Modelling sensitivity of urban thermal comfort on street-level adaptation measures; case study of Prague-Holešovice, Czech Republic

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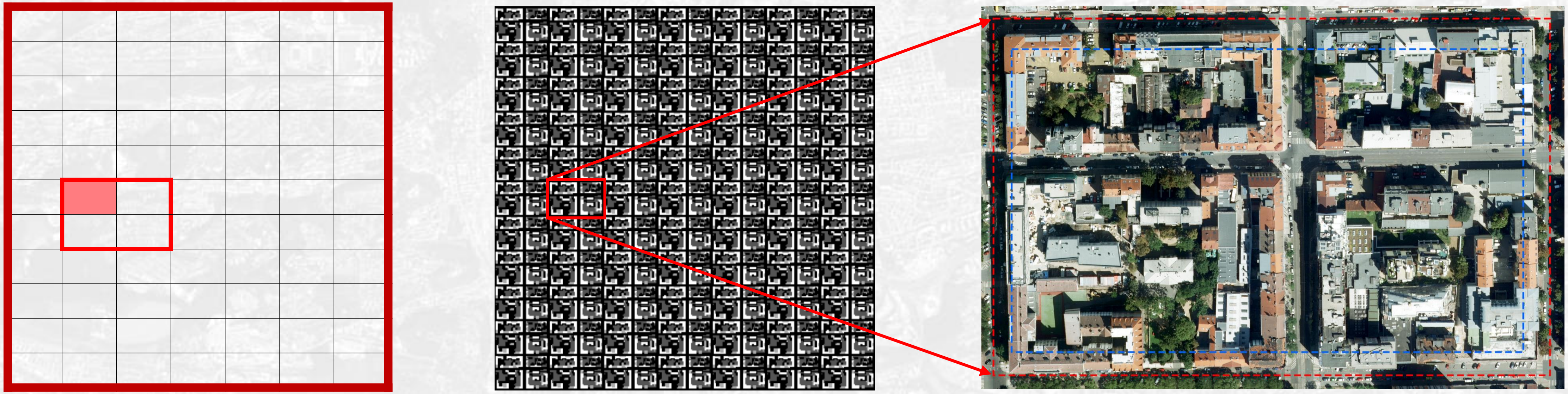
Motivation

- More than 60% of world population living in cities
- Urban heat island (UHI) and air quality (AQ) influences health and life quality of inhabitants
- Assessments of local measures need a street level modelling tools – high-resolution model outputs
- Unique outputs for developers, urban planners, engineers etc.

- How important are detail and validated input data for PALM-4U?
- How sensitive LES-based model is?

Design experiment

- Real domain: 400×256m, high-resolution GIS mapping (1m)
- Parent domain: 7×11 in 8m (2,800×2,816m), vertical extent 3,500m
- Child domain: 2×2 in 2m (800×512m), vertical extent 40m
- Validated heat wave period on 2 July 2015 (Resler et at. 2017)



