Noise vs. Depth Study Update

USGS/ASL

24 April 2015

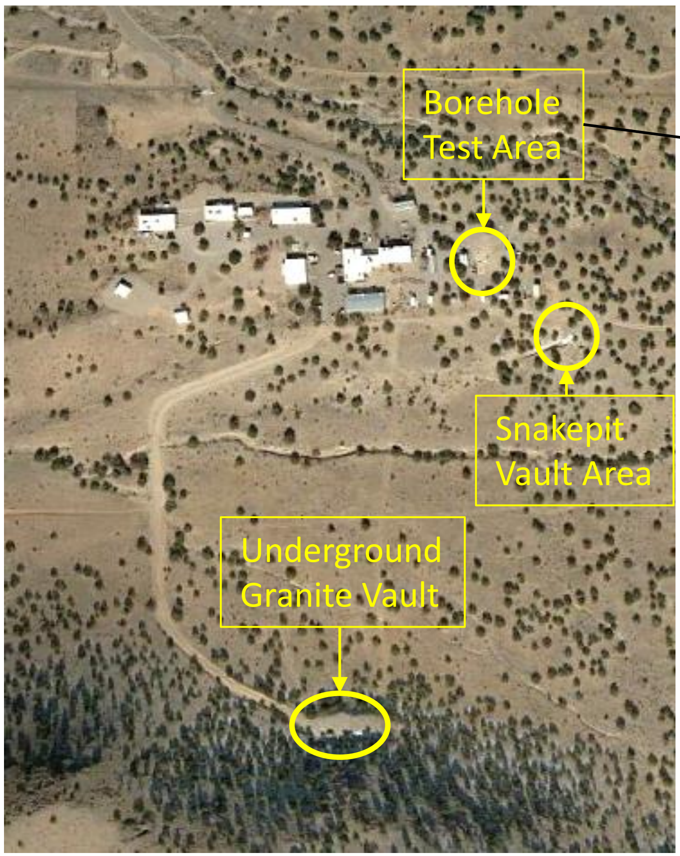
Objective: Update noise attenuation vs. depth over a broad frequency range

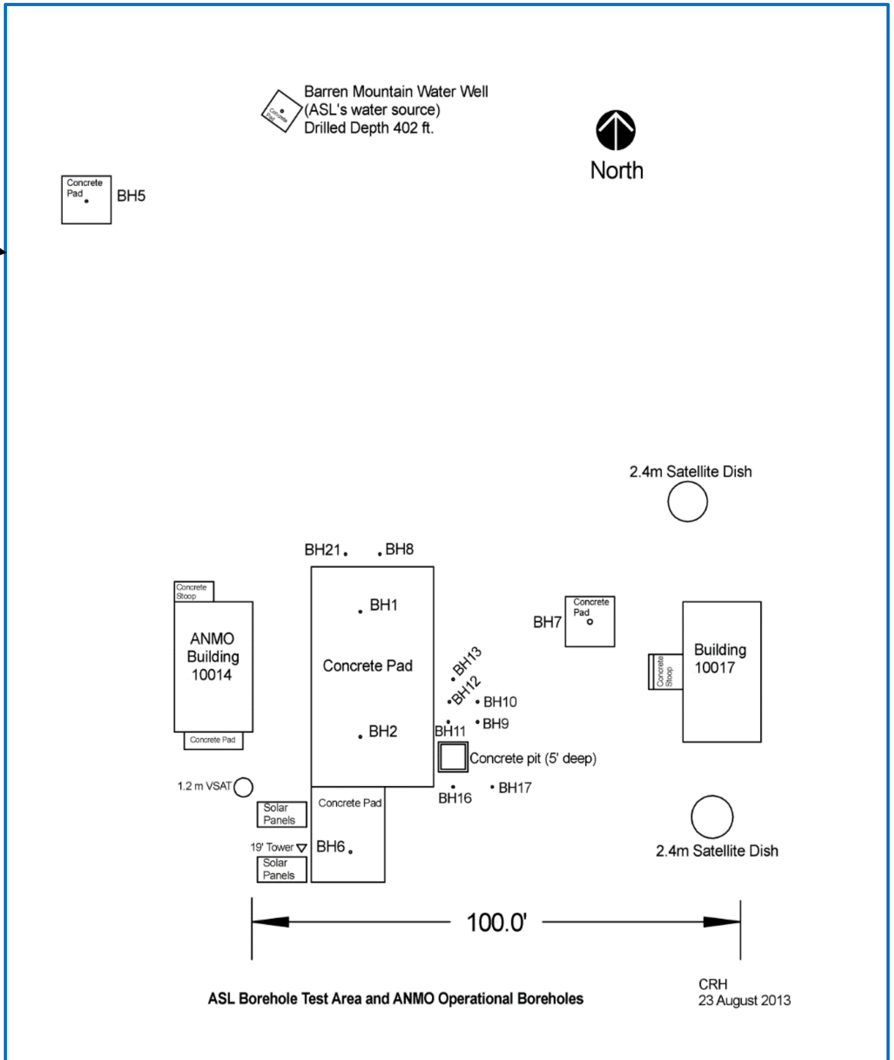
- Most previous studies concentrated on narrow bands
  - Short period (nuclear monitoring applications)
  - Long period (for surface waves and normal modes)

Test Plan

- Use modern BB and VBB instrumentation
- Install at various depths
  – Posthole or shallow vault in soil
  – Posthole in solid rock (granite)
  – Deeper boreholes in granite
  – Underground granite vault
  – Depths range from 1.5m to 188m

Depth Study Test Areas at ASL





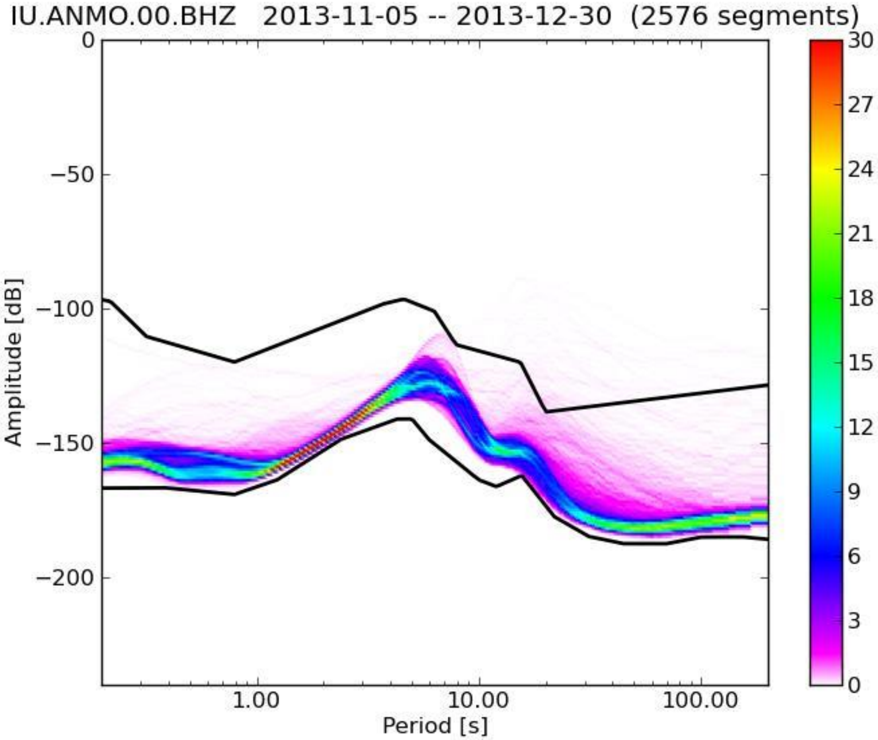
Sensors and depths

Sensor	Location	Description	Depth & Type*	Data Logger Name & Loc. Code
STS2 HG #99428	GTSN Pit	Shallow concrete pit (5’ x 5’ x 5’), floor is on soil	1.5m SV	FBA1.00
STS-4B (on loan from TA)	ASL BH14	Uncased 8.0” ID hole in granite near Snake Pit Vault	1.54m BH	TST2.00
STS2 HG #30741	Snake Pit Vault	Shallow surface vault, floor is on granite	2m SV	TST2.10
T120PH #252	ASL BH13	PVC-cased (uncemented) 6.0” ID posthole drilled into soil	2.7m BH	TST5.10
T120PH #251	ASL BH11	PVC-cased (uncemented) 6.0” ID posthole drilled into soil	7.6m BH	TST5.00
STS-2 HG #30734	ASL Underground Tunnel (in granite)	Installed in cross-tunnel on granite slab. Sensor is sealed inside a steel pressure-tight enclosure.	11m UV	TST1.00
T120PH #245	ASL BH16	Steel-cased 6.5” ID borehole drilled into granite	29.0m BH	TST3.10
ANMO CMG-3TB	ASL BH2	Steel-cased 6.5” ID borehole drilled into granite	57m BH	ANMO.10
T120BH #1000	ASL BH17	Steel-cased 6.5” ID borehole drilled into granite	58m BH	TST3.00
T120PH #250	ASL BH7	Steel-cased 12.5” ID borehole drilled into granite (“Russian hole”)	106.7m BH	TST4.10
ANMO KS54000	ASL BH1	Steel-cased 7.0” ID borehole drilled into granite	145m BH	ANMO.00
T120PH #249	ASL BH5	Steel-cased 6.5” ID borehole drilled into granite	188.2m BH	TST4.00
			*SV = Surface Vault	
			*BH = Bore Hole	
			*UV = Underground Vault	

