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Impact of stratospheric volcanic eruption on the climate system under various background conditions

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This study presents the results of numerical modeling of a supervolcanic eruption's impact on the climate system under various background conditions. The eruption in question is comparable in magnitude to the historical Tambora cataclysm of 1815, which significantly influenced global climate. For analysis, the comprehensive chemistry-climate model SOCOL-MPIOM was utilized, allowing for consideration of the interrelationship between chemical and physical processes in the atmosphere. Experiments were conducted for three time periods: contemporary conditions and two future climate scenarios according to SSP2-4.5 and SSP3-7.0 models. The methodological approach was based on quasi-random sampling using Sobol sequences, ensuring optimal exploration of the model's parameter space while minimizing computational costs.

Analysis of the results demonstrates an intensification of the climatic effect of supervolcanic eruptions in the warmer climate projected for the late 21st century. This manifests as a more pronounced global temperature decrease and a significant extension of the recovery period for the climate system compared to present conditions. Such intensification is caused by complex interactions between radiative and dynamic processes in an atmosphere with altered chemical composition.

The ozone layer response to volcanic forcing is characterized by a complex spatial structure with pronounced latitudinal asymmetry. High latitudes exhibit substantial ozone depletion, while tropical regions register increased concentrations. This phenomenon is explained by modifications in atmospheric circulation and transformation of photochemical processes of ozone formation and destruction under the influence of volcanic aerosols and altered temperature regimes.

Among the investigated scenarios, the most intense analog of the historical "year without summer" is projected under the SSP3-7.0 scenario. This phenomenon is likely attributable to elevated concentrations of methane and nitrogen oxides characteristic of this scenario, which significantly influence photochemical processes in the atmosphere and enhance the radiative effect of volcanic aerosols.

Future climate scenarios reveal a more complex vertical structure of temperature anomalies with a pronounced contrast between stratospheric warming and tropospheric cooling. This feature indicates intensified interactions between dynamic and photochemical processes in an atmosphere with modified chemical composition. Disruption of stratosphere-troposphere exchange leads to climatic consequences affecting a wide spectrum of atmospheric phenomena.

Recovery periods for the ozone layer significantly exceed the timescales of temperature relaxation, evidencing substantial impacts of volcanic forcing on atmospheric chemical composition. This fact underscores the critical importance of accounting for chemical feedbacks when comprehensively assessing the climatic consequences of supervolcanic eruptions. Disregarding this aspect could lead to substantial underestimation of the long-term effects of volcanic activity on the global climate system.

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