WET NGU P1-1D : Conjugate Gradient&Cosine-Squared WET update weighting 3.36 & DeltatV+XTV starting model / 1D-gradient starting model with topography smoothing over 2 stations & WDVS@1200Hz & discard WET smoothing & extrapolate tomograms 4.06 :

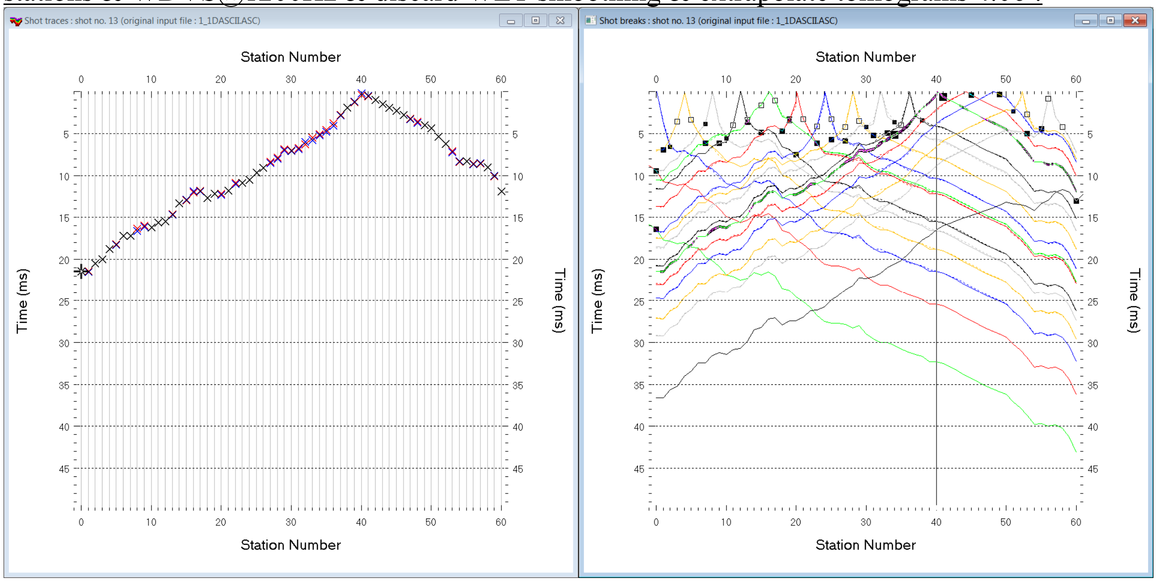

Fig. 1 : left : *Trace|Shot gather*, right : *Refractor|Shot breaks*. Shows fit between picked times (solid colored curves, red crosses) and modeled times (dashed colored curves, blue crosses) obtained for multirun WET output (Fig. 10)

To create the profile database, import the data and browse the imported shots do these steps :

- ***File|New Profile****…*, set *File name* to `1_1D` and click *Save button*
- in ***Header|Profile****…* set *Line type* to `Refraction spread/line` . Set *Station spacing* to 2.0 m.
- check *box Force grid cell size* and set *Cell size[m]* to 0.4m. See Fig. 2.
- unzip [`1_1D.zip`]() with files `1_1DASCII.ASC, 1_1DCOORDS.COR, 1_1DSHOTS.SHO & 1_1D.CLR` in directory `C:\RAY32\1_1D\INPUT`
- select ***File|Import Data****…* and set *Import data type* to `ASCII column format`. See Fig. 3.
- leave *Default spread type* at `10: 360 channels`
- click *Select button*, navigate into `C:\RAY32\1_1D\INPUT` and select file `1_1DASCII.ASC`
- set *Default sample count* to 500 to setup the y scale for *Trace|Shot gather* & *Refractor|Shot breaks*
- click ***Import shots button***. The *Import shot dialog* is shown for each shot in the `.ASC` file.
- for each shot leave *Layout start* and *Shot pos.* at shown values and click *Read button*
- select *File|Update header data|**Update Station Coordinates***
- navigate into directory `C:\RAY32\1_1D\INPUT`
- select file `1_1DCOORDS.COR` . Click *Open button*.
- *File|Update header data|**Update Shotpoint coordinates*** with `1_1DSHOTS.SHO`
- select *Trace|Shot gather* and *Window|Tile* to obtain Fig. 1

To configure and run DeltatV+XTV inversion and display the pseudo-2D starting model :

- uncheck *DeltatV|DeltatV Settings|Reduced offset 0.0 is valid trace with time 0.0*. See Fig. 12.
- check *DeltatV|DeltatV Settings|Suppress velocity artefacts*
- check *DeltatV|DeltatV Settings|Process every CMP offset*
- check *DeltatV|DeltatV Settings|Smooth CMP traveltime curves*
- select *DeltatV|XTV parameters*. Click buttons *Layer model* & *Accept*. See Fig. 14.
- select *DeltatV|Interactive DeltatV*. Confirm prompt and edit parameters as in Fig. 13.
- click button *DeltatV inversion*
- in dialog *Save DeltatV output* click yellow *Create new folder* icon at upper right

- name new folder as **Nov18Regr4**. Double-click this new folder to enter it.
- set *File name* to **Nov18Regr4**. Click *Save* button.
- wait for the *DeltatV+XTV inversion* to complete to obtain Fig. 8

