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Automatic Seismic Tomography : Do You Believe Human or Computer ?

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Abstract

How much laboratory automation is possible in seismology ? We conducted an experiment to compare seismic tomography images using arrival times picked by a computer and a human. If the computer gives the same tomographic image as that the human gives, seismologists have no need to insist upon a manual picking of arrival times. We found that unexpectedly a computer is able to provide rather good results.

1. Introduction

In the near future seismologists should entrust a computer with all the process in a seismic tomography, which is a powerful method to image the Earth's interior (e.g. Hasegawa et al., 1991 ; Zhao et al., 1996 ; van der Lee and Nolet, 1997 ; van der Hilst et al., 1997 ; Dunn and Toomey, 1997 ; Zhao et al., 1997 ; Ekstrom and Dziewonski, 1998 ; Shen et al., 1998). Lots of arrival time data of compressional and shear seismic waves (called P- and S-waves, respectively) are required to obtain accurate tomographic images with high resolution. In general seismologists spend much time to inspect waveforms one by one and estimate the arrival times manually. Although an automatic picking and hypocenter determination by a computer had came true in 1980's (e.g. Yokota et al., 1981 ; Morita and Hamaguchi, 1984 ; Takanami and Kitagawa, 1988 ; Sleeman and van Eck, 1999), the arrival times estimated by a computer were not applied to the seismic tomography because (1) an automatic picking was commonly believed to be not so accurate and (2) the number of seismic stations was not so large in a regional or a global network. However the manual picking becomes awfully hard as seismic stations increase rapidly in Japan : A dense

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short-period seismographic network called Hi-net is under construction covering all over the country with 1000 telemetered seismic stations. This paper presents the first experiment that critically compare tomographic images obtained by a computer and a human, and found that unexpectedly a computer is able to provide rather good results.

2. Data

Since Hi-net is under construction, we have used data from a temporary seismic network conducted by a research group for the seismicity and the structure of the Hidaka Collision Zone, Hokkaido, Japan. The temporary seismic network consists of 80 short period seismic stations, which is as dense as Hi-net. Seismometers have a natural frequency of 1 Hz and one vertical and two horizontal components. Waveforms are converted to digital data with a sampling rate of 100 Hz and continuously transmitted to Hokkaido University using a communication satellite.

In our institute at Hokkaido University the WIN system (Urabe and Tsukada, 1992) works for automatic processing: detecting a seismic event, cutting out waveforms of the event, storing them into an event file, picking arrival times of P- and S-waves in the event file (Yokota et al., 1981 ; Morita and Hamaguchi, 1984) and locating preliminary hypocenters by using HYPOMH (Hirata and Matsu'ura, 1987). After the automatic processing Naoto Wada skilled in identifying seismographs glanced over the output from a computer, removed the event files without an earthquake, and stored them in the WIN database. This preliminary manual procedure was completed easily and quickly every day, and the arrival times were remained to be values picked by a computer. On the other hand a careful manual inspection was applied to all waveforms recorded in the event files one by one and the arrival times were picked to produce the inspected database. The only one seismologist, who is Kei Katsumata, worked for the manual inspection in order to make the standard of data selection homogeneous.

Seven hundreds thirty-four earthquakes occurring from August 1, 1999 to January 31, 2001 were selected from the WIN database, which had forty and more arrival times of P-wave (Fig. 1a). We did not place any other constrain to the data selection: the number of S-wave readings, the sharpness of onset, the error of hypocenter determination and so on. The numbers of arrival time data were 40688 for P-wave and 28712 for S-wave.

