brane fraction of muscle fibres (see figure), challenging another NO catechism that holds that neuronal and macrophage NOS are always cytoplasmic, while only endothelial NOS is associated with cell membranes.

What does skeletal muscle NOS do? Inhibitors of the enzyme increase skeletal muscle contraction, effects that are reversed by NO donors, indicating that NO presumably physiologically relaxes skeletal muscle in much the same way that it relaxes the smooth muscle of blood vessels[3]. So, how might it bring about this effect? In blood vessels NO binds to haem in the active site of guanylyl cyclase to augment its activity with the newly formed cyclic GMP, eliciting relaxation by some undefined mechanism. Evidence for some involvement of cGMP in NO activity in skeletal muscle comes from observations that 8-bromo cGMP elicits modest relaxation, as does an inhibitor of phosphodiesterase, whereas an inhibitor of guanylyl cyclase causes contraction[3].

Kobzik *et al.*[3] suggest another intriguing way in which NO might regulate skeletal muscle. They observe release of NO but not of reactive oxygen intermediates in uncontracted skeletal muscle, whereas in contracting muscle they detect high levels of the reactive oxygen intermediates (presumably comprising superoxide and possibly other oxygen free radicals). It is well known that NO binds to superoxide, thus inactivating it. On the other hand, the combination of NO and superoxide can form peroxynitrite which decomposes to hydroxide free radical, one of the most reactive of all free radical species. One can speculate that NO modulates the effects of oxygen free-radical species formed by contracting muscle, though whether NO diminishes or enhances such effects is unclear. Conceivably, during states of great hyperactivity of muscle, hydroxyl free radicals formed from NO and superoxide could lead to muscle damage — in such circumstances, NOS inhibitors might display therapeutic actions. □

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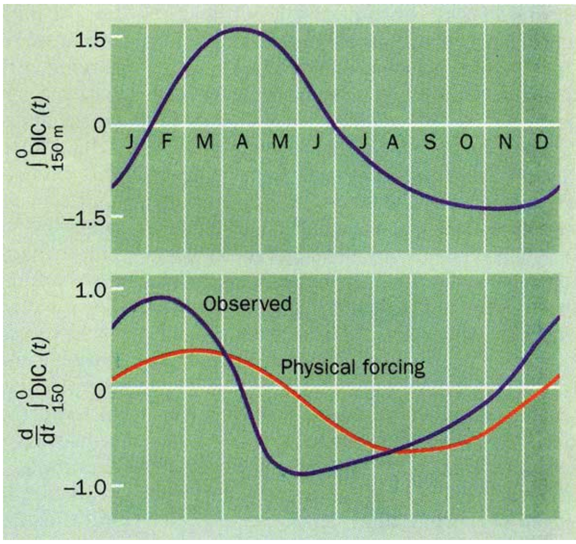
CARBON CYCLE

Vanishing in Bermuda

J. R. Toggweiler

SIX years ago the Bermuda Atlantic Time Series station (BATS) was set up to document changes in the carbon, nutrient and productivity cycles at a single point in the open ocean. Measurement capabilities there have increased to the point where a complete suite of carbon system parameters is measured at least once a month. Photosynthetic carbon uptake and the downward flux of biogenic carbon in sinking particles is measured, along with fluxes of carbon dioxide across the air–sea interface. On page 537 of this issue, Michaels *et al.*[1] report on the first two years of carbon system results. They find a repeating seasonal cycle in which dissolved inorganic carbon (DIC) stocks rise during the late autumn and winter and decline during the spring, summer and early autumn.

This was largely expected. What was not expected is that only 20 per cent of the decline during the spring and summer period can be accounted for in the flux of biogenic carbon in sinking particles. The authors rule out most of the obvious unmeasured carbon sinks and conclude that most of the carbon drawdown in the spring and summer has somehow escaped detection.



Top, sketch of the seasonal anomaly in dissolved inorganic carbon (DIC) in the ocean near Bermuda. Units are moles m^{-2}. The DIC anomaly is integrated over the top 150 m of ocean. Bottom, time derivative of the observed vertically integrated DIC anomaly (purple), plotted together with a sketch of the physical forcing effect on DIC (red). Units are mol m^{-2} $month^{-1}$. The forcing curve shows mainly the effect of seasonal temperature changes on the solubility of CO_2; its mean value is set slightly below the zero line to reflect the fact that the North Atlantic is a net carbon sink because of its thermohaline circulation.

