EVALUATION OF A SEVERE AIR POLLUTION EPISODE IN HELSINKI, 27 - 29 DECEMBER, 1995

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INTRODUCTION

This paper forms part of the work of the COST 715 action "Meteorology applied to Urban Air Pollution Problems" (e.g., Fisher et al., 2001). Specifically, it is part of the Working Group 3 "Meteorology during peak pollution episodes" (e.g., Kukkonen, 2001). This paper is closely related to papers by Sokhi et al. (2002), Berge et al. (2002) and Karppinen et al. (2002) that are part of the proceedings of a workshop that was edited by Piringer and Kukkonen (2002) (can be downloaded at http://cost.fmi.fi/workshoptoulouse.html).

Sokhi et al. (2002) presented the analysis and evaluation of air pollution episodes in several European cities. Berge et al. (2002) presented results from Numerical Weather Prediction (NWP) modeling in Northern Europe during strong wintertime inversions, and discussed how realistic these simulations are. They utilised numerical results produced by two NWP models (HIRLAM and ECMWF), combined with the utilisation of the non-hydrostatic MM5 model. These analyses also included numerical modelling of the episode in Helsinki that is addressed in the present paper.

Karppinen et al. (2002) evaluated the meteorological data measured at a radio tower of 327 m height, called the Kivenlahti mast, situated in the Helsinki Metropolitan Area. The data extracted from such measurements needs to be carefully evaluated in order to find out possible disturbances caused, e.g., by the presence of the tower itself.

This paper describes an evaluation and analysis of a particularly severe air quality episode that occurred in the Helsinki Metropolitan Area during 27th -29th December, 1995. We have evaluated the synoptic, meso- and microscale meteorological conditions, both by using directly measured and pre-processed meteorological data, and predicted by the numerical weather prediction model HIRLAM. In particular, we have analysed the vertical temperature profiles at two locations: at a 327 m mast in a suburban location at Kivenlahti in the Helsinki Metropolitan Area, and at the sounding station of Jokioinen in Southern Finland.

THE MATERIALS AND METHODS

The Kivenlahti mast is situated in the Helsinki Metropolitan Area (World Meteorological Organisation, station number 05601, location: $60^{o}11'$, $24^{o}39'$). The location of the mast is presented in Figure 1. For a more detailed description of the measurements and the site, the reader is referred to Karppinen et al. (2002).

The concentration data used is from the urban air quality monitoring network stations in the Helsinki Metropolitan Area. The data from two of these stations is presented in this paper; the locations of these are presented in Figure 1. The predicted temperature profiles were obtained using a numerical weather forecasting model HIRLAM, version 4.6.2 (operational in 2001).

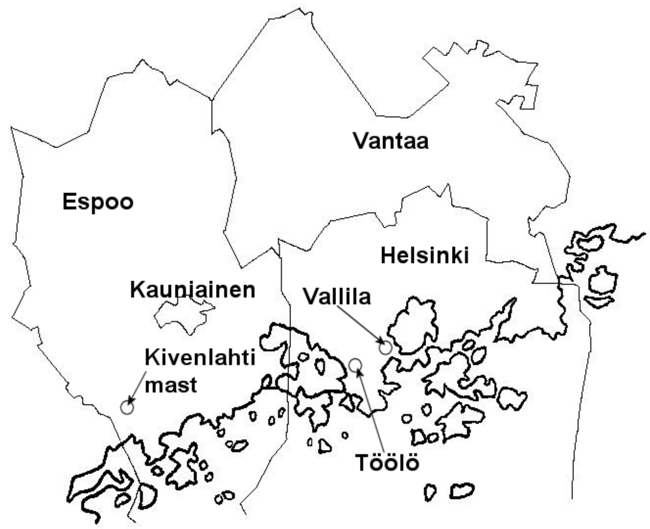


Figure 1. Location of the Kivenlahti meteorological mast within the Helsinki Metropolitan Area, comprising four cities (Helsinki, Espoo, Vantaa and Kauniainen). Two air quality stations in central Helsinki have also been shown (Vallila and Töölö). The size of the depicted area is approximately 35 km x 25 km.

