# The 2011 off the Pacific Coast of Tohoku earthquake: Forecast and observations

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***Abstract***

The Mw9.0 earthquake on March 11, 2011 located east of northern Honshu is the largest earthquake ever instrumentally recorded in Japan and possibly the largest even in the last 1000 years. Broadband, and strong ground motion, GPS, seafloor geodetic and tsunami data have been analyzed by a number of groups to estimates its source processes. The common features obtained are thrust mechanism with a fault length and width of 400km and 200km, respectively with a 10-30m fault slip. In comparison with the 2004 Sumatra earthquake, the seismic moment of Mw9.0-9.1 is almost similar, but the fault length is shorter, suggesting that the NE Japan earthquake is dominated by higher frequency components than the 2004 Sumatra event.

Large tsunami struck the 800 km long coasts over NE Honshu and Hokkaido areas. It reached an onshore height of more than 15-20 m with the highest inundation of 40m, resulting in at least 25,000 deaths or missing and destroyed/washed out about 50,000 houses. The two cabled ocean-bottom pressure gauges located at 40 and 70 km offshore recorded a tsunami with very long duration and a height of 3m including a pulse-like 5m high tsunami. The estimated fault slip from these records of pressure gauges and tide gauges is about 30 to 50 m near the trench axis. This implies that the shallow plate interface near the trench axis can sustain tectonic stresses for a very long time.

With regard to precursory signal, a report was indicated a large scale deep slow slip that started in 2008 over the southern epicentral area, but the relation to the main shock of March 11, 2011 is uncertain. There is not much significant deformation detected near the source area before the earthquake with scales of several days by static GPS analyses to several minutes by KGPS analyses. As of this moment, no other immediate precursory phenomena except for the TEC (Total Electron Content) data have been found.

Preceding this earthquake, earthquake magnitudes and resultant hazards of strong ground-motions and tsunamis in NE Japan were assessed and announced by the government. The plate interface of the fault associated with the NE Japan earthquake has 6 segments mainly based on the earthquake history of the last 300 years in the area. Each segment was evaluated on the basis of numerous documents and scientific papers, and given its possible size and probability of risk as a function of time. These segments were assumed to move independently or sometimes together with the neighboring segment(s). The linkage effect of neighboring segments is a linear combination. However, the March 11 event occurred and ruptured through all segments with seismic moment 10 times larger than the linear sum of these 6 seismic moments.

On the basis of GPS measurements the accumulated slip deficit that had been accumulated on the plate interface was estimated by five research groups implying a large slip deficit in the northeastern

Japan, particularly off Sendai. The maximum deficit rate reached 10 cm/y, resulting in a 30m slip deficit for 300 years. This large slip deficit rate was also defined by seafloor geodetic survey accomplished at 70-140km away from the coast. Since major events that occurred in the area are medium-size earthquakes (~M7.5) in the last several hundred years, the accumulated slip deficit was not sufficiently released by these ordinary events. This deficiency was previously known, but the common belief is that the accumulated slip would be released aseismically considering that there was no documented > M8.0 earthquake in the historical past in this region.

Historical documents showed that a large earthquake and tsunami happened in 869 A.D. in the Sendai area. In the 1990's tsunami sediments corresponding to this documented event of 869 A.D. were found while other older events were likewise established. Since 2000 more systematic excavations were carried out on numerous sites along the coasts. Furthermore, numerical tsunami simulations were performed to fit the tsunami heights from these sediments. However, the estimated earthquake was significantly smaller, which is only about Mw8.2. If the earthquake would have been just this size, serious damage would never have been like what had occurred on March 11.

Lessons learned from this earthquake are as follows: risk assessment should be made based on the longest history if possible or longer than 1000 years. The obtained data must be analyzed not dependent or limited on particular scenarios or models. All possible ideas that can explain the data must be carefully considered.

Lastly, if ever the size of an earthquake is considered by collapsing the adjacent asperities relative to another by chance, it should be noted that the power law holds for earthquake frequency distributions. This fact holds true for the seismicity in Japan in the last 100 years. The extrapolation of this law suggests the occurrence of a M9.0 event in the area from a statistical point of view. Similarly, taking into account the records in the CWB catalogue, an Mw 8.0 or larger is quite possible to occur in Taiwan. Giant and large earthquakes are ubiquitous in the world, particularly along the plate boundaries.