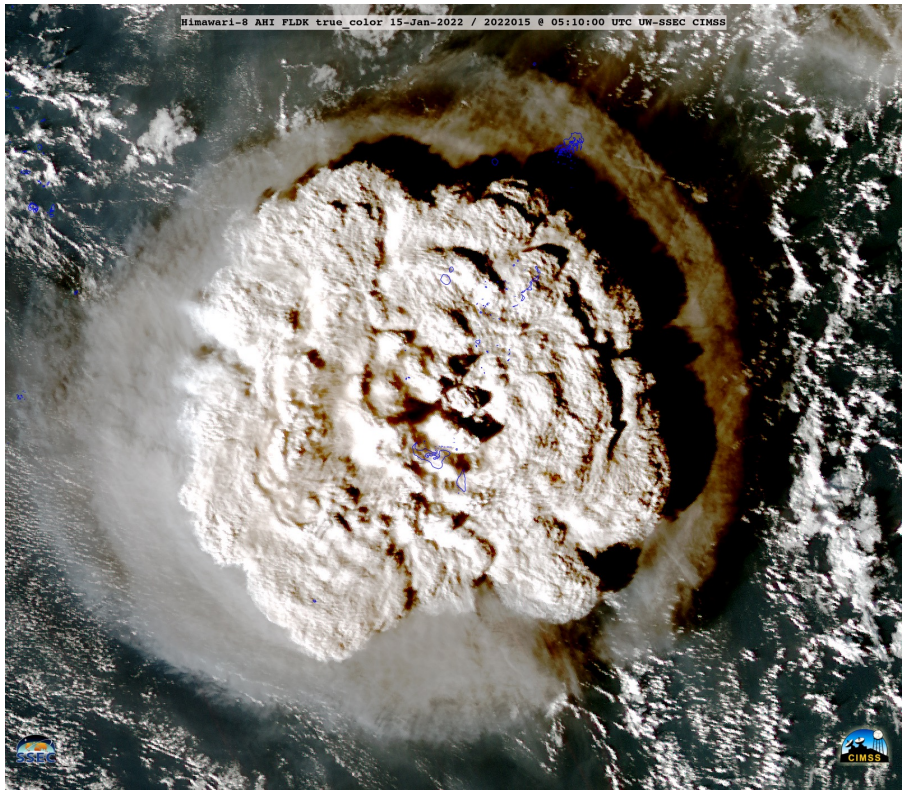
Tonga Rapid Response Experiment (TR^2Ex)

NOAA Chemical Sciences Laboratory
NOAA Global Monitoring Laboratory
University of Houston
St. Edwards University
LACy, CNRS/Université de la Réunion/Météo-France
OSUR, CNRS/Université de la Réunion/Météo-France

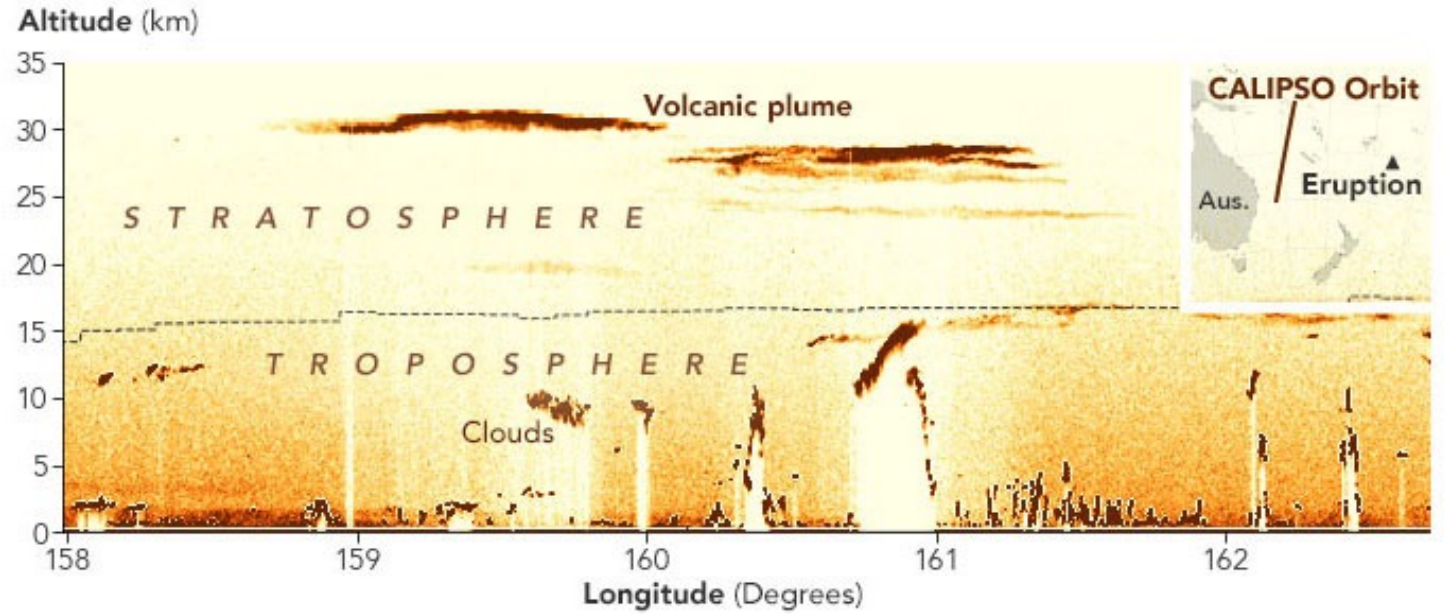
Web site: https://csl.noaa.gov/projects/b2sap/tr2ex/

Prepared by Karen Rosenlof, NOAA CSL, karen.h.rosenlof@noaa.gov

Hunga Tonga - Hunga Ha'apai volcano erupted on Jan. 13 and 15, 2022



Himawari image, UW-SSEC



NASA CALIOP spaceborne lidar image

- The plume from the eruption on Jan 15th reached altitudes of 25-30 km and higher. The SO_2 mass injected has been estimated to be ~0.4 Tg (1-2% of 1991 Mt. Pinatubo)

- The plume went high into the stratosphere where where the sulfate aerosol formed from the volcanic SO_2 will persist, affecting the radiative balance in the atmosphere and possibly Southern Hemisphere stratospheric ozone for a year or more.

Volcanic eruptions are common, but this one was unusual in that:

1) The energy released was large
   - The sound was heard up to 10,000 km away from the eruption
   - Estimates put the force of the eruption at equivalent to a 10 megaton TNT blast (or potentially even higher)
   - It produced shockwaves that circled the earth multiple times and a veritable zoo of other atmospheric waves
   - It triggered a tsunami

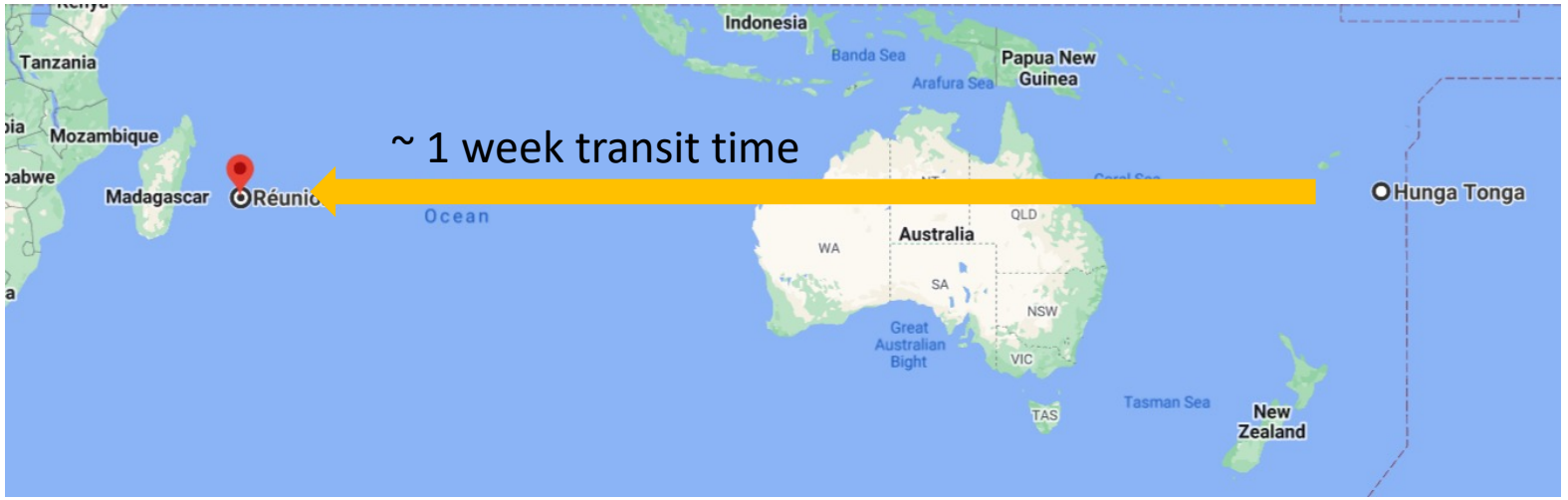
2) Material was injected very high in the stratosphere (above 25 km) Besides SO_2 and ash, it also produced a huge stratospheric H_2O perturbation (50-150 Tg).

