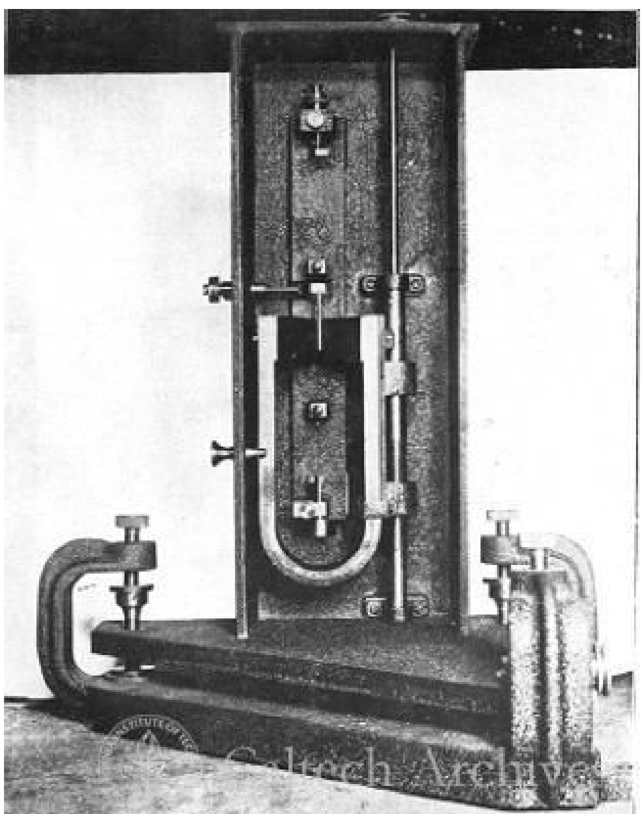
Seismographs Come to Citizen Science

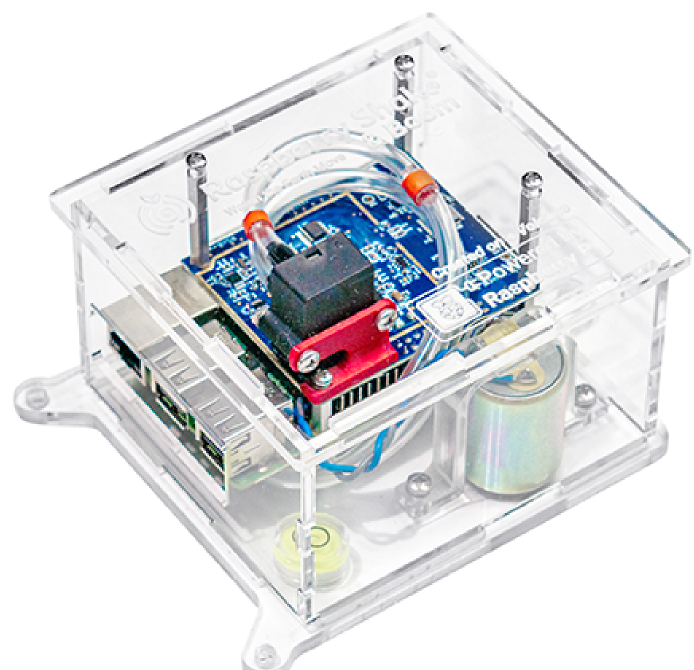
1920s: Wood-Anderson seismometer

1935: Richter Scale

2016: RaspberryShake.org

19xx: Moment Magnitude scale

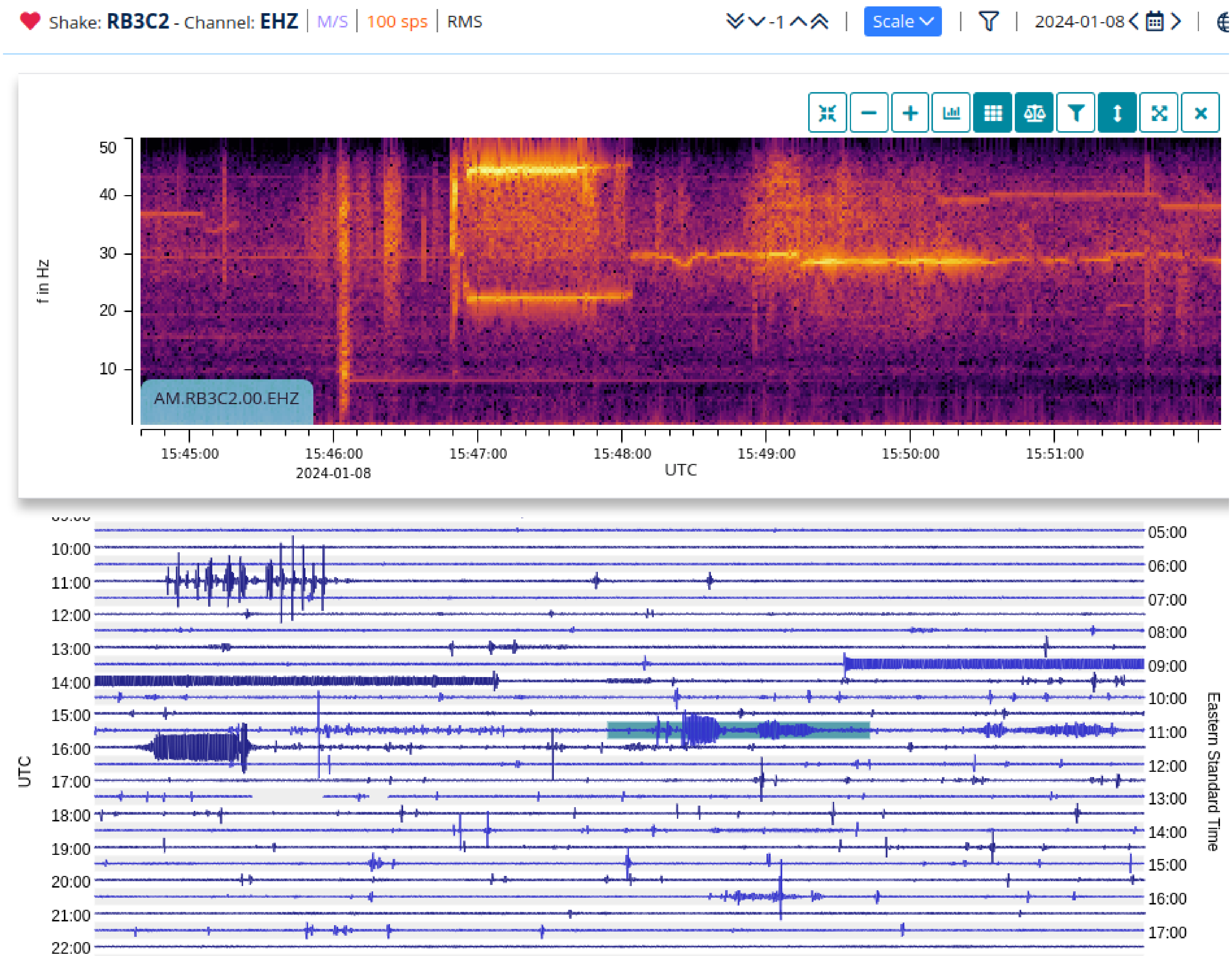




Raspberry Shake & Boom

- Raspberry Pi single-board computer
- Raspberry Shake & Boom circuit board:
  - Vertical Earth motion “geophone”, 4.5 Hz
  - Infrasound sensor – microbarometer
- Placement – Bedrock, “seismic pier,” vault, basement, garage floor.

