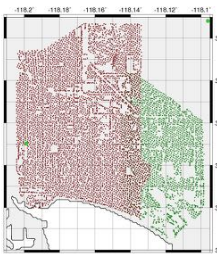
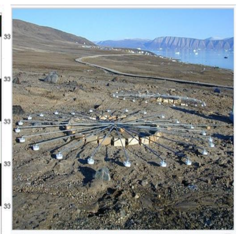
EAS 4801 - Planetary Sound
Lec #11: Basic Processing Tools

Dr. Zhigang Peng
01/31/2020
Spring 2020




Infrasound arrays at infrasound monitoring station in Qaanaaq, Greenland

Geophysics Seminar Today

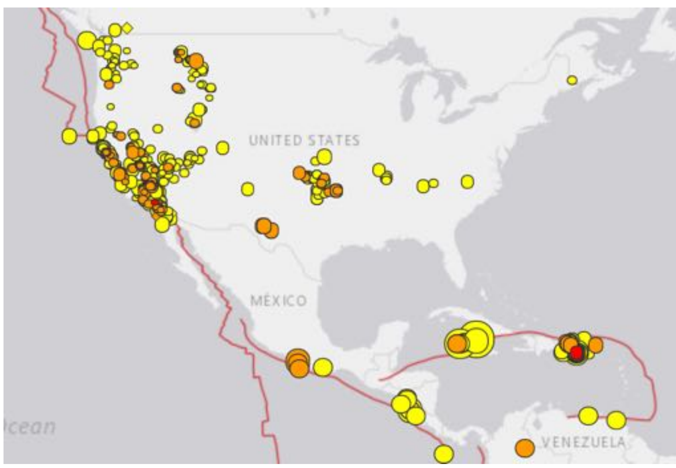
EAS Geophysics Seminar Today!

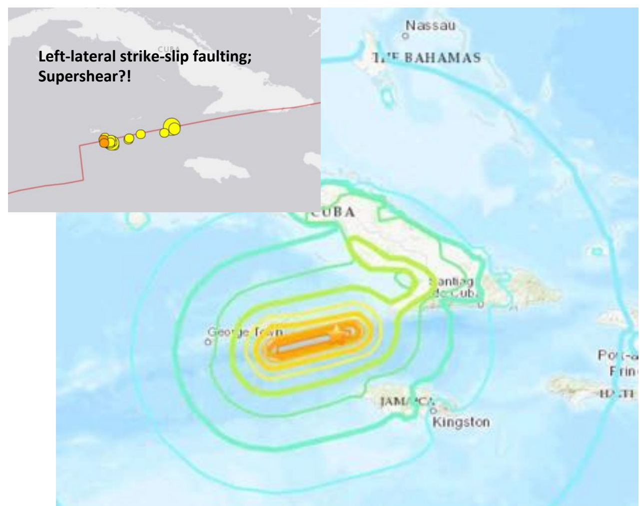
Speaker: Dr. Zhongwen Zhan
Affiliation: Seismological Laboratory, California Institute of Technology

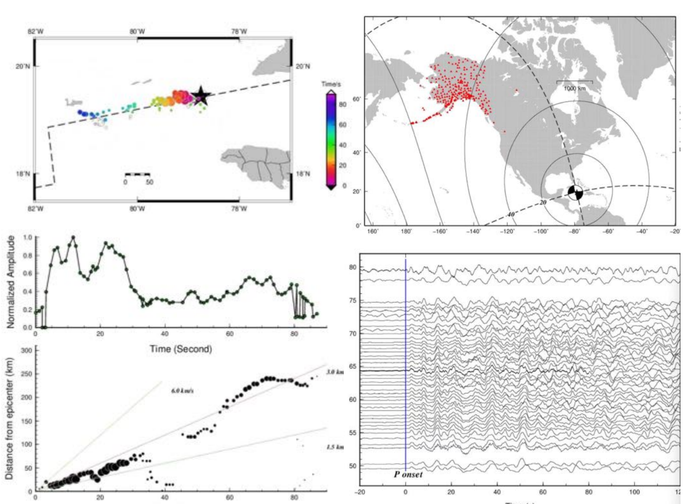
Turning fiber optic cables into the next-generation seismic networks

