12.3 NUMERICAL SIMULATIONS OF MICROPHYSICAL PROCESSES INVOLVED DURING THREE MAP CASES (IOP8, IOP2A AND IOP3)

Franck Lascaux* and Evelyne Richard
Laboratoire d'Aérologie, CNRS/UPS, Toulouse, France

ABSTRACT

Numerical simulations of three MAP events (IOP2A, IOP3 and IOP8) have been performed with the MESO-NH model, run over three nested domains with horizontal grid increments of 32, 8 and 2 km. The simulations make use of an explicit microphysical scheme predicting the evolution of seven water species and including a four-class ice scheme (pristine ice, snow/aggregates, graupel and hail categories).

These three MAP events are associated with different flow regimes: stable stratification with blocked flow during IOP8, and unstable or potentially unstable conditions with flow over during IOP2a and IOP3.

In response to these different flow regimes, the numerical simulations exhibit a contrasted behaviour in the microphysical structure of the clouds. In the case of IOP2a and IOP3, the cloud systems are deep and the contribution of ice microphysics is very active. In both cases the dominant microphysical process is clearly the riming, but only IOP2a produces a thick layer of graupel and provides conditions leading to the generation of hail in a significant amount. In the case of IOP8, cloud tops hardly reach the height of 5 km and the prominant microphysical processes are typical of stratiform clouds: coalescence below the freezing level, and vapor deposition onto pristine ice above. However, the model tends to produce too much graupel for this IOP (and subsequent conversion into hail) whereas no hail and only a small amount of graupel was detected by the S-POL polarimetric radar. The processes involving ice microphysics like riming seem to be too active in the model.

1. INTRODUCTION

The three Intensive Observing Periods (IOPs), number 2a, 3 and 8, of the Mesoscale Alpine Programme (MAP, Bougeault et al., 2001) took place respectively on 17 September 1999, 25 September 1999 and 20-21 October 1999. During IOP2a, a deep convective system develops over the south-facing slopes of the Alps, in the Lago Maggiore area and propagating south-eastwards (see Richard et al., 2003 for further details). IOP3 is characterised by a south-westerly moist flow generated by a trough extending from Scotland to Morocco, leading to moderate orographic precipitation. Contrary to IOP2a, only isolated convective cells are triggered over the slopes. IOP8 is a stratiform event, with a trough located over western Europe producing intense precipitation in northern Italy (see Medina and Houze, 2003).

These three IOPs have been simulated with the French non-hydrostatic model MESO-NH (Lafore et al., 1998), run over three nested domains with horizontal mesh-sizes of 32, 8 and 2 km. The innermost domain is centered above the Lago Maggiore area. At such a resolution of 2 km, the cloud and precipitation are explicitely resolved with a microphysical scheme predicting the evolution of the mixing ratio of seven water species, including a four-class ice scheme (pristine ice, snow/aggregates, graupel and hail). The IOP2a simulation starts on 17 September 1999 at 12 UTC and was integrated for 12 hours. The IOP3 simulation starts on 25 September 1999 at 12 UTC and was integrated for 12 hours. The IOP8 simulation starts on 20 October 1999 at 12 UTC and was integrated for 30 hours.

In order to investigate the different microphysical processes involved in the three IOPs, bugdet analyses have been performed in the 3D box shown in fig. 2. In each case, the budget is integrated over a 15 minutes period: from 20 UTC to 20:15 UTC on 17 September for the IOP2a, from 18:30 UTC to 18:45 UTC on 25 September for the IOP3 and from 20:00 UTC to 20:15 UTC on 20 October for the IOP8.

2. BRIEF OVERVIEW OF THE THREE IOPS

On 17 September 1999 (IOP2a), at 12 UTC, a short-wave trough is located over southern France.

* *Corresponding author adress:* Franck Lascaux, Laboratoire d'Aérologie, 14 Av. Edouard Belin, 31400 Toulouse, France

During its progression towards the East, the atmosphere above northern Italy is destabilized by advection of cold moist air in the upper levels as it can be seen from the evolution of the Milano-Linate radiosounding between 12 UTC and 18 UTC (Richard et al, 2003). The sounding at 12 UTC is shown fig. 1a.

