THE 2005 M7.2 MIYAGI-OKI EARTHQUAKE, NE JAPAN: POSSIBLE RE-RUPTURING OF ONE OF ASPERITIES THAT CAUSED THE PREVIOUS M7.4 EARTHQUAKE

Tomomi Okada, Tadashi Yaginuma, Norihito Umino, Toshio Kono, Toru Matsuzawa, Saeko Kita, Akira Hasegawa

Research Center for Prediction of Earhquakes and Volcanic Eruptions, Graduate School of Science, Tohoku Univerisity

A large (M7.2) interplate earthquake occurred on 16 August 2005 in the Miyagi-Oki region, where large interplate earthquakes with magnitude of ~7.5 have occurred repeatedly at a recurrence interval of ~ 37 yrs, NE Japan. We compared aftershock distribution of the 2005 Miyagi-Oki earthquake with that of the previous 1978 Miyagi-Oki earthquake (M7.4) using double-difference hypocenter locations. The aftershock area of the 2005 Miyagi-Oki earthquake is partly overlapped with the southern/southeastern part of that of the 1978 event. Locations of aftershock clusters of the 2005 event correspond with those of the 1978 event and those of the background seismicity. Coseismic slip area of the 2005 event estimated by seismic waveform inversion is also partly overlapped with that of the 1978 event. These observations suggest that spatial seismicity pattern on the plate boundary in subduction zone persists and the 2005 event possibly ruptured a part of the source area of the 1978 event.

1. Introduction

On August 16, 2005, a large earthquake occurred in the Miyagi-Oki region (offshore of Miyagi Prefecture) in northeastern Japan. The JMA (Japan Meteorological Agency) magnitude of this event is 7.2 and its seismic moment is estimated to be 5.4×10^{19} Nm (Mw7.1; F-Net, NIED, 2005). Hypocentral location and focal mechanism (e.g. F-Net, NIED, 2005) show that the 2005 Miyagi-Oki earthquake occurred along the boundary between the subducting Pacific Plate and the overriding plate (Fig. 1). In this area, large interplate earthquakes with magnitude of ~M7.5 have occurred repeatedly at a recurrence interval of ~37 yrs (The Headquaters for Earthquake Research Promotion, MEXT, Japan, 2003). Base on this recurrence of large earthquakes, the Headquarters of Earthquake Research Promotion of the Japanese government released the information of high probability (~50% within 10 years from now) of the impending earthquake to the public (The Headquaters for Earthquake Research Promotion, MEXT, Japan, 2003). The last earthquake (the M7.4 Miyagi-Oki earthquake) occurred in 1978. Seno et al. (1980) showed that focal mechanism of the 1978 M7.4 (on the JMA scale) Miyagi-Oki earthquake is thrust-type and the seismic moment is 3.1×10^{20} Nm. They also proposed two- and three-segment fault models to explain the seismograms of both far and nearby stations. Recent research on interplate earthquakes east off northeastern Japan (Nagai et al., 2001, Okada et al., 2003a, Yamanaka and Kikuchi, 2003, Matsuzawa et al., 2004, Hasegawa et al., 2005) suggests the existence of asperities along the plate boundary in this region. Asperities are persistent areas of strain accumulation that prevent slippage in interseismic period, but cause

