Documentation of the Changes in the Microphysics Scheme (ICON/COSMO)

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Different switches have been implemented in order to test the sensitivities of the numerical weather prediction model behaviour. The default setting of the switches are :

$$lorig\_icon = .TRUE. \quad \text{switch for original ICON setup (only for hydci\_pp)} \tag{1}$$
$$lsedi\_ice = .FALSE. \quad \text{switch for sedi of cloud ice (Heymsfield \& Donner 1990 *1/3)} \tag{2}$$
$$lstickeff = .FALSE. \quad \text{switch for sticking coeff. (Guenther Zaengl)} \tag{3}$$
$$lsuper\_coolw = .FALSE. \quad \text{switch for supercooled liquid water (Felix Rieper)} \tag{4}$$
$$\tag{5}$$

The three-category ice scheme is depicted in Fig.1. Changes that have been performed by, e.g., Günther Zängl and Felix Rieper, are documented in the following.

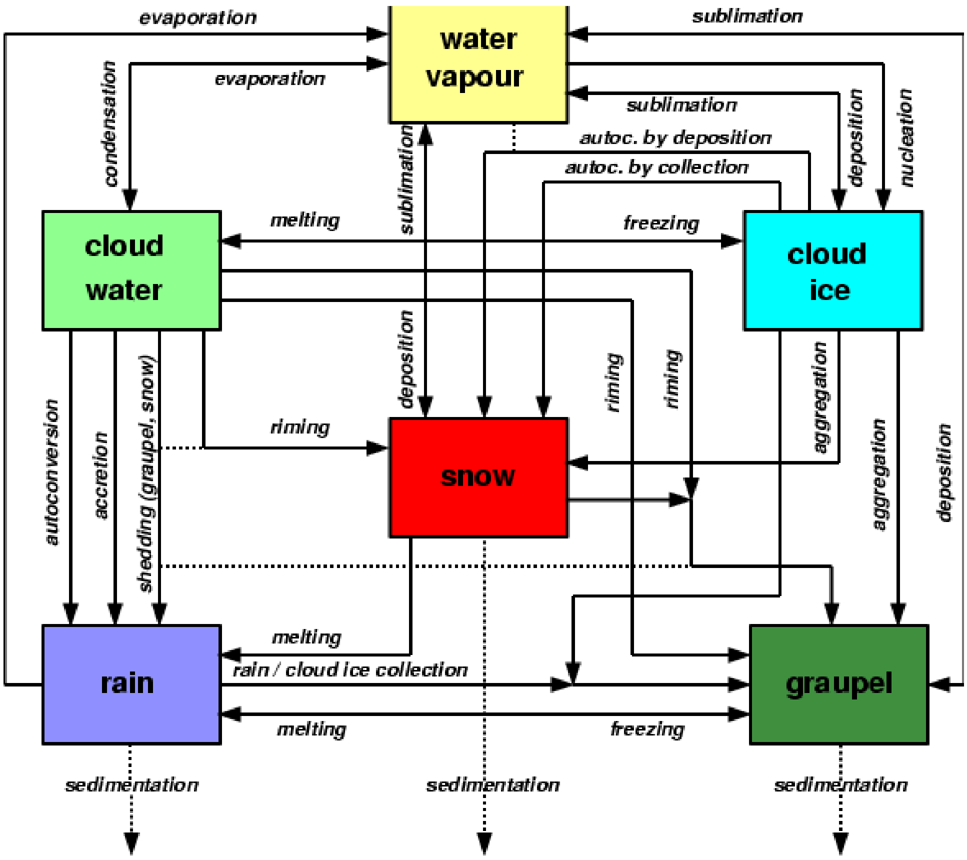

Figure 1: *Cloud microphysical processes from the three-category ice scheme*

S_c	condensation and evaporation of cloud water
S_{au}^c	autoconversion of cloud water to form rain
S_{ac}	accretion of cloud water by raindrops

S_{ev}	evaporation of rain water
S_{nuc}	heterogeneous nucleation of cloud ice
S^c_{frz}	nucleation of cloud ice due to homogeneous freezing of cloud water
S^i_{dep}	deposition growth and sublimation of cloud ice
S^i_{melt}	melting of cloud ice to form cloud water
S^i_{au}	autoconversion of cloud ice to form snow due to aggregation
S_{aud}	autoconversion of cloud ice to form snow due to deposition
S^s_{agg}	collection of cloud ice by snow (aggregation)
S^g_{agg}	collection of cloud ice by graupel (aggregation)
S^s_{rim}	collection of cloud water by snow (riming)
S^g_{rim}	collection of cloud water by graupel (riming)
S^s_{shed}	collection of cloud water by wet snow to form rain (shedding)
S^g_{shed}	collection of cloud water by wet graupel to form rain (shedding)
S^i_{cri}	collection of cloud ice by rain to form graupel
S^r_{cri}	freezing of rain due to collection of cloud ice to form graupel
S^r_{frz}	freezing of rain to form graupel
S^s_{dep}	deposition growth and sublimation of snow
S^g_{dep}	deposition growth and sublimation of graupel
S^s_{melt}	melting of snow to form rain water
S^g_{melt}	melting of graupel to form rain water
S_{csg}	conversion of snow to graupel due to riming

1 Cloud Ice Sedimentation

Cloud ice sedimentation plays an important role in restructuring the high clouds and counteracting overprediction or too long lifecyles of cirrus. Thus, in the ICON cloud ice sedimentation was implemented (Felix Rieper) and tuned (Günther Zängl). This sedimentation is now also implemented into the graupel scheme and can be controlled by use of the switch **lsedi_ice**. The equation used for the sedimentation velocity of cloud ice is

$$zvzi(iv) = zvz0i * (0.5 q_i \rho)^{zbvi}) \tag{6}$$

with the terminal fall velocity of ice based on Heymsfield and Donner (1990) (multiplied by 1/3) $zvz0i = 1.1$ and $zbvi = 0.16$.