RESULTS

The concentrations during the episode

The concentrations of NO_2, PM_{10} and CO were substantially high during the episode at all of the Helsinki Metropolitan Area air quality measurement stations. As an example, the concentrations of NO_2 and CO at the Vallila measurement station are presented in Figure 2. There was a weekend on the 30th and 31st of December, 1995. The emissions from local traffic during the last week of December were actually smaller, compared with an average working week, caused by the Christmas holidays.

In order to set the measured concentrations in a proper context, these can be compared with the currently applicable European Union limit values for the short-term concentrations of NO_2 and CO. The hourly EU limit value for NO_2 concentrations is 200 $\mu g/m^3$, allowing 18 exceedings per calendar year, to be obtained latest in 2010. For CO, the corresponding eight-hourly gliding average EU limit value is 10 mg/m^3, to be obtained latest in 2005.

The numerical limit value of the NO_2 concentration was exceeded at all urban and suburban measurement stations in the Helsinki Metropolitan Area during the 28th and 29th of December. The highest hourly average concentration of NO_2 during the episode measured in the Helsinki Metropolitan area occurred at the station of Vallila, this value was 401 $\mu g/m^3$ (9 p.m. on December 28th). For instance, the limit value for concentration of NO_2 was exceeded during December 28th and 29th at the Töölö measurement station during a total of 25 hours.

The eight-hourly EU limit value for CO was also exceeded during the episode at two measurement stations, at Leppävaara on the 29th December and at Töölö on the 28th December.

The highest hourly average of CO measured in the Helsinki Metropolitan area during the episode was at the station of Töölö, 16.8 mg/m^3 at 6 p.m. on the 28th of December.

However, the limit values were not exceeded at the regional background station of Luukki; the fairly low levels of regional background concentrations refer to a mainly local origin of the pollutants. Substantially elevated concentrations of NO_2, PM_{10} and CO were measured during this period also in other cities located in Southern and Western Finland (the cities of Turku, Tampere, Lahti, Lohja and Vaasa), but not in cities situated in Eastern and Northern parts of the country.

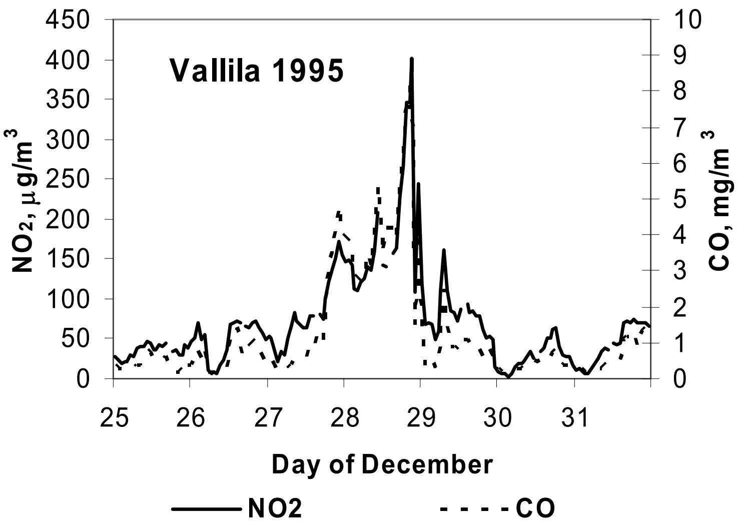


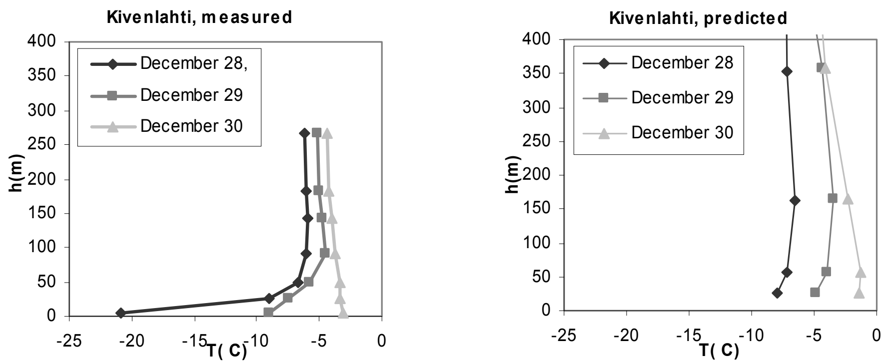
Figure 2. The evolution of the NO_2 and CO concentrations in the course of the air pollution episode during 25 – 31 December, 1995 at the station of Vallila in central Helsinki.

