Eddy covariance methodologies revisited for urban measurements

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19th Symposium on Boundary Layers and Turbulence
Ninth Symposium on the Urban Environment

1. Background

- the eddy covariance method is the state of the art method for measuring turbulent fluxes
- when studying energy fluxes, most interest directed to the residual of the surface energy balance

$$Res = R_n - H - LE = Q_S - Q_F$$

Net radiation

Sensible heat flux

Latent heat flux

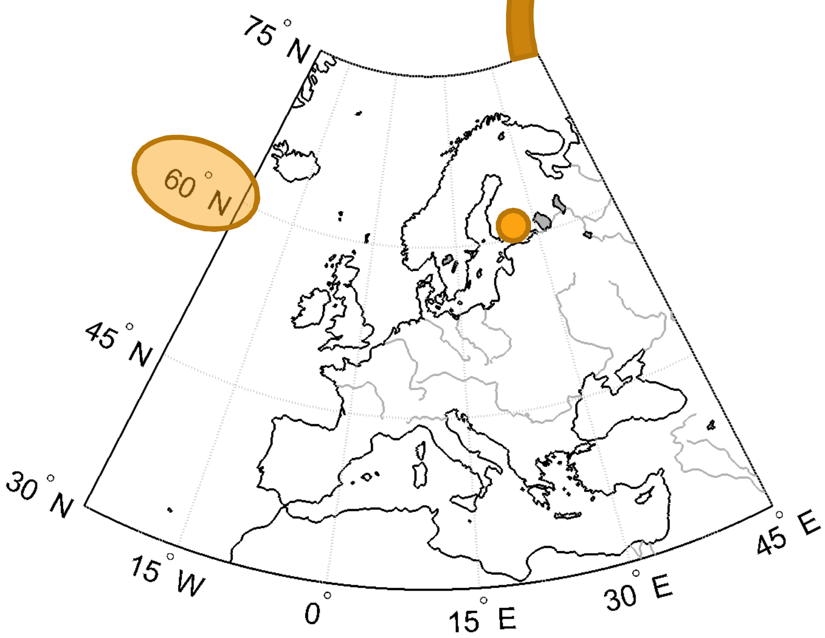
Heat storage change

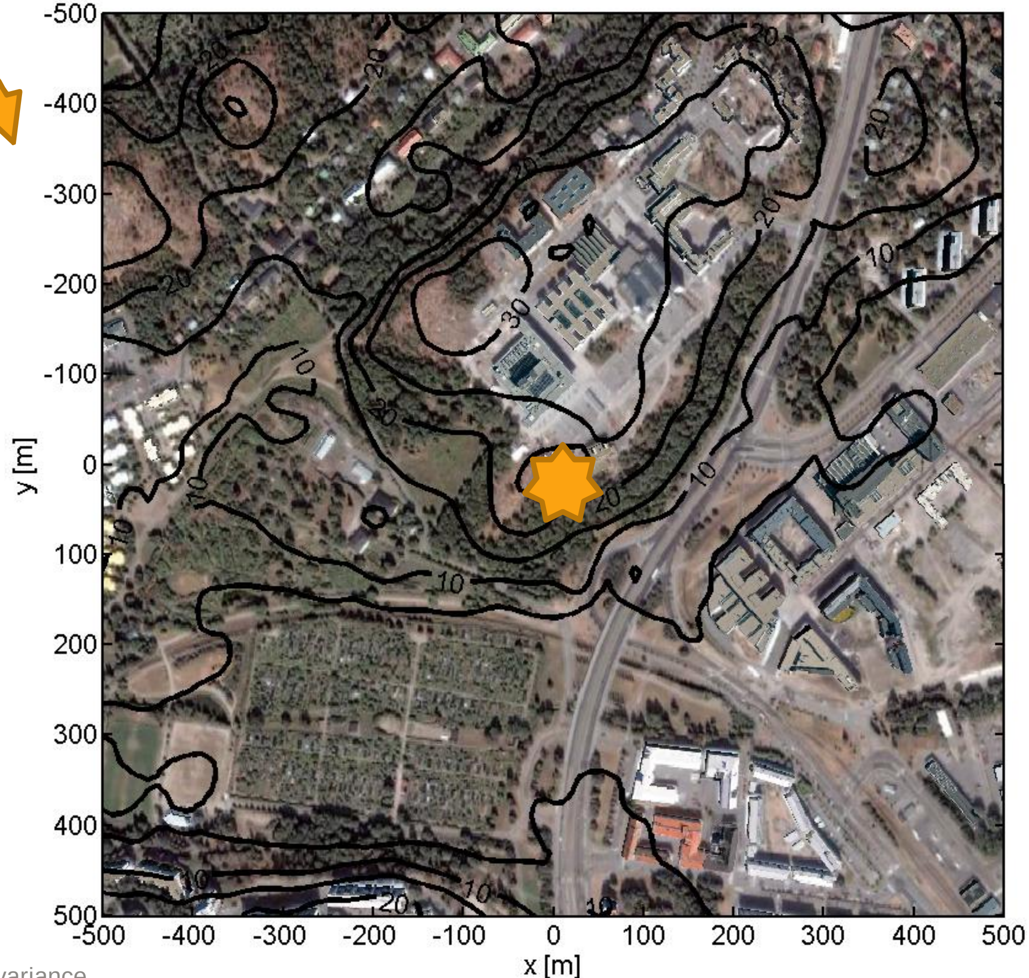
Antropogenic heat flux

- EC calculation systems have not yet reach consistency

→ differences / errors propagate to the residual

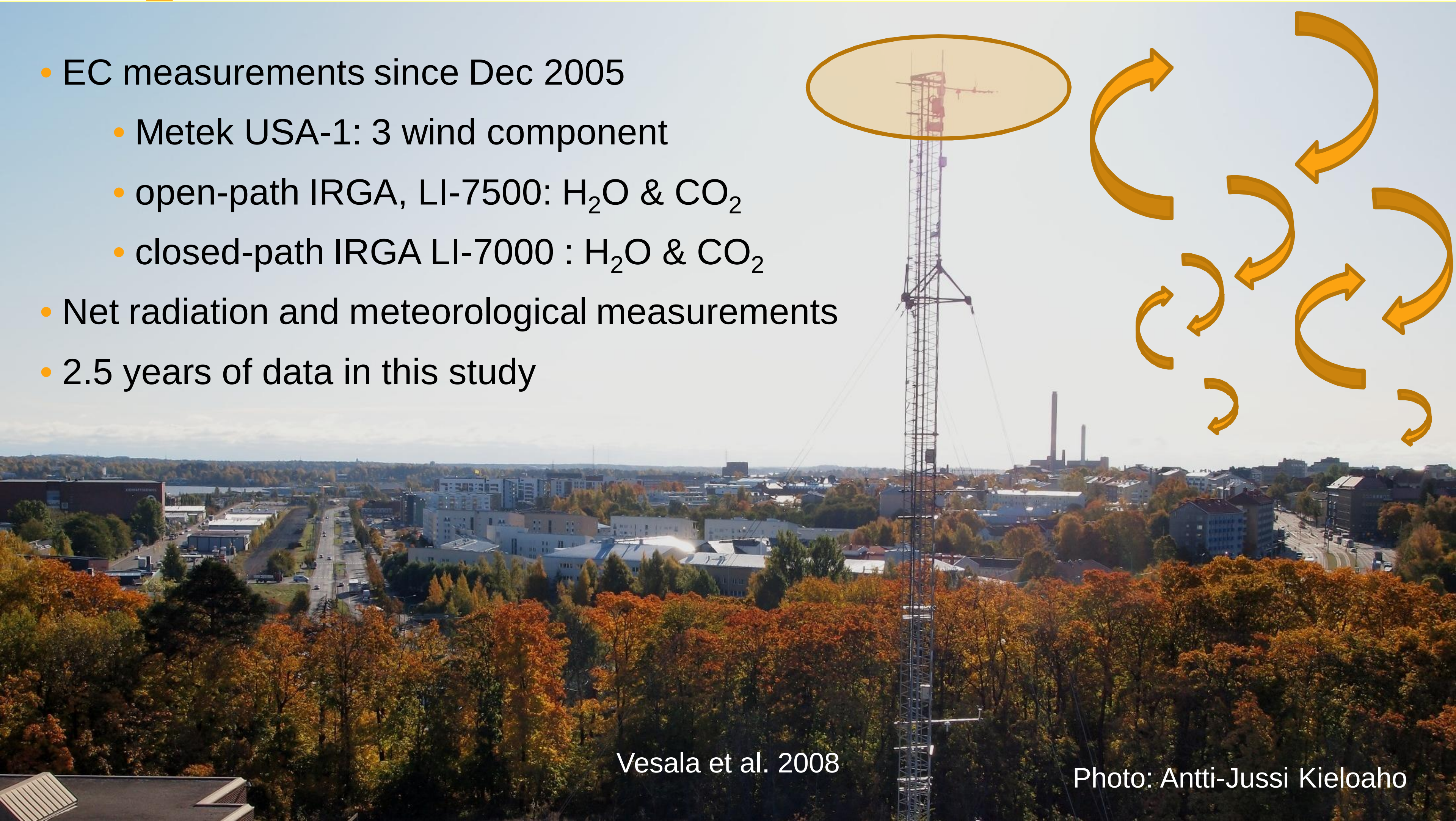
2. Study site in Helsinki, Finland





3. Measurements, SMEAR III, Helsinki

- EC measurements since Dec 2005
