Homework 2:

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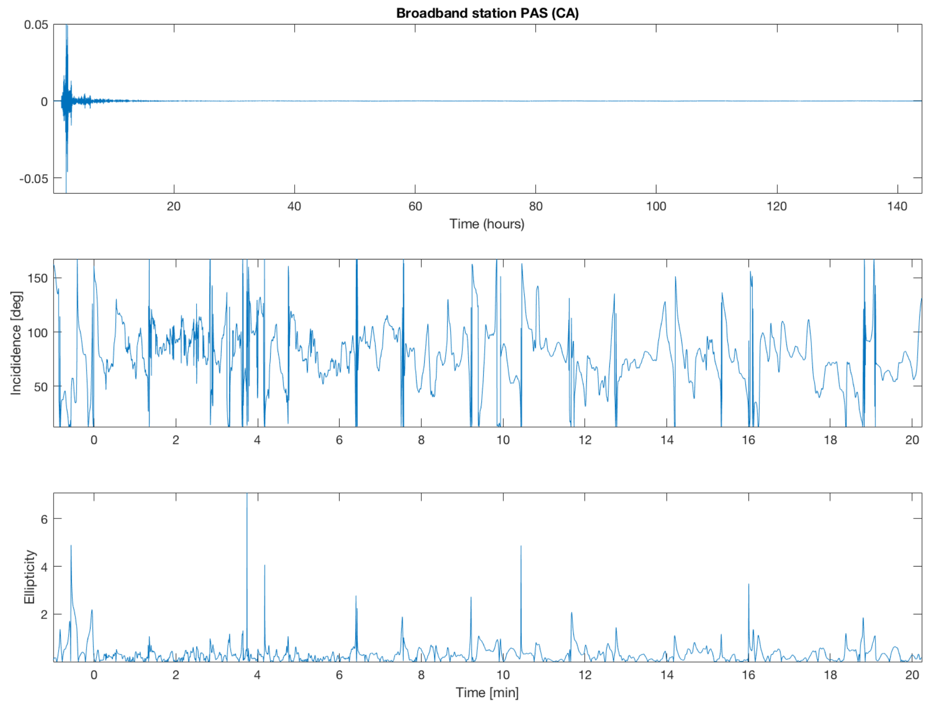
Normal mode observations, Polarization analysis and component rotation Rebekah Lee Due 2/13/17

Part 1 Normal Mode Observations

1.1 Plot the raw time series; use dimension hours on the time axis

```
% Load the data
load('sumatra.txt')
sumatra = sumatra(1:end-1);
% create the time vector
n = length(sumatra);
dt = 10; %seconds
t = 1:dt:n*10; % time in seconds
t = t./3600; %time in hours

% plot the raw data
figure(1);
plot(t,sumatra)

title('Broadband station PAS (CA)')
xlabel('Time (hours)')
axis tight
```



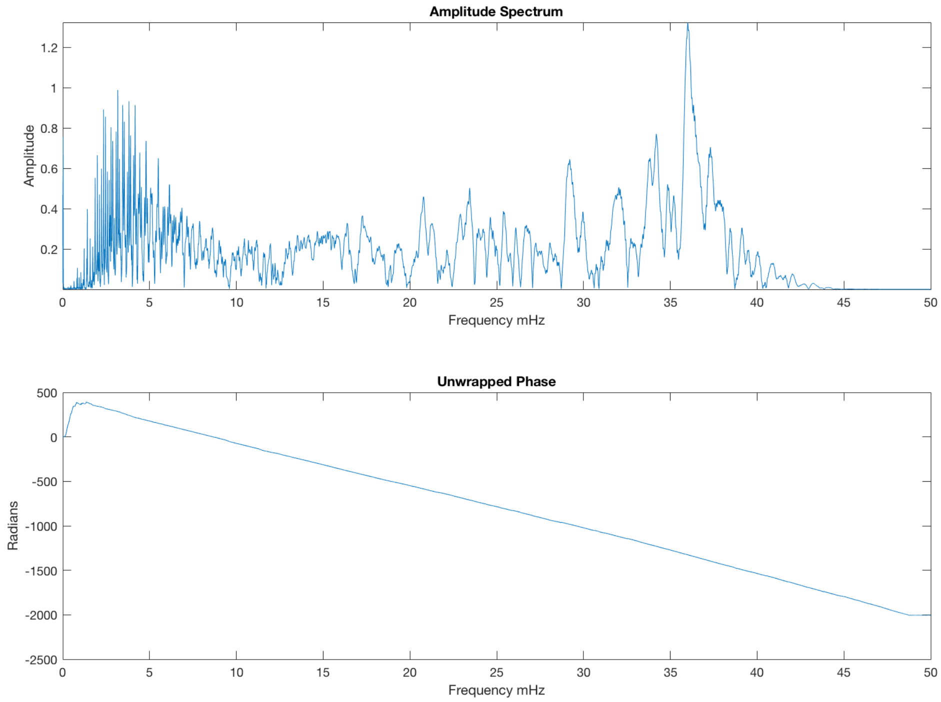
1.2. Fourier transform the time series and plot amplitude and unwrapped phase spectra; use dimension mHz on the frequency axis

```
fs = .1; %Hz
fs = fs*1000; % sampling frequency in mHz
nyq = fs/2; % [mHz]

% frequency vector
freq = linspace(0,nyq,n/2+1); % [mHz]
freq2 = freq*1000; %micro hertz

% fft
Y = fft(sumatra);
Amp = abs(Y);
Amp = Amp(1:n/2+1);
phase = angle(Y);
phase = unwrap(phase(1:n/2+1));
```

Plot Amplitude Spectrum and Phase

```
figure(2)
subplot(2,1,1)
plot(freq,Amp)
xlabel('Frequency mHz')
title('Amplitude Spectrum')
ylabel('Amplitude')
axis tight
```

```
subplot(2,1,2)
plot(freq,phase)
xlabel('Frequency mHz')
ylabel('Radians')
title('Unwrapped Phase')
```



