ALARO TRAINING COURSE

MICROPHYSICAL PROCESSES (L05)

BART CATRY

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ACPLUIE → APLMPHYS

This presentation will focus on a new microphysical scheme which entered the ALARO-0 library: APLMPHYS

APLMPHYS is the follow-up of the ACPLUIE scheme

The formulation in APLMPHYS is as close as possible to the one of ACPLUIE

Some new microphysical processes are included (sedimentation, auto-conversion, WBF,...)

OUTLINE LESSON

PART I:	REMEMBER ACPLUIE
PART II:	SEDIMENTATION OF PRECIPITATION
PART III:	NEW PROCESSES
PART IV:	ADDITIONAL FEATURES

PART I

REMEMBER ACPLUIE

What existed in ACPLUIE

1. A mechanism of condensation and evaporation

2. A rule for evaporation of falling rain and snow

3. A parallel rule for the melting or freezing of falling precipitation

4. A distinction between the mechanical and thermodynamical properties of the mixed case when both precipitating species exist together (which implied the concept of graupel)

CONDENSTATION/EVAPORATION

in ACPLUIE

The mechanism of condensation/evaporation aims to return at the 'wet bulb point' $[T_w , q_w]$ rather than $[T , q_{sat}]$ which allows to hide the thermodynamics in the interfacing (see L02)

In case of super-saturation, the full equilibrium is found in one time step (no suspended water, infinite fall-speed of precipitations having a zero volume)

In case of under-saturation, reaching the equilibrium fixes the maximum rate that the evaporation of precipitation can take

EVAPORATION OF PRECIPITATION

in ACPLUIE

Given a precipitation flux, the computation simply depends on the under-saturation level of the encountered layer (constrained however by the upper limit, see previous slide)

The formulation is as follows:

$$\frac{d\sqrt{R}}{d(1/p)} = E_{vap}.(q_w - q)$$

with R the rainfall rate (in kg/m^2/s) and p the pressure (in Pa) and $E_{vap} = 4.8 \times 10^6$

MELTING / FREEZING

in ACPLUIE

The computation now depends on the difference between the local temperature and the treble point one. Here also the thermodynamics is hidden in the change of type of precipitating fluxes

The formulation is as follows:

$$\frac{d\,m_i}{d(1/p)} = F_{ont}.(T - T^*)/\sqrt{R}$$

with m_i the thermodynamical snow proportion of the precipitation flux, T^* the treble point temperature (in °K) and the constant $F_{ont} = 2.4 \times 10^4$

Distinction when mixed case

in ACPLUIE

The physical proportion of condensed ice depends on the temperature below the treble point (via an exponential function)

This function ensures continuity for the proportion which reaches zero above the treble point

REVGSL

in ACPLUIE

The proportionality constants for the melting or freezing and evaporation rates are higher for more slowly falling precipitations

They are hence modulated by the square root of the ratio 'fall speed of rain over fall speed of snow' (REVGSL in the code):

$$E_{vap} = EVAP\sqrt{(1-m_e.(1-REVGSL))}$$

$$F_{ont} = FONT\sqrt{(1-m_e.(1-REVGSL))}$$

with m_e ($\neq m_i$) the physical proportion of ice in the precipitation flux

PART II

SEDIMENTATION OF PRECIPITATION

SEDIMENTATION: PROBLEMS

One of the constraints for a new microphysical routine was that it should preserve the characteristics of ACPLUIE

One of the main advantages of ACPLUIE was the construction with a single vertical loop

A pure advective sedimentation process however needs a double loop

An advective method also requires a single fall speed for any type of precipitation

Sedimentation: Statistics

Assume that one replaces the above mentioned single fall speed by a spectrum of fall speeds (going from zero to infinity)

The above mentioned single fall speed is assumed to be the mass weighted average of this spectrum, i.e. the first moment of the associated PDF

For a given time interval, the spectrum of fall speeds can be replaced by a spectrum of reachable distances

This seems to be worse (infinite number of trajectories to handle), but...

