STS-1-VBB Sensor Replacement Program

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Program Background and Scope

Maintenance/replacement of global network of STS-1-VBB sensors a long-term concern
- e.g., 2004 IRIS Broadband Seismometer Workshop
- Created in part by decision of Streckeisen AG to discontinue manufacturing/support

Metrozet and BSL proposed a unique solution: Design and test of modern STS-1 Replacement
- Non-virgin design: maintains essential elements of original STS-1 architecture
- Added enhancements (remote control, calibration capability, simplified installation, etc.)

IRIS/NSF/GSN embraced concept: $1M+ of Development Funding to Metrozet/UC Berkeley
- 2006-2007: IRIS funded development of STS1-E300 replacement electronics
  - Currently being deployed/operated primarily within GSN, GEOSCOPE, and BDSN
- 2008-Present: NSF (EAR/IF) follow-on program: Replacement sensor/triaxial package
  - Community advocacy (specifically IRIS and GSN) were critical to receiving funding

Fairly unique public-private partnership with respect to VBB sensors
- Metrozet and UC Berkeley as NSF EAR/IF awardees
- Focused collaboration between supplier and customer (involving IRIS, ASL, and UCSD)

Different from more traditional arm's-length sensor procurement

Metrozet Acquired by Kinemetrics in July, 2009

Brought additional engineering and manufacturing resources to the program

Allowed Quanterra (Joe Steim) to play a more formal role in the sensor development process

- Unique knowledge base in "observational VBB sensor phenomenology"

- Good complement to ASL's testing expertise and to the field experience of end users (USGS and UCSD)

VBB Sensor Design and Status

Non-Galperin architecture (separate H and V sensor designs)

Very similar to original STS-1

Factory-leveled sensor elements: no field leveling required (ala STS-2)

Triaxial package with "warpless" design and kinematic sensor mounting

External electronics (slightly modified version of STS1-E300)

Modern, "volume-manufactured" design with adequate production throughput

High-level of modularity:

Sensors, electronics, and cabling can be swapped out during field maintenance

Individual components can be replaced by Metrozet

Rather than returning entire system for repair

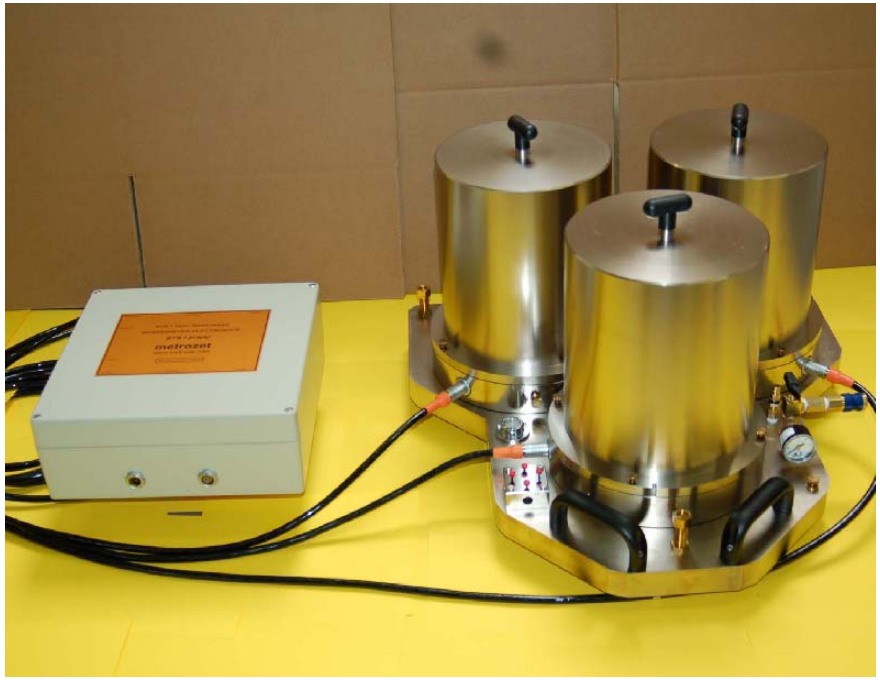
2008-2009 development testing at UC Berkeley (BKS) indicated sensor performance similar to BKS STS-1 sensors

