PSDM-SRF Package

Wave Equation-Based Poststack Depth Migration of S-wave Receiver Function

User Manual
Version 1.0

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Change Log

Manual Version	PSDM-SRF Version	Release date of the manual
1.0	1.0	2021-08-27

List of Maintainers

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Contents

1 Brief Introduction

PSDM is a software package for efficiently imaging S-wave velocity contrasts in the crust and upper mantle. It applies 2D wave equation-based migration technique, which was originally used in exploration seismology, to the teleseismic receiver function (RF) data from dense seismic arrays.

The migration method consists of two basic procedures: common conversion point (CCP) stacking and backward wavefield extrapolation. In the CCP stacking procedure, CCP binning and stacking are performed on the moveout-corrected receiver functions. Backward wavefield exploration is a migration process to project the Sp or Ps phases to their true positions by backward-propagating the zero-offset wavefield observed at the surface (the CCP stacked cross-section being moveout-corrected to ray parameter = 0) to the whole space and to the time at which the conversions occur. More details of the migration methodology can be found in the following literature:

1. Chen, L., Wen, L., and Zheng, T. (2005), A wave equation migration method for receiver function imaging: 1. Theory. *J. Geophys. Res.*, 110, B11309, doi:10.1029/2005JB003665.

2. Chen, L., Wen, L., and Zheng, T. (2005), A wave equation migration method for receiver function imaging: 2. Application to the Japan subduction zone. *J. Geophys. Res.*, 110, B11310, doi:10.1029/2005JB003666.

PSDM-SRF is an extended package for applying the technique to S-wave receiver functions (S-RF) and has been successfully used to image both lithospheric and asthenospheric structures in regions with various tectonic settings (e.g., craton, orogenic belt/plateau, subduction zone). Although there are differences between the two packages, their workflows are very similar. Systematic comparisons on the performances of S-RF and P-RF imaging using the packages have been conducted in the following study, which meanwhile discusses the advantages and shortcomings of the two imaging methods and their frequency-dependent resolutions:

3. Chen, L., (2009), Lithospheric structure variations between the eastern and central North China Craton from S- and P-receiver function migration. *Physics of the Earth & Planetary Interiors,* 173(3-4), 216-227, doi:10.1016/j.pepi.2008.11.011.

This manual is aimed principally at beginners and shows how to run the PSDM-SRF program to obtain a migrated image with the example (a synthetic

S-RF dataset). It is noteworthy that some input parameters adopted in this manual should be modified according to the actual situations. Here, we also provide some of the related publications for reference, which may be conducive for new users to have a further knowledge of the parameter configurations in different applications:

4. Chen, L., Tao, W., Zhao, L., Zheng, T. (2008), Distinct lateral variation of lithospheric thickness in the northeastern North China Craton. *Earth Planet. Sci. Lett*., 267, 56–68, doi:10.1016/j.epsl.2007.11.024.

5. Chen, L., Jiang, M., Yang, J., Wei, Z., Liu, C., Ling, Y. (2014), Presence of an intralithospheric discontinuity in the central and western North China Craton: Implications for destruction of the craton. *Geology*, 42(3), 223–226. doi: 10.1130/G35010.1.

6. Wu, Z., Chen, L., Talebian, M., Wang, X., Jiang, M., Ai, Y., et al. (2021), Lateral structural variation of the lithosphere-asthenosphere system in the northeastern to eastern Iranian plateau and its tectonic implications. *Journal of Geophysical Research: Solid Earth*, 126, e2020JB020256, doi:10.1029/2020JB020256.

Again, note that the setting of input parameters is flexible, depending on the data and research target.

2 Setup

Command line inputs are shaded, and information associated with the given example data has been marked in brown. Descriptions of the input parameters are shown in blue.

2.1 Files and Directories in the Package

Name	Type	Descriptions
data	Directory	example S-RF data
m660q_new	Directory	Sp delay time calculation
model	Directory	1D velocity models
stack	Directory	piercing point calculation, moveout correction, time-domain CCP
poststack	Directory	post-stacking depth migration
plot	Directory	Matlab scripts for plotting CCP & migrated cross-sections
temp	Directory	storage of temporary files
Package_content.txt	.txt file	marked with the version number, the date of last update for the package, and other annotations
...		

2.2 Installation

Operation system:
- x64/x32 Linux or macOS
- has been tested in Ubuntu 14.04, Debian 4.6.3/4.8.4, Centos 7.1, macOS Mojave.