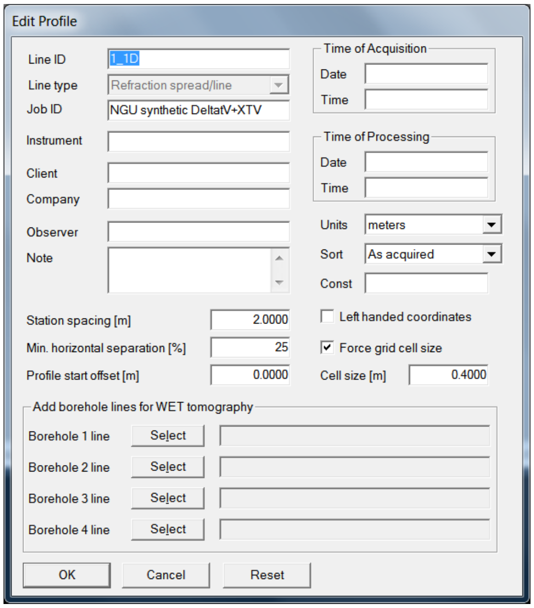

Fig. 2 : *Header|Profile*

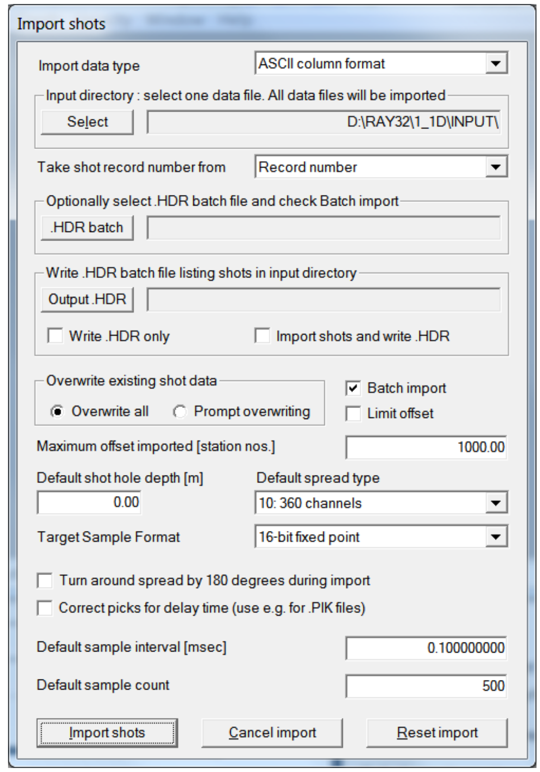

Fig. 3 : *File|Import Data*

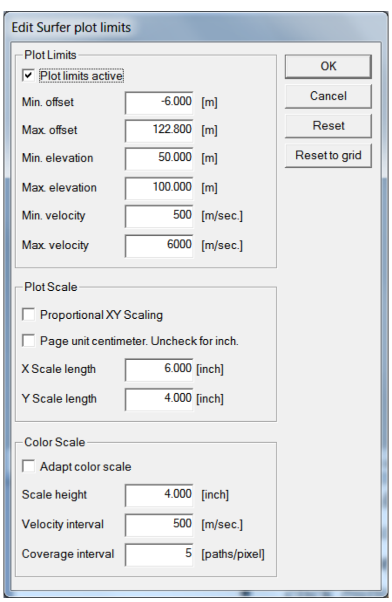

Fig. 4 : *Grid|Surfer plot Limits*

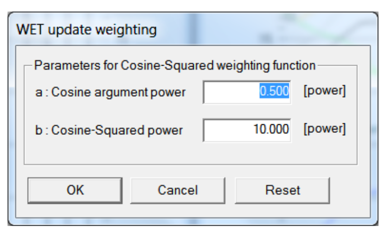

Fig. 5 : *WET Tomo|WET Update weighting*

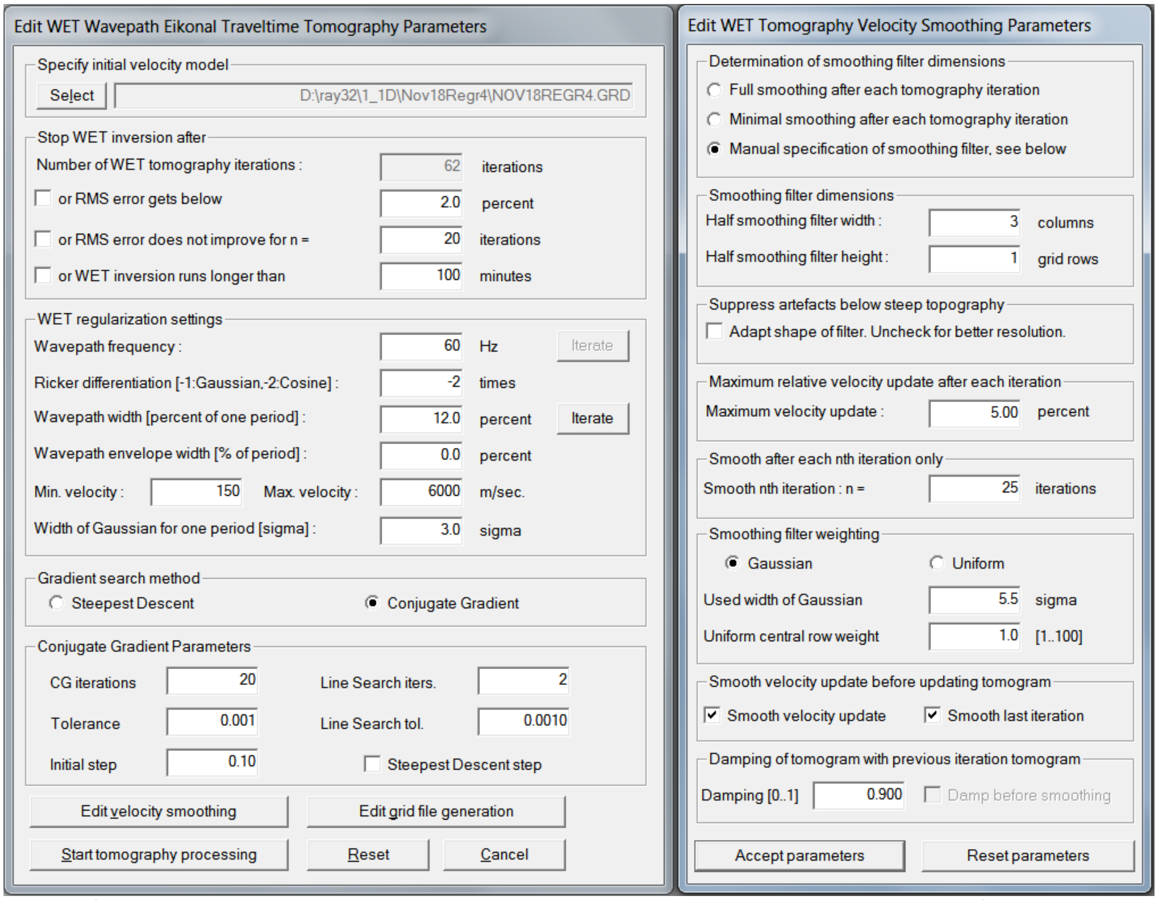

Fig. 6 : left : *WET Tomo|Interactive WET tomography* right : *Edit velocity smoothing* . See also Fig. 16 .