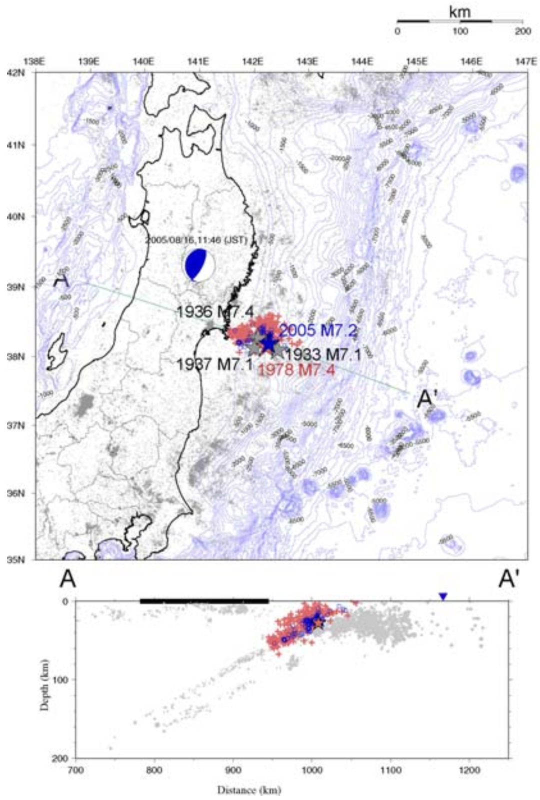

Fig 1. Hypocenters of the 2005 Miyagi-Oki earthquake (M7.2; blue star), the 1978 Miyagi-Oki earthquake (M7.4; red star), and the corresponding aftershocks (blue circles and red crosses, respectively). Gray circles denote background seismicity in the period from August 16, 2002 to May 2005 according to the Japan Meteorological Agency (JMA) catalog. (Upper) Epicenter map showing the locations of the 1933 (M7.1), 1936 (M7.4) and 1937 (M7.1) earthquakes (gray stars) according to the JMA catalog. Blue contour lines denote bathymetry. Moment tensor solution of the 2005 earthquake by F-net, NIED, Japan is also shown by lower hemisphere projection. (Lower) Across-arc vertical cross-section (A-A') of the earthquakes showing the lateral extent of land area (bold line) and the trench axis (blue inverted triangle).

large slip upon failure, leading to earthquakes at repeated intervals. From GPS observations, it is estimated that large back slip occurred before the 2005 Miyagi-Oki earthquake in the region around the hypocenter, where the plates were in tight contact (Suwa et al., 2004, Hasegawa et al., 2005). Although the magnitude of this earthquake was slightly smaller than those of the major earthquakes in the past, the hypocentral position was close to that determined for previous earthquakes. It is important to clarify the relationship between this latest earthquake and past Miyagi-Oki earthquakes in order to understand the mechanism of occurrence of earthquakes at plate boundaries and to predict the location and the size of the next earthquake in this area. In the present study, the distributions of aftershocks and coseismic slip of the latest 2005 earthquake are investigated and compared with those for the last 1978 earthquake.

2. Aftershock distribution

The aim of the present research is to compare the aftershock distributions of the 2005 earthquake with that of the 1978 earthquake. The hypocenters are determined by the double-difference method (Waldhauser and Ellsworth, 2000) using travel-time differences between earthquakes at each station. This method resolved the relative hypocenters of many earthquakes. We relocated the 1978 earthquake and its 343 aftershocks within 2 days of the main shock, and the 2005 event and its 132 aftershocks within 2 days of the main shock. Hypocenters of 1150 earthquakes that occurred from January 2002 to August 15, 2005 are also relocated as background seismicity. We used P-wave arrival time data which were recorded at 133 stations of the seismic network maintained by various universities, the JMA, and Hinet of the NIED. The S-wave arrival times recorded for the 1978 earthquake are considered to be of poor accuracy due to saturation of the waveforms. Therefore, only P-wave arrival times are employed in this study. Fourteen stations were common during both the 1978 and 2005 earthquakes, allowing the relative hypocentral positions to be determined between the 1978 and 2005 earthquakes, as well as between the aftershocks of each event. Standard error of the relative location is estimated to be about 3km. The velocity structure used in hypocenter determination is that of Hasegawa et al. (1978). Note that, as most of the stations adopted in the

