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Experiments with pilot balloon soundings at some power station sites

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Ente Nazionale per l'Energia Elettrica (E.N.E.L.), like other large electric power agencies all over the world, is facing the problem of smoke dispersion from the stacks of large power stations. We are carrying out a research programme on some aspects of this problem.

Because of topographical and orographical features of our country, the usual formulae for effective stack height and gas dispersion have to be used very carefully and a deep understanding of the local behaviour of the low atmosphere is always necessary.

For this purpose, we tried pilot balloon sounding at three power stations, on the Po valley, on the shore of the Ligurian sea and in a mountain valley in southern Italy.

We obtained useful informaton about the motion and the layering of the low atmosphere between 75 and 1500 m.

Power generation certainly is not the main source of air pollution, and its contribution is small compared with such other sources, as space heating or transportation (Cisler 1966), but, like other power agencies over the world, E.N.E.L. feels it necessary to make a large effort in order to reduce to a minimum the air pollution coming from its thermal power plants. Consequently E.N.E.L. is studying on a large scale the problems of smoke diffusion and air pollution.

E.N.E.L. activity in this field is divided in two main branches. The first is aiming to study in general some aspects of local meteorology and atmospheric diffusion, such as temperature field studies on a meteorological tower 120 m high at Trino Vercellese. The goal of the other one is to determine local conditions on sites suitable for new power plants, to achieve the best compromise between the plant and the surrounding environment.

Results from research and experience all over the world give us a well founded confidence that, apart from a few exceptional cases, tall stacks are the best way to reduce to a minimum the air pollution at ground level arising from thermal power station (Scorer 1968*a*). But always we must answer two questions: First, is there any local effect—such as a wave, for instance—that could bring effluents near to the ground? Secondly, how tall should a stack be?

Topographical and meteorological peculiarities of our country made the answer a problem to be solved locally on each case (Scorer 1968*b*).

Temperature soundings with tethered balloons are well known and we do them too (Borgese, Giovanardi & Pagliari 1967; W.M.O. 1966). But soundings with spherical balloons are impracticable except in a very low wind, and rather large blimps are necessary. In many sites, too, aeronautic safety regulations impose severe restrictions or completely forbid the use of tethered balloons.

Searching for an alternative method to rely upon when tethered balloon soundings are difficult or impossible, we tried to exploit to the full the usual pilot balloon technique, also employed by us in order to obtain the wind profile at the smoke plume level and above.

It is unnecessary to describe the standard pilot balloon technique we employ. Soundings are made at each synoptic hour, or each hour if required, and balloons are given the standard ascent speed of 2.5 m s^{-1}. A lower ascent speed would be desirable, in order to allow more detailed scanning, but unless the double-theodolite technique is employed (doubling the number of personnel) we preferred an ascent speed high enough to reduce errors due to vertical movements of the air. Balloons are followed for 10 min until they have reached the height of 1500 m, and leave the Earth's boundary layer.

If we assume the same behaviour of the vertical transfer of momentum, heat and mass, then the profile of the wind should indicate, roughly at least, also the profile of stability.

Our calculations of Sutton's stability parameter *n* (Sutton 1953) from wind speed ratios met only with moderate success. Obviously, *n* values deduced from real wind observations cannot behave completely according to the theory, because many of its conditions are not satisfied. But from a qualitative standpoint, the results were fairly good, as long as the speed ratios did not exceed the span where the parameter *n* itself is defined.

