

From

Sensor Network In a Box

To

The Next Tier of The Internet

Wei Hong

Arched Rock Corporation

Nov. 15, 2005

Background



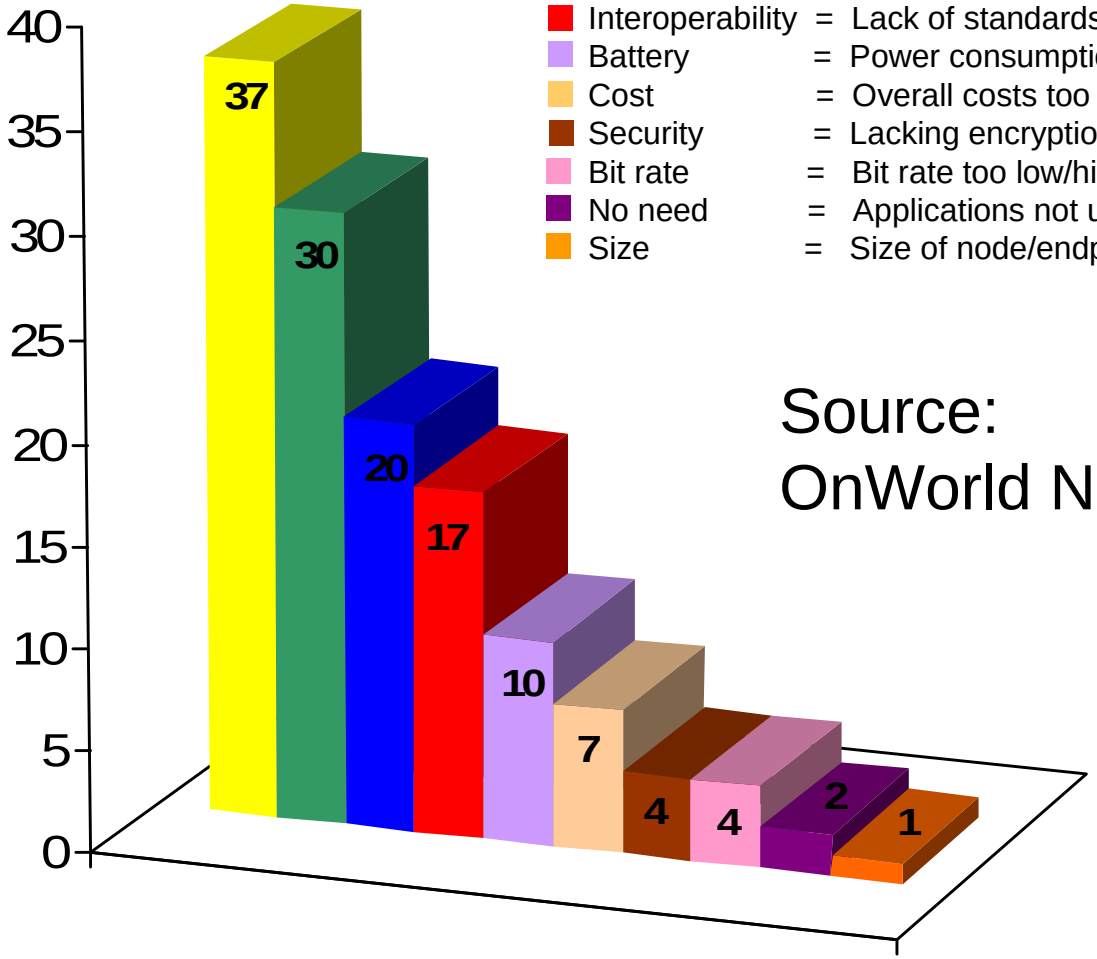
- Sensor Network In a Box
  - 5+ years of technology development at Intel Research Berkeley and UC Berkeley
  - Half a dozen real-world deployments
  - Early frustrations
  - Success in small-scale applications
- The Next Tier of The Internet
  - Technology is almost ready
  - Applications are pulling
  - Time to go internet-scale
  - Connecting everyBody → connecting everyThing

Barrier to Adoption



Legend:

Ease/Install	=	Lack of installation ease/ease of use
Reliability	=	Lack of /concerns about reliability or robustness
Interference	=	Concerns about interference
Interoperability	=	Lack of standards/ interoperability
Battery	=	Power consumption still too high/battery life too short
Cost	=	Overall costs too high
Security	=	Lacking encryption and other means of security
Bit rate	=	Bit rate too low/high
No need	=	Applications not understand/clearly defined
Size	=	Size of node/endpoints too big



Source:
OnWorld Nov. 04 Report

Outline



- Sensor Network In A Box: TASK
- Case Study: Monitoring Redwood Trees
- Larger Deployment Experiences
- Building The Next Tier of The Internet
- Summary and Conclusions

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The Sensor Network Vision

















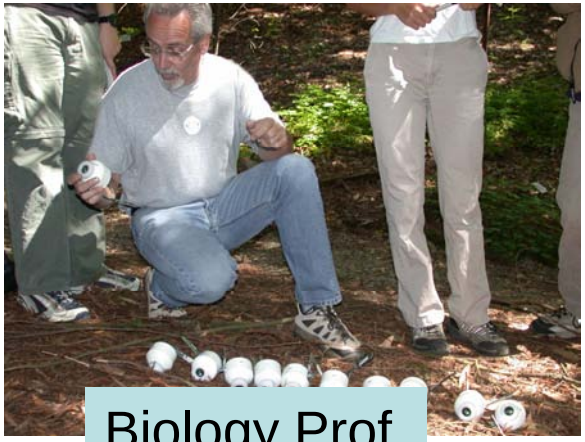






What Really Happened





Biology Prof.



Biology S





y Staff



Biology Grad. Student



CS Ph.D.



CS Ph.D.

Tiny Application Sensor Kit (TASK)



- Ease of S/W Installation
- Deployment Tools
- Reconfigurability
- Health Monitoring/Mgmt
- Minimum Network Reliability Guarantee
- Interpretable Sensor Results
- Integration w/ Existing Tools
- Audit Trails
- Lifetime estimates

~ For Developers ~

- Familiar API
- Extensibility of S/W for Motes and Gateway
- Modular services

Tiny Application Sensor Kit (TASK)



ENTEK

The MathWorks

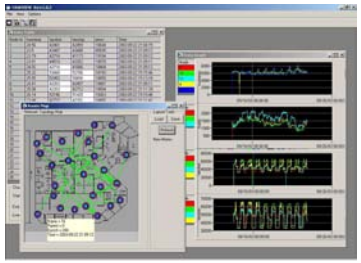
SAP

Microsoft Office

External Tools

TASK Client Tools

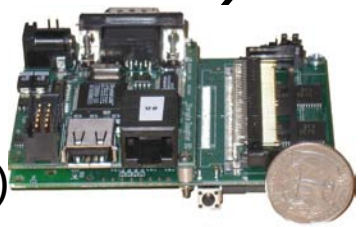
TaskView



Internet

Stable Store (DBMS)

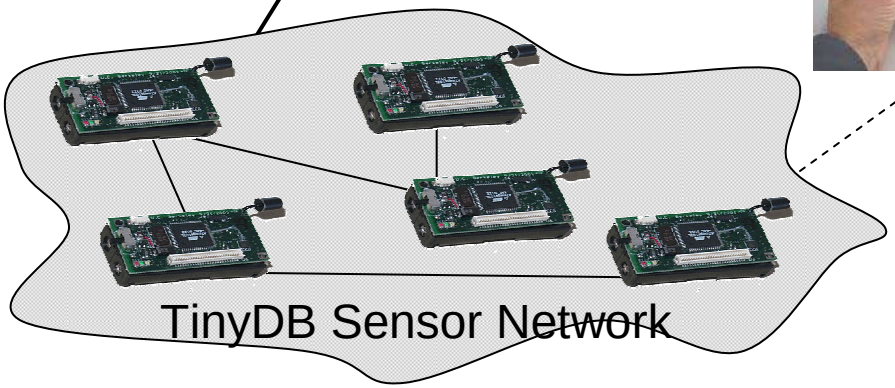
SensorNet Appliance (SNA)



