~~Down the Rabbit Hole~~

~~Drilling Down into Postholes~~

~~Postholes Posthaste~~

~~(Post)Hole in One~~

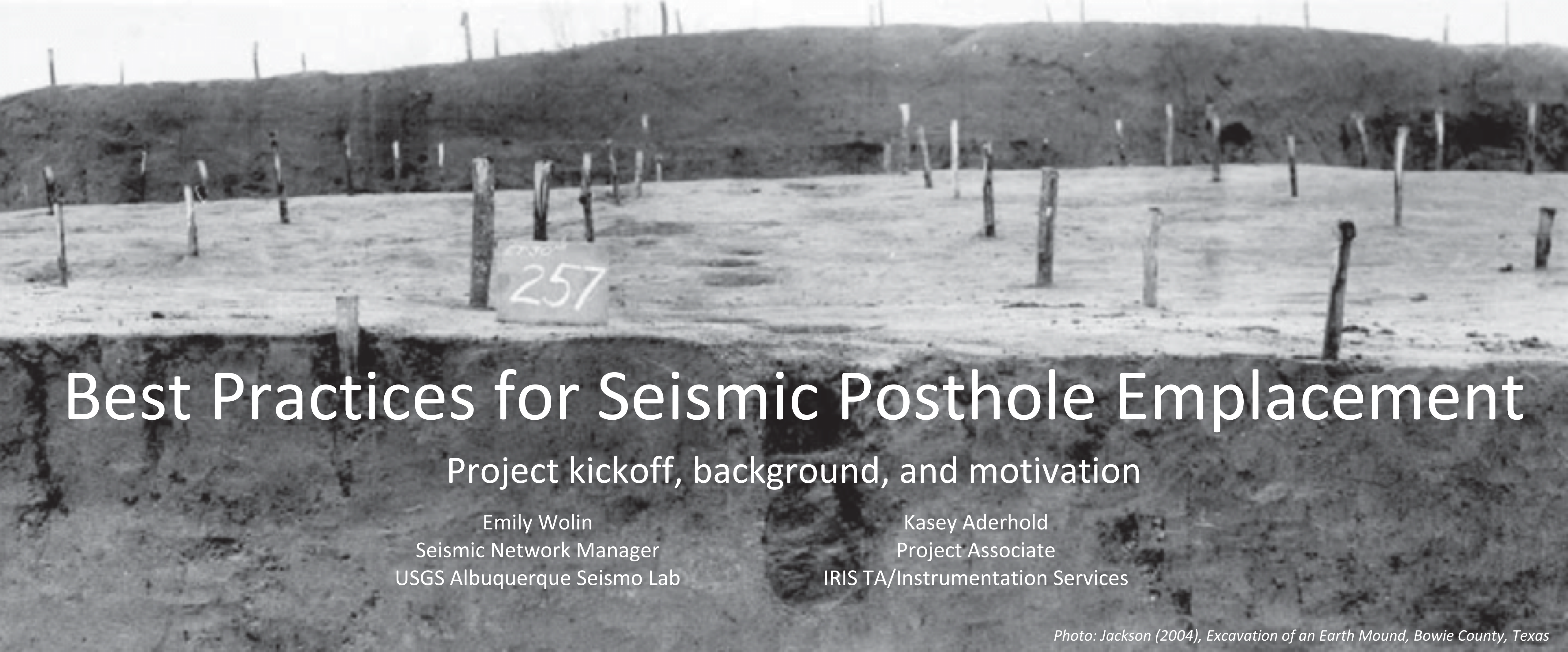
~~Fantastic Holes and How to Dig Them~~

~~This is Not a Drill~~

~~PostMalone Hole~~

~~Just in Case~~

~~A Boring Webinar Series: Part I~~



Best Practices for Seismic Posthole Emplacement

Project kickoff, background, and motivation

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USGS Albuquerque Seismo Lab

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Project Associate
IRIS TA/Instrumentation Services

Photo: Jackson (2004), Excavation of an Earth Mound, Bowie County, Texas

Posthole discussion **series**: mission

By pulling together the expertise of our community, we will learn from combined previous experiences and recommendations going forward, ensure future seismic posthole emplacements will be of the highest quality possible, and will outline the areas ripe for exploration and technical development.

Deep pockets of posthole emplacement expertise already exist in the seismology community.
Let’s make this information discoverable, accessible, and actionable.

Posthole discussion **series**: goals

- **Summarize** the history, motivations, and developments of seismic posthole emplacement for the seismology community and the public.
- Draw on the vast experience of seismic network operators and principal investigators who have installed seismic sensors in postholes. Foster the **sharing of successes, failures, and lessons learned** through technical presentations and discussions on focused topics within seismic posthole emplacement.
- **Assemble examples** of posthole emplacement sites that have publicly accessible data and are **sufficiently documented** for reproducibility of results. Known noise sources can be included.
- Identify a set of recommended **best practices** for seismic posthole emplacement.

Timeline and deliverables

- January 2021: Kickoff webinar and panel
- February - May 2021: Organize discussions of focused topics within posthole emplacement, held every 3-4 weeks
  - We warmly welcome topic suggestions and presenter self-nominations!
- June 2021: Solicit information on posthole emplacement sites and documentation.
- December 2021: Submit manuscript with a compilation of recommended best practices for posthole emplacement. Publish archive of posthole sites and documentation.

Deliverables:

1. A **digital database** of posthole emplacement sites with documentation suitable for reproducing results (location, data availability/epochs, materials, measurements, narrative construction/install descriptions or videos, site photos, diagrams - map/cross section, known noise sources).
2. A **manuscript or chapter** in New Manual of Seismological Observatory Practice (NMSOP-2) summarizing recommended current best practices for posthole emplacement.

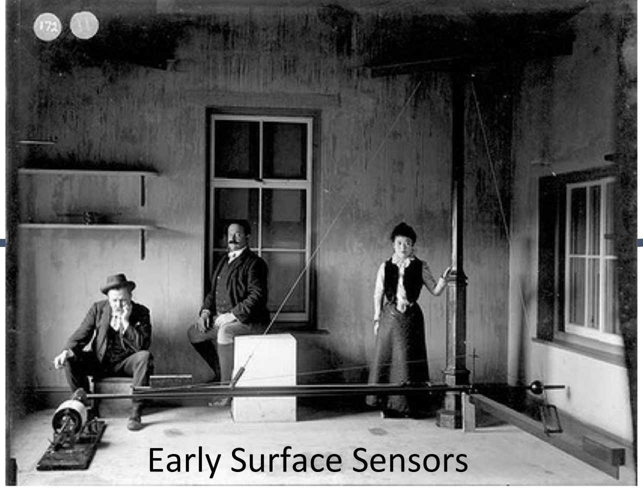
Project website: https://www.iris.edu/hq/initiatives/posthole_emplacement

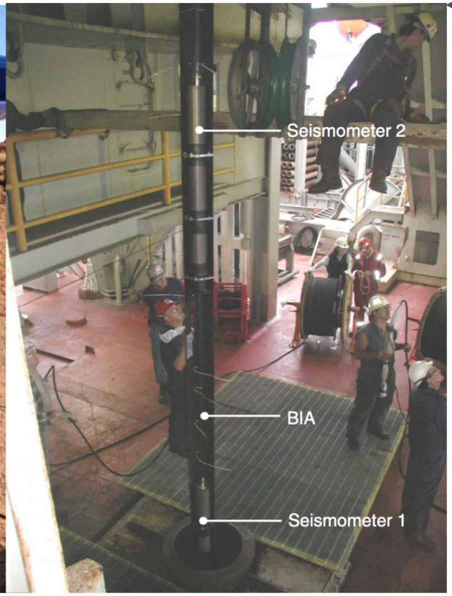
Kicking off: basics for non-specialists

Case studies and discussions will delve deep into technical details and the history of posthole sensor development.

First, a bit of background for folks who may be less familiar with seismic instrumentation, data quality control, or field operations, but who are still interested in learning about posthole emplacements.

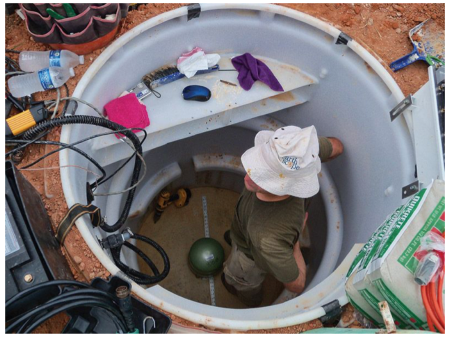
- What is a posthole, anyway?
- Noise 101 for non-specialists
- One network manager's motivation for learning more





100 yrs of sensor evolution in one slide

Cased Posthole

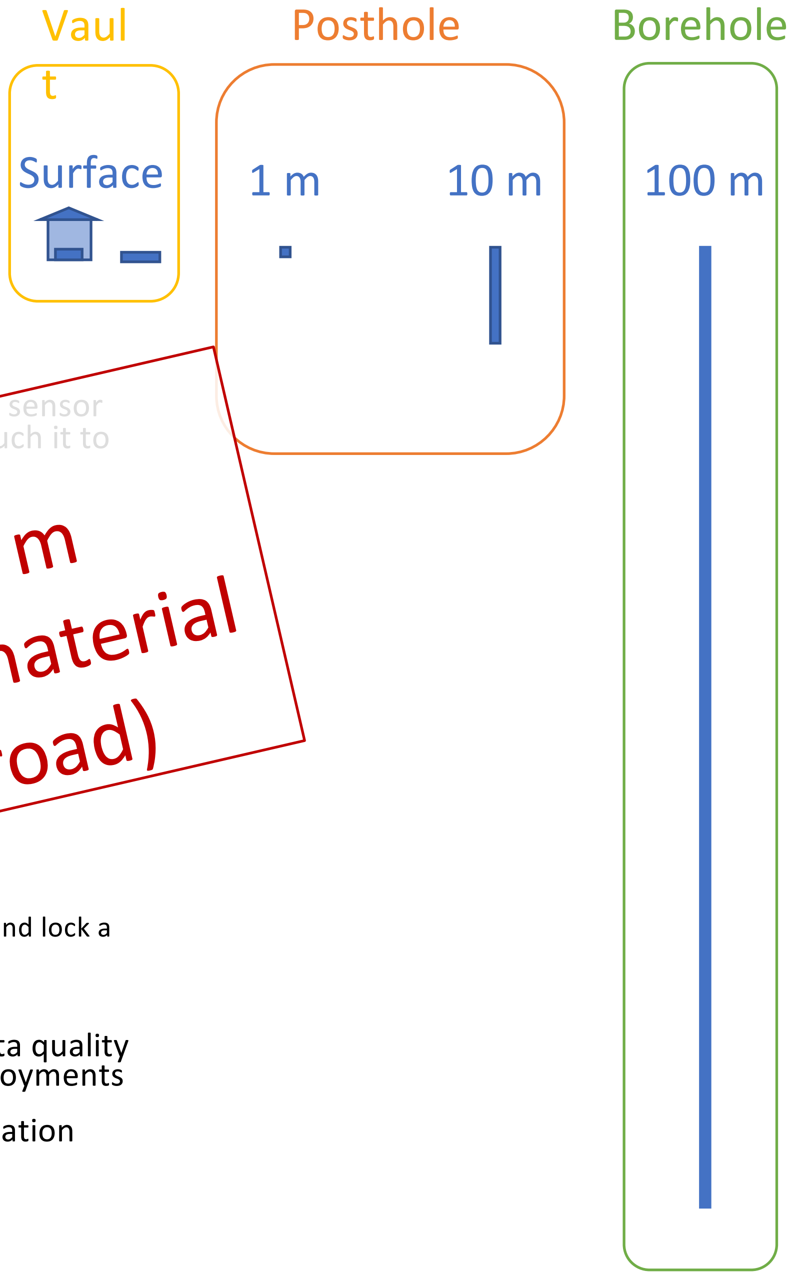


Semi-permanent Vault

Direct Burial

Ice Burial

What is a “posthole”?



