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 (Steglitz-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 $g(x,t)$ of high-frequency time series are decomposed into fluctuating parts according two schemes, namely

- The inter-temporal-inter-physical scheme:
  $$T_s(x,t) = T_s^g(x,t) + T_s^g(x,t) + T_s^g(x,t)$$

- The inter-temporal-inter-temporal scheme:
  $$T_s(x,t) = T_s^g(x,t) + T_s^g(x,t) + T_s^g(x,t)$$

An consequence of the large area covered in the field of view, for stationary time series $x_T(x,t)$ 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.

**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).

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

**Daytime dataset over 10 minutes** illustrating mean surface temperature distribution. Sunlit areas generally show higher standard deviations.

**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.