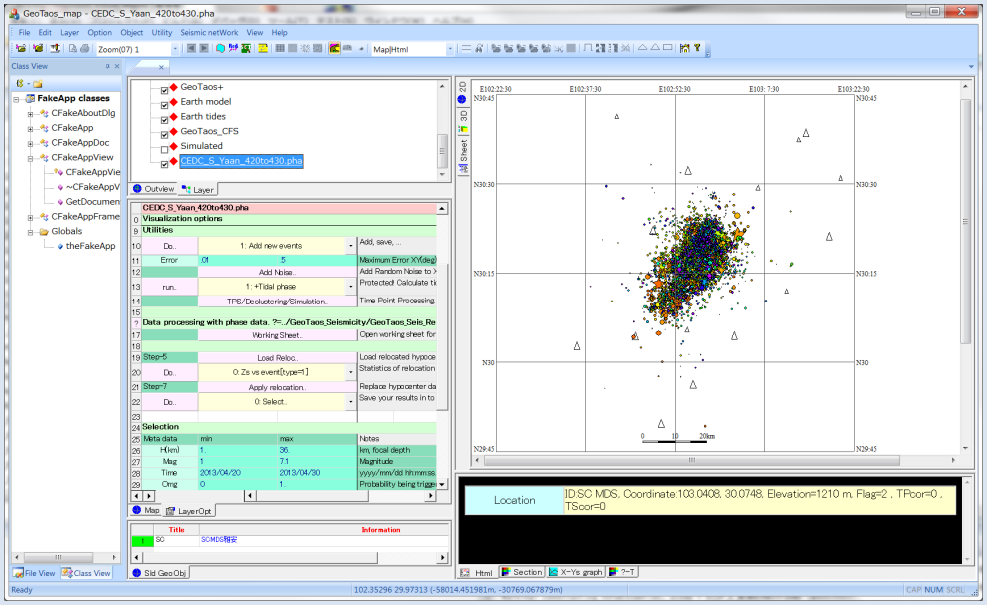
GeoTaos::Seismicity user guide

4. Relocation of earthquake hypocenters using hypoDD

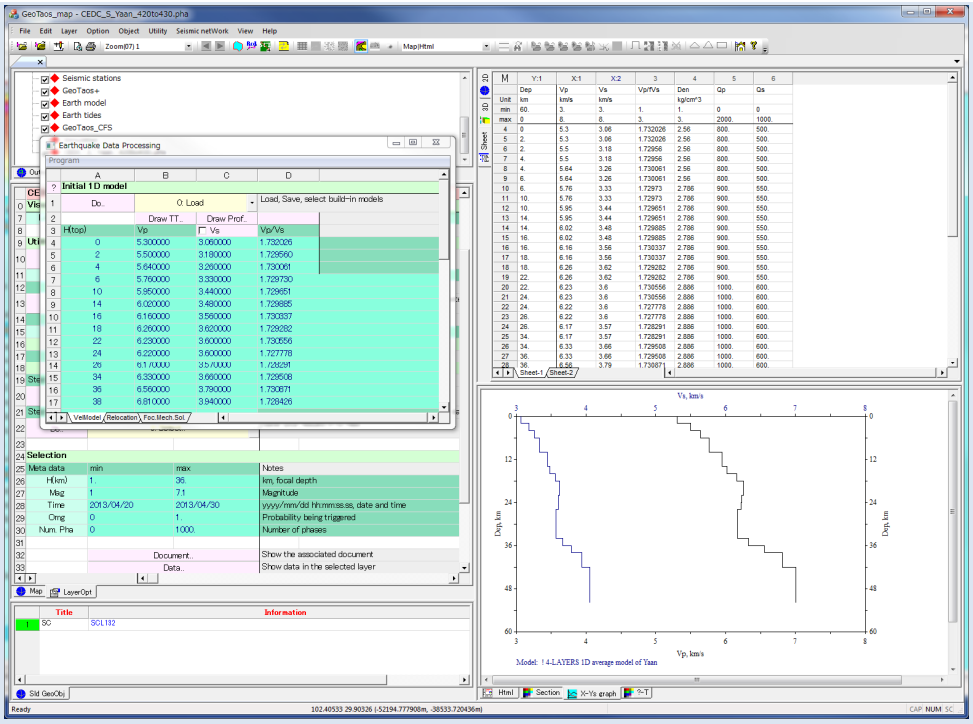
4.1 Introduction

The well-known HypoDD program for relocating earthquakes with the double-difference algorithm of Waldhauser and Ellsworth (2000) can be used directly from GeoTaos_map or GeoTaos. Through interactive interfaces, one can easily prepare data files required for using HypoDD and update hypocenter data set with the relocated hypocenters. The following step-by-step tutorial use the Yaan aftershocks of the 1st 10 days as an example to show the general steps for relocating hypocenters by use of HypoDD. The data set is the same one used in Lei et al. 2013.

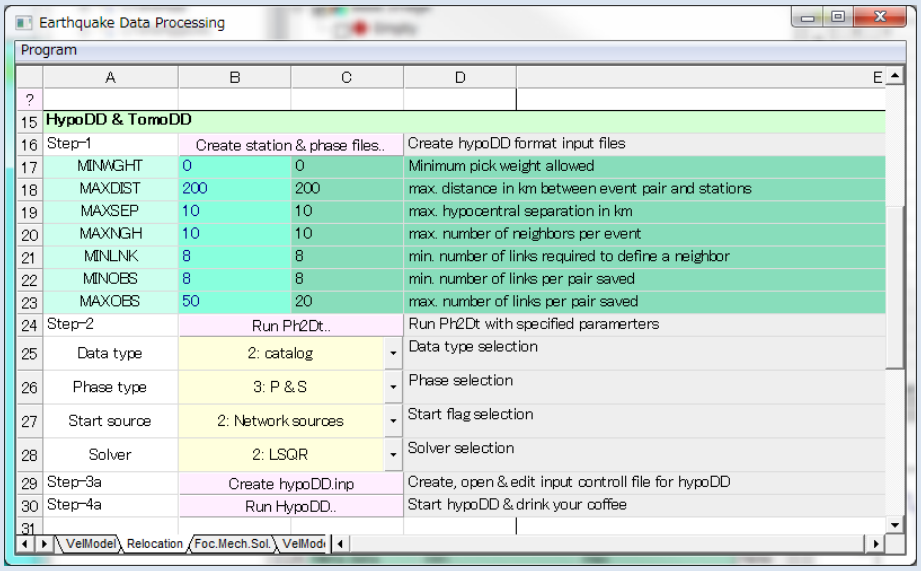
1) Prepare phase data. The phase data of the Mw6.9 Yaan earthquake is given as "**CEDC_S_Yaan_420to430.pha**" in "GeoTaos/Data_Yaan_M7/" folder.
2) Drag the phase data file "CEDC_S_Yaan_420to430.pha" and drop it into GeoTaos_map. Specify the file, "**GeoTaos/Gmap_Obj/Seistation_China.txt**", for seismic stations when asked.
3) Zoom the map to the area within which hypocenters to be relocated is distributed.



4) Click [Working Sheet..], from the [Layer] working sheet of the phase layer to show [Earthquake Data Processing], then click [VelModel] tag.
5) From row-1 select [0:Load] and then click [Do..], do load a velocity model. Specify "**GeoTaos/Data_EQ/Crust_Model/Vel_Yaan_15layer.txt**". You can click [Draw Prof..] to see the depth-velocity profile.



6) Click [Relocation] tab.



6) Move to "HypoDD & TomoDD".

7) Step-1: Click [Create Station & phase files..], you will be asked consecutively to specify files for station data and phase data, which will be created in formats ready for Ph2Dt. It is convenient to prepare a new working folder in your PC, few tens of file will be created during the relocating processes. Save the station data and phase data as, for example, "station.dat" and "phase.pha", respectively.

8) Step-2: Change parameters in the B column from row 17 to -23. The default parameters are basically fine for most cases; however, these parameters should be optimized for case by case. Then click "Run Ph2Dt" to convert phase data to differential time data for HypoDD. If GeoTaos cannot find

"Ph2Dt.exe" and "HypoDD.exe" program, a dialogue box will displayed to ask you to specify them, which are distributed in "GeoTaos" folder. You can copy "Ph2Dt.exe" and "HypoDD.exe" to the working directory for later use.

