How water vapour injections affect stratospheric chemistry

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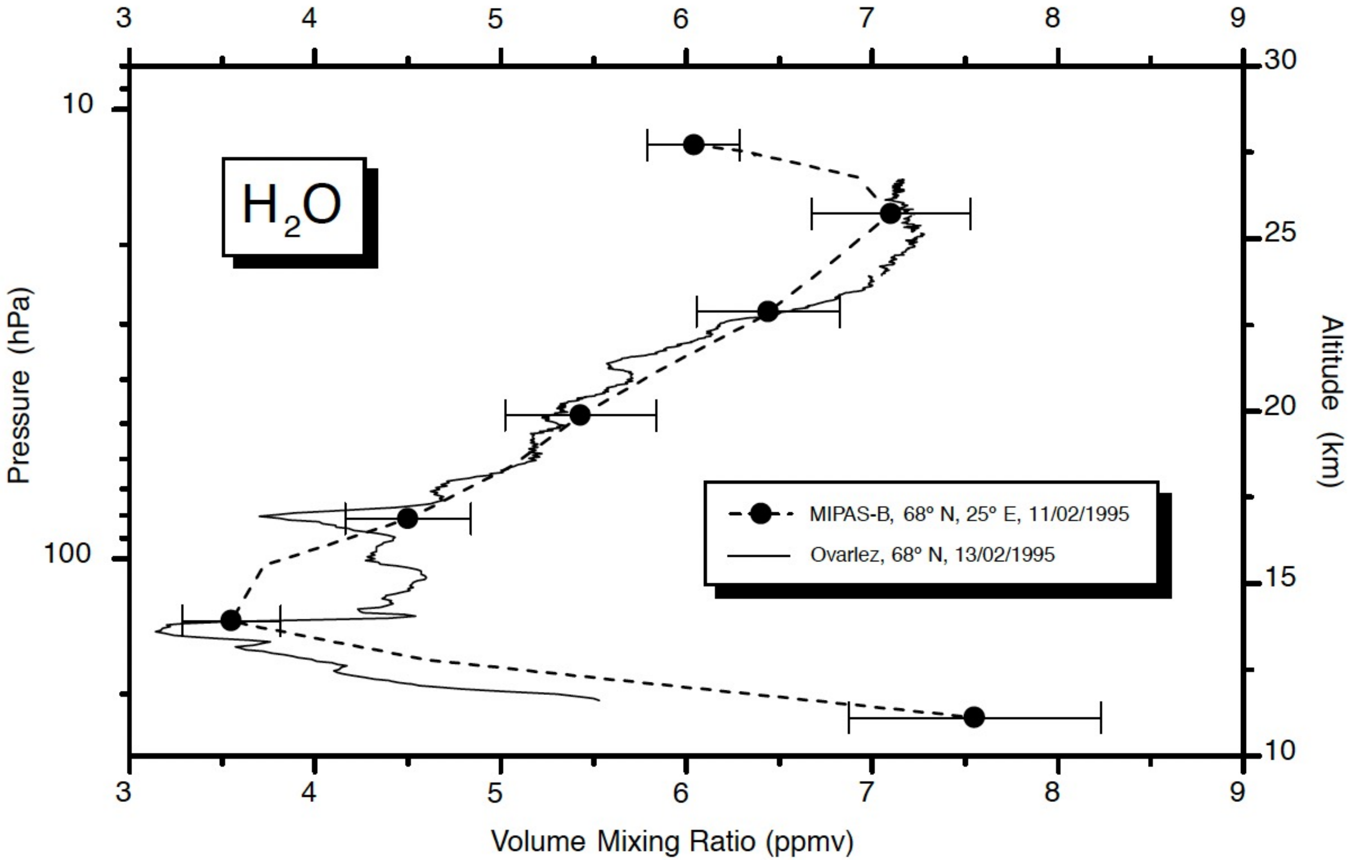
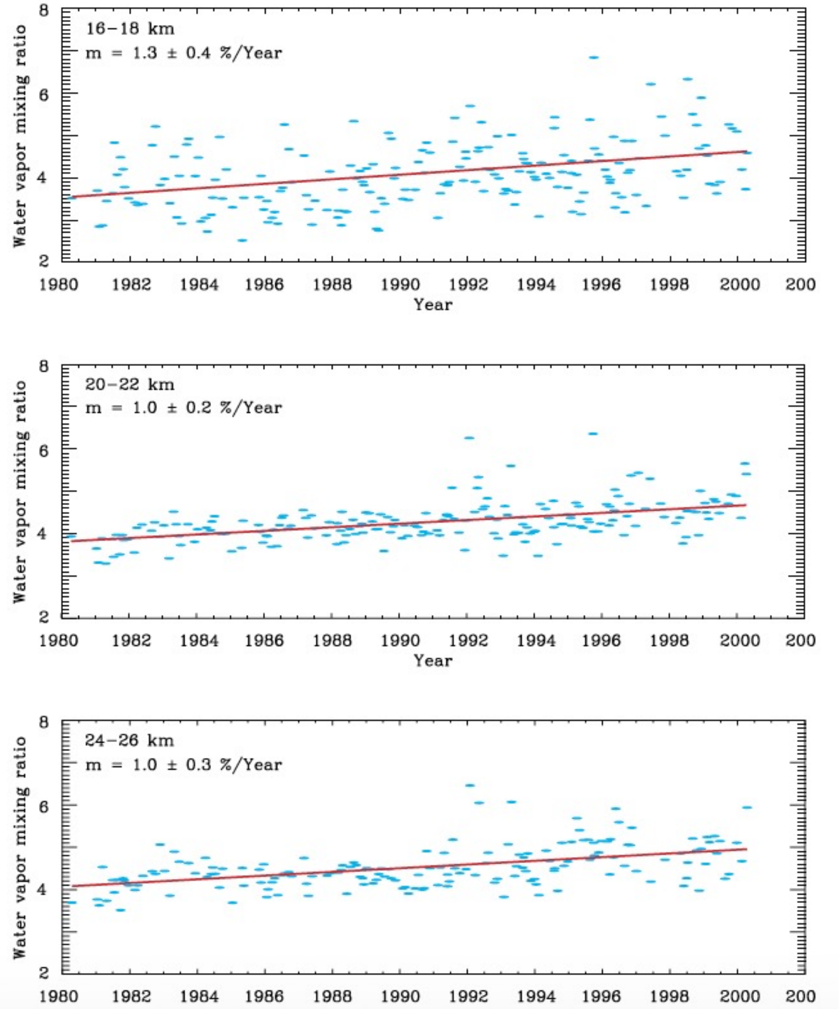
Why measure and study stratospheric H2O?

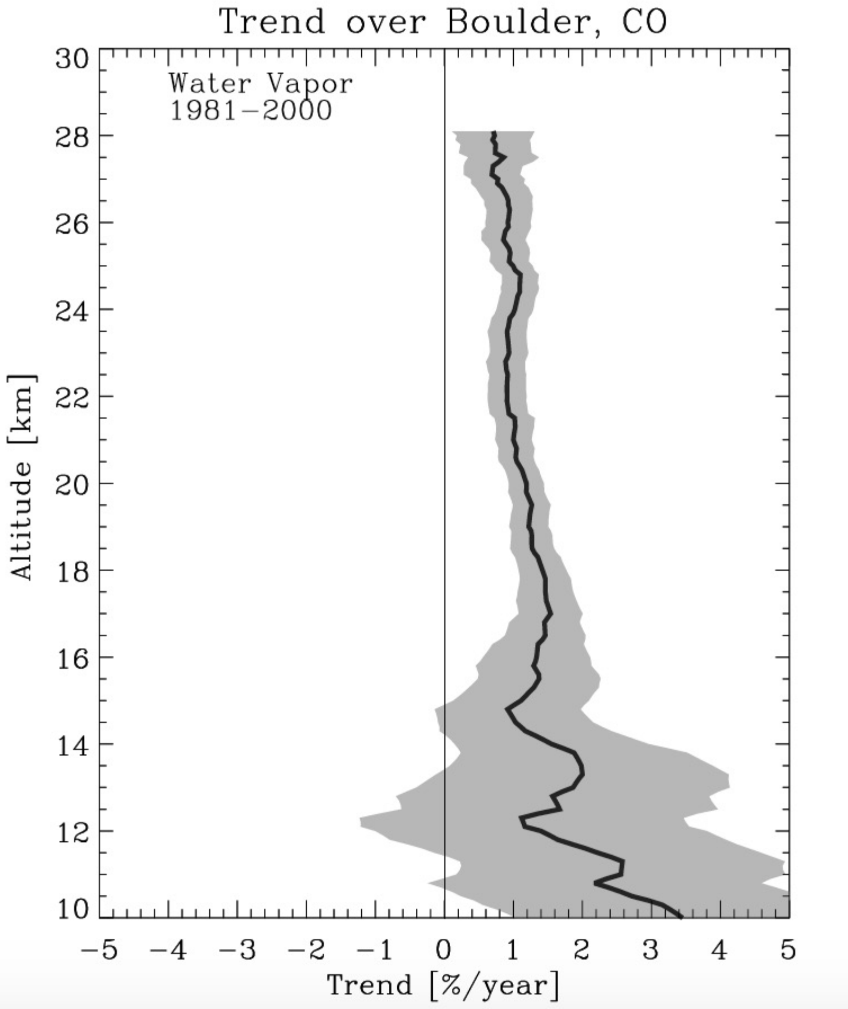


Balloon-borne frost-point hygrometer and MIPAS satellite measurements of H2O profiles inside the Arctic vortex in Feb. 1995 [SPARC, 2000]

