MAGNETIC RESONANCE SOUNDING:

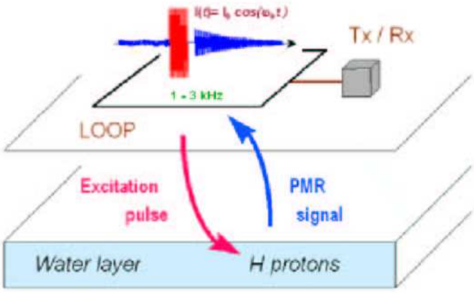
step-by-step operation of NUMIS systems

The Magnetic Resonance Sounding method (MRS):

The MRS is the only non-invasive method which directly studies groundwater reservoirs from surface measurements:
A pulse of current, at a given frequency, is transmitted into a loop.
The signal produced in return by the H protons (water molecules) is measured within the same loop.

DIRECT DETECTION OF GROUNDWATER

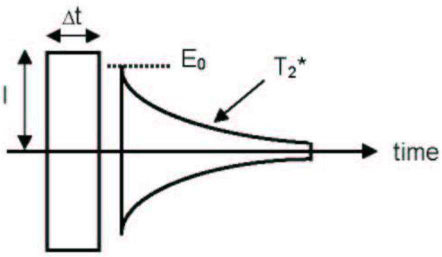
water content
permeability estimate
depth of water layers



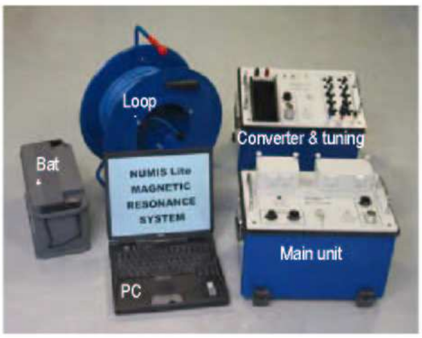
Principle of the MRS method

How to carry out a Magnetic Resonance Sounding ?

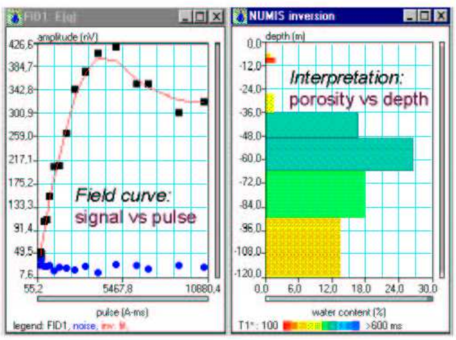
1- ***Measure the Earth magnetic field*** to know the frequency to apply
2- ***Transmit a pulse of current*** into a loop, at this frequency
3- ***Measure the amplitude*** of the water MR signal (≈ porosity)
4- ***Measure the time constant*** of the signal (≈ mean pore size)
5- ***Change the pulse intensity*** to modify the depth of investigation
6- ***Use the inversion program*** to get the porosity versus the depth



E_0: Initial amplitude of signal (nV)
Proportional to the **water content** (%)
T_2^*: Decay time constant of signal (ms)
Related to the **mean pore size** (permeability)
I. Δt: Excitation pulse moment, Q , (A.ms)
Related to the **investigation depth** (m)



NUMIS Lite, down to 50m depth



Raw data and interpretation results

NUMIS Poly, down to 100-150m depth

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MRS DATA ACQUISITION: FIELD SET-UP

SET-UP THE LOOP WIRE

- ***set-up the cables*** of the loop according to the investigation depth and to noise conditions.
- ***the maximum investigation depth*** mentioned in the table is given for a resistive ground.
- in case of ***high noise***, use the noise-tester to select the places.
- The main diagonal of the eight-shape loop must be set ***parallel to power lines*** to minimize the noise

conditions	loop shape	**NUMIS Lite** 240m wire length	**NUMIS Poly** **(1 converter)** 400m wire length	**NUMIS Poly** **(2 converters)** 600m wire length
standard	square (L)	L= 60m max depth 50m or L= 30m 2 turns max depth 25m	L= 100m max depth 100m	L= 150m max depth 150m
noisy	eight square (L)	L= 30m max depth 25m	L= 50m max depth 50m	L = 75m max depth 75m

NOISE SOURCES IN MRS MEASUREMENTS

- **ACTIVE CONDUCTORS** : POWER LINES, INDUSTRIAL ACTIVITY, HOUSES, RADIO ANTENNAS, MOTORS, PUMPS, ...

