Multiscale Steepest Descent SAGEEP11 with Rayfract® 3.34



Fig. 1 : Basement step with fault model. See <u>Zelt et al.</u> 2013 : blind test of refraction methods.



Fig. 2 : 1D-Gradient starting model : laterally average DeltatV inversion. RMS error 4.9%=7.80 ms.



Fig. 3 : 4th WET run. Starting model is 3rd run output. Wavepath width 10%. RMS error 0.8%=1.26ms.



Fig. 4 : WET wavepath coverage plot for Fig. 3. Unit is wavepaths per pixel. Wavepath width 10%@25Hz.



Fig. 5 : 6th WET run. Starting model is 5th run output. Wavepath width 5%. RMS error 0.7%=1.11ms.





Fig. 6 : 8th WET run. Starting model is 7th run output. Wavepath width 3%. RMS error 0.7%=1.07ms.

Colin Zelt data RMS error 0.7%=1.07ms 50 WET iters. 25Hz Width 3.0% initial RUN7IT50.GRD Version 3.34



Fig. 7 : WET wavepath coverage plot for Fig. 6. Unit is wavepaths per pixel. Wavepath width 3%@25Hz.



Fig. 8 : True times (colored solid curves forward modeled for Fig. 1 with added Gaussian noise) and inverted times (dashed blue curves for Fig. 6)



Reset Smooth Inversion settings Fig. 9 : Smooth invert|Smooth inversion Settings



it well wavepath Elkonal Traveitime Tomography Pal	rameters	Edit WET Tomography Velocity Smoothing Parameters	
Specify initial velocity model	Determination of smoothing filter dimensions Full smoothing after each tomography iteration Minimal smoothing after each tomography iteration		
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Stop WET inversion after		Manual specification of smoothing filter, see below	
Number of WE I tomography iterations :	100 iterations		
or RMS error gets below	2.0 percent	Smoothing filter dimensions	
or RMS error does not improve for n =	50 iterations		
or WET inversion runs longer than	100 minutes	Hair smoothing filter height: 2 grid rows	
WET regularization settings		Filter shallow dipping wavepath artefacts from model	
Wavepath frequency :	25 Hz Iterate	Automatically adapt shape of rectangular filter matrix	
Ricker differentiation [-1 is Gaussian bell] :	-1 times	Maximum relative velocity update after each iteration	
Wavepath width [percent of one period] :	3.0 percent Iterate	Maximum velocity update : 15 percent	
Wavepath envelope width [% of period] :	0.0 percent	Smooth after each nth iteration only	
Min. velocity : 10 Max. velocity :	3500 m/sec.	Smooth nth iteration : n = 50 iterations	
Width of Gaussian for one period [sigma] :	3.0 sigma	Smoothing filter weighting	
Gradient search method		C Gaussian	
Steepest Descent Conju	Used width of Gaussian 1.0 sigma		
Conjugate Gradient Parameters		Uniform central row weight 100.0 [1100]	
Tolerance 0.001 Line Search tol.	0.0010	Smooth velocity update before updating tomogram	
Initial step 0.10 Line Search iters	s. 3	Smooth velocity update 🔽 Smooth last iteration	
-	Damping of tomogram with previous iteration tomogram		
Steepest Descent step CG iterations			
CG iterations	ile generation	Damping [01] 0.000 Damp before smoothing	

Fig. 11 : WET Tomo|Interactive WET tomography... (left), Edit velocity smoothing (right)

Run No.	Freq. [Hz]	Width [%]	Width [ms]	Iterations		ОК
Run 1	25.0	30.0	12.0	50	Blank	
Run 2	25.0	22.0	8.8	50	Blank	Cancel
Run 3	25.0	16.0	6.4	50	Blank	Reset
Run 4	25.0	10.0	4.0	50	Blank	WET runs active
Run 5	25.0	7.0	2.8	50	Blank	Scale default widths
Run 6	25.0	5.0	2.0	50	Blank	Plot runs in Surfer
Run 7	25.0	4.0	1.6	50	Blank	Prompt run mistit
Run 8	25.0	3.0	1.2	50	Blank	All runs completed
Run 9	25.0	2.0	0.8	0	Blank	Current run no1
Run 10	25.0	1.0	0.4	0	Blank	Resume current run
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Fig. 12 : multirun WET settings (WET Tomo|Interactive WET tomography|Iterate button)

To obtain Fig. 2 to Fig. 8 proceed as following :

