Research Networking Programmes

Short Visit Grant ☒ or Exchange Visit Grant ☐

(please tick the relevant box)

Scientific Report

The scientific report (WORD or PDF file – maximum of eight A4 pages) should be submitted online within one month of the event. It will be published on the ESF website.

***Proposal Title*:** Laboratory volcano geodesy

Application Reference N°: 6427

1) Purpose of the visit

The aim of the proposed project was to integrate the quantitative experimental approach developed at UiO with the volcano geodetic expertise of scientists at NordVulk, Iceland. The project plan had two stages.

The aim of Stage 1 was to run laboratory experiments to produce a quantitative laboratory geodetic dataset. For this purpose, Dr. Galland designed an experimental apparatus scaled to model shallow magma intrusions of different shapes. This experimental apparatus allows to: (i) monitor the evolution of the oil pressure through time, which reflects the dynamics of intrusion; (ii) compute subtle (<0.1 mm) high-resolution 3D displacement vector maps of the model surface resulting from oil intrusion through time; (iii) calculate the full 3D, complex shape of the solidified intrusion, after it has solidified and has been excavated (Figure 3).

The aims of Stage 2 were to (i) transfer knowledge on geodetic modeling from Icelandic geodesists (Dr. Rikke Pedersen) to Norwegian scientists (Dr. Olivier Galland) and (ii) adapt and modify geodetic models commonly used to invert geodetic measurements on active volcanoes to invert deformation data measured in the laboratory.

2) Description of the work carried out during the visit

The main objective of this short visit for Dr. Galland was to integrate two drastically different fields: geodetic modeling and quantitative laboratory modeling. The main initial challenge was to find a common language between Dr. Galland's laboratory expertise and the Icelandic geodesists. The visit thus started with a brainstorming meeting involving Dr. Galland and Dr. Pedersen and her colleagues. Dr. Galland presented his experimental model of shallow magma intrusions along with deformation data from preliminary experiments to the deformation group at the Nordic Volcanological Center at the University of Island.

This brainstorming session was greatly fruitful. The results of this were that the group found relevant and feasible applications of the experimental models to validate current approaches in crustal deformation modeling in response to magma transport in volcano plumbing systems. Overall, it was a first step to highlight the strengths and limitations of numerical deformation models and of their input displacement data (acquired through GPS and InSAR measurements), which correspond to the starting point for establishing the whole strategy of the collaborative project.

Dr. Galland studied and used numerical crustal deformation models used in modeling of pre-eruption inflation of the Eyjafjallajökull volcano in 1994 and 1999; the simple expanding point source model by Mogi (1958), and a model describing finite rectangular, tensile dislocation in an elastic half-space by Okada (1985), simulating both dyke and sill geometries. The inverse problem was approached through simulated annealing followed by a derivative method, and further investigations of the Okada-model was done through applying variable sill-opening and optimizing the opening to the deformation data.

The subsequent days were dedicated to work specifically on the codes commonly used to analyze geodetic data and to adapt them to the laboratory system Dr. Galland has implemented. Therefore, the main tasks of the visit were to dive into existing codes and to correct them to be used with the laboratory data. The code used for this modeling was hard-coded to the specific problem of Eyjafjallajökull, so great effort has been done to generalize and implement the code on our experimentally computed deformation data. The code is in fact a suite of linked Matlab and C programs, that call each other. Therefore, correcting one program required changing most of the others, as a cascading effect. Therefore, before doing any correction, large effort was paid to understand perfectly each step of the program suite.

Describing the programming work accomplished during the visit is not an easy task in this report, especially because it is not finished yet, but in the following I list a few key points that needed to be solved to run the code on the laboratory deformation data.

First problem: Matlab version incompatibility. The code used as a starting point was designed in MatLab 6.5 (R13) and some trivial compatibility issues was encountered in MatLab 8 (R2012b), the one Dr. Galland is currently using. However, these version issues were relatively easily solved through changes in function syntax of e.g. addpath, patch. In addition, moving from Mac to Linux rendered useless the MEX-files used to call external C functions for calculating Okada dislocations. Identification of the problem was not straightforward as the main code hid the relevant error messages, but when identified building new Linux-native MEX-files was an easy fix.

