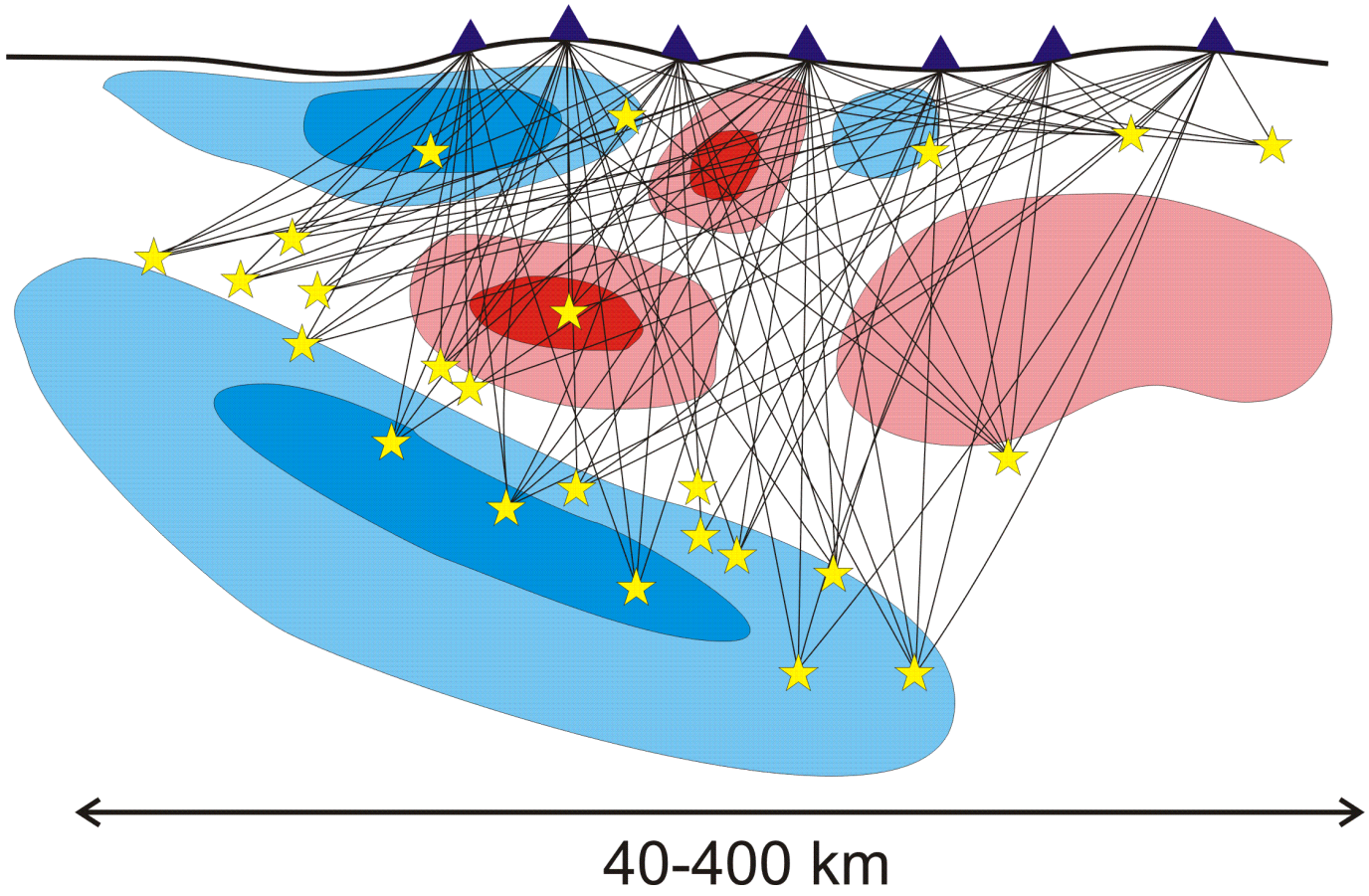
Local earthquake tomography (LET) scheme
LOTOS code (version 12)
Brief description of workflow



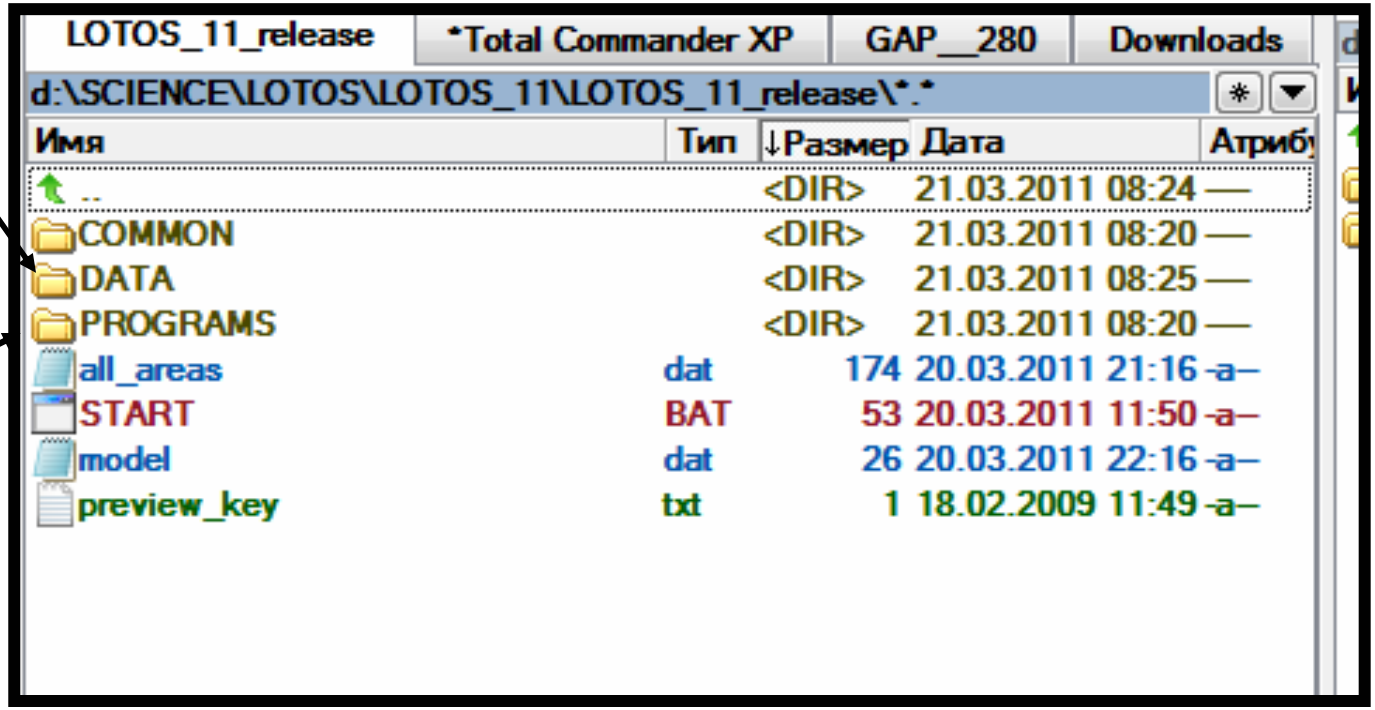
www.ivan-art.com/science/LOTOS

Structure of the LOTOS code:

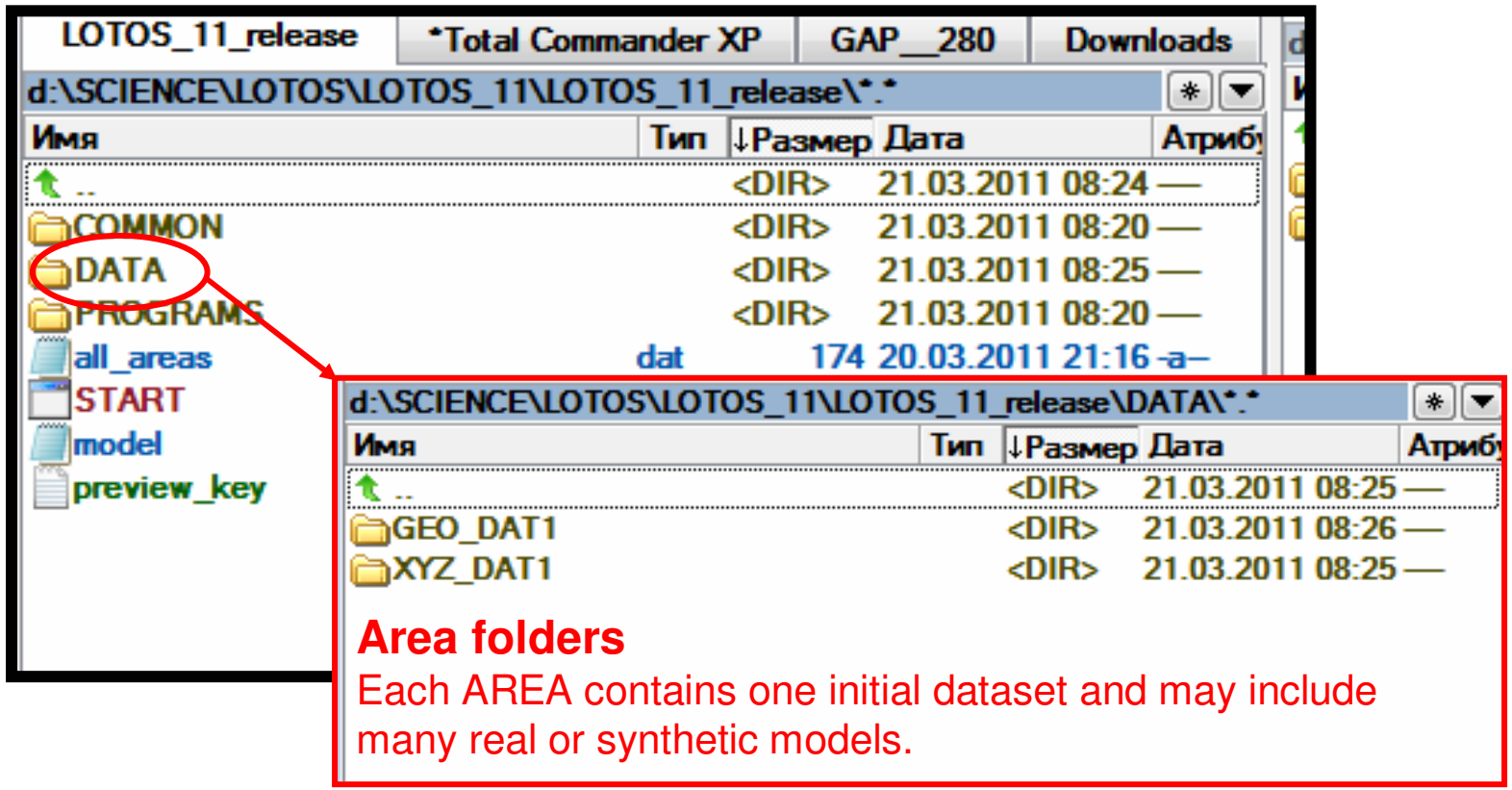
Root folder:

DATA folder contains all the initial and computed data files

PROGRAMS folder contains all the programs (source and exe files)



Data structure (2-step hierarchy):