- Vertical shape results from 2 sources**: tropospheric flux and stratospheric CH4 oxidation**
- Important gas for:
  - **Radiative balance/climate**
  - **Chemistry**, in particular for O3 destruction because H2O is primary source of the dominant O3-destroying HOx radicals & a key component of Polar Stratospheric Clouds

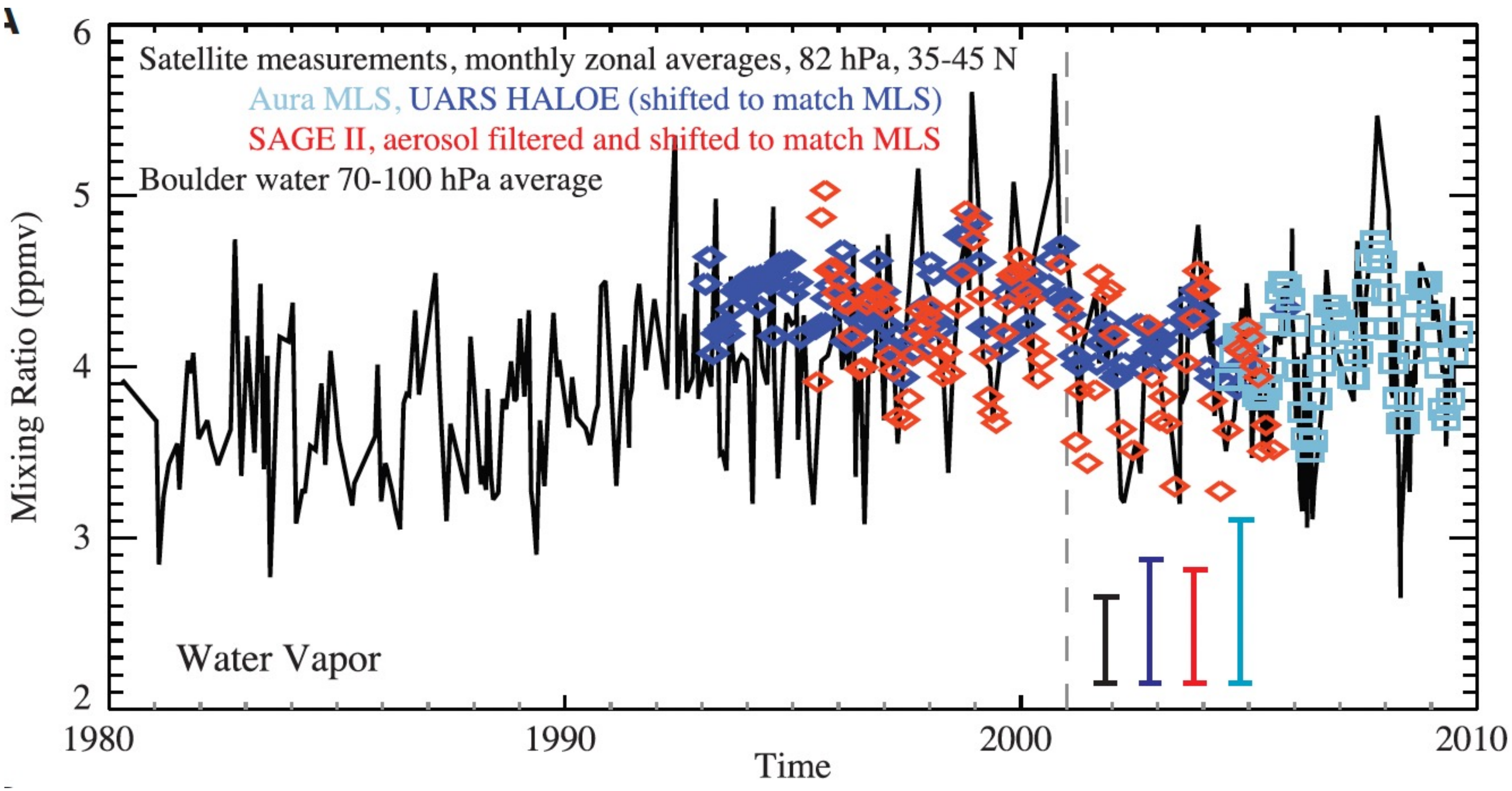
Stratospheric H2O trend (1980-2000)





Time series of 2 km layer average H2O (in ppmv) over Boulder.
Data from balloon-borne frost point hygrometers [SPARC, 2000].

Stratospheric H2O trend(S)

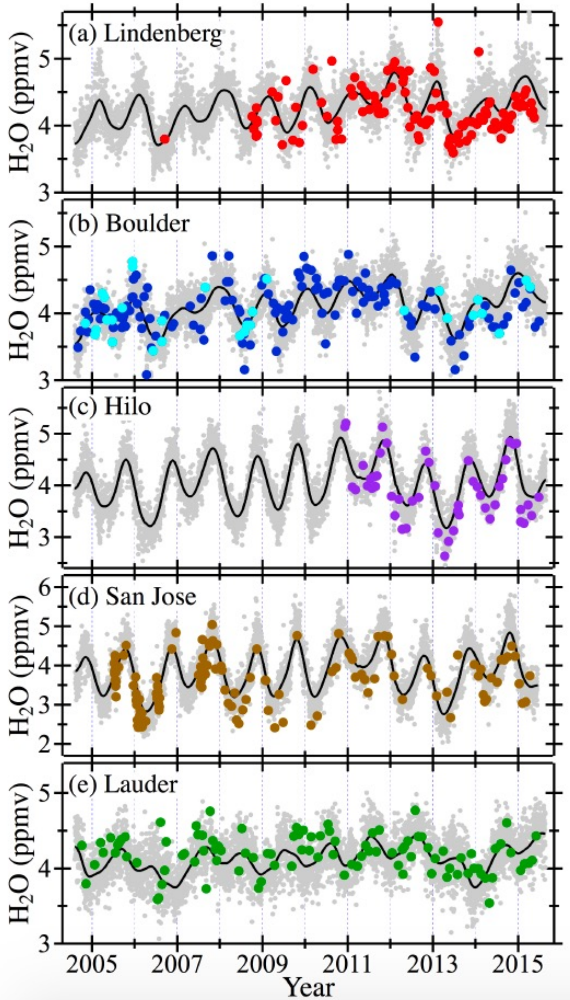


Time series of lower stratospheric H2O [Solomon et al., 2010].

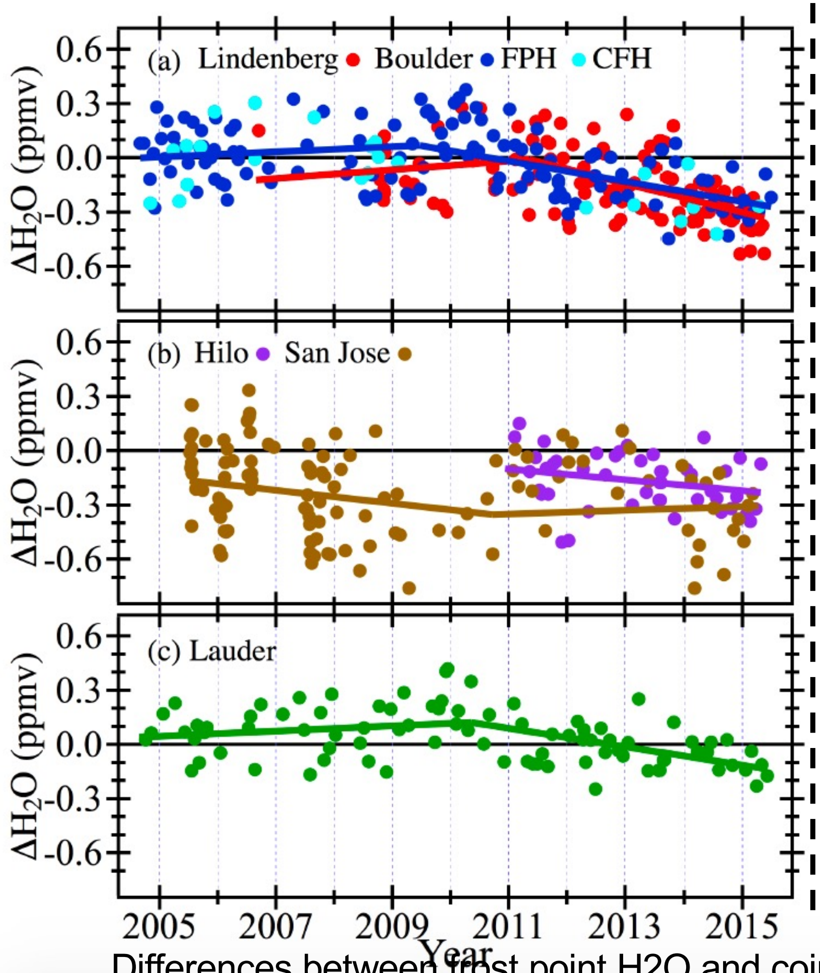
Positive trend during 1980-2000, followed by a drop after 2000. Then, back up slowly

