EFFECTS OF NOCTURNAL THERMAL CIRCULATION AND BOUNDARY LAYER STRUCTURE ON POLLUTANT DISPERSION IN COMPLEX TERRAIN AREAS

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Mesoscale and Microscale Atmospheric Modelling and Research

HARMO 13. 13th International Conference on Harmonization within Atmospheric Dispersion Modelling for Regulatori Purposes

Paris, France 1-4 June 2010.
Introduction

- Stable boundary layer present a challenge for mesoscale models (MM5, WRF).

- Errors in meteorological forecasts have consequences for atmospheric transport and dispersion predictions and for other air quality applications.

- Difficulties in a complex terrain area with heterogeneities in flow and thermal structures.

- Mesoscale systems and local effects become important in nocturnal SBL (forced by night-time temperature gradients): mountain and valley breeze regimes, including drainage and down-valley winds (Whiteman, 2000).
Aims of the study

- Check MM5 and WRF simulations in a complex terrain in the nocturnal stable boundary layer with available data from the a 100m height meteorological tower.

- Examine the performance of different PBL schemes in MM5 and WRF to simulate the mesoscale systems at night time: drainage winds, down valley winds, low level jets and turbulence episodes.

- Couple meteorological simulations with photochemical model CMAQ under different PBL schemes

- Analyze distribution patterns of air pollutant concentrations placing different virtual sources at interesting areas.
Overview

1. Introduction
   Aims of the study

2. Experimental design and model description
   Area and data description
   Meteorological characteristics of the simulation period
   Numerical model configuration

3. Meteorological results and evaluation
   Wind field at 10m
   Vertical temperature gradient
   CIBA tower data
   Temporal and vertical variations within the BL

4. Distribution of pollutants
   Virtual source placements
   $SO_2$ field distribution at P1: CIBA
   Wind speed at steep terrain area
   $SO_2$ field distribution at P2: steep terrain area
   $SO_2$ distribution differences

5. Conclusions
2. EXPERIMENTAL DESIGN AND MODEL DESCRIPTION

Northern Castillian plateau, Iberian Peninsula, Spain
Mountains 2000 m ASL
Duero River

Montes Torozos 840 m ASL
CIBA meteorological tower: 100m height

Database at different heights:
- Wind speed at: 2.2, 9.6, 20.5, 34.6, 74.6 and 98.6 m A.G.L.
- Wind direction at: 2.2, 9.6, 20.5, 34.6, 74.6 and 98.6 m A.G.L.
- Temperature at: 2.3, 10.5, 20.5, 35.5 and 97.5 m A.G.L.
- Humidity at: 10 and 97 m A.G.L.
- Turbulent wind and temperature fluctuations with sonic anemometers: 5.6, 19.6, 49.6 and 96.6 m A.G.L.
Meteorological characteristics of the simulation period

Simulation period: 12th - 15th January 2003
Night between 14-15th January 2003

- High surface pressure: 1025 hPa
- Stability at height
- Little humidity

Clear skies and weak winds

Mesoscale systems:
- Valley and drainage winds
- Low level jets
- Intermittent turbulent episodes
Numerical model configuration

Two meteorological models:
- PSU/NCAR mesoscale model **MM5 v3.7**
- Weather Research and Forecasting model **WRF-ARW v3.1.1**

Two nested domains (one way nesting):

<table>
<thead>
<tr>
<th>Outer domain – D1</th>
<th>Inner domain – D2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Km horizontal resolution</td>
<td>1 Km horizontal resolution</td>
</tr>
<tr>
<td>Initial boundary conditions from ECMWF</td>
<td>One way nesting</td>
</tr>
<tr>
<td>150x100 grid cells</td>
<td>161x101 grid cells</td>
</tr>
<tr>
<td>24 h long → 1200 UTC 14th - 1200 UTC 15th January</td>
<td>12 h long → 1800 UTC 14th– 0600 UTC 15th January</td>
</tr>
</tbody>
</table>

86 vertical sigma levels
2m close to the surface
First 100 meters in 23 first levels

