Import SEG-2, Smooth invert, DeltatV & Plus-Minus & WDVS 4.02. Discard WET smoothing :

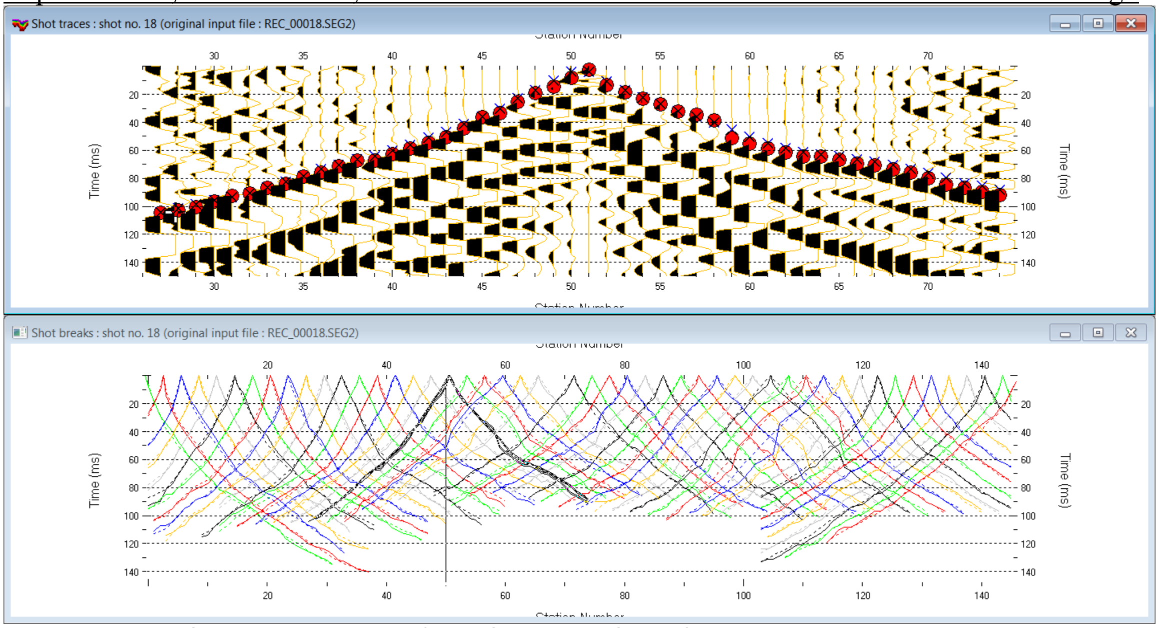


Fig. 1 : top : *Trace|Shot gather*, bottom : *Refractor|Shot breaks*. Shows fit between picked times (solid curves, red circles) and modeled times (dashed curves, blue crosses) obtained for Smooth inversion (Fig. 7). Browse shots with F7/F8.

To create the profile database, import the data and browse the imported shots with `F7/F8` do these steps :

- ***File|New Profile***..., set *File name* to `3016_SEG2` and click *Save button*
- in the prompt (Fig. 42) click ***No*** button to leave ***Profile start*** and first receiver at station no. 0.
- in ***Header|Profile***... set *Line type* to `Refraction spread/line` . Set *Station spacing* to 5.0 m.
- check *box Force grid cell size* and set *Cell size[m]* to 0.5m. See Fig. 2.
- unzip updated archive `3016_SEG2.zip` with `DMT SUMMIT .SEG2` shot files & `COORDS.COR` & `SHOTPTS.SHO` & `BREAKS.LST` in directory `C:\RAY32\3016_SEG2\INPUT`
- check *File|SEG-2 import settings|Ignore SEG-2 station numbers in trace headers*. See Fig. 17.
- check *File|SEG-2 import settings|Receiver coordinates specified in SEG-2 trace headers* (Fig. 17).
- select ***File|Import Data***... and set *Import data type* to `SEG-2`. See Fig. 3.
- click *Select button* and navigate into `C:\RAY32\3016_SEG2\INPUT`
- set *Files of type* to `DMT files (*.SEG2)` and select any file e.g. `Rec_00001.seg2` & click button *Open*
- click button ***Import shots button*** . For each shot shown in dialog click ***Read*** button.
- select *File|Update header data|Update Station Coordinates* & `COORDS.COR`. Click *Import & Reset*.
- *File|Update header data|Update Shotpoint coordinates* with `SHOTPTS.SHO`. Click *Open button*.
- select *File|Update header data|Update First Breaks*. Select file `BREAKS.LST` & click *Open button*
- select *Trace|Shot gather* and select *Window|Tile horizontal* to obtain Fig. 1
- click on title bar of *Refractor|Shot breaks* window (Fig. 1 bottom) and press `ALT+P`. Edit *Maximum time* to 150 ms & press `ENTER` key to redisplay. Do same for *Trace|Shot gather* window (Fig. 1 top).
- select *Trace|Shot gather*. Select *Display|Show picks on time axis* (Fig. 11 a).

To configure and run *Smooth inversion* :

- select *Grid|Surfer plot Limits*. Edit fields as in Fig. 4. Click *OK button*.
- uncheck *WET Tomo|WET tomography Settings|Blank|Blank below envelope after last iteration*
- uncheck *Grid|Label shot points on tomogram.* Check *Grid|Receiver station ticks on top axis* (Fig. 9).
- select ***Model|WDVS Smoothing*** and configure as in Fig. 5. Check option ***discard WET smoothing***.
- check *Smooth invert|Smooth inversion Settings options* ***Extra-wide smoothing for 1D initial velocity profile*** and ***Extra-wide stack for 1D-gradient initial*** (Fig. 10).

- select *DeltatV|Interactive DeltatV|Static Corrections.* Set *Inverse CMP offset power to 0.2* (Fig. 11). *Click Accept & Cancel buttons.* This gives a smoother 1D-gradient DeltatV-based starting model.
- select ***Smooth invert|WET with 1D-gradient initial model***
- wait for the starting model to display as in Fig. 6. Confirm to continue to obtain WET output Fig. 7&8.

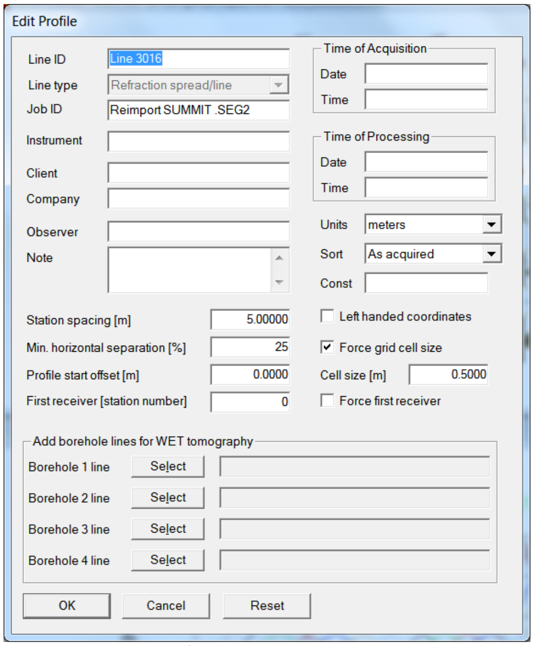


Fig. 2 : *Header|Profile*

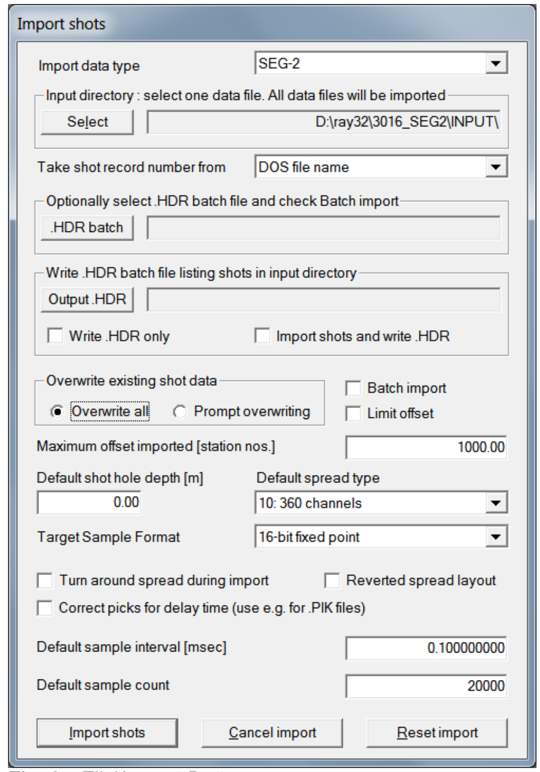


Fig. 3 : *File|Import Data*

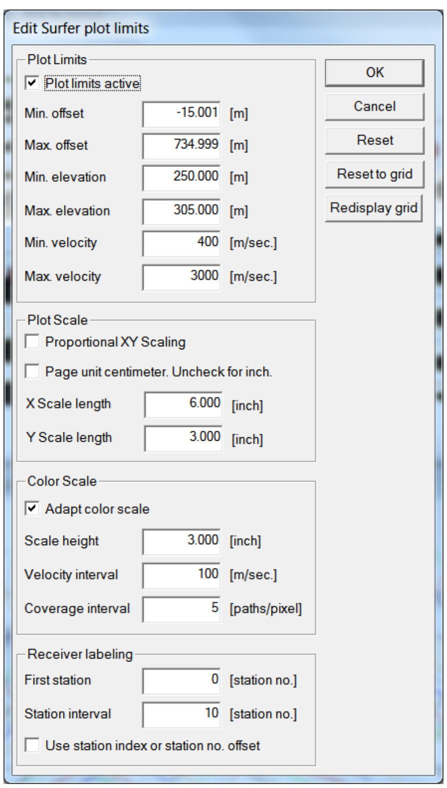
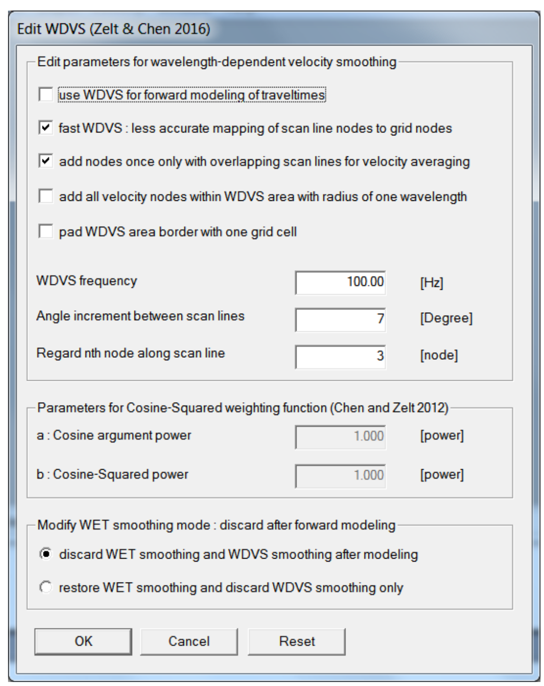


