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A secondary zone of uplift caused by megathrust earthquakes: Insights from seismo-thermo-mechanical models and geodetic data

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The 1960 M9.5 Valdivia and 1964 M9.2 Alaska megathrust earthquakes caused a zone of secondary coseismic uplift a few hundred kilometers landward of the trench. The secondary uplift exceeds 1m in Valdivia and 0.3m in Alaska. Its universal occurrence during other earthquakes as well as the physical mechanisms governing this process remain unclear, although several mechanisms have been proposed in the last century.

We combined survey data from these megathrust earthquakes in the last century with recent high-quality GPS data recorded during the 2010 M8.8 Maule and 2011 M9.0 Tohoku-Oki megathrust earthquakes. Based on these natural observations, we confirm the existence of a zone of secondary uplift in all earthquakes studied and discuss the similarities and differences between them. Dip and curvature of the slab and overriding plate structure seem to influence the amplitude of this phenomenon as well as the location of the transition from subsidence to secondary uplift. This transition ranges from 200 km distance to the trench up to 500 km. The amplitude of the secondary zone of uplift scales with the size of the earthquakes.

Using numerical seismo-thermo-mechanical modeling, we identified the low-viscosity lower crust as a crucial factor. A weak viscous lower crust does not accumulate significant stresses and allows for the bending and elastic buckling of a thin and strong elastic upper crust. The amplitude and relative position of the secondary zone of uplift also depends on the interplate decoupling depth as well as the shear modulus and thickness of the upper crust. We further investigate the timing of the secondary uplift using GPS data acquired after the most recent megathrust earthquakes and results from numerical models.

In conclusion, a secondary zone of coseismic uplift due to megathrust earthquakes exists and it is mainly controlled by the difference between a rheologically strong elastic upper and weak ductile lower crust. Since a weaker lower crust is observed to affect surface displacements distinctly, ignoring this feature will have a profound impact on the estimated slip on the interface. Therefore we suggest including this unequivocal feature in geodetic-based source inversions, especially for settings with a warm, continental overriding plate.