The ability of MM5 to simulate thin ice clouds: systematic comparison with lidar/radar measurements

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1. Introduction

The ability of mesoscale models to simulate thin ice clouds still remains to be demonstrated. This study is intended to compare MM5 results with permanent measurements by active remote-sensing (radar and lidar) and passive remote-sensing (infrared and visible fluxes) on the Site Instrumental de Recherche par Télédétection Atmosphérique (SIRTA) in France. The ambitions are (i) to understand which parameterization of ice is adapted to mid-latitude ice clouds, and (ii) to combine observations with model results in order to have a complete description of the atmospheric column when there are ice clouds. The most adequate parameterization is chosen by comparing simulated lidar and radar profiles (with model results) to observed ones (from SIRTA instruments) with the advantage that this method does not requires any inversion of the lidar and radar profiles. With this parameterization, it is then possible to do systematic comparisons during the ice cloud days, and completely describing the atmospheric column. For this preliminary study, a total of 38 cases have been selected.

2. Model and instruments

2.1. Simulations

The MM5 model is run through a complete year starting in March 2003 and ending in February 2004. In order to compare the simulated atmospheric profiles with the observed ones, we use a relatively high resolution (5 km) mesh over a domain covering about 200x200 km around Paris. In order to force this model configuration, a looser-resolution version is also using a 500km x 500km (approximately) with a 15 km resolution. The two domains communicate through a two-way nesting procedure. The whole system is forced by the NCEP 1X1 degree analyses given every 6 hours. Since long-term runs are carried out the model run is kept relatively close to the analysis using a nudging procedure with a time scale of 10000 s for wind and temperature and 50000 s for humidity, which does not constrain too much this latter key field for our analysis.

We choose 62 vertical layers from surface to the 100 hPa top surface. Model layers are about 200-400m thin in the upper troposphere. The parameterizations are the MRF boundary layer, the Grell (1994$) scheme for cumulus clouds on the larger-scale domain and no cumulus parameterization on the fine grid domain. The RRTM radiation scheme is used. Several available microphysics are available, of which the two Reisner ($) schemes and the Schultz scheme are tested here. Outputs are taken on a hourly time step.

The complete simulation is carried out by 5-day+6-hour pieces initialized at 18 UT on the day preceding the first one. A 6-hour spin-up period is therefore assumed, during which model output are not considered.

2.2. Observations

The SIRTA 532-nm backscatter lidar operates 4 days a week from 8 am to 8 pm, with a time resolution of 20 shoots/second, and a vertical resolution of 15 m. It is a zenith viewing lidar that measures both the backscattered signal and linear depolarization ratio. The lidar signal is normalized to a molecular signal calculated from Météo-France radiosounds launched in Trappes (20 km away from SIRTA). For this study, lidar profiles are averaged over 10 minute periods and taken every hour for comparison with MM5 outputs.

The SIRTA 95GHz radar operates continuously. Its frequency of repetition is 25 kHz, and its vertical resolution is from 30 to 60 m. It can produce reflectivity and vertical Doppler velocity profiles from 0.2 to 15 km. Its resolution is -50 dBZ at the ground, and it looses -3 dBZ/km of resolution.

For the same reason as for the lidar, the radar profiles are averaged over 10 minutes and sampled every hour.

Concerning the value of fluxes, they are measured by a pyrheliometer for the direct shortwave flux, by a pyranometer for the diffuse shortwave flux, and by a pyrgeometer for the net longwave flux. Those instruments are at ground on the SIRTA.

2.3. Method of comparison

The method consists in comparing lidar and radar profiles observed at SIRTA with profiles simulated as an output of MM5.

The normalized lidar signal $S_{norm}(z).z^2$ profile is simulated using equation 1:

$$S_{norm}(z).z^2 = (\alpha_{sca,ice}(z).k_{ice}(z) + \alpha_{sca,liq}(z).k_{liq}(z) + \beta_{sca,mol}(z)) \times e^{-2\int(\alpha_{sca,ice}(z)+\alpha_{sca,liq}(z)+\alpha_{sca,mol}).dz} \quad (1)$$

$k_{ice/liq}(z)$ is the lidar ice/liquid particle backscatter-to-extinction ratio that depends on the particle scattering phase function at 180°, $\alpha_{sca,ice/liq}(z)$ is the ice/liquid particle attenuation by scattering, $\beta_{sca,mol}(z)$ is the molecule backscattering coefficient, and $\alpha_{sca,mol}(z)$ is the molecule attenuation by scattering .