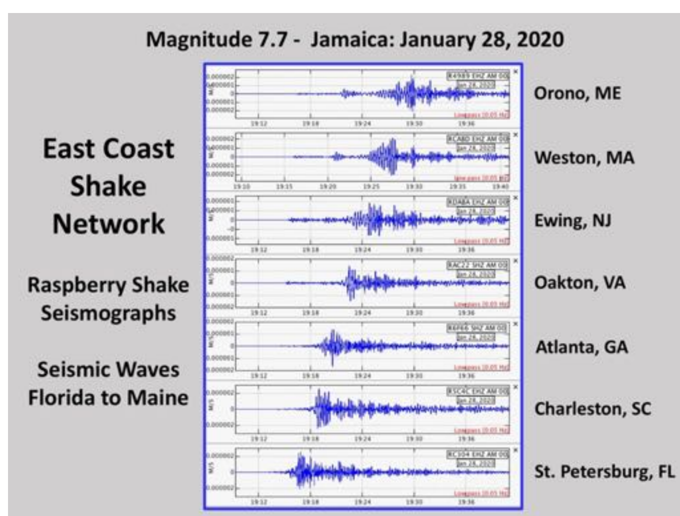
Date: Today, January 31, 2020 2-3pm
Location: ES&T, Rm. L1116
Host: Dr. Zhigang Peng

https://earthquake.usgs.gov/

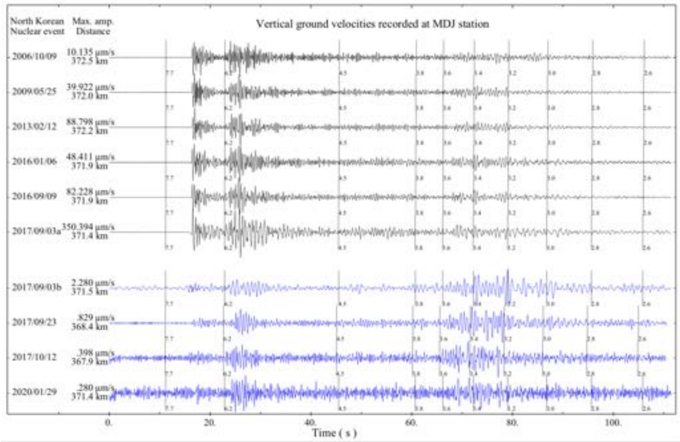








A M2.5 seismic event in North Korea on 2020/02/29 (earthquakes or nuclear test?!)



Signal and Noise

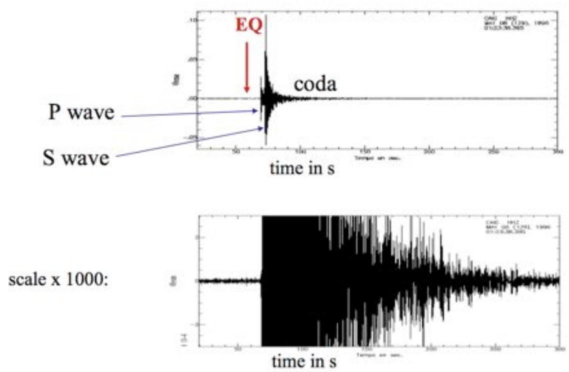
- What is the definition of signal and noise?

•"We shall introduce the concepts of signal and noise. We define the signal as the desired part of the data and the noise as the unwanted part".

