Ozone and the greenhouse effect

SIR—Two global air-pollution problems — ozone depletion and the greenhouse effect — are linked in many ways. Most of the so-called source gases from which ozone-destroying radicals are produced in the stratosphere, or which otherwise intervene with the ozone photochemistry, contribute to the greenhouse effect. Indeed the anthropogenic changes in the ozone layer (particularly the altered vertical distribution) also add to the greenhouse effect. Conversely the greenhouse effect, particularly its CO_2 component, produces stratospheric cooling, which reduces the effect of CFCs in causing ozone depletion in the upper and middle stratosphere. Thus the feedback between ozone depletion and global warming is partly positive and partly negative.

The increase in the CO_2 content of the atmosphere (the biggest single contributor to the greenhouse effect) results from the still steadily rising use of fossil fuels. But not all the emitted CO_2 stays in the air; there is an almost equal partitioning between atmosphere and ocean which is governed by an equilibrium between the partial pressure of CO_2 in the atmosphere and in the surface water (determined by the temperature-dependent solubility of the gas). The partial pressure of CO_2 in sea water is linked to the total CO_2 ($CO_2 + HCO_3^- + CO_3^{2-}$). Because solubility increases with decreasing temperature, the tropical ocean is a source, and high-latitude oceans a sink, for atmospheric CO_2.

We must also consider biological processes. Phytoplankton assimilates CO_2 and can thereby lower its partial pressure in the surface water, leading to increased uptake of the gas from the atmosphere or reduced emission into the air. Dead organic matter or carbonate shells produced by organisms settle through the water column and transfer total CO_2 (as well as nutrients) to the deep sea.

Recent investigations show that increased ultraviolet-B (UVB) radiation (a consequence of a total ozone decrease) would hamper the photosynthesis of phytoplankton[1] in the ocean's surface layer, resulting in an increase of CO_2 partial pressure; the parallel rise in atmospheric CO_2 content leads to an enhancement of the greenhouse effect.

As our knowledge of the influence of increased UVB on phytoplankton photosynthesis is far from adequate, considerable work in this field is needed. There is the possibility of an adjustment by pigmentation and different plankton types may respond differently.

The continuous mixing of the ocean surface layer makes it difficult to calculate the reduction of photosynthesis that would result from an increase in UVB and the resulting change of CO_2 partial pressure in the exchange layer. The exposure of a given phytoplankton unit changes rapidly, which may reduce the influence of UVB because the penetration depth of the visible light needed for photosynthesis is considerably larger than that of UVB. Experiments with increased UVB in a watertank may therefore produce misleading results; but it is difficult to carry out such experiments in the open ocean.

Another difficulty in assessing quantitively the link between changes in the ozone layer and the CO_2 contribution to the greenhouse effect lies in the geographical diversity of the ocean surface conditions that are relevant to the ocean–atmosphere exchange processes. The high-latitude uptake and the low-latitude emission regions may be affected very differently by changes in the ozone layer.

It seems that the Antarctic (circumpolar) ocean plays an important role in this problem, because there the nutrients necessary for plankton growth (NO_3^-, PO_4^{3-}) are abundant due to strong vertical mixing with the deep sea. Although the Antarctic ozone hole is at present more or less confined to the continent, the related ozone loss around 60° S was already of the order of 10 per cent during the past 10 years[2]. It can therefore be assumed that UVB has already increased considerably in this region, which, subject to the uncertainties mentioned above, could lead to a significant reduction in CO_2 uptake from the atmosphere in the Southern Hemisphere.

Changes in photosynthesis and thus in phytoplankton growth may also influence the atmosphere by reducing the emission by plankton of certain chemicals, in particular dimethylsulphide which may affect cloud formation through the production of sulphate condensation nuclei by oxidation in the atmosphere[3]. The consequent reduction of the Earth's albedo would contribute further to an increase in atmospheric temperature. The uncertainties associated with this effect are, however, considerable.

Further information on three factors — inhibition of photosynthesis in phytoplankton by increased UVB levels in the open ocean, the influence of such a change on the CO_2 exchange with the atmosphere, and the geographical distribution of such changes — should allow us to estimate the influence of ozone depletion on the atmospheric CO_2 content and thus on the greenhouse effect. The problem clearly calls for close cooperation between biologists, oceanographers, atmospheric physicists and chemists.

