How to tell when the sea rises?

Fears that, if the greenhouse effect is real, we shall drown rather than fry, require better ways of measuring sea level. There is a little progress to report.

THE present wave of interest in the linked problems of the atmospheric greenhouse effect and the integrity of the high-altitude ozone layer that spans the tropopause (see page 102, this issue) has also stimulated interest in what happens when the ice-sheets of Antarctica and Greenland begin to melt. Crude calculations of how mean sea level will be changed are easy enough. What we tend to overlook is that such a process would be novel only in degree, and that the consequences for the level of the oceans of the melting of the ice sheets of the last glaciation are still with us.

So much would have been plain to the participants in a conference on sea-level measurements and their interpretation held in Hawaii last year; some of the papers presented on that occasion have now been reprinted in the *Geophysical Journal* of the Royal Astronomical Society, and serve collectively as a reminder of the several influences that complicate the interpretation of the measurements, with all the complications arising from the need to distinguish mean sea level from the records of tidal gauges which are dominated by the variations due to solar, lunar and planetary tides.

It is remarkable, in the circumstances, that it has been possible to correlate changes of sea level along the south-eastern seaboard of the United States with the speed of the offshore Florida current, and mean sea level around the coast of Australia with a variety of oceanic and atmospheric phenomena, the Southern Oscillation linked with the El Niño phenomenon.

Obviously the time-span covered by a data set is crucial to the use that can be made of it. This is how it has been possible to infer, from tidal records around the margins of the North Sea, which parts of the coastline appear to be shrinking (the coast of England north of the Thames, for example) and which rising (the north coast of the Straits of Dover). But the statistical problems are formidable. People are looking for change of the order of 1 mm a year in data that may be distributed about the mean, after correcting for known seasonal variation, with a standard deviation of a few centimetres. Much of the incentive for the more detailed analysis of the effects of weather and ocean currents on sea level is the hope that it may, thereby, be possible to find meaningful signals in data sets that span shorter intervals. For what it is worth, those who believe that global warming may already be reflected in a steady rise of sea level suppose the magnitude of the change is approximately 2 mm a year.

That is why attention has also turned to the feasibility of direct synoptic measurements of movements of the Earth's surface topography of this order, where radio-interferometers on very long baselines (whence VLBI), already capable of measuring the distance across the Atlantic to within a couple of centimetres, are an obvious starting point.

W.E. Carter of the US Geodetic Survey (*Geophys. J. R. astr. Soc.* **87**, 3–13; 1986) seems to have explained to last years conference the accidental virtue of the US Defense Department's new navigation system (the Global Positioning System, which will have 18 satellites in three different orbital planes soon after the shuttle is in operation again) which has turned out to be a more convenient and cheaper version of VLBI. He offered the prospect that a sufficient density of suitable ground receivers, linked for accuracy with the VLBI network, should be able to monitor the level of tide gauges over reasonably short periods of time, less than a decade perhaps. But, rightly, people will first use this technique at the places where the surface level is changing much more rapidly; the post-glacial rebound of the area of the ex-Laurentian ice-shield (largely north of the Great Lakes) and Fennoscandia, where the change of level of the land surface approaches 10 mm a year (which is why the Great Lakes system is tilting towards the Mississippi Valley by rather more than 2 mm a year).

Another way of tackling the problem of direct measurement is to fix on some global quantity that can be measured accurately, and which depends somehow on the global sea level, so as to infer changes of the latter from measured changes of the former. What kind of quantity will fill that bill? The length of the day is obviously such a quantity, depending as it does on the moment of inertia of the Earth which in turn will depend on the mean sea level. The obvious difficulty is that there are many other influences on the length of the day, including both steady processes (such as the post-glacial rebound of North America) which progressively affect the Earth's moment of inertia, and dynamic processes (in the atmosphere or the oceans) which affect the Earth's rotation impulsively, and appear in the records as noise. How to distinguish all these factors?

Last year's symposium in Hawaii can have been left in no doubt of the difficulties after hearing the paper by W.R. Peltier, R.A. Drummond and A.M. Tushingham of the University of Toronto on the problem of post-glacial rebound (*ibid.* **87**, 79–116; 1986). Peltier is the one who, more than a decade ago, put the subject on a sound footing by showing that post-glacial rebound in North America and Scandinavia can be accounted for only by supposing that the present rate is controlled by viscous processes deep in the mantle of the Earth.

That is a curious tale. The Laurentian post-glacial rebound would not have taken 7,000 years if the compression caused by the loading of the ice had been a near-surface phenomenon. The calculations require that the effects of covering North America with ice would have been apparent 1,000 km or so beneath the surface, and that the rheology of material at that depth would imply a large viscosity. But in the past few years, it has emerged that that may be an illusion, one caused by what seems to be a phase transition at a depth of 640 km and which serves as a boundary through which influences cannot diffuse more quickly than the latent heat of the phase transition can escape.

For the once-glacial parts of the Earth's surface, the direction of sea-level change is determined by competition between isostatic rebound and the filling of the oceans with meltwater (which has long since ceased). In general, the changes involved are an order of magnitute greater than those now of interest — tens of metres per thousand years, not a millimetre or so each year. But much of the interest in Peltier's argument is that he is able to relate, for example, the changing topography of ice-sheets to the process of polar wander. Could it be that the best synoptic lookout for the predicted rise of sea-level after the greenhouse effect begins to bite will be a measurement such as that of the Earth's rotation poles?

Something of the kind is evidently necessary. The obvious indicator of global warming is the temperature of the Earth's surface, but that is even more complicated by noise (and incomplete coverage). But if the oceans act as a temporary sink for heat that would otherwise already be sufficient to make us over-warm, changing sea level might be the first indicator. **John Maddox**