The upper few tens of metres of the ocean constitute what oceanographers call the 'mixed layer'. It is illuminated by light from the Sun and is stirred by the wind. In a place like Bermuda it is devoid of the nutrients nitrate and phosphate for most of the year. The seasonal cycle helps pump carbon and nutrients through the mixed layer as follows. Winter cooling overcomes the stratification at the base of the mixed layer and allows the mixed layer to deepen (to as much as 200 m at Bermuda). Inorganic nutrients and old respired carbon from subsurface layers become entrained into the mixed layer as it deepens. Although the nutrients are welcome to photosynthetic algae, the deep mixing is not. When mixing extends to 200 m these single-celled organisms do not remain in the illuminated upper layers long enough to maintain high rates of photosynthesis.

Warming of the upper layers during the spring restores a shallow mixed layer. Photosynthetic organisms suddenly find themselves in a well-lit environment along with nutrients left over from winter mixing. They manufacture new pigment and reproduce rapidly, converting inorganic carbon to organic carbon in the process. Some of the fixed carbon finds its way into particles that are large enough to sink. This leads to a downward carbon flux into subsurface layers where the particles decompose. Inorganic CO_2 and nutrients from the decomposition thus become available for the next cycle.

The area around Bermuda was originally thought to be an ideal place to budget the carbon cycle. It comes as quite a shock that the system should be so leaky. Michaels *et al.* suggest two alternatives: either the sediment traps which are designed to measure the sinking flux are simply missing 80 per cent of the flux, or else physical advection is dominating the budget in ways that were not foreseen. The first hypothesis implies that the biological carbon export at Bermuda is fairly substantial: some 30 to 40 per cent of all the carbon fixed by photosynthesis would have to be exported to explain the spring and summer drawdown of dissolved inorganic carbon.

The best evidence that the sediment traps are deficient comes from levels of ^{234}Th in the water column. This isotope is a short-lived (24-day half-life) daughter of ^{234}U which has a strong affinity for particles. A level of ^{234}Th activity in the mixed layer that is less than the activity of the parent implies that some of the ^{234}Th has become attached to particles that have sunk out of the mixed layer on a timescale short with respect to its half-life. ^{234}Th provides a fairly direct way of measuring the efficiency with which sediment traps capture the vertical flux.

During the spring of 1993 the amount of ^{234}Th caught in the sediment traps at Bermuda was substantially less than the amount expected given the ^{234}Th deficit observed in the mixed layer. This implies that the sediment traps did indeed miss part of the organic carbon flux. To convert ^{234}Th information quantitatively into a carbon flux, one must know the ratio of organic carbon to ^{234}Th in the sinking particles that were not caught. There are a lot of pitfalls here, but Michaels *et al.* show that the sediment-trap hypothesis closes the carbon budget only if a high ratio of organic carbon to ^{234}Th is used. So this hypothesis probably explains some of the budget problem, but not all.

The second hypothesis, that of advection, has some attractive features. The temperate latitudes of the North Atlantic are well known as an area where the ocean's thermohaline circulation influences the carbon cycle[2]. Warm water advected north from the tropical Atlantic loses a tremendous amount of heat to the atmosphere just north of Bermuda before sinking into the deep sea at even higher latitudes. The cooling process leads to a net uptake of CO_2 by the ocean. This CO_2 uptake could be part of the carbon budget at Bermuda if the process produces a CO_2 deficit at the right time of year.

In the upper panel of the figure, I have sketched out the seasonal cycle of DIC based on the two years of data used by Michaels *et al.*.The levels peak between the beginning of March and the beginning of May, and reach a trough in November and December. In the lower panel I have sketched the time derivative of this DIC curve. DIC levels increase most strongly in January and February and decrease most strongly in May and June.

