climate change initiative

LONG-LIVED GREENHOUSE GAS PRODUCTS PERFORMANCES

Halocarbon Radiative Forcing

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It was (almost) 30 years ago today …

Method to calculate halocarbon radiative forcing directly from laboratory cross-section data. The “Pinnock Curve” ☺

- Updated many times to include better atmospheres, HITRAN and water vapour continuum updates, atmospheric adjustments, higher spectral resolution …
- e.g. Hodnebrog et al. 2020 10.1029/2019RG000691

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 100, NO. D11, PAGES 23,227–23,238, NOVEMBER 20, 1995

Radiative forcing of climate by hydrochlorofluorocarb and hydrofluorocarbons

Simon Pinnock,[1] Michael D. Hurley,[2] Keith P. Shine,[1] Timothy J. Wallington,[2] and Timothy J. Smyth[1]

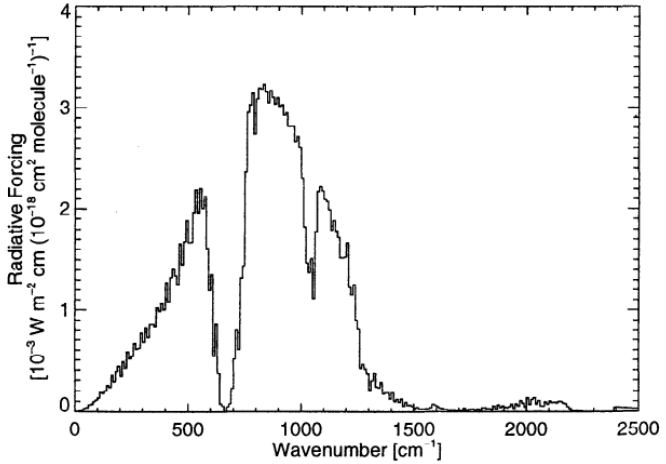
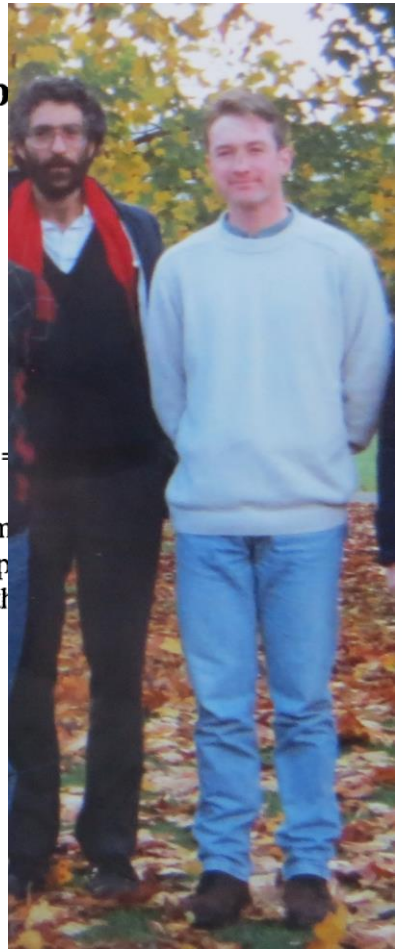


Figure 3. Radiative forcing per unit cross section for the GAM atmosphere including clouds, for a 0–1 ppbv increase in mixing ratio. This graph is repeated in tabular form in the Table 8.

