Implementing TERRA_URB in COSMO-Model Version 5.04g

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The urban-canopy land-surface scheme TERRA_URB has been implemented in COSMO-Model Version 5.04g. The TERRA_URB version used is 2.3, which is taken from the CCLM version COSMO-5.0-clm9. in the following we want to document this implementation into COSMO and try to highlight the technical differences to the implementation in COSMO-5.0-clm9.

This branch of the COSMO-Model is called COSMO-Model 5.04g_urb1.

1. Using a Tile Approach in the COSMO-Model

1.1. Implementation of Tile Variables

The poor man's tile approach from TERRA_URB has been adopted in the COSMO-Model in a slightly different form. For every variable `var` an additional variable `tl_var` is declared in COSMO-5.0-clm9 with an extra dimension for the tiles. For example

surface roughness * g	`gz0 (ie,je)`	`tl_gz0 (ie,je,0:ntiles)`
fraction of plant cover	`plcov(ie,je)`	`tl_plcov(ie,je,0:ntiles)`

where `ntiles` is the number of tiles used. Before calling a routine which should use the tiles, the corresponding index from the tile-variable is copied to the usual variable and this is used in the routine. Afterwards, the result in the usual variable is copied to the corresponding tile index. Index 0 is used for aggregating the different values for the tiles.

In COSMO-Model 5.04g the new COSMO-ICON physics is written using argument lists for all subroutines. With this the copying of variables can be avoided easily by just writing a loop over all tiles around the call to subroutines. Therefore, in the implementation in COSMO-Model 5.04g we only use the tile-variable `tl_var(ie,je,0:ntiles)`. If no tiles are used, `ntiles` is 0 and the usual values are in `tl_var(:,:,0)`.

Implications to the rest of the COSMO-implementation:

- Throughout the COSMO-Model the use of tile-variables has to be adapted from `var(...)` to `tl_var(...,0)`, but not in the I/O.
- In the I/O we do not want to change the pointers in `src_setup_vartab.f90`. Some special implementation is needed for that. For more details see Section 3.

For the COSMO-ICON physics all variables are needed in a different data structure, which we call the blocked structure. One block consists of a part of the grid points of the

two-dimensional domain and can be considered as a vector of grid columns. The name of the blocked variables is just the name of the variable with a suffix `_b`. For variables with a time dimension `tl_var(:,:,ntim=2)`, two variables in blocked format are allocated: `tl_var_b(:,:)` and `tl_var_new_b(:,:)`. Automatic copying of the `ijk`-structure to the block structure and back has been implemented for the tiles.

1.2. List of Variables with a Tile Dimension

The following table shows all variables from the COSMO-Model which are now implemented as tile variables (usual variable with dimensions, tile-variables now used in the COSMO-Model with dimensions, corresponding block variables with dimensions). The first line gives the dimensions of the variables in the program.

Two-dimensional variables:

(ie,je)	(ie,je,0:ntiles)	(nproma,0:ntiles)
gz0	tl_gz0	tl_gz0_b
plcov	tl_plcov	tl_plcov_b
lai	tl_lai	tl_lai_b
tai	tl_tai	tl_tai_b
sai	tl_sai	tl_sai_b
eai	tl_eai	tl_eai_b
tcm	tl_tcm	tl_tcm_b
tch	tl_tch	tl_tch_b
tfm	tl_tfm	tl_tfm_b
tfh	tl_tfh	tl_tfh_b
tfv	tl_tfv	tl_tfv_b
t_2m	tl_t_2m	tl_t_2m_b
qv_2m	tl_qv_2m	tl_qv_2m_b
td_2m	tl_td_2m	tl_td_2m_b
rh_2m	tl_rh_2m	tl_rh_2m_b
u_10m	tl_u_10m	tl_u_10m_b
v_10m	tl_v_10m	tl_v_10m_b
shfl_s	tl_shfl_s	tl_shfl_s_b
qvfl_s	tl_qvfl_s	tl_qvfl_s_b
lhfl_s	tl_lhfl_s	tl_lhfl_s_b
runoff_s	tl_runoff_s	tl_runoff_s_b
runoff_g	tl_runoff_g	tl_runoff_g_b
freshsnow	tl_freshsnow	tl_freshsnow_b
snow_melt	tl_snow_melt	tl_snow_melt_b

