Post-doctoral project: Satellite gravimetry observations and models of slab deformation during the seismic cycle of great subduction earthquakes

At the interface between a continental plate and an oceanic plate plunging into the mantle, subduction zones constitute geological boundaries where most great earthquakes (Mw > 8) occur. Identifying in real time short-term (~months) anomalies before these great ruptures and understanding how they are initiated at depth remains a major challenge in Earth Sciences, which requires to better constrain the role of deeper subduction processes in a rupture initiation. The deep aseismic deformations of the subducted plates are indeed not well known, because they are difficult to observe. An original approach consists in documenting the gravity field variations caused by mass redistributions associated with deeper motions in subduction systems. Thus, we have evidenced anomalous gravity changes of deep origin during the months before the 11 March 2011 Tohoku earthquake (Mw 9.0, Japan) and the 27 February 2010 Maule earthquake (Mw 8.8, Chile)(Panet et al., 2018 ; Bouih et al., 2022). The gravity signals suggest transient motions of the subducted plates in the upper mantle, between 150 and 300km depth. Their migration towards the surface could have contributed to create favourable conditions to the initiation and the propagation of these large ruptures.

In addition to their spatio-temporal scales, an important characteristics of these signals is the very small amplitude of the associated surface displacement signals. These unique features remain poorly understood today, and still not simulated numerically. The nature of the internal deformation mechanisms and the rheological structure of subduction zones thus remain a key, in order to document the dynamics of slabs in the upper mantle and its impact on seismicity and shallow earthquakes.

This post-doctoral project complements the GRACE satellite gravity data analyses carried out in our team, in order to improve their geophysical modelling and couple different geophysical observables via numerical simulations. For that aim, we propose to apply the numerical modelling code SPECFEM-X and collaborate with Dr. Hom Nath Gharti (Queen's University, Canada). This program relies on the use of infinite spectral elements to solve the gravito-visco-elastic system govering the deformations associated with an earthquake (Gharti et al., 2019). This approach performs a coupled resolution of the equation of conservation of linear momentum, together with the Poisson equation for the disturbed gravitational potential, while introducing a realistic tri-dimensional modelling of subduction zones. It leads to a precise calculation of the associated gravity variations, at the Earth's surface as well as at the satellites altitude.

The first stage of the work will consist in validating the use of this code, by comparing its numerical predictions with results obtained in the case of dislocation models in a radially stratified Earth. Then, we will conduct a sensitivity study of the modelled signals to the lateral structure of subduction zones. We will also investigate the response to an extensional thinning of the slab. Finally, based on these tests, simulations will be carried out in order to jointly model the gravimetric and crustal displacement signals associated with the pre-, co- and post-seismic phases of the 11 March 2011 Tohoku earthquake (Mw 9.0, Japan) and the 27 February 2010, Maule (Mw 8.8, Chile) earthquake.

These developments will allow us to make progress in the integration of satellite gravity data in deformation models at subduction zones, data which remain today under-exploited for this purpose. They will contribute to a better understanding of the whole sequence of deformations during the seismic cycle of great ruptures.

References

Bouih, M., Panet, I., Remy, D., Longuevergne, L. et Bonvalot, S. (2022). Deep mass redistribution prior to the 2010 Mw 8.8 Maule Earthquake (Chile) revealed by GRACE satellite gravity, Earth and Planetary Science Letters, 584, 117465.

Gharti, H.N., Langer, L., & Tromp, J. (2019). Spectral-infinite-element simulations of earthquake-induced gravity perturbations, *Geophysical Journal International*, 217, 451–468.

Panet, I., S. Bonvalot, C. Narteau, D. Remy and J.M. Lemoine (2018). Migrating pattern of deformation prior to the Tohoku-Oki earthquake revealed by GRACE data, Nature Geoscience, 11(5), p. 367-373.

Required skills

The candidate should have a strong background in the field of scientific computing (in particular using finite elements or high performance computing) applied to geophysical modelling. Knowledge of the softwares Coreform Cubit or gmesh will be appreciated.

Context

The post-doctoral project (25 or 26 months) will be realized mostly at the Institut de Physique du Globe de Paris, with missions of a few months at Toulouse, to work with the members of Geosciences Environnement Toulouse. It is funded by the Grand Prix Scientifique 2023 from the Simone et Cino Del Duca Foundation of the Institut de France.

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