  - Metek USA-1: 3 wind component
  - open-path IRGA, LI-7500: H_2O & CO_2
  - closed-path IRGA LI-7000 : H_2O & CO_2
- Net radiation and meteorological measurements
- 2.5 years of data in this study



Vesala et al. 2008

Photo: Antti-Jussi Kieloaho

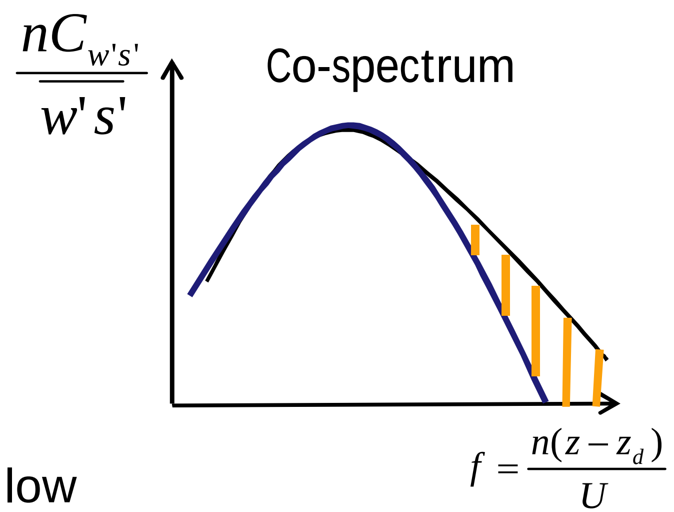
4. EC calculation systems

What should be compared?

- **High frequency spectral correction methods**
  - Theoretical
  - Experimental (τ_{H2O}(RH))
- **Averaging period**
  - 5, 30 & 60min
- **Iteration**
- **Lag time of closed-path H_2O**
- **Measurement accuracy**

5. Method details and results

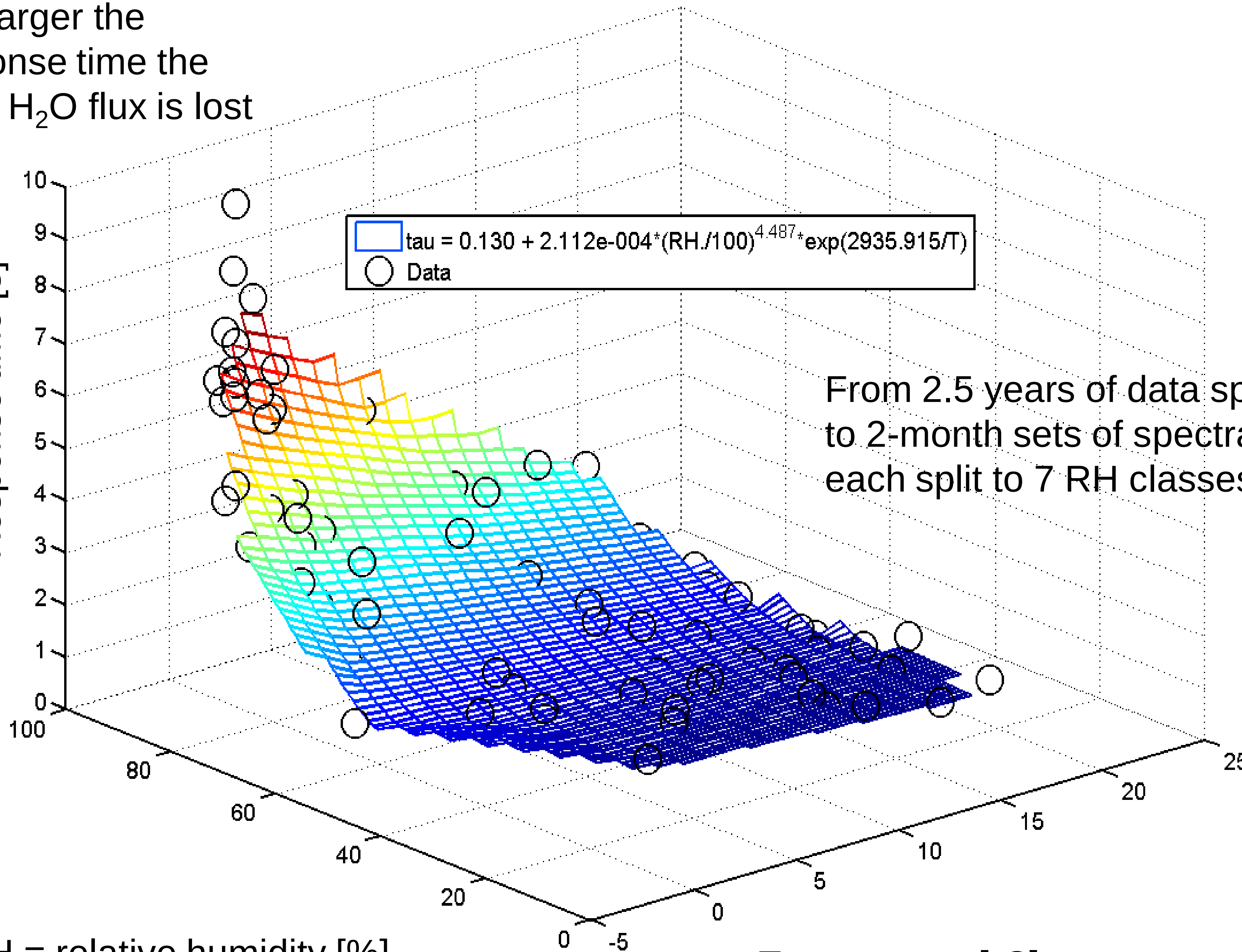
5.1 Spectral correction methods



- a huge difference is seen for closed-path LE
- the response time from theoretical equations is too low
- reason: adsorption to tube walls (41m tube) governed by relative humidity; desorption governed by temperature

