General Aspects of Parameterization of Cumulus Convection

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Cumulus convection affects the large scale atmospheric motion in three ways:

1. It heats the atmosphere by the release of latent heat,
2. It provides vertical transports of heat, of moisture and of momentum and
3. It modifies the short-wave and long-wave radiation, thereby changing the atmospheric state.

By means of these effects cumulus convection becomes important for the development of tropical and extra-tropical disturbances, which have been the subject of many papers in the last 15 years. Cumulus convection also has an important influence on the general circulation by generating zonal available potential energy. Zonal available potential energy A^Z is most efficiently produced if the heating decreases with latitude as

$$\frac{\partial A^Z}{\partial t} = \int \gamma \, [Q]'' \, [T]'' \, dm, \qquad (1)$$

$[Q]''$ and $[T]''$ are the deviations of the zonal means of heating rate and of temperature from the global mean values, γ is a stability dependent parameter and the integration is made over the whole mass of the atmosphere. As is seen from Fig.1, heating by latent heat release changes drastically with latitude, having a maximum at the equator in the mid-troposphere and another weaker maximum at mid-latitudes in the lower troposphere. The equational heating is mainly associated with convection, whereas the mid latitudinal heating is more related to large scale processes. As the condensational heating shows larger latitudinal variation than the heating by radiation and by surface fluxes (Fig. 1), the latent heat release contributes more to the generation of zonal available potential energy. At low latitudes the generation of available potential energy A^Z is almost entirely due to convection. The total amount of generation of A^Z as derived from observational data by NEWELL et al (1969) is shown in Fig. 2. Note the large contributions near the equator caused by convective heating. The contribution of convective heating to the generation of available potential energy was mentioned here because it also seems important for medium range weather prediction. This has been confirmed by numerical 10-day forecast experiments at the ECMWF where two different parameterization schemes have been tested. It was found that when one parameterization scheme was replaced by another scheme, which gave less latent heat release by about 40%, the generation of zonal and eddy available potential energy was also considerably smaller. This in turn affected the conversion rate from potential to kinetic energy and thereby the dissipation rate, which were both reduced; the conversion from potential energy to kinetic energy by as much as 40%.

Parameterization of cumulus convection

Cumulus convection must be parameterized in models which only resolve scales larger than those of convective elements. The scale of convective elements ranges from about 100m for shallow clouds up to 10km for cumulonimbus or even up to 100km for organized mesoscale convective patterns. This rather large range has consequences for mesoscale models when cumulus convection must be included.

Parameterization of cumulus convection in mesoscale models

The scale of mesoscale motion ranging from 1km to 10^3km overlaps with that of the larger convective elements, so that for instance deep convection cannot be parameterized, i.e. taken into account as a statistical contribution from a large ensemble of convective elements, but instead can probably be included explicitly in models which have a grid length of a few km. Consequently, there have been several attempts in the past to consider explicitly deep convection in mesoscale models, recently by ROSENTHAL (1978), who used a 20km grid point model to simulate the development of a hurricane. As subgrid scale moist convection is not considered in this model by means of parameterization, latent heat is released on the resolvable scales only. ROSENTHAL's experiment shows that the grid scale moist convective processes remove conditional instability sufficiently well. Also, a realistic simulation of a hurricane development is obtained from the latent heat release. Moreover, the explicit treatment of convection in a mesoscale model enables us to study the interaction of convective motion with the larger scale motion and may therefore lead to improvements in parameterizing cumulus convection in large-scale models.

Parameterization of cumulus convection in large-scale models

Various moist convection schemes have been designed for large-scale models in the past. Some of them are listed and briefly described in the appendix of the introduction. None of the present schemes has proved to be valid as not enough is known about the interaction between cumulus convection and the large-scale flow. It is also doubtful whether all the different types of convection observed in the atmosphere can be parameterized by only one scheme or whether several schemes must be used in models to cover the different convection processes. Convection differs with regard to

vertical extension (shallow - deep convection)

horizontal extension (isolated cumulus - stratocumulus - mesoscale convection patterns) forcing (diurnal insolation over land, heat transfer in cold air outbreaks over warmer sea, mass convergence at squall lines, orography, etc.)

