# Improved Generalized Inversion Technique (GIT) and its implementation to a synthetic dataset, to retrieve seismic source, propagation path and site factors

I. Grendas[1,2], N. Theodoulidis[2], F. Hollender[3] and P. Hatzidimitriou[1]

(1) Laboratory of Geophysics, Aristotle University of Thessaloniki, Greece, igrendas@geo.auth.gr
(2) Institute of Engineering. Seismology and Earthquake Engineering, Elaionon, 28 ,Pylaia, Greece,
(3) CEA Cadarache, French Alternative Energies and Atomic Energy Commission, St. Paul Les Durance

## Introduction

Generalized Inversion Technique (GIT) first introduced and applied by Andrews (1986), consists a seismological "tool" where seismic source, site effect and propagation path spectral terms, is feasible to be separated from the Fourier Spectra of an S-wave earthquake record. The application of this technique requires a dataset of Fourier spectra based on a satisfactory number of seismic records from several common earthquakes and stations at a non-extended area. The last is theoretically considered so that the assumption of an average representative attenuation for the investigated area to be tested. Several studies have been achieved under this assumption by the application of the GIT, concluding in encouraging results about the three controlling terms (source, path, site), in comparison with other methods. Drouet et al. 2008a first applied the non-linear Gauss-Newton inversion method, at a parametric Generalized Inversion Technique in order to investigate for a set of earthquakes in France-Alps, the site spectral amplification where the recording stations were located and an average wave attenuation for the study area. In Greece the GIT method was applied by *Drouet et al. 2008b*, aiming at the estimation of the station site effect in Lefkas island and by Grendas et al. 2018 investigating seismic sources, average attenuation and site effect of the ITSAK (Institute of Engineering Seismology and Earthquake Engineering) accelerometric stations. The intention of this study is to introduce a reasonable way of spatially separating and studying the attenuation model. The goal of this effort is to improve the parameterization of the attenuation and consequently the GIT computing precision of the study parameters (seismic source, attenuation, site effect). At the end, a synthetic dataset was created and inverted by the new inversion algorithm that was developed following the one by Drouet et al. 2008a.

## Method

GIT inversion developed here is based on the fundamental Eq. [1], where the first term of the product refers to the seismic sources (*Brune, 1970*), the second and the third refer to the attenuation and the last term consists the site effect. The product of these terms is equal to the Fourier spectrum $A_{ijk}$ of the S-wave record. The investigated parameters are the seismic moment $M_o$ and corner frequency $f_c$ for each $i$ earthquake, the $\gamma(r_{ij})$, $Q_{sn}$ and $a_n$ parameters for the attenuation as mentioned below and the non-parametric site spectral amplification for the specific $k$ frequencies at each station $j$. Gauss-Newton inversion algorithm (Tarantolla, 2004) uses the partial derivatives of Eq. [1] in relation to the above investigated parameters, as well as the initial values for these parameters and their corresponding a priori covariance values. Wave attenuation is controlled by the geometrical spreading and anelastic attenuation. The first one is analyzed and studied here as a distance dependent factor, controlled by a distance dependent gamma factor ($\gamma(r_{ij})$) that is investigated (Eq. [1]). The second one is separately studied for the different $n$ sub-divided areas (Figure 1b), controlled by the frequency dependent quality factor $Q_n(f) = Q_{sn}\, f^{\,a_n}$, as well as by the specific epicentral distance $r_{ijn}$ that passes through each specific "rectangular".

$$A_{ijk}(f_k) = \left( \frac{\boldsymbol{M_{o_i}} \times \left( {}^{2R_{\theta\varphi}}\!/\!{}_{4\pi\rho\beta^3} \right)}{\left[1 + \left(f_k/\boldsymbol{f_{c_i}}\right)^2\right]} \right) \times \left( \frac{1}{r_{ij}{}^{\gamma(r_{ij})}} \right) \times \prod_{1}^{n} \left( exp\left( - \frac{\pi\, r_{ijn} f_k}{\boldsymbol{Q_{s_n}} f_k^{\boldsymbol{a_n}} v_{s_n}} \right) \right) \times \left( \boldsymbol{S_{jk}}(f_k) \right) \quad (1)$$

