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# Improving the Resolution of Fresnel Volume Tomography with Wavelength-Dependent Velocity Smoothing

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# Abstract


❑We show improvement in resolution of subsurface P-wave velocity tomograms incorporating Fresnel Volume Tomography and Wavepath Eikonal Traveltime inversion (WET) by engaging Wavelength-Dependent Velocity Smoothing (WDVS; Zelt and Chen 2016).

❑We interpret synthetic traveltime data for Sheehan 2005 Broad Epikarst model to obtain sharper imaging of layer boundaries with WDVS (Sheehan et al. 2005).

❑We use our default 1D-gradient starting model and a layered refraction Plus-Minus method starting model.

❑Also we show improved resolution using WET+WDVS for a field survey using 9 shots into 24 channels.

❑WDVS is most beneficial for profiles shorter than 100m with traveltime paths not much longer than a few wavelengths.

❑WDVS will not help if reciprocal traveltime picking errors are too large. WDVS requires the exact specification of the used recording geometry (Rohdewald, S. 2020c : NGU Aaknes-1 interpretation).

❑Lowering the WDVS frequency results in higher velocity contrast at top-of-basement and stronger overburden anomalies.

❑The top-of-basement is imaged too shallow and RMS error increases when decreasing WDVS frequency too much.

❑Activating WDVS allows decreasing WET regularization (smoothing and damping) to a higher degree than without WDVS.


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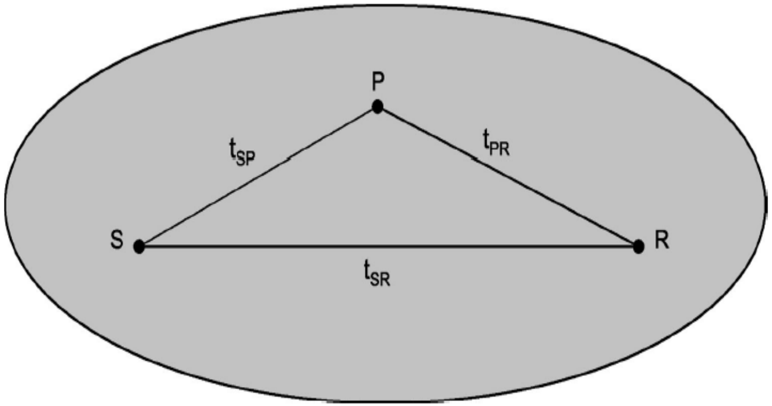
# 2D WET Wavepath Eikonal Traveltime inversion

Fresnel volume or wave path approach :




- rays that arrive within half period of fastest ray : $t_{SP} + t_{PR} - t_{SR} <= 1 / 2f$ (Sheehan, 2005a, Fig. 2)
- nonlinear 2D optimization with steepest descent, to determine model update for one wavepath
- SIRT-like back-projection step, along wave paths instead of rays
- natural WET smoothing with wave paths (Schuster 1993, Watanabe 1999)
- partial modeling of finite frequency wave propagation
- partial modeling of diffraction, around low-velocity areas
- WET parameters sometimes need to be adjusted, to avoid artefacts
- see RAYFRACT.HLP help file

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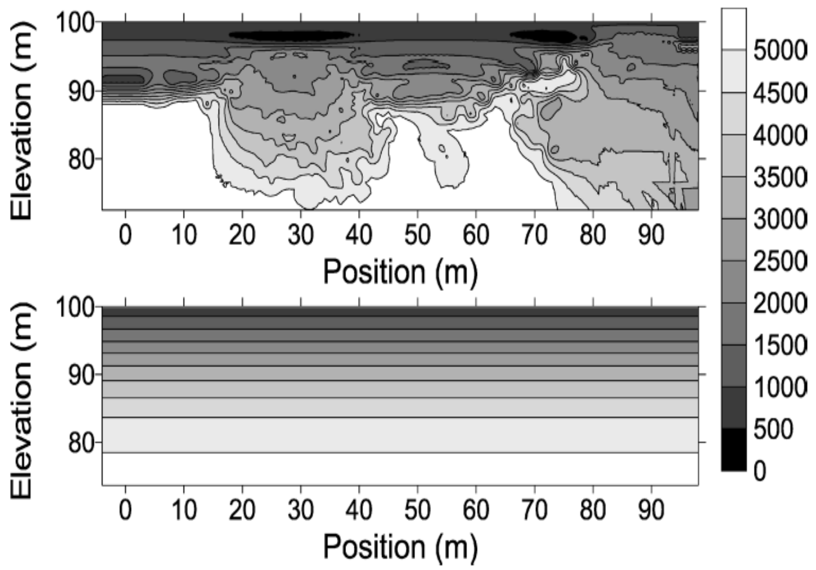
# Smooth Inversion = 1D gradient initial model + 2D WET Wavepath Eikonal Traveltime tomography

