Measuring Sensible Heat Flux with High Spatial Density

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Outline

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- Motivation
- Methods for measuring sensible heat flux
  - Eddy Covariance (EC)
  - σ_T-method
- Measurement setup
- Experimental results
- Conclusion and outlook

Motivation

measure and model surface energy balance

high spatial variability → many sensors → low sensor cost

Eddy Covariance Method

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- Prerequisites [1]
  - homogenous, flat land surface
  - buoyancy is dominant force
- Well established method

$$H_{EC} = \rho c_p \overline{w'T'}$$

- Requires fast (≈ 20 Hz) measurement of
  - vertical wind speed fluctuation w'
  - temperature fluctuation T'
- $\overline{w'T'}$ are obtained with sonic anemometer ($10'000/unit)

[1] e.g. Schotanus, P., Nieuwstadt, F. T. M., and de Bruin, H. A. R.: 1983, "Temperature Measurement with a Sonic Anemometer and its application to Heat and Moisture Fluxes", *Boundary-Layer Meteorol., 26, 81-93.*

σ_T-method

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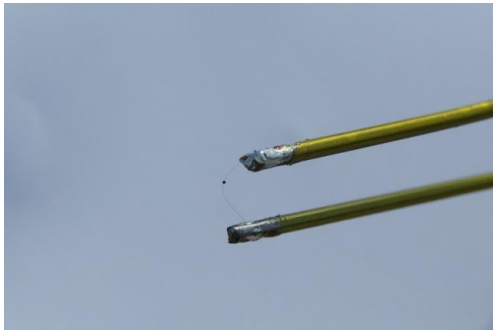
- Prerequisites
  - homogenous, flat land surface
  - buoyancy is dominant force



$$H_{\sigma_T} = \sigma_T^{3/2} \overline{T}_a^{-1/2} \rho c_p C_1^{-3/2} (kgz)^{1/2} \quad [1]$$

- Requires
  - variance of temperature (sampled at high speed) σ_T
  - average temperature (sampled at high speed) $\overline{T}_a$
- Can be obtained using NTC sensor ($50/unit)

[1] J. D. Albertson, M. B. Parlange, G. G. Katul, C.-R. Chu, H. Stricker, and S. Tyler, “Sensible heat flux from arid regions: A simple flux-variance method,” *Water Resources Research, vol. 31, no. 4, pp. 969–973, 1995.*

Sensorscope station

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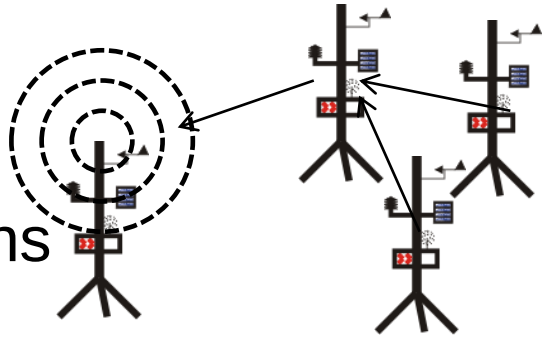
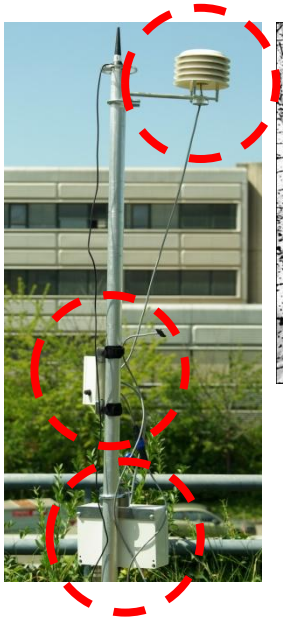
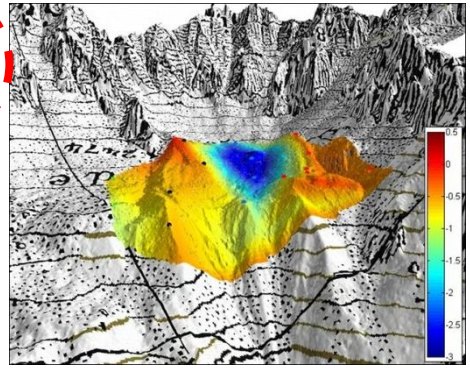
- "Off-the-shelf" wireless sensor network system for microclimate research [1]
- Dozens of experiments with 20+ stations
- Measures temperature, humidity, solar radiation, soil moisture, etc.
- Local ad-hoc + with 3G data connection
- Each station consists of
  - One data logger with radio(s)
  - Several sensors with processing node for each sensor







[1] G. Barrenetxea, F. Ingelrest, G. Schaefer, M. Vetterli, O. Couach, and M. Parlange, "Sensorscope: Out-of-the-box environmental monitoring," in *Proc. Int. Conf. Information Processing in Sensor Networks IPSN '08,* 2008, pp. 332–343.

Sensorscope modification

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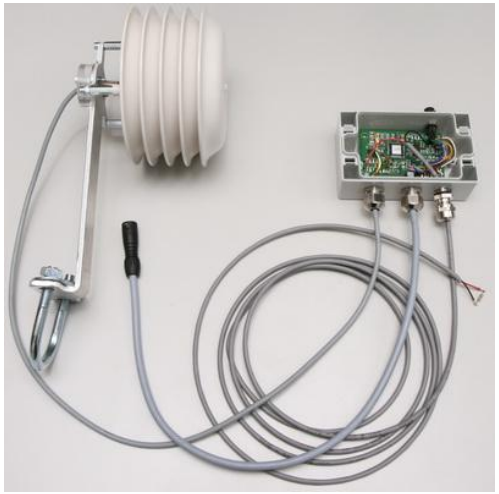
- Data logger:
  - MSP430 running TinyOS
  - no modifications
- Sensor module:
  - MSP430 running TinyOS
  - added NTC to free A/D port
  - Custom software which identifies NTC as standard Senorscope sensor
  - Sensor remains on, computes running average
- Price: $50/unit



Reference experiment

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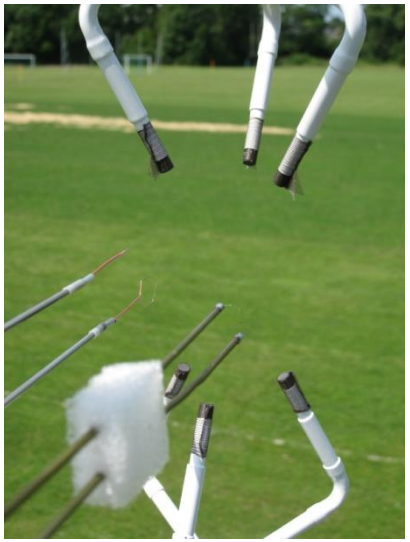
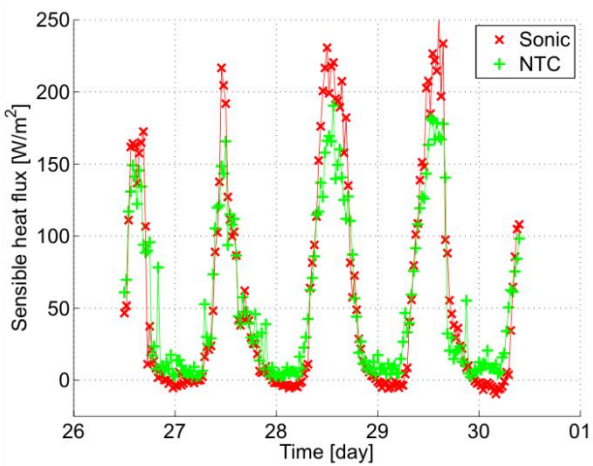
- compare EC-method with σ_T-method
- several sensors in same sample volume
  - Campbell Scientific CSAT3 } EC
  - NTC (Honeywell 111, d=0.36mm) } σ_T
- good match between methods
  - varying sampling frequency
  - varying averaging window length

→ σ_T -method is a valid

- for details see [1]





[1] C. Higgins, H. Huwald, A. Bahr, A. Martinoli, and M. Parlange, “Sensible heat flux from wireless environmental sensor networks,” *Water Resources Research, submitted.*

