APLMPHYS Documentation

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1 Purpose

The routine APLMPHYS is computing the precipitation fluxes for water and snow and the linked pseudo-fluxes (condensation, autoconversion,evaporation). For cloud geometrical properties LRNUMX is used to decide whether random cloud overlap is considered (LRNUMX=.FALSE.) or maximum overlap of adjacent clouds (LRNUMX=.FALSE.).

2 Computation of parameters and security constants, upper boundary conditions

In addition to defining some auxiliary and security constants, fluxes (precipitation) and pseudo-fluxes (condensation, autoconversion and evaporation/sublimation) are initialized by setting them to zero in the highest level. Before initializing PFCSQL and PFCSQN, being liquid and solid condensation fluxes minus evaporation and sublimation (computed in ACCDEV), they are saved as locals (ZFCSQL and ZFCSQN). The ratio of ice α_i (ZRME) is calculated via exponential function FONICE (see documentation for ACNEBCOND).

3 Effective calculations of precipitation fluxes in vertical loop JLEV=KTDIA,KLEV

3.1 Local copies for actual layer and temperature dependencies

At the beginning of each vertical iteration, local copies of various variables are made and information is passed from the layer above. There are two options for taking into account the cloud geometry: Switch LRNUMX defines whether flux reorganization is done for random cloud overlap (LRNUMX=.F.) or for maximum overlap of adjacent clouds and random overlap of clear air separated parts (LRNUMX=.T.). To handle the geometrical properties of clouds, each layer is divided into four parts, where the ones of interest are the top-seeded part, the non-top-seeded part of the cloud and the fraction of clear air covered with precipitation. Cloud water content q_l and cloud ice content q_i (ZQLST and ZQIST in local scope) are assumed to be homogenous everywhere

$$q_l' = \frac{q_l}{n} \quad \text{and} \quad q_i' = \frac{q_i}{n}, \tag{1}$$

with n denoting cloud fraction (ZNEBLOC). Whereas rain content q_r (ZQRST[X]) and snow content q_s (ZQNST[X]) are depending on whether they account for the cloudy part ([X] is replaced by "O") or the clear air part ([X] is replaced by "E")

$$q_{r_o} = \frac{\text{ZIPSLO}}{P_{l[jlev-1]}} q_r \quad , \quad q_{s_o} = \frac{\text{ZIPLSNO}}{P_{s[jlev-1]}} q_s \tag{2}$$

$$q_{r_e} = \frac{\text{ZIPSLE}}{P_{l[jlev-1]}} q_r \quad , \quad q_{s_e} = \frac{\text{ZIPLSNE}}{P_{s[jlev-1]}} q_s, \tag{3}$$

with $P_{l[jlev-1]}$ (PFPLSL) and $P_{s[jlev-1]}$ (PFPLSN) being liquid and solid precipitation fluxes from the layer above. Locals ZIPLSL[X] and ZIPLSN[X] representing the fluxes connected to cloudy ([X] replaced by "O") and clear air parts ([X] replaced by "E") respectively.

For the different snow-related processes, there are several temperature dependencies, which have to be taken into account (these dependencies are taken from Lopez (2002) with some simplifications):

- Variation of autoconversion time scale (for ice and snow) with temperature (increasing efficiency with increasing temperature).
- Variation of critical threshold for ice to snow autoconversion with temperature (increasing threshold for increasing temperature, maximum given for $T = 0°\mathrm{C}$)
- Variation of snow fall speed with temperature (increasing fall speed for increasing temperature). Related parameters are fall speed ratios snow/rain ZEVGSLP and ZEVGSL (including graupel effect)
- Variation of collection efficiency for ice crystals (increasing efficiency for increasing temperature). Related parameters are ZRCOLLP and ZRCOLL (including graupel effect).
- Variation of snow volume for collection with temperature (increasing volume of snow flakes with increasing temperature, decreasing collection efficiency through worse surface to volume ratio).

