Towards an operational implementation of Lopez's prognostic large scale cloud and precipitation scheme in ARPEGE/ALADIN NWP models

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I) Motivations

The large scale precipitation and the cloudiness schemes used operationally at Météo-France in the global ARPEGE and limited area ALADIN numerical weather prediction (NWP) models for short range forecasting are described in details in the on-line documentation of physical parameterisations prepared and maintained by Luc Gérard (*). The brief description below is from Geleyn (2003).

The operational large scale precipitation scheme includes neither storage of the liquid and solid phases in the clouds, nor consideration of partial cloudiness. The large scale precipitation occurs when water vapor is above wet bulb water vapor and falls in one time step. A revised Kessler (1969) method is used for computing precipitation evaporation, melting and freezing. A ratio of the falling speed for the two types of precipitation allows distinguishing some aspects in the liquid/ice partition. The diagnostic scheme for the "radiative" clouds link the cloudiness to the production of stratiform and convective precipitations, and to the existence of inversions. The cloudiness functionally depends on the diagnosed total cloud condensate (Xu and Randall, 1996). The convective cloud condensate is obtained from the rate of generation of convective precipitation at the previous time step. The stratiform cloud condensate is estimated from the instantaneous super-saturation of the air properties averaged along a certain delta-theta thickness below, with respect to the local saturation state multiplied by a "critical relative humidity" vertical profile. The partition between ice and liquid state depends only on temperature with a progressive transition below 0°C.

Used operationally since many years, these schemes have proved their robustness and utility for short range forecasting. However the use of more sophisticated microphysics is promising for improving the simulation of clouds, precipitations and surface conditions. Therefore the large scale cloud and precipitation scheme developed by Lopez (2002) has been implemented for evaluation in the last research version of ARPEGE and ALADIN NWP models and also in the ARPEGE climate model which includes the statistical scheme for large scale precipitation and cloudiness developed by Ricard and Royer (1993).

II) Original Lopez's scheme

A brief overview of the scheme is given below, taken from the whole description available in Lopez (2002).

In short, the scheme of Lopez is based on the approach of Fowler and Randall (1996), where the prognostic could contents and the precipitations are not split into separate liquid and solid components, and where any time-stepping is overcame by the use of a semi-lagrangian scheme for the falling of rain and snow, valid for the long NWP and GCM time-steps.

The large scale cloud and precipitation scheme is based on the addition of two prognostic quantities: the amount of cloud condensate (liquid and ice water) and the precipitation content (rain and snow). A prognostic treatment of precipitation has been chosen to provide a finer description of the temporal evolution of the vertical distribution of precipitation (especially snow) and, thus, of the effects of latent-heat release associated with sublimation and evaporation. Furthermore, the scheme has been also designed for future variational assimilation of cloud and precipitation observations for which a prognostic treatment for precipitation should lead to a more direct link between model variables and observations.

The calculations of large scale condensation/evaporation and cloud fraction are based on a triangular probability-density functions (Smith, 1990). The width of this function is adjusted via a critical relative humidity threshold, above which clouds start to appear. The parameterized microphysical processes that involve precipitation are autoconversion, collection and evaporation/sublimation. The autoconversion rate of cloud droplets (ice crystals) into precipitating drops (snowflakes), is given by the simple formulation of Kessler (1969). Three types of collection processes are considered: accretion, aggregation and riming for which the classical continuous collection equation has been integrated over the Marshall-Palmer (1948) exponential particle spectra for specified distributions of particle fall speed and mass. Precipitation evaporation is calculated by integrating the equation that describes the evaporation of a single particle over the assumed spectra of particle number, mass, and fall speed. The fall of rain and snow is considered as a specific process, and is computed using a semi-Lagrangien approach that is separate from the standard semi-Lagrangian advection scheme used in ARPEGE/ALADIN model. Constant values of 5m/s and 0.9m/s are assumed for rain and snow fall speeds, respectively.

At each time step, the partitioning of stratiform cloud condensate into cloud liquid water and cloud ice is diagnosed from the local temperature. Rain is supposed to be present whenever the local temperature is above freezing point, and snow is present otherwise. Falling snow is, therefore, assumed to melt instantaneously as soon as it enters a model layer with temperature above 0°C, provided the associated cooling does not lead to freezing.

