Early Results from Testing and Deployment of Cascadia, Instruments With Over 200dB of Dynamic Range

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Abstract

The new Cascadia Compact combines a compact broadband seismometer and class A accelerometer managed as a single instrument that can be quickly buried at shallow or posthole depths to provide always on-scale high-dynamic range recordings. With total dynamic range of 200 dB and the ranges of the two sensors overlapping by 136 dB, both weak motion and strong motion signals up to +/- 4g are captured with high fidelity. The orientation of the two sensors are precisely aligned, achieving a very high degree of coherence between the accelerometer and seismometer for events that lie within the range of both. There is no discernible crosstalk between the two, which ensures that accelerometer self-noise never affects the seismometer, and conversely signals that clip the seismometer never affect the on-scale waveforms from the accelerometer.

We present results from testing and verification of the integrated sensors along with data quality reviews of recent deployments. The results confirm the Cascadia meets its design intent: self-noise of the two sensors as expected, coherence of the two sensors during real events, and no crosstalk is evident even when driving each sensor with calibration signals.

Description of Cascadia Integrated Sensors

The combination of proven high-performance strong motion and weak motion seismic sensors into a single integrated modular unit that can be installed as a single instrument provides several advantages for installation as well as improved performance.
Several options can be considered, incorporating a variety of physical form factors, seismometer technology, and accelerometer signal range selections.

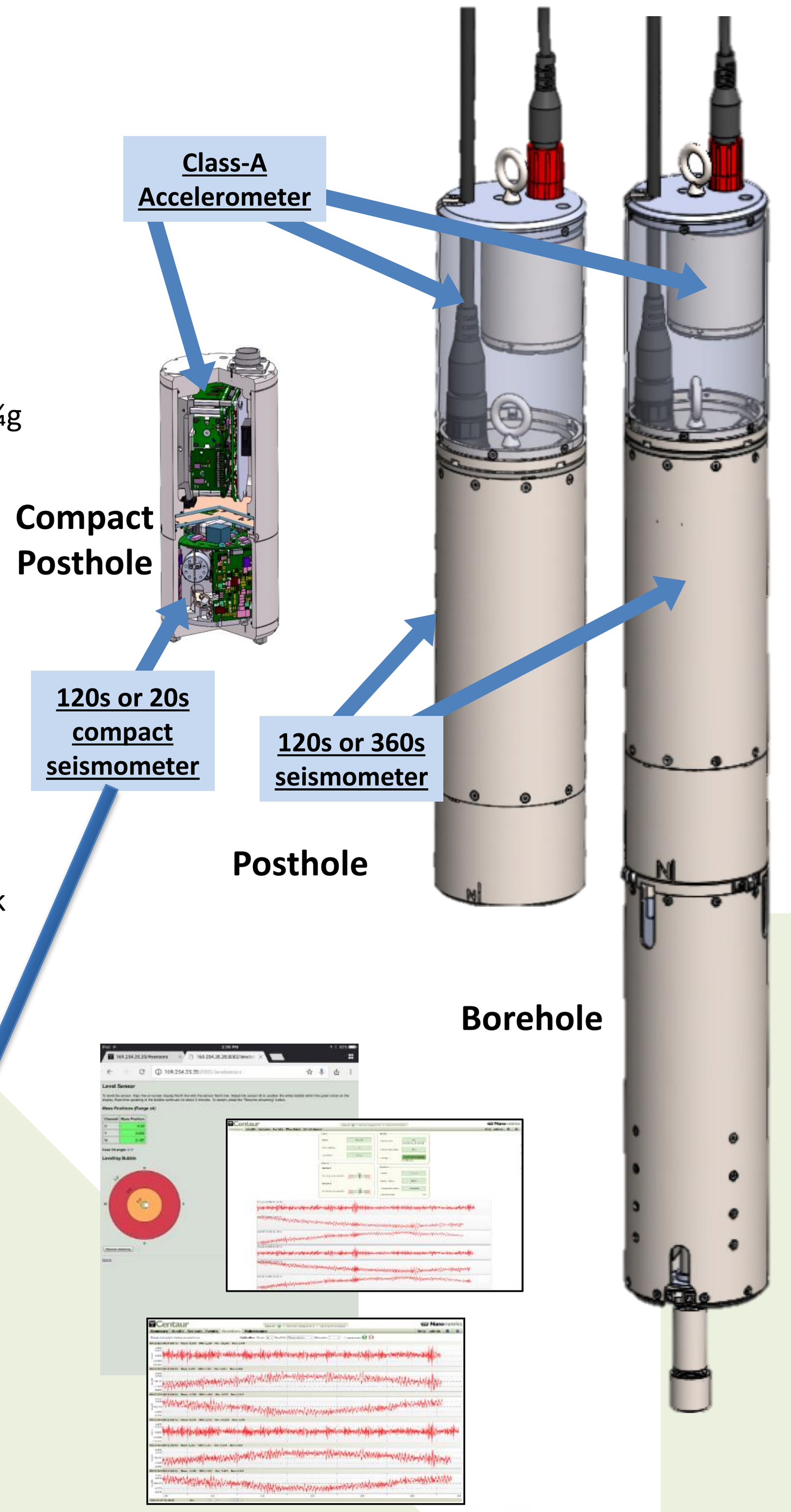
Form-factors:
- Compact posthole 97mm(3.8") diameter
- Auto-leveling full Posthole 143mm(5.75") diameter
- Observatory-class Borehole 143mm(5.75") diameter

