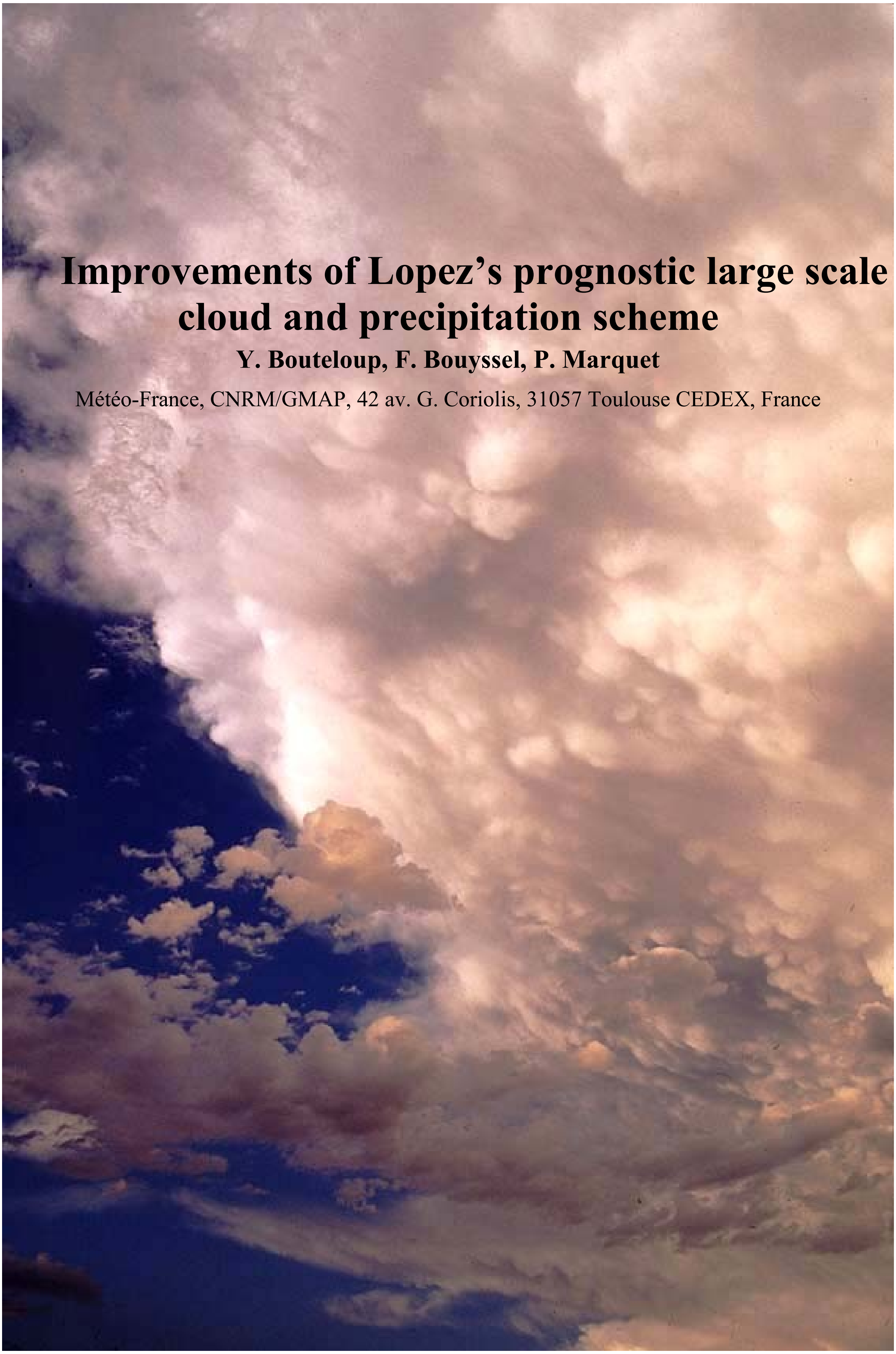

Improvements of Lopez's prognostic large scale cloud and precipitation scheme

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1. General description

In this article some modifications and tests made with an intermediate complexity microphysics scheme are described. This scheme has been developed by Philippe Lopez during its PhD in the context of data assimilation. For a general description of this scheme see Lopez (2002), and for a description of the first modifications made at Météo-France see Bouyssel et al (2005). An improved version of the original scheme has also been developed by Gerard (2005).

