Monitoring Volcanic Activity with a Wireless Sensor Network

Geoff Werner-Allen, Matt Welsh, Harvard University
Jeff Johnson, University of New Hampshire
Mario Ruiz, UNC and Instituto Geofisico, EPN
Jonathan Lees, UNC

Introduction

Volcanic monitoring experiments involve both seismic and infrasonic sensors

Seismometers capture vibrations due to earthquakes/tremors typically associated with an eruption

Infrasound (very low frequency acoustic – 1-50 Hz)

- Very high amplitude (130 dB at 1 km!) but not audible
- Large “shock wave” caused by gas emission from volcanic conduit

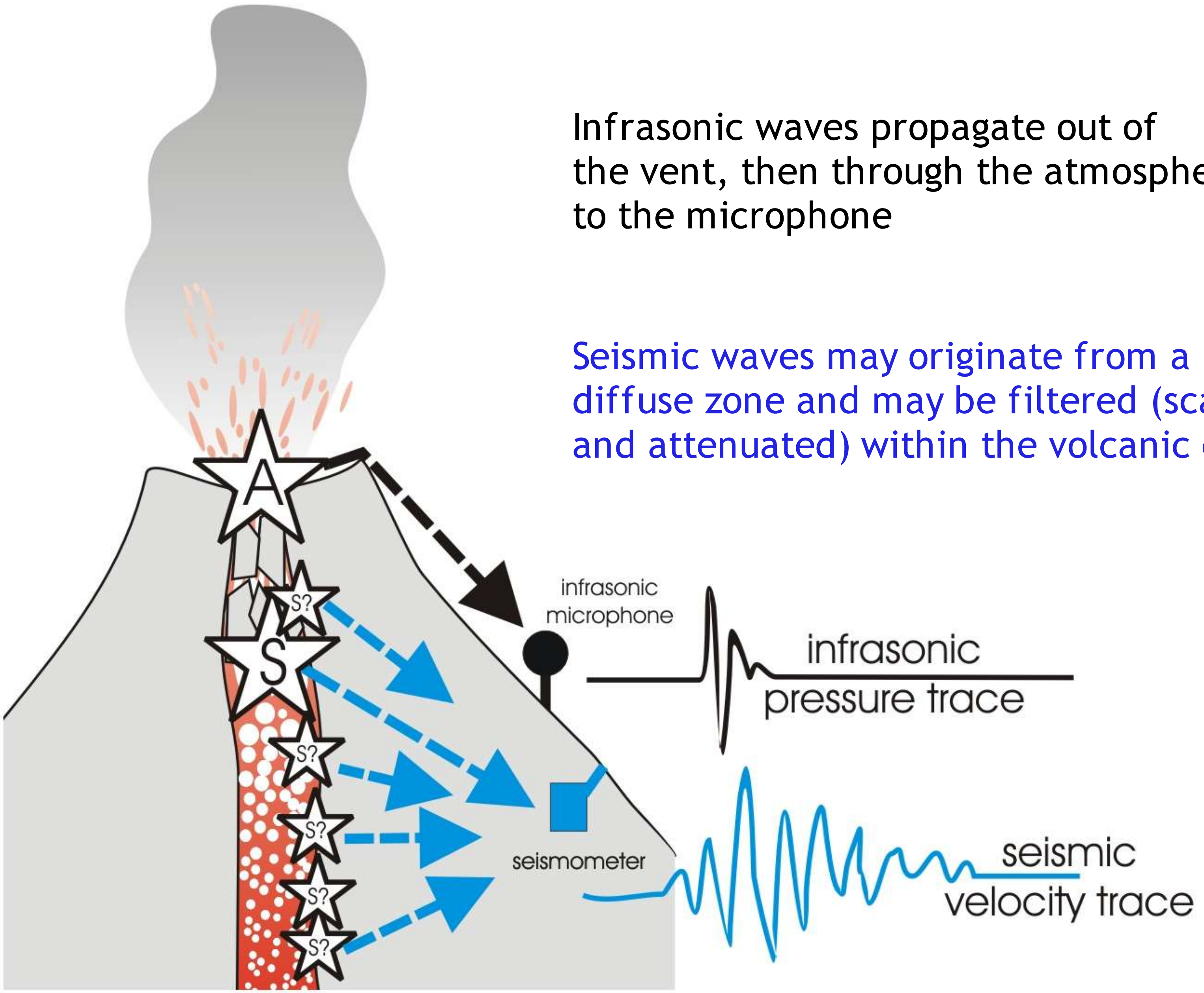
Can be used to understand nature of eruption

- Recover source of explosive event (triangulation from multiple stations)
- Frequency analysis (harmonics, multiple pulses, etc)
- Comparison with seismic activity to understand eruption

Infrasound is inexpensive and easier to deploy than seismic stations

- Opportunity to lay out large arrays of microphones

Seismo-acoustic monitoring



Infrasonic waves propagate out of the vent, then through the atmosphere to the microphone

Seismic waves may originate from a diffuse zone and may be filtered (scattered and attenuated) within the volcanic edifice.

Current Instrumentation

GURALP SYSTEMS

GÜRALP CMG-40T

BROADBAND SEISMOMETER

! Truly portable seismometer with lifting handle, and easy access to electric connection.

! Direct velocity output broadband feedback seismometer.

! Suitable for local, regional and teleseismic recording.

! Mass clamp not required.

! Mass centering not required.

! Adjustable feet with sapphire tips to reduce analogue ground loops.

! High and low gain differential velocity outputs.

! Long period response; 10, 20, 30, 60 and 120 seconds options.

! Short period response up to 50 Hz.

! Low power consumption, 0.5 Watts.

! Stainless steel construction.

The CMG-40T portable broadband seismometer is a three-component seismometer of rugged design, designed to meet the requirements of rapid installation, minimum setting up and optimum sensitivity and dynamic range. The sensor is completely waterproof and self-contained apart from the external dc power supply and recording device. For strength and long term durability it is constructed entirely from stainless steel.

GÜRALP SYSTEMS LIMITED
3 Midas House, Calleva Park, Aldermaston,
Reading, Berks, RG7 8EA, United Kingdom.
Tel: +44 (0) 118 9819 056
Fax: +44 (0) 118 9819 943
e-mail: sales@guralp.com
Website: http://www.guralp.com

