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Stress adjustment revealed by seismicity and earthquake focal mechanisms in northeast China before and after the 2011 Tohoku-Oki earthquake

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ABSTRACT

In order to understand the influence of the March 11, 2011, M_W 9.0 Tohoku-Oki earthquake on regional-scale seismicity, we study the seismicity rate and focal mechanism solutions (FMSs) of earthquakes in northeast China (NEC) before and after the megathrust event. Broadband seismic waveforms from 270 permanent and temporary stations are used to invert for the moment tensors of 69 earthquakes between 2009 and 2013 in the NEC. Our results show that there are distinct changes in seismicity rate on major NEC faults before and after the 2011 Tohoku-Oki event although the seismic moment rate of the whole region remains roughly constant. In comparison to a wide distribution of earthquakes before the Tohoku-Oki event, FMSs of crustal earthquakes in the NEC after the megathrust event can be categorized into two groups: strike–slip events with E–W compression and normal-faulting events with N–S extension. Stress field inversions before and after the Tohoku-Oki event suggest that the variations in seismicity and FMSs are due to a minor adjustment of regional stress state imposed by the megathrust event, which is further confirmed by static Coulomb stress change calculations. Mantle-depth seismicity is also influenced by the megathrust event, possibly via a down-dip transfer of compressional stress along the subducting plate, as manifested by the absence of moderate-sized mantle-depth earthquakes (~M_W 4–5) between May 2011 and April 2013 and the occurrence of deep-focus events with P axes along the dip direction of the subducting Pacific Plate in E–W vertical cross-sectional view and in WNW–ESE direction in map view.

1. Introduction

The March 11, 2011, Tohoku-Oki earthquake (M_W 9.0) ruptured an area of approximately 500 × 200 km^2 along the northeastern Japan megathrust (Ammon et al., 2011; Fujii et al., 2011; Hayes, 2011). Coseismic slip reached to more than 50 m near the trench (Yue and Lay, 2011; Simons et al., 2011; Shao et al., 2011; Ito et al., 2011), and was detectable in GPS measurements in a large area of East Asia (Shestakov et al., 2012; Hwang et al., 2012; Wang et al., 2011). Near-field static Coulomb stress change calculations have shown that some aftershocks were triggered by the coseismic stress perturbation (Toda et al., 2011a,b), and can be used to assist in the estimation of earthquake occurrence probabilities in Japan (Hiratsuka and Sato, 2011). However, it is not clear whether seismicity and stress in eastern China could be obviously influenced by the Tohoku-Oki event.

The Northeast China (NEC) region (Fig. 1a) has a prevailing low-level E–W compression (Ning and Zang, 1987; Xu, 2001), and is characterized by two conjugate fault systems (Fig. 1b): a NNE–SSW-trending right-lateral system, mainly containing the Nenjiang–Laohahe Fault (NLF), Central Songliao Basin Fault (CSBF), Yilan–Yitong Fault (YYF), Hunhe Fault (HF), and Dunhua–Mishan Fault (DMF); and a NW–SE-trending left-lateral system involving mainly the Chenshu–Boli Fault (CBF, Xu and Deng, 1996). The locations of these faults approximately control the spatial pattern of seismicity in the NEC (Fig. 2a).

Located more than 1200 km away from the Japan Trench (Fig. 1a), the NEC is a suitable area for studying the possible influence of a megathrust event on regional seismicity and stress field. In particular, this is the only region in China where deep-focus earthquakes (>350 km) are recorded as a result of the subduction of the Pacific Plate under the Eurasian Plate extending northwestward beneath NEC (Huang and Zhao, 2006). These deep-focus events allow us to simultaneously examine if and

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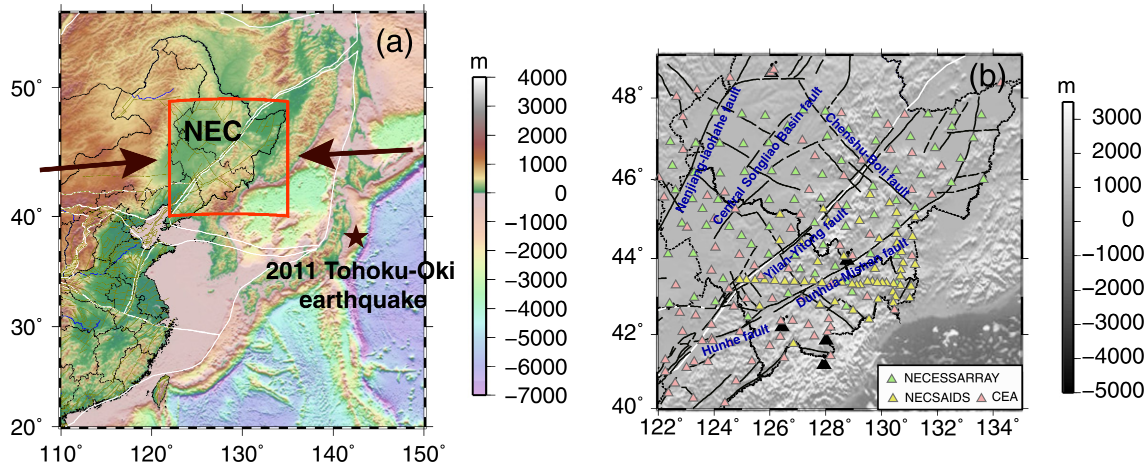

Fig. 1. (a) Topography of East Asia. Our study area, Northeast China, is indicated by the red box. The star marks the hypocenter of the 2011 Tohoku-Oki earthquake. Arrows indicate the direction of maximum compressional stress in the region, modified from Xu (2001). (b) Seismic station distribution in Northeast China. We used waveform records from stations of the NECESSARRAY (green) and NECSAIDS (yellow) temporary networks and the CEA (China Earthquake Administration) permanent stations (pink). Major faults are depicted by black lines (Deng et al., 2007), and locations of volcanoes are marked by black triangles.

how the megathrust event might influence the stress state at mantle-depth, as their epicentral distances to the Japan Trench are similar to those of the shallow events above them.

