Estimation of elastic properties of H313_HTI sample

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Introduction

Some bla bla bla here))

Add MLIB library

```
clear; close all; clc;
mlibfolder = '/home/ivan/Desktop/MLIB';
path(path, mlibfolder);
add_mlib_path;
```

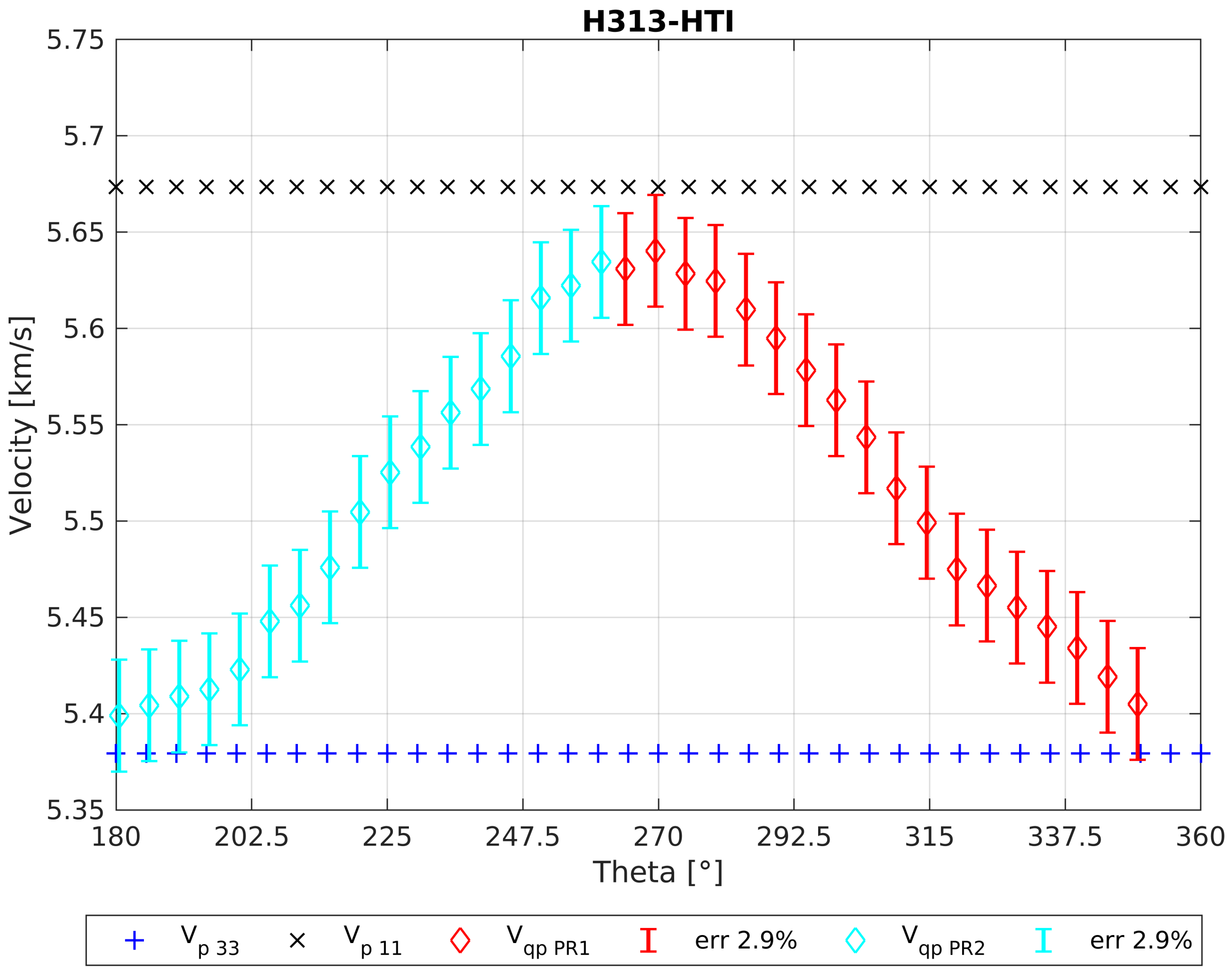
1. Upload the data

```
Sample = MLD('/remote/data/ivan/Ultrasonic_data/H313_HTI_ivan/Sample_H313_HTI_data.mat
Sample.Theta = Sample.Theta+90;
Sample.Theta(Sample.Theta>360) = Sample.Theta(Sample.Theta>360)-360;

%ind1 = [1:9 13:35];          % seria of measurements
%ind2 = [38:48 54:72];            % another at 90 degree
ind1 = 18:35;          % seria of measurements
ind2 = 56:72;            % another at 90 degree
```

Plot velocities

```
figure(1733)       % P velocities
fig = figure('Position', [1 1 700 550]);
plot (Sample.Theta, Sample.Vp33,'b+','MarkerSize', 7, 'LineWidth', 2)
hold on
plot (Sample.Theta, Sample.Vp11,'kx','MarkerSize', 7, 'LineWidth', 2)
plot (Sample.Theta(ind1)-0.5, Sample.Vqp(ind1),'rd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind1)));
errorbar(Sample.Theta(ind1)-0.5,Sample.Vqp(ind1),err,'r','LineStyle','none', 'LineWidt
plot (Sample.Theta(ind2)+0.5, Sample.Vqp(ind2),'cd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind2)));
errorbar(Sample.Theta(ind2)+0.5,Sample.Vqp(ind2),err,'c','LineStyle','none', 'LineWidt
xlabel('Theta [\circ]','LineWidth', 2)
ylabel('Velocity [km/s]', 'LineWidth', 2)
legend('V_{p 33}','V_{p 11}','V_{qp PR1}','err 2.9%','V_{qp PR2}','err 2.9%', 'Locatio
title('H313-HTI')
xticks(180:22.5:360)
xticklabels(180:22.5:360)
```

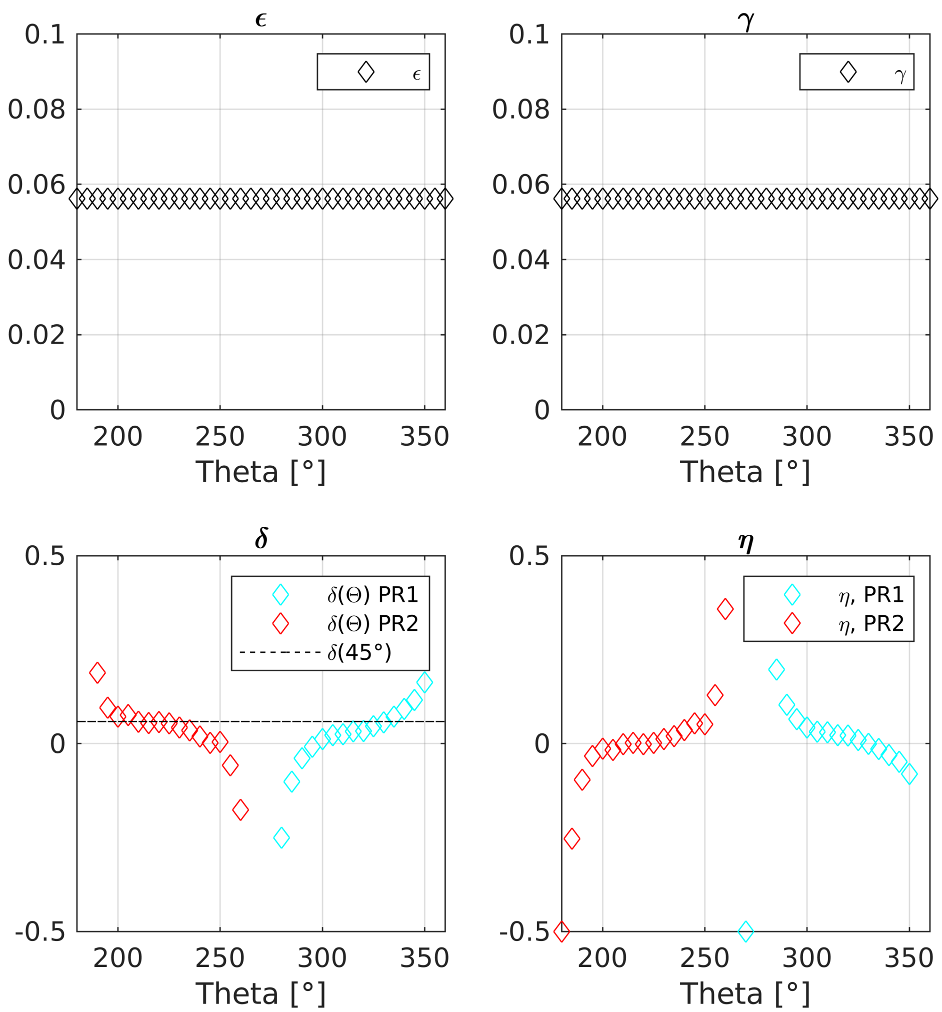
```
axis([180 360 5.35 5.75]);
grid on
```