TASK Field Tools



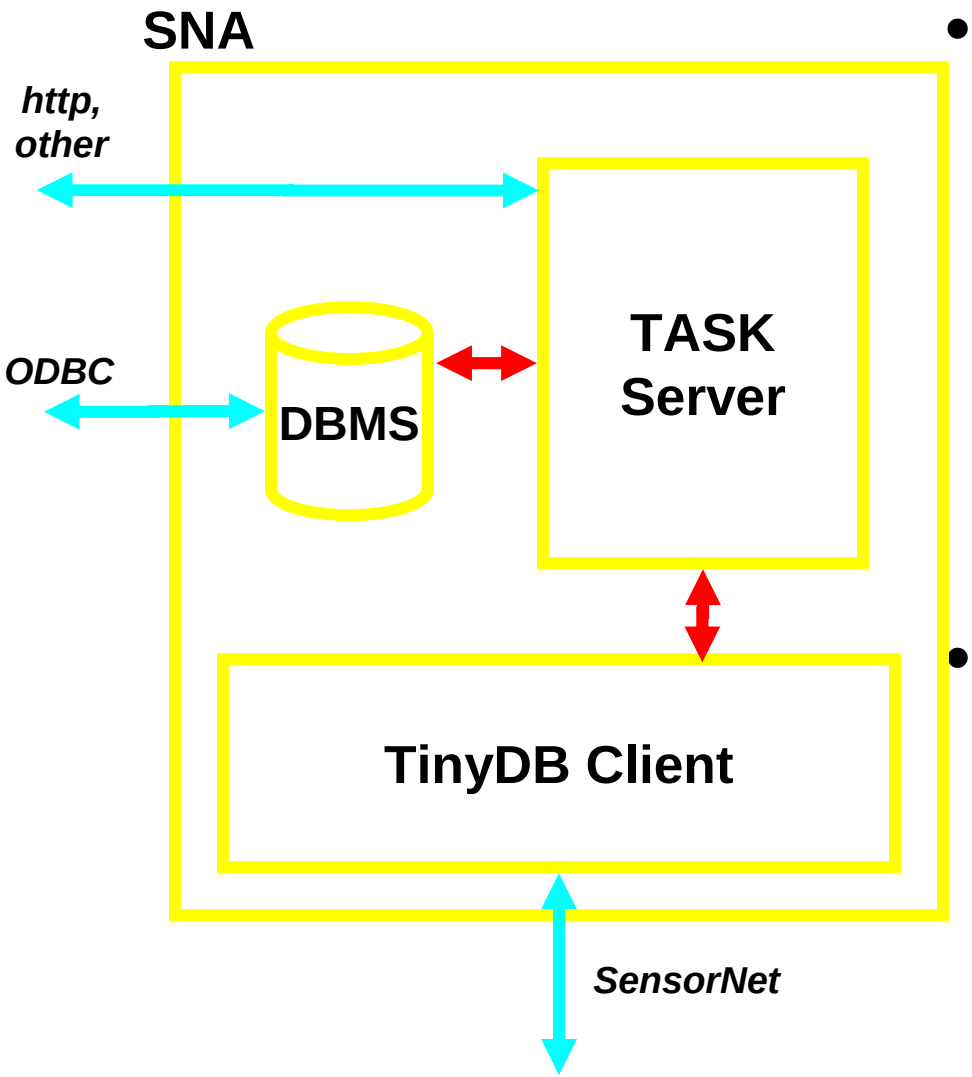
TASK



- Simplicity vs. Functionality
- Modularity
- Remote control
- Fault Tolerant

SensorNet Appliance





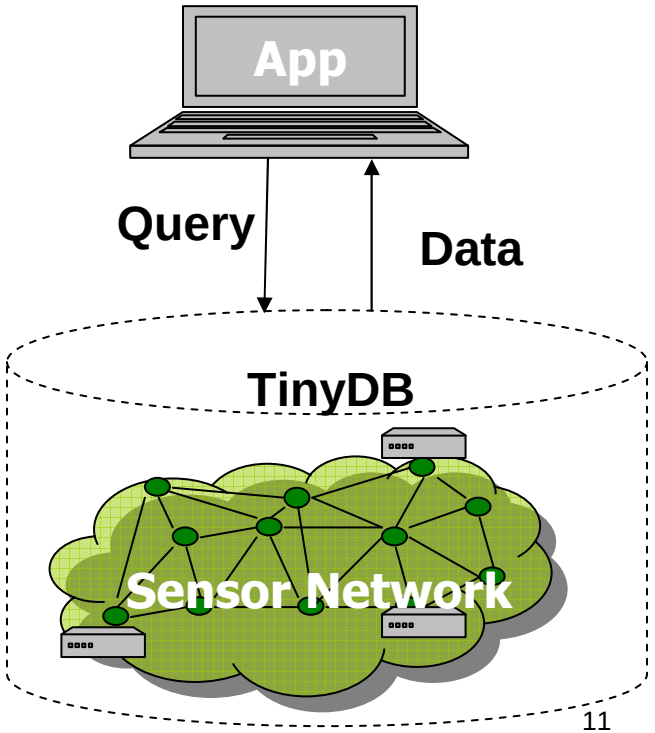
- Intelligent Gateway
  - Proxy for the sensornet
  - Distributes query
  - Stages results
  - Manages configuration
- Components
  - TASK Server
  - TinyDB Client
  - DBMS
  - WebServer (Jetty)

Sensor Nodes



- TinyDB
  - Declarative Query interface to SensorNet
  - Modular attribute drivers
  - Power Management
  - Time Sync
  - Query Sharing
  - Watchdog
  - Local Logging

```
SELECT nodeid, parent,
temp, light, …
FROM sensors
SAMPLE PERIOD 5 min
```



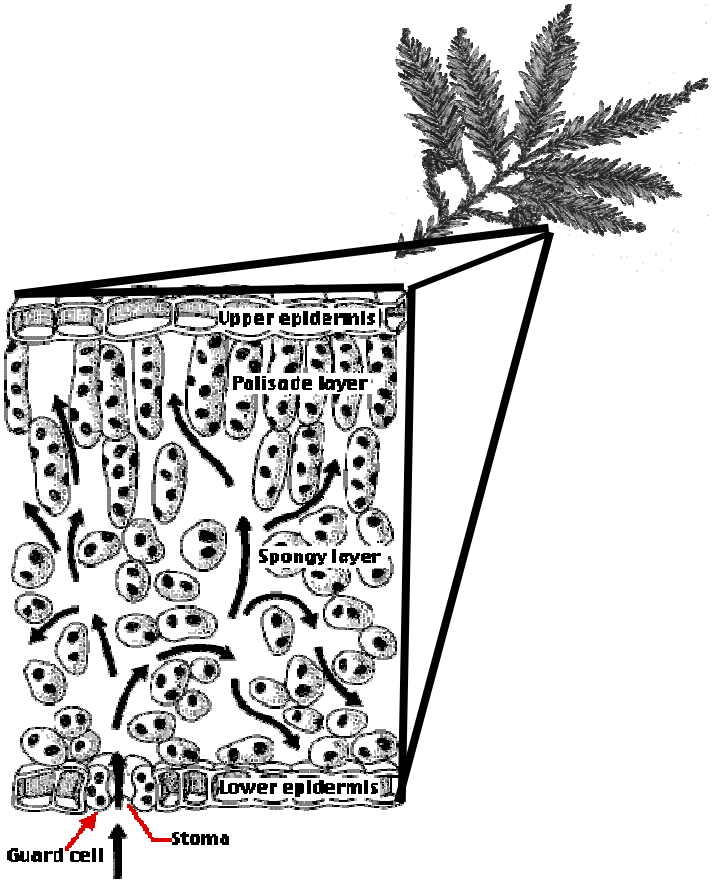
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A Macroscope In The Redwoods





We understand leaf behavior



How can we understand the behavior of a tree? A forest?

Gilman Tolle, et al. ACM SenSys 2005

Study Format

- Site: Sonoma Coast “Grove of the big Trees”
  - Near Occidental
  - Adjacent to winery
- Interior and Exterior Trees
- 40-50 nodes per tree
  - Range of elevations
  - Multiple nodes per level, center and periphery
- 1 month duration
- 5 min sample interval
  - all sensors, battery, parent
- Ground level weather station, fog sensors
- Sap Flow sensors
  - Internal indicator of level of photosynthetic activity











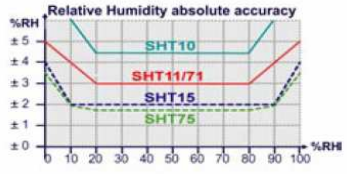
Sensors And Packaging



Let the experts choose the sensors



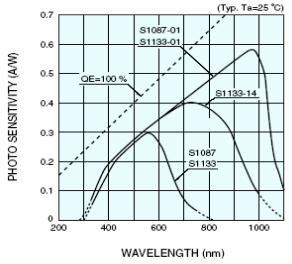
Sensirion SHT11 Humidity & Temp

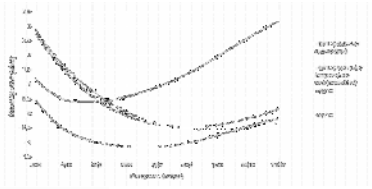


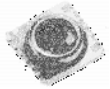




Hamamatsu S1087 PAR
TAOS TSL2550 TSR



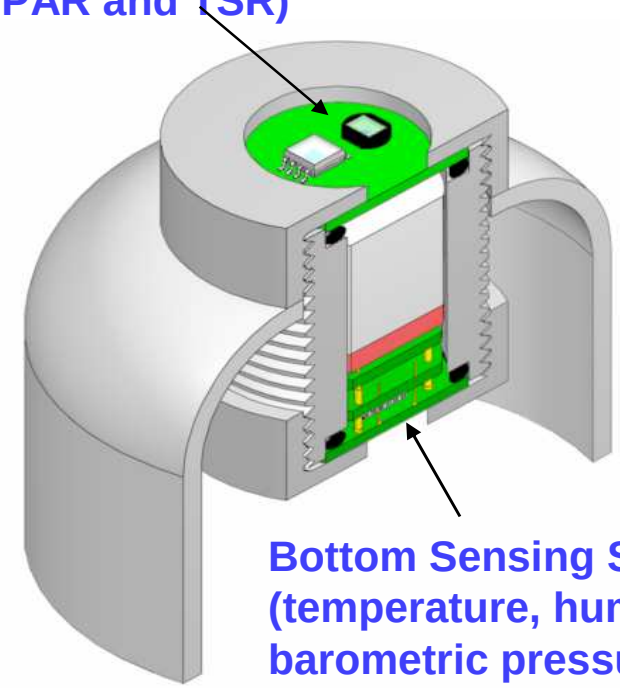




Intersema MS5534 Barometric Press.

