A.A. 2021-2022

Corso di Laurea Magistrale in GEOSCIENZE

Metodi Elettromagnetici in Geofisica (6 CFU)
- MEMAG -

UD-4c: Ground Penetrating Radar - GPR - processing and analysis

Docente: Emanuele Forte

Tel. 040/5582271-2274

e-mail: eforte@units.it

Ground Penetrating Radar: processing, analysis, inversion

*GPR data usually cannot be interpreted on the field because require a dedicated processing including a few or even many different algorithms applied in cascade ➔ **PROCESSING FLOW**.*

Some definitions:

*-**Processing** refers to one or more algorithms which modify irreversibly the data after the application.*

*- **Analysis** refers to a reversible procedure applied to better evaluate specific characteristics of the data. Often analysis is applied before a corresponding processing step (e.g. frequency analysis before frequency filtering).*

*- **Geophysical** data **inversion** is a mathematical technique for recovering information on subsurface physical properties from observed geophysical data.*

About processing let always remember that** (Jol, 2009)**:

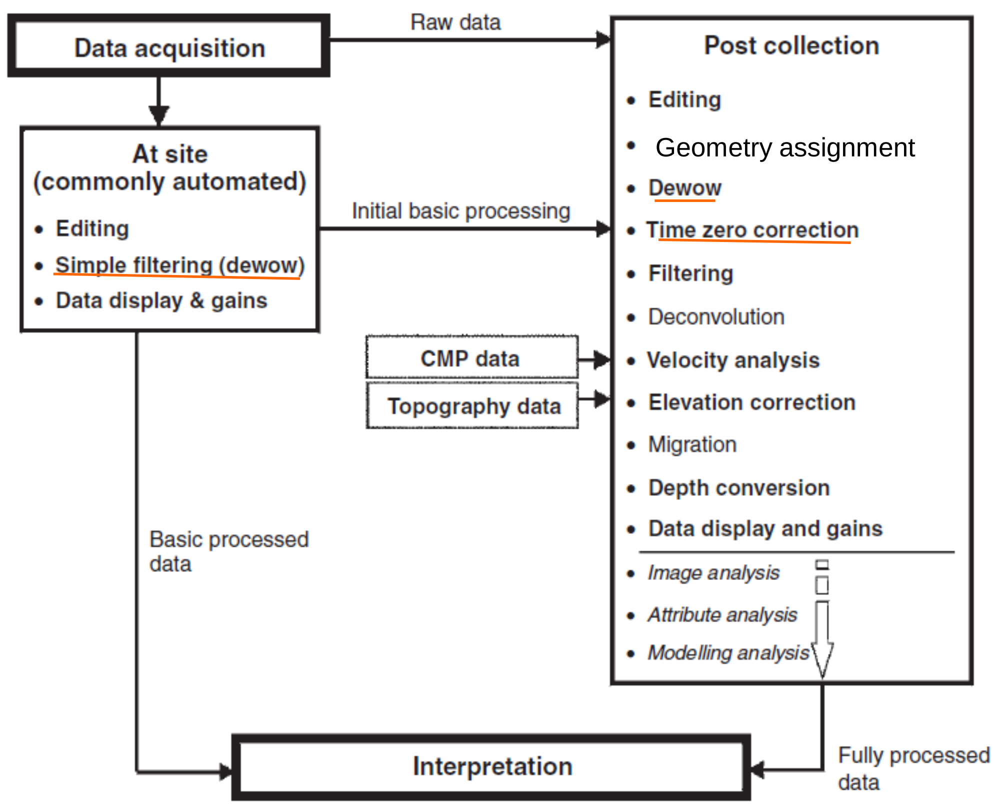
- ***Keep it simple** (also depending by the original data quality and objectives of the survey)*
- ***Keep it real ➔** Informative data instead of "looking good data"!*
- ***Understand what you are doing***
- ***Be systematic and consistent***

Ground Penetrating Radar: processing

*GPR **processing flow is never a standard** but it rather depends from the original data quality and it is strictly site dependent!*
GPR data processing is overall VERY SIMILAR to the one applied in reflection seismic, with some peculiar steps (in orange)

Typical GPR data processing flow for 2D Common-Offset datasets

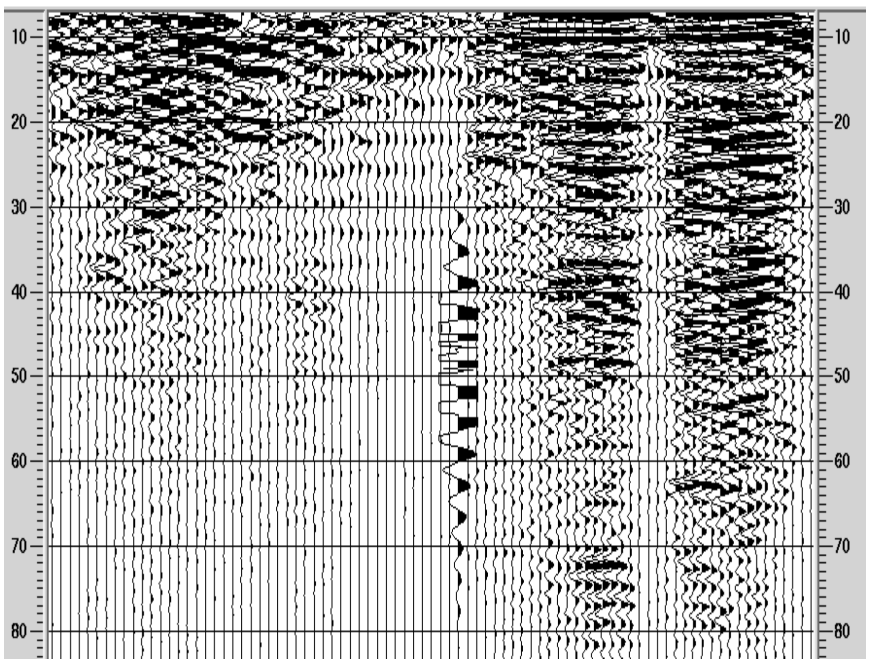
Usually just for QC purposes:
It is always better recording the data in the original version!

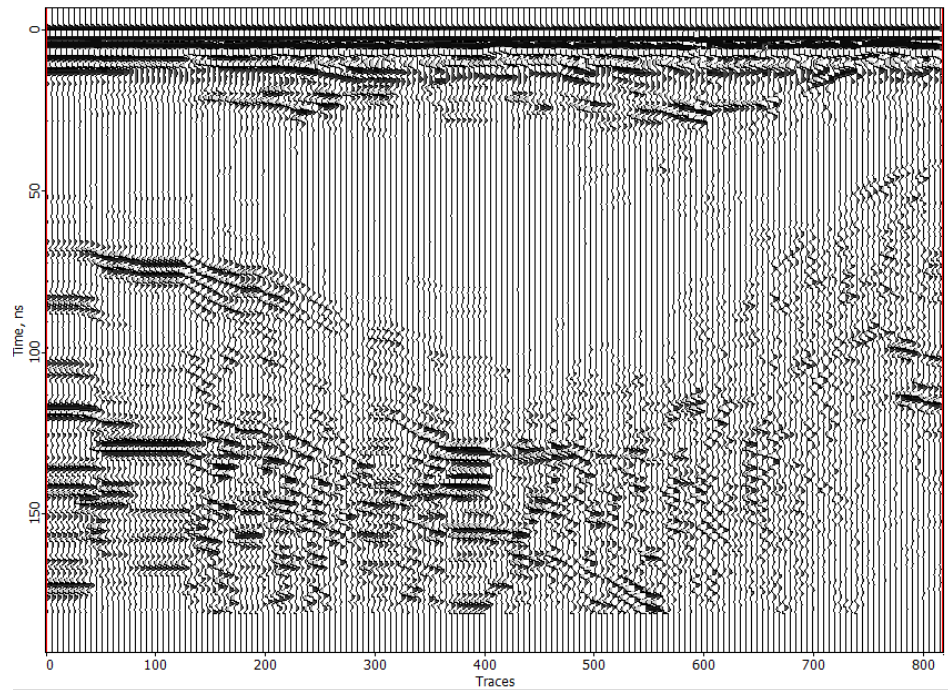


Modified from Jol, 2009

Ground Penetrating Radar: editing

Editing refers to all the (simple) algorithms applied to correct/cancel out specific data distortions or problems (e.g. spikes, clipped data, repeated traces, dead traces, …).

