



Life Under your Feet:

A Wireless Soil Ecology Sensor Network

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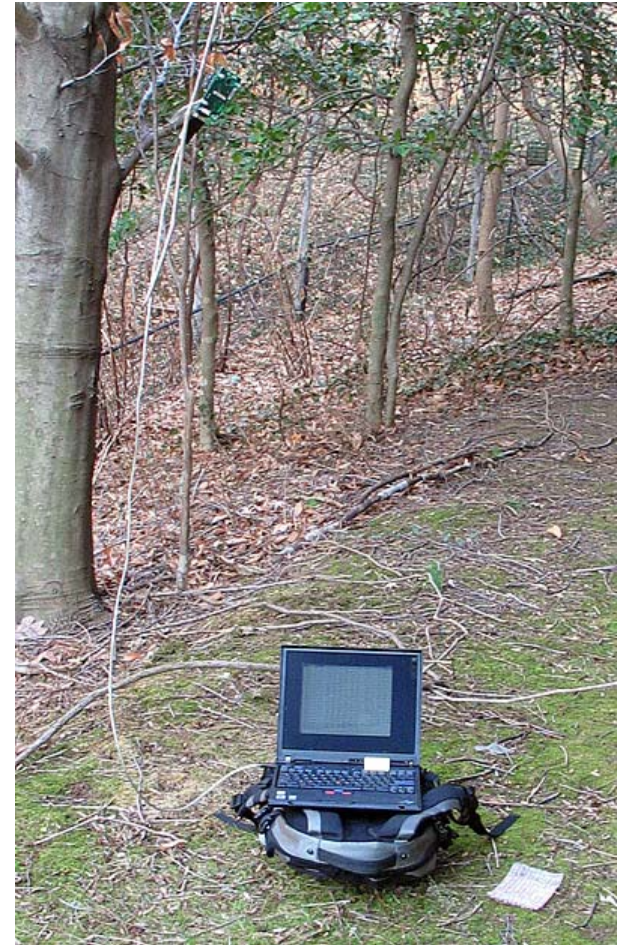
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[◇] Microsoft Research

In the Beginning...

- The Cast
 - An ecologist: *Katalin Szlavecz*
 - An undergrad student working in a summer project: *Joshua Cogan*
- The Stage
 - The urban forest near the JHU campus
 - Off-the-self soil moisture and temperature sensors
 - A few Mica2 motes
- The Goal
 - *Test whether WSNs can be used to collect soil monitoring data at spatial and temporal scales larger than that of data loggers*



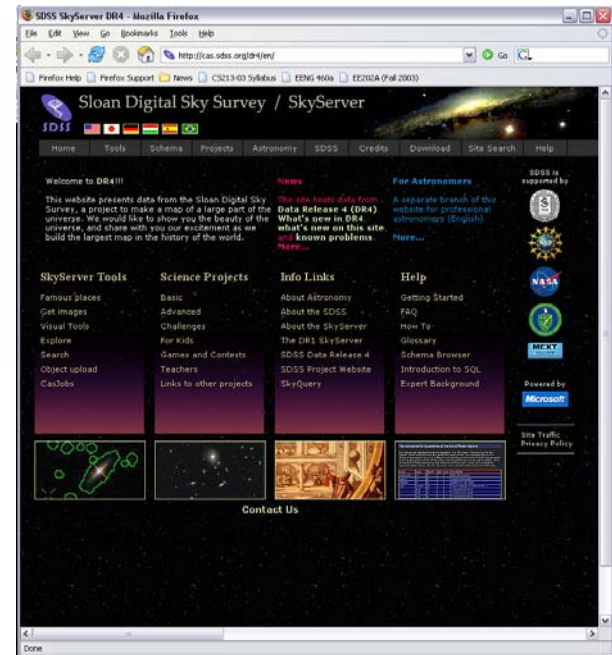
First Step

- The sensors were thoroughly tested in the lab
 - 2 out of 6 sensors misbehaved
 - Relatively precise ($\pm 0.5^{\circ}\text{C}$)
 - ... but offset of 1.5°C from a NIST approved thermocouple.
- Next step: teach the motes to play their part.



