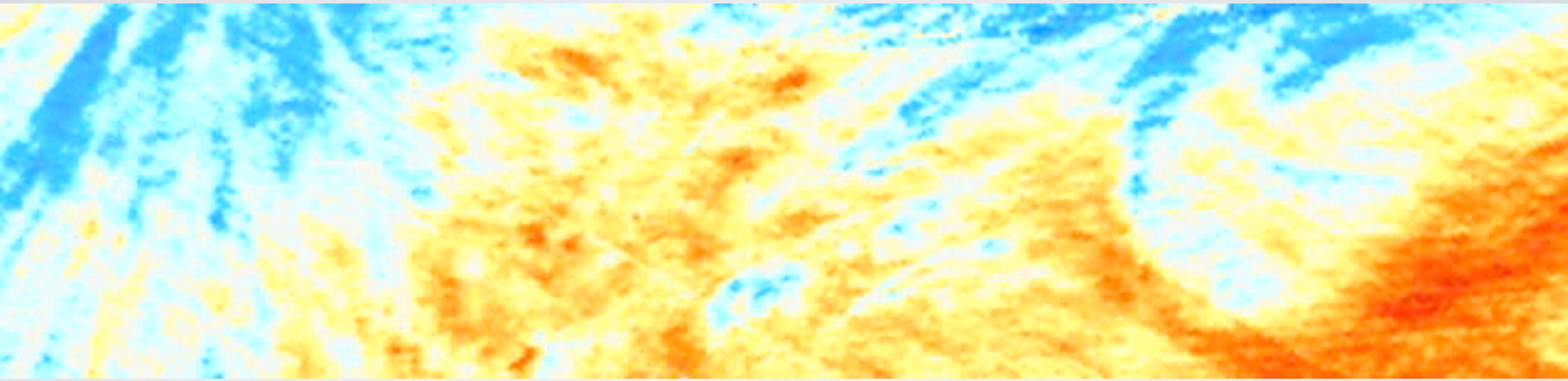
Mapping coherent structures responsible for heat exchange between land-surfaces and atmosphere using time-sequential thermography



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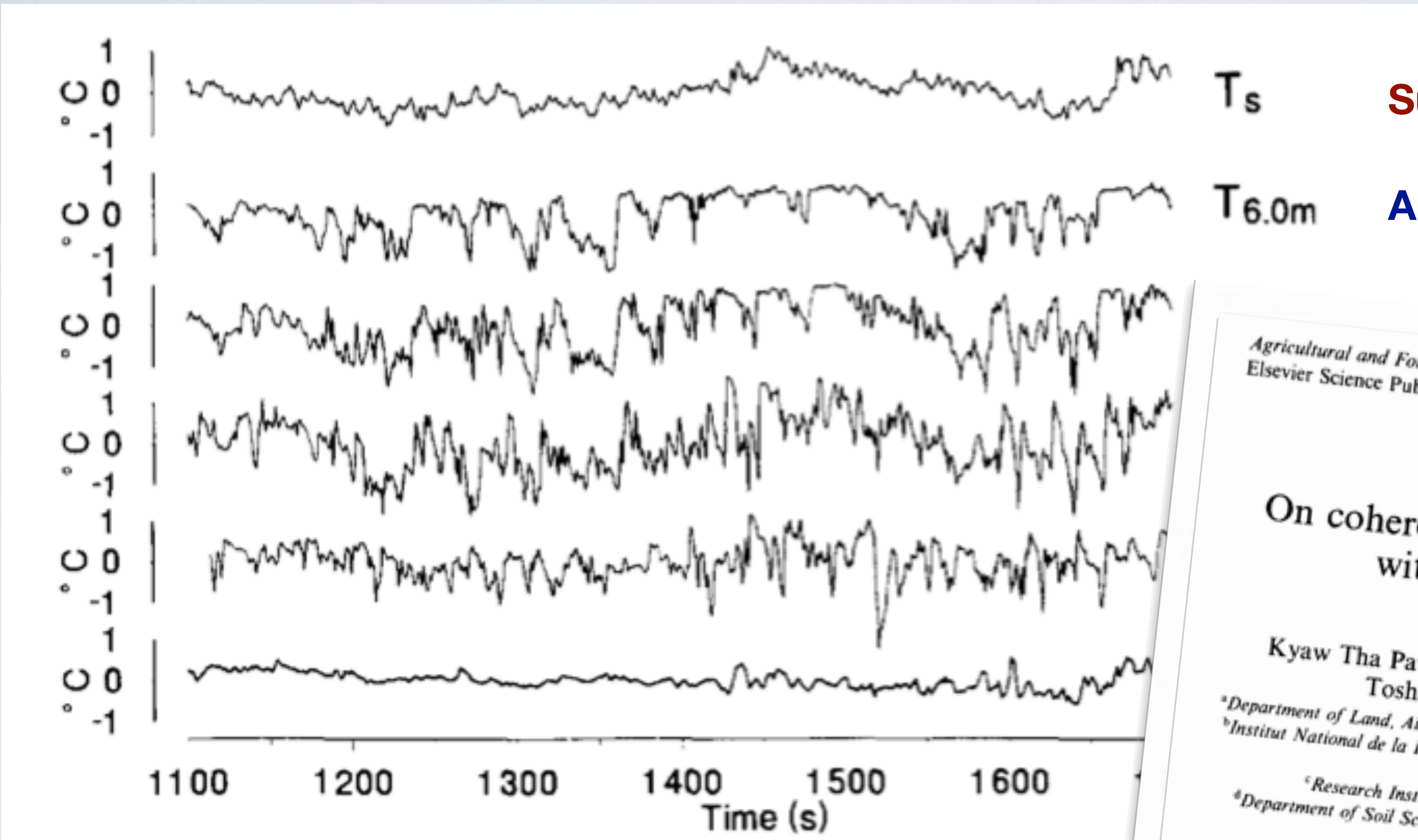
[4] University of Basel, Basel, Switzerland
[5] University of Western Ontario, London, ON, Canada
[5] Tokyo Institute of Technology, Tokyo, Japan

a place of mind

CFS II, Vancouver
A. Christen, August 4, 2011

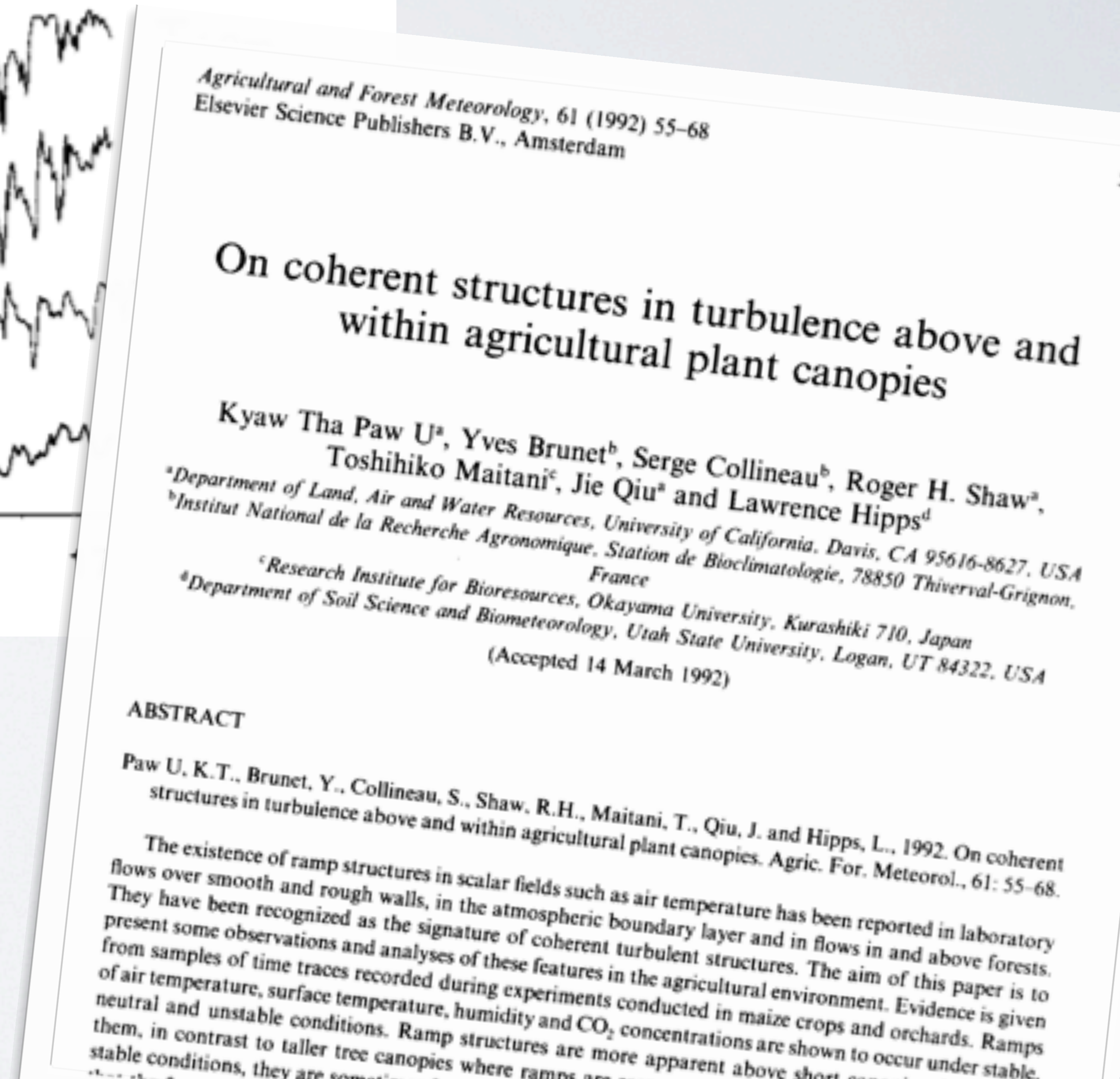
Land-surface temperatures are coupled with overlaying turbulent atmosphere



Surface temperature

Air temperatures

Paw U et al. (1992)



Agricultural and Forest Meteorology, 61 (1992) 55–68
Elsevier Science Publishers B.V., Amsterdam

On coherent structures in turbulence above and within agricultural plant canopies

Kyaw Tha Paw U[a], Yves Brunet[b], Serge Collineau[b], Roger H. Shaw[a], Toshihiko Maitani[c], Jie Qiu[a] and Lawrence Hipps[d]