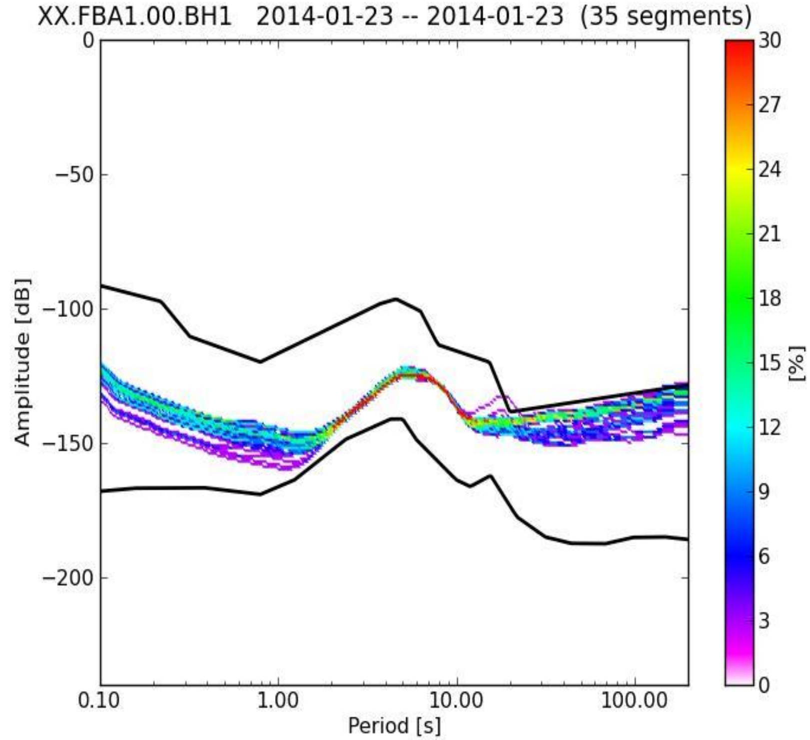
Examples of PSD PDF plots

Medians used in attenuation plots to follow

Vertical data from 145m depth
for 5 Nov through 30 Dec 2013



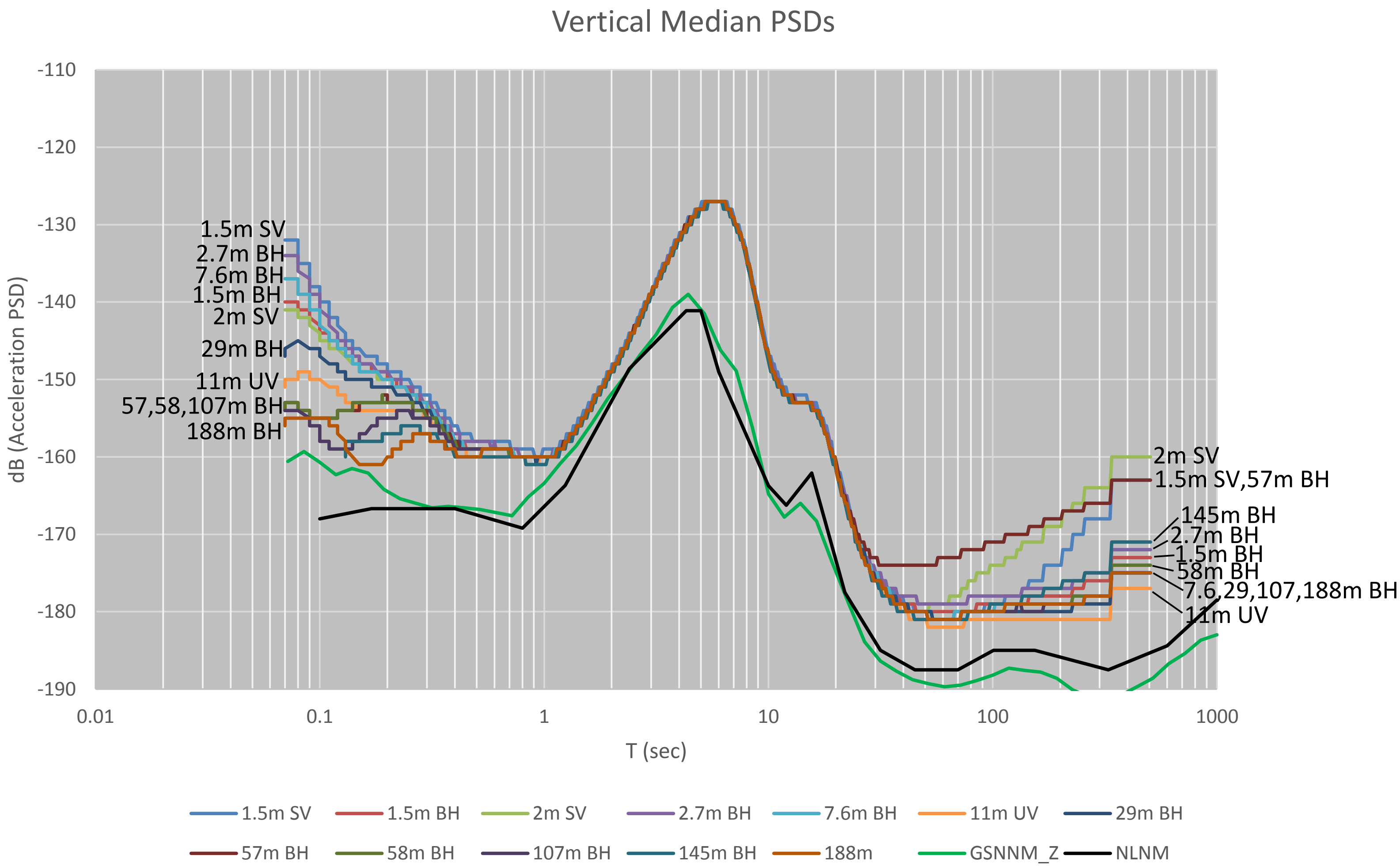
Horizontal data from 1.5m depth
during a 1-day windy period