1.3 The nyquist frequency is .05 Hz or 50 mHz

1.4 Identify Normal Modes

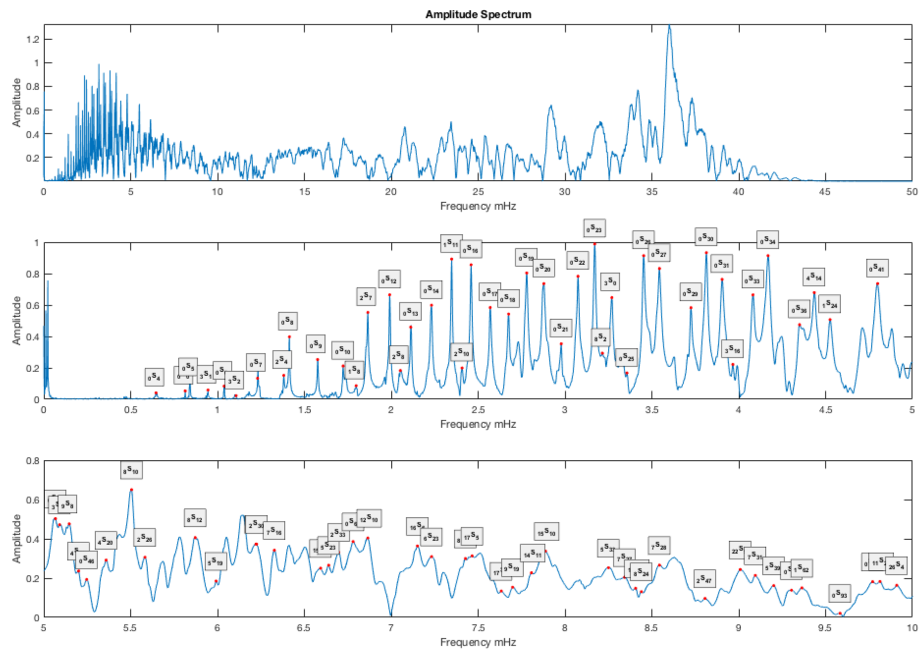
```
% mode locations
mloc =
 [646.2,814,841,945.2,1038,1107,1231,1381,1414,1576,1723,1798,1865,...

 1991,2052,2112,2232,2348,2407,2459,2569,2676,2780,2878,2978,3075,3171,...

 3216,3270,3356,3453,3544,3725,3814,3904,3966,4082,4169,4350,4435,4525,...

 4799,5068,5091,5147,5201,5247,5359,5505,5583,5872,5992,6221,6225,6327,...

 6593,6640,6698,6780,6865,7151,7232,7427,7465,7633,7699,7807,7888,8250,...

 8343,8407,8439,8544,8806,9008,9095,9201,9304,9363,9583,9770,9813,9909]; %in
 microhertz
mloc = mloc./1000; % in mHz

% Find index number for frequencies located during manual inspection
nmodes= length(mloc);
idx= zeros(nmodes,1);
```

```
for imode =1: nmodes
    [~,idx(imode)] = min(abs(freq-mloc(imode)));
end

% mode labels
mlabels=
 {'_0S_4','_0S_0','_0S_5','_3S_1','_0S_6','_3S_2','_0S_7','_2S_4'...
    ,'_0S_8','_0S_9','_0S_{10}','_1S_8','_2S_7','_0S_{12}','_2S_8',...

  '_0S_{13}','_0S_{14}','_1S_{11}','_2S_{10}','_0S_{16}','_0S_{17}',...

  '_0S_{18}','_0S_{19}','_0S_{20}','_0S_{21}','_0S_{22}','_0S_{23}',...

  '_8S_{2}','_3S_0','_0S_{25}','_0S_{26}','_0S_{27}','_0S_{29}','_0S_{30}',...

  '_0S_{31}','_3S_{16}','_0S_{33}','_0S_{34}','_0S_{36}','_4S_{14}',...

  '_1S_{24}','_0S_{41}','_0S_{44}','_3S_{23}','_{9}S_{8}','_{4}S_{19}',...

  '_{0}S_{46}','_{4}S_{20}','_{8}S_{10}','_{2}S_{26}','_{8}S_{12}','_{5}S_{19}'...

 ,'_{16}S_{3}','_{2}S_{30}','_{7}S_{16}','_{15}S_{6}','_{5}S_{23}',...

  '_{2}S_{33}','_{0}S_{63}','_{12}S_{10}','_{16}S_{6}','_{6}S_{23}',...

  '_{8}S_{10}','_{17}S_{5}','_{17}S_{7}','_{9}S_{19}','_{14}S_{11}','_{15}S_{10}'.

 ,'_{5}S_{33}','_{7}S_{27}','_{12}S_{15}','_{8}S_{24}','_{7}S_{28}',...

  '_{2}S_{47}','_{22}S_{5}','_{7}S_{31}','_{5}S_{39}','_{0}S_{90}','_{1}S_{62}'...
    ,'_{0}S_{93}','_{0}S_{95}','_{11}S_{25}','_{26}S_{4}'};
```

Plot Normal Modes

```
figure(3);
% plot fft
subplot(3,1,1)
plot(freq,Amp)
xlabel('Frequency mHz')
title('Amplitude Spectrum')
ylabel('Amplitude')
axis tight


% Identify Modes
subplot(3,1,2)
plot(freq,Amp)
hold on
plot(freq(idx(1:42)),Amp(idx(1:42)),'.r')
xlim([0,5])
text(freq(idx(1:42)-24),Amp(idx(1:42))+.1,mlabels(1:42),'fontweight','bold','EdgeC
[.94 .94 .94],'fontsize',7,'FontName','Arial')
xlabel('Frequency mHz')
ylabel('Amplitude')
```

```
subplot(3,1,3)
plot(freq,Amp)
hold on
plot(freq(idx(42:end)),Amp(idx(42:end)),'.r')
xlim([5,10])
text(freq(idx(43:end)-24),Amp(idx(43:end))+.1,mlabels(43:end),'fontweight','bold',
[.94 .94 .94],'fontsize',7,'FontName','Arial')
xlabel('Frequency mHz')
ylabel('Amplitude')

set(gcf,'Position',[190 50 1141 740]);
```



1.5 Discrepancies between table by Masters and Ridmer Some of the peaks in the Sumatra data were not included in the table from Masters and Ridmer while others were missing. The table in Masters and RIdmer is a result of several methods to determine degenerate frequency including correcting the signal from 3-dimensional structure. This could account for some of the frequencies being off by a few hertz from what was in the table. Also the amplitude of each peak depends on the source and whether that source excited a mode or not. Some of the missing modes may be due to the modes not being excited. Additionally, for low frequencies many of the fundamental modes were present with few of the overtones. In the paper Masters and Ridmer explained that large earthquakes excite longer wavelengths and that unless the earthquake is very deep the fundamental modes dominate the spectra. The higher frequency modes show more of the overtones. Since higher frequencies correspond to smaller depths it makes sense that there would be more overtones because they are not overshadowed by the shorter frequency fundamental modes.

1.6 Highest frequency normal mode

The highest frequency normal mode I found was _26S_4 at about 9.9 mHz. Attenuation affects limit the maximum normal mode frequencies we can observe. At great distances (like the california station) higher frequencies attenuate. This is the alpha_k term in Master and Ridmer which is the decay rate of the kth mode.