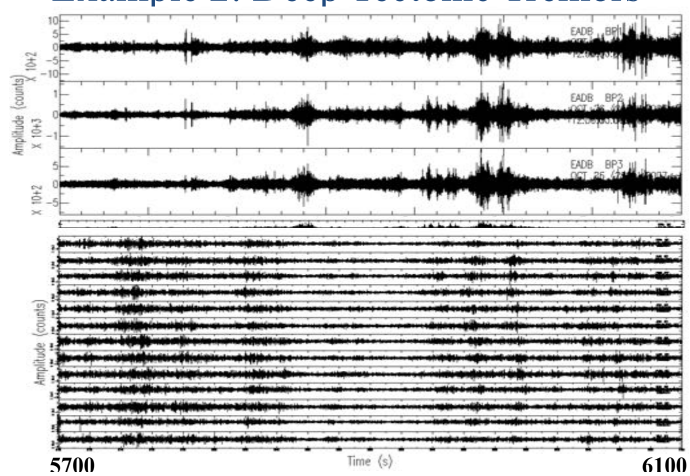
•"Our definition of signal and noise is subjective in the sense that a given part of the data is "signal" for those who know how to analyze and interpret the data, but it is "noise" for those who do not".

Aki and Richards, Quantitative Seismology, 1980

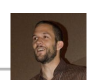
An example of turning noise into signals