2. Conventional analyses of Thomsen's parameters

```
C11 = Sample.rho*Sample.Vp11.^2;
C33 = Sample.rho*Sample.Vp33.^2;
C44 = Sample.rho*Sample.Vs31.^2;
C66 = Sample.rho*Sample.Vs21.^2;
Cqp = Sample.rho*Sample.Vqp.^2;
C12 = C11 - 2*C66;

ST2 = (sin(Sample.Theta/180*pi)).^2;
CT2 = (cos(Sample.Theta/180*pi)).^2;

A = (C11 + C44).*ST2 + (C33 + C44).*CT2;
B = (C11 - C44).*ST2 - (C33 - C44).*CT2;

C13 = sqrt(((2*Cqp-A).^2 - B.^2)./(4*ST2.*CT2)) - C44;
```

```
gamma   = (C66 - C44)./(2*C44);
epsilon = (C11 - C33)./(2*C33);
delta = ((C13+C44).^2 - (C33-C44).^2)./(2*C33.*(C33-C44));
eta = (epsilon-delta)./(1+2*delta);

ind = ((Sample.Theta == 45) + (Sample.Theta == 135) + (Sample.Theta == 225)+ (Sample.Th
delta45.mean = mean(delta(ind));
delta45.std = std(delta(ind));


figure(21);
fig = figure('Position', [1 1 550 550]);

subplot(2,2,1)
plot(Sample.Theta,epsilon,'kd');
xlabel('Theta [\circ]','LineWidth', 2)
axis([180 360 0 0.1]);
legend('\epsilon')
grid on
title('\epsilon')

subplot(2,2,2)
plot(Sample.Theta,gamma,'kd');
xlabel('Theta [\circ]','LineWidth', 2)
axis([180 360 0 0.1]);
legend('\gamma')
grid on
title('\gamma')

subplot(2,2,3)
plot(Sample.Theta(ind1),delta(ind1),'cd');
hold on
plot(Sample.Theta(ind2),delta(ind2),'rd');
plot(Sample.Theta,delta45.mean*ones(size(Sample.Theta)),'k--');
legend('\delta(\Theta) PR1', '\delta(\Theta) PR2', '\delta(45\circ)')
xlabel('Theta [\circ]','LineWidth', 2)
axis([180 360 -0.5 0.5]);
grid on
title('\delta')

subplot(2,2,4)
plot(Sample.Theta(ind1),eta(ind1),'cd');
hold on
plot(Sample.Theta(ind2),eta(ind2),'rd');
xlabel('Theta [\circ]','LineWidth', 2)
legend('\eta, PR1','\eta, PR2')
axis([180 360 -0.5 0.5]);
grid on
title('\eta')
```

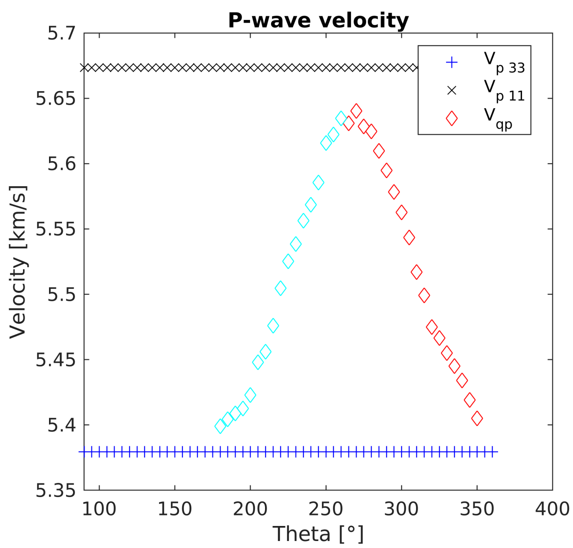


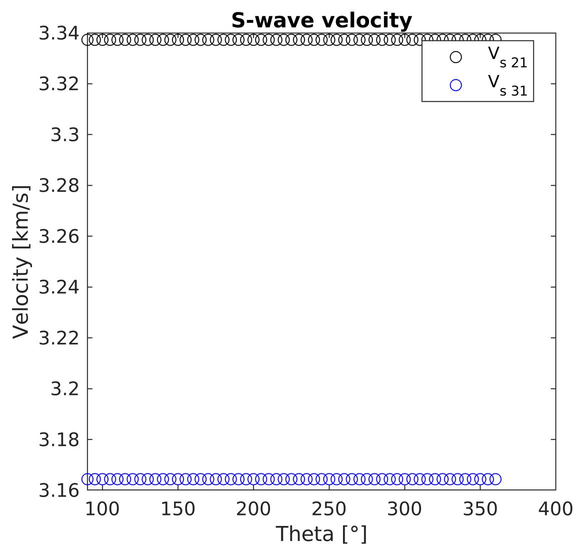
3. Least squares analysis of Thomsen's parameters

Visualize the data

```
figure(122)
fig = figure('Position', [1 1 1000 400]);
subplot(1,2,1)
plot(Sample.Theta, Sample.Vp33, '+b');
hold on
plot(Sample.Theta, Sample.Vp11, 'xk');
plot(Sample.Theta(ind1), Sample.Vqp(ind1), 'dr');
plot(Sample.Theta(ind2), Sample.Vqp(ind2), 'dc');
xlabel('Theta [\circ]')
ylabel('Velocity [km/s]')
legend('V_{p 33}', 'V_{p 11}', 'V_{qp}','Location','best')
title('P-wave velocity')

subplot(1,2,2)
```

```
plot(Sample.Theta, Sample.Vs21, 'ko');
hold on
plot(Sample.Theta, Sample.Vs31, 'bo');
xlabel('Theta [\circ]')
ylabel('Velocity [km/s]')
legend('V_{s 21}','V_{s 31}','Location','best')
title('S-wave velocity')
```





