planetesimal systems form and evolve quite differently than our solar system.

In the most recent extrasolar planet "discovery," Terebey and her collaborators purport to actually image a candidate planet with the Hubble Space Telescope (*13*). The key to interpreting the faint point of light they observe as a planet is knowing the distance—if it is very far away, then it could be a background star. Terebey's group finds this distance by claiming that the planet is physically associated with a stellar system of known distance, as evidenced by a streak of dust-scattered light connecting the two.

Their interpretation is bold because anyone who has photographed the sky in regions that are rich in star formation finds all sorts of filaments and arcs of dust that are produced for a variety of reasons, none associated with planets. Background stars can peek out from behind the dust, but Terebey's group claims only a 2% chance of seeing a background star in their field. Nevertheless, a background star remains as a viable alternate interpretation.

Even if the object lies at the distance claimed, it is also possible that the candidate planet is a star whose light is dimmed by foreground dust. One fascinating case in point is the companion to the binary star HK Tauri. At the June meeting of the American Astronomical Society, Stapelfeldt and Koresko revealed that what was previously considered a star is actually a tiny reflection nebulosity created by a young star that itself is completely hidden by foreground dust (*14*).

A more critical problem with the planet interpretation is that the streak of dust connecting the candidate planet to the stellar system coincides with a ridge of dense gas along the edge of a stellar outflow cavity mapped by Hogerheijde (*15*). Therefore, it seems more likely that the arc is created by a well-known stellar phenomenon rather than the slight gravitational influence of an ejected Jupiter. The latter point has been tested by Mac Low, Bate, and Burkert (*16*), who find that a Jupiter-mass planet cannot produce a trail of material as large as the one observed. In summary, a key piece of evidence required to support the planet interpretation—its spatial association with the young binary stars to the northwest—is lost.

The Terebey group plans to obtain a spectrum of the object, which should pin down its physical nature. Astronomers will certainly be finding new extrasolar planets in the near future, but in this case the existing evidence suggests that planet mania has struck once again.

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PERSPECTIVES: THE GLOBAL CARBON CYCLE

In Balance, with a Little Help from the Plants

Pieter P. Tans and James W. C. White

Our industrial civilization needs energy and lots of it. The major source of that energy has been coal, oil, and natural gas. What has happened so far to the carbon dioxide emitted into the atmosphere as a result? About half remained airborne, contributing to the concern about man-made climate change, but where did the rest go?

It is overwhelmingly clear from the geologic record of trace gas concentrations preserved in ice and firn that the atmospheric concentration of CO_2 is much higher now than during the past hundreds of thousands of years (*1*). Its rise has been especially steep during the latter half of the 20th century. These facts continue to surprise some people who point out that the annual rate of CO_2 emission from fossil fuel burning is less than one-tenth that of natural processes such as global photosynthesis or the exchange of CO_2 between the atmosphere and the oceans. Furthermore, the oceans contain 50 times more carbon than the atmosphere. How could there possibly be a problem?

There are three reservoirs of carbon in constant exchange with each other: the atmosphere, the oceans, and the terrestrial biosphere, consisting of plants and soils. The oceanic and terrestrial reservoirs are in near equilibrium or near steady state with the atmosphere, with enormous fluxes of carbon moving to and from the atmosphere, in each case nearly canceling each other. However, it is the small non-canceling ("net") portion that causes atmospheric CO_2 to increase or decrease. For decades, the emissions from fossil fuel burning have been substantially larger than either the net exchange with the oceans or the net difference between photosynthesis and respiration.

Exchange with the really large geological reservoirs, such as limestone, is so slow that for thousands of years the carbon added to the atmosphere will stay confined to the three "mobile" reservoirs mentioned above. Neglecting the biosphere, we can calculate that, once steady state has been restored after 1000 years or so, 85% of today's emissions will have been added to the oceans and 15% to the atmosphere. Worse, the atmospheric portion will increase with continuing emissions. Thus, we are either committing our Earth "permanently" to enhanced greenhouse forcing or ourselves to never-ending global management of carbon stocks.

Early estimates of huge losses of carbon from plants and soils due to biomass burning and deforestation (*2*) have recently given way to the idea of a terrestrial biosphere nearly balanced (globally) with respect to carbon. From a climate management point of view, this is good news. Apparently, we are getting an assist from plants. This change in thinking was forced most strongly by atmospheric data. There are now seven independent lines of evidence.

First, carbon-cycle modelers have always had difficulty accommodating high terrestrial emissions in their model oceans calibrated with ^{14}C and tritium from nuclear tests and with chlorofluorocarbons (*3*). The smaller than expected north-south gradient of atmospheric CO_2, combined with data on the partial pressure of CO_2 in