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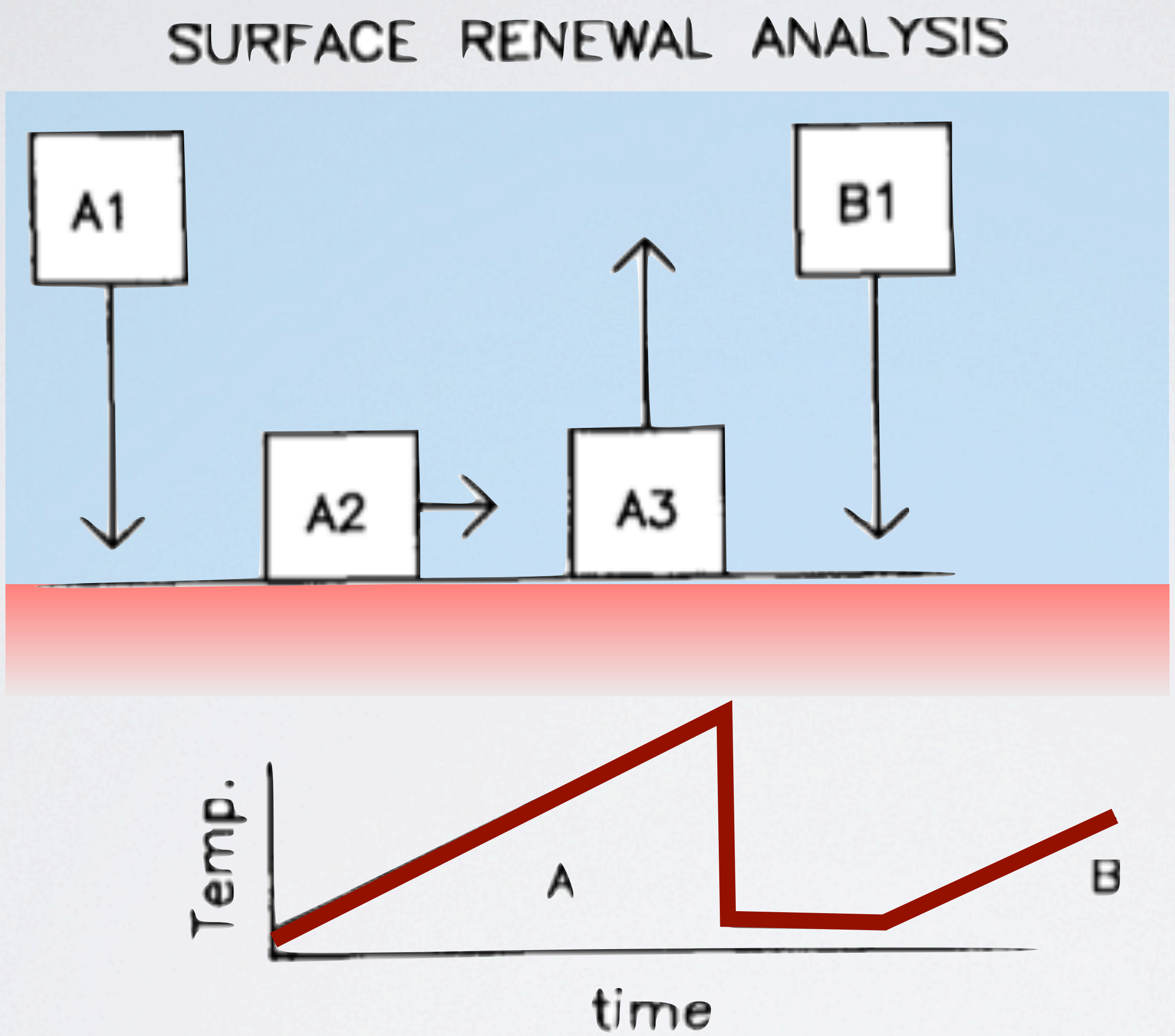
(Accepted 14 March 1992)

ABSTRACT

Paw U, K.T., Brunet, Y., Collineau, S., Shaw, R.H., Maitani, T., Qiu, J. and Hipps, L., 1992. On coherent structures in turbulence above and within agricultural plant canopies. Agric. For. Meteorol., 61: 55–68.

The existence of ramp structures in scalar fields such as air temperature has been reported in laboratory flows over smooth and rough walls, in the atmospheric boundary layer and in flows in and above forests. They have been recognized as the signature of coherent turbulent structures. The aim of this paper is to present some observations and analyses of these features in the agricultural environment. Evidence is given from samples of time traces recorded during experiments conducted in maize crops and orchards. Ramps of air temperature, surface temperature, humidity and CO_2 concentrations are shown to occur under stable, neutral and unstable conditions. Ramp structures are more apparent above short canopies ... them, in contrast to taller tree canopies where ramps ... stable conditions, they are ...

Land-surface temperatures respond to coherent structures in the atmosphere



Atmosphere

Heated land surface

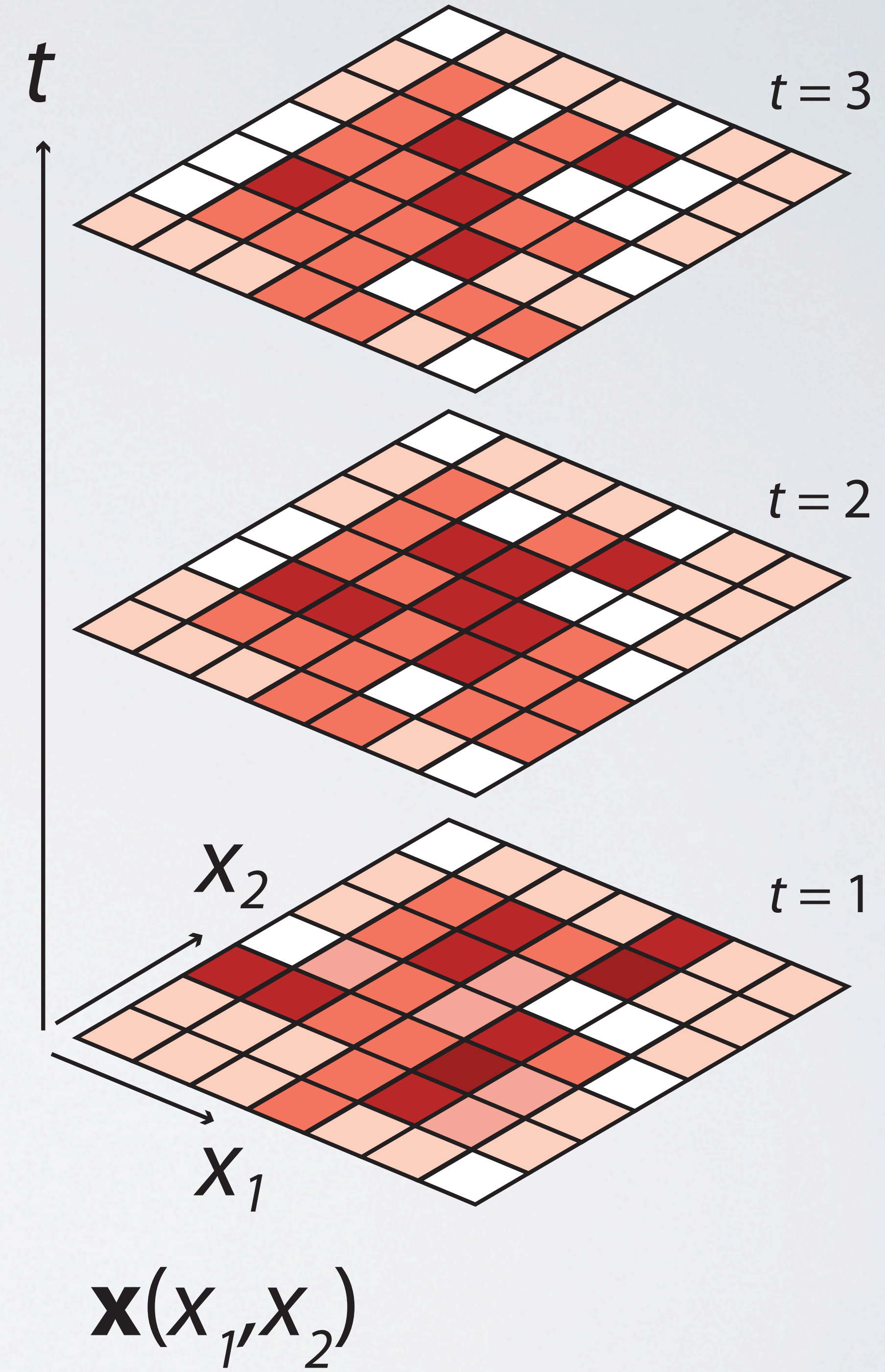
Surface temperature trace

Paw U, K., Qiu, J., Sun, H., Watanabe, T., & Brunet, Y. (1995). Surface renewal analysis: a new method to obtain scalar fluxes. Agricultural and Forest Meteorology, 74(1-2), 119–137.

Time-sequential thermography

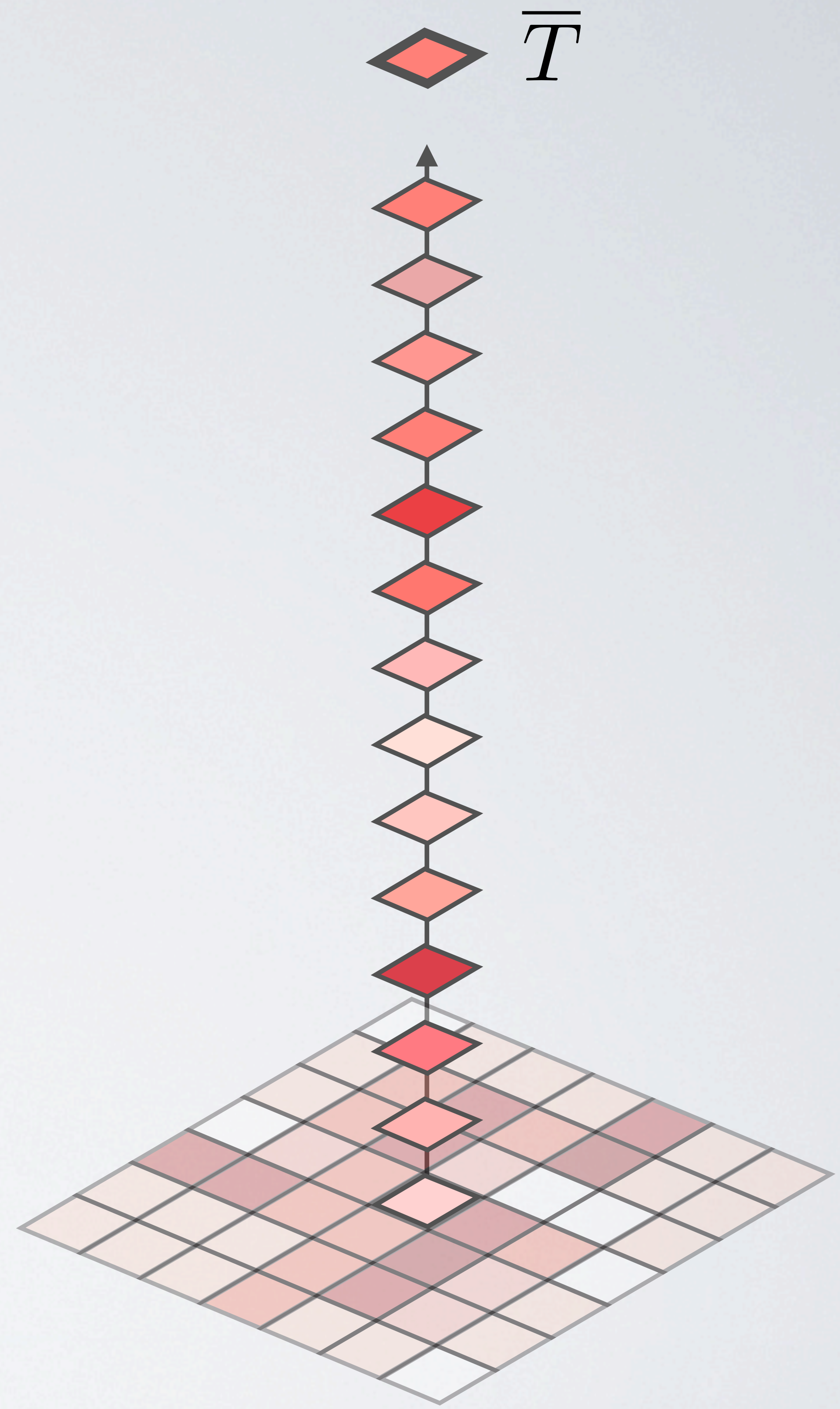
The **temporal-spatial field** of surface temperature fluctuations can be recorded using ground- or tower-based **thermal cameras** that are operated at relatively high frequency resulting in time-sequential thermography (TST)