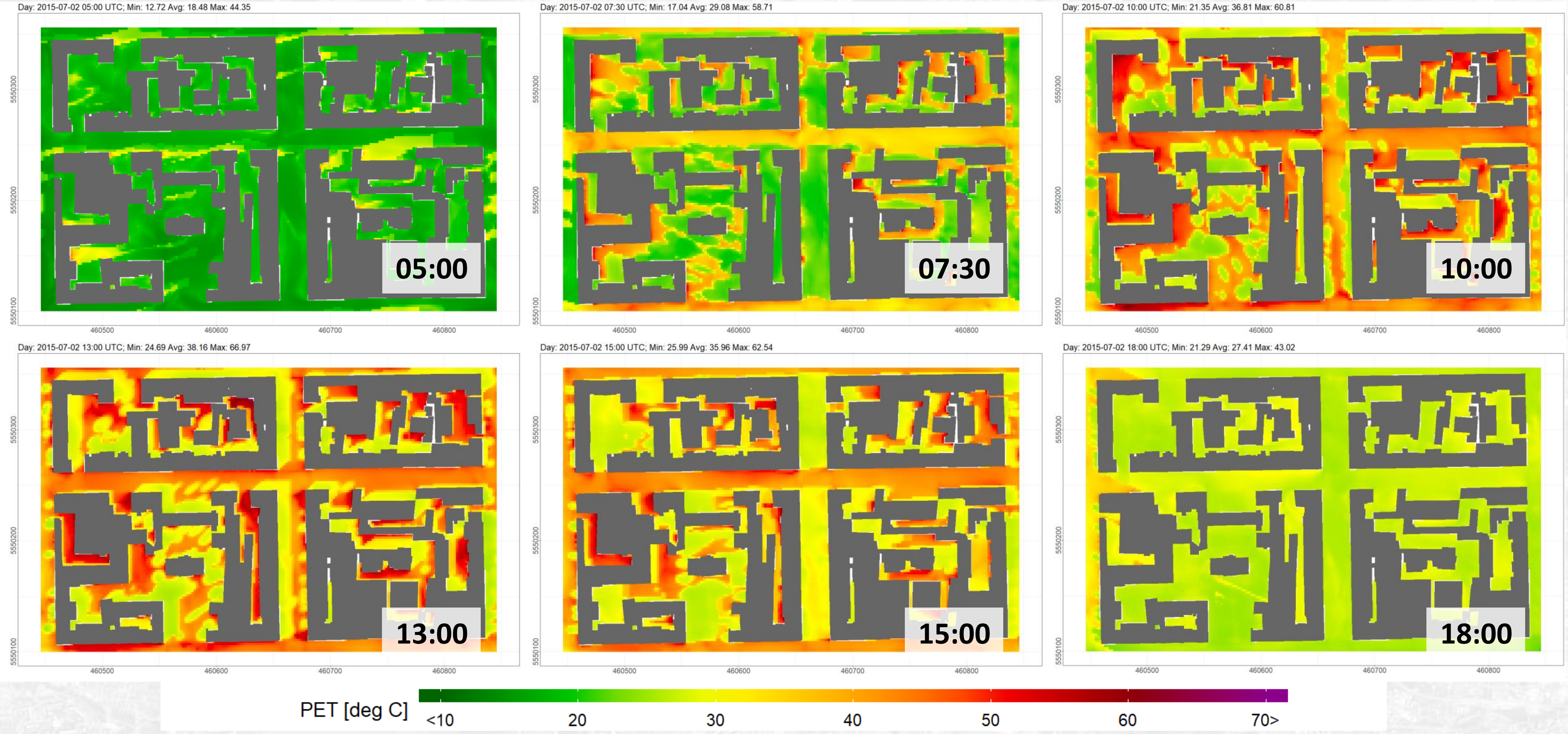
Model scenarios

- A-type: sensitivity on input data (21)
  - ±20% in general parameters typically
  - e.g. albedo, emissivity, leaf area density, volumetric heat capacity, thermal conductivity, roughness, window fraction, soil moisture etc.
- B-type: urbanistic scenarios (17)
  - typical adaptation scenarios
  - e.g. new trees (+ position in street canyon), surface changes, insulated buildings, blue infrastructure, green roofs, green tram rails etc.
- Comparison of averages, minimums, maximums, streets, selected points, courtyards, surfaces… of many variables
  - Thousands of graphs, maps, animations and tables

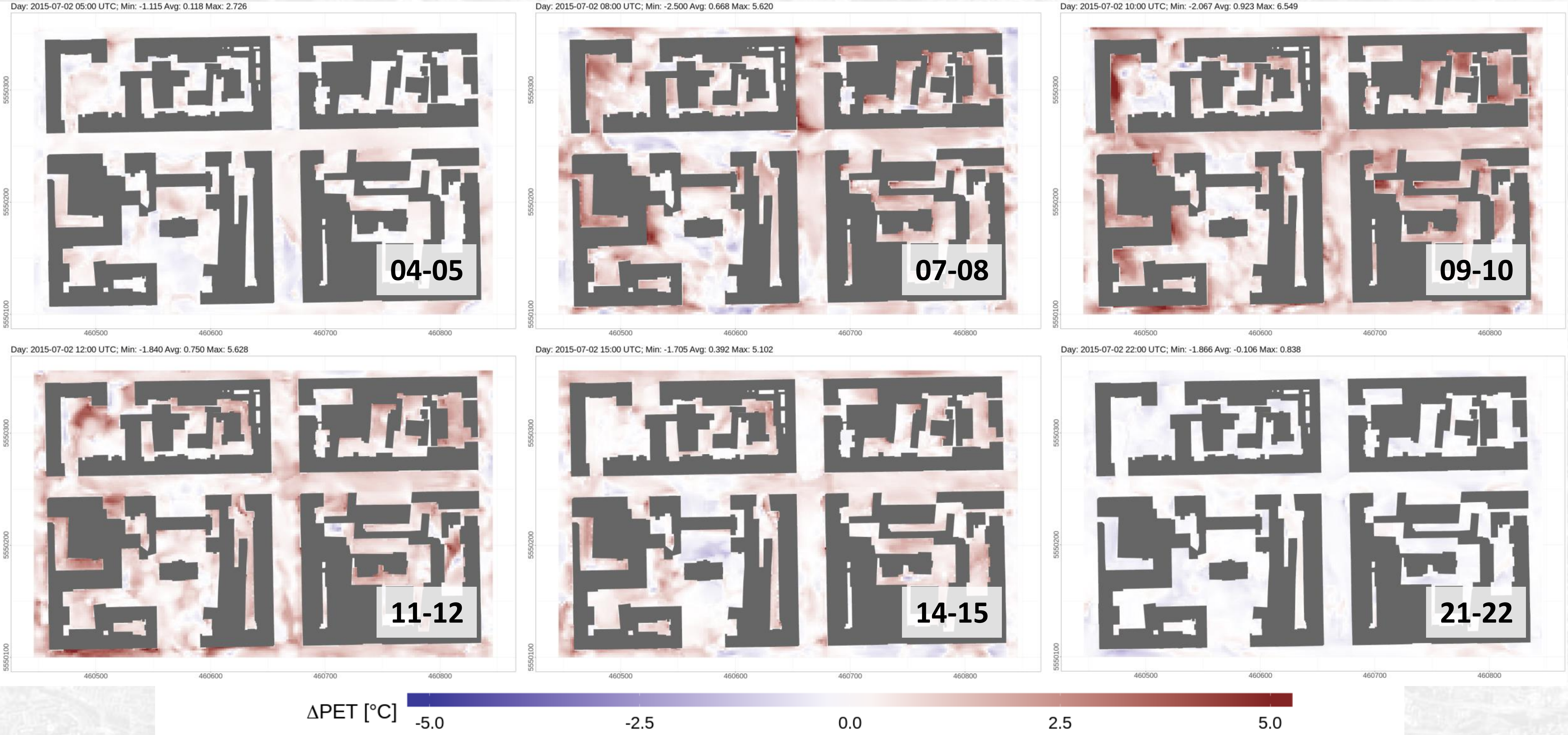
PET calculation

- Mean Radiant Temperature (MRT)
  - Radiative Transfer Model (RTM; see poster 1411, Krč and Resler) in PALM 6.0 calculates MRT from SW and LW irradiance using Stefan-Boltzmann law
  - 3 possible parametrizations: black globe thermometer ($\varepsilon = 1$) and two types of human bodies (cylinder and ellipsoid)
  - SW and LW calculation is using angular discretization; default: 40 steps in vertical and 80 in horizontal direction
  - For each step is calculated SW, LW, direct, diffused, reflected radiation and radiation balance
  - SW and LW flux is provided to biometeorological module
- PET (and other biometeorological indices) calculation is described in Fröhlich and Matzarakis (2019)