Second Step

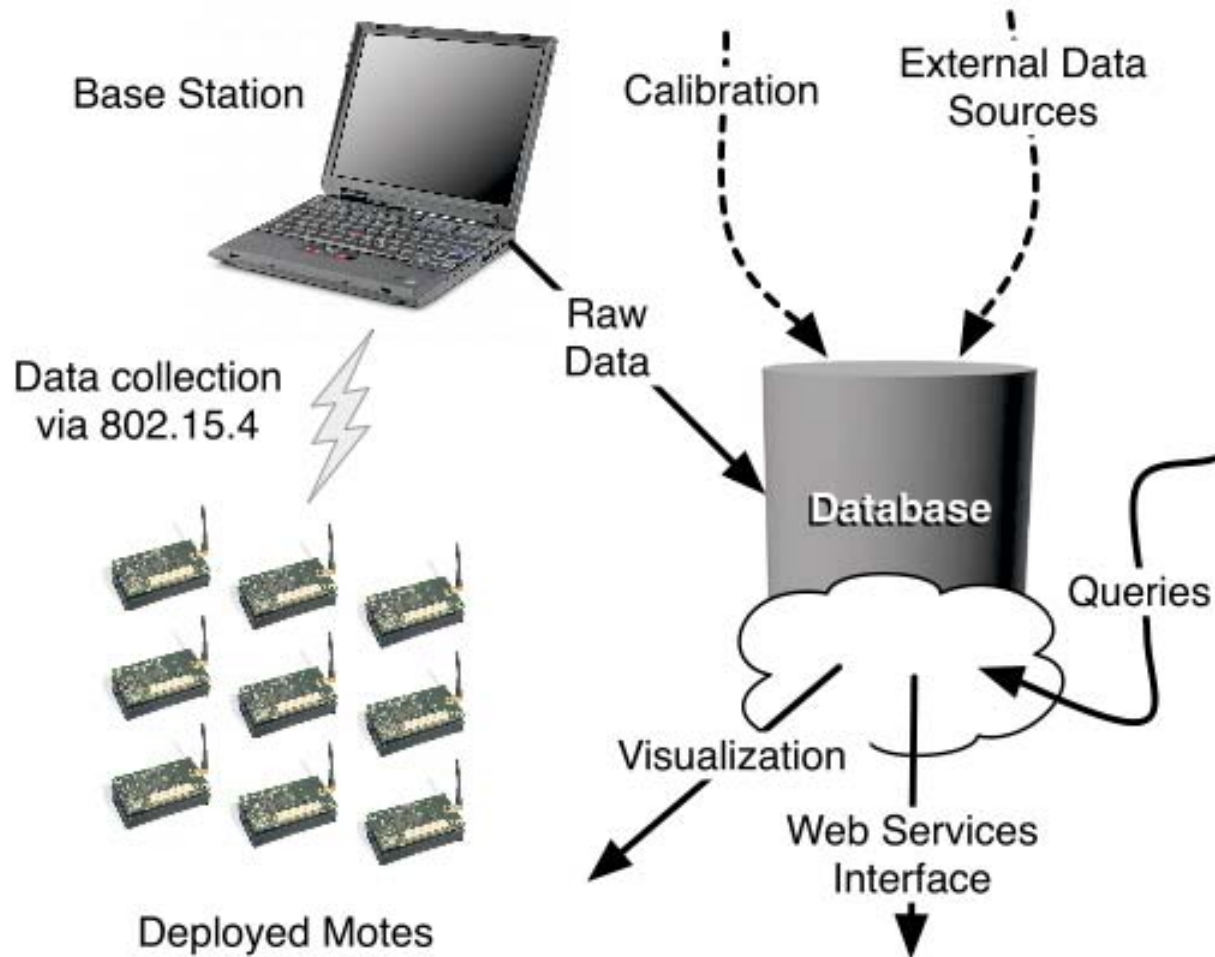
- More actors:
 - CS faculty (Andreas Terzis)
 - CS grad student (Razvan Musaloiu-E.)
 - DB experts: Alex Szalay and Jim Gray
- More setup:
 - MicaZ notes
 - MSSQL
 - Skyserver DB software
- The goal
 - Build an *end-to-end data collection system*



