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Tilting Movements of the Japanese Islands as Deduced from GPS Dense Array Data

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Synopsis

In this paper we have estimated the continuous distribution of tilt from GPS dense array data in the Japanese islands for the first time using the least squares prediction technique (**Moritz, 1980**). Maximum tilting is found to occur around the Eastern half of North East Japan. Large north - south tilts of Kyushu island is evident. This may be due to the extensional force generated by the rifting of the okinawa trough, Japan (**Tada, 1984**). A remarkable agreement is also found between the tilt vectors and GPS horizontal displacement vectors in the Japanese Islands. We therefore conclude that the tilting movement of the Japanese Islands may be due to the subducting oceanic plates.

Keywords: GPS; prediction; tilt; seismicity; block boundaries

1. INTRODUCTION

Recent introduction of GPS dense array 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.

Unfortunately, our experience has shown that height accuracy of GPS is still very low for the meaningful delineation of crustal deformation in the Japanese islands. Vertical displacement rates of GPS may be non-linear due to climatic, atmospheric pressure, wind and tidal variations. As a result strain analysis in the Japanese islands from displacements observed on the earth's surface has always been treated as a two dimensional problem (**Kato et al., 1998**). As a result of the above shortcoming valuable information relevant to earthquake prediction may be lost.

We want to suggest in this paper that the best way to interprete GPS vertical displacement rates is by tilts, not uplifts. This will reduce the non-linear elements since tilts are less affected by observational errors. For determining tilt, all that is required is the difference in the amount of uplift with distance, the true amount of uplift being irrelevant. Tilt is thus known at many places where uplift is uncertain (**Wellman, H.W. 1972**).

We would therefore introduce a new concept of crustal tilt estimation based on the Least Squares Prediction Technique. Its relation with earthquake activity would be studied. Since the tilting axes of land blocks usually coincide with block boundaries this would be the first time that such a technique would help identify block boundaries in the Japanese Islands.

2. CONCEPT OF ANALYSIS

The concept of analysis is based on the general assumption that a physically, geometrically and elastically defined thin plate is deformed. This deformation **V** determined from uplift rates of the GPS dense network (see Kato et al.,1998) is used as input-parameter for calculating the strain tensor within the plate. Data of GSI's GPS array are provided on a daily basis. We used daily files from April 1st to October 31st, 1996 so that the period spans about seven months. We performed a linear regression analysis to obtain average vertical velocities of all sites. The average velocities or signal

V predicted at selected grid points (**7km by 7km**) were then differentiated with respect to x and y respectively as

$$\frac{dv}{dx} = \sum_{i=1}^{n} -2 * C_{VS} * k_v^2 * (x - x_i) * \exp(-k_v^2 d_i^2) * C_{VV}^{-1} * v$$

$$\frac{dv}{dy} = \sum_{i=1}^{n} -2 * C_{VS} * k_v^2 * (y - y_i) * \exp(-k_v^2 d_i^2) * C_{VV}^{-1} * v$$

where

n = number of observations

C_{VS} = Gaussian crosscovariance function between average velocity and the Signal.

$d_i = ((x - x_i)^2 + (y - y_i)^2)^{1/2}$

(x , y) = coordinates of signal points **V**

(x_i, y_i) = the coordinates of observation point i

k = a constant in the Gaussian function

C_{vv} = **n*n** variance matrix of V

V = **n*1** vector of known vertical displacements.

From the above equations the total tilt, **T** and the azimuth of tilting **θ** can be obtained respectively as

$$T = \sqrt{\left[\left(\frac{dv}{dx}\right)^2 + \left(\frac{dv}{dy}\right)^2\right]}$$

and

$$\theta = \arctan\left[\frac{dv}{dx} \Big/ \frac{dv}{dy}\right]$$

3. RESULTS AND DISCUSSION

Figures 1 and **2** are the magnitude and azimuth of tilting respectively. **Figures 1 and 2** show that maximum tilting occurs around the Eastern half of North East Japan. This correlates well with seismicity in the region (see Kato et al., 1998). We may therefore suppose that the tilting movement in this region may be due to the high activity offshore. **Figures 1 and 2** show that the west Japan arc system is less active in general than the east Japan arc system. **Figure 2** shows that large north-south tilts of Kyushu island is evident. **Tada (1984)** hypothesized using conventional triangulation data that the area is under the extensional force due to the rifting of the okinawa trough. The present analysis is harmonious with those conventional triangulation data. We may therefore suppose that the tilting movement is due to north-south stretching of Kyushu island. Apart from northern Kyushu, NS to NW-SE tilting is predominating in SW Japan. This may be due to the

