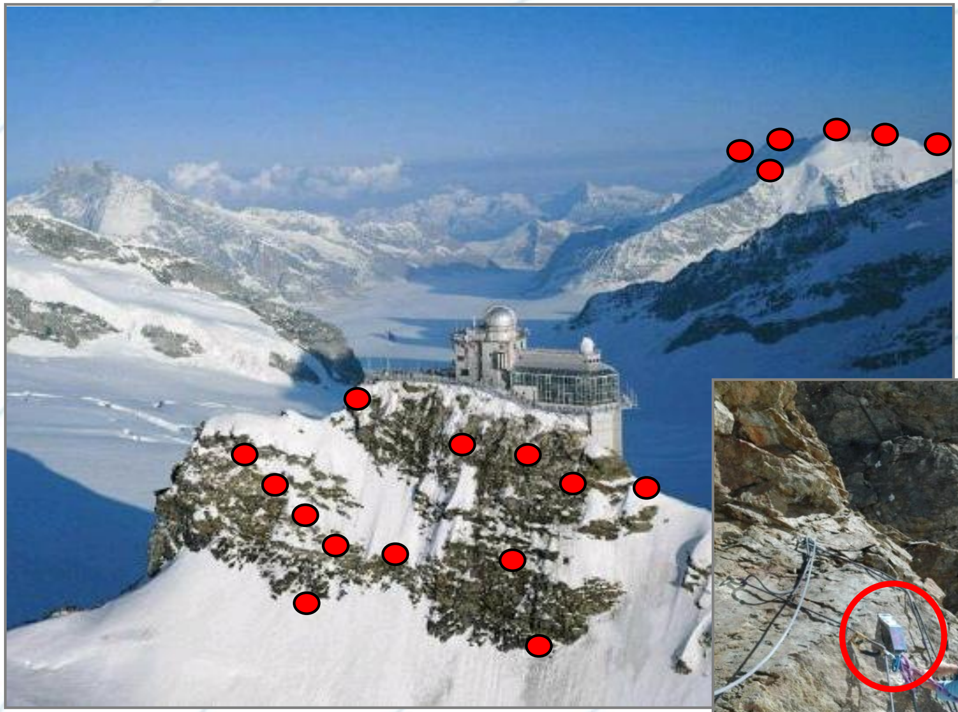
PermaSense

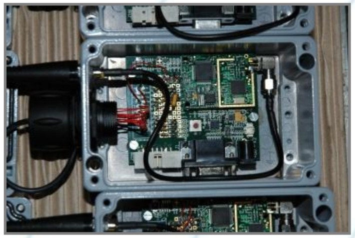
Sustainable Wireless Sensor Networks in Environmental Extremes

Jan Beutel, ETH Zurich

PermaSense Project – Alpine Permafrost Monitoring



- Cooperation with Uni Basel and Uni Zurich



Geo-science motivation to use WSNs

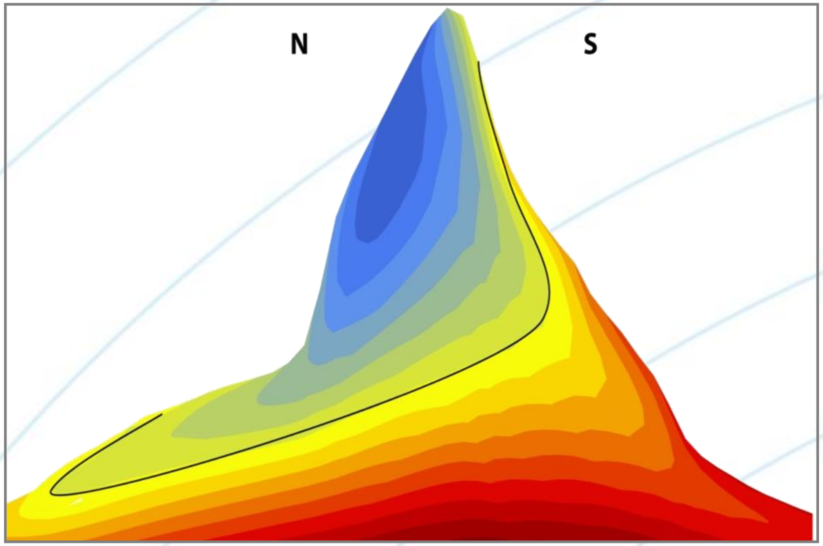
Climate rapidly affects the high-mountain hazard regime.
Anticipation and minimization of adverse effects requires:

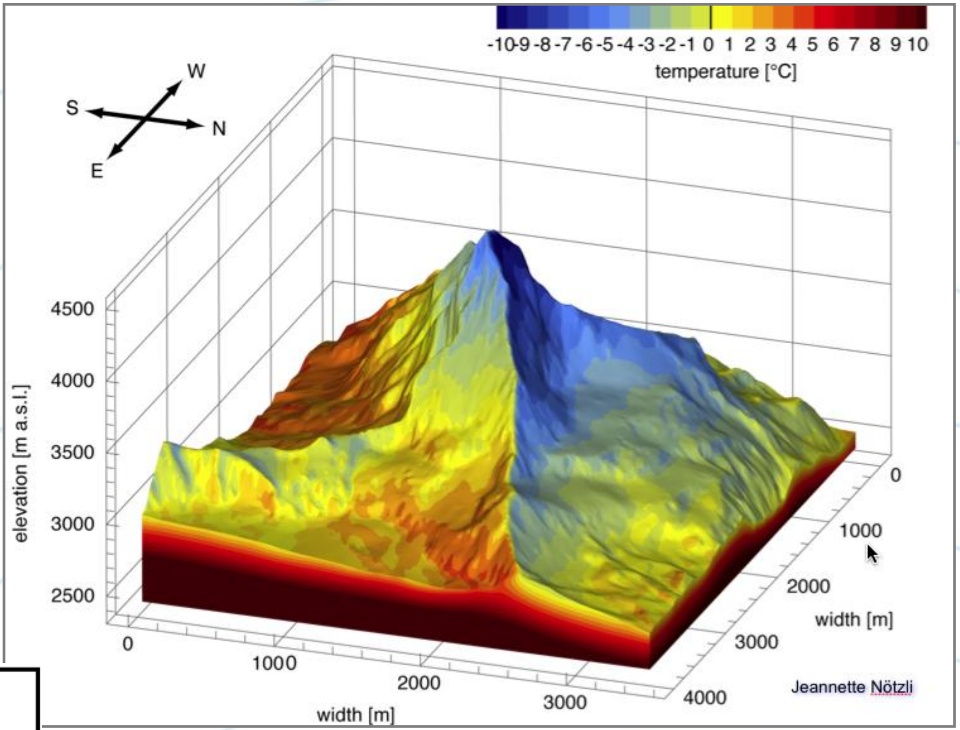
- Understanding mechanisms of thaw and cryogenic rock movement
- Provision of transient spatial data fields of relevant variables

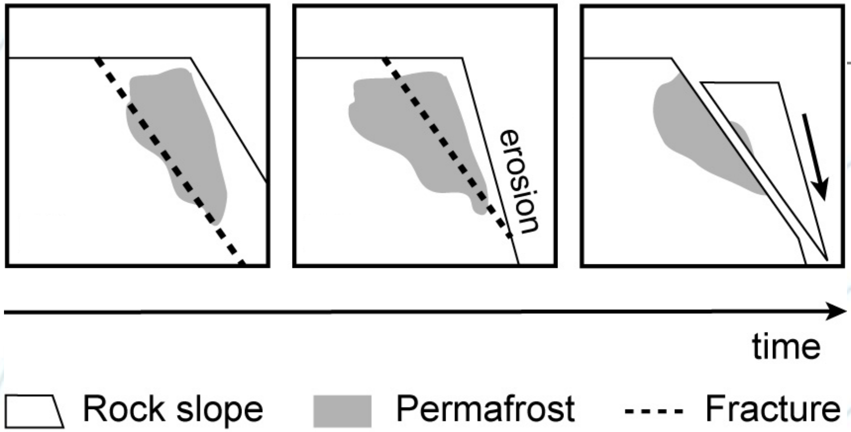
High lateral variability as well as difficult access and environmental conditions constrain measurements:

- Weight and size of equipment
- Time consumption (installation, maintenance, data gathering)
- Completeness of data recovery
- Robustness (temperature, lightning, mechanical wear)
- Synchronization
- Sacrificial sensors

