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Identification and simulation of seismic supercycles along the Japan Trench including the 2011 Tohoku earthquake

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The devastating Tohoku earthquake of magnitude (M) 9.0 occurred on 11 March 2011 UTC along the Japan Trench, where the Pacific plate is subducting beneath the Tohoku district. The national program of seismic hazard assessment, which was initiated by the Japanese government after the 1995 Kobe earthquake, failed to foresee this earthquake, because no supercycle of megathrust events had been identified along the Japan Trench. For example, the program identified a normal cycle of six M7 to 8 earthquakes in the land side of the Miyagi-oki region, and only reported the high probability of having another M7 earthquake there.

The Japanese government also built nation-wide dense arrays of seismometers and GPS receivers after the Kobe earthquake. We have recovered annual rates of back slip, which is the drag of the overriding plate by interplate coupling, using GPS data during a calm period before the Tohoku earthquake. We then recovered coseismic slips through a inversion of GPS data during the earthquake. The distributions of recovered coseismic slips and back slip rates bear a close resemblance to each other. An area of large back slip rate was previously thought to be related to a normal cycle of M7 to 8 earthquakes. However, our result demonstrates that the area is related to a supercycle of megathrust earthquakes.

From the coseismic slips and back slip rates in the Miyagi-oki region, we calculated the coseismic moment release and moment accumulation rate of the Tohoku earthquake to 15 x 10**21 Nm and 0.04 x 10**21 Nm/year, respectively. Since normal earthquakes occasionally release some part of accumulated seismic moment, those in the Miyagi-oki region were compiled. We then calculated the moment releases by them to be 5 x 10**21 Nm. These moment releases and accumulation rate lead to a supercycle period of about 500 years.

However, this period is too short, if the 869 Jogan earthquake is the only documented event to have occurred with a possible magnitude and location similar to that of the Tohoku earthquake. Within the compilation, the 1611 Keicho earthquake can be a hidden candidate between the 869 Jogan and 2011 Tohoku earthquakes. Extensive tsunami damage caused by this earthquake was documented over the Tohoku district. The time series, which was drawn using the moment releases and accumulation rate, is mostly controlled by the moment releases of megathrust earthquakes.

We next conducted a numerical simulation of the seismic supercycles and normal earthquake cycles identified above. A strong patch (asperity) with higher effective normal stress and a large value of characteristic slip distance is assumed at a shallower part of the plate interface. This strong patch controls the occurrence of megathrust earthquakes that broke the entire seismogenic plate interface with recurrence intervals of several hundred years. The present model explains coseismic slips at a shallower part of the Tohoku earthquake and back slip rates at deeper parts, where normal events repeatedly occurred before the earthquake.