with thermotidal forcing, modulated by rapid changes in the atmospheric dust load.

It still is not clear why the otherwise regular seasonal variations on Mars are differentiated by the occurrence of planet-encircling dust storms in some years which in others are replaced by alternating synoptic weather fronts. Leovy *et al.*[3] offer the fascinating conjecture that the two-regime behaviour is a meteorological example of bifurcation (forking), with alternate branches selected by small random fluctuations in the coupling between dust, atmosphere and the polar caps during the preceding seasons. Further study of the Viking data and further space missions to Mars are needed to resolve the riddle. Whatever the answer, it is interesting to have found what could be a branch point in atmospheric chaos signalled by the clearly tuned ring of an almost normal mode. □

Michael Allison is in the NASA Goddard Institute for Space Studies, 2880 Broadway, New York, New York 10025, USA.

Forest ecology

Blow, blow thou winter wind

Peter D. Moore

WINDS of hurricane force (with wind speeds in excess of 33.5 metres per second) are rare in the British Isles, but the storms of last year raised important ecological questions. Of particular interest is the influence of such rare catastrophes on natural woodlands. New studies of forest recovery in North America by Foster[1,2] are pointing to the important role of high winds in temperate forests; they could be instrumental in the creation and maintenance of mosaic patterns and hence the diversity of these woods.

The frequency and strength of wind in the recent history of the Earth's climate has been studied by extrapolation from numerical modelling[3], but more direct information on wind history is also available from fossil sources and from the study of historically documented wind damage to vegetation. In their reconstructions of the history of winds, Hobgood and Cerveny[3] conclude that during the last glacial maximum (about 18,000 years ago) tropical storms generating winds of hurricane force were scarcer, less intense and shorter than those of the present day. As a consequence, less precipitation was brought into some warm temperate areas, such as Florida, which remained fairly arid. But occasional high winds have nevertheless been a feature of the temperate climate throughout the past 10,000 years and could have influenced the development, structure and composition of the migrating and reassembling forests of the mid- and higher latitudes.

Direct evidence of the effects of wind on forests is hard to come by. Perhaps the most convincing comes from the fossil record — tree-trunk alignment in the peaty remains of swamp forests, submerged and preserved beneath the rising sea-levels of coastal lowlands in post-glacial times. A 6,000-year-old fossil forest in mid-Wales (see figure) has been sufficiently well preserved and is adequately exposed at low tide for Taylor to analyse[4] the orientation of 160 fallen tree trunks. There is a strong tendency for alignment along an approximately south-west to north-east axis. It is not known whether individual trees died as a result of a single catastrophic storm or of a strong prevailing wind.

In New England, Foster[1,2] studied directly the effects of a hurricane which in 1938 devastated many forests in the area. The storm was accompanied by heavy rain, generated winds in excess of 55 metres per second and caused damage to forests along a 100-kilometre-wide track northwards through central New England. In the study site, Harvard forest, 70 per cent of the trees had been torn down. Foster shows that the damage is positively related to the age of each stand, and that some species, such as white pine (*Pinus strobus*), are more susceptible to damage than others, for instance hardwood species. Wind susceptibility, however, may vary with season, for trees in full leaf with roots in wet soils are more likely to suffer wind damage.

The regular orientation of fallen timber at Harvard forest is reminiscent of the fossil data from Wales and lends support to the conclusion that the fossil forest was influenced by wind. But the subsequent recovery of the damaged forest in New England has left a mosaic of successional stages, depending on the local physiography and the original vegetation cover.

In the Harvard forest, most trees had been uprooted rather than broken off, which could have been a consequence of the accompanying rainfall and the poorer anchorage afforded by waterlogged soils. The same is true of the British storm last year, which happened after several weeks of very wet weather. Thomas Hardy, in his account[5] of tree planting in the nineteenth century, describes how the roots of saplings were spread towards the south-west to provide subsequent strength in just such times of gales. So victorian foresters in Britain were evidently aware of the dangers of uprooting by wind.

Uprooting, rather than the breakage of tree boles, could be significant for the pattern of subsequent regeneration. In a piece of experimental forest destruction, Collins and Pickett[6] created gaps in hardwood forest in Pennsylvania by cutting canopy and understorey trees at 1 metre above the ground. Herb layer vegetation shows very little response to such gaps. It is reasonable to suppose that soil disturbance is needed if there is to be additional recruitment from the seed bank. Uprooting of trees by wind would be expected to generate a more diverse response in the vegetation, for it would result not only in the creation of a greater range of light micro-environments but also the stimulation of dormant seeds assembled at earlier successional stages.

A woodland affected by periodic winds will therefore consist of a mosaic of recovery stages, micro-successions within the forest that add variety to the range of habitats available to plants and animals within the system. There is a catastrophic storm in New England about once every 100–150 years. In Britain, it may be 300 years since a storm like that of 1987 was experienced. But in natural forest ecosystems, such an infrequent event may be very significant in determining the structure and composition of the canopy and perhaps even the diversity of the ground flora. □

Buried treasure — submerged forest peat at Borth, mid-Wales, contains well-preserved fossils.

1. Foster, D.R. *J. Ecol.* **76**, 105–134 (1988).
2. Foster, D.R. *J. Ecol.* **76**, 135–151 (1988).
3. Hobgood, J.S. & Cerveny, R.S. *Nature* **333**, 243–245 (1988).
4. Taylor, J.A. *Prog. Geogr.* **5**, 247–334 (1974).
5. Hardy, T. *The Woodlanders* (Macmillan, London, 1974).
6. Collins, B.S. & Pickett, S.T.A. *J. Ecol.* **76**, 437–450 (1988).

Peter D. Moore is Reader in Ecology in the Division of Biosphere Sciences, King's College, Campden Hill Road, London W8 7AH, UK.