TECHNICAL MEMORANDUM

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A note on the release of precipitation in numerical prediction models

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Introduction

In most numerical weather prediction models the condensed water vapour is immediately precipitated. This is not in strict agreement with what really happens in the atmosphere, where the condensed water may stay suspended in the air as clouds, and may later either evaporate or form larger, precipitable drops or ice crystals.

In the following we indicate a procedure by which some of these shortcomings may be cured in a rather simple way. The method is based upon a few concepts in cloud physics which will be reviewed very briefly.

More sophisticated methods are available (Sundqvist, 1977), and may very well give better results. The virtue of the present procedure is that it is fairly simple to implement in most models.

Cloud water

Assuming that the product of the condensation is small water droplets or ice nuclei which are suspended in the air, one obviously may assume that q, the mixing ratio of water (all three phases taken together) is conservative, as long as no liquid or frozen water is removed (precipitated). The "cloud water" mixing ratio, used in the following, is defined as

$$q_{cw} = 0 \quad \text{if} \quad q < q_s(p,T)$$

$$q_{cw} = q - q_s\,(p,T) \;\text{if}\; q > q_s(p,T)$$

where $q_s(p,T)$ is the saturation mixing ratio of vapour. Therefore, q_{cw} is at any time defined by the values of q, p and T, and need not be carried as an additional variable.

There are two important processes to be considered separately:

a) The precipitation which removes water from the air.

b) The variation in the content of latent heat, which may produce heating or cooling of the air.

In the following we shall first discuss the former process. Later on we discuss briefly how the latter may be implemented.

Ice nuclei: Precipitation may be triggered by ice nuclei in the uppermost part of the cloud. The nuclei grow quickly and fall through the cloud, sweeping up the cloud droplets. Ice nuclei are abundant as soon as the temperature of the cloud reaches values between -12 and -16 ^{o}C. A simple way of taking this into account in the model is to define a threshold value for the cloud top temperature, and assume that precipitation starts as soon as this temperature is reached.

Coalescence: Several mechanisms may act to create somewhat larger droplets (20 - 30μm). These larger droplets have larger fall velocity than the smaller ones and will start to collect them. If the vertical velocity of the air is large enough, the droplets may be lifted to greater heights during this process, but eventually start to fall down through the cloud, reaching the cloud base as rain. The process is very complicated and not fully understood, but a few facts stand out quite clearly:

a) The intensity of the coalescence increases as the number of droplets per cubic meter increases.

b) A thick cloud layer is more effective in forming rain droplets than a shallow one.

c) No precipitation is observed from cloud layers less than about 1 km deep.

As a simple synthesis of these points we propose to use the precipitable cloud water (PCW) as a single threshold value to decide if rain is formed in the cloud by coalescence. It may be defined by

$$P_{cw} = \int_{p_t}^{p_b} q_{cw} \, g^{-1} \, dp$$

and obviously depends strongly on air temperature and thickness of the cloud layer.

Mixing: Above it has implicitly been assumed that the cloud is formed by lifting of the humid air mass. However, clouds may also be formed by turbulent mixing and radiation, especially in the surface boundary layer. Such clouds are unlikely to produce rain, but drizzle may be formed by coalescence. How much precipitation is produced in this way is difficult to assess, and few relevant observations are available. Mason (p.311) states that "liquid water content greater than 0.4 g/m^3 is rarely exceeded in layer clouds". Since there seems to exist such an upper limit to the amount of cloud water in these clouds, it must be either because the cloud-producing effects in general are small, or else that the drizzle produced by coalescence prevents the water content from becoming larger. However, here, as in the rest of the book a "layer cloud" seems to mean "not convective cloud". Little distinction is made between layer clouds formed chiefly by mixing and radiation, and those formed by large-scale lifting, although one would think that the two types behave quite differently in relation to the release of precipitation. We propose to treat all types of non-convective clouds in the same way, mainly because we are ignorant about what special methods to use.

