later, during the further development of the tRNA molecules. This eventuality has interesting implications, including the possibility of early polypeptide replication and even reverse translation[11]. In any case, the development of the classical code as a "frozen accident" (ref. 12) becomes more easily understandable if it was superimposed on a more fundamental, deterministic code.

Finally, the two codes are linked by the physical association of anticodons and paracodons in the same tRNA molecules. □

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Fluid dynamics

Meteorology of a flat Earth

Ian N. James

In a recent paper[1], D. L. Boyer and R.-R. Chen claim that several features of the climate flow in the Northern Hemisphere can be reproduced in a laboratory apparatus. Their experiment involves towing models of the Rockies, Himalayas and Greenland through a rotating tank containing stratified salt solution to represent the troposphere. Such an arrangement differs from that of the real Earth in several respects, most important of which are the absence of spherical geometry and of temperature gradients. The experiments, however, successfully reproduce the main troughs and ridges of pressure found in association with the Rockies and Himalayas (see figure), and a characteristic oscillation with a period that corresponds to one of about 40 days which has been identified in atmospheric data[2].

The experiments reported were carefully designed so that 15 dimensionless parameters take similar values to those characterizing atmospheric circulation. These include measures of rotation rate and stratification. Of course other parameters such as those measuring the typical horizontal temperature gradients and the curvature of the Earth could not take atmospheric values. Both these, but especially the latter, are generally accepted as being crucial in accounting for the observed patterns of troughs and ridges in planetary-scale flow. The most successful theories of the longitudinal variations of the mean flow are in terms of steady trains of 'Rossby' waves excited by mountain ranges and land–sea contrasts[3].

The most remarkable results of the experiments are the successful reproduction of the troughs and ridges associated with the Rockies and Himalayas, and the characteristic oscillation. This oscillation period is close to the time for elements of fluid to circumnavigate the apparatus; its persistence implies that dynamical processes continually replenish the eddy energy of the travelling disturbances.

A rotating fluid supports various kinds of wave motion, characterized by different frequencies. The kind of waves excited by a mountain depend on the typical frequency with which it deflects air parcels. In the atmosphere, it takes a day or two for air to pass over mountain ranges such as the Rockies, with the result that mainly low-frequency 'Rossby' waves (north–south transverse waves) are forced. Internal gravity (or buoyancy) waves have much shorter periods, in the range 10–20 minutes, and so are not significantly excited. Air flow over much smaller hills (such as individual ridges and valleys within the Rockies) is on this sort of timescale and there has recently been renewed

Horizontal streak pattern from the dish-pan experiment of Boyer and Chen. The solid white objects are the forms representing the Rockies, the Himalayas and Greenland. (From ref. 1.)

interest in the gravity waves forced by the roughness of the main mountain ranges[4]. But in the laboratory experiments, Rossby waves could not exist because they require curvature — absent from the system — to propagate. Without any substantial wave propagation, disturbances would be confined to the region close to the artificial mountains; it must be that other kinds of wave motion generate the distant effects observed. The question remains whether Boyer and Chen obtained their apparently realistic results through the operation of very different dynamics. The radiation of stationary internal gravity waves would seem to be a possible mechanism.

The reproduction of a 40-day oscillation is interesting. Current theories of the oscillation suggest it is an essentially tropical phenomenon, driven by the interaction of Kelvin waves (buoyancy-driven edge waves trapped on the equator) with latent heating in convective cloud systems. The problem with this theory is that most computer models designed to test it produce an oscillation with much too short a period. Triggering by disturbances in the mid-latitude flow, with an essentially advective timescale, could be important in increasing the period to that observed.

The paper is thought-provoking; the issues it raises are perhaps rather philosophical. In particular, I worry about the validity of laboratory analogues of geophysical flows. That Chen and Boyer's experiments leave out certain important effects present in the atmosphere does not matter — it could help to separate important from secondary effects. But diagnosis of the flow must be subtle enough to distinguish dynamically significant parallels from merely superficial resemblance. I question whether they have succeeded.

More fundamentally, ensuring dynamical similarity may not be enough. The boundary conditions and geometry of the apparatus could also be important. This is certainly true in the case of the radiation of Rossby waves from mountains. The reflection of such waves from the rigid walls of a laboratory apparatus contrasts with the behaviour of such waves as they propagate into the Earth's tropics. As the westerly winds of the mid-latitudes are replaced by the easterlies typical of the tropics, a 'critical line' where the local flow speed matches the phase speed of the Rossby waves is encountered. The behaviour of the wave train near the critical line is complex and poorly understood. If enough dissipation is present, it will be absorbed. In inviscid flow, a highly nonlinear, amplitude-dependent partial reflection may occur[5].

Laboratory studies have an honourable history in geophysical fluid dynamics. But one can question whether they continue to be a fruitful line of enquiry. Only when geometrical as well as dynamical similarity can be guaranteed will they provide exact analogues. Technical and practical difficulties rarely allow this. On the other hand, the more abundant geophysical data now available, interpreted in conjunction with mathematical and numerical models of varying complexities, do enable the fluid dynamics of natural geophysical fluid systems to be explored[6]. □

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