Seismometer technology:
- Compact Broadband - 120s (in compact form-factor)
- Compact 10° tilt-range - 20s (in compact form-factor)
- Observatory-class – 120s (in full posthole or borehole)
- GSN-class – 360s (in full posthole or borehole)

Accelerometer range:
- Dynamic selection of signal range: ±4g, ± 2g, ± 1g, ± ½g, ± ¼g

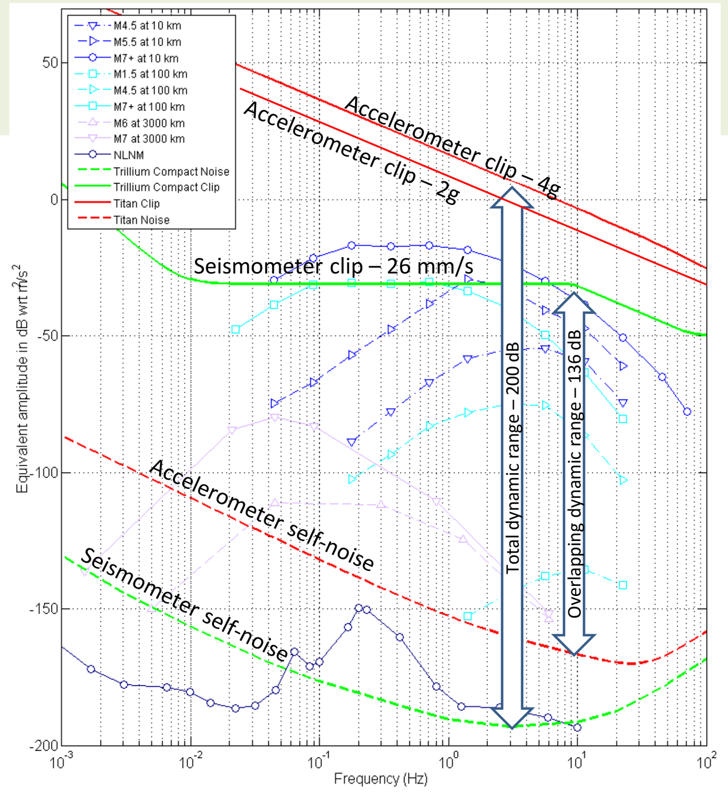
Site and Installation Improvements
- Two sensors managed as one
- Bore or dig one hole, whether shallow or deep borehole
- Manage one cable (compact form-factor)
- Level and align once
- Electronic leveling bubble on digitizer GUI
  - Easily manipulate the compact posthole in a dark hole
  - Check vertical orientation of sensor at any time remotely
  - Observe verticality of borehole casing during installation

Performance and Operational Improvements
- Always on-scale: local large magnitude as well as very weak signals recorded with the high combined dynamic range of the two sensors
- All six channels precisely aligned
- Surface noise (cultural, temperature, tilt) reduced, even with shallow burial

