Misc stuff

MATLAB

lookfor command – to look for commands based on “keyword”

(searches all m files in path, including your files, for the keyword).

what command – lists matlab related files

(returns structure with fields for m, mat, mex, mdl, classes, and packages files)., Help window (pull down menu).

Helpdesk (internet)

http://www.mathworks.com/access/helpdesk/help/helpdesk.shtml

workspace

```
>> help workspace
 WORKSPACE Open Workspace browser to manage workspace
WORKSPACE Opens the Workspace browser with a view of the
variables in the current Workspace.  Displayed variables may
be viewed, manipulated, saved, and cleared.
```

path

```
>> help path
 PATH Get/set search path.
    PATH, by itself, prettyprints MATLAB's current search
path. The initial search path list is set by PATHDEF, and is
perhaps individualized by STARTUP.
    P = PATH returns a string containing the path in P.
PATH(P) changes the path to P.  PATH(PATH) refreshes MATLAB's
view of the directories on the path, ensuring that any changes
to non-toolbox directories are visible.
    PATH(P1,P2) changes the path to the concatenation of the
two path strings P1 and P2.  Thus PATH(PATH,P) appends a new
directory to th current path and PATH(P,PATH) prepends a new
directory.  If P is already on the path, then PATH(PATH,P)
moves P to the end of the path, and similarly, PATH(P,PATH)
moves P to the beginning of the path.
    For example, the following statements add another
directory to MATLAB’s search path on various operating
systems:
      Unix:     path(path,'/home/myfriend/goodstuff')
      Windows:  path(path,'c:\tools\goodstuff’)
```

format command

```
>> help format
. . .
FORMAT Set output format.
. . .
FORMAT does not affect how MATLAB computations are done.
```

To separate multiple commands on one line use ";" for no output, and ',' for output

Cmd line editing

arrows: move cursor by character

ctrl arrows l and r: move cursor by word

ctrl a, e: move cursor to beginning, end line

ctrl u, d, h, k: clear line, delete char at cursor, delete char before cursor, delete to end of line.

Running an m file from the command line (should not be interactive)

```
>> matlab < somefile.m
```

Don't show output on terminal (send to bit bucket), run in background to not lock up terminal

```
matlab -nosplash < eig_mov.m > /nl &
```

Global variables

When you define a variable at the matlab prompt, it is defined inside of matlab's "workspace."

Running a script does not affect this, since a script is just a collection of commands, and they're actually run from the same workspace.

If you define a variable in a script, it will stay defined in the workspace.

Global variables

Functions, on the other hand, do not share the same workspace.

A function won't know what a variable is unless

- the function gets the variable as an argument, or

- the variable is defined as a variable that is shared by the function and the matlab workspace, i.e. a global variable.

Global variables

To use a global variable, every place (function, script, or at the matlab prompt) that needs to share that variable must have a line near the top identifying it as a global variable, ie:

```
global phi;
```

Then when the variable is assigned a value in one of those places, it will have a value in all the other places that have the global statement.

Linear Algebra (a la Matlab) Review

MATLAB

```
>> a=[1 2 3;4 5 6;7 8 9]
a =
    1    2    3
    4    5    6
    7    8    9
>> c=trace(a)
c =
   15

>> a=[.96 -.28; .28 .96]
a =
   0.9600   -0.2800
   0.2800    0.9600
>> inv(a)
ans =
   0.9600    0.2800
  -0.2800    0.9600
>> a'*a
ans =
    1    0
    0    1
>>
```

trace of a Matrix is Tr(A) =

$$\sum_{i=1}^{N} a_{ii}$$

(the sum of the diagonal entries)

In matlab use trace(A)

a matrix A is **orthonormal** if

$$A^T = A^{-1}$$

and in this case

$$AA^T = I$$

Block matrices

```
>> b=[2 2;1 3]
b =

     2     2
     1     3
c =
     0     2     3
     5     4     7
>> d=[1 0]
d =
     1     0
>> e=[-1 6 0]
e =
    -1     6     0
>> a=[b c;d e]
a =
     2     2     0     2     3
     1     3     5     4     7
     1     0    -1     6     0
```

Linear Dependence

- A set of vectors is **linearly dependent** if one of the vectors can be expressed as a linear combination of the other vectors.

Example:

$$\begin{bmatrix}1\\0\\0\end{bmatrix}, \begin{bmatrix}0\\1\\0\end{bmatrix}, \begin{bmatrix}2\\1\\0\end{bmatrix}$$

a b c

2a + 1b = c

Linear Independence

- A set of vectors is **linearly independent** if none of the vectors can be expressed as a linear combination of the other vectors.

Example:

$$\begin{bmatrix}1\\0\\0\end{bmatrix}, \begin{bmatrix}0\\1\\0\end{bmatrix}, \begin{bmatrix}2\\1\\3\end{bmatrix}$$

a b c

There is no simple, linear combination of a and b what will produce c.

Rank of a matrix

- The **rank** of a matrix is the number of linearly independent columns of the matrix.

  Examples:

  $$\begin{bmatrix} 1 & 0 & 2 \\ 0 & 1 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$ has rank 2

  $$\begin{bmatrix} 1 & 0 & 2 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$ has rank 3

- Note: the rank of a matrix is also the number of linearly independent *rows* of the matrix.

```
>> a=[1 2; 3 4]
a =
     1     2
     3     4
>> rank(a)
ans =
     2
>> rref(a)
ans =
     1     0
     0     1
>> >> a=[1 2 3;4 5 6;7 8 9]
a =
     1     2     3
     4     5     6
     7     8     9
>> rank(a)
ans =
     2
>> rref(a)
ans =
     1     0    -1
     0     1     2
     0     0     0
```

There are a lot of matrix math functions

```
>> help matfun
  Matrix functions - numerical linear algebra.

  Matrix analysis.
    norm        - Matrix or vector norm.
    normest     - Estimate the matrix 2-norm.
    rank        - Matrix rank.
    det         - Determinant.
    trace       - Sum of diagonal elements.
    null        - Null space.
    orth        - Orthogonalization.
    rref        - Reduced row echelon form.
    subspace    - Angle between two subspaces.

  Linear equations.
    / and /     - Linear equation solution; use "help slash".
    linsolve    - Linear equation solution with extra control.
    inv         - Matrix inverse.
    rcond       - LAPACK reciprocal condition estimator
    cond        - Condition number with respect to inversion.
    condest     - 1-norm condition number estimate.
    normest1    - 1-norm estimate.
```

```
    cholinc    - Incomplete Cholesky factorization.
    ldl        - Block LDL' factorization.
    lu         - LU factorization.
    luinc      - Incomplete LU factorization.
    qr         - Orthogonal-triangular decomposition.
    lsqnonneg - Linear least squares with nonnegativity
constraints.
    pinv       - Pseudoinverse.
    lscov      - Least squares with known covariance.

  Eigenvalues and singular values.
    eig        - Eigenvalues and eigenvectors.
    svd        - Singular value decomposition.
    gsvd       - Generalized singular value decomposition.
    eigs       - A few eigenvalues.
    svds       - A few singular values.
    poly       - Characteristic polynomial.
    polyeig    - Polynomial eigenvalue problem.
    condeig    - Condition number with respect to eigenvalues.
    hess       - Hessenberg form.
    schur      - Schur decomposition.
    qz         - QZ factorization for generalized eigenvalues.
```

```
    ordschur   - Reordering of eigenvalues in Schur
decomposition.
    ordqz      - Reordering of eigenvalues in QZ factorization.
    ordeig     - Eigenvalues of quasitriangular matrices.

  Matrix functions.
    expm       - Matrix exponential.
    logm       - Matrix logarithm.
    sqrtm      - Matrix square root.
    funm       - Evaluate general matrix function.

  Factorization utilities
    qrdelete   - Delete a column or row from QR factorization.
    qrinsert   - Insert a column or row into QR factorization.
    rsf2csf    - Real block diagonal form to complex diagonal
form.
    cdf2rdf    - Complex diagonal form to real block diagonal
form.
    balance    - Diagonal scaling to improve eigenvalue
accuracy.
    planerot   - Givens plane rotation.
    cholupdate - rank 1 update to Cholesky factorization.
    qrupdate    - rank 1 update to QR factorization.

>>
```

Data Analysis

MATLAB

Flow Charts

2 tasks

Understanding How a Process Works

Communicating How a Process Works (translating it into computer code, communicating to the computer.)