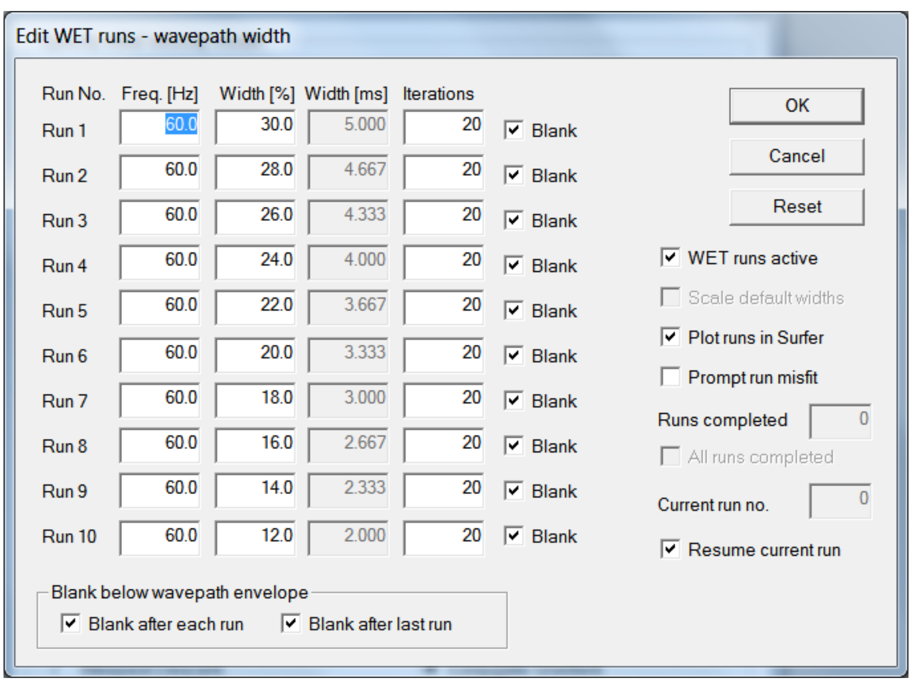

Fig. 7 : *WET Tomo|Interactive WET tomography|Iterate* lets you edit the multirun *WET wavepath width* or *WET frequency* schedule. Also lets you edit the number of *WET iterations* for each run (effective for *Steepest Descent* only) and blanking after each run. For *Conjugate Gradient* the number of WET iterations is determined with controls *CG iterations* (outer loop) and *Line Search iters.* (inner loop; Shewchuk 1994).

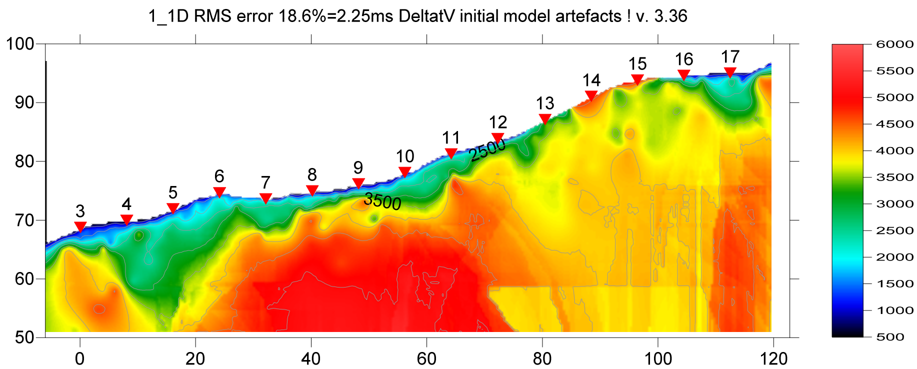

Fig. 8 : *DeltatV|Interactive DeltatV* output. See Fig. 12&13&14 for *DeltatV Settings & parameters* and *XTV parameters*.

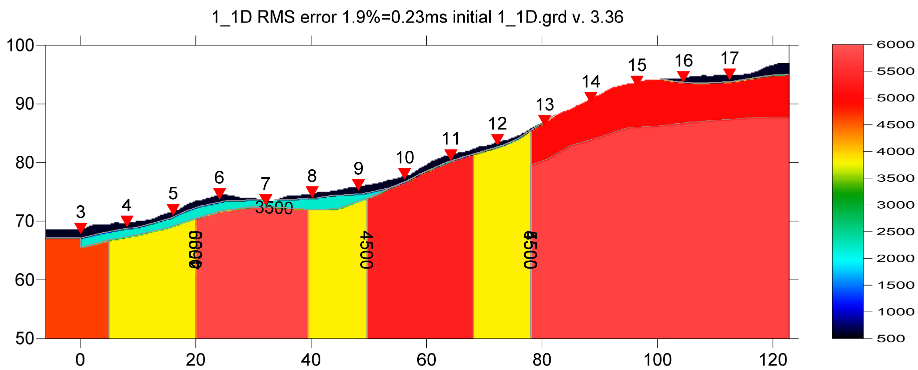

Fig. 9 : true model for line 1_1D built by NGU and used for synthetic shots (Fig. 1) forward modeled by NGU. See ...**\MODEL** subdirectory in [.RAR archive]() for Surfer **.GRD** file.

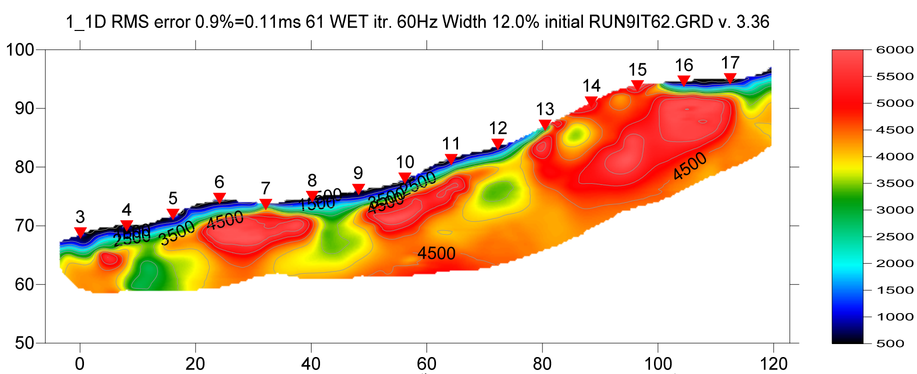

Fig. 10 : Multirun WET showing output of 10th run. Starting model for 1st run is Fig. 8. See Fig. 1 for misfit between modeled and picked traveltimes.

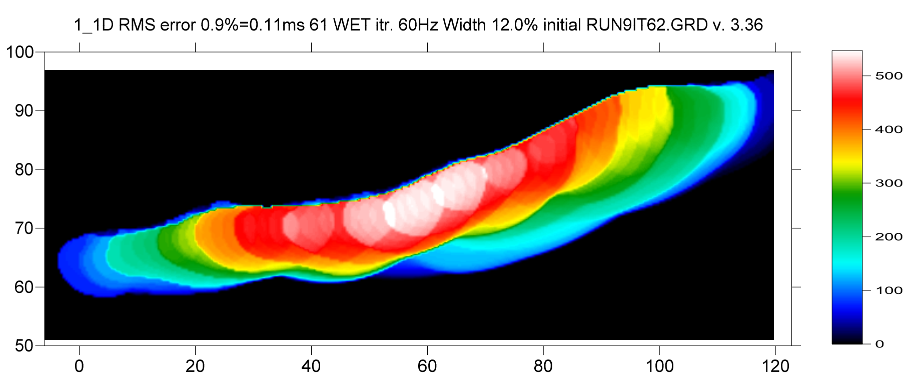

Fig. 11 : WET wavepath coverage plot obtained with Fig. 10. Unit is wavepaths per pixel.