Part 2

*2.1 Download Data from IRIS. *

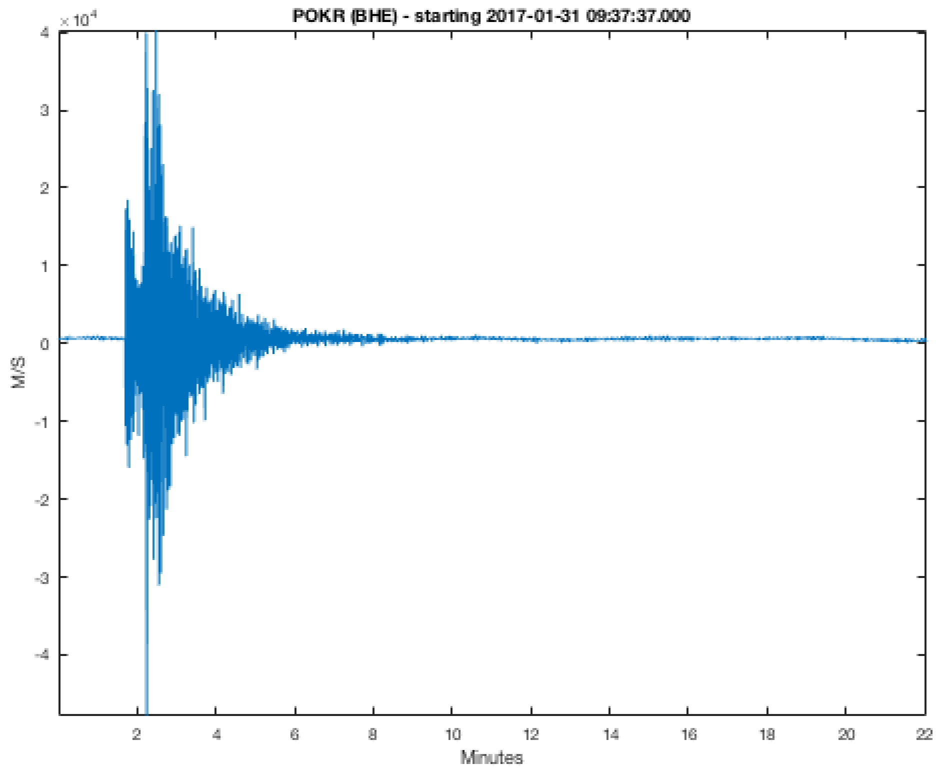
```
ds = datasource('irisdmcws');
% POKR -----------------------------------------
startTime = '2017/01/31 09:37:37';
endTime = '2017/01/31 09:59:40';

% E component
ctags = scnlobject('POKR', 'BHE', 'TA', '--');
POKR_E = waveform(ds, ctags, startTime, endTime);

% N component
ctags = scnlobject('POKR', 'BHN', 'TA', '--');
POKR_N = waveform(ds, ctags, startTime, endTime);

% vertical component
ctags = scnlobject('POKR', 'BHZ', 'TA', '--');
POKR_Z = waveform(ds, ctags, startTime, endTime);

%Purkeypile,AK -----------------------------------
startTime = '2017/01/31 09:37:37';
endTime = '2017/01/31 09:58:51.000';

% East
ctags = scnlobject('PPLA', 'BHE', 'AK', '--');
PPLA_E = waveform(ds, ctags, startTime, endTime);

% North
ctags = scnlobject('PPLA', 'BHN', 'AK', '--');
PPLA_N = waveform(ds, ctags, startTime, endTime);

% vertical
ctags = scnlobject('PPLA', 'BHZ', 'AK', '--');
PPLA_Z = waveform(ds, ctags, startTime, endTime);
```

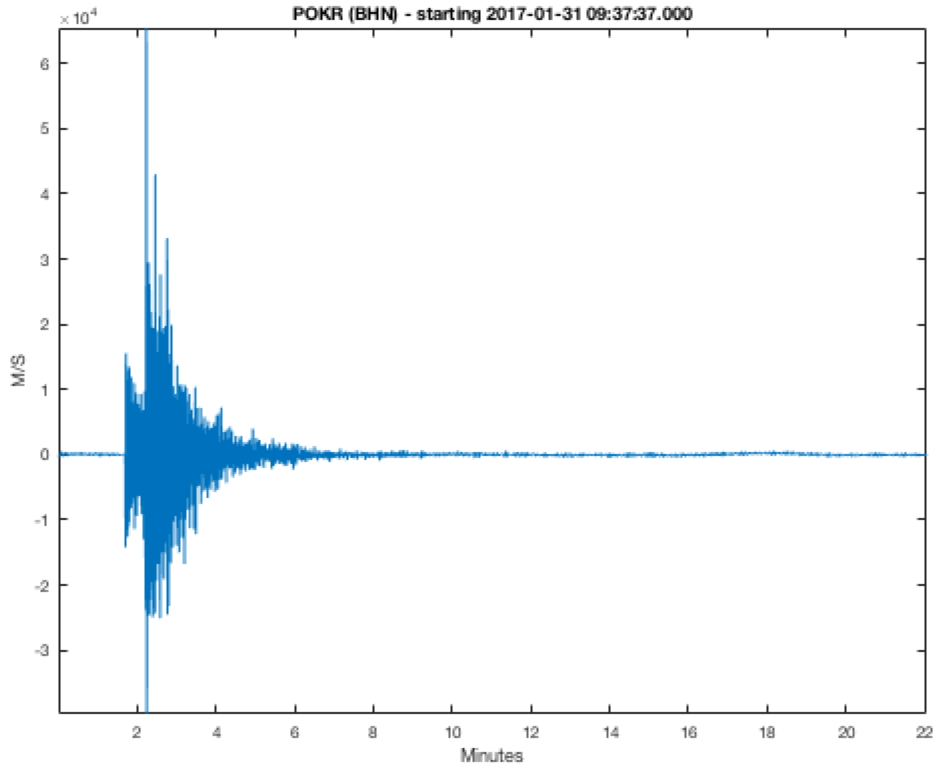
```
Requesting Data from the DMC...
Requesting Data from the DMC...
Requesting Data from the DMC...
Requesting Data from the DMC...
Requesting Data from the DMC...
Requesting Data from the DMC...
```

