Small repeating earthquakes and interplate creep around the 2005 Miyagi-oki earthquake (M7.2)

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Abstract:

The 2005 Miyagi-oki earthquake (M7.2) occurred on August 16, 2005 near the hypocenter of the 1978 Miyagi-oki earthquake (M7.6) which is one of the recurrent 'Miyagi-oki eathquakes'. We have estimated the spatial-temporal distribution of quasi-static slip (creep) around the 2005 earthquake by using small repeating earthquakes. Taking advantage of the feature that creep around an asperity is necessary for the recurrent rupture of the same small asperity, we estimated the distribution of creep from the distribution of small repeating earthquakes. The creep is detected mainly outside of the asperities for the 2005 Miyagi-oki, 1978 Miyagi-oki and 2003 Fukushima-oki (M6.8) earthquakes. The creep rates estimated from the recurrence intervals and slip amounts of small repeating earthquakes for 21 years were almost constant for the areas near the western limit of interplate earthquake but vary temporally in the areas near the Japan trench. The changes in the creep rates before and after the 2005 Miyagi-oki earthquake were not significant except for small slip accelerations in some areas near the Japan trench. It suggests the plate boundary around the asperity for the 2005 earthquake is mostly still locked.

1. Introduction

The 2005 Miyagi-oki earthquake occurred on August 16, 2005 in the anticipated source area for the recurrent 'Miyagi-oki earthquakes'. However, it was estimated that the earthquake did not destroyed the whole area of the asperity which caused the previous Miyagi-oki earthquake in 1978 (The Headquarters for Earthquake Research Promotion, 2005; Yaginuma et al. 2006). It is important to know the spatio-temporal evolution of a plate-boundary coupling to understand the earthquake cycle in this area. Repeating earthquake analysis is one of the powerful tools to estimate the quasi-static slip on the plate boundary (Ellsworth, 1995; Nadeau and McEvilly, 1999; Igarashi et al., 2003; Uchida et al., 2003). It has advantages that the spatial resolution of slip distributions is as high as earthquake location and that long term data are available compared to the GPS data analysis.

In the present study, we estimate cumulative slips for small repeating earthquakes assuming that they were equal to the quasi-static slip histories in the surrounding areas on the plate boundaries (Igarashi et al., 2003; Uchida et al., 2003).

2. Data and Method

We used digital seismograms recorded by the microearthquake observation network of RCPEV, Tohoku University, for the period from July 1984 to January 2006. The sampling frequency was 100Hz and most of the seismometers were of 1Hz velocity type. In total, we searched about 10,000 shallow (depth<70km) earthquakes with magnitude 2.5 or larger.

The small repeating earthquakes are identified based on similarity of seismograms. We calculated coherence of waveforms for events whose epicenter separations are less than 30 km. The time windows for the analysis were set to 40s from P wave arrivals. The time window always contain S phase which assure the same S-P time (ie. the same location) if they have high coherence. We treated an earthquake pair as a pair of repeating earthquakes when the averaged coherences for 1 - 8 Hz were larger than 0.95 at two or more stations. Then, a pair (group) of repeaters was linked with another if the two pairs (groups) shared the same earthquake.

The cumulative slip was estimated using the same procedure as Uchida et al. (2003, 2004). The slip for each small repeating earthquake was estimated from the relationship between the seismic moment and slip (Nadeau and Johnson, 1998). Igarashi et al. (2003) confirmed that the slip calculated from this relation is consistent with the slip estimated from the relative plate motion and repeating intervals using the data for several events in NE Japan. The seismic moment was estimated from the relationship between the moment and magnitude (Hanks and Kanamori, 1979). Cumulative slip was then estimated by adding all the slips of small repeating earthquakes in one group.

3. Distribution of small repeating earthquakes

Figure 1 shows the distribution of small repeating earthquakes around the 2005 Miyagi-oki earthquake. Blue circle shows the centroid of repeating earthquake sequence. Orange circle indicates the centroid of repeating earthquake sequence that showed activity for the period of 4.5 month before (Fig.1a) and after (Fig. 1b) the 2005 event. Yellow star shows earthquake with magnitude 6 or larger for the periods. The contours denote coseismic slip distributions for the 1978 Miyagi-oki earthquake, 1981 M0.0 event, 2003 M6.8 event (Yamanaka and Kikuchi, 2003) and the 2005 M7.1 event (Yaginuma et al., 2006). Peaks of each coseismic slip distribution correspond to asperities. Most of small repeating earthquakes are distributed outside the asperities. Some of small repeating earthquakes that occurred after the 2005 event (orange circles in Fig.1b) are distributed near the earthquakes of M6 or larger (yellow stars in Fig. 1b).