Decadal fluctuations rather than continuous trend

Balloon-borne stratospheric H2O data are the reference data



Daily MLS H2O, reference satellite data, vs. in situ frost point hygrometer data at 68 hPa (filled circles).

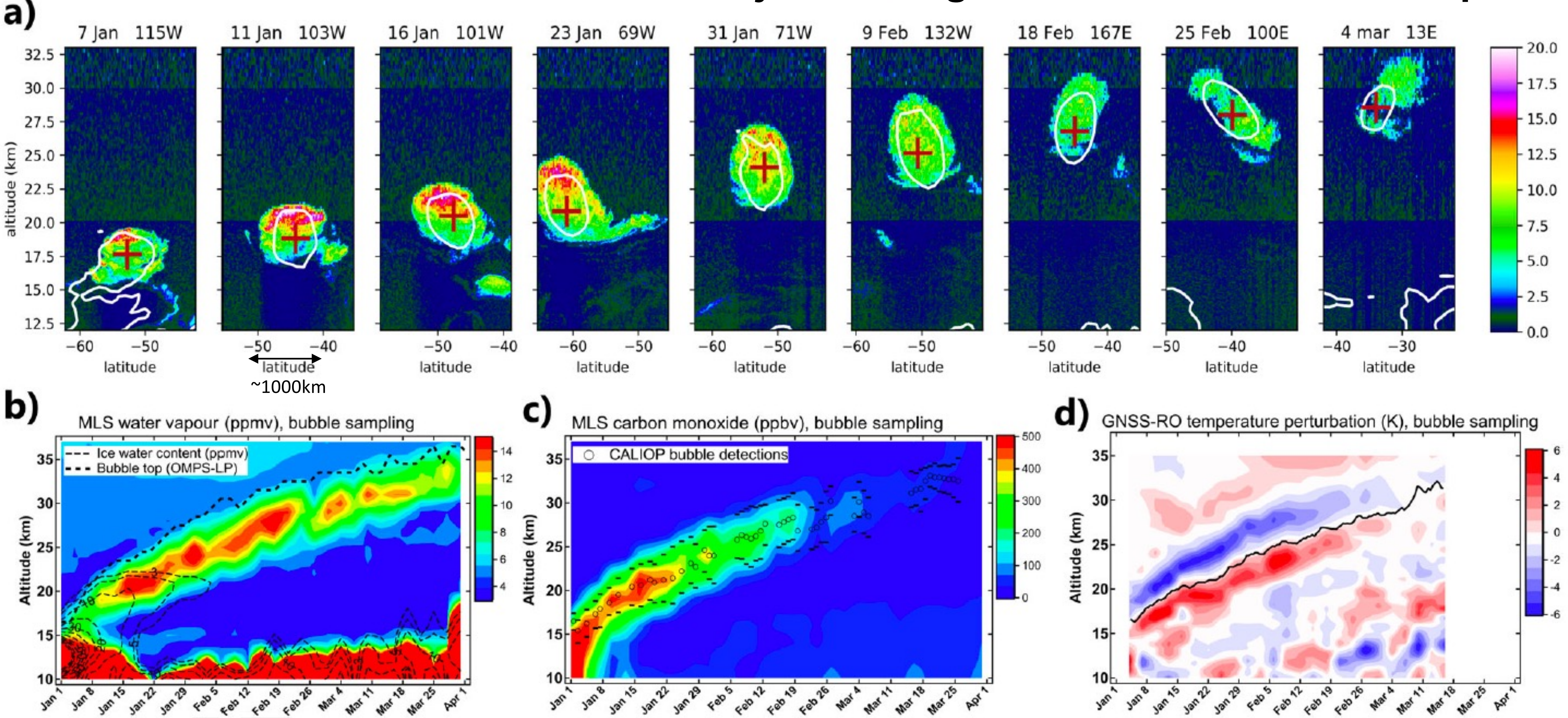


Differences between frost point H2O and coincident MLS H2O over the five sounding sites. Two distinct periods separated by a changepoint [Hurst et la, 2016]

Frost point data essential
for small-scale studies
and
for satellite H2O data
Intercomparison, filtering, and merging.

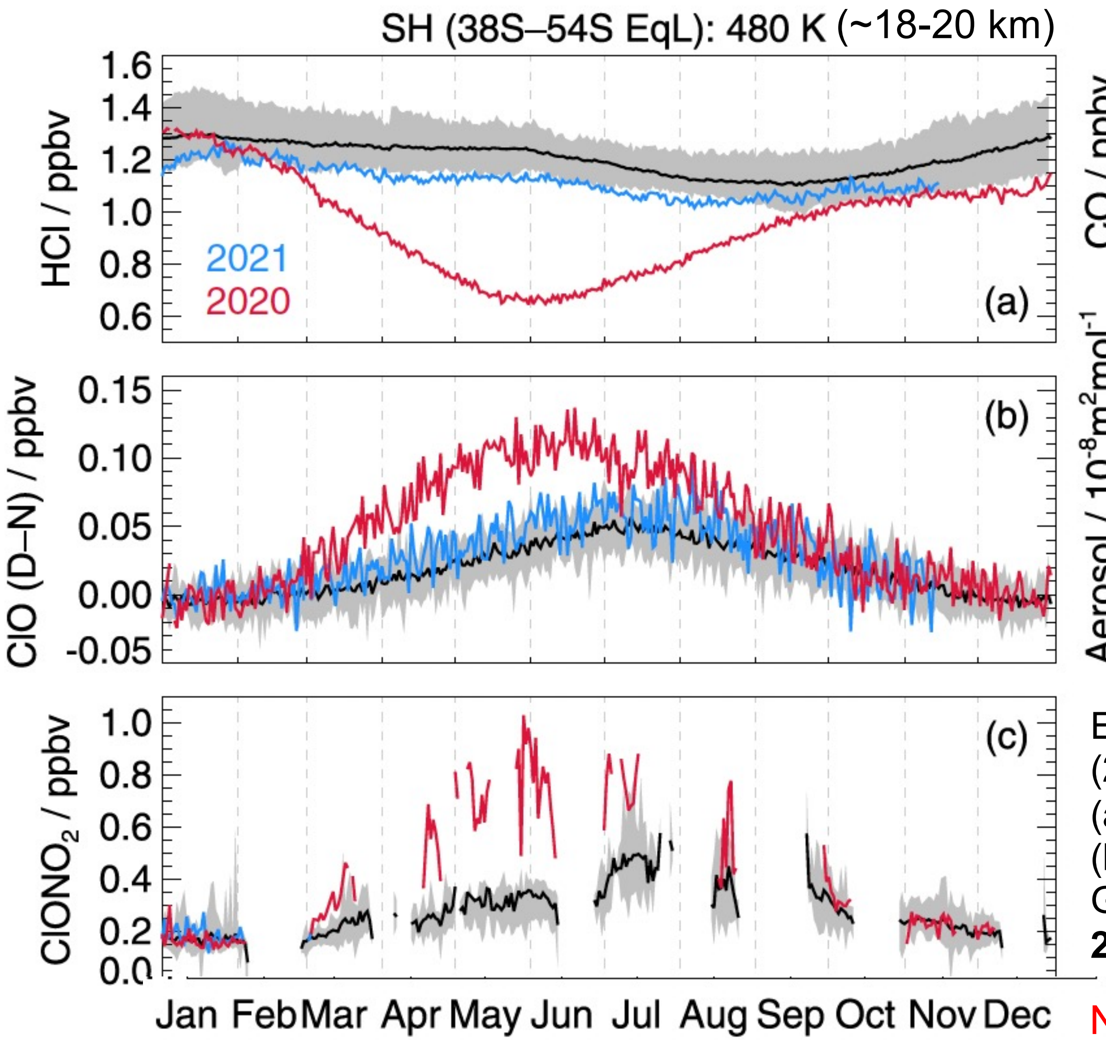
Continuous satellite validation required

