Impact of unmitigated HFC emissions on stratospheric ozone at the end of the 21st century as simulated by chemistry-climate models

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1. Introduction

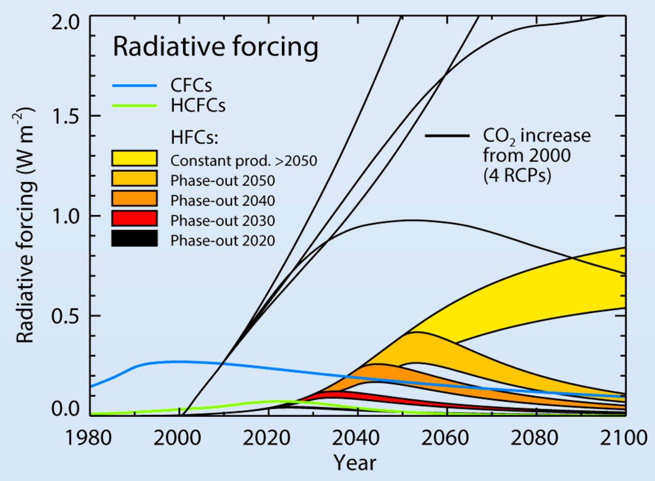
Hydrofluorocarbon (HFC) concentrations in the atmosphere have increased rapidly since the early 1990s because of their use as substitutes for chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).

HFCs do not contain chlorine and bromine atoms, thus do not contribute to direct chemical ozone destruction. However, because of their long lifetimes and strong infrared absorption in the atmospheric window, they affect stratospheric temperature and circulation patterns. This, in turn, influences the concentration and variations of stratospheric ozone.

In this study, we performed numerical experiments using two 3-dimensional (3-D) Chemistry-Climate Models (CCMs) to investigate the effect of unregulated HFC concentration increases on stratospheric ozone. Results of the two CCMs are cross-compared and compared with the previous 2-D model results of Hurwitz et al. (2015).