Assign C values

```
Sample.C11 = C11;
Sample.C33 = C33;
Sample.C44 = C44;
Sample.C66 = C66;
Sample.Vqp = Sample.Vqp;

ind = [ind1 ind2];
iSample.Theta = Sample.Theta(ind);
iSample.Vp33 = Sample.Vp33(ind);
iSample.Vp11 = Sample.Vp11(ind);
iSample.Vs31 = Sample.Vs31(ind);
iSample.Vs21 = Sample.Vs21(ind);
iSample.Vqp = Sample.Vqp(ind);
iSample.C11 = Sample.C11(ind);
iSample.C33 = Sample.C33(ind);
iSample.C44 = Sample.C44(ind);
iSample.C66 = Sample.C66(ind);
iSample.rho = Sample.rho;
```

Find optimum delta

```
testdelta = -0.1:0.001:0.2;
dtheta = -10:0.1:10;
tic
```

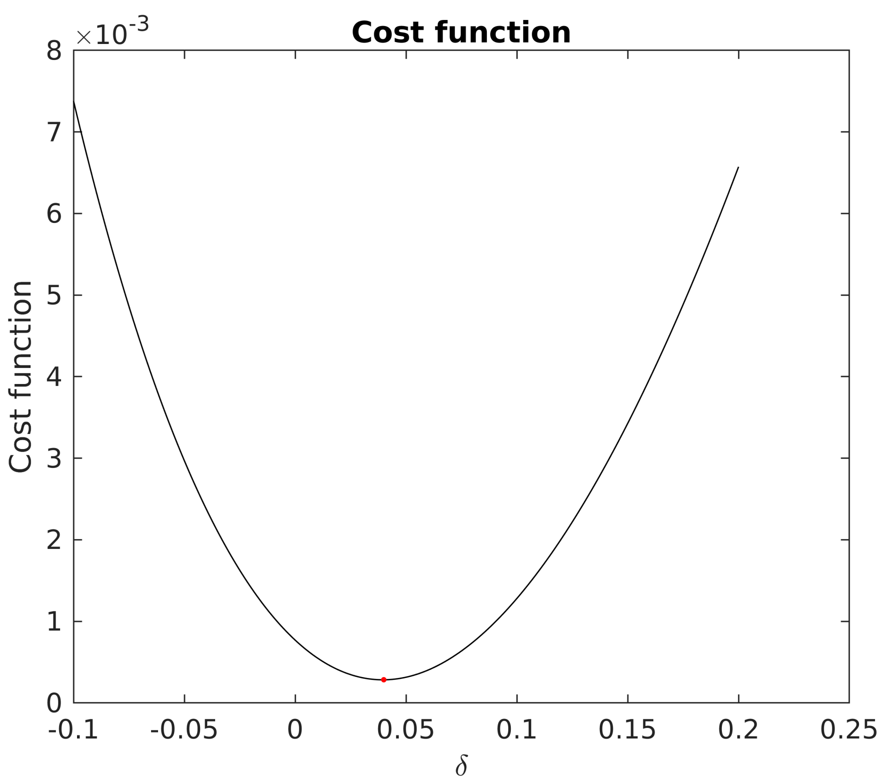
```
nSample = iSample;
JJ = zeros(length(dtheta),length(testdelta));
for i=1:length(dtheta)
    nSample.Theta = iSample.Theta + dtheta(i);
    J = costFunction_delta(nSample,testdelta);
    JJ(i,:) = J;
end
toc
```

```
Elapsed time is 0.236809 seconds.
```

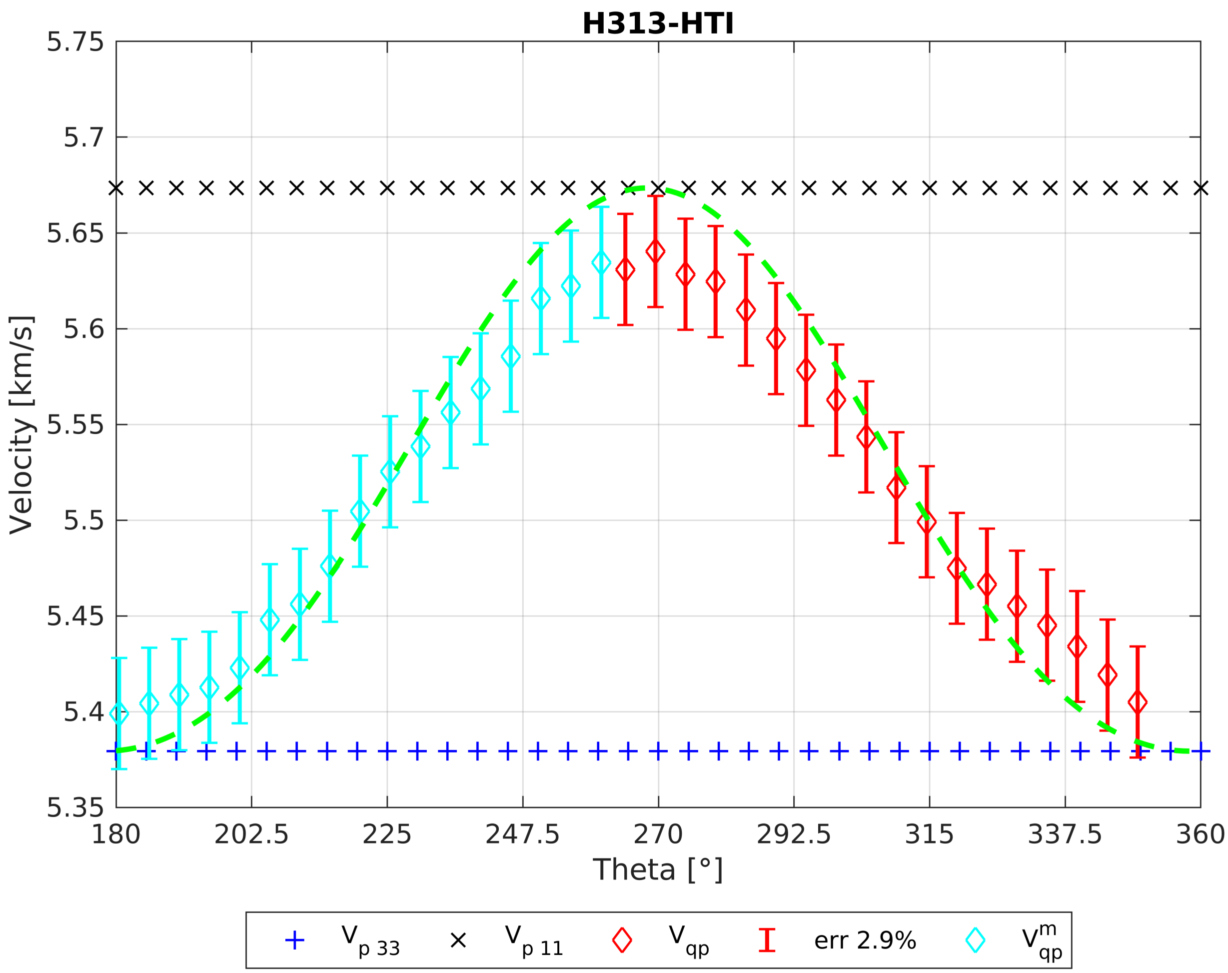
```
[~, minind] = min(JJ(:));
[inda, indd] = ind2sub(size(JJ),minind);

thetapl = dtheta(inda);
delta = testdelta(indd);
```

