Dynamic definition of the iterative time schemes

RC LACE stay report
Scientific supervisor: Petra Smolíková

Alexandra Crăciun
NMA, Romania

CHMI, Prague

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1 Introduction

The temporal scheme of the ALARO model can be applied having two options available which allow the choice between two schemes: SETTLS and NESC. The first scheme is second order accurate but may lack stability especially in extreme weather events, while the second is more stable, but only first order accurate. For obtaining higher accuracy with NESC, the predictor-corrector (PC) scheme is enabled, increasing the computational cost. More detailed theoretical considerations can be found in [1] and [2].

In order to combine best features (accuracy and stability) of these schemes, a dynamic definition of the temporal scheme was proposed. This study is focused on finding a diagnostic that is able to discriminate points or regions that may lead to instability. According to its values, SETTLS, NESC or a combination of both could be enabled. Furthermore, this would allow a configuration in which SETTLS scheme is used as default option, with corrector step activated only when a certain threshold of "problematic" points is reached.

2 Implementation in the cycle 46

The diagnostic introduced was based on the vertical divergence non-linear residual in consecutive timesteps and was defined as follows:

$$zdiag = \frac{|(VD)^t - (VD)^{t-\Delta t}|}{|(VD)^t| + |(VD)^{t-\Delta t}|}, \tag{1}$$

This computation is made in every gridpoint. With this definition, $zdiag \in [0, 1]$. The SETTLS scheme may be formulated as the basic NESC part A, plus the SETTLS departure B. Then the combined scheme may be written as

$$COMB = A + \varepsilon B, \tag{2}$$

where $\varepsilon \in [0, 1]$. Using $\varepsilon = 1 - zdiag$ we get a scheme equivalent to SETTLS for $zdiag = 0$, while $zdiag = 1$ behaves as NESC and for other values a combined SETTLS/NESC scheme is obtained.

All necessary changes were implemented in version cy46 of the model. The stability diagnostic was introduced in routine *latte_nl*, which is called from routine *lacdyn*. This variable is further used in routine *lattex_dnt* to compute necessary quantities.

3 Results

Experiments were performed for the case of 30 October 2017, 00 UTC run. The forecast is run as the dynamical adaptation from the ARPEGE LBC files, for 72 hours, with full ALARO-1 physics. The time step of 90s is used, in 2.3 km horizontal resolution.

Initial experiment with SETTLS scheme activated and disabled PC scheme crashes after 35 timesteps (experiment V000). This demonstrates the necessity of investigating alternative schemes.

The integration is completed in the reference experiment with PC scheme using NESC in the predictor (experiment V001). Moreover, with the combined scheme using *zdiag*, the model run does not crash anymore (experiment V002). We calculate the temporal evolution of spectral norms averaged over the whole horizontal domain and over all vertical levels, as an indicator of stability. Figure 1 shows the evolution of averaged spectral norms for model variables obtained in the two experiments V001 and V002 and for two experiments V003 (NESC) and V004 (combined with pressure departure based characteristic of stability) mentioned in Chapter 4.

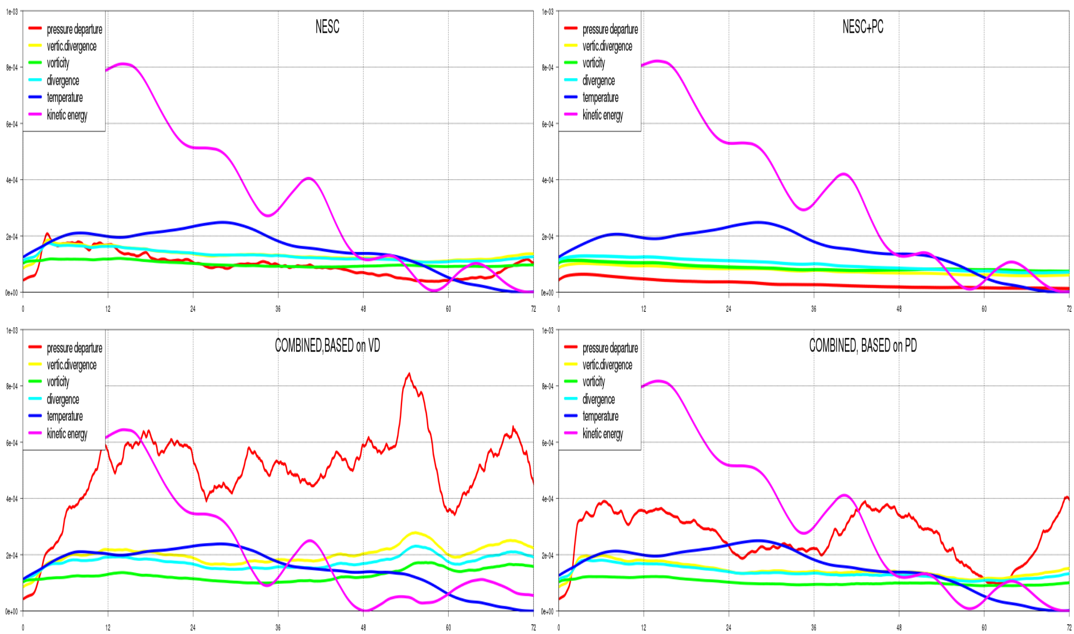

Figure 1: *Averaged spectral norms for model variables obtained for each experiment (courtesy of Petra Smolíková)*

All four experiments may be considered stable. The most visible difference is in the pressure departure norm (red). Compared to this, spectral norms for vertical divergence (yellow) have more stable values. First, we choose the vertical divergence as the basis for stability characteristics because it is less sensitive to the temporal scheme design.