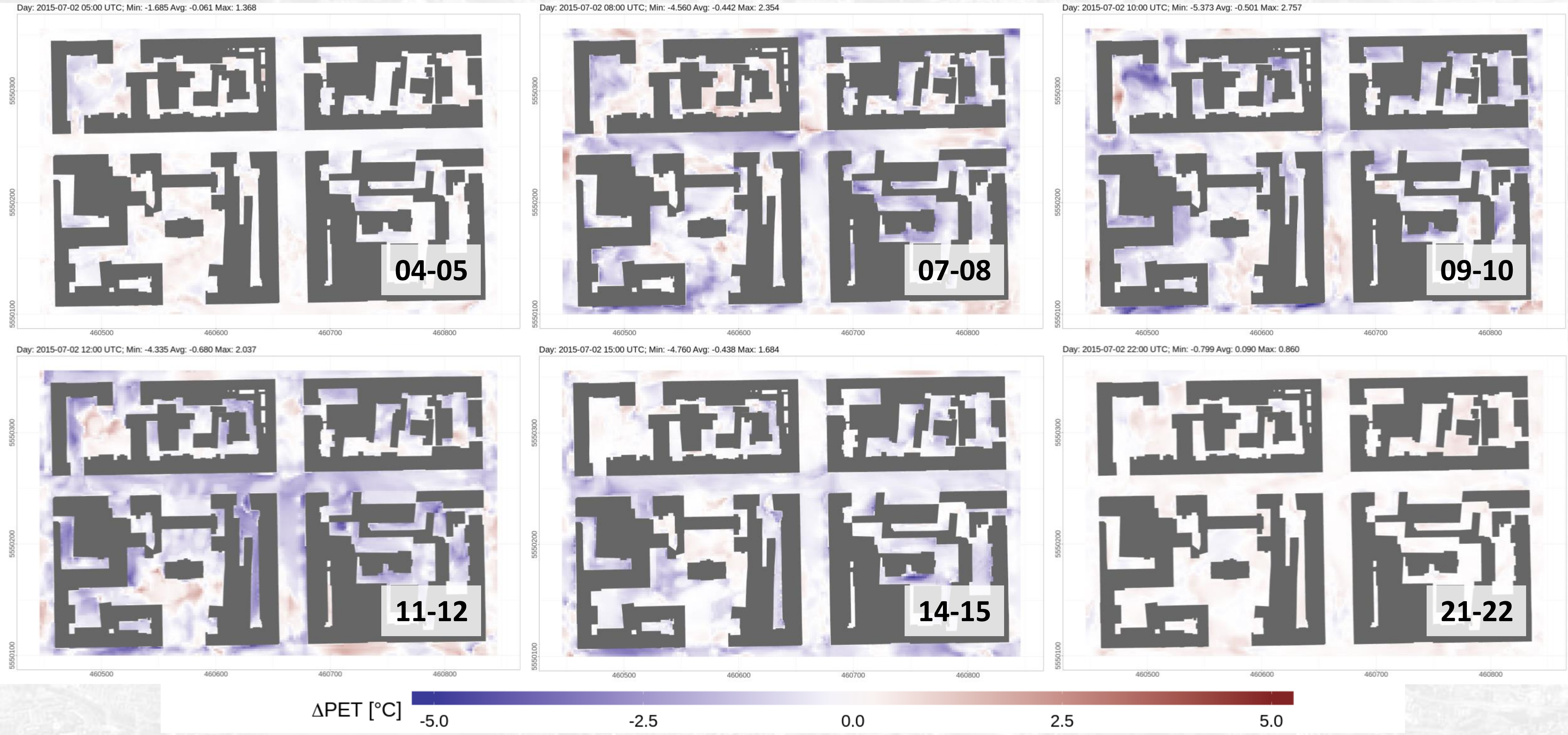
PET: current situation



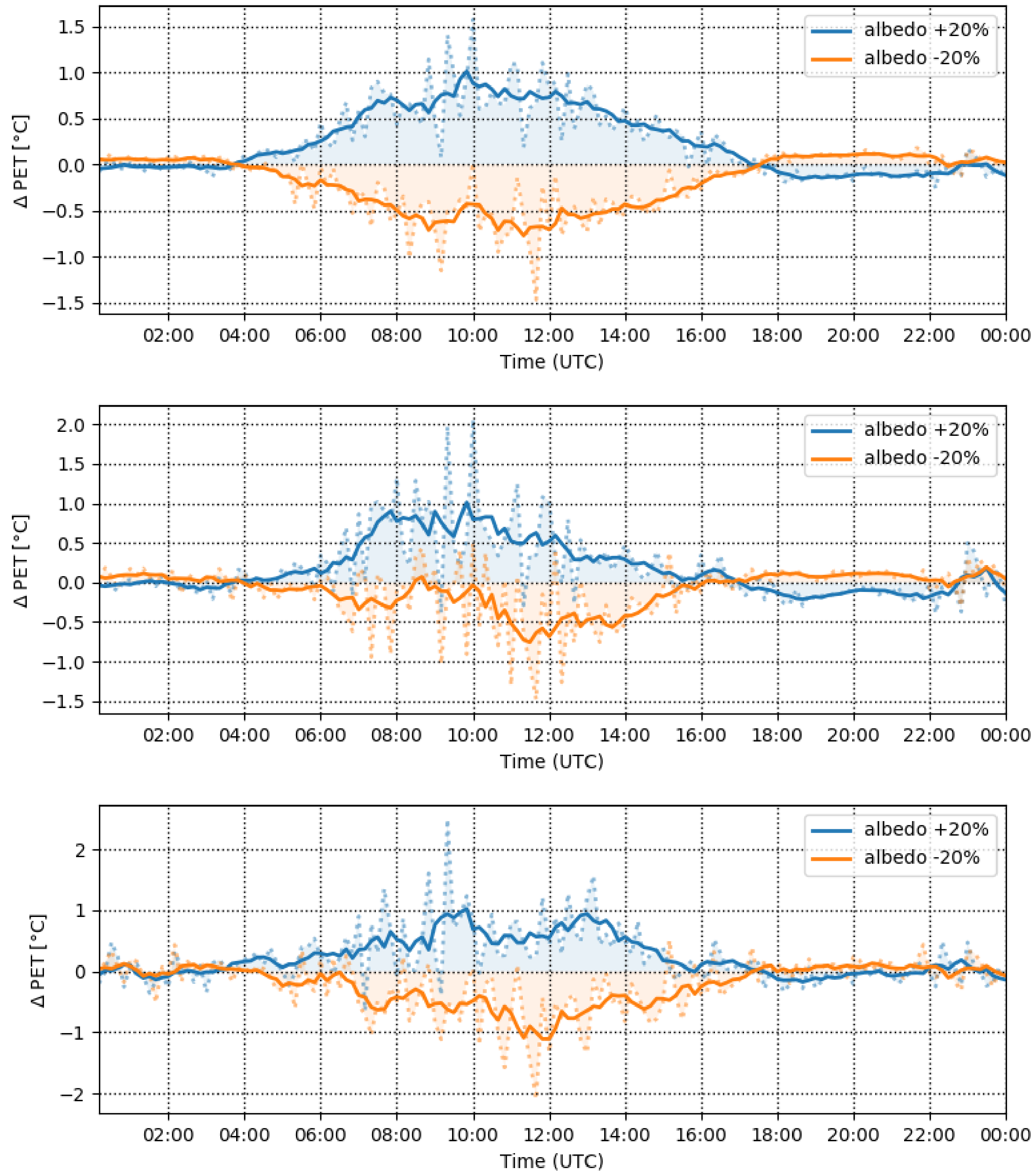
PET: albedo +20%, AVG: 01h



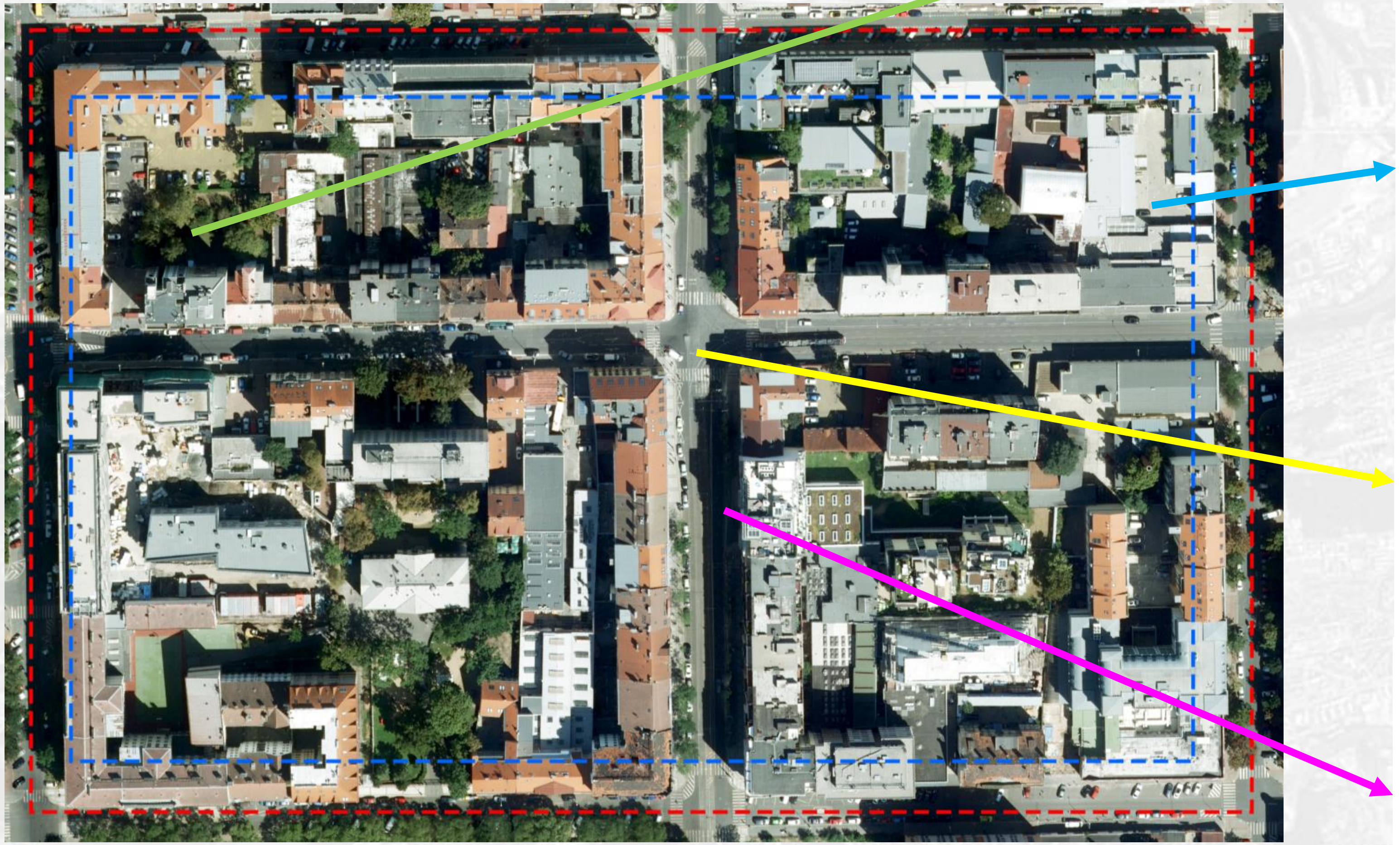
PET: albedo -20%, AVG: 01h

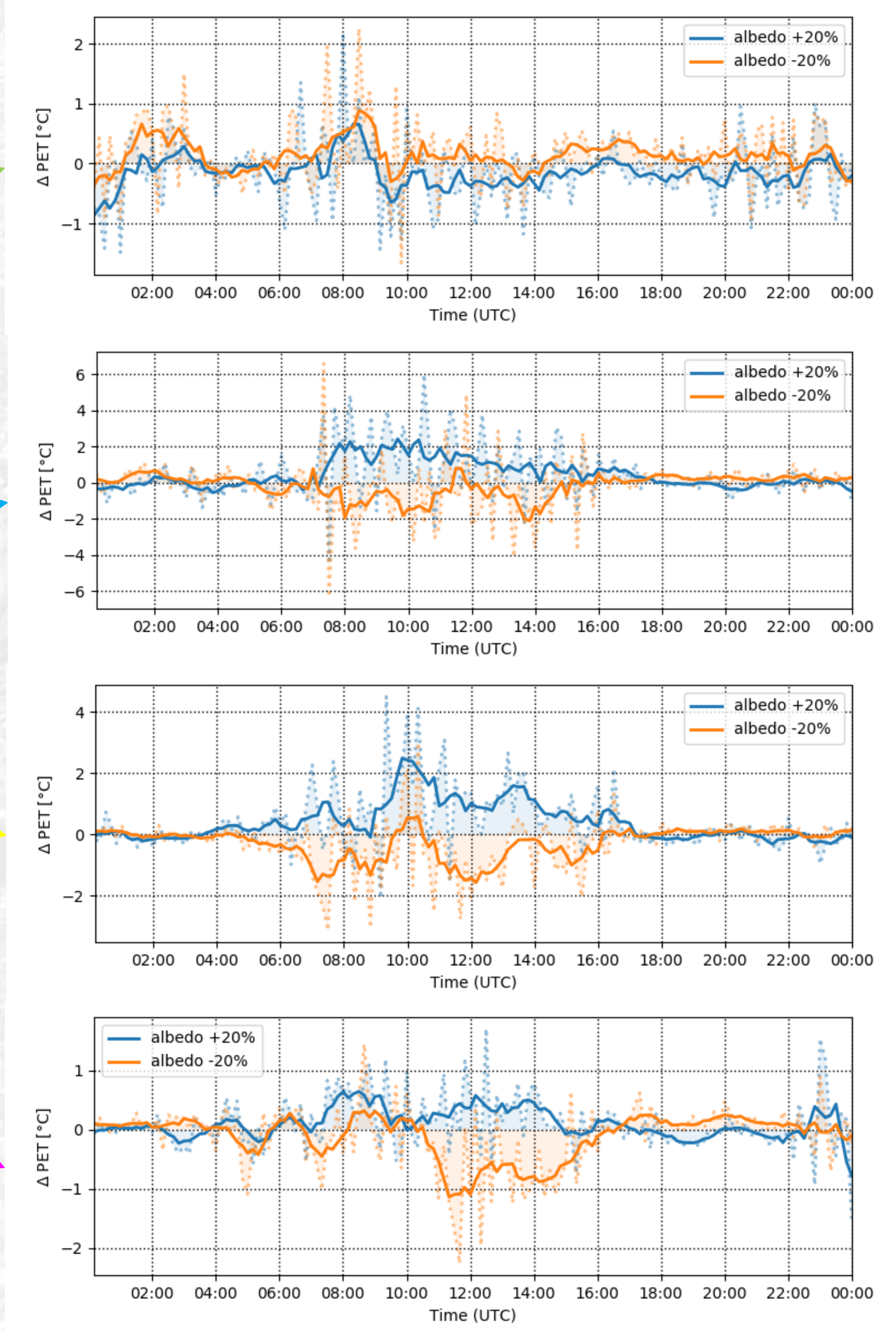


PET: albedo ±20%



PET: albedo ±20%





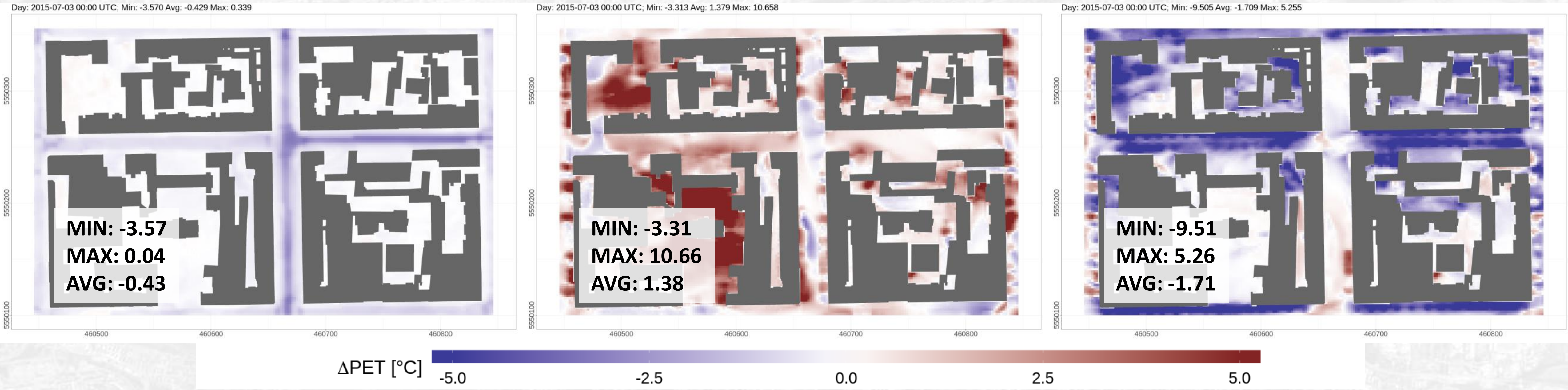
PET: A-type scenario summary

Scenario	AVG	00-03	03-06	06-09	9-12	12-15	15-18	18-21	21-24	MIN	TIME	MAX	TIME
albedo increase +20%; all surfaces	0,240	-0,025	0,107	0,576	0,804	0,532	0,123	-0,130	-0,072	-0,262	22:10	1,575	10:00
albedo decrease –20%	-0,194	0,056	-0,091	-0,433	-0,633	-0,490	-0,109	0,098	0,049	-1,472	11:40	0,179	21:40
emissivity average for whole domain	-0,008	-0,006	-0,005	0,006	-0,018	0,001	-0,022	-0,012	-0,007	-0,585	11:30	0,481	09:40
avg. emissivity +20 %	0,079	0,043	0,055	0,101	0,107	0,114	0,088	0,039	0,086	-0,388	08:30	0,500	09:20
avg. emissivity –20 %	-0,295	-0,137	-0,161	-0,398	-0,499	-0,481	-0,310	-0,171	-0,207	-0,971	10:40	0,072	06:40
