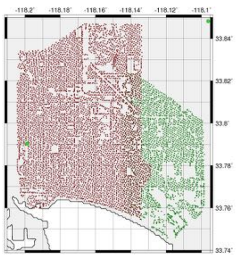
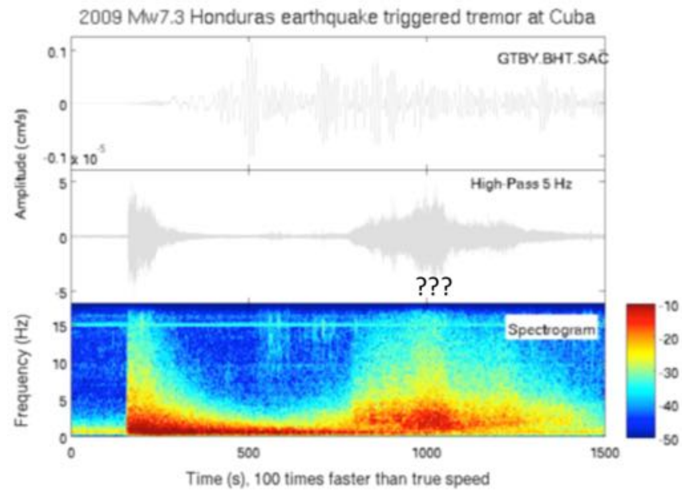
EAS 4801 - Planetary Sound
Lec #9: Snell's Law; Recording devices (Cont)

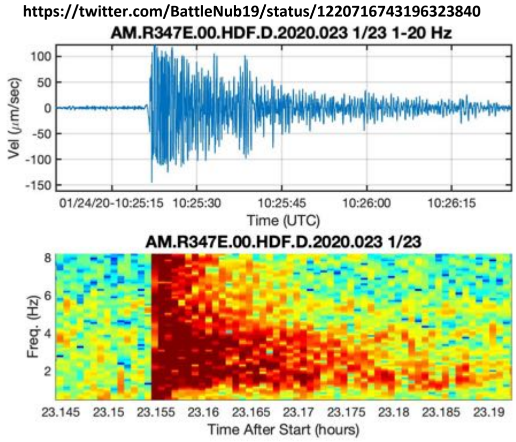
Dr. Zhigang Peng
01/22/2020
Spring 2020

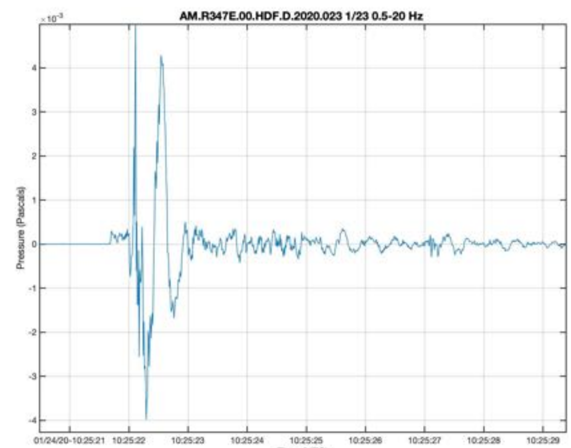




2 people have been killed in an explosion at a Houston manufacturer that shook the city and damaged homes (CNN)

https://twitter.com/BattleNub19/status/1220716743196323840





https://raspberryshake.net/stationview/boom/stationview/
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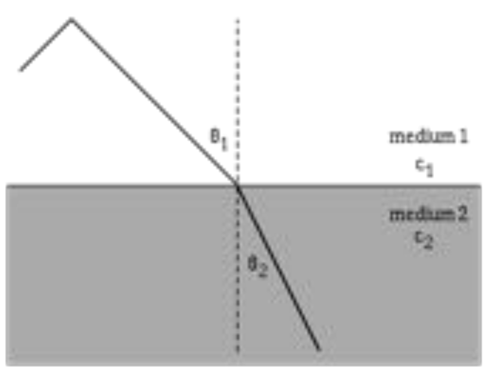
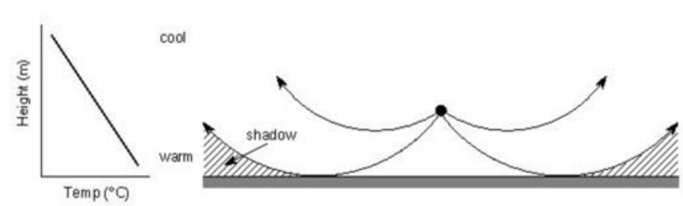
Snell's Law for sound waves



