Cloud in the operational DWD mesoscale model

An extensive documentation of the physics included in the Lokal Modell (LM) can be found in Doms et al. (2004). Here a short summary of the cloud physics is given, including the parameterizations of convection and cloud cover. This short overview given here is far away from being complete, and the aim is only to give the well-educated reader a quick overview.

1 Grid-scale clouds

Since 26th of April 2004 the Lokal Modell (LM) uses a two-category ice scheme which explicitly predicts the mass fractions of cloud water q_c, rain water q_r, cloud ice q_i and snow q_s at every grid point and includes the advection of all hydrometeors. For the non-precipitating categories we apply the budget equation including turbulent fluxes $\mathbf{F}^{c,i}$, but neglecting sedimentation:

non-precipitating categories (cloud water and cloud ice)

$$\frac{\partial q^{c,i}}{\partial t} + \mathbf{v} \cdot \nabla q^{c,i} \;=\; S^{c,i} - \frac{1}{\rho} \nabla \cdot \mathbf{F}^{c,i} \,, \tag{1}$$

While for precipitation-sized particles only sedimentation is taken into account, since for larger particles the sedimentation fluxes are usually much larger than the turbulent fluxes:

precipitating categories (rain, snow and graupel)

$$\frac{\partial q^{s,r}}{\partial t} + \mathbf{v} \cdot \nabla q^{s,r} - \frac{1}{\rho} \frac{\partial \rho q^{s,r} v_T^{s,r}}{\partial z} \;=\; S^{s,r} \,, \tag{2}$$

Prior to 26. April 2004 the so-called diagnostic precipitation scheme has been used which neglects the advection of precipitation particles. The (diagnostic) two-category ice scheme had been introduced on 16. Sept. 2003, before that date cloud ice was not included. The diagnostic version of the two-category ice scheme and also the old one-category ice scheme are described in Doms et al. (2004).

Figure 1 gives an overview of the microphysical sources and sinks S that are considered in this two-category ice scheme of LM. The individual microphysical processes are:

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_{frz}^c	nucleation of cloud ice due to homogeneous freezing of cloud water
S_{dep}^i	deposition growth and sublimation of cloud ice
S_{melt}^i	melting of cloud ice to form cloud water
S_{au}^i	autoconversion of cloud ice to form snow due to aggregation
S_{aud}	autoconversion of cloud ice to form snow due to deposition
S_{agg}	collection of cloud ice by snow (aggregation)

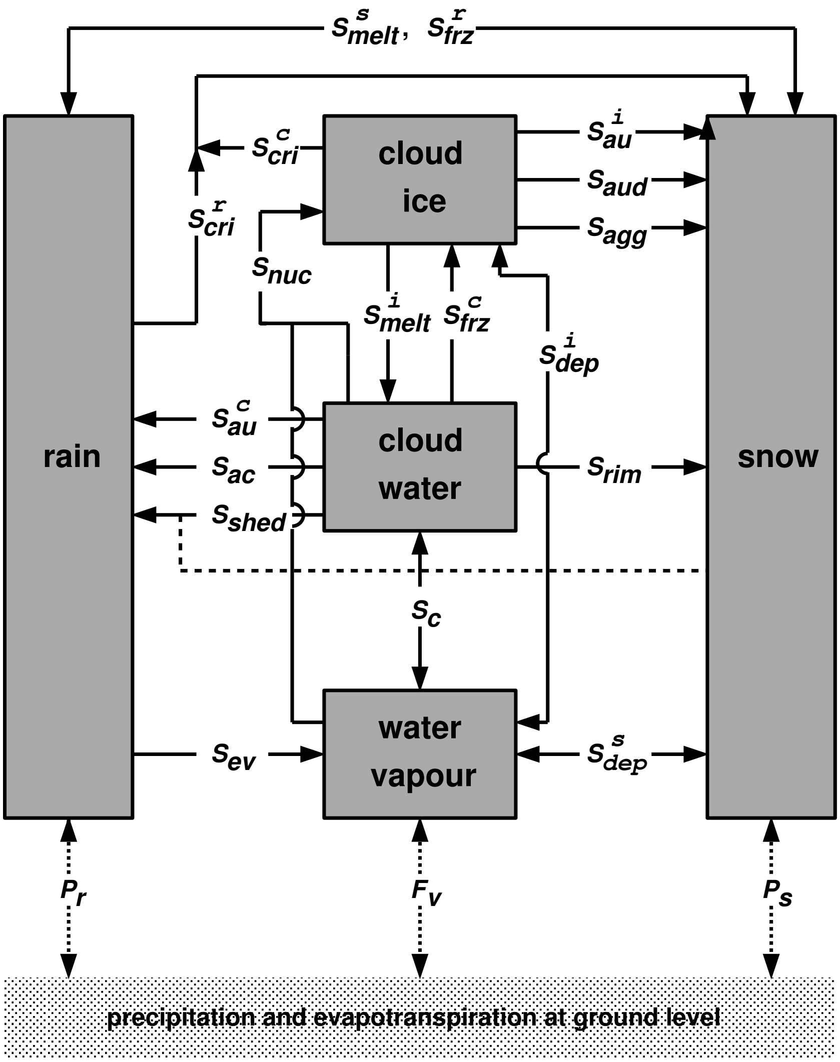

Figure 1: *Cloud microphysical processes considered in the two-category ice scheme*

