Fault slip distribution of the 2016 Fukushima earthquake estimated from tsunami waveforms

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A large earthquake occurred on 21 November 2016 UTC offshore Fukushima prefecture approximately 40 km to the east from the dismantled Fukushima Daiichi nuclear power plant and 120 km to the southeast of Sendai city. Based on the JMA earthquake catalog, the hypocenter of the earthquake is located at 37.355° N, 141.604° E, and 25 km of depth and the magnitude (Mjma) is 7.4. There are four moment tensor solutions available for the event from Global CMT, JMA (two solutions), and USGS. All of these moment tensor solutions suggest that the earthquake is a normal faulting event and has a moment magnitude (Mw) of 6.9. The depths of the centroids are all at 12 km, which is shallower than the hypocenter depth provided in the JMA catalog. The earthquake generated a tsunami that was clearly recorded at tide gauges in Iwate, Miyagi, Fukushima, Ibaraki, and Chiba prefectures, and five cabled-pressure-gauges offshore Iwate (TM1, TM2, YTM1, YTM2, and YTM3).

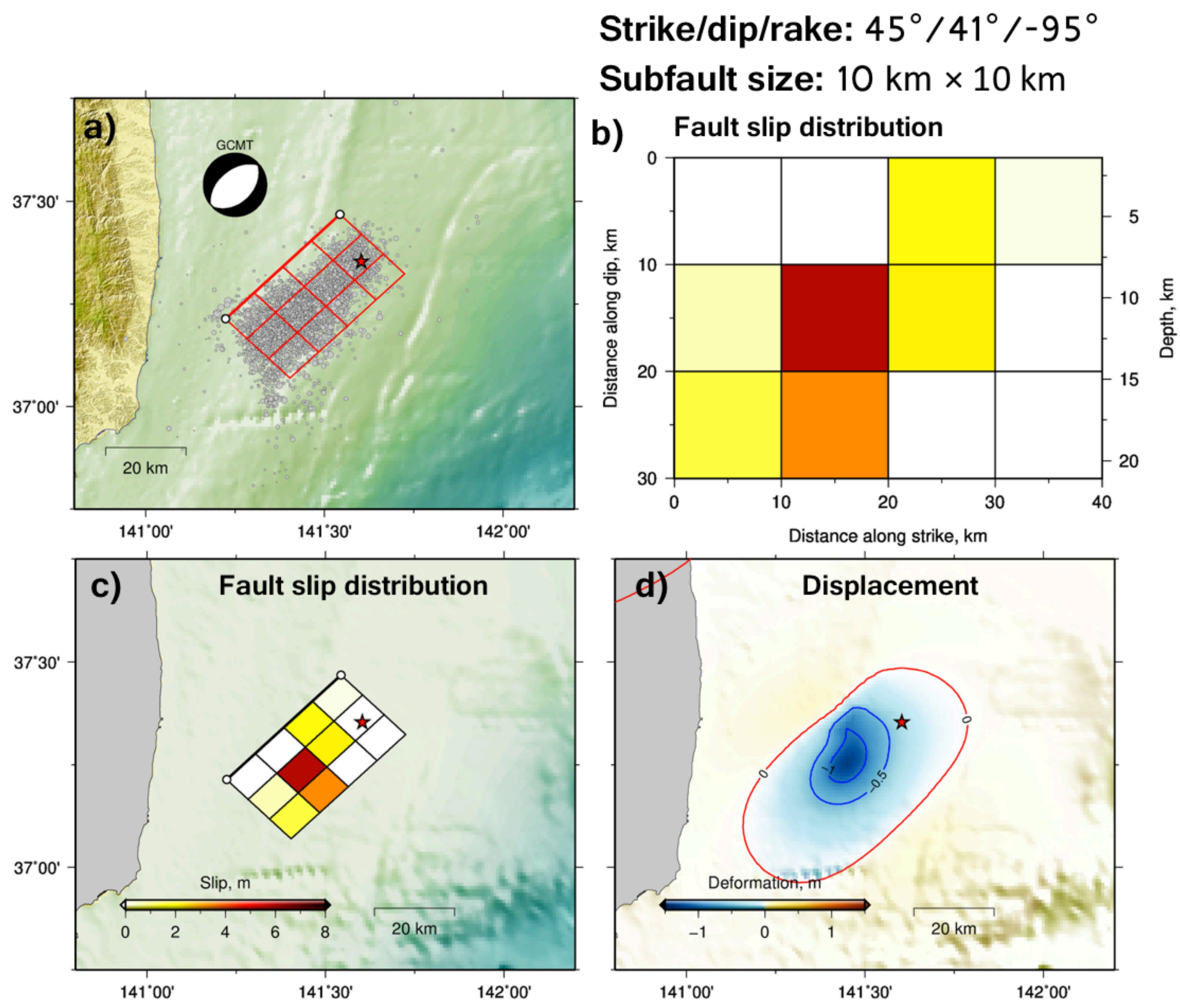
The simulated tsunami waveforms from GCMT, JMA-CMT, JMA-WCMT, and USGS-WCMT solutions generally underestimate the observations. The tsunami waveform of USGS-WCMT northwest dipping (Normalized RMS error = 1.21) and GCMT southeast dipping (Normalized RMS error = 1.26) solutions better fit the observations compared to those from the other solutions. The centroid locations of JMA-CMT and JMA-WCMT are located on the edge of the aftershock region, that of USGS-WCMT is located outside and to the northwest of the aftershock region, and that of GCMT is located inside the aftershock area. Because the centroid and hypocenter depths are significantly different, we also run simulations with depths of 8, 12, 20, and 25 km. The results show that the simulated tsunami waveforms at offshore pressure gauges are more sensitive to the fault depth than those at tide gauges.

