P1.1 MESOSCALE CLOUD SCHEME ASSESSMENT USING SATELLITE OBSERVATIONS

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1. INTRODUCTION

Mesoscale models offer an ideal framework where to perform detailed and explicit simulations of cloud and precipitation because these models are able to follow the evolution of several microphysical species in the context of real meteorological flows. The amount, top height, thickness and precipitation rate of the clouds result from complex interactions between three-dimensional resolved motions and a stratified moist thermodynamical environment. The later can be highly perturbed locally by the water cycle through the unsteady storage and release of heat and water vapor. Once cloud formed however, it is the role of the microphysical scheme to parameterize the physical processes that lead to heat and water transfers between and within the vapor, liquid, and ice water phases. Thus a successful simulation of cloud systems in a mesoscale model outlines at first a geographically and timely accurate prediction of the vertical motions in the atmosphere and then a correct representation of the condensed phase amounts. This makes the objective evaluation of simulated cloud fields against observational datasets, here satellite pictures, so difficult because of the well-known intricate links between small-scale dynamics and the microphysical state of the clouds.

The purpose of this work is to show that a model-to-satellite approach, in which satellite brightness temperature (BT) images are directly compared to synthetic BTs computed from predicted model fields (e.g., Morcrette, 1991), is fruitful to validate mesoscale simulations but owing to the fact that these are already of sufficiently good quality.

Only a few cases that are well simulated by mesoscale models, are candidate for a direct assessment with satellite data because of the rather high accuracy required a priori to predict the cloud location. In a previous study, Chaboureau *et al.* (2000) experienced a model-to-satellite method to evaluate simulations of Fronts and Atlantic Storm-Track Experiment (FASTEX) Intensive Observing Period 17 (IOP17), performed with the Meso-NH mesoscale model. Synthetic BTs corresponding to the METEOSAT infrared and water-vapor channels were computed by a narrow-band radiative transfer code, that mimics the METEOSAT viewing angles and the filter functions. As a result, Chaboureau *et al.* (2000) confirmed that for a mid-latitude frontal event a much better agreement between observed and synthetic BTs could be obtained if the cloud scheme includes explicitly an ice-phase parameterization. The study revealed also that without specific tuning, the model forecast increasingly overestimated the upper-level cloud cover of non-precipitating ice. It is the purpose of this work to understand the recurrent default of the cloud parameterization and to remedy to it by changing a critical ice-to-snow autoconversion threshold. Due to its high sensitivity to cloud cover, only information brought by the thermal window (the so-called IR channel of METEOSAT) is necessary to adjust a sensitive coefficient in a satisfactory way.

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2. MODEL AND THE SIMULATIONS

The simulations are carried out with the Meso-NH model (Lafore *et al.*, 1998) and its full physical package. In the present model version, the microphysical scheme is a bulk mixed-phase cloud parameterization developed by Pinty and Jabouille (1998) and Stein *et al.* (2000), which predicts the mixing ratio of six atmospheric water categories: water vapor, cloud water, rain water, non-precipitating ice, snow and graupel. The fields included in the initial (17th February 1997, 12Z) and boundary conditions of the numerical experiments are only temperature, winds, and water vapor, taken from the operational ARPEGE analyzes of Météo-France. The model domain encompasses the North Atlantic sector covering 9000 km $\times$ 6000 km with a 75 km grid mesh. It is integrated forward for 24 hours. Two simulations (E1 and E2) have been run with $r_i^\star$, a cloud-ice threshold set to two different values.

3. RESULTS

3.1 Tuning of the ice-to-snow autoconversion threshold

As a first example, Figure 1a,b presents the comparison between observed and E1 simulated BTs, after 24 h of simulation. In the mid-Atlantic, the cloud cover of the surface low L41 system and the contiguous cloud head, as well as the so-called Iceland low and its associated cold front crossing Norway, are represented by low BTs, less than 250 K, of the same intensities in the two images. However, off the low centers and the frontal areas, the model clearly overestimates the cloud system extent, mostly at upper levels.