Closed-path H_2O spectral correction

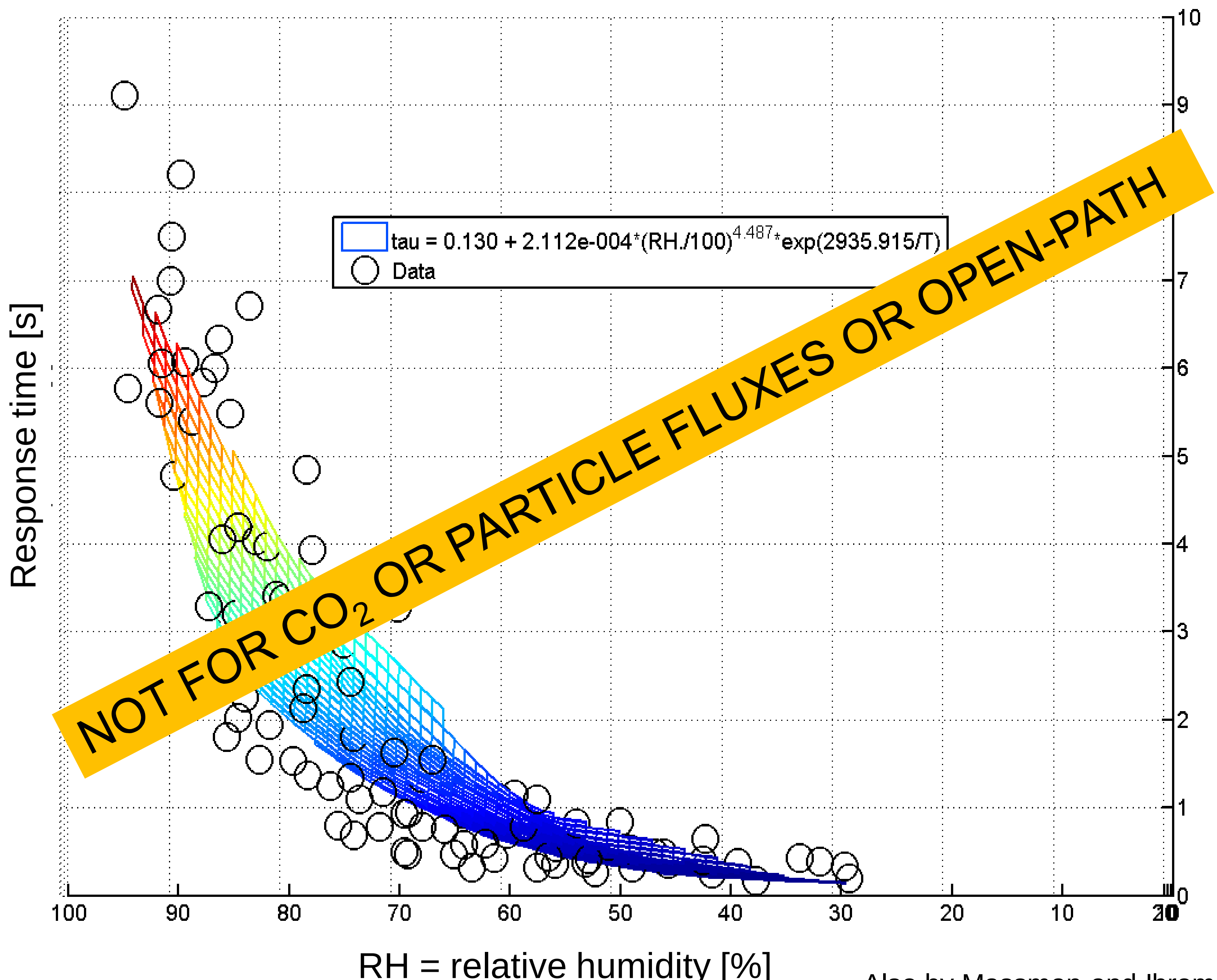
The larger the response time the more H_2O flux is lost



From 2.5 years of data split to 2-month sets of spectra each split to 7 RH classes

RH = relative humidity [%]

Temperature [^oC]



Also by Massman and Ibrom 2008

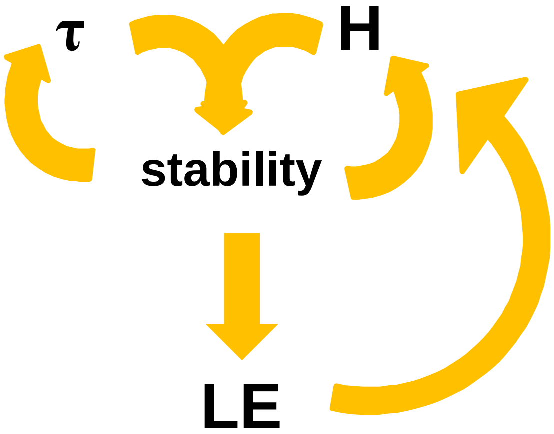
5.2 Averaging period

- the longer the averaging period the larger the flux
- 60 min observed to be good for urban environments

