Impact of HFCs on stratospheric ozone and temperature as simulated by chemistry-climate models

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Hydrofluorocarbons (HFCs) are anthropogenic compounds used as substitutes for ozone-depleting substances (ODSs). While they do not chemically interact with ozone (O_3), as greenhouse gases (GHGs) they substantially affect stratospheric temperature and circulation patterns, thus indirectly influencing O_3 concentrations. Steps have been taken to curb production of HFCs (Kigali Amendment to the Montreal Protocol, 2016). Assuming global compliance, HFC emissions should, therefore, reach their peak around 2040. Until then, however, their atmospheric abundance will keep increasing [1]. We present ensemble model simulations designed to assess the response of O_3, temperature and atmospheric circulation to increasing levels of HFCs. We analyze this response for climate conditions of 2095, following the Representative Concentration Pathway (RCP) 2.6 [2]. In this scenario, uncontrolled HFC emissions would induce a radiative forcing comparable to that of carbon dioxide, methane and nitrous oxide combined.

We simulate the effect of varying HFC concentrations in a 2095 climate, using the CCSRNIES-MIROC3.2 and CCSRNIES-MIROC5.0 three-dimensional (3D) chemistry-climate models [3,4]. These models use the same chemical module, but their physical modules are partly different. For each model, three ensemble simulations (“experiments”) are performed with different amounts of HFCs: no HFCs (control run), and two or three times (“2xHFC”, “3xHFC”) the HFC concentrations of Hurwitz et al. (2015) [5]. These correspond to abundance estimates for 2050, in the case of unregulated HFC emissions. Each experiment is an ensemble of 100 independent, year-long simulations. Background atmospheric levels of GHGs follow the RCP2.6 scenario for 2095. Estimated abundances of ODSs assume full compliance with the Montreal Protocol.

For each model version, results for the “2xHFC” and “3xHFC” cases are qualitatively similar. Therefore, we focus our analysis on the “3xHFC” experiment and illustrate ensemble-mean results for total column O_3, as well as for latitude/pressure cross-sections of O_3, temperature and zonal mean zonal wind.

At tropical and subtropical latitudes, we obtain ozone responses to increasing HFC concentrations which are roughly consistent with those from the zonal-mean two-dimensional (2D) model of Hurwitz et al. (2015) [5]. In addition, at these latitudes, the O_3 responses of the MIROC3.2 and MIROC5.0 models are consistent. For O_3, this robust response is a decrease around 50 hPa and an increase above and below. The temperature response to HFC increases is a warming of the stratosphere below 20 hPa. The resulting total ozone response is very small, because the positive and negative O_3 anomalies cancel each other vertically. When considering the high latitudes, however, the calculated O_3 responses are quite different, not only between the 2D model and both 3D MIROC models, but also between MIROC3.2 and MIROC5.0.

Such discrepancies in the high-latitude responses may be due to differences of planetary wave activity in the models, and of their interaction with stratospheric HFCs and O_3.

References

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