Activities and updates from RHM/MSU team

Mikhail Varentsov

and COSMO-Ru team

Outline

1. Overview TERRA_URB developments
2. Testing recent version COSMO + TERRA_URB version
3. Towards improving external parameters for PP CITTA
4. Outlook

History of COSMO+TERRA_URB development

- **cosmo_191107_5.05_urb5**: a basic stable version with TERRA_URB which we have as an outcome from AEVUS PT
- **cosmo_191107_5.05_urb5up* with 2D urban canopy parameters, see Varentsov et al. (2020)**

  … several intermediate versions with different bug fixes and minor developments

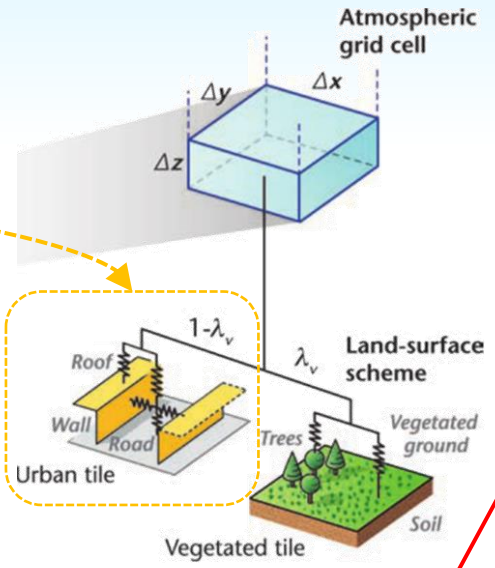
- **cosmo_191213_5.05_urb6up5 (September 2020):**
  - Provided to Ulrich Schättler for merging to GitHub
  - Used for simulations in recent TERRA_URB papers by **Varentsov et al. (2020)** and **Garbero et al. (2021)**
- **cosmo_210309_5.10_beta**
  - Several bugs found and fixed, resulting in intermediate versions 5.10f, 5.10f2
  - **Probably a bug related to impervious surface evaporation revealed (fixed in master version, yet I am not fully sure that it is a bug)**
- **COSMO 5.11 (5.12) with TERRA_URB in master version in GitHub! Congrats!!!**
  - Reviewed by me in GitHub, but not tested yet, planned to be tested ASAP

Development around external parameters

- **Basic external parameters for TERRA_URB in (Wouters et al., 2016):**
  - Impervious area fraction (ISA)
  - Annual-mean anthropogenic heat flux (AHF)

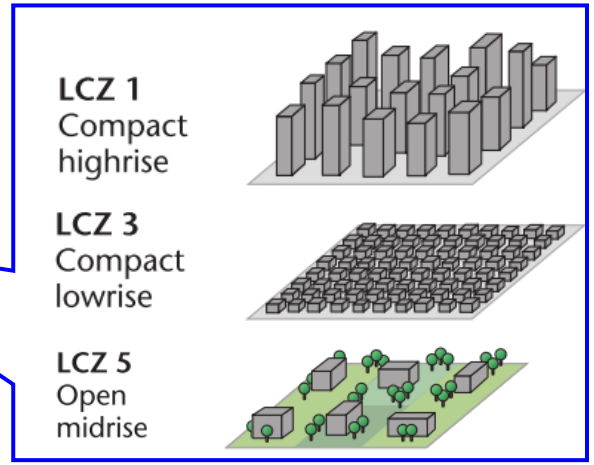
- **Additional 2D external fields to replace hard-coded values introduced in v5.05urb:**

Urban canopy parameters (input of SURY)		
Parameter name	Symbol	Default values
Surface albedo	α	0.101
Surface emissivity	ϵ	0.86
Surface heat conductivity	λ_s	$0.767\,\mathrm{W\,m^{-1}\,K^{-1}}$
Surface heat capacity	$C_{v,s}$	$1.25 \times 10^6\,\mathrm{J\,m^{-3}\,K^{-1}}$
Building height	H	15 m
Canyon height-to-width ratio	$\frac{h}{w_c}$	1.5
Roof fraction	R	0.667



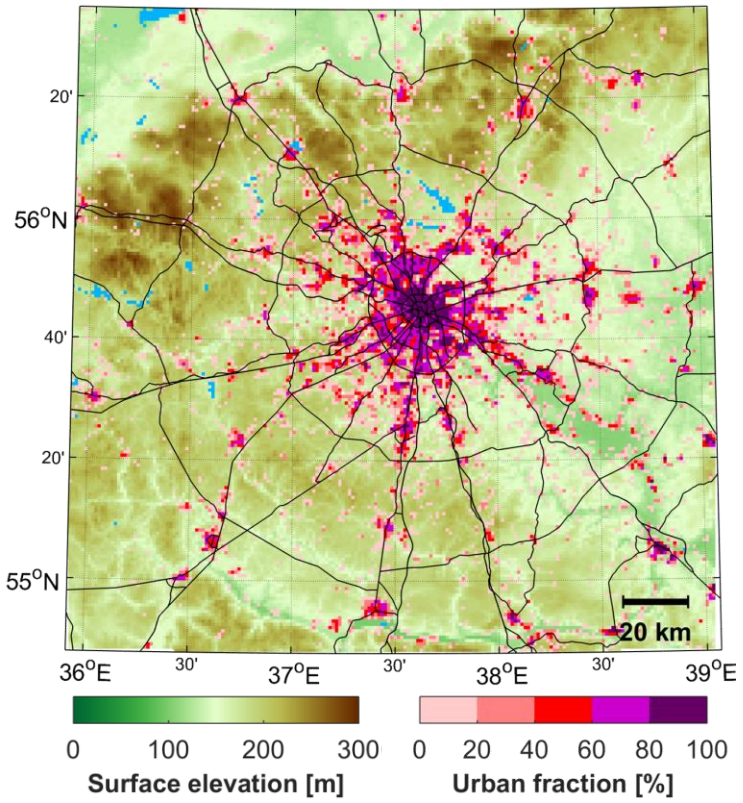
Thermal and radiative parameters of urban materials

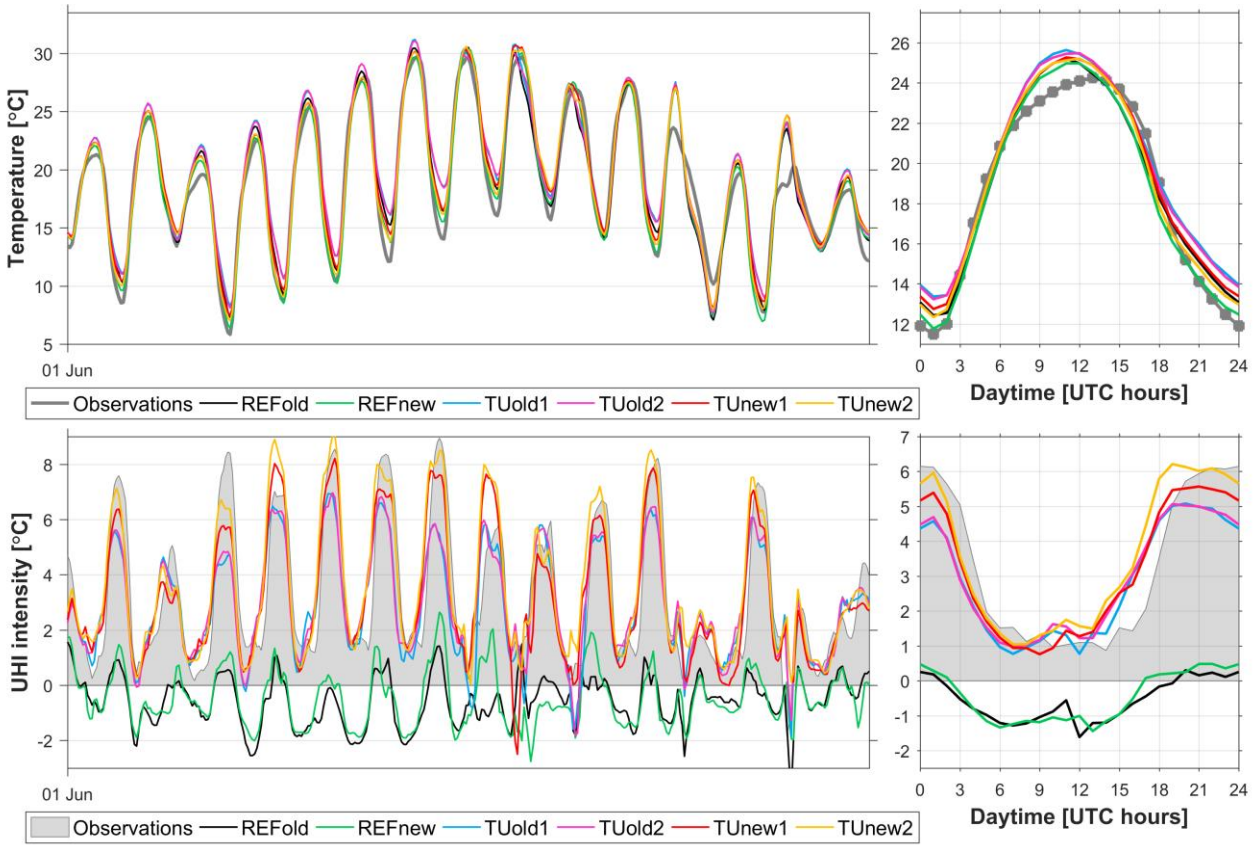
Building morphology parameters



Testing the recent 5.10beta version

- Runs based on TUnew2 simulation from AEVUS paper **(Garbero et al., 2021)**, 1-15 June 2019
- New version tested only for finest 1-km domain, IBC taken from 5.05 run for intermediate domain
- No tuning for rooting depth (fac_rootdp2 = 1 instead of 2.5 in previous runs) since it is limited by 1.5 in v2.10
- GIS-based ISA & AHF, model defaults for thermal and morphological UCPS
- Test runs with zero ISA & AHF (*EMPTY runs)





Testing the recent 5.10beta version

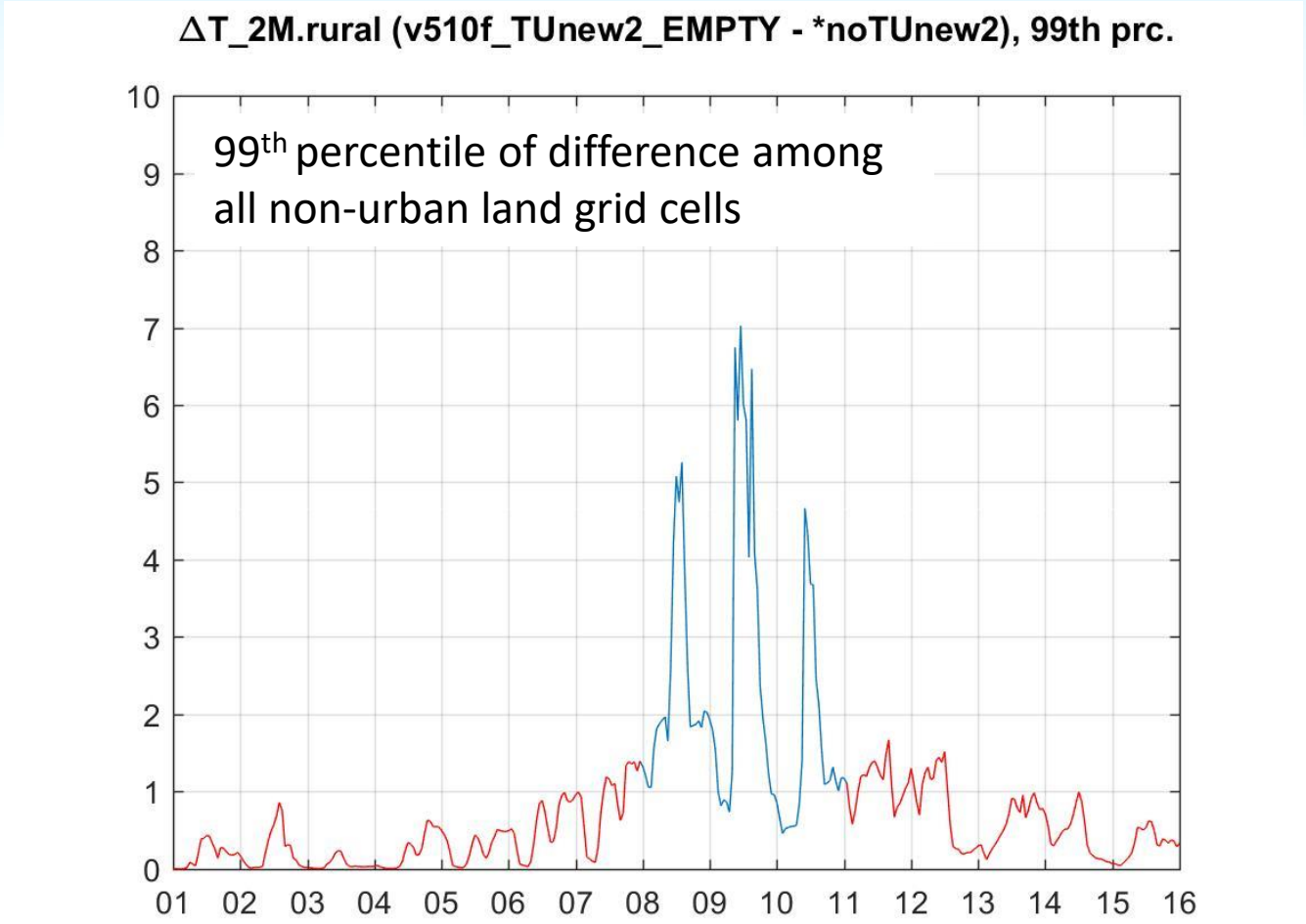
- **Technical test 1:** simulations without TU (***noTU**), with TU and ISA = 0, AHF = 0 **(*EMPTY)** To check is TU implemented correctly.
- **Technical test 2:** simulations with constant UCPs, provided through namelist settings and as 2D fields. To check that 2D parameters are loaded correctly.
- **H-L sensitivity tests:** simulations with higher (H) and lower (L) values of each specific parameter (H_BLD, FR_BLD, H2W, albedo, emissivity, heat capacity and conductivity), to check that UCPs work physically correct.

