Noise Floor of Quartz Crystal Sensors

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“The standard by which other standards are measured”

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Abstract:

The noise floors of Quartz Crystal Resonator Barometers, Depth Sensors, Accelerometers, and Tiltmeters are described.

Background:

A low instrument noise floor is very important for making good geophysical measurements (See http://paroscientific.com/pdf/P10_Quartz_Sensors_Solutions_Slides.pdf). Barometers, Depth Sensors, Accelerometers, and Tiltmeters using resonant quartz crystal sensing elements have a sensor resolution of a few parts-per-billion of full scale. Reference 1 describes counting and filtering methods that result in high resolution over an expanded frequency spectrum.

All of the different sensors use equivalent quartz crystal resonators, oscillators and nano-resolution processing electronics and thus have similar noise floors that are related to the full-scale (FS) range of the sensors. The noise floor has been measured by completely isolating the quartz resonator from external inputs. Another way of making noise floor measurements is to determine the uncorrelated noise between two sensors.

Noise Floor of Isolated Quartz Crystal Resonator:

Figure 1 shows the noise floor with fractional full-scale scaling and PSD units of (Fractional FS)^2/Hz. Figure 2 shows the noise floor in (Pa)^2/Hz for a barometer and a depth sensor of 3000 meters range. Figure 3 shows the noise floor in (m^2/s^2)^2/Hz for a ± 20 m/s^2 accelerometer and a ±10 degrees tiltmeter.

