Preliminary tests with the use of separate prognostic treatment of cloud water and ice in Hirlam

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1 Introduction.

Cloud condensate is very small droplets of water and of very tiny ice crystals in clouds. Correct amounts of cloud ice and cloudwater are important in atmospheric models since the precipitation release and the both shortwave and longwave radiation depend on the size and type of cloud condensate. Here, cloud ice and cloud water are both defined as particles of such small size that the falling speed (sedimentation) could be neglected.

Larger ice or liquid water particles are regarded as hydro meteors and thus participating in the precipitation release. In the present Hirlam reference version (6.3.5), the partition of cloud condensate into a liquid part and a ice part is determined by the temperature only. This is an easy and strait-forward way, but there are disadvantages as well. One is that the evolution of clouds and systems of clouds can not be simulated in a realistic way. Mixed phase clouds normally form as liquid water. Ice crystal then grow by water deposition and then fall out as precipitation. At the same time, supercooled water droplets evaporate and thus become smaller or disappear. This process is often called the Bergeron-Findeisen process, and is driven by the difference between the saturation pressure over ice and water. Another one is that the amount of ice and water in the cloud can not be predicted in a realistic way. For instance, if a cloud becomes warmer, some cloud ice is forced to melt and becomes supercooled water. Occasionally, there are events with supercooled rain from clouds with only supercooled water, which are not possible to predict without a prognostic treatment of cloud water and ice.

A parameterization of prognostic scheme of content of ice and water is described in this paper. Some details of the parameterization is given in section 2, and tests with the scheme is evaluated in section 3. There are a short discussion and some conclusions in section 4 and section 5 contains a reference list.

2 Description of the parameterization.

2.1 General

This parameterization has be implemented in the framework of Hirlam 5.1.4, with some updates to a more recent versions. The code has only been implemented in the current Hirlam version of the Rasch-Kristjansen scheme (RK-scheme) see Rasch and Kristjansen, (1998) for details. Technically, cloud ice has been introduced as an extra scalar, in a similar way as turbulent kinetic energy was introduced for the turbulence parameterization.

2.2 Parameterization of the transformation from cloud water to cloud ice

The most important part of 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

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

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 $10exp(12.96(e_{sw}/e_{si} - 1.) - 0.639)$, which is 1 % of the concentration given by Meyers et al (1992). ρ is the density of the air, e_{sw} and e_{si} is the water vapor 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

$$A_2 = \frac{L_s}{K_aT}(\frac{L_s}{R_vT} - 1) \tag{3}$$

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

$$B_2 = \frac{R_vpT}{2.21e_{si}} \tag{4}$$

Here, p is pressure. Two different assumptions about the in-cloud spatial distribution of cloud-ice and cloud-water where tested by Rotstayn et al. One with ice and water totally separated, one with ice and water completely mixed. The relation above is derived for the latter assumption. Here, the in-cloud spatial distribution is assumed to be as follows:

1. One part containing all cloudwater but also cloud-ice with a fraction of $(1 - f_{ice})C$
2. A second part with only cloud-ice with a fraction of $f_{ice}C$
3. The concentration of cloud-ice is assumed to be the same in both fractions

Here, f_{ice} is the part of the cloud condensate that is ice ($q_i/(q_i+q_w)$) . The in-cloud spatial distribution is chosen to let the mean relative humidity used in Eq (**??**) be consistent with the assumption that there is saturation with respect to water in the mixed-phase part and with respect to ice in the cloud-ice part. This distribution should probably be related to the size of the gridbox, but that should make the parameterization more complex. By this assumption the fraction of cloud containing only cloud-ice increases as the amount of cloud-ice increases. Eq. (**??**) becomes

$$\Delta q_i = min(q_w, (1 - f_{ice})C(2/3c_{vd}\Delta t + q_{i0}^{\frac{2}{3}})^{\frac{3}{2}} - (1 - f_{ice})q_i) \tag{5}$$

2.3 Parameterization of precipitation release by the Bergeron-Findeisen process

When clouds-ice crystals grow and reach a critical size, they are assumed to fall out as precipitation. A typical time scale for ice crystals to reach that size is computed as a precipitation release by the Bergeron-Findeisen effect. (PBF) This parameterization is based on the ideas described in Hsie el al, (1980) and in Lin el al, (1983). This time-scale Δt_{bf} is computed as

$$\Delta t_{bf} = \frac{1}{8} q_i D_{crit}^2 \frac{e_{sw}/e_{si} - 1}{A_2 + B_2} \tag{6}$$