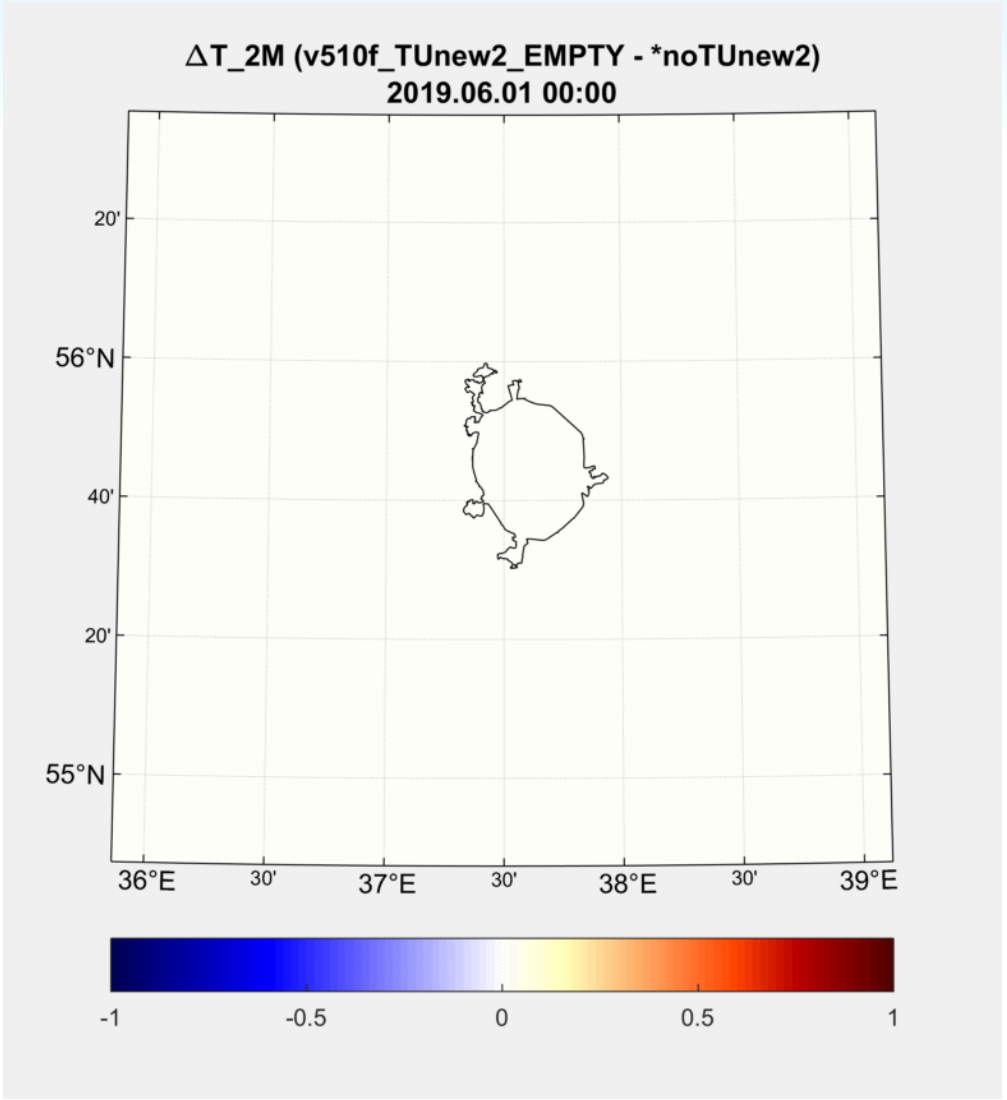
EXP-ID	Urban canopy parameter	Symbol	L	H
A	surface albedo	α	0.10	0.25
B	surface heat conductivity	λ_s [W m^{-1} K^{-1}]	0.200	0.968
C	surface heat capacity	$C_{v,s}$ [10^6 J m^{-3} K^{-1}]	0.321	1.56
D	canyon height-to-width ratio	$\frac{h}{w_c}$	0.75	2.0
E	building height	h [m]	3	30
F	roof fraction	R	0.40	0.70
G	anthropogenic heat emission	AHE	0	2 × FL09

My suggestions (MV columns):

	D (HW)	L (HW)	H (HW)	L (MV)	H (MV)
H2W	1.5	0.75	2	0.5	2
building height	15	3	30	3	30
roof fraction	0.667	0.4	0.7	0.3	0.8
albedo	0.101	0.1	0.25	0.05	0.25
emissivity (1 - thermal albedo)	0.86			0.75	0.95
heat conductivity	0.767	0.2	0.968	0.2	1.3
heat capacity	1.25	0.32	1.56	0.3	2

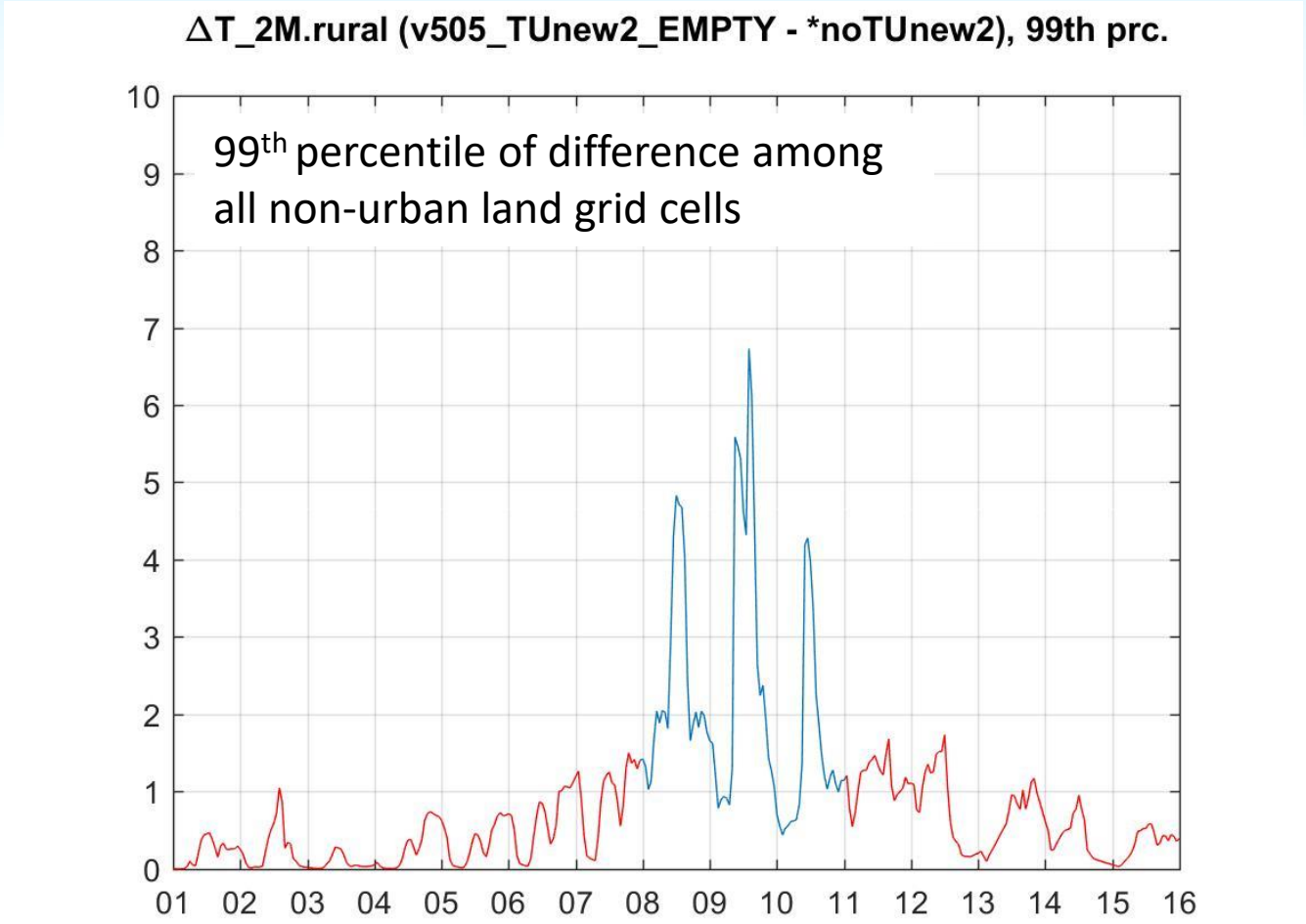
Testing 5.10beta version: technical test 1

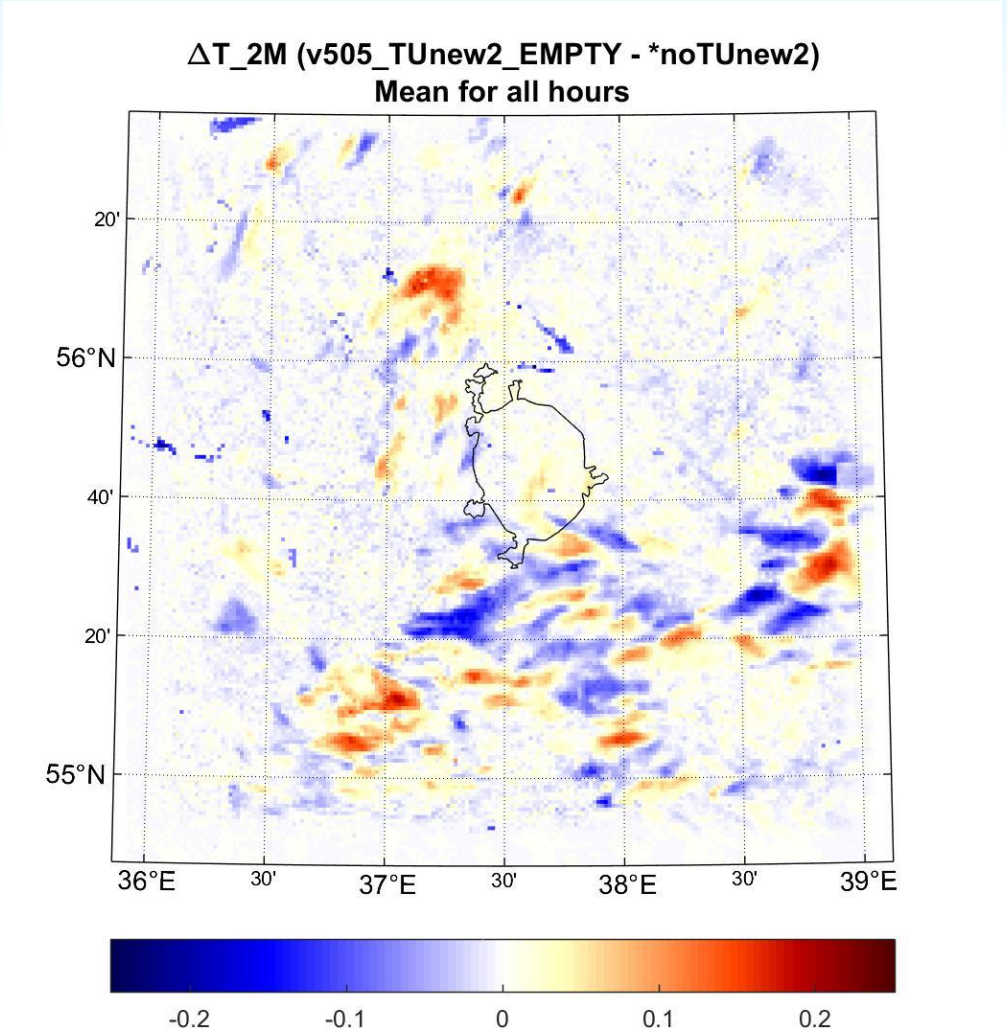




V510: not a systematic difference, but stochastic perturbations of the modelling results

