# Snow suppresses seismic signals from Steamboat Geyser

Mara H. Reed and Michael Manga
Department of Earth and Planetary Science, University of California, Berkeley
geyserite@sfba.social
mhreed@berkeley.edu

## Meet the *tallest* active geyser in the world.

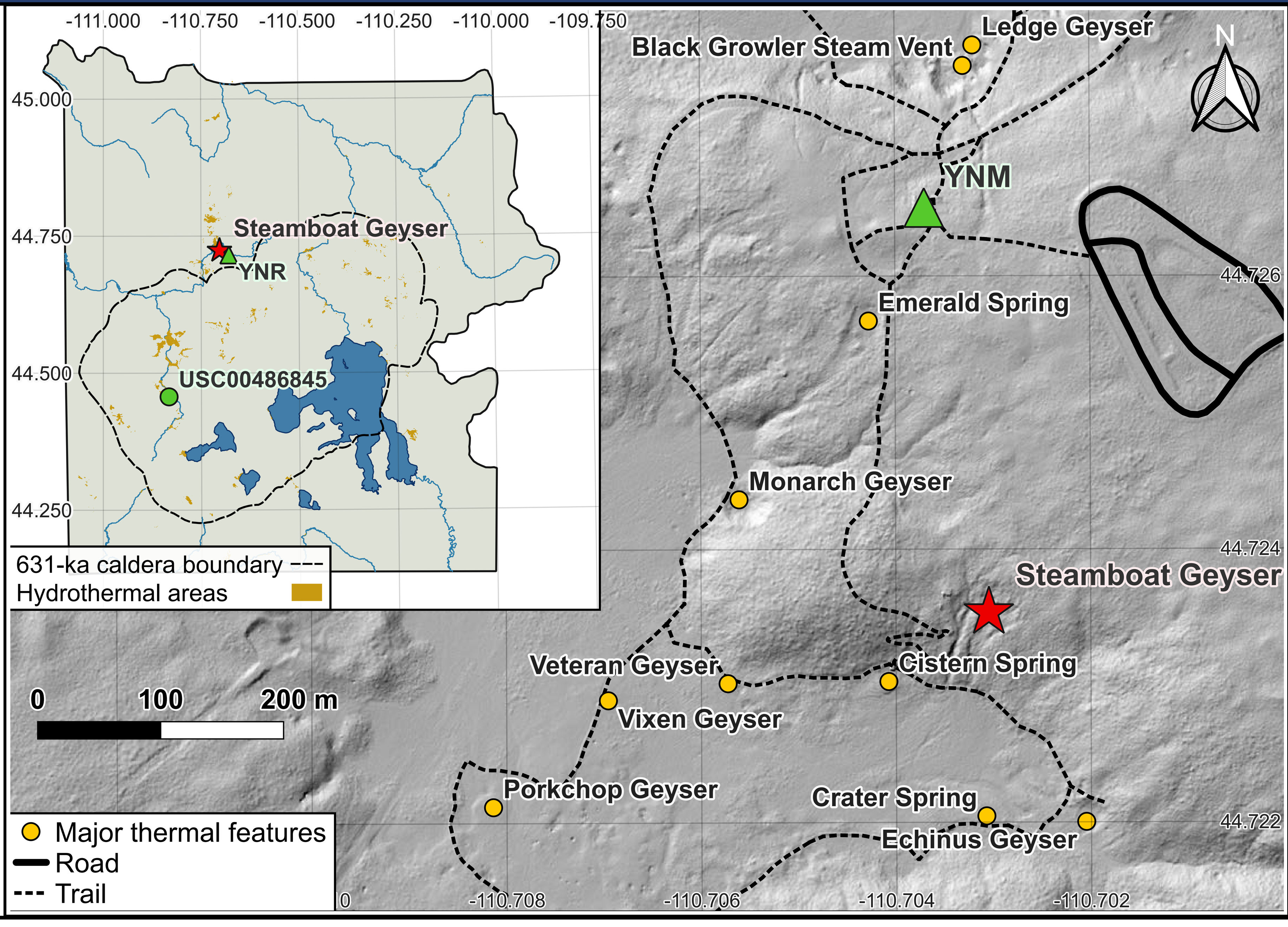
**Location:**
- Norris Geyser Basin, Yellowstone, USA