PermaSense Scientific Goals – Validation of Models







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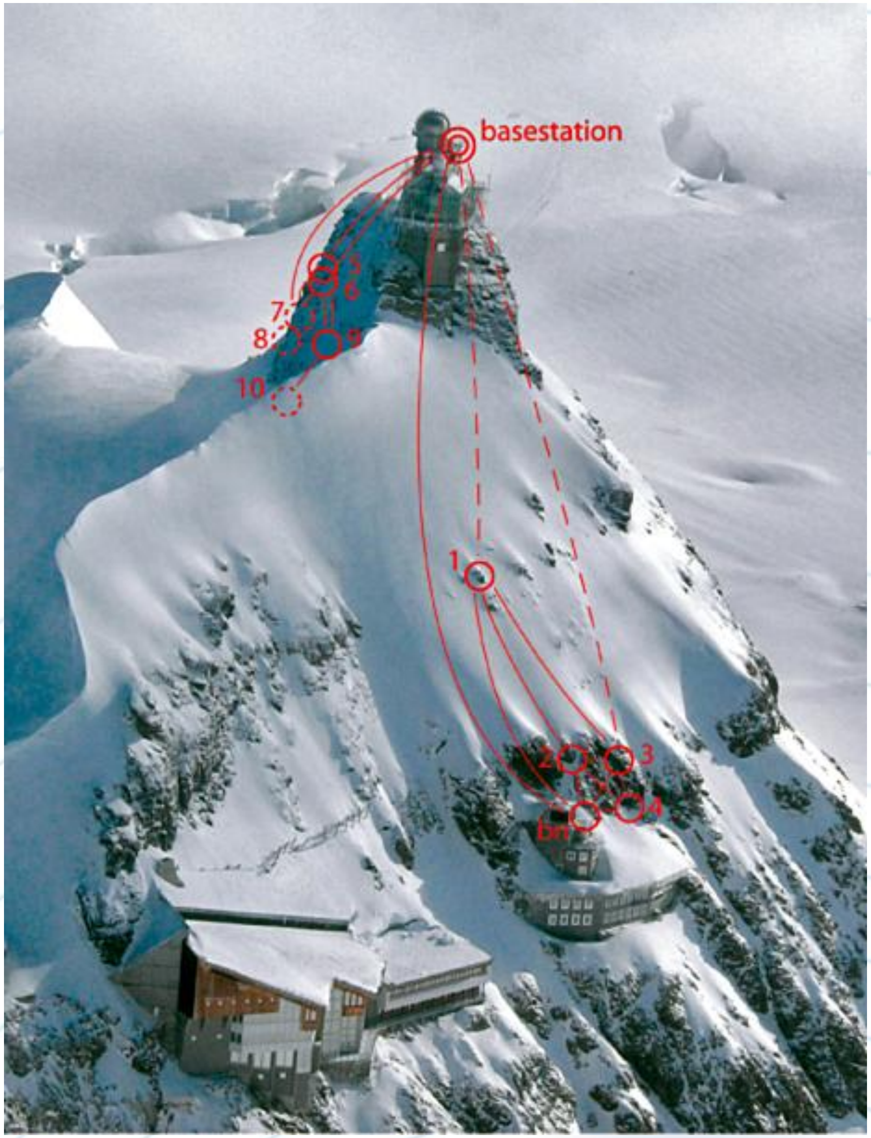
[Uni Zurich, Physical Geography]

Deployment 2006 – Jungfraujoch, 3500m

Focus: heat transfer

Status: ready for upgrade

Data: exploratory data gathering in winter 06/07



Deployment 2007 – Matterhorn, 3450m

Focus: cryogenic rock movement

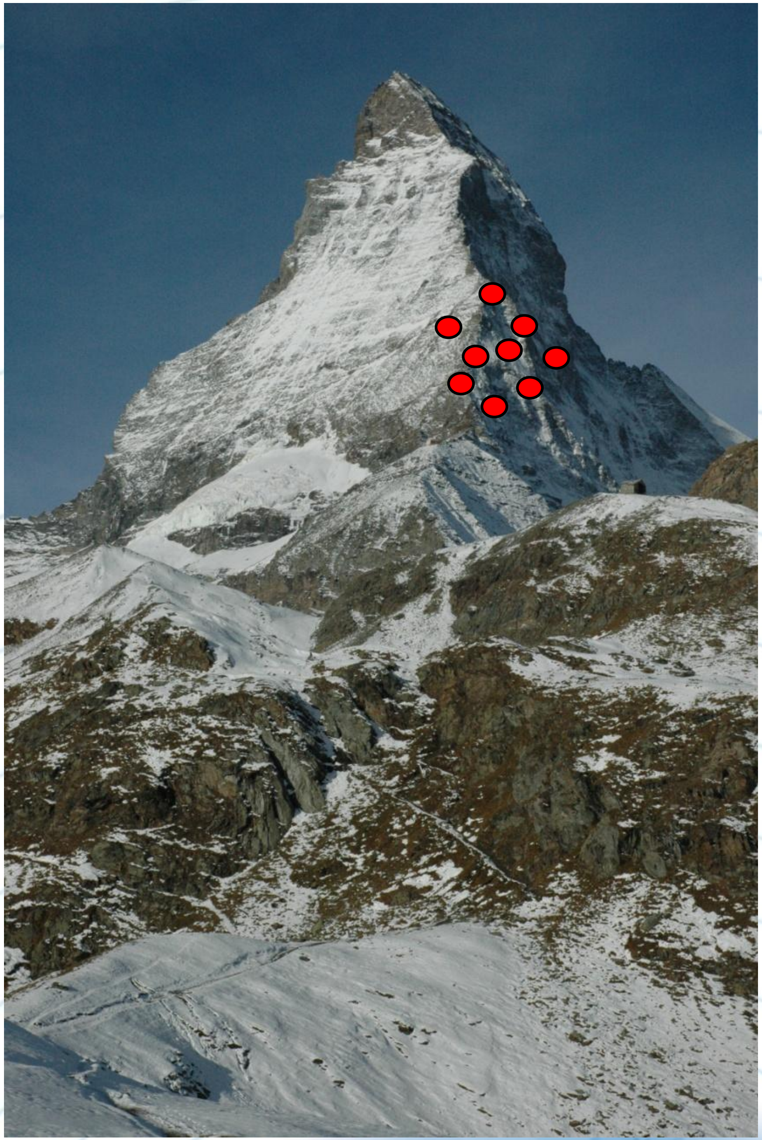
Status: productive

Data: Oct 07 - Jun 08 (logging only)

PermaSense 2007 – Matterhorn Site Details

- Site of recent rockfall due to extreme warming (07/2003)

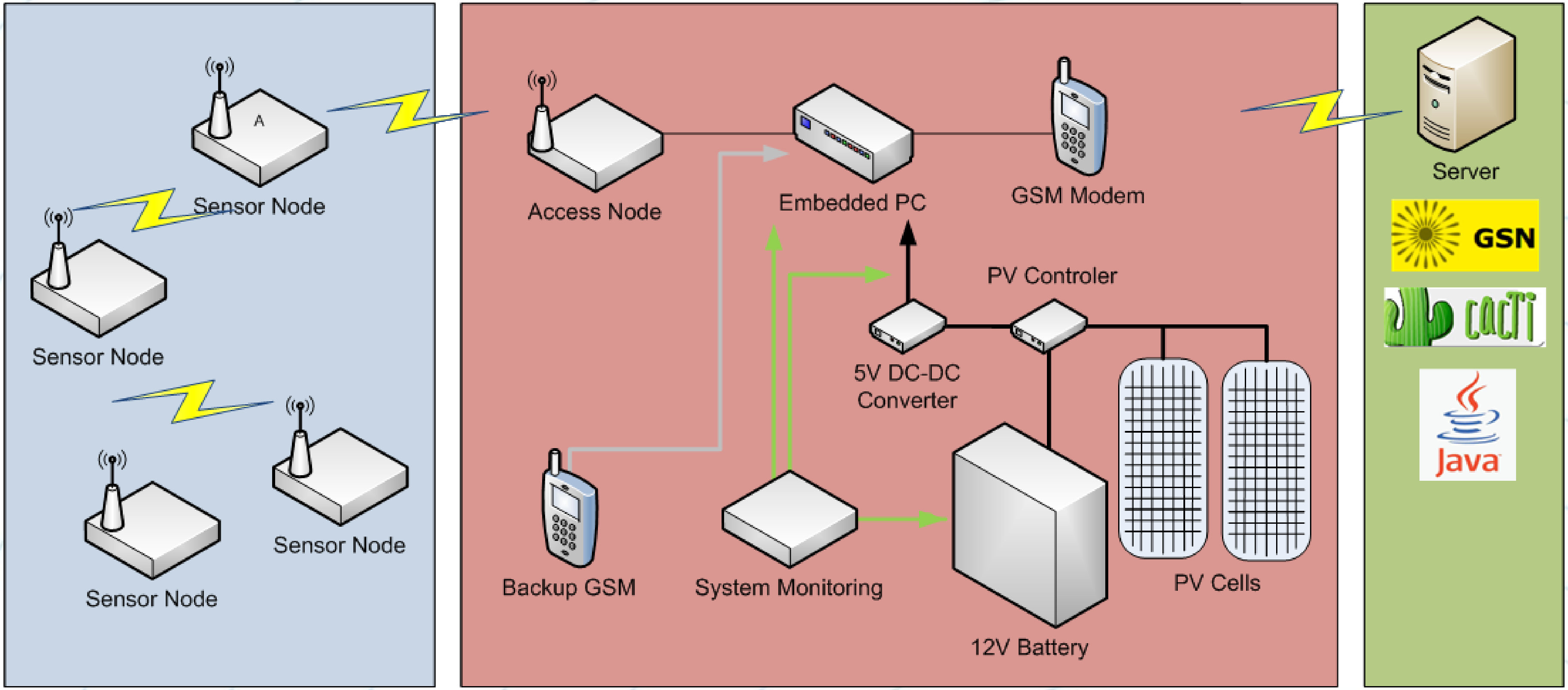
- Key parameters
  - 25 nodes
  - Different sensors
    - Temperatures, electrodes, crack motion, ice stress, water pressure
  - −40 to +65° C
  - Rockfall, snow and ice, avalanches
  - 30 min. duty-cycle
  - 3 years unattended lifetime



