MOP38

2–6 NOVEMBER 2026 | KIGALI, RWANDA

The 2026 WMO/UNEP Scientific Assessment of Ozone Depletion

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International **Ozone** Assessments: A 40+ year history of policy support

WMO/UNEP Scientific Assessment of Ozone Depletion:
1989, 1991, 1994, 1998, 2002, 2006, 2010, 2014, 2018, 2022

1980 1990 2000 2010 2020

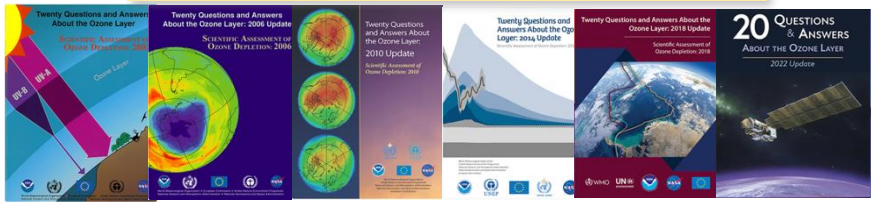
WMO World Plan of Action on the Ozone Layer - 1977



WMO The Stratosphere 1981: Theory and Measurements



Twenty Questions and Answers



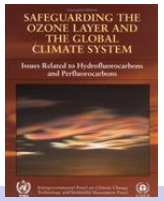


WMO Atmospheric Ozone - 1985

Other NASA and Climatic Impact Assessment Program (CIAP) reports prior to 1981 were primarily performed in the USA



WMO Report of the International Ozone Trends Panel – 1988



Safeguarding the Ozone Layer and the Global Climate System: 2005 (IPCC/TEAP)

https://csl.noaa.gov/assessments/ozone/

2026 Assessment Terms of Reference

Topics to include in the 2026 report of the Scientific Assessment Panel:

(a) State of the ozone layer and its future evolution

(b) Global and polar stratospheric ozone

(c) Contributions of the Montreal Protocol to mitigating climate change

(d) Top-down derived emissions, abundances and fate in the atmosphere of trace gases of relevance to the Montreal Protocol

(e) Consistency with reported production and consumption of relevance to the Montreal Protocol

(f) Stratospheric ozone and the climate system

(g) Scenarios for policymakers

(h) Early identification and quantification of any substances that could be of concern (e.g., VSLS, TFA, N_2O)

(i) Solar radiation modification and the potential effects of supersonic aircraft, rockets, satellites, wildfires and volcanic eruptions (Hunga)

(j) Any other issues relevant to the objectives of the Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol

Full text: Decision XXXV/3, 35MOP, Nairobi, Kenya, 23-27 October 2023

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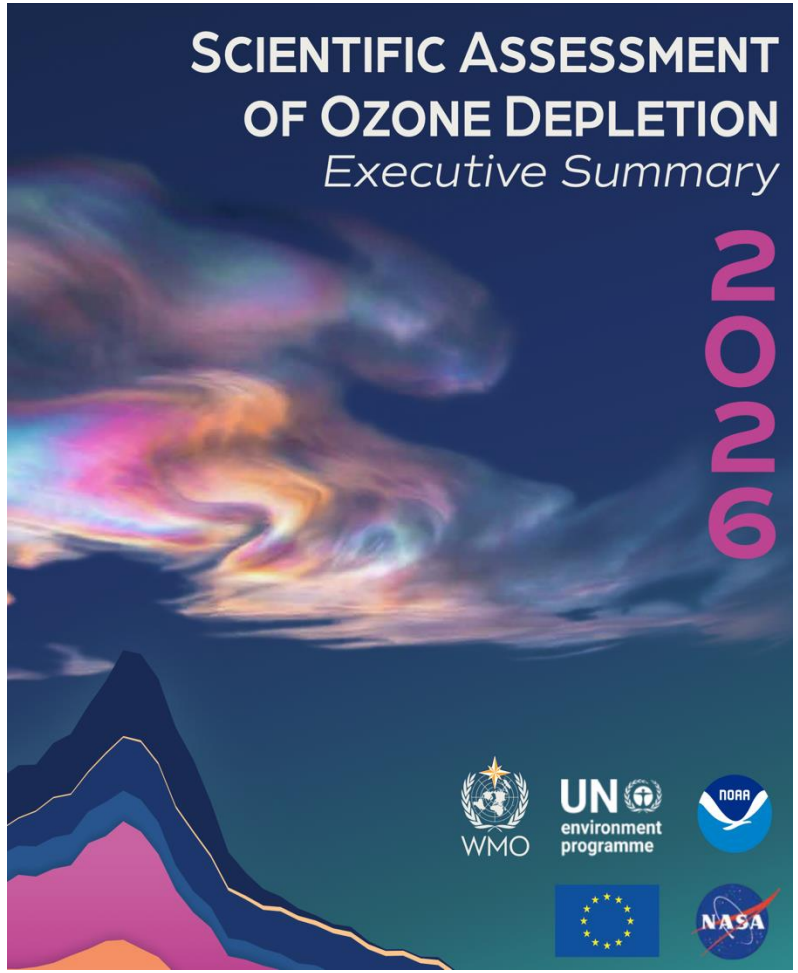
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2026 Ozone Assessment Executive Summary



HIGHLIGHTS
of the
Scientific Assessment of Ozone Depletion: 2026

A. Achievements of the Montreal Protocol

The atmospheric abundances of chlorine and bromine contained in controlled ozone-depleting substances (ODSs) continue to decrease because of the actions taken under the Montreal Protocol. As a consequence, clear signs that the stratospheric ozone layer is beginning to recover have emerged. The decline in total atmospheric chlorine has increased in recent years due, in part, to a more rapid decline in chlorofluorocarbons (CFCs). In addition, atmospheric chlorine from all hydrochlorofluorocarbons (HCFCs) reached a peak during the last four years and has begun to decrease. The timing of this decline of HCFCs indicates that the Parties are complying with the HCFC phase-out ahead of schedule.

Total column ozone (TCO) in the Antarctic continues to recover, notwithstanding substantial interannual variability in the area, depth, and longevity of the ozone hole, primarily driven by dynamical forcings. In a middle-of-the-road greenhouse-gas scenario, Antarctic TCO is projected to return to 1980 values during the 2060s. Observations show a slightly larger annual increase in near-global (60°S–60°N) TCO compared to the previous Assessment. Near-global-mean TCO is projected to return to 1980 values around 2040. Altogether, the findings show that the Montreal Protocol is working well and is expected to meet its goals and those of the Vienna Convention provided there is continued compliance.

