Evaluate the influence of arrival-time uncertainties on event localization

Introduction

This script reproduces Figures 7 published in the paper:

Abakumov, I., Roeser, A., and S. A. Shapiro (2020) The arrival time picking uncertainty: theoretical estimationsand their application to microseismic data, Geophysics

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Add MLIB library

In this project we use several functions from MLIB library.

You can download the whole library at github:

https://github.com/Abakumov/MLIB

Add MLIB library

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

Load event file

```
Events = MLD('/local_ssd/ivan/ESG/mat/Events_ivan_STALTA.mat');
```

Make G-file

```
G=GridClass;

% [m]         [m]           [m]           [s]
G.x0=-200;  G.y0=-650;  G.z0=1400;     G.t0 = 0.00;          % initial point
G.nx=201;   G.ny=251;   G.nz=126;      G.nt = 6000;          % grid size
G.dx=4;     G.dy=4;     G.dz=4;        G.dt = 0.00025;       % grid step (meter)

G.gridInfo;
```

```
Information about grid:
x0=-200, dx=4, Nx=201.
y0=-650, dy=4, Ny=251.
z0=1400, dz=4, Nz=126.
t0=0, dt=0.00025, Nt=6000.
```

```
G.setGrid;
```

```
Gold = oldGrid(G);
```

Load event file

```
Events = MLD('/local_ssd/ivan/ESG/mat/Events_sponsor.mat');

PTTI = MLD('/local_ssd/ivan/ESG/tti_tables/PTTIFSM.mat');

STTI = MLD('/local_ssd/ivan/ESG/tti_tables/STTIFSM.mat');

Gtti = MLD('/local_ssd/ivan/ESG/tti_tables/G_file.mat');
```

Acquisition

```
acq.sx = Events(1).SensorEasting;
acq.sy = Events(1).SensorNorthing;
acq.sz = Events(1).SensorDepth;
```

Create traveltime

```
nsta = length(acq.sx);
Ptti = zeros(G.nx,G.ny,G.nz,nsta);
Stti = zeros(G.nx,G.ny,G.nz,nsta);

for s=1:nsta
    for i=1:G.nx
        for j=1:G.ny
            off = sqrt((acq.sx(s)-G.xx(i)).^2 + (acq.sy(s)-G.yy(j)).^2);
            goff = x2grid(off,Gtti.x0,Gtti.dx,Gtti.nx);
            Ptti(i,j,:,s) = squeeze(PTTI(goff,1:4:501,s));
            Stti(i,j,:,s) = squeeze(STTI(goff,1:4:501,s));
        end
    end
end
```

Start localization of events

```
event =  801;
```

Upload traveltimes of P- and S-waves

```
% P-wave arrival time (in seconds)
Tp(1:nsta,1) = 0;
for i=1:length(Events(event).PTime)
    Tp(i) = Events(event).PTime(i);
end

% S-wave arrival time (in seconds)
Ts(1:nsta,1) = 0;
for i=1:length(Events(event).STime)
    Ts(i) = Events(event).STime(i);
```

```
end
```

Create SNR

```
tmin = 0.4;
tmax = 0.7;

ind1 = ((G.tt > tmin) == 1);
ind2 = ((G.tt < tmax) == 1);
ind = (ind1 + ind2 == 2);

Tx = zeros(G.nt,31);
Ty = zeros(G.nt,31);
Tz = zeros(G.nt,31);

Tx(ind,:) = Events(event).tracesx(ind,:);
Ty(ind,:) = Events(event).tracesy(ind,:);
Tz(ind,:) = Events(event).tracesz(ind,:);

get_beta = @(signal,dt)(   sqrt(sum((diff(signal,1)/dt).^2)/sum(signal.^2))   );
get_CRB = @(SNR,beta)(   1./beta.^2./SNR   );

[~, indm] = max(abs(Tx));
Tm = G.tt(indm);
fd = 400;   % dominant frequency == beta/2/pi
Td = 1/400;  % dominant period


W = zeros(1,31);
N0 = zeros(1,31);
Beta = zeros(1,31);

for i=2:31
    tnmin = x2grid(Tp(i)-0.02,  G.t0, G.dt, G.nt);
    tnmax = x2grid(Tp(i)-0.005, G.t0, G.dt, G.nt);

    tsmin = x2grid(Tm(i)-Td,    G.t0, G.dt, G.nt);
    tsmax = x2grid(Tm(i)+Td,    G.t0, G.dt, G.nt);

    indn = tnmin:tnmax;
    inds = tsmin:tsmax;

    signal = Tx(inds,i);
    noise  = Tx(indn,i);

    N0(i) = var(noise)*G.dt;
    W(i)  = sum(signal.^2)*G.dt;
    Beta(i) = get_beta(signal,G.dt);
end

W = W-N0*length(inds);

SNR = W./N0;
```

```
SNRdb = 10*log10(SNR);
beta = mean(Beta(2:31));
CRB = get_CRB(SNR,beta);
err = sqrt(CRB)*1000*1.96*3; % in ms, + 95% confidence interval
```

Compute PDF

```
weight = zeros(size(err));
weight(err <= 0.1) = 2;
weight((err > 0.1) + (err <= 0.2) == 2) = 1;
weight((err > 0.2) + (err <= 0.3) == 2) = .5;
weight(err > 0.3) = .25;
weight(1) = 1;


dTp(1:nsta,1) = 0.003;            % Accuracy of P-wave arrival time (in seconds)
dTs(1:nsta,1) = 0.003;            % Accuracy of S-wave arrival time (in seconds)

pdfT = zeros(G.nx,G.ny,G.nz);
for s=1:nsta
    if Tp(s)>0
        pdfT = pdfT + Tp(s) - Ptti(:,:,:,s);
    end
    if Ts(s)>0
        pdfT = pdfT + Ts(s) - Stti(:,:,:,s);
    end
end
pdfT = pdfT/(sum(Tp>0)+sum(Ts>0));


pdf = zeros(G.nx, G.ny, G.nz);
for s=1:nsta
    if Tp(s)>0
        pdf = pdf - ((Tp(s)-Ptti(:,:,:,s)-pdfT)/dTp(s)).^2/2;
    end
    if Ts(s)>0
        pdf = pdf - ((Ts(s)-Stti(:,:,:,s)-pdfT)/dTs(s)).^2/2;
    end
end
pdf = exp(pdf)/(sum(exp(pdf(:))));
pdf1 = pdf;

%Find optimal location
[pdfi1, pdfj1, pdfk1, pdfx1, pdfy1, pdfz1] = get_max_of_pdf(pdf1, G);
T0pdf = pdfT(pdfi1,pdfj1,pdfk1);

PDF1.sx = pdfx1;
PDF1.sy = pdfy1;
PDF1.sz = pdfz1;
PDF1.t0 = T0pdf;


% now use weight
```