Eq (**??**) is also based on the growth of spherical ice crystals. The average ice crystal is assumed to be half-way in time to reach that critical size. Thus, $(q_i + \Delta q_i) min(1, 0.5\Delta t_{bf}/\Delta t)$ is assumed to be transformed from cloud ice to precipitation each timestep. Δq_i is computed by Eq (**??**). Technically, the term $(q_i + \Delta q_i)/min(1, 0.5\Delta t_{bf})$is transported to the routine for cloud-micro physic (FINDMCNEW) .

2.4 The cloudcover calculation

The calculation of cloudcover follows the original code based on Slingo but with some minor changes. It is based on relative humidity, (RH_{mix}) which is a mixture of saturation with respect to water (RH_w) and ice (RH_i). This mixture is only temperature dependent in the original code. Here, it is dependent on the actual value of f_{ice} and of the total amount of cloud condensate.

$$RH_{mix} = \alpha RH_{start} + (1 - \alpha) RH_{cloud} \tag{7}$$

where α is set to unity if there is no cloud condensate and a linear transition to zero when the cloud condensate is larger than a critical value. The critical value is set to $1/300 * (f_{ice} * q_{si} + (1 - f_{ice}) q_{sw})$. q_{si} and q_{sw}. RH_{start} is computed as $\beta RH_w + (1 - \beta) RH_i$ where β is set to unity above -35 C , and to 0.25 below -69, and a linear transition in between. The values 1/300, -35, -69 and 0.25 are chosen in such way that parameterization should be not too far from some cirrus-parameterizations found in the literature e.g. Heymsfield et al., (1995) or Zurovac-Jevtic, (1999), but without making the parameterization unnecessarily complicated. It is also consistent with the assumption that mixed-phase clouds in the the beginning only contains cloudwater. RH_{cloud} is just a linear function of f_{ice}:

$$RH_{cloud} = (1 - f_{ice}) RH_w + f_{ice} RH_i \tag{8}$$

2.5 Other important modifications

The fraction of ice used in the radiation scheme is only temperature dependent in the reference version. Here, it is replaced by f_{ice}. The relative humidity used in the condensation routine is computed in the same way as RH_{mix}. The convective cloud condensate which is computed in the convection scheme should also be divided into a liquid part and an ice part. The same should also be done for the change of the total condensate that is computed in the stratiform condensation scheme. Also here, f_{ice} is used, which is an easy way, but a weak part of the parameterization and will be discussed later.

3 Test results

3.1 0-D tests

"0-D tests" are simulations with just a single gridbox in this context. They have been used to study the two new parameterizations, the one of the transformation from cloud water to cloud ice, and the parameterization of PBF. One example of such tests are seen in figure 1. To the left is the evolution of the cloud condensate amount and the fraction of cloud ice if only the transformation from cloud water to cloud ice using Eq (**??**) is considered. The same evolution is seen to the right, when also the PBF is included. In all experiments, f_{ice} are zero in the beginning and the amount of cloud condensate is set to 3% of value of q_{sw} in all simulations. The cloud fraction is assumed to be 0.5, and the threshold diameter for ice-crystals to become precipitation is 0.5 mm.

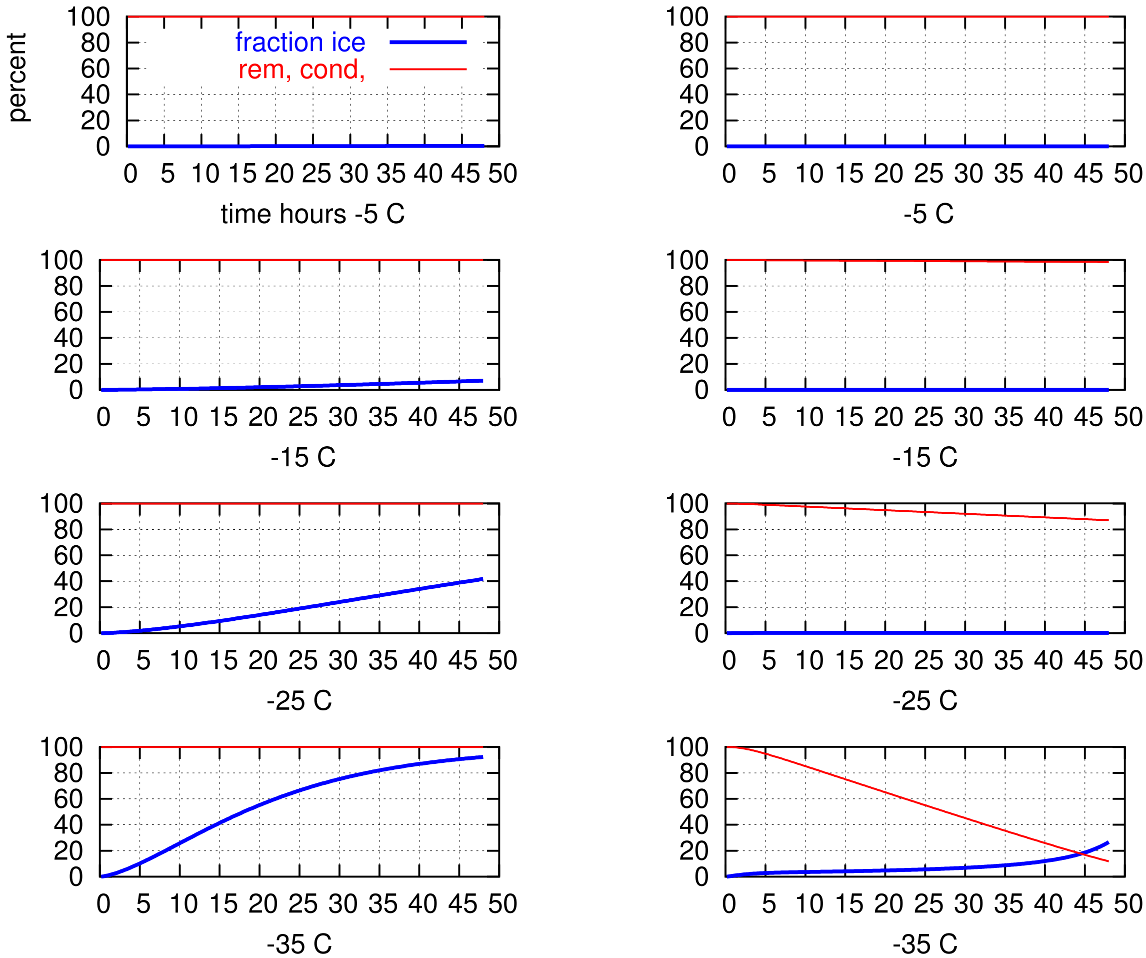

Figure 1: Time evolution of the fraction of ice for -5, -15 , -25 and -35 C. The red curve is the remaining amount of cloud condensate, and the blue is f_{ice}.

The ice crystal concentration is only 1% of the value proposed by Meyers et al (1992). The reason for using that low value is to prevent the amount of cloud ice to get unrealisticly high in the 3-D runs. Here, the opposite seems to be the case, at least for -35 C. Homogeneous freezing of cloud drops is an important process for temperatures lower than about -33 C, (Heymsfield and Miloshevich, 1993) and that is not taken into account here. It is also seen that including the PBF, the increase of cloud-ice is suppressed, which seems to be realistic.

3.2 3-D tests

Our operational Hirlam version have been run for a cold winter period, (Jan 14 - 29 1999) and then the same version, but with separated prognostic equation for cloud water and cloud ice based on the parameterizations described in this paper. This two runs are called C22 and i22 respectively. The operational version is based on the framework of Hirlam-5.1.4, but with some updates from later versions. The RK-scheme is used together with the Kain-Fritsch convection scheme. The area contains 306 x 306 gridpoints and 40 vertical levels. It covers mainly the North Atlantic, Europe, western Russia and a part of the Arctic sea. Semi-Lagrangian advection is used and a timestep of 10 minutes. The horizontal resolution is 0.2 degrees (22km). An analysis cycle length of 6 hours is used and the analysis technique is 3-DVAR. The verification result for the surface parameters is seen in figure 2. It is basically the same for both runs, there are some small differences that one

