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Simulation of Climatic Response to Supervolcano Eruption using MRI-CGCM3

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1. Introduction

Eruptions of large volcanoes inject sulfur dioxide (SO_2) gases into the stratosphere, which leads to increases of sulfate aerosol loading, and decrease of solar radiation that reaches the ground surface. The lifetime of sulfate aerosol can be as long as several years, which might bring significant impact on Earth's climate. Current climate change experiments such as the Coupled Model Intercomparison Project Phase 5 (CMIP5) include the effects of aerosols, but few models treat the volcanic aerosols interactively.

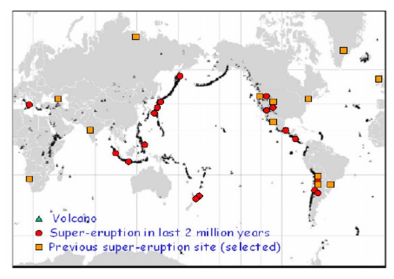
The coupled climate model MRI-CGCM3 (Yukimoto et al., 2011; 2012), which is developed and used in the Meteorological Research Institute of Japan Meteorological Agency, includes a global aerosol model and directly treats the effects of volcanic sulfate aerosols to evaluate their effects. In this study, we investigated the climatic response to the virtual super-volcano eruption using our global climate model MRI-CGCM3 in order to evaluate the capability of the climate model to reproduce the cooling effect of the volcanic sulfate aerosol.

Volken

2. Supervolcano

A supervolcano is a volcano capable of eruption that producing ejecta amounts more than 10^{15} kg (150 times the 1991 Pinatubo volcano, VEI 8 or more). Historically, although the frequency is as low as once in several hundreds of thousands years, supervolcanoes such as the Yellowstone of the United States and Indonesia's Toba volcano erupted with ejecta of several hundred to several thousand tons. Mt. Toba is considered to have catastrophically erupted with 2800 km^3 about 74000 years ago. The cooling effects by the aerosols bring long-lasting "volcanic winter" and the population of total human beings that inhabited in Africa might be reduced to several thousand. Although the huge volcanic eruption is a very low-frequency events, it may bring enormous impact to the environment.

Lake Toba, after the eruption of the Toba supereruption. The size of the Caldera is about 35 x 100 km. (Photo: Smithsonian's Global Volcanism Program)

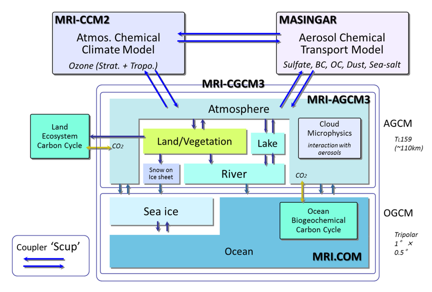


Distribution of the known supervolcanoes (Mason *et al.*, 2004)

3. Model description

In this study, we used the climate model MRI-CGCM3 (Yukimoto et al., 2012). The model consists of an atmospheric general circulation model MRI-AGCM3, an ocean general circulation model MRI.COM, and a global aerosol model MASINGAR mk-2. These model components are interactively connected using a coupler library called Simple coupler (SCUP, Yoshimura and Yukimoto, 2008). The sulfate aerosol by volcanic eruption is produced via chemical reactions of SO_2 and transported in the aerosol model. The spatial resolution is set to TL159 (~ 1.125 x 1.125 deg) and 48 vertical layers up to 0.4 hPa.

