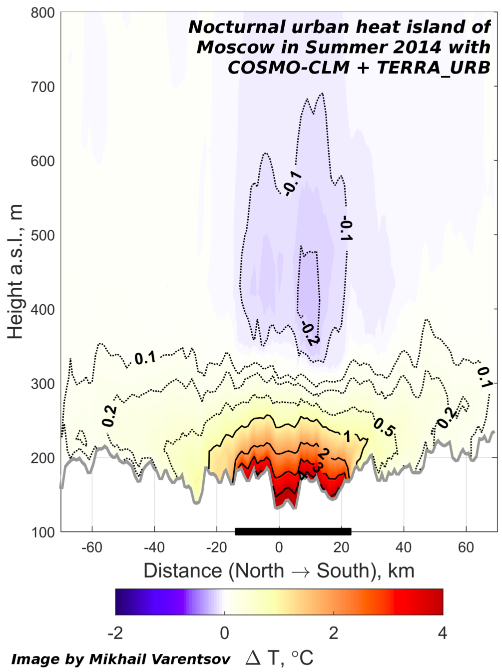

User guide for TERRA_URB v2.2: The urban-canopy land-surface scheme of the COSMO model

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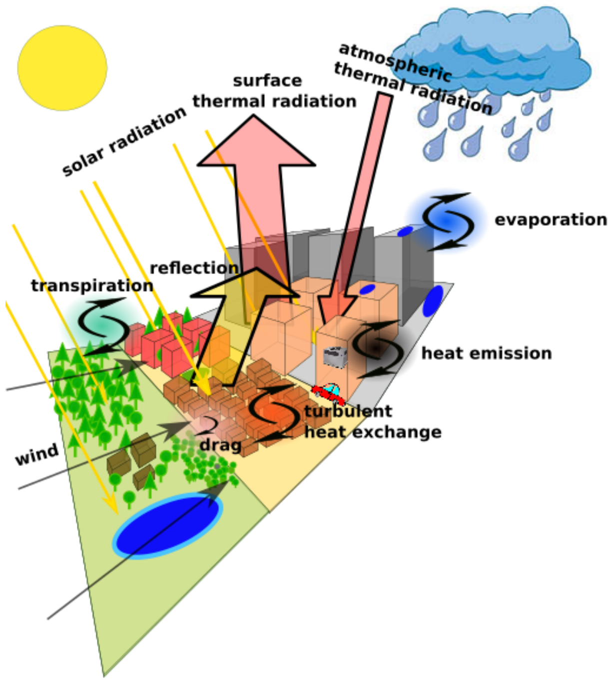

Figure 1: The urban-atmospheric interactions resolved by TERRA_URB.

1 Introduction

The urban-canopy land-surface scheme TERRA_URB (*Wouters et al.*, 2016, 2015) offers an implementation of urban physics in the COSMO(-CLM) model (*Doms et al.*, 2011; *Rockel et al.*, 2008; *Steppeler et al.*, 2003) by modifications to the input data, the soil-vegetation module TERRA_ML (*Schulz et al.*, 2016) and the land-atmospheric interactions. The central goal is to perform urban-climate research and weather forecasting for cities with the COSMO(-CLM) model. Since version 1 (released in May 2014), it consists of the following features:

- Bulk representation of the urban canopy (*De Ridder et al.*, 2012; *Demuzere et al.*, 2008), taking appropriate parameters for albedo, emissivity, heat capacity and heat conductivity and aerodynamic roughness length.
- Anthropogenic heat emission (*Flanner*, 2009)
- 'Bluff-body' thermal roughness length parameterisation (*Brutsaert*, 1982; *Kanda et al.*, 2007; *Demuzere et al.*, 2008)
- Impervious water storage based on a density distribution of water puddles (*Wouters et al.*, 2015)
- A poor man's tile approach for resolving the urban canopy alongside natural land

Since version 2 (released February 2016), the following features have been added:

- Application of the Semi-empirical URban canopY dependency parameterisation SURY (*Wouters et al.*, 2016). Based on urban experimental studies, it converts urban-canopy parameters containing the three-dimensional urban-canopy information into bulk parameters, see also Table 1.

