EDDIE: Spectral Seismology

This module was initially developed by Soule, D. S., M. Weirathmuller, G. Kroeger, and R. Darner Gougis. 20 March 2017. EDDIE: Spectral Seismology. EDDIE Module 10, Version 1. https://cemast.illinoisstate.edu/data-for-students/modules/seismology.shtml. Module development was supported by NSF DEB 1245707.

Overall Description: This module that is based on a conceptual presentation of waveforms and filters. "Spectral Seismology" will engage students using seismic and acoustic signals available through Incorporated Research Institutes for Seismology (IRIS) in the manual manipulation of waveforms with the goal of developing students' ability to go beyond basic terminology. I hypothesize students completing "Spectral Seismology" will demonstrate:

1. The vocabulary needed to describe signals in the time and frequency domain
2. The ability to conceptualize a waveform as the sum of separate frequency components
3. The ability to relate a signal presented in the time domain to its conjugate in the frequency domain
4. The ability to use a signal presented in either the time or frequency domain to develop an analysis plan and choose an appropriate filter.

Pedagogical connections:

Phase	Functions	Examples from this module
Engagement	Introduce topic, gauge students' preconceptions, call up students' schemata	Reflection questions, short introductory lecture, in-class discussions
Exploration	Engage students in inquiry, scientific discourse, evidence-based reasoning	In class creation of seismic waves, constructing complex waves, downloading and analyzing seismic data
Explanation	Engage students in scientific discourse, evidence-based reasoning	In-class discussion, homework
Expansion	Broaden students' schemata to account for more observations	Application questions in the homework
Evaluation	Assess students' understanding, formatively and summatively	Suggested questions to ask during discussions, and the formulation of figure captions.

Learning Objectives:

- Develop the vocabulary needed to describe a seismic signal in both the time and frequency domain
- Use spectral information to formulate an analysis plan
- Demonstrate the ability to identify body and surface waves on seismic record.
- Demonstrate the ability to differentiate between seismic and acoustic signals

Resources used:

1. Smart phones with the application of a seismometer app.
2. Computer terminals with access to the Internet.

Activity A - what is an acoustic wave?

Seismic waves are acoustic vibrations that travel outward in all directions through the earth carrying the energy released during an earthquake much like the ripples on a pond. Take a moment and hold your hand to your throat and make the sound "AHHHHHHH". You should be able to feel your vocal chords vibrating. You are also able to hear the sound they make. How does the sound move from your vocal chords to your ears? When you make the sound "AHHHHHHH" your vocal chords are moving… and when they move they displace the nearby air molecules causing them to either be *compressed* or *dilated*. When your vocal chords vibrate they are basically moving back and forth, and every time they move, they disturb the air molecules nearest to them. The air molecules alternate between being crowded together (compression) or more spread out (dilation). Those nearby air molecules, in turn, disturb other air molecules and this continues in a sort of "domino effect" as the sound travels further from the source (your vocal chords!). In this manner the sound is able to *propagate* outward from the original disruption caused by your vocal chords to the eventual receiver, your ears. This is the same phenomena that you observe when you drop a pebble into a pond and watch the water ripples propagate outward from the spot where the pebble contacted the water surface.

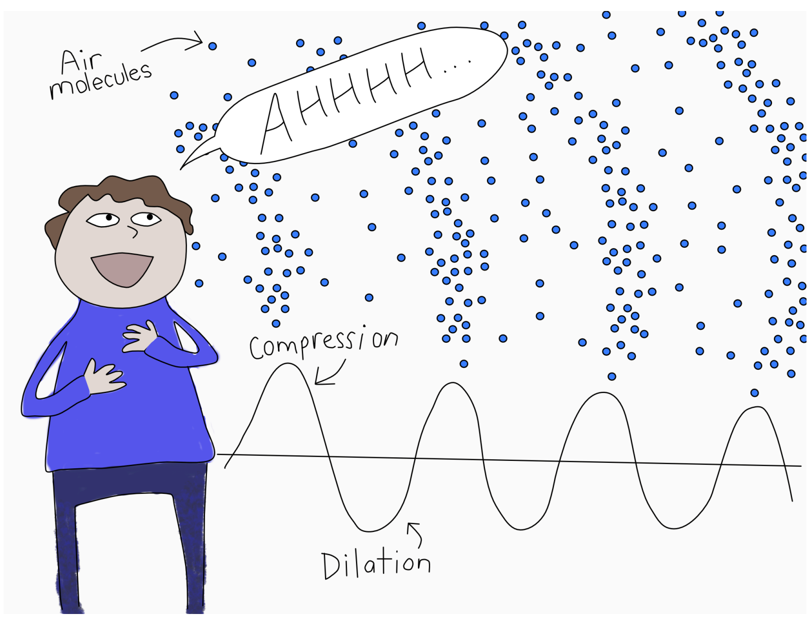


Figure 1. When you use your voice to make a sound, it causes the air molecules around you to compress and dilate, moving away from you in waves.

The sound you hear is a function of both the "pitch" of your voice and the volume you create. The exact same "ahhhhhhhh" can be quite different coming from someone with a deep "bass" voice than it would from a "soprano". Your "pitch" of the sound you hear is affected by how quickly your vocal chords oscillate. If you have a high-pitched soprano voice, your vocal chords will oscillate at a higher frequency (or number of oscillations per second) than they would if you had a low-pitched "bass" voice (Figure 2). The volume of the sound you make is a function of how forcefully you displace the air molecules adjacent to your vocal chords. A larger displacement ('ahhhhhhhh" vs. "**AHHHHHHH!!!!"**) correlates to a larger *amplitude* wave propagating outward from the source (Figure 2).