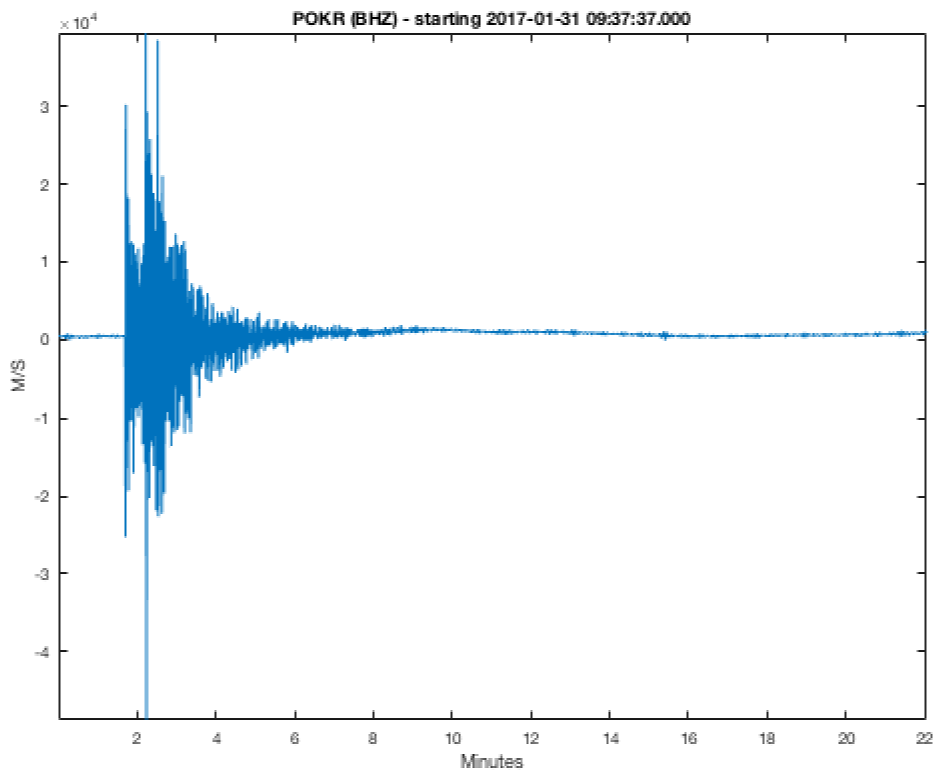
plot the data

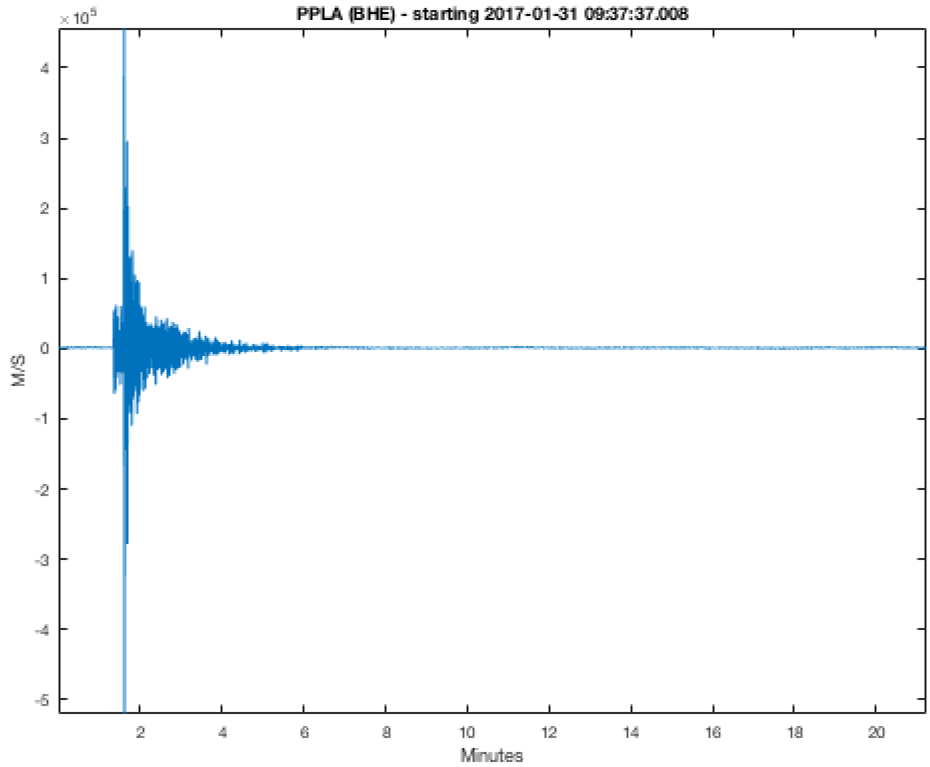
```
% POKR
h=plot(POKR_E, 'xunit', 'm');
axis tight

h2= plot(POKR_N, 'xunit', 'm');
axis tight
```

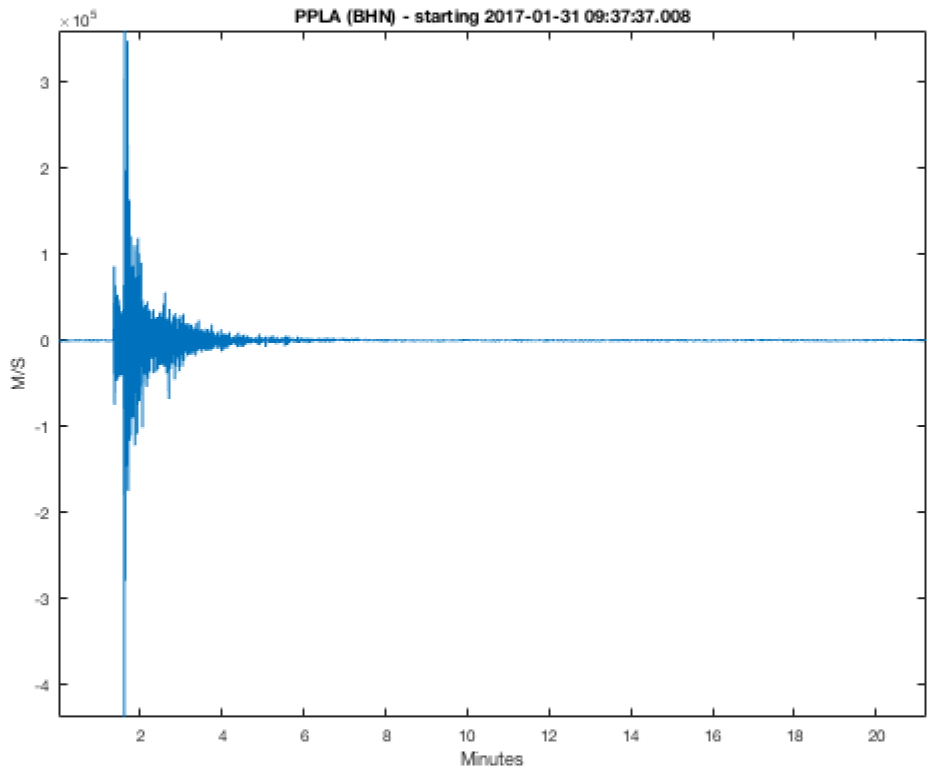
```
h3=plot(POKR_Z, 'xunit', 'm');
axis tight

% PPLA Purkeypile, AK
plot(PPLA_E,'xunit','m');
axis tight
plot(PPLA_N,'xunit','m')
axis tight
plot(PPLA_Z,'xunit','m');
axis tight
```

