Dynamic definition of the iterative time schemes

RC LACE stay report

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20.11 - 01.12.2023

Introduction

The study carried out during this stay represents a continuation of the previous work related to the exploration of the possibility to find a dynamic definition of the temporal scheme that is accurate, stable and cheaper than those currently available. The dynamic scheme is enabled through a choice at the beginning of each integration step between two available schemes. Previously, the choice was made between SI+SETTLS (one step SI with SETTLS treatment of non-linear terms) and PC+NESC (predictor-corrector with one iteration and NESC for non-linear terms) schemes. The results showed that we are able to find such alternative scheme and we concluded that a longer test period should be considered in order to see whether the stability of the scheme and the number of integration steps where the more expensive scheme is called is dependent on the meteorological context or it is more or less constant for a given domain, time step and dynamics setting used. Furthermore, in this study, the main interest is in finding how such scheme can be adapted for very high-resolution grids. In this type of experiments, usually the SI+SETTLS scheme is not enough to achieve stability of the integration and the PC+NESC scheme is called instead. For this reason, now we want to be able to choose between the PC+NESC scheme that uses one or two iterations.

Code implementation

To achieve this aim some changes were introduced in the code following the structure prepared during the previous stay [1]. Modifications are introduced on top of the cycle 46t1_bf07 enhanced with physics development used in the current Czech operations under the version cy46t1mp_op2. To summarize, the choice of the scheme employed is done through a global stability criterion. Based on its values, we decide in the beginning of every integration step if it is necessary to use two iterations in the predictor-corrector scheme, or if one iteration is enough. First, an instability diagnostic (ZDIFFNL) is computed, based on vertical divergence or pressure departure non-linear residual computed in the consecutive integration steps (the choice is made through the namelist parameter RCRIT). This quantity is computed in the routine *lacdyn* in every grid point and when it is larger than a certain threshold value (namelist parameter RTHRESH), the given grid point is considered unstable. The global diagnostic (RPD_AVE), expressed as a percentage of grid points of potential instability, is obtained in the routine *cpg_drv* as the relative number of all potentially instable grid points to the total number of grid points on all vertical levels and processors. Then, RPD_AVE is compared with the value of another threshold (set as the namelist parameter RDMAX) in the routine *cnt4* and finally, the choice is made accordingly between one or two iterations (through the setting of variable NSITER). The main key LPC_DYNNS serves to switch on this dynamical scheme. All newly introduced parameters and logical keys are listed in the namelist *namdev* and default values are set and listings are made in the module *yomdev*. The modified code may be found in Prague, at kazi1:

/local/mma231/CY46/CY46t1mp_op2_nhxhypc23.

Experiments and results

The experiment runs use the current Czech operational version of ALARO with the current operational namelist setting. We chose an experimental domain with 200m horizontal resolution over central Alps with 2048x2048 grid points and 87 vertical levels. The selected domain covers the alpine region near the Italian, Austrian, German and Swiss borders, situated between 8°53' - 14°17' E and 45°22' - 49°2' N. The initial files are prepared with DFI after interpolation from 500m ALARO run over a bigger domain. We chose the case of 18 August 2022 and run the forecast from 00 UTC for 24 hours. Severe storms and wind gusts occurred during this period over Corsica, Italy and Austria [2].

The time step used for the first test was 8 s. Since the experiment with NSITER=1 was stable, longer time steps were used in order to see which value gives an unstable integration and when the integration crashes. We tested several values as 16 s, 24 s, 25 s, 30 s. It was observed that longer time steps determine bigger values of the instability index which may indicate that the instability index is well designed.

It was found that when only one iteration is used, and the value of the time step is 30 seconds, the integration crashes in the very beginning (after few integration steps). With two iterations, the integration is stabilized. The next step was to find a setting of the dynamic scheme which would give stable integration with second iteration applied as rarely as possible. We use first the instability diagnostic based on vertical divergence (RCRIT=1).