Preinstalled environment:
- gcc/gfortran compiler

Compile the package:
- cd ./stack > make

cd ./poststack   > make

- 'Warning' may occur but it would not affect the efficiency of the code.
- make clean + make after you make changes to the .f files

2.3 Data Preparation

Data format

- SAC, with necessary headlist information (e.g., user0 = ray parameter)

Arrangement of the data folders and files

- Arrange the S-RF traces following the order as below:

./data/Name_of_Array/Name_of_Station/Name_of_Trace

for example:

./data/SYN_Tilt10d/N03/N03_epi55_baz90.eqz

Record file

- Give a .txt record file that includes the names of S-RF waveforms to be used.

for example:

SYN_S.txt

```
------------------------------------------------------------
N01                         % Station name
12                          % Number of S-RF traces in this station
N01_epi55_baz270.eqz        % Trace name
N01_epi55_baz90.eqz         % . . .
...                         % . . .
N01_epi80_baz90.eqz         % . . .

N02                         % Station name
12                          % Number of S-RF traces in this station
N02_epi55_baz270.eqz        % Trace name
N02_epi55_baz90.eqz         % . . .
...                         % . . .

...


Total RF number: 384        % Total number of S-RF traces
------------------------------------------------------------
```

- Put the record file under the directory ./data/Name_of_Array/

for example:

./data/SYN_Tilt10d/SYN_S.txt

- Tip: just make changes to the record file after you re-select the data.

2.4 Velocity Model

Model format

- Give the 1D velocity model file used for moveout correction and depth migration.

for example:

```
new_iasp91.par
----------------------------------------------------------
164      % Number of layers to be adopted (≤ max number in the model)
  5.8000    3.3600    2.7200    20.0000      20.0000      1
%   Vp        Vs      density   thickness     depth      which layer
  6.5000    3.7500    2.9200    15.0000      35.0000      2
  8.0400    4.4700    3.3198    15.0000      50.0000      3
  8.0400    4.4700    3.3198     5.5000      55.5000      4
  8.0424    4.4771    3.3320    22.0000      77.5000      5
  8.0450    4.4850    3.3455    20.0000      97.5000      6
  8.0474    4.4921    3.3576     2.5000     100.0000      7
  8.0474    4.4921    3.3576    20.0000     120.0000      8
  8.0500    4.5000    3.3713    20.0000     140.0000      9
  ...
  11.2409   3.5645   13.0122     0.0000    6371.0000    164
----------------------------------------------------------
```

- Put the velocity model file under the directory ./model/

for example:

./model/new_iasp91.par

2.5 Delay Time File

The delay time (essentially is advance time for S-RF) file ending with '.out' includes theoretic arrival time (relative to direct S-wave) of Sp phases converted at chosen depths for each ray parameter (slowness). This file will be used for moveout correction. In this section, we will show how to generate a '.out' file with program *M660_new.for*

Three input files are required to create a new '.out' file with program *M660_new.for*

1. Velocity model
2. Slowness file
3. Ray file

All these files should be placed under the directory ./m660q_new/

Brief descriptions of these files are given, respectively.

Velocity model
- Copy the 1D velocity model in section 2.4 (e.g., new_iasp.par) to the directory ./m660q_new/

Slowness file
- Give a slowness file that determines the range of epicentral distance to be considered in the delay time calculation. This file also gives the theoretic ray parameter of mother phase for each epicentral distance, which affects the resulting delay time of converted phases. The example file is calculated based on a global average model, and can be modified according to demand.
for example:

nmo_dep0.dat

```
------------------------------------------------------------------------------------------------
 121                              % Total number of the epicentral distances
 40    14.9587    823.79    -1    -1
% Epicentral distance, S-wave slowness, S-wave arrival time (relative to
source time), SKS-wave slowness, SKS-wave arrival time (-1 represents 'not
considered')
 40.5    14.9134    831.25    -1    -1
 41    14.8674    838.70    -1    -1
    ...
 99.5    8.3233    1518.36    4.9642    1464.32
 100    8.3233    1522.52    4.9212    1466.79
------------------------------------------------------------------------------------------------
```

- Tip: in the example above, SKS-wave will be considered if it arrives earlier than the S-wave (e.g., ≥83.5 degree). Let the SKS-wave arrival time be -1 when you want to consider S-wave only.
- Copy the slowness file to the directory ./stack/

Ray file
- Give a ray file that determines the type of the wave (P or S) when the ray passes through a certain layer in the 1D model. This file also determines the layers in the 1D model (i.e., depths) to be taken into account in the delay time calculation.
for example:

mray_n.dat

```
------------------------------------------------------------------------------------------------
                    29                % Total number of the rays to be considered
% Ray1 (represents direct S-wave here)
29 2928272625242322212019181716151413121110 9 8 7 6 5 4 3 2 1
```

% Deepest layer (**29 corresponds to 500.0 km in the new_iasp91.par**), layers above the deepest layer (from layer29 to layer1)

3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3

% Type of the wave when the ray passes through each layer (3->S, 5->P)

% Ray2 (S-layer2(35km)-p)

29 2928272625242322212019181716151413121110 9 8 7 6 5 4 3 2 1

3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5

% Ray3 (S-layer3(50km)-p)

29 2928272625242322212019181716151413121110 9 8 7 6 5 4 3 2 1

3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 5 5 5

...

