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The Vorticized Volcanic Plumean unusual stratospheric phenomenon revealed by Aeolus wind profiling

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Mathieu Ratynski

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The Vorticized Volcanic Plume – an unusual stratospheric phenomenon revealed by Aeolus wind profiling



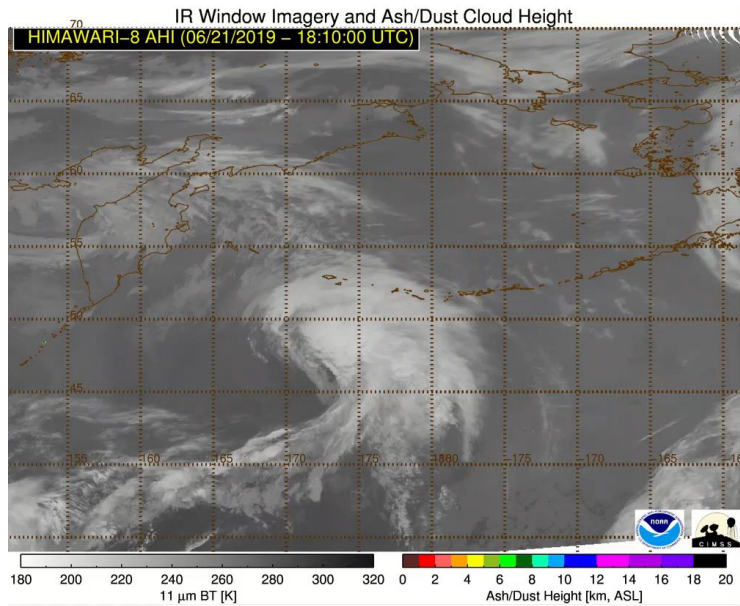
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Sophie Godin-Beekmann¹, Alain Hauchecorne¹, and Mathieu Ratynski¹

¹ *Laboratoire Atmosphères, Observations Spatiales (LATMOS), INSU-CNRS, Guyancourt, France*

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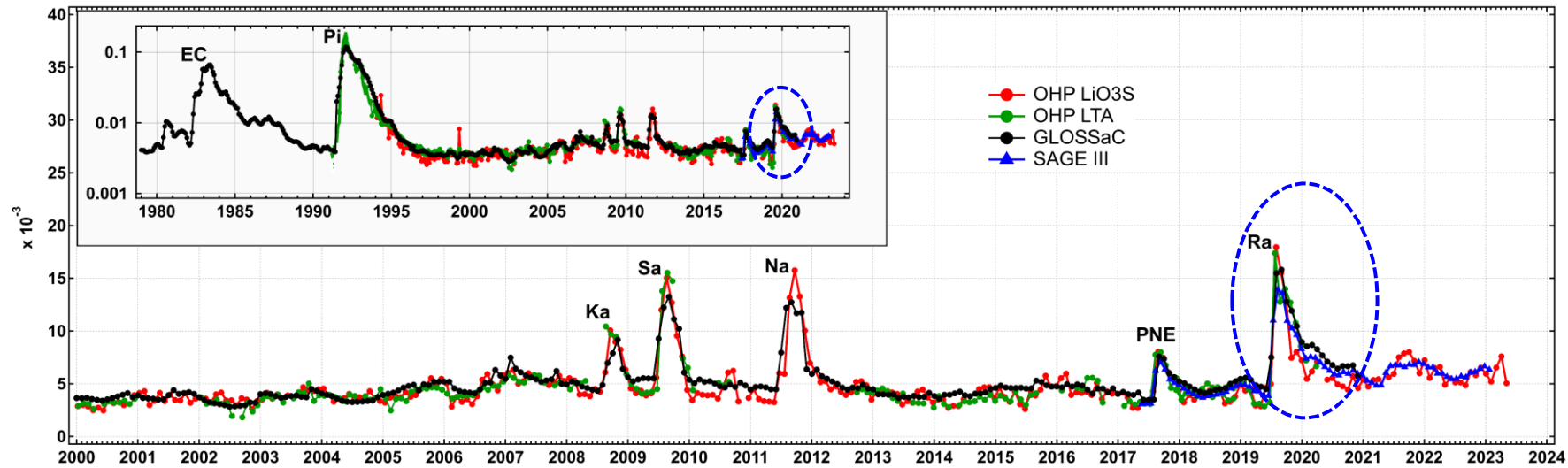


Raikoke eruption 21 June 2019

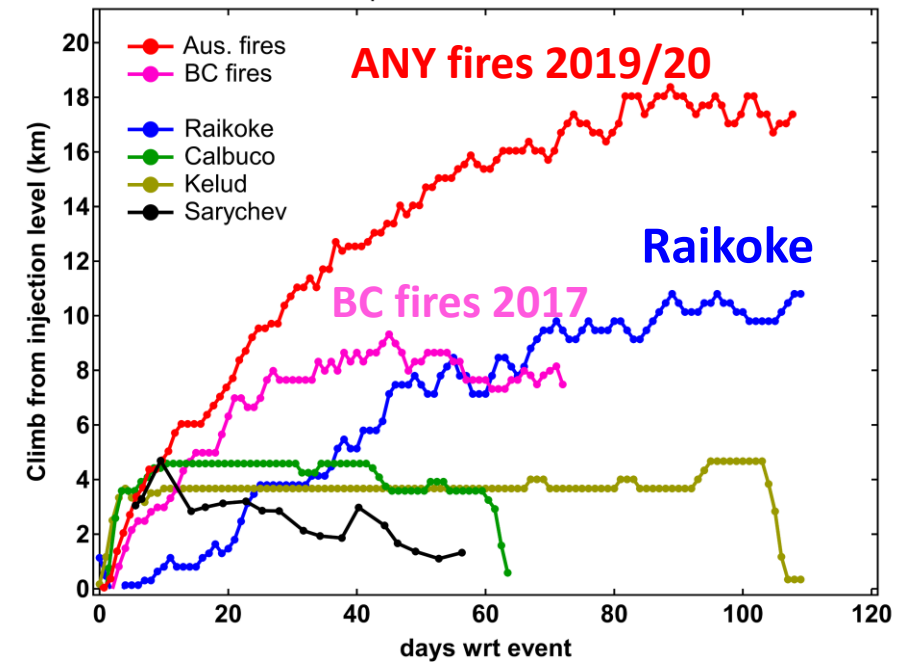


- Injection altitude: 14 – 17 km
- SO₂ injected mass: 1.4 – 2.1 Tg
- Fine ash injected mass: 0.4 - 1.8 Tg
- Strongest NH eruption since Pinatubo
- Unusual self-lofting of Raikoke plume rising diabatically by 11 km (up to 27 km)
- Behavior similar to wildfire smoke plumes

SAOD@532 nm, above 380 K, OHP lidars (44°N) and satellites zonal/monthly means 40° N - 50° N

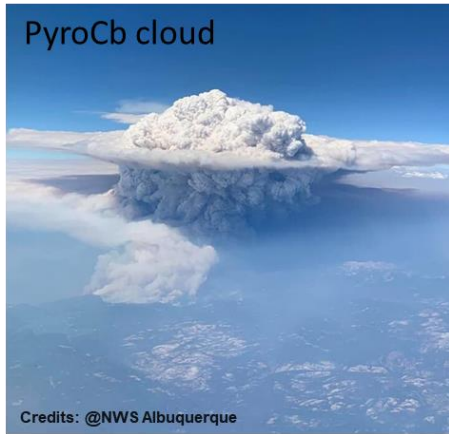


Evolution of aerosol plume maximum altitude

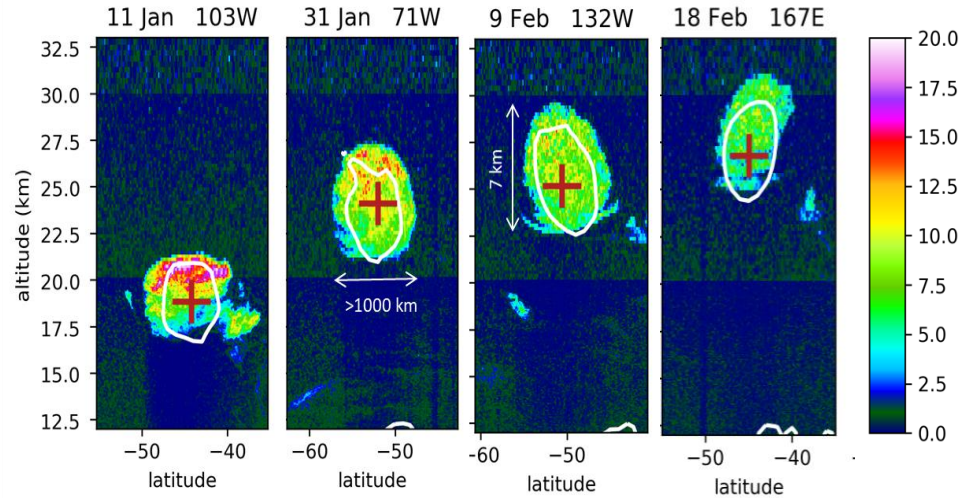


SCV – Smoke-Charged Vortex

Australian ANY fires 2020



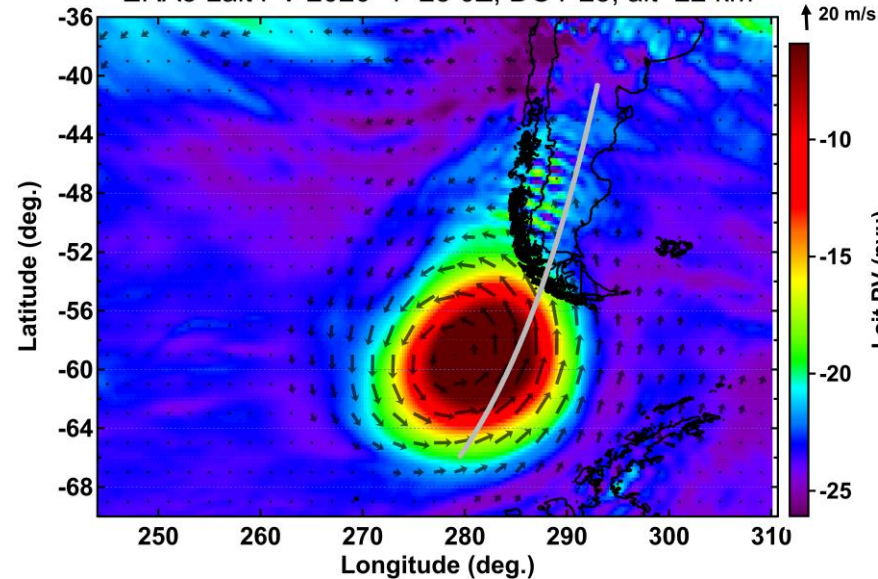
Compact bubble of smoke (CALIOP)