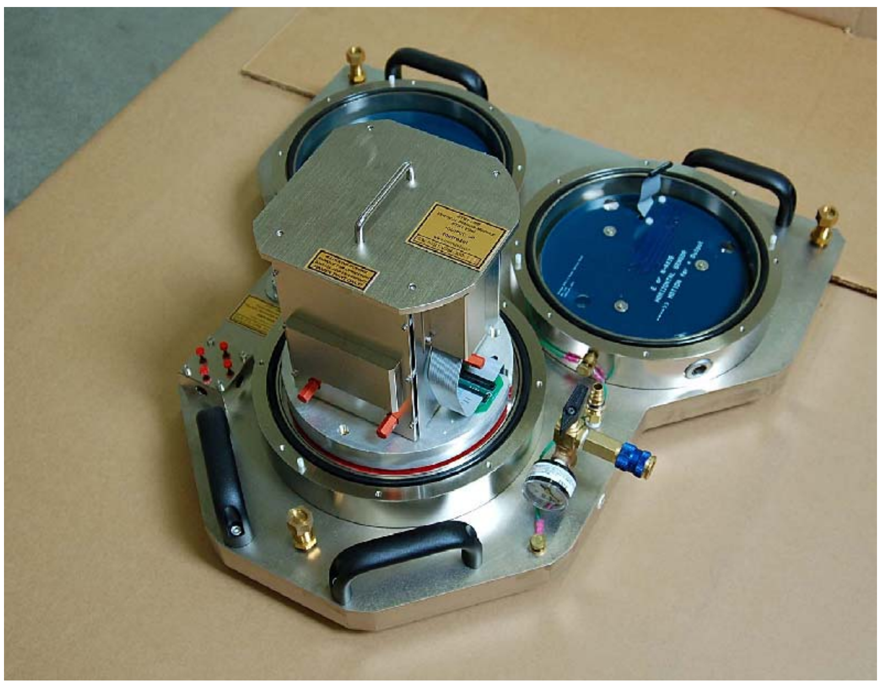
2010 Has focused on development of VBB commercial prototypes:

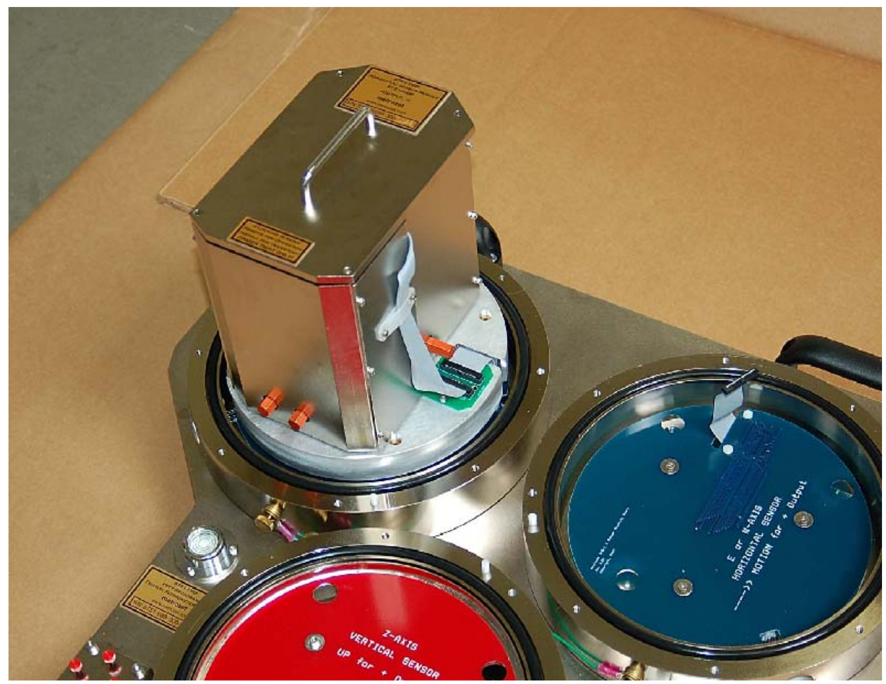
12 triaxial packages

12 sets of modified electronics,

15 triaxial sets of sensor elements


metrozet




Z-AXIS
VERTICAL SENSOR
E or N-AXIS
HORIZONTAL SENSOR
MOTION for + Output

VBB Commercial Prototype Testing

Initial functional test at Byerly Vault (BKS)

Began in April, 2010

8 systems evaluated to date

Longer-term performance testing at HRV

Began in May, 2010;

6 triaxial packages and 7 triaxial sensor sets evaluated to date

2 to 3 month measurement period

Cross-comparison with HRV GSN STS-1 sensors in vault

Partner/Customer evaluation at ASL began in September 2010

2 complete systems installed: one in cross-tunnel and one in outer vault

Cross-tunnel system installed on granite slab with (unpackaged) STS-1H pair

Sand-packed STS-1Z is on tunnel floor, adjacent to slab

Testing Philosophy

HRV tests (and experience) indicate the need for long-term test deployments

Sensors may require many weeks to stabilize at lowest noise levels

Thermal stability of vault important to settling process

Unfortunate degradation of settling environment with periodic access to vault

Deployments longer than what is "convenient"/customary may be important!