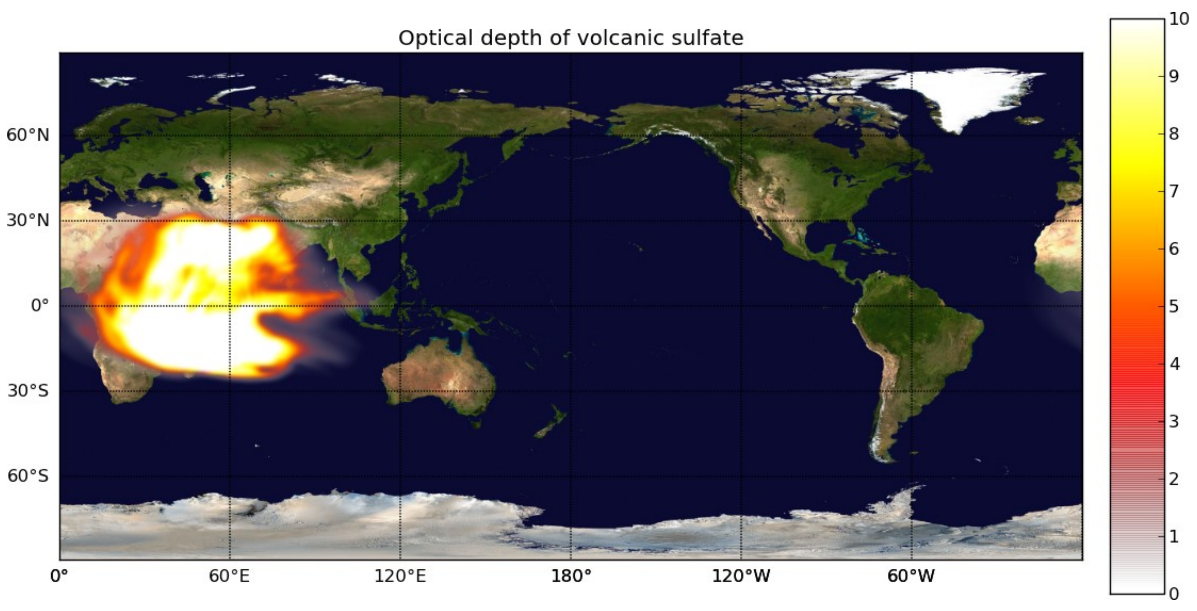
We carried out a virtual super-eruption experiment of Mt. Toba in Indonesia, which is considered to have erupted about 74000 years B.P. Following Robock et al. (2009), we conducted virtual Toba super-eruption experiments with sulfur dioxide injection 2Gt SO_2 and 6 Gt SO_2, which correspond to 100 and 300 times that of the Mt. Pinatubo eruption in 1991. The 2Gt and 6Gt SO_2 experiments are expressed as X100 and X300 experiment in this poster, respectively.