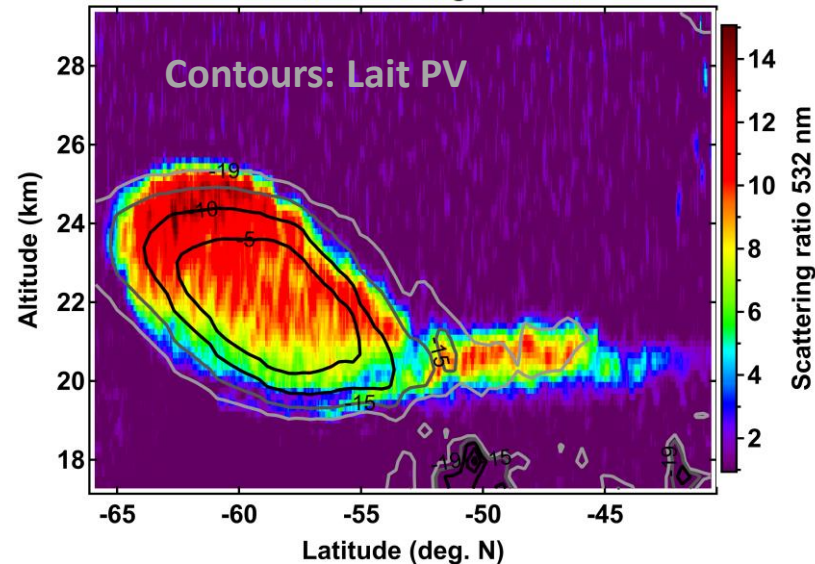
SCV – Smoke-Charged Vortex, confining the injected material and maintaining high concentration of absorptive aerosols inside the bubble and its heating

Khaykin et al., Nat. Com. EE, 2020

ERA5 Lait PV 2020 1 25 0Z, DOY 25, alt=22 km

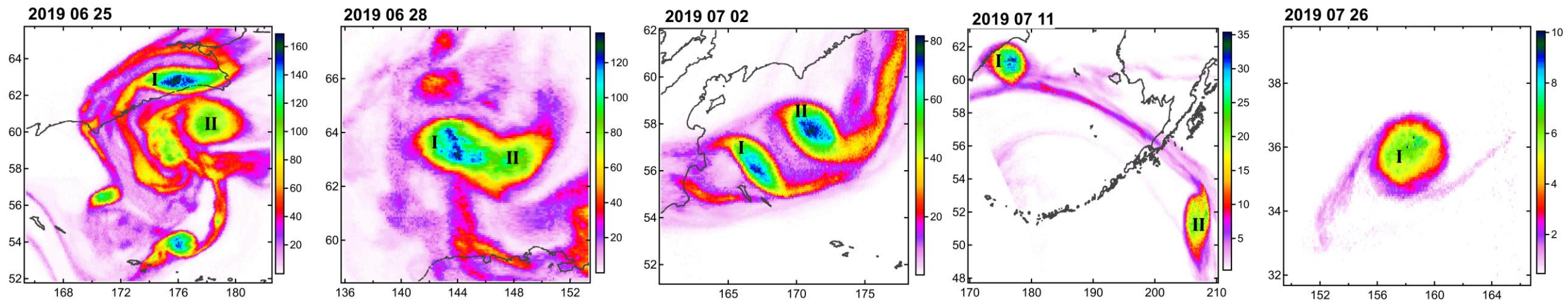


SCV1 DOY 25, Lon 287 deg.E

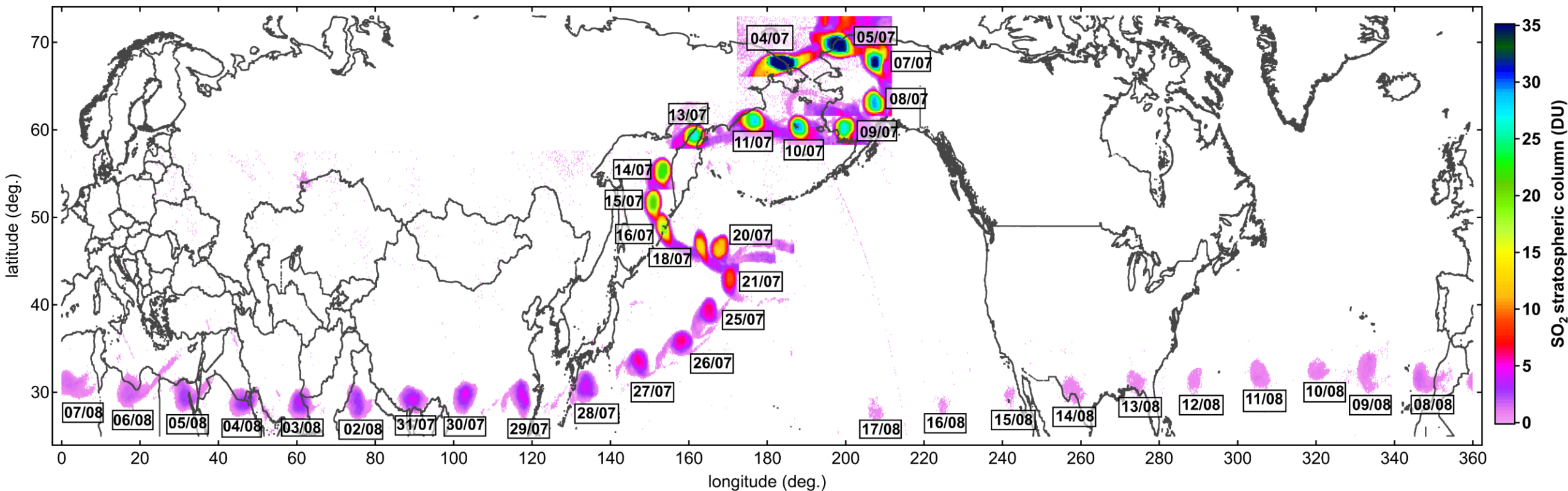


Any sizable injection of smoke into the stratosphere produces an SCV

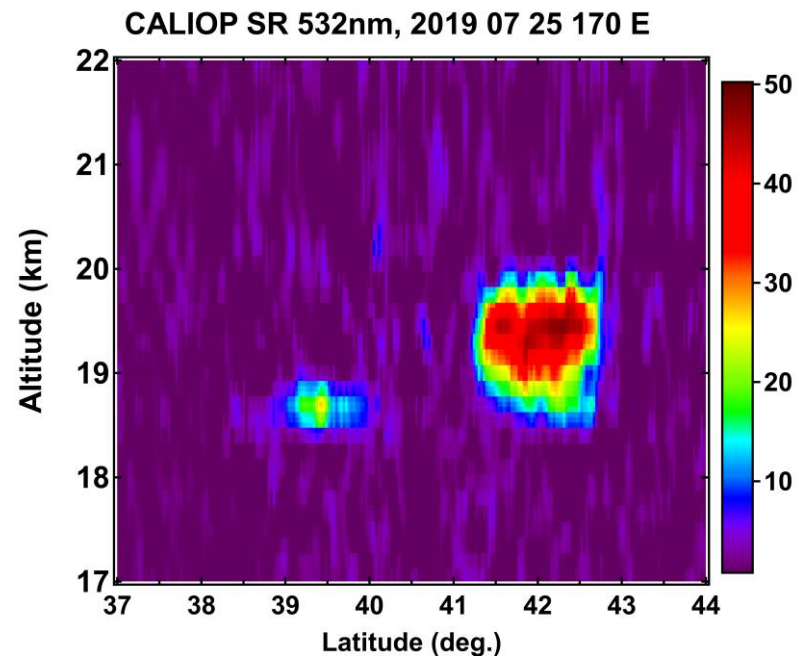
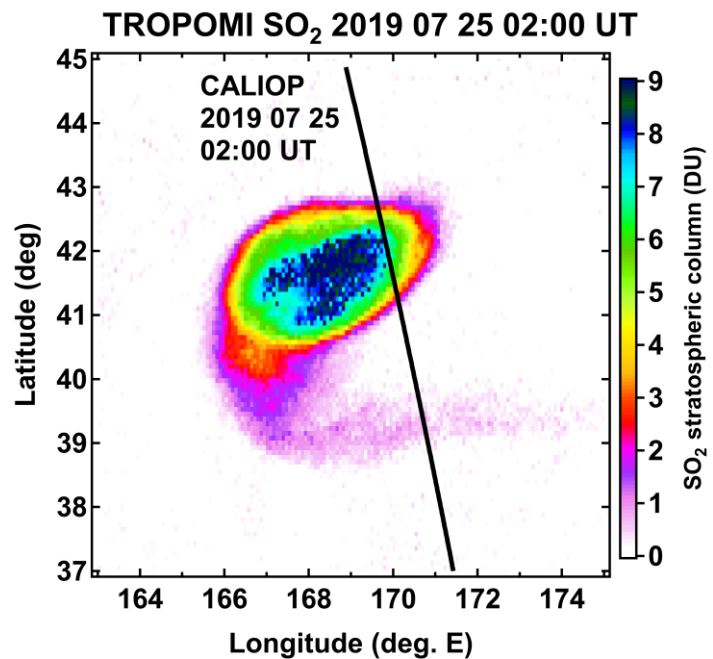
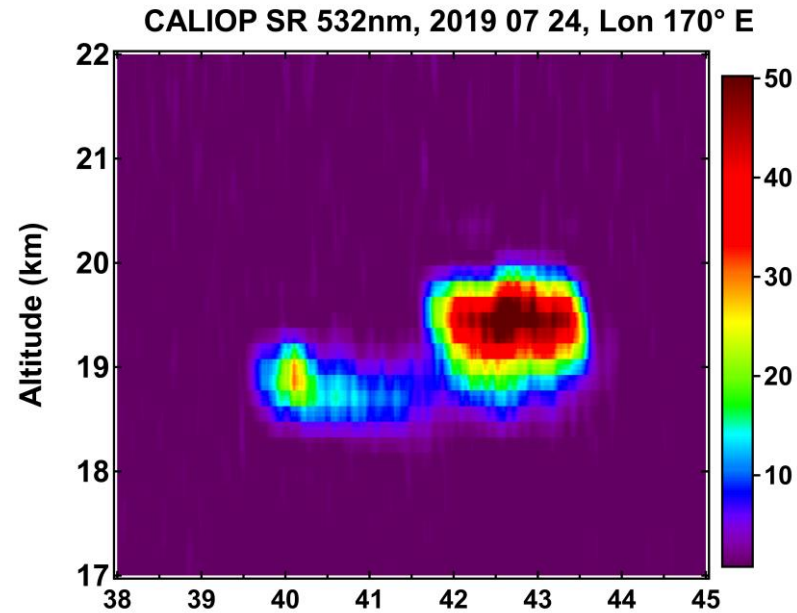
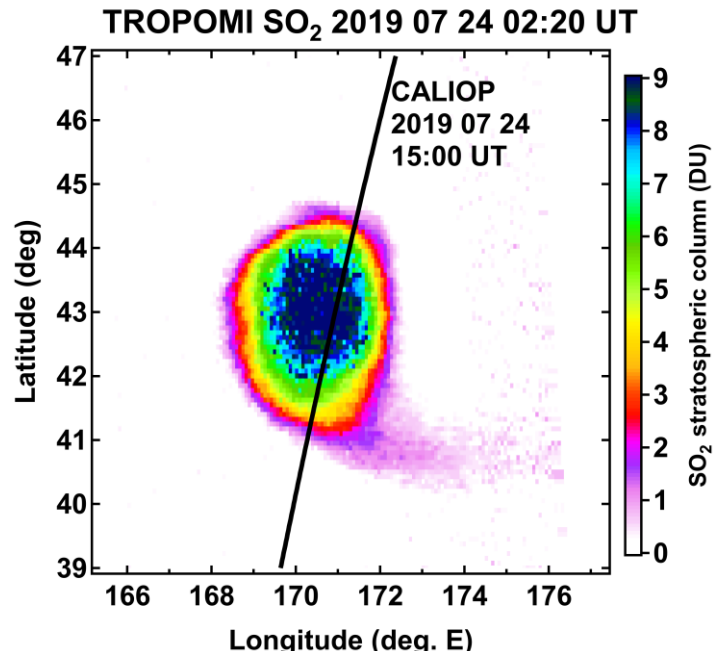
Confinement of volcanic material (TROPOMI SO₂)