- Application of TURBTRAN, the TKE-based surface-layer transfer scheme of the COSMO model.

- Buildings and pavements are represented on top of the natural soil (instead of a separate 'paved soil-type'). It enables a comprehensive representation of the heterogeneous urban environment that consists of impervious surfaces, bare soil, vegetation, water puddles and snow.

- Inclusion of the new bare-soil evaporation resistance formulation (*Schulz and Vogel*, 2016) and the vegetation skin-temperature parameterization (*Schulz and Vogel*, 2017; *Viterbo and Beljaars*, 1995).

An overview of the urban-atmosphere interactions resolved by TERRA_URB is given in Fig. 1. The technical information of TERRA_URB can be found in the appendix of *Wouters et al.* (2016).

TERRA_URB is being applied in both offline and online applications for many cities around the world (*Demuzere et al.*, 2017; *Wouters et al.*, 2016, 2015), including Toulouse, Basel, Singapore, Vienna, Turin, and urban areas in Belgium. It has also been compared to other urban land-surface schemes for Moscow, Zürich, Basel and Berlin (*Trusilova et al.*, 2016) in the Urban Model Intercomparison project of the CLM-community.

2 Configuration

2.1 First steps

The TERRA_URB model package `cclm-sp_2.4_terra_urb_2.2.tgz` is available on the CLM-community project website, see `http://redc.clm-community.eu/projects/wg-soilveg/files`. This is basically a copy of the standard COSMO-CLM model package `cclm-sp_2.4.tgz` (*Rockel et al.*, 2008) - including both the INT2LM and COSMO-CLM model code `cosmo5.0_clm9` - to which TERRA_URB is supplemented. As such, the TERRA_URB model package works in a similar way as the standard COSMO-CLM model package. As a first step, one requires a working setup with the standard package, see COSMO documentation (*Schättler et al.*, 2009) and the COSMO(-CLM) training courses. Afterwards, the TERRA_URB model package can be used by following the configuration steps described in the next sections. In order to have access to the TERRA_URB model package, you need to be member of the SOILVEG working group of the CLM-community (`http://www.clm-community.eu`).

urban-canopy parameters (input of SURY)		
parameter name	symbol	default values
substrate albedo	α	0.101
substrate emissivity	ϵ	0.86
substrate heat conductivity	λ_s	$0.777\,\mathrm{W\,m^{-1}\,K^{-1}}$
substrate heat capacity	$C_{v,s}$	$1.25 \times 10^6\,\mathrm{J\,m^{-3}\,K^{-1}}$
building height	H	$15\,\mathrm{m}$
canyon height-to-width ratio	$\frac{H}{W}$	1.5
roof fraction	R	0.667

bulk parameters (output of SURY)		
parameter name	symbol	surface-level values corresponding to urban-canopy defaults
bulk albedo	α_{bulk}	0.081 (snow-free)
bulk emissivity	ϵ_{bulk}	0.89 (snow-free)
bulk heat conductivity	λ_{bulk}	$1.55\,\mathrm{W\,m^{-1}\,K^{-1}}$
bulk heat capacity	$C_{v,\mathrm{bulk}}$	$2.50 \times 10^6\,\mathrm{J\,m^{-3}\,K^{-1}}$
bulk thermal admittance	$\mu_{\mathrm{bulk}} \left(= \sqrt{C_{v,\mathrm{bulk}}\,\lambda_{\mathrm{bulk}}}\right)$	$1.97 \times 10^3\,\mathrm{Jm^{-2}K^{-1}s^{-1/2}}$
aerodynamic roughness length	z_0	$1.125\,\mathrm{m}$
inverse Stanton number	kB^{-1}	13.2 [in case that $u_* = 0.25\,\mathrm{m\,s^{-1}}$]

Table 1: The upper panel shows the urban-canopy parameters, which are taken as input for the Semi-empirical URban canopY dependency parameterisation (SURY) implemented in TERRA_URB. The default values are adopted from the medium density urban class in *Loridan and Grimmond* (2012). The lower panel shows the bulk parameters, which is the output of SURY. Herbey, u_* refers to the friction velocity. The table is adapted from *Wouters et al.* (2016).

