Coupled Aerosol-Chemistry Simulations of the January 2022 Eruptions of Hunga Tonga-Hunga Ha'apai in the NASA GEOS Earth System Model

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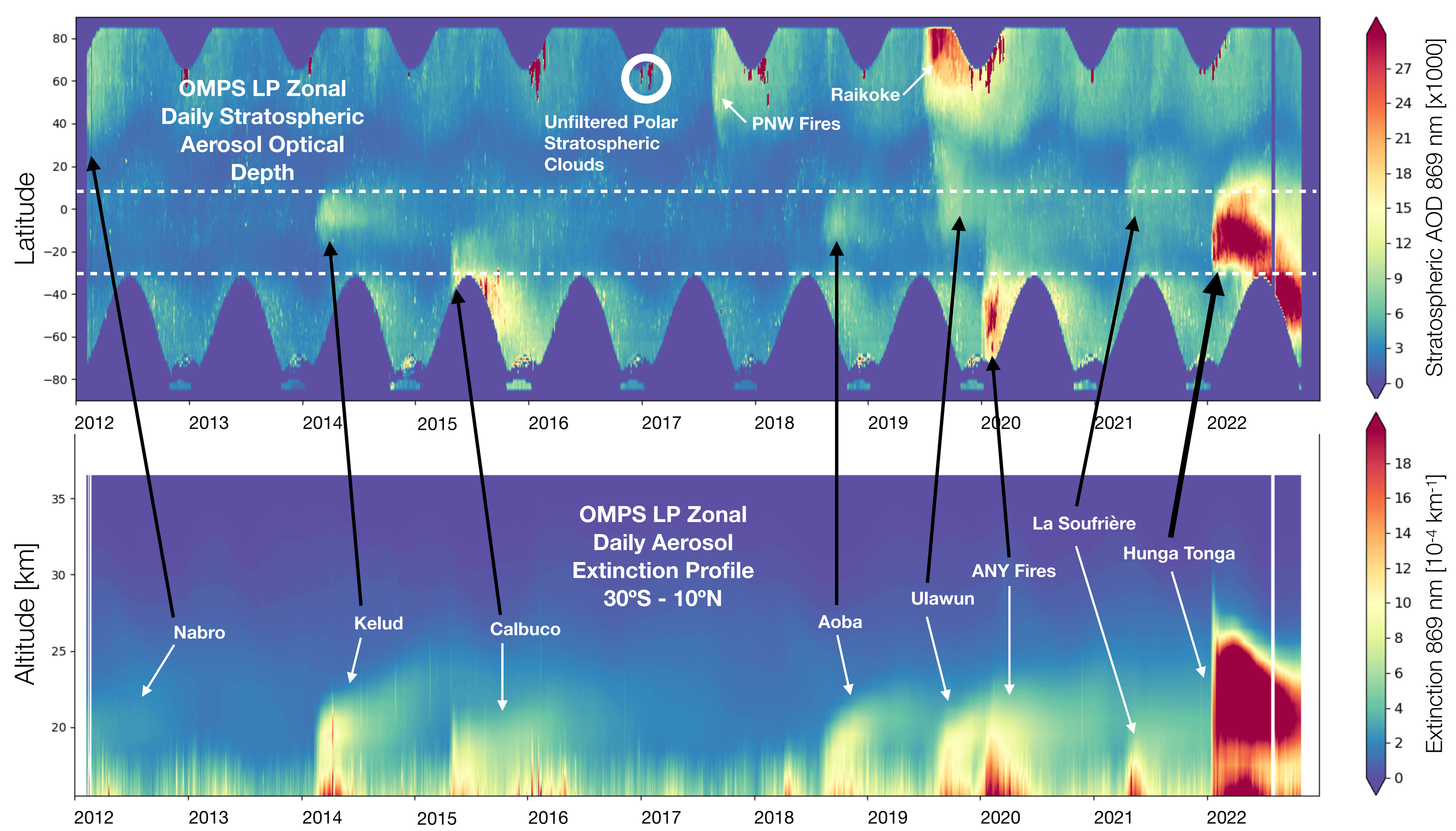
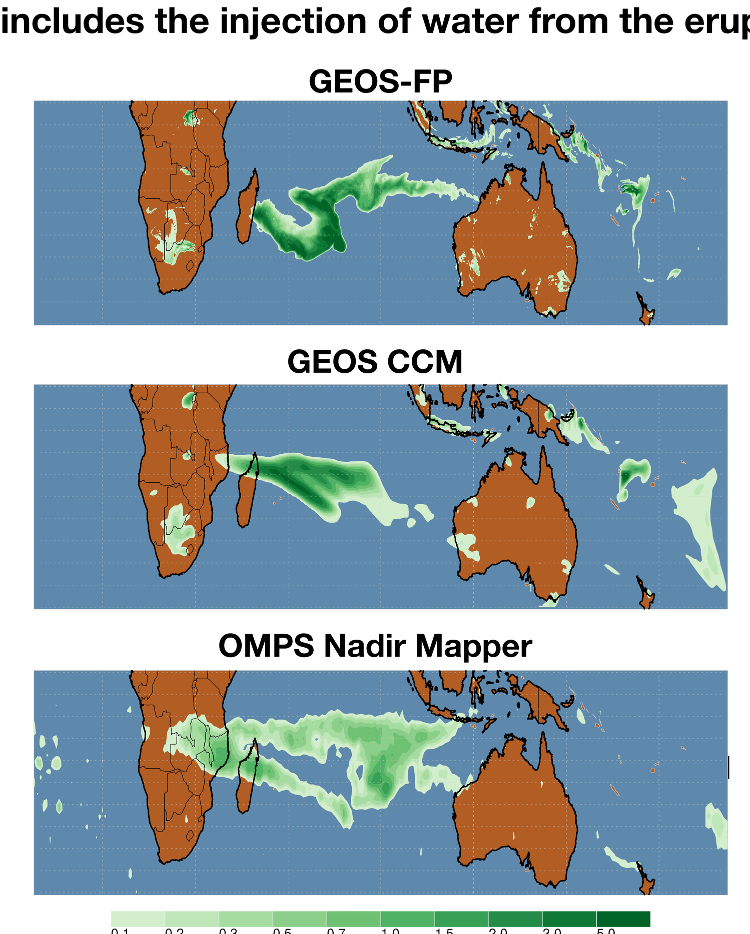
Introduction

