Guidelines for Focal Depth Estimate and Uncertainty in *mloc*

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This document discusses several matters related to the specification of focal depth in the program ***mloc***, which implements an extensively modified version of the Hypocentroidal Decomposition algorithm ("HD", *Jordan and Sverdrup*, 1981) for multiple event relocation.

Formally, the "**dept**" command only sets the starting depth, but in most cases focal depth is fixed in the relocation. As of v9.4.1 (release date 12/20/2011) of ***mloc***, the 4th character of the old "**dept**" command is converted to a flag to indicate the source of information used to constrain the starting depth (e.g., "**depn**" indicates depth constrained by near-source readings) and this code is carried through to the HDF file(s). In some cases it is useful to keep track of more than one estimate of depth, by commenting out the ones that are not used, and it becomes necessary to decide which estimate to prefer when there are several available.

Precision

Given the uncertainties in depth determination for earthquakes, much less the estimation of those uncertainties, I think it is misleading to use a precision less than 10^0 (i.e, 1 km) for either depth or depth uncertainty. I use unitary precisions.

Precedence for Depth Estimates

Based on my experience with the 2010 Maule, Chile sequence, in which there are many events with multiple estimates of depth from near-source readings, teleseismic depth phases and regional moment tensors, I have determined the following standard order of precedence.

If there are multiple estimates of depth, the order of precedence (decreasing) is normally:

1. Near-source readings
2. Moment tensor centroid depth
3. Relative teleseismic depth phases
4. Raw teleseismic depth phases

This order can be shifted in cases where there are reasons to doubt one of the estimates. The estimated or assigned uncertainties (see below) also come into play in this decision.

Depth Uncertainty

As of v9.4.8 (release date 5/10/2012) of ***mloc***, the "**dep_**" command can carry an estimate of the uncertainty for the starting depth, which is carried through to the HDF file(s). This estimate may be symmetric or asymmetric. If only a single uncertainty parameter is given after the depth itself, a symmetric uncertainty is assumed. If two uncertainty parameters are provided after the depth, the first is taken as "plus" (i.e., deeper) and the second is "minus" (shallower).

All uncertainties are specified by the user in the command file—***mloc*** only assigns a default value of 99.9, and the uncertainties have no bearing on the relocation algorithm. They are strictly informational (this could change in later releases). The statistical significance of these estimates is up to the user. I usually think in terms of 90% confidence limits.

My rule-of-thumb estimate of symmetric uncertainty for depth estimates is:

- Near-source readings: ±3 km
- Moment tensor centroid depth: ±4 km
- Relative teleseismic depth phases: ±3 km if both pP-P and sP-P readings are used.
- Raw teleseismic depth phases: ±5 km if both pP-P and sP-P readings are used.

Asymmetric Depth Uncertainty

A full evaluation of depth uncertainty for moment tensors requires construction of a curve of error vs. depth, from which an asymmetric uncertainty can be derived.

When estimating depth from teleseismic depth phases (either raw or relative) of a single type (e.g., pP or sP) there is a bimodal distribution of uncertainty because it is usually possible to re-identify all depth phases as the other type and still get a reasonable set of residuals. Unless there is reason to have confidence in the phase ID, the uncertainty should reflect this bimodal uncertainty. This is based on a determination of the alternative depth solution, to which is added or subtracted (depending on whether it is an upper or lower bound, respectively) the "symmetric" uncertainty above.

For example, suppose a set of pP-P (and only pP-P) readings are consistent with a depth of 25 km. This is taken as the preferred depth, but if they were all re-identified as sP-P, the best-fitting depth would be about 18 km, 6 km shallower. If the "symmetric" uncertainty for depth uncertainty using teleseismic relative depth phases is ±3 km, the uncertainty for depth of this event, using the formalism of the "**dep_**" command in ***mloc***, would be:

depd 25 3 9

Meaning the error bar would extend from 16 to 28 km in depth, with the preferred depth at 25. In terms of a probability density function, this should be thought of as the combination of two quasi-Gaussian distributions, one centered at the "sP-P" depth, one centered at the "pP-P" depth. The probability of the focus being midway between the two is quite small.

Inflation of Uncertainties for Larger Depths

Larger focal depths are subject to greater uncertainty because of the uncertainty about the velocity structure. An analysis of reasonable limits for the effect of unknown velocity structure, as a function of depth, is needed. The type of depth constraint would also have to be considered, as, for example, the delay of direct phases to local stations would be only about half as much as the delay of teleseismic depth phases, given the same focal depth and perturbation to the velocity structure.