Implementation of a High-Complexity Urban Surface Parametrization in the COSMO Model

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Model Resolution

**COSMO7**
\[ \Delta x = 6.6 \text{ km} \]
2 urban gridpoints

**COSMO2**
\[ \Delta x = 2.2 \text{ km} \]
25 urban gridpoints
Motivation

• Strong increase in urban land-use
• Operational mesoscale model will begin to see urban surfaces
• Implement a complex urban canopy parametrization (BEP, Martilli et al. 2002) into the operational mesoscale model of MeteoSwiss
• Investigate impact on mesoscale fields over a typical Swiss city such as Basel
What does traditional COSMO see?

- Roughness length (0–2m)
- Vegetation cover (0–100%)
- Albedo
- Soil type
- Deep soil temp
- LAI
COSMO surface fluxes

Standard bulk-transfer scheme using drag-law formulation

**momentum**
\[ \tau_x = -\rho C_m |\vec{v}_h| u \]
\[ \tau_y = -\rho C_m |\vec{v}_h| u \]

**heat**
\[ H_s = -\rho C_h |\vec{v}_h| (T - T_s) \]
\[ H_l = -\rho C_h |\vec{v}_h| (q^v - q_s^v) \]

The transfer coefficients \( C_m \) and \( C_h \) are computed using MOST (Louis, 1979)
Building Effect Parametrization (BEP)

Input parameters
• urban fraction (0-100%)
• city morphology (building density, geometry)
• roof, wall and street temperatures
• thermal properties
• radiative properties

Outputs
• Source terms for momentum, temperature and TKE on each urban level
• Modified turbulent length scale
• Urban T2m, UV10m
Implementation

- Interpolation of fields between grids (each $\Delta t$)
- “Urban” momentum, heat and TKE source/sink terms averaged onto mesoscale grid
- Source terms are weighted according to urban fraction

\[ \Delta z = 5\text{m} \]
Case study: Basel

- operational configuration used by MeteoSwiss
- domain 80 x 80 km
- horizontal resolution 2.2 km
- lowest layer depth 20 m
- period of 25 to 27 June 2002 (BUBBLE)
- boundaries: 7 km analysis
- BEP parameters according to Y.-A. Roulet 2004
- landuse: KABA (BUBBLE), fractional aggregation
UHI increase of ~2.3°C
Time evolution

Strongest UHI increase during the night (18h to 2h)
Urban Heat Island

Difference
- **measured**
- **REF**
- **BEP**

Average of gridpoints
- urban
- rural
10m Wind (21h)
Vertical Profiles

Night
26 June 2002  02:00

Day
26 June 2002  14:00

POTENTIAL TEMPERATURE

Z [m]
0  200  400  600  800  1000

[C]
17.5  18.5  19.5  20.5  21.5  22.5

BEP, ∆z=20m
REF, ∆z=20m
BEP, ∆z=60m
REF, ∆z=60m
Interpolation Problem

- Interpolation of fields between grids (each $\Delta t$)
- “Urban” momentum, heat and TKE source/sink terms averaged onto mesoscale grid
Idea: Urban Profile

- Compute urban profiles consistent with source terms
- Use mesoscale fields as upper boundary condition
- Conserve profiles between timesteps

\[ \vec{v}, \theta, \rho \]  
\[ \bar{\vec{S}}_v, \bar{\vec{S}}_{\theta}, \bar{\vec{S}}_E \]
Urban Profiles

• Basic equations...
  - 1 dimensional
  - steady state
  - no advection

\[
- \frac{\partial}{\partial z} \left( K_z \frac{\partial \theta}{\partial z} \right) = -S_\theta
\]

\[
- \frac{\partial}{\partial z} \left( K_z \frac{\partial \bar{v}}{\partial z} \right) = -\bar{S}_v
\]

\[
\rho K_z \left( \left| \frac{\partial \bar{v}}{\partial z} \right|^2 - \frac{g}{\theta} \frac{\partial \theta}{\partial z} \right) - \rho C_\epsilon \frac{E^{3/2}}{l_\epsilon} - \frac{\partial}{\partial z} \left( K_z \frac{\partial E}{\partial z} \right) = -S_E
\]

• Turbulence closure
  (Bougeault and Lacarrere, 1989)

\[
K_z = C_k l_k \sqrt{E}
\]

• 4 equations, 4 unknowns

\[
\theta, \bar{v}, E
\]

• Boundary conditions

bottom: zero gradient

top: \( \theta_{\text{top}}, \bar{v}_{\text{top}}, E_{\text{top}} \)
Upper Boundary Condition

Use surface layer scaling to compute boundary conditions at top of urban grid
Upper Boundary Condition

Use surface layer scaling to compute boundary conditions at top of urban grid
Upper Boundary Condition

- **Scales**
  \[ U_*^2 = \int |\vec{S}_v| \, dz \]
  \[ \theta_* U_* = \int S_\theta \, dz \]

- **Displacement height**
  \[ z_d = 0.67 < h_{building} > \]

- **Interpolation**
  e.g.
  \[ \theta_{top} = \theta_{meso} - 0.75 \frac{\theta_*}{\kappa} \ln \left( \frac{z_{top} - z_d}{z_{meso} - z_d} \right) \]
Vertical Profiles

Night
26 June 2002  02:00

Day
26 June 2002  14:00

POTENTIAL TEMPERATURE

- **BEP, Δz=20m**
- **BEP, Δz=60m**
- **BEP2, Δz=20m**
- **BEP2, Δz=60m**
## UHI Sensitivity

<table>
<thead>
<tr>
<th>CASE</th>
<th>$\Delta x$</th>
<th>$\Delta z$</th>
<th>UHI</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF</td>
<td>7 km</td>
<td>60 m</td>
<td>0.1°C</td>
</tr>
<tr>
<td>REF</td>
<td>2 km</td>
<td>60 m</td>
<td>0.1°C</td>
</tr>
<tr>
<td>REF</td>
<td>2 km</td>
<td>20 m</td>
<td>-0.1°C</td>
</tr>
<tr>
<td>BEP</td>
<td>2 km</td>
<td>20 m</td>
<td>2.3°C</td>
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<tr>
<td>BEP</td>
<td>2 km</td>
<td>60 m</td>
<td>1.5°C</td>
</tr>
<tr>
<td>BEP2</td>
<td>2 km</td>
<td>20 m</td>
<td>2.3°C</td>
</tr>
<tr>
<td>BEP2</td>
<td>2 km</td>
<td>60 m</td>
<td>2.4°C</td>
</tr>
<tr>
<td>BEP2</td>
<td>7 km</td>
<td>60 m</td>
<td>2.4°C</td>
</tr>
</tbody>
</table>
Sensitivity

Change in heat capacity and conductivity of walls?

- increased $c_p, k_h$
- REF

Change of $45^\circ$ of the road direction?

- E-W roads
- N-S roads
Sensitivity

Change in ground roughness length?

- \( z_0 = 5 \text{ cm} \)
- \( z_0 = 1 \text{ cm} \)
Conclusions

- Implementation of BEP in COSMO ➔ Interested?
- 2% urban domain costs 4% more CPU time
- Winds: *deflection* of surface windfields and convergence/divergence due to urbanization
- Temperature: *UHI* increased and magnitude corresponds well in case study
- Solution with computation of *urban profiles* within BEP removes dependence and gives consistent results
- *Sensitivity to input parameters* of BEP which are hard to chose ➔ tuning necessary
- Verification over large domain and long time-series is the next step
Thank you!

Questions?