- **PASSIVE CONDUCTORS**: BURIED PIPES, FENCES, ...

- **NATURAL FIEDS**: CYCLIC SOLAR ACTIVITY, RAIN AND MAGNETIC STORMS

MEASURE THE EARTH MAGNETIC FIELD

- ***with a standard magnetometer***, take readings of the amplitude of the Earth magnetic field every 10m in two perpendicular lines over the loop surface.
- ***compute the average amplitude B_0***: the Larmor resonance frequency is f (Hz) = 0.04258 x B_0 (nT).
- ***the lateral variation*** of the amplitude should be lower than +/- 20 nT for good measurements (~ +/- 1 Hz)

MEASURE THE GROUND MAGNETIC SUSCEPTIBILITY

- ***measure the magnetic susceptibility*** of the ground or of the outcrops in various places around the loop area.
- for susceptibility ***values lower than 10^{-3} SI units***, the MRS measurements are usually good. Between 10^{-3} and 10^{-2} they may be good or difficult to carry out, depending on sites.
- above 10^{-2} SI units, which is often the case ***in volcanic rocks***, no MRS signal is usually observed from water.

BEFORE STARTING

- ***CAPACITOR TUNING:*** as the loop is mainly inductive, capacitors have to be used to increase the maximum current available in the loop. This operation has to be made manually, after the introduction of the frequency: the screen of the PC displays the combination of capacitors to apply. Usually, a given combination is convenient for an area several tens km wide
- ***PULSE MOMENT NUMBER:*** a pulse moment value determines the depth of investigation. To carry out a full sounding, usually 10 pulse moments are sufficient for NUMIS Lite, and 16 for NUMIS Plus. The values of the moments (logarithmically spaced) are automatically fixed once their number has been introduced
- ***STACKING NUMBER:*** the stacking number has to be determined in relation with the local noise level and the signal level. It can be set for instance to 64, 96, 128, 192…
- ***PRELIMINARY SOUNDING:*** before starting the full sounding, it is recommended to carry out a preliminary sounding with 3 or 5 pulse moments, on the one hand to confirm the frequency to use (1 to 2 Hz difference can be observed with the magnetometer value, due to the variations of the Earth field), on the other hand to determine the stack number to use to get an adequate data quality

PRACTICAL ASPECTS

- ***Two 12V batteries*** supply NUMIS Lite and NUMIS Plus when used with 1 converter. Four of them are necessary for NUMIS Plus with 2 converters
- ***the PC*** needs a separate battery
- it is recommended ***to recharge*** the batteries every night, even if sometimes one set can last 2 days
- ***tighten all the equipment cords*** including the battery cords, and all the loop cables, because of high currents going through the loop
- ***do not touch any cable*** during measurement due to high voltages

MAGNETIC RESONANCE SOUNDING DATA SHEET

IRIS INSTRUMENTS

area:
equipment:
date:
operator:

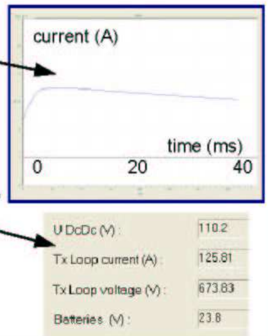
start time	end time	duration (h.mn)	sounding file name	square side (m)	8-square side (m)	field (nT) Δ field (nT)	frequency (Hz)	moment #	stack #	noise (nV)	Qmax (A.ms)	Vmax (dc V)	impedance (ohm)	capacitors (C1 ; C2)
9:15	10:30	1:15	Test_01	60	-	46 145 +/- 10	1965.8	10	64	1200	4 000	110	5.8	(1-2 ; 1-1)
...														