roughness increase +20%	-0,085	-0,029	-0,043	-0,163	-0,085	-0,122	-0,113	-0,073	-0,048	-0,653	08:10	0,274	09:40
roughness decrease –20%	0,093	0,031	0,039	0,113	0,084	0,160	0,136	0,107	0,077	-0,458	09:10	0,595	08:50
thickness increase +20%	-0,002	0,008	-0,011	-0,046	0,032	0,029	-0,006	-0,006	-0,015	-0,674	08:00	0,509	10:00
thickness decrease –20%	-0,005	-0,005	-0,012	0,020	0,016	-0,036	0,005	-0,001	-0,023	-0,349	12:50	0,435	12:10
transmissivity of windows increase +20%	0,000	0,004	-0,008	0,021	0,010	-0,008	-0,007	-0,007	-0,005	-0,518	07:20	0,328	11:00
transmissivity of windows decrease –20%	-0,003	-0,007	0,023	-0,044	0,006	0,010	-0,015	-0,008	0,009	-0,484	08:30	0,350	07:30
thermal conductivity inside of wall increase +20%	-0,059	0,056	0,020	-0,101	-0,202	-0,179	-0,100	-0,007	0,040	-0,619	11:20	0,374	06:40
thermal conductivity inside of wall decrease –20%	0,027	-0,122	-0,048	0,131	0,140	0,126	0,084	-0,016	-0,081	-0,326	11:30	0,800	10:00
