hydrolysed, though a careful statistical analysis still needs to be done. This supports the fundamental hypothesis underlying the standard models[5]: that there is a one-to-one association between the mechanical states and the biochemical states.

This hypothesis has been challenged by Yanagida and colleagues[6], who have noted an apparent discrepancy between the speed of movement and the rate of ATP hydrolysis. For example, a single kinesin molecule moves at a rate of approximately 600 nm s^{-1} (at saturating ATP concentration at room temperature) yet the maximum microtubule-activated ATPase in solution is only about 3 per second per native molecule[7]. On the face of it, this would imply that each ATP causes a movement of 200 nm, some 25 8-nm steps, quite inconsistent with the results of Svoboda and co-workers. However, there is an elegant resolution of the discrepancy. Hackney and colleagues have proposed that in solution the kinesin molecule is folded up on itself such that the tail binds to and inhibits the motor domains[8]. The binding of the tail to organelles or to the glass surfaces used in motility assays *in vitro* is presumed to open up the structure and enable the kinesin to hydrolyse ATP: the cargo turns the motor on. Consistent with this idea, proteolytic removal of the tail increases the microtubule-activated ATPase to 40–80 per second[9] (corrected to room temperature).

These are heady times for everyone involved in the study of motor proteins. High-precision recordings such as these for kinesin and others being developed for myosin[10] promise to give us a detailed kinetic and mechanical description of the reaction pathway. A recently solved structure of myosin[11] portends the atomic resolution of the massive conformational change — up to several nanometres — needed to explain the huge motions that these motors undergo. The combination of structural studies, genetic engineering and molecular physiology should ensure that biological motors make great strides in the next several years. □

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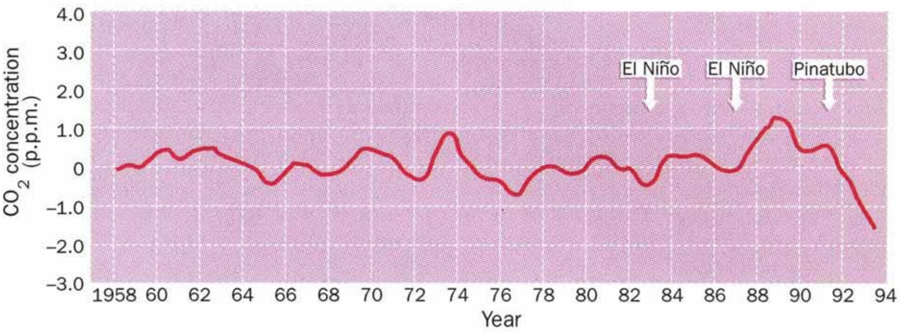
CARBON CYCLE

Atmospheric CO_2 stalled

Jorge L. Sarmiento

DURING the past year the growth rate of atmospheric carbon dioxide resulting from anthropogenic emissions has slowed by an amount that is unprecedented in the 35 years of David Keeling's time series of samples from Mauna Loa. Keeling unveiled these dramatic results at a meeting in Snowmass this summer*. Once the long-term trend and seasonal signal have been removed from the Mauna Loa record, the variability is strongly correlated with the huge changes in ocean and atmosphere circulation of the El Niño–Southern Oscillation (see figure)[1]. When an El Niño event occurs, atmospheric CO_2 usually increases above its expected level. This has been attributed by Keeling to reduced uptake by terrestrial vegetation resulting from the collapse of the Southeast Asian monsoon. The ocean actually reduces CO_2 from its expected level during an El Niño because of the collapse of equatorial Pacific upwelling of carbon-rich waters. However, the terrestrial effect of opposite sign is generally larger.



The Mauna Loa carbon dioxide anomaly obtained by removing the seasonal signal and detrending the remaining signal using a constant airborne fraction (58.58%) of the industrial release (D. Keeling, personal communication). After the two recent El Niño events of 1982–83 and 1986–87 (labelled in December of the first year), atmospheric carbon dioxide increased; but although it started to rise with the most recent El Niño, which began in 1991, there was an unexpected change in trend just after Mount Pinatubo's eruption. The slowing of the growth rate over the past year is unprecedented on this record.