2 Sticking Efficiency

With cloud ice sedimentation change sticking efficieny as done in ICON (implemented by Gnther Zängl) switch is **lsedi_ice**. The sticking efficieny influences the aggregation and ice autoconversion. It can be turned off with the switch **lstickeff**. In the following this change is documented. Scaling factor $1/K$ for temperature-dependent cloud ice sticking efficiency $zceff_{fac} = 3.5e-3$, the temperature at which cloud ice autoconversion starts $Tmin_{iceautoconv} = 188.15$ and the minimum value for sticking efficiency $zceff_m in = 0.02$.

$$stickeff = min(\exp(0.09 * (T - T_0)), 1.0) \tag{7}$$

$$stickeff = max(stickeff, zceff_{min}, zceff_{fac} * (T - Tmin_{iceautoconv})) \tag{8}$$

$$zsiau = zciau * max(q_i - q_{i,0}, 0.0) * stickeff \tag{9}$$

The sticking efficiency of cloud ice of the operational COSMO model code is

$$stickeff = min(\exp(0.09 * (T - T_0)), 1.0) \tag{10}$$
$$stickeff = max(stickeff, 0.2) \tag{11}$$
$$zsiau = zciau * max(q_i - q_{i,0}, 0.0) * stickeff. \tag{12}$$

The resulting equations for the source/sink terms are

$$sagg(iv) = stickeff\, q_i * zcagg(iv) * zcslam(iv)^{ccsaxp} \tag{13}$$
$$sagg2(iv) = stickeff\, q_i * zcagg_g * zelnrimexp_g(iv) \tag{14}$$
$$siau(iv) = stickeff * zciau * max(q_i - q_{i,0}, 0.0). \tag{15}$$
$$\tag{16}$$

3 Evaporation

Günther Zängl also implemented a limitation for maximum evaporation. This is needed to provide numerical stability for large horizontal resolutions. The limit for the evaporation rate is introduced in order to avoid overshoots towards supersaturation. The pre-factor approximates $(esat(T_{wb}) - e)/(esat(T) - e)$ at temperatures between $0C$ and $30C$

$$T_c = T - T_0 \tag{17}$$
$$maxevap = (0.61 - 0.0163 * T_c + 1.111e - 4 * T_c * *2) * (zqvsw - q_v)/\Delta\, t \tag{18}$$
$$sev(iv) = min(zcev * zx1 * (zqvsw - q_v) * \exp(zcevxp * zlnqrk), maxevap) \tag{19}$$
$$\tag{20}$$

4 Changes from Felix Rieper

4.1 Supercooled Liquid Water Vapor

The change for the supercooled liquid water based on the work done by Felix Rieper can be switched on/off with the switch **lsuper_coolw**. The supercooled liquid water approach reduces the depositional growth for temperatures below $ztmix = 250\,\mathrm{K}$ which is assumed to be the threshhold for mixed-phase clouds (Forbes 2012). Also, a different parameterization for the cloud ice number is required. In the operational COSMO model a modified version of the Fletcher equation is used while Thompson (NCAR) proposed the use of the Cooper (1986)

$$fxna_{cooper}(T) = 5.0 * \exp(0.304 * (T_0 - T)) \tag{21}$$

with the maximal number of ice crystals $znimax_{Thom} = 250.0e3$ and $znimix = fxna_{cooper}(ztmix)$. The reduction coeff. for dep. growth of rain and ice is $reduce_{dep} = 1.0.$.
Calculation of reduction of depositional growth at cloud top (Forbes 2012)

$$znin = min(fxna_{cooper}(T), znimax) \tag{22}$$
$$fnuc = min(znin/znimix, 1.0_ireals) \tag{23}$$
$$zdh = 0.5 * (hhl(i, j, k - 1) - hhl(i, j, k + 1)) \tag{24}$$
$$\tag{25}$$

Then the distance from cloud top is calculated and the depositional growth rate for cloud ice and snow reduced accordingly.

$$reduce_{dep}(i, j) = min(fnuc + (1.0 - fnuc) * (reduce_{dep,ref} + dist_{cldtop}(i, j)/dist_{cldtop,ref}), 1.0) \tag{26}$$

4.2 Reduced Freezing Rate

Felix Rieper also implemented the reduction in freezing rate of in-cloud and below cloud rain-water. This reduction takes effect for temperatures below the threshhold for heterogeneous freezing of raindrops $ztrfrz = 271.15\,\mathrm{K}$ according to Bigg (1953)

$$srfrz(i,j) = zcrfrz1 * (EXP(zcrfrz2 * (ztrfrz - T)) - 1.0) * (q_r \rho)^(7/4) \tag{27}$$

The changes performed by Felix Rieper where all tested within the COSMO-EU model scheme (*hydci_pp*) and where chosen to be introduced in the COSMO Model V5.1 in order to improve the forecast for aircraft icing (ADWICE) (decided in a Routine Besprechung).