deducing evolving carbon fluxes during the past 15 years.

Three independent tracer approaches constrain rates of CO₂ uptake by the oceans. One approach is based on the uptake rate by the oceans of ¹⁴CO₂ generated by nuclear bomb tests, on the difference in partial pressures of CO₂ between the atmosphere^{4,5} and the surface ocean, and models of ocean mixing⁶.

A second method examines the rate of change of the stable-isotope ratio of carbon in the atmosphere and sea water⁷⁻⁹. Burning of fossil fuel CO₂ (with ¹³C/¹²C ~ -28 parts per thousand, relative to the PDB-1 standard) and its invasion into the oceans is causing the isotope ratio of total dissolved CO₂ in surface sea water (¹³C/¹²C ~ +2 parts per thousand) to decrease.

The third technique¹⁰ is to measure the CO₂ concentration and the ¹³C/¹²C ratio of atmospheric CO₂ as a function of latitude, in order to partition the total uptake rate between the oceans and the land biosphere (CO₂ uptake by the land biosphere discriminates against the heavier isotope). All three CO₂ tracer approaches estimate oceanic uptake at about 2 Gt C yr⁻¹ for various periods between 1980 and 1994.

On land, recent history is more complicated. The global net CO₂ uptake by the land biosphere estimated by Keeling *et al.*¹, 2.0 Gt C yr⁻¹ for 1991-94, is in good agreement with that of the last tracer method¹⁰, 2.6 Gt C yr⁻¹ for 1992-93, and both these approaches indicate that the land biosphere was an important CO₂ sink during the early years of the current decade. But in contrast, several studies¹¹ suggest that between 1980 and 1989 the biosphere was roughly in balance.

The CO₂ mass balance during this earlier period is constrained by the modelled estimates of oceanic CO₂ uptake outlined above, as well as studies of the O₂/N₂ ratio of air in the firn (the partly compacted layer of snow) at the surface of polar glaciers¹². According to these results, fossil fuel emissions during the 1980s (~5.4 Gt C yr⁻¹) were balanced by the atmospheric increase (3.2 Gt C yr⁻¹) and oceanic uptake (~2 Gt C yr⁻¹). By the 1991-94 period, emissions had risen to about

6 Gt C yr⁻¹, ocean uptake remained at about 2 Gt C yr⁻¹, and the atmospheric increase fell from ~3 to ~2 Gt C yr⁻¹. Tracer studies summarized above indicate that the global land biosphere took up the imbalance, ~2 Gt C yr⁻¹.

While tracer studies suggest that the global land biosphere was nearly in CO₂ balance during the 1980s, they nevertheless indicate that some areas were a net sink. A largely equatorial CO₂ source from deforestation was compensated for by sequestration of CO₂ elsewhere. If deforestation has added 1.6 Gt C yr⁻¹ of CO₂ since 1980 (ref. 13), then the rest of the land biosphere took up about 1.6 Gt C yr⁻¹ during the decade of the 1980s and 3.6 Gt C yr⁻¹ between 1991 and 1994. Carbon-isotope tracer modelling¹⁰ agrees with the O₂/N₂ measurements of Keeling *et al.* in indicating net CO₂ uptake of ~3 Gt C yr⁻¹ by the land biosphere above 30° N, and measurements of the CO₂ uptake rate in a northern temperate forest are consistent with such rapid uptake¹⁴. Plausible causes include CO₂ fertilization of the land biosphere^{15,16}, nitrogen fertilization resulting from industrial emissions¹⁷, and warmer temperatures and increased precipitation¹⁸ (but see ref. 19 for a contrary view).

During the past year or so, the rate of atmospheric CO₂ rise has accelerated and is once again comparable to the average rate during the 1980s (P. Tans, personal communication). This observation emphasizes the dynamic nature of the carbon cycle. Although ocean CO₂ uptake does fluctuate, the land biosphere is probably the main cause of variability, some of which appears to be caused by El Niño events⁴. More generally, land biosphere variability must reflect changes in the small imbalance between photosynthesis and respiration, with their gross fluxes of about 100 Gt C yr⁻¹. Variability in that imbalance presumably relates to changes in climate, but the nature of the link is unknown. □

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DAEDALUS

Snow growing

GLOBAL warming poses several kinds of threat. Perhaps the most ominous is the rising of sea level from melting ice and snow. Much of the world's water is held as 'eternal snows' on the tops of high mountain ranges. If those snows stop being so eternal, there will be trouble.

A mountain top, says Daedalus, is a good place to store frozen water. The cold of altitude keeps it below zero; snow precipitates on it from the clouds that sweep over it, and piles up to even higher altitudes where the temperature is colder still. However, the stored snow has two ways of escape. It can evaporate in the sunlight, and it can descend under gravity — either rapidly as an avalanche, or slowly and viscously as a glacier. Daedalus now plans to frustrate both modes of escape.

During the Second World War, there was a scheme to adapt a North Atlantic iceberg as an aircraft carrier. Natural ice is rather weak; so the boffins planned to freeze their own iceberg, from water with a little wood-pulp in it. The resulting fibre-reinforced ice was admirably tough, and also melted much more slowly. Innumerable fibres protruded from the melting surface, forming a blanket which impeded heat transfer.

So, says Daedalus, what we need is some way of launching fine fibres into the wind traversing the Andes, the Himalayas and the other snowy mountain ranges. Once their snow is reinforced with fine fibres, it will be much more eternal. It won't creep like a glacier, nor tumble like an avalanche; and its insulated, whiskery surface will evaporate far more slowly. Less than one per cent of fibre has a dramatic effect on the toughness of ice or snow. Even so, millions of tons of fibre will be needed.

Daedalus's bold idea is to make it from our growing mountain of plastic waste. Long-chain polymers easily form fibres; some process of air-blown melt-spinning or violent pulverization should give a suitably fine, feathery, fibrous dust. Released into the air upwind of the mountains, it will be incorporated into the snowfall at the summit. But volcanic dusts are often blown halfway round the world on the wind. So rather than transporting the powder at great expense to the mountainous regions, Daedalus hopes to release it at the site of manufacture. Modern meteorology may be able to identify just that favourable wind which will carry it from the fibre factory to the far mountain of its destiny. The world's plastic waste will be put to good use, the sea level will stop rising, and the high eternal snow will rise instead. Mountaineers will tread more surely on its toughened surface.

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