A flow chart can therefore be used to:

Define and analyze processes;

Build a step-by-step picture of the process for analysis, discussion, communication, and coding;

and

Define, standardize or find areas for improvement in a process.

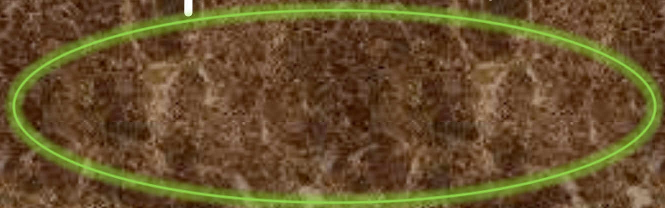
Also

by conveying the information or processes in a step-by-step flow, you can then concentrate more intently on each individual step,

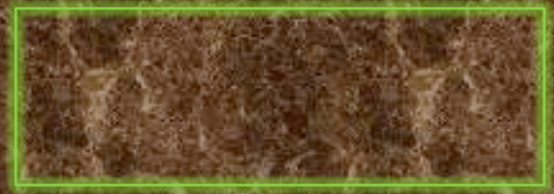
without feeling overwhelmed by the bigger picture.

Most flow charts are made up of three main types of symbol:

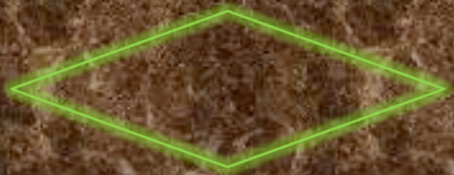
Elongated circles, signify start or end of a process;



Rectangles, show instructions or actions;



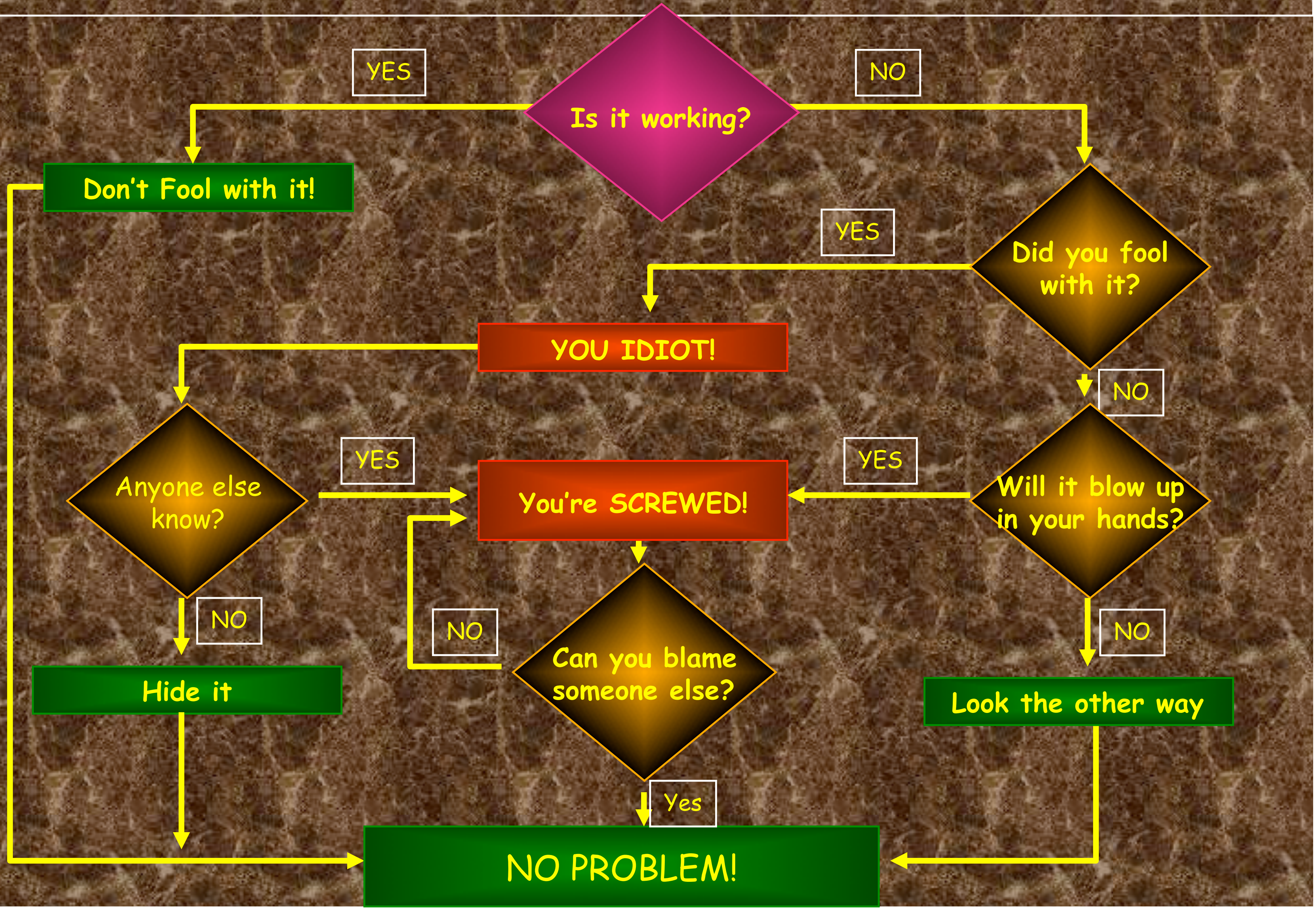
Diamonds, show decisions to be made



Within each symbol, write down what the symbol represents. This could be the start or finish of the process, the action to be taken, or the decision to be made.

Symbols are connected one to the other by arrows, showing the flow of the process.

Worlds most famous Flowchart:
General Flowchart For Problem Resolution -



Coding and Flow Charts

Today's presentation will focus on understanding Chuck's matlab script for polarization analysis using 3 component recordings of body and/or surface waves

Chucks example codes:

http://www.ceri.memphis.edu/people/langston/matlab/programming.html

GOAL: solve for polarization using 3 component seismic data

Starting data: 3 component single station SAC formatted data

Result: Identify the azimuth(s) of the primary wave(s) recorded in the data

How to we get from A to B?

Principal Component Analysis

Principal component analysis (PCA) is a vector space transform often used to reduce multidimensional data sets to lower dimensions for analysis.

Principal Component Analysis

PCA involves the calculation of the eigenvalue decomposition of a data covariance matrix or singular value decomposition of a data matrix, usually after mean centering the data for each attribute.

Its operation can be thought of as revealing the internal structure of the data in a way which best explains the variance in the data.

What we are looking for:

New set of axis (basis) that maximizes the correlation of HT(Z) with R, and minimizes the correlations between both HT(Z) and R with T.

We are not using the full power of PCA, since we already have some model for the result of the analysis

(and have therefore preprocessed the data by taking the Hilbert transform of the z component).

What is the idea?

Seismic waves are polarized

P wave longitudinal (V and R)

S wave transverse with SH and SV polarizations (T, V and R)

Rayleigh waves (V and R)

Love waves (T).

If we take a short time period we can think of each component as a vector of n terms.

If we take the dot product of each vector with itself and with the other two components we can find the "angle" between tnem.

We can also make these dot products by making a 3xn arrary using each seismogram as a row.

Multiplying this array with its transpose results in a 3x3 matrix with the various dot products in the elements of the matrix.

Now find the eigenvectors and eigenvalues of this matrix.

From the eigenvectors we can make a rotation matrix that will rotate our matrix to a diagonal matrix.

The off diagonal elements are now all zero and from the geometric interpretation of the dot product this means that the two vectors used to make that dot product are perpendicular.

So we can rotate the original horizontal components into a new set of seismograms rotated to the principal directions defined by the eigenvectors.

The dot products of the off diagonal terms will now be zero, indicating the vectors are perpendicular.