Get minimum-structure 1D gradient initial model :




**Top : pseudo-2D DeltatV display**

- 1D DeltatV velocity-depth profile below each station
- 1D Newton search for each layer
- velocity too low below anticlines
- velocity too high below synclines
- based on synthetic times for Broad Epikarst model (Sheehan, 2005a, Fig. 1).

**Bottom : 1D-gradient initial model**

- generated from top by lateral averaging of velocities
- minimum-structure initial model
- DeltatV artefacts are completely removed

# Generalized Rayfract® Flow Chart

**Create new profile database**

**Define header information**

(minimum: Line ID, Job ID, instrument, station spacing (m))

**Import data**

(ASCII first break picks or shot records)

**Update geometry information**

(shot & receiver positional information)

**Run inversion**

Smooth invert|WET with 1D-gradient initial model

(results output in Golden Software's Surfer)

**Edit WET & 1D-gradient parameters & settings**

# Smooth Inversion, DeltatV and WET Parameters

- ❑always start with default parameters: run Smooth inversion without changing any setting or parameter
- ❑next adapt parameters and option settings if required, e.g. to remove artefacts or increase resolution
- ❑more smoothing and wider WET wavepath width in general results in less artefacts
- ❑increasing the WET iteration count generally improves resolution
- ❑don’t over-interpret data if uncertain picks : use more smoothing and/or wider wavepaths.
- ❑explain traveltimes with minimum-structure model
- ❑tuning of parameters and settings may introduce or remove artefacts. Be ready to go one step backwards.
- ❑use Plus-Minus layered refraction method (Hagedoorn, 1959) as alternate starting model

# **WET tomography main dialog:** see help menu

| | |
|---|---|
| Number of WET tomography iterations | Default value is 20 iterations. Increase to 50 or 100 for better resolution and usually less artefacts. WET can improve with increasing iterations, even if RMS error does not decrease. |
| Wavepath frequency | Ricker wavelet used to modulate/weight the wavepath misfit gradient, during model update. Leave at default of 50Hz. One period is 1/50Hz = 20ms. See (Schuster, 1993). |
| Degree of differentiation of Ricker wavelet | 0 for original Ricker wavelet, 1 for once derived wavelet. Value 1 may give artefacts: wavepaths may become “engraved” in the tomogram. New default is -1: Gaussian weighting. Set to -2 for Cosine-Squared weighting, for better imaging of vertical fault zones. |
| Wavepath width | In percent of one period of Ricker wavelet. Increase width for smoother tomograms. Decreasing width too much generates artefacts and decreases robustness of WET inversion. Click Iterate button to specify multirun WET schedule for decreasing wavepath width between consecutive WET runs. |
| Envelope wavepath width | Width of wavepaths used to construct envelope at bottom of tomogram. Default is 0.0. Increase for deeper imaging. |
| Maximum valid velocity | Limit the maximum WET velocity modeled. Default is 6,000 m/s. Decrease to prevent high-velocity artefacts in tomogram. |
| Full smoothing | Default smoothing filter size, applied after each WET iteration |
| Minimal smoothing | Select for more details, but also more artefacts. May decrease robustness and reliability of WET inversion. |
| Manual smoothing | Specify half-width and half-height of smoothing filter in grid columns and grid rows. Gaussian or Uniform weighting. Smooth nth iteration. Smooth velocity update. Maximum velocity update. Check No smoothing to disable WET smoothing. Specify Damping for Conjugate-Gradient WET inversion. |

