

JOANNEUM OT0608 refraction line : Smooth inversion vs. 1.5D XTV inversion :





OT0608 test, Delta-t-V initial model artefacts !!!, RMS error 3.5 %, Version 3.21

Fig. 2 : XTV inversion OT0608, with Rayfract® version 3.20 . CMP stack width 150, Inverse CMP offset power 0.20, Surface-consistent static corrections. Enabled Dix inversion, Intercept-time inversion in addition to DeltatV inversion for gradient layers. See http://rayfract.com/xtv_inversion.pdf . For all parameter settings see XTV .par file in ot0608.zip .

We thank Dr. Grassl, JOANNEUM RESEARCH Forschungsges.mbH, Austria, for making available this dense and consistently picked data set, with 275 shots into 200 or more channels. For .ASC, .COR and .SHO files see ot0608.zip . Process as gs0801.pdf. Set Station spacing to 3m in Header Profile, then import .ASC, and update with .COR and .SHO.

See Fig. 3 for 1D initial model, obtained during Smooth inversion and resulting in Fig. 1. Fig. 4 shows WET wavepath coverage, also obtained with Smooth inversion and Fig. 1.





OT0608 wavepath width 20%, 20 WET iterations, RMS error 1.8 %, 1D-Gradient smooth initial model, Version 3.21



Fig. 4 : WET wavepath coverage, obtained with Smooth inversion (Fig. 1). Coverage of subsurface with first break energy.

Note the low wavepath coverage at offset 1000m and elevation 580m (Fig. 4). This is the only location where Fig. 1 and Fig. 2 differ. Low wavepath coverage means locally higher uncertainty, in the obtained WET velocity tomogram (Fig. 1). Wavepaths are almost vertical, similar to reflected rays (Fig. 4).

Processing time for default Smooth inversion (Fig. 1) was about 1 hour on an Intel Core i3. Fig. 2 was obtained in minutes. But DeltatV parameters need to be tuned, to approach Smooth inversion output. So DeltatV imaging is an iterative and more interactive process, when compared to Smooth inversion.

The good match between Fig. 1 and Fig. 2 confirms these two interpretations, obtained with quite different methods.

On the next page, we detail all processing steps required to obtain above output :

First, import the data and review shot-sorted traveltime curves :

- Start up Rayfract® via desktop icon. Select *File*|*New Profile*...
- Set *File name* to OT0608 and click *Save button*
- Specify Station spacing of 3 m in Header|Profile
- Unzip archive <u>ot0608.zip</u> in directory \RAY32\LINE8\INPUT
- > Uncheck File|Import Data Settings|Round shot station to nearest whole station number
- Select File Import Data... and specify Import data type ASCII column format
- Click button Select and select file OT0608_ASCII.asc in directory \RAY32\OT0608\INPUT
- > Check option *Batch import*. This option is supported for ASCII.ASC files only.
- Leave Default spread type at 10: 360 channels
- Click *button Import shots*, and confirm prompt
- ► File|Update header data|Update Station Coordinates... with \RAY32\OT0608\INPUT\OT0608_COR.COR
- > File|Update header data|Update Shotpoint coordinates... with \RAY32\OT0608\INPUT\OT0608_SHO.SHO
- Select *Refractor*|*Shot breaks* to display traveltime curves

Now run Smooth inversion, with default parameters :

- Select Smooth invert WET with 1D-gradient initial model, and obtain 1D initial model
- Confirm prompts, for default WET output after 20 iterations (Fig. 5 and 6)
- Note artefact in Fig. 5, at offset 500m and elevation 600m. This is due to low wavepath coverage (Fig. 6).