TST returns surface temperatures *T* (more precisely: brightness temperatures) as a function of space (x_1,x_2) and time (t)



Time-sequential thermography

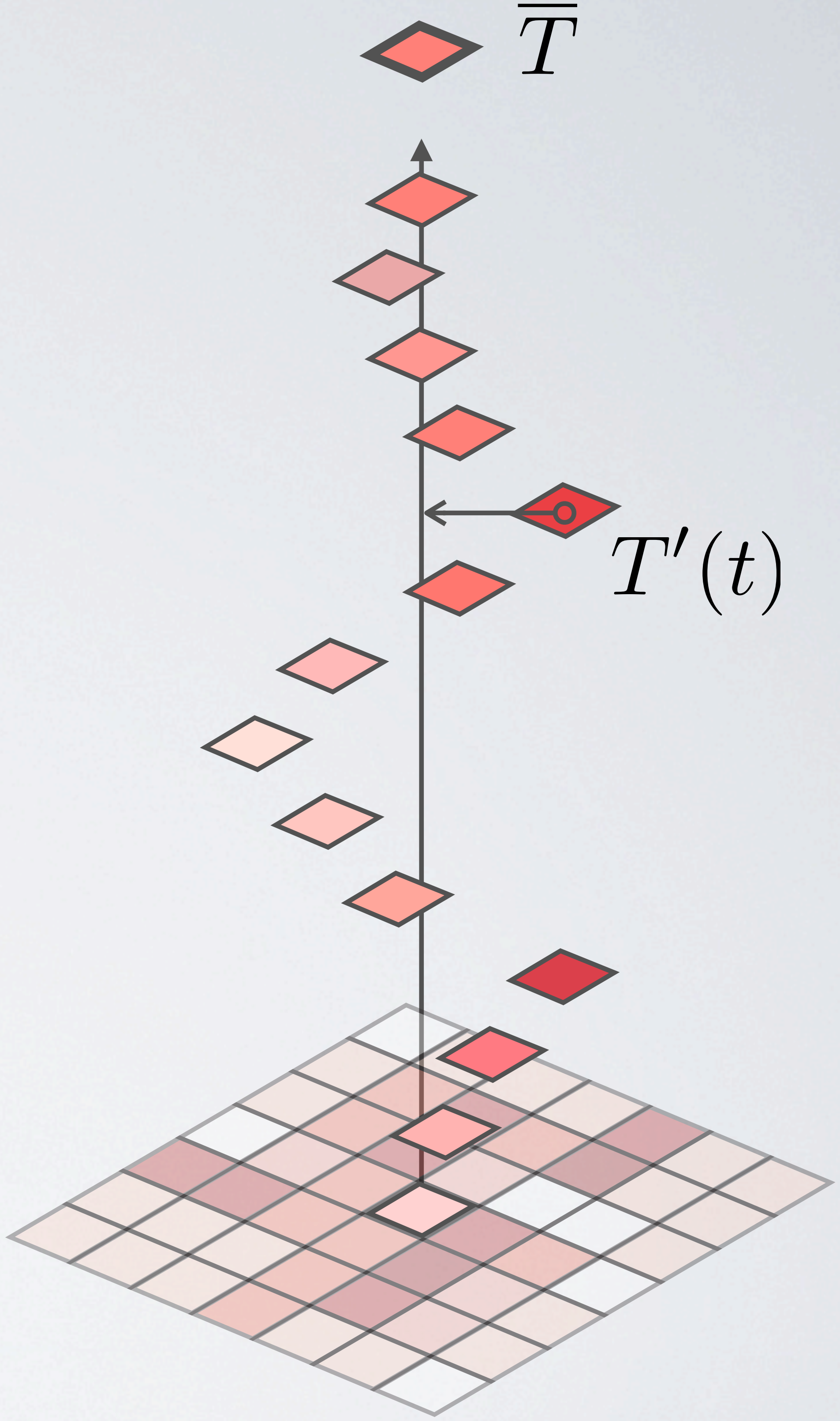
The spatio-temporal field of measured apparent surface temperatures of each pixel can then be decomposed into a high-frequency fluctuating and a long-term mean (drifting) part.

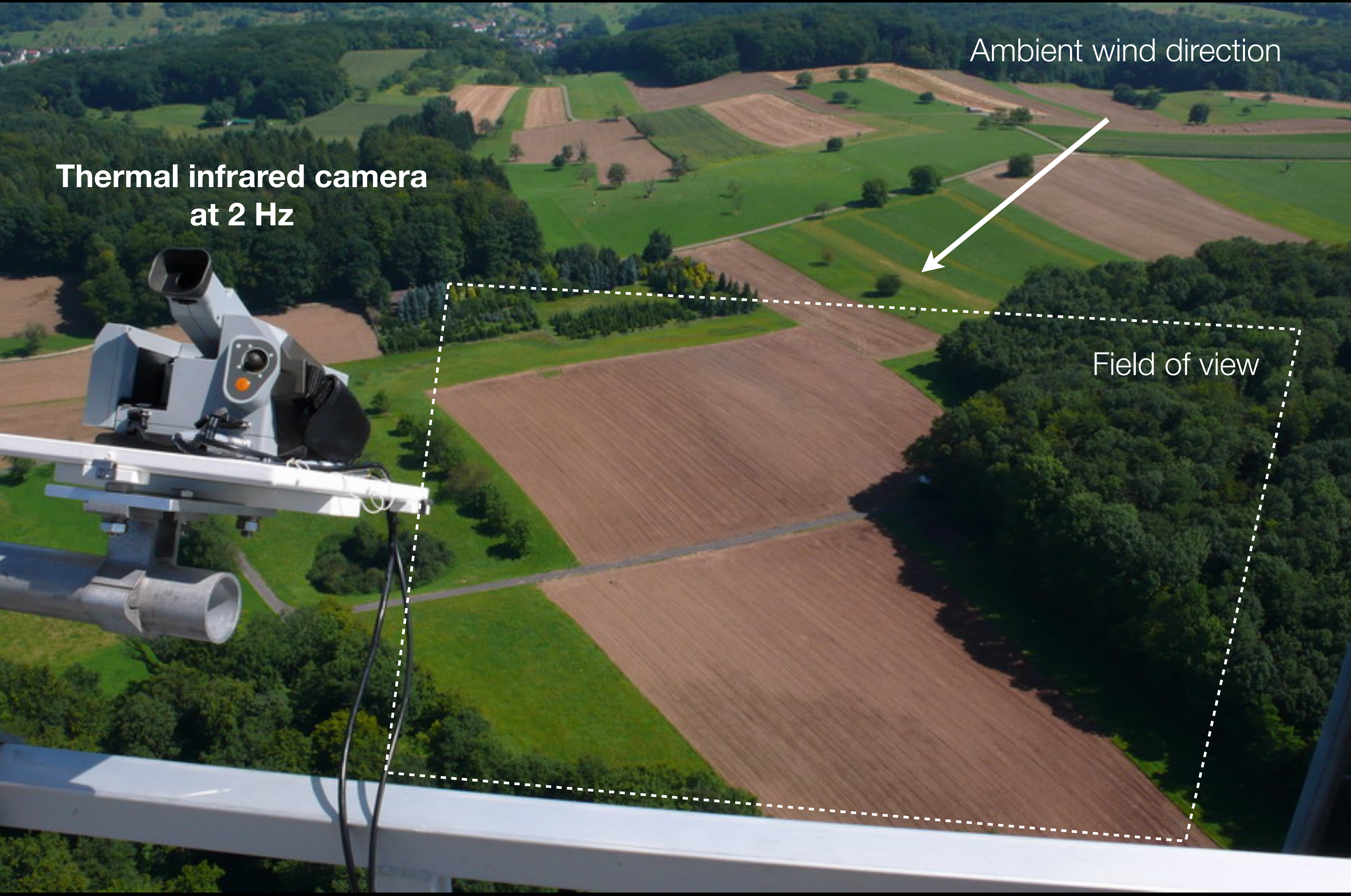


Time-sequential thermography

The spatio-temporal field of measured apparent surface temperatures of each pixel can then be decomposed into a high-frequency fluctuating and a long-term mean (drifting) part.

We will only look at *T'* (fluctuations) in the following examples.