Since Bouyssel et al (2005) some tuning have been made in the description of the dependency of "critical relative humidity" with height and horizontal resolution (Fig. 1a). The partition of stratiform cloud condensate into cloud liquid water and cloud ice has been also tuned to allow the coexistence of liquid and ice water at temperatures between -25 °C and 0 °C (Fig. 1b).

The cloudiness reduction applied for thick vertical layers is suppressed to increase the consistency between the moist adjustment and the precipitation scheme. Consequently the threshold values for solid water specific humidity, from which start auto-conversion, have been strongly reduced (factor 10).

A schematic representation of the scheme as it is used in test at GMAP is shown on Figure 2.

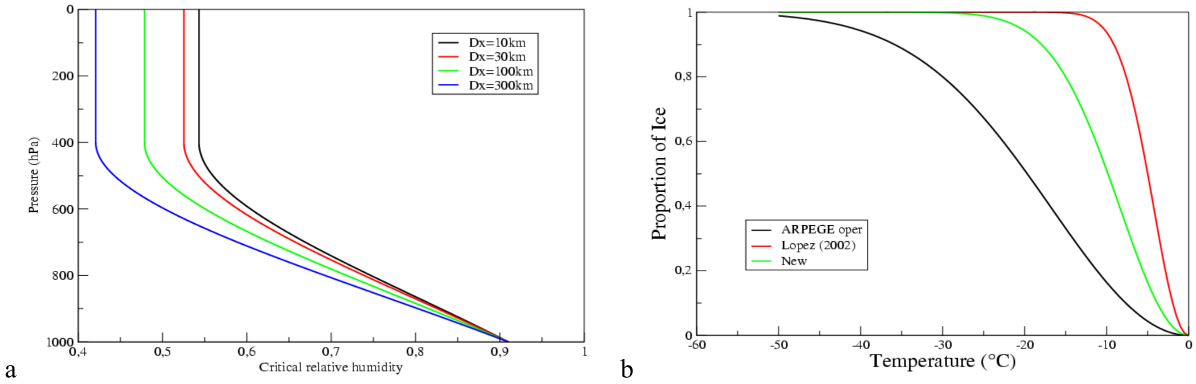


Figure 1a (left): “Critical relative humidity” as a function of pressure and horizontal resolution.
Figure 1b (right): Function of temperature which determines the fraction of ice for stratiform cloud condensate.