Network deployment

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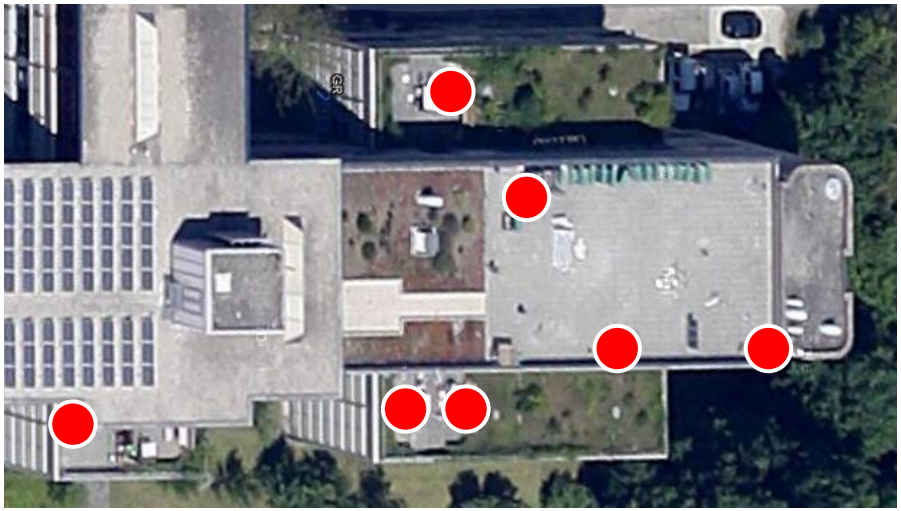
- *Goal: testing the system's robustness*
- 7 stations deployed (5 with NTCs)
  - f_{sample}= 10 Hz
  - all stations reported $\overline{T}_a$ and σ_T every 1' (→ 15' in post processing)



Network deployment results

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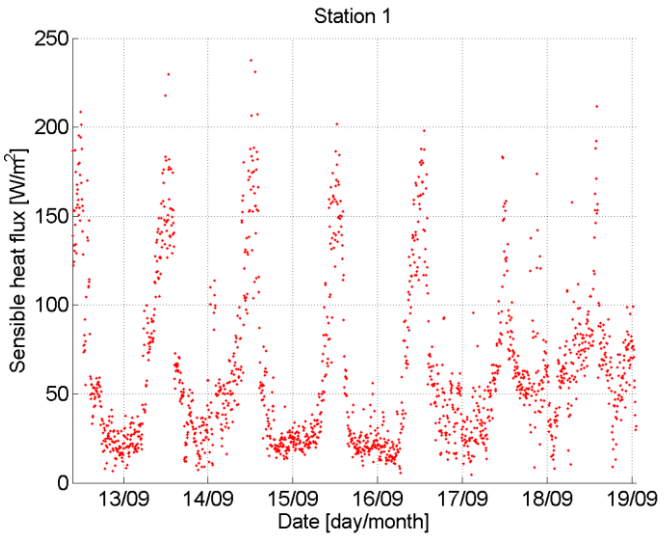
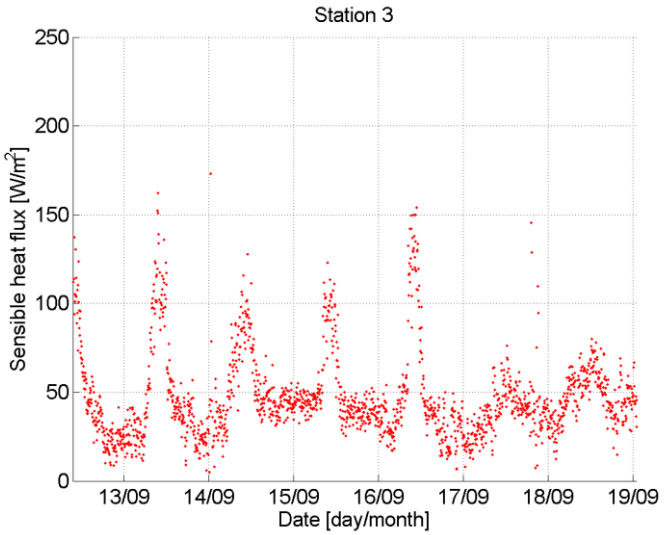
- 1 week of data from 4 stations
- no sensor failures
- additional power consumption: 30mW
- <100 byte RAM
- robust collection and processing method
- collected data qualitatively matches reference experiment





Conclusion and future work

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- We adapted a known method for sensible heat flux measurements by leveraging WSN technology
- We developed an affordable and thus scalable approach for measuring sensible heat flux with *high spatial density*

- Large-scale, long-term deployment
- Cross validation with multiple fast anemometers