A new Option for Rayleigh Damping: Preliminary Tests

Lucio Torrisi

CNMCA, Via Pratica di Mare 45, 00040 Pomezia (RM), Italy

1 Introduction

An absorbing layer is used in a non-hydrostatic model to reduce spurious downward reflections of vertically propagating waves from the rigid top boundary (rigid lid condition), which can completely distort the numerical solution. This viscous damping layer is usually applied at the top of the computational domain to absorb upward propagating wave disturbances, before they reach the rigid top boundary. The prevention of wave energy reflection at the upper boundary is of crucial importance for a proper simulation of orographically induced flow. In the numerical model formulation a damping term is added to all the prognostic equations. In the traditional Rayleigh friction formulation, the damping term is defined by:

$$R_\phi = -r(z) \cdot (\phi - \phi_{base\ state}) \,, \tag{1}$$

where $r(z) \neq 0$ (increasing with z) in the damping layer between the top z_T (top boundary) and the base z_D. In LM it is

- $z_D = 11000$ meters (base of the damping layer),
- $\phi = T, u, v, w, p', q_v, q_c, q_i$, and
- $\phi_{base\ state}$ = large scale fields provided by the driving model (boundary condition fields).

The current LM Rayleigh damping formulation does not work with frames, because it requires boundary condition fields defined on a full grid. Although LM forecast fields, which come from runs without any absorbing layer, may be contaminated by spurious reflected waves, IFS *frames* are routinely used in EuroLM (UGM) and aLMo (MeteoSwiss) model configuration. A possible solution to the spurious waves' problem for these configurations is, to have boundary fields defined on the full grid above a certain model level, where the Rayleigh damping is active (three dimensional frames). Unfortunately, inaccurate calculations of the pressure perturbation p' from the boundary condition fields can generate further contamination in the numerical solution. A more satisfactory solution to the spurious waves' problem than the damping layer would be to specify a radiative upper boundary condition at the domain top. The implementation of the radiative upper boundary condition in LM is work in progress and its impact both from the numerical and from the computational point of view has still to be evaluated (Herzog, 2004).

2 A new Rayleigh damping option

A simple and effective way to overcome the spurious waves' problem is to change the formulation of the base state fields currently used in the Rayleigh damping layer. The *new* base state fields $\phi_{base\ state}$ are obtained by spatially filtering the LM forecast fields ϕ instead of using large scale fields provided by the driving model (boundary conditions fields). The basic idea is to have base state fields consistent with the LM prognostic variables. This is not always true in the current Rayleigh damping formulation, because of the difference in resolution, parameterization, numerics, etc. between LM and the driving model used. Inconsistencies between the LM and the driving model forecast could turn the damping layer in a source of further contamination.

The representation of the base state in the new Rayleigh damping option is strongly dependent on the choice of the filter applied to the LM fields. The current parallelization strategy (decomposition in subdomains surrounded by a 2 grid-line halo) allows the use of a filter with length=1 (using 9 points) without an excessive increase of the communication time. The digital filter has to be applied each time step to the prognostic fields $(T, u, v, w, p', q_v, q_c, q_i)$ The new Rayleigh damping option can also be switched on with boundary condition fields defined on a frame. The namelist variable `itype_spubc` (1 old, 2 new) is used to switch on the old or the new option. It was implemented in the LM version 3.14.

3 Preliminary tests

Preliminary tests of the new Rayleigh damping option were performed using real data. The EuroLM configuration showed in Table 1 was used in this experiment.

Table 1: **LM Configuration (Version 3.11)**

Domain Size	465 x 385 gridpoints
Horizontal Grid Spacing	0.0625° (~ 7 km)
Number of Layers	35, base-state pressure based hybrid
Time Step and Integration Scheme	40 sec, 3 time-level split-explicit
Forecast Range	60 h
Initial Time of Model Runs	12 UTC
Lateral Boundary Conditions	Op. IFS (preproc. with CNMCA-IFS2LM)
L.B.C. update frequency	3 hrs.
Initial State	Op. IFS (preproc. with CNMCA-IFS2LM)
Orography	Filtered (`eps=0.1`)
Initialization	None

Three different runs were performed (12 UTC - 12 September 2004): the first one using the old option, the second one using the new option and the other one without any damping layer. 60 h accumulated total precipitation fields from these runs (Fig. 1) and their differences (Fig. 2) were compared to each other, in order to evaluate the impact of each option.