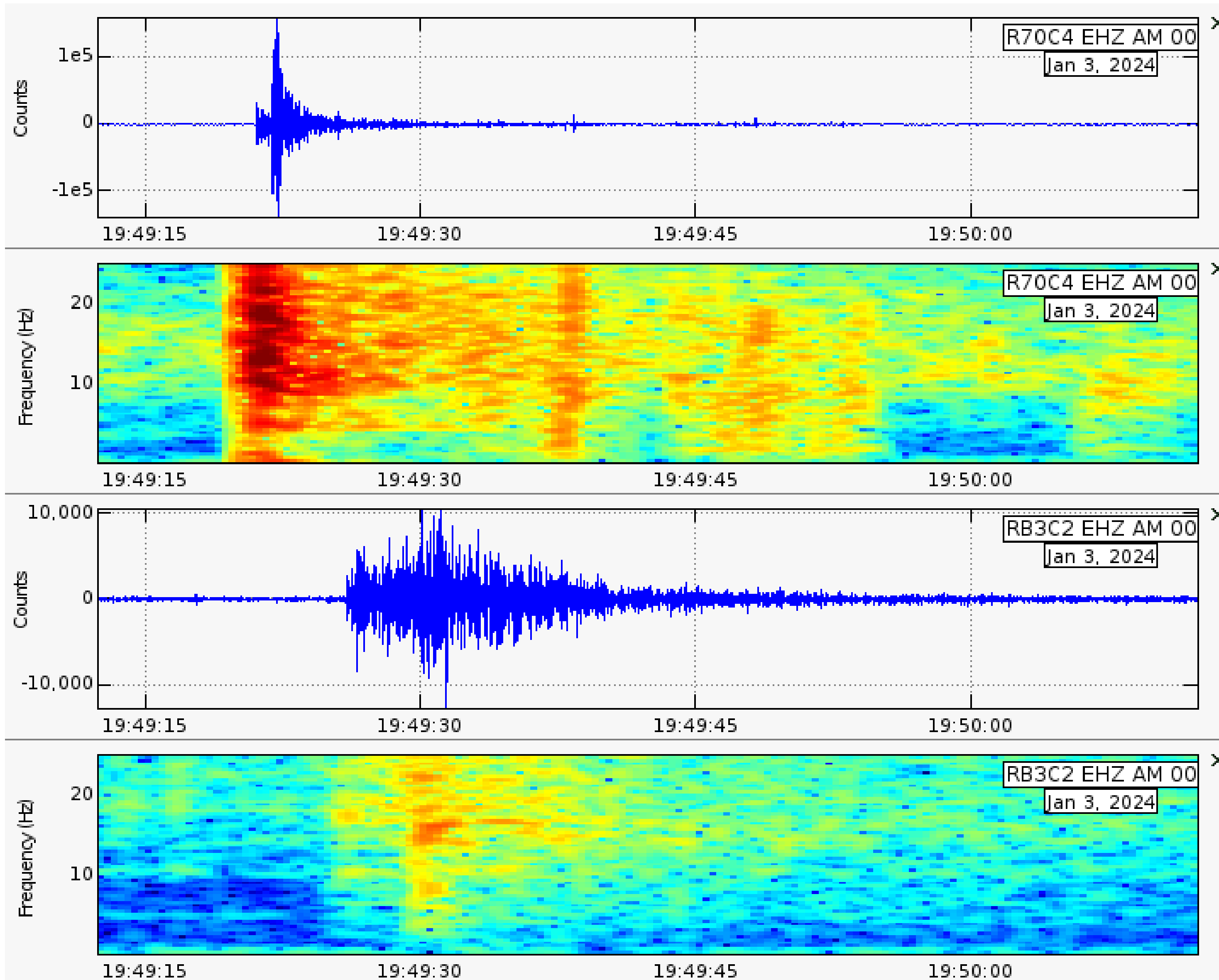
A snowy day in Sutton – 2024-01-08



Loudon NH, M2.0
2024 Jan 3, 19:49:19 UTC

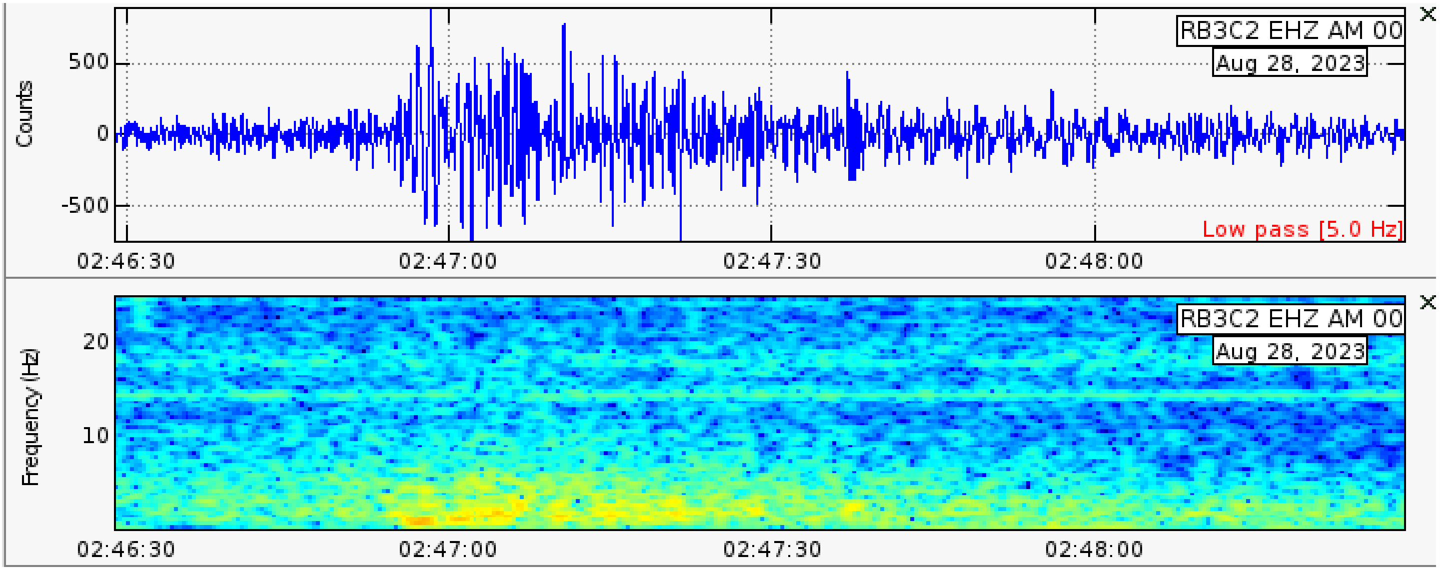
3.8 mi
Canterbury
R70C4

22.7 mi
Sutton
RB3C2



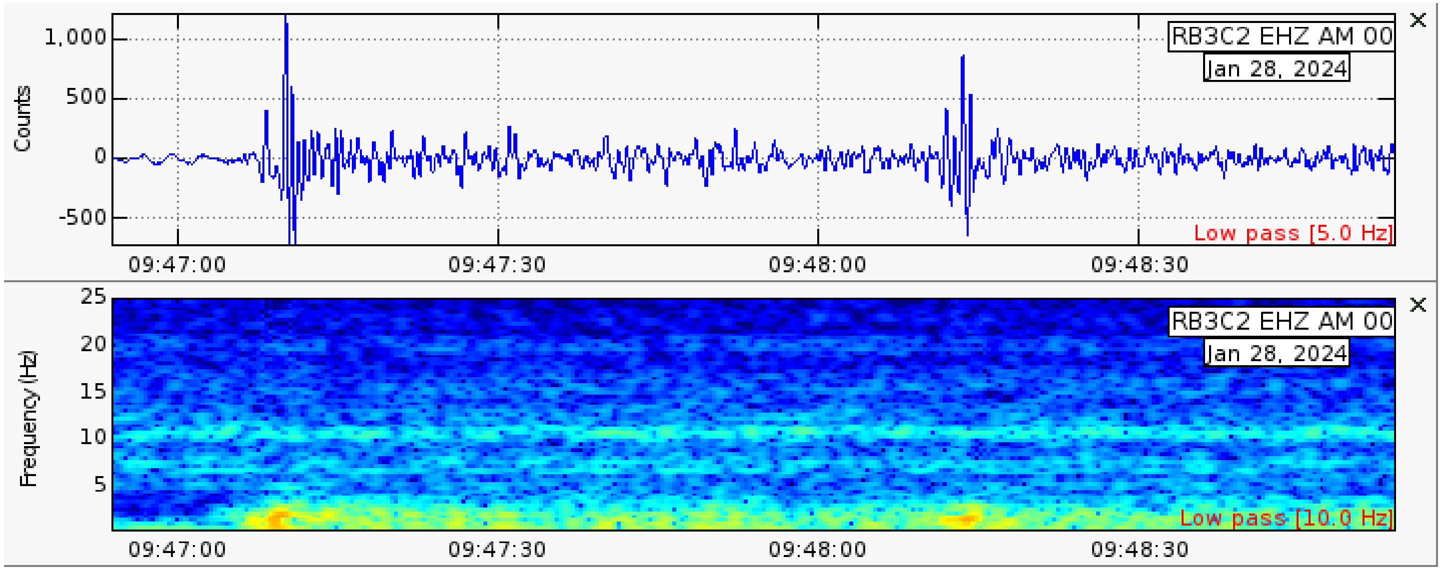
Northeast OH, M3.6
2023 Aug 28, 02:43:26 UTC

470 mi
Sutton
RB3C2

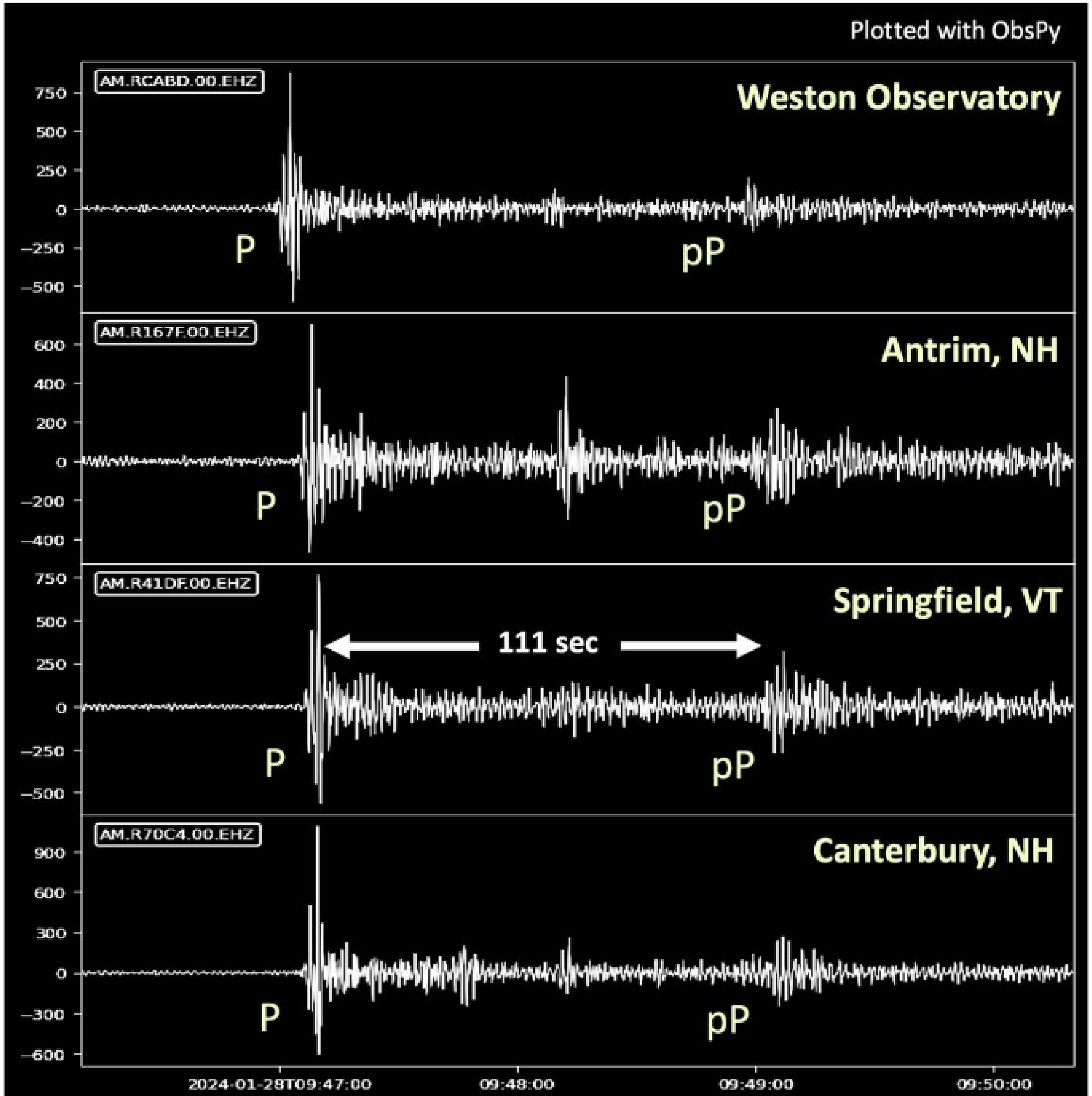


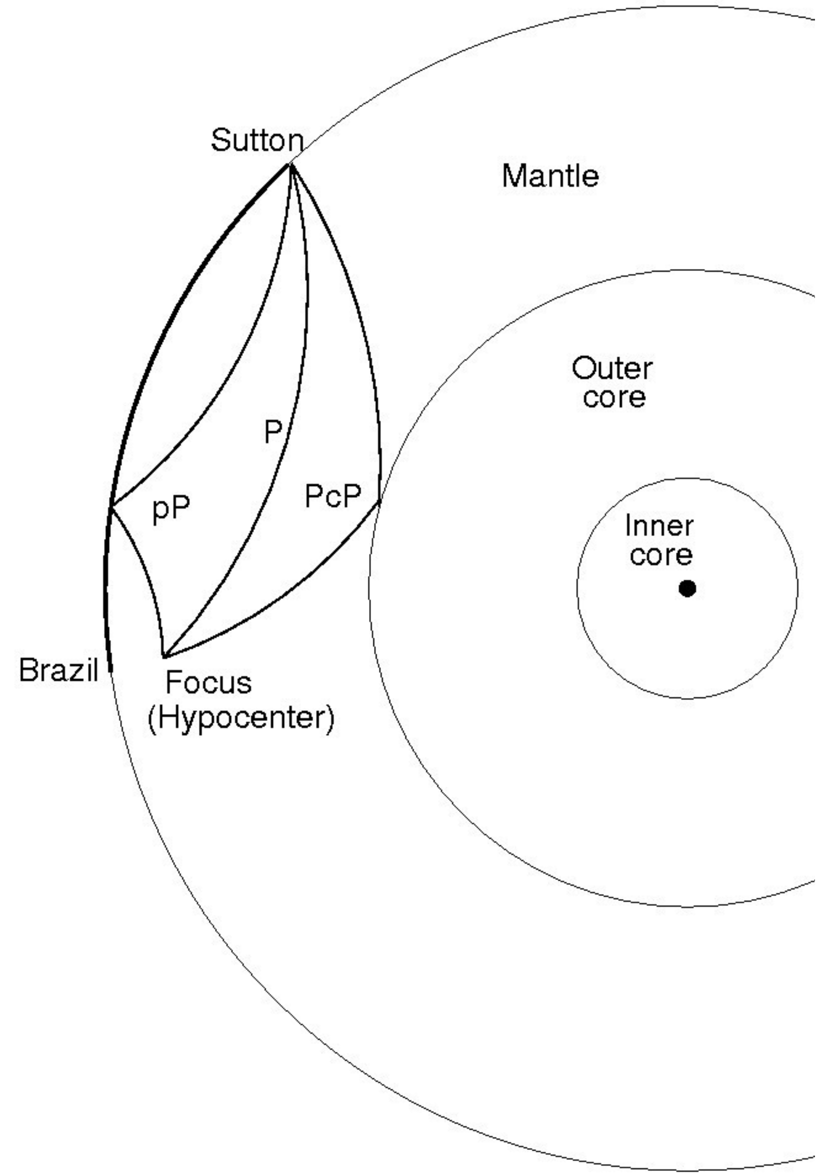
Western Brazil, M6.5 609 km depth
2024 Jan 28, 09:38:56 UTC