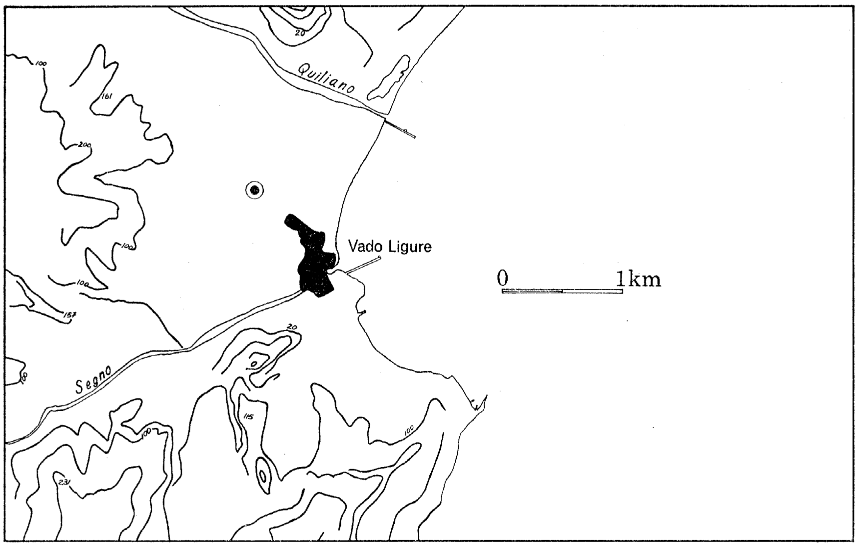


FIGURE 1. Site of station 1 (SSW of Savona).

If we accept that the vertical transfer of the horizontal component of the momentum be related to the turbulent diffusion coefficient, a layer of high shear should be also a layer of reduced turbulence (Csanady, Hilst & Browne 1968). More generally speaking, a layer of strong shear generally indicates a boundary between two different bodies of air, whose behaviour is sometimes markedly different, and whose very existence cannot be ignored by people concerned with plume dispersion.

When we were able to perform simultaneous tethered and pilot balloon soundings, we found good agreement between the two sets of results, within the limitations inherent to either method.

We can see, for example, three cases on which pilot balloon soundings gave us a better understanding of the air environment we were dealing with. The first one refers to a site on the shore of the Ligurian Sea, then proposed for a large coal fired power station (figure 1). The plant, now under construction, is located on a small coastal plain, at the mouth of a creek. Just behind, there are the foot hills of the Maritime Alps, whose watershed is there about 800 m high and 10 km away from the sea. A small urban area is between the plant and the sea. Pilot balloon soundings show that in unperturbed weather there is often a strong north or north westerly wind superposed on the more obvious sea breeze régime. In wintertime, when sea breezes are weak, the first is the dominant feature; in summertime the NW wind delays the onset of the sea breeze until noon, and later on anticipates and reinforces the land breeze. This air mass moving down the valley from N or NW has a definite thickness, usually more than 600 m but seldom exceeding 1000 m, and a maximum speed at some level not far from one half of the thickness (figure 2). This wind is a fair weather one, but it shows no direct dependence on cloudiness or diurnal evolution; therefore, its origin is different from that of the strong katabatic wind described by Davidson as a valley-plain wind (Davidson & Krishna Rao 1963).

A reconnaissance up the head of the valley suggested a probable origin of this down slope wind; there is an easy pass, only 600 m high, joining the Po basin with the Ligurian slope. Anytime there is a pressure difference between the two sides, moderate or strong winds develop down the valley. Near the mouth, the valley fans out, and so does the wind, getting to the sea from NW, and its direction being practically constant, as imposed by the orography.

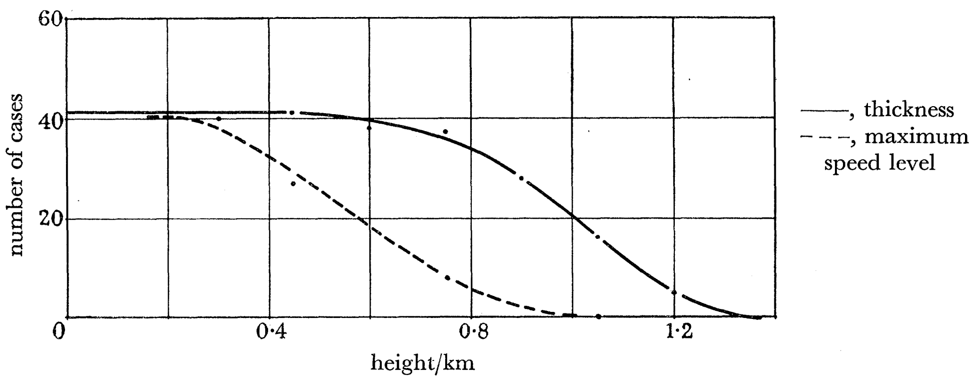


FIGURE 2. Cumulative distribution of thickness and maximum speed level of down-valley wind at station 1.