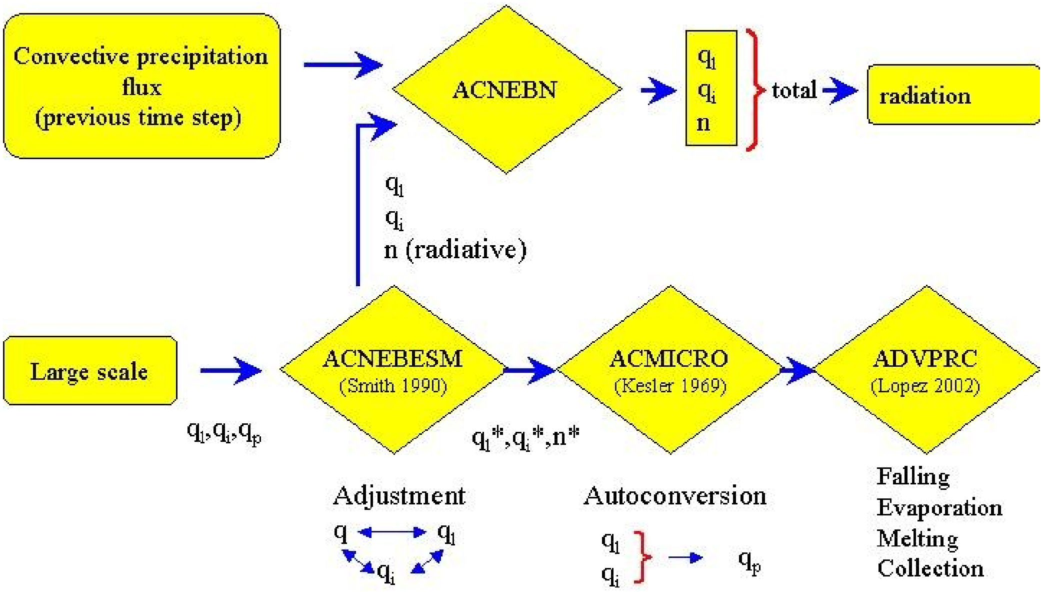


Figure 2: Schematic representation of the Lopez scheme as it is used in test at GMAP

2. Improvement of the falling process

The main weakness of the original scheme lies in the semi-Lagrangian handling of the falling of rain and snow. The treatment of evaporation and collection processes is not correct and the auto-conversion process is applied at the beginning of the time-step, which give an unrealistic 3D field of precipitating water.

A semi-Lagrangian algorithm for the falling of rain and snow may be regarded as a simulation of the evolution of the Probability Density Function (PDF) of the age of droplets. The meaning of "age of droplets" is "since how long does the droplet fall?". If the falling speed is known this is equivalent to "which level does it come from ?". Philippe Lopez tried to answer the second question without completely taking into account his significance. The main idea is to consider at each level a PDF of the age of the droplets. In this context the falling process is just a shift of the PDF along the time axis. Droplets which become older than the time-step stay at the current level. All the processes can be described in this framework. For auto-conversion, which is a continuous process during the time step, an equi-partition is applied. For collection and evaporation, a partition proportional to the initial precipitating water content is made. In the code, the PDF can be described by an array. Due to the variable thickness of the vertical levels this array should have a size larger than the number of vertical levels. It is necessary to move at least by one box in the array when the droplets fall from one level. It seems more interesting to use the vertical axis for temporal description. The link between both is the vertical falling speed. The variable thickness of the levels impose to compute the time equi-partition in term of level thickness.

Using the average constant bulk values for vertical speed, each model layer is advected backward in time from $t+\Delta t$ to time t, where Δt denotes the time step. The location of the layer at time t is fully determined by its top and bottom altitudes, Z_{top} and Z_{bot} respectively. Let us first number model layers starting from 1 at the top to N at the bottom, and let us denote Z_h the altitude of model half-levels (numbered from 0 at the top to N at the surface). These notations are illustrated by Figure 3.

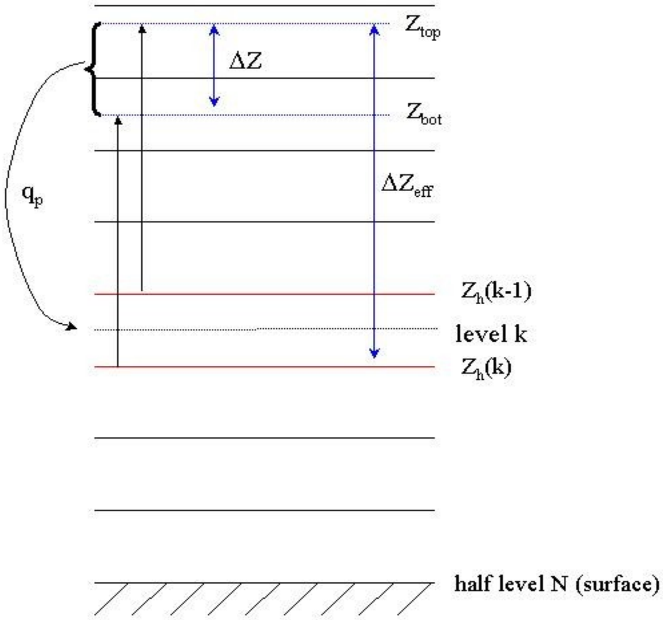


Figure 3: Visualisation of the notations used in the semi-Lagrangian calculus.
Except for level k only half-levels are shown