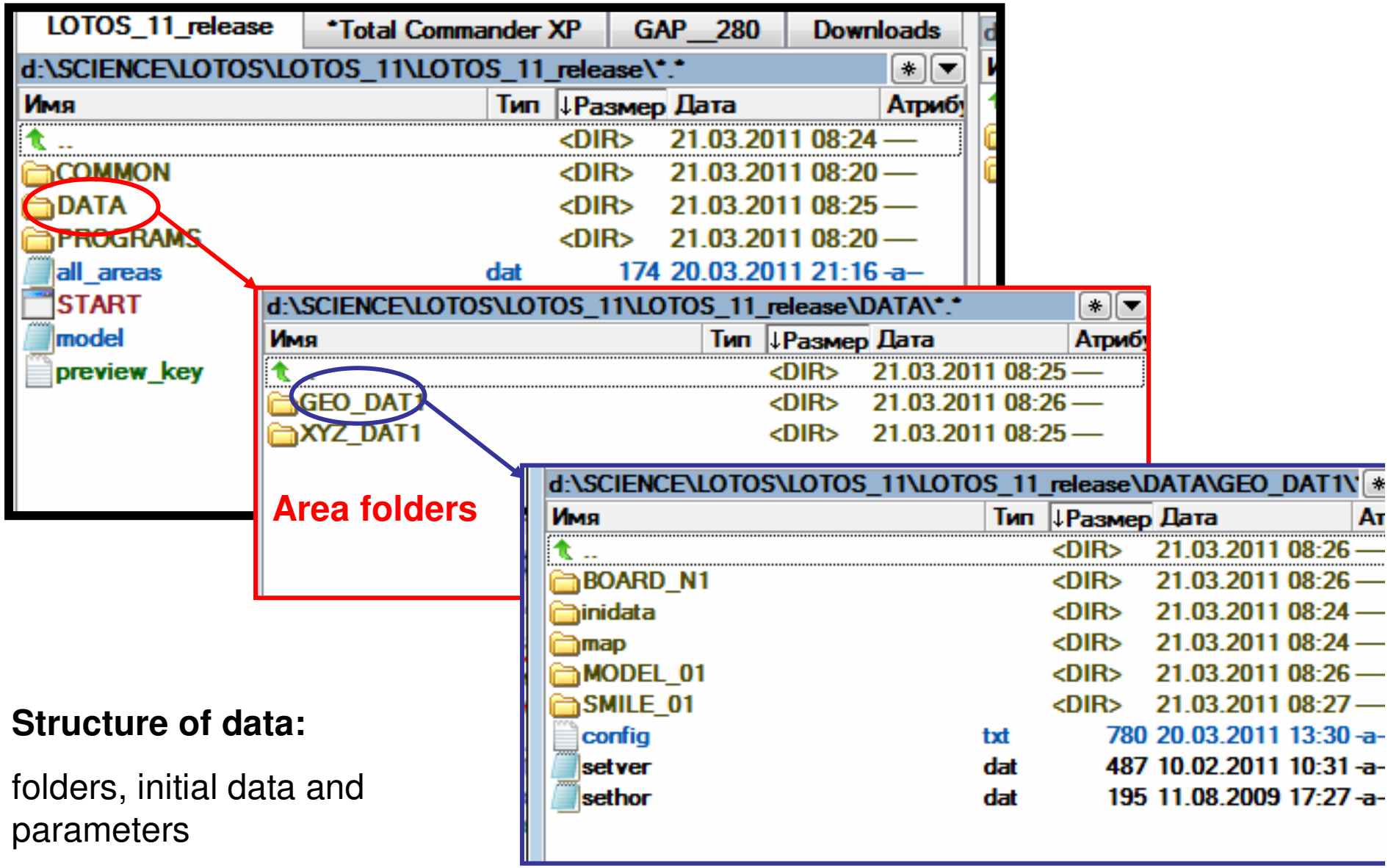


Names of AREAs consist of 8 characters !!!

Structure of data:

folders, initial data and parameters

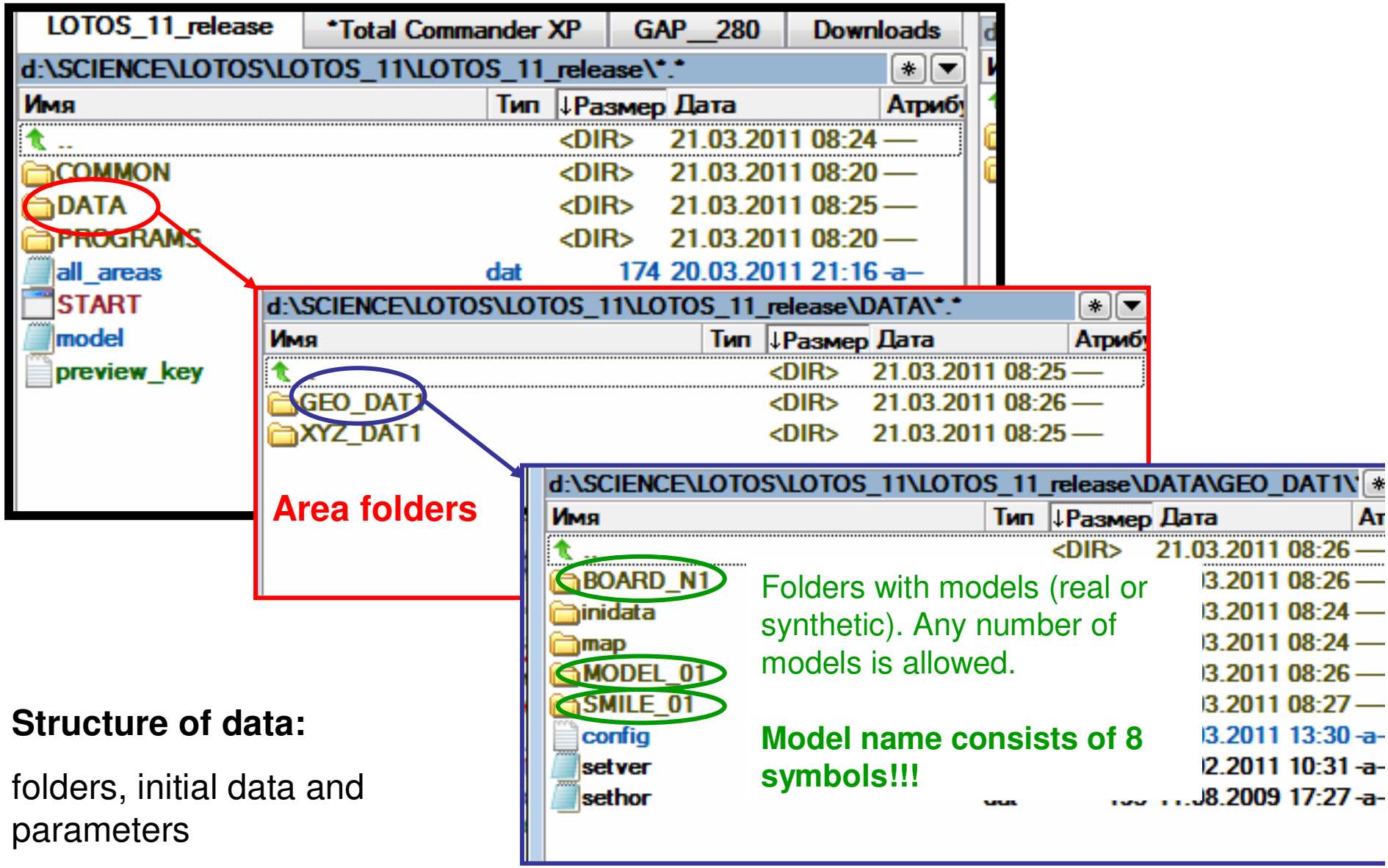
Data structure (2-step hierarchy):



Structure of data:

folders, initial data and parameters

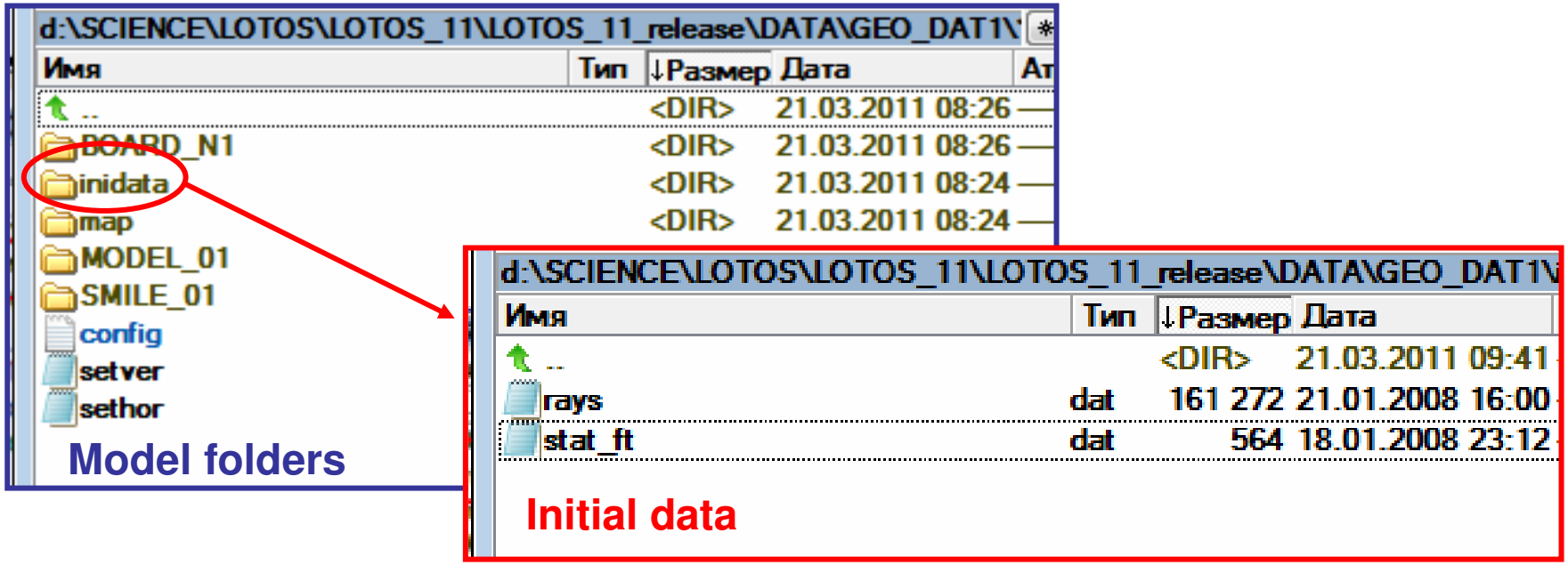
Data structure (2-step hierarchy):



Structure of data:

folders, initial data and parameters

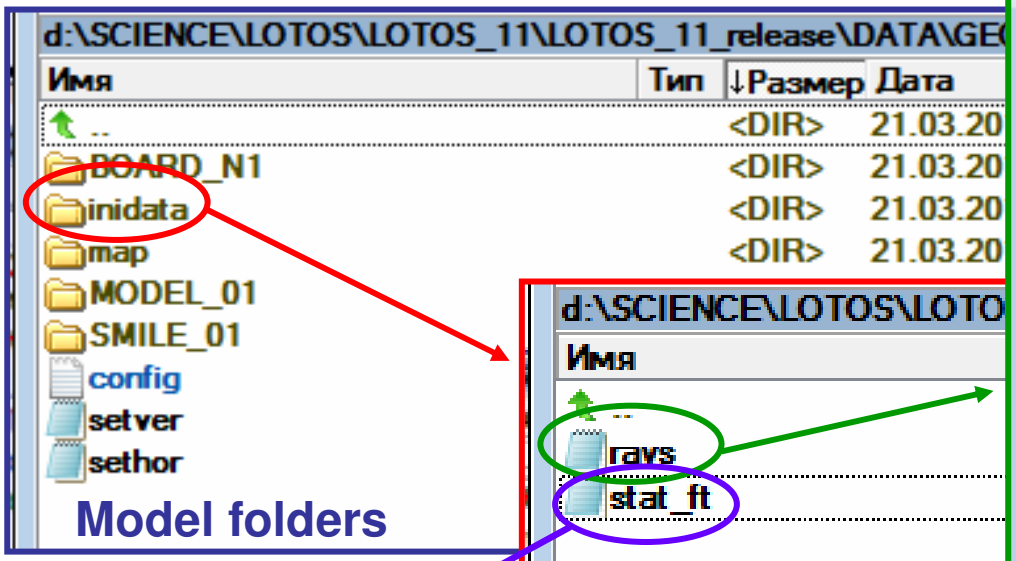
Folder with initial data:



Structure of data:

folders, initial data and parameters

Initial data files:



stations

Lister - [D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_release\DATA\GEO_DAT1\inidata\stat_ft.dat]

