Project: **1093**

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

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The major goal of **VolIMpac**t is to improve the scientific understanding of the volcanic influence on atmosphere and climate (von Savigny et al., 2020). It is divided into five individual science projects. Below, we summarize the main contributions of the different subprojects over the last year.

VolPlume contributions

We investigated the water-rich Hunga eruption (Jan 2022) using ICON-ART. Large-eddy simulations (LES, R2B12 grid) with a surface water vapor source showed convection driving the plume up to 55 km, with plume rise and umbrella spreading agreeing with observations. The simulations also reproduced Lamb and gravity wave generation. To understand rapid ash removal within 1–2 days, we performed global simulations (R2B06 grid), revealing that water vapor emissions accelerated ash aging and particle growth, though not enough to explain the ash loss (Bruckert et al., 2025). We tested various emission scenarios, including sea salt, water uptake, and enhanced coagulation to account for aggregation processes beyond Brownian coagulation. These experiments show water uptake is more efficient with sea salt, but still insufficient to remove ash. Considering enhanced coagulation leads to relatively efficient ash removal. Furthermore, activation of coated ash to hydrometeors and its effect on ash removal via growth is investigated.

Additionally, combining previous work, we developed a setup including volcanic eruptions as a multi-phase multi-component flow, aerosol dynamics, SO_2 adsorption on ash, and aqueous-phase chemistry on aged aerosols in one simulation. We ran the first successful LES simulation of the Eyjafjallajökull 2010 eruption.

VolARC contributions

The quasi-biennial oscillation (QBO), the downward propagation of easterly and westerly jets in the tropical stratosphere, lies at the heart of stratospheric dynamics. In ICON XPP, the representation of these dynamics and the QBO depends on the horizontal and vertical grid resolution. We performed simulations with horizontal grid distances of 160 km (R2B4) and 40 km (R2B6) and vertical levels of 90 and 130. While the model version with 90 vertical levels cannot generate a QBO, a good QBO is generated with 130 vertical levels and a maximum vertical resolution of 500 m in the stratosphere (Müller et al., 2025). However, the higher horizontal resolution does not lead to a better representation of the QBO. Instead, a strong easterly jet develops at an altitude of around 20 km, which blocks the upward-moving westerly waves and dissipates the wave energy. We performed several simulations to determine the origin of this easterly jet, using different tuning variables for the gravity wave drag. We tested the damping vertical diffusion with different damping values and mechanisms. We concluded that advection plays an important role, yet the easterly jet persisted.

VolCloud contributions

In 2025 we performed simulations of the Raikoke eruption 2019 with horizontal resolutions of 5 km and 2.5 km. To analyze the effect of the volcanic aerosols on cloud hydrometeors we performed a reference simulation with emission of seasalt as a background aerosol and compared it to a simulation with volcanic SO2 (reacting to sulfate) and a simulation including volcanic ash. In all simulations aerosol-radiation-interaction is enabled for all aerosols. Seasalt and sulfate act as a cloud condensation nuclei (CCN) and volcanic ash acts as an ice nucleating particle (INP). A comparison of the simulation results show that the emission of volcanic sulfate leads to more but smaller cloud droplets whereas the impact on frozen hydrometeors is negligible. The simulation including the emission of volcanic ash leads to slightly fewer but larger cloud droplets and more but smaller ice particles.

To further investigate these results, online diagnostics of microphysical process rates have been implemented, which show a shift towards more heterogeneous freezing of cloud droplets taking place at higher temperatures and therefore lower altitudes so more cloud droplets are converted to cloud ice.

VolDyn contributions

In 2025, the VolDyn project focused on the transport of simulated water vapour though the middle atmosphere (50 - 100 km altitude). We aimed to study a more idealized tropical volcanic eruptions with water vapour emissions of approximately 150 Tg and used the general circulation chemistry - climate model Hamburg Model of the Neutral and Ionized Atmosphere (HAMMONIA) with a triangular truncation at wavenumber 31 (T31), a model top at 1.7*10 -7 hPa altitude (approx. 250 km) and 119 vertical levels. For the simulation experiments, we increased the specific humidity of a restart file before letting the simulation run freely for up to 3 years. The results were each compared to a non - H_2O reference run. The water vapour transport time to the polar summer mesopause and the amount of the additional mesopause H2O was investigated regarding different injection seasons and heights. HAMMONIA model simulations show that the transport time from the tropics to the polar summer mesopause is approximately 1.5 - 2 years, although small amounts of water vapour were already apparent in this region after 6 months. A higher injection height results in a shorter transport time to the mesopause.

VolClim contributions

We have performed large ensemble simulations for different aerosol size distributions to study the impact of the volcanic forcing structure on Northern Hemisphere (NH) winter warming. We use a tropical NH summer eruption as our reference simulations and consider in the sensitivity experiments only volcanic forcing within or outside of the tropics. We found no significant warming in NH winter over Eurasia without tropical aerosol and no dependence on the width of the tropical aerosol belt. We further analyzed our large ensemble of idealized volcanic eruptions, which differ only in their sulfur emission strength and geographical location, with respect to El Niño Southern Oscillation (ENSO). We found that both the eruption location and strength can lead to distinct ENSO responses, depending on the position of the Intertropical Convergence Zone (Fang et al, 2025).

Accurately estimating uncertainty in climate scenarios typically demands the generation of large ensembles of high-resolution simulations, a process that is computationally expensive and memory intensive. To address this challenge, a machine learning model capable of generating low-resolution ensemble simulations of surface temperatures has been developed (Meuer et al, accepted).

References

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