Clouds in AROME forecast project

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ABSTRACT

AROME is the future weather forecast mesoscale model of Meteo-France, with a non hydrostatic dynamics, 2.5 km horizontal resolution and a sophisticated physical package with an explicit microphysical scheme. This single moment microphysical scheme including five water species (liquid cloud, ice crystals, rain, snow and graupel) was originally developed in MESO-NH (Pinty and Jabouille, 1998). With this scheme, MESO-NH has shown in numerous studies a good ability to reproduce deep convective events at meso-scale (for instance Ducrocq et al., 2002). Interfacing this with the semi-implicit semi-lagrangian dynamics of ALADIN-NH in AROME also gives realistic simulations of deep convective organizations. The introduction of the droplet sedimentation process in microphysics has improved the representation of fog and its life cycle. Nevertheless, the horizontal and vertical resolutions of AROME are not sufficient to explicitly resolve all types of clouds. In particular, the daily runs of AROME prototype showed that a subgrid representation of cumulus cloud was needed. The development of a new effective shallow convection scheme for dry and cloudy thermics and the corresponding subgrid cloud scheme show promising results.

1 Introduction

A strong tendency in NWP is to develop new operational forecast systems with horizontal grid sizes less than 10 km in order to get a better resolution of mesoscale flows. Some projects like the Unified Model (UK Met Office), the LMK (COSMO group, leadership DWD, Germany), WRF (NCAR-NOAA, USA), GEM (Environment Canada), MRI-LNH (Japan Meteorological Agency), ALARO (ALADIN community) and AROME (Meteo-France) illustrate this. At high resolution, the representation of clouds is then becoming a big issue for the simulation of mesoscale weather systems, because clouds are at the origin of many interactions with the dynamics, the radiation, the surface energy budgets, the aerosols and the chemistry. There are many cloud types to simulate: the fogs, the extended warm cloud sheets, the cirrus, the cumulus and stratocumulus, and the heavily precipitating clouds.

Despite the fact that less sub-grid scale parameterization of cloud effect may be necessary as horizontal and vertical resolution increase, allowing deep convection to be resolved, consideration of subgrid cloud variability remains important at meso-scale especially for high non linear processes like precipitation. In this matter, Weisman et al. (1997) showed that a scale resolution of 4 km is sufficient to reproduce much of the mesoscale structure and evolution of the squall line type convective systems produced by 1 km simulations. However it is not certain that this applies to boundary layer clouds or thin clouds like cirrus, for which horizontal or vertical extension are most of the time subgrid.

AROME is the future weather forecast mesoscale model of Meteo-France (Bouttier et al., 2006), with an horizontal resolution of 2.5 km. It is planned to become operational at the end of 2008. The current prototype of AROME leads to a preliminary estimation of the capability of the model to represent different types of clouds.

The paper is organized as follows. Section 2 provides a description of AROME and of MESO-NH. Section 3 details the treatment of the water cycle in AROME. Section 4 focuses on the representation of subgrid clouds in AROME, whereas section 5 is devoted to microphysics and its behaviour for real flow studies. Section 6 treats the interaction of the clouds with the ECMWF radiative scheme with a proposed improvement in the case of a refined vertical resolution. A short conclusion is given in the final section.

2 Presentation of AROME and MESO-NH

AROME (Applications of Research to Operations at MesoscalE) is a numerical weather forecast system, which comprises a data assimilation tool associated to a non hydrostatic numerical model. The model is built upon the ALADIN-NH dynamical core (bi-Fourier spectral limited-aera model with a semi-implicit, semi-lagrangian timestep solver, and Laprise-type compressible dynamical equation in terrain-following hybrid mass coordinates). The physical package is exported from the research model MESO-NH (Lafore et al., 1998).

MESO-NH is a multi-purpose non-hydrostatic anelastic model, that has been jointly developed by Météo-France and Laboratoire d'Aérologie. It contains multiscale physical parametrizations to simulate idealized and real flows with the grid-nesting technique. The physical package incorporated in AROME from MESO-NH includes an eddy-diffusivity turbulent scheme with a 1.5 order closure for pronostic TKE (Cuxart et al.(2000)), a microphysical package (Pinty and Jabouille, 1998), a shallow convection scheme (Bechtold et al.(2000), hereafter KFB), subgrid condensation (Bougeault, 1982). Both models make use of the ECMWF radiative scheme. MESO-NH remains an useful tool to develop or to improve parametrizations for AROME, because they can be compared to more sophisticated schemes existing in MESO-NH (2-moment microphysical schemes for example). MESO-NH also includes many diagnostics and budgets terms which are of a valuable help for process understanding and validation. The drawback is that MESO-NH is computationally very expensive because its dynamics is based on low order eulerian advection schemes and an explicit temporal scheme integration. It is therefore difficult to validate MESO-NH statistically on a long period. An AROME prototype, limited to a small domain of $600 * 600 km^2$ and without data assimilation, is running experimentally since 2005, for technical demonstration purposes. Initial and boundary conditions are provided by ALADIN, the current meso-scale forecast model of Météo-France, running at 10 km resolution with data assimilation. The AROME prototype also gives an insight of the capability of the model to reproduce the broad range of meteorological situations.

3 The water representation in Arome

In AROME, five pronostic variables are devoted to describe the water condensates : mean mixing ratio of cloud droplets $\overline{q}_c$, cloud ice crystals $\overline{q}_i$, rain drops $\overline{q}_r$, snow flakes $\overline{q}_s$ and graupel particles $\overline{q}_g$. The water vapor and the five water condensates are grid point variables. Each of these pronostic contents describes both the reservoirs of " resolved " and " subgrid " condensates (if subgrid sources/sinks exist). They are advected by the semi-Lagrangian scheme but they also react with the " dynamics " through inertia and gravity terms in the momentum equation and their thermal inertia in the thermodynamic equation.

