ALARO-0 microphysics: autoconversion, collection, evaporation/melting

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0. GENERALITIES

The ALARO microphysical scheme uses four completely independent prognostic quantities for liquid and solid cloud water, falling rain and snow, besides water vapour. The microphysical parameterisations describe the processes among them.

ALARO microphysics is used by APLMPHYS, which calls three routines: ACACON, ACCOLL and ACEVMEL.

The parameterisations calculate contributions to the transfer between the different phases:

crystals= condensation - autoconversion - collection
droplets = condensation - autoconversion (also WBF) - collection
rain = autoconversion + collection - evaporation - freezing
snow = autoconversion (also WBF) + collection - sublimation+ melting
vapour = - condensation + evaporation + sublimation

In this paper we describe the three microphysical processes between water species in ALARO:

1. **autoconversion** –> is a combination of two mechanisms:
   - rain or snow droplets grow on the account of cloud water or cloud ice
   - snowflakes grow by watervapour flux from supercooled cloud droplets (WBF)
2. **collection** –> how rain and snow particles are collecting smaller droplets whilst falling

(also taking in account a diagnostic flux of graupel and collection by graupel)

1. **evaporation and melting** –> rain evaporates and snow sublimates in dry air below cloud base and snow melts in warmer air or rain freezes in colder air

(again taking in account the diagnosed graupel portion of snow precipitation flux)

ACACON, ACCOLL, ACEVMEL within APLMFPHYS

In a vertical loop in APLMFPHYS, the autoconversion (ACACON) is called first.

Follow two calls to collection (ACCOLL) - first for seeded part: the portion of layer with precipitation (when there is flux of either snow or rain reaching current level from the top) and secondly for the non-seeded part: the portion of column without the precipitation (where no precipitation are reaching our level from the top).

Finally, evaporation and melting/freezing of falling species are computed for clear sky part and after that for the precipitation inside the cloud (no evaporation here!).

1. AUTOCONVERSION

Is computed in ACACON

Simulates the effect of the initial growth and collision processes allowing the conversion of cloud particles *(which aren't falling!)* to falling precipitation.

These comes in three ways:

1. generation of solid precipitation from cloud ice,

2. generation of rain from cloud droplets,

(the two so far are "pure" autoconversion)

1. and generation of solid precipitation from cloud droplets *(Wegener-Bergeron-Findeisen mechanism).*

How does it do it:

For the points 1) and 2) (*autoconversion*) we have the most simple and continuous possible expression (Sundquist type):

$$\left(\frac{dq_{l/i}}{dt}\right)_{ACO} = -\frac{q_{l/i}}{\tau_{l/i}(T)}\left[1 - e^{-\frac{\pi}{4}\left(\frac{q_{l/i}}{q^{cr}_{l/i}(T)}\right)^2}\right].$$

Where $\tau_{l/i}$ is the time scale of the process (defined as $\frac{1}{\tau_{l/i}} = RAUTEF(R/S)$. The autoconversion time scale for ice to snow varies with temperature (the colder the air, the less efficient is the process) [with a common temperature dependency factor as the other microphysical processes].

$q^{cr}_{l/i}$ is the critical threshold for liquid water to rain (ZQLCR) or ice to snow (ZQICR) autoconversion, and the latter varies with temperature (the colder the air, the lower is the threshold).

In the mixed phase the Wegener-Bergeron-Findeisen (WBF) process is dominant and is parameterised as an autoconversion from cloud water to snow.

The basic idea is to parameterise the WBF process as a direct transfer from liquid cloud droplets to snowflakes, the intensity depending on the quantity of cloud ice-crystals as well, but without interference of the raindrops. Though in reality the WBF process is involving supersaturated droplets and crystals we are following van der Hage's conclusion, that the time spent in the crystals phase is relatively short and we can parameterise WBF as a direct flux to snow.

The basis of the mathematical treatment is to rely on the ratio of the water depletion rates both by 'classical' auto-conversion and by the WBF process.

For the WBF mechanism we have:

$$\left(\frac{dq_l}{dt}\right)_{WBF} = -F^a_{WBF}\frac{q_l}{\tau_l}\frac{q_l.q_i}{(q_l+q_i)^2}\left[1-e^{-\frac{\pi}{4}\left(\frac{q_l.q_i}{q_l^{cr}.F^b_{WBF}.q_i^{cr}(T).F^b_{WBF}}\right)}\right].$$

The WBF formula is similar to the one for 'classical' autoconversion. One can easily verify this by letting ql -> qi or qi -> ql and thus obtaining a dynamically similar equation to the one above - the pure autoconversion one.

