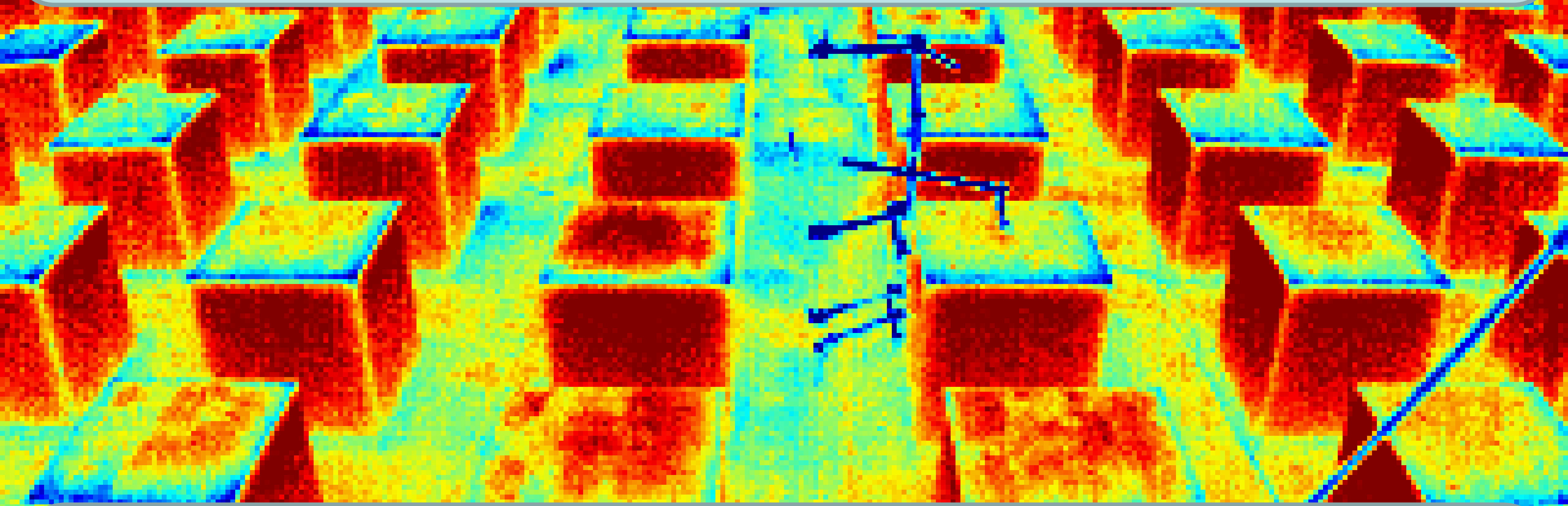
Physical and numerical modelling of sub-facet surface temperature variability



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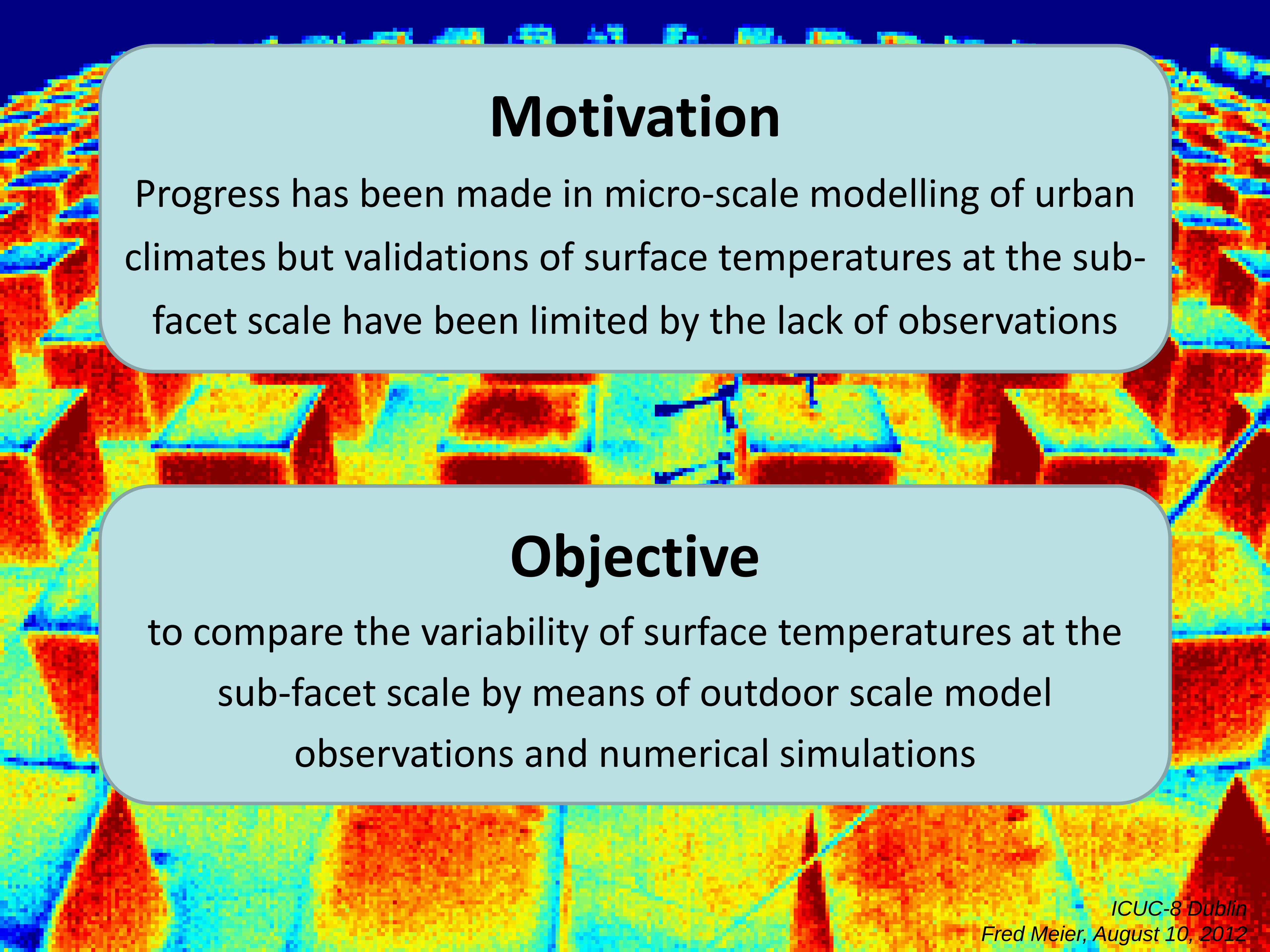
[(2)] Department of Geography, University of British Columbia, Vancouver, BC, Canada
[(3)] Department of International Development Engineering, Tokyo Institute of Technology, Tokyo, Japan

ICUC-8 Dublin
Fred Meier, August 10, 2012



Motivation

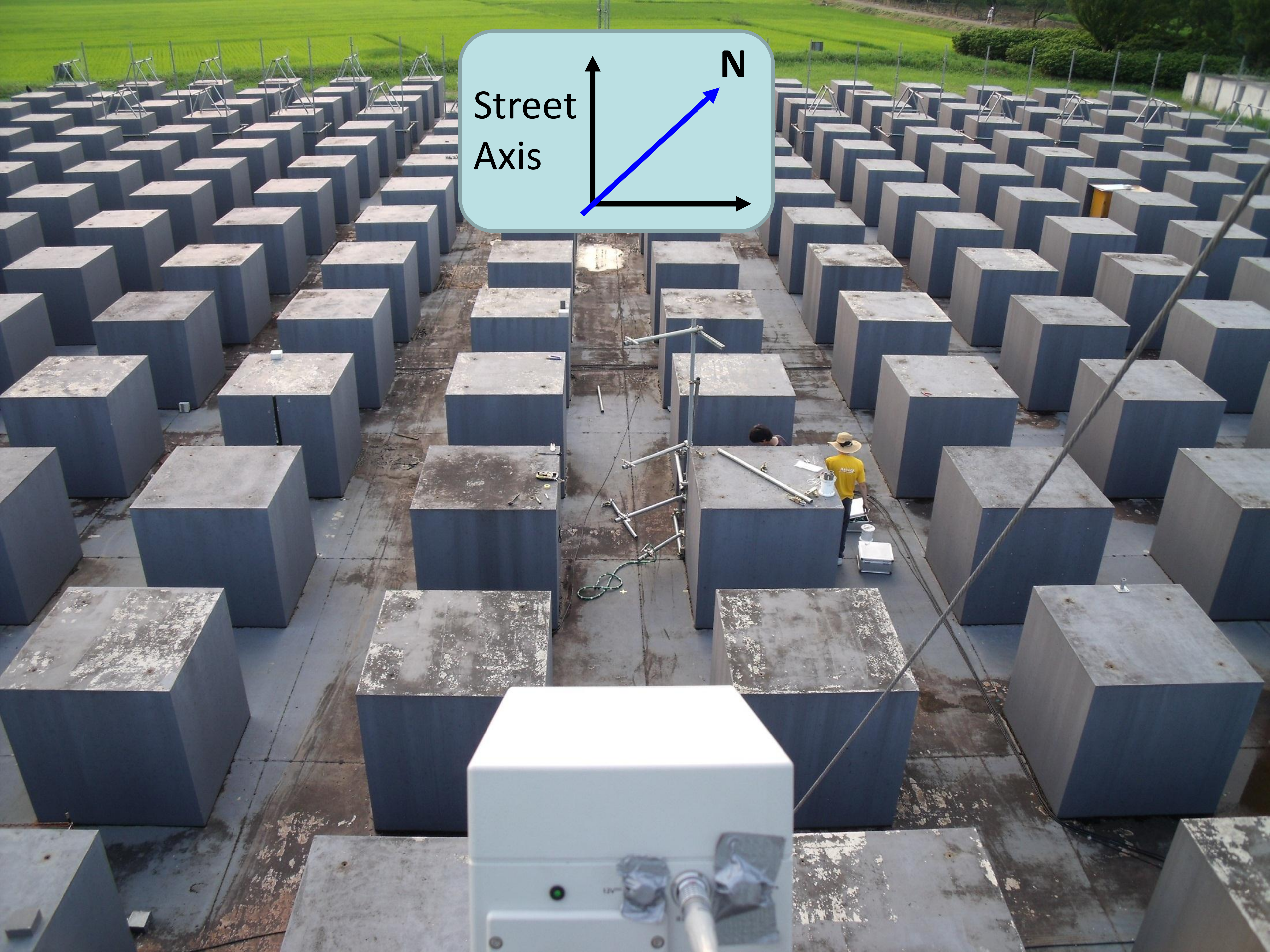
Progress has been made in micro-scale modelling of urban climates but validations of surface temperatures at the sub-facet scale have been limited by the lack of observations

Objective

to compare the variability of surface temperatures at the sub-facet scale by means of outdoor scale model observations and numerical simulations

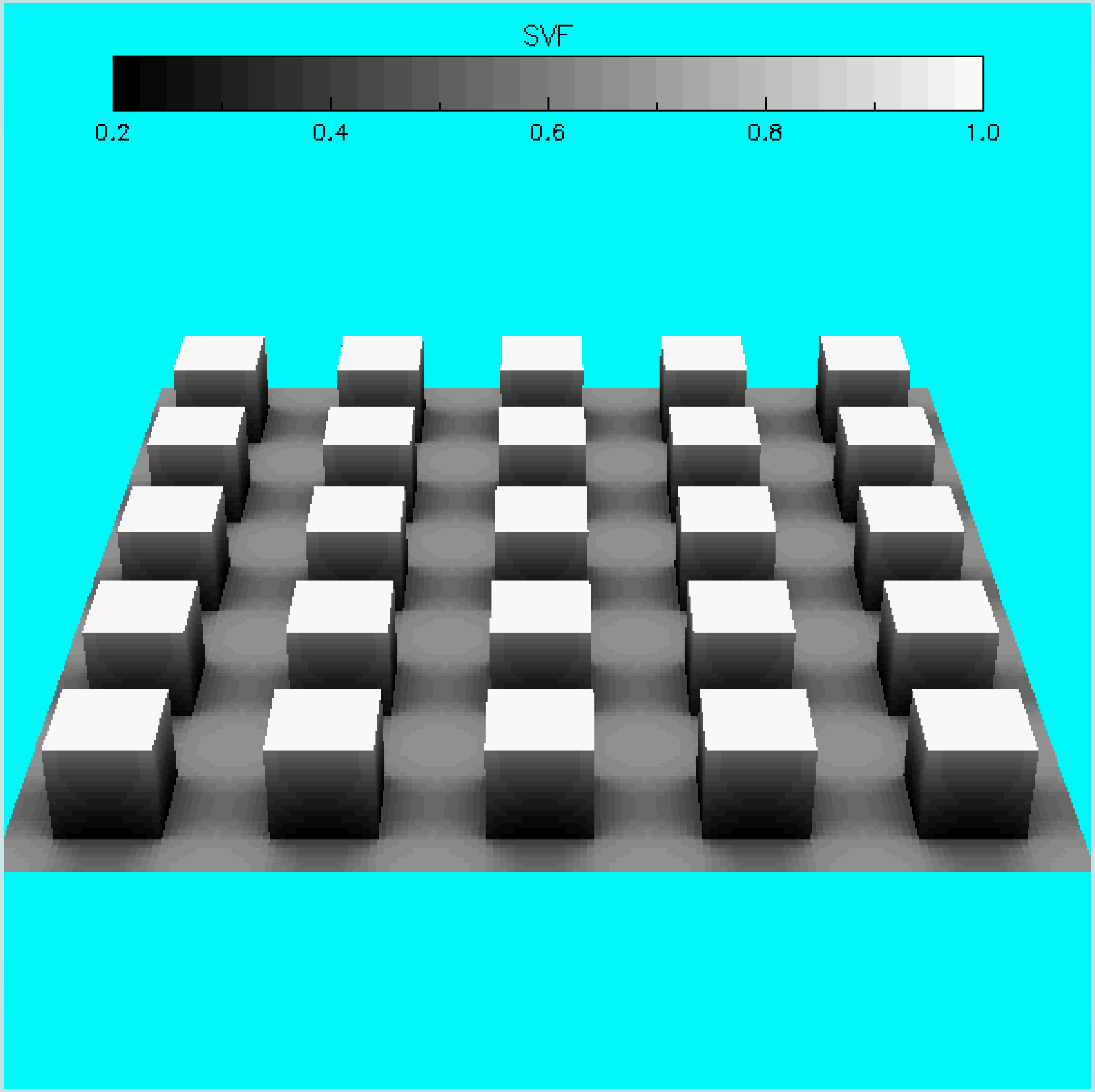
Comprehensive Outdoor Scale Model
COSMO

Kanda M., Kanega M., Kawai T., Sugawara H. & Moriwaki R. (2007): Roughness lengths for momentum and heat derived from outdoor urban scale models. Journal of Applied Meteorology and Climatology, 46, 1067-1079.



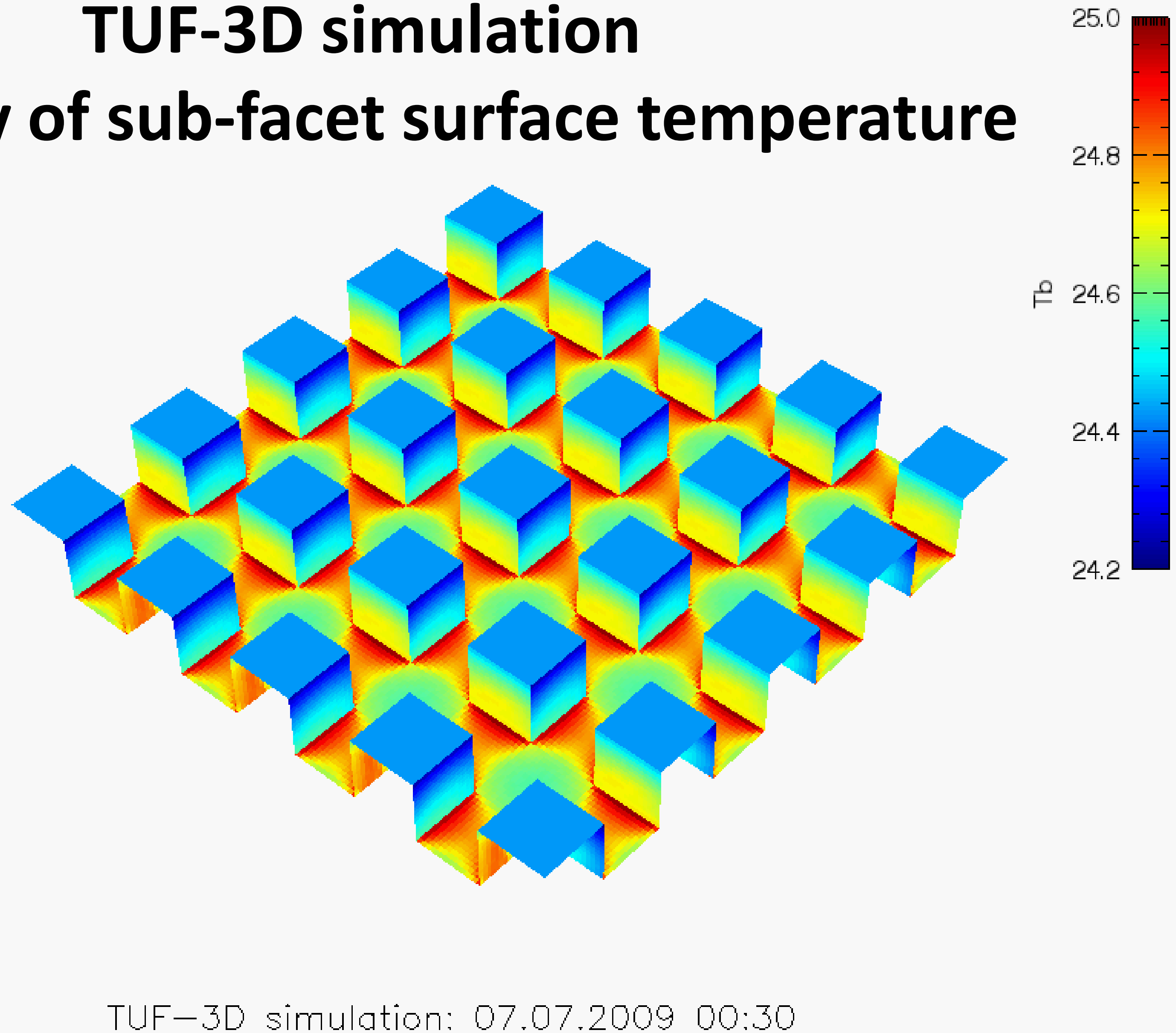
Street
Axis
N

TUF-3D Temperature of Urban Facets in 3D



Krayenhoff E. S. & Voogt J. A. (2007): A microscale three-dimensional urban energy balance model for studying surface temperatures. Boundary-Layer Meteorology, 123, 433-461.

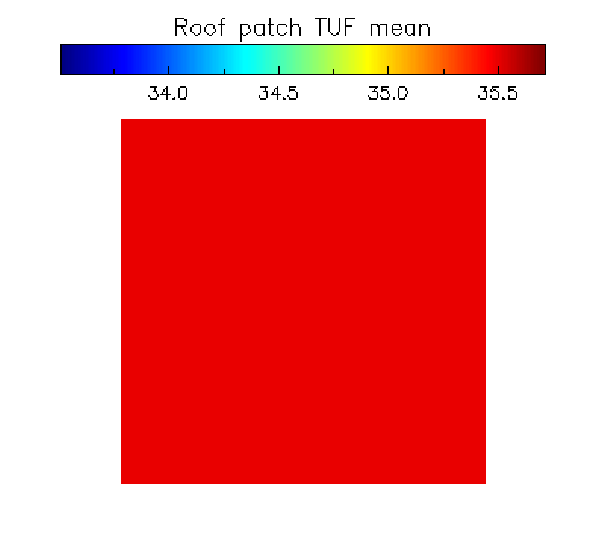
TUF-3D simulation
Variability of sub-facet surface temperature

