6.24 EVALUATION OF VARIOUS VERSIONS OF HIRLAM AND MM5 MODELS AGAINST METEOROLOGICAL DATA DURING A WINTERTIME AIR POLLUTION EPISODE IN HELSINKI

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INTRODUCTION

Air pollution episodes can be evaluated by using first numerical weather prediction (NWP) models in order to predict meteorological conditions and then atmospheric dispersion models to predict the pollutant concentrations. In this study, three versions of the HIRLAM model and the MM5 model are inter-compared and evaluated against the observational data during an air pollution episode that occurred in the Helsinki Metropolitan Area on 27-29 December, 1995. The evaluation has been performed for selected relevant meteorological parameters, such as temperature, wind speed and relative humidity.

MATERIALS AND METHODS

The NWP models HIRLAM and MM5

Some properties of the numerical weather prediction models considered here are presented in Table 1.

Table 1. Some characteristics of the NWP models that are included in this study.

Model and version	Horizontal Resolution and nesting	Number of vertical computational levels	Boundary values extracted from
HIRLAM 4	22 km, single nesting	31	ECMWF, HIRLAM (nested)
HIRLAM 5	33 km	40	ECMWF
HIRLAM 6	22 km	40	ECMWF
MM5 v3 (a)	1 km, triple nesting	17	ECMWF, MM5 (nested)
MM5 v3 (b)	1 km, triple nesting	17	HIRLAM 6, MM5 (nested)

The properties of various versions of the HIRLAM model

The numerical weather prediction model HIRLAM is a hydrostatic limited area grid model with boundary values updated every 6 hours from the ECMWF global NWP model. The HIRLAM model is based on the primitive equations; the independent variables are the spatial coordinates and the dependent variables are temperature, humidity, the horizontal wind components and surface pressure. For a more detailed description, the reader is referred to *Källen* (1996) and *Undén et al*. (2003).

The numerical computations were performed with the HIRLAM model versions 4.6.2, 5.1.4 and 6.2.1 for the period from 27th to 30th December 1995. The HIRLAM 4 model was executed using one single nest; the horizontal resolutions were 44 km and 22 km. The HIRLAM 5 and 6 models have horizontal resolutions of 33 km and 22 km, respectively. The most representative computational grid points in the vicinity of the Kivenlahti mast and the Jokioinen radiosonde station were chosen for comparison with the meteorological observations (*Pohjola et al*., 2004). In this study, the output time steps used were 1 hour for HIRLAM 4, and 6 and 3 hours for HIRLAM 5.

Compared to HIRLAM 4, the subsequent versions of the model HIRLAM 5 and 6 have a new surface scheme known as ISBA (The Interaction Soil-Biosphere-Atmosphere, *Noilhan and Mahfouf* (1996)), together with its related surface analysis scheme. The ISBA surface scheme is a refinement of the *Deardorff* (1978) scheme, which is expected to improve surface temperature and humidity forecasts. In ISBA, the grid squares are further divided into smaller areas with different surface types, such as water, ice, bare ground, low vegetation and forest (*Navascués et al*., 2002).

In HIRLAM 5 and 6, variational data assimilation (3D-VAR) has replaced the upper air analysis based on optimum interpolation used in HIRLAM 4. This makes it possible to use remote sensing data more effectively in the HIRLAM analysis. In HIRLAM 6, the length of the data assimilation cycle has been reduced to 3 hours, from the 6-hour cycle adopted in HIRLAM 5 (*Järvenoja*, 2004).

The properties of the MM5 model

Numerical computations were performed with the non-hydrostatic MM5 model version 3 (more details in *Dudhia* 1993, 1996) for the period from 26th to 30th December 1995. Some of the MM5 runs were executed with ECMWF initial data and boundaries (referred to as ‘a’ in table 1) with a resolution of 120 km, while other runs were executed using HIRLAM 6 initial data and boundaries (referred to as ‘b’ in table 1) with a resolution of 22 km. In both cases, the MM5 model was used with triple-nesting configuration that had resolutions of 9km, 3km and 1km. Both model runs have been performed with 17 sigma levels; the highest model level is located at 100 hPa. The physical parameterization did not include convection, whereas in the HIRLAM parameterizations convection is included.

Meteorological data

The most representative grid points close to the Kivenlahti mast and the Jokioinen radiosonde station were chosen for comparison with the meteorological observations (*Pohjola et al*., 2004). The predicted model parameter values were compared with the observations from three locations: (i) a 330 m high mast in a suburban location at Kivenlahti, (ii) the synoptic station of Helsinki-Vantaa airport in the Helsinki Metropolitan Area, and (iii) the sounding station of Jokioinen in a rural area in Southern Finland.

