NOAA RESEARCH

Theme 3:

Guiding Recovery of Stratospheric Ozone

Steve Montzka

Outline for today's session:

Topic	Presenter
1. Overview	Steve Montzka
2. Ozone-Depleting Substances	Isaac Vimont
3. Ozone Over Antarctica	Bryan Johnson
4. Tracking Global Ozone & Water Vapor Trends	Elizabeth Asher

Followed by Q&A

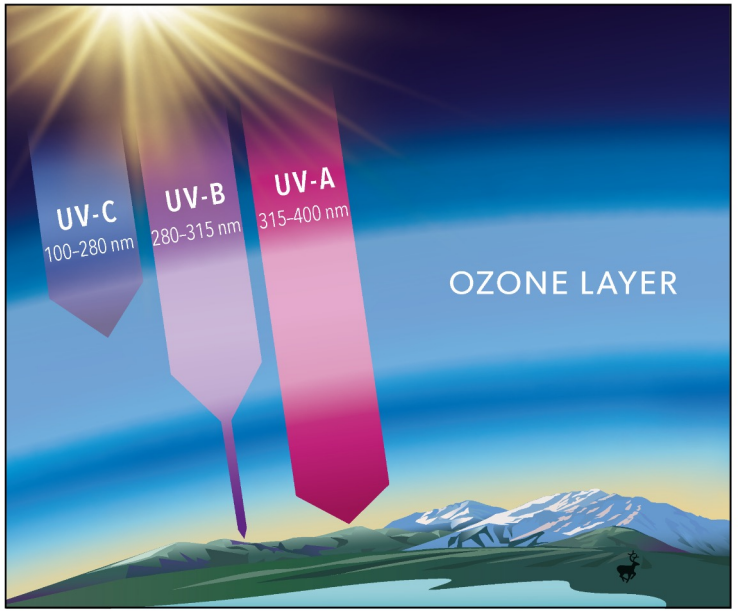
GML's high-quality research on stratospheric ozone

→ relevant to NOAA's mission and societal challenges

- Managing the atmospheric resource that is stratospheric ozone helps
  → *sustain a healthy environment and economy*
  → *protect human health against environmental hazards*
- Stratospheric ozone & ozone-depleting gases influence climate

→ Providing Science, Service and Stewardship relevant to OAR's societal challenges and NOAA & DOC priorities

UV Protection by the Stratospheric Ozone Layer



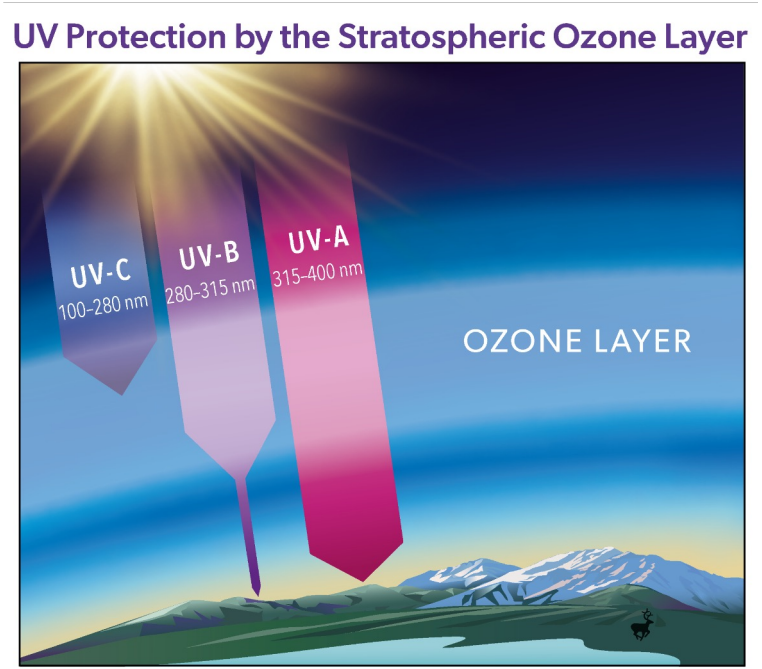
GML's high-quality research on stratospheric ozone

Objectives and goals:

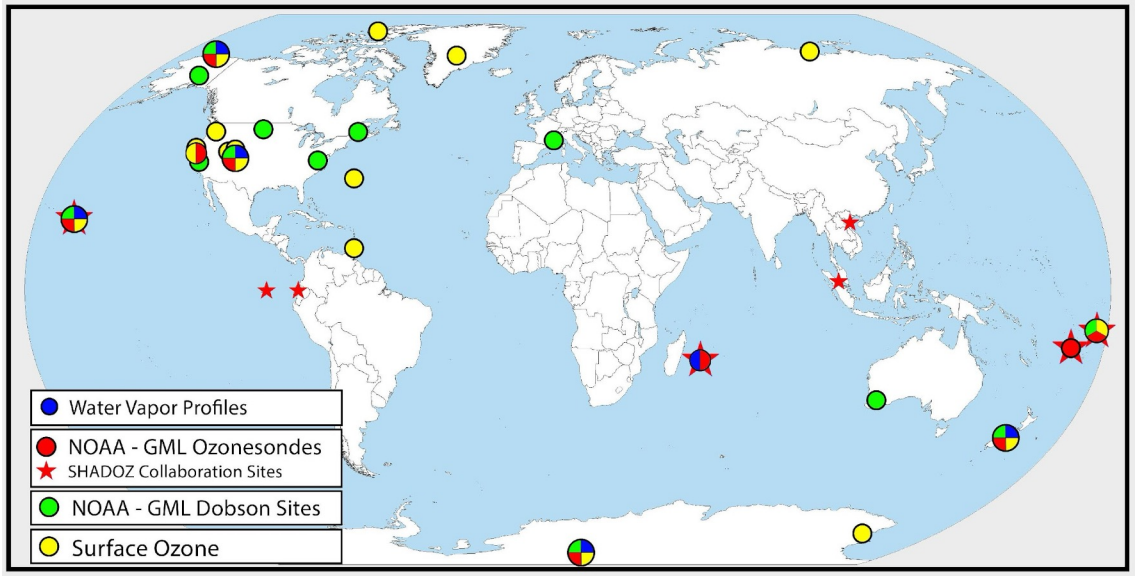
To make long-term measurements of ozone and ozone-depleting gases on global to regional scales

To diagnose observed changes, advancing scientific understanding

To effectively communicate results to broader audiences



GML's supporting infrastructures for ozone:
observing networks standards innovation



Complementary measurement methods:

13 Dobson sites

13 Ozonesonde sites (including SHADOZ collaborative sites)

6 Water vapor profiling sites

Ozone from Dobson instruments:

Providing a stable reference

(e.g., WMO reference Dobson)

- for the wider global Dobson network
- for satellites

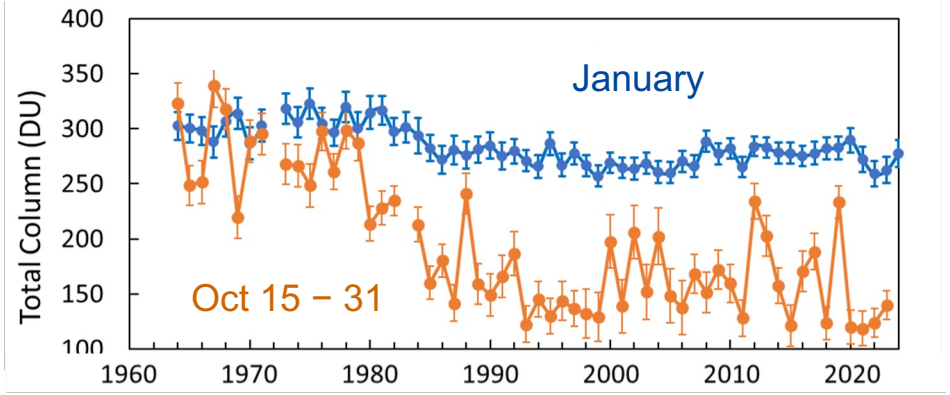
Ozone from ozonesondes:

- **Supplying high-resolution, vertical profiles**
- Strengthens and augments data from the tropics (SHADOZ) and over Antarctica

Related measurements:

- Water vapor profiling
- Surface ozone

Result highlight: Ozone above Antarctica



Dobson ozone total column at South Pole

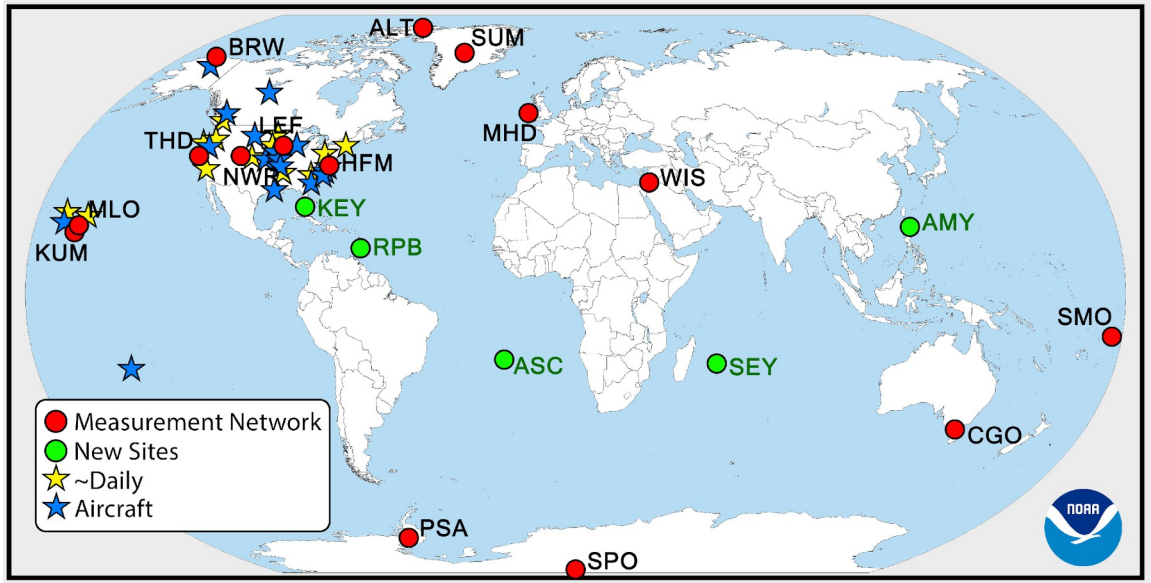
Ozonesonde partial column at South Pole

14-21 km layer

→ *ozone depletion persists despite the Montreal Protocol*

Johnson et al., 2023

GML's supporting infrastructures for ozone-depleting gases:
observing networks standards innovation



20 sites: ~ weekly flask pairs
5 sites: ~ hourly (using on-site instrumentation)
16 sites: ~ daily flask samples at US sites
14 sites: ~ monthly aircraft profiling

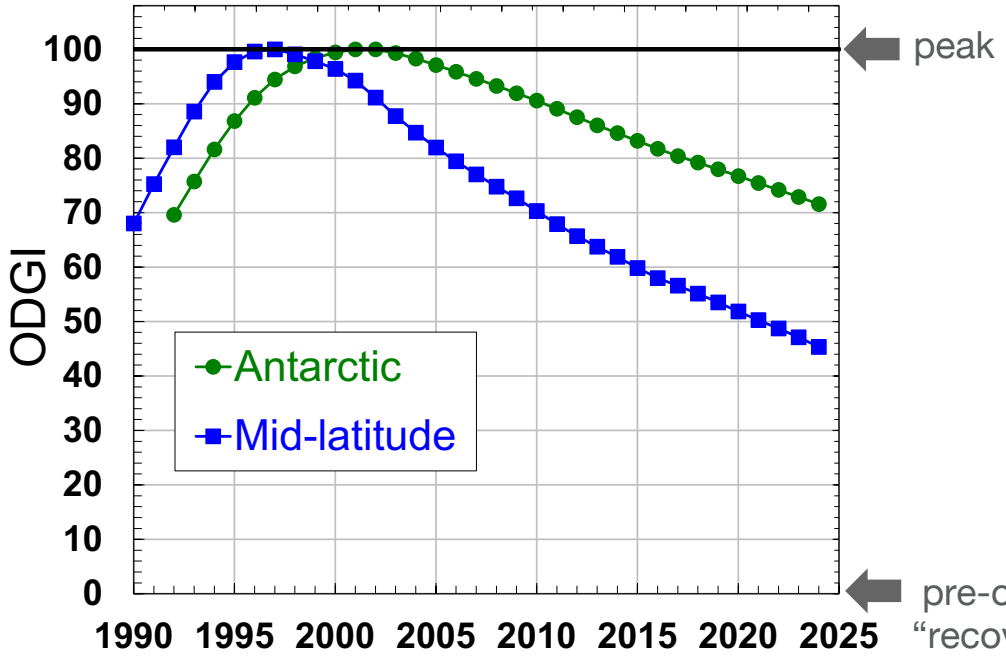
GML Halocarbon measurements:

- Measuring a full suite of ozone-depleting substances (ODSs), substitutes, & others
  (1 of 2 global networks)
- Globally, and with a US focus (3-D)
- With key redundancies
- In support of the Montreal Protocol

More to follow in Isaac's presentation

NOAA's Ozone Depleting Gas Index:

Tracking the overall decline in ozone-depleting halogen in the stratosphere



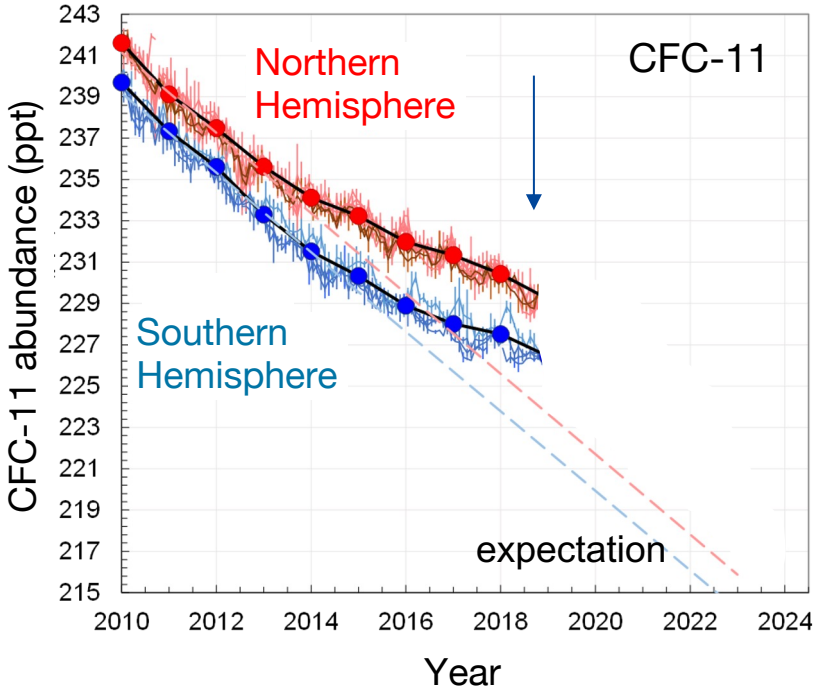
- Created with GML's measurements of all major ozone-depleting gases
- Updated annually

→ Progress towards recovery is substantial, but far from complete

→ Recovery expected in mid-late century ***with continued adherence to the Montreal Protocol***

All other things being unchanged

Results highlight: Long-term monitoring of ozone-depleting substances at GML



GML's monitoring and research effort:

- Detected a violation of the Montreal Protocol
- Identified the potential source region
- Led to a resolution

