Chapter 5

PROBABILISTIC EARTHQUAKE LOCATION IN 3D AND LAYERED MODELS

Introduction of a Metropolis-Gibbs method and comparison with linear locations

Anthony Lomax and Jean Virieux
Géosciences-Azur, University of Nice - Sophia Antipolis, Valbonne, France

Philippe Volant and Catherine Berge-Thierry
Institut de Protection et de Sûreté Nucléaire, Fontenay-aux-Roses, Paris, France

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Abstract: Probabilistic earthquake location with non-linear, global search methods allows the use of 3D models and produces comprehensive uncertainty and resolution information represented by a probability density function over the unknown hypocentral parameters. We describe a probabilistic earthquake location methodology and introduce an efficient Metropolis-Gibbs, non-linear, global sampling algorithm to obtain such locations. Using synthetic travel times generated in a 3D model, we examine the locations and uncertainties given by an exhaustive grid-search and the Metropolis-Gibbs sampler using 3D and layered velocity models, and by a iterative, linear method in the layered model. We also investigate the relation of average station residuals to known static delays in the travel times, and the quality of the recovery of known focal mechanisms. With the 3D model and exact data, the location probability density functions obtained with the Metropolis-Gibbs method are nearly identical to those of the slower but exhaustive grid-search. The location PDFs can be large and irregular outside of a station network even for the case of exact data. With location in the 3D model and static shifts added to the data, there are systematic biases in the event locations. Locations using the layered model show that both linear and global methods give systematic biases in the event locations and that the error volumes do not include the "true" location – absolute event locations and errors are not recovered. The iterative,

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linear location method can fail for locations near sharp contrasts in velocity and outside of a network. Metropolis-Gibbs is a practical method to obtain complete, probabilistic locations for large numbers of events and for location in 3D models. It is only about 10 times slower than linearized methods but is stable for cases where linearized methods fail. The exhaustive grid-search method is about 1000 times slower than linearized methods but is useful for location of smaller number of events and to obtain accurate images of location probability density functions that may be highly-irregular.

1. INTRODUCTION

The accurate location of earthquakes and a complete understanding of the location uncertainties are critical to seismotectonic and seismic hazard studies, to "real-time" seismic notification, and to nuclear test ban treaty verification. With the increasing availability of three-dimensional structural models from geologic and geophysical interpretations and seismic travel-time inversion, it is important to have location methods valid for 3D velocity models. Probabilistic earthquake location with non-linear, global-search methods allows the use of 3D models and produces comprehensive uncertainty and resolution information.

A complete, probabilistic earthquake location is represented by a probability density function over the unknown parameters, i.e. three spatial co-ordinates of the hypocenter and an origin time. This hyper-volume representation of a location may include multiple "optimal" solutions and may have a highly irregular form. Many studies of seismicity and seismotectonics make explicit use of a probabilistic representation of earthquake locations (i.e. Wittlinger et al., 1993; Vilardo et al., 1996; Calvert et al., 1997; Gresta et al., 1998; Jones and Stewart, 1997).

Commonly used iterative-linearized location programs produce a single, point solution, the preferred hypocenter, and uncertainty estimates based on Gaussian, or normal, statistics evaluated at this point. Such a solution will be a good representation of the complete, probabilistic location only for the case that the density function has a single optimum and a near-ellipsoidal form. Non-linear, global-search methods can be used to identify irregular volumetric, probability density functions required for complete, probabilistic locations. In addition, unlike linear approaches, these methods can be easily applied with 3D models because they do not require partial derivative information, which is difficult or impossible to obtain in complicated models. However, non-linear, global-search methods can be very time consuming, particularly exhaustive grid-search or pure Monte Carlo methods. For "near real-time" seismic notification and for CTBT