6.12 EVALUATION AND COMPARISON OF OPERATIONAL NWP AND MESOSCALE METEOROLOGICAL MODELS FOR FORECASTING URBAN AIR POLLUTION EPISODES - HELSINKI CASE STUDY

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INTRODUCTION

Predicting potentially harmful air pollution episodes is the purpose of Urban air quality information and forecasting systems (UAQIFSs) that are established in several European cities especially after the implementation of stricter European Air Quality directives. As nested numerical weather prediction models have recently approached urban scale resolution, UAQIFSs may benefit largely from using the output of operational weather prediction and mesoscale meteorological models (*Baklanov et al*., 2001).

The improvement and urbanisation of NWP models applied in UAQIFSs and their application in several European target cities (Oslo, Turin, Helsinki, Valencia/Castellón, Bologna) is the aim of the European Union FP5 project FUMAPEX (Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure, http://fumapex.dmi.dk) established in the COST 715 action (*Fisher et al*., 2001). This paper presents results from the Working Package WP3 "Testing the quality of different operational meteorological forecasting systems for urban areas". A wintertime inversion episode in Dec 1995 and spring dust episodes in March 1998 and April 2002 in Helsinki are investigated. Simulations are performed and inter-compared for four numerical weather prediction (NWP) models (DMI-/FMI-/DNMI-HIRLAM and LM of the DWD/COSMO group) and the mesoscale meteorological models MM5 and RAMS.

METEOROLOGICAL CONDITIONS DURING THE EPISODES

The chosen episodes are typical northern/central European occurring in winter and spring and characterised by strong and shallow surface inversions, low wind speeds, and relatively low temperatures leading to high concentrations of particulate matter and nitrogen oxides:

- 27-29 Dec 1995: high NO_2, CO and PM_{10}, extremely strong ground inversion (-18°C in 120m), stable to very stable stratification, high pressure, low westerly winds, cold and dry, snow cover, no widespread ice cover over sea, warm front passage on Dec 29.
- 22-24 Mar 1998: resuspended particle spring episode, ground inversion, moderately to extremely stable (night), high pressure, very low south(-westerly) winds, dry.
- 8-13 Apr 2002: resuspended particle spring episode, ground inversion, high pressure, very slight south-easterly winds, sunny and dry with cold nights, no snow or ice.

RESULTS

The episodes described were simulated by the WP3 partners with their operational NWP models, using their specific operational data assimilation, numerics, and parameterisations. Model runs were performed with increasing grid resolution down to 1km to investigate the model behaviour for near-urban scale NWP modelling. Model details are given in Table 1.

The model results are evaluated using e.g. horizontal fields, vertical cross sections, vertical profiles and time series at station locations (Figure 1) and standard statistics.

Table 1. NWP model details.

Partner	Model	Resolution [km]	Levels	Nesting	Initial/boundary conditions	Non-hydrost.
CEAM	RAMS	27, 9, 4.5, 1.5	45	2-way	ERA-40	X
DMI	DMI-HIRLAM	45, 15, 5, 1.4	31	1-way	ECMWF	
DNMI	MM5	9, 3, 1	17	2-way	DNMI-HIRLAM	X
DWD	LM	7, 2.8, 1.1	35,45,45	1-way	GME / ERA-40	X
FMI	HIRLAM 6.2.1	22	40	1-way	ECMWF	

Figure 1. Helsinki area (approx. 250km x 200km) with locations of meteorological stations. A: Jokioinen, B: Vantaa, C: Kivenlahti, D: Kaisaniemi, E: Isosaari.

INFLUENCE OF NWP MODEL GRID RESOLUTION

Comparison of the results of the different horizontal and vertical resolutions of the model suites generally reveal only small differences due to grid refinement in most of the predicted variables. This is mainly caused by the fact that the Helsinki area exhibits little topographic change with increasing grid resolution. It may partly also be explained by the insufficient vertical grid refinement in the lowest atmospheric layers. For the DWD LM, a predominant influence of horizontal grid refinement is found due to changes in the land-sea distribution. With increasing grid resolution, more Helsinki observation stations were situated on the model land surface and the concurrent changes in external parameters partially have a large impact on magnitude and diurnal variation of temperature, wind speed, and surface fluxes. Similar effects are stated for coastal areas for FMI-HIRLAM (*Rantamäki et al.*, 2003).

COMPARISON OF NWP MODEL RESULTS

The main meteorological criteria for predicting the potential for the formation and persistence of the described episodes are investigated. They especially comprise valid forecasts of inversion strength and height, low wind speed, and atmospheric stability for the episodes discussed (*Sokhi et al*., 2002).

Figures 2 and 3 show vertical profiles of three model suites, interpolated to the location of the Kivenlahti mast and compared to measurements provided by FMI. Figure 2, left, contains the exceptionally strong and shallow inversion in the morning of Dec 28, 1995. Its intensity is best captured by the DNMI suite although the inversion height is too large. DWD's LM model exhibits a smaller but shallower temperature inversion while CEAM's RAMS shows no inversion. In the 24h forecast for the less extreme inversion on Dec 29, 00 UTC (Figure 2, right), the results improve for all models with the CEAM RAMS also developing a weak but otherwise well-fitting inversion. Strong underestimation of the 28 Dec inversions is also reported for different versions of FMI-HIRLAM with 33 and 22km resolution, with much better fits for the 29th (*Kukkonen et al.,* 2001, *Rantamäki et al.,* 2003). Generally, the inversion strength is underestimated by CEAM RAMS and (less) by the DWD LM model and overestimated by the DNMI MM5 (as confirmed by other DNMI tests).

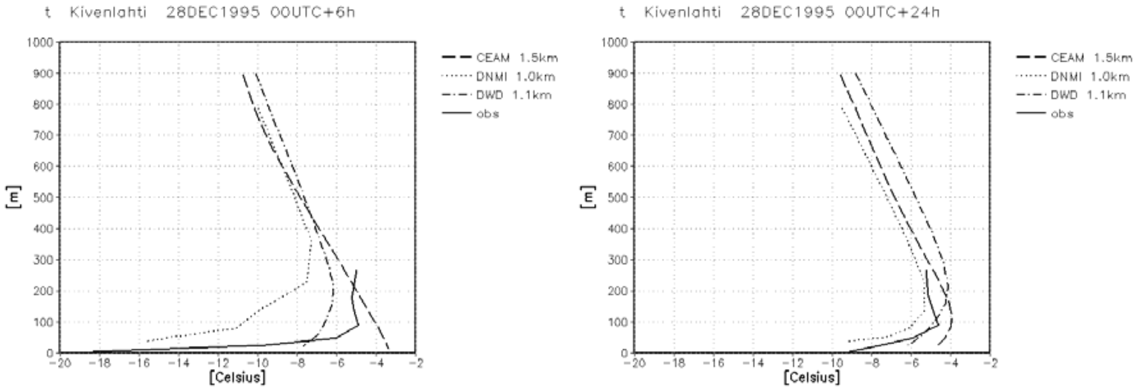

Figure 2. Temperature results of CEAM, DNMI and DWD model suites and observations at Kivenlahti mast. Left: 28 Dec 1995 00UTC+6h. Right: 28 Dec 1995 00UTC+24h.

Figure 3 depicts the horizontal velocity. The vertical profile in the morning of Dec 29, 1995, is described quite well by all three model suites (Figure 3, left). Very low wind speeds are constituent for and prevailing during the 1998 spring episode. They are overestimated by CEAM and DWD models while the DNMI model again performs quite well (Figure 3, right). The overestimation of near-surface winds is also reported for DMI's HIRLAM suite (*Baklanov et al*., 2002).