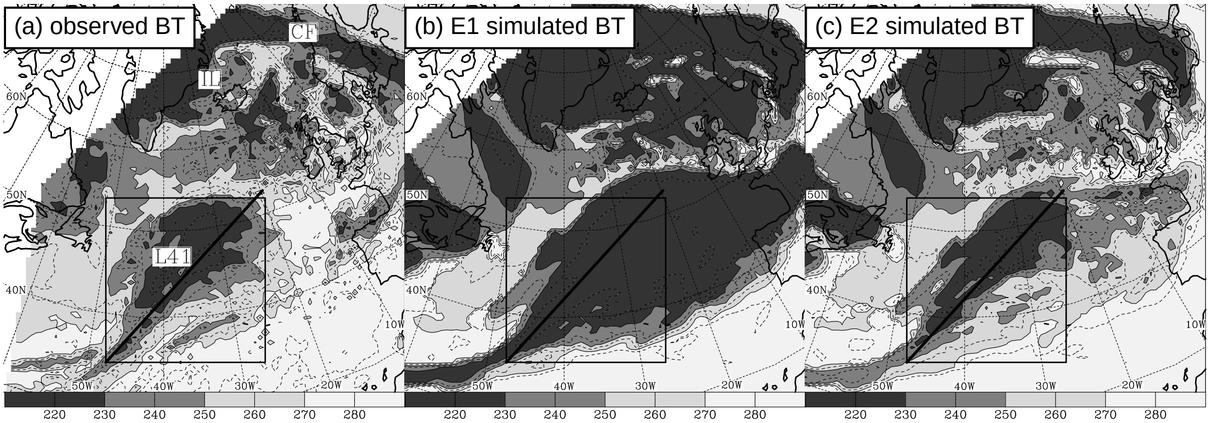


Figure 1: (a) observed and (b,c) simulated BTs (K) at 24h of simulation in the IR channel. Contours are every 10 K alternatively dashed and solid. The main synoptic features are marked (L41 for Low 41, IL for Icelandic Low, and CF for Cold Front).

The upper-tropospheric cloud amount is here mainly controlled by a balance between cloud-ice (non-precipitating) production by water vapor deposition in the ascending area, and cloud-ice destruction by the autoconversion process, which converts (non-precipitating) cloud ice to (precipitating) snow when some cloud-ice threshold, $r_i^\star$, is reached. In the current Meso-NH scheme, this autoconversion process is parameterized in a heuristic way following Lin *et al.* (1983) and $r_i^\star$ is set equal to 5×10^{-4} kg kg^{-1}.

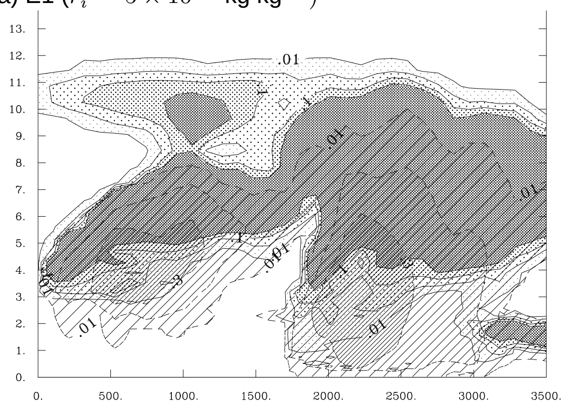
In order to test the sensitivity of the cloud scheme to the process of autoconversion of ice to snow, an additional simulation, E2, has been run with a $r_i^\star$ threshold value set to 2×10^{-5} kg kg^{-1} (Figure 1c). This value has been objectively adjusted, by minimizing the bias with the observations. The positioning of the main cloud systems is similar in experiments E1 and E2, as a result of the strong dynamical organization of the flow which by the way is not very sensitive to details on the ice parameterization at such a scale. Besides, the overall cloud cover for the E2 experiment is much more satisfactory, particularly at the high levels, where the new tuning clearly improves the agreement with the satellite BTs. Nevertheless some discrepancies still remain. For example, the shape of the cloud system has a more pronounced stretched structure along the front as compared to the observations. These BTs differences on the cloud edges are partly due to the limited quality of the dynamical fields, due to the 75 km resolution, not able to fully resolve the mesoscale circulations. Other sources of errors are from the prediction of cloud ice by Meso-NH whereas the METEOSAT BTs are typical of clear sky (for example, in the area to the east of the box in figure 1c), but presumebly also from errors in the vertical placement of the cloud layer or in the amount of condensates. However, large areas indicate BT differences less than 8 K, which are commensurate to our estimate of the error of the model-to-satellite approach (Chaboureau *et al.*, 2000).

3.2 Consequences for the vertical distribution of ice

We examine a vertical cross-section to show the effects of varying $r_i^\star$ on the amounts of non-precipitating and precipitating ice in the cold and warm front areas (Figure 2). The vertical structure of the ice mixing ratio appears to be quite sensitive to the $r_i^\star$ value: clouds are denser with a higher threshold. At upper levels, above 10 km, the ice mixing ratio isocontours range from 10^{-5} kg kg^{-1} (for the E2 experiment) to more than 10^{-4} kg kg^{-1} (for the E1 experiment). On the contrary, isocontours of snow greater than 10^{-5} kg kg^{-1} are visible for simulation E2 but not for the E1 one where snow is absent above 10 km. This means that the cirrus cover is thick in the E1 simulation because high $r_i^\star$ prevents from a fast conversion of cloud ice to snow which finally leads to a partial dissipation of the cirrus by precipitation. At lower levels, a higher threshold value also corresponds to denser clouds. However, the area where snow is in excess of 0.3 g kg^{-1} is similar in the two experiments because once formed, the snow crystals grow by collecting small ice crystals at an equivalent rate in the two experiments. So it can be concluded that because the upper level small ice crystals are more sensitive to the choice of the autoconversion threshold, therefore the $r_i^\star$ threshold can be adjusted objectively using BT observations.

Many experimental studies have been performed recently to characterize the microphysical composition of high-level ice clouds. All of these agree to consider that a bimodal structure of the ice crystal distribution is often observed. Therefore the bulk microphysical parameterization must be modified indeed to discriminate between the small and large sized crystals because of their contrasted radiative and aerodynamical properties. So far the present parameterization like many others includes a snow/aggregate category of unrimed to lightly rimed crystals, it is legitimate to increase the pristine ice autoconversion rate by simply lowering the $r_i^\star$ threshold. Note that now the autoconversion term identifies crudely the growth of small ice crystals with habit change, due to self-aggregation and to vapor deposition on the largest ones. Consequently, it seems no worth to consider a sedimentation rate of pristine ice crystals to dissipate cirrus clouds in our simulations as it is often recommended in numerical studies because the snow/aggregate particules are already precipitating. Finally, the snow/aggregate category of ice may contain also now intermediate size crystals at high altitude at least, a region where self-aggregation process is less efficient, this means that these hydrometeors should be taken into account to compute the cloud radiative properties.

(a) E1 ($r_i^\star = 5 \times 10^{-4}$ kg kg^{-1})



(b) E2 ($r_i^\star = 2 \times 10^{-5}$ kg kg^{-1})

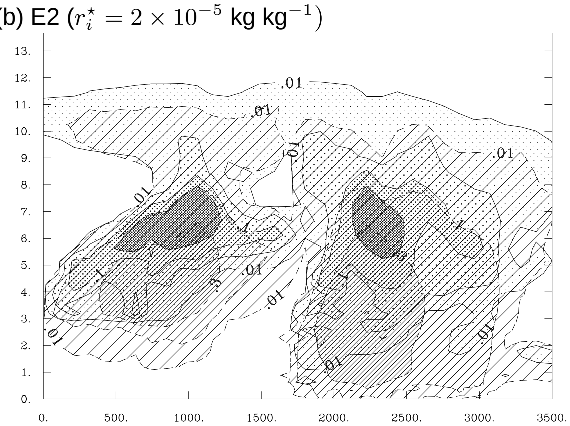


Figure 2: Vertical cross-section between (35°N, 47.5°W), left-hand, and (50°N, 20°W), right-hand, of non-precipitating ice and precipitating ice (snow and graupel) mixing ratios for two different threshold values of the ice-to-snow autoconversion (section shown by solid line in Figure 1). Figures on axis represent distance in km. The solid lines are non-precipitating ice contours representing 0.01, 0.05, 0.1 and 0.15 g kg^{-1}. The dashed lines are precipitating ice contours representing 0.01, 0.1 and 0.3 g kg^{-1}. The shading are made with dots for the non-precipitating ice and with hatching for the precipitating ice (the darker the pattern the larger the amount of ice).

3.3 Sensitivity to the cloud radiative properties

As the radiative properties of ice in clouds are subject to uncertainty, we now test the sensitivity of our synthetic BTs to another gray body approximation. These differ substantially on the dependence of the emissivity (through the mass absorption coefficient) and its relation to the mean size of the particles. In the current radiative code, the ice emissivity is parameterized following Smith and Shi (1992) (hereafter, SS92), where the effective radius varires from 10 μm at 1000 hPa to 40 μm at 100 hPa following Morcrette (1991). Another parameterization comes from Kristjánsson *et al.* (1999) (hereafter, KEM99), where the maximum dimension increases with temperature, from 25 μm at 210 K to 200 μm at 250 K.

