Brief instructions for easy start working with the LOTOS code, version 12

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Stage 1: Preparation of the code

Step 1.1. Download the file “lotos_10_exe.zip” from the web site on: www.ivan-art.com/scence/LOTOS/lotos_10_exe_win.zip or copy from the CD at “`LOTOS/lotos_10_exe_win.zip`”.

Step 1.2. Unzip and copy to any location of your computer. ADVISE: try to use simple paths, (for example `D:/PROGRAMS/LOTOS`) and **avoid** the system paths related to “`My Documents`” or “`Desktop`”. This will make operating with files much easier.

Step 1.3. Check if visualization tool works correctly at your computer. Go to “`/COMMON/visual_exe`” and run “`visual.exe`”. As a result, a new file “`picture.png`” will appear in the same folder (check the time of the file producing). In the case of correct work of the program, it should be identical to “`picture_correct.png`” located in the same folder. In the case if it does not work, the problem can probably be solved if a free package “`dotnetfx.exe`” is installed. It can be downloaded from www.ivan-art.com/scence/dotnetfx.zip , unzipped and executed.

Stage 2. Observed data inversion using an existing example

Step 2.1. Define the model to proceed. Open the file “`model_all.dat`” in the root directory: `/model_all.dat`

```
1: name of the region
2: name of the model
3: number of iterations
DATASET1 MODEL_01 5
```

Starting from line 4, one or several models are defined (no more than 10). The structure of the data has two-steps hierarchy: AREA - MODEL. In this example “`DATASET1`” means the AREA folder. “`MODEL_01`” is the name of the current model. “`5`” is the number of iterations to perform.

Step 2.2. Check if this model exists in folder “`DATA/DATASET1/MODEL_01`”. In the case of observed data inversion, there should be at least two files inside this directory: `MAJOR_PARAM.DAT` and `ref_start.dat.`

Step 2.3. Check the availability of the initial data in folder “`DATA/DATASET1/inidata`” There are two mandatory files:

1. “`rays_xyz.dat`” information about observed source-receiver pairs and travel times.
2. “`stat_ft.dat`”: list of the stations in geographical coordinates

Step 2.4. Check the availability the files required for visualization and previewing which should be created as described in Section 4 of the manual.
`DATASET1/sethor.dat`
`DATASET1/setver.dat`
`DATASET1/config.txt`

Step 2.5. Check if file “`preview_key.txt`” exists and contains any nonzero number. Otherwise previewing will not be performed.

Step 2.6. Run the batch file "START.BAT" in the root directory. A console with information about running the program will appear. Running the entire inversion procedure (5 iterations) for the selected procedure will take 20-40 minutes depending on the computer.
ADVICE: We recommend defining larger console buffer to be able to check the course of calculations backward. Click right bottom of mouse on upper panel of console – select Properties – select Position (3rd Tab) – update Height of the Screen Buffer (for example up to 3000 lines).

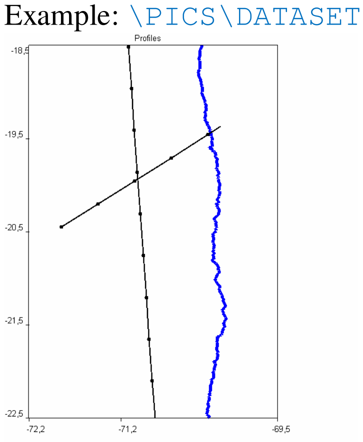
Step 2.7. If calculations are finished successfully and preview tool is available (checked in Step 1.3), a set of PNG image files should appear in the corresponding folder. In the considered example they will be created in "`PICS/DATASET1/MODEL_01/`".

Indications:
`//it//` is a number of iteration,
`//gr//` is a number of grid,
`//ps//` is 1 for P or 2 for S model,
`//lev//` is a number of depth level,
`//ver//` is a number of vertical section

Preview files created:

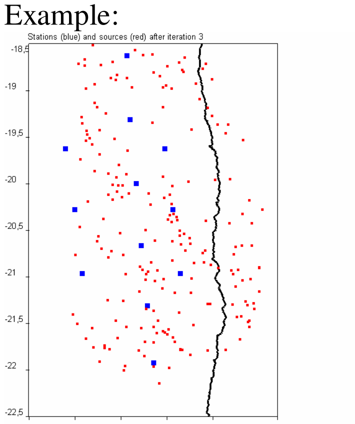
1. Locations of the profiles:

`profiles.png`: locations of profiles in map view;
Example: `\PICS\DATASET1\MODEL_01\profiles.png`



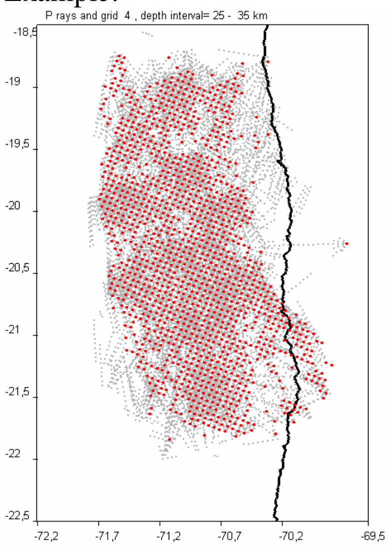
2. Locations of the sources in iterations:

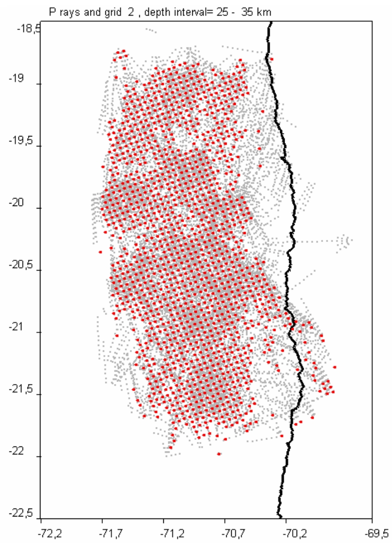
`sources//it//.png`: locations of sources after a current iteration;
Example:



`\PICS\DATASET1\MODEL_01\sources3.png`

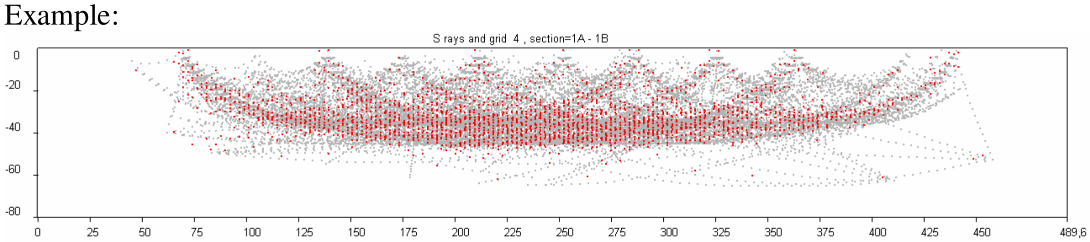
3. Distributions of grids and rays in 1st iteration in map view:
RAYS_GRID\rays_hor//gr//ps//lev//.png: node distributions and ray paths after 1st iteration in different depth intervals (defined in sethor.dat);
Example:





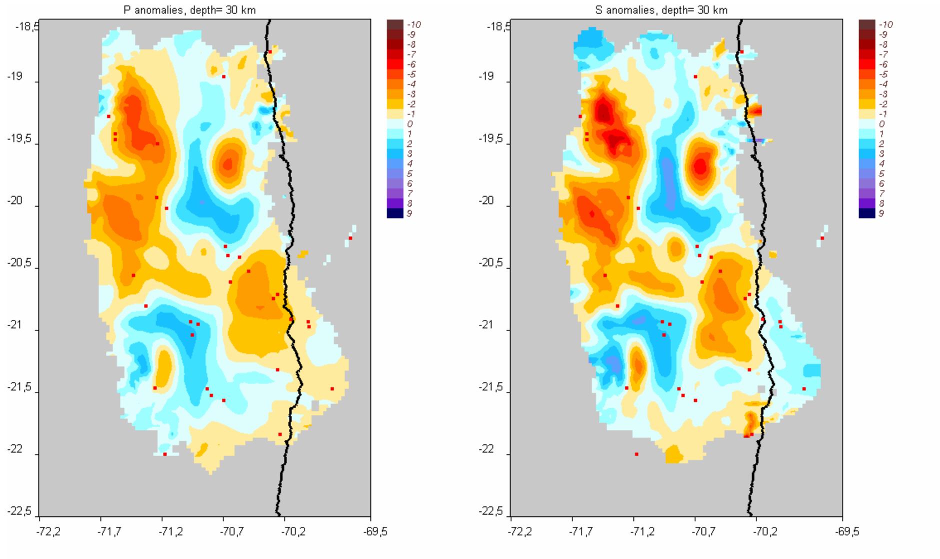
\PICS\DATASET1\MODEL_01\RAYS_GRID\rays_hor413.png
\PICS\DATASET1\MODEL_01\RAYS_GRID\rays_hor213.png

4. Distributions of grids and rays in 1st iteration in vertical sections:
RAYS_GRID\ver_rays_nodes//gr//ps//lev//.png: node distributions and ray paths after 1st iteration in different vertical sections (defined in setver.dat);
Example:



\PICS\DATASET1\MODEL_01\RAYS_GRID\ver_rays_nodes421.png

5. Resulting velocity anomalies in horizontal sections:
IT\//it//\hor_dv//ps//lev//.png: velocity anomalies in horizontal sections after a current iteration;
Example:

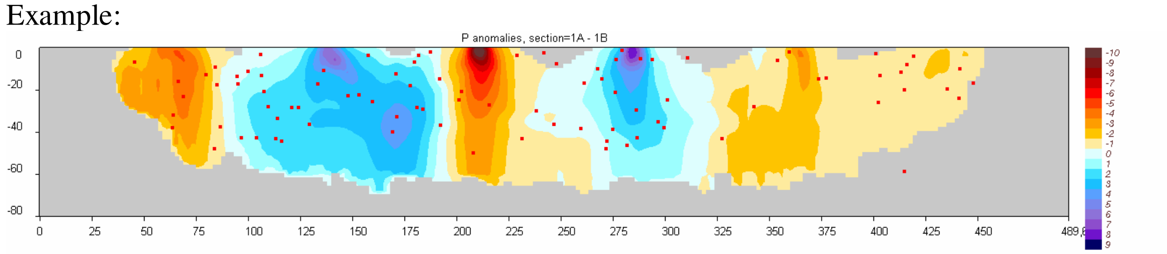


\PICS\DATASET1\MODEL_01\IT3\hor_dv1 3.png
\PICS\DATASET1\MODEL_01\IT3\hor_dv2 3.png

6. Resulting velocity anomalies in vertical sections:

IT\//it//\ver_dv//ps//lev//.png: velocity anomalies in horizontal sections after a current iteration;

Example:



\PICS\DATASET1\MODEL_01\IT3\ver_dv1 1.png

The high quality pictures can be created using a commercial tool (e.g. Surfer). The program creates .DAT, .GRD and .BLN which can be used directly in Surfer. The generated files are stored in FIG_files directory and they overwrite the older ones.