Example Sensor Station on the Mountain

PermaSense Technology

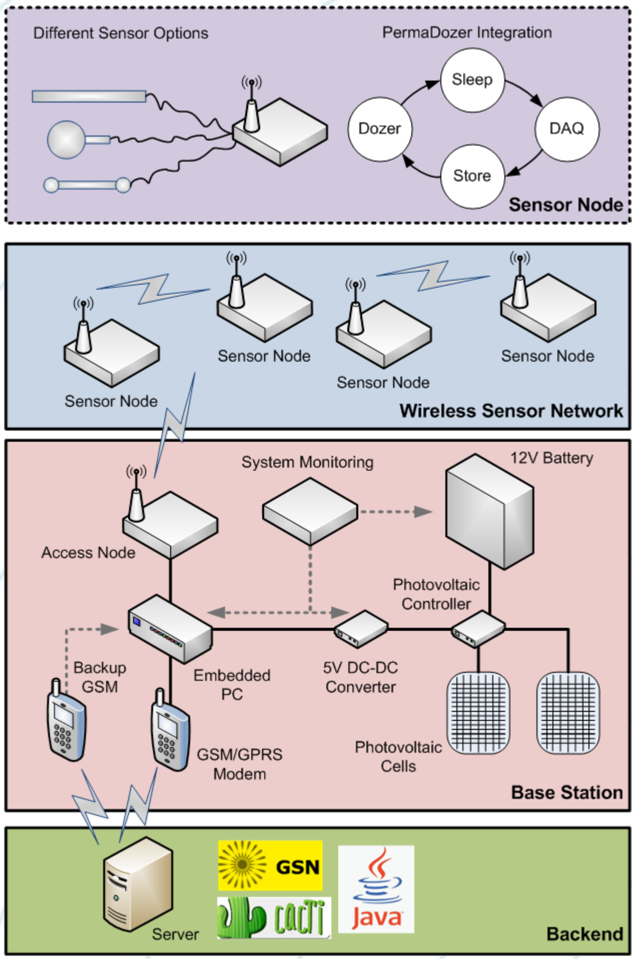
PermaSense – System Architecture



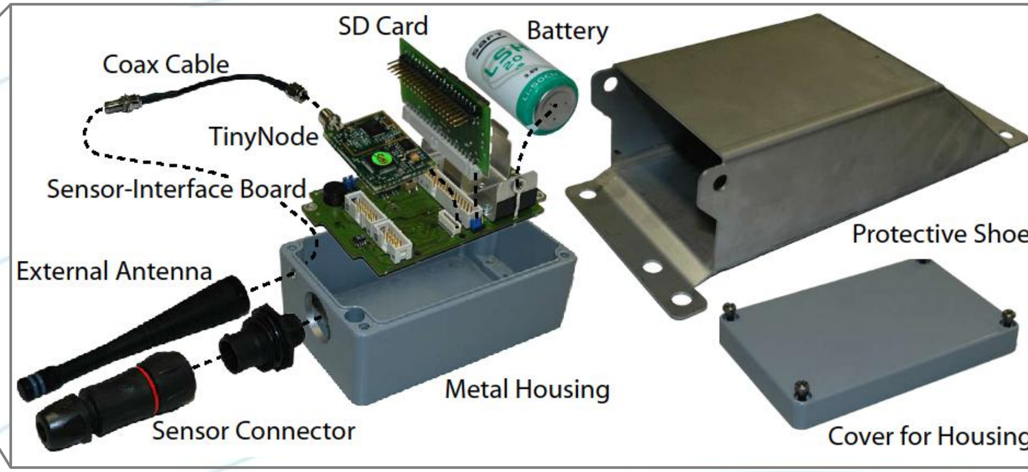
PermaSense – Sensor Nodes

- Shockfish Tiny Node
- Protective shoe, easy install
- Waterproof housing and connectors
- Sensor interface board
- 3-year life with single battery
  (~300 μA average power budget)

PermaSense Architecture

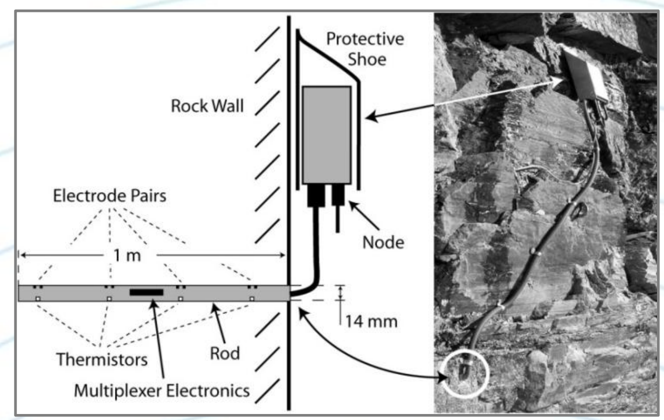


Sensor Node and Enclosure



Dozer
[Burri2007]

Mounting Situation



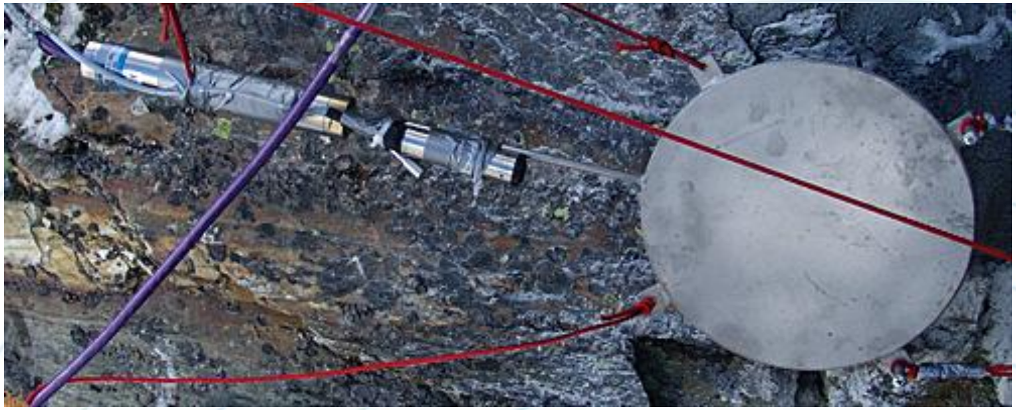
GSN Data Backend
[Salehi2007]

PermaSense – Sensor Interface Board (SIB)

- Development started in 2007
- Diverse interfaces, low power
- New: 1 GB memory (redundancy and validation)
- Provides very stable measurements

PermaSense – Sensors

- Sensor rods (profiles of temperature and electric conductivity)
- Thermistor chains
- Crack meters
- Water pressure
- Ice stress
- Self potential



PermaSense – Base Station

- Powerful embedded Linux
- 4 GB storage, all data duplicated
- Solar power (2x 90W, 100 Ah, ~3 weeks)
- Backup modem