Fig. 4 : *Grid|Surfer plot Limits* (left)

Fig. 5 : *Model|WDVS Smoothing* (right)



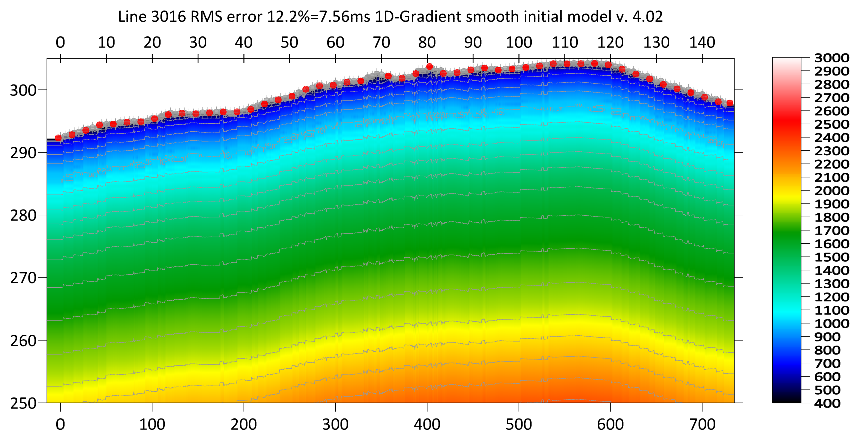


Fig. 6 : 1D-gradient starting model obtained with *Smooth invert|WET with 1D-gradient initial model*

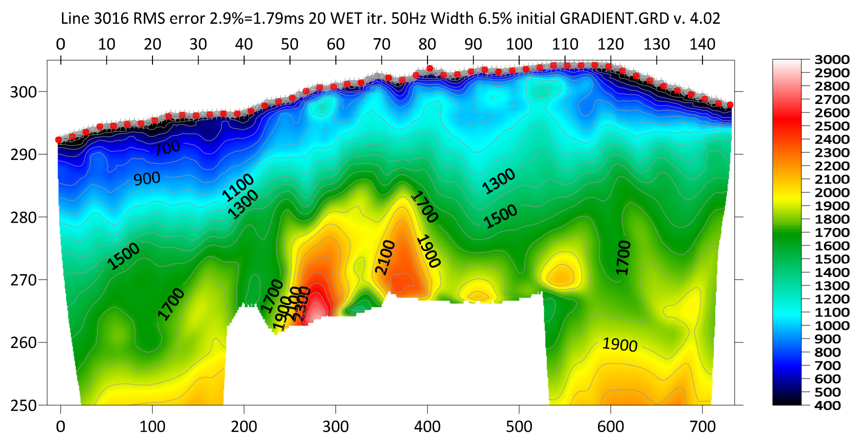


Fig. 7 : 2D WET output obtained with *Smooth invert|WET with 1D-gradient initial model* & starting model shown in Fig. 6. 20 WET iterations using Steepest Descent method & Gaussian update weighting & full WET smoothing. Check *discard WET smoothing after forward modeling* (Fig. 5) to speed up WET convergence towards small RMS error.

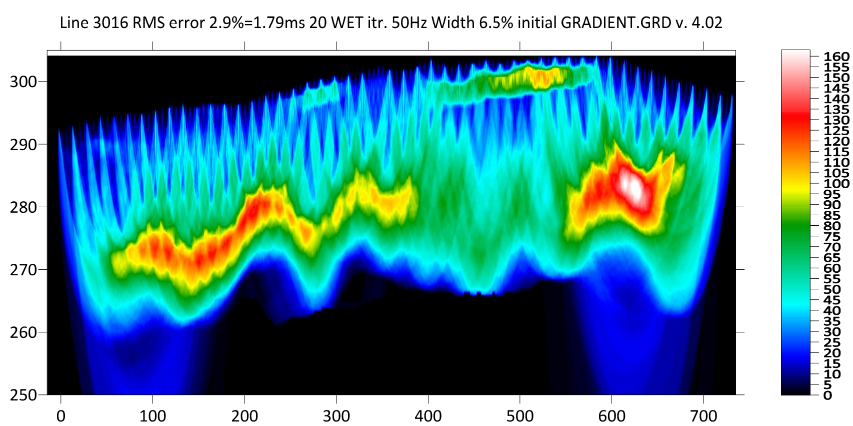


Fig. 8 : WET wavepath coverage plot obtained with Fig. 7. Unit is wavepaths per pixel.

A ***borehole*** at station no. 101 shows strongly weathered and fractured sandstone at bottom depth of 12m (absolute elevation 292m) for this geotechnical refraction profile in Australia. At depth of 5m (elevation 299m) a detached sandstone layer was drilled in the same borehole, with thickness of about 0.4m and with alternating/interbedded gravelly and clayey sand layers below this sandstone layer and sand layers above.

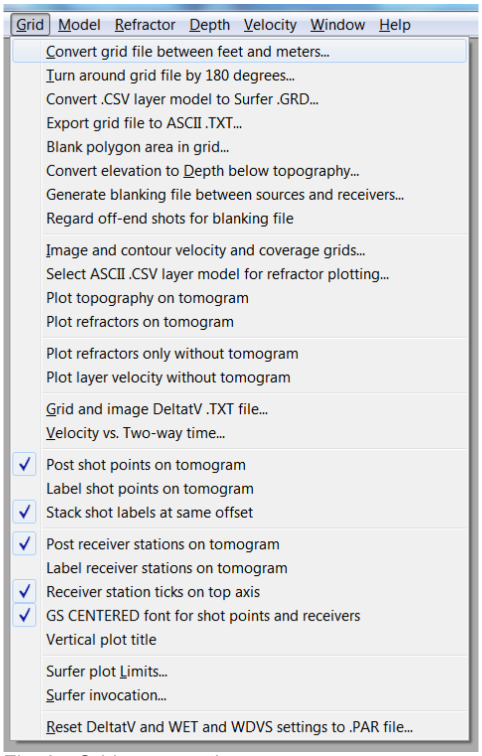


Fig. 9 : *Grid menu* setting

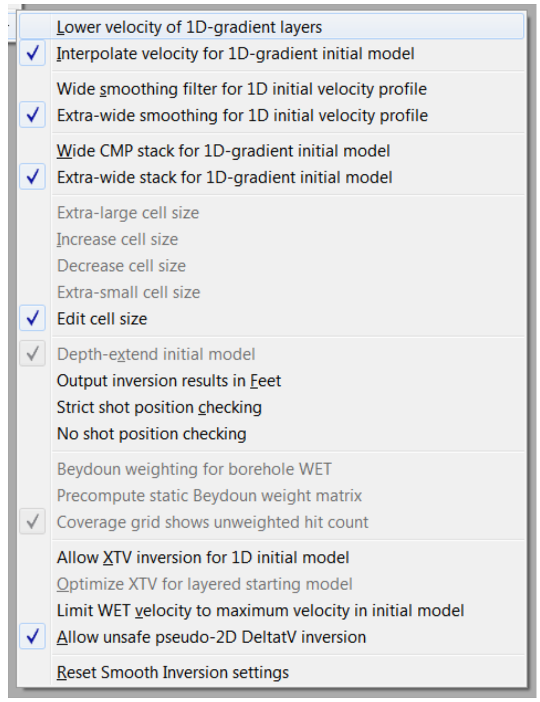


Fig. 10 : *Smooth invert|Smooth inversion Settings*

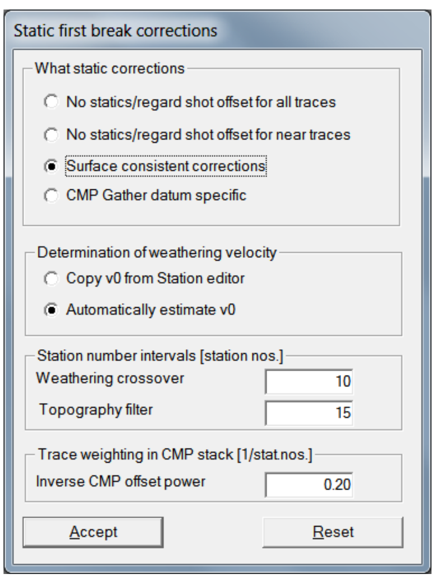


Fig. 11 : *DeltatV|InteractiveDeltatV|Static Corrections*

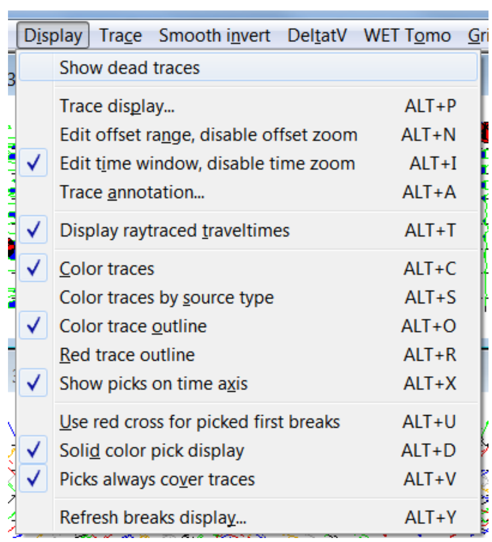


Fig. 11a : *Trace|Shot gather*, *Display* menu

Decreasing ***Inverse CMP offset power*** from default 0.5 to 0.2 (Fig. 11) results in a more laterally and vertically smoothed 1D-gradient initial model plot for this profile (Fig. 6) especially in overburden just below topography. See our updated .pdf reference chapter ***DeltatV Static Corrections*** on page 208.