Temperature dependency is introduced through an exponential function in the form

$$\mathsf{ZEXPN} = \mathsf{min}\left(1, \exp(c_t(T - T_f))\right), \tag{4}$$

with temperature T and triple point temperature T_f. While Lopez introduced differing values of c_t (ZEXTMP) for different efficiencies, a common value for c_t ($= 0.0231$) is used here, representing the geometrical average over Lopez' slightly differing values. After computing temperature depending factors for collection processes ZRCOLLP, ZRCOLL and the snow/rain velocity ratios ZEVGSLP, the flux of ice phase precipitation falling as graupel (ZFSGRPL) is initialized for actual layer via

$$P_g = r_g(P_{s[jlev-1]}), \tag{5}$$

with r_g (ZRMG) being the graupel proportion of ice precipitation flux P_s (PFPLSN) entering from the layer above. These ratio is calculated at the end of every vertical loop iteration.

3.2 Preparation for sedimentation

The sedimentation of precipitation is realized through the use of probability density functions (named PDF in the following). In contrast to rather expensive computations via Eulerian- or Lagrangian-typed advection steps, this method allows computation within a single vertical loop. Another advantage is that while advective methods require an unique or overall mean fall velocity for any precipitation species, the use of PDFs allows the replacement of mean fall speed by a velocity-spectrum, which is finally converted into a probability for precipitation species to reach the bottom of a given layer. To speak more detailed, at the bottom of a layer there are three PDFs defined for falling species:

- species already present in the layer at the beginning of time step: P_1 (ZSTAL1 for liquid species, ZSTALN1 for solid species), representing the probability that precipitation already present reaches the bottom of the layer during actual time step Δt
- species coming from level above: P_2 (ZSTAL2, ZSTALN2), denoting the probability that precipitation falling from above reaches the bottom of the layer during actual time step Δt
- species which are locally produced (through autoconversion, collection, melting): P_3 (ZSTAL3, ZSTALN3), being the probability that locally produced hydrometeors reach the bottom of the layer during actual time step Δt

The computation of these probabilities is grounded on a basic PDF P_0 (ZSTAL0, for liquid part, ZSTALN0 for solid part) for crossing the considered layer within one time step. Starting with the air density ρ (ZRHOAIR) for actual layer, the precipitation intensity dependent fall velocities for rain ω_r (ZFALLL) and snow ω_s (ZFALLN) are computed

$$\omega_l = \Omega^r \left(\frac{P_l'}{\rho^4}\right)^{\frac{1}{6}}, \tag{6}$$

$$\omega_s = \Omega^r \left(\frac{P_s'}{\rho^4}\right)^{\frac{1}{6}} \frac{1}{\mathsf{ZEVGSL}}, \tag{7}$$

with Ω^r (FSPRAIN) being the constant value (= 13.4), P_l' (ZFPLSL) and P_s' (ZFPLSN) liquid and solid precipitation fluxes from the layer above, modified through actual layer ratios for rain q_r, liquid water q_l, snow q_s and ice q_i respectively. Further, ω_r and ω_s are limited to avoid violation of the Courant-Friedrichs-Levy condition (CFL) using limiting factor ZCFLIM (= 0.004)

$$\omega_l = \mathsf{max}\left(\omega_l, \frac{\Delta p}{\rho g \Delta t}\mathsf{ZCFLIM}\right), \tag{8}$$

$$\omega_s = \mathsf{max}\left(\omega_s, \frac{\Delta p}{\rho g \Delta t}\mathsf{ZCFLIM}\right). \tag{9}$$

The input quantity for the computation of PDFs is built by a kind of inverse mean Courant number Z_x (ZZSLS for liquid part, ZZSNS for solid)

$$Z_l = \mathsf{max}\left(\epsilon, \frac{\Delta p}{\rho g \Delta t}\frac{1}{\omega_l}\right), \tag{10}$$

$$Z_s = \mathsf{max}\left(\epsilon, \frac{\Delta p}{\rho g \Delta t}\frac{1}{\omega_s}\right). \tag{11}$$