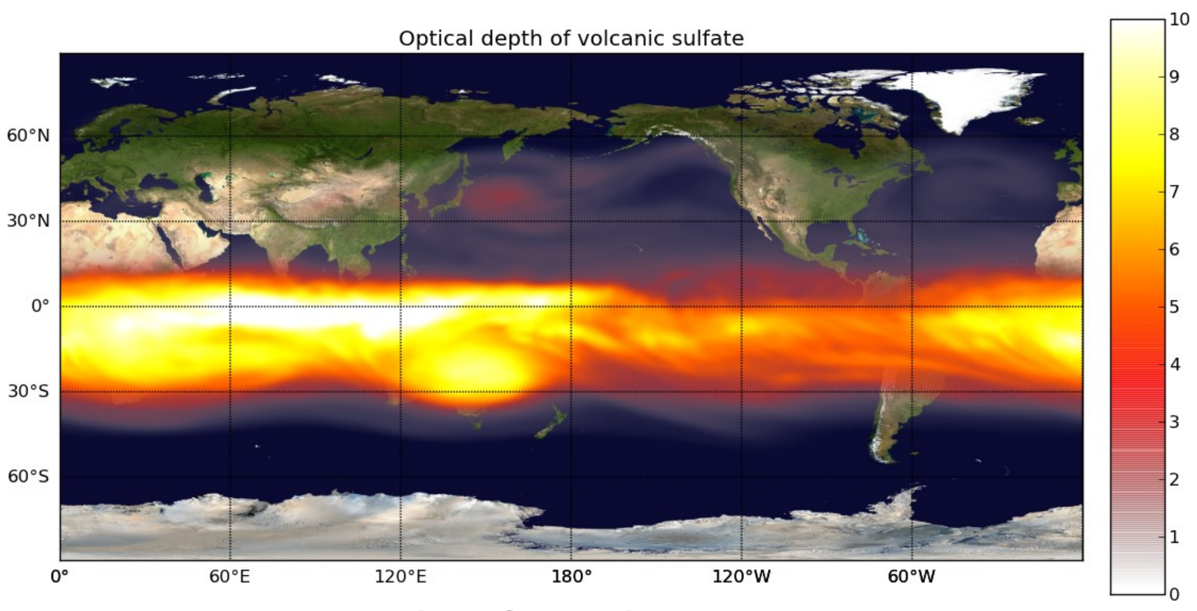
4. Results

Virtual Toba Supervolcano eruption experiments

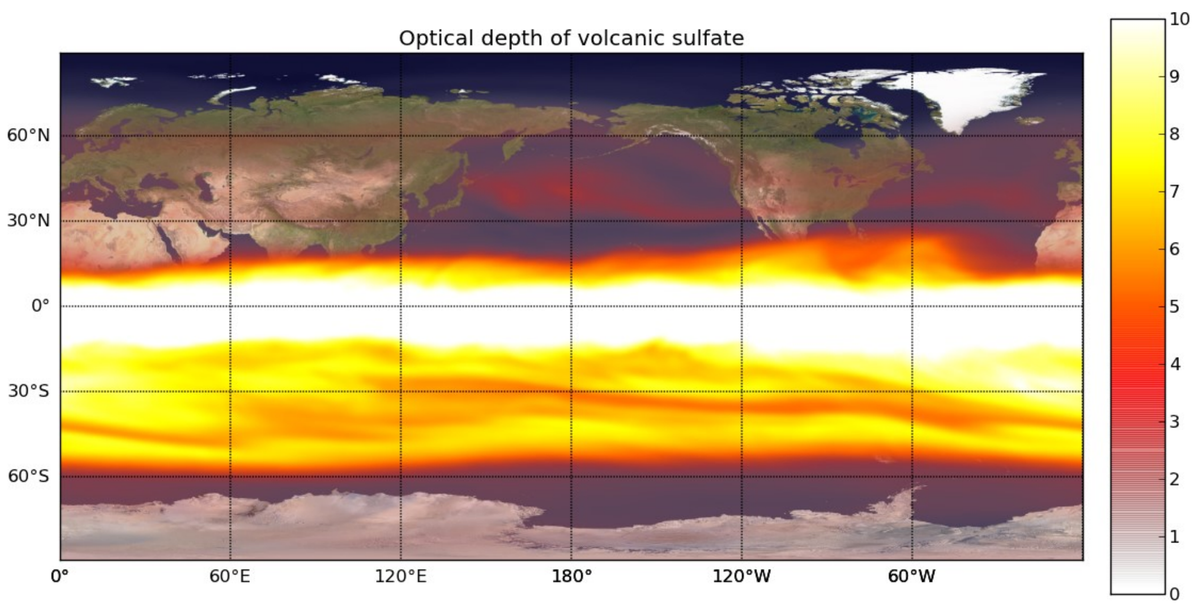
Horizontal distribution of optical thickness of the volcanic sulfate aerosol due to the super-eruption (Pinatubo X300 (6Gt SO_2) case)