System requirements

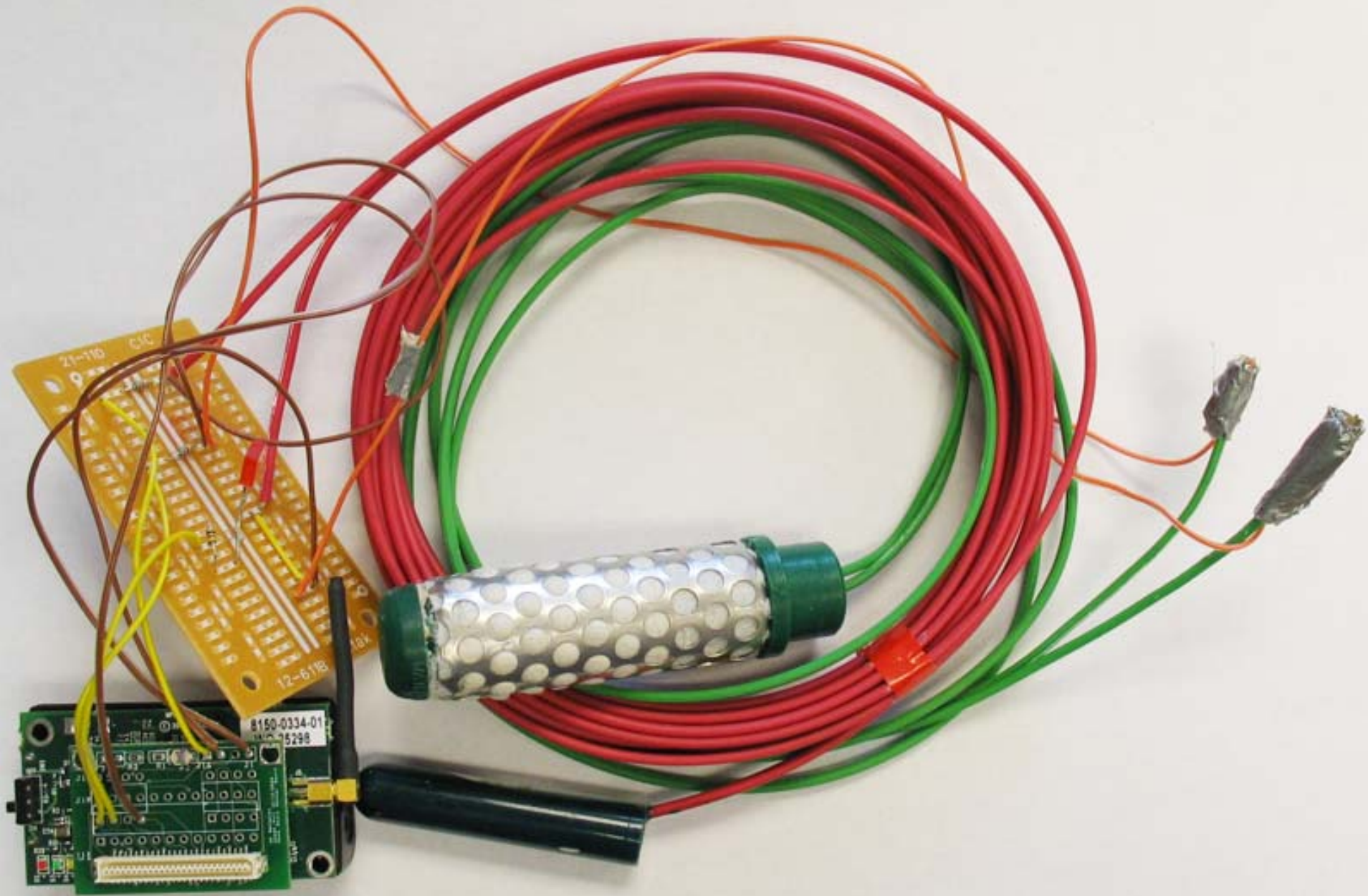
- Measurement fidelity
 - *All* the raw measurements should be collected and persistently stored
- Measurement accuracy and precision
 - Temperature data error < 0.5 C, volumetric moisture data error < 1%.
- Fusion with external sources
 - Comparing measurements with external data sources is crucial
- Additional Requirements
 - Sampling Frequency: *minutes*
 - Experiment Duration: *years*
 - Deployment Size: *networks should be deployed in ways that capture the heterogeneity of land use*

System Architecture



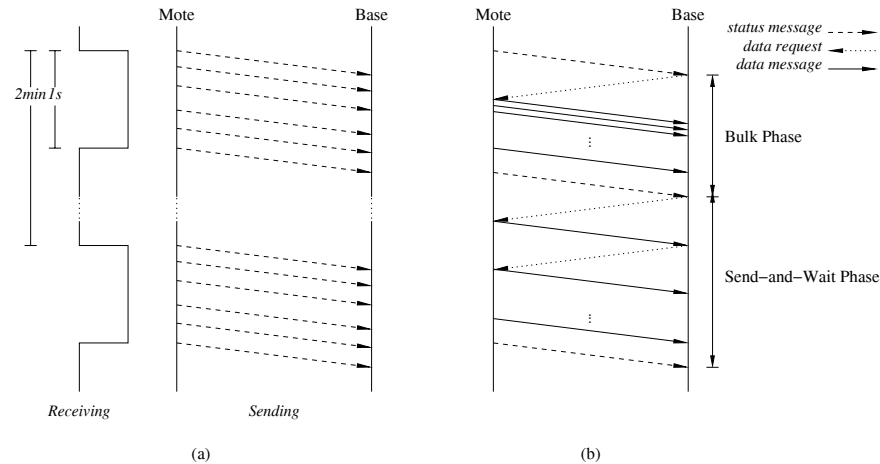
Sensor Node Hardware

- Sensors:
 - Watermark soil moisture
 - Irrrometer soil thermistor
 - Onboard Temperature and Light
- MicaZ motes
- Waterproof cases, cables, connectors, ...





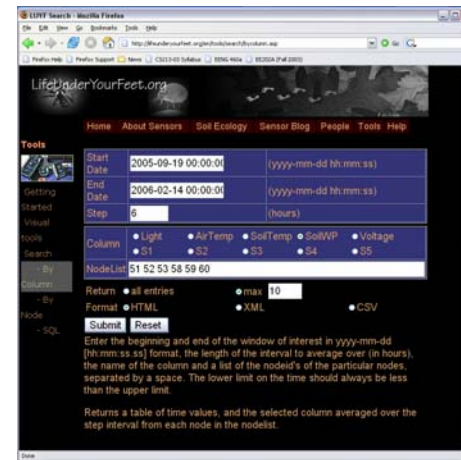
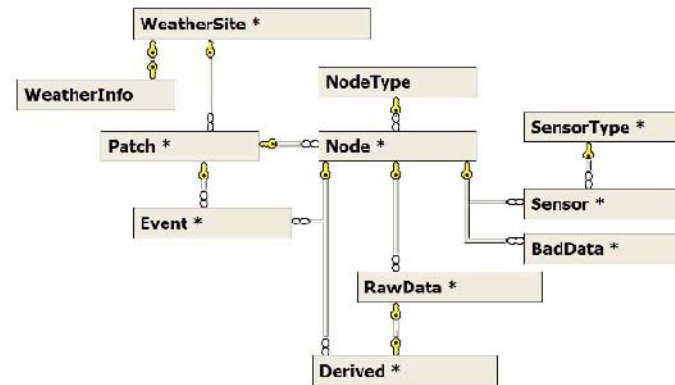
Mote Software



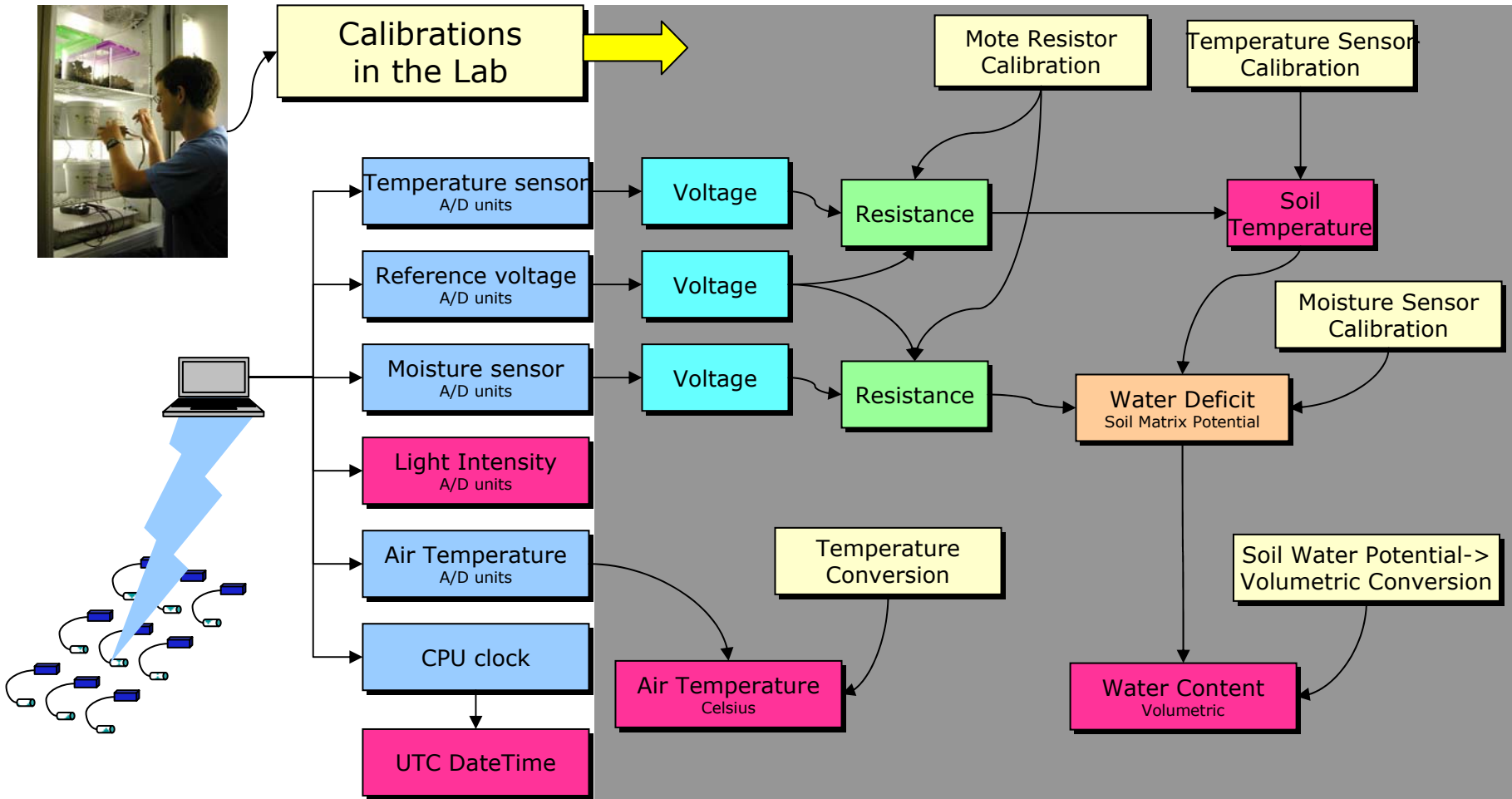
- Sensors are sampled every minute
- Raw measurements are stored in flash
 - Storage overrun in > 20 days
- Data retrieved using NACK-based sliding window protocol
- Each mote sends every 2 min a status messages to base-station: (#meas, bat voltage)
 - Web-accessible real-time monitoring

