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Cluster Analysis of Recent GPS Dense Array Data in the Japanese Islands

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Synopsis

We have hierarchically clustered recent GPS dense array data (**Kato et. al.,1998**) in the Japanese Islands for the first time. The idea is to see if a continuous tectonic structure emerges without knowing of any physical conditions.

Several hinge lines associated with past earthquakes (**Ando, 1975**) can be found along the south - western coast of the Japanese Islands. Several crustal block boundaries like the Beppu - Shimabara graben (**Tada, 1984**), Tsurugawan - Isewan tectonic line (**Kanaori et al., 1992**) have also been identified in the Japanese Islands and we suppose that this may be a good technique for delineating block boundaries in future.

Keywords: GPS; cluster analysis; block boundaries

1. INTRODUCTION

Recent introduction of GPS dense array (**see Kato et al., 1998)** by the Geographical Survey Institute of Japan, provides 3-dimensional relative positions with the precision of a few millimeters to approximately one centimeter over baseline separations of hundreds of meters to thousands of kilometers. The three-dimensional nature of GPS measurements allows one to determine vertical as well as horizontal displacement at the same place and time. In this analysis we have tried to determine groupings in the above data using **Hierarchical Cluster Analysis**. The idea is to see if a continuous tectonic structure emerges without knowing of any physical conditions.

Data of GSI's GPS array is provided as daily **SINEX** (Software Independent Exchange) format files. We used daily files from **April 1st 1996 to March 31st 1997** so that the period spans about 1 year. We used a total of 649 stations. Since the estimated coordinates of data points in the SINEX files are written in geocentric coordinates, the estimated horizontal and vertical displacements in the geocentric reference frame are transformed to the local reference frame to obtain daily coordinate changes of the sites. Since there were missing observations for most of the sites, we interpolated the missing observations linearly before clustering all data hierarchically. Since we have a large number of data points we divided the Japanese Island into six geographical regions . The East-West, North-South and Up-Down components for each region were clustered separately. Any visible tectonic boundaries were then digitized.

If we assume a homogeneous deformation then points in the same group are assumed to have the same or similar deformation. We therefore assumed that points in the same group lie on the same land block and then compared these with tectonic or geological boundaries in the Japanese Islands.

2. CONCEPT OF ANALYSIS

Cluster analysis is a multivariate procedure for detecting groupings in data. The objects in these groups is deformation data in our analysis. We assume that the members of the groups are unknown. That is, we begin with no knowledge of group membership and we do not know how many clusters there are.

Clustering begins by finding the closest pair of objects according to a distance measure and combines them to form a cluster. The algorithm continues one step at a time, joining pairs of data points, pairs of clusters, or a data point with a cluster, until all the data are in one cluster. The clustering steps are displayed in an icicle plot or tree. The method is **hierarchical** in the sense that once two objects or clusters are joined, they remain together until the final step. That is, a cluster formed in a later stage of the analysis contains clusters from an earlier stage that contains clusters from a still earlier stage.

The software used in our analysis is **SPSS**. Because of problems with the large dimension of all one year data, the Japanese Island was divided into six regions with an average of 100 stations per region. The analysis was performed separately for each region in **E - W**, **N - S** and **U-D** direction respectively.

3. RESULTS AND DISCUSSION

Figure 1 is an example of the time series used in our analysis. The missing observations were linearly interpolated before clustering.