% Ray29 (S-layer29(500km)-p)

29 2928272625242322212019181716151413121110 9 8 7 6 5 4 3 2 1

5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5

- Modify the ray file if you invoke a new 1D velocity model.

Run *M660_new.for*

- Rewrite the input file names in the .for script.
- make clean + make after you make changes to the .for file
- Run ./M660q_new

Output

- The description of '.out' file can be found in Appendix A.

3 Parameter Configuration

There are three steps to obtain the structural migrated image by invoking the core programs in PSDM-SRF package (Figure 1).

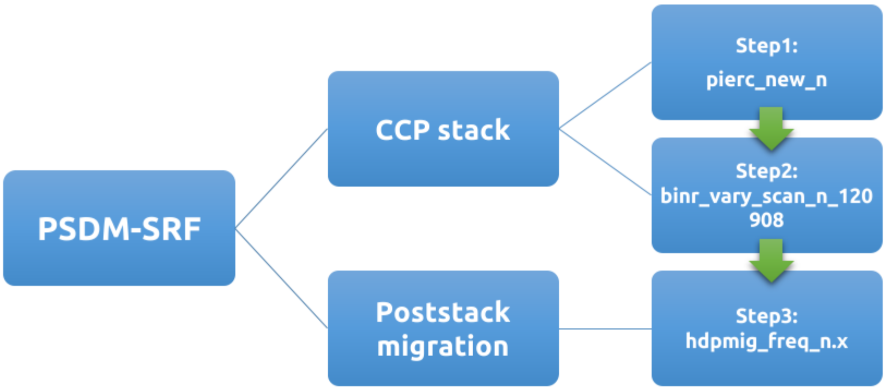

Figure 1. Main workflow of the PSDM-SRF package.

The input and output for each step will be illustrated below, respectively.

3.1 Step1: *pierc_new_n*

In this step, ray tracing is conducted and piercing point locations at chosen depths are calculated according to the 1D velocity model.

Input

- pierc_new_n.in

 The modification of texts or parameters in gray is not recommended.

for example:

pierc_new_n.in

----

* output file name: iaj

pierc_step1.dat

% Give a name to the main output file.

* the coordinate center of line: evla0,evlo0

0,6

% Set the location of reference point (latitude, longitude), which should be near the center of the array.

* output time point number: np0, irayp

2401 0

% All the SAC files should have the same npts (=np0).

* model file

../model/new_iasp91.par

% Path for the velocity model file.
* * ivar (0: dist; 1: gcarc; 2: baz),varmin,varmax
1 55.0 83.0
% Set a limit range (varmin, varmax) of geographic distance (in km, ivar=0), epicentral distance (in degree, ivar=1) or back-azimuth (in degree, ivar=2) for the data.
- Data out of the range will not be used.
* NW,(NWI(I),NWID(I),I=1,NW):
23,2 2,3 3,4 4,5 5,6 6,7 7,8 8,9 9,10 10,11 11,12 12,13 13,14 14,15 15,16 16,17 17,21 21,22 22,23 23,24 24,25 25,26 26,27 27
% Total number of designated depths (NW), Indexes of each depth in .out file & in velocity model file (NWI(I), NWID(I), I=1,NW).
- For instance, the fourth index pair (5 5) means that the 5th depth (77.5 km) in *new_iasp91_MultiMode.out* corresponds to the 5th layer in *new_iasp91.par*
- Moveout correction is efficient only within the depth range.
* NDW(1:5): indexes in NWI for outputting piercing points at 5 depths
2 6 7 9 12 50-, 100-, 120-, 150-, 200-km
% Choose 5 depths (50, 100, 120, 150, 200 km) that correspond to the 2nd, 6th ,7th , 9th and 12th index pair shown above (3 3;7 7;8 8;10 10;13 13).
- Piercing point locations at these depths will be output as depth1-5.dat
* directory containing RFs
../data/
% Path for the data pool.
* number of subdirectories
-1
SYN_Tilt10d
% Array directory
SYN_S.txt
% Record file