THE METEOROLOGICAL CONDITIONS DURING THE EPISODE

The air pollution episode considered was formed in an anticyclonic high pressure synoptic situation, which lead to the formation of an extremely strong ground-based inversion. The ground surface temperatures during the episode were of the order of –25 °C, the wind speeds were very small or it was calm (defined as the wind speed ≤ 1 m/s at the height of 10 m), and the sky was predominantly clear or mostly clear; although there was also some snowfall on 28th December. There was a snow cover over the area. However, there was no widespread ice cover in the sea areas (Gulf of Finland); the ice layer existed only in the immediate vicinity of the coastline.

The measured and HIRLAM -predicted temperature profiles during the episode at the Kivenlahti mast are presented in Figures 3a-b. The lowest measurement height was at 5 m, while the lowest predicted height was approximately 30 m. The measured temperature profiles at 00 UTC show that there was an extremely strong ground-based temperature inversion on 28th December, and a fairly strong inversion also on 29th December, but the inversion had totally disappered on 30th December. At 00 UTC on 28th December, the measured temperature increased 15 °C within the lowest 91 m of the atmosphere. Detailed examination of the diurnal variation of the measured inversion shows that the maximum vertical inversion was approximately 15˚C over the lowest 30 m of the atmosphere (Karppinen et al., 2002). An evaluation of inversion statistics shows that inversions of such a magnitude and duration are exceptional in southern Finland (Karppinen et al., 2001).

For the HIRLAM –predicted temperature profiles, the lowest predicted height is 30 m; the measured and predicted profiles can therefore not be compared below this altitude. On December 28th and 29th, the HIRLAM model predicts a temperature inversion of a couple of degrees from 26 m to approximately 150 m. Although the HIRLAM model does detect the inversion on these days, the model substantially underpredicts the inversion strengths (in °C), and slightly overpredicts the inversion layer heights.



Figures 3a-b. The evolution of the measured (a) and predicted (b) temperature profiles at the Kivenlahti mast from 28 to 30 December, 1995 at 00 UTC (Universal Time Coordinated). The measurements were conducted at the radio tower of Kivenlahti, and the predictions were computed with the numerical weather prediction model HIRLAM, a version that was operational in 2001 (4.6.2).

CONCLUSIONS

A synoptic situation involving anticyclonic high pressure conditions lead to very low wind speeds and the formation of an extremely strong ground-based inversion in the Helsinki Metropolitan Area on the last days of December in 1995. A detailed analysis of the mesoscale meteorological conditions (not presented here) showed that there was a land-sea breeze over the area on the 28th December that was in the opposite direction to the synoptic scale wind flow in the vicinity of the coastline.

As a result, a severe air pollution episode was formed in the course of which the concentrations of NO_2, PM_{10}, and CO were substantially high for a period of several days. The comparison of measured regional background concentrations with those measured at urban and suburban stations indicated that the elevated concentrations were predominantly originated from local sources. The same result was also obtained quantitatively by dispersion model computations (not shown here).

According to measured results at the Kivenlahti radio tower, the maximum vertical inversion in the course of the episode was approximately 15˚C over the lowest 30 m of the atmosphere; this corresponds to an average temperature gradient of approximately 0.5 ˚C/m. The maximum total strength of the inversion was approximately 18 ˚C within the lowest 100 m of the atmosphere.

Both the HIRLAM -predicted inversion strengths (°C) and temperature gradients (˚C/m) were substantially smaller than the values extracted from the Kivenlahti mast data. A detailed analysis shows that this underprediction is related especially to an overprediction of surface temperatures and near-surface wind velocities by the HIRLAM model. The deviations of predictions and data are partly caused by deficiencies in the mathematical treatment of humidity and the state of the ground surface (e.g., the existence of a snow cover) in the HIRLAM model version that was applied here (Järvenoja, 1999). The deviations are partly also caused by the inadequate computational grid resolution both vertically and horizontally, regarding evaluations on such a small scale. Clearly, the model has originally been designed for numerical weather prediction in synoptic and meso-scales; instead of smaller meso- or microscale predictions within the lowest atmospheric layers.

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