High-frequency patterns in urban surface temperatures

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Surface temperature T_s is a key parameter in urban climatology. Satellite, aerial, and ground-based remote-sensing approaches addressing the urban surface energy exchange typically measure the instantaneous spatial distribution of T_s and discuss it in the context of relative sun position, urban morphometry, material properties, storage, and radiation anisotropy. However, little is known on high-frequency dynamics of T_s in a range below one hour down to seconds.

Embedded into the experimental framework of EXCUSE (Energy Exchange of Urban Structures and Environments), a thermal IR scanner located on a 119 m high-rise building in Berlin (Steglitzer Kreisel) continuously observes and records long-wave radiation fluxes of an urban neighborhood. The field of view of the scanner can be adjusted by a tilting and rotation device. For selected periods, high frequency runs (2 Hz) were recorded.

Data decomposition: By using two averaging operators, a temporal average denoted by an overbar, and a spatial average denoted by angle brackets, 3d-stacks (**x**,t) of high-frequency time series are decomposed into fluctuating parts according two schemes, namely

The inner-temporal-outer-spatial scheme

$$T_s(\mathbf{x},t) = T_s'(\mathbf{x},t) + \overline{T_s}''(\mathbf{x}) + \langle\overline{T_s}\rangle$$

The inner-spatial-outer-temporal scheme

$$T_s(\mathbf{x},t) = T_s''(\mathbf{x},t) + \langle T_s\rangle'(t) + \overline{\langle T_s\rangle}$$

$\langle T_s\rangle$ spatial average $\overline{T_s}$ temporal average

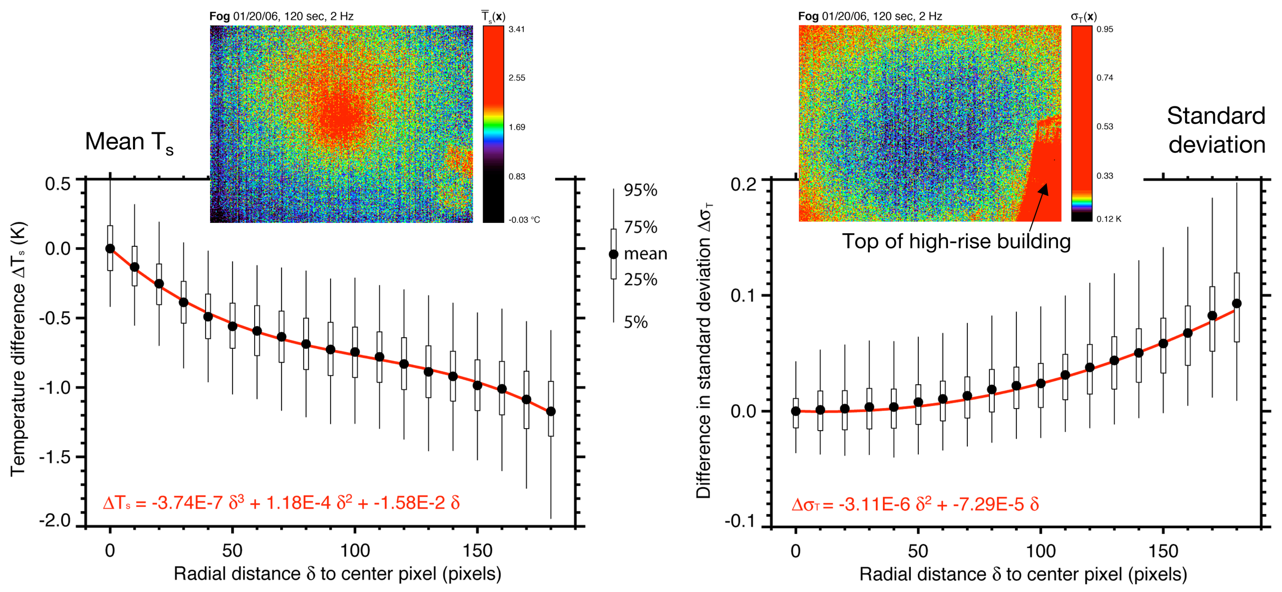
T_s'' spatial departure T_s' temporal departure