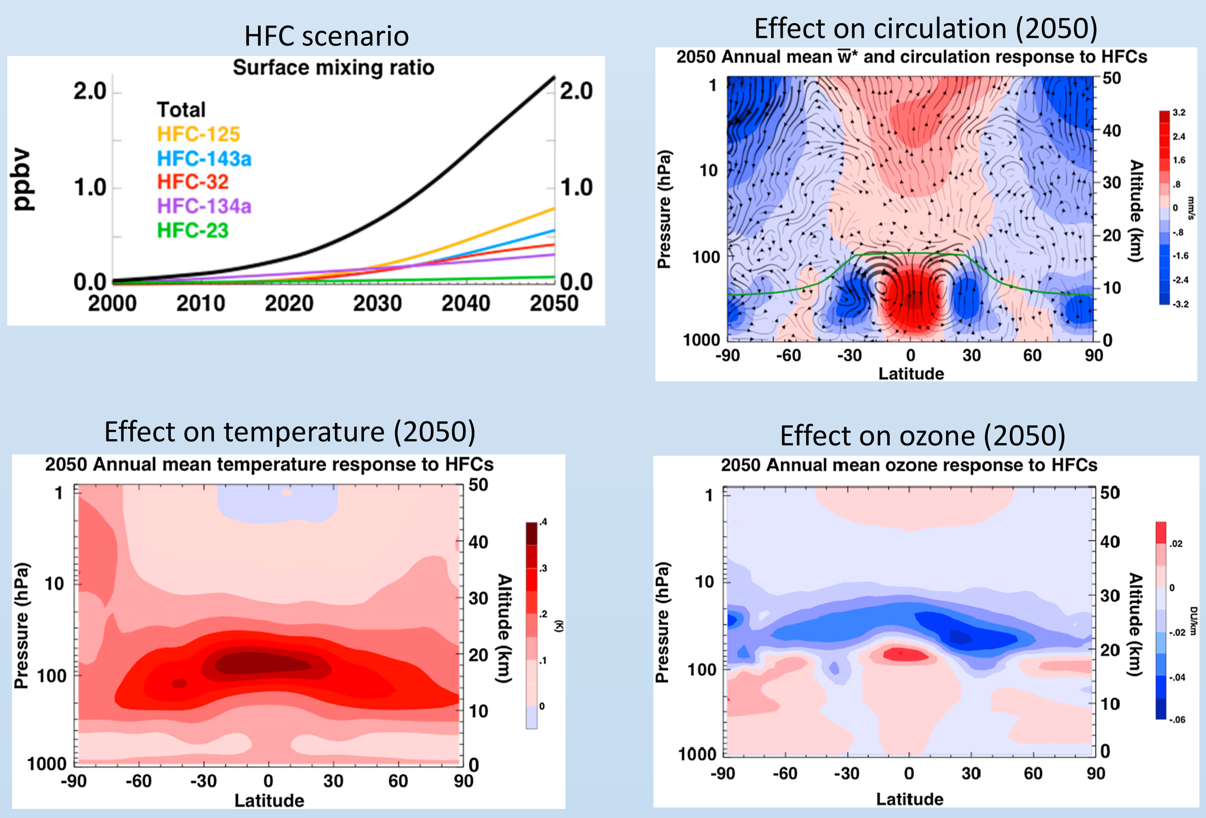
2. Future radiative forcing from HFC

Radiative forcing from HFCs could become comparable with that of CO_2 by the end of this century if HFCs are not regulated and the future CO_2 concentration follows the RCP2.6 scenario. In this case, how seriously would the ozone layer be affected by HFCs?



(Velders et al., 2014)

3. Preceding study: HFC effect estimation from a 2-D model (Hurwitz et al., 2015)



Streamlines: annual mean circulation change induced by the HFC increase

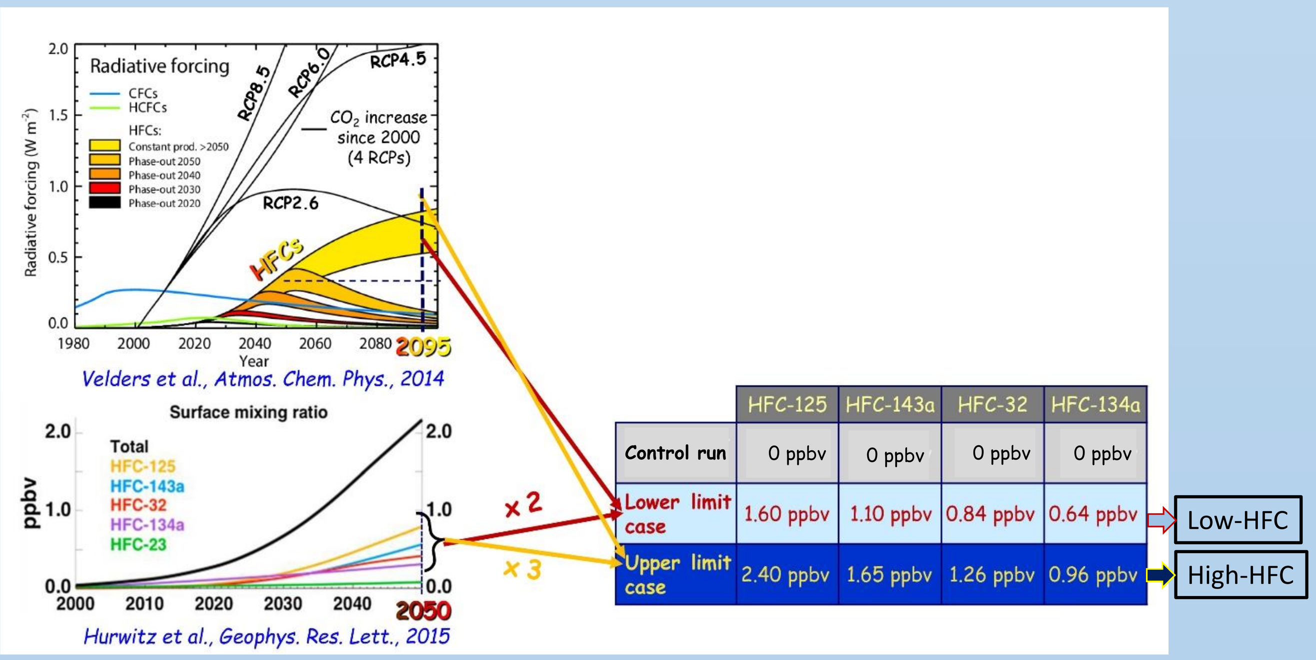
Color: Annual mean vertical motion changes (mm s^{-1})
Red: upwards Blue: downwards

Hurwitz et al. (2015)

Are the responses similar or different between the 2-D model and our 3-D models?