PermaSense – Software

- Based on a first generation system
- TinyOS-based, fully customized
- Integration of **Dozer**
  [Burri, IPSN07]
- DAQ routine, profited from Sensor Network Platform Kit
- Integration of GSN data backend
  [Salehi VLDB_06]

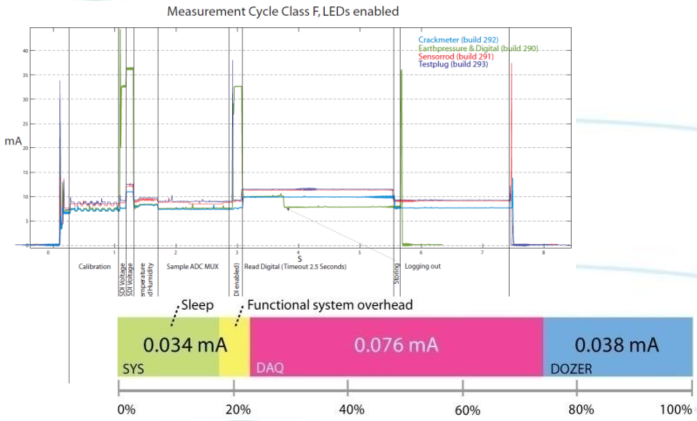
PermaSense – Testing Facilities

- Networking performance (**D**eployment-**S**upport **N**etwork, MICS)
- Power profiling
- Temperature cycling
- Sensor calibration
- Rooftop system break-in



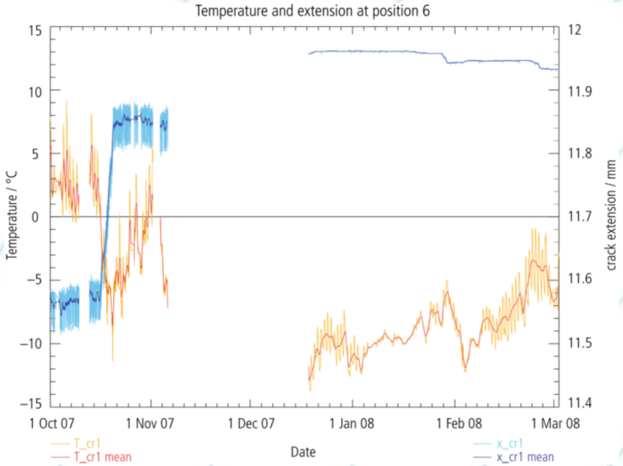
Key PermaSense Challenges

System Integration



Correct Test and Validation

Actual Data



Interdisciplinary Team

PermaSense – Test and Validation

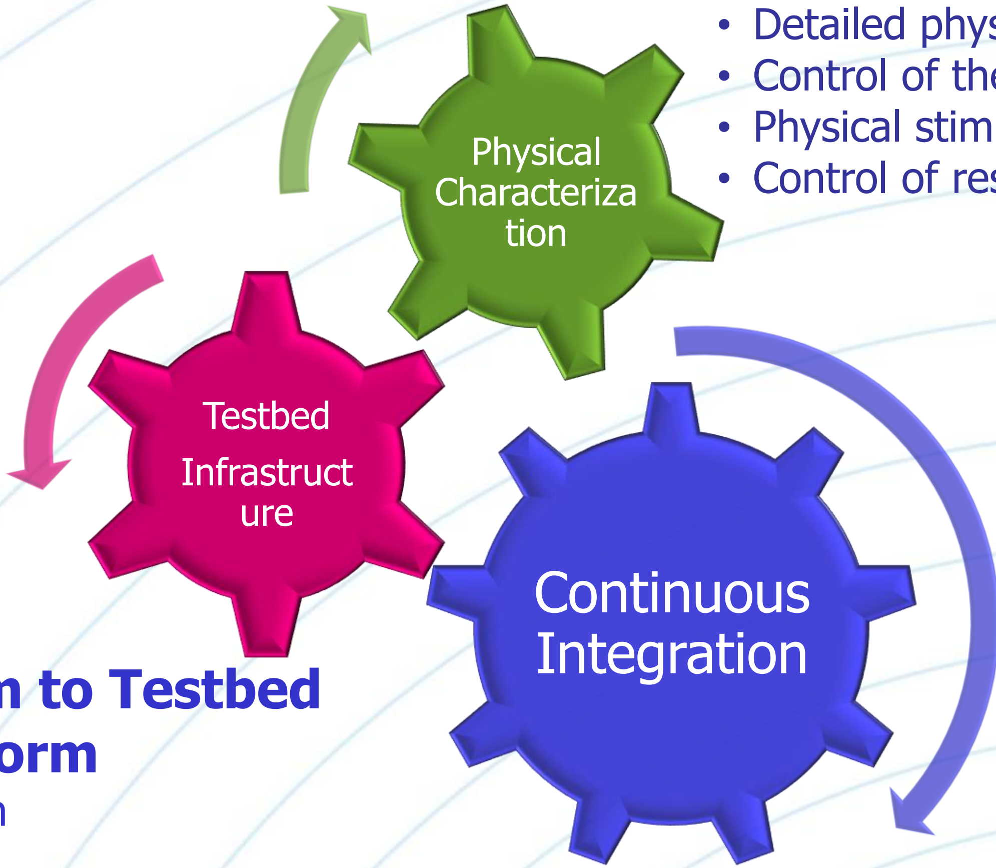
Performance is Poor – Causes Are Not Understood

Sensornets Are Hard

- Sensor networks often fail/operate poorly
  - Great Duck Island network: median yield 58% [SenSys 2004]
  - Redwood network: median yield 40% [SenSys 2005]
  - Volcano network: median yield:68% [OSDI 2006]
- Survey of causes
  - Protocol conflicts/interference
  - Collisions and congestion induced loss
  - Neighbor management (with layer 2 scheduling, e.g. TMAC)
  - Don't know!
- Low-power, limited resources make complete logging prohibitively expensive...

[Phil Levis, Stanford]

Methodology and Development Tools



Extending the Logical View

- Detailed physical monitoring
- Control of the environment
- Physical stimulation
- Control of resources

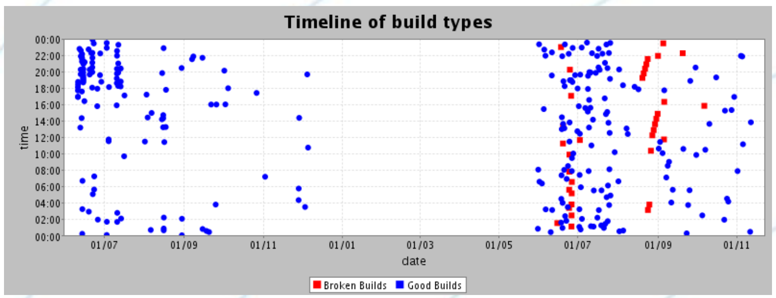
From Platform to Testbed to Multi-Platform

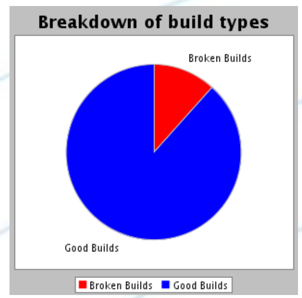
- Native execution
- Log file analysis
- Influence of the environment

Advanced Software Engineering Practices

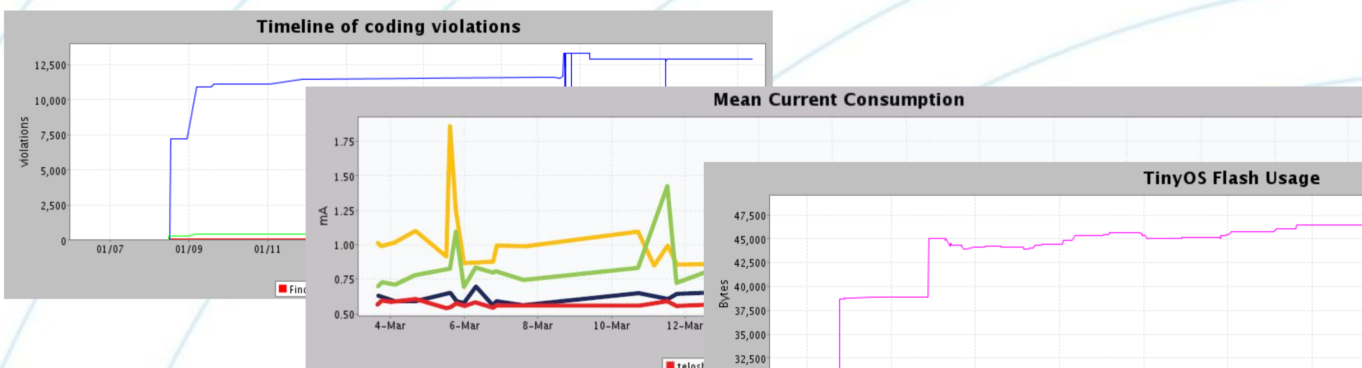
Continuous Integration for the TinyOS Core WG