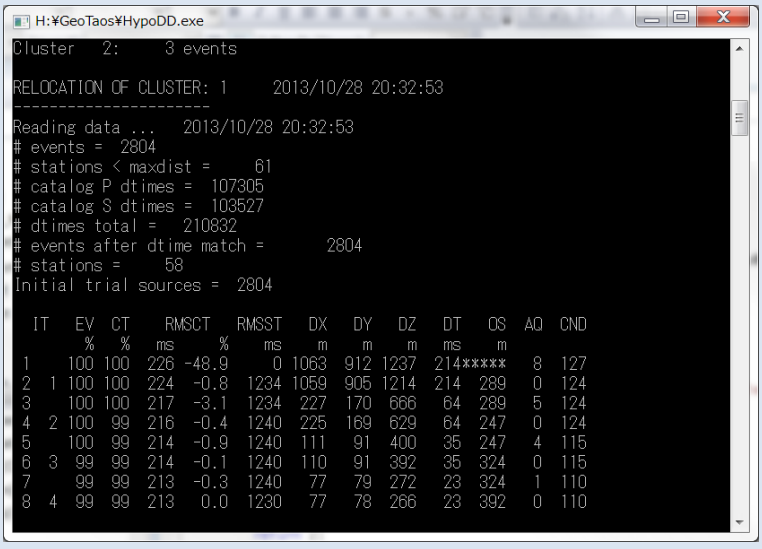
9) Step-3: Click [Create hypoDD.inp] to create an input file for hypoDD. The created "hypoDD.inp" will be automated open to allow you verifying and making further modification.

```
* RELOC.INP:
*--- input file selection
* cross correlation diff times:
dt.cc
*
*catalog P diff times:
dt.ct
* event file:
event.dat
*
* station file:
Station.dat
*--- output file selection
* original locations:
hypoDD.loc
* relocations:
hypoDD.reloc
* station information:
hypoDD.sta
* residual information:
hypoDD.res
* source paramater information:
*hypoDD.src

*--- data type selection:
* IDAT:  0 = synthetics; 1= cross corr; 2= catalog; 3= cross & cat
* IPHA: 1= P; 2= S; 3= P&S
* DIST:max dist [km] between cluster centroid and station
* IDAT   IPHA   DIST
    2    3    200
*
*--- event clustering:
* OBSCC:    min # of obs/pair for crosstime data (0= no clustering)
* OBSCT:    min # of obs/pair for network data (0= no clustering)
* OBSCC  OBSCT
     0     8
*
*--- solution control:
* ISTART:          1 = from single source; 2 = from network sources
* ISOLV:  1 = SVD, 2=LSQR
* NSET:            number of sets of iteration with specifications following
*  ISTART  ISOLV  NSET
     2       2     2
*
*--- data weighting and re-weighting:
* NITER:           last iteration to used the following weights
* WTCCP, WTCCS:             weight cross P, S
* WTCTP, WTCTS:             weight catalog P, S
```