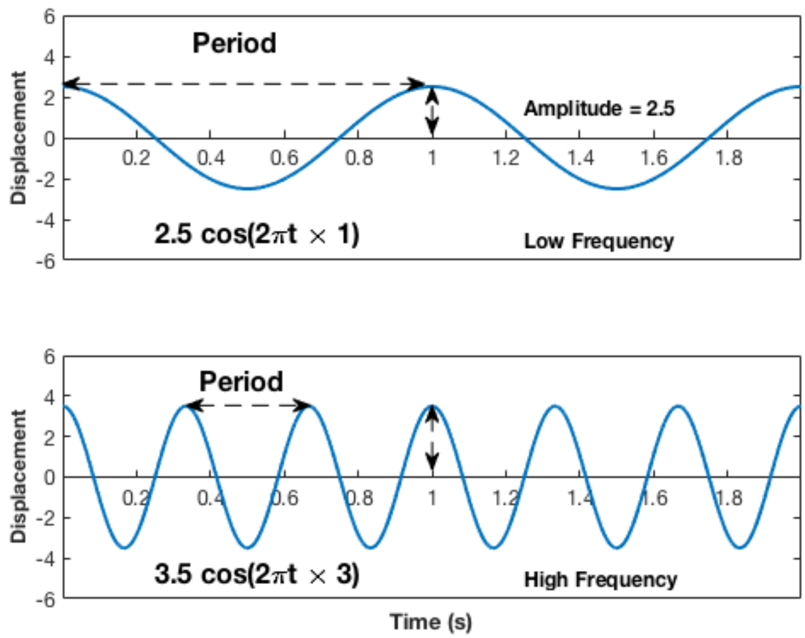


Figure 2. This figure plots cosine waves for two different frequencies and two different amplitudes. Time is on the horizontal axis, and displacement (or amplitude) is on the vertical axis. Any wave can be described as a function of its frequency and its amplitude using the general formula $A\cos(2\pi f)$ *in which the A represents the amplitude or vertical displacement of the wave and f equals its frequency. In panel (a) the "low frequency" wave can be described using the formula* $2.5\cos(2\pi \times 1)$ *in which the amplitude is 2.5 and the frequency is 1 Hz. In panel (b) the "low frequency" wave can be described using the formula* $3.5\cos(2\pi \times 3)$ *in which the amplitude is 3.5 and the frequency is 3 Hz. Comparing the two shows that the "period" or the amount of time required for one full oscillation is longer for the "low frequency" wave in panel (a) than for the "high frequency" wave in panel (b).*

What is an earthquake?

The earth's crust is not made up of a single continuous block of material – it is broken up into many pieces the can move around over time and can even crack or break. An earthquake happens when two blocks of crust suddenly slip past each other along a fault. When the earth ruptures like this, it causes a motion that displaces particles of the earth's crust just like we displaced the air with our vocal chords. The energy from this rupture propagates outwards from the event through the earth as a wave. This is why, even though an earthquake might occur miles below the earth's surface, it can be felt on the ground above it. The actual location of the earthquake is called the "focus", while the "epicenter" is the point on land directly above the focus (Fig 3).

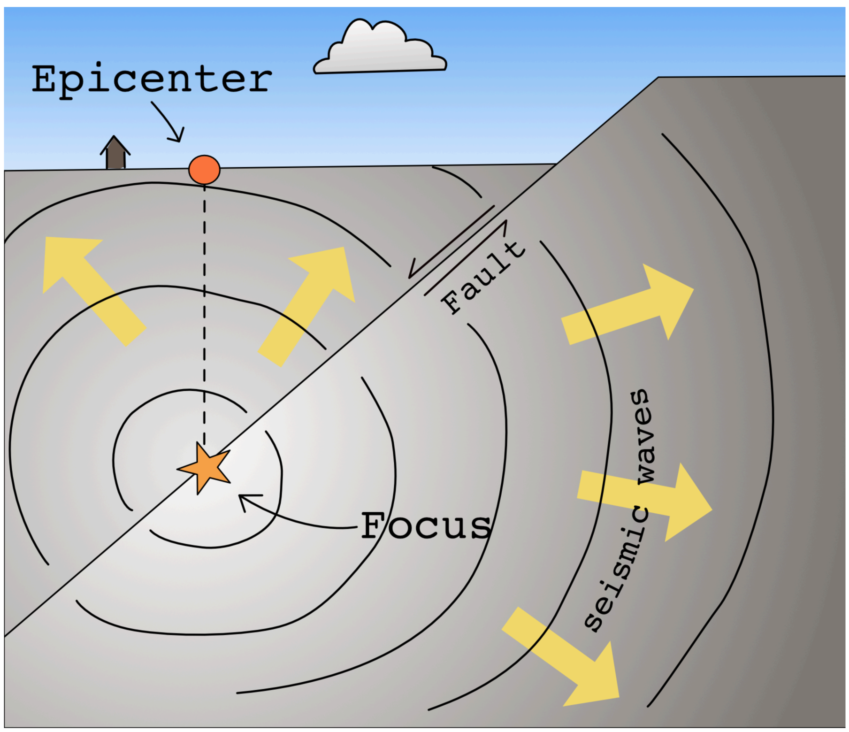


Figure 3. Seismic waves propagating outward from a rupture within Earth .

"*One of the most frightening and destructive phenomena of nature is a severe earthquake and its terrible aftereffects. An earthquake is a sudden movement of the Earth, caused by the abrupt release of strain that has accumulated over a long time. For hundreds of millions of years, the forces of plate tectonics have shaped the Earth as the huge plates that form the Earth's surface slowly move over, under, and past each other. Sometimes the movement is gradual. At other times, the plates are locked together, unable to release the accumulating energy. When the accumulated energy grows strong enough, the plates break free. If the earthquake occurs in a populated area, it may cause many deaths and injuries and extensive property damage.*" –USGS

Seismic Waves

Seismology is the study of earthquakes and seismic waves. When the earth is ruptured, energy is released and propagates in the form of seismic waves. Seismic waves that travel through the interior of the Earth called ***body waves*** and seismic waves that travel along the surface of the Earth called ***surface*** *waves*. *Body waves* travel through the earth with two types of motion, called *primary* and *secondary waves*. ***Primary waves*** are compressional waves whose direction of propagation is parallel to the direction of oscillation. The primary wave has the highest ***seismic velocity***; so on a seismogram it is the first arrival. ***Secondary waves*** are *shear* waves whose direction of propagation is perpendicular to the direction of oscillation. This is the second arrival and is characterized by lower *frequency* and a lower *velocity*.

Because body waves travel through the Earth's interior, they are primary tools for investigating Earth's properties.