On 25 September 1999 (IOP3), at 12 UTC, the Milano sounding exhibits a layer of a warm and wet potentially unstable air extending from the ground to 700 hPa (fig. 1b).

During IOP8, the air is close to saturation (see the radiosounding in Milano fig. 1c), except for a very thin layer below 975 hPa (Medina and Houze, 2003). They showed by calculating Brunt-Väisälä frequencies that IOP8 was absolutly stable. No convection was observed.

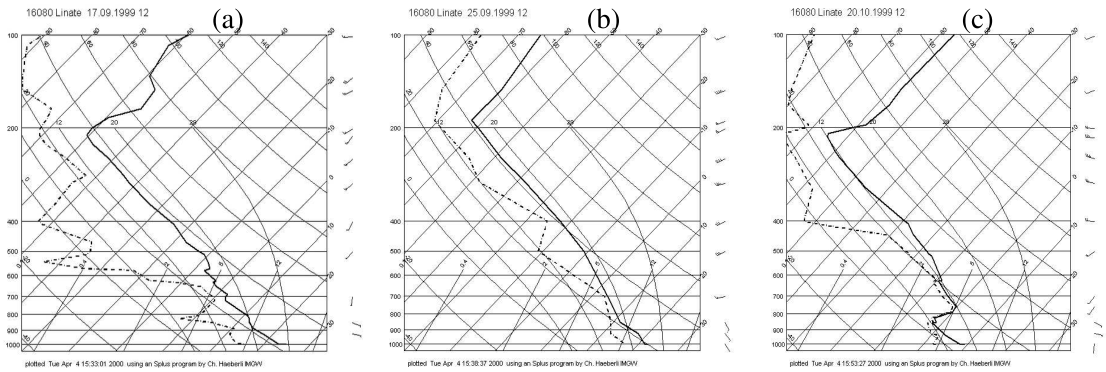

Figure 1: Milano-Linate soundings (a) on 17 September 1999 (IOP2a) at 12 UTC, (b) on 25 September 1999 (IOP3) at 12 UTC and (c) on 20 October 1999 (IOP8) at 12 UTC.

3. BUDGET ANALYSIS

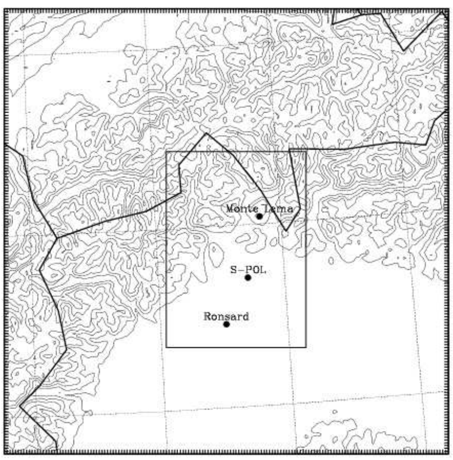

Figure 2: Innermost 2 km grid mesh domain common to the three simulations and its topography (isocontours every 500 m). The black dots represent the locations of the radars. The budget are performed in the inner black box.

The MESO-NH software allows to perform microphysical budget computations. The horizontal contours of the box in which the budget analysis is performed is shown fig. 2. It is common to the three IOPs, and includes approximatively half points over plain, and half points over a mountainous area.
For each hydrometeor, the mean vertical distributions of the mixing ratio (averaged during the time integration of the budget) and of the associated microphysical processes are plotted fig. 3 and fig. 4, respectively.

3.1 Mean vertical structure of the hydrometeors

To outline the mean vertical distribution of the hydrometeors according to the MAP event, the temporal average of each hydrometeors mixing ratio was horizontally averaged every 500 m on the vertical. As expected, the plots show significant differences between the three IOPs (fig. 3).

As the convective system of the IOP2a is well extended on the vertical (clouds top easily reaches 10 km), high amounts of ice and snow particles can be found at highest levels. The mean pristine ice maximum (0.20 g/kg) is at approximatively 10 km, and it is at 9 km for the snow/aggregates category (0.18 g/kg). As for the IOP3, during which convection is less intense and occurs only in isolated cells, the system is more shallow. As a consequence, the maximum for pristine ice and aggregates are less important (both 0.08 g/kg) and are found at lower elevations. Large amount of graupel and hail is present above the freezing level during IOP2a. In IOP3, graupel and hail are also present, but only in a small amount (less than 0.02 g/kg on average), which is in agreement with radar observations of this IOP (Pujol, 2003). For both IOPs, the amount of hail is larger in the updrafts (0.45 g/kg in the updrafts and 0.04 g/kg in the downdrafts on average for the IOP2a, not shown here).

