CHAPTER - I

INTRODUCTION

1. A Brief Survey of the History of the Cumulus Problem.

The thermodynamic investigation of clouds is centred around the moist adiabatic process. The classical theory of the moist adiabatic process, which, despite its deficiencies, still represents the basic process upon which all refinements must be made, provides a simple tool — the thermodynamic diagram — to deduce the cloud properties at any level. In applying thermodynamics to the study of the nature of vertical motions of the cloud air in the atmosphere, it visualises the updraught as being unaffected by the environment through which it ascends so that there should be no transfer of heat and mass either of water or air between the parcel and the environment. A further assumption is that the latent heat of condensation (or of evaporation) should be exchanged so rapidly between the condensing water vapour (or evaporating water) and the air that no temperature differences will develop.

In addition to the above assumptions the classical theory envisages two types of adiabatic variations of state of moist air. The first process, termed the saturated adiabatic process, was discussed by Hertz (1884) and Neuhoff (1900) on the assumption that the products of condensation are retained with the air, none being precipitated as rain or snow. Hertz considered four successive stages of the dynamic cooling of moist air :

the gaseous stage when the air remains unsaturated and no condensation is taking place; the rain stage when the air is saturated with water vapour and condensation of water vapour occurs while the temperature is above the freezing point; the hail stage when the temperature reaches 0°C and the condensed water which has been carried up by the ascending air freezes; and the snow stage when the temperature is below the freezing point and the air is saturated with respect to ice so that the water vapour sublimates on ascent. This process is strictly reversible for if the moist air and condensed or frozen water products are again brought downward, evaporation of these water substances uses up at each stage the same amount of latent heat as is released by condensation (and/or freezing) on their ascending motion.

On the other hand the pseudo-adiabatic variations of state of the moist air as envisaged by Wilhelm Von Bezold (1888) are irreversible, since in this process all the products of condensation are precipitated. This means a loss of mass and since the precipitated mass of condensed water substances takes its part of entropy with it, the process ceases to be isentropic. Further, in this process the latent heat of fusion is excluded. However, it has been shown by Fjeldstad (1926) and others that the differences which arise according as we regard the products of condensation as falling out or being retained are so small as to be negligible in practice.

The influence of this line of thinking has led to the neglect of the effect of the products of condensation on the thermodynamics of the convective clouds. Unfortunately, we are not yet in a position to have a definitive reformulation of the thermodynamics of moist air, in spite of the fact that a large volume of work has been done to explain the processes that lead to the formation and development of precipitation in clouds. In the absence of such a reformulation, we can, however, hope to have some sort of refinement of the basic moist adiabatic process, whereby we can take account of the influence of liquid water on the thermo - and hydro - dynamics of clouds. While the latter effect is caused by the weight of the liquid water the former effect stems from the fact that the liquid water is dispersed into drops and droplets and condensation (or evaporation) takes place on (or from) such drops and droplets.

Even in the discussion given by Schmaidt (1943), while revising and checking the fundamental concepts of the classical theory of the moist adiabatic process, no attention has been paid to the above aspects. He has merely considered (i) the cloud adiabatic, in which all the condensed water is retained and carried up with the rising air currents (ii) the general pseudo-adiabatic variations, in which part of the water drops out, and part is carried along with the rising air currents and (iii) the special pseudo-adiabatic process according to which all the water falls out. The first process may be true so long as the drops do not grow to precipitation size, that is so long as the liquid water is dispersed into a large number of small droplets which remain suspended, and are borne away by the ascending air currents, and the third process does not occur in nature. In nature, the normal process is the second one. However, the percentage of water which falls out varies widely with the atmospheric conditions, so that no general rule can be given for its computation. Hence the "general pseudo-adiabatic changes" introduced by Schnaidt can not be given in an explicit form.

In explaining the sourse of energy of the convective clouds Refsdal (1930) and Normand (1938) have considered the pseudo-adiabatic ascent of a parcel of moist air to obtain a representative temperature of the parcel, with the help of a thermodynamic diagram, and the cause of all the buoyancy of the parcel has been ascribed to this temperature — thereby excluding the effect of liquid water on the buoyancy of the cloud parcel. Even when it is found that this simple parcel theory of the growth of convective clouds, in terms of the classical theory of the moist adiabatic process, over - estimates the heights of the tops of the cumulus clouds the liquid water has not been considered as a possible causative factor in reducing the buoyancy of the parcel. An explanation for such an over-estimation has been sought in the "slice method" advanced by Bjerknes (1938) and Petterson (1939). The slice method takes into account the fact that an ascending air parcel is surrounded by air which must descend in order to preserve continuity of mass. However, this does not show where or over what extent the sinking motion of the compensating currents will occur. A suggestion has been given by some writers that the sinking motion may be distributed over such a wide area, extending beyond the region of convection, that its effects are not appreciable.

Stommel (1947) has suggested an "entrainment" model of cumulus, that explains the observed heights of the tops of the trade-wind cumuli which are much below the level which cloud air could reach if it rose as a non-interacting adiabatic parcel. Further, the theories of entrainment due to Austin (1948), Houghton and Cramer (1951), Haltiner (1959) and others have tended to regard the observed average lapse rates steeper than the saturation adiabatic lapse rate and the less than adiabatic liquid water content inside the clouds as entirely due to entrainment — thus ignoring the effect of liquid water.

Departing from the conventional approach, Scorer and Ludlam (1953) have evolved a model of convection in which the rising saturated current consists of an aggregate of buoyant bubbles of air. According to them a buoyant bubble, as it rises, lifts the dry environmental air above it, which cools adiabatically and so begins to sink along the surface of the bubble. This sinking environmental air causes "erosion" from the bubble cap and produces beneath the rising tower a wake of turbulent air which is a mixture of cloud and environmental air. While in the entrainment model that the major reduction of vertical momentum relative to that of the non-interacting parcel has been assumed to arise from buoyancy reduction by dilution, in the bubble theory no dilution of the bubble cap has been assumed and all loss of vertical momentum has been thought to take place by means of form drag. Thus, although a mechanism for entrainment has been suggested, no thought has been given to the effect of liquid water in reducing the violence of convection. However, this is understandable since the bubble model is concerned with the growing stage only and has not attempted to discuss a precipitating cloud.

Thus, this brief survey of the history of cumulus problem reveals how the role of the products of condensation, which themselves have been considered to be the products of thermodynamical processes, on the life cycle of convective clouds has not been recognized while much importance has been given to the processes of mixing and entrainment. However, by holding this view, we do not mean that the processes of mixing and entrainment are unimportant. There is no doubt about the importance of such processes in reducing the excess temperature difference between the cloud air and environment, and in modifying the other properties of the convective clouds. We only wish to point out that some of the differences between the observed properties of the clouds and those predicted by the simple non-interacting adiabatic parcel theory are, at least, to some extent the natural consequences of the assumption, underlying the classical theory of the moist adiabatic process,