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: **2022-11-01 to 2023-10-31**

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. Below, we summarize main contributions of the different subprojects[1].

VolPlume contributions

We performed high resolution simulations with ICON-ART in a LAM setup (2.5 km) for the 2019 Raikoke eruption to study gas-aerosols partitioning. Therefore, we assumed aerosol dynamics and a complex chemistry mechanism including not only the gas phase but also heterogeneous chemistry on aerosols. The main findings are that aqueous phase chemistry on aged aerosols is negligible in this case, but SO_2 adsorption on fresh ash particles leads to a faster aging of ash (Bruckert, 2023). Furthermore, we investigated the dispersion of the plume after the 2022 Hunga Tonga - Hunga Ha'apai (HTHH) eruption in ICON-ART with R3B07 and three nests. As reliable ash mass observations are not available until today, we constrained the value for the mass eruption rate (MER) with 1-D plume modeling and ran simulations with different MER in ICON-ART to study the evolution of ash after the HTHH.

VolARC contributions

The eruption of the HTHH volcano on January 15, 2022 injected an exceptionally large amount of water vapor (H_2O) into the middle atmosphere. Simulations of the spatial evolution of the HTHH H_2O cloud with the ICON-Seamless model are very close to observations from the Aura Microwave Limb Sounder. ICON-Seamless was used in the AMIP mode. The model was specially tuned for the R2B4 horizontal resolution in cooperation with the DWD. The vertical resolution was set to 130 levels to get a good representation of stratospheric dynamics. Passive tracers were added to the simulation to determine the role of the water vapor for transport in more detail. Radiative cooling of H_2O clearly affects the transport of the H_2O cloud, as demonstrated with passive tracers, and is the main driver within the subsidence phase. It also counteracts the large-scale rising motion in the tropics, leading to a stable phase, and modulates the large-scale transport of the H_2O cloud for about nine months. This holds for different QBO phases, where the H_2O cloud differs mainly in its vertical extent (Niemeier et al., submitted).

VolCloud contributions

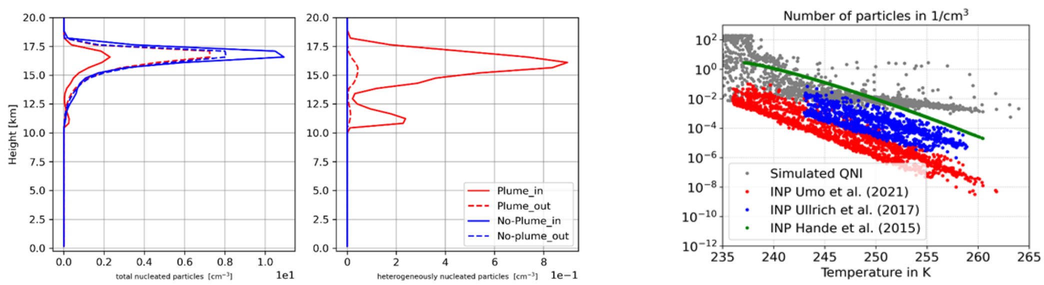

Figure 1: Vertical profile of the total nucleated particles (left), and the heterogeneously nucleated particles (middle) in the Plume (red) and in the No-plume (blue) simulations. Solid lines illustrate these variables inside the plume (everywhere mass (ash+Sulfate)>1e-4 kg/kg), and dashed lines show them outside of the plume (everywhere mass (ash+Sulfate)>1e-4 kg/kg). These variables were averaged over the time and the horizontal domain. Calculated number of ice nucleating particles for different parameterizations compared to simulated results (right).

In the reporting period, we conducted the requested additional simulations for the La Soufrière and the Kilauea volcanic eruptions. The important result was that the droplet number concentration perturbation was not as straightforward to detect and attribute as for the Holuhraun eruption (Haghighatnasab et al., 2022). Further, a range of sensitivity studies for the Holuhraun eruption was performed to identify the exact causes for the lack of cloud liquid water path response to the volcanic aerosol. Specifically, the resolution dependence was evaluated, by simulations down to 625 m (R2B12), and by changes to the autoconversion efficiency. The resolution did not show a strong impact on the results. For the changes in autoconversion, it was found that at slow cloud-to-rain conversion rates, clouds needed to be much thicker to respond positively to the volcanic aerosol in terms of cloud liquid water path (and the inverse for fast conversion rates). The results are part of the PhD thesis which was submitted in July 2023 (Haghighatnasab, 2023). In this project, we have also simulated the 5 days following the 2021 La Soufrière eruption using the ICON-ART model to study the cloud response to this eruption. We then analyzed the results of different sensitivity runs. In our studies, we conducted two different simulations, in one of which the volcanic emission is considered, while in the other one, it is not (Plume and No-plume simulations). The results showed well the effect of volcanic aerosols on the heterogeneous ice nucleation in the Plume simulation. Figure 1 illustrates the vertical profile of the heterogeneously nucleated particles and the total nucleated particles. It shows that although ash particles caused an enhancement of the heterogeneously

