AUT/
LHTEE

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

George Tsegas[1], Theodoros Nitis[2], Eleftherios Chourdakis[1] and Nicolas Moussiopoulos[1]

[1] Laboratory of Environmental Quality and Geospatial Applications, Department of Marine Sciences, University of the Aegean, GR-81100, Greece

[2] Laboratory of Heat Transfer and Environmental Engineering, Aristotle University, Thessaloniki, GR-54124, Greece

AUT/
LHTEE

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

AUT/
LHTEE

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?

AUT/
LHTEE

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

AUT/
LHTEE

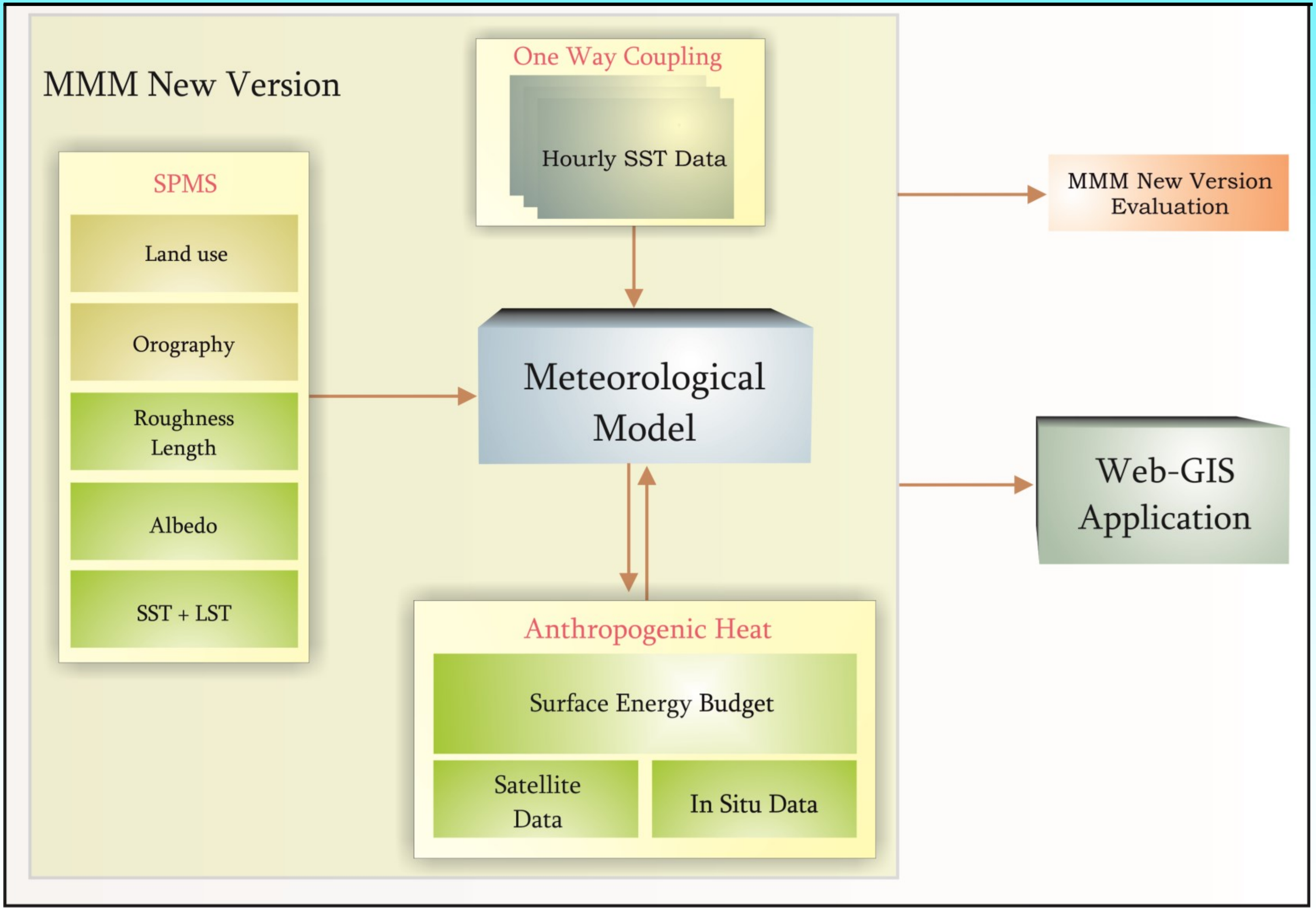
The mesoscale Model MEMO

- 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

- 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

AUT/
LHTEE



Quantification of the urban anthropogenic heat flux

AUT/ LHTEE

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

AUT/
LHTEE

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.