Sedimentation: Statistics (2)

Assume that the PDF is a decreasing exponential P_0

One makes the following distinction between three types of precipitation:

1. Already present in the layer (PDF P_1)
2. Coming from the layer above (PDF P_2)
3. Locally produced during time step (PDF P_3)

The PDFs will be derived later

SEDIMENTATION: STATISTICS (3)

Each PDF determines the fraction of precipitation that will leave the layer through its bottom

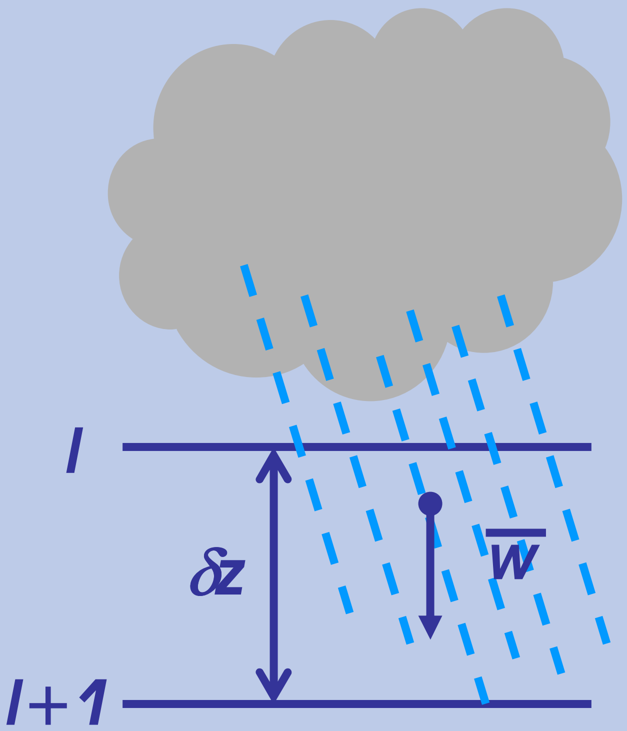
The total flux of precipitation through the bottom of this layer is then used at the top of the layer below

The advective treatment is replaced by a statistical one

If one assumes an infinite fall speed, the method degenerates in the one of ACPLUIE

Although the proposed PDF of fall speeds is far from the observed truth, it is probably better than the dirac-type fall speed associated with an advective method

THE BASIS: PDF P_0



P_0 expresses the probability to cross one layer in one time step

Consider the following form:

$$P_0(\delta z/(\overline{w}.\delta t)) = P_0(Z) = e^{-Z}$$

This expression will serve as basis for the following PDFs

SOME MATHS: PDF P_1

P_1 is for the case of rain drops present in the layer at the beginning of the time step

One assumes a homogeneous distribution in space:

$$P_1(Z) = \frac{1}{\delta z}\int_0^{\delta z} P_0(z,\delta t)\,dz = \frac{1}{\delta z}\int_0^{\delta z} e^{-\frac{z}{\overline{w}.\delta t}}\,dz$$

$$= \frac{\overline{w}.\delta t}{\delta z}\left[1 - e^{-\frac{\delta z}{\overline{w}.\delta t}}\right]$$

$$= (1 - P_0(Z))/Z$$

SOME MATHS: PDF P_2

P_2 is for the case of rain drops coming from the layer above, we will use for now P'_2

One assumes a homogeneous arrival in time (at the top):

$$P'_2(Z) = \frac{1}{\delta t}\int_0^{\delta t} P_0(\delta z, t)\,dt = \frac{1}{\delta t}\int_0^{\delta t} e^{-\frac{\delta z}{\overline{w}.t}}\,dt = E_2(\delta z/(\overline{w}.\delta t)) = E_2(Z)$$

This will be approximated by

$$P'_2(Z) = E_2(Z) = \frac{P_0(Z)}{Z+1+X} \qquad with \qquad X = \frac{\sqrt{(1+Z)^2+4Z}-(1+Z)}{2}$$