Custom Sensor Subsystem

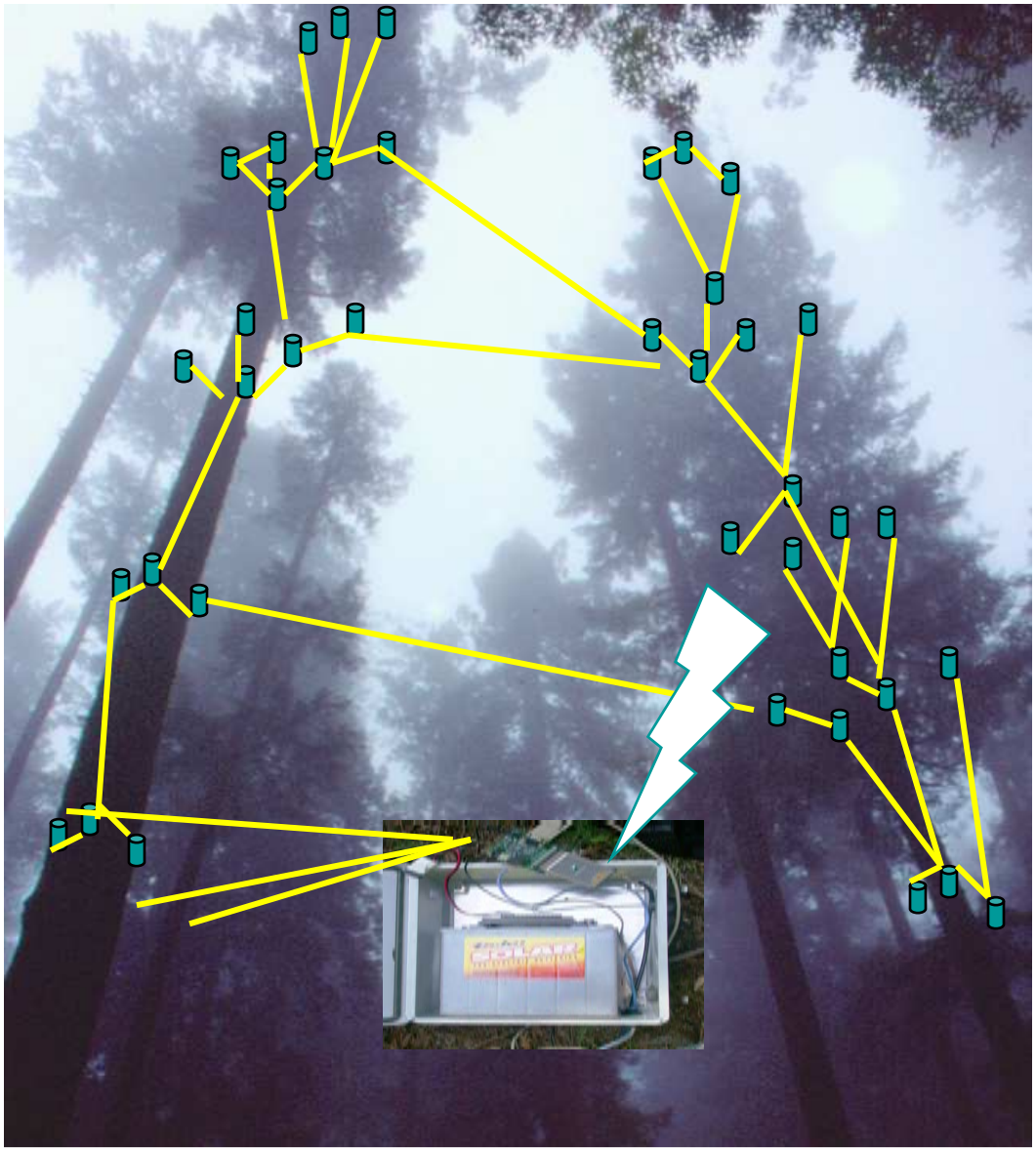
Top Sensing Surface (incident PAR and TSR)



Bottom Sensing Surface (temperature, humidity, barometric pressure reflected PAR and TSR)

Deployment and the Scientific Process







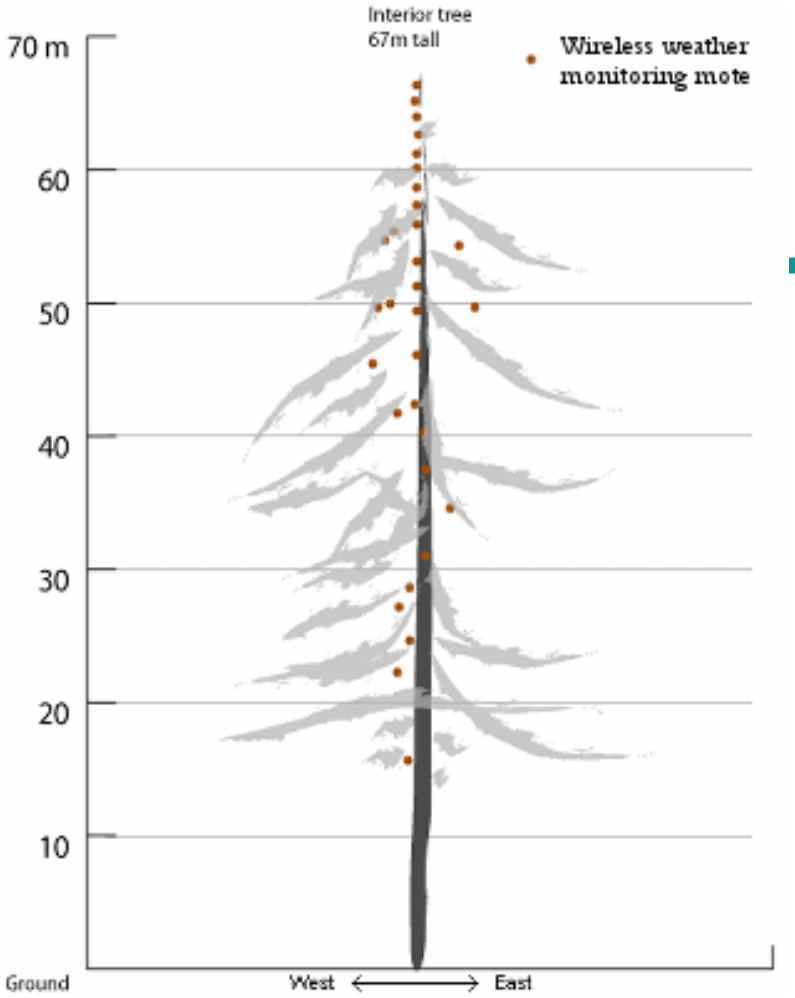
Pre-deployment exercise

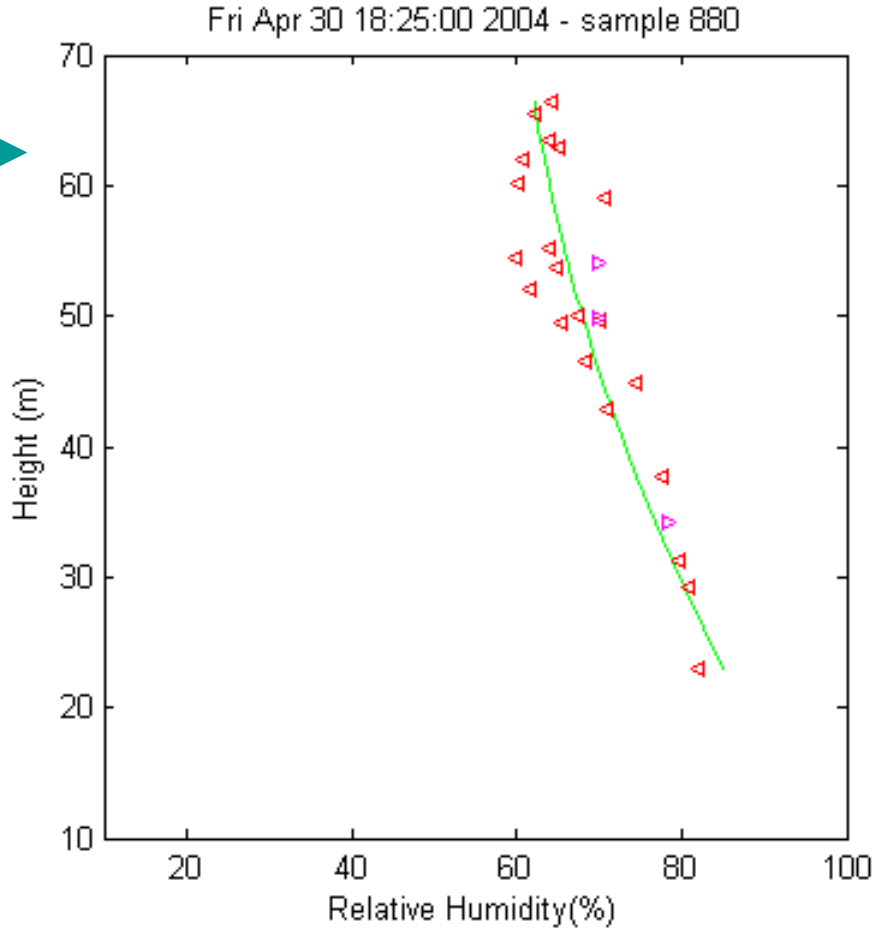
Node calibrations against high-precision reference center on roof top.