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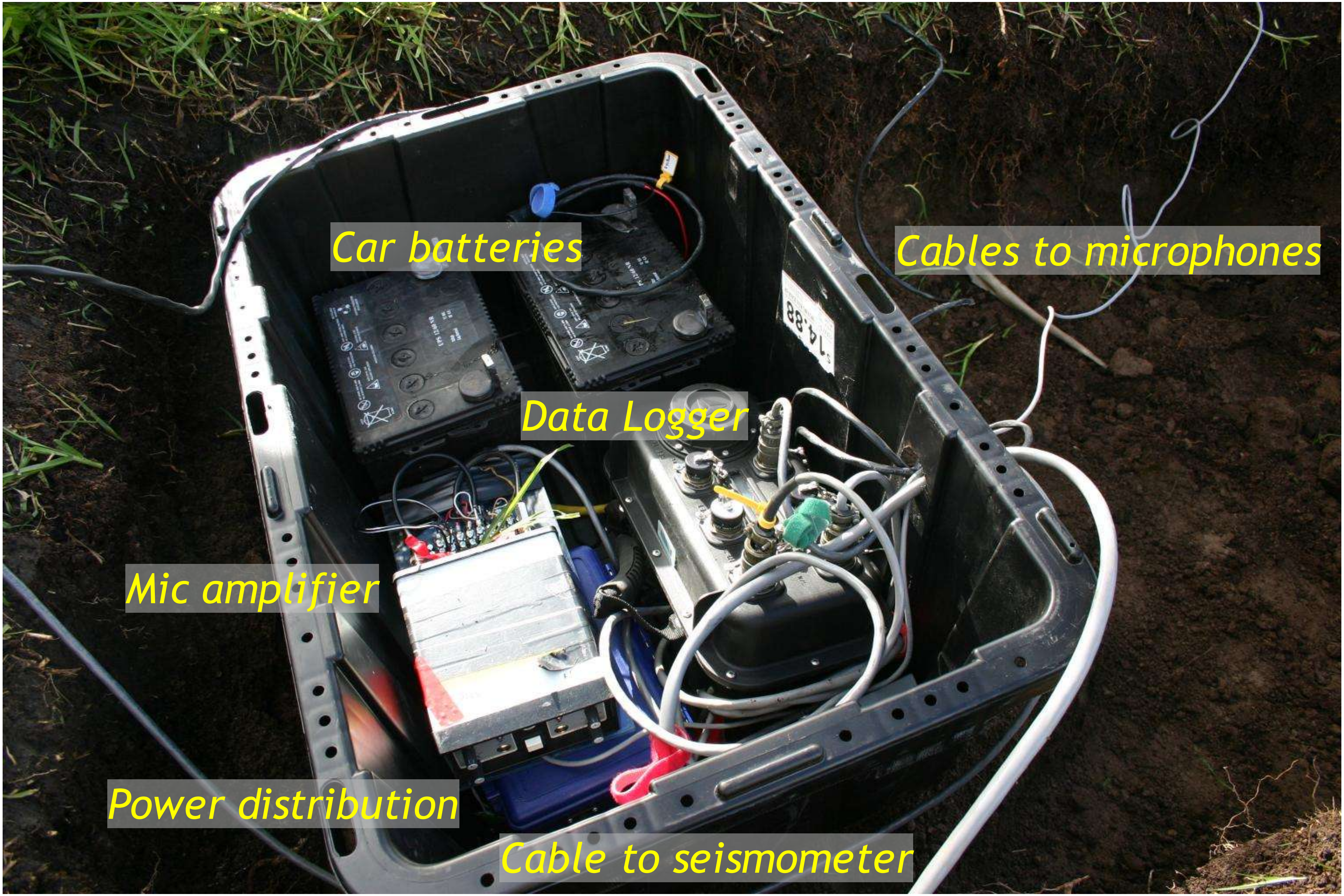
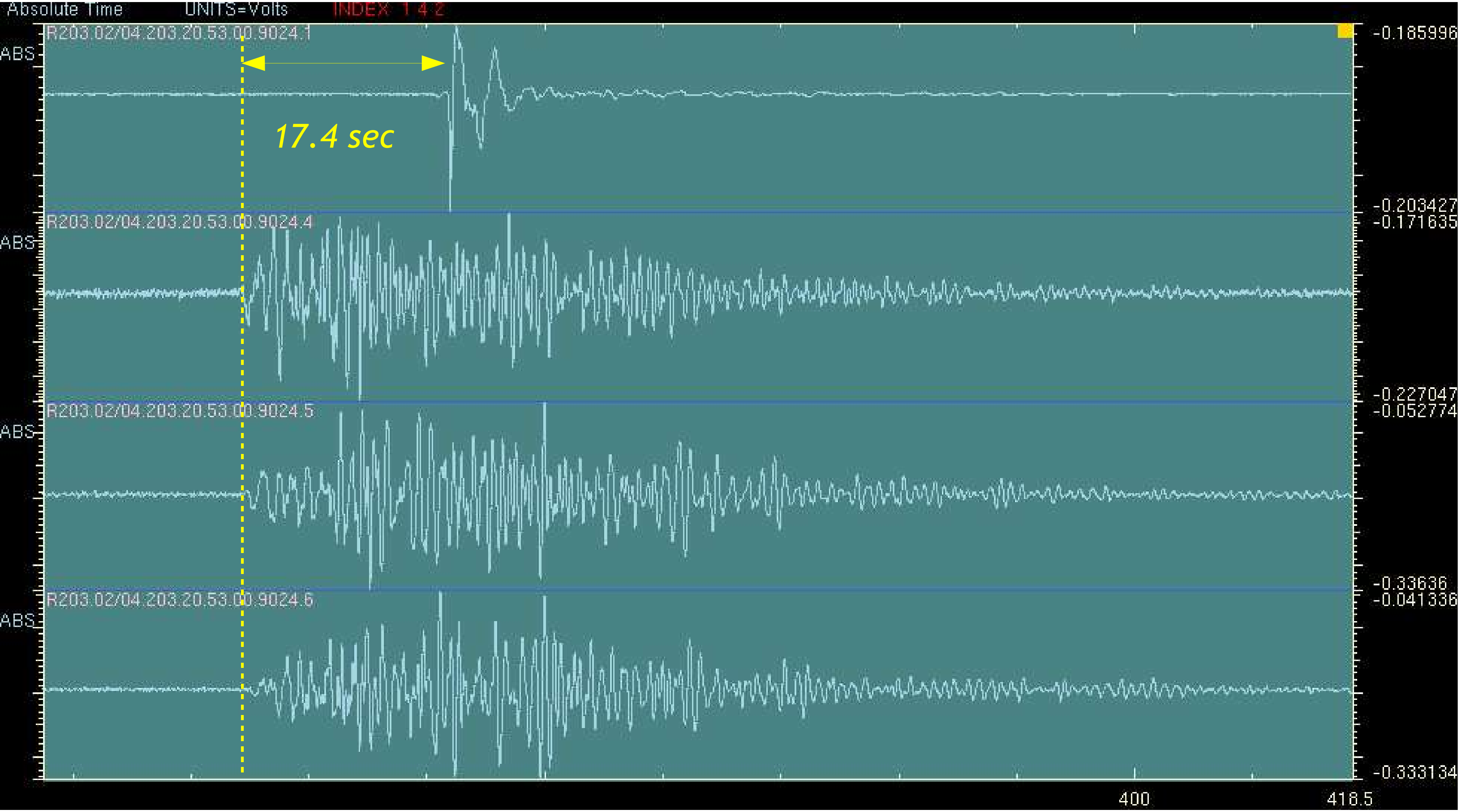
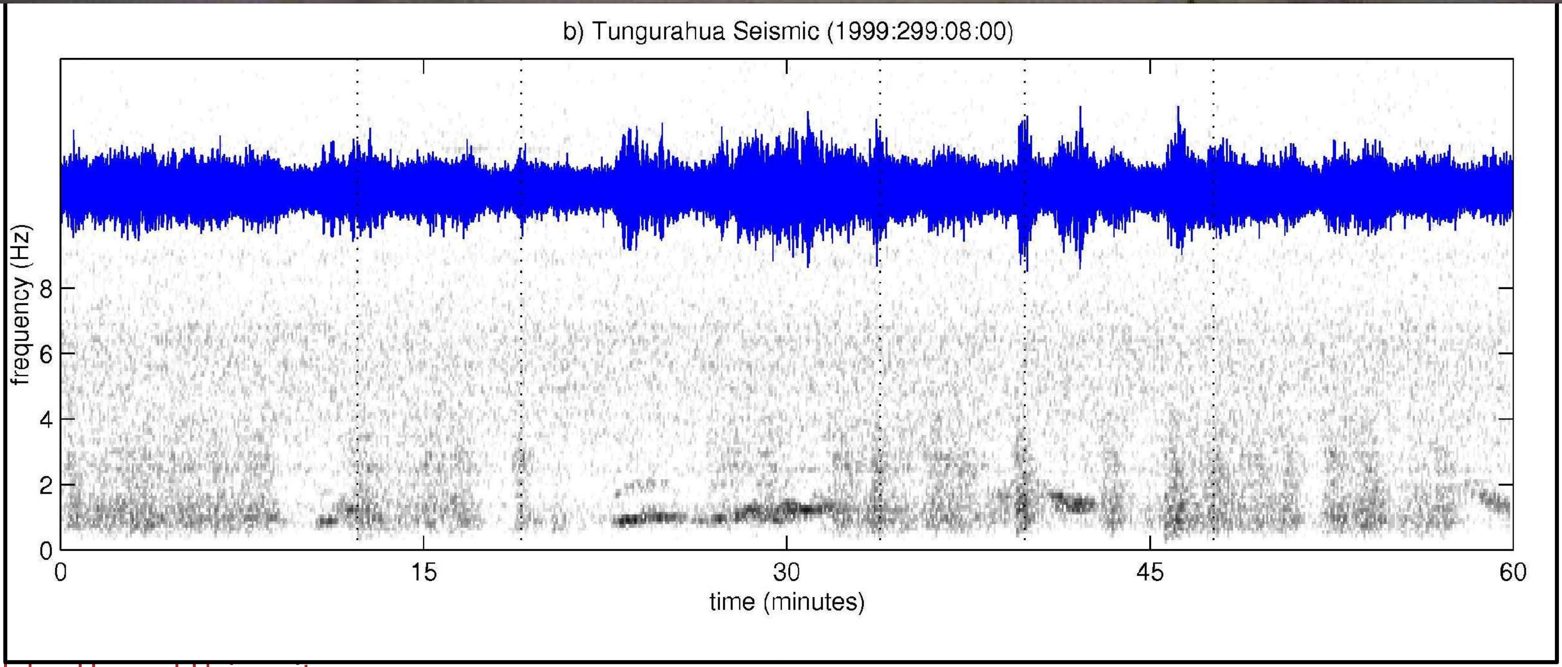
Current Monitoring Station



