should be the same as those in the Sun.

However, all other meteoritic and planetary materials analysed have $^{18}O/^{16}O$ and $^{17}O/^{16}O$ ratios that are several per cent greater than the calcium–aluminium-rich inclusion values[7], implying that this matter has been enriched in the heavy isotopes (in roughly constant $^{18}O/^{17}O$ ratios) by passing through the inner part of the accretion disk. This matter could have been returned to the colder, planet-forming regions by an X-wind process, involving an outflow of matter constituting as much as several tenths of a solar mass[1]. Photochemical self-shielding by O_2 has been considered previously in the context of earlier models of the solar nebula[8,9].

Photochemical self-shielding may also be important in the photodissociation of N_2, which is isoelectronic with CO. If nitrogen anomalies were caused by isotopically selective photodissociation of N_2 molecules, there must have been a chemical trap for the ^{15}N-enriched atoms; candidate traps include H_2 to form NH and more complex molecules, and metal grains to form nitrides.

A direct test of the self-shielding model is being carried out by the Genesis mission, which will return a sample of solar wind to Earth for isotope analysis.

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Atmosphere science

Clean air slots amid atmospheric pollution

Layering in the Earth's atmosphere is most commonly seen where parts of the atmosphere resist the incursion of air parcels from above and below — for example, when there is an increase in temperature with height over a particular altitude range. Pollutants tend to accumulate underneath the resulting stable layers[1–5], which is why visibility often increases markedly above certain altitudes. Here we describe the occurrence of an opposite effect, in which stable layers generate a layer of remarkably clean air (we refer to these layers as clean-air 'slots') sandwiched between layers of polluted air.

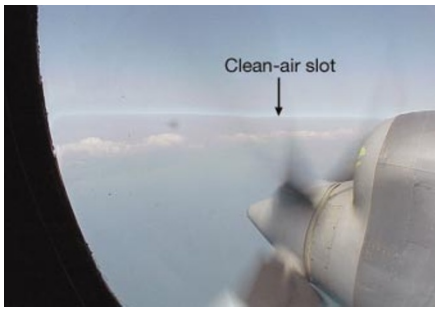

Figure 1 Clean-air slot near Maputo, Mozambique, photographed on 24 August 2000.

We have observed clean-air slots in various locations around the world, but they are particularly well defined and prevalent in southern Africa during the dry season (August–September). This is because at this time in this region, stable layers are common and pollution from biomass burning is widespread.

We were readily able to identify clean-air slots from our research aircraft by looking towards the horizon as our altitude changed. Visibility was very limited in the polluted air above and below a slot, but increased suddenly and markedly upon entering the clean air. The clean-air slot thus appears momentarily as a thin, white, horizontal layer (Fig. 1).

In 26 flights over southern Africa during a period of 6 weeks, we saw 12 well defined clean-air slots. These were most commonly encountered in the morning, a fact that is probably explained by heating of the ground during the day, with a resulting increase in convective activity which causes stable layers to dissipate. During the night, as the land cools, stable layers and clean-air slots can be re-established.

All of the clean-air slots occurred within narrow regions a few hundred metres thick, where the atmosphere was stable and the air was very dry; they were generally located about 2 km above sea level. The particle concentrations contained in these slots were only about one-third of those measured in the polluted air above and below them.

In southern Africa, pollution beneath these clean-air slots is produced as a result of widespread biomass burning, and is augmented by industrial emissions. The polluted air above the slot probably derives from pollutants that have been carried up by convective activity in regions that are not dominated by stable layers. Once in this higher band, the polluted air can presumably be transported horizontally over large distances.

Stable layers are common in southern Africa during the dry season, because of the occurrence of atmospheric subsidence[6]. If the subsiding air originates high in the troposphere, it will generally be clean and dry. The subsiding air thus has both of the principal attributes of a clean-air slot. In addition, the dryness of the air will enhance visibility, because the particles will be devoid of condensed water[7]. The stability of the layer of subsiding air to intrusions of polluted air from both below and above will cause it to retain its pristine state. The horizontal transport of layers of clean marine air may also have been responsible for some of the clean-air slots that we observed.

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COMMUNICATIONS ARISING

Climate change

Terrestrial export of organic carbon

Dissolved organic matter in the oceans represents one of the biosphere's principal stores of organic carbon. A large proportion of this matter is drained from the continents — particularly from northern peatlands, which contain 20% of the global soil carbon[1]. Freeman *et al.*[2] have suggested that rising temperatures may enhance this transport of dissolved organic carbon (DOC) from peatlands to the oceans. We argue here that warming can affect DOC export in different ways, depending on whether it is accompanied by increased or decreased precipitation. An alteration in the rate of relocation of organic carbon from the continents to the oceans cannot therefore be predicted on the basis of temperature change alone.

The increase in DOC transport proposed by Freeman *et al.*[2] is based on an observed 65% increase in DOC concentrations in British lakes and streams during the 1990s, when the mean air temperature was 0.66 °C higher than during the three preceding decades (there was no reported increase in temperature during the 1990s that was concomitant with the increasing DOC), and on a positive relationship between experimentally manipulated temperatures and DOC leakage from peat soil.