The most recent El Niño began during 1991 and continued into 1992, so its effect may explain the increase in atmospheric CO_2 that began in early 1991. This time, however, instead of continuing to grow, the CO_2 began to drop in mid-1991, just after the time of the eruption of Mount Pinatubo (14–15 June). This 'Pinatubo carbon anomaly' reached −1.5 p.p.m. in Mauna Loa in May of this year; if this applied to the whole Northern Hemisphere it would correspond roughly to a loss of 1.6 Pg (1.6×10^{15} g) of carbon. The magnitude of the effect is even more remarkable when one considers that the 1991–92 El Niño should have led to increased growth of CO_2.

We can be relatively confident that the anomaly is not due to a reduction of CO_2 released to the atmosphere from fossil sources by industrial processes. Fossil-fuel emissions in 1991, estimated from the most recent United Nations statistics, were 6.19 Pg carbon, comparable to the 6.10 Pg emitted in 1990, and well within the trend of previous years (Greg Marland, Oak Ridge National Laboratory). There is no reason to believe that the past year-and-a-half were unusual.

The cause must therefore be processes in the terrestrial biosphere or ocean. Here is where measurements of the $^{13}C/^{12}C$ ratio can help. Photosynthesis preferentially takes up the lighter isotope, increasing the atmospheric $^{13}C/^{12}C$ ratio. Oceanic uptake by gas exchange, on the other hand, has little effect on the ratio. This is true even if the reason for the oceanic uptake is biological removal of carbon in the surface ocean, because the large amount of carbon in the ocean strongly dilutes the isotopic effect of this photosynthesis. One can make use of the difference between terrestrial biosphere and oceanic behaviour to determine the relative contribution of these two processes through what David Keeling calls a 'double-deconvolution' of CO_2 and $^{13}C/^{12}C$ measurements[1].

Initially it seemed that the data on the carbon isotope ratio suggested a large oceanic sink and small terrestrial source (or reduced sink) for the Pinatubo carbon anomaly, but later corrections to the ^{13}C calibration reported by Keeling at a meeting in Carqueiranne† now point instead to the terrestrial biosphere being more responsible.

A further source of information is

**Global Change Institute on the Carbon Cycle*, Snowmass, Colorado, 18–30 July 1993.
†*Fourth International CO_2 Conference*, Carqueiranne, France, 13–17 September 1993.

atmospheric oxygen, measured by David Keeling's son Ralph. Keeling *fils* showed preliminary results and model simulations at the Snowmass meeting based on his record of atmospheric oxygen initiated at La Jolla in 1989 (ref. 2). The idea is that the ratio of atmospheric O_2 to CO_2 for a given anomaly depends on whether the anomaly is caused by changes on land or in the ocean. Synthesis of organic matter releases oxygen, and remineralization or burning consumes it in a ratio of about 1:1 on land but about 1.4:1 in the ocean. Moreover, in the oceans, dissolved CO_2 can be taken up into the large inorganic carbon pool through a series of chemical reactions, whereas dissolved oxygen is chemically neutral.

The upshot of this is that an oceanic sink for the Pinatubo anomaly would give an oxygen/carbon dioxide ratio of somewhere between 2 and 8, whereas a terrestrial sink would give a ratio of about one. In fact, Ralph Keeling's La Jolla observations show a positive Pinatubo oxygen anomaly about twice that of the negative carbon anomaly. So although it is possible that a terrestrial sink is responsible for part of the anomaly, the oxygen data imply that a significant proportion is due to the ocean.

Now we come to the difficult part: what mechanisms could cause the Pinatubo carbon and oxygen anomalies? Answering this question will first require explaining the disagreement between the carbon isotope and oxygen interpretation, but already plenty of speculations have been offered. The El Niño anomalies themselves have yet to be explained satisfactorily. For example, model estimates of the oceanic impact of the 1982–83 El Niño give a carbon uptake anomaly of only 0.8 Pg of carbon[3,4] as contrasted with an uptake anomaly of 4.5 Pg estimated from the double-deconvolution method[1]. It will be difficult to understand the Pinatubo anomaly without first understanding the background El Niño signal.

At Carqueiranne, Ralph Keeling showed that the anomaly seems to be primarily a Northern Hemisphere effect (Alert at 82° N is similar to La Jolla, but Cape Grim data at 41° S show no anomaly). His results add a further constraint: he estimates that the Northern Hemisphere oxygen anomaly between May 1991 and the end of 1992 requires a source of about 3×10^{14} moles of oxygen to the Northern Hemisphere atmosphere (or a corresponding sink in the Southern Hemisphere). This source is equivalent to a sink of 2.5 Pg of carbon in this time, or 1.5 Pg of carbon a year, if all the oxygen is released by an increase in oceanic photosynthesis. Global oceanic new production today is about 10 Pg of carbon a year.

