Precursory seismic anomalies and transient crustal deformation prior to the 2008 Mw=6.9 Iwate-Miyagi Nairiku, Japan, earthquake

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The epidemic-type aftershock sequence (ETAS) model has been widely used for detecting seismicity anomaly, such as quiescence or activation during aftershock sequences of large earthquakes and background levels of seismicity. The causes of such anomalies are sought to be associated with spatiotemporal changes in stress, even tiny perturbation of local stress. Here we analyze the seismic activities during a decade prior to the 2008 Iwate-Miyagi inland earthquake of M7.2 (Mw6.9) to fit the ETAS model to the seismicity from various regions around the source over the northern Honshu, Japan. From the viewpoint of the ETAS models, we find northern Honshu is divided into three distinctive areas, increased seismicity, decreased seismicity, and normal relative to the ETAS prediction. As other previously published papers, here we hypothesize that Coulomb stress changes due to the year-order precursory slip of the Iwate-Miyagi earthquake resulted in the seismicity changes in and around the 2008 source region. The confirmed significant seismic anomalies in respective regions are consistent with the increments of the Coulomb failure stress of the corresponding regions that are calculated by the assumed slow-slip on the southern part of the faults of the main shock. The local crustal deformations observed from a dense GPS network support that slow slip on the fault had been taken place during about five years prior to the occurrence of the focal earthquake, and suggest that the slip terminated or migrated to down-dip extension of the fault during one and odd years prior to the rupture.

Introduction

An earthquake rupture transfers stress in neighboring faults, which normally leads to increased off-source seismicity (Harris and Simpson, 1998; Toda and Stein, 2002). Seismicity drop-off associated with coseismic stress changes is also found in several cases in which high background seismicity allows us to detect the rate of decrement (e.g., Toda and Stein, 2003). A significant common finding from majority of stress triggering studies is that seismicity is highly sensitive to small stress changes down to 0.01 MPa, if occurred in a stepwise fashion. It allows us to forecast roughly the areas where subsequent seismicity becomes active, and consequently the occurrence of the potential next large shock.

However, such hazard estimates can be argued only after we observed a large earthquake. Majority of large earthquakes are neither apparently doublet nor clear-triggered events but rather isolated singletons, which nature requires us to seek further tiny signals of triggering that lead a larger event. The important steps are hence to survey triggering background of a large earthquake by smaller leading events, and also to detect anomalies in seismicity due to stress changes by predictable causes. Many leading works (e.g., see Ogata 2001) in fact report anomalies, quiescence or activation, in seismicity before the occurrence of a large event. Fitting and extrapolating a reasonable statistical model to a seismic sequence provides a visual method to search for such anomaliesin seismicity due to stress changes transferred from outside. In view of this, our main objective is to show the possibility that the diagnostic analysis with the epidemic-type aftershock sequence (ETAS) model applied to regional seismicity will help in detecting external stress changes (Ogata et al., 2003; Ogata, 2004a, 2004b, 2005), and furthermore in estimating and evaluating the source mechanism of these changes in stresses.

Our application here is on the active regions all over northern Honshu, Japan, around the source of the 2008 Iwate-Miyagi earthquake of M7.2 (Mw6.9). This earthquake is thought to be enhanced by the preceding two large earthquakes on the Pacific side to the east, which are the 2003 southern Sanriku-coast earthquake of M7.1 and the 2003 northern Miyagi-Ken earthquake of M6.2 (see Figure 1). Both earthquakes raised the Coulomb failure stresses over the north-south strike reverse fault systems in the northern Honshu inland including the fault of our concern (Ogata, 2005). We hence hypothesize that, years before the 2008 event, slow slips have also been triggered on the fault or its down-dip extension, and then perform statistical diagnostic analysis in line with it.