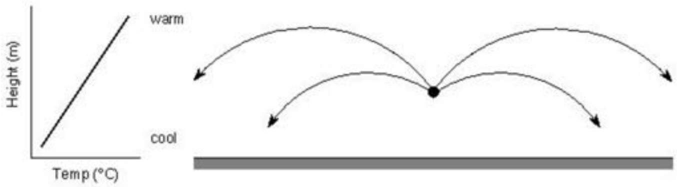
$$\frac{\sin\theta_1}{c_1} = \frac{\sin\theta_2}{c_2}$$

https://www.acs.psu.edu/drussell/Demos/refract/refract.html



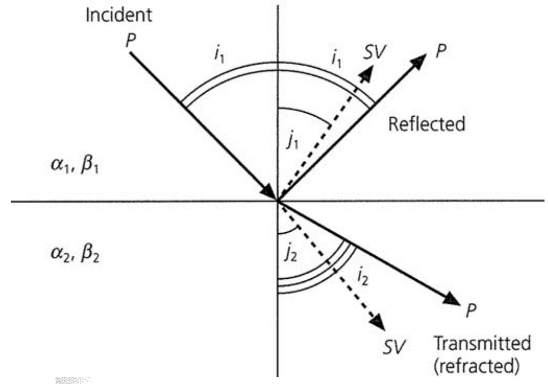
The speed of a sound wave in air depends on the temperature (c=331 + 0.6 T) where T is the temperature in ^{o}C.

During the day the air is warmest right next to the ground and grows cooler above the ground. This is called a temperature lapse. Since the temperature decreases with height, the speed of sound also decreases with height. This means that for a sound wave traveling close to the ground, the part of the wave closest to the ground is traveling the fastest, and the part of the wave farthest above the ground is traveling the slowest. As a result, the wave changes direction and bends upwards. This can create a "shadow zone" region into which the sound wave cannot penetrate. A person standing in the shadow zone will not hear the sound even though he/she might be able to see the source. The sound waves are being refracted upwards and will never reach the observer.



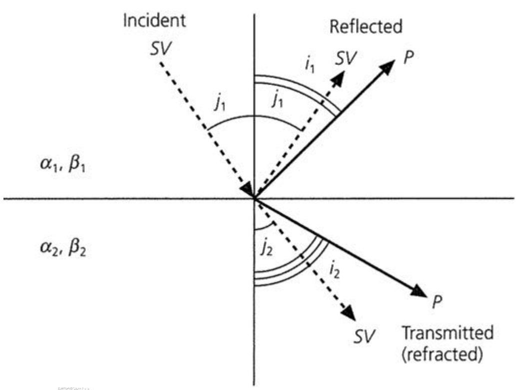
A **temperature inversion** **is when the temperature is coolest right next to the ground and warmer as you increase in height above the ground. Since the temperature increases with height, the speed of sound also increases with height. This means that for a sound wave traveling close to the ground, the part of the wave closest to the ground is traveling the slowest, and the part of the wave farthest above the ground is traveling the fastest. As a result, the wave changes direction and bends** **downwards****. Temperature inversions most often happen at night after the sun goes down when the ground (or water in a lake) cools off quickly, while the air above the ground remains warm. This downward refraction of sound is why you can hear the conversations of campers across the lake, when otherwise you should not be able to hear them. (remember that they can probably hear you too!)**