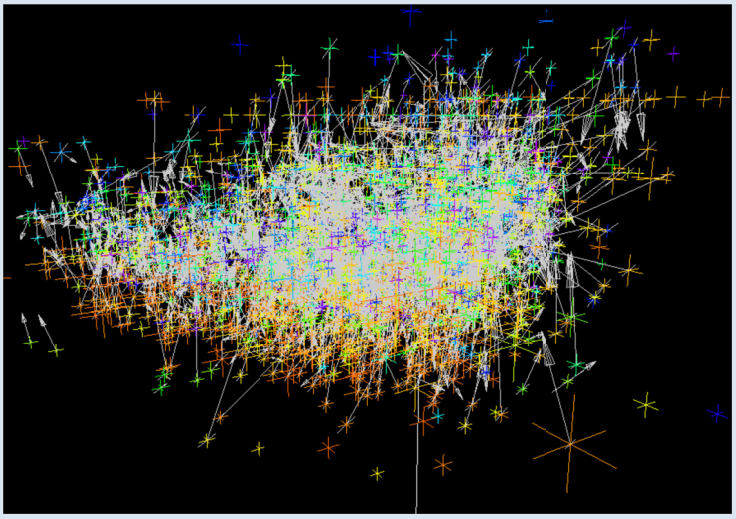
```
* WRCC, WRCT:               residual threshold in sec for cross, catalog data
* WDCC, WDCT:               max dist [km] between cross, catalog linked pairs
* DAMP:                     damping (for lsqr only)
*       ---  CROSS DATA ----- ----CATALOG DATA ----
* NITER WTCCP WTCCS WRCC WDCC WTCTP WTCTS WRCT WDCT DAMP
  5     0.01  0.01   -9   -9   1.0    0.5  -9    -9    80
  5     0.01  0.01   -9   -9   1.0    0.5   6     4    80
*--- 1D model:
* NLAY:           number of model layers
* RATIO: vp/vs ratio
* TOP:            depths of top of layer (km)
* VEL:            layer velocities (km/s)
* NLAY  RATIO
   15     1.73
* TOP
0 2 4 6 10 14 16 18 22 24 26 34 36 38 42
* VEL
5.30 5.50 5.64 5.76 5.95 6.02 6.16 6.26 6.23 6.22 6.17 6.33 6.56 6.81 7.01
*
*--- event selection:
* CID:    cluster to be relocated (0 = all)
* ID:     cuspids of event to be relocated (8 per line)
* CID
   0
* ID
```

10) Click [Run HypoDD] to run HypoDD.exe. It is a DOS consol program, you will see following output windows, which will be closed automatically when the program is terminated. You can type "Ctr+C" to stop the program on if the program takes abnormally long time for a iteration, indicating the problem might be poorly determined.



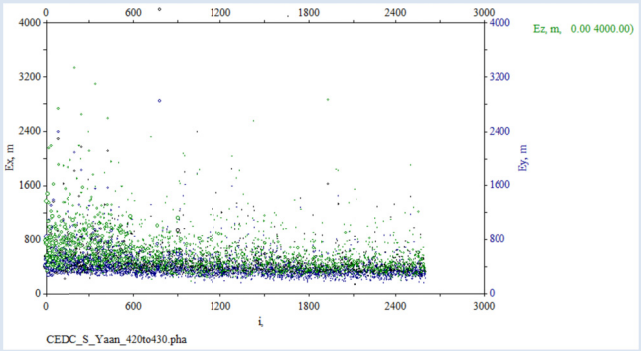
11) On normal termination, a file named as "**hypoDD.reloc**" will be created for new hypocenter data. You can drag and drop it the GeoTaos_Map as new layer of earthquake hypocenters. **It should be noted that events are grouped in clusters and thus are disordered if there are more than one clusters have been relocated**. In such cases, one should sort the data with increasing event number.

12) If you want to check statistics of the relocation, you should click the "Load Reloc.." button from the Phase layer to load the relocated hypocenters. By this way sorting "hypoDD.reloc" is not essential.