3) It was a powerful underwater eruption which may have also injected halogens (in sea water) that play a role in ozone chemistry.

Why did NOAA initiate a rapid response?

- There have not previously been *in situ* measurements made in a volcanic plume immediately after the eruption
- To be able to parameterize the processes involved in the conversion of SO_2 to sulfate aerosol, it is advantageous to get measurements shortly after eruption and ideally extend those measurements in time as the plume evolves.
- To achieve that goal, NOAA CSL and collaborators rushed to get people and instruments to a suitable location for sampling the volcanic plume.

The Hunga-Tonga volcano is at ~20 S. The wind was blowing the stratospheric plume towards the Maïdo climate observatory 8000 miles to the west, at ~21 S on Réunion Island



Fortuitous circumstances enabled the TR^{2}Ex campaign to take place

1) Colleagues on Reunion Island agrees to help with the balloon deployment, and have a climate observatory (Maido) with relevant remote sounding observations

   Their GRUAN and SHADOZ expertise and facilities on Reunion were critical for success

2) We had aerosol instruments to send because we have an existing aerosol ballooning program (NOAA CSL B^{2}SAP).

3) We had just enough time to get people and instruments in place

What is the NOAA B^{2}SAP Project?

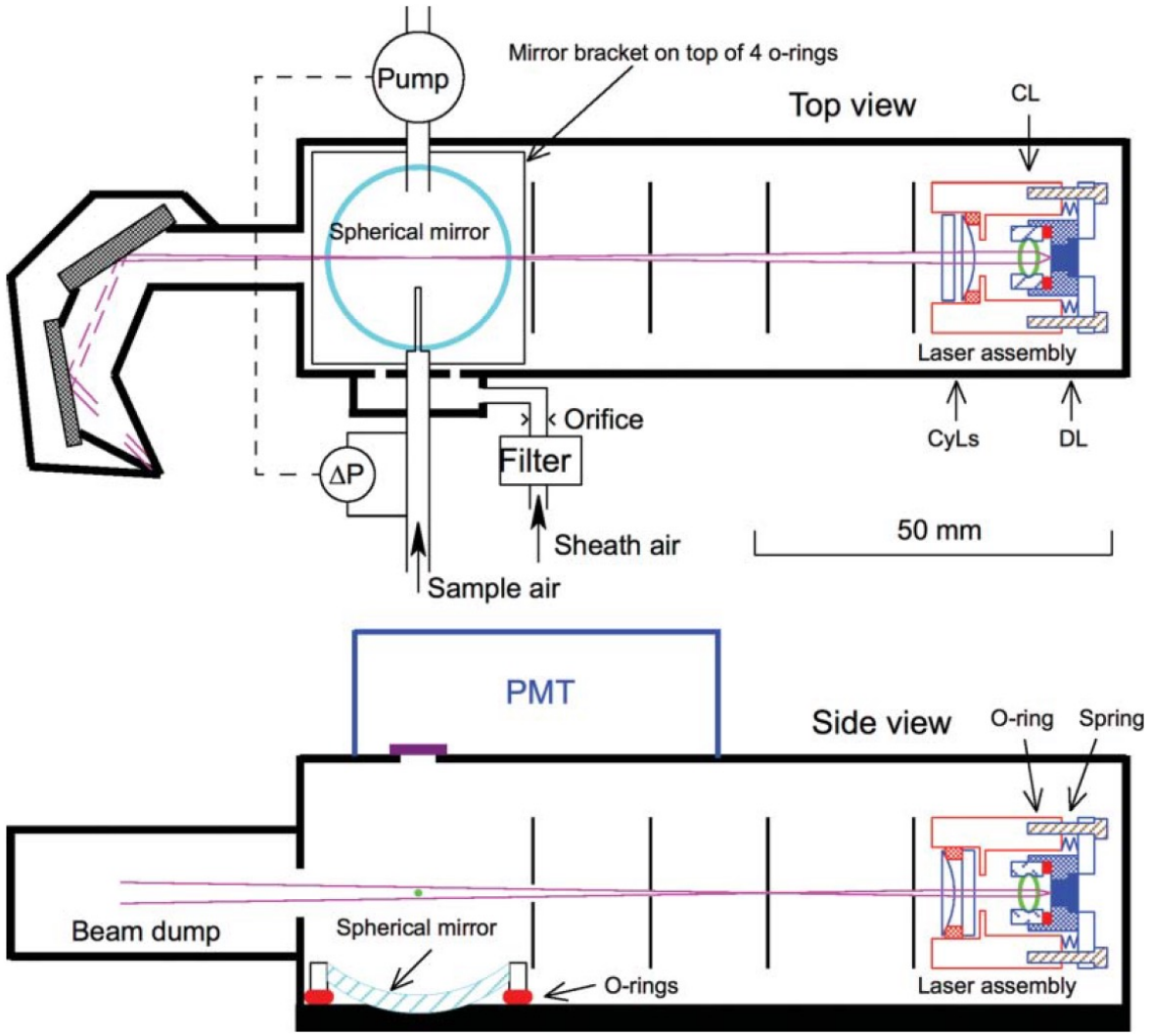
Balloon Baseline Stratospheric Aerosol Profiles

Troy Thornberry, PI

Goal: A latitudinally distributed network of systematic balloon sonde measurements of stratospheric aerosol number and size distribution to improve satellite retrievals and constrain stratospheric aerosol processes in climate models

- Add aerosol size distribution measurements to NOAA Global Monitoring Laboratory O_3 + H_2O sondes for combined stratospheric profiles
- Expand the record of balloon-borne in situ stratospheric aerosol measurements from the University of Wyoming started in 1971 (flights until 2020)
  - Regular soundings from Laramie, Wyoming (41.3° N)
  - Campaign soundings from Laramie and other locations around the world
  - Measurements following numerous volcanic perturbation events
  - Resulted in significant advances in the understanding of stratospheric aerosol