Namelist ID	Full name	Symbol[a]	Unit	I/O
ISA	Impervious surface area	f_{imp}		I
AHF	Annual-mean anthropogenic heat flux	-	$\mathrm{W\,m^{-2}}$	I
UCS_SALB[b]	Urban-canopy substrate shortwave albedo	α	-	I
UCS_TALB[b]	Urban canopy substrate thermal albedo	$(1-\epsilon)$		I
UCS_LAM[b]	Urban canopy substrate heat conductivity	λ_s	$\mathrm{W\,m^{-1}\,K^{-1}}$	I
UCS_RHOC[b]	Urban canopy substrate heat capacity	$C_{v,s}$	$\mathrm{J\,m^{-3}\,K^{-1}}$	I
UC_H[b]	Building height	H	m m	I
UC_HTW[b]	Canyon height-to-width ratio	$\frac{H}{W}$	1	I
UC_ROOF[b]	Roof fraction	-	1	I
KBMO	Inverse Stanton number	κB^{-1}	-	O
W_IMP	Water-storage content on the impervious surface area	w_{imp}	$\mathrm{kg\,m^{-2}}$	O
W_ISA	Water-storage content on the impervious surface area (weighted according to the ISA fraction)	$w_{\text{imp}} f_{\text{imp}}$	$\mathrm{kg\,m^{-2}}$	O
AHF_NOW	Anthropogenic heat flux of the current timestep	Q_{A}	$\mathrm{kg\,m^{-2}}$	O

[a] see (*Wouters et al.*, 2016)

[b] Fixed values are hardcoded. For 2D varying fields, please contact Hendrik Wouters and Mikhail Varentsov.

Table 2: Additional namelist variables provided by TERRA_URB

2.2 Urban parameters with EXTPAR

TERRA_URB requires additional urban input parameters, which are listed in Table 2. These urban-canopy parameters are interpreted in TERRA_URB by means of the SURY framework. Please note that SURY is fully implemented in the TERRA_URB model code, so there is no need to apply the standalone SURY Python module (`https://github.com/hendrikwout/sury`).

The mandatory fields are the Impervious Surface Area (ISA) and the Annual-mean anthropogenic heat Flux (AHF). These fields can be generated with the EXTPAR Consortium version 3 through the WebPEP on `http://www.clm-community.eu`. Several options are available, which are listed in Table 3. Please note that the quality of these parameter fields largely depends on the region. As such, one needs to perform a quality assessment, and - when necessary - look for other (local or global) parameter databases for reliable urban-climate modelling. Still, the provided parameter fields should be suitable at least for model testing purposes. The other urban-canopy parameters provisionally obtain fixed values over the entire domain according to table 1 in TERRA_URB, and they are not provided yet by EXTPAR out-of-the-box. However, there is a TERRA_URB implementation available that allows 2D varying urban-canopy parameter fields. If you are interested, please contact Hendrik Wouters and Mikhail Varentsov. If a user know about a new (global) product on ISA or AHF, he or she can provide this information to the developers of the scheme.