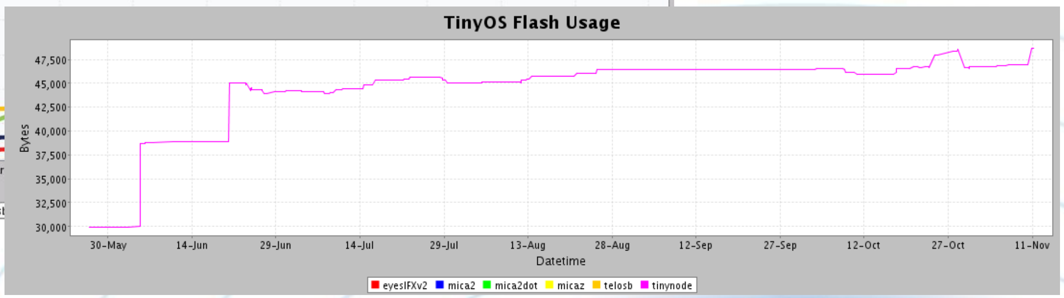
- On code change all TinyOS-2.x applications are built and analyzed
  - Service to the TinyOS community, increasing software quality
  - Deeper understanding of long term development trends





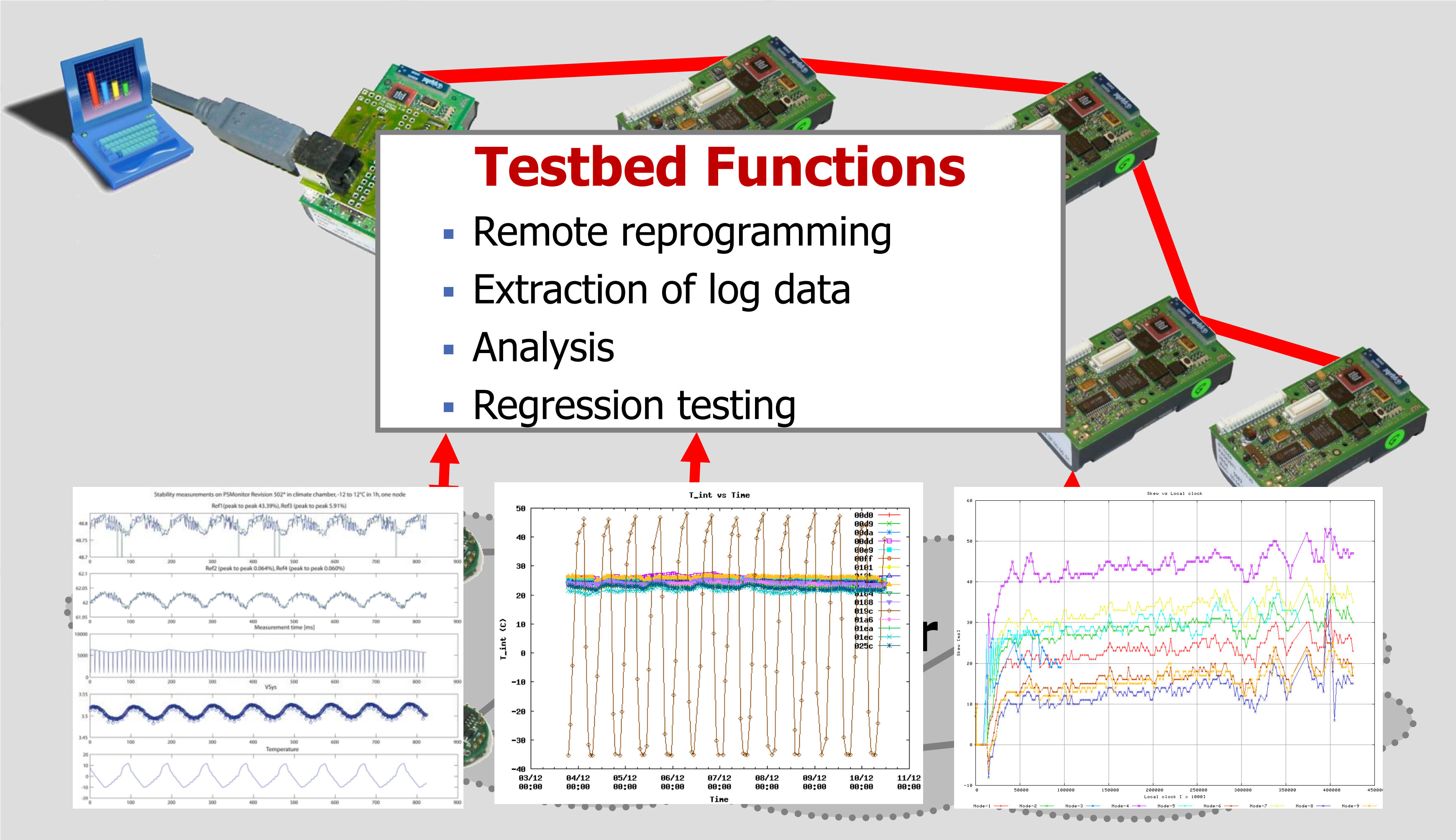
+4137 TinyOS-2.x regression builds over the last 2 years at TIK





[http://tik42x.ee.ethz.ch:8080]

Testbed – The Deployment-Support Network

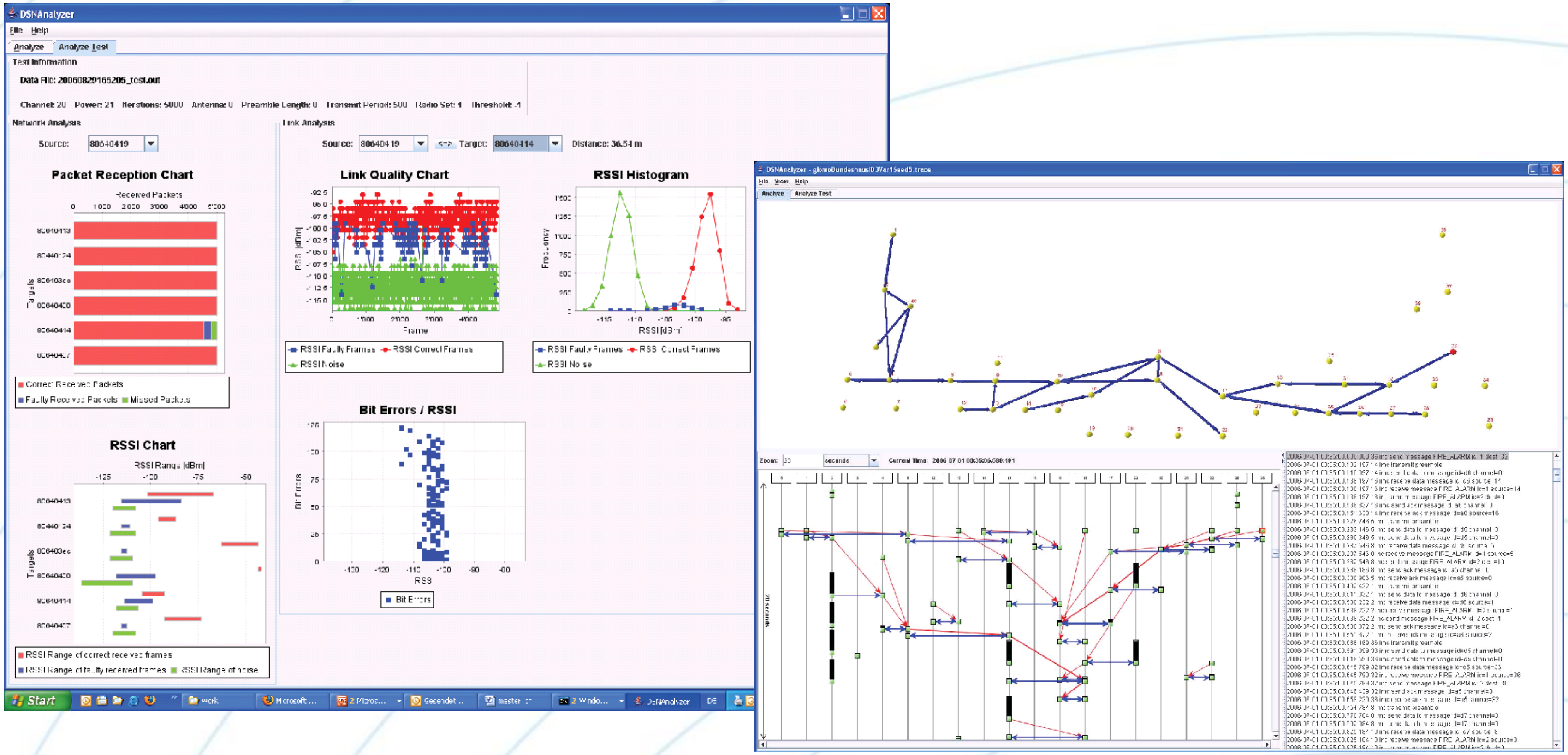


Testbed Functions

- Remote reprogramming
- Extraction of log data
- Analysis
- Regression testing

[SenSys2004, IPSN2005, EWSN2007]