Forcing =

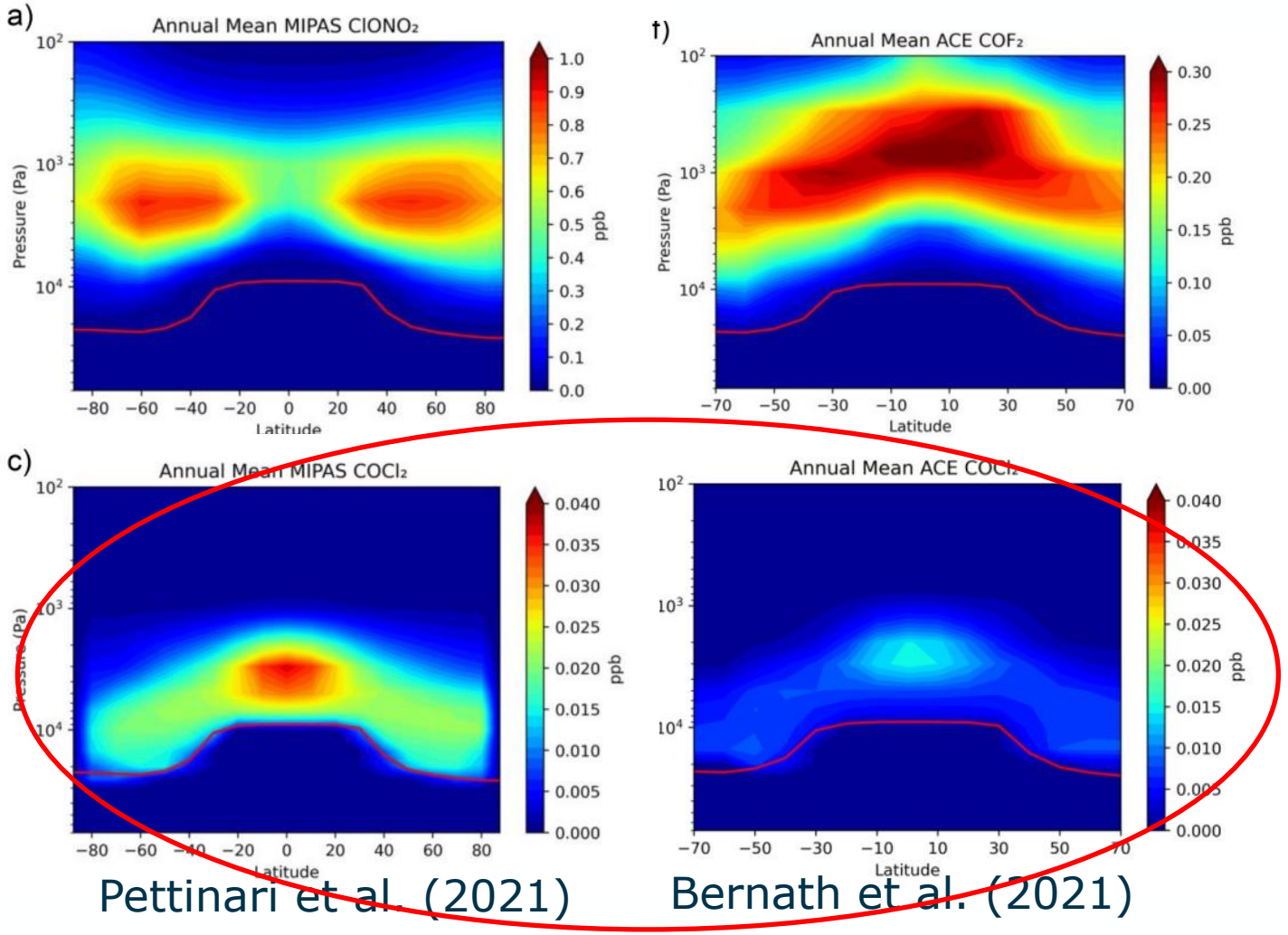
where F_σ^i (W m^{-2} (cm^{-1})$^{-1}$ (cm
forcing per unit cross section p
and σ_{av} (cm^2 molecule^{-1}) is th



Open Issues 1: Forcing from breakdown products

Many halocarbon breakdown products and reservoir species are complex IR-absorbing molecules. Important?