ASL focus on determining best-case incoherent self-noise figure

Very important to this class of sensor

Testing sensors on slab, comparison to sand-packed sensors, etc. are useful tools

GSN-specific tests are also important

i.e., new triaxial sensor on vault floor next to old triaxial sensor

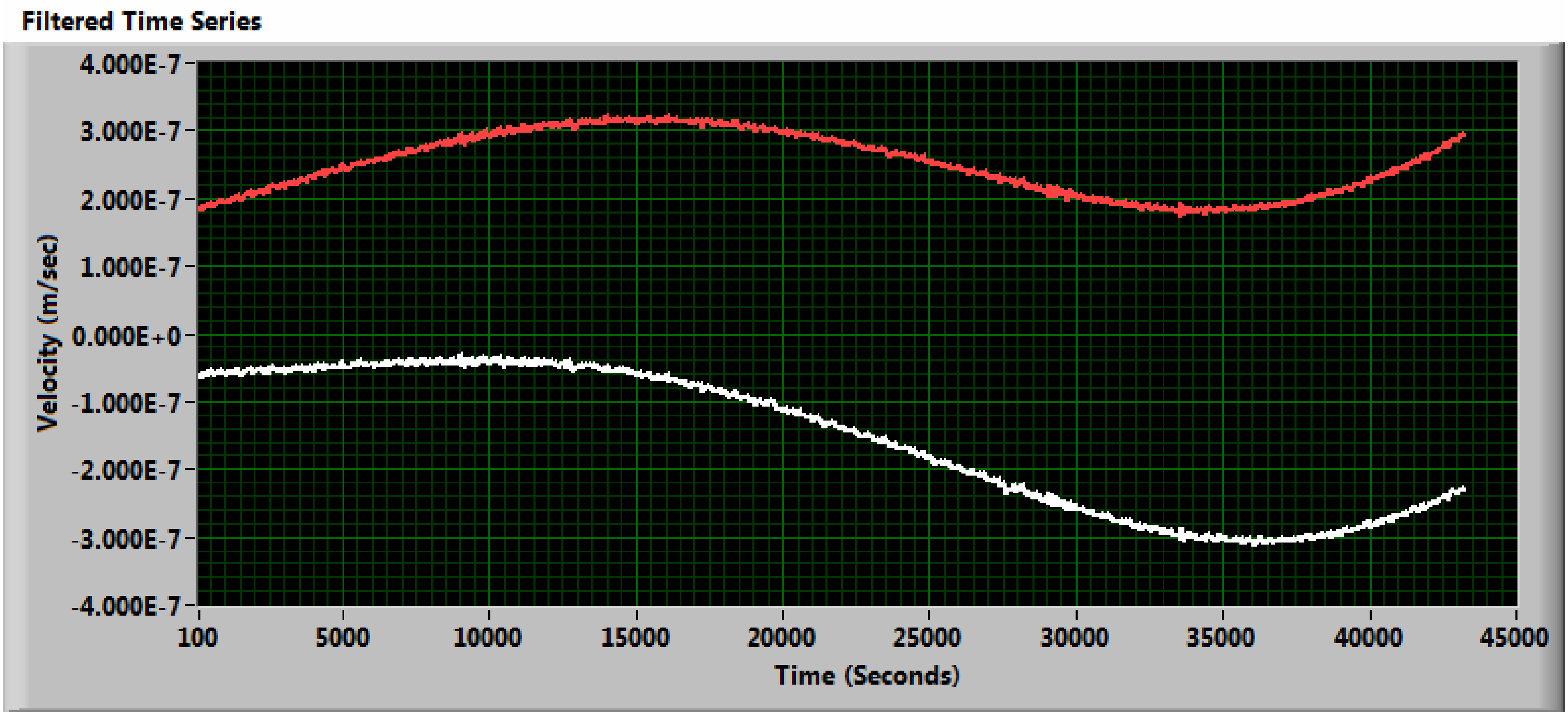
With similar environmental shielding

Apples-to-apples testing, rather than ultimate best-case

Note: Low self-noise under best conditions does not guarantee low self-noise in less ideal conditions