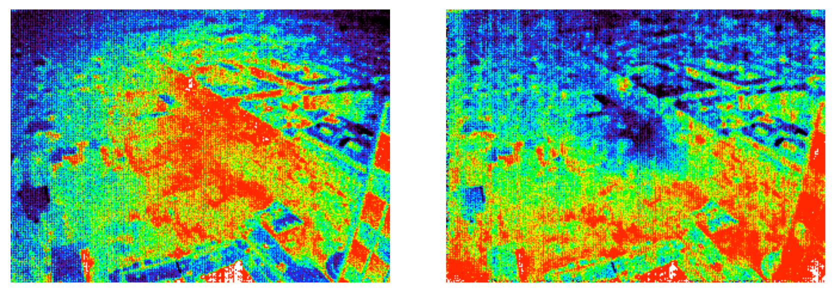
An a consequence of the large area covered in the field of view, for stationary time series $\partial\langle T_s\rangle/\partial t$ vanishes. Hence temporal variations in this term are supposed to be solely effects of sensor noise, large scale trends and atmospheric processes close to the lens.

Instrumental setup of the thermal scanner 'Steglitzer Kreisel'

Scanner manufacturer	Infratec
Scanner model	VarioCam Head
Spectral bandwidth	7.5 - 14 µm
Data resolution	14 bit
Recording frequency	2 Hz
Height above ground	119 m
Field of view	32° x 25°
Covered area in oblique view	~400 x 400 m

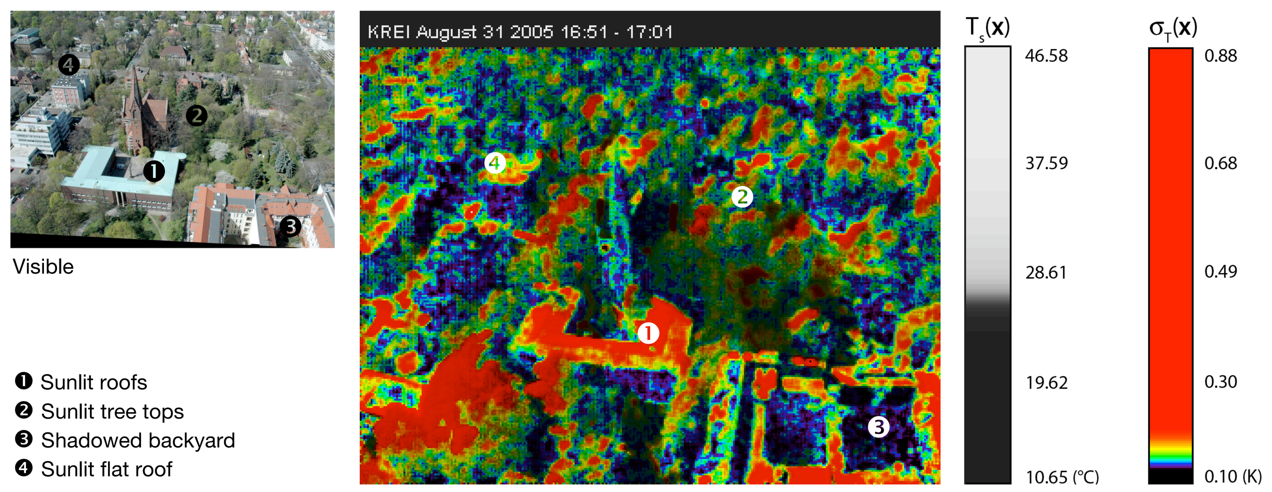
▼ Sensor noise and lens effects were estimated and corrected using a dataset with dense fog and assuming isotropic distribution of radiance. The lens characteristics result in a distinct -1.2 K difference from the center of the scanner image to the corners (left). Standard deviation is lowest in the center and increases by + 0.1 K towards the corners (right).





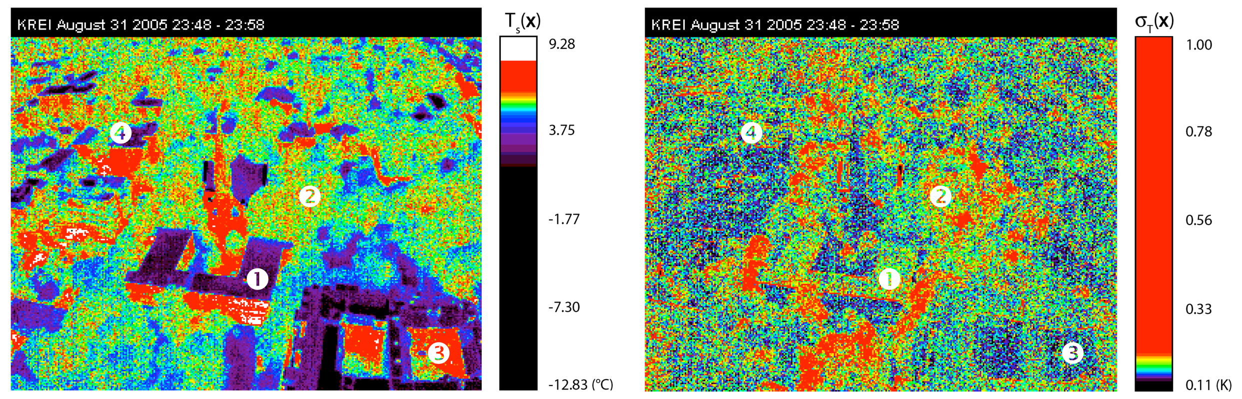
Uncorrected data (Mean T_s)   Corrected for radial lens effects