Shots were stacked at the same shot point 5 times using the DMT SUMMIT X One seismograph. See **.SEG2** files in your **C:\RAY32\3016_SEG2\INPUT** folder, trace header field STACK. Use e.g. the free XVI32 hexadecimal editor available at http://www.chmaas.handshake.de/delphi/freeware/xvi32/xvi32.htm . We fixed bad RECEIVER_LOCATION for dead trace from 1 to 115.0 in DMT SUMMIT X One .SEG2 files using XVI32 editor for this profile.

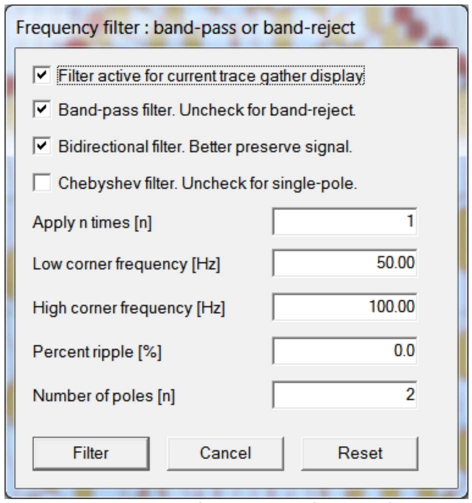


Fig. 12 : Band-pass filter. Press SHIFT+Q in *Trace|Shot gather*.

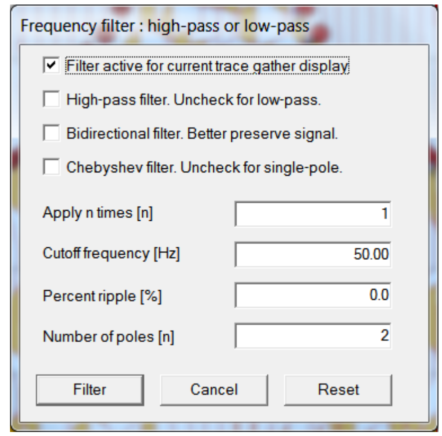


Fig. 13 : Low-pass filter. ALT+Q in *Trace|Shot gather*.

For optimal noise suppression and enhanced visibility of first breaks at large source-receiver offsets use both ***band-pass filter*** (Fig. 12) and ***low-pass filter*** (Fig. 13). These two filters are applied to recorded traces after each other, for trace display.

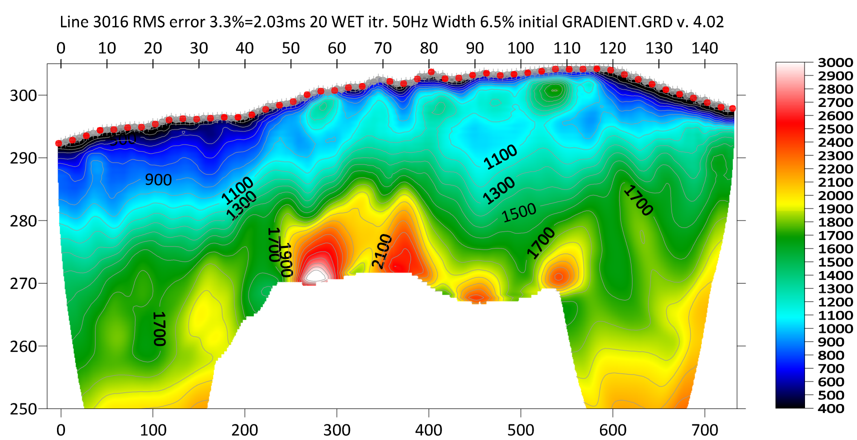


Fig. 14 : same as Fig. 7 but WDVS activated at 100Hz with check box ***Use WDVS for forward modeling*** (Fig. 18). Note the enhanced velocity contrast between layers in the overburden, compared to Fig. 7.

Discarding WET smoothing after forward modeling but leaving WDVS smoothing deactivated (Fig. 5) helps to improve resolution especially in overburden without incurring increased WET runtime needed for WDVS smoothing.

Compare Fig. 7 (no WDVS smoothing but discard WET smoothing after forward modeling, Fig. 5) with Fig. 14 (WDVS activated with check box ***Use WDVS for forward modeling***, Fig. 18). WDVS does help to further enhance velocity contrast between layers in overburden and improves fit with borehole stratigraphy described below Fig. 8.

Smooth inversion shown in Fig. 7 with WDVS deactivated (Fig. 5) and using 20 Steepest-Descent WET iterations took about 2 minutes on 2017 Apple iMac. This iMac comes with 2.3 GHz Intel Core i5 processor running 4 OpenMP threads under Windows 7/10/11 Pro 64-bit in Parallels Desktop 17 for Mac. The same *Smooth inversion* but with WDVS activated (Fig. 18) shown in Fig. 14 took about 6 minutes. We determined these WET runtimes under Windows 7 Pro 64-bit.