NOAA / Handix POPS Instrument

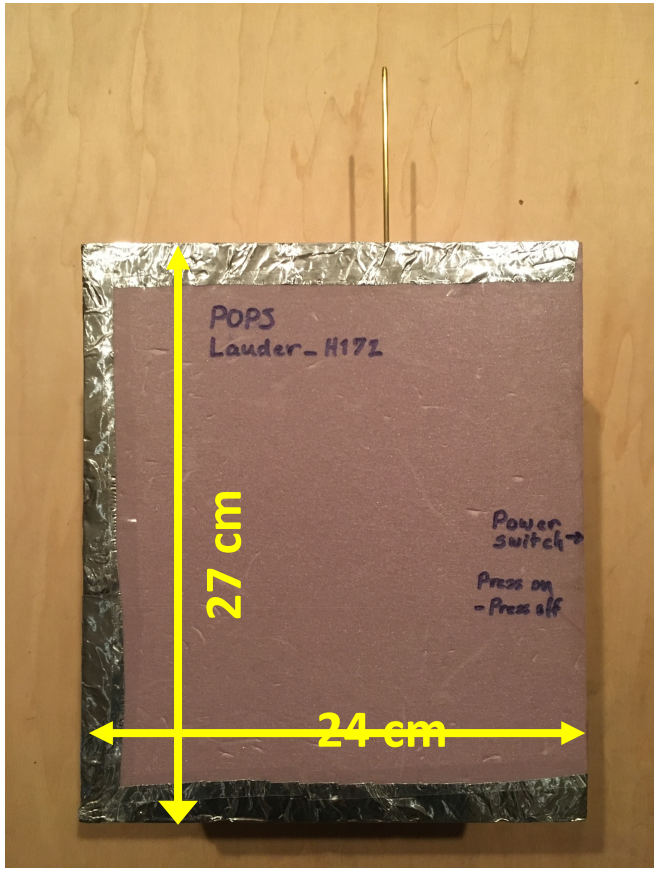


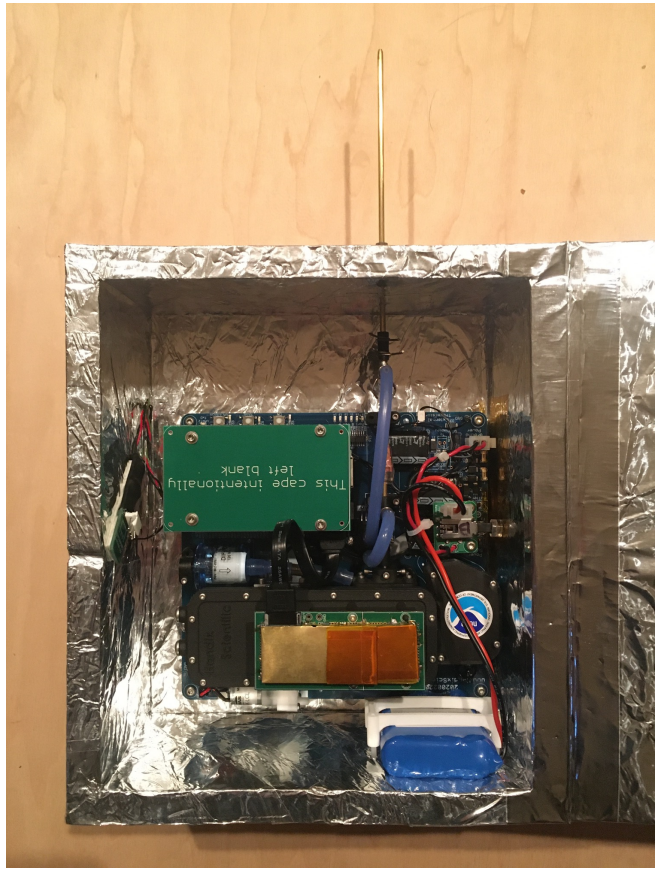
- Measures light scattered from a 405 nm (Blu-Ray) laser when a particle passes through the beam
- The intensity of the scattered light is a function of the particle size
- Peak height and width are recorded for each individual particle
- Particle counts within preselected size bins are reported each second
- Calibrated Mie theory calculation used to determine particle geometric size from the measured signal

Gao et al., AS&T 2016

Instrument developed at NOAA CSL, commercially manufactured by Handix Scientific

The POPS Sonde





Specifications:

- 950 g
- 5 Watts (> 4 hour run-time)
- Single-particle detection
- 140 – 2500 nm diameter range
- 3 - 5.5 cm^3 s^{-1} sample flow
- Box temperature remains above ambient (dry particle diameter)
- Measurements to > 26 km
- 15 size bin telemetry (currently, xdata via iMet RS-1/RS-4)

Continuing to fly here on Reunion after the initial TR^2Ex IOP to study post-Hunga Tonga-Hunga Ha'apai stratospheric aerosol evolution.

B²SAP Network: Current and Future

Aerosol (POPS), O_3 (ECC) and H_2O (FPH)

Utqiagvik, Alaska, March 2023*

Boulder, February 2019

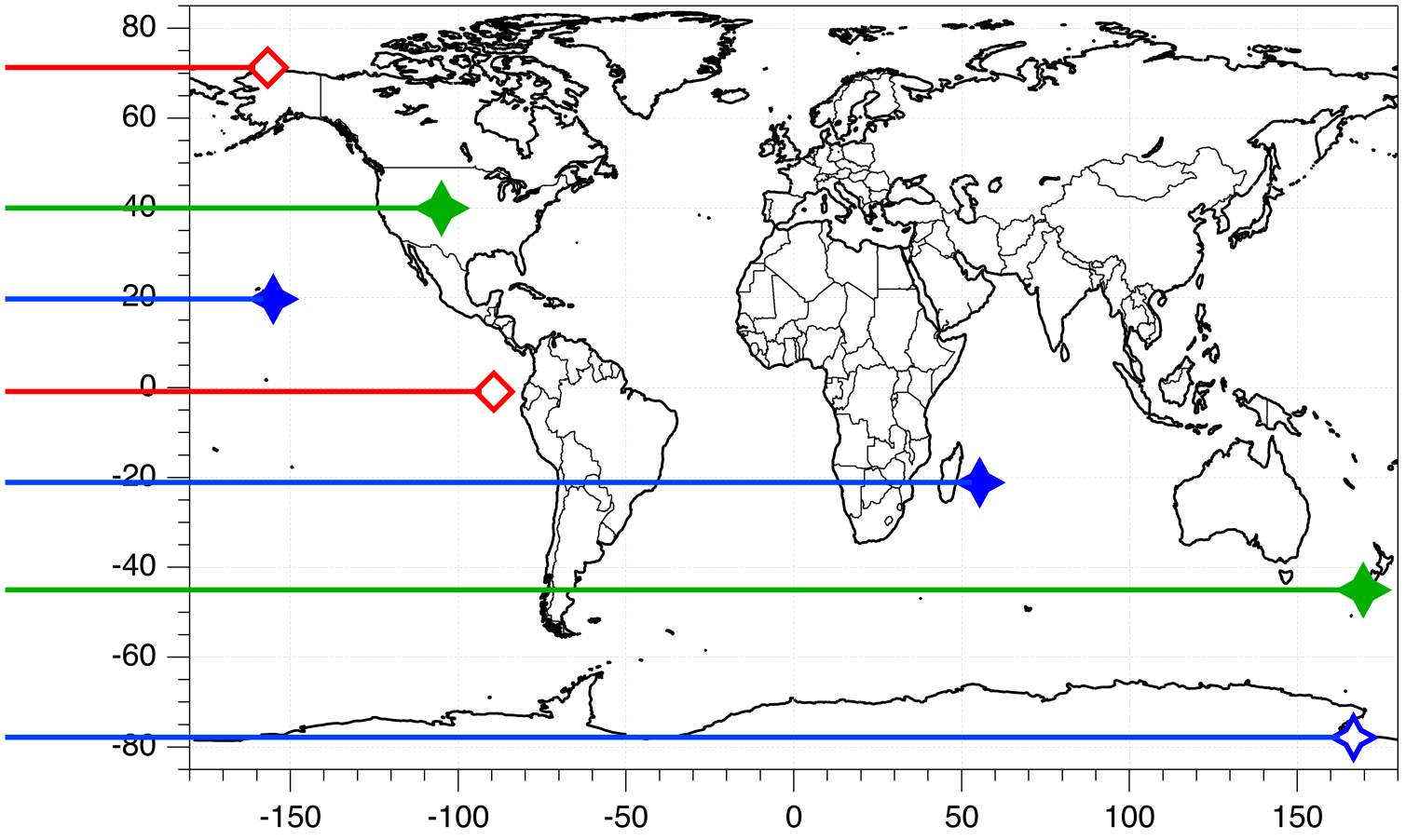
Hilo, May 2022

Deep tropical site (San Cristobal?)