Looking to the physics of the water substance, the cloud evaporation/condensation is represented by a diagnostic adjustment (Bougeault (1982), Bechtold et al.(1995)). The parametrization describing the phase equilibrium in a grid box of AROME is a current subject to improve the representation of cumulus clouds which are not resolved with a grid of 2.5 km (see section 4).

The subgrid vertical mixing which may be at the origin of subgrid clouds is based, in MESO-NH and AROME, on the mixing of conservative variables (conservative in the sense of Lagrangian conservation even if water

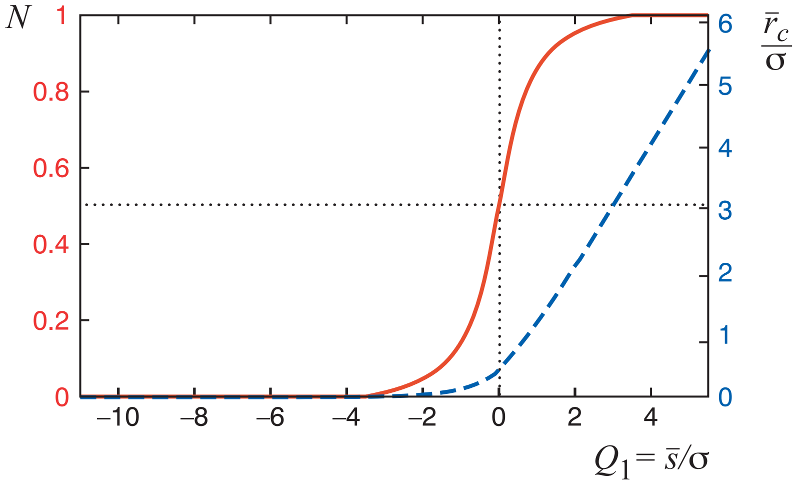

Figure 1: Cloud fraction (solid line) and normalised cloud mixing ratio (dashed line) as a function of the normalised mean departure to saturation $\overline{s} = \overline{r}_{np} - r_{sat}$ for the statistical cloud scheme of MESO-NH. σ^2 is the variance of the departure to saturation which is estimated in the subgrid mixing parametrization (turbulence and possibly shallow convection).

phase changes occur). Tendencies are then naturally obtained for these conservative variables (liquid potential temperature and total non precipitating water), the final separation between vapor and liquid and ice cloud reservoirs being done only by the adjustment.

In AROME the adjustment to saturation is the first step of the physical package. The adjusted variables are then used in the rest of the physics. For the time being, the guess of the atmospheric state for the next time step at the end of the physics is not adjusted (it will be adjusted only at the begining of the next time step when entering the physics).

The microphysics described in section 5 corresponds to the microphysics of precipitation. These pronostic processes are supposed to be significantly slower than the process of adjustment to the water phase equilibrium.

4 The subgrid cloud processes in Arome

4.1 Clouds in the daily prototype

In the first version of the AROME prototype, the subgrid cloud scheme is the statistical cloud scheme which is available in MESO-NH (Bougeault (1982), Bechtold et al.(1995)). The scheme is based on the computation of the variance of the departure to a local saturation inside the grid box. If the grid box is saturated with respect to the mean variables ($\overline{q}_{np} > q_{sat}(\overline{T})$) and if the variance is small, the cloud parameters (cloud contents and cloud fraction) are close to the ones obtained with an all or nothing adjustment. If the mean variables are saturated but the variance is high, the cloud parameters are given by a gaussian PDF (the cloud fraction is larger than 0.5 but smaller than one). If the mean variables do not reach saturation, but the variance is relatively high, the cloud fraction (smaller than 0.5) and the cloud condensate content are given by a combination between a gaussian and a skewed exponential PDF (Figure 1).

In MESO-NH, the subgrid cloud scheme was originally developed in the context of a classical ” eddy diffusivity turbulent " scheme. Then, even if a shallow convection scheme is activated, the cloud scheme may not produce any cloud in the convective updrafts. A simple formulation of a cloud variance linked with the mass flux of the convection scheme was later developed by Chaboureau and Bechtold (2002). But the 1D validation of this formulation showed that it was not adapted for shallow clouds. It was then decided not to switch it in AROME, but rather to take the responsability of an underestimation of the cumulus cloud cover in the preliminary daily runs of AROME.

4.2 Towards a better representation of cumulus clouds in AROME

Subgrid vertical mixing parametrized by the eddy turbulent fluxes may produce clouds depending on the departure to saturation σ_{turb} which is computed from the variances of the liquid potential temperature $\overline{\theta_l'^2}$ and of the total non precipitationg water $\overline{r_{np}'^2}$ derived from the eddy diffusivity turbulent scheme (Cuxart et al., 2000). A similar approach is possible for shallow quasi-non precipitating clouds if the variances of θ_l and r_{np} are computed from the shallow convection parametrization.

A formulation for the computation of these variances from the convective mass flux is proposed by Lenderink and Siebesma (2000) and Soares et al. (2004) and it was implemented in the different version of EDMF (Eddy-Diffusivity-Mass-Flux) schemes plugged for test in AROME (see below). A series of 1D tests showed that the structure of the cloud deduced with the resulting cloud scheme is not always in agreement with the LES mean profiles. In fact, they are even not always coherent with the cloudy updraft of the convection scheme (clouds are often shallower, with cloud water profiles showing sometimes incoherent and instable shapes).

As the vertical profiles of the cloudy updraft computed by the KFB scheme or the different versions of EDMF seemed in better agreement with cloudy profiles deduced from LES simulations, it was tempter to use more directly the cloud profile of the shallow updrafts to deduce the convective contribution of the mean cloud parameters, instead of the variance of the convective part. This is actually easy with the modified version of EDMF (Soares et al., 2004) developed for MESO-NH and AROME (EDKF by Pergaud et al.(2007)). Actually, in EDKF, the updraft is described by the mass flux M computed level by level from the ground by :

$$M^{k+1} - M^k = \varepsilon^k - \delta^k$$

where ε and δ are the entrainment and detrainment rates.