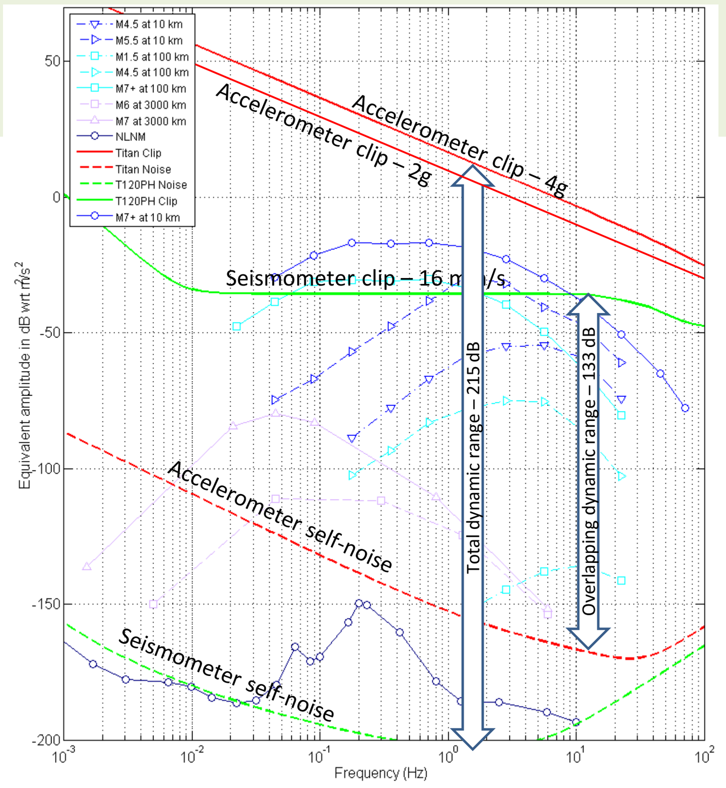


Dynamic Range

The purpose of combining an accelerometer and a seismometer at one station is to ensure all desired signals from largest to smallest amplitudes are recorded with fidelity and sufficient signal-to-noise ratio. It is crucial that both sensors have high dynamic range, and that these ranges overlap significantly. The region between the seismometer clip level and the accelerometer self-noise floor is the "overlap dynamic range" of the combined instrument. The region between the accelerometer clip level and the seismometer self-noise floor is the "total dynamic range" of the station.



4g Class A Accelerometer + Compact 120s Seismometer



4g Class A Accelerometer + Observatory 120s Seismometer

Two examples are shown: a Titan 4g accelerometer combined with a Trillium Compact 120s seismometer, and the same accelerometer with a Trillium 120 Posthole. Other options can be considered, e.g.: GSN-class 360s seismometers, configuring the accelerometer to 2g.

Integration Verification Testing: Crosstalk Plots

Figure 1 shows waveforms of both sensor modules on a Centaur 6-channel digitizer, with a calibration pulse on Compact at bottom. No crosstalk is visible. Figures 2 and 3 show a more sophisticated measurement where a PRB calibration signal was injected on Compact and crosstalk was measured via a Sleeman coherence analysis between the two sensors. In the PSD (Fig. 2) there is up to 115 dB separation between Compact (solid lines) and Titan Z (dotted lines), and Titan Z is still well below its noise spec limit. Titan X and Y (dashed lines) are higher due to horizontal ground motion at the site. The logarithmic coherence plot (Fig.3) shows no correlation between the calibration signal on Compact and the noise on Titan, all the way down to 2000 seconds period, indicating no detectable electrical or thermal crosstalk . The solid blue line at 0 dB indicates the threshold of detectable correlation and the dashed blue line indicates the threshold of statistically significant correlation.

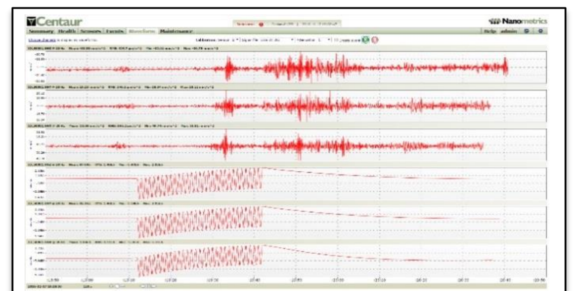


Figure 1: Waveforms of Compact seismometer calibration pulses and background signal on Titan accelerometer