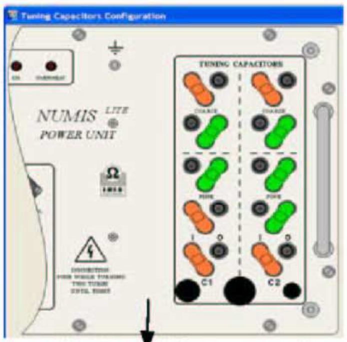
MRS DATA ACQUISITION: CONFIGURATION WINDOW

The **Prodiviner NUMIS acquisition software** basically consists in three windows :

- the ***"configuration" window*** for initialising the measurement (this page)
- the ***"signal" window*** for following up the readings (next page)
- the ***"system" window*** for checking some technical parameters (see right)

The ***"system" window*** gives the shape of the current (A) versus time (ms), also measurements of converter voltage, output current, output voltage, battery voltage, gain factor, phase signal, …



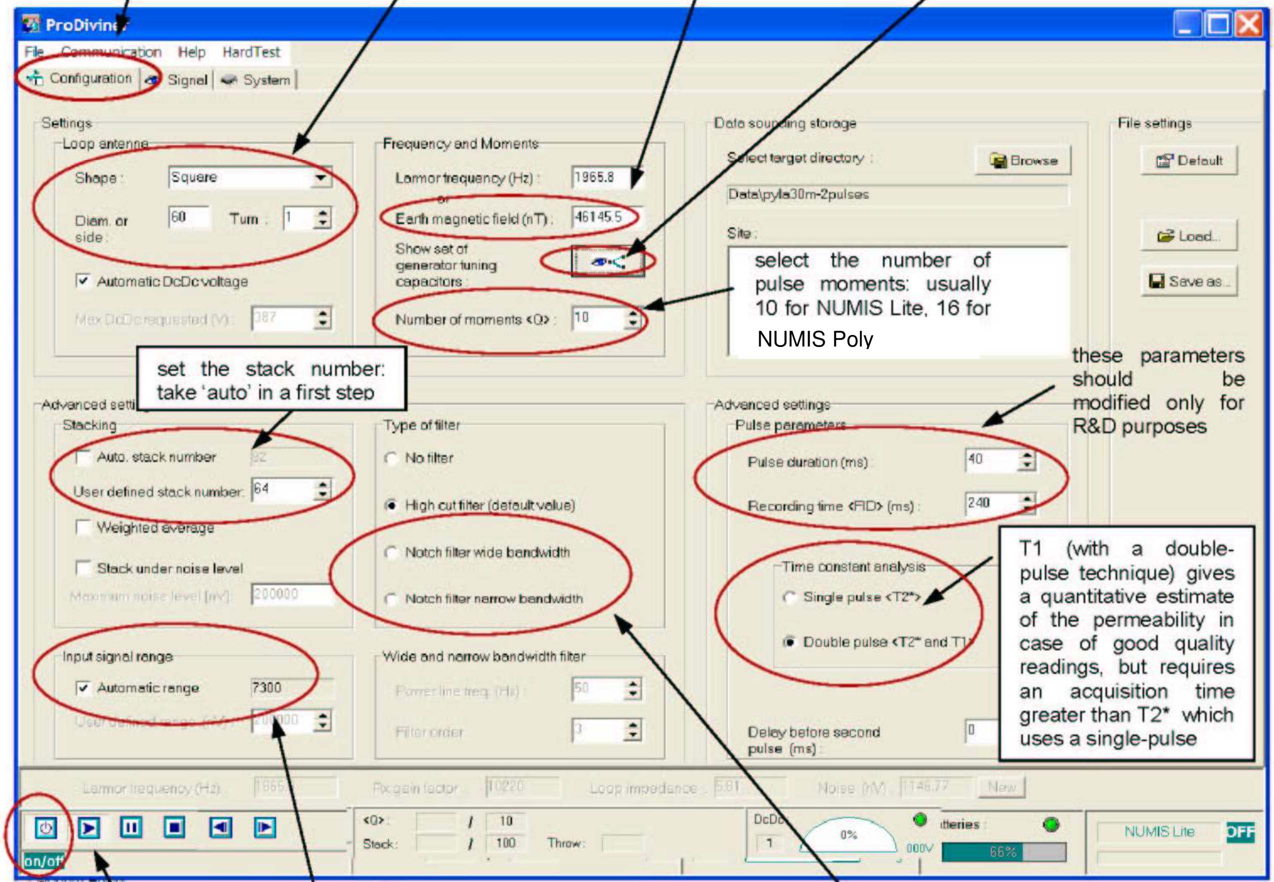


A combination of tuning capacitors has to be manually set-up, in relation with the frequency and the size of the loop; click on the icon to know the combination to apply (see above)