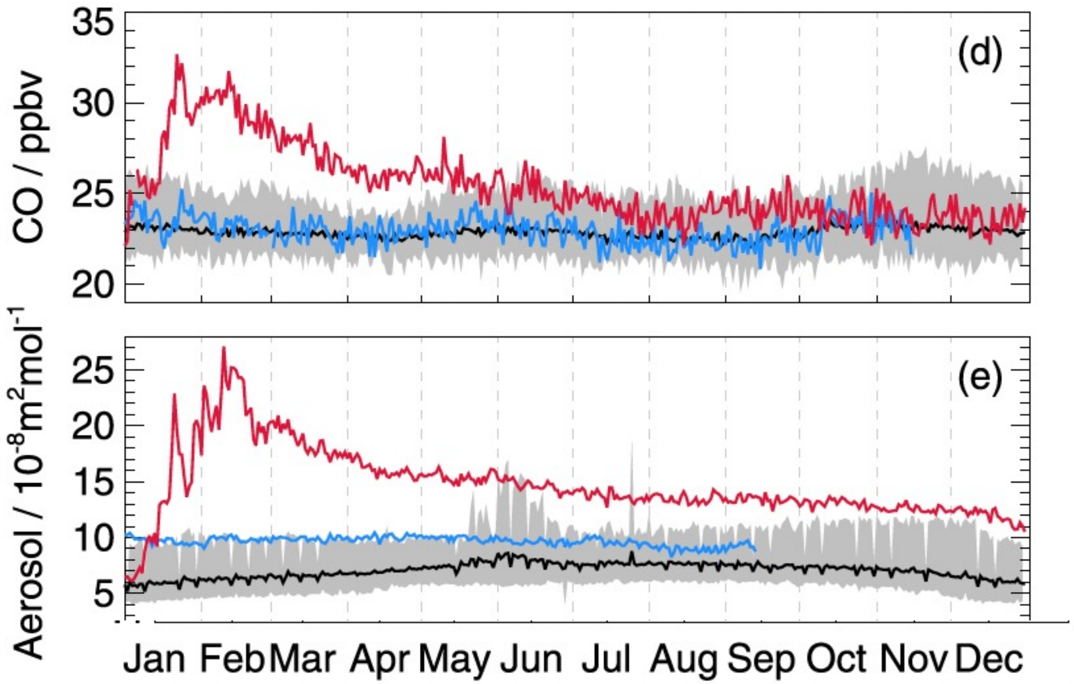
Australian New Year's Fires: massive injection of gases/aerosols into stratosphere



Vertical evolution of the smoke bubble, chemical composition and thermal structure. a) Satellite CALIOP scattering ratio profiles with crosses indicating vortex vorticity centroid (ECMWF), b) Time evolution of satellite MLS H2O within the slowly rising bubble, c) Evolution of MLS CO within the bubble, d) Composited T perturbations from Metop GNSS radio occultation [Khaykin et al, 2020]

Australian wildfires: Unexplained large changes in chlorine partitioning





EqL–band (38S–54S) averages at 480 K (~18-20 km) (**2020 in red**, **2021 in blue**) of :

(a) MLS HCl, (b) MLS ClO (day minus night);

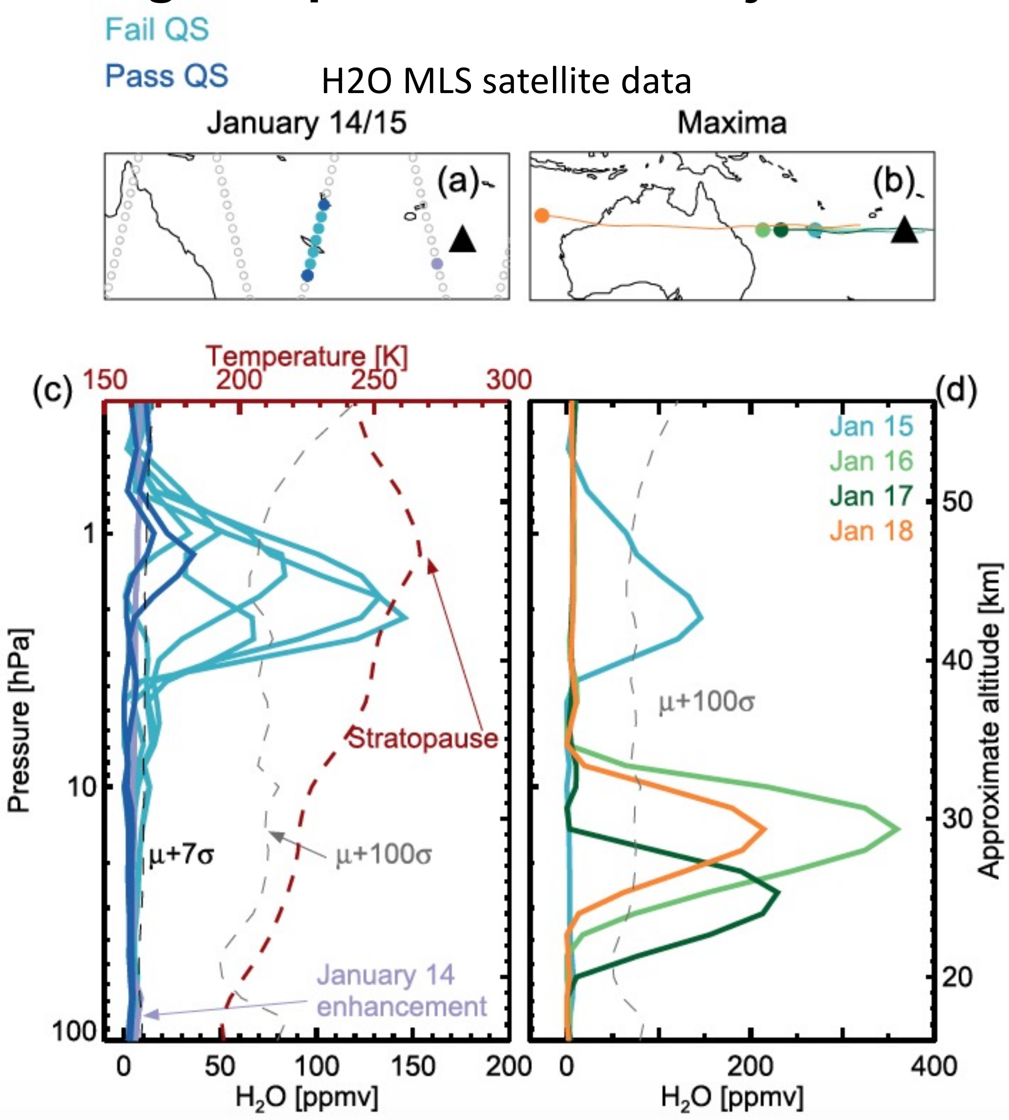
(b) (c) ACE-FTS ClONO2; (d) MLS CO; (e) OMPS aerosol

Gray shading depicts the envelope of behaviour over **2005–2019** and black line gives the mean [Santee et al., 2021]

Not understood. Heterogeneous chemistry on 'wet' smoke?

