Atmospheric Fluorocarbons: Possible Effects of a Large Increase on the Global Climate

For the past two years there has been growing concern over the potential environmental effects of fluorocarbons (chlorofluoromethanes, primarily CF_2Cl_2 and $CFCl_3$) in the atmosphere. Originating entirely from man-made sources, these compounds are insoluble in water and are also chemically inert within the troposphere; therefore they are not subjected to the usual atmospheric removal processes that occur in the troposphere. Consequently, as indicated by Molina & Rowland (1974), their concentration seems likely to increase significantly in the atmosphere as a whole if anything like the present rate of injection is maintained.

Such a buildup in atmospheric fluorocarbon concentrations may modify the environment in either of two ways; first, these compounds may deplete the stratospheric ozone (O_3) concentration (Molina & Rowland, 1974) and, secondly, the fluorocarbons may have an appreciable warming effect on the climate (Ramanathan, 1975). The former modification concerns the effect on the chemical balance of the atmosphere, and this has been the subject of several studies. A detailed review of this effect is given by Rowland & Molina (1975). The latter modification, which concerns the effect on the thermal energy-balance of the earth–atmosphere system, will be summarized and elaborated upon further in the present paper.

The molecules CF_2Cl_2 and $CFCl_3$ have strong infra-red bands in the spectral region 8–12μm, and hence these fluorocarbons absorb and emit radiation in this spectral region. The fluorocarbons in the atmosphere would absorb the surface radiation (i.e. the radiation emitted by the surface of the Earth) and would emit radiation at the atmospheric temperatures obtaining in the layer where fluorocarbons are located. As, on an average, the surface is much warmer than the atmosphere, the fluorocarbons would absorb more radiation energy than they emit. Alternately stated, the fluorocarbon infra-red bands would cause a net reduction in the radiative energy emitted to space by the earth–atmosphere system, which implies that more of the infra-red radiation would be retained than otherwise within the earth–atmosphere system owing to the presence of the fluorocarbons. This enhancement in the amount of radiation that is retained within the earth–atmosphere system may tend to increase the global surface temperature.

Adopting a simple, one-dimensional model of the earth–atmosphere system, Ramanathan (1975) indicates that the global surface temperature may increase by about 0.9°K or °C (an increase which may be climatically significant) if the tropospheric concentrations of CF_2Cl_2 and $CFCl_3$ each increases to 2 ppb (by volume) from the present levels of about 0.1 ppb.* This analysis also suggests that the increase in the Earth's surface temperature is linearly related to the concentration of the fluorocarbons.

The strong sensitivity of the Earth's surface temperature to fluorocarbons in the atmosphere is due to a combination of two factors. First, the fluorocarbon bands are very strong, i.e. they have very large absorption coefficients. Second, the fluorocarbon bands are located in the 8–12μm region, and as in this region the atmosphere is relatively transparent (more than 75 per cent of the radiation emitted by the Earth's surface in this spectral region escapes to space, and for this reason this spectral region is referred to as the 'atmospheric window'), the atmospheric and surface temperatures are most sensitive to gases that have bands in the 8–12μm region.

In addition to the above-mentioned effect, the depletion of stratospheric ozone by the fluorocarbons may further affect the global surface temperature. Ozone absorbs the solar UV and visible radiation and also has a band in the 9.6μm region, and hence depleting the stratospheric ozone would alter the existing global energy-balance. To investigate the magnitude of this effect, surface temperature calculations were performed by employing the one-dimensional model of Ramanathan *et al.* (in press) and by adopting theoretical model predictions of Crutzen (1974) for the decrease in O_3 due to fluorocarbons. However, these calculations indicate a negligible effect on the surface temperature of the Earth due to ozone reduction resulting from addition of fluorocarbons at least to date.

The warming effect of fluorocarbons is similar to the well-known warming effect that an increase in the atmospheric CO_2 concentration may have on the global climate (*see* Schneider, 1975, for a recent review on the warming effect of CO_2). The atmospheric CO_2 concentration has been increasing over the past several decades, and it is suggested by Hoffert (1974) that the CO_2 concentration may double by the middle of the twenty-first century. Rowland & Molina (1975) suggest that the fluorocarbon concentrations may reach values of the order of 1 ppb during the twenty-first century if the present rate of atmospheric injection is maintained. It should be pointed out that the potential warming effects of increase in CO_2 and increase in fluorocarbons are additive, as the infra-red bands of CO_2 and fluorocarbons occur in different spectral regions.

The results discussed here are based upon one-dimensional models of the atmosphere that neglect several potentially important feedback mechanisms between surface temperature, cloud cover, ice cover, and circulation. The list of variables mentioned is by no means exhaustive. Due to the present lack of quantitative climatological data, it is not clear whether the inclusion of all of these feedback mechanisms will have an amplifying or an ameliorating effect on the situation as currently visualized. Accordingly it is suggested that the present results be considered as merely indicative of the potential effects of fluorocarbons on the global surface temperature.

* A referee comments: 'The calculations of Dr Ramanathan are based on a hypothetical 20-fold increase of fluorocarbons, but in fact, because of the currently-growing concern as to their effect on the [stratospheric] ozone layer, the increase is not now expected to be even 2-fold by the end of this century, because measures for curbing production and release of fluorocarbons are being globally imposed. Further, the calculations are made by following a very simple model, and the results of such one-dimensional models are very sceptically received by the scientific community.'—Ed.

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