THE IMPACT OF TOPOGRAPHY AND SEA SURFACE TEMPERATURE ON THE EVOLUTION OF THE URBAN BOUNDARY LAYER

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Outline

- Scope and objectives
- The mesoscale model MEMO
- Use of remote-sensing data
- Quantification of the anthropogenic heat flux
- Athens case and model setups
- Sensitivity to topography
- Conclusions
Scope and objectives

- In what extend is the BL structure accurately simulated by a mesoscale model?
- ...particularly in the case of very complex topography?
- How much improvement is expected from better surface characterisations / parameterisations?
- Are terrain features the dominating factor?
The mesoscale Model MEMO

- Non-hydrostatic prognostic mesoscale model
- Radiation physics, layered soil model
- Used as a driver for the chemical dispersion model MARS-aero with an option for two-way coupling (Halmer et al, 2012)
- Core model of the LHTEE Operational Air Quality Management System (Cyprus & Thessaloniki)
- Optional: two-way coupling with the CFD model MIMO
Non-hydrostatic prognostic mesoscale model

Radiation physics, layered soil model

Used as a driver for the chemical dispersion model MARS-aero with an option for two-way coupling (Halmer et al, 2012)

Core model of the LHTEE Operational Air Quality Management System (Cyprus & Thessaloniki)

Optional: two-way coupling with the CFD model MIMO

Surface scheme with 11 land use classes (Nitis et al, 2011)

Surface parameters: albedo, aerodynamic roughness dynamically updated from satellite data

Scheme from assimilating anthropogenic heat flux

Assimilation of LST & SST data
MEMO v.8 : incorporating forcings

MMN New Version

SPMS
- Land use
- Orography
- Roughness Length
- Albedo
- SST + LST

One Way Coupling
- Hourly SST Data

Meteorological Model

Anthropogenic Heat
- Surface Energy Budget
- Satellite Data
- In Situ Data

Web-GIS Application

MMM New Version Evaluation
Quantification of the urban anthropogenic heat flux

1. In situ measurement
   - Field measurements of the energy fluxes
   - Estimate the anthropogenic heat flux using the surface energy balance equation
   - Carefully selected observation sites, not possible to obtain the flux distribution over large region for study of UHI and urban vs rural energy budget.

2. Inventory approach
   - Bottom-up method, counting energy consumption objects and analyzing their spatial distribution
   - Can be used for the spatial-temporal disaggregation of top-down estimates
   - Constraints of resources and feasibility limit spatial resolution
   - Assumption: energy consumption is equivalent to anthropogenic sensible heat emissions

3. Remote-sensing measurement
   - Can obtain the flux distribution as “continuous” fields with high spatial resolution
   - It is feasible to combine with ground-based meteorological data to quantify the urban surface biophysical parameters, then estimate the anthropogenic heat flux with the method of energy budget closure

\[ Q^* + Q_f = LE + H + G \]

- Drawback: small uncertainties can lead to large relative error, esp. in rural areas
Athens area case study

Evaluate:

- Performance of the new urban scheme, including high-resolution SST and LST
- The effect of anthropogenic heat flux
- Sensitivity of BLH to the surface scheme
- Sensitivity of BLH to input topography

Selected study periods:

- June 23rd – 24th 2002
- June 29th – 30th 2002
- September 19th – 20th 2002

Periods of prevailing anticyclonic conditions were selected, in order to focus on effects of local circulation.
### Athens area case study

#### Model setup and surface schemes

<table>
<thead>
<tr>
<th>Model setup</th>
<th>LU</th>
<th>Surface parameters</th>
<th>Sea surface temperature</th>
<th>Anthropogenic heat flux</th>
<th>Topography</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>7 classes</td>
<td>Literature</td>
<td>Constant</td>
<td>No</td>
<td>Real</td>
</tr>
<tr>
<td>B1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B4</td>
<td>11 classes</td>
<td>Remote-sensing products</td>
<td>Varying (from satellite data)</td>
<td>Derived from satellite products</td>
<td></td>
</tr>
<tr>
<td>B4f</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flat</td>
</tr>
</tbody>
</table>

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**Athens area case study**

<table>
<thead>
<tr>
<th>Grid</th>
<th>No of cells</th>
<th>Cell dimensions</th>
<th>Total grid extent</th>
<th>Initial/Boundary Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100×100×25</td>
<td>3x3 km²</td>
<td>300×300 km²</td>
<td>Radiosondes, Satellite</td>
</tr>
<tr>
<td>B</td>
<td>100×100×25</td>
<td>1x1 km²</td>
<td>100×100 km²</td>
<td>Obtained from the coarse grid</td>
</tr>
</tbody>
</table>

