Volcanic ash chemical aging from multiple observational constraints for the Pinatubo eruption.

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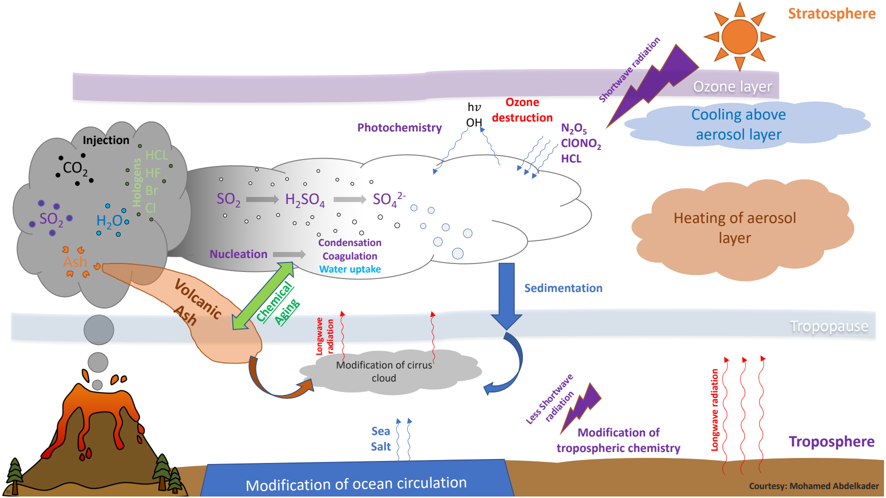
Volcanic eruption in the earth system (modeling approach)



Schematic representation of the volcanic eruption in the earth system and its microphysical and chemical processes.

Time scales

Volcanic research topics timescale

Initial plume development | **Intermediate plume development** | **Climatic effects**

Weeks → **Months/years** → **Years/decades**

- **Chemical aging of volcanic ash**

- **Radiative forcing**
- **Stratospheric chemistry budget**

- **Ocean response**
- **Ozone depletion**
- **Stratospheric methane oxidation capacity**

Model setup

- Aerosol composition and microphysics submodel GMXe with 7 log-normal modes, 4 soluble and 3 insoluble modes;
- Explicit aerosol thermodynamics ISORROPIA-II (Fountoukis and Nenes, 2007) and EQSAM4clim (Metzger et al., 2016).
- Aerosol water are calculated explicitly from aerosol thermodynamics based on cation-anion neutralization and deliquescence relative humidities (gas-liquid-solid partitioning).
- CCMI stratospheric and tropospheric chemistry mechanism following Brühl et al. (2015)
- Detailed chemical aging of volcanic ash (Abdelkader et al., 2015).
- Introduced new tracers for volcanic ash (VA).
- Experiments
    - "1s1" : Injection of 17Mt of SO_2 only.
    - "1w1" : Injection of 17Mt of SO_2 + 150Mt of water vapor.
    - "va0" : Injection of 17Mt of SO_2 + 150Mt of water vapor + 75Mt of dry volcanic ash.
    - "va1" : Injection of 17Mt of SO_2 + 150Mt of water vapor + 75Mt of volcanic ash with ash aging.

Evaluation of volcanic aerosols

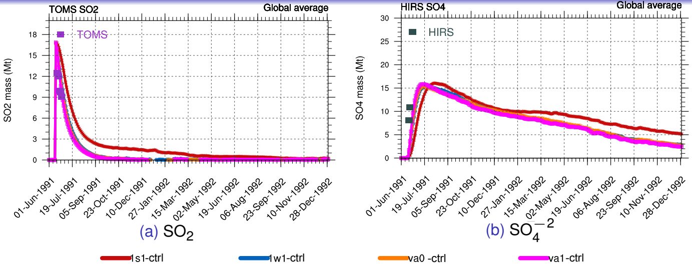


Figure 2.2: Evaluation of SO_2 mass from TOVS retrievals and HIRS SO_4^{-2} retrievals (Guo et al., 2004a).