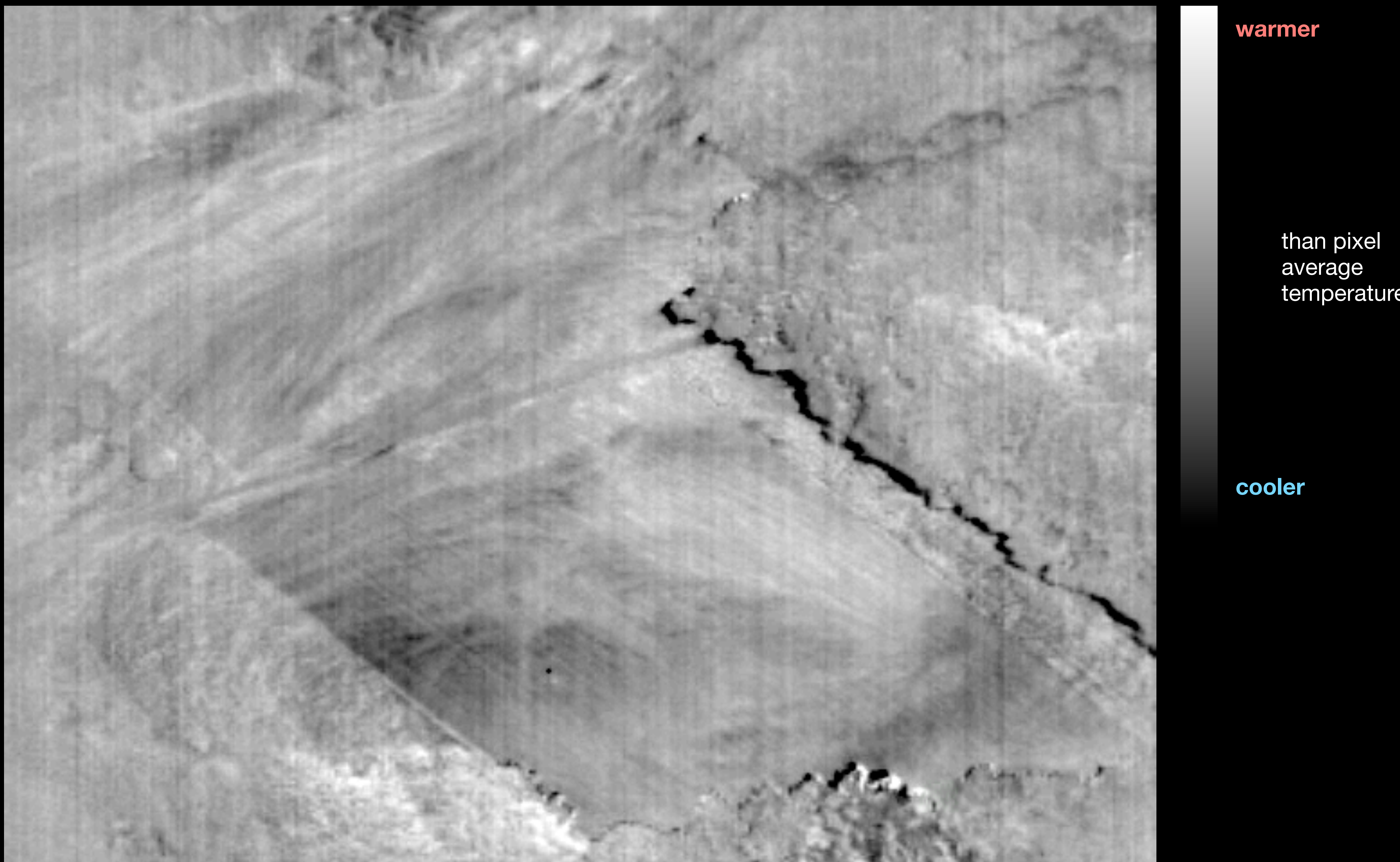




St. Chrischona Tower 2007 / Roland Vogt, University of Basel, Switzerland

Time-sequential thermography

Surface temperature fluctuation (relative)

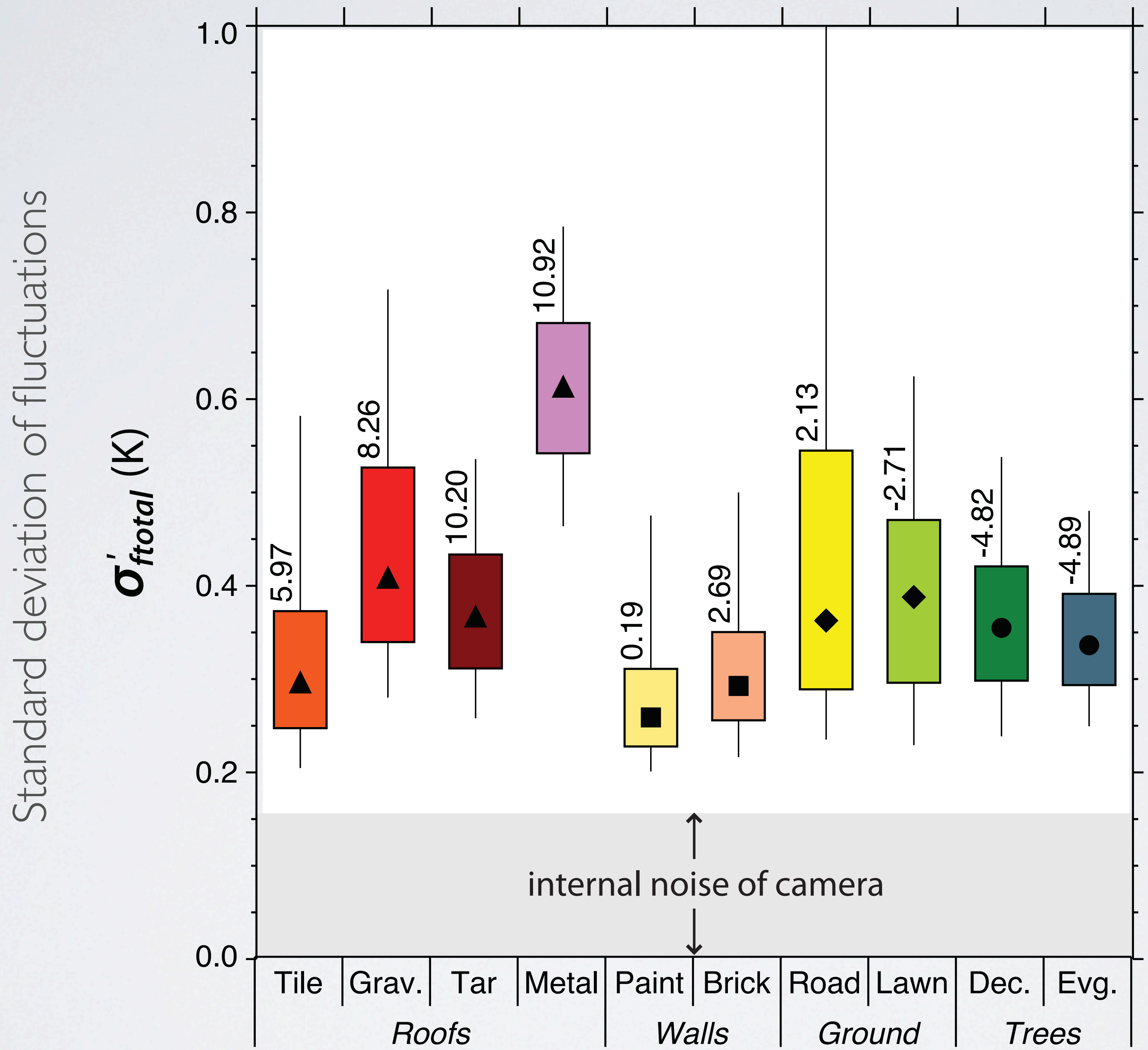


St. Chrischona Tower 2007 / Roland Vogt, University of Basel, Switzerland

48 x time lapse

Proof of concept

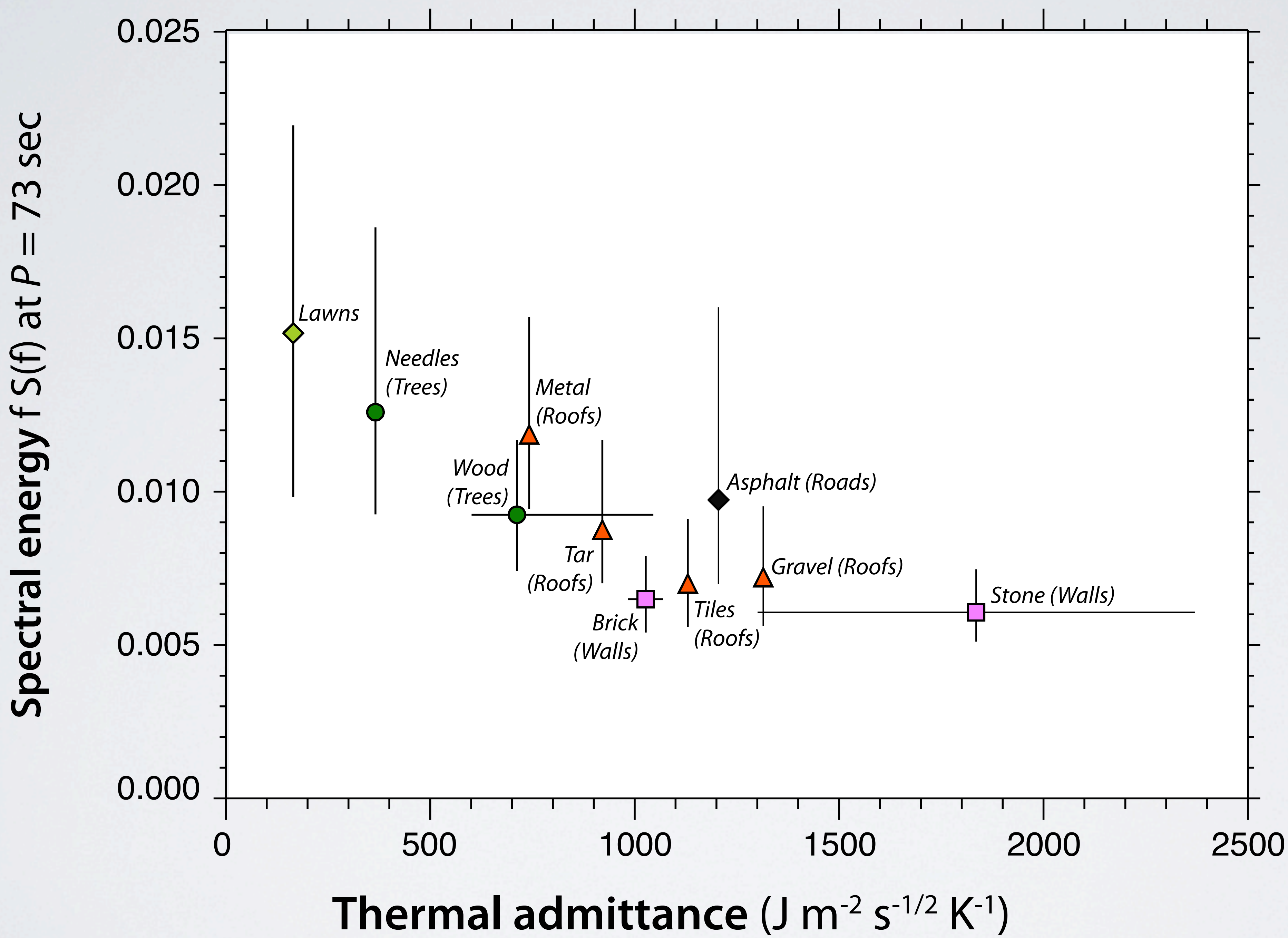
Magnitude of surface temperature fluctuations are controlled by surface material



1 Hz data over 20 min

Christen A., Meier, F. Scherer D. 'High-frequency fluctuations of surface temperatures in an urban environment', *Theoretical and Applied Climatology* (to appear, 2011)

Energy of surface temperature fluctuations correlates with thermal admittance



Christen A., Meier, F. Scherer D. 'High-frequency fluctuations of surface temperatures in an urban environment', *Theoretical and Applied Climatology* (to appear, 2011)

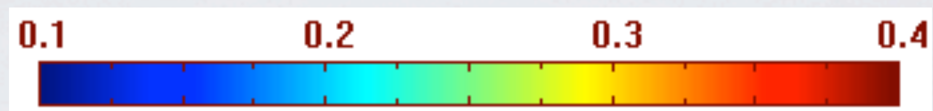
COSMO Array
Tokyo Institute of Technology, Japan, 2009

Uniform material (ground, walls, roofs)