Finally, in the case of activating statistical sedimentation (LLSTASED=.TRUE.), probabilities are given by

$$P_0^x = \exp(-Z_x), \tag{12}$$

$$P_1^x = \frac{1 - P_0^x}{Z_x}, \tag{13}$$

$$P_2^{x\prime} = \frac{P_0^x}{Z_x + 1 + Z'}, \mathsf{with} Z' = \frac{\sqrt{(1+Z_x)^2 + 4Z_x} - (1+Z_x)}{2}, \tag{14}$$

$$P_3^x = \frac{P_2^{x\prime} + P_1^x}{2}, \tag{15}$$

$$P_2^x = \frac{P_2^{x\prime} + P_3^x}{1 + P_3^x}. \tag{16}$$

The probabilities ($P_0^x, P_1^x, P_2^x, P_3^x$) are presented here for undefined species, in the routine they are computed for liquid ($P_0^x \rightarrow P_0^l$,...) and solid hydrometeors ($P_0^x \rightarrow P_0^s$,...).

3.3 Autoconversion and sedimentation

Autoconversion routine ACACON is called using q_{r_o} and q_{s_o} (for the cloudy part). The outcoming arrays of ACACON, which are ZACONI (ice-snow autoconversion increment), ZACORL (water-rain autoconversion increment) and ZACONL (water-snow autoconversion increment), are used to perform modification of actual precipitation fluxes P_l (PFPLSL), P_s (PFPLSN) and the pseudo historical graupel flux P_g (ZFSGRPL)

$$P_l = P_{l[jlev-1]}P_2^l + \frac{\Delta p}{g\Delta t}(P_1^l q_r + P_3^l \mathsf{ZACORL}'), \tag{17}$$

$$P_n = P_{n[jlev-1]}P_2^s + \frac{\Delta p}{g\Delta t}(P_1^s q_s + P_3^s \mathsf{ZACONI}'), \tag{18}$$

$$P_g = P_{g[jlev-1]}P_2^l + \frac{\Delta p}{g\Delta t}(P_1^l q_s + P_3^l \mathsf{ZACONL}'). \tag{19}$$

Variables labeled by a prime (ZACORL, ZACONI, ZACONL) indicate variables multiplicated with the cloudy proportion of actual cloud or grid-box.

3.4 Collection and sedimentation

Call of collection subroutine ACCOLL is done twice to perform computation for the top-seeded and non-top-seeded part separately. Outcoming fields from ACCOLL are ZCOLNI, ZCOLNL, ZCOLRI and ZCOLRL, representing the collection increments for ice-snow, water-snow, ice-rain and water-rain. Collection increments for the seeded part have to be saved before calling again. For the second call of ACCOLL (not seeded part), the precipitation fluxes at the top of actual layer passed to the subroutine are set equal to zero (ZHPLSL, ZHPLSN). As a consequence the fluxes at the bottom given to ACCOLL include just the collection increments for the given layer (ZLPLSL, ZLPLSN). After second call of ACCOLL the modification of precipitation fluxes (including "local" graupel flux) are performed through following formulations

$$P_l = P_l + \frac{\Delta p}{g\Delta t} P_3^l(\mathsf{ZCOLRL} + \mathsf{ZCOLRI}), \tag{20}$$

$$P_s = P_s + \frac{\Delta p}{g\Delta t} P_3^s(\mathsf{ZCOLNL} + \mathsf{ZCOLNI}), \tag{21}$$

$$P_g = P_g + \frac{\Delta p}{g\Delta t} P_3^l(\mathsf{ZZCOLN}), \tag{22}$$

using probability P_3^x (ZSTAL3, ZSTAN3) for falling species produced in the actual layer and ZCOLRL, ZCOLRI, ZCOLNI and ZCOLNL being the combination of collection increments gained from the seeded and not seeded part of the collection computation.

