Oceanography

Ocean productivity from space

Paul Falkowski

THE central ocean basins are sometimes characterized as miles and miles of miles and miles. Shipboard observers of the nutrient-poor waters of the open oceans have frequently commented on the weak horizontal gradients in chemical and biological properties, compared with the continental ocean margins. The lack of horizontal gradients has hampered the validation of empirical mathematical models that relate phytoplankton pigments, as perceived by satellite, to primary production. By a combination of skill and luck, Lohrenz *et al.*[1] have now been able to test a model relating surface chlorophyll, obtained from the now-defunct coastal zone colour scanner aboard the Nimbus-7 satellite, to shipboard measurements of primary productivity in a normally oligotrophic ocean region, the western Mediterranean Sea. The importance of the report by Lohrenz *et al.* on page 245 of this issue is not the model *per se*, which is similar to one developed by Eppley *et al.*[2], but that the "precision [is] adequate to resolve, for the first time, short-term fluctations in primary productivity with a mesoscale circulation feature".

The average primary productivity in the oligotrophic ocean basins has been keenly debated within the past decade. Although primary productivity per unit area in the central ocean basins is undoubtedly lower than it is in continental shelves and in coastal upwelling regions, the total global carbon flux is greater in the former simply because of the enormity of ocean basins. The extent to which atmospheric inorganic carbon can be sequestered in the oceans by phytoplankton photosynthesis and the subsequent sinking of particulate organic carbon is important for understanding the degree to which the oceans will mitigate the build-up of CO_2 in the atmosphere.

The introduction of satellite images of oceanic chlorophyll in the late 1970s provided the potential for observing the surface distributions of phytoplankton on spatial scales of tens to thousands of kilometres. These images revolutionized thinking and enabled biologists to address the fluxes of carbon and nutrient elements on the same spatial scales as geochemists. But the extrapolation of surface estimates of chlorophyll to estimates of aerially integrated primary production has been difficult; the variations in estimates of production derived from models of satellite images are as great as the variations between shipboard observations.

In part this problem may result from the fact that the range of production values normally measured by one investigator on a cruise is too low to validate an empirical model. To obtain a sufficiently useful range of production values to examine the robustness of a model, data sets from various investigators, often from different environments, are mixed. The result of such data mixing is usually such a large variance in the modelled production as to render the models almost useless in rigorous calculations of carbon flux.

Lohrenz *et al.* observed that on 8 May 1986 a phytoplankton bloom had developed off the coast of western Algeria which had disappeared by 11 May. The bloom was associated with a sporadic physical mixing event: the differences between surface chlorophyll concentrations during and after the bloom spanned an order of magnitude. Observations of such a large difference in surface chlorophyll in such a brief period are rare, particularly in oligotrophic regions of the oceans. The large range of surface chlorophyll concentrations allowed Lohrenz *et al.* to use regression analysis first to relate the satellite image of surface chlorophyll, C_k, to measurements of surface chlorophyll, C_s, and second to relate C_k to aerially integrated primary production, π.

The importance of short-term transient events of the type described by Lohrenz *et al.* to overall production has increasingly been realized[3,4]. Whether such events significantly displace estimates of production from the mean remains to be seen. There is no satellite in orbit capable of measuring surface chlorophyll in the oceans. The coastal zone colour scanner, launched in 1978, failed to return data by the end of 1986. The next satellite planned for ocean-colour data collection is the sea wide-field sensor to be launched aboard Landsat-6 by NASA and Eosat Corp. in 1991.

The development of satellite sensors is occurring in parallel with the development of new types of instruments which can be moored for extended periods in the oceans. Instruments for measuring phytoplankton pigments and even primary productivity based on variable fluorescence can be moored in different locations for use as a base for the development of satellite algorithms[5]. It is to be hoped that the combination of satellite images and moored instrumentation will eliminate the 'luck factor' in observations of transient mixing events. If so, by the end of the century we should have a clear consensus about the magnitude and importance of oceanic production in the global carbon cycle. □

1. Lohrenz, S. E. *et al. Nature* **335**, 245–247 (1988).
2. Eppley, R. W. *et al. J. Plankton Res.* **7**, 57–70 (1985).
3. Platt, T. & Harrison, W. G. *Nature* **318**, 55–58 (1985).
4. Jenkins, W. J. *Nature* **331**, 521–523 (1988).
5. Falkowski, P. G. *et al. Cont. Shelf Res.* **8**, 457–484 (1988).

Paul Falkowski is Head of the Oceanographic Sciences Division at Brookhaven National Laboratory, Upton, New York 11973, USA.

Solar System

Interior and origin of Pluto

David W. Hughes

OUR knowledge of Pluto is increasing painfully slowly. At the time of discovery (1930) astronomers were shocked at its faintness and its low mass. It was not the planet 'X' for which they were searching in the hope of explaining Neptune's perturted orbit. Pluto's orbit is inclined at 17.2° to the plane of the Solar System and it has an eccentricity of 0.250, a value that brings it within the more circular orbit of Neptune. Naturally, astronomers have speculated that Pluto has an unusual origin, perhaps as the escaped satellite of an inner planet. Elsewhere in this issue (*Nature* **334**, 240–243; 1988), W. B. McKinnon and S. Mueller use the measured mean density of Pluto and its moon Charon to constrain the possible models of Pluto's interior and hence its origin.

Since 1985, and until 1990, Pluto and Charon have been undergoing a series of mutual eclipses, a phenomenon that occurs twice every 248 years. The timing these eclipses gives accurate values for the radii of Pluto and Charon, 1,122.7 ± 3.5 and 599.7 ± 5.8 km, respectively. Charon is tidally locked to Pluto and has the same face always pointing towards it. It orbits every 6.38718 days, so that the system has a total mass of 1.36×10^{25} g, a mere 18.5 per cent of the mass of our Moon. Together, Charon and Pluto have a mean density of 1.991 ± 0.018 g cm^{-3}.

If Charon has a density of 1–3 g cm^{-3}, a range that spans all the known values for icy satellites, then the density of Pluto lies between 1.84 and 2.14 g cm^{-3}. So Pluto must be extremely rocky. In fact, with these densities, rock makes up 68–80 per cent of its total mass. McKinnon and Muller use models of Ganymede (radius 2,638 km) and Callisto (radius 2,410 km) as their guides, but with one important proviso: Pluto is so small that its gravitational pressure has not significantly increased the rock density in its interior over its atmospheric-pressure value.

They also consider two types of rock.