3440 mi
Sutton
RB3C2



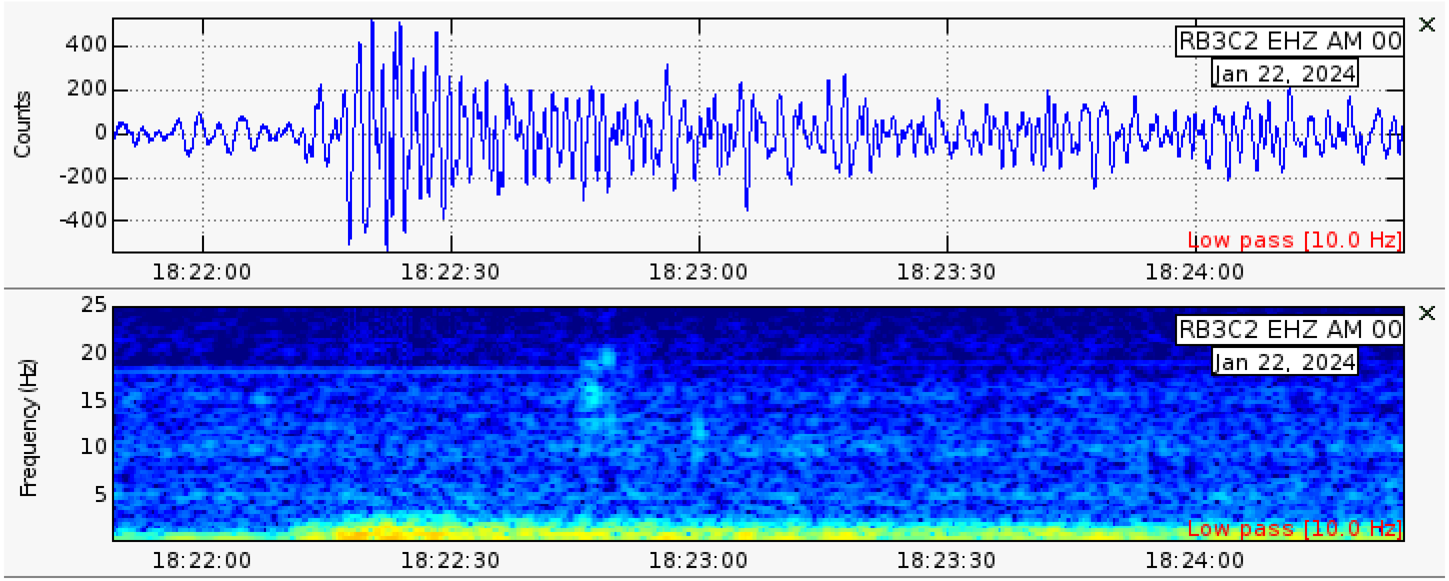
Western Brazil, M6.5 609 km depth



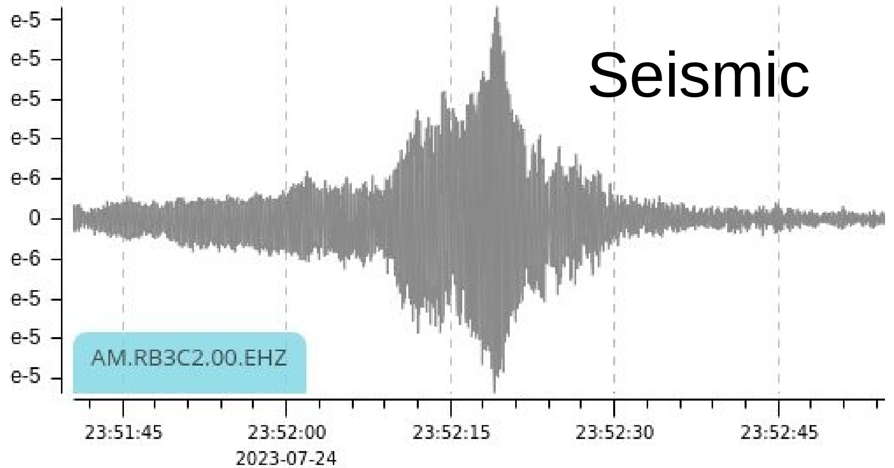


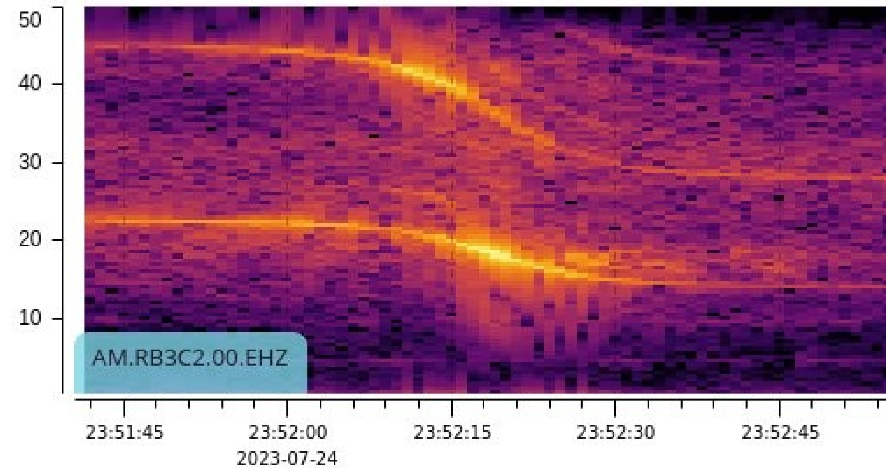
Western China, M7.0 15 km depth
2024 Jan 22, 18:09:04 UTC

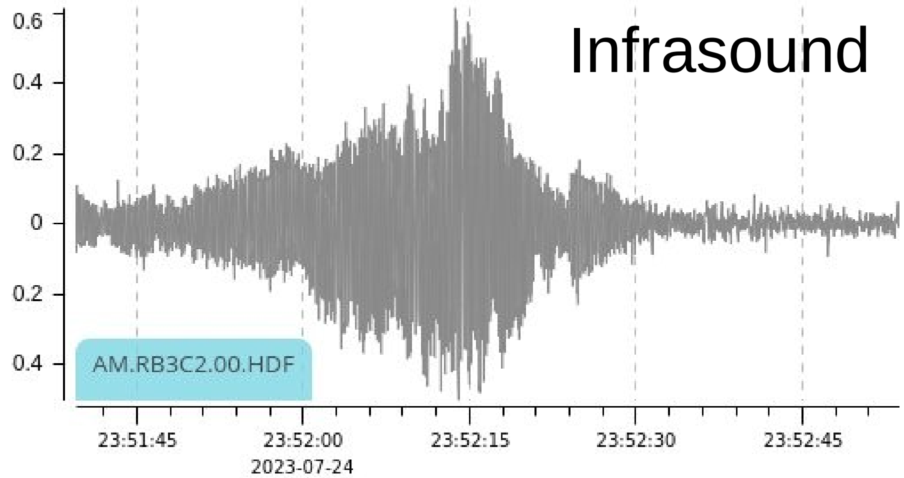
6300 mi
Sutton
RB3C2

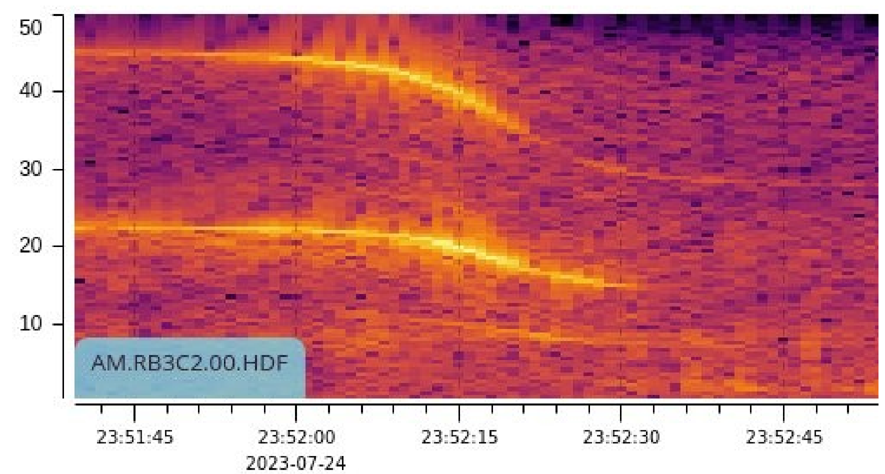


Helicopter passes

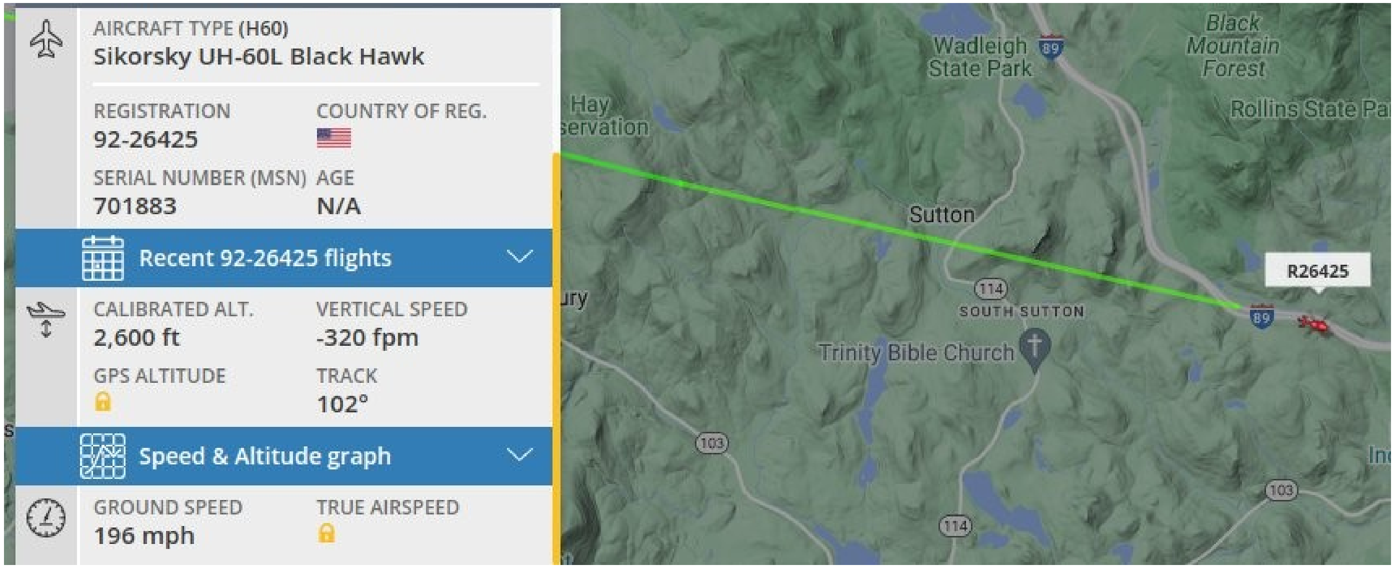








Helicopter speed



v: Helicopter speed (196 mph above)

f_a, f_d: approach and departure frequencies

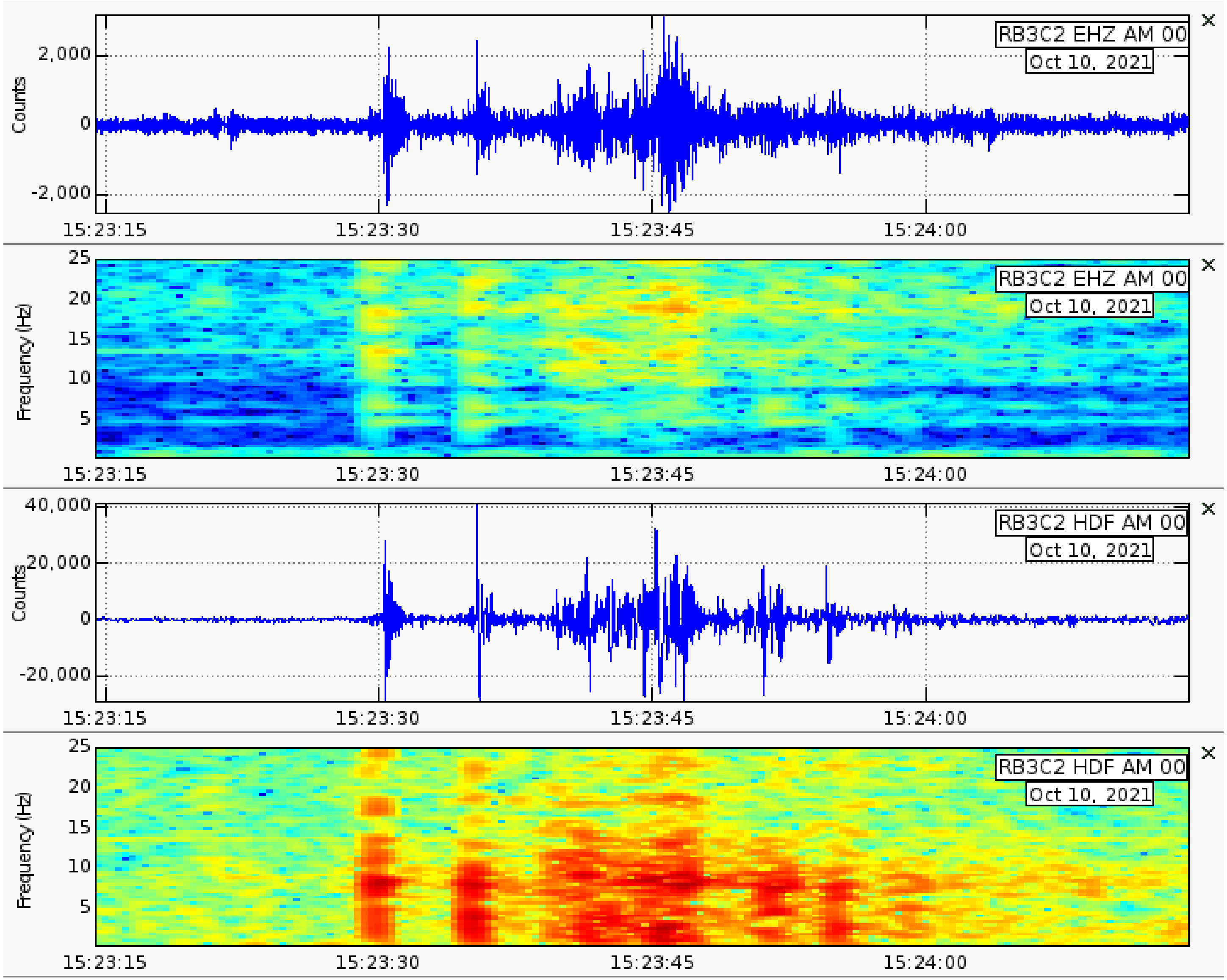
c: Speed of sound, 760 mph, but slower in cold air

$$v = \frac{f_a - f_d}{f_a + f_d} \times c \qquad \frac{46-27}{46+27} \times 760 = 198$$

