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Challenges in physical modeling of landslides, glaciers, and generated seismic and tsunami waves for hazard assessment

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One of the great challenges facing our society is to cope with the increase in natural risks induced by climate change and human activity. The frequency of heavy rains and changes in vegetation cover have intensified over most areas, leading to enhanced risks of landslides and the tsunamis they can generate. Rising sea levels, partly induced by polar ice mass loss due to ice sheet melting and iceberg calving, make the increasing coastal population and infrastructures even more vulnerable to tsunamis. This creates an urgent need for precise quantification of landslides, tsunamis, and sea level rise impact to build reliable hazard maps for early warning systems and evacuation plans.

Accurate prediction of landslides and ice sheet mass loss is usually unreachable despite a tremendous amount of high quality data from imagery, GPS and dense arrays of seismic and oceanic sensors that record the seismic and water waves generated by landslides and iceberg calving at distances of more than 1000 km from the source, depending on the event volume (m^3 to km^3). These waves carry key information on the source such as mobilized mass, friction of the sliding material, and interaction with water. Therefore, beyond mere detection and localization of landslides and iceberg calving, full exploitation of these wave data should provide unprecedented clues to the complex characteristics and dynamics of these sources. Despite increasing research in environmental seismology this last decade, this is still a highly challenging issue because of the complexity of natural processes and their intricate imprint on wave characteristics. Until recently, only very simplified models have been used to simulate the generated seismic signal, making it difficult to separate the effects of model uncertainties or other parameters such as topography, flow dynamics, and wave propagation on the recorded signal. In parallel to environmental seismology, key advances are being made in the mechanics of granular materials, mathematics, and computing capacity.

By bridging geophysics, mathematics, and mechanics, we have developed sophisticated source models describing granular flows over complex topography. By coupling them with seismic wave propagation models, we have shown that the low frequency seismic signal can be simulated and inverted to constrain the flow dynamics, rheological properties, and physical processes involved. In a similar way, we have quantified ice mass loss due to calving in Greenland over the last twenty years by coupling the inversion of seismic waves with advanced modeling of iceberg calving. To

illustrate this multidisciplinary approach, I will present recent laboratory experiments and numerical modeling of granular flows, iceberg calving, and emitted seismic waves. In particular, I will demonstrate the key role of topography, rheology, erosion, and solid/fluid interaction in these phenomena and generated waves, as well as the challenges in their accurate description in numerical models applicable at the field scale at tractable computational costs. Addressing these issues in the future will break new ground in the detection and modeling of landslides, tsunamis, and glaciers, leading to improved assessment of related hazards and the quantification of their link with climatic, seismic, and volcanic activity.

multidisciplinary group of her collaborators: in geophysics, mathematics, mechanics, and acoustics