Greenhouse Effect of Chlorofluorocarbons and Other Trace Gases

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We compare the radiative (greenhouse) forcing of the climate system due to changes of atmospheric chlorofluorocarbons and other trace gases. We find that CFCs, defined to include chlorofluorocarbons, chlorocarbons, and fluorocarbons, now provide about one-quarter of current annual increases in anthropogenic greenhouse climate forcing. If the growth rates of CFC production in the early 1970s had continued to the present, current annual growth of climate forcing due to CFCs would exceed that due to CO₂.

1. INTRODUCTION

It has been realized for more than a century [Tyndall, 1861] that if it were not for the presence of infrared-absorbing (greenhouse) gases in the Earth's atmosphere, mainly H₂O and CO₂, the Earth's surface would be several tens of degrees Celsius colder than it is. The possibility of global climate change due to anthropogenic and natural variations of CO₂ has been debated increasingly during the past century. Ramanathan [1975] fundamentally altered the greenhouse issue when he showed that CFCs, entirely man-made, also cause a significant greenhouse effect. Wang et al. [1976] argued that a broad range of other trace gases, including CH₄ and N₂O, are also contributing to greenhouse changes. Lacis et al. [1981] showed that the combined measured changes of CFCs, CH₄, and N₂O in the period 1970–1980 caused a greenhouse climate forcing in the range 50–100% of that for the CO₂ change in the same period. Ramanathan et al. [1985] argued that during the next several decades the net greenhouse forcing for projected changes of trace gases other than CO₂ would exceed the greenhouse forcing due to projected CO₂ growth.

We calculate the contribution of CFCs to the increase in greenhouse climate forcing over the decade of the 1980s, comparing it with the greenhouse forcing by CO₂ and other trace gases. The result shows that CFCs have grown to be a large fraction of current increases in greenhouse climate forcing. But this comparison also points out the importance of the sharp reduction in the growth of CFC production that occurred in 1974, illustrating the great impact that a communication, 1989) show band strengths for CFC-22 that are 35% smaller than Ramanathan et al., 1985]. We compare the radiative (greenhouse) forcing of the climate system due to increases of atmospheric CFCs in the regime.
TABLE 1. Global Mean Radiative Forcing of the Climate System ($\Delta T_o$) due to Estimated Changes of Several Trace Gases During the 1980's.*

| Growth Rate, Estimated Abundance, Band Strength, Remarks |
|--------------------------------------------------------|
| $\Delta T_o$, °C | %/yr | 1980 | 1990 | cm$^2$ atm$^{-1}$ stp |
|------------------|------|------|------|---------------------|
| CCl$_2$F$_2$ (CFC-12) | 0.0143 | 4.6 | 297 | 468 | 3642 | a, S |
| CCl$_2$F (CFC-11) | 0.0067 | 4.7 | 173 | 275 | 2782 | a, S |
| CClFCClF$_2$ (CFC-113) | 0.0057 | 13.3 | 20 | 70 | 5315 | a, R |
| CHCIF$_2$ (CFC-22) | 0.0034 | 8.2 | 50 | 110 | 2627 | a, F |
| CF$_4$ (CFC-14) | 0.0009 | 2.5 | 70 | 90 | 4640 | b, S |
| C$_2$F$_4$ | 0.0007 | 1.5 | 100 | 115 | 1437 | a, P |
| CCl$_2$FCClIF$_2$ (CFC-114) | 0.0004 | 5.8 | 4 | 7 | 6570 | a, R |
| CF$_3$Cl (CFC-13) | 0.0004 | 4.7 | 7 | 11 | 4452 | b, S |
| CF$_3$CPF$_2$Cl (CFC-115) | 0.0003 | 9.0 | 2 | 5 | a, X |
| C$_2$H$_2$Cl$_2$ | 0.0002 | 4.4 | 110 | 170 | a, Y |
| CH$_2$Cl$_2$ | 0.0002 | 3.9 | 30 | 44 | 583 | b, P |
| CH$_2$ClCH$_2$Cl | 0.0002 | 2.4 | 30 | 38 | b, Z |
| CF$_3$Br | 0.0002 | 18.2 | 0.6 | 3.2 | 4144 | a, P |
| C$_2$F$_6$ (CFC-116) | 0.0001 | 3.2 | 4 | 5.5 | 4861 | b, P |
| CHCl$_3$ | 0.0001 | 2.2 | 10 | 12.5 | 1149 | b, P |

* CFC growth rates are based on (a) data of the International Ozone Trends Panel as summarized by Watson et al. [1988] and (b) on Ramanathan et al. [1985] estimates. Abundances are in parts per trillion by volume. Absorption data used to compute $\Delta T_o$ were obtained from the following sources or assumptions indicated under the Remarks column: S [Smith et al., 1985], R [Rogers and Stephens, 1988], F (D. Fisher, private communication, 1989), P [Pugh and Rao, 1976], X (assumed to absorb like CFC-113), Y (scaled from Hummel and Reck [1981]), Z (assumed to absorb like CH$_3$CCl$_3$).

The results tabulated in Table 1 and summarized in Figure 1 are useful in estimating the impact upon future greenhouse forcings of possible controls on CFC emissions. The Montreal Protocol restricts future growth in production of CFCs 11, 12, 113, 114, and 115, but as currently ratified it does not restrict growth in CFC-22 production. Given current growth rates, it seems likely that CFC-22 will become a substantial greenhouse gas in the future, especially if it becomes a major substitute for CFC-12 and CFC-11.