volumetric heat capacity increase +20%	-0,002	0,108	0,105	-0,014	-0,120	-0,132	-0,041	0,020	0,061	-0,497	10:40	0,328	06:20
volumetric heat capacity decrease –20%	-0,015	-0,166	-0,114	0,051	0,138	0,080	0,042	-0,047	-0,101	-0,310	22:30	0,461	10:00
window fraction increase +20%	-0,057	-0,057	-0,027	0,010	-0,041	-0,104	-0,070	-0,110	-0,056	-0,335	09:10	0,420	10:00
window fraction decrease –20%	0,048	0,024	-0,004	0,013	0,066	0,023	0,092	0,095	0,072	-0,486	08:00	0,399	07:40
leaf area density increase +20%	-0,031	0,001	0,006	-0,043	-0,071	-0,083	-0,046	-0,009	-0,003	-0,468	10:20	0,701	10:00
leaf area density decrease –20%	0,038	-0,025	-0,007	0,099	0,096	0,121	0,070	-0,012	-0,038	-0,376	08:30	0,450	09:40
soil moisture increase +20%	-0,025	-0,014	-0,017	-0,034	-0,021	-0,027	-0,039	-0,027	-0,021	-0,392	06:30	0,455	08:50
soil moisture decrease –20%	0,027	0,000	0,009	0,041	0,039	0,048	0,049	0,008	0,025	-0,426	09:10	0,459	09:50