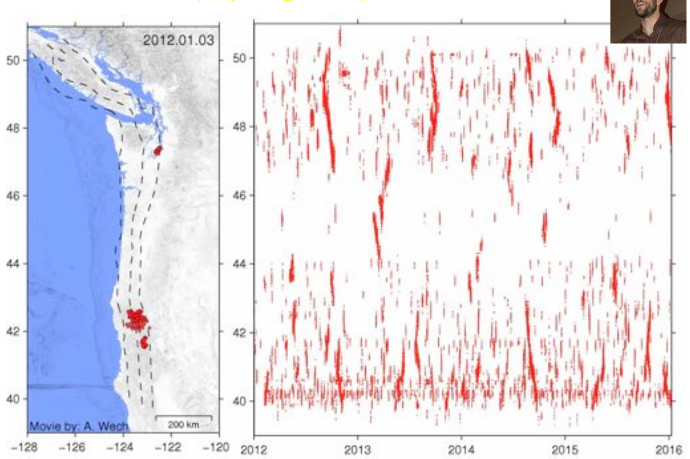


Example 2: Deep Tectonic Tremors

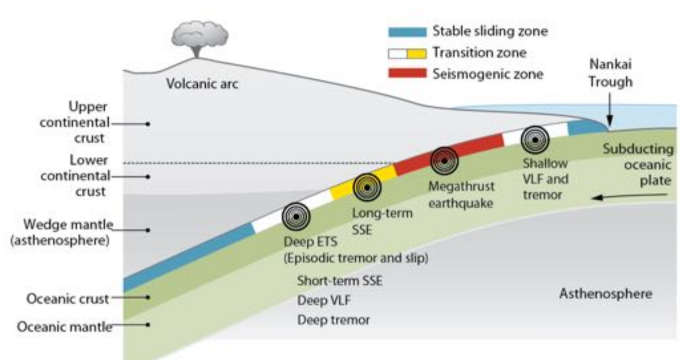


https://pnsn.org/tremor by Arron Wech

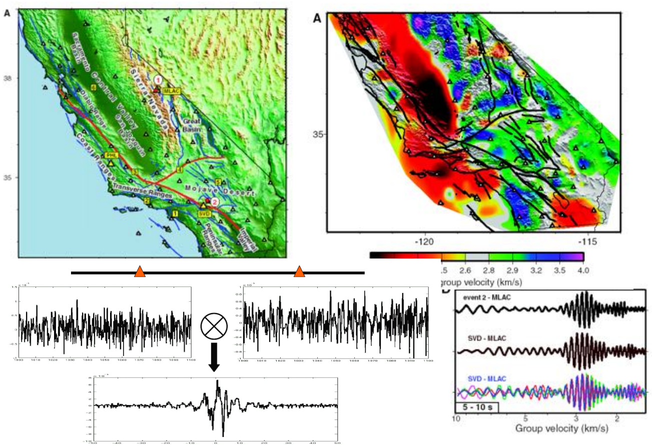


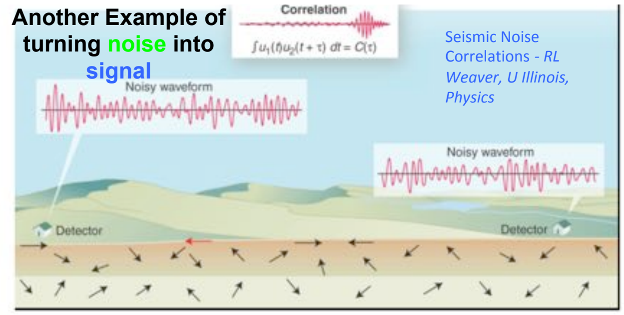


Traditional and New Subduction Zone Model (Obara and Kato, Science, 2016)



Example 3: Ambient noise tomography





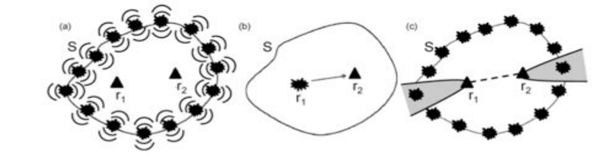
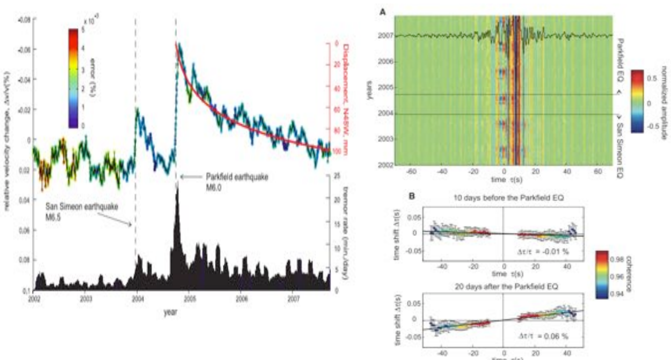


Fig. 1. A schematic explanation of the seismic interferometry method. (a) Two receivers (triangles) are surrounded by a boundary *S* of sources (explosions), each of which sends a wavefield into the interior and exterior of *S* (wavefronts shown). (b) The seismic interferometry method turns one of the receivers ($\mathbf{r}_1$) into a virtual source from which a real seismogram is obtained. (c) Sources located within the grey regions contribute the most to the Green's function computation.

Temporal changes from ambient noise - long-time average, poor temporal resolution

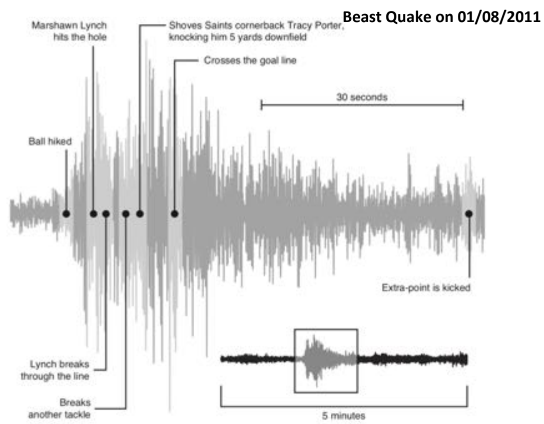


[Brenguier et al. Science, 2008]

* The "12th man" is a term used to describe the fans in the stadium at American football games.

story, many reporters showed a spectrogram, hits on my name

Beast Quake on 01/08/2011



▲ **Figure 1.** Vertical acceleration from strong-motion station KDK, annotated to illustrate progress of the football play. Drafted by Alicia Hotovec (after Mark Nowlin and Sandi Doughton, *Seattle Times*).