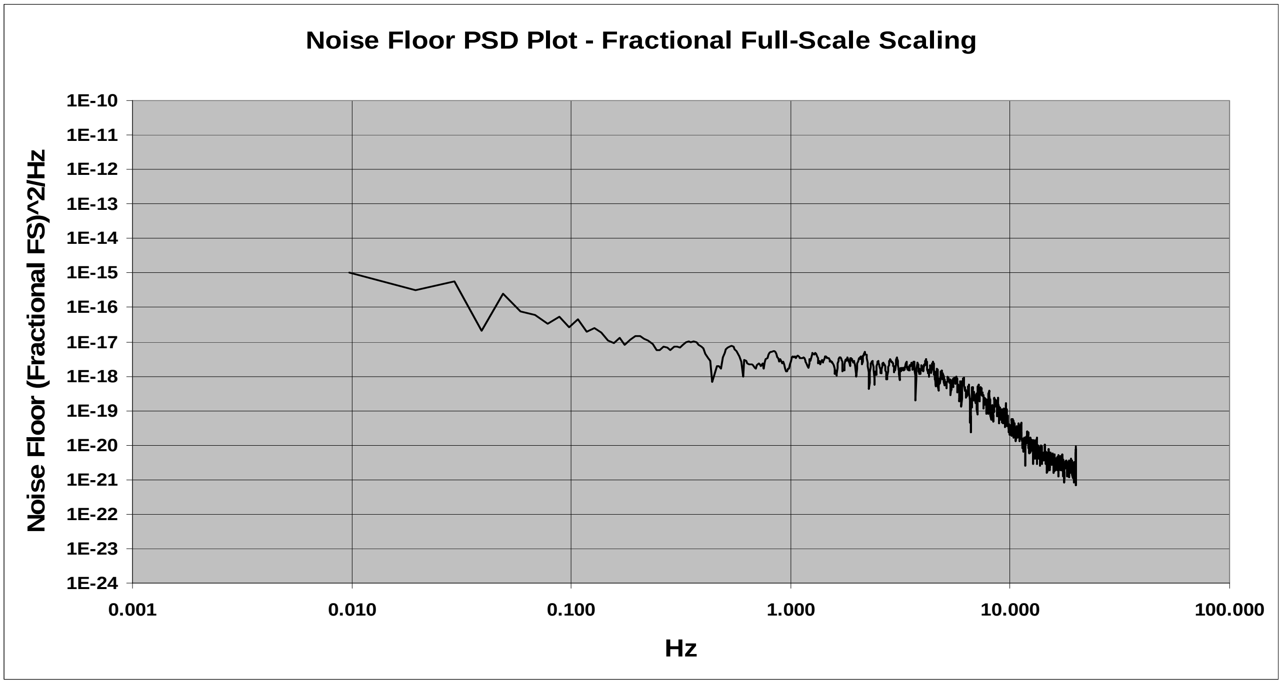


Figure 1

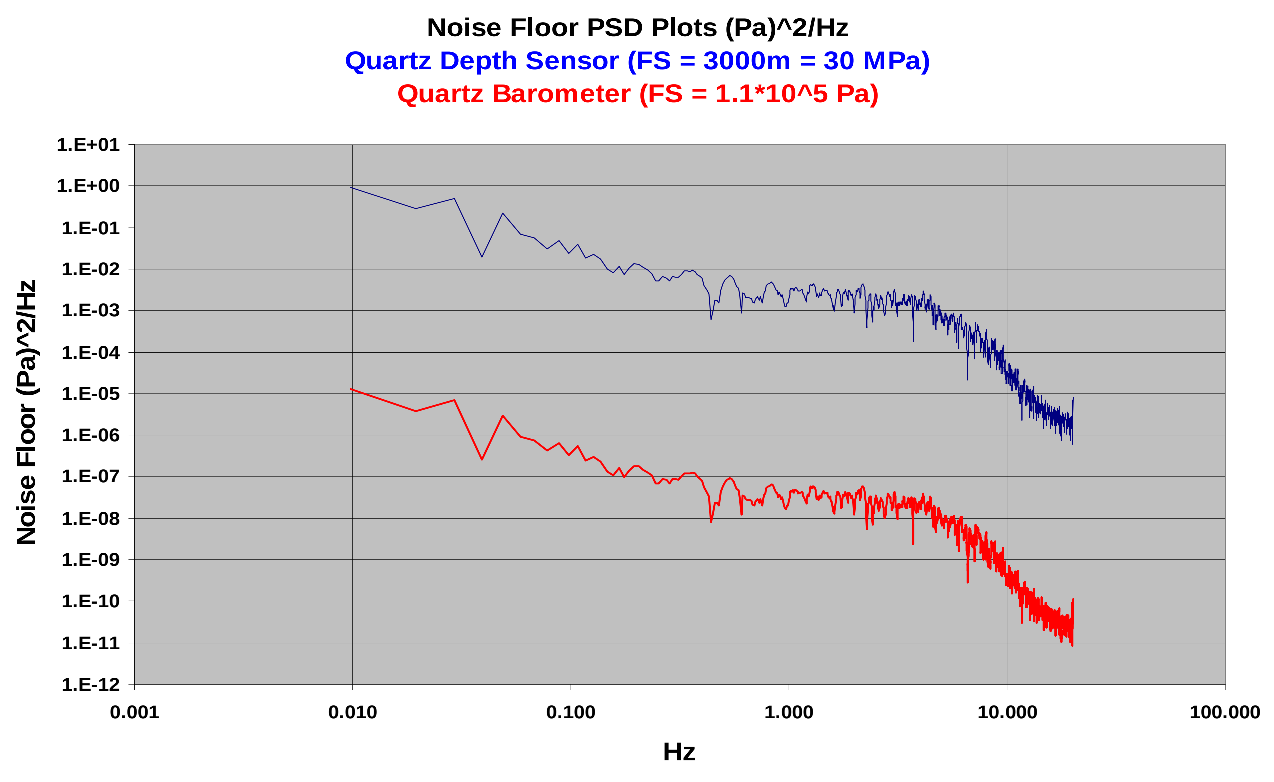


Figure 2

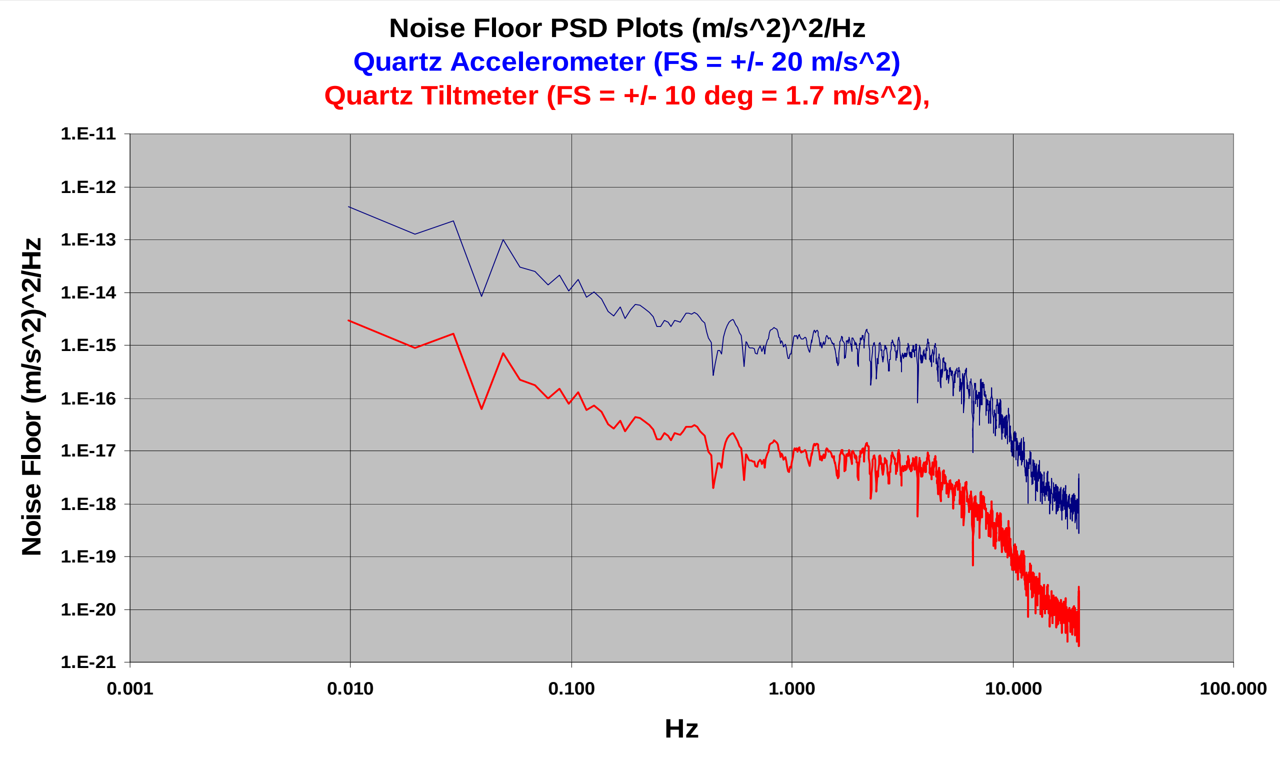


Figure 3

Figure 4 are PSD plots of ambient acceleration signals measured with a quartz accelerometer with a range of ±20 m/s^2 and various ranges of Force-Balance Accelerometers. The microseismic