# Sheehan 2005 Broad Epikarst Model Synthetic Data

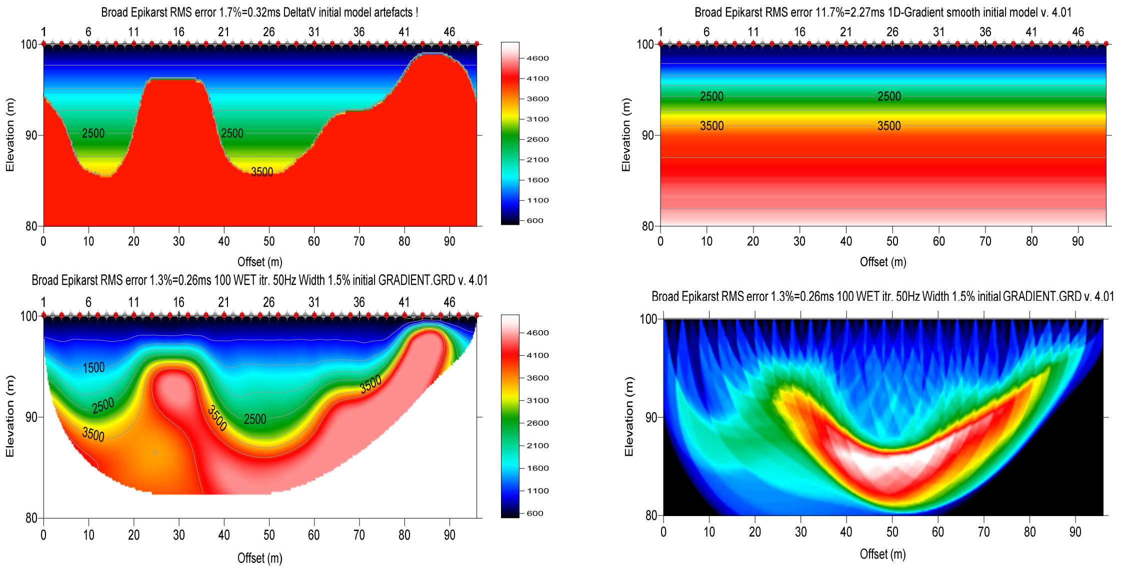



**Figure 1**: **Top**: Broad Epikarst model (left) and 1D-gradient starting model (right).
**Bottom**: 100 Steepest-Descent WET iterations using **Wavelength-Dependent Velocity Smoothing (WDVS; Zelt and Chen 2016)** at 400Hz and 1D-gradient starting model (left). WET wavepath coverage plot using unit wavepaths per pixel (right).

- In Fig. 1 we show WET inversion (Schuster, 1993) of the synthetic traveltime data modeled for the Broad Epikarst model (Sheehan, 2005).
- We use our default 1D-gradient starting model obtained by laterally averaging the pseudo-2D DeltatV velocity (Sheehan, 2005).
- We enable WDVS (Zelt and Chen, 2016) for WET inversion (Rohdewald, 2020a) at 400Hz.
- We use a WET wavepath width of 1.5% and minimal WET smoothing.
- Note the too low basement velocity where the wavepath coverage is lower (Fig. 1 Bottom).