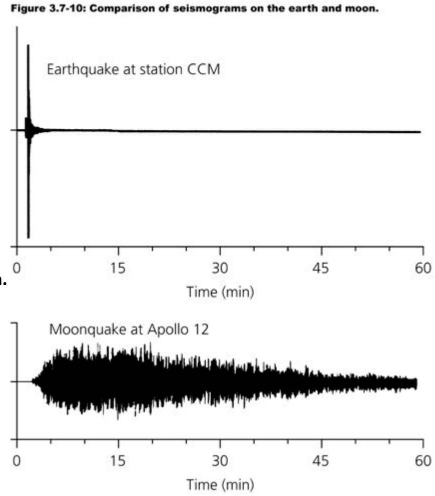
What's the major difference?

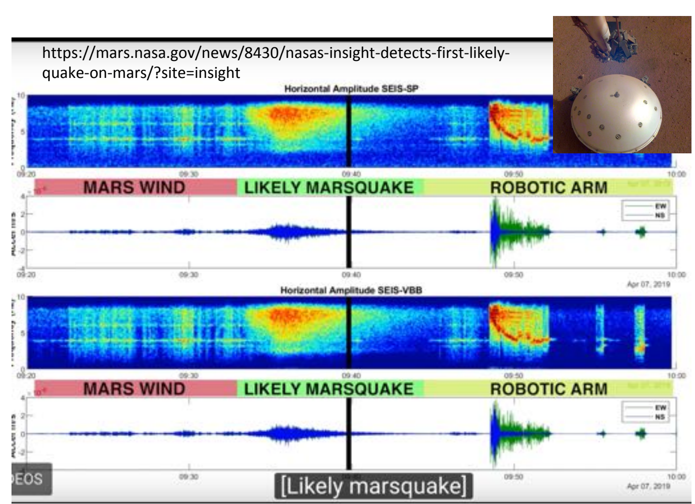
Any idea why?

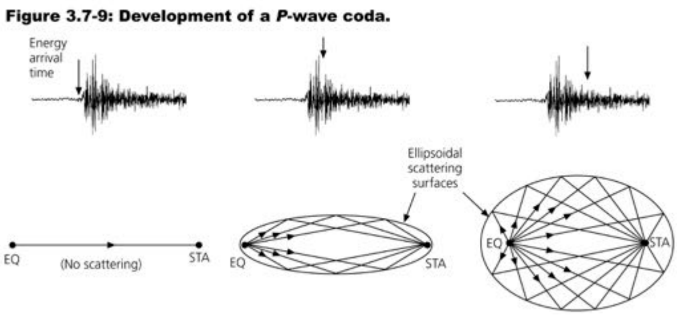
Fractured rocks near the surface with fluid-filled cracks cause lost of energy due to movement of fluid and other permanent deformation in the medium.

Highly fractured rocks, lack of water, little lose of seismic energy.

Figure 3.7-10: Comparison of seismograms on the earth and moon.