Previous statistics studies suggest that seismicity in the NEC has some relation with the activities in the Japan Trench, manifested by delayed seismic activities following large earthquakes in the Japan Trench area (Wu et al., 1979; Li and Wang, 1996; Gao, 2011), although clear descriptions and explanations are still lacking. However, recent Coulomb Failure Stress change (△CFS) computations show that the Tohoku-Oki earthquake is unlikely to significantly alter the stress field in the NEC (Cheng et al., 2014). Therefore, it is important to quantitatively analyze if a small △CFS (<0.01 MPa) might still have influence on the seismicity and the focal mechanism solutions (FMSs), in particular given the newly acquired high-quality data. Earthquake detectability in the NEC has improved tremendously during the last decade. As shown in Fig. 2(b), the number of detected events grows significantly, providing a more complete dataset for studying the regional response to a remote event in seismicity and the FMSs (Zheng et al., 2010). Moreover, temporary deployments of 129 stations of the NorthEast China Extended SeiSmic Array (NECESSArray, 2009–2011) and 60 stations of the NorthEast China Seismic Array to Investigate Deep Subduction (NECSAIDS, 2010–2013) provide additional data and greatly enhance our ability to study the seismicity and stress field in this region (Fig. 1b).

In this paper, we first report variations of seismicity around different geological units (major faults) in our study region before and after the Tohoku-Oki earthquake. Then we determine FMSs of moderate events by the generalized Cut and Paste (gCAP) method (Zhu and Ben-Zion, 2013) and use them to invert for the spatial and temporal variations

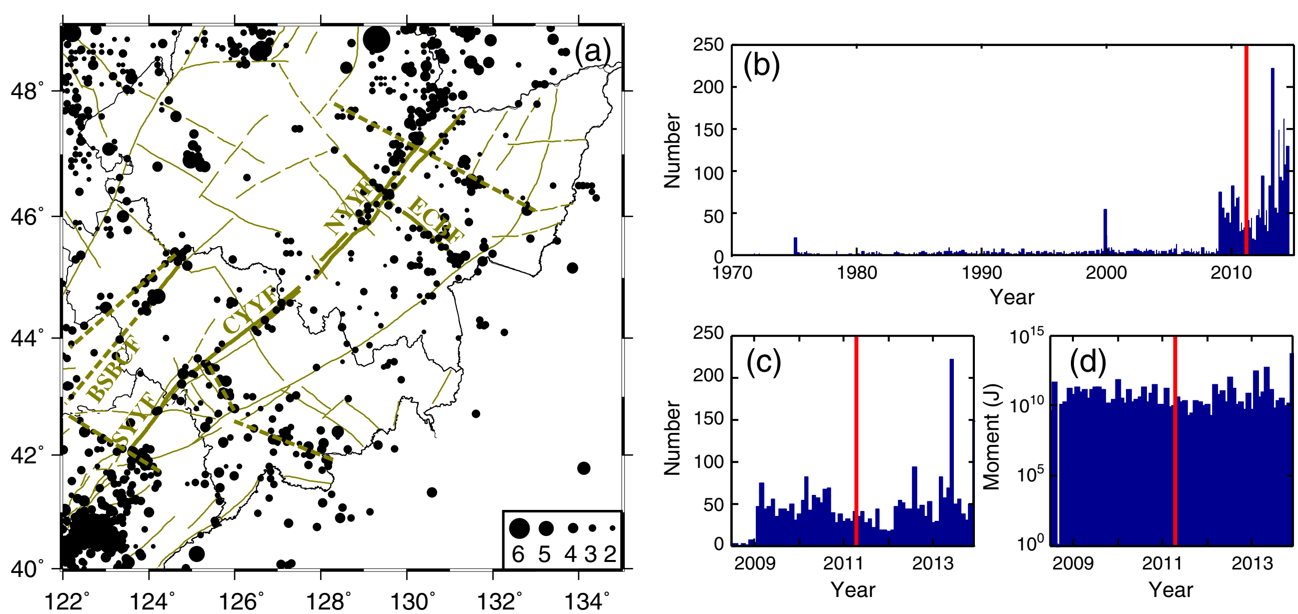

Fig. 2. Seismicity in northeast China. (a) Epicenters of 2024 earthquakes occurred before the Tohoku-Oki earthquake (1970–2011, $M_L \geq 1.0$) in our study area from the China Earthquake Network Center (CENC) catalog. The sizes of circles are proportional to event magnitudes. Green solid lines mark the faults in the NEC. In between, thick green solid lines show faults introduced in the text. Thick green dashed lines indicate the buried faults inferred from lineations in seismicity. (b) Monthly seismicity rate from the CENC catalog between 1970 and 2014. The red line marks the time of the 2011 Tohoku-Oki earthquake. (c) and (d) show the monthly seismicity rate and moment, respectively, between July 2008 and November 2013.