Figures 2 and 3 show the value of the diagnostic for experiments V000, V001 and V002 after 10, 20 and 30 timesteps, in order to observe the behavior close to the timestep the model crashed. The results are presented for two vertical levels: 10 and 20. It can be seen that the number of points indicating instability (yellow regions) is gradually increasing with timestep, reaching a maximum in experiment with SETTLS scheme activated, after 30 timesteps.

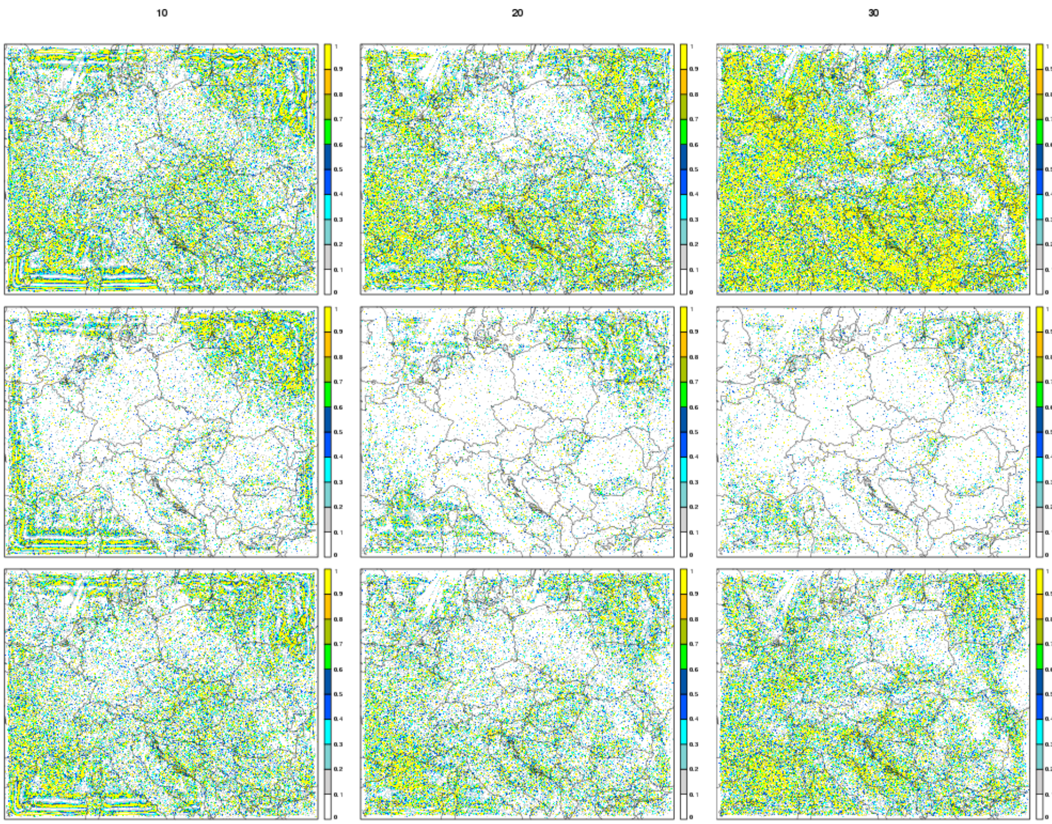

Figure 2: *Diagnostic for experiments V000 (first row), V001 (second row) and V002 (last row), level 10, after 10, 20 and 30 timesteps*