Réunion (LACy), January 2022

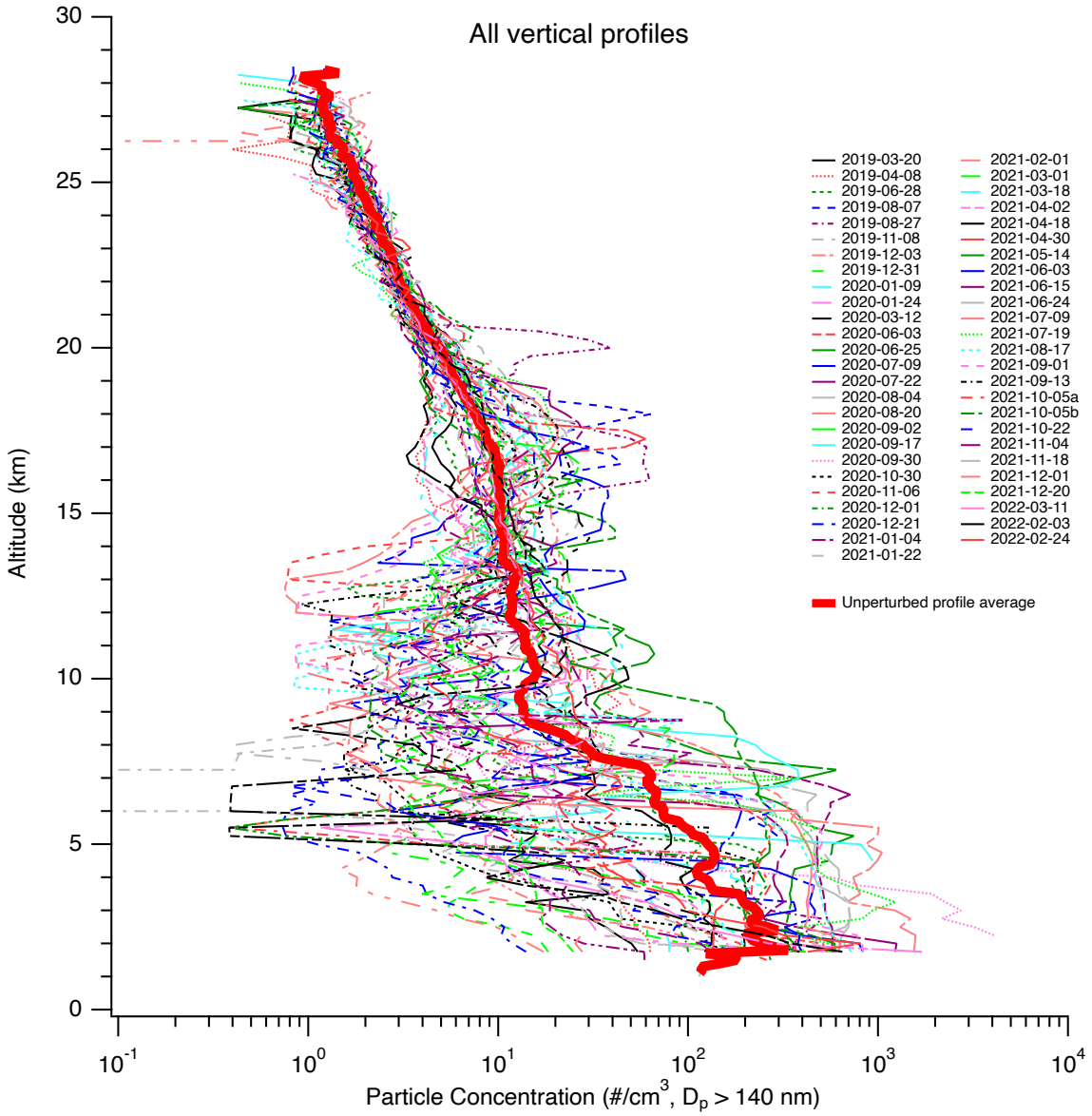
Lauder, NZ (NIWA), April 2019

Scott Base (NIWA), November 2022



*Flights planned in conjunction with the NOAA SABRE project aircraft deployment

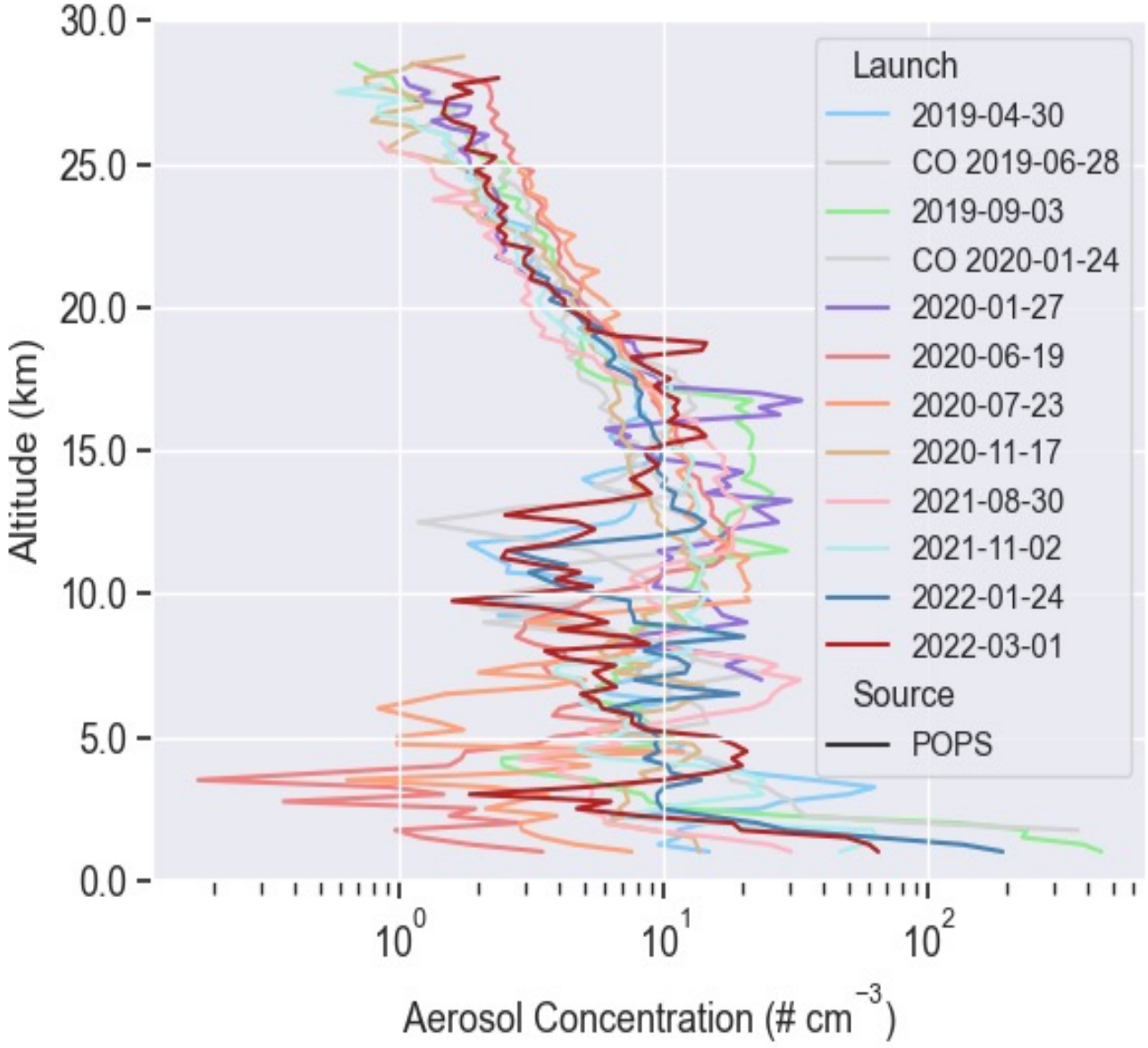
Boulder Profiles



- Measurements started in February 2019
  - ~1 / month Feb 2019 - June 2021
  - ~2 / month June 2021 - present
- Episodic perturbations from volcanoes (Raikoke, La Soufière) and wildfires observed in individual profiles in the lower stratosphere at altitudes up to ~20 km
- Minimum in variability (< x3) at 21-22 km
- POPS measurement compared to University of Wyoming OPC during co-flights in 2017 and 2018

M. Todt et al., submitted

Profiles from Lauder, NZ



- Measurements started in April 2019
- 2 – 5 / year
- Similar minimum in variability at 21-22 km
- January 27, 2021 sonde (purple trace) sampled ANY pyro-Cb plumes
- March 1, 2022 sonde (dark red trace) shows evidence of aerosol from the Jan 15 Hunga Tonga-Hunga Ha’apai eruption

TR^{2}Ex Field Deployment

4 research scientists from NOAA/CIRES, University of Houston and St. Edwards University were able to get instruments prepared, make travel arrangements, and arrived on Réunion Island 6 days after the eruption.

Our colleagues on Réunion Island made baseline balloon and lidar measurements 5 days after the eruption.

