Project 2 (WP2): Volcanism during the last millenium

Project lead: Myriam Khodri
Post-doctoral researcher: Virginie Poulain
Project start/end: September 2013 – August 2015

Position offer:

The excellence laboratory L-IPSL of the Institut Pierre-Simon Laplace offers a post-doctoral position of 2 years to address impacts of volcanism on climate in the last millenium.

Context: It is now generally recognised that volcanic eruptions have an important effect on climate variability from inter-annual to decadal timescales. Using comprehensive Earth system models, much progress in understanding volcanic climate effects have been achieved in recent years, including the impacts on atmospheric chemistry and dynamics, on ocean dynamics, marine and terrestrial biochemistry and on the hydrological cycle. These results are however hampered by many assumptions on the reconstructed past volcanic activity, but also on the choice on sulphate aerosol size distribution and their implementation in the radiation scheme of models themselves. Several outstanding questions remain and concern the behaviour of huge SO_2 cloud injected into the stratosphere after super eruptions such as those that did occur during the last centuries.

Description of work: All in all, these results call for more process-oriented sensitivity experiments. The challenging task for the hired post-doctoral fellow would be to improve the actual volcanic forcing reconstructions and its implementation in the IPSL models. As a first step, the focus will be on the calculation of the temporal evolution of volcanic aerosol size distribution, global fields, and optical characteristics, for the two biggest volcanic eruptions of the last millennium, i.e. the 1258 AD and the Tambora (1815). Such calculations will be done with a global 2-D stratospheric climate model including detailed microphysical and chemical processes for stratospheric volcanic aerosols. This model has been developed at the LATMOS laboratory (IPSL). New estimates of SO_2 release are now available for these two eruptions and will be used to constrain the SO_2 loading in the 2-D model. This will allow the calculation of (1) consistent evolution of the global distribution and size of stratospheric sulphate aerosols after each eruption and (2) deduce the related optical properties (AOD, single scattering albedo and parameters of asymmetry) for both v*isible* and *infrared* spectral bands.

In a second step and in collaboration with LMD laboratory (IPSL), the deduced new size distribution and optical parameters will be implemented into the LMDz radiation scheme for both spectral bands (visible and infrared). Sensitivity experiments with chemistry-climate models (CCM), LMDz-REPROBUS and/or LMDz-INCA, coupled to NEMO, including the new stratospheric aerosol radiation schemes will then be used to run sensitivity experiments and evaluate the impact of competing non-linear radiative and chemical processes on the simulated climates for volcanic eruptions. We will start by a test case, simulating the Mont Pinatubo eruption in the CCM model. The results will be validated against the large datasets of observations (satellite, balloon, reanalysis,…) and serve as a reference control run. Then we will tackle the two biggest volcanic eruptions for the last millennium (i.e. 1815, 1258 AD).

In the last step, cross validations of the sensitivity experiments for the mega eruptions with proxy data will be essential to better evaluate the realism of the new volcanic forcing parameterisation for the largest eruptions. More proxy reconstructions are now available at IPSL (LSCE, LOCEAN, etc.) and in other national and international laboratories. They will help constrain the climate sensitivity. In interaction with the LOCEAN laboratory (IPSL), further tests will be required on the influence of the initial state (including the ocean) on the simulated climatic response following these volcanic eruptions before extending our approach to the whole millennium.

Supervision team : The work will be conducted under the main supervision of M. Khodri (LOCEAN), in close connection with other researchers : M. Marchand (LATMOS), S. Bekki (LATMOS), O. Boucher (LMD), J. Mignot (LOCEAN), D. Swingedouw (LSCE). The work will be mainly conducted at LOCEAN, but in other IPSL sites also.

Duration and salary: The post-doctorate will be recruited for 24 months with a net monthly salary qaround 2000 euros, commensurate with experience. This includes social services and health insurance.

Contact for applications: Applications should include a vita, a statement of research interests and the names of at least two references including e-mail addresses and telephone numbers. Applications should be submitted by e-mail to Myriam Khodri (Myriam.Khodri@ird.fr).