Plot final results

```
figure(343)
fig = figure('Position', [1 1 500 400]);
plot(testdelta, squeeze(JJ(inda,:)), 'k-');
hold on
plot(testdelta(indd), JJ(inda,indd), 'r.','MarkerSize', 7);
xlabel('\delta')
ylabel('Cost function')
title('Cost function')
```



```
nSample.Theta = 0:1:360;
Vqp = get_Vqp_VTI(nSample,delta);


figure(147)
fig = figure('Position', [1 1 700 550]);
plot (Sample.Theta, Sample.Vp33,'b+','MarkerSize', 7, 'LineWidth', 2)
hold on
plot (Sample.Theta, Sample.Vp11,'kx','MarkerSize', 7, 'LineWidth', 2)
plot (Sample.Theta(ind1)-0.5, Sample.Vqp(ind1),'rd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind1)));
errorbar(Sample.Theta(ind1)-0.5,Sample.Vqp(ind1),err,'r','LineStyle','none', 'LineWidtl
plot (Sample.Theta(ind2)+0.5, Sample.Vqp(ind2),'cd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind2)));
errorbar(Sample.Theta(ind2)+0.5,Sample.Vqp(ind2),err,'c','LineStyle','none', 'LineWidtl
plot(nSample.Theta-thetapl, Vqp, 'g--', 'LineWidth', 2)
xlabel('Theta [\circ]','LineWidth', 2)
ylabel('Velocity [km/s]', 'LineWidth', 2)
legend('V_{p 33}','V_{p 11}','V_{qp}','err 2.9%','V_{qp}^m', 'Location', 'southoutside
title('H313-HTI')
xticks(180:22.5:360)
xticklabels(180:22.5:360)
axis([180 360 5.35 5.75]);
grid on
```



3. Least squares analysis of Thomsen's parameters (weak anisotropy approximation)

```
Alpha   = linspace(5.35,5.45,101);
Delta   = linspace(-0.0,0.10,101);
Epsilon = linspace(0.02,0.12,101);
dTheta  = linspace(-5,5,26);

tic
J = costFunction_delta_weak(iSample,Alpha,Delta,Epsilon,dTheta);
toc
```

```
Elapsed time is 60.167498 seconds.
```

```
[~, ind] = min(J(:));
[inda,indd,inde,indt] = ind2sub(size(J),ind);
```

```
result.alpha = Alpha(inda);
result.delta = Delta(indd);
result.epsilon = Epsilon(inde);
result.dtheta = dTheta(indt);
```

3a. Alternative idea with L-BFGS-B method

```
save('/home/ivan/Desktop/MLIB/UMM/TempSample.mat','Sample');


x0  = [5.40 0.05 0.07   0];   % The starting point.
lb  = [5.35 0.0  0.02 -10];  % Lower bound on the variables.
ub  = [5.45 0.1  0.12 +10];  % Upper bound on the variables.

tic
x = lbfgsb(x0,lb,ub,'ComputeObjectiveSample','ComputeGradientSample',...
               [],'genericcallback','maxiter',80,'m',4,'factr',1e-12,...
               'pgtol',1e-5);
```

```
   1  0.000533
   2  0.000469
   3  0.000245
   4  0.000244
   5  0.000239
```

```
toc
```

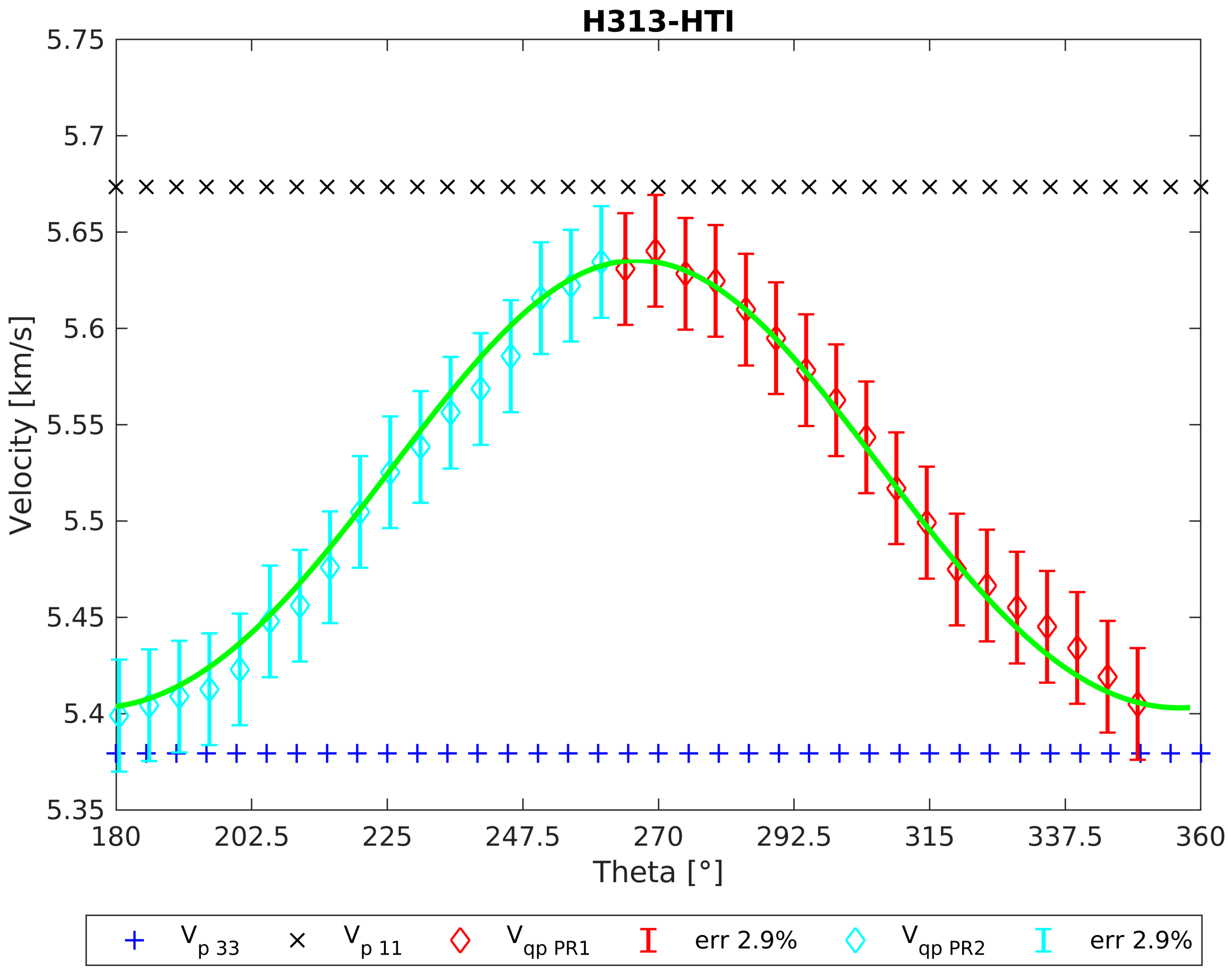
```
Elapsed time is 0.713724 seconds.
```

```


result.alpha = x(1);
result.delta = x(2);
result.epsilon = x(3);
result.dtheta = x(4);
```