GOAL: Solve for polarization

Data Preparation

- load SAC data
- remove mean
- plot waveforms
- filter waveforms to highlight waves of interest
- plot filtered waveforms

Main Code

- principal component analysis using 3-component data
- note, this technique requires zero-mean data

Results

- plot azimuths of eigenvectors
- plot azimuths exceeding 50% of maximum value

Step 1: Data Preparation

Load SAC data

3 files (Z,E,N)…. suggests using a subroutine

Provide station name

↓

Remove the mean

↓

Plot waveforms vs time

↓

Filter waveforms to highlight waves of interest

Design a filter; allow flexible input of corner info

Work on 3 files…suggests a subroutine

↓

Plot filtered waveforms

Create function 'polarize'

```
function polarize(station,delt,ttot,twin,hilb,flp,fhi)
%
%  function polarize(station,delt,ttot,twin,hilb,flp,fhi)
%
%  Program to read in 3 component waveform data
%  Create the covariance matrix for a moving time window
%  Find the principal components and infer polarization
%
%   input:
%          station = station name for sacfile prefix
%          delt = sampling interval
%          ttot = total number of seconds to analyze in traces
%          twin = time window length, each time shift will be 1/2 of the
%                    window length
%          hilb = 0, no hilbert transform of vertical component
%                = 1, hilbert transform
%          flp = low passband corner frequency of a 2nd order butterworth
%                  filter used to filter the data, if 0, then no filtering
%          fhi = hi passband corner frequency of the filter
```

Loading SAC data

Many matlab scripts exist to read in sac data.

I modified one so it is

- not sensitive to byte order
-returns the data, plus: npts, delta, and begin point of the SAC file

- data is a column vector

Read the data

```
[e,npts,delt,date,hour,minu,seco,fname]=get_sac_fn('../
                2007.308.20.37.16.3856.IU.SBA.00.BHE.R.SAC');

[n,npts,delt,date,hour,minu,seco,fname]=get_sac_fn('../
                2007.308.20.37.16.3856.IU.SBA.00.BHN.R.SAC');

[z,npts,delt,date,hour,minu,seco,fname]=get_sac_fn('../
                2007.308.20.37.16.3856.IU.SBA.00.BHZ.R.SAC');
```

Removing the data mean

We need to remove the mean of the data for principal component analysis (PCA).

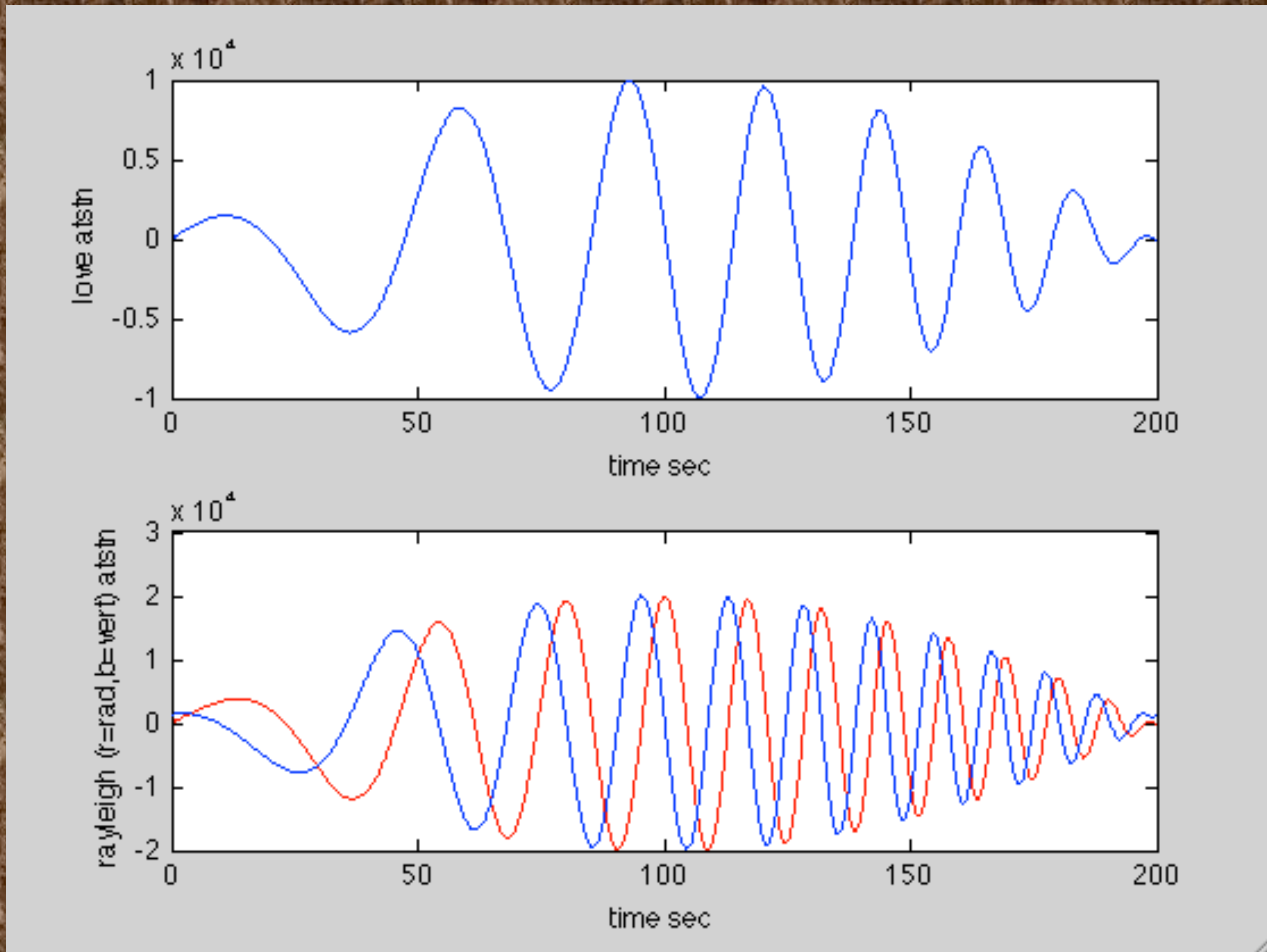
We also need to transpose the column vector data into row vectors.

```
e=dmean(e');                % remove the mean from each
n=dmean(n');         % and transpose the data
z=dmean(z');
```