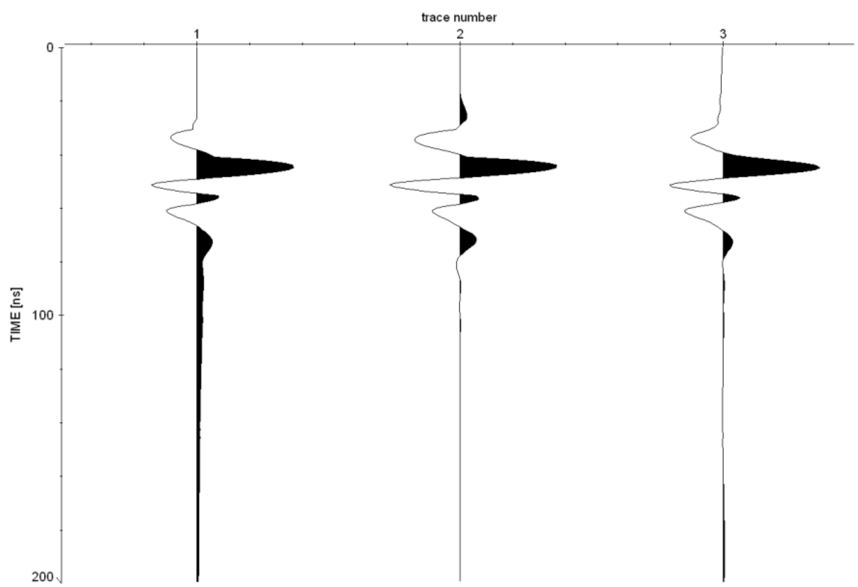


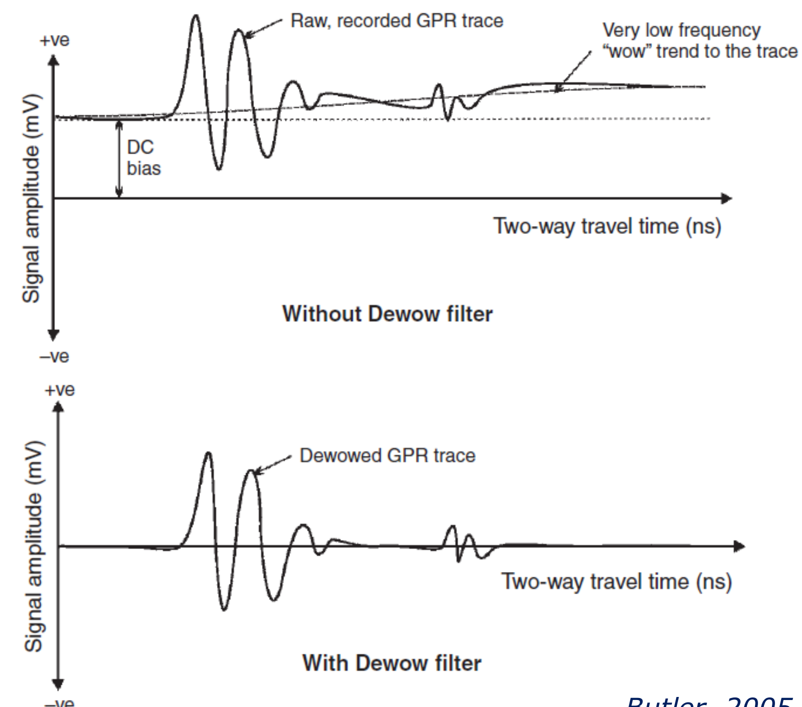


Even apparent small problems have to be "solved" at this stage in order to introduce later on possible artifacts and/or distorting the data interpretation

Ground Penetrating Radar: dewow

Wow effect is related to a DC noise component, i.e. a very low frequency trend typical of GPR measurements .
It is caused by the swamping or saturation of the recorded signal by early arrivals (i.e., ground/air wave) and/or inductive coupling effects.
De-wowing is a vital step as it reduces the data to a mean zero level and, therefore, allows positive–negative color filling to be used in the recorded traces (Figure 5.3). If applied incorrectly, the data will contain a decaying, low-frequency component that distorts the spectrum of the whole trace.

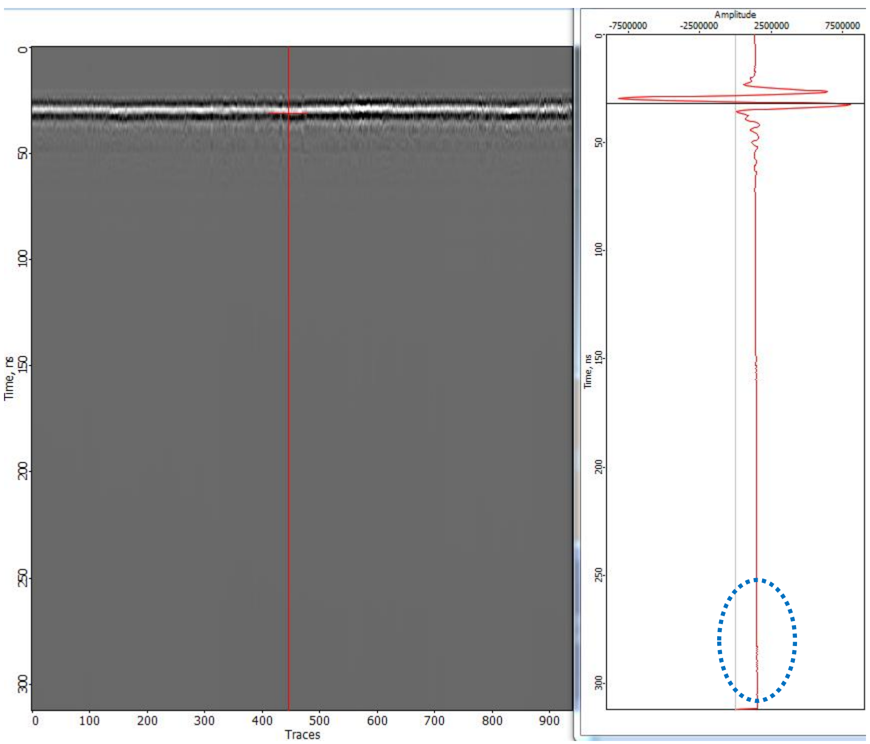


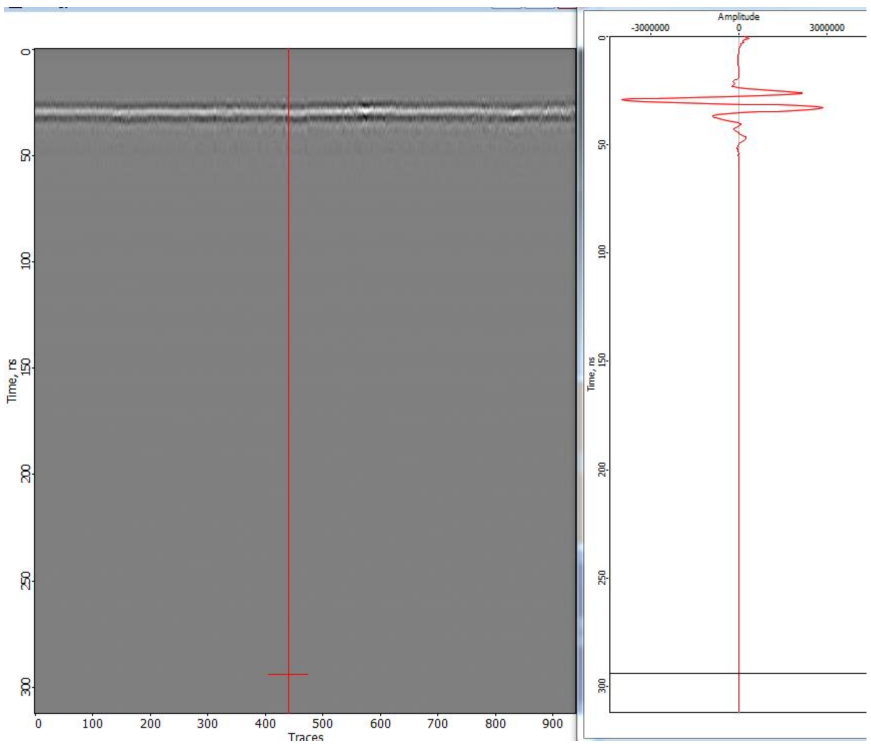


Butler, 2005

Ground Penetrating Radar: dewow

The easier way to remove the DC component is just to remove the mean samples value within a window usually centered at the end of the trace where the signal is components are negligible.





Another possible strategy is to apply an high frequency bandpass filter.

Ground Penetrating Radar: filtering (background noises)

GPR data are often affected by ringing phenomena occurring especially in lossy materials. In such environments, strong antenna–ground coupling and shallow near surface layers can cause significant reverberation in the signal that can mask signals.

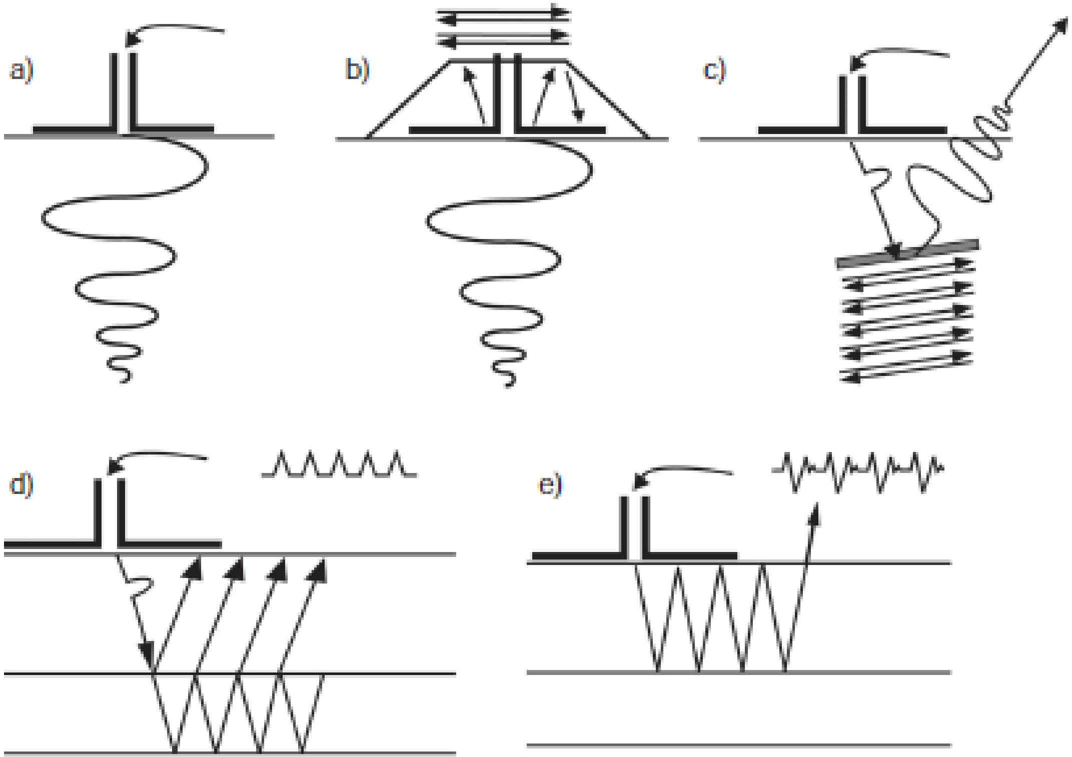
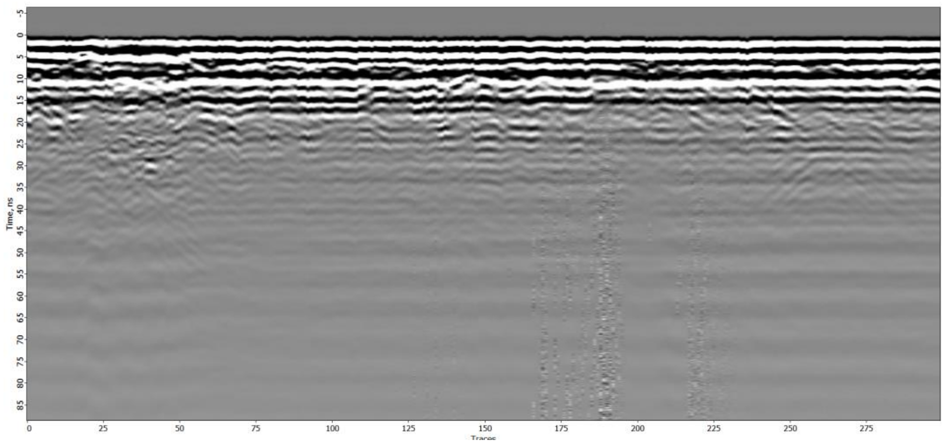