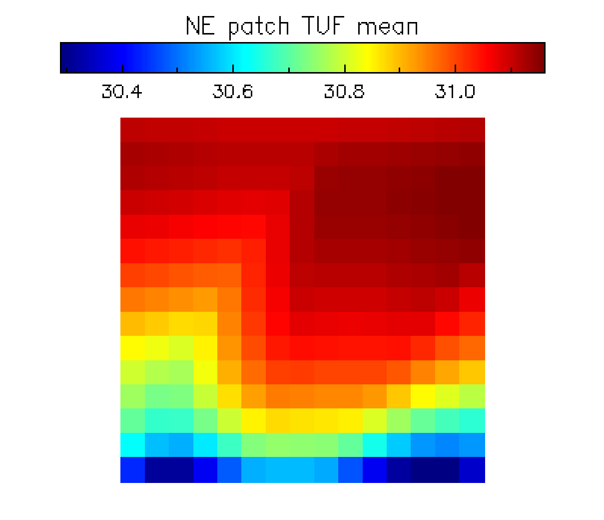


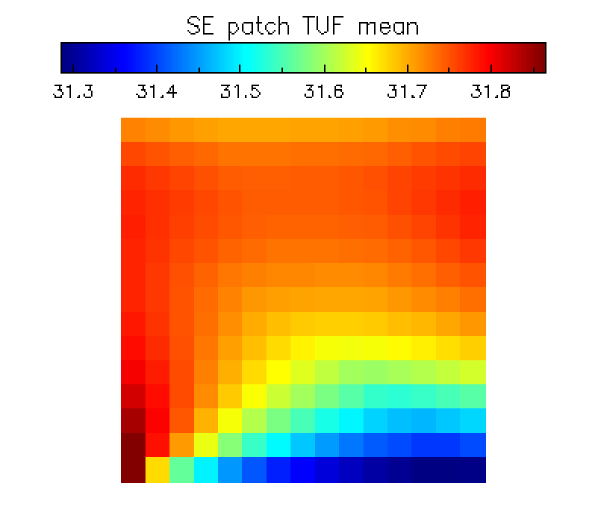
Resolution: 10 cm

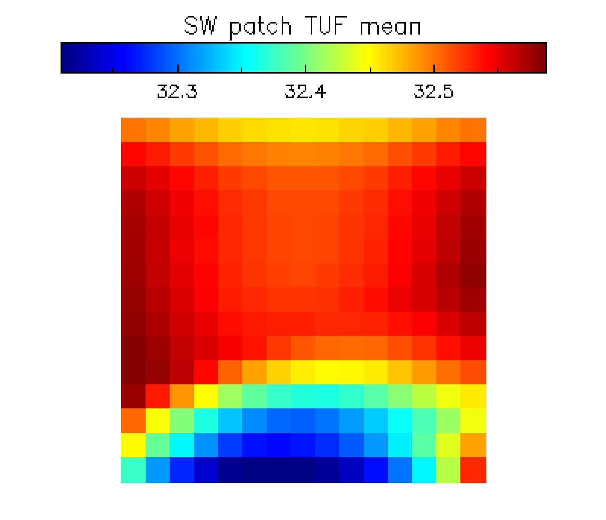
Spin up time: 24 h

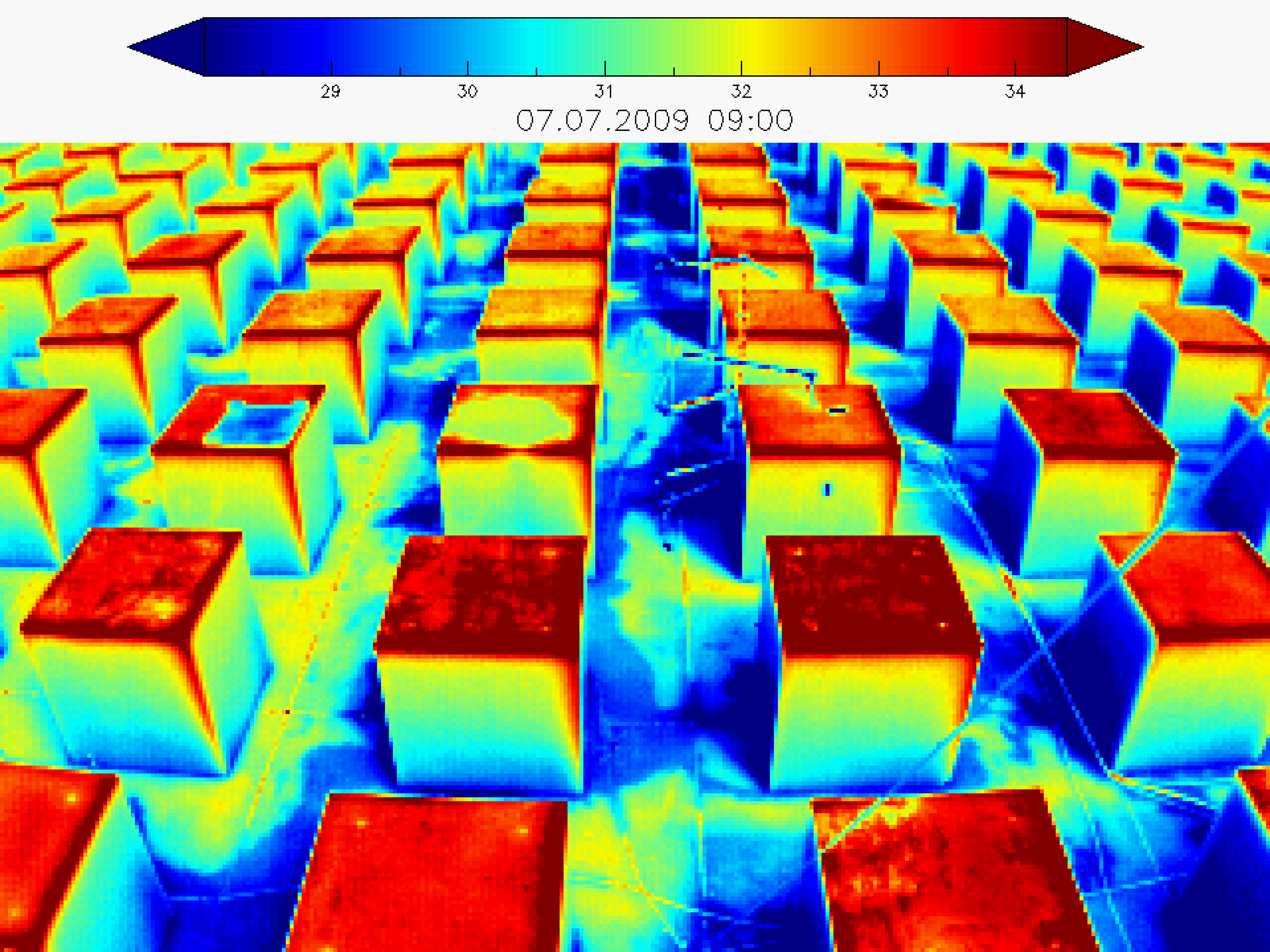
TUF-3D simulation
Variability of sub-facet surface temperature







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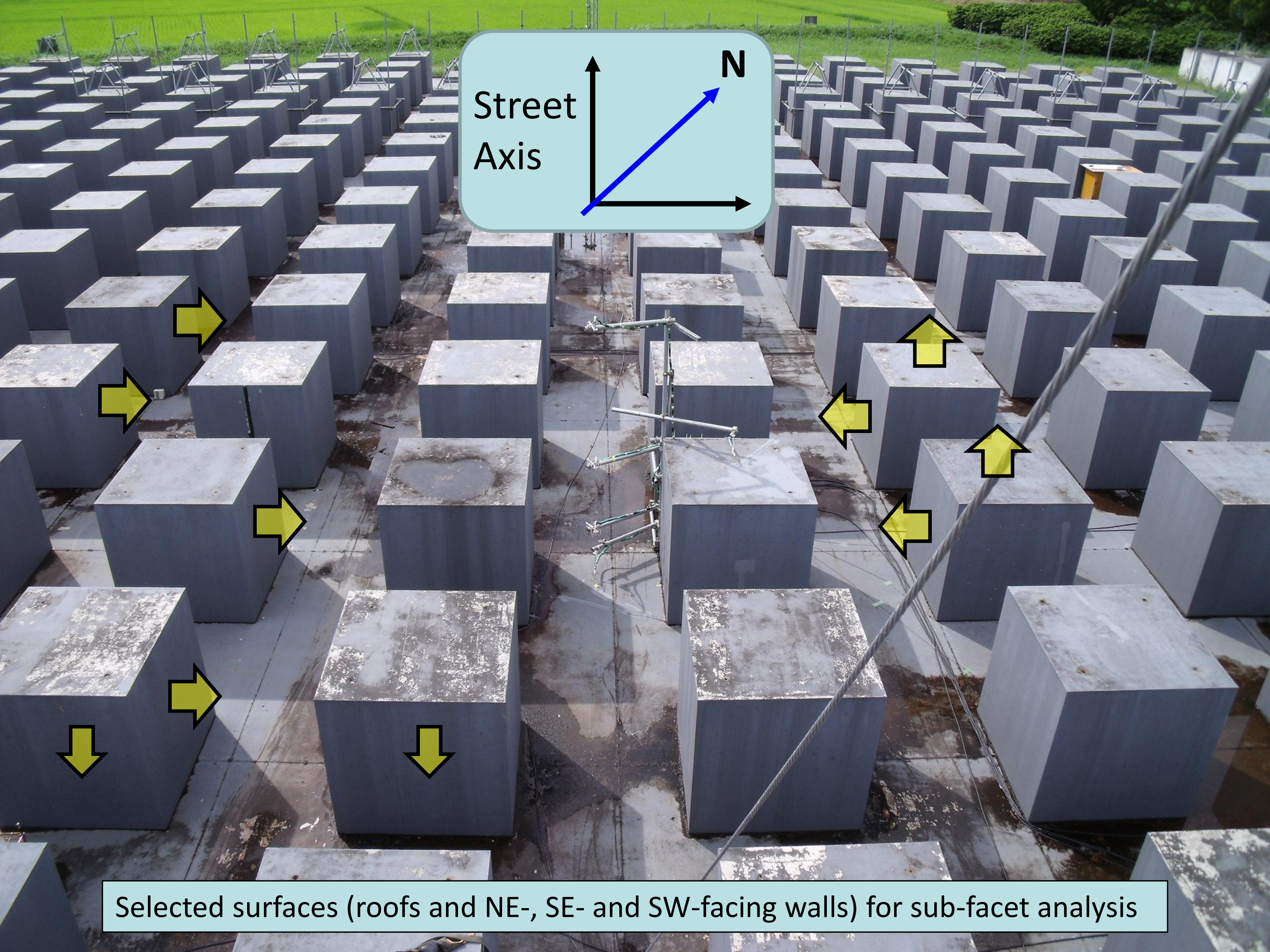
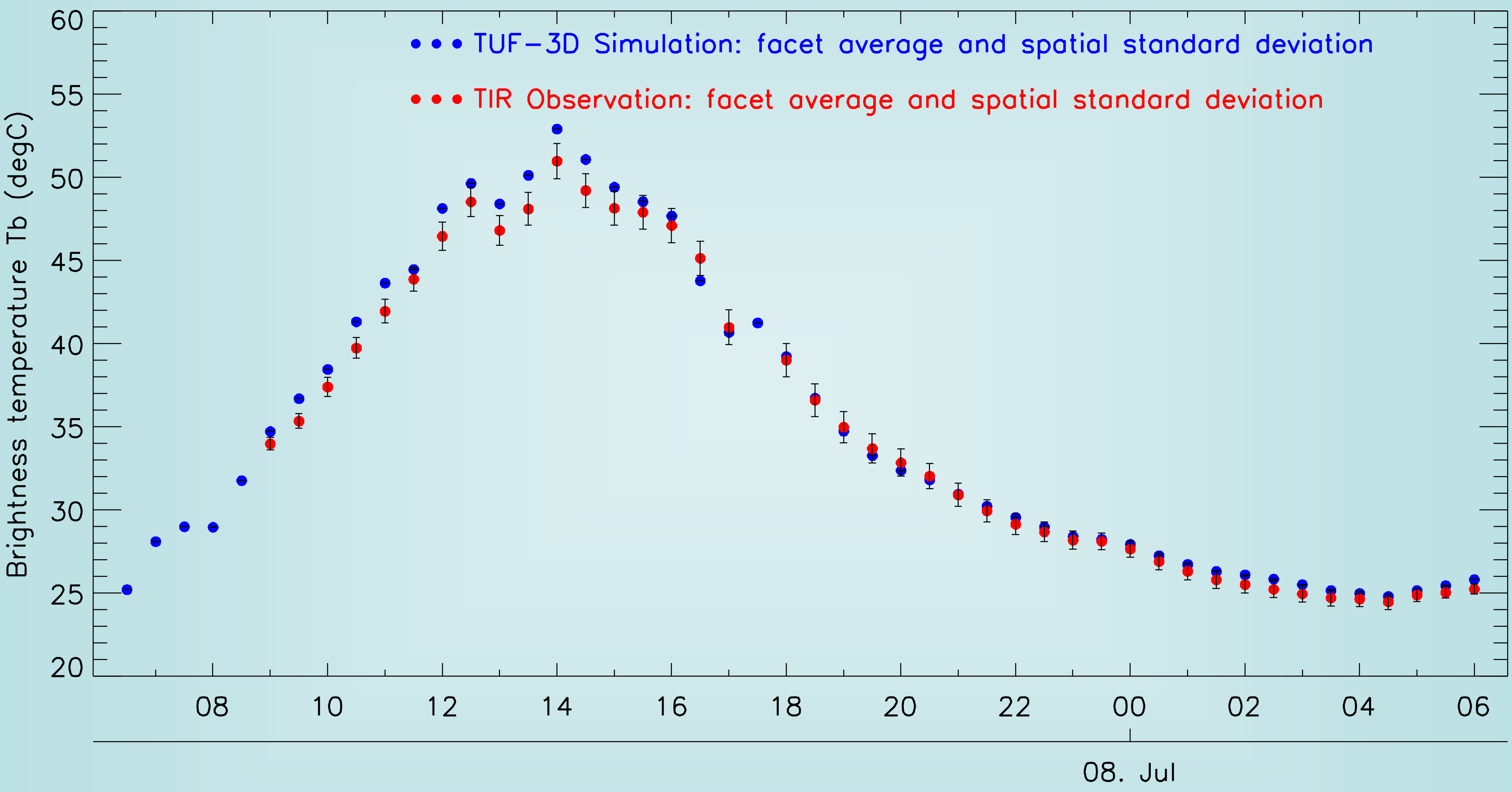
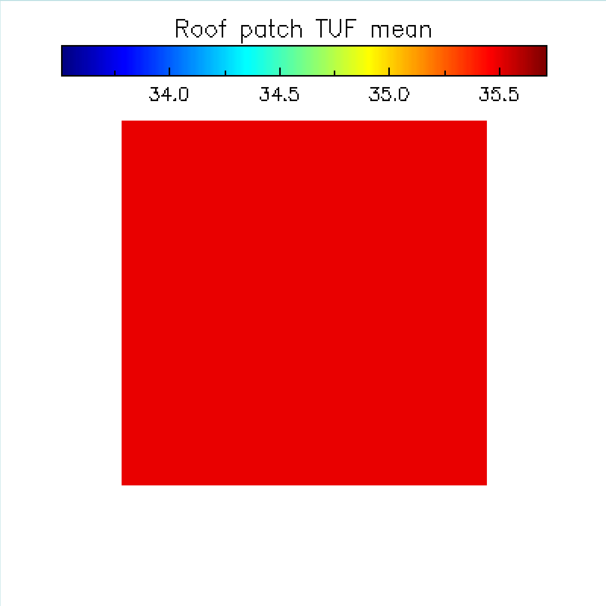
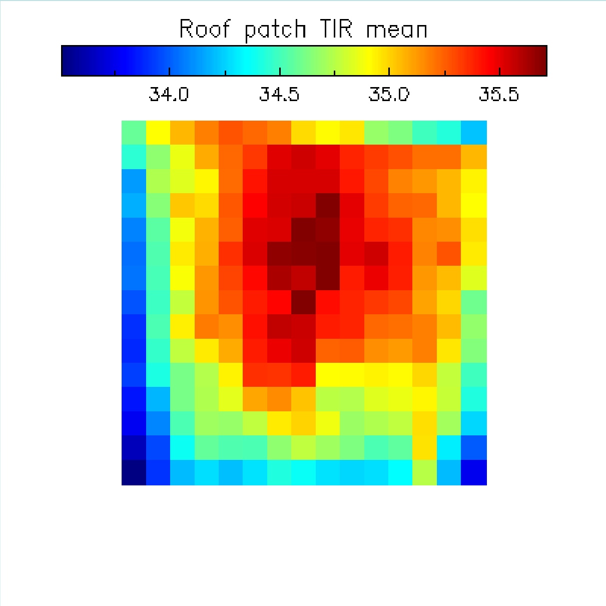