List of the main files for visualization:

FIG_files/result/hor/vabs//lev//it//.grd: Absolute velocities in horizontal sections;

FIG_files/result/hor/dv//lev//it//.grd: Velocity anomalies (in%) in horizontal sections;

FIG_files/result/vert/abs//ver//it//.grd: Absolute velocities (in km/s) in vertical sections;

FIG_files/result/vert/ver//ver//it//.grd: Velocity anomalies (in%) in vertical sections;

FIG_files/result/vert/topo_line//ver//.bln: Topography line in vertical sections;

FIG_files/result/vert/shots//ver//.dat: Shots projected onto vertical sections;

FIG_files/result/vert/stat//ver//.dat: Stations projected onto vertical sections;

FIG_files/result/vert/mark_//ver//.bln: Locations of the profiles in map view;

FIG_files/result/rays/rays_hor.dat: Rays in a defined depth interval;

FIG_files/result/rays/nodes_hor.dat: Parameterization nodes in a defined depth interval;

Step 2.7 Create a new model (e.g. "MODEL_02") and play with parameters in "MAJOR_PARAM.DAT". The most important parameters are:

1. **Smoothing** (3rd line in "INVERSION PARAMETERS" in "MAJOR_PARAM.DAT")
2. **Amplitude damping** (4th line in INVERSION PARAMETERS in "MAJOR_PARAM.DAT")
3. **Horizontal node spacing** (3rd number in 1-2 lines in GRID PARAMETERS in "MAJOR_PARAM.DAT")
4. **Vertical node spacing** (5th line in GRID PARAMETERS in "MAJOR_PARAM.DAT")
6. **Velocity model** (values in file "refmod.dat")

Produce the results as PNG images and SRF files. Analyze the effect of each of these parameters on the result.

Stage 3. Real data inversion and synthetic modeling based on different schemes using existing datasets

Step 3.1. Define all the models to proceed. Open the file "model_all.dat" in the root directory (**10 models, maximum**):

/model_all.dat

```
1: name of the region
2: name of the model
3: number of iterations
DATASET1 NODE_PX1 5
DATASET1 CELL_PS1 5
DATASET1 BOARD_N1 5
DATASET1 SMILE_01 5
```

In this example we consider four different models for the same dataset:

1. NODE_PX1: is inversion using Vp-Vp/Vs scheme and node parameterization
2. CELL_PS1: is inversion using Vp- Vs scheme and cell parameterization
3. BOARD_N1: is synthetic modeling using a checkerboard model
4. SMILE_01: is synthetic modeling using a free-shaped model

Step 3.2. Check if all these models exist in folder "DATA/DATASET1".

In the case of observed data inversion (NODE_PX1 and CELL_PS1), there should be two files inside the corresponding directory: MAJOR_PARAM.DAT and ref_start.dat.

In the case of synthetic modeling (BOARD_N1 and SMILE_01) there should be three additional files: (1) anomaly.dat, (2) ref_syn.dat and (3) noise.dat

In the case if a synthetic model is defined using free shaped polygons, they should be defined in a subfolder forms. For example, in model SMILE_01 in file anomaly.dat four polygons are mentioned: circl, glaz1, glaz2 and smile. For all of them, corresponding files should exist:

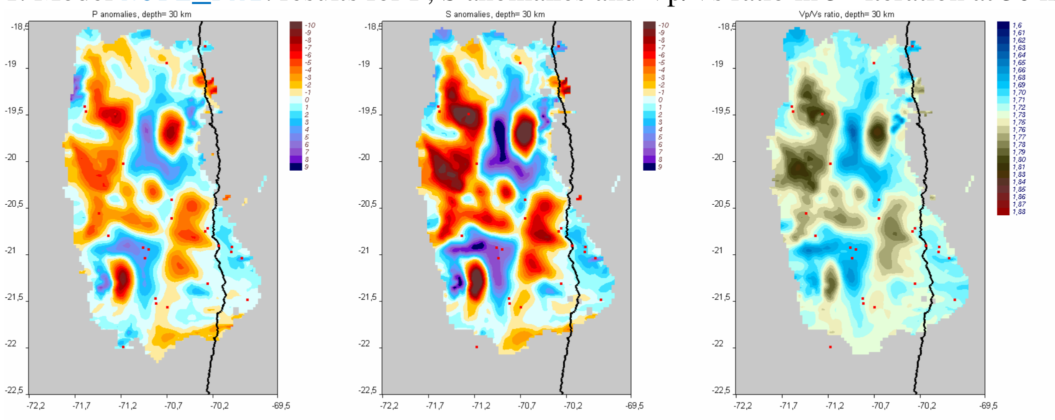
forms/circl.bln
forms/glaz1.bln
forms/glaz2.bln
forms/smile.bln

In addition there may be a file `forms/scaling.bln` which contains parameters for scaling the entire model and rotating. If it does not exist, the anomalies are constructed according to coordinates in polygons.

Step 3.3. Run the batch file "START.BAT" in the root directory.

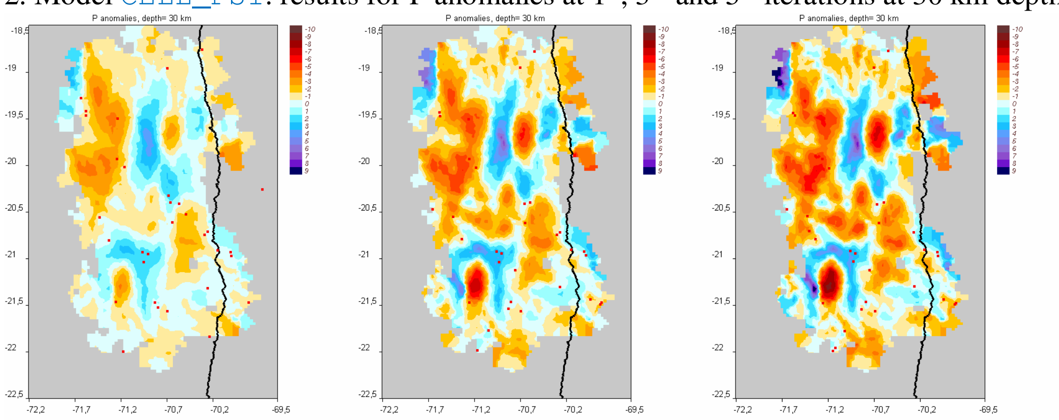
As a result, a set of PNG pictures will appear in folder PICS. Below we present some examples of pictures obtained using the presented sets of parameters. Compare with the results obtained after calculations at your computer. They should be identical.