Global compliance with the Montreal Protocol's phaseout of ODS production has been beneficial in reducing global warming and is expected to prevent warming of 0.25–0.89 °C by 2050. Measured abundances and derived emissions of most hydrofluorocarbons (HFCs) are consistent with expectations from the production and consumption phase-down controls of the Kigali Amendment to the Montreal Protocol. Continued compliance with these Kigali Amendment provisions is estimated to prevent an additional 0.05–0.06 °C of warming by 2050 and up to 0.4 °C by 2100.

Antarctic stratospheric ozone depletion has driven substantial trends in summertime Southern Hemisphere atmospheric circulation. These trends have slowed since around 2000, indicating that the impact of ozone recovery on the circulation is already apparent. Ozone recovery will continue to drive Southern Hemisphere circulation changes that oppose those driven by increased greenhouse gases.

B. Ongoing and Emerging Issues

Atmosphere-derived global emissions of HFC-23 are substantially larger than reported emissions plus those from additional known sources. Future HFC-23 emissions could lead to warming of around a quarter of that from all HFC emissions by 2100. This projection is highly uncertain, primarily because of the poor understanding of current and future HFC-23 emissions from HCFC-22 production and other pathways for HFC-23 generation and emission.

Atmospheric observations of some ODSs used as feedstocks or produced as intermediates and by-products suggest emission factors substantially higher than those adopted in earlier Assessments. Furthermore, the production and use of ODSs as feedstock continue to rise, driven primarily by a rapidly expanding polymers industry and the chemical production of alternatives to ODSs and controlled HFCs. If ODS emissions associated with feedstock use were eliminated now, by 2100 global-mean ozone depletion of 1 Dobson unit (DU) (or about 0.4%) would be prevented, largely due to reductions of carbon tetrachloride (CCl_4), and globally averaged surface warming of about 0.01 °C would be prevented.

Emissions of chlorinated very short-lived substances (VSLSs), which are dominated by anthropogenic emissions of dichloromethane (CH_2Cl_2), continue to grow and contribute to ozone depletion. VSLSs currently contribute approximately 4.4% of the total chlorine entering the stratosphere. At their current level, CH_2Cl_2 emissions account for a reduction in global annual mean TCO of approximately 1 DU.

Ozone-depletion-weighted emissions of anthropogenic nitrous oxide (N_2O) have grown in relative importance as emissions of ODSs have been largely eliminated. Atmospheric observations indicate that the annual increase of N_2O abundance is now exceeding all projections made by the Intergovernmental Panel on Climate Change (IPCC) in its most recent assessment (2023). Future N_2O emissions are likely to have a larger impact on global stratospheric ozone and climate than future emissions of controlled ODSs.

New Earth system model projections of ozone changes in response to stratospheric aerosol injection (SAI) were assessed. Choosing a middle-of-the-road greenhouse-gas scenario and assuming an injected sulfate aerosol mass sufficient to stabilize global warming, global ozone depletion becomes 3–5 DU at mid-century, which delays the recovery of global TCO by around 15–20 years.

Currently, the known effects on ozone from aerosols and gaseous emissions attributed to space activities are minor compared to those of ODSs. The future impacts remain highly uncertain due to possible alteration of ozone depletion chemistry by particles produced during launch and reentry, dependencies on the number of launches and their location, and the fuel type used. The expected continued rapid expansion of space activity over the coming decades will make understanding these impacts increasingly important.

Exceptional events can temporarily perturb stratospheric composition and chemistry. There is now improved understanding of how smoke particles injected into the stratosphere from the 2019–2020 Australian New Year's wildfires led to enhanced halogen-based ozone depletion and a larger Antarctic ozone hole. The meteorological conditions conducive to similarly large and intense wildfires are expected to become more common in the future. The 2022 Hunga Tonga-Hunga Ha'apai submarine volcanic eruption was sufficiently explosive that water injected at high altitude increased the global stratospheric water vapor burden by about 10%. This increase in water vapor led to stratospheric cooling and changes in circulation, while limited amounts of injected volcanic sulfur led to some additional ozone depletion.

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https://ozone.unep.org/sites/default/files/2026-10/OA2026ExecSummary.pdf

1 ABUNDANCES AND TRENDS IN OZONE-DEPLETING SUBSTANCES (ODSs)

- **The atmospheric abundances of chlorine and bromine contained in controlled ODSs continue to decrease.**
- Total chlorine abundance has declined by 14% between the 1993 peak and 2024. Total bromine abundance has declined by 16% between the 1999 peak and 2024

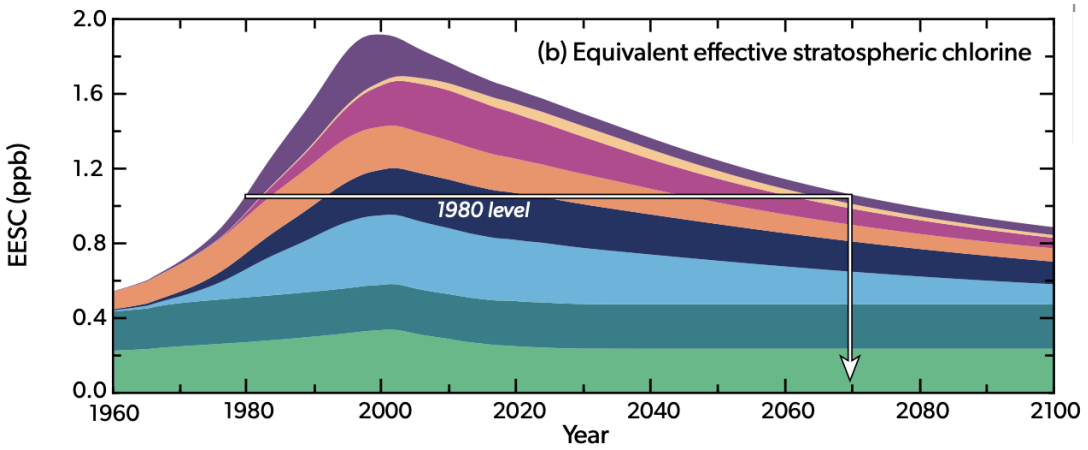


Figure ES-1 panel (b)

Annual abundances of Equivalent Effective Stratospheric Chlorine (EESC) for the mid-latitudes

EESC is the chlorine-equivalent sum of chlorine and bromine weighted to reflect their expected depletion of stratospheric ozone

- **The decline in total atmospheric chlorine has accelerated in recent years due to a more rapid decline in CFCs and a change from increasing to decreasing Cl from the major HCFCs.**
- **Chlorine from HCFCs declined sooner than projected, indicative of an acceleration of the HCFC phase-out ahead of schedule.**
- **The observed rate of decline in tropospheric bromine was in line with the decline projected in the 2022 Assessment report and mainly due to decreases in the abundance of halons.**

1 ABUNDANCES AND TRENDS IN OZONE-DEPLETING SUBSTANCES (ODSs)

- **Atmospheric observations of some ODSs used as feedstocks or produced as intermediates and by-products suggest emission factors substantially higher than assessed historically** (on the order of 3–5% of production, rather than about 0.5%). Emissions have increased since 2010 for several controlled substances with few or no known dispersive uses, including CFC-115, CFC-113a, CFC-13, CFC-114a, and CFC-112a.