Surface waves propagate along the surface of the Earth and they also have two primary types of motion: *Rayleigh* and *Love waves*. ***Rayleigh waves*** produce a particle motion that is both longitudinal and transverse with respect to the direction of wave propagation. ***Love waves*** create a particle motion that also oscillates transverse to the direction of wave propagation. On a seismogram these are characterized by very low *frequency* and large *amplitude*.

Because surface waves have high amplitudes and travel along the surface of the Earth they are what causes much of the damage commonly associated with earthquakes.

In this exercise we will examine seismic data from earthquakes that result from the rupture of faults located at the intersection of tectonic plates.

Seismometers

The ground motions from earthquakes can be measured at the earth's surface (or on the seafloor!) using an instrument called a seismometer (Figure 4). A simple seismometer that is only sensitive to up and down motions uses the principle of inertia, which states that a mass will remain stationary unless a force is applied to it. If we have a weight hanging from a spring[1], an earthquake would move the base and as the earth moves, the relative motion between the weight and the earth provide a measure of the vertical ground motion. A recording system can be made by attaching a rotating roll of paper to the base of the seismometer and a pen to the weight. As the paper moves up and down with the ground the stationary pen records the ground motion.

Instead of a pen and drum, modern seismometers use the electrical voltage generating by suspending a magnetic weight inside a coil of wire. Earth motion creates a voltage that is

[1] http://www.iris.edu/hq/inclass/fact-sheet/how_does_a_seismometer_work?zoombox=0

proportional to the amount of displacement and allows for easy data storage (no big roll of paper) and motion detection in three components.

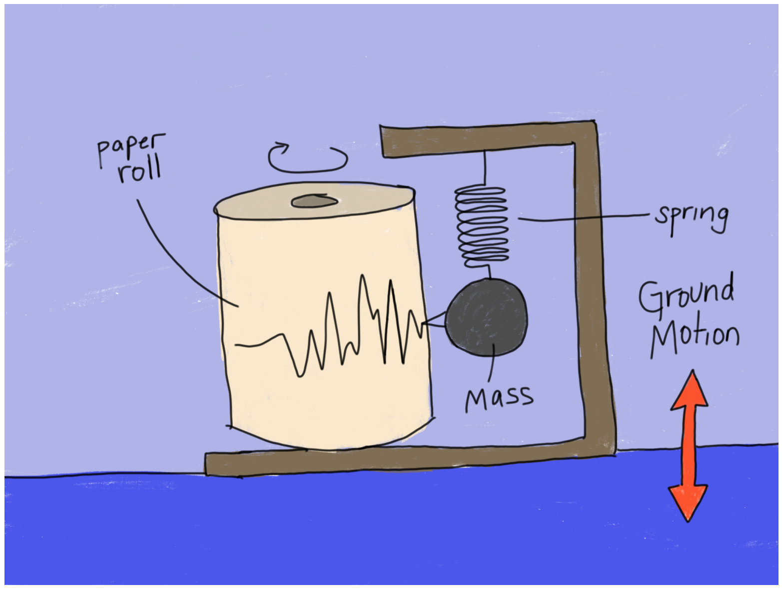


Figure 4. A simple seismometer

Take a moment and explore the concept of seismometers by downloading a free seismometer app to your phone. There are a number to choose from that will utilize the three component accelerometer in your phone. The iSeismometer app (or equivalent app on other platform) gives you the ability to view the seismograph (Figure 5).

Figure 5. You can turn your smartphone into a seismometer! Many smartphones have accelerometers built in that can detect vibrations similarly to a real seismometer.

Once you have it installed, put your phone on the floor or on a desk, and make a mini-earthquake by jumping up and down – you'll see the signal on your screen. Use the app to compare the response of the X Y and Z channels to the different types of ground motion. If you do not have a phone with this capability, work with one of your classmates who does or see your instructor.

Place the phone on your desk and make a sharp, vertical impact on the surface of the desk.

1. How does the Z component respond to your stimulus?

2. How do the x and y components respond to vertical motion?

3. Now do the same thing by exciting the two horizontal channels with a displacement in the horizontal plane. Take a moment to experiment and note how the different channels record the different types of motion.

Play with trying to create different frequency responses by oscillating the seismometer slowly in the vertical plane until you have a predictable waveform and see how you can make this waveform vary as a function of how fast you oscillate the seismometer. Sketch two figures that show how this is sketch two figures based on what you see on your app, one showing higher frequency oscillations and one showing lower frequency oscillations.

What does seismic data look like?

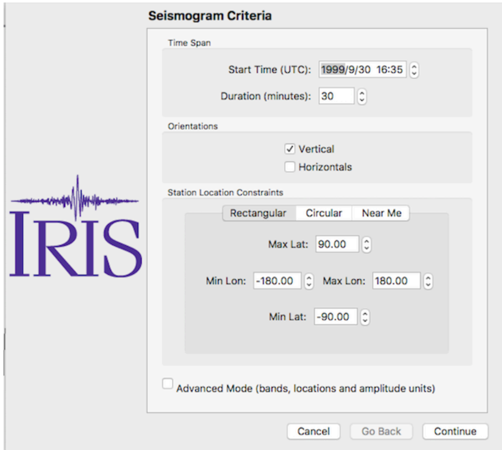
In this section we will use software called Seismic Canvas that allows you to import seismic data, plot it up and do basic analysis.

Full explanation for how to set up Seismic Canvas:
For now this is housed in my Dropbox. We will need to post it on our site and perhaps link to where this will be come available through IRIS.
Seismic Canvas for a Mac:
Seismic Canvas For Mac

Seismic Canvas for a PC:
Seismic Canvas for PC

Once you have installed and opened Seismic Canvas we are ready to look at some data. Lets import a big Earthquake and take a look. Starting with a blank Seismic Canvas, import data by using the IRIS icon .