TROPOMI SO₂ primary plume evolution



Confinement of volcanic material

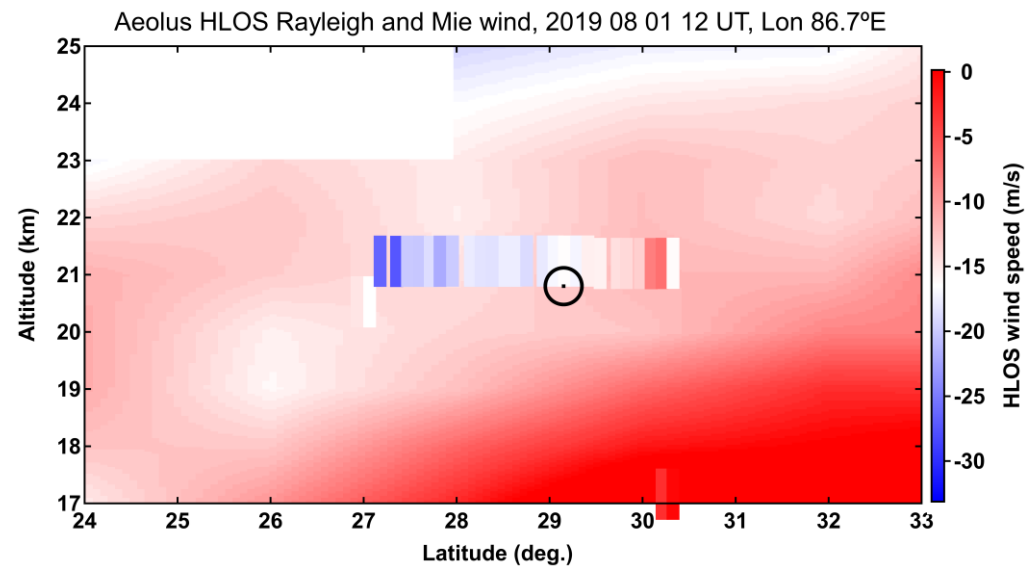
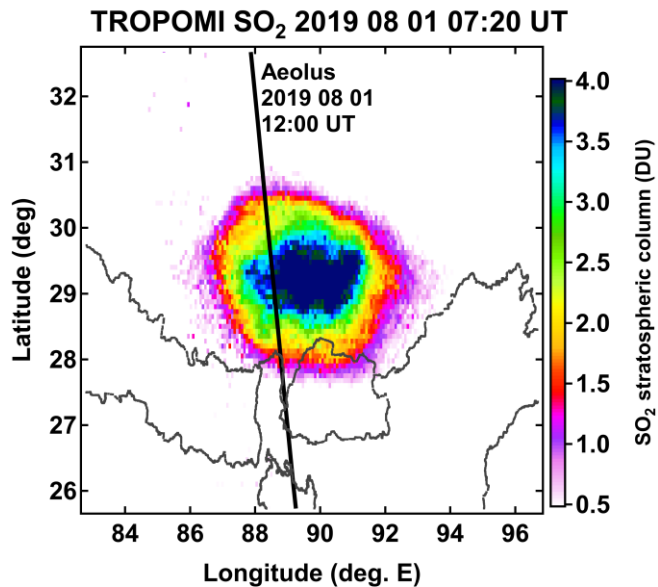
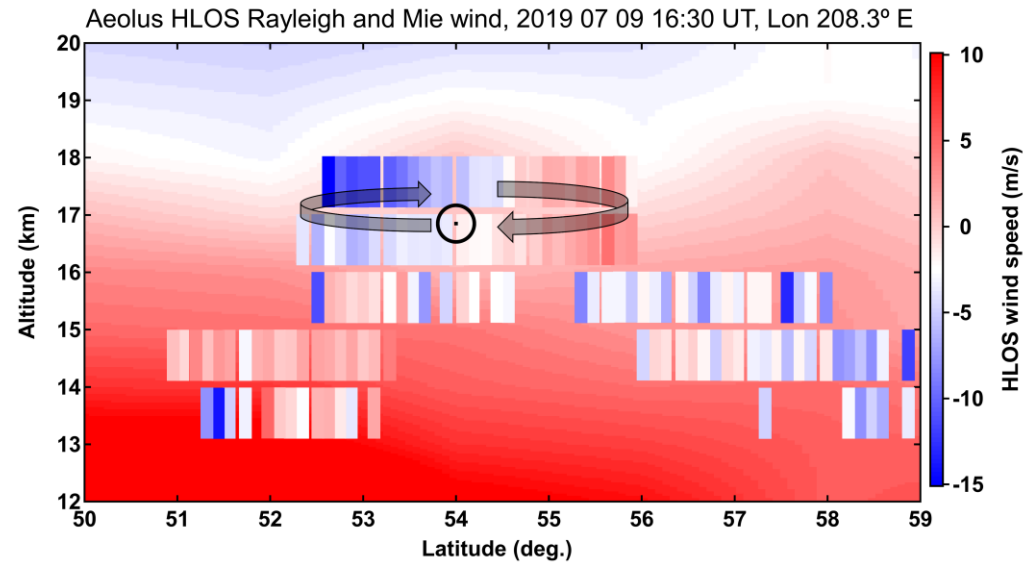
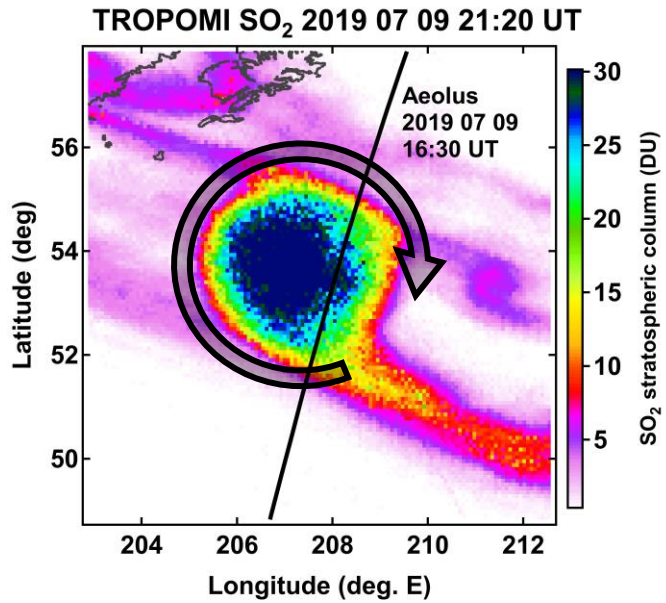


- Persistent compact and circular shape of the volcanic plume's core
- Bottom-side tailing and inverted comma shape
- Indications for anticyclonic motion but no clear confirmation from ERA5 data