Then, the mass flux formulation does not use directly an equation for the updraft vertical velocity as the one proposed by Simpson and Wiggert (1969) for example. Instead such an equation is used for an independent computation of the updraft vertical velocity w_u which is used to diagnose the updraft fraction as :

$$\alpha_u = M_u/(\rho w_u)$$

The updraft fraction α_u is therefore predicted from the shallow convection scheme (and is not an input as it is the case in most of the convection schemes). The convective cloud fraction is deduced from α_u by $N_{conv} = k_1\alpha_u$, and the convective cloud contents are estimated by $\overline{q}_{cconv} = k_2\alpha_u q_{cu}$ and $\overline{q}_{iconv} = k_2\alpha_u q_{iu}$ (where the updraft cloud contents q_{cu} and q_{iu} are computed by a classical all or nothing adjustment in the saturated part of the updraft). The convective cloud parameters are then combined with the cloud parameters resulting from the statistical adjustment which uses only the eddy turbulent variance σ_{turb} (σ_{turb} represents either the resolved clouds when the statistical cloud scheme degenerates into an all or nothing expression or the subgrid clouds limited to the boundary layer under inversion).

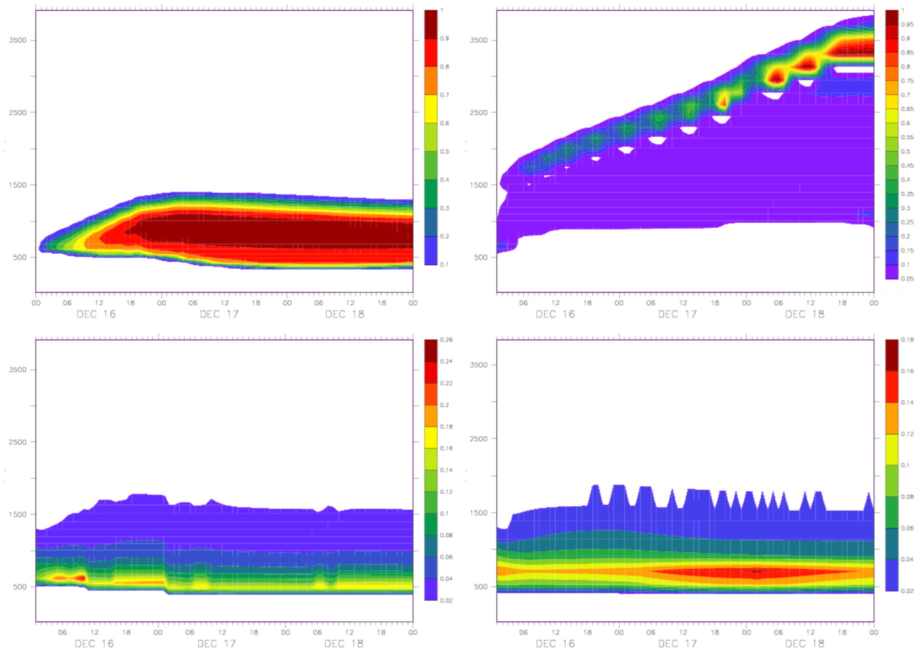

Figure 2: Evolution of the cloud fraction profile along the 72 hours of the short range composite Rico case (`http://www.knmi.nl/samenw/rico/background1d.html`) simulated with MUSC (1D version of AROME): 80 vertical levels whithout shallow convection scheme but with the statistical cloud scheme (upper left), 80 vertical levels with KFB and with the statistical (turbulent+ convective cloud variance) cloud scheme proposed by Chaboureau and Bechtold (2002) (upper right), 80 vertical levels with EDKF and the associated cloud scheme for convection (lower left), 41 vertical levels with EDKF and the associated cloud scheme for convection (lower right)

4.3 Cloud parametrization validations

The variant shallow convective mixing formulations and the different versions of the associated cloud schemes were first validated with the single column version of AROME (integrated 1D version : MUSC) on classical 1D cases especially designed for shallow cumulus studies (Bomex, Eurocs/ARM/Cumulus, Rico) or dry thermics representation (Ayotte, Wangara) (Fig.2 for the RICO case).

3D case studies show a positive impact of EDKF and the associated convective cloud scheme (Fig. 3) but more general validation are needed now.

A more systematic cloud validation should start at the beginning of 2007 using CloudNet observations of the Cabauw site and the different 3D derived products which are available (`http://www.cloud-net.org/`).

5 Microphysics

5.1 Generalities

A key question in explicit cloud modelling turns around the optimal number of different ice species to carry out, and the prognostic fields used to describe them.