AUT/
LHTEE

Athens area case study

Model setup and surface schemes

<table>
<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>
<tr><td>A1</td><td>7 classes</td><td>Literature</td><td rowspan="2">Constant</td><td rowspan="2">No</td><td rowspan="3">Real</td></tr>
<tr><td>B1</td><td rowspan="3">11 classes</td><td rowspan="3">Remote-sensing products</td></tr>
<tr><td>B4</td><td rowspan="2">Varying (from satellite data)</td><td rowspan="2">Derived from satellite products</td></tr>
<tr><td>B4f</td><td>Flat</td></tr>
</table>

Selected study periods:

June 23rd – 24th 2002

June 29th – 30th 2002

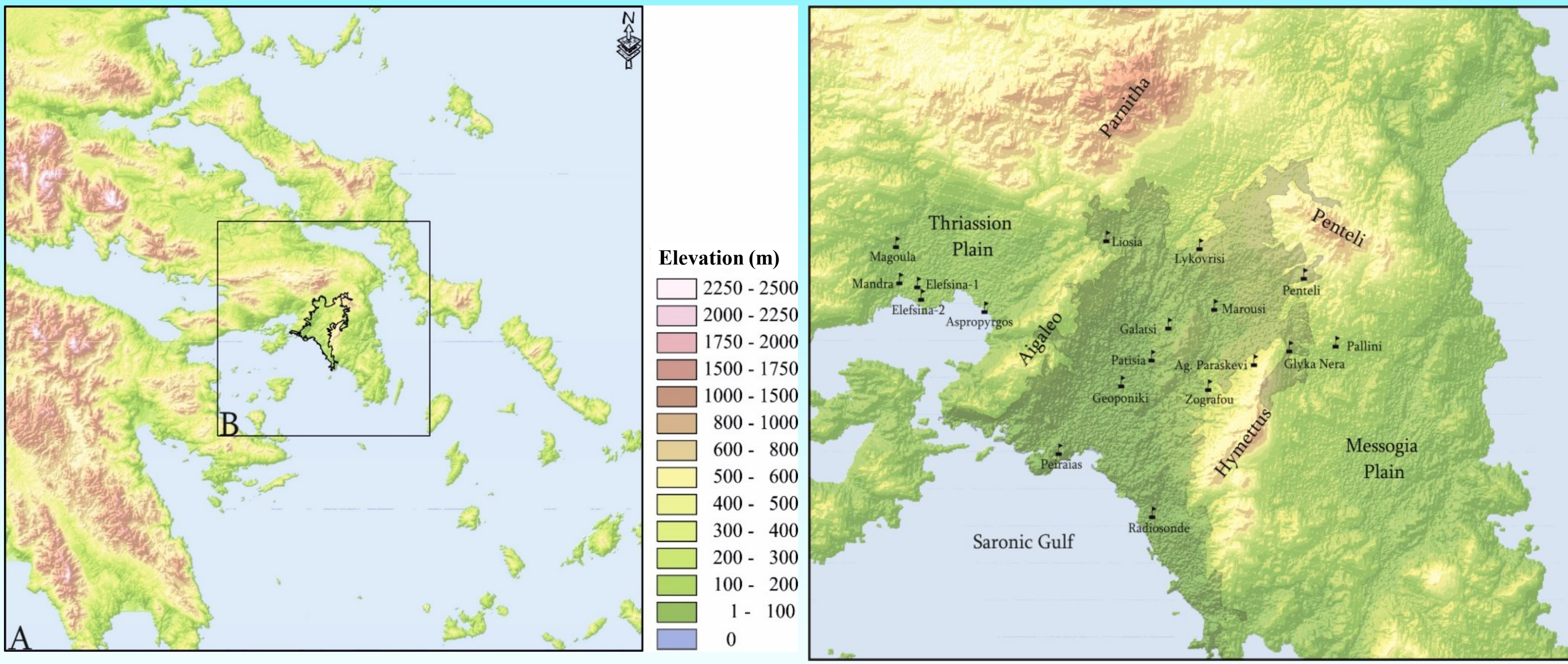
September 19th – 20th 2002

Periods of prevailing anticyclonic conditions were selected, in order to focus on effects of local circulation.

AUT/
LHTEE

Athens area case study

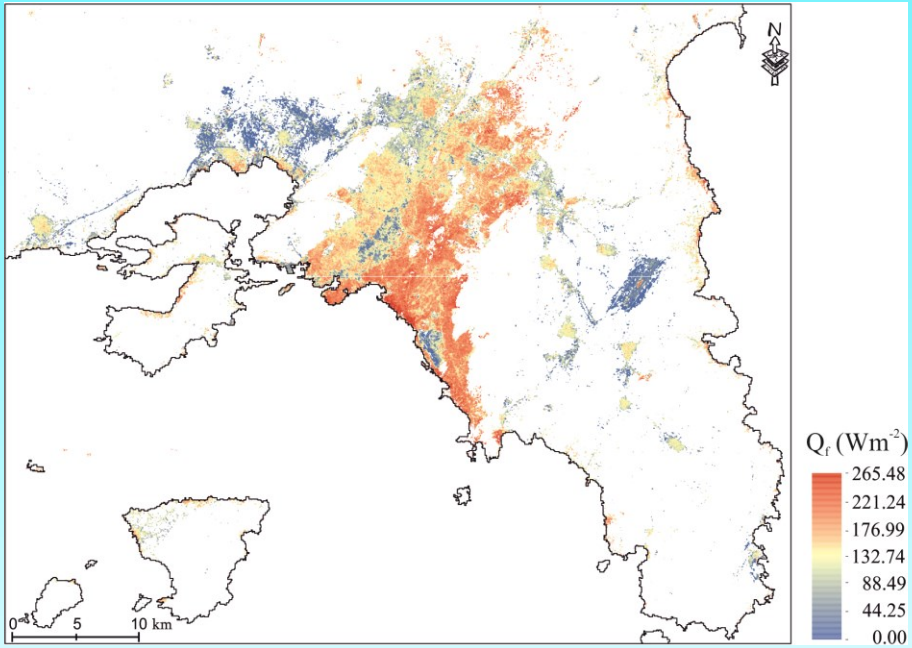
Grid	No of cells	Cell dimensions	Total grid extent	Initial/Boundary Conditions
A	100×100×25	3×3 km²	300×300 km²	Radiosondes, Satellite
B	100×100×25	1×1 km²	100×100 km²	Obtained from the coarse grid