Snell's Law for Seismic Waves



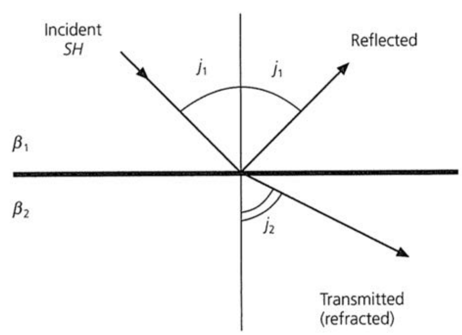
$$c_x = \frac{\alpha_1}{\sin i_1} = \frac{\beta_1}{\sin j_1} = \frac{\alpha_2}{\sin i_2} = \frac{\beta_2}{\sin j_2}$$

Snell's Law for Seismic Waves



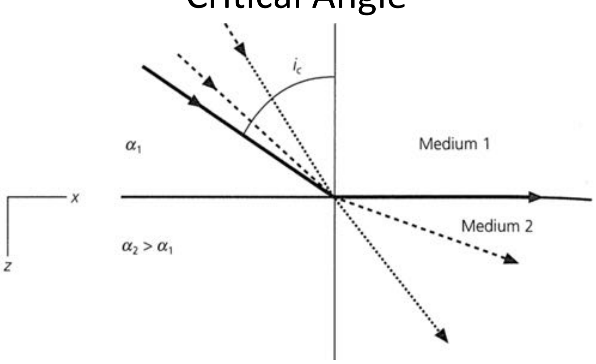
$$c_x = \frac{\alpha_1}{\sin i_1} = \frac{\beta_1}{\sin j_1} = \frac{\alpha_2}{\sin i_2} = \frac{\beta_2}{\sin j_2}$$

Snell's Law for SH Waves



$$c_x = \beta_1/\sin j_1 = \beta_2/\sin j_2$$

Critical Angle



$$\sin i_c(\alpha_2/\alpha_1) = 1 \quad \text{or} \quad \sin i_c = \alpha_1/\alpha_2.$$

Thus for a wave incident at this *critical angle* of incidence, transmitted wave grazes the interface.

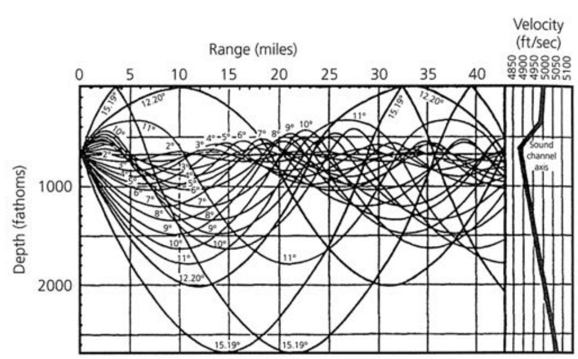
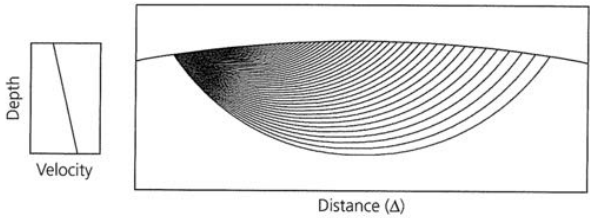
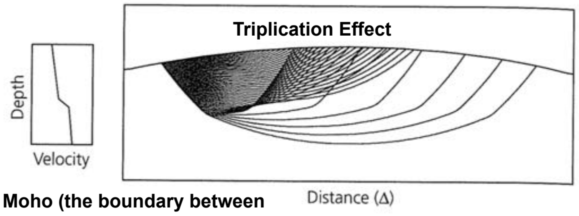
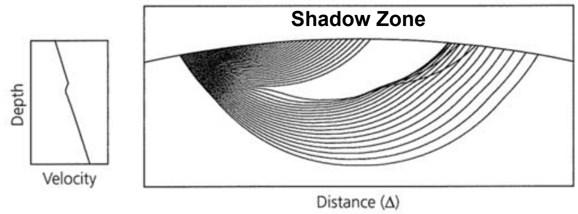