subroutine: dmean

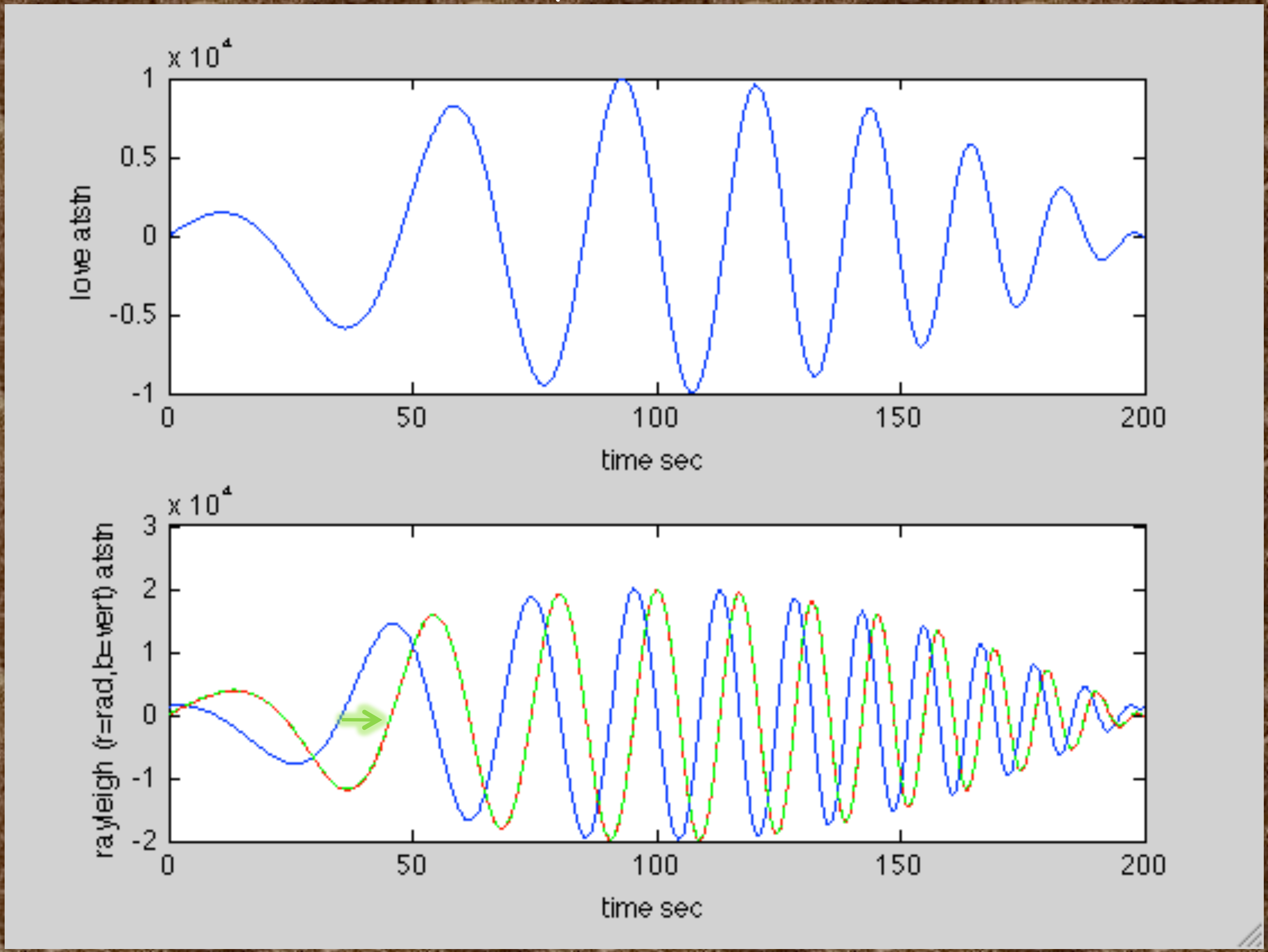
```
function [a]=dmean(b)
%
% [a]=dmean(b)
%
%       Remove the mean from a row vector
m=mean(b);
a=b-m;
return;
```

Make Love and Rayleigh waves (Z, R and T)

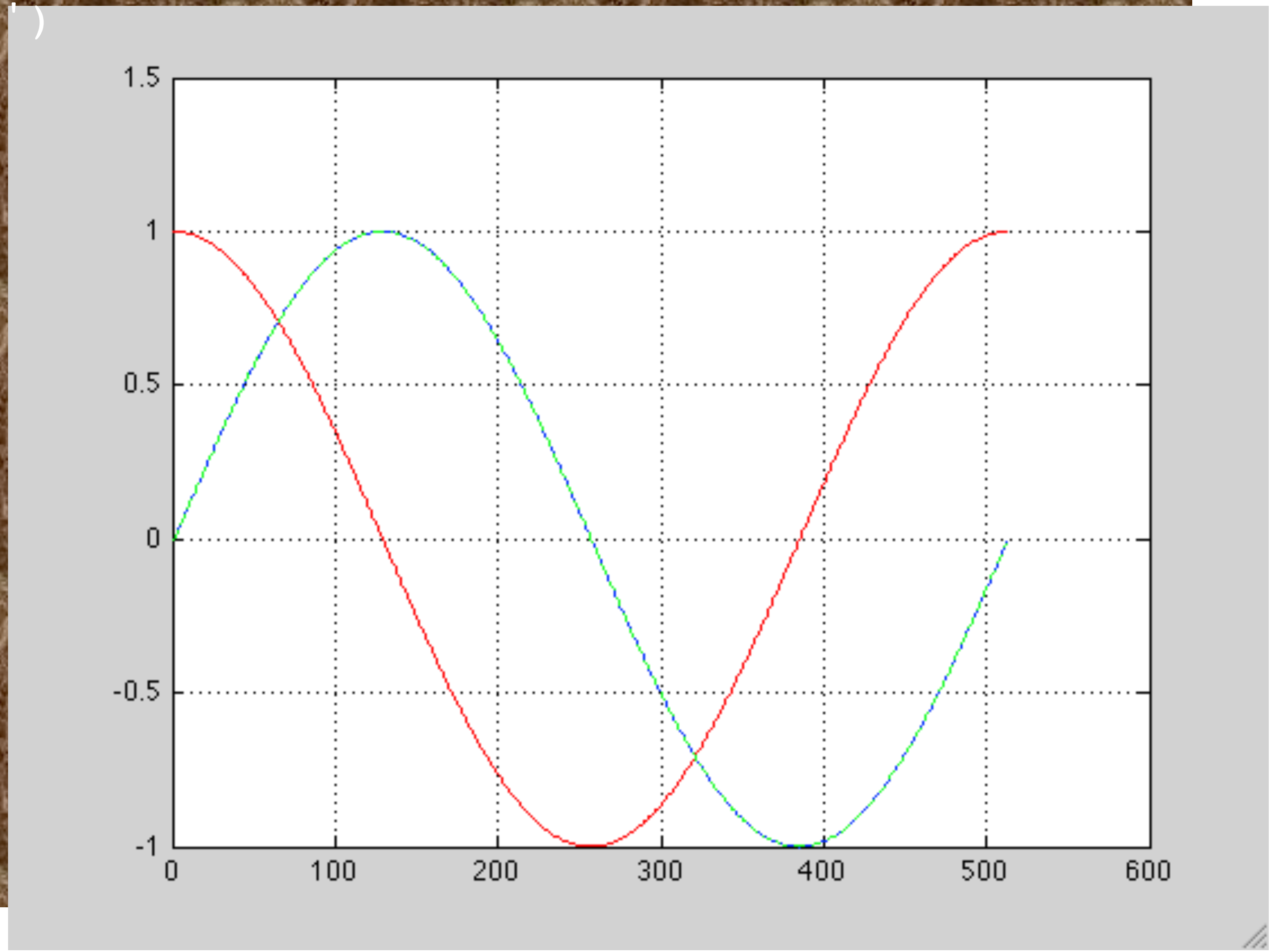


Rayleigh R and Z related by Hilbert X-form

(90° phase shift, blue trace is Hilbert Transformed to green trace, then overlays red trace.).



