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

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- **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 cylce 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 habe 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 z0m / z0H = 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)

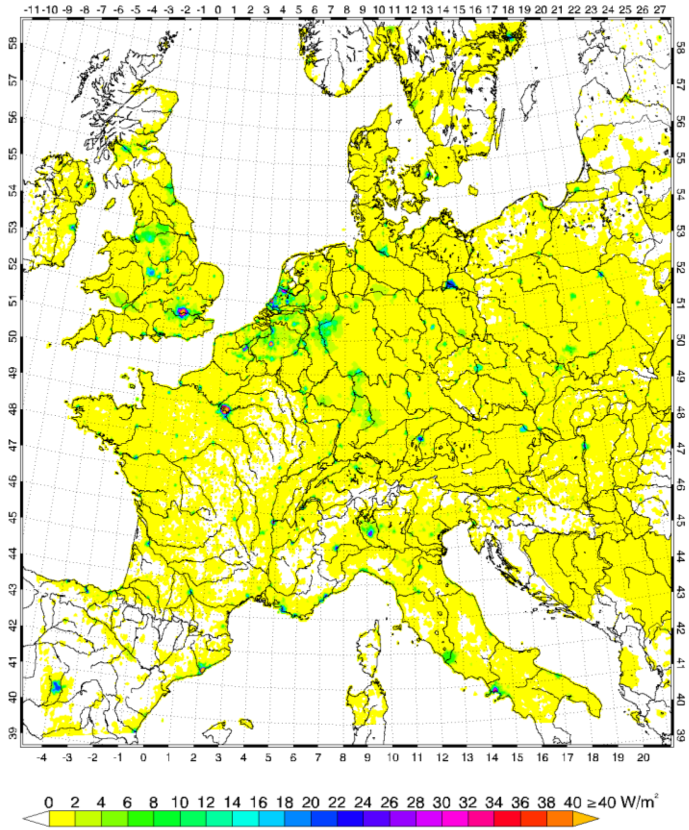
- We also discussed about the following possible future extention:

  - 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

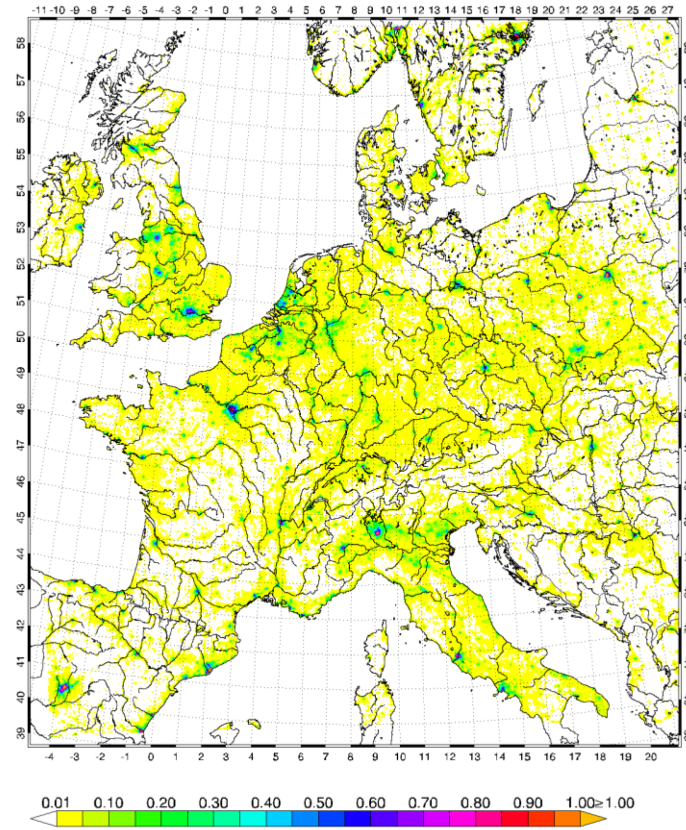
Annual mean AHF @ COSMO-D2 resolution



	Min	Max	Mean	Var
AHF (colors):	0.000	141.981	0.451	2.797

COSMO-D2 resolution

ISA (impervious surface area) @ COSMO-D2 resolution



	Min	Max	Mean	Var
ISA (colors):	0.000	1.000	0.015	0.002

COSMO-D2 resolution

Technical implementation roadmap from our 2014 Workshop

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- **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)**