New two-dimensional variables for TERRA_URB:

(ie,je)	(ie,je,0:ntiles)	(nproma,0:ntiles)
frc	tl_frc	tl_frc_b
isa	tl_isa	tl_isa_b
isa_uc	tl_isa_uc	
sa_uc	tl_sa_uc	tl_sa_uc_b
w_imp	tl_w_imp	tl_w_imp_b
w_isa	tl_w_isa	tl_w_isa_b
kbmo	tl_kbmo	tl_kbmo_b

Two-dimensional variables with a time-dimension. Note that the time-dimension is always the last one!

(ie,je,ntim)	(ie,je,0:ntiles,ntim)	(nproma,0:ntiles,ntim)
t_snow	tl_t_snow	tl_t_snow_b
		tl_t_snow_new_b
t_s	tl_t_s	tl_t_s_b
		tl_t_s_new_b
t_sk	tl_t_sk	tl_t_sk_b
		tl_t_sk_new_b
t_g	tl_t_g	tl_t_g_b
		tl_t_g_new_b
qv_s	tl_qv_s	tl_qv_s_b
		tl_qv_s_new_b
w_i	tl_w_i	tl_w_i_b
		tl_w_i_new_b
w_p	tl_w_p	tl_w_p_b
		tl_w_p_new_b
w_s	tl_w_s	tl_w_s_b
		tl_w_s_new_b
h_snow	tl_h_snow	tl_h_snow_b
		tl_h_snow_new_b
rho_snow	tl_rho_snow	tl_rho_snow_b
		tl_rho_snow_new_b

And for the multi-layer snow model:

(ie,je,ntim)	(ie,je,0:ntiles,ntim)	(nproma,0:ntiles,ntim)
t_snow_mult	tl_t_snow_mult	tl_t_snow_mult_b
dzh_snow_mult	tl_dzh_snow_mult	tl_dzh_snow_mult_b
wliq_snow	tl_wliq_snow	tl_wliq_snow_b
w_snow_mult	tl_w_snow_mult	tl_w_snow_mult_b
rho_snow_mult	tl_rho_snow_mult	tl_rho_snow_mult_b

Three-dimensional variables:

(ie,je,ke1)	(ie,je,ke1,0:ntiles)	(nproma,ke1,0:ntiles)
tkvm	tl_tkvm	tl_tkvm_b
tkvh	tl_tkvh	tl_tkvh_b
edr	tl_edr	tl_edr_b

Three-dimensional variables with a time-dimension. Note that `kex` stands for a variable third dimension, because all these variables do have a different extent in the vertical. Again note that the time-dimension is the last one!

(ie,je,kex,ndim)	(ie,je,kex,0:ntiles,ndim)	(nproma,kex,0:ntiles,ndim)
tke	tl_tke	tl_tke_b
t_so	tl_t_so	tl_t_so_b
		tl_t_so_new_b
w_so	tl_w_so	tl_w_so_b
		tl_w_so_new_b
w_so_ice	tl_w_so_ice	tl_w_so_ice_b
		tl_w_so_ice_new_b

NOTE:

This is just a slightly different way of implementing the poor man's tile approach. It is not (and even not similar) to the tile approach used in ICON!

2. Additional Namelist Variables for TERRA_URB

Several new namelist variables have been implemented in COSMO-5.0-clm9, TERRA_URB 2.3 in the group `/PHYCTL/`. All but one have also been implemented in COSMO-Model 5.04g_urb1. The one not implemented is the logical variable `itype_tile`, which is redundant. The actions of `itype_tile` (0: no tiles, 1: tiles) can also be taken from the number of tiles being $= 0$ or > 0.