- **Tropospheric chlorine from VSLSs increased on average by 4.1 ppt Cl /yr from 2020 to 2024** and accounted for about 4.5% of total global tropospheric chlorine in 2024.

- **Global CCl_4 emissions have remained approximately constant during the last 15 years** at ~44 Gg/yr. The discrepancy between bottom-up and top-down emission estimates has been reduced since the previous Assessment, mainly due to an increase in feedstock-related bottom-up estimates.

- **Emissions of CFC-11 have continued to decline** following a period of enhanced emissions between 2013 and 2018.

2 HYDROFLUOROCARBONS (HFCs)

Kigali Amendment

- Global HFC emissions are aligned with the phase-down schedule of HFC production and consumption under the Kigali Amendment.
- Adherence to the limits on HFC production and consumption in the Kigali Amendment is projected to prevent up to 0.4 °C of global temperature rise by 2100.
- The contribution of HFCs to global temperature increase is projected to remain below 0.06 °C through the 21st century

Emerging uses

- Atmospheric measurements in Europe, East Asia, and the USA show that HFO-1234yf, HFO-1234ze(E), and HCFO-1233zd(E) emissions are increasing.

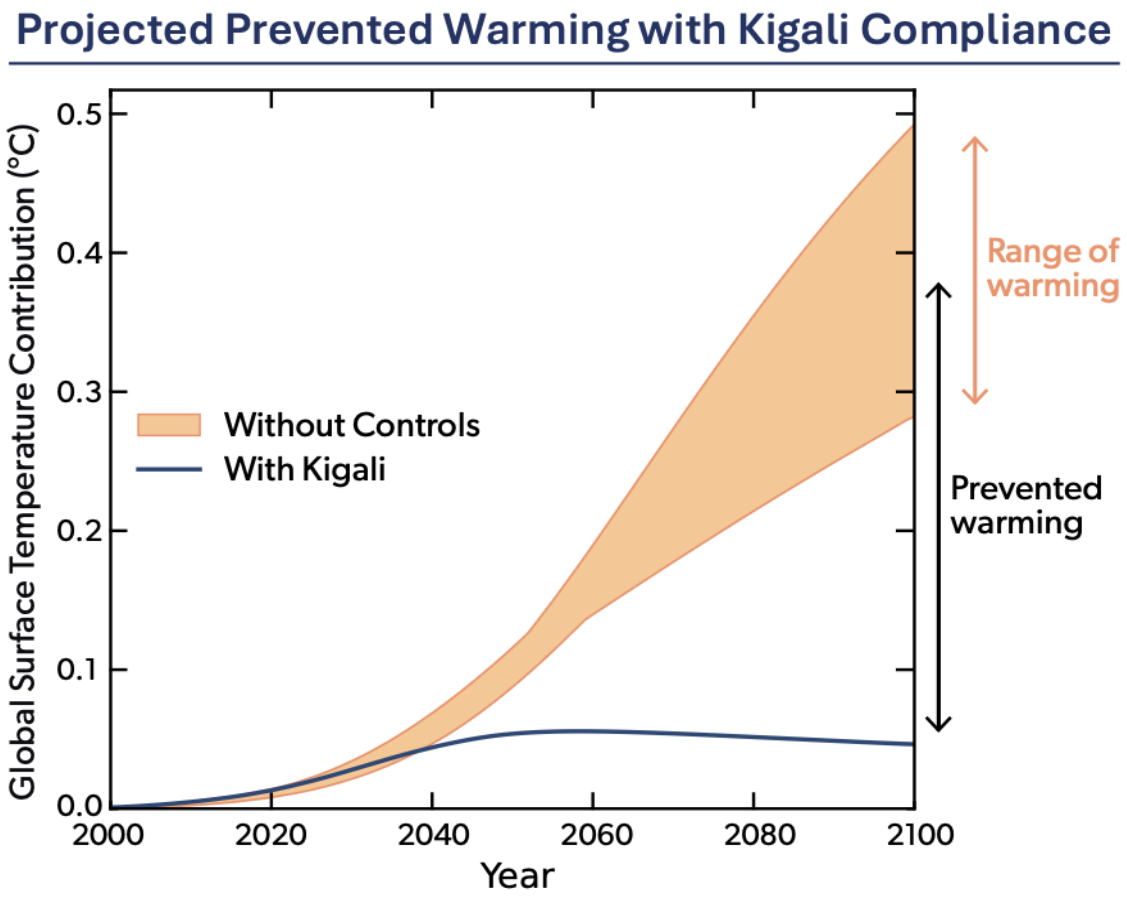


Figure ES-3. HFC contributions to global average surface temperature change during the 21st century.

2 HYDROFLUOROCARBONS (HFCs)

Emissions of HFC-23

- **HFC-23 emissions have decreased from 16 ± 1 Gg/yr in 2020 to 14 ± 1 Gg/yr in 2024.**
- **More than three quarters of HFC-23 emissions in 2024 derived from atmospheric measurements cannot be explained by reported emissions and other known sources.**
- **The atmospheric breakdown of some HFCs, HFOs, and HCFOs in the atmosphere to form HFC-23 contributes less than 2% of current global HFC-23 emissions and is projected to remain under 20% throughout the 21st century** relative to current emissions of HFC-23.