Domain top at 100hPa
## Numerical model configuration

### 3 sets of model experiments:

- MM5 with ETA PBL scheme → **MM5** Experiment 1
- WRF with MYJ PBL scheme → **WRF-MYJ** Experiment 2
- WRF with QNSE PBL scheme → **WRF-QNSE** Experiment 3

<table>
<thead>
<tr>
<th>Physics</th>
<th>MM5</th>
<th>WRF-MYJ</th>
<th>WRF-QNSE</th>
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<tbody>
<tr>
<td>Microphysics</td>
<td>Reisnel graupel (Reisner2)</td>
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<td>New Thompson</td>
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<tr>
<td>Atmospheric Radiation</td>
<td>Cumulus radiation scheme</td>
<td>Short wave: Dudhia</td>
<td>Short wave: Dudhia</td>
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<td></td>
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<td>Long wave: RRTM</td>
<td>Long wave: RRTM</td>
</tr>
<tr>
<td>Surface Layer</td>
<td>ETA similarity (Monin Obukhov)</td>
<td>ETA similarity (Monin Obukhov)</td>
<td>ETA similarity (Monin Obukhov)</td>
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<td>Land Surface</td>
<td>Noah Land-Surface Model</td>
<td>Noah Land-Surface Model</td>
<td>Noah Land-Surface Model</td>
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<tr>
<td>Planetary Boundary Layer</td>
<td><strong>ETA scheme</strong> $\text{TKE}_{\text{MIN}} = 0.2 \text{ m}^2\text{s}^{-2}$</td>
<td><strong>Mellor-Yamada-Janjic</strong> (MYJ)-ETA scheme $\text{TKE}_{\text{MIN}} = 0.1 \text{ m}^2\text{s}^{-2}$</td>
<td><strong>Quasi-Normal Scale Elimination (QNSE)</strong> $\text{TKE}_{\text{MIN}} = 0.01 \text{ m}^2\text{s}^{-2}$</td>
</tr>
<tr>
<td>Cumulus</td>
<td>Grell</td>
<td>Grell 3D</td>
<td>Grell 3D</td>
</tr>
</tbody>
</table>

Photochemical model **CMAQ v4.6** with virtual industry source of emissions
No initial boundary conditions are considered
Results and evaluation

• Wind field at 10m

• Vertical temperature gradient

• CIBA tower data

• Temporal and vertical variations within the BL
2300 UTC: stronger winds in steep terrain areas → drainage winds

0400 UTC: QNSE experiment forecasts the strongest winds
Big differences in temperature gradient between models

QNSE forecasts the highest gradients at CIBA plateau and at steep areas
CIBA tower data

Temperature at different levels
   Cold air at surface

Wind speed
   Jet at the end of the night

Turbulent variables
   TKE ~ 0
   Heat flux ~ 0
   $U^* \sim 0$

Turbulence at the end of the night due to wind shear at CIBA tower
Temporal and vertical variations within the BL