- Vault = enclosure designed to keep a sensor clean, dry, and accessible to humans; sensor can be accessed without uninstalling it (STS-2 is a typical “vault” sensor – must touch it to lock it)
- Very loosely:
  - depth on the order of 10^0-10^1 m
  - usually in soft(ish) sediments
  - dug by hand or with a relatively small auger/drill
    - hand auger, truck-mounted auger, or helicopter-slingable drill
  - cased or uncased, grouted or ungrouted
  - sensor designed with groundwater in mind
- Contrast with a borehole:
  - spend considerable $$ to minimize cultural, thermal, and/or atmospheric noise
  - may be instrumented w/very broadband (VBB) sensors (i.e. GSN)
  - may need special equipment to push analog signal voltage up a 100 m cable, or install and lock a 30 kg VBB sensor in a cased steel hole
  - drilled with dedicated rig into hard rock
- Postholes = logistically/financially attainable for broader user group, improved data quality for observational targets of regional/national seismic networks or temporary deployments
- Boreholes = dedicated permanent monitoring facilities seeking the quietest installation possible for frequency band(s) of interest

Not a vault, not a borehole
Depths of a few m to a few tens of m
Minimal disturbance to surrounding material
(this definition left intentionally broad)

Outline

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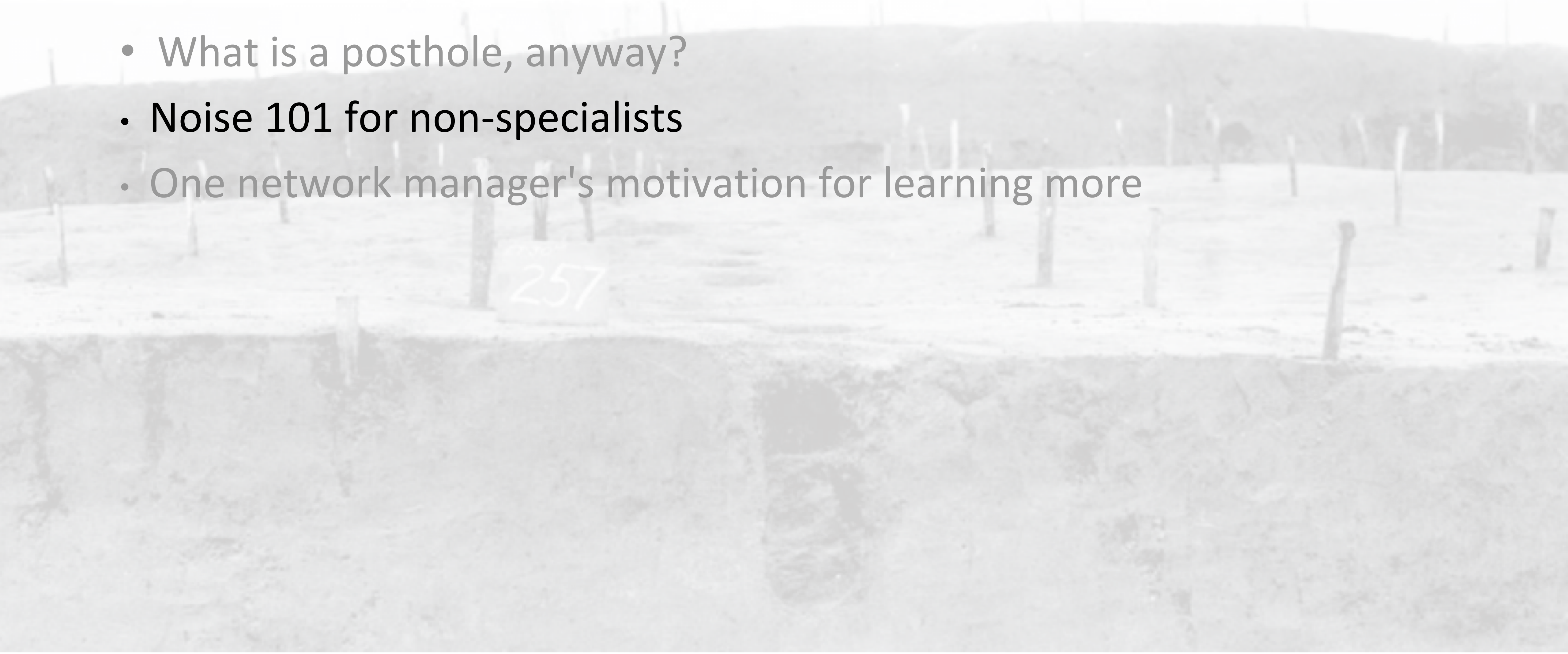


PSDs, PDFs, and noise models

- Peterson (1993) established seismic noise models widely used to assess station performance
- Defined by a range of power spectra observed at high-quality permanent sites
- “New” High and Low Noise models (NHNM, NLNM)

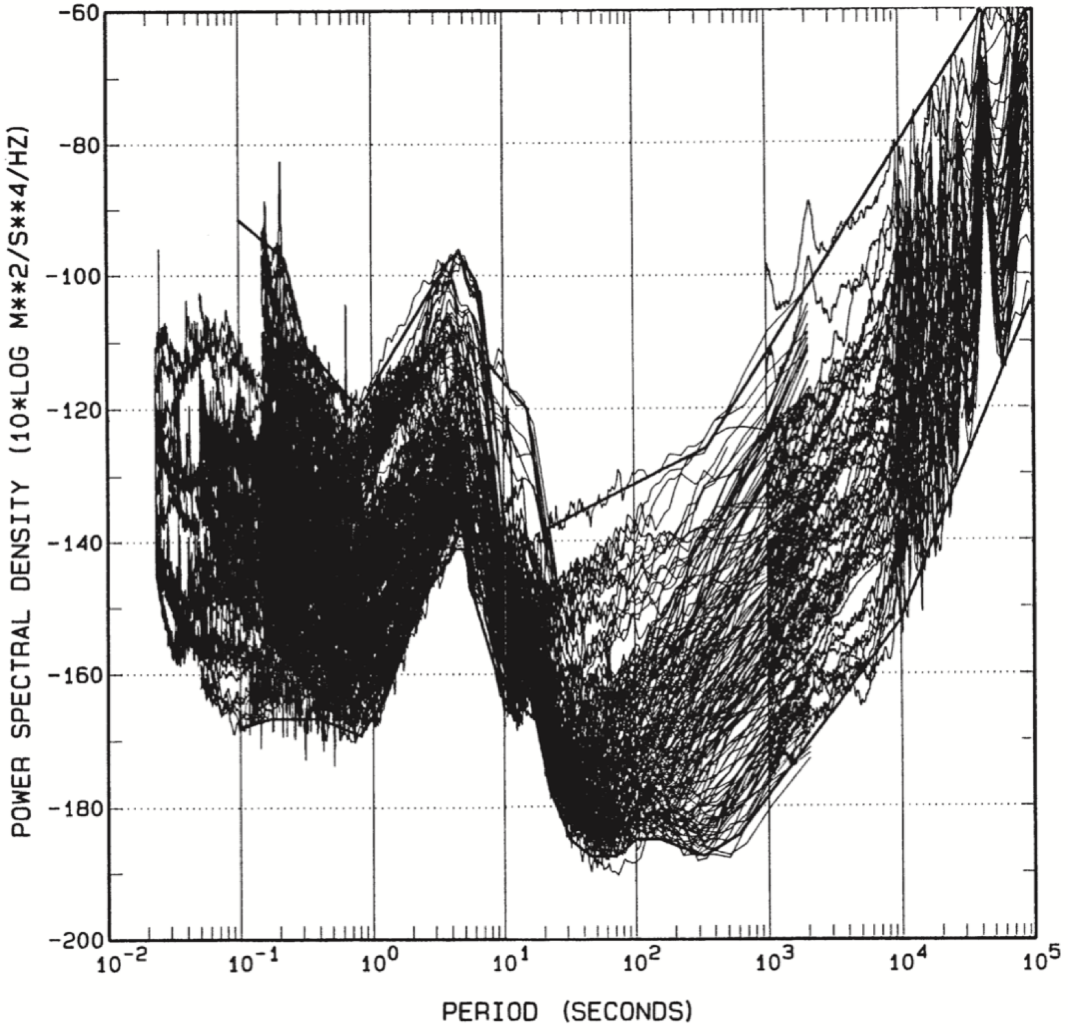
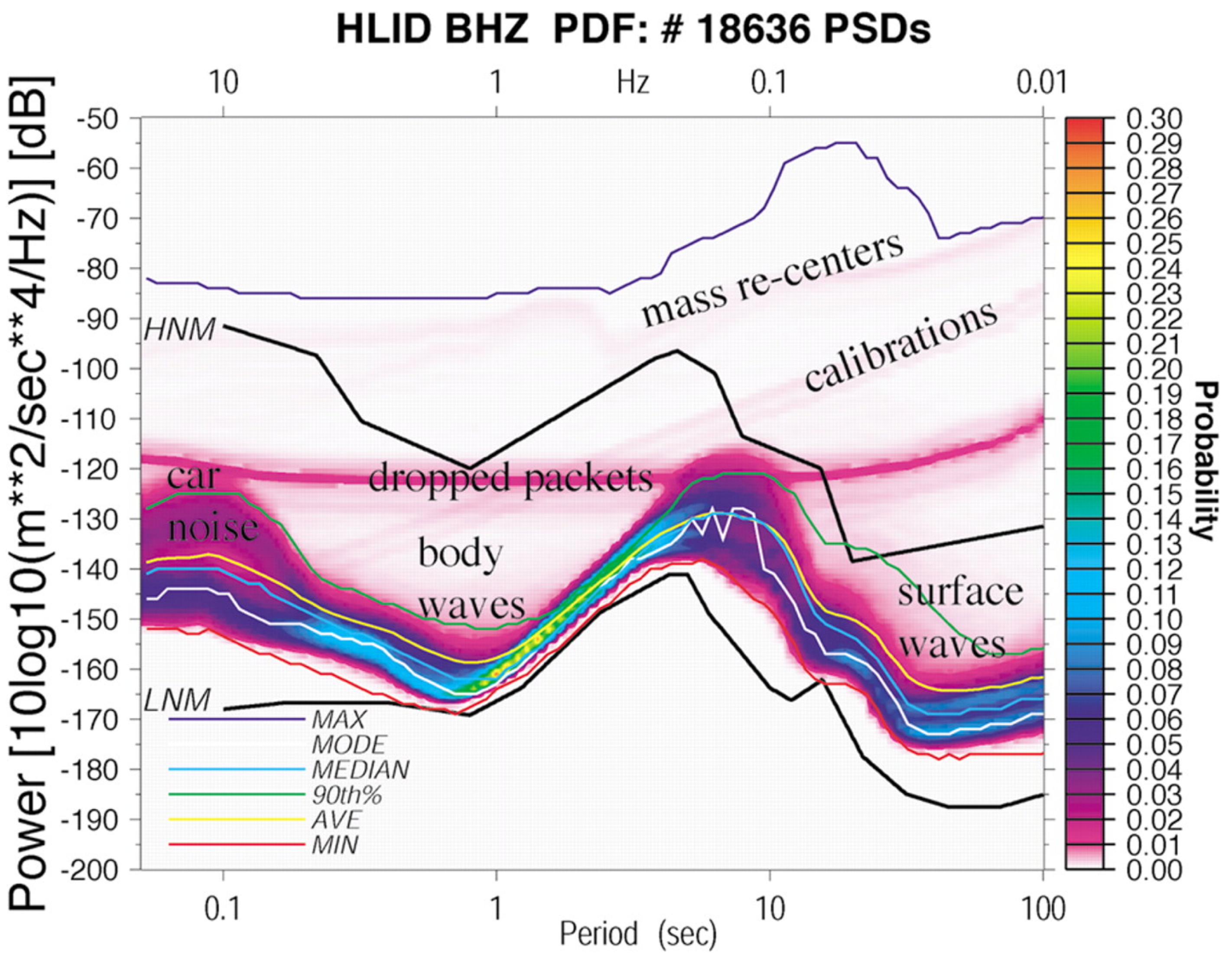


Figure 13.--An overlay of network spectra with straight-line segments fitted to the high-noise and low-noise envelopes of the overlay.