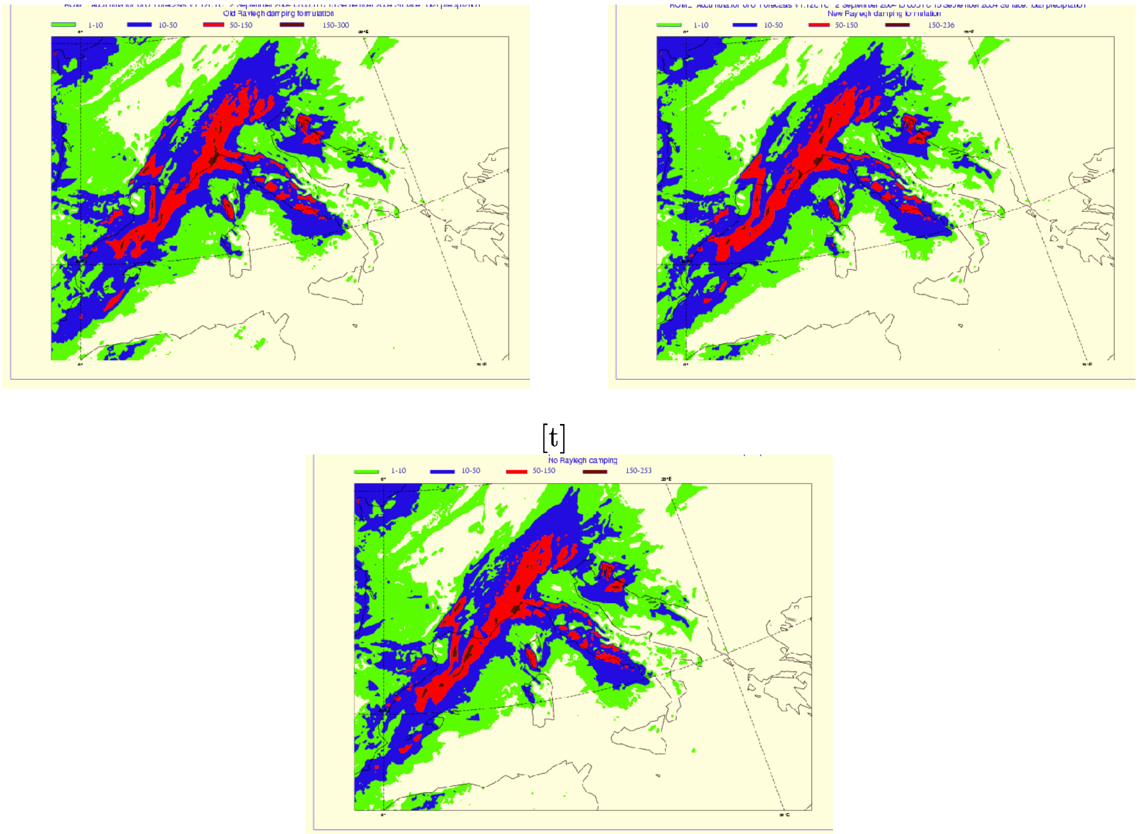

Figure 1: 60 h accumulated total precipitation fields from runs with the old (upper left) and the new (upper right) damping option and with no damping at all (lower).

The comparison of the old and new option runs to the run without any damping layer showed:

- a slight eastern shift in the precipitation pattern of the old option run;
- no significant distortion in the precipitation pattern of the new option run.

The following results were also verified for a three month period:

- runs with the new option have less accumulated total precipitation over the domain ($1.027 \cdot 10^6$ mm for the 12 September run) than runs with the old option ($1.044 \cdot 10^6$ mm for the 12 September run) and runs without any Rayleigh damping layer ($1.030 \cdot 10^6$ mm for the 12 September run);
- runs with the old option have often more accumulated total precipitation over the domain than runs without any Rayleigh damping layer.