Big booms, 2021 Oct 10, 15:23:30 UTC

Sutton seismic

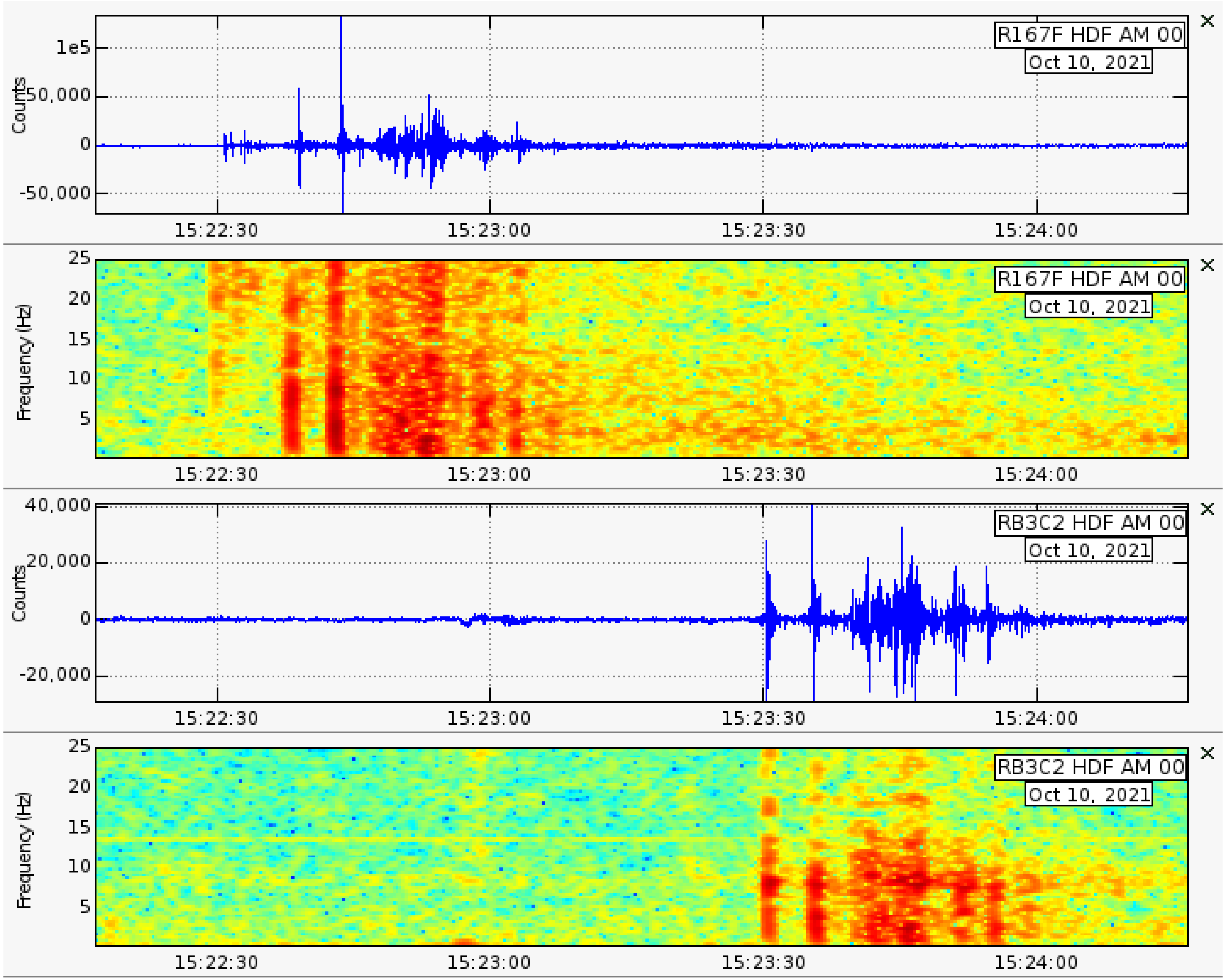
Sutton infrasound



Aha! Meteor?, 2021 Oct 10, 15:22:40 UTC

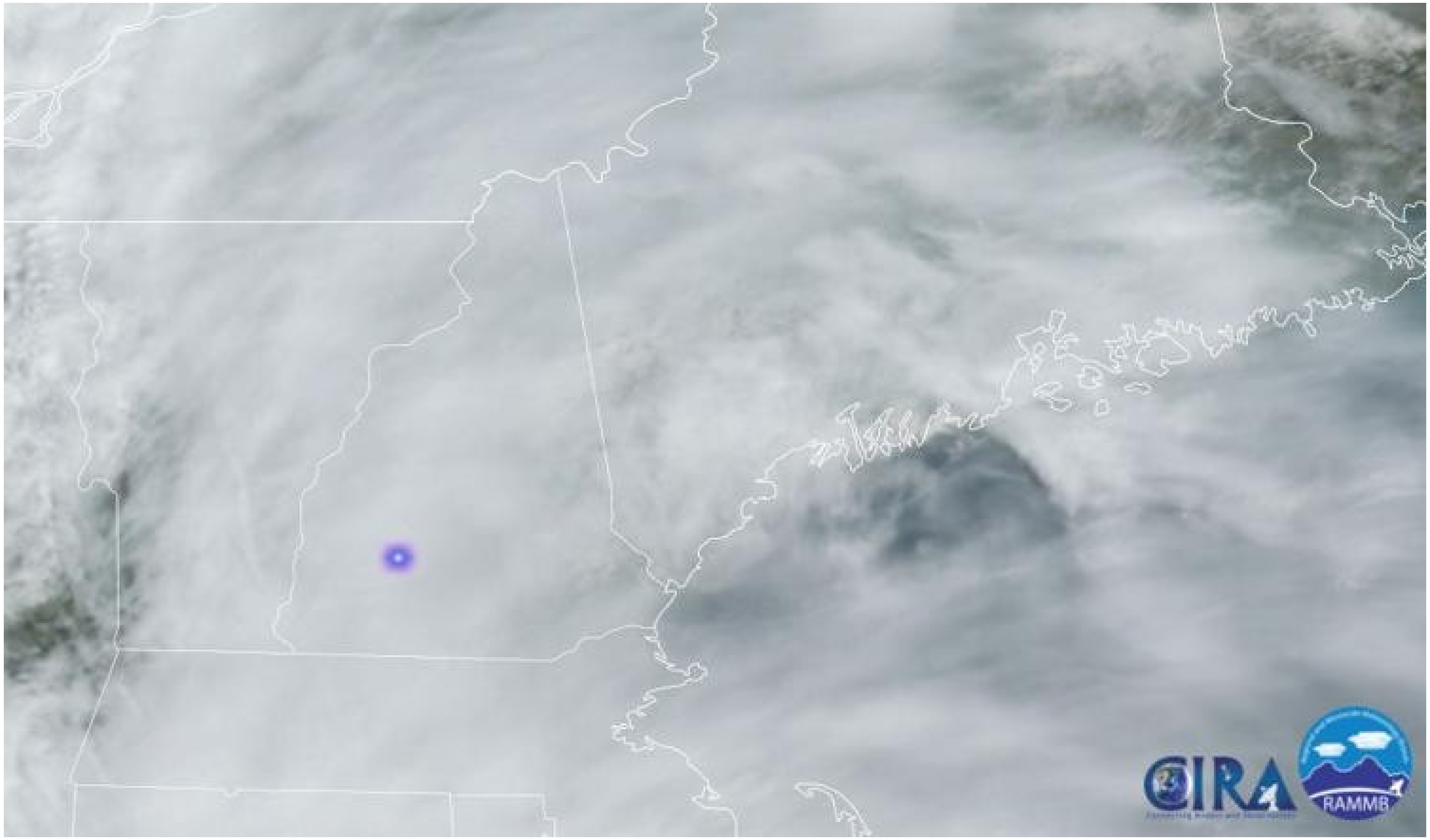
Antrim infrasound

Sutton infrasound



Meteor, 2021 Oct 10, 15:22:40 UTC

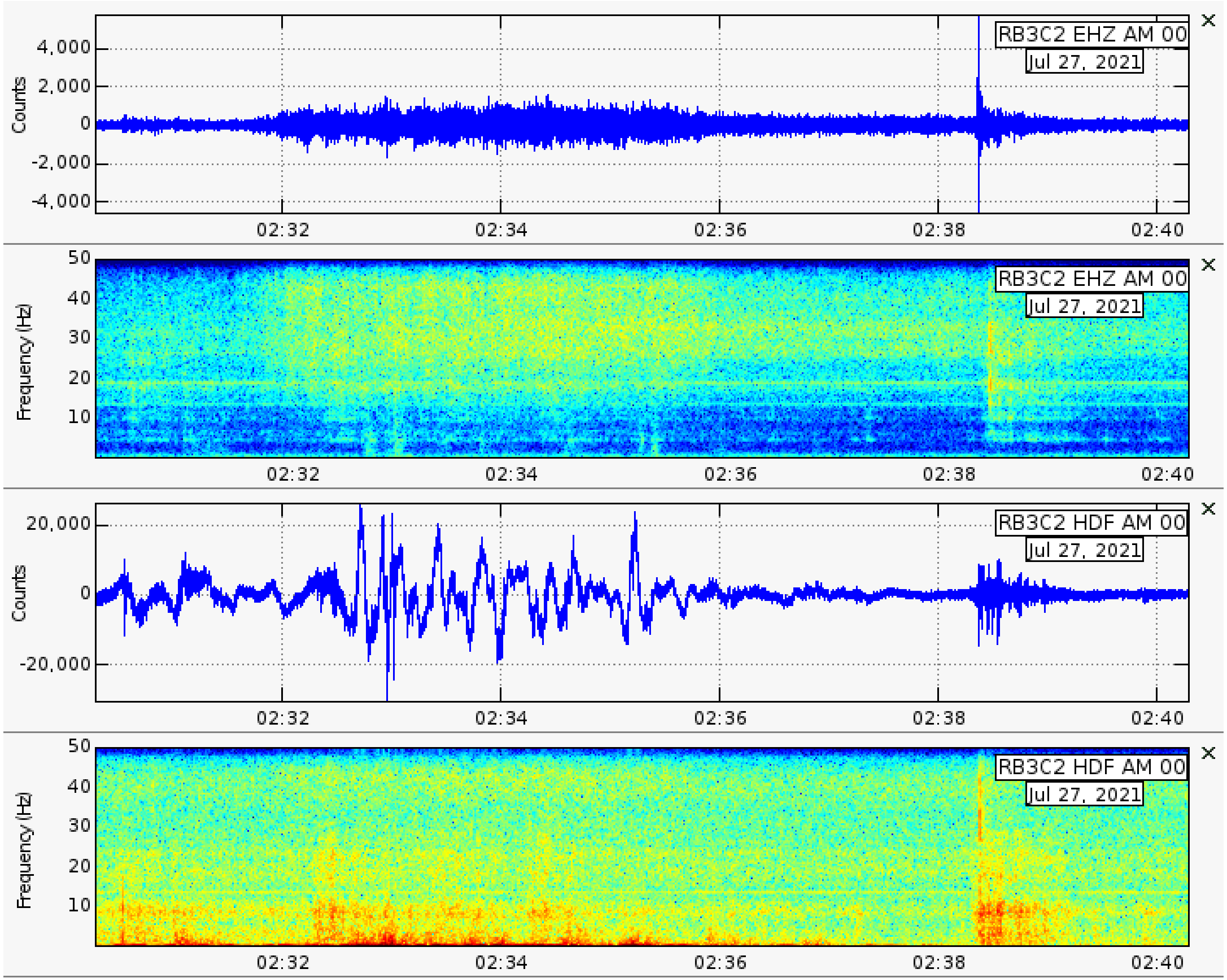
GOES-16 GLM (Geostationary Lightning Mapper) 15:21:17



