Slowness-Enhanced Back-Projection

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1. Prepare the data

Firstly, we need a BP result of MUSIC BP. For information about MUSIC BP, please see the master branch.

Create a folder for SEBP. In my project, it is "/home/liuwei/HPSSD/Qinghai/Tele_Cali/TeleDD_Loc/AU". In the "AU" directory, create the "Events" folder.

In the "Events" directory, create folders for all aftershocks. In my example, they are "afXX_Myy", where XX is the arbitrary event number and yy could be the magnitude of aftershocks:

In each directory, create a "Data" folder and copy seismic data (in "sac" format) of each aftershock to the corresponding data folder.

Open "AU102_Auto_read_and_match.m". The input parameters:

```
%% INPUT
mother_loc = '/home/liuwei/HPSSD/Qinghai/Tele_Cali/TeleDD_Loc/AU/Events';
main_mat   = '/home/liuwei/HPSSD/Qinghai/BP/TeleDD_Loc/AU/Input/Par0.5_2_10.mat';
address= '/home/liuwei/HPSSD/Supershear/BP2/Workshop2019/';           % address of paths that need t
addpath(genpath(strcat(address,'funcLib/')));   % directory of Back-Projection functions
ori      = 60; % please refer to your request on IRIS
display  = 360; % please refer to your request on IRIS
Preshift = false;   % no change! About readBP
plotscale= 1.5;     % plotscale:  scaling of the amplitudes of seismograms
```

"mother_loc" is the directory of SEBP. "main_mat" is the directory of BP file for MUSIC BP. "address" is the directory of MUSIC BP. Please make sure the directory has funcLib of MUSIC in it. Run the script, we will have the aftershock waveforms read in and the time shifts are assigned based on the mainshock time shift.

Then we need to put "create_ev.m" in the "Events" folder. Input your aftershocks folder name and run it:

```
evtlst_char=['af04_M51';'af06_M52';'af08_M52'];
evtlst_name=['af04_M51';'af06_M52';'af08_M52'];
```

A mat file named "evtlst.mat" is created. This file stores the folders' names for later aftershocks BP.

2. Run MUSIC BP for aftershocks

Open "AU103_Auto_run_music.m" and set some directories:

```
%% INPUT
mother_loc = '/home/liuwei/HPSSD/Qinghai/Tele_Cali/TeleDD_Loc/AU/Events';
address='/home/liuwei/HPSSD/Supershear/BP2/Workshop2019/';           % address of paths
addpath(genpath(strcat(address,'funcLib/')));   % directory of Back-Projection functions
```

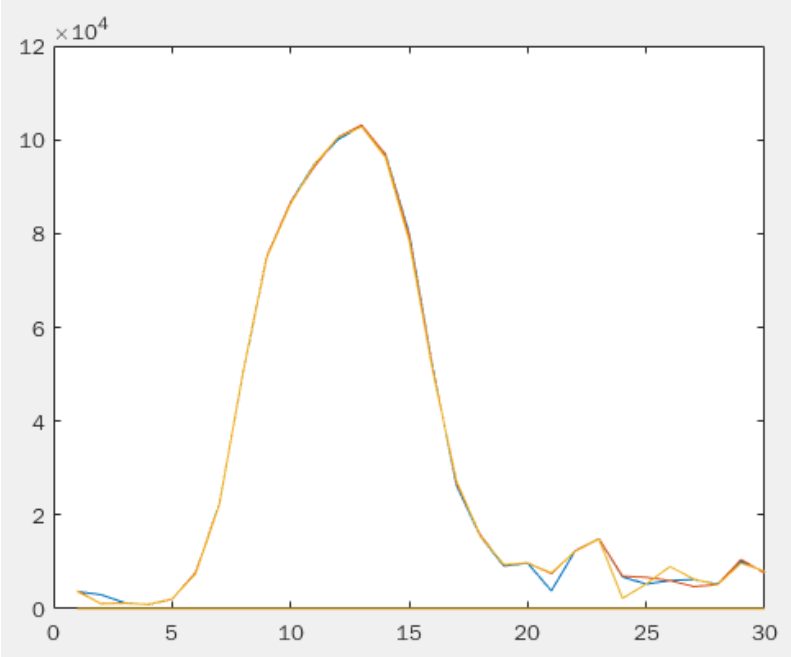
"mother_loc" and "address" are the same as in the previous step.

```
%% Loop for all events
% for j=1:2
for j = 1 : n_evt

    load 'evtlst.mat'
    evtlst_name(j,:)
    cd (evtlst_name(j,:))
        mother_loc = '/home/liuwei/HPSSD/Qinghai/Tele_Cali/TeleDD_Loc/AU/Events';
        % Parameter set for runBP
            lon0=98.3622588499;     % MAINSHOCK lontitude
            lat0=34.6202641954;     % MAINSHOCK latitude
            dep0 = 7.607;    % MAINSHOCK depth
            sr=10;          % sample rate
            parr=45;        % start time
            begin=0;        % always 0
            over=30;        % end time
            step=1;         % time step
            ps=120;          % number of grids for lat
            qs=120;          % number of grids for lon
            latrange=[-0.8,0.8]; % lat range
            lonrange=[-1.5,1.5]; % lon range
            fl=0.5;        % frequence low of bandpass
            fh=2;           % frequence high of bandpass
            win=8;         % window length for BP

            inputband=5;    % i.e. data5.mat
            Band = 4; % band4: [0.5,2]
```