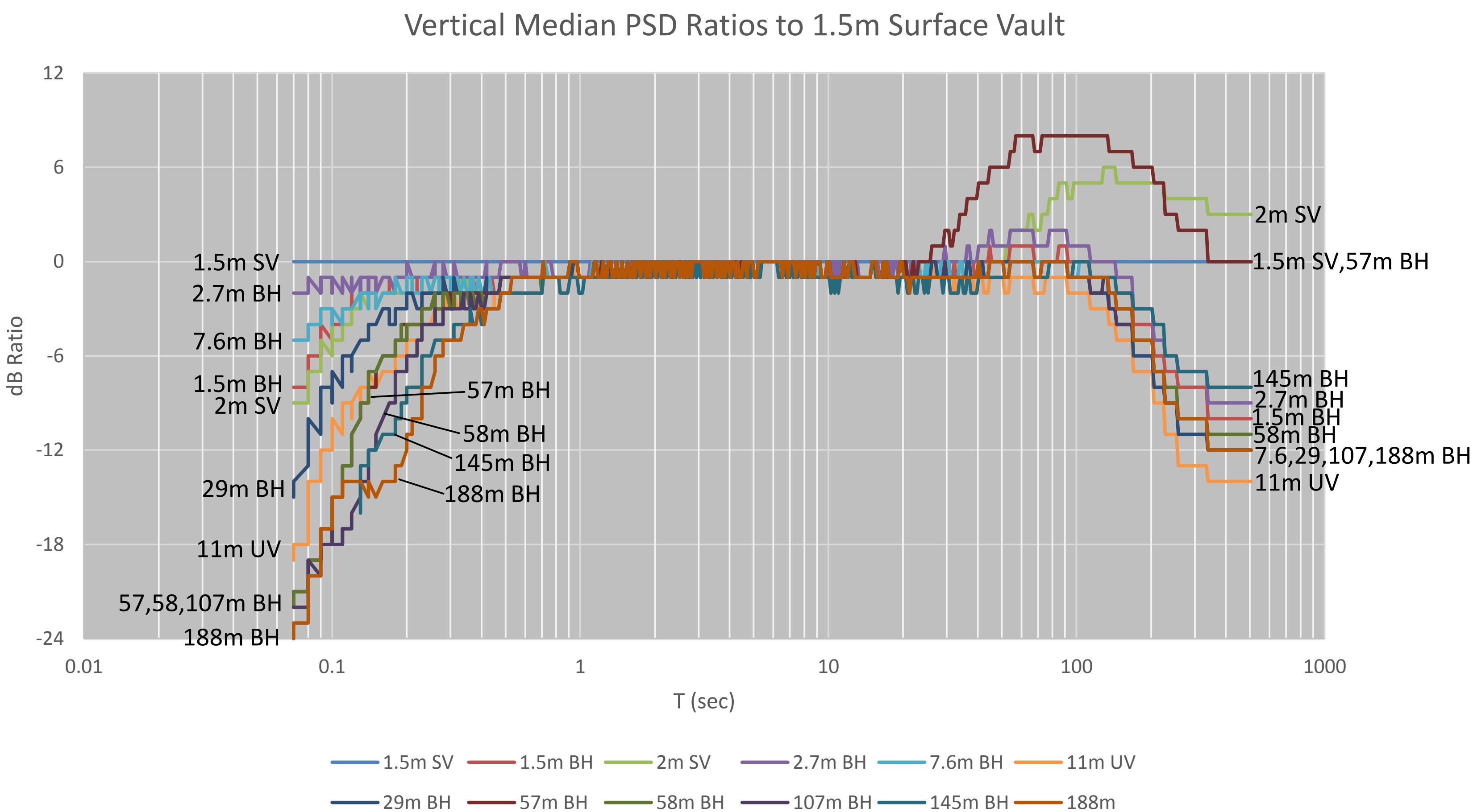
Peak wind: 22.2 m/s (50 mph)
Average wind: 10 m/s (22 mph)

Vertical Medians

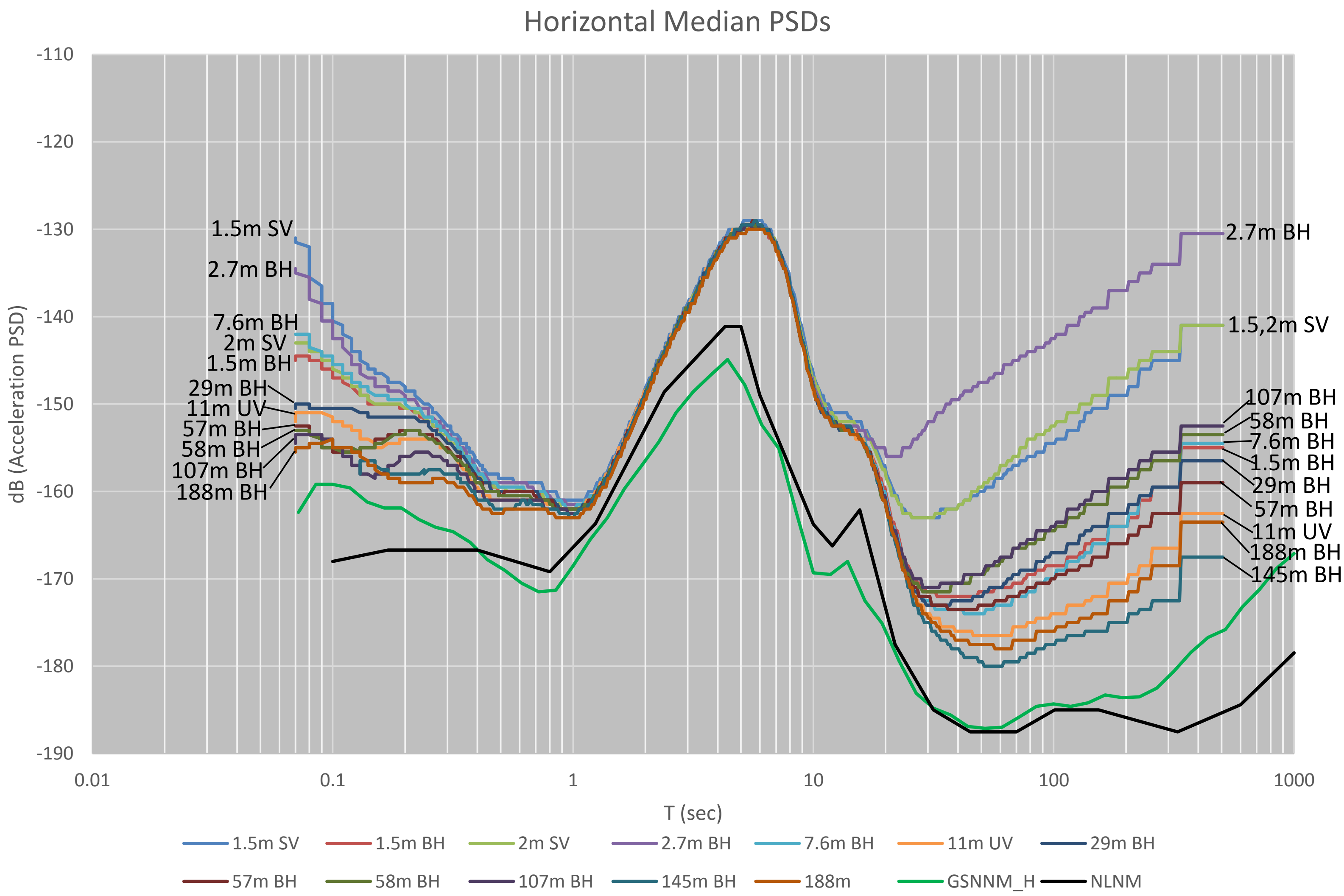
for 5 Nov through 30 Dec 2013



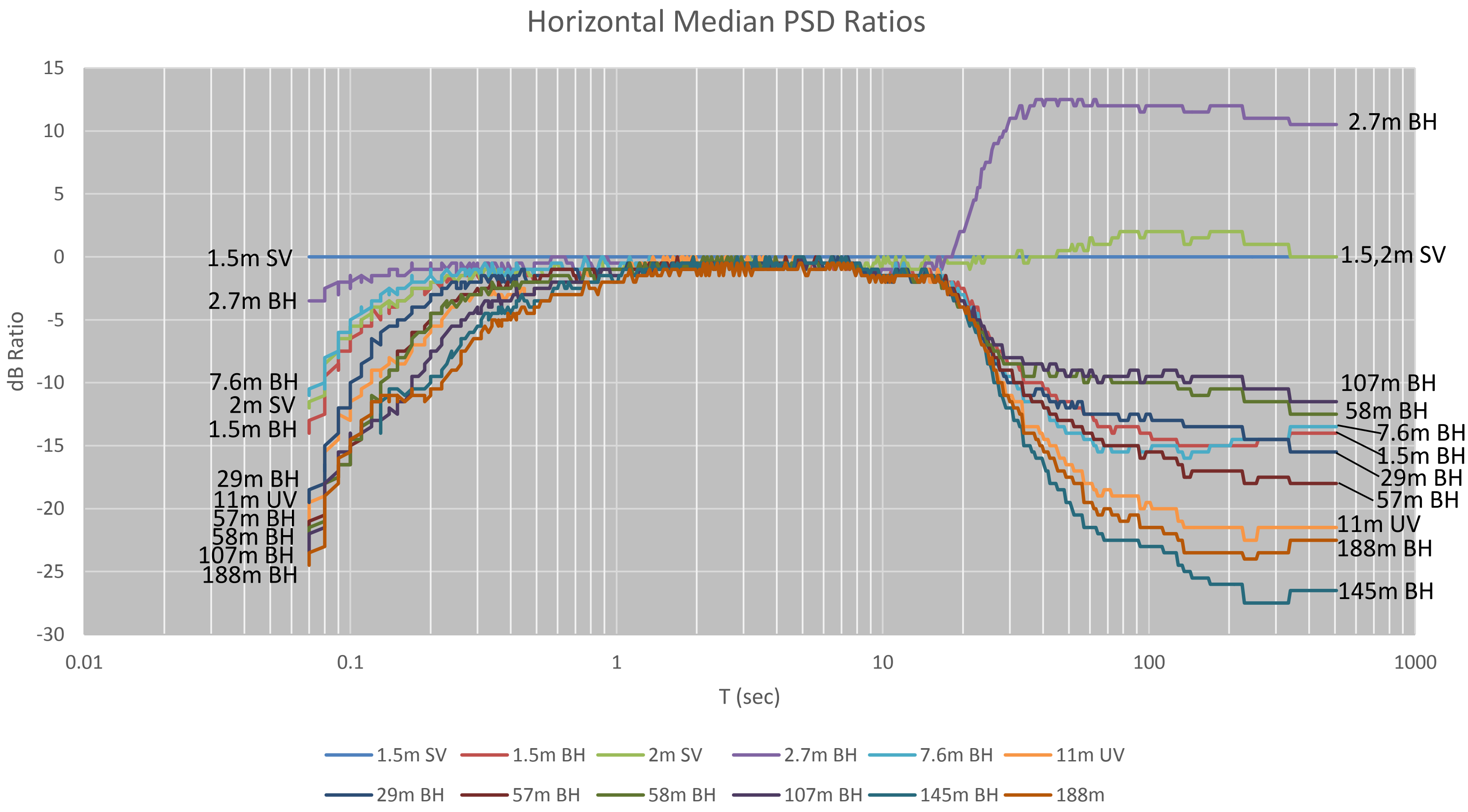
Vertical Median Ratios to 1.5m Surface Vault