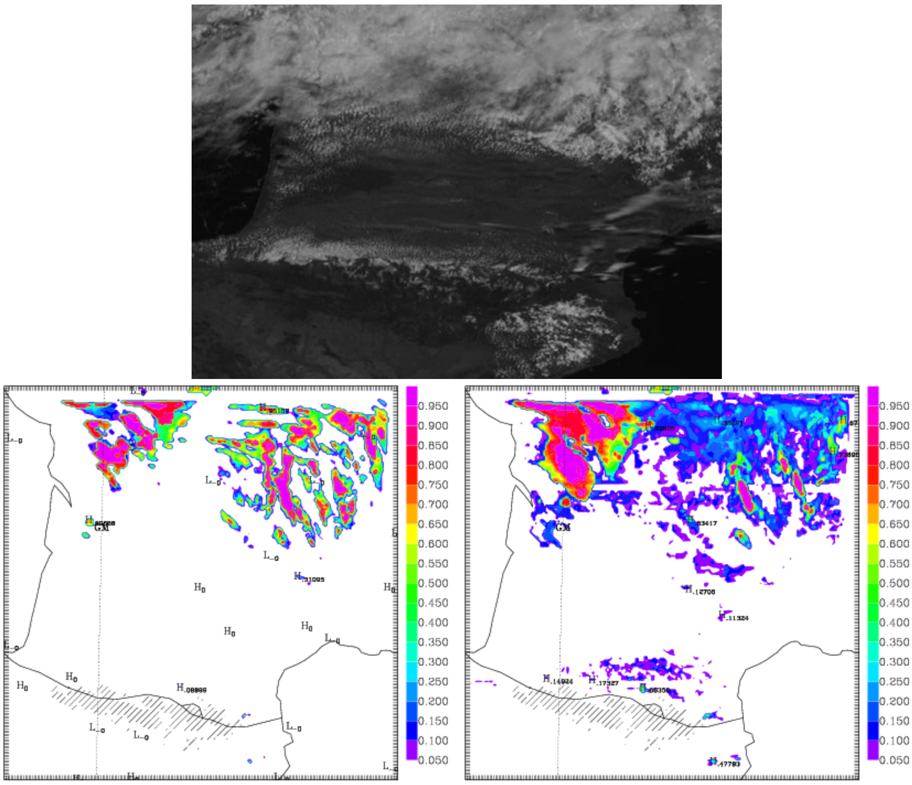

Figure 3: Cloud cover at 1500 m during an IOP of the CARBO-EUROP experiment the 06/06/2005 at 11 UTC. High resolution visible image at 11 UTC (top). Cloud fraction obtained with the AROME prototype (KFB and statistical cloud scheme with a cloud variance computed by the turbulence only) (left). Cloud fraction obtained with EDKF and the associated cloud scheme for shallow convection (right).

Most of mixed-phase microphysical schemes consider 2 variables for the liquid water (cloud droplets and rain drops) and 3 variables for the ice phase (small ice crystals, low rimed or aggregated large crystals and graupels). The graupels, presenting an increasing degree of riming compared to snow, are abundant in convective cores. A matter of discussion can be found regarding the last category of ice particles as a physical discrimination exists in the growth mode of low density rimed particles (assumed to be dry for the graupels) from that of high density hailstones which grow in the wet mode. Both graupel and hail particles can be considered as the most elaborated species adapted to the convective scale.

Concerning the prognostic fields, as the prediction of number concentrations critically depends on yet poorly known aerosol properties (activation and nucleation), this issue seems out of reach in current NWP models.

The microphysical scheme of AROME/MESO-NH has been developed by J.-P.Pinty on the basis of Caniaux et al.(1994), following the approach of Lin et al.(1983), that is a three-class ice parameterization coupled to a Kessler's scheme for the warm processes. Hail is also implemented (Lascaux et al., 2006) but is not activated in the current version of AROME.

This microphysical scheme does not currently handle the effects of partial coverage in a grid box, except a simple modification for the autoconversion process (see 5.2.2) which just allows the initiation of subgrid-scale precipitation. But otherwise, we don't use neither the vertical distribution of partial cloudiness nor environmental and cloud-scale values for the thermodynamic variables instead of their grid-mean values. A consequence is that there could be a limit of validity of the microphysical scheme at large scale ($> 10km$ resolution), when the subgrid variability is not negligible any more.

The concentration of the precipitating particles is parameterized with a total number $N_j = C_j \lambda_j^x$, where λ is the slope parameter of the size distribution, C and x are empirical adjustments drawn from radar observations. Each category of particle is supposed to be distributed according to a Gamma law :

$$n(D)dD = Ng(D)dD = N\frac{\alpha}{\gamma(\nu)}\lambda^{\alpha\nu}D^{\alpha\nu-1}exp(-(\lambda D)^{\alpha})dD \tag{1}$$

where $g(D)$ is the normalized distribution while ν and α are ajustable parameters. A Marshall-Palmer distribution law is chosen for precipitating species ($\alpha = \nu = 1$) (rain, snow, graupel and hail) and a modal distribution for cloud and ice. Power law relationships are used to relate the mass to the diameter ($m(D) = aD^b$) and the terminal speed velocity to the diameter ($v(D) = cD^d$).

The moments of the Gamma law are expressed according to the classical formulation :

$$\mathrm{M(p)} \quad = \quad \frac{\int_0^\infty D^p n(d)\, dD}{N_i} = \frac{\Gamma(\nu_i + \frac{p}{\alpha_i})}{\lambda_i^p \Gamma(\nu_i)} \tag{2}$$

where $M(p)$ is the p^{th} moment of $g(D)$. The mixing ratio is expressed as $\rho r_j = aNM_j(b)$ where ρ is the air density. Values of α, ν, a, b, c, d, C and x are given for each hydrometeor from observations.

5.2 Microphysical processes

5.2.1 Generalities

The microphysical scheme is sketched in Fig. 4. The detailed documentation of the scheme can be obtained at (`http://mesonh.aero.obs-mip.fr/mesonh/`) and in Lascaux et al.(2006). Pristine ice is initiated by homogeneous nucleation (HON) when $T < -35°C$ or more frequently by heterogeneous nucleation (HEN). These crystals grow by water vapor deposition (DEP) and by the Bergeron-Findeisen effect (BER). The snow