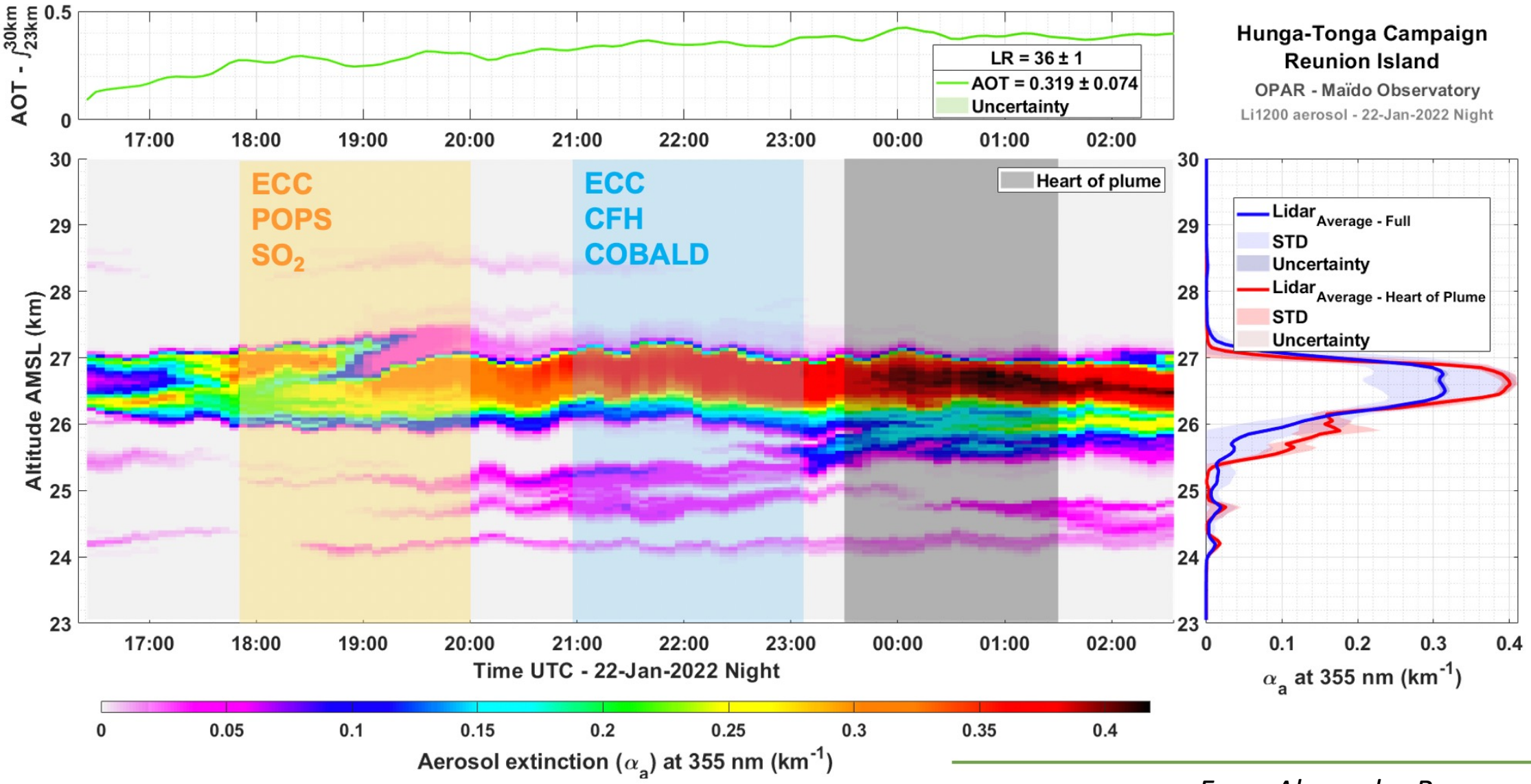
The entire team (of ~10 people) spent 5 days (and nights) at the Maïdo Observatory launching about a dozen balloons with multi instrument payloads into the plume.

Sunset at Maido Observatory, red color due to presence of volcanic aerosols, photo by Lizzy Asher (NOAA/CIRES)

LIDAR data used to identify when to launch and in post flight analysis.

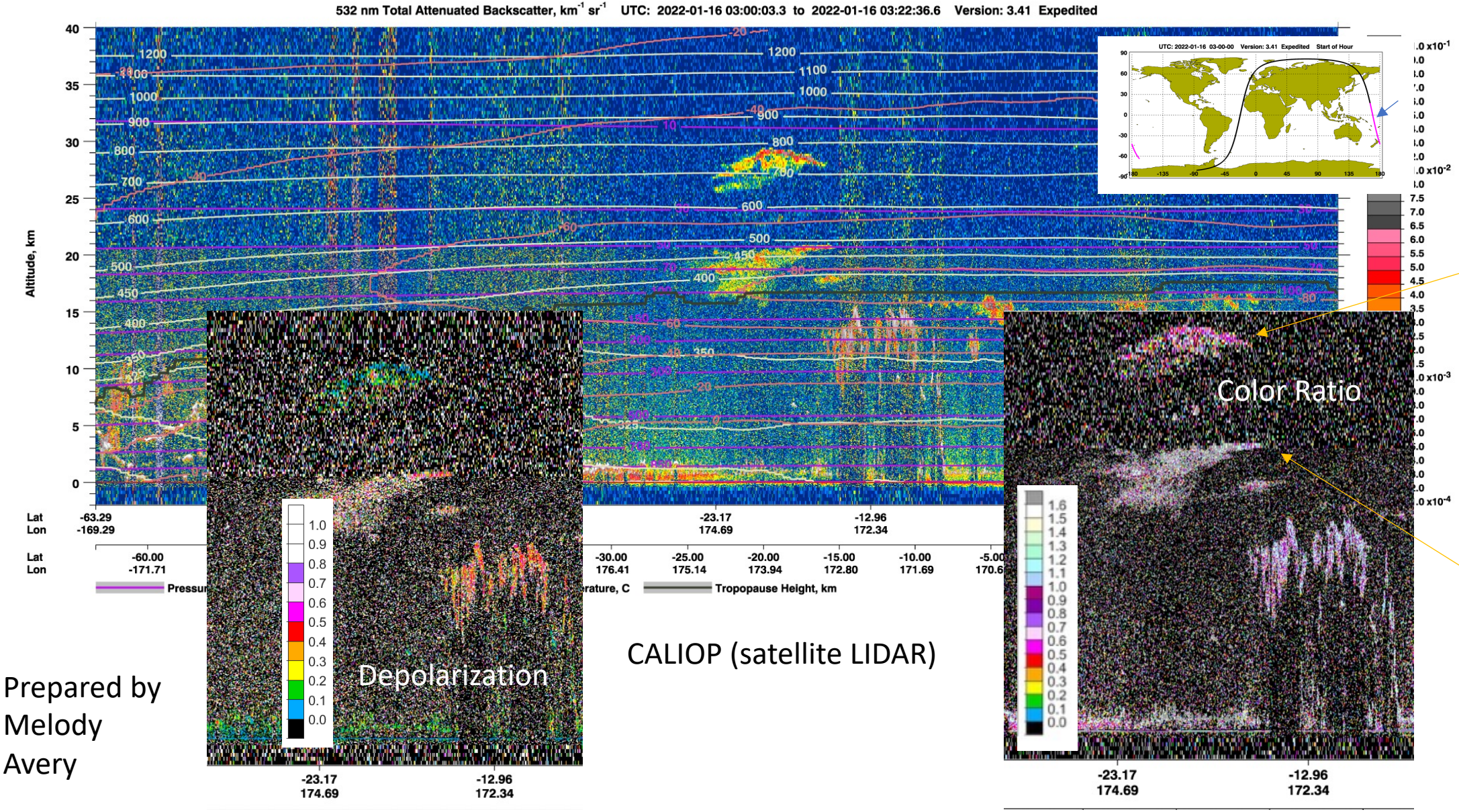
22 January – Li1200

Baron et al. 2022a In prep.



From Alexandre Baron

Jan. 15 Eruption observed on Jan. 16 ~ 3:15 Z



Top of layer looks like sulfate, very low color ratio and depol.

ICE

CALIOP (satellite LIDAR)

Prepared by Melody Avery

Summary of balloon flights

Pre-plume

	Burst altitude (km)	ECC O3	CFH	COBALD	POPS	SO2	LOAC
20/01 17UTC	28.8	X	X	X			
21/01 19UTC	30.3	X			X	X	
21/01 21UTC	19.9	X	X	X			
22/01 18UTC	31.6	X			X	X	
22/01 21UTC	31.5	X	X	X			
23/01 00UTC	26.4	X			X	X	
23/01 14UTC	30.0	X			X	X	
23/01 18UTC	30.6	X	X	X			
23/01 21UTC	33						X
24/01 15UTC	31.2	X			X	X	
24/01 17UTC	31.05	X	X	X			
24/01 22UTC	27.8	X					
25/01 17UTC	30				X	X	
25/01 20UTC	33						X
26/01 15UTC	36						X

