TURBULENCE STATISTICS ESTIMATION AND DISPERSION SIMULATION SCENARIOS IN URBAN ENVIRONMENT

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INTRODUCTION

The Electricity Board of Turin (Northern Italy) Municipality, AEM, has planned the installation of a new Combined Heat and Power Plant (CHP-plant) in the town centre, having the task to supply central heating to a town district (about 7.6 km^2) by teleheating. It is expected that this operation, district heating, will improve the urban air quality by the fact that local heat boilers will be replaced by a high chimney connected to the new CHP-plant.

The present paper deals with a part of the Environmental Impact Analysis presented to Administrative Authorities. It refers to a study in which the NOx g.l.c. over the town due to the present emission situation (one CHP-plant, named BIT, already active plus normal single houses heating - S1) is compared to the future emission situation (the old CHP-plant with modified operating plans, plus the new one, named Politecnico, and without the single houses heating included in a district located around the new plant - S2). In another part of the study, not discussed here, the annual g.l.c distribution was studied by means of simple Gaussian models. However, since this area experiences many episodes of low wind or calm situations (more than 70%), associated to strong stability conditions, it was also agreed (also taking into account the Regional Environmental Protection Agency (ARPA Piemonte) suggestions) to study the g.l.c. distribution during a particularly severe pollution episode. This was identified in a 5 days period (14 to 18 December 1998) during which such poorly dispersion conditions prevailed. This choice was confirmed by the statistical analysis presented below. In fact the daily NO_2 hour maxima recorded in the town air quality network were included between 159 and 360 $\mu g/m^3$. Notice that: i) the operating hours of BIT will be modified in the future scenario and, ii) the emissions from the other houses not included in the district interested to the teleheating, and the other industrial or traffic emissions located in the town were not considered, since they will give the same contributions to both scenarios S1 and S2 (see Tables 1 and 2 for the details). Considering the average buildings height, their emission height was set to 20 m and uniformly distributed over their area.

These two g.l.c. scenarios were studied by means of the modelling system RSM (Kerr et al., 2000; Tinarelli et al., 2000; Trini Castelli, 2000; Carvalho et al., 2002). RMS includes the Lagrangian particle model SPRAY (Tinarelli et al., 2000), computing the 3-D diffusion, the circulation model CSU-RAMS, giving the flow field and surface layer parameters (Pielke et al., 1992) and the interface code MIRS (Trini Castelli, 2000), connecting the outputs of RAMS to the input of SPRAY and also preparing those turbulence fields not directly given by RAMS. SPRAY was used in this work as a regulatory model, according to the suggestion of the Regional Environmental Protection Agency (ARPA Piemonte). SPRAY ability to correctly prescribe g.l.c. was tested many times (see, for instance: Ferrero et al., 1997 and 2001; Ferrero and Anfossi, 1998).

SIMULATION DETAILS

Two nested grids were used: the outer grid had 26 x 26 points and 4 km horizontal resolution and the inner grid had 26 x 26 points and 1 km horizontal resolution. Vertical terrain-influenced coordinates were used. A vertical stretched grid with 24 levels was utilized. RAMS was initialised with the ECMWF gridded (0.5^o latitude/longitude) analysis fields. Updated data were used to nudge the lateral boundaries of the outer grid every 6 hours. Simulation started at 12 LT of 13 December and ended at 00 LT of 19 December.

Table 1. S1 scenario – present emission situation.

	operating hours	Power (MW)	stack heig (m)	exit velocity (m/s)	exit temp. (^oC)	NOx emission (kg/h)
houses	06.00 – 13.00	225				51,1
houses	17.00 – 24.00	225				51,1
CHP-plant BIT	06.00 – 10.00	235	43	17.2	120	41.7
CHP-plant BIT	11.00 – 13.00	35	43	8.8	120	6.9
CHP-plant BIT	18.00 – 20.00	10	43	4.4	120	3.4

Table 2. S2 scenario – future emission situation

	Operating hours	Power (MW)	stackheight (m)	exit velocity (m/s)	exit temp. (^oC)	NOx emission (kg/h)
New CHP-plant	05.30 – 22.00	180	50	17.2	120	31,3
CHP-plant BIT	06.00 – 10.00	160	43	17.2	120	27.8
CHP-plant BIT	11.00 – 13.30	75	43	17.2	120	13.9
CHP-plant BIT	16.30 – 20.30	20	43	4.4	120	3.4

