PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Reflection and Review

J. L. Monteith

Phil. Trans. R. Soc. Lond. B 1989 **324**, 433-436
doi: 10.1098/rstb.1989.0057

Phil. Trans. R. Soc. Lond. B **324**, 433–436 (1989)
Printed in Great Britain

Reflection and review

By J. L. Monteith, F.R.S.

International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India

Reflection

The papers presented at this meeting have given us a comprehensive account of the state of the art in what one is tempted to call 'forest meteorology' though 'meteorological forestry' is probably nearer the mark. Older members of the audience like myself who can recall the descriptive and anecdotal nature of the subject in the early 1950s have enjoyed hearing how it has come of age through the painstaking collection of measurements in the field and through the emergence of principles that have guided the development of mathematical models. Forest meteorologists have been fortunate that much of the foundation of their subject has been laid by the pioneers of agricultural meteorology who have had an easier task experimentally and are therefore a little ahead, but not much!

A psychologist might have felt quite at home at this meeting because there have been so many references to the way systems 'behave'. It seemed that systems were 'well behaved' when processes being observed were consistent with theoretical predictions where they existed, or with intuition where they did not. Bad behaviour (by a forested catchment in Rob Roy's territory for example) meant a discrepancy between performance and expectation. We should remember, however, that the recognition of so-called bad behaviour is the first step towards new developments in most branches of science; and that progress in forest meteorology will depend on the skill and patience of people who feel challenged to tackle the anomalies, the uncertainties and the loose ends that we have heard about yesterday and today.

Closely associated with this somewhat anthropomorphic view of forest meteorology has been the contrast between success in using simple models (e.g. the 'big leaf' canopy) in some analyses and frank admissions of failure in others where essential features are still missing. As one speaker put it 'models are the best way of using physics to sort out the complexities of biological measurements'. He might have added 'and the complexities of interactions between forests and the atmospheric boundary layer', a subject that several speakers have dealt with. I believe that success in modelling depends on identifying what corners can safely be cut without violating the laws of physics or the principles of biology, so that the final product is no more complicated than it needs to be to fit independent observations or to guide decisions for management. None of the models discussed here has been unnecessarily complex, but most speakers have drawn our attention to weaknesses in current models that reveal our limited understanding of how trees and forests respond to the atmosphere and vice versa.

One of the most striking aspects of the papers that have been presented has been the very wide range of scales they have encompassed both in space and in time. In space, we have moved from the functioning of stomata with dimensions around 10^{-5} m to atmospheric processes on a global scale, say 10^{7} m, a range of 12 orders of magnitude. In time, we have been concerned with transfer processes induced by eddies sweeping past sensors in 10^{-1} s or less; but we have also considered the response of trees to climate over annual cycles (1 year $\approx 3\times10^{7}$ s). Dealing with such a broad space-time spectrum makes heavy demands on instrumentation, and the availability of very stable and robust sensors on the ground, in the air and in space has been essential to the success of much of the experimental work described.

Review

I now try to illustrate some of these general reflections by reference to material in specific papers presented at this meeting.

Leuning showed us how simple heat transfer theory can be used to estimate leaf temperature with acceptable accuracy. (This procedure is now well established, but when I used it in my Ph.D. thesis, my external examiner said 'you don't really believe these estimates do you?'; and to avoid his displeasure I said 'no'!) Although scaling up from leaves to tree presented no major problem, even with a chamber, not enough is known about the significance of wakes from neighbouring leaves on transport processes in canopies. This topic was dealt with by Raupach, who described a canopy in aerodynamic terms as 'a vast array of scalar sources each emitting a plume'. Such treatment seems to cope well with the vexed problem of counter-gradient fluxes of scalars, but not so well with momentum transport because of 'wicked feedback, like a snake eating its tail', a good illustration of antisocial behaviour.

Black used the concept of 'coupling' to analyse processes of exchange between an understorey and the microclimate within a forest, reporting that the understorey vegetation had stomata that responded strongly to saturation vapour-pressure deficit. Although this phenomenon is often ascribed to 'feedforward' associated with peristomatal transpiration, I wonder how often it is simply a feedback response occurring when the supply of water to the root system (in competition with trees in this case) is inadequate to meet the demand (albeit reduced by shade). Grace's paper continued the physiological emphasis, speculating about responses to microclimatic variables that may have a strong influence on morphology near the treeline where temperature is critical. There were important implications for climatic change here, which we did not have time to consider.

Climatic change is usually regarded as a physical response to pollution of the atmosphere by man but an increase in the concentration of pollutant gases is also a direct form of climatic change as far as plants are concerned. Fowler and his colleagues from the Institute of Terrestrial Ecology, U.K., showed us how 'deposition velocities' can be estimated for droplets and for gases so that budgets of sulphur, nitrogen and other elements can be drawn up for different types of surface, when the scale and direction of concentration differences are known. In this analysis, relatively simple transfer models appeared to provide estimates of fluxes precise enough to be useful to ecologists and planners.

