UNIVERSITÄT GREIFSWALD
Wissen lockt. Seit 1456

VOLIMPACT

SAGE III/ISS
virtual meeting

14.07.2023

Stratospheric aerosol size reduction after volcanic eruptions

Authors: Felix Wrana (speaker)[1], Ulrike Niemeier[2], Larry W. Thomason[3], Sandra Wallis[1], Christian von Savigny[1]

[1] Institute of Physics, University of Greifswald, Germany
[2] Max Planck Institute for Meteorology, Hamburg, Germany
[3] NASA Langley Research Center, Hampton, Virginia, USA

Correspondence: felix.wrana@uni-greifswald.de

VolImpact

1. Overview VolImpact research group

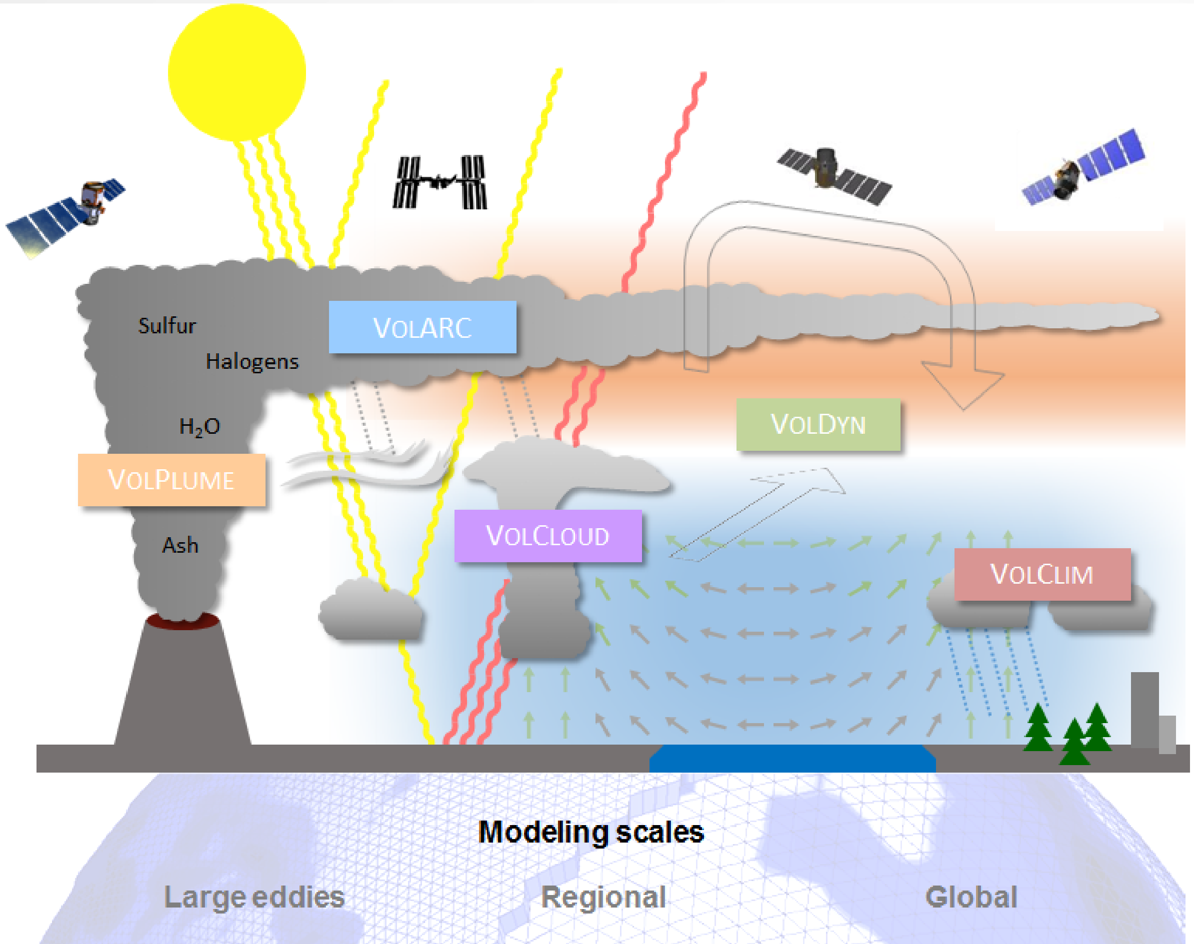
2. Aerosol size retrieval method

3. Aerosol size reduction after smaller volcanic eruptions

4. Model simulations of Raikoke/Ulawun

5. Short look at Hunga Tonga – Hunga Ha'apai

The VOLIMPACT projects

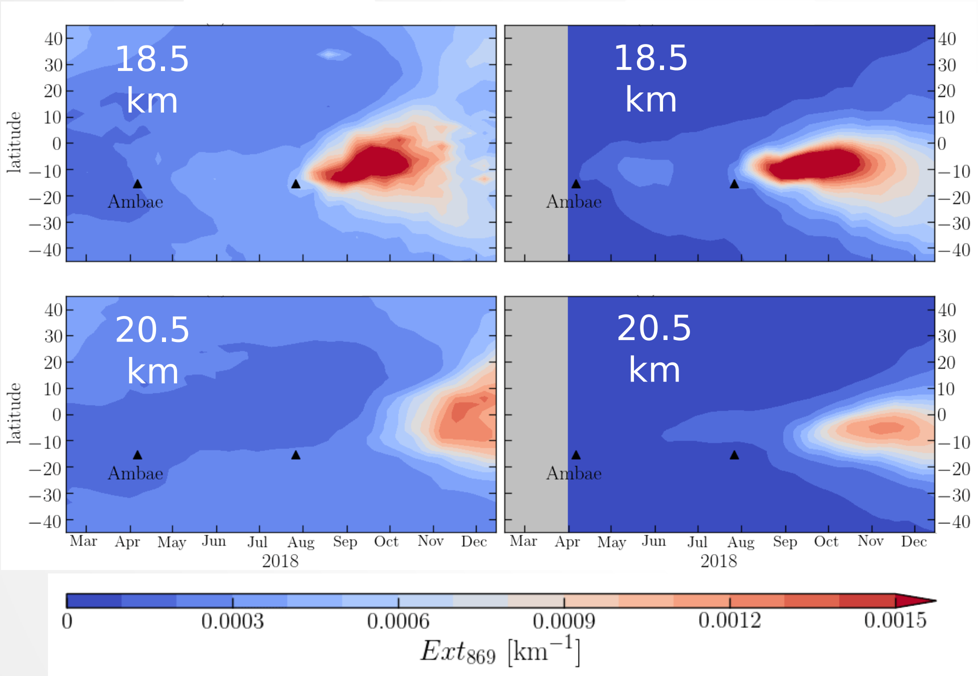


- Phase I: 2019 – 2022
- Phase II: 2022 – 2025

- Important: Synergy between global modelling (ICON-Family & MA-ECHAM) and satellite observations (Algorithm development & usage of other data products)

1. VolImpact: Some results from recent eruptions

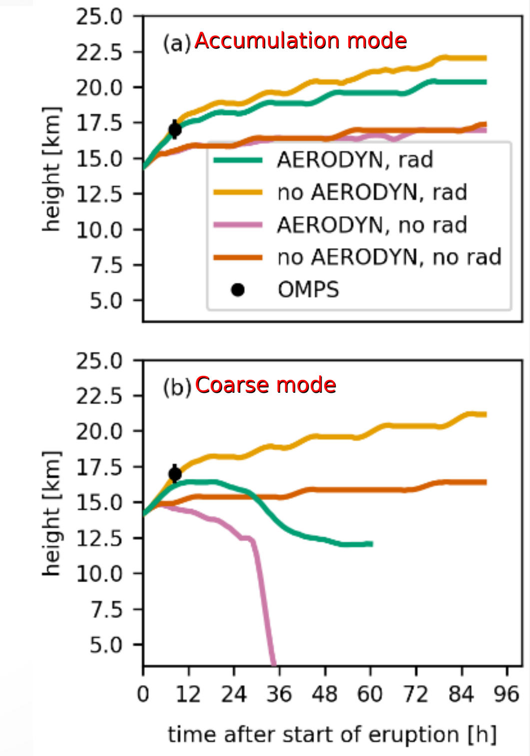
Ambae 2018 eruption



Malinina et al., ACP (2021)

- Important for good agreement: Good knowledge of the injected SO_2 amount, injection height & also dynamics

Raikoke 2019 eruption



Muser et al., ACP (2020)

- Essential roles of the ash and aerosol aging in self-lofting

1. VolImpact publications on optical phenomena

On the phenomenon of the blue Sun

Wullenweber et al., Clim. Past (2021)

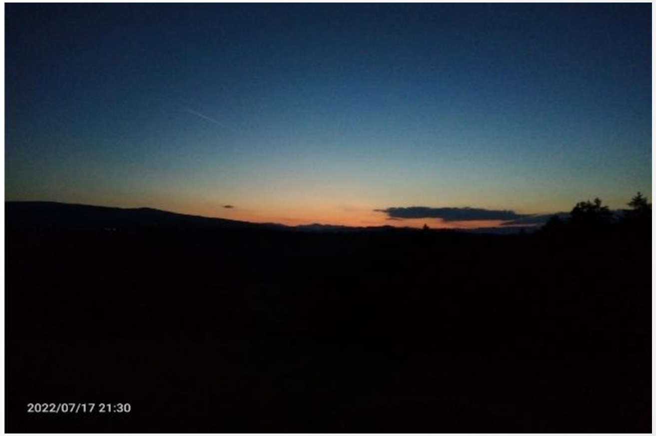
Is it possible to estimate aerosol optical depth from historic colour paintings?

von Savigny et al., Clim. Past (2022)

On the colour of noctiluent clouds

Lange et al., Ann. Geophys. (2022)

Revisiting the question "Why is the sky blue?"



Lange et al., Appl. Opt. (2023), subm.

1. Faces of VolImpact

People associated with VolImpact phase I:

1. Overview VolImpact research group

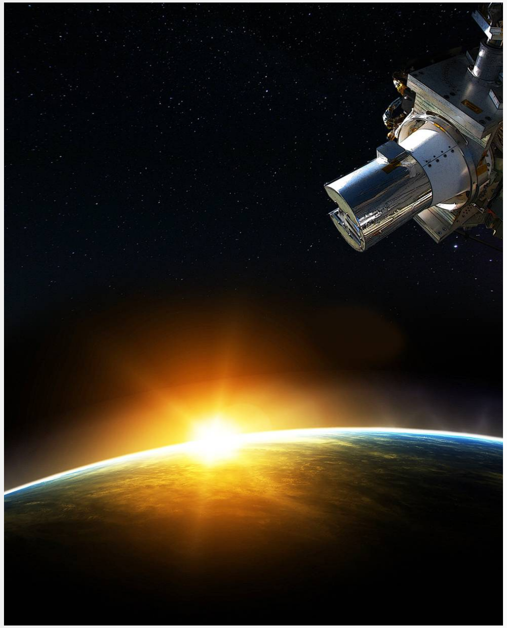
2. Aerosol size retrieval method

3. Aerosol size reduction after smaller volcanic eruptions

4. Model simulations of Raikoke/Ulawun

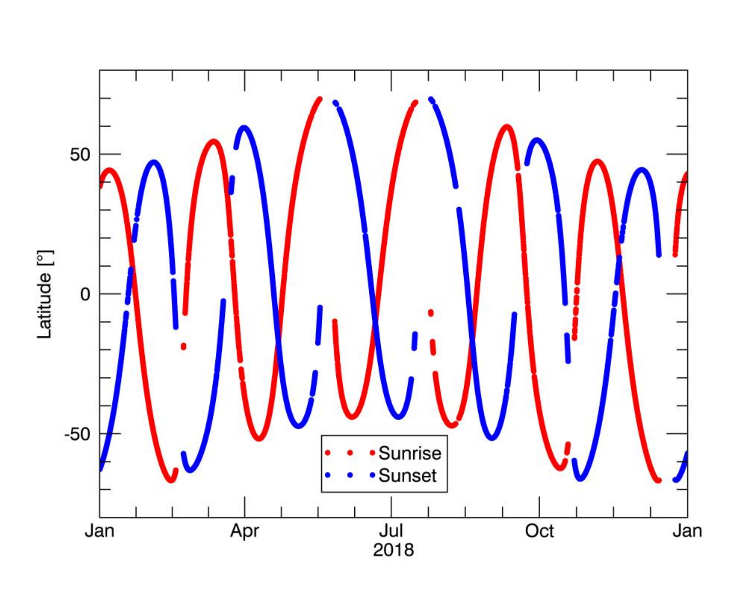
5. Short look at Hunga Tonga – Hunga Ha’apai

2. Stratospheric aerosol retrieval method



SAGE III on the International space station.
Source: NASA (https://go.nasa.gov/3FCGR1J)

- Retrieval of stratospheric aerosol size from SAGE III/ISS (solar occultation)
- Latitudinal coverage ~ between 70°N and 70°S
- Limited spatial and temporal coverage
- Retrieval uses aerosol extinction coefficients at 3 wavelengths



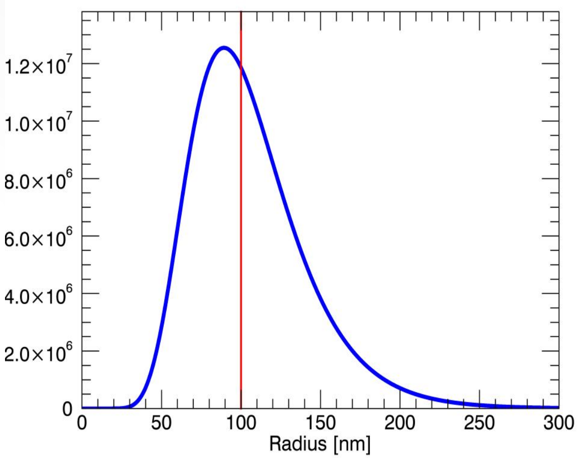
Latitudinal coverage of SAGE III/ISS solar occultation measurements, exemplary for 2018.

Assumption: Monomodal lognormal size distribution

$$\frac{dN(r)}{dr} = \frac{N_0}{\sqrt{2\pi} \cdot r \cdot ln\sigma} \cdot exp(-\frac{ln^2(r/r_{med})}{2ln^2\sigma})$$

Needs to be retrieved:

- Median radius r_{med}
- Distribution width σ
- Number density N_0



Exemplary monomodal log-normal particle size distribution. Red line marks the median radius (100 nm).

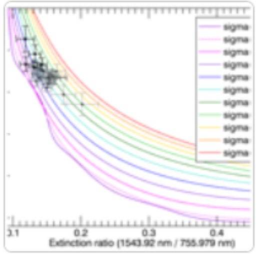
2. Stratospheric aerosol retrieval method

- Paper on the retrieval method published in Atmospheric Measurement Techniques (AMT)

  doi: 10.5194/amt-14-2345-2021

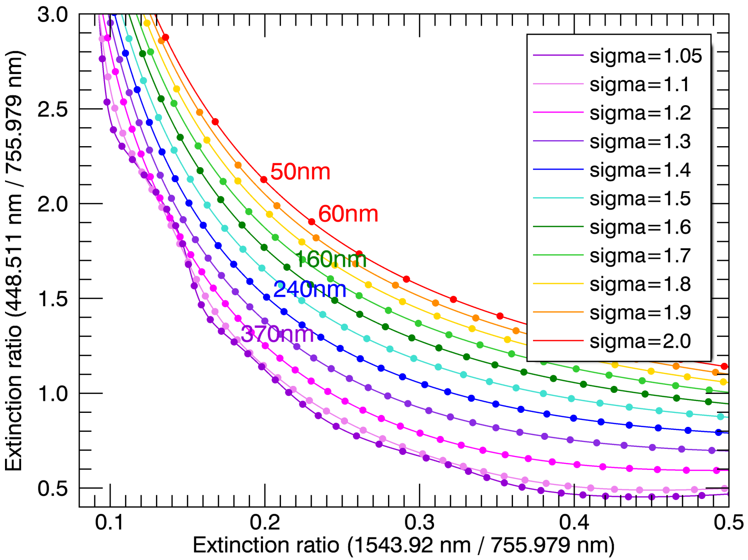
Research article | cc by 26 Mar 2021

Retrieval of stratospheric aerosol size distribution parameters using satellite solar occultation measurements at three wavelengths



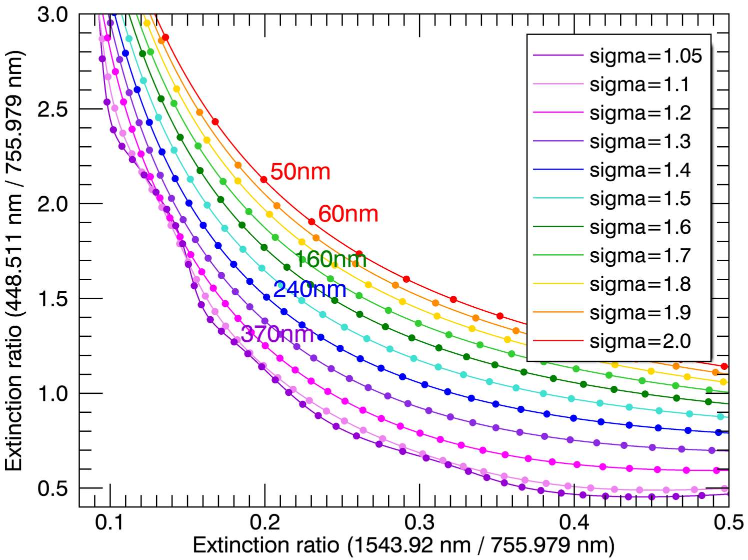
Felix Wrana ✉, Christian von Savigny, Jacob Zalach, and Larry W. Thomason

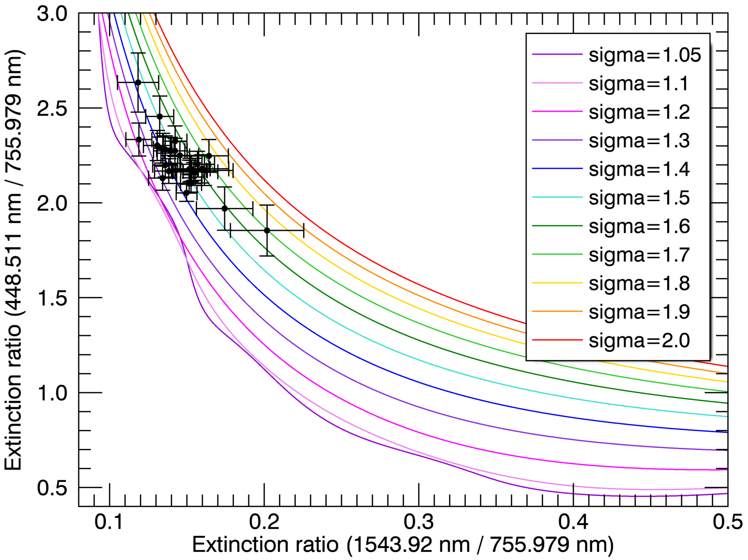
2. Stratospheric aerosol retrieval method



- Lookup table with extinction ratios at 3 wavelengths for many combinations of median radius and mode width
- Calculated with Mie Code
  - Assumed aerosol composition: 75% sulfuric acid and ~25% water
  - Assumed shape of size distribution: monomodal lognormal

2. Stratospheric aerosol retrieval method

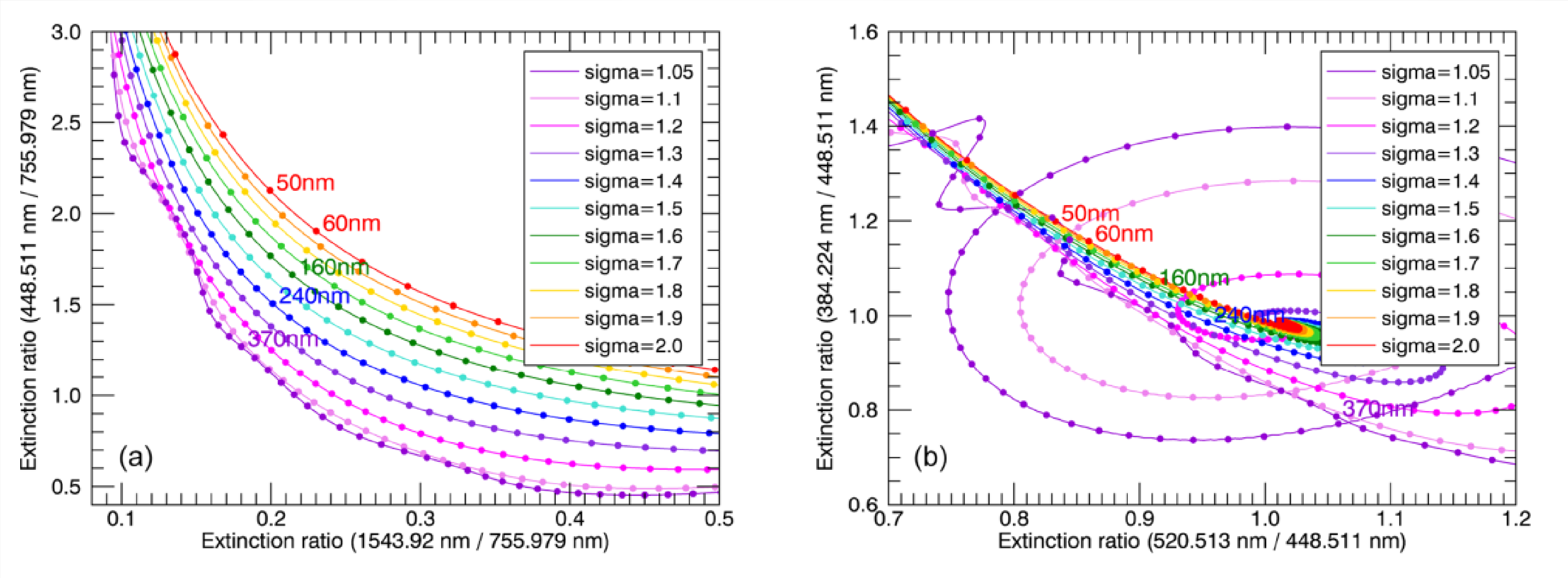




- Lookup table with extinction ratios at 3 wavelengths for many combinations of median radius and mode width
- Calculated with Mie Code
  - Assumed aerosol composition: 75% sulfuric acid and ~25% water
  - Assumed shape of size distribution: monomodal lognormal

- Plot measurement data into the lookup table (right plot)
- → Retrieval of r_{med} and σ through interpolation
- N, r_{eff}, etc. can be calculated afterwards

2. Stratospheric aerosol retrieval method



- Best wavelengths: 449, 756 and 1544 nm
- Bad example: Wavelengths: 384, 449, 520 nm

- The **broad wavelength spectrum** of SAGE III instruments is important for this method!

