Status of TERRA_URB implementation into the COSMO-model

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The 2014 workshop in Offenbach

 Goal: develop a roadmap for implementation of the simple urban parameterization TERRA_URB (Wouters et al. 2014) into COSMO

 Held in Offenbach from 3.-5.11.2014

 Invited Hendrik Wouters of KU Leuven / VITO with support from COSMO for discussions

 Participants: Hendrik Wouters, Ulrich Blahak, Ekaterina Machulskaya, Matthias Raschendorfer, Dmitrii Mironov, Jürgen Helmert, Daniel Lüthi (via Phone) Barbara Fay, Kristina Trusilova, Ulrich Schättler, Daniel Reinert, Jan-Peter Schulz

 Schedule:

 3.11. 14:00 – 18:00  Presentations of Hendrik on TERRA_URB, Ekaterina on tile approach in ICON, Matthias on relevant theory of the surface layer transfer scheme

 4.11. 9:00 – 18:00  Discussions in smaller groups on needed new external parameters, on code implementation strategy and on coupling to the surface layer transfer scheme „turbtran“

 5.11. 10:00 – 12:30  Final discussion, Review of this presentation
**TERRA_URB Summary**

- **Parameterization of two major urban effects**
  - modified sensible and latent heat fluxes (Urban „heat buffering“, paved surfaces)
  - Anthropogenic heat emissions

- **Low level of complexity, yet the main features of urban heat islands are captured:**
  - Tile approach: Urban pixels repres. by 2 tiles, paved (sealed) surfaces, and non-paved (parks, …)
  - New external parameters
    - paved surface fraction (subset of urban fraction!)
    - yearly average anthropogenic heating (yearly and daily cycle by analytic functions in COSMO)
  - (Perhaps also in future: Floor Space Index (approximate sum of horizontal floors area of buildings divided by the total urban area), representing the total building density of a city. Would have be transformed to an estimate of the total „wall“ area index relevant for „turbtran“ (parameter A0 from Matthias’ code) -> SAI for urban pixels (if it is not exactly fitting, could also live without it) )
  - Modified radio of $z_0m / z_0H = fct(Re^*)$ based on two parameterizations from literature, representative for wind- and temperature profiles over cities („bluff“ bodies)
  - Modified surface albedo in the radiation
  - New soil type „paved“, essentially a copy of „rock“, but with modified heat capacity and heat conductivity, in such a way that the urban „heat buffering“ simulation resembles data from satellite surface temperatures
  - PDF-based parameterization of puddles on paved surfaces (rest of precip is runoff)
New external parameters

- **Impervious Surface area fraction (ISA):** (sealed/paved surfaces)
  - European Environ. Agency product (~100 m resolution) for Europe (GeoTIFF format)
  - Rest of the world: try to use GLOBCOVER (~ 300 m resolution) „urban fraction“, reduction to paved fraction by regression analysis over Europe in comparison with above EEA data set. Global product with ~300 m resolution.

- **Anthropogenic heat flux (AHF):**
  - Global data set of Flannery (2009) at ~7 km resolution for the years of 2000 – 2006. Will use 2006 data for now and monitor current and future changes in real world with the help of other sources as good as possible.
  - Have to clarify legal issues

- Both are now available in EXTPAR (NetCDF only, because of lack of grib numbers/shortnames for grib1 and grib2)

- **Floor Space index (FSI):**
  - Have to find good dataset from internet and have to check how it fits into the framework of „turbtran“ (parameter is however not immediately needed)
New external parameters

- Available in EXTPAR as NetCDF (because of current lack of grib numbers)
- Need grib-numbers and implementation in INT2LM
The following road map was proposed:

- generation/processing of new external parameters as described (FULFILLED)
- wait for ICON -> COSMO of TERRA (NOT YET, but was circumvented for now)
- 3 options:
  - When ICON tile approach will be adopted, simply implement new paved/sealed tile, and if necessary non-sealed urban tile. The last could also be taken as the same as the surroundings. (SHOULD BE EASY BASED ON HENDRIKS CODE)
  - If no tile approach, alternative 1: implement a two-tile approach for urban tiles by calling TERRA and TURBTRAN a second time for the paved tiles, do corresponding flux aggregation (in terms of averaged exchange coefficient) and save paved T_S, T_SO, puddle water by ways of Interception Store W_I in separate fields for the next timestep and the following model run in operations (database, restart, assimilation cycle) (FULFILLED)
  - If no tile approach, alternative 2: try to find modified parameters for TERRA_URB to represent averaged properties and fluxes for cities in a single call to TERRA and TURBTRAN. This could be developed with the above alternative 1 as a reference in a test code. (TESTED, BUT NOT SUCCESSFUL AT THE MOMENT)
At the moment, the $z_0m/z_0H$ ratio parameterization for cities is only implemented in the old Louis Scheme.

