INITIAL RESULTS AT REDUCING SYSTEMATIC ERRORS FOR SEISMIC EVENT LOCATIONS USING A MODEL INCORPORATING ANISOTROPIC REGIONAL STRUCTURES

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ABSTRACT

We are utilizing a mapping of the lateral and anisotropic variations in Pn velocities beneath continents across the globe (Smith and Ekstrom, 1999) to predict travel times of P-wave propagation at distances of 2-14 degrees. At such distances the phase Pn is the seismic phase that is most frequently reported and that thus controls the location accuracy. This is important in CTBT applications as many events of interest are only detected at these distances. We are thus working on reducing the systematic errors in Pn travel-times and the resulting seismic event location at regional distances using our mapping.

In our investigations we have begun by establishing a list of ground truth events by which to test locations using our different models. In establishing this list we have endeavored to include a variety of geographic areas and sizes of events. We have also developed a grid-search algorithm to relocate each of these events using isotropic, laterally varying, and full anisotropic models. In our initial studies we have not accounted for ray-path effects which may prove to be significant. Our results from the first stage of this study indicate a progressive improvement in the relocation with increased model complexity. However, significant systematic errors remain in locations where heterogenity is accounted for but anisotropy is not. The most significant results appear to be for events with few stations reporting but with reasonable azimuthal distribution.

KEY WORDS: Pn, anisotropy, regional phases, CTBT, relocation

OBJECTIVE

Introduction

In CTBT applications many events of interest are only detected at regional distances. Our objective is identification and reduction of systematic errors in the location of events determined using regional seismic data. At such distances (2-14 degrees) the phase Pn is the seismic phase that is most commonly reported and which thus controls the location accuracy. In order to accurately locate seismic events, whether natural or artificial, by traditional travel-time methods one must first be able to accurately predict arrival times. Historically travel-times have been calculated using one-dimensional seismic velocity models (e.g. Jeffreys and Bullen, 1940; Herrin et al., 1968; Herrin and Taggart, 1968; Herrin, 1968; Dziewonski and Anderson, 1981; Kennett and Engdahl, 1991). However, the Earth is composed of rocks which vary laterally at varying length scales (e.g. Crosson, 1976; Engdahl et al., 1977, 1982; Engdahl and Billington, 1986; Dziewonski, 1984; Su and Dziewonski, 1993) and can be anisotropic (e.g. Christensen, 1966; Kumazawa and Anderson, 1969; Hess, 1964; Raitt et al., 1969; Forsyth, 1975; Tanimoto and Anderson, 1984), resulting in travel-times which do not match those predicted by these one-dimensional velocity profiles. In addition, at regional length scales global Earth models, which are largely based on long-period surface waves and vertically arriving body waves, provide poor first arrival travel-time predictions. Providing more accurate prediction of P-wave propagation at regional distances is therefore of particular importance in event location. When attempting to satisfy the location requirements of the CTBT it is essential to obtain the most accurate location possible, with the minimum necessary computing time

The question remains as to whether the current generation of regional models can usefully contribute to relocation problems. While it has already been well established that variations in regional phases such as Pn can lead to large mislocations of the epicenter (Herrin and Taggart, 1962), progress has been slow in routinely applying regional models to locations for global catalogs. This is probably because most of the Pn velocity models produced are of a highly local nature (e.g. Hess, 1964; Raitt et al., 1969; Bamford, 1977; Fuchs, 1977; Hirn, 1977; Vetter and Minster, 1981), and no systematic global mapping of Pn velocities has been attempted. In addition although azimuthal anisotropy is a known feature of Pn propagation (e.g. Beghoul and Barazangi, 1990; Hearn, 1996), most previous studies of Pn anisotropy have not mapped lateral variations in azimuthal anisotropy, but instead produced, if anything, a single estimate for an entire region.

In recent work the P.I. has mapped lateral and anisotropic variations in Pn velocities beneath continents across the globe (Smith and Ekstrom, 1999). This work represents the most comprehensive and possibly the most accurate mapping of anisotropic Pn velocities available to date. This provides the first opportunity to truly test the possibility of applying an anisotropic Pn velocity model to calculation of travel-times to improve regional locations for events distributed in different parts of the world. The question remains whether this new mapping can provide, in a practical application, significant reductions in systematic event location at the regional scale. Our work is aimed at applying this new mapping of Pn anisotropic structure to investigate the possible systematic errors produced by lateral heterogeneity and azimuthal anisotropy

RESEARCH ACCOMPLISHED

Grid Search Relocation Algorithm

We have begun our study by developing and applying a grid search relocation algorithm to ground truth events. In this study we use travel-time data from the ISC database. The ISC location is used as a first estimate. The fit of travel times is then calculated for this location and for a set of points on a rectangular grid at 10-km spacing. The minimum in the rms of the travel times is then selected as the new location estimate and the travel-time misfits recalculated using a smaller grid spacing. This is repeated until the travel-time misfit appears to converge. This procedure has been performed for a selection of PNE for isotropic, laterally heterogeneous, and anisotropic structures. In this stage of our study great-circle raypaths were used.

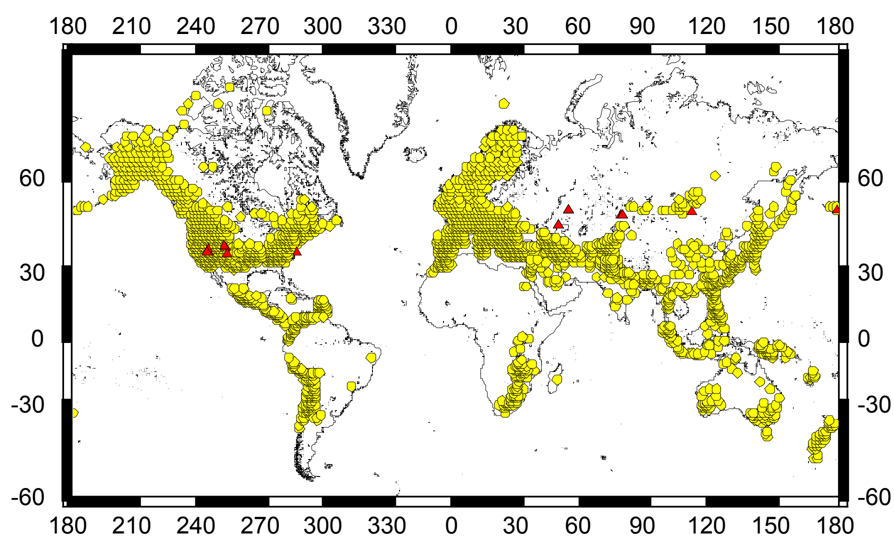

Figure 1. Worldwide distribution of Pn velocity estimates in the model of Smith and Ekstrom (1999). Triangles show the locations of PNEs used in Smith and Ekstrom (1996).

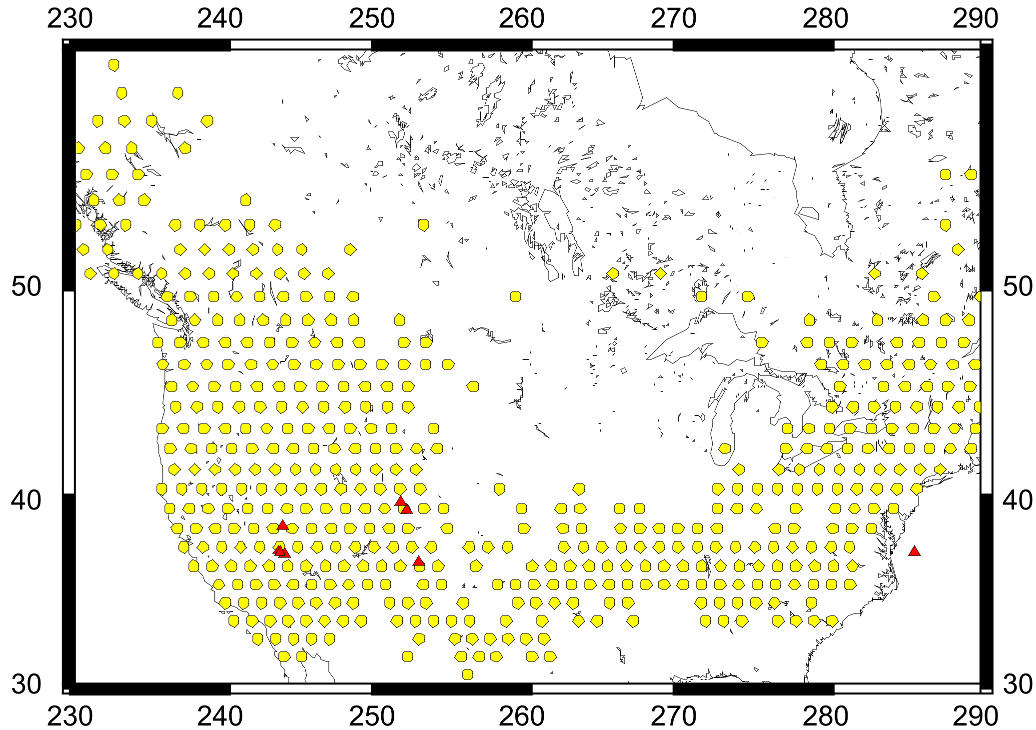

Figure 2. US distribution of Pn velocity estimates in the model of Smith and Ekstrom (1999). Triangles show the locations of PNEs used in Smith and Ekstrom (1996).