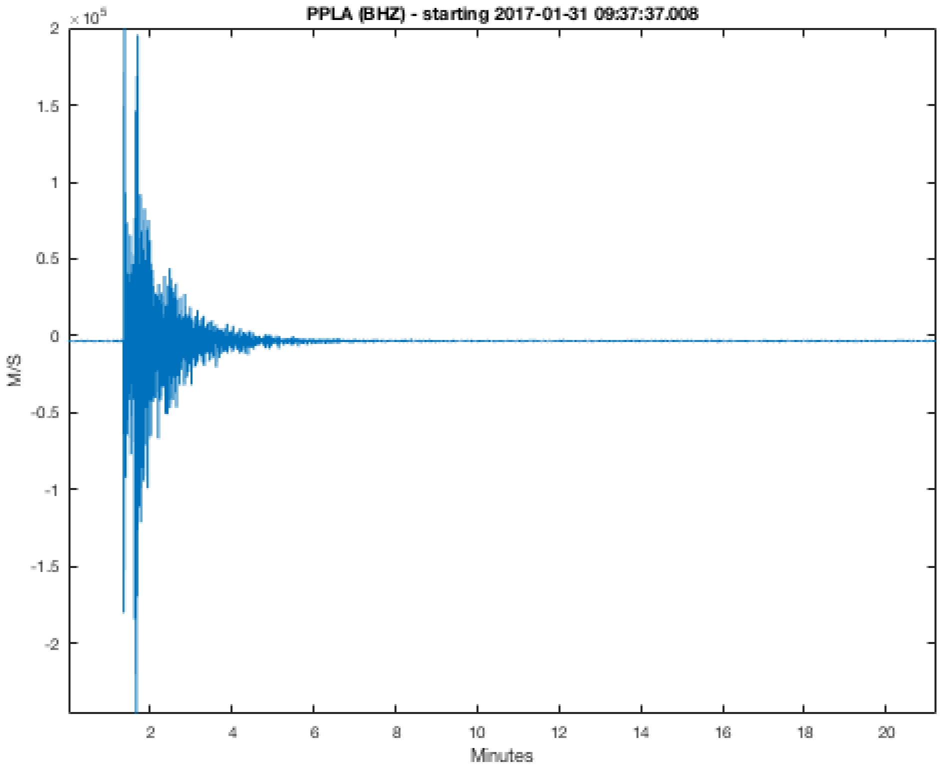



POKR (BHN) - starting 2017-01-31 09:37:37.000
× 10^4
M/S
Minutes


POKR (BHZ) - starting 2017-01-31 09:37:37.000
× 10^4
M/S
Minutes


PPLA (BHE) - starting 2017-01-31 09:37:37.008
×10^5
4
3
2
1
0
-1
-2
-3
-4
-5
M/S
2
4
6
8
10
12
14
16
18
20
Minutes


PPLA (BHN) - starting 2017-01-31 09:37:37.008
×10^5
3
2
1
0
-1
-2
-3
-4
M/S
2
4
6
8
10
12
14
16
18
20
Minutes



Part 2.2 Polarization analysis

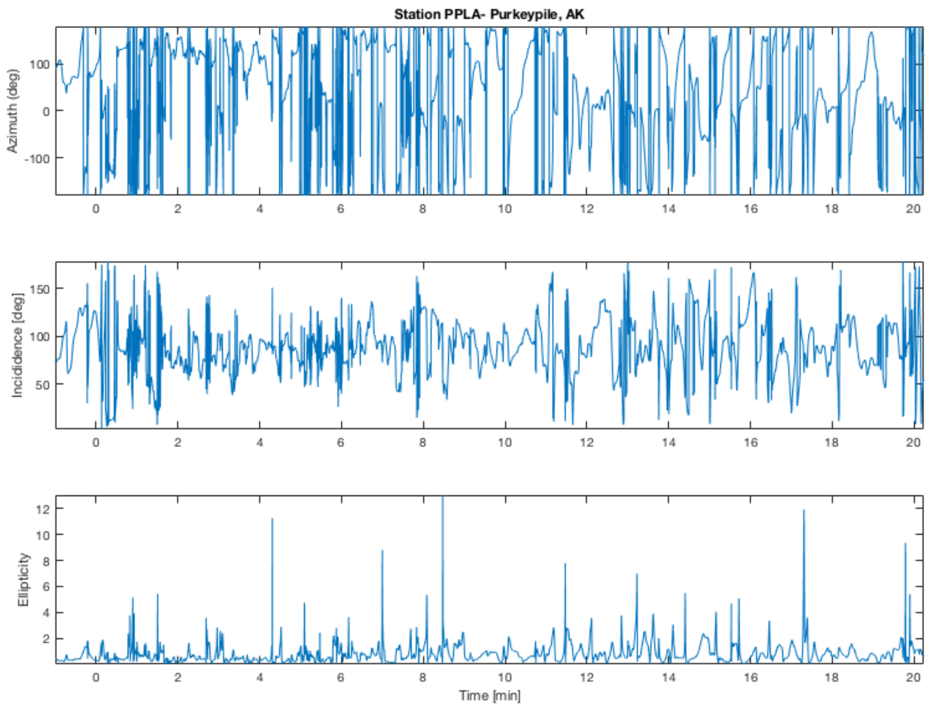
```
%find window------------------------
% Dominant frequency
%plot_spectrum(POKR_Z)
%plot_spectrum(PPLA_Z)

%dominant frequency of synthetic time series in Hz
f = .5; % [Hz]

%time sample interval
freq_PPLA = get(PPLA_E,'FREQ');
freq_POKR =get(POKR_E,'FREQ');
dtPPLA = 1/freq_PPLA; % [s]
dtPOKR = 1/freq_POKR;
%Determine window to calculate polarization over, in samples
cycs = 2; % number of cycles (2 to 3 is usually sufficient)
wndoPPLA = floor( (1/f) * (1/dtPPLA) ) * cycs; % samples per cycle
 times # of cycles
wndoPOKR = floor( (1/f) * (1/dtPOKR) ) * cycs; % samples per cycle
 times # of cycles
%-----------------------------------------
addpath ./Polarizemic/functions

%PPLA
dataE = get(PPLA_E,'DATA');
```