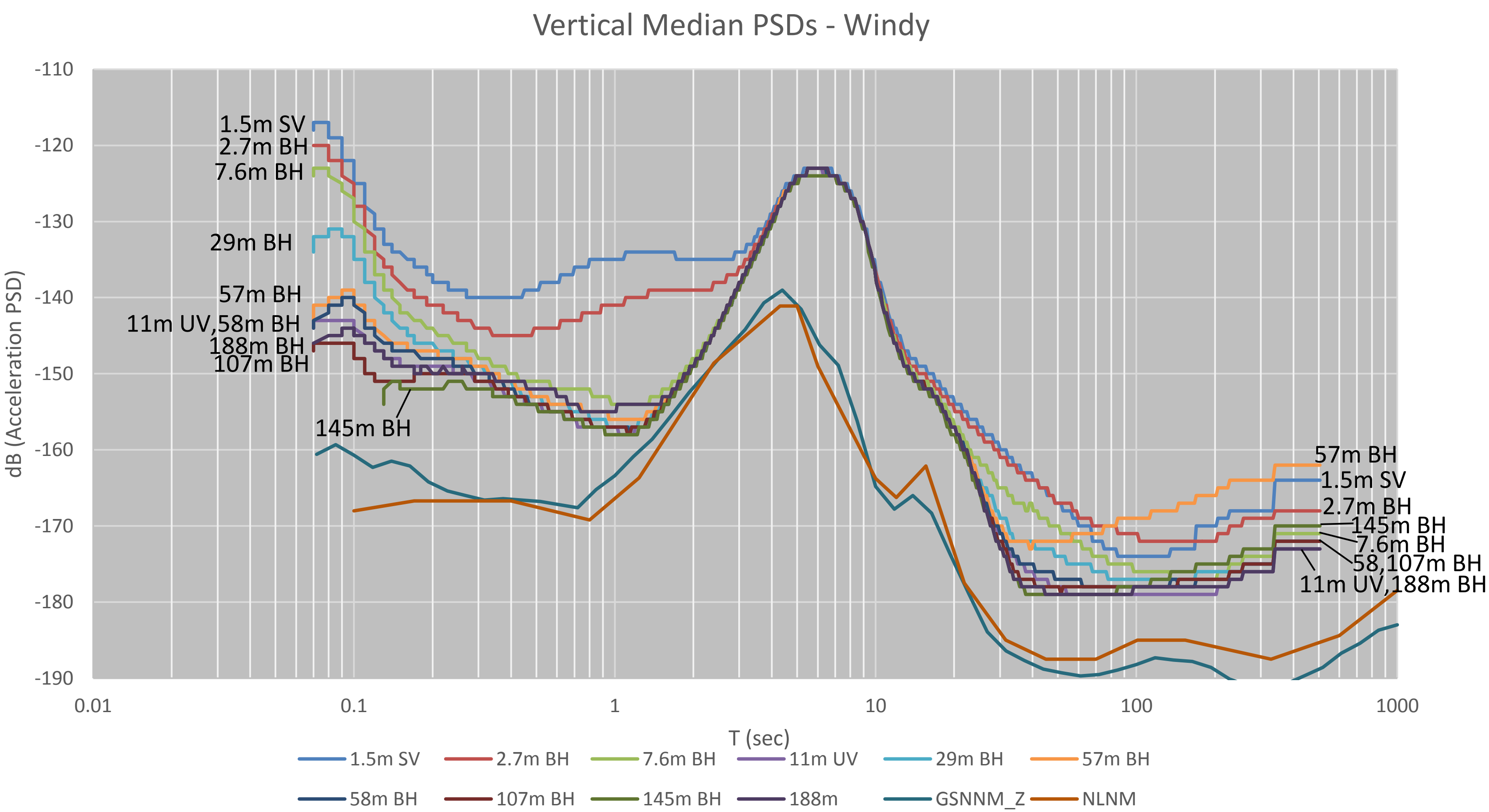
Horizontal Medians for 5 Nov through 30 Dec 2013



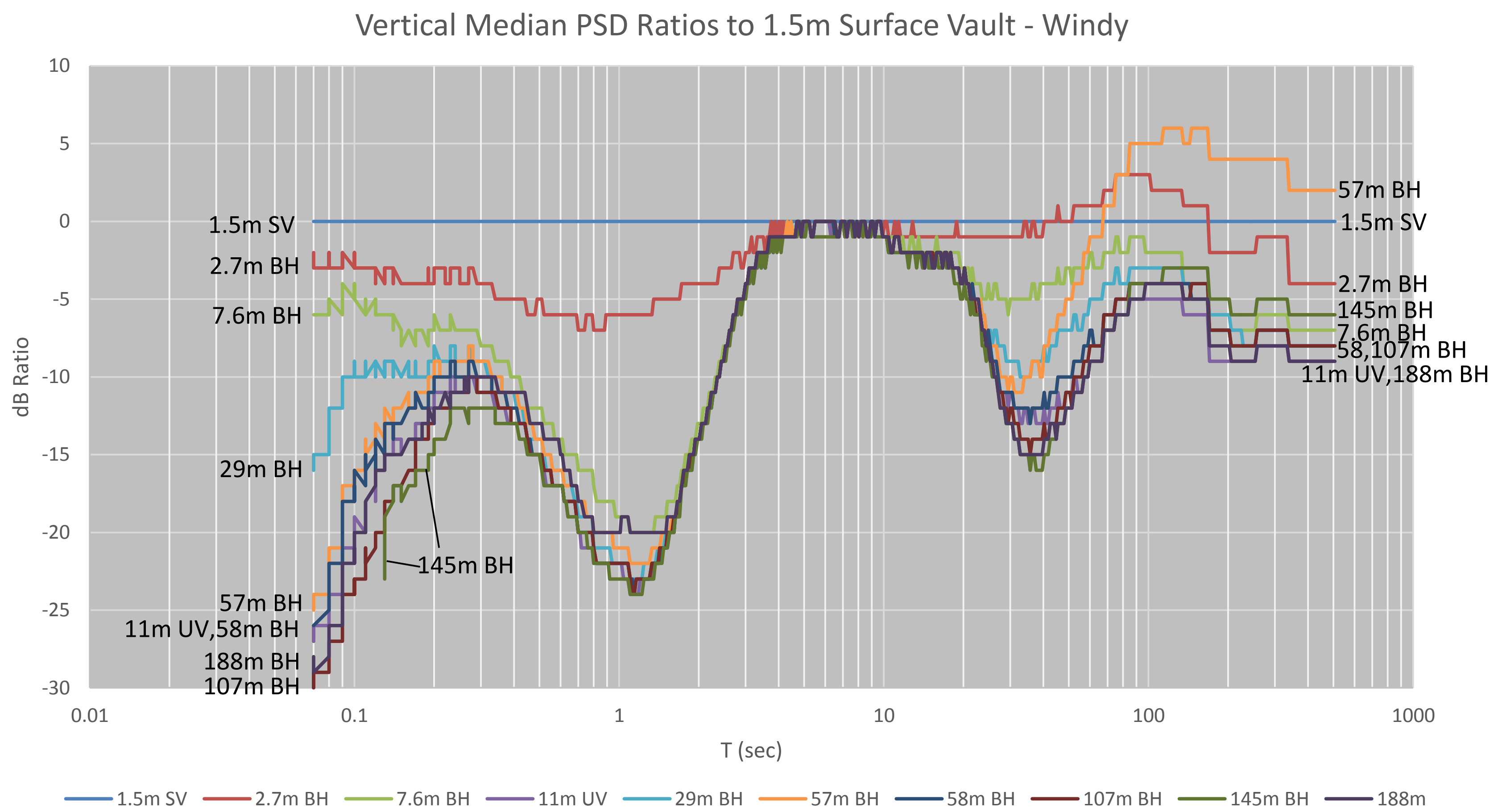
Horizontal Median Ratios to 1.5m Surface Vault