The wind velocity standard deviations and the Lagrangian time scales were computed in MIRS according to the Hanna (1982) scheme. SPRAY was run in the inner grid and the following options were used: dynamic plume rise (Anfossi et al., 1993), variable time step, Gaussian PDF in the horizontal plane and a skewed Gram-Charlier PDF (Ferrero and Anfossi, 1998) in the vertical. Concentrations were computed in grid boxes having size to 250 x 250 x 15 m.

RESULTS

First of all, a statistical analysis on the turbulence surface layer characteristics produced by the model system was carried out, aiming at verifying that the poor dispersion conditions of the chosen period were verified. This analysis could not be done on measured values, since these last were not available on this site. The friction velocity u_* and the Monin-Obhukov length L were considered because the vertical profiles of all the turbulence parameters needed in the SPRAY simulation are derived, in MIRS, on the basis of these two quantities. Figure 1 illustrates the time trend of u_*, during the simulation period (125 hours) at a grid point located in the centre of the domain. u_* shows the expected behaviour (higher values during daytime and lower ones during night-time), but the values are rather low for most of the time (79% of hours $u_* < 0.2$ m/s and 62% < 0.1 m/s). Figure 2 shows the frequency distribution of the corresponding L values. It is immediately apparent that most of the hours (about 85%) belong to the stable conditions and, in particular, among these, the cases of strong stability are 72%. Thus, this analysis confirms that the period chosen has the wanted dispersion conditions, namely: low wind and strong stability.

Figures 3 and 4 show the comparison of the maximum hourly NO_x gl.c. ($\mu g/m^3$) for each of the five simulated days, computed for the two scenarios *S1* (shaded line) and *S2* (continuous line) at three stations: the first two (Figure 3) are located within the district to which the teleheating will be supplied and the third one (Figure 4) is located outside of it, but within the town.