Data from ASL

Vertical Sensor: 2 Days after "final" installation of sensors in cross-tunnel

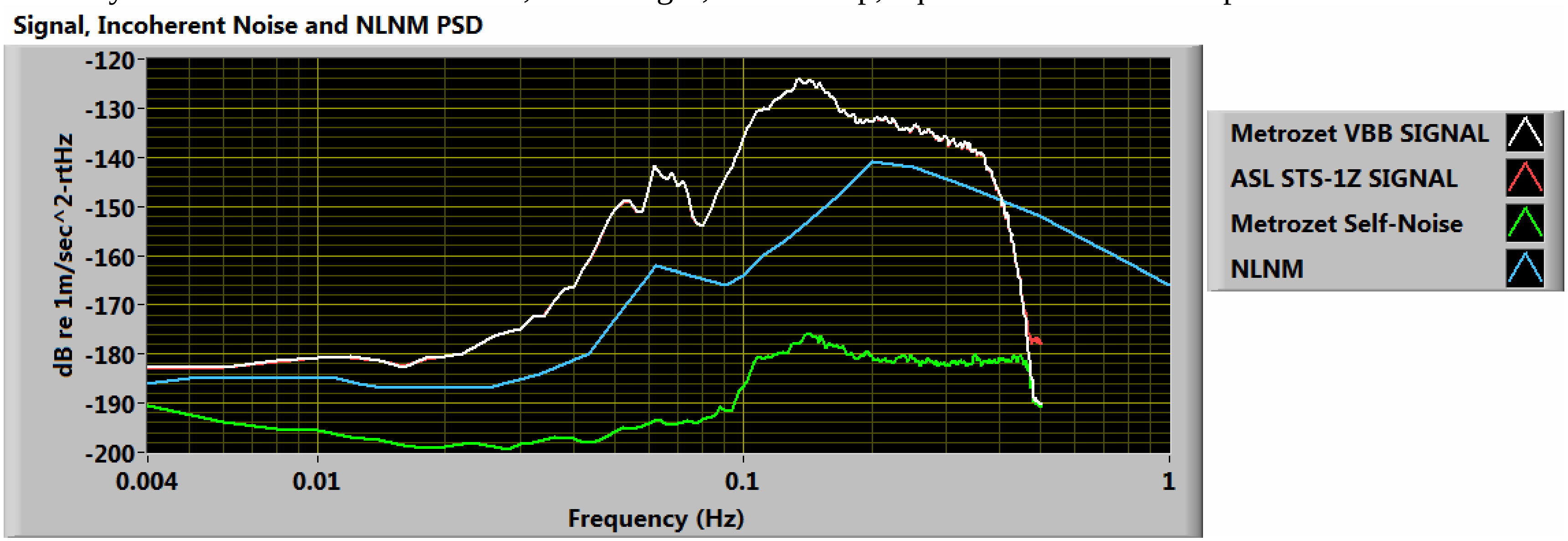


White: Metrozet Z Prototype in Triaxial Package
Red: ASL Reference STS-1Z Sand-Packed

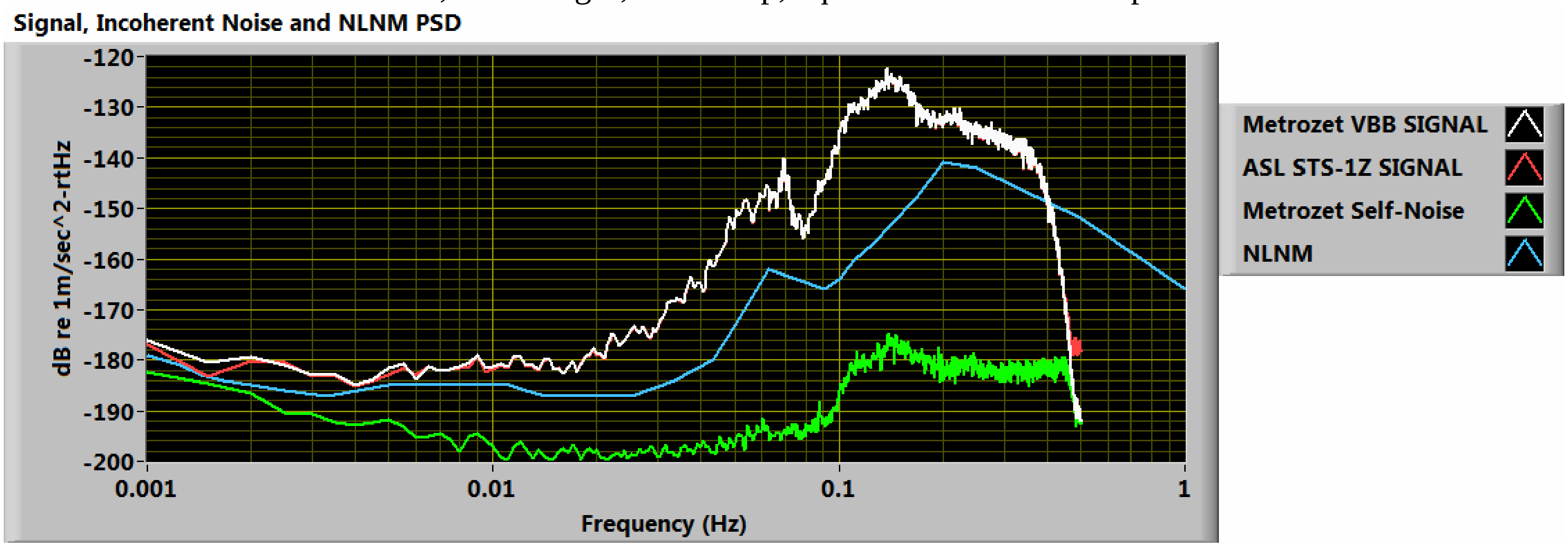
Day 274 data; 30 second LP Filtered; Scalar-Deconvolved Only;
Not Deconvolved of Poles/Zeros

Power Spectral Density (PSD) Analysis

ASL day 274 data: 500 Second Pieces, 80 averages, 0% overlap; equivalent sensor assumption



Same data: 2000 Second Pieces, 20 averages, % overlap; equivalent sensor assumption