When you select you will be given a dropdown menu:



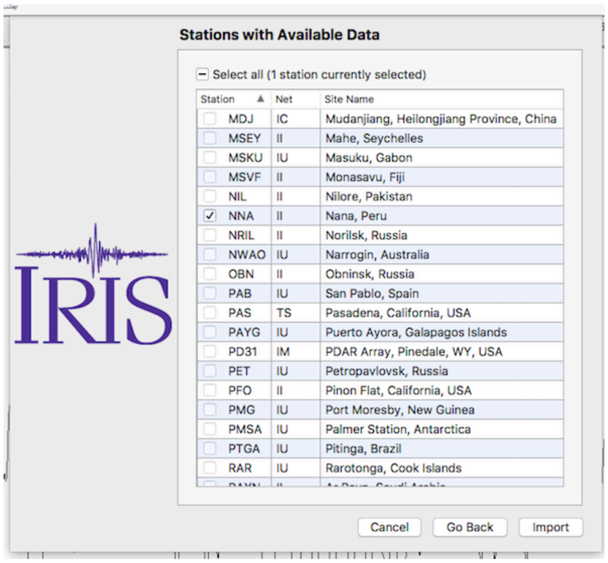
The event we want to look at occurred…

Advanced Mode: **yes**
Start time: 1999/09/30 16:35:00 (This will be the UTC time for your event)
Duration (minutes): 30
Check Vertical Only
Select "Continue"

Advanced Criteria:
Defaults should be set as follows
Broadband: yes
Amplitude Values: Raw Counts
Locations: Primary Location Only

On the next page you will be able to select the network.
Networks
Network: **GSN (Global Seismic Network)**

On the next page you will be given a list of stations with available data. Find the station site at Nana, Peru (NNA)
Select it by **checking the NNA box**.



Once you have found your station select **Import**. The seismogram you import should look like this:

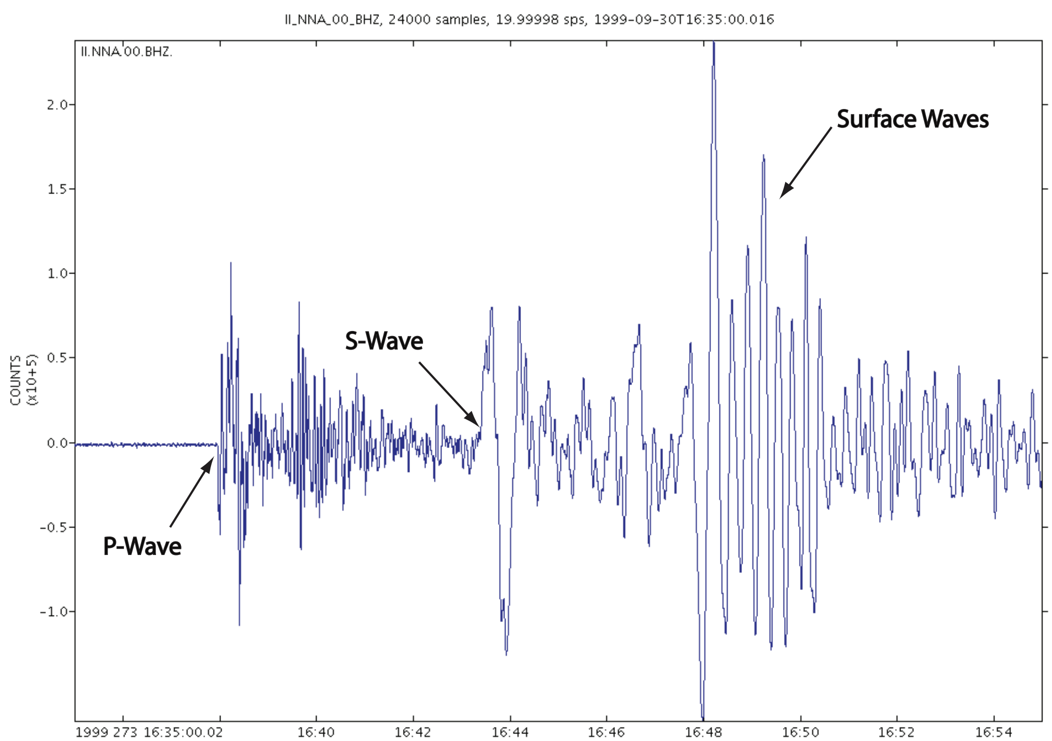


Figure 4. This is the timeseries data from a large earthquake recorded on station II_NNA_00_BHZ from the 30th of September 1999. Note that the P-Wave is the first seismic arrival followed by the S-Wave and finally the high-amplitude surface waves.

Time (minutes)

Let’s explore the tools along the left hand side and across the top of the window that Seismic Canvas makes available.

1. Use the picking tool (bottom most icon on the left hand side (LHS) ) to identify the primary and secondary arrivals. Note that the exact time of your pick is displayed below the plot window in the “Analysis Output” area.
    a. What time does the P-Wave arrive? _______

    b. What time does the S-Wave arrive? _______

    c. What time is the highest amplitude arrival? _______

2. Use the time measurement tool (Second from the bottom on the LHS ) to calculate the time difference between the primary and secondary arrivals. Note that the time difference is recorded in the “Analysis Output” area.

3. Since the P-waves, S-waves and Surface waves all originate at the same moment; what does the order of these arrivals tell you regarding their relative speed of travel through the Earth?

4. Stretch your timeline (fifth icon from the right across the upper tool bar ) so that you are able to estimate the frequency of the primary arrivals and the secondary arrivals. Remember that frequency is equal to the number of oscillations in a given unit of time (frequency = oscillations/time).
    a. Estimate the frequency of the P-wave by 10 seconds of data and counting the major oscillations. Do the same for the S-wave and the Surface wave.
        i. P-wave frequency ________
        ii. S-wave frequency ________
        iii. Surface wave frequency _______

b. Compare the frequency and amplitude content of these seismic arrivals to the frequency and amplitude content in the simple waves we examined in Figure **2**. Note that the different parts of the arrival have distinctly different frequencies. Also note that the seismic signal you observe is never a simple waveform like the synthetic arrival in Figure 1. Please examine the P-wave arrival closely and think of an explanation as to why the signal is so complex by comparison.