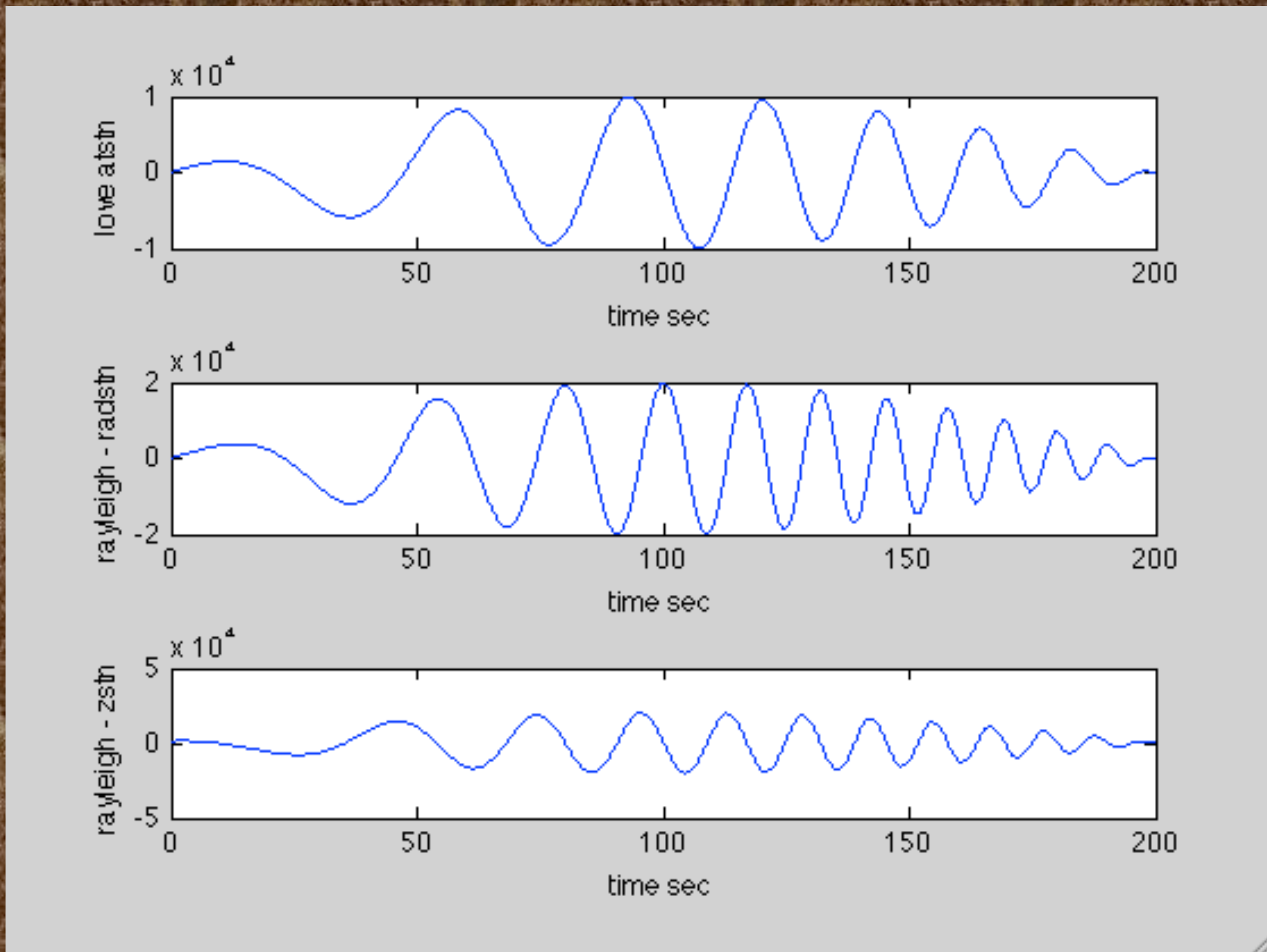
```
n=512;
a=sin(2*pi*[0:(n-1)]/n);
b=hilbert(a);
clf
plot(a)
hold
plot(-imag(b),'r')
plot(real(b),'g--')
grid
```



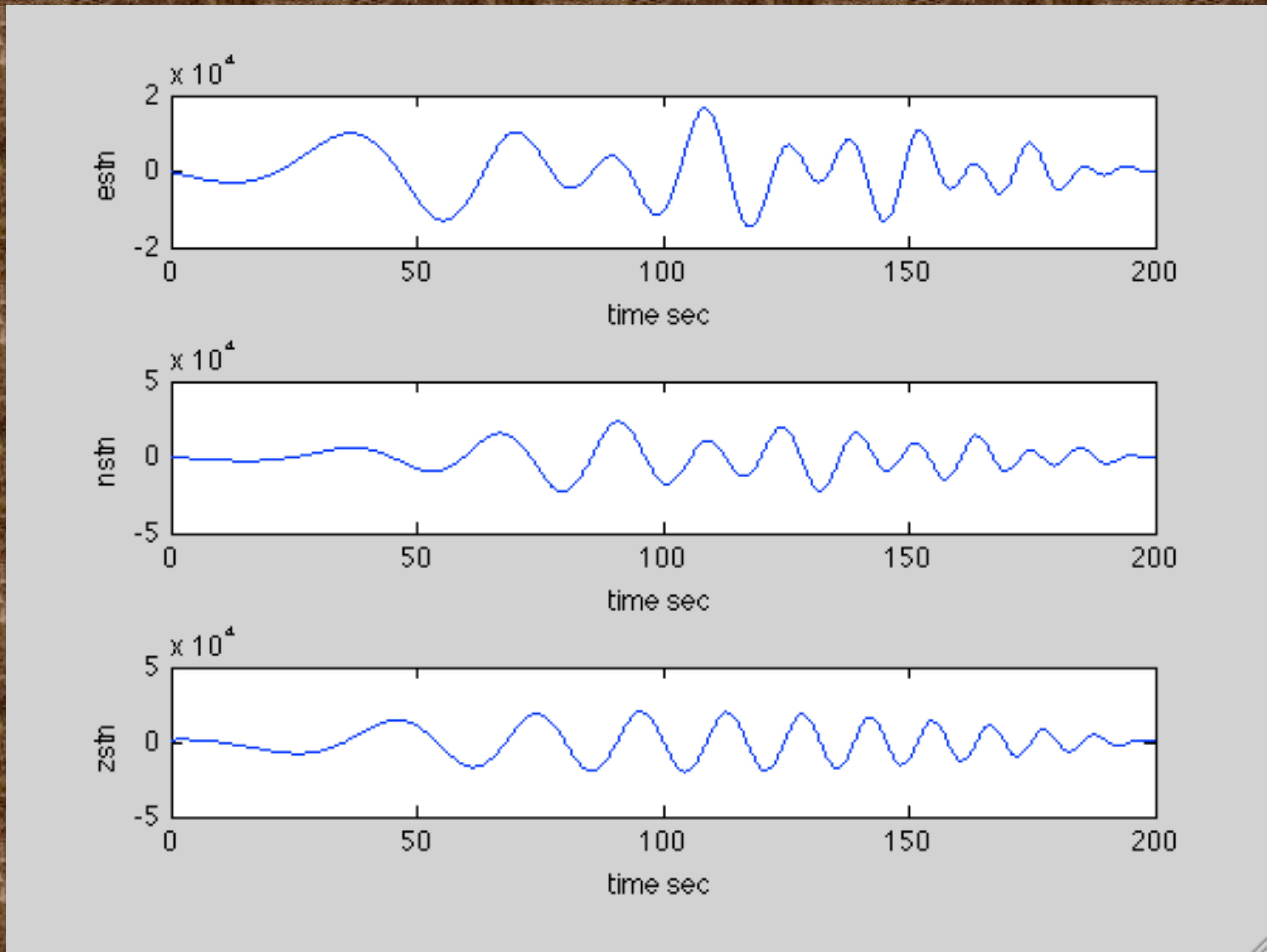
Hilbert Transform

```
if hilb ==1;            % hilbert transform the vertical component
 zh=hilbert(z);         % to make Rayleigh wave in phase on vert
                                          and horz
 z=-imag(zh);           % if present (z constructed from HT, so
                        used +imag to make overlay for last
                        figure)

 else;
end;
```

Make Love and Rayleigh waves (Z, R and T)



Rotate horizontals into seismograms @ 30°.



Plot the data

```
% plot the raw data
f1=figure('name','DATA SEISMOGRAMS');
subplot(3,1,1);
plot(t,e);
xlabel('time sec');
ylabel(strcat('EW Comp at ',station));
subplot(3,1,2);
plot(t,n);
xlabel('time sec');
ylabel(strcat('NS Comp at ',station));
subplot(3,1,3);
plot(t,z);
xlabel('time sec');
ylabel(strcat('Z comp at ',station));
```

Filtering

Filtering is a two step process in Matlab

Design the filter
Apply the filter

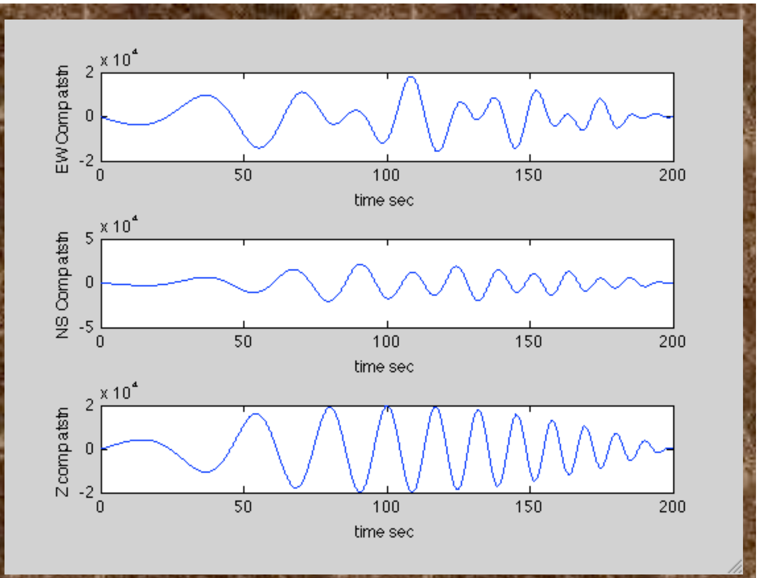
There is a filter design GUI you can use to design the perfect filter called fdatool

Or you can design filters using pre-built filter types (Butterworth, Bessel, etc.)