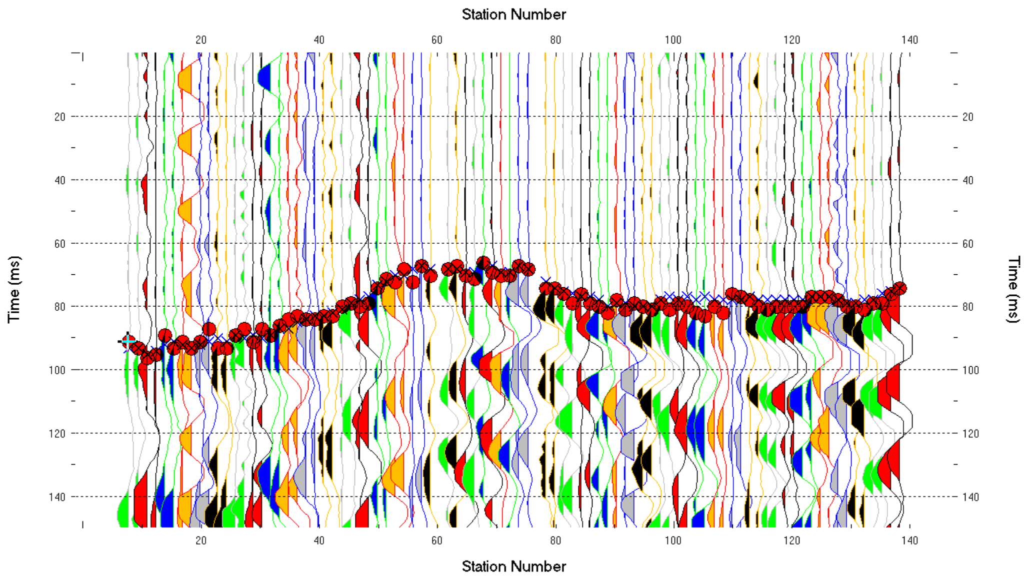


Fig. 15 : *Trace|Offset gather* for common offset of 82.5m

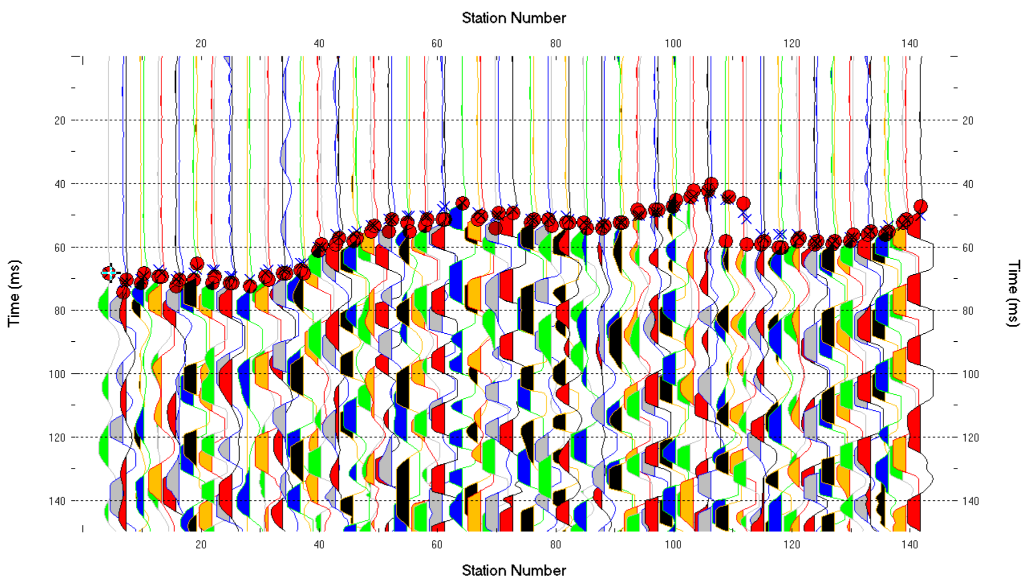


Fig. 16 : *Trace|Offset gather* for common offset of 47.5m

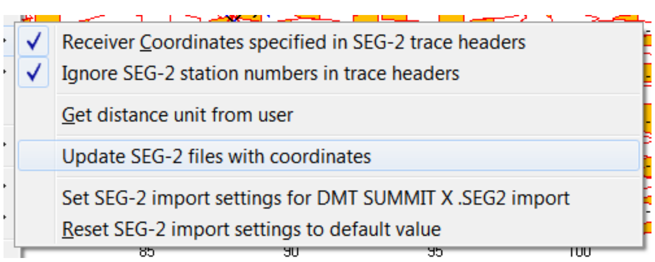


Fig. 17 : *File|SEG-2 import settings*

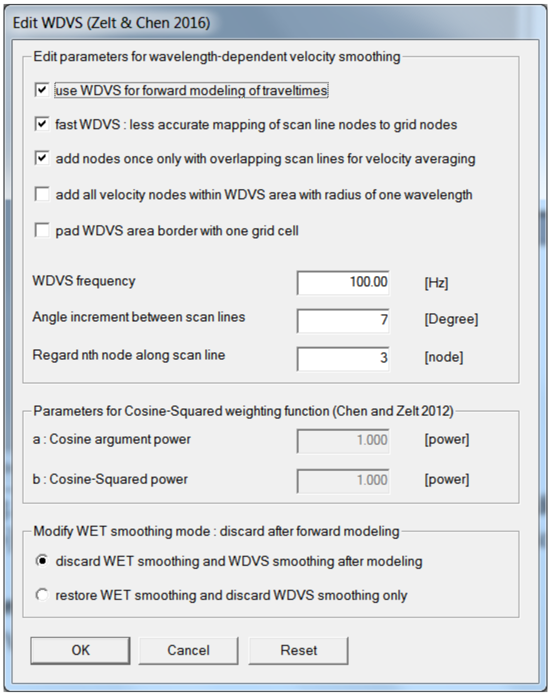


Fig. 18 : *Model|WDVS Smoothing* with WDVS activated

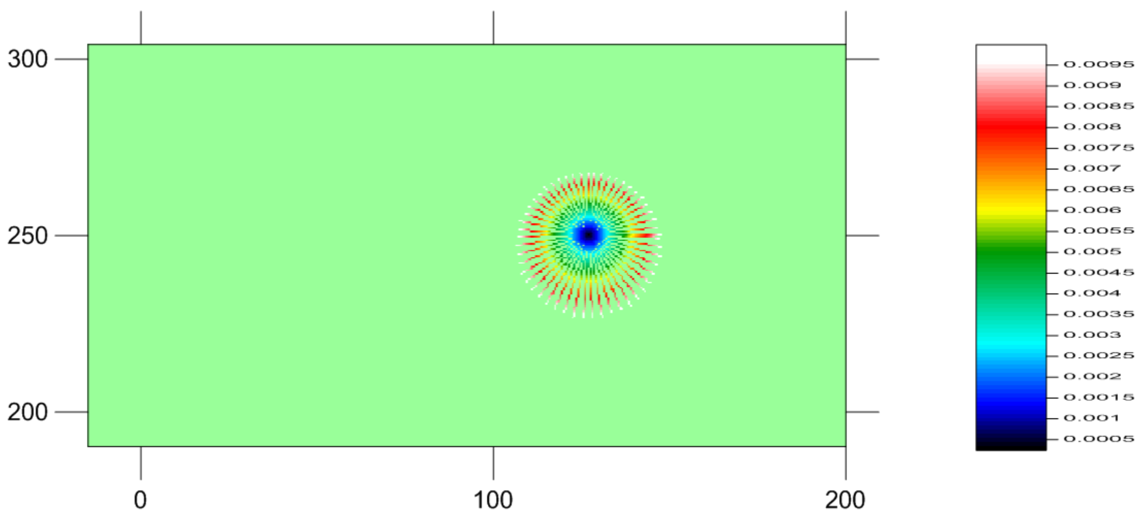


Fig. 19 : WDVSTIME.GRD written to C:\RAY32\DAT during Smooth inversion with option *WET|WET tomography Settings|Write|Write blanked and mask grids and WDVS debug grids* checked. Unit is delay time in seconds, along scan lines originating at center of WDVS area. See our updated .pdf reference chapter *Forward model traveltimes* section *WDVS velocity smoothing* on page 167.

In Fig. 19 we image the **WDVSTIME.GRD** written to **C:\RAY32\DAT** folder during WET inversion with option *WET Tomo|WET tomography Settings|Write|Write blanked and mask grids and WDVS debug grids* checked. The color scale shows time incurred from center of WDVS area along scan lines and using current WET grid velocity, in seconds. *WDVS frequency* of 100Hz (Fig. 18) corresponds to one period of 0.010s. See (Zelt and Chen 2016) Fig. 4 and equation (1).

You may notice that scan lines in Fig. 19 are not completely straight when zooming into this figure. To obtain more straight scan lines uncheck option *Fast WDVS* in *Model, WDVS Smoothing* dialog (Fig. 18) and click *OK* button. Now reselect *Smooth invert, WET with 1D-gradient initial model.*

To image the **WDVSTIME.GRD** as shown in Fig. 19 using Golden Software Surfer version 23 :

- open Windows Explorer window
- navigate into folder **C:\RAY32\DAT**
- create subdirectory named after your current profile e.g. **C:\RAY32\DAT\3016_SEG2**
- copy **WDVSTIME.GRD** from **C:\RAY32\DAT** into **C:\RAY32\DAT\3016_SEG2** during WET inversion
- select *File, New, Plot document*
- in box *Search commands and Help...* type Map Wizard and click *Map Wizard*
- in *Map Wizard - Select Your Data dialog* click *Browse...* button
- select **C:\RAY32\DAT\3016_SEG2\WDVSTIME.GRD** and click *Open* button. Click *Next* button.
- in *Map Wizard - Select Your Map Type* dialog select ***Color Relief***. Click *Finish* button.
- in *View* menu check *Properties* box
- left-click image map to show properties in tab on left (Fig. 20)
- in *General, Terrain representation* change from Hill shaded to Color only (Fig. 20)
- in *General, Colors* change to Rainbow2 (Fig. 20)
- uncheck *Interpolate pixels* box (Fig. 20)
- check *Show color scale* box (Fig. 20)
- in NoData change *Color* to Ghost Green (Fig. 20)
- select *View, Fit to window*
- in box *Search Commands and Help...* type Limits. Click on *Set Limits*.
- position mouse cursor over yellow square in center of right or left vertical axis and drag to left or right
- position mouse cursor over yellow square in center of bottom horizontal axis and drag upwards
- press **ENTER** key to confirm changed plot limits
- select *View, Fit to window*
- left-click color scale and drag left next to right axis of resized image map
- drag top and bottom of color scale down/up to align with top/bottom of resized image map
- left-click color scale
- position mouse cursor over green square in center of right vertical boundary of color scale
- drag left double-arrow cursor until text labels of color scale look fine / are readable
- click on left vertical axis of image map
- click on *Labels* tab in *Properties* tab on left (Fig. 21)
- expand *Font properties* by clicking on plus symbol (Fig. 21)
- decrease *Size (points)* to 4 (Fig. 21)
- click on bottom horizontal axis of image map
- decrease *Size (points)* to 4
- select *File, Save As* and enter *File name* and click *Save* button

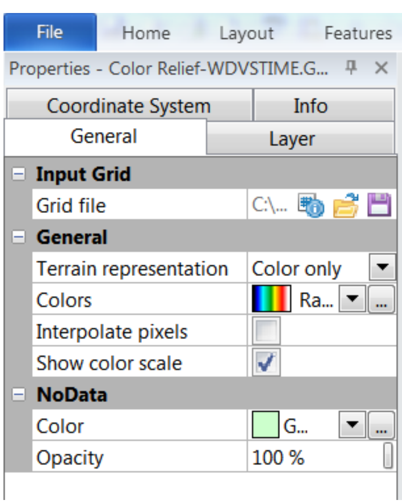


Fig. 20 :
Properties for WDVSTIME.GRD

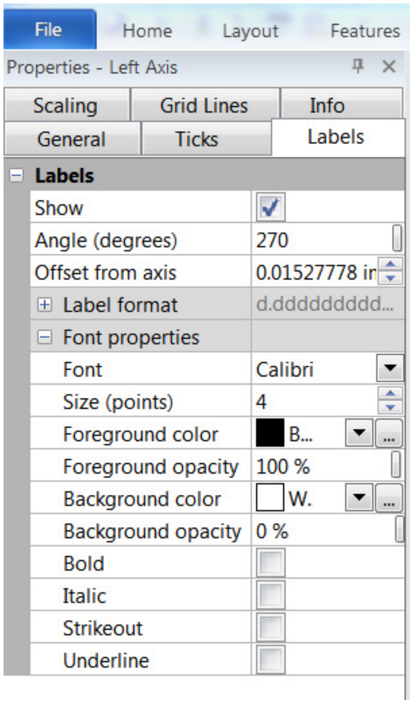


Fig. 21 : edit left axis

Surfer plot limits shown in Fig. 4 are used for WET inversion output (Fig. 7&8) only and not for the 1D-gradient starting model (Fig. 6). To display the starting model using these plot limits :

- select ***Grid|Image and contour velocity and coverage grids***
- navigate into directory `C:\RAY32\3016_SEG2\GRADTOMO`
- select file `GRADIENT.GRD`

For correct geometry specification during SEG-2 import we recommend to first update SEG-2 trace header fields SOURCE_LOCATION and RECEIVER_LOCATION with true x/y/z coordinate triples as shown in our SR6 tutorial using SEG2_EDIT utility. You can use our SEG2_Update utility for batch invocation of SEG2_EDIT for updating trace headers of SEG-2 files with matching _3D.TXT response files. See bullet dated Dec 5, 2021 in our release notes. Run our SEG2_Update installer and then invoke SEG2_Update via *File, SEG-2 import settings, Update SEG-2 files with coordinates* or via its desktop icon.

Once you have updated SEG-2 trace headers with correct source and receiver x/y/z coordinates as described in previous paragraph you can import these updated SEG-2 files as shown above on first page with *SEG-2 import settings* as shown in Fig. 17. Also check import option ***File, SEG-2 import settings, Receiver coordinates specified*** before importing these updated SEG-2 trace files.

Also you can use our .HDR batch import as shown in our P6 tutorial and as described in our updated .pdf reference chapter ***File formats*** on page 257.

Here is DropBox link to .RAR archive with seis32.* profile database files for Fig. 7.
Here is DropBox link to .RAR archive with GRADTOMO folder files for Fig. 7.
Here is DropBox link to .RAR archive with GRADTOMO folder files for Fig. 14.

