Global distribution of tectonic plates revealed by cluster analyses of geodetic data

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The surface of the Earth is divided into more than a dozen of rigid plates. Since most tectonic events such as earthquakes and volcanic activities occur around plate boundaries, it is of fundamental importance to clarify the distribution of tectonic plates. Owing to the increase of space geodetic data, finer partitions of tectonic plates have been proposed, but it is unclear whether such partitions are relevant. We need an appropriate objective method in dividing tectonic plates.
In recent years, cluster analysis has been applied to GNSS velocity data to explore crustal block structure of a deformation zone (Simpson et al., 2012). In this paper, to obtain a global plate distribution, we consider formulating a cluster analysis of velocity data measured from all over the world, to which we cannot directly apply cluster analysis due to the sphericity of the Earth.
It is known that any rigid motion on a sphere can be expressed as a rotation along an axis passing through the center of the sphere; the rotation vector (angular velocity) is called the Euler vector. It turns out that each velocity data is represented by a straight line through the (unknown) Euler vector in the angular velocity space (AVS). Therefore we project observed velocity data to AVS, and formulate a cluster analysis of Euler vectors. If observed data locate in the same rigid plate, the lines of these data projected onto the AVS should cross at the point of the Euler vector of that plate. If we can appropriately cluster accumulation points of such lines, we can obtain the distribution of tectonic plates with the values of Euler vectors.
Given that cluster analysis of straight lines is not established, we here propose three methods and compare their performance. We use 206 velocity data obtained by space geodetic techniques (Altamimi et al., 2012). In evaluating the performance, we refer to the classification of plates which is based on geological knowledge by Altamimi et al., (2012).
First, we modify the hierarchical algorithm to this problem: the nearest two lines are combined to a new one at the center of mass of the old two lines (weighted according to their cluster sizes). This method works well for a smaller number of partitions less than six, but some clusters become geographically discontinuous for a larger number. This is because each line includes the true Euler vector just as a point on the line; when two lines of velocity data on different plates happen to cross one another, the crossing point is mistakenly picked up as the Euler vector of them. A more robust clustering algorithm is necessary to avoid such misclassifications.
Next, we modify the K-means method: cluster centers are put as points in AVS; each line is assigned to the cluster of the nearest center, and then each cluster center is renewed to the points where the square sum of the distances to the lines takes the minimum. This method does not work well for a small number of partitions, possibly because this algorithm tends to generate similar sizes of clusters. In contrast, the performance improves for a larger number. A drawback is that sudden changes of cluster boundary sometimes occur because K-means is not a hierarchical method.
Finally, we newly develop an iterative estimation method of accumulation points of lines, and then apply the hierarchical algorithm of points in AVS. The method works best among the three methods for the number of partitions not more than ten. The obtained results are almost consistent with the plate distribution by Altamimi et al. (2012). On the other hand, inconsistent plate distribution is obtained for the cases of more than ten clusters. This may be due to a smaller number of observed points on each

plate; when the number of observed data is not enough, the algorithm to estimate accumulation points does not work well. Denser observation points would be required to reveal finer structures of tectonic plates.