Fig. 2.5-11 *Top*: A low-velocity layer surrounded by high-velocity material acts as a waveguide. Rays incident on either interface at angles exceeding the critical angle undergo total internal reflection. *Bottom*: The SOFAR channel, a low-velocity zone (*right*) in the ocean, acts as a waveguide, as shown by ray paths from a source in the channel (*left*). Note the non-SI units for distance and velocity. (Ewing *et al*., 1957)



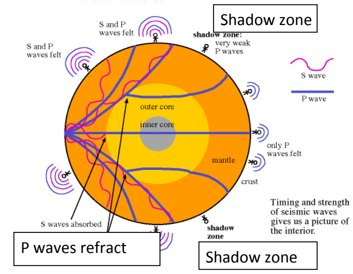


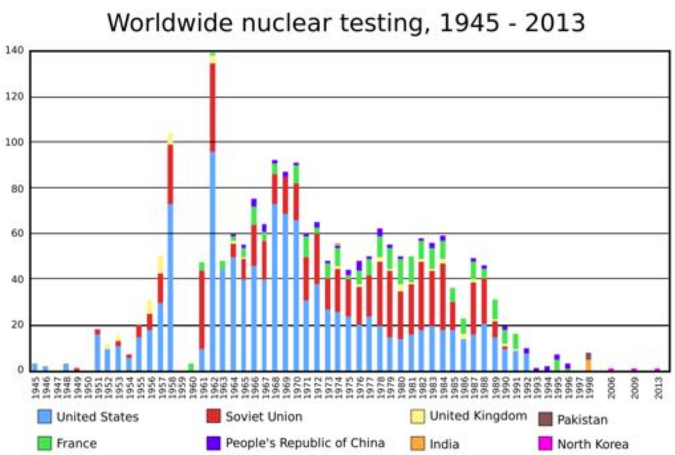
e.g., Moho (the boundary between the crust and mantle)



How do we know that the Earth's out core is liquid and has slower P wave velocity than the bottom of the mantle?

Liquid Outer Core (1906 Oldham; 1913 Gutenberg; 1926 Jeffreys)



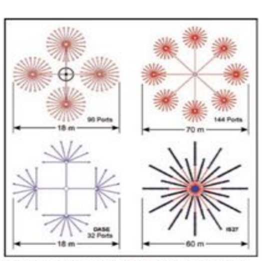


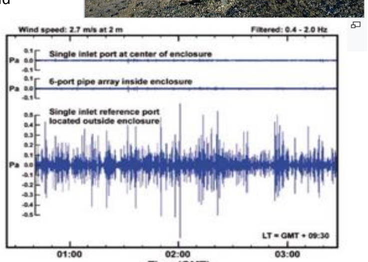
Here is a comparison between the 2013/02/12 North Korea nuclear explosion, and an M5.1 earthquake in Nevada on 2013/02/13 recorded at seismic stations a few hundred kilometers away. The initial sound of the nuclear explosion is much stronger, likely due to efficient generation of compressional wave (P wave) for an explosive source. In comparison, the earthquake generated stronger shear waves that arrived later than the P wave.

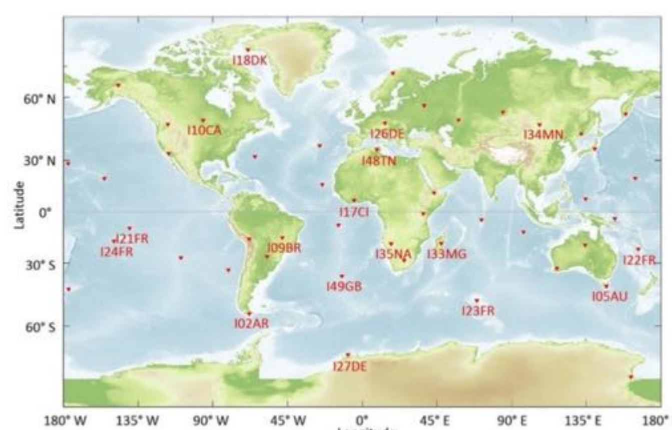
Infrasound Monitoring

The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) Preparatory Commission uses infrasound as one of its monitoring technologies, along with seismic, hydroacoustic, and atmospheric radionuclide monitoring. The loudest infrasound recorded to date by the monitoring system was generated by the 2013 Chelyabinsk meteor.