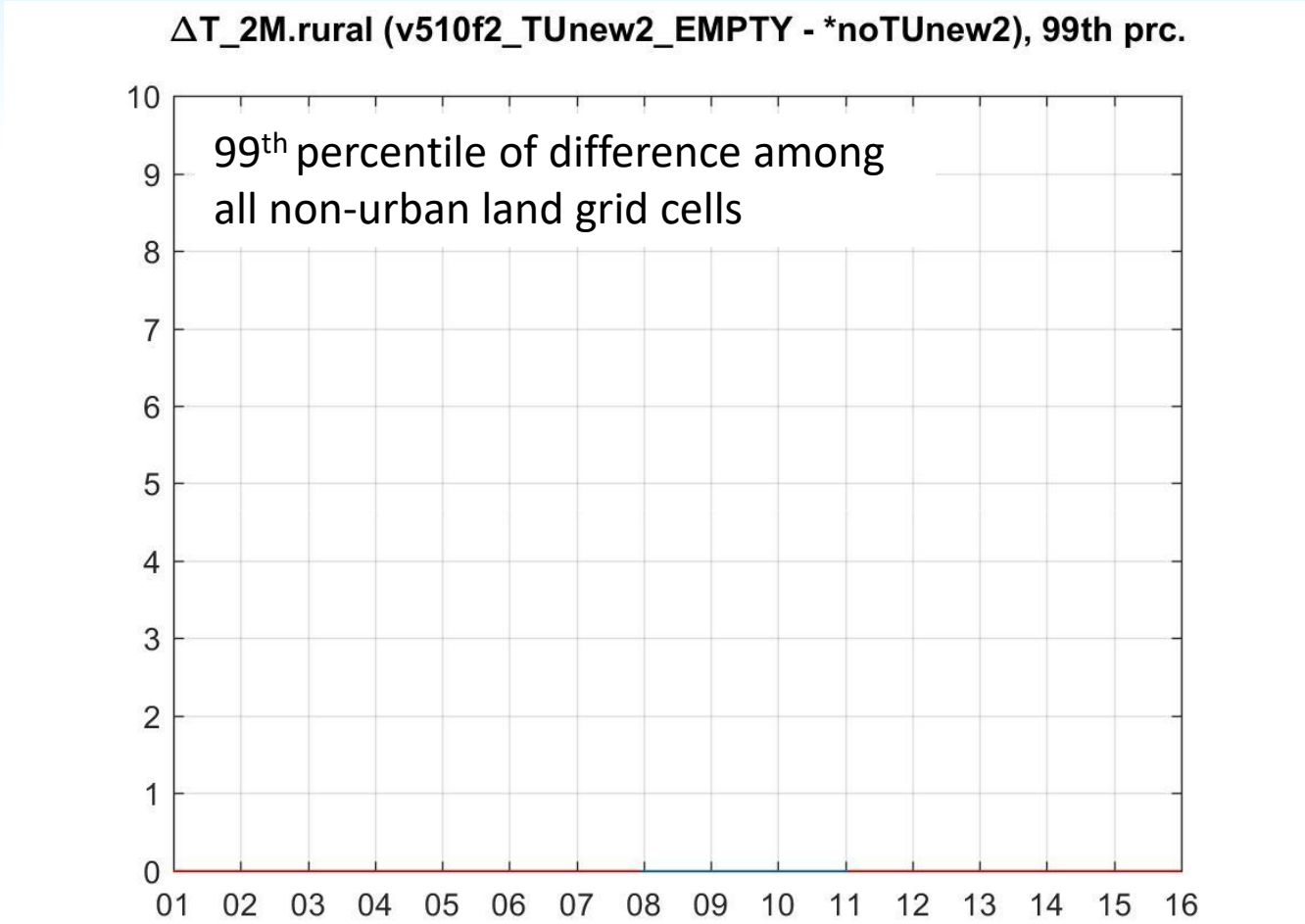
Testing 5.10beta version: technical test 1

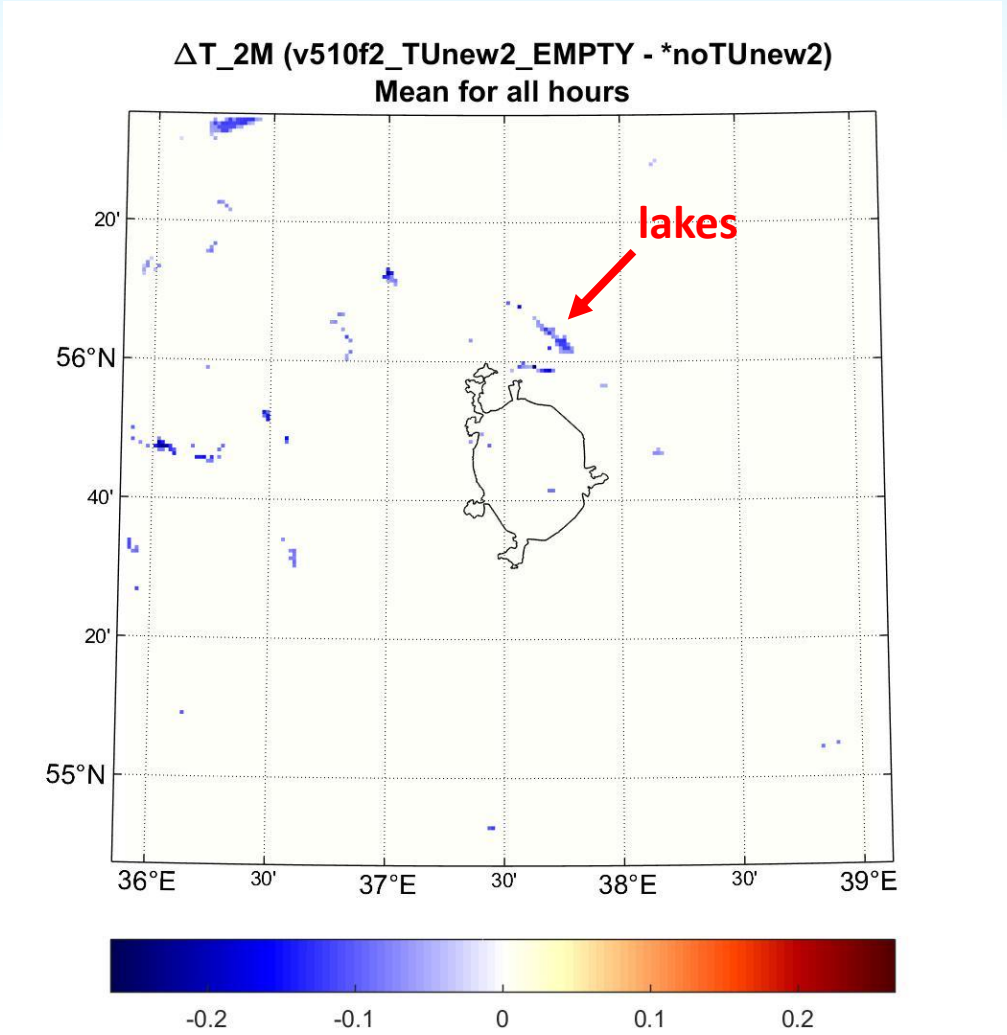




Same patterns in “old” and “well-tested” 5.05urb

Testing 5.10beta version: technical test 1



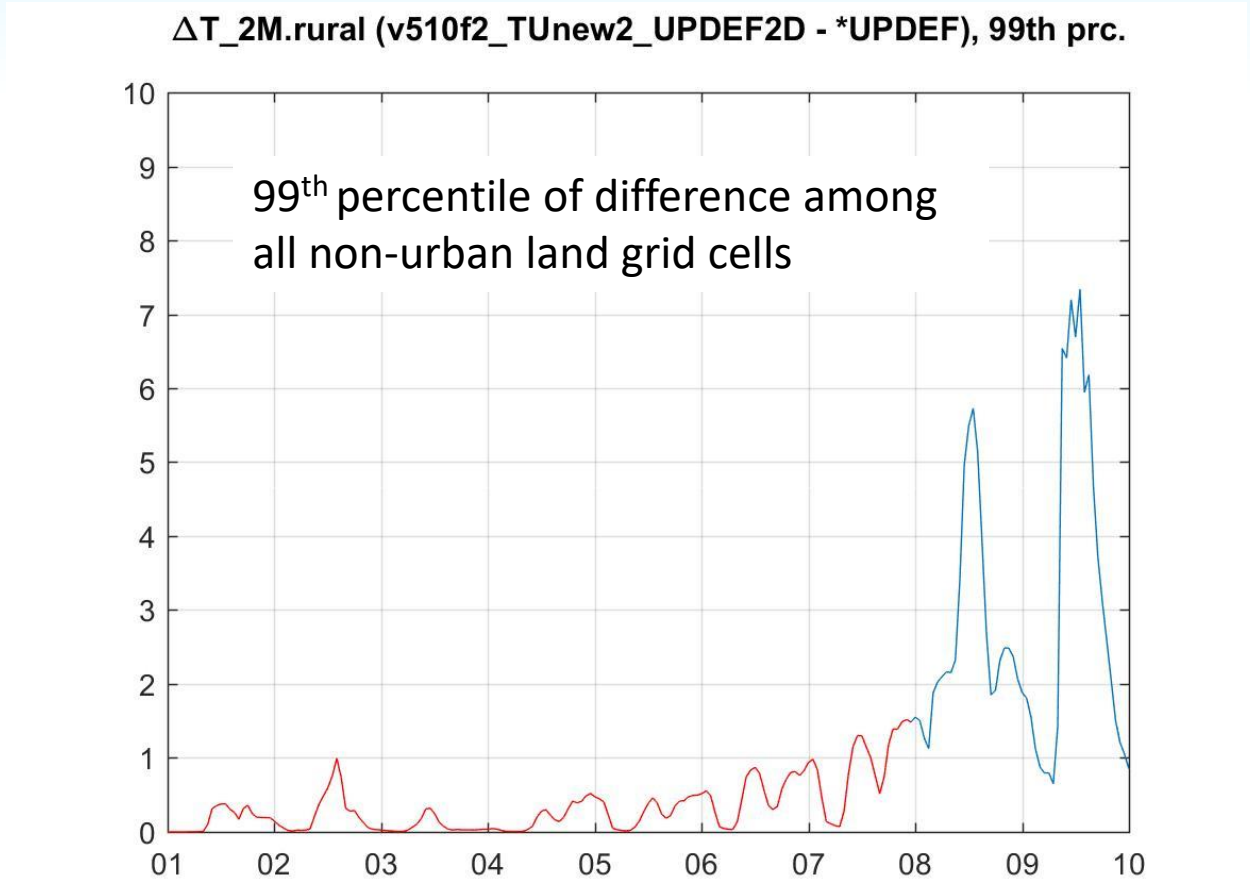


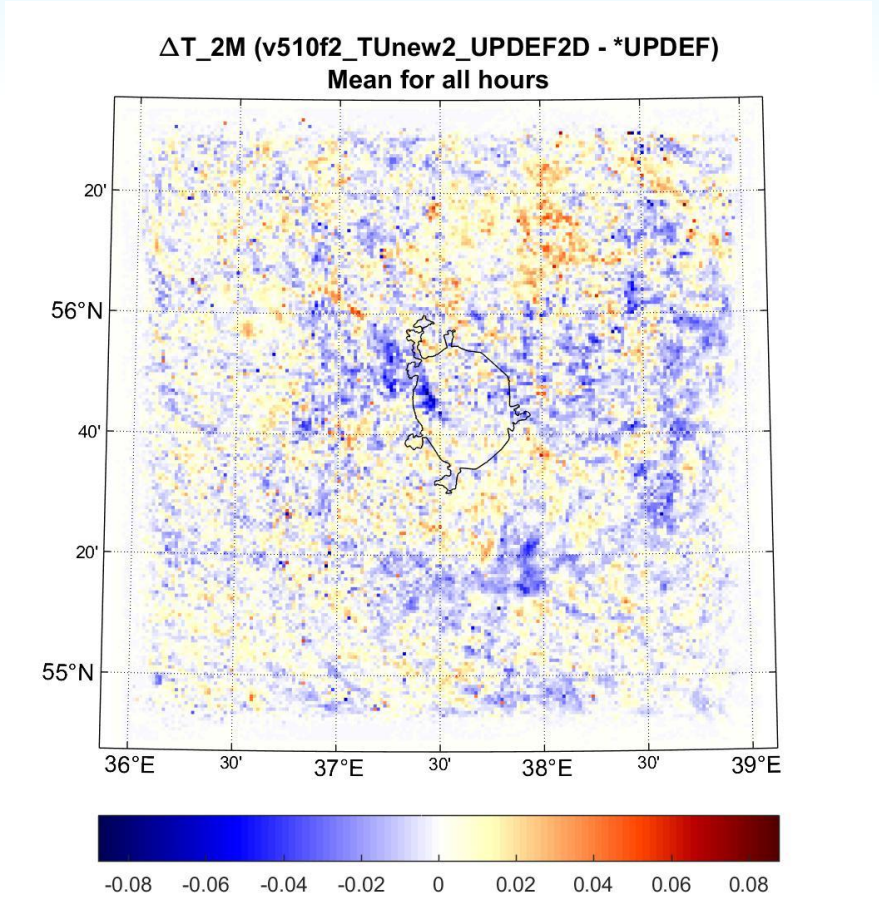
Bug fixed with 5.10f2, thanks to Uli!

The only remaining difference is over lakes (something only in diagnostic, since other grids are not affected)

Testing 5.10beta version: technical test 2

Urban canopy parameters are defined by same values using namelist constants (*UPDEF) or 2D fields (*UPDEF2D)





Explanation from Uli: stochastic effects are due to issues connected single/double precision of URB_FR_BLD and URB_H2W

	urb_fr_bld	ai_uc	alb_red_uc
Reading NL curb_fr_bld=0.69:	0.6899999999999999	1.9300000000000002	0.8160365945195858
Reading ext. field URB_FR_BLD:	0.6899999976158142	1.9300000071525574	0.8160365931047375

Zero differences if changing the way to define only URB_H_BLD!

