Impact of a Cloud Ice Fall Scheme Based on an Analytically Integrated Solution

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1. Background

Cloud Ice Fall in global NWP model or climate model is very bothersome to treat because the product of the fall speed (v_{ice}) and the time step (Δt) often exceeds the thickness of a vertical layer (Δz) of the model. Since explicit time integration cannot be used practically, the process in our Global Spectral Model (GSM) has been treated as follows:

- In cases $v_{ice}\Delta t \le \Delta z$, cloud ice content ($q_{ice}$) in a layer is distributed into the layer itself and a layer just below the original layer exactly.
- In cases $\Delta z < v_{ice}\Delta t \le 2\Delta z$, a part of cloud ice content is distributed into only a layer just below the original layer exactly and the other part of it falls through into ground surface within a time step.
- In cases $v_{ice}\Delta t > 2\Delta z$, all the cloud ice content falls into ground surface within a time step.

The treatment works appropriately as far as $v_{ice}\Delta t$ is smaller than Δz. Time step in T213 Euler model, which is our operational short-range to 1-week forecast model, meets this condition in almost all cases. But in T106, which is our 1-month forecast model, and in T63, with which we will start 3-month dynamical forecast from March 2003, the condition is not satisfied and a large part of cloud ice falls into ground surface within one time step. Moreover, long time step will become a serious problem for cloud ice fall process in T213 after an adoption of semi-Lagrangian time integration scheme in T213 (T_L319) scheduled in 2003.

2. Scheme based on Analytically Integrated Solution

To avoid the above problem, time integration for cloud ice fall is implemented following analytically integrated solutions below (Rotstayn 1997, Jakob 2000).

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

$$C = \frac{R_f}{r\Delta z} + C_{gnrt}, \qquad D = \frac{a_{<100}v_{ice}}{\Delta z} + \frac{a_{>100}}{\Delta t}$$

where R_f is the cloud ice flux from the above layer, r is the air density, $a_{<100}$ ($a_{>100}$) is the ratio of cloud ice particles whose sizes are smaller (larger) than 100 micrometer. Cloud ice content is separated into two categories following Jakob (2000) and McFarquhar and Heymsfield (1997). Since GSM adopts the cloud distribution concept by Sommeria and Deadorff (1977), cloud water content has been distributed into cloud water (ice) and water vapor at first step (to produce $q_{ice}^*(t+\Delta t)$) and then, cloud ice fall process has been calculated at second step (to produce $q_{ice}(t+\Delta t)$). But this two-step procedure leads to an unreasonable overestimation of amount of cloud ice fall and consequent lack of cloud ice content. Therefore cloud ice generation rate C_{gnrt}($=(q_{ice}^*(t+\Delta t) - q_{ice}(t))/\Delta t$) is introduced in order to treat generation and fall of cloud ice simultaneously. This procedure is more correct theoretically and avoids abrupt change of cloud ice content.

3. Result

The results of one-month integration using T63 for December 1988 are shown. Figure 1 shows zonal means of cloud water content (including both the liquid and solid state) of analytical and original schemes. Cloud water content is considerably increased at an altitude where the state is solid. The increase is preferable because cloud water content of analytical scheme is closer to equilibrium one ($q_{ice}{}^{*}(t+\Delta t)$) provided by the cloud distribution scheme. Fig.2 shows an impact and a current scheme error from Earth Radiation Budget Experiment (ERBE) data on outgoing longwave radiation (OLR). Analytical solution scheme reduces the positive error on OLR to some extent, for example, over Amazon. It has also been confirmed that new scheme improves the overestimation on net downward shortwave radiation at the top of the atmosphere a little bit (not shown). The remaining biases are probably resolved by sophisticated treatments of radiation processes (Kitagawa and Yabu 2002) and by increasing cloud amount based on a review of a probability distribution function in the cloud distribution scheme.

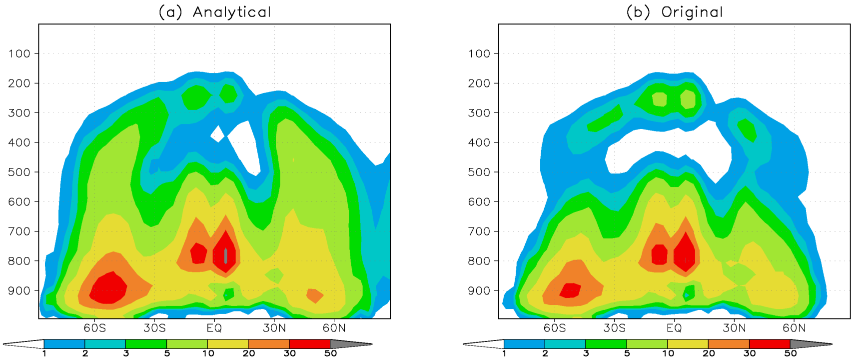

Fig. 1: Zonal means of cloud water content in unit of 10^{-6}[kg/kg] for December 1987 calculated by (a) analytical solution scheme and (b) original scheme. Vertical axis shows pressure [hPa].

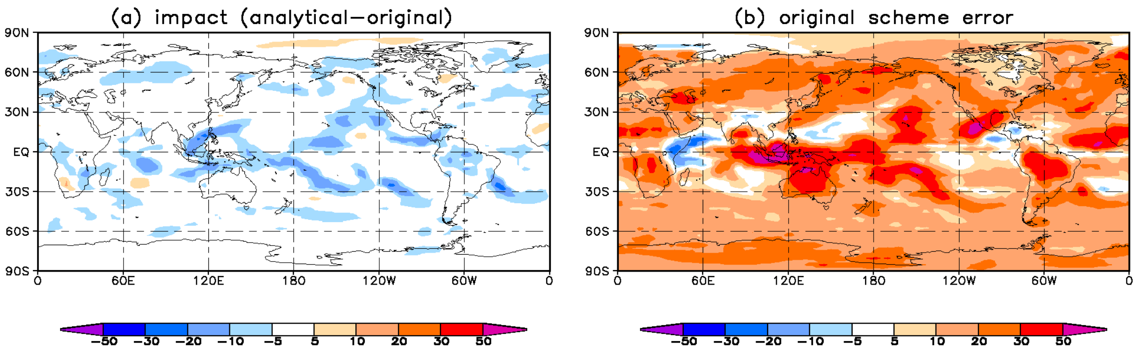

Fig. 2: Outgoing longwave radiation [W/m^2] (a) impact and (b) error for December 1987. Error is calculated based on ERBE observation data.

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