**Two eruption types:**
- minor (splashing to <15 m)
- major (jetting to 90+ m)

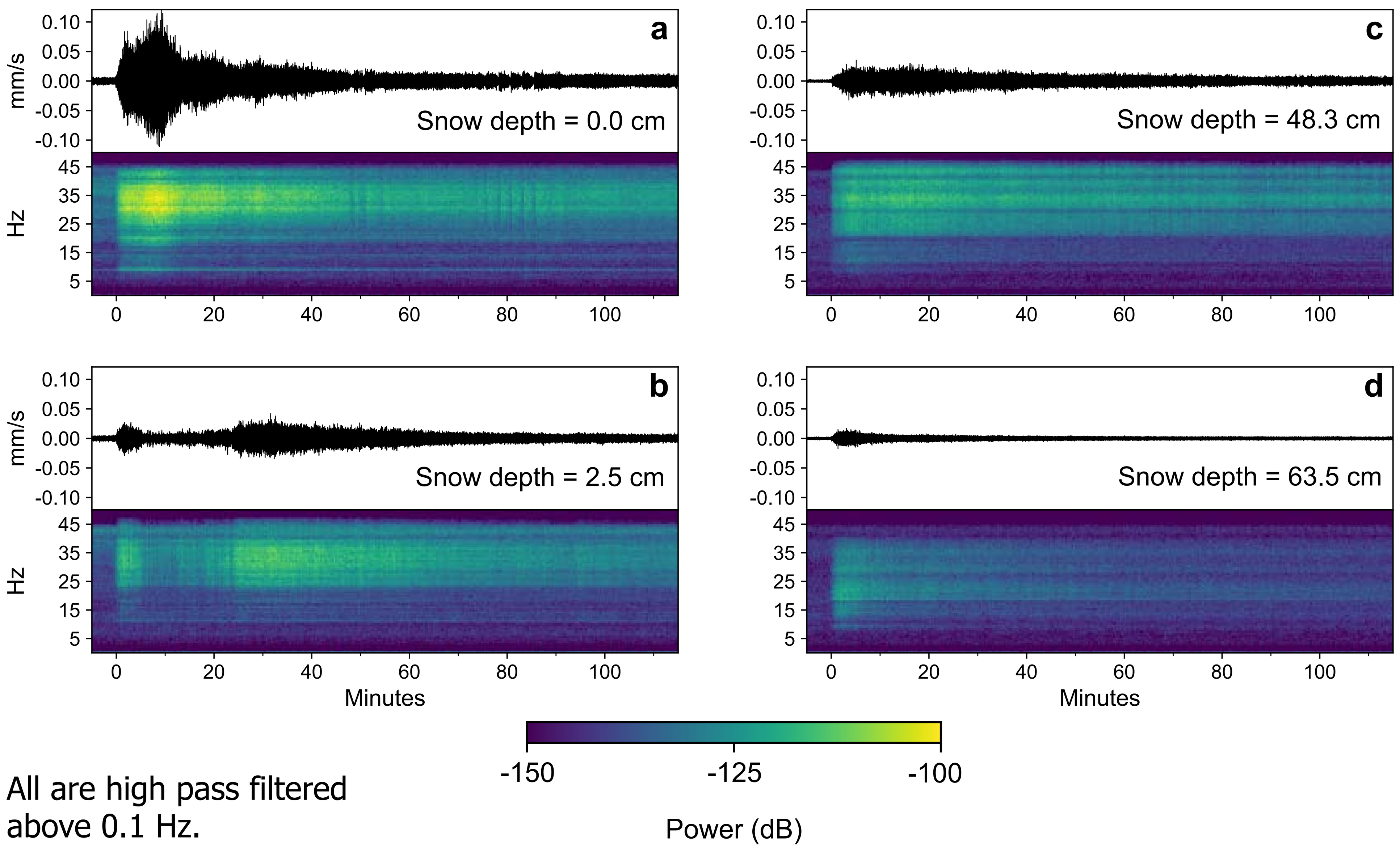
**Maximum measured jet height:**
- 137 m (North Vent)