Next, configure smoother DeltatV settings (Fig. 7) :

- Check Smooth invert Smooth inversion Settings Wide CMP stack for 1D-gradient initial model
- Check Smooth invert|Smooth inversion Settings|Allow unsafe pseudo-2D Delta-t-V inversion
- Check DeltatV DeltatV Settings Enforce monotonically increasing layer bottom velocity
- 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 Interactive DeltatV... and confirm prompt. Configure smoother DeltatV Static corrections (Fig. 8):

- Click button *Static corrections*
- Check Surface consistent corrections
- Increase Weathering crossover to 20 stations
- Increase Topography filter to 200 stations
- Decrease Inverse CMP offset power to 0.2, click Accept button
- Click Esc key, to exit from *interactive DeltatV inversion* without running it

Redo Smooth inversion with smoother DeltatV initial model, and increased WET wavepath width 20% :

- Select Smooth invert | WET with 1D-gradient initial model, obtain 1D initial model (Fig. 3)
- When prompted to continue with WET tomography, click No button
- Select WET Tomo Interactive WET tomography...
- Set *Wavepath width* to 20%, click *button Start tomography processing*
- Confirm prompts to obtain smooth WET output with 20 iterations (Fig. 1 and 4)
- > Note removed artefact at offset 500m and elevation 600m. Also note deeper imaging, compared to Fig. 5.
- Uncheck DeltatV DeltatV Settings Enforce monotonically increasing layer bottom velocity

Select DeltatV|XTV parameters for constant-velocity layers, and configure XTV options as follows (Fig. 9) :

- Check Enable Modified Dix layer inversion
- > Check Enable Intercept time layer inversion
- Check Allow adjacent Intercept layer inversion
- Check Prefer measured layer top velocity over inverted

Select DeltatV Interactive DeltatV... and confirm prompt. Reconfigure DeltatV Static corrections (Fig. 8) :

- Click button *Static corrections*
- Leave Surface consistent corrections checked
- Reset Weathering crossover to 10 stations
- Reset *Topography filter* to 100 stations
- Leave Inverse CMP offset power at 0.2, click Accept button

Now configure and run DeltatV inversion, with XTV inversion enabled :

- Set *CMP curve stack width* to 150
- Set *Export Options*|*Gridding method* to *Nearest Neighbor*, click *Accept button*
- Click button DeltatV inversion, and confirm prompts, to obtain Fig. 2



Fig. 5 : Default Smooth inversion, wavepath width 8%



Fig. 7 : DeltatV|DeltatV settings



Fig. 9 : DeltatV XTV parameters



Fig. 6 : wavepath coverage obtained with Fig. 5



Fig. 8 : DeltatV|Interactive DeltatV...|Static Corrections

For Wavefront refraction method interpretation :

- Select Refractor Midpoint breaks
- Press ALT+M, to edit Mapping dialog (Fig 10)
- Click Map traces button, confirm prompt
- Press ALT+G, to edit Crossover dialog (Fig. 11)
- Click Accept, to smooth refractors (Fig. 10)
- Check Depth|Depth conversion Settings|Link traveltime curves for Wavefront
- Select Depth Wavefront... (Fig. 13)
- ► ALT+P, set *min./max. elevation* to 580/700m
- > ALT+M, edit *Wavefront parameters* (Fig. 12)
- Select Velocity Wavefront... (Fig. 13)
- ► ALT+P, set *maximum velocity* to 5000 m/s

Note the good match between Wavefront refraction (Fig. 13), WET inversion (Fig. 1) and XTV (Fig. 2).

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Fig. 10 : Refractor|Midpoint breaks, press ALT+M to edit mapping dialog



 Wavefront Model Parameters

 Regression parameters

 □
 Recompute traveltime characteristics

 □
 Prefer CMP overburden refractor mapping

 □
 Prefer regressed traveltimes

 Regression tolerance [msec.]
 0.000001

 Smoothing parameters
 0

 Overburden filter [station nos.]
 30

 Base filter width [station nos.]
 70

 Surface consistency [0..100]
 50

Fig. 11 : press ALT+G to edit crossover dialog

Fig. 12 : ALT+M for Wavefront params.



Fig. 13 : Wavefront|Depth (left), Wavefront|Velocity (right). Note good match with WET (Fig. 1) and XTV (Fig. 2).