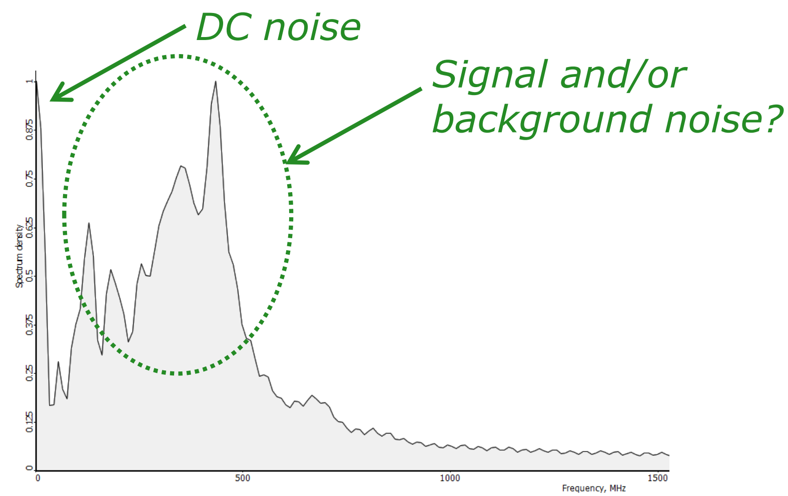
Figure 140. Reverberating GPR signals can come from many sources. Some of the more common are depicted here. (a) Undampened antenna current travels back and forth. (b) Currents generated on the antenna shield bounce back and forth. (c) Induced current runs back and forth on a metal object. (d) Partially transparent layer structure traps signal which can bounce back and forth. (e) Strong reflector generates signals which bounce back and forth between the object and the antenna or ground surface.

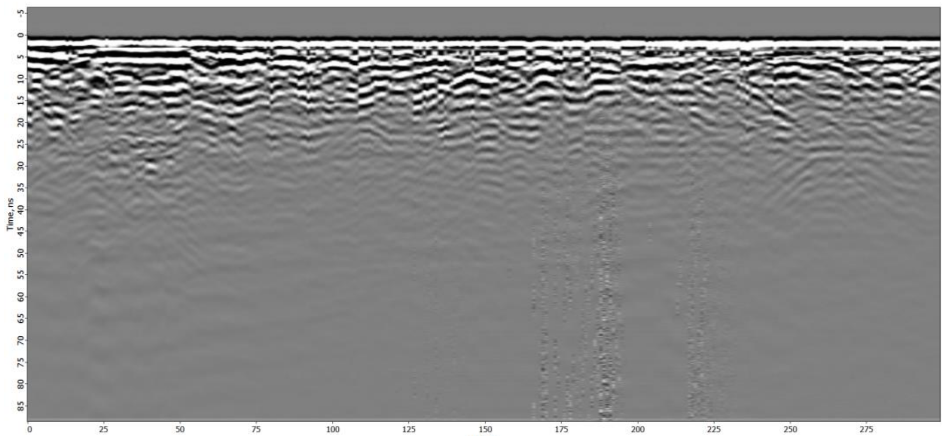
Butler, 2005

Ground Penetrating Radar: filtering (background noises)

Background noises can be canceled out exploiting the constant arrival times and amplitude → subtraction of the mean value calculated over a long enough trace windows sample by sample or for a few sample length.







Frequency filters don't work efficiently since the signal and background noise components are superimposed and very similar.

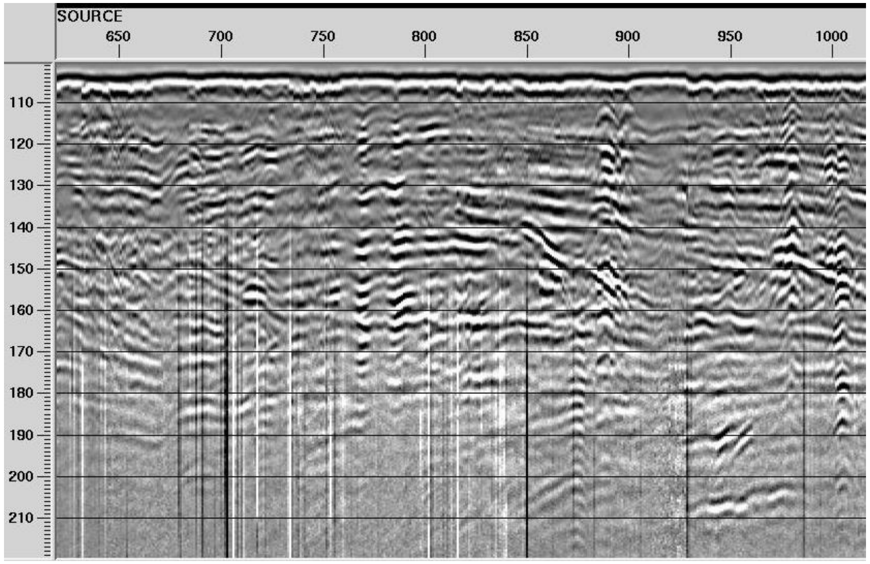
Ground Penetrating Radar: filtering

Temporal vs Spatial

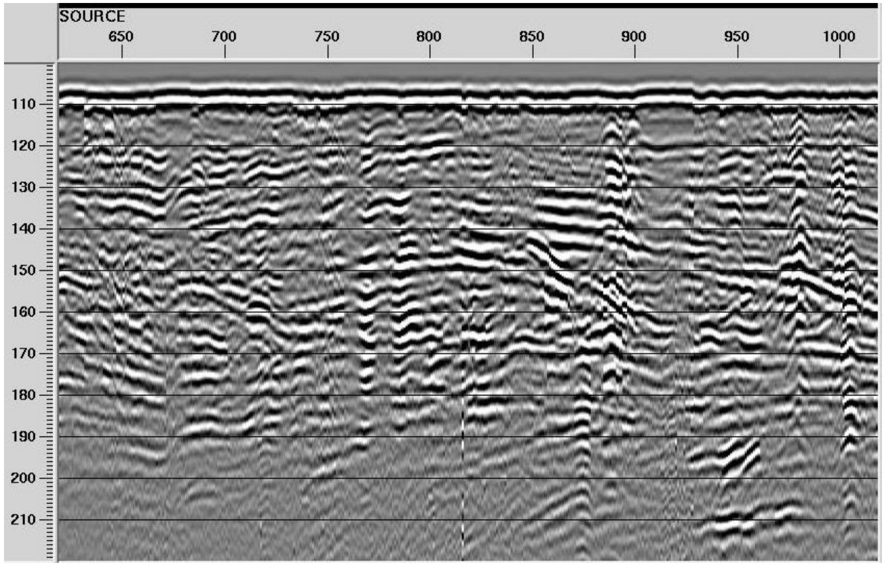
In general, filters can be classified into two basic types: temporal (down the individual traces in time) or spatial (across a number of traces in distance). These are often combined to produce advanced 2D filters that operate on the data in both time and space simultaneously.

Time vs frequency domain

Frequency filters are good only for removing noise at frequencies either higher or lower than the main GPR signal bandwidth. If a too narrow pass region is selected, then the filter will remove components of the actual recorded signal and the resultant GPR section will have less informative content than the original one. On the other hand time domain filters can discriminate only by using amplitudes, while spectral components are not exploited.