S_{rim}	collection of cloud water by snow (riming)
S_{shed}	collection of cloud water by wet snow to form rain (shedding)
S^i_{cri}	collection of cloud ice by rain to form snow
S^r_{cri}	freezing of rain due to collection of cloud ice to form snow
S^r_{frz}	freezing of rain due heterogeneous nucleation to form snow
S^s_{dep}	deposition growth and sublimation of snow
S^s_{melt}	melting of snow to form rain water

The following main assumption are made in the parameterization:

- The raindrops are assumed to be exponentially distributed with respect to drop diameter D:

$$f_r(D) \,=\, N_0^r \exp(-\lambda_r D)\,, \tag{3}$$

where $N_0^r = 8\times10^6\ \mathrm{m}^{-4}$ is an empirically determined distribution parameter (Marshall-Palmer distribution). As similar exponential distribution is assumed for snow with

$N_0^s = 4 \times 10^5$ m^{-4} (Gunn-Marshall distribution).

- For the terminal fall velocities of single raindrops and snow particles as functions of size we use the following empirical relations

$$v_T^{rp}(D) \,=\, v_0^r D^{1/2}\,, \qquad v_T^{sp}(D) \,=\, v_0^s D^{0.3}\,, \tag{4}$$

  where $v_0^r = 130$ m$^{1/2}$s^{-1} and $v_0^s = 9.356$ m$^{0.7}$s^{-1}.

- Snow particles are interpreted as rimed aggregates. The equation

$$m \,=\, a_m(T)\,(D_s)^2 \tag{5}$$

  is used to specify their mass-size relation where $a_m(T)$ is a temperature dependent form factor given by

$$a_m(T) \,=\, \begin{cases} a_{mc} - a_{mv}\left[1 + \cos\left\{\dfrac{2\pi(T - T_{m1})}{(T_0 - T_1)}\right\}\right] & \text{if } T_0 > T > T_1, \\ a_{mc} & \text{else,} \end{cases} \tag{6}$$

  where $T_0 = 273.15$ K, $T_1 = 253.15$ K, $T_{m1} = 0.5(T_0 + T_1)$, $a_{mc} = 0.08$ kgm^{-2} and a_{mv} $= 0.02$ kgm^{-2} are constant parameters. According to (6), the snow aggregates will attain their largest extension D_s at - 10° C.

- The rate of autoconversion from cloud water to rain due to cloud droplet collection (S_{au}^c) and of autoconversion of cloud ice to snow due to cloud ice crystal aggregation (S_{au}^i) is parameterized by the simple relations

$$\begin{aligned} S_{au}^c &= \max\{c_{au}^c\,(q^c - q_0^c)\,,\,0\,\}\,, \\ S_{au}^i &= \max\{c_{au}^i\,(q^i - q_0^i)\,,\,0\,\}\,. \end{aligned} \tag{7}$$

  Currently we do not use any autoconversion threshold values (hence, $q_0^c = q_0^i = 0$). The rate coefficients are set to $c_{au}^c = 4 \cdot 10^{-4}\,\text{s}^{-1}$ for cloud water and $c_{au}^i = 10^{-3}\,\text{s}^{-1}$ for cloud ice.

- We assume a monodispers size distribution for cloud ice with a mean crystal mass given by

$$m_i \,=\, \rho q^i N_i^{-1}\,, \tag{8}$$

  where N_i is the number of cloud ice particles per unit volume of air. The number density N_i is parameterized as a function of temperature by

$$N_i(T) \,=\, N_0^i \exp\{\,0.2\,(T_0 - T)\}\,, \qquad N_0^i \,=\, 1.0 \cdot 10^2 m^{-3}\,. \tag{9}$$

  Note that depositional growth is explicitly parameterized, thus the model predicts ice supersaturation.

2 Convective clouds

The cumulus parameterization scheme used in LM uses the mass-flux approach of Tiedtke (1989) with some extensions and modification. In contrast to the current ECMWF model, LM still uses moisture convergence closure as given by Eq. (19) of Tiedtke (1989) and no direct feedback between grid-scale clouds and convective clouds is taken into account, e.g. cloud ice from the convection scheme is not detrained into grid-scale cloud ice. Hence, the only coupling between convective clouds and grid-scale variables is by changes in water vapor/temperature and convective precipitation reaching the surface. Sub-grid cumulus clouds contribute to cloud fraction as described in the next section.