Downpour (and thunder?) 2021 July 27, 02:34 UTC

Sutton seismic

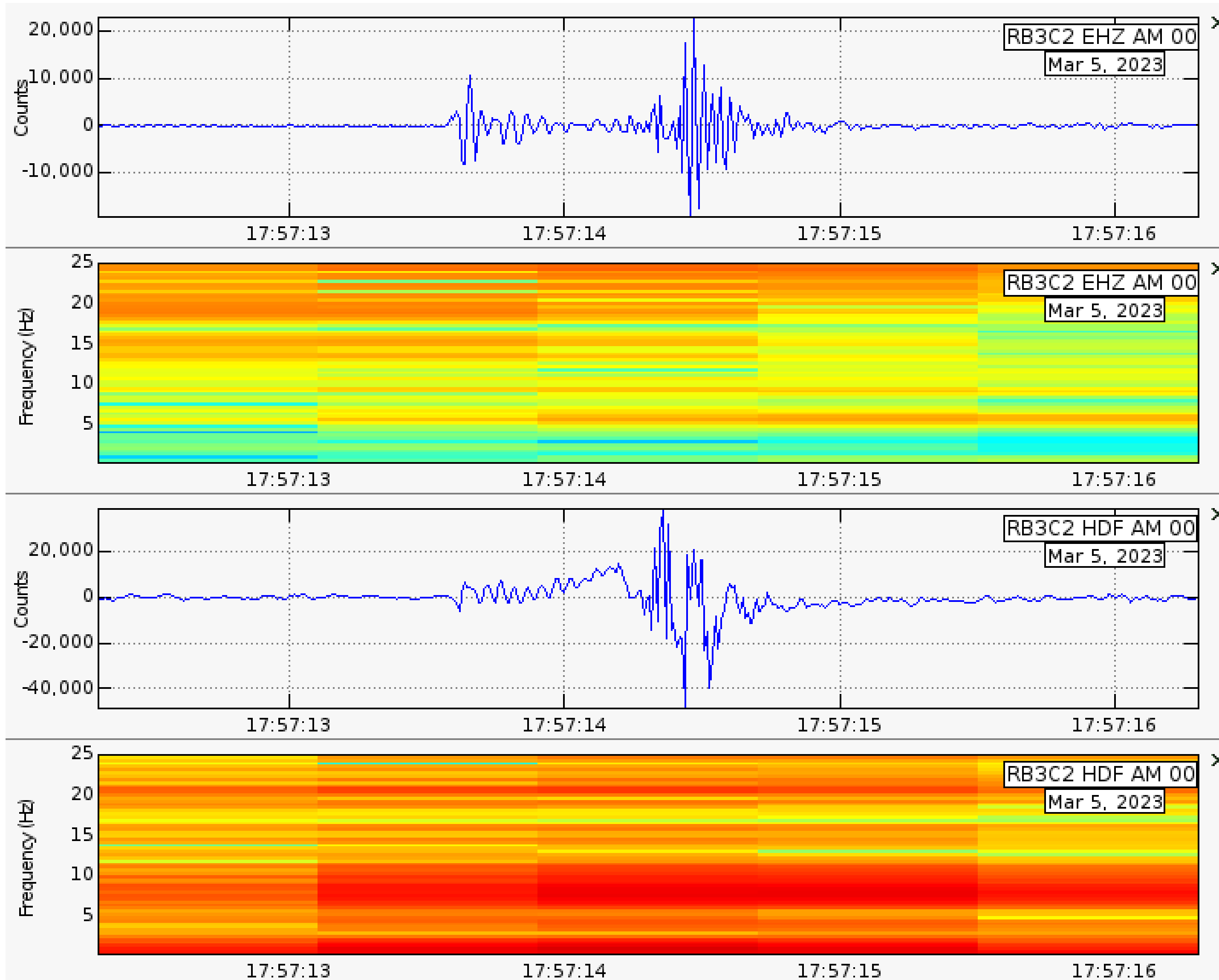
Sutton infrasound



Snow slide, 2023 March 5, 17:57:13 UTC

Sutton seismic

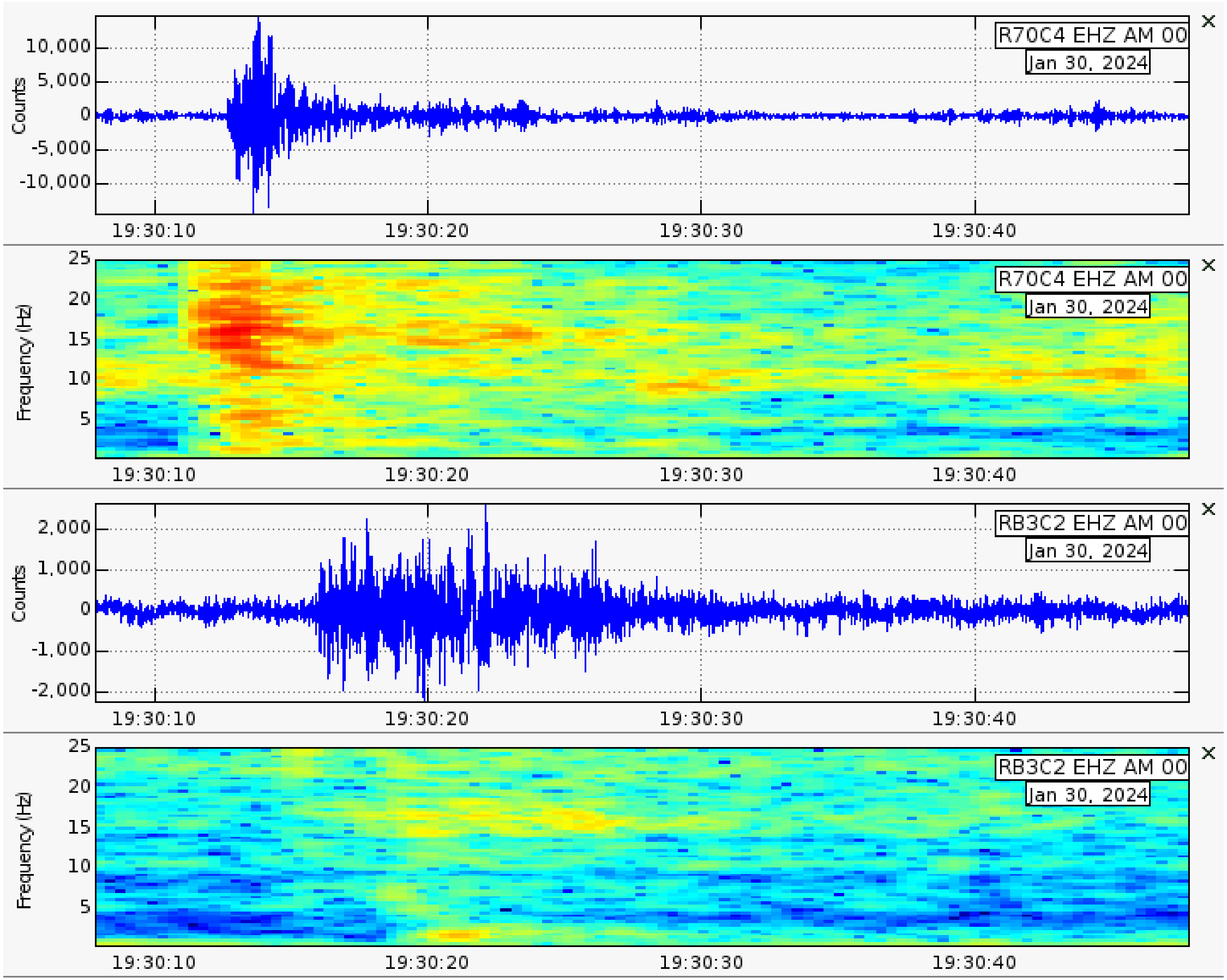
Sutton infrasound



Cold Brook Sand and Gravel blasting
2024 Jan 30, 19:30:15 UTC

3.0 mi
Canterbury
R70C4

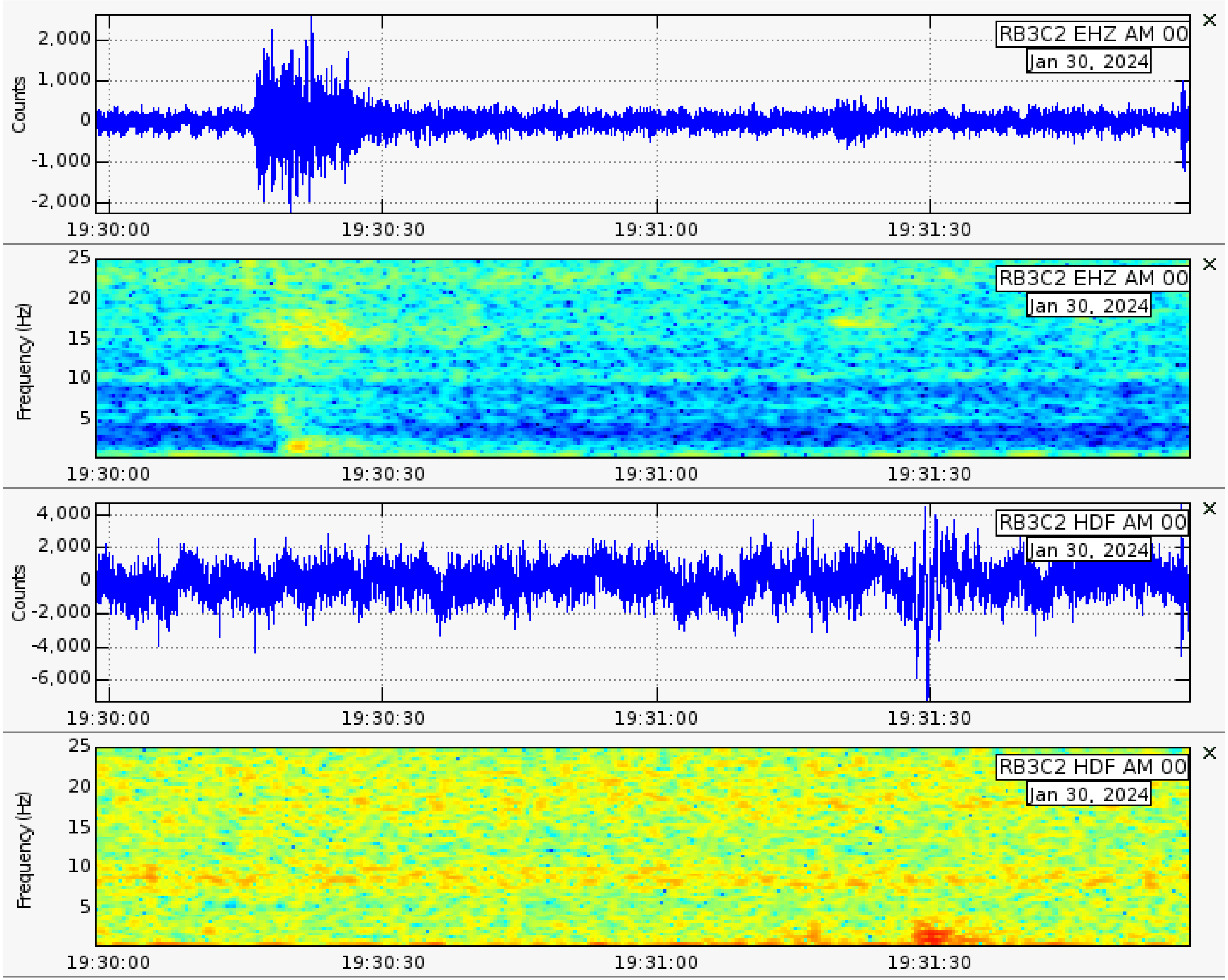
16.0 mi
Sutton
RB3C2



Cold Brook Sand and Gravel blasting, seismic vs. infrasound

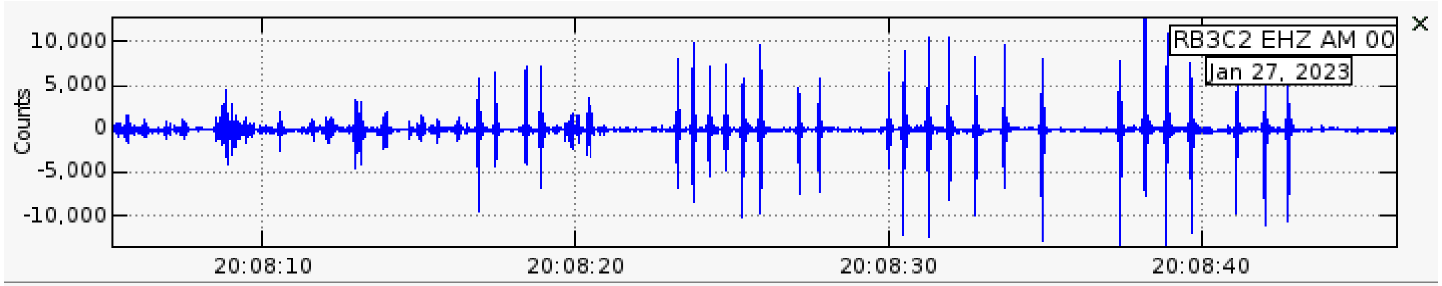
Sutton seismic ~3 secs

Sutton infrasound 16x5 = 80

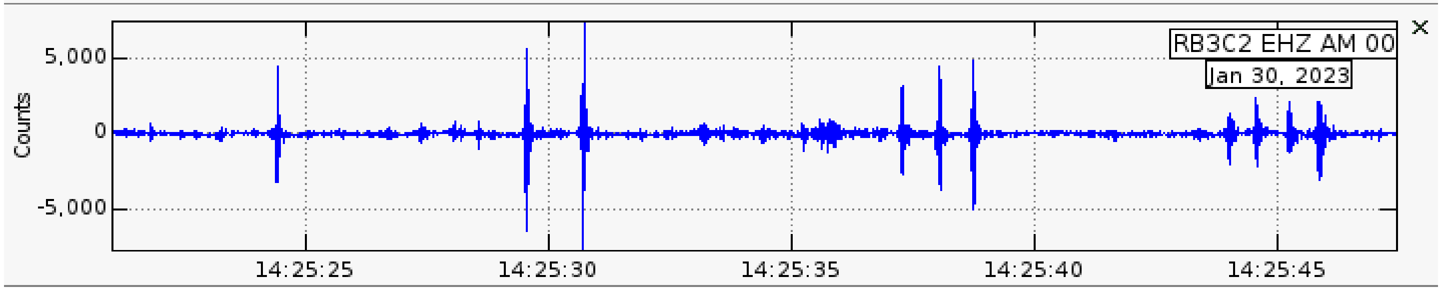


Sutton driveway ice chipping

Clearing

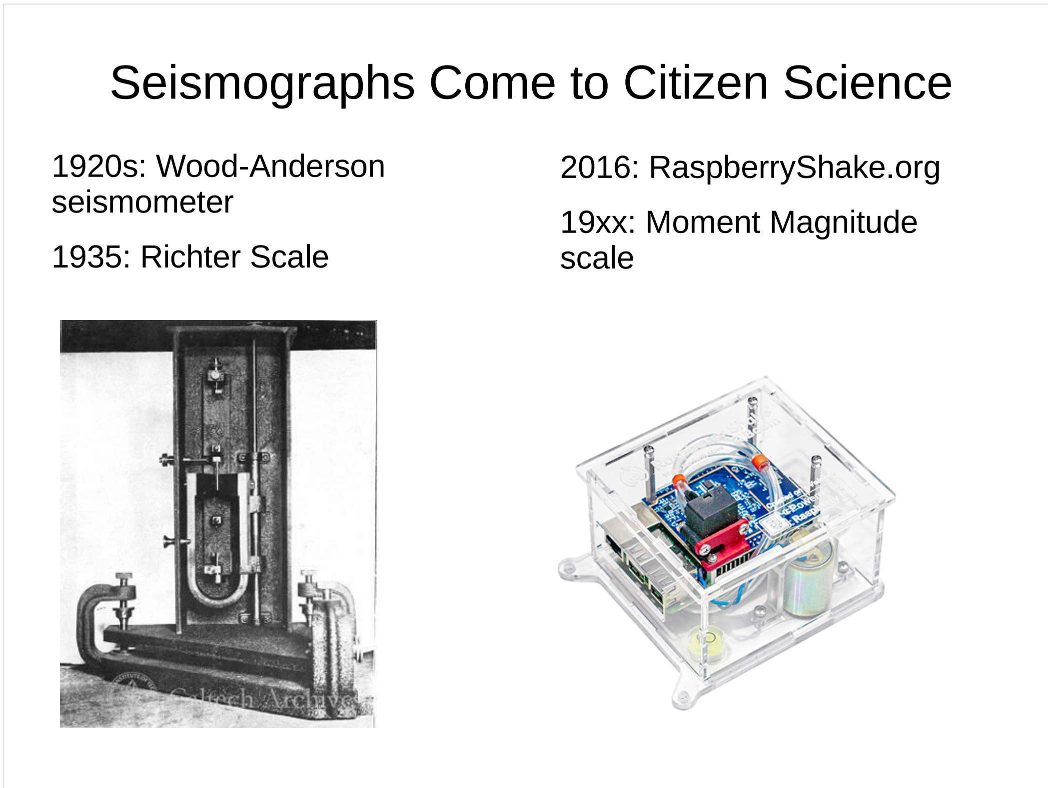


Testing



Resources and Credits

- https://www.concordmonitor.com/earthquake-monitor-49407723
  Concord Monitor article about my Raspberry Shake & Boom
- https://stationview.raspberryshake.org/#/?zoom=8.000&net=AM&lat=43.060&lon=-72.011
  New England Raspberry Shakes
- https://dataview.raspberryshake.org/#/AM/RB3C2/00/EHZ
  My RSB realtime display
- https://www.usgs.gov/software/swarm
  Seismic display software for most of the above
- Prof. Alan Kafka, Weston (Seismic) Observatory, Department of Earth and Environmental Sciences, Boston College.
  Source of a few images, much knowledge, and purveyor of bad puns for over half a century.



The well known “Richter Scale” is tied to this particular seismometer. It was replaced with the Moment Magnitude Scale, a measure of energy released in an earthquake.

Schematic drawing of the Wood-Anderson torsion seismometer, 1948, 10.50-14. Caltech Images Collection, Images. California Institute of Technology Archives and Special Collections. https://collections.archives.caltech.edu/repositories/2/archival_objects/111814 Accessed February 02, 2024.

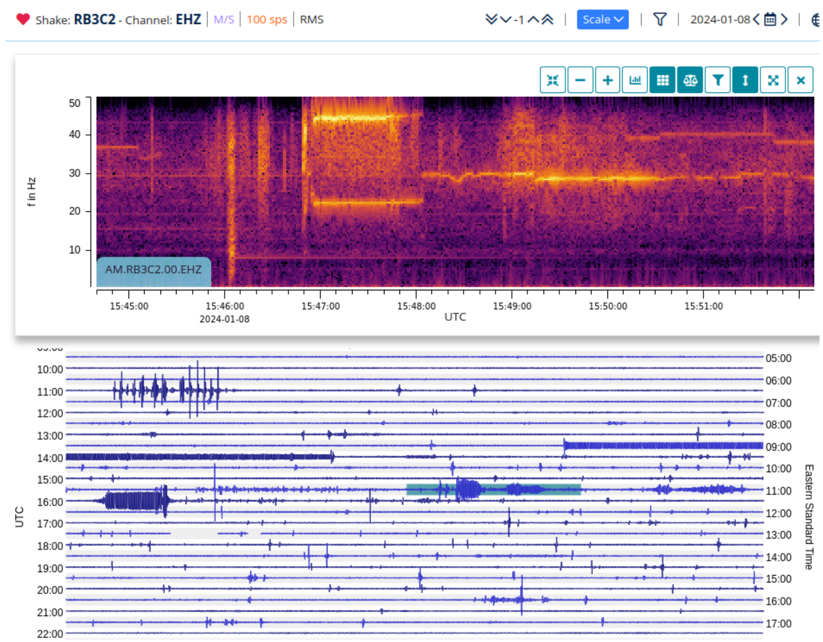
Raspberry Shake & Boom

- Raspberry Pi single-board computer
- Raspberry Shake & Boom circuit board:
  - Vertical Earth motion “geophone”, 4.5 Hz
  - Infrasound sensor – microbarometer
- Placement – Bedrock, “seismic pier,” vault, basement, garage floor.

Models include:

- 1D Shake (sensitive vertical(Z) geophone)
- 3D Shake (sensitive X/Y/Z geophones)
- 4D Shake (1D plus less sensitive X/Y/Z accelerometers)
- &Boom (1D with micro barometer)

A snowy day in Sutton – 2024-01-08



Timelines: UTC on the left, ET on the right.

Upper left: Snow plowing

Upper middle: Town snow plow?

Long bar: TDS Telecom Monday AM generator test

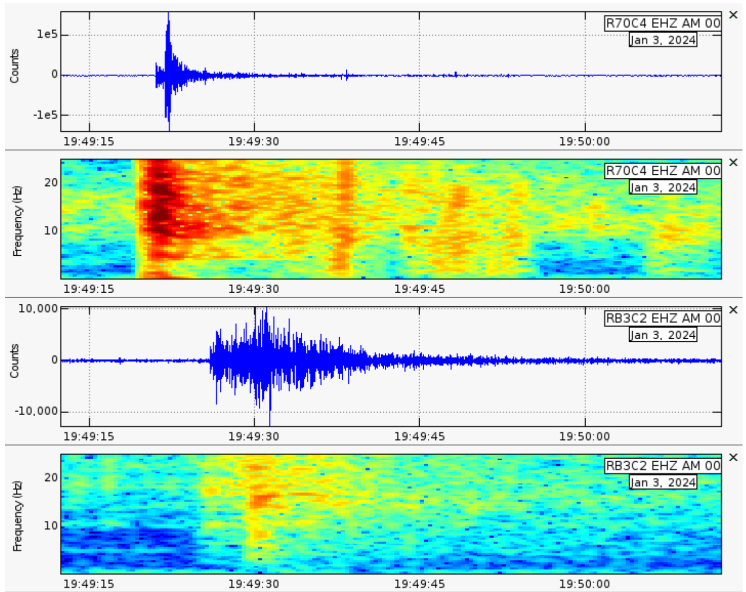
Highlight and spectrogram: Starting, idling, and using snow blower

Bottom third: Miscellaneous traffic

Loudon NH, M2.0
2024 Jan 3, 19:49:19 UTC

3.8 mi
Canterbury
R70C4

22.7 mi
Sutton
RB3C2

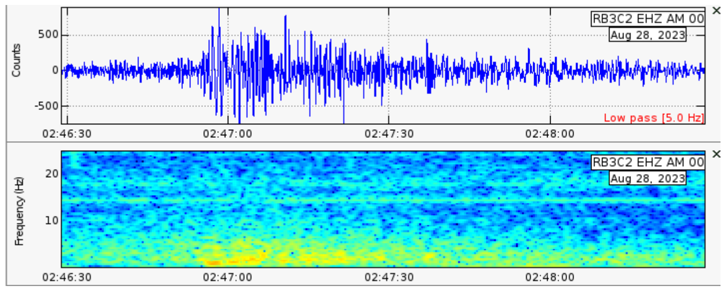


Nearby earthquake

After a M2.7 earthquake on Dec 22 a few miles east of the Concord airport, this M2.0 quake happened 12 days later, only a few miles from a Raspberry Shake in Canterbury. People felt it in Canterbury, but not out in Sutton.

Northeast OH, M3.6
2023 Aug 28, 02:43:26 UTC

470 mi
Sutton
RB3C2



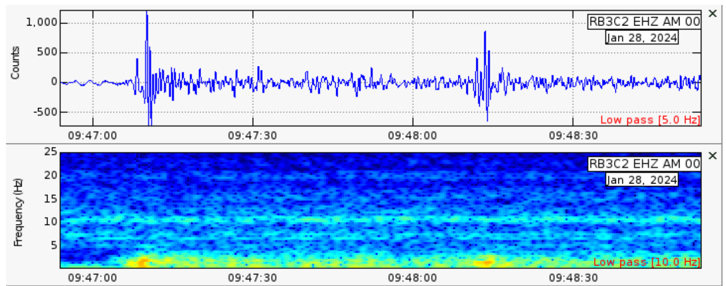
Moderately close earthquake

I grew up in northeast Ohio and was out there for my 55th high school reunion in early August. So I missed this rare quake.

Coming home I caught SARS-CoV-2 at the Corning Glass Museum. I would have preferred catching the quake and missing Covid-19. At least it was a mild case.