"configuration" window

Introduce the shape (square, eight-square, …) and the dimension of the loop

Introduce the value of the Earth magnetic field given by the magnetometer



select the number of pulse moments: usually 10 for NUMIS Lite, 16 for NUMIS Poly

set the stack number: take 'auto' in a first step

these parameters should be modified only for R&D purposes

T1 (with a double-pulse technique) gives a quantitative estimate of the permeability in case of good quality readings, but requires an acquisition time greater than T2* which uses a single-pulse

Input voltage range (4 000 to 200 000nV): take 'automatic', except in case of repetitive bad stacks, where the pre-selected value has to be increased (see next page)

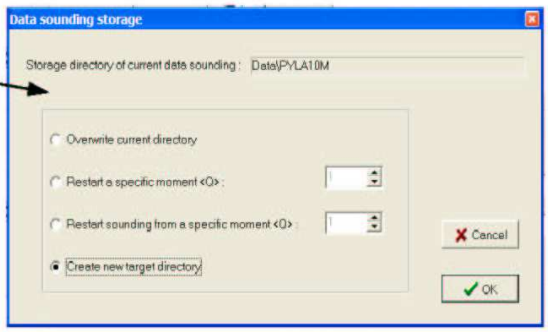
Use the notch filters when power lines are close to the sounding place: "wide" if Δf > 5 Hz, "narrow" if Δf < 5 Hz

Use the ON / OFF key to connect or disconnect the NUMIS equipment to the PC

Once the various parameters have been introduced, press the "start" key: enter the name of the file where the data will be stored. Then:

Calibration in progress
please wait…

At the end of this receiver tuning period (about 2 minutes), a few test pulses are transmitted, then the "signal" window is displayed (see next page)



MRS DATA ACQUISITION: SIGNAL WINDOW

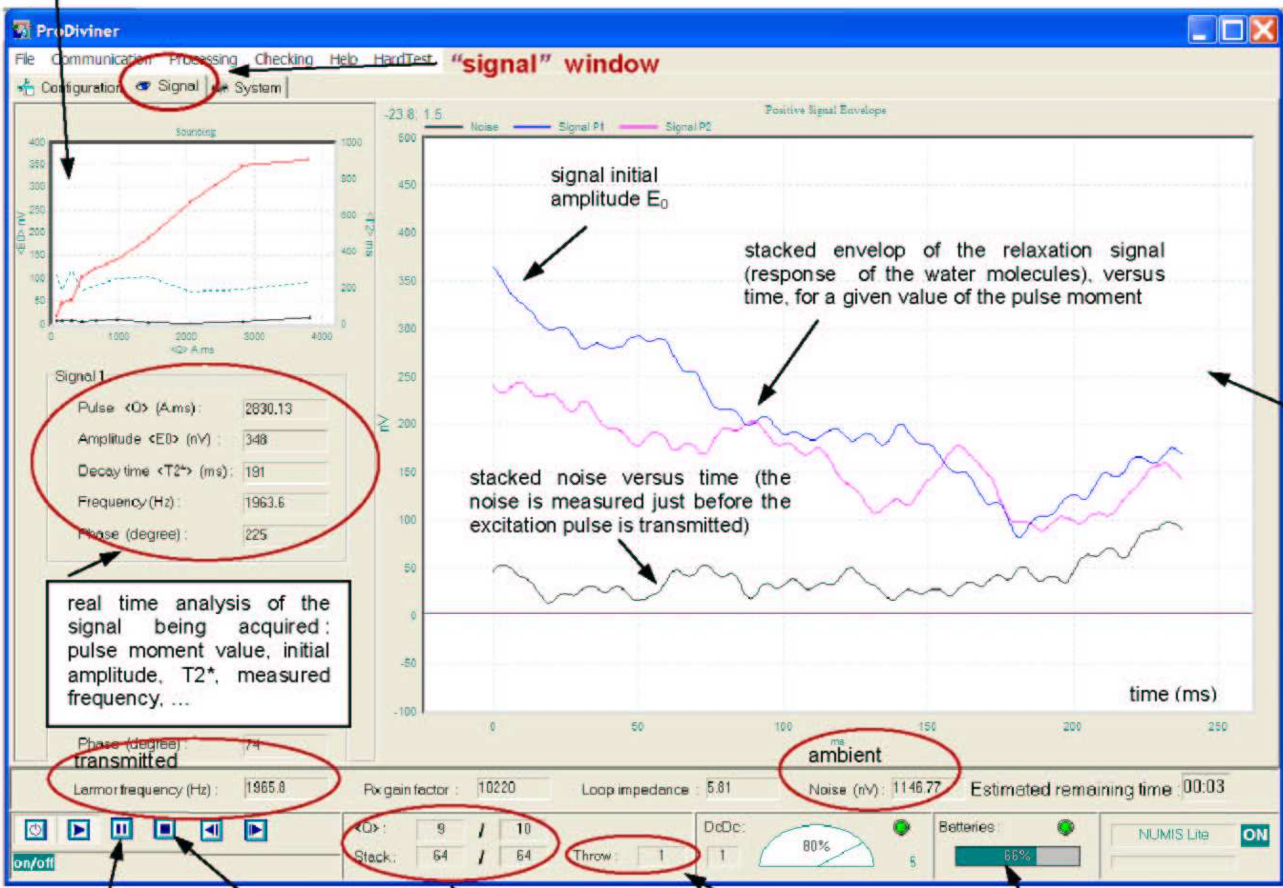
in red: ***sounding curve***: initial amplitude E_0 (nV) versus the pulse moment Q (A.ms)

