Dynamic definition of the iterative time schemes

RC LACE stay report
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1 Introduction

In the dynamical core of the ALARO model, the two-time level time marching scheme is applied. Here, all terms on the right-hand side of the prognostic equations are split up in the linear part and in the non-linear residuum. Then the linear terms are treated semi-implicitly, while the non-linear terms are extrapolated to the time level $t+\Delta t/2$. This extrapolation is done with SETTLS (Hortal, 2002), or omitted with NESC where only time level t is used. Moreover, with the iterative centered implicit time scheme (ICI, Bénard, 2003) the implicitness is brought to the non-liner terms through an iterative process converging to the full Cranck-Nicholson scheme. If only one iteration is applied, we speak about a predictor-corrector (PC) scheme. PC uses NESC calculation for the non-linear terms averaged along the SL trajectory and is second order accurate. The one step SI+SETTLS scheme is as well second order accurate with the benefit of being less expensive in the CPU time usage. Unfortunately, the price to be paid is the deficiency in the stability of the method. In other words, with a given time step we may employ one of two methods which are both second order accurate in time: less expensive, but less stable SI+SETTLS, or more expensive, but more stable PC+NESC.

The topic of this stay was to assess the possibility to find a dynamic definition of the temporal scheme that is accurate, stable and cheaper than those currently available using the strategy of the choices in the time scheme at the beginning of each time step depending on dynamical stability evaluation. Other possibilities to enhance the stability of the integration exist, among which shortening of the time step is the most commonly used in practice.

2 Code implementation

Previous study from 2019 was dedicated to find a combined SETTLS/NESC scheme that was activated separately in each gridpoint based on an instability condition [1]. The resulting time scheme was simple one step kind, no corrector step was applied. Now, we would like to find a global criterion such that a choice between SI+SETTLS and PC+NESC scheme can be made at the beginning of every time step. The way in which this dynamic scheme is employed is as follows: the setup starts with SI+SETTLS scheme (NSITER=0). Then, according to the values of an instability diagnostic, a check is made in every time step if it is necessary to switch to PC+NESC scheme. The instability diagnostic proposed is based on vertical divergence non-linear residual (noted VD in equation 1) computed in consecutive time steps:

$$ZDIFFNL = \frac{|(V\,D)^{t} - (V\,D)^{t-\Delta t}|}{|(V\,D)^{t}| + |(V\,D)^{t-\Delta t}|}, \qquad (1)$$

ZDIFFNL is computed in each gridpoint, in routine lacdyn. Other necessary quantities for this are computed in routine latte nl. The overall diagnostic for a given time step (RPD AVE) is then computed as an average on all gridpoints, levels and processors, following the structure that was available in routine cpg_drv. The final result is equivalent to a percentage of grid points with potentially unstable calculation. In the case the value of this percentage exceeds a certain established threshold (RDMAX), then PC+NESC is switched on, in routine cnt4. In the predictor step, the mechanism of the choice between SETTLS and NESC extrapolation type is based on the value of PEXTRA already available in the code and described in [1].

3 Experiments and results

These changes were implemented in the ALARO model based on the code version cy46t1. To illustrate the problems that were encountered when SI+SETTLS scheme was used, the experiments are performed for weather cases that are characterized by dynamical instability. The forecasts are run from 30 October 2017 00 UTC (case 1) and

