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Deforming plate boundaries and their transients – challenges for modelers from the observational record

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A number of recent observations have drawn our attention to the fact that the accumulation of deformation at convergent plate boundaries appears to be transient at a large range of time scales. At the short time end, it is particularly the seismic cycle which is known to exhibit temporal variation of locking and various modes of rapid creep to slow earthquakes in between major earthquake events. Yet, the physical nature of locking and slip transients remains a matter of debate. At the time scale of multiple rupture cycles, superseismic cycles as well as earthquake clustering begin to emerge as a potentially characteristic behavior of faults slip. This questions simple assumptions on perfect cyclicity and repetitive properties from plate interface failure to the related deformation response of the upper plate. At the long term, temporal variations of shortening and faulting in orogenic belts are increasingly resolved where high resolution data are available. Here, deformation appears no less discontinuous or irregular as that observed at the shorter time scales.

Linking geophysical and geodetic data collected from recent earthquakes along the Chilean plate boundary as well as records on shortening and faulting provides a more coherent image of the processes controlling creep, seismogenic rupture and deformation transients at plate boundaries. Seismic, seismological and geodetic data collected from the southern part of the Maule 2010 earthquake rupture zone and correlation of these features with the rock record of an exhumed plate interface in the European Alps yield important clues: temporal fluctuations of a pore-fluid under near-lithostatic pressure conditions not only control the geophysical image but likely, also the kinematic behavior – and the emerging transients. Such detail is as yet not available for analysis of the behavior of earthquake clustering or deformation pulses on faults. Due to the observation that this behavior only emerges where several faults combine in distributing deformation or convergence, it appears likely that, here, fault interaction and stress diffusion in coupled, weak faults play an important role. Finally, at the long-term it is features such as the influence of the mantle via its viscosity structure and the strain-localization and weakening trend of maturing fault systems that appear to control longer term transients.

Finally, extending the known duration-moment scaling properties of these various styles of seismic slip to slow creep to longer time scales and converting these into properties potentially observable in the rock record, we note that several strain rate regimes are distinguishable separating normal earthquakes from a group of slower features – such as slow slip, afterslip, transient creep etc. – and a final one of creep at convergence rates. Interestingly, the scaling properties of transient deformation styles at all time scales seem to follow the same simple scaling law separating them from earthquakes. The physical nature of this scaling law and the factors controlling it across this range in scales are enigmatic but define an important requirement in any modeling approach.