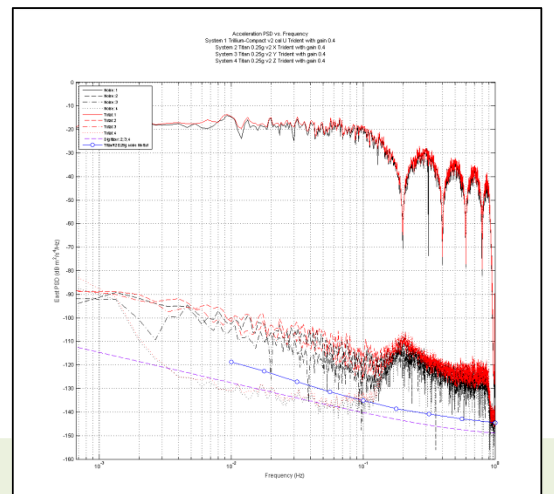


Figure 2: Acceleration PSD with calibration signal on Compact

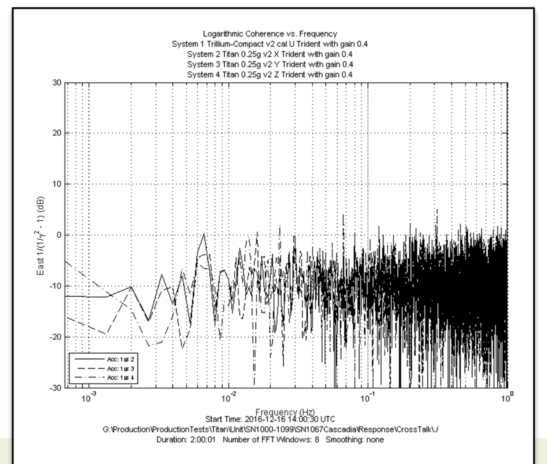


Figure 3: Logarithmic coherence between Compact calibration signal and Titan X, Y, and Z outputs.

Similarly, Figures 4, 5, and 6 show no correlation between calibration signal on Titan and noise on Compact. This was a daytime lab measurement with significant background activity which limited the resolution of the measurement. The PSD shows signal up to 70 dB lower on Compact, and it is not correlated with Titan, indicating crosstalk is <-70 dB and possibly much lower.

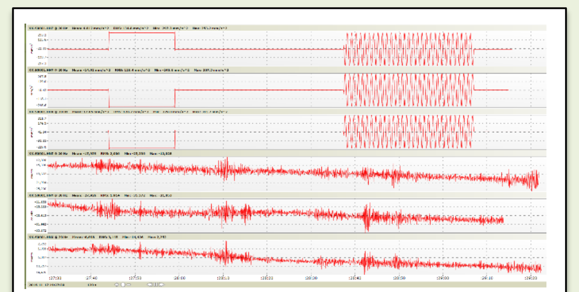


Figure 4: Waveforms of Titan accelerometer calibration pulses and background signal on Compact seismometer