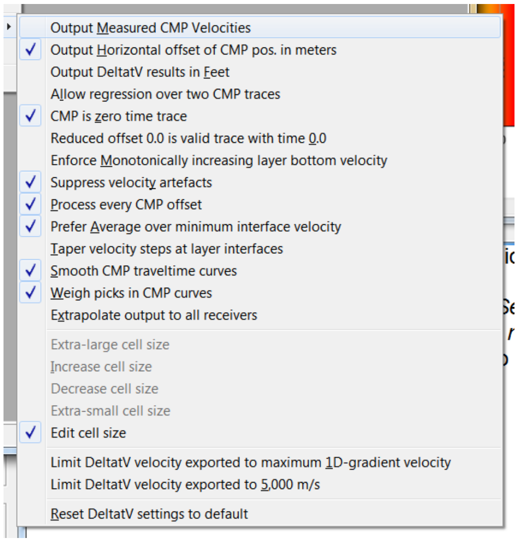

Fig. 12 : *DeltatV|DeltatV Settings*. Check *Suppress velocity artefacts* to enforce continuous CMP sorted traveltime curves and filter out bad picks from traveltime curves.

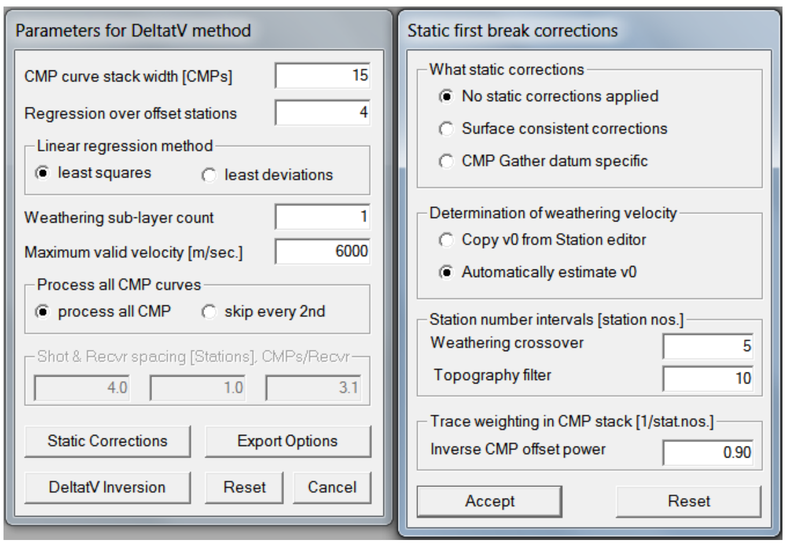

Fig. 13 : edit parameters in dialog *DeltatV|Interactive DeltatV* (left). Click button *Static Corrections* to edit more parameters (right). Check radio button *No static corrections applied* to completely disable static corrections. Increase *Inverse CMP offset power* from default 0.5 to 0.9 to give more weight to central CMP curve when stacking CMP curves. This increases the lateral resolution. Decreasing *Inverse CMP offset power* increases lateral smoothing.

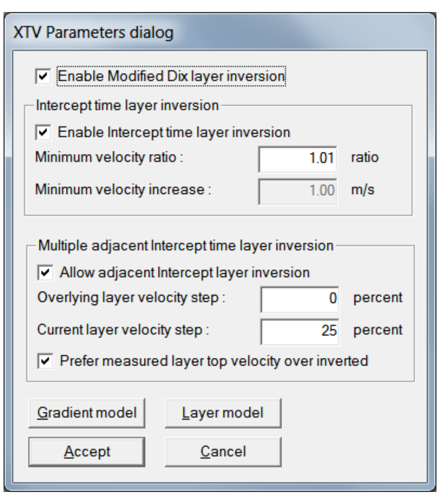

Fig 14 : edit *XTV parameters*. Click button *Layer model* and button *Accept*.

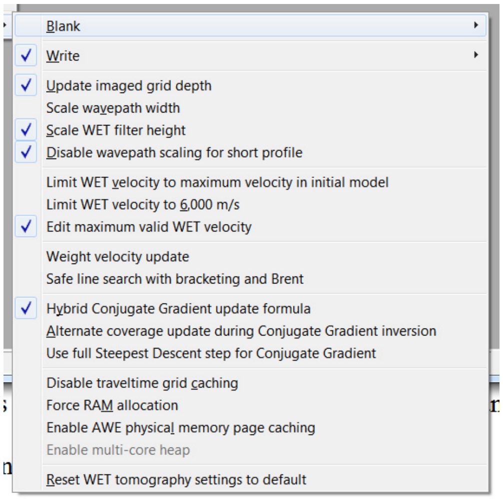

Fig. 15 : edit menu *WET Tomo|WET tomography Settings*

To configure and run WET inversion and display 2D inversion output :

- select *Grid|Surfer plot Limits.* Click *button Reset to grid*. Navigate into profile subdirectory **`C:\RAY32\1_1D\Nov18Regr4`**. Click on **`Nov18Regr4.GRD`** and click *Open*.
- check *box* ***Plot limits active***. Set *Min. elevation* to 50m. Set *Max. elevation* to 100m. See Fig. 4.
- set *Min. velocity* to 500 m/s and *Max. velocity* to 6,000 m/s. Click *OK*.
- *Grid|Image and contour velocity and coverage grids* & …**`\model\1_1D.grd`** to obtain Fig. 9
- check *WET Tomo|WET tomography Settings|Blank no coverage after last iteration*.
- uncheck *WET Tomo|WET tomography Settings|Blank below envelope after last iteration*
- uncheck *WET Tomo|WET tomography Settings|Scale wavepath width*. See Fig. 15.
- check *WET Tomo|WET tomography Settings|Scale WET filter height*
- check *WET Tomo|WET tomography Settings|Edit maximum valid WET velocity*
- in *WET Tomo|WET velocity update* set *a* to 0.5 and *b* to 10.0. Click *OK*. See Fig. 5.
- set *WET Tomo|Interactive WET tomography|**Ricker differentiation*** to -2 [Cosine-Squared]
- set *Min. velocity* to 150 m/s & *Max. velocity* to 6,000 m/s. See Fig. 6 (left).
- click radio button ***Conjugate Gradient***
- set *CG iterations* (outer loop) to 20 and *Line Search iters.* (inner loop) to 2. See Shewchuk 1994 .
- click button *Edit grid file generation* & set *Store each nth iteration only : n =* to 20. Click *OK*.
- click ***Edit velocity smoothing***. Check ***Manual specification of smoothing filter*** . See Fig. 6 (right).
- set ***Half smoothing filter width*** to 3 columns & set ***Half smoothing filter height*** to 1 rows
- uncheck ***Adapt shape of filter***. Set ***Maximum velocity update*** to 5% .
- set ***Smooth nth iteration : n =*** to 25 .
- click ***Gaussian*** *button*. Set *Used width of Gaussian* to 5.5 sigma
- in latest version 3.36 click box ***No smoothing*** to completely disable WET smoothing. See Fig. 16 .
- leave ***Damping*** at default 0.9 for Conjugate-Gradient method
- click ***Accept parameters*** and ***Iterate*** & check ***WET runs active***. Edit as in Fig. 7 and click ***button OK***.
- click *button* ***Start tomography processing*** to obtain Fig. 10 & 11
- in Surfer 16 click on *menu View*. Check *Properties check box*.
- in Surfer 16 click on *Custom colormap* button to right of *Colors label*. Click on *Load button*. Navigate into **`C:\RAY32\1_1D\INPUT`** and select **`1_1D.CLR`** . Click *Open&Apply&OK buttons*.