Файл Правка Вид Справка

-71.12700	-18.63300	1.000000
-71.09300	-19.31700	1.000000
-71.02700	-20.00000	1.000000
-70.97700	-20.66700	1.000000
-70.91000	-21.31700	1.000000
-70.84300	-21.93300	1.000000
-70.71700	-19.63300	1.000000
-70.63300	-20.28300	1.000000
-70.55000	-20.96700	1.000000
-71.80000	-19.63300	1.000000
-71.70000	-20.28300	1.000000
-71.61700	-20.96700	1.000000

longitude latitude depth

Number of line corresponds to the number of station

Here all stations are 1 km below sea level

-70.18384	-20.90750	33.93000	16
1	11	25.35048	
2	11	43.90528	
1	8	13.87840	
2	8	24.04150	
1	3	19.67791	
2	3	34.08391	
1	9	8.231387	
2	9	14.26471	
1	4	15.32037	
2	4	26.55076	
1	5	14.31970	
1	2	27.74261	
1	6	20.04849	
1	10	31.38969	
1	12	21.47189	
1	7	22.69749	
-70.29102	-20.40950	25.36000	18
1	10	25.71727	
2	10	44.54014	
1	3	14.10538	
2	3	24.42953	
1	11	22.75151	
2	11	39.39725	
1	1	30.41859	
2	1	52.68230	
1	2	21.69525	
2	2	37.57591	
1	5	18.71232	
2	5	32.39684	
1	7	15.83892	
2	7	27.43102	
1	12	23.01083	
2	12	39.85330	
1	8	7.472907	
1	4	13.51934	
-69.77667	-19.91317	87.49000	19
1	12	31.83058	
2	12	55.10392	
1	5	28.49355	
2	5	49.32567	
1	7	18.32809	
2	7	31.74103	
1	3	20.44025	
2	3	35.39606	
1	4	23.34798	
2	4	40.42942	
1	8	17.68709	
2	8	30.62856	
1	10	38.36367	

Picks and events

File with events and picks:

inidata/rays.dat

Event line:

longitude latitude depth N picks per event

```
-70.18384      -20.90750       33.93000                16
         1             11    25.35048
         2             11    43.90528
         1              8    13.87840
         2              8    24.04150
         1              3    19.67791
         2              3    34.08391
         1              9    8.231387
         2              9    14.26471
         1              4    15.32037
         2              4    26.55076
         1              5    14.31970
         1              2    27.74261
         1              6    20.04849
         1             10    31.38969
         1             12    21.47189
         1              7    22.69749
-70.29102      -20.40950       25.36000                18
         1             10    25.71727
         2             10    44.54014
         1              3    14.10538
```

Block with picks (here 16 picks indicated in source line)

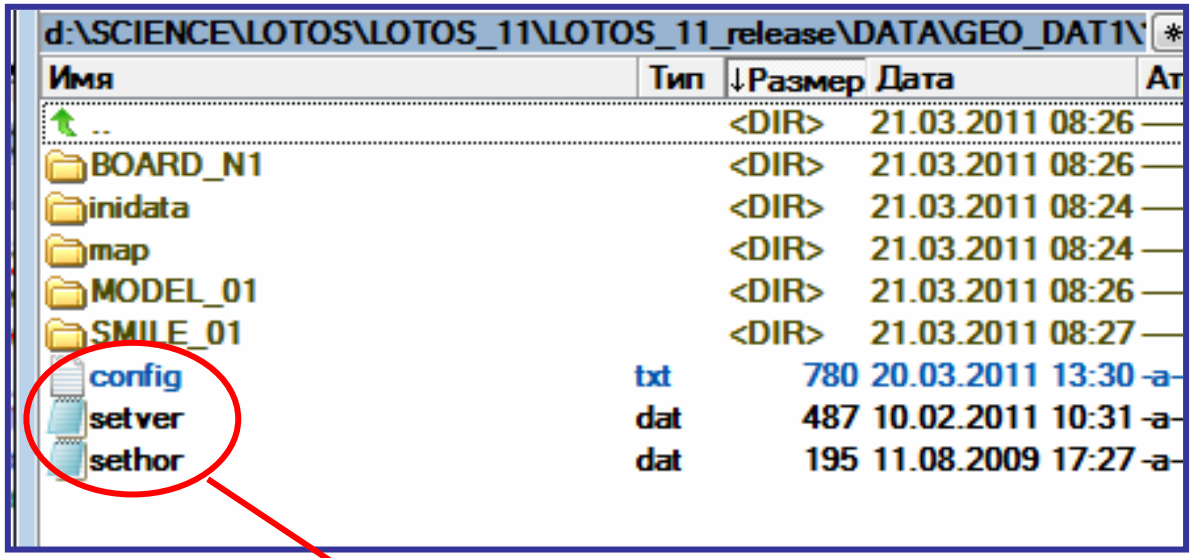
1 column: phase indicator (1-P and 1-S)

2 column: station number (line in stat_ft.dat)

3 column: travel time

Picks and events

Visualization parameters:



Visualization parameters are defined in the AREA folder and are same for all MODELS

Lister - [D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_release\DATA\GEO_DAT1\setver.dat]

Файл Правка Вид Справка 100 %

```
2                Number of different sections
-70.82538797 -22.55326057 -71.14119379 -18.15829857
-71.8469497472, -20.4519256383 -70.119017599, -19.3716502746
40  distance from section for visualization of events
2                      dx
0 80 2           zmin,zmax,dz
50                Marks for indication of position of section
8                Distanse to the nearest node
0                Smoothing factor
1                If 0, no sources are visualized
2 1              horizontal section and PS to show the location of profiles
0.05 0.05                dfi,dtet: shift for marks
```

Lister - [D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_release\DATA\GEO_DAT1\sethor.dat]

Файл Правка Вид Справка 100 %

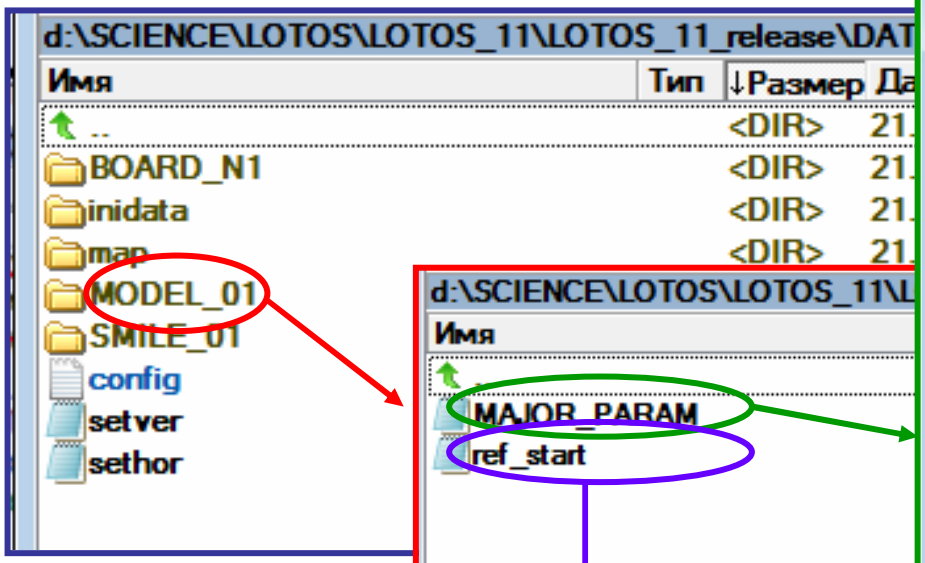
```
4                              Number of sections
10 20 30 40              Depths of sections
-1.2 1.5 0.03 -2.0 2.0 0.03 fi1, fi2, dfi, tet1, tet2, dtet
8                distance from nearest node
0                Smoothing factor1                Number of summary
```

Lister - [D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_release\DATA\GEO_DAT1\config.txt]

Файл Правка Вид Справка 100

```
******* MAP VIEW *********
400 600                  size in pixels for horizontal section
0.5 0.5                  ticks on axes for horizontal sections
******* VERTICAL SECTION *********
0 200                    size in pixels for vertical section
25 20                    ticks on axes for vertical sections
******* PLOTS WITH 1D VELOCITIES *********
500 500                  size in pixels for the 1D models
2 9                              Limits of P and S velocity distribution
-60 0                    Depth limit
0.5 10                   ticks on axes for 1D velocity plot
******* SCALES *********
blue_red.scl    scale for velocity anomalies
-10 10                   diapason for velocity anomalies, %
blue_brown.scl  scale for Vp/Vs
1.6 1.9                  diapason for Vp/Vs
rainbow_small.scl        scale for absolute Vp
4.0 8.5                  diapason for absolute Vp
rainbow_small.scl        scale for absolute Vp
2.5 5                    diapason for absolute Vp
```

Model parameters (real case):



Vp/Vs ratio

Lister - D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_relea

Файл Правка Вид Справка

1.7		Ratio vp/vs
-1.000	4.3	2.22
6.000	5.5	3.26
12.000	6.7	3.67
15.000	6.8	3.96
35.000	8.1	4.42
74.000	8.3	4.54
104.000	8.4	4.60
124.000	8.45	4.62
154.000	8.5	4.66
400.000	9.0300	5.00

Starting 1D velocity model.

depth, km. Vp. Vs (only used if Vp/Vs in 1st line is zero)

MAJOR_PARAM.DAT - AkelPad

Файл Правка Поиск Кодировки Настройки Справка

```
**********************************************************
GENERAL INFORMATION :
1       KEY 1: REAL; KEY 2: SYNTHETIC
1       KEY 1: Vp and Vs; KEY 2: Vp and Vp/Vs
0       KEY 0: all data, KEY 1: odd events, KEY 2: even events
1       Ref. model optimization (0-no; 1-yes)

**********************************************************
AREA_CENTER :
-71 -20.5       Center of conversion to XY

**********************************************
ORIENTATIONS OF GRIDS :
4                       number of grids
0 22 45 67              orientations

**********************************************
1D MODEL PARAMETERS :
2               Iterations for 1D inversions
-10 3. 5                zmin, dzstep depth step f
1 1 300                 dsmin, dzlay,zgrmax : par
5.              dz_par, step for parameterizati
0.2
6. 9. sm_p,sm_s
0.0 0.0 rg_p,rg_s
10 10 1 w_hor,w_ver,w_time
300             LSQR iterations
0 nsharp
27 27  z_sharp

**********************************************
INVERSION PARAMETERS :
40 1                    LSQR iterations, iter_max
1 1. Weights for P and S models in the upper
0.7 1.2  level of smoothing (P, S and crust)
0.0 0.0 regularization level (P, S and crust)

0.0001    0.0001        weight of the station cor
2.0     wzt_hor
2.0     wzt_ver
1.0     wzt_time



**********************************************
Parameters for location in 1D model using ref
and data selection:
**********************************************
LIN_LOC_PARAM :
9               Minimal number of records
100             km, maximum distance to nearest station
1.7             S max resid with respect to P max resid
100             dist_limit=100          : within this distance the weight is equal
1               n_pwr_dist=1  : power for decreasing of W with distance
30              ncyc_av=10

! For output:
30              bad_max=30              : maximal number of outliers
0.05    maximal dt/distance
30              distance limit

10              Frequency for output printing

3               Number of different grids
```