Calibrate entire deployment set in climate chamber en route to install

Capturing Dynamic Gradients



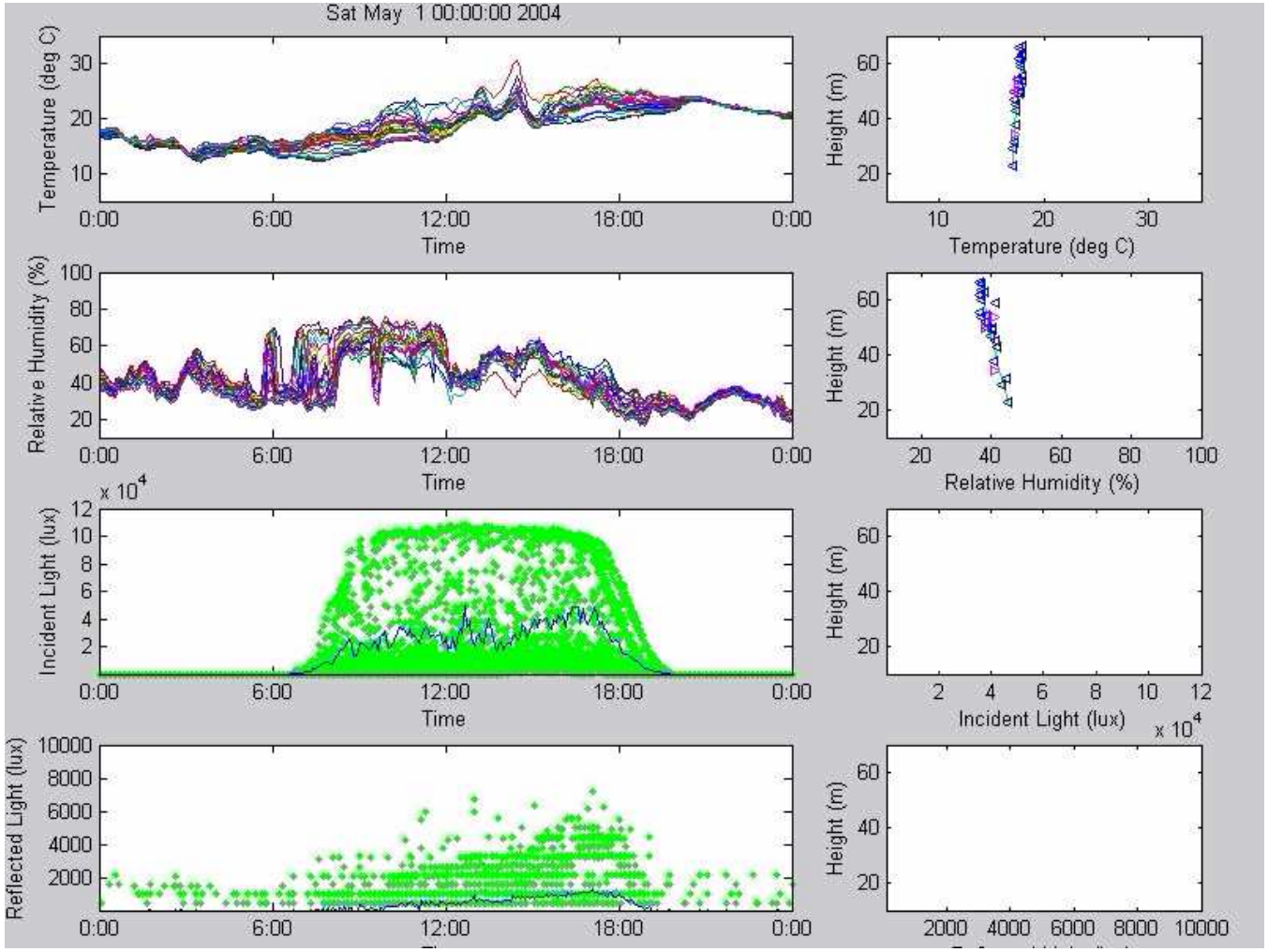




Dense instrumentation

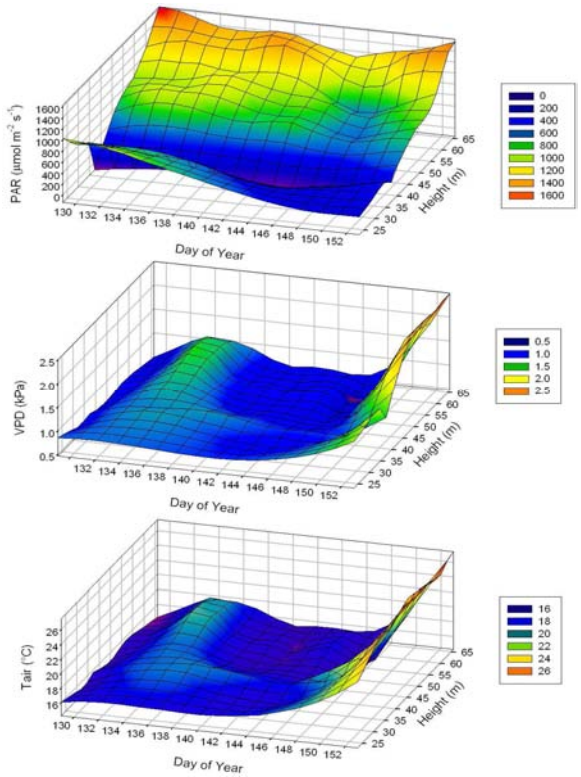
A Day's Life Of a Redwood Tree



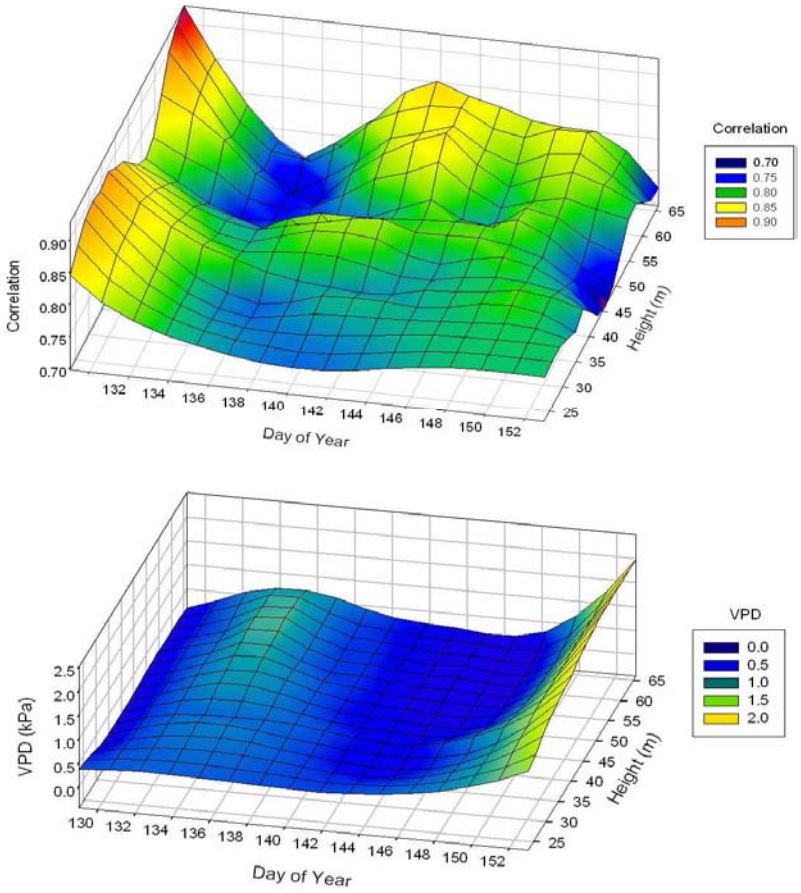


Flying-carpet Analysis





Correlation Between Sap Flow and Light, VPD and Temperature with Height in the Canopy Through Time (Loess Smoothing)



(unpublished work in progress)

Experiences In Deploying TASK



- Overall success: all in a day's work! But
- Need better site survey tools
  - Link characteristics
  - Placement of gateway
- Need better remote management infrastructure
  - Network performance
  - Sensor failures
  - Gateway failures
- Calibration process is cumbersome

Outline

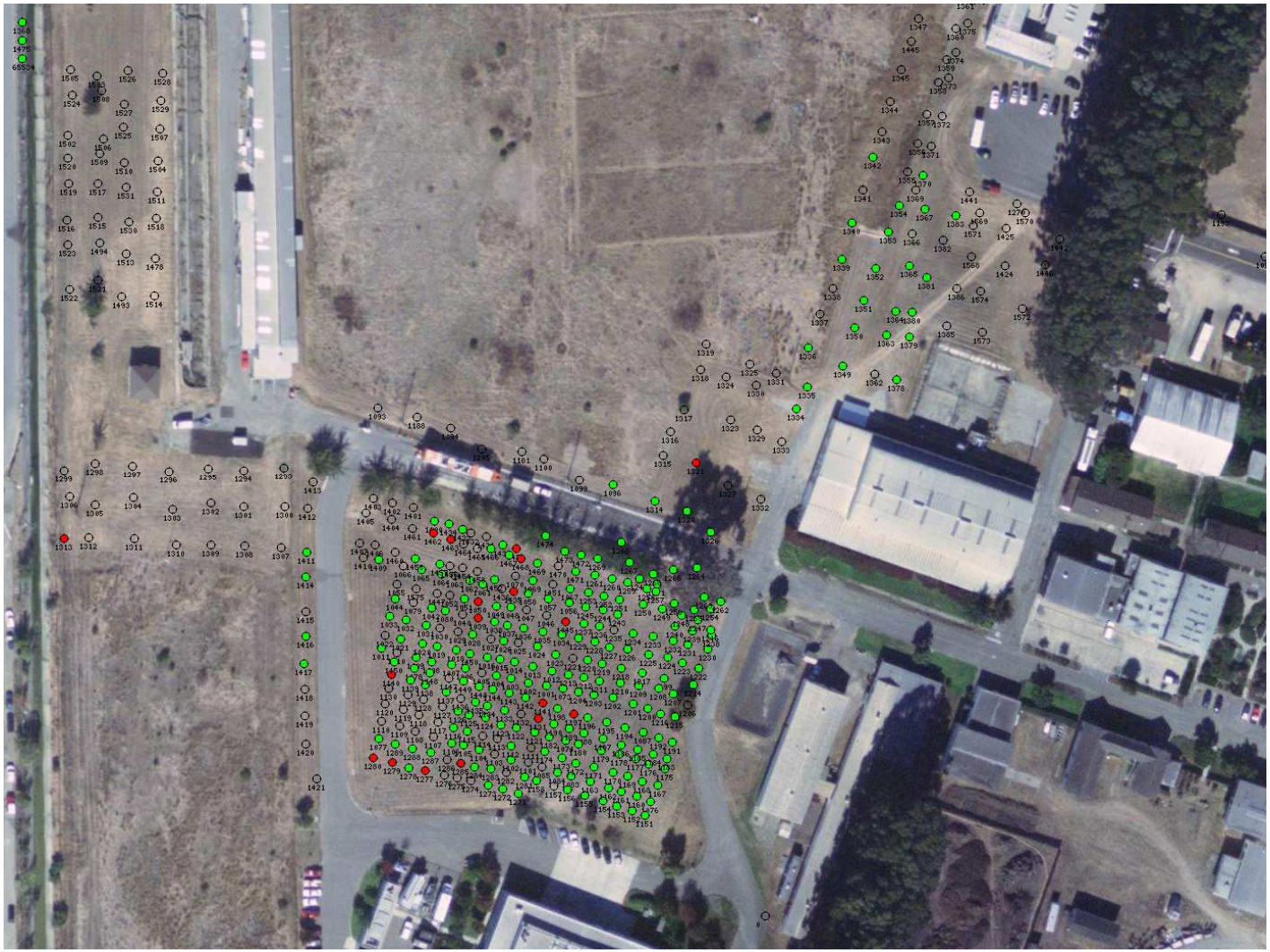


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UCB DARPA NEST Final Deployment

