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Towards assessing the link between slow slip and seismicity with a Deep Learning approach

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The deployment of increasingly dense geophysical networks in many geologically active regions on the Earth has given the possibility to reveal deformation signals that were not detectable beforehand. An example of these newly discovered signals are those associated with low-frequency earthquakes, which can be linked with the slow slip (aseismic slip) of faults. Aseismic fault slip is a crucial phenomenon as it might play a key role in the precursory phase before large earthquakes (in particular in subduction zones), during which the seismicity rate grows as well as does the ground deformation. Geodetic measurements, e.g. the Global Positioning System (GPS), are capable to track surface deformation transients likely induced by an episode of slow slip. However, very little is known about the mechanisms underlying this precursory phase, in particular regarding to how slow slip and seismicity relate.

The analysis done in this work focuses on recordings acquired by the Japan Meteorological Agency in the Boso area, Japan. In the Boso peninsula, interactions between seismicity and slow slip events can be observed over different time spans: regular slow slip events occur every 4 to 5 years, lasting about 10 days, and are associated with a burst of seismicity (Hirose et al. 2012, 2014, Gardonio et al. 2018), whereas an accelerated seismicity rate has been observed over decades that is likely associated with an increasing shear stress rate (i.e., tectonic loading) on the subduction interface (Ozawa et al. 2014, Reverso et al. 2016, Marsan et al. 2017).

This work aims to explore the potential of Deep Learning for better characterizing the interplay between seismicity and ground surface deformation. The analysis is based on a data-driven approach for building a model for assessing if a link seismicity – surface deformation exists and to characterize the nature of this link. This has potentially strong implications, as (small) earthquakes are the prime observable, so that better understanding the seismicity rate response to potentially small slow slip (so far undetected by GPS) could help monitoring those small slow slip events. The statistical problem is expressed as a regression between some features extracted from the seismic data and the GPS displacements registered at one or more stations.

The proposed method, based on a Long-Short Term Memory (LSTM) neural network, has been designed in a way that it is possible to estimate which features are more relevant in the estimation process. From a geophysical point of view, this can provide interesting insights for validating the results, assessing the robustness of the algorithms and giving insights on the underlying process. This kind of approach represents a novelty in this field, since it opens original perspectives for the joint analysis of seismic / aseismic phenomena with respect to traditional methods based on more classical geophysical data exploration.