The biggest greenhouse still intact

The CFCs are plainly headed for extinction, but those at this week's London conference should not on that account believe the greenhouse effect has been banished.

QUITE what last weekend's conference on the ozone inhibitors accomplished is a matter for conjecture, but there is a high chance that many of those present believed they were assisting decisively in the preservation of the familiar pattern of the Earth's climate. In some ways, of course, they were. The chlorofluorohydrocarbons, sometimes called chlorofluorocarbons or CFCs, are also greenhouse gases, with absorption spectra scattered throughout the infrared.

More intricate processes must also be considered. To the extent that increasing concentrations of CFCs may diminish the average concentration of stratospheric ozone, and because stratospheric ozone is an element in the determination of the Earth's radiation balance, there is also a possibility that the increasing concentration of the CFCs may undermine, in more subtle ways, the climate as we know it. But, also, it may not.

What we all need, in circumstances such as these, is some kind of yardstick. Here is one — the average external radiation flux reaching the Earth, roughly 236 W m^{-2}. At equilibrium, that is the power that enters the atmosphere with a temperature equivalent to that at the surface of the Sun; it is also the power that escapes from the top of the Earth's atmosphere. The yardstick, of course, is huge. Each 2-m patch on the Earth's surface must receive and then get rid of enough power to keep a person warm indefinitely.

The notion that CO_2 may influence this balance is antique; John Tyndall of Manchester seems to have been the first to draw attention to the possibility that the ubiquitous product of combustion may affect the radiation balance (*Phil. Mag.* **22**, 161; 1861). In reality, we now know that, were it not for CO_2, life on the surface of the Earth would not be possible. During the last glaciation, the concentration of CO_2 was low, as was the average temperature.

The surface of the Earth, with an average temperature of 288 K, emits radiation (mostly in the infrared) at a power of 390 W m^{-2}, more than half as great again as the incoming flux of solar radiation. There follows an exchange of energy within the troposphere, which we call weather, that evens out the temperature. If it were otherwise, the Earth would be like Mars, unable to sustain life at any season.

These are also the reasons why we have a troposphere, a layer of the atmosphere within which the temperature decreases with increasing altitude. The Earth's atmosphere is literally a blanket within which the passage of infrared radiation is everywhere impeded by absorption and re-radiation. The temperature gradient is a measure of how much of the energy is diverted to meteorological processes.

Lovelock's Gaia hypothesis notwithstanding, there is no simple reason why this lucky state of affairs should persist indefinitely. There are two ways of regarding the recognition that the CFCs are greenhouse gases (infrared absorbers) as well as destroyers of ozone. One is that their accumulation may increase the temperature uncomfortably, another is that they would have seemed a godsend to those who, just twenty years ago, believed that the then downward trend of temperature presaged another glaciation. Why not make a few million tonnes of the stuff and pump it into the atmosphere, they might have said?

This is where the yardsticks come in. First, CO_2 absorbs infrared radiation principally on the long wavelength side of 12 μm, while the CFCs in their role as infrared absorbers are active in regions scattered on the high-frequency side of that. In other words, they occupy what would otherwise be a window of wavelengths transparent to the relatively high-frequency infrared.

Second, molecule for molecule, CFC molecules are much more efficient absorbers than CO_2. So much should be self-evident: molecules of both kinds absorb in the infrared because they vibrate, but CFCs are more significantly polar molecules in which dipolar interactions with radiation must be more significant. Some CFC molecules are said to be 10,000 times as efficient as CO_2 molecules at absorbing infrared radiation of an appropriate frequency. So should not their accumulation in the atmosphere bring trouble?

The question is not whether, but how much. And the same is true for CO_2. It would be an assault on rational expectations to suppose that increasing the concentration of a greenhouse gas would make the greenhouse less effective, but Le Chatelier's principle would similarly lead one to expect abatements of simple expectations which are comparable in size but necessarily smaller.

Broadly speaking, most calculations carried out so far are in agreement with one other. A doubling of the concentration of atmospheric CO_2 (to a total concentration of 600 p.p.m.) would increase the surface temperature of the Earth by about 3° Centigrade, or by roughly six times as much as a doubling of the concentrations of the two principal infrared absorbers among the CFCs (see Ramanathan *et al. Rev. Geophys.* **25**, 1441; 1987). These estimates do not allow for the obvious feedbacks in the system, among which the more plentiful formation of clouds with increasing temperature must be conspicuous. (Ordinarily, clouds will cool, although there may be circumstances in which they do the opposite.)

The reason for worrying about CFCs as greenhouse gases is that their chemistry is different, perhaps significantly so. The production of CO_2 by combustion is now so great that its concentration would double every half-century, but the observed increase of concentration is only half as quick, presumably because of interaction with the oceans and the biosphere (which should on paper be luxuriating).

By contrast, some CFCs are believed to have half-lives measured in centuries, but on the assumption that they are removed from the atmosphere only by the photolytic processes that lead to the destruction of ozone, while their rate of release to the atmosphere has recently been increasing much more quickly than that of CO_2. In principle, CFCs could indeed be a bigger worry than CO_2 a few decades from now, which is why it is creditable that their removal has been given such attention.

Even so, there are some persisting doubts, of which the chief must be that CFCs may not be as chemically stable as reputed. What of the possibility that the great Antarctic ozone hole is a place where some of this material is washed out onto the ice-cap? But there is also some certainty that, whatever happens to the CFCs, the concentration of CO_2 will continue inexorably to increase, whatever is done to amend the Montreal Protocol at Helsinki in May. That, in the circumstances, is the greenhouse that matters.

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