A different type of climatic hazard – storm damage – was dealt with by Mayer from the Lehrstuhl für Bioklimatologie und Angewandte Meteorologie in Munich (where modern microclimatology began with Rudolf Geiger's pioneering studies of forest climate). He had measured the oscillation of mature conifers in a forest after releasing a force that bent the crown. This large-scale experiment yielded new information about the frequency range of eddies from which swaying trees can extract energy.

On an even larger scale, we then considered the influence of trees on the quantity and quality of water emanating from upland catchments, having been warned by Newson that hydrologists felt they could 'take liberties with environmental science' to make progress with their work. Just when it seemed that the Institute of Hydrology, U.K., had settled the controversy about

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

trees and water supplies in Britain by comparisons of evaporation from catchments at Thetford and Plynlimmon, along came results from Balquidder to raise new doubts and to keep the controversy alive.

Elsewhere in the Institute of Hydrology, consistency is the order of the day. With an excellent set of measurements from the Amazonian forest to refer to as an extreme case, Shuttleworth demonstrated remarkable similarities between stands with different species, for example in terms of the diurnal change of canopy conductance. If Howard Penman had been present, he might have said to the author (as he once said in jest to me) 'you seem to be trying to prove that everything is equal to everything else, everywhere and all the time'. But this was part of his own philosophy and it was interesting to see how well it stood up in this analysis.

Two papers concerned with the usefulness of living trees then followed. Oke dealt with the way in which trees, wisely planted, can improve the microclimate of city streets and parks by providing shade, reducing air temperature, and filtering particles. I was reminded that a former Physical Secretary of the Royal Society, Sir David Brunt, used to walk home across Wimbledon Common, London, with his eyes shut to see whether he could detect the proximity of trees from small changes of air temperature!

Trees forming shelter belts on the farm were the subject of McNaughton's analysis using sets of non-dimensional parameters and variables in an attempt to provide a rigorous basis for interpreting experimental records. Many of these are of limited value, however, because inappropriate instruments such as cup anemometers have been used. The new theory provides a very convenient basis for relating changes in scalar quantities in the lee of shelter belts to their geometry.

The last four papers at this meeting took us well beyond the scale of individual forests to consider how trees contribute to regional climates and how they serve as global reservoirs of carbon. De Bruin tackled exchanges on a regional scale by combining models of the planetary boundary layer and of vegetated surfaces. Although both were treated one-dimensionally, conclusions were plausible except in highly stable conditions. The formidable problem of horizontal inhomogeneity remains, but helpful ideas may emerge from international cooperation on studies of land surface climatology, such as the HAPEX programme in southern France described by Andre. Using information from satellites combined with observations at the surface, the interaction of vegetation with the atmosphere can certainly be analysed in two dimensions and possibly even in three.

Satellite imagery of vegetation has already been linked to annual cycles of atmospheric carbon dioxide in which forests play a major role; this was reviewed by Jarvis. Figures for the amount of carbon stored in the biosphere are becoming more precise and it is possible to predict how rates of photosynthesis by the world's forests are likely to increase as the concentration of atmospheric CO_2 rises ever faster towards a doubling of the pre-industrial level. However, these predictions are made very uncertain by ignorance about possible morphological and physiological responses to CO_2 and about climatic changes induced by rising CO_2, e.g. global warming and shifts of rainfall distribution. To predict such changes, climatologists need better models of the interaction of vegetation with the atmosphere, another tail-eating snake problem.

Finally, we came back to the global scale when Dickinson examined some of the implications of a general circulation model which he developed with Henderson-Sellers in the light of the measurements in the Amazon Basin by the Institute of Hydrology, already reviewed by Shuttleworth. This comparison drew attention to weaknesses in the scheme used to estimate solar radiation. The lessons were clear: global modelling should never run too far ahead of experimental confirmation. The funding of field work remains just as important as support for ambitious modelling exercises.

Synthesis

In this review, I have referred to Professor Rudolf Geiger and to Sir David Brunt, contemporaries whose main contributions to meteorology were made in the first half of this century. Brunt's *Physical and dynamical meteorology* was almost the only comprehensive text available 40 years ago, and Geiger's *Climate near the ground* was unique in microclimatology. There was virtually no material common to these two books because the micro and macro scales of meteorology had not met. Although this meeting was designed primarily to focus attention on forests in relation to weather and climate, it has also demonstrated most impressively that the spectrum of meteorological research is now a continuum. I am sure that both Brunt and Geiger would have found this a most stimulating meeting and would have applauded the speakers as enthusiastically as those attending have done.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES