Selected issues in Microphysics

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1. Improved representation of the raindrop size distribution

2. Prognostic graupel

Weakness of Marshall-Palmer law

- Collection- and evaporation processes all based on Marshall-Palmer raindrop size distribution (DSD):

$$N(D) = N_0 \exp(-\lambda D)$$

$$\lambda(q_R)$$

- This DSD becomes highly invalid in case of low rain rates (drizzle).
- Mostly due to N_0 being a constant.

Solution

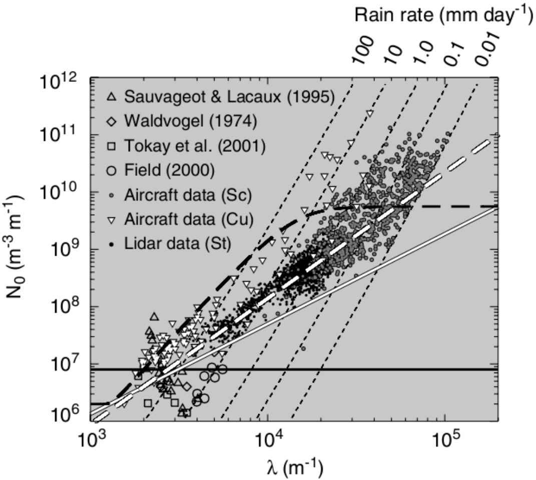
- Make N_0 prognostic
- Find relation between N_0 and λ (Abel & Boutle 2012)

Method of Abel & Boutle

- Try to predict N_0 from $\lambda(q_r)$ using the relation

$$N_0 = x_1 \lambda^{x_2}$$

- Fit x_1 and x_2 to observations.



Method of Abel & Boutle

- Try to predict N_0 from $\lambda(q_r)$ using the relation

$$N_0 = x_1 \lambda^{x_2}$$

- Fit x_1 and x_2 to observations.
- DSD becomes:

$$N(D) = x_1 \lambda^{x_2} \exp(-\lambda D)$$

- with $x_1 = 0.22$ and $x_2 = 2.20$

Auto-conversion

- Routine: ACACON
- No changes since auto-conversion process is based on Sundquist formulation

$$\frac{\mathrm{d}q_r}{\mathrm{d}t} = \frac{q_l}{t_l}\left(1 - \exp(-\frac{4}{\pi}(q_l/q_l^{cr})^2)\right)$$

- Formulation dependent on critical amount of cloud water and/or cloud ice and a time-scale

Fall-speed

- Need an average fall speed for the statistical sedimentation scheme
- Single drop:

$$w = aD^{\alpha} \qquad a = a_0 \left(\frac{\rho}{\rho_0}\right)^{\alpha} \qquad \alpha = 0.7706$$

- Mass weighted average:

$$\bar{w} = \frac{\int_0^{\infty} w(D)N(D)m(D)dD}{w(D)N(D)m(D)dD} = a\frac{\Gamma(\alpha+4)}{\Gamma(4)\lambda^{\alpha}}$$

- write λ in function of rain-rate (flux)
- old: $R = \frac{\Gamma(4+\alpha)aN_0\pi}{6\nu_l\lambda^{4+\alpha}}$
- new: $R = \frac{\Gamma(4+\alpha)ax_1\pi}{6\nu_l\lambda^{4+\alpha-x_2}}$

Fall-speed

- Need an average fall speed for the statistical sedimentation scheme
- Single drop:

$$w = aD^{\alpha} \qquad a = a_0 \left(\frac{\rho}{\rho_0}\right)^{\alpha} \qquad \alpha = 0.7706$$

Old

- $\bar{w} = \Omega \left(\frac{R}{\rho^4}\right)^{1/6}$
- rounding of $\alpha \approx 0.8$
- rescaling of a_0

New

- $\bar{w} = 2.25 \times \Omega \left(\frac{R}{\rho^{1.8}}\right)^{0.3}$
- No rounding on α
- Final rounding of exponent $0.2998 \approx 0.3$