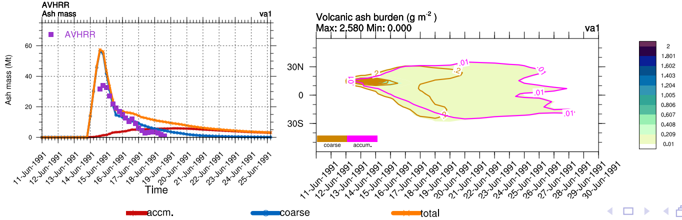
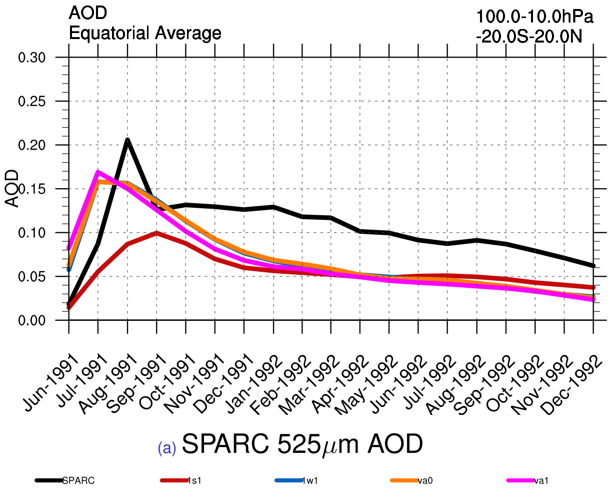


Figure 2.3: Right) Time series for the total volcanic ash mass compared to AVHRR retrieval (Guo et al., 2004b), left) Hovemoller diagram for the total volcanic ash burden.

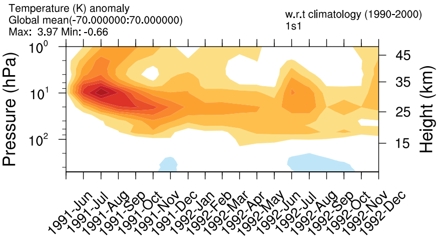
Evaluation of volcanic optical depth



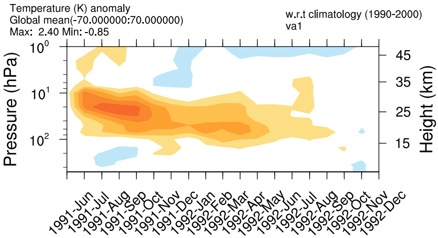
(a) SPARC 525μm AOD

Figure 2.5: Time series for stratospheric equatorial average AOD (0.55μm) compared to SPARC (0.525μm) retrievals of AOD for the injection of SO_2 *"1s1"*, SO_2 and water vapor *1w1*, volcanic non-aged ash with water vapor and *va0* and aged volcanic ash *va1*. Water vapor accelerates the sulfate formation and increases the sulfate mass, as a result, the optical depth in creases.

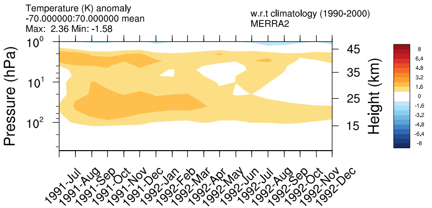
Temperature response



(a) 1s1



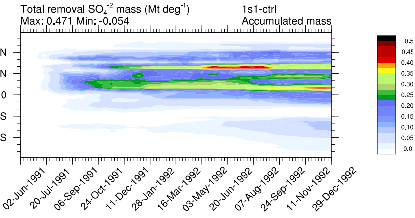
(b) va1



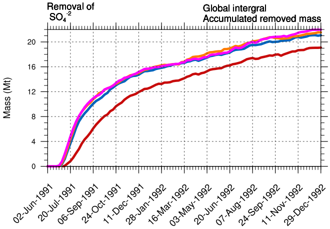
(c) MERRA2

Vertical profile for the global temperature anomaly w.r.t 7 ensemble members for the ”ctrl” simulation for the ”1s1” and ”va1” compared to MERRA 2 anomaly. ”1s1” shows higher temperature response compared to ”va1” which shows better comparison to MERRA2 for the absolute temperature anomaly and also the vertical distribution.