Valid only for constant-velocity medium, single scattering

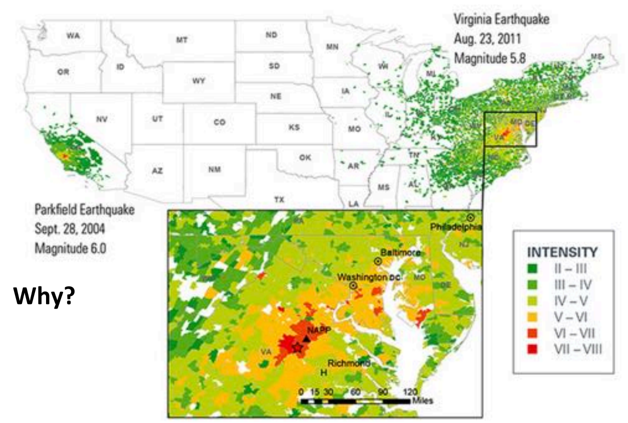
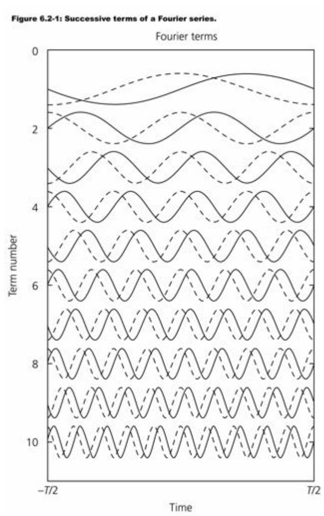
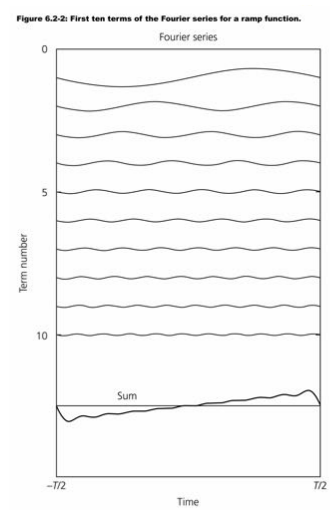


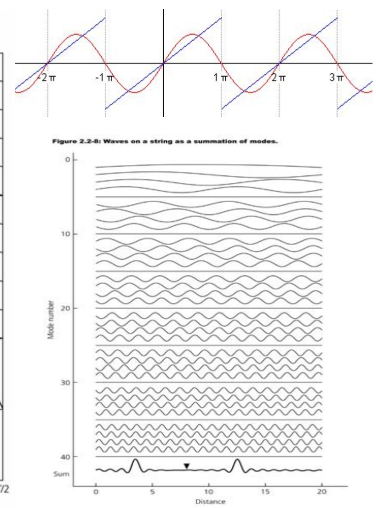
Figure 2: "Did you feel it?" Earthquake Data: U.S. Geological Survey "Did You Feel It?" data from the 2011 magnitude 5.8 Virginia and the 2004 magnitude 6.0 Parkfield, California, earthquakes. Colors illustrate the Modified Mercalli Intensity (MMI) scales. Red star and black triangle in the inserted map show the locations of the 2011 earthquake and North Anna Power Plant (NAPP).

Fourier analysis

- Any time series can be decomposed into the sum or integral of harmonic waves of different frequencies.
- Harmonic waves: a sinusoid with a single frequency.







Complex Fourier Series

- The Fourier series can be written in a simpler form by expanding the sine and cosine functions into complex exponentials, so that the Fourier series becomes

$$f(t) = F_0 + \sum_{n=1}^{\infty}[F_n e^{iw_n t} + F_{-n} e^{-iw_n t}]$$

- The negative exponentials can be written as

$$\sum_{n=1}^{\infty} F_{-n} e^{-iw_n t} = \sum_{n=-1}^{-\infty} F_n e^{iw_n t}$$

- So the Fourier series can be written in complex number form as:

$$f(t) = \sum_{n=-\infty}^{\infty} F_n e^{iw_n t} \qquad F_n = \frac{1}{T}\int_{-T/2}^{T/2} e^{-i\varpi_n t} f(t)dt$$

Fourier Transforms

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\varpi) e^{i\varpi t} d\varpi \qquad F(\varpi) = \int_{-\infty}^{\infty} e^{-i\varpi t} f(t)dt$$

- If $f(t)$ is a seismogram that has the dimensions of displacement, its Fourier transform $F(\omega)$ has the dimensions of displacement multiplied by time (from the *dt* term).
- The Fourier transform can be written in terms of two real-valued functions of ω:

$F(\varpi) = |F(\varpi)| e^{i\phi(\omega)}$ Amplitude spectrum

$$|F(\varpi)| = [F(\varpi)F^*(\varpi)]^{1/2} = [\mathrm{Re}^2(F(\varpi)) + \mathrm{Im}^2(F(\varpi))]^{1/2}$$

$\phi(\varpi) = \tan^{-1}(\mathrm{Im}(F(\varpi)/\mathrm{Re}(F(\varpi)))$ Phase spectrum

Figure 6.2-3: Amplitude spectra for the body and surface wave segments from a large earthquake.

