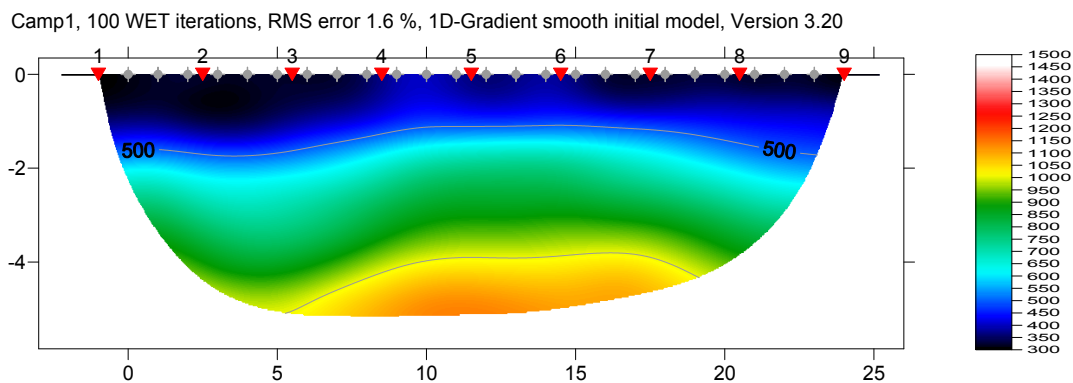
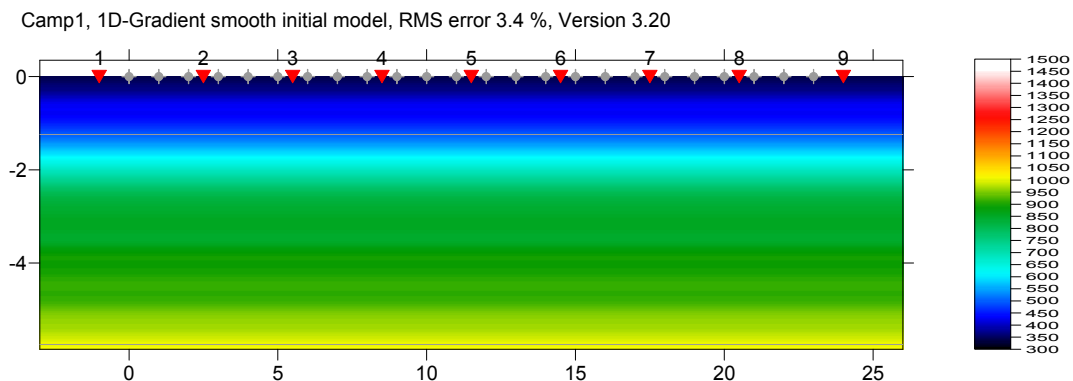


Smooth inversion and layer-based inversion, of profile CAMP1 sent by IGS IdroGeoStudi in April 2011, with Rayfract® version 3.20 & 4.01 + WDVS :

Import data into profile database, run Smooth inversion with 100 WET iterations :

1. Create a new profile database named CAMP1 with a *Station spacing* of 1 meter. See our manual <http://rayfract.com/help/manual.pdf> chapter 1.1.
2. Download <http://rayfract.com/tutorials/camp1.zip> , and copy into directory \RAY32\CAMP1\INPUT .
3. Unzip archive \RAY32\CAMP1\INPUT\CAMP1.ZIP, and store the contents into the same directory.
4. Uncheck *File|Import Data Settings|Round shot station to nearest whole station*, to round to .5 station numbers e.g. 0.5, 1.0, 1.5 etc.
5. Select *File|Import Data...* . Specify *Import data type* SEG-2, *Default shot hole depth* of 0.0. Leave *Default spread type* at 10:360 channels, or choose 02: 48 channels.
6. Click on *Select button* and navigate into directory \RAY32\CAMP1\INPUT. Change *Files of type* from default .DAT to .SG2 . Select one .SG2 file e.g. 0001.SG2 . Click *Open button* and *Import shots button*.
7. Click *Read* to import shot 0001.SG2, with *Layout start [station no.]* 1.0 and *Shot pos. [station no.]* 0.0.
8. For shots 0002.SG2,..., 0009.SG2, edit *Shot pos.* to 3.5, 6.5, 9.5, 12.5, 15.5, 18.5, 21.5, 25 in *Import shot dialog*, before clicking *Read button*. Leave *Layout start* at 1.0 for all shots.
9. *File|Update header data|Update First Breaks...* with file \RAY32\CAMP1\INPUT\BREAKS.LST .
10. *Header|Station...* . Set *z* to 0.0 for one station and hit ENTER. This interpolates coordinates for all stations.
11. Invert the data with *Smooth invert|WET with gradient initial model*. See chapter 1.4 of above manual.pdf .
12. *WET Tomo|Interactive WET tomography....* , set *Number of WET tomography iterations* to 100.
13. Click on *button Edit grid file generation*, and set field *Store each nth iteration only* to 20.
14. Click on *button Accept parameters*, and *button Start tomography processing*, to redo the WET inversion.