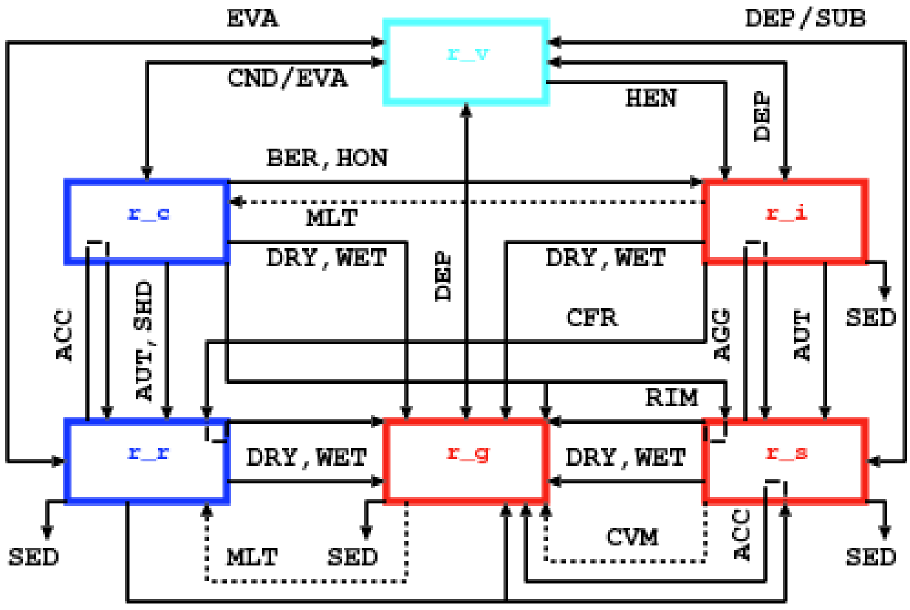

Figure 4: Microphysical processes in the mixed-phase scheme

phase is initiated by autoconversion (AUT) of the primary ice crystals. Snow grows by deposition (DEP) of water vapor, by aggregation (AGG) through small crystal collection and by light riming after impaction of cloud droplets (RIM) and of raindrops (ACC). The graupels are produced by the heavy riming of snow (RIM and ACC) or by rain freezing (CFR) when supercooled raindrops come in contact with pristine ice crystals. According to the efficiency of their collecting capacity on one hand and to a heat balance on the other, graupels can grow either in a DRY mode or in a WET mode respectively. When temperature is positive, the pristine crystals immediatly melt into cloud droplets (MLT) while the melting snowflakes are converted (CVM) into graupels. Graupel particles progressively melt (MLT) into raindrops as they fall. The other (warm) processes are described by the Kessler scheme: autonversion of cloud droplets (AUT), accretion (ACC) and rain evaporation (EVA). Each condensed water specie has a substantial fall speed, except cloud droplets in a first step, thus leading to an integrated sedimentation rate (SED).

For the temporal integration, processes are treated explicitely (in terms of tendencies) and independently, but the sequence of the processes give the availability of the species, as the occurrence of the process is limited by the current state of the guess of the depleted prognostic variable before integration. Some specy may be available or not for the next process depending on the chosen order in the sequence of integration : there is therefore an indirect influence of the order of the processes during the integration.

In the next section, we focus on a few processes, that need a special attention.

5.2.2 Autoconversion

Autoconversion is classically parametrised according to Kessler (1969), with a threshold on the cloud water content or ice water content:

$$[\frac{\partial(q_{r/s})}{\partial t}]_{AUTO} = -[\frac{\partial(q_{c/i})}{\partial t}]_{AUTO} = KMax(q_{c/i} - LWC/IWC_{crit}, 0) \quad (3)$$

where K is the time scale and LWC/IWC_{crit} are the thresholds of liquid/ice water contents.

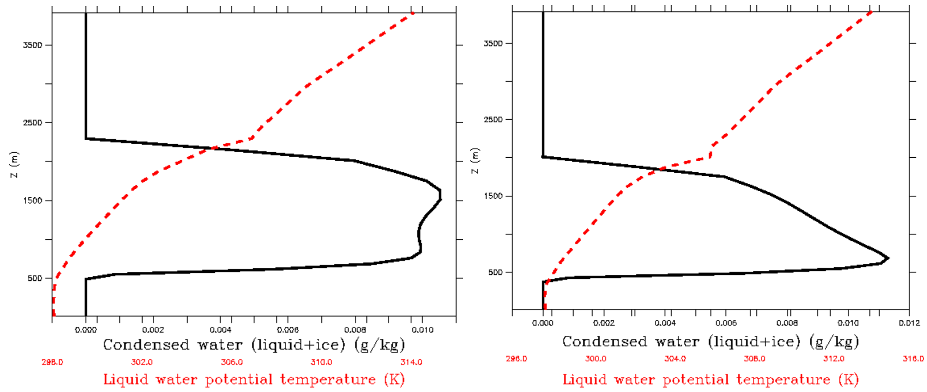

Figure 5: Vertical profiles of cloud water content (black solid line) and liquid water potential temperature (red dashed line) after 36 hours of simulation without (on the left) and with subgrid autoconversion (on the right)

The effects of partial cloudiness on the precipitation rates have been introduced for AROME by using the cloud-scale water content $\frac{q_c}{N}$ with the partial cloudiness N obtained from the partial cloudiness scheme (Part.4) instead of the corresponding grid-scale value q_c. This modification has been preliminary tested and seems to generate significative subgrid-scale precipitation and to improve precipitation rates for weakly precipitating shallow clouds. In the RICO case (Fig.5), it allows to produce weak rain on the ground comparable with LES. It also influences the vertical structure of the cloud with a shallower cloud and a maximum of cloud water shifted downward. This modification needs to be broadly evaluated on 3D cases. The preliminary introduction of partial cloudiness in autoconversion process could be extended in the future to other processes including vertical distribution of partial cloudiness, according to Bechtold et al.(1993).

5.2.3 Collection

When cloud or primary ice species are involved, the collection rates with other precipitating categories are computed analytically using the geometric sweep-out concept of the collection kernels defined for the large collecting particles (raindrops, snow or graupel). When both interacting particles are precipitating, an analytical integration over the spectra is no longer possible and look-up tables are prepared. For all the ice-ice interactions, a major point of concern is the tuning of the sticking coefficients, that are poorly known. In most of the case, sticking coefficients are taken from Ferrier et al. (1995).

5.2.4 Sedimentation

For all the species, the sedimentation term is computed for stability reasons with a time splitting technique applied to a 2nd order upstream differencing scheme. However the scheme is very diffusive and also computationally expensive for AROME. A way of improvement could be to implement a new algorithm developed by Bouteloup et al. in a modified version of "Lopez" microphysical scheme of ARPEGE/ALADIN, based on a local approach of sedimentation instead of the semi-lagrangian algorithm of Lopez (2002). But the adaptation to AROME is not straightforward as hydrometeor fall speeds strongly depend on the spectrum distribution of each specie. A careful evaluation of this implementation will be evaluated in the next few months.

