Simulating the climate forcing of volcanic aerosols with a simplified interactive model

Plain Language Summary: Volcanic eruptions deposit aerosols into the upper-atmosphere, which are capable of altering temperature and wind patterns for years following. This poster describes a method of simulating this effect within a computational model of the Earth system. From top-to-bottom of the poster’s central section, we describe the simulated injection of volcanic substances into the stratosphere, followed by the response of the atmosphere.

Abstract: Here we present a stand-alone module for the representation of climate forcing by volcanic aerosols within an ensemble climate model framework, as demonstrated in the Energy Exascale Earth System Model (E3SM). Our implementation does not require the presence of any radiation or aerosol parameterizations, but rather computes global point-level heating rates (in K/s) directly through idealized Beer-Lambert forms on two broad shortwave (SW) and longwave (LW) radiation bands. Our model’s lack of these other parameterization dependencies allows it to be activated in any atmospheric component set; here we demonstrate it in a modified Held-Suarez-Williamson (HSW) atmosphere. The experimental design was specifically chosen to produce datasets for use in climate attribution studies through the CLDERA (Climate Impact: Determining Etiology Through Analytical) initiative at Sandia National Laboratories.

COAUTHORS

Christiane Jablonowski1, the CLDERA Team2

1University of Michigan, Ann Arbor, Michigan
2Sandia National Laboratories, Albuquerque, New Mexico

REFERENCES

Motivation

THE CLDERA PROJECT
Climate attribution: Detecting Etiology through pathways

The CLDERA project is an initiative at Sandia National Laboratories in New Mexico striving to develop tools to solve the attribution problem. Clustering and analyzing observed climate impacts to spatio-temporally localized source events. Ultimate goal: discover and characterize the causal pathways that exist within the climate system (schematic below) via e.g. causal inference, in-situ profiling, spatio-temporal clustering.

Contribution of this work: CLDERA has chosen a high signal-to-noise externally-forced source event as an exemplar for the development of its attribution methods: the 1991 eruption of Mt. Pinatubo. Our work provides databases which embed Pinatubo-like climate impacts with a minimized set of known temperature forcings (as in the simplified pathway schematic below) for CLDERA tool development and validation.

THE HIERARCHY OF VOLCANIC FORCING

We choose an implementation that compromises between the simple and complex established forcing approaches (schematic below).

Above left: sketch of the spectrum of aerosol forcing implementations. Left: simple prescribed forcing, where forcing is prescribed from a database of forcings, or functions. Right: accurate/interactive approach forcing is co-located with the model’s atmosphere and radiatively simulated to high detail. For atmospheric intermediate complexity Aerosols are instantaneously “forced” while local forcing calculations are highly simplified.

In this way, we attempt to embed the climate’s “pathways” within our data, without compromising on the full spatio-temporal description of the tracer distribution.

Transport & Impacts

Aerosol Radiative Feedback

Aerosol radiative feedback is modeled as an alteration of the atmospheric temperature and shortwave and longwave heating rates; the model includes feedback from a single Beer-Lambert Law form (SW) and a simple absorption (LW) model.

Longwave Absorption: Aerosol radiative forcing in EAM column

Within LW radiation models as aerosol heating rate:

Shortwave Scattering: Aerosol radiative forcing in EAM column

Within SW radiation models as aerosol heating rate:

Atmospheric Model

COUPLED CLIMATE MODEL: E3SM (Energy Exascale Earth System Model)

DYNAMICAL CORE: EAM (E3SM Atmosphere Model)

SPECTRAL ELEMENT: SE

VERTICAL DISCRETIZATION: 72 levels to ~60 km (~0.1 hPa)

HSW (Held-Suarez-Williamson)

Transport & Impacts

Above: Transport of the aerosol phase after stratospheric injection, being advected by east-west and south-north winds. The aerosol consists of the SO2 and aerosol sulfate (not shown) for 24 months, demonstrating SO2 and sulfate mixing ratios are dependent on the atmospheric dynamics and radiatively simulated to high detail. For atmospheric intermediate complexity Aerosols are instantaneously “forced” while local forcing calculations are highly simplified.

Aerosol radiative feedback is modeled as an alteration of the atmospheric temperature and shortwave and longwave heating rates; the model includes feedback from a single Beer-Lambert Law form (SW) and a simple absorption (LW) model.

At all times, we gently modulate the atmosphere’s field toward this reference profile, driving the model toward a reference profile (Held+Suarez 1994, Williamson 1998). At all times, we gently modulate the atmosphere’s field toward this reference profile, driving the model toward a reference profile (Held+Suarez 1994, Williamson 1998).