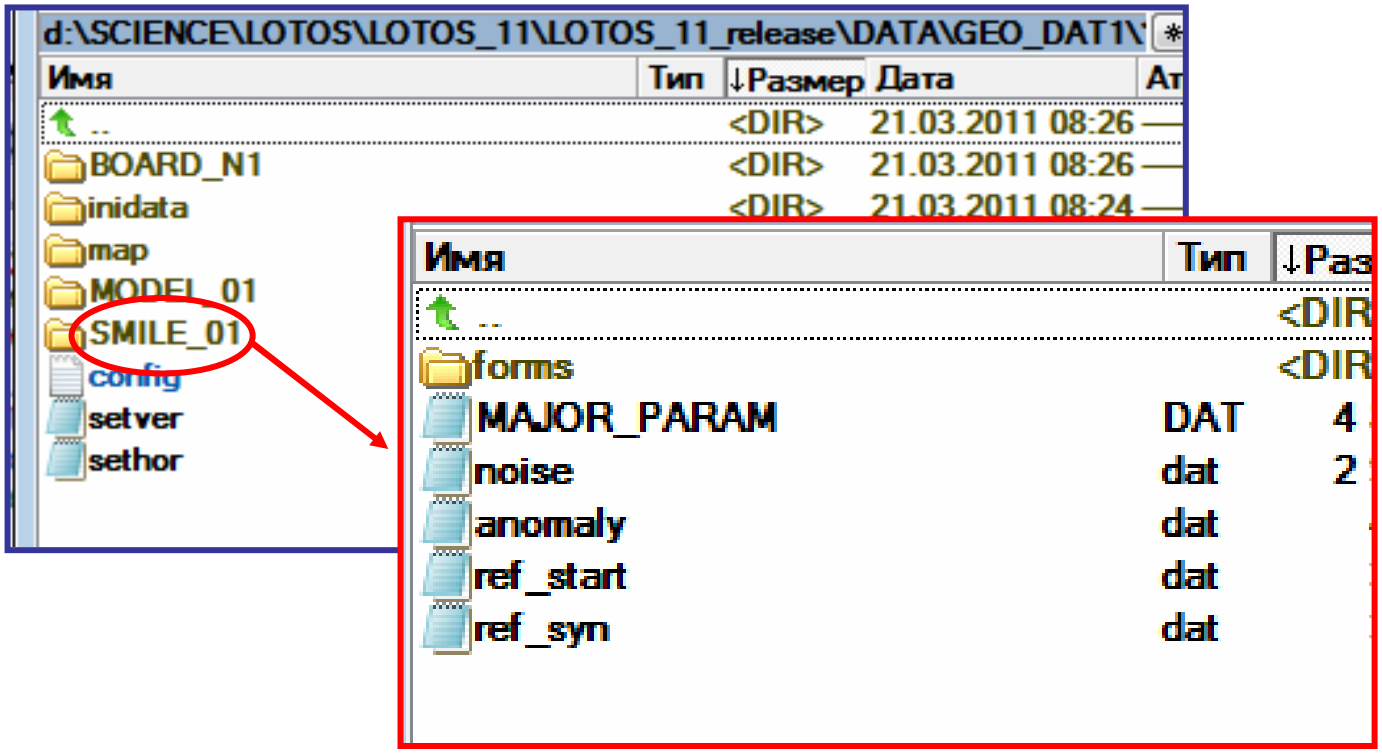
1:1 Вставка Windows-1251 (ANSI)

This file include all parameters that control the inversion workflow.

The parameters are grouped in rubrics. The order of rubrics can be changed.

The order of lines within each rubric should be respected

Model parameters (synthetic case):



Besides two files **MAJOR_PARAM.DAT** and **ref_start.dat**, additional files and one folder "**forms**" are included:

ref_syn.dat: 1D basic velocity distribution for the synthetic model (same format as in ref_start.dat)

anomaly.dat: file with the description of anomalies

noise.dat: definition of noise (if not presented, the data are noise free)

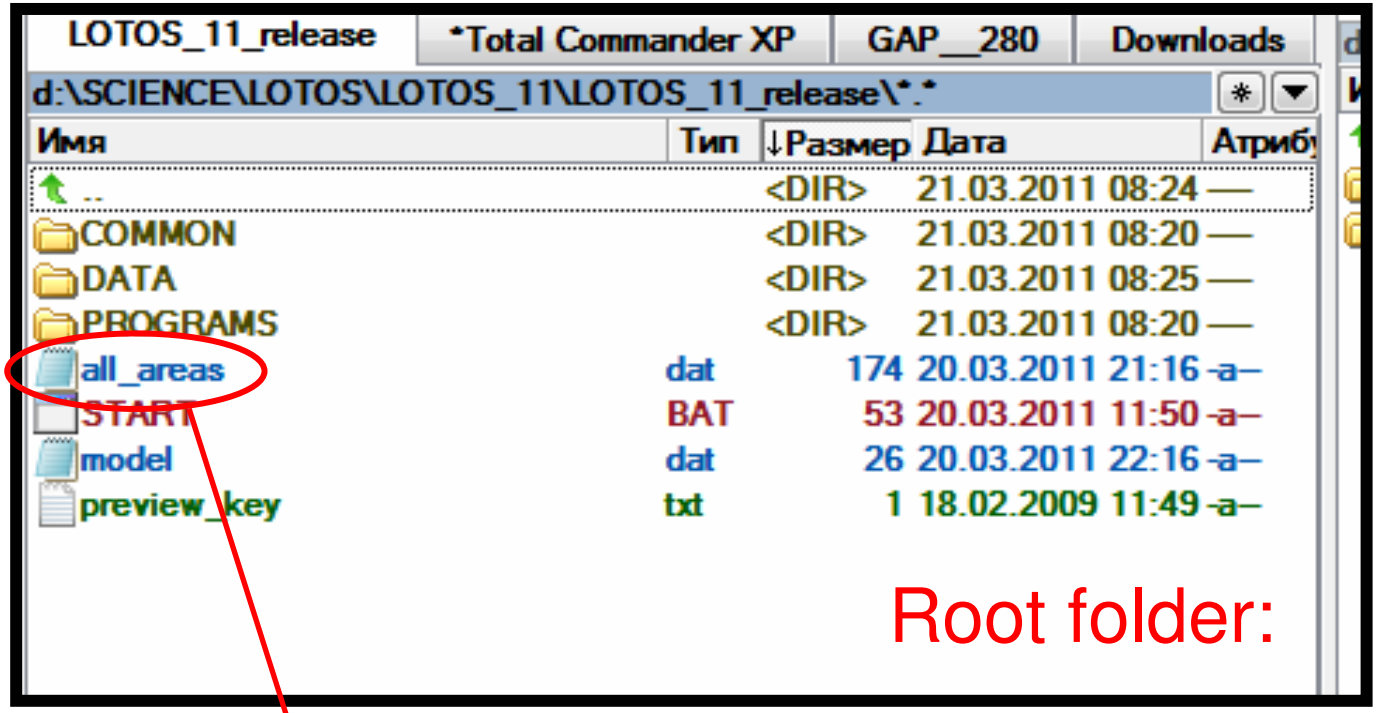
Run calculations for selected model(s):

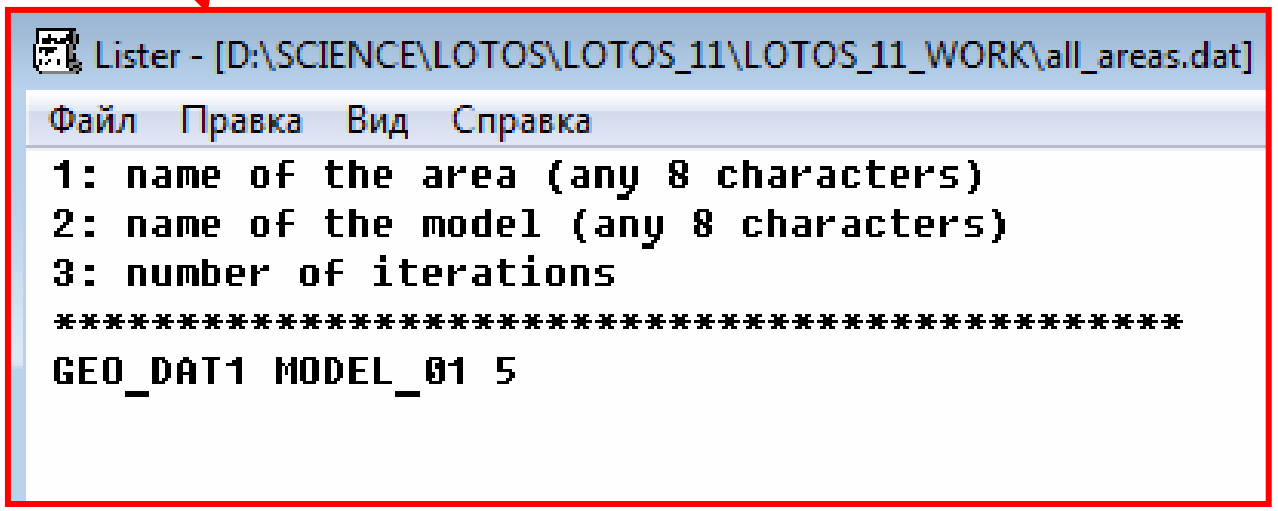
For example, we wish to run 5 tomographic iterations for model **MODEL_01** from area **GEO_DAT1.**

We include the corresponding information to **all_areas.dat**

The format should be respected

Any number of models in the following lines can be defined

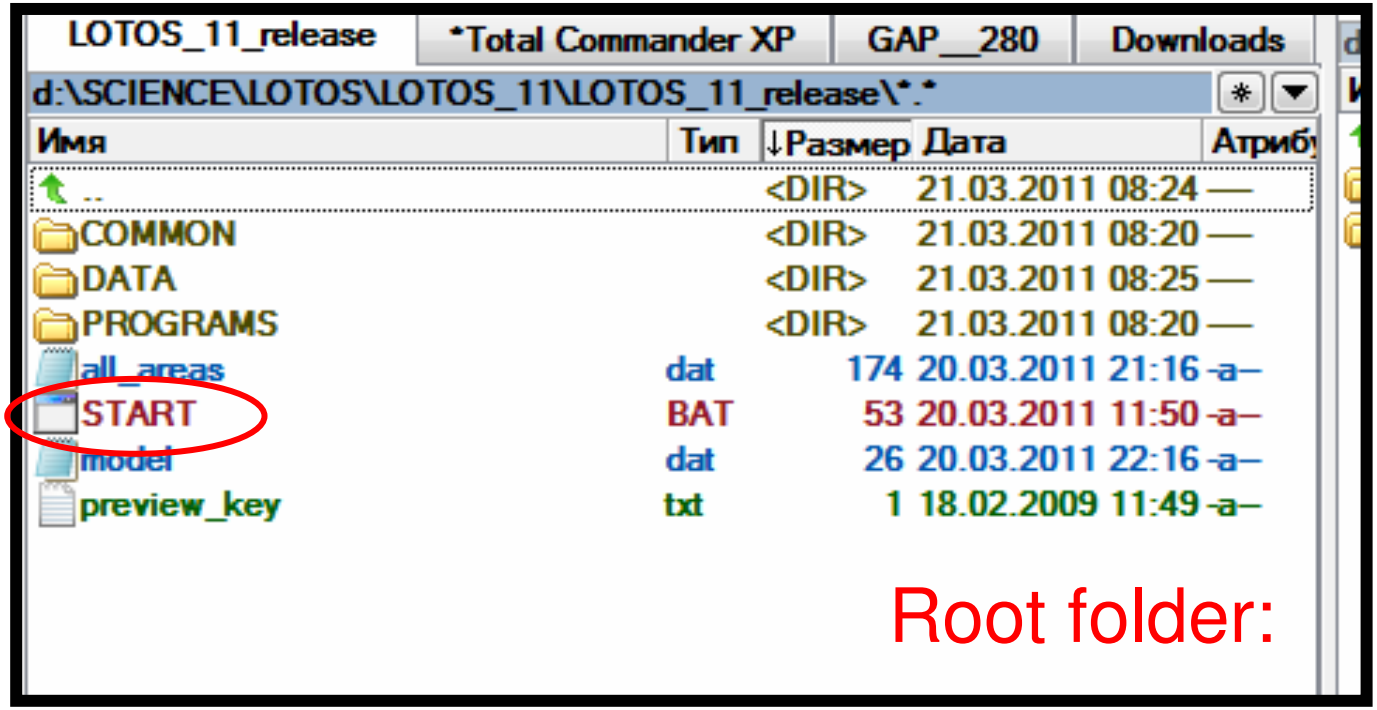




Run calculations for selected model(s):

Run the file **START.BAT**,

and the console will appear



Console with the execution of the program:

This workflow corresponds to real data inversion.