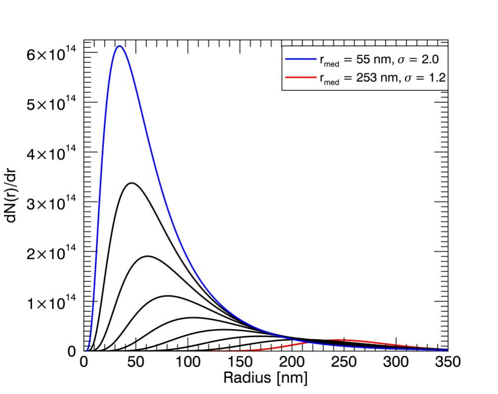
2. Using three vs two wavelengths

- The 3-wavelength retrieval approach is important to learn how stratospheric aerosol size evolves over time **because**:

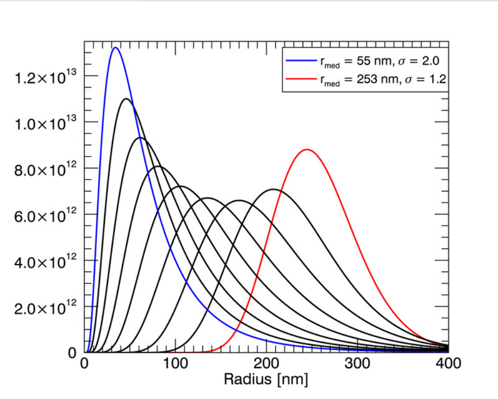
- if only 2 wavelengths (like it was necessary for e.g. SAGE II) were to be used:
  → σ would have to be assumed, often at ~1.5 - 1.6

- However, σ is very variable (e.g. ~ 1.25 for Hunga Tonga)

- Wrong σ assumption can lead to very different PSDs! → see plots to the right



Different PSDs, but each one is consistent with the same extinction ratio at 449 nm / 756 nm of 2.0.



Same plot, but PSDs scaled to same number density for visual clarity.

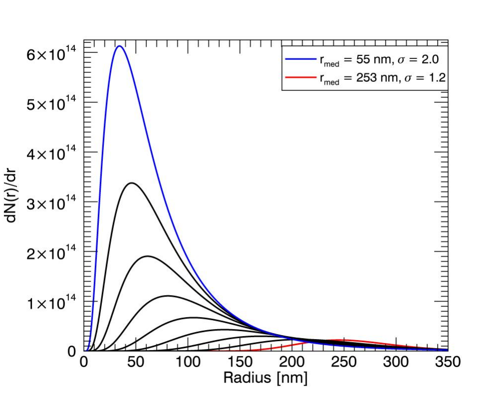
2. Using three vs two wavelengths

- The 3-wavelength retrieval approach is important to learn how stratospheric aerosol size evolves over time **because**:

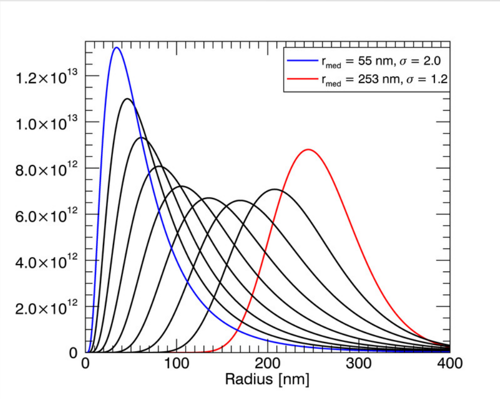
- if only 2 wavelengths (like it was necessary for e.g. SAGE II) were to be used:
  → σ would have to be assumed, often at ~1.5 - 1.6

- However, σ is very variable (e.g. ~ 1.25 for Hunga Tonga)

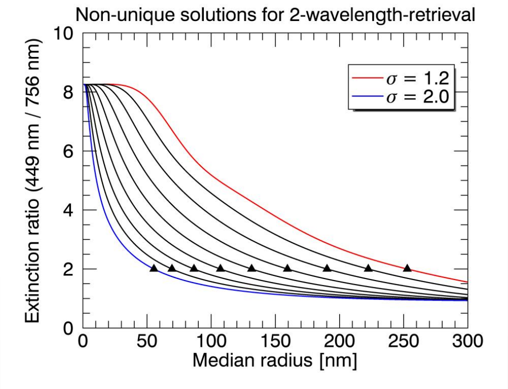
- Wrong σ assumption can lead to very different PSDs! → see plots to the right

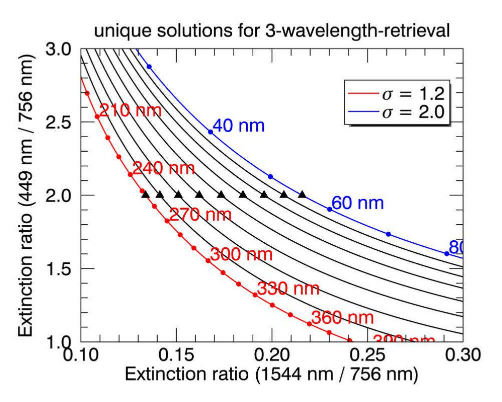


Different PSDs, but each one is consistent with the same extinction ratio at 449 nm / 756 nm of 2.0.



Same plot, but PSDs scaled to same number density for visual clarity.





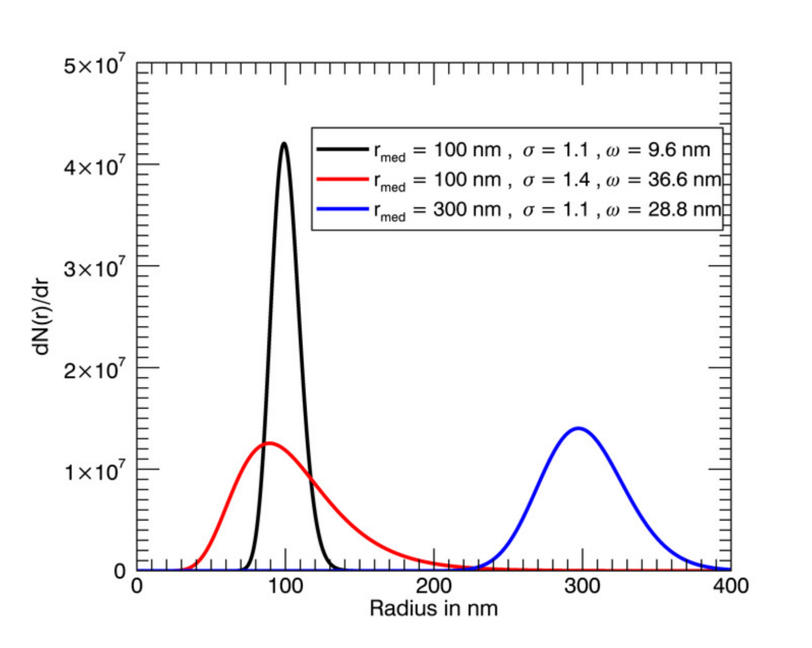
2. Why I will show ω instead of σ

- Distribution width σ often misunderstood → not useful to understand how wide the size distribution is

- Instead absolute distribution width ω will be shown:

$$\omega = \sqrt{r_{med}^2 \cdot exp(ln^2(\sigma)) \cdot (exp(ln^2(\sigma)) - 1)}$$

  - ω, as introduced by Malinina et al. (2018), is the standard deviation of the PSD in linear radius space
  - Will be shown in results instead of σ



Three exemplary monomodal log-normal size distributions to illustrate relation between ω instead of σ

1. Overview VolImpact research group

2. Aerosol size retrieval method

3. Aerosol size reduction after smaller volcanic eruptions

4. Model simulations of Raikoke/Ulawun

5. Short look at Hunga Tonga – Hunga Ha’apai

3. Strat. aerosol size reduction

Results to be shown are submitted to
Atmospheric Chemistry and Physics (ACP):

04 May 2023

Stratospheric aerosol size reduction after volcanic eruptions

Felix Wrana, Ulrike Niemeier, Larry W. Thomason, Sandra Wallis, and Christian von Savigny