Next we obtain the pseudo-2D DeltatV starting model with *DeltatV|Automatic DeltatV* (Fig. 22) and then use interactive WET tomography with minimal WET smoothing (Fig. 25) and with WDVS activated (Fig. 27) to obtain Fig. 23 :

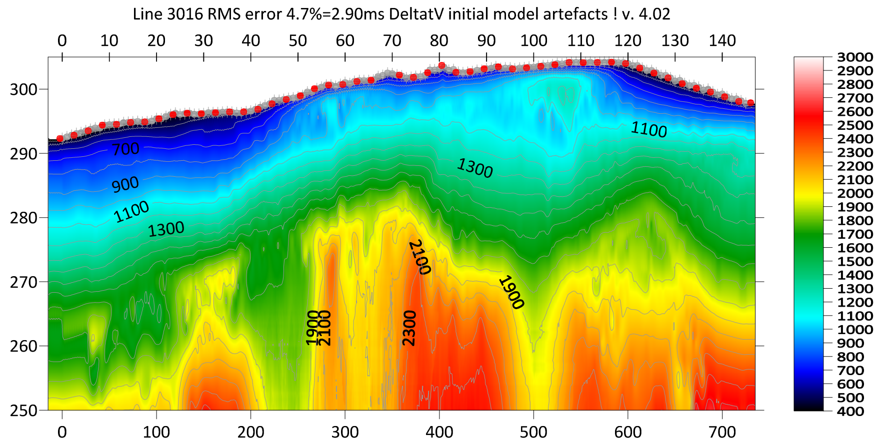


Fig. 22 : DeltatV starting model obtained with *DeltatV|Automatic DeltatV* and default DeltatV settings (Fig. 26). When prompted to continue with WET inversion press *Cancel* button.

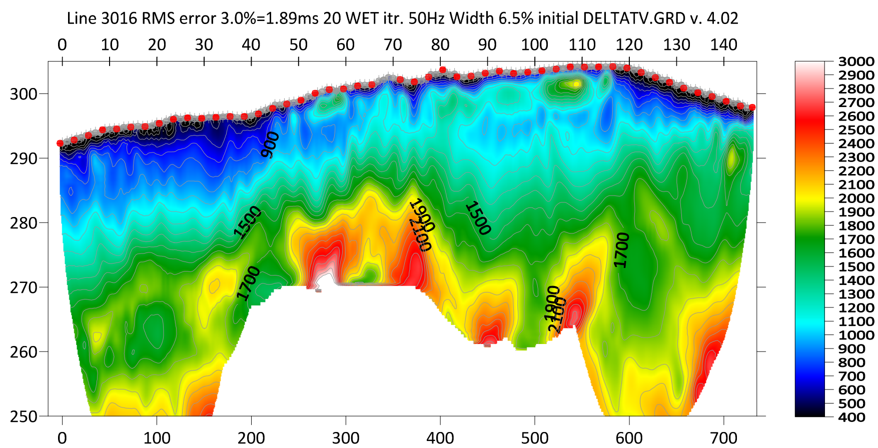


Fig. 23 : 20 Steepest Descent WET iterations obtained with interactive WET (Fig. 25) using DeltatV starting model Fig. 22. Ricker differentiation 0. Wavepath width 6.5%. Wavepath frequency 50Hz (Fig. 25 left). Minimal WET smoothing (Fig. 25 right). WDVS active @100Hz. Fast WDVS disabled. Discard WET smoothing (Fig. 27).

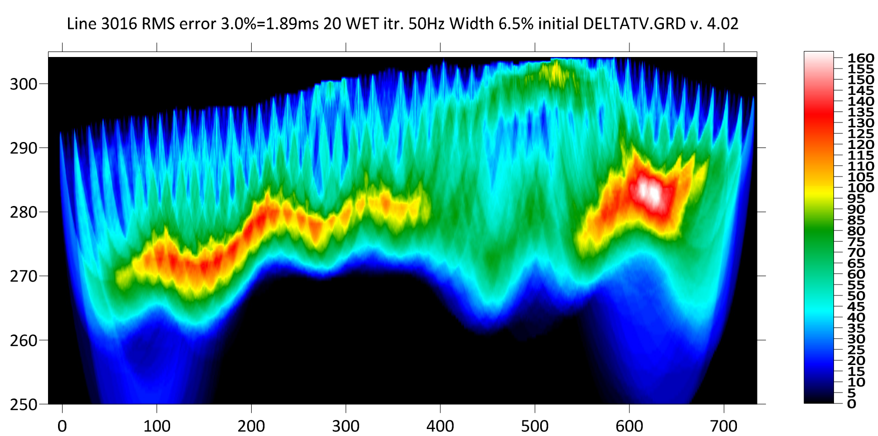


Fig. 24 : WET wavepath coverage plot obtained with Fig. 23. Unit is wavepaths per pixel.

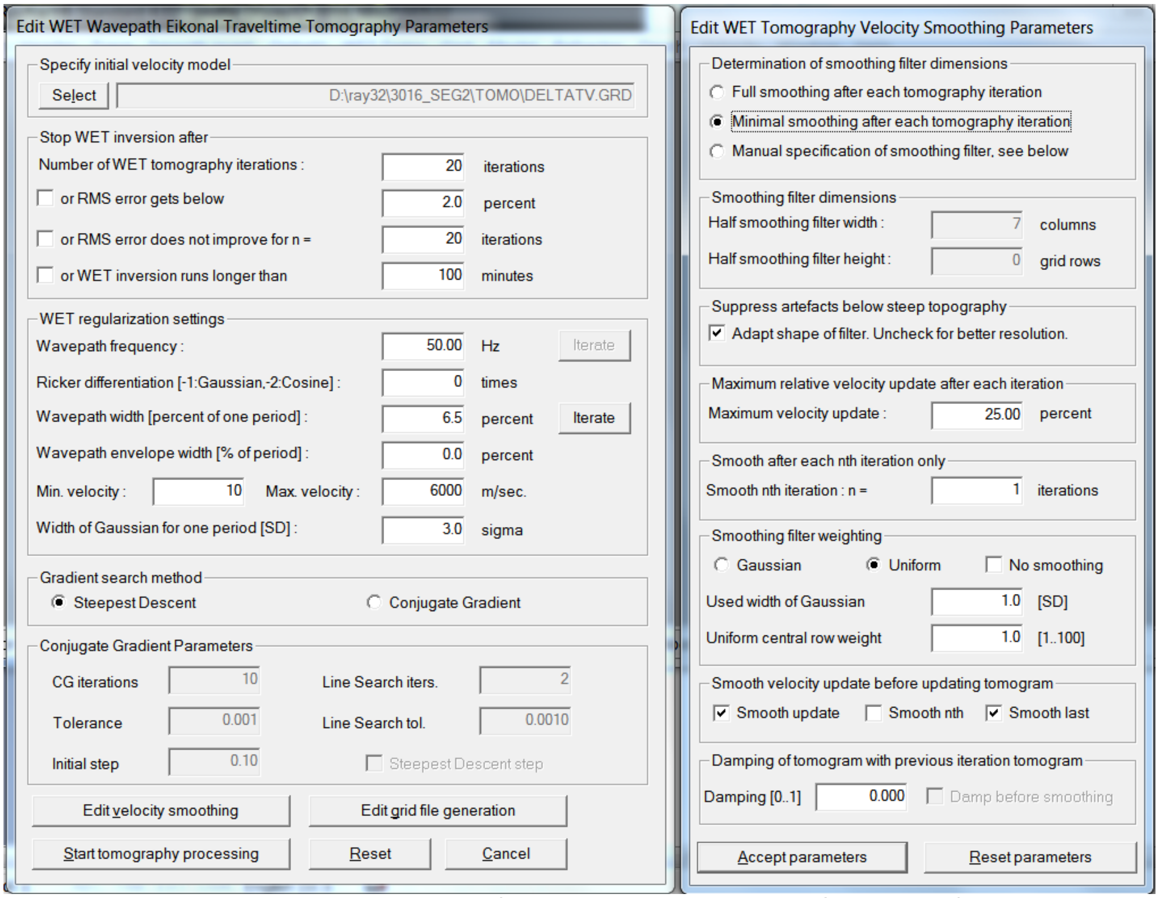
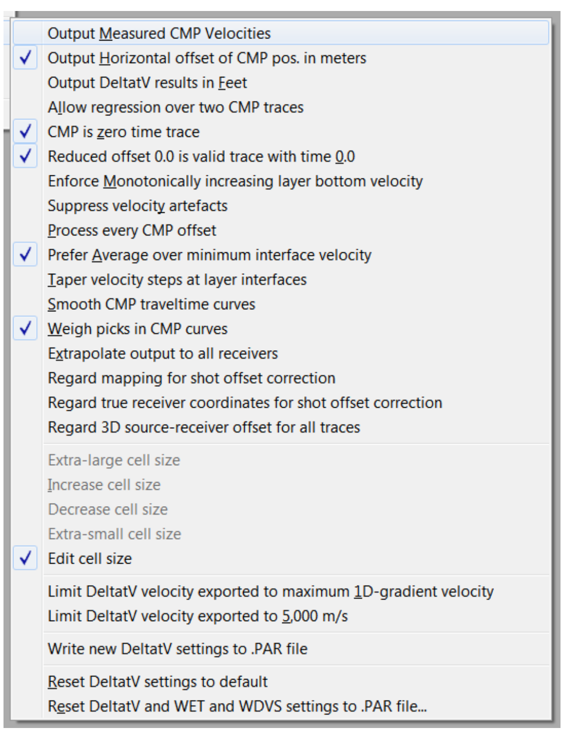


Fig. 25 : *WET Tomo|Interactive WET* main dialog (left). Edit velocity smoothing (right). Settings used for Fig. 23.



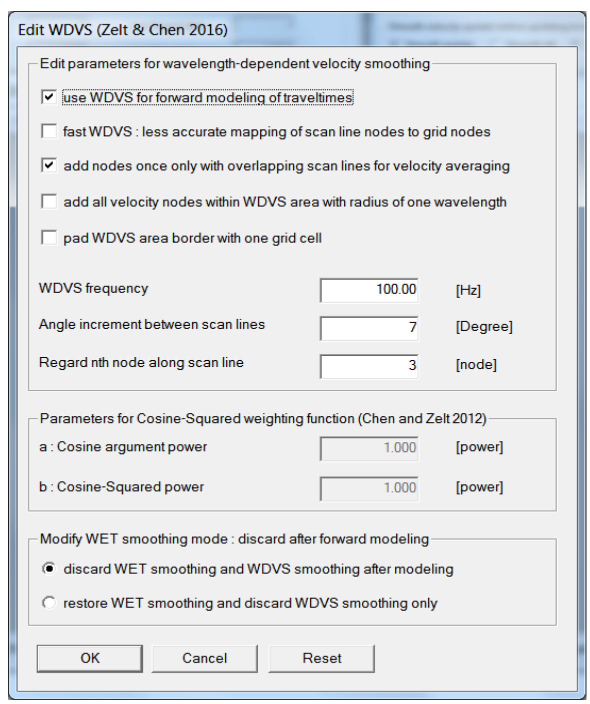


Fig. 26 : *DeltatV|DeltatV Settings* used for Fig. 22

Fig. 27 : *Model|WDVS Smoothing* settings for Fig. 23.

Note the further improved resolution in overburden of WET tomogram (Fig. 23) compared to Fig. 14 and Fig. 7 for both of which we used full WET smoothing and Ricker differentiation -1 (default settings for *Smooth invert, WET with 1D-gradient initial model*).

Also note the good match between DeltatV starting model (Fig. 22) and final WET tomogram (Fig. 23) using default DeltatV settings (Fig. 26).

The RMS error for DeltatV starting model (Fig. 22) is 2.9ms only while RMS error for default 1D-gradient starting model (Fig. 6) is 7.56ms, more than twice as high.

- to determine the RMS error of our DeltatV starting model select *Model|Forward model traveltimes*
- select **C:\RAY32\3016_SEG2\TOMO\DELTATV.GRD** and click *Open* button
- select *Grid|Image and contour velocity and coverage grids*
- again select **C:\RAY32\3016_SEG2\TOMO\DELTATV.GRD** and click *Open* button to obtain Fig. 22

As shown in Fig. 4 in our synthetic thrust fault zone tutorial our pseudo-2D *DeltatV inversion* can image local velocity inversions, with close enough shot and receiver spacing and favorable subsurface geology.

However in general and especially for short lines and with strong topography and/or with strong refractor curvature in overburden we recommend using our default 1D-gradient initial model for 2D WET inversion instead of using DeltatV starting model. See (Sheehan et al. 2005).

When you select *DeltatV menu* items *Automatic DeltatV* or *Interactive DeltatV* we warn you about pseudo-2D DeltatV artefacts and ask you to confirm if you want to continue anyway (Fig. 28).

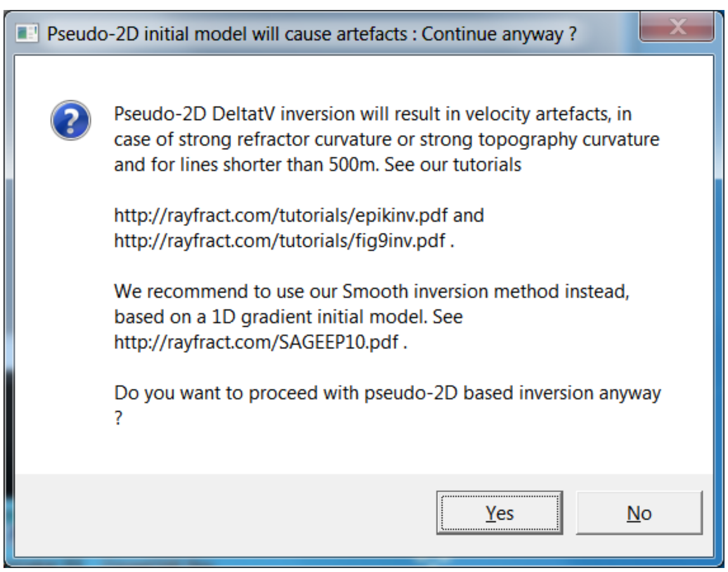


Fig. 28 : DeltatV artefacts warning prompt shown when selecting *DeltatV menu* items *Automatic DeltatV* or *Interactive DeltatV*.

Here is DropBox link to .RAR archive with seis32.* profile database files for Fig. 23.
Here is DropBox link to .RAR archive with TOMO folder files for Fig. 23.

For above seis32.* profile database we checked option *WET Tomo|WET tomography Settings|Write|Write blanked and mask grids and WDVS debug grids* so you can copy and image WDVSTIME.GRD files as described for Fig. 19. This does slow down WET inversion significantly.

Next we redo Fig. 23 with same parameters but using WET *wavepath frequency* of 30Hz instead of default 50Hz to obtain Fig. 29 :

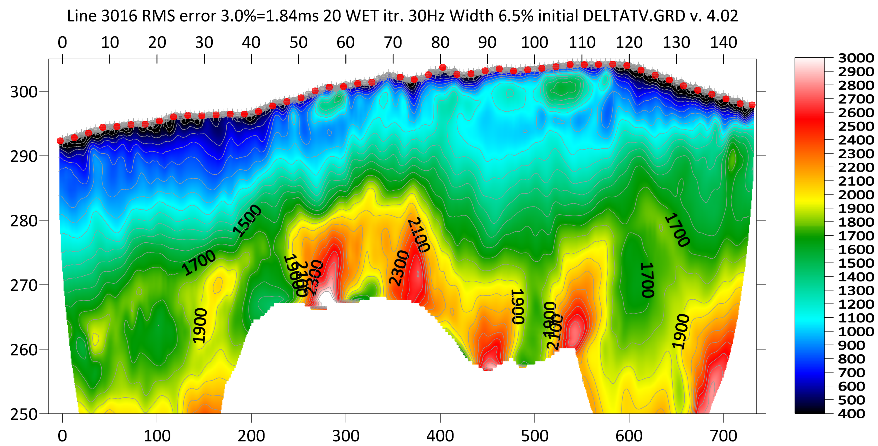


Fig 29 : same as Fig. 23 but decreased WET wavepath frequency to 30Hz from default 50Hz.

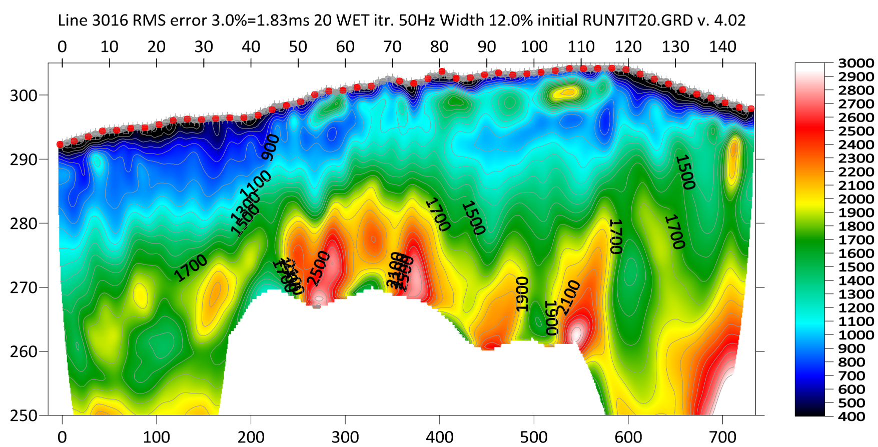


Fig. 30 : multirun Steepest-Descent WET. Manual WET smoothing. Half-width of WET smoothing filter is 10 columns (Fig. 38 and Fig. 39). Showing 8th WET run. DeltatV starting model for 1st WET run is Fig. 22. WDVS@100Hz (Fig. 27).

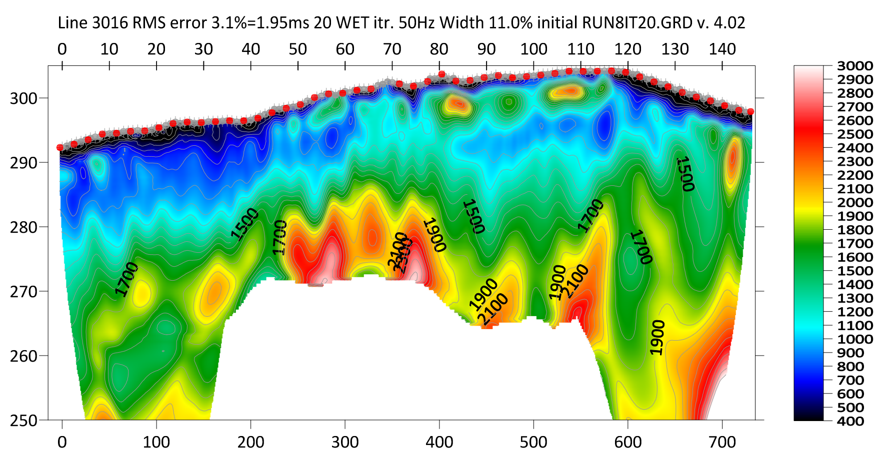


Fig. 31 : multirun Steepest-Descent WET. Manual WET smoothing. Half-width of WET smoothing filter is 10 columns (Fig. 38 and Fig. 39). Showing 9th WET run. DeltatV starting model for 1st WET run is Fig. 22. WDVS@100Hz (Fig. 27).

Compare Fig. 29 WET tomogram with Fig. 23. The low-velocity layer in overburden is imaged a bit less clearly in Fig. 29. But there are fewer vertical artefacts in Fig. 29 in overburden due to wider wavepaths. For Fig. 30 and Fig. 31 we increase lateral smoothing with half-width of *WET smoothing filter* set to 10 columns instead of default 7 grid columns for minimal WET smoothing.

Here is [DropBox link] to .RAR archive with seis32.* profile database files for Fig. 29.
Here is [DropBox link] to .RAR archive with TOMO folder files for Fig. 29.

Here is [DropBox link] to .RAR archive with seis32.* profile database files for Fig. 30 and Fig. 31.
Here is [DropBox link] to .RAR archive with TOMO folder files for Fig. 30 and Fig. 31.

Next we map traces to 2 refractors and 3 layers in *Refractor|Midpoint breaks* (Fig. 32) and run our *Plus-Minus refraction* method to obtain layered refraction starting model (Fig. 35).

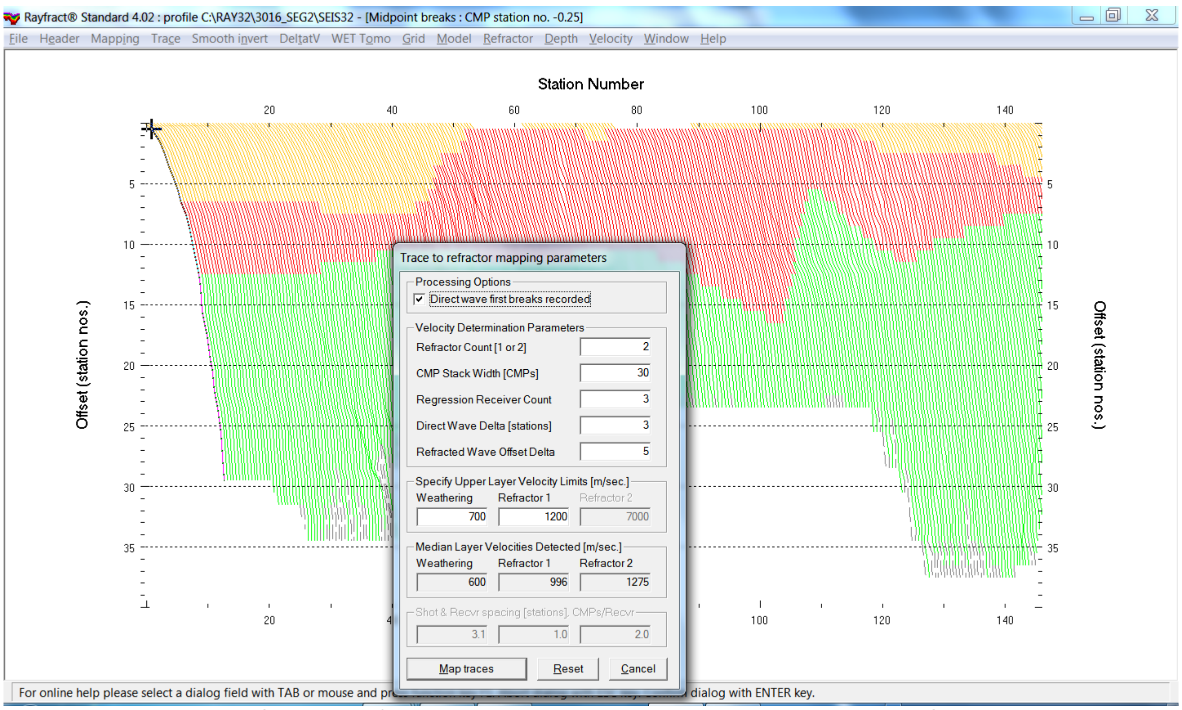
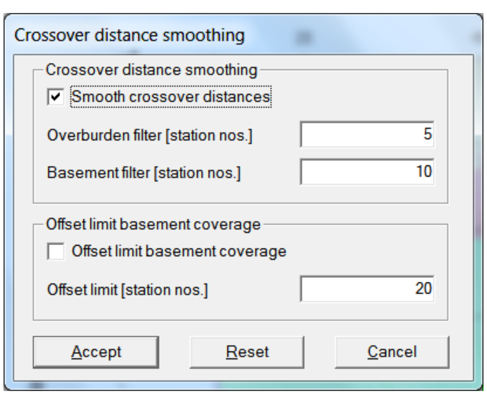


Fig. 32 : map traces to 2 refractor in *Refractor|Midpoint breaks*. Press ALT+M and edit as shown. Click *Map traces* button. Pess ALT+G to edit crossover distance smoothing dialog (Fig. 33).



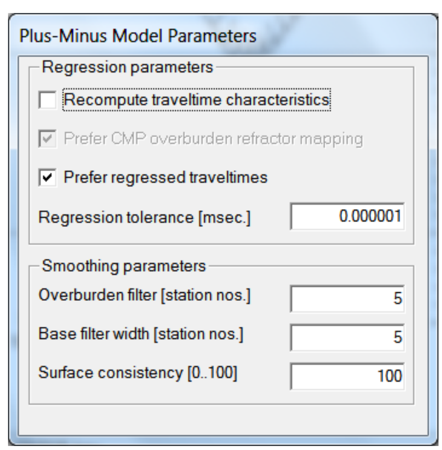


Fig. 33 : edit crossover distance smoothing parameters. Press ALT+G in *Refractor|Midpoint breaks* after mapping traces to refractors with ALT+M (Fig. 32).

Fig. 34 : edit Plus-Minus method parameters. Select *Depth|Plus-Minus*. When prompted to continue with WET click No. Reselect *Depth||Plus-Minus* and press ALT+M in Plus-Minus depth section window.

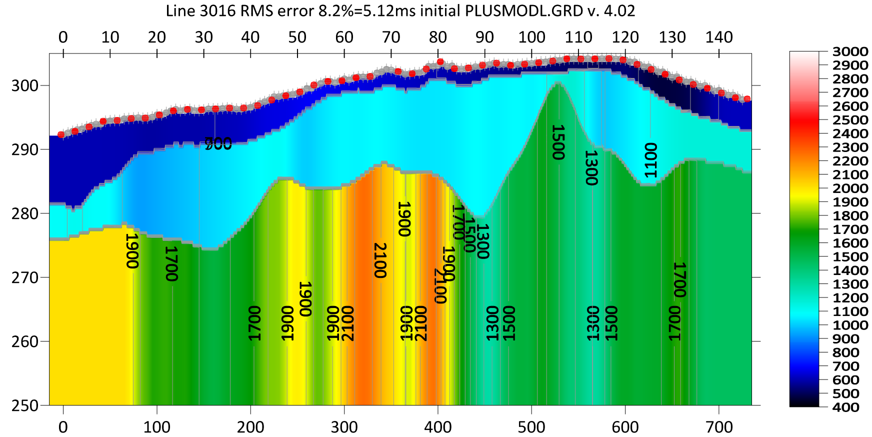


Fig. 35 : select *Depth|Plus-Minus* and click No button when prompted to continue with WET. Press ALT+M in *Plus-Minus depth section* window. Edit as in Fig. 34 and press ENTER key to obtain this Plus-Minus method layered refraction starting model.

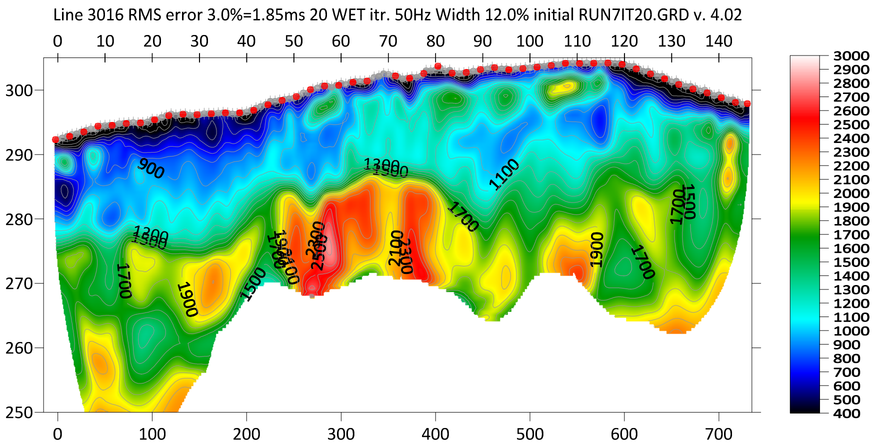


Fig. 36 : multirun Steepest-Descent WET. Manual WET smoothing. Half-width of WET smoothing filter is 10 columns (Fig. 38 and Fig. 39). Showing 8th WET run. Plus-Minus starting model for 1st WET run is Fig. 35. WDVS@100Hz (Fig. 27).

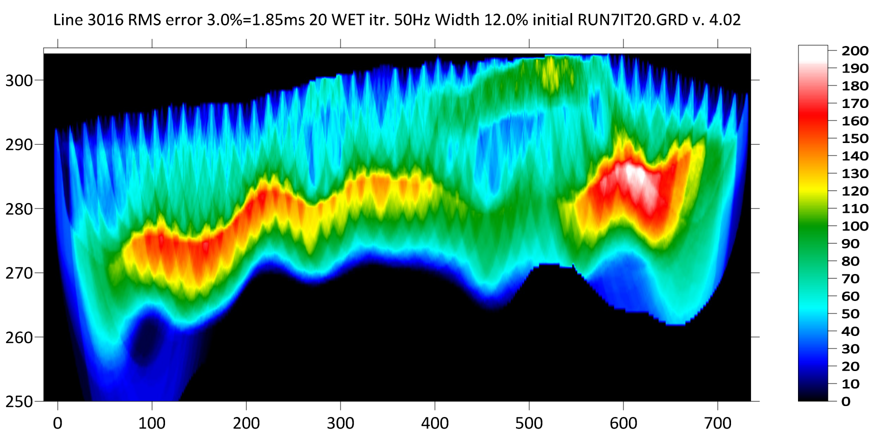


Fig. 37 : WET wavepath coverage plot obtained with Fig. 36. Unit is wavepaths per pixel.

Note the good match between Fig. 36 using Plus-Minus starting model and Fig. 30 using DeltatV starting model. Multiscale WET inversion output can be quite independent of the starting model.

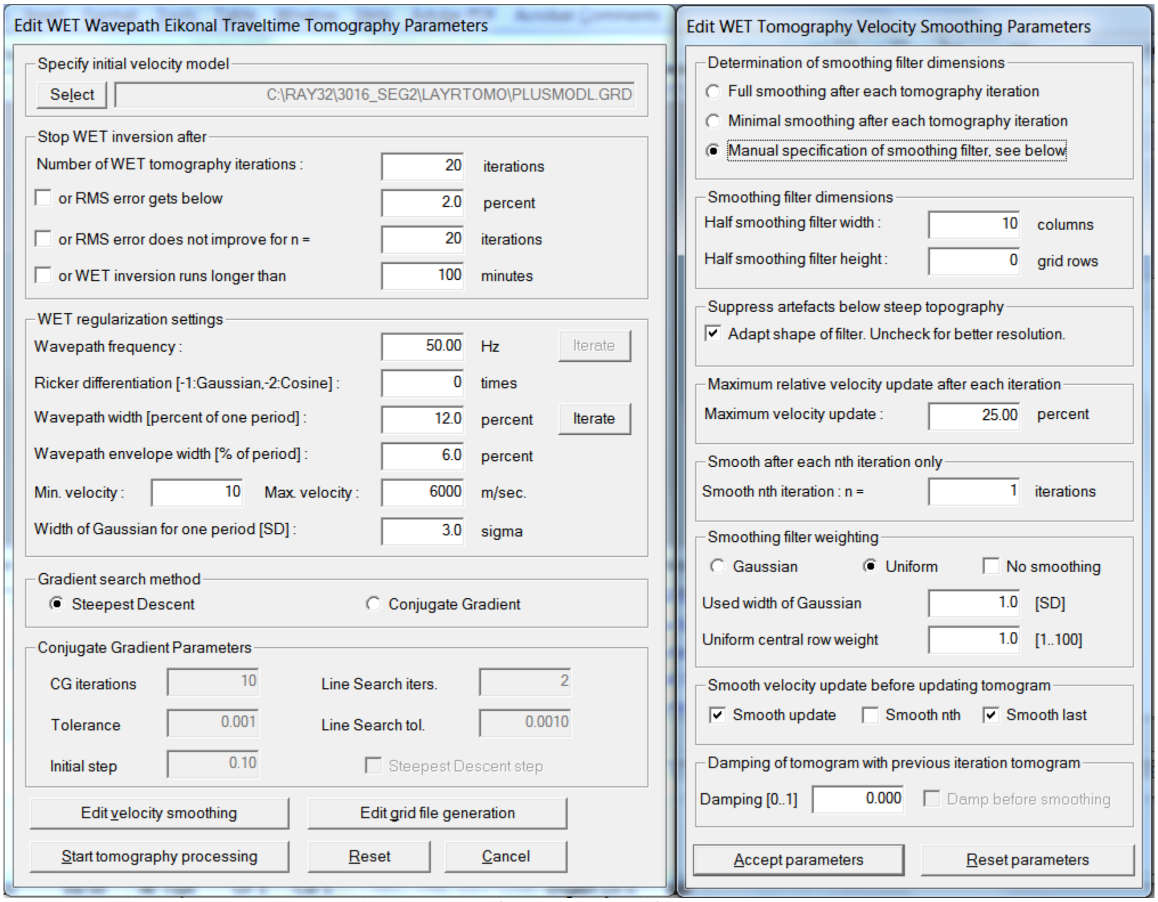


Fig. 38 : *WET Tomo|Interactive WET* main dialog (left) settings used for Fig. 36. *Edit velocity smoothing* (right).

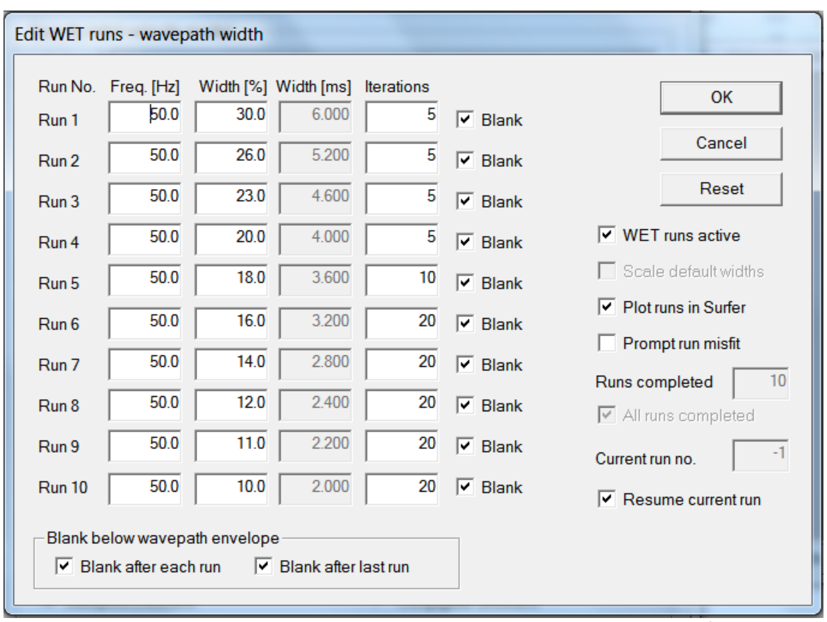


Fig. 39 : *WET Tomo|Interactive WET|Iterate*. Edit WET run schedule used for Fig. 36.

Here is [DropBox link] to .RAR archive with seis32.* profile database files for Fig. 36.
Here is [DropBox link] to .RAR archive with LAYRTOMO folder files for Fig. 36.

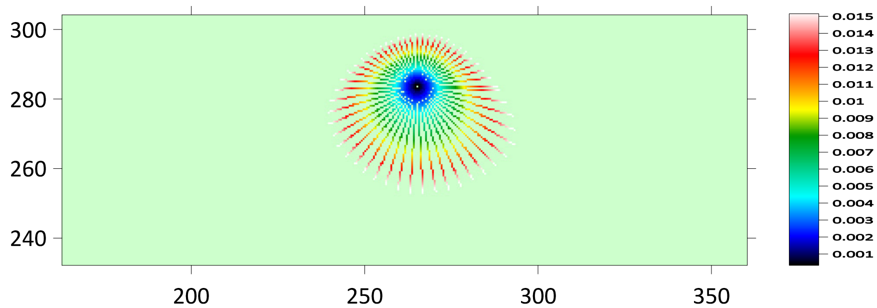


Fig. 40 : WDVSTIME.GRD with *WDVS frequency* set to 66Hz in *Model|WDVS Smoothing* dialog (Fig. 27). Unit is delay time in seconds along radial scan lines with origin at center of current WDVS area. See (Zelt and Chen 2016) Fig. 4 and equation (1).

In Fig. 40 we show another sample WDVSTIME.GRD obtained during WET inversion using DeltatV starting model (Fig. 29). We imaged this WDVSTIME.GRD using Surfer 23 as described below Fig. 19.

Note the asymmetry of the WDVS area in Fig. 40 determined by maximum delay time of 0.015 seconds (one period for *WDVS frequency* of 66Hz) along radial scan lines. This asymmetry is caused by decreasing grid velocity towards upper left of WDVS area compared to lower right of WDVS area. See Fig. 29 at elevation 285m and horizontal offset 260m. For WDVS theory see (Zelt and Chen 2016) Fig. 4 and equation (1).

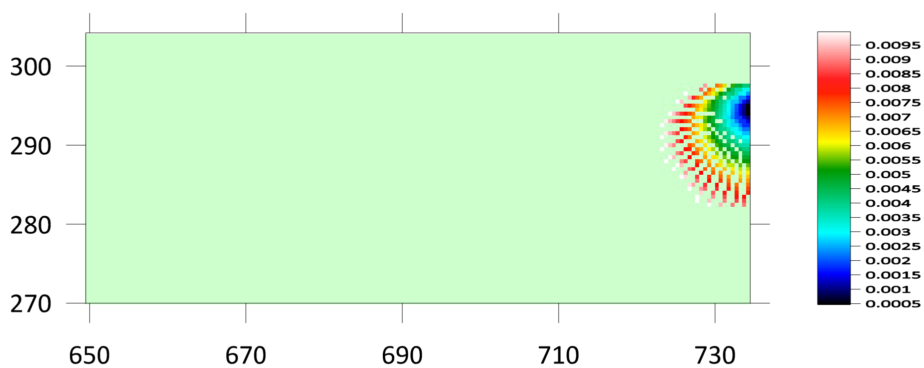


Fig. 41 : WDVSTIME.GRD with *WDVS frequency* set to 100Hz in *Model|WDVS Smoothing* dialog (Fig. 27). Unit is delay time in seconds along radial scan lines with origin at center of current WDVS area.

In Fig. 41 we show another sample WDVSTIME.GRD centered at elevation 295m and horizontal offset 734m with *WDVS frequency* set to 100Hz (Fig. 27). One period amounts to 0.010 seconds. Compare with Fig. 29 to explain the shape of the WDVS area.

In our experience WDVS smoothing can help to obtain better resolved WET tomograms using fewer WET iterations. Tuning of *WDVS frequency* and *WET smoothing* is subjective and trial-and-error based. See also our updated .pdf reference chapter *WDVS velocity smoothing* on page 167 and our SAGEEP 2021 and EGU 2021 publications.

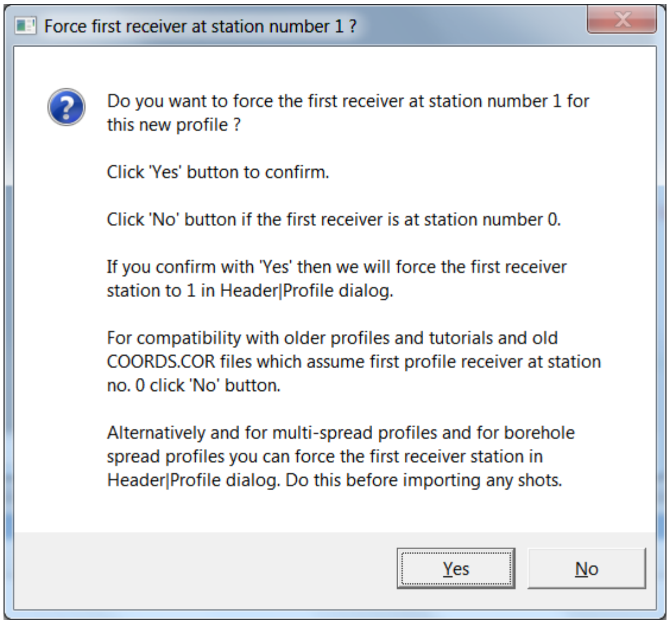


Fig. 42 : click No button to leave ***Profile start and first receiver station*** at station no. 0.

For compatibility with older profiles and tutorials and old COORDS.COR files which assume first profile receiver at station no. 0 click No button.