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Users Guide for NLDiffLoc

Non-Linear Differential Location

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Introduction

The program NLDiffLoc performs differential earthquake location (e.g., Got, 1994; Waldhauser and Ellsworth, 2000) using a direct, global-search inversion algorithm to optimize the relative position of nearby earthquakes using differential, phase arrival time measures at common stations for pairs of events. NLDiffLoc can be used with 3D velocity models and produces comprehensive solution uncertainty information in the form of a probability density function (PDF). Other differential locations codes, such as HypoDD (Waldhauser, 2001), use iterative, linearized inversion for optimization and extract approximate and simplified (i.e. Gaussian) solution uncertainty information from the inversion matrices. These linearized approaches, however, can be applied to much larger data sets than can NLDiffLoc.

The NLDiffLoc program is part of the NonLinLoc earthquake location package (http://alomax.net/nlloc); the use of NLDiffLoc requires use of NonLinLoc tools to construct the velocity model (NonLinLoc program Vel2Grid) and to calculate travel times and ray angles (NonLinLoc program Grid2Time). The results can be visualized using SeismicityViewer (http://alomax.net/seismicity) and can be contoured and plotted using the NonLinLoc program Grid2GMT and the GMT plotting package (http://gmt.soest.hawaii.edu).

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Program Requirements

Use of NLDiffLoc requires that the NonLinLoc software package (available at http://alomax.net/nlloc; latest build: http://alomax.net/nlloc/softbeta/tar) is installed and that the NonLinLoc executables are on the system executable path. Optionally, for plotting location results, SeismicityViewer (http://alomax.net/seismicity) should be installed, and, for model, travel-time and map plotting, the executables from the plotting package GMT (available at http://www.soest.hawaii.edu/GMT/) must be installed and available on the system executable path.

NLDiffLoc has been developed and tested on Mac OS X 10.6.3 (BSD UNIX). NLDiffLoc should compile and run correctly in a command-line shell on all Linux/UNIX based systems with GCC 4.2 or higher, or equivalent C compiler and linking support.

Installing NLDiffLoc

Install the NonLinLoc software package as described in the NonLinLoc distribution documentation. Run **`make`** or **`gmake`**, and then **`make NLDiffLoc_`** or **`gmake NLDiffLoc_`**. Install all executable files to a directory that is on the **`PATH`** environment variable.

Running NLDiffLoc, Examples

TODO:

Output Files

TODO:

See NonLinLoc documentation http://alomax.net/nlloc.

Algorithm Description

NLDiffLoc optimizes the relative x, y, z, and t coordinates for a set of hypocenters given a set of differential phase arrival time measures at each station for multiple hypocenters.

NLDiffLoc optimizes the hypocenter coordinates using a non-linearized, global-search (a Metropolis random walk, see Mosegaard and Tarantola, 1995; Lomax et al., 2000; Lomax et al., 2009), which tests a large number of possible solutions in a forward manner. In this search, NLDiffLoc seeks to maximize the probabilistic solution likelihood (minimizing the misfit between measured and calculated differential phase arrival times) as the hypocenter coordinates are perturbed.

NLDiffLoc evaluates the double-difference equation from Waldhauser and Ellsworth (2000; eq. 4) to determine the misfit and a solution likelihood; this is done using an L2 norm (equivalent to HypoDD) or an L1 norm (more robust with outlier data) in the function **NLDiffLoc.c → DiffLocCalcSolutionQuality_LN_NORM()**. The equation for the contribution to the likelihood for all arrival-time difference measures that concern an event *i* with coordinates *x*, *y*, *z*, and *t* is, for the L2 norm:

$$L_i(x,y,z,t)=\exp\left(-\frac{1}{2}\sum_k \left[w_k^2 \frac{\left[(t_k^i-t_k^j)^{obs}-(t_k^i-t_k^j)^{cal}\right]^2}{\sigma^2 T^2}\right]\right) \quad , \tag{1}$$

and for the L1 norm:

$$L_i(x,y,z,t)=\exp\left(-\sum_k \left[w_k \frac{\left|(t_k^i-t_k^j)^{obs}-(t_k^i-t_k^j)^{cal}\right|}{\sigma T}\right]\right) \quad , \tag{2}$$

where *k* is a station with an arrival-time difference measure $(...)^{obs}$ between event *i* and another event *j*, $(...)^{cal}$ is the calculated arrival-time difference at station *k* for events *i* and *j* (difference, for events *i* and *j*, of the sum of the calculated origin time *t* and the calculated travel time from station *k* to point *x*, *y*, *z*.), σ is the uncertainty for a differential time measure, and *T* is the current Metropolis temperature ($T \geq 1.0$).

Outline of NLDiffLoc program flow:

Main program [**NLDiffLoc.c→main()**]:

1. Read control file,
2. Read phase difference data,
3. Read initial hypocenter locations,
4. Assign event indices to each phase difference datum,
5. Perform differential location (see below),
6. Save final phase arrival differences to files in NLL diff format and hypoDD cc format.

Differential location [**NLDiffLoc.c→LocateDiff()**]:

1. Save initial hypocenter locations (***.diff_init.loc.hyp**),
2. Initialize Metropolis random walk,
3. Apply Metropolis random walk [**NLDiffLoc.c→DiffLocMetropolis()**]:

   In this walk, one of the hypocenters, *i*, with current total likelihood $L_i^{current}$ for all arrival-time difference measures that concern event *i* (eq. 1), is perturbed in *x*, *y*, *z*, and *t*. Next, the likelihood for the perturbed *i*, $L_i^{perturbed}$, is evaluated to check if the perturbation improves the fit to the data, in the sense of the Metropolis rule: always accept the perturbed solution if $L_i^{perturbed}$ has higher likelihood than $L_i^{current}$, otherwise, accept with probability ($L_i^{perturbed}/L_i^{current}$); see Mosegaard and Tarantola, 1995, eq. 17. Note that this application of the Metropolis rule acts on the partial likelihood L_i for event *i*, and not the total likelihood *L* for all hypocenters and over arrival-time difference measures.

   The hypocenters are perturbed in sequential order, skipping hypocenters which are fixed (see control file → **DLOC_HYPFILE**) or which have no phase difference data. Hypocenters for which the acceptance rate of Metropolis samples or the average likelihood becomes too low are also skipped.

The perturbation in *x*, *y*, *z*, and *t* is based on a variable step in *x*, *y*, *z* and *t*/**`MetVelocity`**, see **`NLDiffLoc.c→DiffLocGetNextMetropolisSample().`** The step is **`temperature*metrop_dx[nHypo],`** where **`temperature`** decreases from **`MetInititalTemperature`** at the start of the walk to 1.0 after **`MetStartSave`** Metropolis samples have been accepted, and **`metrop_dx[nHypo]`** varies as a function of the rate of acceptance of Metropolis samples, with a minimum value of **`MetStepMin`** (see control file → **`DLOC_SEARCH`**).

4. Save the final, best locations, PDF scatter files, location statistics, etc.; write differential time event links to plot file (**`*_DiffTimeLinks.xyz`**).

References

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Revision History Notes

See NonLinLoc distribution change notes: CHANGE_NOTES.txt