Project: **1093**

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

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Report period: **2020-11-01 to 2021-08-31**

In **VolIMpact** we are developing physical and chemical modules which will be combined into a seamless modelling suite starting with convection-resolving simulations of a volcanic eruption and continuing with a global simulation including several nests with finer grid size, which is still ongoing. Below, we summarize main contributions of the different VolImpact projects[1].

VolPlume contributions

We have coupled the atmospheric model system ICON-ART (ICOsahedral Nonhydrostatic – Aerosols and Reactive Trace gases) with the 1-D plume model FPlume to calculate the eruption source parameters (ESPs) online. This is necessary to resolve complex eruption dynamics and its impacts on volcanic plume dispersion. The main inputs are the plume heights for the different eruption phases that are geometrically derived from satellite data. We tested these developments for the 2019 Raikoke (Kuril Islands) eruption, which was characterized by several eruption phases. We carefully compared the simulations with different satellite observations. The results confirm that coupling the atmospheric model system and plume model enables detailed treatment of the plume dynamics (phases and ESPs) and leads to significant improvement of the ash and SO_2 dispersion forecast. This approach can benefit the operational forecast of ash and SO_2 especially in case of complex and multi-phase volcanic eruptions like the one of Raikoke 2019 (Bruckert et al., 2021).

VolCloud contributions

In the reporting period, the works on assessing the cloud response to volcanic aerosol, using the example of the 2014 Holuhraun (Iceland) eruption, have been continued. After several sensitivity studies and model calibrations and extensions (e.g. now applying the MODIS simulator, and a plume definition based on satellite SO_2 retrievals) now meaningful and publishable results have been obtained. The results of the detection and attribution of the aerosol impact on clouds is shown in Fig. 1. Thanks to the comparison between in-plume and out-of-plume (environment) statistics of cloud properties and the comparison between the perturbed and control simulation, it is possible to clearly detect and attribute a signal in Number density (Nd) in the observations, but also a signal in LWP. These results will be published now, and also feed into international collaboration with colleagues in the UK and Norway.

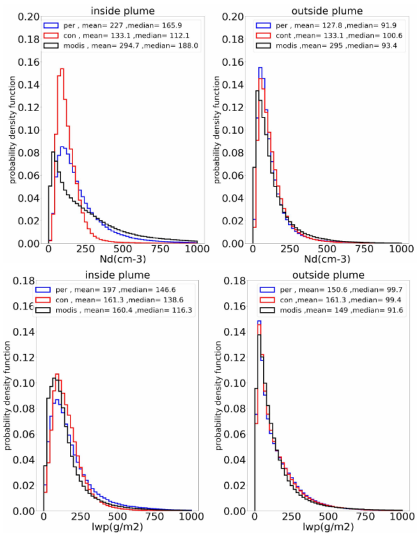

Figure 1

VolARC contributions

Dated to ca. 13,000 years ago, the Laacher See (53°N) eruption was one of the largest mid-latitude Northern Hemisphere volcanic events of the Late Pleistocene. We have simulated the evolution of its fine ash and sulfur cloud such that it reflects the empirically known ash distribution (Niemeier et al., 2021). In our models, the heating of the ash causes a mesocyclone which changes the dispersion of the cloud itself. The rotation adds a southerly component to the transport vectors with the consequence of stronger transport to low-latitudes, and increased sulfate lifetime, burden, and radiative forcing. Further, we compared the aerosol plume evolution observed by OMPS-LP and simulated with MAECHAM5-HAM after the two main eruptions of Ambae in July 2018 (Malinina et al., 2020). We varied the vertical injection area and the injected

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

mass in ECHAM, using several estimates from OMI/OMPS-NP and TROPOMI as constraints. Both changed the aerosol microphysical processes and consequently, the simulated tropical burden maximum and radiative forcing, which varied roughly by a factor of two between the experiments. Thus, improving the estimates of the volcanic injection rate from satellite products, together with model changes, clearly improved the agreement between model and observations.