Global Estimates of HFC-23 Emissions and Generation

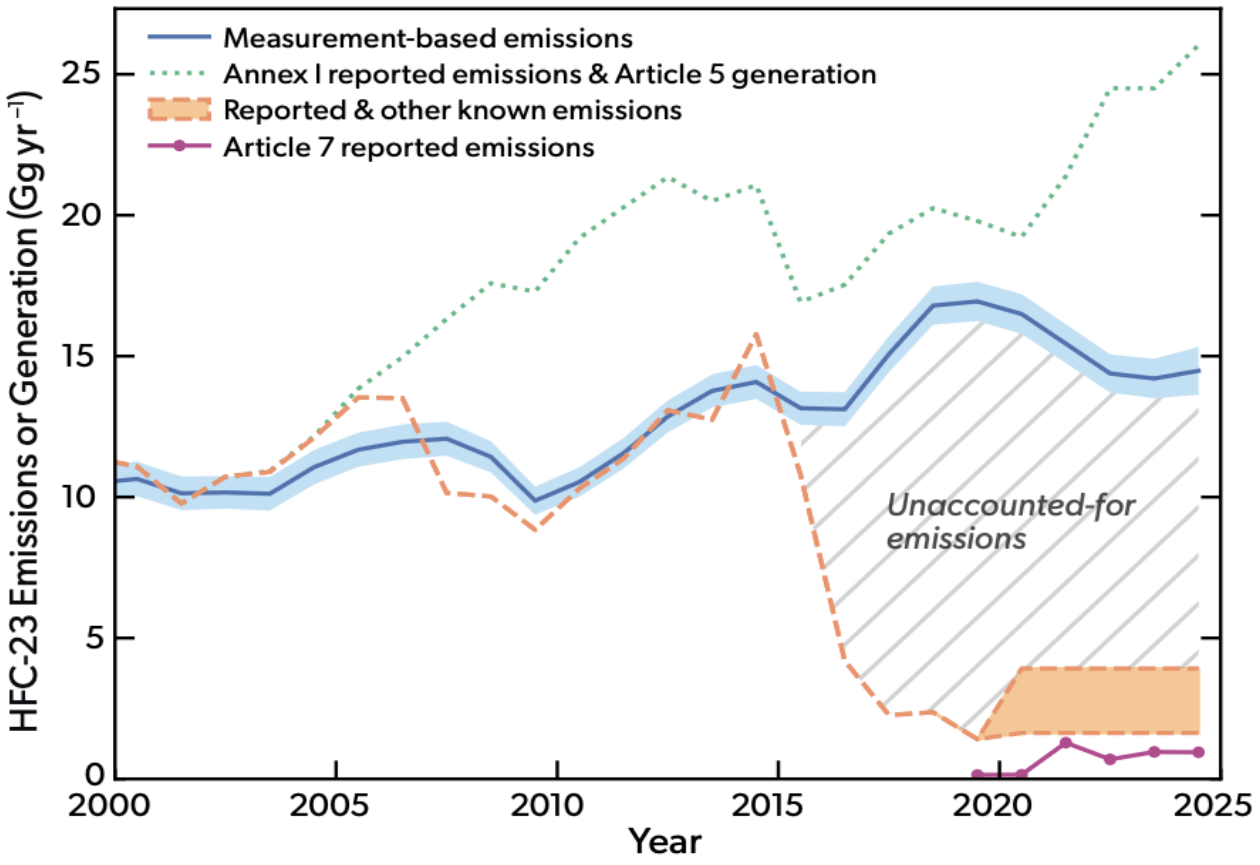


Figure ES-4.

2 HYDROFLUOROCARBONS (HFCs)

TFA and PFAS

- **The molar yields of persistent breakdown products (including TFA and HFC-23) in the atmospheric degradation of Montreal Protocol substances and alternatives are summarised in Table A-4 of the Annex.** Example definitions of PFAS and substance categorization are also included.

		PFAS [2]			Sector Breakdown [3]		Metrics [4]			Persistent Breakdown Product Molar Yield (%) [5]					
		B	O	P	Feedstock Use	Market Use	Lifetime (Years)	ODP	GWP (100)	TFA	PFPrA	PTBA	CHF_3	CF_4	$CClF_3$
I. Persistent Breakdown Product [6]															
TFA	$CF_3C(O)OH$	1	1			na	~5 days	0	<1						
PFPrA	$C_2F_5C(O)OH$	1	1	1		na	~5 days	0	<1						
PFBA	$C_3F_7C(O)OH$	1	1	1		na	~5 days	0	<<1						
HFC-23	CHF_3					FS, R	228	0	14500						
CFC-13	$CClF_3$					R	640	0.3	16100						
PFC-14	CF_4					R	50000	0	7250						
II. Montreal Protocol Controlled Substances with Monitored Global Atmospheric Abundance [7]															
CFC															
CFC-11	CCl_3F				Feedstock	A, FB, R, S	52	1	6170	–[8]	–	–	–	–	–
CFC-12	CCl_2F_2				Feedstock	FB	102	0.75	12400	–	–	–	–	–	–
CFC-13	$CClF_3$					R	640	0.3	16100	–	–	–	–	–	–
CFC-112	CCl_2FCCl_2F				Feedstock	H, R	63.6	0.98	4570	–	–	–	–	–	–
CFC-112a	CCl_3CClF_2						52	0.86	3510	–	–	–	–	–	–
CFC-113	CCl_2FCClF_2			1	Feedstock	H, R, S	93	0.82	6460	–	–	–	–	–	–

Snapshot of Table A-4

- **The atmospheric formation of TFA is expected to increase in the coming decades due to increased use of HFOs and HCFOs.**

3 STRATOSPHERIC OZONE

Ozone changes to date

- **Measurements continue to show unambiguous increases in upper stratospheric ozone for 2000–2024**

- **New lines of evidence and analyses strengthen previous findings that the Antarctic ozone hole has generally diminished in area and depth since the year 2000,** notwithstanding substantial interannual variability, primarily driven by dynamical forcings.

- **Aggregated observations indicate an increase of 0.5 ± 0.3 %/ decade in near-global total column ozone over 1996–2024.** This trend is consistent with model simulations.

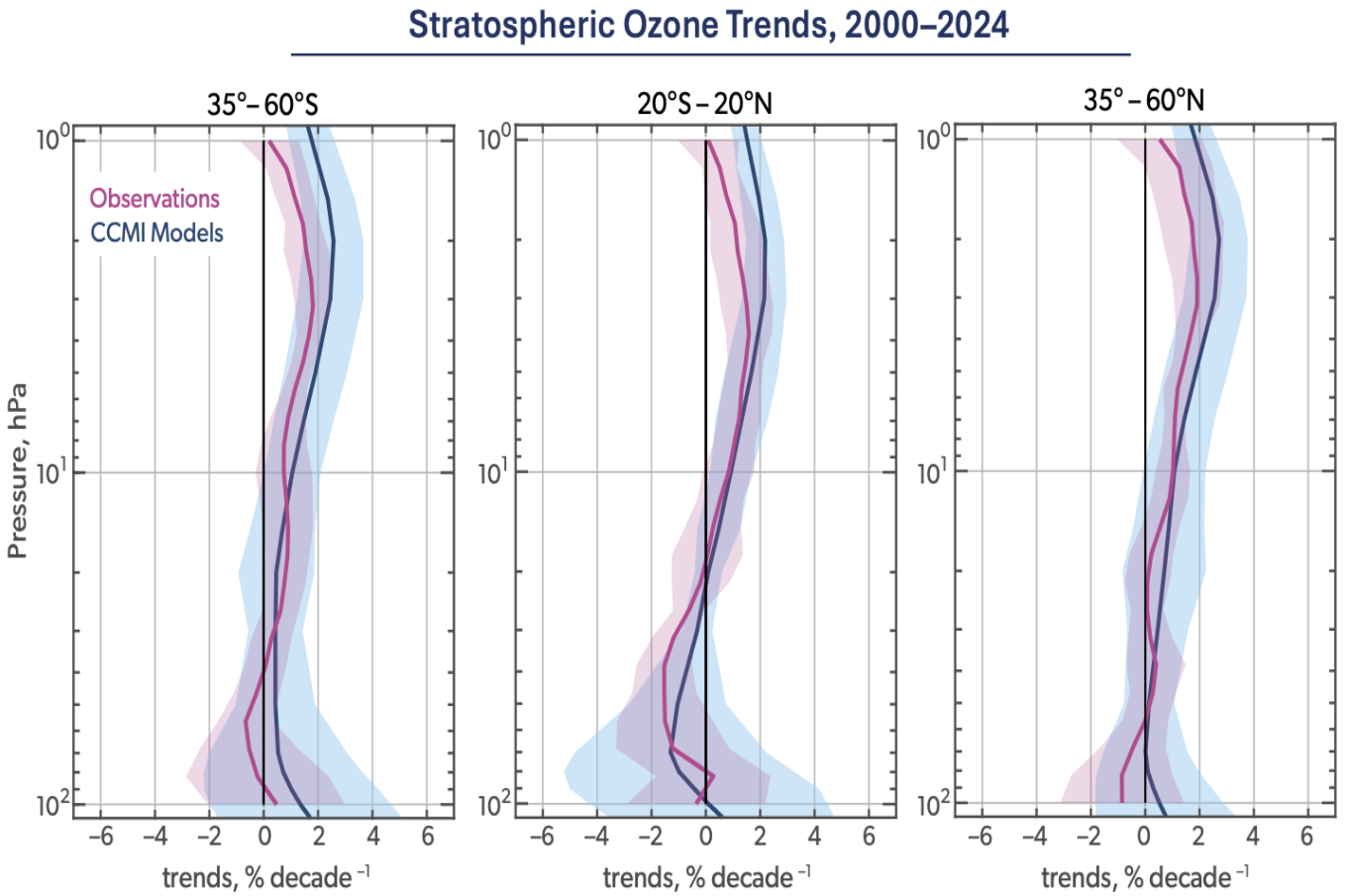


Figure ES-5. Ozone trends in the stratosphere from 2000 to 2024 for three latitude bands

3 STRATOSPHERIC OZONE

- **Antarctic total column ozone is projected to return to 1980 values during the 2060s** and **near-global-mean total column ozone is projected to return to 1980 values around 2040.*** These projections are consistent with those in previous Assessments.

- **Exceptional events can temporarily perturb stratospheric composition**. The Australian New Year's wildfires and the Hunga volcanic eruption both caused reductions in SH mid-latitude total column ozone of around 5% during the 2020–2024 period.

- **Currently, the known effects on ozone from aerosols and gaseous emissions attributed to space activities are minor compared to those of ODSs.** The future impacts remain highly uncertain due to possible alteration of ozone depletion chemistry by particles produced during launch and re-entry, dependencies on the number of launches and their location, and the fuel type used.

*In a middle-of-the-road greenhouse-gas scenario (SSP2-4.5)

4 STRATOSPHERIC OZONE CHANGES AND CLIMATE

- **The control of ODS emissions due to the implementation of the Montreal Protocol and its Amendments has prevented additional global warming, and these benefits will grow over the 21st century.** The prevented global warming from ODSs due to the Montreal Protocol is estimated to be 0.09-0.41°C by 2025 and 0.25–0.89 °C by 2050.

- **New evidence increases confidence that ODSs have had a positive direct radiative forcing since the mid-20th century.** The magnitude of the indirect radiative effects is larger - and therefore the net effective radiative forcing is smaller - than previously assessed.

- **Antarctic stratospheric ozone depletion and recovery have caused substantial changes in Southern Hemisphere atmospheric and oceanic circulation.**

5 STRATOSPHERIC AEROSOL INJECTION AND POTENTIAL IMPACTS ON OZONE

- Since the 2022 Assessment, there have been advances in understanding the response of stratospheric ozone to various stratospheric aerosol injection (SAI) scenarios and strategies.

- If models simulate subtropical SAI from 2035 to limit warming to 1.5 °C above the pre-industrial era*, global average total column ozone decreases 3 to 5 DU around the middle of the century (2045–2055).

- Gaps in the understanding of aerosol microphysics and their optical and chemical properties, as well as limitations in the ability to model stratospheric chemistry, transport, dynamics, and plume-scale effects, contribute to significant uncertainties in quantifying the effects of SAI on stratospheric ozone.