In Fig. 3 the cell-flatness (ratio of diameter to depth of convective cells) is plotted against convective depth for various convective phenomena observed in the atmosphere. The open cells and the closed cells which both belong to the mesoscale are generally observed in polar air moving over the warmer sea (AGEE (1976)). Very little is known about the processes forcing the different mesoscale cloud patterns. The variation in the width-height ratio may be caused by the anistropy of turbulence (PRIESTLEY (1962), AGEE(1976)).

As our present knowledge about the different types of convection observed in the atmosphere is poor, the schemes used in large-scale models have been designed on rather simple arguments.

One class of schemes is based on the idea of convective adjustment. Given a layer of conditional instability, convection is assumed to take place and to bring the atmosphere back to a neutral state. This assumption is made in the moist convection adjustment scheme (MANABE et al. (1965)) and is also implemented in the scheme proposed by ARAKAWA and SCHUBERT (1974).

Use of this type of convection scheme implies:

Conditionally unstable stratified layers cannot exist in the model. This is not so in the atmosphere, where unstable layers can persist for a rather long time. The existence of unstable layers does not necessarily imply convection. Furthermore, the adjustment is made instantaneously in the model, which may affect the moisture and heat budgets, as the vertical transfer of moisture and sensible heat may be unrealistic. McGREGOR (1977) reports on problems when applying the ARAKAWA-SCHUBERT scheme. It turned out that it was necessary to spread the adjustment over several time-steps in order to guarantee convection occurring over deep layers.

Other schemes, such as the KUO-type convection scheme, are based on the hypothesis of deep convection. In KUO's scheme (KUO (1965, 1974)) convection is assumed to occur in regions of conditionally unstable stratification and moisture convergence due to the large-scale flow and due to evaporation from the surface. The KUO-scheme, which was designed for simulation of tropical cyclones, agrees in this respect with the CISK-theory, which is now generally accepted. FRITSCH et al. (1975) has tested this assumption on observations at a squall line associated with intense, deep convection. They found that only about 40% of the rainfall rate can be explained by the large-scale moisture convergence. They concluded that convective transports may be strongly related to the potential buoyant energy rather than to the large-scale convergent flow. CHO (1975) found that KUO's scheme gives realistic vertical distribution of released latent heat in disturbed areas in the tropics, but an unrealistic effect on the moisture field. He also found that the total amount of precipitation is too small.

In contrast to KUO, ARAKAWA and SCHUBERT (1974) consider in their scheme a spectral distribution of clouds. The vertical mass flux of cloud type λ at pressure level p is given by

$$m(\lambda,p) = m_B(\lambda)\ \eta(\lambda,p)$$

where $m_B(\lambda)$ is the massflux at cloud base and η represents the vertical variation of the massflux due to entrainment and detrainment. OGURA and CHO (1973) calculated the spectral distribution of the massfluxes at cloud base for the averaged summertime conditions over the Marshall Islands area, which is shown in Fig. 4. A similar distribution was found for the REED and RECKER's (1971) composite wave by CHO and OGURA (1974). The main results obtained by CHO and OGURA are:

> The cloud spectrum of the cloud base mass-fluxes shows a bimodal distribution with maximum values for shallow clouds and for deep clouds.
>
> The total cloud mass flux at cloud base is linearly correlated to the large-scale vertical velocity for deep clouds, whereas there is no similar dependency found for shallow clouds.

The ARAKAWA-SCHUBERT scheme has been verified against observational data by S. LORD (submitted paper to this Workshop). He found that the effect of deep clouds on the temperature and moisture fields are underestimated, whereas it is overestimated for the shallow clouds.

The presently available parameterization schemes consider only the thermodynamical effects, mainly through latent heat release, but neglect the effect by convective momentum transport. Convective momentum transport is likely to be important for the simulation of the general circulation and probably also for medium range weather prediction. Unfortunately, not much progress has been made to consider convective momentum transport in models, mainly because very little is known about it from observations. However, results obtained from cumulus cloud models may provide a basis for parameterization in large-scale models (see submitted papers for this seminar by MILLER and MONCRIEFF).