https://en.wikipedia.org/wiki/Infrasound

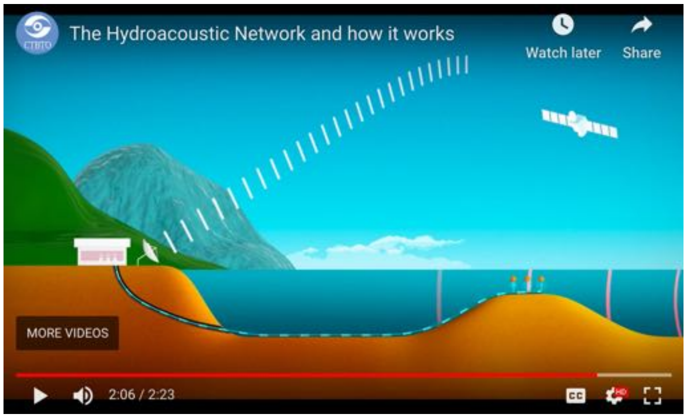




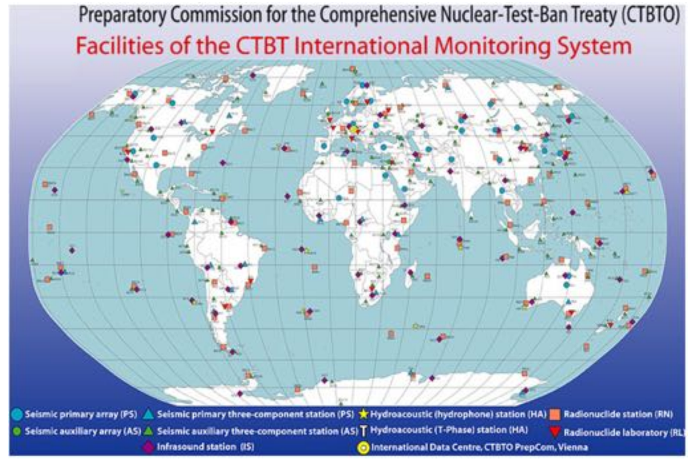


https://www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/infrasound-monitoring/

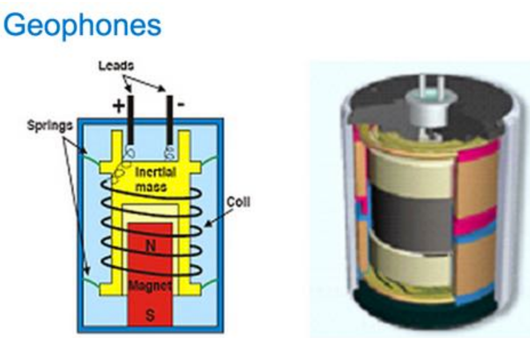
https://www.ctbto.org/fileadmin/content/reference/outreach/ctbto_spectrum_10/p18_19_Recent_developments_in_IS_monitoring_technology.pdf

