The width-height ratio of large convection cells

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According to KRUEGER and FRITZ (1961), one of the outstanding features calling for explanation in the cellular cloud patterns revealed by satellites is that the diameter-to-depth ratio is around thirty, instead of about three as predicted by classical theory and verified by laboratory experiments. It seems to the writer that, assuming the cells to be of the Benard type, the most direct and simple possible cause of the change in geometry might be found in the anisotropy of the sub-cell scale of turbulence. At the least it seems worth while at this stage to consider what such an explanation would entail.

The classical theory shows that the ratio of cell width to cell height is independent of the physical properties of the fluid (see e.g. STOMMEL, 1947). But this no longer holds when the "braking role" played by molecular conductivity and viscosity is taken over by turbulent counterparts. The latter will be denoted by constants, K_x and K_y in the horizontal and K_z in the vertical (the fact that they will normally be functions of position and state need not concern us here). They enter the equations of motion and heat conduction exclusively through operators of the type

$$\frac{\partial}{\partial t} - K_x \frac{\partial^2}{\partial x^2} - K_y \frac{\partial^2}{\partial y^2} - K_z \frac{\partial^2}{\partial z^2}. \qquad (1)$$

The relativity of their effects will accordingly be preserved if the x, y, z scales are altered in proportion to $K_x^{\frac{1}{2}}$, $K_y^{\frac{1}{2}}$, $K_z^{\frac{1}{2}}$ respectively. Thus the change in geometry is broadly accounted for provided

$$K_x, K_y \gg K_z. \qquad (2)$$

Physically, the overall part played by K_x and K_y is to strive to reduce the temperature and velocity differences between the ascending current A and the descending D (see Fig. 1). K_z operates in the same way as between the low level inflow or outflow L and the return current R. Now in all the individual cases described by Krueger and Fritz there was a common feature in that a well-defined inversion was found at quite a low level (800 mb or thereabouts). This was surmounted by a statically stable layer into which, in the only case where cloud heights were reported, the rising currents penetrated a considerable distance. If the return flow takes place mainly in the stable region, K_z will operate across a stabilizing barrier and K_x and K_y more or less parallel to the barrier.

The inequality (2) is not a general property of turbulence, but it may well be a general property under conditions of stable stratification. It certainly holds under these conditions for the only two well-documented scales of atmospheric turbulence, namely the heat and momentum transporting scales of the boundary layer and of the general circulation. There seems then every reason to expect it to be true of whatever scales are dominant in the eddy viscosity and conductivity in the present context. Nor, by comparison with the other cases referred to, does a ratio of order 100 between K_x and K_z appear excessive, so that a tenfold geometrical distortion in the sense observed is not unreasonable.

Over land there is normally some set of local circumstances which concentrate the strong convection before the stage is reached at which regular cells can develop. Moreover strong low-level instability over land results from diurnal heating whilst over sea it can only occur as a consequence of advection (PRIESTLEY, 1957). If the present explanation is correct, and bearing

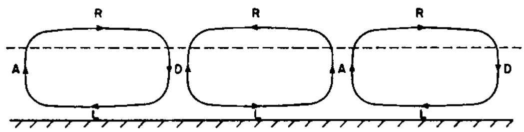

Fig. 1. Schematic diagram of cellular circulation.

in mind that penetration of a stable layer constitutes a part of it, it would seem likely that the phenomenon would be found mainly, or even solely, over the oceans: and the major change in geometry would be a feature of shallow polar outbreaks which have managed to reach areas of warm waters without too much warming on the way. Krueger and Fritz mention that many other examples of large cells have been observed. They do not, however, indicate whether all show a similar change in geometry and it would be interesting to see this factor studied against the type of synoptic parameter here suggested to be relevant.

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