Peterson (1993): https://pubs.er.usgs.gov/publication/ofr93322

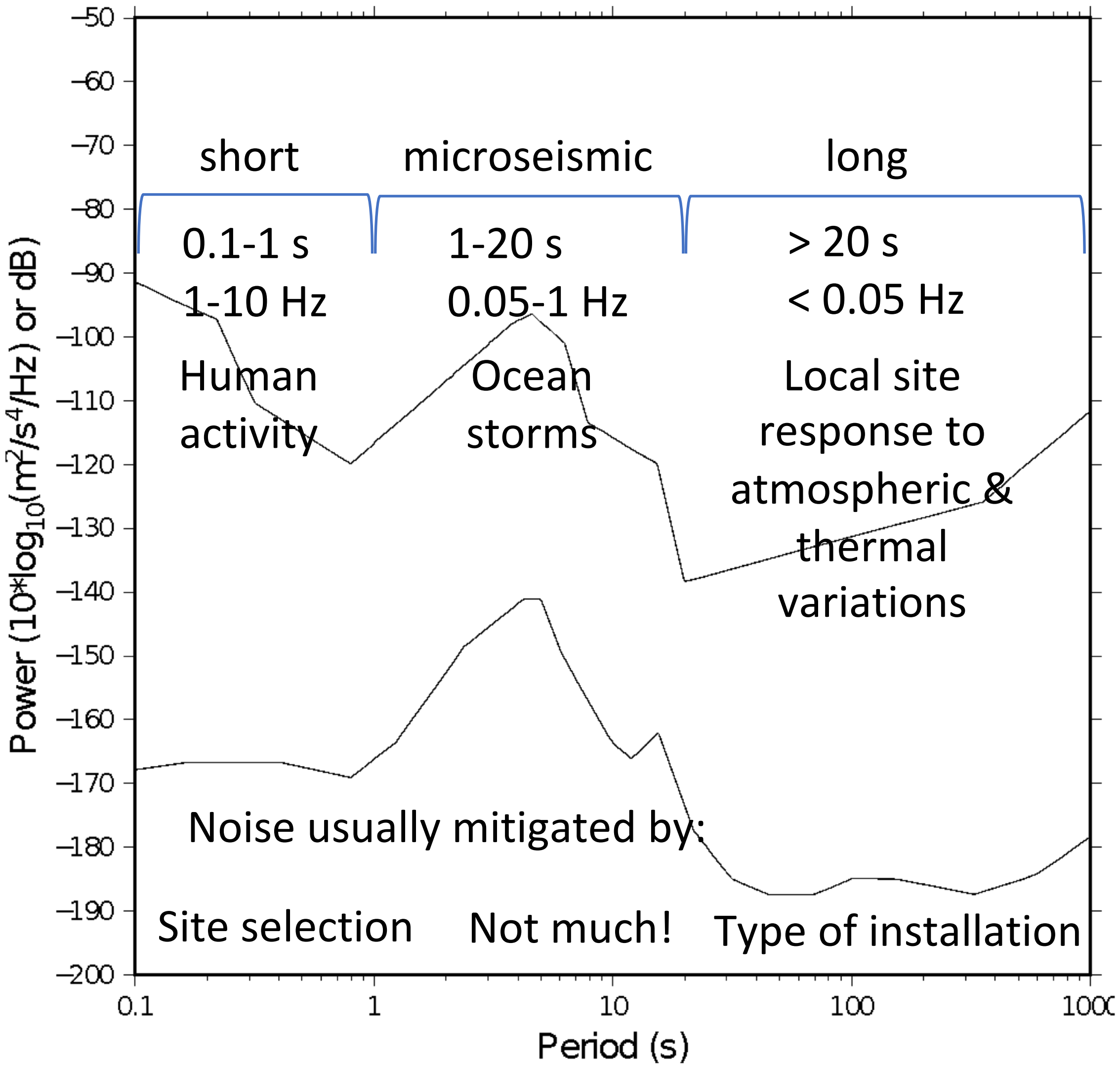
PSDs, PDFs, and noise models

- Power spectral density (PSD) probability density functions (PDFs) show distribution of noise in a given time period
  - Slice seismogram into many overlapping segments
  - Calculate power spectra
  - Create 2D histogram of power vs. frequency
- Widely used in network quality control
- Choice of processing parameters matters! Tune carefully to avoid biasing or smoothing through signals of interest (Anthony et al., 2018)
- Often plotted in units of dB with respect to acceleration
  - 6 dB change = 2x difference in amplitude



(McNamara and Buland, 2004; McNamara and Boaz, 2019)

PSDs, PDFs, and noise models



Keep in mind: every seismologist has a different idea of what “high frequency” or “long period” means!

Lots of switching between units of frequency (Hz) and period (s)

At T > 20 s, horizontal components are usually noisier than verticals due to highly localized effects of temperature and pressure changes

Horizontal noise typically decreases with increasing depth of installation

Seismometers record signals from many sources

15 km area of flexibility around an initial point
Telemetry (cell or AC VSAT) is feasible, including sufficient power requirements
Landowner is agreeable
Site is sufficiently removed from sources of vibration • Roads: >300 m from minor roads and >1.5 km from major roads • Railroads: >3 km or >10 km in a basin • Pipelines: >2 km • Oil and gas production: >3 km from wells and injection facilities • Irrigation: >2 km from large agricultural and water storage pumps • Rivers: >3 km from dams and weirs, >1 km for whitewater, n/a for slow moving water • Wind: ridgetops w/hard rock may be considered, but constant high winds should be avoided • Construction and mining: >2 km from large projects • Sedimentary basins: avoid when possible in favor of competent rock to mitigate multipathing effects

Table 2-1. General criteria used for selecting TA sites.

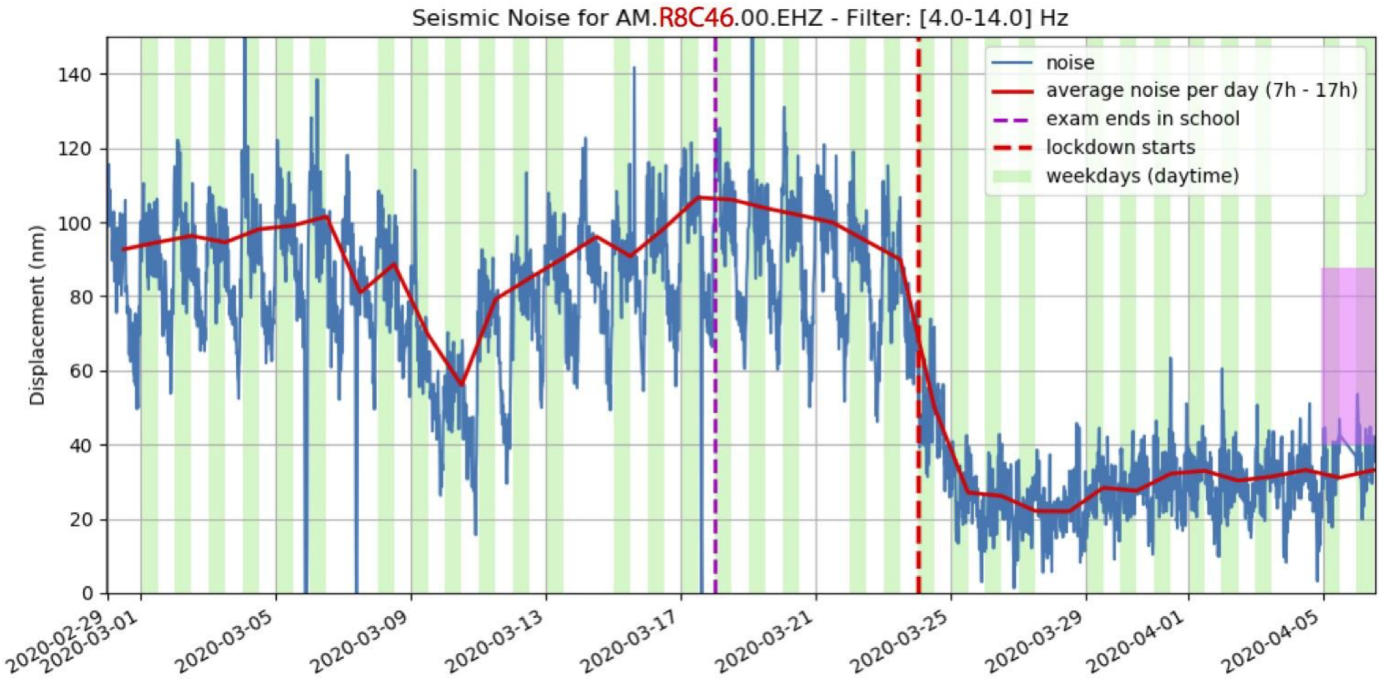
Lower 48 Transportable Array (Busby et al., 2018)

Superior Province Rifting Earthscope Experiment (SPREE) Siting Criteria

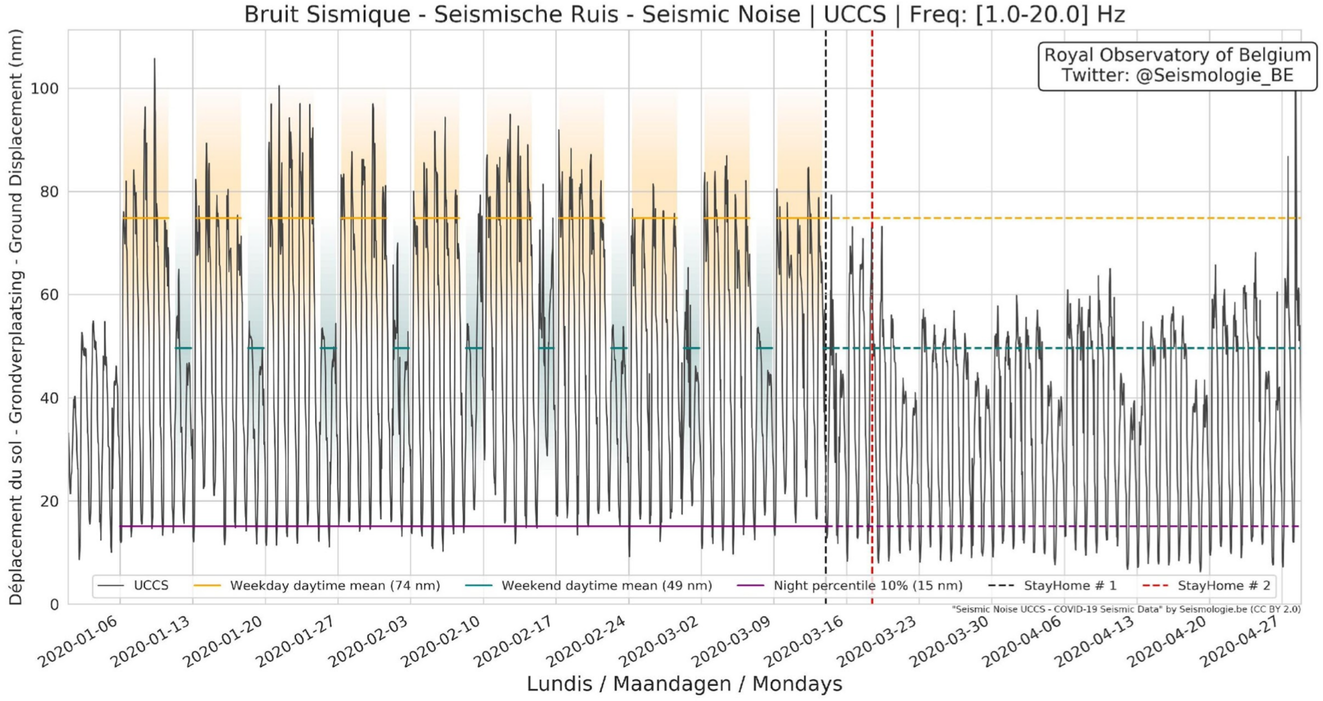
Feature	Preferred Distance	Minimum Distance
Railroads	10 km	5 km
Highways (interstate)	5 km	3 km
Highways (county)	1.5 km	1 km
Local roads	1 km	500 m
Driveways	400 m	200 m
Occupied buildings	400 m	200 m
Tall objects (trees, towers)	$2 \times$ height	$1 \times$ height
Oil wells and pipelines	2 km	1 km
Dams	3 km	1 km
Construction	3 km	1 km

SPREE Flexible Array deployment (Wolin et al., 2015)

Many seismic stations around the world observed a drop in high-frequency noise levels due to covid-19 lockdowns



Raspberry Shake installed in a school in Nepal (@AtSeismo/Shiba Subedi)