Khaykin et al., Sci. Rep., 2022

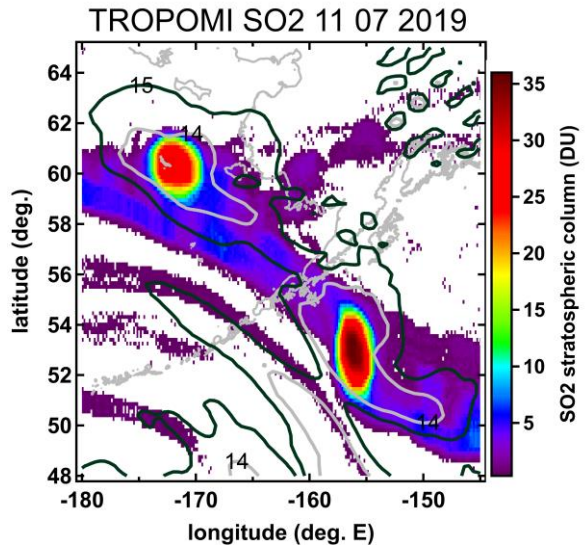
VVP – Vorticized Volcanic Plume

AEOLUS to provide unique observational evidence for rotation of the plume

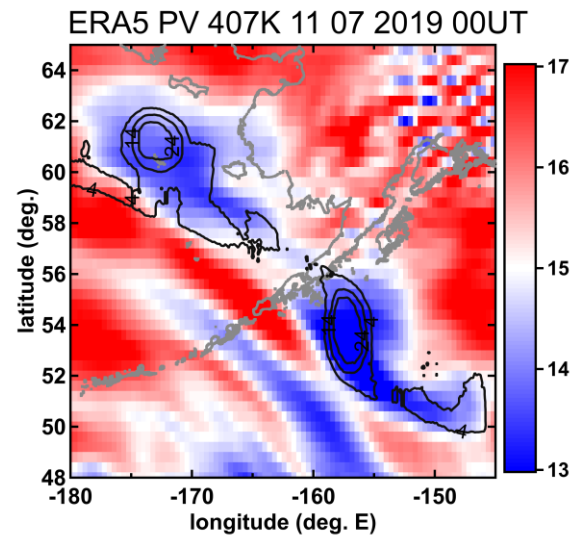


VVP in ERA5

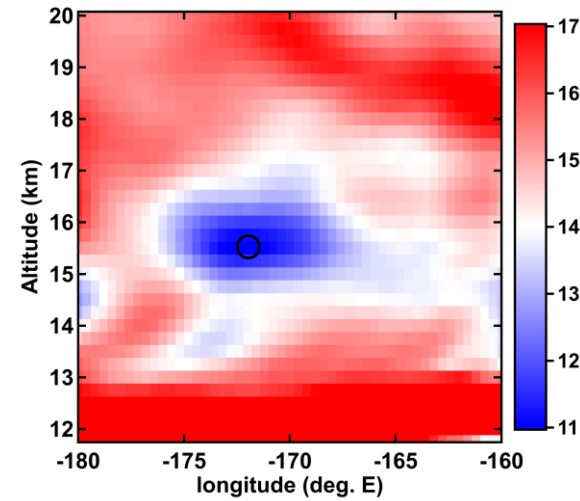
TROPOMI SO₂



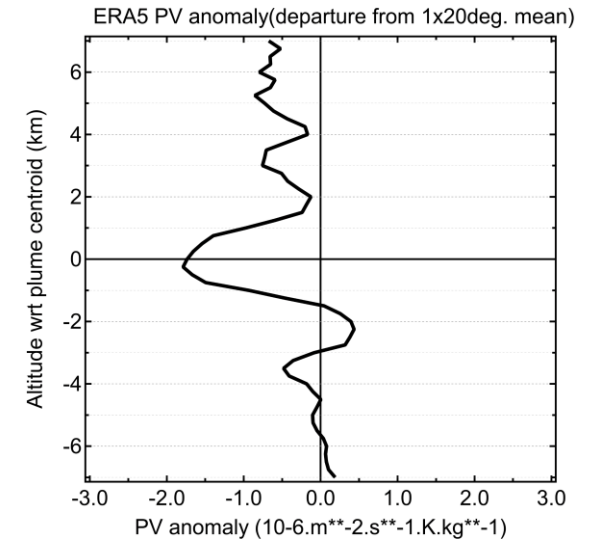
ERA5 Potential vorticity



ERA5 Lait PV 61°N 11 07 2019

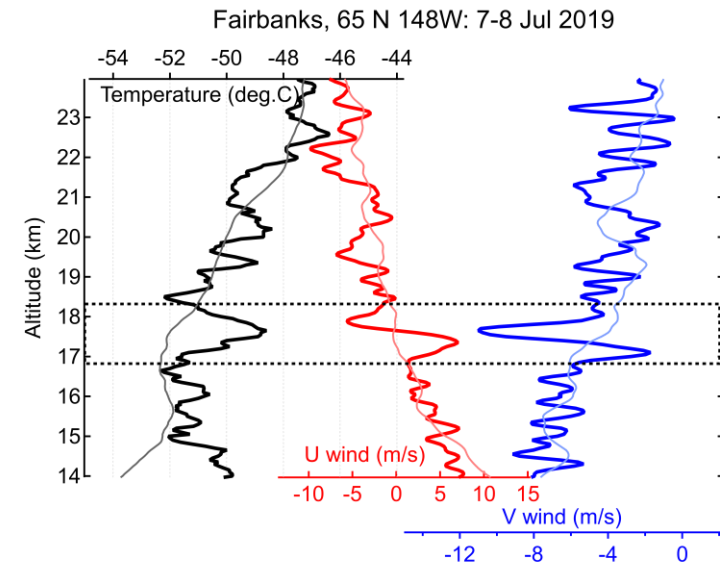


ERA5 PV anomaly composite

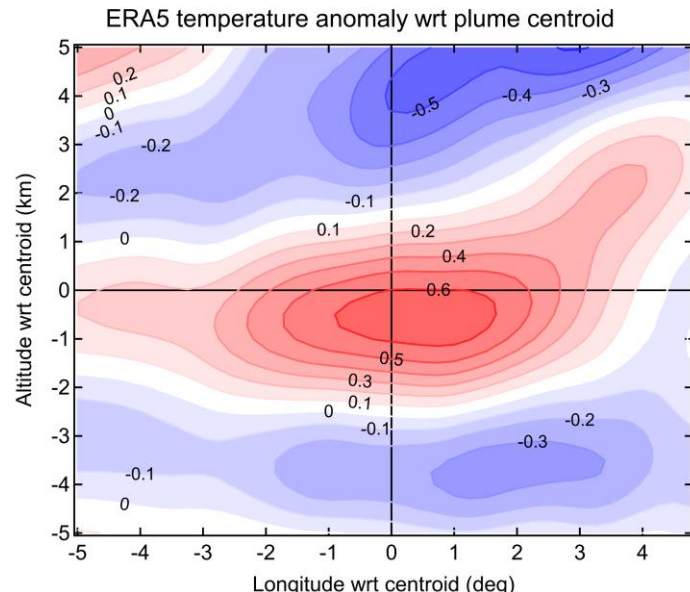
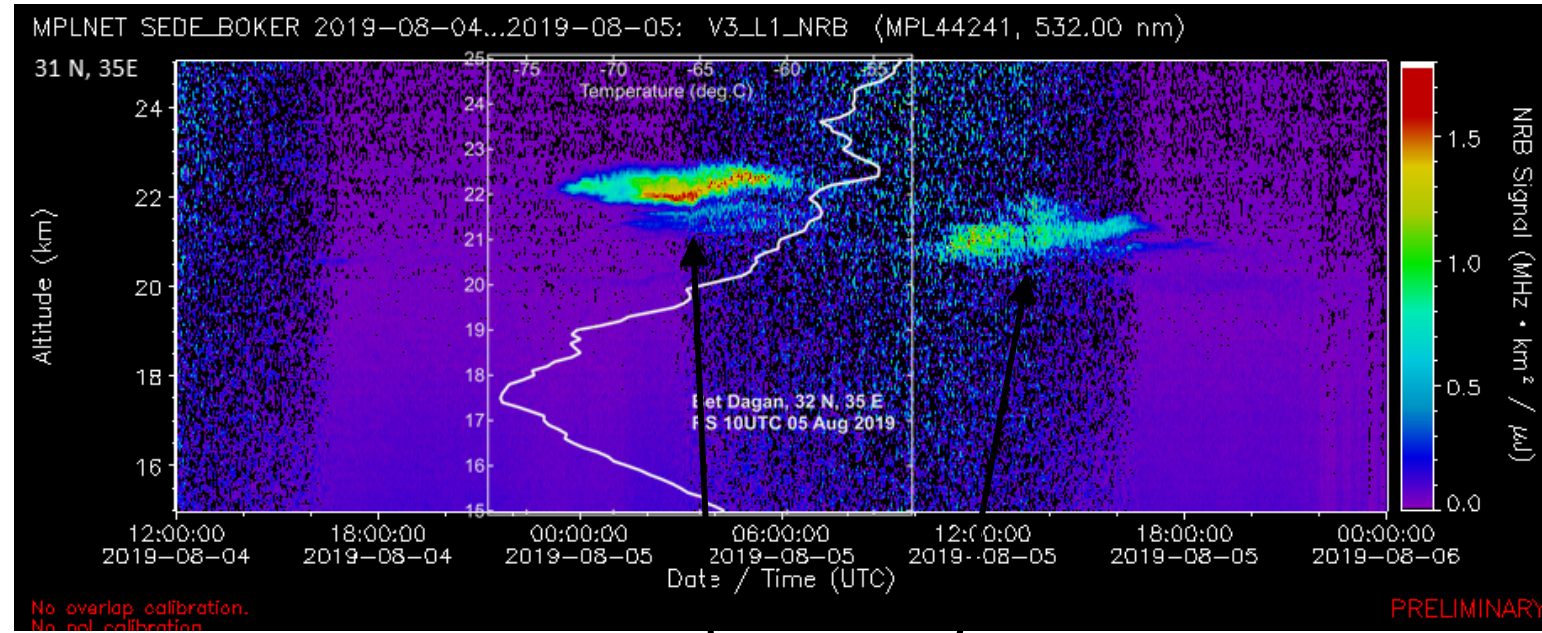
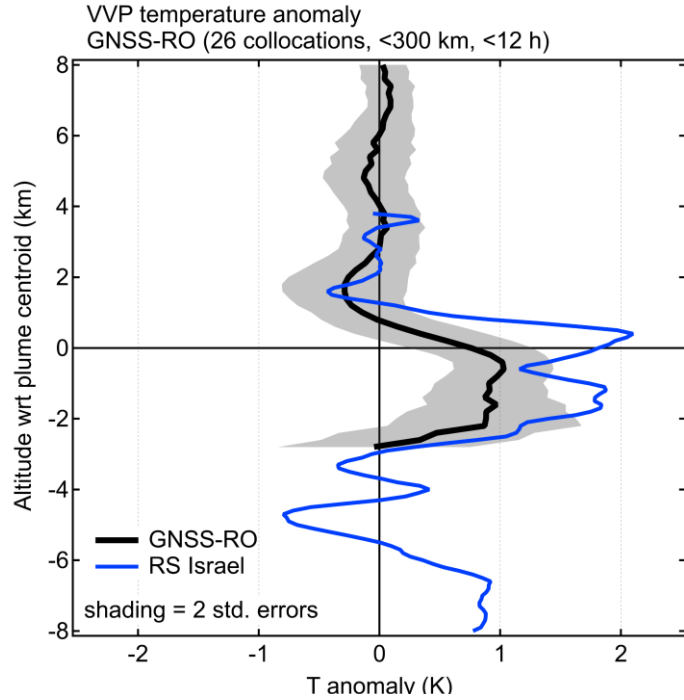


ERA5 reproduces the PV anomaly associated with the plume

VVP sampling by Alaskan radiosoundings

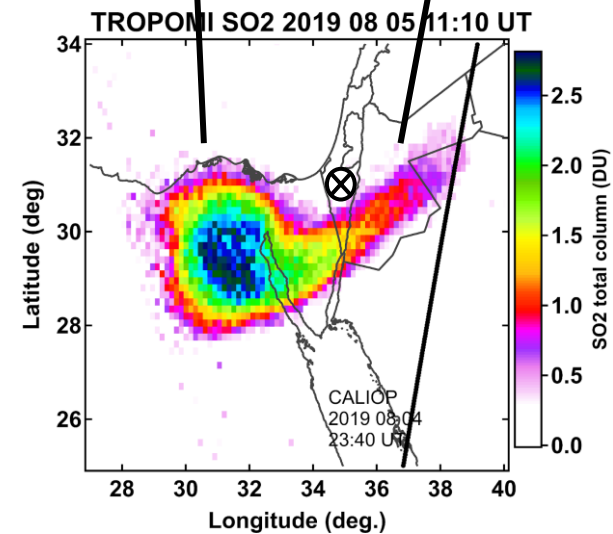


Internal heating of the plume



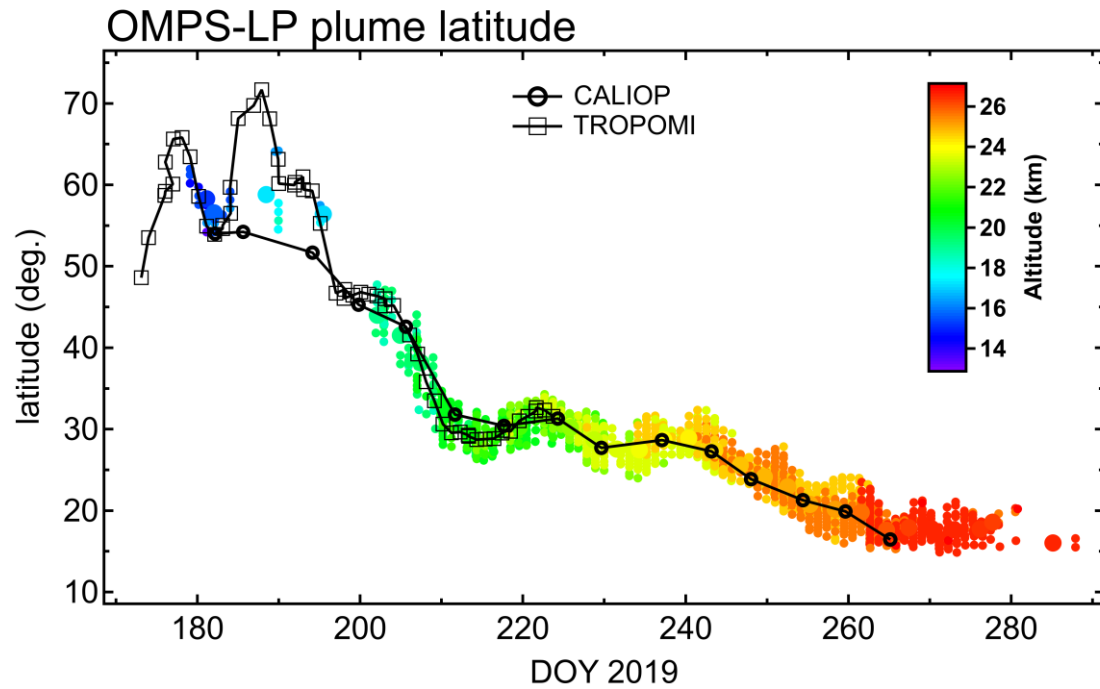
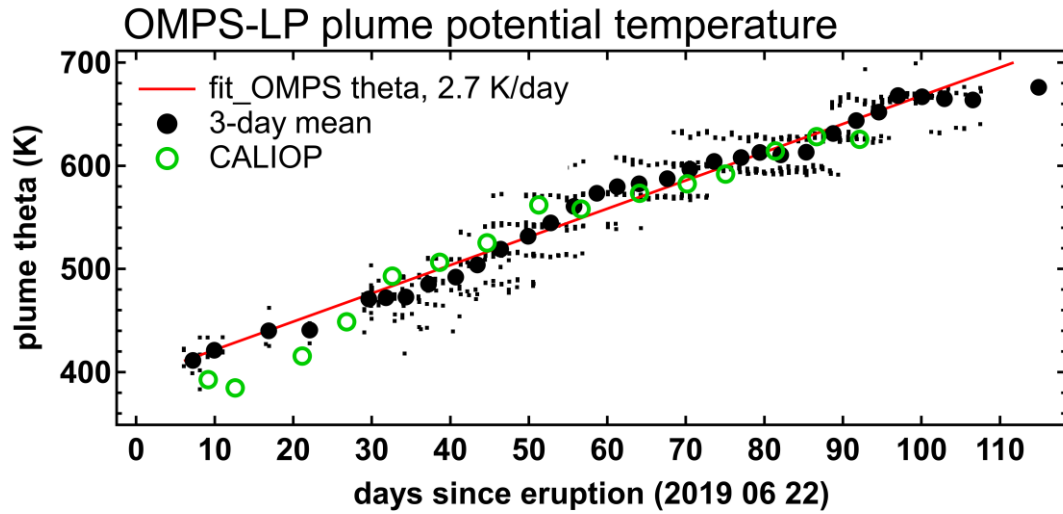
Warm anomaly:

- 1 K (GNSS-RO)
- 0.6 K (ERA5)
- Up to 2 K (RS)

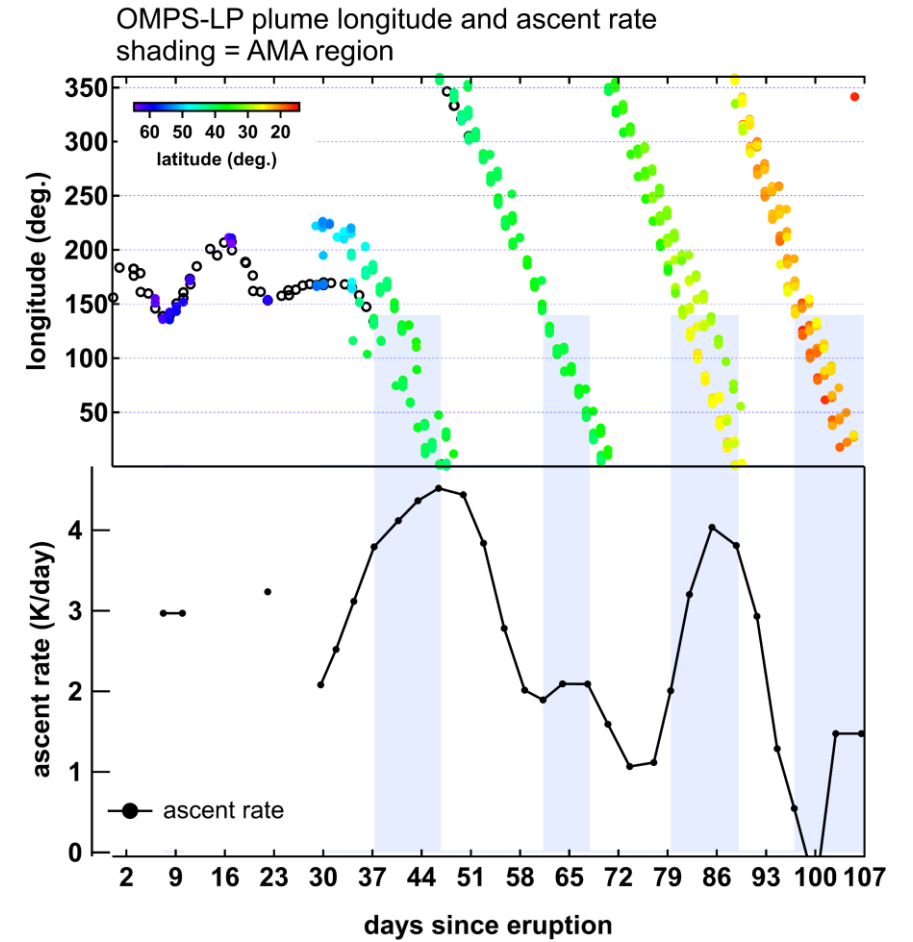


Self-lofting of Raikoke VVP

Diabatic ascent at 2.7 K/day rate up to 27 km



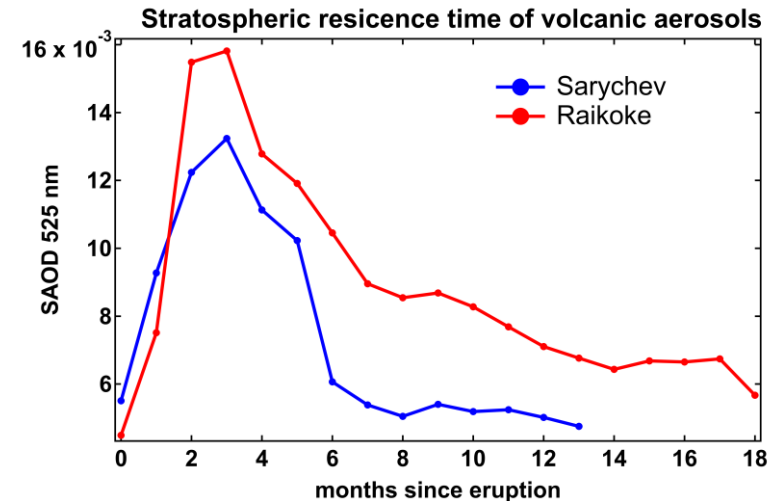
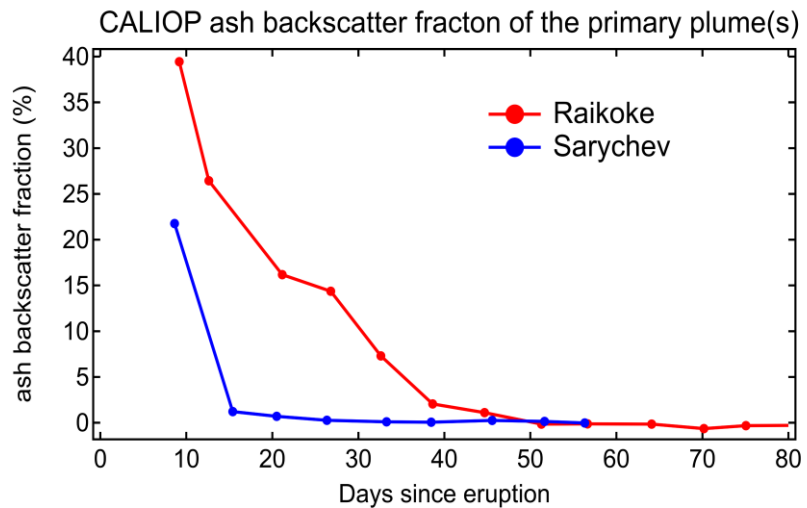
VVP tracking for 3+ months, 3+ circumnavigations



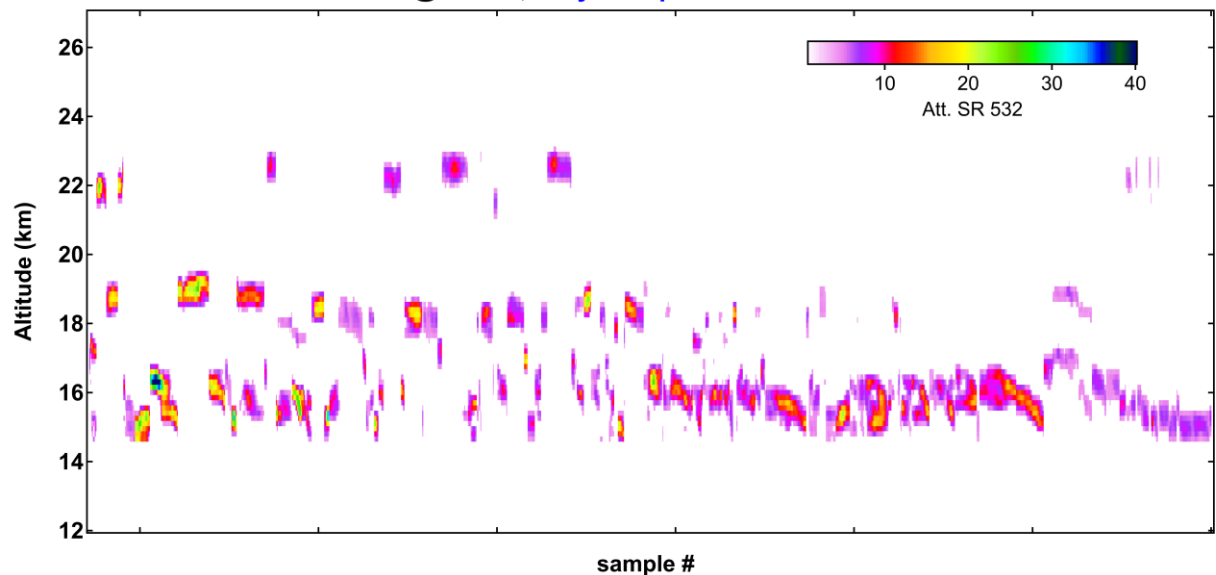
**Acceleration of diabatic rise
during ASM overpasses**

Raikoke vs Sarychev

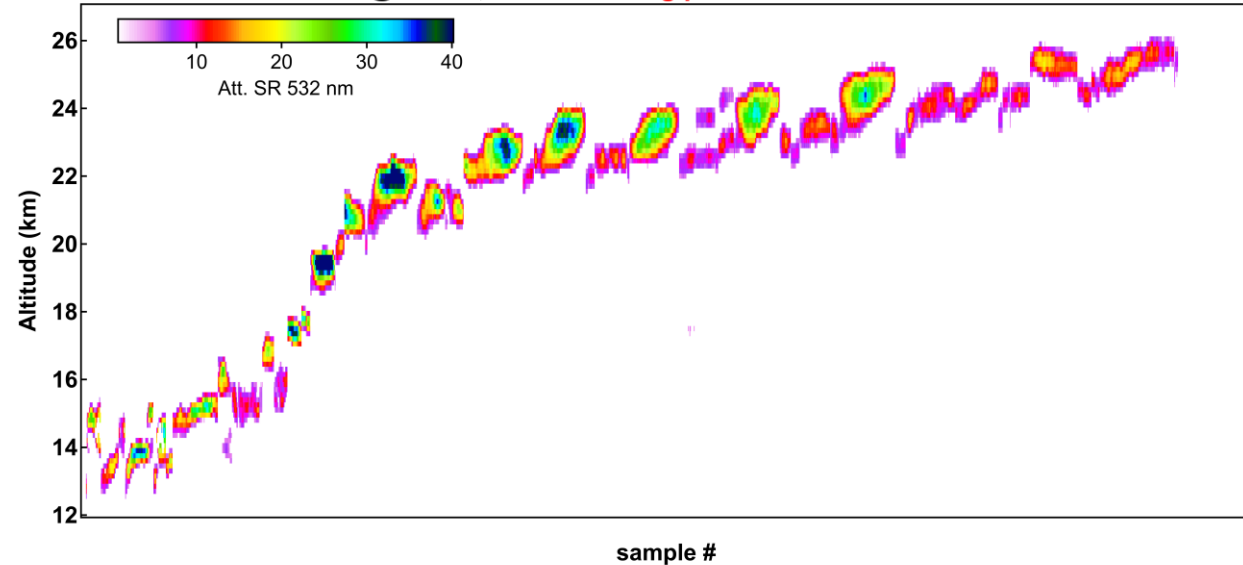
- **Raikoke eruption** was rich in fine ash (strong and persistent depolarization of the plume) as opposed to **Sarychev eruption**
- No self-lofting of **Sarychev** plume
- Prolonged residence time of **Raikoke** aerosol in the stratosphere