NOAA/GML as a trusted agent

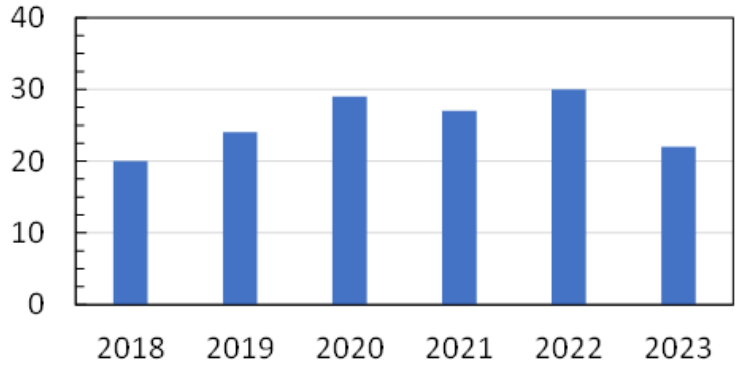
Montzka et al., 2018; Rigby et al., 2019; Montzka et al., 2021; Park et al., 2021

GML: Providing high-quality science, sustained for decades

2018 - 2023

- 152 publications
- 11 awards; 8 recognitions
- 2 patent filings initiated
- 50 records of calibrated trace-gas data, regularly updated & maintained, for gases relevant to ozone
- 9 international databases repost GML ozone- and ODS-related data

Theme 3 publications by year



***25-45%** of all GML publications*

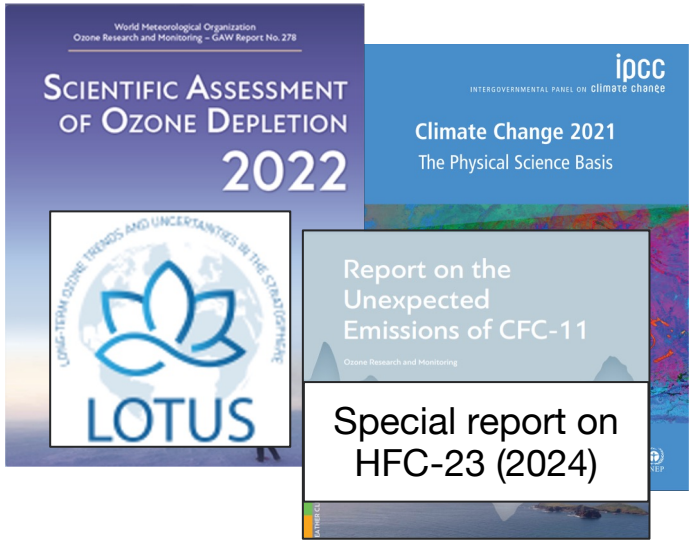
GML: Providing highly relevant insights to societal issues

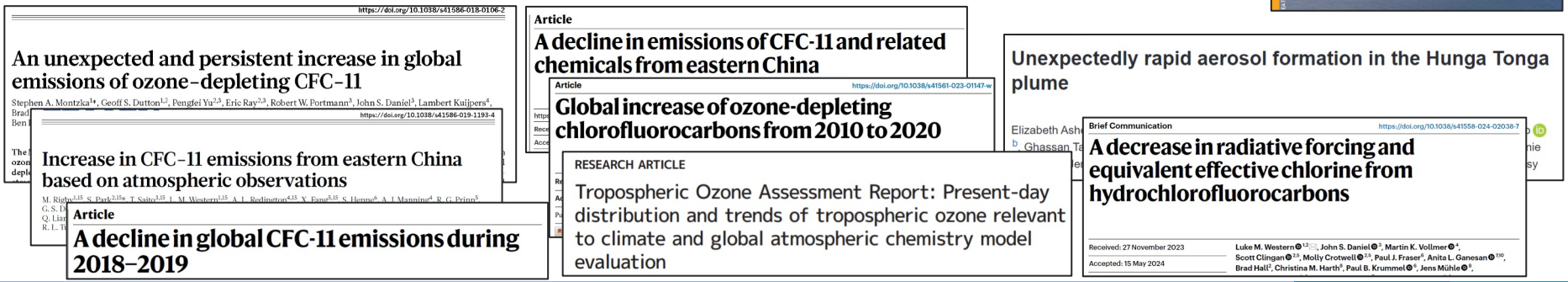
GML data are fundamental to international scientific assessments of ozone depletion and climate

- Documenting the progress and remaining challenges to the parties of Montreal Protocol
- Highlighting other factors influencing ozone

GML scientists play key roles in these assessments

- As lead authors, co-authors, and contributors
- Through the advances in scientific understanding via publications in high-profile journals





Summary:

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- GML **conducts high-quality measurements** of ozone, ozone-depleting gases, and related substances throughout the global atmosphere on long time-scales
- GML **provides scientific and engineering advances** that enhance our understanding of atmospheric ozone and its changes over time
- GML **shares its measurements, expertise and understanding** to enhance the global effort to ensure the timely recovery of the ozone layer

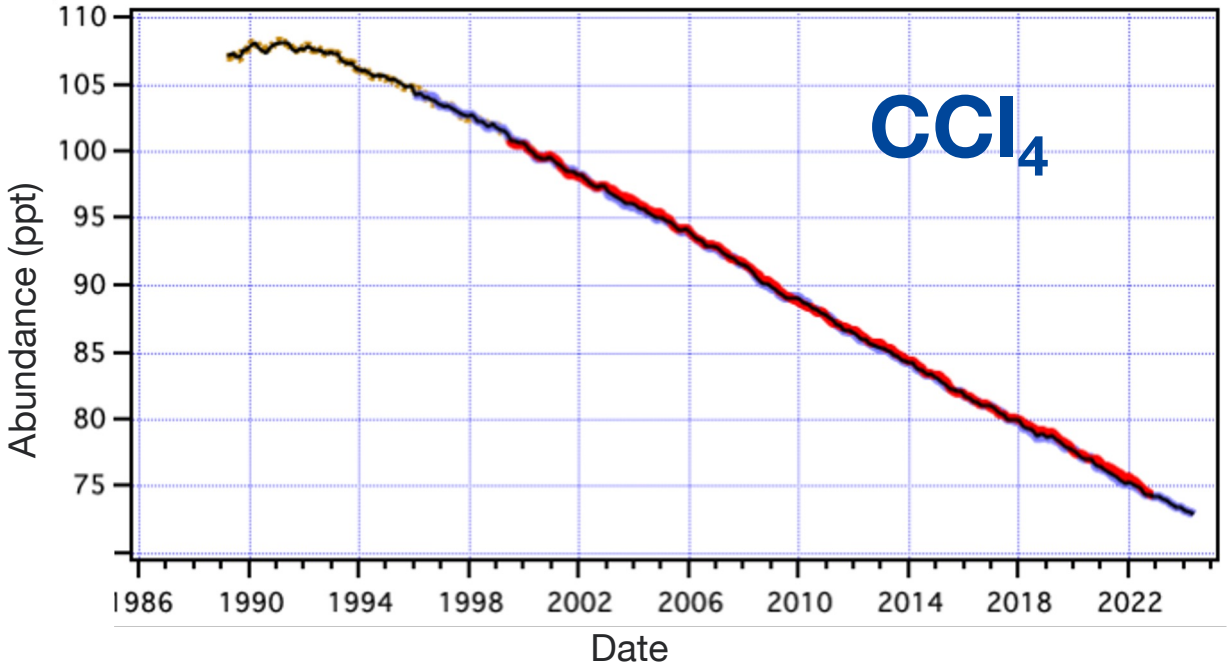
Theme 3:

Ozone-Depleting Substances

Isaac Vimont

- Providing unassailable long-term measurement records to the public
- Providing critical scientific information to the international community in support of the Montreal Protocol
- Consistently contributing to the highest degree of scientific excellence and technological innovation

GML is a world leader in making measurements to produce long-term records tracking ozone-depleting substances relevant to the Montreal Protocol

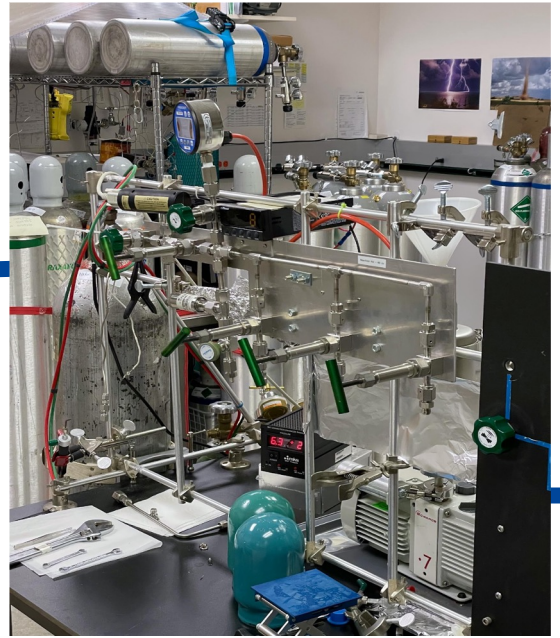


Every year:

- 10,000 flasks
- 17,000 analyses
- 47 species published
- >1M data points QC'd

Redundancy is critical for accurate quantification of small changes in the global atmosphere

