Project: **1093**

Project title: **Revisiting the volcanic impact on atmosphere and climate – preparations for the next big volcanic eruption (VolImpact)**

Principal investigator: **Christian von Savigny**

Report period: **2020-01-01 to 2020-12-31**

Short summaries of the contributions from the different VolImpact projects are listed below[1].

**VolPlume contributions**

To simulate the microphysical evolution of the eruption plume, the ICON equation system is extended in a manner that the model is capable of simulating multiphase density flows. To test these implementations, idealized 2D simulations have been performed with ICON-ART, which show an ash bubble in a completely dry environment that falls down due to higher density compared to dry air. This first step represents a simplified multiphase density flow and approves the scientific and technical aspects of our approach. For the chemical evolution of the plume, ICON-ART is coupled with the 1D-plume rise model FPlume to better represent the effects of eruption source parameters on plume dynamics. With this new set-up the ash and $SO_2$ plumes from the Raikoke eruption, June 2016, are simulated. The comparison of the first results with satellite observation shows a very good agreement. These developments provide the basis for the high-resolution simulations with ICON-ART (up to 300 m) that are planned for 2021.

**VolArc contributions**

Within VolARC we performed several simulations of the evolution of a volcanic cloud with MAECHAM5-HAM in two projects: A comparison to OMPS satellite data of the volcanic cloud after the Ambae 2019 eruption (Malinina et al., 2020), and a study of the historic Northern midlatitude Laacher See eruption (Niemeier et al., 2020). The study of Malinina et al. (2020) showed very nicely that the model, used with nudged meteorology, reproduced the observed volcanic cloud very well.
Global aerosol simulations of a Laacher See (53 N) type eruption indicated that the volcanic ash induced heating plays a crucial role for the transport of ash and sulfate. Depending on the altitude of the injection, the volcanic cloud begins to rotate one to three days after the eruption. The rotation changes the transport patterns of ash and sulfur shortly after the eruption. This adds a southerly component to the transport vectors and causes sulfate to be transported stronger towards low-latitudes, resulting in longer sulfate lifetime and increased radiative forcing. Thus, the impact of fine ash is important for extra-tropical eruptions.

**VolCloud contributions**

In the reporting period, further in-depth studies of the Holuhraun fissure eruption were conducted that has proven useful to analyse aerosol-cloud interactions (Malavelle et al., 2017). In the ICON-NWP model (Zängl et al., 2015), key improvements of Costa-Surós et al. (2020) were implemented, and here in particular a time-varying cloud condensation nuclei (CCN) concentration distribution derived from the COPERNICUS atmospheric service (CAMS) re-analysis (Bellouin et al., 2020). One of the central developments was to enable the comparison to satellite data. For this, the Cloud Feedback Model Intercomparison Project (CFMIP) Observational Simulator Package (COSP; Bodas-Salcedo et al., 2011) was implemented on-line in the ICON-NWP model. Specifically, the simulator for an apples-to-apples comparison with the MODerate Resolution Imaging Spectroradiometer (MODIS; Platnick et al., 2017) cloud products was applied (Pincus et al., 2012). A full-week integration was conducted and showed a remarkable match in terms of the synoptic situation, even if model improvements are necessary for a full match of the retrieved cloud properties. The works to allow for an apples-to-apples comparison to MODIS data required more time than anticipated. Further, a number of model improvements (following Kretzschmar et al., 2020) were implemented and tested in comparison to the satellite data. In consequence, we did continue to work on the Holuhraun eruption. This will further be worked on in 2021 with an ensemble of month-long integrations. This increased length proved necessary in the comparison to satellite data as else a too noisy signal is obtained in the

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[1] Common results are listed under the project of the 1st author

data. As the next step, the Ejyafjallajökull studies will be started.

**VolDyn contributions**

Mesospheric response to large volcanic eruptions: The UA-ICON model was used to simulate the dynamic response of the lower and middle atmosphere to an explosive volcanic eruption. It was combined with the EVA aerosol module that injected 20 Tg S into the lower stratosphere. The simulation produced dynamic variables needed for a Transformed Eulerian Mean diagnostics as a 3-hour output as well as a monthly output of additional tendency terms. Ten ensemble members spanning three years after the eruption were generated and compared to a non-volcanic reference run. The comparison shows a clear circulation response up to the lower thermosphere.