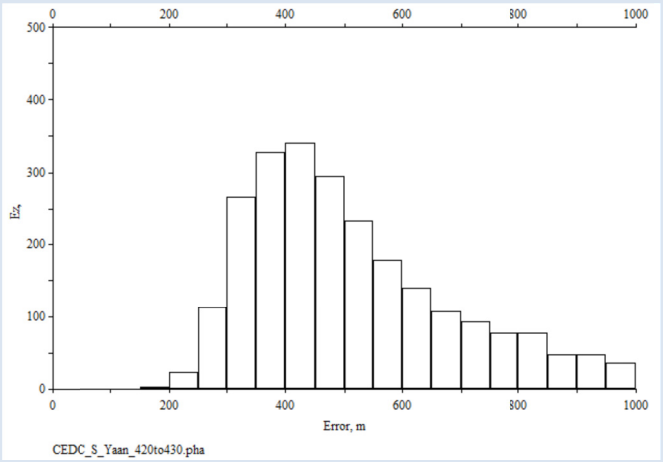


A stereo plot show hypocenter shifts by relocation

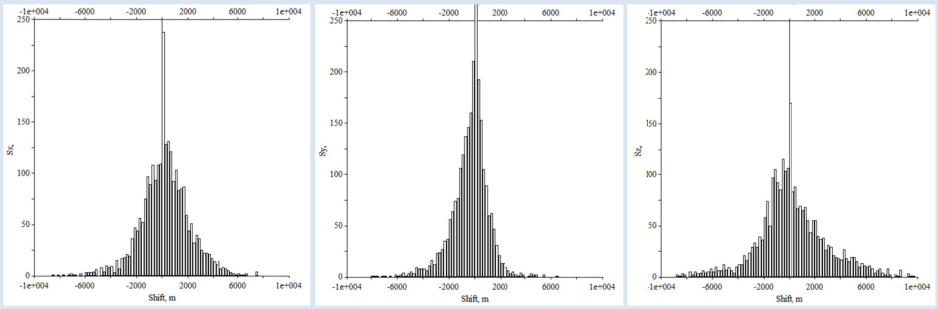
13) Select a function from the list box in row-15, and then click [Do..] to see error or shift distributions.



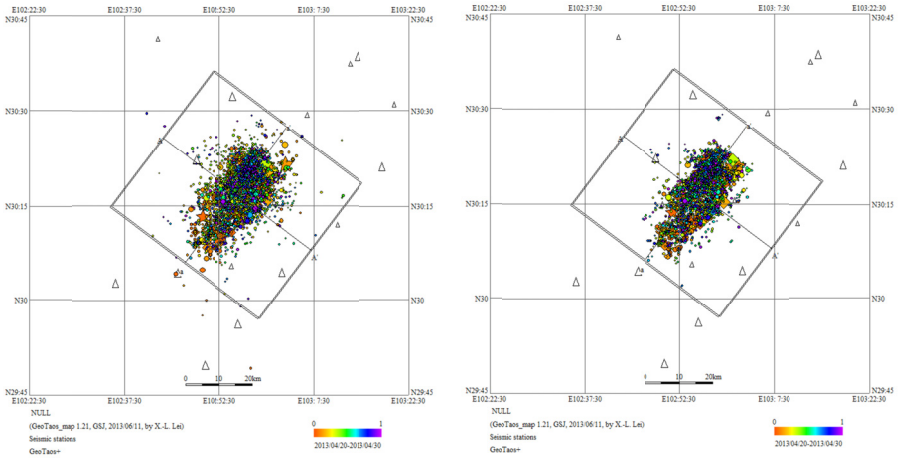
Error Ex, Ey, and Ez, are plotted against sequential event number



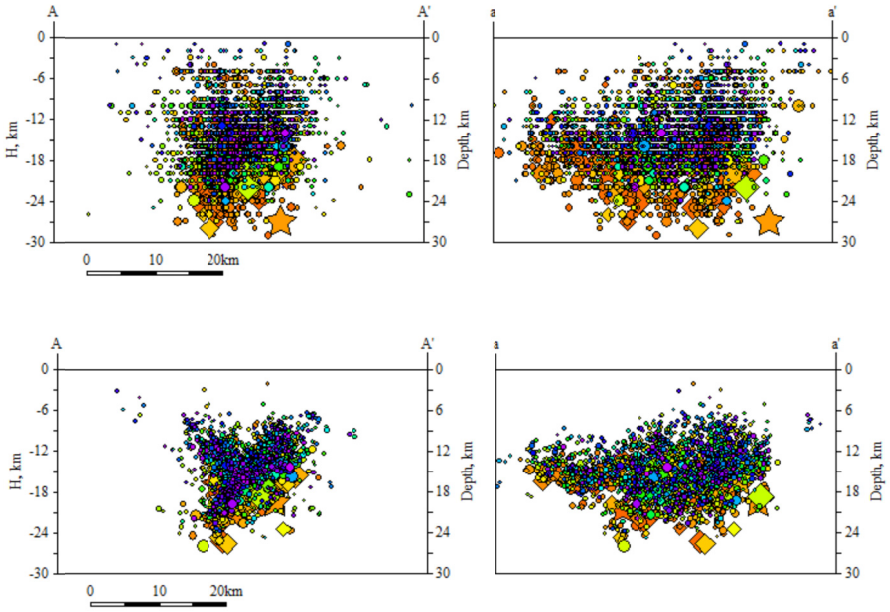
Estimated error distribution in depth direction