3. COMPARISON OF CFC AND OTHER GREENHOUSE FORCINGS

We compare the radiative forcing due to CFCs and other greenhouse gases, for the past few decades and the preceding century. Estimated abundances for the gases are given in Table 2. The estimates for recent decades are based mainly on atmospheric measurements, while the estimates of CO$_2$ and CH$_4$ for 1850 are based on measurements of air bubbles trapped in polar ice as summarized by Oeschger and Siegenthaler [1988], Cicerone and Oremland [1988], and Ehhalt [1988]. The CFC history was estimated from production figures for reporting companies [Chemical Manufacturers Association, 1988] and the assumption of simple lifetimes (60 and 120 years for CFC-11 and CFC-12, respectively) with no lag between production and release. The calculated CFC atmospheric amounts are in good agreement with observations over the past several years (perhaps accidentally because failure to include production by nonreporting companies approximately compensates for the time lag between CFC production and release into the atmosphere).

Figure 2 compares the decadal increments of climate forcing due to measured greenhouse gas changes since 1850. CO$_2$ is the dominant greenhouse gas (62%) for the full period 1850-1990, with CH$_4$ next at 21%, CFCs at 13%, and N$_2$O 4%. The rate of increase of greenhouse forcing has accelerated in recent decades. Indeed, more than 50% of the total added
forcing for the period 1850–1990 has been added during the last 30 years.

The increase of CFC forcing in the 1980s represents about one-quarter of the total growth in radiative forcing by trace gases (Figure 3). Indeed the CFC contribution to growth of the greenhouse forcing now clearly exceeds that of CH₄ and N₂O combined. The CFC component of the greenhouse forcing has continued to increase, despite slowdowns for CFC-11 and CFC-12, because of rapid growth of other CFCs, as shown in Figure 3.

We note that there are at least two other changing greenhouse gases: ozone and stratospheric water vapor. Increases of tropospheric ozone and decreases of stratospheric ozone would both cause surface warming [Lacis et al., 1989]. However, the meager available observational data suggest that the dominant O₃ change, for greenhouse purposes, is a decrease in the upper troposphere and lower stratosphere [Lacis et al., 1989], especially at high latitudes in both hemispheres. Such an O₃ change would cause a negative radiative forcing (cooling) which would partially offset the warming by other greenhouse gases, at these latitudes.

Water vapor is the dominant greenhouse gas in the Earth's atmosphere. Change of tropospheric water vapor is considered to be a climate feedback, rather than a climate forcing, because the water vapor amount is determined by the climate, especially by the temperature. But stratospheric water vapor may be increasing as a result of the increasing abundance of atmospheric methane [Ehhalt, 1986]. This could cause a significant greenhouse warming; for example, a doubling of stratospheric water vapor from 3 to 6 ppm at altitudes between 0.08
20 and 50 km would yield \( \Delta T_o \) of approximately 0.06°C. Because adequate measurements are not available, we do not include either ozone or stratospheric water vapor changes in our results. Based on the discussion above, it seems likely that these two omissions are partially offsetting.

4. IMPACT OF PRODUCTION CONSTRAINTS IN 1970s

Prior to 1974 the production of CFC-12 and CFC-11 was increasing by about 8–11% per year (Figure 4a). After public concern was raised that CFCs may destroy stratospheric ozone there was a sharp break in the growth of CFC production, initially because consumers voluntarily turned to alternative products and, shortly thereafter, because legislatures in the United States, Canada and a few European countries passed laws restricting certain CFC uses.

If the growth rates of the early 1970s had continued to the present, the annual increments of greenhouse forcing by CFCs would now exceed that for \( \text{CO}_2 \) (Figure 4b). Of course, some slowdown in CFC growth probably would have occurred due to economic forces, even without environmental concerns. But it appears that CFC greenhouse forcing would now be much greater than it is, at least comparable in magnitude to that for \( \text{CO}_2 \), if there had been no public concern about possible adverse effects of continued CFC growth.

5. DISCUSSION

These results illustrate that CFCs are a large fraction, about one quarter, of current additions to greenhouse climate forcing. Thus, if the rate of release of CFCs to the atmosphere can be reduced, there is the potential for a major reduction in the rate of increase of the greenhouse effect. It should be noted that many of the proposed halocarbon substitutes for CFCs contain only fluorine, and, while posing no threat to the ozone layer, they may still contribute to an increased greenhouse effect. Assessment of the greenhouse impact of possible constraints on CFC emissions requires better data for the infrared absorption coefficients of various CFCs. These data are needed especially for compounds, such as CFC-22, which may be substituted for other CFCs.

If the growth of CFC production in the early 1970s had continued to date, the CFCs would now cause a much larger greenhouse effect, greater than that for \( \text{CO}_2 \). This illustrates that growth trends of greenhouse forcing are not inevitable; in this example decisions of consumers and legislators had a major impact on global climate forcing. This example also shows that, even if emissions are not eliminated, there is eventually a great difference between the greenhouse forcing with continued rapid growth of emissions and the greenhouse forcing with more constant emission rates. Of course, this conclusion applies for \( \text{CO}_2 \) emissions as well as CFCs. Trace gas scenarios that reach a greenhouse forcing equivalent to a doubling of atmospheric \( \text{CO}_2 \) in about 40 years, such as those of Ramanathan et al. [1985] and scenario A of Hansen et al. [1988], are based on an assumption of continued exponential growth. If rapid growth of emissions can be avoided, the
actual climate forcing may be much less than in these "business as usual" scenarios.

Finally, we emphasize that full analysis of greenhouse climate forcing requires better measurements of other atmospheric constituents. The biggest uncertainties appear to arise from the lack of adequate monitoring of ozone in the upper troposphere and lower stratosphere, and of water vapor in the stratosphere.

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