Results:

The impact of large volcanic eruptions on the stratosphere and climate lies in principle among the potential predicable features of climate after volcanic eruption took place. However such predictability is hindered by several knowledge gaps in the aerosol emission and in the climate response. **In a first phase** the microphysical model (*Bekki et al, 1994*) was improved against observations (*CCMI, satellite observations; balloons, etc)* and the computed aerosols radiative properties were implemented in the IPSL model solar spectral bands. An ensemble of simulations was performed for major past eruptions (Mt Pinatubo, Samalas, Tambora), using ice-core data to produce realistic scenarios of SO_2 injection into the stratosphere. The uncertainties related to the season of eruption and the altitude of the volcanic plumes deduced from geological evidences were also explored, using dendro-climatological data, historical documents, and improved temperature reconstructions for the last 1500 years. For the first time, tree-ring proxies and climate simulations yield similar magnitudes for northern hemisphere summer cooling over land induced by these eruptions, estimated between –0.8 and –1.3°C. This challenges earlier climate simulations of these eruptions impacts (Stofell et al, NGEO 2015).

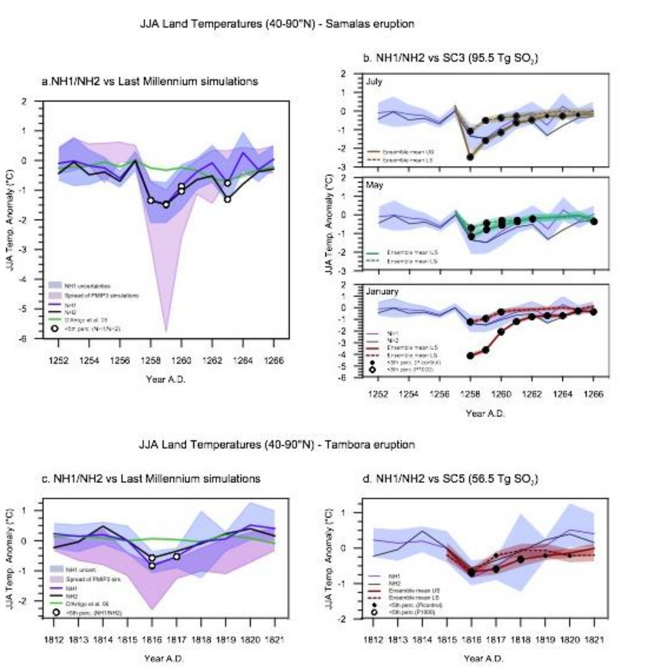

Figure 1. Summer cooling induced by the 1257 Samalas eruption as reconstructed in the tree-ring records (NH1, NH2), D'Arrigo2006[4], (a) PMIP3 Last Millennium simulations and by (b) the mean SO_2 yield scenario (SC2 = 137.8 Tg) in the IPSL model and for eruptions in May 1257, July 1257 and January 1258. LS and US indicate the lower and upper scenarios for injection heights and correspond to 70% of the mass injected to 26–33 and 36–43 km, respectively. (c) and (d) same as (a) and (b) but for the 1815 Tambora eruption.

In a second phase, results from a range of eruption of various amplitudes and seasons reveal that there is no universal linear relationship between the global cooling and the magnitude of the eruptions due to self-limiting microphysical processes and stratospheric dynamics impacting the main modes of climate variability.

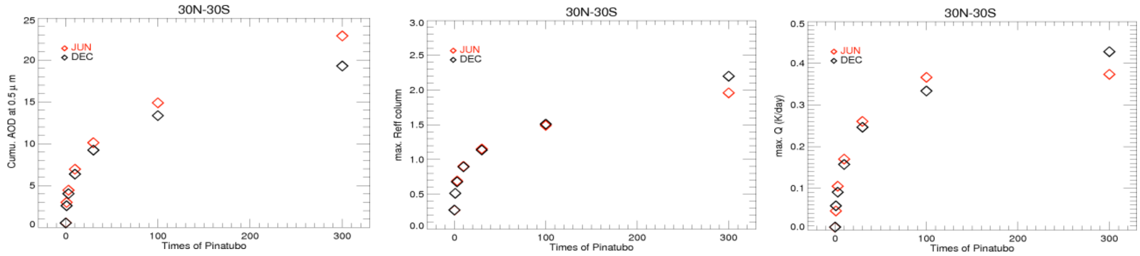

Figure 2. Simulated tropical (30N-30S) mean cumulated Aerosol Optical Depth at 550nm (left), maximum column effective radius (middle) and diagnosed volcanic aerosol heating rate trend in the lower stratosphere (right) for a set of sensitivity experiments spanning a large range of SO_2 injections from 0.1 to 300 times Pinatubo. The black symbol corresponds to December tropical eruptions and the red symbol to a June tropical eruptions. Poulain et al., to be submitted.