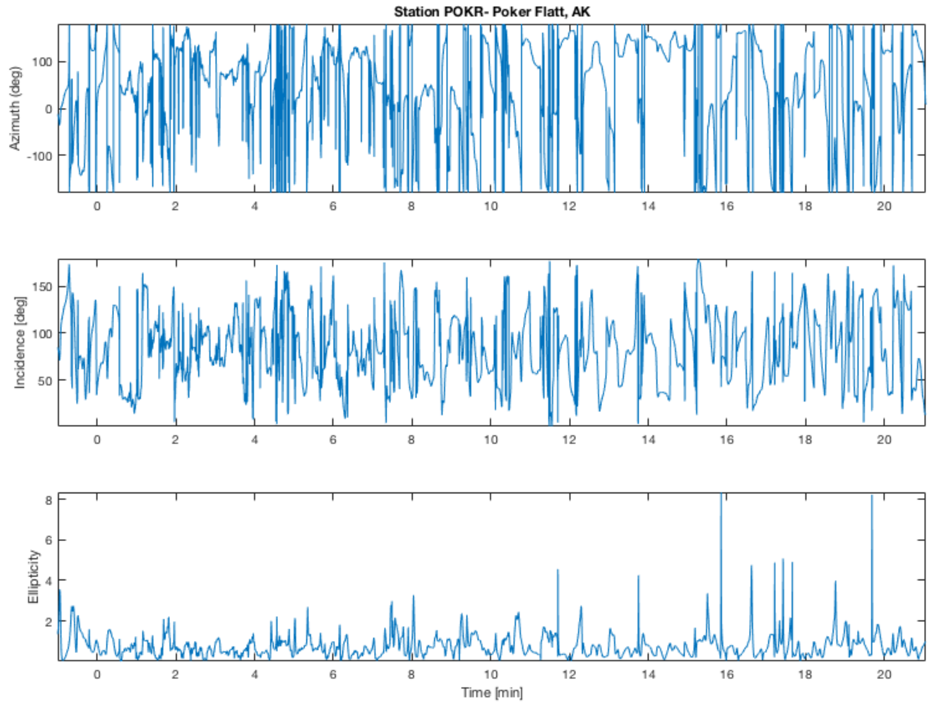
```
dataN = get(PPLA_N,'DATA');
dataZ = get(PPLA_Z,'DATA');
nPPLA =length(dataE);

dtac = [dataZ';dataE';dataN'];

[azim incd ellip] = polar_coherency(dtac,wndoPPLA);

%POKR
POKRdataE = get(POKR_E,'DATA');
POKRdataN = get(POKR_N,'DATA');
POKRdataZ = get(POKR_Z,'DATA');
nPOKR = length(POKRdataE);

dtac = [POKRdataZ';POKRdataE';POKRdataN'];

[azimPOKR incdPOKR ellipPOKR] = polar_coherency(dtac,wndoPOKR);
```

Plot Polarization Analysis

```
%set time for x axis
tPPLA = 0:1/freq_PPLA:nPPLA/freq_PPLA-1/freq_PPLA;
tPOKR = 0:1/freq_POKR:nPOKR/freq_POKR-1/freq_POKR;

tPPLA = tPPLA./60-1; % time in minutes
tPOKR = tPOKR./60-1;

% Plot polarization analysis
figure;
subplot(3,1,1)
plot(tPPLA,azim)
title('Station PPLA- Purkeypile, AK')
axis tight
ylabel('Azimuth (deg)')

subplot(3,1,2)
plot(tPPLA,incd)
axis tight
ylabel('Incididence [deg]')

subplot(3,1,3)
plot(tPPLA,ellip)
axis tight
xlabel('Time [min]');
ylabel('Ellipticity');

set(gcf,'Position',[230 65 902 629])

figure;
subplot(3,1,1)
plot(tPOKR,azimPOKR)
title('Station POKR- Poker Flatt, AK')
axis tight
ylabel('Azimuth (deg)')
```

```
subplot(3,1,2)
plot(tPOKR,incdPOKR)
axis tight
ylabel('Incidence [deg]')

subplot(3,1,3)
plot(tPOKR,ellipPOKR)
axis tight
xlabel('Time [min]');
ylabel('Ellipticity');

set(gcf,'Position',[230 65 902 629])
```





2.3 Observations on polarization analysis

The azimuth and incidence angle both jump around quite a lot. The Incidence angle is a little better as there does seem to be an average of about 83.5 degrees. Some of the peaks between azimuth and incidence angle line up but it is really quite noisy. I assume this is because we have not yet rotated the data. Perhaps what we are seeing is a response to the ambient noise that happens to align with the seimometer components. If I understand ellipticity correctly, a peak represents an higher intermediate access which i assume would be N-S or E-W or analogous to shear waves. The elipticity doesn't seem to show many shear waves, again I think this is because the source did not produce a waveform that arrived in line with the three channels.

Part 3

3.1 Comparison of Azimuth

The p wave arrival for station PPLA is 8 seconds. At this time the azimuth is -164 degrees compared to -107.58 degrees listed on the IRIS sight. The azimuth for station POKR ranges between about 28 and 47 degrees near the time of the p wave arrival. IRIS gives the azimuth for POKR as 35.41 Each of these is not terrible, prehaps the difference comes from using unrotated data.

