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## **An integrated approach coupling physically based models and probabilistic method to assess quantitatively landslide susceptibility at different scale: application to different geomorphological environments**

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Landslide hazard assessment is the estimation of a target area where landslides of a particular type, volume, runout and intensity may occur within a given period. The first step to analyze landslide hazard consists in assessing the spatial and temporal failure probability (when the information is available, i.e. susceptibility assessment). Two types of approach are generally recommended to achieve this goal: (i) qualitative approach (i.e. inventory based methods and knowledge data driven methods) and (ii) quantitative approach (i.e. data-driven methods or deterministic physically based methods).

Among quantitative approaches, deterministic physically based methods (PBM) are generally used at local and/or site-specific scales (1:5,000-1:25,000 and >1:5,000, respectively). The main advantage of these methods is the calculation of probability of failure (safety factor) following some specific environmental conditions. For some models it is possible to integrate the land-uses and climatic change. At the opposite, major drawbacks are the large amounts of reliable and detailed data (especially materials type, their thickness and the geotechnical parameters heterogeneity over a large area) and the fact that only shallow landslides are taking into account. This is why they are often used at site-specific scales (> 1:5,000).

Thus, to take into account (i) materials' heterogeneity, (ii) spatial variation of physical parameters, (iii) different landslide types, the French Geological Survey (i.e. BRGM) has developed a physically based model (PBM) implemented in a GIS environment. This PBM couples a global hydrological model (GARDENIA<sup>®</sup>) including a transient unsaturated/saturated hydrological component with a physically based model computing the stability of slopes (ALICE<sup>®</sup>, Assessment of Landslides Induced by Climatic Events) based on the Morgenstern-Price method for any slip surface. The variability of mechanical parameters is handled by Monte Carlo approach. The probability to obtain a safety factor below 1 represents the probability of occurrence of a landslide for a given triggering event. The dispersion of the distribution gives the uncertainty of the result. Finally, a map is created, displaying a probability of occurrence for each computing cell of the studied area. In order to take into account the land-uses change, a complementary module integrating the vegetation effects on soil properties has been recently developed.

Last years, the model has been applied at different scales for different geomorphological environments: (i) at regional scale (1:50,000-1:25,000) in French West Indies and French Polynesian islands (ii) at local scale (i.e.:10,000) for two complex mountainous areas; (iii) at the site-specific scale (1:2,000) for one landslide. For each study the 3D geotechnical model has been adapted. The different studies have allowed : (i) to discuss the different factors included in the model especially the initial 3D geotechnical models; (ii) to precise the location of probable failure following different hydrological scenarii; (iii) to test the effects of climatic change and land-use on slopes for two cases. In that way, future changes in temperature, precipitation and vegetation cover can be analyzed, permitting to address the impacts of global change on landslides.

Finally, results show that it is possible to obtain reliable information about future slope failures at different scale of work for different scenarii with an integrated approach. The final information about landslide susceptibility (i.e. probability of failure) can be integrated in landslide hazard assessment and could be an essential information source for future land planning. As it has been performed in the ANR Project SAMCO (Society Adaptation for coping with Mountain risks in a global change CONtext), this analysis constitutes a first step in the chain for risk assessment for different climate and economical development scenarios, to evaluate the resilience of mountainous areas.