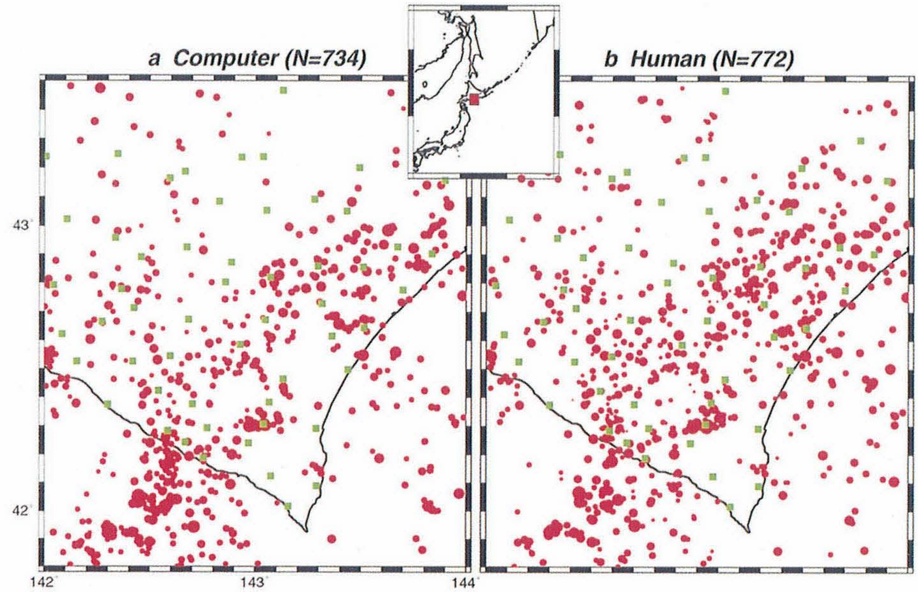

Fig. 1. Seismic stations (green rectangles) and earthquakes (red circles) using for a tomographic imaging of a seismic velocity structure in the Hidaka Mountain region, Hokkaido, Japan. The size of circles is in proportion to a magnitude of earthquake. Earthquakes occurring from August 1, 2000 to January 31, 2001 are plotted. (a) a computer selected 734 earthquakes with forty or more arrival time data of P-wave. Magnitudes and depths of hypocenter ranged from 1.5 to 5.9 and from 0 to 240 km, respectively. (b) Dr. Katsumata as the only human picker selected 772 earthquakes as uniformly distributed as possible. Magnitudes and depths ranged from 0.8 to 5.8 and from 0 to 230 km, respectively.

3. Results

We applied a computer software (Zhao et al., 1992 ; Zhao et al., 1994) to the arrival time data for obtaining tomographic images. The imaging area was divided into grids with a size of 0.1×0.1 degrees in latitude and longitude, and 3, 10, 20, 30, 40, 50, 60, 80, 100, 150 and 200 km in depth. The initial P-wave velocity was assumed to be 6.0 km/s for the depths ranging 0 to 15 km, 6.7 km/s for 15 to 40 km and the Jeffreys-Bullen's model (Jeffreys and Bullen, 1958) for the depth deeper than 40 km. The Poisson's ratio was assumed to be 0.25 for calculating the initial velocity of S-wave. The depths to the Conrad, the Moho and the upper boundary of the Pacific plate were assumed to be same as the previous study (Zhao et al, 1994). The damping factor was five, the number of iteration was three and hypocenters were relocated every iteration.

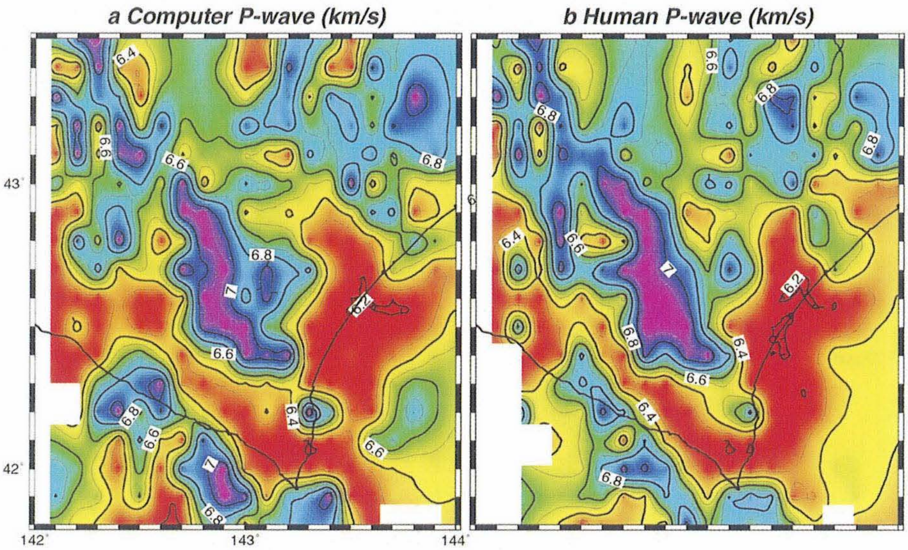

Fig. 2. Tomographic images of P-wave at a depth of 20 km. The velocity in km/s was contoured by a interval of 0.2 km/s. Red and blue/violet colors indicated slow and fast areas. Only grids that one hundreds or more rays went through were plotted. (a) and (b) are the images based on arrival time data picked by a computer and a human, respectively.

We also calculated tomographic images using the inspected database and compared with the results in the case of using the WIN database. The inspected database included 772 earthquakes occurring from August 1, 1999 to January 31, 2001, 25592 arrival times of P-wave and 10731 arrival times of S-wave (Fig. 1b). All parameters for the computer software were given to be same as in the case of the WIN database.

