The Rasch Kristjansson large scale condensation. Present status and prospects

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1 Introduction

The Rasch-Kristjansson stratiform condensation scheme (RK-scheme) was introduced as an option in the HIRLAM system about 5 years ago. It has also been used together with the Kain-Fritsch convection scheme for the operational forecasts in Sweden since 2003.

Significant developments of the RK-scheme have been done at SMHI (Swedish Meteorological and Hydrological Institute) in order to improve the operational forecasts, but most of those developments have not been introduced in the reference Hirlam system until recently (Hirlam 7.1)

Here, a summary this development will be presented in section 2, followed by further, not yet implemented developments in section 3. A short description of a parameterization for using separate prognostic cloud water and ice is in section 4, followed by some short conclusions in section 5.

2 New features of the current (Hirlam 7.1) RK-scheme

This scheme is based on the work of Rasch and Kristjansson (1998) and originally designed for climate simulations with a coarse horizontal and vertical resolution. It has not been strait forward to just plug the scheme into Hirlam since Hirlam uses much higher resolution. The main problem has been numerical noise. In 1D-simulations it has been seen mainly as oscillations of the cloud water and sometimes also cloud fraction of a $2\Delta t$ type. For more details see Ivarsson, (2005). But there where other things as well. The problems seen in the operational forecast could be summarised in this way:

- Small amount of precipitation occurred too frequent.
- Too much precipitation behind mountains (The mountain-shadow effect was too weak.)
- To much low clouds in case of very cold winter conditions.
- Cooling due too snow melt was not accounted for, and poor parametrisation of snow melt (rain too often in case of 2metre temperature just above melting point.)
- Too much middle level clouds.
- Noisy cirrus cloud field in case of strong jets. Short time step may increase the noise.

The changes that are included in the new reference version are basically:

- The conversion of cloud water into precipitation is based on a parameterization suggested by Kogan et. al. (2000) This reduces the tendency of getting small amount of precipitation too frequent.

- Revised precipitation release calculation, assuming higher sub grid-scale variation of cloud water over mountains and larger fraction of super cooled cloud water for low temperatures have all together mainly solved the problem with the too weak mountain-shadow effect.
- Assuming larger fraction of super cooled cloud water for low temperatures also reduced the tendency of getting too much low clouds in case of very cold weather.
- The parametrisation of snow melt is corrected.
- The critical relative humidity has been tuned on order to get reasonable amounts of middle level clouds.
- The revised precipitation release calculation reduces the tendency of getting noisy cirrus cloud field in case of strong jets. It is more or less absent if a short time step is used.

The present scheme behaves better than the original one, but there are some problems left. The most serious one is that the reduction of small amount of precipitation is not satisfactory. There is also still somewhat too much low clouds in case of very cold weather although it is perhaps not a big problem. If one wants to avoid noisy cirrus cloud field in case of very strong jets, one has to use an unnecessary short time step. Duty forecasters have not complained about this noise so it is probably not a serious problem, but it is of course an advantage to get rid of it. Attempts to solve those remaining problems will be presented in the next section.

3 Further development of the RK-scheme

As mentioned in the previous section, this scheme is based on the work by Rasch and Kristjansson (1998). It will refereed to as RK98. A further development of the RK-scheme is presented in a paper by Zhang et al (2003). It will be called RK03 here. The two most interesting improvements are :

- There is normally less numerical noise due to a new way of calculate the tendency of new cloud condensate. This reduces the over prediction of small amount of precipitation and also the noisy structure of the cirrus cloud field, except in case of the very strongest winds.
- The code based on this new parameterization is implemented in the Community Atmospheric Model version 3.1 (CAM3) in FORTRAN 90, which makes it more easy to create an “IFS -FORTRAN 90” version also.

It seems possible to avoid noise also in case of very strong winds near the tropopause level by simply filter out “unphysical” tendencies of cloud condensate. Those tendencies are :

- Tendencies predicting negative cloud water amounts.
- Tendencies predicting drier air at the same time as there tendencies predicting a considerably increase of cloud water content. This combination is strictly speaking not impossible, but is very unlikely.

The effect of introducing this filter seems to be completely absent in case of using a short time step. The reason is that those tendencies never happens when a sufficient short time step is used. For longer time step the main effect is that the noise is gone. It only works with the RK03 scheme. Only a small noise reduction is seen for RK98, which indicates that the noise in RK98 is manly due to other reasons than those “unphysical” tendencies.

The CAM3 code also includes a routine for the sedimentation of cloud condensate. It seems to give a slightly more realistic cloud distribution of middle level clouds and high clouds.

