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SUBJECT TITLE: Coherent interferometry methods for imaging and characterizing the dynamics and the radiation of the finite source associated to large earthquakes.

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Presentation of the subject:

Seismological space-time characterization of the radiation and the kinematics of large earthquake sources is a challenging issue for advancing physical understanding of earthquake dynamic rupture processes and tectonic interpretations, with important implications in terms of seismic hazard mitigation and tsunami warning. Today, finite-source models are estimated by parallel inversions of seismic, geodetic (GPS and/or InSAR) and tsunami observations. However rapid finite-source inversions are still based primarily on teleseismic observations, since numerous data become available as soon as the body and surface waves propagate to global stations and the recorded ground motions are telemetered to data centres. Classical finite-source inversion has intrinsic space-time resolution limitations, explicit dependence on a-priori parameterization – of the fault geometry and of the rupture kinematics – and regularization constraints. Much larger and higher quality broadband data sets are rapidly available today due to continuously improving acquisition technics and local densification of global seismic observation systems. Today a number of seismic antennas raise new possibility for detection and imaging of Earth's seismic sources. This is reinforced by rapid development of new seismic interferometry methods – e.g., beam forming and back-projection imaging – exploiting the coherence in space and time of the seismic signal recorded within an antenna, with minimal a-priori assumption on the seismic source processes. These methods provide a paradigm shift for the detection and the characterization of the coherent "high-frequency" seismic signatures associated to the source and the propagation of non-volcanic tremors, e.g. Kao et Shan (2004), Gosh et al. (2010), and of large earthquakes, e.g. Ishii et al. (2005), Krüger and Ohrnberger (2005), Walker and Shearer (2009).

The potential of coherent seismic interferometry methods for constraining complex large earthquake rupture – avoiding some of the biases associated with a-priori parameterization – has been clearly illustrated by the studies of two recent great earthquakes: the subduction earthquake of Tohoku-oki (Mw 9.1, 11 March 2011, offshore east Japan); the oceanic intra-plate earthquake offshore Sumatra

(Mw 8.6, 11 April 2012, Indonesia). In the case of the Tohoku-oki earthquake, large aperture teleseismic array back-projection imaging revealed a space-time distribution of striking localized coherent "high-frequency" radiation sources in the deep portion of the subduction interface, and guided a teleseismic "low-frequency" finite-source inversion (Satriano et al., 2012a). This combined analysis – exploiting teleseismic broadband P-wave signals – evidenced the broadband signature of the earthquake rupture with a partition between large coherent slip asperity toward the trench – controlling the tsunami source – and localized "high-frequency" radiation sources in the deeper portion of the interface – controlling the complex strong ground motion. Similar results were recently obtained (Kiraly et al., in preparation) for the great offshore Maule earthquake (Mw 8.7, 27 February, 2010). These studies raise new and important observations for advancing understanding of large earthquake broadband source dynamics and seismic cycle in relation with the subduction zone structure (Satriano et al., 2012a). In the case of the offshore Sumatra earthquake, teleseismic array "high-frequency" back-projection imaging revealed for the first time a unique and complex and rupture process; and guided a teleseismic surface wave analysis. This combined analysis suggests a complex rupture process involving the reactivation of an inherited seafloor strike-slip fault fabric through surface wave dynamic triggering (Satriano et al. 2012b). This result raises new concern on the seismic potential of similar oceanic deformation zone.

These first studies raise new and challenging methodological and theoretical questions that will be addressed during this thesis. In term of methodology, the aim is to extend and improve the resolution of seismic coherent interferometry method for detection and finite-source imaging of large earthquakes and other seismic sources. A first aspect is to improve the exploitation of the space and time coherence of the signal recorded within an antenna. This will make use of recent advances in statistical signal analysis methods to improve and develop a new multi-windowed adaptive time-frequency beamformer. Another aspect is to enhance the statistical stability, resolution and signal-to-noise ratio of coherent interferometry imaging through back-propagation of local space-time cross-correlation of array data, and iterative deconvolution techniques in the case of heterogeneous geological media. In terms of theory, the aim is to advance our physical understanding of coherent interferometry imaging in the case of space-time distribution of non-coherent radiation sources that characterize large earthquake ruptures in contrast to more classical coherent imaging applications in seismic exploration and medical imaging. This new and important development is required to relate physically the localized coherent radiation sources - imaged by interferometry methods - to statistical heterogeneities of the earthquake source kinematic and material properties, and to the rupture dynamics. In relation, methods for characterizing the spectral signature and scaling laws of these coherent "high-frequency" radiation sources will be investigated.

These developments will be driven by the analysis of two main subduction zones: the subduction zone east and south of Japan in relation with the seismic hazard in the area of Tokyo; the subduction zone in Central and North Chile, in relation with advancing our understanding of the seismic hazard in the Valparaiso and Tarapacá segments. Another application will be a re-analysis of the few great oceanic strike-slip intraplate earthquakes recorded, i.e. the offshore Sumatra earthquake (Mw 8.6, 2012), the Antarctic plate earthquake (Mw 8.1, 1998) and the Tasman Sea earthquake (Mw 8.1, 2004), in relation with the seismic potential of inherited oceanic fabric. Those studies will lead to new important results in terms of the development of robust and accurate coherent interferometry methods for the detection and the imaging of seismic finite-sources, and their applicability in other geodynamical context in particular in the Antilles seismic arc. This thesis will benefit from on going and active collaborations with the Earthquake Research Institute (ERI) of the University of Tokyo and the University of Tsukuba, with the Department of Geophysics of the University of Chile (Santiago), through the Laboratoire International Associé "Montessus de Ballore". It will also benefit from collaborations with the Langevin acoustic physics laboratory that recently moved into the IPGP building.

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