It is unfortunate that we do not have an ocean colour imager in space at present, as a signal of 1.5 Pg of carbon a year concentrated in the Northern Hemisphere would almost certainly have been detectable. It would close the problem nicely if an increase in oceanic biological production could also explain the negative Pinatubo carbon anomaly, but there are two problems: first, only a small fraction of the CO_2 taken up by an increase in oceanic photosynthesis would come from the atmosphere; second, the carbon-13 data seem to suggest that the carbon anomaly is mostly terrestrial.

The coincidence of the onset of the carbon and oxygen anomalies with the eruption of Pinatubo suggests a causal connection, and one way would be iron fertilization of the oceans. Removal of 2.5 Pg of carbon would require about 0.1×10^6 tonnes of iron. Pinatubo ejected about 3 to 5 km^3 of rock equivalent in the form of tephra and pyroclastics[5]; for a density of 2.8 g cm^{-3} and iron content of about 5 weight per cent, the total iron content is about 500×10^6 tonnes. So only 1/5,000 of the iron would have to be released to organisms in areas of excess surface nutrients (such as nitrates and phosphates) to provide the requisite amount. Another mechanism for a Pinatubo connection is the reduction in sunlight and the cooling caused by the eruption. The reduced radiative forcing due to reflection of light by volcanic aerosols peaks at about 4.5 W m^{-2} (ref. 6) compared to the mean supply of 237 W m^{-2}.

Cooling accompanied by changes in rainfall could perhaps affect the balance of respiration (a CO_2 source) and photosynthesis (a CO_2 sink) on land. It could also affect the ocean's capacity to act as a carbon sink, as cooler water takes up more CO_2. But Keeling *père* estimated that this mechanism accounts for only about 0.1 Pg of carbon.

If the anomaly is indeed attributable to the climate effect of Pinatubo, the story becomes still more interesting. We understand so little of the likely response of the carbon cycle to climate change that even discovering the effect of cooling could lead to important insights into the complex feedbacks that will surely be associated with future global warming. □

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DAEDALUS

Electric traction

LAST week Daedalus invented the converse of a stretch-fabric. Instead of tending to contract in its own plane under an internal surface tension, it tends to expand in its own plane under an internal 'surface compression'. It is woven from conducting wire in such a way that when a current flows, adjacent wires repel each other. The previously slack and flexible fabric then expands tautly, as if it were under tension.

Daedalus intended his new fabric for vacuum-vessels, in which duty its surface expansion could counter the compression of the atmosphere. But such large currents would be needed that only superconducting wire could carry them. So to test the principle, he is weaving more mildly self-tensioning fabrics from normal wire, and is studying their uses.

Already DREADCO tailors have cut out a pair of self-ironing electric trousers. When the current is switched on, the folds and creases of the garment are hauled flat, and it expands taut as if inflated. The way seems open for a military uniform which brings the wearer automatically to attention. Its arms and legs could then be tensioned and relaxed alternately under remote control, thus marching him along semi-automatically at a defined rate. The sergeant-major with the master transmitter could bring parade-ground precision to the most shambling squad of recruits.

In the home, self-tensioning fabrics could be made into self-straightening carpets, self-closing curtains, and even a self-making bed. Hospitals would welcome such a time saver. The matron could remake all the beds of her ward at the flick of a switch, without even removing the patients. Out of doors, rigid self-erecting hoardings should become feasible, and a self-erecting tent needing no guy-ropes or central pole. It will snap skywards when the current is passed through it, and collapse limply when disconnected.

Stressed-skin engineering structures could benefit as well. An electrically pre-stressed skin could carry compressive and shear loads without further reinforcement. DREADCO engineers are planning boats that need no ribs or stringers, tanks and containers rigid without inflation, and aircraft wings and fuselages with no internal bracing. Even the pneumatic tyre could be redesigned as a self-tensioning structure, needing no inflation and unaffected by punctures. But these serious and fiercely stressed applications need such high internal currents that they must await the coming of room-temperature superconductors. David Jones