The "lat0, lon0, dep0" is the hypocenter of the mainshock and should be the same as used in the MUSIC BP for the mainshock. "parr" is the beginning time for the aftershocks BP, and "over" is the duration. In my project, the theoretical P arrival is 60 s, so I use 45 and 30 to make sure the time window covers the possible aftershocks time (45 s < 60 s < 75 s). Other parameters could be the same as those used in mainshock BP.
Run the script, and it will perform the MUSIC BP for aftershocks.

3. Pick the BP inferred locations for aftershocks

In Matlab, cd the directory of aftershock BP results. In my project, it is "/home/liuwei/HPSSD/Qinghai/Tele_Cali/TeleDD_Loc/AU/Events/af04_M51/Input/Par0.5_2_12_MUSIC_Dir". Open "movieBP.mat", and input "plot(Power(:,:))". Matlab will plot a figure for the BP power of aftershock:



Pick the rising time of the BP power. In this example, it is 7 to 13 s. In this time window, the aftershock is imaged by MUSIC BP. Open the “bux” and “buy” variables in Matlab, and read the mean x and y values in the 7 to 13 s time window:

bux | buy

30x10 double

	1	2	3
1	34.3043	34.3043	34.2909
2	34.3043	34.6404	34.6270
3	34.6404	34.6270	34.6135
4	34.7614	34.7480	34.7614
5	34.4791	34.4925	34.4656
6	34.4388	34.4253	34.4253
7	34.4388	34.4253	34.4253
8	34.4388	34.4388	34.4253
9	34.4253	34.4253	34.4119
10	34.4253	34.4119	34.4253
11	34.4253	34.4388	34.4253
12	34.4388	34.4253	34.4119
13	34.4253	34.4119	34.3984
14	34.4119	34.3984	34.3850
15	34.3850	34.3715	34.3984

bux | buy

30x10 double

	1	2	3
1	98.2992	98.2740	98.2992
2	98.2992	99.2320	99.2320
3	99.2320	99.2320	99.2320
4	98.9547	98.9547	98.9295
5	98.4505	98.4253	98.4505
6	98.8791	98.9043	98.8791
7	98.9547	98.9799	98.9547
8	99.0051	98.9799	99.0051
9	99.0303	99.0051	99.0303
10	99.0303	99.0303	99.0051
11	99.0555	99.0303	99.0303
12	99.0555	99.0555	99.0555
13	99.0555	99.0555	99.0555
14	99.0555	99.0555	99.0555
15	99.0555	99.0555	99.0303

In this example, the average bux could be 34.43, and the average buy could be 99.03. So (34.43N, 99.03E) is the BP inferred location for the first aftershock. Repeat the procedure for all aftershocks.

Copy the "create_ca.m" to the "Events" directory. Open the script:

```
lat_ap=[34.44;34.41;34.65];
lat_ca=[34.49;34.43;34.70];
lon_ap=[99.03;99.28;98.09];
lon_ca=[98.91;99.14;98.03];
lat_cali=[];
lon_cali=[];

save ca_ap_loc.mat lat_ca lat_ap lon_ca lon_ap lat_cali lon_cali
```

Use "lat_ap" to record the latitude for BP inferred locations, and use "lon_ap" to record the longitude for BP inferred locations. Use "lat_ca" and "lon_ca" to record the catalog locations. Run the script, and a file named "ca_ap_loc.mat" will be created. The file stores the BP inferred locations and catalog locations for all aftershocks.

4. Calibrate the aftershocks

Open "AU104_Auto_cali_music.m", and set some parameters:

```
%% PRE-SET

address='/home/liuwei/HPSSD/Supershear/BP2/Workshop2019/';            % address of paths
addpath(genpath(strcat(address,'funcLib/')));   % directory of Back-Projection functions
%%% INPUT
mother_loc = '/home/liuwei/HPSSD/Qinghai/Tele_Cali/TeleDD_Loc/AU/Events';
ap_ca_loc  = '/home/liuwei/HPSSD/Qinghai/Tele_Cali/TeleDD_Loc/AU/Events/ca_ap_loc.mat';
ref = 25;
```