For output as displayed in Golden Software Surfer, see below Fig. 1, Fig. 2 and Fig. 3 :



Camp1, 100 WET iterations, RMS error 1.6 %, 1D-Gradient smooth initial model, Version 3.20

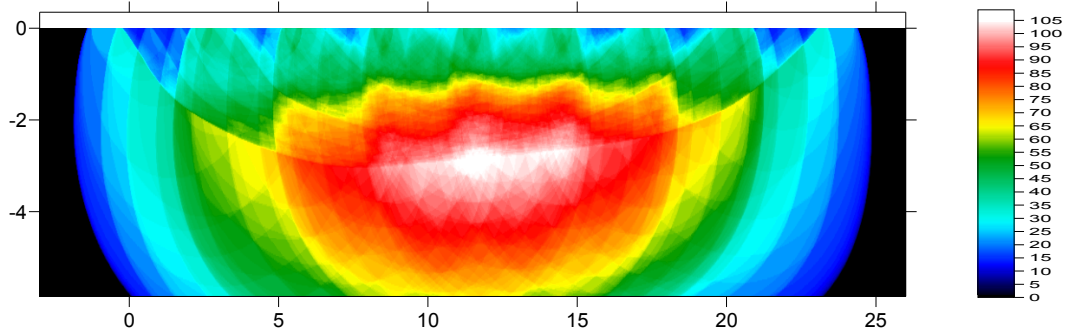


Fig. 3 : Coverage CAMP1 subsurface with first break energy, corresponding to tomogram in Fig. 2

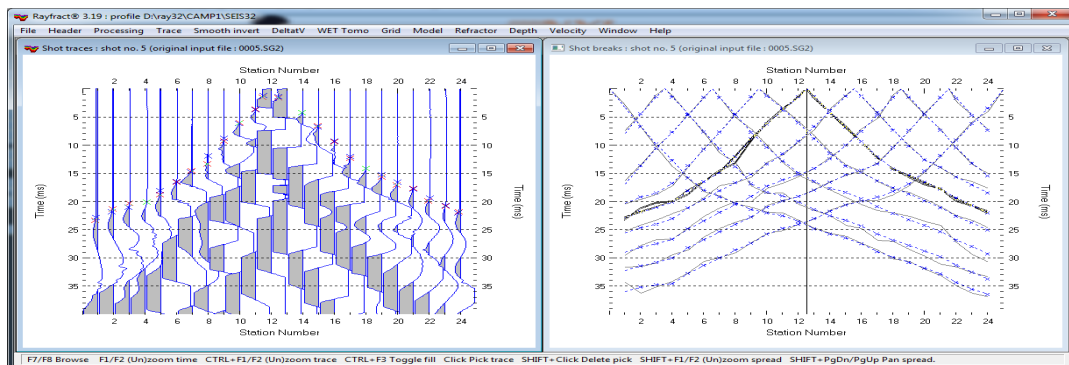


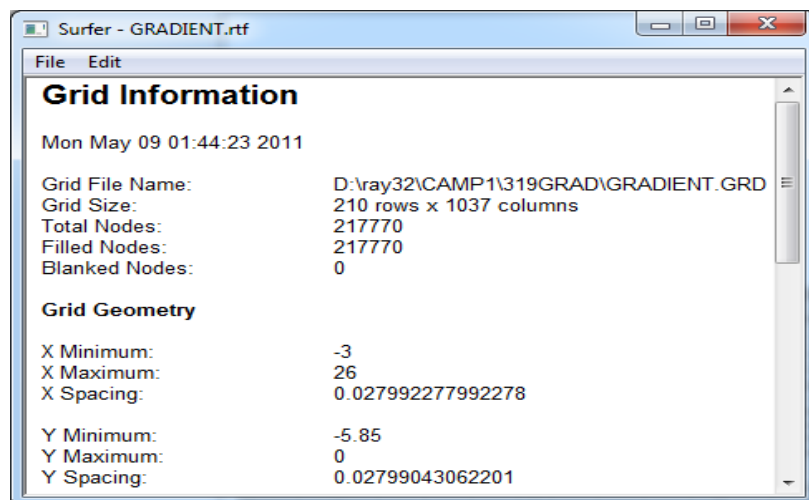
Fig. 4 left : *Trace|Shot gather* trace display. Red crosses are picked times. Blue crosses are modeled times.
right : Match of modeled blue times, to picked grey times in *Refractor|Shot breaks* display.

See Fig. 4 above, for match between picked times and modeled times, after 100 WET iterations.

Build layer-based initial model, in Golden Software Surfer

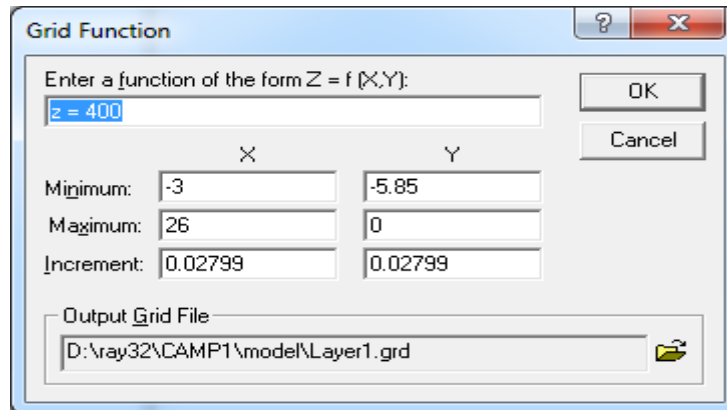
Instead of using the default 1D initial model (Fig. 1), we now build our own layer-based initial model, and then redo the WET inversion. First we determine the required **dimensions of the initial model** :

1. Start up Golden Software Surfer, via *desktop icon* .
2. Select *File|Open...* and `\RAY32\CAMP1\GRADTOMO\GRADIENT.GRD` .
3. Select *Options|Grid Info...* and click *Ok* button. Obtain this *Grid Information* window :



Next we generate a **constant-velocity Surfer .GRD grid file for each layer**, with above dimensions :

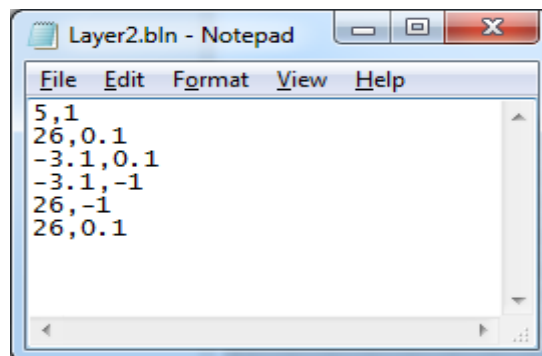
4. In Surfer, select *File|New* and choose *Plot Document*, then click *OK button*. Now select *Grid|Function...* and specify the parameters for generation of our weathering-layer grid as follows :



5. Click on *OK button* to generate our constant-velocity weathering-layer grid file LAYER1.GRD .
6. Select *Grid|Function* again, and change *Enter a function of the form...* to *z = 700*.
7. Change *Output Grid File* to LAYER2.GRD and click *Ok button*, to generate overburden layer grid.
8. Select *Grid|Function* again, and change *Enter a function of the form...* to *z = 1200*.
9. Change *Output Grid File* to LAYER3.GRD and click *Ok button*, to generate basement half-space grid.