Run

- cd ./stack > ./pierc_new_n

Output

1, depth1/2/3/4/5.dat

Piercing point locations at 5 chosen depths (latitude, longitude, northward-measured distance to the reference point, eastward-measured distance to the reference point);

2, sta_name.dat

Names of the used stations;

3, station.dat

Locations of the used stations (latitude, longitude, northward-measured distance to the reference point, eastward-measured distance to the reference point);

4, events.txt

Locations of the used teleseismic events (longitude, latitude);

5, pierc_step1.dat

The major output file in this step, which is also the input for the next step. This file records several important input parameters, headlist and piercing point information of each S-RF trace.

for example:

pierc_step1.dat

```
-----------------------------------------------------------------------------------------------------
          23            2    35.0000000        3    50.0000000
4    55.5000000         5    77.5000000        6    97.5000000
7    100.000000         8    120.000000        9    140.000000
10    150.000000       11    165.000000       12    185.000000
13    200.000000       14    210.000000       15    230.500000
16    260.000000       17    280.000000       21    350.000000
22    360.000000       23    380.000000       24    400.000000
25    410.000000       26    430.000000       27    460.000000
% Total number of designated depths (NW), Index of each depth in .out file &
Corresponding depth value (NWI(I), DEP(I), I=1,NW)
   0.00000000       6.00000000
% Location of the reference point (latitude, longitude)
    0    70.5000000       70.2504349      0.104807667
9.11956504E-02
% 0, Average epicentral distance, True average epicentral distance, Average
ray parameter, Minimum ray parameter
         342        2401
% Total number of used S-RF, Number of sampling points for each trace (npts)
../data/
% Path for the input S-RF data pool
SYN_Tilt10d/N01/N01_epi55_baz270.eqz
% Trace name
            1    0.00000000      -256.482605
% Trace number, Station-reference point distances in Cartesian coordinate
system
    57.64   270.00   0.1192E-07   0.1177E+00     8
% Epicentral distance, Back-azimuth, cos(back-azimuth), Ray parameter,
Number of traceable depths (NW0)
      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
```

-293.37 -340.88 -358.65 -431.94 -501.89 -510.90 -584.89 -663.12
% Northward-measured piercing point-reference point distances for each depth (xox(I), I=1,NW0), Eastward-measured piercing point-reference point distances for each depth (xoy(I), I=1,NW0)
3.99 4.56 4.76 5.55 6.25 6.33 6.99 7.62
% Theoretic delay time for each depth (TTO(I), I=1,NW0)
...

- Use Matlab script ./plot/pierc_viewer.m to have a very preliminary view of the piercing point distribution (Figure 2).

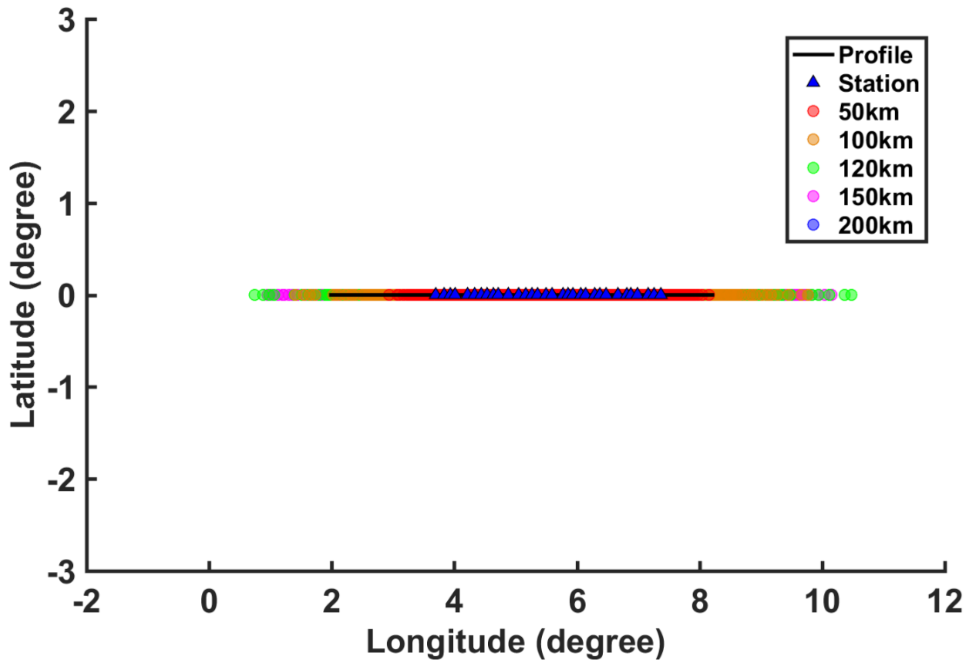

Figure 2. Piercing point distribution and observation system.

