Earthquakes and the Earth's rotation

A new calculation of the effects of past earthquakes on the speed of the Earth's rotation does not account for the observations, but raises important questions in geophysics.

THAT the speed of the Earth's rotation is not constant is, of course, familiar — although the world's observatories can still count on a little publicity for their annual announcements that the year just passed happened to be a few milliseconds longer or shorter than expected. Moreover, there is no shortage of explanations for seasonal and secular changes of the speed of rotation. Differential expansion of the atmosphere north and south of the Equator is one obvious cause of seasonal changes. Tidal dissipation and post-glacial changes in the distribution of material (melting ice followed by post-glacial rebound) have secular consequences, while earthquakes are usually also listed among the reasons why the moment of inertia of the Earth may be changed, but only qualitatively.

Now, mercifully, the issue has been made quantitative, by means of an interesting study by B. Fong Chao, of the Goddard Space Flight Center in Maryland, and Richard S. Gross, of the Los Alamos National Laboratory (*Geophys. J. R. astr. Soc.* **91**, 569; 1987). Unsurprisingly, the authors of this study find that earthquakes do indeed serve to make the Earth more compact, thus decreasing its moment of inertia and, because they leave total angular momentum unchanged, increasing the rotation speed and thus decreasing the length of the day (LOD), which is what would be expected.

But there is a substantial puzzle. The size of the calculated effect of all the substantial earthquakes (of magnitude greater than 5.5) between 1977 and 1985 is two orders of magnitude smaller than that expected from observation. Moreover, there seem to be systematic trends in the data suggesting that earthquakes do not occur randomly, but that there is a bias in favour of those events which, among other things, decrease the LOD. Quite properly, Chao and Gross say that this raises awkward questions about the interaction between the mechanism of earthquakes and other geophysical processes, those of plate tectonics for example.

Tackling such a complicated problem is naturally a complicated business, involving first a scheme for representing the gravitational potential of the Earth in terms of spherical harmonics and then of working out a way of calculating the changes of density distribution caused by individual earthquakes. Chao and Gross are able to relate the changes of the inertial constants of the Earth to the seismic moment of an earthquake, and discover, with the approximations they use in passing, that the effects of separate earthquakes are cumulative — whence the feasibility of their calculation of the effects of 2,146 events over nearly a decade.

Apart from simplifications which are mathematical approximations, there is however one that could deserve much closer attention than it has been given. Chao and Gross work with a symmetrical model of the Earth, noting that departures from sphericity are only one part in 300 or thereabouts, and that the effect of these small variations on the calculation of other geophysical quantities appears to be small. But is there a chance that, in programmes of calculation from which interesting departures from randomness emerge, the non-spherical character of the Earth may be qualitatively important, perhaps helping to explain the large difference between the results of calculation and observation? Chao and Gross would be well within their rights to say that questions such as that are more easily asked than answered.

The outcome of the calculations as they are is disconcerting, but not surprisingly so. To the extent that earthquakes should change all the components of the Earth's inertial tensor, the off-axis components as well as the principal moments of inertia along the diagonal, earthquakes should be one of the causes of the measured drift of the position of the Earth's rotation axis, or the geographical position of the poles, which is now well measured by the laser ranging of the motion of Earth satellites.

In the event, the calculated motion of the poles is in almost the opposite direction to that observed, which merely shows that other causes of excitation are more important than earthquakes. But it also seems that the calculated cumulative effect of earthquakes has been to nudge the position of the pole towards 150°E ever since good seismic records were first kept at the beginning of the century. That is one of the non-random effects to which Chao and Gross rightly draw attention.

The calculated effect of earthquakes on the inertial constants of the Earth is equally striking, affecting the moment of inertia about the rotational axis but not the two components at right angles. This, of course, is the quantity most directly linked with LOD. The result, as expected, is a cumulative decrease of the moment of inertia, but not a steady decrease: some earthquakes increase the moment of inertia. But the value of the rate of decrease works out at merely 0.1 microseconds a year, roughly one per cent of the measured rate of decrease. One conclusion is that the effects of earthquakes are swamped by those of other processes, another is that the calculations may underestimate what earthquakes do.

The importance of this calculation is that it provides a technique that may be applied, cumulatively, to events that have not yet occurred. It is not unreasonable to hope that, as the years go by, it may be possible to recognize in the short-term variations of the Earth's rotation speed the effects of major earthquakes, however great may be the other influences upon it. That, in the end, is how Chao and Gross will be tested.

Meanwhile, the questions remain of why the effect of earthquakes on the Earth's rotation should have the effect of predominantly decreasing the polar moment of inertia (and also of nudging the rotation pole in a specific direction). Chao and Gross are right to say that these questions point deeply into geophysics.

Even the question of why the Earth's matter is redistributed, as a consequence of an earthquake, so as to decrease the moment of inertia, is not as simple as it sounds. It is true that this is the direction in which the potential energy of the system as a whole will be decreased, but that does not give a good account of how the rocks about to rupture sense what the principle of least energy requires of them. The fact that some earthquakes increase the moment of inertia shows that the problem is not simply a static problem.

If there are preferred directions built into the problem, such as the tendency for earthquakes to nudge the rotation pole in a specific direction, the need for an explanation linking the causation of earthquakes with tectonic processes will be even more apparent. For while it requires no imagination to appreciate how earthquakes along, say, the San Andreas Fault, are driven by the well-logged relative motion of the Pacific plate, consistency in the direction in which the rotation pole is moved by earthquakes would suggest a much more global bias in favour of earthquakes with particular seismic moments. Chao and Gross ask if the phenomena point to some "behind the scenes" process not yet recognized.

John Maddox