Here some references to help file chapters and other relevant tutorials :

- for our ***multiscale WET*** inversion see updated help file chapter ***WET tomography processing***
- see also our SAGEEP11 tutorial showing ***Conjugate Gradient WET*** inversion using 1D-gradient initial model for SAGEEP11 synthetic data forward-modeled over fault zone model

- see also our [2017 tutorial] showing ***Steepest Descent WET inversion*** using Plus-Minus layered refraction starting model for [NGU 2017] P1_1 synthetic data

To restore database files and result files :

Subdirectories **`C:\RAY32\1_1D\Nov18Regr4\WETRUN1`** to **`…\WETRUN10`**, **`…\INPUT`**, **`…\MODEL`** and **`…\seis32_Nov18Regr4`** are available in this [.RAR archive]. Open the **`…\WETRUN10\VELOIT62.PAR`** file e.g. with Windows Notepad editor to review *WET inversion* parameters used.

Use Rayfract® 3.36 command ***Grid|Reset DeltatV and WET settings to .PAR file…*** with file **`…\Nov18Regr4\WETRUN10\VELOIT62.GRD`** to reset your profile's *DeltatV and WET inversion settings* to **`…\Nov18Regr4\WETRUN10\VELOIT62.PAR`** .

Or quit our software via ***File|Exit*** and copy all 33 **`seis32.*`** database files from directory **`C:\RAY32\1_1D\seis32_Nov18Regr4`** into **`C:\RAY32\1_1D`** directory in Windows Explorer. Now reopen your profile with ***File|Open Profile…*** and **`C:\RAY32\1_1D\SEIS32.DBD`** .

Summary, optimization of interpretation parameters :

NGU 2018 report with Fig. 4.5.1 showing *multirun WET inversion* of above synthetic model data is available at http://www.ngu.no/upload/Publikasjoner/Rapporter/2018/2018_015.pdf . In above Fig. 6 & Fig. 7 we further improve our WET inversion settings compared to settings used for Fig. 4.5.1.

WET inversion shown in Fig. 10 using 10 WET runs with 20 Conjugate-Gradient iterations each and parameters shown in Fig. 6 and Fig. 7 took about 4 minutes on 2017 Apple iMac. This iMac comes with 2.3 GHz Intel Core i5 processor running 4 OpenMP threads under Windows 10 Pro 64-bit in Parallels Desktop 14 for Mac.

- the first interpretation attempt in Fig. 4.2.1 of above report apparently used too much *WET smoothing* e.g. ***Used width of Gaussian*** 3.0 sigma instead of our 5.5 sigma. This contributes to the horizontal smearing artefacts.
- in Fig. 4.2.1 ***WET damping*** was reset to 0.0. We use default damping setting for *Conjugate Gradient* of 0.9. The higher the damping the less need to smooth for *Conjugate Gradient* method. *WET smoothing* can destroy the tomogram resolution so WET smoothing needs to be minimized.
- we decrease ***WET wavepath width*** from 30% to 12% over 10 runs. In Fig. 4.2.1 *WET wavepath width* is decreased from 30% to 21% only. This probably also contributes to horizontal smearing artefacts. Per default wavepath width is decreased from 30% to 6% over 10 WET runs.
- we uncheck *WET smoothing* option ***Adapt shape of filter*** for better resolution
- we limit ***Maximum velocity update*** to 5% while in Fig. 4.2.1 *Maximum velocity update* is set to 15%. Limiting the maximum velocity update can help to better focus *WET inversion* especially with strong topography curvature.
- in Fig. 4.2.1 31 *WET iterations* per *WET run* are used. We use 62 WET iterations per WET run by increasing ***CG iterations*** from default 10 to 20.
- in Fig. 4.2.1 ***Smooth nth iteration: n=*** is set to 10 while we set this to 25 resulting in less smoothing and less smearing artefacts
- in Fig. 4.2.1 minimum/maximum ***WET velocity*** is limited to range 500 m/s .. 6,000 m/s. We extend this velocity range to 150 m/s .. 6,000 m/s. This helps WET to more easily find a good solution by allowing WET to explore a larger solution space.
- we uncheck option *WET Tomo|WET tomography Settings|Scale wavepath width* to prevent near-surface velocity artefacts in the tomogram (unrealistic low-velocity anomalies below strong topography curvature) and to obtain more realistic imaging at tomogram bottom i.e. less horizontal smearing
- unchecking *WET smoothing* option ***Smooth velocity update*** can help to better focus WET inversion
- we have added a new check box ***No smoothing*** to our *WET Tomo|Interactive WET tomography|Edit WET smoothing* dialog in version 3.36 of our Rayfract® software. See below in Fig. 16. This option makes it easier to completely disable WET smoothing. Enabled *No smoothing* option overrides all other parameters in *Edit velocity smoothing* dialog except *Maximum velocity update* and *Damping*.

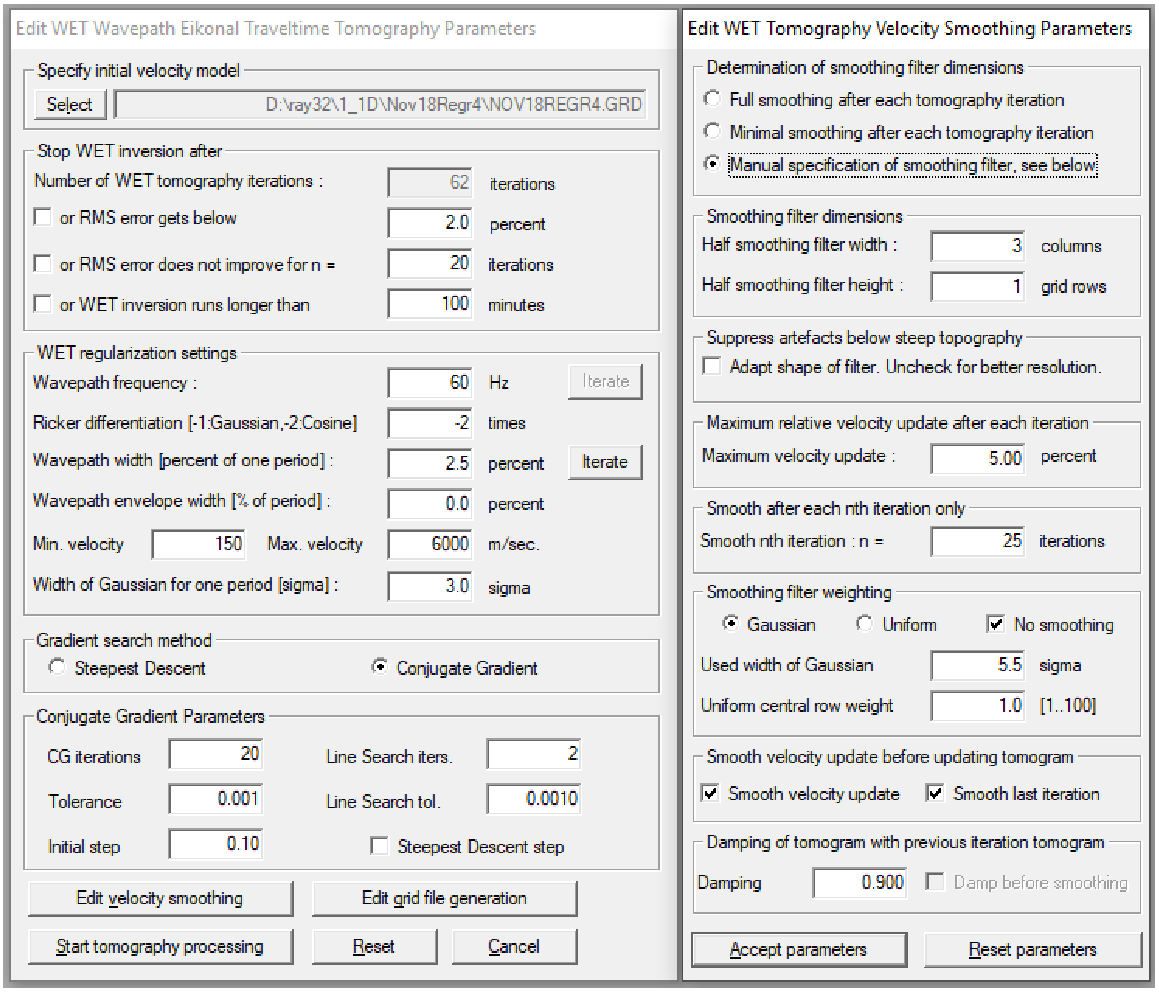

Fig. 16 : *WET Tomo|Interactive WET tomography|Edit velocity smoothing* (right) offers new option ***No smoothing***. Check this box to completely disable smoothing during WET inversion. Enabled *No smoothing* option overrides all other parameters in *Edit velocity smoothing* dialog (right) except *Maximum velocity update* and *Damping*.

When forward modeling traveltimes over ...**\MODEL\1_1D.GRD** with our *Model|Forward model traveltimes*... we obtain an RMS error of 0.23 ms (Fig. 9). Ideally this error should be 0.0 ms when using the same grid cell size and Eikonal solver as NGU used for generating the **1_1DASCII.ASC** synthetic shots. We use the Eikonal solver and "active point process" as described by Lecomte et al. 2001 in Fig. 3.

DeltatV ***apparent velocity*** pseudo-sections can be compared to ER ***apparent resistivity*** pseudo-sections. See e.g. https://pages.mtu.edu/~ctyoung/LOKENOTE.PDF chapter 2.3 on page 8. Quote :

"The pseudosection is useful as a means to present the measured apparent resistivity values in a pictorial form, and as an initial guide for further quantitative interpretation. One common mistake made is to try to use the pseudosection as a final picture of the true subsurface resistivity." quoted from page 8 of LOKENOTE.pdf .

For processing of lines longer than the recommended minimum of 500m with our *DeltatV* method see OT0608.pdf & GEOXMERC.pdf . DeltatV and *Smooth inversion* using ***1D-gradient starting model*** obtained by laterally averaging DeltatV match each other nicely as shown in these .pdf tutorials.

On the following page we show multiscale Conjugate-Gradient WET inversion using our default 1D-gradient starting model obtained with ***Smooth invert|WET with 1D-gradient initial model*** command.

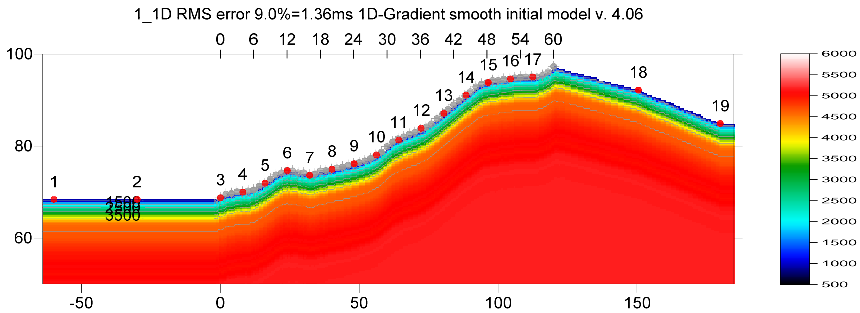

Fig. 17 : fail-safe laterally averaged 1D-gradient starting model obtained with ***Smooth invert|WET with 1D-gradient initial model***. The DeltatV 1D velocity profiles are laterally averaged (Sheehan 2005). Force topography smoothing over 2 stations (Fig. 21). Surfer plot limits as in Fig 24. Extrapolate starting models and tomograms over 32 stations in *Header|Profile* (Fig. 25). Red dots are shot points. Grey dots are receivers.

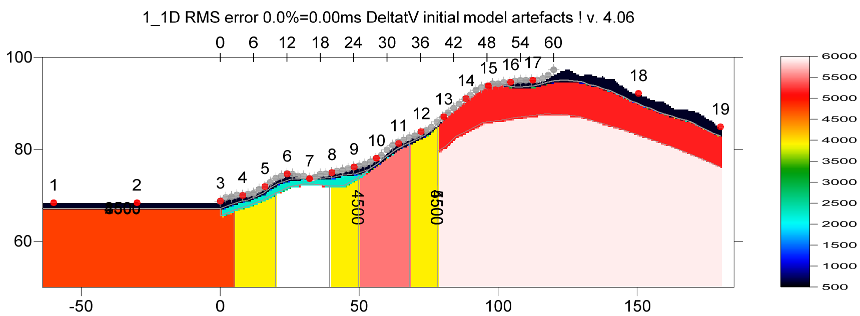

Fig. 18 : True model built and made available by NGU. Surfer plot limits as in Fig 24.

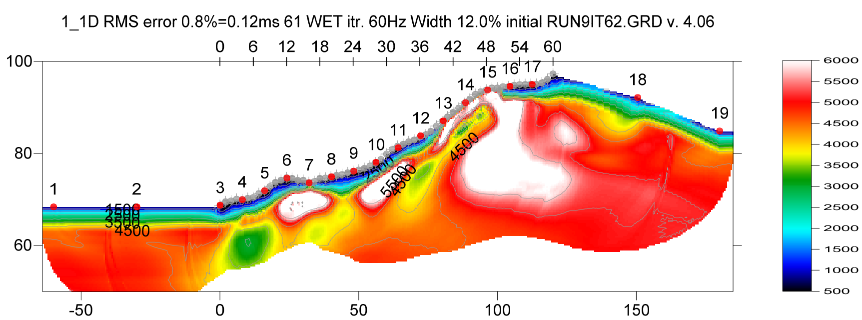

Fig. 19 : multiscale Conjugate-Gradient WET inversion. Output of 10th WET run shown. Starting model for first run is 1D-gradient initial model shown in Fig. 17. WDVS enabled at 1200Hz. Discard WET smoothing after forward modeling (Fig. 22). 10 Conjugate-Gradient WET runs with 20 Conjugate-Gradient iterations per run. Ricker differentiation -2 : Cosine-Squared WET update weighting. Minimized WET smoothing (Fig. 23). Surfer plot limits as in Fig 24.

