To Better Understand Climate Effects of Mega-Eruptions, Just Add Water

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Volcanic Mega-Eruptions Cause Cooling…

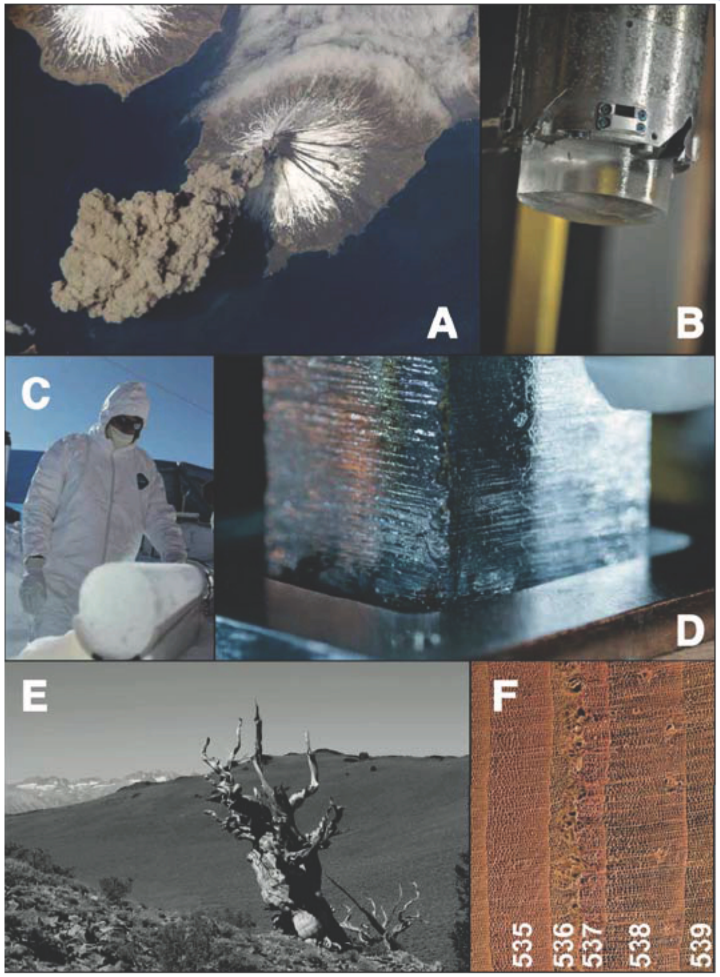
Volcanic mega-eruptions eject volcanic plumes into the stratosphere, the stable layer of atmosphere just above the troposphere, which is the layer closest to (and most influenced by) Earth's surface.

Both satellite observations of 1991's Pinatubo volcanic mega-eruption in the Philippines, and global climate model simulations of the past thousand years, show such mega-eruptions being followed by <u>long cold spells</u> that can dramatically reduce global temperatures.

The June 12, 1991 volcanic plume eruption column from Mount Pinatubo viewed from Clark Air Base. Image credit: U.S. Geological Survey Photograph taken by Richard P. Hoblitt.

Volcanic "Mega-Eruptions" Cause Cooling...

- While the Pinatubo mega-eruption is the only one to date observed via satellite instruments, there is evidence of past mega-eruptions present in tree rings and ice cores thousands of years old.
- Scientists use these natural phenomena to make proxy measurements to infer past climate, and these show cooling following mega-eruptions.



Volcanic "Mega-Eruptions" Cause Cooling…

Proxy measurements, from *PAGES* Magazine 23(2) 2015:

(A) **Injection of ash and aerosols into the atmosphere**

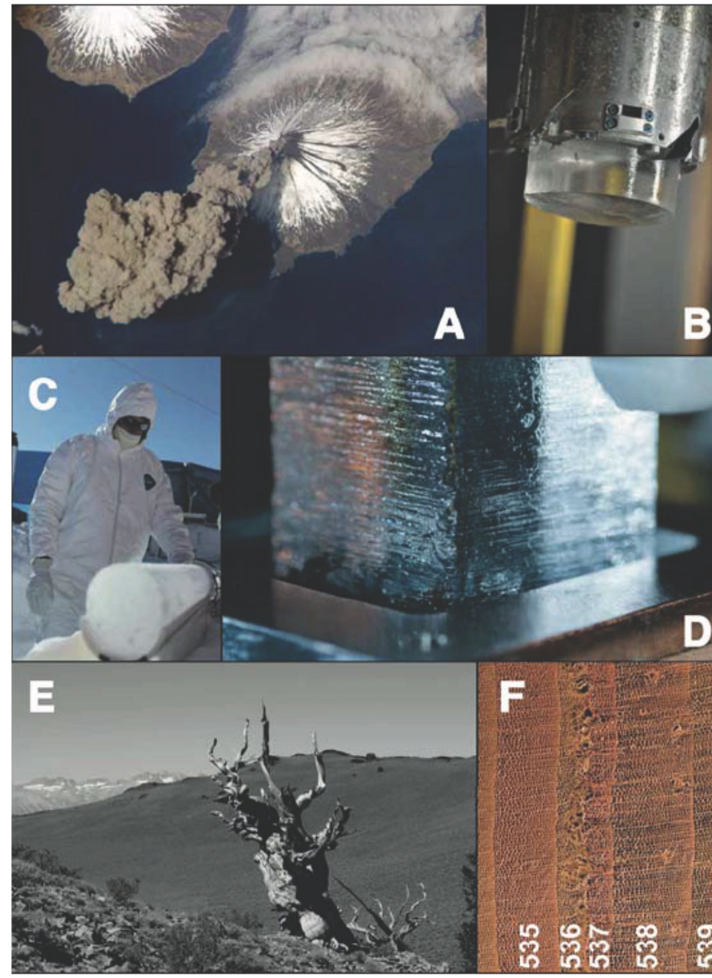
(B) **Ice core section from WAIS Divide (Antarctica) sticking out of the core barrel. High annual snowfall at this site enables individual annual layers to be identified and counted.**

(C) **Ice core section from TUNU (Greenland) that contains a record of volcanic sulfate aerosols.**

(D) **The ice is slowly melted and a variety of elements and chemical species are simultaneously analyzed.**

(E) **Bristlecone pine ring-width minima indicate that summer cooling often occurred when major volcanic eruptions dimmed the Earth's Surface.**

(F) **Frost rings from a Siberian pine in Mongolia. The narrow, distorted rings for 536 and 537 CE indicate a drastic cooling in the northern hemisphere which was caused by a large volcanic eruption.**



…But Previously, Global Climate Models Have Simulated Too Much Cooling Following Mega-Eruptions

The Coupled Model Intercomparison Project Phase 5 (CMIP5), an international study of global climate model performance completed in 2012, included simulated impacts of mega-eruptions on past climate.

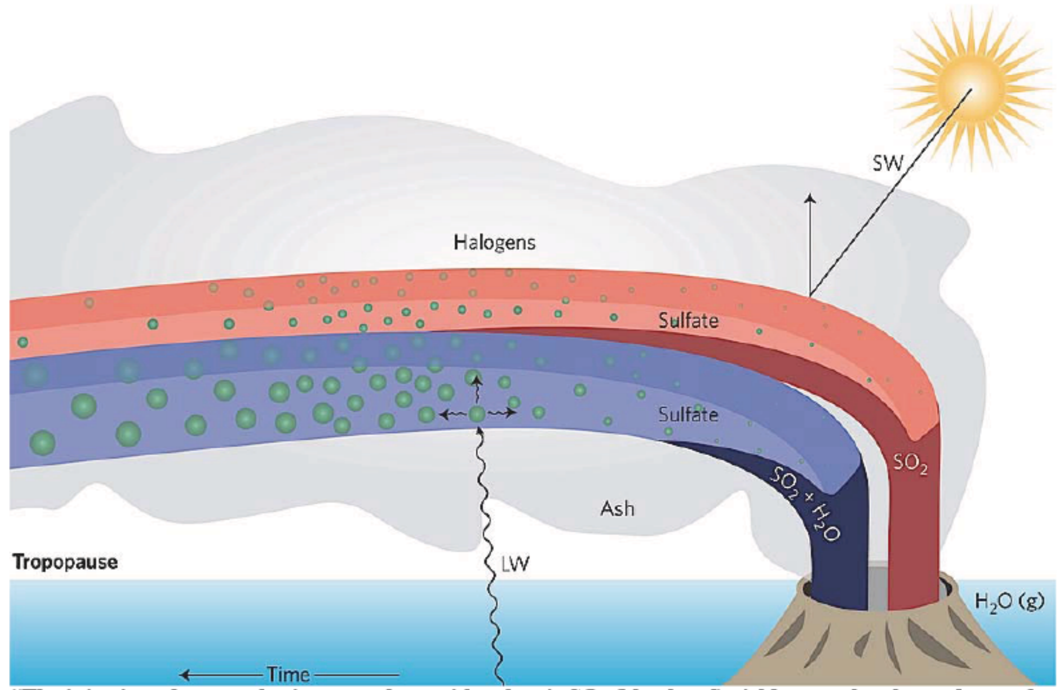
Scientists examined CMIP5 results, and recognized that the proxy measurements of past climate (e.g., tree rings and polar ice cores thousands of years old) did not reveal as drastic, worldwide cooling as did the CMIP5 global climate models.