Database Design

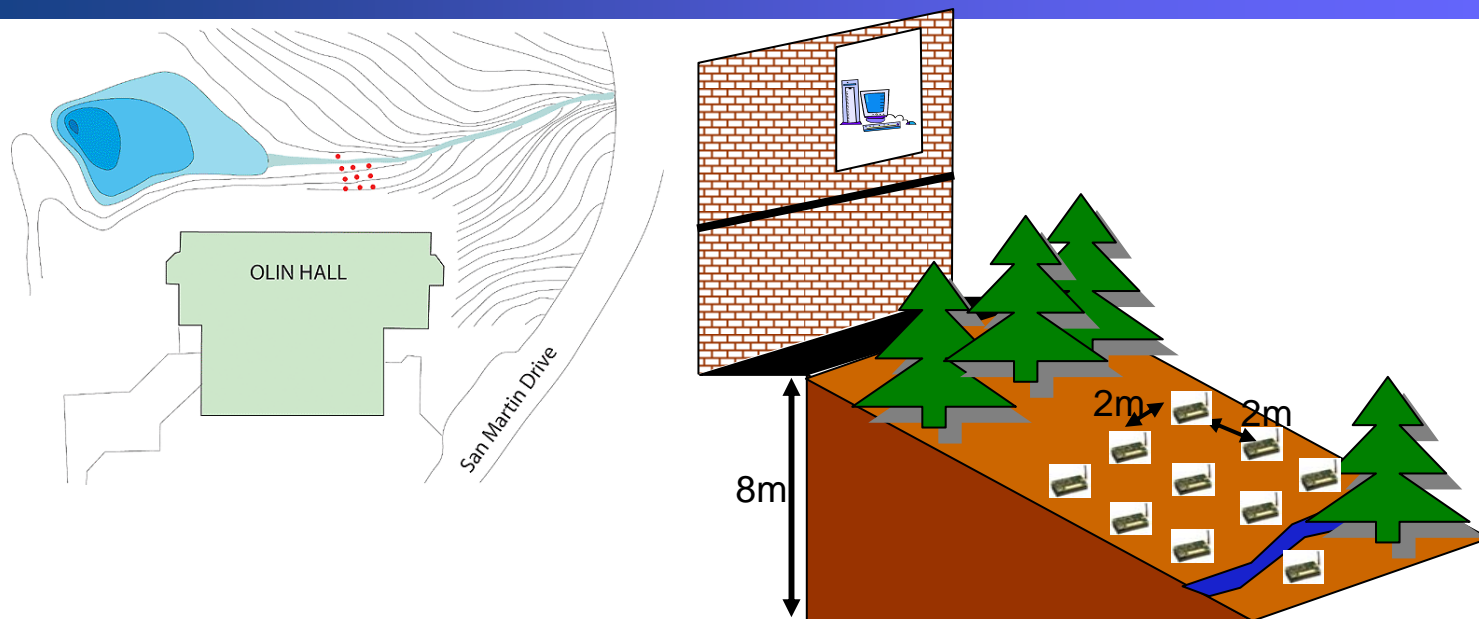
- DB Design derived from experiment and WSN setup
- Self-documenting framework
- Raw data follow a multi-stage validation process
- Stored data available through Web pages and Web Services
- Datacube for analysis
- 7M datapoints collected