4. Method

- Two CCMs (MIROC3.2-CCM and MIROC5-CCM) are used for the numerical experiments.
- The basic model atmospheric state is set to the 2095 atmosphere under the RCP2.6 scenario, when radiative forcing caused by HFCs is nearly equal to that of CO_2.
- 100-member ensemble simulations are performed to evaluate statistical significance of the response.

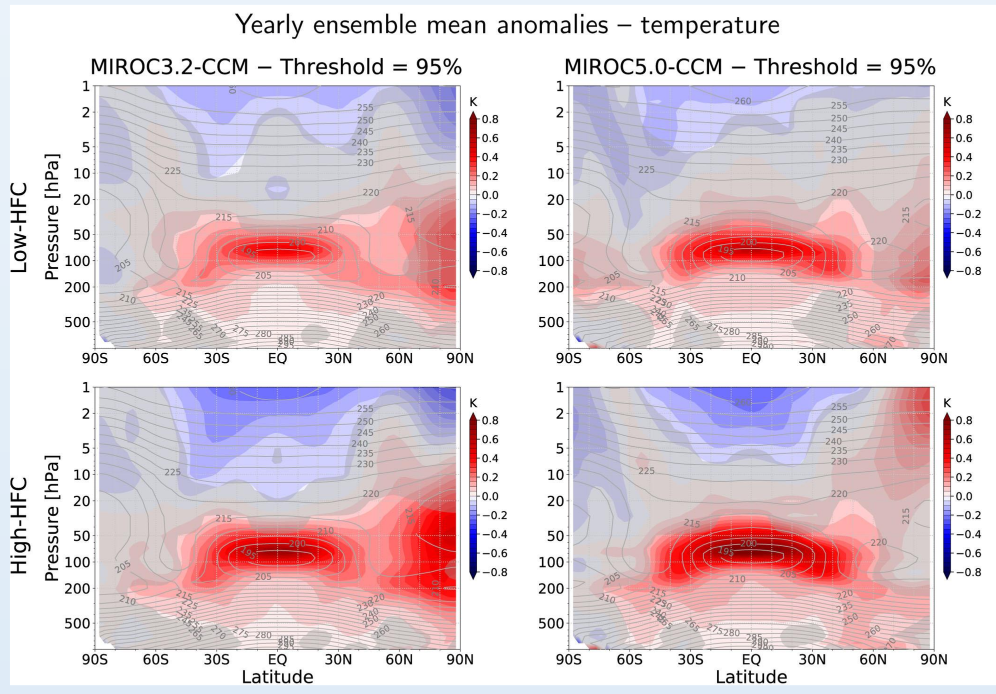


	HFC-125	HFC-143a	HFC-32	HFC-134a	
Control run	0 ppbv	0 ppbv	0 ppbv	0 ppbv	
Lower limit case	1.60 ppbv	1.10 ppbv	0.84 ppbv	0.64 ppbv	Low-HFC
Upper limit case	2.40 ppbv	1.65 ppbv	1.26 ppbv	0.96 ppbv	High-HFC

- ➢HFC profiles are calculated from fixed surface concentrations and chemical reactions with OH, O(1D), and Cl.
- ➢The 2095 output from a sensitivity run of CCMI・REF-C2 with the RCP2.6 scenario is used as initial data. Practically, a 110-year continuous run is performed, then data from the last 100 years are analyzed as 100 distinct ensemble members.
- ➢The lower and upper limits of the projected HFC radiative forcing in 2095 are twice and three times the 2050 forcing, respectively (Velders et al., 2014). Assuming that HFC radiative forcing is proportional to the amount, HFC concentrations in the unregulated increase experiments are set to twice or three times the 2050 concentrations of Hurwitz et al. (2015).