3.5 Evaporation and melting

The subroutine ACEVMEL responsible for calculation of evaporation and melting of precipitating species is called twice, once for evaporation/sublimation in the precipitation covered clear sky part and once for melting/freezing in the cloudy part. Output arguments of ACEVMEL are ZEVAN, ZEVAR, ZFONT, and ZTEST, being the snow evaporation increment, the rain evaporation increment, the snow melt increment (taking into account freezing of rain) and a test variable, defining whether precipitation fluxes are perpetuating. After first call of ACEVMEL arrays ZEVAN, ZEVAR and ZFONT are saved to locals in order to be recombined after second call.

3.6 Final sedimentation computation, pseudo-fluxes

The final computation for the precipitation fluxes (and some connected pesudo-fluxes) is performed as follows:

- solid and liquid condensation (pseudo-)fluxes P_{lc} (PFCSQL) and P_{sc} (PFCSQN)

  $$P_{lc} = P_{lc[jlev-1]} + P_{lc}^{loc} - P_{lc[jlev-1]}^{loc} + \frac{\Delta p}{g\Delta t}(\mathsf{ZCOLRI} - \mathsf{ZCOLNL} - \mathsf{ZACONL}), \tag{23}$$

  $$P_{sc} = P_{sc[jlev-1]} + P_{sc}^{loc} - P_{sc[jlev-1]}^{loc} + \frac{\Delta p}{g\Delta t}(\mathsf{ZCOLRI} - \mathsf{ZCOLNL} - \mathsf{ZACONL}), \tag{24}$$

  where ZFCSQL denotes the temporary flux of condensation minus evaporation. ZCOLRI, ZCOLNL and ZACONL being the water-rain collection increment, the water-snow collection increment and the water-snow autoconversion.

- solid and liquid autoconversion (pseudo-)fluxes P_{la} (PFASL) and P_{sa} (PFASN)

  $$P_{la} = P_{la[jlev-1]} + \frac{\Delta p}{g\Delta t}(\mathsf{ZACORL} + \mathsf{ZCOLRL} + \mathsf{ZCOLRI}), \tag{25}$$

  $$P_{sa} = P_{sa[jlev-1]} + \frac{\Delta p}{g\Delta t}(\mathsf{ZACONI} + \mathsf{ZCOLNI} + \mathsf{ZACONL} + \mathsf{ZACOLNL}), \tag{26}$$

  where ZACORL, ZCOLRL and ZCOLRI are the water-rain autoconversion increment, the water-rain collection increment and the ice-rain collection increment. ZACONI, ZCOLNI, ZACONL and ZCOLNL denote the increments for ice-snow autoconversion, ice-snow collection, water-snow autoconversion and the water-snow collection.

- (pesudo) fluxes for evaporation of liquid and solid precipitation P_{le} (PFESL) and P_{se} (PFESN)

$$P_{le} = P_{le[jlev-1]} + \frac{\Delta p}{g\Delta t}(\mathsf{ZEVAR} - \mathsf{ZFONT}), \tag{27}$$

$$P_{se} = P_{se[jlev-1]} + \frac{\Delta p}{g\Delta t}(\mathsf{ZEVAN} + \mathsf{ZFONT}), \tag{28}$$

  with ZEVAR, ZEVAN and ZFONT being the increments of rain evaporation, snow evaporation and snow melt (minus rain freezing).

- liquid and solid precipitation fluxes P_l (PFPLSL) and P_s (PFPLSN) are finally modified by the outcome of evaporation and melting computation (other processes are already included)

$$P_l = \mathsf{max}\left(0, P_l - \frac{\Delta p}{g\Delta t}P_3^l(\mathsf{ZEVAR} - \mathsf{ZFONT})\right), \tag{29}$$

$$P_s = max\left(0, P_s - \frac{\Delta p}{g\Delta t}P_3^s(\mathsf{ZEVAN} + \mathsf{ZFONT})\right), \tag{30}$$

  with P_3^l and P_3^s again being the probability for a precipitating species produced during actual time step to reach the bottom of the layer

- pseudo historical flux as graupel P_g (ZFSGRPL)

$$P_g = P_g - \frac{\Delta p}{g\Delta t}P_3^l(\mathsf{ZZMUL} * \mathsf{ZEVAN} + (1 - \mathsf{ZZMUL})\mathsf{min}(0, \mathsf{ZFONT})), \tag{31}$$

  with

$$\mathsf{ZZMUL} = \frac{r_g}{r_g + (1 - r_g)\sqrt{1 - \alpha_i(1 - \mathsf{ZEVGSLP})}}, \tag{32}$$

  r_g (ZRMG) being the graupel proportion of solid precipitation flux, α_i (ZRME) the ice-type proportion and ZEVGSLP the ratio of rain fall speed and temperature dependent snow fall speed. The graupel flux is finally zero-protected and not allowed to exceed its ice phased counterpart P_s (PFPLSN). There is no direct effect of graupel ratio and precipitation flux on any prognostic quanitity. It influences the of falling velocity (via ZEVGSL) of solid precipitation phase and the collection efficiency for the falling ice-phase (e.g. ZRCOLL). The statistical sedimentation functions are those for the liquid phase P_3^l (ZSTAL3).

3.7 Recomputation of fall speed

The main characteristics of fall speed computation was already shown in part II.b of this document, hence it is just necessary to add some things at this point. Whereas initial (precipitation intensity dependent) fall speeds computed at the beginning of the sedimentation part are based on precipitation flux from the layer above modified by the already existing rain and snow species in the actual layer, it is possible to use all information about the precipitation intensity (after taking into account several microphysical processes) at this point to recompute fall velocities ω_l (PFALLL) and ω_s (PFALLN). In addition some auxiliary arrays for the graupel computations are calculated (ZQRPN, ZQRPL and ZQGRPG).

3.8 Swap at the end of sedimentation iteration for actual layer

At the end of each vertical iteration the calculation of fractions and flux-intensities at the top of the next layer is done.

3.8.1 LRNUMX=.TRUE.

In the case switch LRNUMX is activated (maximum overlap of adjacent clouds and random overlap of clear air separated parts) following formulations are used:

$$Pr_o = \frac{\mathsf{min}(n_{[jlev+1]}, n_{[jlev]})(1 - Pr_e^*) + n_{[jlev+1]}Pr_e^*}{\mathsf{max}(\epsilon, n_{[jlev+1]})}, \tag{33}$$

where Pr_o is representing the fraction or proportion of the seeded cloudy part (ZPRPLO) for the next layer and Pr_o^* being the same for actual layer. For the clear air proportion Pr_e (ZPRPLE) one can write

$$Pr_e = \frac{\mathsf{max}(n_{[jlev+1]}, n_{[jlev]})(1 - Pr_e^*) - n_{[jlev+1]} + Pr_e^*}{\mathsf{max}(\epsilon, n_{[jlev+1]})}. \tag{34}$$

For the calculation of connected fluxes one has to distinguish between two cases (with ZZTEST being the decisive variable):

- $n_{[jlev+1]} \geq n_{[jlev]}$ (ZZTEST $= 1$):

  $$Fi_e = Fi_e^* \tag{35}$$

  and

  $$Fi_o = f(P_{l/s}, n_{[jlev+1]}, Pr_e, Pr_o, Fi_e^*) \tag{36}$$

  with Fi_e and Fi_o representing the fluxes connected to clear sky part and cloudy part at the top of the layer we are entering the following iteration (ZIPLSLE/ZIPLSLO for liquid part and ZIPLSNE/ZIPLSNO for solid part), where star "$*$" is denoting the fluxes for the layer we are leaving. Computation of Fi_o is done according to the knowledge ($\rightarrow f(...)$) of precipitation fluxes P_l and P_s (PFPLSL, PFPLSN) and cloud cover n (PNEBM).