Street
Axis
N
Selected surfaces (roofs and NE-, SE- and SW-facing walls) for sub-facet analysis

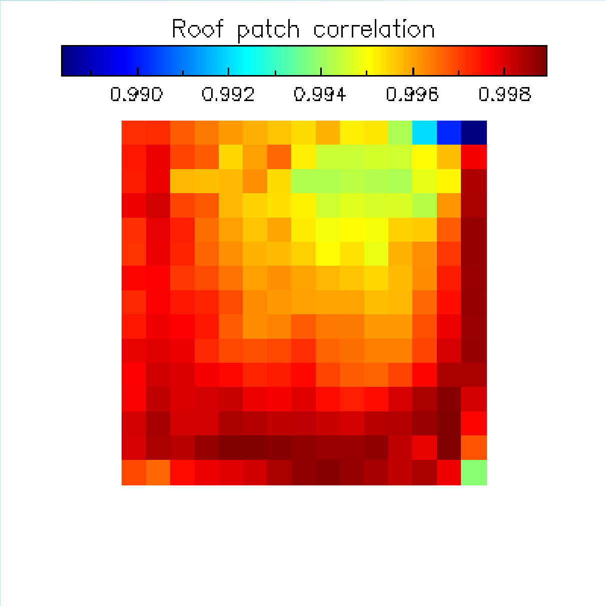
TUF-3D simulation vs. COSMO measurements (roof)

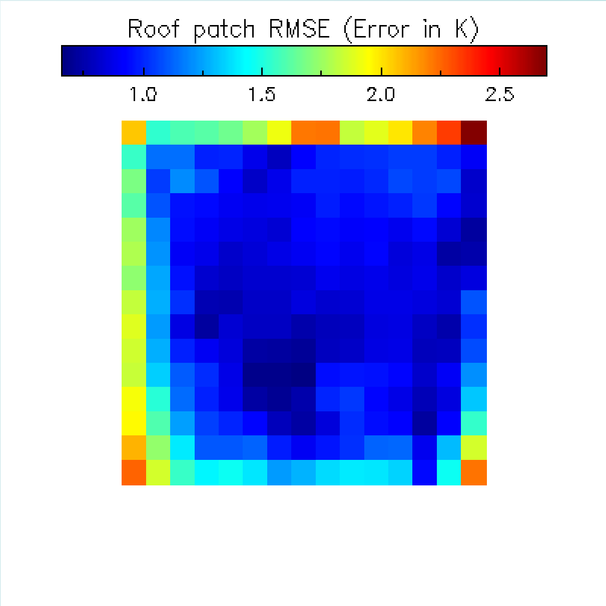


TUF-3D simulation vs. COSMO measurements (roof)

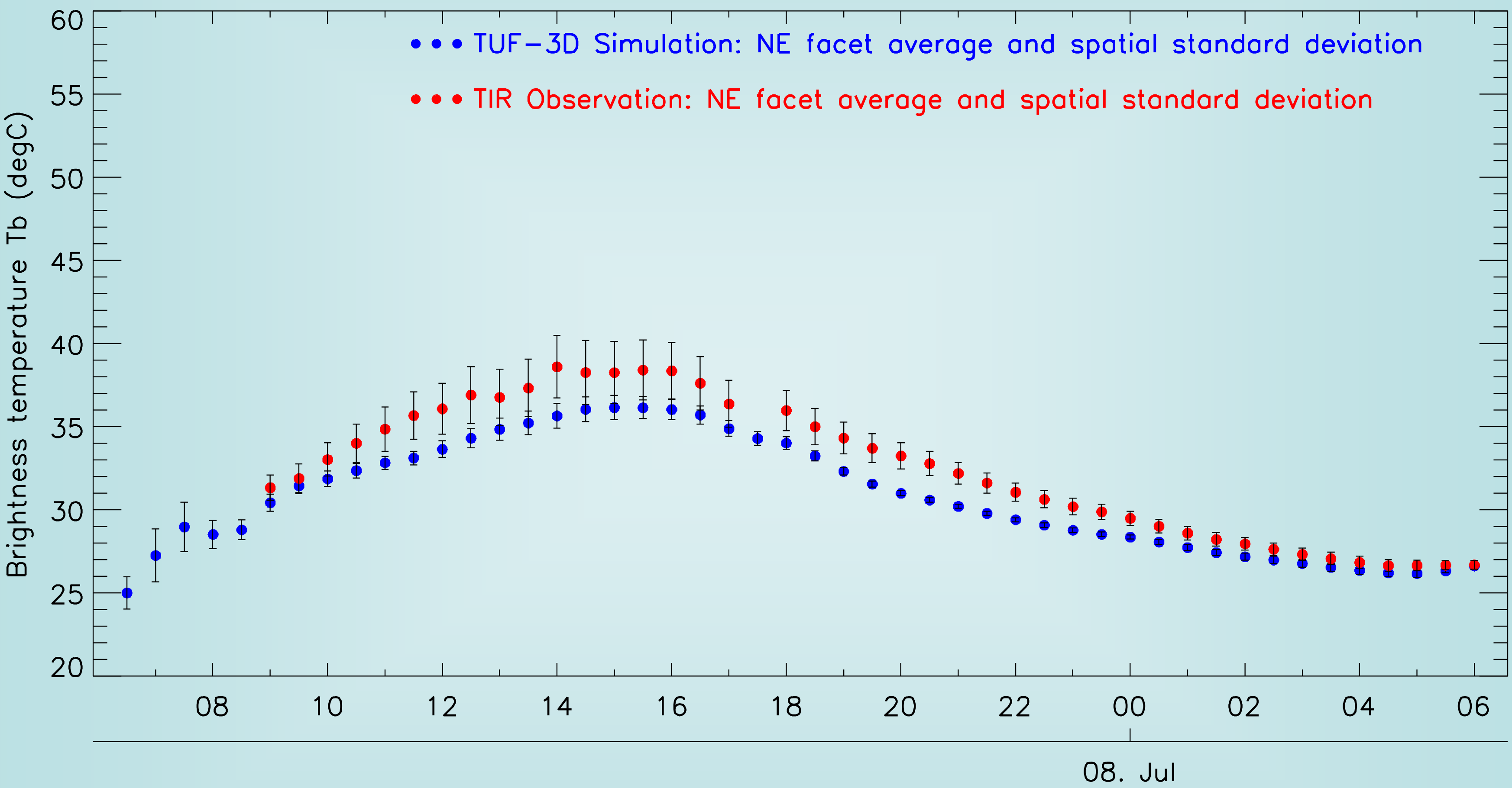




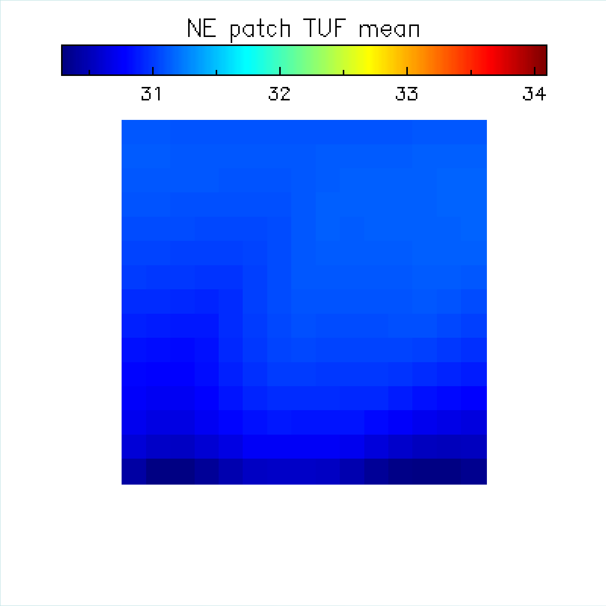


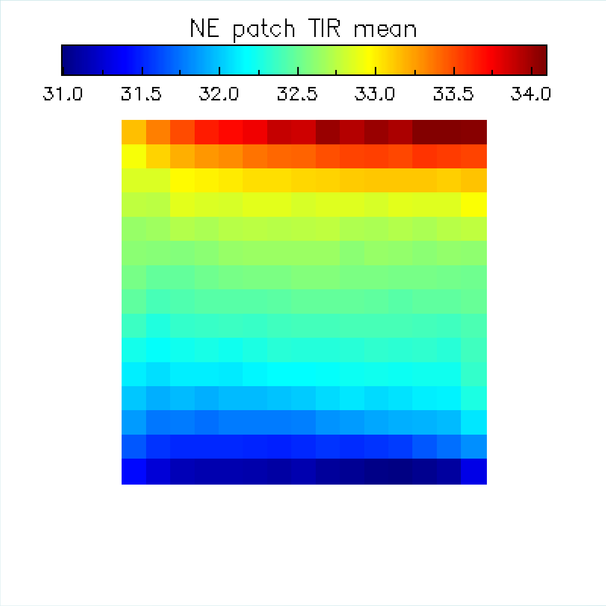


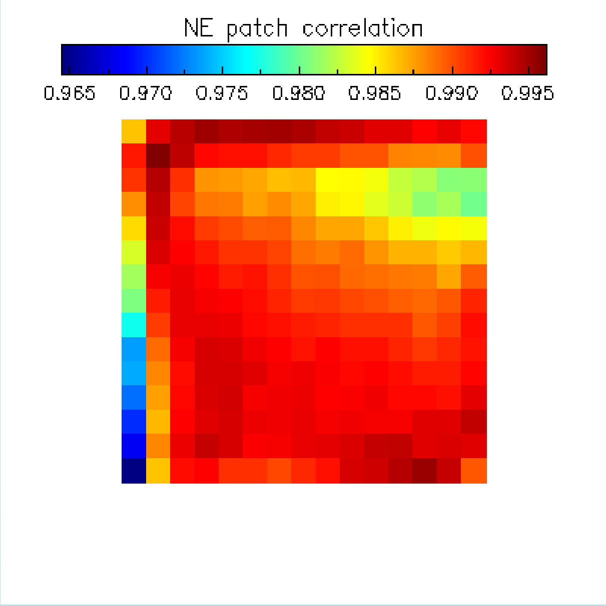
TUF-3D model output vs. COSMO measurements (NE-facing wall)