ISA: Impervious Surface Area [−]				
Filename	Res	Area	WebPEP switch	Source notes
`NOAA_ISA_16bit.nc`	30”	75°N - 65°S 180°W - 180°E	1 (coarse)	NOAA; Global dataset
`EEA_ISA_4_16bit.nc`	10”	90°N - 12.5°N 60°W - 60°E	2 (fine)	From European Environmental Agency (*Maucha et al.*, 2010); recommended for Europe

AHF: Annual-mean anthropogenic Heat Flux [$W\,m^{-2}$]				
Filename	Res	Area	WebPEP switch	Source notes
`AHF_2006_2.5min_latreverse.nc`	2.5’	90°N - 90°S 180°W - 180°E	-	*Flanner* (2009); Global dataset
`AHF_2006_NOAAISAredistr.nc`	30”	75°N - 65°S 180°W - 180°E	1 and 2	*Flanner* (2009), redistributed to NOAA ISA
`AHF_2006_EEAISAredistr_4_16bit.nc`[a]	10”	90°N - 12.5°N 60°W - 60°E	-	*Flanner* (2009), redistributed to EEA ISA; recommended for Europe

[a] not available out-of-the-box in EXTPAR. Please contact: Hendrik Wouters

Table 3: Overview of optional EXTPAR datasets for TERRA_URB

2.3 Configuration of INT2LM for the additional urban parameters

Afterwards, the fields need to be transferred to the initial and boundary conditions for the COSMO(-CLM) model by INT2LM. Hereby, the following switches are required:

```
&CONTRL
...
 l_isa = .TRUE.
 l_ahf = .TRUE.
...
/
```

It should be noted that there is another switch 'lurban' in EXTPAR that generates the field called 'URBAN'. However, this field is not used by TERRA_URB.

2.4 Configuration of the COSMO(-CLM) model

2.4.1 TERRA_URB

Activation of TERRA_URB can be achieved by turning on the main switch:

```
&PHYCTL
...
 l_terra_urb = .TRUE.
...
/
```

This switch automatically activates the different components of TERRA_URB listed below, so they don't have to be activated manually. These switches include:

- `lurbfab`: switch for taking into account the urban canopy (`.TRUE.` is the default setting in TERRA_URB)
- `itype_kbmo_uf`: $kB^{-1} = \ln(z_0/z_{0\mathrm{h}})$ parameterisation in the surface-layer transfer scheme for the urban fabric. Options are:
  - 0: standard from the surface-layer transfer scheme of COSMO5.0
  - 1 (TERRA_URB default): external parameterisation according to Brutsaert/Kanda (*Brutsaert*, 1982; *Kanda et al.*, 2007; *Demuzere et al.*, 2008)
  - 2: external from Zilitinkevich
- `itype_tile`. Options are:
  - 0: no tiles
  - 1 (TERRA_URB default): poor man's tile approach for the separate treatment of the urban canopy alongside the natural land.
- `itype_ahf`. Switch for anthropogenic heat flux. Options are:

- 0: means no anthropogenic heat flux;
- 1 (TERRA_URB default): anthropogenic heat according to *Flanner* (2009); latitudinal, annual, and diurnal-dependent anthropogenic heat flux based on an annual-mean input dataset.

- `itype_eisa`: type of evaporation from impervious surfaces. Options are:
  - 0: evaporation just like bare soil (of course, not recommended).
  - 1: no evaporation (dry impervious surface).
  - 2 (TERRA_URB default): density function of puddle depths (*Wouters et al.*, 2015).

2.4.2 additional COSMO configuration settings

The following COSMO namelist parameters are known to affect urban-climate modelling (see also *Wouters et al.* (2017)):

- `itype_evsl`: Parameter to select the type of parameterization for evaporation of bare soil:
  - 1: Bucket version.
  - 2: BATS version (COSMO default).
  - 3: ISBA version.
  - 4: Resistance version (recommended): calculation of bare soil evaporation using the new resistance formulation, see *Schulz and Vogel* (2016). This option is recommended for urban climate modelling.