The implmented namelist variables are described shortly:

Name	Type	Definition / Purpose / Comments	Default
`ntiles`	`INT`	Number of total tiles. • If the COSMO-Model should run without tiles, the default `ntiles` $= 0$ has to be used. • If the COSMO-Model should run with tiles, `ntiles` has to be set explicitely (in contrast to COSMO-5.0-clm9, where the default of this variable was 2).	`0`
`lterra_urb`	`LOG`	To switch on/off the urban parameterization.	`.FALSE.`
`lurb_urb`	`LOG`	To switch on/off the urban fabric (in a bulk approach). It is only active, if also `lterra_urb` is set.	`.TRUE.`
`itype_ahf`	`INT`	Switch for anthropogenic heat flux. Options are: 0: no anthropogenic heat flux; 1: (default) anthropogenic heat according to *Flanner* (2009); latitudinal, annual, and diurnal-dependent anthropogenic heat flux based on an annual-mean input dataset.	`1`
`itype_kbmo_uf`	`INT`	$kB^{-1} = \ln(z_0/z_{0h})$ parametrization in the surface-layer transfer scheme for the urban fabric. Options are: 0: standard from the surface-layer transfer scheme 1: (default) external parametrization according to Brutsaert/Kanda 2: external from Zilitinkevich	`0`

Name	Type	Definition / Purpose / Comments	Default
itype_eisa	INT	Type of evaporation from impervious surfaces. Options are: 0: evaporation just like bare soil (of course, not recommended) 1: no evaporation (dry surface) 2: (default): density function of puddle depths (Wouters et al., 2015)	0
itype_canopy	INT	Type of skin temperature parameterization. Options are: 1: (default) skin temperature corresponds to top ground layer 2: skin temperature corresponds to vegetation skin-layer from (Viterbo et al., 1995). This is provided by the new COSMO/ICON code by Jan-Peter Schulz, which is recently adopted by TERRA URB. Model sensitivity tests show that this option leads to a better representation of the urban/rural contrasts in surface-atmosphere exchanges, hence largely improves urban climate modelling. This option also allows to investigate the ect of vegetation insulation in urban areas on urban climate. Please note that this feature is still in experimental stage.	0
cimpl	REAL	value of implicitness of the vegetation-skin temperature parameterisation.	120
calamrural	REAL	value of skin-layer conductivity for rural areas (in $Wm^{-2}K^{-1}$).	10
calamurban	REAL	value of skin-layer conductivity for rural areas (in $Wm^{-2}K^{-1}$).	1000

When activating lterra_urb the default of the above variables are used. Only the variable ntiles has to be set explicitely to 2!

3. Input and Output for the Tile Variables

The I/O implemented for the tile-variables in COSMO-5.0-clm9 is not practical with GRIB. But a proper method is not yet implemented in COSMO-Model 5.04g_urb1. Therefore, I/O at the moment is only possible for the *usual* variables in tile 0.

In order not to have to change the pointering in the module `src_setup_vartab.f90` we kept the *usual* arrays for the tile variables without the additional tile dimension, but put a "`z`" in front of the name, to make it different. In `src_input.f90` the fields are read into the fields `zvar` and copied to the tile-variables `tl_zvar` afterwards.o

The reverse method is used in `src_output.f90`, where tile 0 of variable `zvar` is copied to `zvar`. If it happens, that a special variable is completely 0 in the output, then most probably this variable has been forgotten.

This is only a "HACK" and has to be removed as soon as possible.

NOTE:

A restart with the tile-variables therefore is not possible yet!

4. Special Highlights of the Implementation in COSMO-Model 5.04g_urb1

1. Implementation of the 2 new modules:

   - The module `src_ahf` has been named sfc_ahf. It contains one subroutine `ahf`. In COSMO-Model 5.04g_urb1 this routine is called in `organize_physics.f90`, after all parameterizations have been calculated and all data have been copied back to the `ijk`-data structure (because it is written for this data structure).
   - The module `src_tile_approach.f90` has been named `sfc_tile_approach.f90`. It contains the subroutines
     - `tile_define_urban_canopy`:
     - `tile_define_vegetation_canopy`: These two routines are called in the module `organize_data.f90` after reading the initial and the first two boundary data sets (not in `src_input.f90` as in COSMO-5.0-clm9, because after the first boundary data set has been read, also the initial data can be modified again).
     - `tile_filling`: This new subroutine fills all tiles with the initial values and is also called in `organize_data.f90`, as the routines above.
     - `tile_average_ground`: This routine is written for the blocked data format now and is called just after TERRA.
     - `tile_average_near_surface`:
     - `tile_average_near_surface_blocked`: This routine is called after the call to the turbulence transfer scheme. It is now written with an argument list and is the blocked version of `tile_average_near_surface`.

