Tectoclimatology comes of age

Computer modellers have successfully simulated the effects of major mountain-building in the past 10 or 40 million years on the climate we now experience.

THAT we should all now be climatologists, if only from our armchairs, is not surprising, with the prospect that an excess of greenhouse heating may provoke climatic change. But there are still virtues in the long view, especially in efforts to understand the causes of the marked climatic changes evident in the fossil and geological records, the Pleistocene glaciations in particular. For who can tell that these are irrelevant to more immediate worries?

That is why a group of three articles in a recent issue of the *Journal of Geophysical Research* (the purple version, discreetly labelled "Atmospheres" on the spine) deserves more attention than it is likely ordinarily to command. The question is whether changes in the topography of the surface of the Earth in the past 40 million years have influenced the climate and, if so, how. That the Late Cenozoic has been marked by profound changes of topography, with the dramatic uplifting of the western third of North America and of the Tibetan Plateau together with the Himalayas, is not disputed among geologists. The surprise is that the climatic consequences can be traced in rich detail by computer models.

That topography (more strictly, orography) should have a regional influence is credible enough. There is a strong thread of surmise going back to the nineteenth century that the summer monsoon in India is partly driven by the rising column of heated air above the Tibetan Plateau. (So much is now confirmed.) Whether the climatic consequences of orogenesis can be global in character as well as extent remains an open question, although the past 40 million years must be as good a candidate as any previous period.

The distinctiveness of this period is put well by W.F. Ruddiman and M.E. Raymo from the Lamont-Doherty Observatory at Columbia University and W.L.Prell from Brown University (**94**, 18, 379-391; 1989). The Tibetan Plateau has been uplifted by up to 4 km in the past 40 million years and by at least 2 km in the past 10 million years. Similarly, two-thirds of the uplift (and southwest tilt) of the Sierra Nevada has happened in the past 10 million years, But much the same applies to the other mountainous provinces of the American West. The Colorado River, for example, has downcut the Grand Canyon by 1 km in the past 10 million years, a third of that in the past 1.5 million years. Many of these tectonic processes, the uplifting of Tibet for example, are still under way, as (in the Southern Hemisphere) are the uplift of the Bolivean Andes and, probably, the New Zealand Alps.

How to model the consequences of these changes? Ruddiman and Prell, with J. E.Kutzbach and P.J. Guetter from the University of Wisconsin at Madison, describe their use of the Community Climate Model (CCM) at the National Centre for Atmospheric Research (NCAR) to tell what happens (**94**, 18,393-407; 1989). The first step is to model the orography then and now, which is a matter of parcelling out estimated Cenozoic uplift into the geographical blocks (4.4° latitude by 7.5° longitude) used by the CCM. There is a "no mountain" case in which present-day mountains are sliced off at 400 metres, a "half-mountain" case in which the added uplift is half of that known to have occurred and a "mountain" case representing the present.

Inevitably, the computer simulations are artificial — true experiments. Only the Northern Hemisphere is modelled. Insolation is fixed for either 16 January or 16 July, robbing the system of the effects of seasonal oscillation. Sea-surface temperatures are held fixed, and no account is taken of changes of the proportion of the oceans covered by ice or, for that matter, changes in the extent of ice-caps (which means that glaciations are excluded). The trick is to run the model for the equivalent of 900 days, exclude an initial transient period and to select 90-day intervals from the resulting record of changing weather so that, when internally averaged, they serve as independent estimates of the climate. The end result is a synoptic representation of average sea-level pressure, wind speed and the like for January and July.

Ruddiman and Kutzbach (**94**, 18,409-427; 1989) take on the task of saying what this means, but some things are clear even from an armchair. First, the pattern of the average wind-velocity is uniform and symmetrical when there are no mountains, but much distorted when there are. With no mountains, planetary waves tend to be anchored at the boundaries between continents and the oceans, but mountains make the high plateaus dominant.

The details will provide endless fascination, not only for climatologists but, for example, for palaeobotanists. Here are some of the inferences to which Ruddiman and Kutzbach commit themselves. The dry-summer mediterranean climate of the western seaboard of North America in mid-latitudes is, for example, caused by the conversion of the westerlies expected with no mountains into northerly winds flowing south from British Columbia to the Mexican border, associated with a deepened pressure low over the Colorado Plateau.

The other side of the Rockies, the other side of that coin is that both seasons are wetter than previously, the winters because the jet stream is shifted south and the summers because of the monsoon flows engendered by the Colorado low. East of the Rockies, the winters are also now colder than 10 or 40 million years ago, chiefly because previously west winds are now northwesterly. Even Florida has not escaped the consequences of the great Cenozoic orogeny; both winter and summer are wetter now.

One sign that the consequences of uplift can be global is the inference that northern European winters are now colder and Mediterranean summers are drier than they used to be. The first effect is a result of the westward displacement of the statistical Icelandic low, the second a distant consequence of the huge cyclonic flow around the Tibetan Plateau and, simultaneously, of a high above the subtropical Atlantic. For what it is worth, uplift has made Central Asia colder and more arid than it used to be.

Part of the interest of the tale is that it can be compared with what is known from the palaeobotanic record. There were, for example, magnolias (which need water in the summer) growing wild in California late in the Pliocene. The disappearance of broad-leaved evergreen forests such as still flourish in temperate southern China is attributed to the severe winters caused by the seasonal influx of polar air.

So what is to be made of the exercise as a whole? Its most striking feature is that such a wealth of detail can be wrung by skilled interpretation from a computer model whose elements are as rudimentary and whose assumptions are as crude. It is presumably now a challenge to see whether the model can be given the extra components of realism necessary to let icefields form, which will require an ocean that plays a part in weather. Meanwhile, there could hardly be a more vivid proof that the world's climate hangs together as a whole. **John Maddox**