Cross-Scale Modeling of Great Earthquake Cycles: Methodology, Postseismic Relaxation, Maximum Magnitudes

*Iskander A. Muldashev[1], Stephan V. Sobolev[1,2]

1. GFZ German Research Centre for Geosciences, Potsdam, Germany, 2. Institute of Earth and Environmental Science, University of Potsdam, Potsdam-Golm, Germany

We present details of a cross-scale thermomechanical model developed with the aim of simulating the entire subduction process from earthquake (1 minute), postseismic processes (minutes to years), seismic cycle and multiple seismic cycles (centures to milleniums) to tectonic evolution at million years' time scale. The model employs elasticity, non-linear transient viscous rheology, and rate-and-state friction. It generates spontaneous earthquake sequences, and, by using an adaptive time-step algorithm, recreates the deformation process as observed naturally over single and multiple seismic cycles.

A developed technique was used to model postseismic relaxation after great subduction earthquakes and for estimation of the maximum magnitudes of the earthquakes in subduction zones.

The set of 2D models is used to study effects of non-linear transient rheology on postseismic processes after great earthquakes. Models predict that viscosity in the mantle wedge drops by 3 to 4 orders of magnitude during the great earthquake with magnitude above 9 due to the power-law creep rheology (major factor) and transient dislocation creep based on experimental data and theoretical mineral physics considerations. This results in significantly different spatial scale and timing of the relaxation processes following the earthquake than it is currently believed. Our model produce large postseismic creep due to visco-elastic relaxation in the mantle wedge that shows up in surface deformation similar to the classical afterslip and therefore can be misinterpreted as an afterslip. The model fits well the GPS data for postseismic slip of Tohoku 2011 earthquake in the time range of 1 day-4 years.

Developed technique is also applied to study key factors controlling maximum magnitudes of earthquakes in subduction zones. Our models demonstrate that maximum magnitudes of the earthquakes are exclusively controlled by the factors that increase rupture width. These factors are: low slab's dipping angle (the largest effect), low friction coefficient in subduction channel (smaller effect) and high subduction velocity (the smallest effect). In agreement with observations, our models also suggest that the largest earthquakes should occur in subduction zones with neutral (most frequently) or moderately compressive deformation regimes of the upper plate. This is a consequence of the low dipping angles and low static friction coefficients in the subduction zones with largest earthquakes, rather than a reason for the largest earthquakes. The predicted maximum magnitudes for the subduction zones of different geometries are consistent with the observed magnitudes for all events.

Keywords: earthquake modeling, seismic cycle, postseismic relaxation, great earthquakes, maximum magnitude

