Purpose of this exercise: First-arrival travel time tomography

GRADIENT FORMULATION

This exercise will illustrate the least-square inversion of first-arrival times (onset frequency-independent picking) using adjoint formulation where the Fréchet derivatives are not explicitly computed and stored into a matrix A which could be quite big, even when stored in a compressed format.

One should compare results with those obtained by using Fréchet derivatives. The system

$$Ax=b$$

is transformed into the normal equation

$$Hx=A^t Ax=A^t b=-\gamma$$

which is equivalent to minimize the misfit function $\|Ax-b\|^2$. Show this equivalence by yourself? We can estimate the gradient γ and approximate the Hessian H if required. Often the gradient is enough as for the steepest descent, the conjugate gradient, the quasi-Newton l-BFGS.

Instead of using the conjugate code LSMR based explicitly on the sensitivity matrix A, we shall consider the optimization tool box of SEISCOPE for solving this normal equation. We may consider other algorithms such as the lBFGS quasi-Newton method which is a Gauss-Newton approximation because the forward problem is linear.

TOOLBOX_OPTIMIZATION

These libraries could be compiled by typing “make” inside this directory. Commands “make clean” and “make superclean” will clean subdirectories, if needed.

TOMO2D_RAYS_GRADIENT

(inside the directory SRC_UTIL of the TOMO2D_RAYS_GRADIENT)

We assume that you have typed the command “cd SRC_UTIL” for being in the utility source directory. Simples programs are there for building models, sources and receivers distributions.

For compiling these codes, type “make” at the prompt. It will put an executable binary file in the directory BIN. You need the gfortran compiler.

(inside the directory SRC_ADJOINT of the TOMO2D_RAYS_GRADIENT)

This is a simple program where only the gradient γ is built with one row of the matrix A which is not stored. What is the complexity of the problem when the inversion is formulated this way?

For compiling the code, type “make” at the prompt. It will put an executable binary file in the directory BIN. You need the gfortran compiler.

Please have a look at the organization of the code and the successive calls to subroutines performing algorithms mentioned above.

Computing synthetic data

Copy the directory RUN_SYNT_HETERO_TEMPLATE into RUN_SYNT_HETERO by the command “cp –r RUN_SYNT_HETERO_TEMPLATE RUN_SYNT_HETERO”

Go inside this new directory by the command “cd RUN_SYNT_HETERO”

Launch the command “sh run_synth2D_hetero.sh 101 201” which will create acquisition files, a model file with a decaying exponential anomaly to be reconstructed and an output file data_fwd_hetero.dat which are the data we shall use.

A binary file “model_hetero_ref.bin” is created and can be seen using gnuplot by the following command “gnuplot dessin.gnu”. A jpeg file “MAP.jpg” will appear and can be plotted by any ad-hoc software such as display from ImageMagick.or eog under linex/ubuntu

Once done, type “cd ..” to go back to the project directory.

Performing a simple inversion test

Copy the directory RUN_HETERO_TEMPLATE into RUN_HETERO by the command “cp –r RUN_HETERO_TEMPLATE RUN_HETERO”

Go inside this new directory by the command “cd RUN_HETERO”

Launch the command “sh run_tomo2D_hetero.sh 101 201” and analyze what you will see in this directory using three gnuplot files target.gnu, init.gnu and final.gnu. You can use “display” from Image Magick for plotting figures under jpeg format.

Congratulations if you arrive here 🏝

Performing your own inversion test

Design your own velocity anomaly to be reconstructed: the perturbation should be small compared to the background velocity.