QUARTERLY JOURNAL
OF THE
ROYAL METEOROLOGICAL SOCIETY

Vol. 79 JULY 1953 No. 341

REVIEWS OF MODERN METEOROLOGY—10

551.558.1 : 551.576.11

Convection in the atmosphere

By F. H. LUDLAM and R. S. SCORER
Imperial College, London

CONTENTS

1. THE PROCESS OF CONVECTION

Motion in the atmosphere originates almost entirely through the action of gravity on masses of air that are differently heated. At the one extreme is the motion of the pressure systems and at the other is the small-scale stirring motion, usually called turbulence, which very largely originates through the degeneration of motion of a larger scale. In between is the overturning motion in which the vertical velocities are comparable with the horizontal ones. This kind of motion, which is therefore restricted to dimensions not greatly exceeding the depth of the troposphere, is our main concern. We shall not deal with the synoptic situations in which this overturning occurs, nor with the results except in so far as they affect the motion itself, but we shall see how far this complicated process can be comprehended in simple terms.

The fundamental idea of buoyancy was clearly understood by Archimedes (*c.* 220 B.C.), and although the formulation of Newton's laws of motion made it possible for the science of hydrodynamics to advance enormously, the study of convection has lagged far behind. There are even signs that it might be split into two parts, on the one hand *hydrostatics* and on the other *turbulence*, and most of the concepts used in thinking about convection have been derived from one or other of these. An exception to this is the study of *convection cells*. Most of the work on this aspect of convection has been described by Brunt (1937 and 1939) who gave to Bénard the credit for having first recognized cellular motion and studied it seriously. Since 1939, treatments of convection cells have tended to become irrelevant to the motion in the atmosphere.

Since glider pilots began in the 1920's to develop the art of *thermal soaring* they have been, somewhat unwittingly, the chief source of information about the nature of convection currents, and powered aircraft, in spite of their ability to carry instruments and go to any chosen position, have not yet outstripped gliders as a means to discover more about thermals. If the emphasis of effort in aviation had been on ability to remain airborne rather than on speed and independence of the weather, there would undoubtedly be aircraft in existence today which would be ideal for meteorological exploration. As it is, a convection cloud is regarded by aviators as a sometimes hazardous region of bumpiness and possible icing rather than of interesting and helpful motions.

The study of heated jets attracted much attention in the 1940's, particularly in connection with fog dispersal, and had much influence on meteorological thought, particularly in America which was far from the birthplace of thermal soaring in Germany. Finally, the atomic bomb cloud has provided some ideas on the subject, but it can scarcely be said that it demonstrates anything relevant to our problem that cannot be seen in ordinary cumulus clouds.

Because there has so far been no synthesis, and some contradictions of viewpoint have arisen from these various lunges into the field from one side or the other, our chief aim is to present a unified picture of what happens during the process of convection. We shall not discuss the complications which arise when precipitation is formed inside convective clouds.

2. Slow convection

2.1 *Cellular patterns*

Convection occurring in a cellular pattern has been extensively studied on account of its relative simplicity. The pattern is stationary and the motion steady. The mathematical theory has been concerned with a layer of gas confined between two rigid conducting surfaces or with a shallow layer of liquid. The purpose of the theory has been to find the shape of cell that occurs most easily, and it has been assumed that the temperature gradient through the layer is uniform and is slowly increased until convection begins, and that then the transport of heat is maintained at the minimum required to keep the motion going. Acceleration of the motion is prevented by the molecular viscosity which destroys shear and by the molecular conductivity which destroys horizontal temperature gradients produced by the motion.

Laboratory studies by Walker and others (described by Brunt) have been concerned with the same conditions and the cells have been rendered visible by smoke in gas or metallic dust in liquid. It has been possible by applying a relative horizontal motion to the bounding surfaces of the gas or by having a wind across the liquid surface to arrange the cells in a rectangular pattern or to distort the cells into longitudinal or transverse rolls. Jeffreys (1928) suggested that longitudinal rolls, in which the direction of rotation