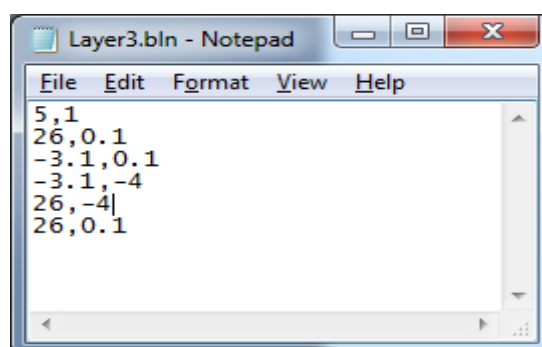
Now we create two **Surfer Blanking or Boundary files**, for masking out the weathering layer from LAYER2.GRD, and masking out weathering layer and overburden layer from LAYER3.GRD :

10. Select *Start|Run...* . Enter NOTEPAD.EXE and hit RETURN. Now enter this content :



Hit ENTER at end of last line 26,0.1, to force an end-of-line character in the disk file. Select *File|Save As...* . Set *Save as type* to *All Files*. Set *File name* to LAYER2.BLN. Click on *Save button*. This file is a *Golden Software Blanking File or Boundary File*; see your Surfer 8 manual Appendix C. Our blanking file describes the weathering layer rectangle which we want to mask out in our LAYER2.GRD overburden grid top. We **add 0.1 to the topmost coordinate of 0.0, so Surfer Grid blanking blanks all rows including topmost grid row**. We **subtract 0.1 from leftmost coordinate of -3, so blanking blanks all columns including leftmost one**.

11. Edit *Notepad window* contents as follows, save as LAYER3.BLN in directory RAY32\CAMP1\MODEL :

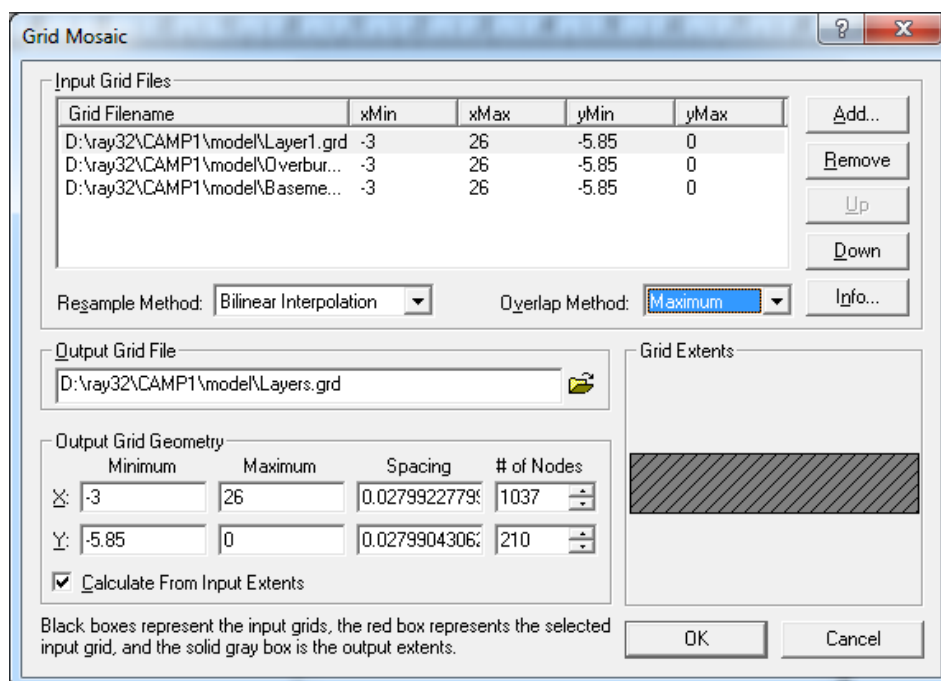


Now we mask out the weathering layer from LAYER2.GRD, and mask out weathering layer and overburden layer from LAYER3.GRD, using above two blanking files :

12. Go back into Surfer, select *Grid|Blank...* and then LAYER2.GRD file. Now select our LAYER2.BLN blanking file. Specify \RAY32\CAMP1\MODEL\OVERBURD.GRD as output file name and click on *Save button* to generate our overburden grid file.
13. Select *Grid|Blank...* again and then LAYER3.GRD file, and our LAYER3.BLN blanking file. Specify \RAY32\CAMP1\MODEL\BASEMENT.GRD as output file name and click on *Save* to generate our basement grid file.