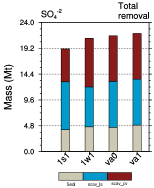
Deposition of volcanic aerosol



(a) Integrated removal



(b) Integrated removal

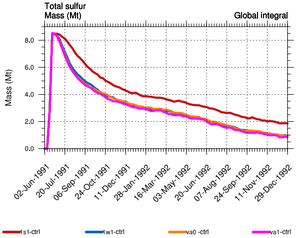


(c) Total removal

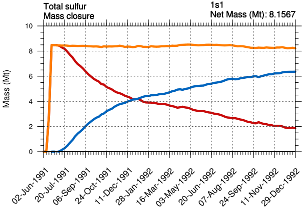
1s1-ctrl 1w1-ctrl va0 -ctrl va1-ctrl

Figure 2.7: Deposition of volcanic sulfate: 2.7a) Hovemoller diagram for the integrated removal of sulfate per unit degree of latitude, 2.7b) time series for the total integrated removal for different experiments. 2.7c) total removal of sulfate over 1.5 years after the eruption by sedimentation ("sedi"), and scavenging from large scale precipitation "scav_ls" and from convective precipitation "scav_cv".

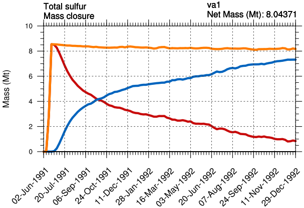
Mass closure of total sulfur mass



(a) Total mass of sulfur



(a) Mass closure for "1s1"

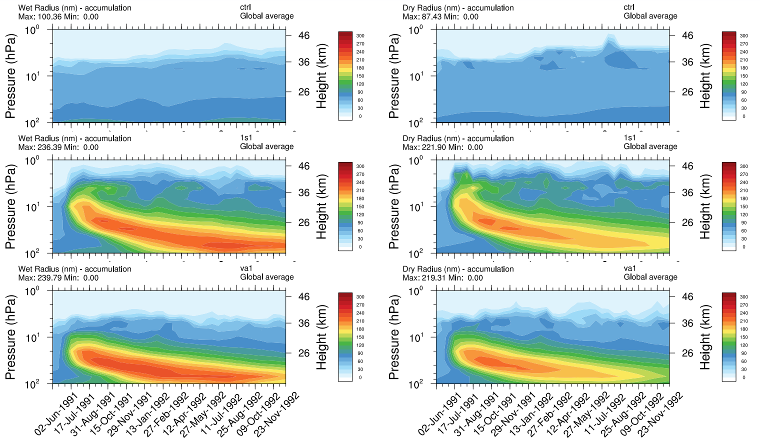


(b) Mass closure for "va1"

1s1-ctrl 1w1-ctrl va0 -ctrl va1-ctrl

Figure 2.10: Time series for: Left) the atmospheric load change in total sulfur mass (perturbed - ctrl) for different cases. Total sulfur calculated as mass fraction of sulfur from different sulfur containing compounds
$S_{total} = 0.5SO_2 + 0.32H_2SO_4 + 0.33SO_4 + 0.40SO_3 + 0.67SO + 0.33HSO_4$ + 0.53OCS + 0.515DMS.
The total sulfur mass is higher for the "1s1" comapred to other cases due to higher removal rates of cases with water and volcanic ash. However, the net sulfur mass is conserved for an average mass of 8.1Mt which also obtained for all cases.