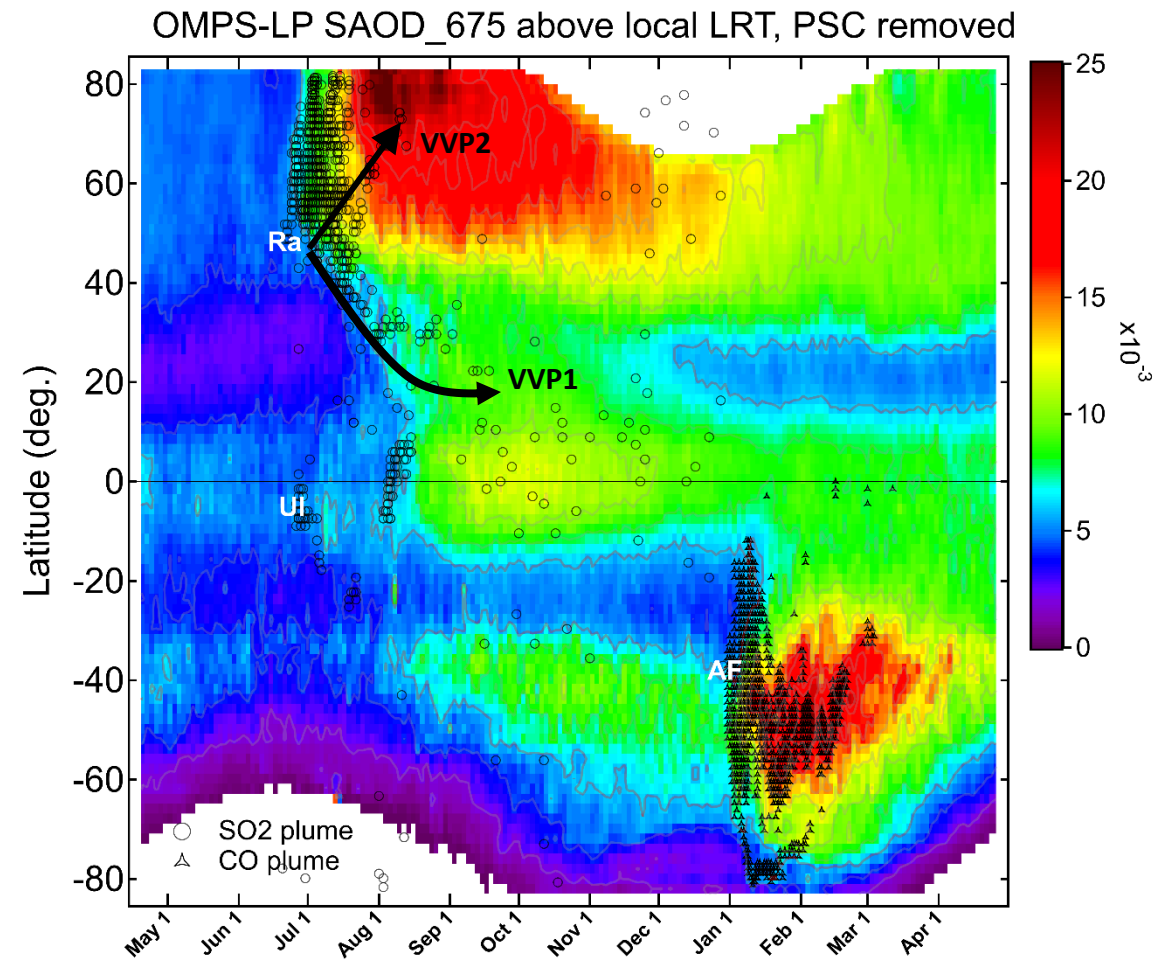
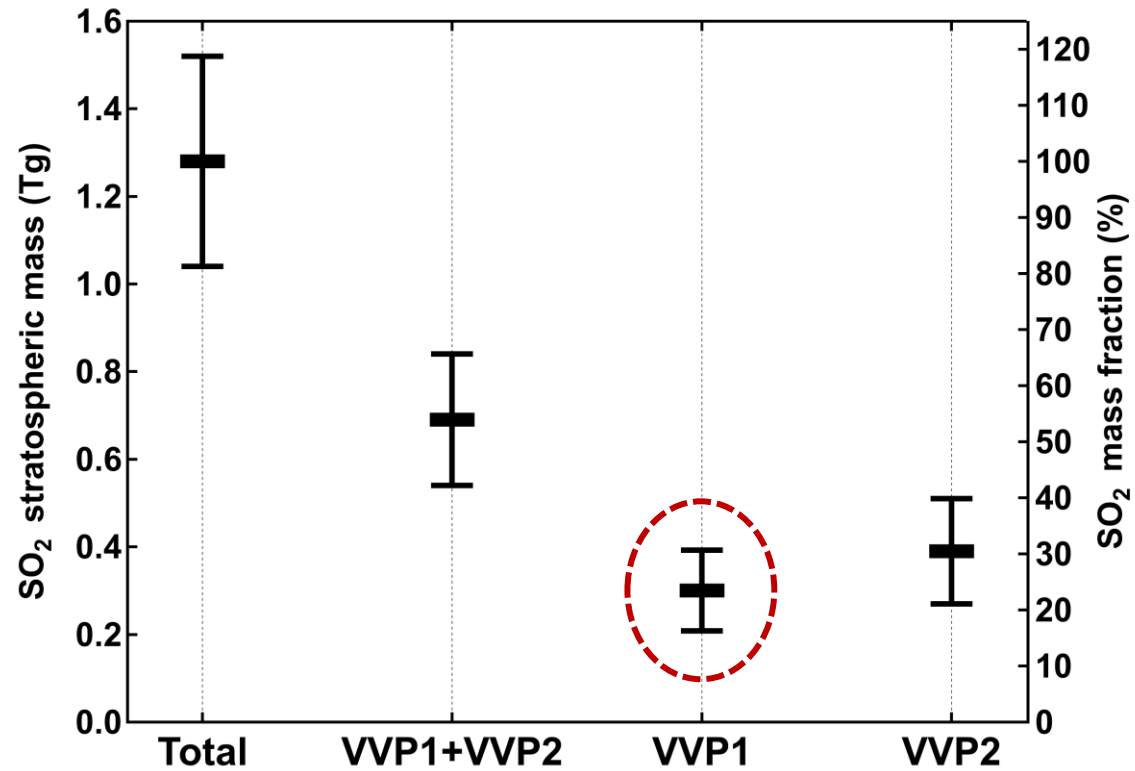
CALIOP attenuated SR@532nm, Sarychev plumes