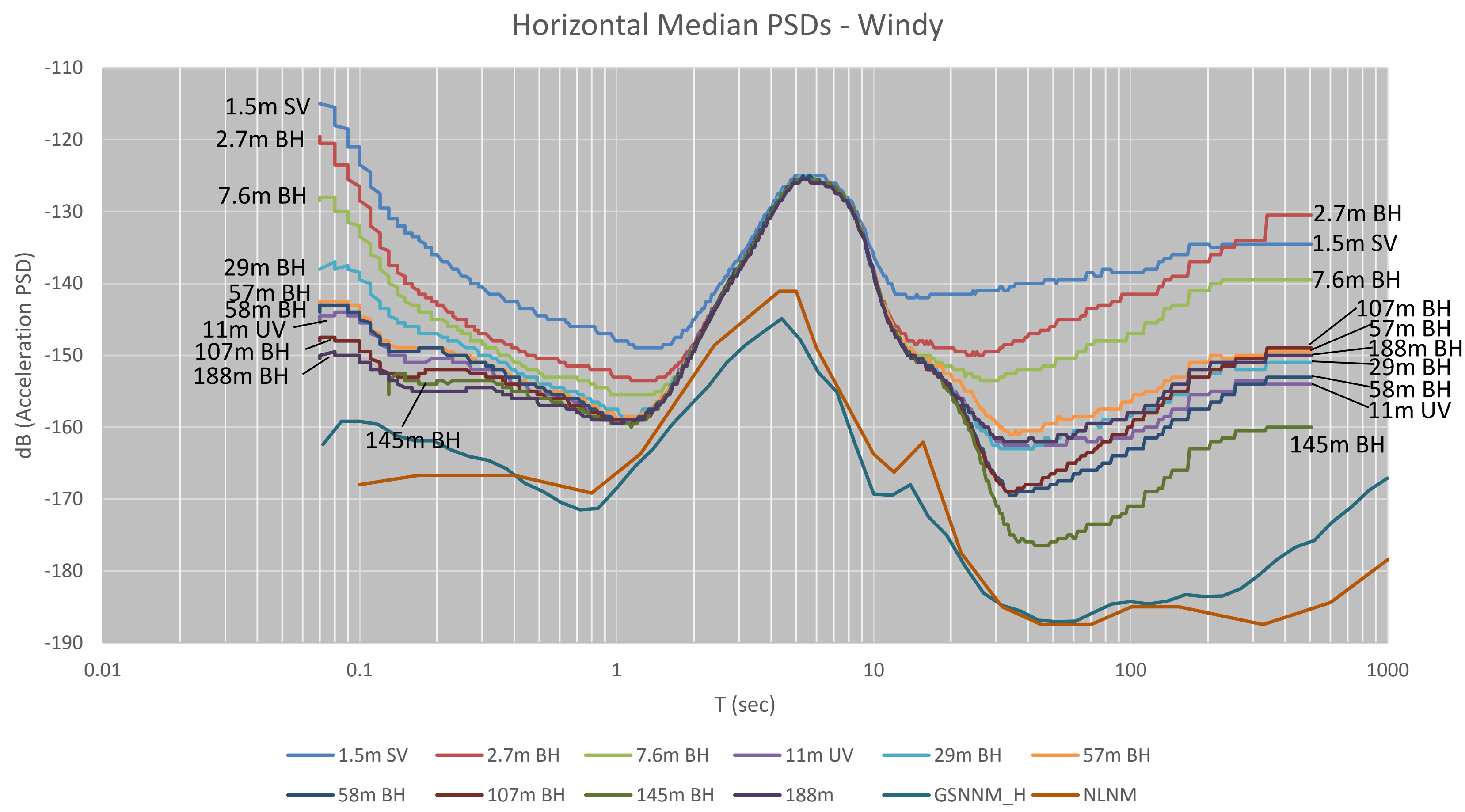
Vertical Median PSDs on a very windy day



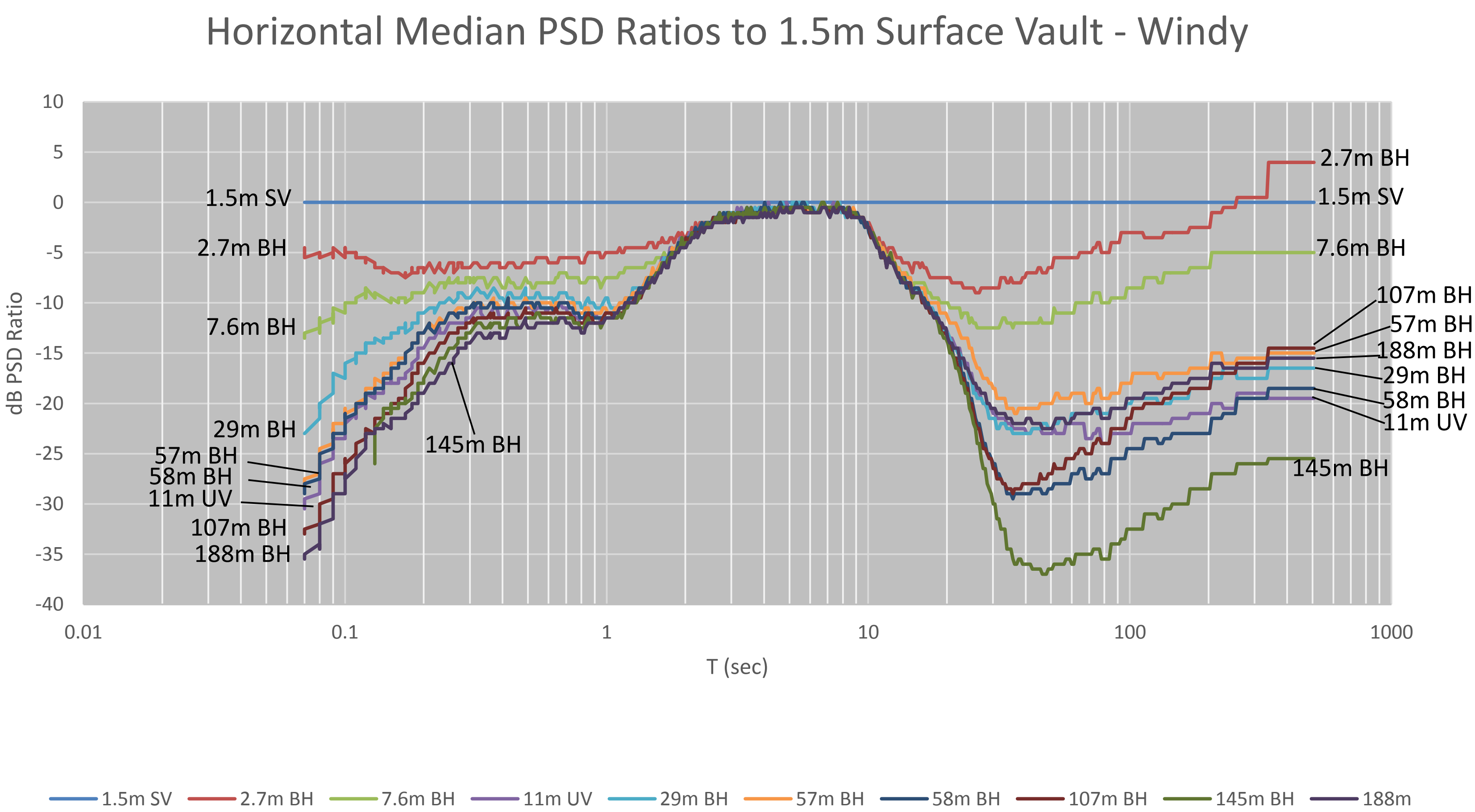
Vertical Median Ratios on a very windy day