Collection

Routine: ACCOLL

$$-\frac{\mathrm{d}R}{\mathrm{d}z} = \int_0^\infty N(D)E_{ff}\frac{\pi D^2}{4}aD^\alpha \rho q_l dD$$

Old

- $\frac{\mathrm{d}q_l}{\mathrm{d}t} = -C_E^r R^{4/5} q_l$
- ρ-dependency in a neglected
- α rounded to 1

New

- $\frac{\mathrm{d}q_l}{\mathrm{d}t} = -0.28 \times C_E^r \left(\frac{R}{\sqrt{\rho}}\right)^{3/5} q_l$
- No rounding on α
- rounding at the end
  $\left(\frac{1}{\rho}\right)^{0.2988} \approx \left(\frac{1}{\rho}\right)^{0.3}$
  $R^{0.611} \approx R^{0.6}$

Evaporation, melting and (re-)freezing

Routine: ACEVMEL

$$-\frac{\mathrm{d}R}{\mathrm{d}z} = \int_0^\infty N(D) b D^\beta \rho (q - q_w) dD$$

Old

- $\frac{\mathrm{d}\sqrt{R}}{\mathrm{d}1/p} = E_{vap}(q_w - q)$
- rounding of β to get exponent 1/2

New

- $\frac{\mathrm{d}R^{0.8389}}{\mathrm{d}p^{-5/4}} = 2.05 \times E_{vap}(q_w - q)$
- No rounding, exact exponent in R

Same principle for symmetric process of melting/freezing

- $\frac{\mathrm{d}m_i}{\mathrm{d}1/p} = F_{freez/melt} \frac{(T - T_t)}{\sqrt{R}}$

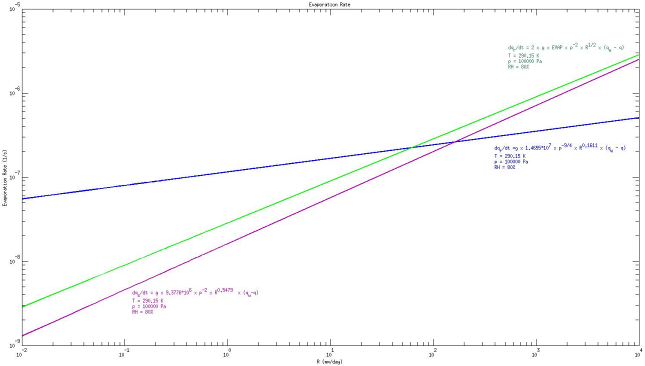
- $\frac{\mathrm{d}m_i}{\mathrm{d}p^{-\frac{5}{4}}} = 1.23 \times F_{freez/melt} R^{-0.8389} (T - T_t)$

Results

- Test done by Radmila and Jean-Francois
- June - July 2009 (11 Cases)
- Positive scores for Temperature and Humidity (at low altitude)
- Less drizzle and more heavy precipitation
- Underestimation of total amount of rainfall
- Bad scores in case of snow

Results

- Bad scores in case of
  - For Evaporation (and melting/freezing): Total amount of precipitation is used (R+S)
    No distinction is made between Rain and Snow
  - The Abel & Boutle fit is not valid for snow (N_0 constant)



Prognostic graupel

- Forms when snowflakes collect droplets of supercooled water
- Balls of 2 - 5 mm
- Needed if we want to go to more complex microphysical schemes
- Continuation of the work done by Joris Vandenberghe

Situation now

- Local switch *LLPSGRP* in APLMPHYS for *pseudo-graupel*
- Effect of *pseudo-graupel* is synthesized in r_g:
  The ratio between the pseudo-graupel flux
  and the total snow flux
- Impact on: Auto-conversion
  - Only the Wegener-Bergeron-Findeisen process contributes to the forming of graupel.
  - Cloud water (q_l) $\rightarrow$ graupel (q_g)