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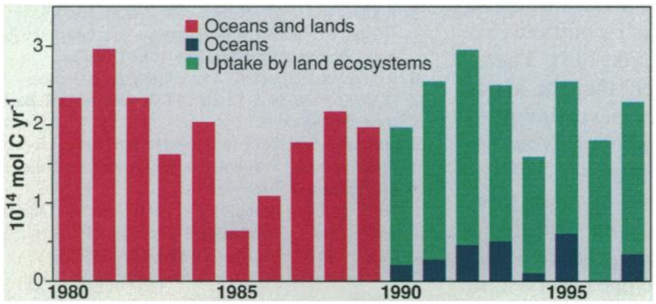
ocean surface waters, suggested that there has to be a large terrestrial CO_2 sink at temperate latitudes in the Northern Hemisphere (*4*). The sink compensates for, or is larger than (see figure), the estimated rate of carbon loss attributable to deforestation in the tropics. Fossil fuel burning consumes oxygen, and the atmospheric ratio of oxygen to nitrogen is declining as a result. The ratio is decreasing as expected from fossil fuel burning, or at a slightly slower rate, indicating that there is no other major net O_2 sink (deforestation) or even a small net source (photosynthesis larger than respiration) (*5*). The existence of a large terrestrial sink at northern latitudes has been confirmed by $^{13}C/^{12}C$ measurements of atmospheric CO_2 (*6*). At these latitudes, the ratio of ^{13}C to ^{12}C is higher than expected from fossil fuel burning alone, suggesting net uptake by photosynthesizing plants (see figure). A new technique is eddy covariance, which can measure vertical transport in a turbulent atmosphere. Flux measurements conducted for several years in different places all tend to show substantial uptake in forest ecosystems (*7*). The increase of the amplitude of the seasonal cycle of atmospheric CO_2 and especially the earlier onset of the summer photosynthetic drawdown are consistent with net uptake by temperate land ecosystems (*8*). Finally, more recent forestry surveys also tend toward carbon uptake, but not as large as the atmospheric data seem to imply (*9*).

The terrestrial biosphere may be purposely manipulated by us for food, fiber, recreation, and, in the future, storage of carbon as well, but the oceans remain the biggest player in the carbon cycle. And like the proverbial 600-pound gorilla, we do not appear to have much control over it, but we must closely monitor its behavior. Rapid progress is being made in narrowing the uncertainties of net carbon uptake by the oceans. Two new techniques are being used with much new data to estimate the ocean's inventory of anthropogenic carbon. Both techniques make use of well-understood relations between dissolved inorganic carbon, oxygen, alkalinity, temperature, and salinity to account for the large range of natural variability encountered, enabling the anthropogenic component to be extracted. In one method, the difference is calculated between preindustrial and modern carbon content (*10*). In the second method, multiple linear regression coefficients of carbon are calculated with respect to the other variables on the basis of data obtained during this decade. When these coefficients are then applied to data from the Geochemical Ocean Sections (GEOSECS) (1970s) expeditions, the measured older carbon data are lower than expected from the regression, especially in the upper part of the water column, giving a measure of the change between GEOSECS and the modern data (*11*).



Sorting out the sinks. Approximate net annual uptake of CO_2 at temperate latitudes in the Northern Hemisphere since 1980. (For comparison, global fossil fuel emissions in 1995 are estimated at 5.4 x 10^{14} mol of carbon.) Up to 1990, only data on total uptake by oceans and land combined are available (red). The addition of isotopic ratio measurements in 1990 enabled the partitioning of total uptake into contributions of land ecosystems (green) and oceans (blue). Uncertainty is due to modeled transport and relative sparseness of data, especially in the early 1980s for CO_2 and in 1990 to 1991 for ^{13}C. The apparent annual variation in ocean uptake is not significant. The current atmospheric data do not allow resolution better than 0.5 x 10^{14} mol.

I would expect that the new estimates will cut in half the error bars of the current Intergovernmental Panel on Climate Change (IPCC) ocean uptake estimate (*12*). So far, it appears that the ocean models have been pretty close globally, but there are very large errors regionally, especially in the Southern Oceans (*13*). An independent third technique is to survey the oceans for the CO_2 partial pressure difference between the air and the surface waters. When the survey data are combined with estimates of air-sea gas exchange velocity, the resulting global ocean uptake is on the low side of the inventory estimates (*14*).

One important lesson is that the carbon cycle is a tightly interacting system—improvements in knowledge of one reservoir help constrain ideas about the others. For example, the question of whether the Southern Oceans are a large CO_2 sink should be answerable both with oceanic and atmospheric data. The ability to account, at least in a global sense, for the CO_2 that has already been emitted does not imply that we can predict the future. Will the terrestrial sink taper off? We have to understand the driving factors. Most projections of future atmospheric CO_2, including those of the IPCC and the calculation mentioned above, assume that the biology and circulation of the oceans do not change, which is unlikely. Over centuries and longer, biological productivity in the high-latitude oceans plays an enormous role in setting atmospheric CO_2 concentrations. In addition, any climate-driven change in ocean circulation is nearly certain to affect the uptake rate of fossil fuel CO_2 (*15*).

A crucial test of hypotheses and process models of the carbon cycle is the prediction of regional fluxes. The models build on our understanding of the processes on small spatial scales, predicting their large-scale consequences. The observational challenge is to produce the data that will distinguish between different processes and models. The atmosphere, in constant motion, integrates the effect of surface sources over large distances between observations, allowing regional sources or sinks to be inferred from concentration differences. Any regime of global carbon management will need to be supported by an improving grasp of natural processes driving the carbon cycle and the human impact on those. Similarly, the success or failure of land use policies designed to store carbon also needs to be assessed on a regional basis. as well as by quantitative assessment of specific measures.

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