WCRP CMIP5

World Climate Research Programme

Complex Chemical and Microphysical Processes in Volcanic Plumes

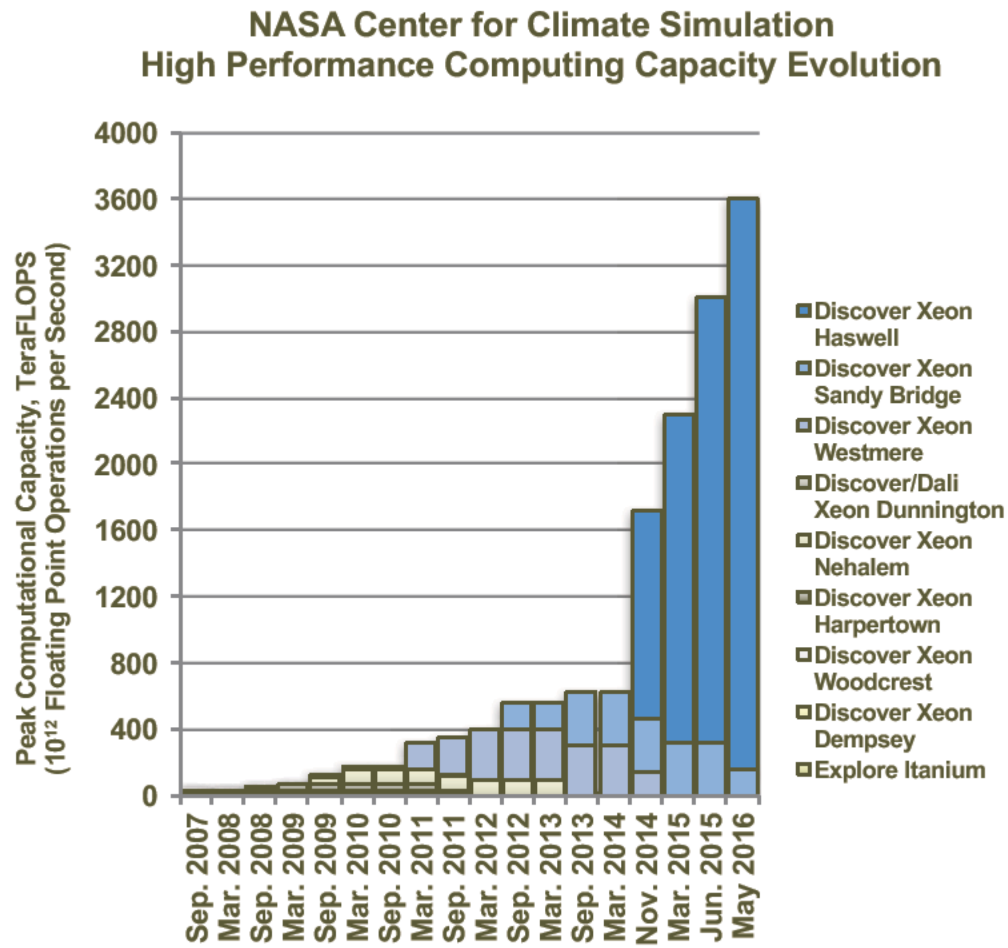
- Although scientists have much knowledge of the complex chemical and microphysical processes in volcanic plumes, limits on computational capacity forced the global climate models used in the CMIP5 study to use much-simplified representations.
- Because effects of sulfur compounds such as sulfur dioxide and sulfate aerosols have a key role in the cooling following mega-eruptions, the simplified representations in CMIP5 global climate models primarily focused on these processes.



"The injection of stratospheric water along with volcanic SO_2 (blue band) yields a much enhanced rate of sulfate formation relative to SO_2 injection alone (red band). Water increases the availability of OH radicals, converting SO_2 more quickly into sulfate aerosols (green spheres) and increasing the rate of aerosol growth. While these aerosols reflect shortwave radiation (SW) from space, leading to cooling, sulfate aerosols may also scatter longwave radiation (LW) from the Earth, promoting warming. The nature, formation rate and abundance of the aerosols formed will control the regional and global climate response following a volcanic eruption. The different altitudes of the two bands is for illustration purposes only." From LeGrande, A.N., K. Tsigaridis, and S.E. Bauer, 2016: Role of atmospheric chemistry in the climate impacts of stratospheric volcanic injections . *Nature Geosci*. , 9 , no. 9, 652-655,, doi:10.1038/ngeo2771.

Increased Computational Capacity Enables More Complex Chemical and Aerosol Microphysical Simulations

- Scientists at the NASA Goddard Institute for Space Sciences (GISS) suspected these simplifications had a large role in the mismatches between simulated and inferred climate impacts for volcanoes, and were inspired to seek out better aerosol microphysics representations.
- By mid-2016, NCCS Discover computational capacity had also more than tripled compared to the 2011-2012 CMIP5 study period, making it feasible to run GISS's global model with these more computationally intensive aerosol microphysics modules.



Adding Water to GISS ModelE with Gas Phase Chemistry and MATRIX Aerosol Microphysics

- GISS Scientists ran initial tests, tracking both sulfur and water (a significant new addition), in the volcanic plume, using the GISS ModelE climate model coupled with gas-phase chemistry and the MATRIX aerosol microphysical module, a more complete aerosol representation than what GISS used for CMIP5.
- GISS simulations included a Pinatubo-sized eruption (injections of ~18 trillion grams of sulfur dioxide and 150 trillion grams of water) and a Samalas-sized eruption (10 times larger, circa 1257 in modern-day Indonesia).

The limb of Earth's atmosphere photographed from space shuttle STS43 on August 8, 1991, showing aerosol layers injected into the stratosphere by the eruption of Mount Pinatubo in mid-June, which cooled the Earth for about 2 years following the eruption. Image credit: NASA courtesy NASA JSC

Improvement!

GISS's simulations using the MATRIX aerosol microphysics module that included the effects of stratospheric water vapor produced more realistic results and showed that the changes in gas-phase chemistry included in "wet" volcanic eruptions have global-scale implications.

For the Samalas-sized simulation, the climate model's subsequent global cooling decreased by about a factor of three compared to simulations that did not include water, and was more in line with climate impacts inferred from ice cores.

In simulations that include effects of stratospheric water vapor, the plume's sulfur dioxide gas converted more rapidly to sulfate aerosols, which then grew more quickly to larger sizes—important because larger particles cause more warming than cooling.

Why HPC Matters

For this initial testing, the GISS team ran millions of core hours of simulations on the NASA Center for Climate Simulation (NCCS) Discover supercomputer.

Discover's capacity has more than tripled, to nearly 3.5 petaflops since GISS's CMIP5 simulations, and this larger capacity makes feasible the climate simulations using the more realistic, and more computationally intensive, MATRIX aerosol microphysics modules.

What's Next

GISS scientists are continuing to make more realistic simulations of volcanic eruptions' climate effects by including a broadening chemical representation of volcanic plumes, and thereby investigating the importance of additional constituents such as ash and halogens.

These studies demonstrate that to better understand the effects of volcanic injections in the atmosphere, it is essential to couple gas-phase chemistry with more representative aerosol microphysics in climate models, so that the climate impact of massive events, and their evolution in space and time, can be quantified.

The research community is using these and similar innovations in the VolMIP effort, a new coordinated model intercomparison project investigating simulation of volcanic forcing in global climate models.