peak is clearly measured by the quartz accelerometer but not by the other accelerometers. The noise floor of the quartz accelerometer is shown as the solid red line and is generally 20 dB lower than the other sensors over the frequency range of interest.

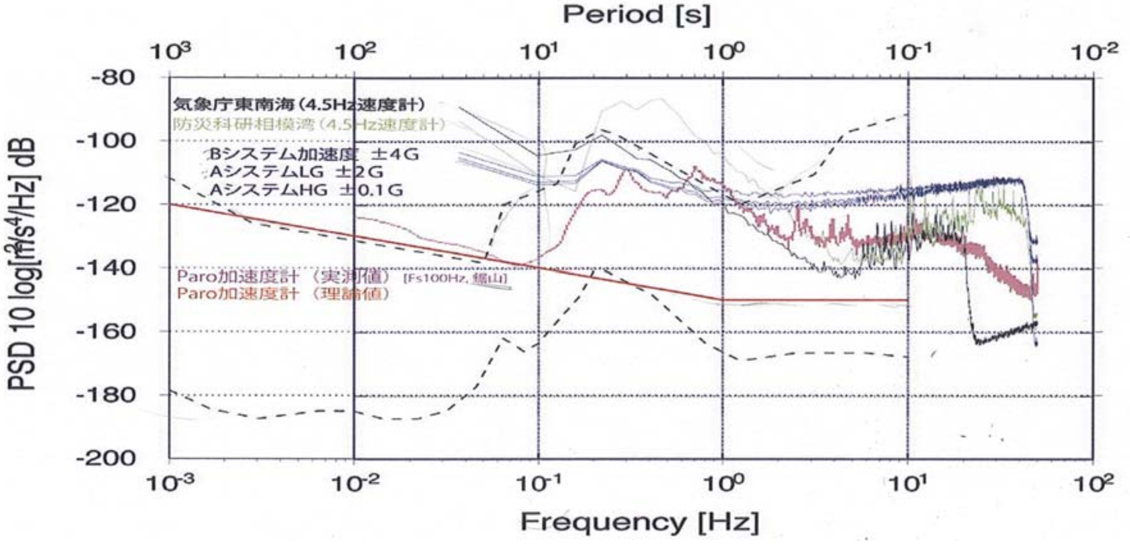


Figure 4 (Courtesy of Dr. Kanazawa)

