the spelling process and may be selectively affected following brain damage" but this selectivity may not be truly specific to writing. It is furthermore difficult to imagine that the direction of the effect could be reversed in other patients. Roberto Cubelli has shown that a dysgraphic patient could write that name as R B R T C B LL ; but the odds do not appear favourable that we shall ever find his name transcribed as O E O U E I. □

John C. Marshall is in the Neuropsychology Unit, University Department of Clinical Neurology, The Radcliffe Infirmary, Oxford OX2 6HE, UK.

CLIMATE CHANGE

Is water vapour understood?

R. L. Jones and J. F. B. Mitchell

On page 244 of this issue[1], Kelly and colleagues describe a marked imbalance in the water to be found in winter in the upper tropospheres of the Northern and Southern Hemispheres. The observation may have considerable implications for modellers attempting to forecast the course of climate change.

Water vapour is the single most important greenhouse gas[2-4]. In the vapour phase in the upper troposphere it modulates the outgoing longwave radiation, and is an integral part of the formation of clouds, which affect both the incoming solar and outgoing longwave radiation fluxes[5]. Concentrations of water in the atmosphere are expected to change in response to changes in concentration of other greenhouse gases. For example, as increases in carbon dioxide warm the surface and atmosphere, more water evaporates from the surface and remains in the atmosphere. In fact the amount of water vapour which can be held increases exponentially with temperature. Because water vapour is such a strong greenhouse gas, this increase traps more longwave radiation, further warming the surface and troposphere and so amplifying the initial warming. This feedback is very significant and can increase the original perturbation by as much as a factor of two[6] in the absence of other feedbacks.

It is thus vital for climate prediction models to be able to predict reliably changes in the global water vapour distribution. Hence an important test of any climate model is its capacity to reproduce the present distribution of water vapour and the extent to which it incorporates the processes which control water vapour in the atmosphere.

Global measurements of the total water content do exist[7], and there are measurements in cloud-free conditions Equatorward of 60 degrees[8]. Kelly *et al.* now present new and highly accurate measurements of water vapour in the upper troposphere at latitudes poleward of 40 degrees. Although these are as yet only for winter months, they provide fresh information on the global distribution of water and, as the authors show, offer insights into the mechanisms which control water concentrations in the upper troposphere.

In their paper, the authors present measurements of water vapour in the upper troposphere and low stratosphere of both hemispheres obtained from hygrometers on board a DC-8 and an ER-2 aircraft. The measurements themselves are striking in that they show that, at middle and high latitudes throughout the upper troposphere and lowest stratosphere, in winter there is two to four times more water vapour in the Northern Hemisphere than in the Southern. Kelly *et al.* then describe a case study which shows that dryness in the upper troposphere of the Southern Hemisphere at mid-latitudes can result from large-scale transport of that mid-latitude air to polar regions. There, adiabatic ascent occurs, cooling the air sufficiently to dehydrate it to the concentrations of water vapour observed at mid-latitudes. In essence, the authors' argument is that the observed interhemispheric water difference is a direct consequence of different polar temperatures in the upper troposphere of the two hemispheres in winter.

It is important to establish whether current climate models reproduce this asymmetric interhemispheric distribution of water (which incidentally does not appear so markedly in the relative humidity), and whether they incorporate the dehydration mechanism Kelly *et al.* describe. Together with G. Cookmartin, we have analysed results from a general circulation model (GCM)[9], run for another purpose, to consider these questions. In the GCM simulations it was found that at high latitudes (polewards of 65 degrees) there is an asymmetry in the water vapour concentrations in the upper troposphere in the same sense as, but less marked (only up to a factor of two) than, that in the observations. At lower latitudes in the GCM, this asymmetry in the concentrations declines and even changes sign.

There are, of course, a number of difficulties with such a comparison. First, the model diagnostics used were seasonal and zonal (or ocean only) averages and were thus not strictly comparable to the authors' data which had different geographical and temporal sampling. Because of this limited coverage there is also a question of the representativeness of the authors' data. For these reasons it is not yet possible to establish whether the discrepancies represent a fundamental limitation of the GCM. Clearly though, the data provide an important and stringent test of it.

The notion raised by Kelly *et al.* of dehydration of middle and upper tropospheric mid-latitude air in polar regions also raises some interesting questions. In GCMs, local water vapour content is controlled by a variety of processes, including condensation and evaporation, which depend strongly on local temperature, and transport of more or less moist air from elsewhere. It is important for the accurate simulation of the water vapour distribution, and the calculation of the water vapour feedback, that the balance of these controlling processes is correctly reproduced by the model. As Kelly *et al.* point out, there are indications that the flows in numerical models of the atmosphere tend to be too zonal in character[10]. If so, and if the contribution of Kelly *et al.*'s mechanism for dehydration is substantial, this balance may not be correct and, for example, GCMs will tend to restrict any water asymmetry to high latitudes, a feature of the results described above.

If, as Kelly *et al.* suggest, polar temperatures control water vapour concentrations at mid-latitudes, because mid-latitude and polar tropospheric temperatures respond similarly to climate forcing[2,11] the simplistic conclusion is that current GCMs may still have the correct water vapour feedback in the extra-tropics, but for the wrong reason. The authors' main achievement, however, is to have demonstrated the value of accurate water vapour measurements in the upper troposphere for assessing climate models, and thereby show the need for a more systematic study. □

R. L. Jones is in the Department of Chemistry, University of Cambridge, Cambridge CB2 1EW, UK. J. F. B. Mitchell is in the Hadley Centre for Climate Prediction and Research, Meteorological Office, Bracknell, Berkshire RG12 2SZ, UK.

1. Kelly, K. K., Tuck, A. F. & Davies, T. *Nature* **353**, 244–247 (1991).
2. Houghton, J. T. *et al. Climate Change: The IPCC Scientific Assessment* (Cambridge University Press, 1990).
3. Raval, A. & Ramanathan, V. *Nature* **342**, 758–761 (1989).
4. Mitchell, J. F. B. *Rev. Geophys.* **27**, 115–139 (1990).
5. Ramanathan, V. *et al. Science* **243**, 57–63 (1989).
6. Manabe, S. & Wetherald, R. T. *J. atmos. Sci.* **24**, 241–259 (1967).
7. Prabhakara, C. *et al. J. appl. Met.* **21**, 59–68 (1982).
8. Rind, D. *et al. Nature* **349**, 500–503 (1991).
9. Smith, R. N. B. *Q. Jl R. Met. Soc.* **116**, 435–460 (1990).
10. Tuck, A. F. *et al. J. geophys. Res.* **94**, D9, 11181–11222 (1989).
11. Manabe, S. *et al. J. Climate* **4**, 785–818 (1991).