5. Compare the amplitude of the P-Wave and the S-Wave to the amplitude of the Surface arrivals.

6. Write a figure caption that describes the seismogram.

Activity B - The Fast Fourier Transform

In Activity A we compared synthetic waveforms that were each comprised of a single frequency and amplitude (Figure 2) to the much more complex signal of an earthquake (Figure 6) and determined that the seismic arrival contained many frequencies. Let's explore that.

Note that when we examined the seismogram we considered how the frequency content changed with each successive seismic arrival (Figure 4). The P-wave is characterized by higher frequencies and lower amplitudes. The S-wave is characterized by generally lower frequencies and higher amplitudes. Think for a moment about what happens to the P-wave when the S-wave arrives… did that higher frequency information just stop?

What is difficult to see by just looking at the seismic arrival is that the lower frequency wave that you observe when you look at the S-wave arrival is actually the SUM of both the propagating P-wave and the propagating S-wave. In fact; most signals in nature are the sum of many simple sine or cosine waves. Consider the wave forms in Figure 2, each is made up of a single component with a discreet frequency and amplitude. If we combine both of these wave forms mathematically it would look like this:

$$2.5\cos(2\pi \times 1) + 3.5\cos(2\pi \times 3)$$

Which would result in a plot that looks like:

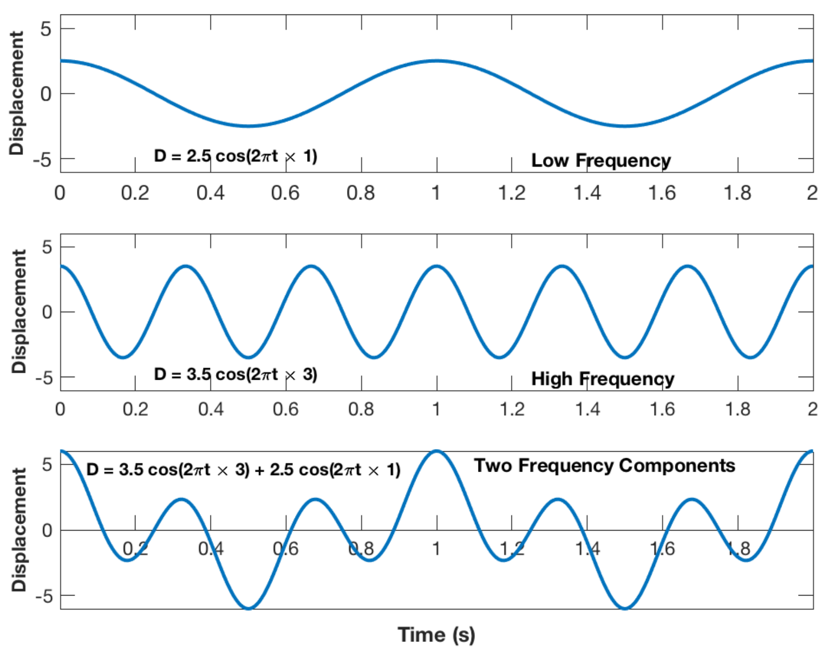


Figure 7. The upper panel shows the low-frequency signal, the middle panel shows the high-frequency signal, and the lower panel shows the sum of the two signals.

Open a web terminal and visit this URL:

MichJW's Amazing Waveform Widget

This web tool will allow you to enter the frequency and amplitude and plot a waveform. It will allow you to save a .png file with the image for your report.

1. Use the widget to plot displacement vs. time for this wave form:

$$d(t) = 3.5 \times \sin(2\Pi t \times 1)$$

amplitude frequency

This formula describes a waveform with amplitude of 3.5 and a frequency of 1 Hz. When you plot chunk of data in the time domain with time along the x-axis and amplitude along the y-axis you will see that you have a simple sine wave (top panel). Another way plot this same data would be to convert it from the time domain to the frequency domain and plot with frequency along the x-axis and amplitude on the y-axis (bottom panel). This is done using a Fast Fourier Transform (FFT), which uses an algorithm to decompose any waveform into its discrete frequency components. (The math it takes to calculate an FFT is beyond the scope of this exercise, but if you would like to explore the mathematical underpinning of this lesson, a great explanation is available here: http://www2.ocean.washington.edu/oc540/lec01-12/. In this case because we only have a single frequency (1Hz) and 1 amplitude (Hz) component the corresponding plot in the frequency has a single peak.

Consider the information you are conveying graphically in the plot you just made. In the time domain you plot time along one axis and then amplitude or displacement along the other axis. Frequency information is visible in the lower frequency domain plot, but for this simple waveform it would be easy to get frequency simply by counting the number of oscillations in a given period of time. When you move from plotting the simple synthetics of Figure 2 and Figure 7 to natural signals like what you observed in Figure 6 it becomes much more difficult to quantify the frequency components. Our goal is to understand how the data we are accustomed to viewing in the ***time domain*** would appear in the ***frequency domain*** and how we can use this information to make decisions about how to best analyze any signal of interest.

If we use an FFT we can plot the frequency spectrum of the simple time series signal shown in Figure 8. Since this is a simple signal with only one frequency component, the frequency spectrum (FFT) plot is simple (Figure 9).

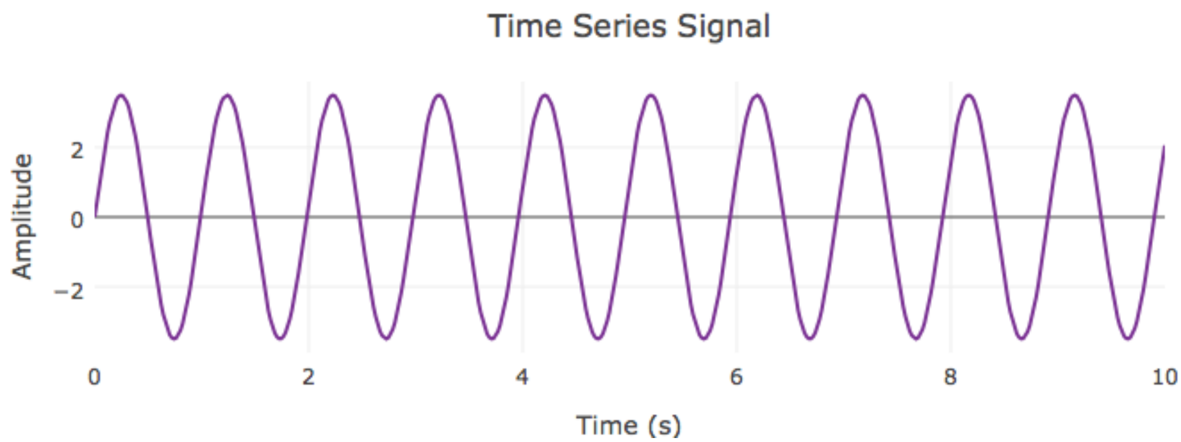


Figure 5. Plots the sine wave $d(t) = 3.5\times sin(2\Pi t)$ with an amplitude of 3.5 and a frequency of 1 Hz in the time domain ..