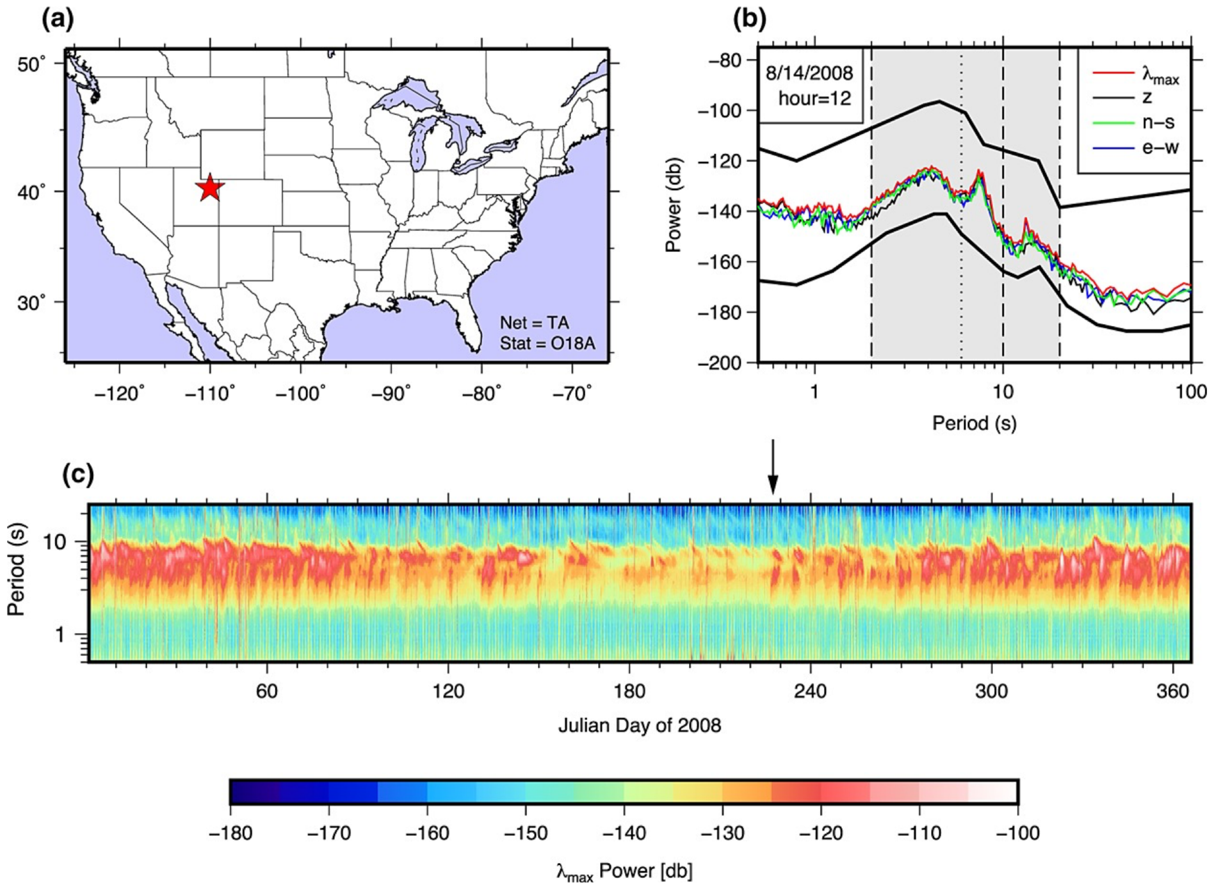


Permanent broadband in Brussels (@Seismologie_be/@seismotom/Thomas Lecoq)

Lecoq et al. (2020), Nature

Seismometers record signals from many sources

Ocean storms generate ambient “microseismic” signals
observed everywhere on Earth - even in continental interiors



(Koper and Burlacu, 2015)

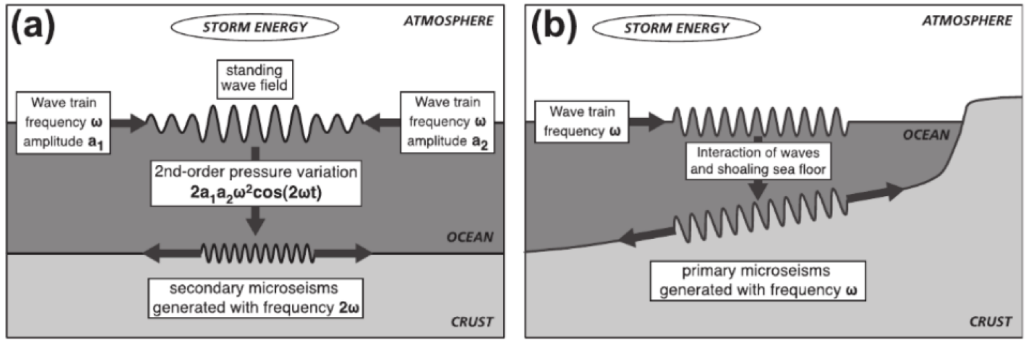
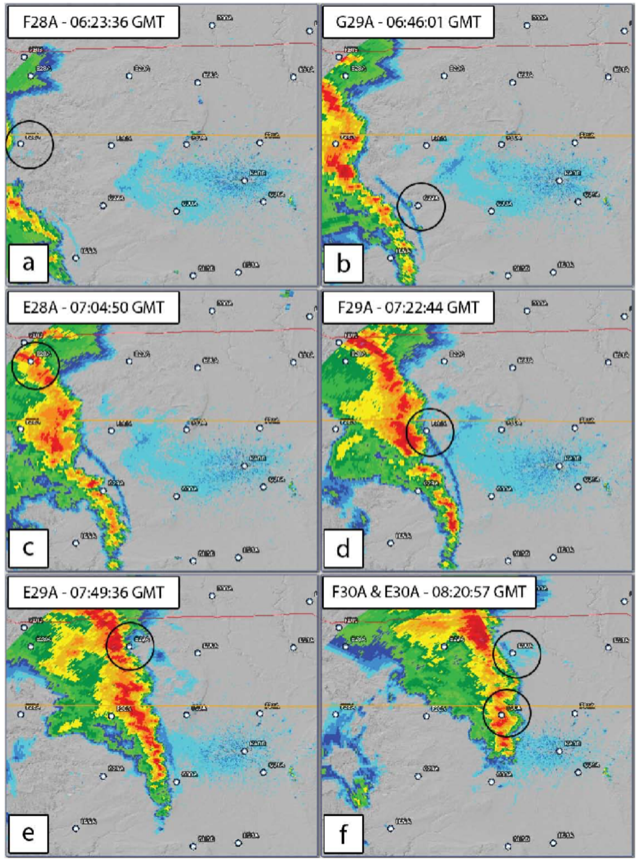
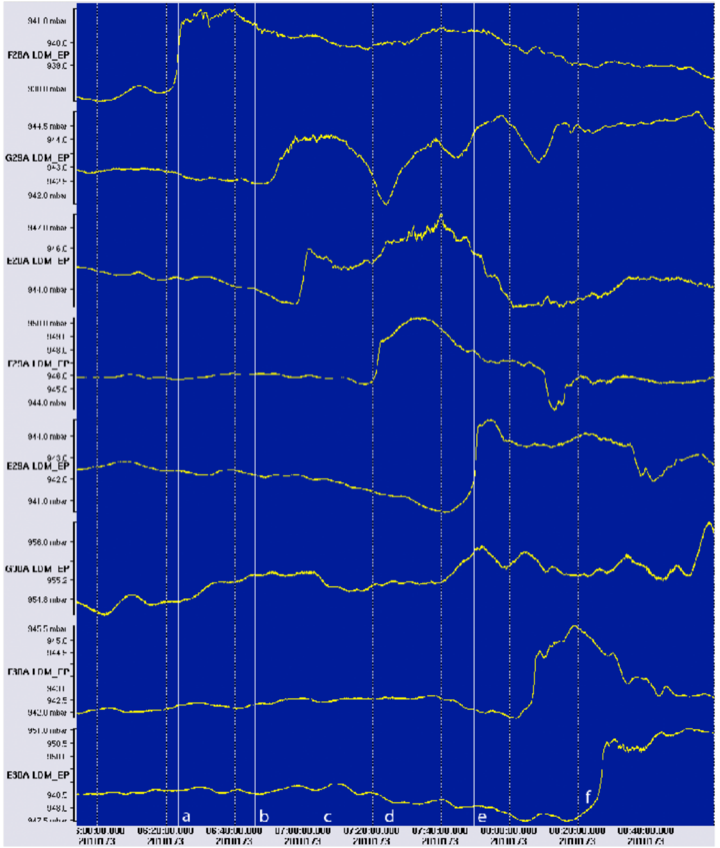


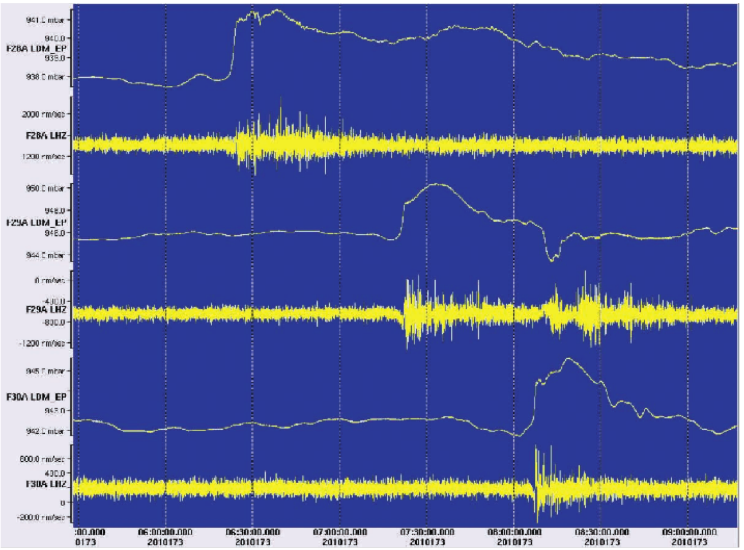
Figure 1.7 Cartoon illustration of microseism generation mechanisms. (a) Secondary microseisms are generated only when ocean wave trains of the same frequency traveling in opposite directions meet. Under these conditions, a depth-independent second-order pressure variation arises, with amplitude proportional to the product of wave amplitudes (a_1 and a_2) and its frequency (2ω) double that of the ocean waves (Longuet-Higgins, 1950). Opposing wave trains can be generated at or near storms in deep or shallow water, or in shallow water when an incoming wave train meets waves reflected from a coast. In the former case, energy is transported from the storm to a receiving station via microseisms; in the latter, it is primarily ocean waves that transport the energy. Both generation modes may be active for any particular storm. (b) Primary microseisms are generated through nonlinear coupling of ocean wave energy into the seafloor by the shoaling action of waves in shallow water (Hasselmann, 1963). Primary microseism frequency ω is that of the ocean waves responsible for their generation, which may travel great distances before primary microseisms are generated.

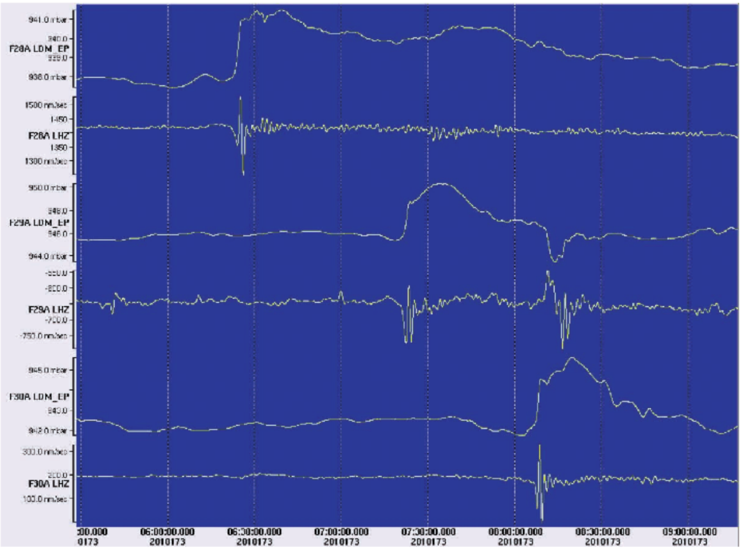
(Ebeling, 2012)

Long-period signals from surface tilt









Passage of storm front over TA stations:
large tilt signal coincides with passage of gust front (initial pressure jump)

Tytell et al. (2011)

Vernon et al. (2011)