1 week after the eruption

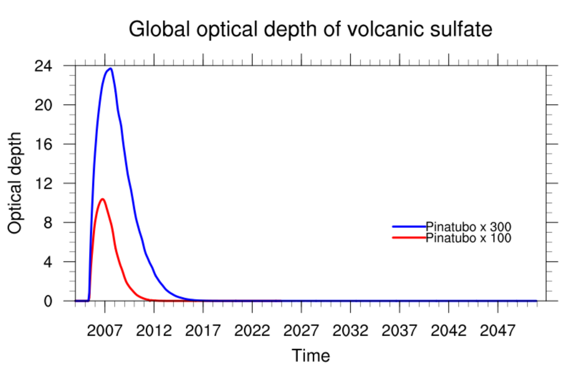


1 month after the eruption

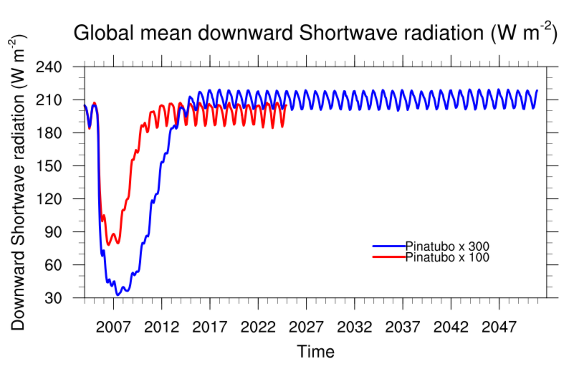


3 months after the eruption

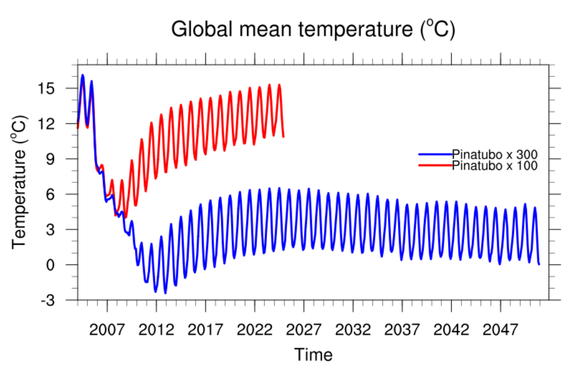
Time series of globally averaged variables