in black: noise curve (nV) versus pulse moment Q

in dash line: time constant T2* (ms) versus pulse moment Q

HOW TO RECOGNIZE A MRS SIGNAL ?

- the "signal" curve must be ***above*** the "noise" curve, after stacking
- the "signal" curve must be ***decaying***, decreasing from left to right
- the frequency of the signal measured after the stacking has be ***close to the frequency*** of the current transmitted (+/- 1 to 2 Hz maximum)



'pause': this function freezes the acquisition until the button is pressed again

'stop': this function manually stops the acquisition

the 64th stack of a series of 64 is currently acquired, for the 9th moment of a series of 10

if the bad stack number becomes large, increase the voltage range

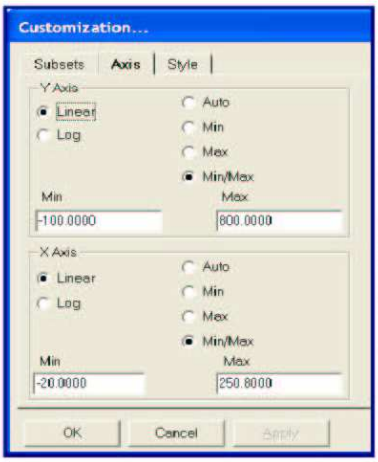
capacity of the batteries 25V = 100%, 20V = 0%

RAW DATA FILES

After a stacking is finished for a given pulse moment (1st, 2nd, ..., 10th), a text file including the time samples of the noise, the current and the signal is stored (**file.1, file.2, ..., file.10**)

When the full sounding is finished (10 or 16 pulse moments), a synthetic text file is created (**file.inp**) which summarizes the main parameters acquired: pulse value, signal amplitude, time constant T2*, noise, frequency,...).

Also, a compact binary file (**.mrs**) includes all previous information



By double clicking on the curve screen, it is possible to modify the graphic units, by fixing the min and max values for each axis: here, the received signal from –100 to 800nV (Y axis), and the time from –20 to 250ms (X axis)

example of ".inp" synthetic sounding file →

N	pulse	signal	T2*	noise	Udc	frequency	phase
1	86	41.48	700	2076.8	6	1960.68	134
2	167	44.87	1000	2374.0	7	1963.93	234
3	294	55.02	291	1124.9	10	1965.15	270
4	444	87.71	662	1173.8	14	1963.91	252
5	644	119.79	550	1109.9	19	1962.54	221
6	949	198.07	129	1173.9	27	1963.38	232
7	1416	201.94	194	886.9	39	1963.40	232
8	2021	306.11	146	1102.4	55	1963.48	220
9	2781	345.48	215	1113.7	78	1963.78	222
10	3740	338.11	290	891.7	110	1963.48	221

