matGPR 3.5: A brief introduction
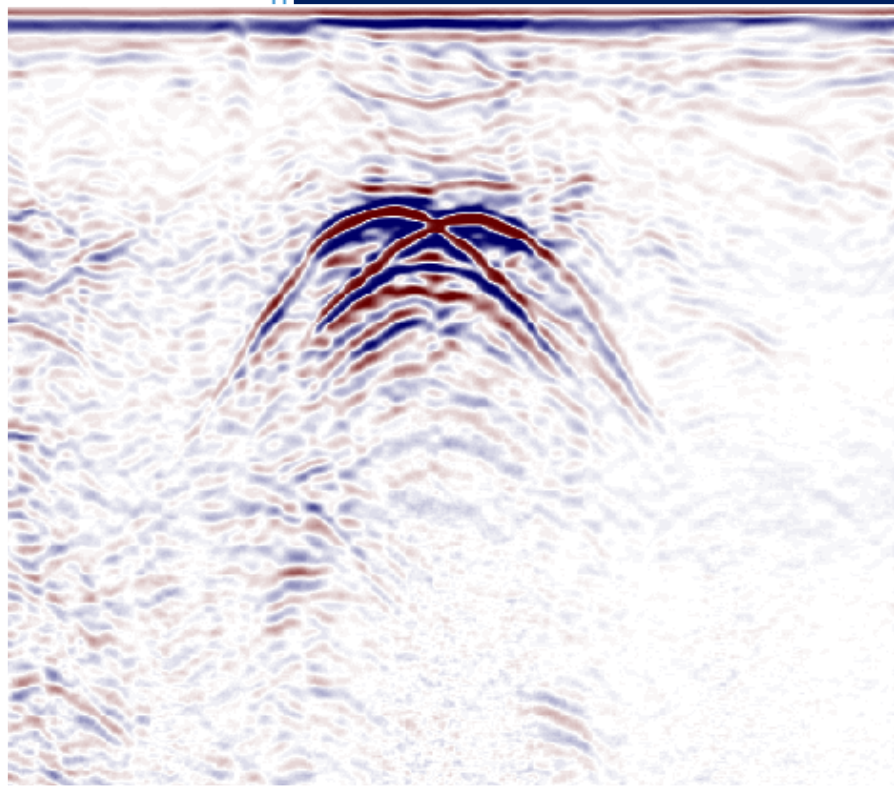
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matGPR is a two-layered software system, in which the bottom layer comprises a suite of functions to handle, display and process the data, while the top layer organizes these functions, automating data management and streamlining the flow of work by means of a GU Interface.

The design philosophy is quite simple: work flows in a continuous cycle between the ***Current Input Data (IPD)***, i.e. that data before some processing operation (step) and the ***Output Data (OPD)***, i.e. the data resulting from this operation. One imports displays and inspects the IPD. Then one applies a processing step (procedure) and evaluates the result, which is the OPD. If satisfied, one may "keep" the Output DPD replacing the current IPD and repeat the cycle with a new processing step. If not, you may ignore or discard the result and cycle with another processing step. A *multi-level* undo/ restore utility is available at any time at which control is returned to the matGPR GUI. You may save or export the current Input Data via the matGPR GUI. Soft and hard copies of the current IPD OPD data (and any figure produced during a session), can be made at any time.

1.   Input and Output Utilities.

☞ matGPR can import raw data in the following formats:
1) **GSSI** (*.DZT files) including 8/16-bit data collected with models up to SIR-3000 and 16/32-bit data collected with model SIR-4000. 🔴new
2) **Måla Geophysics** (RAMAC) including 16-bit data stored in *.RD3 files and 32-bit data stored in *.RD7 files. 🔴new
3) **Sensors and Software** (PULSE EKKO / DT1).
4) **ZOND** (SEG-Y).
5) **Seismic Unix (SU)**.
6) **SEG-Y Revision 0** and **Revision 1** formats. The *integer* 16-bit and 32-bit storage formats of SEG-Y Revision 0 are now supported. 🔴new

☞ *Only single-channel* data files are acceptable, inasmuch as matGPR is currently being offered for zero- or single-offset surveys.
o With reference to RAMAC/ RD3 data, as of Release 3 it is possible to import and assimilate GPS trace positioning, if available, by decoding the associated **.cor** file where GPS information is stored. The positions of the GPS-located traces are projected in the UTM coordinate system and are treated as *marker traces*: they are stored in the **IPD.markertr** field whence they can be manipulated in various ways.
o With reference to bistatic Pulse Ekko (DT1) radars, only data recorded in *reflection mode* (single-offset) are fully supported. Multiple-offset data, (e.g. CMP gathers) can be imported and displayed, but at this stage of development, matGPR does not offer any processing utilities beyond rudimentary editing and filtering.