The original scheme has been widely validated with satellite observations (METEOSAT, SSMI) on FASTEX (Fronts and Atlantic Storm-Track Experiment) case studies, with remote sensing observations over the Southern Great Plains (ARM) and by comparison with meso-scale models (Met Office's Unified Model and Méso-NH). The validation has then continued in GCM mode, prior to the present validation in NWP mode.

III) Some modifications and tunings

The separation of total cloud condensates in two prognostic variables, liquid and solid cloud condensates, has been done to take into account the latent heat exchange resulting from a possible phase change due to the time evolution of the local temperature. This modification makes easier future scientific sophistications and code maintenance since IFS and AROME models use also two prognostic variables for liquid and ice water contents.

The influence of evaporation and collection processes on precipitating water evolution has been improved. The autoconversion process is continuous during the time step and not anymore supposed at the beginning of it. These modifications improve the realism of the 3D field of precipitating water and reduces beneficially the amount of surface precipitations.

An analytical formulation has been designed to describe the dependency of "critical relative humidity" with height and horizontal resolution (figure 1a) in order to fit the experimental values obtained from a large number of aircraft in situ measurements collected during FASTEX (Lopez, 2002).

The partition of stratiform cloud condensate into cloud liquid water and cloud ice has been tuned to allow the coexistence of liquid and ice water at temperatures between –25°C and 0°C (figure 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 autoconversion, have been strongly reduced (factor 10).

An improved version of the original Lopez scheme has also been developed by Gérard (2005) to be part of an integrated scheme for clouds, precipitation and convection. This version uses two separate prognostic variables for liquid and solid water content and some refinements in the autoconversion process. The precipitating water is not advected anymore ; it is either a pseudo-historic or a diagnostic variable.

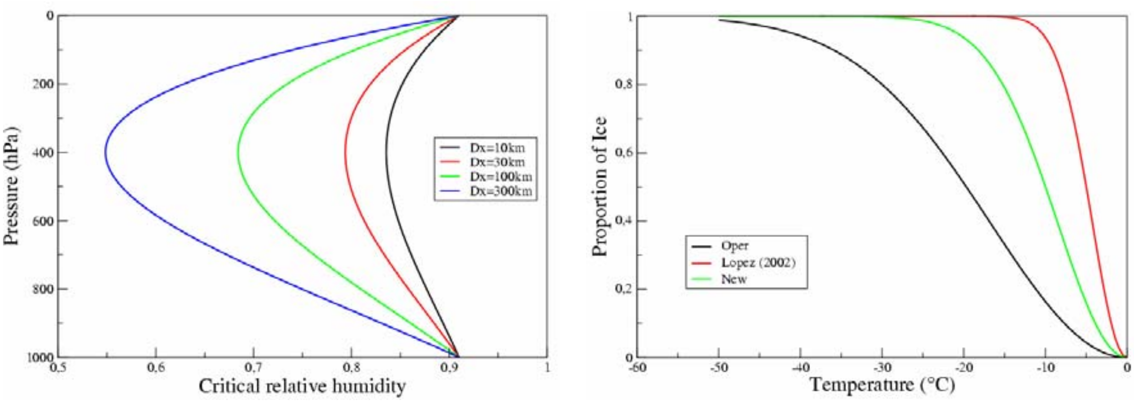
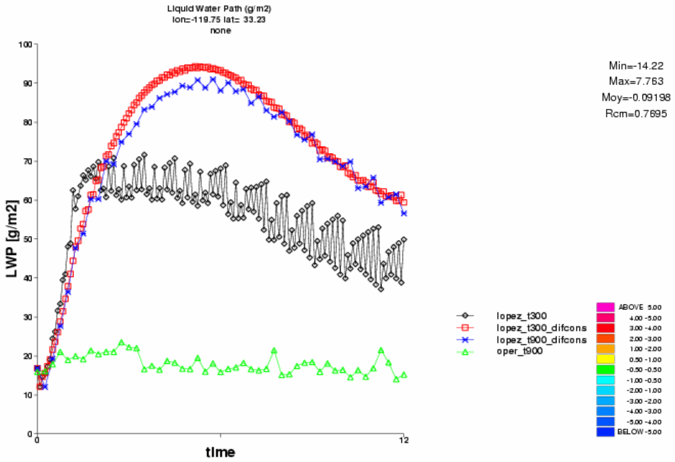


Figure 1a (left): "Critical relative humidity" as a function of pressure and horizontal resolution.
Figure 1b (right): Function of temperature which determines the fraction of ice for stratiform cloud condensate.