- Satellite products central to reliably characterizing distributions and abundances
- Significant and unexplained discrepancy between phosgene ($COCl_2$) abundances (MIPAS v ACE4.1 and ACE4.1(&5.0) v ACE3.4)



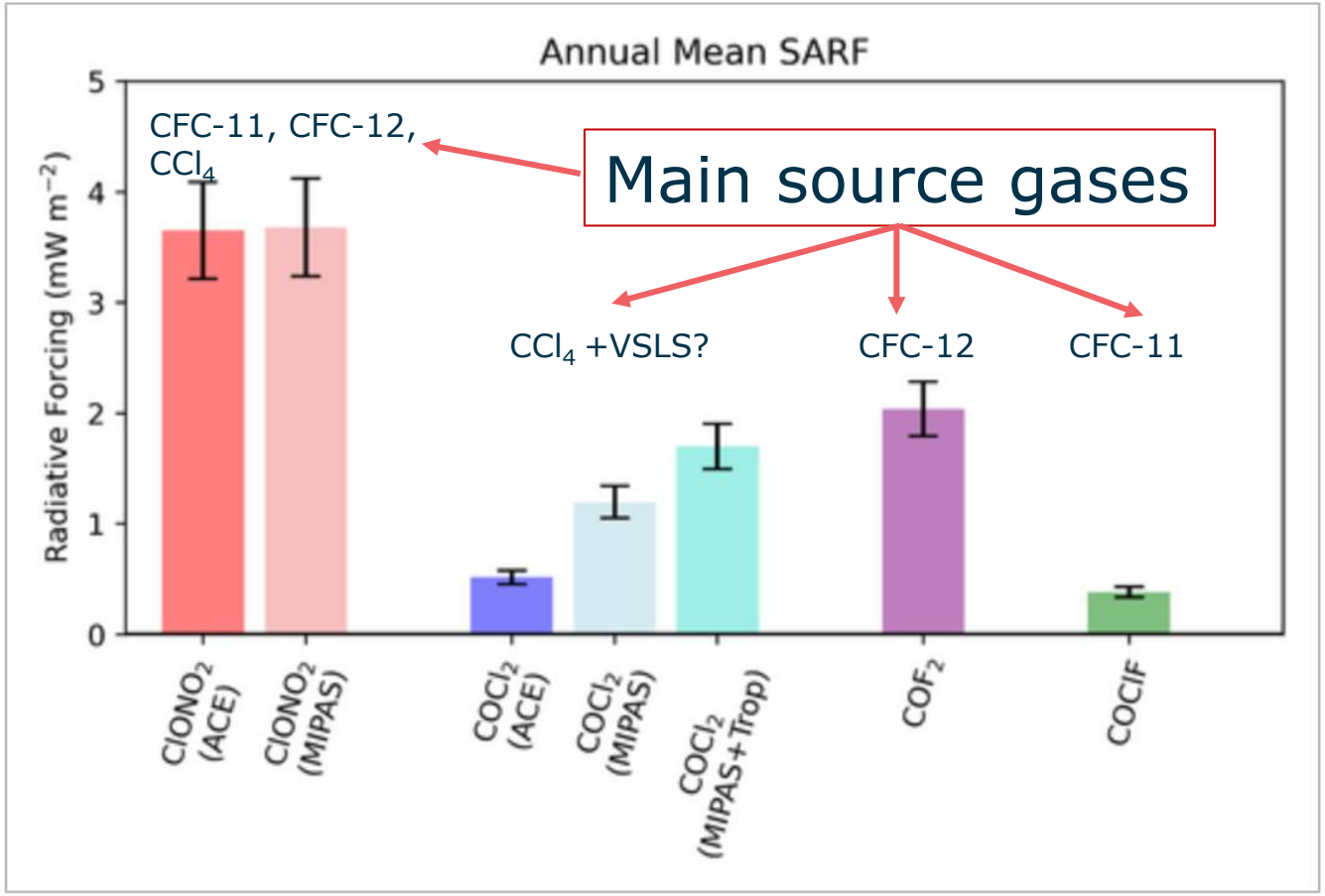
Pettinari et al. (2021) Bernath et al. (2021)