Horizontal Median PSDs on a very windy day



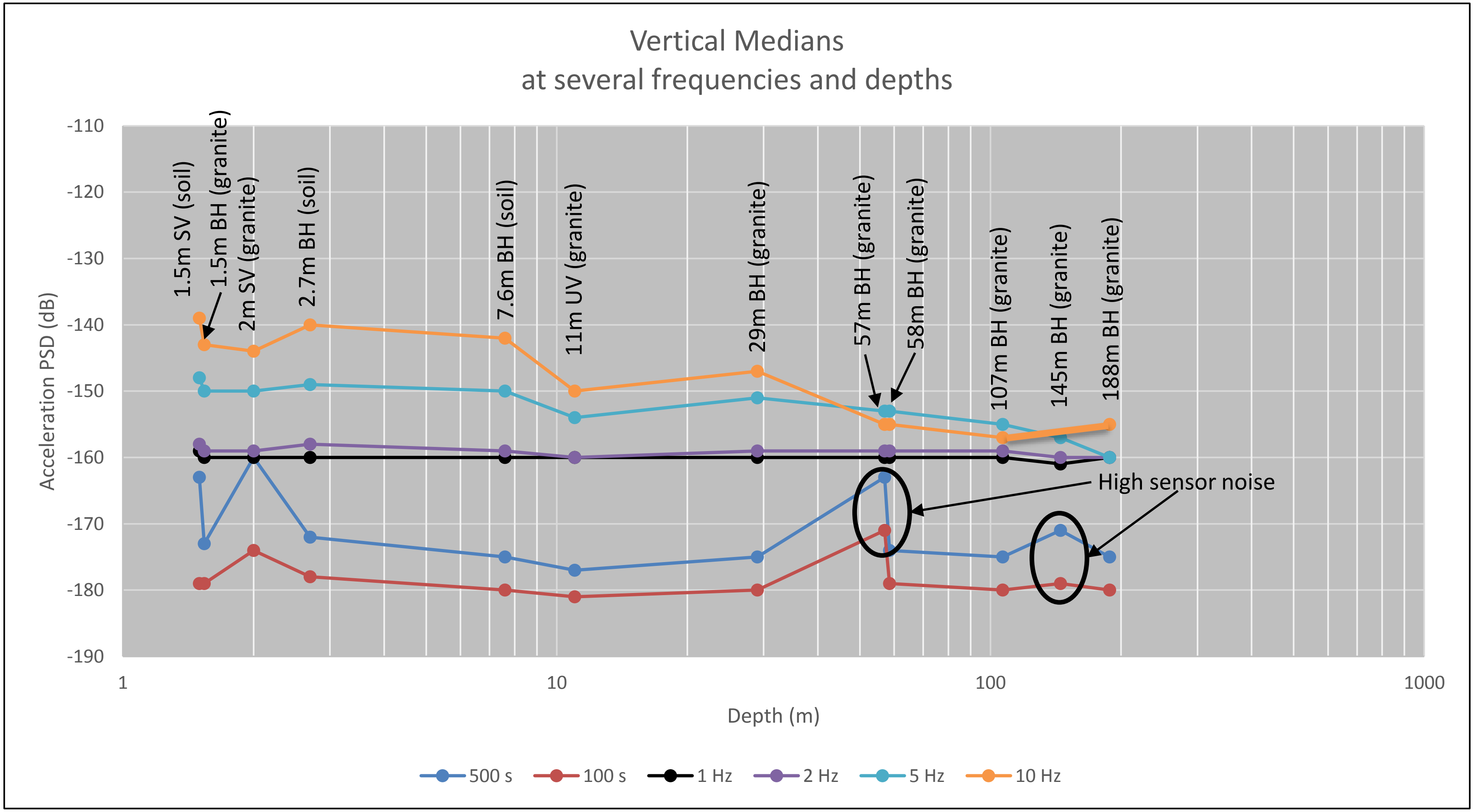
Horizontal Ratios on a very windy day



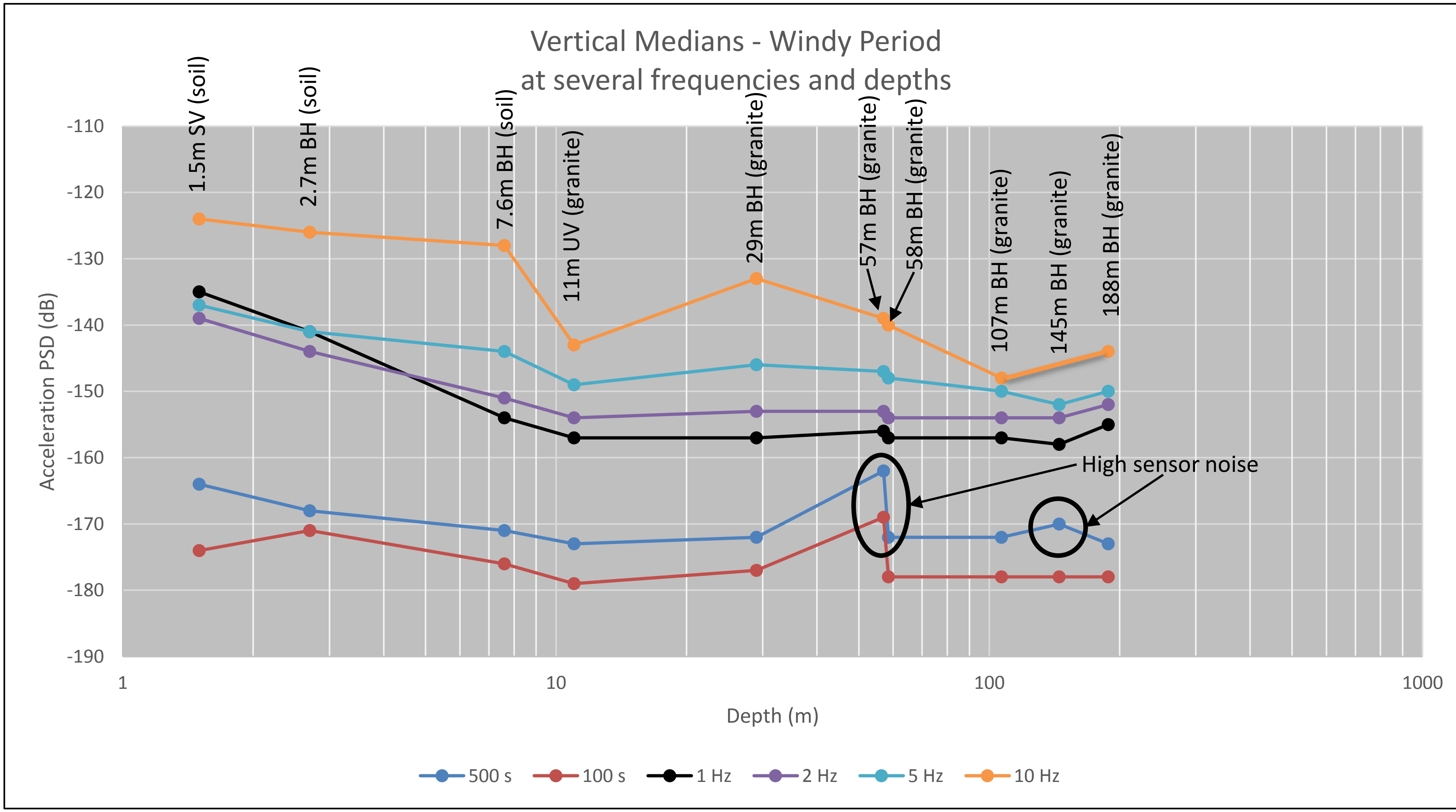
Tabulation of sensor types, depths, and installation type corresponding to depth labels across tops of attenuation *vs* depth curves.

