Variability of the Earth's rotation

from Frank D. Stacey

LONG BEFORE the advent of atomic clocks, it was well known that the Earth's rotation was an imperfect time-keeper. Precise time-keeping has always been one of the roles of astronomy and the stars, planets and satellites provide us with several independent or semi-independent clocks. Rather than clarifying the problem, modern measurements and recent re-analyses of earlier data have found evidence of a multiplicity of superimposed mechanisms. The difficulty is partly, of course, that some of the mechanisms involve time constants that are longer than the period of observation and so, regardless of the precision of observations, a long record is required to sort them out.

The diversity of disciplines that contribute to the study of the rotation of the Earth makes it an interesting theme for a wide-ranging discussion and, at a recent meeting*, astronomy, meteorology, oceanography, palaeontology, cosmology and the physics of the Earth's deep interior were all well represented. New data and ideas were forthcoming, as well as some thoughtful questioning of arguments supposed to be reasonably secure.

It now appears that at least some of the palaeontological data upon which we have relied for direct evidence of the relative lengths of the day, month and year in remote geological periods are very unsure. Certainly growth increments on the shells of marine organisms are well observed, but do they really indicate diurnal, monthly and annual periods, with all time increments faithfully recorded? Some of these questions have recently been brought to the fore by a controversial study of nautiloid growth rhythms (P. G. K. Kahn and S. M. Pompea *Nature* **275**, 606; 1978; see also *Nature* **279**, 452; 1979). W. W. Hughes (Andrew University, Michigan) has been examining a large number of nautiloid specimens from the British Museum (Natural History) collection. At least some organisms record the semi-diurnal lunar tide rather than the day and those observed under controlled conditions give no observable growth increments during the winter months. While we are not ready to give up hope of definitive data from growth rhythms, clearly we need much more work on control specimens and interpretation of ancient samples in the light of it before estimates of rotation rates in earlier epochs can be regarded as secure.

The gradual slowing of the Earth's rotation by tidal friction can be measured in several ways although the obvious and direct measurements of the apparent motion of distant stars with precise clocks (atomic or astronomical) is confused by shorter term fluctuations due to exchange of angular momentum within the Earth. It is agreed that tidal friction in the Earth is dominated by the dissipation of tidal energy in the sea. To extrapolate to the remote past a linear relationship, in the sense that the lunar and solar tides act independently, has generally been assumed,with dissipation proportional to the square of tidal amplitude. For most purposes this may not be too bad an approximation, in spite of the evidence that tides are turbulent and therefore at least to some extent non-linear. However, when fine details of the angular momentum exchange with the lunar and solar orbits are sought, this assumption becomes unsatisfactory. For some years T. C. Van Flandern, at the Naval Observatory in Washington, has sought, with progressively increasing precision, evidence for a time variation of the newtonian gravitational constant, G, in terms of an atomic clock determination of the lunar orbital acceleration. It is important to know whether such an observation may be confused by non-linearity of the tide because the length of the record of atomic-timed observations of the Moon appears to be approaching the point of giving a definite result. According to V. Canuto (NASA Goddard Space Flight Center, *Nature* in the press) and G. M. Blake (University of Sheffield), the bias of presently available data favours an increase in G with time rather than the decrease postulated by P. A. M. Dirac.

Evidence of short-term variations in rotation is improving rapidly. A new analysis by L. V. Morrison (Royal Greenwich Observatory) and F. R. Stephenson (Liverpool University) of the timing of occultations, with some eclipse data back to 1620, gave a much more convincing length-of-day curve than any hitherto for the period from about 1750; the data before that time were of doubtful value. There are no discontinuities like those that appeared in earlier analyses, but the occurrence of changes amounting to a few parts in 10^8 over 5 or 10 years is strikingly confirmed. Irregular motions in the Earth's core are clearly implicated although the mechanism is a subject of controversy. A new examination from French observatory going back to 1700 of the correlation between rotational changes and the geomagnetic westward drift by J. L. Le Mouël and V. Courtillot (IPG, University of Paris) showed that magnetic changes preceded rotational changes by two or three years, contrary to some questionable analyses reported earlier. This indicates a semi-independent electromagnetic coupling of the Earth's solid mantle to the outer region of the core (which carries the westward drifting features of the field, as originally proposed by E. C. Bullard), and, more strongly, to the deeper body of the core. There are clearly difficulties with this hypothesis, although it does provide a quantitative explanation of the rotation observations.

The time scale for core-induced changes in rotation rate is several years and a coupling time-constant of this magnitude is compatible with the electromagnetic torques exerted by the core-generated field on a lower mantle of conductivity 100Ω m^{-1} or so. However, the observations permit the supposition that core–mantle coupling is very tight indeed and that the apparent time constant is a feature of the core motions themselves. This supposition is necessary if the core has any role in exciting or damping the Chandler wobble. The conventional wisdom follows the Rochester–Smylie analysis of wobble coupling, which demonstrates that for the same field and mantle conductivity configuration the coupling time constant for the wobble is about 100 times as long as for the length-of-day changes. This is probably the strongest single reason for believing that tectonic displacements, including earthquakes, within the mantle excite the wobble, but S. K. Runcorn (University of Newcastle upon Tyne) keeps alive the argument that the core may be responsible for the wobble. The necessary mantle layer with a conductivity nearer to $10^4\Omega^{-1}m^{-1}$ is not well supported by observations, but such a layer does have proponents for other reasons, so this particular debate will continue for a while yet.

The smaller, but much more rapid, fluctuations in rotation must be attributed to atmospheric motions. A comprehensive new global analysis of the atmospheric angular momentum, reported by R. Hide, (Meteorological Office, Bracknell; see also *Nature* **286**, 114; 1980; **286**, 104; 1980) confirmed that major changes can occur quite rapidly, reacting on the Earth in a matter of days. The coupling is obscure but must certainly be there if the angular momentum exchange is demonstrated. A comparable analysis of the perpendicular components of atmospheric angular momentum, coupling to which would excite the wobble instead of changes in rotation rate, is promised. This reopens another of those debates that has been closed and reopened several times in the past 25 years.

What are the outstanding problems for the immediate future? If we compile a complete list, practically every problem that has ever been tackled is still on it. A personal list, restricted to four items in order of significance is (i) Adequacy of newtonian mechanics to explain the lunar orbit, (ii) Periodicities in the growth patterns of organisms exposed to a tidal cycle, (iii) Atmospheric excitation of the wobble, (iv) Lower mantle conductivity and core coupling. □

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