The radar reflectivity profile Z(z)dB is simulated following Equation 2:

$$Z(z)dB = 10 \times \log\left[r_{ice}^6(z).n_{ice}(z) + r_{liq}^6.n_{liq}(z)\right] \quad (2)$$

r_{ice} is the ice particle size, , r_{liq} is the liquid particle size, n_{ice} is the number of ice particles, and n_{liq} is the number of liquid particles.

The MM5 values of ground longwave and shortwave fluxes can directly be compared to the measured ones.

A total of 38 cloudy days are studied: 17 cases with both radar and lidar observations, 14 cases with radar only, and 7 cases with lidar only. The cases have been selected using lidar and radar observations, in order to have only thin ice clouds.

3. Sensitivity study: choice of the ice parameterization

In order to select the microphysics parameterization that is most appropriate to our cases study (mid-latitude thin ice clouds), the three ice cloud parameterizations contains in MM5 (Shultz et al. 1995, Reisner et al. 1998 called here Reisner 1, and a revised version of Reisner et al. 1998, called here Reisner 2) have been first tested on 7 thin-cloud "lidar cases". Figure 1 shows lidar profiles observed and simulated using the 3 parameterizations at different times on 17 March 2003. For the specific case described in Figure 1, the Schultz parameterization misses the cloud, clouds are too persistent and too thick with a Reisner 2 parameterization, and the most faithful simulation is that using the Reisner et al (1998) parameterization , although it seems to dissipate the cloud too early. Actually the tendencies present in this case also show up in the other 6 test cases (not shown). Therefore the Reisner 1 parameterization is selected for running the 38 cases of ice clouds. For this parameterization, the number of particles n(z) is not available (it is not a prognostic variable of the parameterization). Hence, it is necessary to make a hypothesis on the particle size in order to compute the lidar profile (Equation 1).

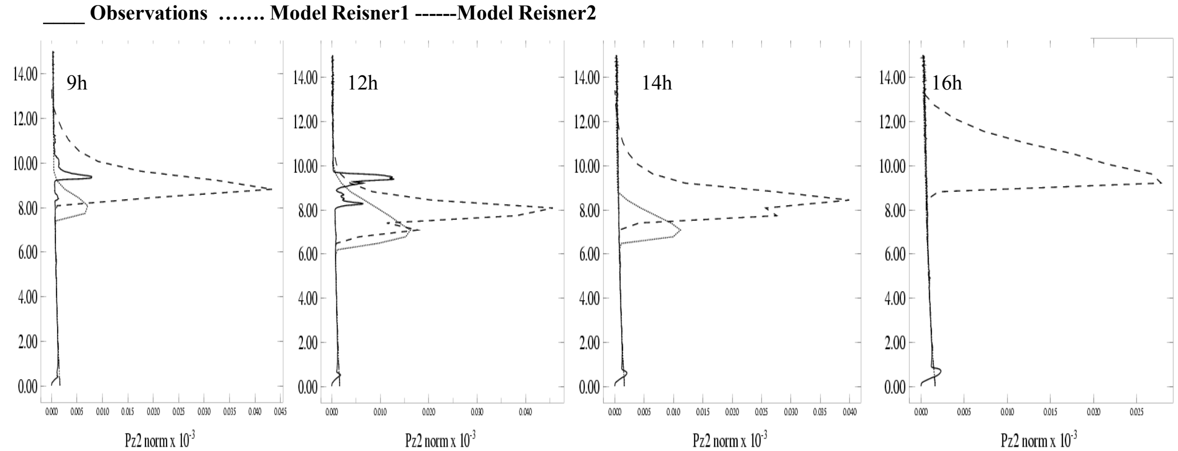

Figure 1: Lidar signal profiles S(z).z², observed (red), computed (green for Reisner1, blue for Reisner2), for the March 17th 2003, at 0900 UT, 1200 UT, 1400 UT, and 1600 UT.