- **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)

AUT/
LHTEE

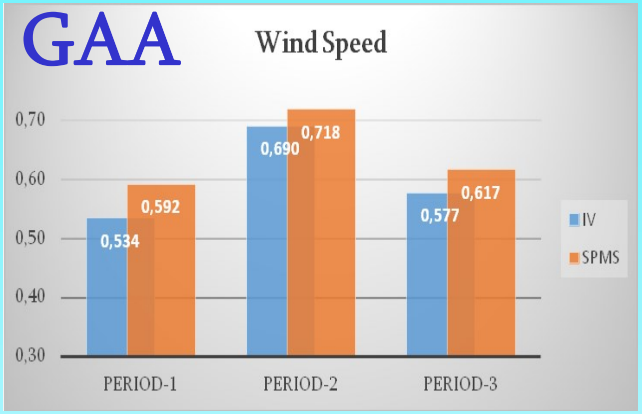


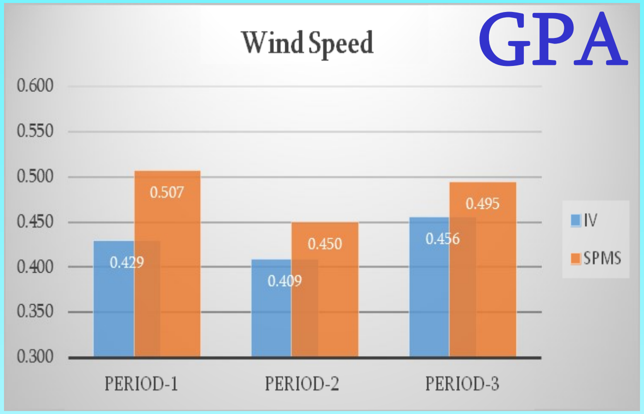
- Landsat ETM+
- All required parameters for flux closure from the above source
- Q_f shows high-frequency spatial variation in both areas
- Horizontal resolution of 30m

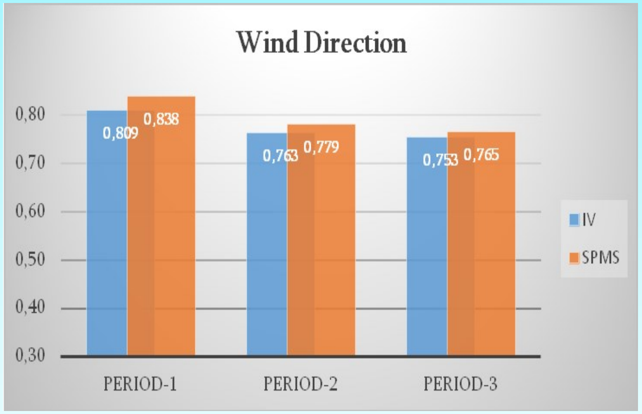
  → How to best accommodate in LSM?
- Daily flux allocate to hourly bins using an average traffic + heating profile (even in summer periods) for Paris
- GAA: coastal areas, Piraeus port

