Greenhouse Effect Due to Chlorofluorocarbons: Climatic Implications
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as an excursion. Genuine global paleomagnetic
excursions can only be confirmed by
evidence of spatial, temporal, and internal
consistency in replicate cores or sampled
sections from each of several areas. Until
such evidence is available, it is premature
to advocate the use of paleomagnetic
excursions as magnetostatigraphic horizons.

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Amherst College,
Amherst, Massachusetts 01002

References and Notes
3. A complete review of all reported paleomagnetic
excursions would require knowledge of the type of
sediment sampled, the method of sampling, the
signature of the excursion, the age and duration of
the excursion, and the age and duration of over-
lying and underlying normal intervals. Such a re-
view is not possible at present. Many reports are
available only as abstracts of papers presented at
meetings. In a few cases information has been dis-
seminated solely as “personal communications” to
other authors.
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8. R. Nakajima, K. Yaskawa, N. Natsubara, N.
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Abstract. The infrared bands of chlorofluorocarbons and chlorocarbons enhance the
atmospheric greenhouse effect. This enhancement may lead to an appreciable increase
in the concentration of these compounds reach values of the order of 2 parts per billion.

It has recently been suggested (1, 2) that concentration of chlorofluorocarbons (CF2Cl2, CFCl3, and CFCl4) may in-
crease by as much as 20 to 30 times the present-day value, 0.1 part per billion (ppb) by volume, if the present level of in-
jection into the atmosphere is maintained. The primary reason for this expected buildup seems to be the lack of any signifi-
cant tropospheric removal mechanisms for these compounds. In addition, Lovelock’s
(3) recent measurements indicate, the vertical distribution of temperature, H2O, and
constituents that have absorption bands in this spectral region. In order to estimate
the increase in the surface temperature (Ts), the reduction in F due to the infrared
bands of the chlorofluorocarbons and chlorocarbons is computed first. The pro-
cedure for the flux calculation is described only for chlorofluorocarbon bands since
the same procedure can be applied to the chlorocarbon bands.

For this analysis I consider only bands in the region 8 to 12 m, since these bands are
stronger by two orders of magnitude than bands located elsewhere in the in-
frared spectrum (5-8). Table 1 shows the band centers and intensities. Radiative
transfer within infrared bands can be conveniently formulated in terms of the total
band absorbance, A (reciprocal centimeters) (9, 10). This is the total spectrally in-
tegrated absorption by the band, and for the present analysis the bands are optically
thin (1f), so A can be written as

\[ A = SX \]  

where S is the band intensity and X is the amount of absorber. The formulation of F
in terms of A is given by Cess and Ramathan (9). Pertinent details of the flux
calculations are given in (12).

The model atmosphere—that is, the vertical
distribution of temperature, H2O, and clouds—is adopted from Rasool and
Schneider (13) and reflects the present-day globally averaged conditions. The mixing
ratio, qa, of CF2Cl2 and CFCl3, is prescribed by

\[ a = K(z); \quad 0 \leq z \leq 12 \text{ km} \]

where K is the attenuation coefficient, and z is the altitude with z = 0 denoting
the surface. H is the prescribed scale size, and a is the tropospheric mixing ratio (parts per billion, by volume) which has
been assumed constant. The shape of the mixing ratio profile given by Eq. 2 is consistent with the model predictions of
Cicerone et al. (2).

When Eqs. 1 and 2 are combined with

<table>
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<tr>
<th>Band</th>
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<tbody>
<tr>
<td>CF2Cl2, r1</td>
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It has recently been suggested (1, 2) that concentration of chlorofluorocarbons (CF2Cl2, CFCl3, and CFCl4) may increase by as much as 20 to 30 times the present-day value, 0.1 part per billion (ppb) by volume, if the present level of injection into the atmosphere is maintained. The primary reason for this expected buildup seems to be the lack of any significant tropospheric removal mechanisms for these compounds. In addition, Lovelock’s (3) recent measurements indicate, the vertical distribution of temperature, H2O, and constituents that have absorption bands in the spectral region 8 to 12 \(\mu\mbox{m}\) where the atmosphere is relatively transparent. Because of this relative transparency, the atmospheric and surface temperatures are most sensitive to constituents that have absorption bands in this spectral region. In order to estimate the increase in the surface temperature (\(T_s\)), the reduction in \(F\) due to the infrared bands of the chlorofluorocarbons and chlorocarbons is computed first. The procedure for the flux calculation is described only for chlorofluorocarbon bands since the same procedure can be applied to the chlorocarbon bands.