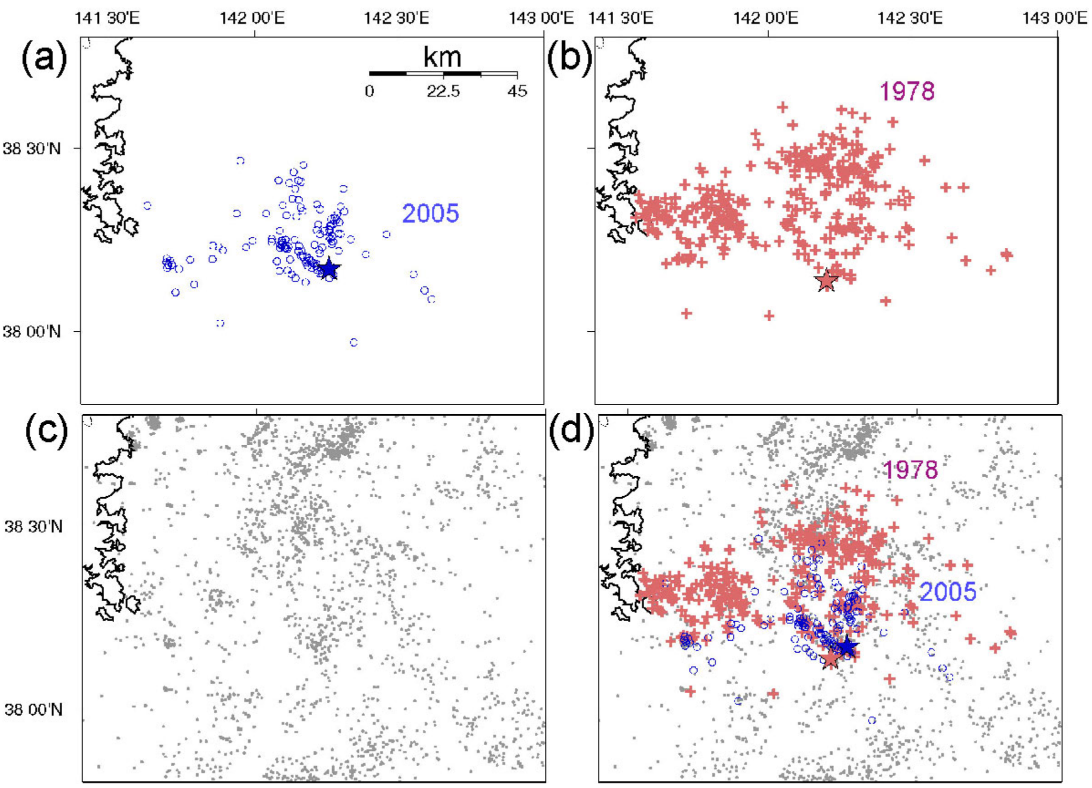

Fig. 2 (a) Hypocenters of the 2005 Miyagi-Oki earthquake (M7.2; blue star), the 1978 Miyagi-Oki earthquake (M7.4; red star), and the corresponding aftershocks (blue circles and red crosses, respectively). Gray points denote relocated background seismicity (January 2002–August 15, 2005). (a) The 2005 event. (b) The 1978 event. (c) Background seismicity. (d) all the events.

present research are located on land, and thus are not just above the hypocentral region, the accuracy of depth determinations for offshore hypocenters needs to be considered, although epicenters can be accurately determined to some extent even without the offshore seismic stations (see Okada et al., 2004).

The distributions of the main shocks and aftershocks are shown in Fig. 2. The main shock of the 2005 earthquake was closely located to that of the 1978 main shock. Spatial extent of the aftershock area of

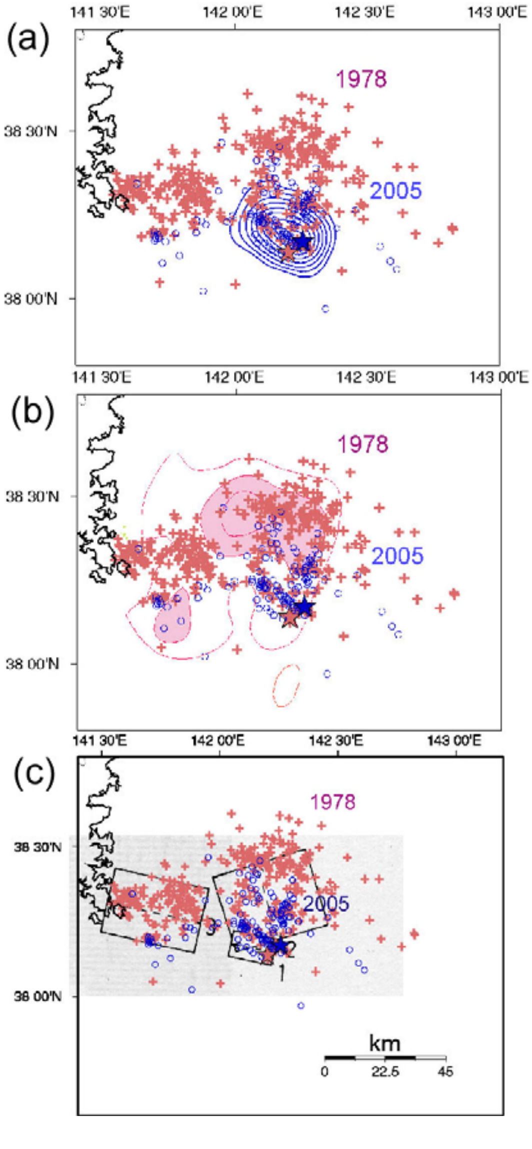

Fig. 3 (a) Coseismic slip distribution for the 2005 Miyagi-Oki earthquake (blue contours; 0.15 m interval) and (b) the 1978 Miyagi-Oki earthquake (red contours; Yamanaka & Kikuchi, 2004; 0.3m interval). (c) The 3-segment fault model of the 1978 Miyagi-Oki earthquake (quadrangles; Seno et al., 1980). The amount of coseismic slip is 4.2m, 2.0m and 2.3m on the 1st, 2nd and 3rd segments, respectively. Locations of aftershocks of the 1978 and 2005 earthquakes are also shown.