F. Meier et al. (2011)

Magnitude of surface temperature fluctuations are also controlled by surface form

K

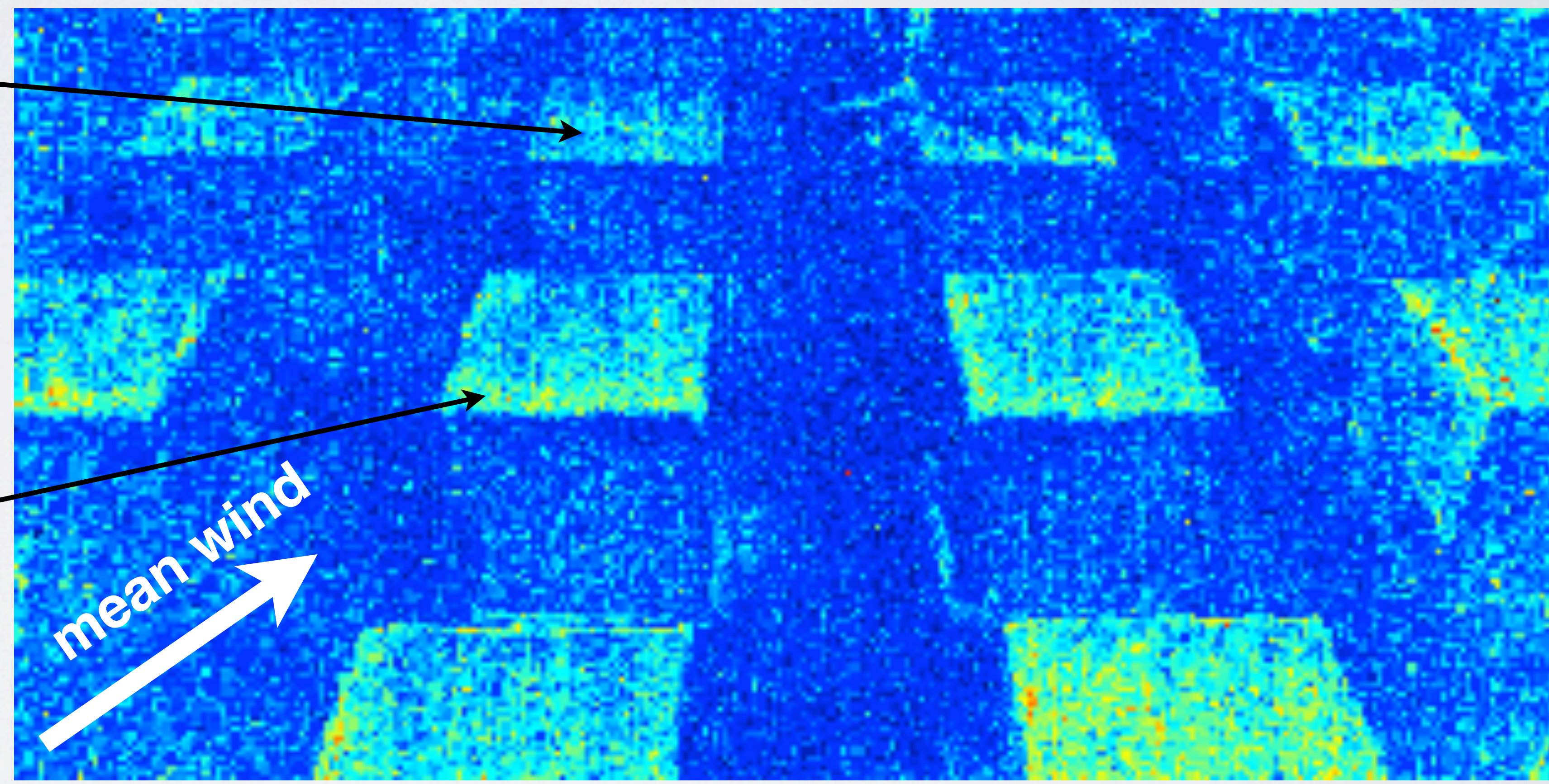


weak fluctuations strong fluctuations

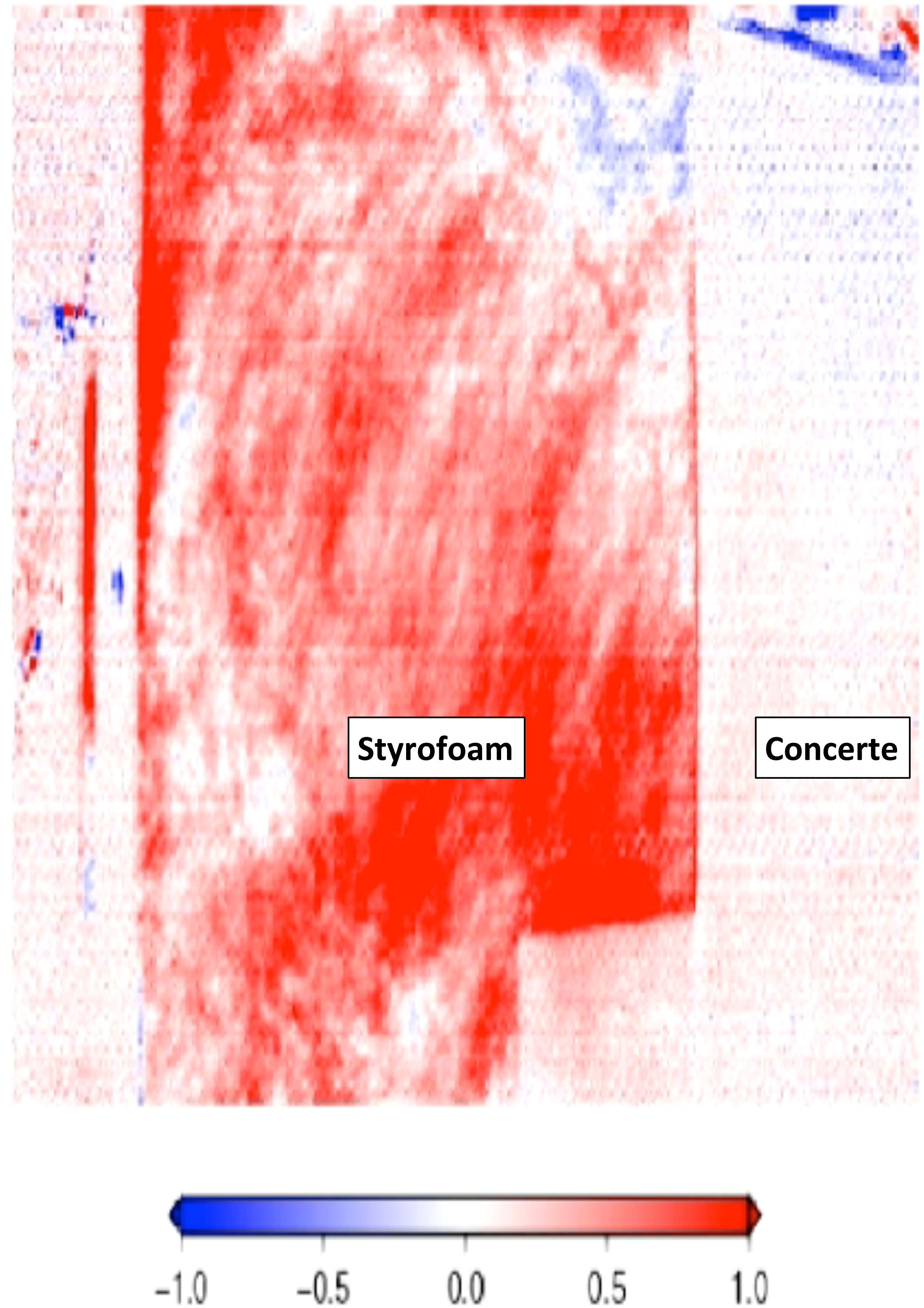
Standard deviation of surface temperature fluctuations

Stronger fluctuations on exposed roofs

Strongest fluctuations where laminar boundary layer is thin



F. Meier,, J. Richters, D. Scherer, A. Inagaki, M. Kanda, A. Hagishima (2011): ‘Outdoor scale model experiment to evaluate the spatio-temporal variability of urban surface temperature’, 28. Jahrestagung des AK Klima, Hamburg, 30. Oktober - 01. November 2009, Tagungsband p. 46.



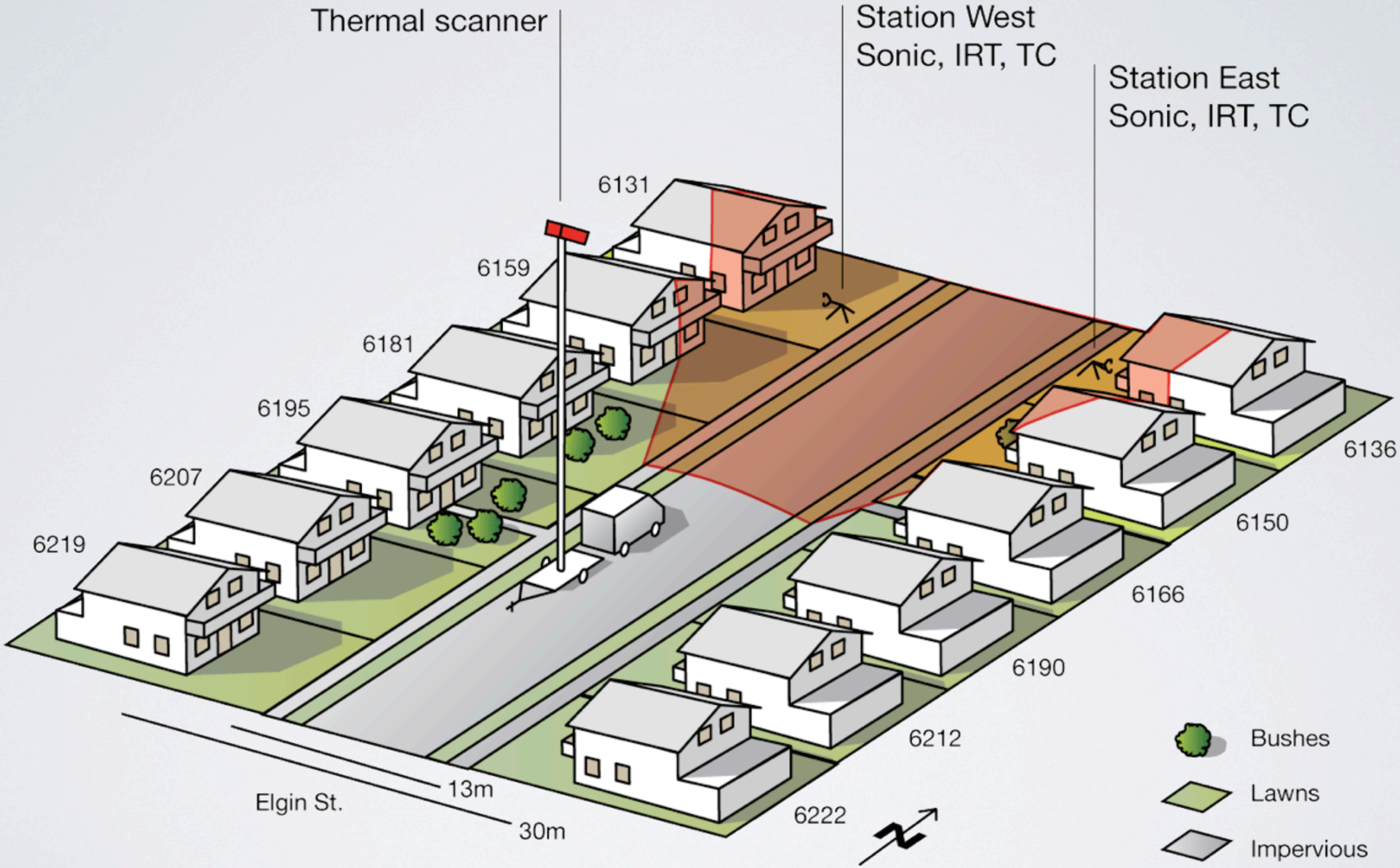
Surface temperature fluctuation

Atsushi Inagaki
Tokyo Institute of Technology

Critical thoughts about the use of TST of surface temperatures to infer atmospheric turbulence