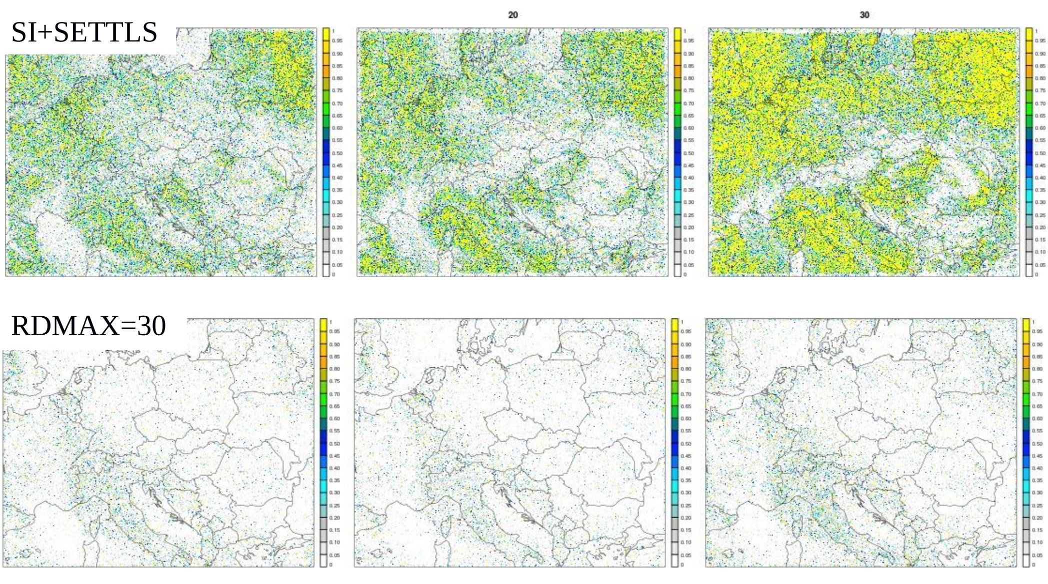

Figure 1: Values of stability diagnostic ZDIFFNL after 10 (left), 20 (middle) and 30 (right) time steps, for experiments T002 (first row) and T001 (second row), for the case of 30.10.2017; the values range between 0 (white) and 1 (yellow).

01 June 2022 00 UTC (case 2) for 72 hours forecast range, using ARPEGE coupling files with 3h coupling frequency. The resolution used is 2.3 km and 87 vertical levels, while the time step is 90 s.

In the initial setting, SI+SETTLS is used (no corrector). These experiments crash in less than 40 steps for both cases. On the other hand, PC+NESC is stable and the integrations complete 72 hours, again in both cases. Several experiments are then performed with the dynamic scheme for different values of the instability threshold RDMAX. The idea is to find a large enough value of RDMAX such that the SETTLS scheme is enabled as many times as possible and at the same time, the integration remains stable. The experiment for which RDMAX=100 is equivalent to the reference experiment (SI+SETTLS), while for RDMAX=0, we obtain the experiment PC+NESC (NSITER=1). The experiments addressed in this report are described in Table 1.

Table 1: Description of experiments.

	Name	**RDMAX**	**Temporal scheme**	**Result**
Case 1				
	T007	0	PC+NESC	ok
	T001	30	dynamic	ok
	T008	40	dynamic	ok
	T004	50	dynamic	ok
	T006	60	dynamic	ok
	T005	70	dynamic	crash h11
	T002	100	SI+SETTLS	crash h1
Case 2				
	F008	0	PC+NESC	ok
	F001	30	dynamic	ok
	F005	40	dynamic	ok
	F002	50	dynamic	ok
	F004	60	dynamic	crash h64
	F003	70	dynamic	crash h15
	F006	100	SI+SETTLS	crash h1

Figures 1 and 2 show values of the instability indicator ZDIFFNL as defined in equation (1). In each figure, two types of experiments are presented: one that crashes (first row) and one that succeeds in completing the numerical integration. The values of the indicator are shown for several time steps before the first experiment crashes, in order to see the behaviour of this indicator in relation to the model instability.