Apart from a few cases of convection near the ground in the early afternoon, the air going down the valley is, as would be expected rather stable. The Sutton stability parameter, n, was calculated whenever possible from the three pairs of wind speeds at 75 to 150, 150 to 300 and 300 to 600 m, and we defined conventionally as 'stability' or 'lapse' the cases that yielded $n \geqslant 0.3$ or $n < 0.3$ respectively.

The results, shown in table 1, can be summarized as follows: (*a*) at the lowest level, stability prevails by night, and also by day when the cloudiness is more than 5/10; in clear days, lapse is

TABLE 1. DISTRIBUTION OF STABILITY† FROM A SET OF PILOT BALLOON SOUNDINGS

(Station 1—number of cases)

level/m		150/75		300/150		600/300	
time	cloudiness	lapse	stab.	lapse	stab.	lapse	stab.
night	clear	0	5	0	4	1	3
(01.00 + 04.00 + 22.00 h)	overcast	0	1	0	0	0	0
day	clear	4	1	1	3	0	2
(13.00 h)	overcast	1	2	0	4	0	3

† 'Stability': $n > 0.3$; 'lapse': $n < 0.3$.

more frequent; (*b*) stability conditions are dominant at higher levels in all conditions. In this statement we are supported also by watching many smoke plumes, whose behaviour never suggested strong lapse conditions.

We are confident from our soundings that with N or NW winds—that is when the inhabited area is down wind of the station—the plume from a tall stack will be embedded in a thick body of air, moderately stable, whose turbulence is mainly dynamic in origin. So, some reliance can be put upon diffusion formulae and it is possible to predict that the smoke will not be taken down to the ground if the stack is high enough to avoid the plume being caught in the wake of the boiler-house or of the nearest hills. For this reason, the station will have a stack more than 180 m high, that is three times the boilerhouse height and about equal to the height of the surrounding hills. The plant is not involved in the wake of more distant and higher mountains, and a possible convective loop will most likely close out at sea.

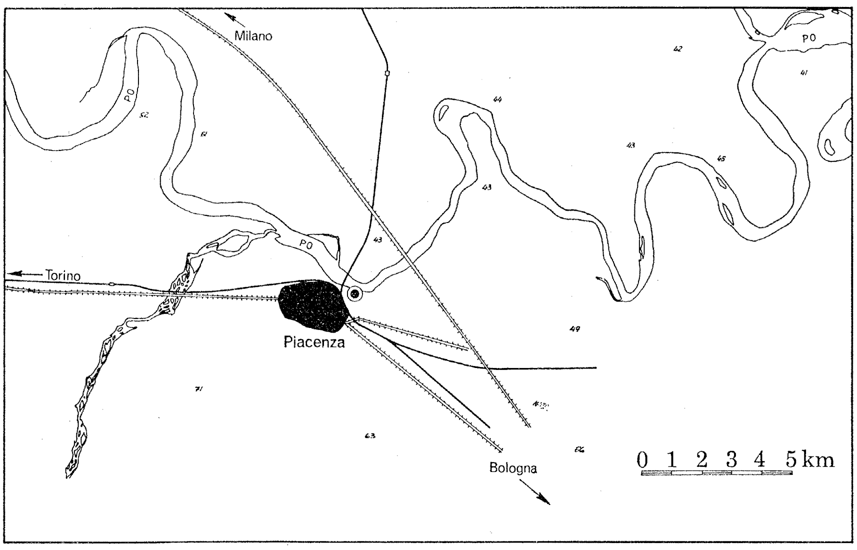


FIGURE 3. Site of station 2 (SE of Milan).