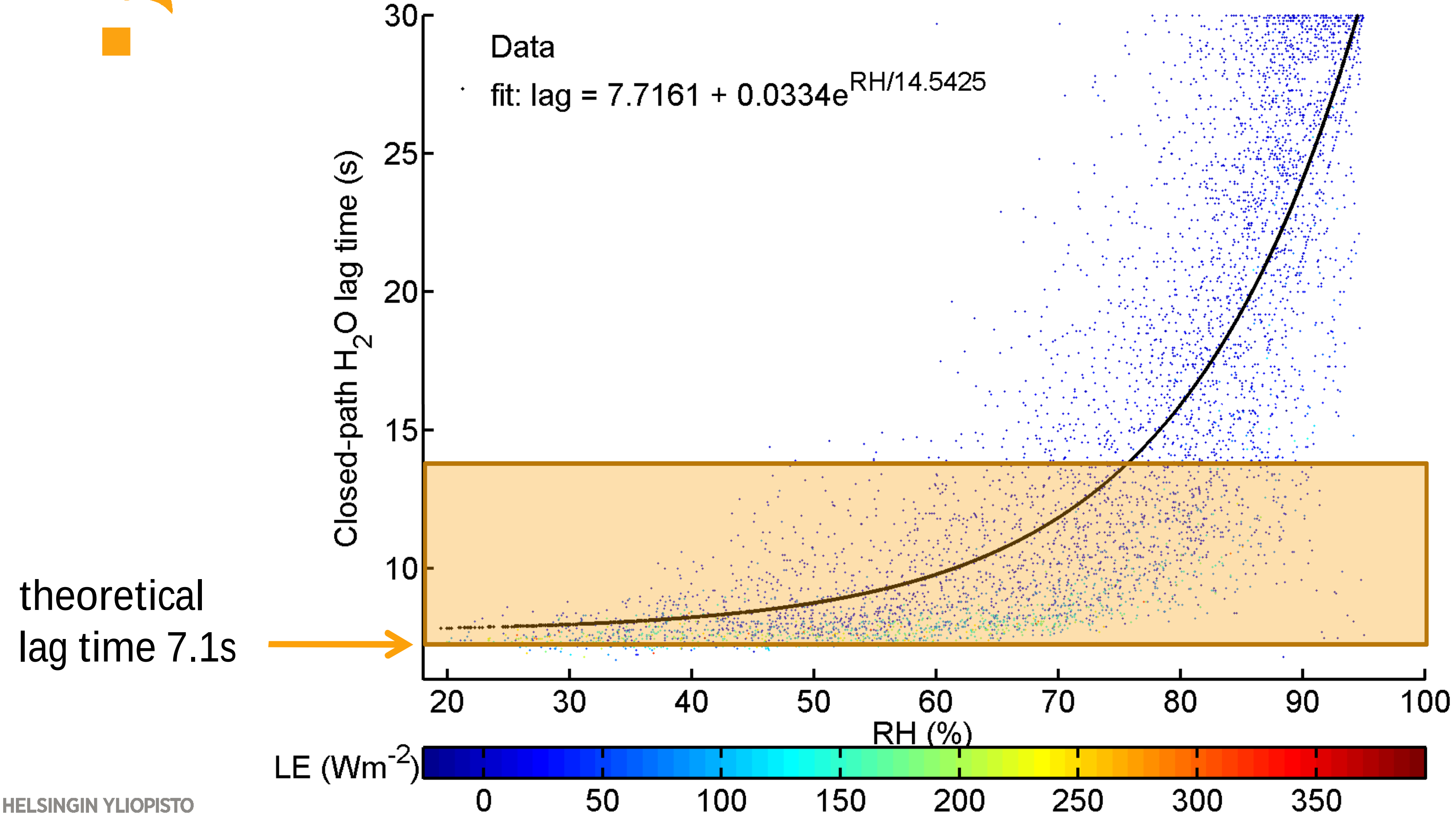
5.3 Iteration

- the fluxes depend on each other through different corrections

→ should be solved iteratively especially in stable conditions



5.4 Closed-path H_2O lag time



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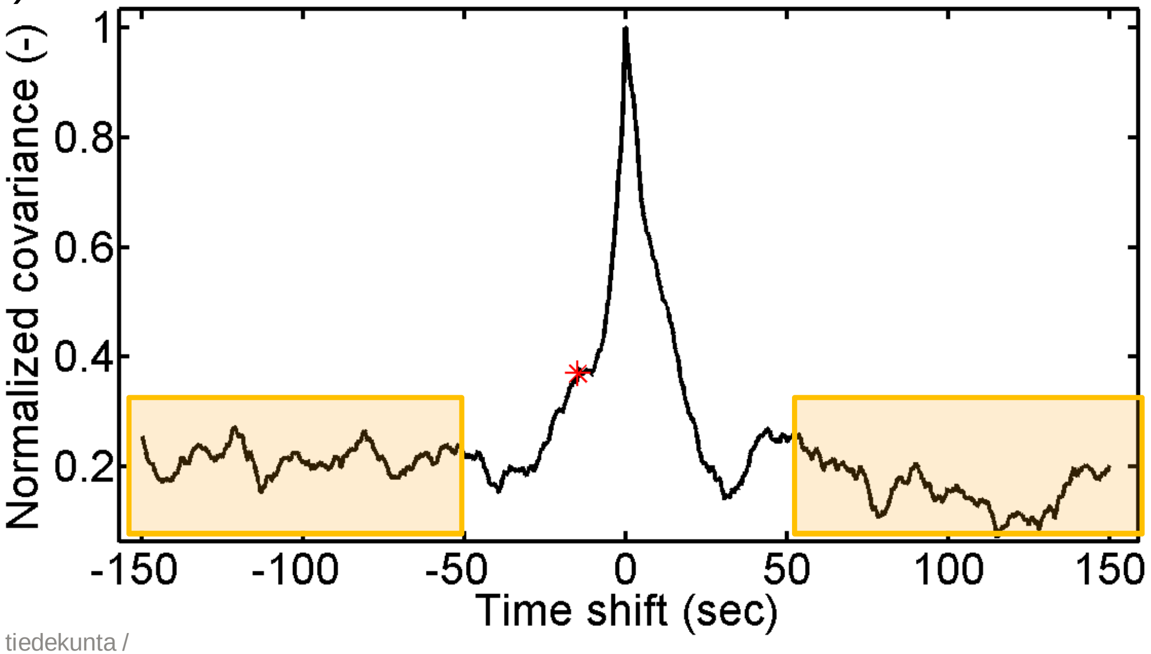
UNIVERSITY OF HELSINKI

5.5 Mesurement accuracy

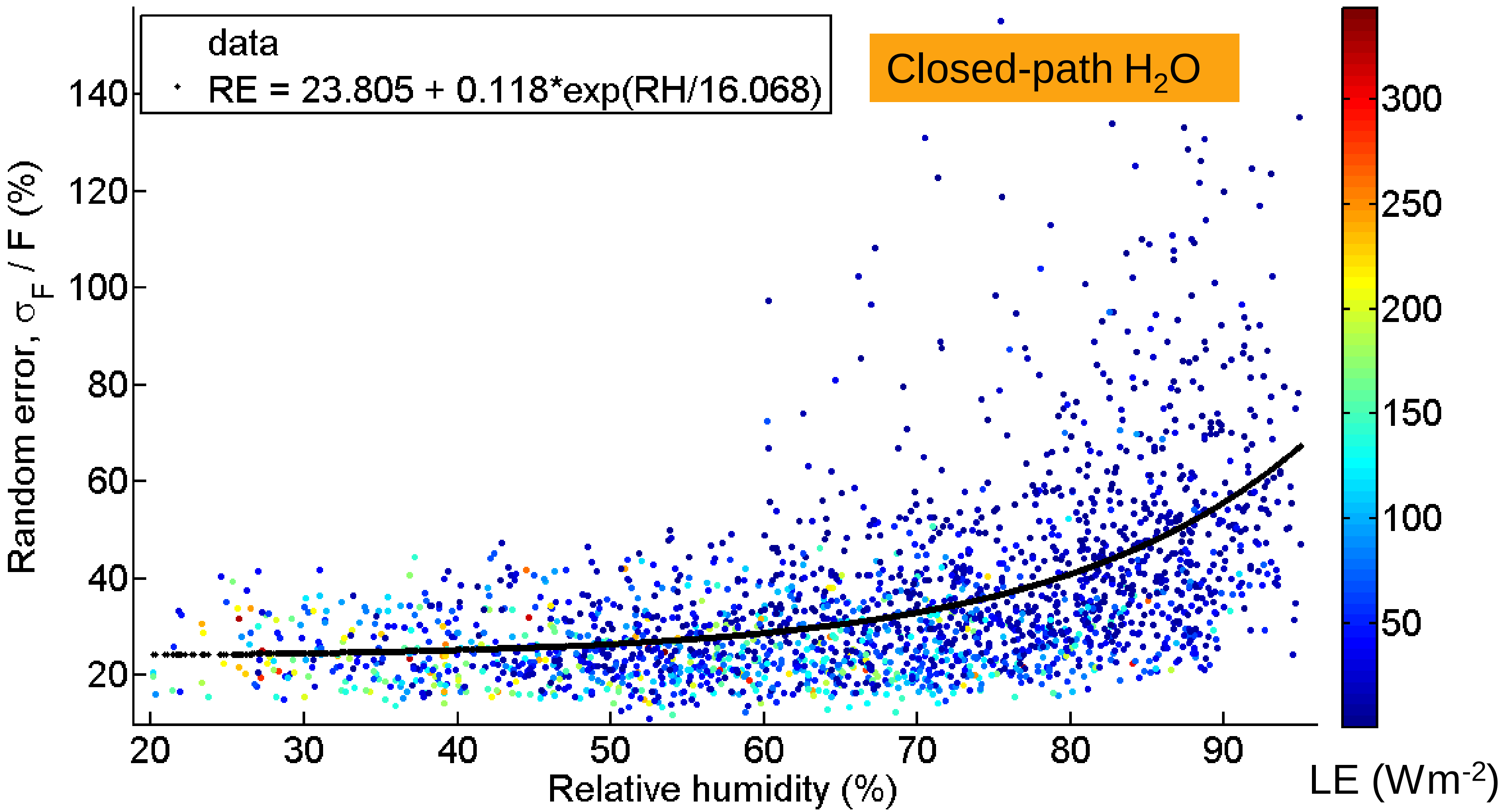
- **Detection limit < 10% for all fluxes**