Second problem: both the main program and the sub-functions were specifically designed for being applied to Eyjafjallajökull Volcano. Another issue making the code less transparent is the different coordinate systems (lat-long for Eyjafjallajökull versus Cartesian for laboratory data). In addition, another challenge was to convert the data, such that the code is scale-independent and can compare data from systems of drastically different scales (geological versus laboratory). To clean the code and make it more generally applicable, Dr. Galland have started removing input from the sub-functions, and implementing dimensionless variables. Dr. Galland has also begun removing the sensor specific treatment of deformation input, as the input should be pre-processed to a general dimensionless format so that comparative analysis of actual volcano deformation and experiments is straightforward.

The codes describing the kinematic models are cleaned and ready for forward modeling, but the codes handling inversion through simulated annealing and optimization of variable sill-opening are untouched yet.

3) Description of the main results obtained

The first result of this visit, and not the least, was to establish a dialogue between two communities that barely speak to each other: the physical laboratory and the geodetic modeling communities. Overall, it was important to coordinate the laboratory activities in very close collaboration with the geodetic community, such that the laboratory approach can be established according to the specific needs of the geodetic modeling community. This crucial step ensures (i) the relevance of the laboratory results for the geodetic community, and (ii) the prevention of a bad feeling that the laboratory modelers criticize the approach of the geodetic community.

The second result is a very valuable knowledge transfer between two MeMoVolc countries: Iceland and Norway. Indeed, though many publication describe the results of geodetic modeling, none of them describe in great details the technical issues and the calculation steps, such that it is almost impossible for the readers to reproduce the published results. Therefore, the only way to learn the geodetic modeling procedure is to visit and stay with the main users and developers of these geodetic models. In addition, Norway is a country where the volcanology expertise is relatively low and the volcanology community very small, therefore this short visit contributed to considerably improve Norway's expertise in volcano monitoring and modeling. The visit was also used to establish the scientific strategy of the next 4 years of collaboration between Norway and Iceland, This short visit results are thus in good agreement with some of the main objectives of these short visit grants.

Finally, the third result is the program suite corrected during the visit. It is incredibly difficult and challenging to dive into a complex code that is not our own, so that most of the visit was dedicated to understand and adapt the existing code used in Iceland. The result of this brain-crushing task if a new program suite almost adapted to be used on laboratory deformation data. Although the visit was two-week long, the correction of the program suite is not entirely finished, but minor adjustments need to be performed now. Therefore, the main outcome of this short visit is conclusion of the long way in implementing classic geodetic inversion models on laboratory data. After some reworking, the corrected program suite will be operational to be used on laboratory deformation data, and so to test - for the first time - the robustness and validity of the geodetic models used on active volcanoes.

4) Future collaboration with host institution (if applicable)

Before this short visit, Drs. Pedersen and Galland never collaborated together. This short visit thus corresponds to the starting point of a developing collaboration between two Nordic countries. The very positive outcomes of this short visit will be the foundation of the starting PhD project of Håvard Bertelsen, a PhD student affiliated at the University of Oslo. The ambitious objectives of Bertelsen's PhD project multiple:

Objective 1: Test the value of real-time analysis of geodetic measurements on predicting the location of preparing volcanic eruptions

Objective 2: Quantify the effects of classic assumptions of geodetic models on geodetic inversions (elasticity, absence of surface topography, simplistic source shapes)

Objective 3: Quantify the effects of input geodetic data quality on inversion results (punctual GPS data, distorted InSAR data).

Objective 4: Unravel the dynamics of the current caldera collapse at Bardabunga volcano, Iceland. Currently, huge geodetic dataset of the ongoing caldera collapse is produced, but there is no realistic geodetic model to analyze this data. Laboratory models prove very suitable to model caldera collapse, and we propose to run systematic laboratory models of caldera collapse and measure the associated geodetic movements to interpret real geodetic measurements at Bardabunga.

The four objectives of the PhD project are founded on the collaboration initiated during this short visit. Dr. Pedersen will be deeply involved in the four objectives of the PhD project as she will be Bertelsen's official co-supervisor.

5) Projected publications / articles resulting or to result from the grant *(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)*

Directly after this short visit grant, there is no publication ready to be submitted, at least during the time frame of the ESF MeMoVolc grant. Nevertheless, the collaboration initiated between Norwegian and Icelandic scientists will become the foundation for long-term collaborations. The short-term collaboration will develop through a 4-year PhD project, the aim of which is to publish several papers founded on the outcomes of this short visit.

During the last day of the visit in Iceland, Drs. Pedersen and Galland listed the potential articles that can come out from this fruitful visit, and the list is substantial. At this stage, it is impossible to give a firm list, but this visit highlighted the high potential impact of this initiating collaboration. In all these publications, the contribution of ESF will be acknowledged.

6) Other comments (if any)