☞ Prior to importing any raw data and at any time during a matGPR session, the user can inspect the complete information held in the file header of any one of the supported data formats.

☞ Consecutive or broken sections can be joined into a single data set via a specialized GUI.

☞ matGPR can save the IPD either in the native MGP-file format (default), or in MATLAB binary format (native MAT-file), for long-term storage and fast access during subsequent analysis sessions. The current IPD can be saved at any time during a processing session.

☞ For distribution or exchange, the data can be exported to **SEG-Y Revision 1, SU** and **DZT 16-bit SIR-200/300** file format.

☞ It is possible to **undo** *any* number of processing steps in order to restore the data to a previous state. A GUI facilitates this operation and lets the user decide at which state he/she desires to restore the data. The number of undo's is user specified and can be changed during runtime

2. Data Visualization and Properties

☞ Data visualization options include image (colour-graded) displays with several colour maps, wiggle-trace displays, variable-area displays as well as their combinations. Utilities are also provided to:
- o Change the colour map and colour scheme of image displays.
- o Edit the colour scheme, zoom, pan, peek elements (pixels) of the data matrix, export the display in all standard graphics formats, print the display and edit the display figure, the data axes figure and their children objects.
- o Option to assimilate *topography* into 1-D or 2-D depth migrated data is now included in the context menu of the "Processed Data" Figure. 🆕

☞ It is also possible to display, zoom, pan, peek, export, print, edit and evaluate:
- o Individual IPD and OPD **traces**.
- o Individual IPD and OPD **trace spectra**.
- o The **time-frequency characteristics** of IPD and OPD traces.
- o The **attenuation characteristics** of the IPD and OPD.
- o The **instantaneous attributes** of the IPD radargram.
- o The **centroid frequency** of the IPD radargram.
- o The maximum, minimum, Most Positive and Most Negative **Curvature Attributes**. 🆕

3. Basic Processing

matGPR offers a collection of rudimentary and data handling (conditioning) procedures that and include:

☞ Graphically assisted determination and adjustment of time-zero.
☞ Trace and Radargram Editing utilities:
- o Graphically assisted Time-Window Trimming**:** It is common for the later parts of the traces to contain noise; matGPR allows one to reduce of the size of the radargram by discarding late-time arrivals. In combination with time-zero adjustment, this is useful for extracting a certain part of the data for some specific purpose.
- o Graphically assisted Spatial-Window trimming**:** This allows one to discard traces at the beginning or the end of the radargram, or extract parts of the radargram to a separate data set.
- o Graphically assisted elimination of errant traces appearing singular or in *small* groups (for instance due to the antenna coupling with local ground features or bouncing on small obstacles).
☞ Per-trace DC component removal
☞ Dewow filtering.
☞ Trace Equalization.
☞ Gain Manipulation with the following options:
- o Standard Automatic Gain Control (AGC).
- o Gaussian-tapered AGC (Automatic Gain Control).
- o Inversion of Amplitude Decay which applies a smooth empirical gain function that *exactly* compensates the mean or median *amplitude* attenuation observed in a radargram.
- o Inversion of Power Decay which applies an inverse power-law compensation of the mean or median *power* attenuation and may also be used for the spherical divergence correction.
☞ Resampling (increase or decrease of the sampling-rate) in *time* and/or *space* with band limited sinc interpolation.
☞ Marker Interpolation and Trace Positioning utilities. These include:

o Editing and management of *marker traces*, i.e. traces whose locations are *a priori* assigned with reference to a local coordinate frame.

o Importation/replacement of marker trace (positioning) information from a disk file; this allows preparation of positioning (marker) data independently of the built-in matGPR marker editing utilities but, *more importantly* facilitates introduction of *updated/more accurate* information so as to *reposition* the traces. 🔴new

o Transformation of data collected in equal-time spacing mode, to data at equal-distance spacing for GPR instruments without survey wheels or other automatic triggering devices. This can be done by piecewise cubic Hermite polynomial interpolation between *marker traces*, or by stacking with reference to the location of the marker traces.

o Assignment of *x*, *y* and *z* coordinates to the IPD traces by reference to the known coordinates of marker traces. This information can be used in the application of static corrections (see below), as well as for 2D and 3D data visualization.