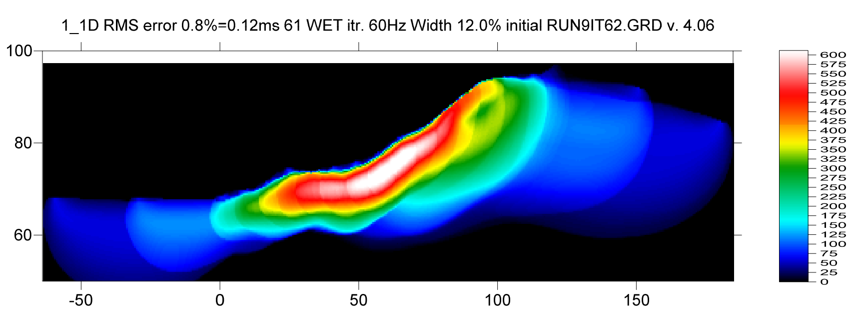

Fig. 20 : WET wavepath coverage plot obtained with Fig. 19. Unit is wavepaths per pixel.

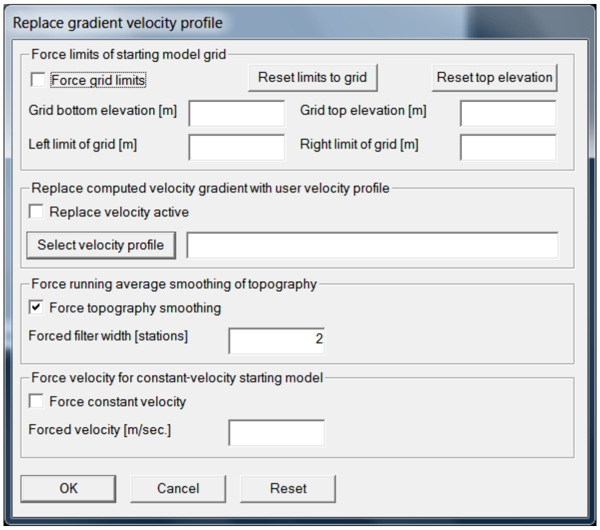

Fig. 21 : ***Smooth invert|Custom 1D-gradient velocity profile*** . Force topography smoothing over 2 stations.

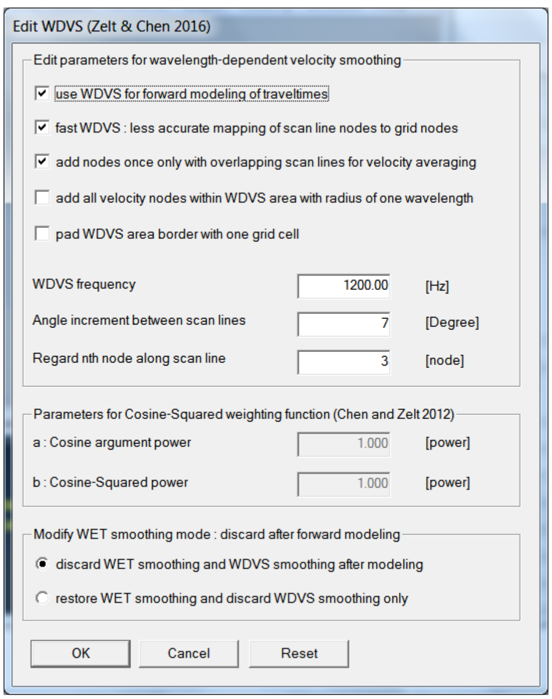

Fig. 22 : ***Model|WDVS Smoothing***. Enable WDVS@1200Hz. Discard WET smoothing and WDVS smoothing after forward modeling.

Here is the DropBox link to .RAR archive with profile database files for Fig. 19 :
https://www.dropbox.com/scl/fi/rcfsexvls2o8s6qa71vov/seis32_Feb13_2024_CGWET.rar?rlkey=tcg0svi4sy7poiqzqorhhymmm&dl=0

Here is the DropBox link to .RAR archive with GRADTOMO subdirectory obtained with Fig. 19 :
https://www.dropbox.com/scl/fi/ll4mcuqm0c1pfq5umhjdr/1_1D_GradTomo_CGWET_WDVS-1200Hz_Feb13_2024.rar?rlkey=4spmve73unfhvyowachig45f6&dl=0

