Adaptations to ALADIN of the Lopez micro-physical package

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1. Introduction

Our ongoing development of a parametrization set combining the convection with other moist physical schemes required to get a suitable micro-physical package.

We started from the one developed by Ph. Lopez (2002) in the frame of ARPEGE-Climat, and dedicated to "resolved" or "stratiform" clouds and precipitation.

2. Original scheme

The original Lopez scheme uses two prognostic variables : a total specific cloud condensate q_c and a total specific precipitation content q_P. However, in each of the micro-physical routines, a diagnostic phase partition is estimated. For the condensate, it assumes a progressive transition of the ice fraction between two temperatures (e.g. -10 and -40 °C). For the precipitation, a nearly step transition at 0 °C is considered (actually it may extend over several levels to avoid that the associated cooling brings the local temperature below 0°C).

The package works as follows :

1) A resolved condensation scheme, base on Smith (1990), yields a condensate tendency and a resolved cloudiness.
2) This tendency is added to the original condensate content (advected from the previous time-step), to yield a transitional value before precipitation.
3) A parametrization estimates the rate of auto-conversion of this condensate to precipitation.
4) The auto-converted part is subtracted from the condensates and added to the prognostic precipitation content, which is then advected vertically in a semi-Lagrangian way. The instantaneous q_P as well as the total precipitation crossing a layer in one time-step are used to compute the precipitation evaporation and the collection of the cloud condensate by the precipitation. For the latter, one distinguishes the aggregation of cloud ice by snow, the accretion of droplets by rain, and the riming of droplets by snow.
5) Some corrections may be brought to the tendencies of the water specific contents to prevent the occurrence of negative values.

The package implied to adapt the expression of the tendencies, to include additional fluxes : condensation fluxes, precipitation evaporation fluxes, both with their associated heat fluxes; a precipitation melting heat flux, and fluxes associated to the precipitation content evaluation : a flux of precipitation generation, and a flux of precipitation evolution, including the different processes they experience during their fall.

The progress of our scheme led us to make several adaptations to the original routines.

First, it appeared advisable to use separate model variables for cloud ice and liquid water. This distinction is essential for radiative properties, and for further refinements of the micro-physical description. At the same time, the use of a full prognostic variable (advected by the mean model wind) for precipitation content seemed less important. In a first step, we replaced it by a pseudo-historic variable, i.e. a passive memory of the values from the previous time-step, with no resolved advection. Later, we found it better to suppress completely the precipitation content (see below). Using separate model variables for cloud ice and liquid water implied to reassess the treatment of the mixed phase : each of the different micro-physical processes tends to modify the phase partition, so that we must care for restoring it at the end, to prevent an unrealistic situation.

We were also confronted to some flaws or hidden approximations in the original scheme. Seen the difference in phase partition for cloud particles and precipitation, cloud droplets may be converted (either by auto-conversion or riming) into falling snow : the released latent heat was not taken into account.

The semi-Lagrangian vertical advection of the precipitation content posed several problems.

The auto-conversion is applied at once at the beginning of the time-step, instead of considering a continuous feeding. It is possible that some layers directly below the cloud receive zero advected content, because the origin of the trajectory is above the cloud. On the other hand, the evaporation calculation is based on the total precipitation crossing the layer, and applied to the final advected content. When the latter is zero, it results into a negative final content. The problem is that the evaporation should be based on the conditions along the trajectory, not at the arrival point. Finally, the resulting precipitation contents could not be directly related to the precipitation fluxes, which posed serious conceptual problems for introducing a downdraught calculation.

3. Scheme adaptations

3.1 The condensation scheme

A peak of condensation was observed near the 0 °C isotherm, associated to the cooling by the melting of the precipitation. To limit this, a smoothing of the temperature profile around the level of the triple point may be applied; the number of levels above and below may be chosen in the namelist.