To compensate for the aerosol induced lower stratosphere-heating rate in the tropics (Figure2), reduced Brower Dobson Circulation in the stratosphere tends to dynamically force polar geopotential high to upper levels (Figure 3). For eruptions equivalent or stronger than Pinatubo, these forced stratospheric processes propagate downwards to the surface and through adjusted subtropical and polar jets result in a strengthened polar vortex and positive NAO. The dynamically induced surface winter warming that emerges over extra tropics outweighs the radiative cooling and justifies the relatively weak cooling on global average the years after very large eruptions (Poulain et al, to be submitted; Poulain et al, in prep).

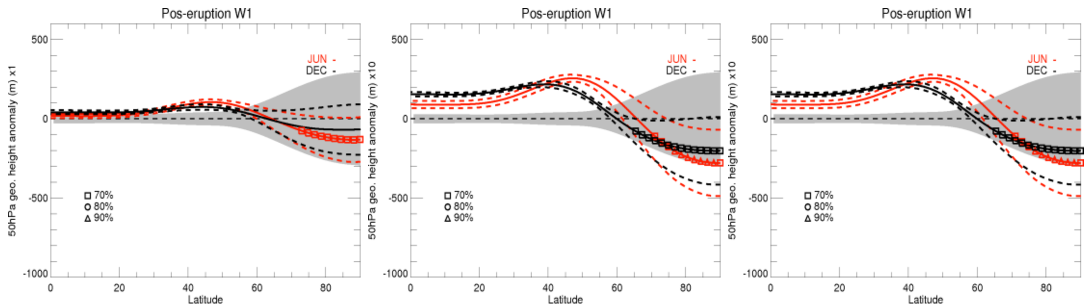

Figure 3. First post-eruption winter mean (December-January-February) geopotential height anomalies (in meters) at 50hPa for three sensitivity experiments corresponding to SO_2 injections 1-time (left), 10-times (middle) and 100-times (right) Pinatubo. The solid line corresponds to the 10-members ensemble mean, the dashed line corresponds to the ensemble spread (90% confidence interval according to a t-welsh test and a pair-to-pair anomaly procedure), and the grey shading to unforced coupled inter-annual variability diagnosed from the CMIP5 Picontrol IPSL-CM5A simulation. The red line corresponds to a June eruption and the black line to a December eruption. The square, circle, triangle symbols correspond to anomalies reaching the 70, 80 and 90% confidence interval level according to a Probability Density Function built by randomly sampling and averaging 10 winters in the Picontrol simulation using a Monte Carlo procedure. Poulain et al., in prep.

As a funded activity for LABEX WP2 scientific animation, Alan Robock visit (two weeks, 13-24 April 2015), was the opportunity for IPSL researcher working on decadal climate variability and volcanic forcing processes to beneficiate from his expertise. Besides giving an IPSL seminar, several workshops were organized during his stay with IPSL oceanographers (LOCEAN team), specialist of aerosol microphysics (from LMD and LATMOS) and paleo-climate proxies (LSCE team). As far I as know, this contributed to orient some model developments and foster collaborations (i.e. the aerosol microphysical model improved and used within this LABEX project is now being implemented in LMDz, O. Boucher and S. Bekki; a common experiment within DCPP and VOLMIP was defined). And finally this allowed several co-authored papers (see publications list).

Current activities

We aim now to contribute to the on-going effort to reduce the large uncertainties regarding the climatic responses to volcanic eruptions in climate models. Challenging the IPCC's high confidence on volcanic forcing estimates (see Table 8.5 in Myhre et al. 2013), climate model results show some gaps in our understanding of the climate's response to volcanic eruptions. For example the largest uncertainties in the estimates of radiative forcing **from historical simulations** performed using state-of-the-art climate models occur during periods of volcanic activity (Santer et al. 2014). Climate models generally **do not produce robust dynamical responses to volcanic eruptions** (e.g. Driscoll et al. 2012; Ding et al. 2014 for the AO/NAO); **tend to overestimate the observed post-eruption global surface cooling** (Marotzke and Forster 2015); **overlook the effects of small stratospheric volcanic eruptions** over the recent decades (Ridley et al, 2014) **and until LABEX-IPSL contribution**, simulated evolutions around large volcanic events often disagree with corresponding reconstructed temperature changes for the last millennium (e.g. Mann et al. 2012; Anchukaitis et al. 2012). **The continuing development of more accurate histories of past eruptions, more realistic volcanic forcing and climate responses to which LABEX-IPSL has significantly contributed** (e.g. Stoffel et al. 2015; Poulain et al, to be submitted; Zanchettin et al., in press) promise to improve climate model simulations of past and future volcanic events.