Fig. 14 : pseudo-2D DeltatV inversion with version 4.01 done in June 2020. Layered XTV inversion enabled. DeltatV stack width 147. Surface-consistent static corrections. Topography smoothing : 15 stations. Smooth CMP curves. Suppress DeltatV artefacts. Process every CMP offset. Limit DeltatV velocity exported to maximum 1D-gradient velocity.





Fig. 15 : 2D Conjugate-Gradient single-run WET inversion using Fig. 14 as starting model. Minimal WET smoothing. Smooth every 5th iteration. Gaussian smoothing. Wavepath width 15%. Cosine-Squared WET update weighting. 10 Conjugate-Gradient iterations. 2 Line Search iterations. See Fig. 17. Compare with Fig. 1 Smooth inversion.



Fig. 16 : WET wavepath coverage plot obtained with Fig. 15. Unit is wavepaths per pixel.

Here are the <u>SEIS32.* profile database files</u> for Fig. 15. Here are the Surfer <u>.GRD files & .PAR files</u> & Surfer 11 .SRF for Fig. 15.

Compare Fig. 15 DeltatV + WET with Fig. 1 : Smooth inversion using 1D-gradient starting model done in 2011. In Fig. 15 the transition from bottom of overburden to top-of-basement is much sharper. In the basement the lateral velocity variation is also much sharper than in Fig. 1 and in Fig. 5.

Our version 3.36 and 4.01 WET inversion normalizes the *RMS error* by average picked traveltime instead of maximum picked traveltime, as used for earlier versions. This is the reason why the RMS error shown on top of Fig. 15 is 4.3% vs. 1.8% shown on top of Fig. 1.

Check option *Model*|*Normalize RMS error with maximum picked time* to restore the method used for earlier versions. Now use command *Model*|*Forward model traveltimes* with ...\TOMO\VELOIT32.GRD to redetermine the relative RMS error as for earlier versions.

The *absolute RMS error* for Fig. 15 is 2.76ms vs. 3.79ms for Fig. 1. So the *Conjugate-Gradient WET and optimized WET smoothing plus Cosine-Squared update weighting* used for Fig. 15 as shown in Fig. 17 really help to decrease the RMS error / to improve the traveltime misfit between picked and modeled times.

Edit WET Wavepath Eikonal Traveltime Tomography Parameters	Edit WET Tomography Velocity Smoothing Parameters
Specify initial velocity model	Determination of smoothing filter dimensions
Select D:\ray32\OT0608\TOMO\DELTATV.GRD	 Full smoothing after each tomography iteration
Stop WET inversion after	Minimal smoothing after each tomography iteration
Number of WET tomography iterations : 32 iterations	C Manual specification of smoothing filter, see below
or RMS error gets below 20 percent	- Smoothing filter dimensions
or BMS error does not improve for n = 20 iterations	Half smoothing filter width : 9 columns
	Half smoothing filter height : 1 grid rows
i or we i inversion runs longer than i i ou minutes	
WET regularization settings	Adapt shape of filter. Unchack for better resolution
Wavepath frequency : 50 Hz Iterate	1. Adapt shape of men. Oncheck for better resolution.
Ricker differentiation [-1:Gaussian,-2:Cosine] : -2 times	Maximum relative velocity update after each iteration
Wavepath width [percent of one period] : 15.0 percent Iterate	Maximum velocity update : 15.00 percent
Wavepath envelope width [% of period] : 0.0 percent	Smooth after each nth iteration only
Min. velocity : 10 Max. velocity : 6000 m/sec.	Smooth nth iteration : n = 5 iterations
Width of Gaussian for one period [sigma] : 3.0 sigma	Smoothing filter weighting
Cradient accred method	Gaussian C Uniform No smoothing
C Steepest Descent C Conjugate Gradient	Used width of Gaussian 1.0 sigma
Conjugate Gradient Parameters	Uniform central row weight 1.0 [1100]
CG iterations 10 Line Search iters. 2	Smooth velocity update before updating tomogram
Tolerance 0.001 Line Search tol. 0.0010	Smooth update Smooth nth 🔽 Smooth last
Initial step 0.10 Steepest Descent step	Damping of tomogram with previous iteration tomogram
Edit velocity smoothing Edit grid file generation	Damping [0_1] 0.900 Damp before smoothing
Start tomography processing Reset Cancel	Accept parameters Reset parameters