Unwanted condensation could also occur near the lowest model level, consecutive to the cooling by the downdraught. We introduce the possibility to use there the arithmetic mean with the surface temperature, which in this case is higher than the air temperature.

3.2 The auto-conversion routine

The rather intricate calculation coded by Lopez has been replaced by a more transparent formulation.

An integrated Kessler formula yields the decrement of cloud water content due to auto-conversion. For liquid condensate q_l, it writes:

$$\Delta q_l = q_l^x \left(1 - e^{E_l \Delta t}\right) \qquad \qquad if \quad q_l > q_l^x$$

where E_l is the auto-conversion efficiency for droplets. In presence of ice, the threshold for liquid auto-conversion q_l^x is lowered to zero.

Subsequently, an auto-conversion gain GWBFAUT, associated to the Bergeron-Findeisen mechanism is applied :

$$\Delta q_l = \Delta q_l^x \left(1 \; + GWBFAUT \cdot E_l \cdot \alpha_i\right)$$

where α_i is the ice fraction in the cloud.

In the mixed phase, the ratio of water to ice must be maintained, so that the final ice content may be derived from the final liquid content. In the pure ice phase, a Kessler integrated formula also holds, but the auto-conversion efficiency is made dependent on the temperature. We introduced additional parameters to tune this dependence.

3.3 The precipitation routine

Given the above-mentioned problems with the precipitation advection routine, we proposed a simpler and more clearly justified approach.

The auto-conversion alone yields a gross precipitation flux P_{au} (which may also include a pseudo-historical flux memorized from the previous time-step), from which we derive :

- the total precipitation crossing the layer in one time-step :

  $$q_{Ptot} = P_{au} \frac{g \Delta t}{\Delta p}$$

  (this makes the hypothesis that the precipitation generation varies slowly enough in time so that even the lowest layers are crossed by a flux corresponding to the present auto-conversion in the layers above)

- the instantaneous densities of snow and rain in the layer :

$$\rho_{Ps} = \frac{P_{au}\alpha_{snow}}{w_{Ps}} \text{ and } \rho_{Pr} = \frac{P_{au}(1-\alpha_{snow})}{w_{Pr}} ,$$

where w_{Ps} and w_{Pr} are the fall speeds of snow and rain, which are assumed constant and may be chosen in the namelist, α_{snow} is the solid fraction of the precipitation.

These quantities allow to compute first the evaporation/sublimation processes, and afterward, the different collection processes.

We now consider that the evaporation/sublimation, occurs in the clear part of the grid box, but only the part of it under a "precipitating" area, which can be estimated from the cloud fractions at different levels. In the original scheme, the same collection efficiency was assumed for aggregation of ice and riming of droplets by falling snow : we introduced separate tunings.

3.4 The final corrections.

An adaptation of the mixed phase composition is performed after the precipitation. It implies a melting/freezing flux and an associated heat flux, between solid and liquid condensate.

The adaptation of the tendencies to prevent negative specific contents has been adapted to :

- extend the treatment to the cloud water variables,
- forbid cloud ice above the triple-point temperature.

4. Conclusions

Most adaptations described above appeared useful or necessary during our work on the integrated scheme for clouds, precipitation and convection, after controlling the profiles and behaviour of the cloud water phases or other associated variables.

We think to have got a more realistic behaviour, together with a reduction of the cost, mainly by suppressing the heavy advection calculation. Now more systematic tests and comparisons should be performed to validate the adapted package.

5. References

Ph. Lopez : Implementation and validation of a new prognostic large scale cloud and precipitation scheme for climate and data assimilation purposes, *Q. J. R. Meteorol. Soc*., **128** (579), 229-258, 2002.

R. N. B. Smith : A scheme for predicting layer clouds and their water content in a general circulation model, *Q. J. R. Meteorol. Soc.*, **116**, 435-460, 1990.

J. C. H. van der Hage : A parametrization of the Wegener-Bergeron-Findeisen effect, *Atmos.Res.*, **39**, 201-214, 1995.

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