The link between P_2 and P'_2 will be explained below

SOME MATHS: PDF P_3

P_3 is for the case of rain drops created in the layer during the time step

One assumes a homogeneous distribution in time and space:

$$P_3(Z) = \frac{1}{\delta z}\int_0^{\delta z}\frac{1}{\delta t}\int_0^{\delta t} P_0(z,t)\,dt\,dz = \frac{1}{\delta z}\int_0^{\delta z} E_2(z/(\overline{w}.\delta t))\,dz = \left(\frac{1}{2} - E_3(Z)\right)/Z$$

This will be approximated by

$$P_3(Z) = \left(\frac{1}{2} - E_3(Z)\right)/Z = 0.5(E_2(Z) + P_1(Z)) = 0.5(P_2'(Z) + P_1(Z))$$

LINK BETWEEN P'_2 AND P_2

The derivation above does not take into account what kind of redistribution happens between the various terms within the layer along the time step

(needed to be compatible with the governing equations)

The problem is tackled from a double angle:

1. the stationary case
2. the full evolution case

STATIONARY CASE

stationary case $\rightarrow$

$$\frac{\partial q_r}{\partial t} \equiv 0$$

but

$$P_l^{bot} = P_l^{top}.P_2 + \frac{\delta p}{g.\delta t}(\Delta_q^{aco} - \Delta_q^{eva}).P_3 + q_r\frac{\delta p}{g.\delta t}.P_1$$

$$\downarrow$$

$$P_l^{bot}(1 - P_3) = P_l^{top}(P_2 - P_3) + q_r\frac{\delta p}{g.\delta t}.P_1$$

A sound physical solution can only be obtained when $P_2 \geq P_3$

EVOLUTIONARY CASE (1)

One can say that the part of the flux at the top which will not be subject to the P'_2 direct transfer will create a source term which will be subject to P_3

$$P_2 = P'_2 + (1 - P'_2) P_3$$

But this is a biased answer: the corresponding part will create a sink that will lower the part of the effect proportional to $1-P'_2$

The multiplier becomes $P_3 - P_3 P_3$

But then there is again a source term: $P_3 - P_3 P_3 + P_3 P_3 P_3$

Infinite series:

$$P2 = P'2 + (1 - P'2) P3 / (1 + P3) \quad \Rightarrow \quad P2 = \frac{P'2 + P3}{1 + P3}$$

Evolutionary Case (2)

$$P2 = \frac{P'2 + P3}{1 + P3}$$

This expression obeys $P_2 > P_3$ when $Z < 0.96$

The difference is never higher than 0.015 (when Z=2.4)

This can be considered as a drawback but any advective method will suffer a similar drawback

PART III

NEW PROCESSES

Fall speed dependency

The link between the mean fall speed and the intensity of the rain flux R is given by

$$\overline{w} = \Omega^r \left(\frac{R}{\rho^4} \right)^{1/6}$$

with ρ the air density (in kg/m^3) and $\Omega^r = 13.4$

The obtained mean fall speed enters the 'Z'-computation for the statistical sedimentation

The extension for snow will be discussed later

COLLECTION

Assume that cloud water is continuously present and hence collected along the volume scanned by the falling rain drops

For collection of water by rain drops we have (***E_{ff}=0.2***)

$$\frac{dq_l}{dt} = -0.335 E_{ff} R^{4/5} q_l = -0.067 R^{4/5} q_l = -C'^{r}{}_{E} R^{4/5} q_l$$

Other cases (snow/ice/rain/water) will be discussed later

AUTO-CONVERSION

Assume the most simple and continuous possible expression:

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

The characteristic times and critical threshold values for water and ice are the main tuning constants of the scheme

The case of cloud water to snow is the WBF effect

WEGENER-BERGERON-FINDEISEN

The WBF effect is parameterized as an auto-conversion form cloud water to snow:

$$\left(\frac{dq_l}{dt}\right)_{WBF} = -F_{WBF}^{a}\,\frac{q_l}{\tau_l}\,\frac{q_l.q_i}{(q_l+q_i)^2}\left(1-e^{-\frac{\pi}{4}((q_l.q_i)/(q_l^{cr}.F_{WBF}^{b}.q_i^{cr}(T).F_{WBF}^{b})}\right)$$