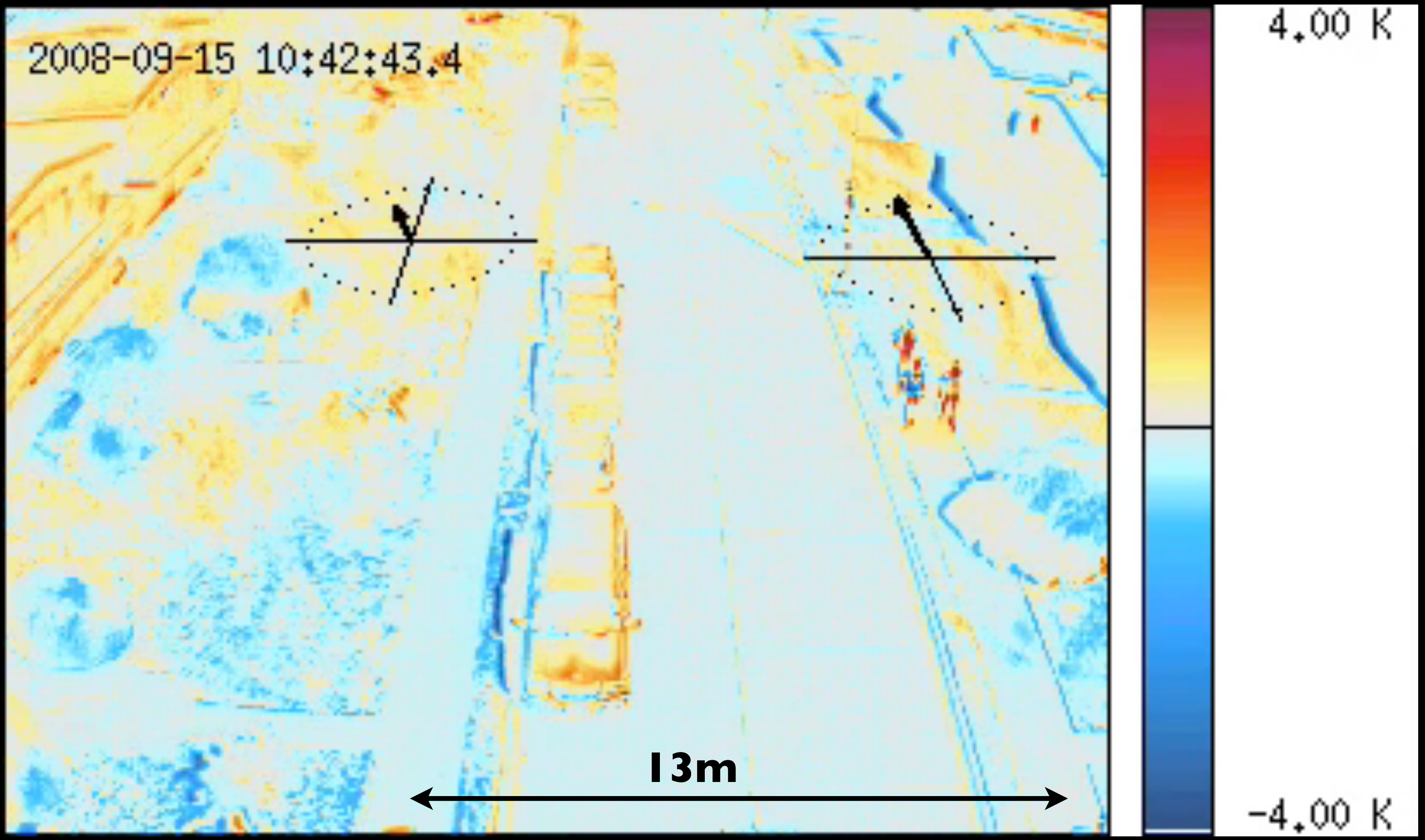
- Images show effect of coherent flow structures on surface temperatures (heat exchange), not structures themselves.
- Represent effects of near-wall coherent structures (streaks, splats), not structures in the inertial sublayer.
- Surface material must be heated or cooled (e.g. by solar radiation). No pure mechanical turbulence possible.
- Thermal inertia restricts visible signal to long-lasting (large) structures.

Vancouver - Street Canyon ‘Channel Flow’

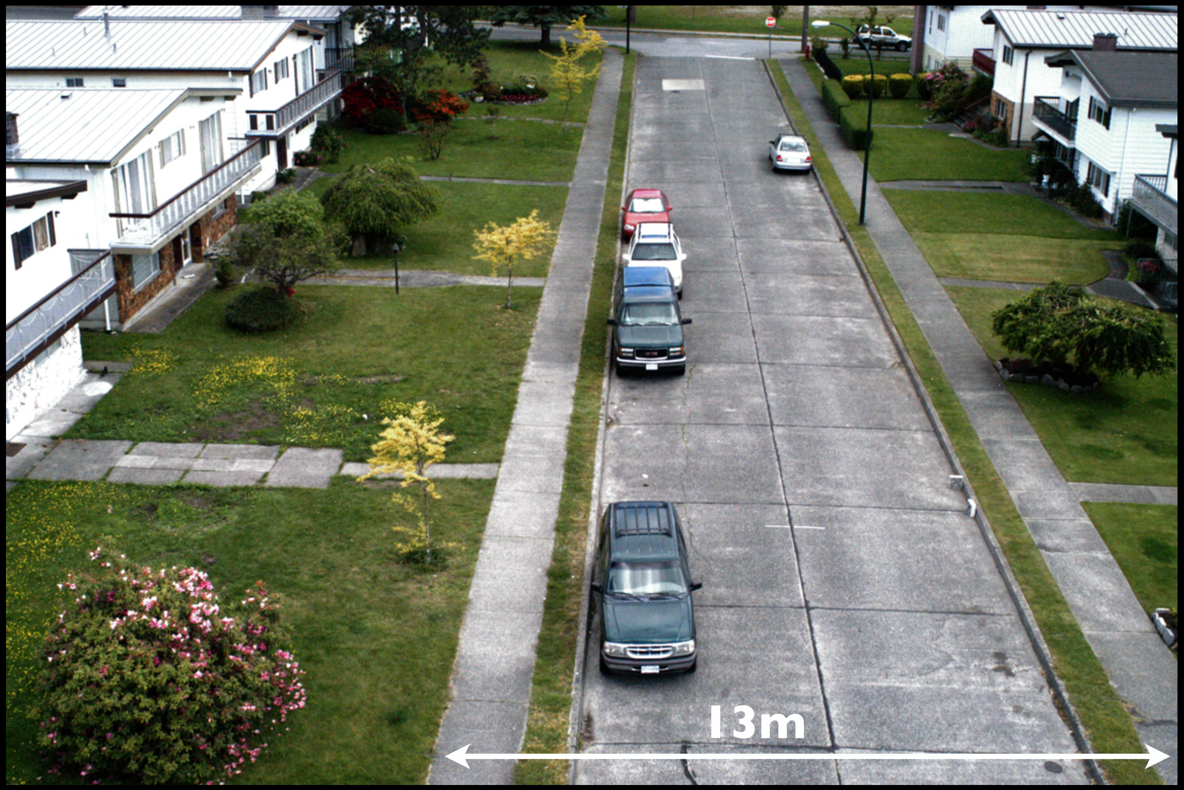


A.. Christen, J. A., Voogt (2010): 'Inferring turbulent exchange processes in an urban street canyon from high-frequency thermography', *19th Symposium on Boundary Layers and Turbulence*, Keystone CO, USA.

Time-sequential thermography of fluctuations with wind vectors overlaid



Approximate visible field of view



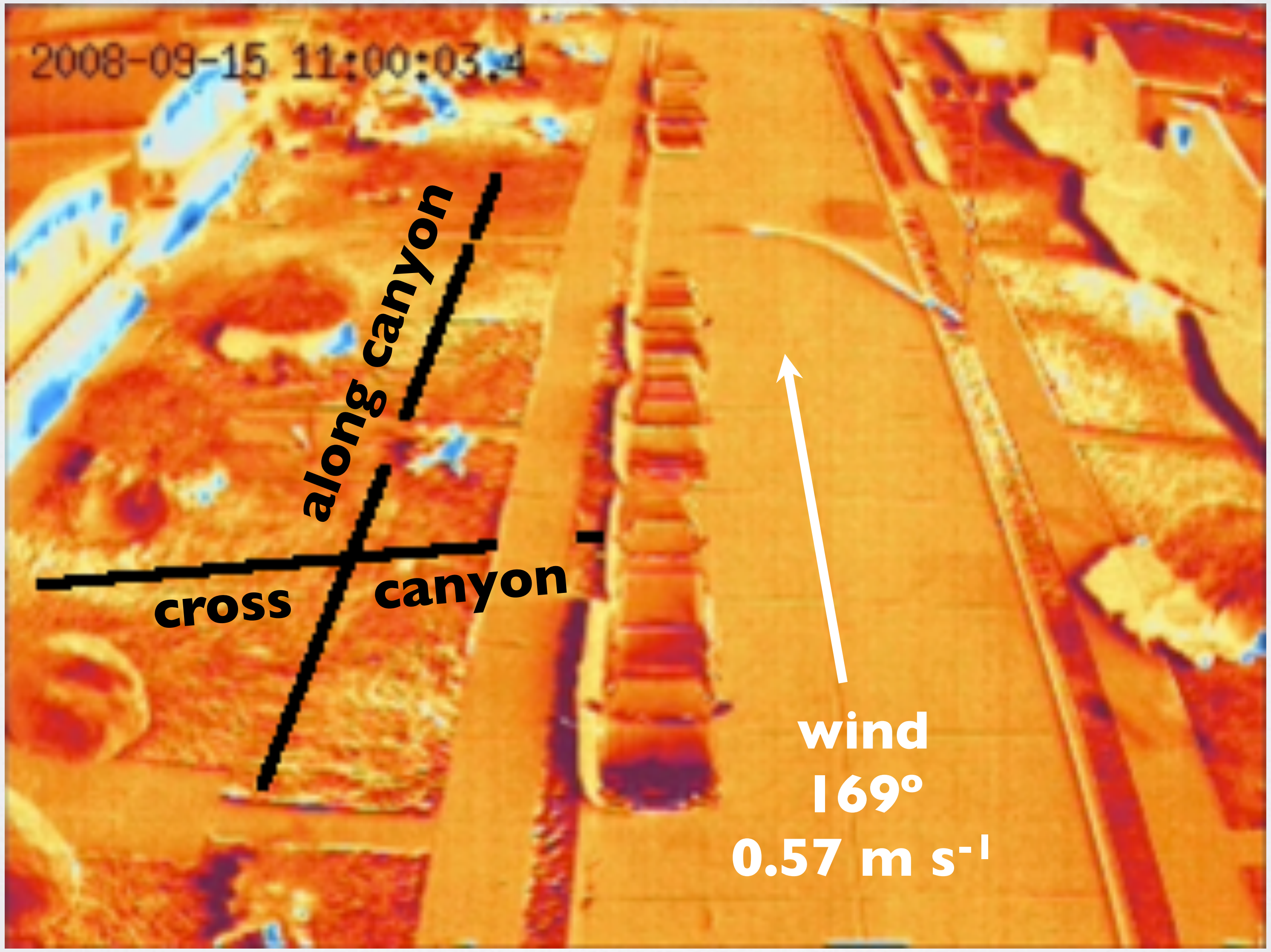
A.. Christen, J. A., Voogt (2010): 'Inferring turbulent exchange processes in an urban street canyon from high-frequency thermography', *19th Symposium on Boundary Layers and Turbulence*, Keystone CO, USA.