The vertical distance representing the place from which droplets are able to cross the current level k during the time-step is :

$$\Delta Z_{eff} = \sum_{j=1}^{k} \Delta Z_{eff}(j)$$

with :

$$\Delta Z_{eff}(j) = max\left[0,\ min\left(Z_{top}, Z_h(j-1)\right) - Z_h(j)\right]$$

If $w(j)$ is the falling speed of the precipitation at level j, the total time necessary to cover this distance is :

$$\tau = \sum_{j=1}^{k} \frac{\Delta Z_{eff}(j)}{w(j)}$$

This can be written :

$$\tau = \Delta t + \frac{\Delta Z_{eff}(k)}{w(k)}$$

The meaning is that τ is the sum of the time-step plus the time necessary to cross the current layer. A temporal equi-repartition of the content of precipitable water (liquid or solid) which comes from the auto-conversion process is needed (auto-conversion is continuous during the time step). The multiplication coefficient for the level j is the ratio of the time spent in level j by the total time τ :

$$\left(\frac{\Delta Z_{eff}(j)}{w(j)}\right) / \tau$$

At each level j between 1 and k the content of precipitable water is then modified using the following formula :

$$q_p(j,t) = q_p(j,t) + \left[q_{auto}(k)\,\rho(k)\,\Delta Z(k)\,\Delta t\right] \frac{\left(\frac{\Delta Z_{eff}(j)}{w(j)}\right)}{\tau} \frac{1}{\rho(j)\,\Delta Z_{eff}(j)}$$

where $q_{auto}(k)$ is the auto-conversion flux, coming from Kessler (1969) formulation.

Then, as in Lopez (2002) we compute the effective average precipitation content that crosses model layer k during one time-step :

$$q_p^{eff}(k) = \frac{1}{\rho(k)\,\Delta Z(k)} \sum_{j=1}^{k} \rho(j)\,\Delta Z_{eff}(j)\,q_p(j,t)$$

The effective precipitation content q_p^{eff} serves as an input to both the collection and the evaporation equations (6)-(9) of Lopez (2002). After computation of the precipitation, evaporation and collection rate ($q_{evap}(k)$ and $q_{coll}(k)$ respectively), at each level between 1 and k, the precipitating water content is again modified :

$$q_p(j,t) = q_p(j,t)\left[1 + \frac{q_{coll}(k) - q_{evap}(k)}{q_p^{eff}(k)}\right]$$

Finally the precipitating water content at level k at time $t + \Delta t$ is computed following Lopez (2002) :

$$q_p(k,t+\Delta t)=\frac{1}{\rho(k)\Delta Z(k)}\sum_{j=1}^{k}\rho(j)\Delta Z(j)q_p(j,t)$$

where

$$\Delta Z(j)=max\left[0\ ,\ min\left(Z_{top},Z_h(j-1)\right)-max\left(Z_{bot},Z_h(j)\right)\right]$$

For a better understanding $\Delta Z=\sum_{j=1}^{k}\Delta Z(j)$ is shown in Figure 3.

The effective precipitation content $q_p^{eff}(k)$ is also recomputed with the new values of $q_p(j,t)$ in order to determine the flux of precipitation $F_p(k)$ at the half-level k . The precipitation flux is the difference between the effective precipitation content and the precipitation content which stay at level k :

$$F_p(k)=\frac{\rho(k)\Delta Z(k)}{\Delta t}\left(q_p^{eff}(k)-q_p(k,t+\Delta t)\right)$$

3. Results

3.1 Results with the Single Column Model (SCM)

Some tests have been done in the SCM, in particular with the EUROpean Cloud Systems (EUROCS) stratocumulus case. The EUROCS project used observations of stratocumulus off the coast of California during FIRE I (Hignett 1991 ; Duynkerke and Hignett 1993). For more information about EUROCS stratocumulus case see Duynkerke et al (2004). The forcing required to simulate the case has been coded in the SCM by Blazenka Vukelic and Jean-Marcel Piriou. These experiments were made more for technical tests than in a scientific goal. All the same the results are interesting.