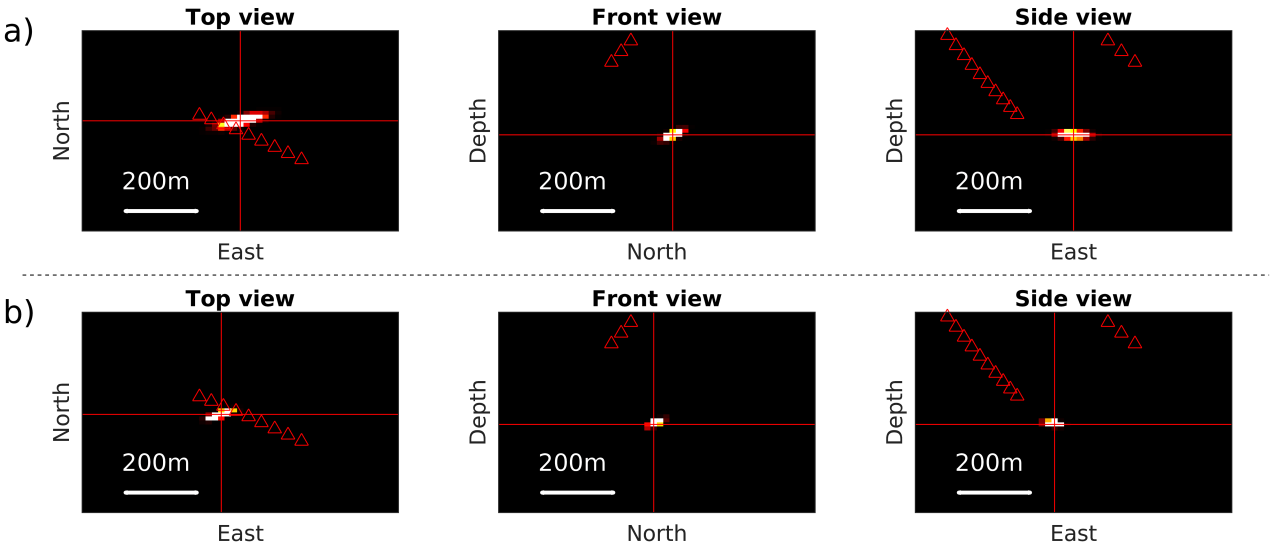
```
dTp = dTp./weight';
dTs = dTs./weight';

pdfT = zeros(G.nx,G.ny,G.nz);
for s=1:nsta
    if Tp(s)>0
        pdfT = pdfT + Tp(s) - Ptti(:,:,:,s);
    end
    if Ts(s)>0
        pdfT = pdfT + Ts(s) - Stti(:,:,:,s);
    end
end
pdfT = pdfT/(sum(Tp>0)+sum(Ts>0));


pdf = zeros(G.nx, G.ny, G.nz);
for s=1:nsta
    if Tp(s)>0
        pdf = pdf - ((Tp(s)-Ptti(:,:,:,s)-pdfT)/dTp(s)).^2/2;
    end
    if Ts(s)>0
        pdf = pdf - ((Ts(s)-Stti(:,:,:,s)-pdfT)/dTs(s)).^2/2;
    end
end
pdf = exp(pdf)/(sum(exp(pdf(:))));
pdf2 = pdf;

% Find optimal location
[pdfi2, pdfj2, pdfk2, pdfx2, pdfy2, pdfz2] = get_max_of_pdf(pdf2, G);
T0pdf = pdfT(pdfi2,pdfj2,pdfk2);

PDF2.sx = pdfx2;
PDF2.sy = pdfy2;
PDF2.sz = pdfz2;
PDF2.t0 = T0pdf;
```

