Project: 1114
Project title: Development and evaluation of cloud glaciation processes in ECHAM-HAMMOZ

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Aerosol-cloud interactions are the main source of uncertainty in current climate models. In particular, the impact of Ice Nucleating Particles (INP) in the climate is poorly understood [1]. Therefore, we looked to improve the parameterization for immersion freezing of mineral dust in the ECHAM-HAM model. We evaluated different freezing schemes against the cloud ice frequency retrieved from satellite instruments. Specifically, we compared the simulated hemispheric and seasonal contrasts in cloud ice frequency against the observations.

We used the COSP simulator to relate the modelled droplet freezing rate to the frequency of ice cloud tops. In this way, we could link the large-scale satellite observations to the different assumptions in the microphysical scheme responsible for cloud glaciation. We used the CALIPSO-GOCCP cloud-phase product and an A-Train product combination as constraints for the model [2].

In the standard parameterization in ECHAM-HAM, the fraction of activated dust aerosols and the Turbulent Kinetic Energy (TKE) may limit the droplet freezing rate. Thus, we evaluated the impact of these limiting factors using simpler formulations for the freezing rate. In the simplest scheme, only the surface concentration of dust aerosol determines the freezing rate. In the standard parameterization, all dust aerosol is assumed to have the freezing efficiency of the dust mineral Montmorillonite. To assess the sensitivity of the model to different minerals, we assumed different efficiencies ranging from low- (e.g., Illite) to high-efficient (e.g., K-feldspar) dust minerals.

The last resources allocation allowed us to more configurations for the different freezing schemes. Using satellite observations as a reference, we could improve key features related to cloud glaciation, such as the hemispheric and seasonal contrast in cloud phase. These experiments yielded a higher understanding of the impacts of INP on climate. Among others, we could estimate the effect of INP on the liquid and ice water path, as well as on the cloud radiative effect (see Fig. 1).

We explored further the effects of INPs on climate, expanding our study from natural INP to anthropogenic INP. These included unintentional, as well as the potential effect of intentionally emitted INP. We are currently working in analyzing this results and pouring them into a new publication.

We successfully published results from our last two allocation periods [3].

During the last allocation period, we run further test simulations focusing on the effects of black carbon as INP. Unfortunately, this yielded negative results that are not publishable.

After the new gained insights on the effects of INP on radiation, we studied the effects of INP concentration on climate and precipitation. We applied the model to assess a series of geoengineering scenarios based on cloud seeding, and are currently producing a manuscript summarizing the results.

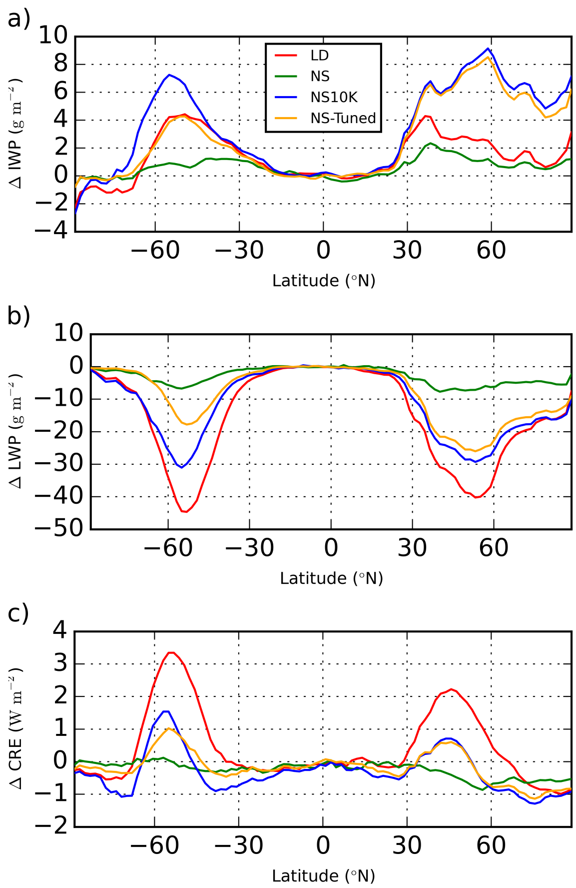

Figure 1: Dust-driven change in: (a) Ice Water Path (IWP) (b) Liquid Water Path (LWP) (c) Cloud Forcing at the Top Of the Atmosphere (TOA; positive values associated to warming). For the runs of the main study in [3]. Nudged simulations for 2003-2012.

References

[1] D. Villanueva, B. Heinold, P. Seifert, H. Deneke, M. Radenz, and I. Tegen. The day-to-day co-variability between mineral dust and cloud glaciation: a proxy for heterogeneous freezing. *Atmospheric Chemistry and Physics*, 20(4):2177–2199, 2020.

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[3] Diego Villanueva, David Neubauer, Blaž Gasparini, Luisa Ickes, and Ina Tegen. Constraining the impact of dust-driven droplet freezing on climate using cloud-top-phase observations. *Geophysical Research Letters*, 48(11), Jun 2021.