Calibration workflow

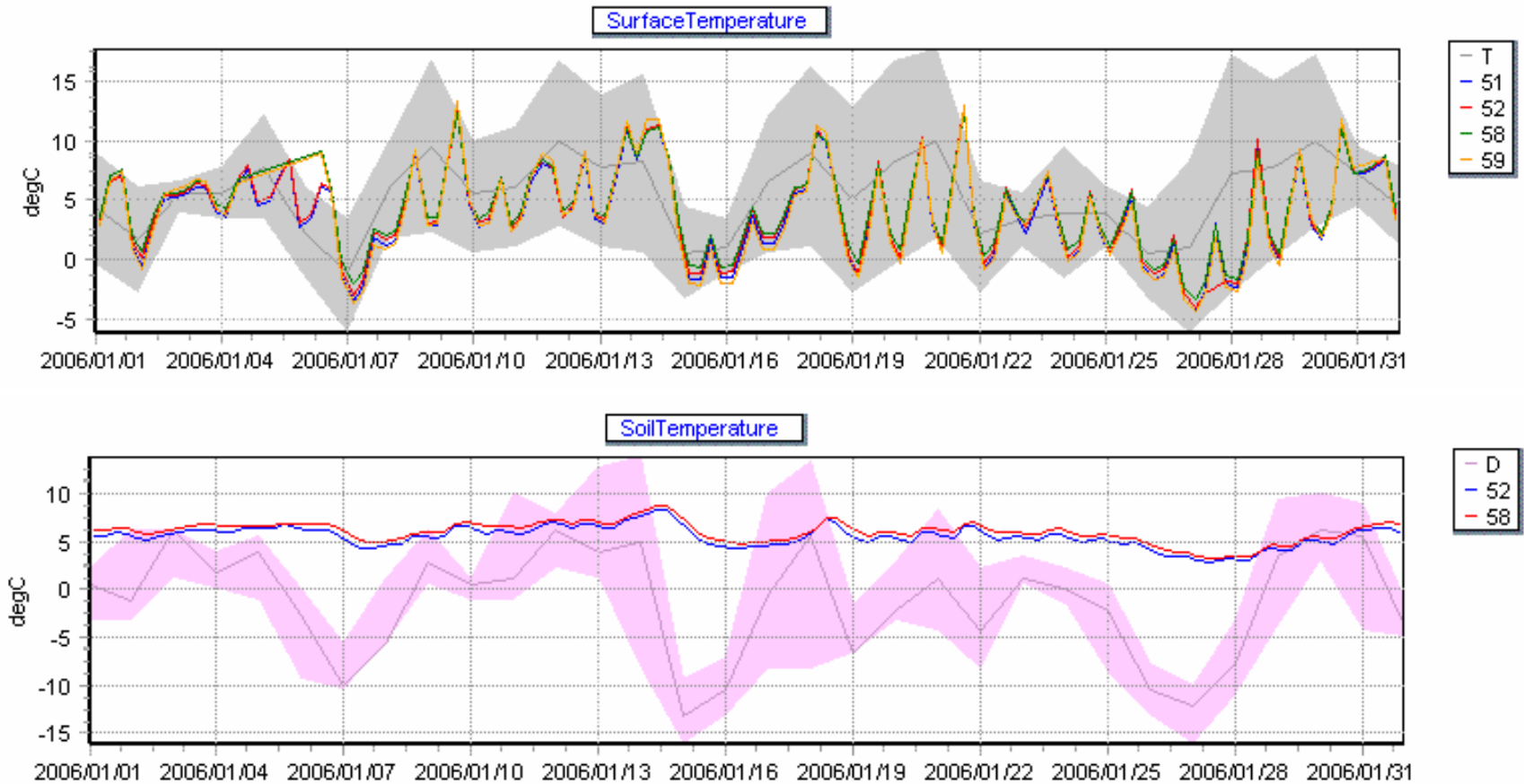


Deployment Site

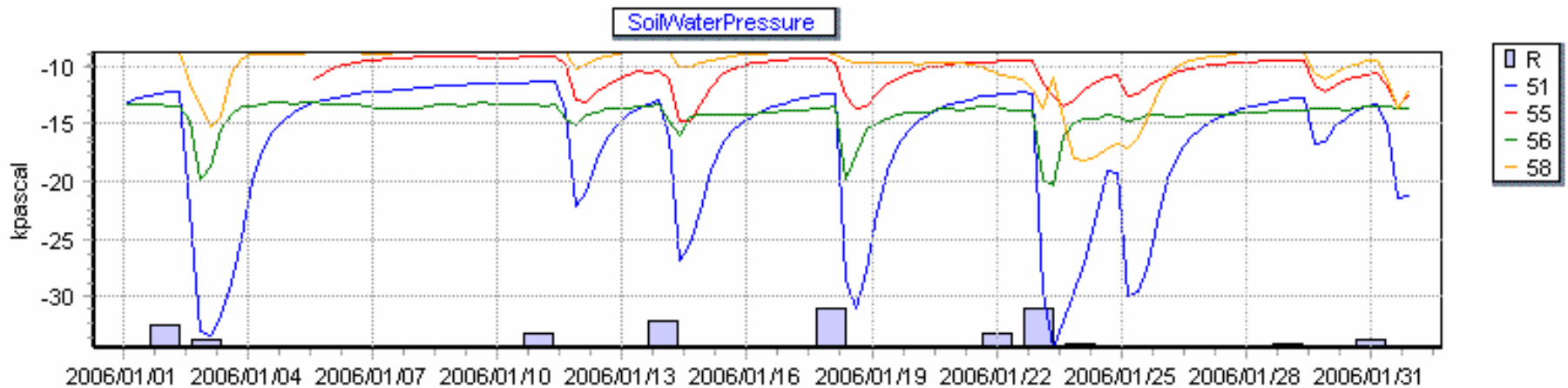


- 10 motes deployed on a slanted grid, $\sim 2\text{m}$ apart
- 147 days of deployment
- Basestation within direct radio range