Thornhill et al. 2024 10.1029/2024JD040912

Open Issues 1: Forcing from breakdown products

Systematically increases radiative forcing from parent species

- For most species we studied, it is a modest (1-3%) but systematic increase
- But CCl_4 is the major source gas for phosgene – its forcing is enhanced by 5-15% depending on which satellite product we use

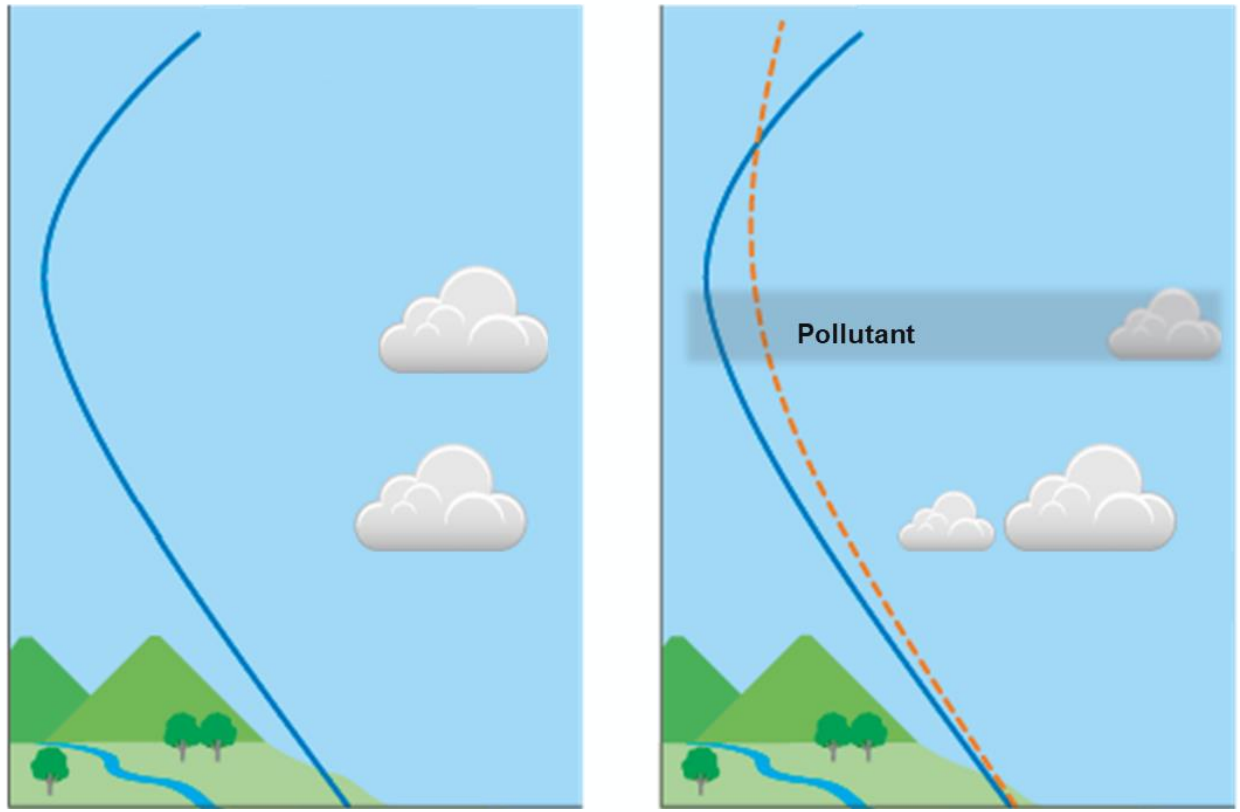


Thornhill et al. 202410.1029/2024JD040912

Open Issues 2: Effective Radiative Forcing

The definition of radiative forcing has evolved. IPCC now prefers “Effective Radiative Forcing” (ERF)