Fig. 17 : interactive WET and WET smoothing settings used to obtain Fig. 15 & 16

With grid cell size forced to 1.2m in *Header*|*Profile* the 32 WET iterations required to obtain Fig. 15 took **28 minutes** on **2017** *iMac with Intel Core i5* @ 2.3 GHz running Windows 7 64-bit Pro in Parallels Desktop 14 using MacOS High Sierra, using 4 logical CPU cores in parallel. Our <u>Pro version</u> allows using up to 16 CPU cores in parallel for faster WET inversion. We also fully support running our latest software version 4.01 under latest Windows 10 64-bit Pro.

Below we show reprocessing of this line with our version 4.01 software with WDVS (Zelt and Chen 2016) enabled, as done in Feb 2021. 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





OT0608 GrassI/JOANNEUM RMS error 4.2%=2.72ms 20 WET itr. 50Hz Width 8.0% initial GRADIENT.GRD v. 4.01 101 151 201 251 301 351 401 451 501 551 601 651 701 751 801



Fig. 19: 20 Steepest-Descent WET iterations with minimal WET smoothing (Fig. 22) and WDVS engaged at 90Hz, discard WET smoothing after forward modeling (Fig. 21). 1D-gradient starting model shown in Fig. 18. Wavepath width 8%. Gaussian WET update weighting. Smooth every iteration. Uniform smoothing filter weighting. Blank no coverage after last iteration. RMS error 4.2%=2.72ms. White lines are refractors obtained with Wavefront method (Fig. 25). Compare with Fig. 15 obtained without WDVS smoothing and with XTV method starting model Fig. 14.

OT0608 Grassl/JOANNEUM RMS error 4.2%=2.72ms 20 WET itr. 50Hz Width 8.0% initial GRADIENT.GRD v. 4.01



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

E	Edit WDVS (Zelt & Chen 2016)			
	Edit parameters for wavelength-dependent velocity smoothing			
	✓ use WDVS for forward modeling of traveltimes			
	✓ fast WDVS : less accurate mapping of scan line nodes to grid nodes			
	WDVS frequency 90.00	[Hz]		
	Angle increment between scan lines 7	[Degree]		
	Regard nth node along scan line 3	[node]		
	Parameters for Cosine-Squared weighting function (Chen and Zelt 2012)			
	a : Cosine argument power 1.000	[power]		
	b : Cosine-Squared power 1.000	[power]		
	Modify WET smoothing mode : discard after forward modeling			
	 Idiscard WE I smoothing and WUVS smoothing after modeling 			
	C discard WDVS smoothing only and restore WET smoothing			
	OK Cancel Reset			

Fig. 21 : Model|WDVS Smoothing.