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where \(S\) is the band intensity and \(X\) is the amount of absorber. The formulation of \(F\) in terms of \(A\) is given by Cess and Ramathan (9). Pertinent details of the flux calculations are given in (12).

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As expected, the outgoing flux decreases with the addition of chlorofluorocarbons. Further, $\Delta F$ increases linearly with the mixing ratio since the band absorption increases linearly with the mixing ratio (see Eq. 1). The optically thin condition imposed on Eq. 1 restricts the applicability of Eq. 3 to values of $K$ less than 5 ppb.

The implications of Eq. 3 for the global climate can be examined by invoking the global energy balance condition (14), which states that on a global average the net incoming solar radiation should be in balance with the net outgoing terrestrial radiation. Since the net incoming solar radiation would not change with the addition of chlorofluorocarbons, the energy balance condition implies that $F$ has to be the same for both the perturbed and the unperturbed atmosphere. Recall that the $\Delta F$ given by Eq. 3 was calculated by fixing the atmospheric and surface temperature. Hence, it follows that the decrease in $F$ has to be compensated by an increase in the tropospheric and surface temperature. The decrease in $F$ can be related to an equivalent change in $T_s$ through the relation

$$\Delta T_s = -\frac{\Delta F}{dF/dT_s}$$

where $dF/dT_s$ is obtained by differentiating Budko’s (14) empirical formulation for $F$ with respect to $T_s$, which yields $dF/dT_s = -1.425$ watt m$^{-2}$ K$^{-1}$. The increase in $T_s$ obtained by substituting Eq. 3 in Eq. 4 is shown in Fig. 1. The surface temperature calculations were also performed using the detailed radiative-convective model described by Ramanathan et al. (15) and the results were identical to those shown in Fig. 1; this verifies the simpler procedure defined by Eqs. 3 and 4. Chlorocarbons also have strong infrared bands, and the contributions of the chlorocarbons to the increase in $T_s$ are listed in Table 2. If the addition of chlorofluorocarbons results in a net reduction in the atmospheric $O_3$ concentration, as has been predicted (1, 2), the results for $\Delta T_s$ will be slightly modified (16).

The increase in $T_s$ will be higher by about 15 percent if the coupling between $T_s$ and the amount of H$_2$O and solar absorption by H$_2$O is included. Including this effect, it is seen from Fig. 1 that the mean global surface temperature could, under the assumption of this simplified model, increase by as much as 0.9 K if the concentrations of CFCl$_2$ and CFCl$_3$ were each increased to 2 ppb. Such a concentration of chlorofluorocarbons is expected to be reached by the year 2000 if the present level of injection is maintained (1, 2). Further, Table 2 shows that the chlorocarbons can also have appreciable effects on $T_s$. The increase in $T_s$ may be amplified several times in the polar regions because of the positive feedback mechanism between ice cover, albedo, and surface temperature (17). This possibility underscores the importance of these results. However, the model presented here is a simplified one that neglects several atmospheric feedback mechanisms and all effects due to circulation. Hence, these calculations should not be considered as a definitive prediction of the response of the actual atmospheric system, but rather as indicative of the potential consequences for the climate of anthropogenic sources of chlorofluorocarbons.

The significance of these results can best be evaluated by referring to the papers by Bryson (18) and Schneider (19), which indicate that a surface temperature change of the order of 0.5 K may be sufficient to substantially alter some of the important climatic variables (rainfall and ice cover) in at least parts of the globe. The effect of chlorofluorocarbons and chlorocarbons on the chemical balance of the earth-atmosphere system is currently a subject of concern. The major conclusion of this report is that their effect on the earth’s thermal energy balance must also be given serious consideration.