The results are summarized in Figure 3. As there is no cloud initialization in Meso-NH, the bias between METEOSAT and the simulated BTs is the largest at the initial time (24 K). Then, as the mixing ratio of the cloud water species build themselves, the bias decreases in time until the 18th at 00Z. After this date and until the end of the simulation, the bias either decreases more slowly (E1) or is steady (E2). So this 12-hour initial period corresponds to the model spin-up.

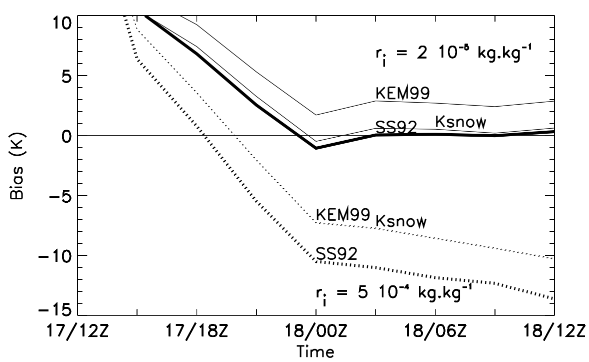


Figure 3: Time evolution of the bias between the simulated and the observed BTs (K) in the IR channel for the E1 (E2) experiment in dashed (solid) line. Results with the SS92 (KEM99) parameterization are with thick (thin) line. (KEM99: only integrating the ice mixing ratio; Ksnow: integrating all the icy particules mixing ratios (ice, snow, and graupel).)

When focusing on the results with the SS92 parameterization, with the highest threshold, (E1 experiment), the bias between METEOSAT and the simulated BTs decreases in time down to -14 K after 24 h of simulation. As time increases, a larger and larger amount of cloud ice is created, due to the permanent dynamical forcing, leading to a severely overestimated cloud cover later in the simulation (Figure 1b). So the processes leading to cloud-ice dissipation are underestimated when the autoconversion threshold is too high. For the E2 experiment, the bias becomes negligible after the spin-up period.

When examining the sensitivity of the cloud radiative properties, the synthetic BTs obtained with the KEM99 emissivity are warmer than those obtained with the SS92 parameterization. Whatever the radiative parameterization chosen, the synthetic BTs from the E1 simulation are definitively too low compared to the observed BTs. This demonstrates the need of a reduced ice-to-snow autoconversion threshold. Moreover, the gray body assumption is valid as long as the ice crystals are small compared to the wavelength of the observation. This is questionable as soon as the size exceeds 50 μm, or so. Furthermore as these parameterizations should involve all the categories of icy particules, it is important to test whether the precipitating ice contents (snow and graupel) should contribute to the BT calculation. Figure 3 also displays the case of including snow in the KEM99 parameterization (Ksnow). In case of the E1 simulation, no BT change is discernable because the non-precipitating ice layers are too much absorbing or the precipitating ice layers are too thin or at a too low level. In the case of the E2 simulation, the addition of snowflakes leads to lower the BTs. Thus, a bias close to zero is obtained satisfactorily with the KEM99 emissivity but accounting for the contribution of snow.

4. CONCLUSION

An evaluation of the cloud scheme of the Meso-NH model has been made by comparing synthetic and observed METEOSAT BTs. It is shown that the model is able to simulate realistic synthetic BTs. Moreover, this model-to-satellite approach, which combines an explicit cloud scheme implemented in a mesoscale model with a detailed radiative transfer code, gives access to the tuning of the ice parameterization. A comparison made with two different values of the ice-to-snow autoconversion threshold shows a significant improvement of the synthetic BTs, and thus a minimization of the difference between simulated and observed BTs.

The useful reduction of ice-to-snow autoconversion threshold is interpreted by the presence of bimodal distributions of ice at high altitude as observed extensively in cirrus clouds. In addition, the results have been tested in regard of the uncertainty to the radiative properties of ice in clouds. Whatever the radiative parameterization is chosen, the simulation with the largest threshold underestimates the BTs. The best tuning of the autoconversion threshold depends upon the choice made in the BT calculation. In this respect, we recommend to incorporate the snow/aggregate category of ice in the BT calculation with the Kristjánsson *et al.* (1999) parameterization.

More generally, parameterizations of the cloud water cycle and of the radiative properties of cloud particles, contain implicit assumptions about the number and the geometry of the particles. Recent schemes have been tested to treat the microphysical and the radiative aspects in a consistent way. The model-to-satellite technique is also sensitive to these two aspects while keeping in mind the errors arising from the simulated dynamical fields. It is hoped that a multi-frequency approach and more experience gained by testing the model-to-satellite technique on a large set of cases, should reduce the uncertainties in the characteristics of the high level ice clouds.

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