 - *Some links had unexpectedly poor quality*
 - *Had to collect some of the data using laptop*

Ecology Results (Temperature)

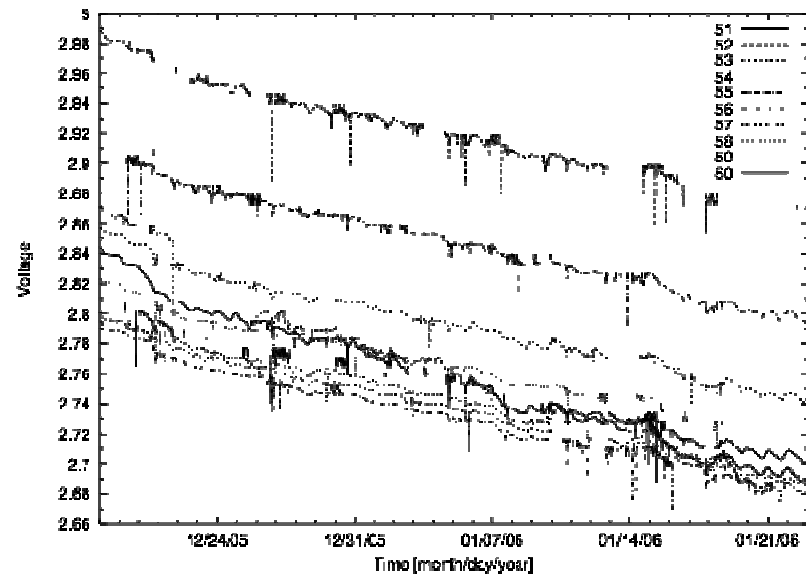
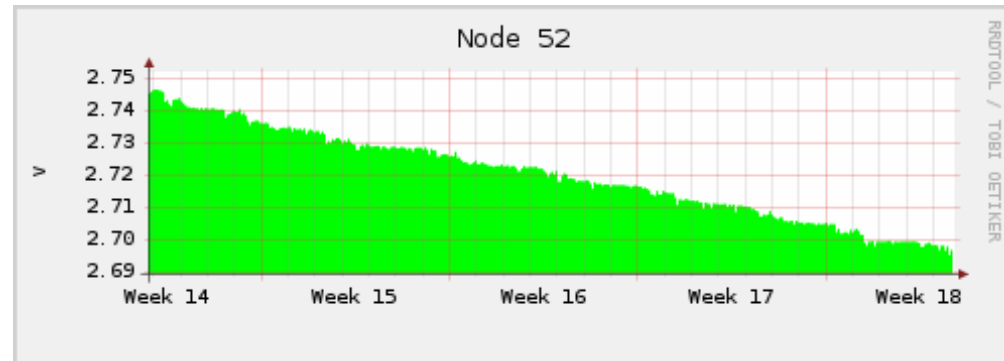


Ecology Results (Soil Moisture)



