"Generalization and application of the flux-conservative thermodynamic equations in the Arome model of the Aladin system",

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1 General comments

Ensuring the consistency of the coupling between a dynamical core and a physics package is a delicate matter when building a NWP model from two blocks which have been developed independently. This article present a new physics/dynamics interface which has been designed to interface the Aladin non-hydrostatic dynamical core with the convection permitting physics package originally developed for the research model Meso-NH. The new interface which is a generalization of a concept proposed by Catry et al, 2007, is supposed to improve mass and energy conservation and thermodynamical consistency between the two packages.

The authors claim that, thanks to the equations used in this interface "the conservation of mass and energy is a built-in feature of the system". I don't agree with this affirmation. I think the problem is much more complicated, and the best solution for the coupling depends a lot of the method which has been chosen inside the physics driver and inside the parametrisations themselves. I don't think this interface replaces a global solver which would be the only clean way to solve consistently together all the processes represented by the system of equations (2)-(8).

I think that what is really missing in this paper is a proper discussion about the discretization of the complex system given by equations (2)-(8). The only example which is given in page 8, line 12 is actually not valid for any physics package. In section 3 below, I illustrate with a simple example extracted from the paper why I don't think that the conservation of mass and energy is necessarily a built-in feature of the system of equations (2)-(8).

I don't think either that for local processes such as autoconversion or condensation, pseudo-fluxes are necessary to ensure conservation. The pseudo-fluxes are not necessary to express the system in a barycentric form. If a parametrisation has not been written in term of pseudo-fluxes but the parametrisation gives tendencies for the q_x, how should the pseudo-fluxes be computed ? Should for example the method take into account the fact that the latent heat used in a parametrisation is $L(T)$ instead of $L(T_o)$?

The test case of section 4 shows that the main impact of the new interface has been to include a term which was missing (had been neglected ?) in the parametrisation of the precipitation sedimentation. From the text, it is not clear if adding this term in the parametrisation, but still using the old interface, would produce the same effect. Could the author try to separate more clearly the impact of the new design of the interface from the impact of the missing term ?

I also think that the title of the paper is very misleading. The formulation of the Aladin dynamical core is not based on conservative flux-form equations. The new interface

will surely not improve the non-conservative aspects of the Aladin semi-Lagrangian advection scheme for example. In the paper, conservative flux-form equations are used only to compute the tendencies from information provided by the physics parametrisations. This should be made clearer in the title and in the abstract.

I don't think there is a lot new information in the current state of the manuscript about physics/dynamics interface compared to Catry et al (2007) (the generalization to more water species and processes is quite straightforward). A more careful and general analysis of the physics/dynamics interfacing problem should be added to the manuscript to make it useful to the community. The results concerning the impact of the missing term in the sedimentation of precipitation are interesting but only more systematic sensitivity tests and comparison to observation would prove the importance of this effect versus many other sources of model errors for the simulation of organized convection in convection permitting NWP.

2 More detailed comments

1. p 2, l3 : It is not correct to say that the dynamical core equations are equations written for a perfect gas. The equations of the Aladin dynamical core are written for a "barycentric" multiphase system which may contain condensed water phases, even if the physics is switched off. The water vapor but also the condensed species are taken into account to compute the mass of air in a given volume (e.g. liquid and solid species are "loading" the air parcel) and are then changing the "inertia" of the air parcel in the momentum equation. The gas law also knows about the composition of the air parcel, and only the "gas" part of the total mass is used in the gas law. But the full weight is used for the hydrostatic equilibrium. The information about the composition of the air parcels is known thanks to the definition of the specific water contents which are defined as the ratio between the mass of a given species and the total mass (including condensates). The specific quantities are used to compute the virtual temperature and the moist c_p (thermal inertia) and the moist gas constant R which are also used inside the dynamics.
2. p 2, l1-2 : Why only mass and enthalpy budgets but no momentum budget in this interface ?
3. p2 l25 : I don't really understand this sentence. Shouldn't it be "to be described" instead of "to described" ?
4. in section 2.1, the authors list the main hypotheses made for the design of Catry et al (2007) interface. However, nothing is said about the "Eulerian" and "vertical column" hypotheses used to write the system of equation (2)-(8) and how such a system should be interfaced with the dynamics. For example, in the case of a semi-Lagrangian dynamics, should the tendencies be computed at the beginning/middle/end of the semi-Lagrangian trajectories or along the trajectories ?
5. p3 l7-10 : It is not clear if the precipitation are supposed to immediately get the

temperature of the layers they are crossing during a time step, or only the temperature of the layer where they "seat" at the end of the time step (in other word, is there an exchange of energy with all layers which are crossed by the condensed phases or only inside the layer where they stop at the end of the time step).