The two tuneable constants of WBF mechanism are F^a_{WBF} (RWBF1) and F^b_{WBF} (RWBF2) and the formula contains also the two critical thresholds that are already used in autoconversion mechanicm.

The WBF process is also the only part of ACACON with thermodynamics involved. This is why there is a temperature increment at the end, due to freezing of water on crystals and in accordance with cascading approach.

ACACON's technicalities:

input arguments (besides the obvious KIDIA, KFDIA and KLON):
melting latent heat divided by cp (PLSCP),
specific cloudiness (PPART),
a common temperature dependency factor (PEXPN)

input and output arguments:
cloud ice - qi (PQIST),
cloud water -ql (PQLST),
rain - qr (PQRST),
snow -qn (PQNST),
temperature (PTST).

output arguments:
cloud ice to snow increment (PACONI)
cloud water to rain increment (PACORL)
cloud water to snow conversion increment (PACONL).

Tuning parameters of the autoconversion scheme:
the characteristic time and critical 'threshold' value for water
the characteristic time and critical 'threshold' value for ice (with a temperature dependency)
two WBF scaling constants

2. COLLECTION

Computed in ACCOLL

Rain drops and snow flakes are collecting cloud ice and cloud droplets whilst falling. The amount of rain and snow is growing on the account of cloud particles. In this parameterisation, rain drops are not collecting other rain drops neither the snow flakes are growing by collecting other snowflakes. We do not need these, because the two are resolved with the sedimentation parametrization.

The hypothesis is that the cloud water is continuously present and hence collected along the volume scanned by the falling rain drops. We parameterise the collection:

$$\begin{aligned}
\left(\frac{dq_l}{dt}\right)_R &= -\,C_E^r \,.\, R^{4/5} \,.\, q_l \\
\left(\frac{dq_i}{dt}\right)_R &= -\,C_E^r \,.\, R^{4/5} \,.\, q_i \,\times\, f^*_{s/i}(T) \\
\left(\frac{dq_l}{dt}\right)_S &= -\,C_E^s \,.\, S^{4/5} \,.\, q_l \,/\, f^*_{s/i}(T) \\
\left(\frac{dq_i}{dt}\right)_S &= -\,C_E^s \,.\, S^{4/5} \,.\, q_i
\end{aligned}$$

where R and S are two precipitation fluxes at a certain level: R for rain and S for snow. They are computed as averages between top and bottom values of those levels.

And the constants' values are $C_E^r = 0.0671$ and $C_E^s = 0.0174$. The f presents the relative efficiency of the collection processes and also takes into account temperature dependency of the mechanism (PRCOLL) – the colder the temperature, the more escaping are the ice crystals.

Again, in the spirit of cascading, the temperature is also updated due to phase changes.

How does the collection efficiency factor for ice crystals varies with temperature (the colder the temperature, the more 'escaping' the crystals are)?

ACCOLL's technicalities:

Input only:

flux of solid precipitation at the top of a level (PHPLSN)
flux of solid precipitation at the bottom of a level (PBLSN)
flux of liquid precipitation at the top of a level (PHPLSL)
flux of liquid precipitation at the bottom of a level (PBPLSL)
cloudiness (PPART)
ratio for collection efficiencies between snow and rain (PRCOLL)

Input and output:

the four water species: ql, qi, qr, qn (PQIST, PQLST, PQRST, PQNST) and temperature (PTST).

Output:

increment for cloud ice to snow collection process (PCOLNI),

increment for
cloud water to snow collection process (PCOLNL),
increment for cloud ice to rain collection process (PCOLRI),
increment for cloud water to rain collection process (PCOLRL)
Tuneable parameter of the collection scheme:
The efficiency factor (0.2)

3. EVAPORATION AND MELTING

Computed in ACEVMEL

Evaporation

Evaporation in unsaturated air is computed with a Kessler-type formula (revisited with some simplifications)

Precipitation divergence linked to evaporation (in pressure coordinates, standard atmosphere and other approximations)

$$\frac{d\sqrt{P}}{dp} = -\frac{C_{evap}}{p^2}(q_{sat} - q_v)$$

P is precipitation flux, C_{evap} depends on the cloud type; the bigger the value –> the more evaporation outside the cloud occurs; for stratiform clouds the value of C_{evap} is 4.8 10^6 .