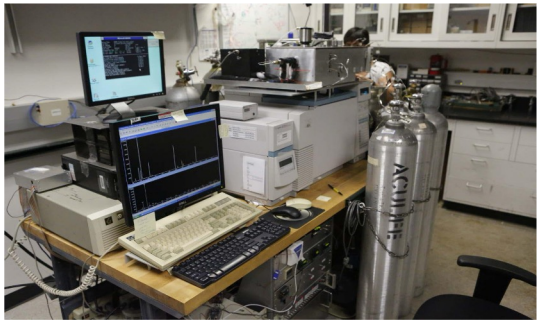
In situ measurements



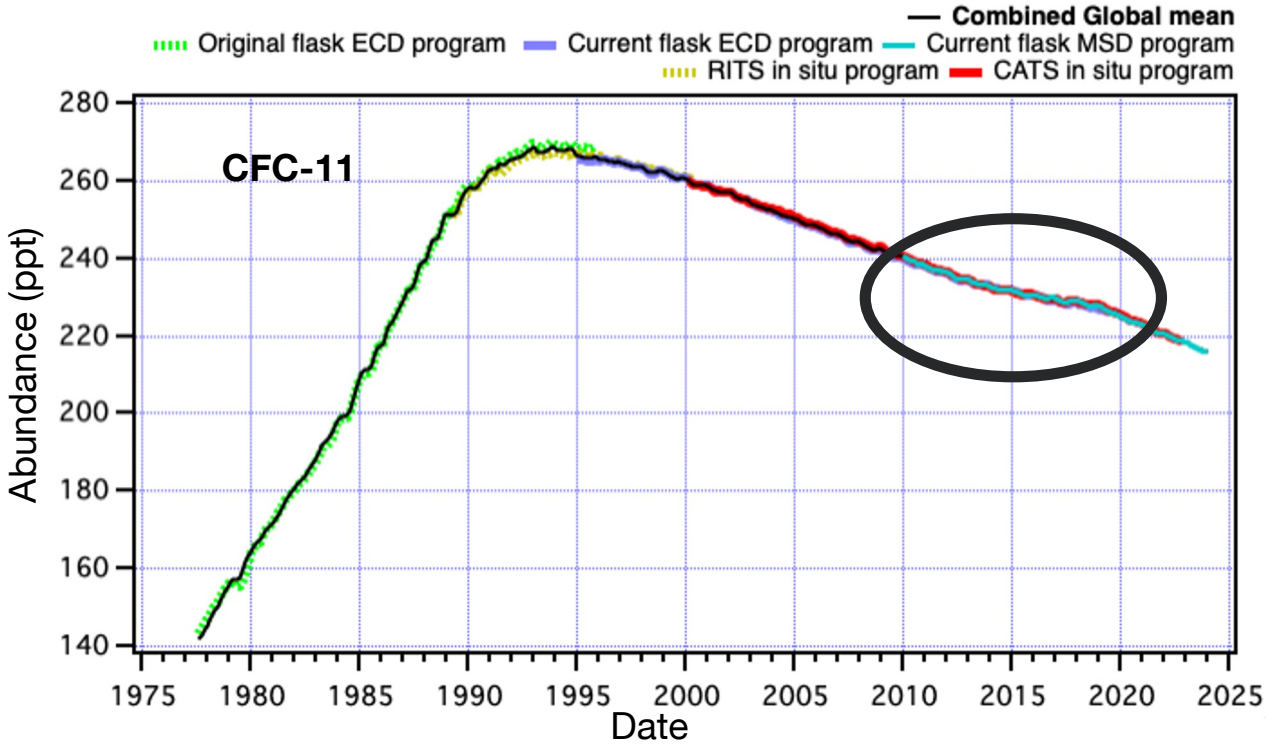
Calibrated standards

Discrete sampling

Laboratory measurements



Detecting a violation of the Montreal Protocol



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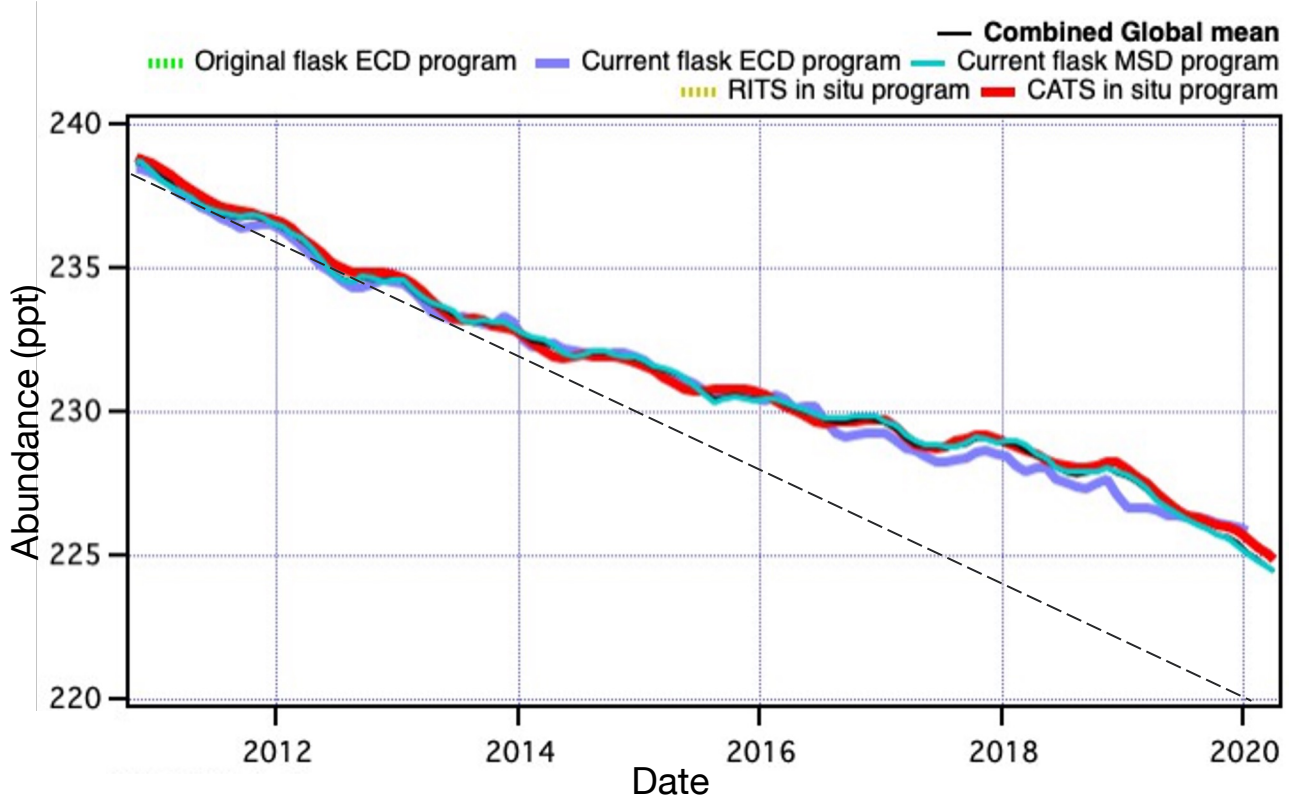
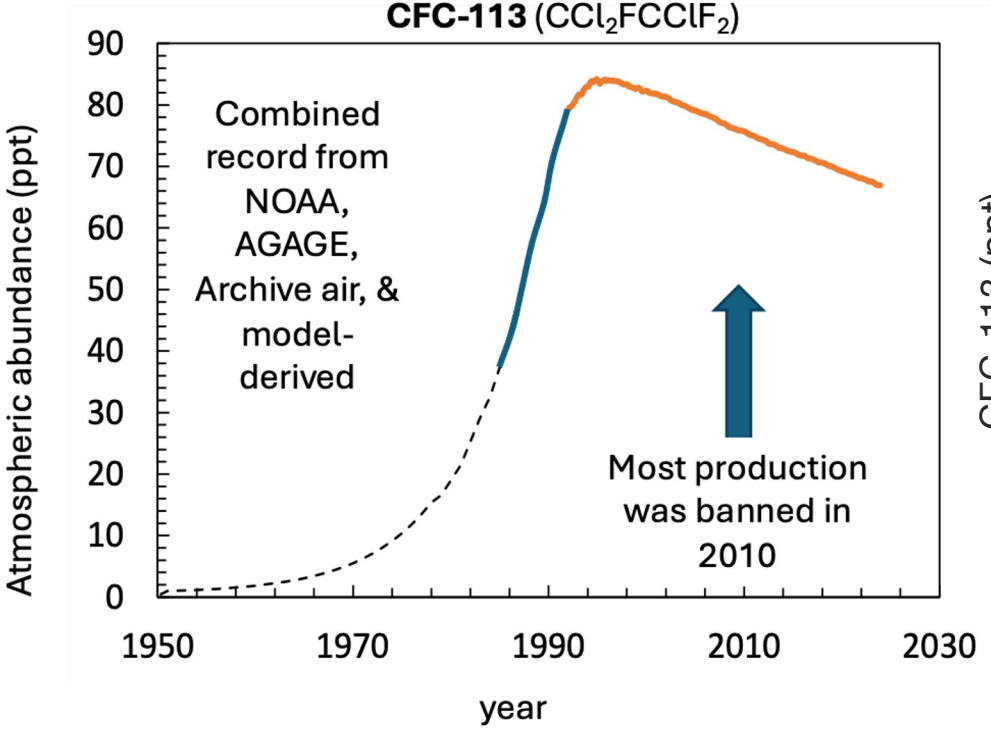
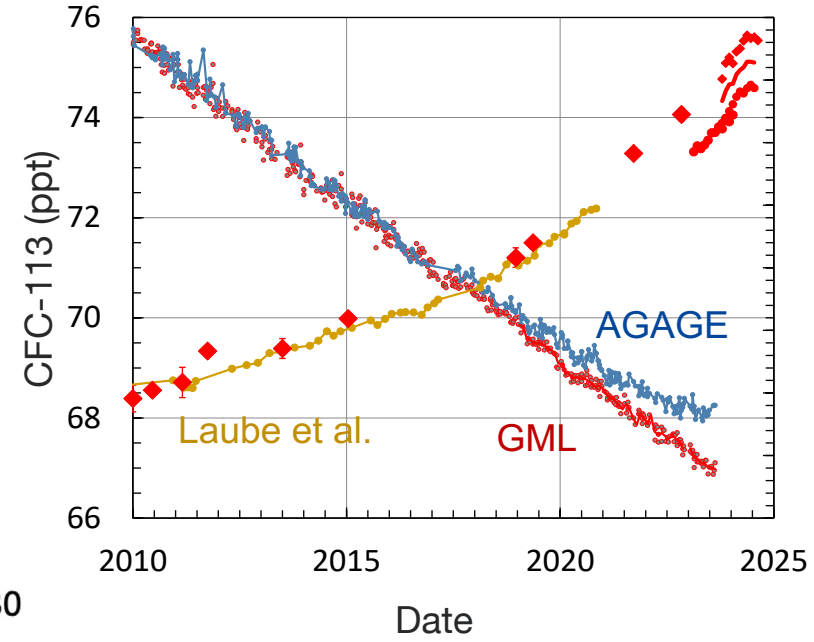


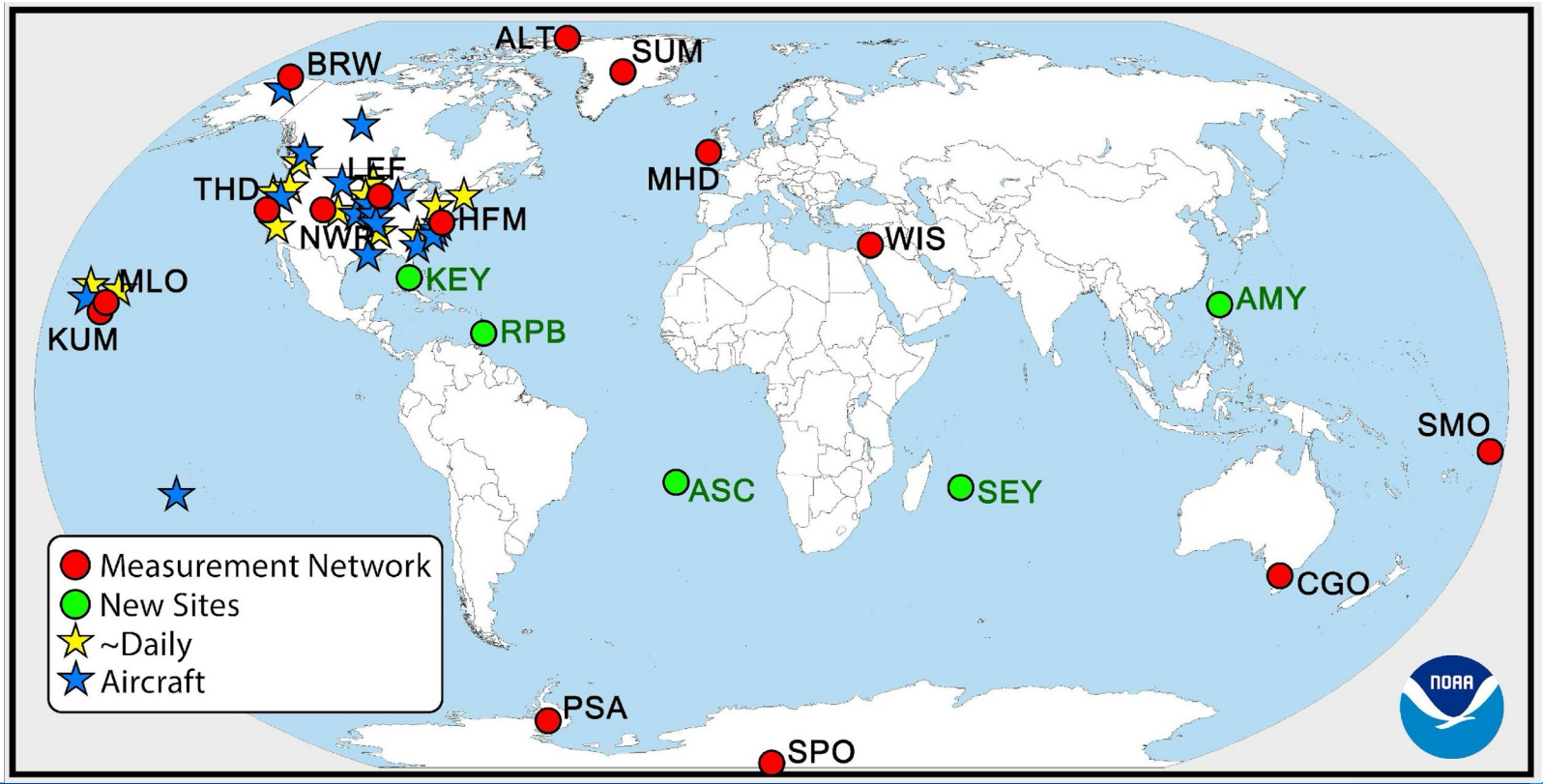
GML innovation: Refine existing measurement records, initiate new ones





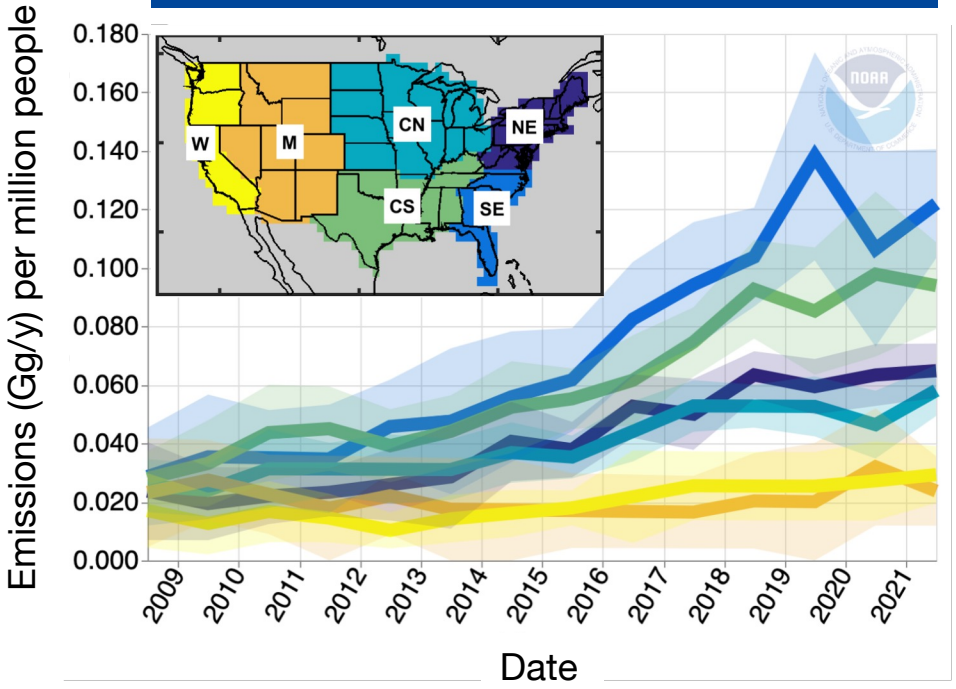
GML's expanding ODS measurement network improves global coverage

GML's North American GHG and ODS Network

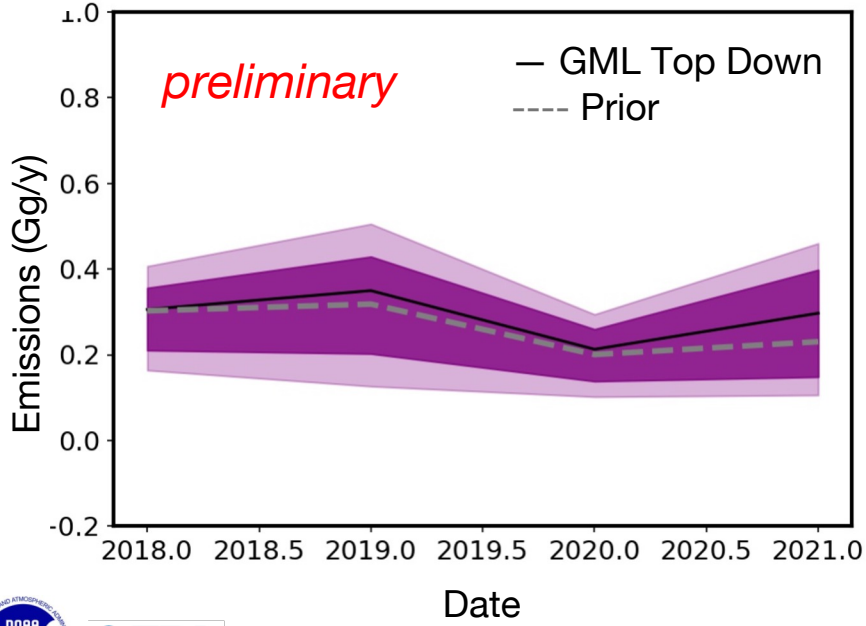


GML partners with EPA: Regional emissions for the US

HFC-125

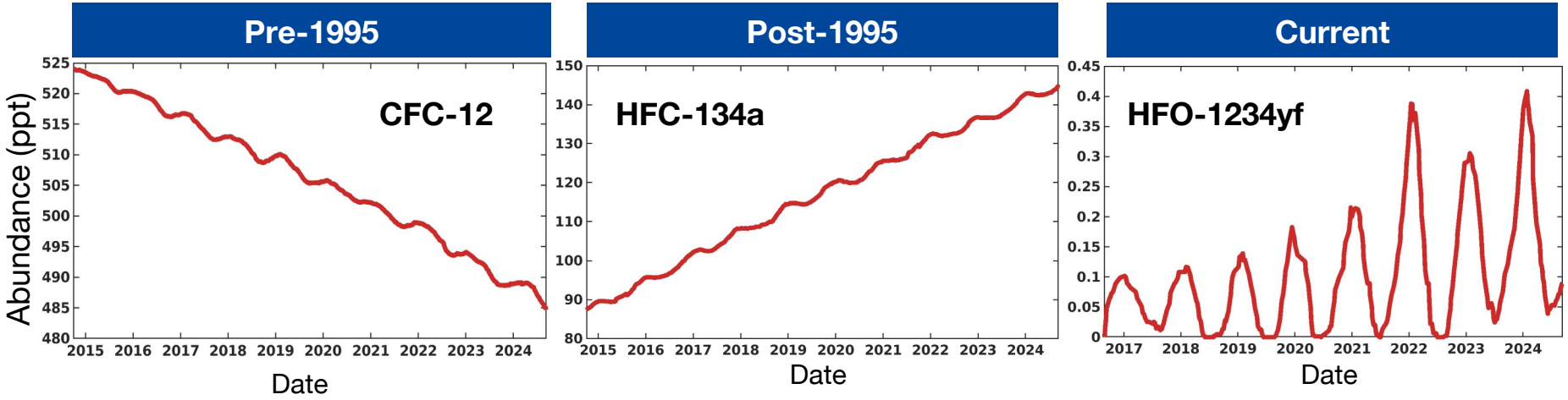


HFC-23



GML measures growth of next-generation halogenated compounds

Mobile refrigerants measured at 71ºN



Summary:

NOAA RESEARCH

- Providing the public unassailable long-term measurement records
- Providing critical scientific information to the international community in support of the Montreal Protocol
- Consistently contributing to the highest degree of scientific excellence and technological innovation

Theme 3:

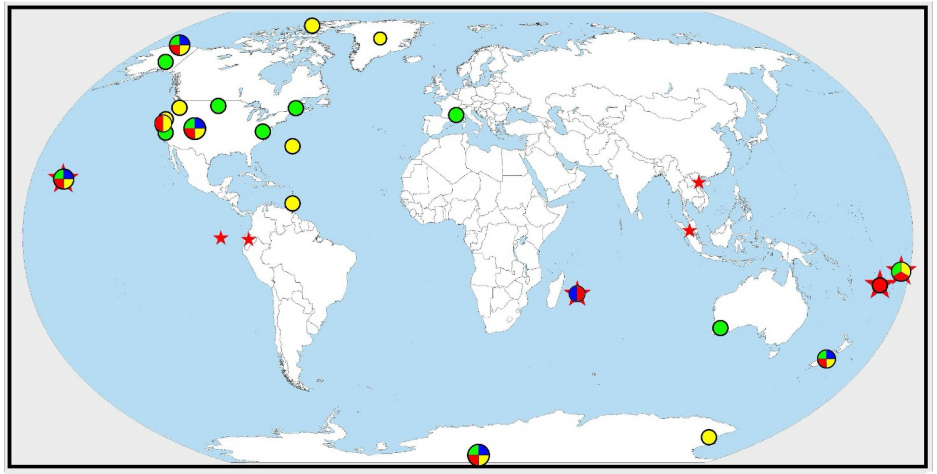
NOAA RESEARCH

Monitoring the Springtime Antarctic Ozone Hole from South Pole Station

Bryan Johnson

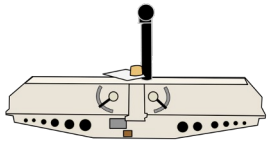
- GML ozone & water vapor network
- South Pole Station: Ozone hole monitoring
- Future measurements & summary

Monitoring the springtime Antarctic ozone hole from South Pole Station



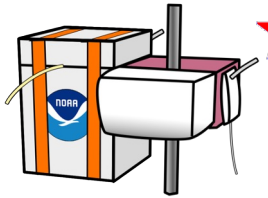
- Long-term trends in ozone & water vapor
- Satellite validation & quality control
- Monitoring ozone depletion & recovery in the stratosphere

Long-term measurement sites



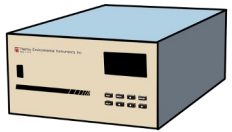
Dobson
- 13 sites – 3 x daily

Ozonesondes
- 8 sites – up to 52 flights/ yr



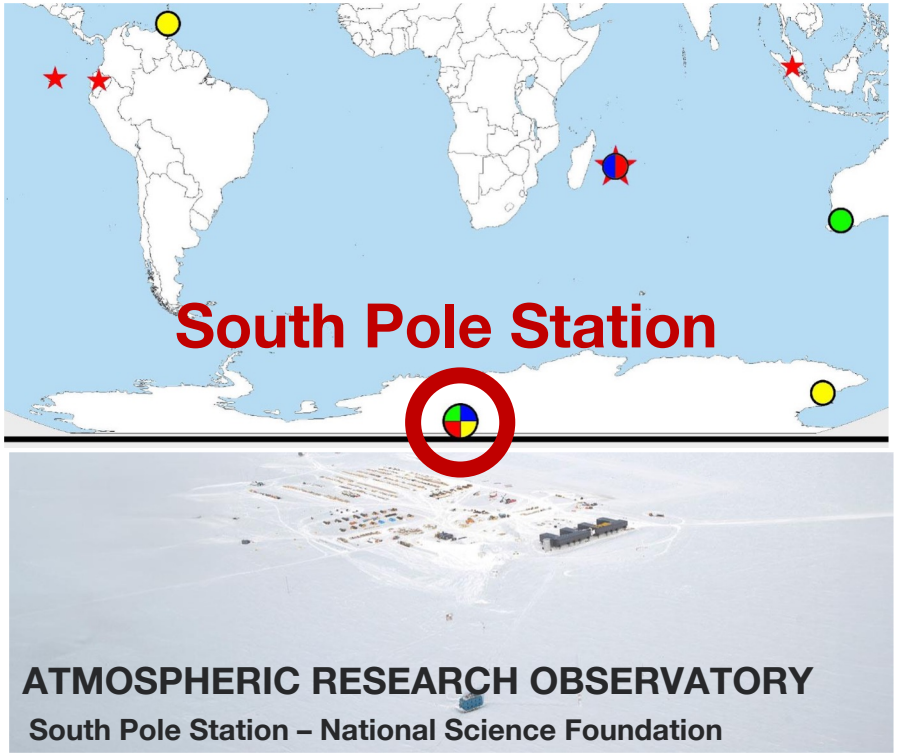
SHADOZ collaboration sites
- 5 sites – 26 flights / yr

Water vapor / FPH
- 3 sites – 12 flights / yr
- 3 sites – 4 flights / yr



Surface ozone
- 14 sites – continuous

Monitoring the springtime Antarctic ozone hole from South Pole Station



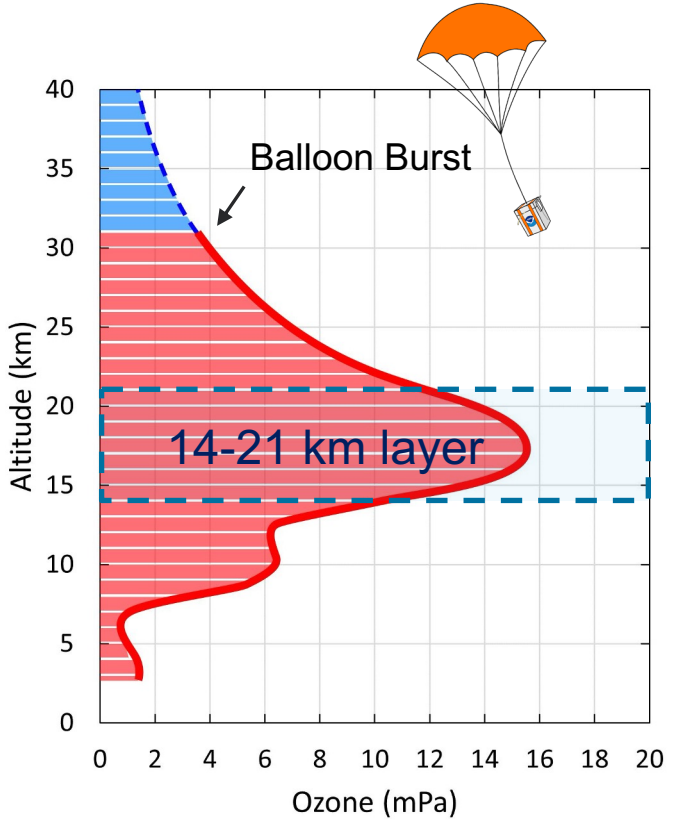
- Extreme environment & remote location
- Near the core of polar vortex – 6 months of darkness (sun below horizon)
- Satellites and Dobson requiring solar UV radiation are limited in the dark months

Stratospheric ozone measurements: South Pole

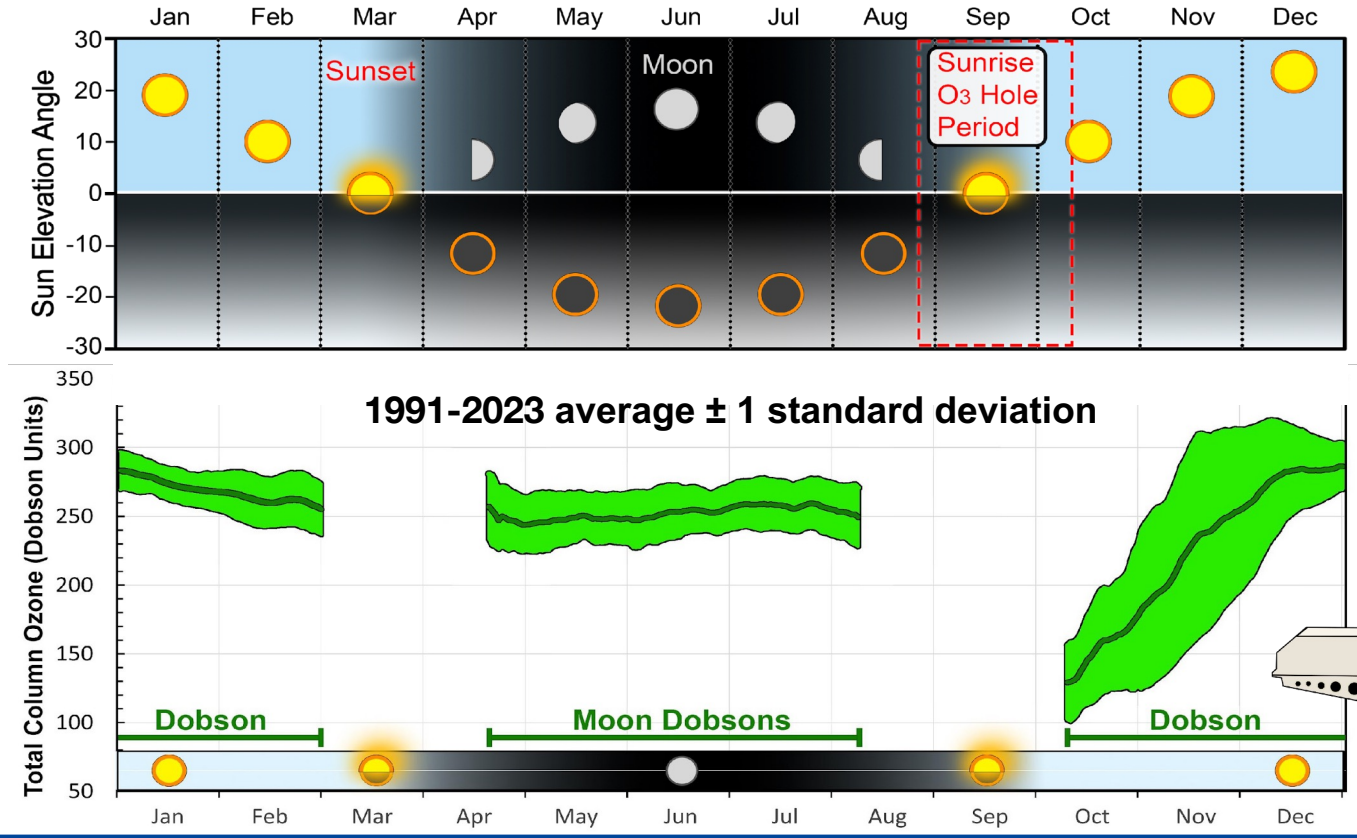
- **Dobson spectrophotometer**
  1) Total column ozone (Dobson Units)

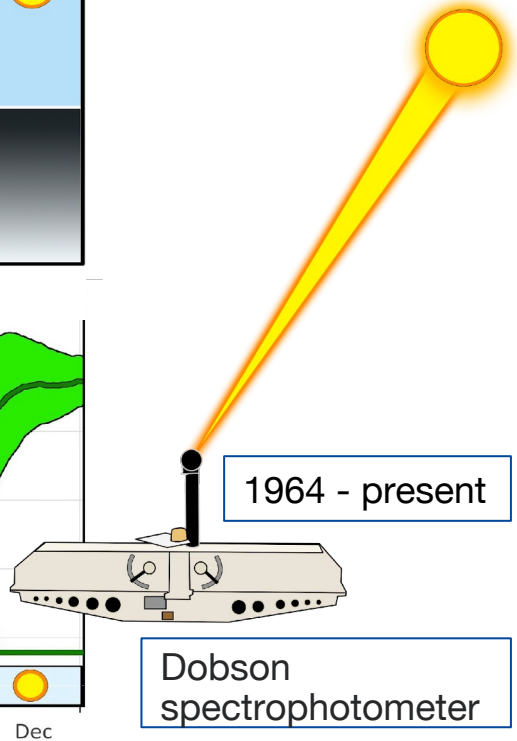
- **Ozonesondes**
  1) Total column O_3 (Dobson Units)
  2) 14-21 km layer partial column O_3
  3) 1 km layer partial column O_3

- **Radiosonde** *(temperature, pressure, RH)*

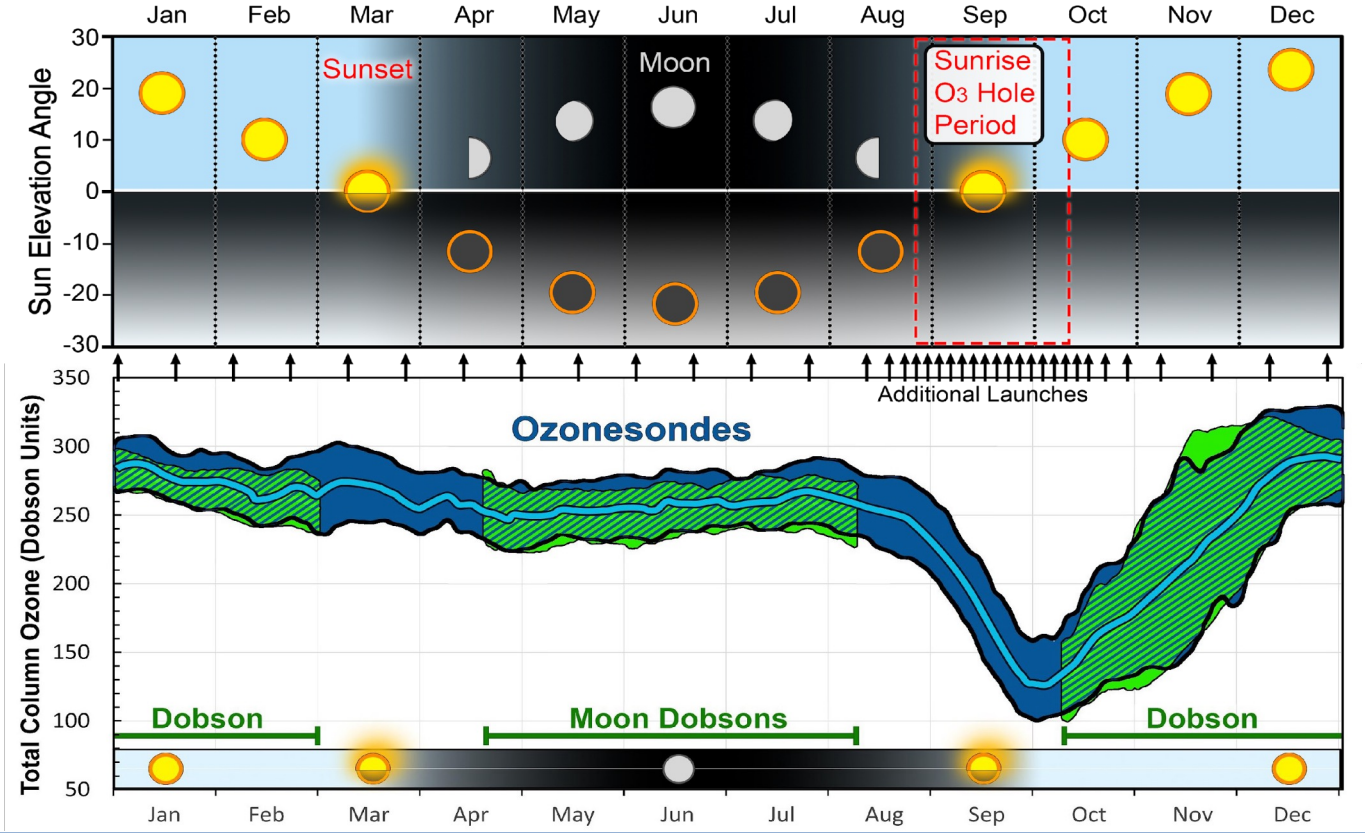


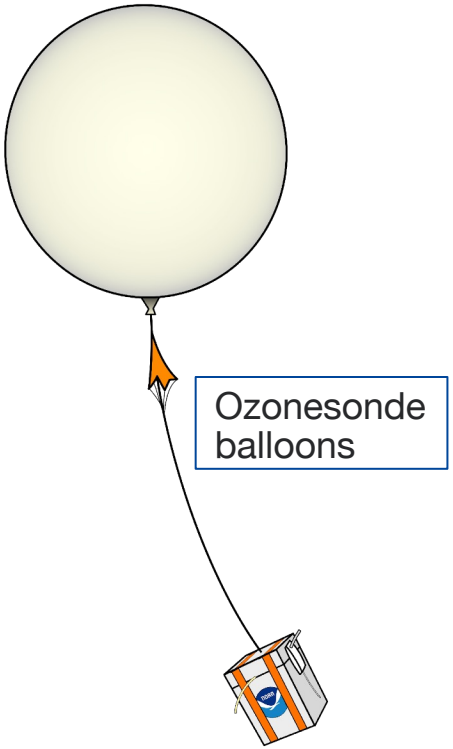
Total column ozone: Dobson at South Pole