Sensor Type	Depth (m)	Vault Type and Comment
STS-2 HG vault-type	1.5m	Concrete pit in soil next to ANMO boreholes
STS-4B posthole type	1.5m	Uncased posthole in granite next to Snake Pit vault
STS-2HG vault type	2m	Snake Pit Vault (semi-buried) with concrete floor on granite
T120PH posthole type	2.7m	6” ID PVC-cased hole in soil (not cemented)
T120PH posthole type	7.6m	6” ID PVC-cased hole in soil (not cemented)
STS-1 High Gain	11m	Underground vault mined into granite
T120PH posthole type	29m	6.5” ID steel-cased hole in granite (cemented)
CMG-3TB borehole type	57m	6.5” ID steel-cased hole in granite (cemented)
T120BH borehole type	58.5m	6.5” ID steel-cased hole in granite (cemented)
T120PH posthole type	106m	12.5” ID steel-cased hole in granite (cemented)
KS54000 borehole type	145m	6.5” ID steel-cased hole in granite (cemented)
T120PH posthole type	188m	6.5” ID steel-cased hole in granite (cemented)

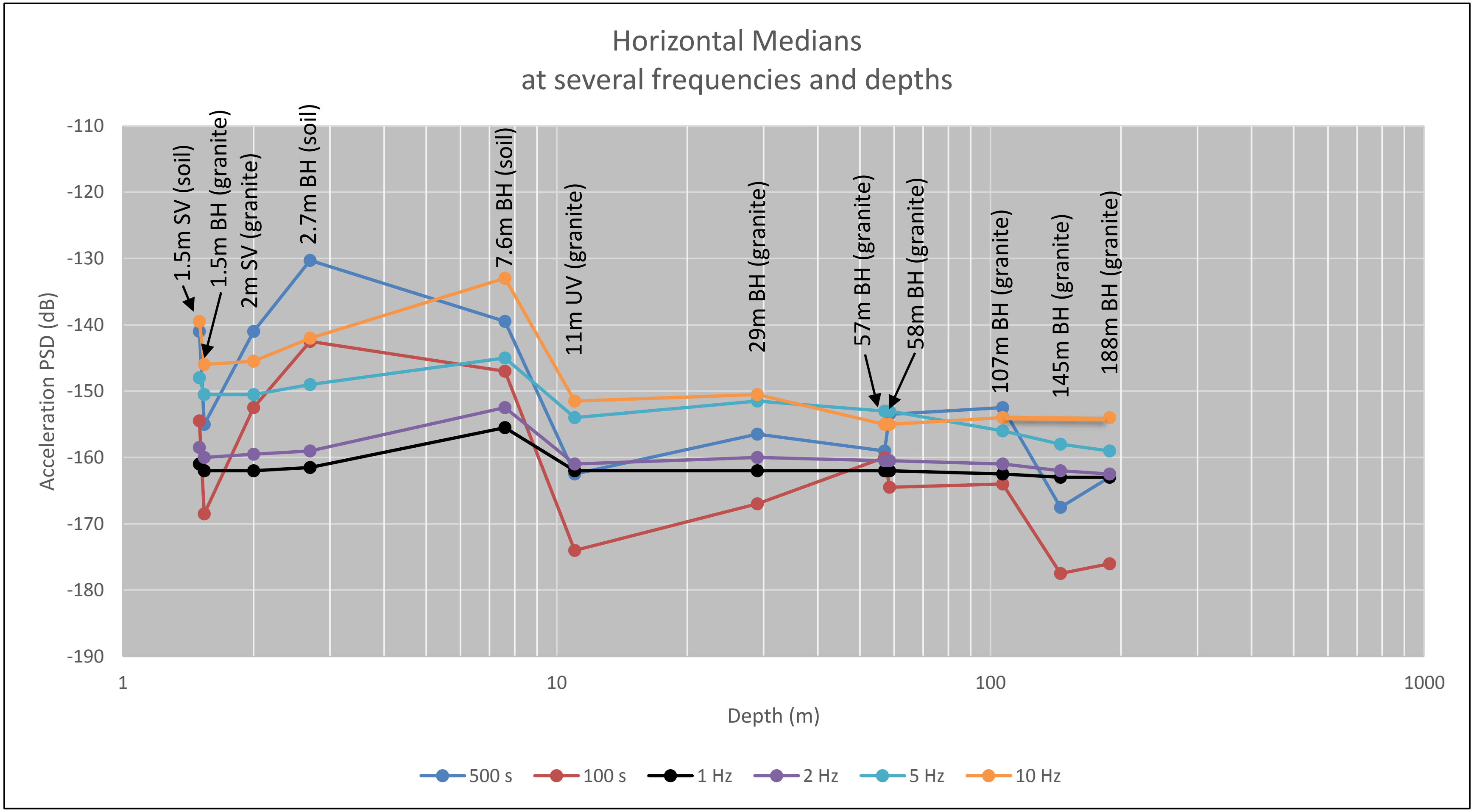
Vertical noise vs. depth at several frequencies



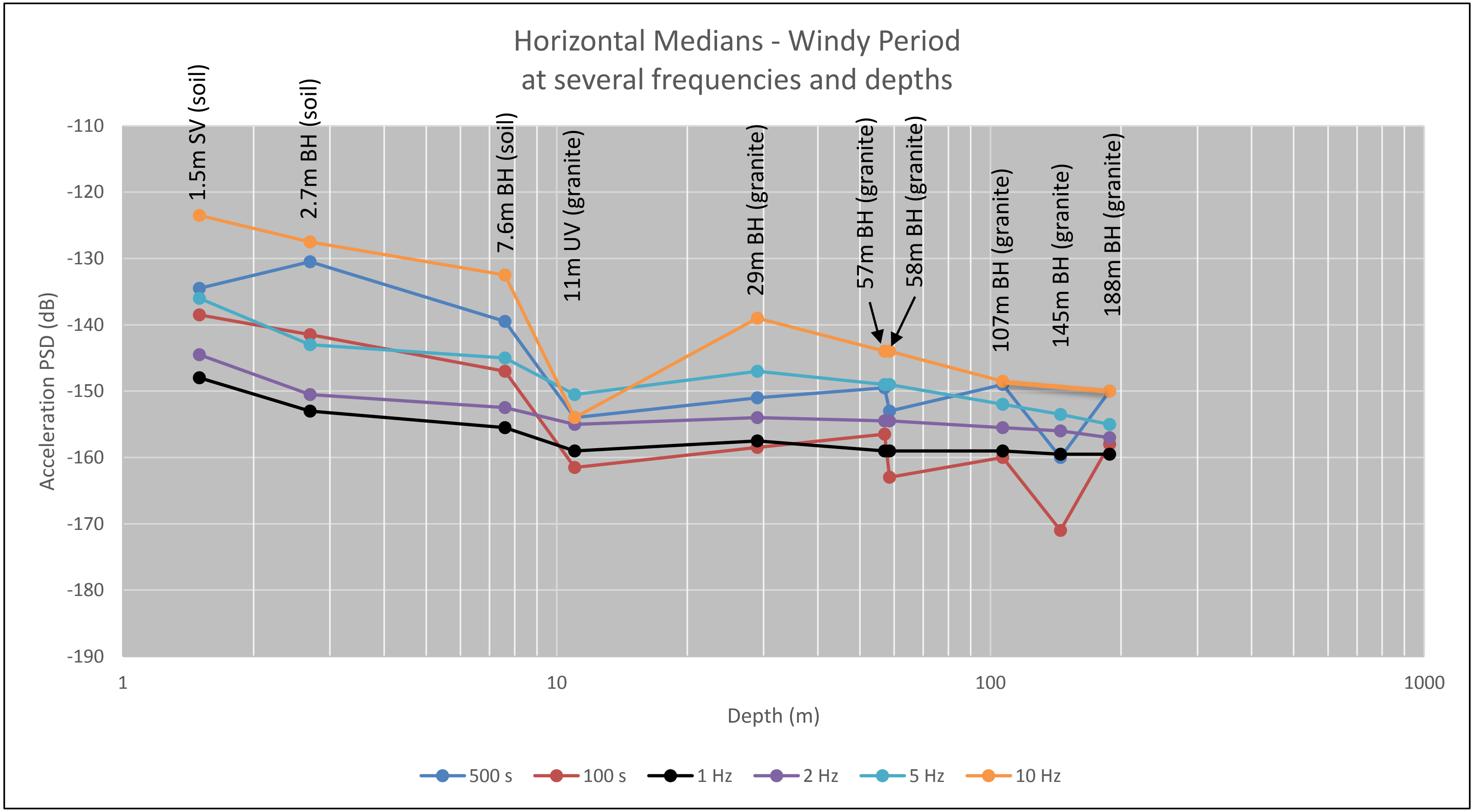
Vertical noise (windy) vs. depth at several frequencies