☞ Planning and execution of **batch jobs** (sequential processing) on *single* or *multiple* data sets (IPDs). All operations available for batch-mode execution pertain to data conditioning; those manipulating structural or geometric information are deliberately not included in a batch job. Operations available for execution in batch mode include: **1)** Time-zero adjustment; **2)** Time-window trimming; **3)** Per-trace subtraction of the DC component; **4)** Dewow; **5)** De-amplification of raw SIR-200/3000 DZT data; **6)** Standard Automatic Gain Control; **7)** Gaussian-tapered AGC; **8)** Amplification by the Inverse Power Decay method; **9)** Amplification by the Inverse Amplitude Decay method; **10)** Modification of the sampling rate; **11)** Modification of trace spacing; **12)** Trace equalization; **13)** Global Background (mean trace) subtraction; **14)** Karhunen – Loeve Filtering; **15)** FIR Frequency Filtering; **16)** B-Spline Wavelet Filtering; **17)** F-X Deconvolution; **187)** Predictive Deconvolution **19)** 1-D Migration with choice between F-K (Stolt) or Phase-shifting (Gazdag) Migration 🔴new; **20)** 1-D Time-to-Depth Conversion 🔴new.

4. Advanced Processing

matGPR offers an extensive suite of advanced to *very* advanced processing utilities. These include:

☞ Mean and median spatial filtering in one and two dimensions.

☞ Noise and outlier suppression with a powerful Robust Smoothing Spline method 🔴new

☞ Foreground/ Background Trace manipulation:
o Background (mean) trace subtraction to reduce source effects.
o Removal of a sliding window's mean (background) trace to expose high-angle dipping reflections.
o Removal of a sliding-window's "foreground" traces to eliminate high-angle reflections and enhance horizontal (e.g. hydrogeologic features).

☞ Karhunen–Loeve filtering based on a low-dimensional subspace approximation of the radargram. This is extremely useful in eliminating small-scale data components to enhance lateral coherence, or very large-scale (low frequency/ short wavenumber) spatio-temporal components and noise (e.g. banding).

☞ Graphically assisted design and implementation of zero-phase FIR filtering (low-pass, high-pass, band-pass, band-stop and notch),
o in the frequency domain (applied 'vertically' to traces), or,
o in the wavenumber domain (applied 'horizontally' to equally spaced traces).

☞ Interactive (graphically assisted) F-K filter design and implementation, facilitating the application of zone pass/stop filters, fan filters and up-dip/ down-dip mapping in the frequency - wavenumber domain.

☞ Advanced S/N enhancement and *orientation-and-scale-sensitive* data manipulation and information retrieval with:
o *orientation-and-scale selective* 2-D Wavelet and Gabor Filters,

- o *tuneable multidirectional scale-selective* 2-D Wavelet and Gabor Filters, and,
- o graphically assisted *multi-scale & multidirectional curvelet based optimal filtering*.
- ☞ Interactive (graphically assisted) <u>Tau-P domain modelling and filtering</u>.
- ☞ <u>F-X Deconvolution</u> for the suppression of random noise.
- ☞ <u>Predictive Deconvolution</u> to suppress multiple reflections and other reverberation (e.g. banding) in 2-D radargrams.
- ☞ <u>Sparse Deconvolution</u> to estimate a maximally parsimonious reflectivity structure of the subsurface.

4.   Data Imaging.

matGPR offers a collection of imaging (migration) and modeling tools to assist in the interpretation. These require velocity analysis and velocity models constructed with in-house utilities. Notably, some migration routines incorporate frequency dependence of the phase velocity due to the frequency dependence of the dielectric constant, (resistivity and magnetic permeability are assumed to be constant). matGPR also provides a utility to manually calculate phase velocities.

- ☞ At present, "velocity analysis" means the graphically assisted manual fitting of diffraction front hyperbolae based on the premise of non-dispersive propagation in a uniform halfspace and targets comprising point diffractors, or finite sized objects with quasi-circular cross section.

Imaging utilities include:

- ☞ Static (topographic) corrections (elevation data is necessary).