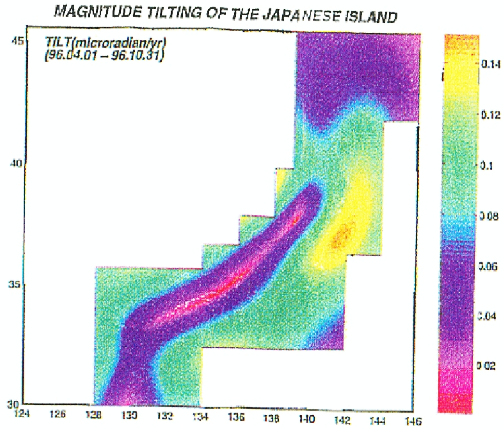

Fig. 1 The magnitude of tilting in the Japanese islands

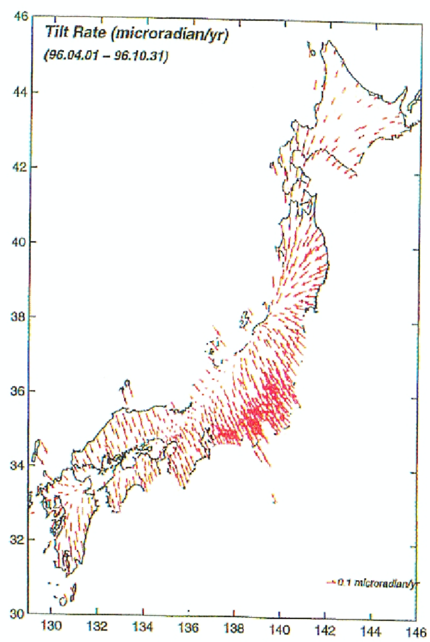

Fig. 2 The azimuth of tilting in the Japanese islands

compressional force acting at the convergent plate boundary between the Phillipine Sea plate and the continental plate (**Tabei et al., 1996**). A comparison between the tilt vectors (**Fig. 2**) and GPS horizontal displacement rates in the Japanese islands (Kato et al., 1998) shows a remarkable agreement in the direction of vectors. We therefore conclude that the tilting movement of the Japanese islands may be due to the subducting oceanic plates.

Some block boundaries can be identified in the Japanese Islands in **Figs. 1 and 2.** These are the Beppu-Shimabara graben and a portion of the Median Tectonic Line. This may be a good technique for delineating block boundaries in future.

4. CONCLUSION

Our results have shown that analysis of GPS vertical displacement rates by tilts may reveal valuable information related to earthquake prediction. This technique may also prove useful for block boundary delineation in future. We therefore conclude that tilt analysis is useful for earthquake studies especially for areas where the exact amount of uplift is unknown. Data covering a longer time interval may have to be used to obtain more reliable results.

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要　旨

本研究ではＧＰＳ高密度アレー観測から得られたデータから最少二乗法を用いた推定手法によって日本列島の傾斜の連続分布の推定を行った(Moritz,1980)。最大の傾斜は東北地方の太平洋側で，顕著な南北方向の傾斜は九州地方で見られた。これは沖縄トラフが裂けることによって発生する伸張力によるものと考えられる(Tada,1984)。傾斜ベクトルとＧＰＳの水平変位ベクトルは，驚くほど傾向が一致していた。以上から，日本列島の傾斜運動は海洋プレートの沈み込みによるものと言える。

キーワード：ＧＰＳ，地震予知，傾斜，地震活動，プレート境界