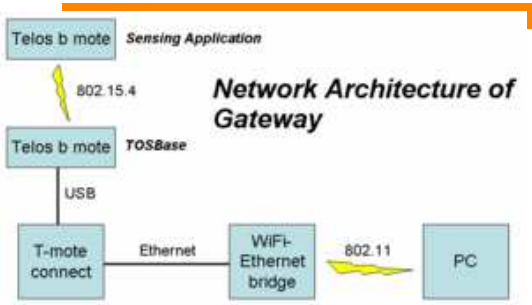


557 Trio Nodes, Self-powered, self-maintaining, GPS ground truth, multiple subsets

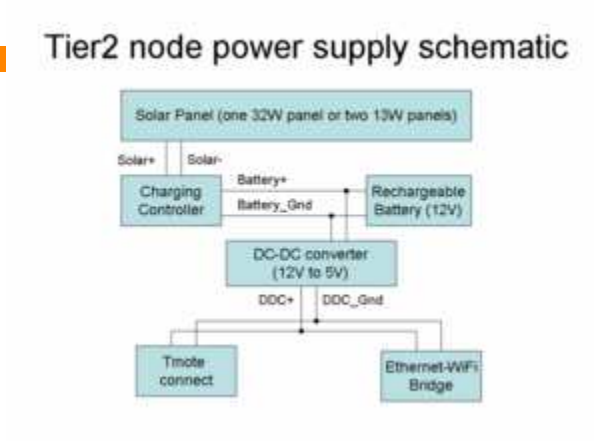


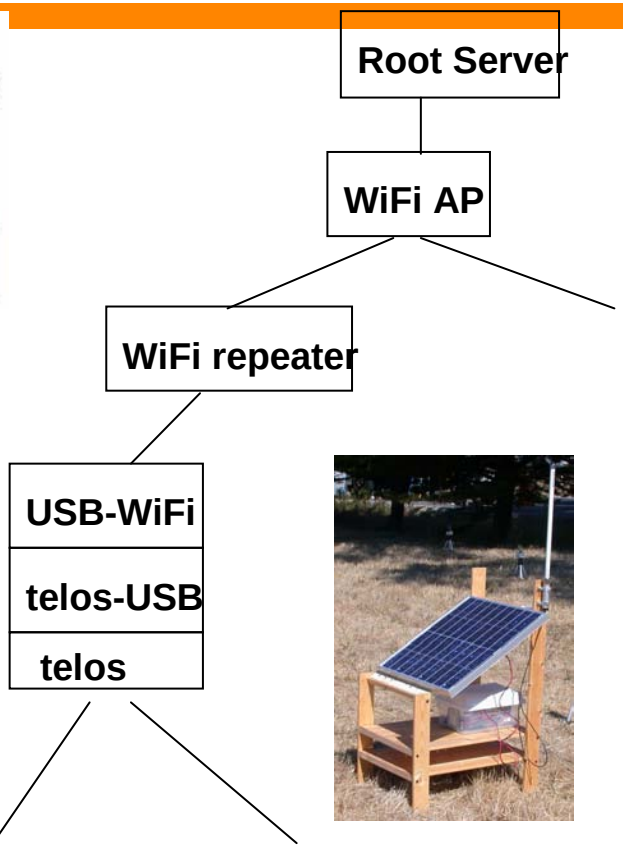
Self-powered MultiTier Network





COTS components









Observations



- Hierarchical network is key to scaling
  - Pay attention to the gateway tier
- High-level Programming Works
  - High-level primitives: RPCs, Get/Set of Attributes, Events
  - Python scripting
- Over-the-air programming
  - Deluge is very robust
- Progress in Management Infrastructure
  - Passive packet sniffer
  - Active management queries
  - Ping

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Success Of The Internet



- Standard Open Protocols
  - IP, TCP, UDP, DNS, SMTP, HTTP(S), SNMP, etc.
- Variety of Links
  - copper, coaxial, fiber optic, WiFi, microwave, etc.
- Killer Applications
  - WWW, Email, IM, file sharing, VoIP, etc.
- Tiers of Platforms
  - J2EE, .Net, Web Services, web authoring tools, etc.
- Large Population of Developers
  - High school kids

Ready For The Internet Effect?



- Standard Open Protocols
  - 802.15.4
  - Not Zigbee, Not IPv6 over 802.15.4
  - Engage the open community, TinyOS as a starting point
- Applications
  - AMR gaining traction
  - Many small-scale success, endless possibilities
- Platforms
  - Web-based proxies
  - App-specific virtual machines
  - Sensor network as a distributed database
- Developers
  - Sensornet developers = Internet developers

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Summary And Conclusions



- “Sensor Network In A Box” technology is mature
- Ready to build the next tier of the internet
- Food industry at the Forefront?

Questions?



Thank You!

Backups

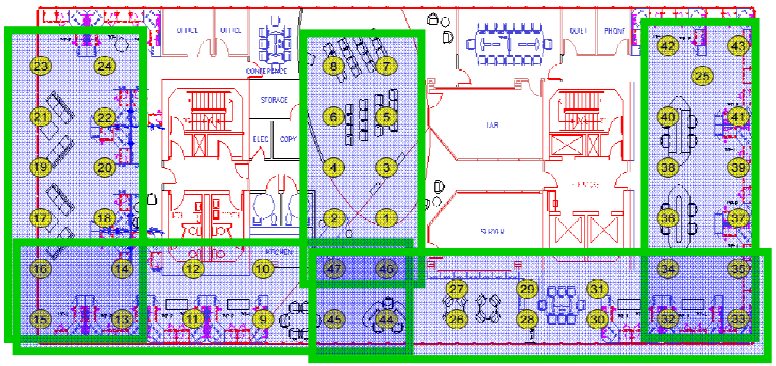


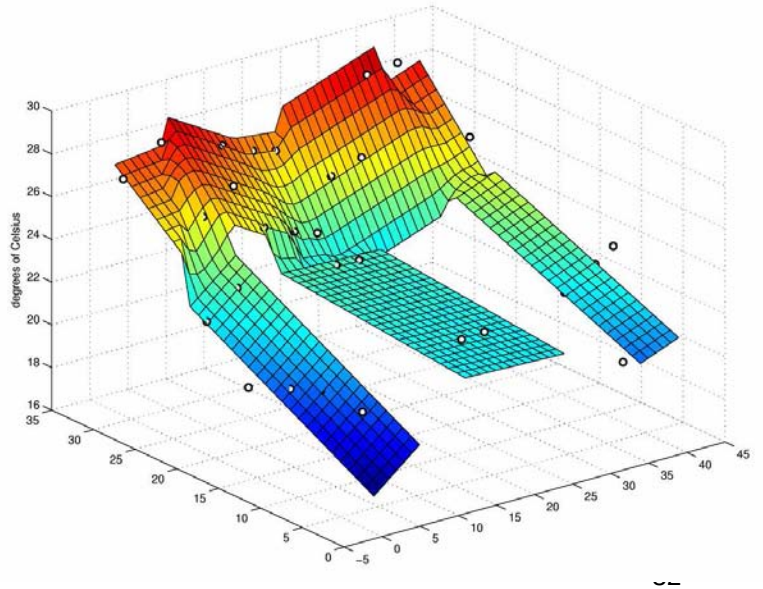
Indoor Environments, Living Things, …



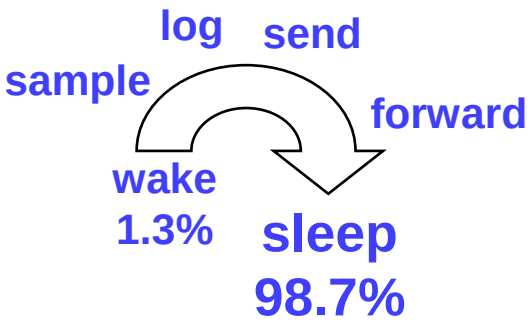


```
From: <plantmon@intel-research.net>
To: <whong@intel-research.net>
Date: Tue, 17 May 2005 06:00:11 -0700
Subject: Help! Water! Water!
Your plant (Bayview, LWPID 10) is dying
- PLEASE WATER IT (humidity 19)
```





Higher-level service platform enables rapid development




```
SELECT
result_time, epoch, nodeid,
parent, voltage, depth,
humidity, humid_temp,
hamatop, hamabot

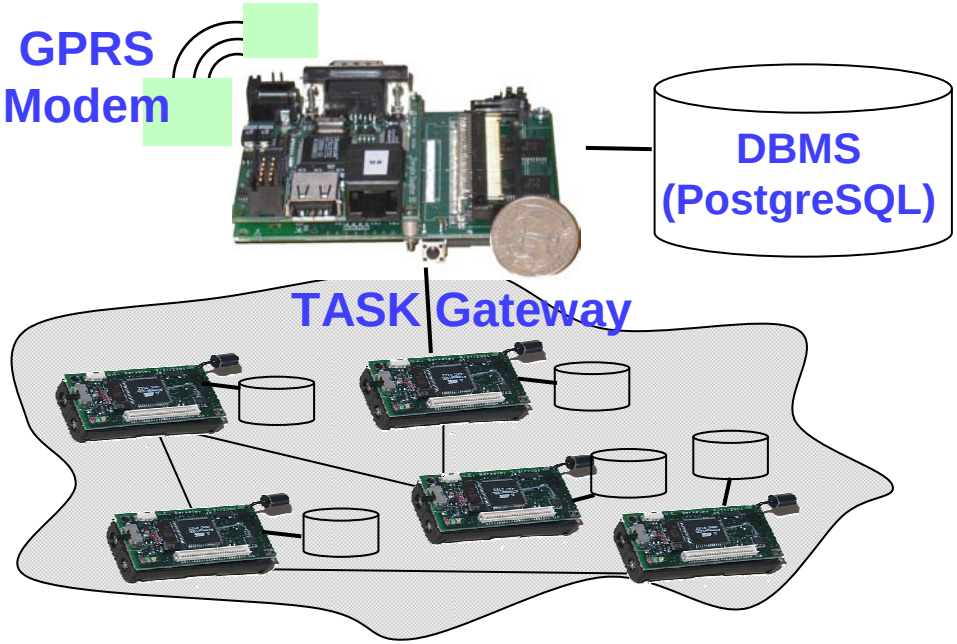
FROM sensors

SAMPLE PERIOD 5 min
```