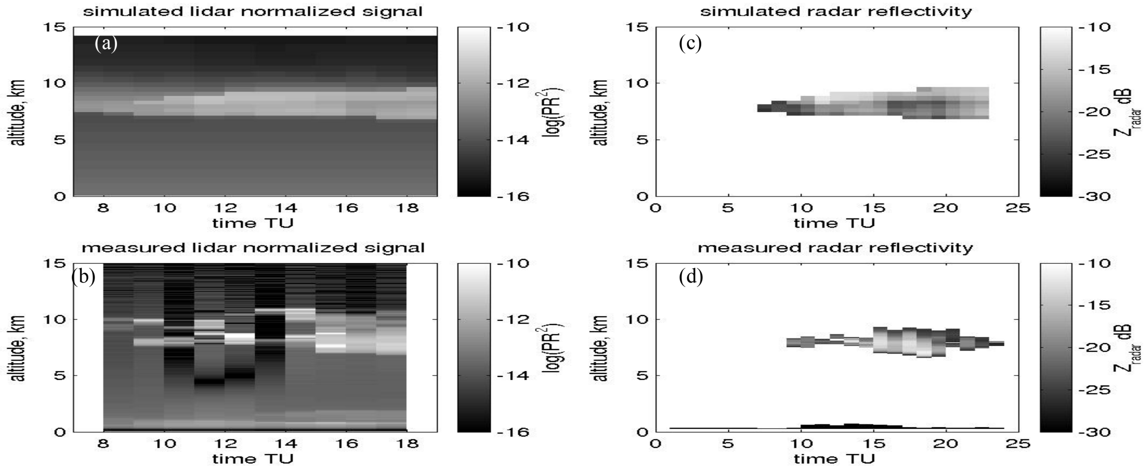

Figure 2: For October 17th 2003: (a) evolution on time of simulated lidar backscattered signal as a function of altitude, (b) same as (a) for the measured lidar backscattered signal, (c) the same for simulated radar reflectivity, (d) the same for measured radar reflectivity.

4. Results

4.1. An illustrative example

The method described in Sect. 2 is applied to the October 17th 2003 case. Figure 1 shows lidar and radar images for both simulations and observations.

Figure 2a shows a simulated cloud lying between 7 and 9 km, persisting from 0700 UT to 1900 UT. The lidar measurements (Fig. 2b) show a cloud between the same altitudes, but with more heterogeneity like multilayer cloud. Furthermore, the boundary layer aerosols detected by the lidar measurements are not represented in MM5. This could explain the differences between the values of the simulated and measured lidar signal, because at each level, the value of lidar signal depends on the layers lying below. Figure 1c also indicates a simulated cloud between 7 and 9-10 km, as for the radar measurements (Fig 2d). There is a quiet good agreement between radar simulations and radar measurements concerning the hour of creation and dissipation of the cloud: between 0700 UT and 0000 UT for the model, between 0800 UT and 0030 UT for the measurements. There is also a good agreement between simulations and measurements concerning the lidar signal and the radar reflectivity. However, the altitude and time of maximum signal are not the same, in particular for the radar reflectivity: it is at the top of the cloud and between 1100 UT and 1500 UT for the simulation, and more at the bottom of the cloud and between 1500 UT and 1900 UT for the measurements.

For the same case, Fig. 3 shows radar Doppler velocity images simulated (Fig. 3a) and measured (Fig. 3b). This velocity is the sum of the crystals sedimentation velocity and the air vertical velocity. In Fig. 3a and 3b simulations and observations display radar Doppler velocity with the same order of magnitude. Nevertheless, the spatial variability is more important for the measurements (between 0 and -0.8 m/s) than for the simulations (between -0.4 and -0.6 m/s), probably due to the actual crystal size $r_{e,ice}$, which is not accounted for in the model output processing.

Figure 4 shows the simulated and measured downward longwave and shortwave fluxes, during 24 hours for the same day. Simulated and measured longwave fluxes (Fig. 4a) are very similar during the day, and less during the night. In both cases, the fluxes increase from 0800 UT to 1500 UT, and are maximal at 15OO UT which corresponds to the middle of the cloud life (Fig. 2).

Simulated and measured shortwave fluxes (Fig. 4b) are similar until 0900 UT, just after the formation of the cloud (Fig. 2).