IV) Diffusion of conservative variables

The operational scheme for the surface and upper-air exchanges is designed according to Louis (1979) and Louis et al. (1981), with the shallow convection incorporated according to Geleyn (1987) and recently modified to cure a tendency to an on/off behavior in time and along the vertical. The turbulent exchange coefficients' dependency on the Richardson number in case of stable situations has been improved. The dynamical and thermal mixing lengths are computed according to a diagnosed PBL height (Troen and Mahrt, 1986 ; Bazile et al., 2005). The dry static energy and the water vapor are diffused.

This scheme has been recently modified in the GCM version of ARPEGE to diffuse the cloud-conserved thermodynamic and water content variables: the moist static energy and the total water content, with the use of cloud cover as a weighting factor to include the subgrid variability of cloud water content. However, for the time being, only the vertical diffusion scheme is changed but not the computation of the turbulent exchange coefficients. This modification stabilizes the scheme as shown on the simulation of a stratocumulus case with the single column model (figure 2a).



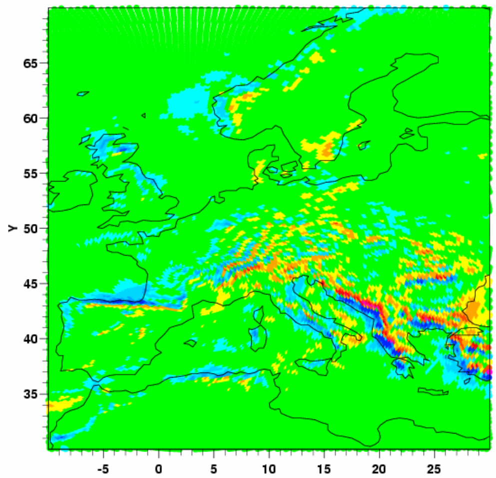


Figure 2a (left): Temporal evolution on 12 hours of Liquid Water Path (g/m2) on Eurocs stratocumulus case with the operational scheme (Δt=900s) and the Lopez's scheme for 2 different time steps (Δt=300s and Δt=900s) and with and without diffusion of conservative variables ("difcons").

Figure 2b (right): Cumulated precipitation difference (mm/day) between Lopez and operational schemes computed with fifteen 96h ARPEGE forecasts over the period 11-25/02/2005.

V) Validation

Validation forecasts have been performed with the modified Lopez's scheme and the diffusion of conservative variables, all the other parameterizations (deep and shallow convection, radiation, subgrid scale orography, surface) being unchanged.

Seasonal global runs at various horizontal resolutions (between 25 and 200 km, in stretched and unstreched configurations) have been performed to validate the scheme against climatologies (ISCCP, CERES, GPCP) and to prove its stability for long time steps (1800s at 250km, 900s at 25km, 450s at 10km). Objective scores against observations (SYNOP, TEMP) and analyses have been performed with a small positive impact on standard deviation of geopotential in the troposphere on North20 and South20 domains and a small negative impact in the Tropics (not shown). The temperature is increased in the Tropics at 200 hPa due to a decrease of water vapor (precipitation occurs now before saturation).