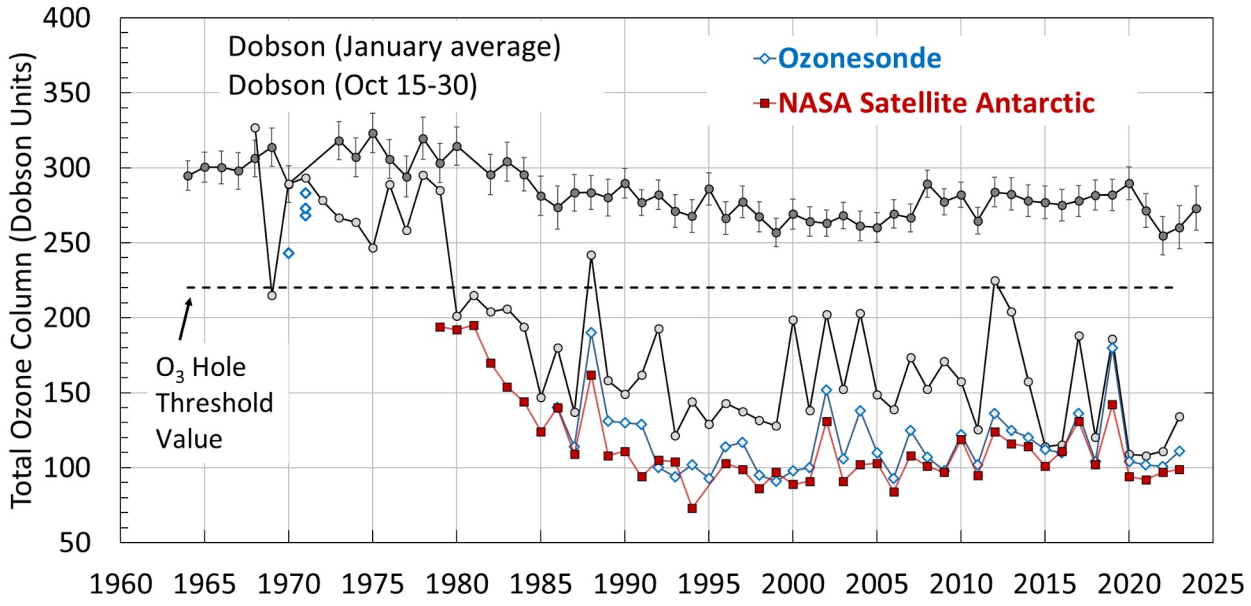


Total column ozone: Dobson and ozonesonde





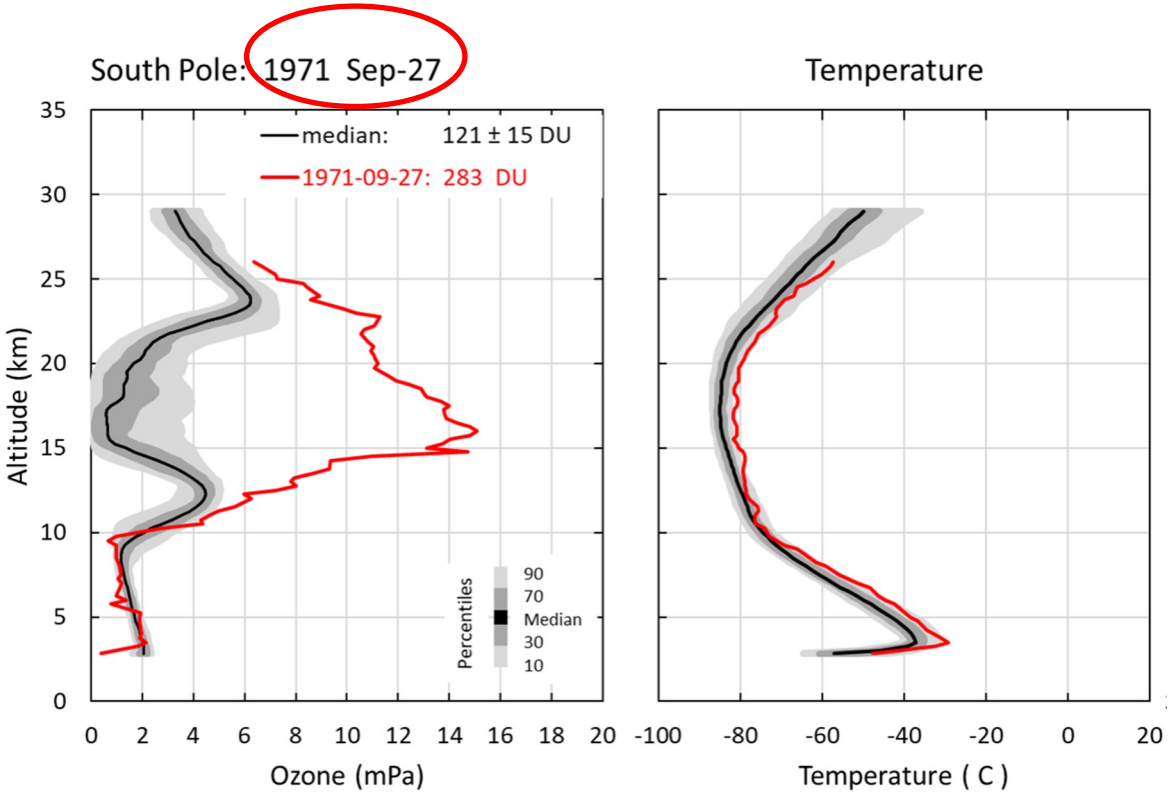
Total column ozone: Yearly minimum



Peak in NOAA Ozone Depleting Gas Index (Antarctic)

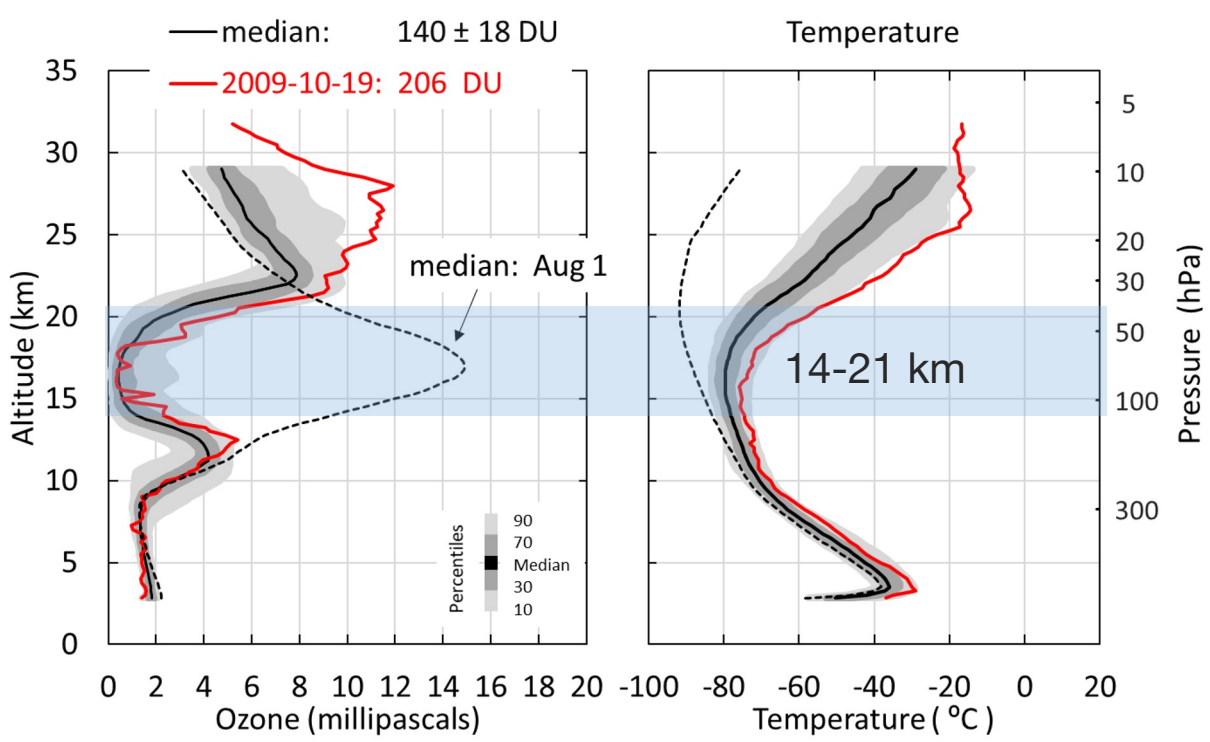
- Total column ozone minimums steadily decreasing until early 1990s
- 1969 - 1971: Several ozonesonde profiles were measured in late September through October

Total column ozone

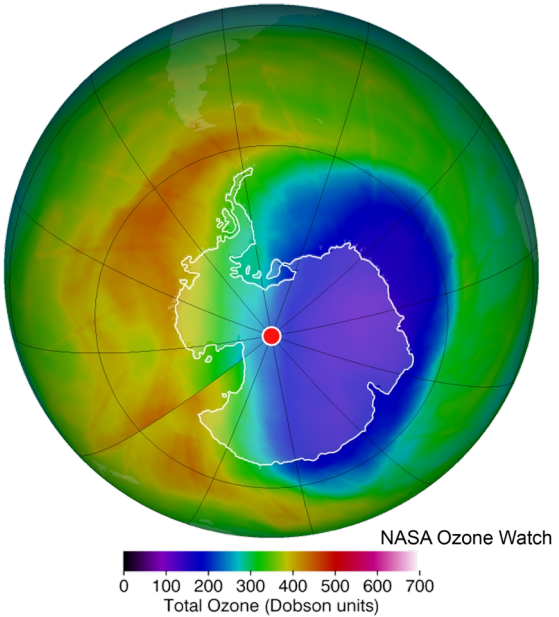


- 1971 September 27:
  A rare glimpse of an ozone profile (left) and temperature (right) well before ODSs were abundant
- Median profiles of ozone and temperature (1991 – 2023) on September 27

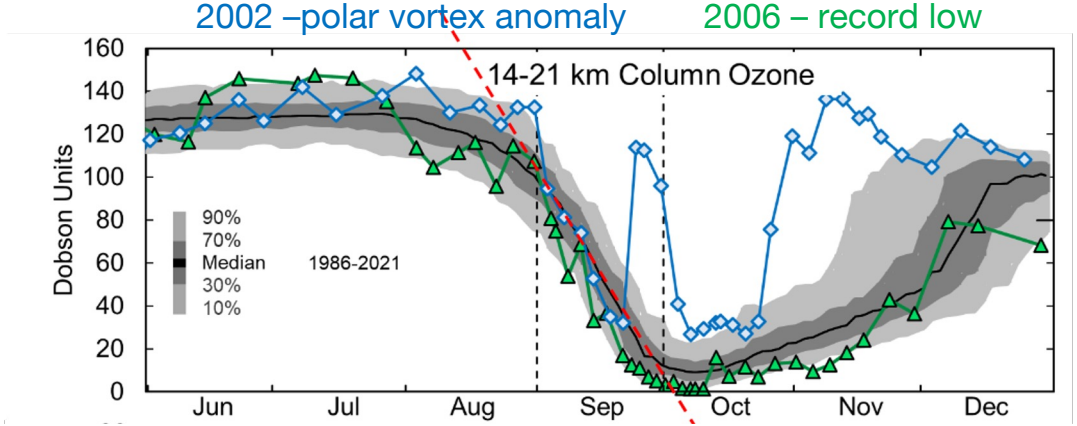
14-21 km partial column ozone

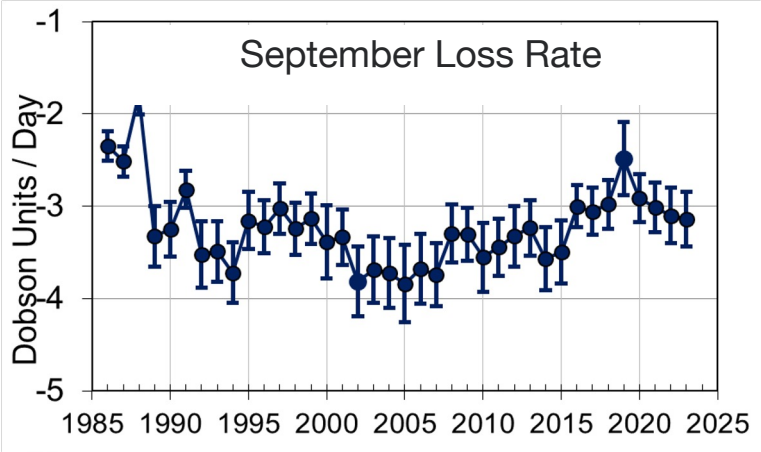


2009 South Pole example: higher concentrations of ozone above 20 km due to weather/dynamics; chemical depletion layer persists below 20 km



14 - 21 km column ozone: September loss rates and minimum

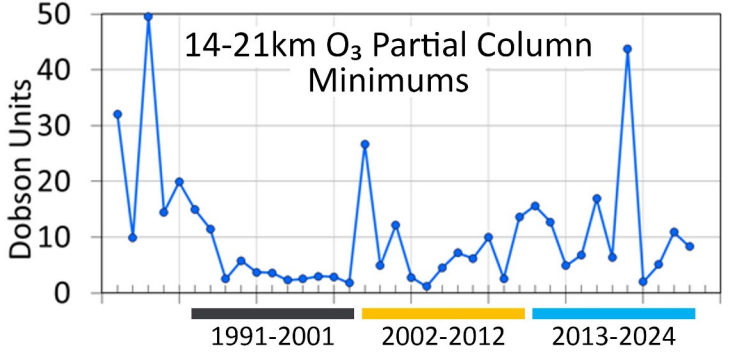




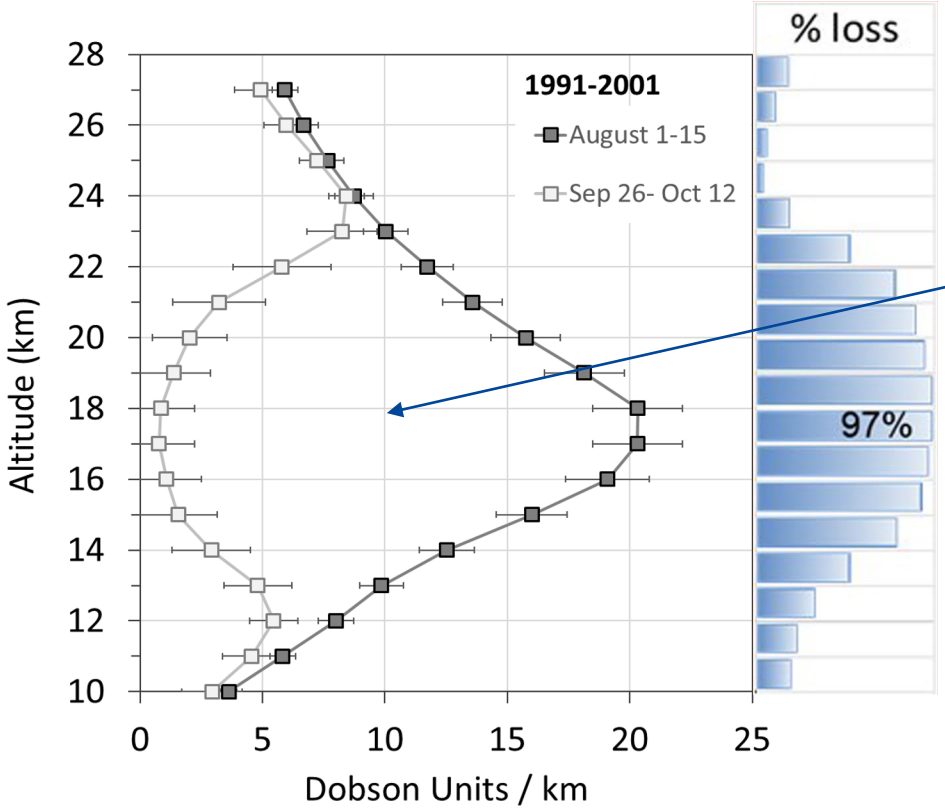
September – key month showing the near-linear decrease in 14-21 km column ozone