- $n_{[jlev+1]} < n_{[jlev]}$ (ZZTEST $= 0$):

  $$Fi_e = f(P_{l/s}, n_{[jlev+1]}, Pr_o, Pr_e, Fi_o^*) \tag{37}$$

  and

  $$Fi_o = Fi_o^*. \tag{38}$$

3.8.2 LRNUMX=.FALSE.

In the case random cloud overlap is chosen, the reorganization of fluxes at the top of the next layer are rather simple compared to the formulations shown above

$$Pr_e = Pr_o = n_{[jlev]} + (1 - n_{[jlev]})Pr_e^* \tag{39}$$

and

$$Fi_o = Fi_e = \frac{P_{l/s}}{Pr_o}, \tag{40}$$

with $P_{l/s}$ denoting the liquid precipitation flux P_l and its solid counterpart P_s respectively.

Table 1: Subroutine **APLMPHYS**

Purpose: COMPUTATION OF PRECIPITATION FLUXES (WATER AND SNOW)
COMPUTATION OF PSEUDO-FLUXES LINKED TO PRECIPITATION

Called by: APLPAR (L3MT=.TRUE.) OR ACCDEV(LSTRAPRO=.TRUE.)

Incoming arguments/fields:

0D

KIDIA	START OF HORIZONTAL LOOP
KFDIA	END OF HORIZONTAL LOOP
KLON	HORIZONTAL DIMENSION (NPROMA)
KTDIA	START OF VERTICAL LOOP IN PHYSICS
KLEV	END OF VERTICAL LOOP AND VERTICAL DIMENSION

2D

PAPRS	PRESSURE ON HALF LEVELS

2D

PAPRSF	PRESSURE ON FULL LEVELS
PCP	SPECIFIC HEAT AT CONSTANT AIR-PRESSURE
PQMP	SPECIFIC HUMIDITY OF WATER VAPOUR
PTMP	TEMPERATURE
PQIMP	RATIO OF SUSPENDED ICE
PQLMP	RATIO OF LIQUID WATER
PQRMP	RATIO OF RAIN WATER
PQNMP	RATIO OF SNOW
PR	GAS CONSTANT FOR AIR
PIPOI	INVERSE OF DP/(RG*DT) GIVEN LEVEL AND TIME STEP
PDQ	SATURATION DEFICIT
PLHS	LATENT HEAT FOR SUBLIMATION
PLHV	LATENT HEAT FOR EVAPORATION
PNEBM	CLOUDINESS FOR MICROPHYSICS
PHCRICS	CRITICAL RELATIVE HUMIDITY
PQSATS	SATURATION SPECIFIC HUMIDITY
PPOID	DP/(RG*DT) FOR GIVEN LEVEL AND TIME STEP

Outgoing arguments/fields:

2D

PFPLSL	STRATIFORM PRECIPITATION AS RAIN
PFPLSN	STRATIFORM PRECIPITATION AS SNOW
PFASL	STRATIFORM AUTOCONVERSION (LIQUID)
PFASN	STRATIFORM AUTOCONVERSION (SOLID)
PFCSQL	STRATIFORM CONDENSATION (LIQUID)
PFCSQN	STRATIFORM CONDENSATION (SOLID)
PFESL	STRATIFORM EVAPORATION OF RAIN
PFESN	STRATIFORM EVAPORATION OF SNOW
PFALLR	FALL VELOCITY OF RAIN
PFALLS	FALL VELOCITY OF SNOW

Used Modules:

YOMPHY, YOMCST, YOMPHY0, YOMPHY2

References

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