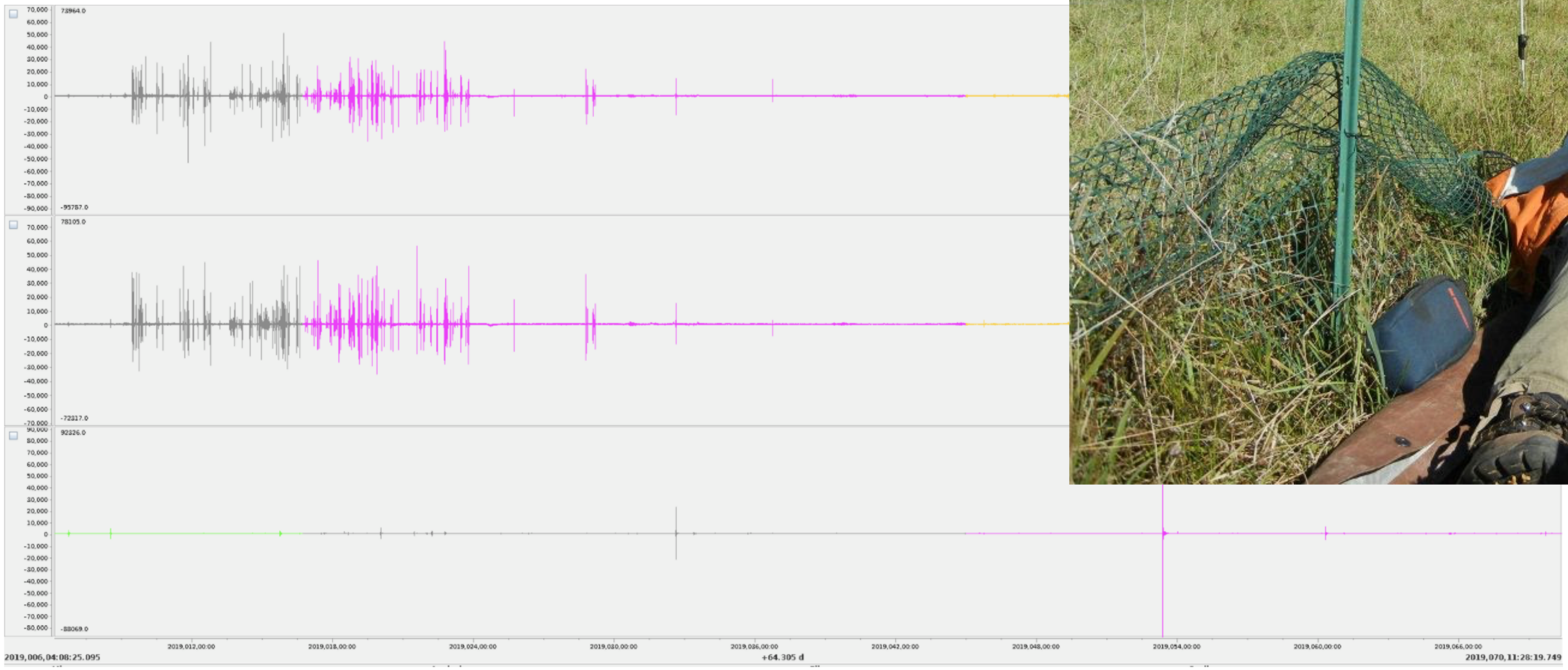
Long-period signals from surface tilt

Tue Mar 26 12:17:21 2019 **aholcomb (Andrew Holcomb) - Ticket created**

Subject: N4_S57A - Noisy channels related to Cattle Grazing
Date: Tue, 26 Mar 2019 12:17:20 -0600
To: [redacted]
From: [redacted]

There is a cattle pasture adjacent to the field where the sensor is buried causing pulsing on all channels.

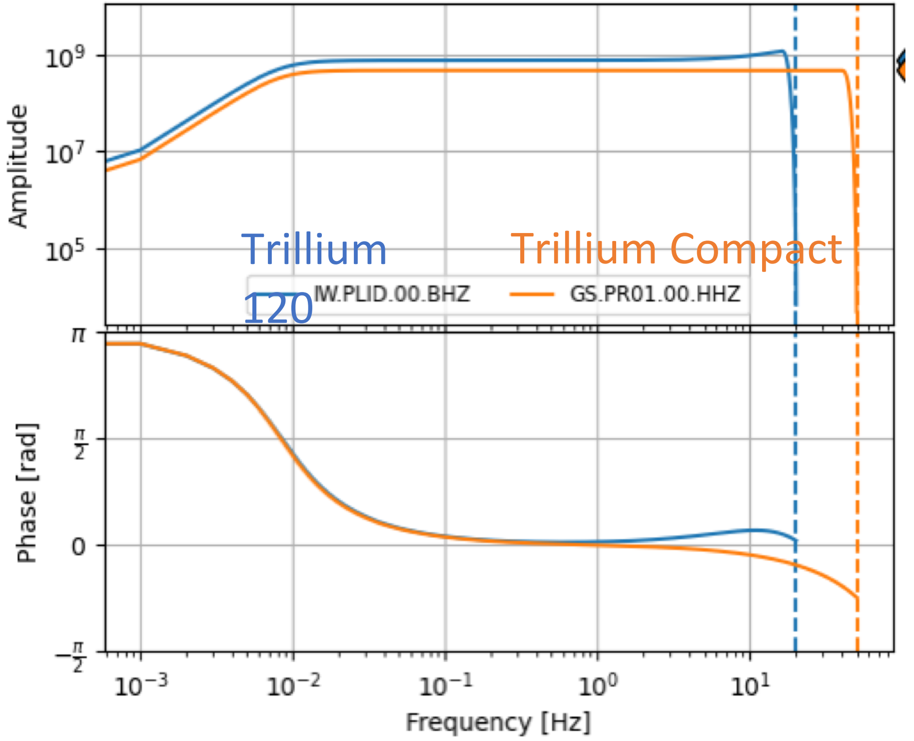
Subject: Screen Shot 2019-03-26 at 12.02.39 PM.png

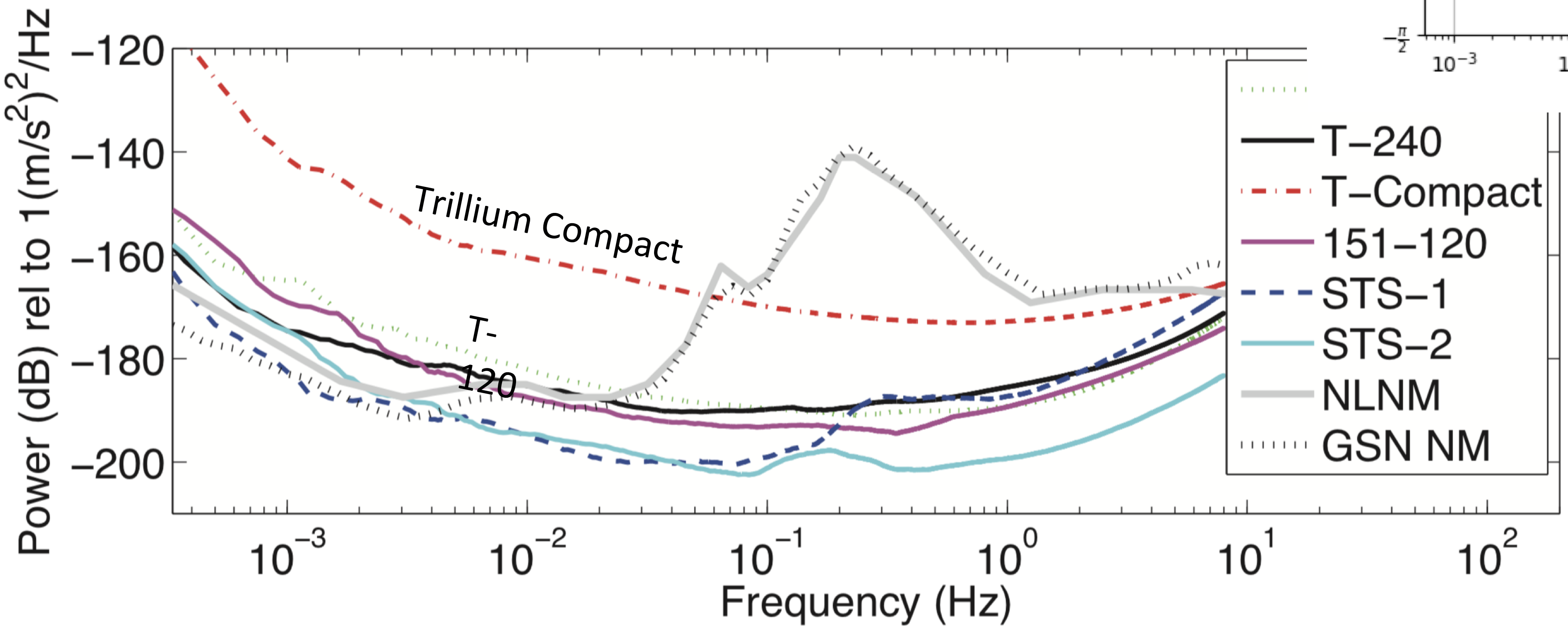


Sensor + digitizer self-noise

Corner frequency ≠ self noise level
Sensors can have the same response shape but different self-noise levels!

- assess performance accordingly
- example: Trillium 120 vs Trillium Compact 120





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Hutt and Ringler (2010)

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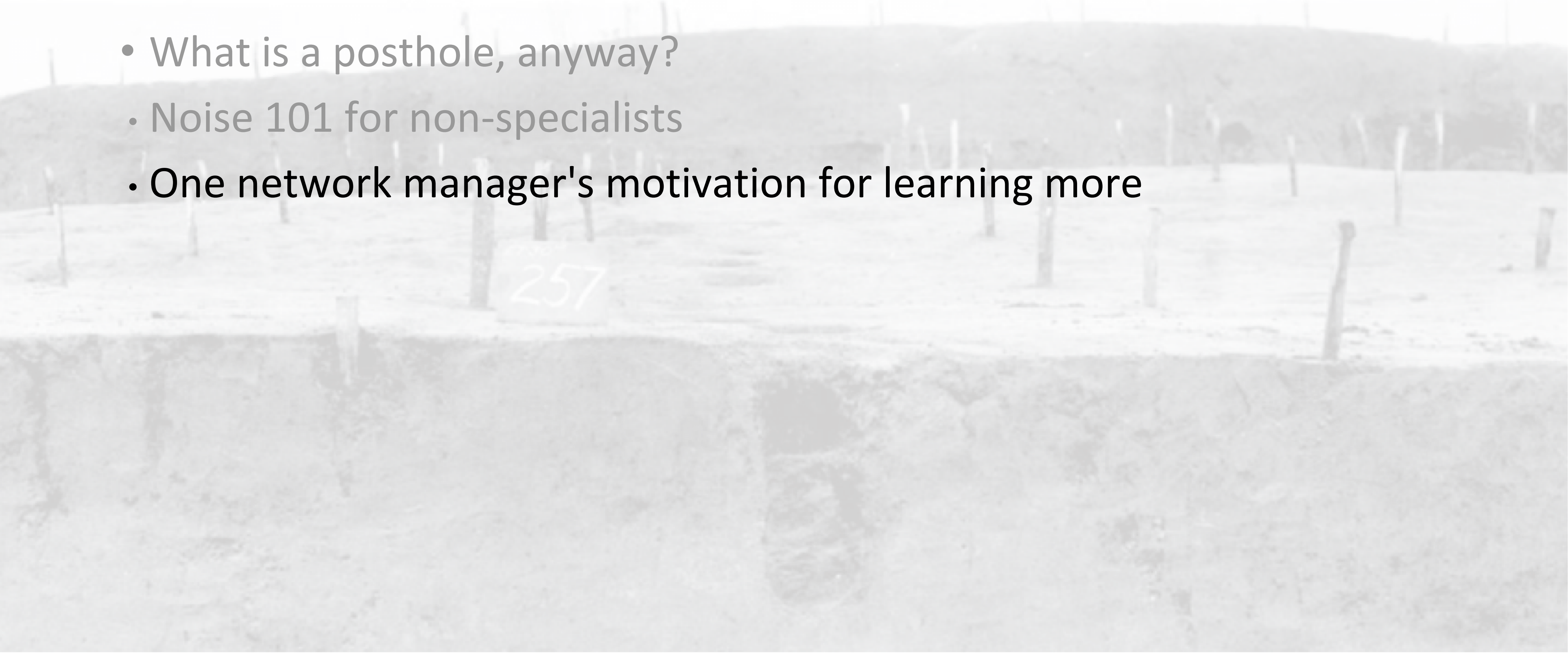
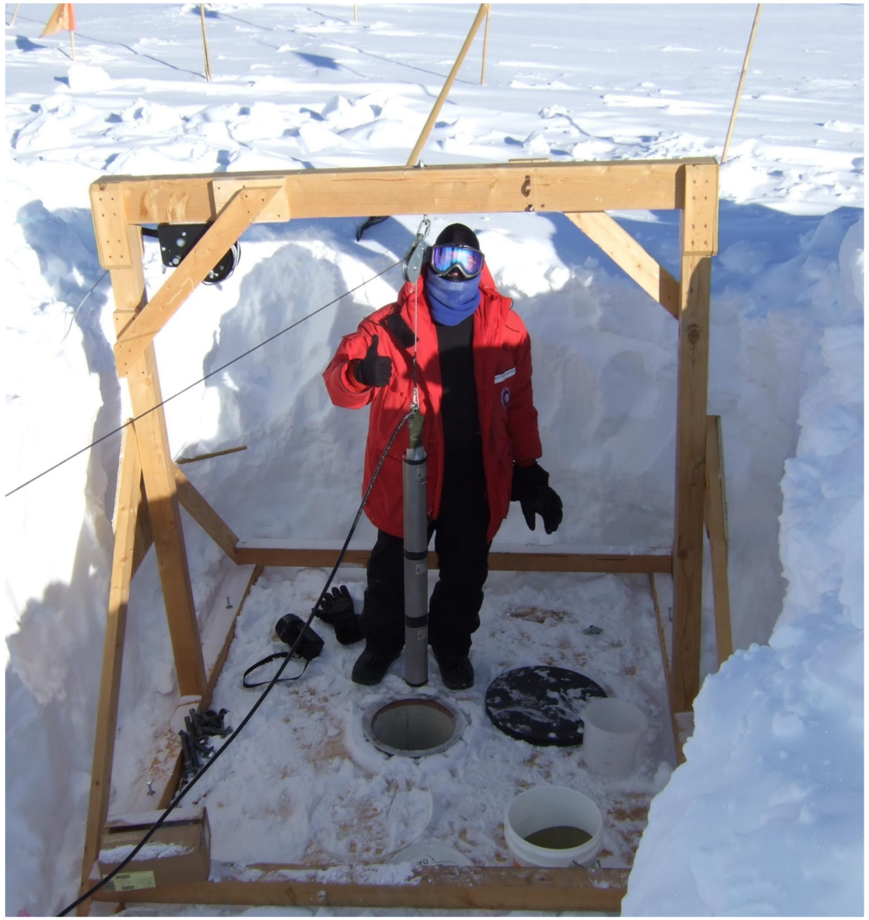


Why am *I* interested in postholes?