Implementation in the code:

$$\frac{\partial\sqrt{P}}{\partial(1/p)} = E_{vap}.(q_w - q),$$

following that, the precipitation flux at the bottom when evaporation is taken into account is:

$$\sqrt{P_b} = \sqrt{P_h} - E_{vap}\max\left[0,(q_w - q)\right]\cdot\left(\frac{1}{p_h} - \frac{1}{p_b}\right),$$

and there is a security for making sure that it is not less than zero.

$P_h$is the precipitation flux at the top of the considered layer (sum of rain and snow).

The E_{vap}(ZEVA) is computed as :

$$E_{vap} = C_{evap}\sqrt{(1 - r_{me})r_{mg}(E_{VGSLP} - 1)}$$

where r_{me} is snow to total precipitating water ratio and r_{mg} the graupel to snow ratio (diagnosed graupel proportion of the ice precipitation flux), $E_{vgslp}$is ratio of fall velocities for rain vs. snow (T dependent). The basic ratio of fall speed between rain and snow is around 4, but it is modified to take into account the temperature dependency.

Finally,

rain evaporation is $PEVAR = (1 - r_{me})\max(0,(P_h - \max(P'_b, P_b))\frac{\Delta p}{g\Delta t})$,

snow evaporation is $PEVAN = r_{me}\cdot\max(0,(P_h - \max(P'_b, P_b))\frac{\Delta p}{g\Delta t})$

where P'$_b$is the precipitation at the top minus the maximum possible amount that can evaporate:

$$P'_b = \max(0, P_h - \frac{q_w - q}{g\Delta t}dp).$$

Melting

Melting occurs when T>Tt and freezing when T<Tt. For melting we have the basic equation (Kessler type) :

$$\frac{\partial r_{mi}}{\partial(1/p)} = \frac{C_{Font}.(T-T_t)}{\sqrt{P}}.$$

Which comes in model as:

$$r_{mie} = r_{mel} + F_{ont}\frac{(T_t - T)}{\frac{1}{2}\left(\sqrt{P_h}+\sqrt{P_b}\right)}\left(\frac{1}{p_h}-\frac{1}{p_b}\right),$$

where r_{mel}(ZRMEL) is snow proportion for the precipitation at the bottom of the layer plus the precipitation formed in this layer with its evaporation already taken into account, $T_t$is treble point temperature, p_h and p_b are the pressure values for top (h) and bottom (b) of the layer and $P_h$and P_b the total precipitation fluxes in the same manner. The parameter F_{ont} is computed as follows:

$$F_{ont} = C_{Font}\sqrt{(1-r_{me})r_{mg}(E_{VGSCP}-1)}$$

where $C_{Font}$is a constant with value $C_{Font=}2.4\times10^4$ and E_{vgslp}, r_{me} and r_{mg} are ratio of fall velocities for rain vs. snow (T dependent), ratio of snow to total precipitating water and graupel to snow ratio respectively.

Finally, we have for melting/freezing:

$$F = (r_{mel} - r_{mie})\frac{1}{2}\left(P_t + P_b\right)\left(\frac{g\Delta t}{\Delta p}\right)$$

in the contrary to evaporation, melting can have positive and negative sign. The negative sign stands for freezing.

At the end of ACEVMEL there is a security block of the code and there it is made sure that rain evaporation plus melting is less or equal to all snow and snow evaporation + freezing (-melting) is less or equal to the total flux rain.

ACEVMEL's technicalities:

Input only:

saturation deficit (PDQ)
ratio for fall velocities rain vs. snow (including graupel effect) (PEVGSL)
inverse pressure at the bottom of the layer (PIPB)
inverse pressure at the top of the layer (PIPH)
rain precipitation flux at the top of the layer (PHPLSL)
snow precipitation flux at the top of the layer (PHPLSN)
rain precipitation flux at the bottom of the layer (PLPLSL)

snow precipitation flux at the bottom of the layer (PLPLSN)
(DP/(RG*DT) for a given level and time step (PPOID)
inverse of the previous (PIPOI)
snow (PQNST)
rain (PQRST)
snow proportion of the precipitation flux (PRME)
probability for rain generation in this level (PSTAL3)
probability for snow generation in this level (PSTAN3)
temperature (PTST)

Output:

snow evaportaion increment (PEVAN)
rain evaporation increment (PEVAR)
snow melting increment [= - rain freezing] (PFONT)
test for the perpetuation of the precipitation flux – either 0 or 1 (PTEST)

Tuneable parameter of the scheme:

Those are C_{Font},C_{evap} and E_{vgslp}. However, there is probably no need for extensive tuning, since this very same scheme has been used in ALADIN for quite some time.