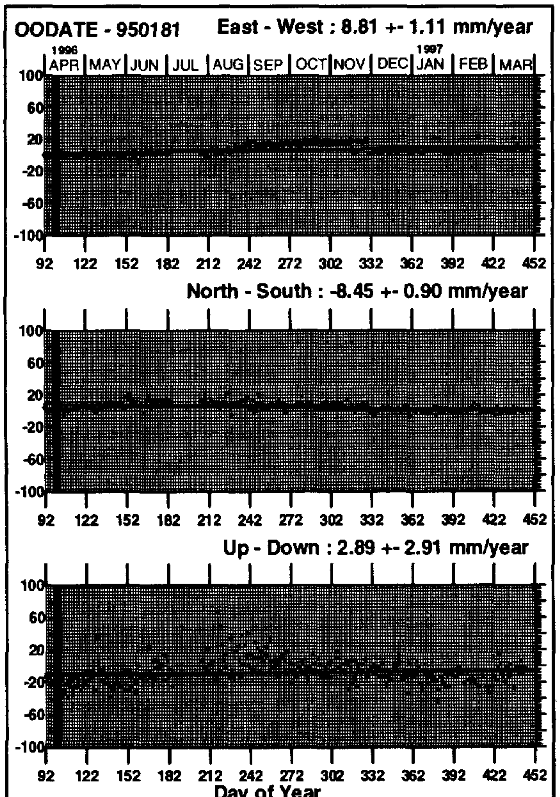

Fig. 1 Time series analysis for Oodate station in the Tohoku district

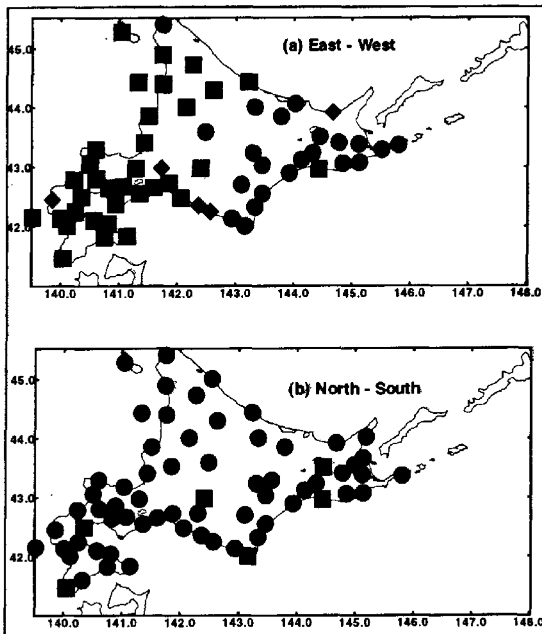

Fig. 2 (a) East - West and (b) North - South Clusters in Hokkaido district

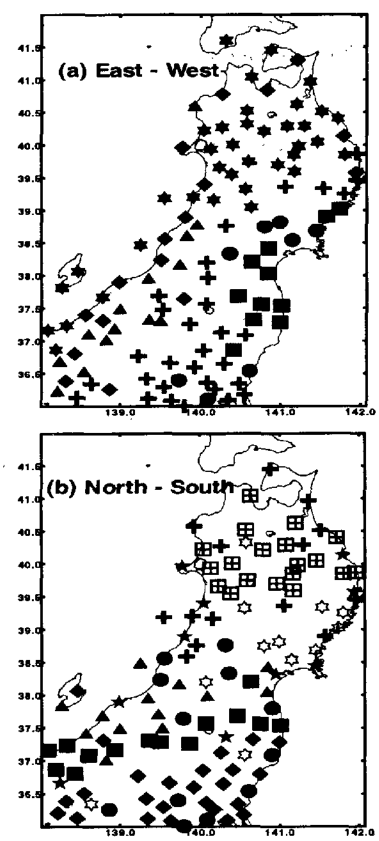

Fig. 3 (a) East - West and (b) North - South Clusters in Tohoku

Figures 2 - 7 are the results of clustering obtained for each region in E-W and N-S directions.