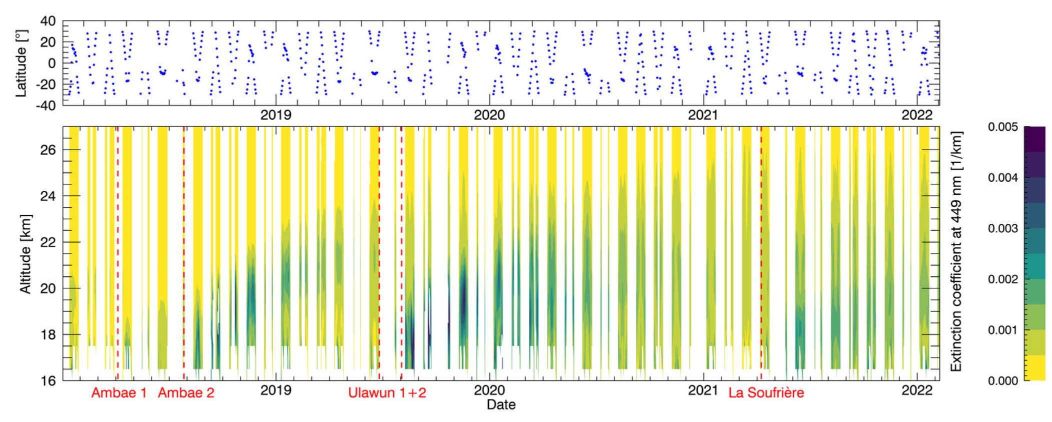
doi: 10.5194/egusphere-2023-837

3. Strat. aerosol size reduction

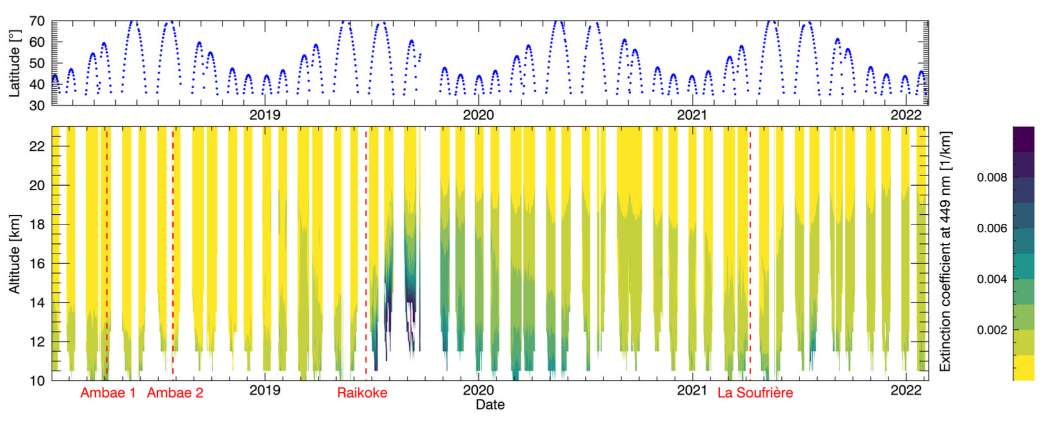
On next slides we will look at 3 phases of volcanic activity in SAGE III/ISS data:

		Latitude	Longitude	Date	SO_2 emission estimate
1	Ambae 1	15°S	168°E	March – April 2018	0.1 Tg
	Ambae 2			July 2018	0.4 Tg
2	Raikoke	48°N	153°E	June, $21^{st}/22^{nd}$ 2019	1.37 Tg
	Ulawun 1	5°S	151°E	June, 26^{th} 2019	0.14 Tg
	Ulawun 2			August, 3^{rd} 2019	0.3 Tg
3	La Soufrière	13°N	61°W	April, 9^{th} – 22^{nd} 2021	0.4 Tg

Aerosol extinction: Tropics



Aerosol extinction: Northern hemisphere

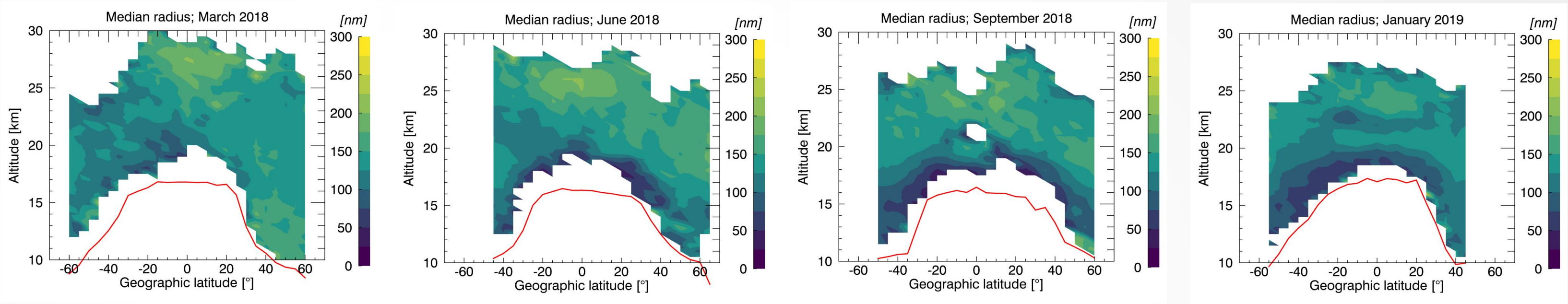


Ambae (15 °S) eruptions

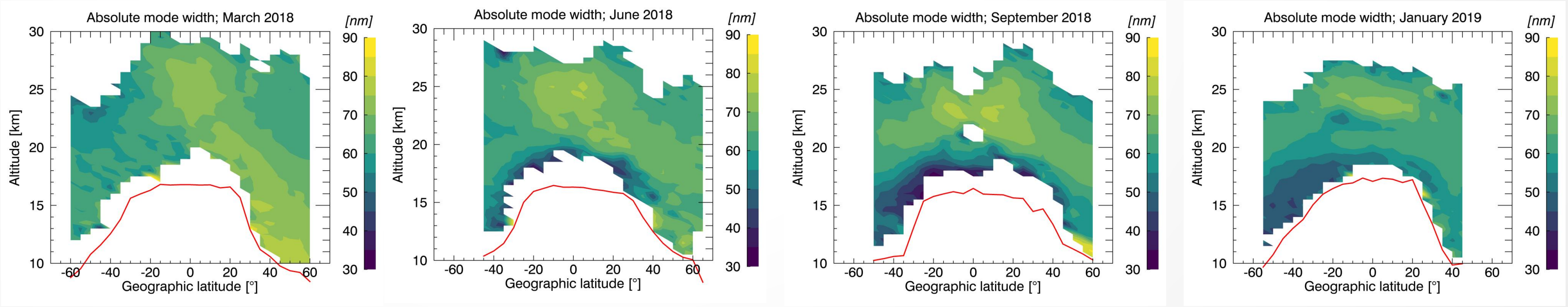
Time

03.2018 06.2018 09.2018 01.2019

Median radius



Absolute mode width



- Ambae (15°S) had 2 main eruptive phases relevant for the stratosphere: In April and in July 2018

  → **Size decrease** (darker colors) in lowermost stratosphere
  → narrower Particle size distribution (PSD) with peak at smaller radius