1. Model `NODE_PX1`: results for P, S anomalies and Vp/Vs ratio in 3rd iteration at 30 km depth



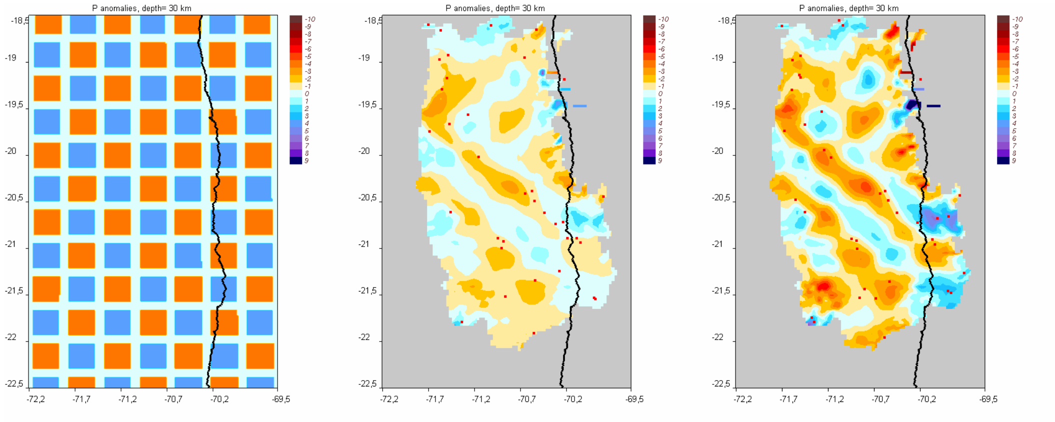

```
\PICS\DATASET1\NODE_PX1\IT3\hor_dv1 3.png
\PICS\DATASET1\NODE_PX1\IT3\hor_dv2 3.png
\PICS\DATASET1\NODE_PX1\IT3\hor_vpvs 3.png
```

2. Model `CELL_PS1`: results for P anomalies at 1st, 3rd and 5th iterations at 30 km depth



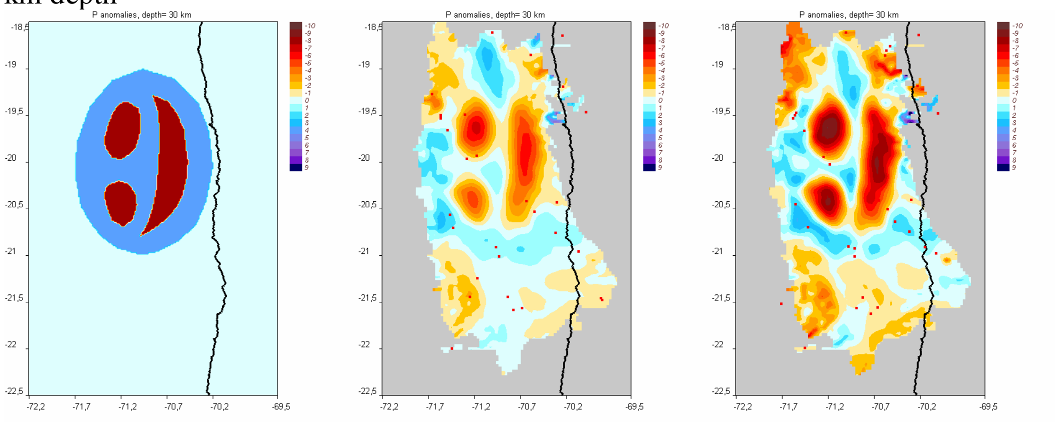

```
\PICS\DATASET1\CELL_PS1\IT1\hor_dv1 3.png
\PICS\DATASET1\CELL_PS1\IT3\hor_dv1 3.png
\PICS\DATASET1\CELL_PS1\IT5\hor_dv1 3.png
```

3. Model `BOARD_N1`: synthetic model and results for P anomalies at 1st, and 3rd iterations at 30 km depth



\PICS\DATASET1\BOARD_N1\hor_syn1 3.png
\PICS\DATASET1\BOARD_N1\IT1\hor_dv1 3.png
\PICS\DATASET1\BOARD_N1\IT3\hor_dv1 3.png

4. Model SMILE_01: synthetic model and results for P anomalies at 1st, and 3rd iterations at 30 km depth



\PICS\DATASET1\SMILE_01\hor_syn1 3.png
\PICS\DATASET1\SMILE_01\IT1\hor_dv1 3.png
\PICS\DATASET1\SMILE_01\IT3\hor_dv1 3.png

Stage 4. Creating the own checkerboard test

Checkerboard test is the easiest synthetic test and it is the most convenient for learning.

Step 4.1. Inside the same AREA folder as used in Stage 3, create a MODEL folder for the checkerboard with the name which consist of eight (8) characters (e.g. DATA/DATASET1/BOARD_02/).

Step 4.2. Create synthetic velocity model which is described by three files:
DATA/DATASET2/BOARD_02/anomaly.dat
DATA/DATASET2/BOARD_02/ref_syn.dat
DATA/DATASET2/BOARD_02/noise.dat

These files can be copied from another model BOARD_01 and then corrected.