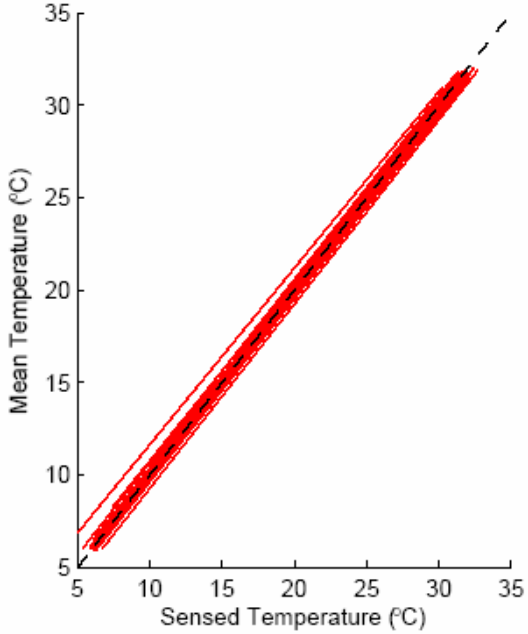
General-Purpose Software Platform



Tiny Application Sensor Kit

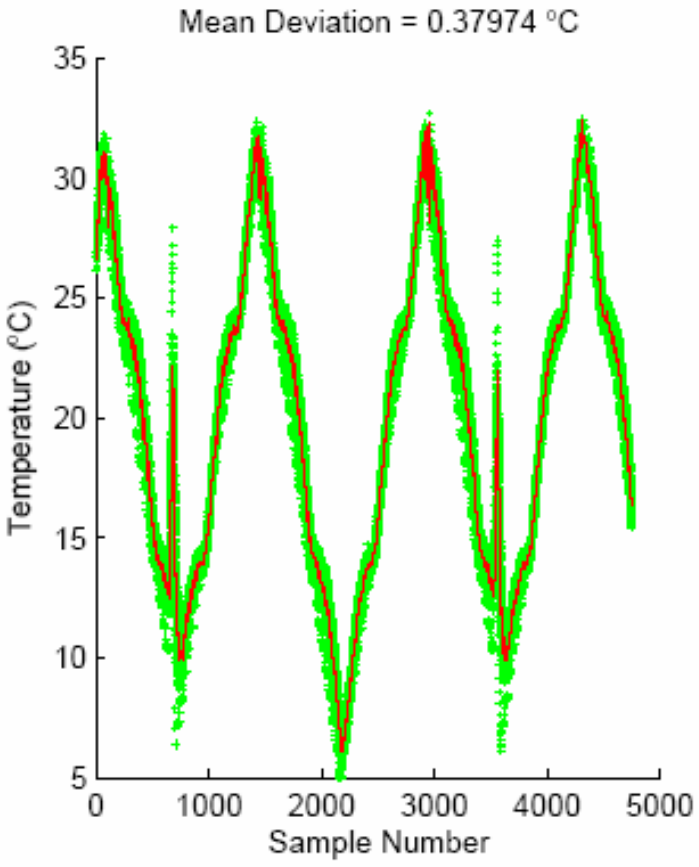


Gain trust through careful sensor calibration



Calibrate Slowly





Keep detailed records

Deploy Quickly



	A	B	C	D	E	F
1	INTERIOR TREE					
2						
3	Wireless Mote Deployment - Sonoma Study Site (Grove of the Old Trees) - 4/27/04					
4						
5	Mote #	Crown height (m)	General orientation (in relation to main trunk)	Distance from main trunk (m)	Chamber	
6	78	66.5	SW	0.1	28	
7	113	65.5	SW	0.1	28	
8	109	64.5	SW	0.1		
9	118	63.5	SW	0.1	28	
10	105	62.9	SW	0.1	28	
11	129	62	SW	0.1	28	
12	122	61.1	SW	0.1		
13	127	60.1	SW	0.1	28	
14	42	59.1	SW	0.1	28	
15	138	57.8	WSW	0.1	28	
16	134	56.1	WSW	0.1	28	
17	119	55.2	WSW	3	28	
18	59	54.5	NW	4	27	



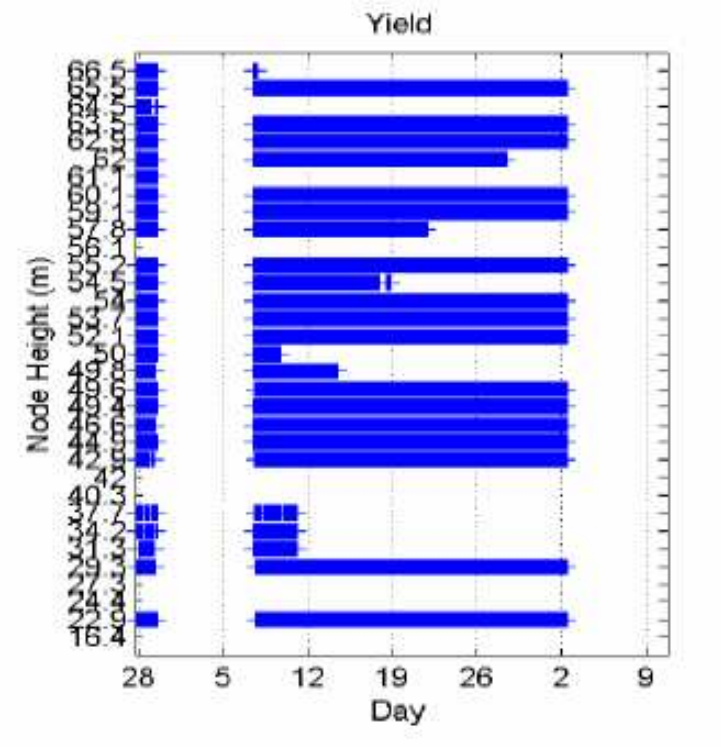
Test the network before you go home

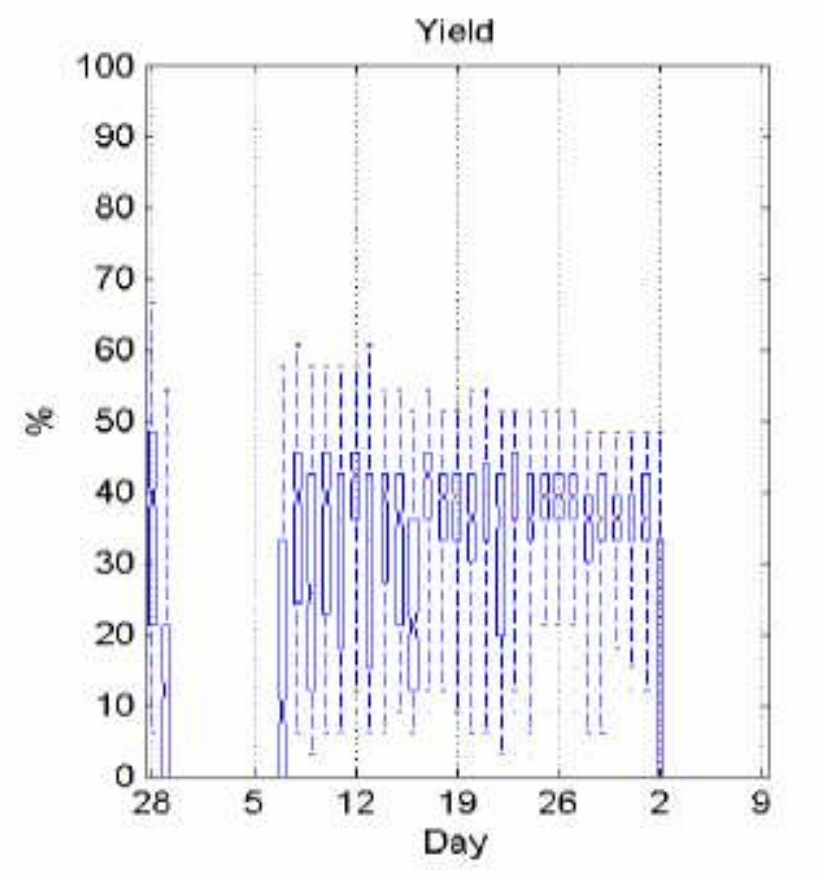


Include health monitoring and respond to failures

Remain Aware







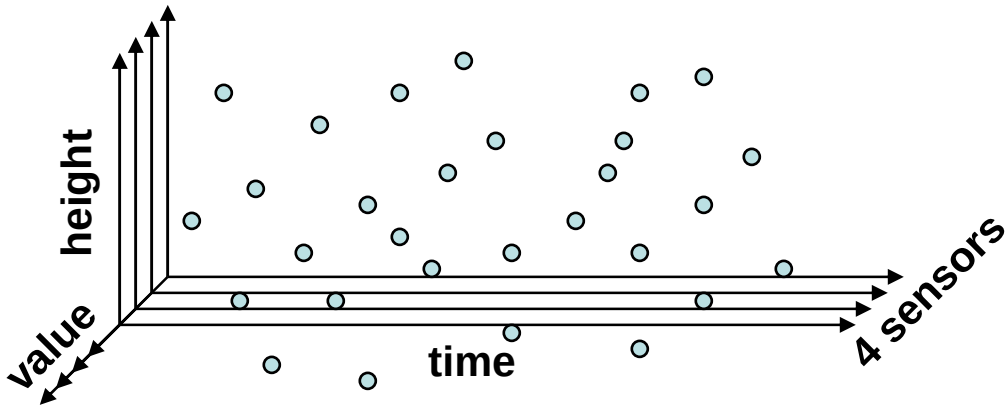
We got 820,700 Data Overview



49% yield

33 motes
44 days
288 samples/day
4 sensors
1,672,704 points

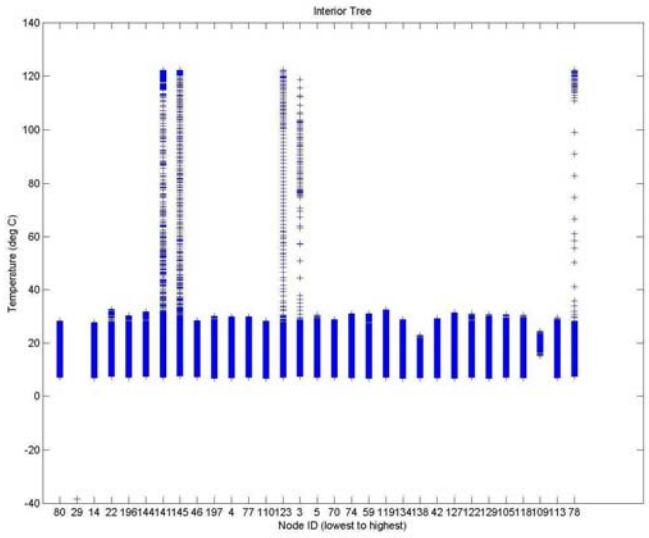
Still more than we knew how to handle!