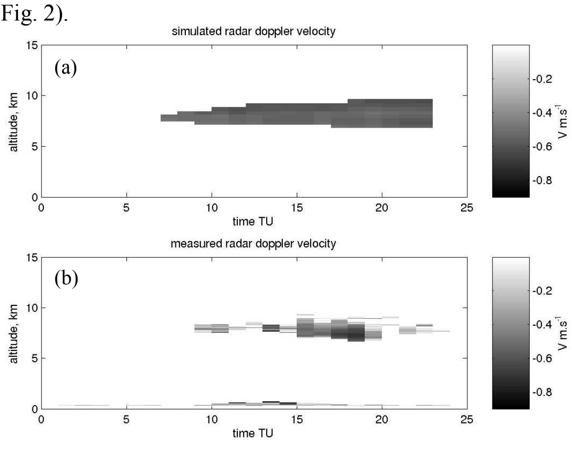

Figure 3: same as Fig. 2 for (a) the simulated radar Doppler velocity, (b) the measured radar Doppler velocity.

From 0900 UT to 1500 UT, measured fluxes are significantly lower than the simulated ones. This is consistent with the differences between simulated and observed lidar profiles (Fig 2a and 2b): the model clouds seem less optically thick than the observed one, especially between 12 UT and 1400 UT.

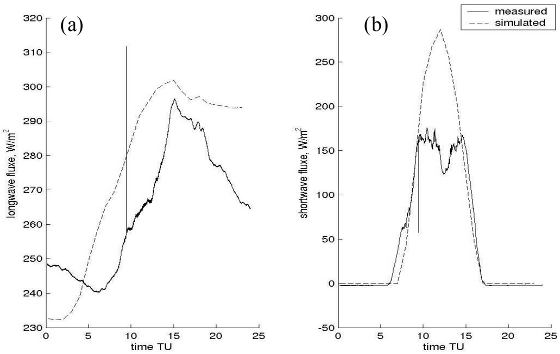

Figure 4: For October 17^{th} 2003: ground fluxes measured in plain lines, simulated in dotted lines (a) longwave, (b) shortwave.

4.2. Statistical study

A total of 38 cases have been analysed using this method, in order to draw conclusions that are more general. For each case, the method has been applied with 3 different hypothesis of ice particle size: $r_{e,ice}$=20 µm, 100 µm, 300 µm. For each value of $r_{e,ice}$, the radar and lidar profiles calculations lead to different results.

Figure 5a shows the measured lidar signal, integrated over the column from 0 to 15 km, as a function of the simulated one. The 24 lidar cases are represented for each hour. Data are represented for the 3 different hypothesis on $r_{e,ice}$. In each case measurements and simulations have the same order of magnitude, although the hypothesis of ice size of 300 µm leads to an underestimation of the signal. The large scatter of points does not allow drawing any quantitative conclusion about the ability of MM5 and its microphysics to simulate the thin ice clouds. However, one noteworthy point is that in all our "lidar cases", the model simulates an ice cloud. The cloud timing may be slightly incorrect, its ice content can be misestimated, but the cloud is present in the simulation. For radar reflectivity, the same conclusion holds, and a better agreement between model and observations is obtained with $r_{e,ice}$=300 µm. Using this hypothesis, vertical radar velocities are also in the correct range, but there are a number of cases with strong vertical velocities which are not recovered in the simulations. In reality, many factors can influence the vertical radar velocity: the ice particle sizes can vary a lot, influencing the sedimentation velocity, while there is no model dependence of sedimentation to particle size in the bulk microphysical parameterization. Turbulence can also lead to unaccounted high vertical velocities.

Figure 6 shows measured as a function of the simulated fluxes, for the 38 selected cases, and for each hour of the day. There is a very good agreement between simulation and measurements concerning the longwave flux (Fig. 6a). This confirms that MM5 is able to simulate the thin ice clouds in a qualitative manner. The simulated shortwave flux (Fig. 6b) is in fair agreement with observations. However there is a general tendency to underestimate low fluxes and to overestimate high fluxes.