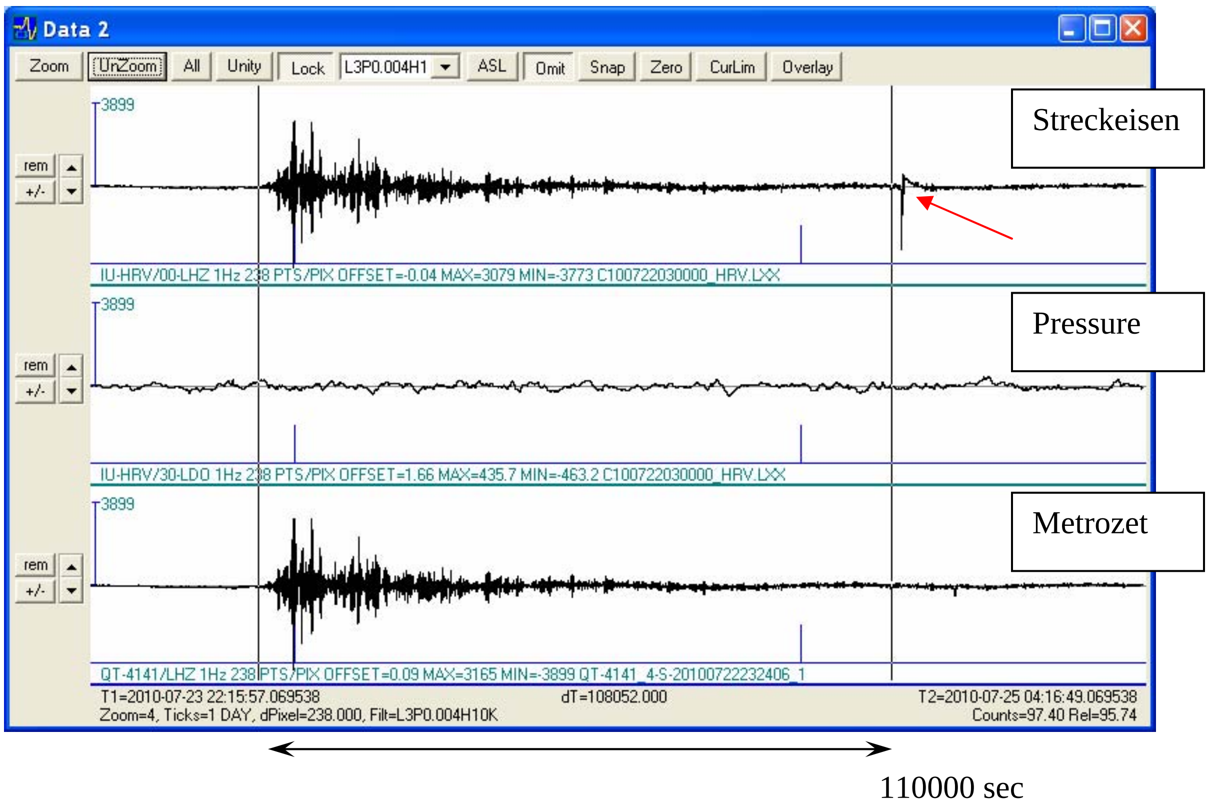


Teleseism Recording at HRV

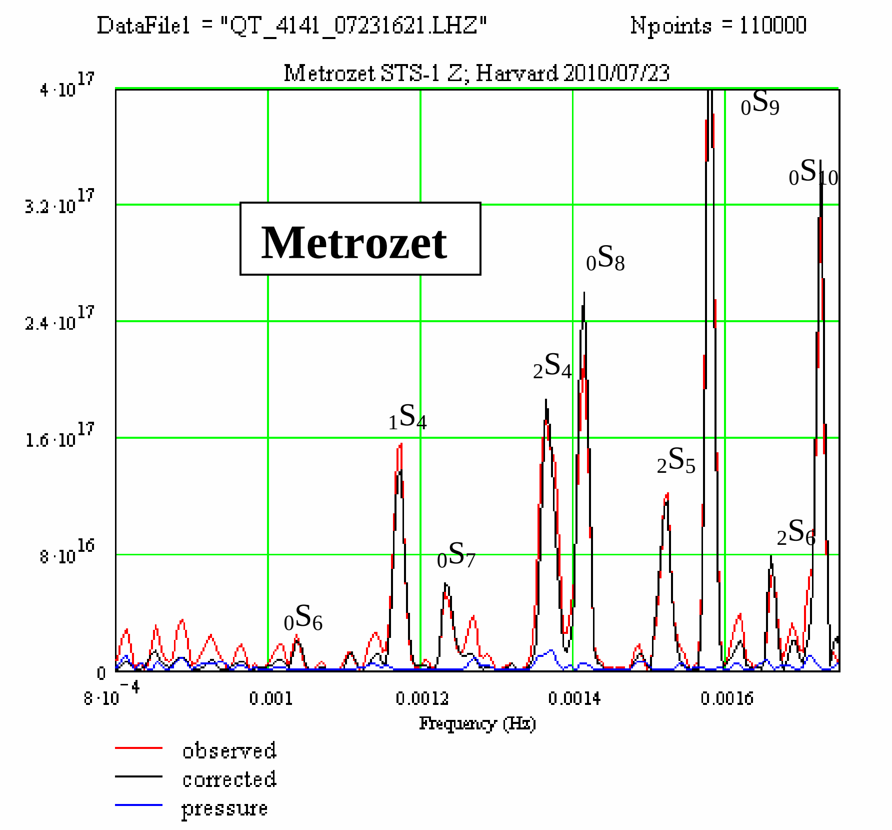
M7.3/M7.6 Overlapping (Deep) Events: Mindanao, 23 July, 2010