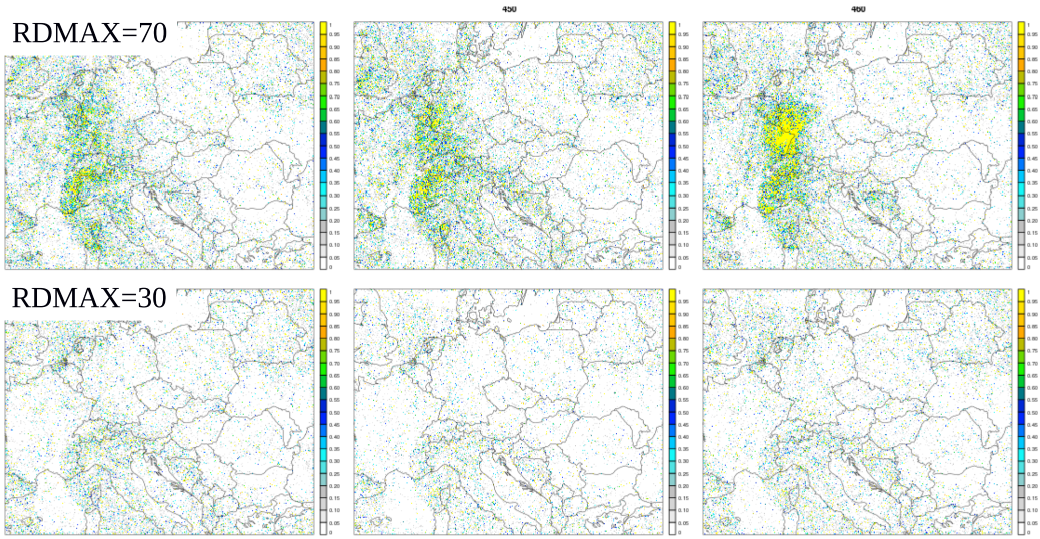

Figure 2: As Figure 1 but after 440 (left), 450 (middle) and 460 (right) time steps, for experiments T005 (first row) and T001 (second row).

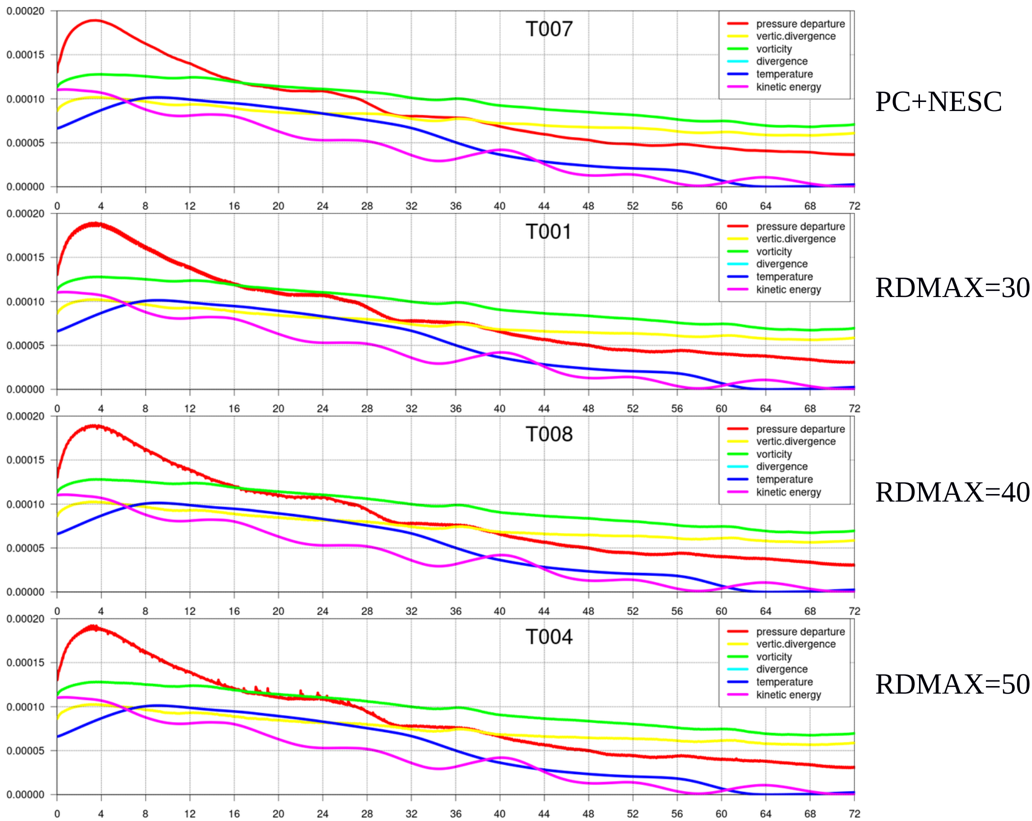

Figure 3: Averaged spectral norms for case 1..