  - standard deviation of the cross-correlation function at points 50 to 150 seconds (Wienhold et al. 1994)
  - example for $\overline{w'T'}$
    - 60min data
    - Detection limit: 3.68%

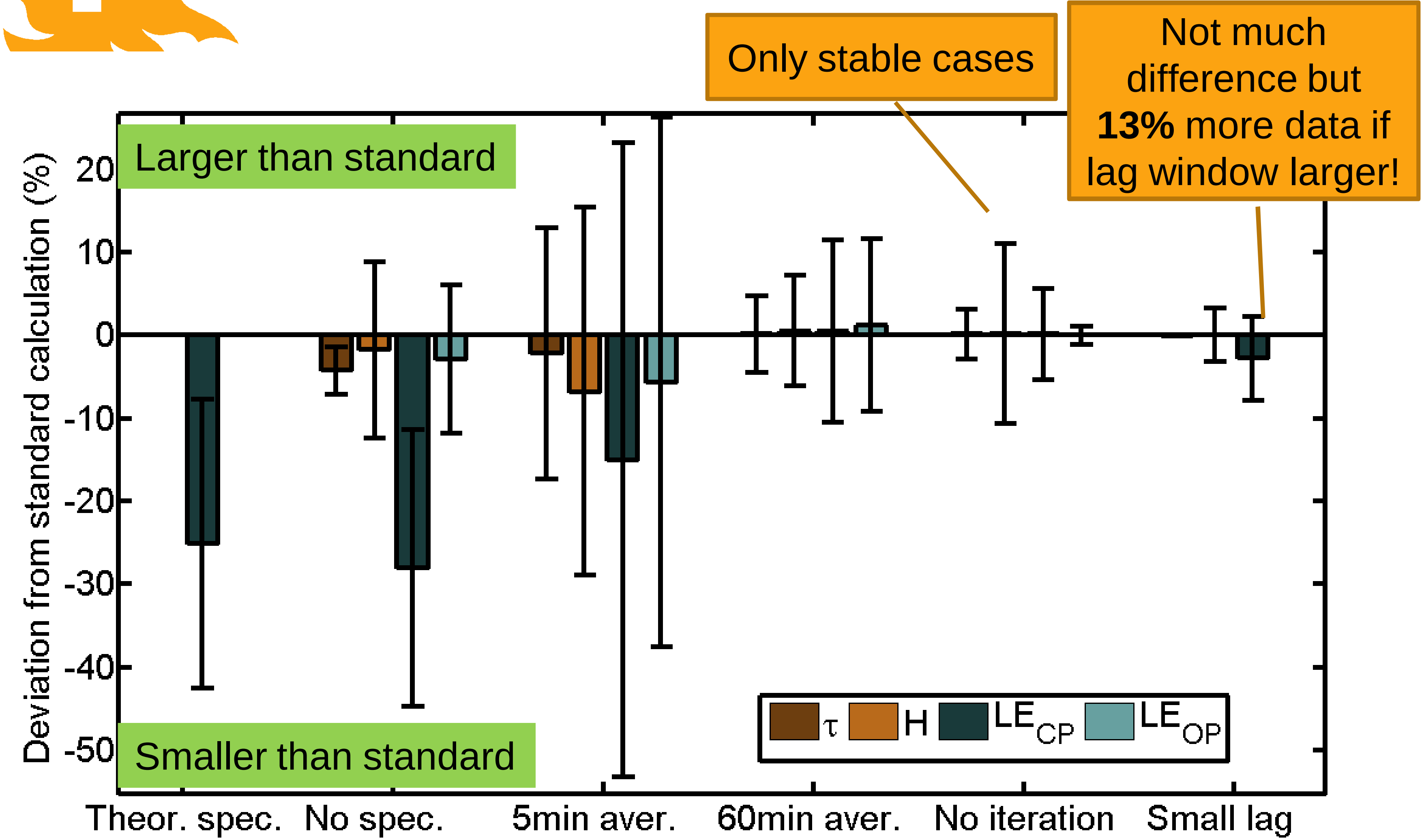


- **Random error < 20%, for most fluxes**

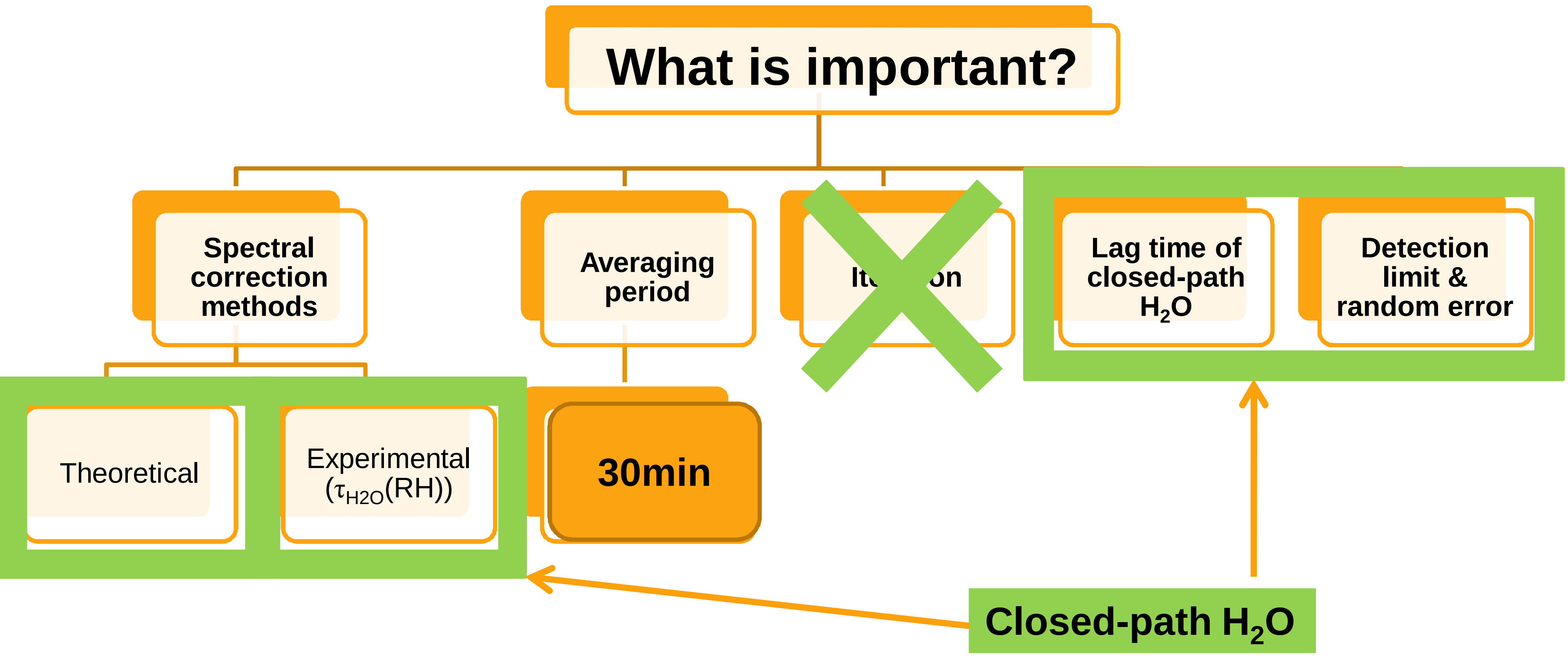
$$\sigma_F^{\ 2}(T) \approx 2\mu_F \frac{\Gamma_F}{T}$$, units of covariance squared (Lenschow et al. 1994)