the 2005 event is 80km and 40km in dip and strike directions, respectively. High aftershock activity was observed in the central part of the aftershock area, which is located to the north-west of the mainshock hypocenter. The aftershock area of the 2005 event is overlapped with the southern/south-eastern part of that of the 1978 event. The positions of aftershock clusters in the 2005 earthquake are in good agreement with the positions of clusters for the 1978 earthquake, and correspond closely with the positions of clusters in the background earthquake distribution. Such agreement in the spatial distributions of aftershocks has also been reported for the 1968 Tokachi-Oki earthquake and the 1994 Sanriku-Haruka-Oki (far offshore of the Sanriku Coast) earthquake (Nagai et al., 2001), and the 1966 and 2004 Parkfield earthquakes (Hardebeck et al., 2005, Langbein et al., 2005). This is though to be due to the long-term persistence of large asperity and its surrounding numerous small asperities (Matsuzawa et al., 2004, Hasegawa et al., 2005).

A complementary relationship between the distribution of coseismic slip in an earthquake and the aftershock distribution has also been reported in previous researches (Mendoza and Hartzell, 1988, Nagai et al., 2001, Okada et al., 2001, 2003b, Seno, 2003). In the present case, the complementary relationship between the coseismic slip distribution and the aftershock distribution of the 1978 earthquake is not so clear (Fig. 3 (b), (c)). However, the aftershock activity along the northern portion of this region was relatively low in the 2005 event compared to the 1978 event. From the partial overlap between the 1978 aftershock distribution and the 2005 aftershock distribution, it can be thought that the coseismic slip area of the 2005 earthquake does not extend further north than that of the 1978 earthquake, and that the coseismic slip areas by the two earthquakes partially overlap. The coseismic slip region of the 2005 earthquake is thus considered to correspond to at least the southeastern part of the 1978 earthquake coseismic slip region.

3. Coseismic slip distribution

The coseismic slip distribution of the 2005 earthquake was determined by using the seismic waveform inversion method developed by Fukahata et al. (2003) and Yagi et al. (2004). Broadband waveforms from the Data Management System of the Incorporated Research Institutions for Seismology (IRIS-DMC) were employed as data. A total of 24 stations are distributed azimuthally well around the hypocenter (Fig. 4). The waveforms are 80 s long, starting 10 s prior to P-wave arrival, and were processed by a 0.01–1 Hz bandpass filter. The fault plane was assumed to have a strike of 198.2° and dip of 22.2° based on results from AQUA-CMT, National Research Institute for Earth Science and Disaster Prevention (http://www.bosai.go.jp). The fault plane was modeled as a 135 km × 135 km plane consisting of 81 sub-faults of 15 km × 15 km. The earth structure model used to compute the teleseismic body wave is based on the Jeffreys-Bullen model.

The coseismic slip distribution obtained by this inversion reproduced the observed waveform well (Fig. 4). The coseismic slip distribution was centered to the northwest of the hypocenter, extending approximately 30 km in the dip direction and 20 km in the strike direction (Fig. 3 (a)). Fig. 3 (b) and (c) show the coseismic slip distribution by Yamanaka and Kikuchi (2004) and the three-segment fault model by Seno et al. (1980) of the 1978 earthquake, respectively. The coseismic slip region of the 2005 earthquake corresponds to the southeastern part of the coseismic slip region of the 1978 earthquake. The