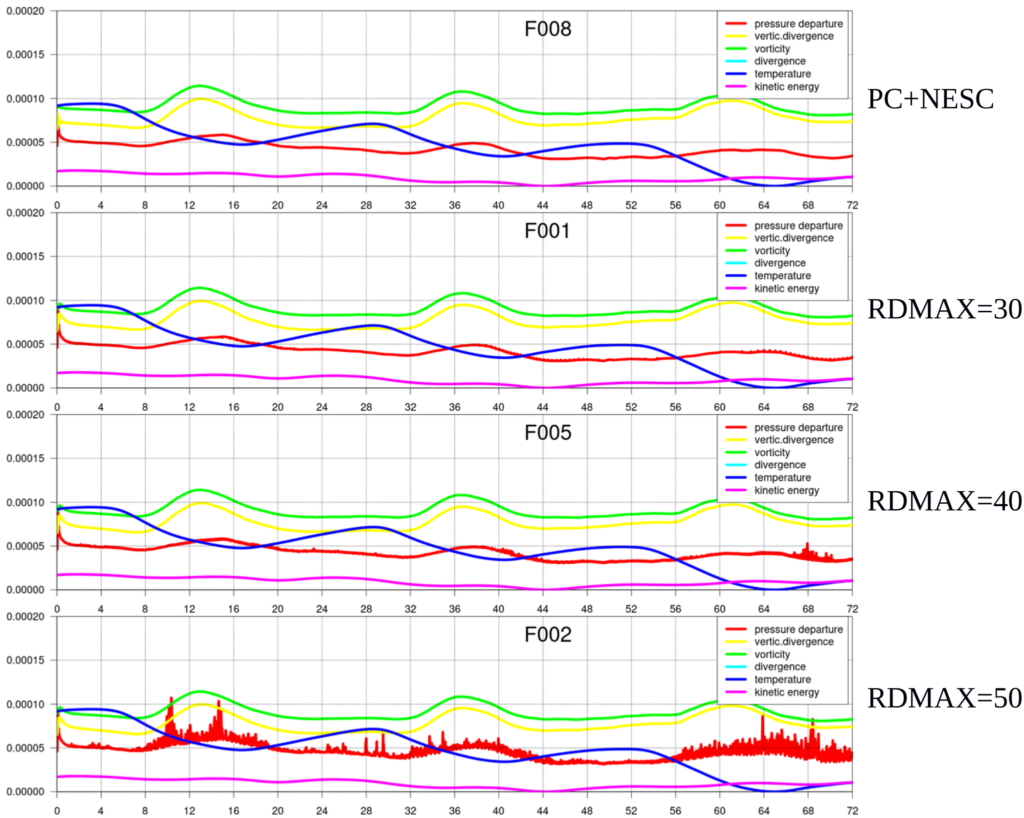

Figure 4: Averaged spectral norms for case 2.

In Figure 1, the first row shows values from the experiment with SI+SETTLS, while the second row, the ones from the dynamic scheme. In Figure 2, both experiments use the dynamic scheme, the difference between row 1 and row 2 is the value of RDMAX: 70, respectively 30. Both figures demonstrate that this definition of the indicator is correlated with the numerical stability. Possible values of this indicator range from 0 to 1, larger values being associated with more instability. Indeed, larger yellow areas that are visible especially before the crash of the first experiment are not found in the experiment that is numerically stable. To exclude a possible deterioration of the solution obtained in the experiments using the dynamic scheme, the value of the spectral norms is checked. Figure 3 shows the time evolution of spectral norms averaged over the whole domain obtained for experiments with several values of RDMAX: 30, 40 and 50 for case 1, while Figure 4 shows the same for case 2.

We can see that in the first case (Figure 3), the norms are comparable, while in case 2 (Figure 4), for higher values of RDMAX, the averaged norms for pressure departure begin to have oscillating patterns suggesting the existence of some instability, starting with earlier forecast hours for RDMAX=50. Though there are many experiments that finish integration for higher values of the threshold RDMAX (Table 1), we can see some differences in the norms. For case 2, the scheme proves still unstable for RDMAX=60, the integration stops after 64 forecast hours. As for other experiments that are not crashing, the norms seem to be more unstable even for lower values of RDMAX than for the same experiments in case 1.