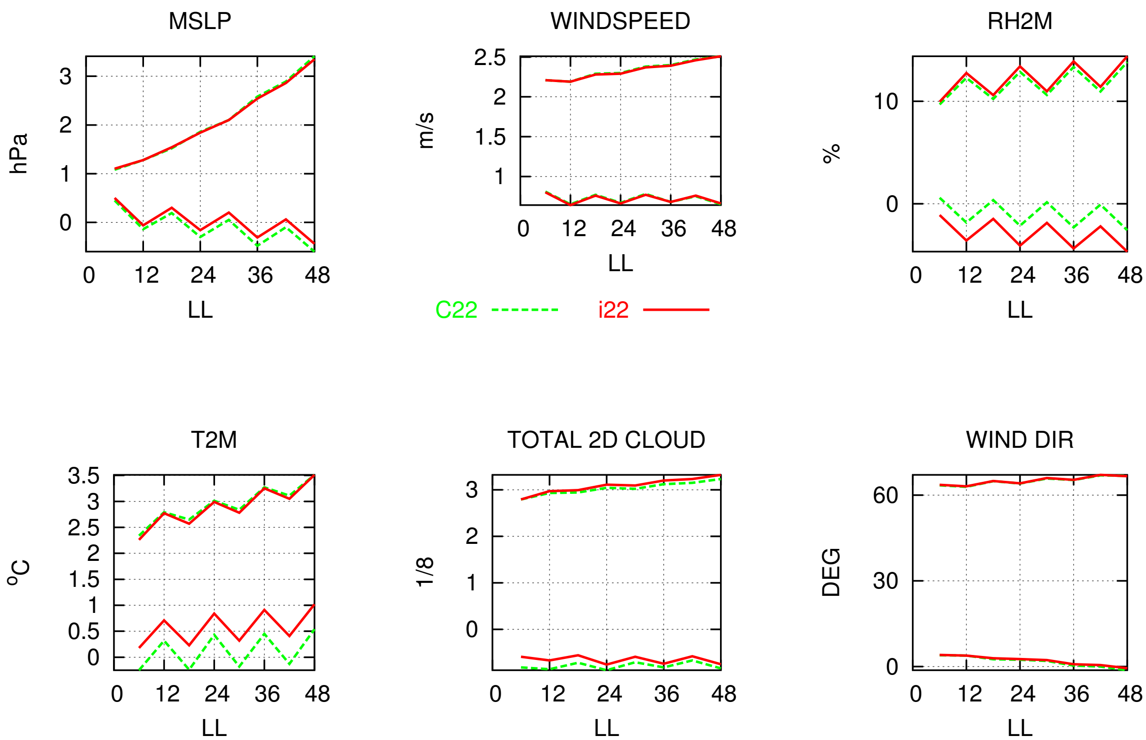

Figure 2: Verification result for European Ewglam stations for some surface parameters and different forecast lengths. C22 is the operational version i22 is with the new parameterization

might notice anyway. The mean 2-meter temperature is a little bit higher in i22. A more detailed analysis shows that the temperature is generally colder in the northern part of the domain and warmer in the southern part than C22. The reason for the differences is not clear. One hypothesis is that a smaller amount of cloud-water in i22, (figure 4), makes the clouds more transparent for both longwave and shortwave radiation. The outgoing radiation is more important in the northern part and this leads to a cooling, but in the southern part in shortwave radiation is more important and thus the net result is a warming.

The verification result for upper air data is seen in figure 3. The main difference between the runs is that the relative warming seen in i22 in the lowest part of the troposphere is compensated by a cooling between 700 and 300 hPa. The higher relative humidity in i22 is probably a second effect of this cooling. The reason for the cooling in not clear. Other differences are small. The mean fraction of ice, f_{ice} for different temperatures are seen in figure 4. The fraction of ice is generally somewhat higher than what is prescribed in the reference run, where it is assumed that f_{ice} increases linearly from zero at 0 C to unity at -40. Is not clear what the "truth" should be. Different studies give different result, and the variation of f_{ice} might also be dependent on the season, the type of weather regime and of the location. The prescribed relation is rather close to that found by Intrieri et al. But Bower et al. (1996), found much more cloud-ice in frontal stratiform clouds, but less in deep convective clouds. Bower et al., included also large ice particles (precipitation), thus giving higher f_{ice} , so those results are difficult to compare with the ones here.

A case study have been done for testing the parameterization for a rare weather event over Denmark and southern Sweden in January 15 1987. Then, supercooled drizzle and supercooled rain was reported for most weather-stations over that area. In this case the precipitating cloud was near the 925 hPa level, and the temperature inside the cloud was -10 to -13 C. It is clear that this cloud had no or very little cloud ice. However, the modeled cloud contained mostly cloud ice, so for this particular case the cloud ice content was far too high. But one have to bear in mind that this was an exceptional case.