Final values



Conclusions



Thank you!

Don't hesitate to contact me!

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References

Lenschow D. H., J. Mann and L. Kristensen, How long is long enough when measuring fluxes and other turbulence statistics?, 1994. *J. Atmos. Oceanic Technol.,* **11,** 661-673**.**

Massman W. J. and A. Ibrom, 2008. Attenuation of concentration fluctuations of water vapor and other trace gases in turbulent tube flow. *Atm. Chem. and Phys.,* **8 (20),** 6245-6259.

Vesala, T., L. Järvi, S. Launiainen, A. Sogachev, Ü. Rannik, I. Mammarella, E. Siivola, P. Keronen, J. Rinne, A. Riikonen, and E. Nikinmaa, 2008. Surface-atmosphere interactions over complex urban terrain in Helsinki, Finland. *Tellus Series B – Chem. Phys. Met.,* **60 (2),** 188-199**.**

Wienhold F. G., H. Frahm and G. W. Harris, 1994. Measurements of N_2O fluxes from fertilized grassland using fast response tunable diode laser spectrometer. *J. Geophys. Res.* **99 D8,** 16,557-16,567**.**

EXTRA SLIDES

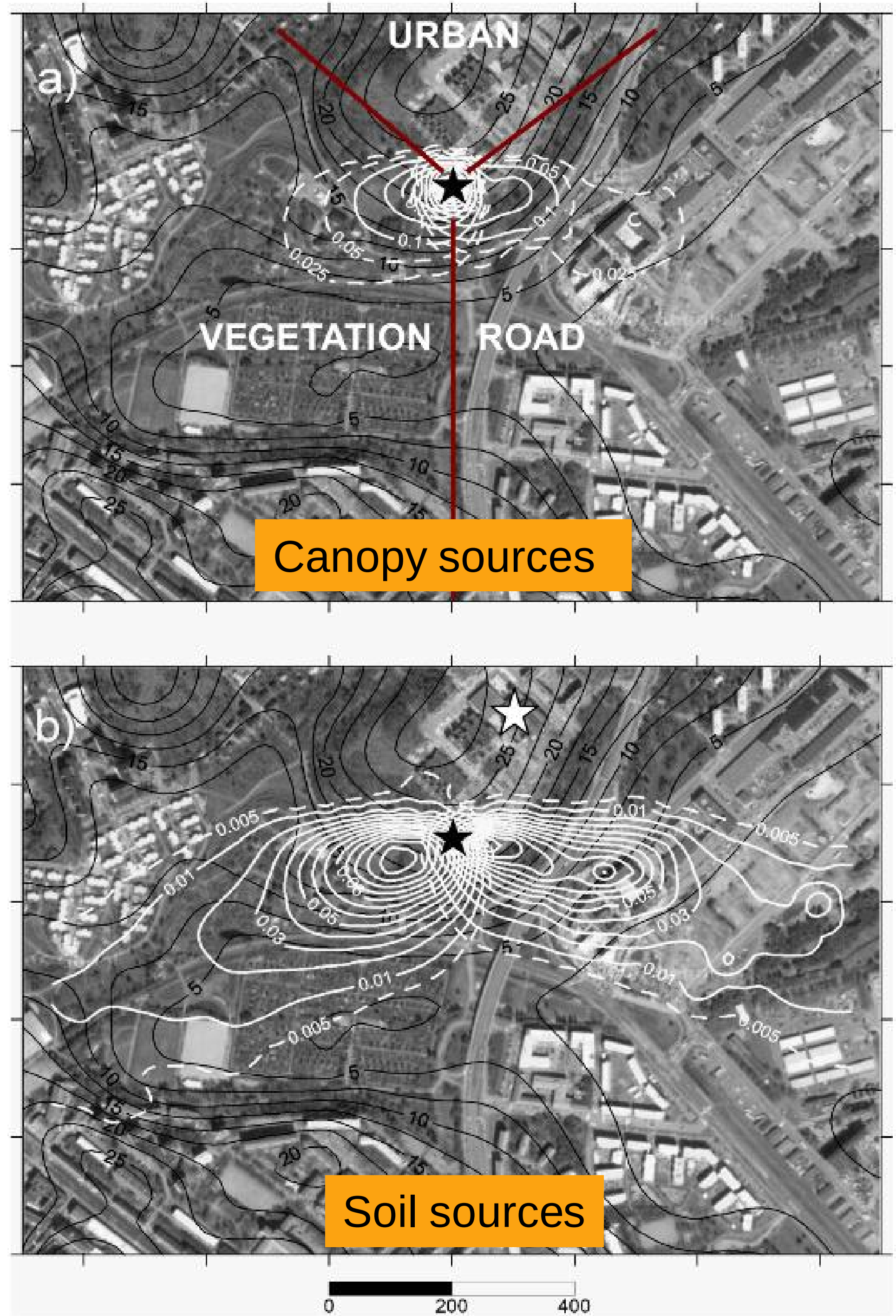
Where does the turbulent flux signal originate from?

Footprint modeling results from Vesala et al. (2008) for <u>neutral stratification</u>