The results are shown on Figure 4. The result for the operational scheme is very close to that shown in Duynkerke et al (2004). The main evolution in the operational model since the experiment made for this article is the use of a new cloudiness scheme from Xu and Randall and the use of the old version of the radiation code of the ECMWF (instead of ACRANEB). One can notice that there is a large impact of a change of the time-step with the operational scheme. The simulations with Lopez are better, but not perfect. Amongst other things there is a too small diurnal cycle, but the impact of a change of the time-step is very small. The Lopez microphysics scheme is prognostic, if there is no cloud condensate in the initial file the cloudiness is equal to zero during the first time-step. With a complex radiation scheme called with a frequency of one hour, the cloudiness seen by the model is equal to zero during the first hour of the simulation. This is shown on Figure 4, the liquid water path decreases during the first hour of the simulation and grows, as it is necessary, afterwards.

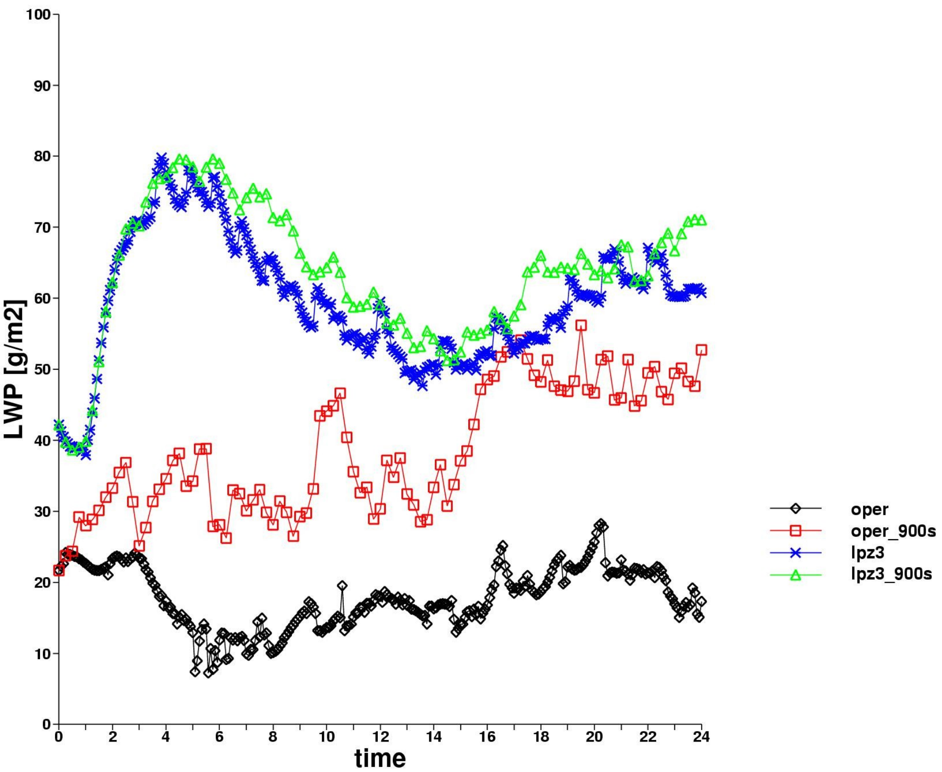


Figure 4: Liquid Water Path (LWP) during a 24 hour simulation of EUROCS stratocumulus.
In black operational scheme with a time-step of 300s, in red operational with a time-step of 900s,
in blue Lopez scheme with 300s andin green Lopez scheme with 900s.

During our first tests with the Lopez scheme in the SCM, we observed an instability, an oscillation from one time-step to the other one (not shown). We found that this instability can be corrected by the use of the diffusion of conservative variables. The modifications of ACDIFUS needed to compute diffusion of conservative variables has been coded in the SCM by Pascal Marquet from the GCM team.