Comment from Uli:

Parameter curb_h2w vs: URB_H2W: You all probably tested with curb_h2w=1.5, which is the default. With this value we get the same results for both COSMO runs. I also tested with curb_h2w (and URB_H2W) set to 1.7: and then I get different results for the two COSMO runs. I get similar stochastic fluctuations as for curb_fr_bld. My explanation is, that the value 1.5 can be exactly represented in double and single precision and even in the grib packing (if GRIB fields are used for the external parameters, what I do for my tests). But 1.7 cannot, and this leads to stochastic differences during the run time. The same is true for curb_fr_bld.

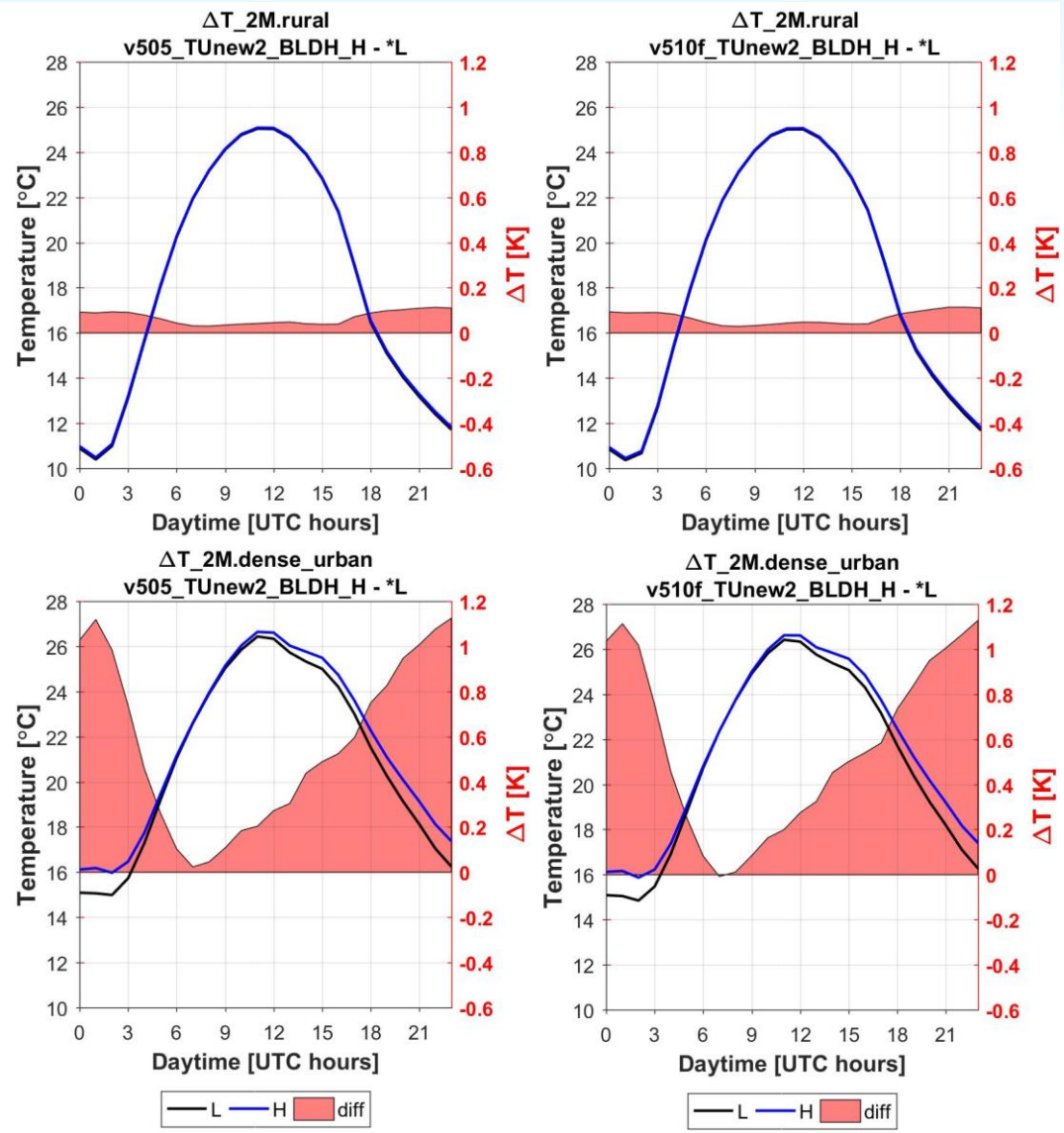
Note that URB_FR_BLD and URB_H2W are used to compute the fields ai_uc and alb_red_uc in src_input.f90, which are not only used in TERRA, but also in the turbulence and in the radiation scheme. I checked that the values for ai_uc and alb_red_uc already show differences up to 10E-8 when running with curb_fr_bld or with URB_FR_BLD. And especially in the turbulence small differences can really lead to the stochastic fluctuations you see. All other external parameters URB... are only used in TERRA, where such small differences are not amplified.

I attach two pictures:
t_2m-diff-nl-ext.png: Difference in T_2M after 36 hours of forecast from a run with namelist value curb_fr_bld set and a run where URB_FR_BLD is used (both set to 0.69)
t_2m-diff-cray-nec.png: Difference in T_2M after 36 hours from a run at ECMWF cca (CRAY) and our NEC machine. These runs were using the same namelist input (all curb-values set, no extra external parameters)

You can see that the pictures are rather similar: so only using a different machine already leads to the same stochastical fluctuations as the ones you can observe by using curb_fr_bld vs. URB_FR_BLD.

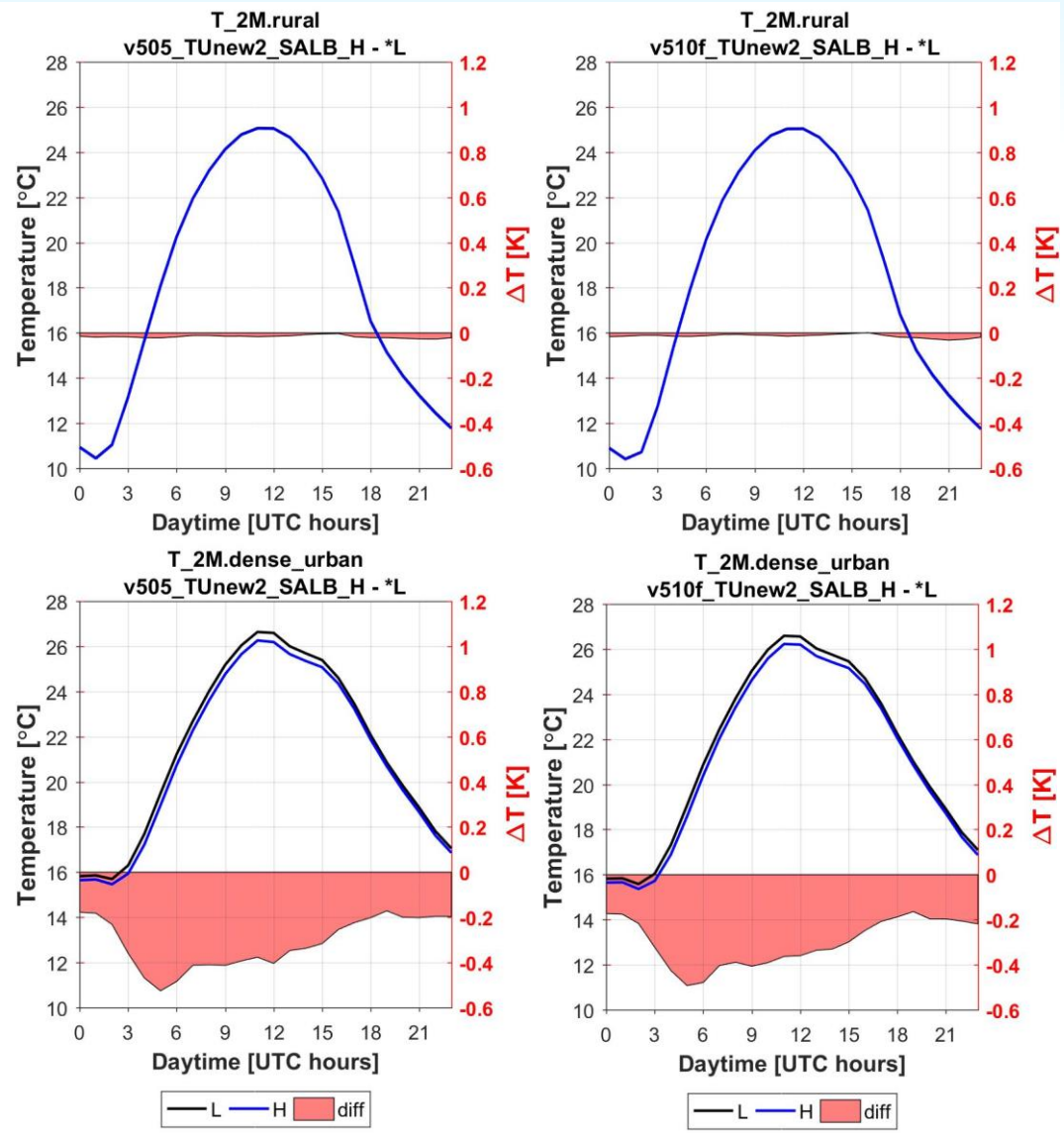
So I am pretty sure (about 99 %) that the differences we see, really come from this fact: When reading a value from a GRIB or NetCDF file, we read a single precision value (from GRIB this value could even be modified by the GRIB packing), and from the namelists we read a double precision value. Just to highlight this, here are the prints for the fields urb_fr_bld, ai_uc, alb_red_uc, right after computing ai_uc and alb_red_uc in src_input.f90, for a point with fr_paved > 0.0:

Testing 5.10beta version: H-L sensitivity



Not a full set of tests is performed yet, but existing results are consistent between 5.05 and 5.10, and agrees with physical expectations

Testing 5.10beta version: H-L sensitivity



Not a full set of tests is performed yet, but existing results are consistent between 5.05 and 5.10, and agrees with physical expectations

New bug with impervious tile evaporation

Urban Climate 11 (2015) 24–50

Contents lists available at ScienceDirect

Urban Climate

journal homepage: www.elsevier.com/locate/uclim

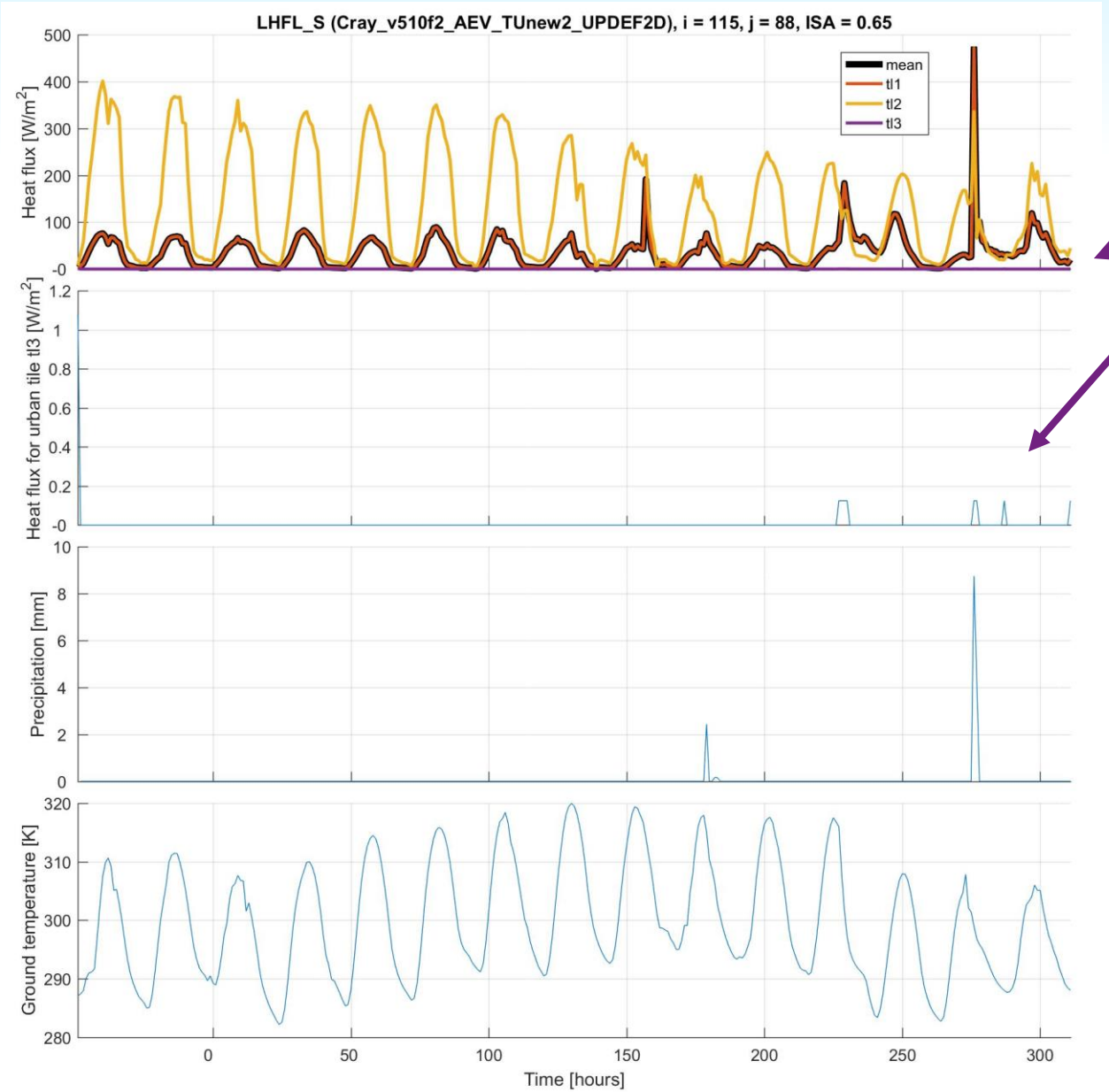
The impact of impervious water-storage parametrization on urban climate modelling