Determining elongation of coherent structure 'imprint' from two-point statistics

spatial separation (m)

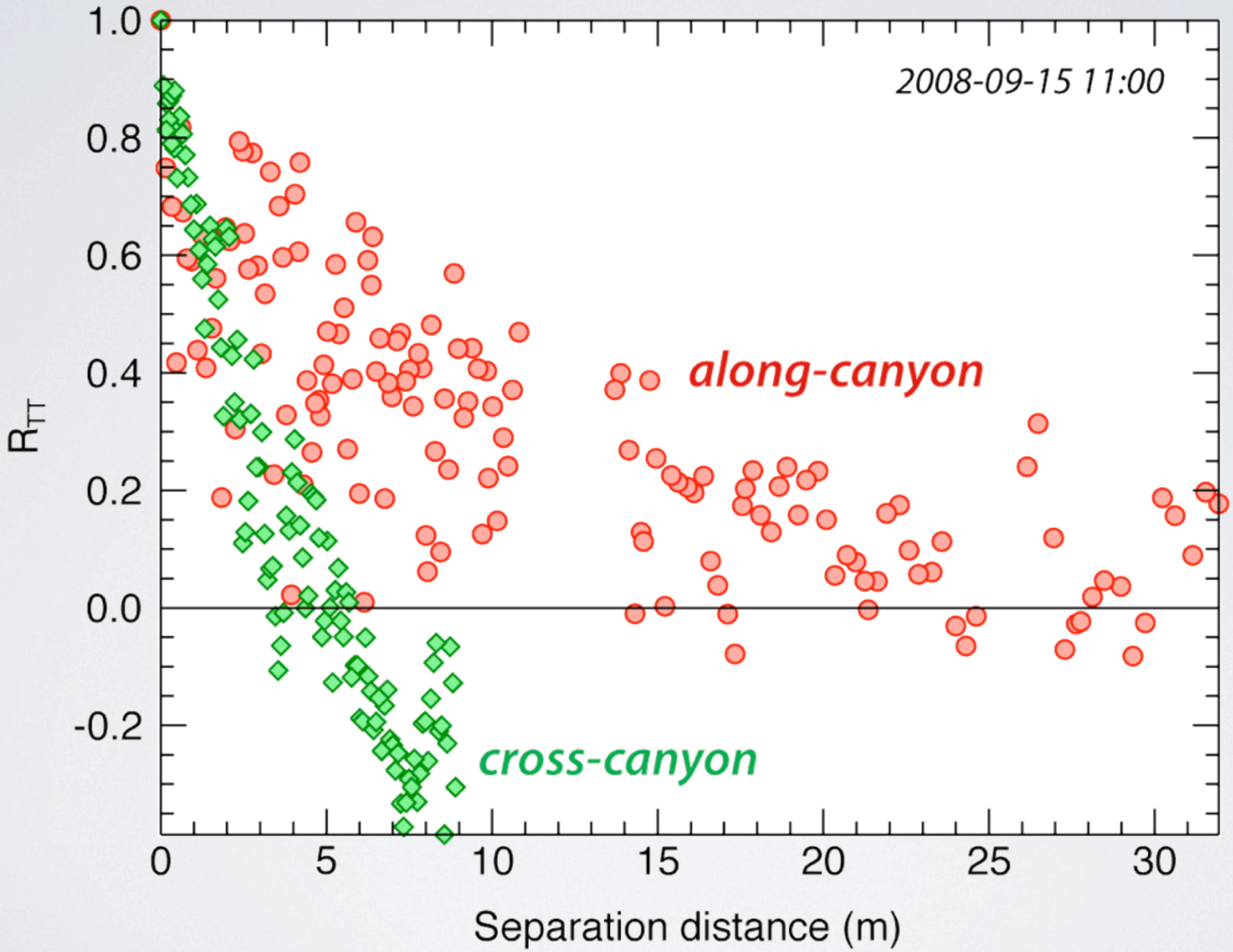
$$\mathbf{R}_{TT}(\mathbf{r}) = \frac{T'(\mathbf{x})T'(\mathbf{x}+\mathbf{r}+\tau)}{\sqrt{T'^2(\mathbf{x})T'^2(\mathbf{x}+\mathbf{r}+\tau)}}$$

temporal lag (sec)