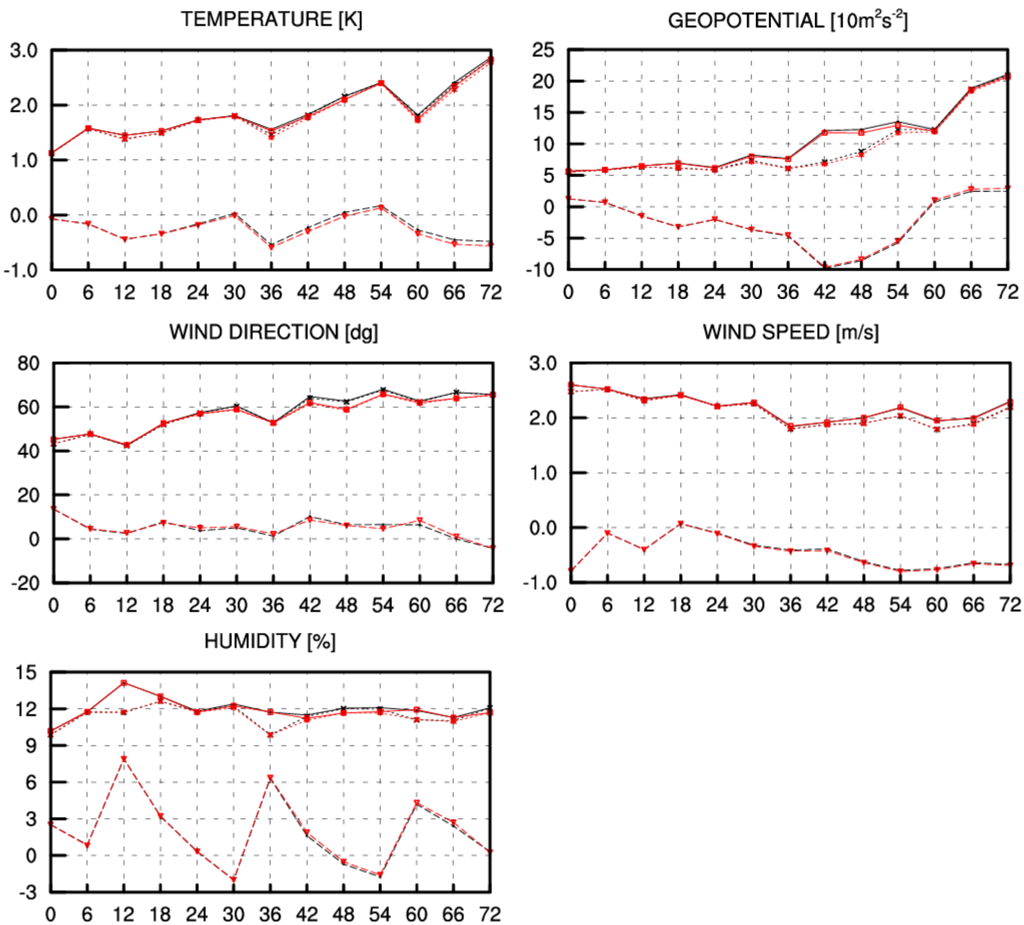

Figure 5: Verification scores for surface, for experiments T001 (black) and T007 (red).