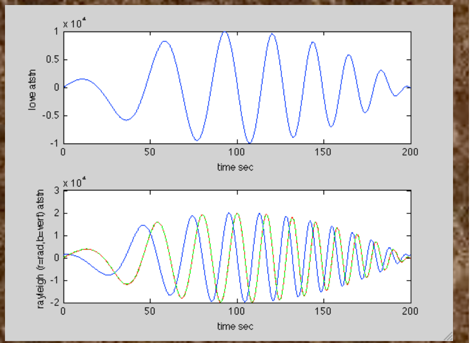
```
function [d]=bandpass(c,flp,fhi,npts,delt)
%
% [d]=bandpass(c,flp)
%
% bandpass a time series with a 2nd order butterworth filter
%
% c = input time series
% flp = lowpass corner frequency of filter
% fhi = highpass corner frequency
% npts = samples in data
% delt = sampling interval of data
%
n=2;                % 2nd order butterworth filter
fnq=1/(2*delt);        % Nyquist frequency
Wn=[flp/fnq fhi/fnq];     % non-dimensionalize the corner
frequencies
[b,a]=butter(n,Wn);       % butterworth bandpass non-
dimensional frequency
d=filtfilt(b,a,c);              % apply the filter: use zero
phase filter (p=2)
return;
```

Filter & plot the filtered data

```
% filter the data
%
if flp > 0;
    e1=bandpass(e,flp,fhi,npts,delt);
    n1=bandpass(n,flp,fhi,npts,delt);
    z1=bandpass(z,flp,fhi,npts,delt);
    e=e1;
    n=n1;
    z=z1;
    %
    % plot the filtered data
    f2=figure('name','FILTERED SEISMOGRAMS');
    subplot(3,1,1);
    ……    removed for clarity
    else;
end;
```



*The vertical channel has also had a Hilbert transform applied so that the Rayleigh wave is in phase on the NS and Z components



GOAL: Solve for polarization

- Recognize that incoming seismic phases should represent the principal components, or the strongest signal, on the 3 component data

- The principal components, in turn, are equal to the eigenvectors of the covariance matrix of the 3 component matrix. This can be derived using PCA techniques

- Eigenvectors/values represent a spatial transformation which maximizes covariance between the 3 components, and they contain information on the azimuth from which the primary signal is derived

- **Since multiple phases may be present, we would prefer to look at short time windows of the 3 component data, or in other words, perform PCA on a running window through the continuous waveforms**

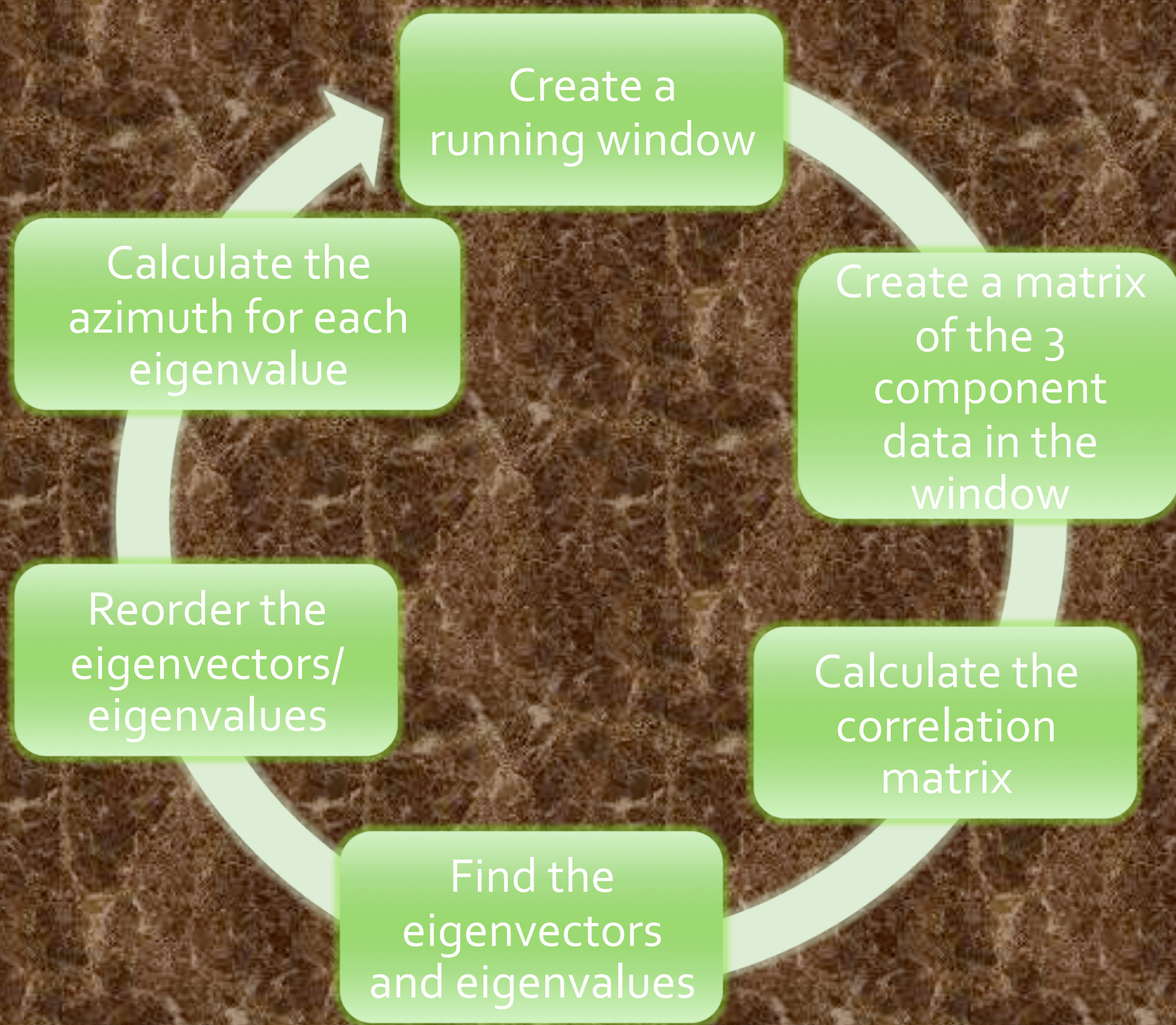
Main Code

Results

- plot azimuths of eigenvectors

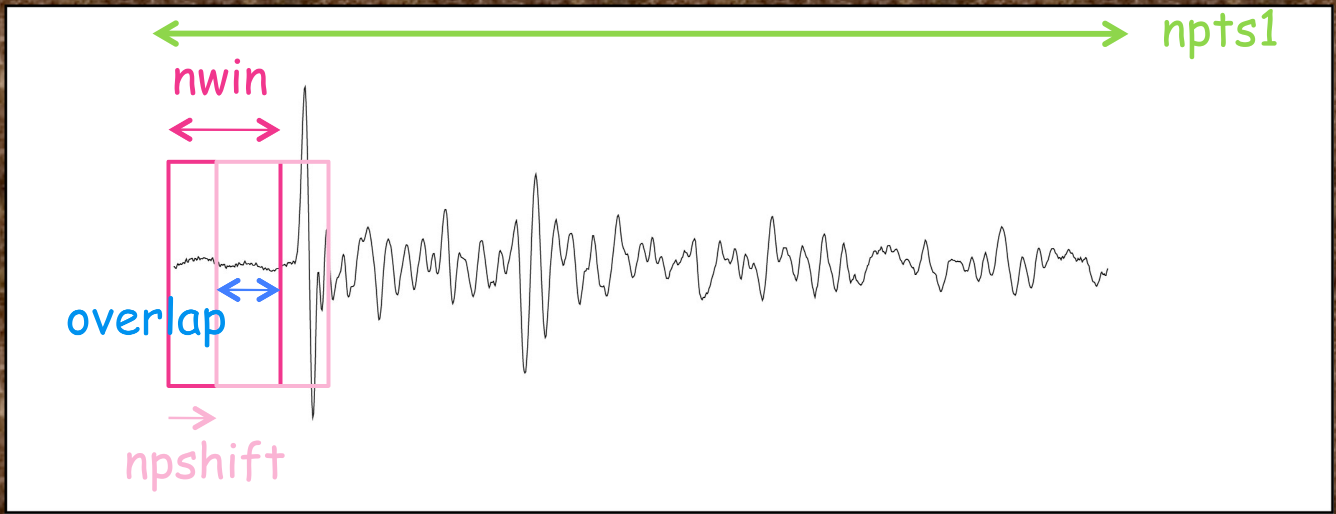
- plot azimuths exceeding 50% of maximum value