Situation now

- Local switch *LLPSGRP* in APLMPHYS for *pseudo-graupel*
- Effect of *pseudo-graupel* is synthesized in r_g: The ratio between the pseudo-graupel flux and the total snow flux
- Impact on: Collection
  - Collection efficiency of *ice-phase* gets averaged over snow and graupel
  - $\frac{1}{\bar{C}_E^s} = \frac{r_g}{C_E^r} + (1 - r_g)\frac{1}{C_E^s}$
  - Proportion of collection attributed to graupel is reduced with respect to r_g
  - $r_g' = \frac{r_g}{r_g + (1 - r_g)C_E^s/C_E^r}$

Situation now

- Local switch *LLPSGRP* in APLMPHYS for *pseudo-graupel*
- Effect of *pseudo-graupel* is synthesized in r_g: The ratio between the pseudo-graupel flux and the total snow flux
- Impact on: Evaporation & Freezing-Melting
  - Ice-phase melting and evaporation are computed globally
  - Attribution to pseudo-graupel according to r_g
  - Freezing of rain water is all attributed to pseudo-graupel

Situation now

- Local switch *LLPSGRP* in APLMPHYS for *pseudo-graupel*
- Effect of *pseudo-graupel* is synthesized in r_g: The ratio between the pseudo-graupel flux and the total snow flux

Remember

Graupel is diagnosed every time-step and only exists in APLMPHYS

Prognostic graupel

- Make graupel a fully prognostic hydro-meteor q_g.
- Some starting assumptions:
  - Dynamical (fall speed, collection efficiency) properties of water
  - Thermodynamical properties of ice
  - WBF-process exclusively accounts for auto-conversion to graupel
  - Freezing of rain only results in graupel
- Infrastructure for graupel is already present down to MF_PHYS

Touched routines

- MF_PHYS
  - APLPAR
    - APLMPHYS
      - ACACON
      - ACCOLL
      - ACEVMEL
    - ACUPM
    - ACMODO
    - ACUPD
  - CPTEND_NEW
  - CPUTQY

- Most of the work is straightforward (ACACON, ACCOLL, ACEVMEL)
- Some thought needed on the downdraught-routines (ACMODO, ACUPD)

Autoconversion

- Auto-conversion process from cloud ice to graupel present but set to zero

$$\text{PACOGI} = \Delta q_g = \frac{q_i}{\tau_g}\left(1 - \exp\left[-\frac{\pi}{4}(q_i/q_i^{cr})^2\right]\right)\Delta t$$

$$\text{with } \frac{1}{\tau_g} = 0$$

- WBF-process: accounts only for creation of graupel

$$\text{PACOGL} = \Delta q_g = F_{WBF}^{a}\frac{q_l}{\tau_l}\frac{q_l q_i}{(q_l + q_i)^2}\left(1 - \exp\left[-\frac{\pi}{4}\frac{q_l q_i}{(F_{WBF}^{b})^2 q_l^{cr} q_i^{cr}}\right]\right)\Delta t$$

Collection

- Collection efficiency of graupel is equal to the one of rain

$$\text{PCOLGL} = (\Delta q_g)_l = C_E^r G^{\frac{4}{5}} q_l \times \Delta t$$
$$\text{PCOLGI} = (\Delta q_g)_i = C_E^r G^{\frac{4}{5}} q_i f_{i/p}(T) \times \Delta t$$

Evaporation

- Total evaporation is calculated on the total precipitation flux (rain+snow+graupel)
- Divided over the 3 species according to flux ratio

$$
\begin{aligned}
P &= R+S+G \quad ; \quad r_g = \frac{G}{R+S+G} \\
\text{ZEVAPO} &= (\Delta q_{evap})_{tot} = 2F_{evap}\sqrt{P}\Delta\left(\frac{1}{p}\right)(q_w - q_v) \times \text{PIPOI} \\
\text{PEVAG} &= -(\Delta q_g)_{evap} = r_g \times (\Delta q_{evap})_{tot}
\end{aligned}
$$

