Improvement of a Cloud Ice Fall Scheme in GCM

Hideaki KAWAI*
Climate Prediction Division, Japan Meteorological Agency, Tokyo, Japan

1 Background and problem

A 20km mesh global model (TL959) have been developed by Japan Meteorological Agency and Meteorological Research Institute for the 4th assessment report of Intergovernmental Panel on Climate Change. In the development, a lack of cloud ice content and cloud cover especially at the upper troposphere in TL959 appeared. Some experiments made it clear that the main cause is not a horizontal resolution dependency, but a time step dependency. A time step on physical processes, Δt, in TL959 is 360[s] in contrast to 1800[s] in TL319. Fig. 1 shows that cloud cover is reduced substantially in the case of $\Delta t =$ 360[s].

Generally a treatment of cloud ice falling is a crucial problem in GCM due to its fast fall speed and long Δt. ECMWF IFS CY25r1 type cloud ice fall scheme (ECMWF 2002) was implemented in the model in 2003 to prevent a disappearance of cloud ice at long Δt (Kawai 2003), but this scheme brings a lack of cloud ice at the extremely short time step. The main cause is that a part of cloud ice larger than 100 μ m is eliminated many times at the shorter time step. The main purpose of the improvement here is to make a flux of larger size cloud ice to be proportional to Δt.

The model is a JMA/MRI unified model and will be used for various researches and operations at a wide variety of resolutions and Δts. Therefore small timestep dependency is crucially important.

2 Cloud ice fall speed and conversion rate to snow

First, each representative cloud ice fall speed for smaller and larger particles was deduced. Observed size distribution functions of cloud ice (McFarquhar and Heymsfield 1997, hereafter MH97) and size-speed relationships for cloud ice (Heymsfield and Iaquinta 2000) were integrated for its size by the similar procedure to Zurovac-Jevtic and Zhang (2003).

The ice fall speed for ice particles smaller (larger) than 100μm,v_{cice} (v_{snow}) [m/s], was obtained as a function of cloud ice concentration smaller (larger) than 100μm, $\mathrm{IWC}_{<100}$ ($\mathrm{IWC}_{>100}$) [kg/m^3], as below (shown in Fig. 3).

$$v_{cice} = 1.56\mathrm{IWC}_{<100}{}^{0.24} \quad (1)$$

$$v_{snow} = 2.23\mathrm{IWC}_{>100}{}^{0.074} \quad (2)$$

*e-mail : h-kawai@met.kishou.go.jp

Conversion rate to snow, C_{I2S} [kg/kg $\cdot$ s], was deduced using a ratio function of ice particle smaller than 100μm by MH97, $\alpha_{<100}$, as below.

$$C_{I2S} = \frac{1-\alpha_{<100}}{\alpha_{<100}}\frac{v_{snow}}{H_c}q_{ice} \quad (3)$$

At the deduction, simple assumptions are introduced: (a) concentration of cloud ice is vertically homogeneous, (b) converted snow concentration is accumulate downward, (c) observation altitude of $\alpha_{<100}$ is H_c [km] from a top of a cloud. Here H_c =2[km] is assumed on the basis of MH97.

3 Procedure of calculation

Prognostic equation of cloud ice is the following, where C_{gnrt} is a source term and $D_{I2S} = C_{I2S}/q_{ice}$.

$$\frac{\partial q_{ice}}{\partial t} = C_{gnrt} + \frac{1}{\rho}\frac{\partial}{\partial z}(v_{cice}\rho q_{ice}) - D_{I2S}q_{ice} \quad (4)$$

1. $\alpha_{<100}$ is calculated using a formula in MH97, v_{cice} from eq. (1), and D_{I2S} from eq.(3) and eq.(2).

2. A snow flux that reaches the ground surface in a moment, $\tilde{P}_{snow}$[kg/m^{2}s], is calculated as below. The first term in {} of r.h.s. corresponds to a snow which is converted from existing cloud ice, $q_{ice}(t)$, and the second term is a snow which is converted from newly generated cloud ice between t and $t+\Delta t$, $C_{gnrt}\Delta t$, each by the time $t+\Delta t$.

$$\tilde{P}_{snow} = \{\frac{q_{ice}(t)}{\Delta t}(1-e^{-D_{I2S}\Delta t}) + (C_{gnrt} - \frac{C_{gnrt}}{D_{I2S}}\frac{1}{\Delta t}(1-e^{-D_{I2S}\Delta t}))\}\rho\Delta z \quad (5)$$

3. The following analytical solutions of eq. (4) are calculated to obtain $q_{ice}(t+\Delta t)$ using cloud ice inflow flux from the upper layer, R_f [kg/m^{2}s]. $q_{ice}(t)e^{-D_{I2S}\Delta t}$ of eq. (6) corresponds to cloud ice after elimination of snow converted by the time $t+\Delta t$, that is, cloud ice at the time t of analytical solution. The second term of eq. (7) corresponds to newly generated cloud ice which is not converted to snow between t and $t+\Delta t$.

