Evaluation and comparison of operational NWP and mesoscale meteorological models for forecasting urban air pollution episodes - Helsinki case study -

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Lina Neunhäuserer, Barbara Fay (DWD)
José Luis Palau, Gorka Pérez-Landa (CEAM)
Alix Rasmussen, Bjarne Armstrup, Alexander Baklanov (DMI)
Viel Ødegaard, Norvald Bjergene (DNMI)
Minna Rantamäki, Ilkka Valkama, Jaakko Kukkonen (FMI)
FUMAPEX: Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure EU FP5 project, CLEAR cluster

Outline

- FUMAPEX: motivation, idea, realisation
- evaluation setup
- impact of NWP model grid resolution
- inter-comparison of NWP model results
- summary
- outlook
Short-term pollution episodes in cities

Kivenlahti 1995: temperatures, measured

Kivenlahti 2002: temperatures, measured

Töölö 1995

Töölö 2002

Data: FMI
Forecasting urban meteorology

Resolution:

- > 15 km ECMWF/HIRLAM, GME
- ~ 1-5 km LM, HIRLAM
- > 0.5 km MM5, RAMS, LM
- ~1-10 m CFD, box models

Meteorological observations

Global / regional NWP models

Limited area NWP

Meso-meteorological models

Local scale models

Met. Preprocessors

Emission data

UAP (Urban Air Pollution) models
**FUMAPEX workflow scheme**

| WP 1 + WP 2: Episode analysis + data, existing UAP modelling approaches |
| WP 3: Testing different NWP-models using different resolutions |
| WP 4: Urbanised parameterisations in meteorological models |
| WP 5: Improved interfaces to UAP models |
| WP 6: Sensitivity of UAP models to NWP model designs |
| WP 7: Population Exposure models |
| WP 8: Implementation and evaluation of improved UAQIFSs (Urban Air Quality Information and Forecasting Systems) |

**WP 3:**
- DMI-/DNMI-/FMI-HIRLAM
- LM/LAMI
- MM5
- RAMS

**WP 4:**
- Urban heat flux
- Urban soil models
- Urban roughness
- Sat. surface info

**WP 5:**
- Mixing height
- ABL param.
- met. param.
- NWP data
FUMAPEX main target cities

- Bologna
- Castellón
- Copenhagen
- Helsinki
- Oslo
- London
- Turin

Deutscher Wetterdienst

9th Harmonisation Conference

Garmisch-Partenkirchen
## Meteorological conditions

<table>
<thead>
<tr>
<th>Episode</th>
<th>Characterisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-29 Dec 1995</td>
<td>- local inversion induced episode (high NO₂, CO and PM₁₀)</td>
</tr>
<tr>
<td></td>
<td>- high pressure, extremely strong ground inversion</td>
</tr>
<tr>
<td></td>
<td>- low westerly winds, cold and dry</td>
</tr>
<tr>
<td></td>
<td>- stable to very stable (nighttime) stratification</td>
</tr>
<tr>
<td></td>
<td>- snow cover, no widespread ice cover over sea</td>
</tr>
<tr>
<td></td>
<td>- warm front passage on Dec 29</td>
</tr>
<tr>
<td>22-24 Mar 1998</td>
<td>- local resuspended particle episode</td>
</tr>
<tr>
<td></td>
<td>- high pressure, ground inversion</td>
</tr>
<tr>
<td></td>
<td>- very low south(-westerly) winds, dry</td>
</tr>
<tr>
<td></td>
<td>- moderately to extremely stable (nighttime) stratification</td>
</tr>
<tr>
<td>8-13 Apr 2002</td>
<td>- local resuspended particle episode</td>
</tr>
<tr>
<td></td>
<td>- high pressure, ground inversion</td>
</tr>
<tr>
<td></td>
<td>- very slight south-easterly winds, sunny and dry, cold nights</td>
</tr>
<tr>
<td></td>
<td>- no snow or ice cover</td>
</tr>
</tbody>
</table>
## Parameters of meteorological stations

<table>
<thead>
<tr>
<th>code</th>
<th>name</th>
<th>h[m]</th>
<th>type</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Jokioinen</td>
<td>103</td>
<td>rural</td>
</tr>
<tr>
<td>B</td>
<td>Vantaa</td>
<td>56</td>
<td>suburban</td>
</tr>
<tr>
<td>C</td>
<td>Kivenlahti</td>
<td>44</td>
<td>rural</td>
</tr>
<tr>
<td>D</td>
<td>Kaisaniemi</td>
<td>4</td>
<td>urban</td>
</tr>
<tr>
<td>E</td>
<td>Isosaari</td>
<td>5</td>
<td>rural/island</td>
</tr>
</tbody>
</table>
Simulation and evaluation methodology

key meteorological factors for episodes in northern/central Europe (Sokhi et al., 2003; Kukkonen et al., 2004):

the temporal evolution of
  - temperature inversion
  - wind speed
  - atmospheric stratification
  - (topography)