Step 4.3. Perform calculations and visualization of the results as described in **Sections 2 and 3**. The particular interest in this case is the relative anomalies.

Step 4.4. Play with different parameters of model, for example:
- Tune the smoothing/damping coefficients to obtain the best reconstruction results.
- Try different sizes of patterns.
- Try different empty spacing between patterns.
- Try single anomalies (when limits of the board coincide with size of the patterns) located in different parts of the study area.
- Try performing the reconstruction when synthetic reference model is not the same as the starting one.

Stage 5. Creating own synthetic models

Step 4.1. Inside the same AREA folder as used in Stage 3, create a MODEL folder for the synthetic model with the name which consist of eight (8) characters (e.g. `DATA/DATASET1/SYN_MOD1/`)

Step 5.2. Create synthetic velocity model which is described by two files:
`DATA/DATASET2/SYN_MOD1/anomaly.dat`
`DATA/DATASET2/SYN_MOD1/ref_syn.dat`
`DATA/DATASET2/SYN_MOD1/noise.dat`

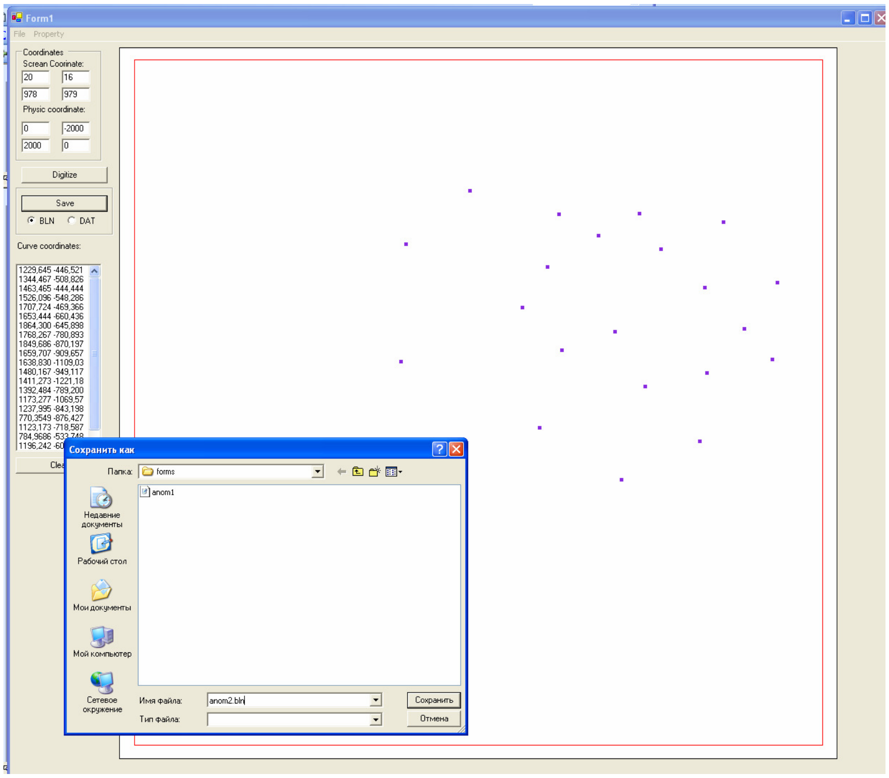
These files can be copied from another model `SMILE_01` and then corrected.

In this step one may need to digitize polygons and polylines to create patterns for anomalies in `anomaly.dat`. We propose two ways for doing this task:

1. **With SURFER.** We use the digitizing tool in Surfer which is very convenient for such tasks. To do it in Surfer, make the following steps:
- Open a plot with some results for the current map or profile (e.g. observed data inversion, main results);
- Select the plot;
- Select Menu: "Map – Digitize";
- Digitize the pattern in the plot (results appear in a separate window);

Save the file in BLN format to subfolder forms (e.g. `DATA/DATASET1/SYN_MOD1/forms/anom1.bln`). The name should contain 5 characters.

2. **With our own digitizing tool**.



We offer a free digitizing tool which performs the similar procedure as SURFER. To use this tool, perform the following steps:

- run the program from /COMMON/digitize_exe/Digitizer.exe;
- If you want to use any forms in an existing bitmap file, use Menu: "File > Load image" and load the bitmap image (for example PICS/DATASET1/MODEL_01/syn_abs.png In the screenshot example which is presented above, we create absolutely new patterns and do not load any image;
- If necessary, resize the panel using Menu "Property > Resize panel". In the presented example the size of the panel is 1000x1000 pixels;
- Set the screen area using Menu "File > set work area" and selecting by mouse from one corner of the plot to another. The frame will be marked with red line. The screen coordinates can be defined manually in fields Screen coordinates.

xscreen_min - yscreen_min
xscreen_max - yscreen_max

- Physical coordinates are defined manually in the corresponding fields:

xphys_min - yphys_min
xphys_max - yphys_max

- Press button "Digitize" and start digitizing
- After finishing digitizing the polyline, save it to the folder "DATA/DATASET1/SYN_MOD1/forms" in bln format. The name of the file should contain five characters (for example, anom1.bln, anom2.bln);
- If another polygon should be digitized, press button "Clear" and start digitizing again.
- If necessary, digitize in the same way the interfaces (for example, surf1.bln, surf2.bln) and save them to the same location;

Step 5.3. Check correctness of the model definition.
1. Define the current model in file

/model.dat

```
DATASET1
SYN_MOD1
```

2. Run visualizing programs in
"PROG\a_set_syn_hor\create.exe",
"PROG\a_set_syn_ver\create.exe"
for horizontal and vertical sections.

3. Check pictures, for example:
\PICS\DATASET1\SYN_MOD1\hor_syn1 3.png

Step 5.4. Run the batch file "START.BAT" in the root directory. After finishing calculations check the results.