2. The namelist variable `tle` has been renamed in `ntiles` (is a more "speaking name").

3. The external parameter data field for the total impervious surface-area index is called `ISA` in the version COSMO-5.0-clm9, but is now called `FR_PAVED` (similar to `FR_LAND`). This has already been implemented at DWD in the GRIB (shortNames) environment. The actual implementation in COSMO-Model 5.04g_urb1 accepts both names (but this is only a hack, because an extra GRIB 1 number is now used for `ISA`).

4. In principle, the new version of the turbulence scheme needs another external parameter `SSO_STDH` (from the SSO scheme). This parameter was not available in the test data set, therefore its usage has temporarily been switched off (hardcoded in COSMO-Model 5.04g_urb1).

5. In `near_surface`, a part "HSM" has been implemented, but only for `itype_synd == 1`, which is normally not used any more.
   This has not yet been implemented in COSMO-Model 5.04g_urb1.

6. In module `src_slow_tendencies_rk.f90`, a part has been implemented in subroutine `implicit_vert_diffusion_uvwt` for "additional security". In my opinion this is not necessary for COSMO-Model 5.04g_urb1, because within TERRA and `tile_average_ground` all variables are only treated for landpoints.

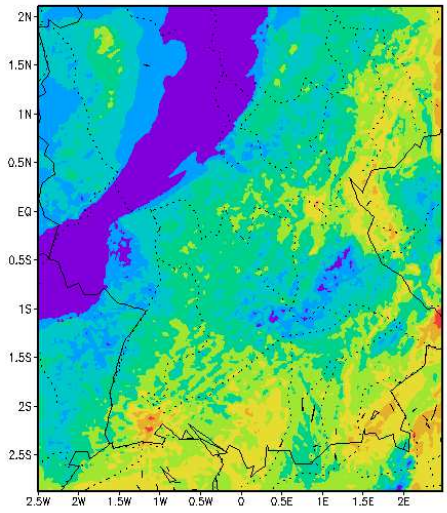
7. Also in module `src_slow_tendencies_rk.f90`, the sensible heat flux is modified by substracting the field `ahf_now` when computing the vertical diffusion of the tendencies. With the new COSMO-ICON physics there is the possibility to compute this vertical diffusion after the physics. This is controlled with the namelist switch `itype_vdif`:

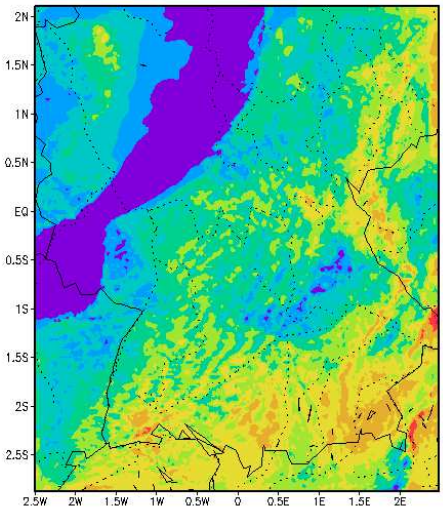
   -1: Vertical diffusion is computed in the dynamics (old behaviour)

   +1: Vertical diffusion is computed after the physics in the blocked data structure. Modification of the sensible heat flux with `ahf_now` is not yet implemented here (still have to think how to do it best).