Stage 1: compute the table of reference times corresponding to the starting 1D model

Stage 2: rough location of sources using tabulated travel times. Grid search allows locating the sources very robustly

```
D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_WORK>cd PROGRAMS

D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_WORK\PROGRAMS>cd 0_START

D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_WORK\PROGRAMS\0_START>cd START

D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_WORK\PROGRAMS\0_START\START>start.exe
A subdirectory or file ..\..\..\TMP_files\tmp already exists.
A subdirectory or file ..\..\..\TMP_files\hor already exists.
A subdirectory or file ..\..\..\TMP_files\rays already exists.
A subdirectory or file ..\..\..\TMP_files\1D_mod already exists.
A subdirectory or file ..\..\..\TMP_files\vert already exists.
  n_ar=           1
  DATASET:GEO_DAT1 MODEL:MODEL_01
  key_ft1_xy2=           1  kref=           1
        1 file(s) copied.
 ------------------------------------------------
 COMPUTING THE REFERENCE TABLE WITH THE STARTING 1D MODEL
 Computing the reference table:
 ar=GEO_DAT1 md=MODEL_01
 nref=          10
 i=          10  z=   9.000000      ips=           1  nref=         160
 i=          10  z=   9.000000      ips=           2  nref=         160
 i=          20  z=   19.00000      ips=           1  nref=         153
 i=          20  z=   19.00000      ips=           2  nref=         154
 i=          30  z=   37.00000      ips=           1  nref=         253
 i=          30  z=   37.00000      ips=           2  nref=         253
 i=          40  z=   66.00000      ips=           1  nref=         281
 i=          40  z=   66.00000      ips=           2  nref=         281
 i=          50  z=   116.0000      ips=           1  nref=         284
 i=          50  z=   116.0000      ips=           2  nref=         285
 i=          60  z=   166.0000      ips=           1  nref=         285
 i=          60  z=   166.0000      ips=           2  nref=         285
 ------------------------------------------------
 LOCALIZATION OF SOURCES USING THE 1D REFERENCE TABLE
 area=GEO_DAT1 model=MODEL_01 koe=           0  k_re1_syn2=           1
 ar=GEO_DAT1 md=MODEL_01
 cannot find SOURCE_LIMITS in MAJOR_PARAM.DAT!!!
 nref=          10
          3
 ****************************************
 REAL DATA INVERSION
   16 Old: x=  112.89 y=  -47.24 z=   58.29 ank=   0.51
   10 New: x=  119.89 y=  -47.24 z=   81.29 ank=   0.90
 nkrat=          12  nk=          12  ntot=         152

   26 Old: x=  124.24 y= -105.66 z=   35.76 ank=   0.42
   20 New: x=  125.74 y= -108.66 z=    7.26 ank=   0.86
 nkrat=          18  nk=          17  ntot=         312

   46 Old: x=  102.35 y=  -89.71 z=   36.70 ank=   0.43
   30 New: x=  109.85 y=  -80.71 z=    0.70 ank=   0.86
 nkrat=          12  nk=          12  ntot=         470

   65 Old: x=  -31.20 y=   54.22 z=    4.01 ank=   0.52
   40 New: x=  -29.70 y=   58.22 z=    0.01 ank=   0.71
 nkrat=          13  nk=          13  ntot=         620

   75 Old: x=   35.80 y=    9.73 z=   30.60 ank=   0.58
   50 New: x=   45.80 y=    8.73 z=   32.10 ank=   0.71
 nkrat=          21  nk=          21  ntot=         780

   85 Old: x=   70.74 y=  -27.83 z=   29.48 ank=   0.45
   60 New: x=   84.24 y=  -27.33 z=   17.98 ank=   0.79
 nkrat=          21  nk=          21  ntot=         941

   95 Old: x=  -61.82 y=    3.80 z=   30.95 ank=   0.46
   70 New: x=  -82.82 y=    1.80 z=   36.45 ank=   0.74
```

Stage 1

Stage 2

Console with the execution of the program:

Stage 3: 1D model optimization

It starts with the selection of events which are distributed as homogeneously as possible over the depth

```
 175 Old: x=   -9.67 y=  170.69 z=   11.46 ank=   0.57
 150 New: x=   -9.17 y=  170.69 z=    0.46 ank=   0.79
nkrat=          15  nk=          14  ntot=        2307

 185 Old: x=  -60.41 y=  117.93 z=   27.76 ank=   0.40
 160 New: x=  -68.41 y=  127.93 z=   16.76 ank=   0.81
nkrat=          16  nk=          16  ntot=        2473

 195 Old: x=   49.05 y=  189.34 z=   33.02 ank=   0.52
 170 New: x=   52.55 y=  190.34 z=    8.02 ank=   0.91
nkrat=          13  nk=          13  ntot=        2625

 207 Old: x=  -28.50 y=  180.03 z=   12.99 ank=   0.45
 180 New: x=  -24.50 y=  186.53 z=    1.99 ank=   0.81
nkrat=          15  nk=          13  ntot=        2778

 217 Old: x=  -27.40 y=  187.05 z=    0.46 ank=   0.34
 190 New: x=  -22.90 y=  204.55 z=    0.46 ank=   0.73
nkrat=          16  nk=          14  ntot=        2928

nztgood=        194
```

End of Stage 2

number of events after location

Stage 3

```
 PERFORM THE OPTIMISATION FOR THE 1D VELOCITY MODEL
A subdirectory or file ..\..\..\IMP_files\1D_mod already exists.
 number of iterations:          2
 Selecting events for 1D optimization: area=GEO_DAT1 model=MODEL_01
 nzt=          222  nray=         3614
 -1.0  16  19  20  16  17
  2.0  17  19  18  18  22
  5.0  18  19  16  16  17
  8.0  18  16  15  16  20
 11.0  18  20  17  17  18
 14.0  23  21  18  17  19
 17.0  17  19  17  22  18
 20.0  18  18  21  19  17
 23.0  18  19  17  20  22
 26.0  19  16  19  21  19
 29.0  21  19  20  17  21
 32.0  16  15  17  16  19
 35.0  17  18  21  17  17
 38.0  17  17  16  16  16
 41.0  17  20  22  19  20
 44.0  24  21  19  22  18
 47.0  16  20  17  20  18
 50.0  15  19  18  21  19
 53.0  18  21  21  18  18
 56.0  15  16  15  21  15
 59.0  18  12
 62.0  18  20  20
 65.0  15  15  12
 68.0  18
 71.0  15  17
 74.0  21  18  14
 86.0  19
  88.36813      -24.28296       20.96000              15
  109.8490      -80.70703      0.7000008              12
  45.79828       8.732178       32.09663              21
 -21.01047      -32.19800       3.900890              14
 -59.33064      -147.1089       52.48458              11
 -12.19430       43.37793      0.2053351              16
 -17.05856      -127.7966       34.70816              16
 -64.69503       170.0834      0.4872608              12
  28.93678       148.4380       1.008860              19
 -73.69241       205.9894       1.185471              12
 nzt=          105  nray=         1595
       ********************************************
       Reference table:
```

number of events after selection

Console with the execution of the program:

Stage 4: Matrix calculation for 1D parameters

Stage 5: Inversion and calculation of the updated 1D velocity model

Then these steps are performed iteratively:

- reference table
- source location
- matrix calculation
- inversion

```
  70 New: x=  -23.89 y= -166.80 z=   15.61 disp=   0.4221
 nkrat=          11  nk=          11  ntot=        1052
 reduction=   2.277389

  81 Old: x=  -35.76 y=  209.36 z=   44.40 disp=   0.4358
  80 New: x=  -35.76 y=  209.36 z=   44.40 disp=   0.4216
 nkrat=          16  nk=          16  ntot=        1192
 reduction=   3.246195

  91 Old: x=   36.30 y=  179.51 z=   18.50 disp=   0.4343
  90 New: x=   36.30 y=  180.01 z=   19.50 disp=   0.4194
 nkrat=          16  nk=          16  ntot=        1351
 reduction=   3.433881

 101 Old: x=  -48.99 y=  214.38 z=    0.49 disp=   0.4314
 100 New: x=  -48.99 y=  214.38 z=    0.49 disp=   0.4176
 nkrat=          18  nk=          16  ntot=        1497
 reduction=   3.205868

 nztgood=         104
       ****************************************************
       Matrix calculation:
 MATRIX: area=GEO_DAT1 model=MODEL_01
 nref=          10
 nst=           12
 npar_max=          20
 nzt=          104  nray=        1557  nonz_tot=       12842
       ****************************************************
       Inversion:
 1D INVERSION: area=GEO_DAT1 model=MODEL_01 iter=           1
A subdirectory or file ..\..\..\TMP_files\1D_mod already exists.
 nref=          10
 nray=        1557  nonz=       12842
 nrows=        1595  ncols=         456  nonzer=       19146
 ir=         1557  nonz=       19070
 N rows=        1595  N columns=         456  N nonzer=       19146

 iter=          20
 iter=          40
 iter=          60
 iter=          80
 iter=         100
 iter=         120
 iter=         140
 iter=         160
 iter=         180
 iter=         200
 iter=         220
 iter=         240
 iter=         260
 iter=         280
 iter=         300
 avres0=  0.4140815      avres=  0.3176602      red=   23.28558
       ****************************************************
       Reference table:
 Computing the reference table:
 ar=GEO_DAT1 md=MODEL_01 it=1
 nrefmod=          22
 i=          10  z=   9.000000      ips=           1  nref=         175
 i=          10  z=   9.000000      ips=           2  nref=         161
 i=          20  z=   19.00000      ips=           1  nref=         159
 i=          20  z=   19.00000      ips=           2  nref=         148
 i=          30  z=   37.00000      ips=           1  nref=         117
 i=          30  z=   37.00000      ips=           2  nref=         257
 i=          40  z=   66.00000      ips=           1  nref=         256
 i=          40  z=   66.00000      ips=           2  nref=         295
 i=          50  z=   116.0000      ips=           1  nref=         296
 i=          50  z=   116.0000      ips=           2  nref=         296
```

Stage 4

Stage 5

variance reduction after matrix inversion

Console with the execution of the program:

After the end of the 1D model optimization, we locate again the sources in the updated 1D model (Stage 2).

After that we start locating the sources in the same 1D model, but using 3D ray tracer (bending) (Stage 6)

Stage 2

```
 140 New: x=   68.78 y= -170.87 z=   33.16 ank=   0.83
nkrat=          12  nk=          12  ntot=        2247

 172 Old: x=  -61.70 y=  170.58 z=   24.99 ank=   0.72
 150 New: x=  -65.70 y=  170.58 z=   12.99 ank=   0.87
nkrat=          14  nk=          14  ntot=        2416

 182 Old: x=  -59.30 y=  114.42 z=   35.58 ank=   0.78
 160 New: x=  -63.30 y=  116.92 z=   37.08 ank=   0.88
nkrat=          17  nk=          17  ntot=        2590

 192 Old: x=   50.17 y=  191.68 z=   17.53 ank=   0.83
 170 New: x=   54.17 y=  193.68 z=   19.53 ank=   0.86
nkrat=          17  nk=          17  ntot=        2754

 204 Old: x=   19.14 y=  191.74 z=    6.60 ank=   0.70
 180 New: x=   32.14 y=  195.24 z=   13.10 ank=   0.80
nkrat=          17  nk=          17  ntot=        2913

 214 Old: x=  -70.69 y=  207.99 z=   30.19 ank=   0.66
 190 New: x=  -68.19 y=  193.99 z=    1.69 ank=   0.85
nkrat=          14  nk=          14  ntot=        3074

nztgood=         198
```