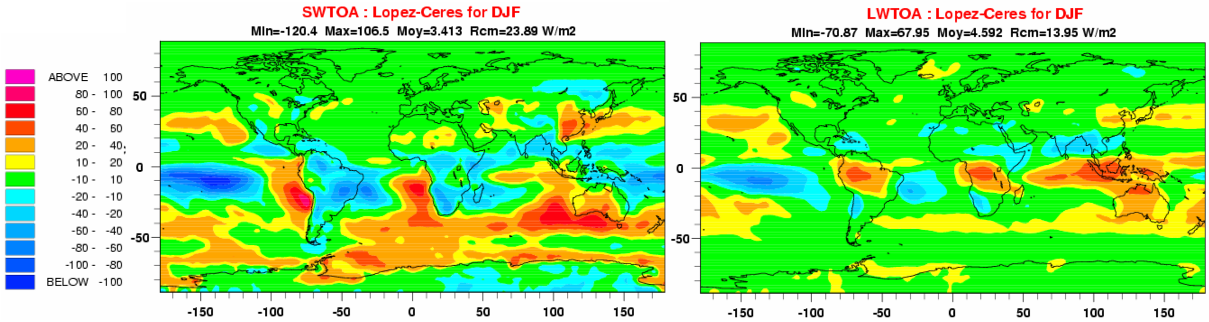


Figure 3: Comparison of the new scheme with CERES climatology for SW and LW net radiation at TOA with ARPEGE at operational resolution (T358C2.4) on DJF.

The impact on cloudiness (figure 4) is an increase of low level clouds at high latitudes and a decrease of low level clouds in the Tropics. There is still an important lack of marine stratocumulus (figure 3), but this problem will be addressed by current developments/validations made jointly with the GCM team on moist TKE scheme (Cuxart, Bougeault, Redelsperger, 2000) and a parametrization of entrainment at the top of PBL (Grenier and Bretherton, 2001). Medium clouds are significantly reduced at high latitudes. Cirrus are higher and more important in the Tropics. The liquid and solid water contents are increased below 900 hPa. Above the amount of ice water content is similar and the amount of liquid water content is significantly reduced in the upper troposphere according to the new partition function (figure 1a).

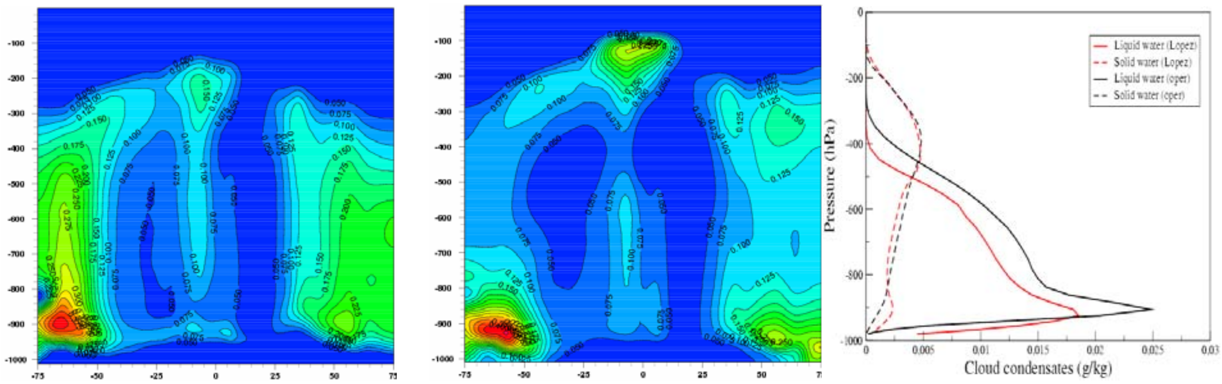


Figure 4: Zonal mean cloudiness with the operational (left) and the Lopez (middle) schemes. Global mean liquid and solid specific humidities for the two schemes (right). Data are computed with fifteen ARPEGE 96h forecasts over the period 11-25/02/2005.

The impact on precipitation is a significant reduction of the extreme amounts of precipitation, particularly above highest mountains. The global amount of total precipitation is slightly reduced, between 0.1 and 0.2 mm/days on average over the globe. The cumulated amount of precipitation is smoother spatially, with more precipitation on the leeside mountains and less on the windward mountains (figure 2b), both aspects being beneficial according to the current model biases. These differences are illustrated on figure 5 which represents the cumulated total precipitation between 6 and 30h ALADIN forecast on a case study with the operational and the new schemes. The comparison with SYNOP observations over Corsica proves that the amount of precipitation was strongly overestimated in the reference and more realistic with the new scheme.