However, with the last version (CY29T2) of the scheme this behaviour disappeared, and we did not succeed in reproducing it. We thus do not know which is its origin. Anyway, the use of the diffusion of conservative variables seems to be more coherent insofar as liquid and ice cloud water are used as prognostic variables.

3.2 Tests in 3D with ALADIN

A 3D simulation of a case of strong precipitations over Corsica has been presented in Bouyssel et al. (2005). One of the known weaknesses of ALADIN is to simulate too strong orographic precipitations in some situations. It seems that with the new scheme the results are better, with less precipitation windward and more precipitations on the sea leeward Corsica. With another situation, over Austria, this aspect can be shown more precisely.

This situation occurred in November 2000 over Austria. Many thanks to Thomas Haiden and Christoph Wittmann (ZAMG) who proposed to simulate this case and provided a reference map, from rain gauge observations (Figure 5). In fig. 6a, the result of a simulation with the present operational physics is shown. One can see that the precipitations are overestimated windward mountains and underestimated (close to 0 m) leeward. On the simulation with the new scheme it is clearly shown that the precipitations are reduced over the highest tops. On a zoom (Figs. 7A-b), one can see that, linked to the reduction of precipitations over the mountains, some precipitations occur in the valley, which gives an overall more realistic field.

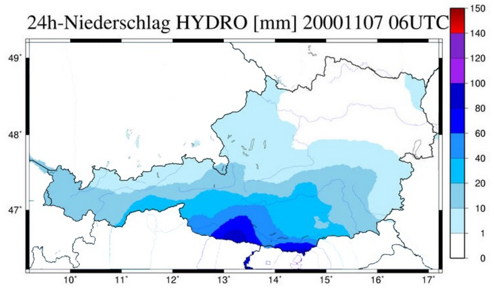
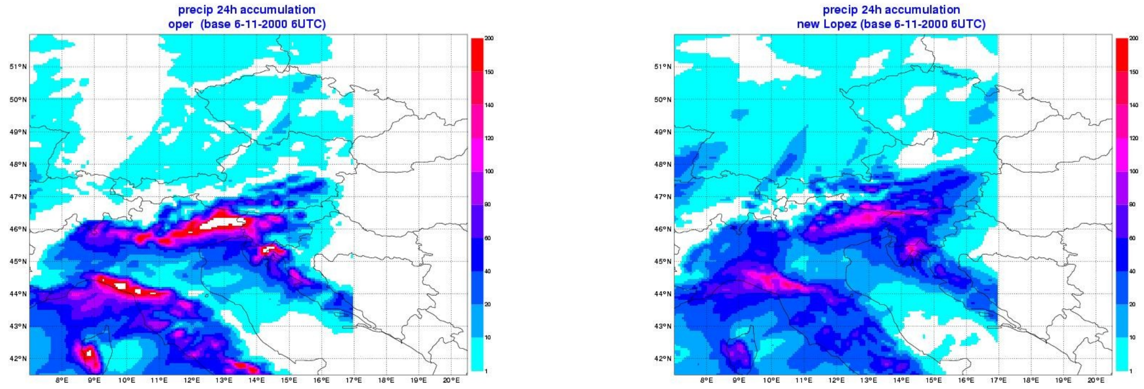


Figure 5 : 24 hours accumulation of observed precipitations over Austria
for the 7 November 2000 case (From ZAMG)



a b

Figure 6 : 24 hours accumulation of precipitations over Austria . a : present operational scheme b : Lopez scheme
Accumulations larger than 200mm are not shown

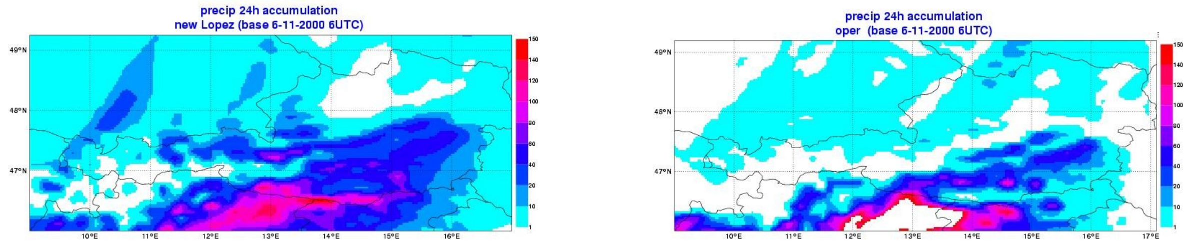


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Figure 7 : Same as Figure 6 but zoom over Austria. a : present operational scheme b : Lopez scheme