Plot results

```
fig3 = figure(37355);
set(fig3, 'Position', [1 1 1000 400])
%fig3.Color = [240/255 240/255 240/255];
%fig3.InvertHardcopy = 'off';
% Create line
annotation(fig3,'line',[0.09 0.93],[0.51 0.51],'LineStyle','--');

subplot(2,3,1);
imagesc(G.xx,G.yy,squeeze((pdf1(:,:,pdfk1)))');
axis xy;
xlabel('East');
ylabel('North');
hold on
plot([G.xx(1),G.xx(end)],[G.yy(pdfj1),G.yy(pdfj1)],'r')
plot([G.xx(pdfi1),G.xx(pdfi1)],[G.yy(1),G.yy(end)],'r')
```

```
plot(acq.sx,acq.sy,'r^');
caxis([0 1e-2])
quiver(150, -80, 25, 0, 'white', 'Linewidth', 2),
quiver(150, -80, -25, 0, 'white', 'Linewidth', 2),
text(125,-50,'200m','FontSize',12, 'Color', 'w')
text(50,100,'a)','FontSize',16);
axis([100 300 -100 100])
xticks([]);
yticks([]);
title('Top view')

subplot(2,3,2);
imagesc(G.yy,G.zz,squeeze((pdf1(pdfi1,:,:)))');
axis xy;
xlabel('North');
ylabel('Depth');
hold on
plot([G.yy(pdfj1),G.yy(pdfj1)],[G.zz(1),G.zz(end)],'r')
plot([G.yy(1),G.yy(end)],[G.zz(pdfk1),G.zz(pdfk1)],'r')
plot(acq.sy,acq.sz,'r^');
set(gca,'Ydir','reverse');
caxis([0 1e-2])
quiver(-50, 1780, 25, 0, 'white', 'Linewidth', 2),
quiver(-50, 1780, -25, 0, 'white', 'Linewidth', 2),
text(-75,1750,'200m','FontSize',12, 'Color', 'w')
axis([-100 100 1600 1800])
xticks([]);
yticks([]);
title('Front view')

subplot(2,3,3);
imagesc(G.xx,G.zz,squeeze(pdf1(:,pdfj1,:))');
axis xy;
xlabel('East');
ylabel('Depth');
hold on
plot([G.xx(1),G.xx(end)],[G.zz(pdfk1),G.zz(pdfk1)],'r')
plot([G.xx(pdfi1),G.xx(pdfi1)],[G.zz(1),G.zz(end)],'r')
plot(acq.sx,acq.sz,'r^');
set(gca,'Ydir','reverse');
caxis([0 1e-2])
title('Side view')
quiver(150, 1780, 25, 0, 'white', 'Linewidth', 2),
quiver(150, 1780, -25, 0, 'white', 'Linewidth', 2),
text(125,1750,'200m','FontSize',12, 'Color', 'w')
axis([100 300 1600 1800])
xticks([]);
yticks([]);

subplot(2,3,4);
imagesc(G.xx,G.yy,squeeze((pdf2(:,:,pdfk2)))');
axis xy;
xlabel('East');
ylabel('North');
```

```
hold on
plot([G.xx(1),G.xx(end)],[G.yy(pdfj2),G.yy(pdfj2)],'r')
plot([G.xx(pdfi2),G.xx(pdfi2)],[G.yy(1),G.yy(end)],'r')
plot(acq.sx,acq.sy,'r^');
caxis([0 1e-2])
quiver(150, -80, 25, 0, 'white', 'Linewidth', 2),
quiver(150, -80, -25, 0, 'white', 'Linewidth', 2),
text(125,-50,'200m','FontSize',12, 'Color', 'w')
text(50,100,'b)','FontSize',16);
axis([100 300 -100 100])
xticks([]);
yticks([]);
title('Top view')

subplot(2,3,5);
imagesc(G.yy,G.zz,squeeze((pdf2(pdfi2,:,:)))');
axis xy;
xlabel('North');
ylabel('Depth');
hold on
plot([G.yy(pdfj2),G.yy(pdfj2)],[G.zz(1),G.zz(end)],'r')
plot([G.yy(1),G.yy(end)],[G.zz(pdfk2),G.zz(pdfk2)],'r')
plot(acq.sy,acq.sz,'r^');
set(gca,'Ydir','reverse');
caxis([0 1e-2])
quiver(-50, 1780, 25, 0, 'white', 'Linewidth', 2),
quiver(-50, 1780, -25, 0, 'white', 'Linewidth', 2),
text(-75,1750,'200m','FontSize',12, 'Color', 'w')
axis([-100 100 1600 1800])
xticks([]);
yticks([]);
title('Front view')

subplot(2,3,6);
imagesc(G.xx,G.zz,squeeze(pdf2(:,pdfj2,:))');
axis xy;
xlabel('East');
ylabel('Depth');
hold on
plot([G.xx(1),G.xx(end)],[G.zz(pdfk2),G.zz(pdfk2)],'r')
plot([G.xx(pdfi2),G.xx(pdfi2)],[G.zz(1),G.zz(end)],'r')
plot(acq.sx,acq.sz,'r^');
set(gca,'Ydir','reverse');
caxis([0 1e-2])
title('Side view')
quiver(150, 1780, 25, 0, 'white', 'Linewidth', 2),
quiver(150, 1780, -25, 0, 'white', 'Linewidth', 2),
text(125,1750,'200m','FontSize',12, 'Color', 'w')
axis([100 300 1600 1800])
xticks([]);
yticks([]);
colormap hot
```


a)
Top view
North
200m
East
Front view
Depth
200m
North
Side view
Depth
200m
East
b)
Top view
North
200m
East
Front view
Depth
200m
North
Side view
Depth
200m
East