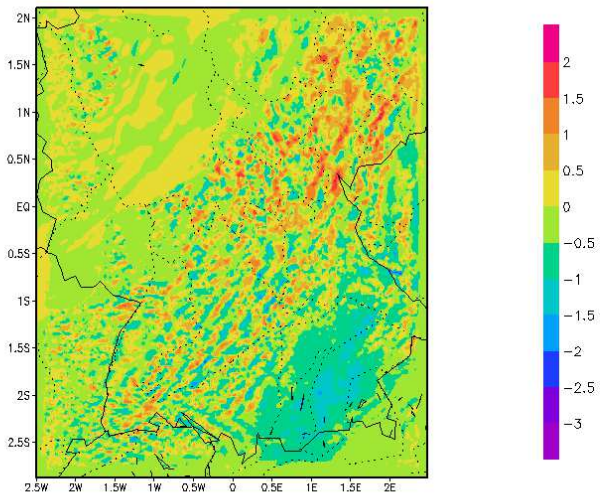
5. Tests

A data set has been provided by Hendrik Wouters for 1st of July, 2012, for up to 15 hours in NetCDF data format. Tests have been performed with COSMO-5.0-clm9 and with COSMO-Model 5.04g_urb1. The following pictures show the 2m temperature computed by COSMO-5.0-clm9 (left) and by 5.04g_urb1 (right). This is just to show that the new version is running and not producing nonsense.





The difference between these two fields is shown below:



Runs have also been performed to test, whether the version COSMO-Model 5.04g_urb1 gives the same results as version COSMO-Model 5.04g without TERRA_URB. This is nearly true, depending on the choice of `itype_vdif`:

-1: Vertical diffusion is computed in the dynamics (old behaviour): Here I still have a problem. Results are not identical

+1: Vertical diffusion is computed after the physics in the blocked data structure. With

this option, results are bit identical.

Still searching, where the problem is.

5. Major Changes between COSMO Versions 5.0 and 5.04g

5.1. Source Code

The following list gives the major changes in the COSMO-Model since version 5.0. Most of these changes had only a minor impact on the results. Only the bug fix in the dynamics for slope-dependent divergence damping coefficients showed clear differences in the results (with a better verification for our NWP tests).

The replacement of the turbulence and the soil and surface schemes by the ICON version has a major impact on the results, depending on the namelist configuration used (see Section 6).

For a full list of changes for each version, please visit
`http://www.cosmo-model.org/content/model/releases/histories/default.htm`

Version 5.01:

- `src_slow_tendencies_rk.f90`: Use `t_g` instead of `t_s` for the flux computations.
- `pp_utilities.f90`: Optimization of the gamma-function.
- Removal of inconsistencies for the tracers
- Work in Dynamics:
  - targeted diffusion to avoid cold pools
  - reformulation of divergence damping coefficients in the new fast-waves solver
  - adaptation of the Runge-Kutta dynamical core to the SPPT (stochastic perturbation of physics tendencies)
- Modifications to lateral Davies relaxation

Version 5.02:

- Bug fix for computation of `kflat` (only when using GRIB2)
- Bug fix in use of MPI data types (only when using `ldatatypes=.TRUE.`

Version 5.03:

- Various bug fixes in the dynamics, TERRA and the radiation.

Version 5.04a:

- Bug fix in the dynamics for slope-dependent divergence damping coefficients

Version 5.04b:

- Introducing a new boundary condition module (only numerical changes)

Version 5.04a-g:

- Introducing ICON versions of parameterizations for turbulence, soil model, sea-ice scheme and FLake. But these schemes can be run in a configuration which reproduces the results from the corresponding COSMO schemes rather closely (see Section 6).

5.2. Namelist Variables

The following namelist variables have been deleted or have changed their meaning (range, default value):

`/DYNCTL/`:

Name	Change	Comment
`crltau`	`renamed`	The new name now is `crltau_inv` and is just the inverse of `crltau`. Since the default is 1.0, this is not changed. Only if you used a different value, you have to adapt that now.
`lexpl_lbc`	`deleted`	No more explicit formulation of lateral boundary relaxation possible.
`divdamp_slope`	`changed`	This variable changed its default and the possible range (due to the bug fix). Before it was 10.0 < `divdamp_slope` <= 100.0 (with default 20.0). Now it is 0.1 < `divdamp_slope` <= 3.0 (with default 1.0).