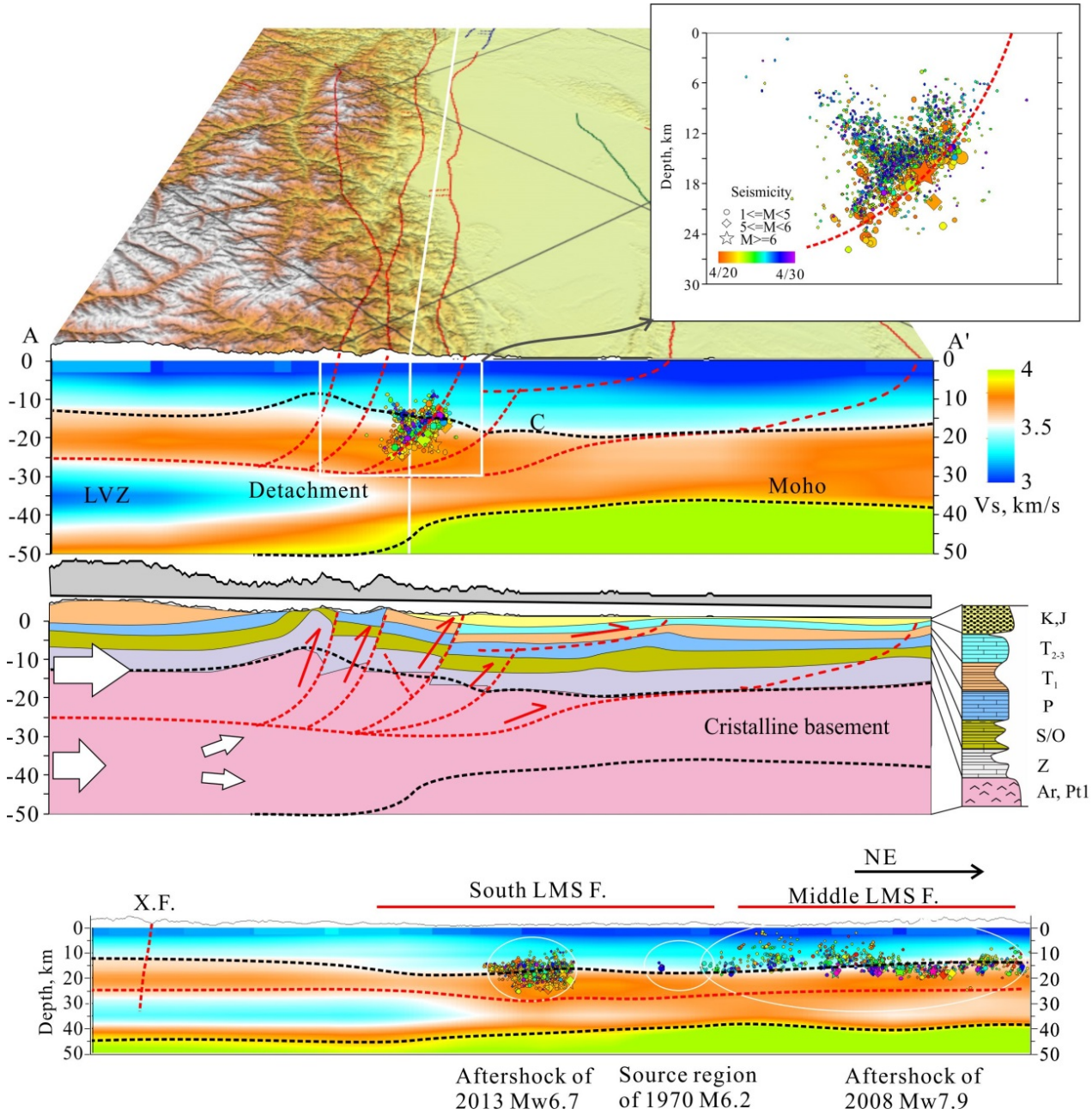
distributions of location shift along X, Y, and Z directions



Map view of original (left) and relocated (right) hypocenters.