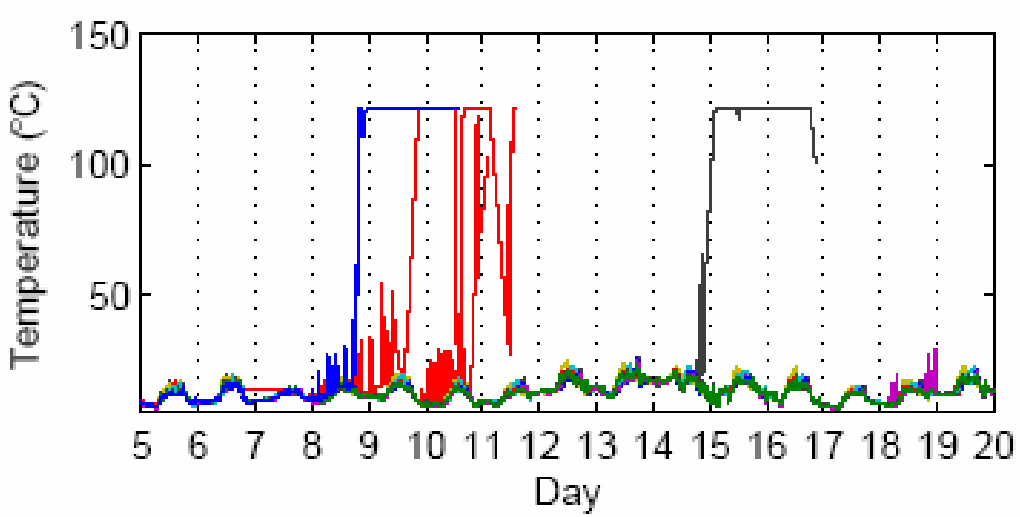


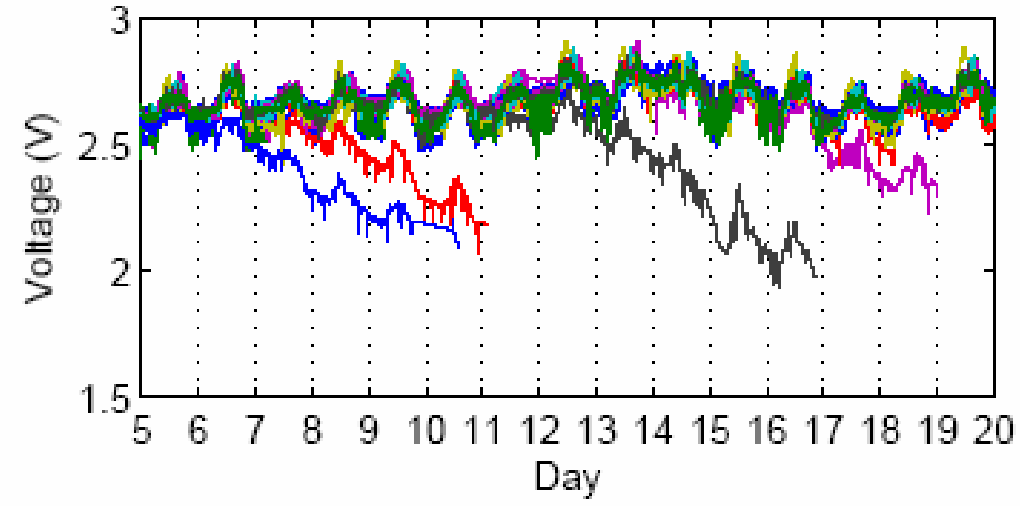
Cross-sensor correlation improves outlier rejection