Western Brazil, M6.5 609 km depth
2024 Jan 28, 09:38:56 UTC

3440 mi
Sutton
RB3C2

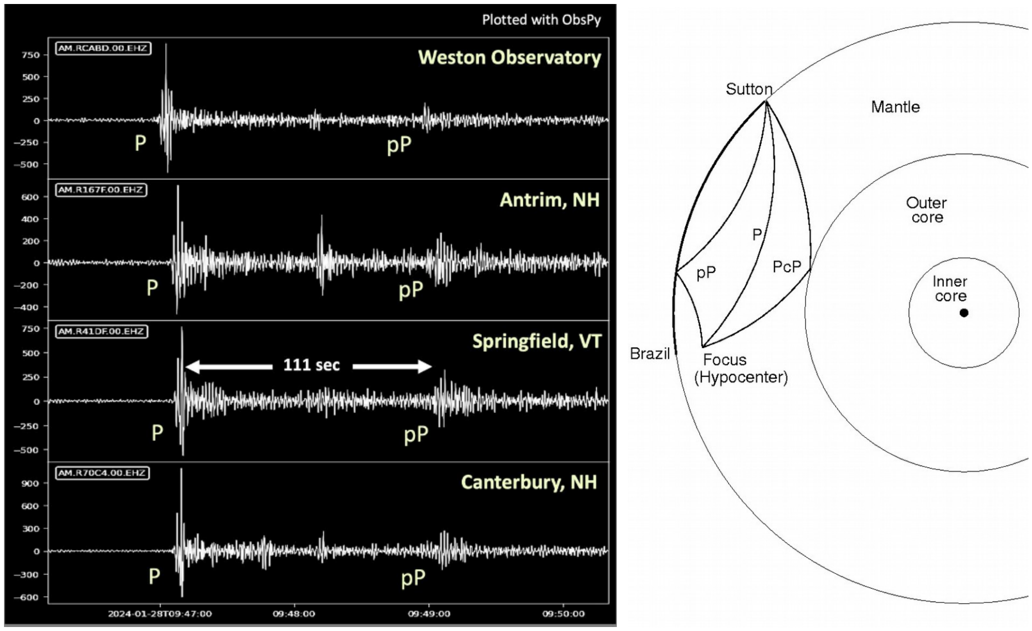


Distant quake

This quake was nearly 51° of latitude due south of me. What looks like two separate quakes is just one. The first signal is from a “pressure wave” that arced through the planet to reach Sutton.

The second signal appears to be a pressure wave that reflected off the Earth's outer core of molten iron.

Western Brazil, M6.5 609 km depth



More signals

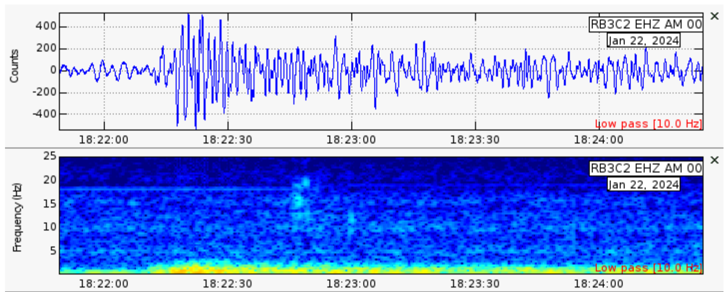
These traces show a “pP” wave – a P wave that bounces off the Earth's surface, goes back below and comes out again at a seismograph.

Note that the wave that bounces off the outer core (PcP wave) shows up with varying intensities. The outer core is not perfectly smooth, but has substantial topography.

It appears that Raspberry Shakes can be used to help determine the actual topography of the core!

Western China, M7.0 15 km depth
2024 Jan 22, 18:09:04 UTC

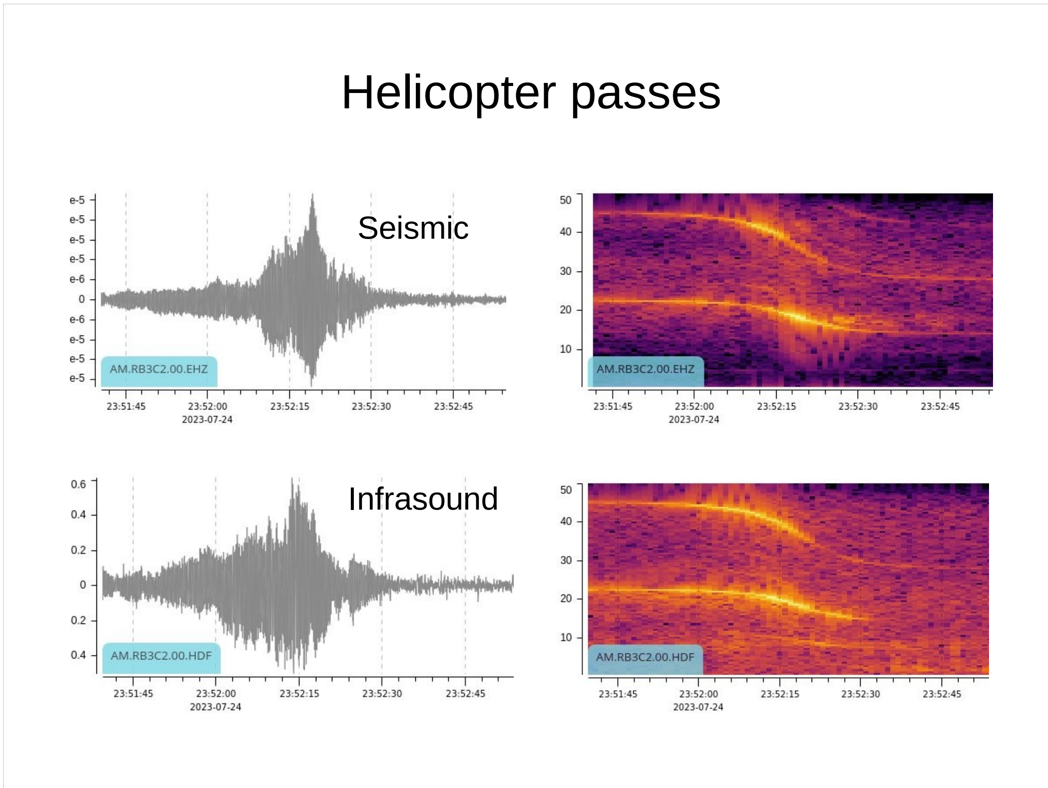
6300 mi
Sutton
RB3C2



Very distant quake

This major earthquake hit China near the border with Kyrgyzstan, about halfway to the other side of the planet. The shortest way here on the surface is to go north, cross the Arctic, and then south to Sutton.

However, the P wave arced underground and came very close to the outer core. Had it been a few hundred miles further away, the P wave would have entered the core and been refracted away from Sutton and we'd be in a “shadow zone” and wouldn't have seen it.

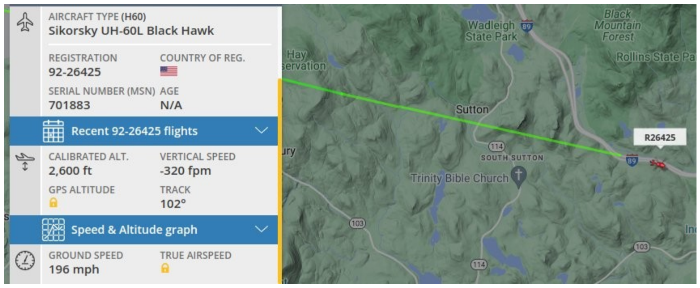


Of all the aircraft in the sky, helicopters and the Doppler effect due to their rotor stand out exceedingly well. It appears that the pulses couple into the ground surprisingly well, especially (and not surprisingly) when the spherical wavefronts are directly over the ground.

It's easy to get low resolution frequencies of both the approach and departure, and I felt that there ought to be a pleasantly simple equation to convert them to the helicopter's speed.

It turns out there is.

Helicopter speed



v: Helicopter speed (196 mph above)

f_a, f_d: approach and departure frequencies

c: Speed of sound, 760 mph, but slower in cold air

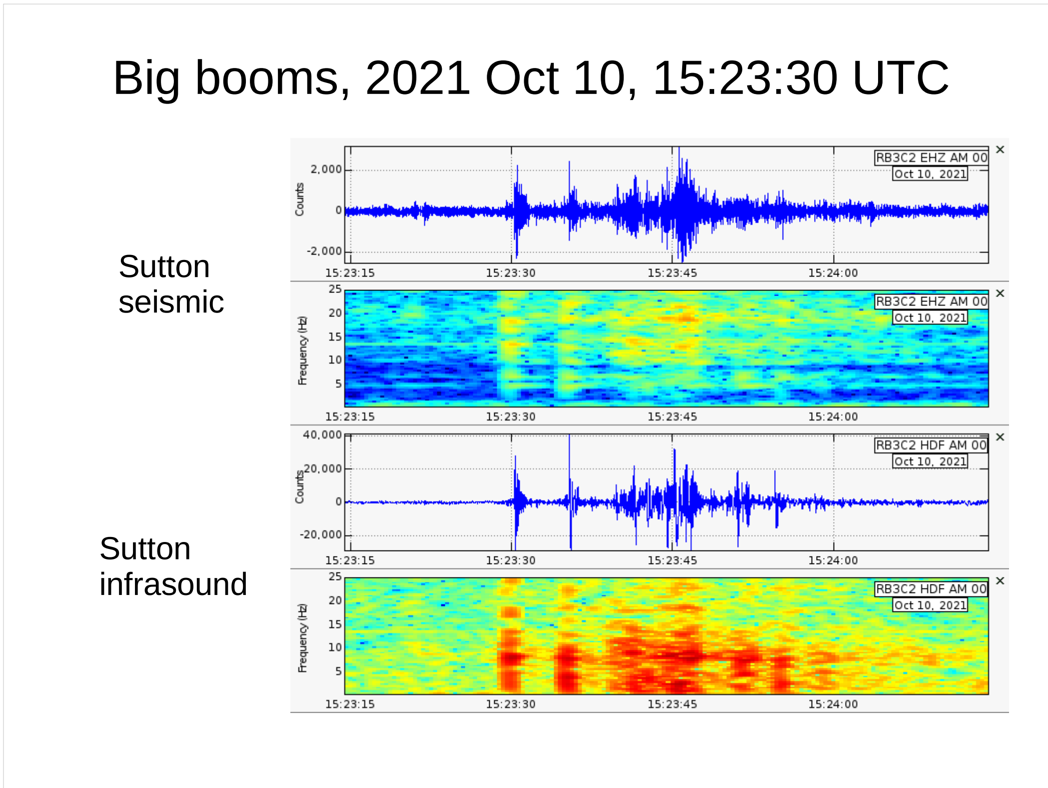
$$v = \frac{f_a - f_d}{f_a + f_d} \times c \qquad \frac{46-27}{46+27} \times 760 = 198$$

This helicopter is a military Black Hawk. In this case it's flying with its Air Traffic Control transponder on and flightradar24's track shows it heading to Concord and passed almost directly over my house.

I derived the equation, it appears to not be well known, and it gave me a surprisingly good match to the helicopter's speed.

Note that at low speed (fa – fd) will be small and that's why the equation gives a low speed.

If a helicopter could get close to Mach 1, fa becomes very large and fd approaches ½ of the base frequency so the fraction becomes close to 1.



This day in October was dry but overcast and many people were outside (I was inside, probably wasting too much time on FaceBook).

Late in the morning the outside folk here and in much of southern NH heard several booms, triggering speculation from local causes to military aircraft breaking the sound barrier.

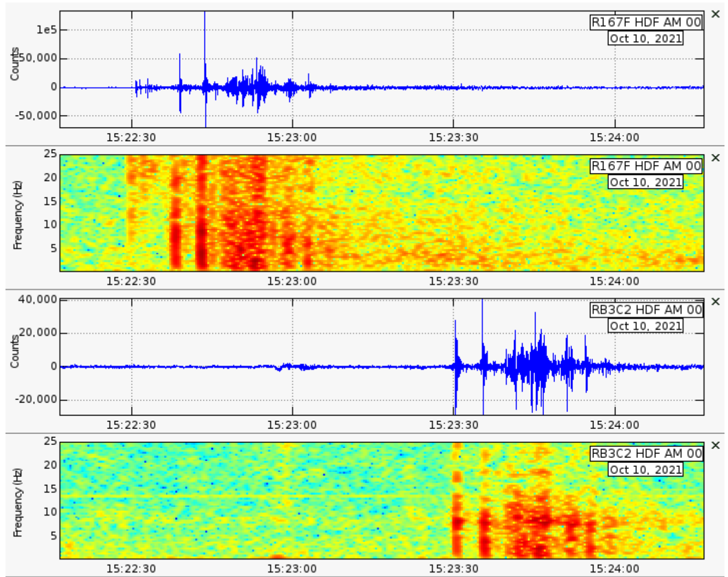
The event was recorded well on both of my RSB's channels, though much better on infrasound (and audible frequencies of course).

My suspicion was that it was a meteor explosion and each sound was a sonic boom from fragments of a meteor that had exploded.

Aha! Meteor?, 2021 Oct 10, 15:22:40 UTC

Antrim infrasound

Sutton infrasound

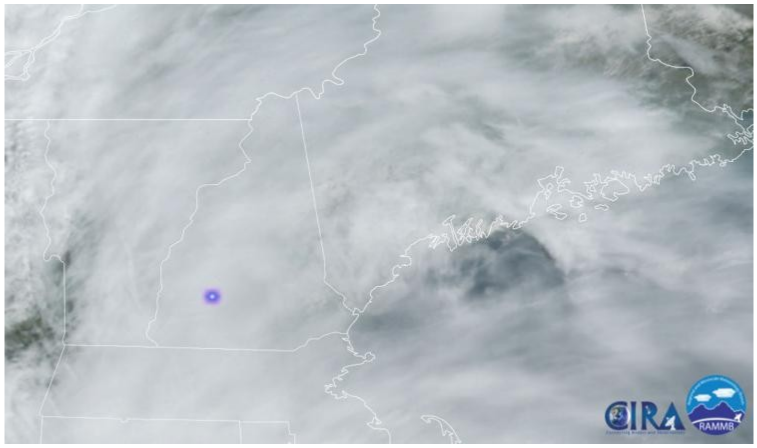


I soon found similar recordings at Antrim, but louder and earlier and with higher frequencies still present. The spacing between booms was nearly identical. This supported a single location for the source and that for a meteor the sounds were from the breakup and not sonic booms.