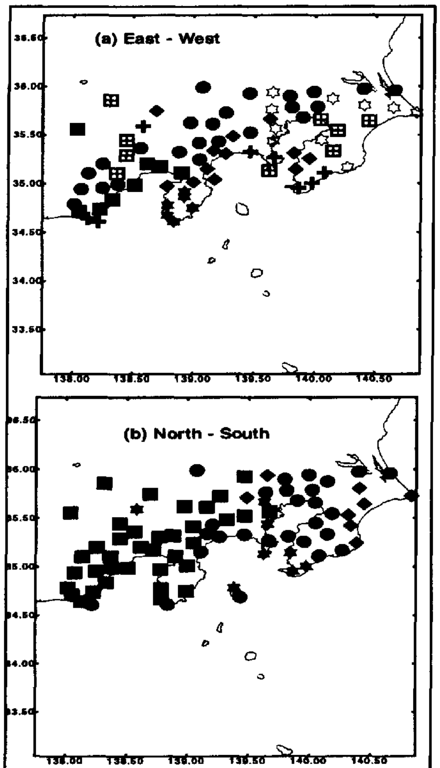

Fig. 4 (a) East - West and (b) North - South Clusters in Kanto - Tokai

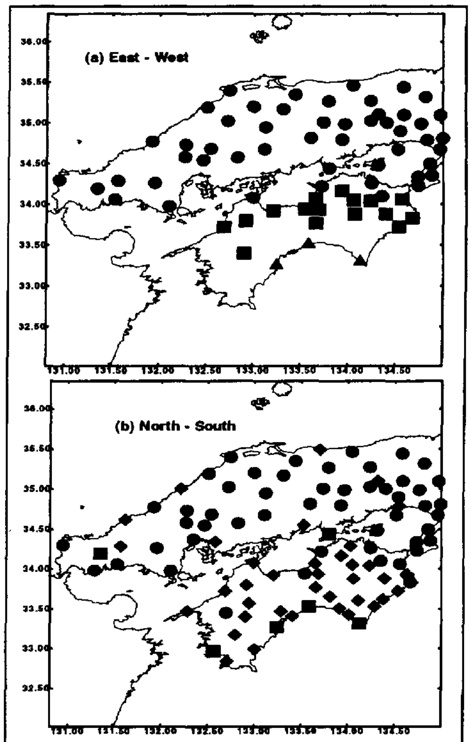

Fig. 6 (a) East - West and (b) North - South Clusters in Shikoku and Chugoku

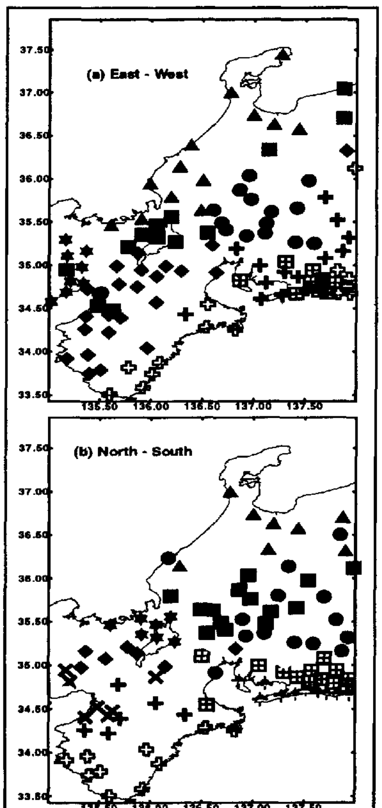

Fig 5 (a) East - West and (b) North - South Clusters in Chubu and Kinki

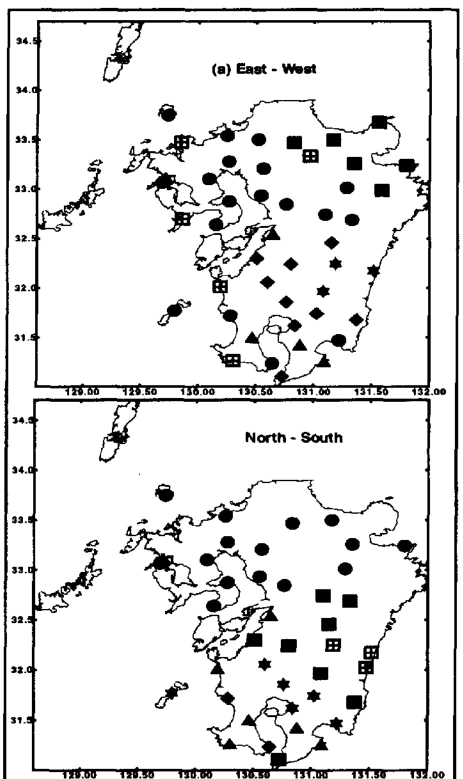

Fig. 7 (a) East - West and (b) North - South Clusters in Kyushu

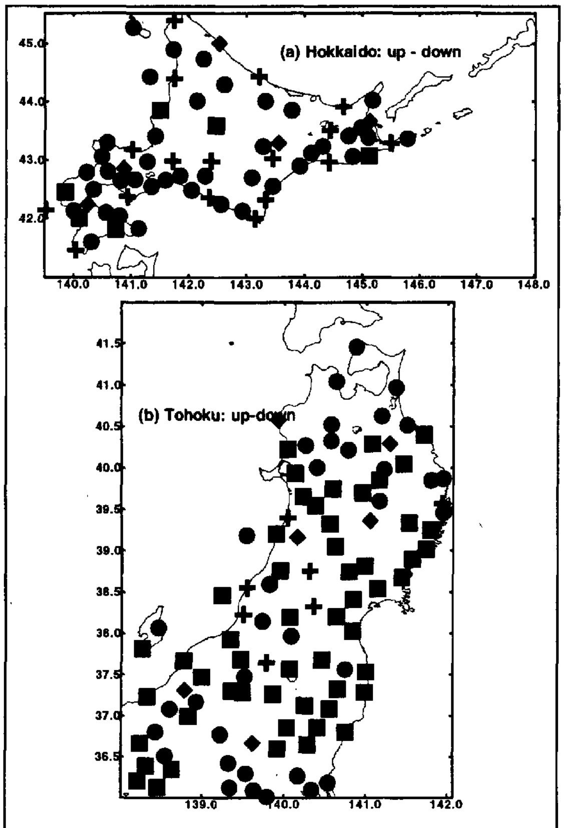

Fig. 8 Up - down Clusters in (a) Hokkaido and (b) Tohoku

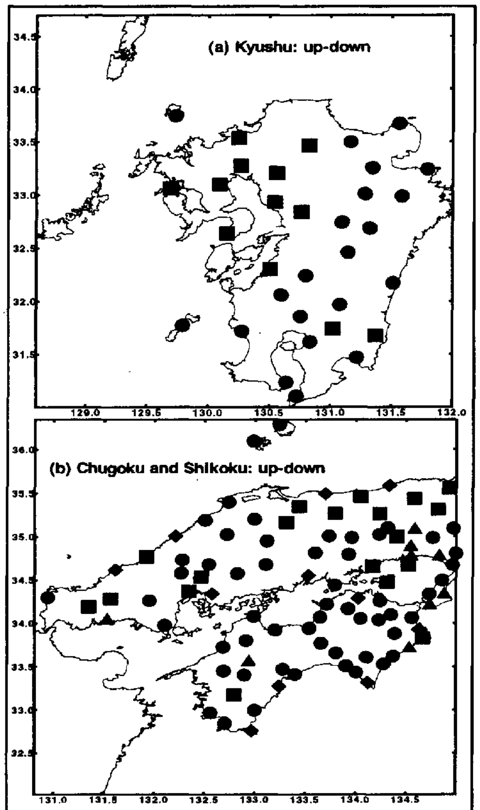

Fig. 10 Up - Down Clusters in (a) Kyushu and (b) Chugoku and Shikoku

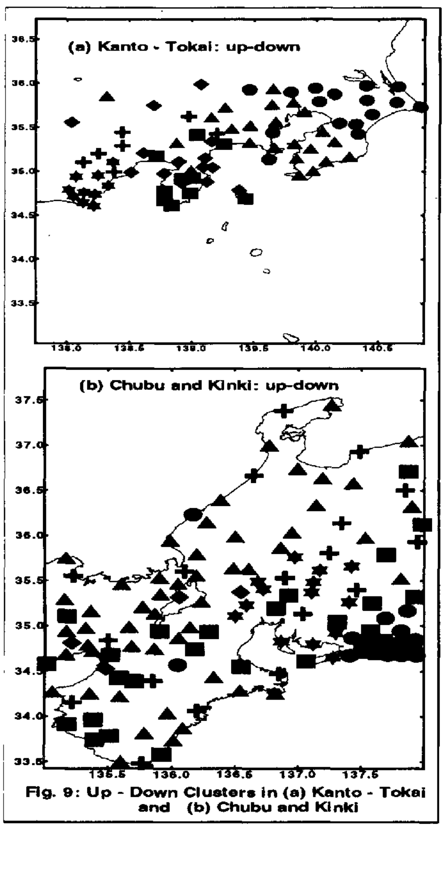

Fig. 9: Up - Down Clusters in (a) Kanto - Tokai and (b) Chubu and Kinki

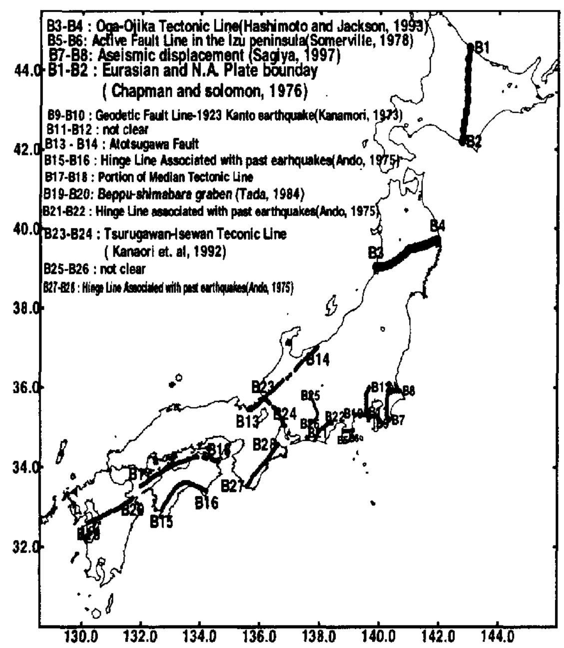

Fig. 11 :Block boundaries identified in the Japanese Islands from the cluster analysis of GPS dense array data by digitization of the boundaries in figures 2 - 10.

Figures 8 -10 are the results obtained for each region in up-down direction. **Figure 11** is a map of the tectonic boundaries obtained from **Figures 2-10.**