DSN Impact – Automated Test Case Generation



- Developed and in-use at Siemens Building Technologies, Zug
- Detailed analysis and replay of simulation and testbed

Today's WSN Design and Development

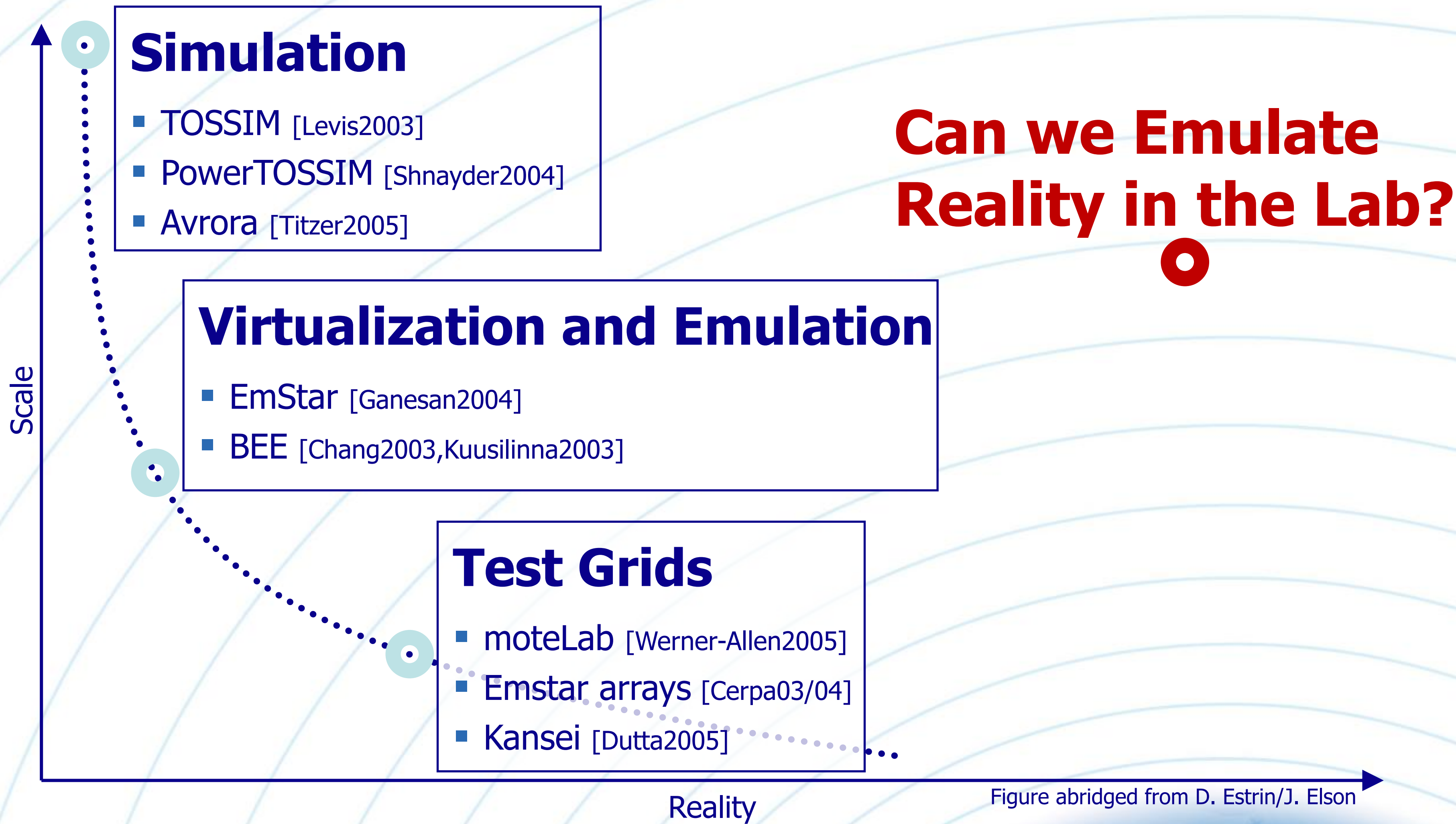
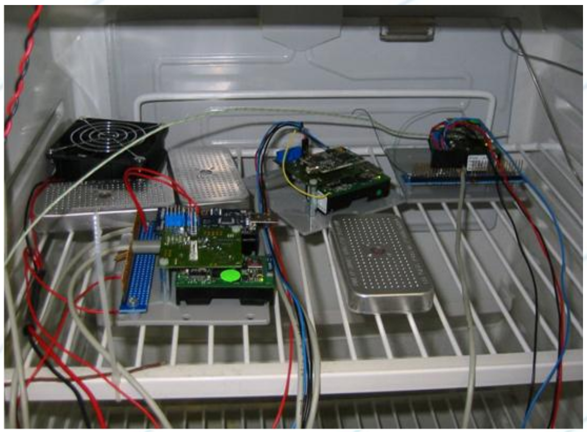
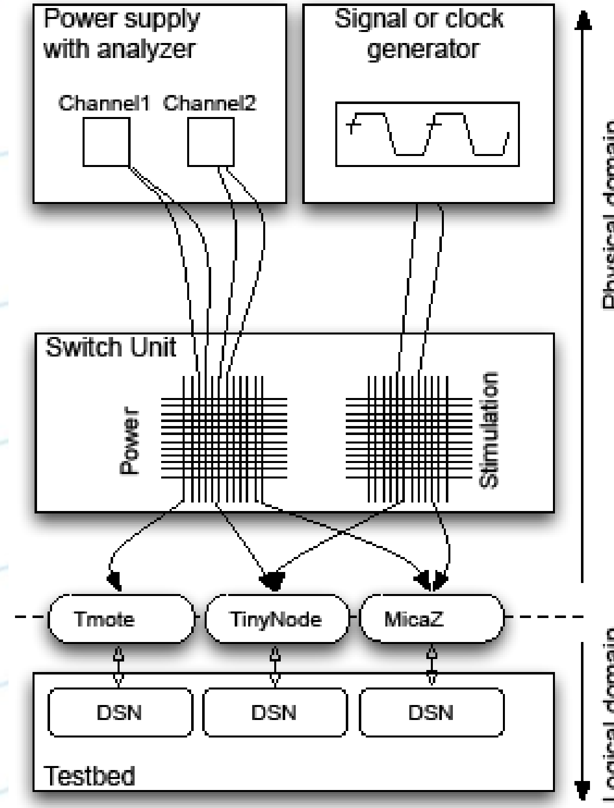