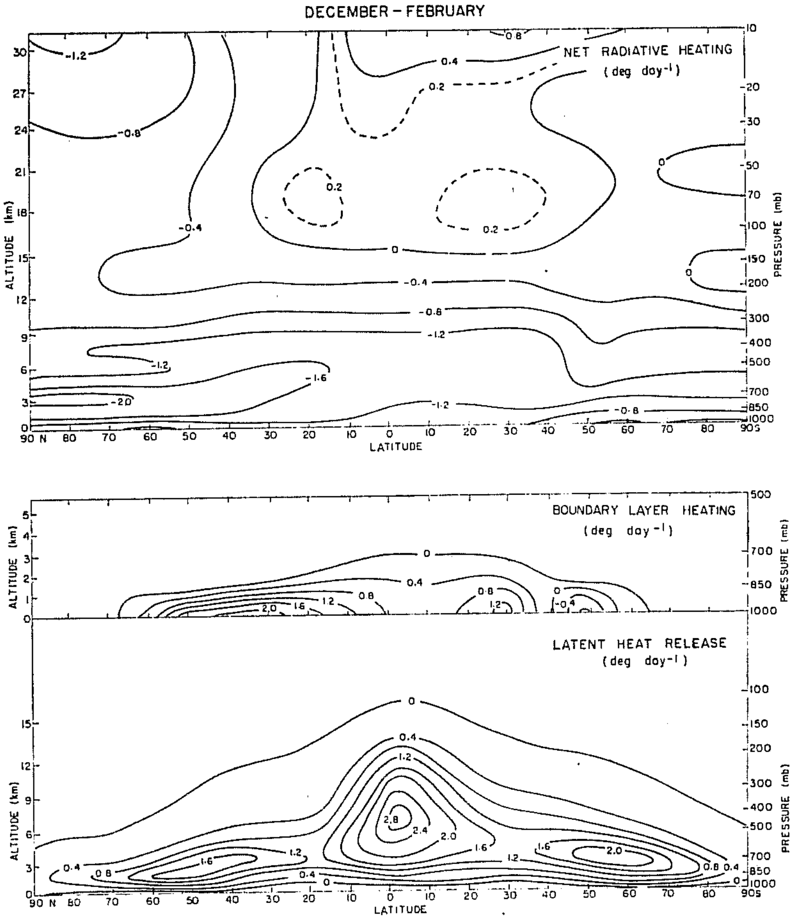

Fig. 1 Components of diabatic heating for the atmosphere for December-February. Units: deg day^{-1}. (Taken from NEWELL et al. (1969)).

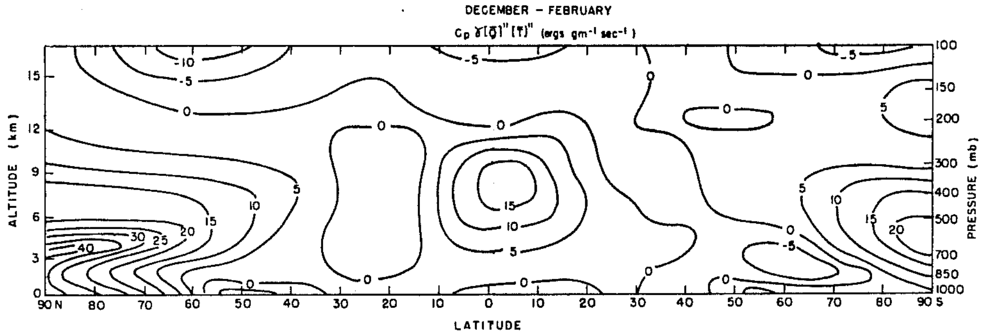

Fig. 2 Integrand of Eq.(1) for December-February Units : ergs gm^{-1} sec^{-1}. (Taken from NEWELL et al. (1969)).

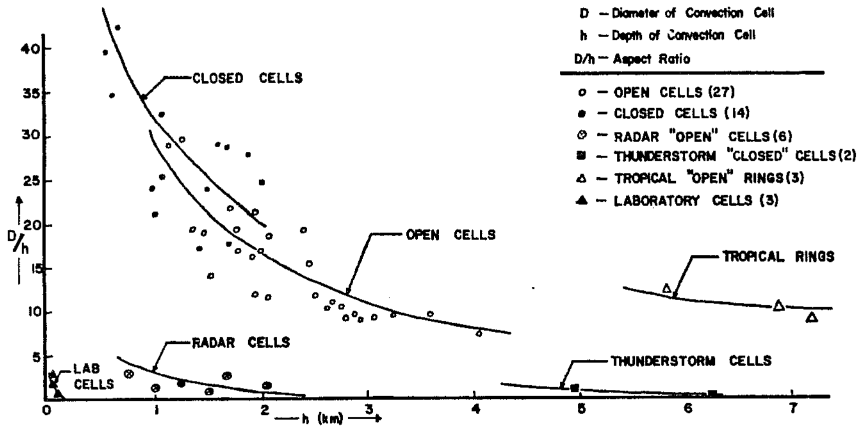

Fig. 3 Scatter diagram of the aspect ratio D/h (or cell flatness) plotted against convective depth, based on observational case studies of various convective phenomena. (Taken from AGEE (1976)).