Stage 6. Performing real and synthetic inversions for other presented datasets

Step 6.1. Open the file "model_all.dat" in the root directory and define the following models (**10 models, maximum**):

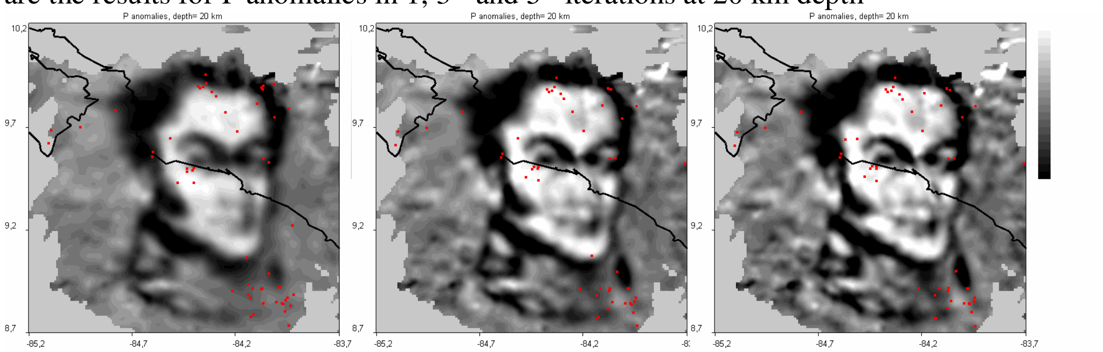
/model_all.dat

```
1: name of the region
2: name of the model
3: number of iterations
BOLIVAR_ NODES_01 5
BOLIVAR_ BLOCK_01 5
BOLIVAR_ Ver_BRD1 5
GAP_180_ MODEL_01 5
GAP_280_ MODEL_01 5
TOBA_001 MODEL_01 5
TOBA_REA REAL_VPX 5
TURKEY__ MODEL_01 5
```

Step 6.2. Run the batch file "START.BAT" in the root directory. For these models calculations will be longer than for previously considered models.

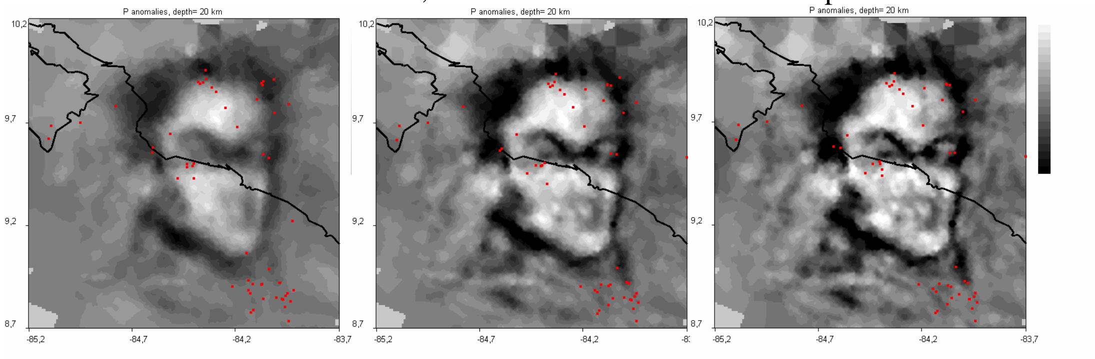
As a result, a set of PNG pictures will appear in folder PICS. Below we present some examples of pictures obtained using the presented sets of parameters. Compare with the results obtained after calculations at your computer. They should be identical.

1. Model BOLIVAR/NODES_01: same results as presented in Koulakov (2009a, BSSA). Below are the results for P anomalies in 1, 3rd and 5th iterations at 20 km depth



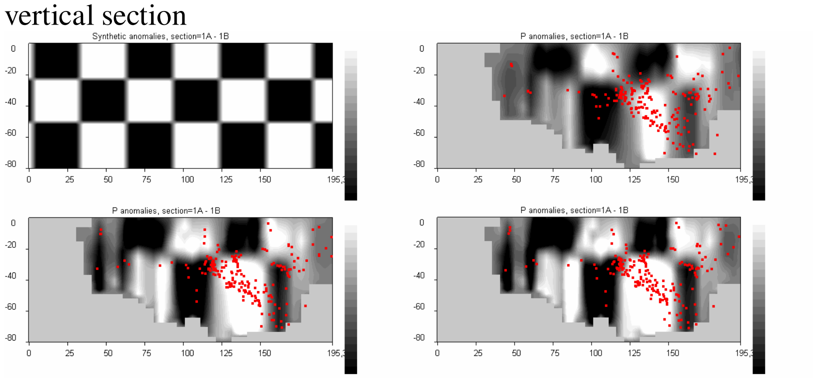
\PICS\BOLIVAR_\NODES_01\IT1\hor_dv1 1.png
\PICS\BOLIVAR_\NODES_01\IT3\hor_dv1 1.png
\PICS\BOLIVAR_\NODES_01\IT5\hor_dv1 1.png

2. Model BOLIVAR/BLOCK_01: same results as presented in Koulakov (2009a, BSSA). Below are the results for P anomalies in 1, 3^{rd} and 5^{th} iterations at 20 km depth