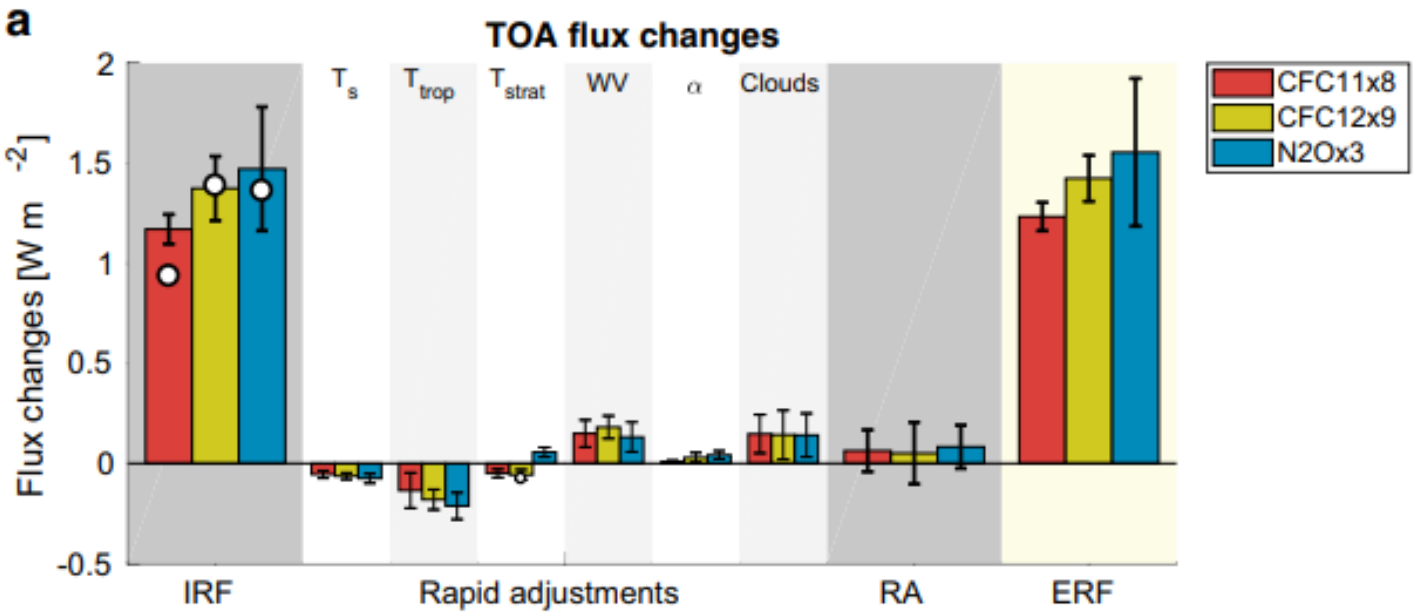
- ERF includes atmospheric adjustments (clouds, stratospheric and tropospheric temperature, humidity …) in absence of surface temperature change
- Require Earth System Models (ESMs) to compute most of these adjustments



Open Issues 2: Effective Radiative Forcing

Halocarbon ERF calculations are limited so far only speciated for direct effects of CFC-11 and CFC-12 (PDRMIP: Hodnebrog et al. 2020)

- IPCC AR6 applied 12±13% tropospheric adjustment to CFC-11 and CFC-12. It assumed 0±13% for all other (several hundred!) halocarbons
- Based on one multi-model study