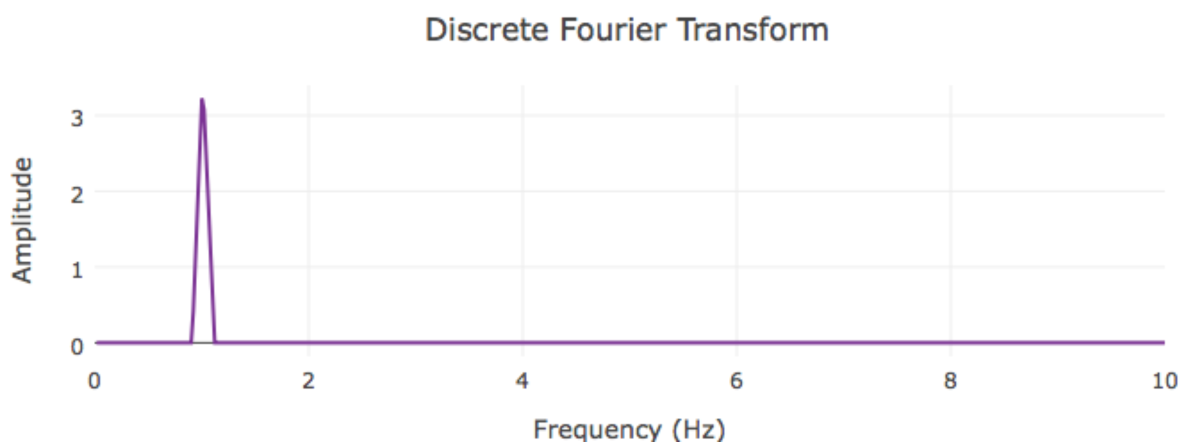


Figure 6. Plots the frequency spectrum of the data used in Figure 8

Use the widget experiment by varying the amplitude and the frequency so you can see how the representation of a sine wave plotted in the time domain relates to it's representation in the frequency domain.

Make a figure (using the .png output of the widget) that shows a simple sine wave and write a caption that describes both panels. State the amplitude and frequency for your sine wave, and include the full formula. Describe the axes on both plots.

2. Since most waveforms are not composed on just a single frequency component. Most waveforms are a summation of many individual frequency components.

   Now let's add some complexity:

   a. Use the widget to define a more complex waveform by adding a second frequency component.

$d(t) = 3.5\times \sin(2\Pi t) + 2.0\times \sin(2\Pi t 2)$ – Is the waveform plotted below with the first frequency component having an amplitude of 3.5 and a frequency of 1 Hz. The second frequency component has an amplitude of 2 and a frequency of 2 Hz.

b. Plot the time and frequency domain graphs so that you can see how the original waveform evolves as we add complexity.

