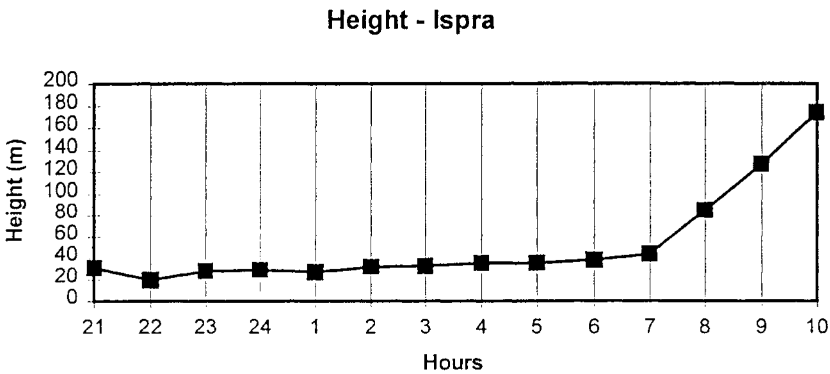

Fig. 9

Radon levels indicate the beginning of the formation of the N.S.L., and the moment when it begins to dissolve.
The NSL forms on 30 – 40% of days in Milan, and on more than 70% of days in Ispra. The EMH for Milan was of the order of 40 – 70m, while that for Ispra was of 30 – 60m.

Radon dispersion in height: morning
The decrease in the radon concentration, which begins in the morning and continues until the early hours of the evening, indicates the rising of the mixing layer.

The box model can be applied to the first phase of this process. With H(t) as the height of the mixing layer:

$$H(t)C(t) = H(t)C(t_0)e^{-\lambda(t-t_0)} + \frac{\phi}{\lambda}(1 - e^{-\lambda(t-t_0)}) \qquad (2)$$

It is assumed that the concentration $C(t_o)$ only goes down as a result of radioactive decay.
Figures 8 and 9 show the increase in the height of the mixing layer in the early hours of the morning.

Afternoon minimum radon concentration
Analysis becomes less straightforward as radon concentrations reach their lowest values in the late afternoon. The box model can still be applied to this phase, but only when the minimum values have been similar for a number of consecutive days. In this case, the maximum height of the box is given by:

$$H_{max} = \frac{\phi}{\lambda\, C_{min}} \qquad (3)$$

Various factors affect analysis, however. At this time of day, mixing takes place over vast areas and at great heights. It is possible that advective motions bring in air with different concentrations of radon, as well as, however, air with a low radon concentration from the free atmosphere.
It is interesting to note that minimum radon concentrations vary seasonally, being higher in winter (10-15 Bq/m^3) and lower in spring and summer, when they go down to values of a few Bq/m^3.

Radon and pollutants

The trend in radon concentration distinguishes clearly between days on which there is nocturnal accumulation of radon and days on which there is mixing and the level of radon remains nearly constant night and day.
On days when there is nocturnal accumulation of radon, mixing is limited within a low layer in which primary pollutants like NO, NO2 and CO accumulate. On such nights, levels of these pollutants rise to particularly high levels starting in the evening and until traffic ceases.
When it is cloudy and windy, pollutants disperse at height during the day and at night; and radon does not accumulate.
We now describe the ozone-radon relation, considering daytime and night hours separately, starting with what happens on a clear day followed by a still night.
Firstly, on a clear day with intense solar radiation, the chain of photochemical reactions between nitrogen oxides and VOCs activates the production of ozone during daylight hours, at the same time as radon disperses. The dispersion of radon marks the start of vertical turbulence, which carries the radon along with the ozone precursors and ozone itself to high quotas.
When radon accumulates at night, minimum ozone concentrations are observed. Ozone is destroyed by the large concentration of nitrogen oxides.

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Secondly, nights when radon does not accumulate, but remains at low concentrations. These nights are characterized by high levels of ozone, which peak sharply in the first hours after midnight.
A hypothesis on the origin of high nocturnal levels of ozone is that nocturnal ozone peaks occur when vertical instability is present; hence, nocturnal ozone is transported downwards from height. (Sesana et al.[2])

Conclusions

Comparing the data from Milan and Ispra shows that the Lago Maggiore area has greater nocturnal stability, both in terms of number of days and in terms of lowest EMH values.
On the other hand, afternoon radon concentrations are similar for the two sites, suggesting the presence of a basic atmospheric condition existing over the whole study area.

References

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