- `itype_canopy`: type of vegetation-canopy parameterisation:
  - 1 : as before, basically no canopy
  - 2 : skin-temperature formulation from (*Schulz and Vogel*, 2017; *Viterbo and Beljaars*, 1995). The code has been recently developed for COSMO/ICON, and has been added to the TERRA_URB package. Model sensitivity tests demonstrate that this option leads to a better representation of the nocturnal temperatures and urban heat islands (*Wouters et al.*, 2017). Please note that this feature is still at an experimental stage.

- `cimpl`: value of implicitness of the vegetation-skin temperature parameterisation. The default is 120.

- `calamrural`: value of skin-layer conductivity for rural areas. The default is $10\,\mathrm{W\,m^{-2}\,K^{-1}}$.

- `calamurban`: value of skin-layer conductivity for urban areas. The default is $1000\,\mathrm{W\,m^{-2}\,K^{-1}}$.

- tkmmin: minimal diffusion coefficients of vertical turbulent transport for momentum (default is $0.4\,\mathrm{m^2\,s^{-1}}$).
- tkhmin: minimal diffusion coefficients of vertical turbulent transport for momentum (default is $0.4\,\mathrm{m^2\,s^{-1}}$).
- pat_len: length-scale of sub-scale patterns of land, which scales the circulation term (default is 500 m).
- tur_len: maximal turbulent length scale (default is 500 m).
- hd_corr_??[_??]: reduction factors for the horizontal diffusion flux for the different model field variables

The additional information of these parameters can be consulted with the COSMO/INT2LM Namelist-Tool at http://www.clm-community.eu/namelist-tool/namelist-tool_portal/index.htm.

2.4.3 Additional output variables

TERRA_URB provides an additional set of two-dimensional output fields, which are listed in Table 2. The poor man's tile approach in TERRA_URB provides the tile values of the different surface variables, for which the namelist IDs are T_2M, T_G, T_S, TD_2M, U_10M, V_10M, QV_S, QV_2M, RELHUM_2M, Z0, TCM, TCH, LHFL_S, W_SNOW, H_SNOW, T_SNOW, SNOW_MELT, FRESHSNOW, RHO_SNOW, H_SNOW_M, W_SNOW_M, T_SNOW_M, RHO_SNOW_M, WLIQ_SNOW, QVFL_S, W_I, T_SO, W_SO, W_SO_ICE. Hereby, the natural tile values can be attained by appending the suffix '_1' to the variable ID, whereas the urban-canopy tile value with the suffix '_2'. For example, the surface-atmosphere sensible heat exchange of the urban-canopy tile can be obtained with the namelist ID SHFL_S_2.

3 Final notes

- In case you are using TERRA_URB for your application or research, please provide a reference to *Wouters et al.* (2015, 2016) and *Schulz et al.* (2016).
- TERRA_URB brings an additional computational cost of about 7% over the original running time of the COSMO(-CLM) model. This generally stems from the implementation of the poor man's tile approach. At the moment, a more general tile approach is being developed for the COSMO model by the DWD. This is will be in accordance to the new ICON/COSMO block structure interface, and will also work with TERRA_URB. As such, the additional computational overhead with this tile implementation will be alleviated. It is expected that TERRA_URB with the ICON-based tile approach will be part of the upcoming COSMO5.6 release.

4 Known bugs

- For some model domains, there are invalid numbers for the fields ISA and AHF for some land points provided by EXTPAR, which makes TERRA_URB to stop at the first timestep. This can be easily fixed by setting all the NAN-values (-1.00000002e+20) in the ISA and AHF fields to zero.

5 Future developments

- Allow 2D variable urban canopy fields. As mentioned above, there is already a custom implementation available for that purpose, which is implemented by Mikhail Varentsov. If you are interested, please contact Hendrik Wouters and Mikhail Varentsov.

- Out-of-the-box EXTPAR availability and application of additional global urban databases (WUDAPT, Openstreetmap...). If you are interested, please contact (Hendrik Wouters) and (Matthias Demuzere).

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