Fig. 2 shows the typical tomographic images for P-wave velocity based on (a) the WIN database and (b) the inspected database. We found that spatial patterns of velocity distribution were consistent with each other in large scale. High velocity areas with a velocity faster than 6.8 km/s were imaged on the both maps around a point of (42.5°N, 143.0°E) and low velocity areas with a velocity slower than 6.4 km/s bounded the high velocity areas. The spatial extent and the shape of these areas were also consistent with each other. Fig. 3 shows the tomographic images for S-wave. We found that the velocity patterns matched each other in large scale as well as the case of P-wave.

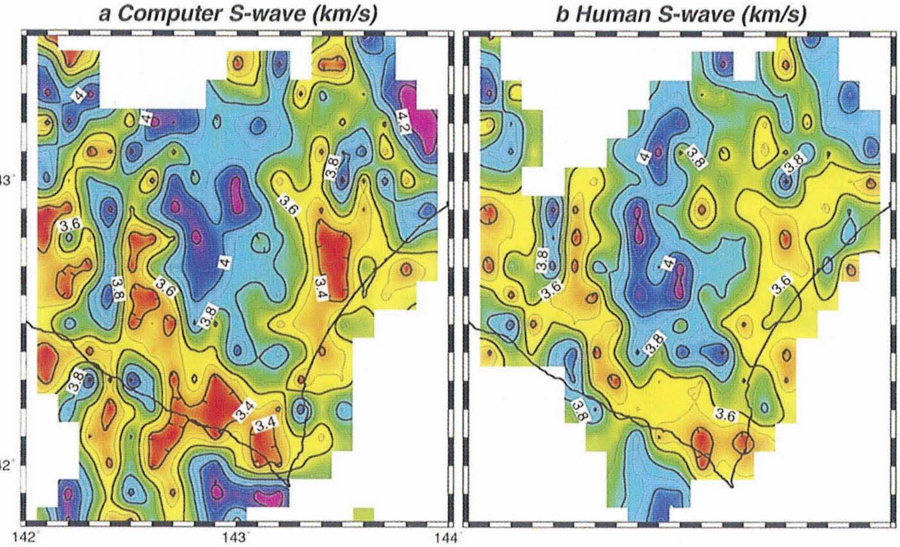

Fig. 3. Tomographic images of S-wave at a depth of 20 km. Legends are same as Fig. 2.

4. Discussion and concluding remark

In order to estimate the difference quantitatively we measured the difference of velocity, V_i- V_w, at all grid points on which the velocities were obtained both in the cases of the WIN database and the inspected database (Fig. 4). V_i and V_w are calculated velocities in the tomography using the inspected database and the WIN database, respectively. We estimated averages of V_i-V_w as -0.01 ± 0.23 km/s for the P-wave tomography and 0.00 ± 0.27 km/s for the S-wave tomography.

These are surprising results because we expected without doubt that the manual picking would overpower the automatic picking in the tomographic imaging, especially in the case of S-wave tomography. In general speaking an automatic picking for arrival times is commonly believed to be less accurate than a careful manual picking, and gives only an insufficient tomographic image. However in this paper we have demonstrated for the local seismic network that a computer can replace a human in a seismic tomography. Though we should extensively continue a case study as this paper, seismologists provably have no need to insist upon a manual picking of arrival times.

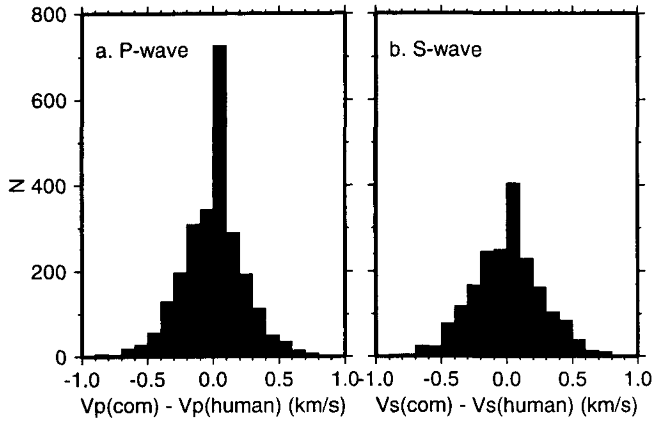

Fig. 4. Histograms of velocity differences between a computer and a human. The velocity differences were calculated for all grids that had velocities both in the cases of a computer and a human. (a) P-wave and (b) S-wave.

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