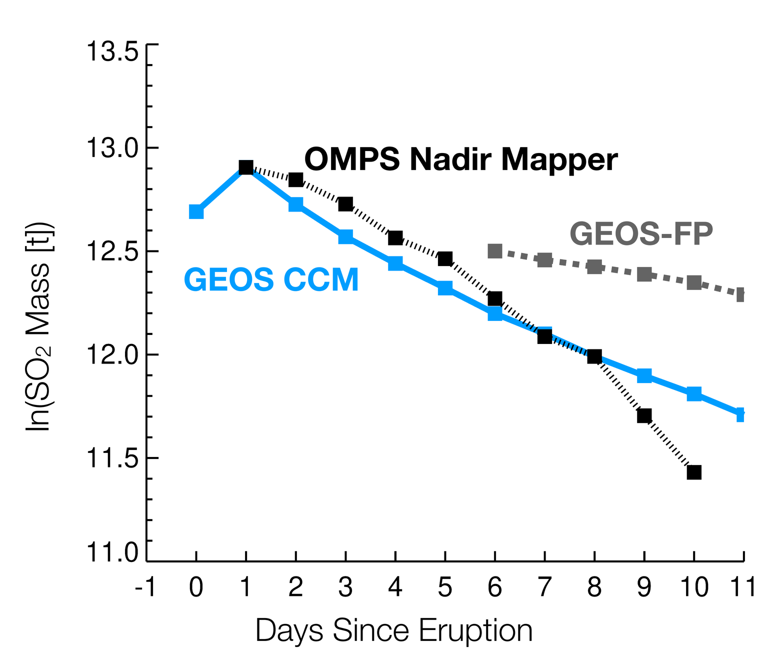
The 10+ year record of observations from the OMPS Limb Profiler (OMPS LP) on the Suomi NPP satellite (**below**) shows that **the January 2022 eruption of the submarine Hunga Tonga-Hunga Ha'apai volcano in the South Pacific resulted in the greatest aerosol perturbation at the highest altitudes in the dataset**. Below we show the OMPS LP record of the zonal mean daily stratospheric aerosol optical depth (AOD, **top**) and the zonal mean vertical aerosol extinction profile (averaged 30°S - 10°N, **bottom**). Major perturbations from volcanic and pyrocumulonimbus events are indicated with arrows.