It is also **necessary to frame the modeling activities within CMIP6 standardized coupled model experiments** designed to systematically tackle specific uncertainty factors. The starting Model Intercomparison Project on the climatic response to Volcanic forcing (**VolMIP,** Co-chairs: D. Zanchettin, C. Timmreck and M. Khodri; http://volmip.org/) has defined a common protocol to subject coupled climate models to the same volcanic forcing, thus aiming for negligible across-model differences in the applied radiative forcing **in order to focus on the climate response** (cf. Figure 4). The coordinated experiments will assess the causes of across-model spread (in temperature and main mode of climate variability NAO/ENSO/AMO/AMOC responses) linked to the different treatment of physical processes, and separate such model uncertainties from uncertainties in the forcing and internal variability.

In this context IPSL is a lead coordinator for several experiments and as a first step, is currently in charge of selecting consensus volcanic forcing input data for VOLMIP Tier-1 experiment. Several modelling centres are currently performing a Tambora-like experiment based on our recently published one (Stofell et al, 2015). We are currently coordinating the assessment of radiative forcing uncertainties across committed modelling group experiments (11 modelling groups). The experimental protocol is available here. The assessment is a preliminary step towards selection of a single, consensus forcing data set for the experiment.

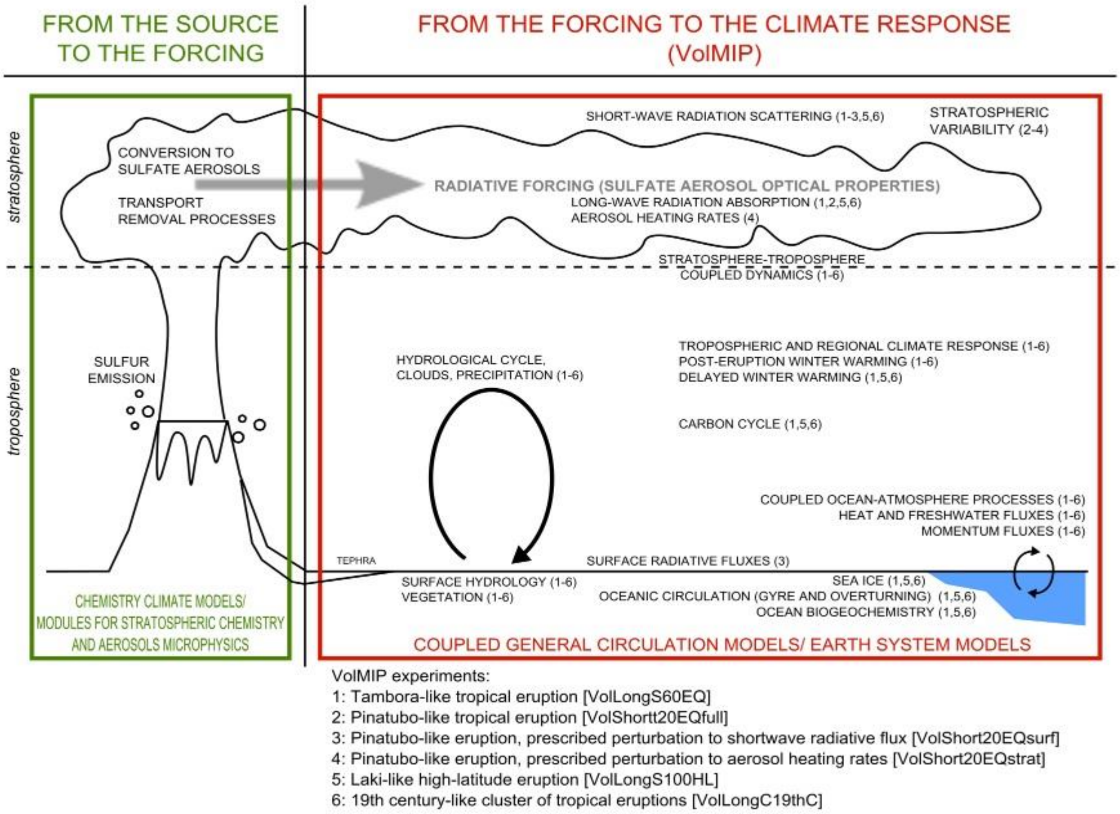

Figure 4: Dominant processes illustrating the link between volcanic eruptions and climate responses, with an overview of VolMIP's experiments as officially endorsed by the World Climate Research Program for CMIP endorsement (1-4: mandatory; 5,6: non-mandatory).

In that context, building upon our first results a reconstruction of a volcanic forcing dataset for the whole two millennia is planned for 2016 (V. Poulain extended post-doc) and will be used in the IPSL CMIP6 Past2K experiment. Other modelling groups have also shown interest for such reconstruction, as there is so far no volcanic forcing dataset available to the community for CMIP6.

<u>Publications:</u>

- Stoffel M., Khodri M, Corona C., Guillet S., Poulain V., Bekki S., Guiot J., Luckman B.H., Oppenheimer, C. Lebas N., Beniston N. and V. Masson-Delmotte, *Estimates of volcanic-induced cooling in the Northern Hemisphere over the past 1,500 years*, Nature Geoscience, *published online: 31 August 2015*, DOI: 10.1038/NGEO2526