The fraction of clouds is only dependent of the relative humidity in the current scheme. The evolution of mixed phase clouds and also of cirrus is complicated and there is a need for more complex parameterizations in order

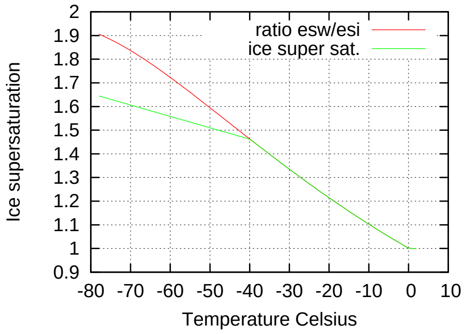

Figure 1: Supersaturation with respect to ice for: Supercooled water (red) and according to the Kärcher and Lohmann parameterization (green).

to describe the life-cycle of those clouds more accurate. A first step is to account for that condensation normally does not start before reaching saturation with respect to water for temperatures between melting point and about -40 °C. The parameterization used here is to let the relative humidity used for cloud fraction calculation be with respect to water if there is no or very little cloud condensate present for temperatures higher than -40 °C. Also below -40 °C the relative humidity must be higher than ice saturation before condensation starts. This supersaturation with respect to ice follows a parameterization suggested by Kärcher and Lohmann, (2002), see Fig. 1. (It is also used at the ECMWF)

With this parameterization the remaining over-prediction of low clouds in very cold weather seems to be very small or totally absent. It is also possible to get a more accurate cirrus cloud forecasts. If all those new parameterizations are included, that is,

- RK03 scheme
- Supersaturation with respect to ice below freezing in cloud-free areas.
- Noise filtering
- sedimentation of cloud condensate

the result is as in Fig. 2. It is a cross section for December 11 2006, a case with unusually strong winds especially near tropopause, but it was more windy than normal also near ground. The case is selected because it is possibly to study both noise problem and is also an example of ice-supersaturation in the upper troposphere. To the left, the reference version and to the right the new version. Notice that the somewhat noisy cloud field and humidity field in the reference version (to the left) is not seen with new version and that there is some supersaturation with respect to ice with the new version between 300 and 400 hPa.

Verification results show that there is an improvement of wintertime temperatures together with the new surface scheme by using the new RK-scheme compared to the reference one but nearly neutral relative to STRACO.

All experiments indicate that there is a problem with too low 2 metre temperatures in case of clear sky and very cold air. This is also seen when the old surface scheme is used, but the error is often hidden due to the slow response of that scheme. It seems unlikely that it is caused by the condensation schemes since it is seen with both STRACO and the RK-scheme and more important: It is seen when both observations and forecasts have no clouds during a longer period. The reason could be some error in the radiation scheme, or that the emissivity factor for snow (currently 0.98) is too high.

The precipitation forecasts are improved especially since there is less over prediction of low precipitation amounts. But some bugs related to the handling of cloud ice are recently detected, so those results are a little doubtful and are not shown here.