Projected Ozone and Temperature Anomalies from a Subtropical SAI Scenario

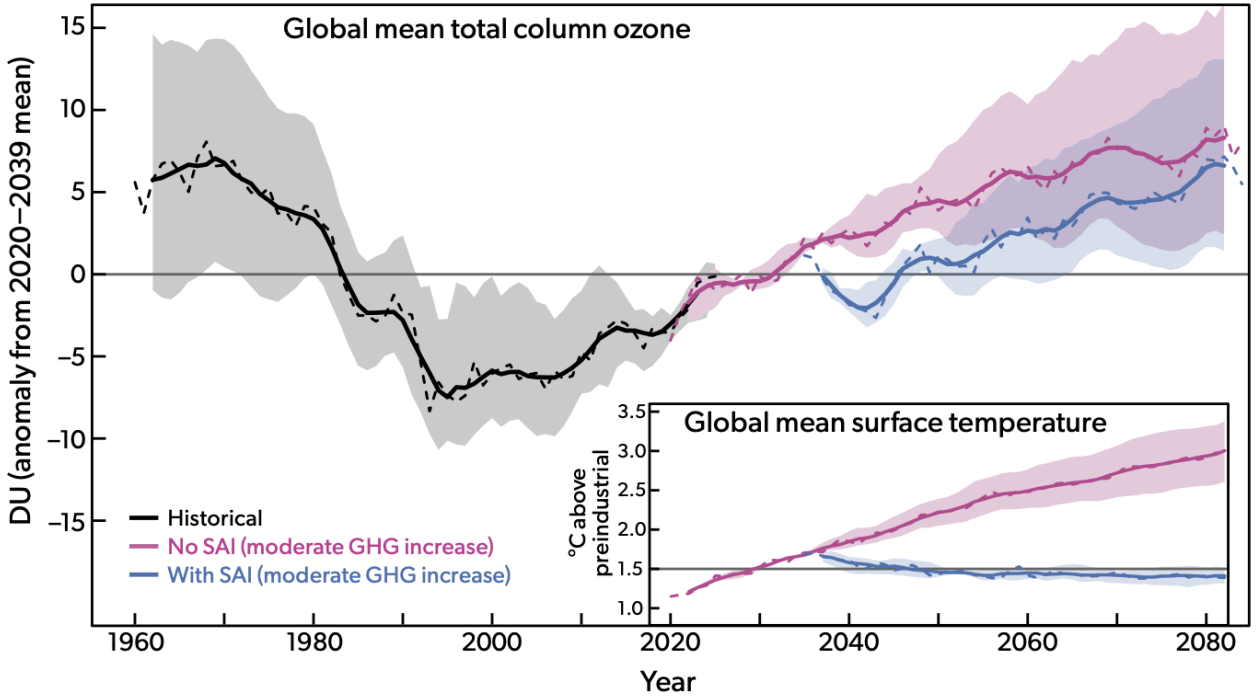


Figure ES-7. Simulated global (90°N–90°S) annual-mean total column ozone (TCO) anomalies from 1960 to 2085 relative to 2020–2039 mean values

*assuming a middle-of-the road greenhouse gas scenario (SSP2-4.5)

6 SCENARIOS AND INFORMATION FOR POLICYMAKERS

- **Scenarios of various hypothetical controls or other changes and their impacts on global total column ozone and surface temperature relative to the baseline scenario have been calculated, for 2050 and 2100.**

- **Scenarios include eliminating all ODS emissions from banks, from production, and from feedstock use, of eliminating CH_3Br associated with QPS uses, eliminating CH_2Cl_2 emissions, and reducing future emissions of N_2O from a higher- emission scenario to a highly mitigated scenario.**

- **The maximum impact on total column ozone is around 1%.** For context, the peak globally averaged ozone depletion was roughly 5% in the early 1990s, relative to the 1964–1980 average.

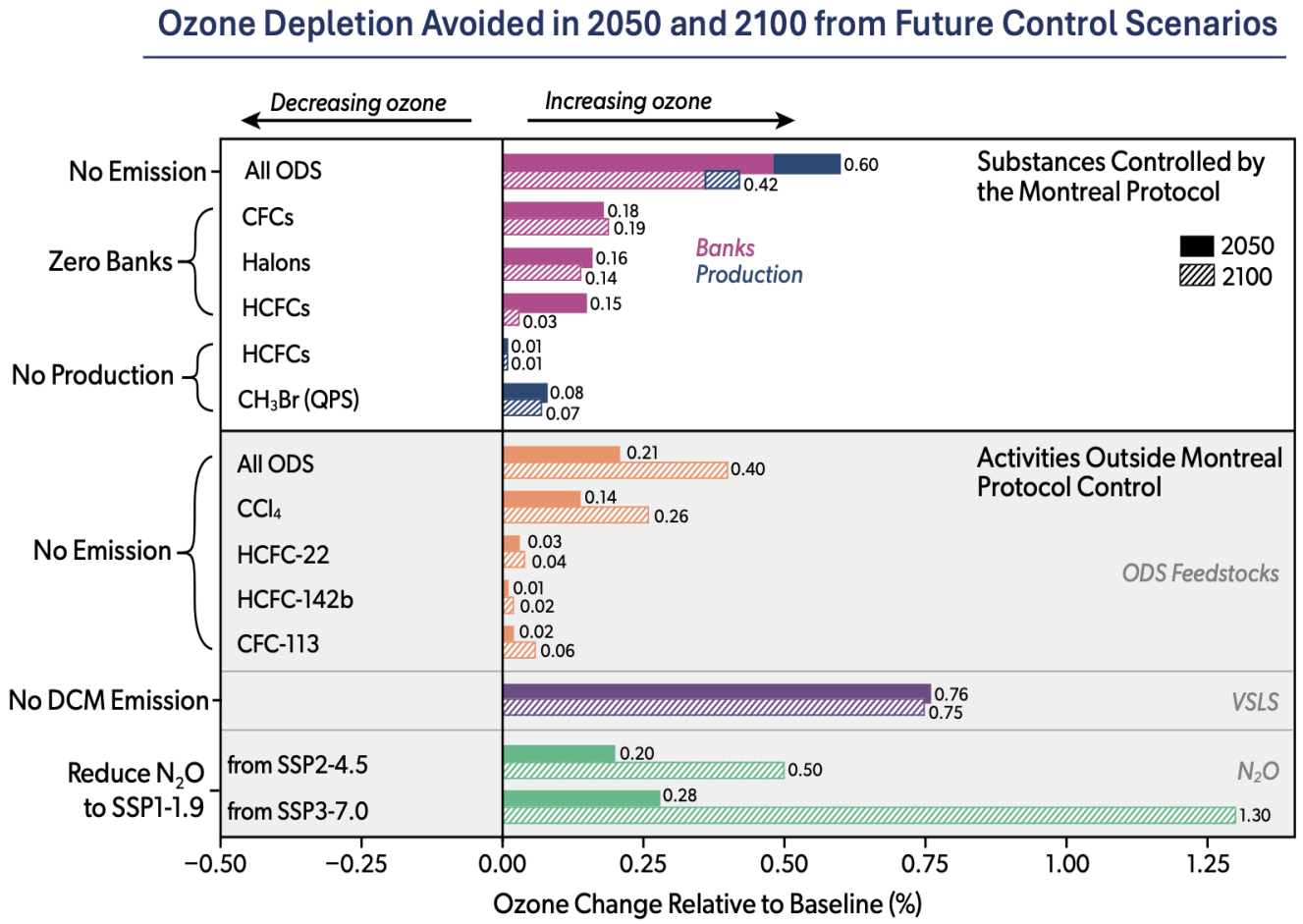


Figure ES-8(a)