▼ Daytime dataset over 10 minutes illustrating mean surface temperature distribution (brightness), and standard deviation of the high-frequency signal (colors). Sunlit areas generally show higher standard deviations.

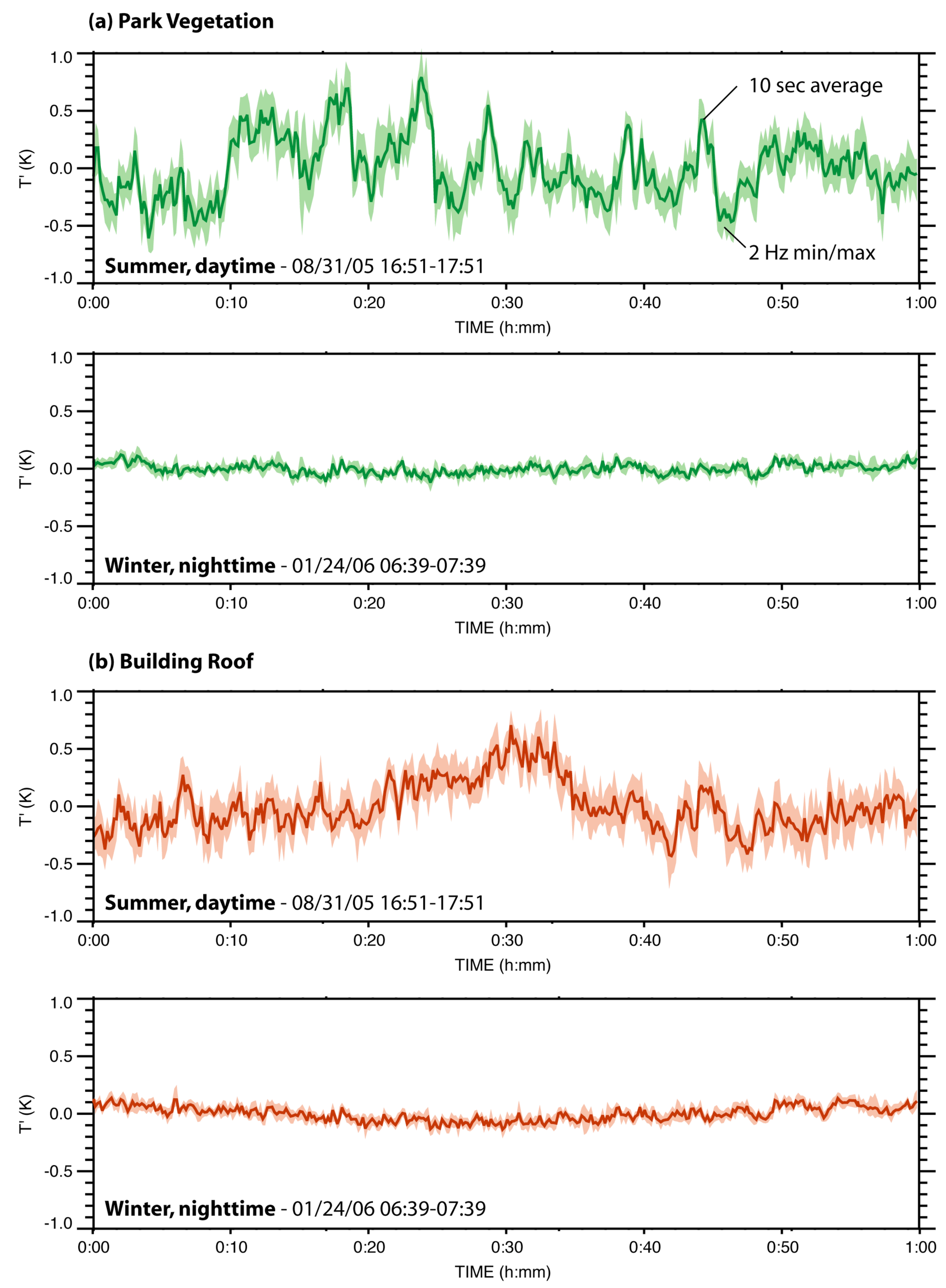


❶ Sunlit roofs
❷ Sunlit tree tops
❸ Shadowed backyard
❹ Sunlit flat roof

▼ Nighttime dataset over 10 minutes with mean surface temperatures (left), and standard deviation of the high-frequency signal (right).