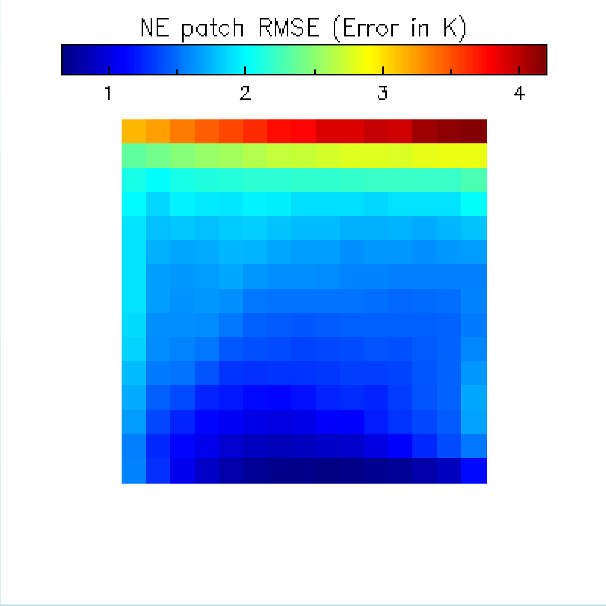


TUF-3D model output vs. COSMO measurements



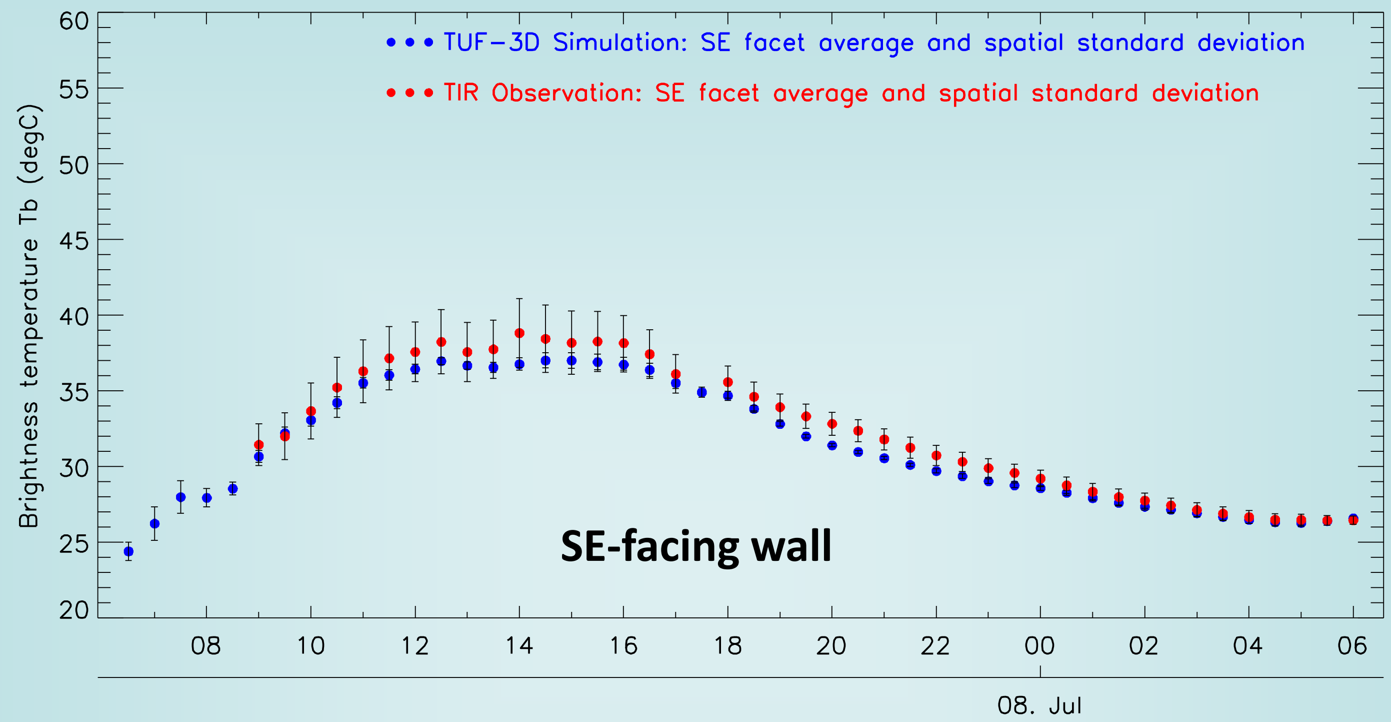


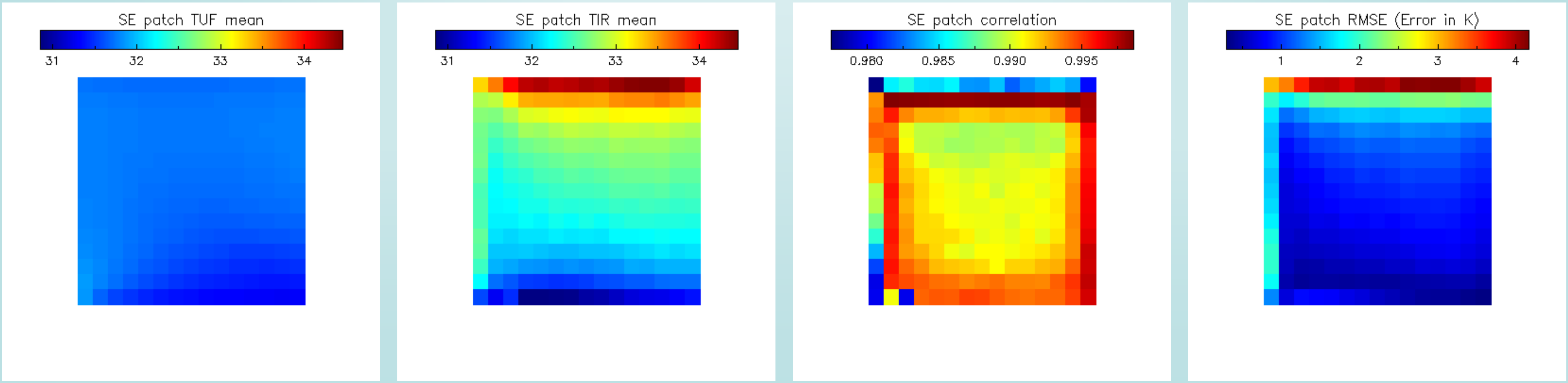




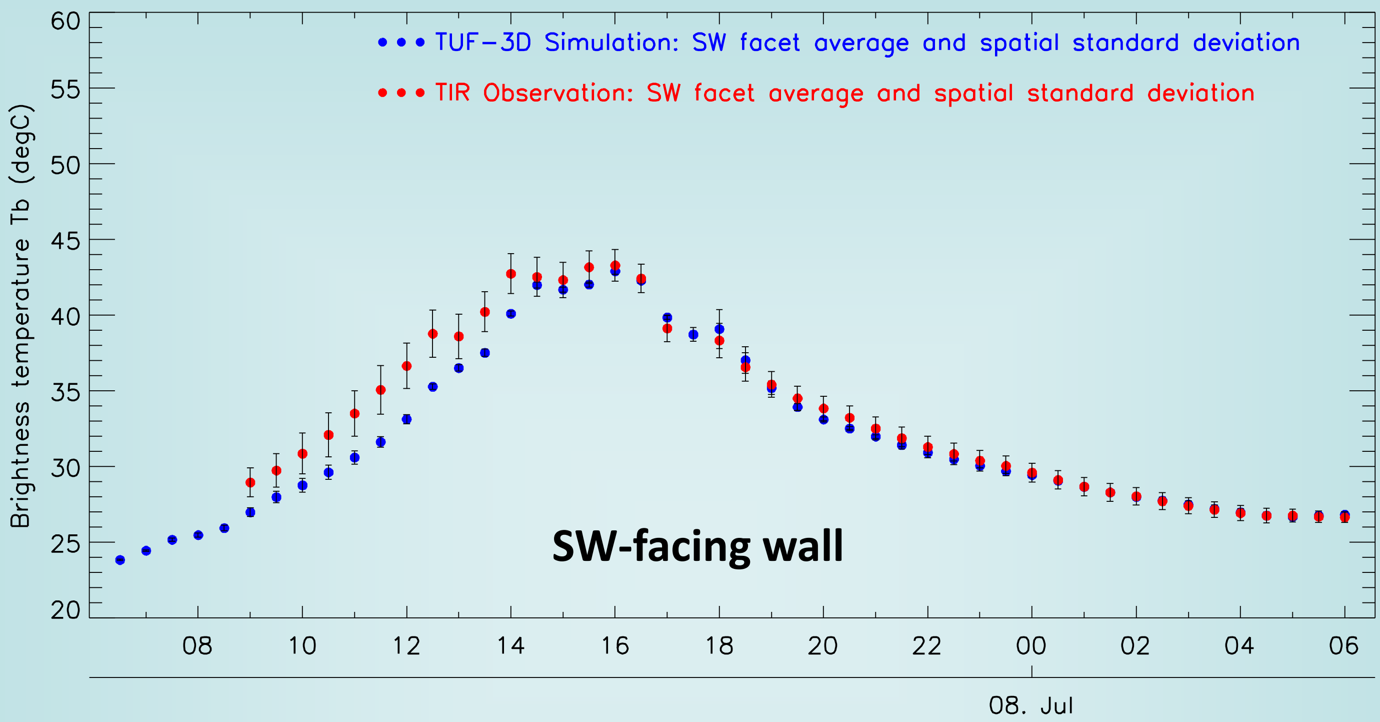
NE-facing wall

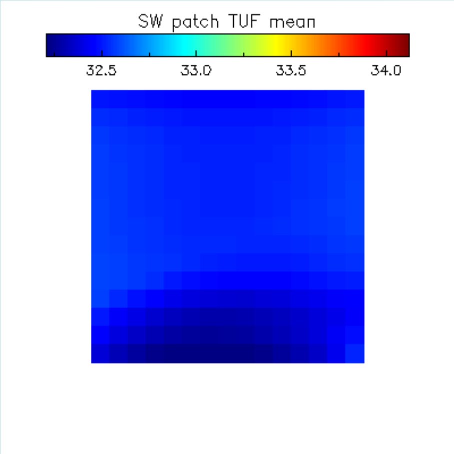
TUF-3D model output vs. COSMO measurements

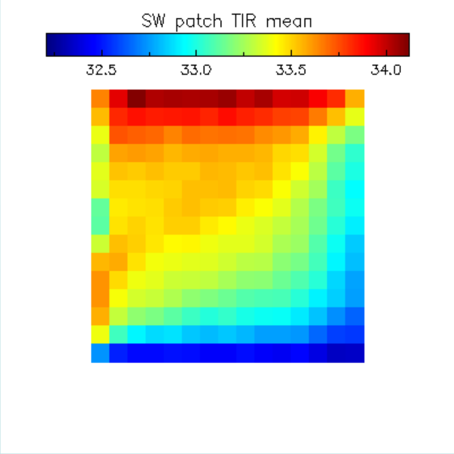


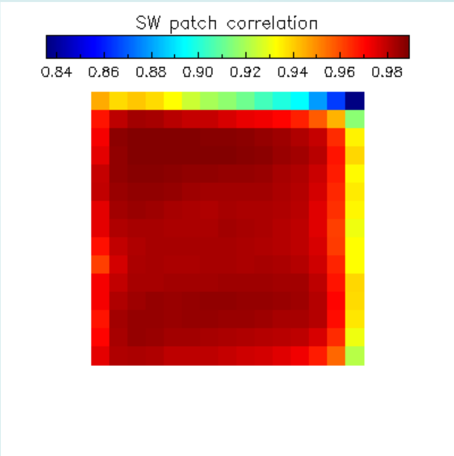


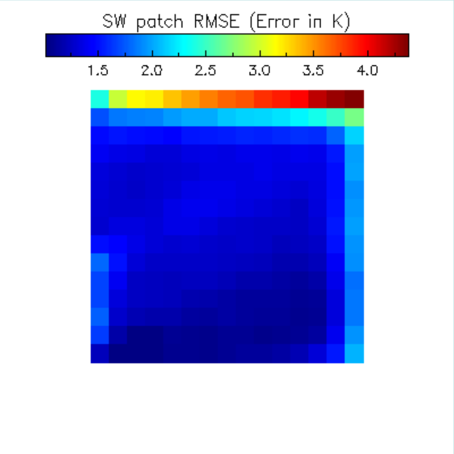
TUF-3D model output vs. COSMO measurements