- ☞ <u>1-D Migration</u>. The required uniform or layered velocity model may be generated internally via the hyperbola fitting procedure, imported from a disk file or supplied via an appropriate UI dialog box (the *Get 1-D Velocity Model* utility under the *Imaging* menu). One-dimensional migration techniques include:
  - o <u>F-K Time Migration</u> for uniform or layered velocity structures (uses Stolt stretching to account for layered velocity structures).
  - o <u>Phase-Shifting Time Migration</u> for uniform or layered velocity structures
  - o <u>1-D Depth Migration</u> with option to include *topography* 🔴new

- ☞ <u>2-D Depth Migration.</u> The necessary two-dimensional velocity model may either be read from a disk file, or generated by a suitable utility form a synthetic structural model previously prepared by the *Model Builder* utility specified in §5. The available options are:
  - o <u>Phase-shift Plus Interpolation</u> (PSPI) migration for zero-offset data. The PSPI migration routine uses only the non-dispersive phase velocity term because, at present, there's no accurate method to interpolate the dispersive terms in the sense required by the Gazdag and Sguazzero algorithm.
  - o <u>2-D Split-step Migration</u> augmented to account for frequency dependence of the phase velocity (dispersion).

5.   Modelling.

matGPR offers a utility, the *Model Builder,* to facilitate graphically assisted construction of 2-D structural models for use with the 2-D Depth Migration methods and for forward modelling. Each structural model comprises an ensemble of objects with polygonal or circular cross-sections and may be edited, saved and modified indefinitely. The model editing utilities include:
- o Graphically assisted deletion of old objects or/and insertion of new objects.
- o Graphically assisted modification of an object's geometry by relocation, removal of old vertices and insertion of new vertices (modifications may be undone).

- o Interactive modification of an object's properties (dielectric constant, resistivity and magnetic permeability).
- o Visualization enhancement utilities (e.g. colouring).

matGPR includes two modelling methods, both of which require synthetic structural models constructed with the Model Builder:

☞ A fast, <u>Adjoint Split-Step</u> approach, (modified and expanded method of Bitri and Grandjean, Geophysical Prospecting, 46, 287-301, 1998). This is a fast and relatively dirty approach, lacking in detail (does not model secondary effects like multiples), and possibly prone to artifacts if applied indiscriminately. Conversely, it is efficient enough to effectively supplement the interpretation.

☞ The slow but precise <u>Finite Difference Time-Domain</u> method of Irving and Knight (Computers & Geosciences, 32, 1247–1258, 2006).

6. 3-D Visualization.

matGPR offers a suite of functions to generate three-dimensional GPR data volumes using a stacking technique: It is assumed that the 3-D GPR survey has been conducted in a local co-ordinate system in which:

- o Radargrams can have any shape, length, orientation and trace spacing with respect to the coordinate axes.
- o The vertical axis can be either time or depth and the data do not need to have the same time window sizes or sampling rates, or depth window sizes, or depth spacing.
- ☞ Volumes can be created for absolute trace values, squared trace values, absolute-log trace values, instantaneous trace amplitude and instantaneous trace power.

The stacking procedure is as follows: The data files (in MGP and/or MAT formats only) are read in. For each file, traces that fall within a two-dimensional horizontal search window around a volume cell are transformed and stacked together. After all the data files have been processed, the final volume cell value is calculated by averaging all values added to it.

Visualization techniques include:

1. The **GPR-slice** utility to generate orthographic opaque or translucent slices that are:
   - o Horizontal and perpendicular to the vertical grid direction (z-axis).
   - o Vertical and perpendicular to the x-axis.
   - o Vertical and perpendicular to the y-axis
   - o Prior to displaying, each slice may be smoothed with a robust discretized smoothing spline technique.

☞ The horizontal and vertical size of the slices is controlled by the user.

☞ Slices may be added or removed from the display, thus enabling an arbitrarily intricate and detailed visualization of the data volume.

☞ The user controls the azimuth and elevation of the viewing position, the aspect ratio, the axes limits and the colour saturation (contrast) of the display.

2. **Isosurface displays**, i.e. orthographic representations of the data in the form of lit isometric surfaces with equal signal amplitudes, or less rigorously stated lit surfaces of equal reflectivity. The user may manipulate the display by:
   - o Specifying the isosurface value (signal amplitude).
   - o Specifying the azimuth and elevation of the viewer position.
   - o Specifying the aspect ratio of the display and the direction of lighting (light position).
   - o Specifying the colour of the iso-surface.

3. The **3-D Slices** utility to visualize the *entire* data volume with orthographic opaque or translucent slices parallel to the *x*-axis.
   o Horizontal slices perpendicular to the z-axis and vertical slices perpendicular to the y-axis can be overlaid one at a time.
   o The user controls the azimuth and elevation of the viewing position, the aspect ratio and the colour saturation of the display.