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Towards a transfer function for tropospheric volcanic sulfur emissions: The Holuhraun 2014-2015 eruption

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Reconstructions of past volcanic forcing and the associated climate response are currently limited to volcanic stratospheric sulfur injections (VSSI) by explosive eruptions. Transfer functions that link volcanic SO_4 depositions in polar ice cores with VSSI are estimated based on observations and climate modeling. Tropospheric sulfur emissions from effusive and explosive eruptions are climate-relevant, yet historical volcanic sulfur fluxes to the troposphere are poorly quantified before the satellite era. Reconstructing volcanic contributions to tropospheric aerosol concentrations is, however, essential to understanding past, present, and future climate, and to correctly assessing anthropogenic versus natural tropospheric aerosol contributions.

Using the Community Earth System Model with the Community Atmosphere Model set-up (CESM2-CAM6), we simulate SO_2 and SO_4 dispersal and deposition during an effusive volcanic eruption with continuous emissions. The case study is based on the 2014-2015 Holuhraun eruption in Iceland, which released up to 9.6 Tg SO_2 between 31 August 2014 and 27 February 2015. We vary the meteorological conditions during the time of the eruption by performing ten free-running simulations as well as one simulation that is nudged towards MERRA reanalysis winds.

From the modeled SO_4 deposition in Greenland, we calculate transfer functions between deposition and total (prescribed) sulfur emissions for three different domains: the Greenland ice sheet, central Greenland, and the location of the EastGRIP ice coring project. This interpretation of a transfer function differs from that used for explosive stratospheric eruptions, which assumes that all emitted SO_2 is converted into SO_4 before deposition. We find, however, that only about half of the total sulfur deposition is in the form of SO_4 in the simulated scenario, and half as SO_2. Owing to Greenland's proximity to the emission source in Iceland, combined with a deposition region limited to the North Atlantic and adjacent areas, the relative local SO_4 deposition is higher than for previously investigated statospheric eruptions with global deposition. Thus, the resulting transfer function values are lower than in previous studies of stratospheric volcanic sulfur.

The presented tropospheric transfer function provides an approach to reconstructing tropospheric sulfur loading from past volcanic eruptions in the northern extratropics based on local SO_4 signals in Greenland ice.