Stage 6

```
 LOCATE THE SOURCES USING THE 3D RAY TRACING
 SOURCE LOCATION: ar=GEO_DAT1 md=MODEL_01 it=1
A subdirectory or file ..\..\..\TMP_files\tmp already exists.
 ar=GEO_DAT1 md=MODEL_01
 cannot find SOURCE_LIMITS in MAJOR_PARAM.DAT!!!
 nan=            0
           4
 nref=           21
  43.28879      -35.68726       37.18000            13
  40.00503      -35.50537       41.76426
 old resid=  0.3320720      new_resid=  0.3415053      red=  -2.840730
           5          80  ds=   5.641951      G=  0.8876871
 ******************************************
  79.43475      -92.03735       30.32000            17
  79.43475      -92.03735       30.32000
 old resid=  0.3429552      new_resid=  0.3653796      red=  -6.538599
          10         155  ds=  0.0000000E+00  G=  0.8646825
 ******************************************
  80.36813      -23.28296       27.96000            15
  79.79790      -23.55014       29.65647
 old resid=  0.3239889      new_resid=  0.3459467      red=  -6.777339
          15         232  ds=   1.809570      G=  0.9253514
 ******************************************
  61.62875      -14.44092       41.37000            15
  61.19062      -14.58665       41.09705
 old resid=  0.3382459      new_resid=  0.3546947      red=  -4.862988
          20         315  ds=  0.5363720      G=  0.8717538
 ******************************************
  108.3622      -28.60693       48.13000            16
  108.3003      -28.46988       48.77671
 old resid=  0.3320437      new_resid=  0.3481846      red=  -4.861081
          25         402  ds=  0.6639651      G=  0.9336005
 ******************************************
  125.0286      -111.2263       25.31000            16
  125.1184      -110.9773       29.05972
 old resid=  0.3322848      new_resid=  0.3481034      red=  -4.760549
          30         488  ds=   3.759051      G=  0.9140469
 ******************************************
  124.1842      -88.22290       45.01000            14
  122.0170      -87.42795       51.80120
 old resid=  0.3240049      new_resid=  0.3380202      red=  -4.325637
          35         562  ds=   7.172826      G=  0.8717250
 ******************************************
```

mean residual reduction in respect to the previous step

Console with the execution of the program:

After the end of stage 6 we can see the results of location in horizontal and vertical sections

Then we start computing the grid. Fist of all – compute the ray density. Then distribute the nodes.

We compute several differently oriented grids and perform independent inversion for each of them

```
       185        2998  ds=  0.0000000E+00  G=  0.8863509
 ********************************************
 -68.19241       193.9894       1.685471              14
 -69.40681       194.1638       3.460068
 old resid=  0.3444673      new_resid=  0.3520968      red=  -2.214874
       190        3074  ds=   2.157405      G=  0.8711076
 ********************************************
  99.32751       117.8909       16.81868              16
  99.83373       117.3375       16.81459
 old resid=  0.3459451      new_resid=  0.3536359      red=
       195        3161  ds=  0.7499866      G=  0.9203693
 ********************************************
 nzt=          198  nray=         3211
      1 file(s) copied.
 Vertical: 1 dist=   489.6824      npix_x=        1224  npi
 Vertical: 2 dist=   216.9237      npix_x=         542  npi
 Horizontal: npix_x=         400  npix_y=         600
 nst=           12
```

Stage 6

visualization of located events in horizontal and vertical sections

```
 COMPUTE THE RAY DENSITY
 Computing ray density
 ar=GEO_DAT1 md=MODEL_01 it=1 gr=1
 orient=  0.0000000E+00
 nx=          120  ny=          120  nz=           31
 nzt=         100  nray=         974         623
 total number of rays:         1968        1243
 ------------------------------------------------------
 DEFINE THE PARAMETERIZATION GRID
 execution grid
 ar=GEO_DAT1 md=MODEL_01 it=1 gr=1
 nx=          120  ny=          120  nz=           31
 nmax_p=      100000
 aver ray lenght in one block=   19.65101
 iy=           30  node=           45  yy=  -152.5000
 iy=           35  node=           98  yy=  -127.5000
 iy=           40  node=          141  yy=  -102.5000
 iy=           45  node=          155  yy=  -77.50000
 iy=           50  node=          168  yy=  -52.50000
 iy=           55  node=          170  yy=  -27.50000
 iy=           60  node=          168  yy=  -2.500000
 iy=           65  node=          141  yy=   22.50000
 iy=           70  node=          149  yy=   47.50000
 iy=           75  node=          143  yy=   72.50000
 iy=           80  node=          144  yy=   97.50000
 iy=           85  node=          125  yy=   122.5000
 iy=           90  node=          110  yy=   147.5000
 iy=           95  node=           90  yy=   172.5000
 iy=          100  node=           41  yy=   197.5000
 number of valuable velocity parameters:          4802
 aver ray lenght in one block=   14.69250
 iy=           30  node=           39  yy=  -152.5000
 iy=           35  node=           72  yy=  -127.5000
 iy=           40  node=          122  yy=  -102.5000
 iy=           45  node=          143  yy=  -77.50000
 iy=           50  node=          158  yy=  -52.50000
 iy=           55  node=          162  yy=  -27.50000
 iy=           60  node=          159  yy=  -2.500000
 iy=           65  node=          137  yy=   22.50000
 iy=           70  node=          132  yy=   47.50000
 iy=           75  node=          128  yy=   72.50000
 iy=           80  node=          123  yy=   97.50000
 iy=           85  node=          108  yy=   122.5000
 iy=           90  node=           98  yy=   147.5000
 iy=           95  node=           73  yy=   172.5000
 iy=          100  node=           25  yy=   197.5000
 number of valuable velocity parameters:          4083
 execution of Tetrad
 ar=GEO_DAT1 md=MODEL_01 it=1 gr=1
 nur=           5  ntet=          73  ntop=          17
```

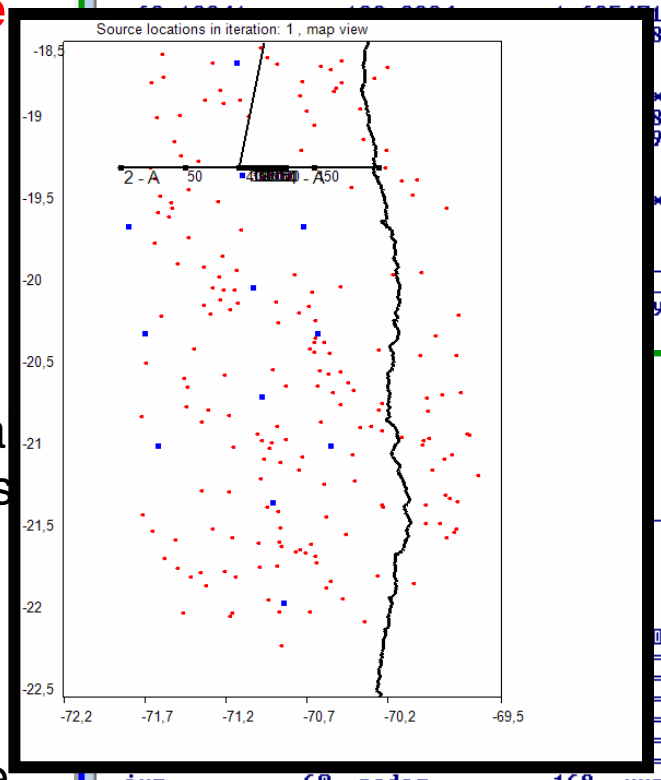
Stage 7

Number of the parameterization nodes for P and S models

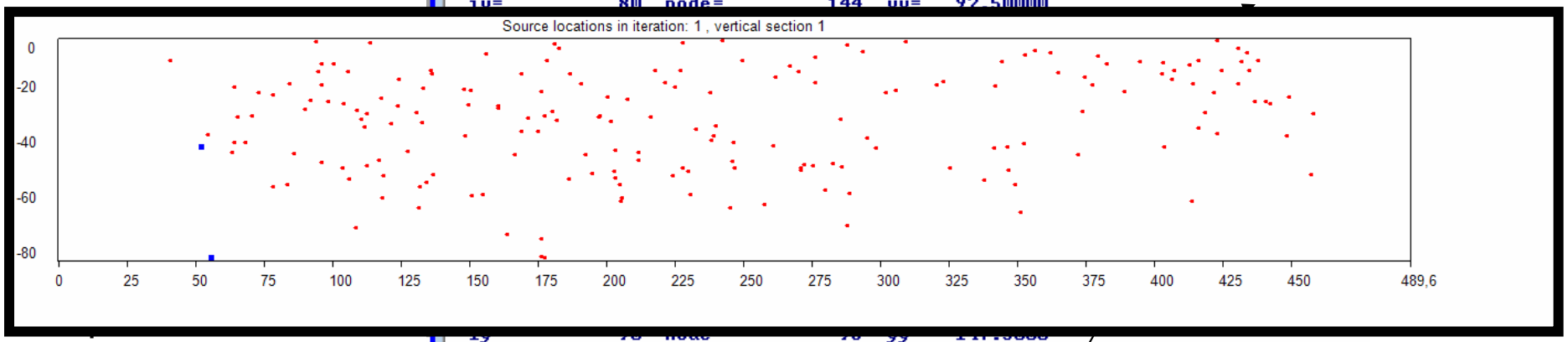
Console with the execution of the program:

After the end of stage 6 we can see the results of location in horizontal and vertical sections

Then we start computing the grid. Fist of all – compute the ray density. Then inversion for each of them




```
      185          2998   ds=   0.0000000E+00   G=   0.8863509
**********************************************
                                                14
                                                16
 0.3520968        red=   -2.214874
      G=   0.8711076
******
 0.3536359        red=
      G=   0.9203693
******
_x=          1224   npi
_x=           542   npi
y=            600
                                                31
                                              623
                                             1243
                                                31
                                                01
=   -152.5000
=   -127.5000
=   -102.5000
=   -77.50000
=   -52.50000
=   -27.50000
iy=          60   node=          168   yy=   -2.500000
iy=          65   node=          141   yy=    22.50000
iy=          70   node=          149   yy=    47.50000
iy=          75   node=          143   yy=    72.50000
iy=          80   node=          144   yy=    97.50000
iy=          95   node=           73   yy=    172.5000
iy=         100   node=           25   yy=    197.5000
number of valuable velocity parameters:          4083
execution of Tetrad
ar=GEO_DAT1 md=MODEL_01 it=1 gr=1
nur=           5   ntet=           73   ntop=          17
```



Stage 6

visualization of located events in horizontal and vertical sections

Stage 7

Number of the parameterization nodes for P and

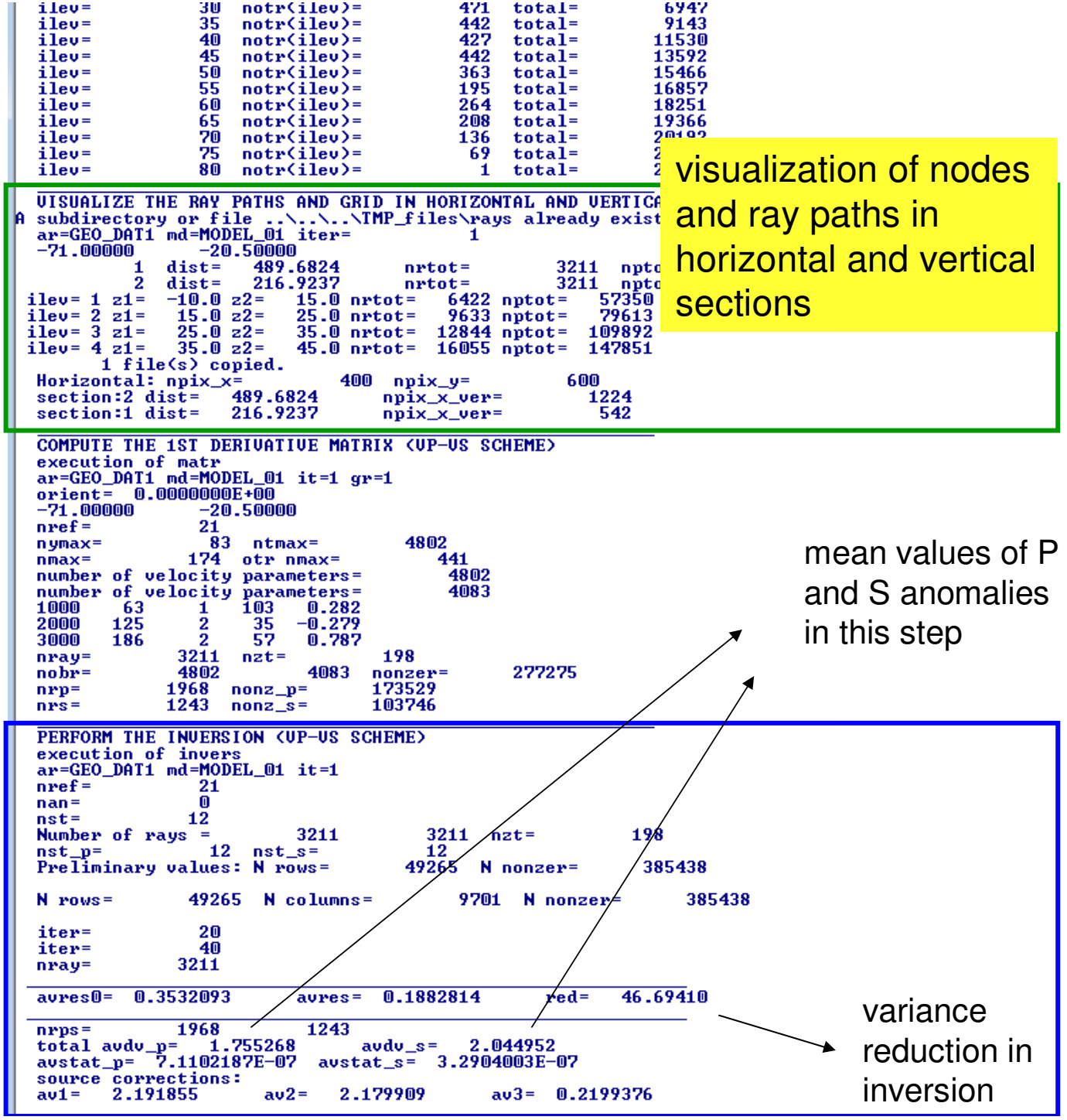
Console with the execution of the program:

After computing the grid, we can see the distribution of nodes and ray paths in hor. and ver. sections.

Then we compute the matrix of 1st derivatives

Then we perform the inversion for P and S anomalies, source parameters (4 for each) and station corrections.

Then the same steps are performed for other grids

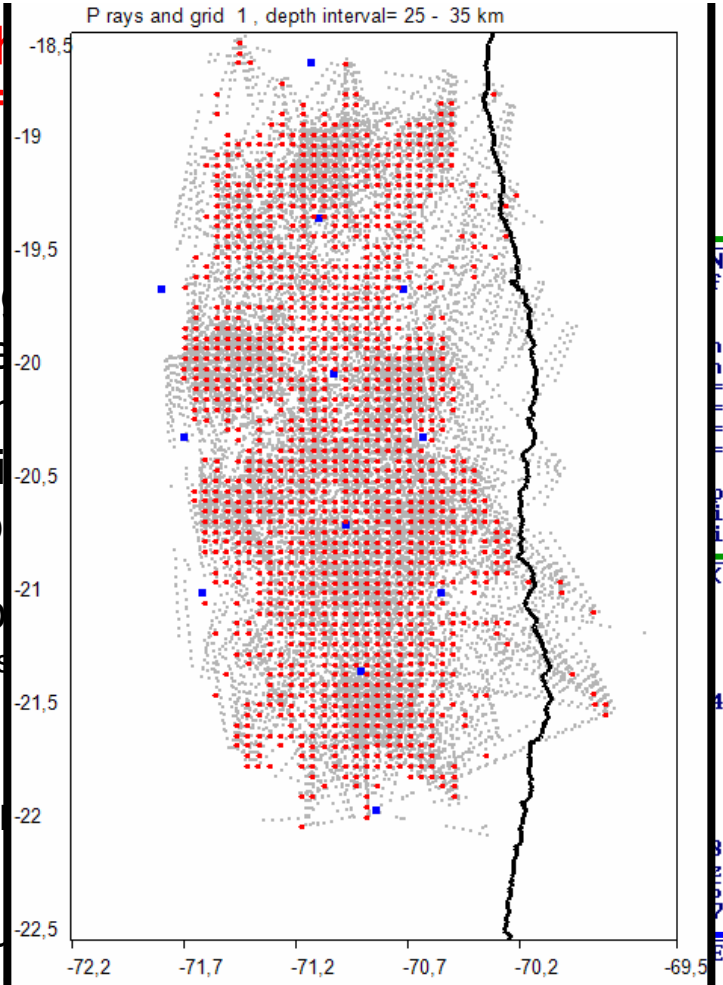


Console with execution of program:

After computin grid, we can se distribution of r and ray paths i and ver. sectio

Then we comp the matrix of 1s derivatives

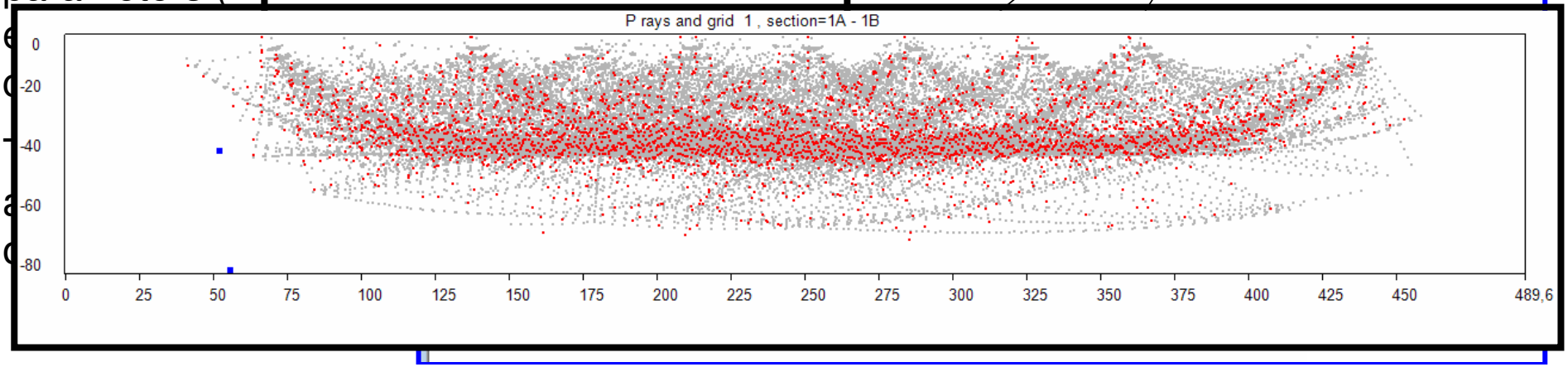
Then we perfo inversion for P anomalies, sou parameters (4




```
471  total=        6947
442  total=        9143
427  total=       11530
442  total=       13592
363  total=       15466
195  total=       16857
264  total=       18251
208  total=       19366
136  total=       20182
 69  total=
  1  total=

N HORIZONTAL AND VERTICA
files\rays already exist
      1

nrtot=        3211  npto
nrtot=        3211  npto
=    6422 nptot=    57350
=    9633 nptot=    79613
=   12844 nptot=   109892
=   16055 nptot=   147851

pix_y=         600
ix_x_ver=     1224
ix_x_ver=      542

(VP-VS SCHEME)

4802
 441
4802
4083

zer=      277275
529
746
```

visualization of nodes and ray paths in horizontal and vertical sections

mean values of P and S anomalies in this step



Console with the execution of the program:

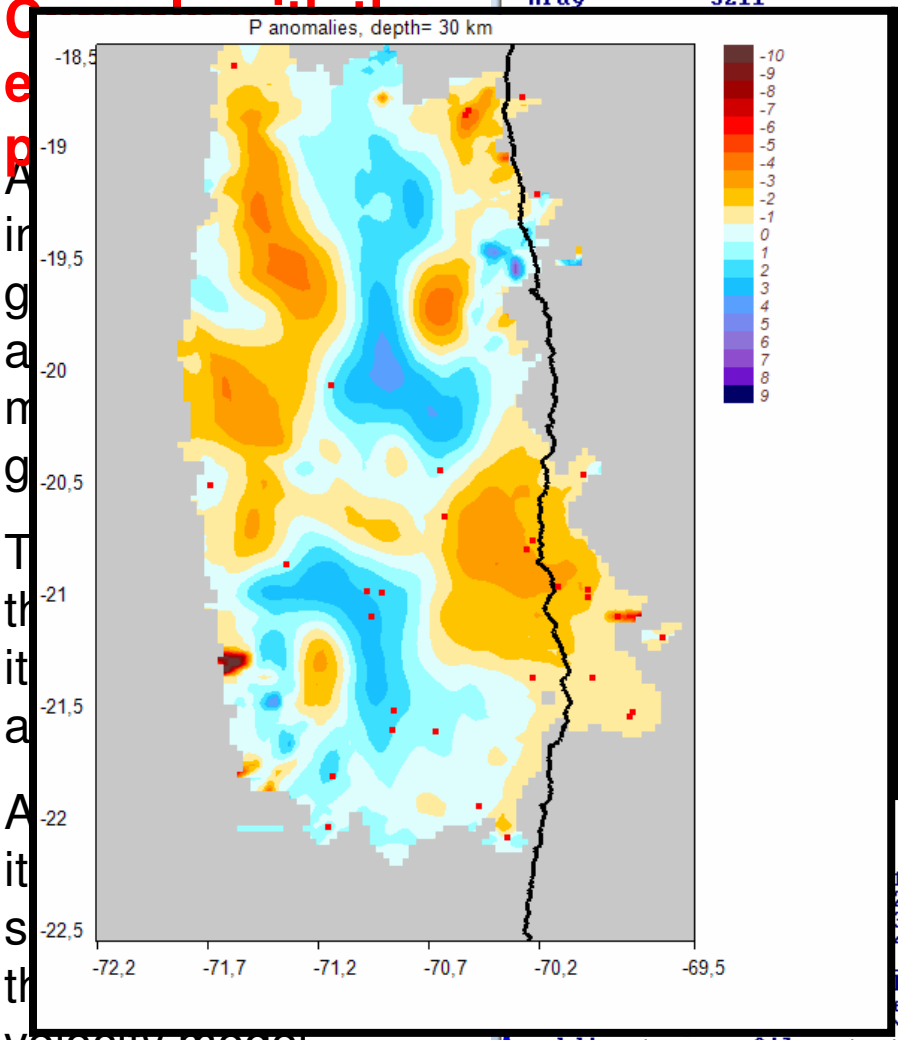
After performing inversion for all grids, we compute an average 3D model in a regular grid

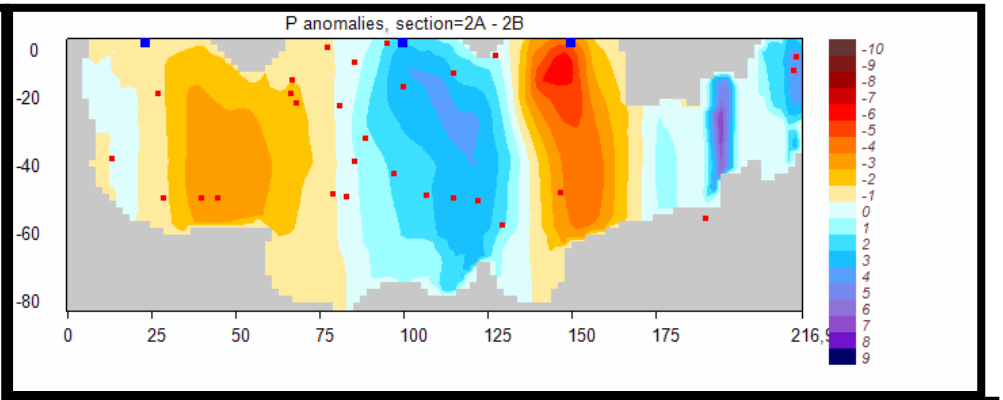
Then we visualize the results of current iteration in horizontal and vertical sections