- Download <u>334GradSDWETGrad smooth50 seis32.zip</u> archive and unzip into directory C:\RAY32\SAGEEP11
- Select File|Open Profile... & database schema C:\RAY32\SAGEEP11\SEIS32.DBD . Click Open button.
- Check Smooth invert|Smooth inversion Settings|Extra-large cell size
- Setup other settings in Smooth invert|Smooth inversion Settings as in Fig. 9
- Uncheck WET Tomo|WET tomography Settings|Disable wavepath scaling for short profile
- Uncheck WET Tomo WET tomography Settings Scale wavepath width
- > Check WET Tomo WET tomography Settings Edit maximum valid WET velocity
- Check WET Tomo|WET tomography Settings|Store modeled picks after last iteration only
- Setup other settings in WET Tomo WET tomography Settings as in Fig. 10
- Select Smooth invert|WET with 1D-gradient initial model and confirm prompts to obtain 1D-gradient starting model (Fig. 2) and default Smooth inversion output after 20 WET iterations
- Select WET Tomo Interactive WET tomography...
- Click Select button and select starting model c:\ray32\sageep11\gradtomo\gradient.grd
- Check box Skip every 2nd shot for forward modeling and click button Accept parameters
- Set edit field Wavepath frequency to 25Hz and set Max. velocity to 3,500m/s
- Click radio button Steepest Descent and edit other fields in WET main dialog as in Fig. 11 (left)
- > Click button Edit velocity smoothing and radio button Manual specification of smoothing filter
- Set Half smoothing filter width to 3 columns and Half smoothing filter height to 2 grid rows
- Uncheck box Automatically adapt shape of rectangular filter matrix
- Set Maximum velocity update to 15% and Damping to 0.0
- Set *Smooth nth iteration : n* = to 50 and click *radio button Uniform*
- Set Uniform Central row weight to 100 and uncheck box Smooth velocity update
- Edit other fields in *Velocity Smoothing Parameters dialog* as in Fig. 11 (right)
- Click button Accept parameters
- Click Iterate button in WET main dialog and click Reset button in Edit WET runs dialog
- > Check box WET runs active and uncheck box Blank after last run
- > Change *Iterations column* fields for *Run 1* to *Run 8* from default 20 to new value 50
- Edit other fields in *Edit WET runs dialog* as in Fig. 12 and click *OK button*
- Click *Edit grid file generation button* and set *Store each nth iteration only* : n = 50.
- Click Accept parameters button and Start tomography processing button
- Confirm prompts to obtain output as in Fig. 3 to Fig. 7
- Select Refractor Shot breaks to obtain Fig. 8
- Uncheck Mapping Display raytraced traveltimes

With these velocity smoothing settings (Fig. 11) we obtain robust convergence of <u>multirun WET inversion</u> with RMS error quasi-monotonically decreasing from Fig. 2 (4.9%=7.80ms) through Fig. 6 (0.7%=1.07ms). In particular we specify :

- Wavepath frequency of 25Hz instead of default 50Hz. This makes multirun WET more robust.
- > Max. velocity = 3,500m/s. This prevents unrealistic oscillation of WET modeled velocity in basement.
- > *Maximum velocity update = 15%* instead of default 25%
- > **Damping = 0.0** equals default 0.0 for <u>Steepest Descent method</u>
- Smooth nth iteration : n = 50 instead of default 1
- Uniform central row weight = 100 instead of default value 1. This increases the vertical resolution in special case of quasi-horizontal layering in subsurface with Uniform Smoothing filter weighting.
- > Manual Smoothing filter specification with Half-width = 3 columns and Half-height = 2 rows
- No smoothing of velocity update before applying the update to the current velocity tomogram

Fig. 3 (wavepath width 10%) is a low-frequency approximation of the true model (Fig. 1) and shows longwavelength features of the true model. Fig. 6 (wavepath width 3%) is the final high-frequency interpretation of the traveltime data and shows more detail (short wavelength scale). By using above *maximum velocity update* of 15% we keep the long wavelength features from Fig. 3 and add shorter wavelength resolution through all WET runs up to Fig. 6.

As stated in <u>Zelt et al. 2013</u> "Uncorrelated Gaussianly-distributed noise with a mean of zero and a standard deviation of 1 ms was added to the synthetic data". This *added Gaussian noise* prevents our WET inversion from reaching an even better resolution in the final tomogram Fig. 6.

Runtime for above 8 WET runs 50 WET iterations each = 400 iterations was about **8** minutes on an Apple *iMac* late 2012 with 2.7 GHz Intel Core i5 processor. Grid size is 80 rows x 200 columns. X spacing & Y spacing are 1.58m. One grid cell is 1.58m square. This short run time enables quasi-interactive variation of *WET smoothing parameters* (Fig. 11). Output of above WET run no. 8 is available in archive 334SDWETGrad smooth50 run8.rar.

To import the ASCII data obtained from http://terra.rice.edu/department/faculty/zelt/sageep2011/:

- Start up Rayfract® via desktop icon. Select File|New Profile....
- Set File name to SAGEEP12 and click Save button. Set Station spacing to 3 m in Header|Profile.
- Unzip archive <u>sageep11_ascii.zip</u> in directory \RAY32\SAGEEP12\INPUT
- Select *File*|*Import Data*... and specify *Import data type* ASCII column format
- Click button Select and select file ASCII.ASC in directory \RAY32\SAGEEP12\INPUT
- > Check option Batch import. Leave Default spread type at 10: 360 channels.
- Click *button Import shots* and confirm prompt
- Unzip archive <u>334SDWETGrad smooth50 run8.rar</u> in \RAY32\SAGEEP12\WETRUN8
- Select Grid|Reset DeltatV and WET settings to .PAR file
- Select \ray32\sageep12\wetrun8\veloit62.grd and click Open button

We have shown that using our default 1D-gradient starting model (Fig. 2) for multiscale tomography gives you a good vertical resolution (Fig. 6) comparable to the true model (Fig. 1). <u>Sheehan et al. 2005</u> evaluate our 1D-Gradient starting model with synthetic data generated for known subsurface models.

Our tutorial <u>http://rayfract.com/tutorials/step.pdf</u> written in 2013 using version 3.25 of our software shows that using our default 1D-Gradient starting model with <u>Smooth inversion</u> and 20 or 100 WET iterations gives a good vertical resolution.

In tutorial <u>http://rayfract.com/tutorials/sageep11_16.pdf</u> we show using the <u>Conjugate Gradient</u> method instead of *Steepest Descent* method for multiscale tomography with above data.

For description of *WET parameters* you can navigate to the relevant field in WET dialogs and press F1 function key for popup help. Or navigate our *Help menu*. Or refer to our .pdf reference at <u>http://rayfract.com/help/rayfract.pdf</u>.

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