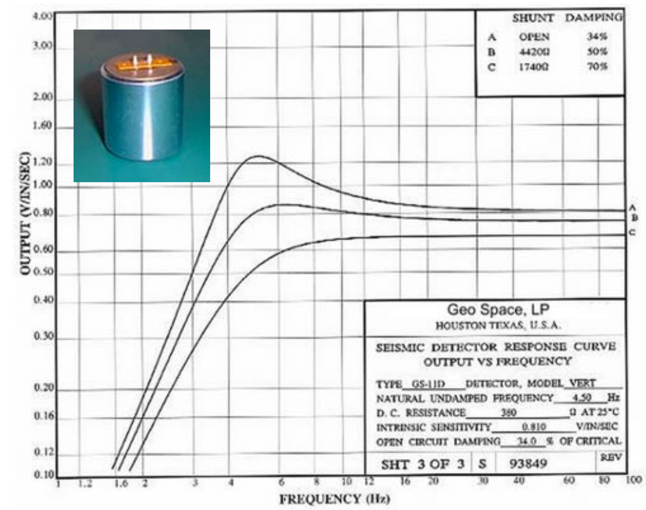


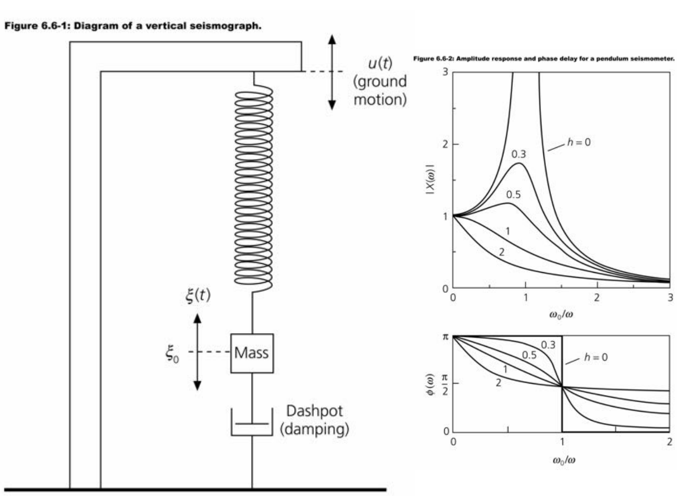
https://www.ctbto.org/verification-regime/monitoring-technologies-how-they-work/hydroacoustic-monitoring/



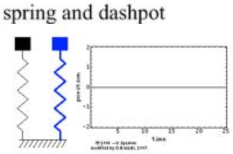
Geophone: a device that converts ground motion into voltage







damped harmonic oscillator composed of a spring and dashpot



Newton's Law: $\mathbf{F} = m\mathbf{a}$

Case for no damping:

$$m\frac{d^2u(t)}{dt^2} + k\,u(t) = 0$$

where k is the spring constant.

Solution is perpetual harmonic oscillation:

$$u(t) = Ae^{i\omega_0 t} + Be^{-i\omega_0 t} \quad \text{or} \quad u(t) = A_0\cos(\omega_0 t)$$

(A and B are constants)

The mass moves back and forth with a natural frequency $\omega_0 = (k/m)^{1/2}$

Once the motion is started, the oscillation continues forever.

Figure 6.6-5: Illustration of an electromagnetic seismograph.

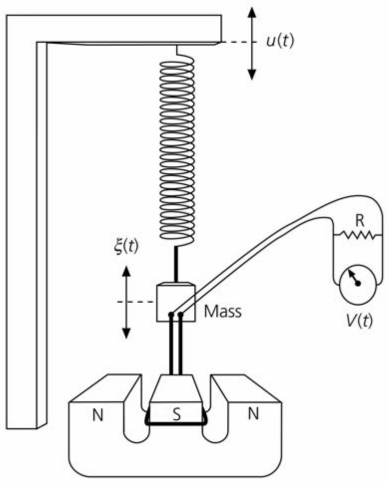
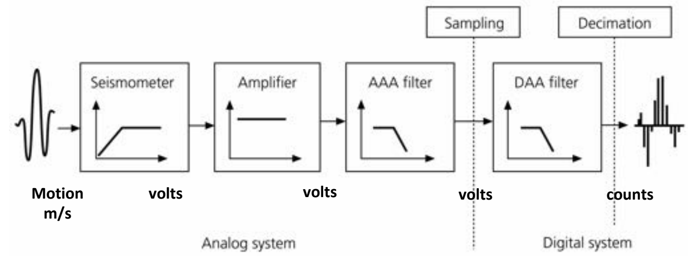