48h forecasting, starting at 00UTC, to be used for UAQIFSs

<table>
<thead>
<tr>
<th>horizontal fields</th>
<th>T, RH, WS, WD</th>
</tr>
</thead>
<tbody>
<tr>
<td>vertical profiles at station locations</td>
<td>S_RAD, L_RAD</td>
</tr>
<tr>
<td>time series at station locations</td>
<td>SHF, LHF</td>
</tr>
<tr>
<td>vertical profiles as time series</td>
<td>Tpot, TKE, MH</td>
</tr>
<tr>
<td>vertical cross section</td>
<td></td>
</tr>
<tr>
<td>standard statistical scores</td>
<td>T2m, RH2m, WS10m</td>
</tr>
</tbody>
</table>
Influence of grid resolution

• in general: small influence, some improvement
• for coastal cities: distinct influence due to changes in physiographic parameters (land/sea mask, soil type)

Example: LM 7.0, 2.8, 1.1km, observations

$T_{2m}$ [°C] 48h time series starting 10 Apr 2002, 00UTC
T [{°C}] for RAMS, MM5, LM, obs

Vertical profiles Kivenlahti 28 Dec 1995

48h time series starting 28 Dec 1995, 00UTC
T [°C] for RAMS, MM5, LM, obs

Vertical profiles Kivenlahti 23 Mar 1998

00UTC + 6h 00UTC + 12h 00UTC + 24h

48h time series starting 23 Mar 1998, 00UTC

Vantaa Kaisaniemi Isosaari
Wind speed [m/s] for RAMS, MM5, LM, obs

1998

Vertical profiles Kivenlahti

23 Mar, 00UTC + 30h

28 Dec, 00UTC + 30h

29 Dec, 00UTC + 6h

1995

48h time series, starting 00UTC

23 Mar, Vantaa

28 Dec, Isosaari

29 Dec, Isosaari
Planetary boundary layer heights

PBL [m], horizontal fields 28 Dec 1995, 00UTC + 12h

CEAM RAMS
DWD LM
DMI-HIRLAM

PBL [m], horizontal fields 24 Mar 1998, 00UTC + 36h

CEAM RAMS
DWD LM
DMI-HIRLAM
MMAS statistics of NWP model results

Correlation coefficients of 48h time series starting 23 Mar 1998

RMSE of 48h time series starting 23 Mar 1998
Summary I: NWP model inter-comparison

- **T2m and ground inversion**
  - poorly modelled by all models for 1995, improved for 1998
  - DNMI MM5 lowest, CEAM RAMS highest, DWD LM mid
  - inversely correlated to modelling results of inversion strength

- **WS**
  - WS10m generally captured well, tendentially overestimated
  - larger WS10m variations on 29 Dec best captured by LM
  - boundary layer WS tendentially underestimated by DNMI MM5 / DWD LM and overestimated by CEAM RAMS

- **Stability**
  - stable atmosphere of episodes is portrayed by all models
  - $u^*$ of DNMI MM5 and FMI-MPP show acceptable agreement
  - Tpot results of DWD LM reveal much stronger stability compared to CEAM RAMS results
Summary II: NWP model inter-comparison

- PBL heights
  - spring: CEAM RAMS / DWD LM / DMI HIRLAM / FMI provide similar results for ‘rural’ daytime mixing height
  - winter: FMI best with 100m-default, other models fail / simulate higher mixing height

- Humidity
  - very variable, close inverse relationship with T

- Sensible heat flux
  - direct dependance on T and grid resolution (external parameters)

- Statistical scores
  - Correlation coefficients highest for T2m, lowest for RH2m
  - RMSE largest for RH2m
  - RMSE of T2m, WS10m smaller for spring time episode results
Summary III: grid refinement

• grid refinement leads to some improvement of model results
  – land/sea distribution and associated soil type distribution improve with increasing grid resolution
  – more improvement expected for mountainous areas (Bologna)

• model deviations remain due to deficiencies in
  – horizontal / vertical resolution (h: FMI HIRLAM, v: all)
  – using hydrostatic version (HIRLAM)
  – land/sea mask in coastal areas (DWD LM, HIRLAM)
  – description of snow cover (CEAM RAMS, DNMI MM5)
  – description of sea ice (most models)
  – urbanised and high-resolution soil and surface layer parameterisation (all)
Outlook for FUMAPEX

model evaluation in WP3:
• episode simulations for Oslo, Bologna, Turin and Castellón
• model inter-comparison for all target cities
• episode and long-term evaluation with standard statistical NWP-scores

standard and guideline to improvements in following WPs:
• WP 4: Improved parameterisations in meteorological models for urban areas
• WP 5: Interface to UAP models
• WP 6: Sensitivity of UAP models to NWP model designs
• WP 7: Population Exposure models

Thank you for your attention!