Hendrik Wouters [a,b,*], Matthias Demuzere [a], Koen De Ridder [b], Nicole P.M. van Lipzig [a]

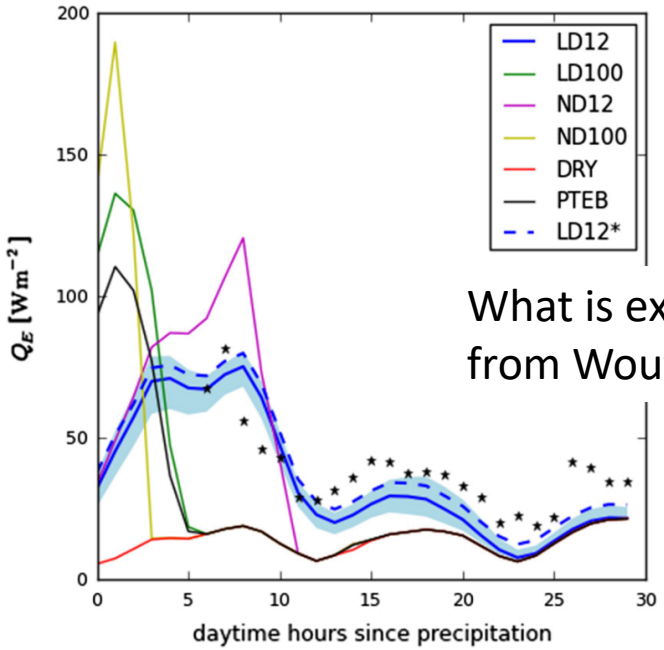
[a] KU Leuven, Dept. Earth and Environmental Sciences, Celestijnenlaan 200E, 3001 Heverlee, Belgium
[b] VITO, Flemish Institute for Technological Research, Boeretang 200, 2400 Mol, Belgium

- `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).

New bug with impervious tile evaporation



The problem: latent heat flux from urban (impervious) tile is always near zero, even after the rain!



What is expected from Wouters et al., 2015

Thanks to Mattias Demuzere and Urban Plumber project for motivating me to check this issue!

New bug with impervious tile evaporation

```
2527        IF (lterra_urb .AND. ((itype_eisa == 1).OR. (itype_eisa == 2))) THEN
2528          ! HW: evaporation of water stored on imperivous ground
2529          !zesoil(i) = zesoil(i)*(1.0_vpp - isa(i))
2530          IF (itype_eisa == 2) THEN
2531            zeisa(i) = zep_s(i) *(1.0_vpp - zf_snow(i)) & ! not snow covered
2532                     * isa(i)*c_isa_delt * (w_imp(i)/c_isa_wmax)**0.6667_vpp
2533
2534            ! no seperate variable is made for the isa evaporation yet.
2535            lhfl_bs(i) = lh_v * (zesoil(i) + zeisa(i))
2536          ELSE
2537            lhfl_bs(i) = lh_v * (zesoil(i))
2538          END IF
2539        ELSE
2540          lhfl_bs(i) = lh_v * zesoil(i)
2541        END IF
```

evaporation from urban tile

lhfl_bs is only diagnostic var

```
3045      DO i = ivstart, ivend
3046        ze_sum = zesn    (i) &
3047               + zepd    (i) &
3048               + zewi    (i) &
3049               + zesoil  (i) &
3050               + ztrangs (i) &
3051               + zdrr    (i) &
3052               + zrrs    (i)
3053
3054        IF (lterra_urb .AND. (itype_eisa == 2)) THEN
3055          ze_sum = ze_sum + zeisa(i)      ! impervious surface evaporation
3056        END IF
3057  !     zqvfl_s(i) = ze_sum    !US:  is this some other variable? zqhfl_sfc or so?
3058
3059        qv_s(i) = qv (i) - ze_sum /(zrhoch(i) + eps_div)
```

It is accounted when calculation surface humidity

New bug with impervious tile evaporation

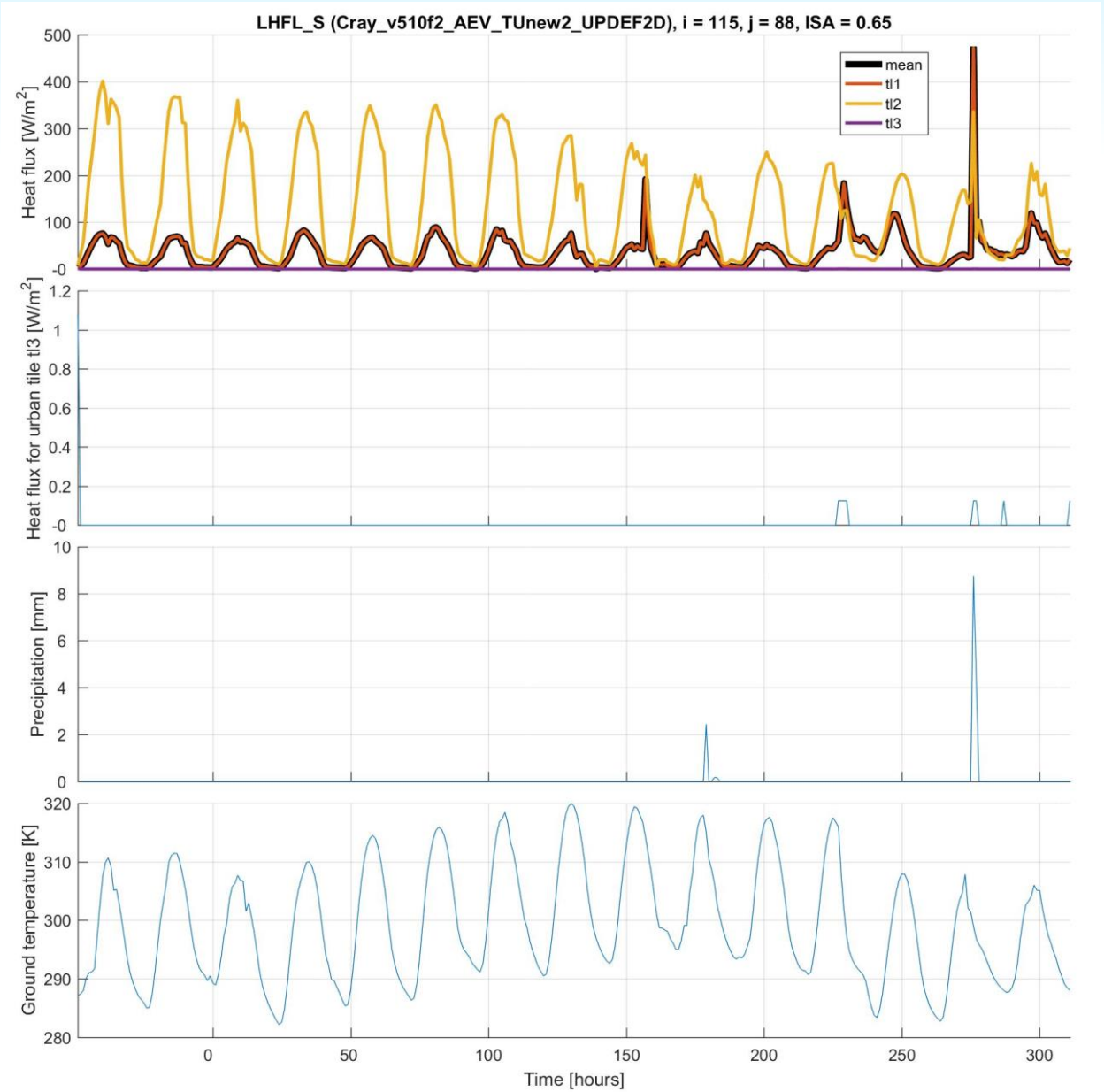
```
3249  !------------------------------------------------------------------------------
3250  ! Section II.3: Estimate thermal surface fluxes
3251  !------------------------------------------------------------------------------
3252
3253    IF (itype_interception == 1) THEN
3254      !$acc parallel async
3255      !$acc loop gang worker vector private(zrime, zfr_ice_free, zalf, zuv, zzz, zinf) &
3256      !$acc private(zdwidtt, zdwieps, zro_wi, zro_inf, zdwsndtt, zwsnstr)               &
3257      !$acc private(zdwseps)
3258      DO i = ivstart, ivend
3259        ! store forcing terms due to evapotranspiration, formation of dew
3260        ! and rime for later use
3261        zverbo(i) = zdwidt(i) + zesoil(i) + ztrangs(i) +                &
3262                    (1.0_vpp-zf_snow(i))*(zrr(i) + zrs(i))
```

```
4839        zrnet_s(i) = sobs(i) + zthsoi(i)
4840        zshfl_s(i) = cp_d*zrhoch(i) * (zth_low(i) - zts(i))
4841        zlhfl_s(i) = (zts_pm(i)*lh_v + (1.0_vpp-zts_pm(i))*lh_s)*zverbo(i) &
4842                     / MAX(eps_div,(1.0_vpp - zf_snow(i)))  ! take out (1-f) scaling
4843        zqhfl_s(i) = zverbo(i)/ MAX(eps_div,(1.0_vpp - zf_snow(i)))  ! take out (1-f) scaling
```

But it is not accounted when calculating total evaporation (zverbo) and resulting latent heat flux

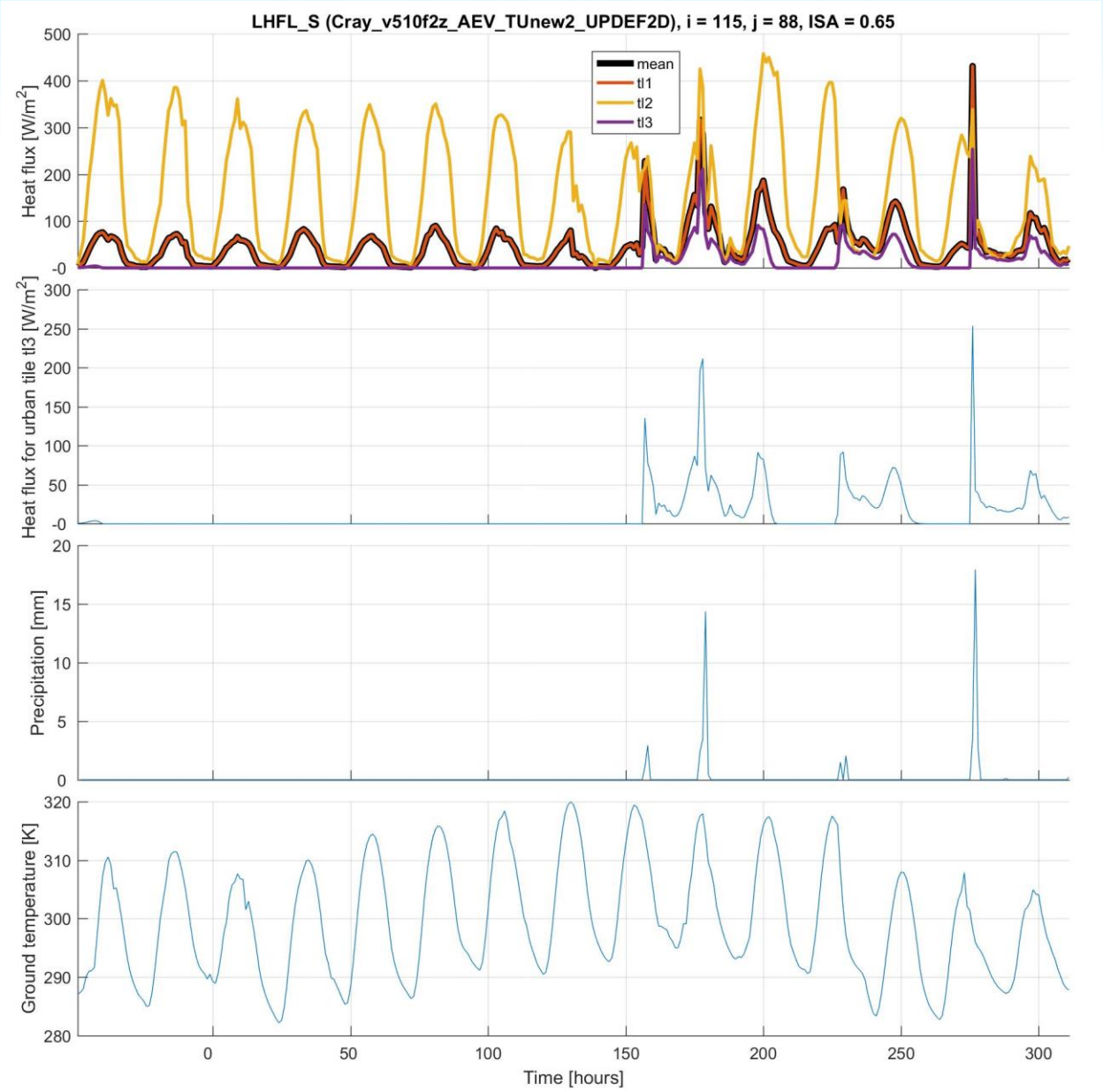
Proposed solution: just to add zeisa to sum when calculating zvero