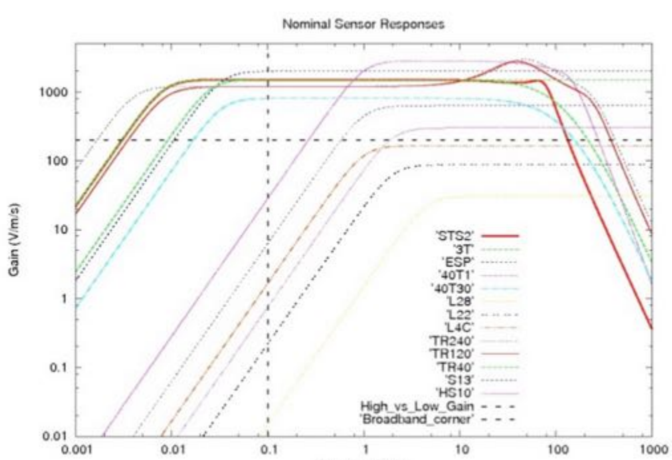
Figure 6.6-12: Diagram showing the analog-to-digital (ADC) process.



AAA: Analog Anti-Aliasing Filter
DAA: Digital Anti-Aliasing Filter

Broadband Seismometers

Typical seismic deployment

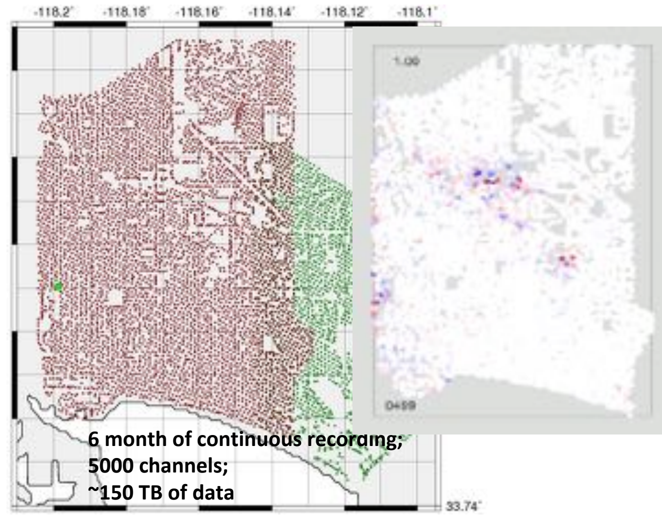


https://www.passcal.nmt.edu/content/instrumentation/sensors/sensor-comparison-chart

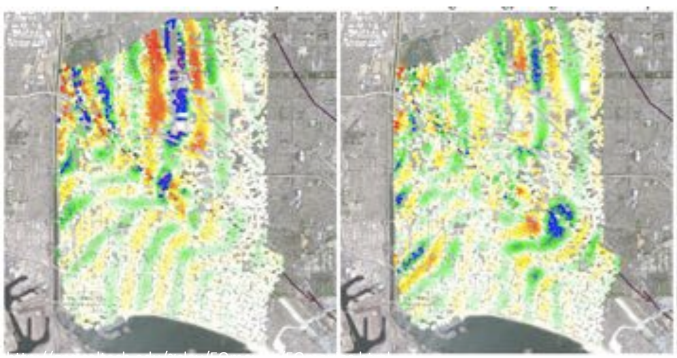
Traditional Land Deployment

Figure 1. Seismic field technician with 20+ Kg cable. Carrying this heavy weight on rough terrain is hazardous, even with experienced personnel.