Two sets of simulations of the Hunga Tonga eruption were performed with the NASA Goddard Earth Observing System (**GEOS**) model. Experimental forecasts with a high resolution version (global ~6 km, 181 level, called here **GEOS-FP**) were run shortly after the eruption with preliminary estimates of the injection parameters. Later simulations were run with the full chemistry version (global ~100 km, 72 level, called **GEOS CCM**). Both versions use the **GOCART** aerosol module, which treats the chemical production of sulfate aerosol from the volcanically injected SO_2. **The GEOS CCM simulation additionally includes the injection of water from the eruption.**



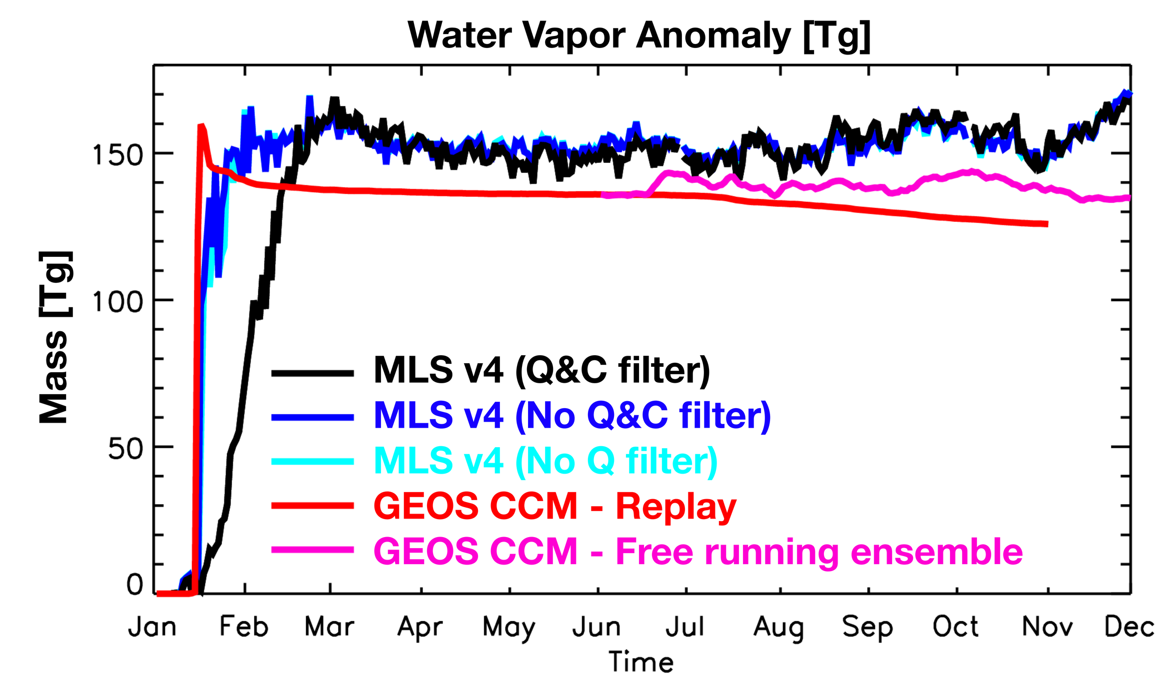
January 22, 2022, SO_2 column amount from GEOS-FP (**top**), GEOS CCM (**middle**), and Suomi NPP OMI Nadir Mapper (**bottom**).