5.3 Examples with AROME/MESO-NH

5.3.1 The Gard flash flood experiment

The Gard flash food event that occurred in South-East of France on Sept.8TH2002 was very devastating. A cumulated precipitation peak higher than 300*mm* of accumulated precipitation was recorded by the Nîmes radar between 12-22 UTC (see Fig.6a). These precipitating events usually result from a southerly flow lifting by the Cevennes ridge in the south edge of Massif Central (a Cevenol event). A previous study leaded with MESO-NH (Ducrocq et al., 2002) has shown that the best simulations are obtained using ARPEGE analyses and additional mesoscale surface observations, radar reflectivities and IR Meteosat data. For comparison purpose, AROME and MESO-NH are initialized in the same way and run at 2.5 km resolution, with a time step of 60s for the AROME prototype and 4s for MESO-NH (Fig.6). Both simulations compare reasonnably well with observations, with a slightly better estimation of the peak precipitation value for AROME but with a less accurate orientation of the rainy area pattern. This test shows that the original microphysical scheme of MESO-NH can be integrated with larger time steps as the one used in AROME. More generally, daily runs of AROME prototype on strong convective case events leads to a similar conclusion of Weisman et al.(1997) that a 2.5 km horizontal resolution is sufficient to reproduce much of the mesoscale structure of a Mesoscale Convective System (MCS).

An example of powerful diagnostics available in MESO-NH is given in Ducrocq et al. (2006), on the same case ”Gard 02”. They examined the physical mechanisms leading to the stationarity of this heavy precipitating system, which occured exceptionally over the Southern region, well upstream of the first Massif Central foothills, just over the central plains of Gard. They showed that this particular Gard case, compared to other Cevenol cases, is well characterized by a low level cold pool, forming just under the simulated MCS resulting from the diabatic cooling associated with the melting of falling cold hydrometeors (Fig.7a). When the evaporative cooling of liquid water is removed (’NOC’ experiment on Fig.7b compared to the reference ’CTRL’ run, including all the terms of the budget), they found that the system looses its stationarity over the plain of Gard, and the resulting precipitating pattern is significantly shifted northwestward over the Massif Central foothills. This illustrates the importance of cloud processes in precipitating clouds, and the impact they induce on the dynamics of a system.

5.4 A 1D Fog case

The AROME prototype is able to catch fog events, but cloud water contents as well as the vertical extension of the cloud layer seem to be overestimated. Cloud droplets sedimentation, not negligible in fogs, have been introduced in the microphysical scheme of MESO-NH / AROME. Including this process allows to reduce the cloud and rain water contents, decreasing consequently the radiative heating (Fig.8a and b.). Droplet sedimentation modifies significantly the fog life cycle, mainly the vertical extension and the dissipation. On the other hand, the onset of fog formation is strongly sensitive to the vertical resolution of the model in the lowest levels, and is delayed when the resolution is coarser (Fig.8c). These improvements will be tested extensively in AROME in January 2007, and the validation will be based on the current campaign PARIS-FOG on the site of SIRTA.

6 Modification of the radiative transfer scheme for fine vertical resolution

Both AROME and MESO-NH use the ECMWF radiative scheme. Thouron et al.(2007) studied the impact of the vertical resolution to the computation of radiative fluxes. They found a strong impact of the vertical

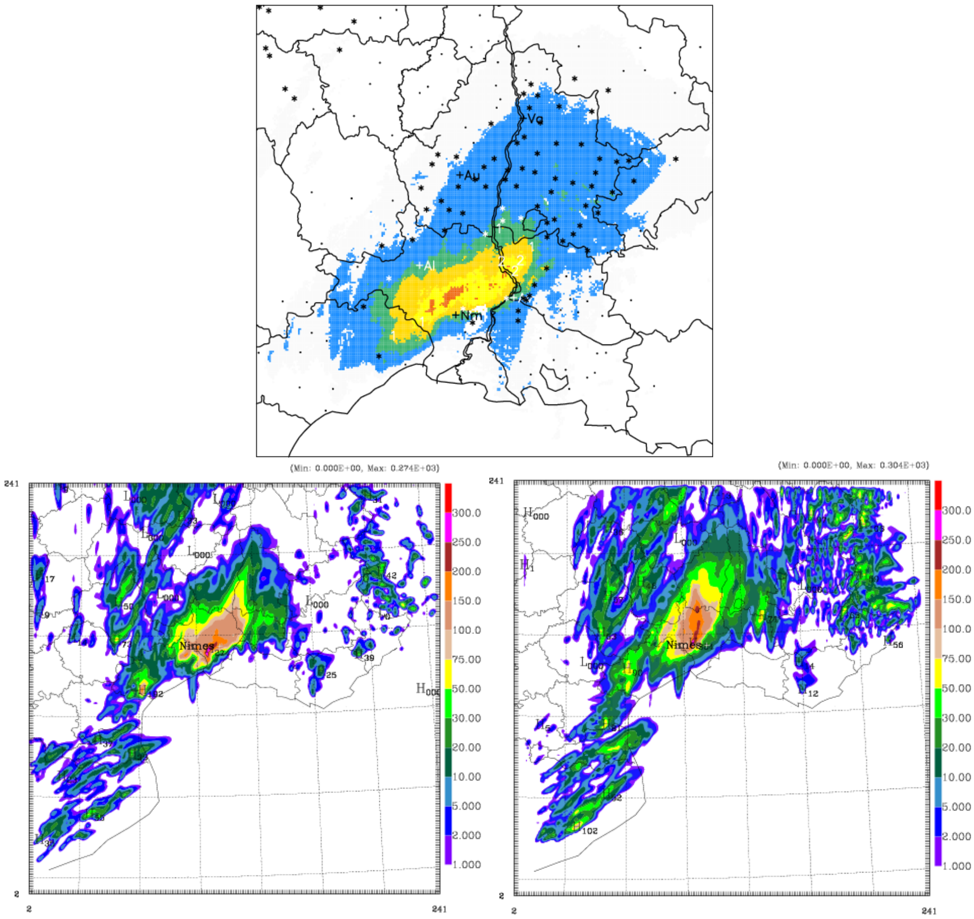

Figure 6: Gard experiment: a) 12-22 UTC Nîmes radar cumulated rainfall. b) MESO-NH simulation (single model, 2.5 km resolution). c) AROME simulation.