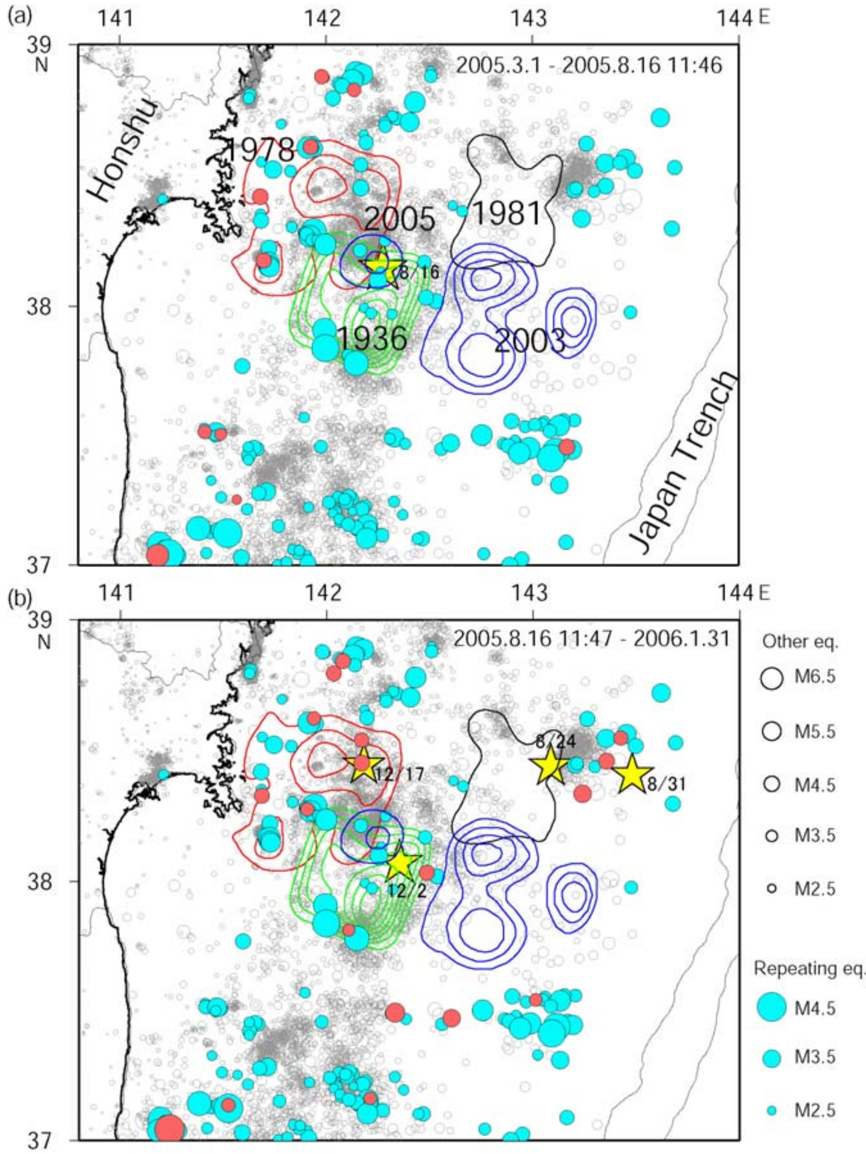

Fig. 1 Distribution of small repeating earthquake groups (blue circles). Orange circles indicate the small repeating earthquake groups that showed activity for the period of 4.5 months before the 2005 earthquake (a) (from 1 March 2005 to 11:46 16 August 2005 [JST]) and for the period of 4.5 months after the 2005 earthquake (from 11:47 16 August 2005 to 31 January 2006). Thin contours show the coseismic slip distributions for the 1978 Miyagi-oki earthquake, 1981 M7.0 event, 2003 M6.8 event and 2005 M7.1 event (Yamanaka and Kikuchi, 2003; Yaginuma et al., 2006). Stars denote the hypocenters with magnitude 6 or larger. Gray circles show the earthquakes shallower than 70 km for the period from January 2005 to January 2006.