Now we combine LAYER1.GRD, OVERBURD.GRD and BASEMENT.GRD into one Surfer .GRD file, with **Surfer Grid|Mosaic** function :

14. Select *Grid|Mosaic...* and LAYER1.GRD file. Click on *Add...button* and select OVERBURD.GRD. Click *Add...* again and select BASEMENT.GRD file. Set *Overlap method* to *Maximum*. Click on the *folder icon* to the right of field *Output Grid File* and enter file name LAYERS.GRD. Our *Grid Mosaic dialog* should now look as follows :



15. Click *OK button* to generate our layered initial model. Select *Map|Image Map...* and LAYERS.GRD file. Double-click the resulting plot with left mouse key. Check *Show color scale* in *General tab*. Click on *Colors bar*, and load *Color scale* \RAY32\RAINBOW2.CLR. In frame *Data to Color Mapping*, set *Minimum* to 300, and *Maximum* to 1800. Adapt *Limits and Scale tabs* to obtain Fig. 5 below :

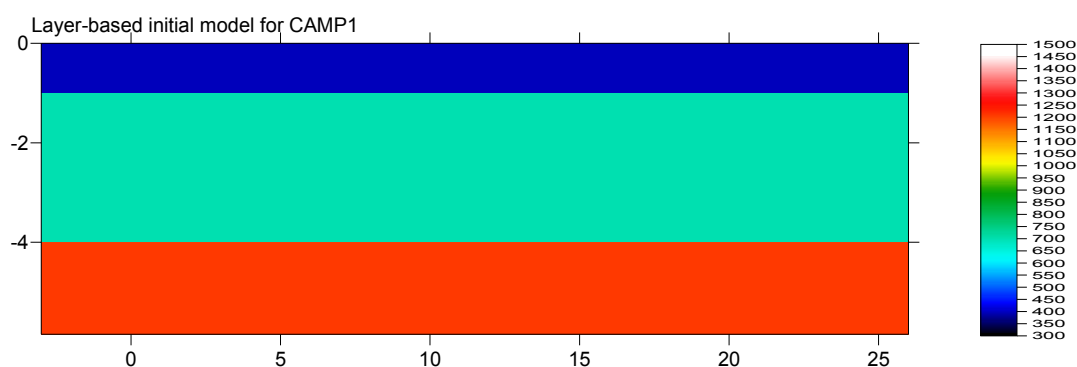


Fig. 5 : Layer-based initial model, for profile CAMP1.

Redo WET inversion of CAMP1, with our LAYERS.GRD layer-based initial model

1. Create a new subdirectory \RAY32\CAMP1\LAYERS, and copy LAYERS.GRD here. Also copy \RAY32\CAMP1\GRADTOMO\GRADIENT.PAR into \RAY32\CAMP1\LAYERS and rename to LAYERS.PAR. We did this in a command prompt. Select *Start|Run...*, enter CMD.EXE and hit RETURN. Then enter these commands :

```
Administrator: Command Prompt
D:\ray32\CAMP1>md Layers
D:\ray32\CAMP1>cd Layers\
D:\ray32\CAMP1\Layers>copy ..\model\layers.grd
1 file(s) copied.
D:\ray32\CAMP1\Layers>copy ..\gradtomo\gradient.par
1 file(s) copied.
D:\ray32\CAMP1\Layers>rename gradient.par layers.par
D:\ray32\CAMP1\Layers>
```

2. Now go back into Rayfract®. Select *WET Tomo|Interactive WET tomography...* . Click *Select button* twice and select \RAY32\CAMP1\LAYERS\LAYERS.GRD .
3. Click *button Accept parameters* and *button Start tomography processing*, to redo WET inversion, with our layered initial model. Obtain output as shown below, in Fig. 6 :

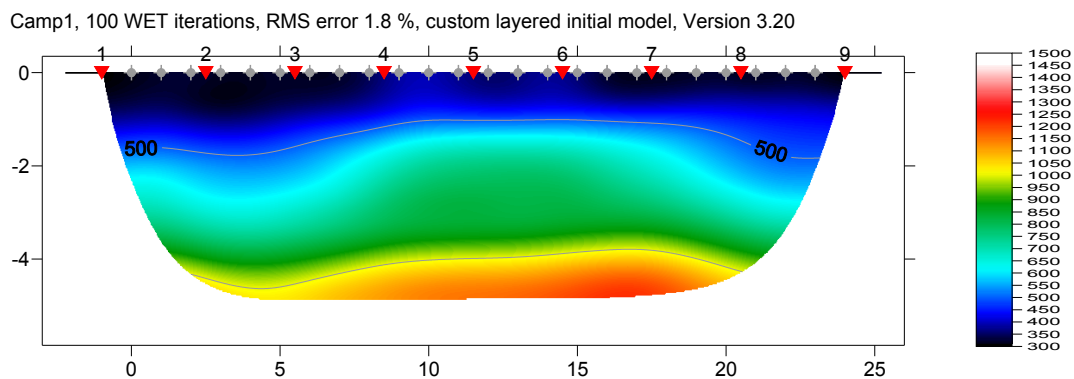


Fig. 6 : WET inversion of CAMP1, with our custom-built layer-based initial model LAYERS.GRD

4. Forward-model traveltimes over our LAYERS.GRD initial model, with *Model|Forward model traveltimes...* and \RAY32\CAMP1\LAYERS\LAYERS.GRD. Select *Refractor|Shot breaks* to obtain travelttime curve plot with shot-sorted first breaks, as shown in Fig. 7 below :

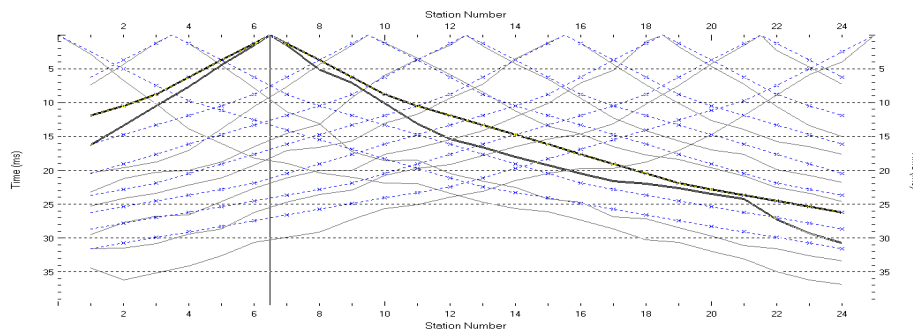


Fig. 7 : Match between grey picked travelttime curves and dashed blue modeled curves, for LAYERS.GRD initial model (Fig. 6). The RMS errors is 7.2%, see \RAY32\CAMP1\LAYERS\LAYERS.FIT .