The Kivenlahti mast is situated about 6 km and the airport about 20 km north of the average southern coastline. Measurement instruments are installed on the mast at nine levels, from 5 m to 327 m. Wind speed and direction data are averaged at 10-minute intervals. The lowest height for wind speed observations is 26 m. The synoptic meteorological conditions at the beginning of the air quality episode are shown in Figure 1.

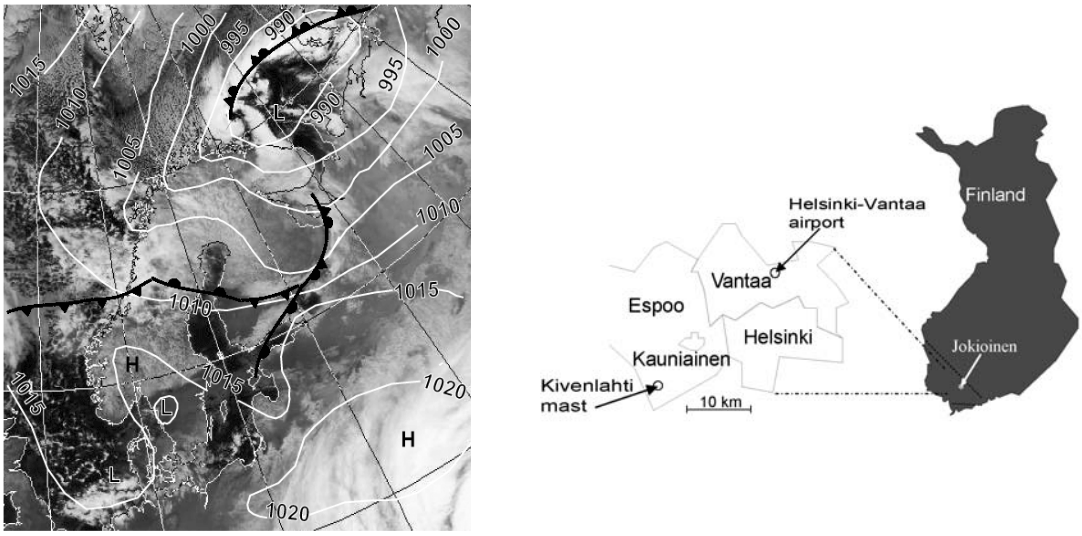

Figure 1. a) Left: The Dundee satellite image that shows the synoptic meteorological conditions in Northern Europe at 00 UTC on 28 December 1995. The isolines correspond to the observed atmospheric pressures (mbar) at the ground level. b) Right: The location of the meteorological station Jokioinen, the meteorological mast at Kivenlahti and the meteorological station Helsinki-Vantaa airport.

RESULTS

In the analysis of air pollution episodes, the focus is on the diffusion characteristics of the lowest atmospheric layers. The NWP modelling results were therefore evaluated particularly in the lowest atmospheric layers. The studied HIRLAM model versions tend to over predict the temperature and wind speed near the surface (*Järvenoja*, 2004), leading to an under prediction of the ground based surface inversions (e.g., *Rantamäki et al*., 2003). Figure 2 shows the profiles of a temperature inversion resulting from two MM5 model runs.