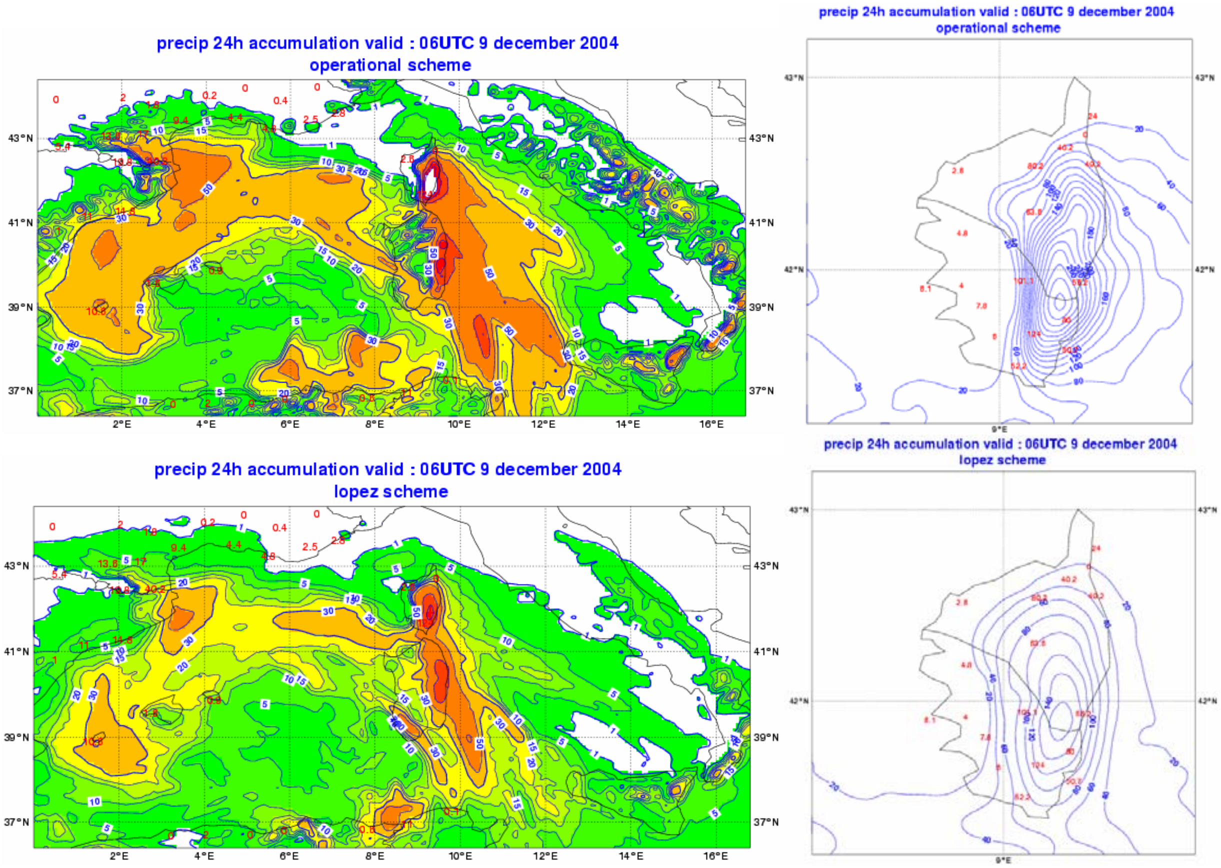


Figure 5: Cumulated precipitation between 6 and 30h forecast obtained from 30h ALADIN forecasts with the operational (top) and Lopez schemes (bottom) starting the 8^th December 2004 at 00h UTC on the western Mediterranean Sea (left) and over Corsica (right). SYNOP observations are in red.

VI) Conclusions and perspectives

The Lopez's large scale cloud and precipitation scheme has been implemented in last research version of ARPEGE and ALADIN models. Some improvements have been performed mainly on the treatment of precipitating water in relation with evaporation and collection processes. The scheme has been tuned to improve comparison with climatologies. The vertical diffusion of conservative variables was found necessary to cure stability problems, but a whole moist turbulence would be preferable (in work). Preliminary validations have been done in forecast mode with objective scores, comparison to climatologies and cases studies. The main improvements are a small increase of low level clouds at high latitudes, a smoother spatial precipitation field and a better repartition of precipitation over orography. 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 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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