5. Forward-model traveltimes over GRADIENT.GRD default 1D initial model, with *Model|Forward model traveltimes...* and `\RAY32\CAMP1\GRADTOMO\GRADIENT.GRD`. Select *Refractor|Shot breaks* to obtain traveltime curve plot as shown in Fig. 8 below :

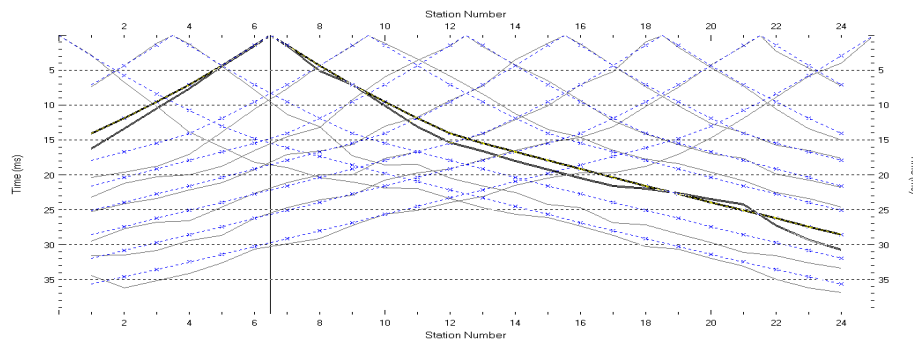


Fig. 8 : Match between grey picked curves and blue modeled curves, for default GRADIENT.GRD 1D initial model (Fig. 1). The RMS errors is 3.4%, see `\RAY32\CAMP1\GRADTOMO\GRADIENT.FIT` .

Both Fig. 2 and Fig. 6 show a similar RMS error after 100 WET iterations (1.6% vs. 1.8%). But Fig. 2 is probably more realistic, since it is based on smooth 1D-gradient initial model GRADIENT.GRD (Fig. 1) with smaller initial RMS error of 3.4% (Fig. 8).

Our custom-built LAYERS.GRD layered initial model (Fig. 6) shows an initial RMS error of 7.2% (Fig. 7), twice as large as for default GRADIENT.GRD (Fig. 8). Obviously Fig. 8 shows a better initial match than Fig. 7, between picked and modeled traveltime curves.

Traveltime tomography and WET inversion are based on the assumption that subsurface velocity varies smoothly, in both vertical and horizontal direction. WET works best with a smooth 1D initial model such as the 1D-gradient initial model GRADIENT.GRD (Fig. 1), which is obtained automatically by horizontally averaging the DeltatV inversion. See <http://rayfract.com/SAGEEP10.pdf> .

For all layered-model component files as built above, see http://rayfract.com/tutorials/camp1_layers.rar .

. To unarchive this, use WinRAR software available at <http://rarlabs.com> .

Also, the smaller the initial RMS error of such a 1D initial model, the higher the chance that WET inversion converges towards a meaningful interpretation. We recommend to always use at least 100 WET iterations instead of the default 20 iterations.

Below we show reprocessing of this data with our version 4.01 software with WDVS enabled, done in Nov 2020. We forced the *grid cell size* to 0.1m in *Header|Profile* to speed up WDVS enabled WET inversion.

WDVS Wavelength-Dependent Velocity Smoothing is described in

Zelt, C. A. and J. Chen, Frequency-dependent traveltime tomography for near-surface seismic refraction data, *Geophys. J. Int.*, 207, 72-88, 2016

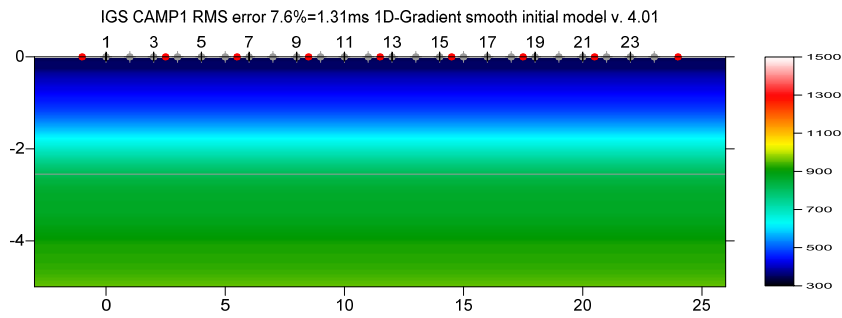


Fig. 9 : 1D-gradient initial model obtained with Smooth invert|WET with 1D-gradient initial model. Compare with Fig. 1 starting model obtained with version 3.20. Grid cell size forced to 0.1m in Header|Profile.

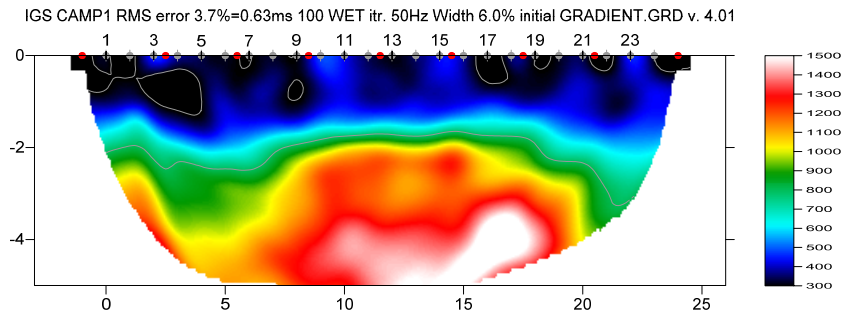


Fig. 10a : 100 Steepest-Descent WET iterations with starting model Fig. 9. Minimal WET smoothing. Smooth nth = 10 (Fig. 16). WDVS frequency 150Hz with Model|Fast WDVS smoothing checked (Fig. 17).