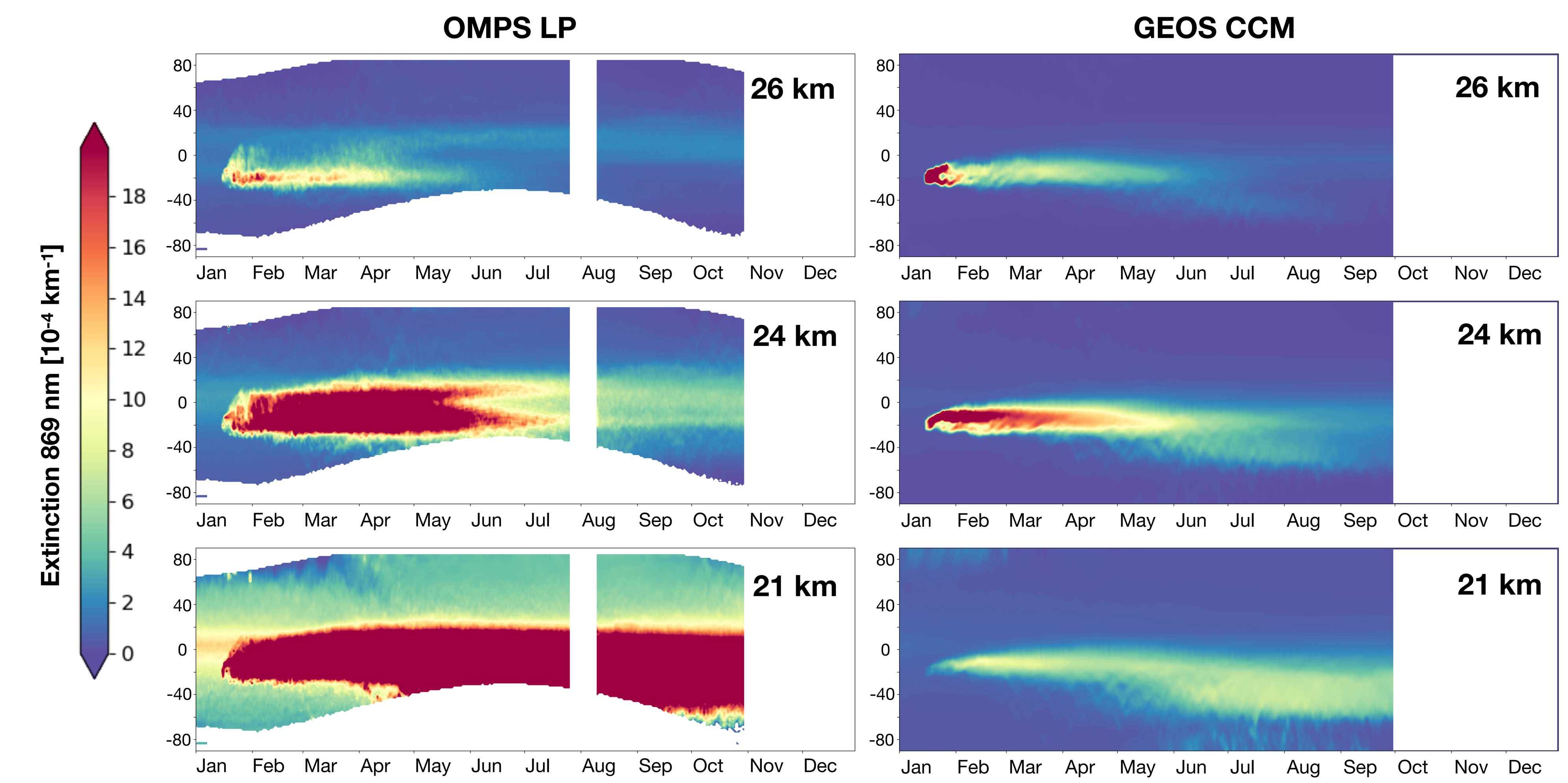
The **GEOS CCM** model run oxidizes SO_2 from the eruption with the online OH fields produced in the **GMI** chemistry module, while the **GEOS-FP** simulation uses offline oxidants from archival runs. We see that although both simulations have realistic transport (**left**) in the first few days after the eruption, **GEOS CCM better agrees with the OMPS Nadir Mapper observed SO_2 amount and lifetime (above)**.