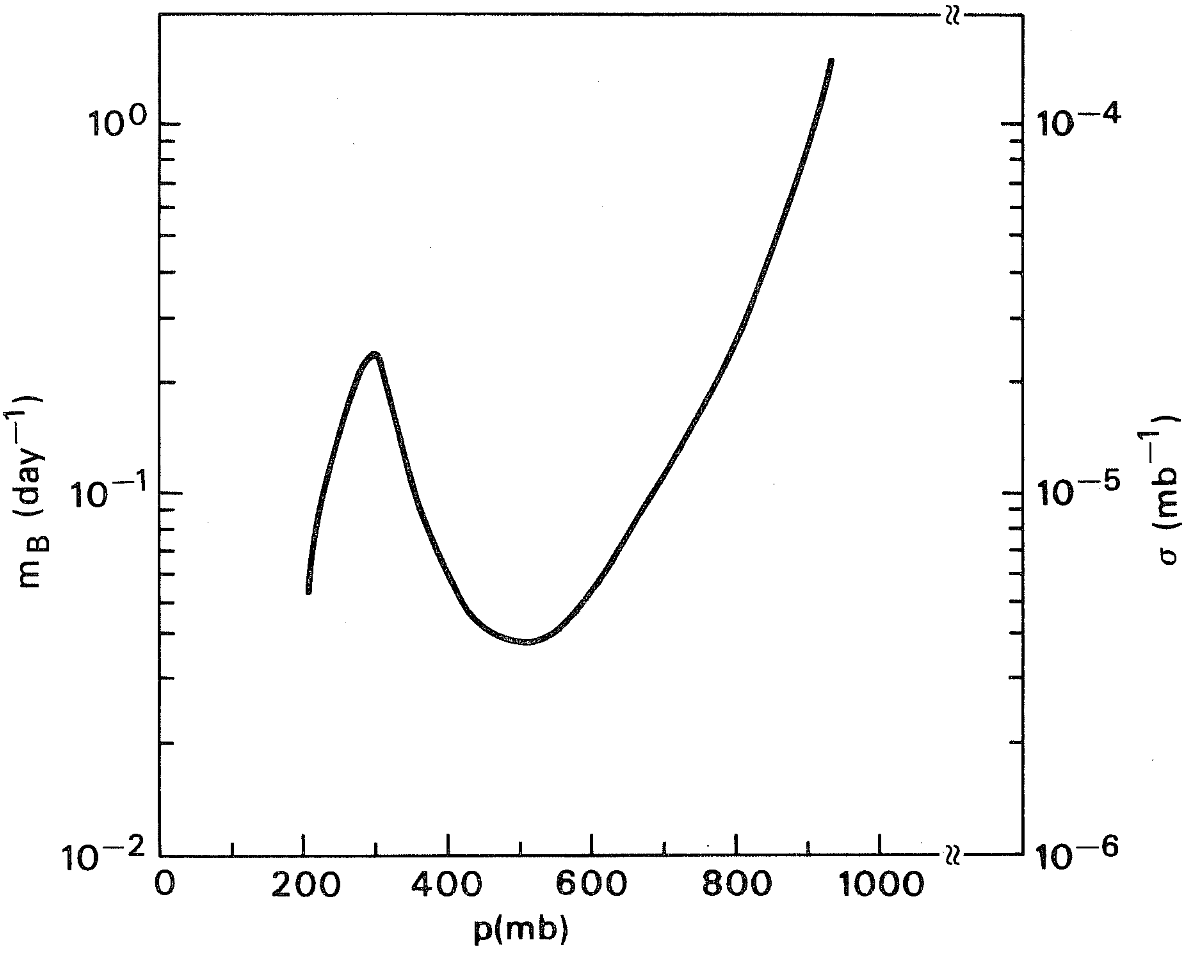

Fig. 4 Cloud spectrum distribution as a function of cloud top height for an average tropical summer condition over the Marshall Islands area.
(Taken from Cho, 1975).

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