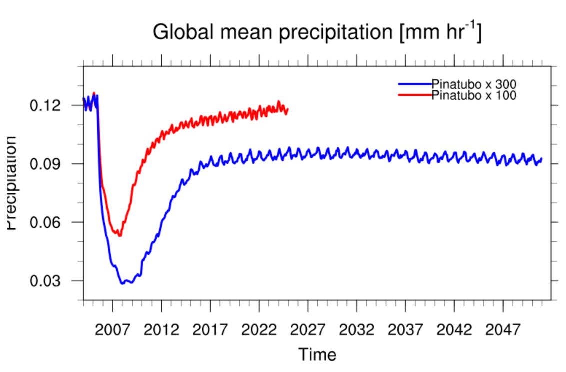
AOT of the volcanic aerosol



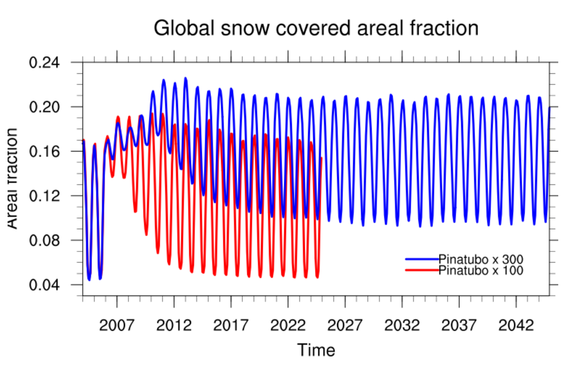
Downward SW radiation



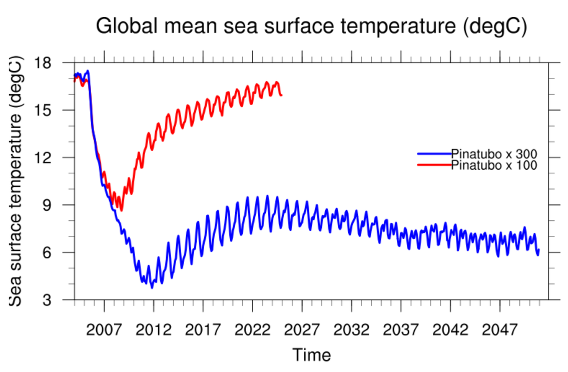
Surface temperature



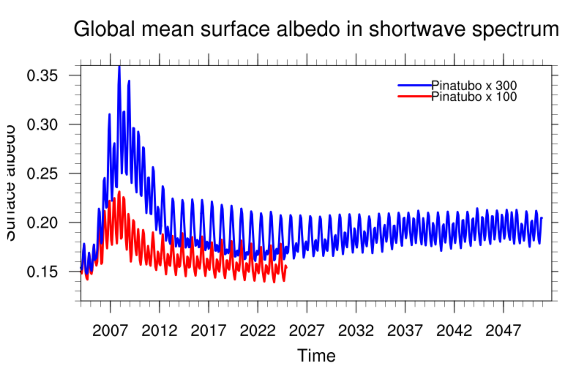
Precipitation



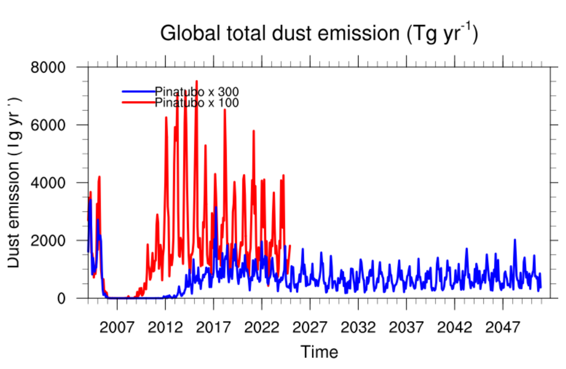
Snow cover fraction



Sea surface temperature

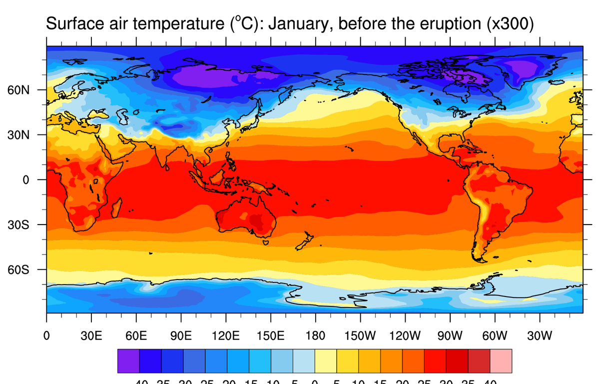


Shortwave surface albedo

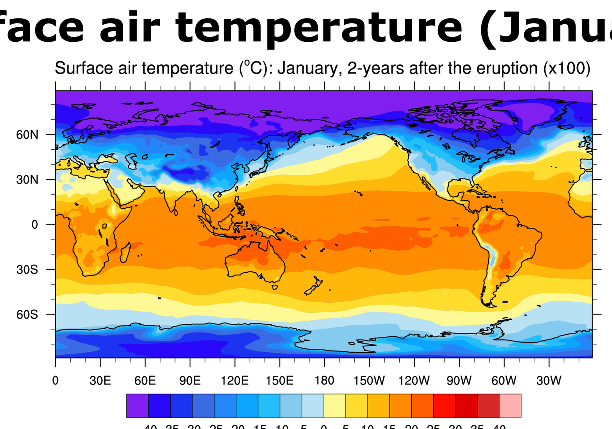


Total dust emission

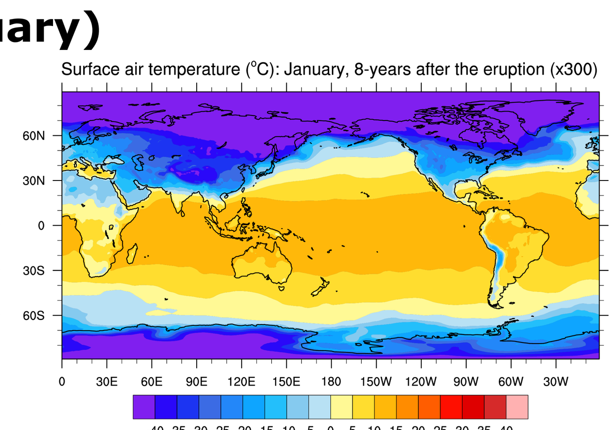
Surface air temperature (January)



Before the eruption (current climate)