# Sheehan Broad Epikarst Plus-Minus starting model

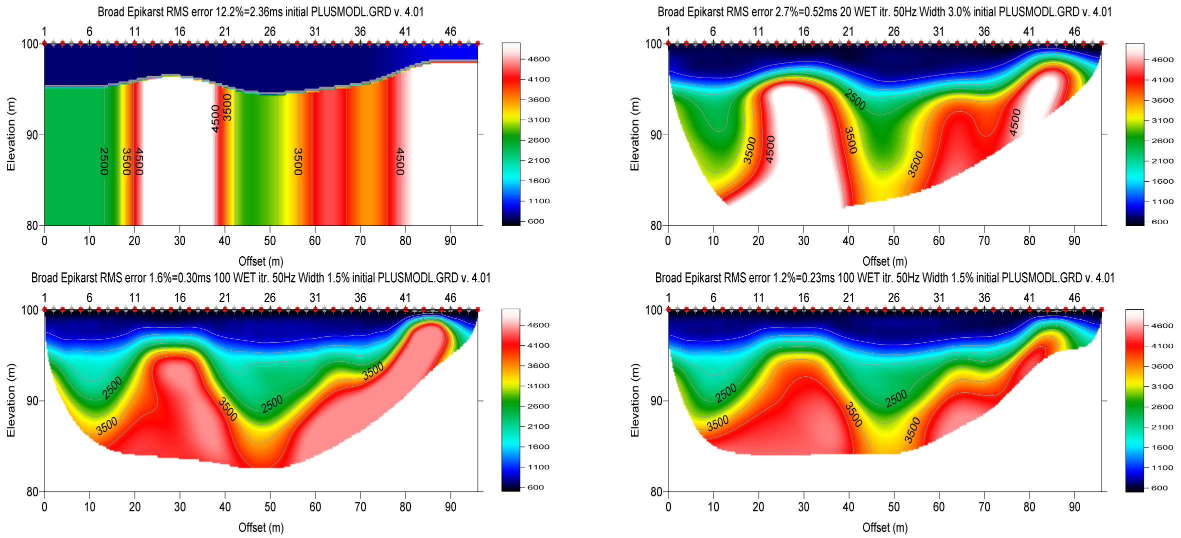



**Figure 2**: **Top**: Plus-Minus starting model (left). Automatic/Smooth WET inversion with Plus-Minus starting model and WDVS engaged at 400Hz (right).
**Bottom**: 100 Steepest-Descent WET iterations using Plus-Minus starting model with WDVS activated at 400Hz (left). Same WET inversion as shown at left but without WDVS (right).

- In Fig. 2 we show WET inversion of the same synthetic traveltime data as shown in Fig. 1 with the same WET settings but using our Plus-Minus method layered refraction starting model (Rohdewald, 2020a).

- Plus-Minus apparent velocity below anticlines is unrealistically high (Fig. 2 Top left).

- Note the lower velocity contrast at top-of-basement (yellow to red color transition) with velocity increasing more gradually with depth when disabling WDVS (Fig. 2 Bottom right).
- The anticline flanks are modeled more steeply with WDVS engaged (Fig. 2 Bottom left) as with 1D-gradient starting model (Fig. 1 Bottom left) and as in true model (Fig. 1 Top left).