This last result and the shift of the precipitation pattern previously found could be the indications that the old Rayleigh damping option is not working correctly, due to the inconsistencies between the LM and the driving model forecast mentioned before. On the other hand, the new Rayleigh damping option seems to work in the right direction decreasing the amount of spurious precipitation.

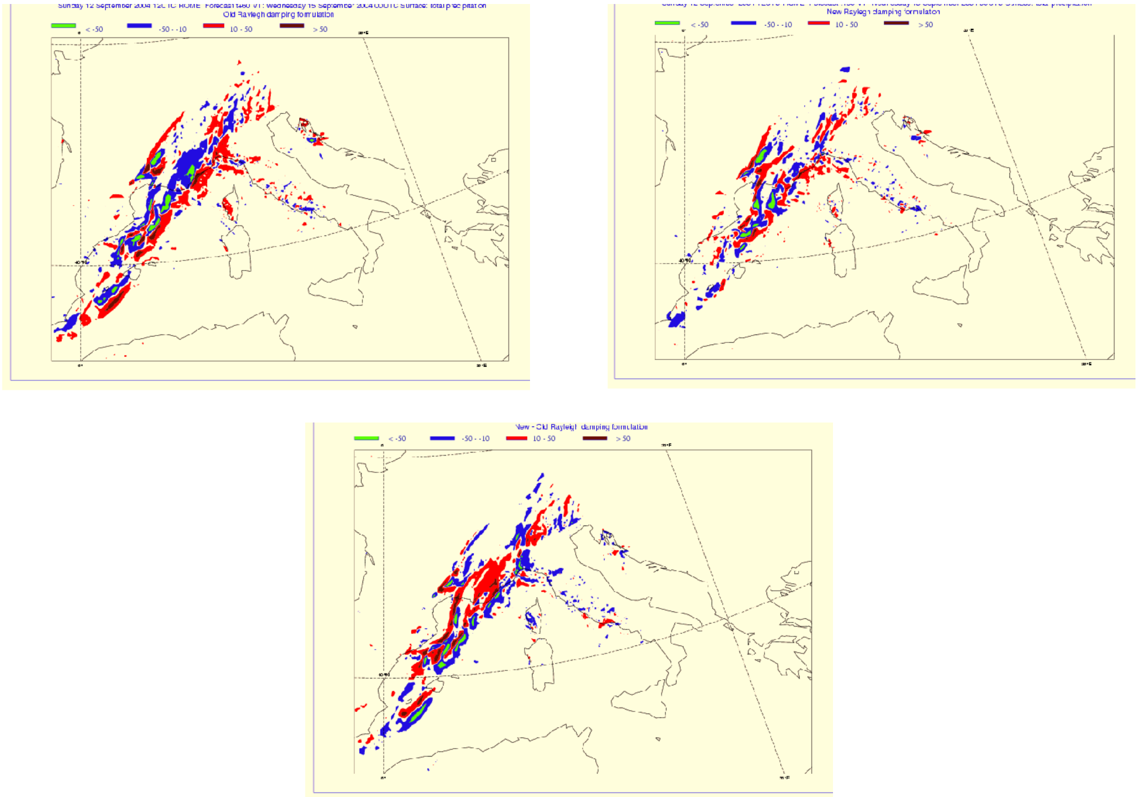

Figure 2: Differences of the accumulated total precipitation fields: old option - no damping (upper left); new option - no damping (upper right) and old - new damping option (lower).

4 Conclusions

A new option for the Rayleigh damping layer near the top boundary was implemented in LM code. It is recommended for LM runs with frames, but it can be used even if the boundary conditions are defined on a full grid. Preliminary tests using the new Rayleigh damping option have showed less accumulated total precipitation over the domain than runs with the old option and runs without any damping layer. These results are a clear indication that the new option is working correctly decreasing the amount of spurious precipitation, but further studies (idealized tests, such as the linear hydrostatic mountain wave test) are necessary to evaluate the impact of the new Rayleigh damping option on LM forecasts and to tune the new base (filtered) state formulation.

References

Herzog, H.-J., 2004: Tests of the radiative upper boundary condition. Presentation at the COSMO General Meeting, 2005 - Milano.