At first sight, the good old cup of tea hardly seems a likely arena for performing ground-breaking science experiments. Indeed, in a highly rigorous survey, 100% of the respondents (my four lab mates) said they would rather just drink the stuff than study it. But the events that take place in the average cuppa are more exciting than most people realise. Specifically, the tea currents in the cup can closely mimic, in microcosm, many of the complex flow phenomena exhibited by the earth’s atmosphere.

It turns out that there is a very intimate connection between the fluid dynamics of a freshly stirred cup of tea, and those of an atmospheric rotation on a rotating planet. It does not matter that tea vortices are only a few centimetres across, whereas typical atmospheric vortices can measure thousands of kilometres. The underlying balance of the physical forces can be the same, and that is all it takes for the governing equations to be mathematically similar. So every time you stir a cup of tea (or coffee) you are running a miniature atmospheric simulation. This invariance in the equations of motion is called ‘dynamical similarity’, and has been known about since at least the nineteenth century. It is a concept of great importance to meteorologists, since it allows conclusions to be drawn about atmospheric phenomena by making observations of the analogous flows in the laboratory.

Vettin (1884) was probably the first person to exploit dynamical similarity, by carrying out rotating laboratory experiments as analogues of atmospheres on rotating planets. He studied the surface flow in a rotating pan of fluid with a lump of ice near the centre, representing a polar ice cap, and (to the scorn of many of his contemporaries) drew meteorological conclusions from his results.

The main benefits of studying atmospheric flows indirectly in the laboratory are that the system is under the complete control of the experimenter; that global high-resolution measurements can be taken systematically; and that experiments can be repeated as many times as required. None of these statements hold when the atmosphere is studied directly. Indeed, it seems clear that we should not want to perform experiments on the real atmosphere, for fear of what the consequences might be if the experiment goes wrong! Dynamical similarity allows us to conduct experiments on miniature ‘atmospheres’ in the laboratory without the many approximations of computer models; without the risks of tampering with our climate system; and with a guarantee that our conclusions will be applicable to the real atmosphere so long as the dynamical similarity principle holds.

Following in the footsteps of Vettin and many subsequent workers, I have spent the past four years exploiting dynamical similarity to draw meteorological conclusions, in pursuit of my DPhil. Admittedly, for practical reasons, my experimentation vessel was actually a bucket-sized steel cylinder rather than a teacup. I didn’t really use tea as the working liquid either, but the principle is exactly the same. A photograph of the apparatus is shown in Fig. 1. The cylinder has a diameter of 25 cm and a depth of 25 cm. A second cylinder, of smaller diameter, has been inserted at the centre of the main cylinder, for practical reasons, and the liquid representing the atmosphere is the bright region which fills the annular gap between the two cylinders. The apparatus is mounted on a rotating turntable to mimic the rotation of the earth, and the tall metal frame supports a video camera which views the system from about 2 m above.

The aim of the laboratory experiments has been to investigate some of the properties of atmospheric waves. Existing high above
on a very small scale, in the laboratory experiment of Fig. 1. Experiments can be performed in which groups of inertia-gravity waves develop in the vicinity of a strong, Rossby-like wave, and one can watch in detail what happens as they attempt to impede its progress. The whole affair is captured on videotape for subsequent analysis. A typical still from the video footage is shown in Fig. 3, clearly showing two groups of inertia-gravity waves (one at ‘12 o’clock’ and one at ‘6 o’clock’) co-existing with a Rossby-like wave (responsible for the near-elliptical shape of the central blue-coloured region). The flow visualisation technique first described by Hart and Kittelman (1986) has been used to produce these coloured maps of the waves. It is interesting to compare the inertia-gravity waves in the atmosphere (Fig. 2) with those in the laboratory (Fig. 3). That waves on such dramatically different scales (around a centimetre in the laboratory and a few kilometres in the atmosphere) can appear so similar in form is testament to the power of dynamical similarity.

We have performed over 200 hours of experiments using the laboratory apparatus, and by carefully analysing the video tapes we have been able to come to conclusions about the circumstances under which the inertia-gravity waves appear, and the dynamical mechanisms by which they are generated. Such issues would have been much more difficult to investigate by looking at the real atmosphere. Importantly, we were also able to study the impacts of the inertia-gravity waves on the large-scale wave with which they coexist. We found that the inertia-gravity waves may be able to have a significantly stronger impact than has previously been thought. There are circumstances in which, via a phenomenon known as stochastic resonance, the inertia-gravity waves can dramatically alter the probability of a change from the state shown in Fig. 3 to that shown in Fig. 4. Transitions such as this seem to occur much more readily in the presence of inertia-gravity waves than in their absence. Our findings are backed up by computer simulations, and are described more fully in Williams et al. (2003).

Since time immemorial, fortune tellers have enchanted us with claims of ability to predict a person’s future. This has often been done by studying the swirls in their cup of tea, as manifested by the shapes of tea-leaf deposits at the bottom of the cup. It is pleasing that the atmosphere’s fortunes can now be told in a similar fashion, and that the scientific basis (for this augury at least) is sound. Cup of tea, anyone?

Fig. 2 Atmospheric inertia-gravity waves in the night sky. In this case, the waves are visible from the surface of the earth because they are travelling within a noclitucent cloud. Had the surrounding air not had such a large water vapour content, condensation might not have occurred, and then the wave would have remained invisible to the human eye and passed by unnoticed.
Acknowledgements

This article is based on a prize-winning entry in the New Scientist Wellcome Trust Science Essay Competition 2002. The work was carried out under a research studentship from the UK Natural Environment Research Council, held at the University of Oxford, with award reference number GT04/1999/AS/0203. The author wishes to thank his supervisors, P. L. Read and T. W. N. Haine. The photograph in Fig. 2 was taken by Dr S. Kirkwood, Dr P. Dalin and Dr A. Moström of the Swedish Institute of Space Physics in Kiruna.

References


Correspondence to: Dr P. D. Williams, NCAS Centre for Global Atmospheric Modelling, Department of Meteorology, University of Reading, PO Box 243, Earley Gate, Reading RG6 6BZ. e-mail: p.d.williams@reading.ac.uk © Royal Meteorological Society, 2004. doi: 10.1256/wea.152.03

Fig. 3 Experimental image taken by the video camera which views the apparatus in Fig. 1. The tank rotates in the anticlockwise direction. The image can be interpreted by imagining that the North Pole is at the centre, and that the large outer circle represents the equator. A water–oil liquid fills the tank, and different colours in this image correspond to different heights of the interface between the water and oil – blue corresponds to a high interface, and yellow to a low interface.

Fig. 4 A second experimental image taken by the video camera. This time, there are three wavelengths of the Rossby-like wave around the globe, as opposed to two in Fig. 3. Inertia-gravity waves seem to play an important role in inducing transitions between states such as those shown in Figs. 3 and 4. Although the atmosphere explores a significantly more chaotic regime than is seen in the laboratory experiments, it seems likely that atmospheric inertia-gravity waves might play a similar role in forcing local transitions.