Figure 5 shows spectra of ambient noise measured with the quartz accelerometer using an IIR filter with a 200 MHz counting frequency (Reference 1). Spectral lines above 1 Hz are associated with noise from nearby vibrating machinery.

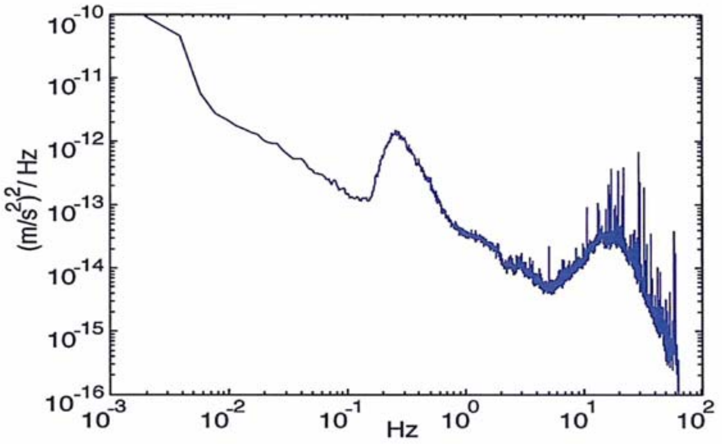
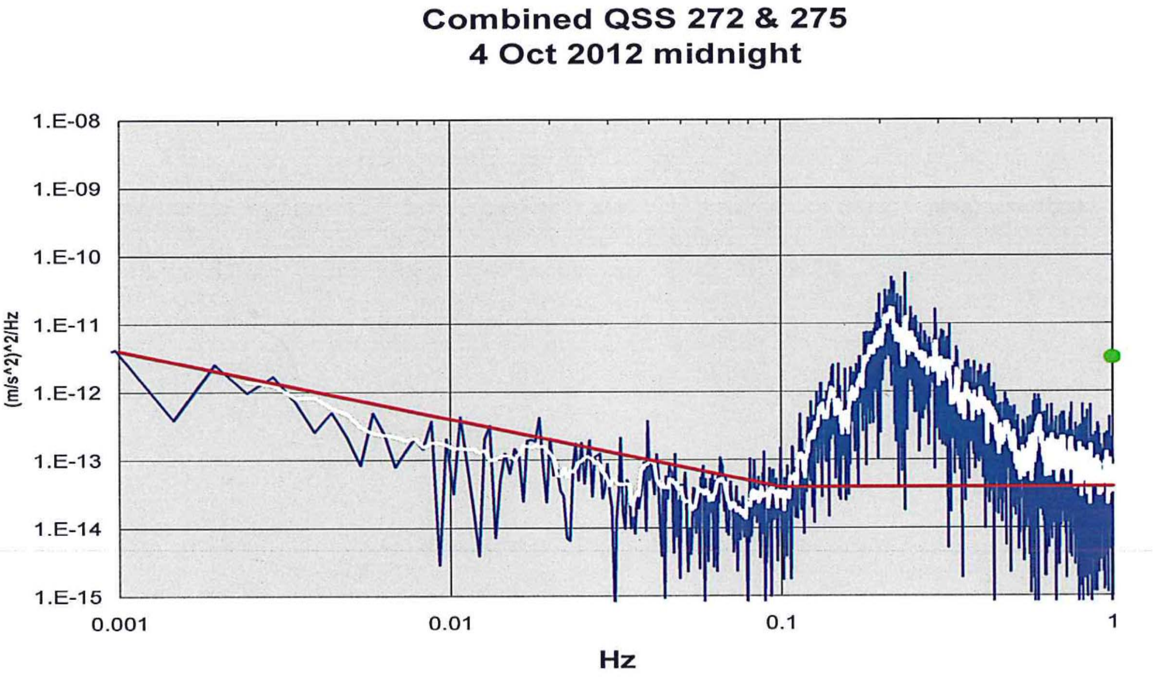


Figure 5 (Courtesy of Dr. Spahr Webb)

Uncorrelated Noise Floor Measurements:

The sensor noise floor can also be determined by measuring the uncorrelated noise between sensors. Figure 6 shows the average and difference ambient spectra between two quartz accelerometers with ranges of ±20 m/s^2.