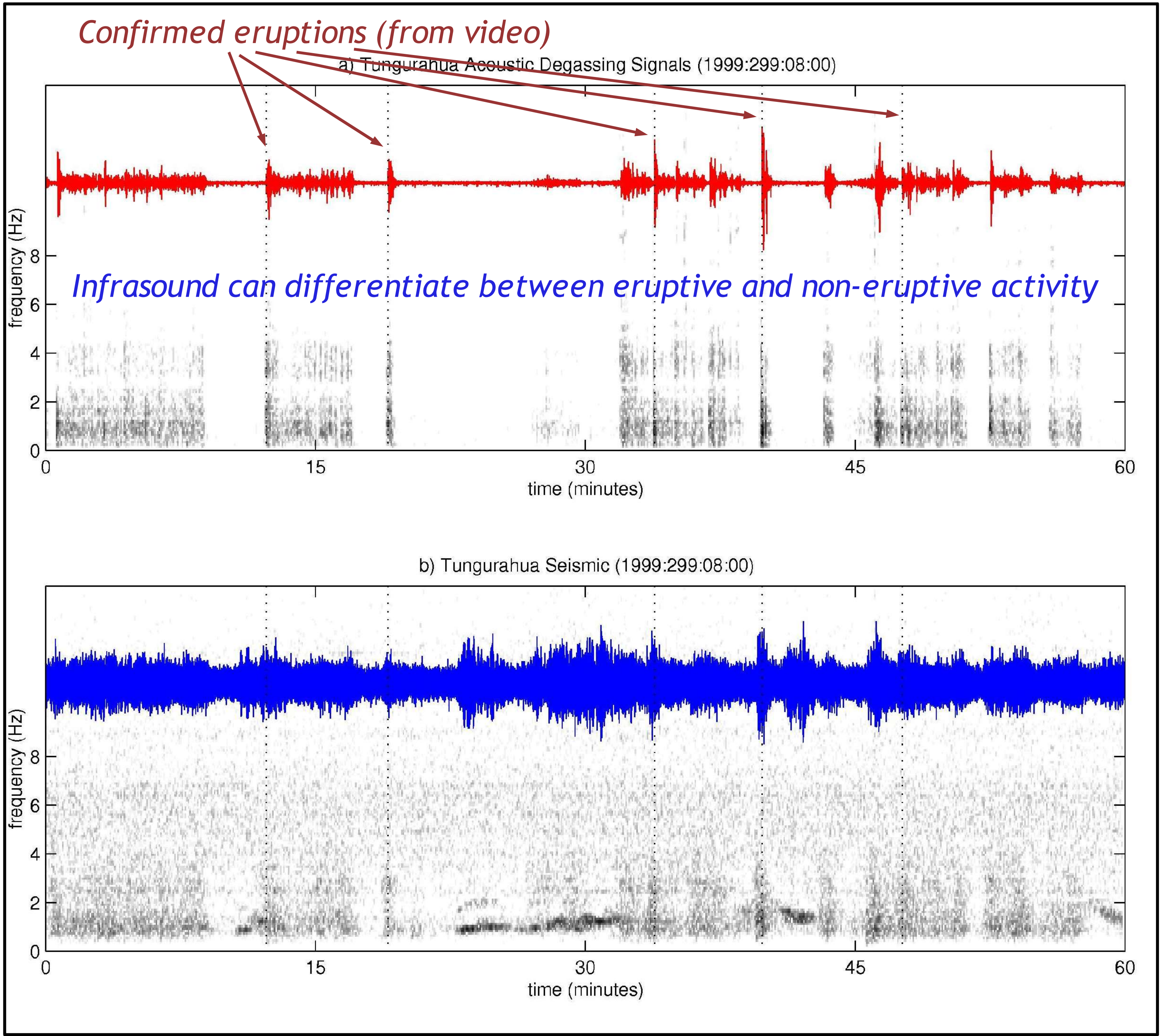
Explosion from Tungurahua



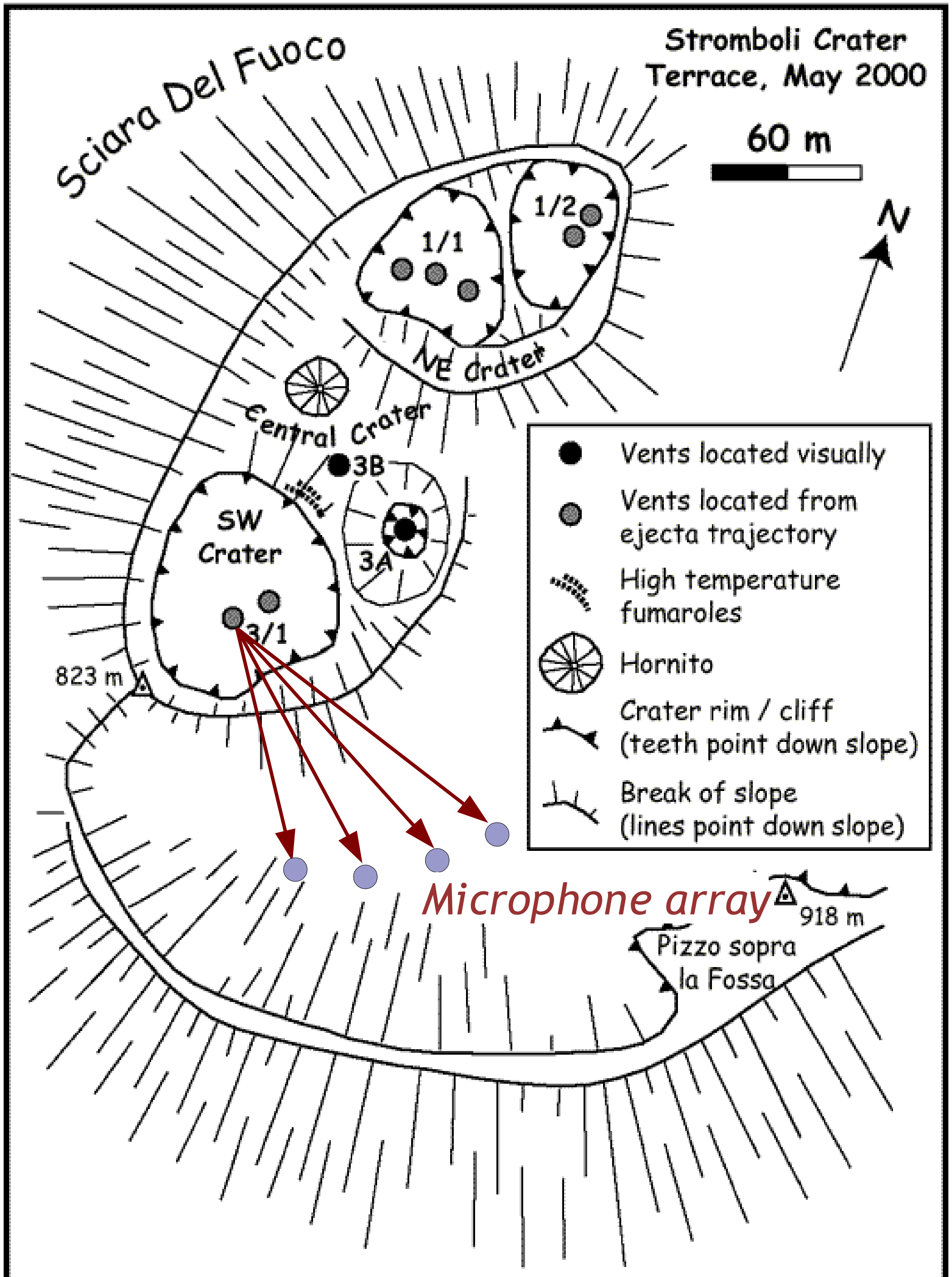
Eruption event discrimination



Eruption event discrimination



Source back-projection



Idea: Use "antenna" of multiple microphones to determine source of eruption.