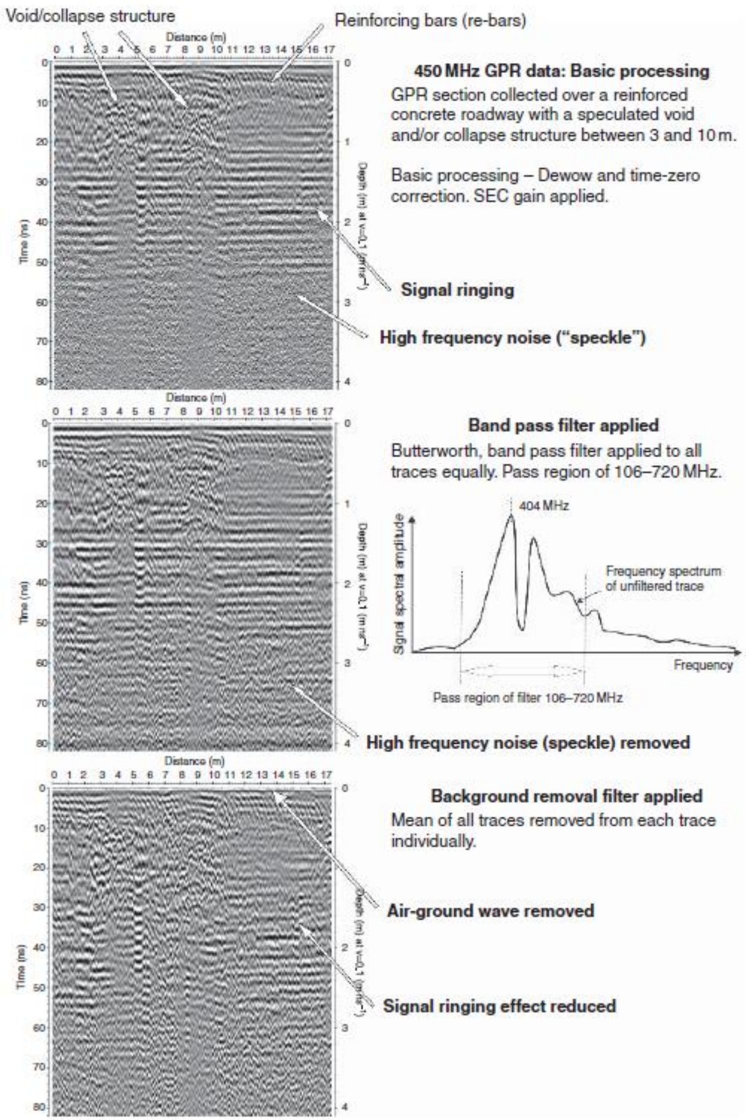


Unfiltered



After BP frequency filtering

Ground Penetrating Radar: filtering



Jol, 2009

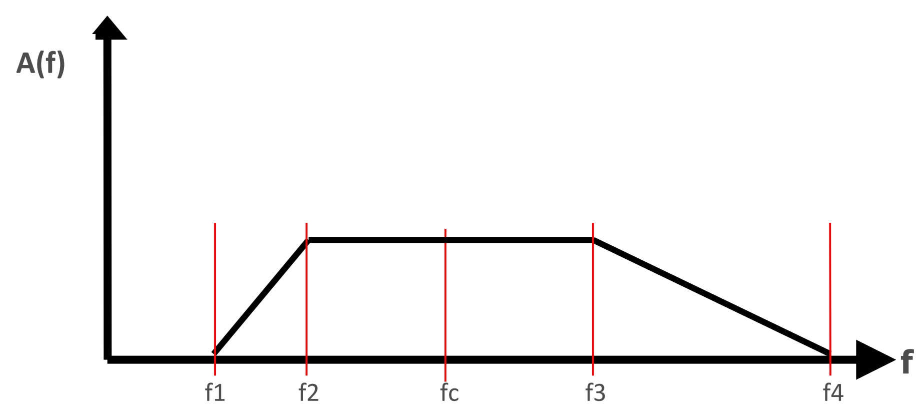
Often combined filters are applied, eventually also space- and time-varying in order to encompass space and time variations, respectively.

Frequency filters are designed with two main analyses referred as:

1) *Windowed frequency spectral analysis*

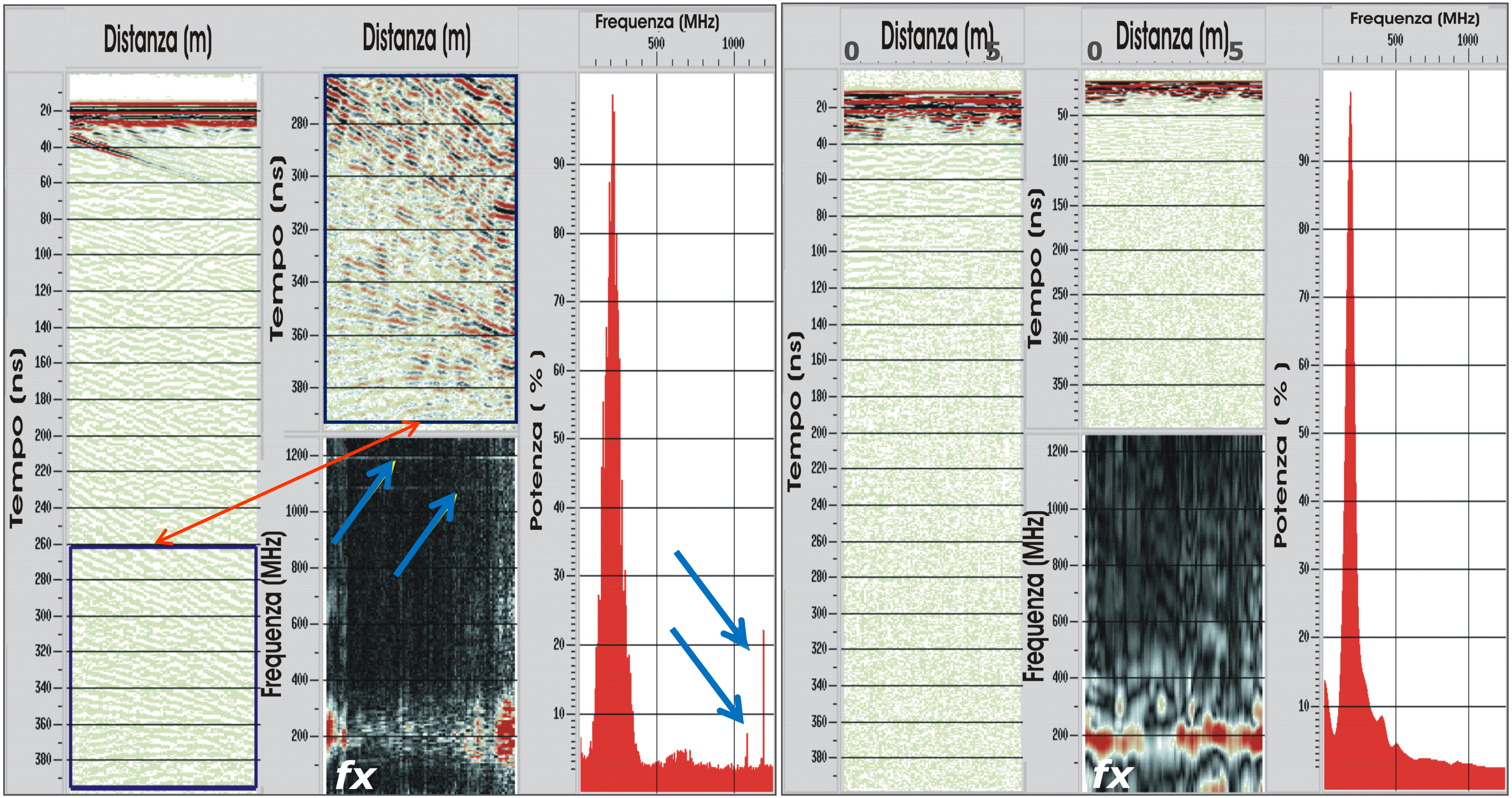
2) *Filtering scan*

Special cares have to be considered during frequency filter design in order to minimize Gibbs phenomena related to abrupt limits between pass and canceling zones. Usually a scalene trapezoidal filter shape is adopted.