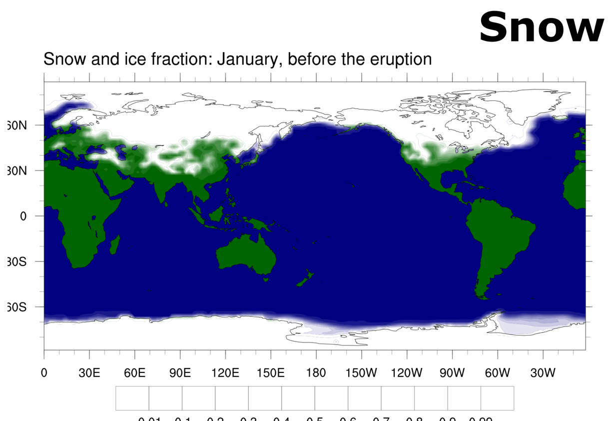


X100 experiment, 2 years after the eruption

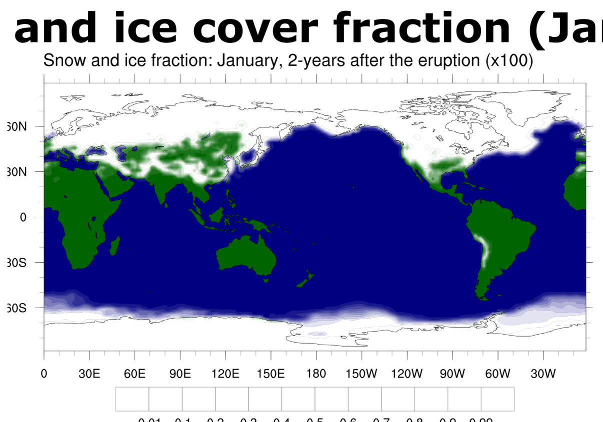


X300 experiment, 8 years after the eruption

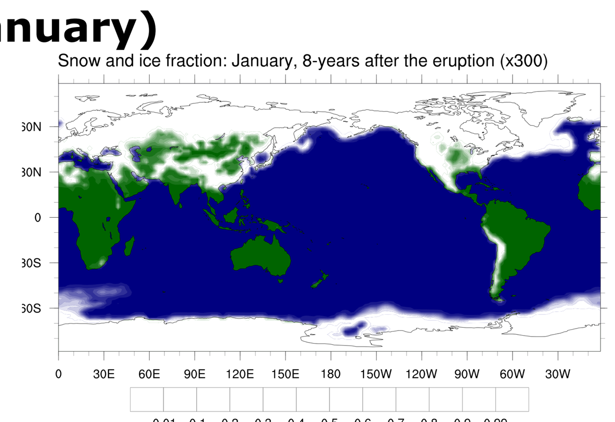
Snow and ice cover fraction (January)



Before the eruption (current climate)



X100 experiment, 2 years after the eruption



X300 experiment, 8 years after the eruption

The global averaged aerosol optical thicknesses of the virtual Toba eruption reach 10 for the X100 (2Gt) experiment, and 24 for the X300 (6Gt) experiment, respectively. Compared with the aerosol optical thickness of about 0.1 – 0.2 for the current climate, these values are extraordinary high. According to these volcanic aerosols, downward shortwave radiations are reduced for long time, 7 years for X100 experiment, and 11 years for the X300 experiment. The simulated results showed that the radiative cooling by the volcanic sulfate by 6 Gt SO_2 of virtual Toba eruptions lasted about 9 – 10 years. The globally averaged decrease in downward shortwave radiation reached its maximum of about 170 W m^{-2} in the second year after the eruption. However, the globally averaged decrease in surface air temperature was delayed, and continued until the seventh year after the eruption, and reached its maximum of about 15 K. The cooling and recovery of surface air temperature was delayed mainly due to cooled ocean that has huge heat inertia of sea water.

The cooling effect lowers the surface temperature, which result in enhanced sea ice and snow cover. The snow cover over land was increased because of the cooling, which leads to the increase of ground surface albedo. However, the ground surface was not exhaustively covered by the snow, due to the weakened precipitation after eruption. The results also suggested that mineral dust aerosol emission ceases just after the eruption, and temporarily increase with X100 experiment but decrease in the extremely cold condition (X300 experiment).

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