Figure 1 shows the worldwide distribution of Pn velocity estimates in the model of Smith and Ekstrom (1999). Triangles show the locations of PNEs used in Smith and Ekstrom (1996). We have used this same list of PNEs as a starting list of ground truth events for the current study. Clearly the geographic area with the best coincident coverage of PNEs and Pn velocity estimates is the United States. Although we are continuing to expand our list of test events the events in this region provide useful insight into effects of our model and algorithm (see Figure 2). Pn anisotropy for this region is shown in Figure 3.

Table 1: Results of relocation using different velocity models

Model	RMS Misfit to Known Location (km)
isotropic	12.1
heterogeneous	11.6
anisotropic	10.9

Table 2: Results of relocation using different velocity models and restricting distance range to arrivals > 6°

Model	RMS Misfit to Known Location (km)
isotropic	14.1
heterogeneous	13.8
anisotropic	11.4

Table 1 shows the RMS misfit using isotropic, laterally heterogeneous, and anisotropic models. Although this table suggests a general location improvement using the anisotropic structures we note that the majority of this improvement is seen in the locations for the western most events. This is explicable by examination of Figures 2 and 3 which demonstrate that for the eastern most event all regional arrivals are from similar azimuths, and so the 3 models converge to the same answer. It is notable that these improvements are minimal and given the minted test-bed perhaps not statistically significant. Possible explanations for this minimal level of improvement are in use of direct raypaths as opposed to calculating the true raypath predicted by our model, and also dependence on the crustal model. Table 2 shows the results of experiments where we have relocated the events but only using travel-times from more distant stations (> 6 degrees). Although this reduces the number of travel-times the significance of accounting for correct uppermost mantle velocities increases.

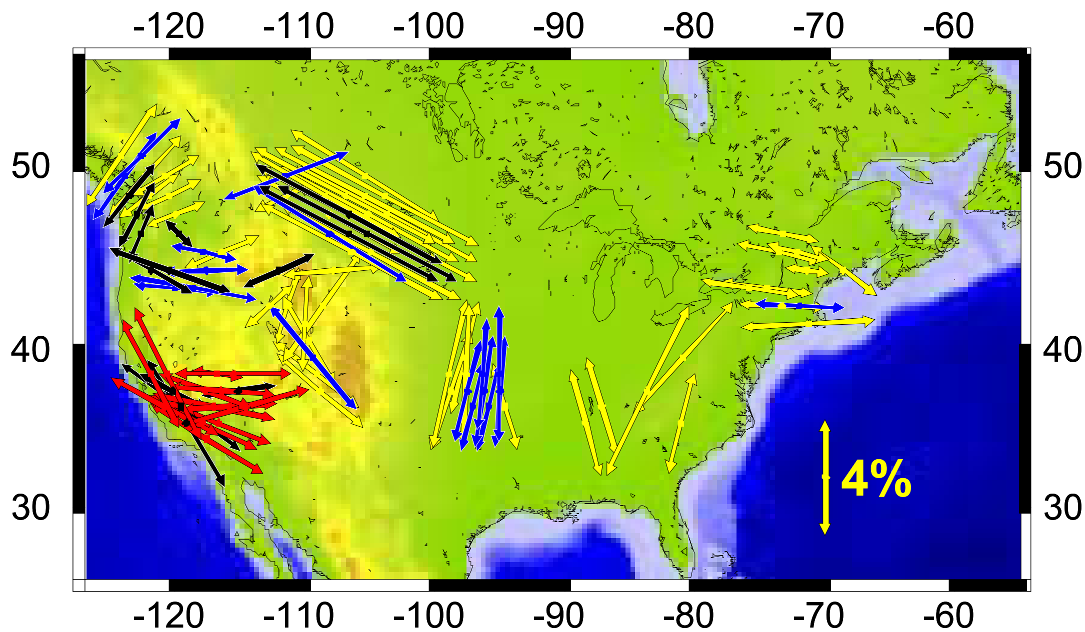

Figure 3. Pn anisotropy estimates in the US. Arrows show the fast anisotropic direction and are proportional to the size of anisotropy. A 4% arrow is shows for scale.

CONCLUSIONS AND RECOMMENDATIONS

Our current study clearly indicates that inclusion of more precise models, incorporating both heterogeneity and anisotropy at the regional scale, can improve the location accuracy. However, the improvements obtained are not as striking as one might expect given the level of anisotropy and heterogeneity in the current models. A variety of explanations for this are possible.

One obvious explanation lies in the use of approximate raypaths as opposed to calculating the raypaths predicted by our model. The second possible source of error is in the calculation of the crustal leg of the travel time. At greater distances this portion of the travel time becomes a less significant percentage of the overall travel time and we are currently examining the fit of travel time versus distance to try to quantify this effect. In addition both the distribution of Pn velocity estimates available, and the azimuthal distribution of travel times for the event being tested appears to have a critical effect on the improvement possible. We are currently examining the effect of azimuthal distribution of travel times to try to quantify at what level application of the anisotropic model becomes useful in a practical sense.

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