All the other speculation fell by the wayside and pretty much all that was left was exploded meteor, likely burning up before reaching the ground.

Meteor, 2021 Oct 10, 15:22:40 UTC

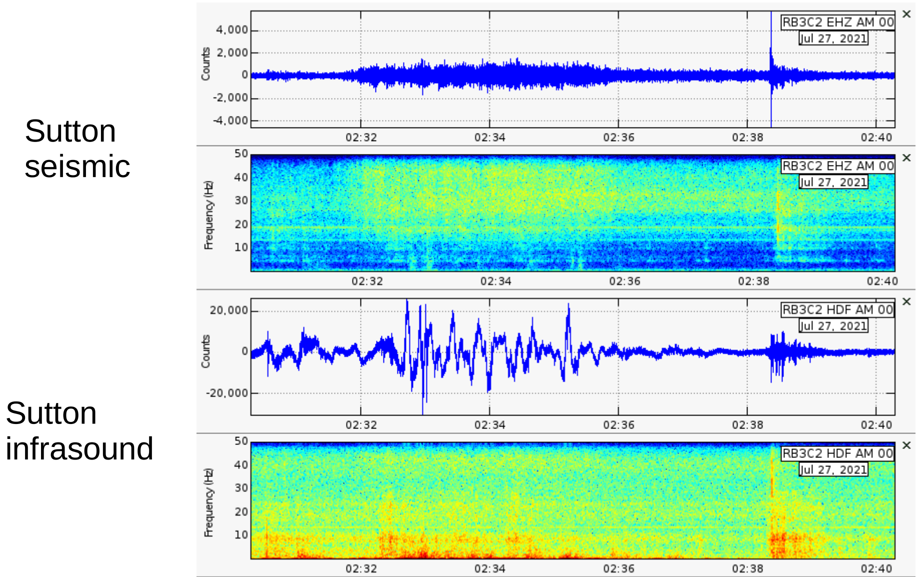
GOES-16 GLM (Geostationary Lightning Mapper) 15:21:17



NOAA's newest weather satellites have lightning imagers that are providing lots of useful bright light events. I looked, but someone else found a reference to this image. I believe this recorded the minute before 15:21:17. This is the only image showing something (some nighttime images show meteors as streaks), so it's very good confirmation that a meteor exploded high enough so the sound took over a minute before reaching Antrim.

The flash appears to be too far north, but I believe that's due to a parallax issue thanks to the height where meteors explode and the GOES-16 satellite over the equator in its geosynchronous orbit.

Downpour (and thunder?)
2021 July 27, 02:34 UTC

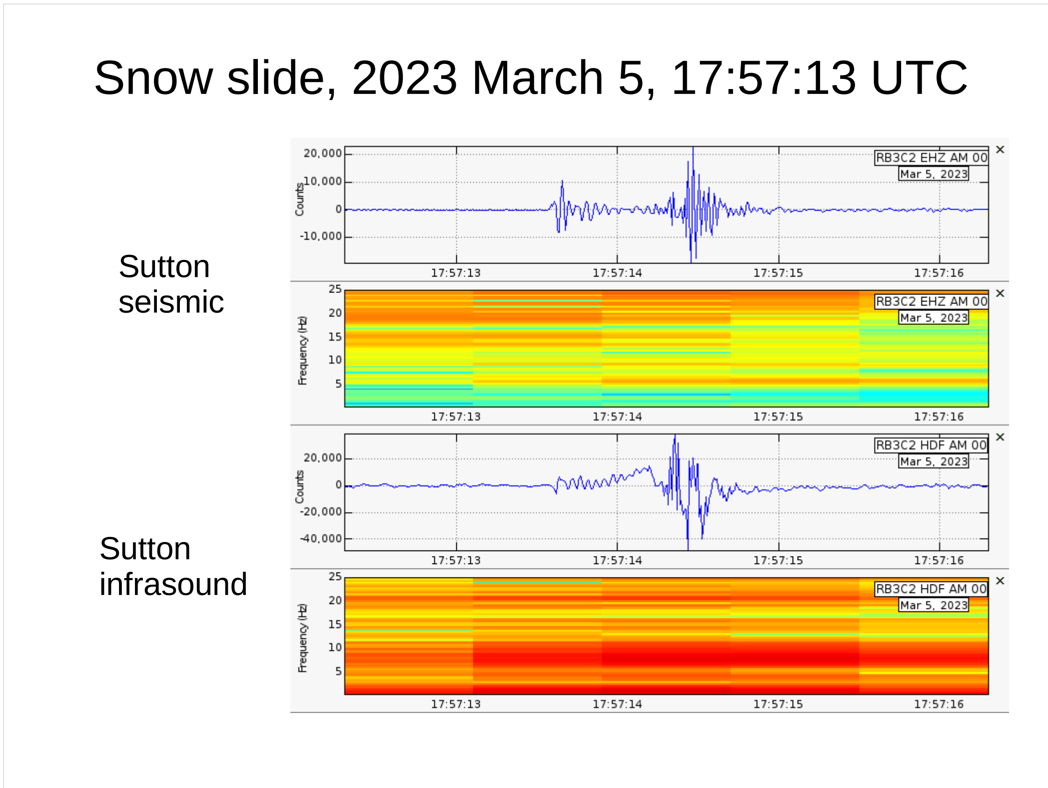


[Mundane curiosities from here on out.]

July and thunderstorms go together. Sometimes they bring downpours. This four minute episode peaked at over 2” per hour. The seismic signal may be partially acoustic, but likely most of it comes from rain to roof to walls to foundation.

The infrasound signal probably shows wind associated with the thunderstorm.

The signal on the right is almost certainly thunder.

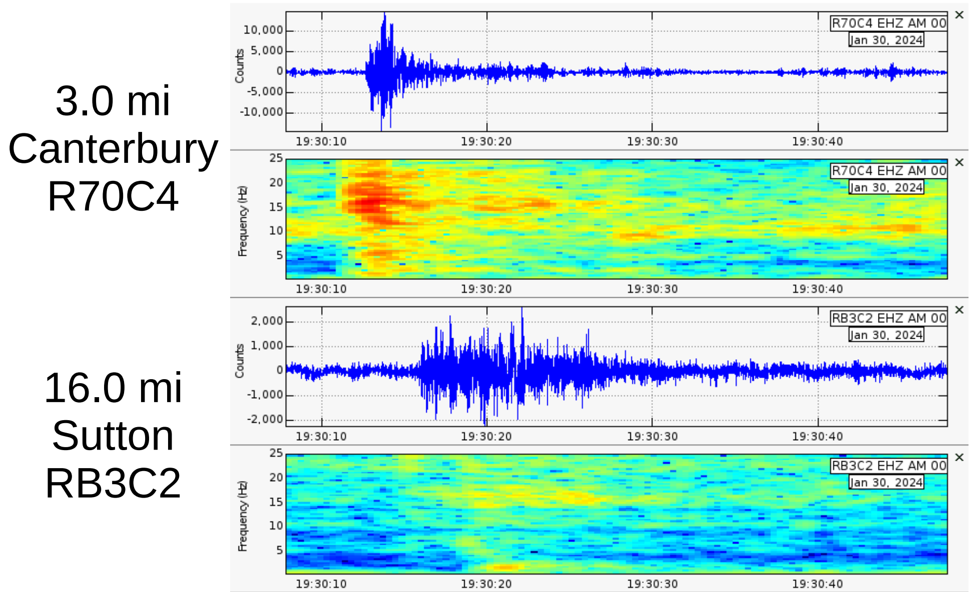


Winter in Sutton means snow (and sleet, freezing rain, graupel, etc). The garage where my RSB lives near the back wall is a two story barn-like gambrel. It has a metal roof and sometimes snow slides off.

In this event sliding snow removes weight from the roof with a gentle whoosh of sound. It takes about 0.8 seconds to fall and appears to displace some air pushing some toward the garage wall. When it hits the ground, kinetic energy splashes around and generates the strongest signals.

The garage seems to have two fundamental frequencies. The first may be what the garage “rings” at, the second may be how the ground and floor respond.

Cold Brook Sand and Gravel blasting
2024 Jan 30, 19:30:15 UTC



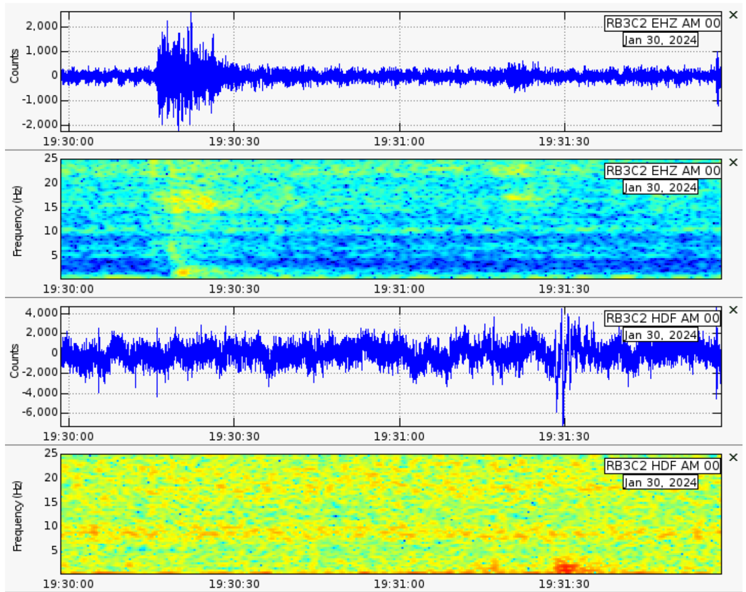
Cold Brook Sand and Gravel is in Boscawen and occasionally does blasting as a step in making crushed granite. I knew about it when I lived in the south end of town, but never felt or heard the blasting.

Raspberry Shakes can feel it, both nearby across the river in Canterbury and out here in Sutton. High frequencies in rock and in air attenuate, So Sutton feels mostly the low frequencies.

Cold Brook Sand and Gravel blasting, seismic vs. infrasound

Sutton seismic ~3 secs

Sutton infrasound 16x5 = 80

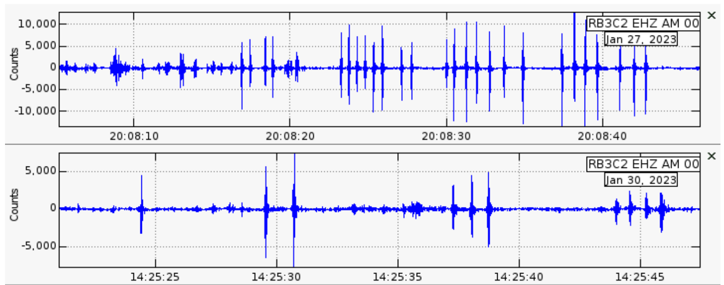


The Canterbury site is a Shake, but not Boom, and doesn't record sound, my Shake and Boom records both. Sound takes about five seconds to travel one mile, so it should (and does) take about eighty seconds to reach me. Very cool!

Sutton driveway ice chipping

Clearing

Testing



[Finally] One day after I cleared some ice off the area in front of the garage, I checked to see what my RSB recorded. The spikes were interesting and were likely from my ice chipping to loosen ice to scrape off.

A few days later I went outside to the far end of the pavement and tapped my shovel there once. Then moved a third of the way back and tapped twice. Then repeated two more times.

This is one final example that:

1) It's easy to make the Earth move.

2) These Shakes are not toys, but amazingly sensitive instruments.

Resources and Credits

- https://www.concordmonitor.com/earthquake-monitor-49407723
  Concord Monitor article about my Raspberry Shake & Boom
- https://stationview.raspberryshake.org/#/?zoom=8.000&net=AM&lat=43.060&lon=-72.011
  New England Raspberry Shakes
- https://dataview.raspberryshake.org/#/AM/RB3C2/00/EHZ
  My RSB realtime display
- https://www.usgs.gov/software/swarm
  Seismic display software for most of the above
- Prof. Alan Kafka, Weston (Seismic) Observatory, Department of Earth and Environmental Sciences, Boston College.
  Source of a few images, much knowledge, and purveyor of bad puns for over half a century.