Several values of RDMAX and RTHRESH were tested. An important question is how to properly choose these variables and how to find a more systematic approach for this search. We know that RDMAX can only take values between the minimum and the maximum of the values of the global diagnostic (RPD_AVE). However, RPD_AVE depends on the selected value of RTHRESH. Hence, experiments were carried out to find the range of RPD_AVE for RTHRESH= 0.1, 0.2, … 0.9.

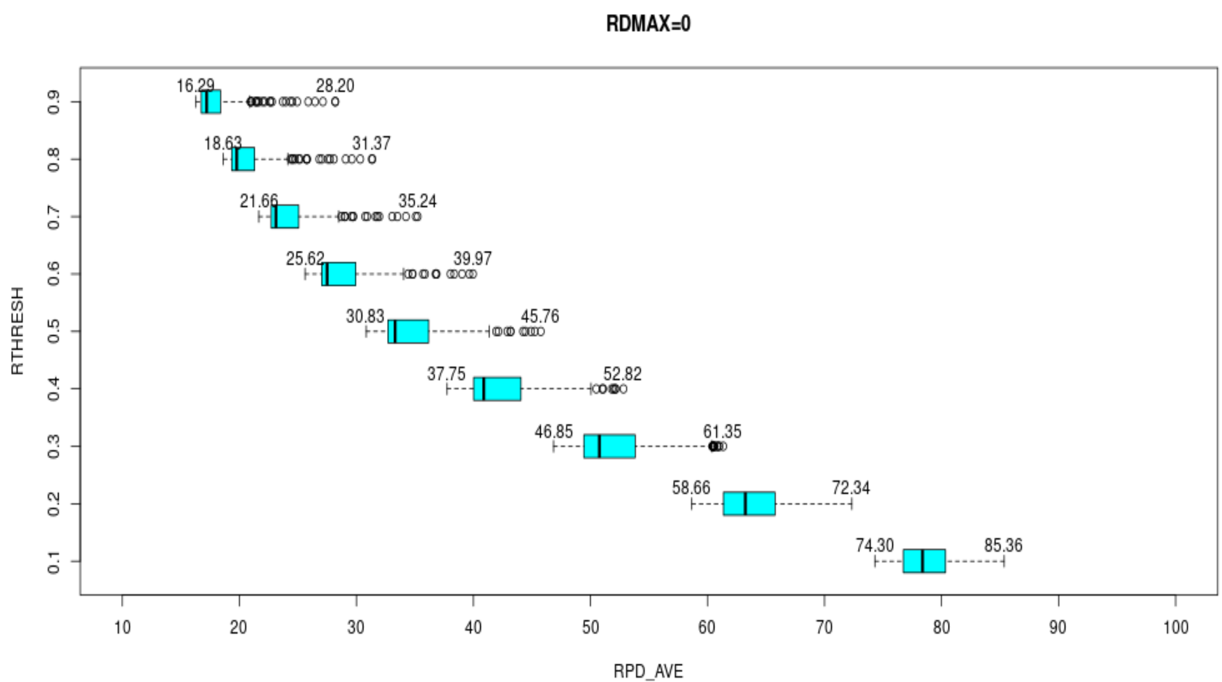

Figure 1. Boxplots of the values of parameter RPD_AVE for each RTHRESH selected, RCRIT=1.

Figure 1 shows the possible values that RPD_AVE can have when certain value of RTHRESH is selected. Since lower values of RTHRESH mean more strict condition of instability in each grid point, we can observe that larger values of the global instability diagnostic are obtained when RTHRESH decreases. In the previous work, RTHRESH was set to 0.5. Since we want to achieve stable integration with second iteration required rarely, we want to find the biggest possible RDMAX we can use for a fixed value of RTHRESH. Also, we should keep in mind that possible values of RPD_AVE change when different values of RDMAX are used. In each integration step with the choice between one or two iterations the numerical stability is affected. For example, we can see in Figure 2 how the instability diagnostic differs when the dynamic scheme is called with the value RTHRESH=0.5 and RTHRESH=0.6.