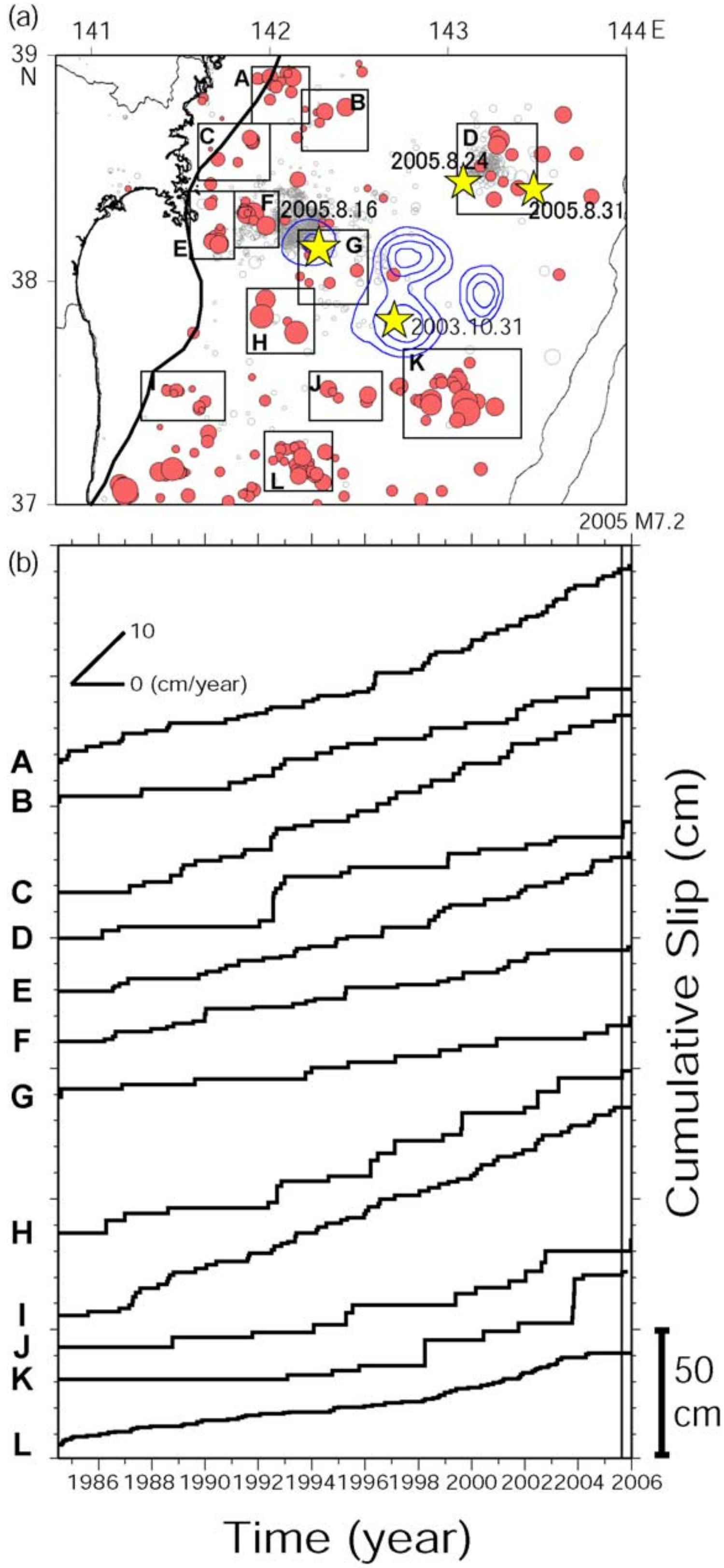

Fig.2 Averaged cumulative slips of small repeating earthquakes for the period from 1984 to December 2005. (a) Distribution of small repeating earthquakes (orange circles) and windows (rectangles) used to estimate averaged cumulative slip. Bold line denotes the western limit of low-angle thrust earthquakes (Igarashi et al. 2001). (b) Averaged (stacked) cumulative slips for the small repeating earthquake groups in the windows shown in (a).

4. Temporal change in creep

Figure 2b shows the averaged cumulative slips for small repeating earthquake groups. We averaged the cumulative slips of all the groups in each rectangle shown in Fig.2a to show the result in Fig.2b. Note that there may be lack of repeating earthquakes before 1992 because of incompleteness in the waveform database. The cumulative slip of small repeating earthquake (creep) increases with almost constant rate for the regions near the western limit of interplate earthquakes (regions A, C, E, and I). On the other hand, the regions near the Japan trench (regions D and K) shows some temporal fluctuations in the creep rate. In-between regions (B, F, G, H, J and L) show relatively low slip rate. The creep-rate change after the 2005 event (vertical line) is insignificant except for region D where two M6.3 earthquakes occurred.