New bug with impervious tile evaporation



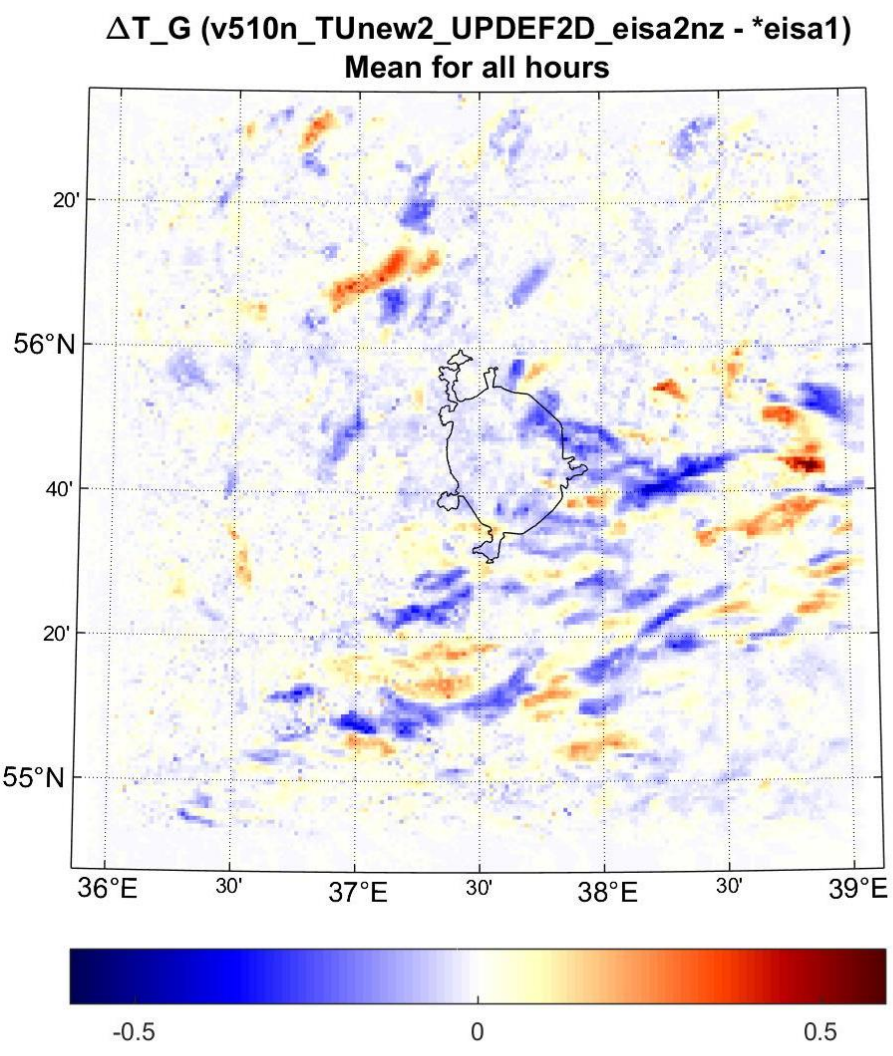
zverbo without zeisa

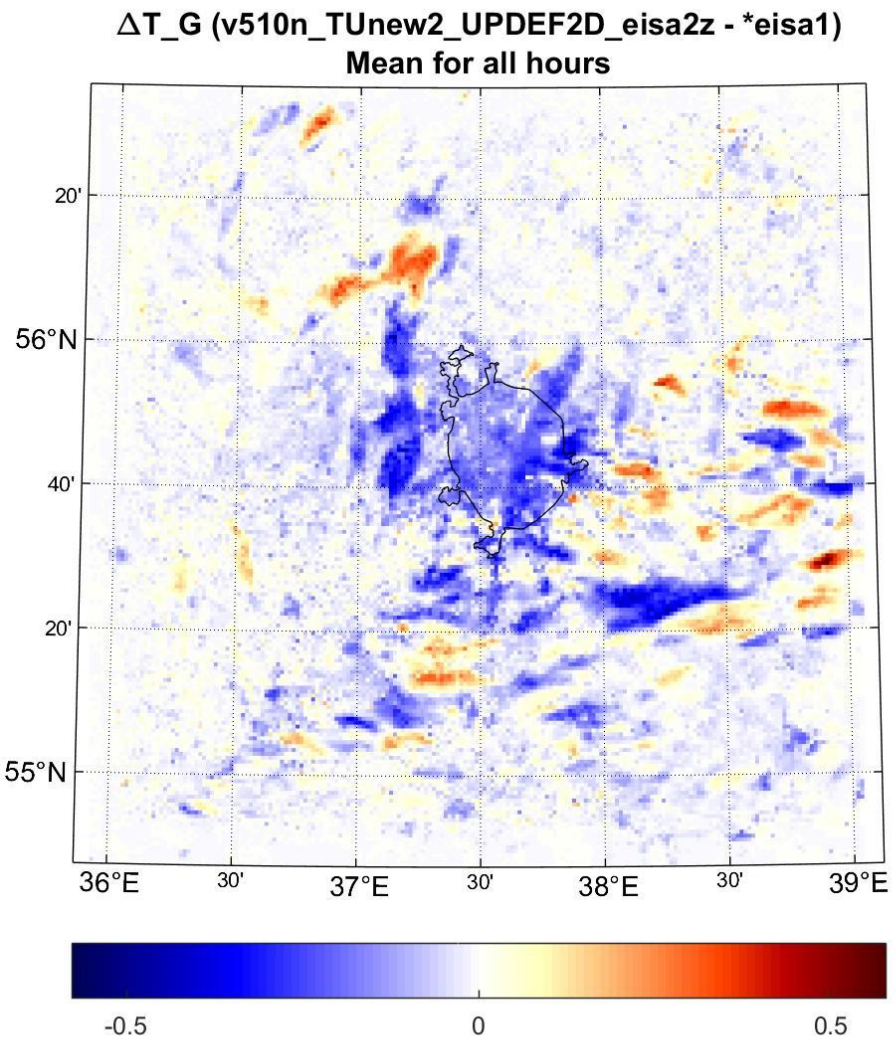
New bug with impervious tile evaporation

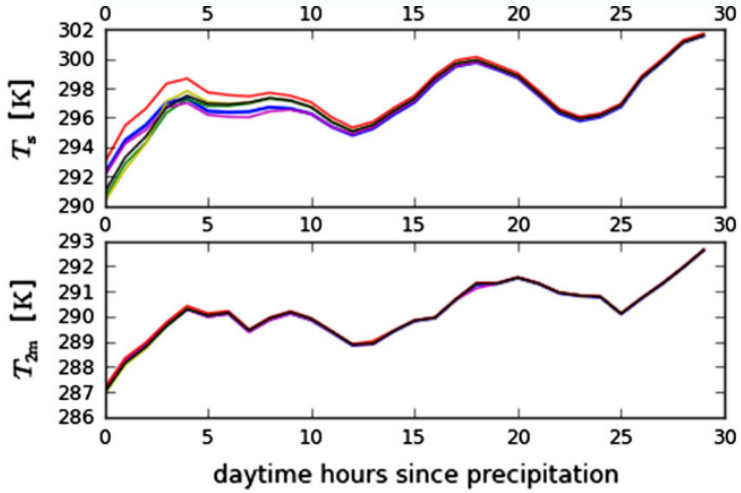


zverbo with zeisa

New bug with impervious tile evaporation







What is expected
from Wouters et al., 2015

Proposed bug fix makes model sensible to urban puddles:
using itype_eisa = 2 against itype_eisa = 1 provides a cooling effect over the city, which is expected

New bug with impervious tile evaporation

Is it really a bug? Hendrik's comments:

- The reason why zeisa is not taken into account in zverbo and zlhfl_s is because it is used to force soil moisture for the bare soil:

```
3646          ! total forcing for uppermost soil layer
3647          zfor_s(i,j) = zrnet_s(i,j) + zshfl_s(i,j) + zlhfl_s(i,j) + zsprs(i,j)*(1._ireals - fr_snow(i,j))       &
3648 !EM                           + fr_snow(i,j) * (1._ireals-ztsnow_pm(i,j)) * zgsb(i,j)
3649                            + (1._ireals-ztsnow_pm(i,j)) * zgsb(i,j)
3650
```

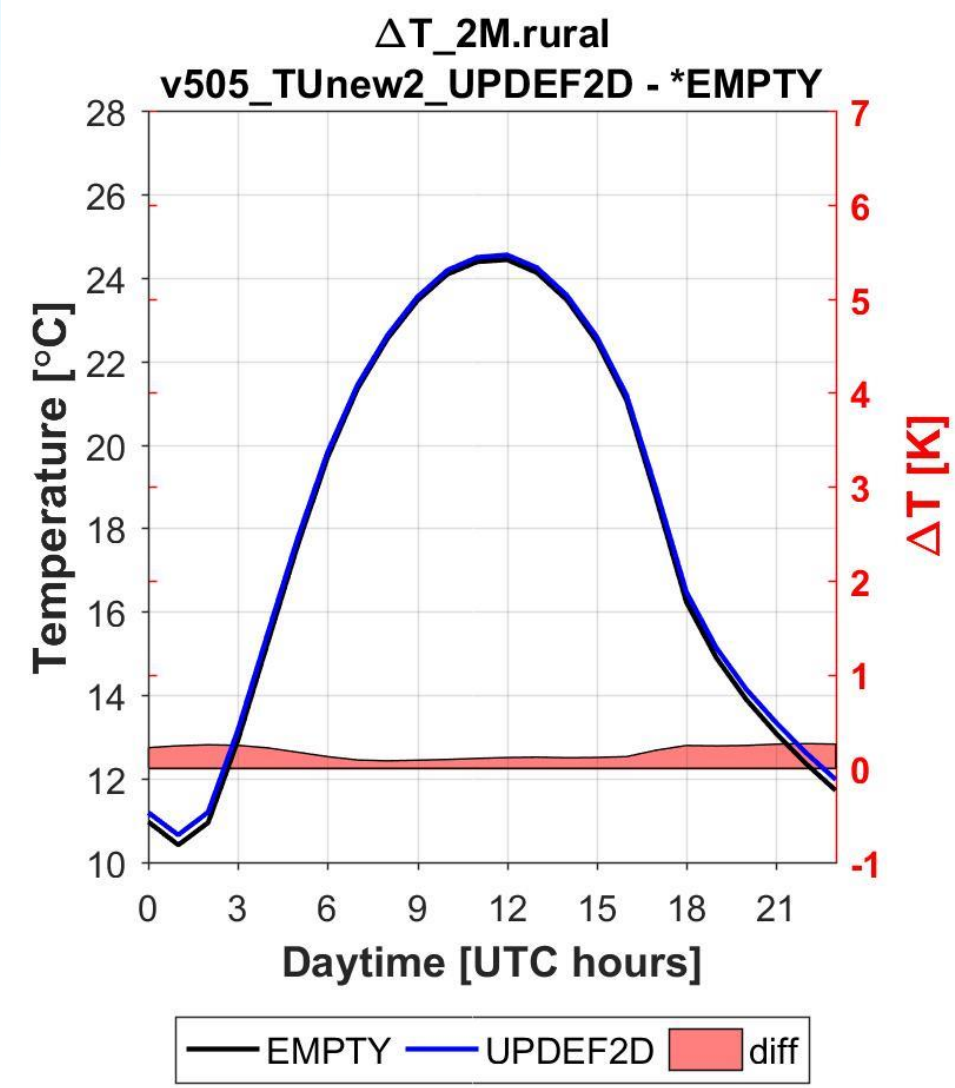
- Note that zlhfl_s is not used to consider evaporation towards the atmosphere. For that, the surface variable qv_s

