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Climatic Effects of Hygroscopic Growth of Sulfate Aerosols in the Stratosphere

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Deliberate climate intervention by injection of sulfate aerosols in the stratosphere is a method proposed to counter anthropogenic climate warming. In such an injection scenario, an improved understanding of the microphysical and optical properties of the injected aerosols is important as these properties alter the radiative forcing and resulting climate. Here we analyze the effect of a specific microphysical property of sulfate aerosols in the stratosphere: hygroscopic growth – the tendency of aerosol particles to grow by accumulating water. In the NCAR CESM model, using idealized climate simulations, we find that, for a given mass, stratospheric sulfate aerosols cause more cooling when prescribed at the lower levels of the stratosphere because of increased hygroscopic growth of the aerosols due to larger relative humidity. The relative humidity in the stratosphere typically decreases rapidly with the increasing altitude. The larger relative humidity in the lower stratosphere causes an increase in the aerosol size through hygroscopic growth, which leads to a larger scattering efficiency. The increase in shortwave back-scattering due to the size change is found to be the primary factor contributing to the additional surface cooling as the aerosols are prescribed in the lower levels of the stratosphere. In our simulations, hygroscopic growth provides an additional cooling of 23% (0.7 K) when 20 Mt-SO₄ of sulfate aerosols are prescribed at 100 hPa, relative to a non-hygroscopic simulation where hygroscopic growth is not allowed in the stratosphere. This additional cooling due to hygroscopic effect becomes weaker higher in the stratosphere where relative humidity is lower. Hygroscopic growth also leads to additional warming in the layers where the aerosols are prescribed due to an increase in near-IR shortwave absorption. This warming causes secondary effects such as a decrease in high clouds and an increase in stratospheric water vapor, which affects the effective radiative forcing. This altitude dependence of the cooling effects of hygroscopic growth is opposite to the altitude dependence of sedimentation effects; while the hygroscopic effect produces larger cooling when aerosols reside in the lower stratosphere, the sedimentation effect produces less cooling when aerosols are injected into the lower stratosphere as the residence time becomes shorter.