Horizontal noise vs. depth at several frequencies

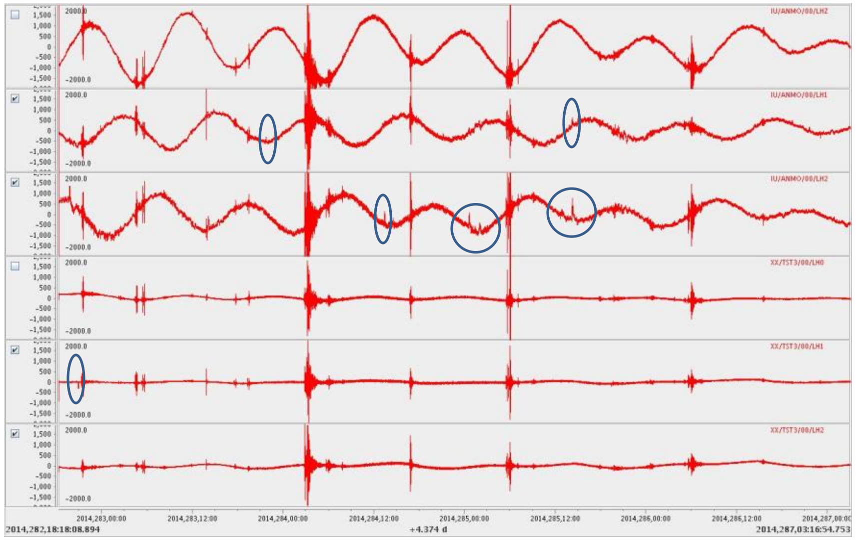


Horizontal noise (windy) vs. depth at several frequencies



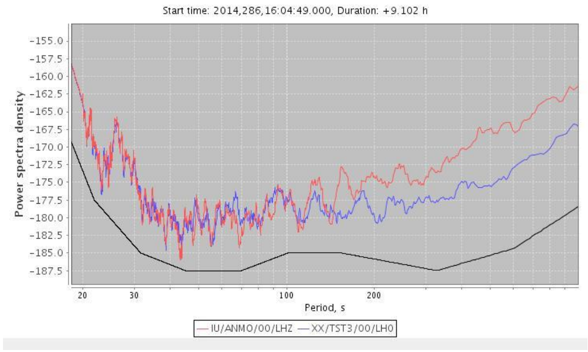
Trial of T120BH (with built-in holelock) in deepest borehole

Top 3: ANMO KS54000 LHZ, LH1, LH2
Bottom 3: T120BH in 188.2m hole

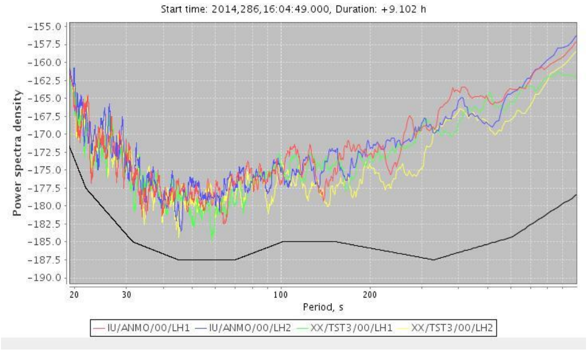


Note pulses (circled) in ANMO horizontal components vs only one pulse in T120BH horizontals. Time scale: 4.374 days. The T120BH was installed one day before the start time of this plot. The ANMO KS54000 has been installed (in sand) for more than 10 years, so is well-settled.

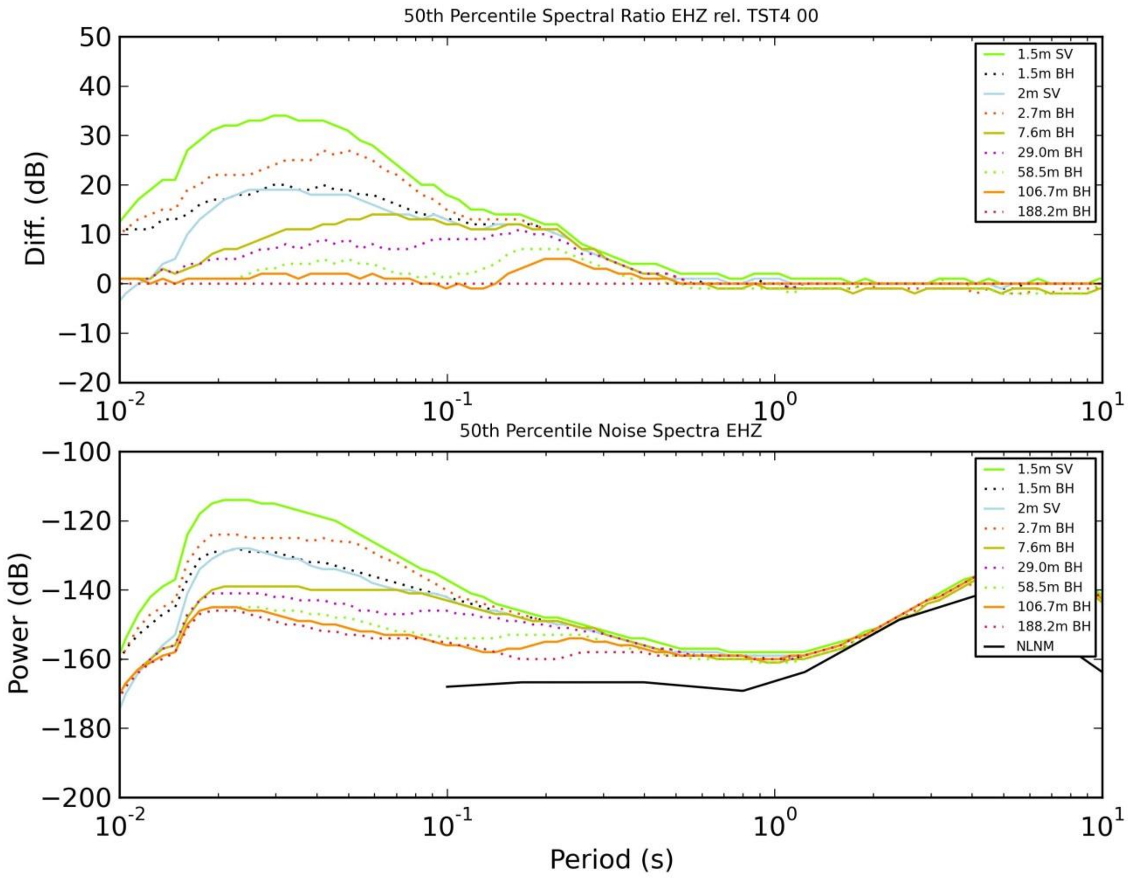
LHZ PSDs during quiet period:
Red = ANMO KS54000 at 145m depth
Blue = T120BH at 188.2m depth



LHH PSDs during quiet period:
Red & blue = ANMO KS54000 at 145m depth
Green & yellow = T120BH at 188.2m depth



EHZ (200 sps) Data
(EHH PSDs and ratios were similar to these.)



Top Panel: Median EHZ spectral ratios compared to deepest hole (188.2 m). This sensor was chosen as the reference sensor for very high frequency data because of its greatest depth. There were no EH data available from the ANMO sensors.

Bottom Panel: Median EHZ PSDs.

Conclusions – Long Periods

- **Vertical LP noise attenuation (188 m *vs* 1.5 m depth)**
  - At 100 s: 1 to 2 dB
  - At 500 s: 12 dB
  - A burial depth of 7.6 m is enough to produce excellent vertical long period data.
- **Horizontal LP noise attenuation (188 m *vs* 1.5 m depth)**
  - At 100 s: 22 dB
  - At 500 s: 23 dB
  - Burial depths of 100 m or greater are usually necessary to produce the best horizontal long period data.
  - Deeper is definitely better, especially when the wind is blowing.

Conclusions – High Frequencies

- **Vertical noise attenuation(188 m *vs* 1.5 m depth)**
  - At 5 Hz: 12 dB
  - At 10 Hz: 22 to 24 dB
  - At 30 Hz: 35 dB
- **Horizontal noise attenuation (188 m *vs* 1.5 m depth)**
  - At 5 Hz: 11 to 12 dB
  - At 10 Hz: 24 dB
  - At 30 Hz: 35 dB

Conclusions (cont.)

- Nanometrics T120BH (with holelock) may work better (at preventing air convection and settling pulses) than backfilling with sand or other materials (such as glass beads or aluminum oxide sand)
  - Excessive noise seen during noise study in the 106.7m and 188.2m holes may have been due to settling or cementing processes in backfill medium (glass beads).

So, how deep is deep enough?

- It depends on your application.
- For quick deployments (like aftershock studies), 1 m is probably enough. More soil over the top is better for good temperature stability (for good vertical data).
- For temporary (but longer-term) deployments (like TA) where low cost can be very important, 2 m to 3 m may be sufficient.
  - Try for maximum burial depth within the budget.
  - Posthole deployments in hard rock are better than in soil.
- For permanent observatories where cost is less important, 100 m to 200 m depth in hard rock is desirable to achieve lowest noise.
  - Or – a good vault in granite. The ASL underground vault compares favorably with the deep boreholes at all frequencies.

For low noise: **Avoid Mike**