The fault geometry with the southeastward dipping of GCMT solution (strike = 45°, dip = 41°, rake = -95°) is chosen for tsunami waveform inversion because it gives small misfit to tsunami waveforms and the centroid is located within the aftershock area. We distributed 4 ×3 sub-faults with sub-fault-size of 10 km ×10 km, which cover the aftershock area. The estimated fault slip distribution has a large slip of 6 m at depth of 12 km (Figure 1). The seafloor displacement is estimated to be subsided by 1.3 m at the lowest point (Figure 1d). From the fault slip distribution, the calculated seismic moment by assuming a rigidity of 4×10^{10} N/m^2 is 2.21×10^{20} Nm or equivalent to Mw = 7.5, which is significantly larger than that from moment tensor solutions.

Using the estimated fault slip distribution, we run a numerical simulation to analyze the behavior of the tsunami propagation. The tsunami wave hit the coast of Fukushima and the coast reflected the wave back to the open ocean. The reflected wave is then refracted to the north direction and clearly observed in the later phase of tsunami waveform at Sendai port, TMs and YTMs stations. This propagation behavior is mainly due to the configuration of bathymetry off the east coast of Japan (from Chiba to Iwate prefecture). This effect of bathymetry is further confirmed by a numerical experiment of tsunami simulation using artificial bathymetry with seafloor deeper than 500 m as flat in which the reflected tsunami was spread in all directions in front of the coast without being refracted to a particular direction. Larger tsunami amplitudes in the later phases of tsunami waveform are observed and modeled at Sendai port, Ishinomaki, Ayukawa, and Ofunato. At Sendai port, the peak of the second arriving wave is larger (1.4 m) than the peak of first arriving wave (0.9 m). We also found that accurate and precise bathymetry around the ports is required in order to get a reliable coastal tsunami prediction.

Figure 1. Earthquake fault model estimated by tsunami waveform inversion. a) Focal mechanism, aftershock distribution, and subfault boundary. b) Cross-section of fault slip distribution along the dip. c) Map of fault slip distribution. d) Estimated seafloor displacement from the fault slip distribution.

Keywords: The 2016 Fukushima tsunami, tsunami waveform inversion, offshore pressure gauge, bathymetry effect, large tsunami later phase



Grouping the normal modes, a way to characterize tsunami sources in Japan Sea

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Satake and Shimazaki (1988) calculated the normal mode solutions of Japan Sea, qualitatively grouped the calculated modes into the whole Japan Sea modes and the regional modes, then discussed the properties of tsunami excitation of the 1963 Niigata earthquake and the 1983 Japan Sea earthquake.

We extended their method and obtained a high resolution normal mode solution of Japan Sea (Wu and Satake, 2015). We also characterized tsunami sources in Japan Sea, for the 60 potential submarine sources recently proposed by Japanese Ministry of Land, Infrastructure, Transport and Tourism.

In this study, we quantitatively grouped the normal mode solutions into basin-wide modes, regional modes and local modes, based on the eigenvectors, or water height distribution. We examined several statistical parameters, such as mean (first moment) or variance (second moment), and Kurtosis, which is the fourth moment divided by the square of the second moment. We finally selected Kurtosis to group the modes. We determined that the modes with Kurtosis < 35 as the basin-wide mode, those with Kurtosis > 350 as local modes, and those between as regional modes. Out of 6000 modes that we have calculated, 622 modes are grouped as basin-wide mode, 4953 modes are regional modes and 425 modes are local modes.

We then calculated the excitation weights of the 60 potential submarine faults. The average excitation weight is larger if the moment magnitude is larger or the source is located at shallower water depth. In order to examine the contribution from the above 3 groups, we compared the average weights of largest 425 modes, and found that those from the regional modes are the largest. For the regional modes, the faults located at shallower water depth generally have larger excitation weights. This indicates that the regional modes excited by an earthquake at shallow water depth is most powerful.

Finally, eigenfunctions of these regional modes with large average weight for the 60 faults show that they have large amplitude in wide shore areas, where these faults are located. This is in agreement with the obtained results and also reminds us to pay special attentions to the regional modes excited by potential sources at relatively shallower water depth.

Global Centre for Disaster Statistics: Connecting UN, academia and policy makers to support the implementation of SFDRR

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The Global Centre for Disaster Statistics was established in 2015 to contribute to the implementation of Sendai Framework for Disaster Risk Reduction (Sendai Framework) and the 2030 Agenda for Sustainable Development (SDGs) through the following three objectives 1) Contribute to monitoring the progress of the Sendai Framework and the 2030 Agenda; 2) Provide scientific and technical advice on disaster loss and damage data in countries; and 3) Provide policy advice to build DRR capacities of national/local governments based on their needs.
To achieve the objectives, the centre has been developing a unique collaboration between UN organizations (UNDP, ESCAP, etc.), academia, and practitioners (national governments, regional DRR-related organizations and private sectors). The centre will focus on establishing a global database of disaster loss and damage by integrating data collected by countries to monitor and evaluate progress in the implementation of the Sendai Framework and SDGs. For the development of the global database, we have been working with six pilot countries to identify needs and develop a scheme for sharing data based on the cooperation with UNDP.
In addition, we have been developing research projects to apply scientific and technical analysis for generating disaster risk reduction policy. For that, it is essential to collect associated statistics such as population, socio-economic, and hazard data. The centre is looking forward to conducting research on tsunami hazard, macro-economic simulation, or health issue.
Eventually, the centre aims to play an important role in the international disaster risk reduction strategy by contributing to the monitoring of the Sendai Framework and SDGs. The centre could be a platform to provide innovative analysis and develop capacity of countries to achieve risk-informed development.

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