6 SCENARIOS AND INFORMATION FOR POLICYMAKERS

- **Elimination of future HFC emissions, which goes beyond compliance with the Kigali Amendment, prevents a further 0.03 °C in 2050 and 0.04 °C in 2100** (beyond the prevented 0.4 °C warming in 2100), **of which HFC banks in 2028 contribute 0.01 °C.**

- **Reducing future emissions of N_2O from a higher- emission scenario to a highly mitigated scenario would prevent 0.12 °C of warming in 2100.**

For context, the observed average warming for the period 2016–2025 relative to 1850–1900 attributable to human activity was 1.24 (1.0–1.5) °C.

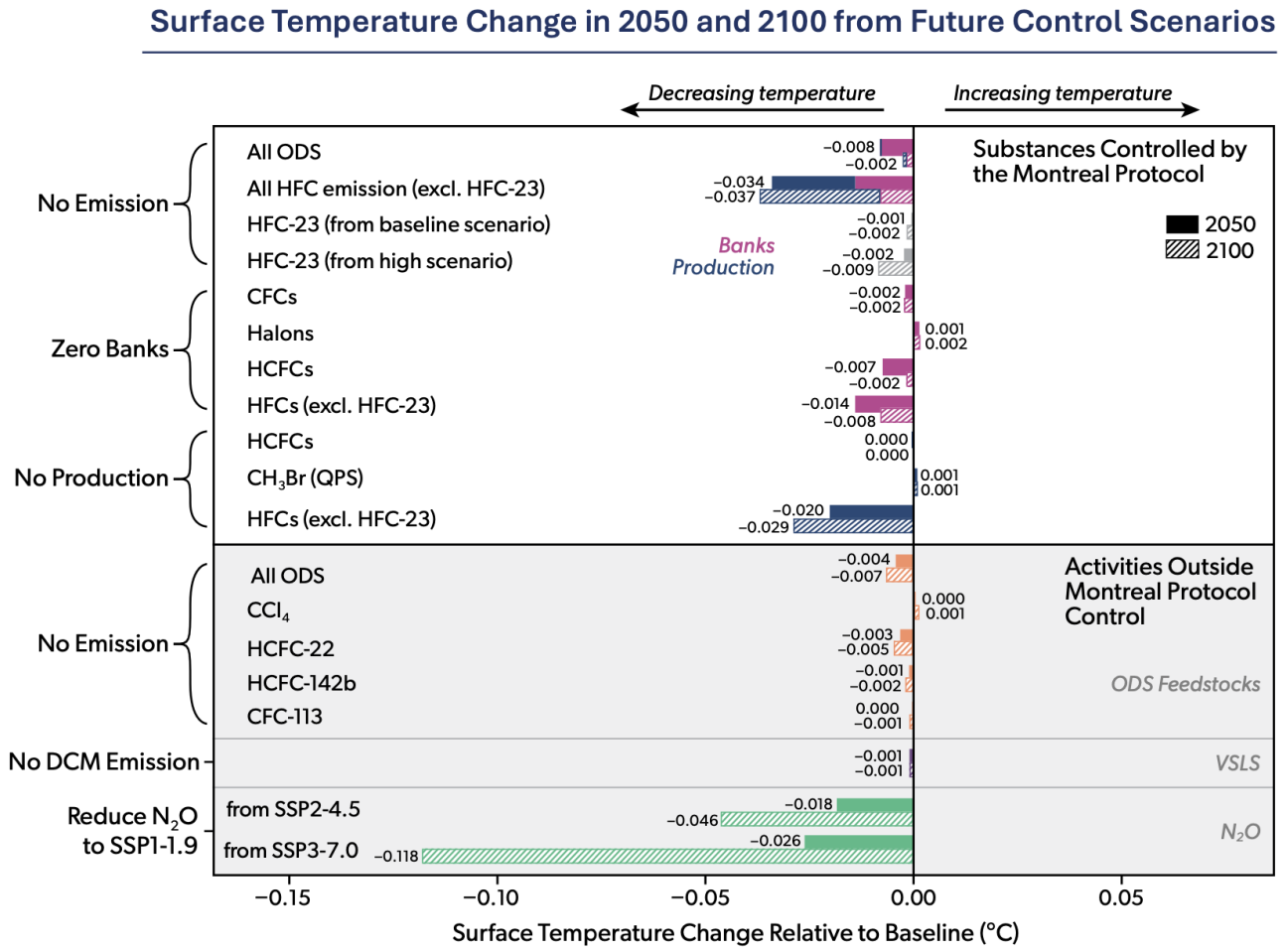
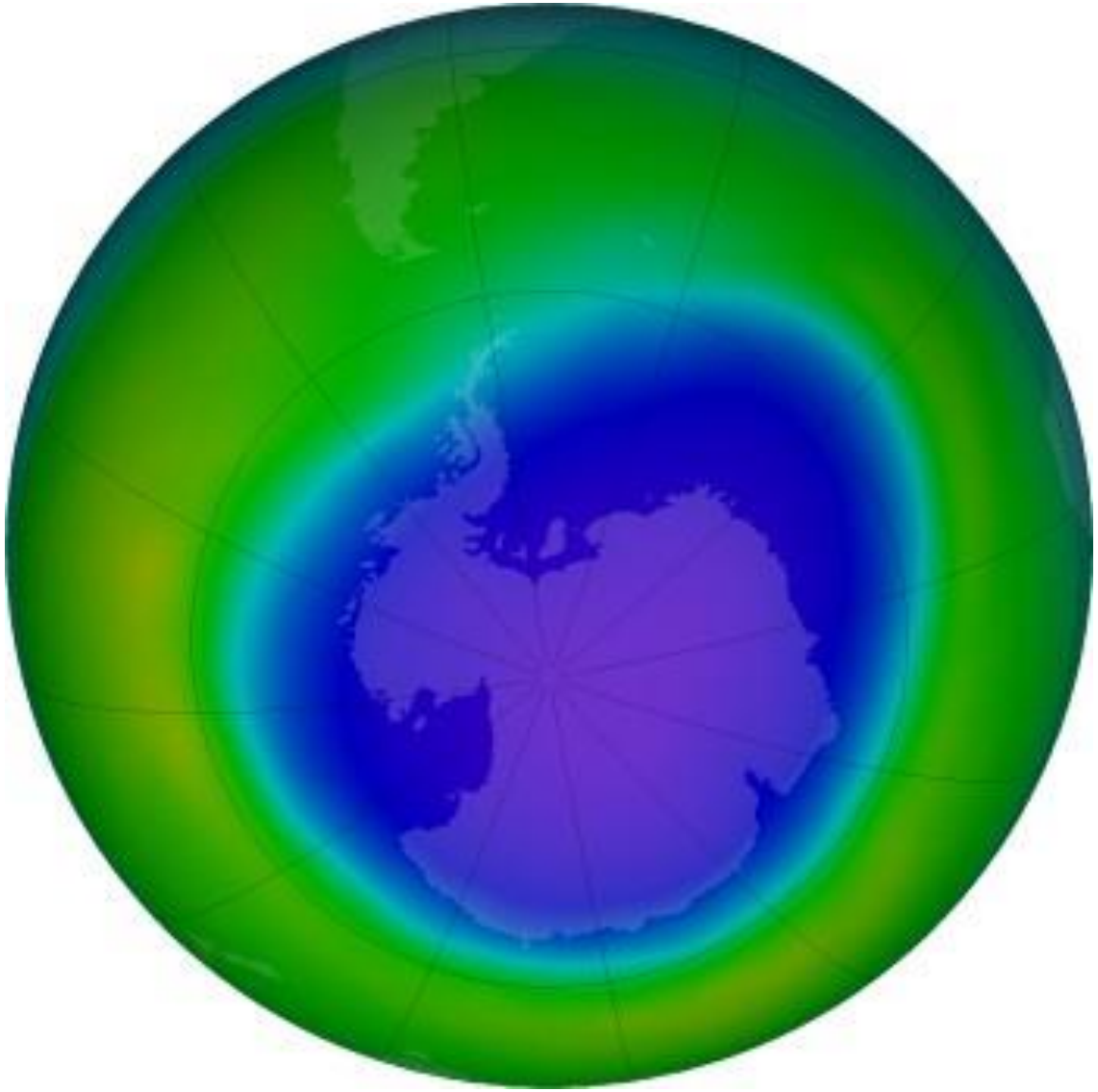