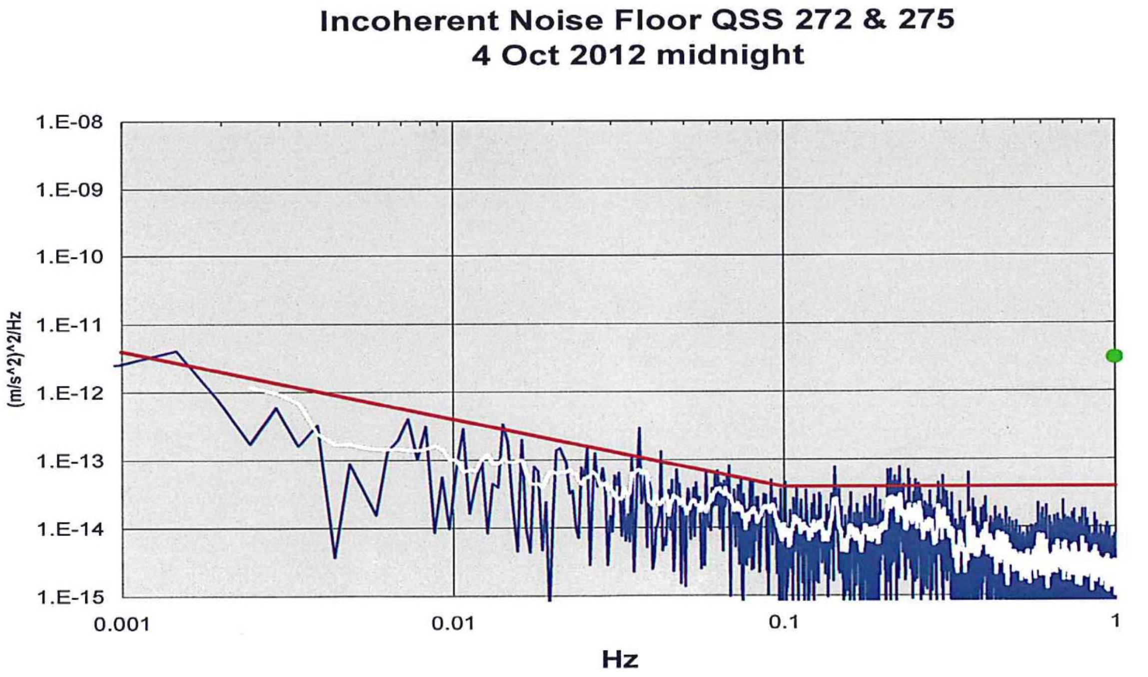
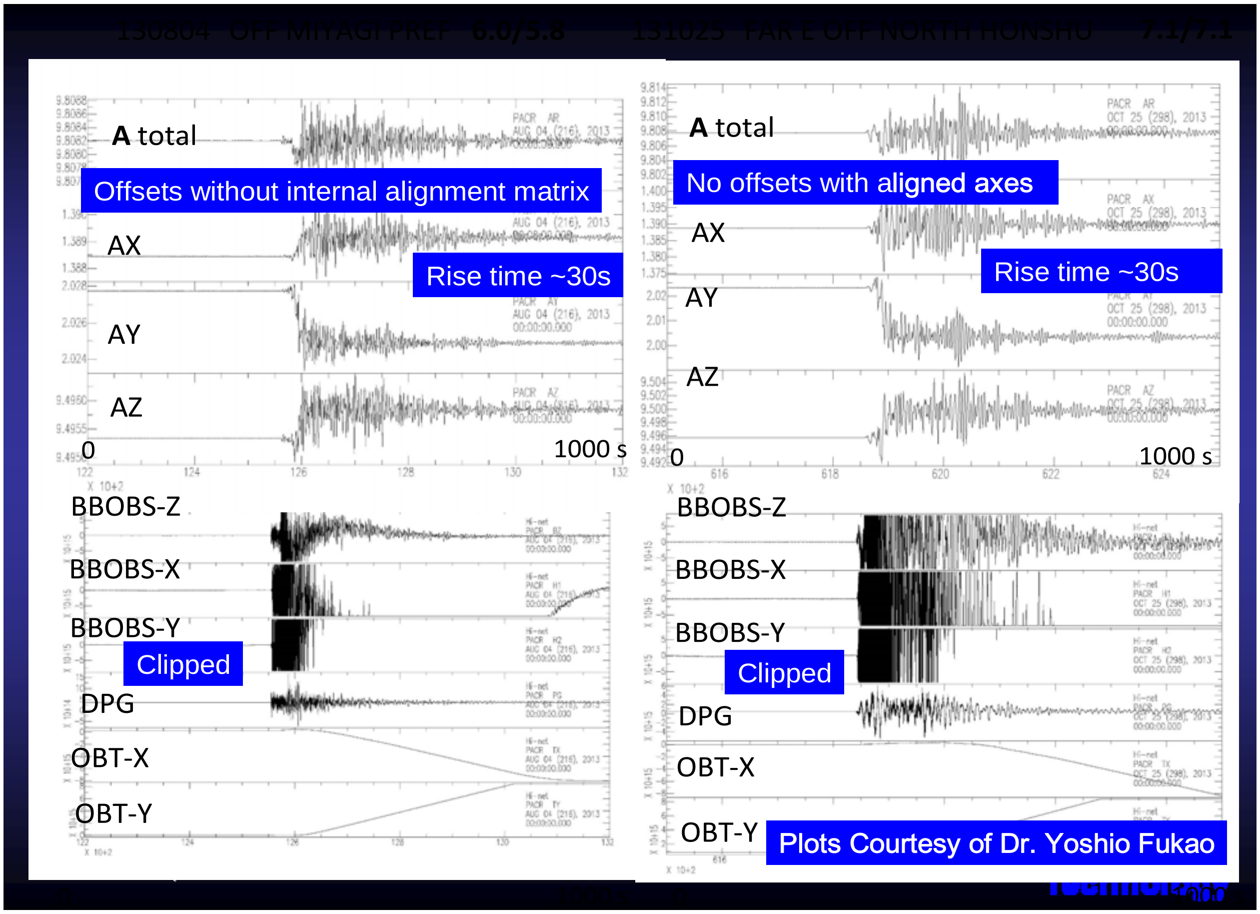