Plot the result:

```
figure(27)
fig = figure('Position', [1 1 1200 800]);

nSample.Theta = 0:1:360;
Vqp = get_Vqp_VTI_weak(nSample,result.alpha,result.delta,result.epsilon,result.dtheta)

figure(144)
fig = figure('Position', [1 1 700 550]);
plot (Sample.Theta, Sample.Vp33,'b+','MarkerSize', 7, 'LineWidth', 2)
hold on
plot (Sample.Theta, Sample.Vp11,'kx','MarkerSize', 7, 'LineWidth', 2)
plot (Sample.Theta(ind1)-0.5, Sample.Vqp(ind1),'rd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind1)));
errorbar(Sample.Theta(ind1)-0.5,Sample.Vqp(ind1),err,'r','LineStyle','none', 'LineWidt
```

```
plot (Sample.Theta(ind2)+0.5, Sample.Vqp(ind2),'cd','MarkerSize', 7, 'LineWidth', 2)
err = 0.029*ones(size(Sample.Vqp(ind2)));
errorbar(Sample.Theta(ind2)+0.5,Sample.Vqp(ind2),err,'c','LineStyle','none', 'LineWidtl
plot(nSample.Theta-result.dtheta, Vqp, 'g-', 'LineWidth', 2)
xlabel('Theta [\circ]','LineWidth', 2)
ylabel('Velocity [km/s]', 'LineWidth', 2)
legend('V_{p 33}','V_{p 11}','V_{qp PR1}','err 2.9%','V_{qp PR2}','err 2.9%', 'Locatio
title('H313-HTI')
xticks(180:22.5:360)
xticklabels(180:22.5:360)
axis([180 360 5.35 5.75]);
```



4. Find errors of estimated parameters

```
% angle error std: 3 grad  =>> error in velocity 25 m/s
% error in velocity due to measurements =>> 15 m/s
% total error: 30 m
%                                     37 mrasurement 73
% variance for velocity error 30 m = 0.010;   0.0060
```

```
% variance for velocity error 100 m = 0.030   0.020

Alpha   = linspace(5.35,5.45,26);
Delta   = linspace(-0.0,0.10,26);
Epsilon = linspace(0.02,0.12,26);
dTheta  = linspace(-5,5,11);

x0  = [5.40 0.05 0.07   0];   % The starting point.
lb  = [5.35 0.0  0.02 -10];  % Lower bound on the variables.
ub  = [5.45 0.1  0.12 +10];  % Upper bound on the variables.

Theta = iSample.Theta;
iiSample = iSample;

clear test;

for i=1:1:100

    iiSample.Theta = Theta + 1*randn(size(Theta));
    Vqptrue = get_Vqp_VTI_weak(iiSample,result.alpha,result.delta,result.epsilon,result

    VqpE = Vqptrue.*(1+0.015*randn(size(Vqptrue)));
    iiSample.Vqp = VqpE;
    iiSample.Theta = Theta;

    %J = costFunction_delta_weak(iSample,Alpha,Delta,Epsilon,dTheta);

    %[~, ind] = min(J(:));
    %[inda,indd,inde,indt] = ind2sub(size(J),ind);



    %test.alpha(i) = Alpha(inda);
    %test.delta(i) = Delta(indd);
    %test.epsilon(i) = Epsilon(inde);
    %test.dtheta(i) = dTheta(indt);

    save('/home/ivan/Desktop/MLIB/UMM/TempSample.mat','iiSample');


    x = lbfgsb(x0,lb,ub,'ComputeObjectiveSample','ComputeGradientSample',...
               [],'genericcallback','maxiter',80,'m',4,'factr',1e-12,...
               'pgtol',1e-5);


    test.alpha(i) = x(1);
    test.delta(i) = x(2);
    test.epsilon(i) = x(3);
    test.dtheta(i) = x(4);

end
```

```
1  0.00353
```

2	0.00348
3	0.0033
4	0.00329
5	0.00325
6	0.00325
7	0.00325
8	0.00325
9	0.00325
10	0.00325
11	0.00325
12	0.00325
13	0.00325
14	0.00325
15	0.00325
16	0.00325
17	0.00325
18	0.00325
19	0.00324
20	0.00324
21	0.00324
22	0.00322
23	0.00322
24	0.00321
25	0.00321
26	0.00321
27	0.00321
28	0.00321
29	0.00321
30	0.00321
31	0.00321
32	0.00321
33	0.00321
1	0.0036
2	0.0036
3	0.00359
4	0.00359
5	0.00359
6	0.00359
7	0.00359
8	0.00359
9	0.00359
10	0.00359
11	0.00359
12	0.00359
13	0.00359
14	0.00359
15	0.00359
16	0.00358
17	0.00358
18	0.00358
19	0.00358
20	0.00358
21	0.00358
22	0.00358
1	0.00292
2	0.00292
3	0.0029
4	0.00289
5	0.00288
6	0.00288
7	0.00288
8	0.00288
9	0.00288
10	0.00288
11	0.00288

12	0.00288
13	0.00288
14	0.00288
15	0.00288
16	0.00288
17	0.00288
18	0.00288
19	0.00287
20	0.00286
21	0.00286
22	0.00285
23	0.00285
24	0.00285
25	0.00285
26	0.00285
27	0.00285
1	0.00369
2	0.00367
3	0.00355
4	0.00353
5	0.00348
6	0.00348
7	0.00348
8	0.00348
9	0.00348
10	0.00348
11	0.00348
12	0.00348
13	0.00348
14	0.00348
15	0.00347
16	0.00347
17	0.00347
18	0.00346
19	0.00346
20	0.00346
21	0.00346
22	0.00346
23	0.00346
24	0.00346
25	0.00346
26	0.00346
1	0.0036
2	0.00343
3	0.00324
4	0.00306
5	0.003
6	0.00299
7	0.00299
8	0.00299
9	0.00299
10	0.00299
11	0.00299
12	0.00299
13	0.00299
14	0.00299
15	0.00299
16	0.00299
17	0.00299
18	0.00299
19	0.00299
20	0.00298
21	0.00296
22	0.00296
23	0.00296

24	0.00296
25	0.00296
1	0.00319
2	0.00313
3	0.00292
4	0.00291
5	0.00286
6	0.00286
7	0.00286
8	0.00286
9	0.00286
10	0.00286
11	0.00286
12	0.00286
13	0.00286
14	0.00286
15	0.00286
16	0.00286
17	0.00285
18	0.00285
19	0.00283
20	0.00281
21	0.00277
22	0.00274
23	0.00272
24	0.00272
25	0.00272
26	0.00272
27	0.00272
28	0.00272
29	0.00272
1	0.00389
2	0.00384
3	0.00357
4	0.00352
5	0.0034
6	0.0034
7	0.00339
8	0.00339
9	0.00339
10	0.00339
11	0.00339
12	0.00339
13	0.00339
14	0.00337
15	0.00332
16	0.00328
17	0.00327
18	0.00327
19	0.00327
20	0.00327
21	0.00327
22	0.00327
23	0.00327
24	0.00327
25	0.00327
26	0.00327
27	0.00327
28	0.00327
29	0.00327
30	0.00327
31	0.00327
32	0.00327
1	0.00276
2	0.00271

3	0.00252
4	0.0025
5	0.00243
6	0.00243
7	0.00243
8	0.00243
1	0.00373
2	0.00372
3	0.00367
4	0.00366
5	0.00364
6	0.00364
7	0.00364
8	0.00364
9	0.00364
10	0.00364
11	0.00364
12	0.00364
13	0.00364
14	0.00363
15	0.00361
16	0.00359
17	0.00358
18	0.00358
19	0.00358
20	0.00358
21	0.00358
22	0.00358
1	0.00374
2	0.00373
3	0.00371
4	0.0037
5	0.00369
6	0.00369
7	0.00369
8	0.00369
9	0.00369
10	0.00369
11	0.00369
12	0.00369
13	0.00368
14	0.00368
15	0.00368
16	0.00367
17	0.00367
18	0.00366
19	0.00366
20	0.00364
21	0.00361
22	0.00354
23	0.0035
24	0.00344
25	0.00344
26	0.00343
27	0.00343
28	0.00343
29	0.00343
1	0.00276
2	0.00272
3	0.0026
4	0.00259
5	0.00256
6	0.00256
7	0.00256
8	0.00256