Cleaning the Data







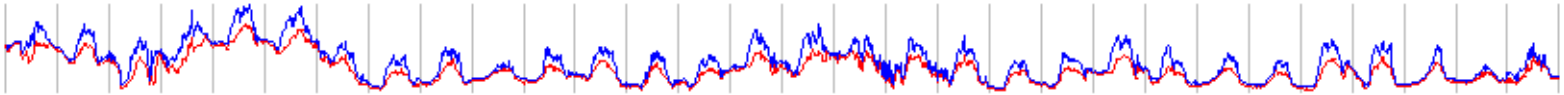


Validate by comparing against norm

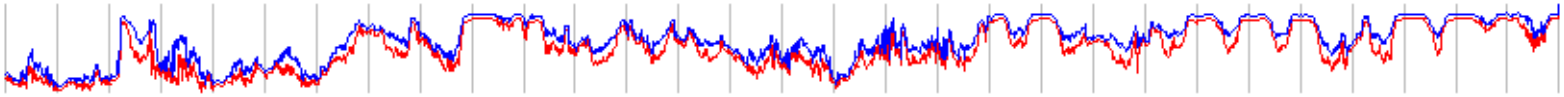
Temporal Trends



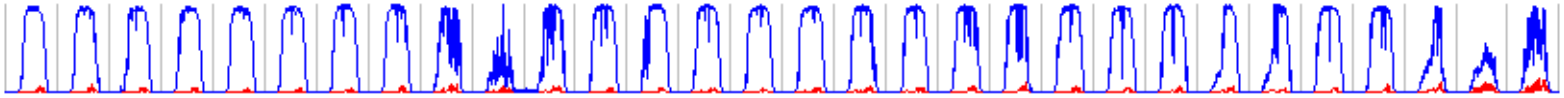
Temperature



Humidity

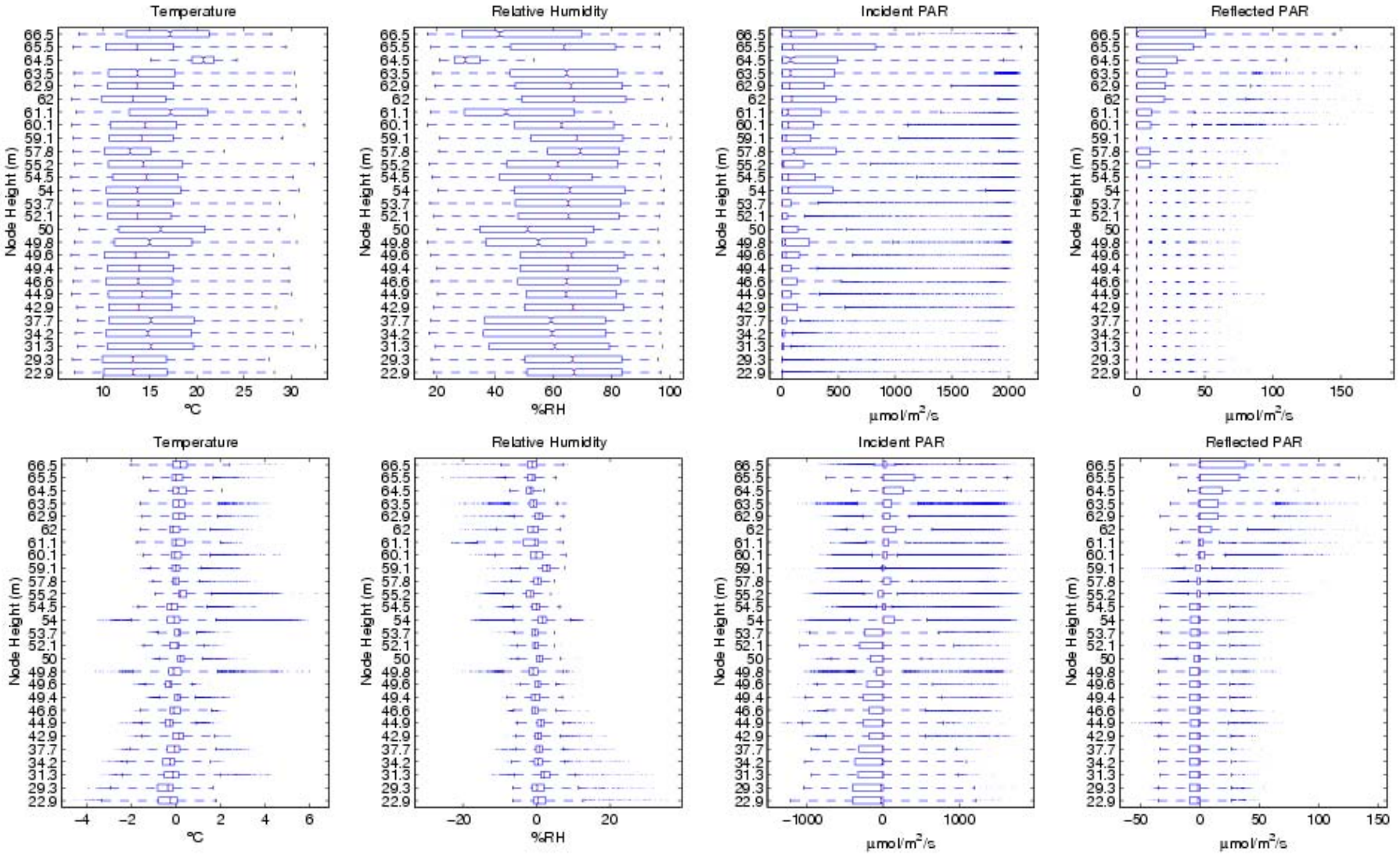


Incident Photosynthetically-Active Radiation

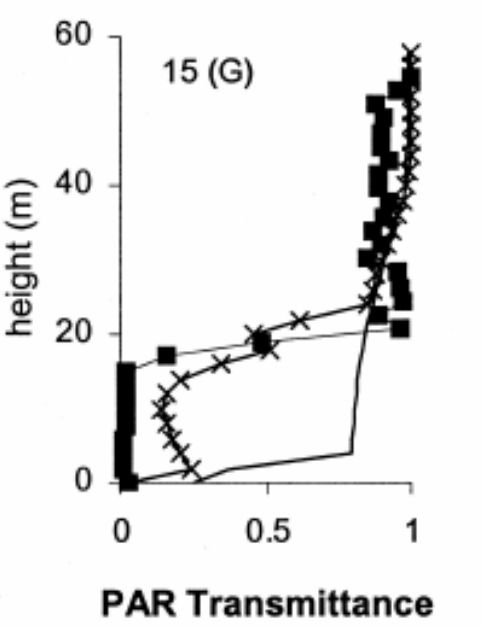


Spatial Trends

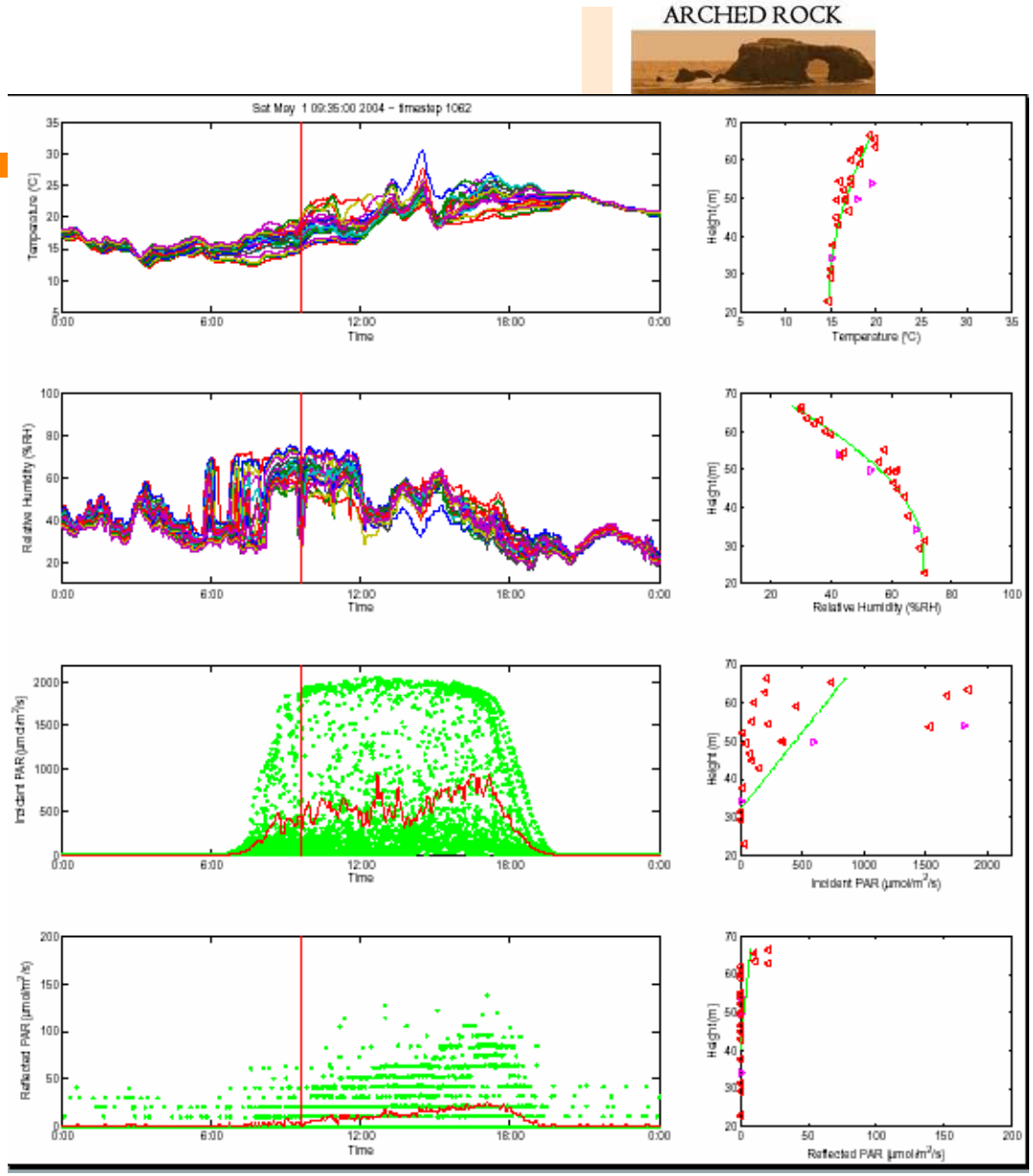




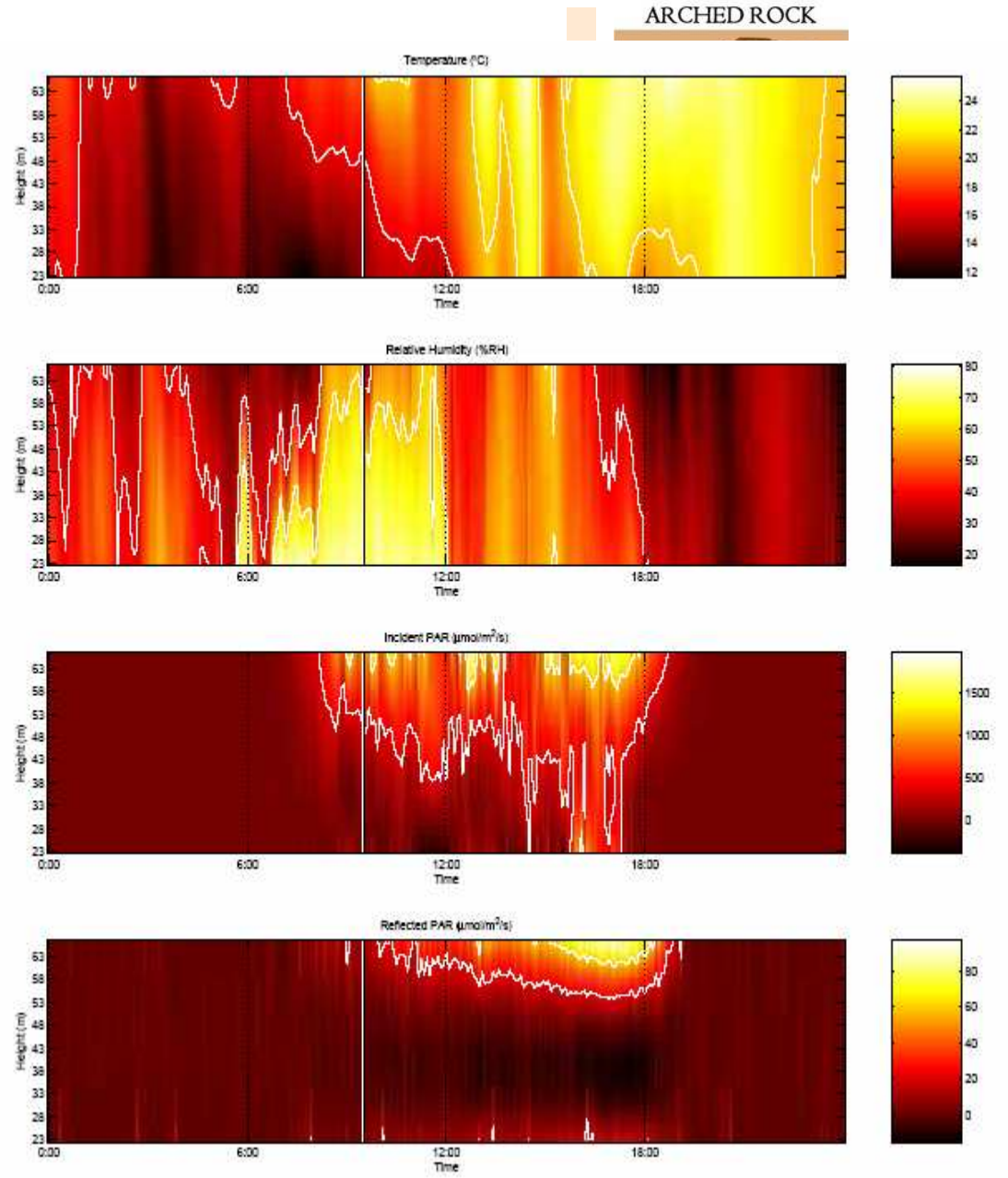
Spatial Gradients for a Snapshot in Time



(Mariscal et al. 2004)



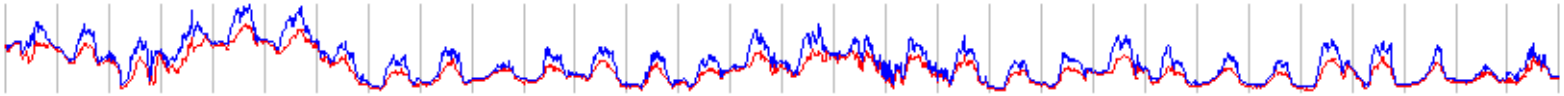
Change in Spatial Gradient over Time



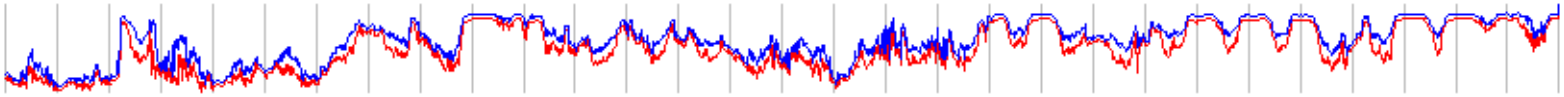
Correlated Phenomena



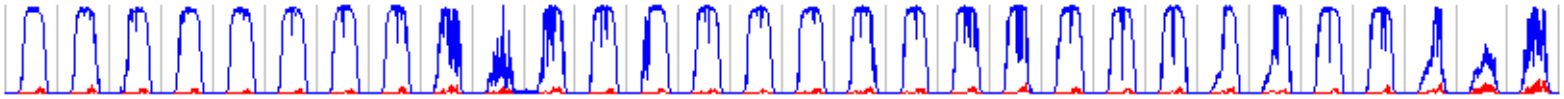
Temperature



Humidity



Incident Photosynthetically-Active Radiation



Sap Flow Rate



Aging Parent Well-being Monitoring



- Pain
  - Aging and ailing parents in China living alone

- Solution
  - Simple sensors to confirm daily routines
    - Morning walk, afternoon tea, bath, etc.
  - Alert when daily routines are missed
  - No fancy activity inferencing

Authenticated Cat Doors



- Pain
  - Cat wants to go out at 4am
  - Simple magnet-based authentication problematic
  - Can't locate cat occasionally
- Solution
  - Smart tag on cat
  - Authenticated cat door
  - tracking

Smart Sprinkler System



- Pain
  - Hard to adapt amount of watering per plant
  - Manual on/off for rain
  - Sprinklers need routine maintenance
- Solution
  - One soil moisture sensor per type of plant
  - Threshold for stop watering
  - Self monitoring critical