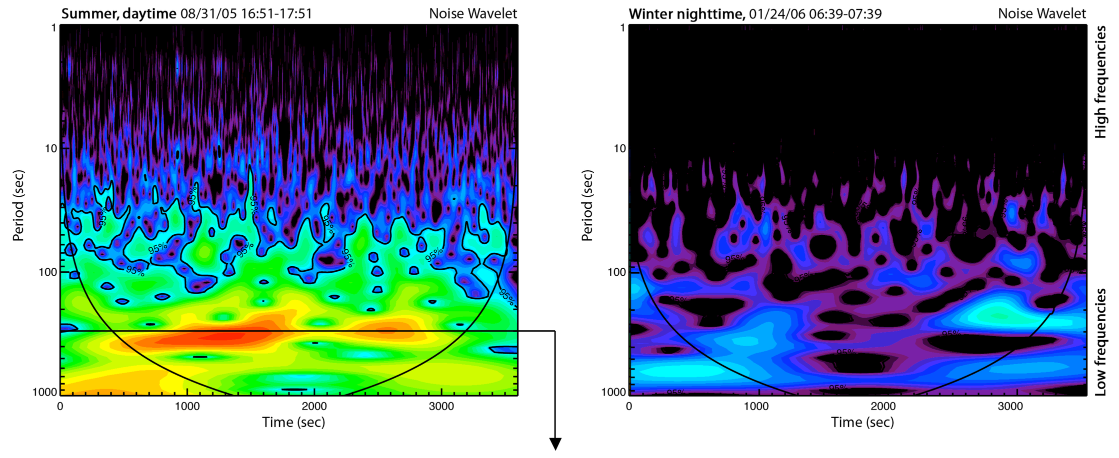


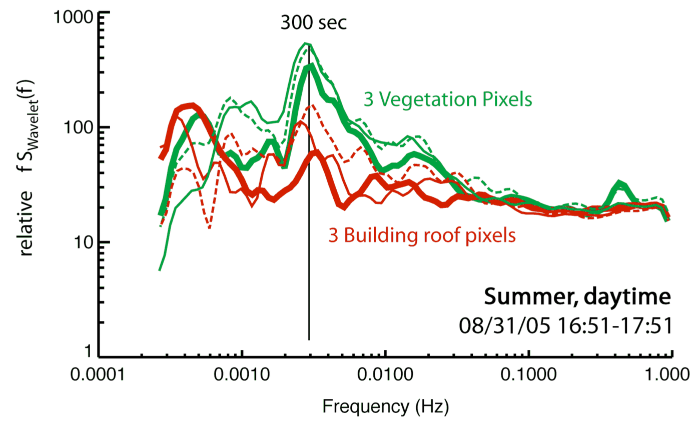
❶ Cool roofs
❷ Tree tops
❸ Warm backyard
❹ Cool flat roof



▲ High-frequency time series illustrating two selected hourly runs of high-frequency data from a summer evening situation and a winter night. The two selected pixels represent vegetation (city park) and an artificial tile roof.

▼ Wavelet transforms of high-frequency time series illustrating relative spectral energy over a vegetated surface for the daytime (left) and the nighttime (right) situation. Red and yellow colors indicate high energy, blue and black colors are regions of low energy.





▲ Integral wavelet spectra of selected high-frequency time series illustrating the difference between vegetation and artificial surfaces for the summer daytime case.

Conclusions

- The high frequency signal can be successfully separated from sensor noise and lens effects.
- High frequency fluctuations of T_s exist in an urban area and are – at least during daytime – well above sensor resolution.
- There are distinct differences between daytime sunlit surfaces, shadowed surfaces and surfaces during nocturnal cooling.
- There are spectral differences between vegetation (low frequency contributions) and artificial structures.

Further steps

- Additionally apply atmospheric correction.
- Spatial correlation and cluster analysis to statistically identify areas of similar characteristics.
- Correlate fluctuations in T_s to simultaneously measured atmospheric turbulence close to the city-atmosphere interface.