Threshold values: According to the evidence referred to above, a threshold value for the cloud top temperature most appropriately may be placed somewhere in the range -12 to - 16 $^{\circ}$C, we propose -12°.

It is much more difficult to assess the similar value for the PCW, since theoretical cloud physics and observations are insufficient on this subject. Assuming that the clouds are formed in a steadily rising air current, the stationary value of condensed vapour may be computed, knowing the pressure and temperature of the condensation level. This we have done, using some cases of reported precipitating water clouds listed in Mason's book. The value of PCW in these cases varies from 2.2 mm to 10 mm. We choose to place the threshold value at 2 mm or 2kg m^{-2}.

The amount of precipitation: Generation of precipitation by ice nuclei is considered to be very effective, and for that reason we assume that all the PCW is removed from the air column as soon as the process starts. In case of coalescence, however, it is not at all obvious that this approach is correct. On the contrary, it seems reasonable that the precipitation stops as soon as the concentration of droplets gets below a certain limit, not much different from the threshold value for the onset of precipitation. Therefore, we assume that only the PCW in excess of the threshold value is precipitated, and that this is achieved by removing the same fraction of the cloud water content at each level.

Clouds in more than one layer: If the precipitation is triggered by the cloud top temperature, we propose to remove all the PCW from the column, allowing evaporation of rain/snow to take place in the cloud-free layers.

In the case of coalescence the PCW may be computed for each cloud layer. If the threshold is reached for one layer, precipitation is removed from this layer in the usual way, but a similar fraction is removed also from the cloud layers underneath.

Latent heat: According to the present proposal, the release of latent heat is not directly tied to the release of precipitation, so that the changes between the phases of water in the atmosphere must be computed independently.

In essence, this amounts to computing the material rate of change of q_s. If clouds exist ($q > q_s$), there will be a corresponding change in latent heat content which has to be accounted for by a change in air temperature.

Convection: Similar threshold values may be used in the parameterization of convection in order to decide whether precipitation is coming out of the clouds. However, the attention now should be focussed on the individual cumulus rather than a mean value over a grid square. For that reason we propose that the PCW should be determined differently. A simple approach is to compute the steady-state water content of a column of cloud formed in ascending saturated air which is not allowed to precipitate or mix with the dry surroundings, i.e.

$$P_{cw} = \int_{p_b}^{p_t} (q_b - q_{sa}\ (p)_{T_b})\ g^{-1}\ dp$$

where p_b and p_t is the pressure at the bottom and top of the cloud, respectively; $q_{sa}(p)_{T_b}$ is the saturation mixing ratio along the moist adiabat having the temperature T_b at pressure p_b, and q_b is the mixing ratio at the base.

The cloud water content so computed is known to be an upper limit which is never reached in nature. However, measurements show that the water content comes closest to this limit in clouds with strong updraft. Therefore, we consider this definition of the PCW to be quite appropriate for cumulonimbus clouds.

Another definition may be more obvious in Kuo's parameterization scheme where the clouds are thought of as being formed by adding water vapour and liberated latent heat to the surrounding air. The PCW could then be related to the total amount of released latent heat in a unit column of cloud air, i.e.

$$P_{cw} = \frac{c_p}{L} \int_{p_t}^{p_b} \left\{ T_{sa}(p\ ,\ T_b) - T_e(p) \right\} g^{-1} dp$$

where $T_e(p)$ is the temperature of the surrounding air. However, since this is not the way convective clouds are created in nature, we consider the former definition to be more appropriate.

If the convective cloud is not allowed to precipitate, one may assume that the droplets evaporate and thereby using the heat previously released. Hence, the result of the cumulus convection in this case is to moisten the atmosphere above the condensation level.

References

Mason, B.J.: "The Physics of Clouds", Second Ed. 1971, Clarendon Press, Oxford.

Sundqvist, H.: "Atmospheric Condensation and Modelling its Non-Convective Regime". "The Parameterization of the Physical "Processes in the Free Atmosphere, ECMWF Seminars 1977, pp. 91-159.