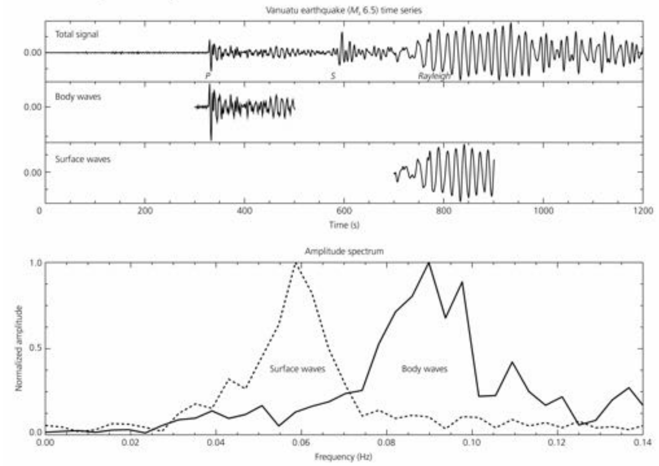
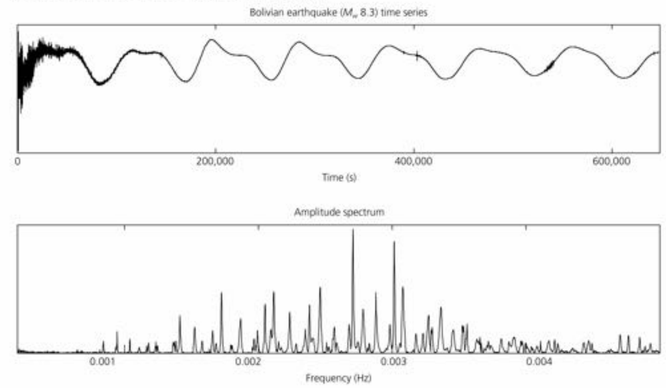
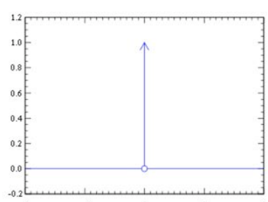


Figure 6.2-4: Amplitude spectra of a vertical-component seismogram from the great 1994 Bolivian earthquake.



What is a Delta Function?

- The Dirac delta function, or δ function, is (informally) a generalized function depending on a real parameter such that it is zero for all values of the parameter except when the parameter is zero, and its integral over the parameter from −∞ to ∞ is equal to one. (From wipipedia)



Delta function

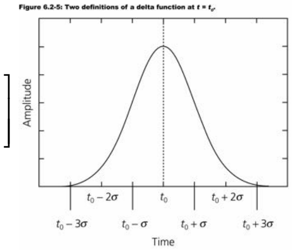
Three ways to define it

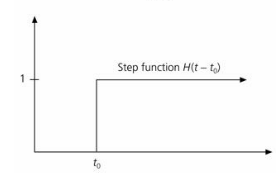
$$\delta(t-t_0) = \lim_{\sigma\to 0} \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-1}{2}\left(\frac{t-t_0}{\sigma}\right)^2\right]$$

$$f(t_0) = \int_{-\infty}^{\infty} f(t)\delta(t-t_0)\,dt$$

$$\delta(t-t_0) = dH(t-t_0)/dt$$

Figure 6.2-5: Two definitions of a delta function at $t = t_0$.