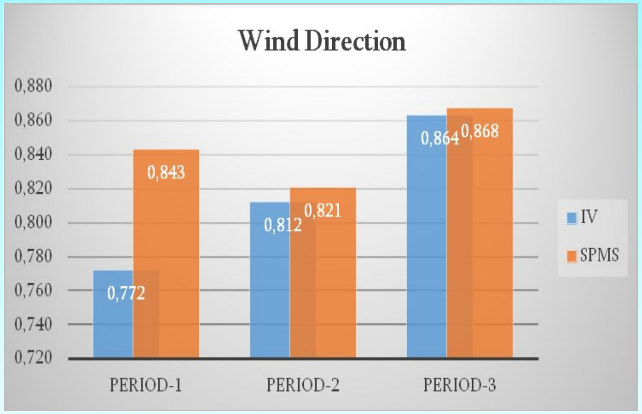
Performance evaluation : d-index

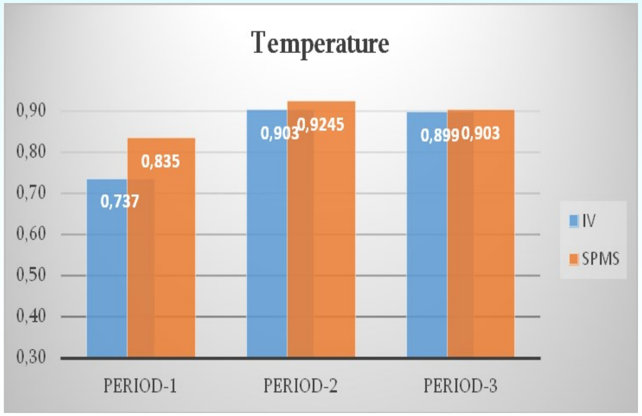
AUT/
LHTEE

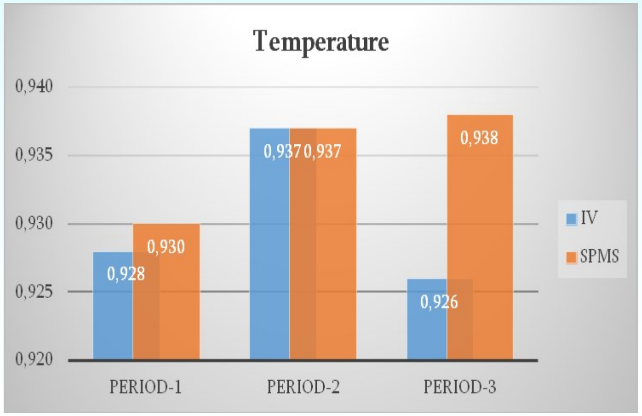




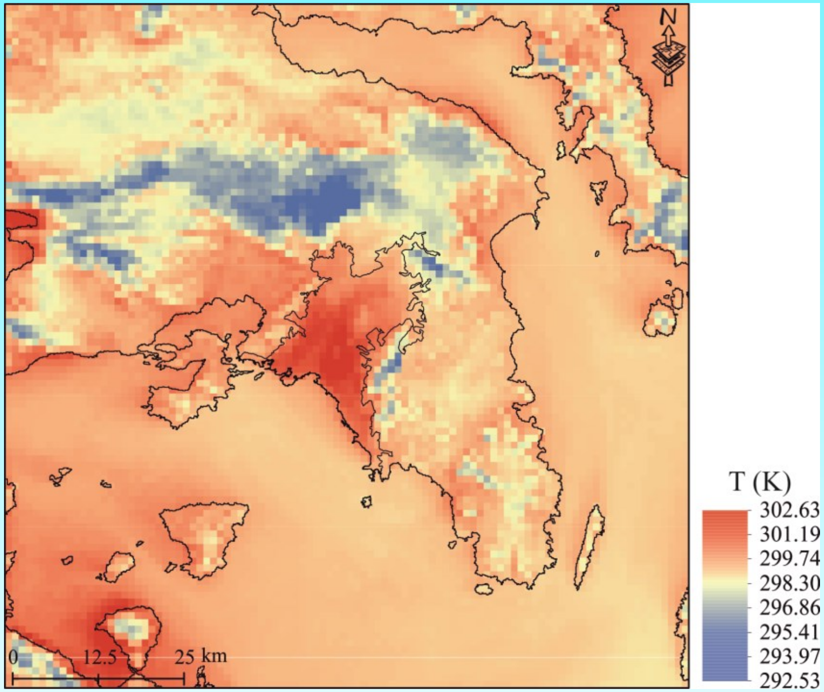