The two WBF scaling constants are also important tuning parameters of the scheme

TEMPERATURE DEPENDENCIES

There are five temperature dependencies to be taken into account:

1. The auto-conversion time scale variation with temperature (colder → less efficient)
2. The critical threshold for ice to snow auto-conversion (colder → lower threshold)
3. The fall speed of snow (colder → lower speed)
4. The collection efficiency for ice crystals (colder → less efficient)
5. The scanned volume for collection by snow (colder → smaller flakes → better surface to volume ratio → more efficient)

Temperature dependencies (2)

These dependencies are based on the figures of Lopez (2002), where one uses functions of the type $\exp(c_t(T-T^*))$

When computing the c_t value for each effect, it seemed that they were all close to each other and an average value of 0.0231 is now used for all c_t values

The collection efficiency for snow becomes

$$\frac{C_E^s}{C_E^r} = 4.085 \quad \Rightarrow \quad C_E^s \approx 2.7410^{-1}$$

COLLECTION (EXTENDED)

The collection between the different phases of water (with $f_{s/i}{}^*(T)=\exp(c_t{}^*(T\text{-}T^*))$):

$$\left(\frac{dq_l}{dt}\right)_R = -C_E^r\, R^{4/5}\; q_l$$

$$\left(\frac{dq_i}{dt}\right)_R = -C_E^r\; R^{4/5}\; q_i \times f_{s/i}^*(T)$$

$$\left(\frac{dq_l}{dt}\right)_S = -C_E^s\; S^{4/5}\; q_l \,/\, f_{s/i}^*(T)$$

$$\left(\frac{dq_i}{dt}\right)_S = -C_E^s\; S^{4/5}\; q_i$$

The fall speed coefficient of snow becomes: $\Omega_s = 3.4\; f_{l/i}{}^*(T)$

PART IV

ADDITIONAL FEATURES

PSEUDO-GRAUPEL

The graupel effect is synthesised in the ratio r_g between a pseudo-graupel flux and the total 'snow' flux

r_g influences the averaged properties of the fall speed and of the collection efficiency for the falling ice-phase:

$$\left[\Omega^r / \overline{\Omega}^s\right] = r_g + (1 - r_g).\left[\Omega^r / \Omega^s(T)\right]$$
$$\left[C_E{}^r / \overline{C}_E{}^s\right] = r_g + (1 - r_g).\left[C_E{}^r / C_E{}^s(T)\right]$$

The statistical sedimentation functions are those of rain water

PSEUDO-GRAUPEL (2)

Only the WBF effect contributes to the pseudo-graupel flux

After the collection (with the above mentioned influence) the proportion attributed to the graupel flux is reduced following (lower relative collection efficiency):

$$r'_g = \frac{r_g}{r_g + (1 - r_g).C_E^s(T) / C_E^r}$$

The ice-phase evaporation and melting is computed like in ACPLUIE (with the above mentioned influence), afterwards r_g is diminished by

$$r''_g = \frac{r_g}{r_g + (1 - r_g).\sqrt{1 - m_e(1 - \Omega^r / \Omega^s(T))}}$$

CLOUD GEOMETRY

Let us name *N** the cloud cover of the layer the rain is leaving and *N* the same for the one it is entering

We use the same *-convention for Pr_o and Pr_e , respectively the seeded proportions of the cloudy and clear air parts

We use the same *-convention for Fi_o and Fi_e the respective flux intensities

Then:

$$\mathrm{Pr}_o = \left[\min(N, N^*) + (N - \min(N, N^*))\,\mathrm{Pr}_e{}^*\right]/N$$
$$\mathrm{Pr}_e = \left[(\max(N, N^*) - N) + (1 - \max(N, N^*))\,\mathrm{Pr}_e{}^*\right]/(1 - N)$$
$$Fi_e = Fi_e{}^* \qquad if \qquad N > N^*$$
$$Fi_o = Fi_o{}^* \qquad if \qquad N < N^*$$

QUESTIONS ??

Time for questions / remarks / comments

A very detailed documentation of
APLMPHYS is available (ask Jean-Francois)