# CAMP1 Field Data Interpretation with WET and WDVS

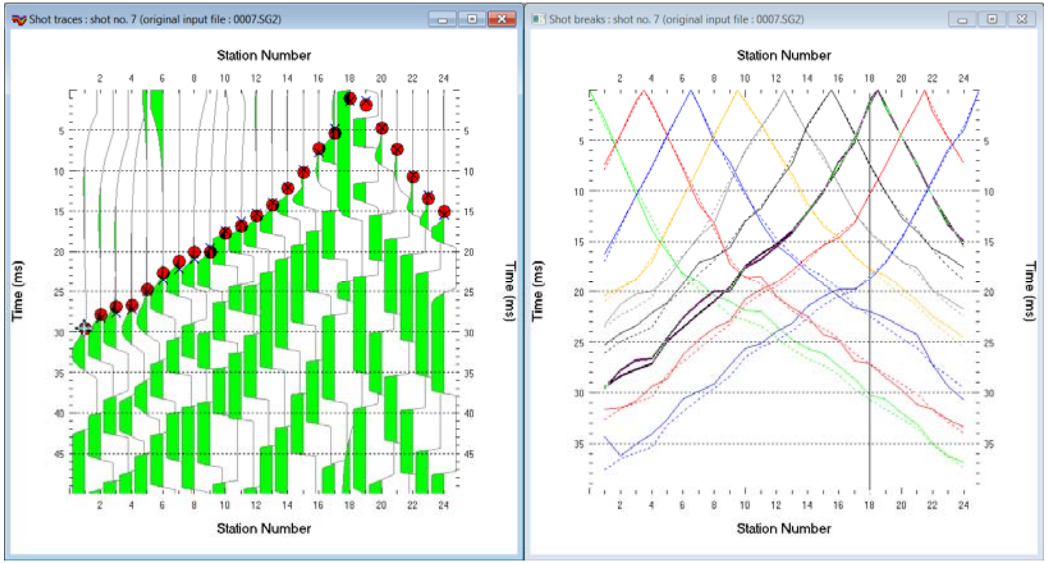



**Figure 3**: Sample shot record (left). Picked times (solid) and WDVS modeled times (dashed) at right. Note the high signal-to-noise ratio of first breaks (left).

According to Dr. Mario Foresta 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

# CAMP1 WET + WDVS with 1D-gradient starting model

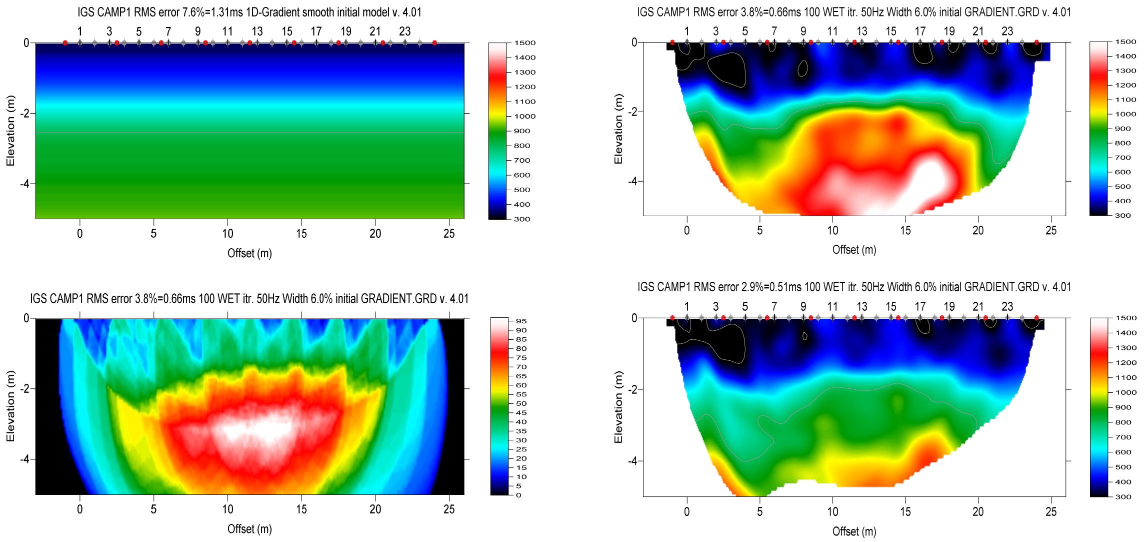



**Figure 4**: **Top**: 1D-gradient starting model for line CAMP1 (left). 100 Steepest-Descent WET iterations using WDVS at 150Hz with 1D-gradient starting model (right).
**Bottom**: WET wavepath coverage plot obtained for tomogram shown at top right. Unit is wavepaths per pixel (left). Same WET settings as used to produce tomogram at top right but without WDVS (right).

- In Fig. 4 we show WET inversion (Schuster, 1993) of the picked traveltime data for field survey CAMP1 (Rohdewald, 2020b).
- We again use our default 1D-gradient starting model obtained by laterally averaging the pseudo-2D DeltatV velocity (Sheehan, 2005).
- We use a WET wavepath width of 6% and minimized WET smoothing: smooth every 10th WET iteration only.
- We engage WDVS at 150Hz (Zelt and Chen, 2016) for WET inversion (Fig. 4 Top right).
- Note the lower velocity contrast at top-of-basement (elevation -2m) when disabling WDVS (Fig. 4 Bottom right).