Coupling to TURBTRAN

- At the moment, the z0m/z0H 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 z0m/z0H ratio.
  - Different possibilities to make use of this:
    - Prescribe constant A0-parameter (which is a „building surface index“ at the surface) representing bluff bodies (~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: $$\ln\left(\frac{z_{0m}}{z_{0T}}\right) = 1.29\left(\frac{z_{0m}u_*}{\nu}\right)^{0.25} + 2$$

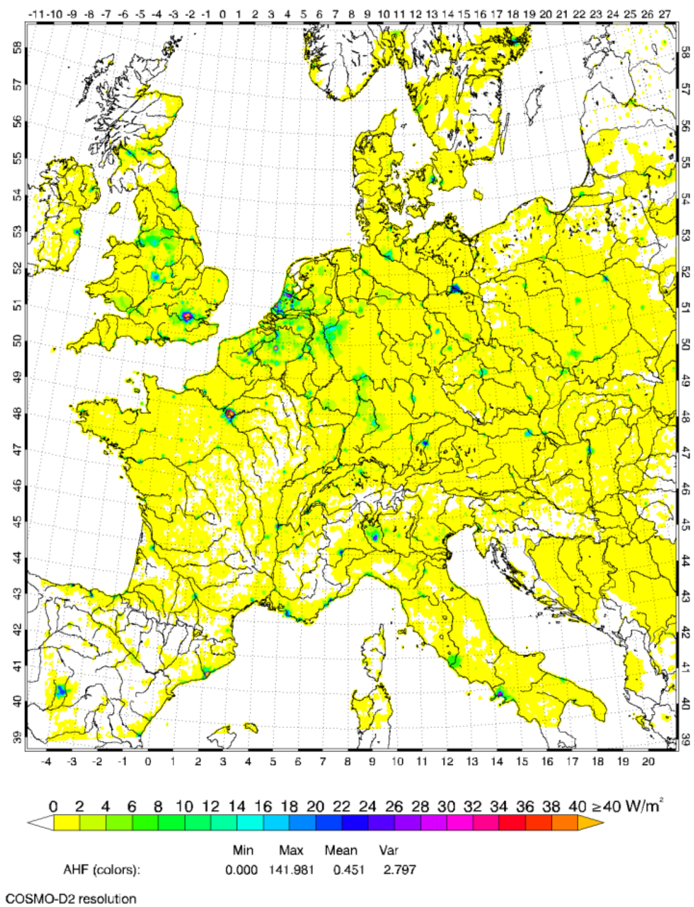
Zilitinkevich: $$\ln\left(\frac{z_{0m}}{z_{0T}}\right) = 0.13\left(\frac{z_{0m}u_*}{\nu}\right)^{0.45}$$

    - In TURBTRAN theory, refine parameterization of vertical profile of A (A0 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*