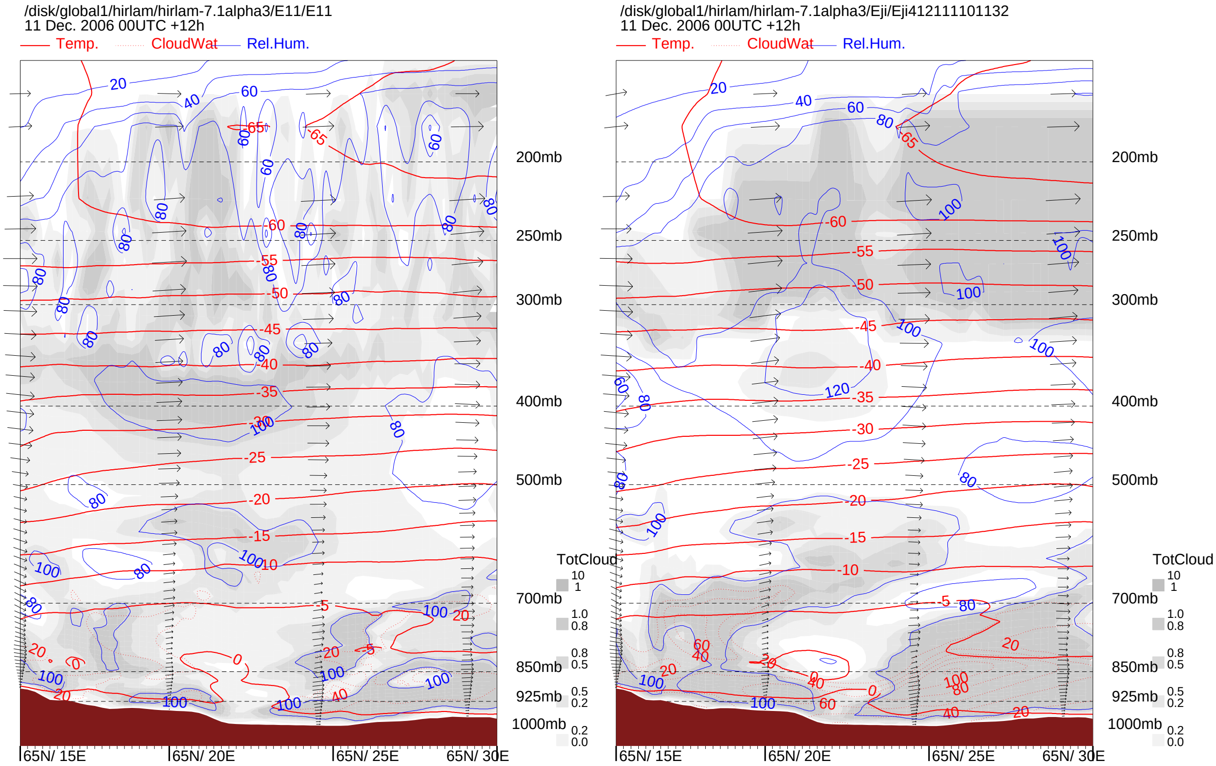

Figure 2: Two cross sections for December 11 2006 00 + 12 UTC over northern Scandinavia and Finland: Present (left) RK98 scheme and with RK03 version, noise filtering,sedimentation and supersaturation with respect to ice using Kärcher and Lohmann parameterization (right). Blue lines are relative humidity with respect to ice, red solid lines are temperature, dotted red lines are cloud water, cloud fractions are shaded in different grey scales.

4 Use of separate prognostic treatment of cloud water and ice

If the fraction of cloud condensate that is assumed to be cloud ice is only a function of temperature, the description of the life-cycle of mixed-phase clouds can not be described properly. Between 0°C and -40 ° C newly formed clouds contain mainly supercooled water. After some time ice crystals grow and if they become big enough they will fall out as precipitation. Between 0°C and -32 °C the main source for new crystals are a process called heterogeneous freezing. This means that supercooled water collides with some usually solid material which triggers a freezing process. Below about -32 °C another process, homogeneous freezing becomes important. Here, supercooled water freeze spontaneously. Below -40 ° C this is mainly the only freezing process and is also very fast, but also at such low temperatures there may be supercooled water, often as a solution of sulphur acid in the very beginning.

In order to study the benefit of using separate prognostic treatment of cloud water and ice, a parameterization of those two processes has been included in Hirlam 7.1. Because of the bugs related to the handling of cloud ice, the code has to be somewhat rewritten and here only some tests with older Hirlam versions will be mentioned.

The most important part of the parameterization is the growth of cloud ice crystals by water deposition. This parameterization closely follows the one suggested by Rotstayn et al, (2000) for spherical ice crystals. The change of the cloud ice (Δq_i) for each timestep can be expressed as

$$\Delta q_i = min(q_w, C(2/3c_{vd}\Delta t + q_{i0}^{\frac{2}{3}})^{\frac{3}{2}} - q_i) \qquad (1)$$

Here, q_i = cloud-ice content , q_w cloud-water content , C = cloud fraction, Δt = time step and q_{i0} = initial ice-crystal mass. (10^{-12} kg). c_{vd} is given by

$$c_{vd} = 7.8\frac{(N_i/\rho)^{\frac{2}{3}}(e_{sw}/e_{si} - 1.)}{\rho_i^{\frac{1}{3}}(A_2 + B_2)} \tag{2}$$

N_i is the ice crystal number concentration, given by $500e^{12.96(e_{sw}/e_{si}-1.)-0.639}$, which is 50 % of the concentration given by Meyers et al (1992). ρ is the density of the air, e_{sw} and e_{si} is the saturation water vapour pressure with respect to water and ice respectively and ρ_i is the density of ice. The value of 700 is used here. A_2 is given by

$$A_2 = \frac{L_s}{K_a T}(\frac{L_s}{R_v T} - 1) \tag{3}$$

L_s is latent heat of sublimation, K_a is the thermal conductivity of air (0.024), R_v is specific gas constant for water, and T is temperature. B_2 is computed as

$$B_2 = \frac{R_v p T}{2.21 e_{si}} \tag{4}$$

Here, p is pressure.