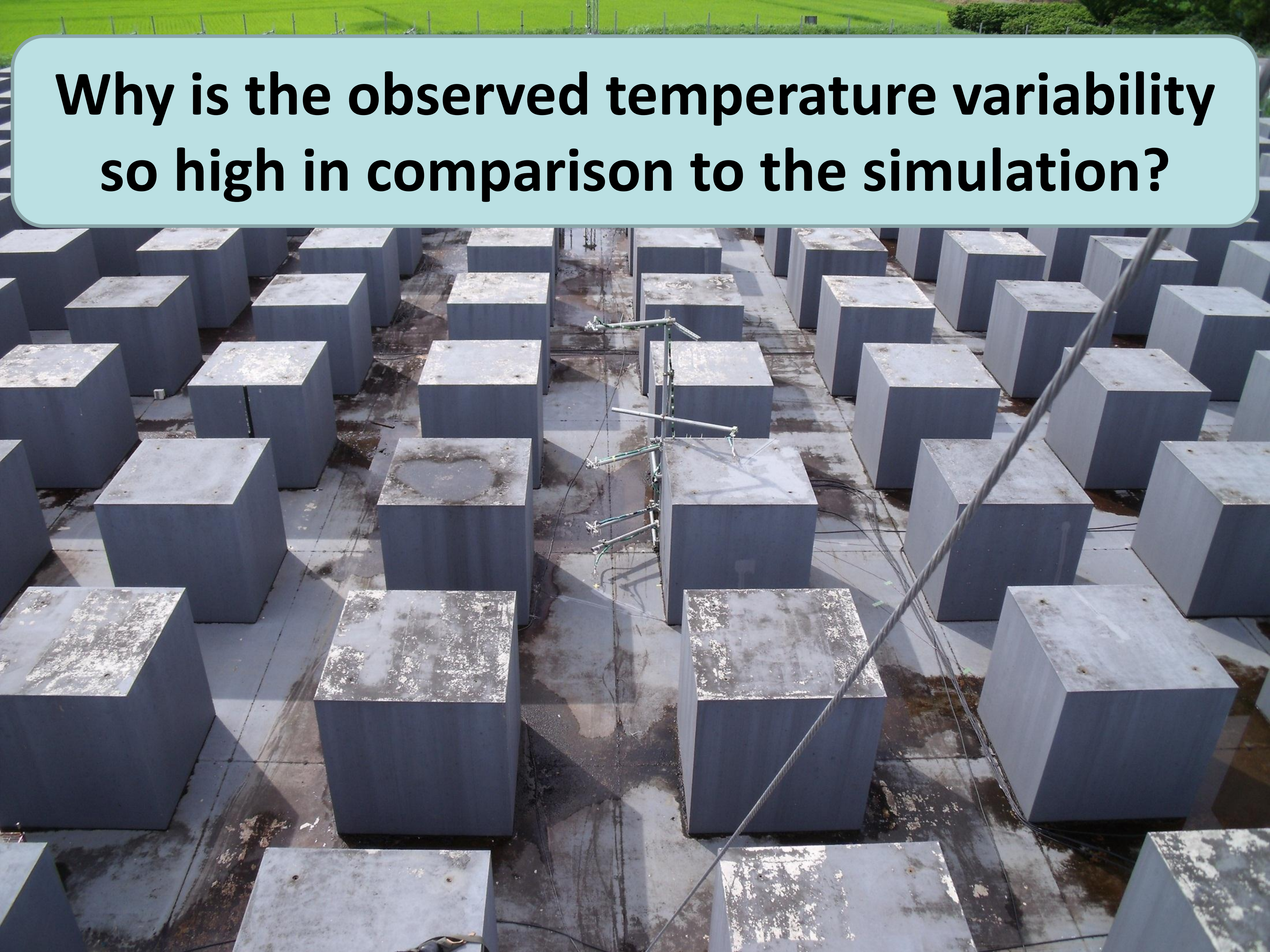




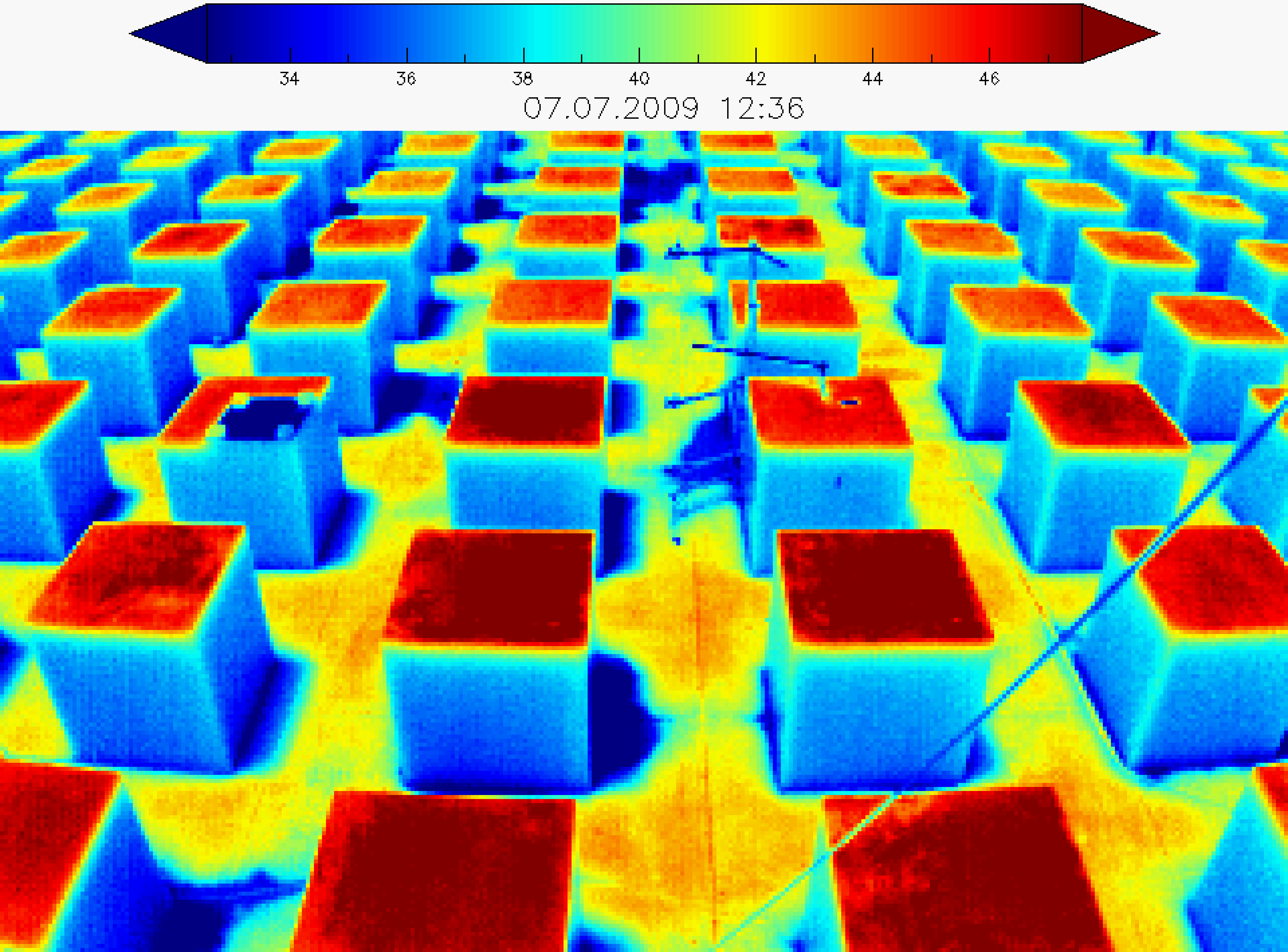




Why is the observed temperature variability so high in comparison to the simulation?