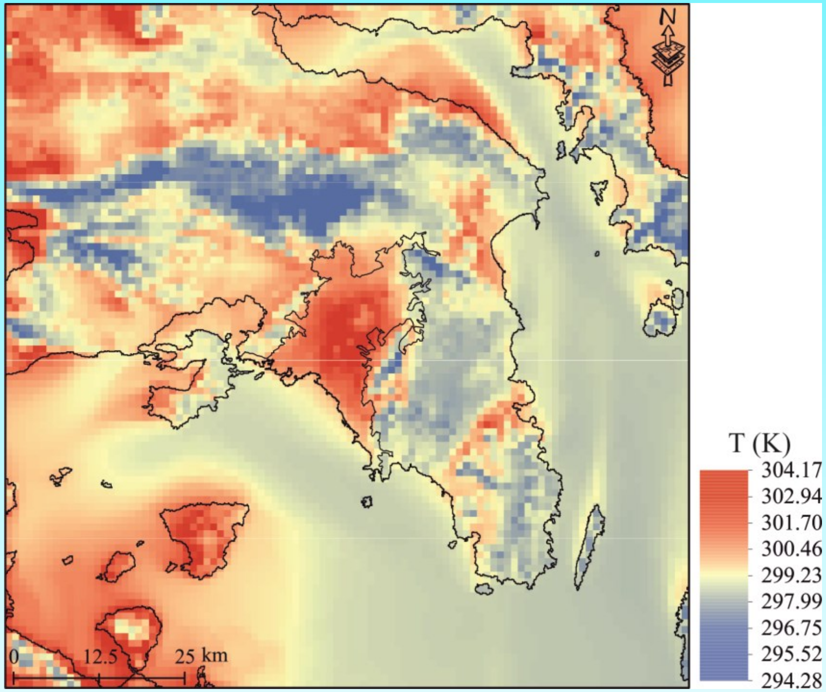






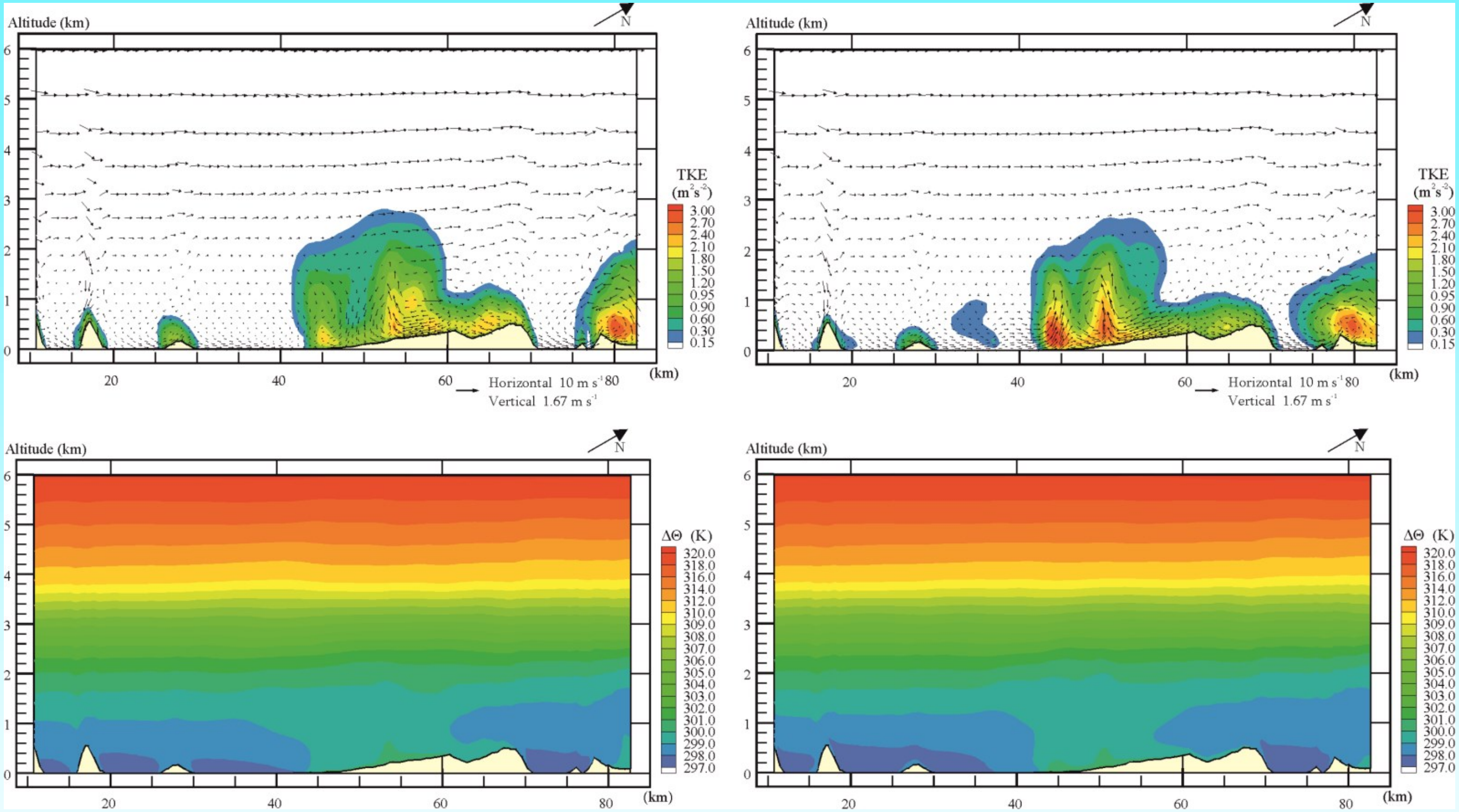
Calculated temperature fields (B4)





- 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.