**Interval between major eruptions:**
- 3 days to 50 years

**Major eruption duration:**
- initial water phase, 3–90 minutes
- including final steam phase, 1–3 days







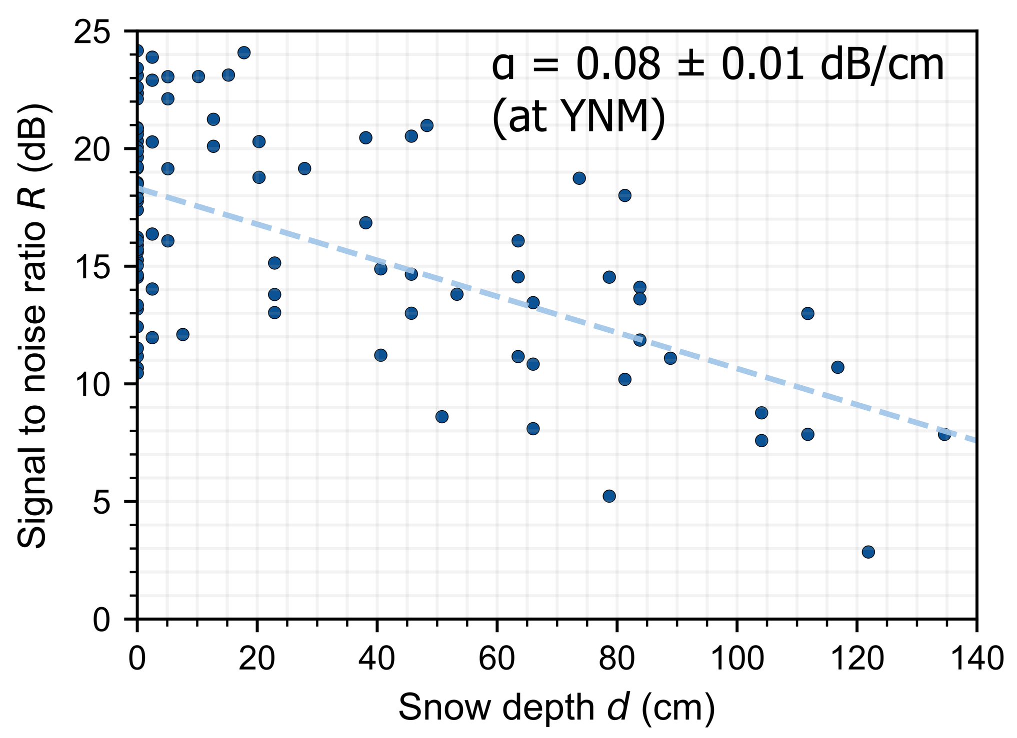

All are high pass filtered above 0.1 Hz.

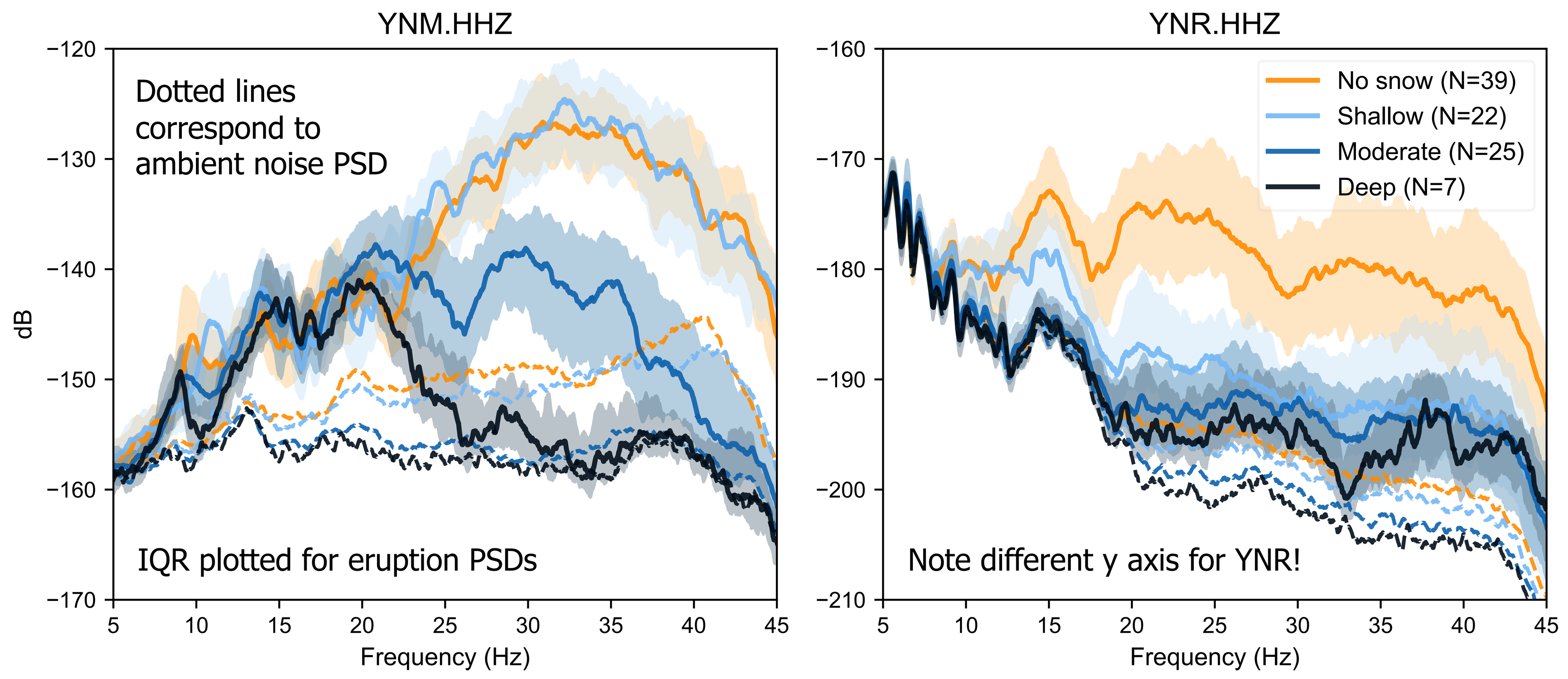
## Major eruptions produce seismic signals.

