Flood Basalt Volcanic Climate Disruptions: Dynamical and Radiative Feedbacks on SO_2 Emissions

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Abstract

Volcanic flood basalt eruptions have covered 1000s of km^2 with basalt deposits up to kilometers thick. The massive size and extended duration result in enormous releases of climactically-relevant gases such as SO_2 and CO_2. However, it is still unknown precisely how flood basalt eruptions influence climate via eruption rates and cadence, height of the volcanic plumes, and relative degassing abundance of species like SO_2. Once eruptions occur, the complex interplay of photochemistry, greenhouse gas warming, changes to the atmospheric circulation, and aerosol-cloud interactions can only be properly simulated with a comprehensive global climate model (GCM). We created an eruption scenario for the Goddard Chemistry Climate Model (GEOSCCM) that emits SO_2 in the near-surface atmosphere constantly and four times per year an explosive eruption that emits much more SO_2 in the upper troposphere/lower stratosphere. The eruption lasts for 4 years and emits 30 Gt of SO_2 total. This corresponds to ~1/10th of what may have been emitted during the Wapshilla Ridge eruption phase of the Columbia River flood basalt eruption 15-17 Ma. We use a pre-industrial atmosphere and otherwise modern initial and boundary conditions. The massive flux of SO_2 into the atmosphere is quickly converted to H_2SO_4 aerosols. Global area-weighted mean visible band sulfate aerosol optical depth reaches 220 near the end of the eruption, comparable to cumulonimbus clouds. This reduces the surface shortwave radiative flux by 85% and top-of-atmosphere outgoing longwave flux by 70%. Contrary to our expectations, we find that the climate warms during and immediately following the eruption after a very brief initial cooling. Global mean surface temperature peaks 3-4 years after the eruption ends with a +6 K anomaly relative to a baseline simulation without the eruption. Post-eruption regional temperatures, particularly near-equatorial continental areas, see drastic rises of summertime temperatures with monthly mean temperatures equaling or exceeding 40°C. These temperature responses are radiative- and circulation-driven. The eruption warms and raises the tropical tropopause, allowing a massive flux of water vapor into the stratosphere. Stratospheric water vapor, usually ~3 parts per million reaches 1-2 parts per thousand.

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Flood Basalt Volcanic Climate Disruptions: Dynamical and Radiative Feedbacks on SO_2 Emissions

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Volcanic flood basalt eruptions in Earth's history have covered thousands of square kilometers with basalt deposits up to kilometers thick. The massive size and extended duration (up to centuries or millennia) result in enormous releases of climactically-relevant gas species such as SO_2 and CO_2. However, what is still unknown is precisely how flood basalt eruptions influence planetary climate via their eruption rates and cadence, height of the volcanic plumes, and relative degassing abundance of climactically-relevant species like SO_2. Once eruptions occur, the complex interplay of photochemistry (e.g., turning SO_2 into H_2SO_4 aerosols), greenhouse gas warming, changes to the atmospheric circulation, and aerosol-cloud interactions can only be properly simulated with a comprehensive global climate model (GCM).

We created an eruption scenario for the Goddard Chemistry Climate Model (GEOSCCM) that emits SO_2 in the near-surface atmosphere constantly and periodically (four times per year) an explosive eruption that emits much more SO_2 in the upper troposphere/lower stratosphere. The eruption lasts for 4 years and emits 30 Gt of SO_2 in total. This corresponds to approximately $1/10^{th}$ of what may have been emitted during the Grande Ronde eruption phase of the Columbia River flood basalt eruption in the mid-Miocene 15-17 Ma. We use a pre-industrial atmosphere and otherwise modern initial and boundary conditions.

The massive flux of SO_2 into the atmosphere is quickly converted to H_2SO_4 aerosols. Global area-weighted mean visible band sulfate aerosol optical depth reaches 230 near the end of the eruption, comparable to cumulonimbus clouds. This reduces the surface shortwave radiative flux by 85% and top-of-atmosphere outgoing longwave flux by 70%. Contrary to our expectations, we find that the climate *warms* during and immediately following the eruption after a very brief initial cooling. Global mean surface temperature peaks 3-4 years after the eruption ends with a +6 K anomaly relative to a baseline simulation without the eruption. Post-eruption regional temperatures, particularly near-equatorial continental areas, see drastic rises of summertime temperatures with monthly mean temperatures equaling or exceeding 40°C. These temperature responses are radiative- and circulation-driven. The eruption warms and raises the tropical tropopause, allowing a massive flux of water vapor into the stratosphere. Stratospheric water vapor, usually ~3 parts per million reaches 1-2 parts per thousand.