The Arctic polar vortex response to eruptions of different strengths: We have analyzed large ensemble simulations of the climate response to tropical volcanic eruptions of different strengths to answer the question how linear the polar vortex response to volcanic eruptions is (Azoulay et al., submitted, 2020). Indeed we can show that there seems to be a threshold for the polar vortex response. The vortex response in simulations for an eruption strength of 2.5 Tg sulfur is indistinguishable from zero and significantly different from the response to larger eruptions (see Fig. 1).

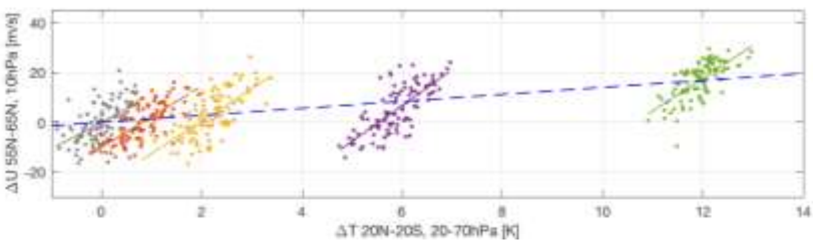


Fig. 1: Scatter plot of simulated polar vortex zonal mean zonal wind anomalies versus tropical temperature anomalies averaged over altitude and latitude ranges indicated at the axes for the first winter (DJF) after the volcanic eruptions. Dots mark all individual eruptions of the ensembles for injections of 0 (gray), 2.5 (red), 5 (yellow), 10 (purple), and 20 (green) Tg(S). Anomalies are calculated with respect to the ensemble mean of the 0 Tg(S) simulations. The blue dashed line is the result from a linear regression, taking into account all anomalies from all ensembles, solid lines are results from regressions for the ensembles for individual injection strengths.

**VolClim contributions**

The ICON-ESM simulations that were originally planned for 2020 have to be postponed to 2021 as the model has only recently be finished. Instead, we have performed VolMIP Pinatubo runs (Zanchettin et al., 2016) with the MPI-ESM1.2 (Mauritsen et al., 2019) in two resolutions (LR/HR) to assess the impact of model resolution on the climate response to volcanic forcing. Analysis is currently ongoing. We have also analyzed the impact of tropical idealized volcanic eruptions of different eruption strengths on the hydrological cycle using a 100-member ensemble of the MPI-ESM-LR (Azoulay et al., submitted, 2020). Volcanic eruptions lead to a tropical reduction although due to a shift in the ITCZ some regions get wetter in the aftermath after an eruption. Significant increases in stratospheric water vapor were found for the mean over all ensemble member from an emission strength of 2.5 Tg S onward and for single ensemble members starting from an emission strength 20 Tg S (Fig. 2). We could also show that not only the eruption volume but also the aerosol layer shape and location with respect to the cold point have to be considered for post eruption stratospheric water vapor increases (Kroll et al., to be submitted 2020).

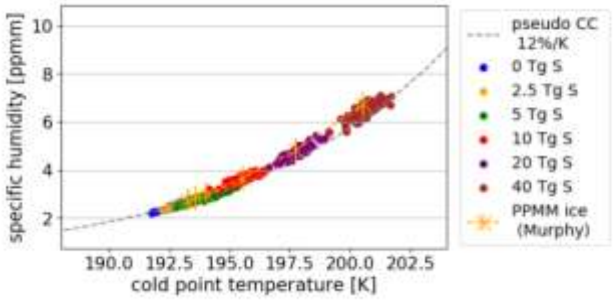


Figure 2: Stratospheric water vapour as a function of cold point temperature for the inner tropical region ([-5,5]°N) in SON 1991. The tropical mean for each ensemble member is denoted with a point to show the ensemble spread. An approximation of the Clausius Clapeyron equation is plotted in dashed grey lines, the exact solution as calculated for the ensemble mean cold point temperature is shown in orange. TG S indicate the different eruption strengths (Kroll et al., to be submitted 2020)

**References**


Azoulay, A. , H. Schmidt, C. Timmreck et al., The Arctic polar vortex response to volcanic forcing of different strength, submitted to J. Geophys. Res., 2020.