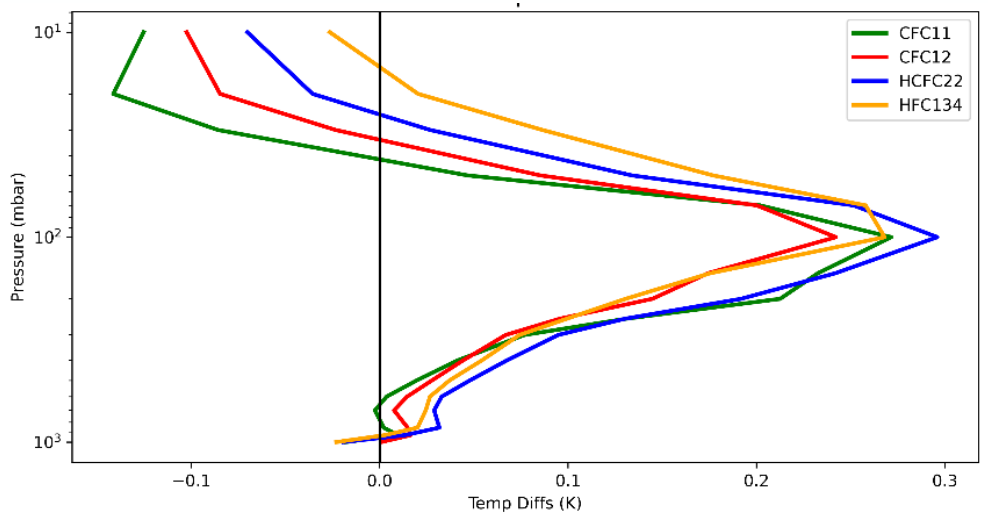


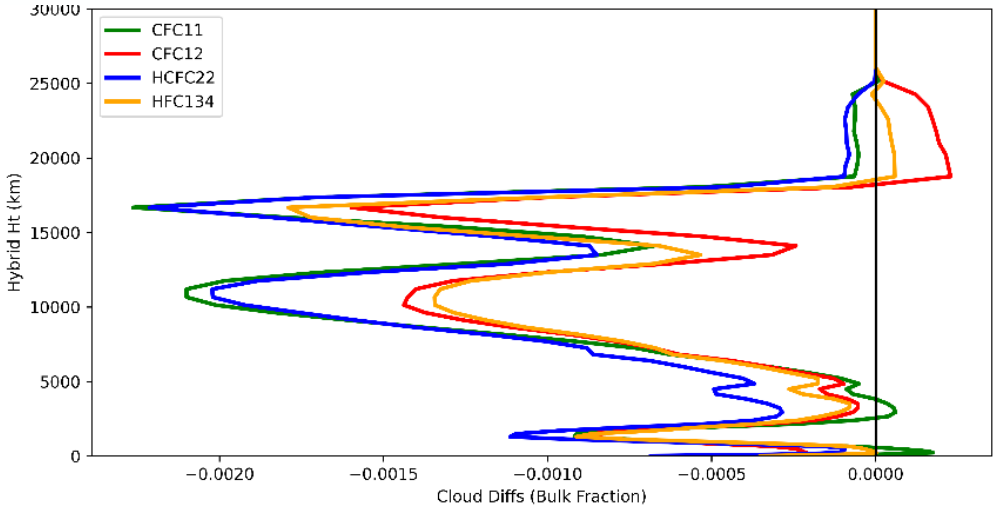
Hodnebrog et al. 2020
10.1038/s41612-020-00150-x

Open Issues 2: Effective Radiative Forcing

Radiation codes in ESMs are limited in the number of halocarbons included

- UKESM has 4 … double the number of many models!
- How generic are these adjustments across those 4 gases?
- We find general similarities – the cloud response is most important (warmer troposphere, less clouds)
- Adjustments enhance forcing by about 10-20%