Metrics:

- Loss rate: > -3 DU/day *(Hofmann, et al.,1997)*
- Minimum 14-21 km partial column

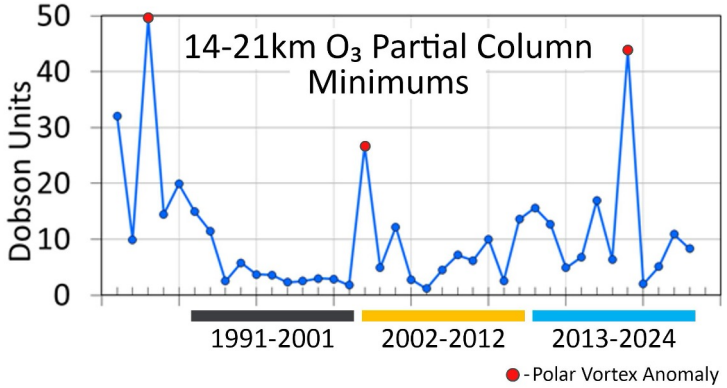


1 km profiles: 11-year intervals

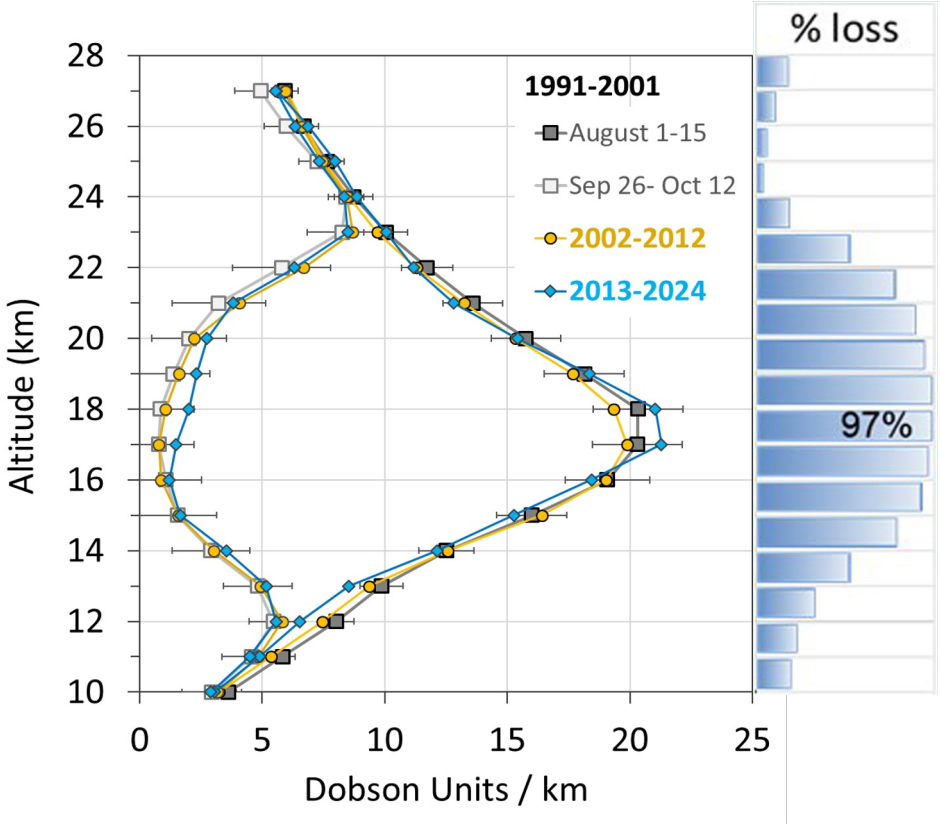


Summing up ozone from 10-26 km:

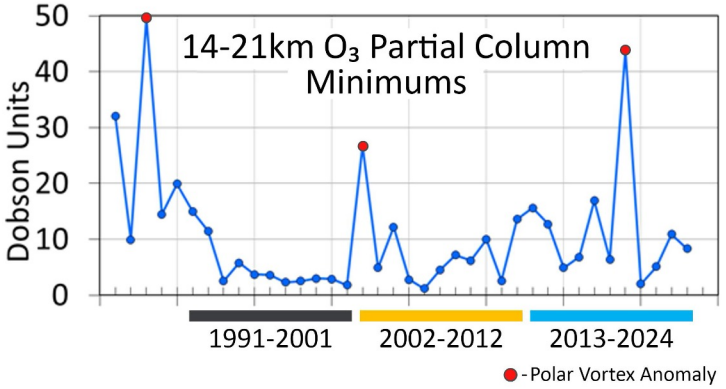
August 1-15	= 214 DU
Sep 26 – Oct 12	= 72 DU
Ozone Hole Loss	= 142 DU



1 km profiles: 11-year intervals

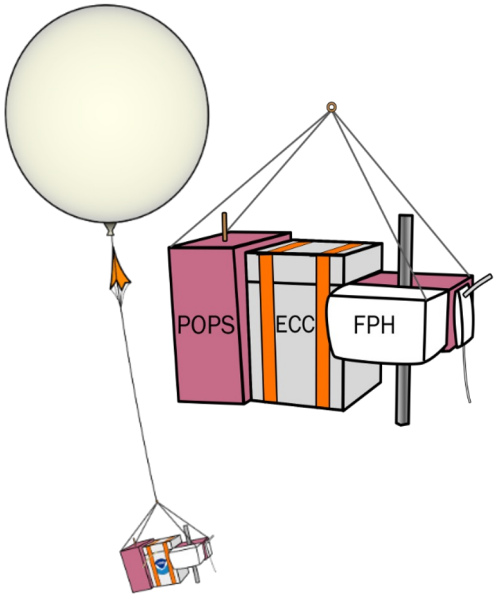


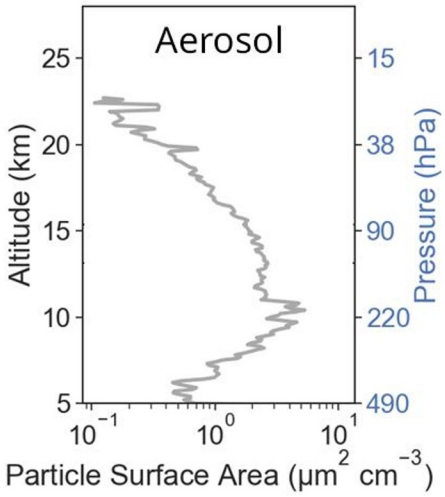
Future tracking each 1 km interval in the race to full recovery throughout the ozone depletion region.

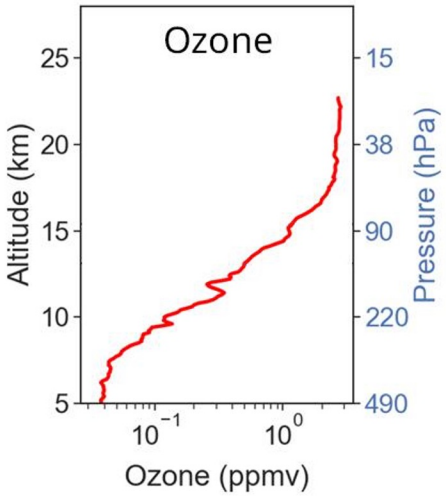


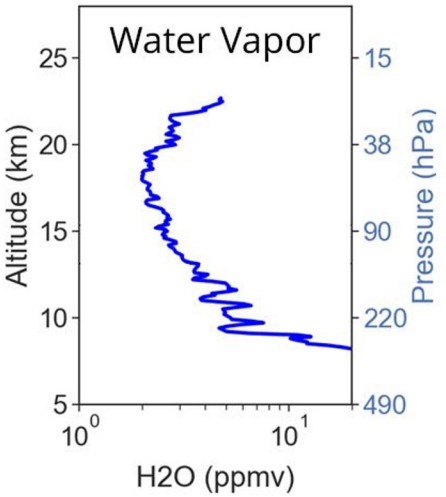
Future: New balloon-borne instruments

A successful first South Pole launch on August 28, 2024: Ozonesonde with two additional instruments measuring aerosols and stratospheric water vapor.









Summary:

NOAA RESEARCH

- Dobson and ozonesonde measurements at South Pole Station provide unique metrics for monitoring ozone hole recovery
  - September loss rates
  - Minimums in total column and partial columns
  - 1 km layers will show where recovery is occurring
  - Potential to launch triple instruments to measure wintertime H_2O and aerosols
- Providing an ongoing powerful database for understanding the processes and evolution of ozone depletion
- Adding insights to address potential deviations in recovery for decades to come

Key South Pole publications

- Hofmann, D. J., Oltmans, S. J., Harris, J. M., Johnson, B. J., and Lathrop, J. A.: Ten years of ozonesonde measurements at the south pole: Implications for recovery of springtime Antarctic ozone, J. Geophys. Res.-Atmos., 102, 8931-8943, 380 10.1029/96jd03749, 1997.
- Solomon, S., Portmann, R. W., Sasaki, T., Hofmann, D. J., and Thompson, D. W. J.: Four decades of ozonesonde measurements over Antarctica, J. Geophys. Res.-Atmos., 110, 10.1029/2005jd005917, 2005.
- Hofmann, D. J., Johnson, B. J., and Oltmans, S. J.: Twenty-two years of ozonesonde measurements at the South Pole, Int. J. Remote. Sens., 30, 3995-4008, 10.1080/01431160902821932, 2009.
- Hassler, B., Daniel, J. S., Johnson, B. J., Solomon, S., and Oltmans, S. J.: An assessment of changing ozone loss rates at South Pole: Twenty-five years of ozonesonde measurements, J. Geophys. Res.-Atmos., 116, 10.1029/2011jd016353, 2011a.
- Johnson, B. J., Cullis P., Booth J. ,Petropavlovskikh I., McConville G., Hassler B., Morris G.A., Sterling C., and Oltmans S.: South Pole Station Ozonesondes: Variability and Trends in the Springtime Antarctic Ozone Hole 1986-2021, Atmos. Chem. & Phys., 23, 5, 3133-3146, 10.5194/acp-23-3133-2023, 202

Theme 3:

Tracking Global Ozone and Water Vapor Trends

Elizabeth Asher

NOAA RESEARCH

- GML provides the highest-quality long-term Dobson, ozonesonde and FPH records, which are the foundation for accurate trend detection and attribution of ozone changes
- GML is at the forefront of developing new technical capabilities and sharing these with the international community
- GML's global network of ozonesonde and FPH launches fill increasing spatial and temporal gaps between satellite instruments

Understanding global stratospheric ozone recovery

Climate change & stratospheric ozone

Volcanoes, large wildfires & stratospheric ozone

Tropospheric ozone & interpreting total column ozone trends

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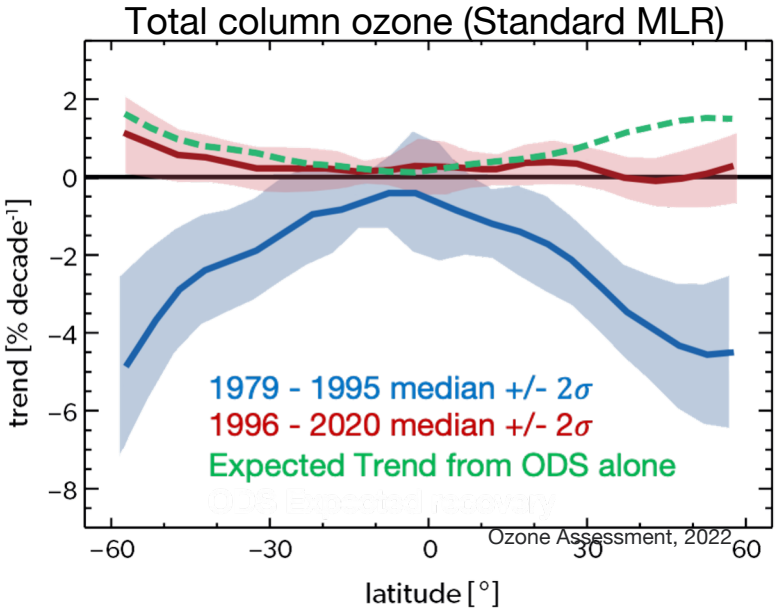

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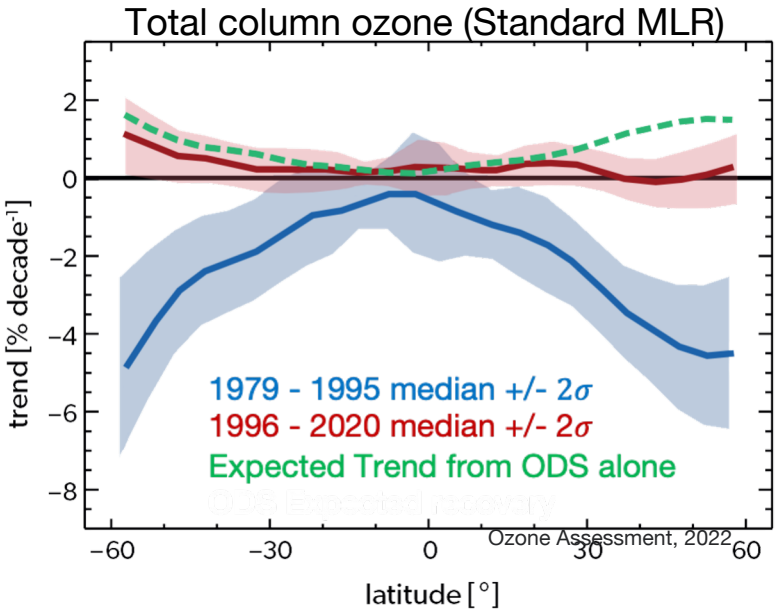
Climate change & stratospheric ozone

Volcanoes, large wildfires & stratospheric ozone

Tropospheric ozone & interpreting total column ozone trends



WHAT'S AT STAKE

- Trend detection requires accurate measurements
- Ozone recovery is impacted by ODS reductions and increasing GHGs
- Variability is comparable to trends
- Total column ozone trends *are a combination of tropospheric and* stratospheric ozone trends

GML provides total column ozone and vertical profile measurements

GML quality assurance

WMO GAW ASOPOS key participants
WMO GAW Dobson World Calibration Center

- High-quality data for trend analysis
- Help minimize errors in satellite merges

Global coverage (pole-to-pole)

Dobson: 13 sites (5 highlighted)
Ozonesonde: 8 sites (3 shown)