As a second example let us consider the site of a large oil fired power station, on the right bank of the Po River, in a very flat country sloping gentle eastward (figure 3). The main results from soundings of November 1966 are:

(1) At the lower levels, from the ground to 300 m (figure 4), the wind frequency distribution stretched from WNW to ESE, that is about the same general direction as the Po River there and of the Apennine Mountains, 20 km distant from the site.

(2) From 450 to 900 m high (figure 5), winds from E or SE were prevailing.

(3) Over 950 m high, the wind direction was in agreement with the pressure field.

In night time conditions, often there was a W or NW wind, from 75 to 300 m; over this level, and up to 1000 m, we had just easterly winds. In day time, instead, easterly winds were clearly prevailing from 75 to 900 m. This diurnal evolution is quite interesting, because during the sounding period the weather was generally foggy or overcast, and there was little sunshine.

By careful examination of each individual sounding we noted also that:

(1) With easterly winds at low level, there are easterly winds at higher levels too.

(2) With W or NW wind at low level, there are easterly winds at levels over 300 to 450 m.

(3) There are no preferred directions above 1000 m.

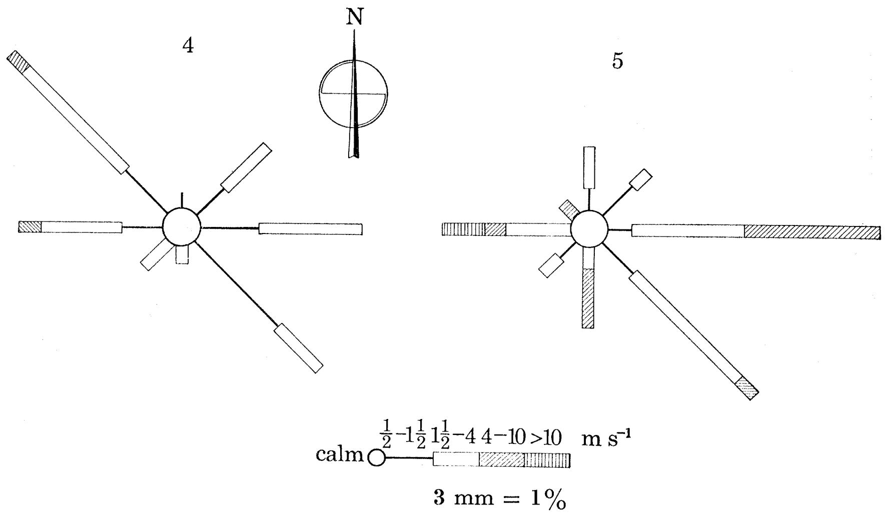
(4) Easterly winds at low level happen with overcast sky, at 07.00, 10.00, 13.00 and 22.00 h (local time).

(5) At 16.00 and 19.00 h westerly winds at low level have practically disappeared, and the wind direction shows no relation with the cloudiness.

The aforesaid behaviour of the wind is somewhat comparable to a breeze régime; and this hypothesis is all the more likely because during the sounding period the diurnal temperature range was less in the eastward part of the plain (Bologna) than it was in the westward one (Torino).

Turning to wind shear, we noted a high frequency of maximum wind shear between 150 and 300 m.

Fortunately, on this occasion we were able sometimes to carry on both pilot and tethered balloon soundings. As can be seen in table 2, temperature profiles fully confirmed the deductions inferred from pilot balloon experiments showing that a layer of stronger stability is more frequent between 150 and 225 m. At 300 m, the agreement is lessened, the effect of wind change being felt.



FIGURES 4 and 5. Wind frequency at 75 m above station 2 (figure 4), and at 600 m above station 2 (figure 5).

TABLE 2. FREQUENCY OF MAXIMUM WIND SHEAR AND MAXIMUM THERMAL STABILITY AGAINST THE HEIGHT

(Station 2—number of cases.)

level/m	wind shear†	thermal stability‡
0–75	9	8
75–150	7	7
150–225	10	7
225–300	9	2
300–450	1	—
450–600	3	—
600–750	2	—
750–900	0	—
900–1050	0	—

† By pilot balloon soundings.
‡ By tethered balloon soundings (maximum height 300 m).