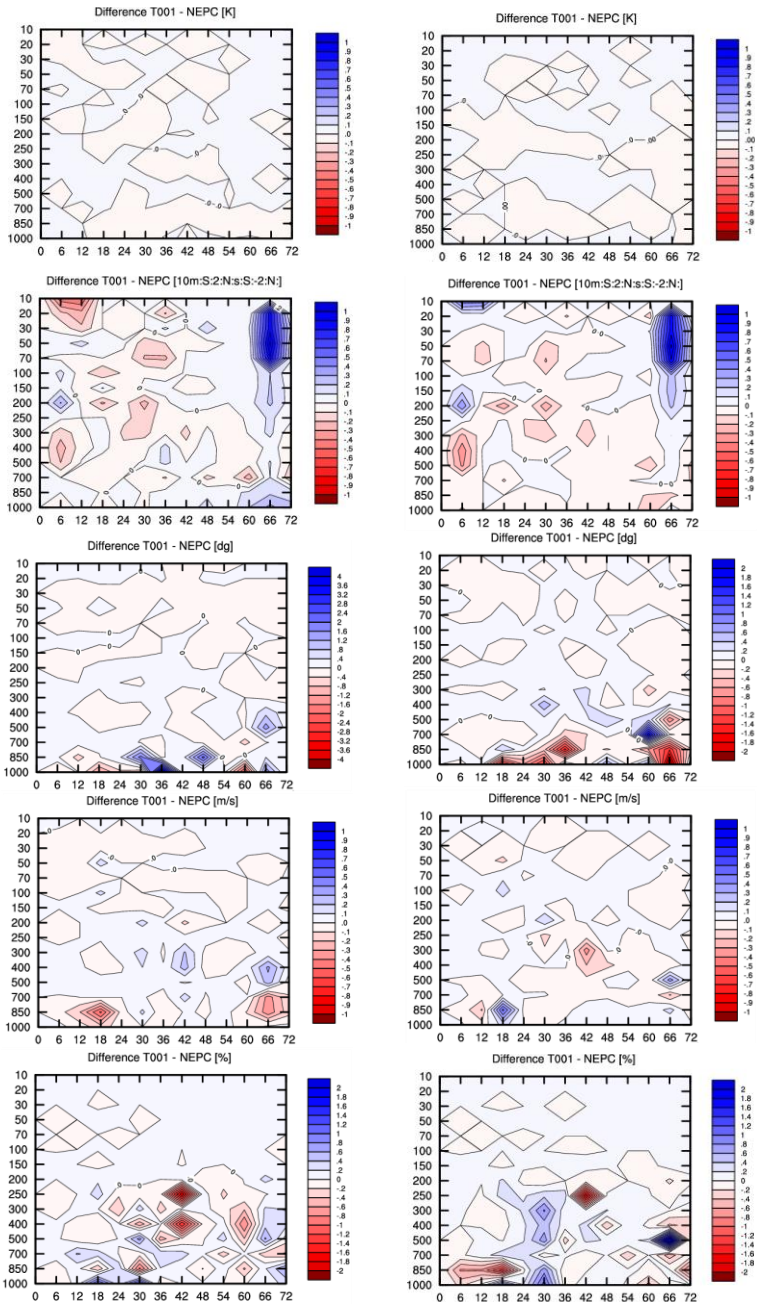

Figure 6: Bias (left) and RMSE (right) for upper levels, differences between experiments T001 and T007; from top to bottom: temperature, geopotential, wind direction, wind speed and relative humidity. Red color shows where T001 is better, blue color means that T007 is better.

The following step in the evaluation of the results of the dynamic scheme was to analyze the verification scores. Of course, since the verification sample consists of only 72 hours forecast, one cannot draw many conclusions from the scores, but it is necessary in order to eliminate a possible worsening of the forecast. The scores were computed for the following parameters: temperature, geopotential, wind speed, wind direction, relative humidity at standard upper pressure levels and surface, and precipitation and cloudiness at surface. In Figures 5 and 6 some scores are shown for experiments T001 and T007. Figure 5 shows the evolution of scores with forecast hour for surface parameters. It can be observed that the scores (bias, RMSE and standard deviation) look almost identical between experiments using either PC+NESC or the dynamic scheme, very small differences appear. Figure 6 shows the evolution in time of the difference in scores: bias (the left plots) and RMSE (on the right) between the two experiments, for pressure levels (on the vertical axis). While some differences in the scores appear here for certain hours, it is mainly in secondary day terms when less observations are available, and they can be considered small.