3.2 Step2: *binr_vary_scan_n_120908*

In this step, moveout correction, CCP binning and stacking are performed.

Input
- binr_vary_scan_n_120908.inp
for example:

binr_vary_scan_n_120908.inp
----
* begin and end coordinate of start point, point interval(km):
begla0,beglo0,endla0,endlo0,dsp
0.0,250.0,0,250.0,100.0
% Cartesian coordinates (in km, relative to the reference point) of the starting point (begla0, beglo0) of the profile.

- If (begla0, beglo0) is not identical to (endla0, endlo0), multiple profiles will be created with the spacing interval (dsp).
* profile length and azimuth range and interval: xlenp,alphab,alphae,dalp
700.0,270.0,270.0,5.0
% Profile length (xlenp), Azimuthal range (alphab, alphae) and Interval (dalp) of the profiles.
- If alphab = alphae, only one profile will be set.
- If there is only one profile, its location is well determined by begla0, beglo0, xlenp and alphab.
* the spacing between bins, least number of traces, rnumtra, UTM_PROJECTION_ZONE
2 1 1.2 31
% Spacing between the two neighboring bins (in km), The least number of traces required in each bin, Suppression coefficient, UTM zone of the study area.
- The least number of traces in each bin is set empirically. It is set to be 1 here because the example data is synthetic and not suffered from noise.
- The bin size will increase self-adaptively (vary within the range set below) until the least number is satisfied. If this cannot be met even when the bin size reaches the upper limit, the summation amplitude will be suppressed by a factor of suppression coefficient*least number.
- UTM zone can be obtained using function 'utmzone' in Matlab.
* time file name: timefile
new_iasp91_MultiMode.out
% Path for the delay time file.
* output file name: outfile
step2
% Give a name to the output files.
* ouput number of time samples in each trace: npt, dt
2401 0.05
% All the SAC files should have the same Number of sampling points (npt) and Sampling interval (dt).
* the indexes of reference ray among 1 -- nw: ninw, (inw0(i),i=1,ninw)
23,1 -200,2 120,3 110,4 100,5,90,6 80,7 80,8 80,9 90,10 100,11 100,12 100,13 100,14 100,15 100,16 100,17 100,18 100,19 100,20 100,21 100,22 100,23 100
% Total number of designated depths (NW), No. of the depth & Half bin length (in km, **the side perpendicular to the profile**) at this depth.
- If the first bin length < 0, this value will be applied at all depths.
- Rectangular bins are employed in this package.
- Bin length is invariant in the self-adaptive adjustment of the bin size.
* minimum YBIN (km)
15,20,20,30,40,40,50,80,80,90,95,100,110,120,130,140,150,150,150,150,150,150,150
% Minimum half bin width (**the side parallel to the profile**) at each depth.
* DYBIN (km)

-2,2,2,2,2,2,3,3,3,3,3,3,3,3,3,3,3,3,4,4,4,4,4
% Increment in the half bin width at each depth when the bin size self-adaptively increases.
* maximum YBIN (km)
15,30,30,50,55,55,70,90,100,115,125,135,145,155,160,165,170,175,185,190,190,190,200
% Maximum half bin width at each depth.
* temporary directory name to store the intermedial files (.img)
../temp
% Path for the temporary directory.
* moveout index: idist, gcarc1 (only useful for idist=1)
1 180.0
% Perform moveout correction (idist=1) or not (idist=-1).
- If yes, correct the data to gcarc1 in degree. Note that gcarc1=180.0 is required for the next step.
* moveout method index: imethod (=0:time domain; else: + t-to-dep conversion),inorm
0 0
% Normalize each trace (inorm=1) or not (inorm=0) before stacking.
- In most cases, normalization is not recommended in this step.
* output number and depth indexes in ninw: noutd,(ioutd(i),i=1,noutd)
5 2 6 7 9 12 50-, 100-, 120-, 150-, 200-km
% Similar to those in *pierc_new_n.in*, but in this step the number of traces in each bin & half bin width will be output.
- Check the output carefully to evaluate the reliability of the imaging results.
- The first number indicates the Total number of chosen depths.
* output index for stacking: istack
1
* output index for gcarc, baz and p: ioutb
1
* piercing point data file number: npief
1
* input file name: infile
pierc_step1.dat
% The major output file of step1.
-1