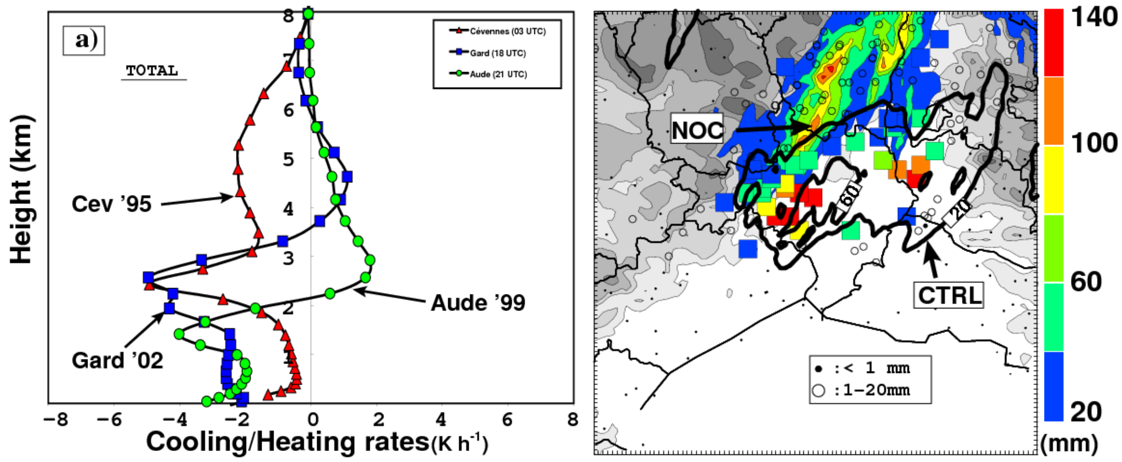

Figure 7: a: One dimensional budgets of the potential temperature for three simulated MCS during the developing stage, performed over the whole convective and stratiform part of the different systems. b: NOC (for "NO evaporation Cooling", shaded areas) vs CTRL (solid lines) runs for Gard case for the simulated accumulated rainfall from 1800 till 2200 UTC on Sept.8^{th}*2002. From Ducrocq et al. (2006).*

resolution due to an unrealistic dependence of effective zenith solar angle (EZA) to cloud overlap assumption. The EZA accounts for the decrease of the direct solar beam and the corresponding increase of the diffusive part of the downward radiation by the upper scattering layers. This result corroborates the loss of accuracy of the ECMWF radiative scheme noted by Barker et al.(2003) when the number of in-cloud layers increases. A new formulation of EZA is then proposed, independent of the cloud overlap assumption, which leads to more accurate fluxes at cloud top and base for cumulus and stratocumulus cases, when compared to a discrete ordinates radiative code (SHDOM code of Evans(1998)) (Fig.9). On the contrary, the use of the overlap assumption cloud on the clear sky fraction computation is not questionable. Even if the correction has a small impact with the current coarse vertical resolution of AROME (36 levels up to 21 km), it could be more important with a finer vertical resolution, planned for the next years. The validation of the radiative scheme at meso-scale will be carried on by the revision of the parameterizations used for the calculation of cloud optical properties. The absence of distinction between cloud and rain water contents for the calculation of effective radius of droplets/drops will be evaluated through the impact on heating and cooling rates, depending on cloud types.

7 Conclusion

The operational production of AROME, the next numerical prediction model of Météo-France, is planned for the end of 2008. From now on, the daily runs of the AROME prototype give an insight of the main strengths and weaknesses of the system, and we currently focus on the ability of the physics to reproduce the broad range of atmospheric clouds. Most of the meso-scale convective systems and their fine scale structures are reasonably well reproduced at the resolved scale of 2.5 km by the bulk microphysical scheme of MESO-NH, based on single moment and 5 hydrometeor species. Fog events seem to be well catched by AROME and the droplet sedimentation recently introduced in the microphysical scheme should improve the cloud water contents and then the fog life cycle. Some important progresses are now expected in the representation of subgrid cloud variability, non negligible at a 2.5 km horizontal resolution. The introduction of horizontal subgrid variability for convective clouds, associated to a new shallow convective mixing formulation, has shown promising results.