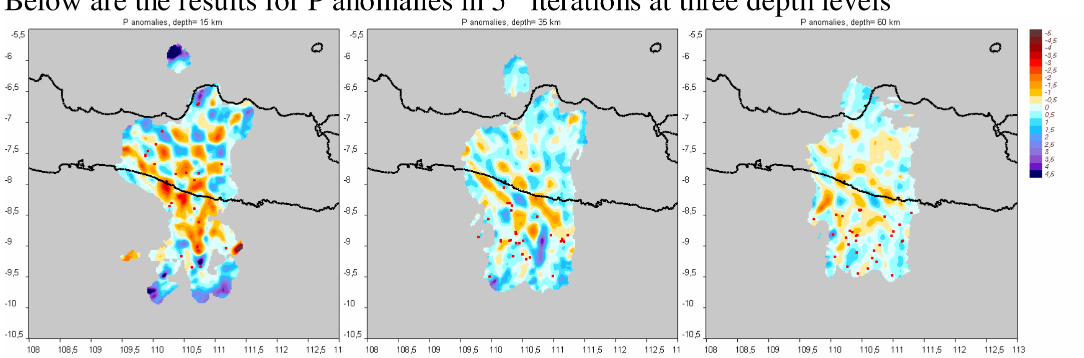
\PICS\BOLIVAR_\BLOCK_01\IT1\hor_dv1 1.png
\PICS\BOLIVAR_\BLOCK_01\IT3\hor_dv1 1.png
\PICS\BOLIVAR_\BLOCK_01\IT5\hor_dv1 1.png

3. Model BOLIVAR/Ver_BRD1: same results as presented in Koulakov (2009a, BSSA). Below are the initial model and reconstruction results for P anomalies in 1, 3^{rd} and 5^{th} iterations in a vertical section



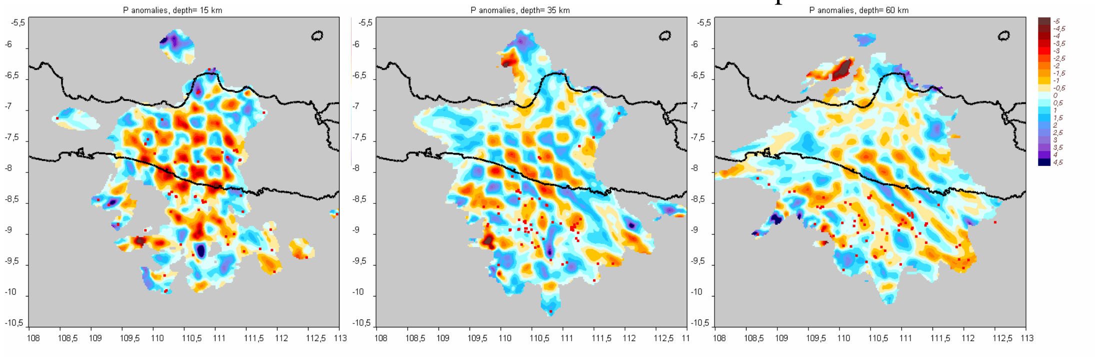
\PICS\BOLIVAR_\Ver_BRD1\ver_syn1 1.png
\PICS\BOLIVAR_\Ver_BRD1\IT1\ver_dv1 1.png
\PICS\BOLIVAR_\Ver_BRD1\IT3\ver_dv1 1.png
\PICS\BOLIVAR_\Ver_BRD1\IT5\ver_dv1 1.png

4. Model GAP__180/MODEL_01: same results as presented in Koulakov (2009b, BSSA). Below are the results for P anomalies in 5^{th} iterations at three depth levels



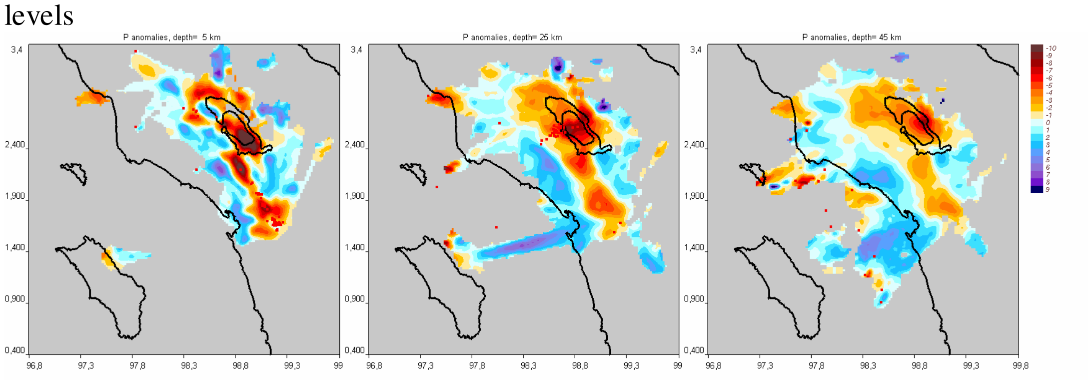
\PICS\GAP__180/MODEL_01\IT5\hor_dv1 1.png
\PICS\GAP__180/MODEL_01\IT5\hor_dv1 2.png
\PICS\GAP__180/MODEL_01\IT5\hor_dv1 3.png

5. Model GAP__280/MODEL_01: same results as presented in Koulakov (2009b, BSSA). Below are the results for P anomalies in 5th iterations at three depth levels



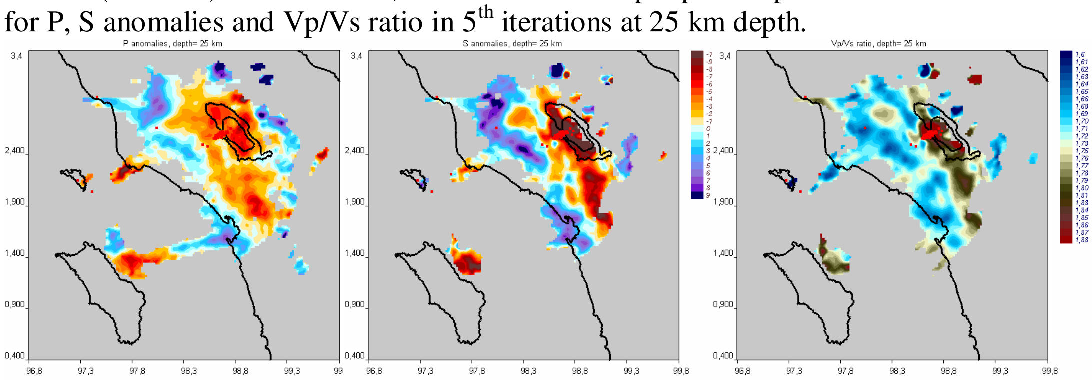
\PICS\GAP__280/MODEL_01\IT5\hor_dv1 1.png
\PICS\GAP__280/MODEL_01\IT5\hor_dv1 2.png
\PICS\GAP__280/MODEL_01\IT5\hor_dv1 3.png