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Pulsar evolution

SIR—Gravitational radiation may be controlling the evolution of the pulsar in supernova 1987A. If the reported 1968.63-Hz frequency[1] of the optical pulsations is the rotational frequency F of the neutron star[2], the rate of change of F resulting from emission of gravitational radiation driven by the CFS instability[3–5] may exceed, by a factor of $\geqslant 10^4$, the rate resulting from electromagnetic and accretion torques. Observational determination of the period derivatives could provide the value of the viscous-damping timescale τ_v. The frequency f_m of the most unstable mode may also be observable.

It is reasonable to assume that this neutron star was born with the maximum rotational frequency allowed. The possible presence of a companion in an 8-hour circular orbit of comparable angular momentum[1] would imply that the collapsing core of the supernova had too much angular momentum for the neutron star to accept. The sharpness[1] of the pulsation frequency indicates that viscous processes brought the star into uniform rotation. A limit can be placed[1] on the present evolution timescale of this frequency: $T_0 = |F/(\mathrm{d}F/\mathrm{d}t)| > 600$ years.

Relativistic neutron stars rotating close to their maxiumum rate $F(\max)$ are unstable to the growth of sinusoidal ($\exp(im\phi)$) modes driven by gravitational radiation[3–6]. All modes whose growth time τ_m is less than τ_v (typically $m = 3$–5) will be excited[7]. Their inertial frequency lies in the range $400\ \mathrm{Hz} < f_m < F$ and might also be detectable in the electromagnetic power spectrum[8]. Gravitational radiation at this frequency has an amplitude $h < 10^{-25}$, which is below current thresholds for detection[8]. This mode frequency is related to the rotational frequency by $f_m \approx m\,(F - F_m)$, where F_m, a decreasing function of m, is the rotational frequency required to excite mode m in the absence of viscosity. The loss of angular momentum through gravitational radiation generated by the dominant mode m leads to the slow-down rate

$$(\mathrm{d}F/\mathrm{d}t)/F_m = -(C_m/\tau_m)[M(\Delta R)^2/I] \qquad (1)$$

Here C_m is an approximate constant of order unity, the growth rate $1/\tau_m = (1/\tau_m')(F/F_m - 1)^{2m+1}$, and the mode amplitude ΔR is proportional to $\exp[(t/\tau_m)$

$- (t/\tau_v)]$. The constant τ'_m (proportional to $(GM/Rc^2)^{-(m+1/2)}$ (refs 9,10), where R is the neutron-star radius) is estimated to lie in the range 1.3×10^{-3} s ($m = 3$) to $3.4 \times 10^{+2}$ s ($m = 5$), by using the growth times calculated for the non-rotating models[11] and their angular-velocity dependence[12,13]. We expect that, at present, $\mathrm{d}^{n+1} F/\mathrm{d}t^{n+1} \approx (-2/\tau'_v)\, \mathrm{d}^n F/\mathrm{d}t^n$ for $n \geqslant 1$, where the approximately constant effective damping rate is $1/\tau'_v = 1/\tau_v - 1/\tau_m$.

The expectation that $\tau_m \ll \tau_v$ and the fact that $\tau_m \ll 1$ year if the neutron star was born with its maximum uniform rotation rate leads to the following evolutionary scenario. The amplitude ΔR of all such modes built up quickly (on a timescale of the order of τ_m) until limited by nonlinear effects to a value $\lesssim R$. The star then spun down rapidly (with constant ΔR but increasing timescale τ_m) until $\tau_m > \tau_v$. At present, $T_0 \gg 0.5$ yr $> \tau'_v$. If τ'_v were larger, the slow-down rate would exceed the observed limit, unless $\tau_v \gtrsim 10^3((\Delta R)_{\max}/R)^2$ yr. If the present temperature of the neutron star is about 10^9 K, we estimate that the viscous timescale τ_v is of the order of 10^6 s if dominated by neutron–neutron scattering (in the absence of magnetic effects)[14–16].

In the phase through which the neutron star is presently evolving,

$$\left(\frac{F(t)}{F_m} - 1\right)^{-2m} \approx \left(\frac{F(0)}{F_m} - 1\right)^{-2m} + \left(\frac{mQ_m\tau'_v}{\tau'_m}\right)[1 - \exp(-2t/\tau'_v)] \qquad (2)$$

Here, Q_m is an approximate constant of the order of $((\Delta R)_{\max}/R)^2$. Although this evolution depends on both the gravitational-growth and the viscous-damping timescales, its rate is controlled mainly by the latter, as the former is somewhat greater at present. From equation (1) we note that if $\tau_m \approx 0.1$ yr now, the present limit on the slow-down time T_0 places an upper limit of ~ 0.01 on $\Delta R/R$. Should an evolution of the frequency similar to that predicted by equation (2) be observed, a good estimate of the value of τ_v, which is poorly known at present, could be derived.