Vertical Sensor Data

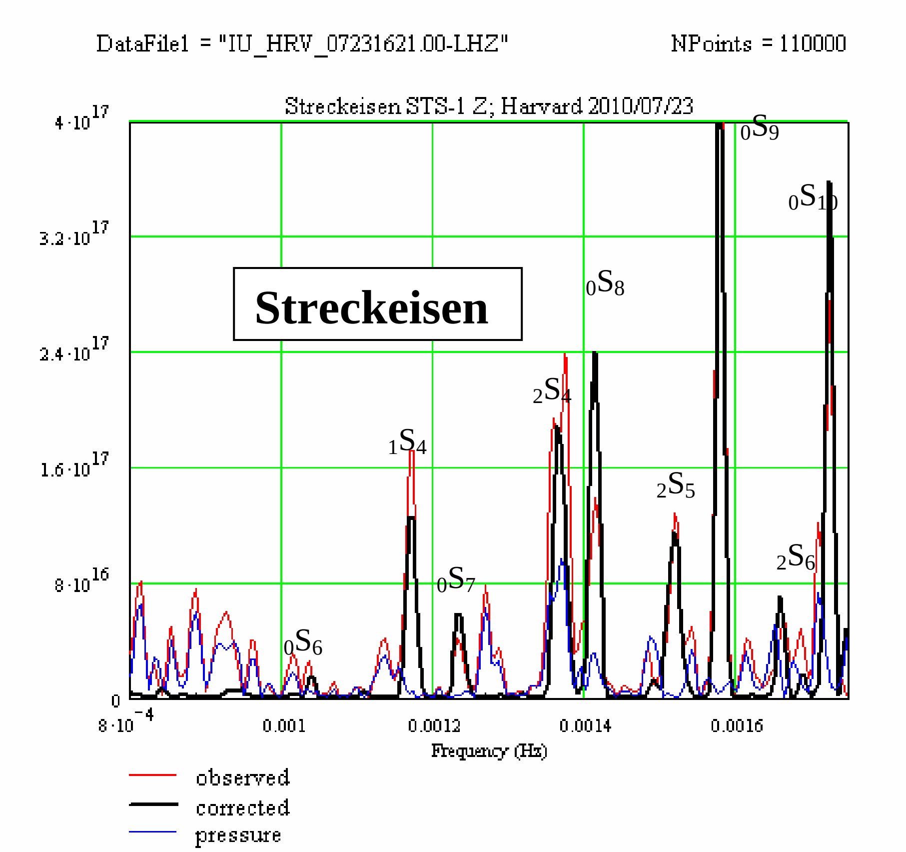
0.1 to 4 mHz Bandpass Filtered Time Series



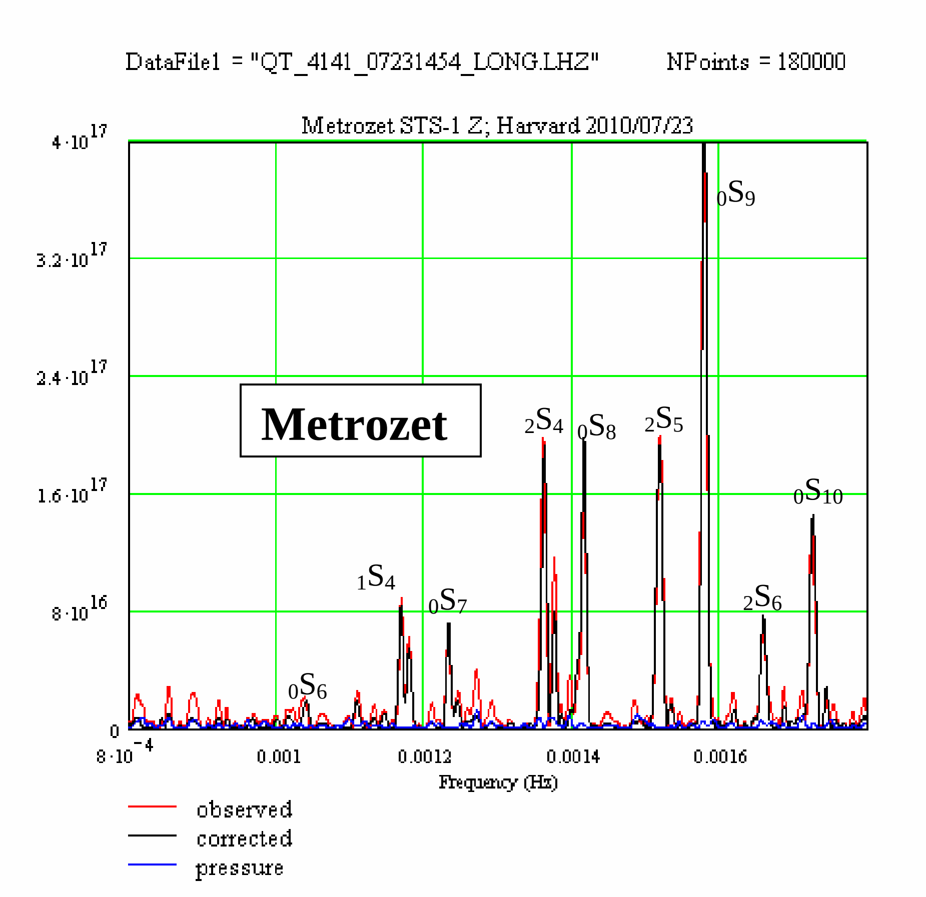
Glitch on HRV STS-1 sensor precludes analysis past 110,000 second window



HRV



Raw and pressure-corrected spectra from 110,000 seconds of data



A longer (180,000 second) interval allows Metrozet sensor to observe splitting!

