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Temporal changes of P and S wave velocities in NE Japan associated to the M9Tohoku-Oki earthquake from doublets analyses

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Application of seismic interferometry using ambient noise and coda waves of regional earthquakes have shown notable seismic wave velocity decreases associated with the occurrence of the M9.0 Tohoku-Oki earthquake. These analyses can be generally attributed to S-wave velocity changes at shallow structures because these waves are dominant in surface waves. On the other hand, analyses of doublets have also succeeded in detecting temporal changes of direct arrival times of P waves as well as those of S waves. Also, the seismic rays pass deeper portions. However as the medium changes by the M9 earthquake are widely observed in East Japan, it is difficult to separate the observed travel time differences into the effects of hypocenter parameters and the travel time differences caused by the change in the medium beneath the stations. In this study, therefore, we develop a new method to determine temporal changes of P and S wave velocities beneath stations by simultaneously determining hypocenter parameters of doublets. We relate travel time differences of doublets to site factors at each station and the differences of hypocenter parameters. We further give a constraint in which the sum of the differences in origin times of the doublets analyzed is set to be zero, since the doublets are considered to randomly occur. As a result, our inverse problem estimates the model parameters, namely the site factors for P and S waves at each station and the relative locations of hypocenters and origin times of the doublets. Seismic data at 454 stations of the Hi-net seismic network in East Japan are used. We analyze 35 doublets with magnitudes ranging from 3.7 to 4.7 and depths from 30 to 60 km located offshore in East Japan for the period from 2005 to 2013. The seismic data are band-pass filtered between 1-2 Hz and travel time differences of arrival times of P and S waves are measured by applying a cross-spectrum method. The inversion results show that hypocenters of doublets differ by about 0.05 km and 0.12 km at a maximum each other in the horizontal and vertical directions, respectively. Even when we change the data set of doublets, the relative hypocenter locations do not significantly change, which indicates our inversion method is stably determining the hypocenter parameters. For the site factors, we find significant delays of arrival times as large as 0.04 s for the S-waves and about 0.01 s for the P-waves. Time delays are observed mainly at stations located widely in Tohoku region between 37 and 40 degrees in latitude, which are west from the M9 fault zone. The observed spatial distributions of time delays seem not to be well matched with the regions strongly shaken, which are located mostly in the eastern area of Tohoku region, or the regions where seismic velocity reductions at shallow medium are detected from analyses of bore-hole and ground surface records. These discrepancies suggest that the time delays detected from doublets originate from different regions, maybe deeper portions beneath Tohoku region.

Keywords: Tohoku-Oki earthquake, Velocity change, Similar earthquakes, Direct P and S waves