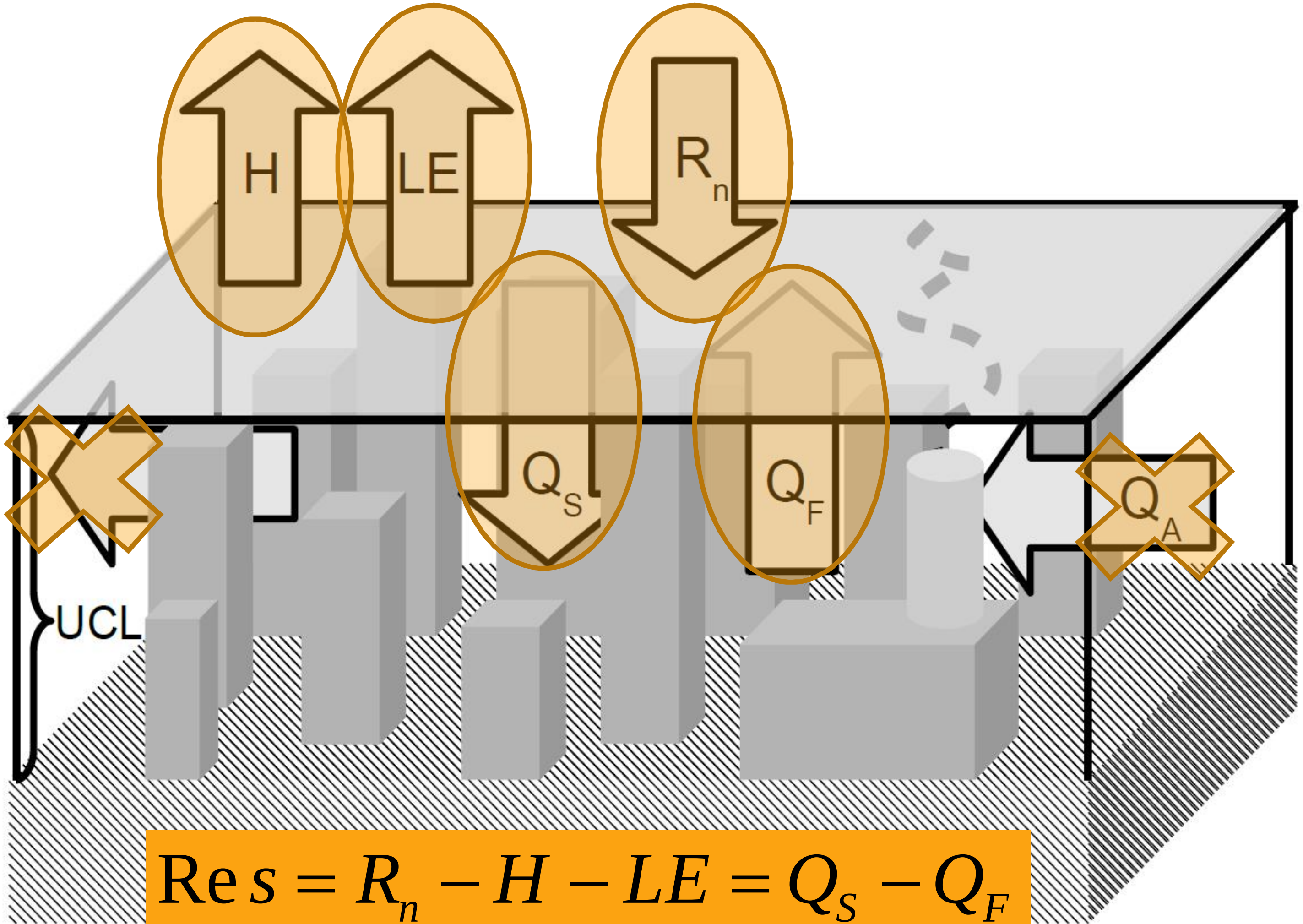
★ = tower

Black = topography

White = contribution function contours [10^{-4} m^{-2}]