New types of sensor/recording system



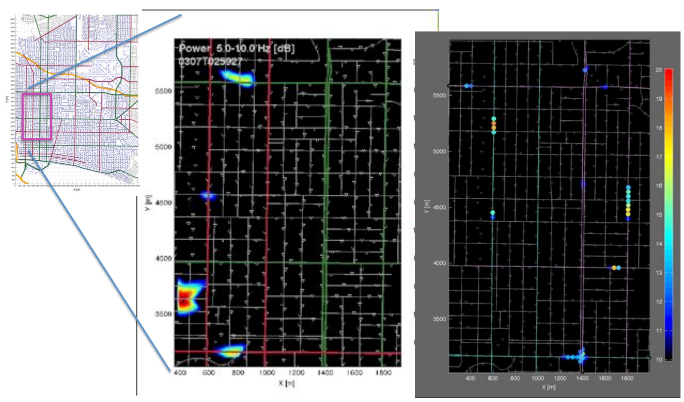
http://www.gps.caltech.edu/~clay/LB3D/Survey.html



Cable free, fast deployment system

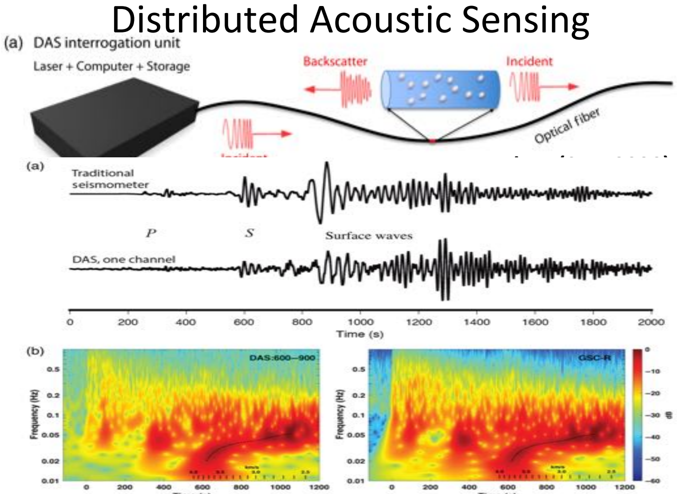
Noise Tracking of Cars/Trains/Airplanes

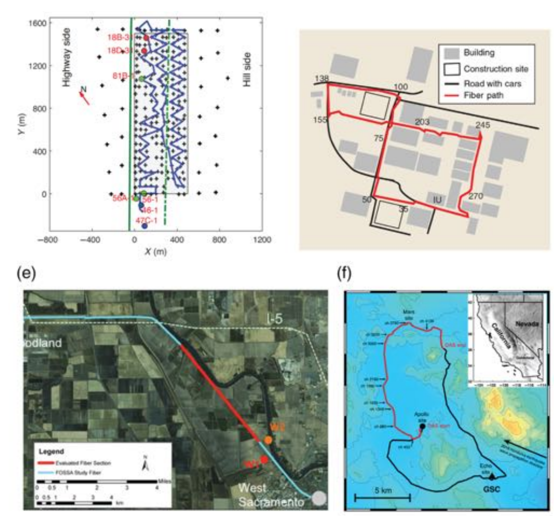
5200 element Long Beach array (Dan Hollis)

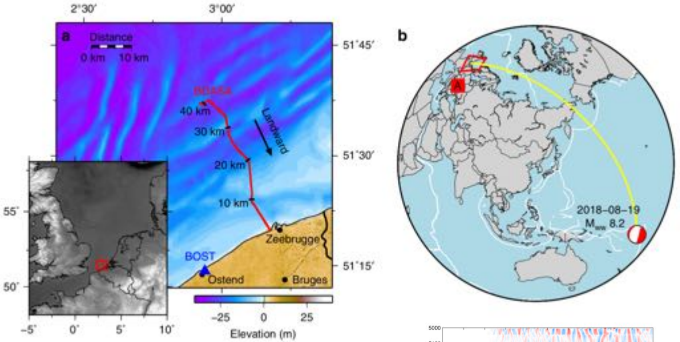


Riahi, Gerstoft, The seismic traffic footprint: Tracking trains, aircraft, and cars seismically, GRL 2015

Distributed Acoustic Sensing







Williams et al. (Nature Comm., 2019)

Dark fiber refers to unused fiber-optic cable. Often times companies lay more lines than what's needed in order to curb costs of having to do it again and again.