Figure ES-8(b)

The 2026 ozone hole

- Area was the **7th largest** (1979-2026)
- Minimum total column ozone was the **26th deepest**



October 2026 average column ozone from numerous satellite data

THANK YOU FOR YOUR ATTENTION,

MURAKOZE!

Extra slide

HFC emissions historical and projected

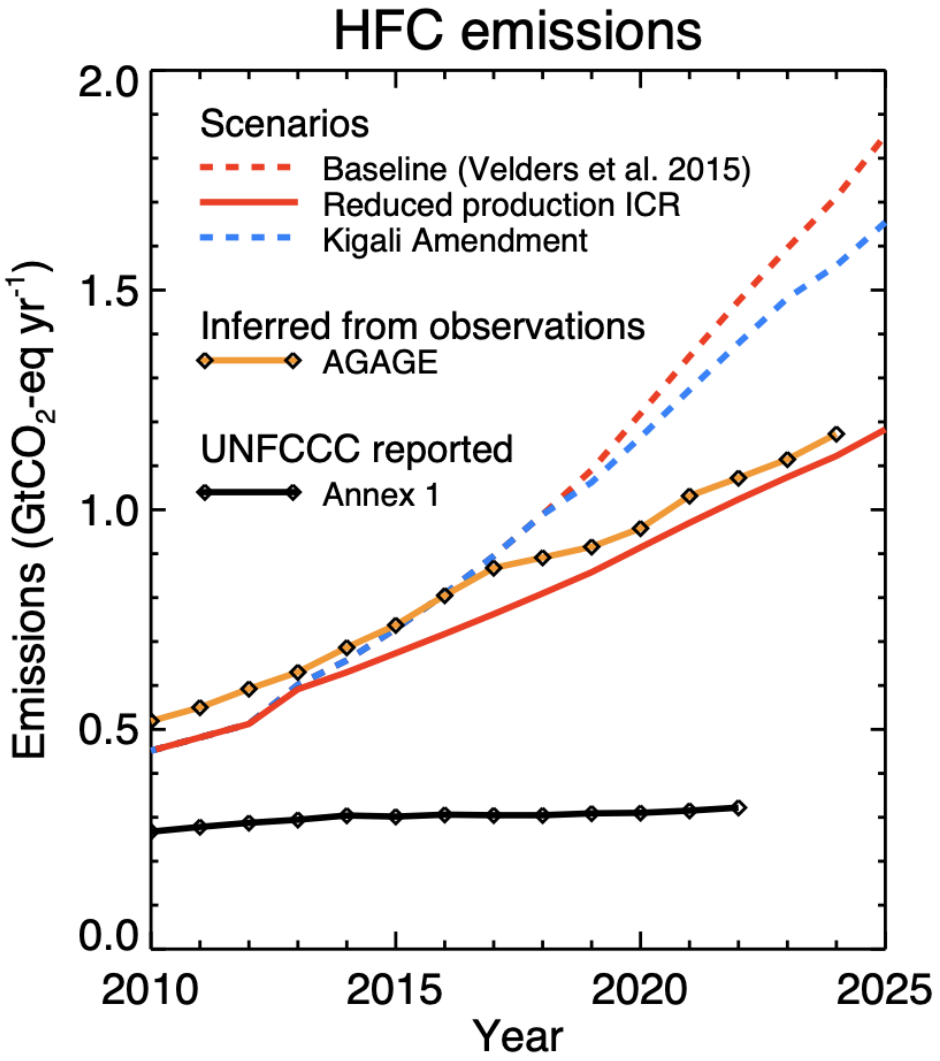


Figure 2-11. Global total HFC emissions (Gt CO_2-eq yr^{-1}) from the baseline (red dashed), taken from Velders et al. (2015), and the Kigali Amendment (blue dashed) scenarios using the methodology Chapter 2 of the previous Assessment (Liang and Rigby et al., 2022). The solid line shows an adjusted scenario with reduced HFC consumption for industrial and commercial refrigeration (ICR) from 2013 onward. The emissions are of 10 HFCs, which are HFCs for which measured-derived emissions are available (see Section 2.2) excluding HFC-23. Also shown are the emissions derived from AGAGE measurements and those reported to the UNFCCC by Annex I countries