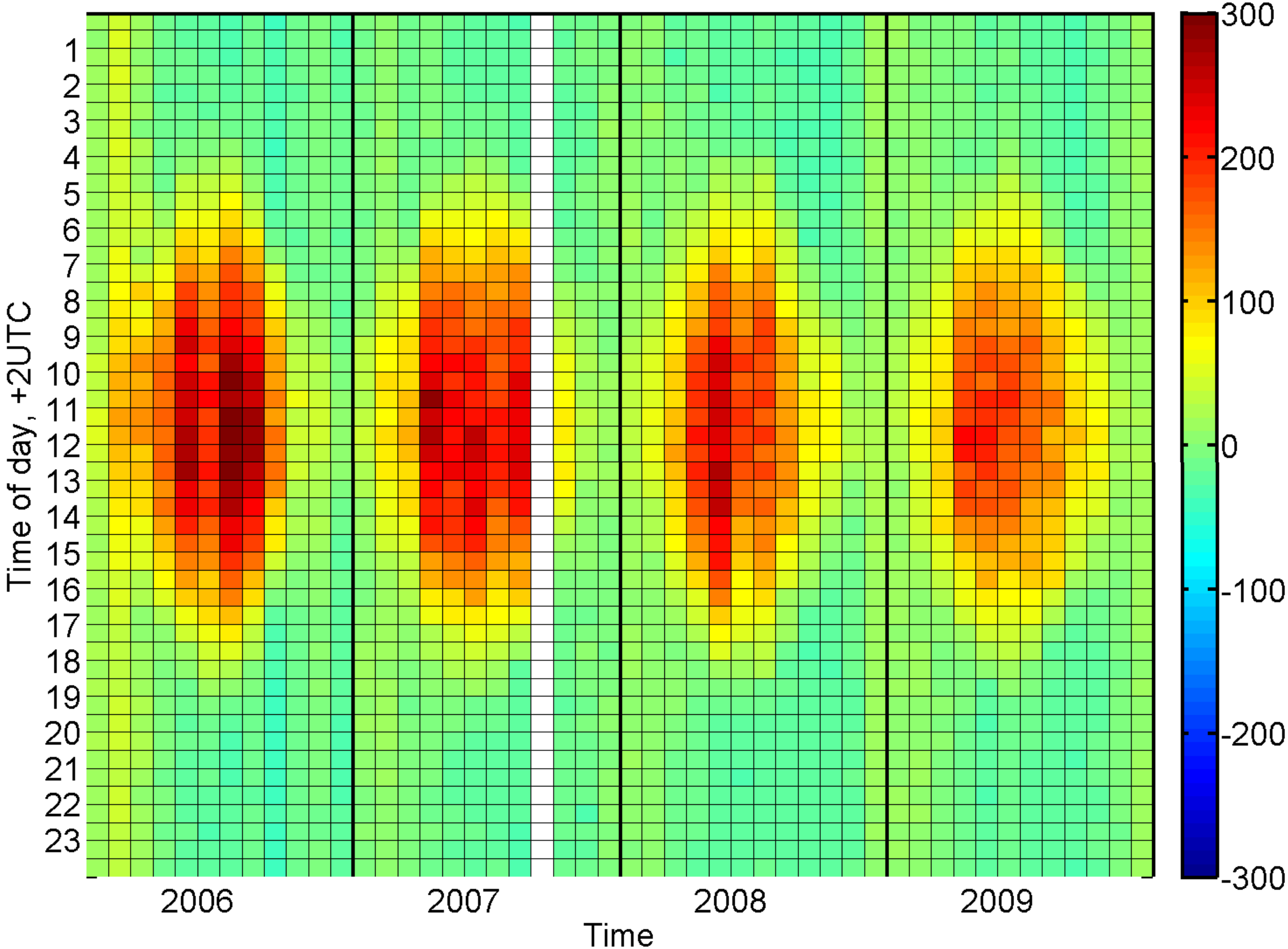
Energy balance of a building-air volume

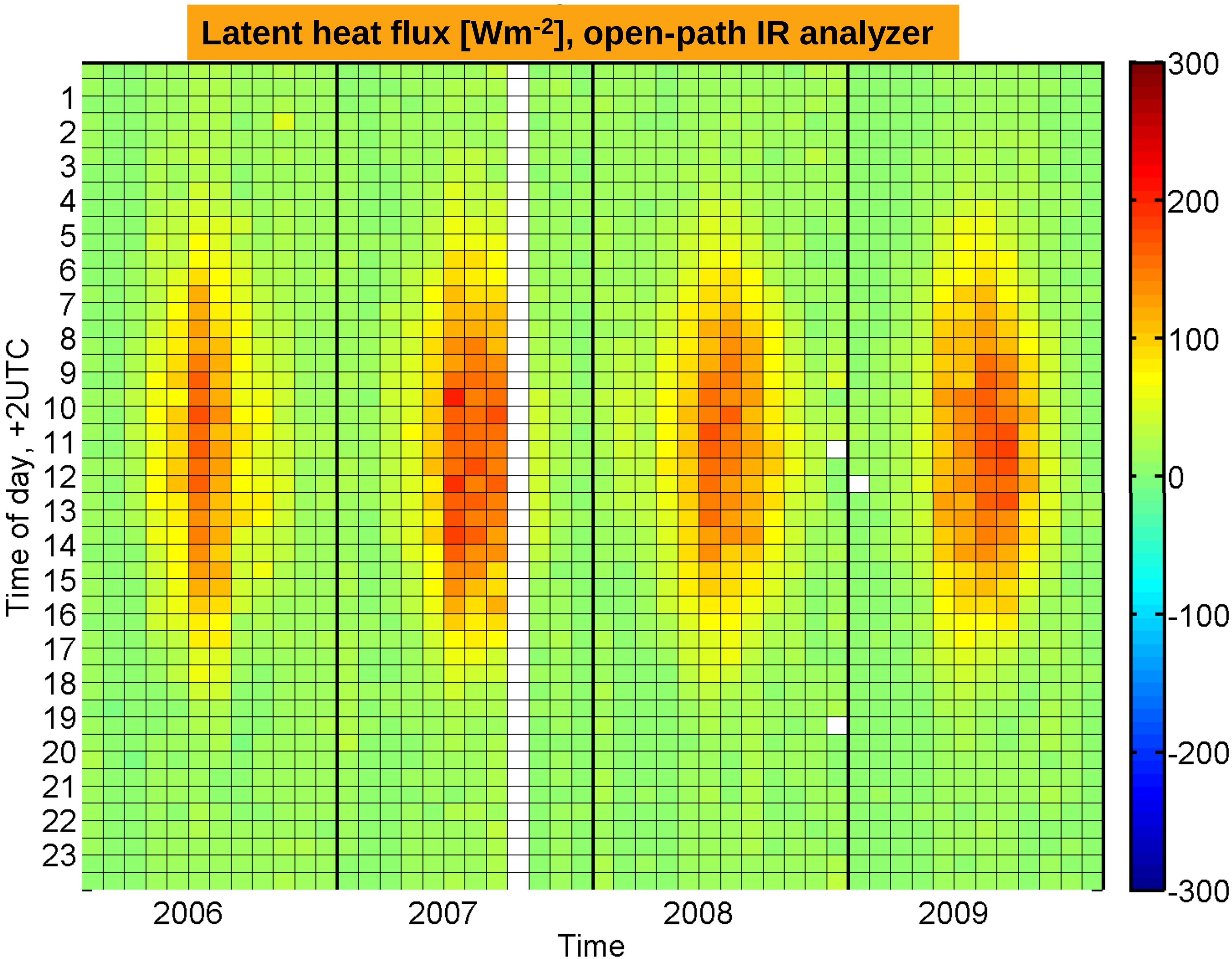


After Oke (1988)

$$\mathrm{Res} = R_n - H - LE = Q_S - \underbrace{Q_F}_{>0}$$

Sensible heat flux [Wm^{-2}]





Latent heat flux [Wm-2], open-path IR analyzer
Time of day, +2UTC
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-100
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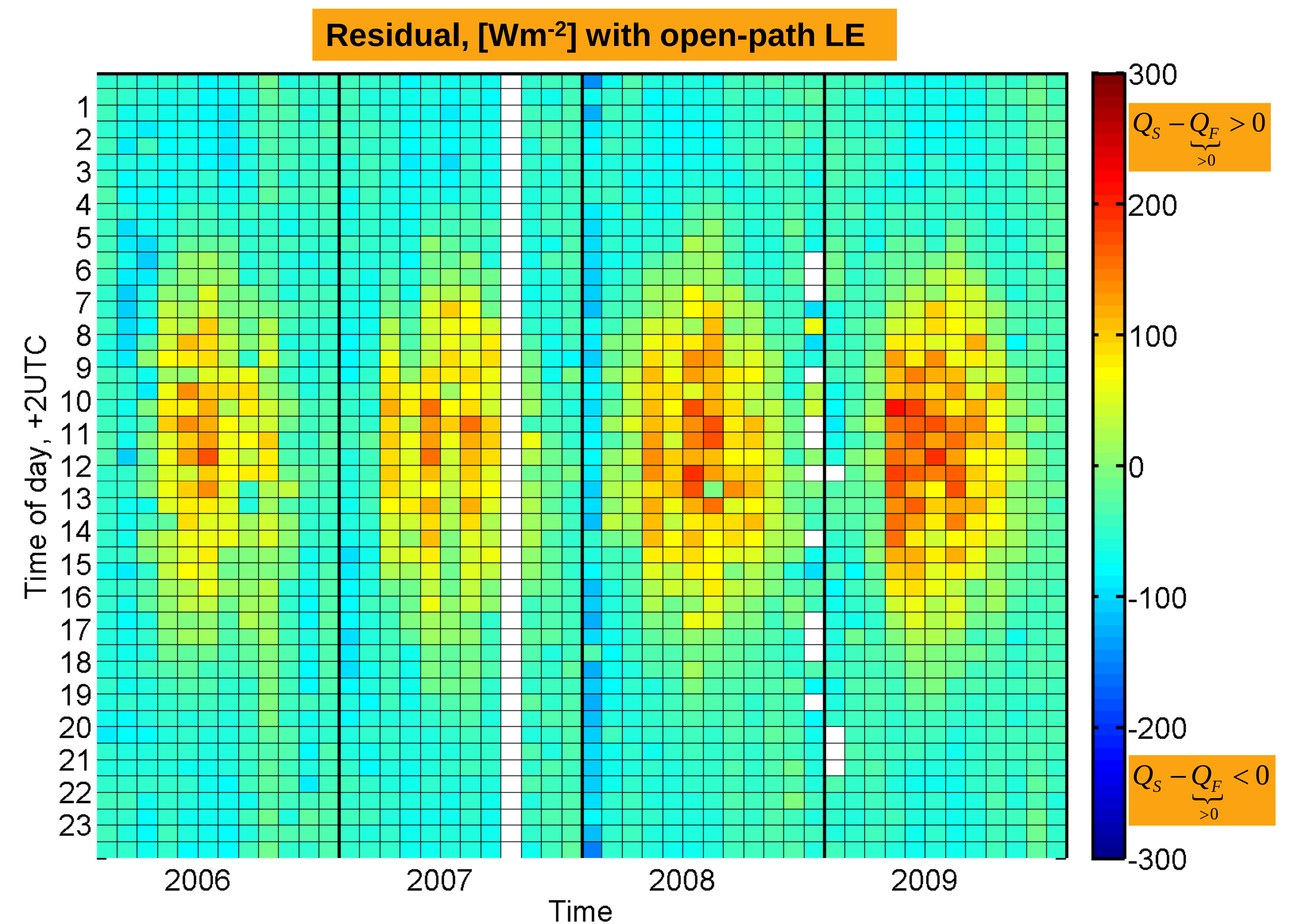
-300



Residual, [Wm-2] with open-path LE
Time of day, +2UTC
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2006
2007
2008
2009
Time
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200
100
0
-100
-200
-300
$Q_S - \underbrace{Q_F}_{>0} > 0$
$Q_S - \underbrace{Q_F}_{>0} < 0$