9	0.00256
10	0.00256
11	0.00256
12	0.00256
13	0.00256
14	0.00256
15	0.00256
16	0.00256
17	0.00256
18	0.00256
19	0.00255
20	0.00255
21	0.00255
22	0.00255
23	0.00255
24	0.00254
25	0.00254
26	0.00254
27	0.00254
28	0.00254
29	0.00254
30	0.00254
31	0.00254
32	0.00254
1	0.00376
2	0.00369
3	0.00344
4	0.00343
5	0.00337
6	0.00337
7	0.00337
8	0.00337
9	0.00337
10	0.00337
11	0.00337
12	0.00337
13	0.00337
14	0.00337
15	0.00337
16	0.00337
17	0.00337
18	0.00336
19	0.00336
20	0.00335
21	0.00332
22	0.00327
23	0.00326
24	0.00325
25	0.00325
26	0.00325
27	0.00325
28	0.00325
1	0.00311
2	0.00308
3	0.00298
4	0.00297
5	0.00292
6	0.00292
7	0.00292
8	0.00292
9	0.00292
10	0.00292
11	0.00292
12	0.00292
13	0.00292

14	0.00292
15	0.00292
16	0.00292
17	0.00292
18	0.00292
19	0.00292
20	0.00292
21	0.00292
22	0.00292
23	0.00292
24	0.00292
25	0.00292
26	0.00292
1	0.00378
2	0.00369
3	0.00338
4	0.00337
5	0.00333
6	0.00333
7	0.00333
8	0.00333
9	0.00333
10	0.00333
11	0.00333
12	0.00333
13	0.00333
14	0.00333
15	0.00333
16	0.00332
17	0.00331
18	0.0033
19	0.0033
20	0.0033
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16	0.00266
17	0.00265
18	0.00264
19	0.00263
20	0.00263
21	0.00262
22	0.00262
23	0.00262
1	0.00348
2	0.00345
3	0.00328
4	0.00322
5	0.00311
6	0.00311
7	0.00311
8	0.00311
9	0.00311
10	0.00311
11	0.00311
12	0.00311
13	0.00311
14	0.00311
15	0.00311
16	0.00309
17	0.00307
18	0.00304
19	0.00299
20	0.00294
21	0.00293
22	0.00293
1	0.00391
2	0.00387
3	0.00372
4	0.00369
5	0.00361
6	0.00361
7	0.00361

8	0.00361
9	0.00361
10	0.00361
11	0.00361
12	0.00361
13	0.00361
14	0.00361
15	0.00361
16	0.00361
17	0.00361
18	0.00361
19	0.00361
20	0.00361
21	0.0036
22	0.00359
23	0.00359
24	0.00359
25	0.00359
26	0.00359
27	0.00359
28	0.00359
29	0.00359
30	0.00359
1	0.00414
2	0.00413
3	0.00408
4	0.00407
5	0.00404
6	0.00404
7	0.00404
8	0.00404
1	0.00376
2	0.00373
3	0.00362
4	0.0036
5	0.00355
6	0.00355
7	0.00355
8	0.00355
9	0.00355
10	0.00355
11	0.00355
12	0.00355
13	0.00355
14	0.00355
15	0.00355
16	0.00355
17	0.00355
18	0.00355
19	0.00354
20	0.00353
21	0.00351
22	0.00351
23	0.00351
24	0.00351
25	0.00351
26	0.00351
1	0.00307
2	0.003
3	0.00276
4	0.00276
5	0.00275
6	0.00275
1	0.0053
2	0.00512

3	0.00447
4	0.00446
5	0.00445
6	0.00445
7	0.00445
8	0.00445
9	0.00445
10	0.00445
11	0.00445
12	0.00445
13	0.00445
14	0.00445
15	0.00445
16	0.00445
17	0.00445
18	0.00445
19	0.00444
20	0.00443
21	0.00442
22	0.00442
23	0.00442
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26	0.00442
27	0.00442
28	0.00442
29	0.00442
30	0.00442
31	0.00442
1	0.0037
2	0.00361
3	0.00326
4	0.00326
5	0.00325
6	0.00325
7	0.00325
8	0.00325
9	0.00325
10	0.00325
11	0.00325
12	0.00325
13	0.00325
14	0.00325
15	0.00325
16	0.00325
17	0.00325
18	0.00325
19	0.00325
20	0.00325
21	0.00324
22	0.00324
23	0.00324
24	0.00324
25	0.00324
26	0.00324
27	0.00324
1	0.00431
2	0.00426
3	0.00405
4	0.00403
5	0.00395
6	0.00395
7	0.00395
8	0.00395
9	0.00395

10	0.00395
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13	0.00395
14	0.00395
15	0.00394
16	0.00393
17	0.00393
18	0.00391
19	0.00387
20	0.00385
21	0.00384
22	0.00384
23	0.00384
24	0.00384
25	0.00384
1	0.0033
2	0.00328
3	0.00318
4	0.00317
5	0.00313
6	0.00313
7	0.00313
8	0.00313
1	0.00419
2	0.00417
3	0.00408
4	0.00407
5	0.00405
6	0.00405
7	0.00405
8	0.00405
9	0.00405
10	0.00405
11	0.00405
12	0.00405
13	0.00405
14	0.00404
15	0.00404
16	0.00404
17	0.00403
18	0.00402
19	0.00399
20	0.00396
21	0.00395
22	0.00393
23	0.00392
24	0.00392
25	0.00392
1	0.00291
2	0.00289
3	0.00282
4	0.00282
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6	0.00282
7	0.00282
8	0.00282
9	0.00282
10	0.00282
11	0.00282
12	0.00281
13	0.00281
14	0.00281
15	0.00281
16	0.0028

17	0.0028
18	0.00279
19	0.00279
20	0.00279
21	0.00279
22	0.00279
23	0.00279
24	0.00279
25	0.00279
26	0.00279
1	0.00438
2	0.00427
3	0.00391
4	0.00389
5	0.00381
6	0.00381
7	0.00381
8	0.00381
9	0.00381
10	0.00381
11	0.00381
12	0.00381
13	0.00381
14	0.00381
15	0.00381
16	0.0038
17	0.0038
18	0.0038
19	0.00379
20	0.00378
21	0.00377
22	0.00374
23	0.00369
24	0.00369
25	0.00367
26	0.00366
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31	0.00366
32	0.00366
33	0.00366
34	0.00366
1	0.00487
2	0.00479
3	0.00449
4	0.00449
5	0.00448
6	0.00448
1	0.00433
2	0.00428
3	0.00409
4	0.00407
5	0.004
6	0.004
7	0.004
8	0.004
9	0.004
10	0.004
11	0.004
12	0.004
13	0.004
14	0.004
15	0.004