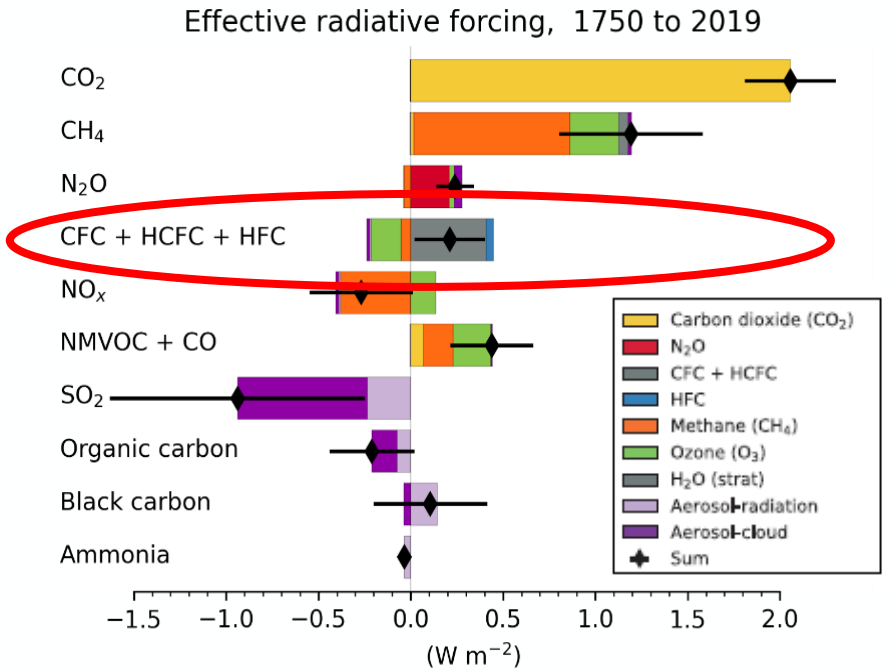




Open Issues 3: Net Forcing from ODSs

Net forcing from ozone-depleting substances (CFCs, HCFCs, halons) still an open issue

- Ozone loss causes a negative radiative forcing …
- … and affects methane lifetime
- … which affects tropospheric ozone, stratospheric water vapour
- Many other potential effects too due to tropospheric OH change

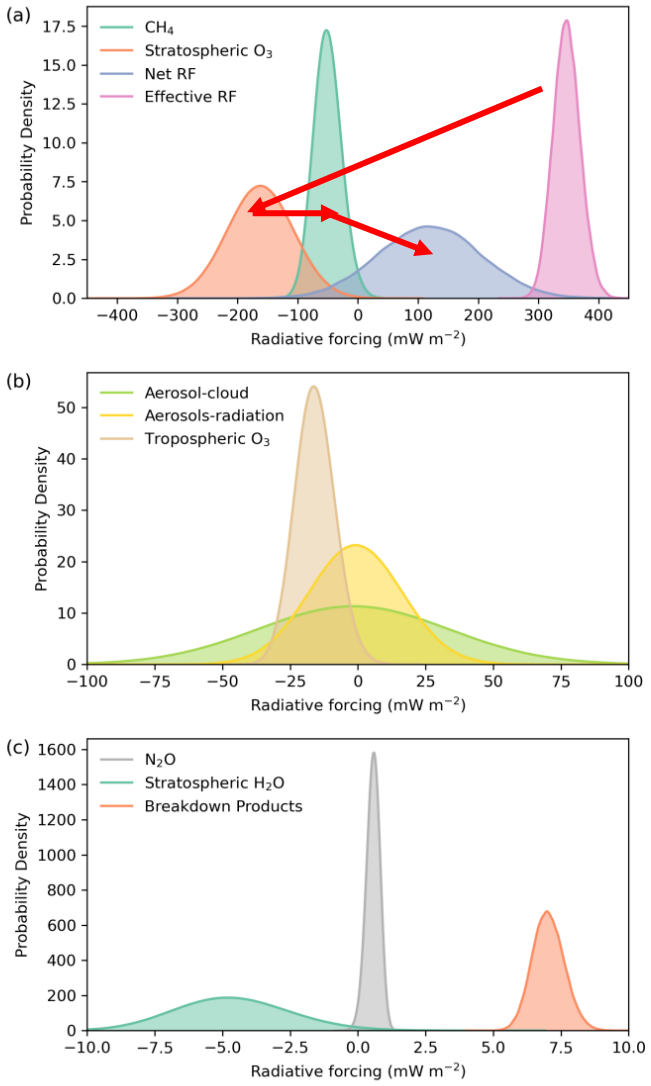


From IPCC AR6 based on Thornhill et al. 2021

Open Issues 3: Net Forcing from ODSs

Multiple indirect effects, mostly acting in opposition to the **direct ODS greenhouse effect**

