Sensitivity analysis of WRF for integrated assessment modelling in Spain

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OUTLINE

1. Introduction
2. Methodology
3. Results
4. Conclusions
5. Next steps
1. INTRODUCTION

The SIMCA project

- SIMCA (Air quality integrated assessment modelling system for the Iberian Peninsula) is a research project funded by the Spanish Ministry of Environment

- Assessment and comparison of environmental policies and control strategies

- Multiscale and multipollutant approach

- Based on national projections from the Spain’s Emission Projection (SEP) project
Modelling system overview

**Meteorological model**
- Met data (gridded, obs.)
- Terrain & land use data

**Chemical-Transport model**
- Initial conditions
- Boundary conditions
- Photolysis rates

**Emission model**
- Emission Inventories
- Ancillary information:
  - Temporal allocation
  - Spatial allocation
  - Chemical speciation
- Large Point Source parameters

**Concentration Deposition Visibility**
The need for a meteorological sensitivity analysis

- Critical input for air quality modelling

- Non-deterministic approach: future-year runs based on 6 meteorological years (2000-2005)

Uncertainty and errors in the final AQ results

Extensive computational (time) resources

\(~ 1600 \text{ h WRF running time / year}\)

\((128 \text{ IBM PPC 2.2 GHz processors})\)
2. METHODOLOGY

- Modelling domains and inputs

  - Lambert conformal projection
  - Three nested domains
  - 30 layers
  - Initialization from NCEP Global Tropospheric Analyses with 1° x 1° spatial resolution and temporal resolution of 6 hours
Episodes

- Two 7-day (9) episodes. Winter and summer 2005

  21-28 February

  20-27 June

- Generalized high pollution levels over the Iberian Peninsula (SO$_2$ and PM$_{2.5}$ in winter and O$_3$ in summer)
Observational datasets

- 39 monitoring stations (met & AQ) representative of geophysical conditions across the Iberian Peninsula
• Surface meteorological variables (1-h resolution)
  • Temperature (2 m)
  • Wind speed and direction (10 m)

• Observations from 3 monitoring networks:
  • Spain’s Meteorological Insititute (SMI) – 19 stations
  • EMEP – 9 stations
  • Portugal’s Meteorological Insititute (PMI) – 7 stations

• Upper air measurements (12-h resolution)
  • Vertical profiles from routinely soundings in 8 locations
Evaluation methodology

• Classical approach (measurements Vs model predictions)

• Statistics from Emery et al., 2001 (specific methodology for mesoscale model evaluation for air quality purposes)

\[
B = \frac{1}{IJ} \sum_{j=1}^{J} \sum_{i=1}^{I} (P^i_j - O^i_j)
\]

Bias error

\[
E = \frac{1}{IJ} \sum_{j=1}^{J} \sum_{i=1}^{I} |P^i_j - O^i_j|
\]

Gross error

\[
RMSE = \left( \frac{1}{IJ} \sum_{j=1}^{J} \sum_{i=1}^{I} (P^i_j - O^i_j)^2 \right)^{1/2}
\]

Root mean square error

\[
IOA = 1 - \frac{IJ \cdot RMSE^2}{\sum_{j=1}^{J} \sum_{i=1}^{I} \left( |P^i_j - M_o| + |O^i_j - M_o| \right)^2}
\]

Index of agreement
• Most-relevant surface variables for AQ modelling
• Benchmarks not considered explicitly
• Comparative (relative) analysis

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Temperature</th>
<th>Wind speed</th>
<th>Wind direction</th>
<th>Humidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE</td>
<td>-</td>
<td>≤ 2 m/s</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>≤ ± 0.5 K</td>
<td>≤ ± 0.5 m/s</td>
<td>≤ ± 10º</td>
<td>≤ ± 1 g/kg</td>
</tr>
<tr>
<td>E</td>
<td>≤ 2 K</td>
<td>-</td>
<td>≤ 30º</td>
<td>≤ 2 g/kg</td>
</tr>
<tr>
<td>IOA</td>
<td>≥ 0.8</td>
<td>≥ 0.6</td>
<td>-</td>
<td>≥ 0.6</td>
</tr>
</tbody>
</table>

Statistic-variable relations and reference values
(for annual runs computed from 24-h averages)
- Upper-air measurements used for PBL height evaluation
- “Observed value” estimated with Bulk Richardson number
• Comparison for combined PBL-LS models

Winter

00 UTC

12 UTC

Summer
**Sensitivity runs**

- Main physics options and other user-defined important parameters in WRF v.2.2
- Base case from previous experiences (MM5)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planetary Boundary Layer (PBL)</td>
<td>Medium Range Forecast Model (MRF) PBL – MM5 surface layer scheme</td>
</tr>
<tr>
<td>(PBL) scheme – Surface layer scheme</td>
<td>Yonsei University (YSU) PBL – Eta surface layer scheme</td>
</tr>
<tr>
<td></td>
<td>Mellor-Yamada-Janjic (MYJ) PBL – MM5 surface layer scheme</td>
</tr>
<tr>
<td>Microphysics</td>
<td>WSM5 scheme</td>
</tr>
<tr>
<td></td>
<td>Purdue Lin scheme</td>
</tr>
<tr>
<td></td>
<td>WSM6 scheme</td>
</tr>
<tr>
<td></td>
<td>Eta Grid-scale Cloud and Precipitation (2001) scheme</td>
</tr>
<tr>
<td>Land-Surface Model</td>
<td>5-layer thermal diffusion</td>
</tr>
<tr>
<td></td>
<td>Noah LSM</td>
</tr>
<tr>
<td></td>
<td>Rapid Update Cycle (RUC) Model LSM</td>
</tr>
</tbody>
</table>