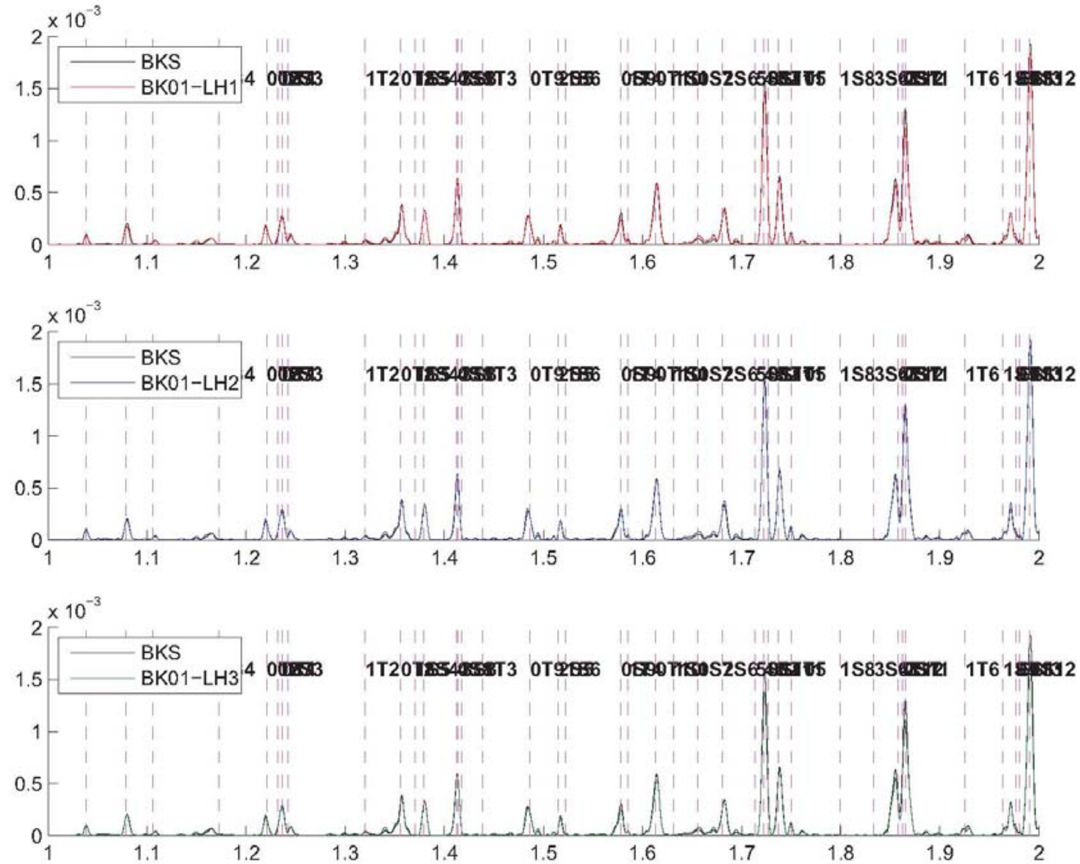
Glitch on HRV STS-1 limits useful data analysis window length

Encouraging Results on Most Critical Component (Vertical)
Viable Candidate STS-1 Replacement Instrument

Teleseism Recording at BKS

3 Co-Aligned Horizontal Sensor Prototypes (at BKS Relative to BKS-STS-1E)

M8.8 Chile Event, February, 2010



Remaining Issues

1. Slightly lower correlation between atmospheric pressure and Z-sensor response

May impact pressure removal that is a tool in normal mode analyses

May reflect higher thermal conductivity of aluminum pressure cans of new design

Direct (on-contact) thermal shielding of cans has likely improved pressure correlation

Part of a larger set of investigations (Wielandt/Steim/Hutt in November 2010)