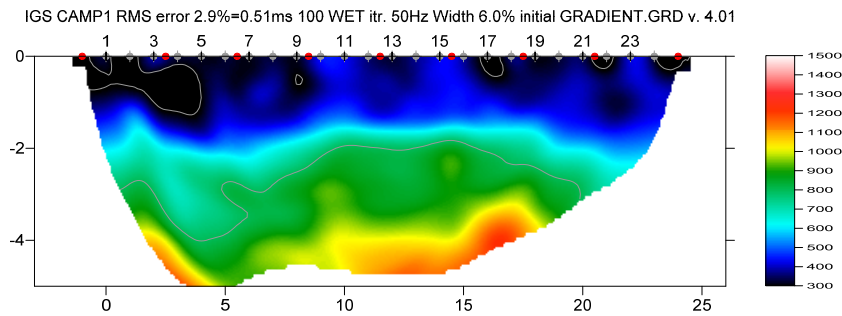


Fig. 10b : same as Fig. 10a but without WDVS. RMS error is smaller than in Fig. 10a but velocity contrast at top of basement (elevation -2m) is much lower.

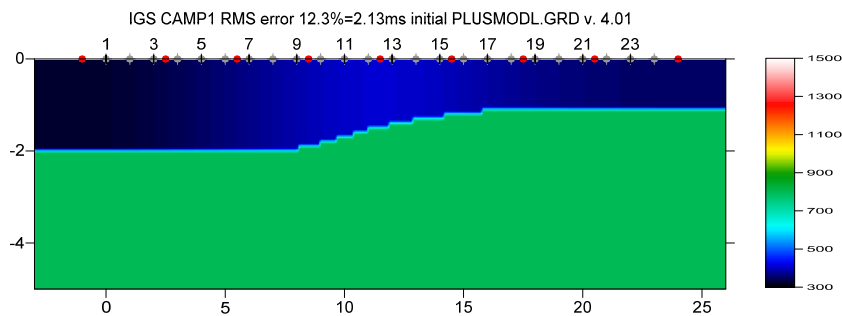


Fig. 11 : Plus-Minus layered refraction starting model. See Fig. 14 & Fig. 15.

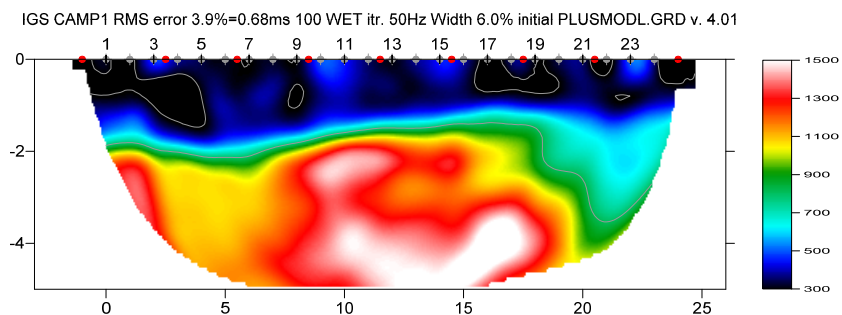


Fig. 12 : 100 Steepest-Descent WET iterations with starting model Fig. 11. Minimal WET smoothing. Smooth nth = 10 (Fig. 16). WDVS frequency 150Hz with Model|Fast WDVS smoothing checked (Fig. 17).

IGS CAMP1 RMS error 3.7%=0.63ms 100 WET itr. 50Hz Width 6.0% initial GRADIENT.GRD v. 4.01

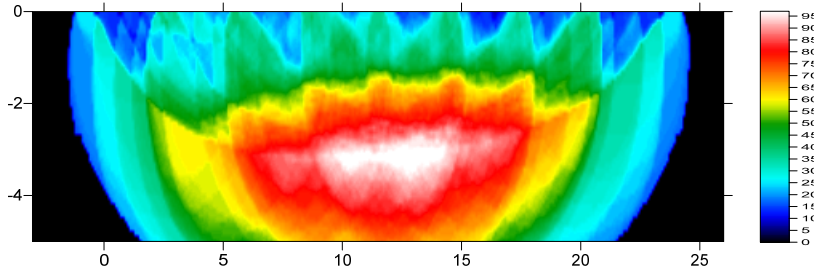


Fig. 13 : WET wavepath coverage obtained with Fig. 10a. Unit is wavepaths per pixel.