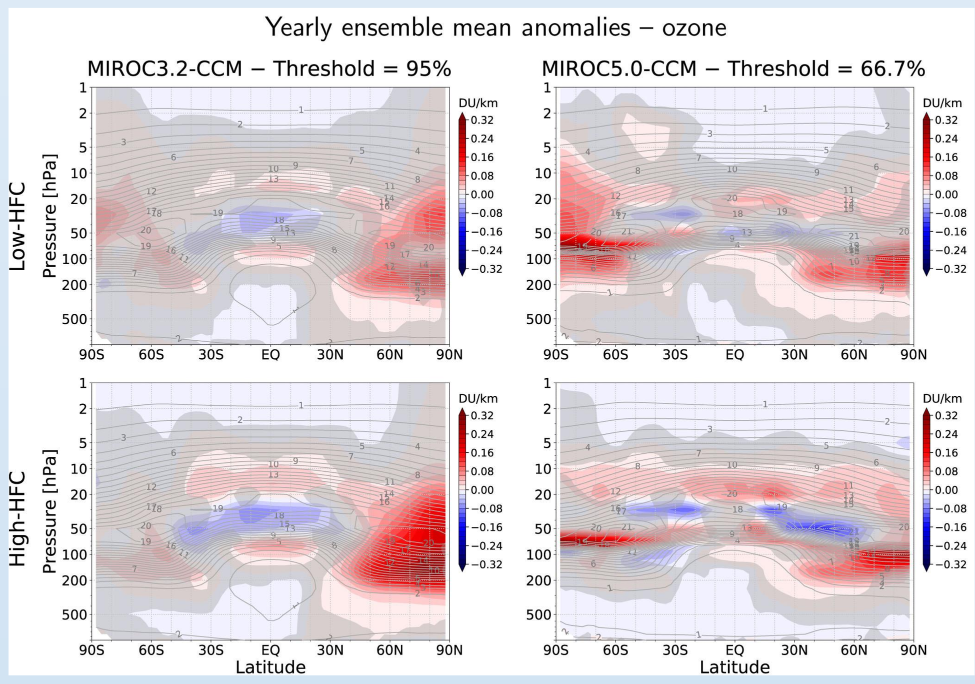
5. Results from CCMs (3-D)

5-1. Temperature response (zonal mean, annual mean, 100-member ensemble mean)



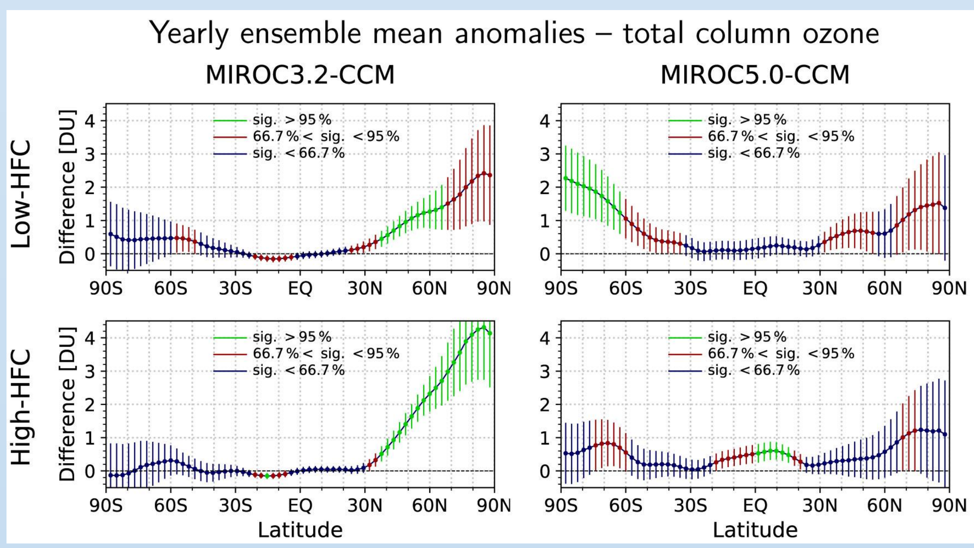
Grey-shaded areas are regions with statistical significance below the threshold (t-test, 95%)