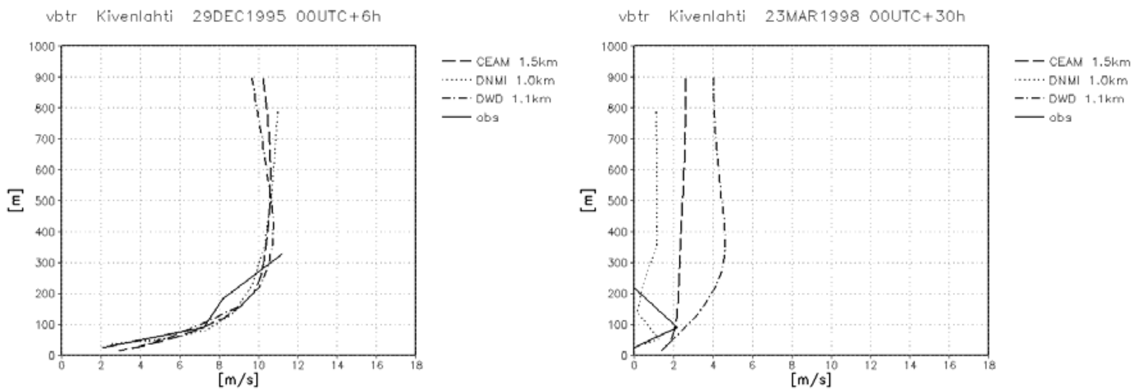

Figure 3. Velocity results of CEAM, DNMI and DWD model suites and observations at Kivenlahti mast. Left: 29 Dec 1995 00UTC+6h. Right: 23 Mar 1998 00UTC+30h.

Figures 4 and 5 show time series of 48h forecasts interpolated to the indicated station locations and compared to the corresponding measurements provided by FMI. In most cases like in the two depicted in Figure 4, the 2m temperature results of CEAM RAMS exceed those of the DWD LM which are again larger than for DNMI MM5. The diurnal temperature variation is not captured in wintertime (Figure 4, left). For the spring episodes it is described quite nicely with a slight underestimation of temperature amplitude (Figure 4, right). Results from a 22km-FMI-HIRLAM run (not shown) exhibit a much smaller amplitude for the spring episode.

Wind speeds are generally captured well (e.g. Figure 5, left), but even the small overestimations of wind speed may be decisive for the failure to forecast the occurrence or persistence of the typical inversion episode and will contribute to the observed under prediction of the ground-based surface inversions. The larger wind speed variations of Dec

29, 1995, foreboding the warm front passage and marking the end of the episode, are well predicted with the DWD LM while CEAM RAMS realises at least the trend well. DNMI MM5 and the 22km-FMI-HIRLAM results (not shown) stay close to the minimum values and thus might fail to predict the close of the episode (Figure 5, right).

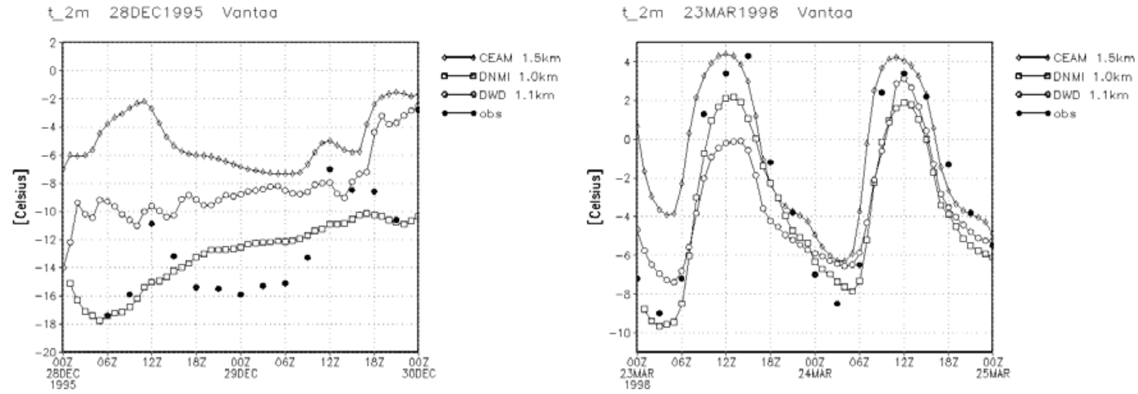

Figure 4. 2m temperature results of CEAM, DNMI and DWD model suites and observations at Vantaa station. Left: 28 Dec 1995. Right: 23 Mar 1998.