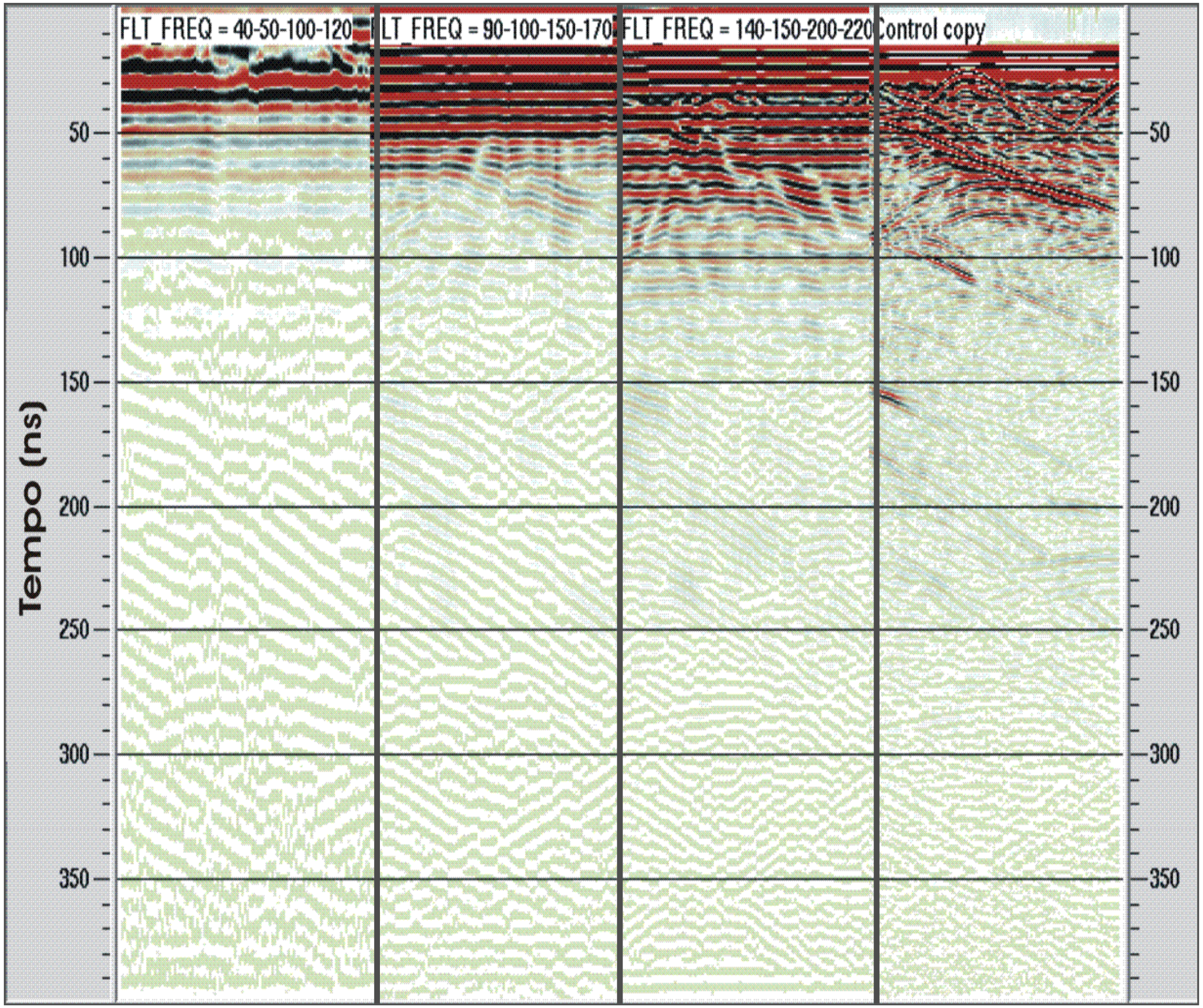
Ground Penetrating Radar: filtering

Spectral analysis and fx analysis



Ground Penetrating Radar: filtering

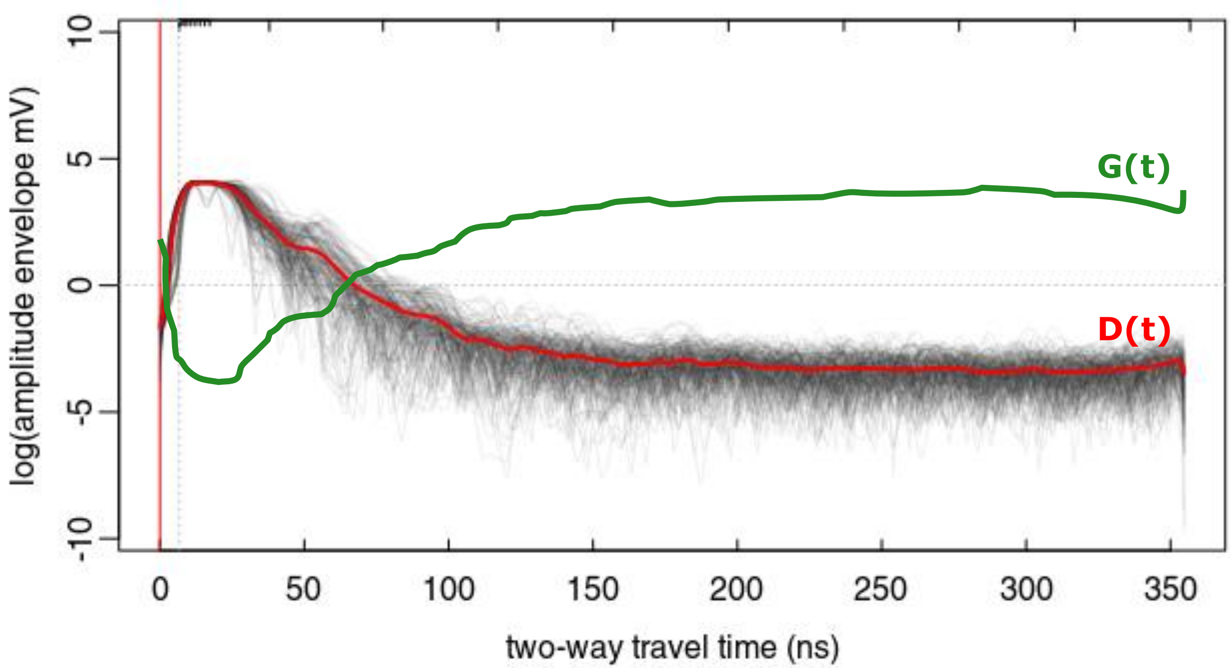
Filtering scan



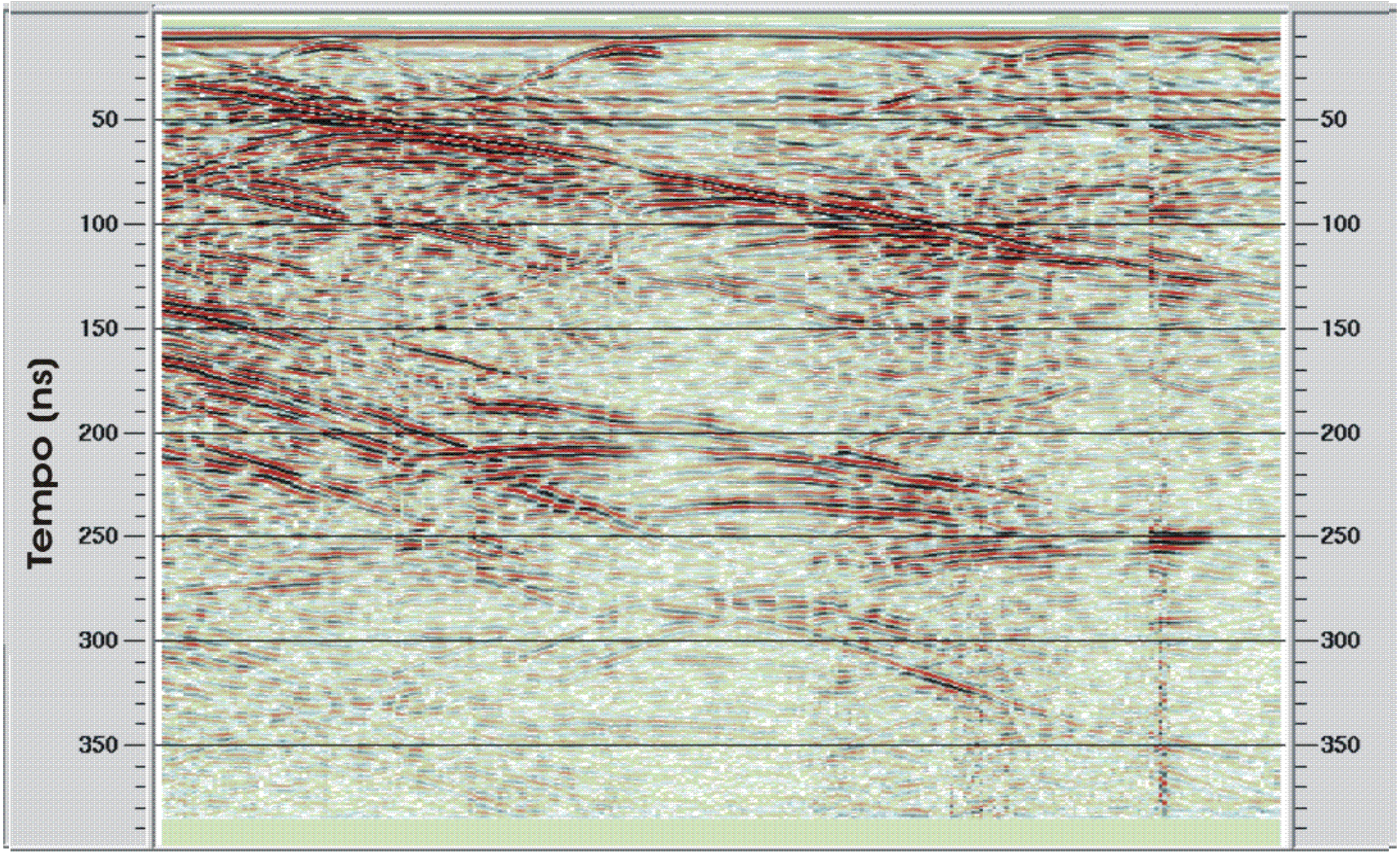
Ground Penetrating Radar: amplitude recovery

Amplitude recovery is essential in GPR data processing due to the high overall attenuation of EM waves, especially in high loss environments.
Different strategies can adopted to recover the amplitude attenuation.
Most efficient and physically compliant are:

- **Inverse of the decay curve**
- **"True amplitude" recovery** trying to analytically remove all the attenuation effects but the intrinsic attenuation which is highly informative on the subsurface media.

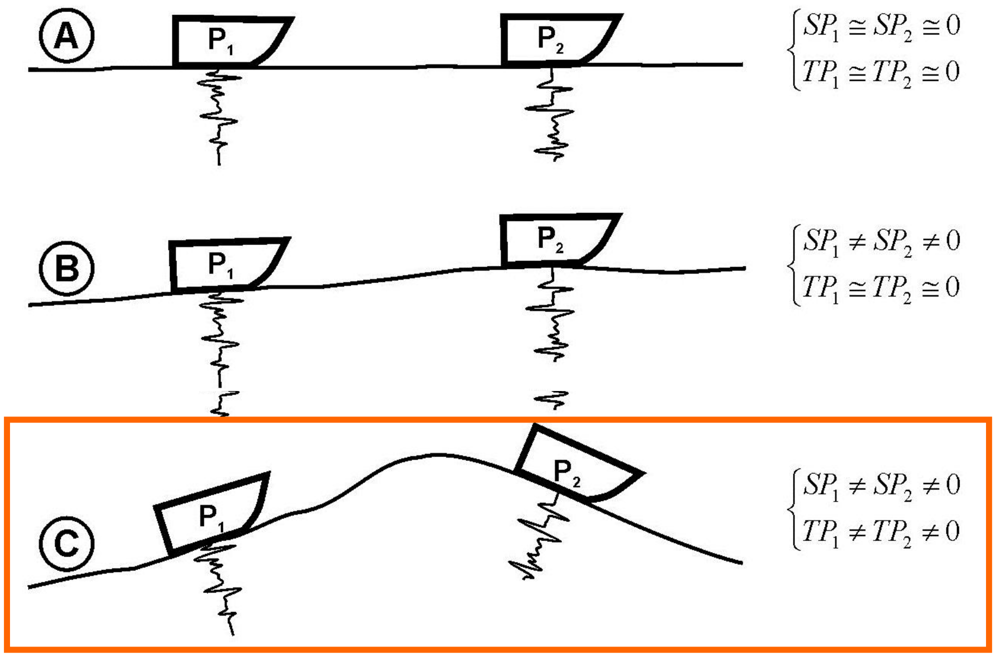


Ground Penetrating Radar: amplitude recovery



Before amplitude recovery the earlier arrivals are stronger than all the others, while after the recovery all the amplitude are balanced ➔ the reflectivity along the same horizon is almost constant, except where the geology actually changes.

Ground Penetrating Radar: topographic correction



Forte and Pipan, 2009

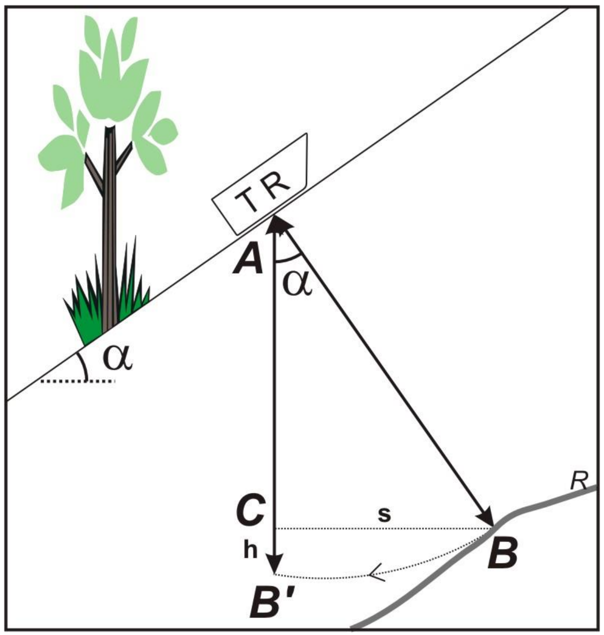
When the elevation changes along a GPR profile a "**Topographic correction**" is mandatory. This is a "static" correction, i.e. constant for each single trace and consists in a time or depth shift proportional to the altitude variations from a predefined DATUM.