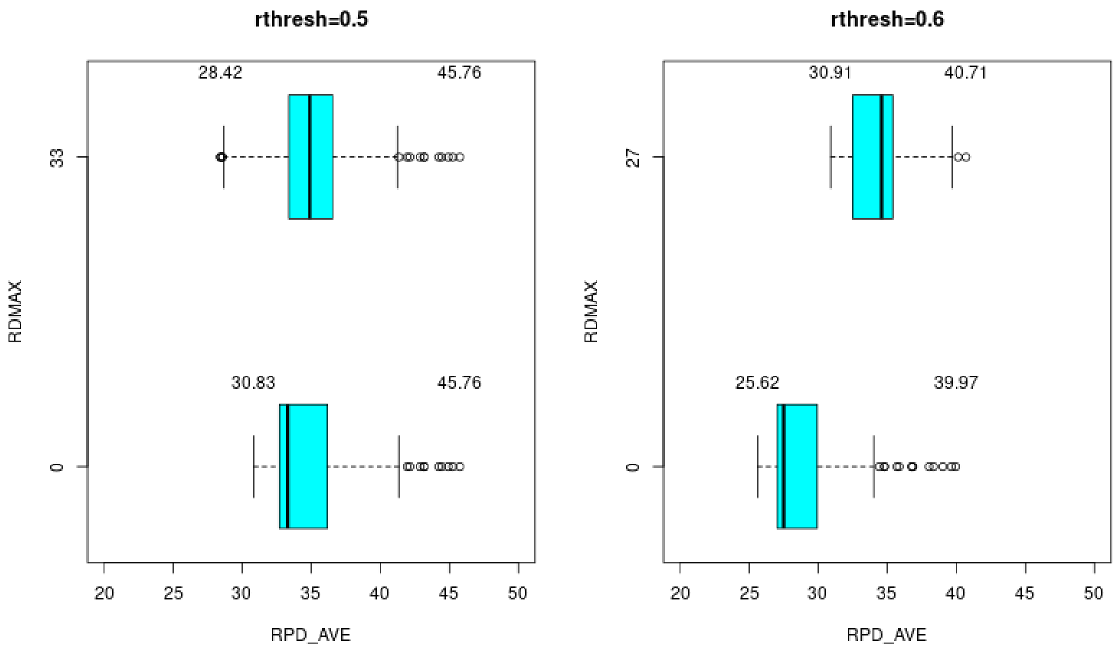

Figure 2. Boxplots of the values of parameter RPD_AVE for RTHRESH=0.5 (left) and RTHRESH=0.6 (right), RCRIT=1.

We were able to reach stable integration with different scenarios of the dynamic time scheme. It was observed that the biggest RDMAX for which the integration is still stable is usually close to the median value of RPD_AVE. For some experiments, though the integration is stable, only few integration steps with one iteration were found. For other experiments, the percentage of integration steps that use only one iteration goes up to 23 %. However, when looking at the pattern of the integration steps that use one iteration, it was observed that this only happens from time to time and we want to check if bigger blocks of such integration steps can appear.

Then similar tests were run for the instability characteristic based on pressure departure (RCRIT=0). In Figure 3 we can see that the global instability diagnostic has a different range of values in this case, but the pattern is similar regarding the relation between RTHRESH and RDMAX.