University of Reunion instruments

US instruments

CNRS instrument

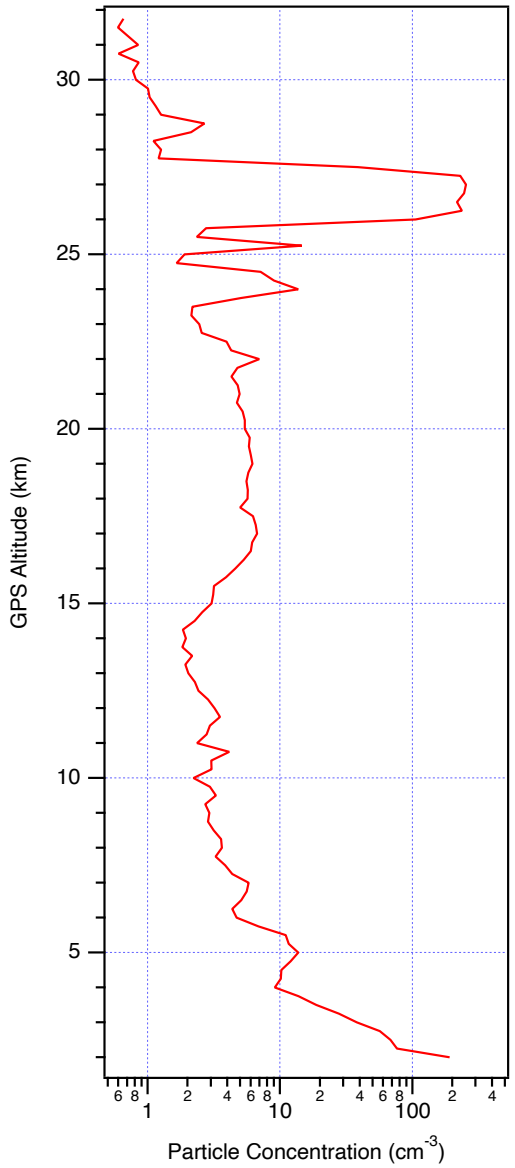
+ CFH/O3/POPS on 11 Feb, 32km
+ FPH/O3/POPS on 12 March, 32 km, had issues
+ FPH/O3/POPS on 31 March, 31 km

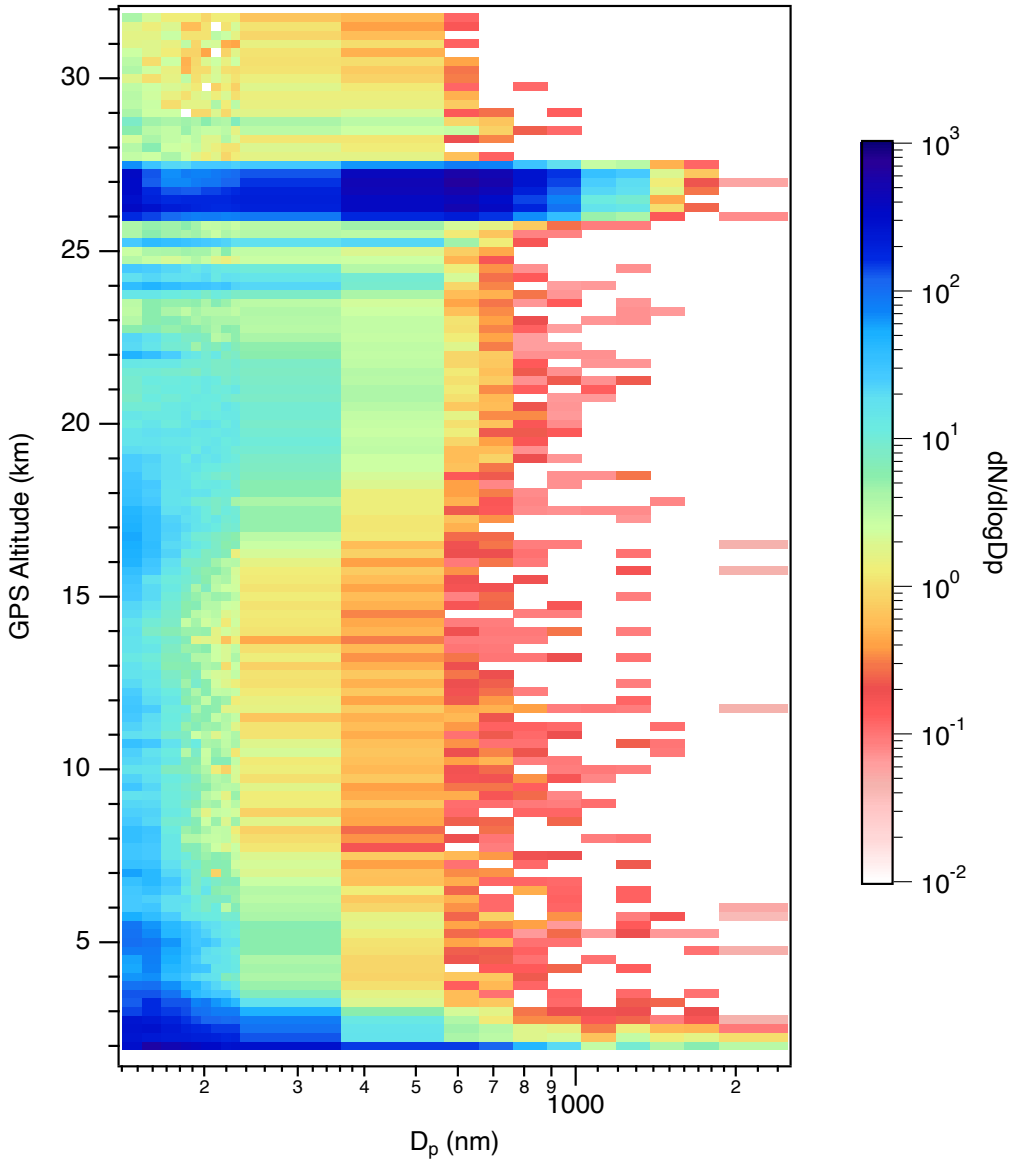
Also June 9 and Sept 22, and one planned next week

and there have been POPS launches at Lauder and recently at Scott Base that seemed to have sampled Hunga-Tonga aerosol

Figure courtesy of Stephanie Evan, LACy, CNRS/Université de la Réunion/Météo-France

Sonde observations

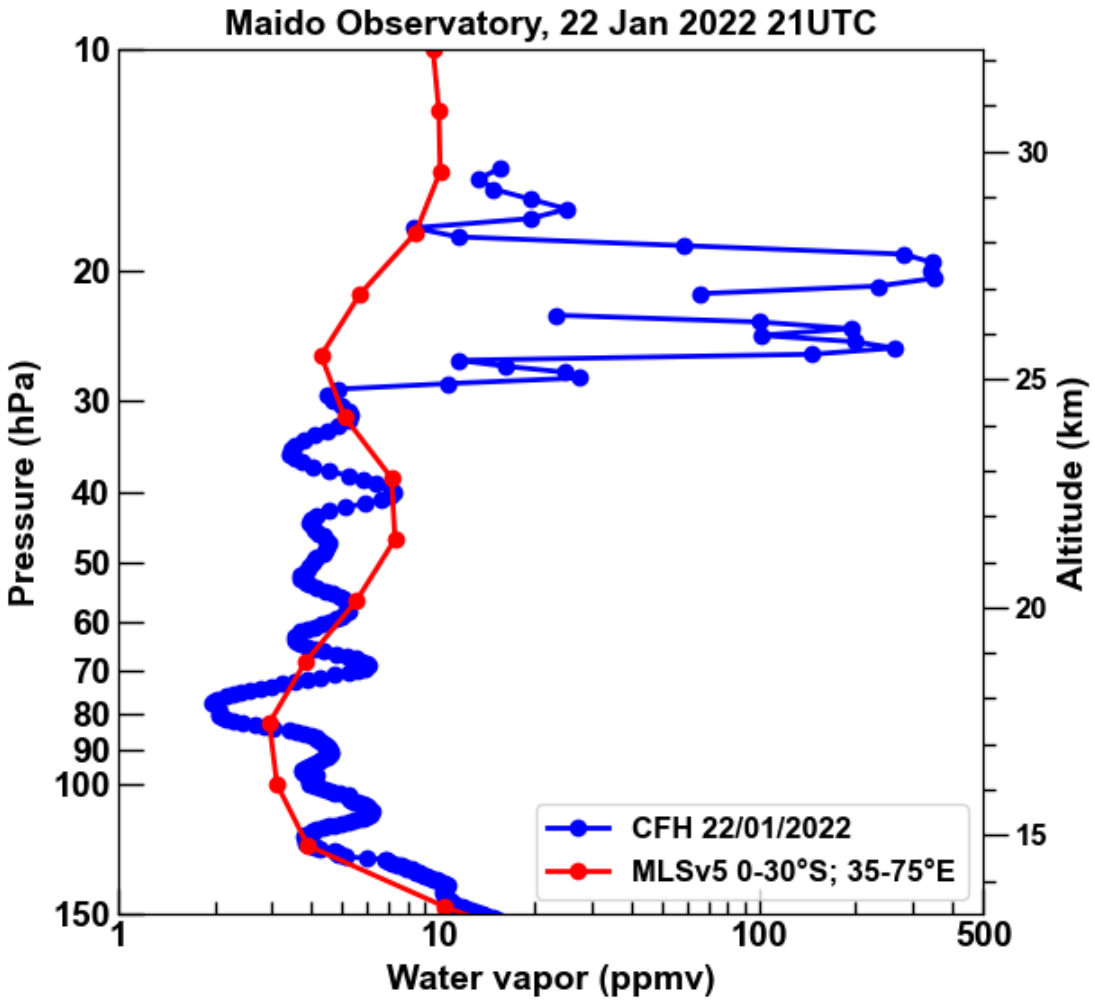




POPS (Aerosol), Jan 22 (POPS)

TR²Ex IOP Water vapor profiles

A total of 4 profiles in stratosphere with CFH instrument +IMET radiosonde from Jan 20 to 24 (ozone was also part of the payload).