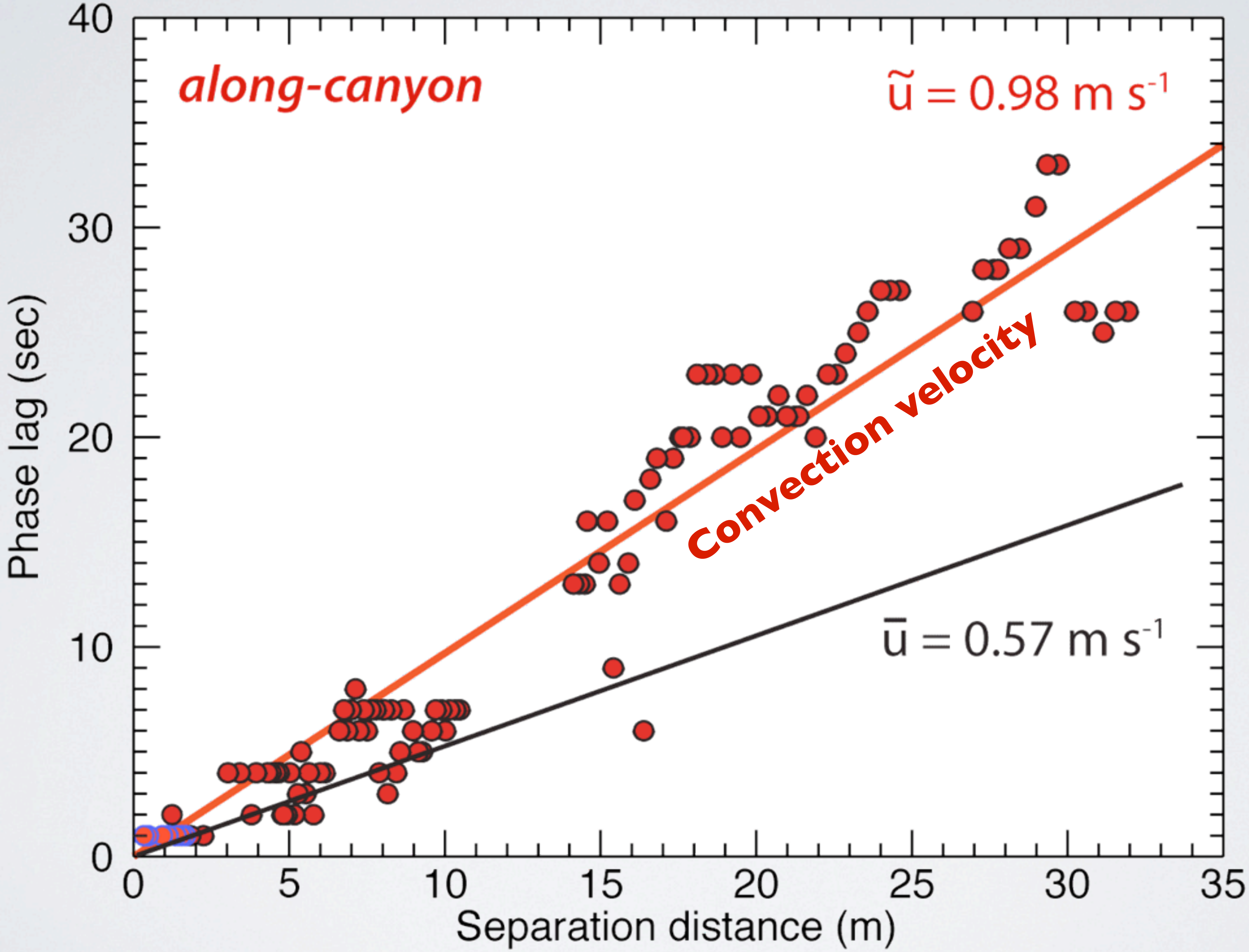


Two-point correlations R_{TT} vs. separation

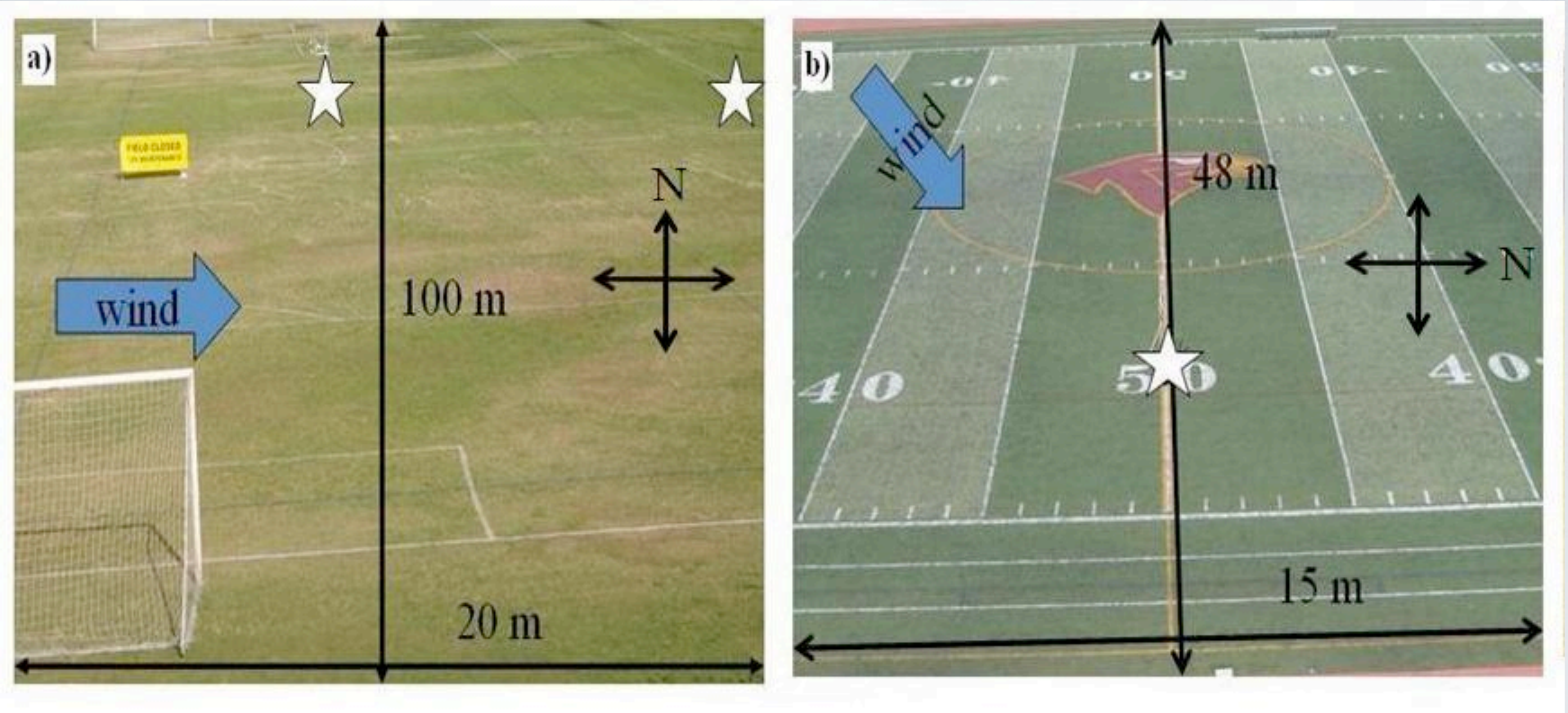
At $\tau = 0$



Phase lag of two-point correlations of *T'*



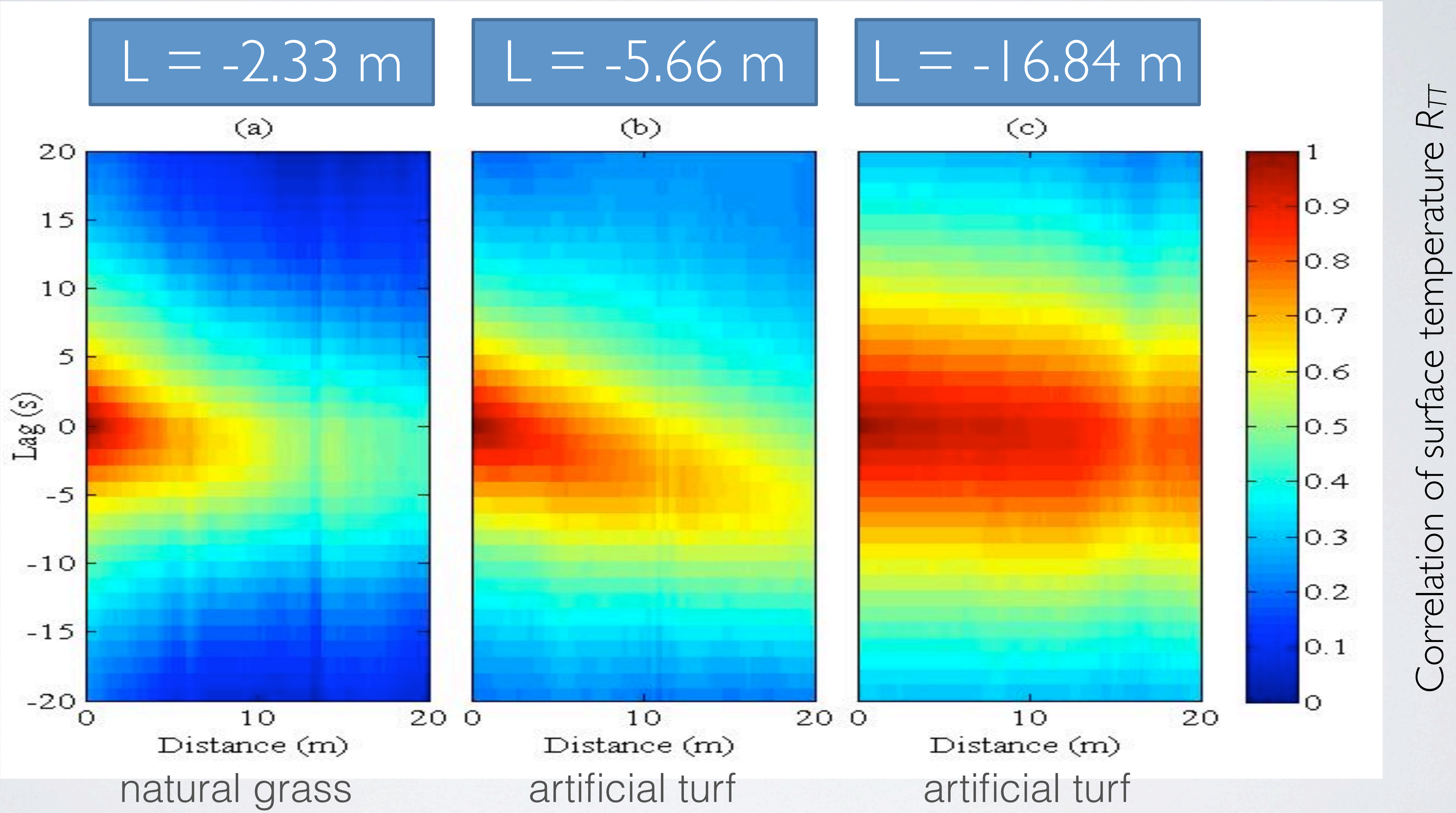
Simpler surfaces - How does size of coherent structures scale with stability?



Over natural grass
At RIMAC field, University of California, San Diego

Over artificial turf
At athletics field of Torey Pines High School, San Diego

Spatial scale of coherent structure increases with atmospheric instability



A. Garai, J. Kleissl (2010): 'Coupling between air and surface temperature in the atmospheric surface layer' , 19th Symposium on Boundary Layers and Turbulence, Keystone CO, USA.

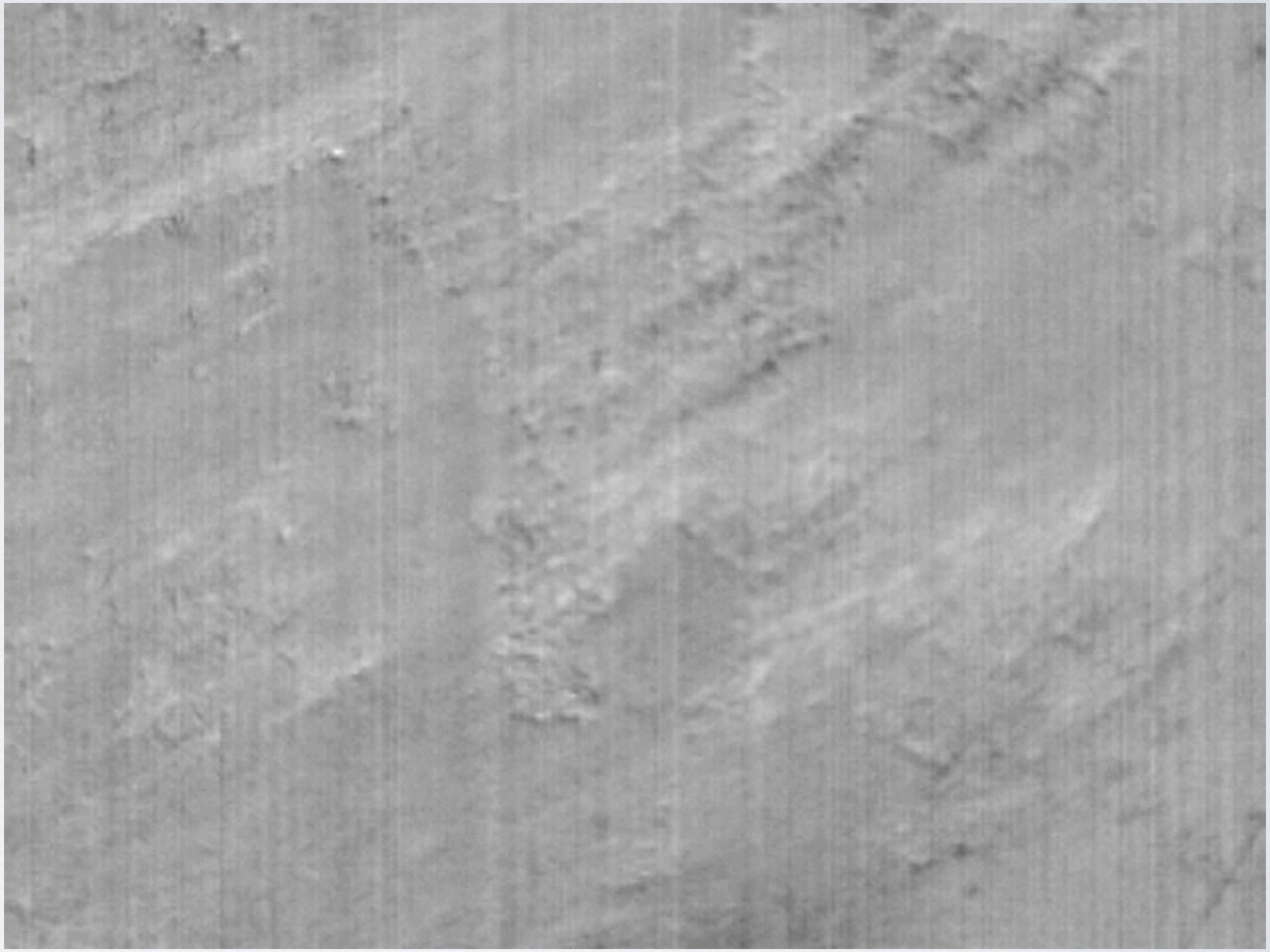
Coherent structure ‘imprint’ recorded on a bare desert surface

Visible

July 29, 2009, Namib Desert

R. Vogt, University of Basel, Switzerland.

Time-sequential thermography



Concluding remarks

- Current thermal imagery systems can resolve surface temperature fluctuations caused by coherent structures exchanging heat between land surfaces and atmosphere.

- TST works well for surfaces that have a low thermal admittance, and are heated (or cooled) substantially.

- Promising TST products include spatial length scales, convection velocities, and possibly turbulent flow field extraction.