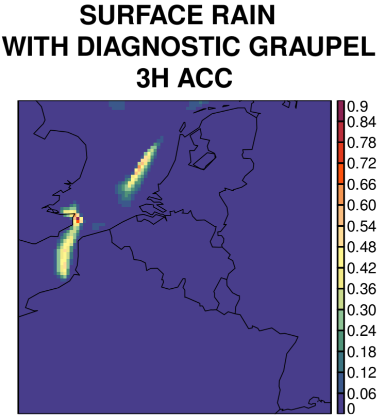
- Melting and freezing are calculated in same manner as evaporation
- Melting is divided between snow and graupel according to r_g
- Freezing all goes to graupel

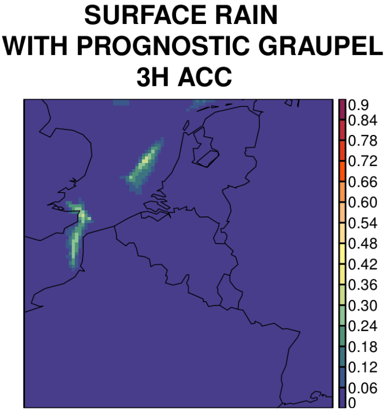
Downdraught

- Evaporating descent calculated using the total precipitation flux
- How to partition between the three different precipitating species?
  - Total ice fraction: $\alpha_{solid} = zsop = (S+G)/(S+G+R)$
  - Graupel fraction: $\alpha_{gr} = zgrp = G/(S+G+R)$
- Easier for:
  - Case of very low total precipitation: $zsop =$ fonice(T) and $zgrp = 0$
  - Latent heat calculations: $L(T, \alpha_{solid})$
- Thermodynamics is taken care of in the interface CPTEND_NEW.

First preliminary tests

Winter SNOW case

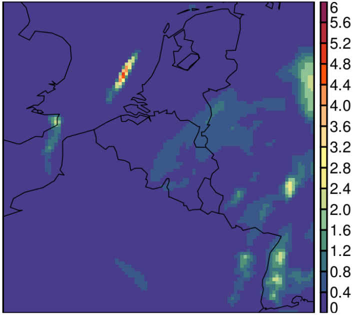




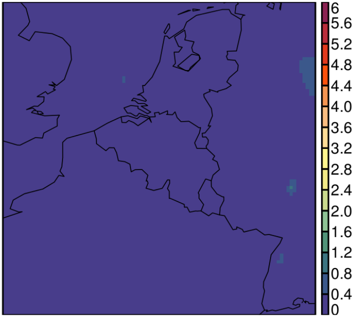
First preliminary tests

Winter SNOW case

SURFACE SNOW
WITH DIAGNOSTIC GRAUPEL
3H ACC



SURFACE SNOW
WITH PROGNOSTIC GRAUPEL
3H ACC



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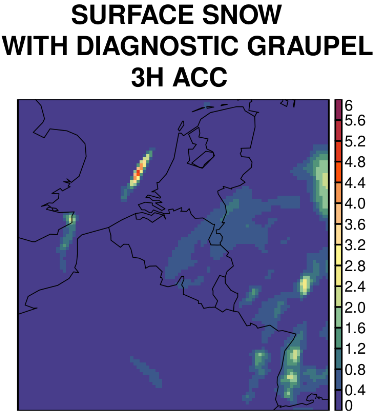