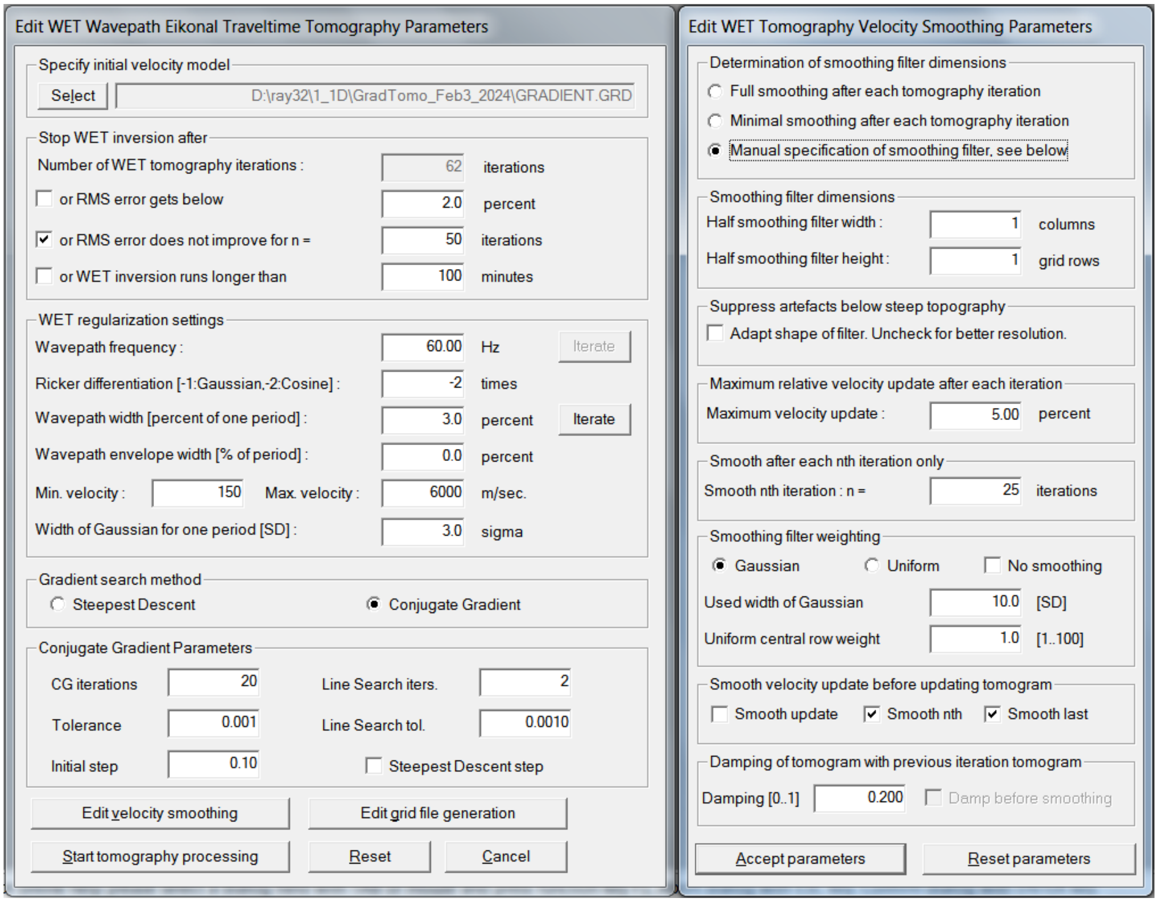

Fig. 23 : ***WET Tomo|Interactive WET*** main dialog (left). Edit velocity smoothing (right).

As shown by (Watanabe 1999, Fig. 4) for crosshole surveys, it is not possible to reliably image seismic subsurface velocity at a resolution much smaller than one wavelength of dominant frequency of the first break pulse. E.g. with 100 Hz and basement velocity of 4,000 m/s, one wavelength is 4000/100 = 40m. In case of bad or noisy picks and recording geometry errors, resolution may not be better than two wavelengths. For refraction surveys, resolution at bottom and edges of tomogram is further reduced, because here rays and wavepaths are aligned predominantly parallel to each other (White 1989). In our above tutorial we are imaging fault zones not wider than 10m @ 4,000 m/s. This is far below one wavelength of 40m @ 100 Hz.

Our Rayfract® software offers multiple interpretation methods and parameters to explore the non-uniqueness of the solution space. It is the user's job to sufficiently explore the solution space with our methods and varying parameters, and to find an appropriate combination of methods and parameters for each individual data set. This choice may be guided by a-priori information e.g. from boreholes or other geophysical methods.

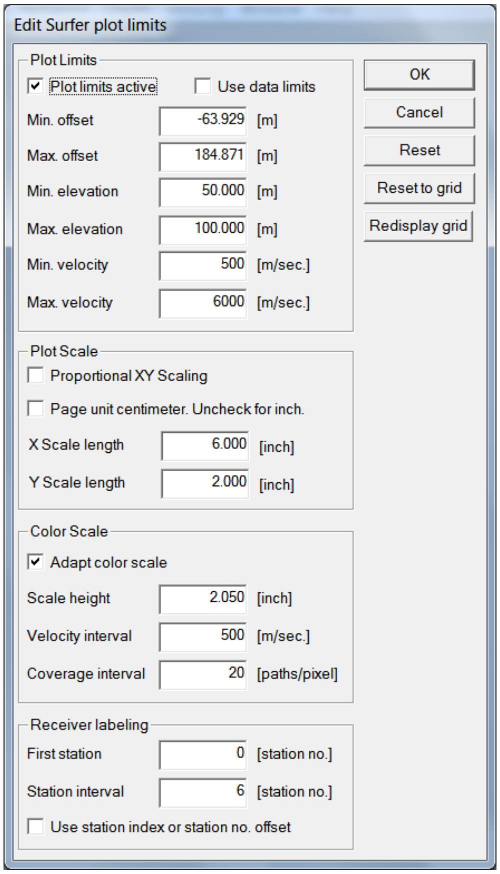

Fig. 24 : ***Grid|Surfer plot Limits***

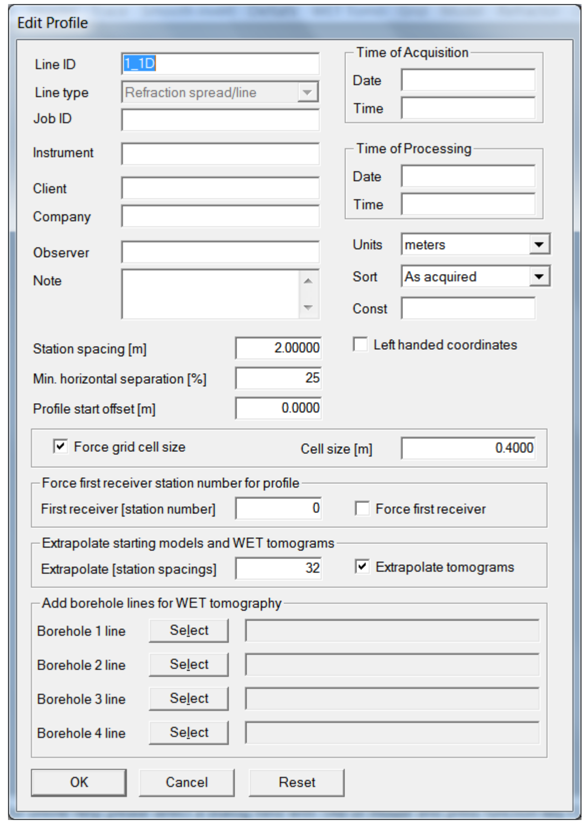

Fig. 25 : ***Header|Profile*** : extrapolate starting models and WET tomograms

We thank Dr. Georgios Tassis for making available above NGU 2018 report and synthetic data & models.

For an objective comparison of tomographic refraction analysis methods see Zelt et al. 2013 (JEEG, September 2013, Volume 18, Issue 3, pp. 183–194).

For an overview of our WDVS (Wavelength-Dependent Velocity Smoothing; Zelt and Chen 2016) see these publications :

Zelt, C. A. and J. Chen 2016. Frequency-dependent traveltime tomography for near-surface seismic refraction data, Geophys. J. Int., 207, 72-88, 2016. See https://dx.doi.org/10.1093/gji/ggw269 and https://www.researchgate.net/publication/305487180_Frequency-dependent_traveltime_tomography_for_near-surface_seismic_refraction_data .

Rohdewald S.R.C. 2021a. Improving the resolution of Fresnel volume tomography with wavelength-dependent velocity smoothing, Symposium on the Application of Geophysics to Engineering and Environmental Problems Proceedings : 305-308. https://doi.org/10.4133/sageep.33-169 . Slides at https://rayfract.com/pub/SAGEEP%202021%20slides.pdf

Rohdewald S.R.C. 2021b. Improved interpretation of SAGEEP 2011 blind refraction data using Frequency-Dependent Traveltime Tomography, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-4214, https://doi.org/10.5194/egusphere-egu21-4214

<u>For an objective comparison of tomographic refraction analysis methods see these publications :</u>

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