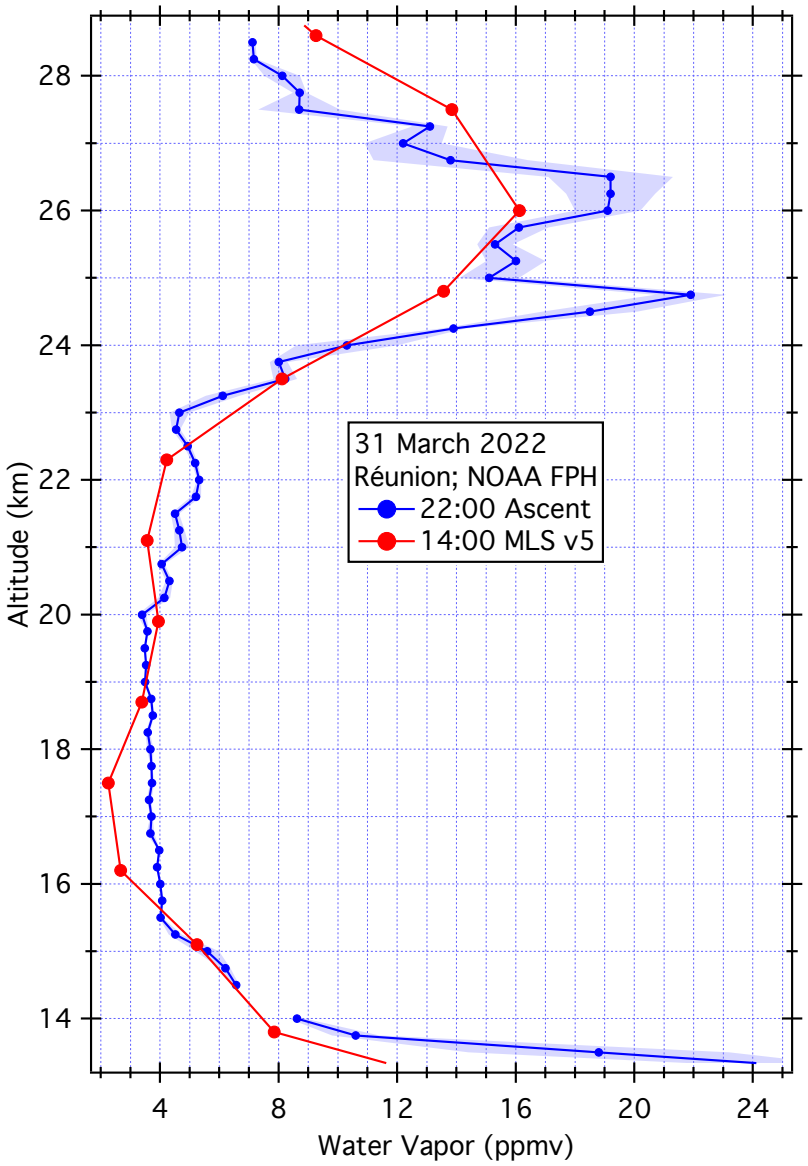


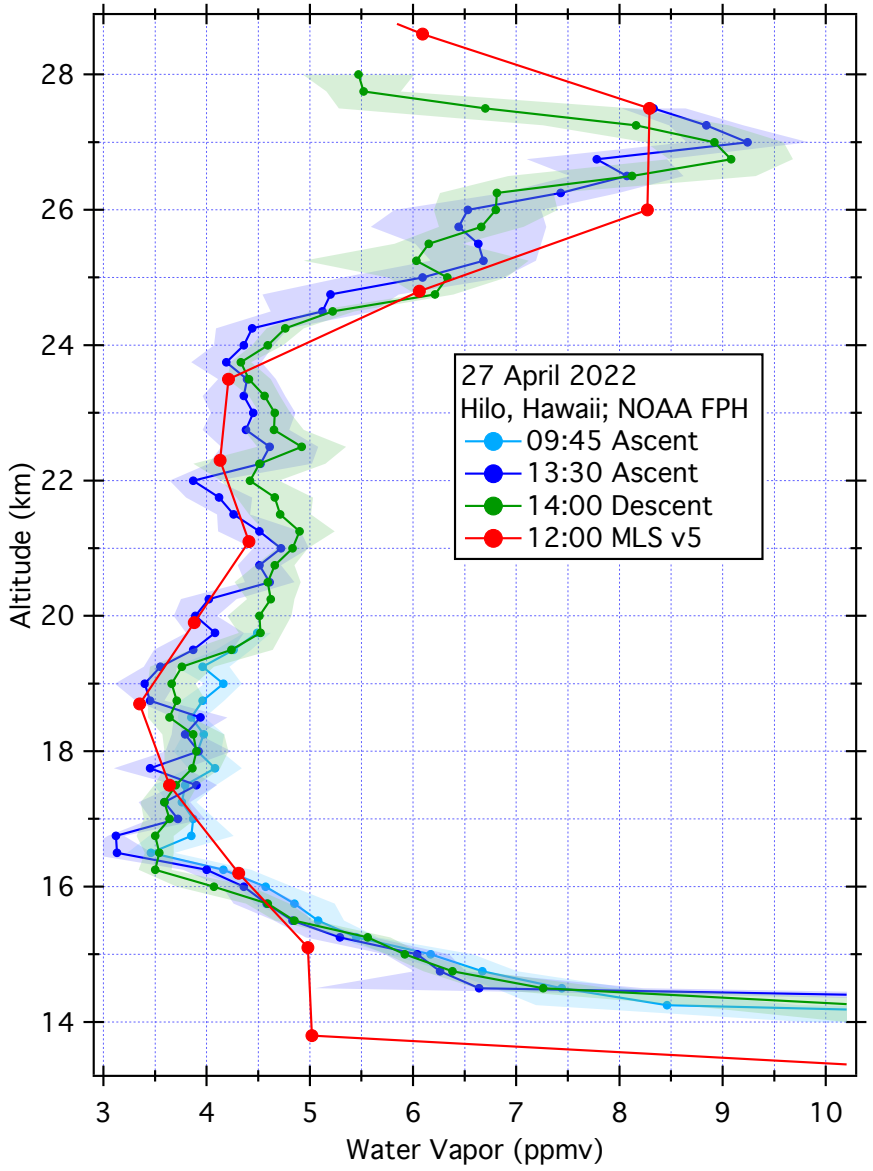
Hunga Tonga injected large amounts of water vapor into the stratosphere, maximum of 358 ppmv observed on 22 Jan.

Individual MLS profiles for the SWIO also show large amount of water vapor in the 100ppmv

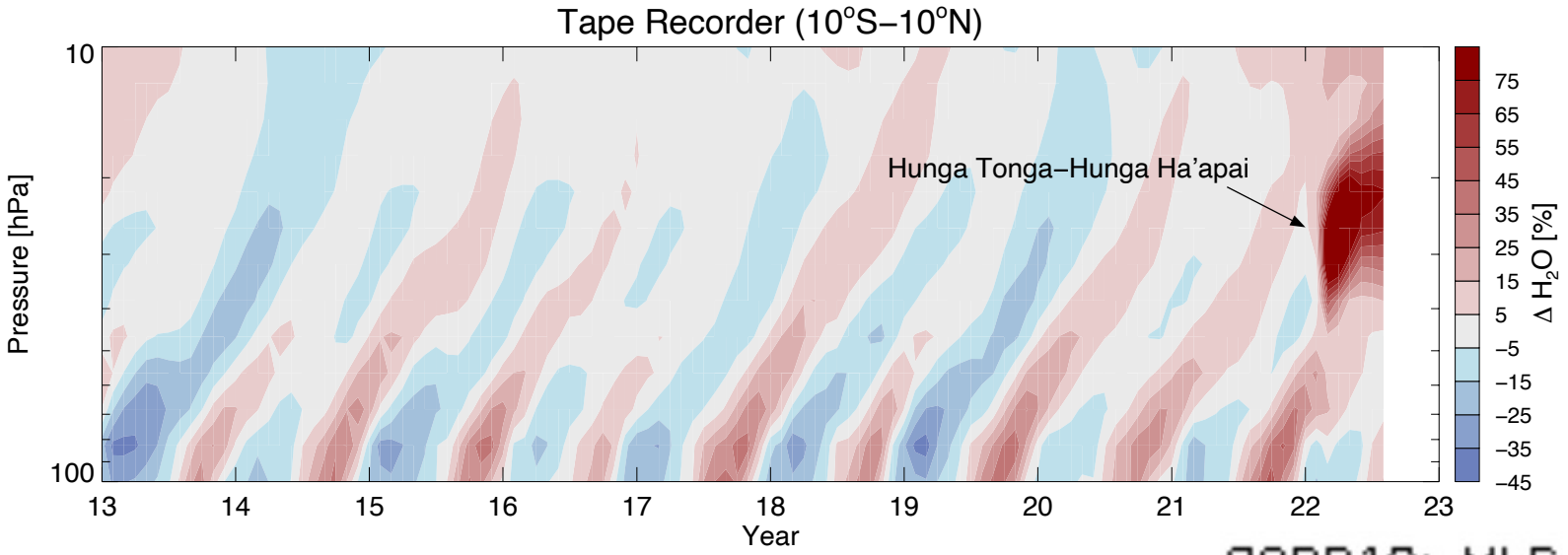
High water vapor values were still observed in recent months over Réunion Island