The USGS Albuquerque Seismological Laboratory operates 300+ seismic stations with a variety of instrumentation, emplacements, environments, and monitoring goals

My job as network manager is to ensure data quality, reliability, and efficiency of operations



Posthole motivation #1: Improve reliability

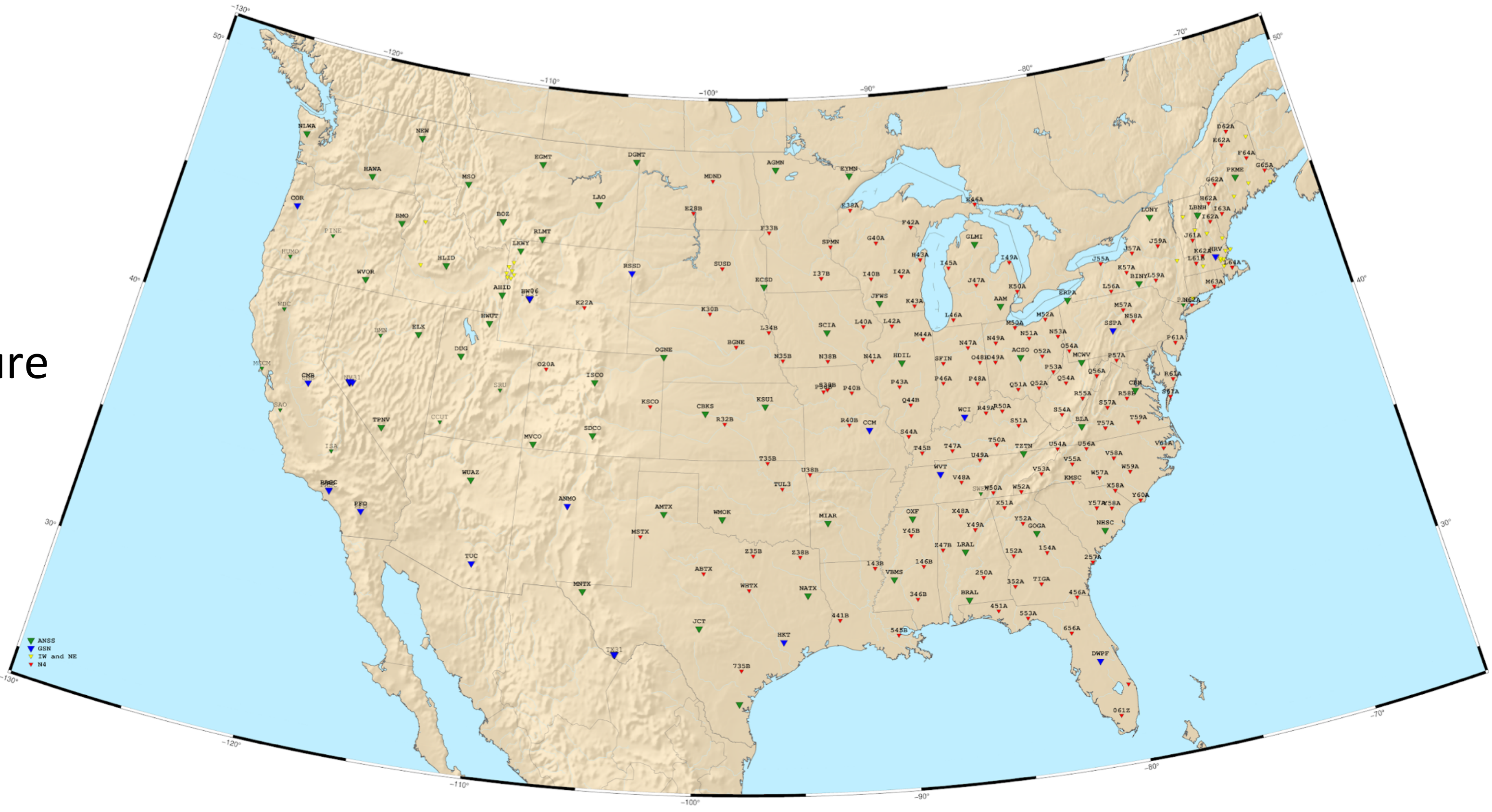
- Aging, leaky vaults are a significant cause of equipment failure
- Posthole sensors are designed to operate in the challenging environmental conditions present at many of our sites
- Posthole emplacements make it harder for curious humans or animals to tamper with an expensive broadband sensor

Broadband sensors do not like to go swimming 😱

Posthole motivation #2:
Improving quality of long-period (T $\gtrsim$ 10 s) horizontal-component data in CEUS

Potential to advance understanding of:

- source processes
- stress orientations
- crust and upper mantle structure
- seismic hazard
- and much more

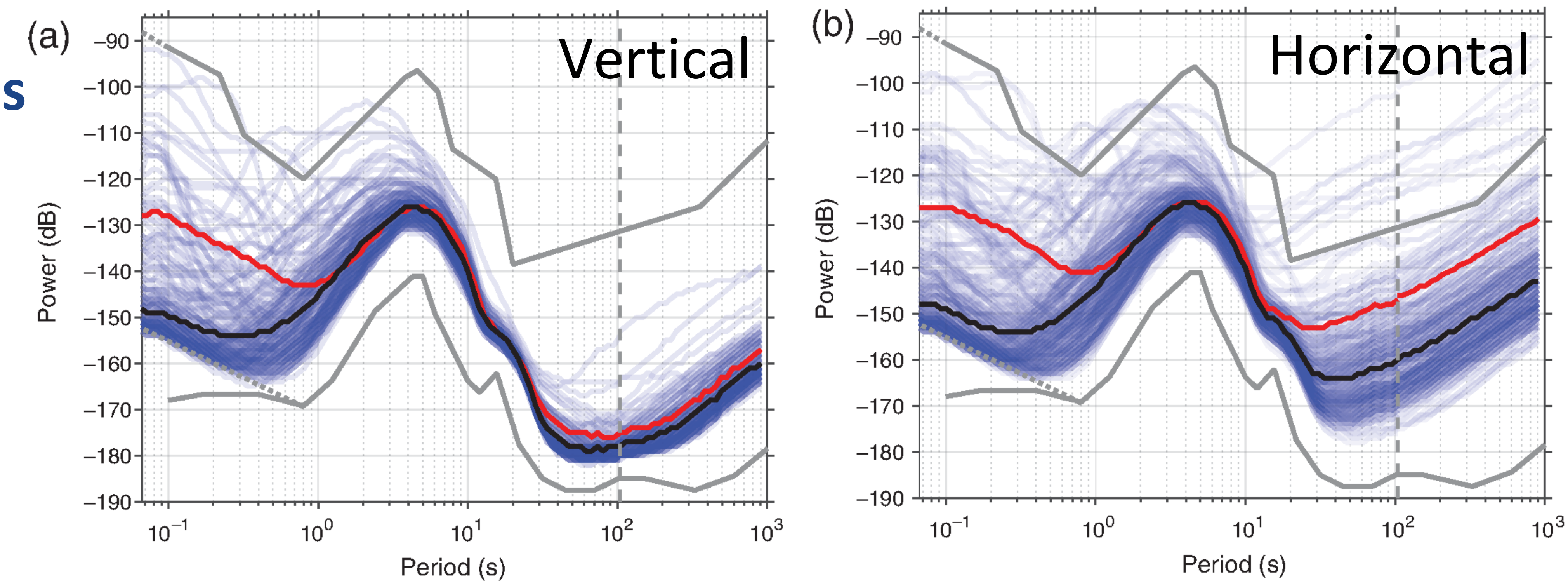


Comparing the median PSDs of the Alaska TA stations (posthole) to the median of the L48 TA (vaults) shows significant improvement at short periods but also long period horizontal noise