An important question is : What is the mechanism which gives this behaviour to the new scheme ? Two experiments were made to try to answer the question. In the first one advection of the new prognostic variables was not performed, in the second one advection was performed on cloud variables but not on rain and snow. On Fig. 8a the cumulative precipitations field of the first experiment is shown. It is very closed to the operational result. The main mechanism to explain the behaviour of the new scheme seems to be the advection, it transports cloud water content and precipitations behind the mountains. On Fig. 8b the result from the second experiment is shown. The impact of the advection of precipitations is clearly highlighted. Contrary to certain generally accepted ideas, the advection of precipitations seems to be necessary to have a realistic forecast. Of course, many other experiments will have to be carried out to check these results.

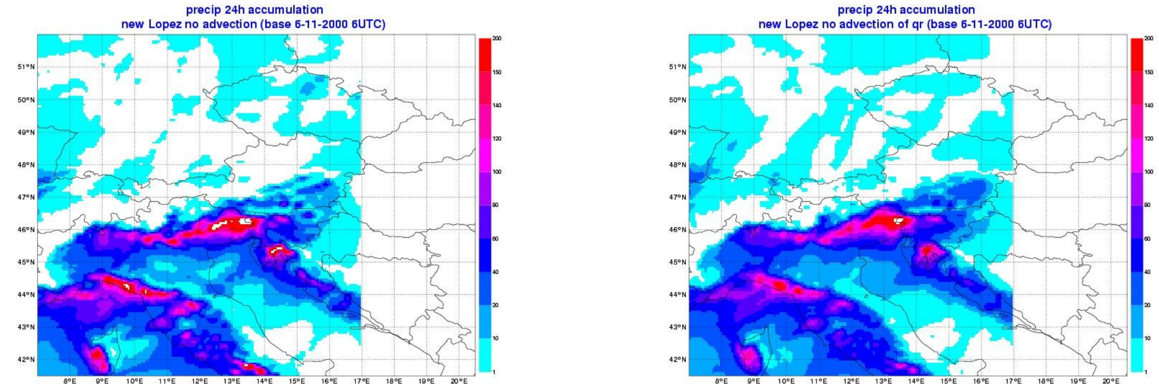

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Figure 8 : Impact of advection. a : No advection (neither of cloud variables nor of precipitations) . b : Advection of cloud water (and ice) but no advection of rain and snow

3.3 Tests with ARPEGE

Validation forecasts have been performed with the modified Lopez scheme and the diffusion of conservative variables, all the other parameterizations (deep and shallow convection, radiation, subgrid scale orography, surface) being unchanged. All these results are described in Bouyssel et al. (2005).

4. Conclusion

This article describe the last improvments made on the Lopez's prognostic large scale cloud and precipitation scheme. The main part is a rewriting of the lagrangian falling process. With the new algorithm the treatment of evaporation and collection processes is correct and the autoconversion process is now continuous during the time step. With these modifications the parametrisation seems to be more stable. Another interesting result is the impact of advection on strong orographic precipitation. The behaviour of the Lopez scheme is better than the operational one and it seems that this behaviour is a consequence of the advection of cloud condensate (liquid and ice) and precipitation (rain and snow). The validation will continue and focus on 4D-Var assimilation experiments. Some sophistications would be interesting, such as a better treatment of the precipitation melting and a separation of precipitating water in rain and snow, but the priority is more likely the implementation of a moist turbulence scheme taking into account the prognostic liquid and ice water contents, a work made jointly with the ARPEGE GCM team.

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