6. Model TOBA_001/MODEL_01: The data are computed in a realistic synthetic model using real source-receiver pairs. Below are the results for P anomalies in 5th iterations at three depth levels



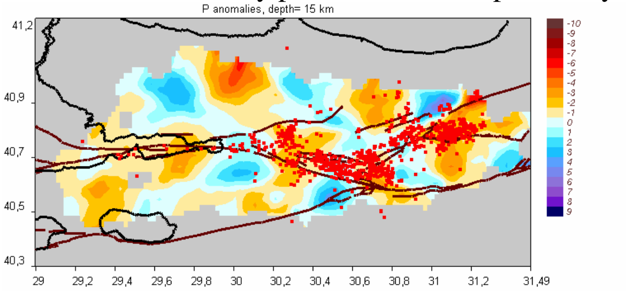
\PICS\TOBA_001/MODEL_01\IT5\hor_dv1 1.png
\PICS\TOBA_001/MODEL_01\IT5\hor_dv1 3.png
\PICS\TOBA_001/MODEL_01\IT5\hor_dv1 5.png

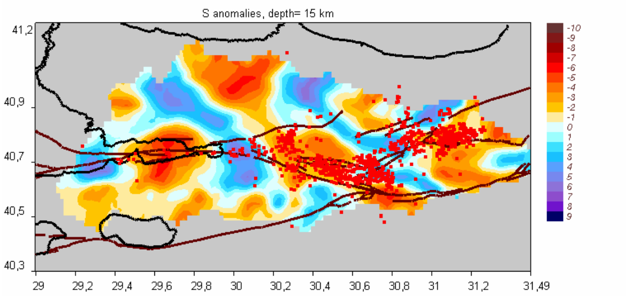
7. Model TOBA_REA/REAL_VPX: Here we present the inversion of real data for the Toba caldera (Sumatra). In this model, the inversion for Vp-Vp/Vs is performed. Below are the results for P, S anomalies and Vp/Vs ratio in 5th iterations at 25 km depth.



\PICS\TOBA_REA/REAL_VPX\IT5\hor_dv1 3.png
\PICS\TOBA_REA/REAL_VPX\IT5\hor_dv2 3.png
\PICS\TOBA_REA/REAL_VPX\IT5\hor_vpvs 3.png

8. Model TURKEY__/MODEL_01: Here we present the inversion of checkerboard data for the real dataset in Turkey. In this model, the inversion for Vp-Vp/Vs is performed. Below are the results for P, S anomalies in 5th iterations at 15 km depth. Despite fairly high data amount, the resolution is relatively poor due to non-optimal ray coverage.





\PICS\TURKEY__/MODEL_01\IT5\hor_dv1 2.png
\PICS\TURKEY__/MODEL_01\IT5\hor_dv2 2.png

Stage 7. Start working with own data

Step 7.1. Create a new AREA folder. The name should consist of any eight (8) characters (e.g. "MY_REGION". Inside this folder create "MY_REGION/inidata" folder. Inside this folder create files with the initial data:

1. "rays_xyz.dat" information about observed source-receiver pairs and travel times.
2. "stat_ft.dat": list of the stations in geographical coordinates

Creating these files is on a responsibility of a user. Use the format which is described in Section 2.2.1 of the main Manual.

In addition, the files used for visualization and previewing should be created as described in Section 4 of the manual.

These files can be copied from the existing examples. Some values of parameters should be scaled according to the size of the study area.

Step 7.2. Create a MODEL folder which should also consist of eight (8) characters (e.g. DATA/MY_REGION/MODEL_01/).

Step 7.3. Create a file
DATA/MY_REGION/MODEL_01/MAJOR_PARAM.DAT
This file can be copied from existing examples. Some of the parameters (e.g. grid spacing, and step for tracing) should be scaled according to the size of the study area. The inversion parameters will be tuned during several trials.

Step 7.4. Define starting 1D velocity model in file:
`DATA/MY_REGION/MODEL_01/ref_start.dat`

Step 7.5. Define the model to proceed. Open the file "`model_all.dat`" in the root directory:
`/model_all.dat`

```
1: name of the region
2: name of the model
3: number of iterations
MY_REGION MODEL_01 9
```

Step 7.6. Run the batch file "START.BAT".

Step 7.7. Produce the results as PNG images and SRF files.

Step 7.8. Create a new model (e.g. "`MODEL_02`") and play with parameters in "`MAJOR_PARAM.DAT`" (e.g. increase or decrease the smoothing or amplitude damping) to find the values which provide the minimum of the residual norm.

Step 7.9. Play with parameters in "`ref_start.dat`" to find the values of the starting model (namely depths of levels and velocities in the 1D starting model) which provide the minimum of the residual norm.

Closing remarks

If you passed successfully all the steps listed in this document, it would be not a problem for you to perform inversion for observed data and synthetic modeling using the *LOTOS-10* code for various datasets.

In case of any problem, please address to Ivan Koulakov (KoulakovIY@ipgg.nsc.ru).

Good luck.