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.

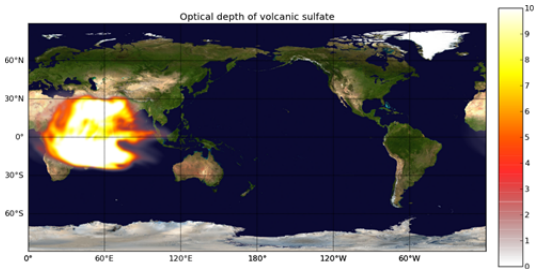
A supervolcano is a volcano capable of an eruption that producing ejecta amounts more than 10^{15} kg (150 times the 1991 Pinatubo volcano, VEI 8 or more) (Self and Blake 2008). Although the historical frequency is as low as once in several hundreds of thousands years, supervolcanoes such as the Yellowstone of the United States and Indonesia's Toba volcano (2.5°N, 99.0°E) 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 of 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. Several recent studies with global climate models investigated the cooling effect of the Toba super-eruption (Robock et al. 2009; Timmreck et al. 2010).

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.

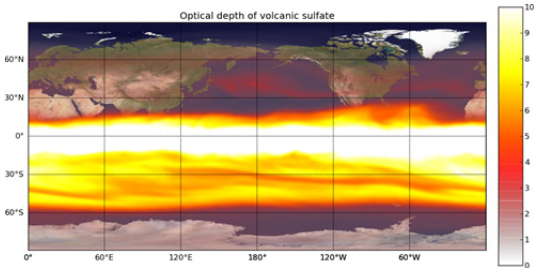
2. MODEL DESCRIPTION

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 called the Model of Aerosol Species IN the Global Atmosphere (MASINGAR; Tanaka et al. 2003) mk-2. The aerosol model treats 5 aerosol species, namely sulfate, black carbon, organic aerosols, sea salt and mineral dust. 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 horizontal resolutions of the AGCM and the aerosol model were set to TL159 (~ 1.125 x 1.125 degrees) and TL95 (~ 1.8 x 1.8 degrees). The vertical coordinates were 48 terrain-following eta layers up to 0.4 hPa for both the AGCM and the aerosol models.

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. The initial condition was taken from the result of the “historical” experiment of the CMIP5 experiment of the



(a) 1 week after the eruption



(b) 3 months after the eruption

Figure 1. Optical depth of volcanic sulfate aerosol (a) 1 week and (b) 3 months after the super-eruption with 6 Gt SO_2 emissions.

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MRI-CGCM3 at the year 2000 with 5-year spin-up run. We performed 20 years and 50 years integrations after the eruption for X100 and X300 experiments, respectively.

3. RESULTS

Figure 1 illustrates the horizontal distributions of optical depths of the volcanic sulfate aerosol due to the super-eruption (Pinatubo X300 (6Gt SO_2) case). The sulfate aerosol rapidly circled around the globe in the tropical stratosphere, and gradually transported to the higher latitudes.

The globally averaged aerosol optical depths of the virtual Toba eruption reach 10 for the X100 (2Gt) experiment, and 24 for the X300 (6Gt) experiment, respectively (Fig. 2a). Compared with the aerosol optical depths of about 0.1 – 0.2 for the current climate, these values are substantially high. According to these volcanic aerosols, downward shortwave radiations are reduced for a 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 value of about 170 W m^{-2} in the second year after the eruption (Fig. 2b). However, the globally averaged decrease in surface air temperature was delayed, and continued until the seventh year after the eruption, and the ground surface temperature reached its minimums of about 5°C and –2°C for X100 and X300 experiments, respectively (Fig. 2c). The cooling and recovery of surface air temperature was delayed mainly due to cooled ocean that has huge heat inertia of sea water.

Figure 3 shows the simulated snow and ice cover fractions of January, 2 years after the eruption for X100 experiment and 8 years after the eruption for X300 experiment. 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) (Fig. 2d).