This approach is accurate enough only when the topographic changes are gradual and the dip of the surface is less than about <u>10°</u> (Lehmann and Green, 2000).

<u>Otherwise additional corrections have to be considered and applied.</u>

Ground Penetrating Radar: topographic correction

An accurate approach encompasses dedicated imaging and additional terms to the migration algorithm, but this is difficult to apply. Approximated solutions have been proposed (e.g. Forte and Pipan, 2009).



$$s = \frac{v(t)t}{2} sen\alpha \qquad h = \frac{v(t)t}{2}(1 - \cos\alpha)$$

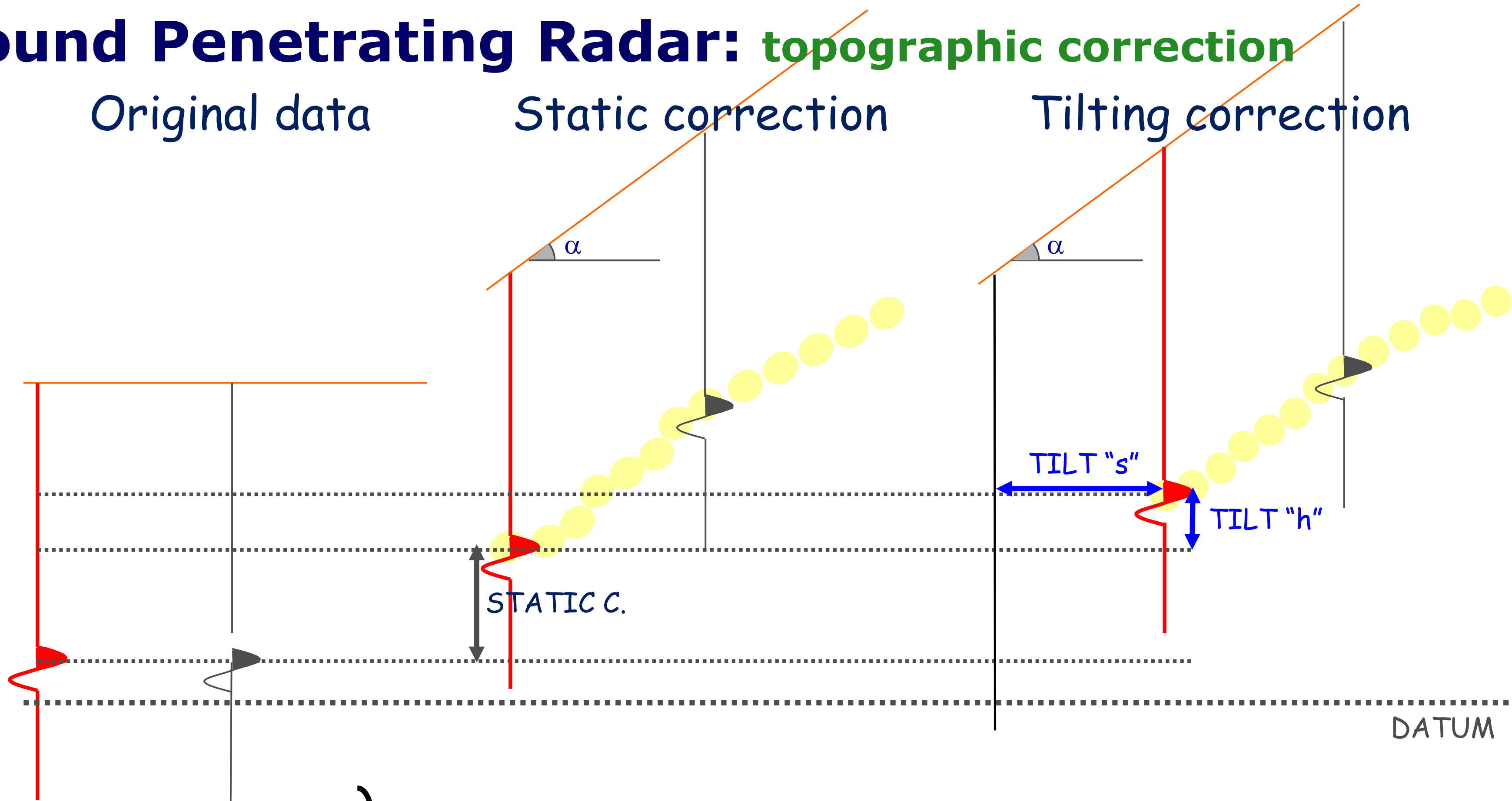
ORIGINAL DATA
↓
STATIC CORRECTION
↓
TILTING CORRECTION (h and s components)
↓
MIGRATION
↓
FINAL DATA

Angle α can be estimated for each trace by the equation:

$$\alpha = \tan^{-1}\frac{dz}{dx}$$

dz is the elevation change between two acquisition points and *dx is their distance.*

Ground Penetrating Radar: topographic correction

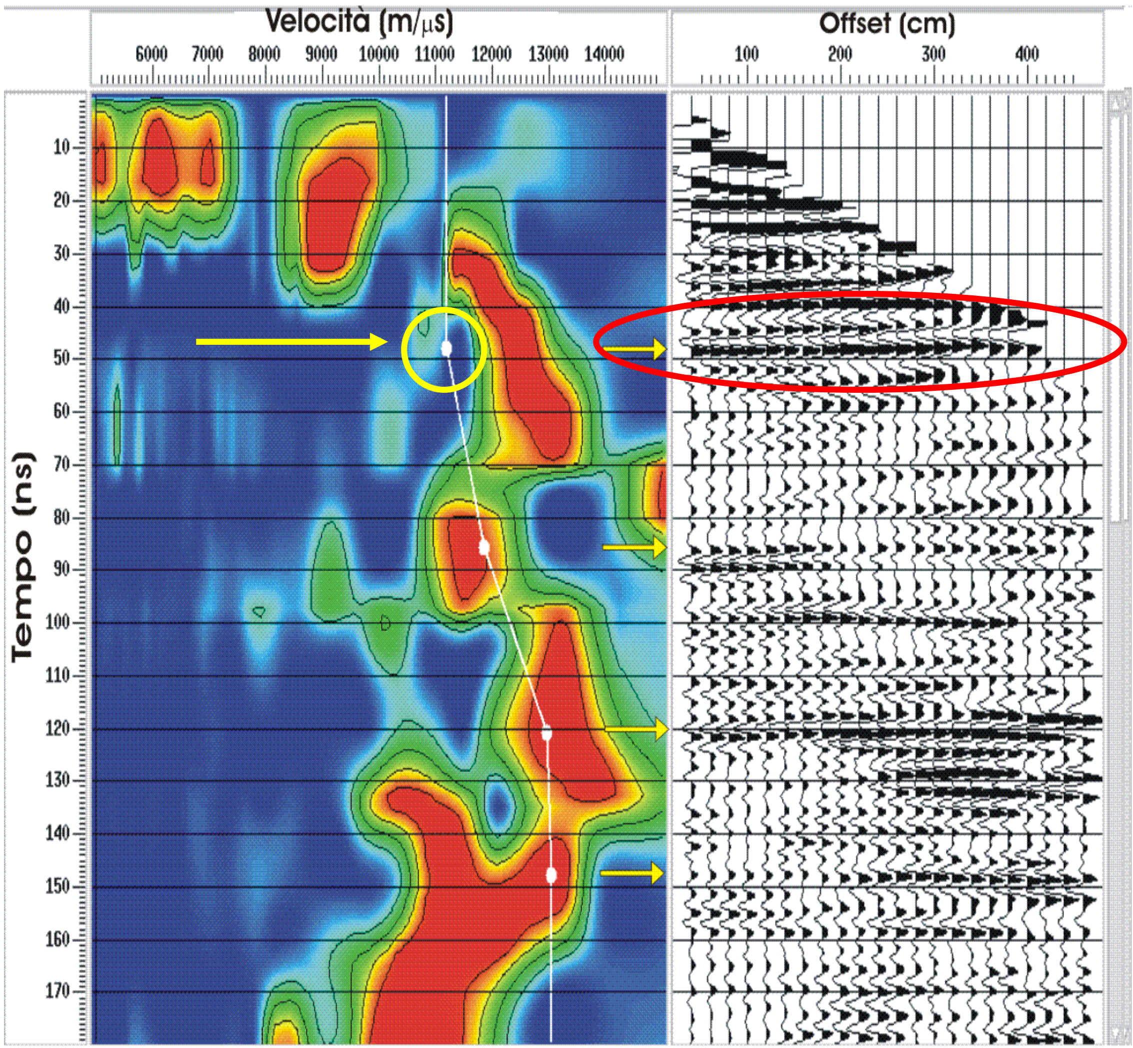


$$h = \frac{v(t)t}{2}(1-\cos\alpha)$$

$$s = \frac{v(t)t}{2} sen\alpha$$

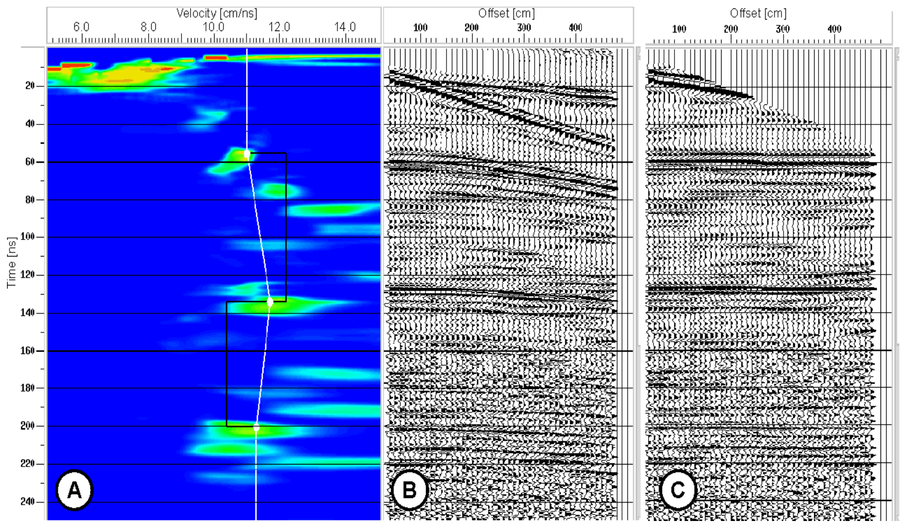
1) For α=0 both additional tilting components are null
2) For v=cost ➔ The correction is constant for all the trac esamples ➔STATIC
For v=v(t)=variable ➔ DYNAMIC CORRECTION