***GML helps support 5** additional SHADOZ sites in the TROPICS*

Long-term monitoring

- Dobson **since 1960s**
- Ozonesonde **since 1960s**
- Water Vapor **since 1980**

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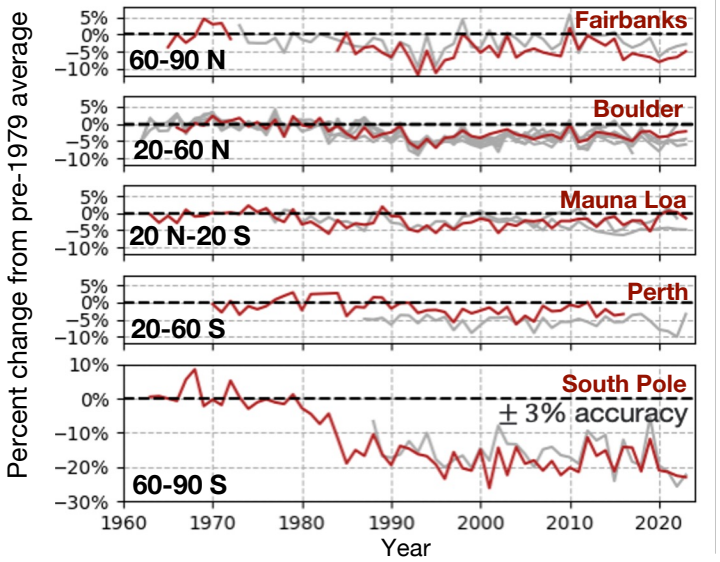
Total column Ozone NOAA GML Dobson measurements



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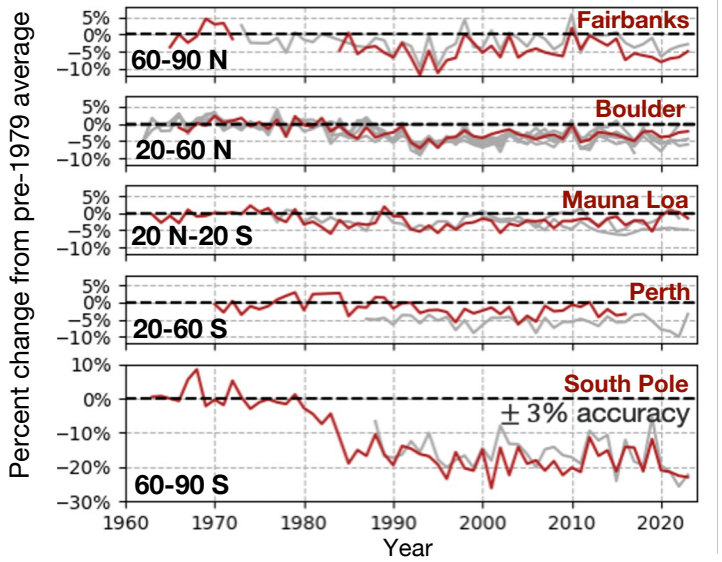
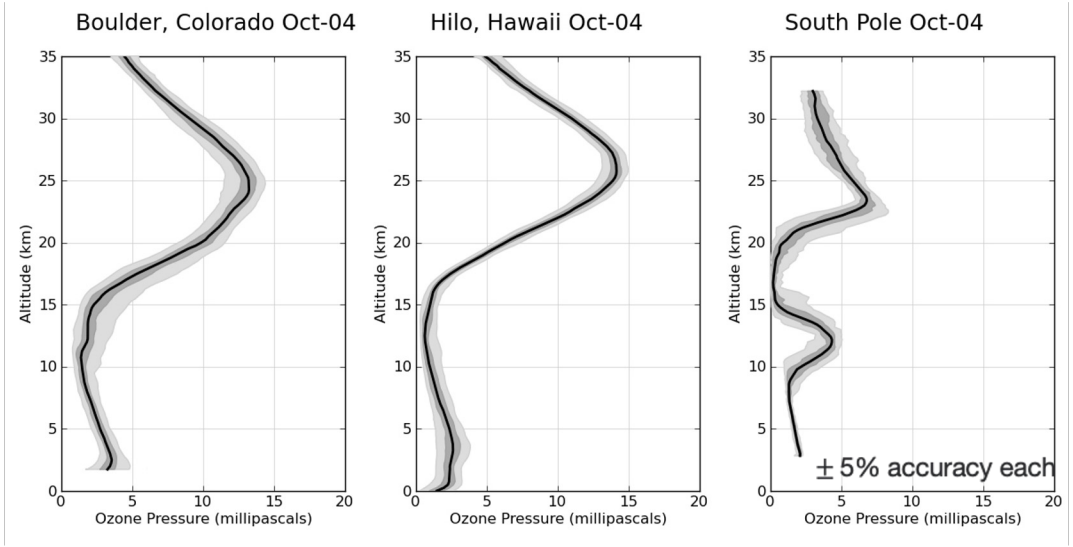
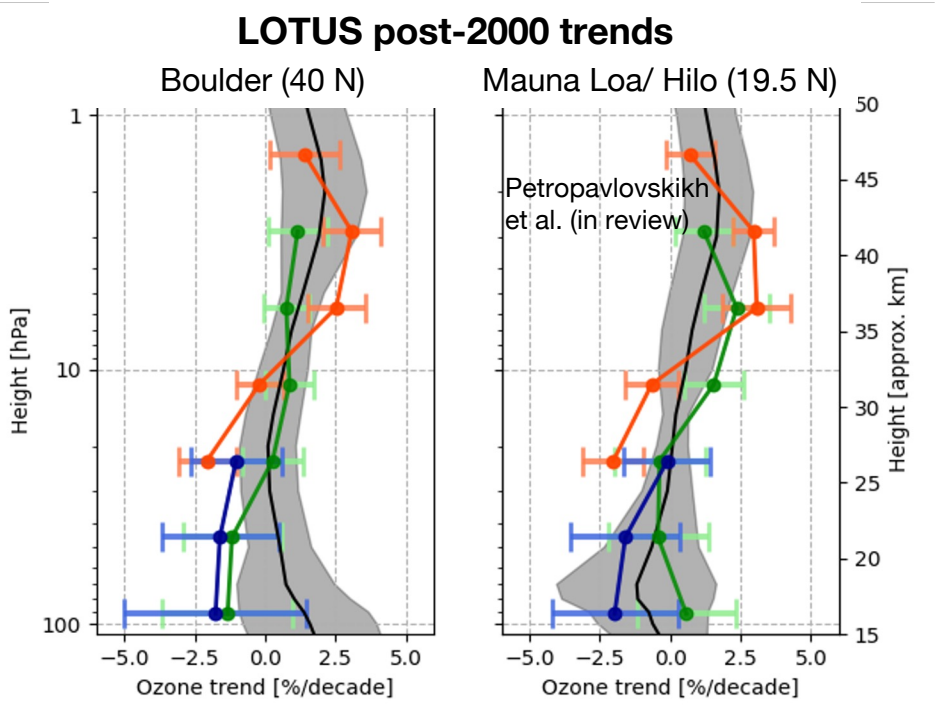
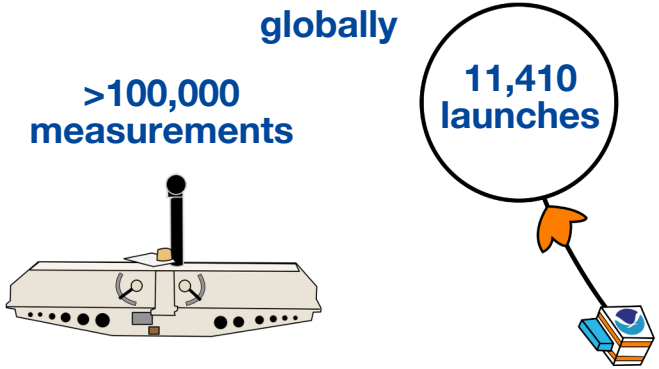


1991-2012 climatology (flight date ± ~15 days)



Satellites, models and GML observations





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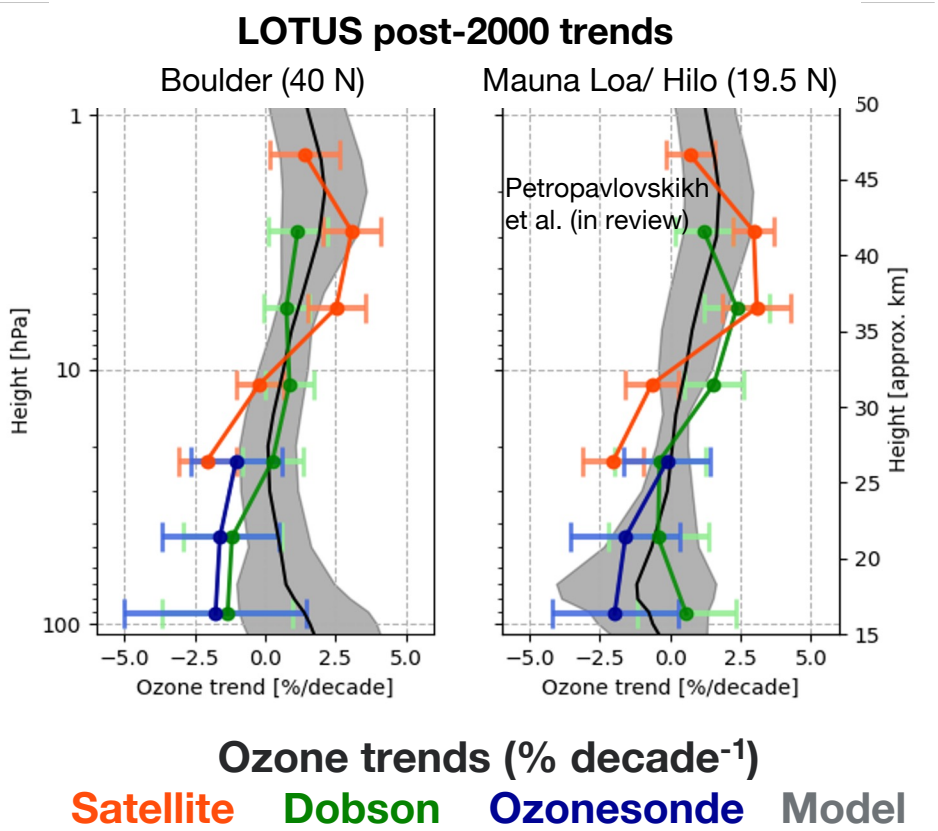
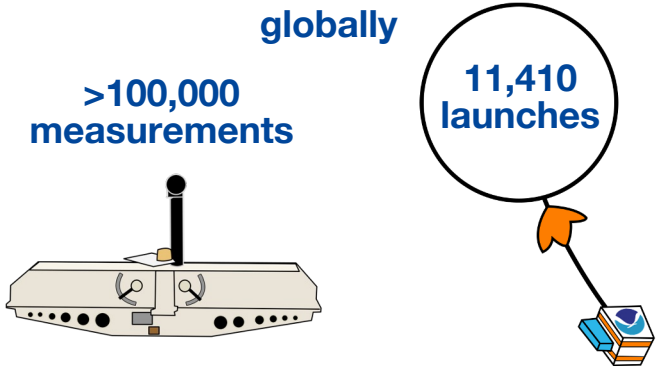
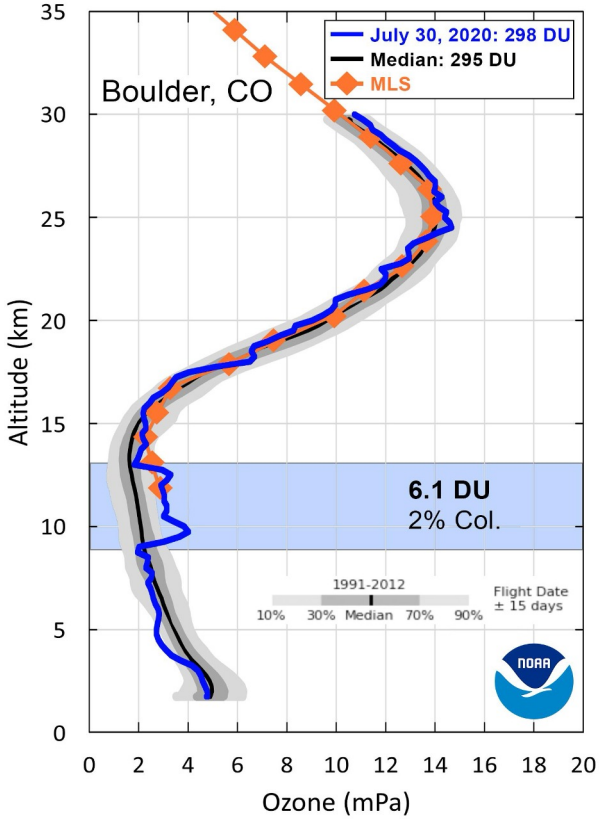


- 40-year GML records show consistency
- Ozone recovery trends vary with altitude
- Apparent disagreements appear in UTLS
- GML has improved ozone records worldwide with standardized ozonesonde procedures and data homogenization



Sondes show tropospheric ozone impacts total column variability



Total column ozone trends are sensitive to:

- Tropopause height in the tropics – SHADOZ
- Tropospheric ozone changes, e.g., from strat/trop exchange

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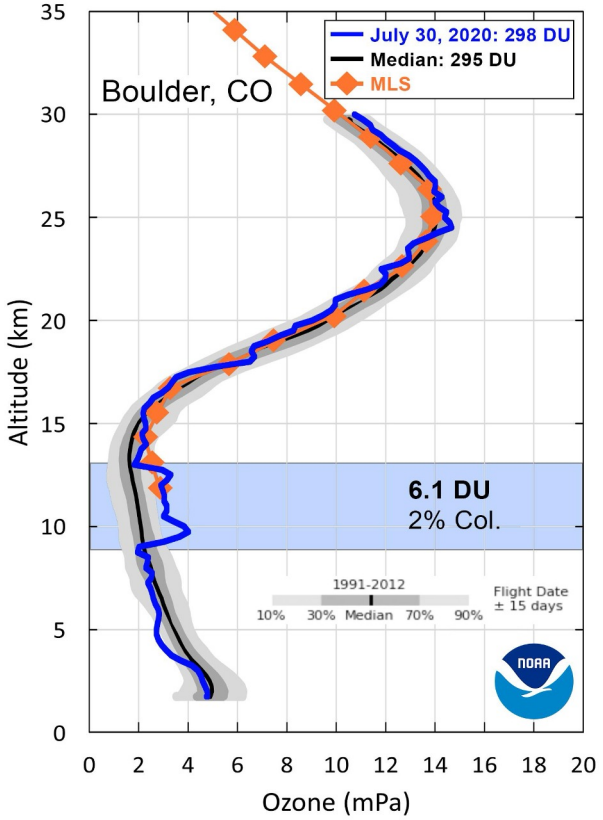