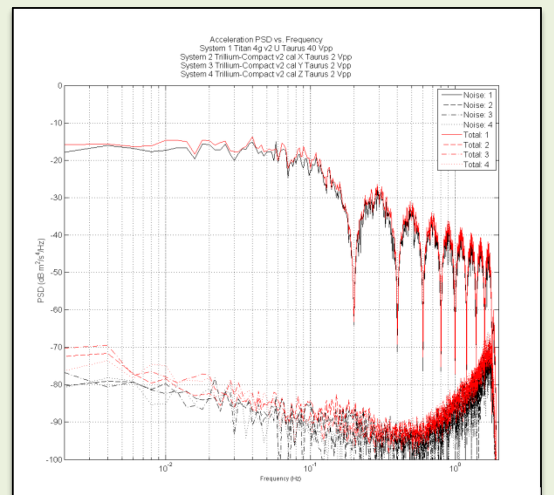


Figure 5: Acceleration PSD with calibration signal on Titan

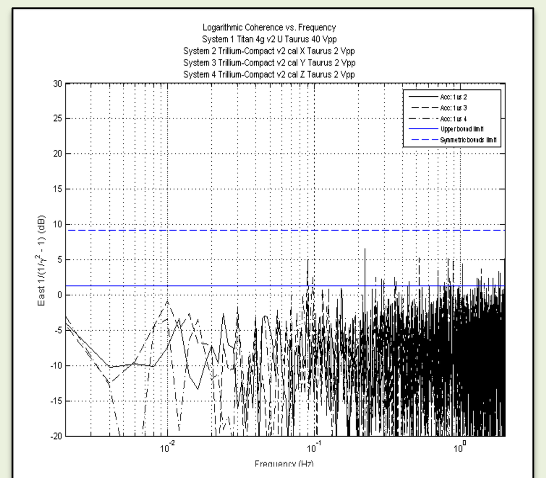


Figure 6: Logarithmic coherence between Titan calibration signal and Compact U, V, and W outputs.

Early Metrics From Field a Deployment Test

Initial Field Deployment Test

A Cascadia Compact sensor and a 6ch Centaur were recently deployed within 50 meters of an Earthscope TA station Y22D in Socorro NM, the Cascadia deployment was in a flex array test vault that is ~1 meter deep. Data available in May 2017 at the IRIS DMC

PDFs
Cascadia Compact station SOC1 noise performance compares favorably to reference sensors at Earthscope TA station Y22D, as shown in Figure 7

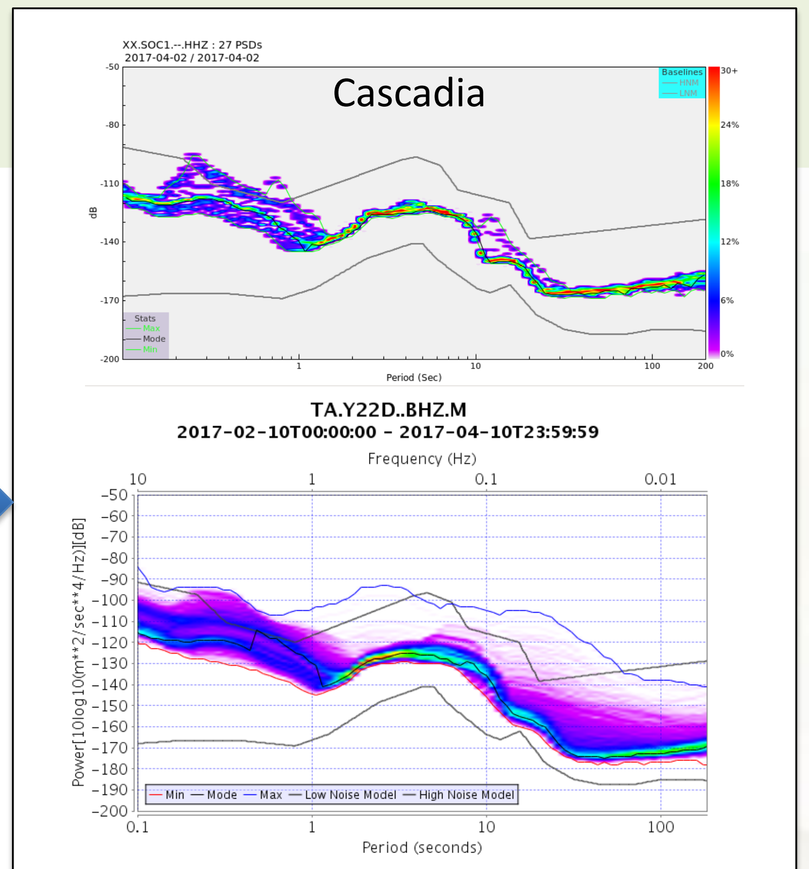


Figure 7 (Y22D PDF obtained from IRIS DMS Web Services)

Earthquake Spectra Comparison
Kamchatzk Russia EQ 130 degrees away
M 6.6 - 78km NNE of Ust'-Kamchatsk Staryy, Russia
2017-03-29 04:09:24 UTC56.921°N 162.734°E22.8 km depth
Figure 8 plot demonstrating coherence of Titan accelerometer and Compact seismometer on recorded teleseism of earthquake