Beesley et al (2000) compared the forecasted f_{ice} in the ECMWF model with observations over the Arctic region in November and December of 1997. The ECMWF model assumes a temperature-dependent partitioning of cloud condensate between water and ice, with a parabolic distribution of f_{ice} from zero at 0 C to unity at -23 C. A much larger fraction of liquid water clouds was observed than the ECMWF model predicted. This study indicates that assuming that f_{ice} increases linearly from zero at 0 C to unity at -40 might not be to far from "reality", but there are rather large uncertainties in the measurements, both regarding the partition between ice and water and between cloud ice and precipitation.

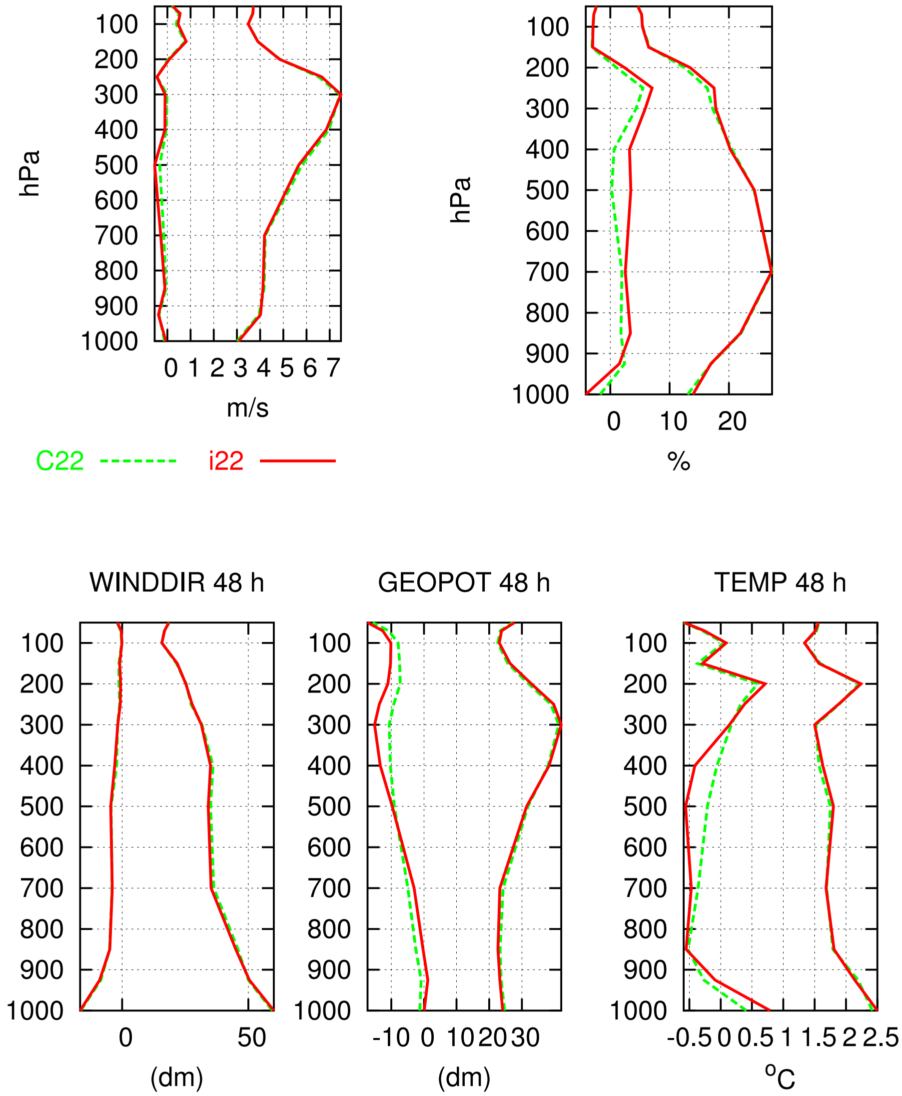

Figure 3: Verification result for European Ewglam sounding stations for 48 hour forecasts. C22 is the operational version i22 is with the new parameterization.