16	0.004
17	0.004
18	0.00399
19	0.00399
20	0.00399
21	0.00399
22	0.00399
1	0.00304
2	0.00299
3	0.00281
4	0.0028
5	0.00278
6	0.00278
7	0.00278
8	0.00278
9	0.00278
10	0.00278
11	0.00277
12	0.00277
13	0.00277
14	0.00277
15	0.00276
16	0.00274
17	0.00272
18	0.00269
19	0.00268
20	0.00268
21	0.00268
22	0.00267
23	0.00267
24	0.00267
25	0.00267
26	0.00267
27	0.00267
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29	0.00267
30	0.00267
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3	0.00351
4	0.00351
5	0.00351
6	0.00351
7	0.00351
8	0.00351
9	0.00351
10	0.00351
11	0.00351
12	0.00351
13	0.00351
14	0.00351
15	0.00351
16	0.0035
17	0.0035
18	0.0035
19	0.0035
20	0.0035
21	0.0035
22	0.0035
23	0.0035
1	0.00328
2	0.00324
3	0.0031
4	0.00309
5	0.00305

6	0.00305
7	0.00305
8	0.00305
1	0.00343
2	0.00342
3	0.00337
4	0.00337
5	0.00336
6	0.00336
7	0.00336
8	0.00336
1	0.00267
2	0.00262
3	0.00244
4	0.00244
5	0.00244
6	0.00244
7	0.00244
8	0.00244
9	0.00244
10	0.00244
11	0.00244
12	0.00244
13	0.00244
14	0.00244
15	0.00244
16	0.00244
17	0.00244
18	0.00244
19	0.00243
20	0.00243
21	0.00243
22	0.00243
23	0.00242
24	0.00242
25	0.00241
26	0.0024
27	0.0024
28	0.0024
29	0.0024
30	0.0024
31	0.0024
32	0.0024
33	0.0024
1	0.00413
2	0.00407
3	0.0038
4	0.0038
5	0.0038
6	0.0038
7	0.0038
8	0.0038
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2	0.00239
3	0.00235
4	0.00233
5	0.00231
6	0.00231
7	0.00231
8	0.00231
1	0.00414
2	0.00411
3	0.00398
4	0.00398
5	0.00397

6	0.00397
7	0.00397
8	0.00397
9	0.00397
10	0.00397
11	0.00397
12	0.00397
13	0.00397
14	0.00396
15	0.00395
16	0.00393
17	0.00388
18	0.00385
19	0.00381
20	0.00379
21	0.00379
22	0.00379
23	0.00379
24	0.00379
25	0.00379
1	0.00383
2	0.00382
3	0.00376
4	0.00376
5	0.00374
6	0.00374
7	0.00374
8	0.00374
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3	0.00394
4	0.00393
5	0.00391
6	0.00391
7	0.00391
8	0.00391
9	0.00391
10	0.00391
11	0.00391
12	0.00391
13	0.00391
14	0.00391
15	0.00391
16	0.00391
17	0.0039
18	0.0039
19	0.0039
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21	0.00389
22	0.00389
23	0.00389
24	0.00389
25	0.00389
26	0.00389
27	0.00389
1	0.00373
2	0.00372
3	0.00367
4	0.00367
5	0.00366
6	0.00366
7	0.00366
8	0.00366
9	0.00366
10	0.00366

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12	0.00365
13	0.00365
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16	0.00357
17	0.00351
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22	0.0034
23	0.0034
24	0.0034
1	0.00351
2	0.00347
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6	0.00329
7	0.00329
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9	0.00329
10	0.00329
11	0.00329
12	0.00329
13	0.00329
14	0.00328
15	0.00326
16	0.00324
17	0.00322
18	0.0032
19	0.00319
20	0.00318
21	0.00316
22	0.00316
23	0.00316
24	0.00316
25	0.00316
1	0.00519
2	0.00514
3	0.00494
4	0.00492
5	0.00483
6	0.00483
7	0.00483
8	0.00483
9	0.00483
10	0.00483
11	0.00483
12	0.00483
13	0.00483
14	0.00483
15	0.00483
16	0.00483
17	0.00483
18	0.00483
19	0.00483
20	0.00483
21	0.00483
22	0.00482
23	0.00482
24	0.00482
25	0.00482
26	0.00482

1	0.00301
2	0.003
3	0.00296
4	0.00295
5	0.00294
6	0.00294
7	0.00294
8	0.00294
9	0.00294
10	0.00294
11	0.00294
12	0.00294
13	0.00294
14	0.00294
15	0.00294
16	0.00294
17	0.00294
18	0.00293
19	0.00292
20	0.0029
21	0.00286
22	0.00283
23	0.00282
24	0.00282
25	0.00282
26	0.00282
27	0.00282
1	0.00429
2	0.00425
3	0.00415
4	0.00414
5	0.00414
6	0.00414
7	0.00414
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9	0.00414
10	0.00414
11	0.00414
12	0.00414
13	0.00414
14	0.00414
15	0.00414
16	0.00414
17	0.00414
18	0.00413
19	0.00413
20	0.00413
21	0.00413
22	0.00413
23	0.00413
1	0.00362
2	0.00352
3	0.00325
4	0.00325
5	0.00324
6	0.00324
7	0.00324
8	0.00324
9	0.00324
10	0.00324
11	0.00324
12	0.00323
13	0.00323
14	0.00322
15	0.00322

16	0.00321
17	0.00321
18	0.0032
19	0.00319
20	0.00318
21	0.00317
22	0.00316
23	0.00316
24	0.00316
25	0.00316
26	0.00316
27	0.00316
28	0.00316
1	0.00369
2	0.00367
3	0.00361
4	0.00361
5	0.00359
6	0.00359
7	0.00359
8	0.00359
9	0.00359
10	0.00359
11	0.00359
12	0.00359
13	0.00359
14	0.00358
15	0.00358
16	0.00357
17	0.00355
18	0.00354
19	0.00354
20	0.00354
21	0.00354
22	0.00354
23	0.00354
24	0.00354
1	0.00301
2	0.00288
3	0.00286
4	0.00276
5	0.00276
6	0.00276
1	0.00239
2	0.00237
3	0.00231
4	0.00229
5	0.00225
6	0.00225
7	0.00225
8	0.00225
9	0.00225
10	0.00225
11	0.00225
12	0.00225
13	0.00225
14	0.00224
15	0.00224
16	0.00224
17	0.00224
18	0.00224
19	0.00223
20	0.00222
21	0.0022
22	0.00217

23	0.00216
24	0.00216
25	0.00216
26	0.00216
27	0.00216
28	0.00216
29	0.00216
30	0.00216
31	0.00216
32	0.00216
1	0.0037
2	0.00366
3	0.00354
4	0.00353
5	0.0035
6	0.0035
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12	0.0035
13	0.0035
14	0.0035
15	0.0035
16	0.0035
17	0.0035
18	0.00349
19	0.00349
20	0.00349
21	0.00348
22	0.00348
23	0.00348
24	0.00347
25	0.00346
26	0.00346
27	0.00346
28	0.00346
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31	0.00346
32	0.00346
33	0.00346
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2	0.00272
3	0.00272
4	0.00272
5	0.00272
6	0.00272
7	0.00272
8	0.00272
9	0.00272
10	0.00272
11	0.00272
12	0.00271
13	0.00271
14	0.0027
15	0.0027
16	0.0027
17	0.0027
18	0.0027
19	0.0027
1	0.00292
2	0.00288
3	0.00269