2022 Plume Evolution

Simulations performed with the GEOS CCM are used in our subsequent analysis of the transport, evolution, and impacts of the Hunga Tonga volcanic plume. One simulation is a "replay" to the MERRA-2 reanalysis observed meteorology; others include an ensemble of free running simulations.

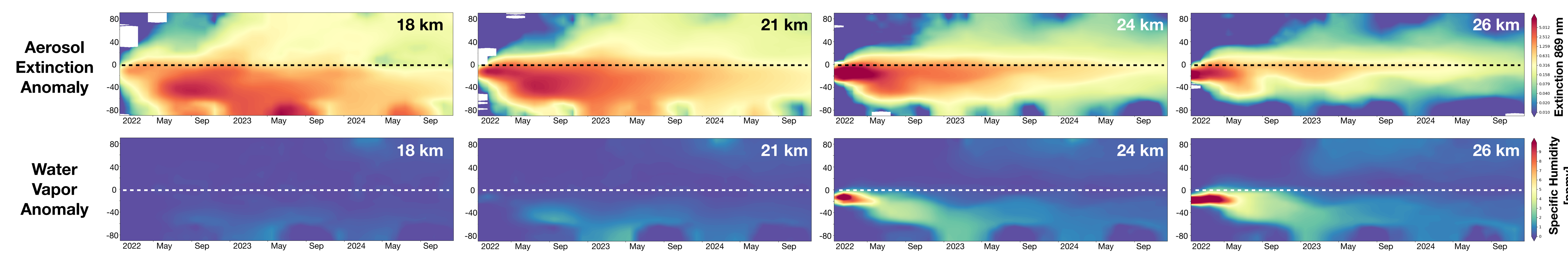


Deseasonalized **MLS version 4 data shows the eruption injected ~150 Tg of water into the stratosphere (~10% of total stratospheric water) that has persisted throughout the year**. Total water injected in our simulations is > 600 Tg, of which ~75% condenses and falls out soon after the eruption.



Above we show the replay simulation zonal, daily mean aerosol extinction compared to OMPS LP observations. The simulated extinctions (**right**) are too low compared to observations (**left**). **This suggests the model is not realistically handling particle microphysics in spite of the fact that simulated SO_2 is comparable to observations. Additionally, the model is not including any directly injected sulfate that may have occurred.**

Forecast Plume Evolution



Free running experiments were run to project the evolution of the atmospheric dynamical and chemical state through the end of 2024. **Above** we show the zonal, monthly average ensemble mean extinction (**top**) and water vapor (**bottom**) anomalies with respect to a control run (i.e., no volcano) at four different altitudes. At 18 km we see enhanced aerosol inside the southern polar vortex in the austral winter, as well as entrainment during the vortex breakdown, also evident at higher altitudes. **Aerosol and water appear to follow different transport trajectories, with water remaining more prevalent aloft. The aerosol and water vapor plumes remain mainly confined to the southern hemisphere and persist for many years.**

Model Configuration

GEOS CCM: Emissions spread horizontally at observed plume radius (~400 km)

- 0.05 Tg SO_2, 12 - 20 km, January 14
- 0.50 Tg SO_2, 20-30 km, January 15
- 12 Tg H_2O,12-20 km, January 14
- 600 Tg H_2O, 20-30 km, January 15

Two 4-member ensembles:

- Control with no volcanic emission
- Volcanic SO_2 and water injection

GEOS-FP: 0.4 Tg SO_2, 20-28 km at volcano location, January 15

Concluding Questions

What is the impact of primary sulfate injection (not simulated here) on the aerosol extinction?
What are the relative roles of high injection altitude versus enhanced oxidants in the SO_2->sulfate conversion?
How does radiative forcing from the aerosol and water in this eruption impact dynamics?
What are the relative roles of water and aerosol in the stratospheric ozone response?
How are aerosols being entrained into the polar vortex?

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