During IOP8, clouds top hardly reaches 5 km, and therefore the hydrometeors are concentrated in the low levels. Above the freezing level the dominant particles are snow and aggregates, and rain below this level. Some graupel can also be found, embedded in the snow layer, and even some hail. S-POL did not detect any hail during this event, therefore it seems that the model produces too many heavily rimed particles. Except for this presence of hail, the distribution of hydrometeors is representative of a stratiform case, with rain below the freezing level and snow aloft.

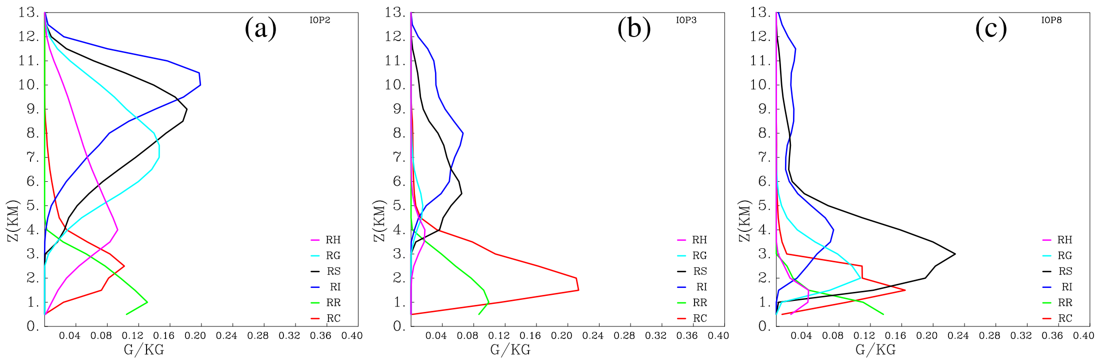

Figure 3: Mean vertical structure of the hydrometeors on the box defined fig. 2 for (a) IOP2a, averaged between 20 UTC and 20:15 UTC on 17 September 1999, (b) IOP3, averaged between 18:30 UTC and 18:45 UTC on 25 September 1999 and (c) IOP8, averaged between 20 UTC and 20:15 UTC on 20 October 1999. RH is for hail (pink), RG for graupel (light blue), RS for snow/aggregates (black), RI for pristine ice (blue), RR for raindrops (green), and RC for cloud droplets (red).

3.2 Main microphysical processes involved in the different IOPs

IOP8 event

During the IOP8 stratiform case, and below the 0°C level, the main process leading to formation of rain is warm coalescence, with especially accretion of cloud droplets by raindrops (fig. 4c). As too much graupel and hail are produced by the model, they melt when falling through the melting layer, increasing the amount of precipitation. Above the 0°C level, the dominant microphysical process is vapor deposition onto ice particles. Even though the riming process remains weak, it allows the growth of aggregates by collection of cloud droplets above the condensation level. In the upper levels, autoconversion of pristine ice into snow is the process initiating aggregates. The snowflakes then grow by aggregation of pristine ice. A part of the snowflakes is converted into graupel by melting-conversion (it represents the mixture of melted water and solid ice dense enough to be categorized as graupel) and by collection phenomena (heavy riming or dry growth of the graupel) in the higher levels.

However the model seems to produce too much hail for this case when comparing to the S-POL polarimetric radar observations (Medina and Houze, 2003). An important fraction of the graupel is converted into hailstones which grow by wet growth, thus consuming graupel and aggregates.

IOP2a and IOP3 events

The typical processes linked to a stratiform case as listed above for IOP8 (warm coalescence below the 0°C level and vapor deposition on ice above) are still present in IOP2a and IOP3 (fig. 4a and 4b, respectively), but as the cloud systems are much deeper and the convection more active, the contribution of ice microphysics is more important. Riming is now the major process above the freezing level, but only IOP2a produces a thick layer of graupel and provides conditions for the generation of hail in a significant amount. This can be seen by the presence of heavy riming of the aggregates in the upper levels leading to the formation of graupel in a large amount. This heavy riming does not exist in IOP3. Only light riming occurs, leading to the growth of aggregates consuming cloud droplets.