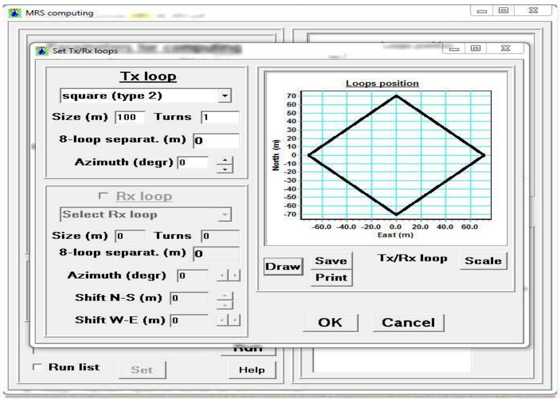
MRS DATA INTERPRETATION: CONFIGURATION WINDOW

MATRIX COMPUTATION

Before inverting sounding data, it is necessary to compute a matrix with the **Nmr.exe** program which takes into account the following parameters:

- the ***type and size*** of the loop
- the ***frequency*** (at this stage, at +/- 100Hz)
- the ***inclination*** of the Earth magnetic field (at +/- 10°)
- the ***resistivities and the depths*** of the various geoelectrical layers: the excitation and response fields are indeed attenuated in conductive layers, which must be taken into account for quantitative interpretation, specially for values of resistivities lower than 200 ohm.m

The computation takes a few minutes. The matrix file stored at the end of the computation (***".mrm"***) is suitable for all soundings of the same area.

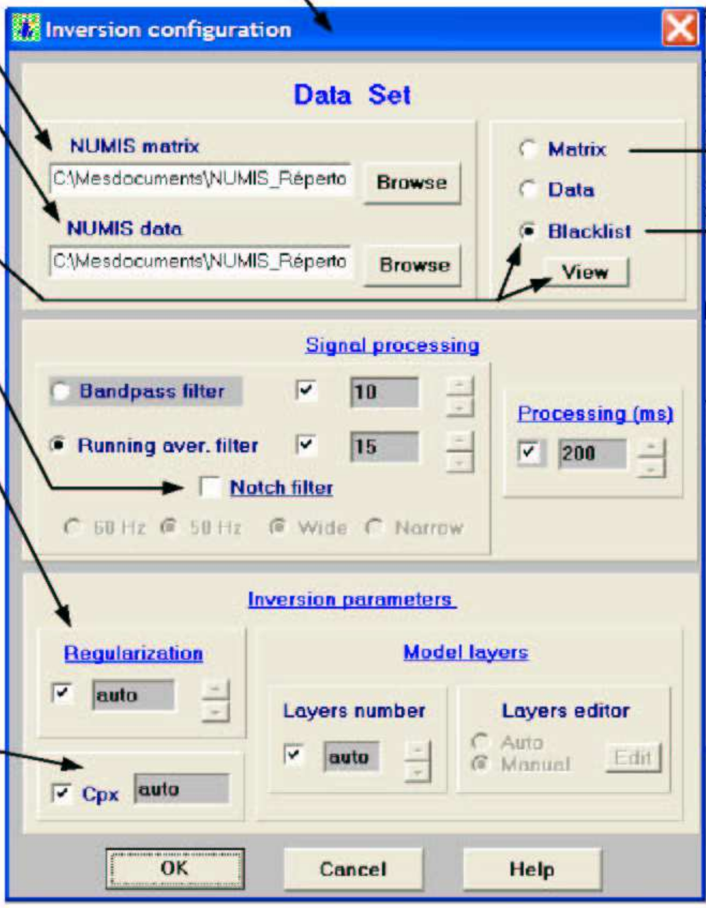


INVERSION COMPUTATION

- Click on ***"RUN Inversion"*** of the **Samovar program**
- Introduce ***the name of the matrix file*** (see above)
- Introduce ***the name of the data acquisition file***
- Select ***"Running Filter"*** and ***"auto"*** parameters
- Click on ***"OK"***: after a few seconds, the inversion results are displayed on a set of curves (§ next page)