Sensitivity runs 1/2
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Surface Temperature (SST)</td>
<td>Time-varying</td>
</tr>
<tr>
<td></td>
<td>Constant</td>
</tr>
<tr>
<td>Radiation scheme</td>
<td></td>
</tr>
<tr>
<td>Longwave</td>
<td>Rapid Radiative Transfer Model (RRTM)</td>
</tr>
<tr>
<td></td>
<td>Eta Geophysical Fluid Dynamics Laboratory (GFDL)</td>
</tr>
<tr>
<td></td>
<td>Community Atmospheric Model (CAM)</td>
</tr>
<tr>
<td>Shortwave</td>
<td>Eta Geophysical Fluid Dynamics Laboratory (GFDL)</td>
</tr>
<tr>
<td></td>
<td>MM5 (Dudhia) Shortwave</td>
</tr>
<tr>
<td></td>
<td>Goddard</td>
</tr>
<tr>
<td>Four-Dimensional Data Assimilation (FDDA)</td>
<td>Analysis (grid)</td>
</tr>
<tr>
<td>Nudging</td>
<td>Stations (observational)</td>
</tr>
<tr>
<td>Without nudging</td>
<td>Both (grid + observational)</td>
</tr>
</tbody>
</table>

Sensitivity runs 2/2
3. RESULTS

- **PBL scheme**

- **Yonsei University (YSU) PBL**
  - Best performance for T in every network
  - T underestimated for SMI, overestimated for EMEP and PMI
  - Overall IOA ~ 0.9, gross error < 2.5 K
  - Best results for wind speed (IOA ~ 0.7)
  - Some seasonal differences
  - No appreciable effect on wind direction
  - PBLH not very sensitive on PBL scheme (YSU slightly better)

_details_
Land-surface model

• 5-layer thermal diffusion (Dudhia, 1996)
  • Similar performance to Noah LSM for T (slightly lower IOA)
  • Best results for wind speed predictions $B=0.2 \text{ m/s}, \text{IOA}=0.65$ and direction $B < 18^\circ$
  • Sensibly better performance for SMI stations
  • Seasonal differences; T performs better in summer, wind is better predicted in winter
  • Bigger influence in PBLH than PBL schemes (RUC scheme performs slightly better)
Microphysics

- **WSM6 scheme**
  - Best B results for T (no differences for E and IOA)
  - Best B results for wind speed (no differences for RMSE and IOA)
  - Best performance for SMI stations
  - Not very influential on temperature and wind
  - Computationally expensive (40% more than WSM5)
Sea surface temperature

- SST values from global NCEP SST analysis (daily, 0.5° resolution)
- During the selected periods, no significant difference was found from variable SST values overall (Vs fixed SST)
- Clear improvement of the IOA for temperature in PMI stations (predominantly by the coast)
- Expected to have a stronger impact on annual simulations
Radiation: longwave

- Eta Geophysical Fluid Dynamics Laboratory (GFDL)
  - Sensitive parameter for T prediction
  - Underprediction of T
  - RRTM provides better results for some stations (SMI) / statistics
  - Overall better performance except for wind direction B (RRTM). Both schemes provided much better results for SMI than for PMI
  - Seasonal differences; T performs better in summer, wind is better predicted in winter
Radiation: shortwave

- MM5 shortwave scheme (Dudhia, 1989)
  - Slightly better than GFDL
  - Not uniform behaviour in time/space
  - Goddard scheme provided the best results for EMEP network but the worst overall performance
**Four-Dimensional Data Assimilation (nudging)**

- FDDA grid + observations
  
  - Combined nudging towards grid and observations provided the best results for most of the statistics / locations
  
  - However, FDDA grid provided better results for wind speed RMSE
  
  - The lower B values for wind directions were obtained when no nudging was applied
Best case summary

- Similar results for temperature
- Best results for all wind speed statistics for all the stations
- Better results for wind direction in some other experiments

<table>
<thead>
<tr>
<th>Variable</th>
<th>Statistic</th>
<th>SMI</th>
<th>EMEP</th>
<th>PMI</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>T (K)</td>
<td>BE</td>
<td>-0.82</td>
<td>0.70</td>
<td>-0.30</td>
<td>-0.33</td>
</tr>
<tr>
<td></td>
<td>GE</td>
<td>2.24</td>
<td>2.89</td>
<td>2.12</td>
<td>2.38</td>
</tr>
<tr>
<td></td>
<td>IOA</td>
<td>0.91</td>
<td>0.83</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>WS (m/s)</td>
<td>BE</td>
<td>-0.10</td>
<td>-0.02</td>
<td>0.09</td>
<td>-0.04</td>
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<tr>
<td></td>
<td>RMSE</td>
<td>2.35</td>
<td>2.86</td>
<td>1.98</td>
<td>2.42</td>
</tr>
<tr>
<td></td>
<td>IOA</td>
<td>0.65</td>
<td>0.76</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>GE</td>
<td>59.97</td>
<td>59.69</td>
<td>65.57</td>
<td>63.17</td>
</tr>
</tbody>
</table>

- Worse performance for PBLH than other combinations (underprediction)
4. CONCLUSIONS

- Usually no single scheme performs better than others for all the locations / periods
- Promising results overall
- Poorer results for wind direction, especially in Portugal
- Model performance seems to be systematically worse for the EMEP network
- PBLH performance hard to evaluate through routinely soundings
- The “best case” actually performs better
- FDDA (grid+observations) to be applied in all domains
5. NEXT STEPS

• Analyze PBLH sensitivity to radiation schemes

• Incorporation of humidity observations in the analysis

• Refinement of IC/BC through WRF-VAR (V 3.0)

• Full performance evaluation (6 years)

• Optimal setup for particular regions / subdomains

• Influence of meteorological variability on future-year annual air quality simulations
Thank you for your attention!

Any question / suggestion?