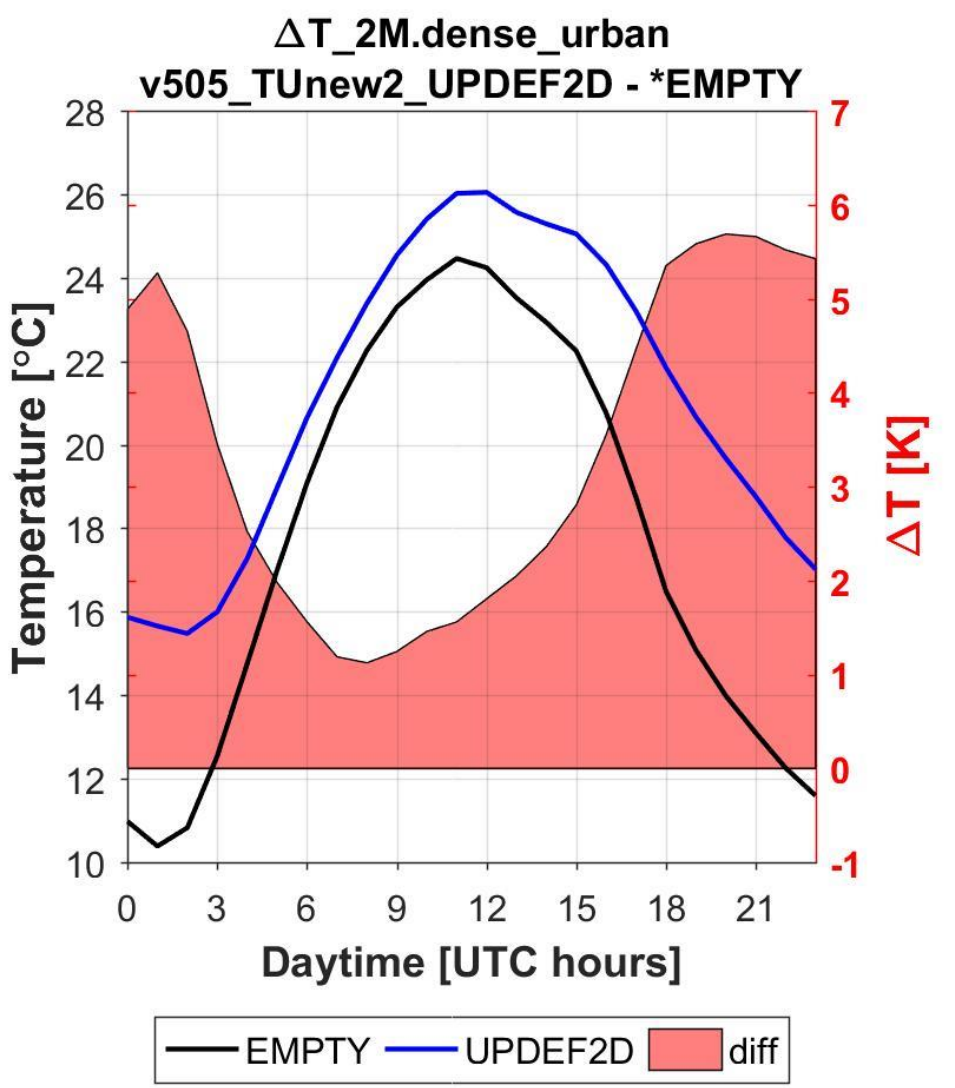
The following questions remains:

1) Should be the moisture fluxes used when calculating qv_s (ze_sum) and zlhfl_s?
2) Should we worry about soil moisture forcing for urban (impervious) tile?

UHI in different model versions

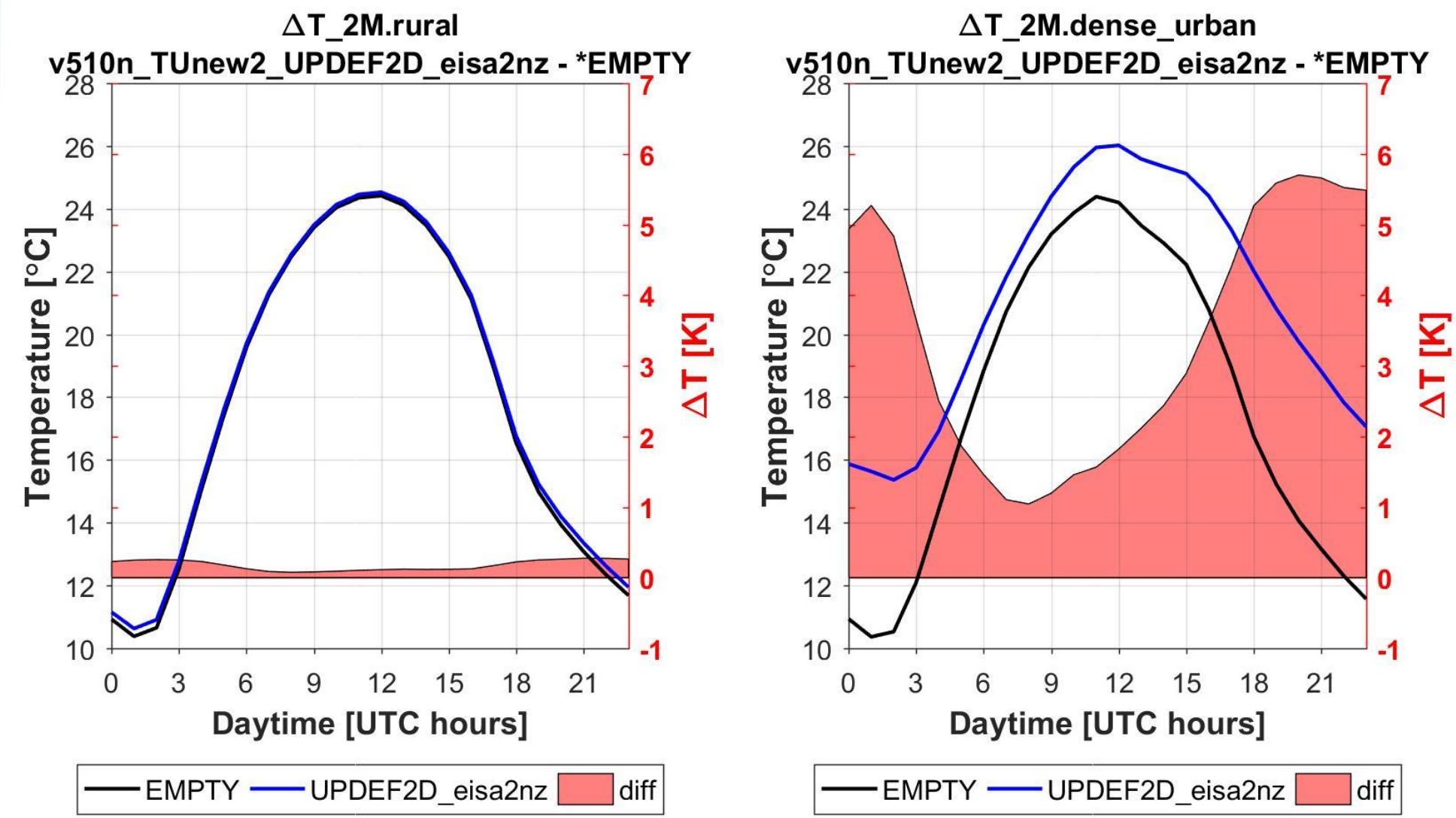
v505





UHI in different model versions

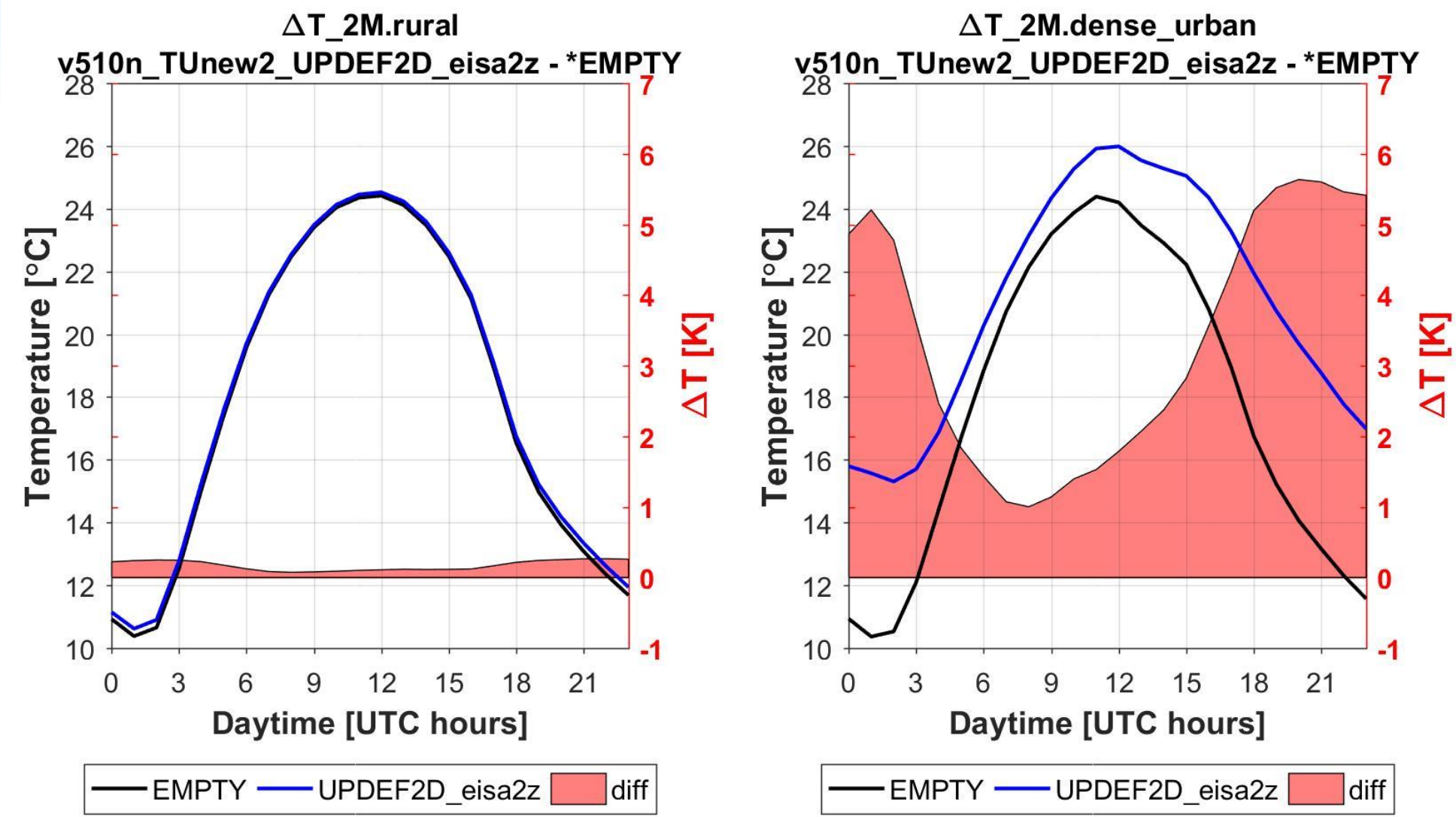
v510



Migration to 5.10 from 5.05 slightly shifts the diurnal temperature and UHI cycles

UHI in different model versions

v510 with proposed "bug fix"



Proposed "bug fix" with urban tile evaporation slightly decreases UHI

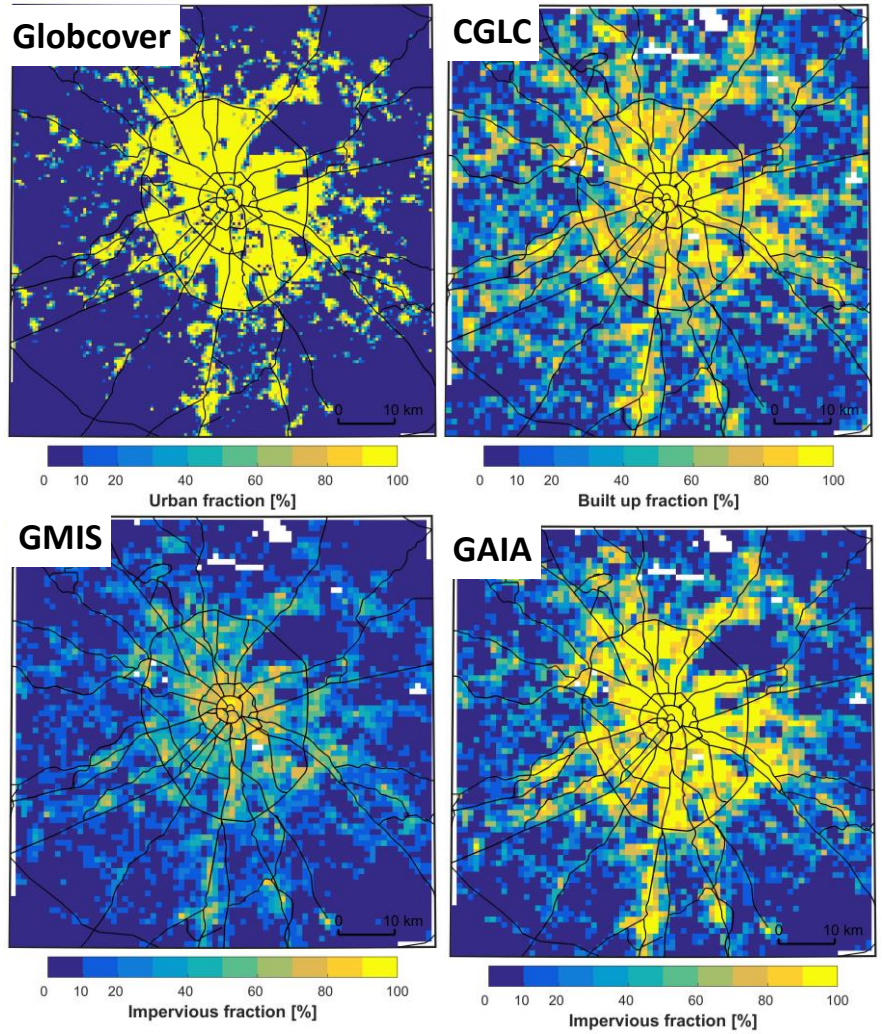
Outlook and discussion: external parameters

Towards to comprehensive review the large-scale data sets

There are so many global data sets that include urban fraction, and the data is so different.