$$q_{ice}(t+\Delta t) = q_{ice}(t)e^{-D_{I2S}\Delta t}e^{-D\Delta t} + \frac{C}{D}(1-e^{-D\Delta t}) \quad (6)$$

$$C = \frac{R_f}{\rho\Delta z} + \frac{C_{gnrt}}{D_{I2S}}\frac{1}{\Delta t}(1-e^{-D_{I2S}\Delta t}) \quad (7)$$

$$D = \frac{v_{cice}}{\Delta z} \quad (8)$$

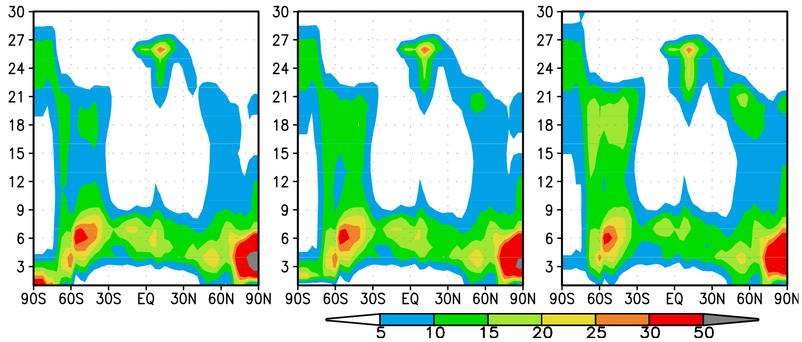

Figure 1. Zonal averaged cloud cover [%] of the original version using TL95. Δt=360, 600, 1800[s] from the left side. Vertical axis shows model layer numbers. One week average from the initial time 12UTC 30 Jun 1992.

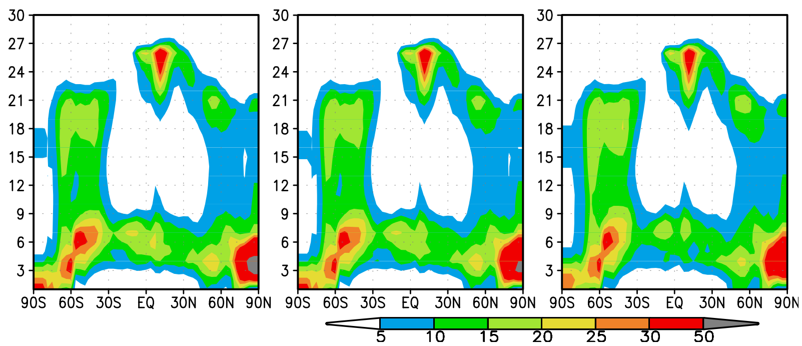

Figure 2. Same as Fig. 1 except for the revised version.

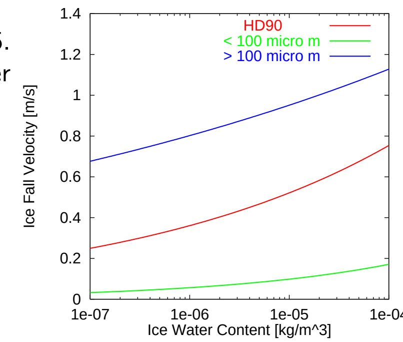

Figure 3. Cloud ice fall speed. v_{cice} of eq. (1) (green line), v_{snow} of eq. (2) (blue), and conventional ice fall speed by Heymsfield and Donner (1990) (red).

4. A sedimentation flux of cloud ice to lower layers, $R_{f,(k-1)}$, is calculated as the following.

$$R_{f,(k-1)} = \{\frac{q_{ice}(t)e^{-D_{I2S}\Delta t} - q_{ice}(t+\Delta t)}{\Delta t} + C\}\rho\Delta z \quad (9)$$

$R_{f,(k-1)}$ is used as R_f of a layer just below the layer at the next loop.

4 Result

Figure 2 shows the result of the revised version. The reduction of upper cloud at short Δt is alleviated by the revised scheme and time step dependency is suppressed. An excess of outgoing longwave radiation flux caused by cloud reduction is also improved (not shown). The increase of cloud cover of tropical anvil is brought by slow fall speed of cloud ice, v_{cice} (eq. (1)).

It is noted that the low cloud cover is less for longer Δt. Larger heating and drying at longer Δt in the cumulus convection process may cause a positive feedback of cloud reduction.

References

European Centre for Medium-Range Weather Forecasts, 2002: IFS Documentation (CY25r1), http://www.ecmwf.int/research/ifsdocs/CY25r1. Part IV, Chapter 6.

Heymsfield, A. J. and L. J. Donner, 1990: A scheme for parametrizing ice-cloud water content in general circulation models. *J. Atmos. Sci.*, **47**, 1865–1877.

Heymsfield, A. J., and J. Iaquinta, 2000: Cirrus crystal terminal velocities. *J. Atmos. Sci.*, **57**, 916–938.

Kawai, H., 2003: Impact of a cloud ice fall scheme based on an analytically integrated solution. *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling*, **33**, 04.11–12.

McFarquhar, G. M., and A. J. Heymsfield, 1997: Parameterization of tropical cirrus ice crystal size distribution and implications for radiative transfer: Results from CEPEX. *J. Atmos. Sci.*, **54**, 2187–2200.

Zurovac-Jevtic, D. and G. J. Zhang, 2003: Development and Test of a Cirrus Parameterization Scheme Using NCAR CCM3. *J. Atmos. Sci.*, **60**, 1325–1344.