Bellouin, N., W. H. Davies, K. P. Shine, J. Quaas, J. Mülmenstädt, P. M. Forster, C. Smith, L. Lee, L. Regayre, G. Brasseur, N. Sudarchikova, I. Bouarar, O. Boucher, and G. Myhre, Radiative forcing of climate change from the Copernicus reanalysis of atmospheric composition, Earth Syst. Sci. Data, 12, 1649 – 1677, doi:10.5194/essd-12-1649-2020, 2020.

Bodas-Salcedo, A., et al., COSP: Satellite simulation software for model assessment. Bull. Amer. Meteor. Soc., 92, 1023 – 1043, https://doi.org/10.1175/2011BAMS2856.1, 2011.

Costa-Surós, M., O. Sourdeval, C. Acquistapace, H. Baars, C. C. Henken, C. Genz, J. Hesemann, C. Jimenez, M. König, J. Kretzschmar, N. Madenach, C. I. Meyer, R. Schrödner, P. Seifert, F. Senf, M. Brueck, G. Cioni, J. F. Engels, K. Fieg, K. Gorges, R. Heinze, P. K. Siligam, U. Burkhardt, S. Crewell, C. Hoose, A. Seifert, I. Tegen, and J. Quaas, Detection and attribution of aerosol-cloud interactions in large-domain large-eddy simulations with the ICOsahedral Non-hydrostatic model, Atmos. Chem. Phys., 20, 5657 – 5678, doi:10.5194/acp-20-5657-2020, 2020.

Kretzschmar, J., J. Stapf, D. Klocke, M. Wendisch, and J. Quaas, Employing airborne radiation and cloud microphysics observations to improve cloud representation in ICON at kilometer-scale resolution in the Arctic, Atmos. Chem. Phys., in press, doi:10.5194/acp-2020-641, 2020.

Kroll, C., S. Dacie, A. Azoulay, H. Schmidt, and C. Timmreck, The Impact of Volcanic Eruptions of Different Magnitude on Stratospheric Water Vapour, to be submitted to Atmos. Chem. Phys., 2020.

Malavelle, F. F., J. M. Haywood, A. Jones, A. Gettelman, L. Clarisse, S. Bauduin, R. P. et al., Strong constraints on aerosol–cloud interactions from volcanic eruptions, Nature, 546, 485 – 491, 10.1038/nature22974, 2017.

Malinina, E., Rozanov, A., Niemeier, U., Peglow, S., Arosio, C., Wrana, F., Timmreck, C., von Savigny, C., Burrows, J.P., Changes in stratospheric aerosol extinction coefficient after the 2018 Ambae eruption as seen by OMPS-LP and ECHAM5-HAM, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-749, 2020

Mauritsen, T., Bader, J., Becker, T., Behrens, J., Bittner, M., Brokopf, R. et al. : Developments in the MPI-M Earth System Model verscion 1.2 (MPI-ESM 1.2) and its response to increasing CO2, Journal of Advances in Modeling Earth Systems, https://doi.org/10.1029/2018MS001400, 2019.

Niemeier, U., Riede, F., Timmreck, C., Simulation of ash clouds after a Laacher See-type eruption, Clim. Past Discuss., doi.org/10.5194/cp-2020-109, 2020

Pincus, R., S. Platnick, S. A. Ackerman, R. S. Hemler, and R. J. Patrick Hofmann, Reconciling Simulated and Observed Views of Clouds: MODIS, ISCCP, and the Limits of Instrument Simulators. J. Climate, 25, 4699 – 4720, https://doi.org/10.1175/JCLI-D-11-00267, 2012.

Platnick, S., et al., The MODIS Cloud Optical and Microphysical Products: Collection 6 Updates and Examples from Terra and Aqua, IEEE Transact. Geosci. Remote Sens., 55, 502 – 525, doi: 10.1109/TGRS.2016.2610522, 2017.

Zängl, G., D. Reinert, M. P. Ripodas, and M. Baldauf, The ICON (ICOsahedral Nonhydrostatic) modelling framework of DWD and MPI-M: Description of the nonhydrostatic dynamical core, Q. J. R. Meteorol. Soc., 141,563 – 579, 10.1002/qj.2378, 2015.