4	0.00266
5	0.00256
6	0.00256
7	0.00256
8	0.00256
9	0.00256
1	0.00271
2	0.00264
3	0.00244
4	0.00244
5	0.00241
6	0.00241
7	0.00241
8	0.00241
9	0.00241
10	0.00241
11	0.00241
12	0.00241
13	0.00241
14	0.0024
15	0.00239
16	0.00235
17	0.00235
18	0.00233
19	0.00232
20	0.00232
21	0.00232
22	0.00232
23	0.00232
24	0.00232
25	0.00232
26	0.00232
1	0.00261
2	0.00255
3	0.00236
4	0.00236
5	0.00236
6	0.00236
7	0.00236
8	0.00236
1	0.00346
2	0.00339
3	0.00315
4	0.00313
5	0.00306
6	0.00306
7	0.00306
8	0.00306
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10	0.00306
11	0.00306
12	0.00306
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14	0.00306
15	0.00306
16	0.00306
17	0.00306
18	0.00305
19	0.00305
20	0.00305
21	0.00304
22	0.00303
23	0.00303
24	0.00303
25	0.00303

26	0.00303
27	0.00303
28	0.00303
29	0.00303
30	0.00303
1	0.00394
2	0.00393
3	0.00391
4	0.0039
5	0.00389
6	0.00389
7	0.00389
8	0.00389
9	0.00389
10	0.00389
11	0.00389
12	0.00389
13	0.00389
14	0.00389
15	0.00389
16	0.00389
17	0.00388
18	0.00387
19	0.00387
20	0.00385
21	0.00385
22	0.00385
23	0.00384
24	0.00384
25	0.00384
26	0.00384
27	0.00384
28	0.00384
29	0.00384
30	0.00384
31	0.00384
1	0.00327
2	0.00324
3	0.00315
4	0.00315
5	0.00313
6	0.00313
7	0.00313
8	0.00313
9	0.00313
10	0.00313
11	0.00313
12	0.00313
13	0.00313
14	0.00313
15	0.00312
16	0.00312
17	0.00311
18	0.0031
19	0.0031
20	0.00309
21	0.00309
22	0.00308
23	0.00308
24	0.00308
25	0.00308
26	0.00308
27	0.00308
28	0.00308
29	0.00308

```
30  0.00308
 1  0.00431
 2  0.00423
 3  0.00398
 4  0.00398
 5  0.00397
 6  0.00397
 7  0.00397
 8  0.00397
 9  0.00397
10  0.00397
11  0.00397
12  0.00397
13  0.00397
14  0.00397
15  0.00397
16  0.00397
17  0.00397
18  0.00397
19  0.00397
20  0.00396
21  0.00396
22  0.00396
23  0.00396
24  0.00396
 1  0.0033
 2  0.00327
 3  0.00318
 4  0.00318
 5  0.00317
 6  0.00317
 7  0.00317
 8  0.00317
 9  0.00317
10  0.00317
11  0.00317
12  0.00316
13  0.00315
14  0.00309
15  0.00301
16  0.003
17  0.00299
18  0.00299
19  0.00298
20  0.00298
21  0.00298
22  0.00298
23  0.00298
```

Plot results:

```
figure(33)
subplot(2,2,1);
histfit(test.alpha',21)
xlabel('V_{P0}, [m/s]')
dist = fitdist(test.alpha(1:100)','Normal');
disp(['ALPHA: Relative error: ' num2str(abs(result.alpha-dist.mu)/result.alpha*100) '%
```

```
ALPHA: Relative error: 0.016694%
```

```
alpha_err = 2*dist.sigma;
title(['\mu=' num2str(dist.mu,4) ' \sigma=' num2str(dist.sigma,2)])

subplot(2,2,2);
histfit(test.delta',11)
xlabel('\delta')
dist = fitdist(test.delta(1:100)','Normal');
disp(['DELTA: Relative error: ' num2str(abs(result.delta-dist.mu)/result.delta*100) '%
```

```
DELTA: Relative error: 6.1698%
```

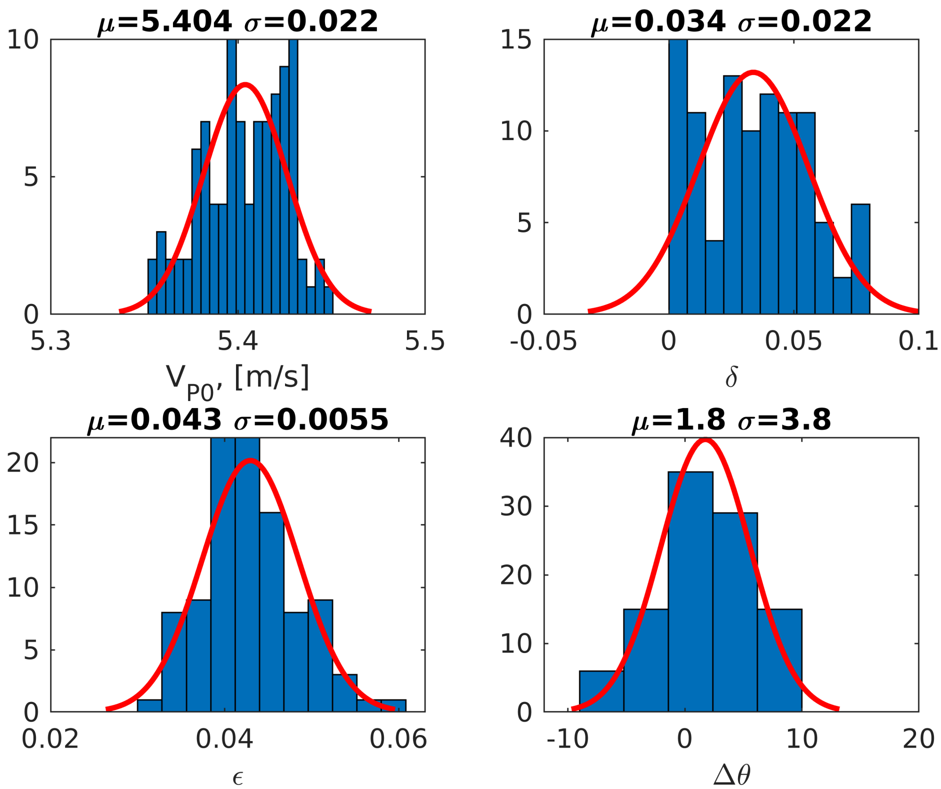
```
delta_err = 2*dist.sigma;
title(['\mu=' num2str(dist.mu,2) ' \sigma=' num2str(dist.sigma,2)])

subplot(2,2,3);
histfit(test.epsilon',11)
xlabel('\epsilon')
dist = fitdist(test.epsilon(1:100)','Normal');
disp(['EPSILON: Relative error: ' num2str(abs(result.epsilon-dist.mu)/result.epsilon*10
```

```
EPSILON: Relative error: 0.11007%
```

```
epsilon_err = 2*dist.sigma;
title(['\mu=' num2str(dist.mu,2) ' \sigma=' num2str(dist.sigma,2)])
%
subplot(2,2,4);
histfit(test.dtheta',5)
xlabel('\Delta\theta')
dist = fitdist(test.dtheta(1:100)','Normal');
disp(['DTHETA: Absolute error: ' num2str(result.dtheta-dist.mu)])
```

```
DTHETA: Absolute error: 0.044541
```

```
dtheta_err = 2*dist.sigma;
title(['\mu=' num2str(dist.mu,2) ' \sigma=' num2str(dist.sigma,2)])
```



μ=5.404 σ=0.022
μ=0.034 σ=0.022
V_{P0}, [m/s]
δ
μ=0.043 σ=0.0055
μ=1.8 σ=3.8
ϵ
Δθ