5-2. Ozone response (zonal mean, annual mean, 100-member ensemble mean)



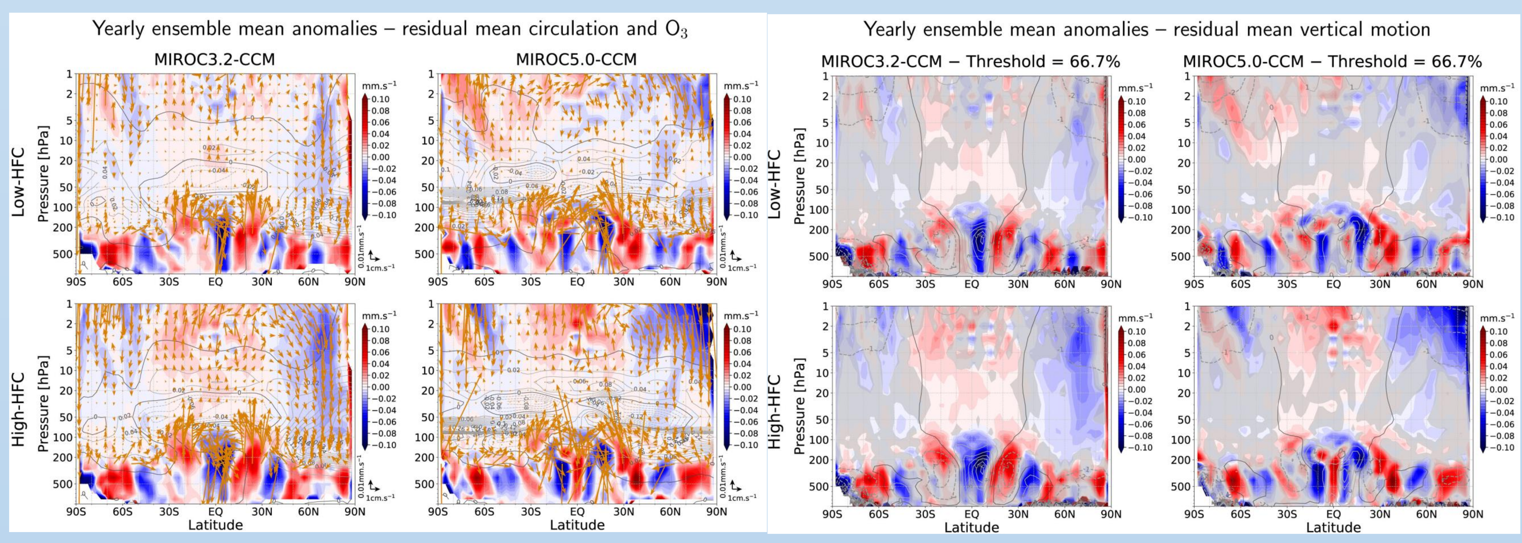
Grey-shaded areas are regions with statistical significance below the threshold (t-test, 95% for MIROC3.2-CCM and 66.7% for MIROC5-CCM)

5-3. Colmun ozone response (zonal mean, annual mean, 100-member ensemble mean)



Due to the vertically alternating positive and negative ozone concentration responses, magnitude of the total ozone response is very small. Proportionality of the response between the low-HFC and high-HFC cases is not clear.

5-4. Residual mean circulation response (zonal mean, annual mean, 100-member ensemble mean)