Figures 3a and 3b show the cumulative slips for 2 months at the region K and region D, respectively. In region D, slip was estimated after the first M6.3 event near the Japan trench as shown in Fig 3b. In region K slip was estimated both before and after the 2003 M6.8 event. These observations show the existence of creep acceleration at the regions.

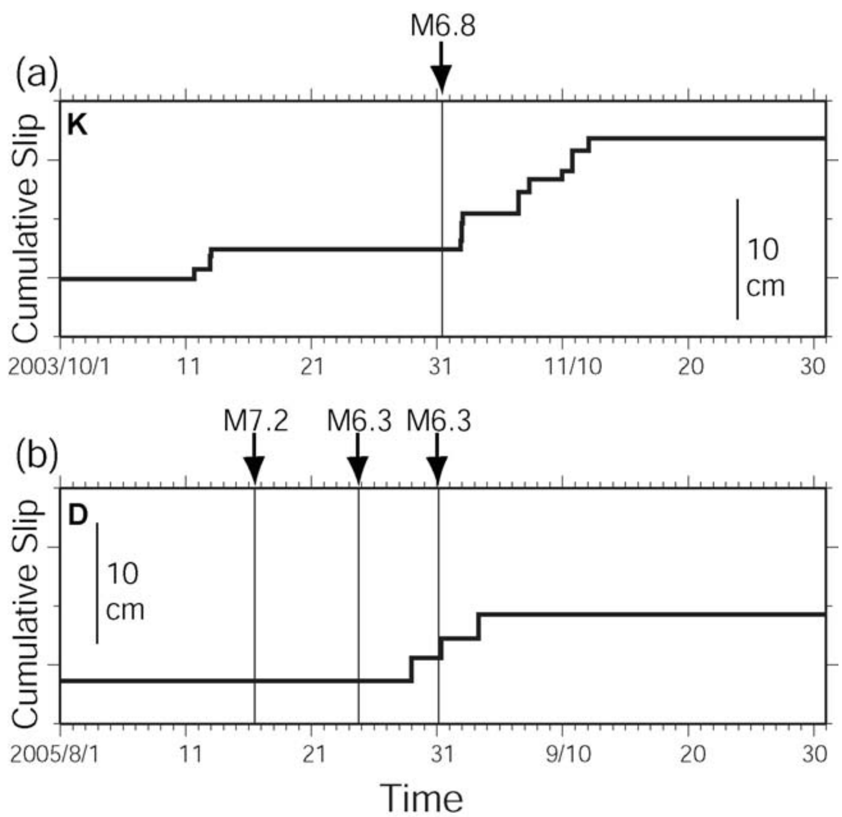

Fig. 3 Averaged cumulative slips for regions K and D for the periods of two months. The occurrence times of major earthquakes are shown by vertical lines and arrows.