Hunga-Tonga eruption: massive injection of H_2O deep into the stratosphere

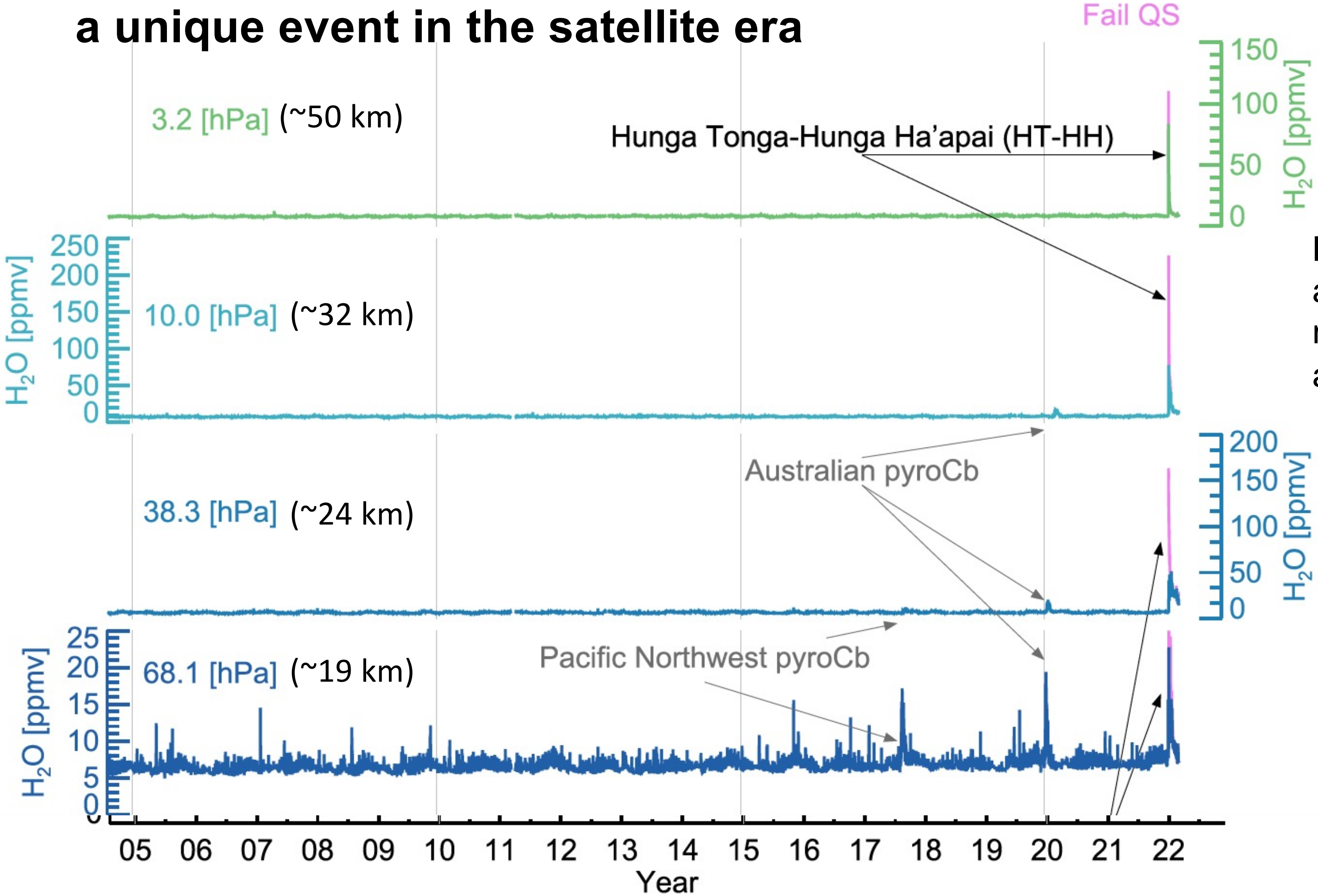
H2O MLS satellite data



Large amounts of H_2O directly injected into the mid- and upper stratosphere during the (submarine) eruption of Hunga-Tonga.
Totally unexpected and unprecedented.

[Millan et al., 2022]

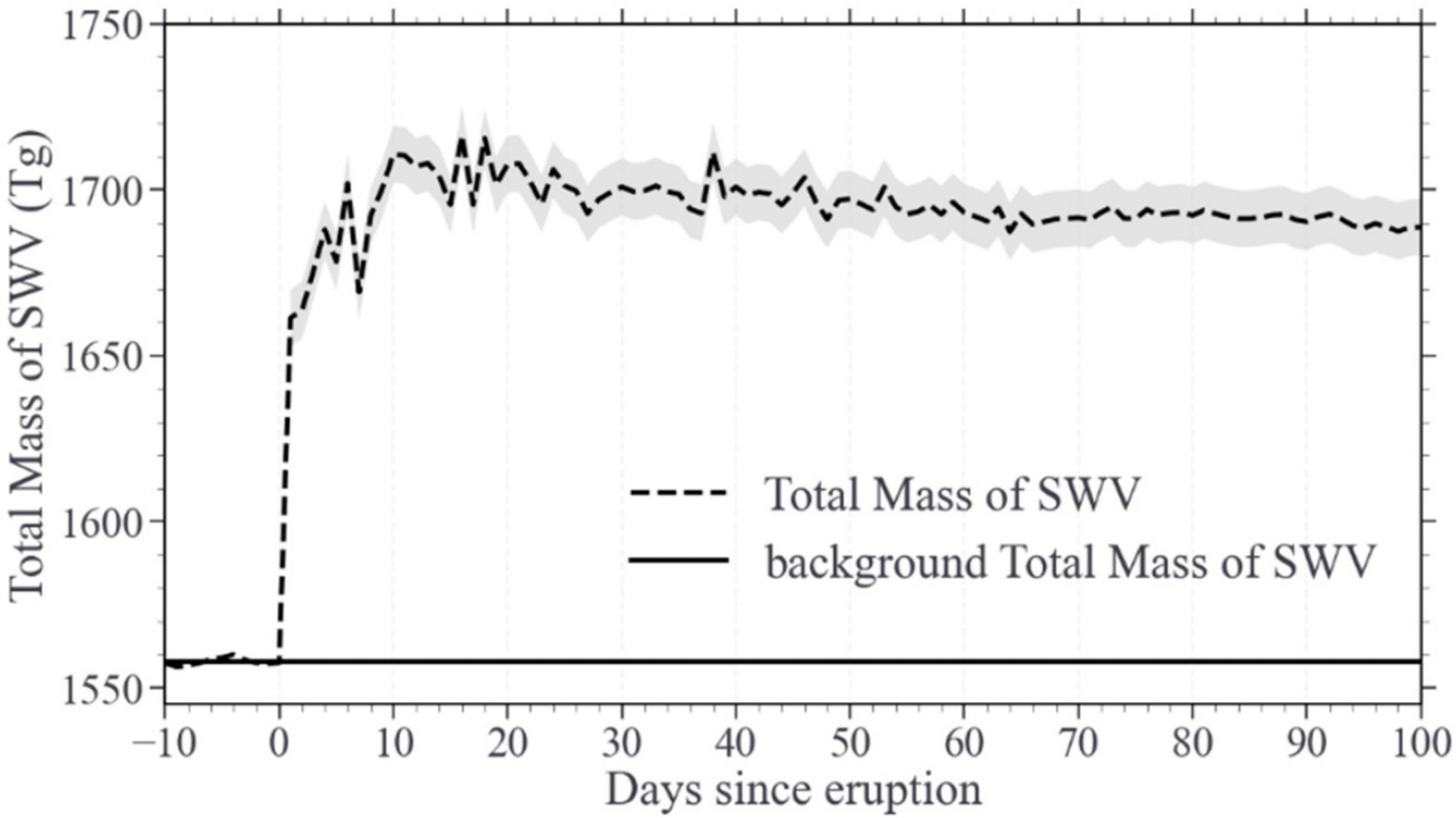
Hunga-Tonga injection of H2O deep into the stratosphere: a unique event in the satellite era



Time series of quality-screened maximum MLS H2O at different levels [Millan et al., 2022].

Breaking by a long way all records for altitude and magnitude of injection, by a volcano or other event