The role of conduction (2D) in terms of surface temperature variability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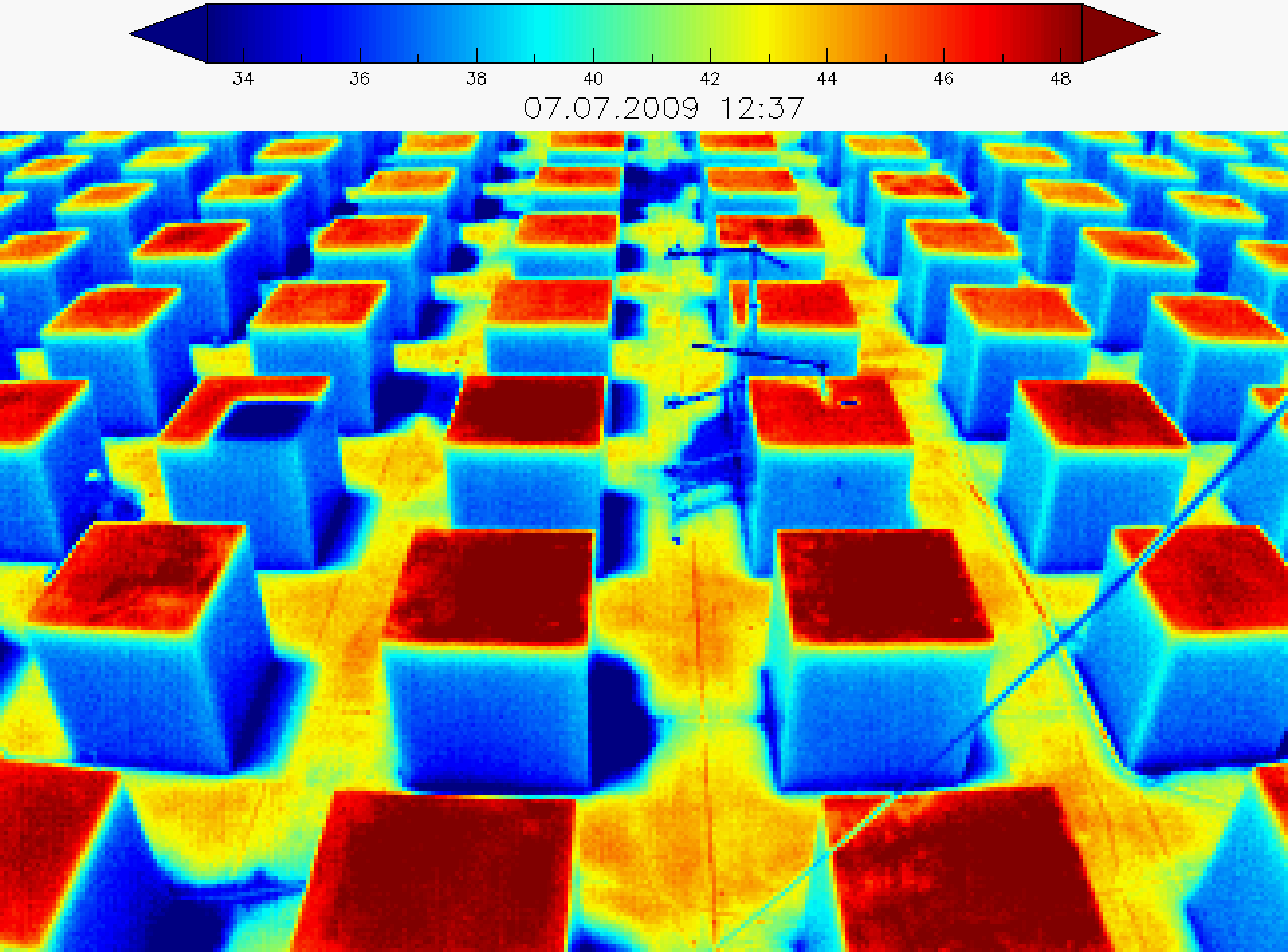
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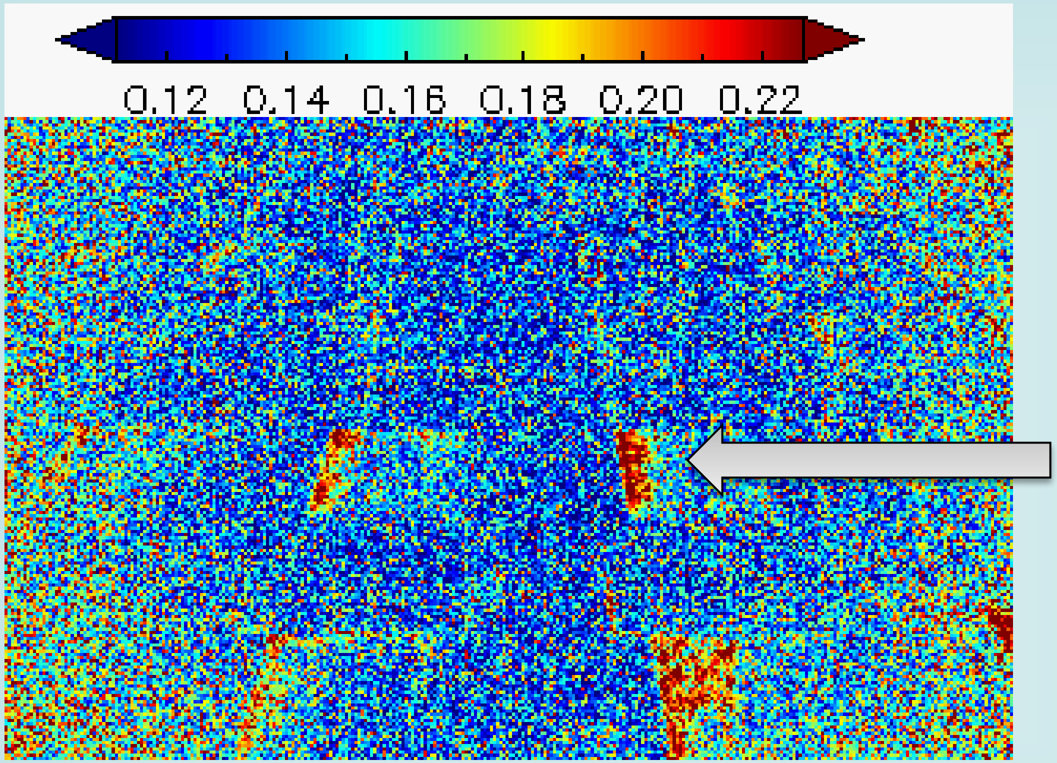
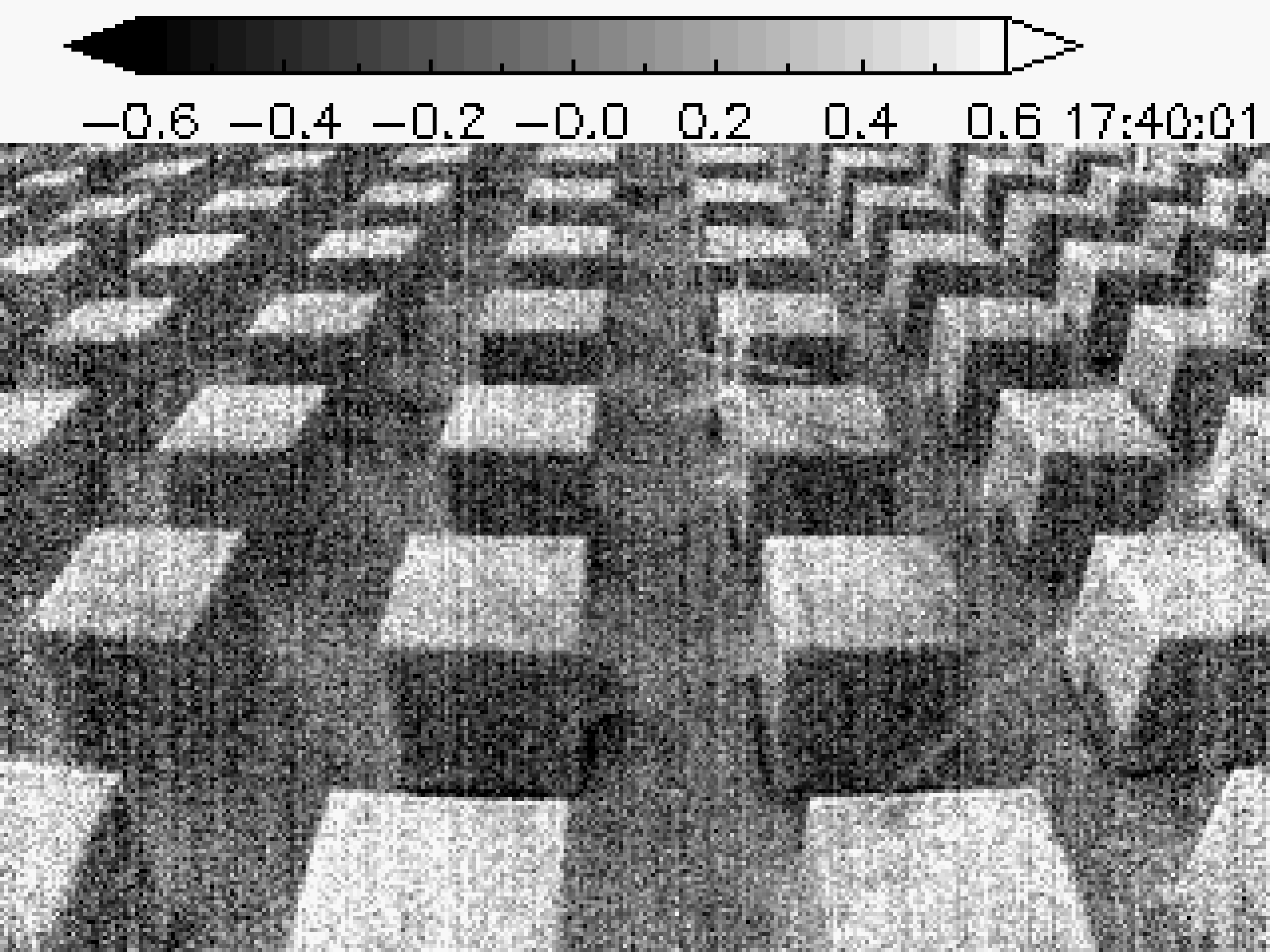
The role of convection in terms of surface temperature variability



Higher fluctuations of surface temperatures close to edges

High-frequency Time-Sequential Thermography (1Hz)

Christen A., Meier F. & Scherer D. (2012): High-frequency fluctuations of surface temperatures in an urban environment. Theoretical and Applied Climatology, 108, 301-324.



−0.6
−0.4
−0.2
−0.0
0.2
0.4
0.6
17:40:01

Conclusions (take home points)

- Take care of your scale model and avoid changes in material properties!
- Be aware of edge effects in scale models in terms of convection and conduction!
- TUF-3D produces less sub-facet temperature variability but shows a good correlation with the measurements

Acknowledgements:

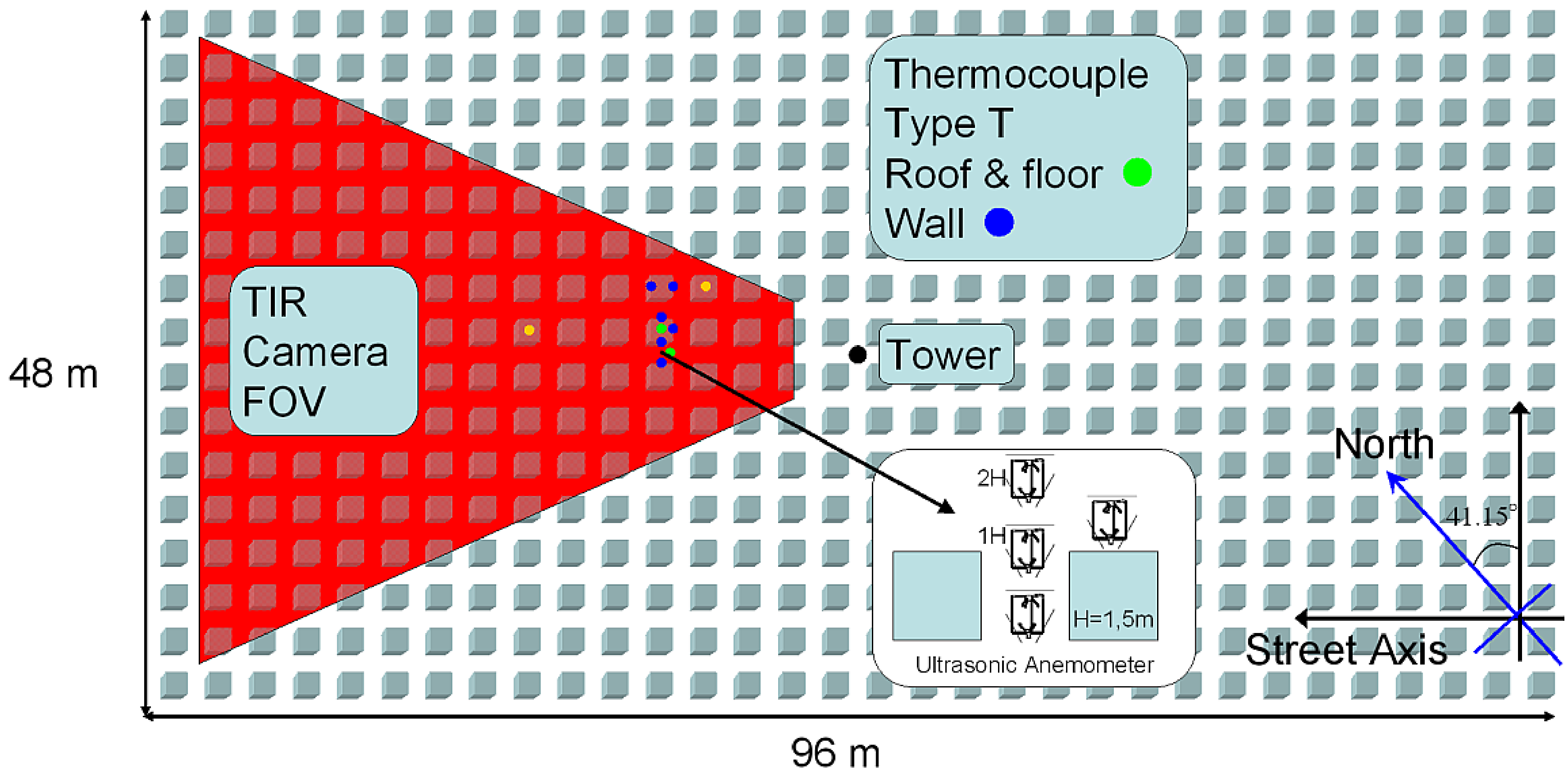
Aya Hagishima

Ken-ichi Narita

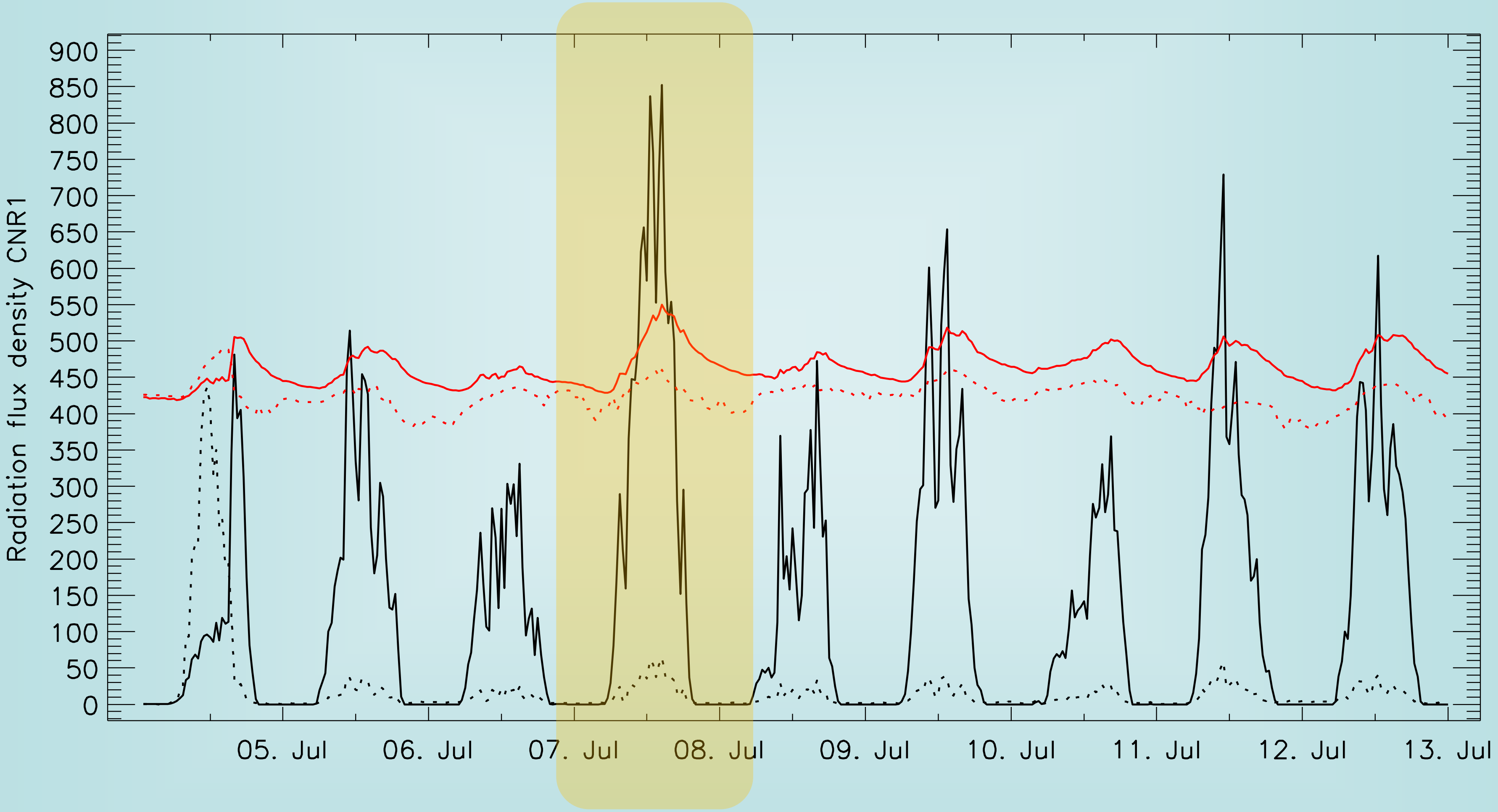
Jochen Richters

Hiroshi Takimoto

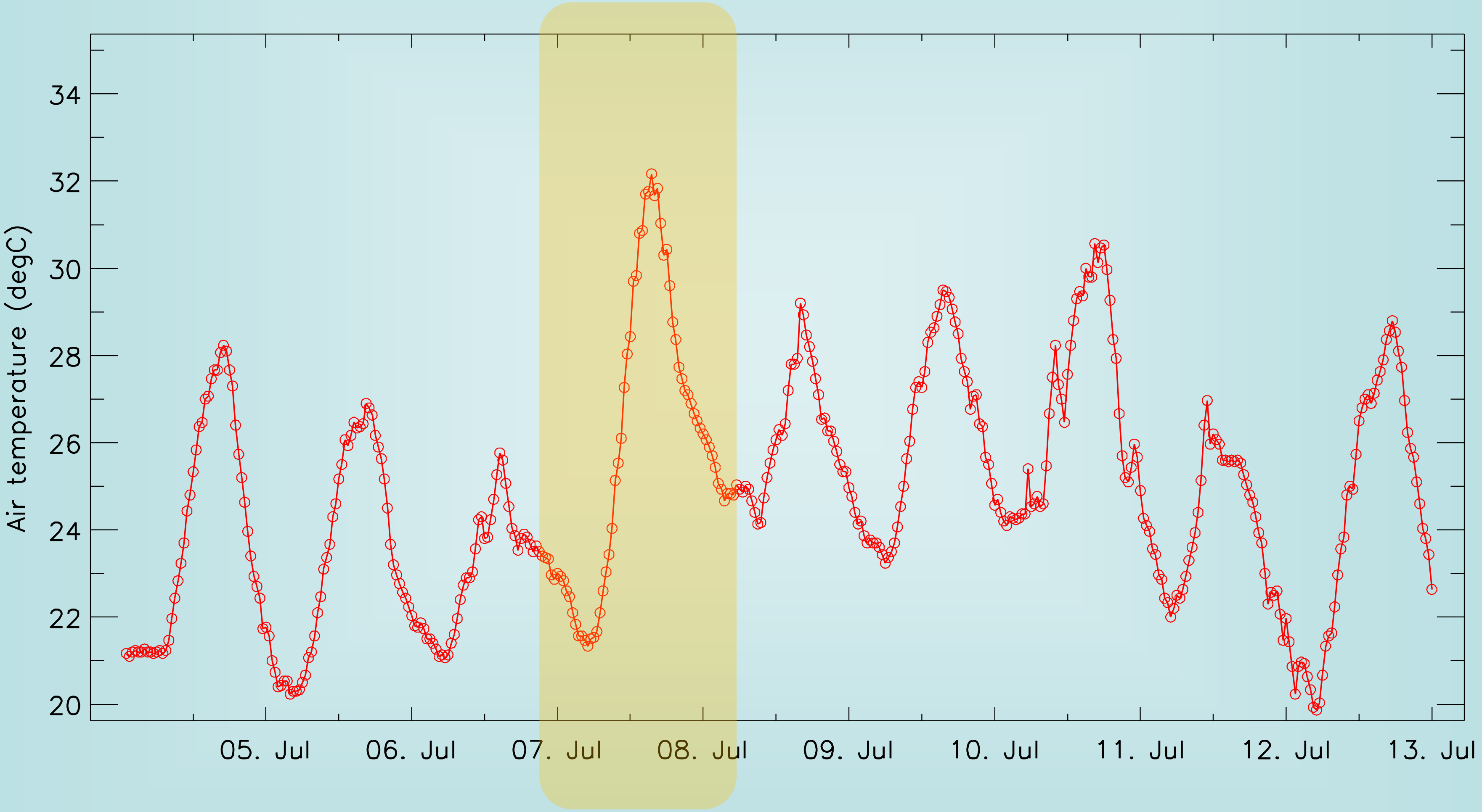
Experimental Setup



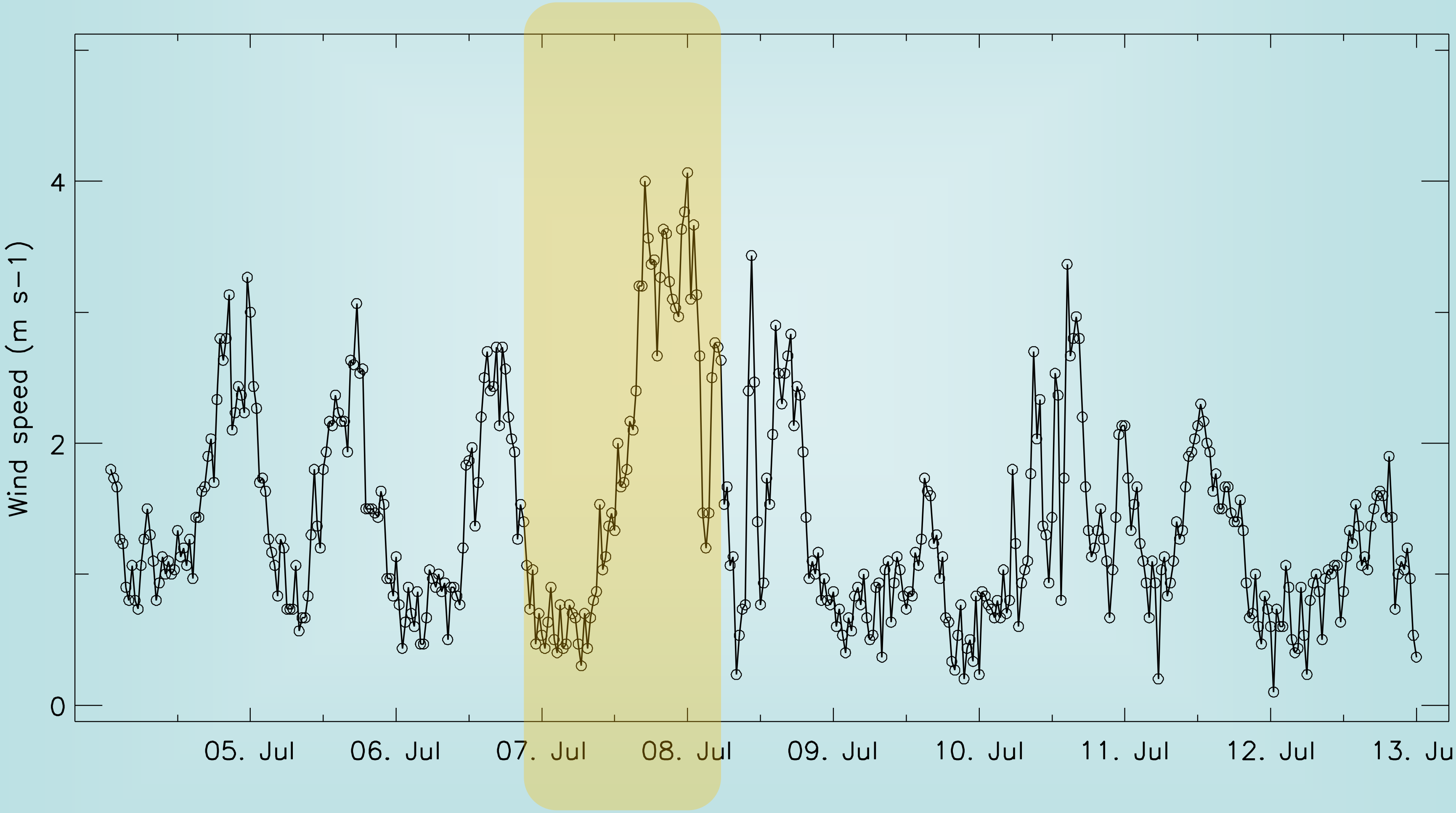
Meteorological forcing data
Radiation fluxes at COSMO site



Meteorological forcing data
Air temperature (JMA Kuki Station)



Meteorological forcing data
Windsped (JMA Kuki Station)



COSMO material properties

	Unit	Value
Geometric parameters	–	–
Plane area index (λ_p)	–	0.25
Frontal area index (λ_f)	–	0.25
Obstacle height (H)	m	1.5
Wall thickness	m	0.1[a]
Street direction (ω)[b]	Degree	47
Radiative properties[c]		
Facet albedo of direct short-wave radiation	–	Equation (18)
Facet emissivity	–	0.89
Thermal properties[c]		
Thermal conductivity ($\lambda_m(i)$)	$W\ m^{-1}\ K^{-1}$	1.06
Volumetric heat capacity ($c_m(i)\rho_m(i)$)	$MJ\ m^{-3}\ K$	2.34
Aerodynamic parameters		
Zero-plane displacement height (z_d/H)	–	0.46[d]
Roughness length for momentum (z_0/H)	–	0.08[d]
Roughness length for heat (z_T/H)	–	Equation (19) with $a = 1.29$
Bulk transfer coefficient of face i ($C_H(i)/C_H(roof)$)[e]	–	1
Reference height (depth)		
Input forcing data height (z_a)	m	3
Zero flux conduction depth	m	1

Thermal inertia

$\mu = \sqrt{1.06 * 2.34e6}$

μ= 1575 J m-2 K-1 s-0.5

Kawai, T., Kanda, M., Narita, K., and Hagishima, A. (2007): Validation of a numerical model for urban energy-exchange using outdoor scale-model measurements. International Journal of Climatology, 27, 1931-1942.