As a result, it is very likely that, at least in weather conditions similar to those studied, a plume emitted at about 200 m will develop above a very stable layer, effectively preventing any transport to the ground. Over 300 m, easily reached by a hot plume, often there is a change in wind direction, and thus the dispersion of pollutants away is enhanced (Dickson, Start, Markee, Richter & Kearns 1967).

For new large units there, stacks over 200 m high have been and will be built.

The last example refers to a rather small fossil-fuelled power plant, sited in a hollow, whose bottom lies 300 to 330 m over the sea level surrounded by ridges about 600 to 700 m high (figure 6). We made a short set of soundings there in October 1966.

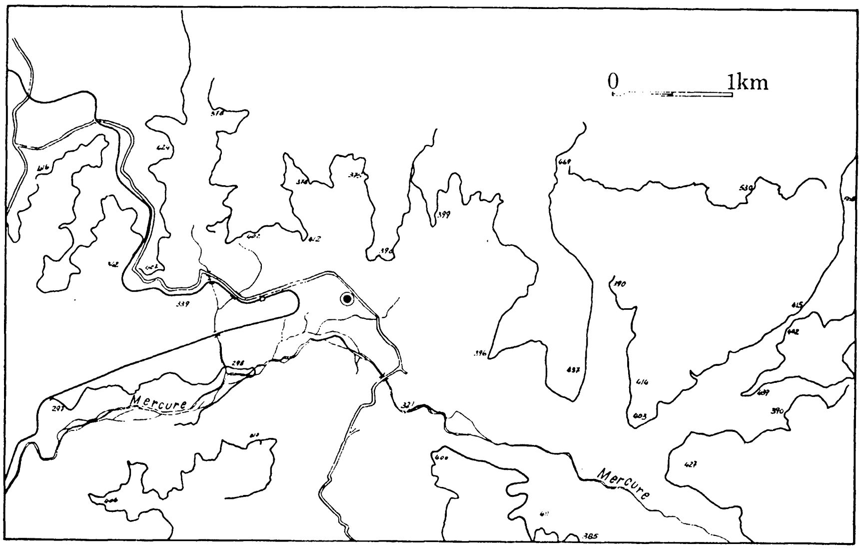


FIGURE 6. Site of station 3 (between Lauria and Castrovillari in southern Italy).

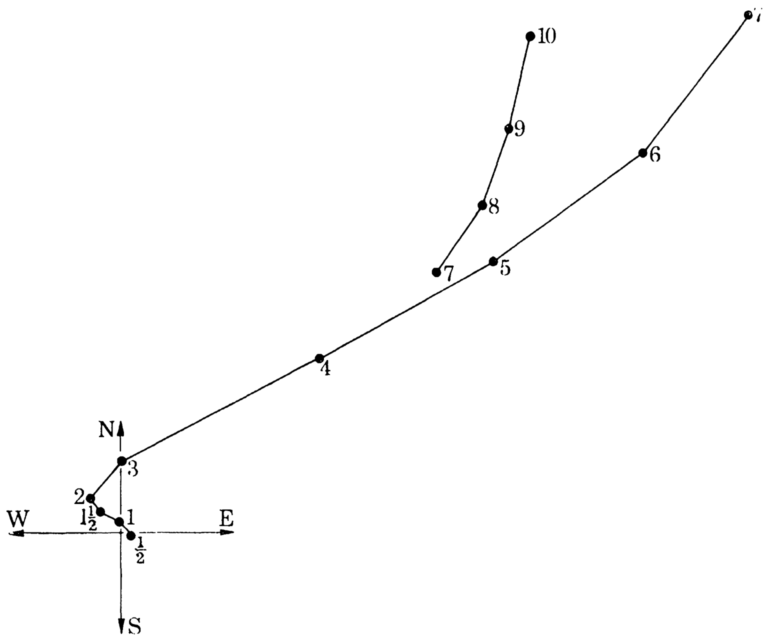


FIGURE 7. Typical pilot balloon sounding at station 3 at 10.00 h on 16 October 1966.
Scale: 1:5000–1:10000.