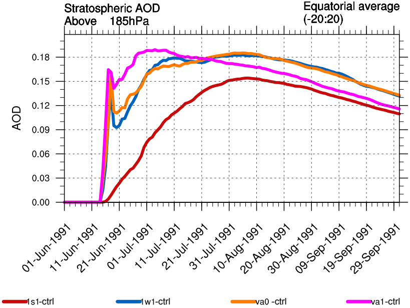
Wet and dry radii

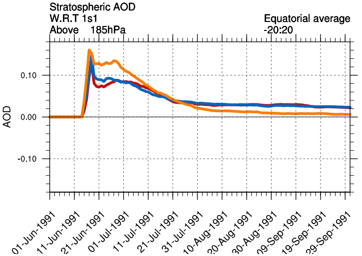


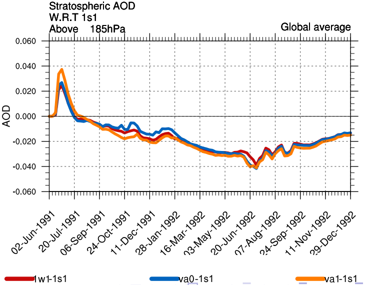
(a) Wet (b) Dry

Figure 2.11: Wet and dry radius of the accumulation mode for three experiments: upper panel) control, middle) "1s1" and lower) "va1". The Wet and dry radii for the va1 is higher compared to "1s1". Injection of dry volcanic ash increases the dry radius while the injection of water vapor and volcanic ash aging increases the wet radius. As a result, removal of the "va1" is higher compared to "1s1"

Impact of water vapor

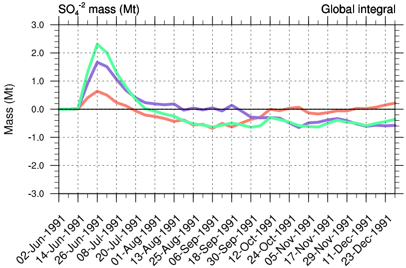




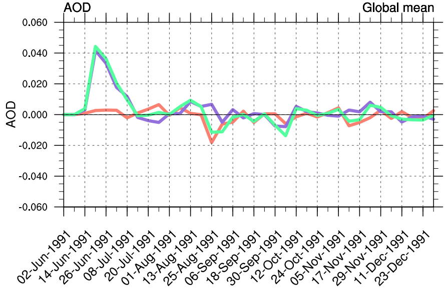


- Time series of the change in stratospheric AOD compared to the "ctrl" simulation. Injection of water vapor increases the AOD in first week after the eruption significantly as a result of the faster oxidation of sulfur dioxide.
- The time series for the change in stratospheric AOD for different cases w.r.t to *"1s1"*: equatorial average between 20°S and 20°N and right) global average shows that in the first month after the eruption, volcanic ash aging increases the AOD as a result of additional water uptake.

Impacts of volcanic ash



(a) SO_4^{-2} with injected water



(b) AOD- with injected water

va0-1w1 va1-va0 va1-1w1

Figure 3.2: Time series for the effect of volcanic ash *"va0-1w1"*, volcanic ash aging *"va1-va0"* and the total effect *"va1-1w1"* on: Left) sulfate total mass and Right) the total optical depth. Injecting of ash without aging increases the sulfate mass by 0.8Mt, while the volcanic ash aging increases the mass by 1.8Mt. The total effect of injecting volcanic ash with the aging effect is 2.4Mt compared to 20Mt (12%). However, the effect of volcanic ash on the total AOD is more obvious in the first month after the eruption. The increase in AOD due to volcanic ash from 0.02 to 0.06, which is roughly 50% increase in AOD compared to a global average AOD of 0.09.

Conclusions

We present the impact of the injection of water vapor and volcanic ash on the development of the volcanic plume.

- We introduced volcanic ash tracer and aging in the EMAC model.
- Evaluation of SO_2, SO_4^{-2}, volcanic ash mass AOD shows all good agreements with observations.
- Water vapor accelerates the oxidation of SO_2 in the first week after the eruption resulted in higher AOD.
- injection of water vapor and volcanic ash aging increase the wet radius resulting in higher deposition of particles.
- The aging of volcanic ash increases the AOD in the first week after the eruption by 50%.
- The aging of volcanic ash increases the sulfate mass by 12%.


Thank you