Thesis title : Assimilation of geodetic data for natural hazards forecasting

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Co-funding: Université Savoie Mont-Blanc, ANR in Artificial Intelligence **(co-funding has already been obtained)**

Profile of candidate : The Ph.D candidate should have good skills in signal/image processing, mathematics/statistics or geophysics.

Ph.D subject description :

This Ph.D thesis is proposed along with the increasing and regular availability of the amount of remote sensing data and the response to the requirement of operational prediction of natural hazards. The main objective is to improve the near-real-time integration of remote sensing data and dynamical geophysical models for the mitigation of natural hazards. This thesis is partly (50%) funded by the national action plan in Artificial Intelligence. The relevance of the methodology developed in this thesis 1) compared to the actually emmerging data-driven methods, lies in the incorporation of geophysical knowledge (which helps increase the interpretability and the accountability of the results for operational purpose) and its near-real-time implementation ; 2) compared to previous attemps to improve the near-real-time integration of InSAR data based on the Kalman Filter, lies in the capability in taking non-Gaussian error statistics (which can represent better the reality) into account. First application will be in volcanology, using InSAR & GNSS data, but the methodology can be easily utilized for other natural hazards (e.g. landslides, slow slip, etc.), as well as for anthropogenic hazards like forest fire.

In a perspective of volcanic hazard assessment, it is fundamental to be able to know, in advance, if magma that has started to propagate from a reservoir will reach the surface, where and when. The propagation phase is generally rapid, lasting a few hours to a few months but it induces seismicity and deformation signals. These signals are recorded by continuous sensors (GNSS) and InSAR data whose temporal sampling frequency as well as latency have been greatly improved in recent years. In addition, we have dynamic magmatic intrusion propagation models that can be used to calculate, depending on the physical parameters of the Earth's crust, the properties of the magma and the state of local stress, the trajectory followed by the magma and its propagation velocity (Pinel et al. 2017). Data assimilation, a method that combines a dynamic model with observations at present and in the past based on error statistics and predicts the future state of the observed system, is therefore an appropriate tool to respond to the need to be able to predict the position and timing of an eruption in volcanology.

Among numerous data assimilation methods, the particle filter is distinguished from others by its great ability to deal with non-linear models and non-Gaussian error statistics (van Leeuwen P.J 2009, van Leeuwen P.J, 2010). The particle filter is based on a representation of the probability density of the dynamic model by a discrete set of states of the model (namely particles) and relies on the Bayes theorem so without worrying about the distribution of model errors (different from most other data assimilation methods which assume a Gaussian distribution of the errors). The evolution of the probability density of the model is realized through the propagation of all the particles (states of the model) over time following the model equation (the physics). When observations of the system are available, the relative contributions of the particles are modified so that the information available in the observations is integrated into the particles swarm. The particle filter does not directly correct the values of particles, but their relative contributions, this is very important for estimating magmatic intrusion propagation trajectories. The particle filter is therefore the appropriate tool in the present specific context of estimating the position of a volcanic eruption.

In this thesis, we will develop an efficient data assimilation strategy using the particle filter allowing to use timely available geodedic data to predict the location and timing of eruptive vents induced by magmatic intrusion propagation. This work will be based on the Ph.D thesis of Mary Grace Bato who, under our supervision and for the first time, successfully applied sequential data assimilation techniques (i.e. Ensemble Kalman Filter) to volcanological problems focussing on the pressurization and rupture of magmatic reservoirs (Bato et al, 2017, Bato et al., 2018). Moreover, this thesis will benefit from the results obtained in the TOSCA AssimSAR project (2018-2019). It will be part of the Franco-German ANR MagmaPropagator (ANR-18-CE92-0037, 2019-2022) with an application to Piton de la Fournaise volcano. It will also be the oppotunity to collaborate with Andy Hooper from the University of Leeds, who is developping new methods to automatically extract a physical signal from InSAR time series (Gaddes et al, 2019).

Selected references :

Bato M.-G., Pinel V., Yan Y., Jouanne F., Vandemeulebrouck J., "Possible deep connection between volcanic systems evidenced by sequential assimilation of geodetic d", Scientific Reports, Nature Publishing Group, 2018, https://doi.org/10.1038/s41598-018-29811-x

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