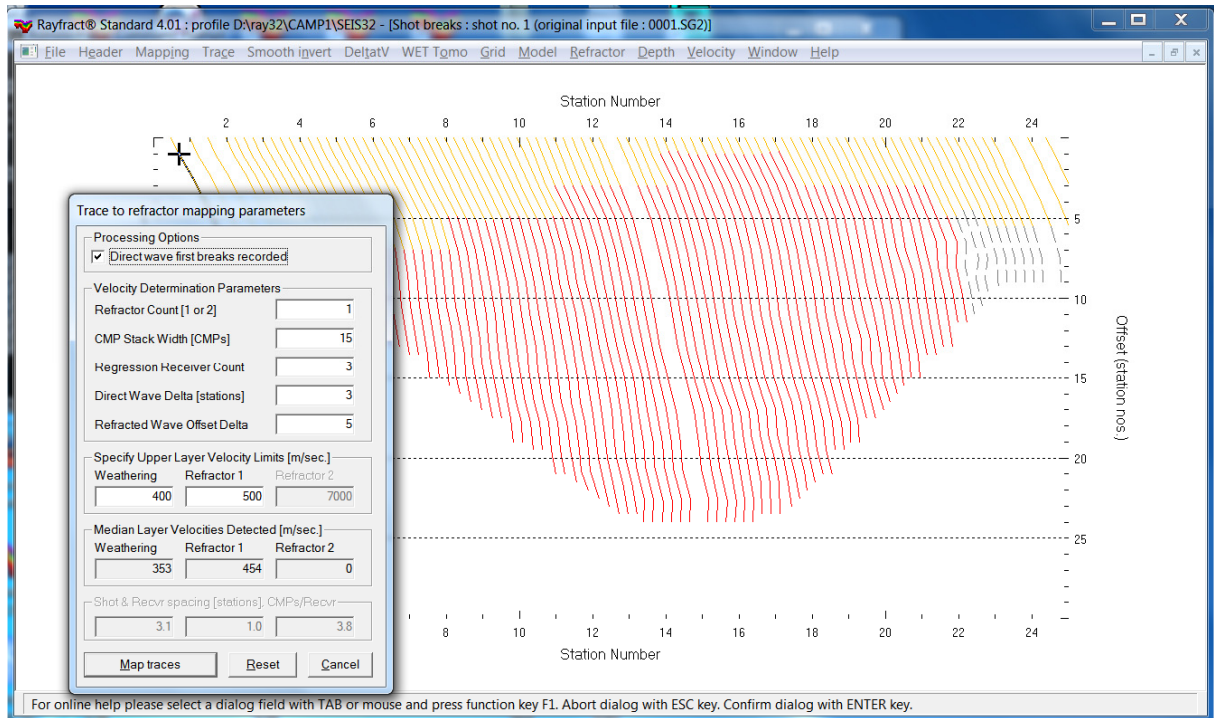


Fig. 14 : map traces to refractors with ALT+M in Refractor|Midpoint breaks.

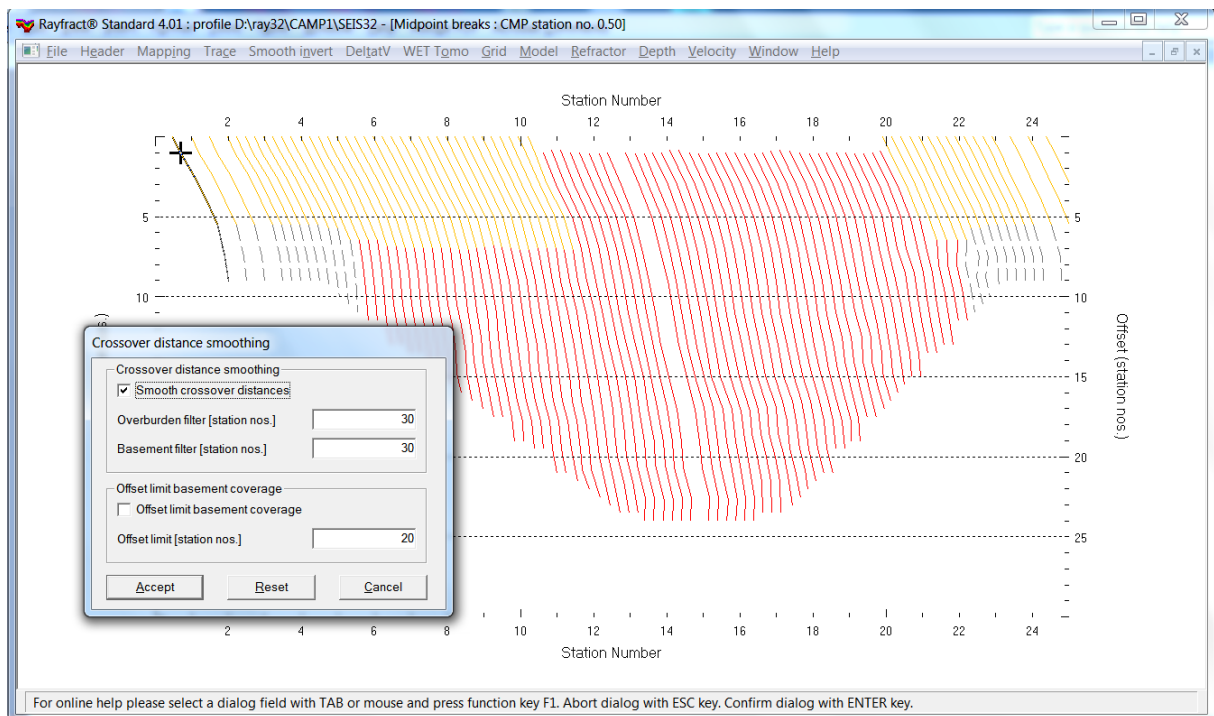


Fig. 15 : smooth crossover distances with ALT+G in Refractor|Midpoint breaks after mapping with ALT+M as in Fig. 14.

.RAR archive with profile database files : http://rayfract.com/tutorials/CAMP1_seis32_Nov21_2020.rar
 Surfer 11 .GRD & .PAR files for Fig. 10a : http://rayfract.com/tutorials/GRADTOMO_Nov21_2020.rar
 Surfer 11 .GRD & .PAR files for Fig. 12 : http://rayfract.com/tutorials/LAYRTOMO_Nov21_2020.rar
 Profile database files for Fig. 10b : http://rayfract.com/tutorials/GRADTOMO_NoWDVS_Dec11.rar
 Surfer 11 files for Fig. 10b : http://rayfract.com/tutorials/CAMP1_seis32_GradNoWDVS.rar

Edit WET Wavepath Eikonal Traveltime Tomography Parameters

Specify initial velocity model
 Select

Stop WET inversion after
 Number of WET tomography iterations : iterations
☐ or RMS error gets below percent
☐ or RMS error does not improve for n = iterations
☐ or WET inversion runs longer than minutes