Note: decimal separator is comma

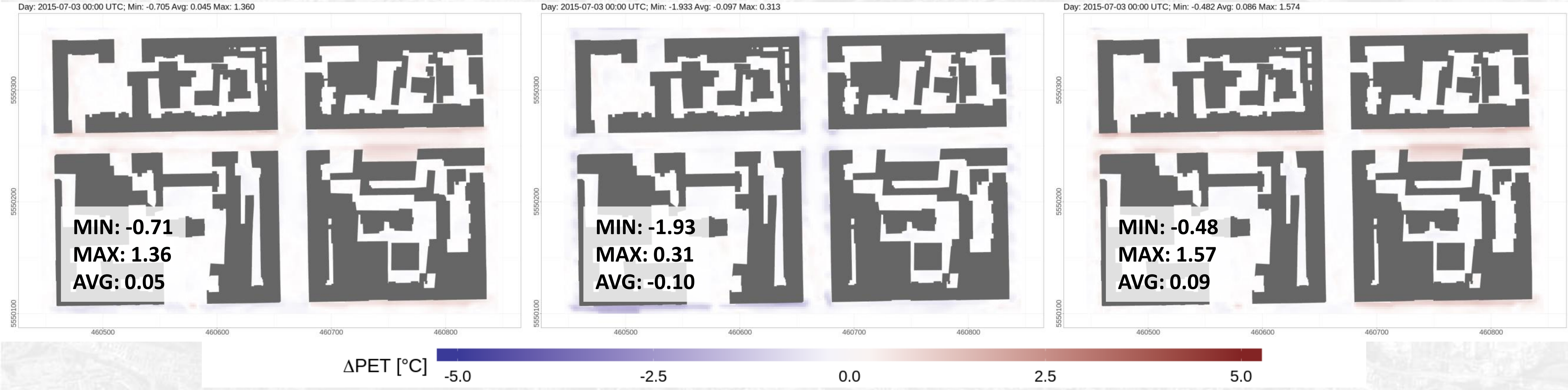
PET: Land cover changes

- 24h PET averages for 3 land cover changes
  - Tram was replaced by river (left)
  - Deleted trees, asphalt instead of grass (middle)
  - Randomly planted trees everywhere possible (right)