`/PHYCTL/`:

In `/PHYCTL/` the following namelist variables have been deleted, because now only the multi-layer version of TERRA is possible: `lmulti_layer`, `nlgw`, `nlgw_ini`, `nlgw_bd`

A few variables have been added for the COSMO-ICON physics: `itype_vdif`, `ltkeshs`, `idiag_snowfrac`, `cwimax_ml`

Please see the web site cited above for a description of these variables.

`/TUNING/`:

In `/TUNING/` the following namelist variables have been deleted: `wichfakt`, `securi`

5.3. A Special Change for the Climate Mode

The treatment of statistically processed fields in the COSMO-Model is different for the NWP- or for the CLM-mode. This is especially true for fields that are accumulated, like the total precipitation `TOT_PREC`. In NWP-mode these fields are summed up from the beginning up to the end of the forecast, while in CLM-mode these fields are reset to 0.0 after every output step.

In COSMO-Model Version 5.04f we introduced special fields for cell tracking, which also have to be reset to 0.0 after every output. Therefore we had to change the handling of such fields and introduced additional namelist variables to control the way how and when statistically processed fields are reset.

We introduced 4 categories of statistically processed fields:

- Temperatures, e.g.: `TMIN_2M`, `TMAX_2M`
- Winds, e.g.: `VMAX_10M`, `VABSMX_10M`
- Summations, Averages, e.g.: `TOT_PREC`, `ASHFL_S`
- Cells, e.g.: `LPI_MAX`, `TCOND_MAX`

Resetting the variables for each category can now be controlled by the namelist variables

- `ireset_temps`
- `ireset_winds`
- `ireset_sums`
- `ireset_cells`

Possible values for these four variables are:

- `0:` no resetting at all (default for sums and averages)
- `1:` reset after given time interval (default for temps and winds)
- `2:` reset after every output (default for cells)

These defaults ensure the current behaviour of the COSMO-Model in NWP-mode.

In CLM Mode (`lbdclim=.TRUE.`), the namelist variable `ireset_sums = 2` has to be chosen to reset all summation variables after every output step!

6. Recommended Namelist Configurations for COSMO-Model 5.04g

At DWD we still have problems when activating all new features in the COSMO-ICON physics, therefore it is difficult to recommend a special namelist configuration. We tested three different configurations:

- Old Settings: Turbulence and TERRA are run in a way to reproduce the results of the old COSMO-Versions as close as possible.
  These settings are now preferred at DWD.
- Conservative: The settings for the turbulence scheme activate the new parts of the code, while settings for TERRA still are for the old scheme. Alternatively, also some new features of TERRA can be activated (e.g. `itype_evsl=4`).
- Advanced: These settings come very close to the ICON settings, but COSMO results are not really satisfying. Please note that you need to run INT2LM also with special namelist settings:
  - `itype_aerosol = 2`
  - `itype_ndvi = 1`
  - `itype_rootdp = 4`
  - `lemiss = .TRUE.`
  - `lstomata = .TRUE.`

List of all namelist variables that have to be set for the three different configurations:

Name	Old Settings	Conservative	Advanced
/TUNING/			
tkhmin	0.4	0.75	0.75
tkmmin	0.4	0.75	0.75
rat_sea	20.0	7.5	7.5
patlen	500.0	750.0	750.0
turlen	150.0	500.0	500.0
a_hshr	0.2	2.0	2.0
c_soil	1.0	1.75	1.75
/PHYCTL/			
loldtur	.TRUE.	.FALSE.	.FALSE.
itype_vdif	-1	-1	1
ltkeshs	.FALSE.	.TRUE.	.TRUE.
itype_sher	1	0	0
imode_tran	1	0	0
imode_turb	1	1	1
icldm_tran	0	2	2

Name	Old Settings	Conservative	Advanced
itype_aerosol	1	1	2
itype_root	1	1	2
itype_heatcond	1	3	3
itype_evsl	2	2	2
idiag_snowfrac	1	1	1
cwimax_ml	1.0E-6	0.0005	0.0005
lemiss	.FALSE.	.FALSE.	.TRUE.
lstomata	.FALSE.	.FALSE.	.TRUE.