3.2 Compute the back azimuth

```
srclat = 63.0817;
srclon = -150.9427;

latPOKR = 65.12;
lonPOKR = -147.43;

latPPLA = 62.9;
```

```
lonPPLA = -152.19;

backAZPOKR = azimuth(latPOKR,lonPOKR,srclat,srclon); % back azimuth
AZPOKR = backAZPOKR-180
backAZPPLA = azimuth(latPPLA,lonPPLA,srclat,srclon);
AZPPLA = backAZPPLA-180

% The azimuth from this computation is in better agreement with the
 IRIS
% data than the polarization computation.
```

```
AZPOKR =

   38.5606


AZPPLA =

 -108.3399
```

3.3 rotate data

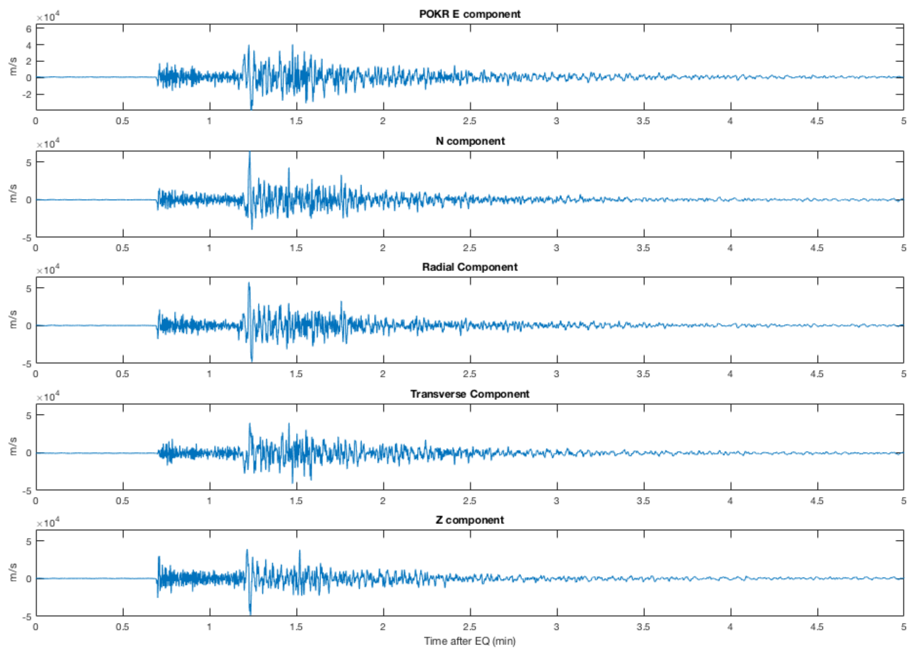
```
thetaPOKR = 3*pi/2 - deg2rad(backAZPOKR);
thetaPPLA = 3*pi/2 - deg2rad(backAZPPLA);

% Radial component
R_POKR = cos(thetaPOKR).*POKRdataE + sin(thetaPOKR).*POKRdataN;
T_POKR = -sin(thetaPOKR).*POKRdataE + cos(thetaPOKR).*POKRdataN;

% Transverse Component
R_PPLA = cos(thetaPPLA).*dataE + sin(thetaPPLA).*dataN;
T_PPLA = -sin(thetaPPLA).*dataE + cos(thetaPPLA).*dataN;
```

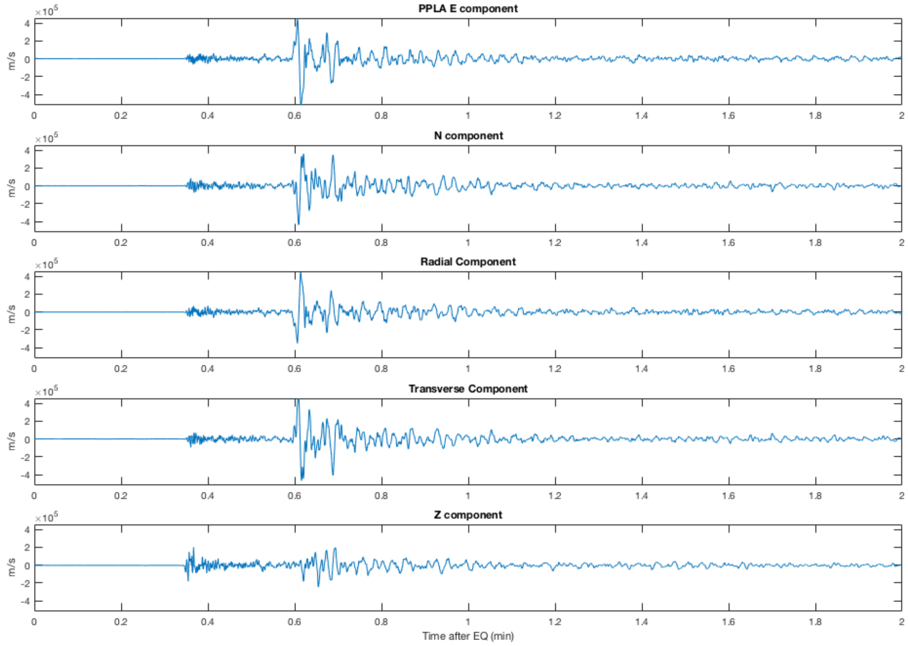
plot the rotated data and the EN data

```
%POKR
figure;
subplot(5,1,1)
plot(tPOKR',POKRdataE)
axis tight
ylabel('m/s')
title('POKR E component')
xlim([0 5])
ylim([-39758 65454])

subplot(5,1,2)
plot(tPOKR',POKRdataN)
axis tight
ylabel('m/s')
title('N component')
xlim([0 5])
ylim([-50000   65454])
```

```
subplot(5,1,3)
plot(tPOKR',R_POKR)
axis tight
ylabel('m/s')
title('Radial Component')
xlim([0 5])
ylim([-50000 65454])

subplot(5,1,4)
plot(tPOKR',T_POKR)
axis tight
ylabel('m/s')
title('Transverse Component')
xlim([0 5])
ylim([-50000 65454])

subplot(5,1,5)
plot(tPOKR',POKRdataZ)
axis tight
ylabel('m/s')
title('Z component')
xlabel('Time after EQ (min)')
xlim([0 5])
ylim([-50000 65454])

set(gcf,'Position',[168 48 1148 750]);
%-----------------------------------------------------
%PPLA
figure;
subplot(5,1,1)
plot(tPPLA',dataE)
axis tight
ylabel('m/s')
title('PPLA E component')
xlim([0 2])
ylim([-520532 456801])

subplot(5,1,2)
plot(tPPLA',dataN)
axis tight
ylabel('m/s')
title('N component')
xlim([0 2])
ylim([-520532 456801])

subplot(5,1,3)
plot(tPPLA',R_PPLA)
axis tight
ylabel('m/s')
title('Radial Component')
xlim([0 2])
ylim([-520532 456801])
```

```
subplot(5,1,4)
plot(tPPLA',T_PPLA)
axis tight
ylabel('m/s')
title('Transverse Component')
xlim([0 2])
ylim([-520532 456801])

subplot(5,1,5)
plot(tPPLA',dataZ)
axis tight
ylabel('m/s')
title('Z component')
xlabel('Time after EQ (min)')
xlim([0 2])
ylim([-520532 456801])

set(gcf,'Position',[168 48 1148 750]);
```