Blue - All Alaska TA PSDs

Black - Alaska TA Median

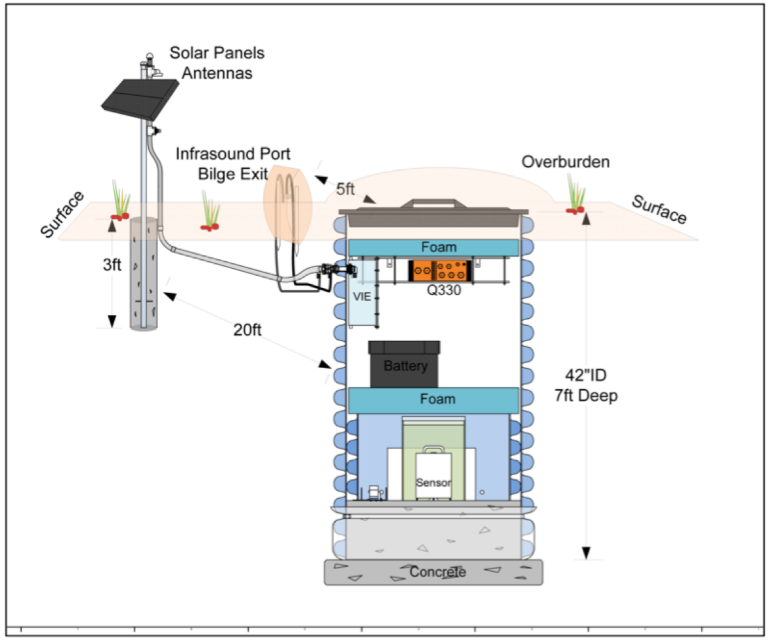
Red - L48 TA Median

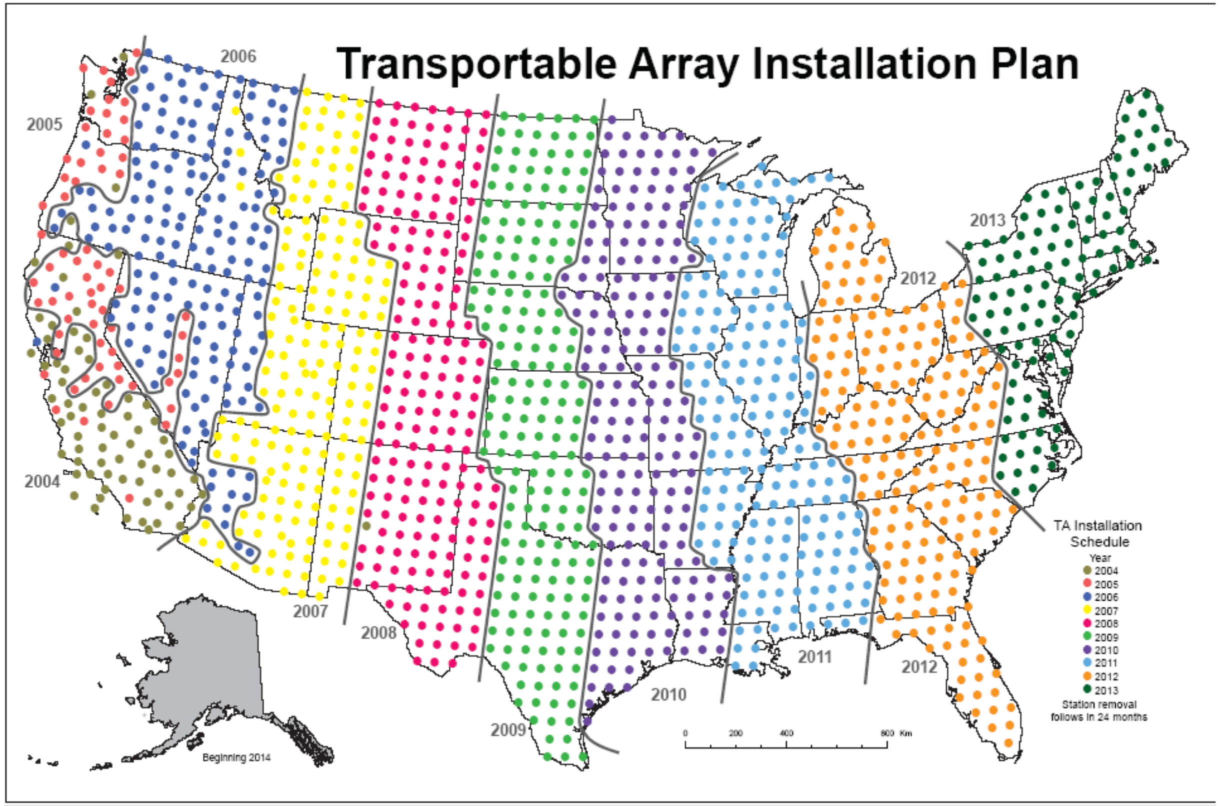


Busby and Aderhold, SRL, 2020

ASL adopted the N4 network in 2019

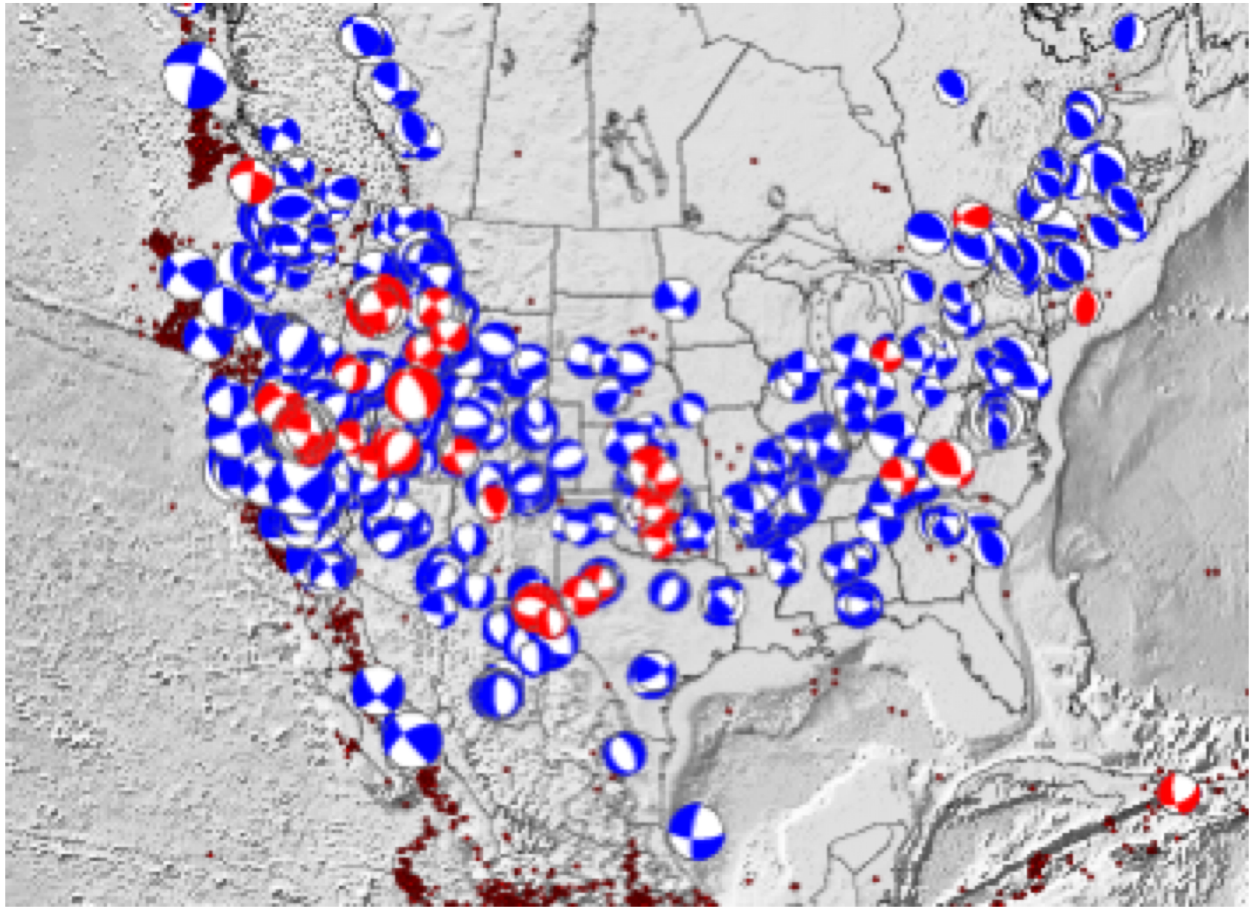
- Stations were installed in 2008-2013 as part of the EarthScope Transportable Array
- ~1 in 4 (N4!) stations retained to densify monitoring in central and eastern US
- Advances in sensor design and emplacement techniques over past 10 years = opportunity to improve long-period horizontal noise (verticals are already quite good!) and improve reliability





One important use of N4 data: Regional moment tensor calculations

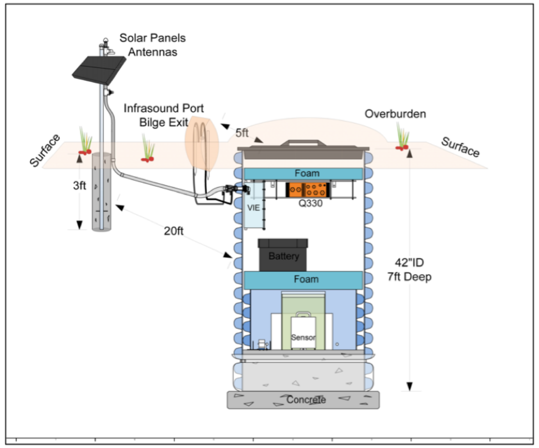
- Regional moment tensors (RMTs) challenging to calculate for M≲3.5 in CEUS (USGS NEIC/Bob Herrmann)
- Value of lower-magnitude RMTs:
  - Info about fault orientation and crustal stresses
  - Consistent magnitudes in source catalogs for National Seismic Hazard Map
    - small-magnitude events affect *b* value; reduce need to convert from other magnitude scales to Mw



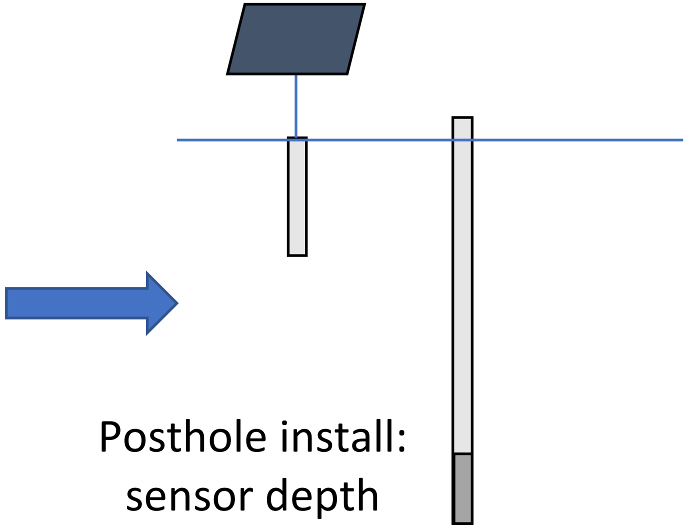
RMTs from Bob Herrmann

Can we get quieter N4 horizontals at T>10 s? How quiet do they need to be for RMTs?

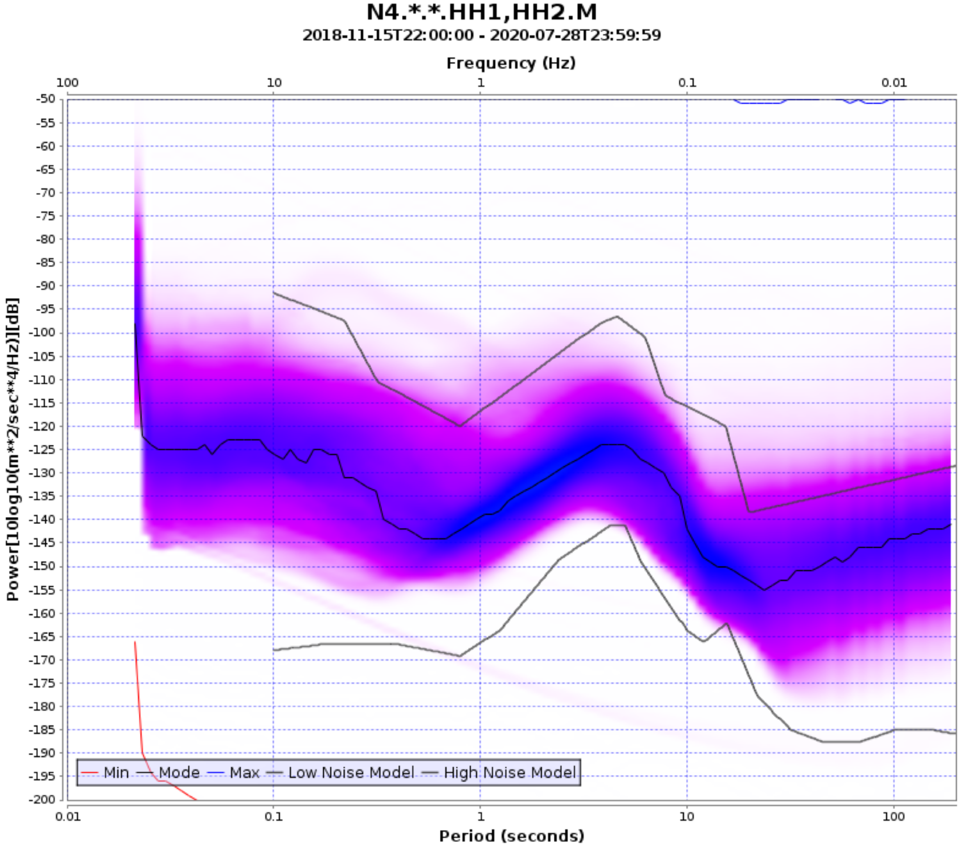
- Can we get RMTs down to M2.5, r ≤ 450 km?
- Goal: get a rough rule of thumb for noise levels that make a station useful for low-magnitude RMTs
- Incorporate this info into future decisions about posthole upgrades and QC procedures