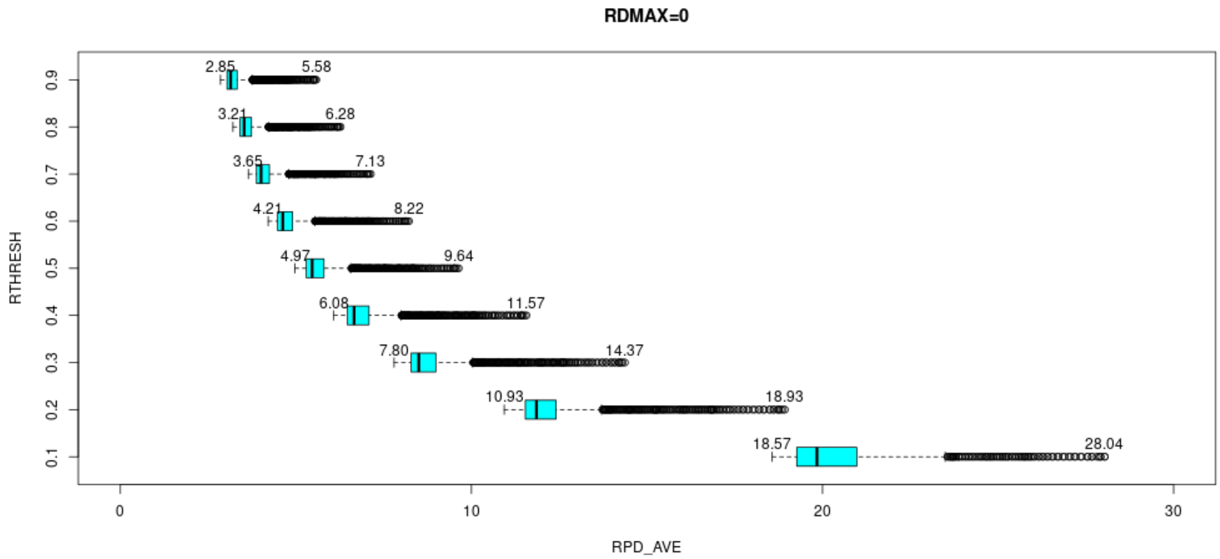

Figure 3. Boxplots of the values of parameter RPD_AVE for each RTHRESH selected, RCRIT=0.