Run
- cd ./stack > ./binr_vary_scan_n_120908

Output
1, step2_profile.txt
Location of each bin center (longitude, latitude, eastward-measured distance to the reference point, northward-measured distance to the reference point,

distance to the starting point of the profile). The location of profile can be previewed using ./plot/pierc_viewer.m (Figure 2);

2, step2_num.dat

Binary data that records the total S-RF numbers in each bin at the chosen 5 depths. The information can be previewed using ./plot/RFnum_image_plot.m in Matlab (Figure3);

3, step2_yb.dat

Binary data that records the half width of each bin at the chosen 5 depths. The information can be previewed using ./plot/RFnum_image_plot.m in Matlab (Figure3);

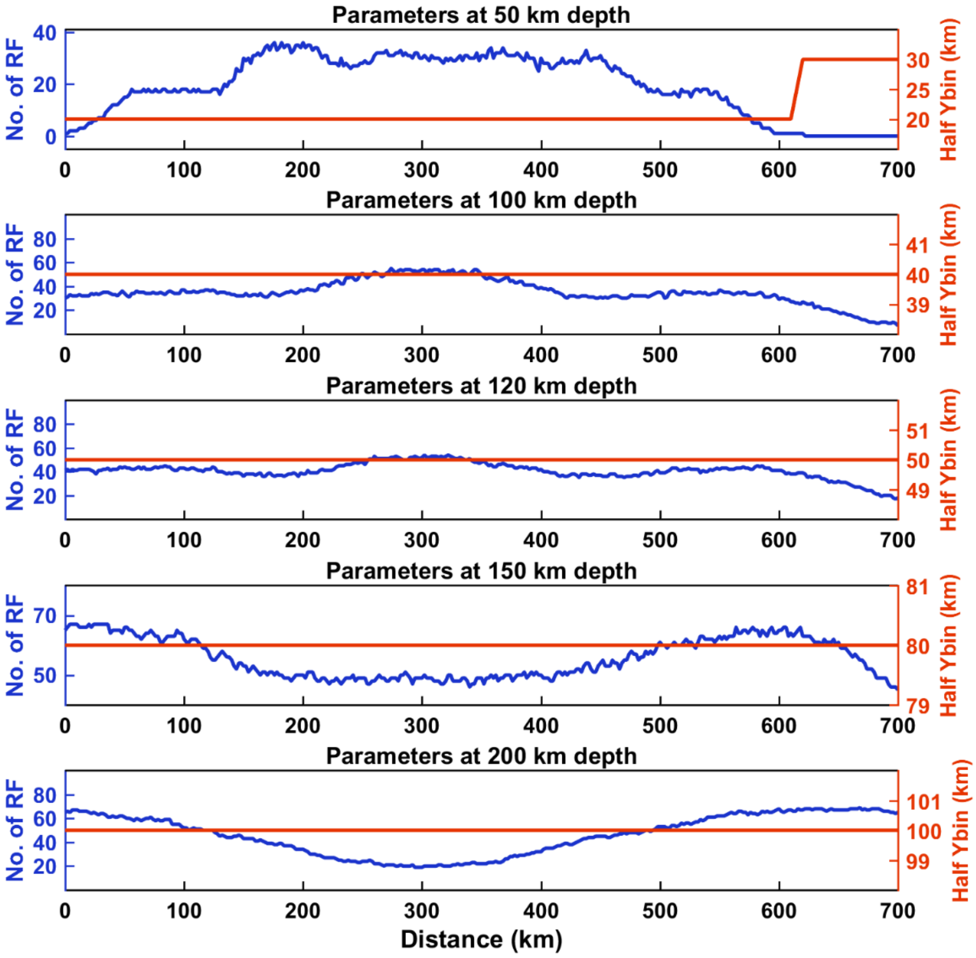

Figure 3. S-RF numbers in the bins (blue lines) and half bin width (red lines) applied in the CCP stacking at 5 chosen depths. Note that the data coverage at the ends of the profile can be very limited.

4, step2_baz.dat

Binary data that records the information of each S-RF (epicentral distance, back-azimuth, piercing point-station distances, epicentral distance*cos(back-azimuth), epicentral distance*sin(back-azimuth));

5, bin.out
A file that contains all the input parameters of this step;

6, bin.dat
Binary data that stores the information of the CCP binning and stacking;

7, stack_step2.dat
The major output file for step2, which is also the input file in the next step. This binary data records the CCP stacked data and can be plotted using ./plot/ccpstack_image_plot.m in Matlab (Figure 4).