4 Discussion and conclusions

Two versions of the Hirlam model have been run for a cold 15-day period in winter. One, using the standard way of determine the fraction of cloud condensate that is ice, f_{ice} based on a temperature dependent relation. A separate prognostic scheme for cloud water and ice have been used in the other one. The verification shows a near neutral impact of the forecast performance. There is a cooling in the upper part of the troposphere and also near the ground in the arctic region compared to the reference run. But there is a warming near the ground at southern latitudes. It is assumed that this might be caused by higher cloud ice content and lower could water content. The total cloud condensate content is nearly the same as in the reference run. (not shown). The fraction of cloud condensate that is ice is higher in experimental run. It is not clear if the contents of cloud ice and water are realistic or not, since this is difficult to validate. Satellite pictures could be used to validate this, but no such studies have been done yet.

The parameterization used here could be improved by a better use of the existing pa-

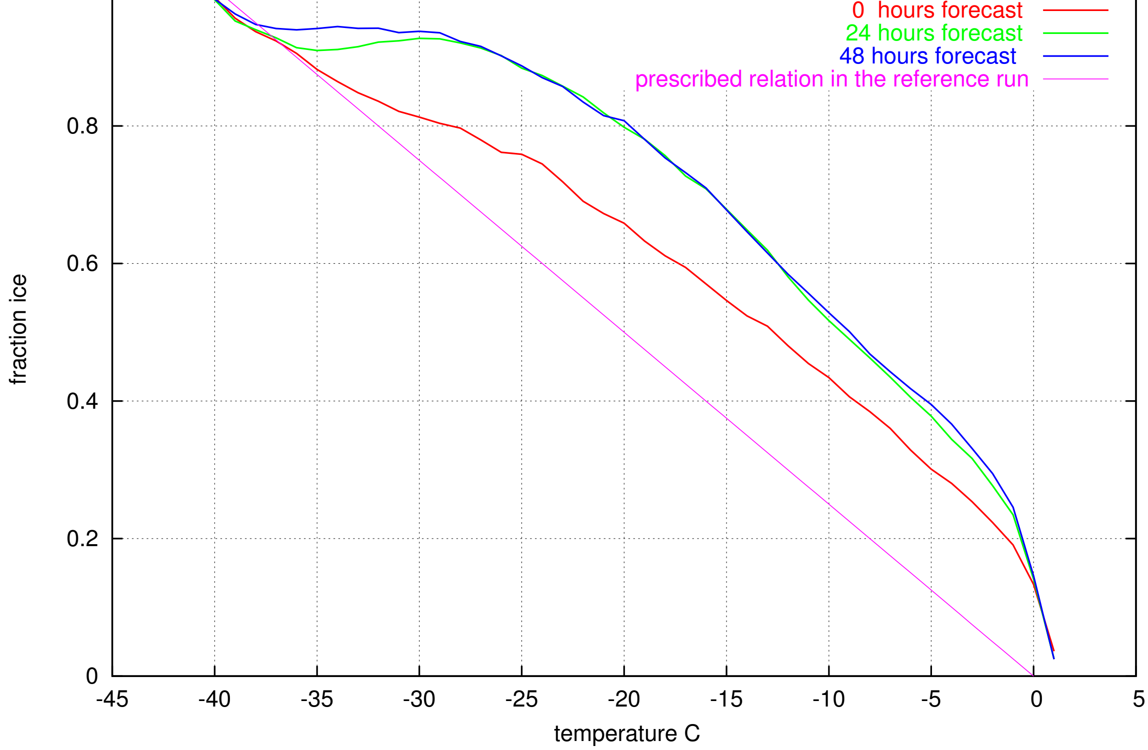

Figure 4: The fraction of the cloud condensate that is ice for different temperatures and forecast lengths, compared to the prescribed temperature dependent relation in the reference run.

rameterization of the precipitation release. Thus, it is possible to determine how much of the cloud ice and how much of the cloudwater that should be transformed into precipitation. Here, this partition is just set to f_{ice}, and sensitivity studies indicate that this is the main reason for the high content of cloud ice, which in this test is suppressed by the use of a low ice crystal concentration. Also, the convective cloud condensate is partitioned in this simple way, and this is probably not the most realistic approach. Another question is how to initialize the ice fraction f_{ice}. Here, the prescribed temperature relation in the reference run is used. Different crystal habits for different temperatures are not considered, but may be of importance. It would also be important to test this parameterization in a more recent version of the Hirlam model, and also to use a more recent version of the RK-scheme.

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