The same panel shows the seasonal cycle of the physical forcing on DIC levels at Bermuda. Part of the physical forcing is due to changes in temperature, and part is due to the large-scale thermohaline circulation of the ocean. When surface temperatures are coldest in late winter, the partial pressure of gaseous CO_2 in the water becomes lower than the partial pressure of CO_2 in the atmosphere. This leads to an increase in ocean DIC through gas exchange. Conversely, when surface temperatures are warmest in late summer, CO_2 is lost to the atmosphere. To reflect the effect of the thermohaline circulation, I have displaced the whole physical forcing curve down slightly with respect to the zero line. The idea here is that the overturning produces a DIC sink which continuously removes carbon from the atmosphere and upper ocean. Recent modelling work by Follows *et al.*[3] shows explicitly how the seasonal subduction of water north and east of Bermuda acts to pump CO_2 downwards in the North Atlantic subtropical gyre.

Juxtaposition of the observed time-derivative curve with the physical forcing curve shows how the advection cycle overlies the biological cycle. During the winter the observed curve is well above the forcing curve because respired DIC from past biological activity is pumped upward by the deepening mixed layer. Much more DIC is injected into the upper 150 m by this mechanism than by gas exchange. During April, May and June, the observed curve is well below the forcing curve, because of intense biological carbon uptake during the spring bloom. During the last half of the year the observed curve largely follows the forcing curve. This is a time when the tendency of the physical forcing is to lower DIC levels in the system. According to Follows and co-workers, this results mainly from the input of low-DIC water from the Gulf Stream. This input occurs all year, but the effect is masked during the winter because the ocean is gaining DIC by gas exchange along the path of the flow. The effect of low-DIC Gulf Stream water should be especially pronounced during the summer and early autumn when temperatures are high and there is an overall tendency for the ocean to lose DIC to the atmosphere.

As Michaels and co-workers point out, the best way to resolve this issue is to investigate systematically the effect of advection on DIC levels around Bermuda. If the explanation proposed by Follows and his collaborators[3] is correct, one would expect to see water with a relatively low DIC content advecting southwards through the vicinity of Bermuda during late summer and early autumn; in other words, DIC concentrations should increase toward the south such that the effect of advection is to decrease DIC levels at Bermuda. If, on the other hand, sediment traps are missing 80 per cent of the downwards flux, advection is probably acting to increase DIC at Bermuda at the same time that the downwards particle flux is removing it. □

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DAEDALUS

Healthily hooked

MEDICAL science is constantly announcing new perils in modern life, and new ways of dodging them. The result is an epidemic of little popular remedies: trace elements, vitamins, plant extracts and so on, all offering salvation from some dire medical fate. In a brilliant marketing ploy, Daedalus aims to corner this whole market. DREADCO pharmacists are devising a single pill to contain everything that the medics currently recommend. As fast as new fads and findings emerge, they will be incorporated into its formulation; as fast as they are discredited, they will be removed again. No longer will the dedicated health freak have to scan the papers endlessly for the latest worries and recommendations. He will simply put in a permanent order for the 'Omnipill' in its successive updates, and leave the whole business to DREADCO.

Sadly, the Omnipill cannot encompass bulky nostrums such as dietary fibre. But the current formulation has all the vitamins, some of them in megadoses; essential elements such as iron, zinc and selenium; catechin and aspirin to minimize the risks of heart attacks; silicates to limit aluminium uptake; chelating agents against heavy metals; and a few other things for good measure. It is aimed at serious health worriers. A wider, less obsessive market will be reached by 'Omnitonic', a more jovial liquid version competing with tonic wines and cordials, and those beers that claim to be good for you.

In a further masterstroke of marketing, the Omnipill will be addictive. Users will stay with it not merely from medical prudence, but from subtly reinforced habit. Even more cunning, the addictive agent will be nicotine. The current anti-smoking crusade, says Daedalus, is leaving millions of ex-smokers with an aching chemical void in their lives. Omnipill will fill it — with the full blessing of medical science. For nicotine itself is harmless in small doses, has a valuable stimulant effect, and aids slimming. There is even a claim that it counters Alzheimer's disease. It is smoke that damages smokers. Nicotine is smoked only because it cannot easily be stored in pill form: it is slowly oxidized by air. Smoking vaporizes it on demand from its stable combination in the tobacco. But the Omnipill contains catechin and vitamins C and E, all powerful antioxidants. They will protect and stabilize its nicotine. Omnipill will be the first stable, health-enforcing addictive agent. The British government in particular, currently trying to nag its citizens into healthy habits, should welcome it with open purse. David Jones