Matthias presented some underlying theory (mainly geometrical considerations on natural canopies vs. buildings) behind his TURBTRAN scheme.

There is implicitly also a parameterization of the $z_0m/z_0H$ ratio.

Different possibilities to make use of this:

- Prescribe constant $A_0$-parameter (which is a „building surface index“ at the surface) representing bluff bodies ($\sim 1.5 – 3$) and see what comes out (TESTED BUT NOT FOUND BENEFICIAL)

- „overwrite“ this ratio by the literature parameterization at urban points. (DONE BUT IMPLEM. HAS TO BE RE-CHECKED WITH MATTHIAS)

Brutsaert-Kanda: $\ln \left( \frac{z_0m}{z_0T} \right) = 1.29 \left( \frac{z_0mU_*}{\nu} \right)^{0.25} + 2$

Zilitinkevich: $\ln \left( \frac{z_0m}{z_0T} \right) = 0.13 \left( \frac{z_0mU_*}{\nu} \right)^{0.45}$

In TURBTRAN theory, refine parameterization of vertical profile of $A$ ($A_0$ would be its value at the ground) to arrive at a more consistent formulation in comparison to the empirical literature relations for cities, that is, a possible scaling parameter for this vertical profile does not or only weekly depend on $Re^*$
New external parameters

- Available in EXTPAR as NetCDF (because of current lack of grib numbers)
- Need grib-numbers and implementation in INT2LM

Annual mean AHF @ COSMO-D2 resolution

ISA (impervious surface area) @ COSMO-D2 resolution
Hendrik has performed the following experiments (3-month period):

T3T: itype_turb = 3, imode_tran = 2, itype_heatcond = 2, z0_buildings = 2.2m, external bluff-body thermal roughness parametrization with daytime values for \( \ln(z0/z0h) = kB-1 \) in urban areas of the order of 25

T3: as T3T, but itype_heatcond = 1

T3T10: (not shown): as T3T, but z0_buildings = 7.3m.
(shows slight colder bias in vertical temperature profiles, hence T3T was chosen as reference)

T1T: as T3T, but itype_turb = 1, imode_tran = 1 (still itype_tran=2)

T3K: as T3T, but no external bluff-body roughness parametrization with kB-1 of the order of 4, Z0 of buildings = 7.3m

STD: as T3T but standard model code (no urban parametrization).

EC: ecmwf forecasts at 12.5km resolution
Results

- CLM Simulations over 3 months period (2.8 km); average T for 0 UTC
- ZWN: station in Antwerpen  
  MOL: rural station to the East

2012-mid-summer | 0 UTC

![Graphs showing temperature vs height and temperature differences](image-url)
Results

- CLM Simulations over 3 months period (2.8 km); average T for 12 UTC
- ZWN: station (tower) near Antwerp  MOL: rural station (tower) to the East
Results

- CLM Simulations over 3 months period (2.8 km); average T for 12 UTC
- KLA: station in Antwerp  VLM: rural station to the East
- Original T_2M from model: somewhat weird profiles according to Hendrik…
Results

- CLM Simulations over 3 months period (2.8 km); average T for 12 UTC
- KLA: station in Antwerp  VLM: rural station to the East
- $T_{5M}$ offline diagnosed according to Monin-Obukhov by Hendrik

![Graphs showing temperature variations over time and diurnal cycle](image)
Results

- CLM Simulations over 3 months period (2.8 km); average T for 12 UTC
- KLA: station in Antwerp  VLM: rural station to the East
- T_G and T_10M as upper and lower bounds for T_2M
Results

Animation from a subtimespace of $T_1T$: 

[Blank animation frame]
Coupling of external $z_{0T}$ parameterization to turbtran correct?

Brutsaert-Kanda: \[
\ln\left(\frac{z_{0m}}{z_{0T}}\right) = 1.29 \left(\frac{z_{0m}u_*}{\nu}\right)^{0.25} + 2
\]

Zilitinkevich: \[
\ln\left(\frac{z_{0m}}{z_{0T}}\right) = 0.13 \left(\frac{z_{0m}u_*}{\nu}\right)^{0.45}
\]

To hook these in, we used following definitions/terms in turbtran. Are these correct?

\[
u_* = |v_h| \sqrt{C_h}
\]

\[
r_{so}^H = z_{0m} \ln\left(\frac{z_{0m}}{z_{0T}}\right)
\]
Open questions: tile averaging

