Measuring Sensible Heat Flux with High Spatial Density

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Outline

• Motivation
• Methods for measuring sensible heat flux
  – Eddy Covariance (EC)
  – $\sigma_T$-method
• Measurement setup
• Experimental results
• Conclusion and outlook
Motivation

*measure and model surface energy balance*

**high spatial variability → many sensors → low sensor cost**

Incoming solar radiation
- reflected solar radiation
- incoming IR radiation
- emitted IR radiation

Temperature sensor
- pyrgeometer
- pyrnometer

Conductive heat flux
- latent heat flux
- sensible heat flux

Radiometer $200-5000$
- temperature sensor $100$
- fast hygrometer $25000$
- fast anemometer $10000$

Sensorapps 2012
Eddy Covariance Method

- 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 \( T' \)
- \( w'T' \) are obtained with sonic anemometer ($10’000/unit)

σ_T-method

• Prerequisites
  – homogenous, flat land surface
  – buoyancy is dominant force

\[
H_{\sigma_T} = \sigma_T^{3/2} \overline{T_a}^{-1/2} \rho c_p C_1^{-3/2} (kgz)^{1/2} \tag{1}
\]

• Requires
  – variance of temperature (sampled at high speed) \( \sigma_T \)
  – average temperature (sampled at high speed) \( \overline{T_a} \)

• Can be obtained using NTC sensor ($50/unit)

Sensorscope station

- “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

Sensorscope modification

• 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

- compare EC-method with $\sigma_T$-method
- several sensors in same sample volume
  - Campbell Scientific CSAT3 $\rightarrow$ EC
  - NTC (Honeywell 111, d=0.36mm) $\rightarrow$ $\sigma_T$
- good match between methods
  - varying sampling frequency
  - varying averaging window length
  $\rightarrow$ $\sigma_T$-method is a valid
- for details see [1]

Network deployment

- **Goal:** testing the system’s robustness
- 7 stations deployed (5 with NTCs)
  - \( f_{\text{sample}} = 10 \text{ Hz} \)
  - all stations reported \( T_a \) and \( \sigma_T \) every 1’ ( → 15’ in post processing)
Network deployment results

- 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

• 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