observations showed only low-level PSCs within the polar vortex (P. McCormick, personal communication), agreeing with National Meteorological Center satellite retrievals which show that the polar stratosphere at 20 km was 10–15 °C warmer in September 1988 than in September 1987.

The increase in dynamical activity in the sub-polar stratosphere is undoubtedly responsible for the weakened ozone depletion this year, but according to the chlorine chemical theory at least two mechanisms may be involved. First, the presence of large-scale eddy activity in late winter increases the polar stratospheric temperature by increasing the adiabatic descent of air over the pole. This reduces the probability of PSC formation and therefore reduces chlorine production and odd-nitrogen removal. Second, a high level of sub-polar dynamical activity means that mid-latitude air is frequently entrained into the vortex, bringing in more odd nitrogen. Again the result is a reduction in active chlorine. The important point is that both of these mechanisms act towards the same end, a reduction in the level of active chlorine. Thus the weak 1988 Antarctic ozone hole shows how sensitive this phenomenon is to year-to-year changes in dynamical activity despite the steady increase in stratospheric halocarbons. □

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Gaia hypothesis

Can plankton control climate?

Tony Slingo

ONE of the more unusual contributions to the climate-change debate last year was the suggestion[1] that oceanic plankton exert an important, and perhaps controlling, influence on climate. The mechanism relies on the indirect effect, via dimethylsulphide (DMS) emissions, that plankton could have on cloud reflectivity. The authors, Charlson, Lovelock *et al.*, proposed that the feedback involved could contribute to Lovelock's Gaia hypothesis, by which the biosphere can maintain the climate within tolerable limits[2,3]. On page 441 of this issue[4], Schwartz reports that a search for similar climate effects from man-made sulphur dioxide reveals no such influence. Because sulphur dioxide should operate in the atmosphere in a similar way to DMS, this null result undermines the effect proposed by Charlson *et al.*, which is the only testable version of the Gaia hypothesis so far put forward.

In proposing their mechanism[1], Charlson *et al.* noted that plankton excrete DMS which is liberated into the atmospheric boundary layer to become oxidized to form sub-micrometre sulphate particles. These constitute the main source of the hygroscopic nuclei on which cloud drops form. Because the concentration of such cloud-condensation nuclei over the remote oceans is much lower than over land, changes in their number can affect the number of drops present in a cloud for a given liquid water content, and hence the mean size of the drops. This in turn alters the amount of solar radiation reflected back to space by the clouds and thereby affects the climate, because it is the absorption of solar radiation which provides the energy input to the climate system. Charlson *et al.* argued that this chain represents a biogeophysical feedback between plankton and climate, because changes in climate would influence plankton population, which in turn would modulate the climate change, and so on.

Schwartz points out in this issue[4] that global man-made emissions of sulphur dioxide are twice those from marine plankton. If Charlson *et al.* are correct, this suggests that anthropogenic emissions are an even more potent factor in climate change. Furthermore, because the anthropogenic sources are predominantly in the Northern Hemisphere and have appeared only during the past century or so, one would expect to see brighter clouds in the Northern Hemisphere (because of the enhanced nucleation and thus smaller drops) as well as a cooling relative to the less polluted Southern Hemisphere, over this period. Schwartz demonstrates that neither of these predictions are borne out by the data he has examined. He concludes that man has not significantly affected climate by his sulphur emissions, which means that the effect of plankton must be even smaller.

The satellite albedo data used by Schwartz certainly show no evidence for an enhanced contribution from clouds to Northern Hemisphere albedos. However, his cloud component of the total albedo (which is essentially the same as the shortwave cloud radiative forcing diagnostic introduced by Ramanathan[5]) is determined not only by the cloud brightness but also by the cloud amount. The brightness is influenced by the column-integrated liquid-water content as much as by the mean drop size. Differences between cloud amounts and liquid-water contents in the two hemispheres could easily mask the effect of any differences between the mean drop sizes, giving a misleading signal in the overall albedo. By the same token, changes in these and other quantities over the period of the temperature record could have combined to minimize the inter-hemispheric differences in cloud forcing and climate change.

Despite these reservations, Schwartz's paper is a notable attempt to subject the DMS mechanism to observational test. Given the importance of cloud feedbacks in model estimates of climate change[6,7] and the central role of cloud forcing to the mechanism, there is an urgent need to elucidate the factors which control both the amount and radiative properties of clouds. The current Earth Radiation Budget Experiment and International Satellite Cloud Climatology Project are thus timely, providing information on the radiation budget and cloud forcing[8] and on cloud amounts and radiative properties[9], respectively. But information on cloud liquid-water contents and mean drop sizes are also required. Techniques to estimate these from satellite data are available and should be applied to complete the picture. More observations are also needed (probably from airborne instruments) to establish more clearly the link between cloud condensation nuclei and mean drop size.

Many scientists are understandably reluctant to take the Gaia hypothesis seriously, and by association the mechanism proposed by Charlson *et al.*. This is unfortunate, because these authors have raised important questions regarding our understanding of the climate system. As with nuclear winter, it is not necessary to believe in a hypothesis to be stimulated by it to tackle *bona fide* problems which may have been neglected. The stimulus of nuclear winter led to practical work on the treatment of aerosol transport, scavenging and radiative transfer in numerical models, as well as giving insights into the importance of radiative–convective coupling. It is to be hoped that the papers by Charlson *et al.* and by Schwartz will provide a similar service in provoking work on the links between biological systems, atmospheric chemistry, cloud physics and climate. □

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