Reformulation of the deep convection scheme for prognostic cloud water in Aladin

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In the quest for higher resolution and better representation of the physical phenomena, introducing cloud water variables is an important challenge.

Most propositions in the literature are aimed to large scale or Global Circulation Models, and focus on the so-called "stratiform" or resolved clouds.
The coherent treatment of this topic in the frame of a meso-scale model and in particular the links with the subgrid convection parameterisation is not yet very satisfying. In particular, using a "stratiform" cloud water scheme while keeping an independent "deep convection" scheme which ignores the cloud water or directly generates its own precipitation, leads to physical contradictions, prejudicial to a good understanding of the model behaviour and its realism.

Hence, beyond the basic decisions about the choice of the prognostic variables, we decided to take the problem the other way round, focusing first on the deep convection scheme in order to get a coherent cloud water package.

1 The micro-physical scheme

It should include

- at least separate cloud ice and cloud liquid water, as their mechanical, hydrological and radiative behaviour are quite different. Precipitation water could also be considered.
- a realistic micro-physics treatment: taking into account most important processes (auto-conversion of condensate to precipitation, different kinds of aggregation processes, evaporation, sublimation, melting/freezing of precipitation, Bergeron effect,...) and the effects of large scale as well as subgrid sources *and sinks* of condensate.

We based our developments on a completed version of Lopez [2001]'s scheme, because it uses simple and acceptable hypotheses, without dangerous assumptions of subgrid homogeneity which would restrict it to large meshes. It implements prognostic cloud condensate and precipitation content, the latter being advected vertically within the parameterisation.
Phase separation was done internally and diagnostically; for Aladin, we introduced separate prognostic variables for ice and liquid water, and simplified the treatment of the precipitation content (this will be described in a subsequent paper).

2 Features needing revision in the operational convection scheme

- All condensation was immediately converted to precipitation, which could either re-evaporate below the cloud or in the downdraught, or reach the surface in one time step.
  When introducing cloud water, the deep convection scheme should rather be a source of condensate, while the micro-physical scheme is responsible for generating cloudiness and precipitation. This touches following items:
  - Energy calculations: effective latent heats were used covering the assumptions on immediate precipitation of all condensate and its potential replacement by dry air.
    Remark that the heat exchanged in this process was affected to the updraught at the level the precipitation was generated (as if the precipitation fell within the updraught), while at the same time the updraught was not perturbed at all by falling precipitation.

- No condensate was present in the air entrained into the draught, and draught condensate was evaluated from a diagnostic relation.
- Water and heat budgets ignored any suspended condensate.
- Convective cloudiness was derived from the convective precipitation fluxes.

- The closure of the subgrid scheme stated that large scale moisture convergence was channeled into the updraught. This is physically difficult to imagine: what occurs actually is that grid box air is pulled into the draught, pushed by (or pulling) large scale flow convergence.

- The interaction of subgrid and large scale schemes was a big problem.
  We observe that

  - the large scale vertical velocity (i.e. mean grid box vertical velocity) induced "resolved" condensation;
  - the deep convection scheme understood that the mean vertical velocity raised from a nearly zero environment velocity and a much bigger updraught vertical velocity. This was represented by considering a *pseudo-subsidence* around the updraught, compensating the mean grid box velocity, so that the net environment velocity stays close to zero outside the updraught.

  If the "resolved scheme" keeps considering the mean grid box vertical velocity, it contradicts the hypotheses of the subgrid scheme and we make a *double count* of the precipitation.
  The natural way to solve this is, to *take into account the pseudo-subsidence* when computing the resolved condensation, rather than modulating more or less empirically one of the two schemes.
  The method of subtracting the large scale precipitation convergence from the moisture convergence flux also implied some superimposition principle, which is abusive for such non linear schemes.

- Downdraught hypotheses:

  - The downdraught was following an entraining moist pseudo-adiabat, fed by precipitation evaporation. But it could only be switched on by prior evaporation (resulting from the layers budgets in the updraught calculation), which lacks of realism.
  - Real downdraughts entrain dry air from above, and are not entirely saturated: so the guessed profile is not realistic, nor the downdraught mass flux, mesh fraction and vertical velocity. This limits the possibility of tuning by comparison of these parameters to observations.
  - The closure was rather arbitrary, assuming that a fixed fraction of the precipitation generated by the updraught had to be evaporated. If the updraught does no longer produce precipitation but condensate, such a treatment becomes impossible.
  - The local mass budget was inconsistent (the mass flux being arbitrarily shaped by a given function, while the detrainment and entrainment are taken completely independently of this).
  - The resolved precipitation did no contribute to the downdraught, which might not survive the end of the updraught.

  This lead us to plead more and more insistently for the complete separation of the updraught and the downdraught.

3 Main features of the proposed scheme

In our anterior work [GERARD, 2001], we introduced prognostic variables for the updraught and downdraught vertical velocity and 2D mesh fractions (representing a vertical mean over the active layers). The present work takes advantage of these developments, but we decided to focus on the updraught and to introduce 3D mesh fractions, to better fulfill local mass budgets. The downdraught is now completely separated and will be the object of further developments.

- The updraught profile is (as before) a moist entraining pseudo-adiabat, built diagnostically (i.e. we still obtain the properties by building a whole profile from the bottom, while the parcels at upper levels would have actually followed the profile that was at previous time steps); the production of condensate along this path gives us access to the updraught condensate content, and a simple phase partition is used in function of temperature.

- A prognostic motion equation yields the updraught vertical velocity; the large scale flow will advect the difference between the updraught velocity and the resolved vertical velocity.

- The updraught mesh fraction *profile* σ_u^l is obtained by writing *local mass flux continuity.* The detrainment process is parted into two contributions:

  - A constant detrainment rate δ over most of the equivalent draught ascent: the budget equation yields the tendency of σ_u^l.
  - Organized detrainment starts at the level where the fluid begins to decelerate. We diagnose this level by the conjunction of a decrease of the absolute value of ω_u and of the buoyancy force. From there, σ_u^l is kept constant up to the top of the updraught, and the detrainment calculated accordingly.

  Effective detrainment rates can the be estimated, for the final budgets, as well as to feed the micro-physical scheme.

- The layer budget can now provide pseudo-subsidence diffusion fluxes for both moisture and enthalpy, as we no longer consider precipitation fluxes at this stage.

- Usually the detrained condensate acts as a direct source in the micro-physical scheme.
  But we 'd like personally to release the hypothesis that the detrained condensate from the updraught mixes in 1 time step with the full grid box. Therefore, we considered to pass the detrained condensate separately to the routine computing the auto-conversion of condensate to precipitation, as the properties of this condensate could significantly depart from those of the "stratiform" condensate, supposed more homogeneously distributed.
  For the rest, we assume no precipitation occurs within the updraught mesh fraction itself, while this fraction is always overcast.

The new scheme also requires a wider re-structuration of the order of the different parameterisations. Layer budgets and downdraught computation occur after the micro-physical calculations, and the downdraught now feeds on both condensate and precipitation. This also opens the way to covering additional processes like Cloud Top Evaporative Instability. For this, we'll consider that the downdraught is not completely saturated, and contains a core of air entrained from above.

References

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