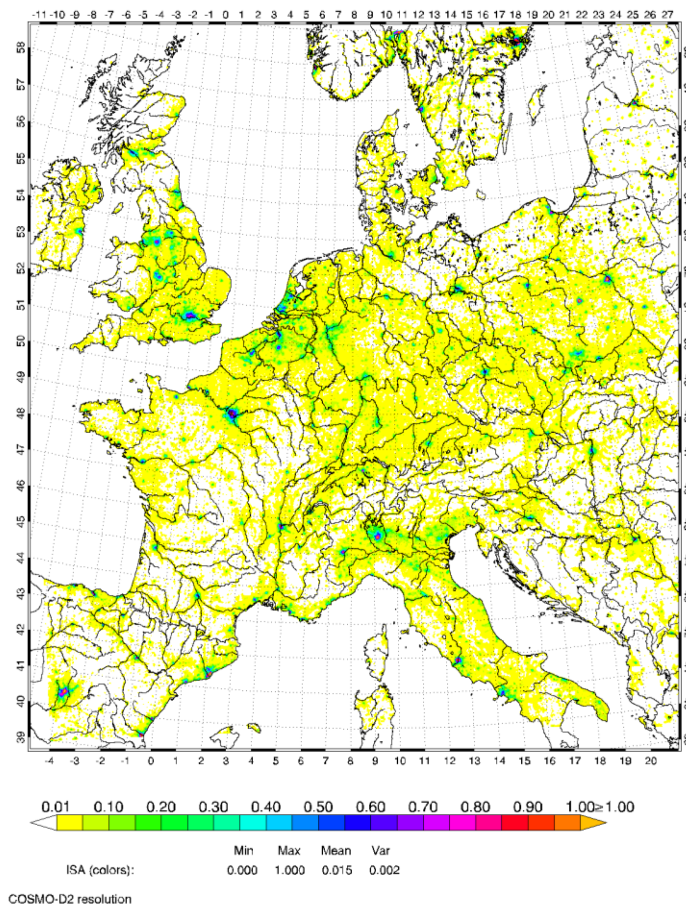
New external parameters

- ➔ 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

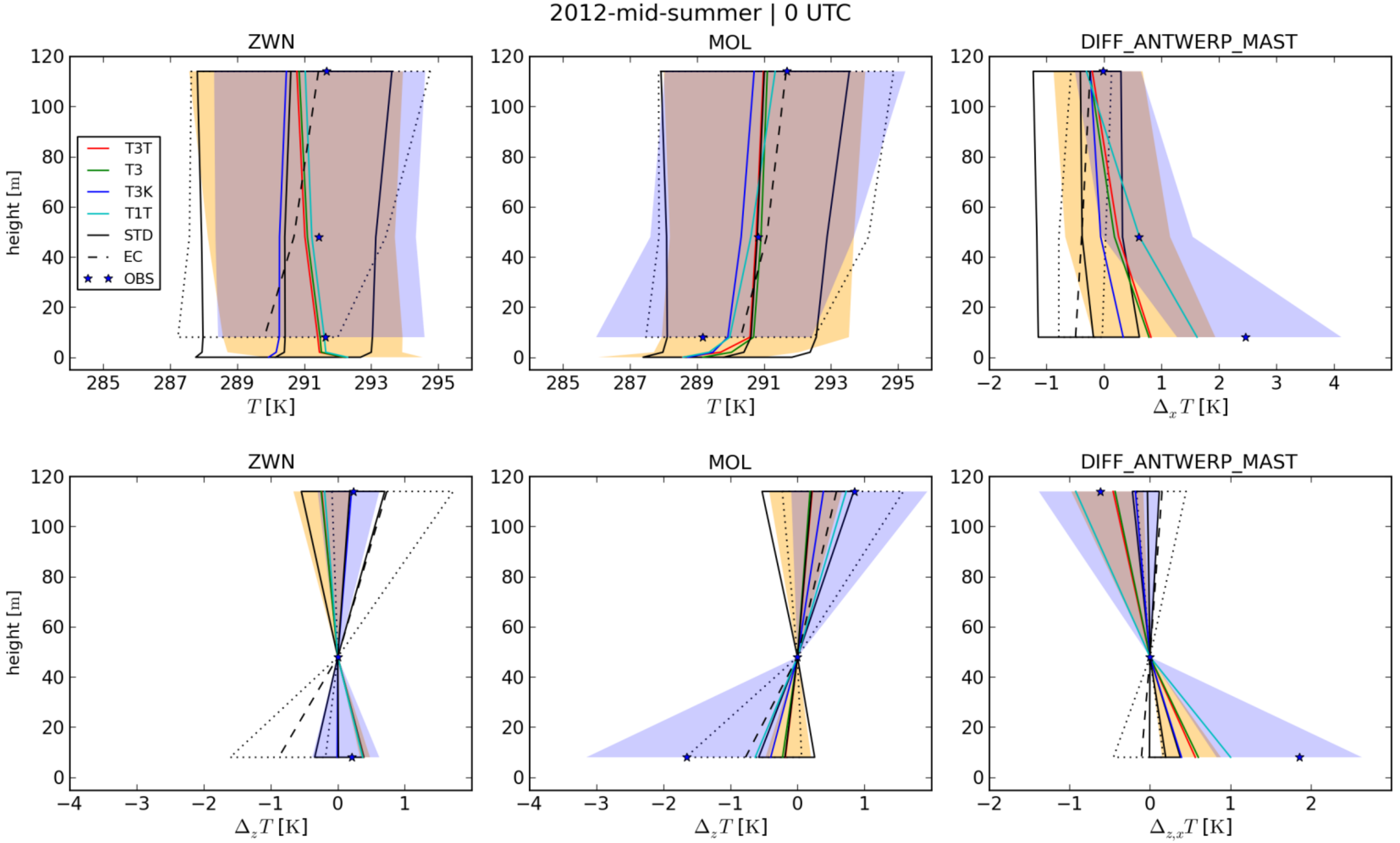