VolDyn contributions

The impact of a strong tropical volcanic eruption on the middle atmosphere was simulated by the UA-ICON model. The EVA model was used to generate an idealized aerosol distribution for an assumed injection of 20 Tg S into the lower tropical stratosphere. Two experiments were performed covering 27 months after the eruption. Each experiment consists of a perturbed and an unperturbed 10 member ensemble The two experiments differ by settings of the gravity wave parameterization resulting in relatively different states of the climatological stratospheric circulation and very different circulation responses to the volcanic aerosol. Only one of the ensembles shows a notable significant anomalous cooling of the lower polar winter stratosphere in the first and second boreal post-volcanic winter together with a strengthening of the polar vortex at 60°N and 1000 Pa (see Figure 2). A similar phenomenon appeared in the Southern Hemisphere. These very different stratospheric responses also have very different consequences for the mesospheric circulation.

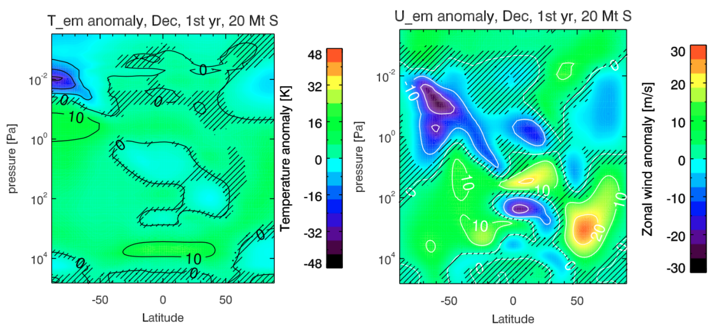

***Figure 2:** Ensemble mean temperature and zonal wind anomalies from UA-ICON simulations for a strong tropical eruption (injection of 20 Tg S) show an anomalously cool lower polar winter stratosphere and a strengthening of the polar vortex (60°N, 1000 Pa) in December of the eruption year. This phenomenon appears in the first two boreal post-volcanic winters and is also visible in the Southern Hemisphere.*

VolClim contributions

The longwave and near IR heating through volcanic aerosols in the tropical tropopause layer (TTL) perturbs the transition space between radiative-dynamical and radiative-convective-dynamical controlled atmospheric regions. We have investigated the impact of these changes on overshooting convection, ice entry into the stratosphere and analyzed the stratospheric water vapour budget. Employing ICON-A in convection resolving resolution (R2B8, ~10 km), experiments were conducted for a volcanic eruption of 20 Tg S with and without surface cooling and a control simulation. Additionally, the sensitivity of the changes in stratospheric ice to varying relative importance of dynamical and diffusion effects is investigated by changing the diffusion length in three experiments (diffusion length of 1000 m, 150 m and 23 m) for the volcanically perturbed and unperturbed scenario making 6 experiments and 16 months of simulation in total. We find a strong dependency of the total stratospheric ice content above the tropopause on the vertical diffusion (Figure 3), but the relative increase of tropical (25S-25N) stratospheric ice with reduced vertical diffusion length in a volcanic perturbed simulation (+ 50 %) is comparable to runs with a larger diffusion length (+ 57 %).

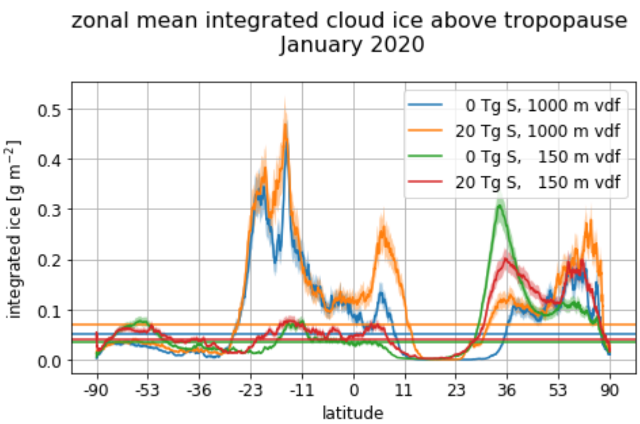

Figure 3: Zonal mean of integrated cloud ice above the WMO defined tropopause for the mean of thirty January 1st. The results for the volcanically perturbed (20 Tg S) and unperturbed simulations (0 Tg S) are shown for the experiments with maximal vertical diffusion length of 1000 m (1000 m vdf) and 150 m (150 m vdf). The horizontal line indicates the

global mean integrated ice above the tropopause.

References

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