Must correlate signals from different microphone stations at different times.

Can essentially triangulate the source based on time of flight (but, signals can be attenuated or distorted by crater and terrain features).

Challenges and Issues

Existing data loggers store data locally

- e.g., 1 or 2 Gb microdrives, store about 15 days' worth of data

Must trek up to the station to retrieve the data

- Usually very inaccessible: can take several hours to drive/hike in

Very high power consumption

- Two car batteries plus solar panels to recharge

Very expensive

- Individual data logger costs thousands of $$$
- Still need Pcs/laptops to process and store data permanently

Hard to deploy large number of stations

- Size, cost, power requirements, number of data logging channels ...

Where sensor nets come in

Motes are a great match for this application!

Data sampling rates of ~100 Hz

Very small, low power, easy to deploy

Can put out a larger number of sensors in an area

Can customize software on the motes for capture, preprocessing, etc.

Volcán Tungurahua

Volcán Tungurahua

Volcán Tungurahua

Active volcano in central Ecuador – 5018 m

- Near town of Baños, about 3 hours drive from Quito
- Observatorio del Volcán Tungurahua (OVT) run by Instituto Geofisico in Quito
- Site of much ongoing seismological research

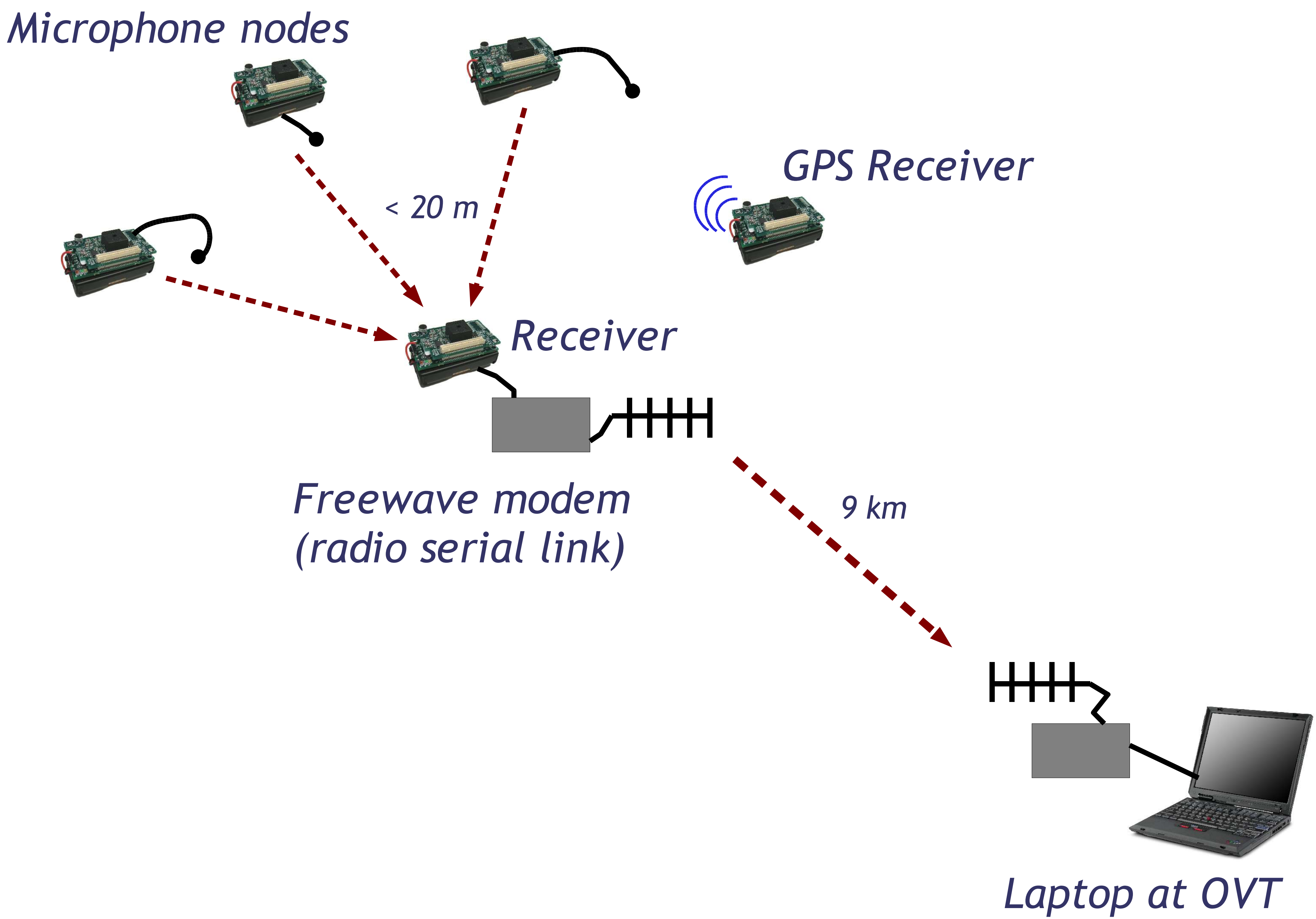
Seismology collaborators

- Jeff Johnson (Univ. New Hampshire)
- Mario Ruiz (Instituto Geofisico)
- Jonathan Lees (UNC)

We designed and deployed a wireless infrasound sensor network there

- Deployment ran continuously from July 19-22, 2004
- Colocated with wired seismic and infrasound station at Juive site (2900 m), about 1 hour drive (and long hike) from OVT