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

nucleated particles, the total nucleated particles decreased because of the suppression of the homogeneous nucleation in the presence of the heterogeneous ice nucleation. As a second case study with strong interactions between ash and sulfate aerosols, we started simulating the eruption of Raikoke 2019 on a global scale using ICON-ART. The results for cloud coverage and aerosol distribution in the following 3 days after the eruption have been compared to satellite images as a first validation of the setup. Additionally, some first comparisons of the ice nucleating efficiency of volcanic ash with data obtained in laboratory experiments by Umo et al. (2021) have been made that show the expected number of ice nucleating particles for different parameterizations used in the model (Figure 1).

VolDyn contributions

The large amount of water vapor emitted by the 2022 HTHH eruption began to rise in October 2022 between 20°S – 10°S and reached the tropical stratopause in March 2023. This observation motivated us to run ICON in an upper atmosphere version (UA-ICON) to estimate if the additional water vapor could reach the polar summer mesopause region (80-85 km altitude). Therefore, we performed two reference runs including at least 22 months as well as two volcanic ensemble members with a strong H_2O perturbation (10 times the amount estimated for the HTHH eruption). We chose such a strong signal in order to simulate a clear H_2O-induced temperature anomaly due to radiative cooling, as this should have an important influence on the middle atmospheric circulation. The simulations allowed us to derive information on the dynamical mechanisms driving the H_2O transport, although for the tropics the simulated H_2O ascends faster than is observed by observation. In the UA-ICON model, the simulated H_2O anomaly reaches the mesopause in May of the second year in the northern hemisphere and in October of the second year in the southern hemisphere, respectively. This study focused on the transport of a large H_2O entry in the mesosphere rather than realistically simulating the HTHH eruption.

VolClim contributions

Historical volcanic eruptions are rare events which differ in their eruption settings (e.g. emission strength, location) and are also often masked by internal variability. To draw robust conclusions about the volcanic climate signal and its emergence from internal variability, we have created large 100-member ensembles of idealized volcanic eruptions (EVA-ENS) within the MPI Grand Ensemble (MPI-GE) historical framework which differ only in their sulfur emission strength and geographical location. With the EVA-ENS, we could show that global and hemispheric mean near-surface temperature and precipitation anomalies scale linearly for different emission strengths if the volcanic forcing pattern is similar. Emergence of cooling occurs on a hemispheric scale, while the precipitation response is more localized, non-uniform and mainly confined to the tropics and subtropics (Timmreck et al., submitted). Because of the clear volcanic fingerprint in our results, we have developed a data driven methodology that is able to classify in reanalysis data and proxy reconstructions whether a volcanic eruption occurred and where it is located based on seasonal mean near-surface temperature anomalies. Figure 2 shows the prediction results of our trained neural network on different reanalysis data. The time period ranges from 1960 to 2000, including 4 significant historic volcanic eruptions. 3 of them (Agung 1963, Fuego 1975, Pinatubo 1991) are well identified by the neural network.

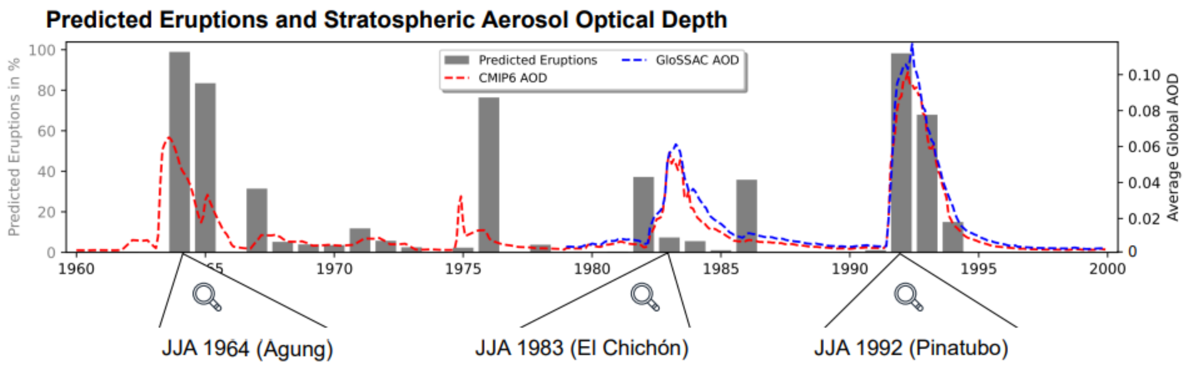

Figure 2: Percentages of predicted eruptions (gray bars) based on global SST anomaly grids from 20CR, 20CR-2c, 20CR-v3, ERA5, JRA55 and UERRA reanalyses next to global AODs from CMIP6 and the GloSSAC data set.

References

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