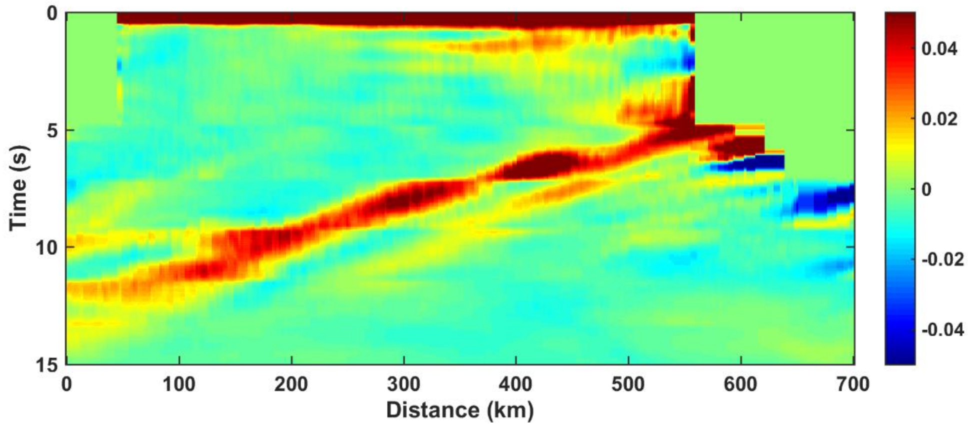

Figure 4. Time-domain CCP stacked cross-section after moveout correction to ray parameter = 0.

3.3 Step3: *hdpmig_freq_n.x*

In the final step, zero-offset (ray parameter = 0) CCP stacked data is backward propagated to construct a subsurface structural image by utilizing a frequency-wave number domain phase screen propagator.

Input
- hdpmig_freq_n.in
for example:

```
    hdpmig_freq_n.in
-----------------------------------------------------------------------------------------------
* imethod (phshift=0; phscreen=1, hybscreen: else),irefvel,vscale
0         0       1.0
* frequency image number: nfreqi
4
% Total number of frequency bands (nfreqi) in the calculation.
```

- If nfreqi > 0, output normalized data.
* freqi(i,1:2): Minimum and maximum frequencies, ifreqind(i,1:2): ifreqindl, ifreqindr

```
0.03    0.50    0    50
0.03    0.40    0    50
0.03    0.35    0    50
0.03    0.30    0    50
```

% Minimum and Maximum frequencies for each band, Frequency-domain tapered points at the lower and upper frequency limits.
* nxmod, nzmod, nx, nz

```
351    600    1024    600
```

% Number of lateral grids (nxmod), Number of vertical grids (nzmod), Number of lateral grids for FFT (nx), Number of vertical grids (nz).
- nxmod = xlenp/dx + 1.
- nx should be > nxmod and meanwhile a power of 2.
* dx, dz

```
2    0.5
```

% Lateral (dx) & Vertical (dz) inter-grid spacing (in km).
- dx = inter-bin spacing.
- dz*nzmod = maximum depth for wavefield extrapolation.
* ntrace, nt, dt (in sec.), nt0, ntb

```
351    2401    0.05    4096    1
```

% Number of lateral grids (ntrace), npts for each data (nt), Sampling interval for each data (dt), npts for FFT (nt0), Starting time point in the calculation (ntb).
- ntrace = nxmod.
- nt0 should be > nt and meanwhile a power of 2.
* FD method (15, 45, 65)

```
45
```

% 45-degree approximation, only activated in hybscreen mode.
* nxleft, nxright

```
45    45
```

% Spatial tapered points at the two ends of the profile.
* ifmat (=0: ascii vel. file; else: binary vel. file), itype(=0: Ps; <0: PpPs; >0: PpPp)

```
0    0
```

% Type of migration velocity (itype).
- itype = 0 because migration velocities for Sp and Ps (with ray parameter = 0) are exactly the same.
* modvelocity

```
../model/new_iasp91.par
```

% Path for the velocity model file.
* tx_data (input seismic data)

```
../stack/stack_step2.dat
```

% The major output file of step2.

* migdata (output imaging data)
../plot/psdm_step3_taper003_0p50.dat
../plot/psdm_step3_taper003_0p40.dat
../plot/psdm_step3_taper003_0p35.dat
../plot/psdm_step3_taper003_0p30.dat
% Give names and paths to the output files.
* itrace
1
* first trace index: itrfirst
1

Run

- cd ./poststack   > ./hdpmig_freq_n.x

Output

1, psdm_step3_*.dat

The final results of this program. These migrated data can be plotted using ./plot/migration_image_plot.m in Matlab (Figure 5).