Data set	Grid spacing	Time period	Urban data type
Globcover, default LC for COSMO/ICON	300 m	2009	urban LC class fraction
ESA CCI Landcover, upcoming LC for COSMO/ICON?	300 m	1992-2015	urban area fraction
Copernicus Global Land Cover (CGLC)	**100 m**	2015-2020	built up area class
ECOCLIMAP SG*	300 m	???	**Fractions of urban LCZs**
Global Man-made Impervious Surface (GMIS)	**30 m**	2010	Impervious cover
Global artificial impervious area (GAIA) between	**30 m**	1985-2018	Impervious cover (but actually not)
And many other….			

*does anybody know how to access ECOCLIMAP SG data?



Outlook and discussion: external parameters

Methods of deriving file-scale parameters

Current method
(Samsonov, Varentsov, 2020)

Source data (OpenStreetMap, Sentinel, CGLC)

↓

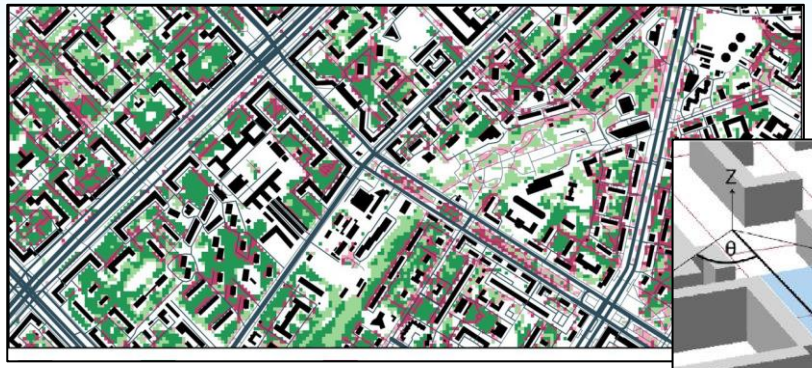
Data processing and averaging in GIS

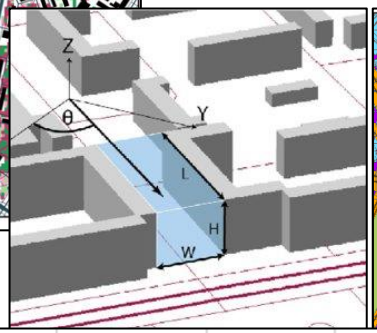
↓

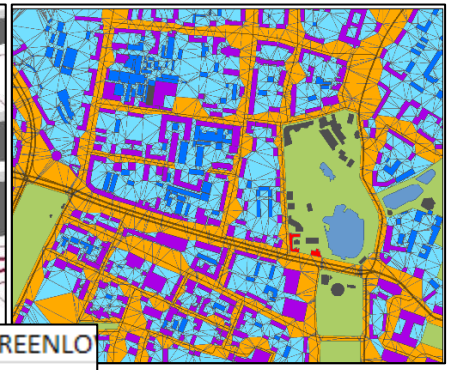
Urban canopy parameters, averaged over model grid cells, in *csv table

↓

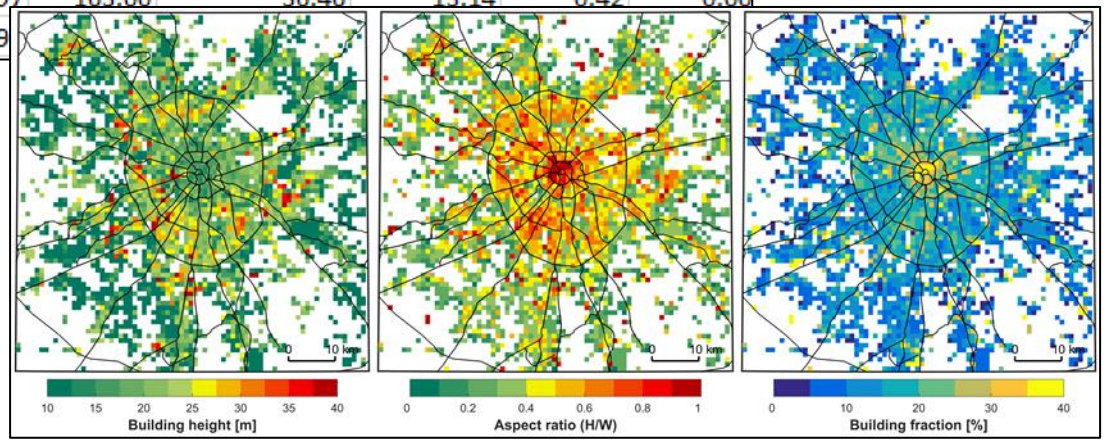
External parameters file (*.nc)







ID	LAT	LONG	ZMEAN	BUILDINGS	ROADS	GREENTAL	GREENLO
9133	55.59192	37.35666	177.00	58.61	2.82	2.31	0.00
11456	55.76295	37.61198	147.00	42.52	16.54	2.51	0.00
11600	55.76293	37.62797	175.00	42.18	15.87	0.04	0.00
11736	55.69092	37.6437	118.00	36.96	2.18	0.00	0.00
11744	55.76292	37.64397	163.00	36.46	13.14	0.42	0.00
11311	55.75396	37.5959					



Outlook and discussion: external parameters

Methods of deriving file-scale parameters

New method under development

Source data (OpenStreetMap, Sentinel, CGLC)

↓

Data processing in GIS

↓

Urban canopy parameters as high-resolution (5 m grid step) rasters in GeoTIFF

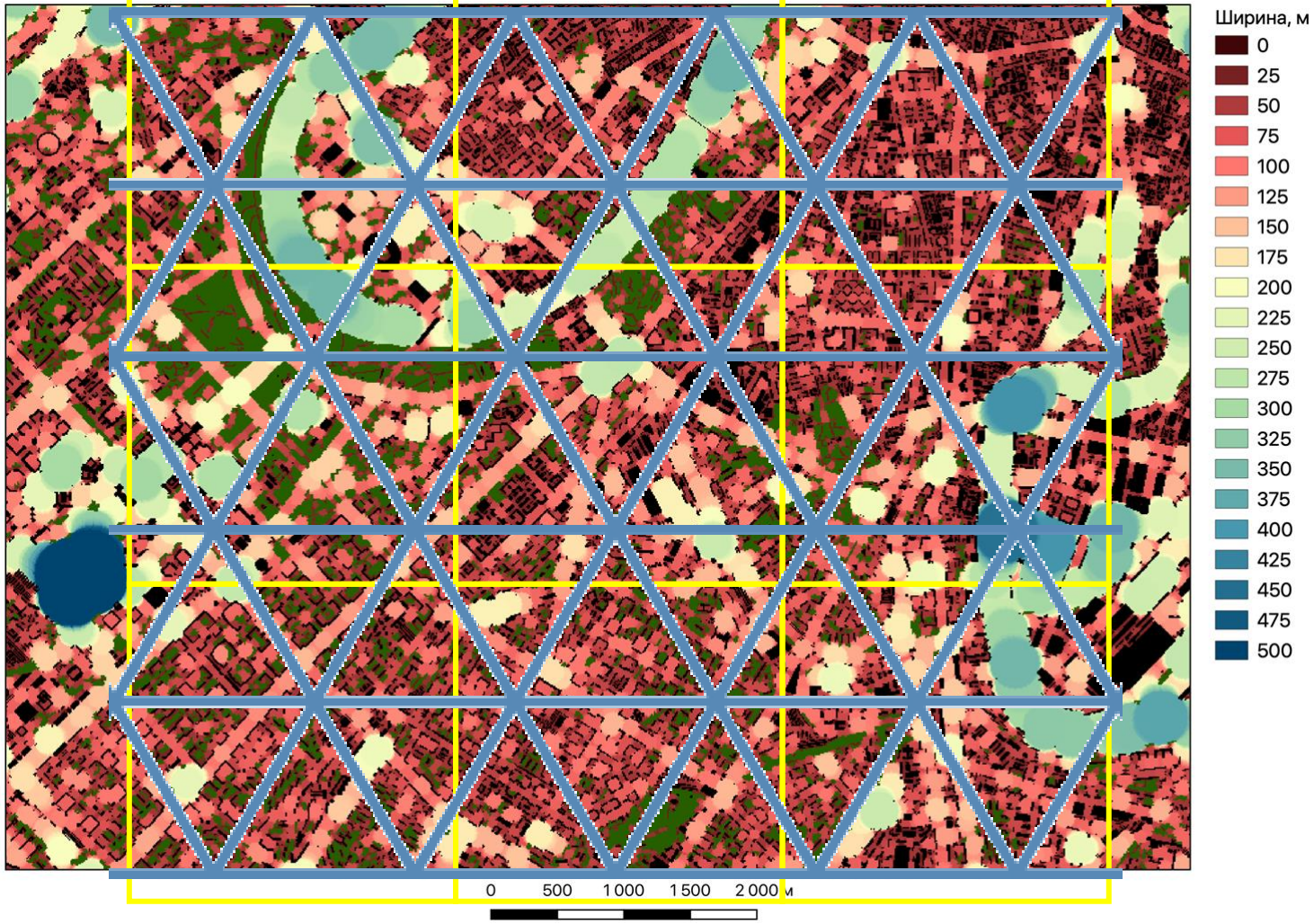
↓

Averaging over given grid cells

↓

External parameters file (*.nc)

Locally defended street canyon height as 5-m raster



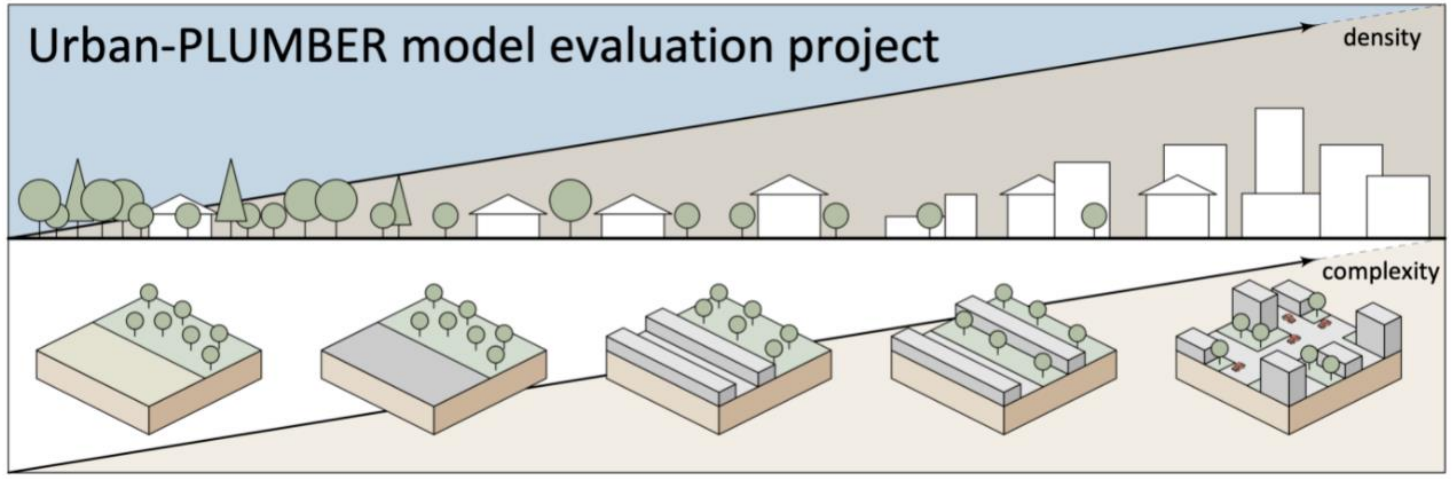
Outlook and discussion: TERRA_URB + TSA

Motivation: TERRA_URB's participation in surface models intercomparison project, Urban Plumber (thanks to Matthias Demuzere for inviting me)

Problem: there is not TSA version that combines TERRA_URB and other recent developments (bare soil evaporation, skin-layer temperature scheme). TERRA_URB is available only for old TSA v4.11.

Questions: who is responsible for TSA development? Are there plans to unify it with recent COSMO version?

Urban-PLUMBER will evaluate the performance of land surface models used in in meteorological or climatic simulations of urban areas. The project is open to any group that wishes to gain a better understanding of how their model performs in a wide range of urban environments.



Outlook and discussion: TERRA_URB + ART

- It is essential to consider UHI and urban air pollution together as part of integrated urban environmental services.
- Coupled modelling of urban aerosol in Moscow with COSMO-ART and TERRA_URB is planned in one of current research projects of MSU and RHN (Russian-Finish megagrant).
- Unfortunately, ART and TERRA_URB are not compatible yet, firstly due to implementation of tile approach in recent COSMO versions.
- **Who is responsible for making ART compatible with recent COSMO version (including TERRA_URB)?**

	5.0	5.05	5.10
URB compiled	✓	✓	✓
ART compiled	✓	✗	✗
URB or ART	✓	✗	✗
URB and ART	✗	✗	✗

Outlook and discussion: other issues

- **Test on the GPUs? Does anybody test TERRA_URB there?**

- **Further TERRA_URB development in COSMO/ICON**
  - Improved treatment for impervious/urban areas
  - Snow in urban areas

- **Participation in WMO Research Demonstration Project “Paris Olympic Games 2024“ (http://www.umr-cnrm.fr/RDP_Paris2024/?page=home)?**

Thank you for attention!

http://vostokfilms.ru/upload/category/project/photo/026_9916.jpg