WET regularization settings
 Wavepath frequency : Hz
 Ricker differentiation [-1:Gaussian,-2:Cosine] : times
 Wavepath width [percent of one period] : percent
 Wavepath envelope width [% of period] : percent
 Min. velocity : Max. velocity : m/sec.
 Width of Gaussian for one period [sigma] : sigma

Gradient search method
☒ Steepest Descent ☐ Conjugate Gradient

Conjugate Gradient Parameters
 CG iterations Line Search iters.
 Tolerance Line Search tol.
 Initial step ☐ Steepest Descent step

Edit WET Tomography Velocity Smoothing Parameters

Determination of smoothing filter dimensions
☐ Full smoothing after each tomography iteration
☒ Minimal smoothing after each tomography iteration
☐ Manual specification of smoothing filter, see below

Smoothing filter dimensions
 Half smoothing filter width : columns
 Half smoothing filter height : grid rows

Suppress artefacts below steep topography
☒ Adapt shape of filter. Uncheck for better resolution.

Maximum relative velocity update after each iteration
 Maximum velocity update : percent

Smooth after each nth iteration only
 Smooth nth iteration : n = iterations

Smoothing filter weighting
☐ Gaussian ☒ Uniform ☐ No smoothing
 Used width of Gaussian sigma
 Uniform central row weight [1..100]

Smooth velocity update before updating tomogram
☒ Smooth update ☐ Smooth nth ☒ Smooth last

Damping of tomogram with previous iteration tomogram
 Damping [0..1] ☐ Damp before smoothing

Fig. 16 : WET Tomo|Interactive WET (left). Edit velocity smoothing (right).

Edit WDVS (Zelt & Chen 2016)

Edit parameters for wavelength-dependent velocity smoothing
☒ use WDVS for forward modeling of traveltimes

WDVS frequency [Hz]
 Angle increment [Degree]
 Regard nth node [node]

Parameters for Cosine-Squared weighting function
 a : Cosine argument power [power]
 b : Cosine-Squared power [power]

Fig. 17 : Model|WDVS Smoothing. Check Model|Fast WDVS Smoothing.

WDVS Wavelength-Dependent Velocity Smoothing is described in

[Zelt, C. A. and J. Chen, Frequency-dependent traveltime tomography for near-surface seismic refraction data, Geophys. J. Int., 207, 72-88, 2016](#)

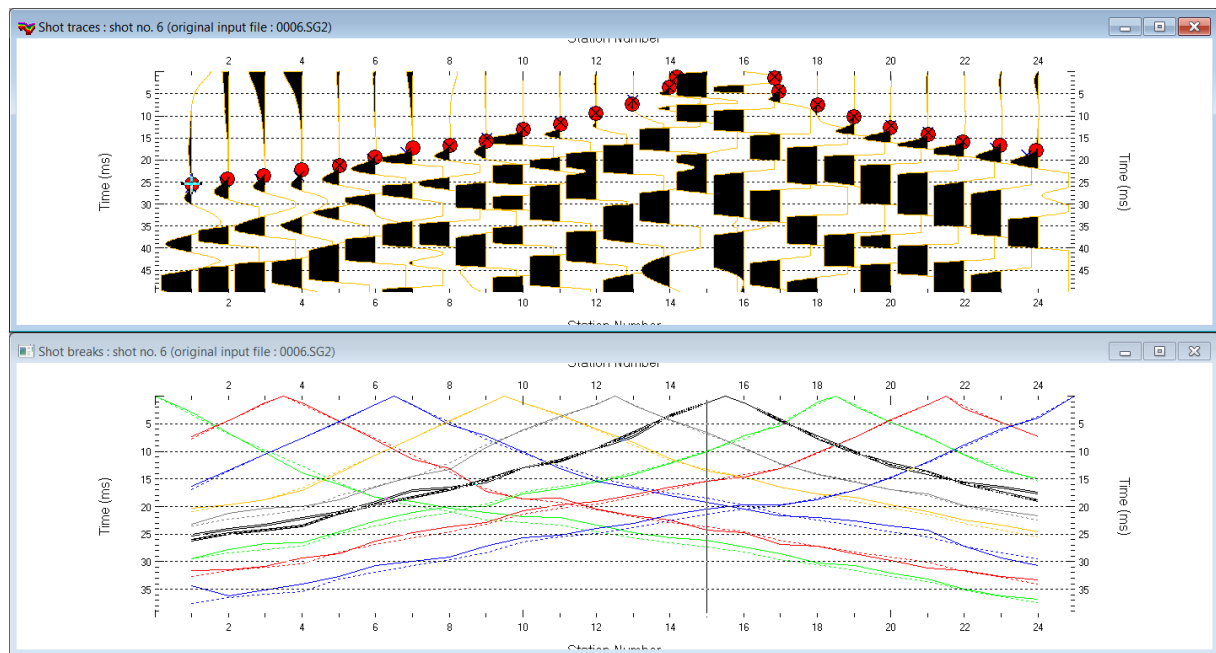


Fig. 18 : Fit between picked and modeled traveltimes for Fig. 10a with WDVS enabled.

Compare WDVS enabled WET in Fig. 10a with Fig. 2 showing interpretation with version 3.20 without WDVS.

Enabling WDVS (Fig. 17) and minimizing WET smoothing (Fig. 16) dramatically improves WET resolution.

Using the same WET inversion settings as for Fig. 10a but without WDVS results in much lower velocity contrast at top of basement (Fig. 10b).

Note the good agreement between Fig. 10a and Fig. 12 obtained with completely different starting models.

We thank our Italian agent Dott. Mario Foresta for making available this data set. According to Dott. Foresta (email Dec 18, 2020) the ***geological setting and stratigraphic layering*** for this profile CAMP1 is :

- brown agricultural soil in the first 1m to 1.5m below topography
- loose volcanic material with lava blocks, down to 3m to 5m depth
- compact lava below 5m depth with velocity 3,000m/s to 5,000m/s