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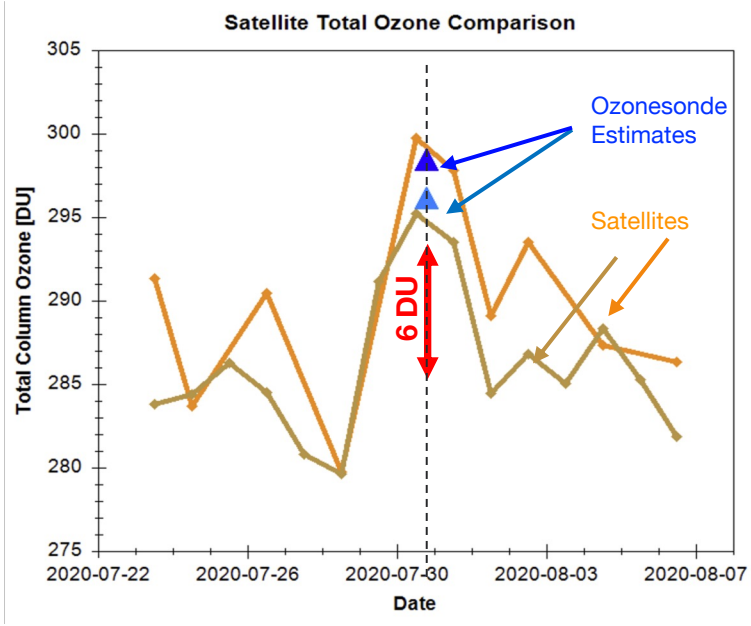

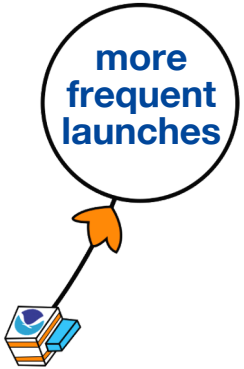

Tracking changes in UTLS water vapor is important for ozone and climate

Water vapor vertical profiles → insight into global ozone changes related to climate dynamics

Trends in UTLS water vapor influence climate

Sources: Increases in tropical cold-point temperatures, methane oxidation, direct injection

Impacts: Identifying drift in Aura MLS satellite retrievals of water vapor

Also for Aura MLS, SAGE III/ISS & high-altitude aircraft instrument validation

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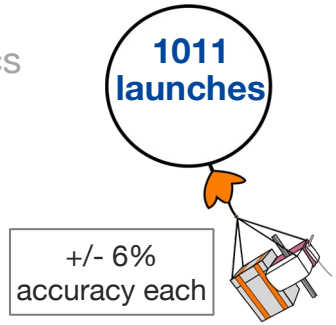

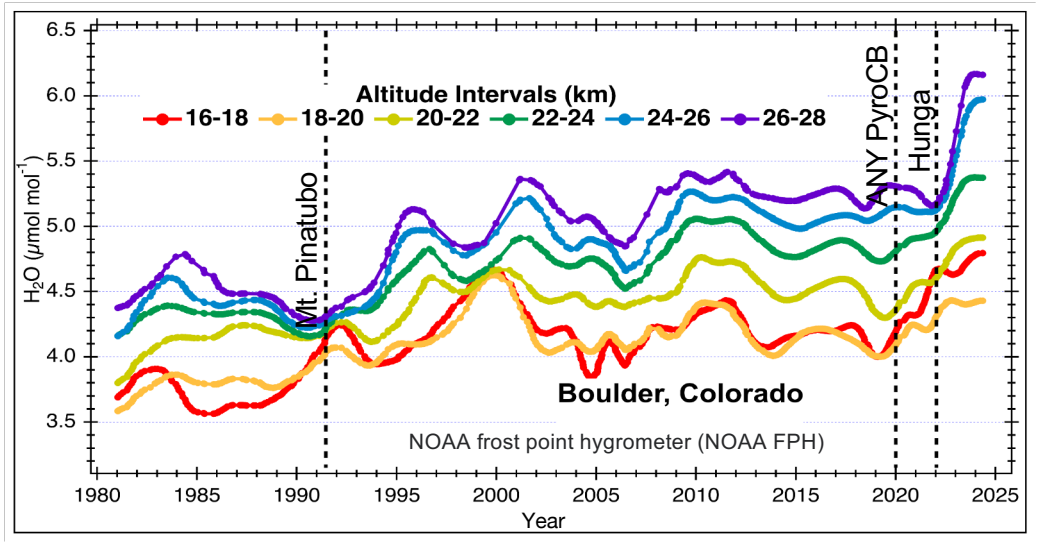

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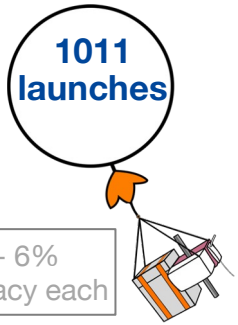
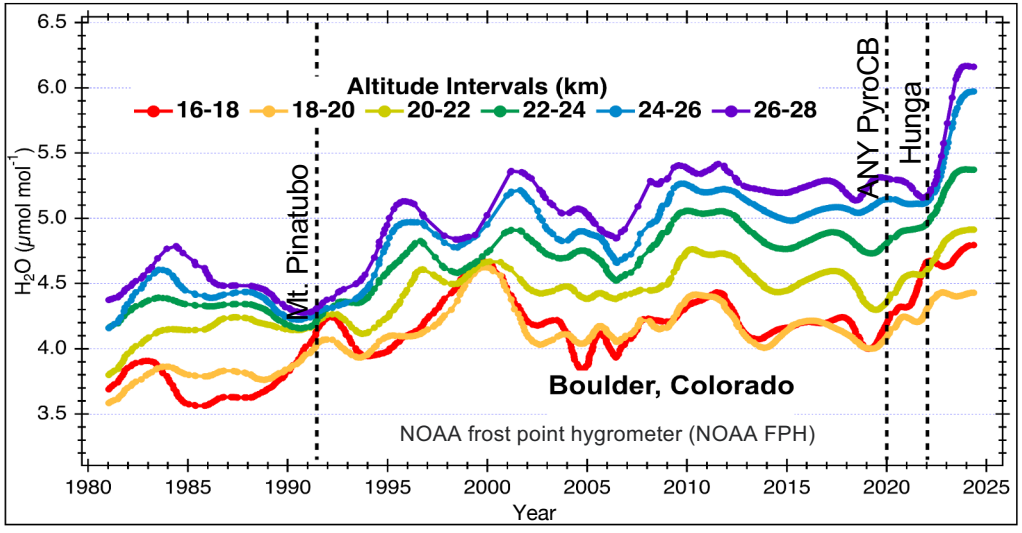
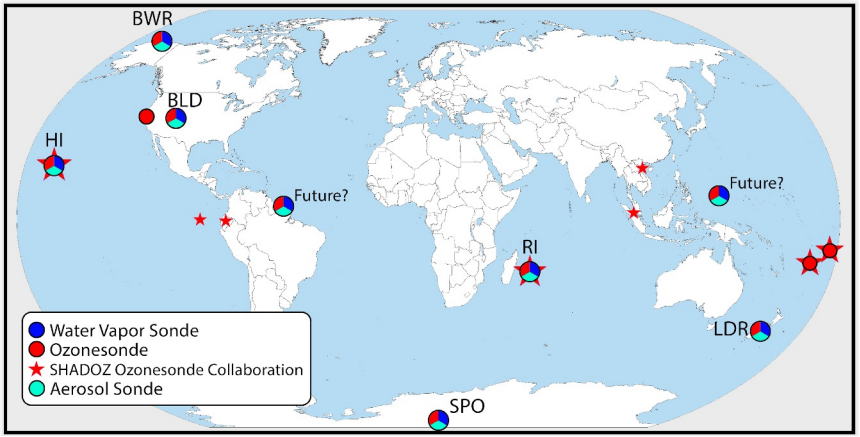




Networks: *NDACC (BLD, LDR, HI) GRUAN (BLD, LDR) B2SAP (BWR, BLD, HI, RI, LDR, SPO); fills satellite gaps*



New frost point technology transitioned to operations

- Transitioning away from **HFC-23 cryogen** (high GWP)
- New methods: **Dry ice and alcohol (DIA) FPH** and **liquid nitrogen (LN_2) FPH** (provisional patent application filed)

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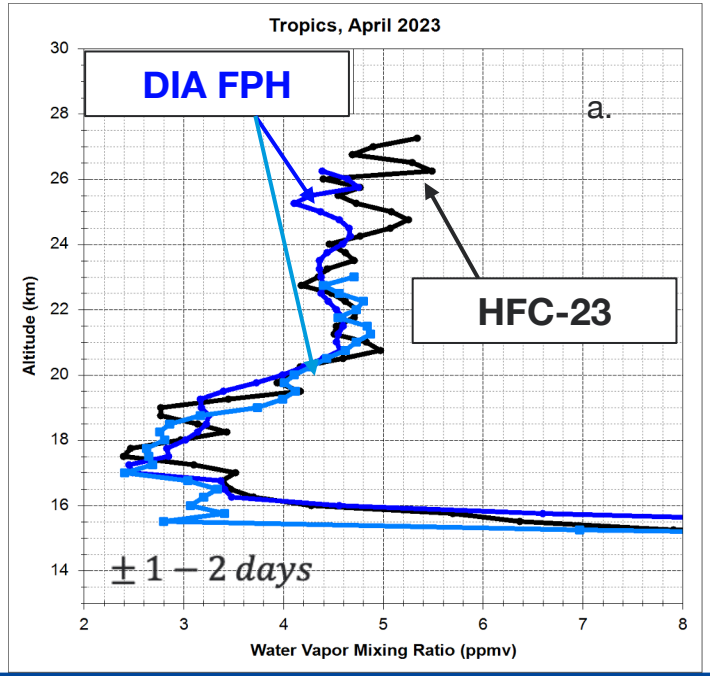

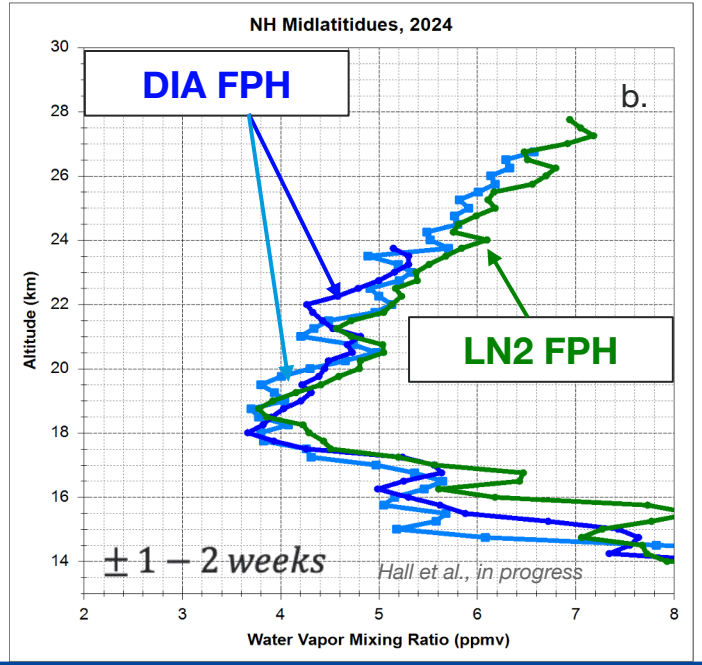

Balloon rapid response to understand disruptive events

- FPH and aerosol sondes track stratospheric plumes from volcanic eruptions (and large wildfires)
- Stratospheric O_3 loss observed in tropics and midlatitudes, increasing variability in total column O_3
- Wildfires are expected to increase in a future climate and impact O_3/H_2O in the stratosphere

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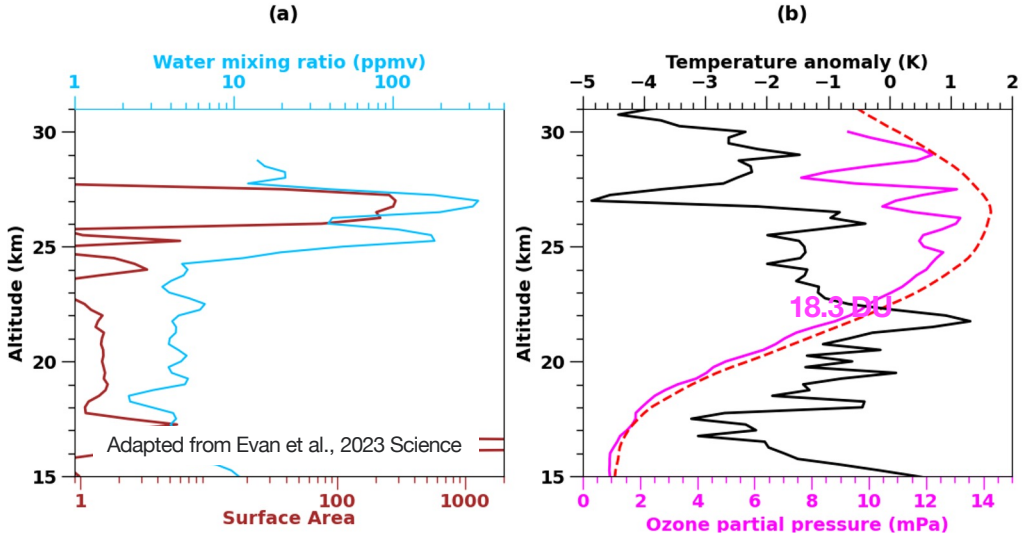

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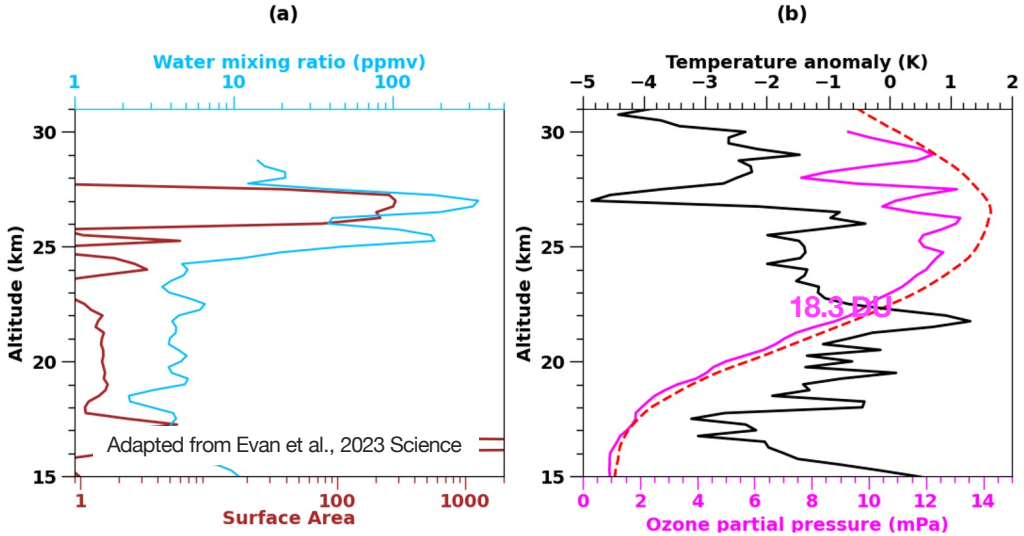
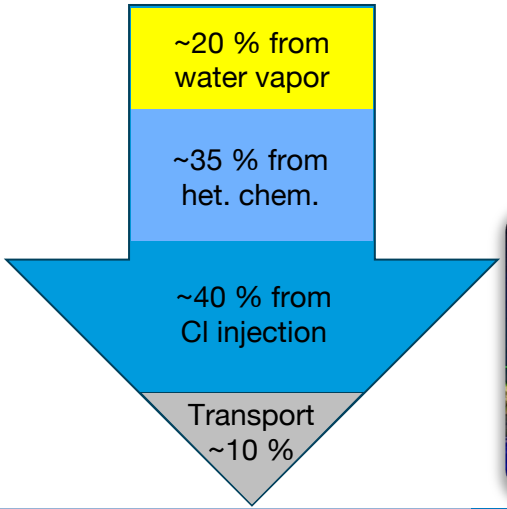


Tropical ozone loss related to volcanic injections of water vapor and a rapidly developing aerosol layer

Measurements within one week of the Hunga eruption in 2022

~ 5% Total column O_3



Expanding the network & rapid response

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