A very simple parameterization of homogeneous freezing is also used. It is based on a study by Heymsfield et al. (1993) The transformation of cloud water into cloud ice is expressed by

$$q_w = q_{w0}e^{-h_f \Delta t} \tag{5}$$

q_{w0} is cloud water in the beginning of the timestep and q_w is the cloud water at the end. h_f is calculated as

$$h_f = e^{T_c C_1 + C_2} \tag{6}$$

Here T_c is temperature in Celsius, C_1 and C_2 are constants, -3.31 and -126.6 respectively. The parameterization is only active below -32 °C The amount of cloud water that is homogeneously freezing to cloud ice is just $q_{w0} - q_w$

Tests with those two parameterizations show that there is normally small impact on surface parameters such as 2metre temperature , 10 metre wind etc. But the precipitation forecast may be improved somewhat. One example is seen in Fig. 3.

5 Some short conclusions

The Rasch-Kristjansson condensation scheme has been further developed during the last years both by including a new version, but also by tuning and implementing new parameterizations. The main problem has been numerical noise, and forecast errors related to that, such as too much small precipitation events. Most of those problems seems to be solved with the new RK03 version.

It is also seem that it is often too cold near surface in the model in case of cold winter conditions and long time events with clear sky. This is seen regardless of the choice of condensation scheme or the choice of surface scheme. The reason for this is not known.

The mean fraction of ice, f_{ice} for different temperatures and forecast lengths are seen in Fig. 4. The main difference between the temperature dependent relation is that f_{ice} near 0.5 is not that common.

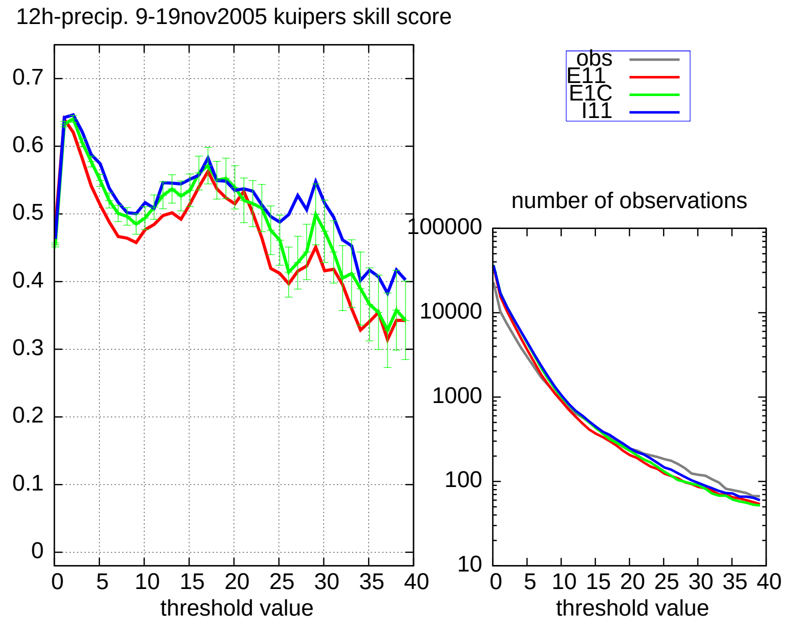

Figure 3: Result of precipitation forecasts for a ten day period in November 2005: green : Basically the same RK scheme as in the present 7.1 version. Blue : The same version but with separated prognostic equations for cloud ice and cloud water. Red : An old version of RK-scheme. To the left : Kuipers skill score for different precipitation thresholds. To the right: The number of observations exceeding the precipitation threshold. Kuipers skill score is the difference between hit rate and the false alarm rate.

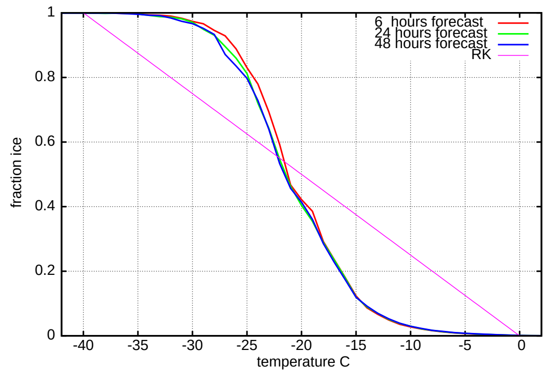

Figure 4: The fraction of the cloud condensate that is ice for different temperatures and forecast lengths, compared to the prescribed temperature dependent relation in the RK-scheme.

6 References

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