ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
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Titre du sujet : Extending the use of InSAR-derived deformation to vegetated volcanoes through error prediction and correction

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Développement du sujet : (Maximum 2 pages)

Overview

We propose a project in remote sensing aiming at improving the accuracy of ground deformation estimates at high spatial resolution, in particular for volcano monitoring. Millimeter-scale ground deformation with very fine spatial resolution can be measured using satellite interferometric synthetic aperture radar (InSAR) every few days. However, such measurements are only possible if the interaction of the radar wave with the atmosphere and ground scatterers are taken into account and corrected. Indeed, successive stages of InSAR processing, combined with the humidity and vegetation cover conditions prevailing at mid-latitude, can introduce systematic errors or biases in deformation measurements, which we can hardly characterize quantitatively (De Zan et al. 2015, Ansari et al. 2021, Zheng et al. 2022). For instance, these biases can reach several centimeters per year in metropolitan France. As a result, the density of "reliable" deformation measurements in temperate zones is much lower than in arid regions. Furthermore, the "reliability" of measurements is not easily quantifiable. This explains why most of deformation products derived from InSAR, e.g. European Ground Motion Service (EGMS), do not specify error margins.

The aim of this project is to extend spatially the use of InSAR for estimating ground deformation to areas subject to biases. We will study the interactions between the radar wave and the ground surface and the associated error characterization, under the supervision of M. Dalaison (MCF, geodesy, IPGP) and B. Pinel-Puyssegur (Researcher, CEA), with regular discussions with R. Grandin (MCF, tectonics, IPGP). A canonical formulation of error estimation should be developed under the supervision of N. Fuji, (MCF, seismology, IPGP) while L. Seydoux (CPJ, seismology, IPGP) will help us establishing a machine learning algorithm based on the analyses described above. Finally, the algorithm will be applied to the real data on volcanic edifices such as Piton de la Fournaise (Réunion island, France) and the Mount Fuji (Japan) in different climates, and compared with *in situ* observations of the nature of the land cover and measurements of deformation.

Error prediction through machine learning

Here in this project, we aim to predict and correct biases in InSAR surface deformation measurements, knowing the properties of a given stack of interferograms covering long time spans. A preliminary study (Drique, MSc thesis in prep.) shows that these biases have a complex spatio-temporal statistical signature and that we need to define a set of features that minimally and sufficiently describe each interferogram. The features may be internal to the complex image (e.g. coherence, backscattered intensity ratios) or auxiliary information (e.g. land cover, vegetation indexes, surface roughness). Feature characterization may involve using other remote sensing products (optical imagery) or numerical weather models. This step will be part of the overall design of an artificial intelligence algorithm to optimize a set of parameters relating these features to errors over different test regions (Fig. 1). Once the interferograms and time series are corrected for biases, deformation in vegetated environments will become accessible.

Challenges of deformation measurement on volcanic edifices

Volcanoes exhibit a diversity of land covers and ground types. Notably, there are a number of challenges to derive InSAR deformation, such as the vegetation on the flanks of the volcano, seasonal snow on the summit, different roughness of lava flows (e.g. pahoehoe, lapilli). This limits the ability to measure deformation and could cause biases in the estimated deformation of hydrothermal, magmatic or tectonic origin, ranging from subtle millimeter-scale deformation at Mount Fuji, under complex tectonic settings and snow on the top, to large meter-scale amplitudes at the Piton de la Fournaise. Both volcanoes are challenging test regions with in situ data to compare the performance of the new corrections. Indeed, the Piton de la Fournaise observatory (OVPF-IPGP) centralizes many observations, InSAR monitoring is active (Service National d'Observation ISDeform, https://www.isdeform.fr/piton-de-la-fournaise/), and previous studies have investigated the influence of vegetation and lava roughness on SAR coherence (Arab-Sedze et al. 2014).

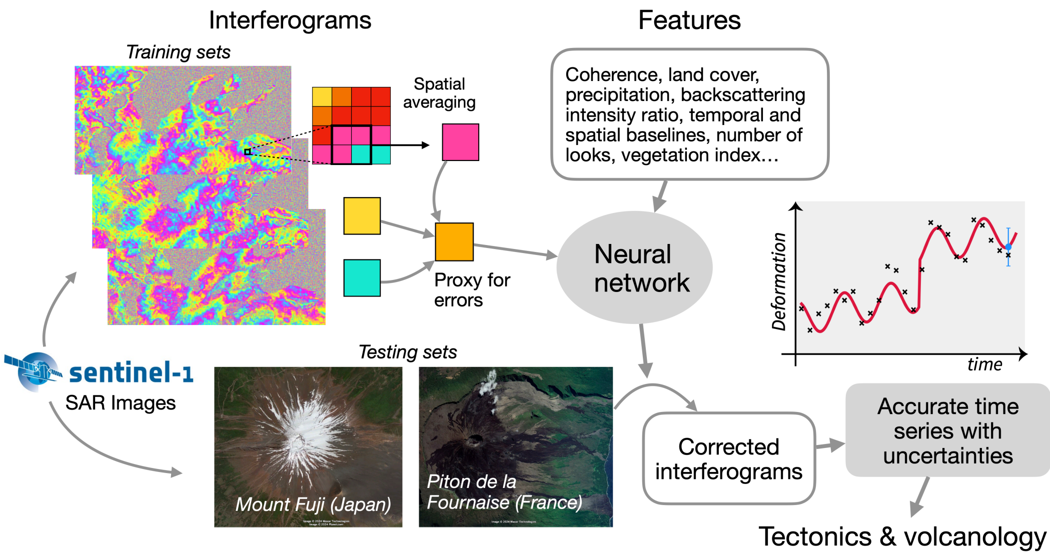

Figure 1 - this thesis will aim to design, train and test an artificial intelligence algorithm (like a neural network) which works on individual pixels belonging to three interferograms, knowing the physical and statistical properties of the resolution cells and a proxy of errors (phase closure) for the three interferograms considered.

Research environment and relation to other PhD projects

The project involves researchers from several IPGP teams (seismology, geodesy and tectonics) and a researcher from CEA, an expert in SAR remote sensing. The PhD candidate, will also participate in wider discussions on the use and limitations of InSAR in the ParInSAR group (IPGP, ENS, CEA).

A. Doucet (under J.-P. Métaxian and L. Seydoux) is currently working on seismic signal characterization of continuous seismic waveform records on Mt. Fuji in order to establish a real-time warning system; N. Fuji is proposing this year another PhD project on the 4D seismic imaging using the same dataset in order to understand the dynamics of Mt. Fuji (with S. Durand). This project will be contributing to infer the dynamics beneath Mt. Fuji with InSAR data: all three projects will be realized in a tight collaboration with ERI, U. Tokyo (especially Y. Aoki). A field work to Mt. Fuji with the whole group is being prepared.

Réferences

- Ansari, H., F. De Zan, and A. Parizzi (2020), *IEEE Trans. Geosci. Remote Sens.,* 59(2), 1285–1301.
- Arab-Sedze, M., et al. (2014), *Remote Sens. Env.*, *152*, 202-216.
- De Zan, F., M. Zonno, and P. López-Dekker (2015), *IEEE Trans. Geosci. Remote Sens.*, 53(12), 6608–6616.
- Drique, L., Master thesis, in prep. 2024 (under supervision of M. Dalaison and L. Seydoux).
- Zheng, Y., et al. (2022), *IEEE Trans. Geosci. Remote Sens.*, 10.1109/TGRS.2022.3167648.