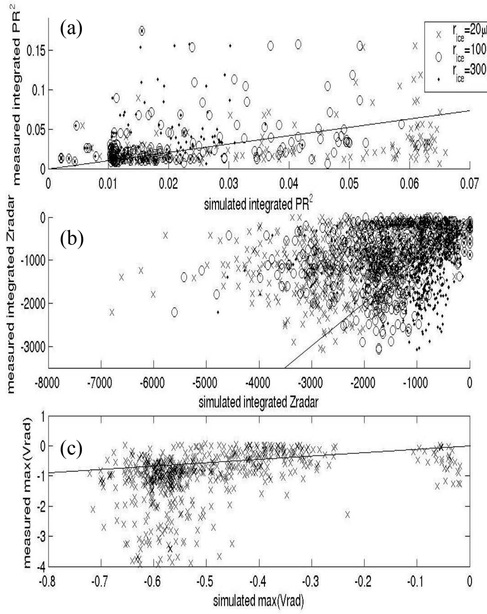

Figure 5: For 38 cases and several hours for each case: (a)measured lidar $S(z).z^2$ integrated between 0 and 15 km, as a function of the simulated one (in log); in red for $r_{e,ice}$=20 µm, in green for 100 µm, in blue for 300 µm, (b) the same as (a) for the radar reflectivity, (c)maximum of the measured radar Doppler velocity as a function of the simulated one which does not depends on $r_{e,ice}$.

It is difficult to estimate whether the flux discrepancies are due to the microphysics or to the radiation schemes. More comparison work is needed, especially with the lidar/radar data. However the good correspondence for longwave fluxes is an indication that the microphysics parameterization should not lead to such biases. One possibility is that the shortwave flux scheme has difficulties in simulating radiation in the presence of thin ice clouds.

5. Preliminary conclusions and perspectives

The first important result of this study is that MM5 model and its Reisner (1998) microphysics is able to systematically produce thin ice clouds using Reisner 1 ice parameterization on all the cases studied in this paper. There is generally a good agreement with the observations concerning the altitude, the time of formation and the persistence of the cloud. Nevertheless, lidar and radar observations differ from their model counterpart in the variability of ice content, which leads to a large scatter when comparing simulated and observed lidar/radar signals. One difficulty is the aerosol load present in the boundary layer, which is not yet accounted for in MM5. Another difficulty is due to the natural variability in ice particle size which is not taken into account in our calculations. The radar also provides an estimate of the sum of the vertical velocity and the sedimentation velocity, for which there is a general agreement between simulation and observations. However the dependence of sedimentation on particle size is not considered here, which may explain part of the differences. The comparison between observed and simulated longwave fluxes exhibit a good agreement, but the equivalent comparison for shortwave fluxes reveals some biases.

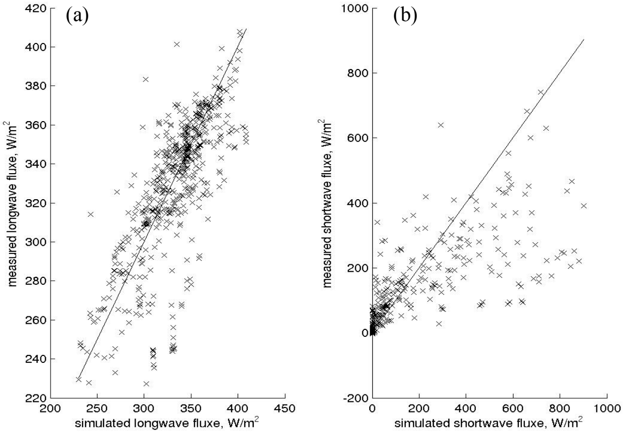

Figure 6: For 38 cases and 24 hours for each case : (a) measured longwave fluxes as a function of the simulated one, (b) the same as (a) but for shortwave.

Above all, our results are preliminary and require much more investigation in order to draw more quantitative conclusions about the ability of MM5 to simulate ice clouds. In order to improve these preliminary results, it will be necessary to take into account a size distribution instead of a single value in the computation of the lidar radar profiles. We also intend, in the near future, to test a microphysics scheme which uses the ice number as an explicit prognostic variable. It will also be interesting to compute the lidar depolarization ratio and compare it with the observed one, as an index of the water phase and the ice crystal shape. Using future Meteosat Second Generation CERES retrieval (Minnis et al. 1998) will enable the comparison of measured fluxes at the top of the atmosphere with simulated ones. This study should be linked to a cloud microphysics study, in order to better understand the radiative properties of thin ice clouds.

References

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