However, we question whether this is sufficient evidence for a simple and direct relationship between increased temperature and increased export of DOC. Although there are broad patterns in DOC concentration in rivers between climatic zones[3], the

variation is related to hydrology as well as to biological productivity, and to how productivity is balanced by decomposition. Hence, despite lower temperatures, DOC concentrations can be higher in rivers in taiga regions — coniferous forests of high northern latitudes — than in rivers in wet tropical and temperate regions[3].

The principal variable that affects the yield of DOC from catchments in the Northern Hemisphere is the proportion of the catchment that constitutes wetland[4]. Variations between and within sites can largely be explained by hydrological variables. This is illustrated by the substantial increase in DOC concentrations in lakes and streams in Sweden during the 1970s and 1980s, despite a reduction in annual temperatures (and in contrast to the British data[2]). This effect has been explained by the increased precipitation and runoff in these locations[5,6], which are typical of the northern boreal region where a large proportion of global peat carbon is stored.

An increase in DOC concentrations was found in headwater streams in the experimental lakes area in northwestern Ontario, where increased temperatures were accompanied by dryer conditions. However, an increase in temperature of 2 °C in association with decreasing precipitation in this area resulted in a drop in DOC concentration in the lakes (and therefore in rivers downstream of the lakes), because dryer conditions led to longer retention times and thus to increased DOC removal by within-lake processes[7]. Such in-lake processes, which are dominated by microbial and photochemical decomposition, effectively degrade DOC in northern lakes with high concentrations of humic substances[8,9].

These examples show that temperature is not in itself a satisfactory predictor of DOC concentration or of continental export of DOC. Freeman *et al.* discuss DOC export on the basis of concentration and do not consider transport. An increase in concentration does not necessarily result in increased river transport, which is the product of concentration and discharge. The authors claim that the increased DOC concentrations they find in British rivers were not affected by river discharge, even though river discharge can often explain variations in DOC export[10].

The export of organic carbon from land affects freshwater environments as well as coastal areas, and it may also contribute greatly to the vast store of organic carbon in the oceans. It is evident that several interacting factors determine the outcome of climate effects on DOC export, and that correlative experimental studies that base their conclusions on temperature or any other single parameter may be overly simplistic.

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Freeman et al. *reply* — Tranvik and Jansson question our proposed link between temperature and DOC export, on the basis of spatial patterns of DOC concentration, confounding effects of hydrology, and apparently conflicting observations from other regions.

In response, it is first necessary to distinguish factors that control spatial variation between sites from those that determine temporal variation at an individual site. For example, a catchment wetland area is unlikely to change on a decadal timescale. Tranvik and Jansson also comment that DOC is higher in cooler regions, where low decomposition rates allow peat to accumulate. In fact, this spatial relationship between temperature and decomposition is fully consistent with our proposed mechanism for peatlands in the United Kingdom, because rising temperature at an individual site will increase peat decomposition, leading to greater DOC export.

We agree that hydrological changes can significantly affect DOC export. It is useful here to consider DOC export as a two-stage process: DOC is first produced in the soil and is then transported from the soil to the drainage network. The transport stage is controlled by discharge, so hydrology influences short-term fluctuations in riverine DOC export. However, long-term changes in discharge, unless accompanied by changes in DOC production, cannot generate a sustained trend in DOC flux. Flowpath changes may affect DOC supply by altering the proportion that is adsorbed onto mineral horizons, but such changes are probably unimportant in peatlands.

The primary hydrological factor that influences peatland DOC production, and hence long-term trends, may therefore be soil moisture, because greater soil aeration under dryer conditions will increase decomposition (for example, through greater enzymatic activity[1]). This could enhance DOC production over and above the temperature-induced increases that we have observed experimentally. Soil moisture is influenced by both rainfall and temperature and, although temperature has increased in the United Kingdom in recent decades, regional rainfall patterns have been more heterogeneous, with few trends in annual means. In some areas, however, increases in winter/summer rainfall ratios[2] may have contributed to DOC increases by reducing soil moisture in summer, with increased washout in winter.

Tranvik and Jansson note that warmer and dryer conditions in northwestern Ontario led to reduced DOC concentrations, partly through enhanced in-lake removal as a result of longer residence times[3]. Soils in this region are thin, and recently decomposed plant material provides a substantial and relatively labile DOC source[4]. DOC from blanket peats in the United Kingdom is older and more recalcitrant, and input–output data for British upland lakes, which generally have lower residence times, suggest that in-lake removal is minimal[5]. Similar DOC trends at our stream sites also argue against in-lake factors. Furthermore, DOC from peat uplands persists into the lower reaches of UK rivers[6], which is consistent with observations that the riverine DOC that enters the oceans largely comprises old, recalcitrant compounds[7].

We agree that terrestrial organic carbon exports are important for both freshwater and oceanic environments, and that climate change may significantly affect these exports. We contend that increasing temperatures, by raising decomposition rates, will increase peatland DOC export, but recognize that other factors, such as hydrological changes, may also be important. Given the ongoing debate about the direction and magnitude of rainfall projections made by the International Panel on Climate Change, future climatic impacts on DOC export remain uncertain.

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