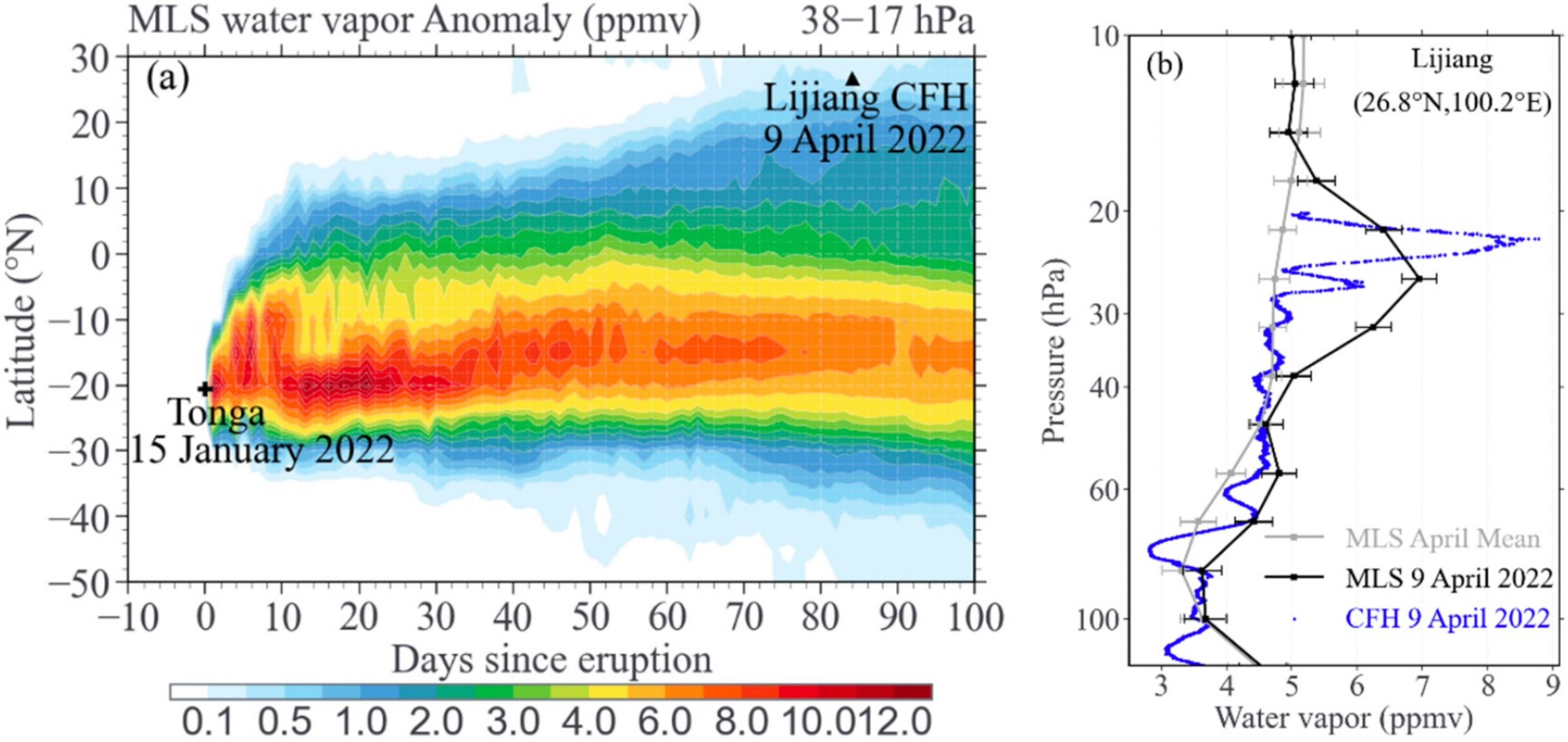
Hunga-Tonga eruption: Massive perturbation to global stratospheric H2O



Stratospheric H2O:
+10% globally

Time series of the total mass of stratospheric H2O (SWV, 1 Tg = 1012 g) before and after the Tonga eruption (15 January 2022). MLS data [Xu et al., 2022]

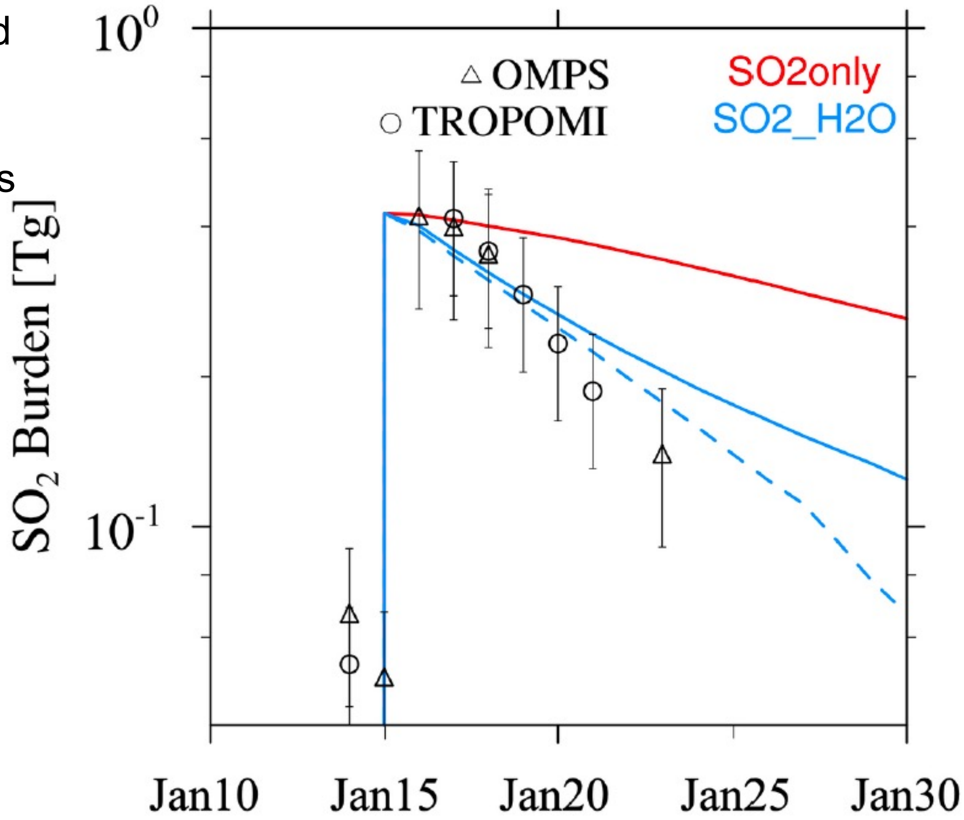
Hunga-Tonga H2O perturbations: layering



(a) Left: Zonal mean H2O anomalies (ppmv) as a function of latitude and time averaged over 38–17 hPa levels.
(b) Right: Vertical profiles of frost point H2O (blue), and MLS H2O(black). The gray line shows the mean April MLS H2O during 2005–2020.[Xu et al., 2022]

Hunga-Tonga eruption: shortening of SO2 lifetime from H2O increase

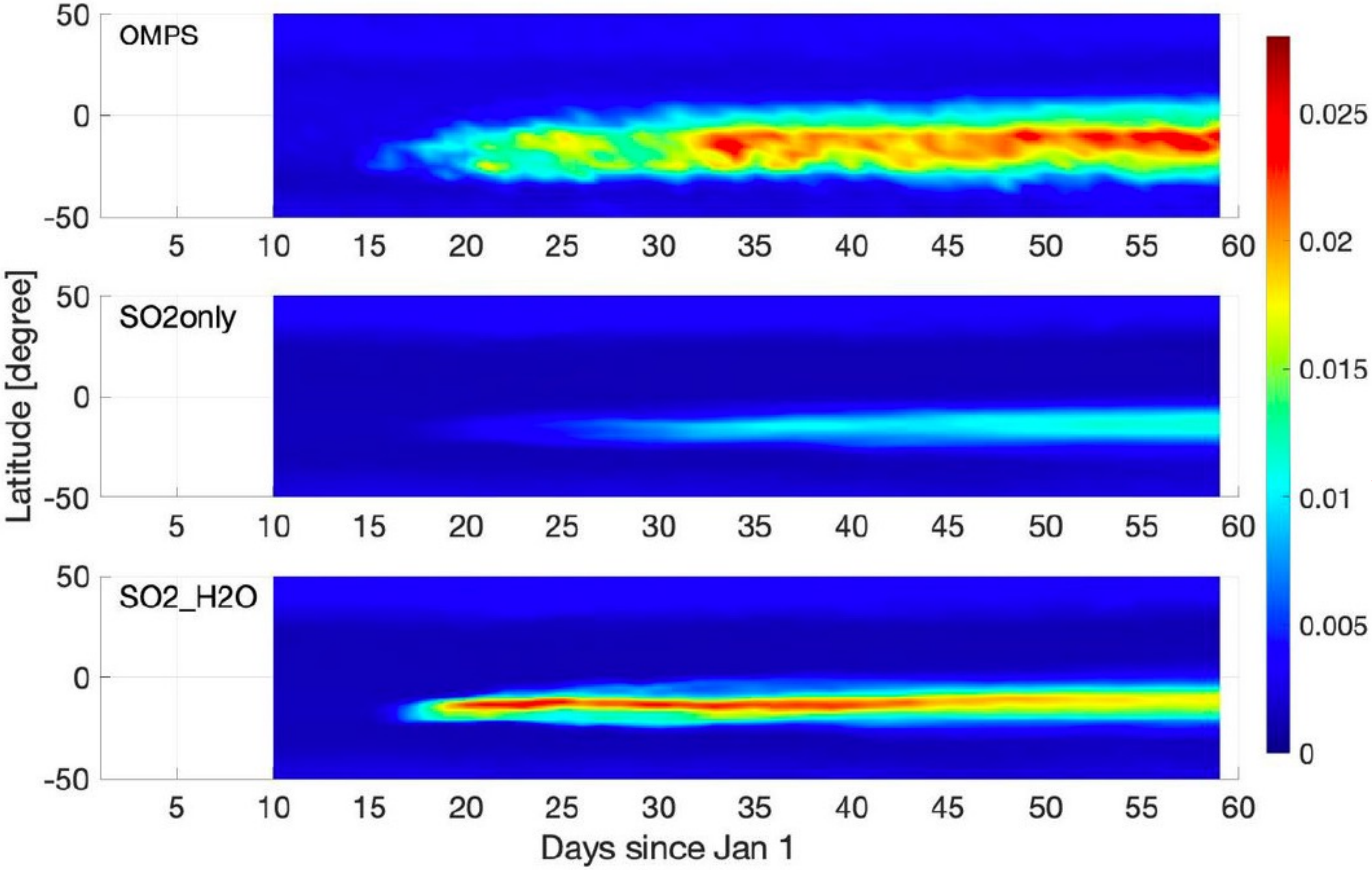
Hunga-Tonga also injected some SO2, an amount similar what is injected by small volcanic eruptions



The effect of high H2O excess on SO2 lifetime is quantitatively understood and modelled correctly

Time series of the stratospheric SO2 burden from two model cases with (blue) and without (red) water injection.
The dashed blue line is the SO2_H2O case excluding the SO2 below 0.2 DU (i.e., the approximate OMPS SO2 detection limit).
The circles and triangles are SO2 measurements by OMPS and TROPOMI.