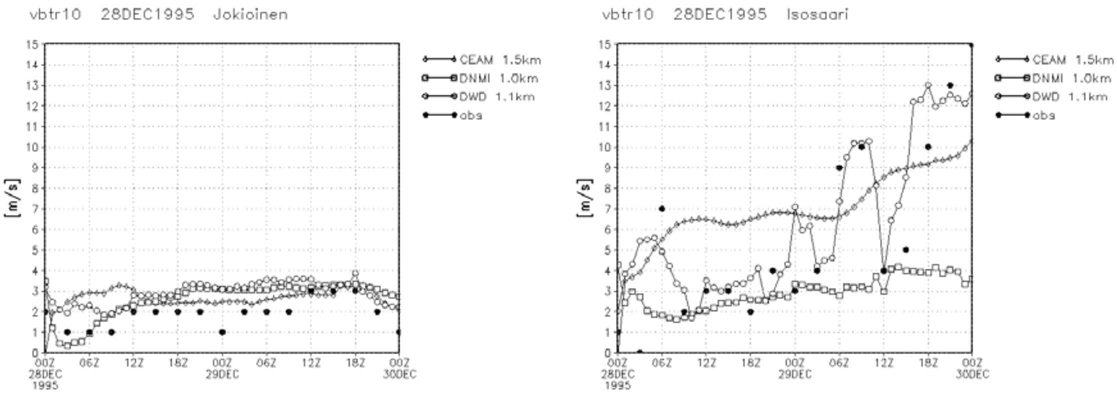

Figure 5. 10m wind speed results of CEAM, DNMI and DWD model suites and observations, 28 Dec 1995. Left: Jokioinen station. Right: Isosaari station.

First investigations of schemes for mixing height/boundary layer top important to most air quality calculations show that mesoscale non-urbanised schemes (FMI's Ulden-and-Holtslag based pre-processor, DWD's LM gradient Richardson number scheme, CEAM's RAMS TKE depletion approach) result in comparable daytime mixing heights with default values during the stable night time conditions for the l998 episode. They fail for the extremely strong and shallow (100 to 200m) inversion of Dec 28, 1995 (although approximated e.g. by LM vertical profiles of temperature, potential temperature, and TKE). The FMI 100m-default for the whole 3-day period is the closest fit while the other two schemes show a boundary layer top of up to 1200m (which is borne out e.g. by modelled vertical LM profiles) and might belong to a higher ‚rural' or elevated residual boundary layer (on top of the shallow inversion/internal boundary layer). This highlights the problems of urban mixing heights/internal boundary layers/suitability of mesoscale schemes and the need for improved schemes for stable (not only night time) conditions and improved parameterisation (including vertical resolution) near the surface in conventional schemes for daytime application (*Baklanov*, 2002).

INTERPRETATION AND CONCLUSIONS

Results show that some improvements (e.g. in thermal inversions and wind speeds) are achieved using higher model resolution. The remaining deviations are most likely explained by deficiencies in the model physical parameterisations. In the DWD LM, the overestimations of T2m and v10m may be due to insufficient stability influence on transfer and diffusion coefficients for stable situations causing overestimation of vertical exchange and possibly also explaining overestimated inversion height and underestimated inversion strength. For extreme inversions, T2m may also be overestimated by specific features of the stability-dependent interpolation between surface and lowest prognostic level. For the FMI-HIRLAM, the most probable reasons for the inaccurately predicted surface temperatures are deficiencies in the algorithm used in computing the latent heat from snow-covered surfaces, but higher horizontal resolution and use of a non-hydrostatic version should also improve results. In coastal areas, higher resolution may also lead to substantial changes in external parameters at the model grid points and thus influence wind, temperature, and surfaces fluxes substantially. Additionally, LM and FMI-HIRLAM e.g. both had no sea ice for the 1995 episode although a narrow ice belt along the coast was observed. This may lead to large model deviations due to the large temperature difference between land and open sea surface in winter and shows the need for improved assimilation of small-scale observation data into the models.

The results of the model inter-comparison and evaluation against observation data for the (partially synoptically extreme) Helsinki episodes clearly show the limitations of even highly resolved mesoscale NWP models. As intended in the context of the FUMAPEX project, they highlight the necessity of improved modified boundary layer parameterisations and surface characteristics. These improvements are being implemented by FUMAPEX partners into their high resolution NWP models with specific adaptations for urban meteorological characteristics, with the aim of leading to better air quality forecasts in European cities.

ACKNOWLEGEMENTS

This work is part of the FUMAPEX project, WP3 „Testing the quality of different operational meteorological forecasting systems for urban areas“ and funded by the European Union.

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