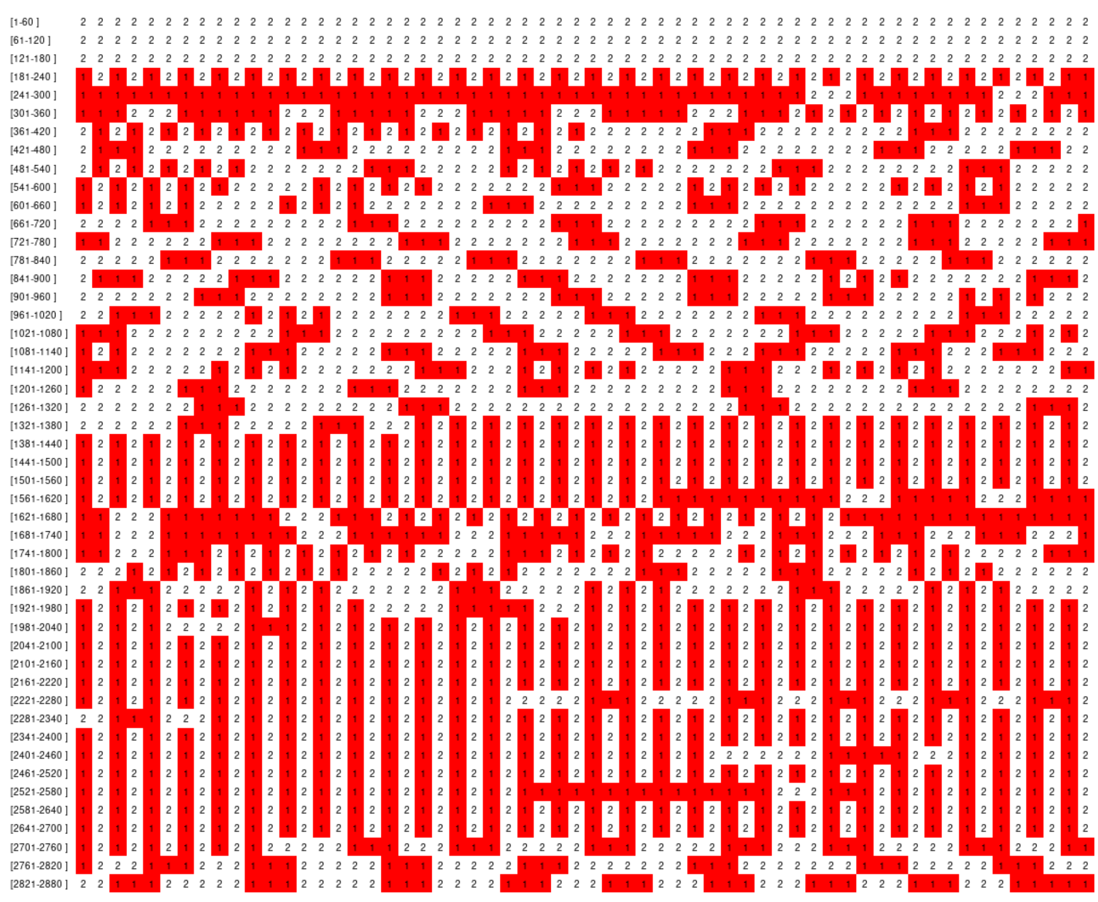

Figure 4. Number of iterations (1 – red cells or 2 – white cells) used in every integration step (indicated on the left side of the figure) of experiment PD07.

It was found that for some values of RDMAX and RTHRESH it is possible to obtain stable integration with even bigger number of integration steps when one iteration is applied than in the previous experiments. Most significant results were obtained for experiment PD07 (RDMAX=5.5; RTHRESH=0.6). Figure 4 shows the number of iterations used in the predictor-corrector scheme in every integration step for experiment PD07. In the beginning of the integration all the steps (1 to 180) require 2 iterations, then bigger blocks with only one iteration appear, followed by another slice when 2 iterations are used quite often and towards the end of the integration one or two iterations alternate for a longer period. Overall, for 41 % of the integration steps one iteration is used.

The next step was to analyze what happens in longer period. We prepared the forecast for following 14 days, starting from 00 UTC and running for 24 hours with the same set up. But just the next day, 19 August 2022, we found that with the time step of 8s and any longer time step when PC with two iterations is used the integration crashes after 1 hour. It was not the case when only one iteration was used. We found this behavior unexpected and surprising and proceed deeper in the analysis of its possible sources.

We found that strong chimneys in the field of vertical velocity are created locally on several places of the domain. Such strong source of instability is not alleviated by further iteration of the PC scheme. To the contrary, the maximum values in these chimneys are even higher when second iteration is applied. To be able to proceed in the evaluation of the dynamic scheme, we must solve first the problem with chimneys. Since there are several cures available, see [3], we believe to be able to continue the work in 2024 during the next scientific stay.

Conclusions

A continuation of the work related to the design of the temporal scheme of ALARO was done. The goal was to find a dynamic scheme that is stable, accurate and cheap. For very high resolution experiments, the new scheme should be able to choose between one or two iterations in the PC+NESC setup, depending on a stability index. Our results showed that it is possible to achieve the desired scenario. However, when longer period tests were prepared, we encountered some strange behavior regarding stability between experiments using one or two iterations for a specific case. The cause of this was found in the occurrence of strong chimneys in the field of vertical velocity on several places of the domain. The work will be continued after this issue will be solved following some already existing solutions.

Acknowledgements: Many thanks to my supervisor Petra Smolíková for overseeing this work and for the helpful ideas, as well to the CHMI team for the pleasant work environment available.

References

[1] Crăciun A., *Dynamic definition of the iterative time schemes*, RC-LACE stay report, Nov 2022

[2] https://www.essl.org/cms/the-derecho-and-hailstorms-of-18-august-2022/

[3] 4th ACCORD All Staff Workshop, Norrköping, 15-19 April 2024, presentation of Petra Smolíková