Step 2: Main Code

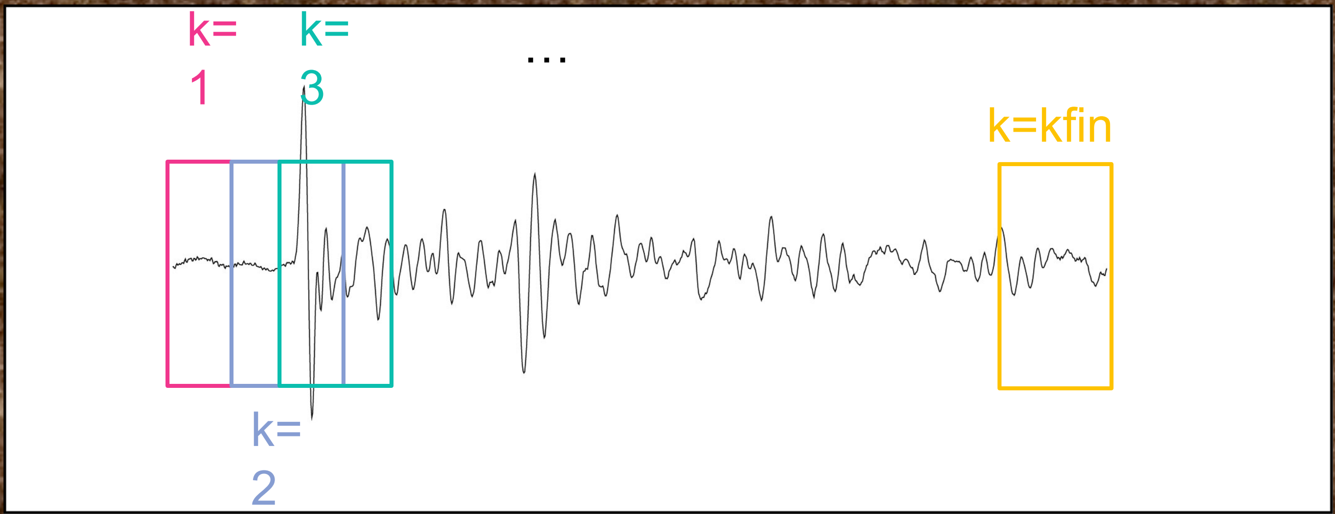


Moving window using loops

```
%    Moving window loop
%
npts1=fix(ttot/delt) + 1;    %  total number of samples to analyze
nwin=fix(twin/delt) + 1;     %  number of samples in a time window
npshift=fix(twin/(2*delt))+1;   % number of samples to shift over
kfin=fix((npts1-nwin)/(npshift+1))+1; % number of time windows considered

mxde1=0.;
mxde2=0.;
mxde3=0.;
```



```
for k=1:kfin;
   nwinst=(k-1)*(npshift-1)+1;   % start of time window
   nwinfn=nwinst+nwin-1;     % end of time window
   …….  missing code to be supplied later
   t2(k)=delt*(nwinst-1);     % assign time for this window to
the window start
end;
```



Eigenvalues/Eigenvectors

When a Matrix multiplies a vector in general the direction and magnitude of the vector will change.

BUT there are special vectors where only the magnitude changes (on multiplication by the Matrix). These are called **eigenvectors** The value by which the length changes is the associated **eigenvalue**

We say that x is an eigenvector of A iff

$$Ax = \lambda x$$

In other words, x is an eigenvector if when you multiply it by A it returns a multiple of itself. λ is called the associated eigenvalue.

In Matlab use [V,D] = eig(A) to get a matrix V whose columns are the eigenvectors of A and a **diagonal** matrix D whose entries on the diagonal are the corresponding eigenvalues.

```
>> A

A =

     1     2
     3     4

>> [V,D] = eig(A)

V =

   -0.8246   -0.4160
    0.5658   -0.9094
```

```
D =

   -0.3723         0
         0    5.3723
```

Missing code from inside our loop

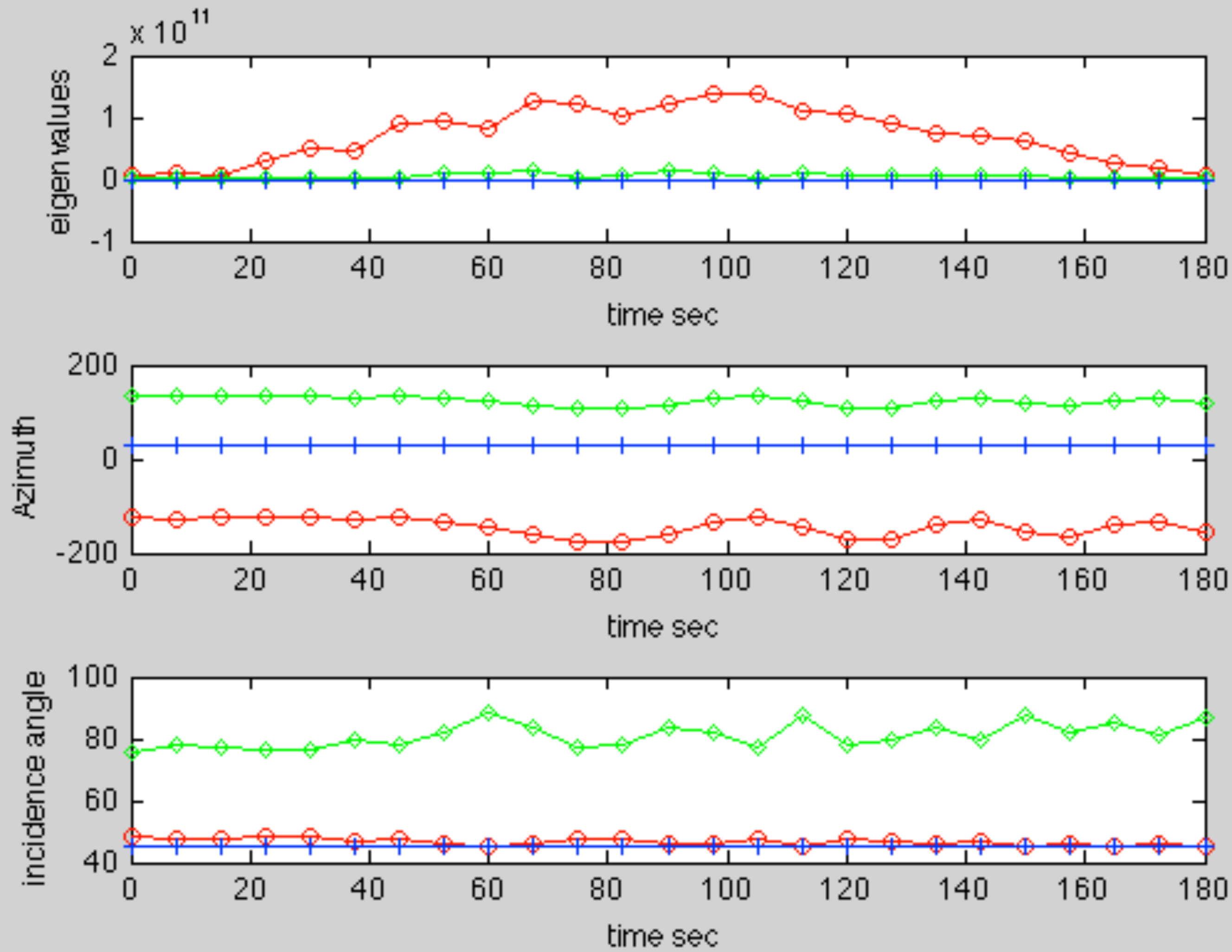
```
a=csigm(e,n,z,nwinst,nwinfn);     % signal matrix
c=a'*a;                          % covariance matrix
[v1,d1]=eig(c);                  % eigenvalue/eigenvectors
[v,d]=order(v1,d1);              % put eigenvalues & eigenvectors
                    in ascending order

% azimuth for each of the 3 eigenvalues
ang1(k)=atan2(v(1,1),v(2,1)) * 180/pi;
ang2(k)=atan2(v(1,2),v(2,2)) * 180/pi;
ang3(k)=atan2(v(1,3),v(2,3)) * 180/pi;

% incidence angle of the 3 eigenvalues
vang1(k)=acos(abs(v(3,1)))* 180/pi; %angle from the vertical
vang2(k)=acos(abs(v(3,2)))* 180/pi;
vang3(k)=acos(abs(v(3,3)))* 180/pi;
```