- **Elevation**: SRTM / 90m
- **Land use**: Corine Land Cover 2000 (44 types → 11 types)
- **Surface albedo**: MODIS (MCD43B3) on a 1km resolution 16-day dataset
- **Aerodynamic roughness**: NOAA AVHRR (Gupta et al., 2002) + LU-based (urban)
- **LST, SST**: satellite products
Anthropogenic heat flux (B4, B4f setups)

- Landsat ETM+
- All required parameters for flux closure from the above source
- $Q_f$ shows high-frequency spatial variation in both areas
- Horizontal resolution of 30m
  - How to best accommodate in LSM?
- Daily flux allocate to hourly bins using an average traffic + heating profile (even in summer periods) for Paris
- GAA: coastal areas, Piraeus port
Performance evaluation: d-index

GAA

Wind Speed

PERIOD-1 | PERIOD-2 | PERIOD-3
---|---|---
0.534 | 0.592 | 0.617

Wind Direction

PERIOD-1 | PERIOD-2 | PERIOD-3
---|---|---
0.607 | 0.838 | 0.799

Temperature

PERIOD-1 | PERIOD-2 | PERIOD-3
---|---|---
0.737 | 0.835 | 0.9245

GPA

Wind Speed

PERIOD-1 | PERIOD-2 | PERIOD-3
---|---|---
0.495 | 0.507 | 0.499

Wind Direction

PERIOD-1 | PERIOD-2 | PERIOD-3
---|---|---
0.772 | 0.843 | 0.868

Temperature

PERIOD-1 | PERIOD-2 | PERIOD-3
---|---|---
0.923 | 0.930 | 0.926

18th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
• Median of the diurnal temperature range for the entire calculation period (left) and for June 29th 2002 (right).
• Strong temperature difference of about 3 K between the urban and the surrounding rural areas.
• Temperature maxima consistently located in the central and south-central parts of the urban area.
• Results for the 29 June also indicate a systematic cooling in the eastern part of the Attica peninsula. The industrialized Elefsis bay area exceeds the domain average.
Vertical BL structure: A1 and B1 setups

- Convergence of the sea breeze cell and a downslope flow over the urban area.
- B1 setup: two distinct convergence areas along the shore and near the center of the urban area. TKE production cell in the north-eastern part of the domain (Evoikos gulf) is enhanced.
Horizontal BL structure: A1 and B1 setups

Spatial distribution of the simulated mixing height for 20/9/2020 12:00 LST calculated using the A1 (left) and B1 (right) model configurations

- Well-developed daytime BL structure, consistent with weak anticyclonic conditions.
- Horizontal features attributed to orographical elements or water bodies
- The 7-class A1 scheme reduces the BLH over the Athens urban area
- Some shifts of the plume boundaries are caused by the low-level wind flow.
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- The 7-class A1 scheme reduces the BLH over the Athens urban area
- Some shifts of the plume boundaries are caused by the low-level wind flow.
The urban plume is more pronounced compared to A1 and B1 setups

Stronger differentiation of the areas characterised by urban LU

In the absence of orography (B4f), the northern maximum almost disappears, the urban BL is extended northward

Some TKE production is still observed over the islands of the Saronic
Horizontal BL structure: B4 and B4f setups

Spatial distribution of the BLH for 20/9/2020 12:00 LST (left) and 19/9/2020 12:00 LST (right) calculated using the B4 and B4f model configurations, respectively

• The BL near the southern coast of the Athens-Piraeus urban areas is enhanced, spatially correlated with an increase in heat flux in this scheme (Nitis, 2016).
• Increase of structure over the sea areas \(\leftrightarrow\) time-dependent SST
• B4f: the urban plume remains but the effects of the mountain on the north of the domain are no longer visible. Isolated plumes over small conurbations.
• The elimination of orographic influences has revealed a strong dependence of the BLH structure on the surface properties
Diurnal BLH evolution

- B4f significantly alters wind field, only qualitative trends can be extracted for a single point
- B1 increases BLH, esp. over denser urban areas
- Much simpler diurnal structure over mountain areas
Conclusions

- The introduction of the new surface module improved the model performance in an urban case with complex topography, at least under anticyclonic conditions.
- Both schemes predict a well-developed UABL during these conditions.
- The new scheme amplifies the differentiation of urban areas from the surrounding areas.
- Horizontal structure comes from LU and soil thermophysical parameters, non-urban flux partitioning has little effect.
- Topography’s role is secondary in this case.
Ongoing work

- [Near-]Operational evaluation (Cyprus, Thessaloniki)
- Further refinement of the residual flux calculation scheme → quantification of uncertainties
- Evaluation of TKE profiles based on measurements
  
- Further calibration of the storage model in the urban canopy
- Evaluation of the use of land use data of even higher resolution and detailed classification for urban areas
Acknowledgments

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