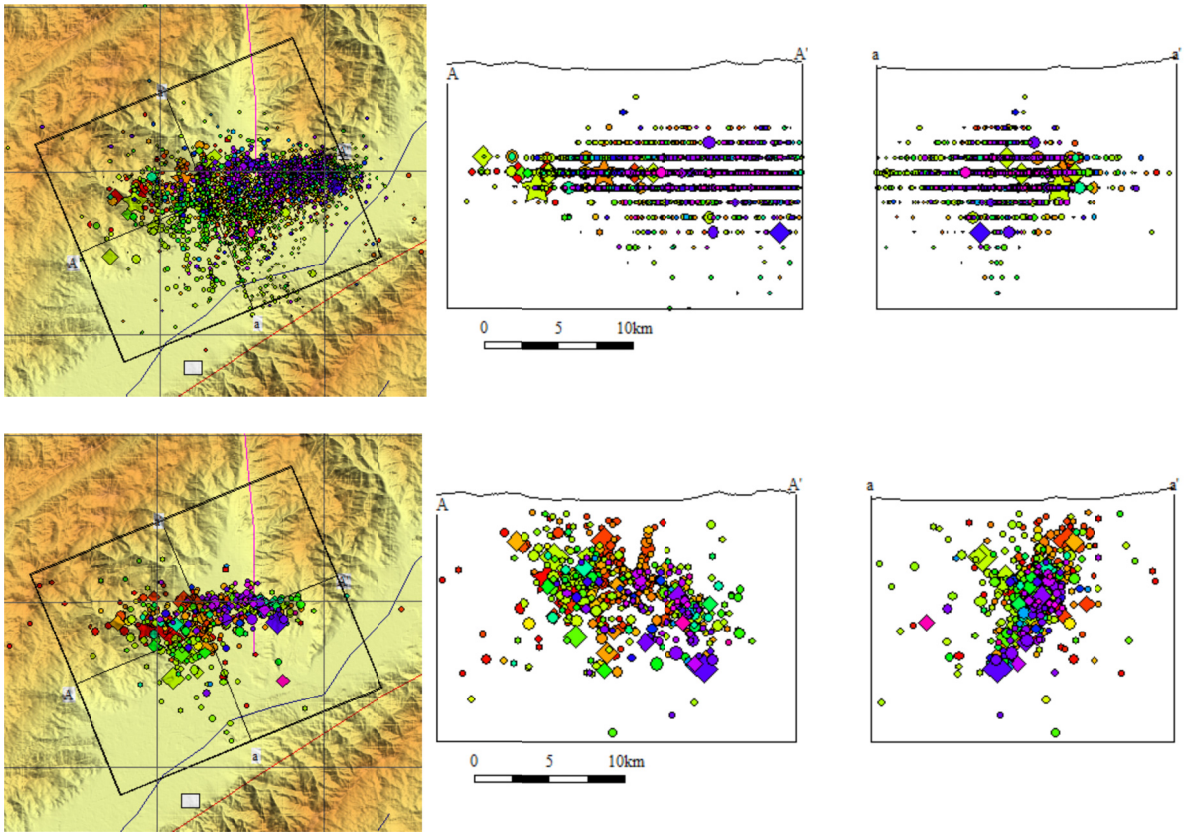
Cross sections show hypocenters before (up) and after (bottom) relocation.



A conceptual model of the 2013 Lushann Mw6.6 earthquake.

Relocated hypocenters (HypoDD) are projected on S velocity sections

obtain from ambient noise Rayleigh wave tomography. (Lei et al., 2013)



Trial relocation of earthquakes occurred in YingJian in 2011.

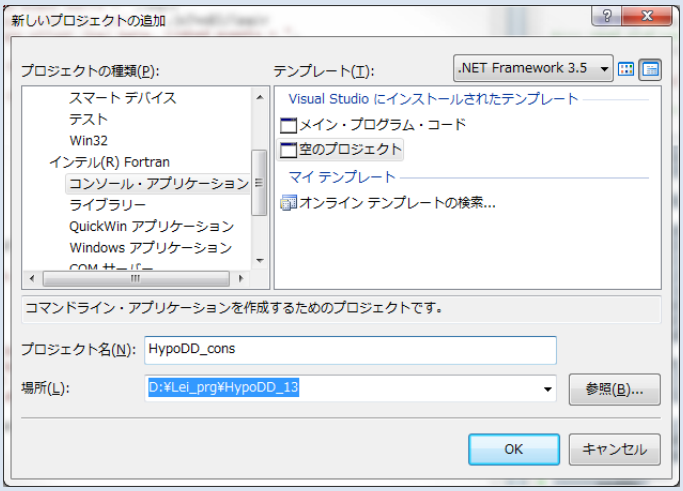
A. Notes on compiling HypoDD for Windows