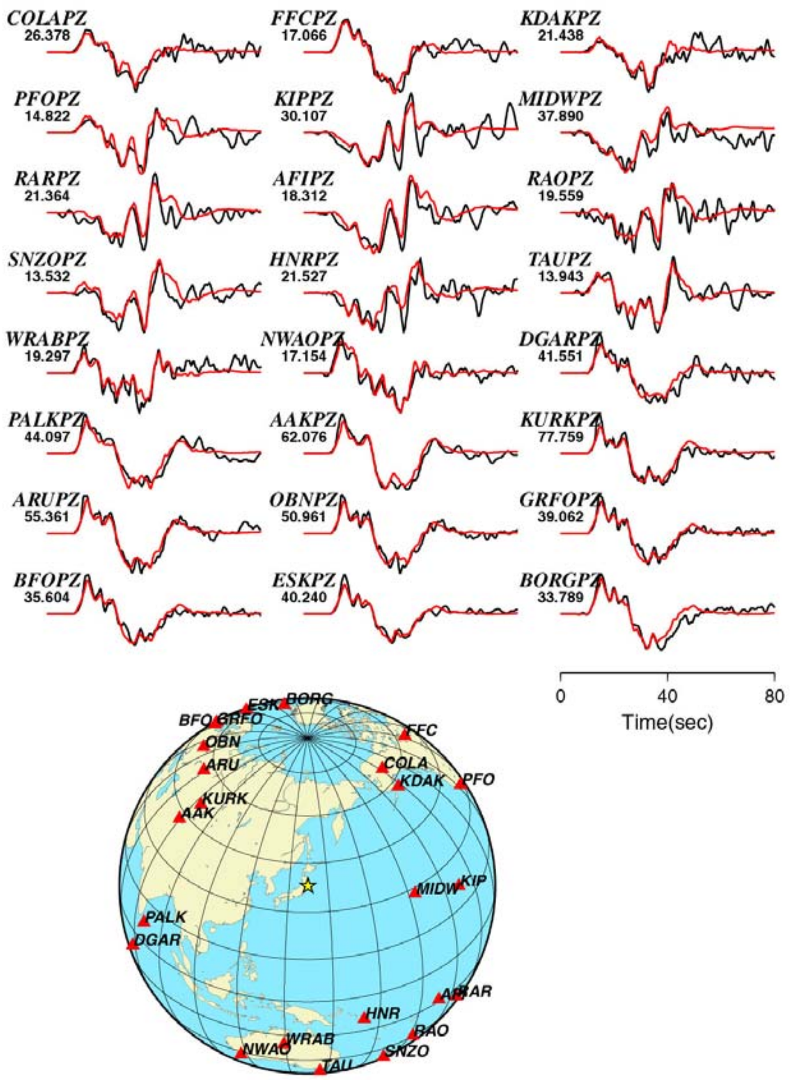

Fig. 4 (Upper) Comparison of observed (black) and synthesized seismograms (red) expected from the slip distribution in Fig. 3. (Lower) Station distribution.

estimated maximum slip in the 2005 event was 1.5 m. From the estimated relative velocity between the plates, 8 cm/yr (Seno et al., 1996), this estimated maximum slip corresponds to less than the 2.2 m of relative displacement between plates that should have occurred in the 27 years since the last 1978 earthquake. The rupture continued for approximately 20 s.

The coseismic slip distribution determined from GPS observations (Miura et al., 2005) exhibited a similar correspondence with the southeastern part of the coseismic slip region of the 1978 earthquake, and is in general agreement with the aftershock distribution and coseismic slip distribution determined in the present research.

4. Conclusions

The present study resolved the aftershock distribution of the M7.2 Miyagi-Oki earthquake on August 16, 2005. The hypocenters were determined by the double-difference method, and were compared with the aftershock distribution of the previous M7.4 1978 earthquake. The coseismic distribution was determined by seismic waveform inversion and also compared with that of the 1978 earthquake. The coseismic slip region of the 2005 earthquake appears to correspond to the southeastern part of the coseismic slip region of the 1978 earthquake, suggesting that the coseismic slip in part involved re-activation of the coseismic slip region of the 1978 event.

Umino et al. (2005) relocated the main shocks and aftershocks for the 1933, 1936 and 1937 Miyagi-oki earthquakes with M > 7, and have suggested the possibility that the aftershock distribution of the 1936 event is similar to that of the 2005 earthquake. They further showed that the combined aftershock distribution of the 1933, 1936 and 1937 earthquakes is in close agreement with that of the 1978 earthquake. One possible interpretation of these results is that the 1978 earthquake involved the simultaneous rupture of the plural asperities which are in close proximity with each other, while the 1933, 1936 and 1937 earthquakes as well as the 2005 earthquake occurred due to rupture of asperities in a more limited region within the group that failed in the 1978 event. These results propose a hypothesis that several asperities exist offshore of Miyagi Prefecture, and that those asperities rupture repeatedly at sometime simultaneously and at other time separately. Note that the amount of coseismic slip during the 1978 event in the 1st segment, which almost corresponds to the source area of the 2005 event, is estimated to be as large as about 4 m from the three-segment model by Seno et al. (1980) although rather small slip (less than 0.3m) is estimated in and around the source area of the 2005 event by Yamanaka & Kikuchi (2004). If we employ the three-segment model by Seno et al. (1980), we can infer that the 2005 event re-ruptured one of the asperities which caused the 1978 M7.4 event. More careful studies on the relative locations of the coseismic slip distributions of the 2005 and 1978 events are necessary to conclude whether or not the 2005 event have actually re-ruptured one of the asperities responsible for the 1978 event. To further understanding of the mechanism of interplate earthquakes, the main shock positions, aftershock distributions and coseismic slip distributions of the past Miyagi-Oki earthquakes should be redetermined with greater accuracy and interpreted.

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ution in Fig. 3. (Lower) Station distribution.