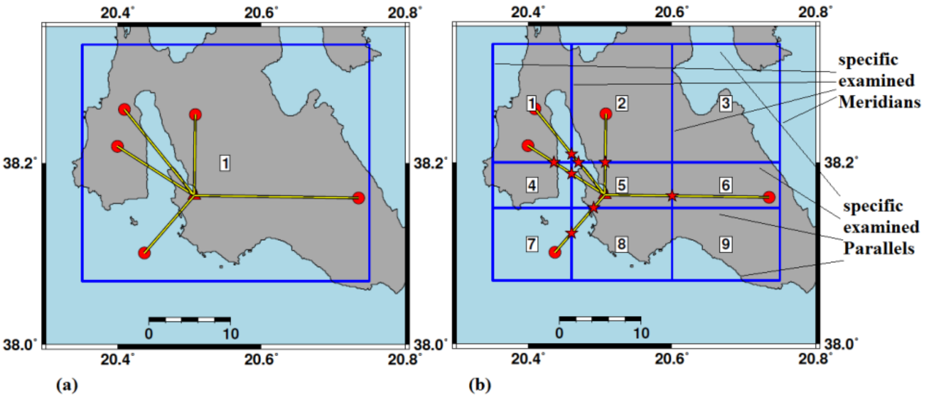


**Figure 1. An example (Cephalonia island) of the separation of a (a) unique attenuation model-area to (b) more than one (nine here) attenuation model-areas. With red circles and triange are some random earthquakes and station, respectively, while with red asterisks are the intersection points of the ray paths (yellow lines) with specific Paralles and/or Meridians, in order to contribute at the part distance ray path $r_{ijn}$.**

**Results & Conclusions**

The developed inversion algorithm in this work was applied to a synthetic dataset of 4313 spectra created by eq. [1] for 126 synthetic seismic sources ($M_o$ and $f_c$) "recorded" at 60 random stations with specific site amplifications, for 20 frequencies (0.5 -15 Hz). The initial values needed for the inversion method were considered to be unknown, taking reasonable initial values and quite large *a priori* covariance values. The only exception was the moment magnitudes that were considered to be the synthetic values affected by a random factor up to 0.2 as can be understandable in Fig. 2a. The use of *a priori known* moment magnitudes, with their standard deviations (~±0.2) from different methods, for a real dataset is a common practice in GIT. Thus, affecting the synthetic values by a common computed factor up to 0.2, an actual practice was implemented.

The results are encouraging enough for the correct process of the algorithm and also for the attenuation separation concept. This can be confirmed in Fig. 2 where the source parameters results are presented. Inverted moment magnitudes $\boldsymbol{M_w}$ (corresponds to inverted seismic moments $\boldsymbol{M_o}$), are equal to the synthetic $\boldsymbol{M_w}$ values (Fig. 2a), as well as the computed corner frequencies, at least for $M_w$ >2 corresponds to stress drop 100 bar, which is the synthetic stress drop value. For $M_w$ < 2 the corner frequencies and stress drop are not well estimated in comparison to synthetic values, but this is more or less a reasonable result since the data are limited at frequencies up to 15 Hz and the inversion process can not easy compute corner frequencies greater than this limit. Attenuation parameters were computed close enough, with a short deviation, to the synthetic values, while site amplifications were computed satisfing enough, having the same "shape" but with a low underestimation as it is presented in Fig. 3 for 5 of the 60 stations. It is worth noting that in case where some of the initial values were considered to be known, the final results were exactly the same as the synthetic values.

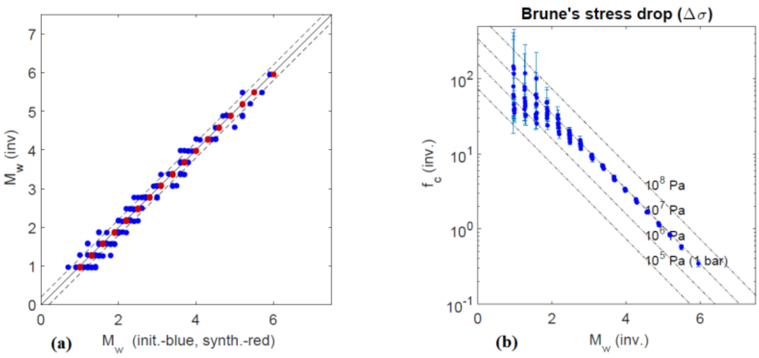


**Figure 2. (a) The comparison of the inversion computed moment magnitude $M_w$ (inv.) to the initial values of $M_w$ (blue points) and to the synthetic $M_w$ (red points). (b) The comparison between the corner frequencies $f_c$ and moment magnitude $M_w$, both computed from the inversion.**

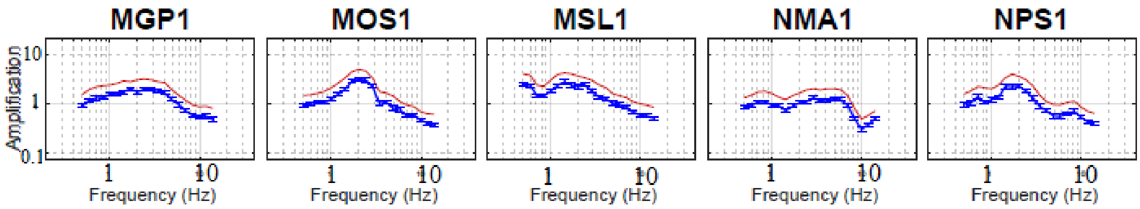


**Figure 3. Site spectral amplification of 5 stations that used for the synthetic data. With red line is depicted the synthetic values, while with blue line is depicted the computed from the inversion values.**

## Acknowledgements

This study consists a part of a doctoral dissertation, the implementation of which was co-funded through the action: "Human research potential support through doctoral research implementation", from financial resources of the operational Program "Human resources development, Education and Lifelong learning", 2014-2020.

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