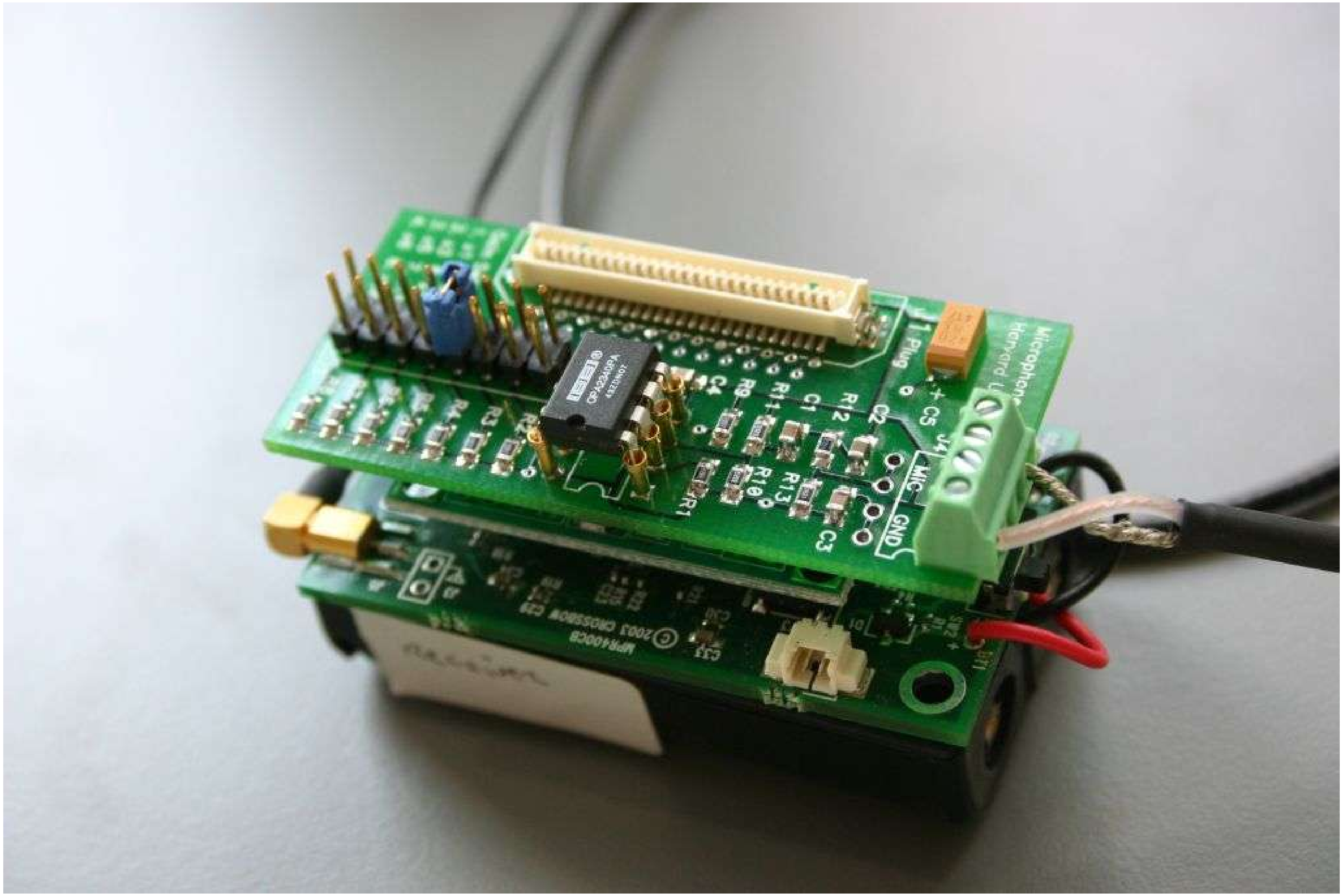
System Architecture



Infrasonic Microphone Mote

Custom sensor board (h/w design by Pratheev Sreetharan)

- Simple amp/filter circuit connecting to Panasonic condenser mic
- Configurable gain setting from 1x – 20x using jumper block



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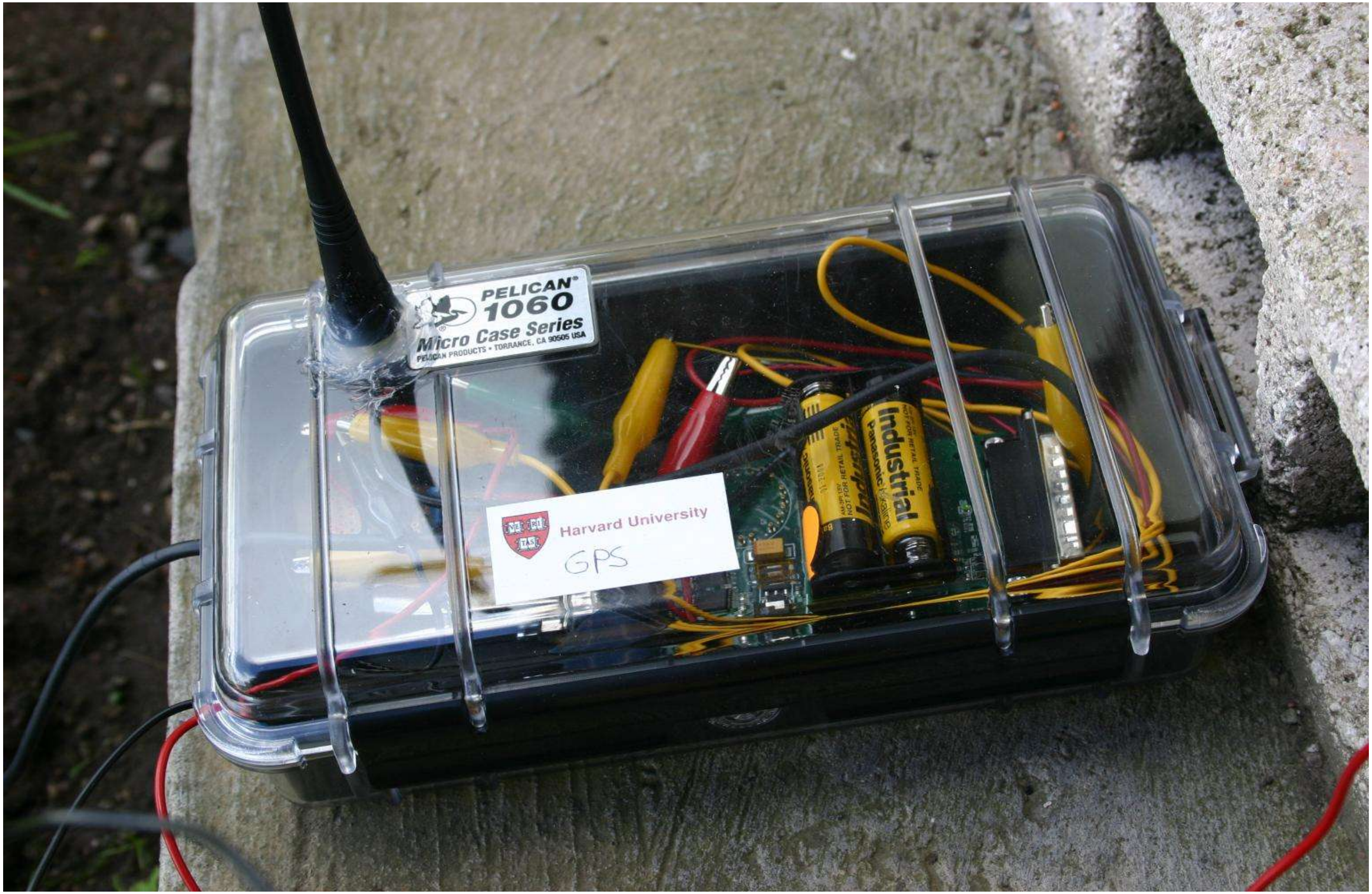
GPS Receiver

Establishes common timebase (essential for signal analysis)

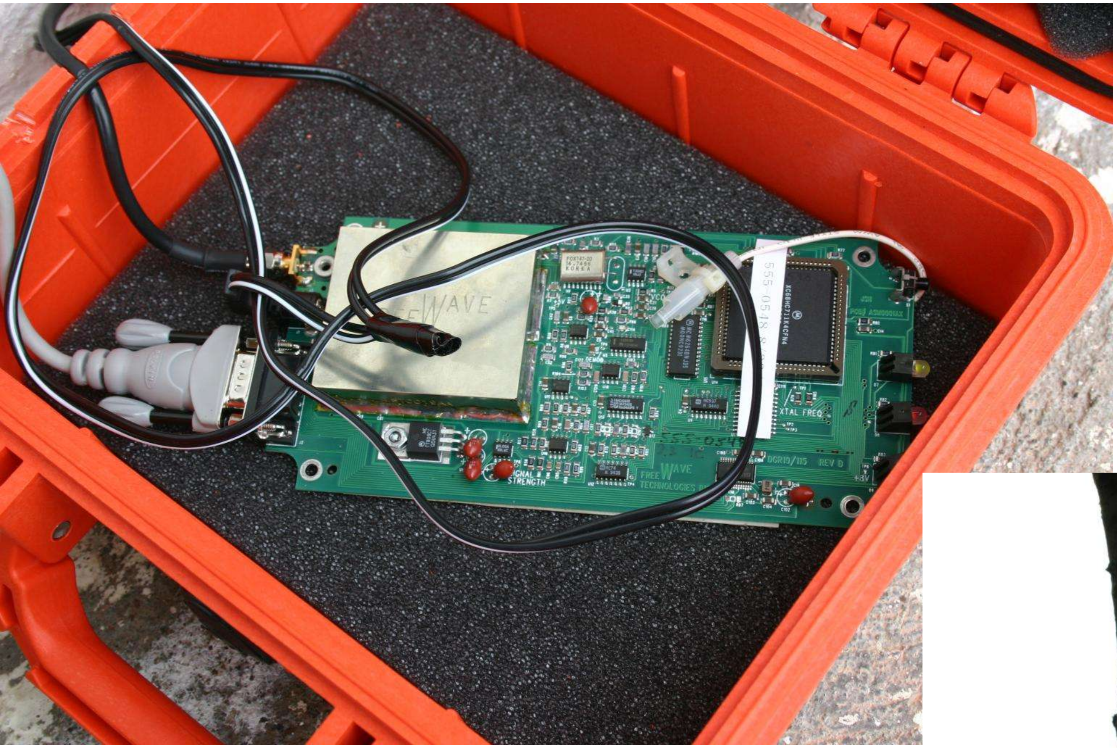
- Triggered by 1 Hz interrupt within 1 usec of each GPS second
- Transmits GPS time sync message to all motes



Freewave Modems

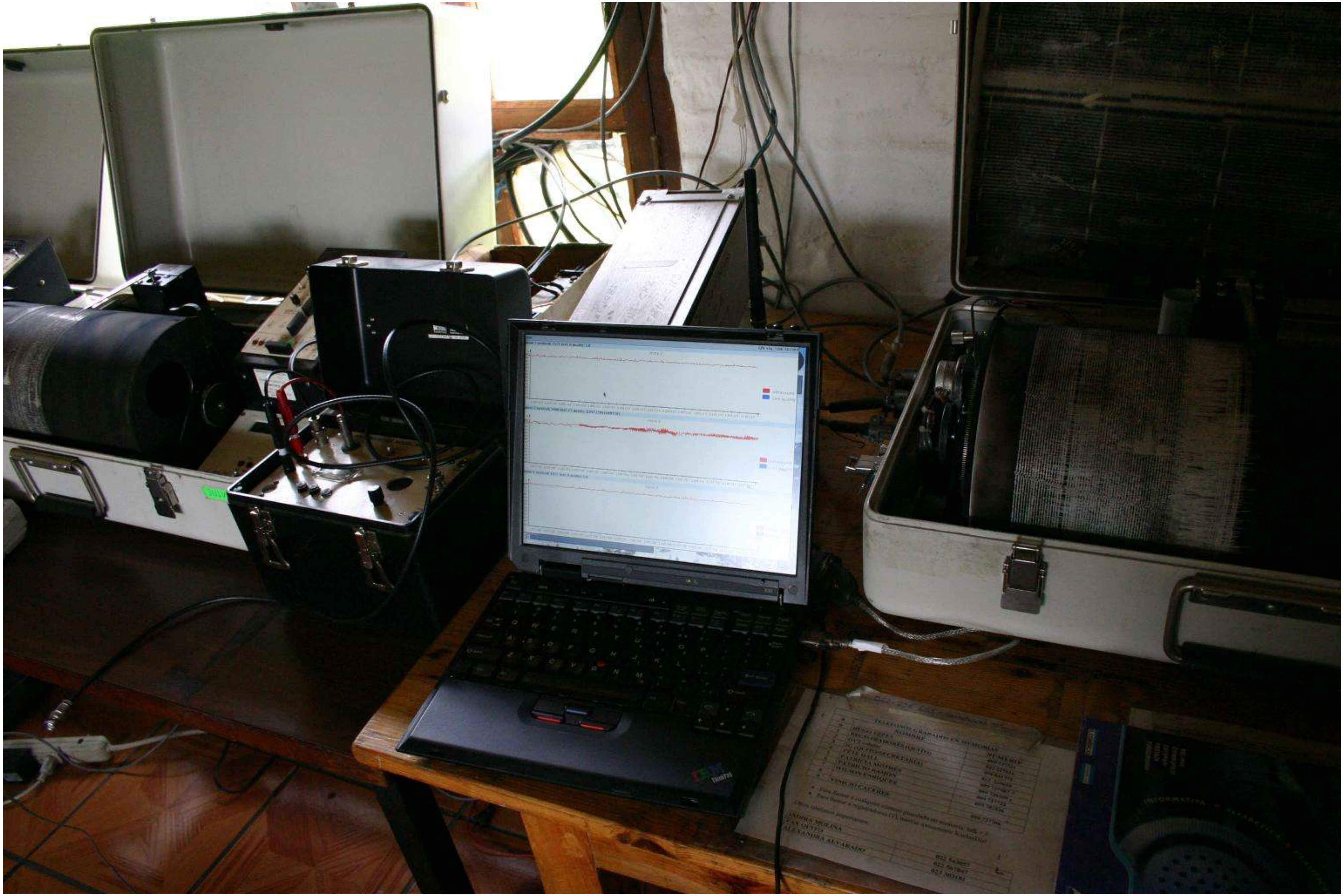
Long distance (9 km) radio link from Juive station to OVT

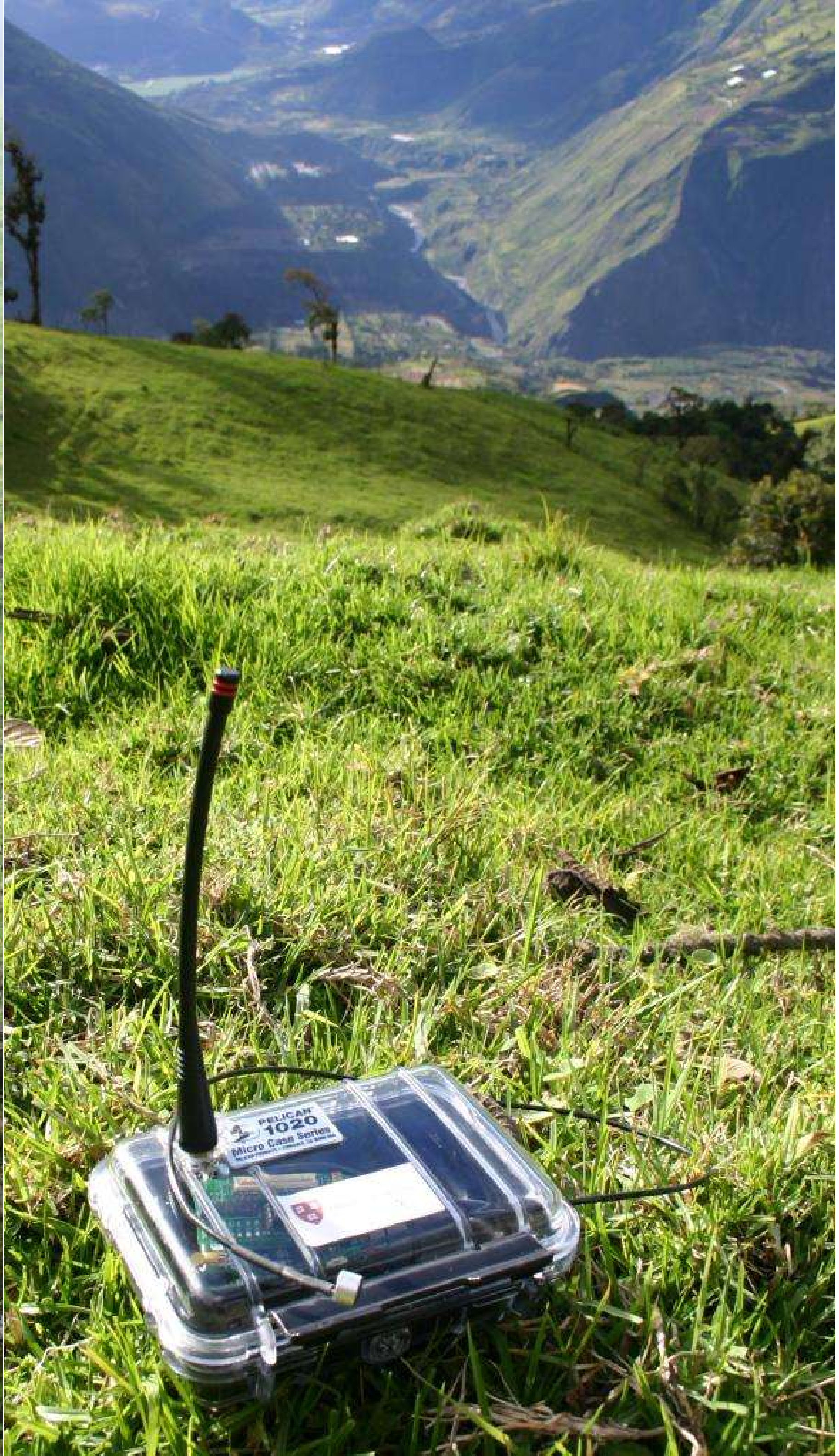
- 916 MHz wireless RS232 port at 115kbps – powered by 12V car battery



