APPENDIX A
ICE3 warm processes formulation

According to the ICE3 microphysics scheme (Pinty and Jabouille, 1998), the following are the equations for autoconversion, accretion, evaporation and sedimentation of rain in the warm part of the scheme. All equations are given in terms of the mixing ratios of water vapor, cloud and rain water, respectively, r_v, r_c and r_r (with units of kg/kg). More information is available online in the scientific documentation of the Meso-NH model (http://mesonh.aero.obs-mip.fr/mesonh/).

Autoconversion in the ICE3 scheme is a Kessler type formulation:

$$\frac{\partial r_r}{\partial t}\Big|_{autoconv} = k_{crit} MAX(0, r_c - r_{c\_crit}) \qquad \text{(A-1)}$$

where $k_{crit} = 10^{-3} s^{-1}$, $r_{c\_crit} = q_{c\_crit}/\rho_d$, ρ_d is the dry air density and $q_{c\_crit} = 0.5 \times 10^{-3}\,\mathrm{kg/m^3}$.

Accretion in the ICE3 scheme is of the form:

$$\frac{\partial r_r}{\partial t}\Big|_{accr} = \frac{\pi}{4} c N_{or} \left[\frac{\rho_o}{\rho_d}\right]^{0.4} \Gamma(d+3) \left[\frac{\rho_d}{\pi \rho_w N_{or}}\right]^{(d+3)/4} r_c r_r^{(d+3)/4} \qquad \text{(A-2)}$$

where $c = 842\,\mathrm{m/s}$, $d = 0.8$, ρ_w is the moist air density, ρ_o is the air density at the reference pressure level, and $N_{or} = 8.0 \times 10^6\,\mathrm{m^{-3}}$ is set constant.

Evaporation in the ICE3 scheme is of the form:

$$\frac{\partial r_r}{\partial t}\Big|_{evap} = -\frac{2\pi S N_{or}}{A \rho_d} \left[\bar{f}_1 \left(\frac{\rho_d r_r}{\pi \rho_w N_{or}}\right)^{1/2} + \bar{f}_2 \left(\frac{\rho_o}{\rho_d}\right)^{0.4/2} \left(\frac{c}{\nu_{cin}}\right)^{1/2} \Gamma(\frac{d+5}{2}) \left(\frac{\rho_d r_r}{\pi \rho_w N_{or}}\right)^{(d+5)/8} \right] \qquad \text{(A-3)}$$

where $\bar{f}_1 = 1$ and $\bar{f}_2 = 0.22$ are ventilation coefficients, ν_{cin} is the air kinematic viscosity, which is here assumed to be constant $\nu_{cin} = 0.15\ 10^{-4}\,\mathrm{kg/(ms)}$. The function S is given by:

$$S = 1 - \frac{r_v}{r_{vs}} \qquad \text{(A-4)}$$

where r_{vs} is the saturated vapor mixing ratio. The thermodynamic function A is:

$$A \simeq \frac{R_v T}{e_s(T) D_v} + \frac{(L_v(T))^2}{k_a R_v T^2} \tag{A-5}$$

where T is the temperature, $R_v = 461.51\,\mathrm{Jkg^{-1}K^{-1}}$, $D_v = 2.26\ 10^{-5}\,\mathrm{m/s}$ is the diffusivity of water vapor in air and $k_a = 24.3\ 10^{-3}\,\mathrm{J/(msK)}$ is the heat conductivity of air. (for simplicity, D_v and k_a are taken constants). $e_s(T)$ is the saturation vapor pressure and is computed according to

$$e_s(T) = \exp\left(\alpha_w - \frac{\beta_w}{T} - \gamma_w \ln(T)\right) \tag{A-6}$$

using

$$\alpha_w = \ln(e_s(T_0)) + \frac{\beta_w}{T_0} - \gamma_w \ln(T_0) \tag{A-7}$$

$$\beta_w = \frac{L_v(T_0)}{R_v}\gamma_w T_0 \tag{A-8}$$

$$\gamma_w = \frac{C_l - C_{pv}}{R_v} \tag{A-9}$$

where $T_0 = 273.16\,\mathrm{K}$ and L_v is the latent heat of vaporization and is computed according to:

$$L_v(T) = L_v(T_0) + (C_{pv} - C_l)(T - T_0) \tag{A-10}$$

where $C_{pv} = 1850\,\mathrm{Jkg^{-1}K^{-1}}$, $L_v(T_0) =$ and $C_l = 4.218E + 3$.

Sedimentation rate in the ICE3 scheme is of the form:

$$\left.\frac{\partial r_r}{\partial t}\right|_{sed} = \frac{c\rho_o^{0.4}}{6\rho_d}\frac{\Gamma(d+4)}{[\pi\rho_w N_{or}]^{d/4}}\frac{\partial}{\partial z}\left[(\rho_d)^{1+d/4-0.4}(r_r)^{1+d/4}\right] \tag{A-11}$$