Figure abridged from D. Estrin/J. Elson

Physical Characterization Architecture

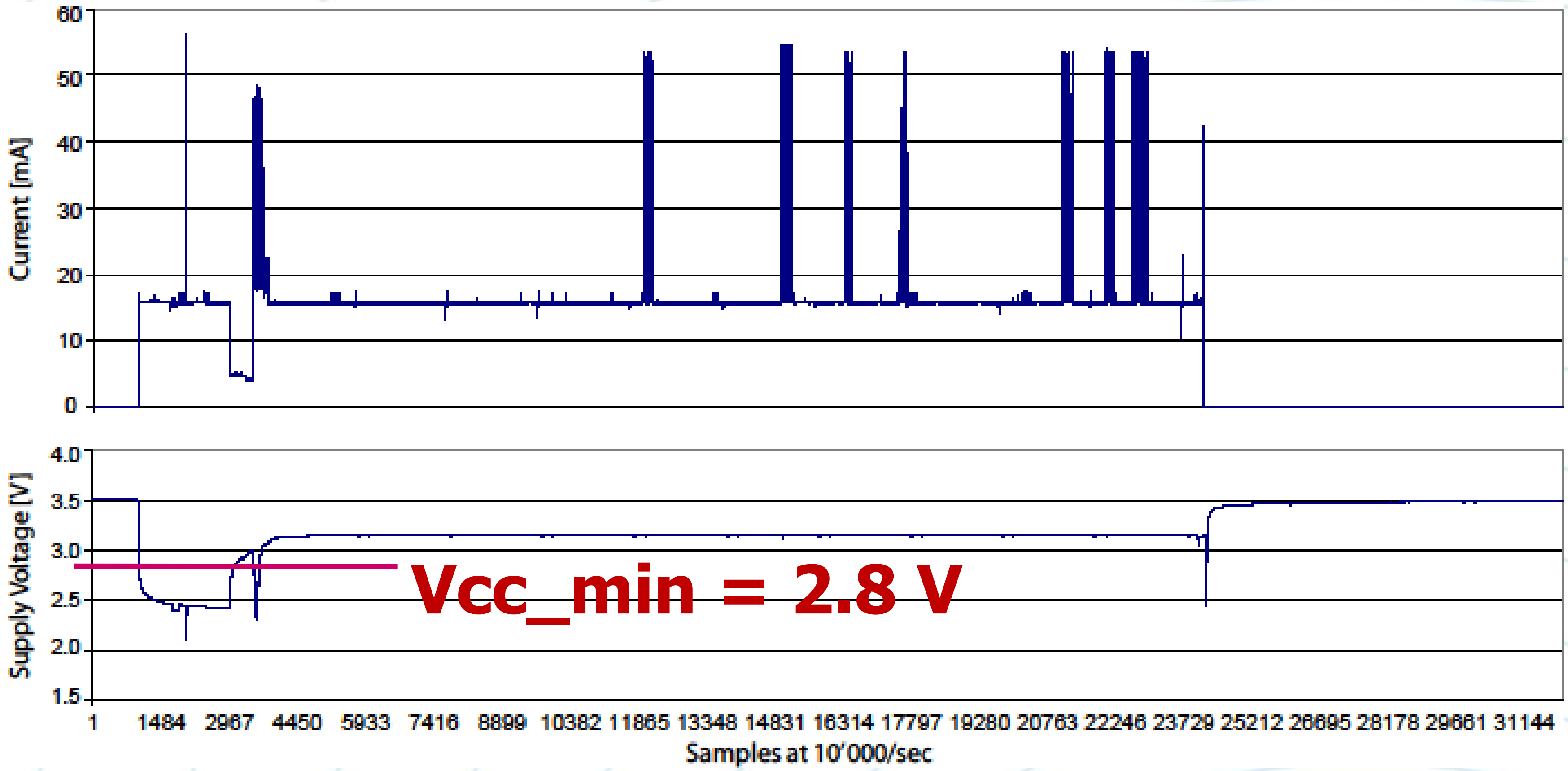
- Emulating the Environment...
  - Temperature Cycle Testing (TCT)





- ... and Resource Usage
  - Different Power Sources: Batteries, rechargeable cells, solar, fixed DC power...

Communication Details – Dangerous Voltage Drops



Detailed Power Tracing – Automated Validation

$$f_i(t) = \begin{cases} a_0 + a_1 \cdot x + \dots & \text{if } t \in [t_{i-1}, t_i) \\ 0 & \text{if } t \notin [t_{i-1}, t_i) \end{cases}$$

$$f_i^-(t) = \begin{cases} f_i(t) - \Delta y^- & \text{if } t \in [t_{i-1}, t_i) \\ 0 & \text{if } t \notin [t_{i-1}, t_i) \end{cases}$$

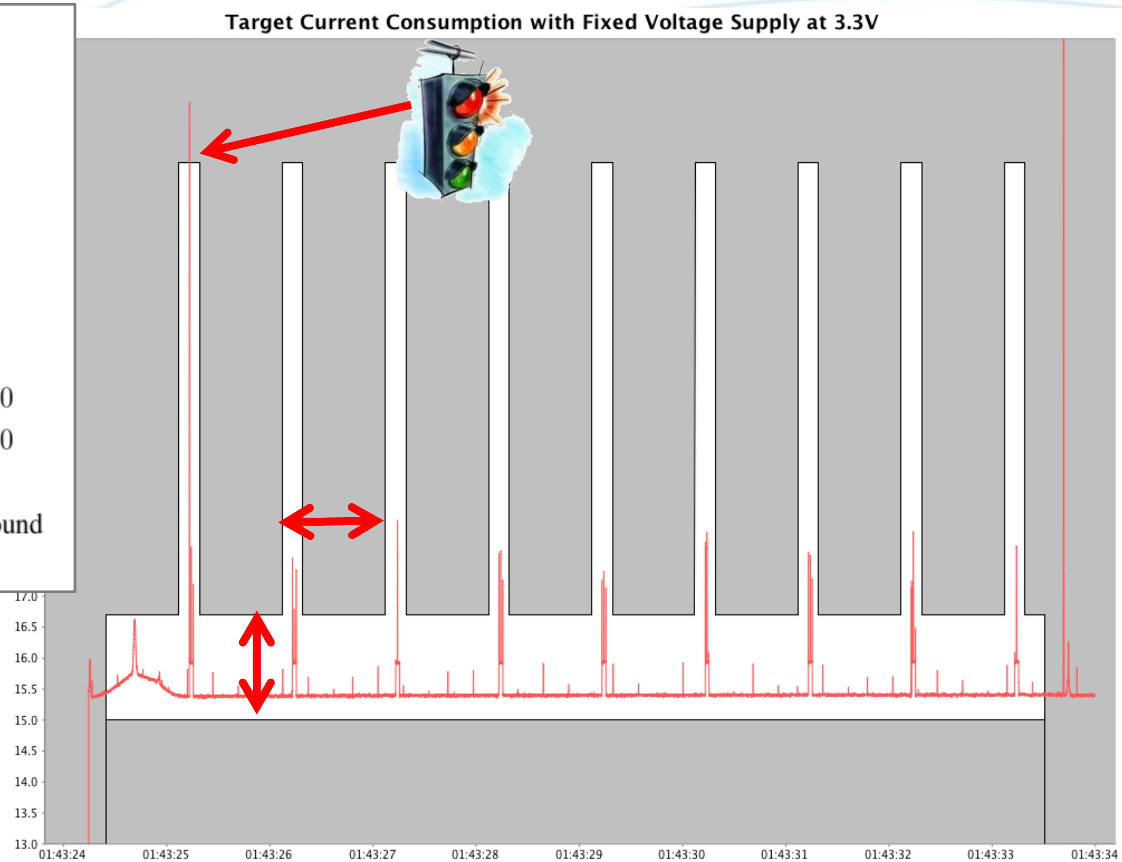
$$f^-(t) = \sum_{i=1}^{n} f_i^-(t)$$

$$\forall \tilde{t} \in [-\Delta t, \Delta t], \forall i \in \mathbb{N} :$$

$$f^-(t + \tilde{(t_k)}) = \begin{cases} f^-(t_i^-) & \text{if } -f(ti^-) + f(t_{i+})) \leq 0 \\ f^-(t_i^+) & \text{if } -f(ti^-) + f(t_{i+})) > 0 \end{cases}$$

