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Understanding the earthquake generation process: key results and present grand challenges

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Earthquake science has made extraordinary progress in the last years promoted by high-quality data, high-precision observations, improved computational facilities and laboratory experiments. Despite these advances and an improved understanding of physical processes generating earthquakes, the grand challenge is nowadays to reconcile seismological measurements, geological observations and the key findings of laboratory experiments. Several different observations on natural and experimental faults indicate that many different physical processes control the earthquake preparation, initiation and the following dynamic rupture.
In my lecture I wish to present the results of original studies on recent earthquakes in order to discuss the complexity of the earthquake generation processes, the progress in understanding these processes and the difficulties in forecasting the spatio-temporal evolution. This in turn represents the progress and the problems in assessing the impact of earthquakes on society.
Among the several different large-magnitude earthquakes, I will pay particular attention to the 2009 L'Aquila main shock (6th of April, Mw 6.1). This seismic event, despite its moderate magnitude, is an important study-case for earthquake science for many different reasons: (i) it is one of the best recorded normal faulting earthquake with a distinctive foreshock-aftershock sequence; (ii) it allowed the collection of an excellent multi-disciplinary near-source data set; (iii) despite its moderate magnitude, it revealed a surprising complexity of source processes, including an unusual rupture directivity; (iv) its impact on society and seismologists is unique.
As many other previous moderate and large magnitude events in Italy, this earthquake has left the scientific community and the involved stakeholders quite evident lessons concerning the necessary prevention actions, as well as the urgent need to train and educate the society to live in earthquake prone areas. These lessons should spur all the public authorities towards a better use of seismic hazard maps and available information concerning the vulnerability of the Italian territory, with particular attention to urban areas. These lessons demand for urgent initiatives to increase the resilience of the Italian society to natural hazards.
Unfortunately, these lessons are still unheard. The missed prediction and the claimed lack of adequate indications for evacuating the population immediately before the earthquake have focused the attention of the media and produced a misleading effect on public opinion. There was the presumption to undertake prevention actions in few days or hours without any existing plan for emergency management; there was the presumption to do in few days what it was not done in previous decades or years.
I will present and discuss this complex nucleation and rupture process for showing how different competing mechanisms control the initial stage of rupture and the dynamic rupture propagation and I will focus on the fact that seismologists provided all the scientific information necessary to undertake the prevention actions to reduce fatalities and mitigate the impact on society.