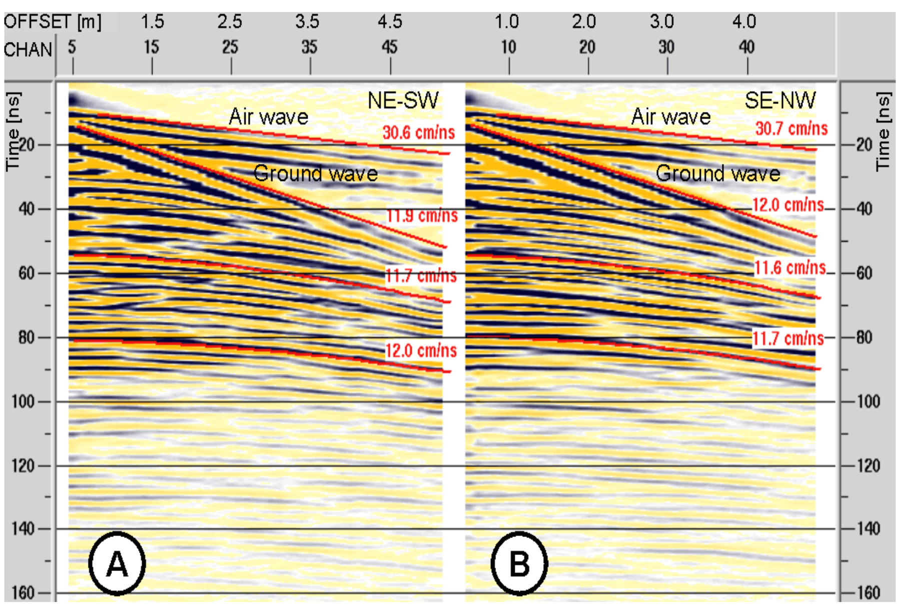
Ground Penetrating Radar: velocity analysis



When multifold data are available, then different algorithms can be used to estimate the EM velocity field. Most of them are based on the **reflection hyperbolas analysis.**

Ground Penetrating Radar: velocity analysis





The velocity analysis is essential to obtain correct:

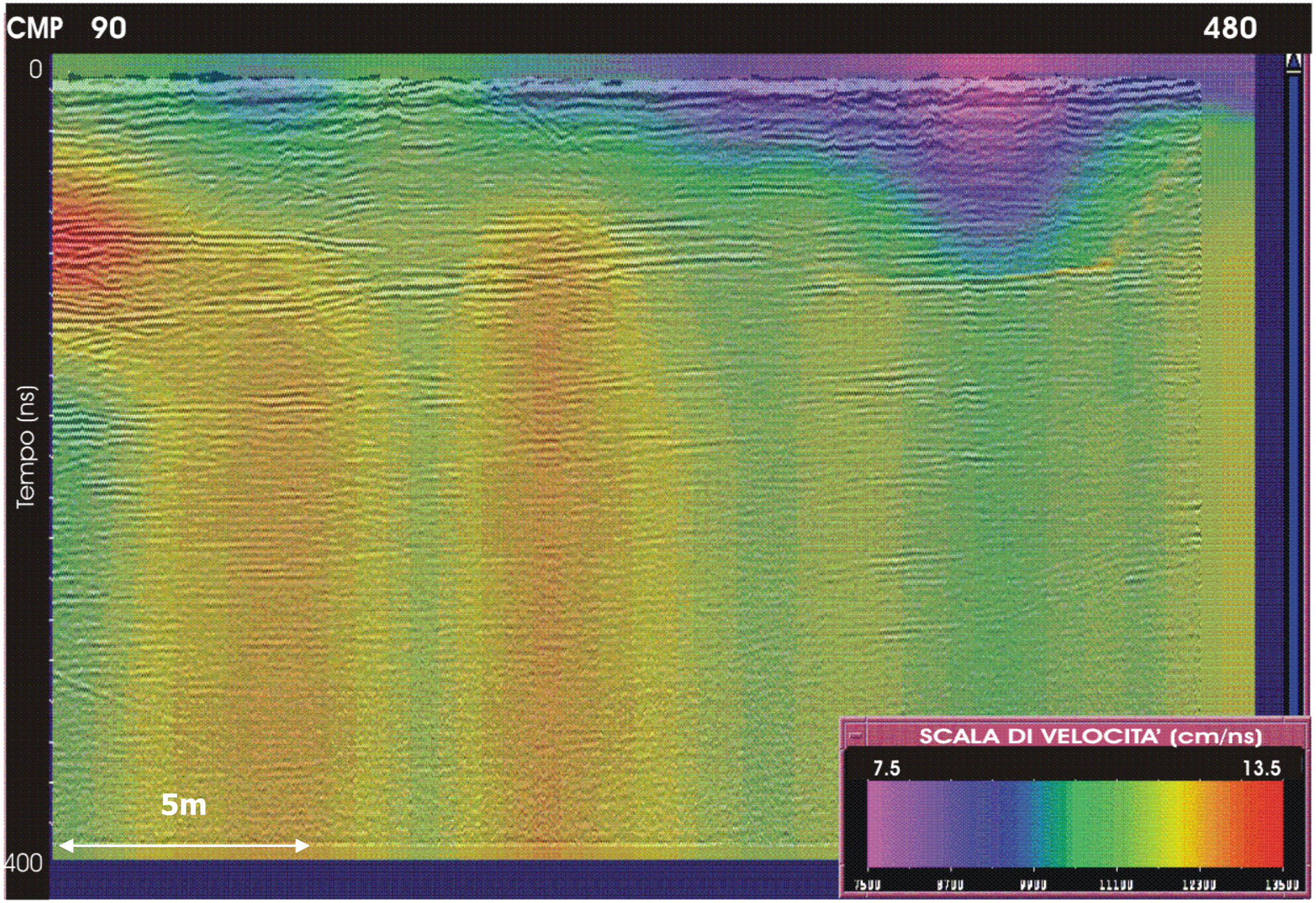
- Topographic/static correction
- Depth conversion
- True amplitude recovery (spherical divergence parameterization)
- Time/depth imaging
- Characterization of the materials and evaluation of anisotropy and inhomogeneity

For multifold data, integrated velocity analyses are applied:, including:

- Semblance,
- Constant Velocity Stack - CVS,
- Constant Velocity Gather - CVG,
- Direct reflection hyperbolas fitting

Ground Penetrating Radar: velocity analysis

It is therefore possible to reconstruct an accurate and realistic EM velocity field, which gives additional quantitative information and allows a precise depth conversion and imaging.

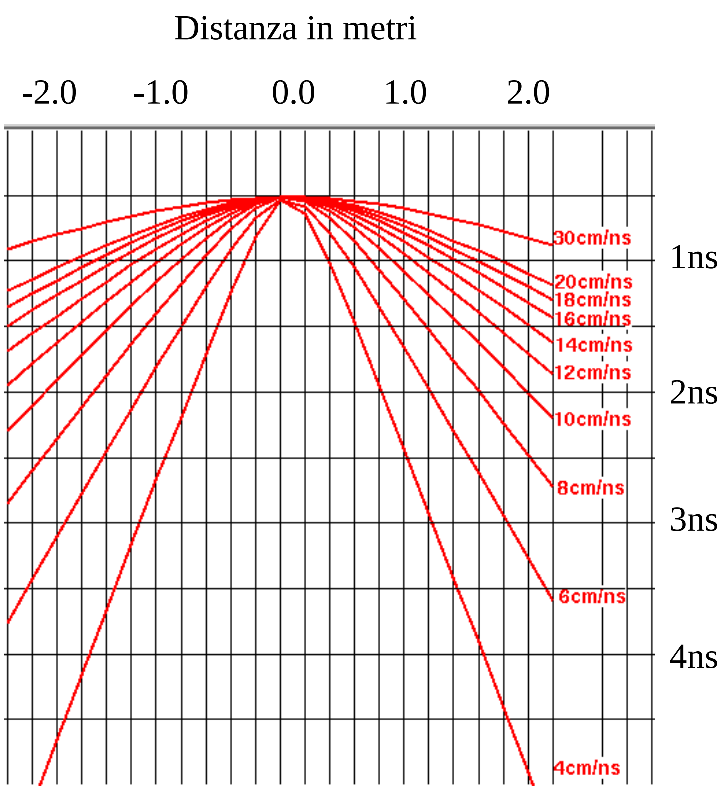


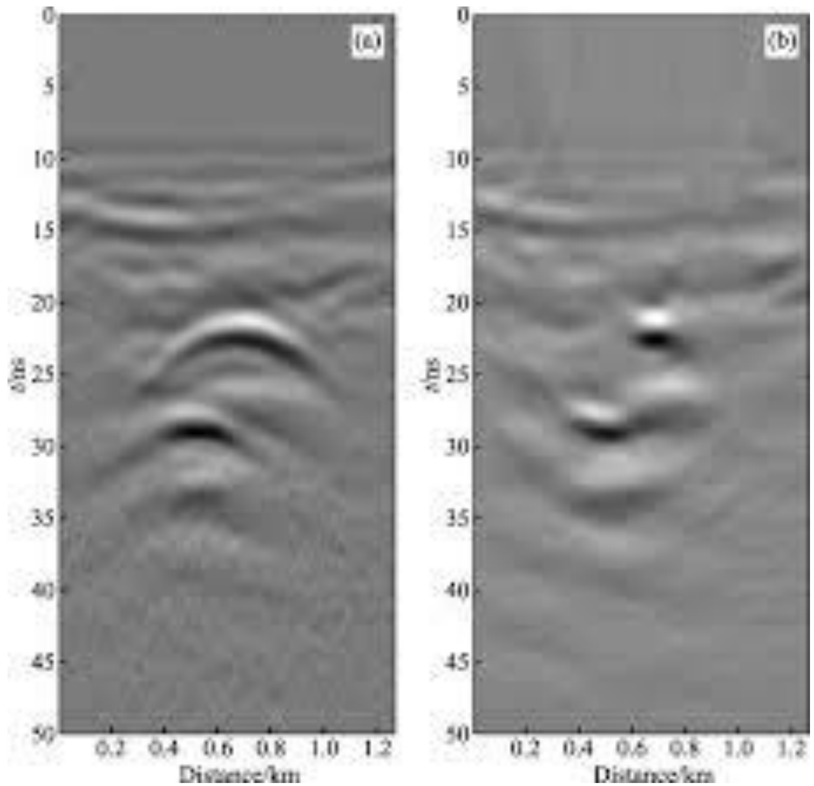
Ground Penetrating Radar: velocity analysis

When just common offset data are available (as in most of the cases!) therefore the only possible strategy to estimate the EM velocity from the data itself exploits the **diffraction** (i.e. scattering) **hyperbolas**.