CALIOP attenuated SR@532nm, Raikoke rising plume

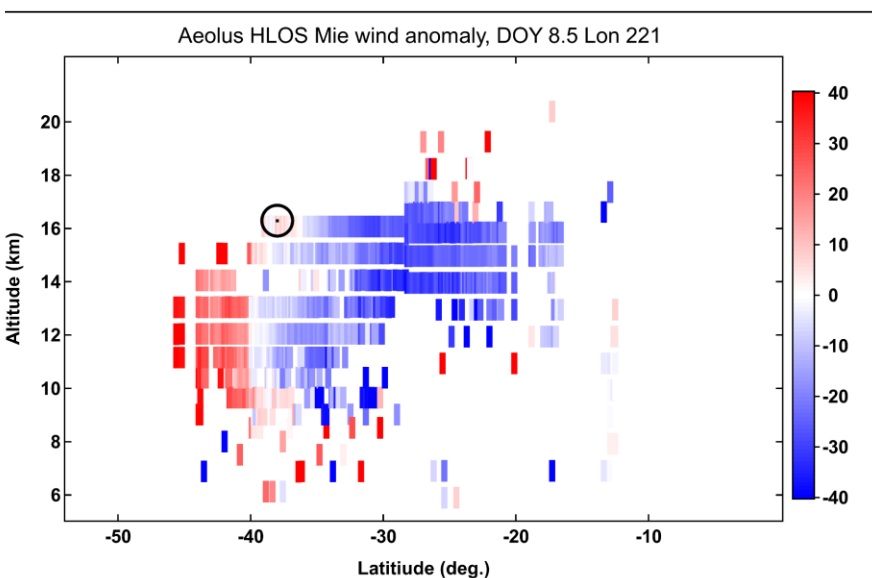
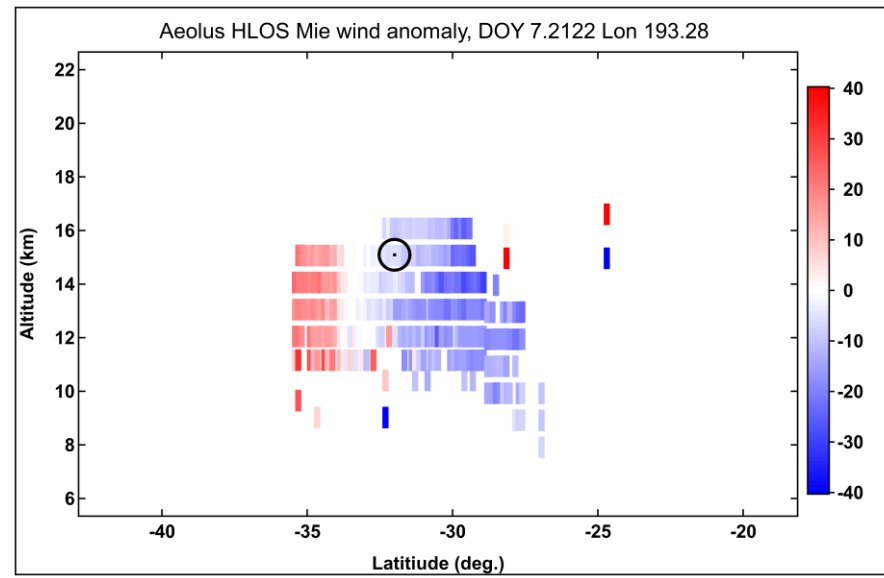
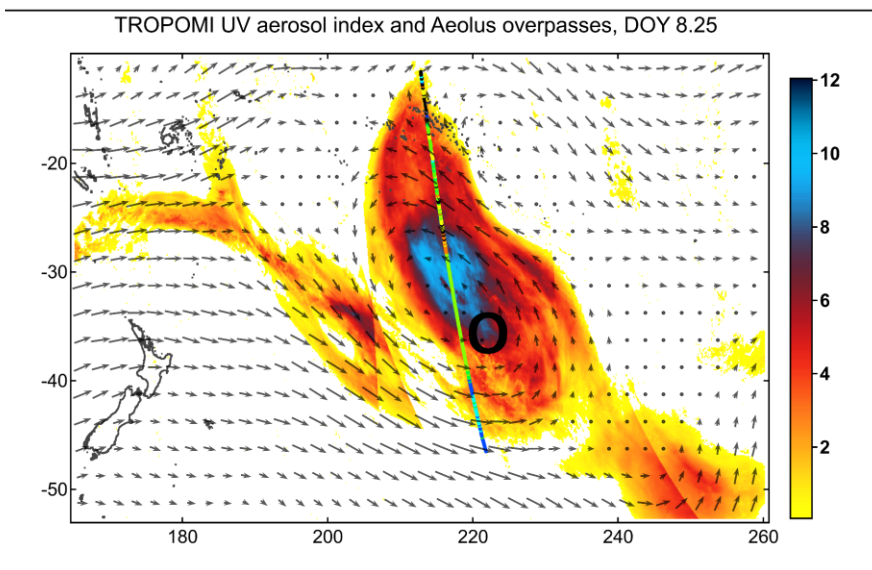
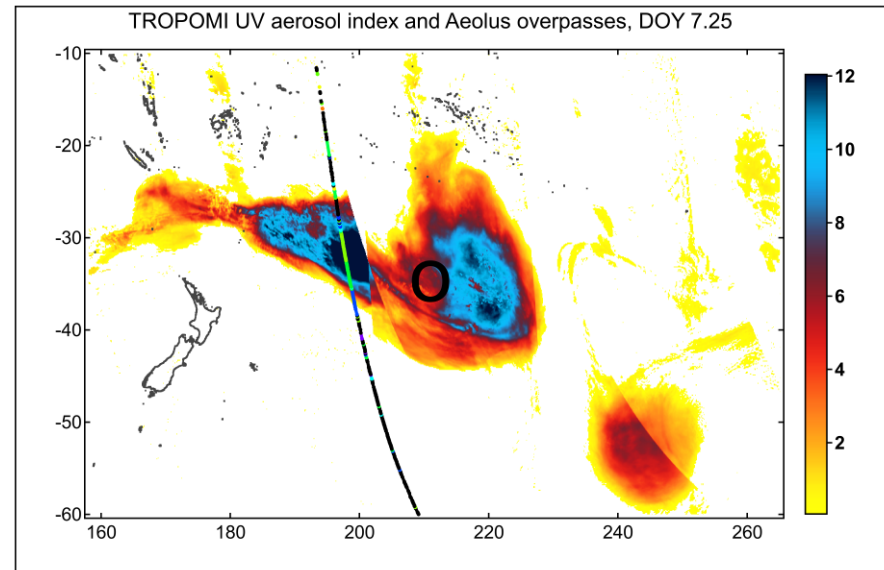
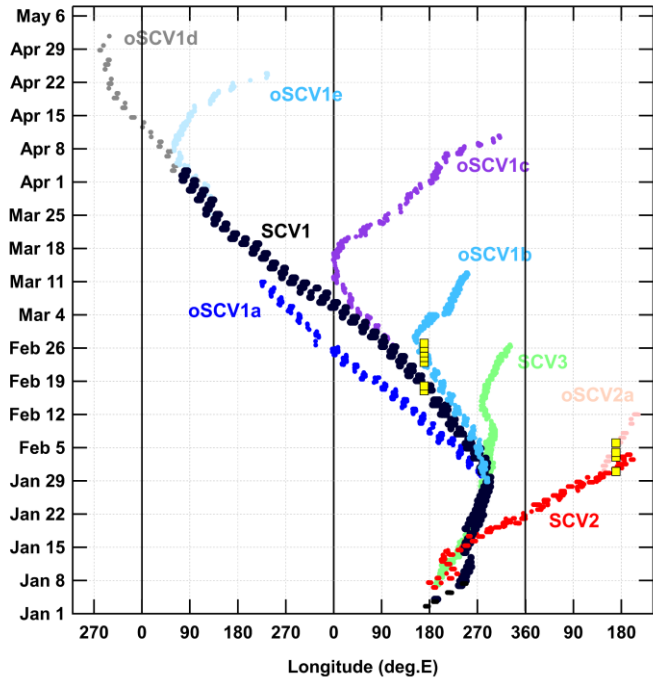


Confined fraction of Raikoke SO₂ emissions



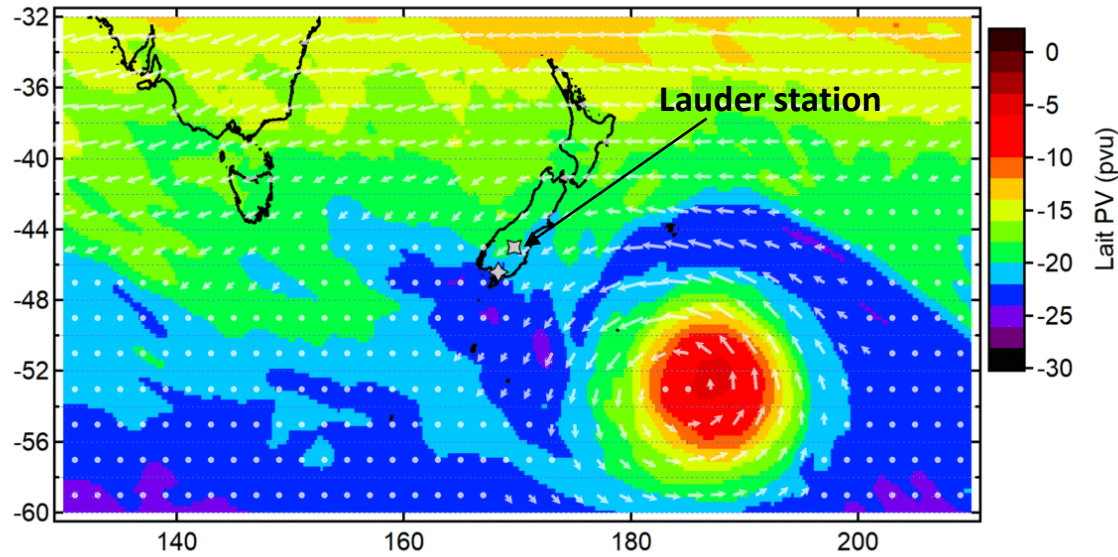
- 25% of the erupted SO₂ mass was contained by the VVP and was subject to significant self-lofting and equatorward transport

Aeolus observations of Australian Smoke-Charged Vortex

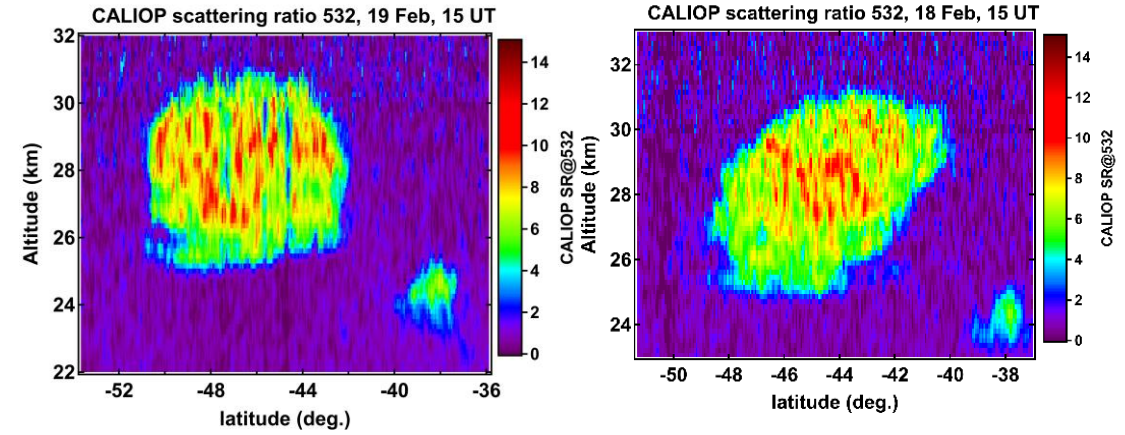


SCV dynamical structure from lidars and ERA5

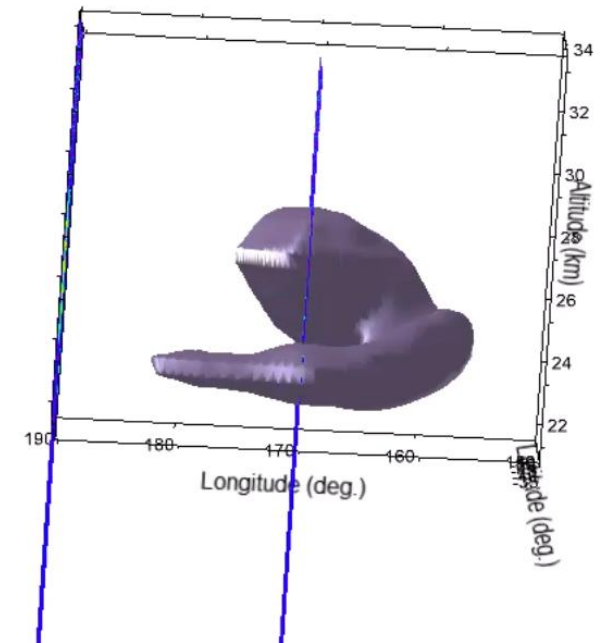
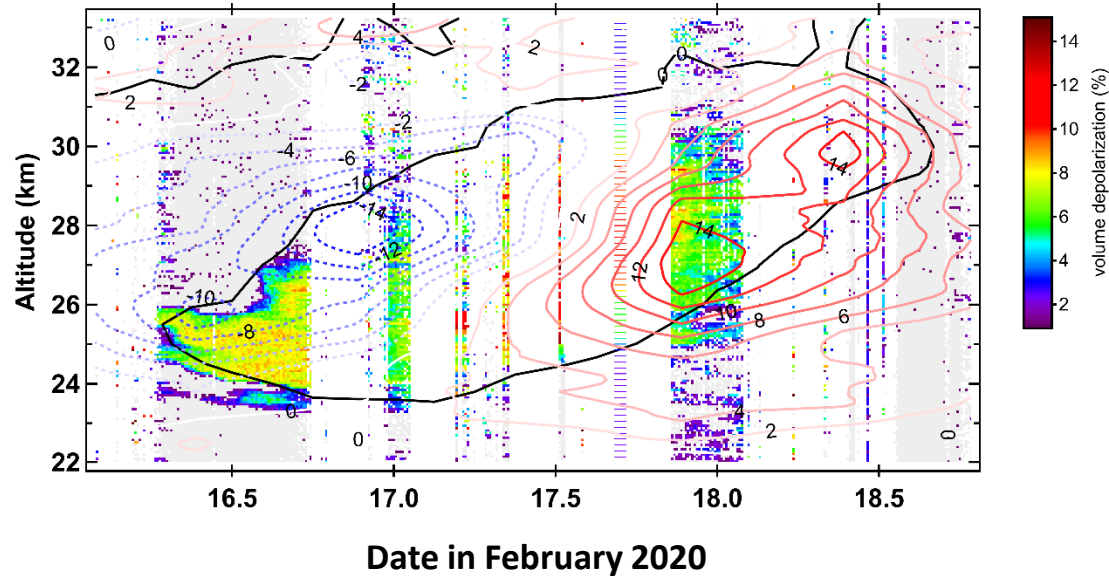
ERA5 Lait PV 2020 2 15 0Z, alt=27.5 km