- Zanchettin D., Timmreck C., Khodri M., Robock A., Rubino A., Schmidt A., and M. Toohey, *A coordinated modeling assessment of the climate response to volcanic forcing*, PAGES/IGBP Newletters special issue "Volcanoes and Climate", in press.
- Poulain V., Khodri M., Bekki S., and M. Marchand, *Simulating the climate responses induced by large volcanic eruptions using a global aerosol model*. *To be submitted*.
- Poulain V., Khodri M., Abalos M., Marchand M. and S. Bekki, *Winter polar vortex and surface temperature response to tropical volcanic eruptions*. *In prep*.
- Khodri M., Izumo K., J. Viallard, C. Cassou, Mignot J., E. Guilyardi, Matthieu Lengaigne, Nicolas Lebas and Alan Robock, *El Niño–Southern Oscillation response to tropical stratospheric volcanism*. *In prep*
- Zanchettin D., Khodri M., Timmreck C. et al, *The Model Intercomparison Project on the climatic response to Volcanic forcing (VolMIP): experimental design and forcing input data*. *In prep for GMD-CMIP6 special issue*.

<u>Invited talks to workshop and solicited contribution to conference:</u>

- Khodri M.: Invited talk to the workshop "*High-latitude volcanic eruptions and climate: filling the gaps* », 5th-7th November, 2014, Stockholm University (Sweden).
- Khodri M.: Contribution (talk) to the *Bicentenary of the great Tambora eruption Conference*, Bern, 7 – 10 April 2015.
- Khodri M.: Solicited contribution (invited talk) to the 26th IUGG 2015 General Assembly on « *Weather and Climate Effects of Volcanic Eruptions* », Conveners: Anja Schmidt, Alan Robock, Jim Haywood. Prague, Czech Republic, June 22 to July 2 2015
- Poulain V.: Participation to the workshop "High-latitude volcanic eruptions and climate: filling the gaps », 5th-7th November, 2014, Stockholm University (Sweden).
- Poulain V.: Poster presentation to the to the *Bicentenary of the great Tambora eruption Conference*, Bern, 7 – 10 April 2015.
- Poulain V.: Poster presentation to the 26th IUGG 2015 General Assembly on « *Weather and Climate Effects of Volcanic Eruptions* », Conveners: Anja Schmidt, Alan Robock, Jim Haywood. Prague, Czech Republic, June 22 to July 2 2015

<u>Related international Project endorsed by WCRP Grand Challenges</u>:

- VolMIP CMIP6-Endorsed MIP. Co-chairs: D. Zanchettin C. Timmreck and M. Khodri. SSC: G. Hegerl, A. Robock, A. Schmidt, M. Toohey and E. Gerber.