Still in loop

```
de1(k)=d(1);
de2(k)=d(2);
de3(k)=d(3);

mxde1=max(mxde1,de1(k));   % find the maximum values
mxde2=max(mxde2,de2(k));
mxde3=max(mxde3,de3(k));
```

Outside of Loop again

```
f3=figure('name','Eigenvalues and Inferred Azimuth');
subplot(3,1,1);
plot(t2,de1,'-or',t2,de2,'-dg',t2,de3,'-+b');
xlabel('time sec');
ylabel('eigenvalues');

subplot(3,1,2);
plot(t2,ang1,'-or',t2,ang2,'-dg',t2,ang3,'-+b');
xlabel('time sec');
ylabel('Azimuth ');

subplot(3,1,3);
plot(t2,vang1,'-or',t2,vang2,'-dg',t2,vang3,'-+b');
xlabel('time sec');
ylabel('incidence angle ');
```


x 10^11
eigen values
time sec
Azimuth
time sec
incidence angle
time sec
0 20 40 60 80 100 120 140 160 180

GOAL: Solve for polarization

Results

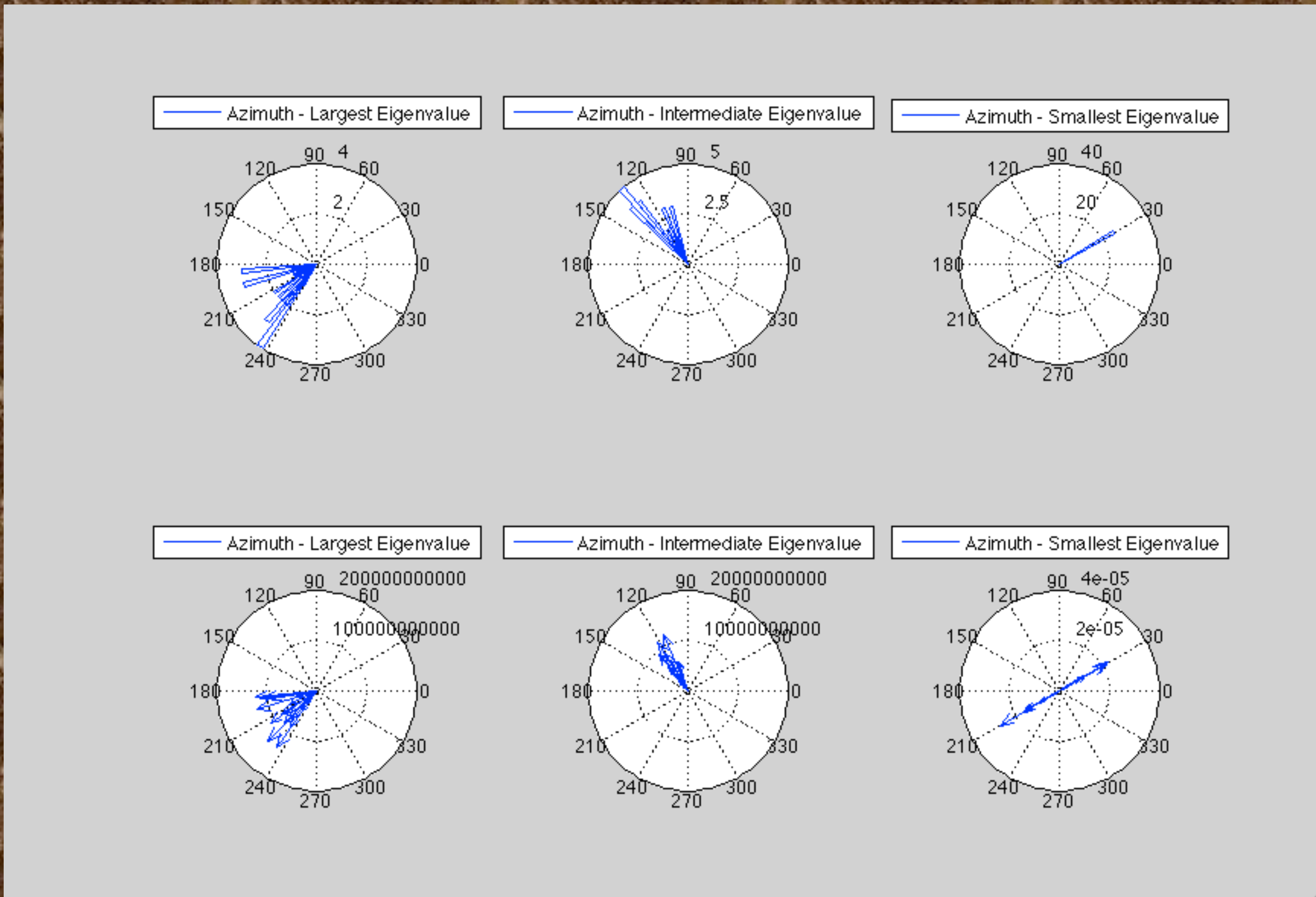
- plot azimuths of eigenvectors
- plot azimuths exceeding 50% of maximum value

Main Code

Rose Diagrams

```
%  Rose plots
f4=figure('name','Azimuth Distribution');
subplot(2,3,1);
title('Azimuth - Largest Eigenvalue');
rose(ang1*pi/180,100);

subplot(2,3,2);
title('Azimuth - Intermediate Eigenvalue');
rose(ang2*pi/180,100);

subplot(2,3,3);
title('Azimuth - Smallest Eigenvalue');
rose(ang3*pi/180,100);
```

```
nskip=1;
if nskip == 1;
  else;
neig1=0;
neig2=0;
neig3=0;
for k=1:kfin;
  if de1(k) >= 0.5*mxde1;
    neig1=neig1+1;
    angm1(neig1)=ang1(k);
  else;
  end;
  if de2(k) >= 0.5*mxde2;
    neig2=neig2+1;
    angm2(neig2)=ang2(k);
  else;
  end;
  if de3(k) >= 0.5*mxde3;
    neig3=neig3+1;
    angm3(neig3)=ang3(k);
  else;
  end;
end;
subplot(2,3,4);
title('Azimuth - Largest Eigenvalue,50%
      Threshold');
rose(angm1*pi/180,100);
subplot(2,3,5);
title('Azimuth - Intermediate Eigenvalue,
      50% Threshold');
rose(angm2*pi/180,100);
subplot(2,3,6);
title('Azimuth - Smallest Eigenvalue,50%
      Threshold');
rose(angm3*pi/180,100);
end;
```


Azimuth - Largest Eigenvalue
4
2
Azimuth - Intermediate Eigenvalue
5
2.5
Azimuth - Smallest Eigenvalue
40
20
Azimuth - Largest Eigenvalue
200000000000
100000000000
Azimuth - Intermediate Eigenvalue
20000000000
10000000000
Azimuth - Smallest Eigenvalue
4e-05
2e-05