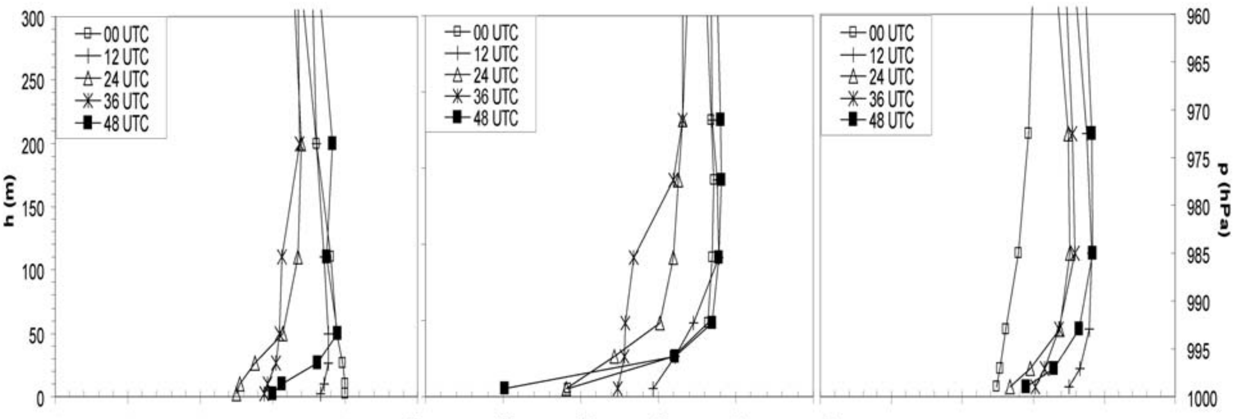

Figure 2. Temperature profiles predicted by two versions of the MM5 model in the vicinity of the Kivenlahti mast in the Helsinki Metropolitan Area, from one to two days before (26-27 December, 1995) the occurrence of the highest concentrations (28-29 December, 1995). The figures show several forecasted profiles, on consecutive intervals of 12 hours. a) Left: MM5 with ECMWF borders, b) Middle: Observations and c) Right: MM5 with HIRLAM borders.

The extremely high measured temperature increase against the height that persisted during the episode was not forecasted by any of the NWP models considered here. The inversions on the night of 29th December at Jokioinen and Kivenlahti could be predicted by some accuracy, but the strong surface inversions were still often missed (Rantamäki et al. 2003). Also, all the models predicted too high wind speeds near the surface. The relative humidity prediction near the surface seems to be improved in the HIRLAM 6 model, and the incorrectly predicted low-level clouds near the surface do not exist anymore in these runs (Figure 3).

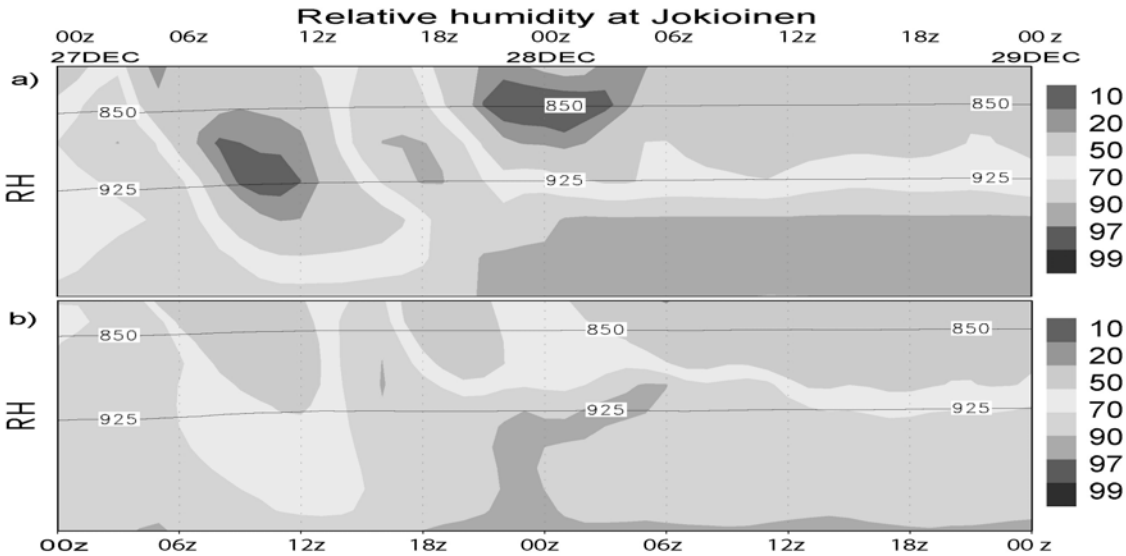

Figure 3 The predicted relative humidity (%) from the surface to a height of 2 km at the station of Jokioinen. The 48h forecasts were performed by the HIRLAM version 4 (upper figure) and the HIRLAM version 6 (lower figure).

There was a partial ice cover over the Gulf of Finland that extended to a distance of 11 km from the southern coastline of the Helsinki Metropolitan Area (*Finnish Institute of Marine Research*: Ice chart nr: 29.12.1995). However, this was not fully taken into account in any of the models, as the modelling of ice cover is a rough approximation.

CONCLUSIONS

Increasing the spatial resolution of a NWP model does not necessarily lead to more accurate numerical results, as can be seen from the examples presented in this study. The MM5 model was able to predict the observed temperature inversions; however, the predicted surface temperature was too high, compared with the measured data. The models have various schemes to treat the snow and ice cover; it is therefore not possible to draw definite conclusions regarding the performance of various surface heat flux parameterisations.

The most probable reasons for the inaccurately predicted surface temperatures with the HIRLAM 4 model during stable wintertime conditions are the deficiencies in the algorithm used in computing the latent heat flux from a snow-covered surface. The relative humidity near the surface seems to be better forecasted in the HIRLAM 6 model, and now there are no longer low-level clouds near the surface like in the HIRLAM 4 model. Further improvements for the surface modelling algorithms are under investigation.

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