"ap_ca_loc" is the directory of "ca_ap_loc.mat" file. The "ref" is the reference station. We can keep it as default.

```
    load 'Input/Par0.5_2_12.mat'
    load(ap_ca_loc);    % Load ca and ap location of afteshocks


    %% STEP 1: Get slowness error for the mainshock.

        lat_sta=ret.lat; lon_sta=ret.lon;               % stations

        lat_ca = lat_ca; lon_ca = lon_ca; dep_ca(1:9,1) = ret.dep0; % AF catalog
        lat_ap = lat_ap; lon_ap = lon_ap; % AF apparent (BP inferred)

        lat_c=mean(lat_ap); lon_c=mean(lon_ap); dep_c =ret.dep0;       % geometrical center

        dS2Dplus = get_dS_2Dplus(lat_sta,lon_sta,lat_c,lon_c,dep_c,...
                            lat_ca,lon_ca,dep_ca,lat_ap,lon_ap,ref); % IMPORTANT
        ret.dS0 = dS2Dplus.dS0;
        ret.dSx = dS2Dplus.dSx;
        ret.dSy = dS2Dplus.dSy;

save Input/Par0.5_2_12_cali.mat
```

Please change the name of “Input/Par0.5_2_12.mat” and “Input/Par0.5_2_12_cali.mat” according to the frequency band and window length you used.
Run the script and we will get the calibrated aftershock BP. In the calibration directory (mine is “/home/liuwei/HPSSD/Qinghai/Tele_Cali/TeleDD_Loc/AU/Events/af04_M51/Input/Par0.5_2_12_music_Cali2Dplus_Dir”), open “movieBP.mat” by Matlab. Again, read the rising time for aftershocks and pick the mean bux and buy in the corresponding time interval.

bux

30x10 double

	1	2	3
1	35.1245	35.1245	35.1110
2	34.1564	35.1379	35.1245
3	34.5194	34.1698	35.1514
4	35.2455	34.6001	33.8606
5	34.5732	34.5060	34.8018
6	34.4925	34.4925	34.5060
7	34.4925	34.4791	34.4925
8	34.4791	34.4791	34.4925
9	34.4791	34.4791	34.4656
10	34.4791	34.4791	34.4656
11	34.4791	34.4791	34.4656
12	34.4791	34.4656	34.4791
13	34.4656	34.4656	34.4522
14	34.4656	34.4656	34.4522

buy

30x10 double

	1	2	3
1	98.7026	98.6774	98.7026
2	96.9127	98.6774	98.7026
3	99.1816	96.9631	98.1228
4	97.2152	98.9547	98.8539
5	98.3244	98.7278	98.3497
6	98.7782	98.7530	98.7278
7	98.8286	98.8539	98.8034
8	98.8791	98.8539	98.8286
9	98.9043	98.8791	98.9043
10	98.9043	98.8791	98.9043
11	98.9295	98.9043	98.9295
12	98.9295	98.9295	98.9043
13	98.9295	98.9043	98.9547
14	98.9295	98.9043	98.9295

In the example, mean x and mean y are 34.47 and 98.92, respectively. They are very close to the catalog location (34.501097N, 98.930649E). This proves that our calibration is valid. Repeat the procedure for all aftershocks.

5. Calibrate the mainshock

Since we validate our slowness calibration, we can now perform that on the mainshock. Open “AU105_Main_cali_music.m”:

```
n_evt=3

    load 'Input/Par0.5_2_12.mat'
    load(ap_ca_loc);    % Load ca and ap location of afteshocks


    %% STEP 1: Get slowness error for the mainshock.

        lat_sta=ret.lat; lon_sta=ret.lon;               % stations

        lat_ca = lat_ca; lon_ca = lon_ca; dep_ca(1:n_evt,1) = ret.dep0; % AF catalog
        lat_ap = lat_ap; lon_ap = lon_ap; % AF apparent (BP inferred)

        lat_c=mean(lat_ap); lon_c=mean(lon_ap); dep_c =ret.dep0;       % geometrical center

        dS2Dplus = get_dS_2Dplus(lat_sta,lon_sta,lat_c,lon_c,dep_c,...
                            lat_ca,lon_ca,dep_ca,lat_ap,lon_ap,ref); % IMPORTANT
        ret.dS0 = dS2Dplus.dS0;
        ret.dSx = dS2Dplus.dSx;
        ret.dSy = dS2Dplus.dSy;

save Input/Par0.5_2_12_cali.mat
```

“n_evt” is the number of aftershocks. Again, please change the name of “Input/Par0.5_2_12.mat” and “Input/Par0.5_2_12_cali.mat” according to the frequency band and window length you used. Run the script, and we get the results of calibrated BP for the mainshock. It is stored in the same directory as mainshock BP before calibration and has “Cali2Dplus_Dir” at the end of the file name. In this example, it is in “/home/liuwei/HPSSD/Qinghai/BP/TeleDD_Loc/AU/Input/Par0.5_2_12_music_Cali2Dplus_Di” .