Graupel and hailstones melt while falling through the melting layer and below, increasing substantially the amount of precipitation.

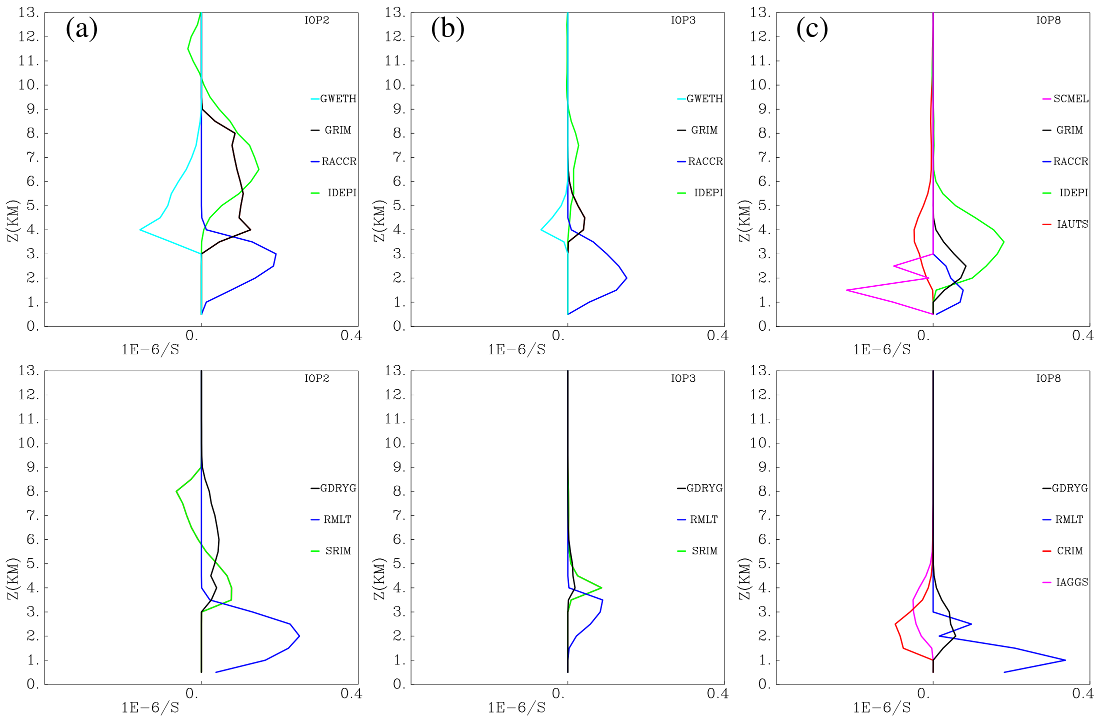

Figure 4: Main averaged microphysical processes involved in (a) IOP2a on the left, (b) IOP3 on the middle and (c) IOP8 on the right. The first letter of each process refers to the hydrometeor under consideration (R, Rain, I, Ice, S, Snow, G, Graupel) with DRYG: dry growth of the graupel; RIM: riming; DEPI: deposition (sublimation); MLT: graupel and hail melting; ACCR: accretion of cloud droplets by raindrops; WETH: wet growth of the hail; CMEL: melting-conversion of the snow; AGGS: aggregation of pristine ice; AUTS: autoconversion of pristine ice.

4. CONCLUSIONS

Three different MAP cases have been simulated with the MESO-NH model in order to investigate the role of different microphysical processes in the evolution of the mixing ratio of hydrometeors. The flow regime during IOP8 is a stable stratification with blocked flow, whereas unstable or potentially unstable conditions with flow over occur during IOP2a and IOP3.

The dominant microphysical processes during IOP8 are typical of a stratiform case, with coalescence under the freezing level and deposition onto ice above. However, MESO-NH seems to produce too much heavily rimed particles for this case and riming is too active in the model.

During IOP2a and IOP3, riming becomes the dominant process above the freezing level, but heavy riming occurs only in IOP2a leading to the production of a thick layer of graupel, and hail in a significant amount. For these two cases, numerical results are quite consistent with S-POL observations.

LITERATURE

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