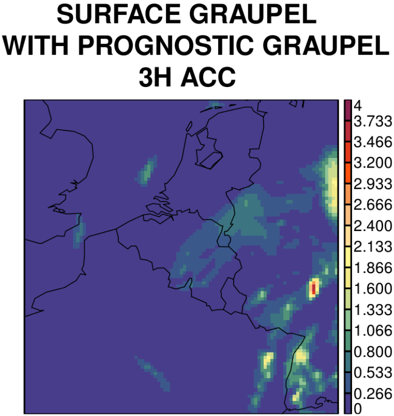

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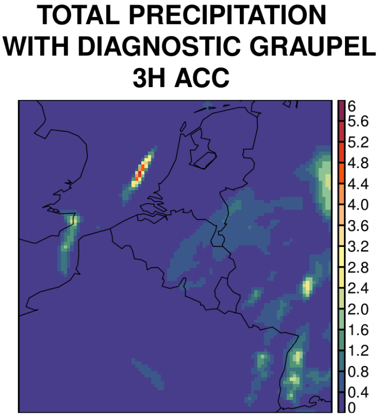
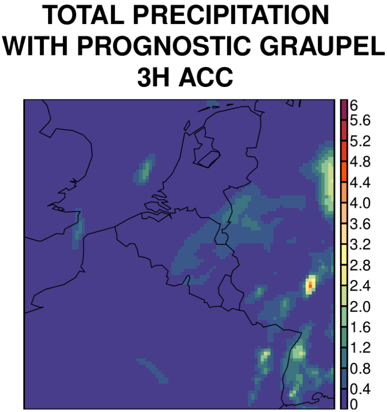
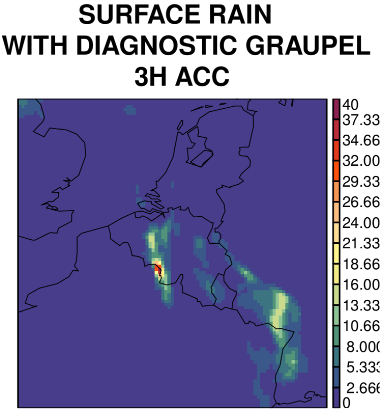
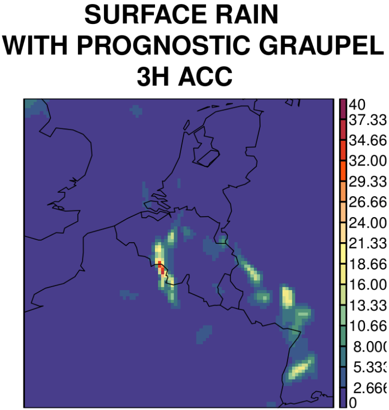




First preliminary tests

summer CONVECTIVE case





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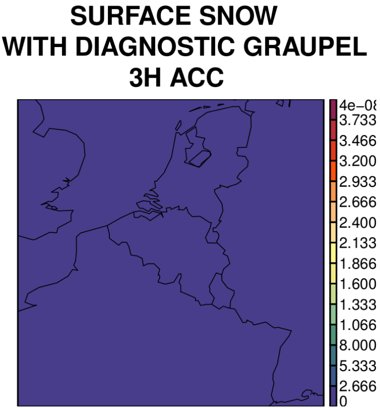

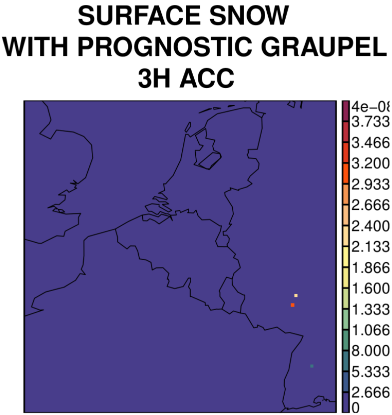

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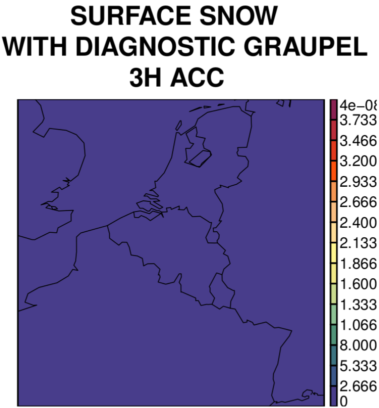

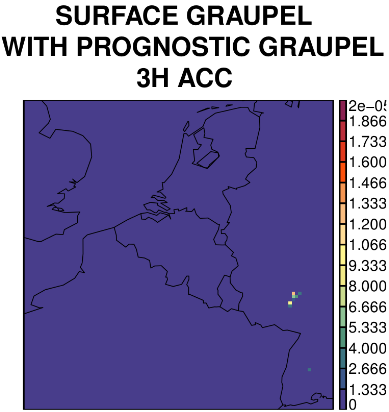

Questions?