Results

- **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

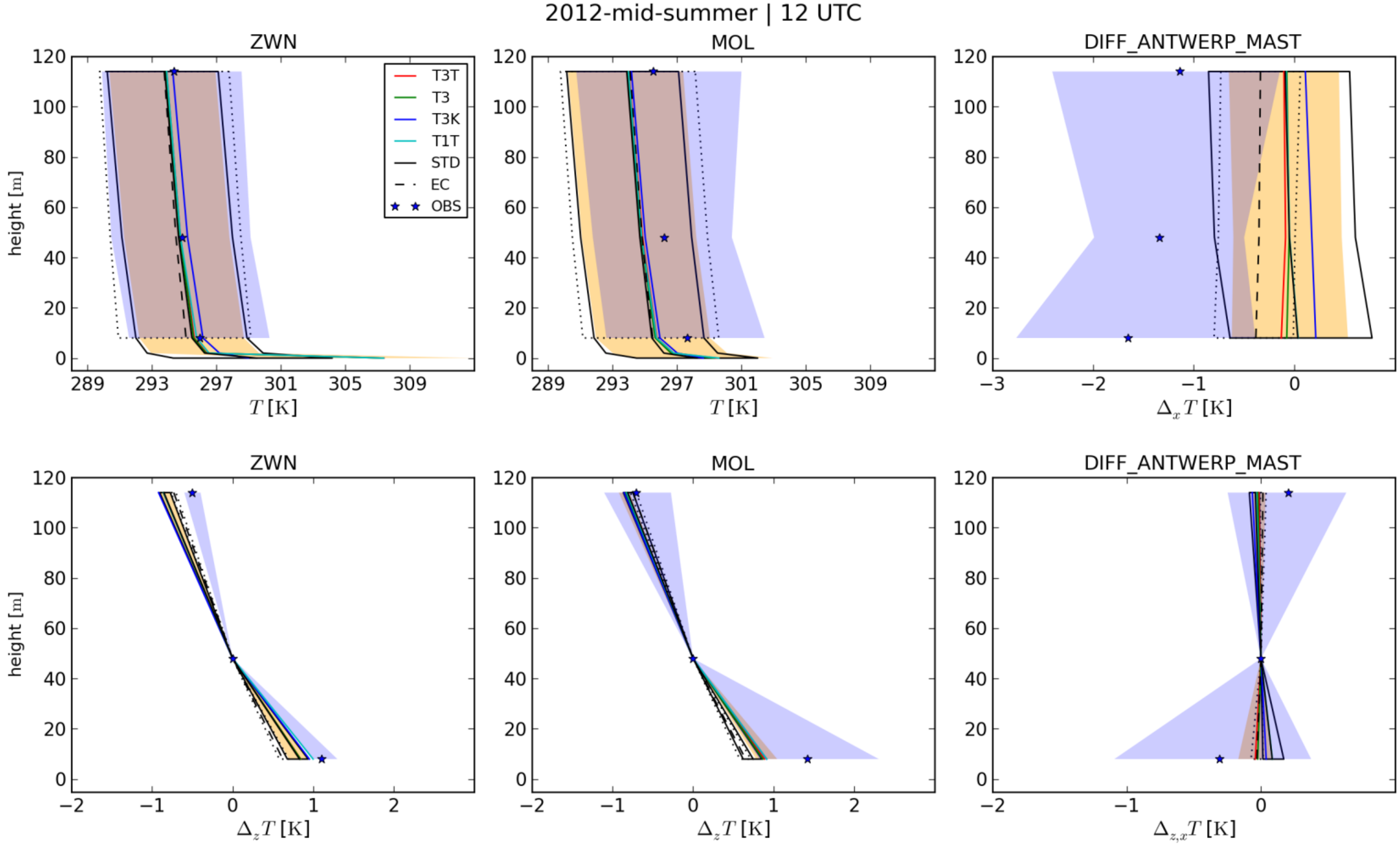
Results

