Monitoring and near-real time forecasting of landslide surface displacements using continuous GNSS observations and a combined statistical-mechanical model: the service of the French Landslide Observatory - OMIV

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The objective of this work is to present a methodology developed by the *French Landslide Observatory* (e.g. OMIV), a collaborative structure aiming at collecting the same type of kinematic, hydrologic and seismic observations on landslides and at disseminating the data to the scientific community (e.g. http://omiv.unistra.fr), for the near-real time characterization of surface displacements using permanent GNSS stations. In France, several GNSS receivers have been installed on active landslides (e.g. *La Clapière* rockslide, *Avignonet* and *Villerville* rotational slides, *Super-Sauze* and *La Valette* mudslides) since a few years. These landslides show very different displacement rates (ranging from a few centimetres to several meters per year) and different kinematic regimes (e.g. continuous displacement of nearly constant rate or succession of periods of acceleration/deceleration).

For the monitoring of landslides where the required degree of accuracy is millimetric, GNSS has been mainly used through campaigns measurements as a complement to conventional geodetic methods. Permanent monitoring is still not usually performed operationally, mostly because of the cost of the stations compared to conventional deformation monitoring techniques. In addition, if GNSS measurements can reach a millimetre-level of accuracy for long observation sessions (typically 12h), their accuracy decreases with the duration of the observation sessions, and attaining a one millimetre-level accuracy requires sophisticated *a posteriori* data processing techniques. To acquire a very precise 3D coordinate that can be used as a reference for other monitoring techniques and to develop early-warning systems, permanent GNSS with automatic data transmission is certainly the only solution that can be used on very constraining sites with either difficult accessibility, absence of long-term stability of the slopes around the landslide, or absence of direct visibility.

The objectives of this work are (1) to present the permanent GNSS monitoring system and data transfer system installed on several landslides in France, (2) to present the automatic processing of the data using the GAMIT/GLOBK analysis package, and (3) to define quantitatively the contribution of permanent GPS observations for the fast detection of small displacements.

Further, a combined statistical-mechanical approach to predict changes in landslide displacement rates from the observed changes in rainfall amounts is presented. The forecasting tool called FLAME (Forecasting Landslides Accelerations induced by Meteorological Events) associates a statistical Impulse Response (IR) model to simulate the changes in landslide rates by computing a transfer function between the input signal (e.g. rainfall) and the output signal (e.g. displacements) and a simple 1D MechAnical (MA) model (e.g. visco-plastic rheology) to take into account changes in pore water pressures. The performance of different combinations of models (IR model alone, MA model alone, and a combination of the IR and MA models) is evaluated against observed changes in pore water pressures and the GNSS surface displacement rates. The approach constitutes however a robust tool to predict changes in displacement rates from rainfall or groundwater time series.