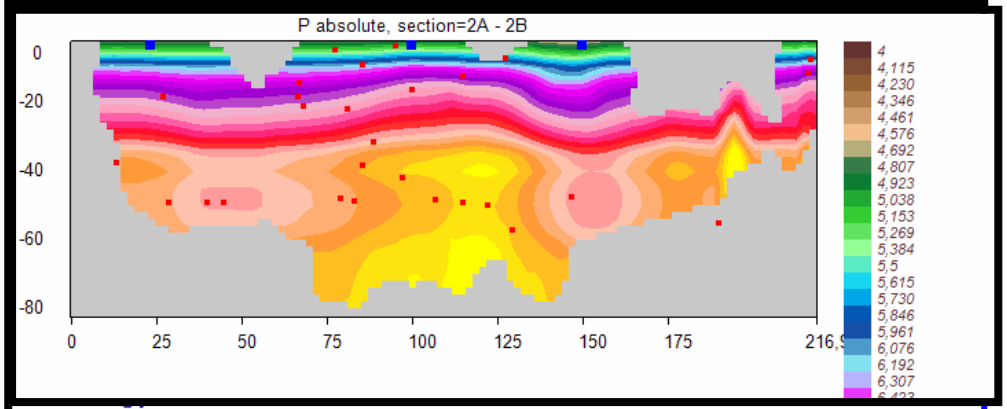
After this, a new iteration starts with source location in the updated 3D velocity model

```
N rows=       48902  N columns=        9697  N nonzer=      391199

iter=            20
iter=            40
nray=          3211

avres0=  0.3532093      avres=  0.1938514      red=   45.11713

nrps=          1968         1243
total avdv_p=   1.651192      avdv_s=   1.855466
avstat_p=  7.5466306E-07  avstat_s=  3.5454650E-07
source corrections:
av1=   2.078001      av2=   2.111728      av3=  0.2062587

COMPUTE THE VELOCITY FIELS IN 3D REGILAR GRID (VP-VS SCHEME)
AREA : GEO_DAT1 model:MODEL_01 iter=           1
nref=           21
nxx=            81  nyy=          121  nzz=           32
izz=             5  zzz=    15.00000
izz=            10  zzz=    40.00000
izz=            15  zzz=    65.00000
izz=            20  zzz=    90.00000
izz=            25  zzz=    115.0000
izz=            30  zzz=    140.0000
nx=             81  ny=          121  nz=            32
izz=             5  zzz=    15.00000
izz=            10  zzz=    40.00000
izz=            15  zzz=    65.00000
izz=            20  zzz=    90.00000
izz=            25  zzz=    115.0000
izz=            30  zzz=    140.0000
nx=             81  ny=          121  nz=            32

VISUALIZE THE RESULT IN HORIZONTAL SECTIONS (VP-VS SCHEME)
A subdirectory or file ..\..\..\TMP_files\hor already exists.
      1 file(s) copied.
      1 file(s) copied.
      1 file(s) copied.
ar=GEO_DAT1 md=MODEL_01
npix_x=          400  npix_y=          600
nfmap=            91  ntmap=          134
nref=             21
ilev=              1  nzzt=            57
ilev=              2  nzzt=            37
ilev=              3  nzzt=            33
ilev=              4  nzzt=            23
ilev=              1  zzz=    10.00000
ilev=              2  zzz=    20.00000
ilev=              3  zzz=    30.00000
ilev=              4  zzz=    40.00000

VISUALIZE THE RESULT IN VERTICAL SECTIONS (VP-VS SCHEME)
ar=GEO_DAT1 md=MODEL_01 iter=             1
A subdirectory or file ..\..\..\TMP_files\vert already exists.
A subdirectory or file ..\..\..\PICS\GEO_DAT1\MODEL_01\IT1 already exist
      1 file(s) copied.
      1 file(s) copied.
      1 file(s) copied.
      1 file(s) copied.
      1 file(s) copied.
nref=             21
nst1=              8  nzt1=            90
section: 1 dist=    489.6824      npix_x=         1224
section: 1 dist=    489.6824      npix_x=         1224
nst1=              3  nzt1=            35
section: 2 dist=    216.9237      npix_x=          542
section: 2 dist=    216.9237      npix_x=          542
npix_x=          400  npix_y=          600
```

visualization of results after 1st iteration in horizontal and vertical sections








```
N rows=       48902  N columns=        9697  N nonzer=      391199

iter=            20
iter=            40
nray=          3211
```

```
              37
              33
              23
10.00000
20.00000
30.00000
40.00000

RTICAL SECTIONS (VP-VS SCHEME)
er=               1
\..\TMP_files\vert already exis
 subdirectory or file ..\..\..\PICS\GEO_DAT1\MODEL_01\IT1
       1 file(s) copied.
       1 file(s) copied.
       1 file(s) copied.
       1 file(s) copied.
       1 file(s) copied.
nref=            21
nst1=             8  nzt1=           90
section: 1 dist=    489.6824      npix_x=        1224
section: 1 dist=    489.6824      npix_x=        1224
nst1=             3  nzt1=           35
section: 2 dist=    216.9237      npix_x=         542
section: 2 dist=    216.9237      npix_x=         542
npix_x=         400  npix_y=         600
```

visualization of results after 1st iteration in horizontal and vertical sections

velocity model

Console with the execution of the program:

The 2nd iteration starts with source location in the updated 3D velocity model.

At this stage we can see the reduction of mean residuals in respect to the previous iteration

Each following iteration contains:

source location

matrix calculation (for all grids)

inversion (for all grids)

```
      1 File(s) copied.
 nref=           21
 nst1=            8  nzt1=           90
 section: 1 dist=   489.6824      npix_x=        1224
 section: 1 dist=   489.6824      npix_x=        1224
 nst1=            3  nzt1=           35
 section: 2 dist=   216.9237      npix_x=         542
 section: 2 dist=   216.9237      npix_x=         542
 npix_x=          400  npix_y=          600
 ___________________________________________________
 LOCATE THE SOURCES USING THE 3D RAY TRACING
 SOURCE LOCATION: ar=GEO_DAT1 md=MODEL_01 it=2
A subdirectory or file ..\..\..\TMP_files\tmp already exists.
 ar=GEO_DAT1 md=MODEL_01
 cannot find SOURCE_LIMITS in MAJOR_PARAM.DAT!!!
 nan=             0
         4
 nref=           21
  39.10743       -36.07619        37.30740              13
  37.25625       -35.44128        38.64124
 old resid=  0.3415053       new_resid=  0.1954426       red=   42.77027
          5           80  ds=   4.160913       G=  0.9350955
 ******************************************
  76.25350       -88.00793        33.62224              17
  79.11083       -89.37656        32.86453
 old resid=  0.3653796       new_resid=  0.2057535       red=   43.68776
         10          155  ds=   3.695864       G=  0.9210382
 ******************************************
  75.01462       -23.90961        28.01371              15
  76.92723       -23.87879        28.02021
 old resid=  0.3459467       new_resid=  0.2084540       red=   39.74390
         15          232  ds=   3.320558       G=  0.9504939
 ******************************************
  53.93977       -16.37654        34.39185              15
  58.13674       -16.16120        38.30306
 old resid=  0.3546947       new_resid=  0.2117647       red=   40.29662
         20          315  ds=   4.428514       G=  0.9112794
 ******************************************
  108.1642       -28.44676        49.17101              16
  108.2196       -28.42055        47.35311
 old resid=  0.3481846       new_resid=  0.2051532       red=   41.07918
         25          402  ds=   1.426739       G=  0.9656105
 ******************************************
  124.8969       -109.6200        29.20693              16
  125.0376       -110.1589        24.90326
 old resid=  0.3481034       new_resid=  0.2065236       red=   40.67177
         30          488  ds=   4.237038       G=  0.9416260
 ******************************************
  119.1898       -88.71314        51.63254              14
  120.1824       -88.91206        48.87899
 old resid=  0.3380202       new_resid=  0.2019821       red=   40.24556
         35          562  ds=   3.755995       G=  0.9288237
 ******************************************
  125.9861       -58.03777        70.95513              12
  126.0662       -58.11623        67.48717
 old resid=  0.3363852       new_resid=  0.2009221       red=   40.27021
         40          634  ds=   4.006930       G=  0.9333081
 ******************************************
 -25.97955        45.83505       0.0000000E+00          16
 -25.97955        45.83505       0.0000000E+00
 old resid=  0.3429964       new_resid=  0.2057636       red=   40.00999
         45          713  ds=   2.179335       G=  0.8338820
 ******************************************
  33.63050        42.13837        48.27345              17
  34.46562        42.30737        48.20716
 old resid=  0.3429932       new_resid=  0.2027317       red=   40.89336
         50          791  ds=   2.328897       G=  0.9635686
 ******************************************
  43.55965        11.18992        35.42822              12
```

old and new mean residuals and reduction

Console with the execution of the program:

After finishing all iterations, a report about values of P and S residuals and variance reduction is produced

```
 izz=          25  zzz=    115.0000
 izz=          30  zzz=    140.0000
 nx=           81  ny=          121  nz=          32
 izz=           5  zzz=    15.00000
 izz=          10  zzz=    40.00000
 izz=          15  zzz=    65.00000
 izz=          20  zzz=    90.00000
 izz=          25  zzz=    115.0000
 izz=          30  zzz=    140.0000
 nx=           81  ny=          121  nz=          32
 ------------------------------------------------------------
 VISUALIZE THE RESULT IN HORIZONTAL SECTIONS (VP-VS SCHEME)
A subdirectory or file ..\..\..\TMP_files\hor already exists.
       1 file(s) copied.
       1 file(s) copied.
       1 file(s) copied.
 ar=GEO_DAT1 md=MODEL_01
 npix_x=         400  npix_y=         600
 nfmap=           91  ntmap=         134
 nref=            21
 ilev=             1  nzzt=           46
 ilev=             2  nzzt=           47
 ilev=             3  nzzt=           31
 ilev=             4  nzzt=           38
 ilev=             1  zzz=    10.00000
 ilev=             2  zzz=    20.00000
 ilev=             3  zzz=    30.00000
 ilev=             4  zzz=    40.00000
 ------------------------------------------------------------
 VISUALIZE THE RESULT IN VERTICAL SECTIONS (VP-VS SCHEME)
 ar=GEO_DAT1 md=MODEL_01 iter=           5
A subdirectory or file ..\..\..\TMP_files\vert already exists.
A subdirectory or file ..\..\..\PICS\GEO_DAT1\MODEL_01\IT5 already exists.
       1 file(s) copied.
       1 file(s) copied.
       1 file(s) copied.
       1 file(s) copied.
       1 file(s) copied.
 nref=            21
 nst1=             8  nzt1=           91
 section: 1 dist=    489.6824      npix_x=        1224
 section: 1 dist=    489.6824      npix_x=        1224
 nst1=             3  nzt1=           35
 section: 2 dist=    216.9237      npix_x=         542
 section: 2 dist=    216.9237      npix_x=         542
 npix_x=         400  npix_y=         600
 ------------------------------------------------------------
 CREATING THE REPORT ABOUT THE VARIANCE REDUCTION
 ar=GEO_DAT1 md=MODEL_01 niter=           5
 nbad=            0
 iter=            1  dtot_p=  0.2900705      red=  0.0000000E+00
 iter=            1  dtot_s=  0.4531744      red=  0.0000000E+00
 ------------------------------------------------------------
 iter=            2  dtot_p=  0.1900430      red=   34.48386
 iter=            2  dtot_s=  0.2610697      red=   42.39091
 ------------------------------------------------------------
 iter=            3  dtot_p=  0.1652456      red=   43.03262
 iter=            3  dtot_s=  0.2175262      red=   51.99946
 ------------------------------------------------------------
 iter=            4  dtot_p=  0.1523561      red=   47.47619
 iter=            4  dtot_s=  0.1964761      red=   56.64448
 ------------------------------------------------------------
 iter=            5  dtot_p=  0.1451021      red=   49.97697
 iter=            5  dtot_s=  0.1840820      red=   59.37944
 ------------------------------------------------------------
 nsrces=        198  nray_p=        1968  nray_s=        1243

D:\SCIENCE\LOTOS\LOTOS_11\LOTOS_11_WORK\PROGRAMS\0_START\START>pause
Press any key to continue . . .
```