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



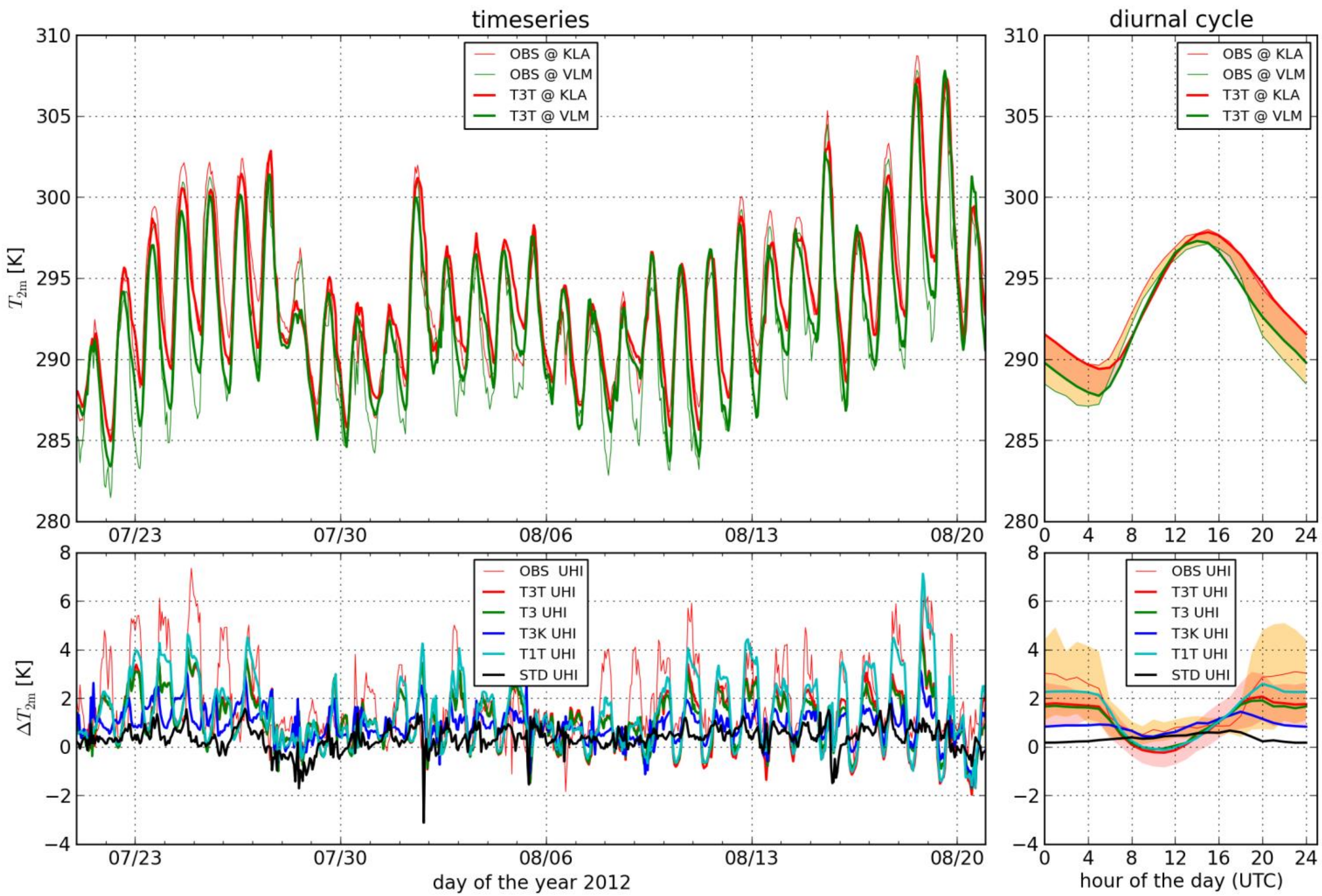
Results

- 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