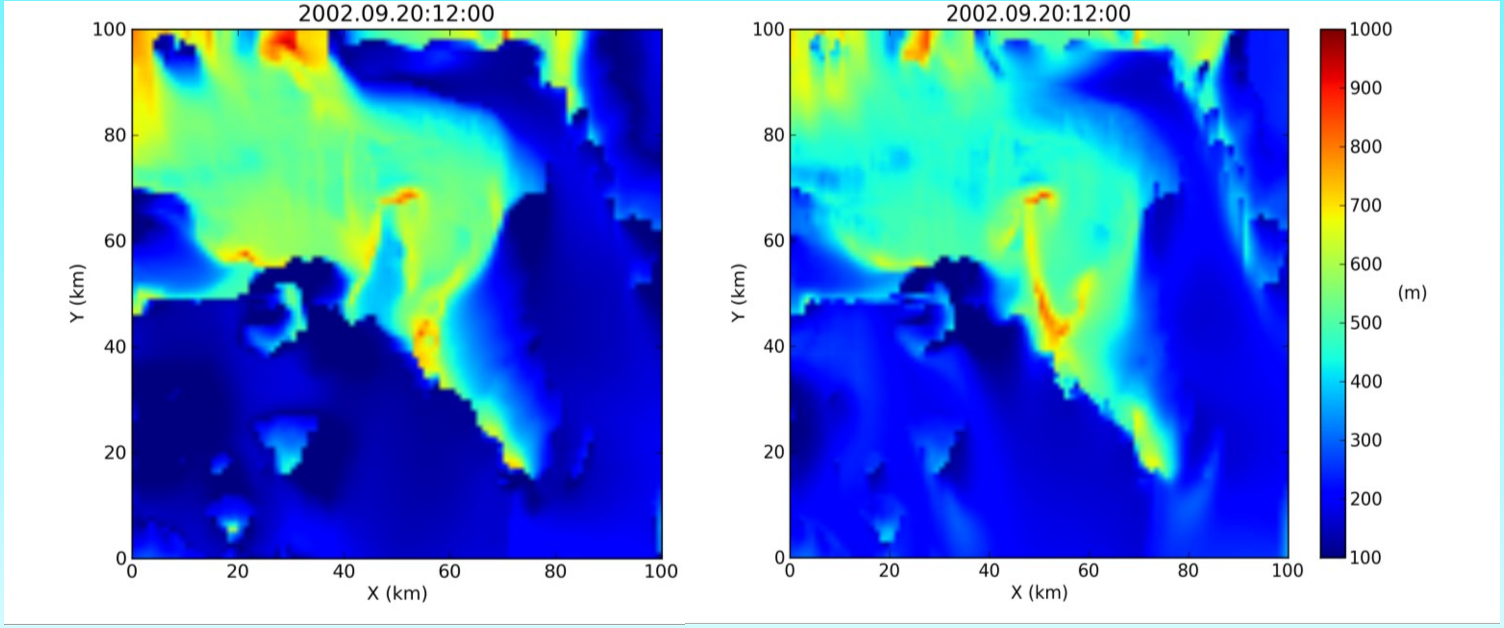
Vertical BL structure: A1 and B1 setups



Vertical sections of TKE (top) and potential temperature (bottom) calculated for 20/9/2002 12:00 LST with the A1 (left) and B1 (right) model configurations. The section plane along a NE-SSW direction.

- 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.

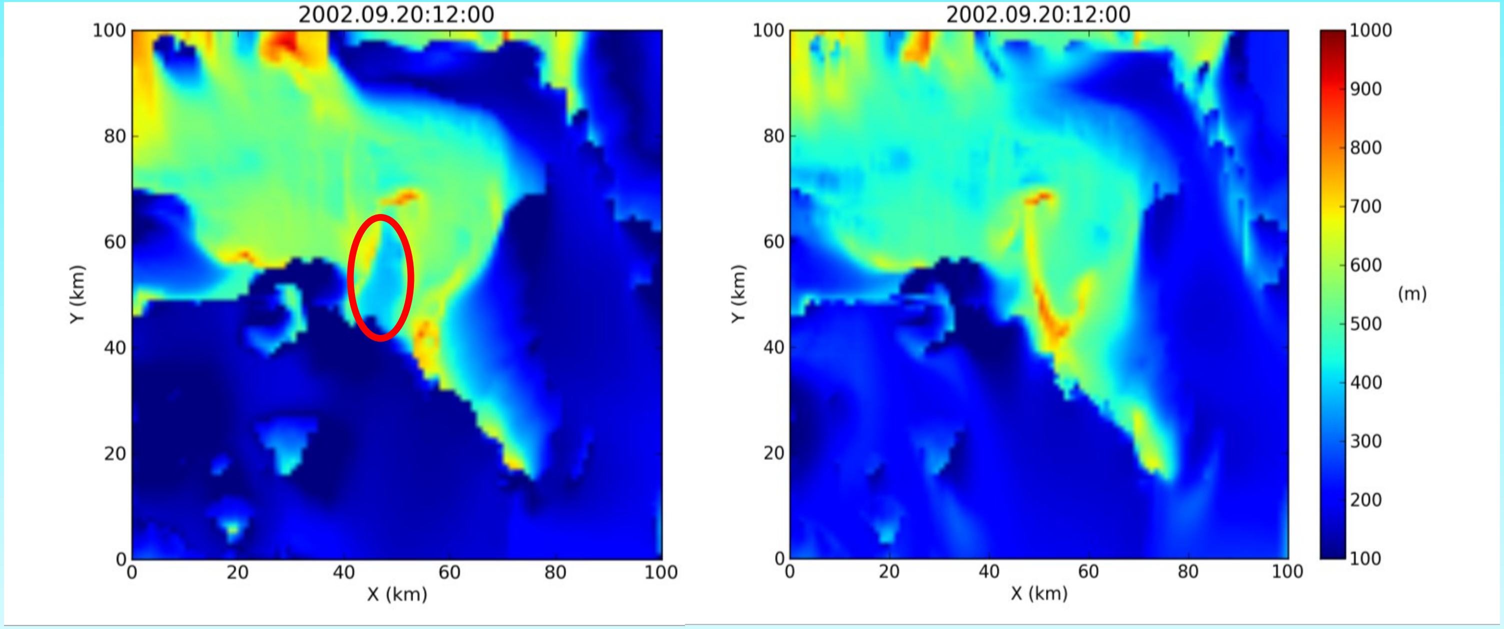
Horizontal BL structure: A1 and B1 setups



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.