Different approaches are used. The simplest are:

1) **Hyperbola fitting**
2) **Migration velocity scan**



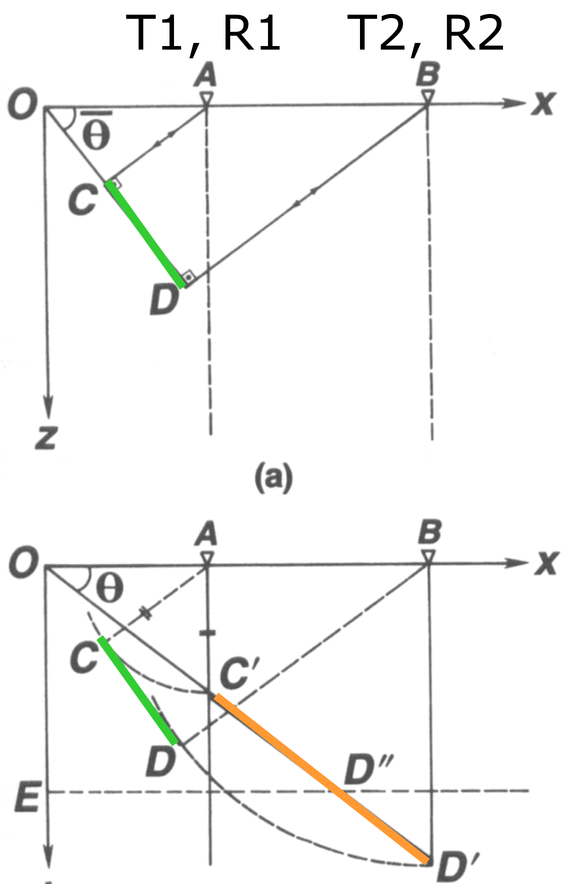


Several other algorithms have been proposed (an example is provided by Dossi et al., 2020)

Ground Penetrating Radar: migration

Migration algorithms are one of the most crucial steps in GPR (and reflection seismics) processing because they are essential to recover the actual positions and shapes of the structures

➔Subsurface imaging ➔ from P(x,y,z=0,t) to P(x,y,z,t=0)



(a)

(b)

Here, for simplicity we consider reflections of rays produced by a co-located source (T) and receiver (R)

Considering the triangle ODB and the sine definition:

$$sen\bar{\theta} = \frac{\overline{BD}}{\overline{OB}}$$

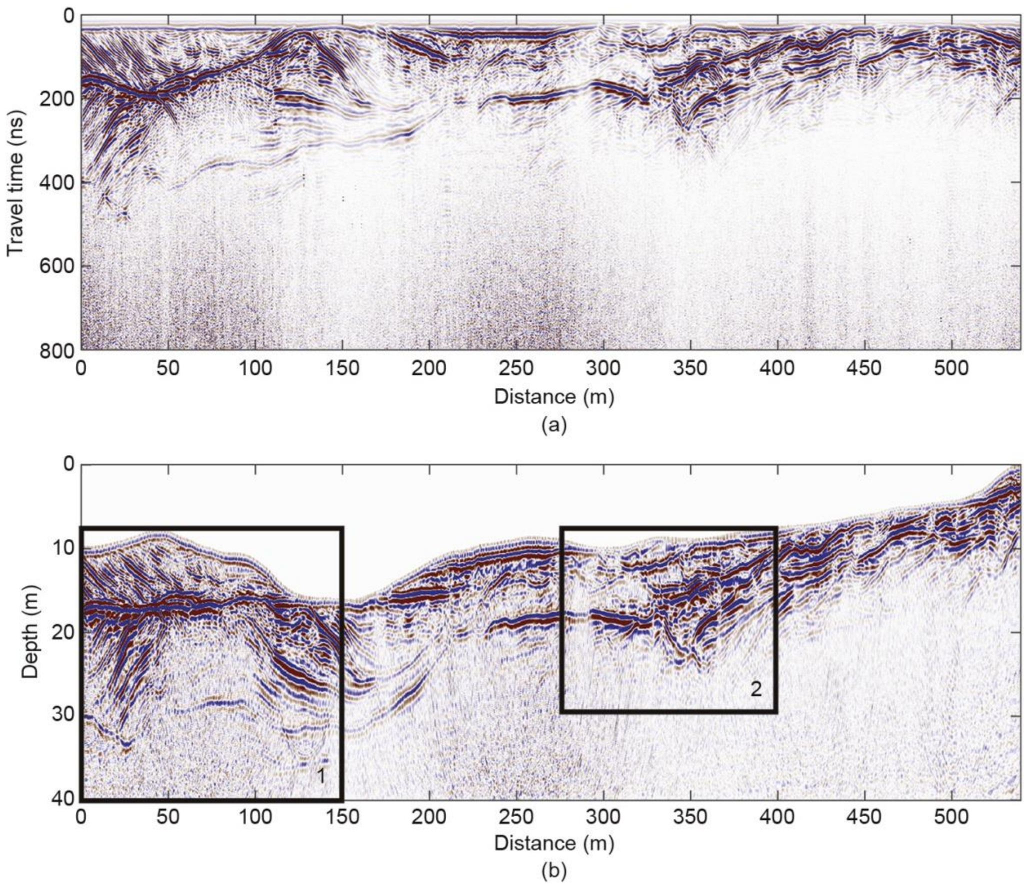
Considering the triangle OD'B and the tangent definition:

$$\tan\theta = \frac{\overline{BD'}}{\overline{OB}}$$

Therefore: $\tan\theta = sen\bar{\theta}$

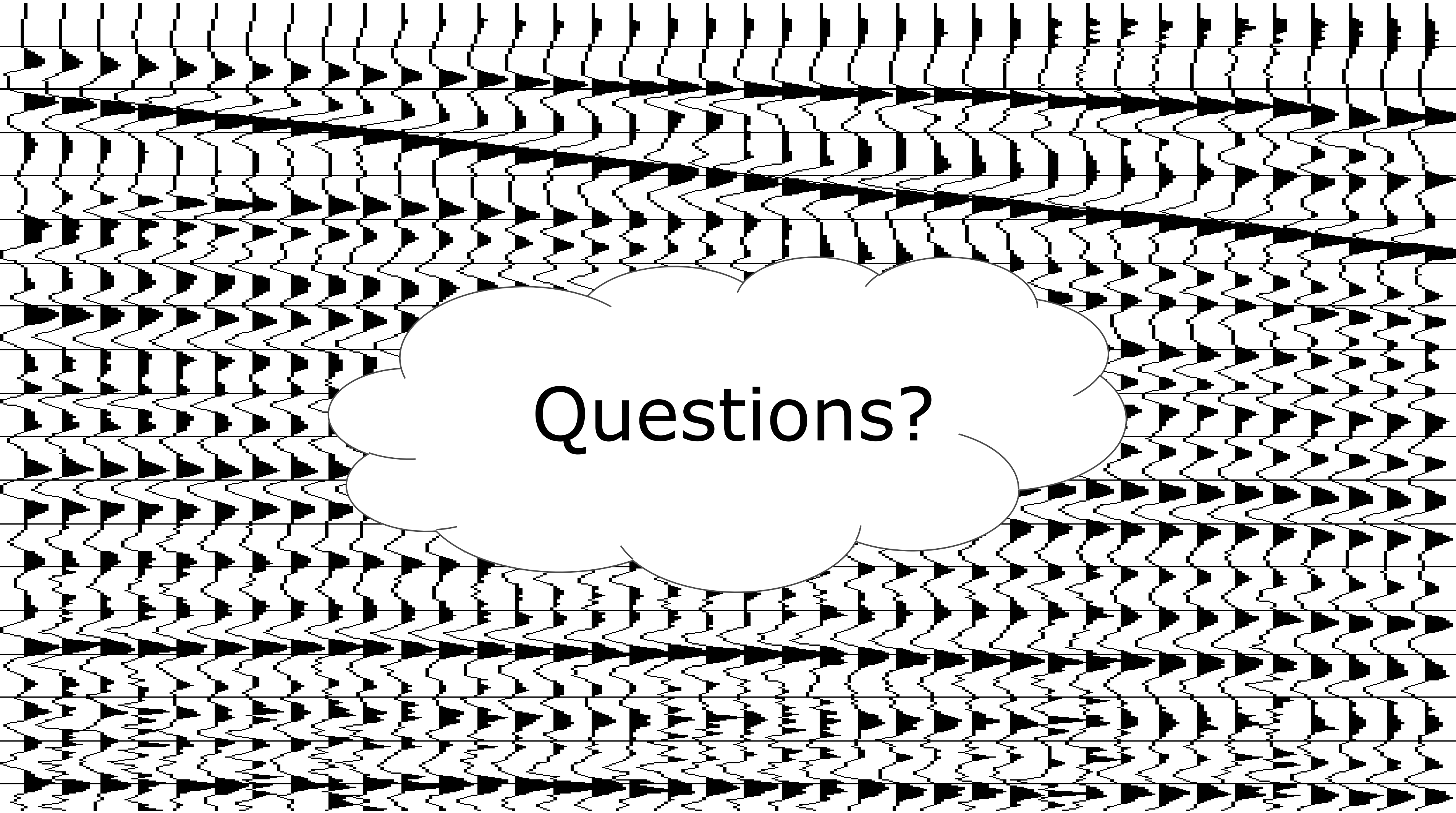
Ground Penetrating Radar: migration

There are a plethora of possible migration algorithms (2D, 3D, in time, in depth, pre- and post-stack,…) but for all of them the most crucial parameter is the accuracy of the estimated EM velocity field.



Bradford_et al., 2018

(a) the preprocessed data prior to migration, and (b) the data after RTM from topography


Questions?