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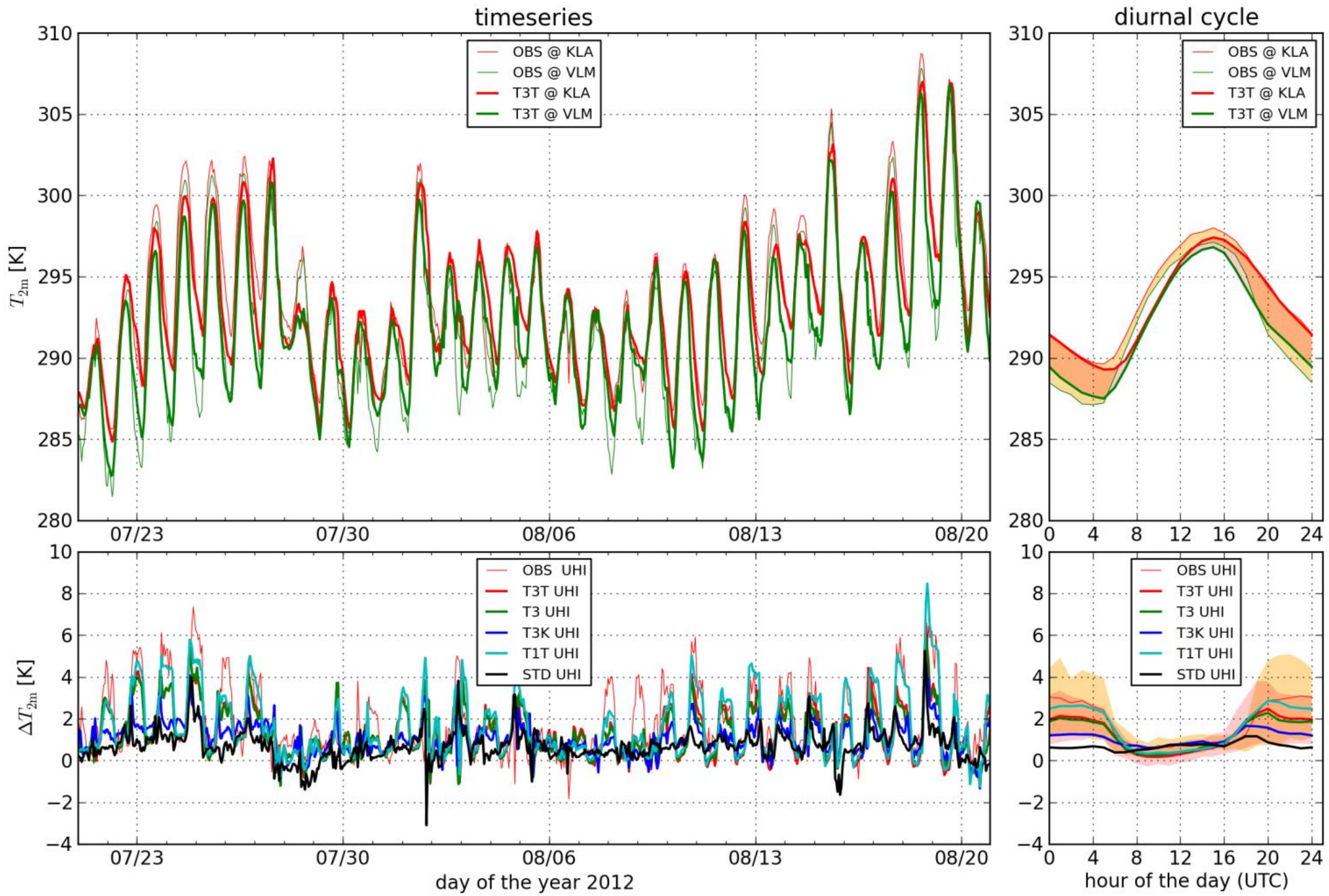
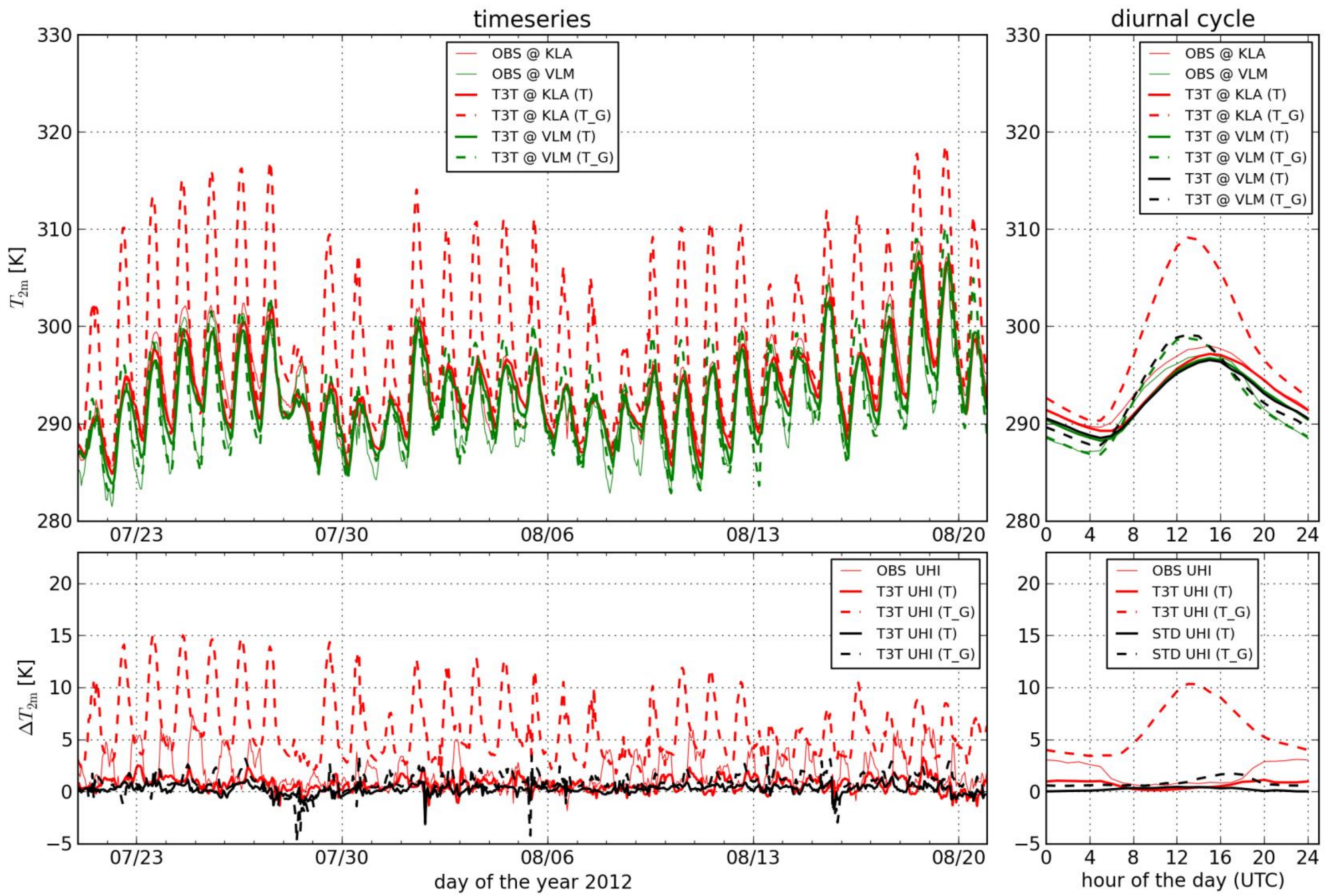
- CLM Simulations over 3 months period (2.8 km); average T for 12 UTC
- KLA: station in Antwerp   VLM: rural station to the East
- T_5M offline diagnosed according to Monin-Obukhov by Hendrik