Edit WET Wavepath Eikonal Traveltime Tomography Parameters	Edit WET Tomography Velocity Smoothing Parameters		
Specify initial velocity model Seject D:\ray32\0T0608\GRADWDVS@90Hz_MinSmooth\GRADIENT.GRD	C Full smoothing after each tomography iteration		
Stop WET inversion after Number of WET tomography iterations : 20 iterations	Minimal smoothing after each tomography iteration Manual specification of smoothing filter, see below		
or RMS error gets below 20 percent or RMS error does not improve for n = 50 iterations	Smoothing filter dimensions Half smoothing filter width : 9 columns Half smoothing filter height : 1 grid rows		
WET regularization settings	Suppress artefacts below steep topography		
Wavepath frequency: 50.00 Hz Iterate Ricker differentiation [-1:Gaussian,-2:Cosine]: -1 times Wavepath width (percent of one period): 80 percent	Maximum relative velocity update after each iteration Maximum velocity update : 25.00 percent		
Wavepath envelope width [% of period]: 0.0 percent Min. velocity: 10 Max. velocity: 6000 m/sec.	Smooth after each nth iteration only Smooth nth iteration : n = 1 iterations		
Width of Gaussian for one period [sigma]: 30 sigma	Smoothing filter weighting C Gaussian C Uniform I No smoothing		
Steepest Descent Conjugate Gradient	Used width of Gaussian 1.0 sigma		
Conjugate Gradient Parameters CG iterations 10 Line Search iters. 2	Smooth velocity update before updating tomogram		
Tolerance 0.001 Line Search tol. 0.0010 Initial step 0.10 Steepest Descent step	Damping of tomogram with previous iteration tomogram		
Edit <u>v</u> elocity smoothing Edit grid file generation	Damping [01] 0.000 Damp before smoothing		
Start tomography processing Reset Cancel	Accept parameters Reset parameters		

Fig. 22 : WET Tomo|Interactive WET main dialog (left). Edit velocity smoothing (right).

Here are the <u>SEIS32.* profile database files</u> for Fig. 19. Here are the Surfer <u>.GRD files & .PAR files</u> & Surfer 11 .SRF for Fig. 19.

Note the more shallow top-of-basement in Fig. 19 and stronger velocity contrast at top-of-basement compared to Fig. 15 obtained without WDVS smoothing before forward modeling.



Fig. 23 : Trace/Shot gather (top) and Refractor/Shot breaks (bottom). Red crosses are picked first breaks, blue crosses are modeled traveltimes (top). Solid curves are picked traveltime curves, dotted curves are modeled traveltime curves (bottom).

In Fig. 23 we show a sample shot gather (top) and all shot-sorted traveltime curves (bottom). Note the good fit between modeled and picked traveltimes (top). Also note highly parallel traveltime curves between adjacent shot points (bottom).



Fig. 24 : Trace|Offset gather (common offset 207m). Red crosses are picked first breaks, blue crosses are modeled traveltimes.

We have shown that for long lines with homogeneous overburden and without strong lateral velocity variation in overburden our <u>1.5D XTV inversion</u> method can work well to obtain a realistic starting model (Fig. 14) which is close to the final WET tomogram (Fig. 15). Also the final WET tomogram is quite independent of the starting model, compare Fig. 19 with Fig. 15.

Layered refraction interpretation with Plus-Minus and Wavefront methods is more difficult for this long line due to discontinuous basement refractor (Fig. 13) but works as well (Fig. 25).

In general we recommend using our 1D-gradient starting model as shown in Fig. 18 and Fig. 19 to avoid DeltatV and XTV artefacts in the initial model due to strong lateral velocity variation in overburden (<u>Sheehan, 2005</u>) or due to strong topography. See our <u>EPIKINV</u> tutorial.



Fig. 25 : layered refraction interpretation with Wavefront method. Traces are mapped to refractors and time is converted to depth as shown in Fig. 10 to Fig. 13.

With *grid cell size* forced to 1.2m in *Header*|*Profile* the 20 Steepest-Descent WET iterations required to obtain Fig. 19 took *16 minutes on 2017 iMac with Intel Core i5* @ 2.3 GHz running Windows 7 64-bit Pro in Parallels Desktop 16 using MacOS High Sierra, using 4 logical CPU cores in parallel.

The same WET inversion took 12 minutes on 2020 macMini with 3.0 GHz Intel Core i5 processor using all 6 cores running native Windows 10 64-bit Pro installed via Boot Camp Assistant using our Pro version.

We again thank Dr. Grassl formerly at JOANNEUM RESEARCH Forschungsges.mbH, Austria, for making available this dense and consistently picked data set, with 275 shots into 200 or more channels.

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