These are the averaged fluxes, based on current flux definitions in COSMO:

\[
\overline{H} = \overline{\rho_s} c_{pd} \overline{C_h} |v_h| \left( \overline{T_g} - \left( \frac{p_s}{p_{ke}} \right)^\kappa T_{ke} \right)
\]
\[
\overline{E} = \overline{\rho_s} L_v \overline{C_h} |v_h| \left( q_{vke} - \overline{q_{vs}} \right)
\]
\[
\overline{\rho_s} = \frac{p_s}{R_d \overline{T_g} \left(1 + 0.61 \overline{q_{vs}} \right)}
\]

And these are the definitions for the single tiles (index i):

\[
H_i = \rho_{si} c_{pd} C_{hi} |v_h| \left( T_{gi} - \left( \frac{p_s}{p_{ke}} \right)^\kappa T_{ke} \right)
\]
\[
E_i = \rho_{si} L_v C_{hi} |v_h| \left( q_{vke} - q_{vsi} \right)
\]
\[
\rho_{si} = \frac{p_s}{R_d T_{gi} \left(1 + 0.61 q_{vsi} \right)}
\]
Open questions: tile averaging

- The fluxes are defined implicitly by $C_h$ and $q_{vs}$.
- So we have to provide averaged $C_h$ and $q_{vs}$ to the rest of the model.
- If $a_i$ are the area fractions of the tiles, we may formally write:

\[
\bar{T}_g = \sum a_i T_{gi} \\
\bar{H} = \sum a_i H_i \quad \overset{!}{=} \quad \bar{\rho}_s c_{pd} \bar{C}_h |v_h| \left( \bar{T}_g - \left( \frac{p_s}{p_{ke}} \right)^\kappa \right) \\
\bar{E} = \sum a_i E_i \quad \overset{!}{=} \quad \bar{\rho}_s L_v \bar{C}_h |v_h| \left( q_{vke} - \bar{q}_{vs} \right)
\]
Accepting the definition of $T_g$ and applying it in the second equality leads to:

$$
\sum a_i H_i = c_{pd} |v_h| \sum a_i \rho_{si} C_{hi} \left( T_{gi} - \pi_s^k T_{ke} \right) \\
\overset{!}{=} c_{pd} |v_h| \bar{\rho}_s \bar{C}_h \left( \left( \sum a_i T_{gi} \right) - \pi_s^k T_{ke} \right)
$$

Solving for a modified transfer coefficient:

$$
\bar{C}_h^* = \bar{\rho}_s \bar{C}_h = \frac{\left( \sum a_i \rho_{si} T_{gi} C_{hi} \right) - \pi_s^k T_{ke} \left( \sum a_i \rho_{si} C_{hi} \right)}{\left( \sum a_i T_{gi} \right) - \pi_s^k T_{ke}}
$$
Open questions: tile averaging

- **One Problem** is that average Flux can be 0 and/or A and/or B can also be 0. Therefore $C_h^*$ could be 0 (or even $\infty$), which cannot be accepted because $C_h^*$ also enters the computation of the average E. **Solution:**

  if: $A \neq 0 \land B \neq 0$ \quad $\Rightarrow$ \quad $C_h^* \neq 0$

  if: $A \neq 0 \land B = 0$ \quad increment $\overline{T_g} = \sum a_i T_{gi}$ by a constant \quad $\Rightarrow$ \quad $C_h^* \neq 0$

  if: $A = 0 \land B \neq 0$ \quad set $\overline{T_g} = \pi_s^k T_{ke} \land C_h^* = \text{const} \neq 0$

  if: $A = 0 \land B = 0$ \quad set $C_h^* = \text{const} \neq 0$

- **Then:**

  $$\overline{q_{vs}} = q_{vke} \left(1 - \frac{\sum C_{hi} a_i \rho_{si}}{C_h^*}\right) + \frac{\sum C_{hi} a_i \rho_{si} q_{vsi}}{C_h^*}$$

- … and we have all ingredients for flux-consistent tile-averaged H and E!
Summary

- Tile approach seems necessary
- Modifications in src_terra.f90, turbulence_tran.f90, src_radiation.f90 are in such a way that these routines can be called for each tile separately after corresponding preparation of external fields.
- Have to clarify implementation in turbtran (itype_tran=2) with Matthias
- Strangely, the experiment using itype_turb=1 + itype_tran=2 (imode_turb=1) seems to be better than our operational setup with respect to the data comparisons of Hendrik…
- Issue with T_2M diagnosis in the model for (partially) urban pixels
- Issue with flux-conserving averaging, so that fluxes can be diagnosed in the rest of the model by averaged T_G, C_h, QV_S:
  - I think there is a solution for tile averaging of C_h* and QV_S in order to preserve fluxes. But this calculation has to be re-checked.
  - This solution has not been part of Hendriks study. He has done this in a different (and maybe slightly inconsistent) way. Has to be checked.