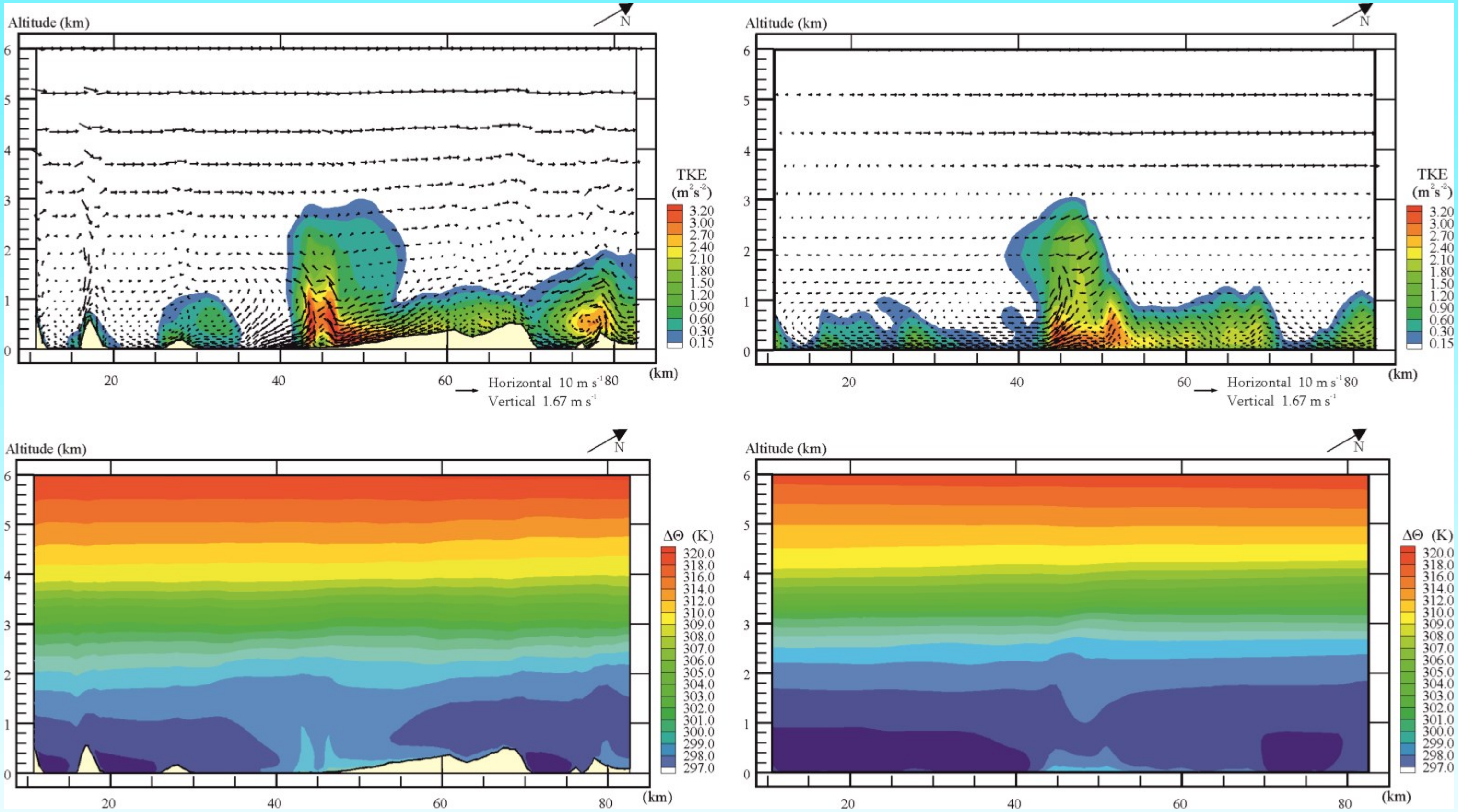
Horizontal BL structure: A1 and B1 setups



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.

Vertical BL structure: B4 and B4f setups

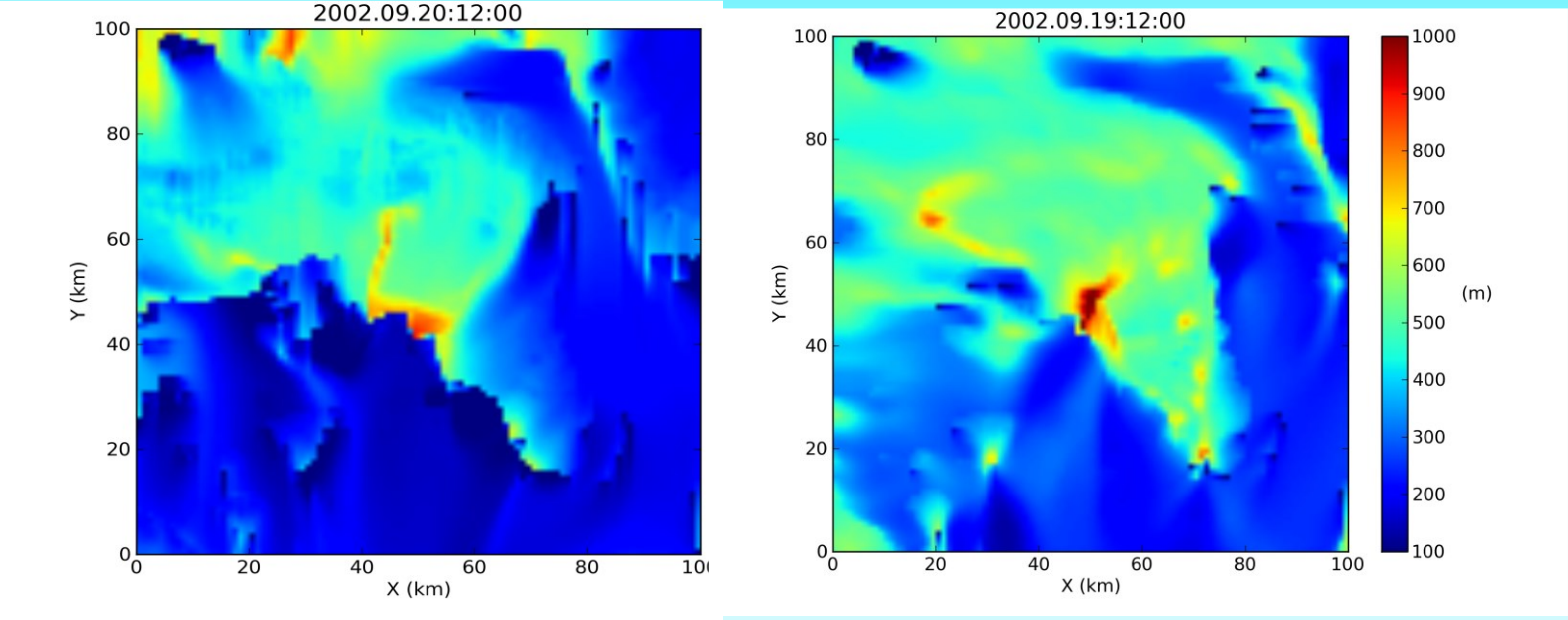


Vertical section of TKE (top) and potential temperature (bottom) calculated with the B4 (left) and with the B4f configurations. Section is taken along the NNE-SSW direction.