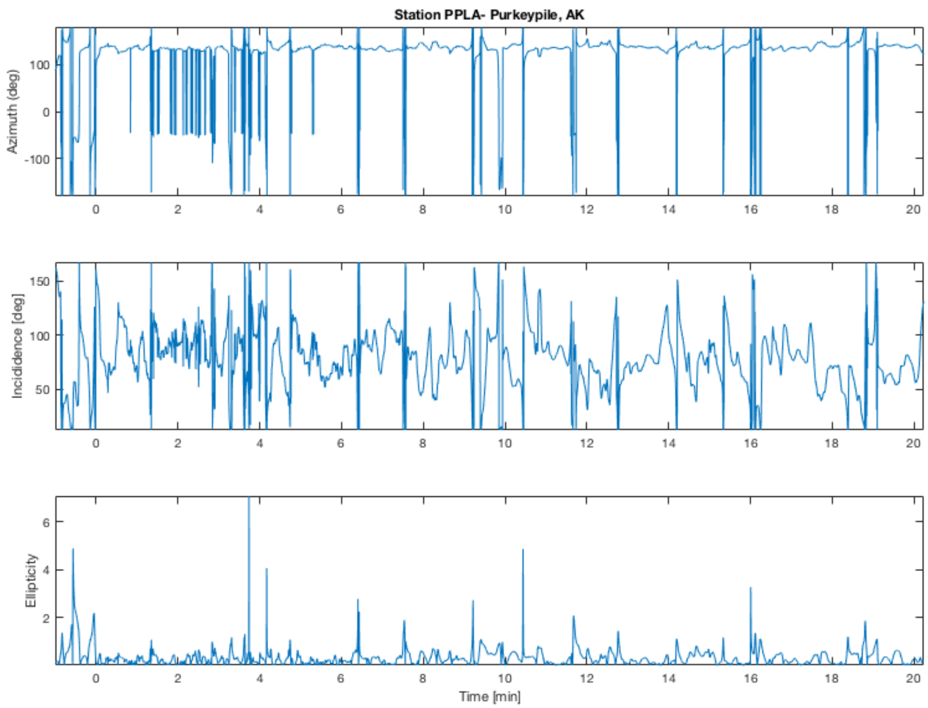
3.4 Polarization of rotated data

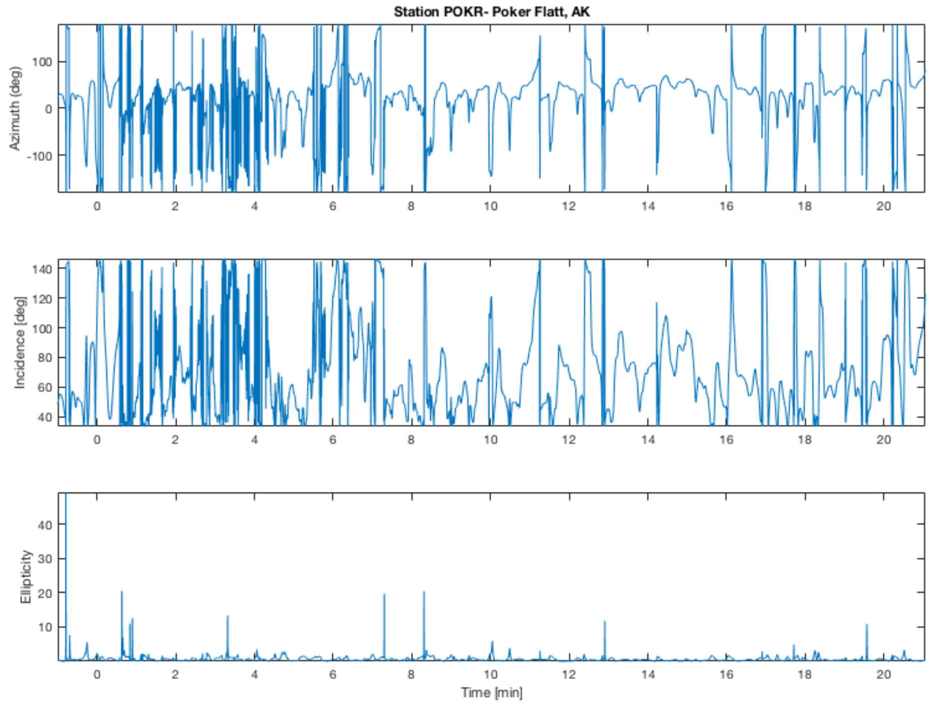
```
% PPLA
dtac = [R_PPLA';T_PPLA';dataN'];
[azim incd ellip] = polar_coherency(dtac,wndoPPLA);

%POKR
dtac = [R_POKR';T_POKR';POKRdataN'];
[azimPOKR incdPOKR ellipPOKR] = polar_coherency(dtac,wndoPOKR);
```

Plot Polarization Analysis set time for x axis

```
tPPLA = 0:1/freq_PPLA:nPPLA/freq_PPLA-1/freq_PPLA;
tPOKR = 0:1/freq_POKR:nPOKR/freq_POKR-1/freq_POKR;

tPPLA = tPPLA./60-1; % time in minutes
tPOKR = tPOKR./60-1;

% Plot polarization analysis
figure;
subplot(3,1,1)
plot(tPPLA,azim)
title('Station PPLA- Purkeypile, AK')
axis tight
ylabel('Azimuth (deg)')

subplot(3,1,2)
plot(tPPLA,incd)
axis tight
ylabel('Incididence [deg]')
```

```
subplot(3,1,3)
plot(tPPLA,ellip)
axis tight
xlabel('Time [min]');
ylabel('Ellipticity');

set(gcf,'Position',[230 65 902 629])

figure;
subplot(3,1,1)
plot(tPOKR,azimPOKR)
title('Station POKR- Poker Flatt, AK')
axis tight
ylabel('Azimuth (deg)')

subplot(3,1,2)
plot(tPOKR,incdPOKR)
axis tight
ylabel('Incidence [deg]')

subplot(3,1,3)
plot(tPOKR,ellipPOKR)
axis tight
xlabel('Time [min]');
ylabel('Ellipticity');

set(gcf,'Position',[230 65 902 629])
```





The azimuth for both stations looks a lot more smooth. For POKR the azimuth hovers from about 20 degrees to about 50, consistent with the 35.41 azimuth given by Iris. The spikes in each figure also correspond much better to each other. That is major peaks in the azimuth have a corresponding peak in the incidence angle and ellipticity. There are fewer ellipticity spikes for the POKR station. It is a closer station so perhaps the surface waves dont have as enough time to separate so that the P waves dominate the signal. Now that the data is rotated this makes sense because we are looking at the data as it is actually. I am not sure why there is a change in sign for the azimuth of the PPLA station.

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