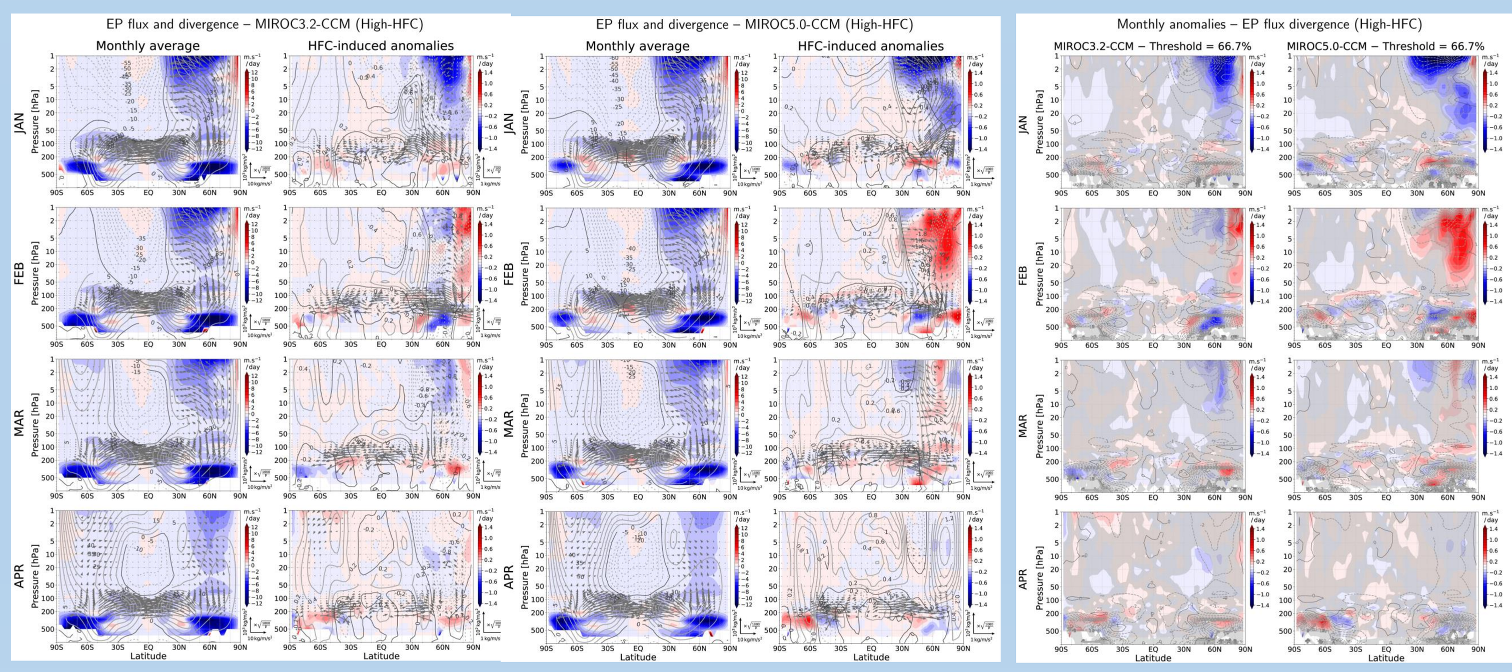


Arrows: Annual mean circulation changes induced by the HFC increase

Color: Annual mean vertical motion anomalies (mm.s^{-1})
Red: upwards Blue: downwards

Grey-shaded areas are regions with statistical significance below the threshold (t-test, 95%)

5-5. EP-flux and EP-flux divergence response (High-HFC case) (zonal mean, annual mean, 100-member ensemble mean)



Seasonal evolution of EP flux and EP flux divergence are similar between the models, but responses to the HFC increase are different.

Red: divergence
Blue: convergence

Grey-shaded areas are regions with statistical significance below the threshold (t-test, 66.7%)

6. Concluding Remarks

(1)The estimated impact of HFCs on total ozone was small, at most 1% (4.2 DU) for MIROC3.2-CCM and 0.3% (1.2 DU) for MIROC5-CCM. In both cases, the net global effect was positive.

(2)The small magnitude of the total ozone response is caused by the altitude-dependent, alternately negative and positive ozone responses.

(3)The observed alternating anomaly pattern can reasonably be explained by competing effects of residual vertical motion anomalies in the lower and middle stratosphere, and temperature anomalies in the upper stratosphere.

(4)Large differences were observed at high latitudes, notably in the NH polar region, not only between the 2-D and 3-D simulations but between the 3-D models themselves. These discrepancies were attributed to differences in wave activity during winter.

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The simulations were completed with the supercomputer (NEC SX-Aurora TSUBASA) at NIES.