Subject offered for a contract starting october 2016

SUBJECT TITTLE: **Radiation complexity of large earthquakes: from regional scale imaging to strong motion modeling.**

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Presentation of the subject:

The complexity and the large frequency range of the radiation generated during the dynamic rupture associated to large earthquakes control their destructive potency. The radiation complexity results from non-local dynamic interactions during the rupture propagation, the fault geometry and structure (free surface, lateral heterogeneities); and from the intrinsic heterogeneous properties and scales of the fault interface. Quenched and dynamic heterogeneities control the radiation complexity and the extension of seismic ruptures, and cannot today be separately resolved by classical signal analysis methods. Even though 2D and 3D numerical simulations are evidencing the importance of those effects, they cannot today simulate or invert high frequency rupture models. Simulating and imaging/inverting extended seismic rupture and the associated radiation generation zones over a wide frequency range is a challenging issue today for the physical understanding and the mitigation of seismic and tsunami hazard in different geodynamical contexts.

Large band spectral models of seismic sources are today restricted to kinematic models. In those models, slip distribution along the fault interface is modelled as a spatial-and-temporal stochastic process, driven at coarse scale by an effective rupture front propagation, and tuned at small scale to produce a ω^{-2} – type seismic radiation. Among those models, the k-square model assumes a k^{-2} final slip spectrum that results from the superposition of a large number of “asperities” - with a power law distribution of sizes – which breaks with the passage of the rupture front over a time proportional to their dimension.

Recent detailed observations of large earthquakes - using new antenna imaging methods exploiting the increasing density and number of seismic arrays at teleseismic distances - are evidencing however non stochastic radiation characteristics of the fault interface. In particular for large subduction earthquakes, the deep portion of the interface seems to exhibit stronger - and higher frequency - coherent radiation than segments closer to the trench. These observations are interpreted today as the signature of variations along dip of the thermo-mechanical and of the heterogeneity of the fault interface in relation with its bulk environment. However, images derived from these antenna methods are still poorly understood. Moreover seismic observations at regional distances, providing a priori a closer observation window of the seismic rupture, are not yet exploited by these methods due to the complexity of the signal and the poor station-to-station signal coherence. Extracting information from these observations requires advanced statistical signal processing and analysis methods together with improved large band numerical models of dynamic rupture.

The objective of the PhD thesis is therefore to improve strong motion hazard assessment through statistical characterisation of the seismic ruptures and the associated radiation, in relation with the thermo-mechanical properties and the geometry of the fault interface. This research will involve a close collaboration with the researchers of the Earthquake Research Institute (ERI), at the University of Tokyo, in the framework of the existing scientific scientific cooperation between ERI and IPGP.

The thesis involves four complementary work components with a balance that will depend on the applicant profile and on the work progress during the thesis.

1. Develop new time-frequency statistical methods for array imaging of seismic sources at regional distances using back-projection and de-convolution techniques. The objective here is to identify and extract pertinent characteristic functions providing coherent station-to-station information through advanced analysis and scale decomposition techniques for non-stationary signal. High quality regional data for a number of large earthquakes recorded in Japan by exceptionally dense arrays will be used.
2. Analyse and interpret these time series of spatial images of the radiation in terms of statistical characteristics of the earthquake sources – spatial-and-temporal slip velocity distribution along the interface, time-frequency-duration properties of the observed coherent radiation generation area…). In particular, this will make use of simulation and inversion of the radiation via advanced nonhomogeneous, stochastic kinematic models based of the k-square methodology.
3. Develop new multi-scale models for large band simulation of dynamic rupture along heterogeneous fault interfaces, including complex geometry and surface interactions. The approach will be to couple coarse scale, deterministic dynamic models and short scale, stochastic kinematic models of the rupture via consistent closure conditions. These models shall allow assessing the heterogeneous spectral characteristics of the radiation associated to the extended rupture of large earthquakes in relation with the mechanical heterogeneities and the geometry of the fault interface and of the seismic zone structure. In turn these data-driven and physically based models will allow to determine the domain of validity of the kinematic approaches and to develop and assess the new imaging methods exploiting observations at regional distance.
4. Analyse statistically the specific characteristics of the distribution of the radiation generation area along fault interfaces in relation with the rupture dynamics, and assess their predictive properties. The goal here is integrate those characteristics in the generation of different rupture scenarios, and in the simulation of the associated strong motions with the objective to improve seismic hazard probabilistic assessment.

The research during this thesis will be conducted between IPGP and ERI. The applicant will share his time between these two scientific environments.