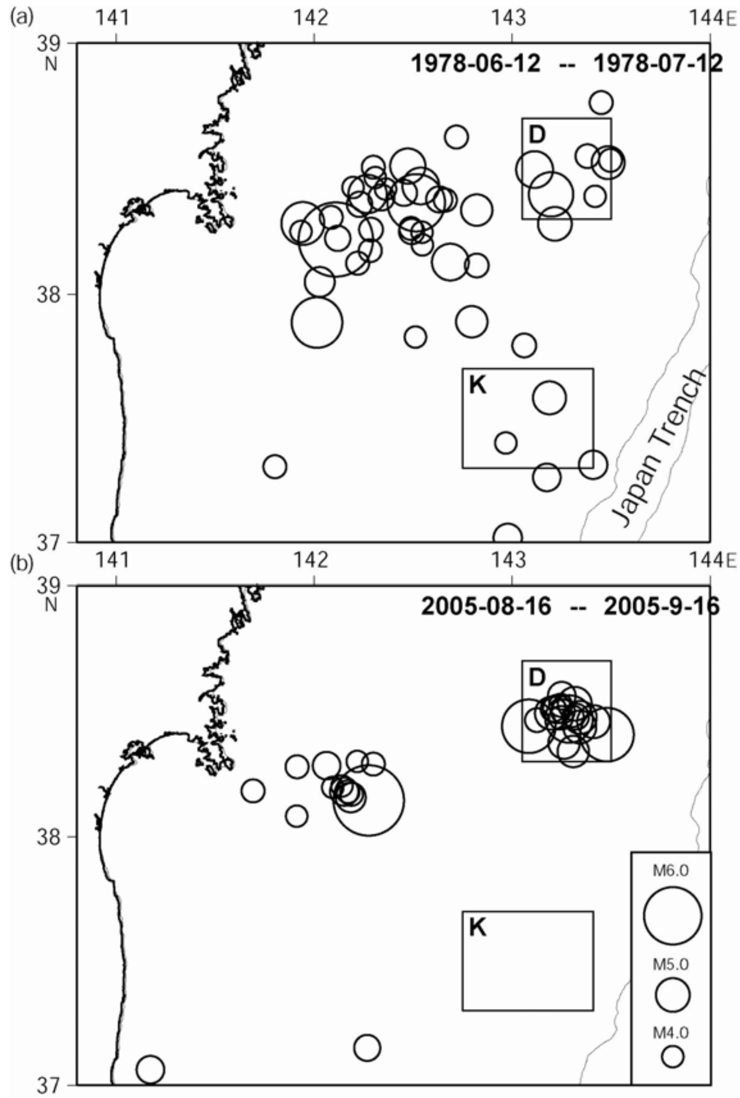

Fig. 4 Aftershock distributions of (a) the 1978 M7.4 and (b) 2005 M7.2 Miyagi-oki earthquakes. Earthquakes shallower than 60km for the period of one month after each main shock were plotted. Two rectangles labeled D and K are the same as those shown in Fig. 2a.

5. Discussions

The small repeating earthquakes are distributed mainly outside the large asperities. This probably shows that the creep is dominant outside the asperities. The numbers of small repeating earthquakes for the period of 4.5 months before and after the 2005 event are 9 and 19, respectively. Therefore, the activities of the small repeating earthquakes are increased after the 2005 event which probably due to creep acceleration in the wide area. However the creep acceleration was not so significant if we see long term (20 years) slip history estimated from small repeating earthquakes shown in Fig. 2. This shows that such weak creep accelerations have frequently occurred in the analyzed 21 years.

Miura et al. (2006) performed GPS data analyses to show that the afterslip of the 2005 earthquake was distributed to the south of the coseismic slip area and that the maximum slip was as small as about 5 cm. This slip is too small to be detected obviously by small repeating earthquake analysis because the slip for the smallest repeating earthquake analyzed here (M2.5) is about 10 cm.

The lack of large afterslip for the 2005 event is peculiar compared to significant afterslips reported for large interplate earthquakes along the Japan trench. For example, the moments for the afterslips following the 1994 Sanriku-oki earthquake (M7.6) and the 1989 Sanriku-oki earthquake (M7.1) were estimated to be almost the same as the coseismic slips (Heki et al., 1997; Nishimura et al., 2000; Kawasaki et al., 2001). As shown in Fig.1, there are many large asperities in the Miyagi-oki region and the 2005 event was estimated to have ruptured only the southeastern part of that of the 1978 event (Yaginuma et al ,2005). Furthermore, the interplate coupling estimated from GPS data is high in this region (Suwa et al. 2006). The lack of large afterslip of the 2005 earthquake was possibly due to the strong locking around the asperity for the earthquake.

The seismic activity near the Japan trench was observed not only after the 2005 earthquake but also after the 1978 Miyagi-oki earthquake as shown in Fig.4. The one month aftershock distributions for the 1978 Miyagi-oki earthquake (Fig. 4a) and the 2005 earthquake (Fig.4b) are similar to each other except for the area near the region K where the boundary already slipped in 2003. The activities of small repeating earthquakes in region D after the 2005 M6.3 earthquake and in region K after the 2003 M6.8 earthquake show there were creep accelerations for the periods. Therefore, unsteady slip at the regions near the Japan trench is probably prone to be triggered by the earthquakes in the deeper part of the plate boundary such as the 1978 and 2005 earthquakes.

6. Conclusions

Spatio-temporal change in the interplate creep off-Miyagi, Japan was investigated from 21 year small repeating earthquake activity. The small repeating earthquakes are distributed mainly outside the coseismic slip areas for large earthquakes which show the creep is dominant outside the asperities. We observed the activation of repeating earthquakes after the 2005 earthquake but the estimated creep rate change was not significant except for a near-trench region where two M6.3 events occurred after the 2005 earthquake. We also found some of seismic activity and creep rate fluctuation at the region near the Japan trench are associated with the interplate earthquake at the deeper part of the plate boundary.

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Acknowledgement

We thank Mr. T. Nakayama and Mr. S. Hirahara at Tohoku University for their cooperation in editing waveform data This work was partly supported by the 21st Century Center of Excellence program, 'Advanced Science and Technology Center for the Dynamic Earth' at Tohoku University. Some of the figures were drawn using Generic Mapping Tools (Wessel and Smith, 1995).

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