All other competing sources of spin-down, such as the usual one due to electromagnetic torques, yield a slow-down time T_0 of at least 10^7 yr. This model-independent value (assuming a moment of inertia $I \approx 10^{45}$ g cm^2) follows from the limit of $\dot{E} \leqslant 3 \times 10^{38}$ erg s^{-1} on the total power emitted by the pulsar in the form of electromagnetic radiation or charged particles, obtained from the bolometric luminosity of the supernova. Accretion torques provide a source of spin-up. If the mass accretion rate is constrained by the Eddington limit (which happens to match the above limit on $\dot{E}$), the accretion timescale is then also at least 10^4 times greater than the observed limit on T_0.

Even such a high accretion rate limits the surface value, B, of the magnetic dipole field to no more than about 10^9 G. A stronger magnetic field (or a lower accretion rate at this field value) would lead to the expulsion of the accreting matter beyond the light cylinder. But for a free pulsar the same limits on $\dot{E}$ also give[1,17] $B < 10^9$ G. If the values of B and the accretion rate $\dot{M}$ are such that the Ghosh–Lamb radius is comparable to the light cylinder radius (2.4×10^6 cm) — for example, if $\dot{M}$ is near the Eddington value and $B \approx 10^9$ G — it is possible that the pulsar turns on and off intermittently. This could explain the lack of pulsations in later observations[1]. The optical emission could arise in the free pulsar phase or in the X-ray (accreting) pulsar phase. Finally, our rotational interpretation of F requires the mean density of the star to be at least five times that of nuclear matter.

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Radiation limits

Sir—If, as John Dunster dubiously argues[1], "latency" is to be regarded as a crucial factor in setting permissible radiation doses, then standards should be set to protect the youngest members of society, as they have the longest latency period and the maximum 'detriment'. Unfortunately, the youngest are also the most radio-sensitive. Thus the excess relative risk of all cancers except leukaemia for those survivors who were under 10 years old at the time of the atomic bombings is about eight times higher than it is for those who were 35 or over[2]. Furthermore, the doubling dose for leukaemia in children under 10 at the time of the bombings is only 80 mSv. Exposure *in utero* may be even more hazardous; data from obstetric radiography indicates a doubling dose for all childhood malignancies as low as 10 mSv[3,4].

The logic of such observations is severely to tighten public dose limits. The International Commission on Radiological Protection (ICRP) has recommended that lifetime exposure should not exceed 1 mSv per annum, but the UK legal limit is still 5 mSv. The National Radiological Protection Board has recommended 0.5 mSv per annum[5], but has since increased its estimate of cancer risk for the general population to 4.5 times the ICRP figure of 1 death per 10,000 per 10 mSv[6]. In the United States the public dose limit has been 0.25 mSv for the past 10 years. Dunster's call for a 'measured response', and ICRP's reluctance to revise its own system of dose limitations[7] are not supported by the scientific data. A legal limit of 0.2 mSv per annum is urgently needed.

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Red Sea salinity

Sir—Thunell *et al.*[1] estimate the palaeo-salinity of the Red Sea for three different sea-surface levels: 80 m, 120 m and 150 m below the present-day level, based on strait-dynamics considerations[2], and show that their results compare favourably with palaeo-salinity estimates based on δ^{18}O of foraminifera. But they fail to take into account the fact that below a certain sea level, there will be a change in the sill responsible for flow control.

The strait of Bab-el-Mandeb, connecting the Red Sea with the Gulf of Aden (insert in figure), is a long strait, in the dynamic sense[3], and contains two main sills (see figure); the Hanish sill, at about 13°40′ N, is shallow and wide, whereas the Dumeira sill, at about 12°50′ N, is deeper but narrower. From strait-dynamics calculations[2], taking width and depth each with its prescribed weight, it is readily shown that at the present-day sea level, the Dumeira sill dominates the flow, and the Hanish sill has only a secondary effect on flow control.

Thunell *et al.* do not take into account that, with a sea-level drop of 70 m or more, the Hanish sill would take over the