9 dBi Yagi antenna

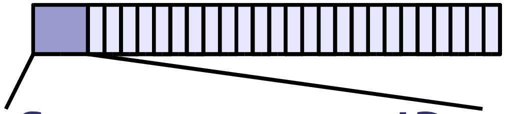
Laptop station at OVT




PELICAN
1020
Micro Case Series

Sampling and message format

25 samples/packet
102 Hz @ 10 bits/sample



Source mote ID
Sequence number
GPS seqno and sample #

GPS Time Synchronization

Motes record sample # and GPS time seq # in message

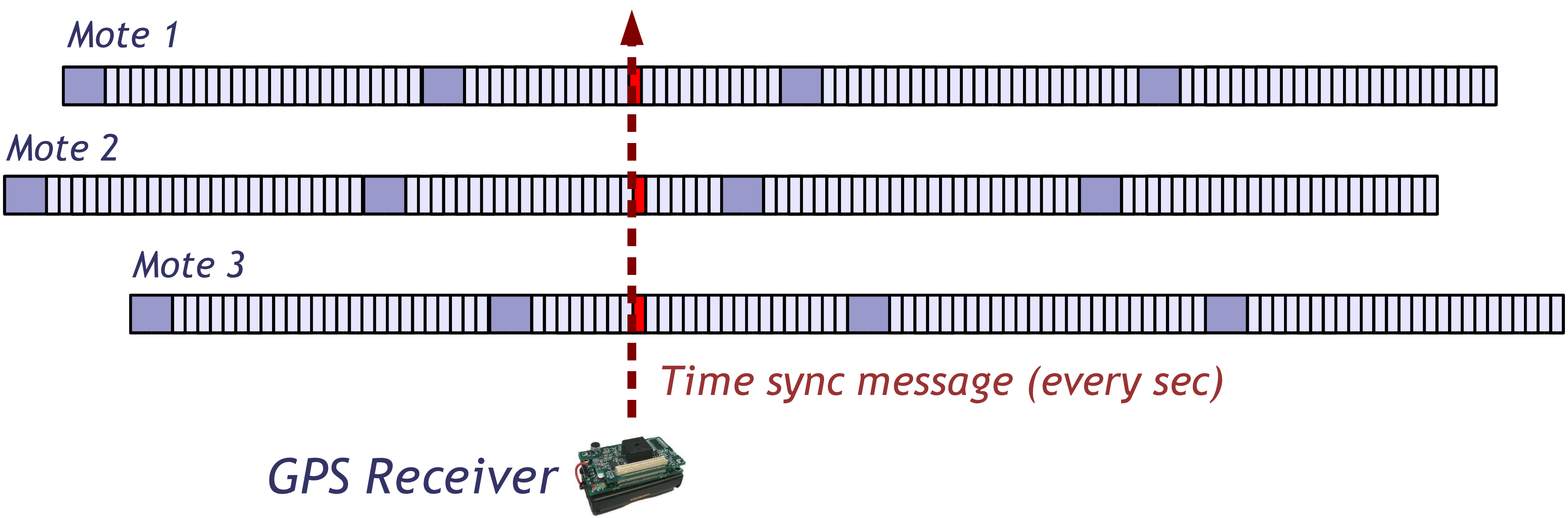
- Can be used to align samples from each mote
- Motes do not know what time it is!

GPS timesync message records delay from interrupt to transmission

- MAC delay on radio transmission may be several milliseconds
- Must correct for this when aligning samples

Linear regression on GPS timestamped samples

- Map each sample to an absolute time anchored by GPS timestamps



Data summary

Collected full trace of packets from 3 mic motes and GPS

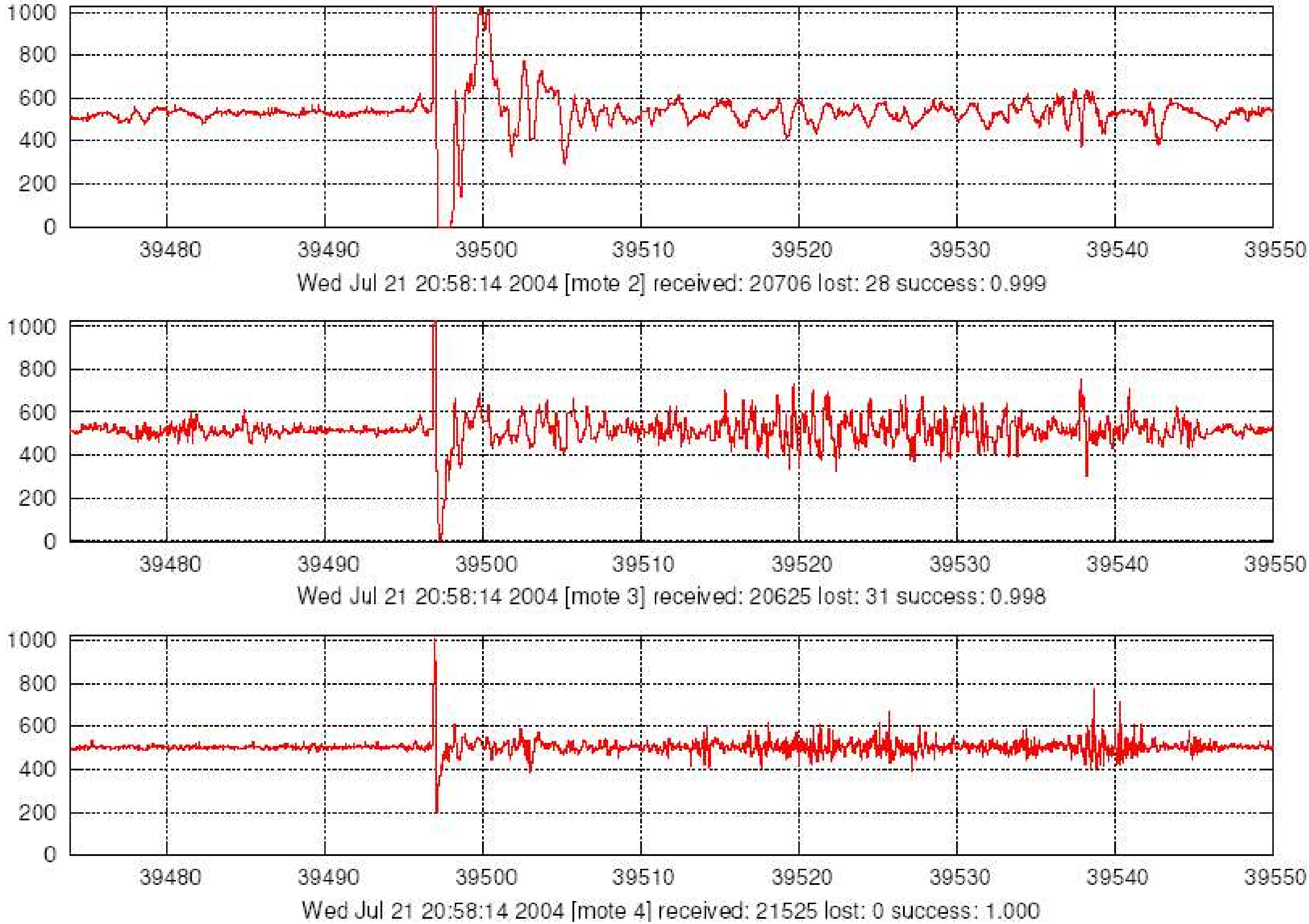
- Continuous sampling started 7/20/04 11:53, ended 7/22/04 18:19
- More than 54 hours of data

Over 1.7 GB of uncompressed ASCII logs (200 MB compressed)