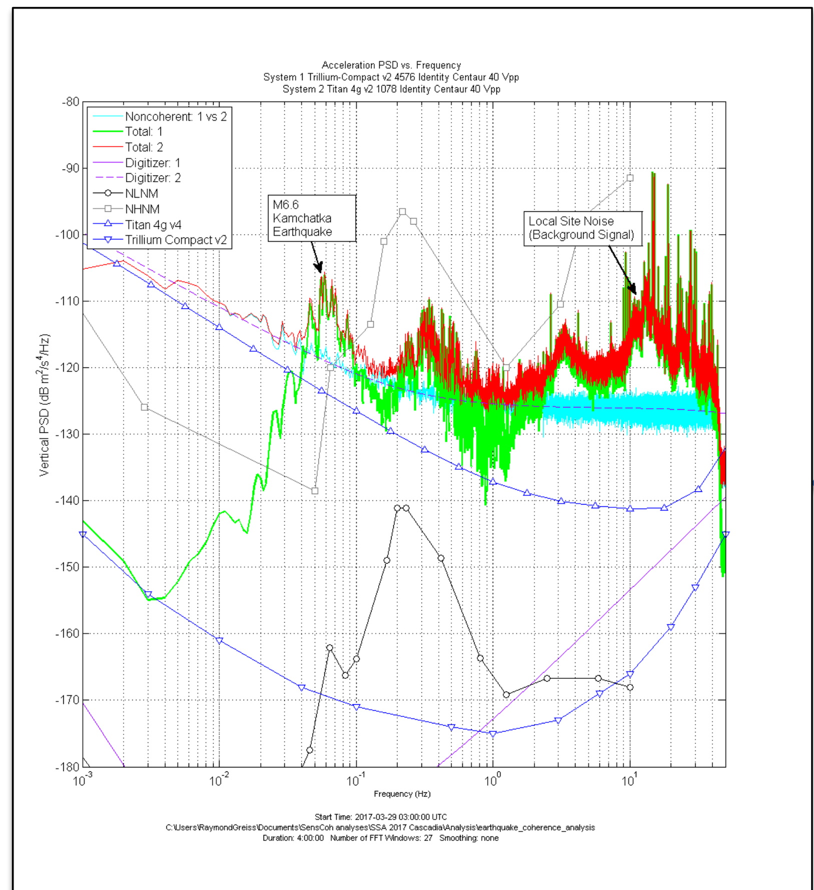


Figure 8

Waveforms
Kamchatzk EQ recorded at SOC1 on Compact seismometer, Figure 9

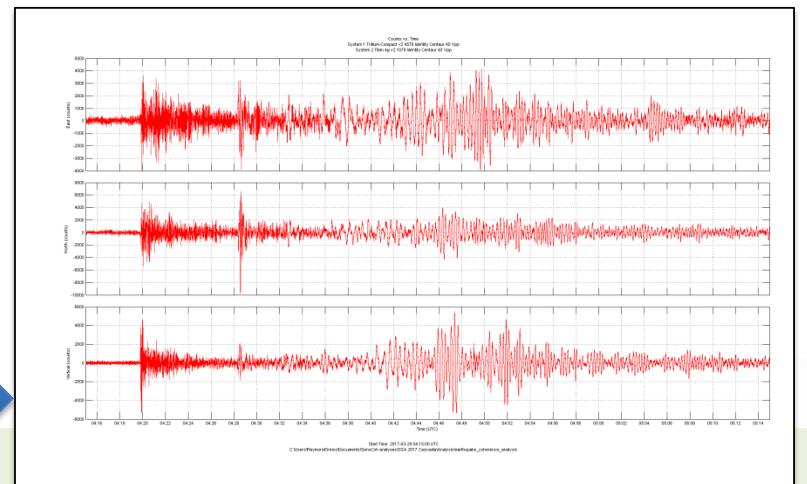


Figure 9

Conclusion

For rapid expansions of seismic monitoring networks, shrinking both the footprint of a seismic station and the costs of deploying a dense seismic network enables easier integration into existing permitted sites and a robust and simpler installation. Being able to record a large dynamic range requires innovative approaches that should not compromise data quality for both operational and research requirements. The development of the Cascadia reduces the required station footprint while preserving the individual performance of these sensors and with a MTBF of over 100 years would reduce future station maintenance requirements.

REFERENCES
Sleeman, R, A. van Wettum, and J. Trampert (2006). Three-channel correlation analysis: A new technique to measure instrument noise of digitizers and seismic sensors, *Bulletin of the Seismological Society of America*, **96** (1), 258-271