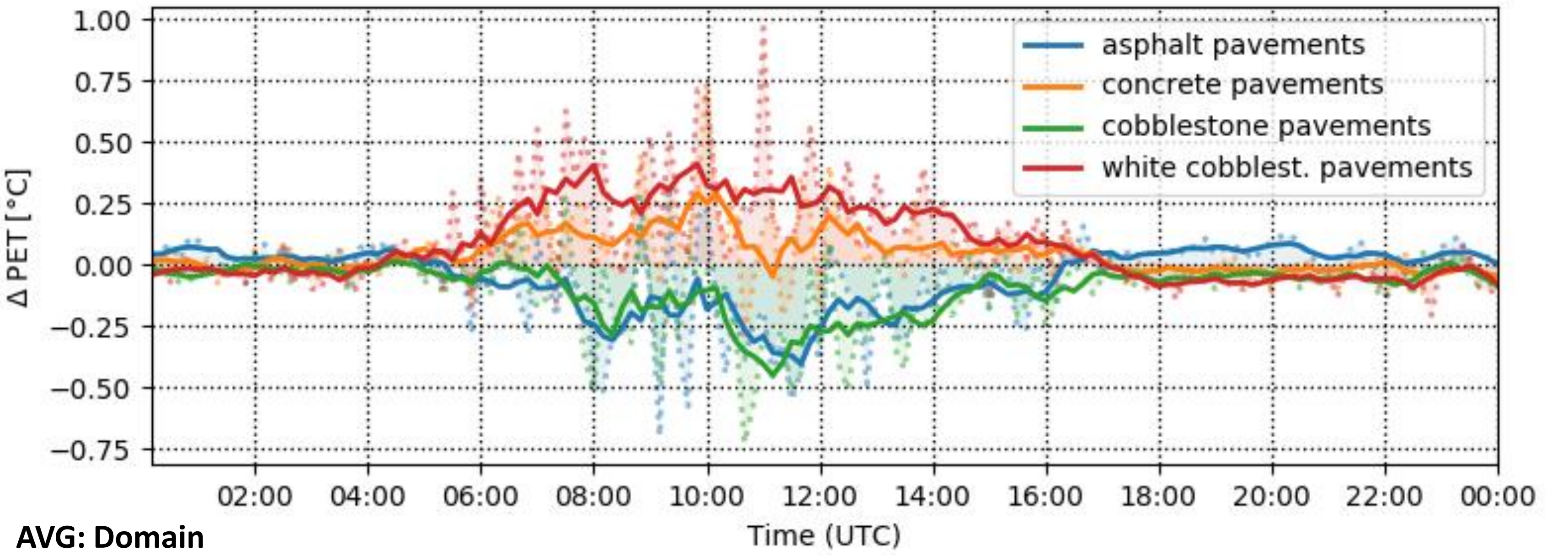


PET: Material changes

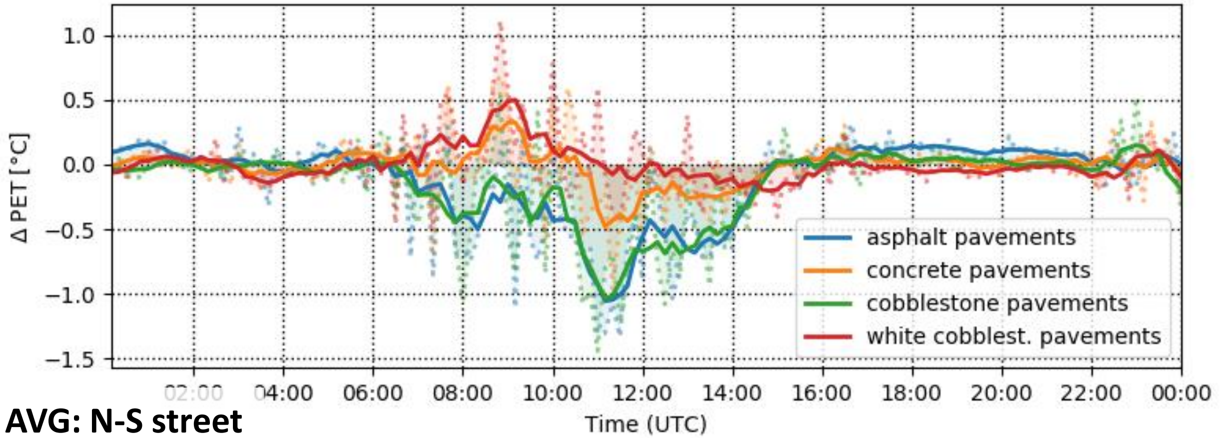
- 24h PET averages for 3 material changes
  - Concrete pavements (left)
  - Granite cobblestones pavements (middle)
  - White granite cobblestones (right)