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# CAMP1 WET + WDVS with Plus-Minus starting model

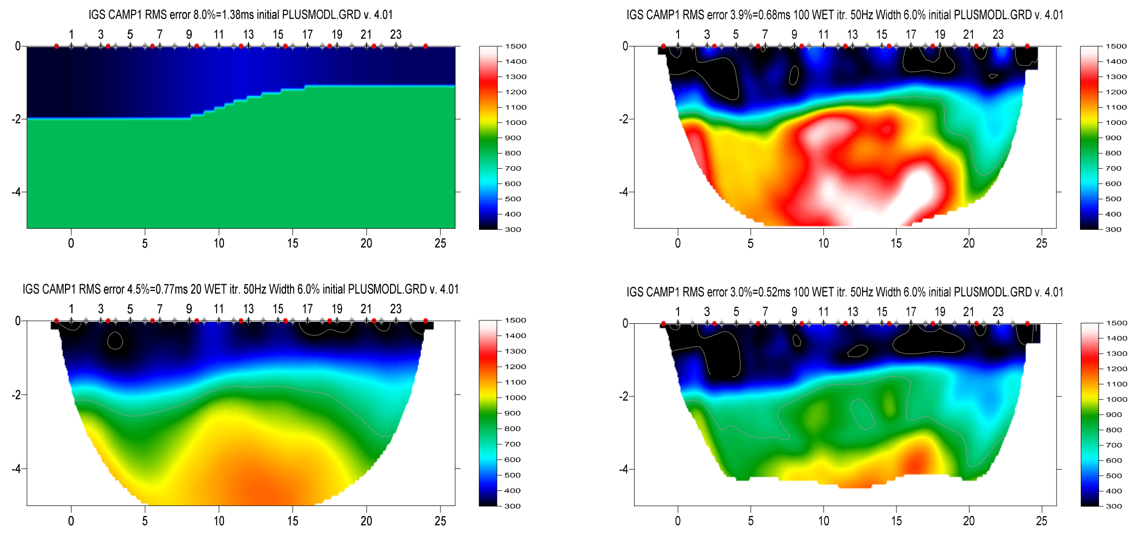


**Figure 5**: **Top**: Plus-Minus starting model for line CAMP1 (left). 100 Steepest-Descent WET iterations using WDVS at 150Hz with Plus-Minus starting model (right).
**Bottom**: Automatic/Smooth WET inversion with Plus-Minus starting model and WDVS engaged at 150Hz (left). Same WET settings as used to produce tomogram at top right but without WDVS (right).

- In Fig. 5 we show WET inversion of CAMP1 traveltime picks with the same WET settings as for inversion shown in Fig. 4 but using our alternative Plus-Minus starting model.
- We mapped traces to refractors in our Common Mid-Point (CMP) display (Rohdewald, 2020b).
- Note the close match with (Fig. 4 Top right) obtained with the same WET settings but using the 1D-gradient starting model.
- At Bottom left we show Automatic WET inversion using full smoothing and 20 WET iterations with WDVS at 150Hz.

# Conclusions

- Using WDVS for WET P-wave velocity inversion can improve the resolution in resulting tomograms. We show this in the examples of synthetic data and field data where the top of the basement is imaged more sharply with stronger velocity contrast between overburden and basement.

- Also we show that WET+WDVS tomograms are independent of the starting model after 100 Steepest-Descent WET iterations. We show this using 1D-gradient and Plus-Minus method starting models.

- WDVS shows the most improvement for profile lengths shorter than 100m with traveltime paths not much longer than a few wavelengths. For longer profiles lower the WDVS frequency to 50Hz or 100Hz.

- WDVS will not help if reciprocal traveltime picking errors are too large or with errors in recording geometry specification (Rohdewald, S. 2020c : NGU Aaknes-1 interpretation).

- Increasing the grid cell size can speed up WDVS.

- Limit the WET velocity to maximum velocity in starting model to suppress a bias towards too high velocities in basement when activating WDVS. This bias gets stronger when lowering the WDVS frequency.

- Lowering the WDVS frequency results in higher velocity contrast at top-of-basement and stronger overburden anomalies.

- The top-of-basement is imaged too shallow and RMS error increases when decreasing WDVS frequency too much.

- Activating WDVS allows decreasing WET regularization (smoothing and damping) to a higher degree than without WDVS.

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