The examination of soundings shows the existence of two layers; in the lower one, the air drift is determined by the orography, while over a level near the height of surrounding ridges, the balloon is seized by an upper wind, always in agreement with the pressure field, and considered therefore as a general wind.

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In the analysis of each sounding, this discontinuity in the wind field is obvious when the wind direction changes suddenly at some level (figure 7), but it can be clearly seen from the speed profile also when the wind direction is about the same in both layers.

To determine the existence of a diurnal cycle in the wind field, in spite of the scarcity of soundings, we defined the wind as calm, if speed was less than 0.5 m s^{-1}, up-slope wind, from W and SW, and down-slope wind from NW to S through E. The different width of the two sectors is due to the shape of the ground. We prefer not to name these winds as 'anabatic' or 'katabatic' because this would imply a statement about the origin of the wind

During the period of the soundings there was a very high frequency of calm at ground (table 3); calm was also frequent at 150 m, and still present at 300 m. At 150 m the up-slope wind is absent

Table 3. Frequency of up- or down-slope wind

(Station 3—number of cases)

time/h	level/m 150			300			600		
	c.	u.	d.	c.	u.	d.	c.	u.	d.
07.00	2	0	2	0	2	2	0	2	2
10.00	1	3	2	0	3	2	0	5	1
13.00	0	5	1	1	5	0	0	5	1
16.00	0	4	3	0	6	1	0	6	1
19.00	0	4	1	0	5	0	0	5	0

c., calm; u., up-slope wind; d., down-wind slope.

at 07.00 h (local time), fairly frequent at 10.00 h, and clearly prevailing from 13.00 to 19.00 h. This diurnal cycle is less marked at 300 m, and almost disappeared at 600 m.

We observed from the speed profiles that the higher frequency of the maximum wind shear happens at levels from 225 to 300 m (and sometimes 450 m). This is also the height of the ridges over the bottom of the hollow, and we think to be not far from the truth to say that there should be as often as not a stable layer. In fact, especially in the morning, the plume can often be seen rising almost vertically and with very little dilution until it reaches about the level of the surrounding ridges, and then spreading in a very thin and extensive layer (Scorer 1958).

Obviously, in this case no help may be obtained by meteorology, and the only way to overcome this situation is to reduce the amount of pollutant at the source. Fly ash being of nuisance there, more efficient electrostatic precipitators were added to old cyclone separators.

We are fully aware of limitations intrinsic in the method we have described. A pilot balloon is not a true Lagrangian tracer, the sounding is of poor accuracy and information we can obtain from it is merely qualitative.

An effort is made by us to extend the range of tethered balloon soundings, and to make neutral balloon tracing practical. Nevertheless, pilot balloon sounding is still a simple and economic method we can rely upon also in difficult situations. We think that information about motion and layering of the lower atmosphere we can get from pilot balloon, even if only qualitative, is not worse than misuse of formulae when they are meaningless.

References (Pagliari)

Borgese, D., Giovanardi, V. & Pagliari, M. 1967 *La Termotecnica* **21**, 657.
Cisler, W. 1966 *Proceedings of the third National Conference on Air Pollution, Washington D.C.* P.H.S. 1649.
Csanady, G. T., Hilst, G. R. & Browne, N. E. 1968 *Atmos. Environment* **2**, 273.
Davidson, B. & Krishna Rao P. 1963 *Int. J. Air Wat. Pollut.* **7**, 907.
Dickson, Start, Markee, Jr, Richter & Kearns 1967 *Meteorology for the loss of fluid test reactor*. I.D.O. 12059.
Scorer, R. S. 1958 *Natural aerodynamics*. London: Pergamon Press.
Scorer, R. S. 1968*a* *Air pollution*. London: Pergamon Press.
Scorer, R. S. 1968*b* *Atmos. Environment* **2**, 35.
Sutton, O. G. 1953 *Micrometeorology*. New York: McGraw Hill.
W.M.O. 1966 Lower troposphere soundings T.N. 77, 192 T.P. 98.

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