INVERSION OPTIONS

- ***Eliminating noisy points:*** click "Blacklist", "View", then on the points chosen to be discarded because they appear noisy ("good" becomes "bad", reversibly)
- ***Filtering power line harmonics:*** click on "Notch filter", then on "60 Hz" or "50 Hz" according to the case, then on "Wide" if Δf > 5 Hz, or on "Narrow" if Δf < 5 Hz
- ***Regularizing the solution:*** due to the equivalence law, several models can fit the data. The coefficient "0" concentrates the water (low contents, thin layers), "1000" spreads the water (high contents, thick layers)
- ***Changing the number of layers:*** in "auto", the layer number is equal to the pulse moment number. In "manual", this number can be changed from 1 to 40, which modifies the smoothness of the solution (model)
- ***Fixing the depth of layers:*** in the "Layers editor", the depths of layers can be introduced and will be kept constant during the adjustment of the water contents.
- ***Changing the permeability coefficient:*** click on "Cpx" to modify the standard value (see formula used for permeability on next page)



Blacklist of measurements C:\Mesdocuments\NU

qualite	record	q(A-ms)	E(nV)	T2(ms)	freq(Hz)	phase(degr)
good	1	88.59	15.37	256.82	1964.30	-105.48
good	2	172.34	38.36	259.09	1964.17	-84.37
good	3	305.17	45.57	384.84	1963.11	-134.47
good	4	462.37	95.37	187.26	1964.24	-102.05
good	5	667.60	106.91	245.14	1963.79	-119.65
good	6	981.39	125.68	278.09	1963.94	-110.66
bad	7	1464.59	173.03	272.17	1964.10	-106.73
good	8	2089.59	238.43	183.38	1963.76	-108.85
good	9	2879.02	317.45	185.25	1963.47	-110.32
good	10	3871.99	318.44	254.68	1963.55	-96.41

manually discarded point — pulse moment A.ms — signal amplitude nV — measured frequency Hz

Matrix C:\Numis\Modelling\MATRIX01.MRM

This matrix has been calculated using following model :

antenna:
square, side = 60.0 m

geomagnetic field:
inclination = 60 degr.; Larmor frequency = 2000.0 Hz

geoelectrical section:
depth from 0.0 to 30.0 m; resistivity 100.0 ohm-m
depth from 30.0 to 100.0 m; resistivity 500.0 ohm-m