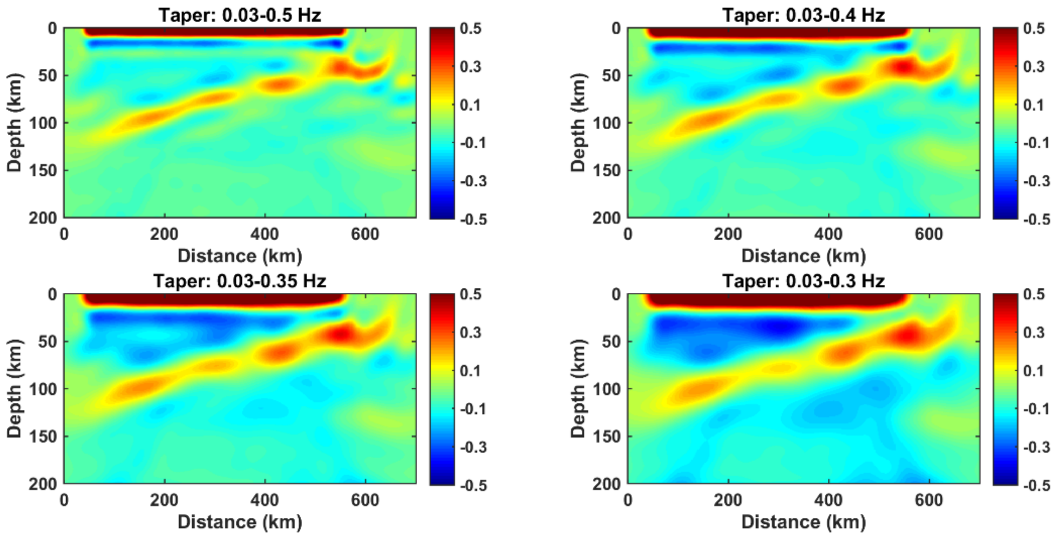

Figure 5. S-RF migrated images with different frequency contents.

4 Acknowlegement

We acknowledge Dr. Ping Zhang and Dr. Xu Wang for their contributions to the Guide Book of PSDM package (in Chinese), which provides us with valuable reference during the writing of this manual.

Comments and suggestions are warmly welcome and can be sent to either the authors or the maintainers by email.

Appendix

Appendix A. Descriptions of the Delay Time File

```
29    122   %Number of depths, number of epicentral distances+1
   0.000       35.000      50.000      55.500      77.500
  97.500      100.000     120.000     140.000     150.000
 165.000      185.000     200.000     210.000     230.500     Each depth
 260.000      280.000     300.000     310.000     330.000
 350.000      360.000     380.000     400.000     410.000
 430.000      460.000     480.000     500.000
   40.00    0.1345267   %Epicentral distance, slowness
 0.00000      5.50086     7.36803     8.04869    10.73849
13.14275     13.44002    15.80253    18.12579    19.25706
20.94134     23.11676    24.70449    25.75490    27.83997     theoretic delay time in use
30.67624     32.45523    34.13626    34.93187    36.46971
37.91430     38.59381    39.90141    41.11936    41.67144
42.43508     43.43555    43.97560    44.42685
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000     0.00000     not in use
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000
 ...
   80.50    0.0940546   %Epicentral distance, slowness
 0.00000      4.67744     6.50800     7.17981     9.86292
12.29923     12.60325    15.03790    17.46967    18.69862
20.54429     23.03790    24.92861    26.19075    28.80737     theoretic delay time for Sp (in use)
32.58099     35.14620    37.71839    39.00772    41.59287
44.18852     45.49137    48.10603    50.73588    52.06041
54.73819     58.80001    61.55666    64.36452
 0.00000      4.38466     5.99400     6.58425     8.93896
11.07355     11.33965    13.46910    15.59253    16.66257
18.26820     20.42953    22.06287    23.15218    25.40144     theoretic delay time for SKSp (not in use)
28.62517     30.79745    32.96127    34.03889    36.19049
38.33423     39.40207    41.53445    43.65957    44.71621
46.75792     49.80116    51.81051    53.80768
 ...
  180.00    0.0000000   %Epicentral distance=180 degree, slowness=0
 0.00000      4.19641     5.68644     6.23279     8.41119
10.38448     10.63035    12.59734    14.55730    15.54384
17.02364     19.01273    20.51399    21.51483    23.57835
26.52869     28.51023    30.47937    31.45781    33.40862
35.34738     36.31081    38.23177    40.14101    41.08698
42.89500     45.58059    47.34550    49.09371
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000     0.00000
 0.00000      0.00000     0.00000     0.00000
```