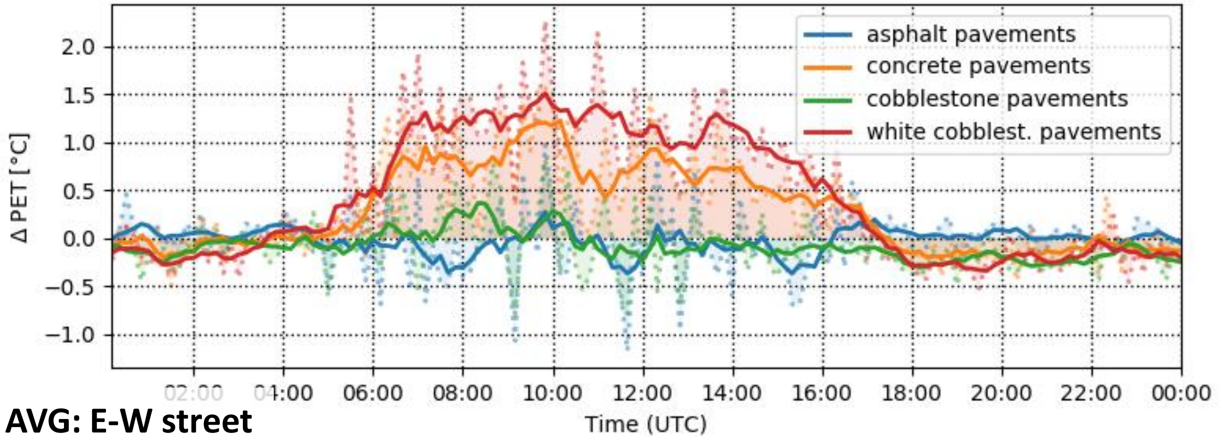
PET: Urbanistic scenarios



AVG: Domain



AVG: N-S street



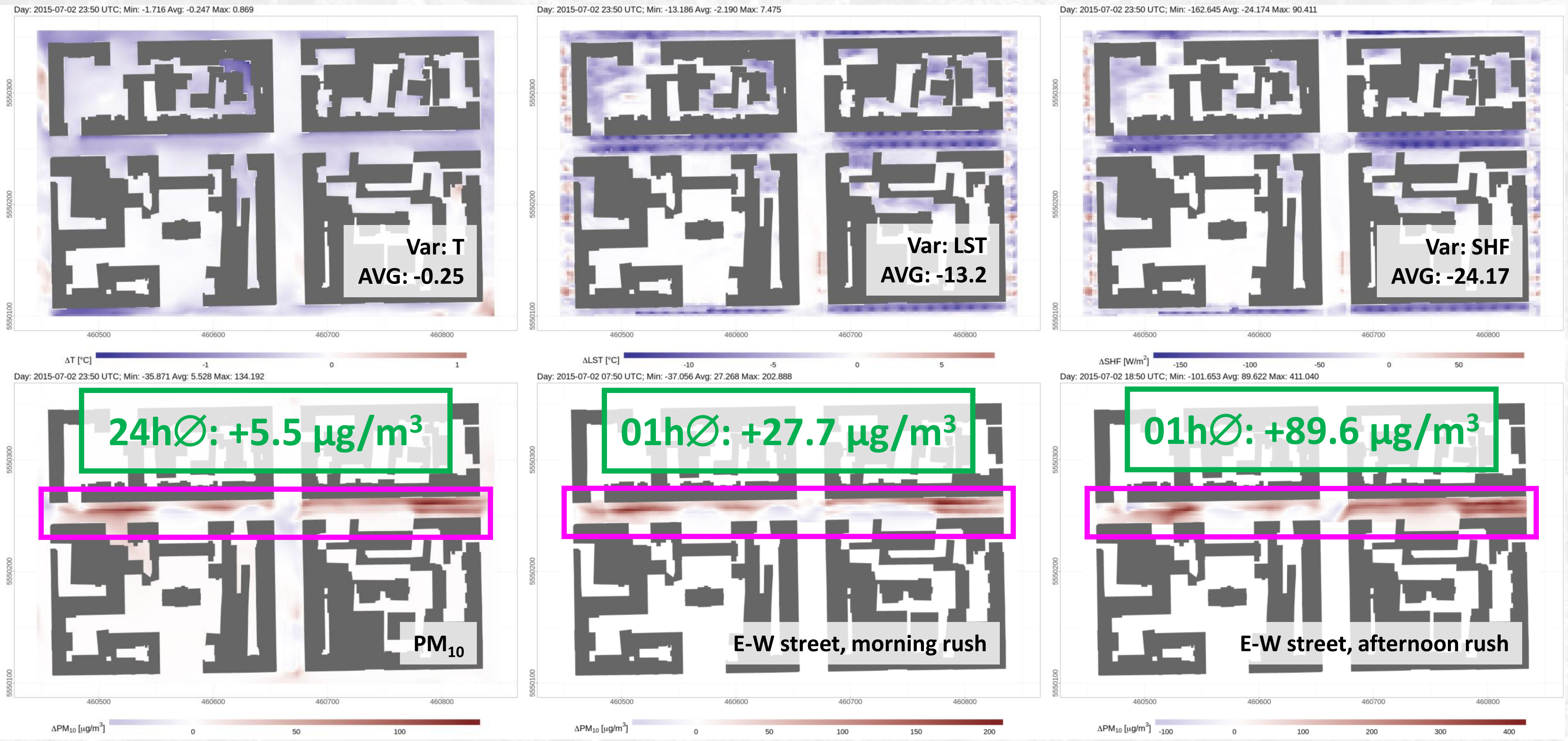
AVG: E-W street

PET: B-type scenario summary

Scenario	AVG	00-03	03-06	06-09	9-12	12-15	15-18	18-21	21-24	MIN	TIME	MAX	TIME
building height increase (street canyon ratio) by 20%	-0,127	0,345	0,074	-0,483	-0,438	-0,530	-0,297	0,145	0,163	-1,150	10:40	0,529	01:00
building height decrease (street canyon ratio) by 20%	0,289	-0,188	0,186	0,660	0,719	0,701	0,511	-0,113	-0,166	-0,291	22:10	1,812	08:50
all surfaces (pavement) asphalt	-0,052	0,041	0,007	-0,140	-0,273	-0,135	-0,015	0,061	0,035	-0,703	09:10	0,295	09:20
all surfaces (pavement) concrete	0,045	0,003	0,012	0,147	0,123	0,093	0,029	-0,022	-0,023	-0,314	10:40	0,756	10:00
all surfaces (pavement) cobblestones	-0,097	-0,023	-0,028	-0,091	-0,277	-0,191	-0,070	-0,048	-0,047	-0,730	10:40	0,290	08:50
all surfaces (pavement) cobblestones white	0,086	-0,028	0,028	0,275	0,309	0,183	0,035	-0,065	-0,052	-0,207	22:50	0,968	11:00
tram green line	-0,036	-0,040	0,017	-0,011	-0,020	-0,094	-0,078	-0,058	-0,002	-0,622	11:30	0,582	10:00
all surfaces (building) insulated	*-0,010*	*-0,828*	*-0,401*	*0,368*	*0,684*	*0,663*	*0,339*	*-0,308*	*-0,594*	*-0,966*	*02:20*	*1,568*	*11:10*
blue infrastructure - river instead of tram line, roads were changed to grass	-0,429	-0,284	-0,160	-0,234	-0,632	-0,673	-0,583	-0,500	-0,362	-1,153	11:20	0,047	06:20
grey city model - green areas to asphalt, deleted trees	1,379	-0,158	0,678	2,502	3,073	3,061	1,914	0,151	-0,190	-0,339	22:10	3,675	13:10
grey city model - asphalt except main roads / pavements changed to grass, all trees deleted	0,600	-0,531	0,371	1,580	1,589	1,672	1,033	-0,338	-0,578	-0,677	22:00	2,488	09:40
green city model - trees everywhere; randomly placed acer platanoides	-1,709	0,313	-0,541	-3,671	-3,644	-3,675	-2,411	-0,247	0,208	-4,256	08:10	0,516	02:50
new tree alley - Delnicka, center-line	-0,335	0,118	-0,111	-0,703	-0,647	-0,713	-0,580	-0,071	0,027	-1,082	08:30	0,257	02:30
new tree alley - Delnicka, both-side	-0,618	0,152	-0,158	-1,356	-1,093	-1,328	-1,071	-0,145	0,051	-1,712	15:30	0,389	03:20
new tree alley - both streets, both-side	-0,665	0,272	-0,063	-1,587	-1,467	-1,491	-1,057	-0,065	0,140	-2,456	08:30	0,438	04:10
all trees coniferous	0,303	-0,005	0,195	0,574	0,722	0,676	0,304	0,005	-0,048	-0,190	21:10	1,308	07:40
include anthropogenic heat flux	0,014	-0,009	-0,002	0,036	0,003	0,030	0,033	0,019	0,004	-0,426	10:20	0,434	12:10

Note: decimal separator is comma

Why do we need complex model (green city)?



Conclusion

- Highest PET increase (A-type): albedo +20%, roughness -20%
- Highest PET increase (B-type): grey city models (deleted trees)
- Highest PET decrease (A-type): albedo -20%, emissivity -20%
- Highest PET decrease (B-type): green city models, new alleys
- Different places have different sensitivities – using of parametrized inputs need not have to provide valid outputs
- Important complex analysis of results – interdisciplinary interpretation
- Potential source for urban developers and architects
- „Special issue“ of Geoscientific Model Development about PALM(-4U) 6.0

Thank you for attention

Contacts

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More details:

Resler, J. *et al*. (2017) PALM-USM v1.0: A new urban surface model integrated into the PALM large-eddy simulation model, Geosci. Model Dev., 10, 3635-3659, https://doi.org/10.5194/gmd-10-3635-2017.

Fröhlich, D., Matzarakis, A. (2019) Calculating human thermal comfort and thermal stress in the PALM model system 6.0, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2019-202. *in review*

Maronga, et al. (2019) Overview of the PALM model system 6.0, Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2019-103. *in review*