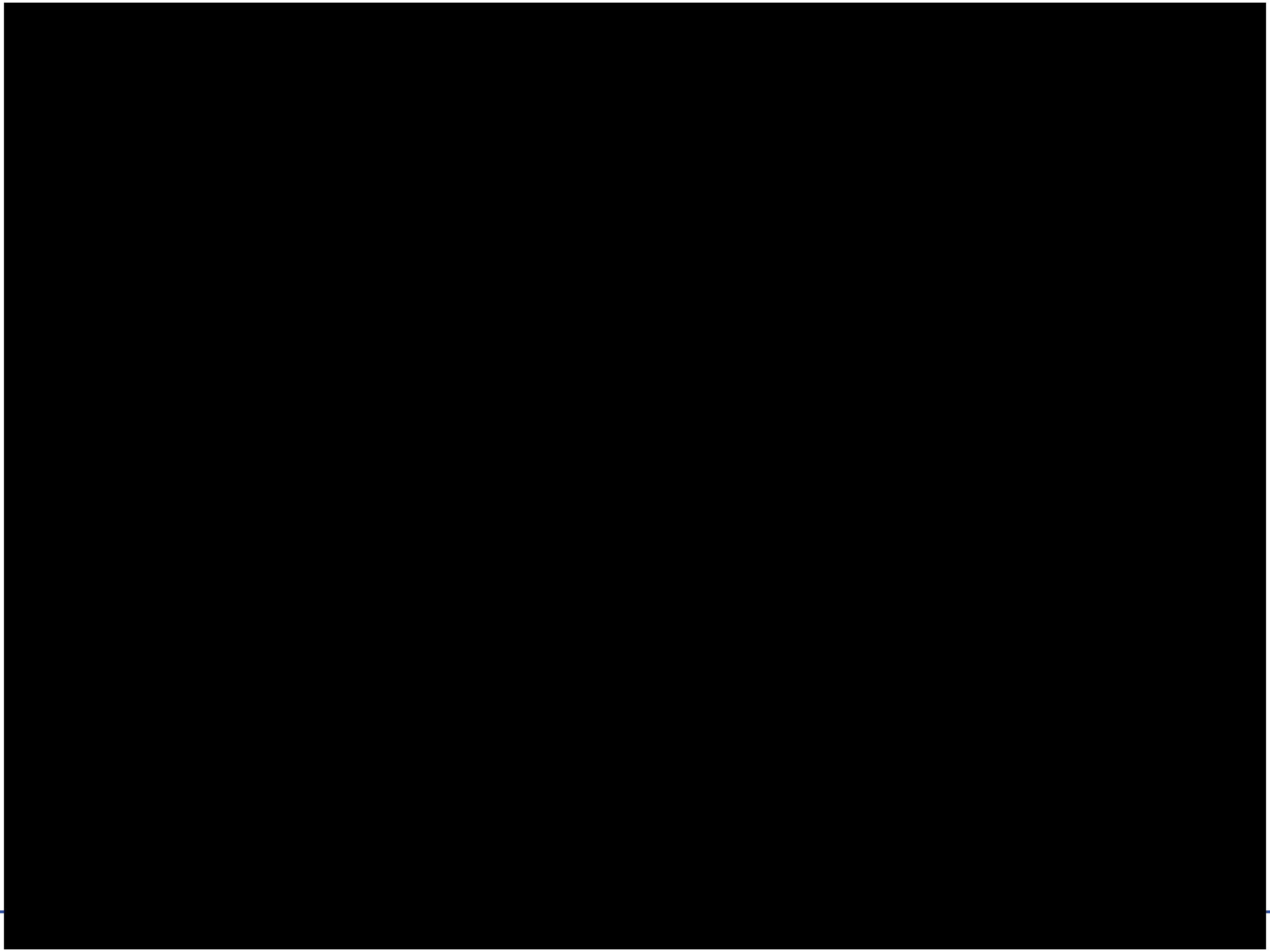
Results

- 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 T1T:



Open questions: turbtran

- 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?

$$u_* = |v_h| \sqrt{C_h}$$

$$r_{s0}^H = z_{0m} \ln\left(\frac{z_{0m}}{z_{0T}}\right)$$

Open questions: tile averaging

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

$$\overline{H} = \overline{\rho_s}\, c_{pd}\, \overline{C_h}\, |v_h| \left(\overline{T}_g - \left(\frac{p_s}{p_{ke}}\right)^{\kappa} T_{ke}\right)$$

$$\overline{E} = \overline{\rho_s}\, L_v\, \overline{C_h}\, |v_h|\, (q_{vke} - \overline{q}_{vs})$$

$$\overline{\rho_s} = \frac{p_s}{R_d\, \overline{T}_g (1 + 0.61 \overline{q}_{vs})} \quad (????)$$

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

$$H_i = \rho_{si}\, c_{pd}\, C_{hi}\, |v_h| \left(T_{gi} - \left(\frac{p_s}{p_{ke}}\right)^{\kappa} T_{ke}\right)$$

$$E_i = \rho_{si}\, L_v\, C_{hi}\, |v_h|\, (q_{vke} - q_{vsi})$$

$$\rho_{si} = \frac{p_s}{R_d\, T_{gi} (1 + 0.61 q_{vsi})}$$

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:

$$\overline{T}_g = \sum a_i T_{gi}$$

$$\overline{H} = \sum a_i H_i \quad \stackrel{!}{=} \quad \overline{\rho_s}\, c_{pd}\, \overline{C_h}\, |v_h| \left(\overline{T}_g - \left(\frac{p_s}{p_{ke}} \right)^{\kappa} \right)$$

$$\overline{E} = \sum a_i E_i \quad \stackrel{!}{=} \quad \overline{\rho_s}\, L_v\, \overline{C_h}\, |v_h| \left(q_{vke} - \overline{q}_{vs} \right)$$

Open questions: tile averaging

- Accepting the definition of T_g and applying it in the second equality leads to:

$$\sum a_i H_i = c_{pd}\,|v_h| \underbrace{\sum a_i \rho_{si} C_{hi} \left(T_{gi} - \pi_s^\kappa T_{ke}\right)}_{A}$$

$$\stackrel{!}{=} c_{pd}\,|v_h|\,\overline{\rho_s}\,\overline{C_h} \underbrace{\left(\left(\sum a_i T_{gi}\right) - \pi_s^\kappa T_{ke}\right)}_{B}$$

- Solving for a modfied transfer coefficient:

$$\overline{C_h}^* = \overline{\rho_s}\,\overline{C_h} = \frac{\left(\sum a_i \rho_{si} T_{gi} C_{hi}\right) - \pi_s^\kappa T_{ke} \left(\sum a_i \rho_{si} C_{hi}\right)}{\left(\sum a_i T_{gi}\right) - \pi_s^\kappa T_{ke}}$$

Open questions: tile averaging

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- **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 ∞), which cannot be accepted because C_h^* also enters the computation of the average E. **Solution:**

if: $A \neq 0 \wedge B \neq 0 \quad \Rightarrow \quad \overline{C_h}^* \neq 0$

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

if: $A = 0 \wedge B \neq 0$ set $\overline{T}_g = \pi_s^\kappa T_{ke} \;\wedge\; \overline{C_h}^* = \text{const} \neq 0$

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

- **Then:**

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

- **… 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.