Hunga-Tonga eruption: unexplained evolution of aerosol optical depth



The zonal mean column stratospheric aerosol optical depth at 997 nm from (top) OMPS, and the model simulations for cases (middle) without (SO2only case) and (bottom) with the water injection (SO2_H2O case).

The continuous increase in aerosol optical depth is not understood and not modelled correctly.
Same for H2O evolution

H2O-aerosols interactions?

CONCLUSIONS

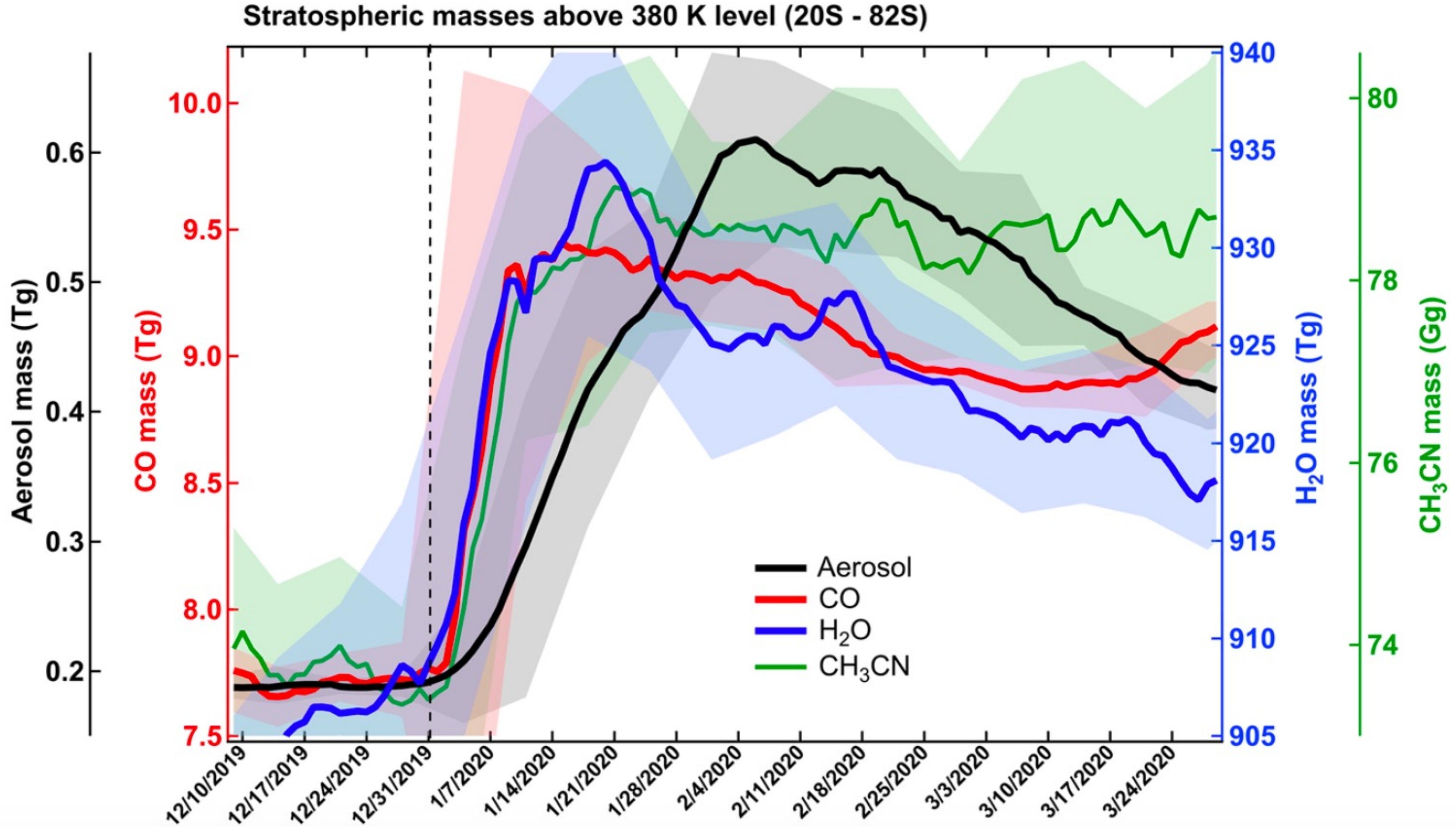
- The impacts of Australian wildfires (2020) and Hunga-Tonga eruption (2022) on the stratosphere were unprecedented and totally unexpected (missing understanding).

- Some effects on stratospheric chemistry and aerosols are not at all understood for both events (wildfires, submarine volcanic eruptions). Still unresolved issues.

- Unfortunately, very few balloon-borne in-situ data available: gases, aerosol size distribution, composition (including volatile and involatile),...

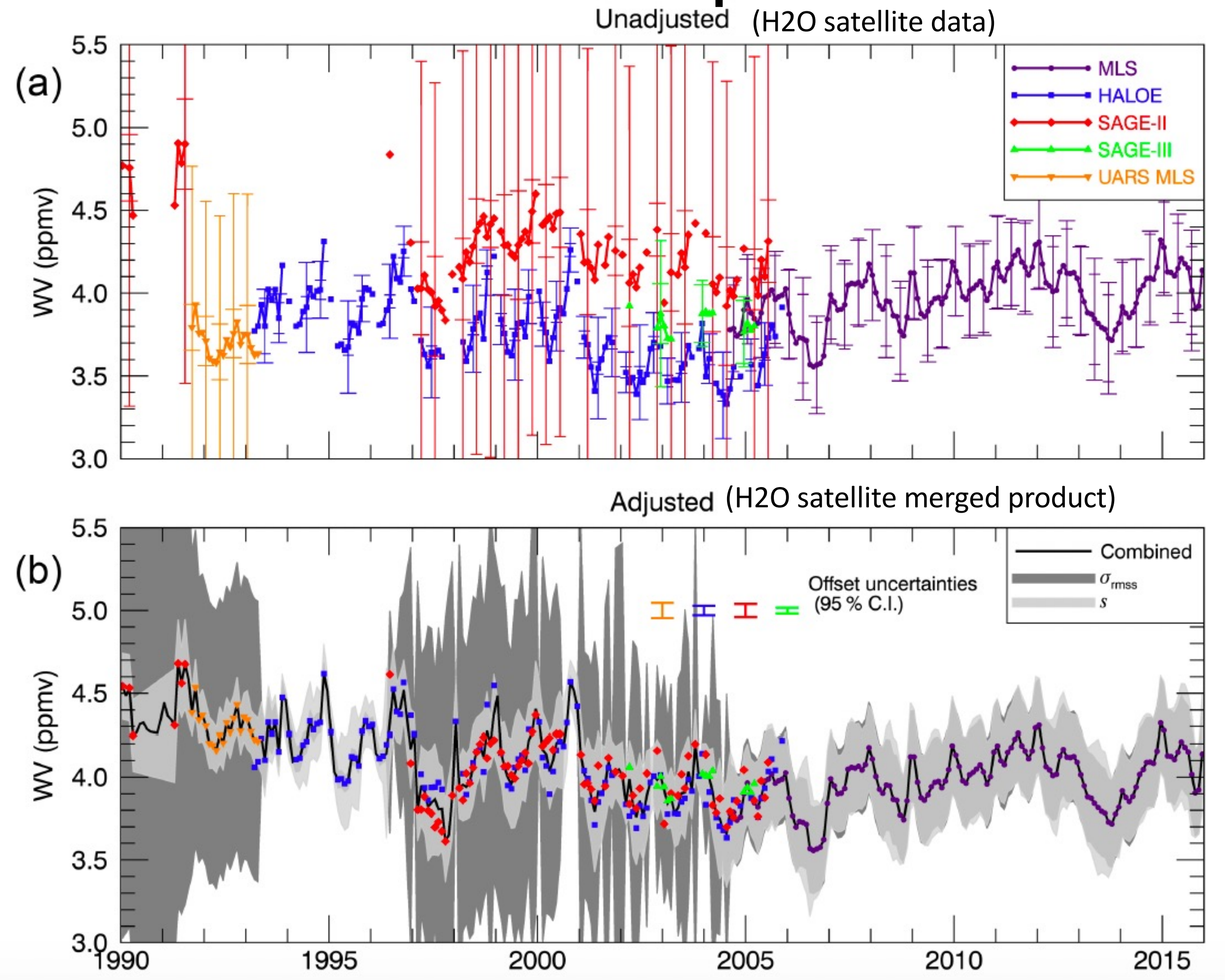
- “How water vapour injections affect stratospheric chemistry”? I don’t know.