CALIOP transects of SCV near New Zealand



SCV transit over Lauder, NZ (color map = depolarization, contours = Vwind summer anomaly)



3D structure of the vortex from ERA5 PV

Summary

- **Volcanic plumes are capable of self-organizing into persistent anticyclonic vortices under certain conditions**

Required ingredients for VVP/SCV formation:

- Absorbing aerosols (ash, smoke)
- Extratropical location (PV gradient across the tropopause)
- Summer season (calm stratosphere)

- **Dynamical confinement, maintaining the absorptive aerosols at high concentration is the key prerequisite for self-lofting**
- **Self-lofting of wildfire and volcanic plumes alters their global transport and prolongs their atmospheric residence time and radiative effects**
- **ESA frontier missions provide new insights into dynamics of volcanic and wildfire plumes**

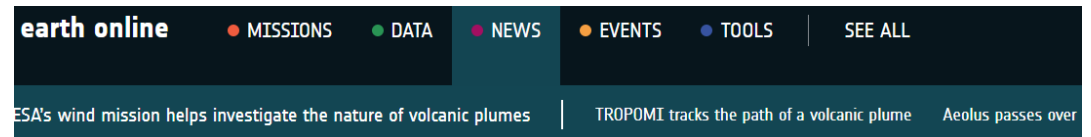
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Unexpected self-lofting and dynamical confinement of volcanic plumes: the Raikoke 2019 case

[S. M. Khaykin](#) , [A. T. J. de Laat](#) , [S. Godin-Beekmann](#), [A. Hauchecorne](#) & [M. Ratynski](#)

[Scientific Reports](#) **12**, Article number: 22409 (2022) | [Cite this article](#)



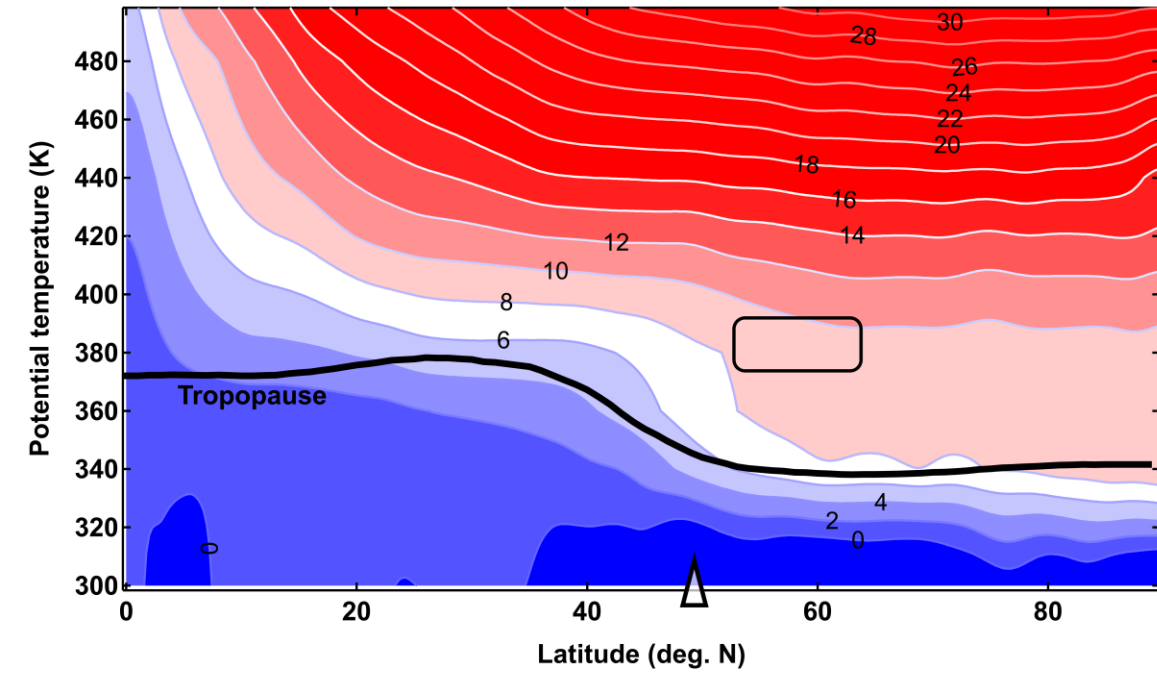
[News](#) / [ESA's wind mission helps inves...](#)

ESA's wind mission helps investigate the nature of volcanic plumes

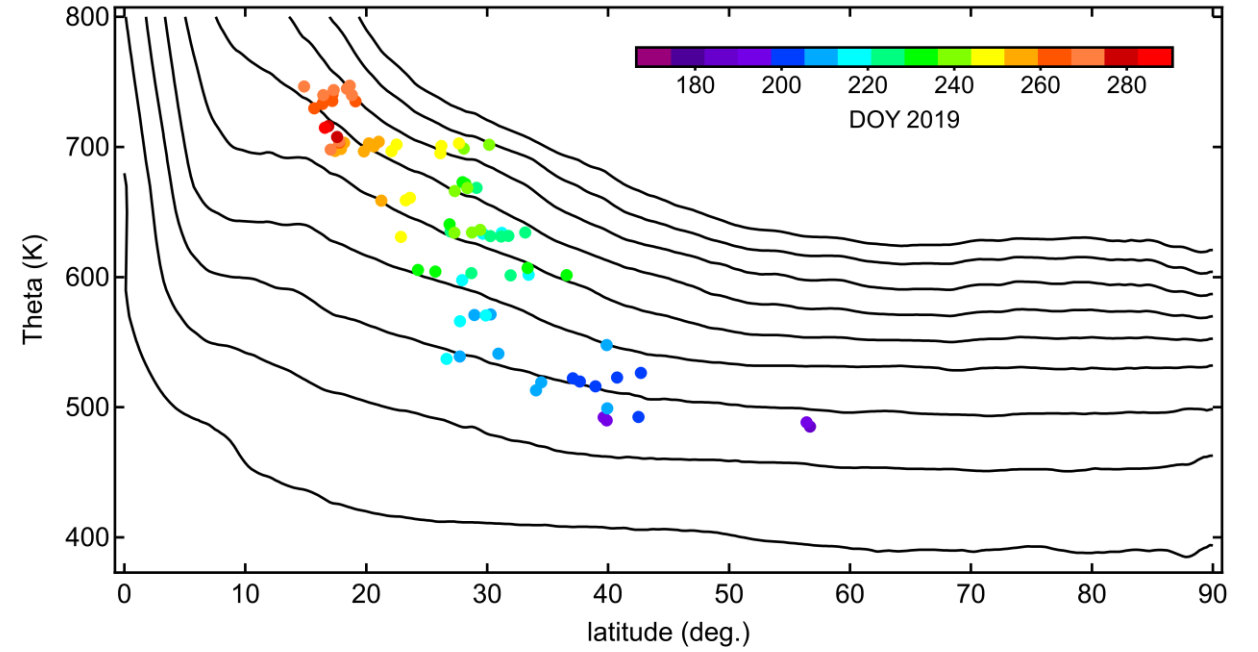
07 Feb 2023

Summary

ERA5 potential vorticity June 2019 zonal mean (pvu)

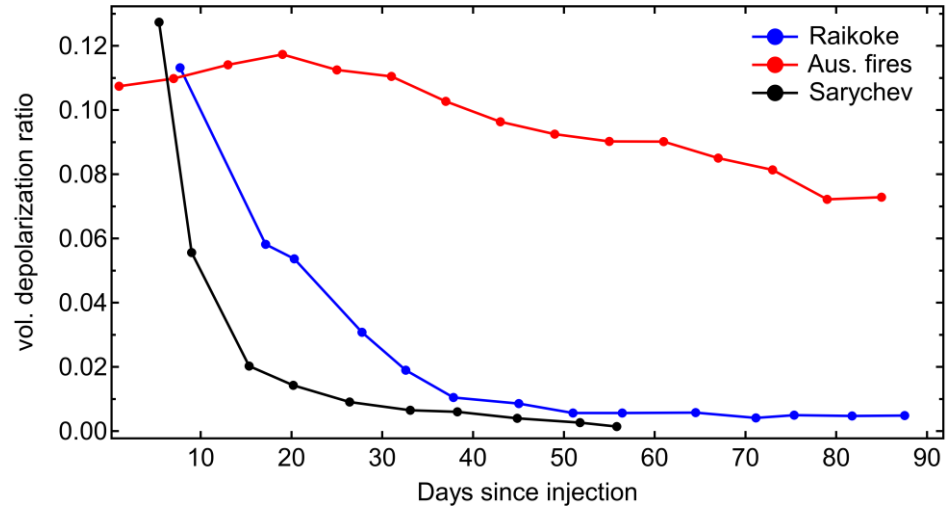


ERA5 PV Aug2019 zonal mean (contours), OMPS-LP plume top theta

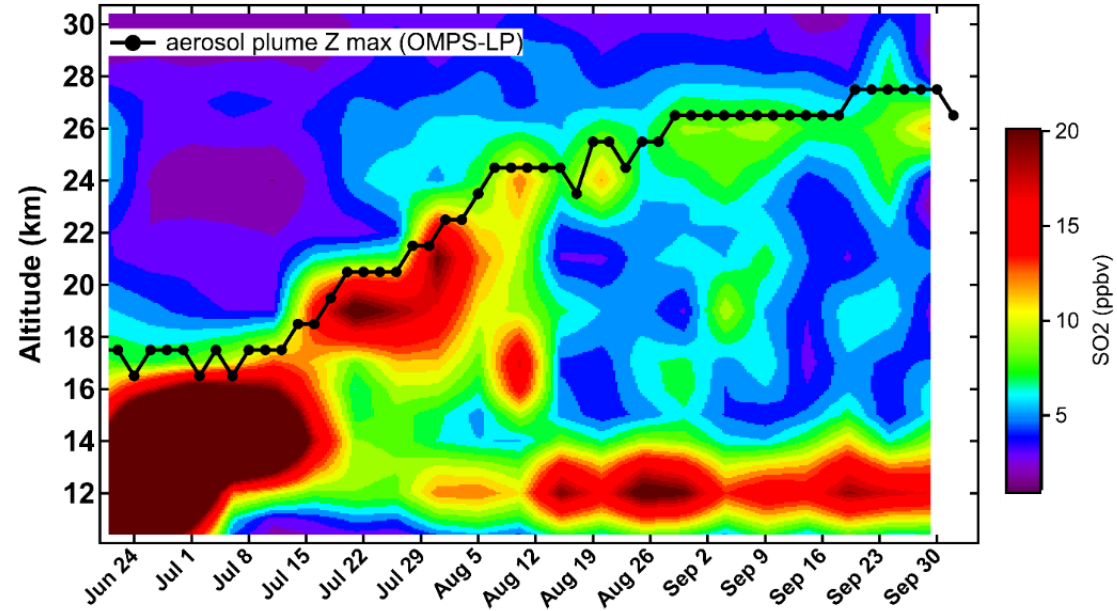


VVP – Vorticity Volcanic Plume

CALIOP vol. depolarization ratio of the primary plume



MLS SO2 Raikoke plume detections (> 6 SD of background level)



VVP overpass above Hawaii

