Cluster Analysis of the Velocity Field in the Japanese Islands Derived from Dense GEONET Data

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Spatial inhomogeneity of crustal deformations is a key for understanding tectonics of plate convergence zones. The concentration of deformation triggers earthquakes and contributes to forming topography. Therefore, detecting deforming zones from observed data is of great importance. Recently, GNSS observation networks have become significantly denser, so that statistical approaches are effective methods for revealing crustal structure associated with geophysical phenomena. Simpson et al. (2012) and Savage and Simpson (2013) conducted cluster analyses of GNSS velocity fields in the San Francisco Bay Area and Mojave Desert, respectively. They successfully found tectonic boundaries. The application of the clustering approach to regional GNSS velocity field is able to yield objective crustal block segmentations based on quantitative criteria.
In this study, we modified the method and applied it to the GNSS velocity field of Japan. The obtained results are compared with geological features to assess the effectiveness of the method.
We performed a cluster analysis of horizontal components of the GNSS velocity field with the Hierarchical Agglomerative Clustering algorithm (HAC). The HAC algorithm organizes data according to their successive geometrical distance. First, we set N-samples (hereafter data) as initial individual clusters. Then we search for the nearest pair of clusters and create a new data at their average position. We merge the nearest pair of clusters in a solution tree (tree space) and replace the clusters with single data in the velocity space. We repeating this procedure successively until a single data remains in the velocity space. At each step, pairs of clusters with minimum geometrical distances in the velocity space are merged.
There is an ambiguity in determining the optimum number of clusters. Previous studies used a statistical method called “Gap Statistics”. The method provides an optimum number of clusters by comparing a random data set and the organized results. However, the sampling zone must be designated manually and may affect the evaluation procedure. For example, if we take a wider area, then a smaller number of clusters will be preferred.
To avoid such a disadvantage, we introduced a new simple cluster evaluation function based on the ratio of the standard deviations for the within-cluster distances and the between-cluster distances. If we divide the much smaller inter-station distances by the larger cluster distances, the cluster size will slowly decrease. Then we select the point where the curvature of the ratio changes, as an optimum number of clusters. This method successively identified larger features in the velocity space which reflect major crustal structures.
The obtained results were well organized in geographic space even though no geographical constraints were applied. Also, obtained cluster boundaries coincided with major known active faults, which suggests that we could make unbiased identification of crustal blocks from GNSS data. In addition, we easily obtained relative motions between the identified clusters, providing an intuitive understanding of the regional deformation. Furthermore, the optimum ratio may reflect the degree of internal deformation in the analyzed area.
We present some results for specific areas. In the central Kyushu region, we identified a stress field which indicates north-south extension and east-west compression. In the Kinki district, the Hanaori fault and the Biwako Seigan fault were suggested as boundaries where strain partitioning is occurs.

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