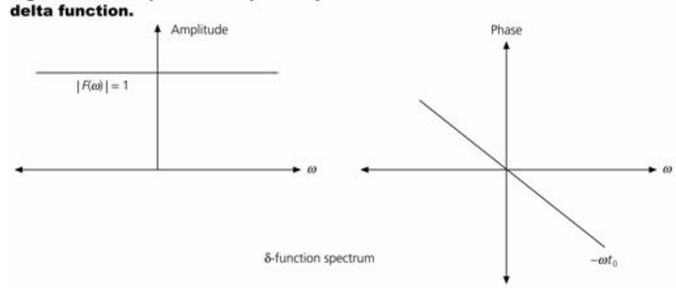
Fourier transform of the delta function

- To find the Fourier transform of the delta function, we use the definition of the transform with $f(t) = \delta(t-t_0)$

$$F(\varpi) = \int_{-\infty}^{\infty} e^{-i\varpi t}\delta(t-t_0)\,dt = e^{-i\varpi t_0}$$

- The amplitude spectrum is $|F(\varpi)| = \left(e^{-i\varpi t_0} e^{i\varpi t_0}\right)^{1/2} = 1$
- The phase spectrum is $\phi(\varpi) = \varpi t_0$

Figure 6.2-6: Amplitude and phase spectra of the Fourier transform of a delta function.



- If the delta function is at time zero,

$$F(\varpi) = \int_{-\infty}^{\infty} e^{-i\varpi t}\delta(t)\,dt = 1$$

Fourier transform of the delta function

- The delta function's amplitude spectrum has unit amplitude at all frequencies.
- The output from a linear time-invariant system with delta function input is called impulse response (in time domain), and transfer function (in frequency domain).
- The inverse transform of the delta function

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-i\varpi t_0} e^{i\varpi t} d\varpi = \delta(t - t_0)$$

Figure 6.2-7: Fourier transform of a delta function as the sum of sinusoids of all frequencies.

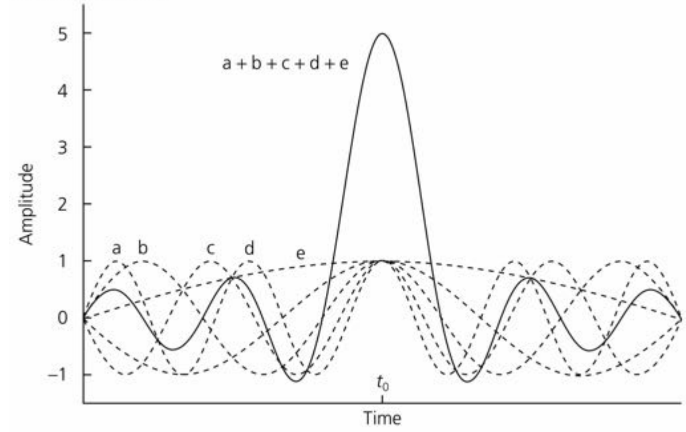
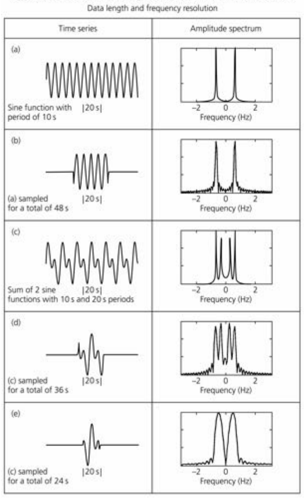


Figure 6.3-9: Effects of windowing time signals on the amplitude spectra.

Data length and frequency resolution



***f*(*t*) is a sine wave. What's the effect?**

Taking a finite length of record "smears" the delta functions of the infinite length record's spectrum into boader peaks with side lobes.

Input signals contains different frequencies

The frequency resolution, the minimum separation in frequency for which two peaks can be resolved, is proportional to the reciprocal of the total length.