Figure 6

Advantages of High-Resolution Absolute Sensors:

As discussed in Reference 1, there are significant advantages to using high-resolution absolute sensors over differential sensors. Differential pressure gauges can only measure fluctuating pressures over a limited range and clip (saturate) with large pressure signals generated by local earthquakes. Quartz absolute pressure gauges operate over a broad spectrum enabling observations of depth, oceanographic currents, tides, infragravity waves, microseisms, Rayleigh waves, and body waves from earthquakes. Similarly, traditional broadband seismometers and tiltmeters operate over a small fraction of 1G and do not have the range to measure strong seismic events. Traditional strong motion sensors do not have the sensitivity or stability to make long-term geodetic measurements. In-situ calibration methods have been developed for quartz absolute pressure sensors and quartz triaxial accelerometers to distinguish earth movements from instrument drift (http://paroscientific.com/pdf/G8097_Calibration_Methods_to_Eliminate_Sensor_Drift.pdf).

Figure 7 shows side-by-side comparisons of quartz triaxial accelerometers to broadband seismometers and tiltmeters deployed near the epicenter of the Tohoku earthquake. Clear measures of co-seismic signals and post seismic tilts were possible only with the quartz accelerometers because the seismometers and tiltmeters saturated not only for this 2013/10/25 event, but for almost all the seismic events.