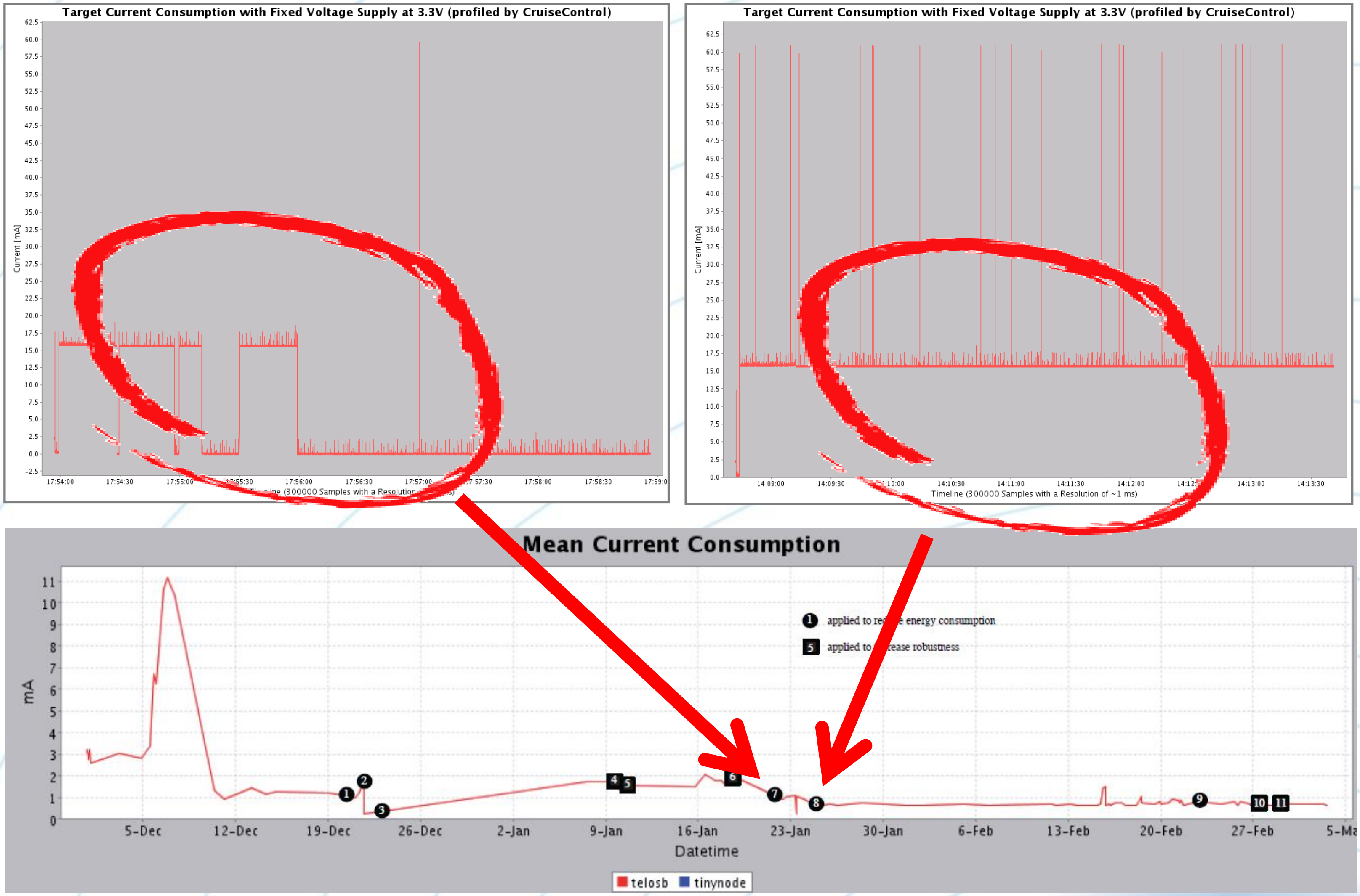
The upper bound f^+ follows accordingly with a bound value Δy^+.

[EmNets2007, WEWSN2008, SUTC2008]



- Integrated with each build (regression testing)

Power Profiling – Trends and Detailed View



PermaSense –
Deployment on the Mountain

Site Overview

Transport

Installation Planning

An Early Start

Installation Work

Moving Between Sensor Sites

Awkward Working Positions

Sensor Stations on the Mountain

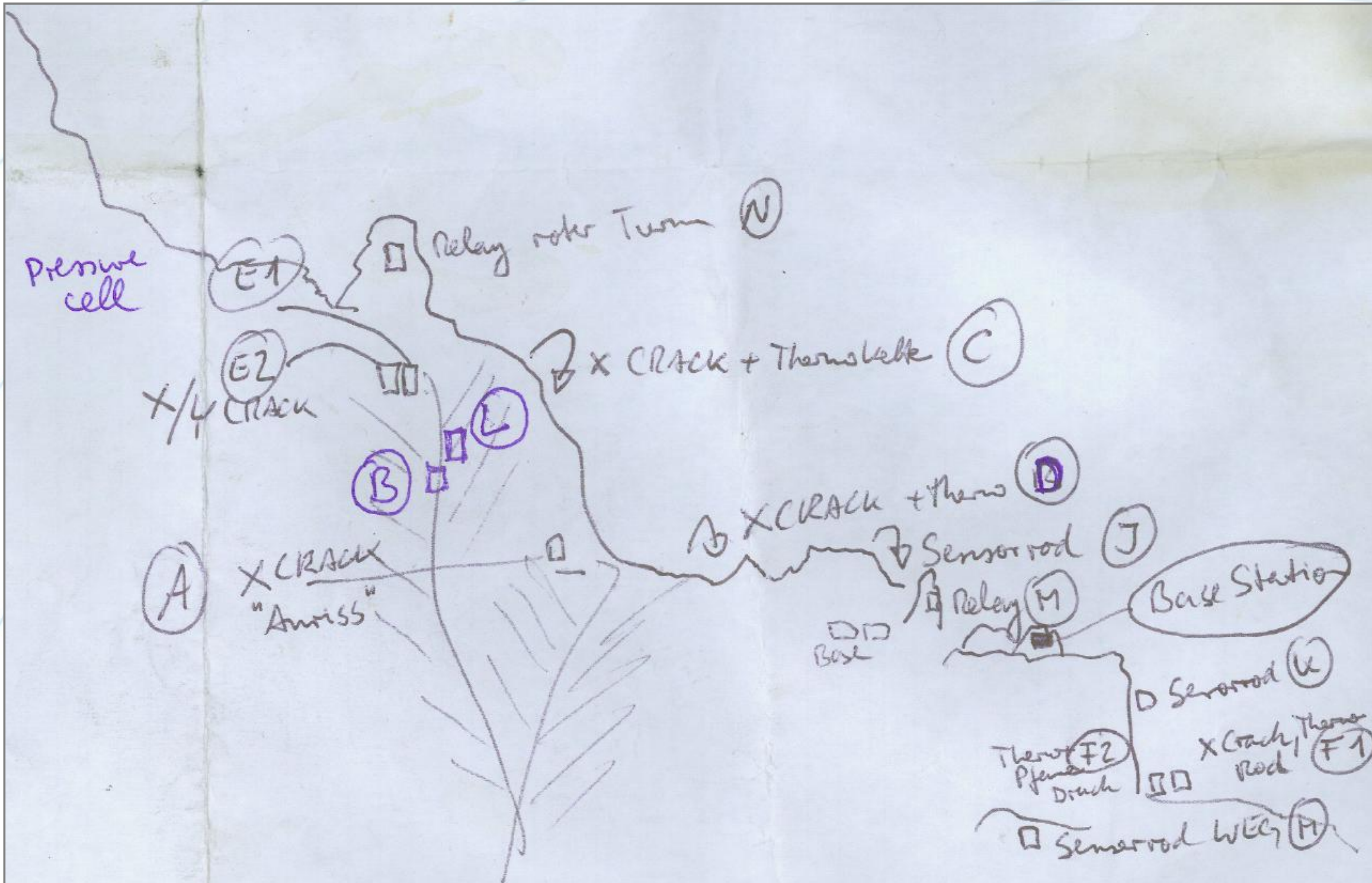
Site Visit in Winter 2008

The Sensor Site Snowed In

Base Station and Solar Panels

Top Down and Bottom Up Views

Metadata and "Sophisticated Field Tools"...




NESTEA

Acknowledgements

- PermaSense Collaboration
  - Stefan Gruber, Andreas Hasler, Janette Nötzli, Sandro Schönborn, Igor Talzi, Christian Tschudin, Christian Plessl
- Related publications

  - M. Wöhrle, C. Plessl, J. Beutel and L. Thiele: *Increasing the Reliability of Wireless Sensor Networks with a Unit Testing Framework* . EmNets 2007.
  - J. Beutel, M. Dyer, M. Yücel and L. Thiele: *Development and Test with the Deployment-Support Network* . EWSN 2007.
  - K. Aberer, G. Alonso, G. Barrenetxea, J. Beutel, J. Bovay, H. Dubois-Ferriere, D. Kossmann, M. Parlange, L. Thiele and M. Vetterli: *Infrastructures for a Smart Earth - The Swiss NCCR-MICS Initiative*. Praxis der Informationsverarbeitung und Kommunikation, pages 20-25, Volume 30, Issue 1, January 2007.
  - N. Burri, P. von Rickenbach, and R. Wattenhofer, "Dozer: ultra-low power data gathering in sensor networks," in Proc. 6th Int'l Conf. Information Processing Sensor Networks (IPSN '07), pp. 450–459, ACM Press, New York, Apr. 2007.
  - A. Hasler, I. Talzi, J. Beutel, C. Tschudin, and S. Gruber, "Wireless sensor networks in permafrost research - concept, requirements, implementation and challenges," in Proc. 9th Int'l Conf. on Permafrost (NICOP 2008), vol. 1, pp. 669–674, June 2008.