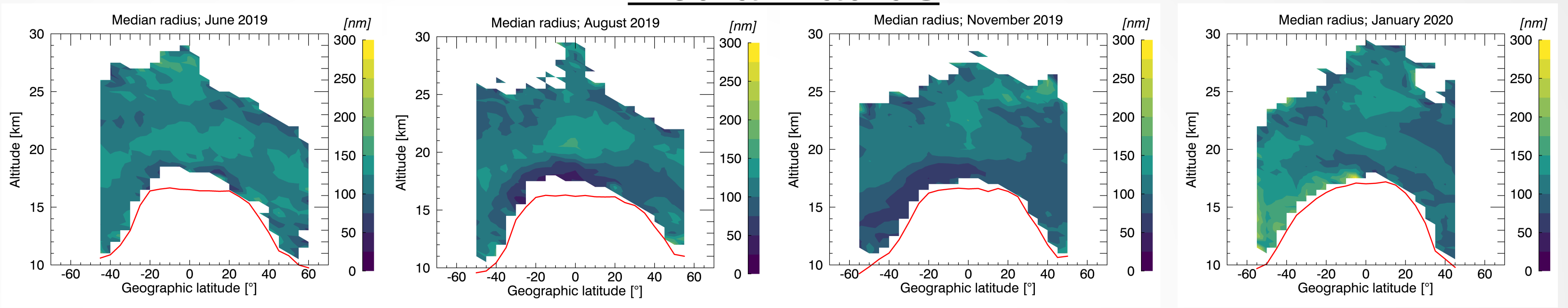
- **Effect lasts for many months!**

Raikoke (48 °N) and Ulawun (5 °S) eruptions

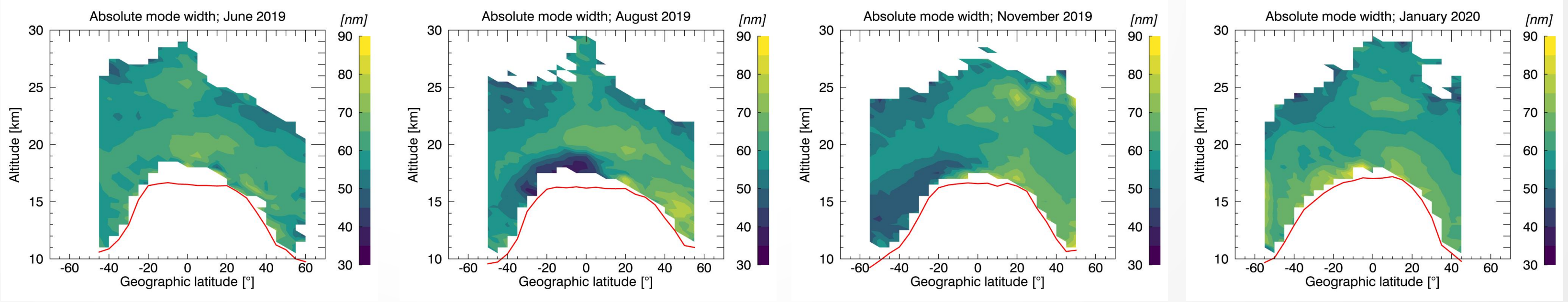
Time

06.2019 08.2019 11.2019 01.2020

Median radius



Absolute mode width



- Raikoke eruption: June 22nd 2019
- Ulawun eruptions: June 26th and August 3rd 2019

→ Size **increase** over Raikoke, while **decrease** over Ulawun!

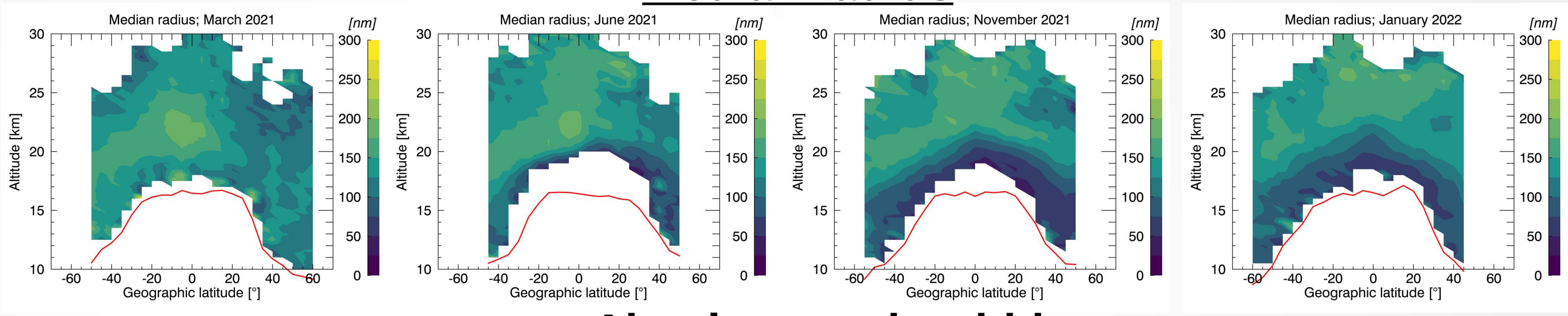
La Soufrière (13 °N) eruption

VOLIMPACT

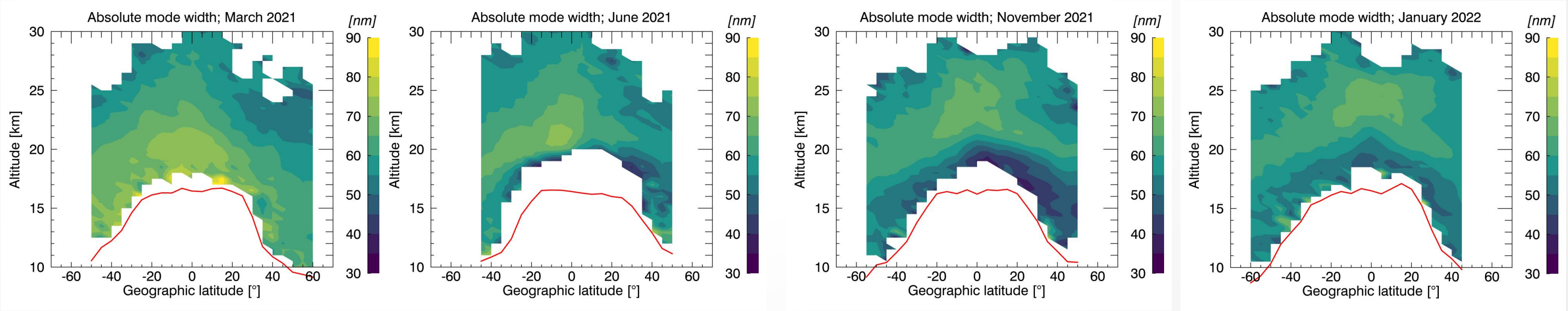
Time

03.2021 06.2021 11.2021 01.2022

Median radius



Absolute mode width



- La Soufrière eruption: April 9th 2021

→ Size **decrease** similar to Ambae eruption

Short summary

Ambae, Ulawun and La Soufrière
- Strong decrease in median radius and absolute distribution width
- Strong increase in number density

- SO_2 injections 0.1-0.4 Tg
- Tropical latitudes → lower temperatures

Raikoke
- Increase in median radius and absolute distribution width
- Increase in number density

- SO_2 injection of 1.37 Tg
- Mid latitude

Possible explanation for size decrease:
Enhanced homogeneous nucleation as opposed to condensation onto existing particles

Factors controlling nucleation vs condensation:
- Temperature
- Background aerosol PSD
- SO_2 mass injected / H_2SO_4 oversaturation

1. Overview VolImpact research group

2. Aerosol size retrieval method

3. Aerosol size reduction after smaller volcanic eruptions

4. Model simulations of Raikoke/Ulawun

5. Short look at Hunga Tonga – Hunga Ha’apai

VOLIMPACT

Comparison to model simulations

- MA**ECHAM**5-HAM = general circulation model coupled with aerosol microphysical model
- ECHAM includes stratospheric sulfur chemistry and aerosol microphysics (nucleation, coagulation etc.)
- ECHAM model simulations in this work set up by Ulrike Niemeier (Max-Planck Institut für Meteorologie Hamburg)
- Can the ECHAM model be used to understand the underlying causes of the aerosol size decrease?

4. Model simulations of Raikoke/Ulawun

- Test case chosen: Raikoke and Ulawun eruptions of 2019
  - Reminder: both had opposite effects on stratospheric aerosol size
- A vertically resolved profile of SO_2 masses is injected into the lower stratosphere for each eruption

	Raikoke	Ulawun	
Latitude	48°N	5°S	
Longitude	153°E	151°E	
Date of eruption	22.06.2019	26.06.2019	03.08.2019
Injected SO2 mass	1.37 Tg	0.14 Tg	0.3 Tg
Injection Pressure Level	140 hPa	100 hPa	90 hPa

Relevant parameters of the Raikoke and Ulawun eruptions as used in the ECHAM simulations

4. Model simulations of Raikoke/Ulawun : Extinction

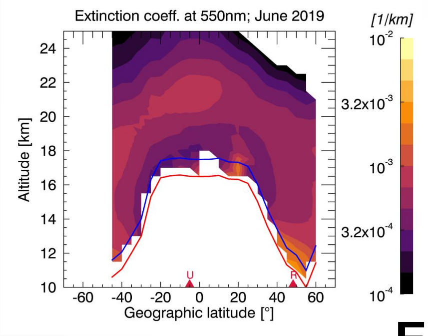
Aerosol extinction at 550 nm

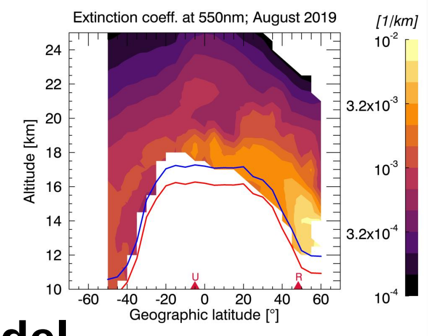
- Temporal and spatial sampling of SAGE III/ISS sampling applied to ECHAM model output
- Good agreement between model and observations
- Important to include previous eruptions in simulations

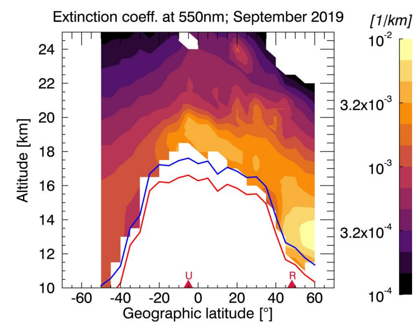
Time

06.2019 ... 08.2019 09.2019

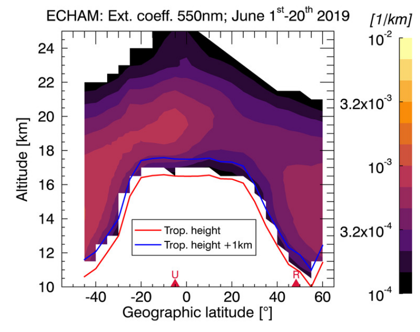
SAGE III/ISS (observational retrieval)

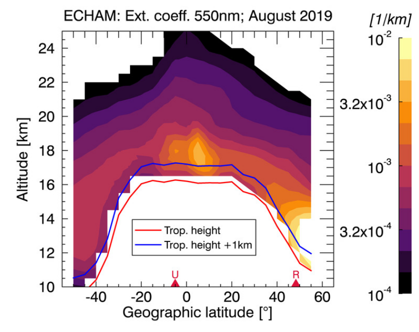


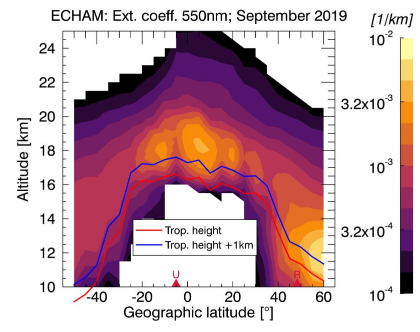




ECHAM model







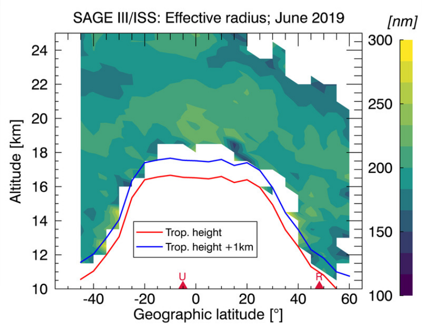
4. Model simulations of Raikoke/Ulawun: Effective radius

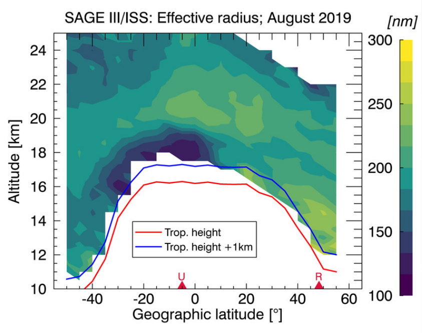
Effective radius

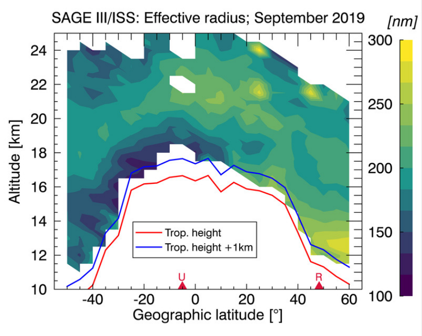
Time

06.2019 ... 08.2019 09.2019

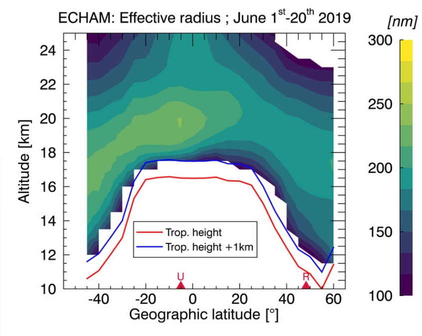
SAGE III/ISS (observational retrieval)

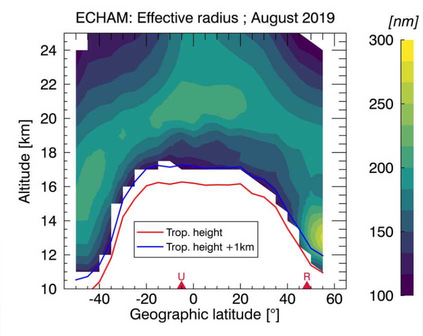


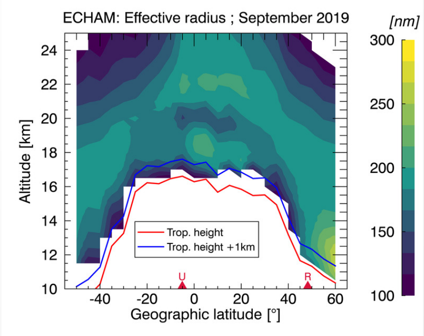




ECHAM model







- Both model and simulations show increase over Raikoke area and decrease over Ulawun area in lowermost stratosphere
- Starting in September tropical values increase strongly in the model, but not in observations

4. Model simulations of Raikoke/Ulawun

VOLIMPACT

- Possible explanations for discrepancy in longer-term aerosol size evolution:
  - possible overestimation of coagulation in the model
  - Lack of interactive OH chemistry in the model
  - Deviations in dynamics
  - Wrong assumption on aerosol composition in retrieval
- → started to compare with other models now (with sectional PSD instead of 4 modes)

1. Overview VolImpact research group

2. Aerosol size retrieval method

3. Aerosol size reduction after smaller volcanic eruptions

4. Model simulations of Raikoke/Ulawun

5. Short look at Hunga Tonga – Hunga Ha’apai

Spatial evolution of aerosol size after Hunga-Tonga

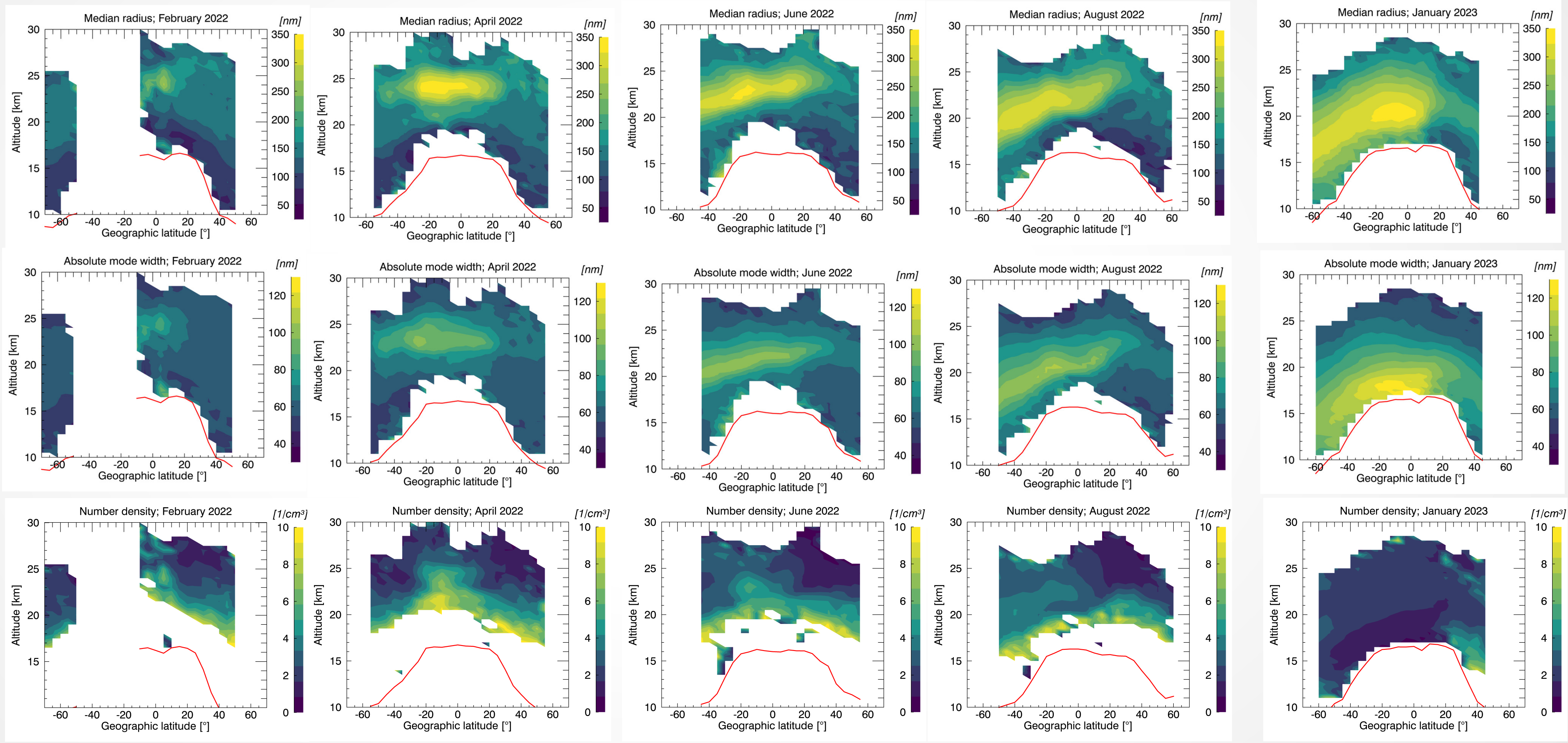
Time

02.2022 | 04.2022 | 06.2022 | 08.2022 | ... | 01.2023

Median radius

Absolute mode width

Number density



How did the size distributions change?

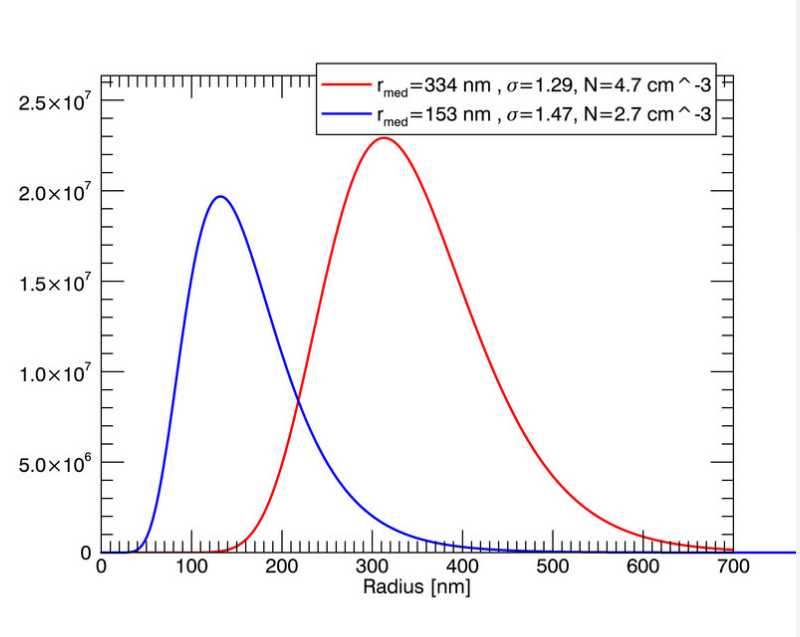
VOLIMPACT

- Plot to the right: Characteristic PSDs before and after HT:

  15°S, 22.5 km altitude, monthly mean
  Graphs shown:
- "Background" November 2021
- After Hunga-Tonga: June 2022

- Although σ decreased the size distribution became wider
  (as previously shown by the increase in absolute mode width ω)

- See more in recently submitted paper: Duchamp et al. (2023,GRL)



Observation of the aerosol plume from the 2022 Hunga Tonga - Hunga Ha'apai eruption with SAGE III/ISS

AEROSOLS | SATELLITE RETRIEVAL | VOLCANIC IMPACT

Clair Duchamp, Felix Wrana, Bernard Legras, Pasquale Sellitto, Redha Belhadji, Christian von Savigny

Summary / Outlook

VolImpact

- Some volcanic eruptions lead to a strong decrease in average stratospheric aerosol size
- This size decrease can last for many months
- MAECHAM5-HAM could well reproduce the first months of strat. aerosol size development after Raikoke and Ulawun
- The model seems to struggle to reproduce the longterm development of the stratospheric aerosol size
- We will look at different models to compare to (e.g. sectional models)

VolImpact summer school on volcanic effects on atmosphere and climate

September 4 – 8, 2023
Institute of Physics
University of Greifswald
Germany

Topics include:

- Volcanic emissions
- Climate effects, cloud effects and dynamical effects of volcanic eruptions
- Plume and global modelling
- Volcanic dispersion modelling
- In-situ and satellite observations
- Retrieval theory

The summer school also includes modelling and remote sensing labs

Confirmed speakers:

Prof. John Burrows FRS (U Bremen)
Dr. Thor Hansteen (Geomar Kiel)
Prof. Jim Haywood (U Exeter)
Dr. Akos Horvath (U Hamburg)
Dr. Ali Hoshyaripour (KIT)
Dr. Christopher Kadow (DKRZ)
Prof. Dr. Kirstin Krüger (U Oslo)
Dr. Alexei Rozanov (U Bremen)
Prof. Pasquale Selitto (IPSL)
Dr. Ghassan Taha (NASA/GSFC)
Dr. Claudia Timmreck (MPI-M Hamburg)
Prof. Matt Toohey (U Saskatchewan)

To apply & for more information visit:

https://volimpact.org

Application deadline: July 15, 2023

Limited to 30 participants

Funding for the summer school is provided by DFG through the research unit VolImpact (FOR 2820)

Appendix

2. Filtering out noisy data

- Uncertainties of the SAGE III/ISS aerosol extinction coefficients accounted for in terms of a defined “accuracy parameter” a:

$$a = \frac{\Delta_x}{\delta_{f_x}} \cdot \frac{\Delta_y}{\delta_{f_y}}$$

- Where Δx and Δy are the distances between the curves and δfx and δfy are the error bars of an individual measurement point
- Noisy data are filtered out at below a threshold