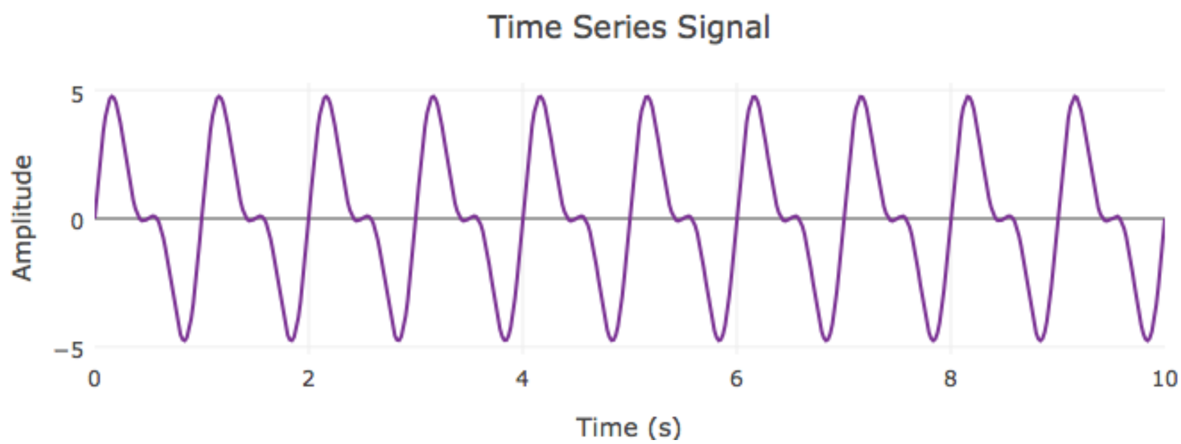


Figure 7. Two-component time domain

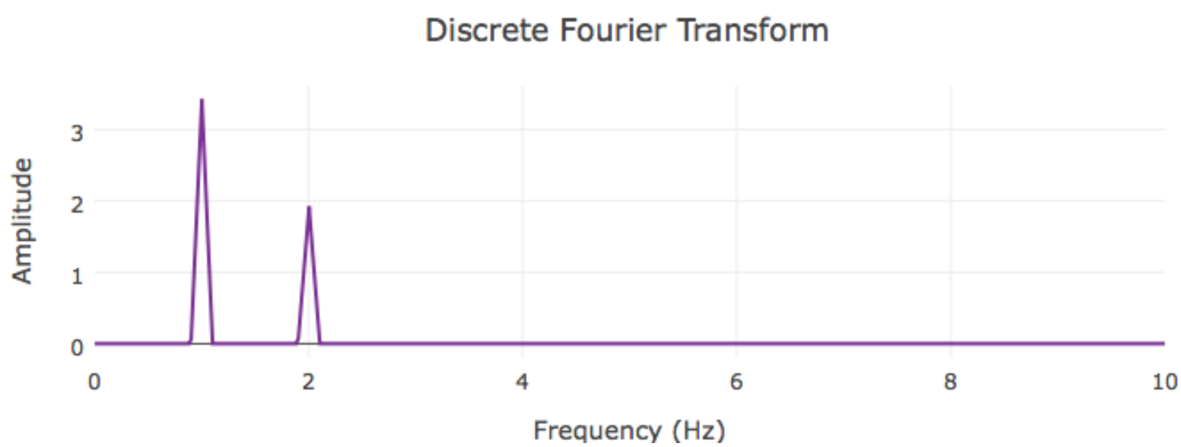


Figure 8. Two-component frequency domain

c. Use the widget to vary the amplitude and the frequency of the second frequency component so you can see how the representation of a sine wave plotted in the time domain relates to its representation in the frequency domain.

d. Make a figure that shows a two-component sine wave and write a caption that describes both panels. State the amplitude and frequency for your sine wave, and include the full formula. Describe the axes on both plots.

3. Now let's add some more complexity:
   Use the widget to define more complex waveform by adding a third frequency component.

   a. $d(t) = 3.5\times \sin(2\Pi t) + 2\times \sin(2\Pi t2) + 5\times \cos(2\Pi t0.5)$ – Plot a third graph showing this final evolution of our synthetic wave form.

   And in the frequency domain it our new composite waveform would look like:

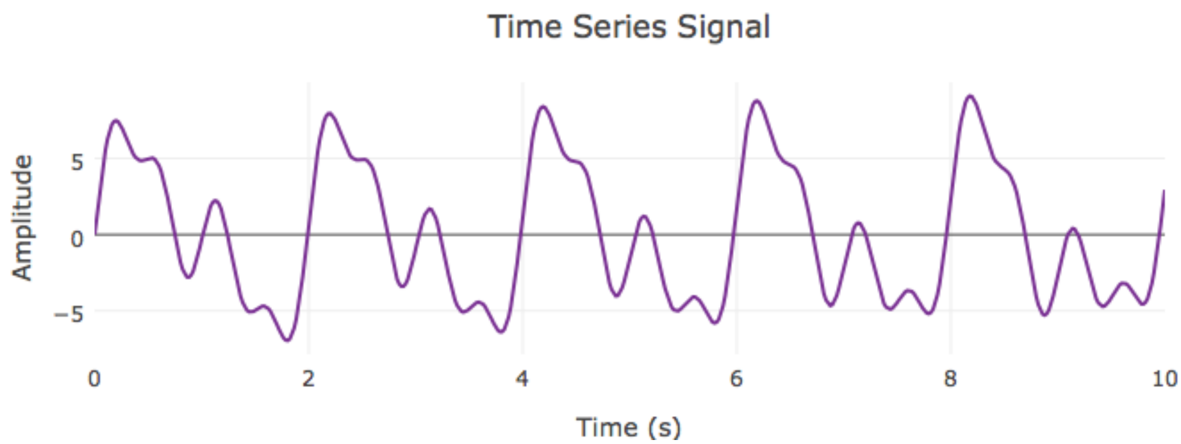


Figure 9. Three components in the time domain.

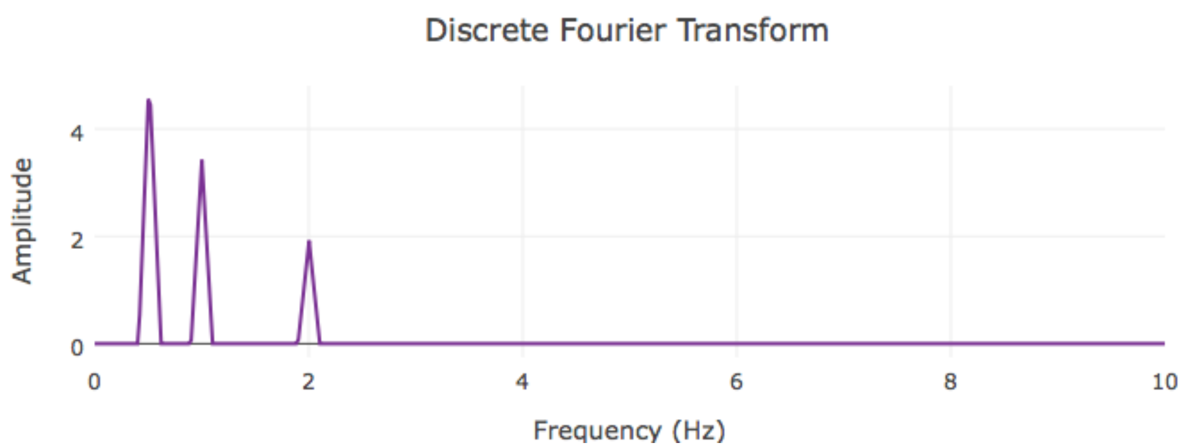


Figure 10. Three components in the frequency domain

   b. Use the widget experiment by varying the amplitude and the frequency of the third frequency component so you can see how the representation of a sine wave plotted in the time domain relates to it's representation in the frequency domain.

   c. Make a figure that shows a three-component sine wave and write a caption that describes both panels. State the amplitude and frequency for your sine wave, and include the full formula. Describe the axes on both plots

Filters

The frequency domain can also be used to take a complex signal and remove information that obscures the signal of interest. Three commonly used filters are the "low pass", "band pass" and "high pass". Looking at our three-component synthetic signal from the previous section:

1. If your signal of interest were the 2 Hz portion of this synthetic waveform, a ***high pass filter*** could be used to isolate this frequency component by "cutting" all the spectral information below 1.5 Hz. Take the formula and modify it so that you only plot the frequency context below 0.05 Hz.

2. If your signal of interest were the 0.5 Hz portion of this synthetic waveform a ***low pass filter*** could be used to isolate this frequency component by "cutting" all the spectral information above .75 Hz.

3. If your signal of interest were the 1 Hz portion of this synthetic waveform; a ***band pass filter*** could isolate this frequency component by "cutting" all the spectral information below 1.5 Hz and above .75 Hz.