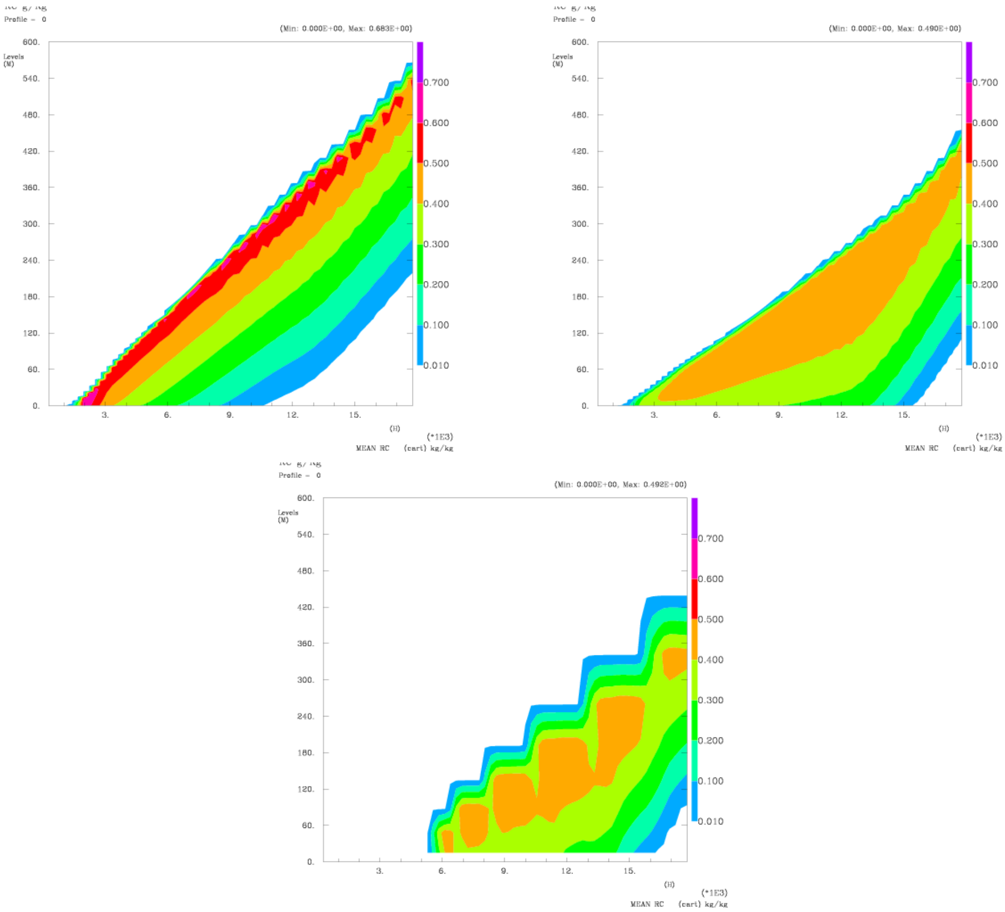

Figure 8: Temporal evolution of cloud water content (in g/kg) for 18h on the first 600 meters height for October 2003 the 1ST *from 18TU for a 1D Meso-NH simulation : (a) Fine vertical resolution without cloud droplet sedimentation (b) Fine vertical resolution with cloud droplet sedimentation (c) Coarser vertical resolution of AROME prototype (36 levels up to 21 km) with cloud droplet sedimentation*

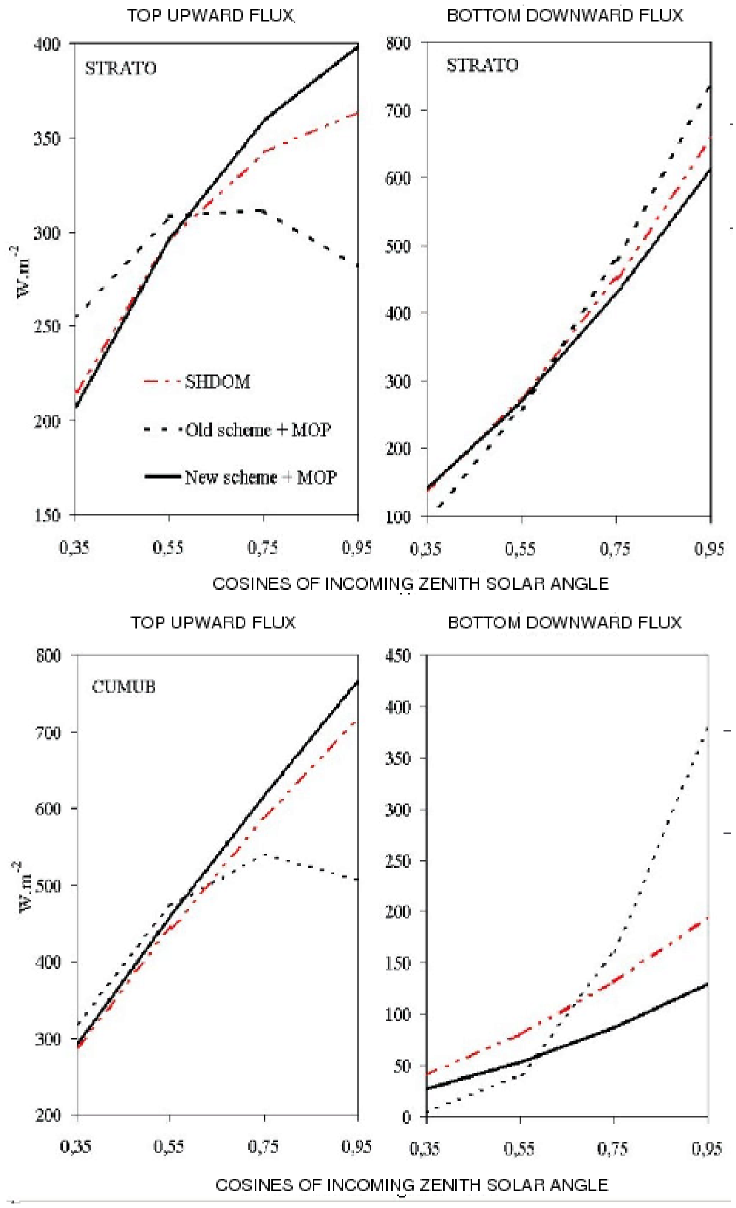

Figure 9: Comparison of SHDOM (dashed lines), ECMWF-old formulation of AZE (EC-Old, dotted lines) and ECMWF-new formulation of AZE (EC-new, full lines) for a stratocumulus case on the top and a cumulus case on the bottom at different cosines of incoming zenith solar angle. On the left: Mean cloud top upward flux. On the right: Mean cloud bottom downward flux. From Thouron et al.(2007).

It must be validated now in a systematic way, using observation dataset such as the Cloudnet database.

The representation of stratiform clouds such as stratocumulus or cirrus in AROME will be considered in the next future. In the case of stratocumulus, the current vertical resolution of AROME may be too poor to accurately simulate the entrainment rate into cloud-topped boundary layers under strong inversions. In such case, different entrainment formulation could be tested in the turbulence scheme. The cirrus parametrization will also be evaluated and a further evolution of the microphysics and the cloud scheme may be expected. Simple tests on autoconversion have shown that the subgrid variability is also important for the precipitation formation processes, which are highly non linear. The final objective will be to find a consistent treatment of subgrid scale variability for all the different physical processes : microphysics, radiation, turbulence, cloud scheme and convection.

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