- Given current uncertainties, we cannot rule out that the **net ODS** forcing is negative
- **Breakdown product** forcing is the only positive indirect effect so far identified



L Western, K Shine, W Collins. The Net Radiative Forcing from Ozone-Depleting Substances and its Uncertainty. *ESS Open Archive*
DOI: 10.22541/essoar.175917321.15002752/v1

Open Issues 3: Net Forcing from ODSs

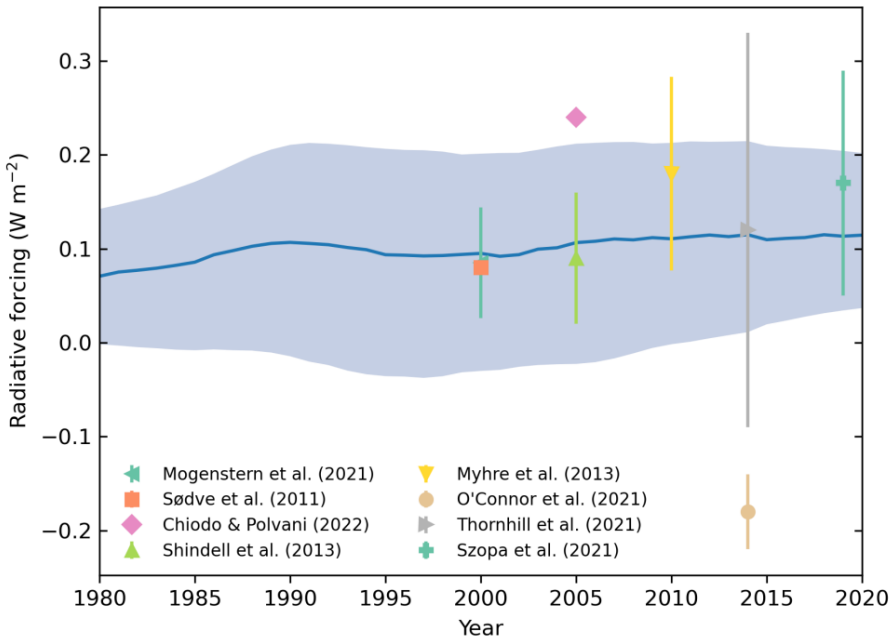


Figure 2. The blue line show the modal net radiative forcing of ODSs, and the 68% (1 standard deviation equivalent) uncertainty is shown by the shading, using the ensemble from this work. Orange circles show the radiative forcing reported in literature, with the error bars showing the 1 standard deviation uncertainty in the reported values (Søvde et al., 2011; Shindell et al., 2013; Myhre et al., 2013; Morgenstern et al., 2021; O'Connor et al., 2021; Szopa et al., 2021; Thornhill et al., 2021; Chiodo & Polvani, 2022). The metric of radiative forcing used differs between literature sources. Please see the main text for details. The 1 standard deviation uncertainty from literature may be that of a single model or from the spread of multiple models.

Individual gases (mW m^{-2}) in 2019

	CFC-11	CFC-12	CCl_4
Direct	62	177	13
Strat ozone	-44	-35	-25
Methane	-13	-10	-8
Trop ozone	-4	-3	-3
Others	-0.2	1.5	1
Net	**0.4**	**129**	**-21**

L Western, K Shine, W Collins. The Net Radiative Forcing from Ozone-Depleting Substances and its Uncertainty. *ESS Open Archive*
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Concluding comments

Understanding of net radiative forcing from halocarbons, and ODSs especially, continues to evolve

- Mix of species is changing
- More refined definition of radiative forcing
- Indirect effects including “long-known” (ozone depletion etc) and more recent (breakdown products)
- Net impact of ODS radiative forcing varies markedly between individual gases
- Overall benefit of Montreal Protocol on climate remains unclear

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