Australian wildfires: Large-scale perturbations to stratospheric composition



Time evolution of daily total mass of CO, CH3CN, H2O and aerosols above 380K (~18 km) between the 20S-82S altitude band. Calculated from MLS satellite data [Khaykin et al, 2020]

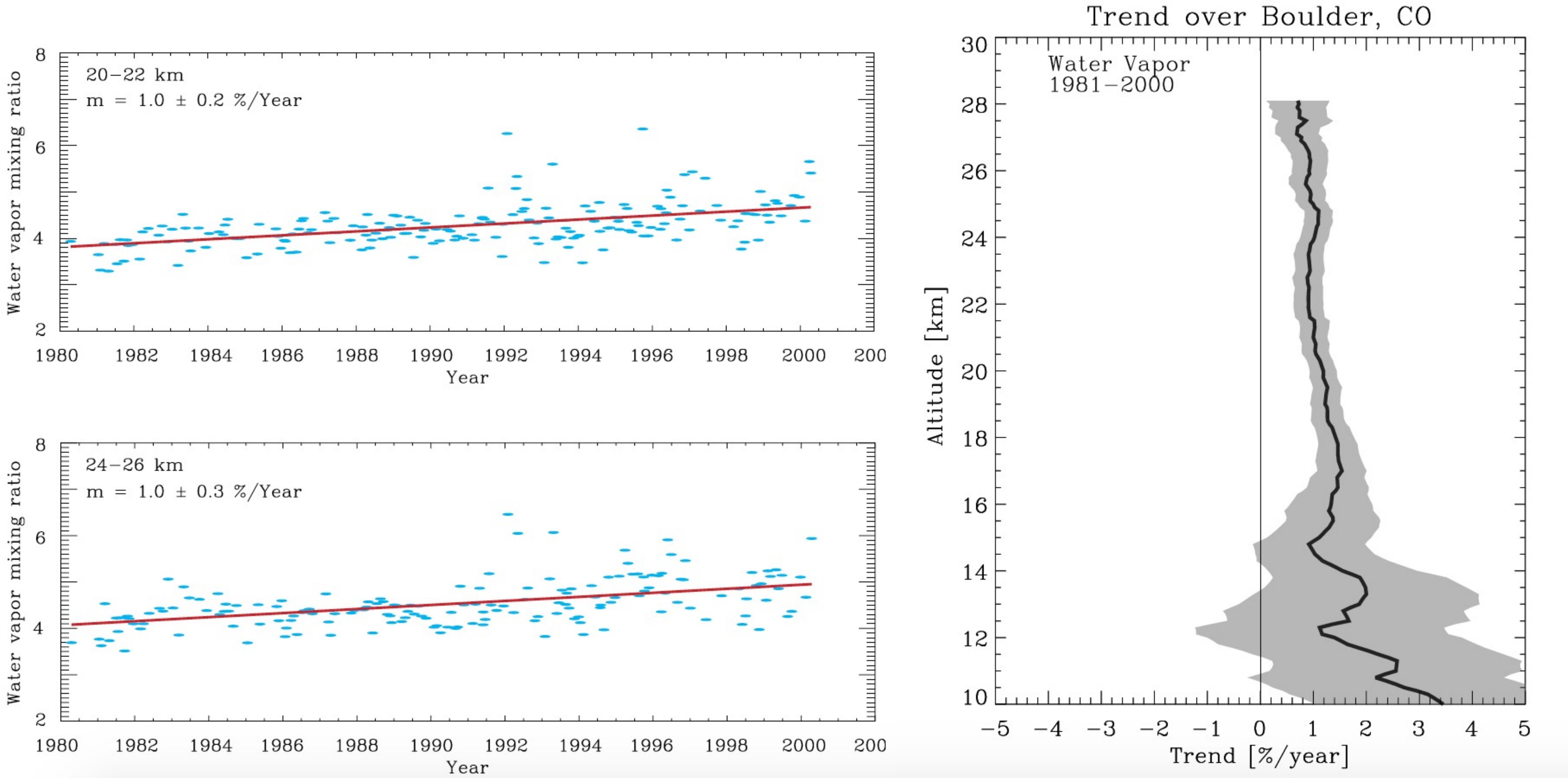
In-situ balloon stratospheric H2O data are the reference for satellite data



(a) Top: Uncorrected satellite H2O time series in 30-40S band at 68 hPa (~18 km), (b) Bottom: Offset-corrected satellite series [Davis et al., 2016]

Station	Latitude	Longitude	No. of soundings	Period
Alert (CAN)	82	−61.5	6	1989–1991
Ny-Ålesund (NOR)	78.9	11.9	6	2002–2004
Thule (GRL)	77.5	−69	4	1994–1995
Kiruna (SWE)	67.8	20.2	19	1991–2003
Sodankyla (FIN)	67.2	26.4	114	1996–2012
Fairbanks, AK (USA)	64.8	−147.7	4	1985–1997
Keflavik (ISL)	64	20.7	2	1994
Lindenberg (GER)	52.2	14.1	77	2006–2012
Laramie, WY (USA)	41.3	−105.6	5	1983–1989
Boulder (USA)	40	−105.2	397	1980–2014
Beltsville, MD (USA)	39	−76.9	37	2006–2011
Washington, DC (USA)	38.9	−77	129	1964–1980
Crows Landing, CA (USA)	37.4	−121.2	3	1993
Lamont, OK (USA)	36.6	−97.5	12	2003
Edwards AFB, CA (USA)	34.9	−117.9	4	1991
Dagett, CA (USA)	34.8	−117	1	1992
Huntsville, AL (USA)	34.7	−86.7	2	2002
Fort Sumner, NM (USA)	34.5	−104.3	10	1996–2004
Wrightwood, CA (USA)	34.4	−117.7	40	2006–2009
Midland, TX (USA)	31.9	−102.2	1	2004
Palestine, TX (USA)	31.8	−95.6	8	1981–1985
Lhasa (CHN)	29.7	91.1	20	2010–2012
Kunming (CHN)	25	102.7	36	2009–2012
Tengchong (CHN)	25	98.5	12	2010
Yangjiang (CHN)	21.9	112	12	2010
Hanoi (VNM)	21	105.8	23	2007–2011
Hilo, HI (USA)	19.7	−155.1	55	1991–2014
Pago Pago (ASM)	14.3	−170.7	5	1986–1988
San Jose (CRI)	10	−84.1	167	2005–2014
Tarawa (KIR)	1.4	172.9	10	2005–2010
Kototabang (IDN)	−0.2	100.3	9	2007–2008
San Cristobal (ECU)	−0.9	−89.6	47	1998–2007
Biak (IDN)	−1.2	136.1	34	2006–2011
Bandung (IDN)	−6.9	107.6	8	2003–2004
Juazeiro do Norte (BRA)	−7.2	−39.3	5	1997
Watukosek (IDN)	−7.5	112.6	7	2001–2003
R/V *Mirai-Cindy*	−8	80.5	39	2011
Vickers Cruise	−9.4	160	14	1993
La Reunion (REU)	−21.1	55.5	11	2005–2011
Lauder (NZL)	−45	169.7	121	1992–2014
McMurdo Station (ATA)	−77.8	166.7	31	1987–1999
South Pole (ATA)	−90	0	22	1990–1994

Frost point hygrometer stations used in satellite H2O intercomparison and filtering [Davis et al., 2016]



20–22 km
m = 1.0 ± 0.2 %/Year
24–26 km
m = 1.0 ± 0.3 %/Year
Water vapor mixing ratio
Year
Trend over Boulder, CO
Water Vapor
1981–2000
Altitude [km]
Trend [%/year]