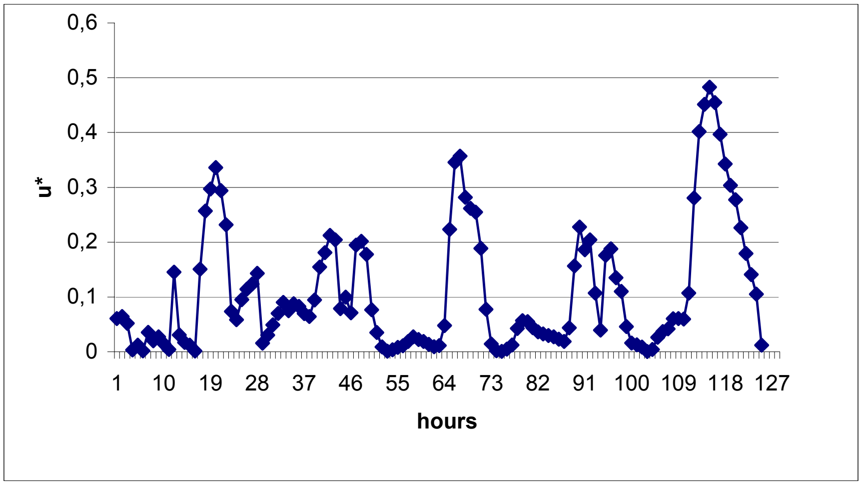

Figure 1. Hourly trend of u_*

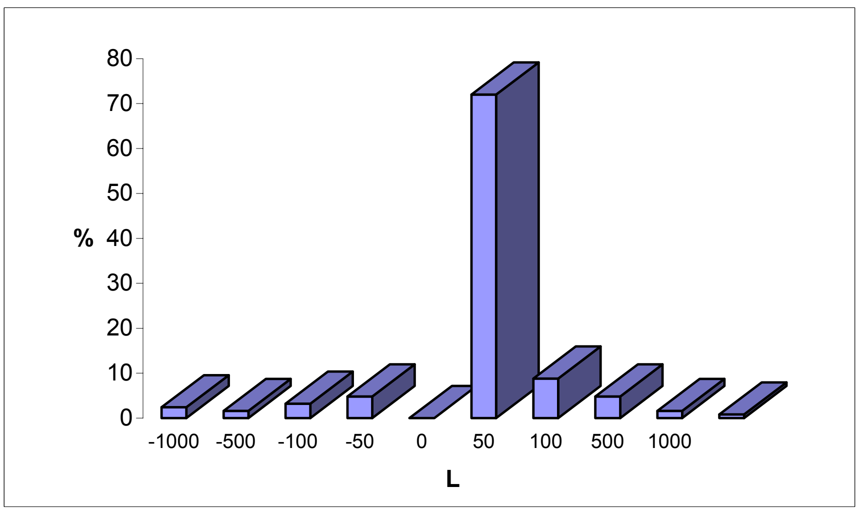

Figure 2. Frequency distribution of hourly L (Numbers on x-axis refer to the upper class).

Examining Figures 3 and 4 suggests the following considerations. While the effect of the new emission scenario is a significant improvement of the air quality in the teleheated district, at a station located far from that district the air quality situation is unchanged. The effect of substituting S1 scenario with S2 is not only a constant reduction in g.l.c. but also a different trend. This is due to the fact that the plumes coming from house heating or from a stack have different behaviours. Besides coming either from distributed sources or from a point source, they travel at different heights, due to their different height emission and buoyancy fluxes, thus experiencing different wind speed and directions, and turbulence characteristics. This different behaviour is particularly evident at the station shown in the right panel of Figure 3. This puts in evidence the advantage of using a Lagrangian stochastic dispersion model associated to a circulation model, thus using a wind variable in direction and speed with the height. In fact, this result, due 3-D distribution of wind and turbulence fields, cannot be obtained by simple Gaussian models, even if updated, that use constant wind data.

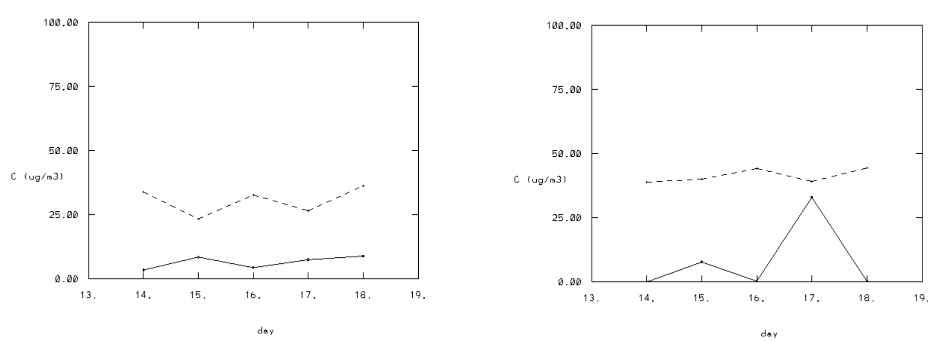

Figure 3. Hourly maximum NO_x concentration for each day at two stations internal to the district interested to the teleheating. Dashed line refers to S1 and continuous line to S2.

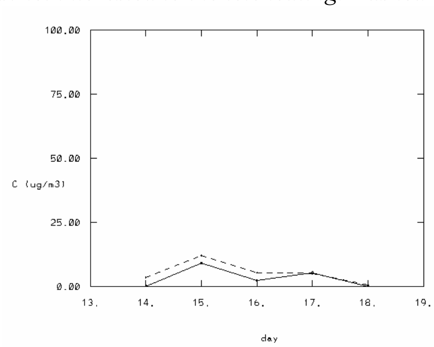

Figure 4. As in Figure 3 except at a station out of the district.

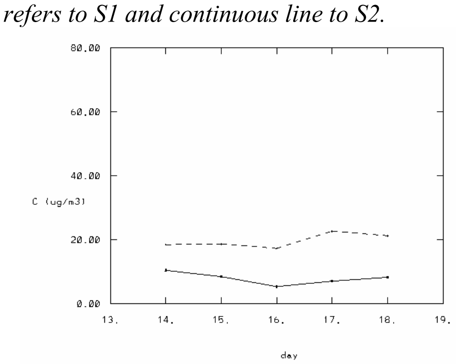

Figure 5. Top-ten concentration for each day.

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