max. depth = 50.0 m; Qmax = 5000.0 A-ms

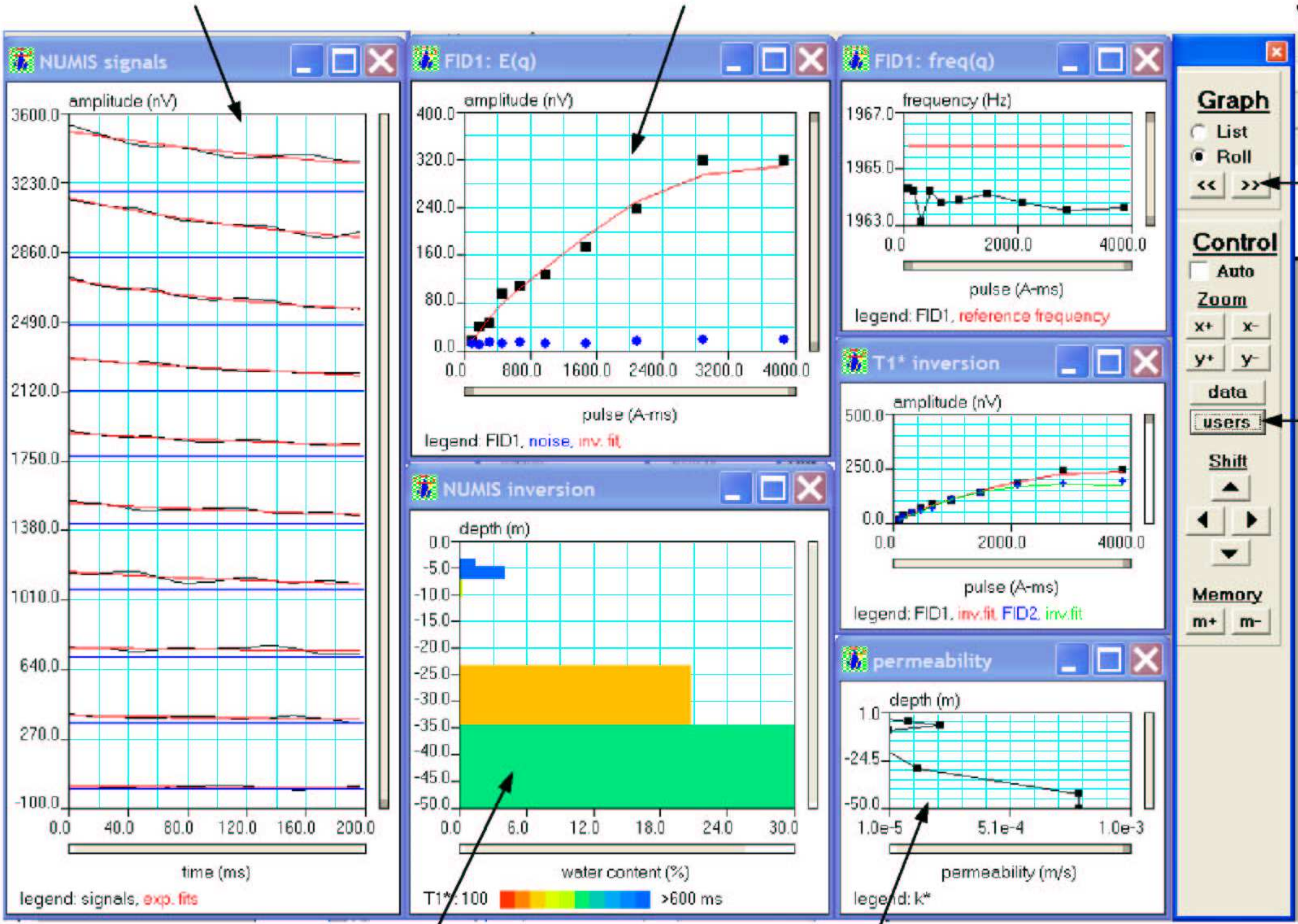
matrix parameters

MRS DATA INTERPRETATION: RESULT WINDOW

Signal relaxation curves (nV) versus time (ms), for the various pulse moments injected (smallest value on bottom, highest one on top)

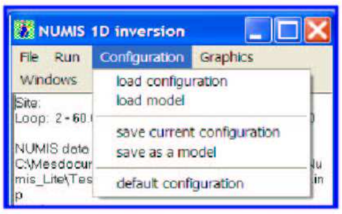
Sounding curve: initial amplitude (nV) of the signal relaxation curves for each value of the pulse moment (A.ms). ***Black dots*** are raw data, ***blue ones*** are noise, the ***red curve*** is the theoretical response of the model determined by the inversion

Other graphs can be displayed, such as noise, phase, T2* time constant, transmissivity

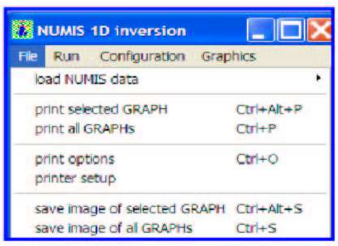


Inversion result: ***water content*** (porosity), in %, versus depth, in m. The colours of the sectors are related to the value of the time constant of the layer

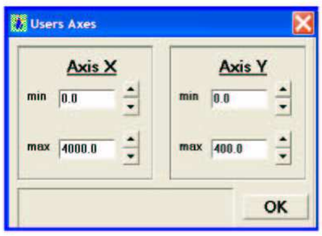
Inversion result: ***permeability***, in m/s, versus depth, in m. The value of the permeability is estimated through the following relation: ***permeability = Cpx*** *x* ***porosity*** *x* ***(T1)***^{2}; Cpx is a coefficient which can be modified in the configuration window (see previous page), after calibration with results of pumping tests



The screen configuration (type and size of windows, scale values for each window, ...) can be saved in a "model" file, for easier future processing



The file management permits to print the graphs with or without header (set-up option), and to save the images of these graphs into a file



The graphic scale of a given window can be modified by clicking on the window, then on "users", then by giving the min / max values for each X and Y axis

INTERPRETATION RESULT FILE

After each inversion, an ASCII file is automatically created (***".nov"*** extension) including the depth, thickness, water content, time constant and permeability values of each layer, for an easy export of these data to a data base software

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