A.1 Modifications by X.L. Lei

All c functions and subroutines are either replaced with FORTRAN codes or removed. As a result, the coordinates of station line in the station file must be in degree unit and other formats as "+ddd:mm:ss.ss" are not supported.

A.2 Notes on Compiling as Windows console application

1) Create and add to GeomapZ+ solution a new project of FORTRAN console application.



2) Add all source files to the project

3) Create a new FORTRAN90 file datetime.f90 for convert current time to string. Revise getdata.f, ph2dt.f, hypodd.f which calls subroutines or functions written in C codes.

4) Change following properties to the given value:

a) Fortran: Additional include directory = "../include/"

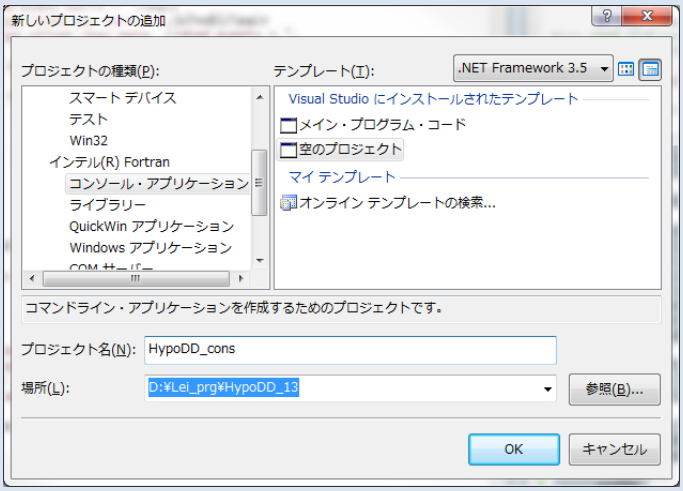
b) Fortran: External proceedings="/name:lowercase", "/assume:"

5) Compile and link to generate an executable file "hydd.exe"

A.3 Notes on Compiling as Windows DLL

Both hypoDD and Ph2Dt can be compiled in a single DLL file.

1) Create and add to GeomapZ+ solution a new project of FORTRAN library.



2) Add all source files to the project

3) Change the main programs HypoDD and Sh2Dt to subroutines can be exported. At first copy hypodd.f and ph2dt.f to hypodd_sub.f and ph2dt_sub.f, respectively. Then remove the line of "program" and following lines. Revise Sh2Dt_sub.f in the same way.

```
c      program hypoDD
      SUBROUTINE HYPODD(STR_INFILE,STR_OUFILE)
      !DEC$ IF DEFINED (_DLL)
      !DEC$ ATTRIBUTES DLLEXPORT::HYPODD
      !DEC$ END IF
```

4) Change following properties to the given value:

a) Fortan: Additionl include directory = "../include/"

b) Fortran:External proceedings="/name:lowercase", "/assume:"

5) Compile and link to generate an executable file "hydd.dll"

Reference

雷兴林，马胜利，苏金蓉，王小龙，2013. 汶川地震后中下地壳及上地幔的粘弹性效应引起的应力变化与芦山地震的发生机制，地震地质, 35, 2, 411-422, doi:10.3969/j.issn.0253-4967.2013.02.01

Lei Xinglin, Ma Shengli, Su Jinrong, Wang Xiaolong, 2013. Inelastic triggering of the 2013 Mw6.6 Lushan earthquake by the 2008 Mw 7.9 Wenchuan earthquake, Seismology and Geology, 35, 2, 411-422, doi:10.3969/j.issn.0253-4967.2013.02.01

Waldhauser, F. and W.L. Ellsworth, A double-difference earthquake location algorithm: Method and application to the northern Hayward fault, Bull. Seismol. Soc. Am., 90, 1353-1368, 2000.