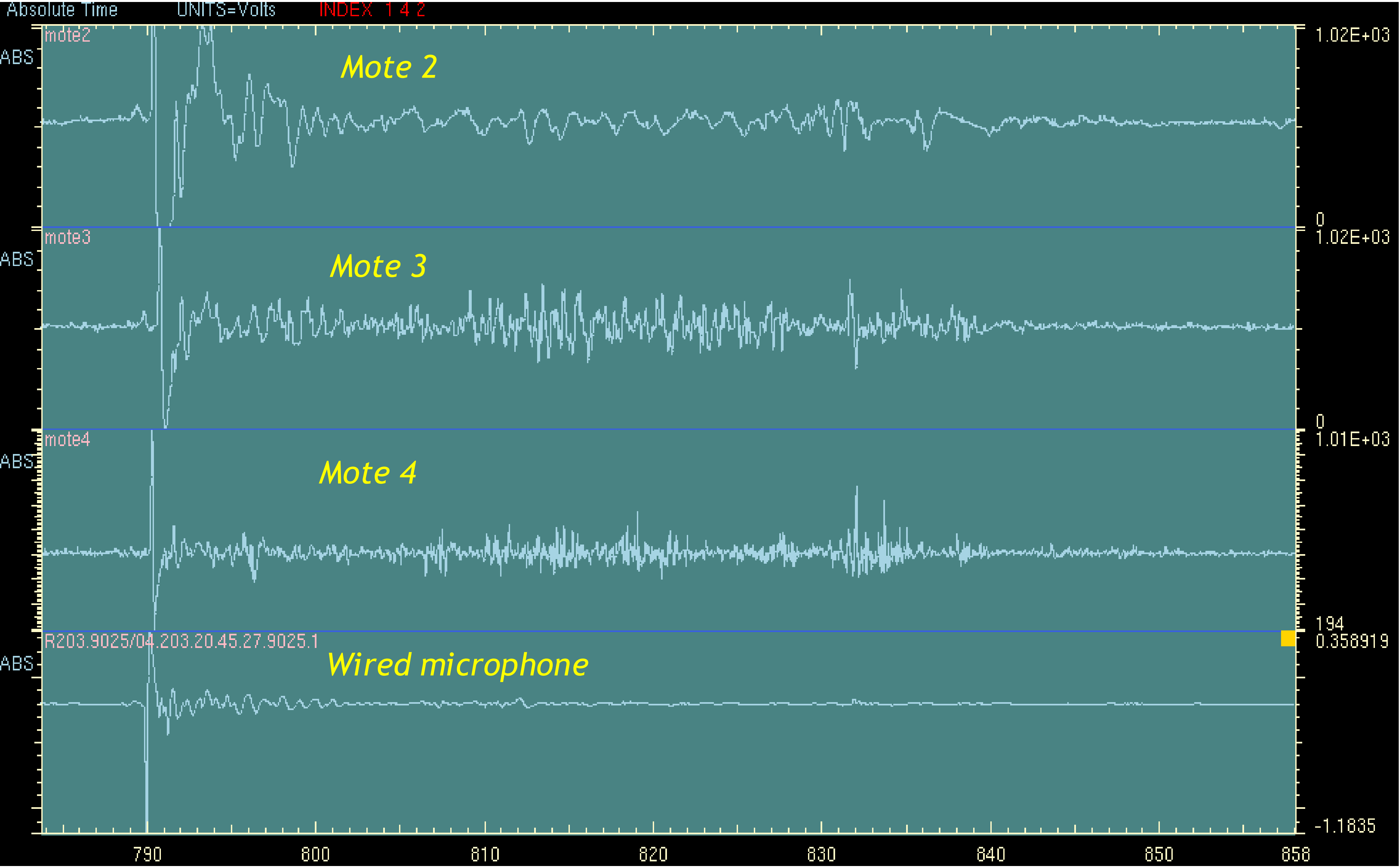
Right now, ugly Perl scripts to process this into time series data

- Lots of work to synchronize signals across multiple motes
- Need to clean up data too: Remove duplicate packets, interpolate missing data, etc.

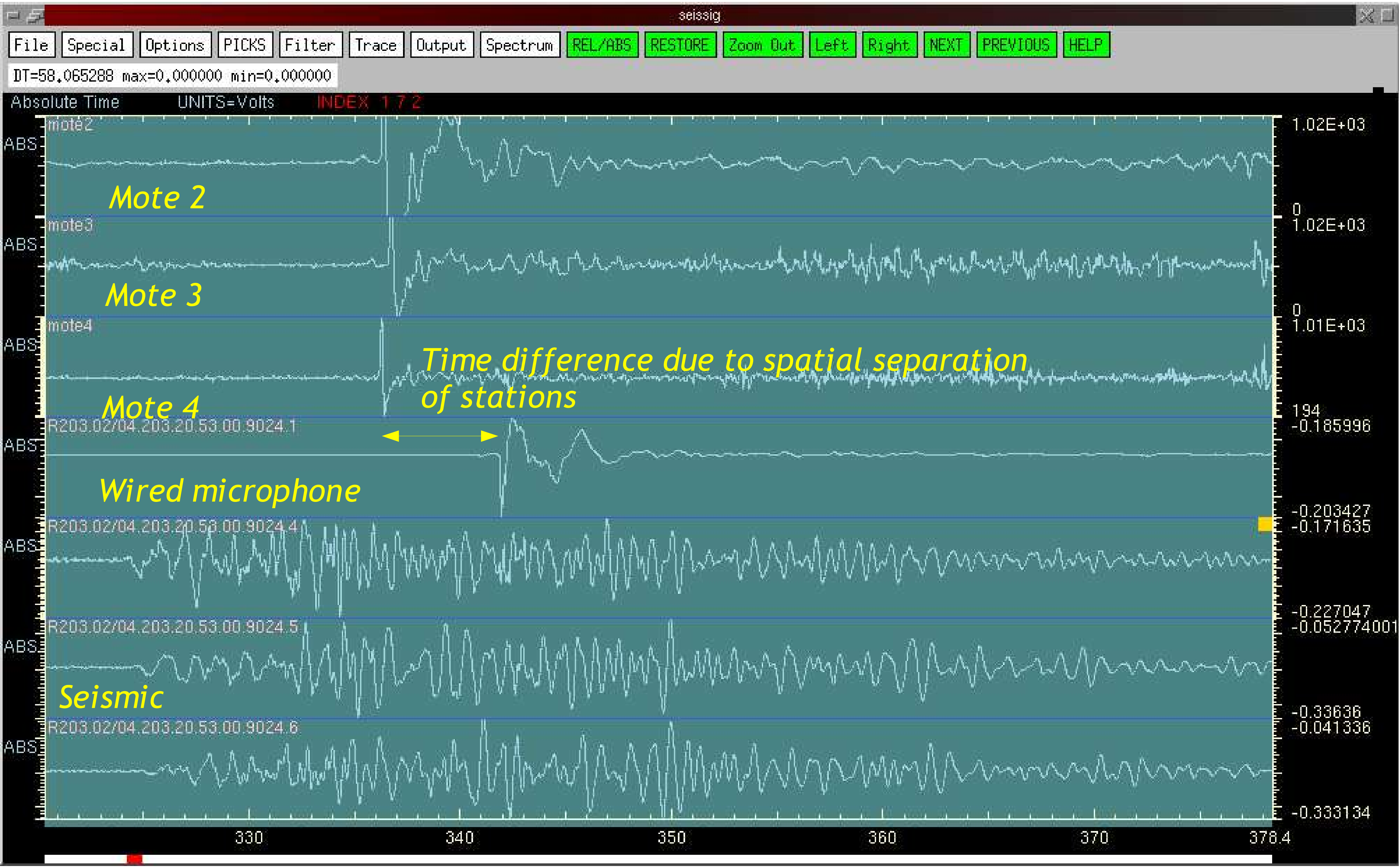
Example of eruption data



Comparison with wired station



Comparison with wired station



Future Research Challenges

Build up a larger, more spatially-separated array

- 20+ motes in a linear or cross configuration
- Use to determine eruption source location
- Need multihop routing to extend range

Dynamic triggering

- Rather than sampling continuously, only transmit “interesting” signals
- Collaborative signal filtering: Nodes communicate to decide if event is true eruption

Integrate with Telos and 802.15.4 radios

- More bandwidth, higher data fidelity
- Need 16-bit ADC though...

Investigate use of seismometers

- Sample at about 120 Hz, but, need 32-bit precision
- Use seismometer to wake up infrasound array

Future Deployments

Larger-scale deployment on Tungurahua

- Probably in Jan-Feb '05

Continue collaboration with Instituto Geofisico

- Look into use of mote arrays for long-term hazard monitoring

Discussing plans to deploy at other volcanoes:

- Volcan Arenal, Costa Rica – easily accessible, very active
- Stromboli, Italy – Multiple vent sources
- Mount Erebus, Antarctica

Credits

Geoff Werner-Allen

- Wrote all of the mote software, most of the PC software, and designed GPS receiver

Pratheev Sreetharan

- Hardware design for infrasonic microphone board

Thaddeus Fulford-Jones and Mark Hempstead

- Hardware debugging and supportb

Jim MacArthur and Bill

- Electronics lab support and lots of last minute debugging

Mario Ruiz, Jeff Johnson, and Jonathan Lees

- Huge amount of help and local arrangements in Ecuador