- 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

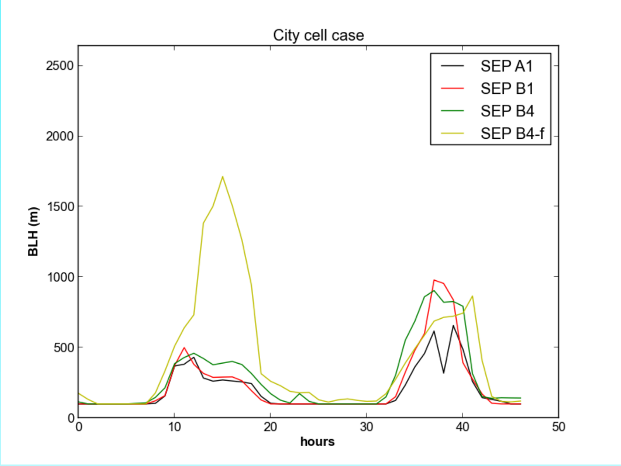
AUT/
LHTEE

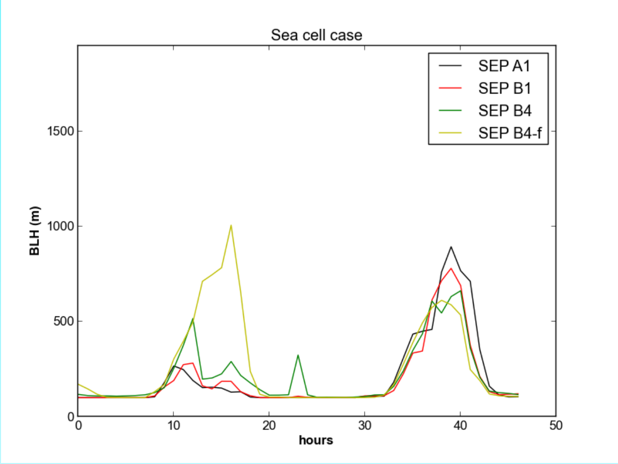


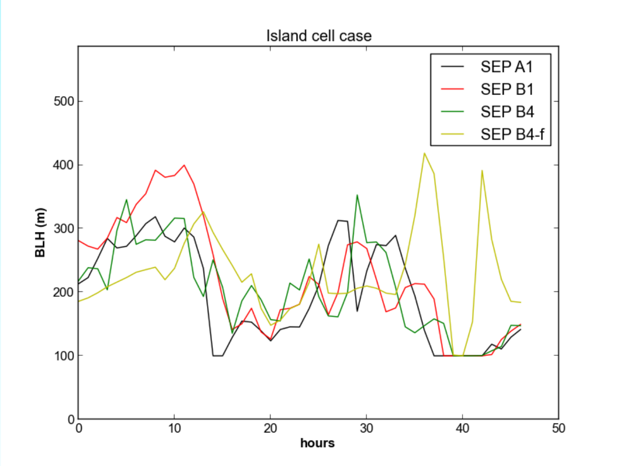
Spatial distribution of the BLH for 20/9/2020 12:00 LST (left) and 19/9/2020 12:00 LST (right) calculateed using the B4 and B4f model configurations, respectively

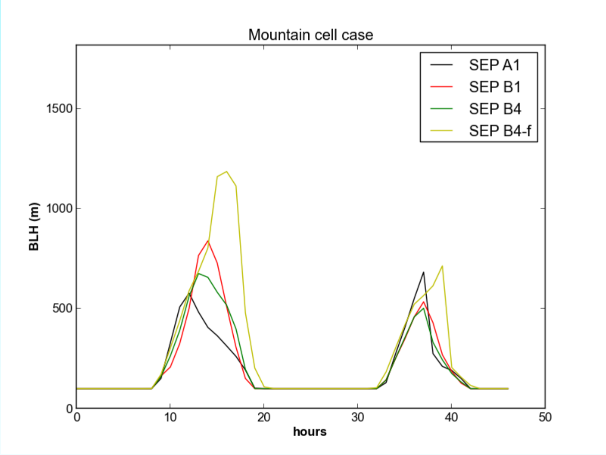
- The BL near the southern coast of the Athens-Piraeus urban areas is enchanced, spatially correlated with an increase in heat flux in this scheme (Nitis, 2016).
- Increase of structure over the sea areas ← time-dependent SST
- B4f: the urban plume remains but the effects of the mountain on the north 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

AUT/
LHTEE

- 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

AUT/
LHTEE

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

  (Tombrou et al. Boundary-Layer Meteorol. (2007) 124:61–79)
- 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

The authors would like to thank the Athens International Airport and the Greek Ministry of Environment and Energy for providing historical time series.