6. p3 l8 : Bott (2008) $\rightarrow$ (Bott, 2008)
7. p3 l 21 : it should be said more clearly that the q_x are specific fractions (i.e. ratios with respect to total mass of the multiphase system).
8. p4 l8 : I understand that in a barycentric system, the total mass should be conserved, i.e the sum of eq 2-7 gives $0 = 0$. Does it mean that the surface scheme should produce diffusive fluxes of condensates to compensate the diffusive flux of water vapor ?
9. p4 l20 : center of mass of what ?
10. p7 l12-l15 : "all vertical transport is compensated by a flux of dry air" : I don't think it applies to "all vertical transport" (in particular, it does not applied to resolved vertical transport), but only to precipitation and subgrid mass transports (top of page 5 of Courtier et al, 1991).
11. p8 l7-12 : Formulae p8, l12 ensure conservation only if the parametrisations are called in parallel (process split in Williamson, 2002). It also supposes that the final specific ratios are given by process (a) and (b) (and not by a common resolution of both process (a) and (b)). If the parametrisations are called sequentially (time split), parametrisation (b) will already know about the evolution in time of both T and c_p after process (a). In this case, the conservation is ensure if $\Delta T = \Delta T_a + \Delta T_b$. See annexe for details.
12. p9, l31-32 and p10 l1-2 : The authors say that, in Arome, it is not possible to take into account the correct mass budget, therefore all vertical transport is compensated by a flux of dry air. Does it mean that equation 43 of Catry et al is used instead of equation (8) in the new interface ? Why the correct mass budget could not be taken into account in Arome ? Is the problem only at the surface or at every level ?
13. p10 l17 : I don't clearly understand why no significant improvement could be expected without a new tuning. Are the author thinking of model error compensation ? If it is the case, it should be explained more clearly.
14. section 4.2 : the discussion for this case study mainly consider the missing term (heat transport by the precipitation). If this term is the main problem in Arome, couldn't it be added to the old interface ? Would it give similar results ?
15. It would also be interesting to see the impact of the new interface independently from the addition of the missing term for the case in section 4.2 (i.e. also neglect the missing term in the new interface).
16. The author should be more modest in their conclusion. The simulation of such convective systems are very sensitive to many other source of model errors (time step, horizontal or vertical resolution, level of complexity in microphysics etc). A

more systematic study would be necessary to really conclude about the importance of the heat transport by precipitation in Arome.

3 Annexe

One of the "moist" quantity which must be conserved in parametrisations involving "warm" water phase changes (pseudo-fluxes) is $s = c_p T + L q_v$ where $c_p = (1 - q_v - q_l)c_{p_d} + q_v c_{p_v} + q_l c_l$ and $L = L(T_{00})$ is the latent heat of vaporisation at $T_{00} = 0$ K.

At time t, $s^0 = c_p^0 T^0 + L q_v^0$.

If the process (a) is conservative :

$$s^0 = c_p^a T^a + L q_v^a = (c_p^0 + \Delta c_p^a)(T^0 + \Delta T^a) + L(q_v^0 + \Delta q_v^a)$$

Process (b) is "called" in parallel and (b) is also a conservative process :

$$s^0 = c_p^b T^b + L q_v^b = (c_p^0 + \Delta c_p^b)(T^0 + \Delta T^b) + L(q_v^0 + \Delta q_v^b)$$

At the end of the physics (i.e. after (a+b) here), we have conservation if

$$s^0 = c_p^+ T^+ + L q_v^+$$

If we keep the water phase changes as given by processes (a) and (b), i.e.

$$c_p^+ = (1 - q_v^+ - q_l^+)c_{p_d} + q_v^+ c_{p_v} + q_l^+ c_l$$

with $q_v^+ = q_v^0 + \Delta q_v^a + \Delta q_v^b$ and $q_l^+ = q_l^0 - \Delta q_v^a - \Delta q_v^b$ we get

$$T^+ = \frac{1}{c_p^+}\,(c_p^0 T^0 + L q_v^0) - L q_v^+$$

after a bit of arithmetics, we get (using the conservation for each process) :

$$T^+ - T_0 = \Delta T^+ = \frac{(c_p^0 + \Delta c_p^a)(\Delta T^a) + (c_p^0 + \Delta c_p^b)(\Delta T^b)}{c_p^+}$$

i.e. formulae p8, line 12.

Note that, in this case, if $T_{a/b}$ and $q_{va/b}$ have been computed in the parametrisations (a/b) in order to fulfill some kind of fast adjustment towards an equilibrium, the adjustment will not be valid anymore with T^+.

Now, if process (b) is "called" sequentially after (a) (and (b) is still a conservative process) :

$$s^0 = c_p^b T^b + L q_v^b = (c_p^0 + \Delta c_p^a + \Delta c_p^b)(T^0 + \Delta T^a + \Delta T^b) + L(q_v^0 + \Delta q_v^a + \Delta q_v^b)$$

In this case, we directly get :

$$T^+ - T^0 = \Delta T^a + \Delta T^b$$

In this case, if T_b and q_{vb} have been computed in order to fulfill some kind of fast adjustment towards an equilibrium, the adjustment will still be valid with T^+.