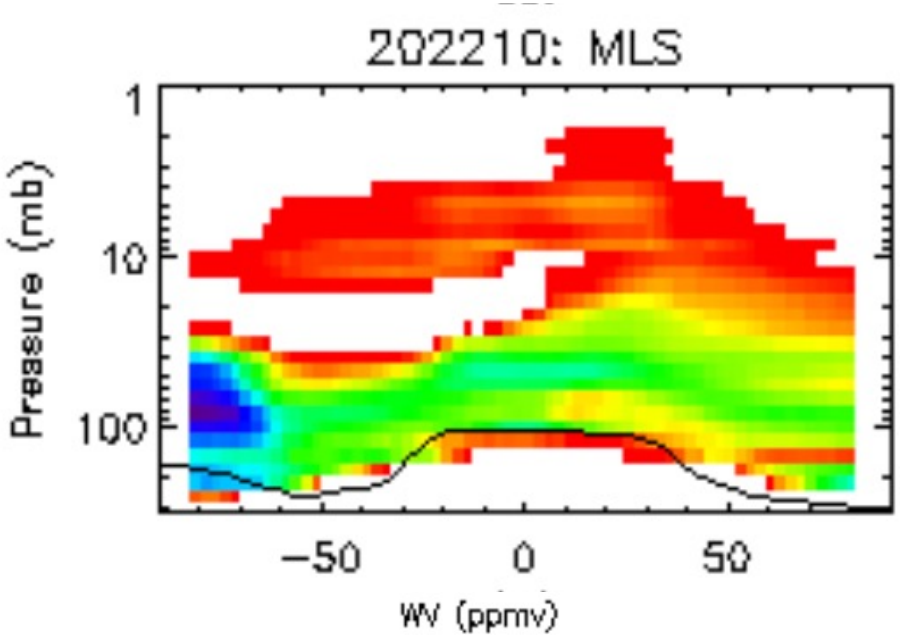
Prepared by Stephanie Evan

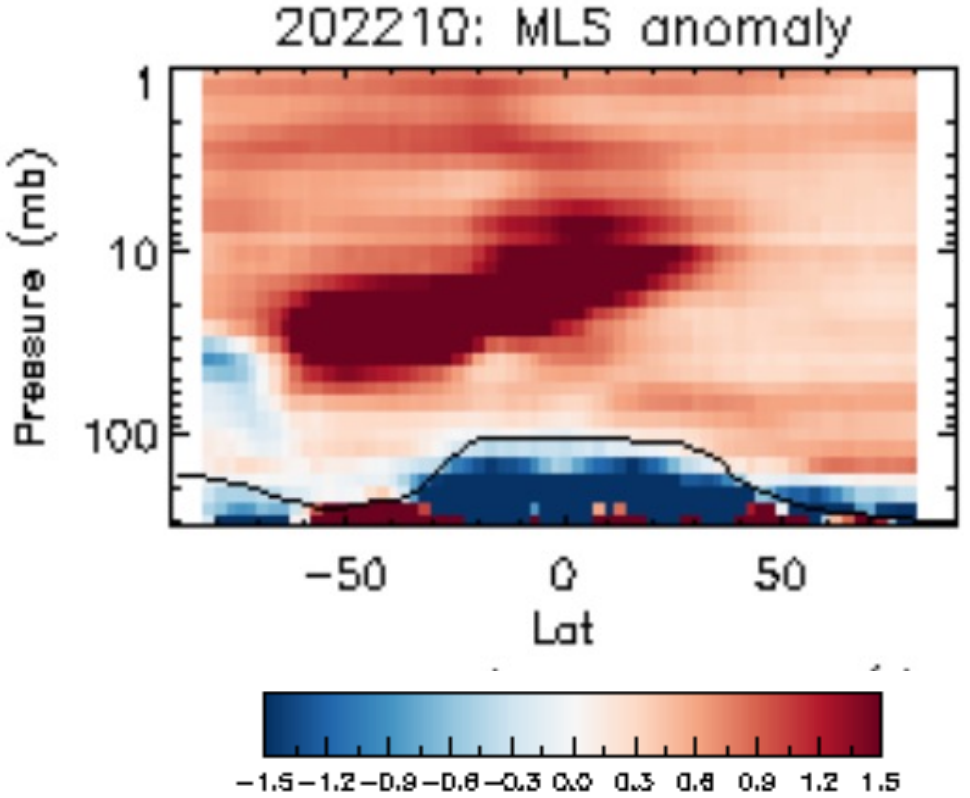




Water vapor anomaly evident using in situ data at other times and locations: here shows Reunion sounding on March 31 and Hilo sounding on April 28, *prepared by Dale Hurst and Kensy Xiong*


Tape Recorder (10°S–10°N)
Hunga Tonga–Hunga Ha'apai
Pressure [hPa]
10
100
13
14
15
16
17
18
19
20
21
22
23
Year
75
65
55
45
35
25
15
5
−5
−15
−25
−35
−45
Δ H2O [%]


202210: MLS
Pressure (mb)
1
10
100
−50
0
50
WV (ppmv)
1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0

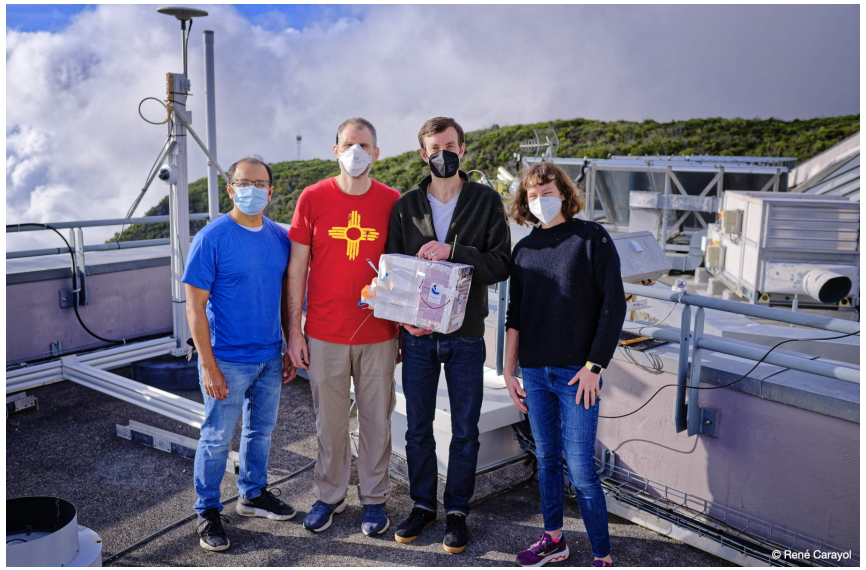

202210: MLS anomaly
Pressure (mb)
1
10
100
−50
0
50
Lat
−1.5 −1.2 −0.9 −0.6 −0.3 0.0 0.3 0.6 0.9 1.2 1.5

Research going forward

- Modeling and data analysis has shown that the increase in H_2O lead to rapid formation of sulfate aerosol (2 to 4 times normal rates). (Paper submitted by E. Asher and published by Y. Zhu.)

- Modeling work is ongoing to understand possible impacts on stratospheric ozone and dynamics. Apparent circulation impacts in the SH resulted in a colder pole this year. (Paper submitted by Xinyue Wang.)

- Formal assessment of impacts is planned for the 2026 WMO Ozone Assessment (team led by Yunqian Zhu, Graham Mann, Bill Randel, & Paul Newman.) Modeling MIP led by Margot Clyne.



Photos courtesy the University of Reunion Island