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References and Notes
12. The optical thin condition requires that $\delta X/\delta T_s < 1$, where $\delta X$ is the bandwidth (9, 10). Person et al. (6) suggest that $\delta X < 0.001$ cm$^{-1}$ even for the strongest band $\delta T_s < 1$. Similar conclusions can also be reached fromPerson et al.’s discussion.
13. In the flux calculations the band absorptance is defined as $A = \delta X\delta T$ where the factor 2 accounts for the angular integration over isotropic radiation. The bands of chlorofluorocarbons and chlorocarbons are overlapped by the continuum band of H$_2$O and this overlap has been accounted for by multiplying the band absorptance by the transmissivity of the continuum band. The absorption coefficients for the continuum band of H$_2$O were obtained from K. J. Bignell, Q. J. R. Meteorol. Soc. 96, 900 (1970).
16. It has been indicated (1, 2) that increasing CFCl$_3$ and CFCI concentrations to 2 ppb would decrease O$_3$ by 10 percent. A 10 percent decrease in O$_3$, if distributed uniformly between 12 to 40 km, would decrease $T_s$ by about 0.07 K (17). Ramanathan et al. (15) consider a uniform reduction in O$_3$ within the stratosphere while, as pointed out by R. E. Dickinson (private communication), the fluorocarbons reduce O$_3$ mainly above 30 km. Preliminary calculations indicate that reducing O$_3$ above 30 km might lead to a slight increase in $T_s$.
A decade ago one of us (I) suggested that certain coccolid microfossils occurring in profusion in the then recently discovered cherts of the Late Precambrian Bitter Springs formation, central Australia, represented the earliest evidence of eukaryotic organisms in the evolutionary record of life. These fossil algae, which were found either as isolated cells or as loose aggregates of few to many individuals, were sometimes devoid of cellular contents, but often possessed an internal discrete structure excentrically or peripherally located with respect to the delimiting wall. Cytoplasmic remnants (interpreted as inner cell walls) surrounded the internal body in certain cells. The well-defined internal structures were interpreted as nuclear or organellar bodies (2-4), and a series of supposedly discrete taxa of both prokaryotic and eukaryotic algae was erected on the assumption that the presence or absence of these blebs and coagulated protoplasmic remnants constituted valid taxonomic characters (2, 3). This interpretation was seriously questioned by Awramik et al. (5), who emphasized that this taxonomy failed to take into account the variability of internal structure caused by partial degradation of blue-green algae.

Because of the importance of proper interpretation of Precambrian fossils, we undertook a new series of degradation experiments and found that the entire range of morphologic variation exhibited by a dozen taxa of coccolid algae (supposedly both prokaryotic and eukaryotic) from the Ellery Creek locality of the Bitter Springs formation could be duplicated in detail by partially degrading a unialgal culture of the chroococcacean species Chroococcus turgidus (Kütz.) Nägeli, demonstrating the variability of internal structure caused by partial degradation of blue-green algae.

The experimental procedure is simple. Unialgal cultures of cyanophytes were grown at room temperature in reduced light, on mineral agar slabs prepared with Bold's basal medium (7). As the cultures became stately, smears were prepared and stained with a dilute aqueous solution of safranin to enhance observation and photomicrography. A Chroococcus turgidus culture was selected for detailed examination because of its almost uncanny resemblance to described Bitter Springs fossils; however, other chroococcacean cultures exhibited a similar pattern of variation and degradation. This pattern has also been observed in algal mats growing in Massachusetts, Australia, and the Persian Gulf by Golubic and his colleagues (5, 6).

Figure 1, A to P, illustrates the range of morphologies which result from the partial degradation of a naturally morphologically varied population of blue-green algal cells. Diameter of individual cells of Chroococcus turgidus range from 6 to 20 μm; the average diameter is approximately 10 to 12 μm. The number of cells per packet varies from one to four, although unicells and dyads are by far the most common. The shape of the cells forming dyads is variable, ranging from spherical, gibbous, or hemispherical to flattened (Fig. 1, A to H). The number of sheaths per cell also varies, as does the degree of protoplasm degradation (6). Particularly important is the observation first made by Awramik et al. (5) that decompositional leaves the sheath intact, but conceals the protoplast into a globular remnant identical in every respect to the "nuclei" and "organelles" observed in Precambrian fossils (Fig. 10). The final product of this process is an empty sheath (Fig. 1P). In spite of the wide range of variation of the organisms pictured here, all represent a single species from a pure culture.

Comparison of the C. turgidus culture with coccolid fossils from the Ellery Creek locality of the Bitter Springs formation (Fig. 1, Q, DD, and GG) demonstrates a remarkable similarity between the two populations, which are separated in time by almost a billion years. It is no exaggeration to state that the Bitter Springs assemblage could easily represent the remnants of a single species of Chroococcus, a species having the same range of variability as C. turgidus. The Bitter Springs organisms in question have been assimilated to the following taxa: Globophycus rugosum, Bigeminococcus lamellosus, B. mucidus, Eozygion grande, E. minutum, Myxococcales reticulata, Glenobrydion aenigmatis, G. majorinum, Gloeodinopsis lamellosa, Caryophycinae pristina, C. tetras, and Eotetrahedron princeps. The last six taxa have been described as eukaryotes. All of the Bitter Springs taxa listed above can be found in three photographic thin sections.