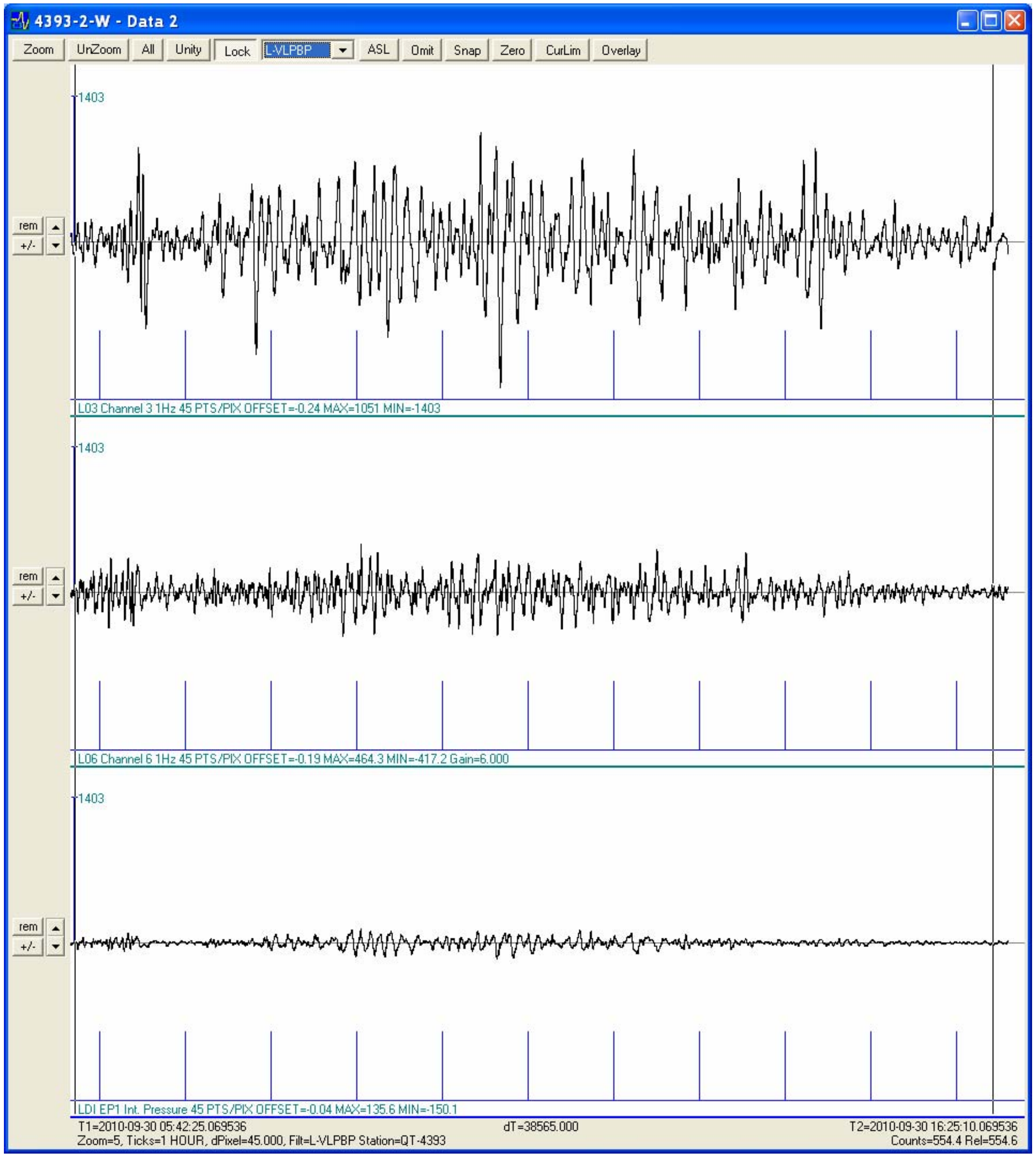
2. Observed horizontal signal energy higher than with old sensors

Clearly higher correlation between H sensor output and atmospheric pressure

Implication is that intended "warpless" nature of package is short of the mark
- Soluble problem, given community's understanding of this phenomenon
- Already considering experiments with ASL to address causes

Small H-sensor transients are also a potential issue
- May be related to settling (tilt) of the package in the cross-tunnel
- Need to understand if H-sensor "settling" is prolonged relative to original STS-1H

EW oriented H Sensors at ASL vs. Pressure: Equal Scale Plots



Metrozet E Sensor
(in new triaxial package)

ASL STS-1E (unpackaged)
Also pressure-sensitive

Vault Pressure

Schedule

Late 2010: Address remaining technical issues and finalize commercial prototype sensors

Early 2011: Release (sell) select prototype systems for customer evaluation

Late 2011: Expect to ship commercial systems in volume

Where Next?

KS-54000 borehole sensor replacement is an oft-mentioned wish from GSN

We believe that IRIS/GSN community would prefer an STS-1-VBB performance sensor rather than another mid-class BB sensor

Streckeisen STS-3 shows promise: subject of November tests at ASL

Alternative concept of eliminating downhole electronics completely is attractive

The widespread utility of an open-loop VBB sensor (Zumberge, et al.) is arguable
Time will tell.... But,

The Metrozet architecture (remote electronics) is potentially applicable to this concept

- Minimal on-board electronics (capacitive preamp only)
- Design is compatible with 100m sensor-to-electronic spacing
  - High-level (i.e., low impedance) signals in cable.

Current Metrozet VBB sensor elements are too large

Compact version currently under development by Metrozet/KMI

- Compatible with 5.38" OD package, including internal coarse leveling system
- Very similar operating principle to larger sensor

Configuring this system for borehole VBB application is worth exploring jointly