3 Parameterization of cloud fraction

3.1 Stratiform and convective cloud fraction

Cloud cover is parameterized based on the contributions from grid-scale clouds, sub-grid convective clouds and sub-grid stratiform clouds. The cloud cover scheme is currently based on cloud water and cloud ice only, the contribution from the precipitation categories snow and rain are neglected.

First, stratiform sub-grid clouds are estimated as a function of the total water mass fraction $q_t = q_v + q_c + q_i$ and

$$\alpha_{sgs} = 0.95 - 0.8\,\sigma\,(1-\sigma)(1+\sqrt{3}(\sigma - 0.5)) \tag{10}$$

with $\sigma = p/p_s$ wherein p are pressure and surface pressure, respectively. The sub-grid stratiform cloud fraction is then parameterized by

$$\mathcal{N}_{sgs} = \max\left\{0, \min\left[1, \left(\frac{q_t}{q_{sat}} - \alpha_{sgs}\right)(1-\alpha_{sgs})^{-1}\right]\right\}^2 . \tag{11}$$

with

$$q_{sat} = q_{sat,l}\,(1 - f_{ice}) + q_{sat,i}\,f_{ice} \tag{12}$$

and

$$f_{ice} = 1 - \min\left[1, \max\left(0, \frac{T_C - (-25)}{(-5) - (-25)}\right)\right] \tag{13}$$

Here T_C is the temperature in degree Celcius. Note that for unstable conditions, i.e. $\partial\theta/\partial z < 0$, the stratiform cloud fraction is set to zero.

Using the grid-scale mass fractions q_c and q_i, the stratiform cloud cover is calculated by:

$$\mathcal{N}_{strat} = \begin{cases} 1, & \text{if } q_c > 0 \\ 1, & \text{if } q_i > 10^{-7} \\ \mathcal{N}_{sgs}, & \text{else.} \end{cases} \tag{14}$$

For convective clouds the cloud fraction is parameterized as a function of cloud depth, i.e. it is assumed that the radius of convective clouds increases with cloud depth.

$$\mathcal{N}_{con} = \min\left[1, \max\left(0.05, 0.35\,\frac{z_{top} - z_{base}}{5000\text{ m}}\right)\right] \tag{15}$$

Here z_{top} and z_{base} are cloud top and cloud base as parameterized within the Tiedtke convection scheme.

3.2 Estimating in-cloud water content

The next step is to estimate the in-cloud water content of stratiform and convective clouds. These values are also used to apply a correction of cloud fraction as a function of the ice water content.

For sub-grid stratiform clouds it is assumed that 0.5% of the saturation mass fraction are condensed water:

$$q_{c,sgs} = 0.005\, q_{sat}\, (1 - f_{ice}) \tag{16}$$

$$q_{i,sgs} = 0.005\, q_{sat}\, f_{ice} \tag{17}$$

Grid-scale clouds are taken into account by

$$q_{c,strat} = \max(q_{c,sgs}, q_c), \qquad \text{if } q_c > 0 \tag{18}$$

$$q_{i,strat} = \max(q_{i,sgs}, q_i), \qquad \text{if } q_i > 10^{-7} \tag{19}$$

For convective clouds either 1% of the saturation mass fraction or at least 0.2 g/kg are assumed as condensed water mass:

$$q_{c,con} = \max(0.01\, q_{sat}, 0.0002)\ (1 - f_{ice}) \tag{20}$$

$$q_{i,con} = \max(0.01\, q_{sat}, 0.0002)\ f_{ice} \tag{21}$$

3.3 Total cloud cover and correction of upper-level ice clouds

For thin upper-level ice clouds ($q_{i,strat} < 0.01$ g/kg) the cloud fraction is reduced based on the estimated ice water content by:

$$\mathcal{N}_{strat,corr} = \mathcal{N}_{strat}\ \min\left[1, \max\left(0.2, \frac{q_{i,strat} - 10^{-7}}{10^{-5} - 10^{-7}}\right)\right], \qquad \text{if } p < 500 \text{ hPa},\ q_{c,strat} > 10^{-10} \tag{22}$$

Note that this correction is also applied if grid-scale ice clouds are present, thus due to this correction cloud fraction can be < 1 even if $q_i > 10^{-7}$.

The total cloud fraction from all three cloud types is then given by:

$$\mathcal{N} = \mathcal{N}_{strat,corr} + \mathcal{N}_{con}(1 - \mathcal{N}_{strat,corr}) \tag{23}$$

In addition, the total liquid resp. ice content can be estimated from:

$$q_{c,tot} = q_{c,strat}\, \mathcal{N}_{strat,corr} + q_{c,con}\, \mathcal{N}_{strat,con}\ (1 - \mathcal{N}_{strat,corr}) \tag{24}$$

$$q_{i,tot} = q_{i,strat}\, \mathcal{N}_{strat,corr} + q_{i,con}\, \mathcal{N}_{strat,con}\ (1 - \mathcal{N}_{strat,corr}) \tag{25}$$