- **Our understanding of geysers is biased in time and space.** Published datasets related to long-term, continuous monitoring are rare but extremely useful. For an example, see the results from a year-long seismic monitoring campaign at Strokkur Geyser, Iceland conducted by Eibl *et al.* (2020).*
- Steamboat's major eruptions are recorded by seismometers 340 m (YNM) and 2.1 km (YNR) away. Since 15 March 2018, Steamboat has been in a rare active phase with eruptions just days to weeks apart.
- Example velocity waveforms recorded at YNM are shown to the left. The majority achieve peak amplitude in the first few minutes and then gradually taper, like in panels *c* and *d*. Others are more complex, like in panels *a* and *b*.
- We compared waveforms with visual observations entered to the GeyserTimes database (geysertimes.org) and learned that abrupt/variable changes in amplitude relate to activity from the North Vent, which can be drowned when spray is blown onto the hillside where it then runs back down toward the vent.
- We also noticed that **winter eruptions had overall lower amplitudes.** Why?

## More snow → lower seismic amplitudes.

- Unfortunately, there are no snow measurements near Steamboat. We used data from station USC00486845. Though it is 31.4 km away, the station is at a similar elevation and is also located near a thermal area.
- We selected **93** out of 147 eruptions that occurred between 15 Mar 2018 and 30 Nov 2021 with relatively low noise contamination and then sorted them into bins:
  - *No snow* = all 0 cm (N = 39)
  - *Shallow* = 2.5–27.9 cm, median 8.9 cm (N = 22)
  - *Moderate* = 38.1–88.9 cm, median 63.5 cm (N = 25)
  - *Deep* = 104.1–134.6 cm, median 111.8 cm (N = 7)
- After removing instrument response and filtering from 5–45 Hz, we calculated the power spectral density (PSD) for 1) a three-minute time window centered on the max velocity and 2) a three-minute noise window prior to each eruption. **The median PSDs for the vertical component are shown at right.**
- For YNM only, we calculated the signal to noise ratio $R$ using the root mean square velocities from the same time windows. ***R* (in decibels) vs. snow depth *d* is shown below.**




## Ground-coupled airwaves and direct seismic arrivals?

- Moderate and deep snow groups show effects for >22 Hz at YNM. All snow groups show amplitude reductions for the entire spectrum at YNR. We interpret these as dominated by ground-coupled airwaves after comparison with infrasound data collected in a separate study.‡
- 12–22 Hz signals may be instead dominated by direct seismic arrivals at YNM.
- $R \propto e^{-\alpha d}$, where α is the attenuation coefficient. A least squares regression yields an α of 0.08 ± 0.01 dB/cm for signal between 5–45 Hz at YNM. This is within a range of 0.05 and 3 dB/cm reported in other studies on a wide range of snowpack properties and signal frequencies.§
- **Snow depth should be taken into consideration when comparing seismic signals that contain ground-coupled airwaves.**
- Outstanding questions for future work: why does shallow snow correlate with lower amplitudes at YNR but not YNM? Are there better estimates for snow data from satellites?

* Eibl *et al.* (2020). Eruption interval monitoring at Strokkur Geyser, Iceland. *GRL*.
‡ Holahan & Johnson (2022). Infrasound monitoring of multi-phase geyser eruptions at Steamboat Geyser, Yellowstone National Park. *2022 AGU Fall Meeting*.
§ Capelli *et al.* (2016). Speed and attenuation of acoustic waves in snow: Laboratory experiments and modeling with Biot's theory. *Cold Regions Science and Technology*.

This research is supported by NSF EAR2116573. We thank Maggie Holahan for sharing her infrasound data and Zach Keskinen for productive conversations about sound attenuation in snow. Finally, we thank the University of Utah for maintaining seismic stations in Yellowstone.

Berkeley UNIVERSITY OF CALIFORNIA

DEPARTMENT OF EARTH & PLANETARY SCIENCE