Appling filters to Seismic Data

Lets apply a filter to the earthquake signal.

Advanced Mode: ***yes***

Start time: 1999/09/30 16:35:00

Duration (minutes): 30

Check Vertical Only

Amplitude Values: Raw Counts

Network: **GSN (Global Seismic Network)**

NNA

1. Choose the selection arrow icon (top icon on the left hand side) and click on your time series plot to select it. Once it's selected, apply a filter to the data (Process->Filter).
    a. Start with a "low pass" filter. The default setting passes data with a period below 5 seconds. It is important that you can describe a filter using either the frequency in Hz or the wavelength in seconds. Take a moment to explore this relationship by changing the default seconds to Hz using the "show details" button.
        i. What this filter is doing in terms of the frequencies it allows to pass?
        ii. Adjust your settings to pass frequencies less than 1 Hz.
        iii. Save this as a .pdf and write a caption answering the above question.
    b. Reset your image to show the raw data (Process-> Revert to original).

2. Plot the spectra from this earthquake by applying an **FFT** to the data.
    a. Go to (Process->Plot spectra for selection)
    b. The FFT uses an algorithm to take this time series and sum the energy within each frequency band. The figure this creates plots power along the y-axis and frequency along the x-axis. As you might expect from your visual inspection, the

majority of the energy from an earthquake is below one Hz. Real earth sources occur over a much broader range of frequencies.

Note that the FFT is plotted using a logarithmic scale that shows frequencies ranging from 10^{-1} Hz to 10^{1} Hz. A logarithmic scale is a non-linear scale that is useful for showing a wide range of quantifies. Another way to express this same range would be to set the range from 0.1 Hz to 10 Hz.

Activity C – The Spectrogram

Taking the FFT of the entire signal will show us the frequency content over the entire time period. Taking the FFT over a short period of time will give us a local snapshot in time of the frequency content of the signal during that short time period, but it would be much more useful if you could examine a snapshot like this in context with the rest of the data in your time series.

A spectrogram does exactly this. It compiles the FFT for the whole time series in discrete time steps and plots frequency along the y-axis, time on the x-axis and uses a color to display the amplitude information.

Go to your seismic canvas window and load this earthquake signal:
Advanced Mode: yes
Start time: 1999/09/30 16:35:00
Duration (minutes): 30
Check Vertical Only
Amplitude Values: Raw Counts
Network: **GSN (Global Seismic Network)**
Station: **NNA**

1. Plot the time series and use the selection tool to select only the P-Wave portion of the data
2. Now plot the spectrogram. Go to (Process->Plot spectrogram for selection).

    a. *Write a caption that describes the spectrogram plot. What are the axes? Compare the spectrogram to the seismogram and the FFT that you made in activity B. Describe how each figure expresses time, frequency and amplitude.*

In the seismogram we plot time vs. amplitude. The frequency information is there, but difficult to interpret except in the broadest of terms. It is easy to spot areas of high and low frequency, but quantifying that would be difficult (Slide 27). The FFT plots frequency vs. amplitude but does not give you any ability to address the timing of different frequency components (Slide 28). The spectrogram gives us all the information in one plot. Time on the x- axis, frequency on the y-axis and amplitude given using the color map (Slide 29).

In what frequency range is most of the energy for this signal (hot colors will correlate to large amplitudes and cool colors will correlate to less energetic components)?

3. Leave your spectrogram window open and compare it to the spectrogram for the portion of the signal that contains the secondary arrivals and the surface waves. Use the selection tool to select the time period between 1999/09/30 16:43:22.482 and 1999/09/30 16:50:45 and create a second spectrogram. Set the two spectrograms side by side on your screen and use the mouse to adjust their scales so that the y-axes match.

How does the frequency information in this portion of the compare to what you plotted from the Primary arrival?

Signal Identification

The frequency domain is a powerful tool that can help identify different types of signals in sometimes extremely large amounts of data. Consider the data on an ocean bottom seismometer that has recorded ground motion for a year. If the signal you are interested in has a known frequency, the spectrogram can be used to identify the portions of the time series that contain data.

Now let's use what you have learned to explore a different types of signal recorded on an ocean bottom seismometer by Neptune Canada.

Go to your seismic canvas window and load this time series:
Advanced Mode: yes
Start time: 2012/02/27 01:00:00
Duration (minutes): 10
Channel: High Broadband;
Amplitude Values: Raw Counts
Select "Continue"
Network: NV (Neptune Canada ~ This is one of the regional networks, so select "more networks")
Station: NC27
Location: --
Filters: none

1. Use the plot output option to generate **a figure**.

a. What do you see? Write a caption that describes this signal in the time domain. Does this look like an earthquake? Do you see any signal that you would like to investigate?

2. Now let's look at this in the frequency domain. Create the FFT (edit-> Select all; Process -> Plot frequency spectrum for the selection. Each FFT you have produced for an earthquake had very little energy over 1 Hz. How does this compare to what you observe in this FFT?

   What you should see is that you have two peaks in power that represent the whole signal. The peak around 20 Hz is our signal of interest and the second peak is all the low frequency earth noise in the background signal. Because the frequency content in our time series varies with time it would be great if we had a better tool to analyze how this occurs.

3. Now plot the spectrogram for the section. Write a caption that describes the areas of the spectrogram where you observe a signal. In which frequency bands to you observe high amplitude information? Relate this to what you observed in the FFT for the same data.

4. The signal of interest if pretty visible when observed in either the FFT or the spectrogram. Why is it difficult to see in the time series?

   In this case the amplitude of the 20 Hz signal of interest is very low amplitude compared to the "background noise". The 20 Hz signal is there… you just can't easily see it.

5. Return to the seismogram and investigate the nature of this signal. Use the tool bar to stretch the time axis until you are displaying ~10 seconds of data on your screen.

    i. How long does each of these signals last?

    ii. What you are looking at is a fin whale call recorded on a seismic network. Can you identify a dominant frequency?

6. Reflect – Write a brief paragraph that summarizes what you have learned about earthquakes, seismic waves, the time domain, and the frequency domain.