From **figure 11**, boundary **B1-B2** coincides roughly with the Eurasian and North American plate boundary **(Chapman and Solomon, 1976). B3-B4** coincides roughly with the Oga-Ojika tectonic line **(Hashimoto and Jackson, 1993). B5-B6** coincides with an active fault line in the Izu Peninsula **(Somerville, 1978).** Aseismic displacement occurred along **B7-B8** in May 1996 **(Sagiya, 1997). B9-B10** roughly coincides with the Geodetic Fault Line associated with the 1923 Kanto earthquake. **B11-B12** has no clear significance. **B13-B14** roughly coincides with the Atotsugawa fault in central Japan. **B15-B16** coincides with a hinge line associated with past earthquakes **(Ando, 1975). B17-B18** coincides with a portion of the median tectonic line. **B19-B20** coincides with the Beppu-shimabara graben **(Tada, 1984). B21-B22** may be an extension of the hinge line, **B27-B28**, due to past earthquakes **(Ando 1975). B23-B24** coincides roughly with the Tsurugawan-Isewan tectonic line **(Kanaori et. al. 1992). B25-B26** has no clear significance. The after effects of the **Hyogo-ken Nambu** and **Hyuganada** earthquakes can also be seen in **figures 5 and 7** making cluster analysis a very good technique also for outlier detection in GPS data.

The above geological or tectonic boundaries have been determined using only one year of GPS data. Even though interesting results have been obtained we need to check the validity of these boundaries using a longer term data in future.

4. CONCLUSION

Our results have shown that cluster analysis of GPS displacement rates may reveal valuable information related to crustal blocking in the Japanese Islands. This may in turn help in the prediction of earthquakes. We may also have to use a longer term data for more meaningful results. More meaningful results were obtained for East-West and North-South components than for the up-down components.This may be associated with errors due to GPS heighting.

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要　旨

著者らは，日本列島における最近の GPS データ（Kato et. al.,1998）を階層的に分類した。本論文の目的は，連続的な地殻構造を，多様な物理的条件を考慮することなしに解明しようとするものである。本手法を適用することによって，過去に発生した地震と関連する数カ所の構造線が日本列島の南西沿岸に見いだすことができた。また，別府ー島原地溝帯や敦賀湾ー伊勢湾構造線などのブロック境界を日本列島内に描くことができた。

キーワード：GPS，クラスター分析，ブロック境界