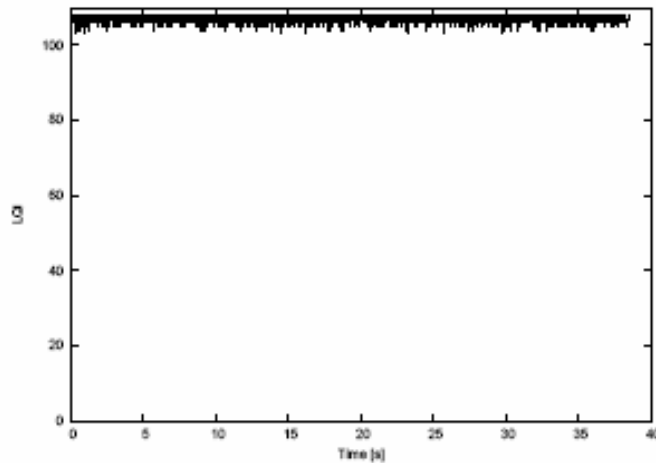
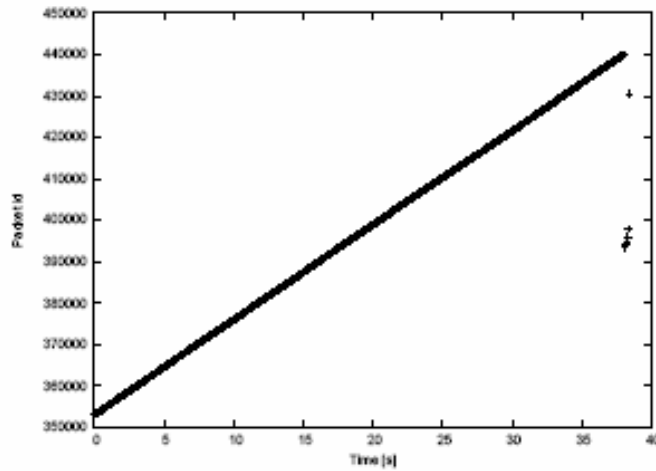
Energy consumption

- Motes go to sleep when not collecting data/sending reports
- Easy to calculate average current draw
- Powered by AA alkaline batteries
- Linear discharge curve
- *Possible to predict node lifetime*

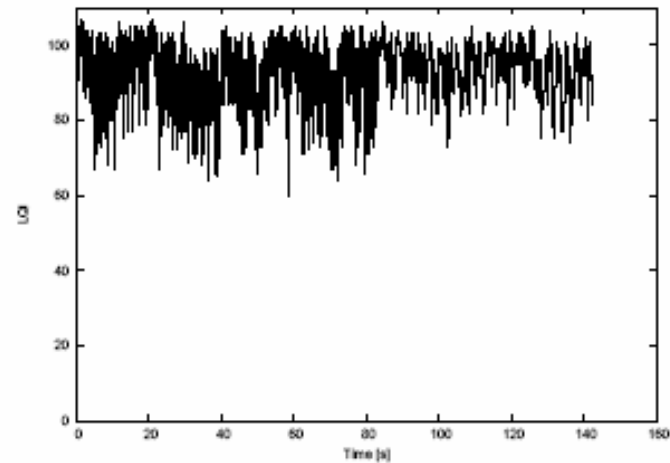
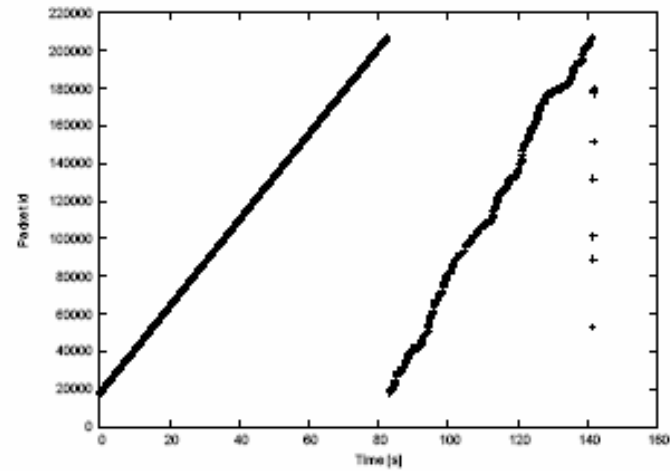


Data Transmission Performance

Good Link



Lossy Link



Problems we encountered

- Waterproofing the boxes
- Moisture sensor behavior in the wild
- Power consumption
- Data provenance
- Reprogramming



Conclusions

- Sensor Networks are still expensive in time, money and know-how
- Need for data analysis tools
- Need for increased confidence in collected measurements
- **End-to-End system that transforms raw measurements to *scientifically significant* data**

Questions?

- For more information
<http://www.lifeunderyourfeet.org/>