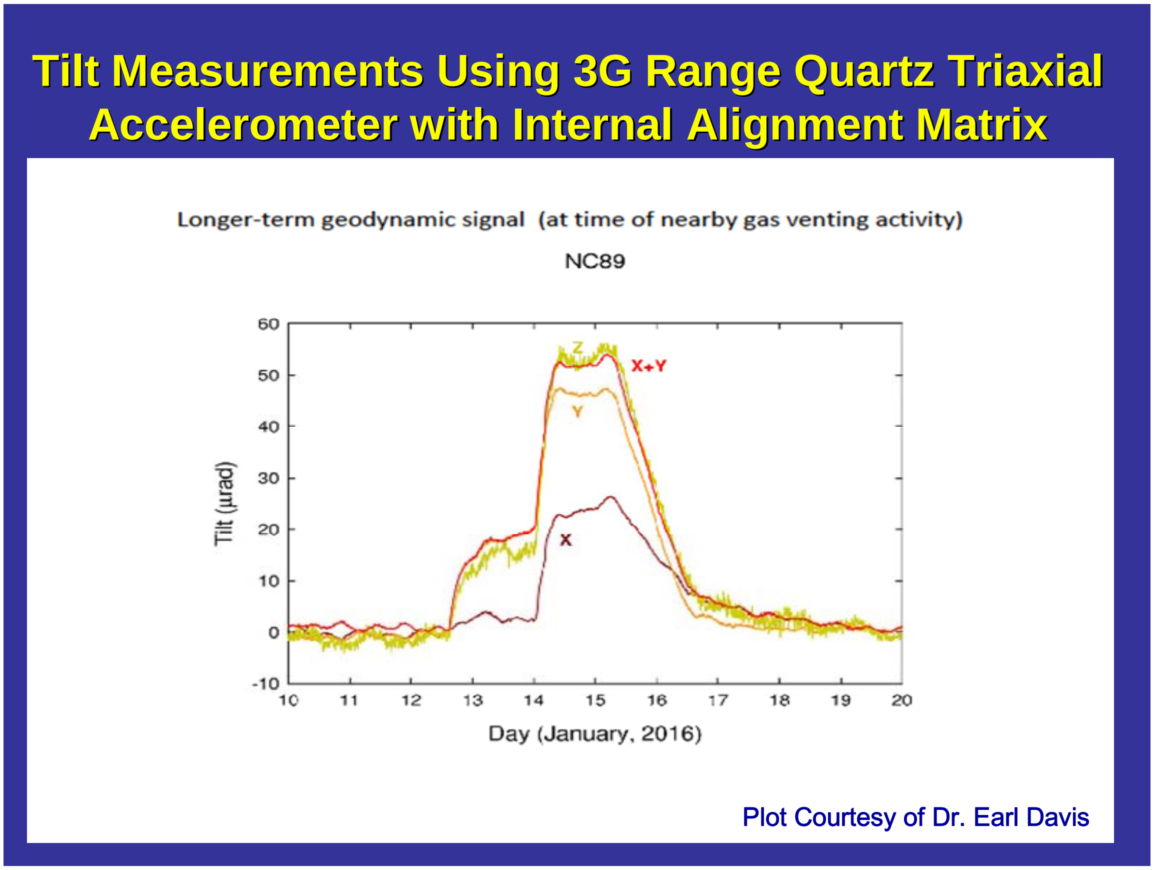


Plots Courtesy of Dr. Yoshio Fukao

Figure 7

See "Sensing of upslope passages of frontal bores across the trench slope break of the Japan Trench" http://onlinelibrary.wiley.com/doi/10.1002/2015JC011432/full .

Comparative measurements between quartz triaxial accelerometers and depth sensors versus broadband seismometers have been made by Earl Davis and his colleagues at NEPTUNE-Canada. See (http://paroscientific.com/pdf/110%20Neptune-Triax%20&%20Pressure%20Update2016.pdf). Figure 8 shows micro-radian tilt measurements made with a ±30 m/s^2 (±3 G) full-scale Triaxial Accelerometer.



Tilt Measurements Using 3G Range Quartz Triaxial Accelerometer with Internal Alignment Matrix

Plot Courtesy of Dr. Earl Davis

Figure 8

Conclusion:

The low noise floor associated with quartz resonator sensors allows high-resolution measurements of pressure, acceleration, and tilt over a frequency spectrum of interest to the geophysical community.

References:

Spahr C. Webb and Scott L Nooner, High-Resolution Seafloor Absolute Pressure Gauge Measurements Using a Better Counting Method, *Journal of Atmospheric and Oceanic Technology*, September 2016, http://journals.ametsoc.org/doi/10.1175/JTECH-D-15-0114.1