Wind speed and Potential temperature profiles

Wind speed CIBA 2300 UTC

- CIBA MAST
- MM5
- WRF-MYJ
- WRF-QNSE

Wind speed CIBA 0100 UTC

- CIBA MAST
- MM5
- WRF-MYJ
- WRF-QNSE

Wind speed CIBA 0400 UTC

- CIBA MAST
- MM5
- WRF-MYJ
- WRF-QNSE

Potential Temperature CIBA 2300 UTC

- CIBA
- MM5
- WRF-MYJ
- WRF-QNSE

Potential Temperature CIBA 0100 UTC

- CIBA
- MM5
- WRF-MYJ
- WRF-QNSE

Potential Temperature CIBA 0400 UTC

- CIBA
- MM5
- WRF-MYJ
- WRF-QNSE
Temporal and vertical variations within the BL

Wind direction

TKE
### Temporal and vertical variations within the BL

Statistics values at 6 vertical levels of 3 model experiments

<table>
<thead>
<tr>
<th>Height</th>
<th>Statistic</th>
<th>Temperature (°K)</th>
<th>Wind speed (ms⁻¹)</th>
<th>Wind direction (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>MM5 Exp. 1</td>
<td>WRF-MYJ Exp. 2</td>
<td>WRF-QNSE Exp. 3</td>
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<tr>
<td>2m</td>
<td>MB</td>
<td>3.14</td>
<td>-0.62</td>
<td>0.43</td>
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<td>MAGE</td>
<td>3.14</td>
<td>0.64</td>
<td><strong>0.55</strong></td>
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<tr>
<td></td>
<td>RMSE</td>
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<td>RMSE</td>
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<td>0.48</td>
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<td>MAGE</td>
<td>0.36</td>
<td>0.70</td>
<td>0.70</td>
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<tr>
<td></td>
<td>RMSE</td>
<td>0.56</td>
<td>0.84</td>
<td>0.81</td>
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<tr>
<td>35m</td>
<td>MB</td>
<td>0.30</td>
<td>0.46</td>
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<tr>
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<td>MAGE</td>
<td>0.42</td>
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<tr>
<td></td>
<td>RMSE</td>
<td>0.84</td>
<td>0.86</td>
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<tr>
<td>98m</td>
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<td>0.52</td>
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<tr>
<td></td>
<td>MAGE</td>
<td>0.84</td>
<td><strong>0.48</strong></td>
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<tr>
<td></td>
<td>RMSE</td>
<td>0.92</td>
<td>0.61</td>
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<td>98m</td>
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<tr>
<td></td>
<td>RMSE</td>
<td>1.15</td>
<td><strong>0.64</strong></td>
<td>1.00</td>
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</tbody>
</table>

Source: EPA Draft Guidance
Distribution of pollutants

- Virtual source placements
- $SO_2$ field distribution at P1: CIBA
- Wind speed at steep terrain area
- $SO_2$ field distribution at P2: steep terrain area
- $SO_2$ distribution differences
Virtual source placement

Virtual industry as an emission source

SO$_2$ emission rate 2537 t·year$^{-1}$

SO$_2$ immission results

- **P1**: CIBA - 20m above ground level

- **P2**: Drainage wind - 10 m above ground level
SO₂ field distribution at P1: CIBA

SO₂ evolution during night time

4. DISTRIBUTION OF POLLUTANTS
SO$_2$ field distribution at P1: CIBA
SO$_2$ field distribution at P1: CIBA
Wind speed at steep terrain area
Wind speed at steep terrain area

Profiles at P2

Wind speed

WRF \(\rightarrow\) Strong LLJ

Potential temperature

WRF \(\rightarrow\) surface cooling
Wind speed at steep terrain area
4. DISTRIBUTION OF POLLUTANTS

Wind speed at steep terrain area

23:00 UTC

01:00 UTC

04:00 UTC

MM5

MYJ

QNSE
4. DISTRIBUTION OF POLLUTANTS

Trajectories of a parcel over P2

- MM5
- WRF-MYJ
- WRF-QNSE

Big differences at 20 meters AGL

WRF parcels move further dragged by drainage winds

Wind speed at steep terrain area

10m AGL

20m AGL
4. DISTRIBUTION OF POLLUTANTS

SO$_2$ field distribution at P2
SO\textsubscript{2} field distribution at P2

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig.png}
\caption{SO\textsubscript{2} field distribution at P2}
\end{figure}
SO$_2$ field distribution at P2
4. DISTRIBUTION OF POLLUTANTS

SO$_2$ field distribution at P2
SO₂ distribution differences

Point T1: 5 Km far from source of pollutants
Point T2: 9 Km far from source of pollutants following WRF trajectories
Point T3: 11 Km far from source of pollutants following WRF trajectories

Higher SO₂ concentrations in MM5 model → dilution of air pollution is inhibited by low wind speeds

No many differences in vertical dispersion
Two meteorological mesoscale models have been run using different PBL schemes over Duero basin under very stable conditions.

WRF provides more realistic meteorological forecast in lower atmospheric region.

MYJ experiment gives better statistical results, mostly for wind speed throughout all night.

A development of a LLJ was fairly well captured by WRF-QNSE scheme at CIBA plateau.

QNSE experiment forecasts strong drainage winds mostly at steep terrain areas.

WRF experiments forecast more effective transport than MM5 experiments in 2 analyzed scenarios: at CIBA and an area near a slope.
THANK YOU FOR YOUR ATTENTION

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