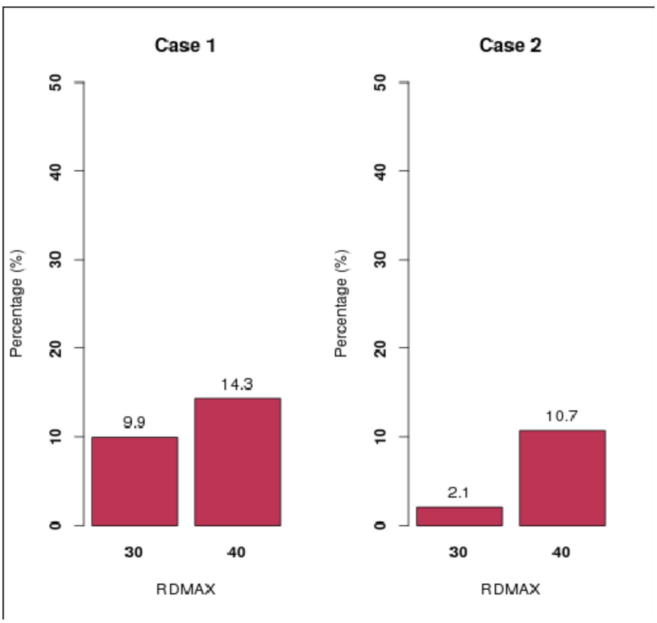

Figure 7: Decrease in the CPU usage (percentage) obtained for experiments T001, T008 compared to T007 (left), and obtained for experiments F001 and F005 compared to F008 (right).

In order to evaluate the CPU time that could be saved when the dynamic scheme is employed, the decrease in CPU time was calculated for experiments T001, T002, F001 and F002 in comparison to the reference experiment that uses PC+NESC scheme. In Figure 7, we can see that there is some saving in computational time for experiments with the dynamic scheme approach. The percentages differ from one case to another and with different RDMAX. Larger savings are obtained with larger value of RDMAX, which was expected, since larger RDMAX means that SETTLS is called more times, thus the experiment is overall less expensive. However, the differences obtained for case 2 between the two experiments are more significant. Indeed, for experiment F001, SETTLS is called for 5,65 % of the time steps, while for experiment F005 SETTLS is called for 41,5 % of the time steps. Figure 8 shows some scenarios representing the

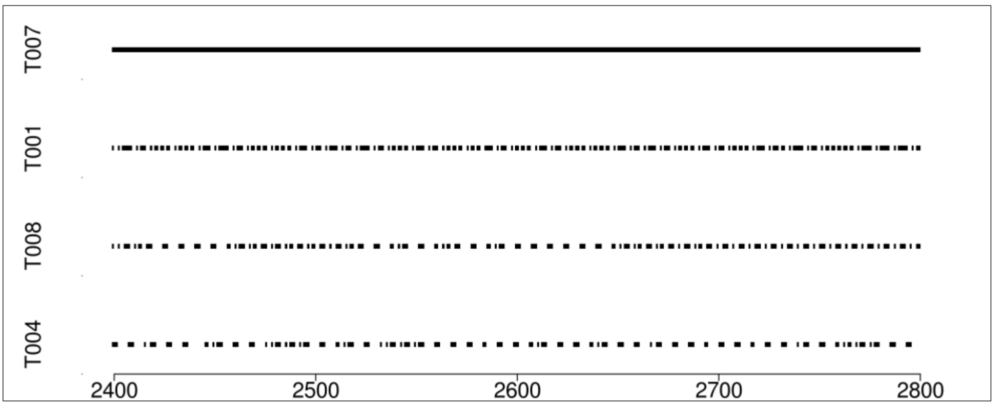

Figure 8: Steps when PC+NESC scheme is enabled (black points), from top to bottom for experiments T007, T001, T008 and T004 (shown for steps between 2400 and 2800).

time steps when PC+NESC scheme is enabled, for experiments T007, T001, T008 and T004. This shows that if larger values of RDMAX are used then less steps with PC+NESC time scheme are necessary and it explains why the run is cheaper in the CPU time usage.

4 Conclusion

A new approach in computation of the temporal scheme of ALARO was proposed and evaluated. The purpose was to find alternative cheaper scheme that is accurate and stable. Such scheme would be even more of interest when going to very high resolution experiments. The scheme allows for a dynamic choice between SI+SETTLS and PC+NESC at the beginning of each time step when certain condition is met. This condition is defined globally through a stability diagnostic calculated in each grid point. Experiments carried out showed that the integration can be stabilized with this dynamic approach in the temporal scheme, while less CPU time is spent.

For near future we plan to continue the study with longer test period to see whether the stability of the scheme and the number of time steps where necessarily the PC+NESC scheme is used is really flow dependent (or meteorological situation dependent) or it is more or less constant for a given domain, time step and dynamics setting used. In the latter case the stability would be more triggered by orography and other parameters chosen for the given domain and experimental setup.

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References

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