Lower 48 TA tank vault: sensor depth

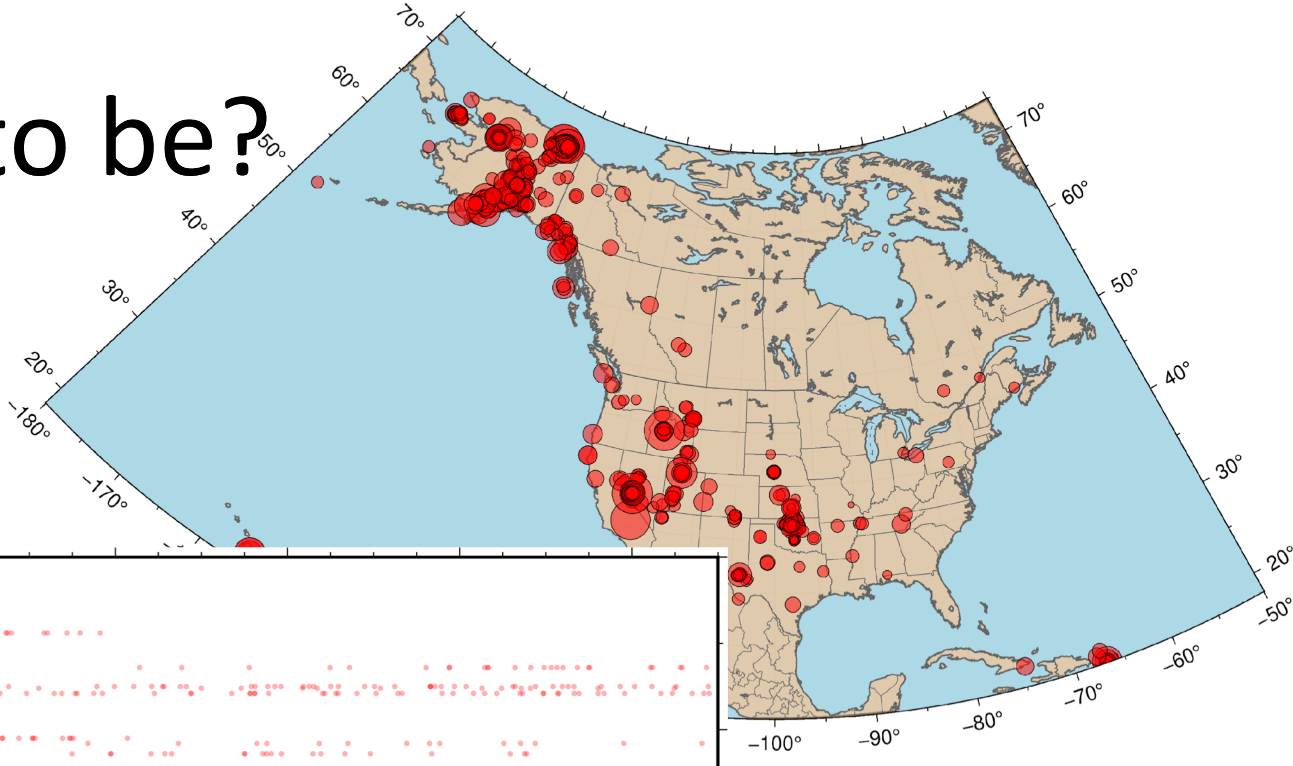


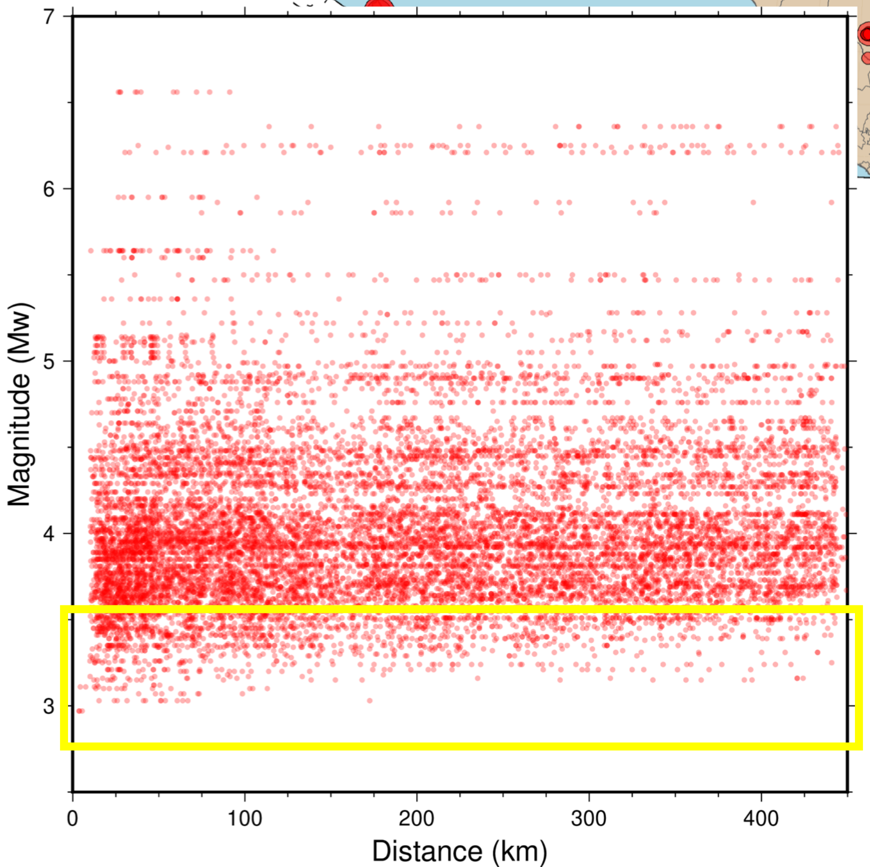
Posthole install: sensor depth 3-10 m (??)



How quiet do they need to be?

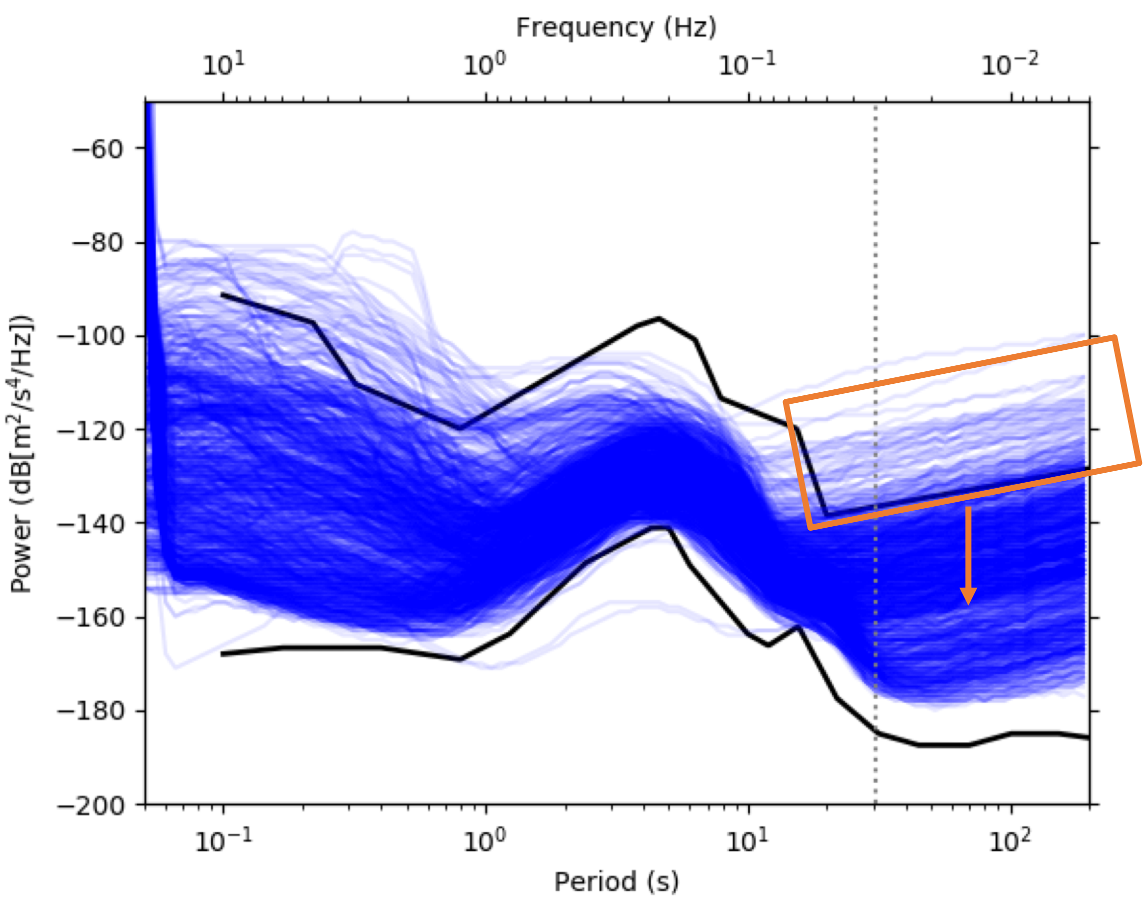
- Data: list of stations used in all RMT solutions 2018-2020 (thank you, Bob Herrmann!)
- Establish empirical relationship between noise level and usefulness in RMTs
- Focus on smallest magnitudes to establish detection limit

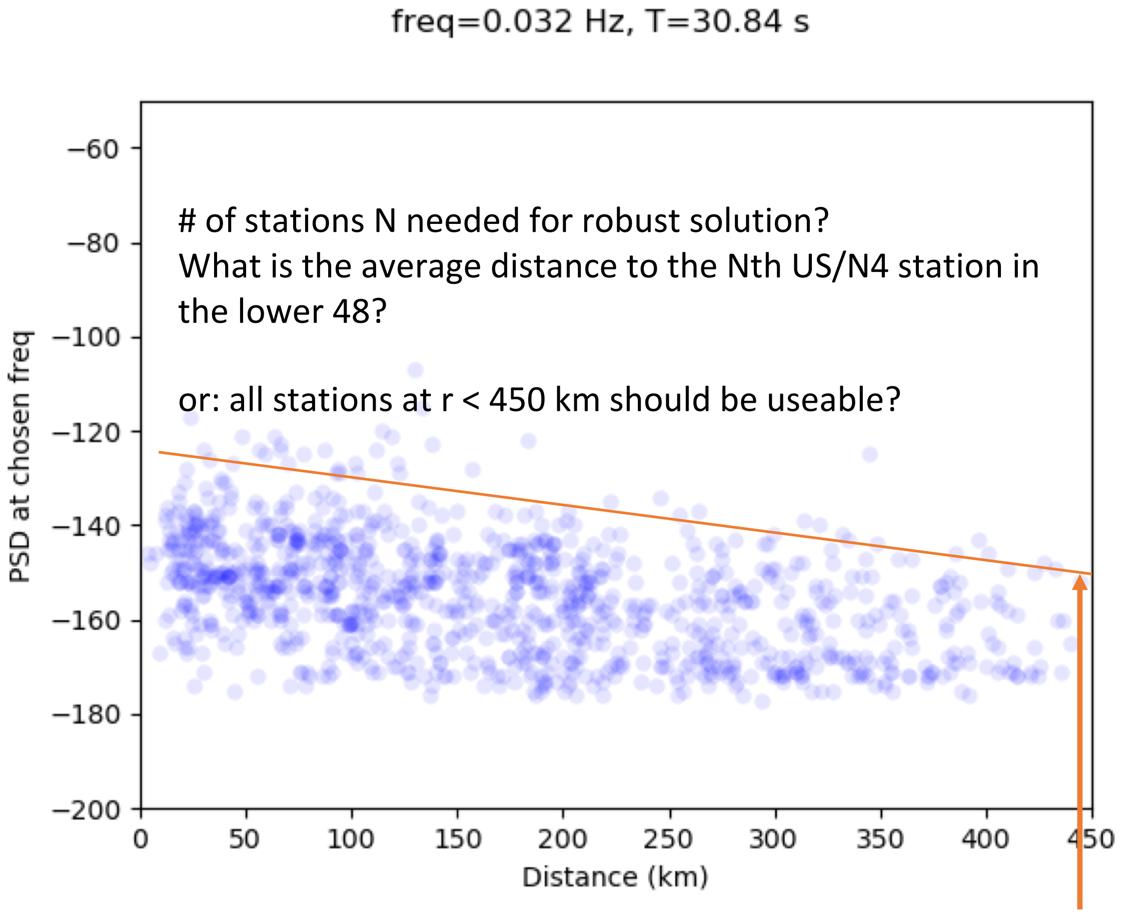




How quiet do they need to be?

Horizontal component 50th percentiles at 30 s for ±3 day window around all M≤3.5 events from IRIS MUSTANG





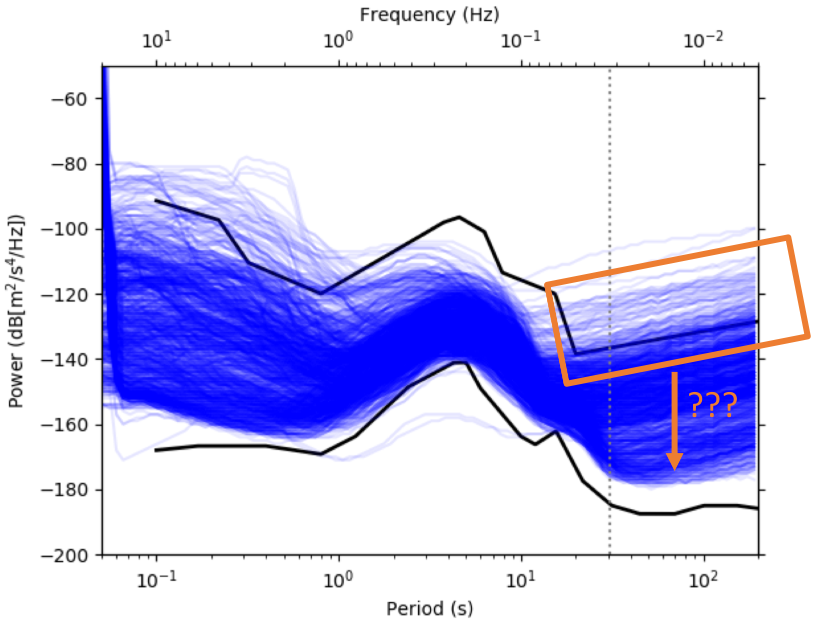
# of stations N needed for robust solution?
What is the average distance to the Nth US/N4 station in the lower 48?

or: all stations at r < 450 km should be useable?

get the 90th percentile of the N4 network below -140 dB at 30 s?

What I hope to take away from this series:

- How will postholes help me improve reliability and efficiency of operations?
- What kinds of improvement in data quality can I expect after converting a station from a vault to a posthole?
- What best practices can my team implement to produce high-quality data?
- How will all of these considerations vary from site to site in the real world?
- Where can we contribute to exploration and development?



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