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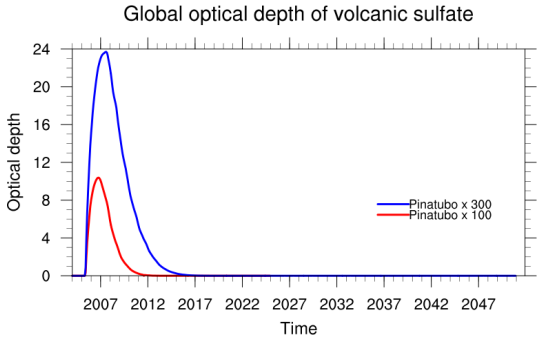
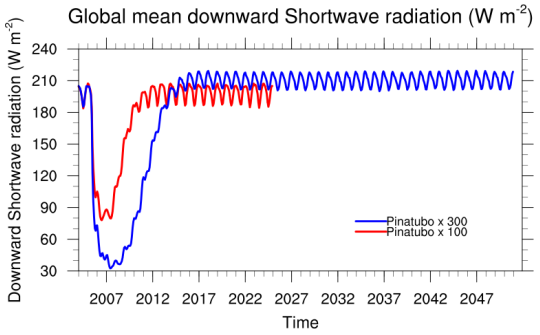
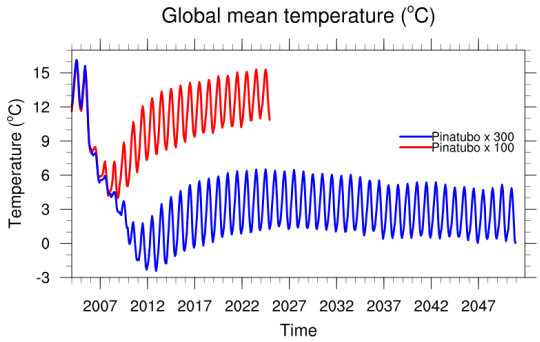


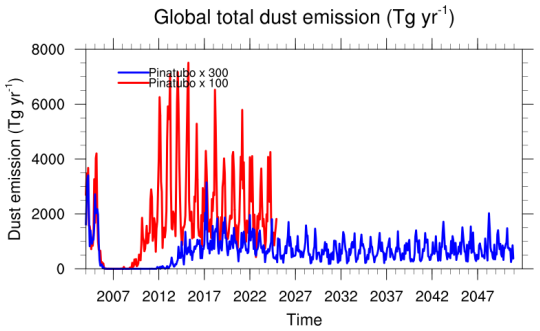
(a) Optical depth of volcanic sulfate



(b) Global downward shortwave radiation at surface



(c) Global mean surface temperature



(d) Total mineral dust emission flux

Figure 2. Simulated monthly averaged global mean variables after the supereruption. (a) Optical depth of the volcanic sulfate at 550nm. (b) Downward shortwave radiation at the ground surface (W m^{-2}). (c) Ground surface temperature (degree C), and (d) total mineral dust aerosol emission flux (Tg yr^{-1}).

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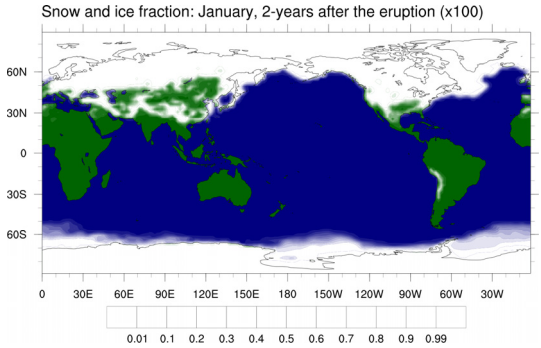
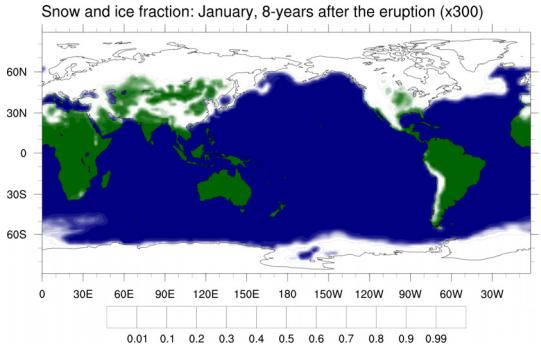


(a) 2Gt SO_2 experiment, January, 2 years after the eruption



(b) 6Gt SO_2 experiment, January, 8 years after the eruption

Figure 3. Simulated snow and ice cover fractions of (a) January, 2 years after the eruption for 2Gt SO_2 experiment (X100), and (b) January, 8 years after the eruption for 6Gt SO_2 experiment (X300).