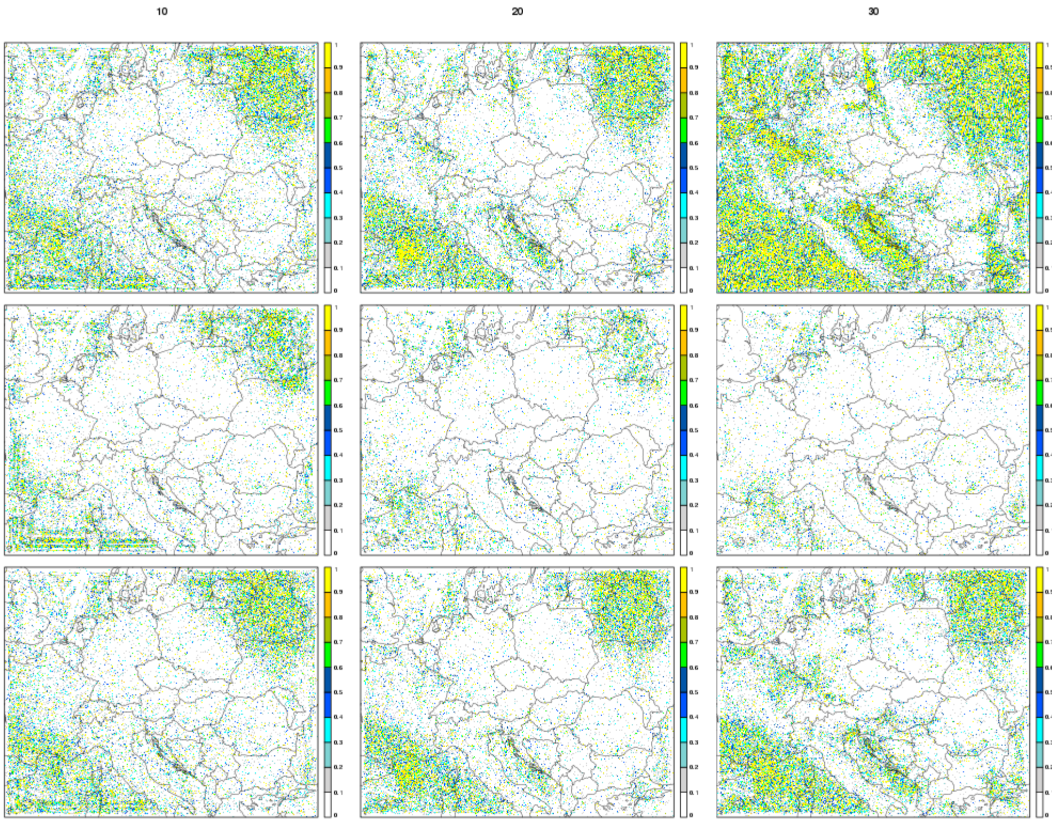

Figure 3: *Diagnostic for experiments V000 (first row), V001 (second row) and V002 (last row), level 20, after 10, 20 and 30 timesteps*

In bottom levels, there are more regions for which the diagnostic is closer to 0 (not shown). Figure 4 shows the percentage of gridpoints in each level where *zdiag* exceeds the 0.5 threshold, after 30 timesteps. It can be observed that in upper levels, there are more points that indicate potential instability. However, these amounts are almost halved in peak levels when combined scheme is used.

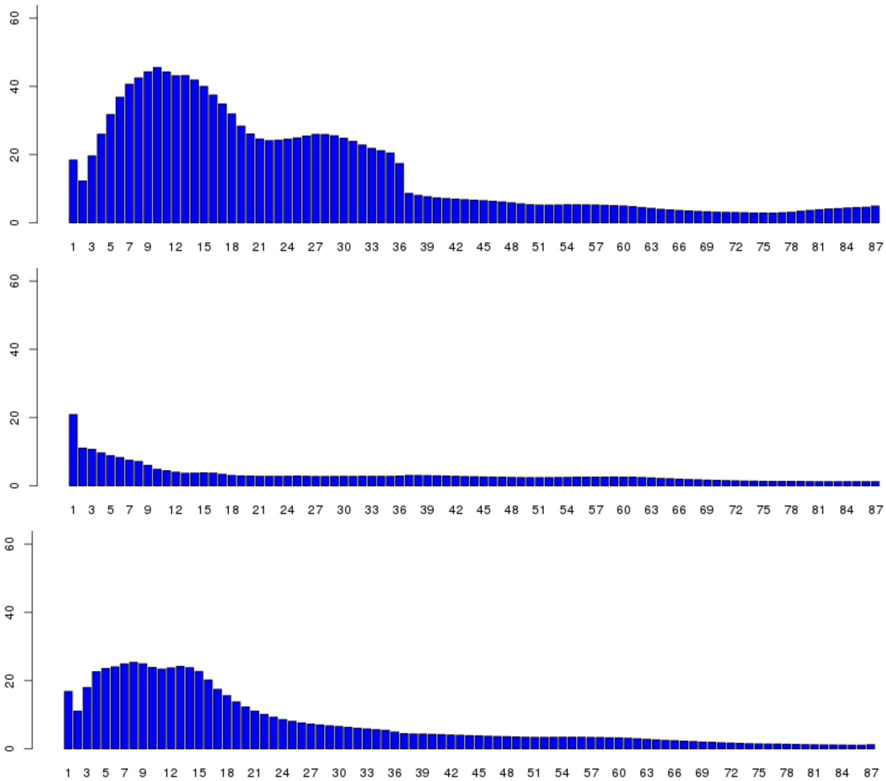

Figure 4: *Percentage of gridpoints with zdiag > 0.5, after 30 timesteps, for experiments V000 (first row), V001 (second row) and V002 (last row)*

In order to check if another variable would lead to more visible representation of instability, an approach based on pressure departure was also considered:

$$zdiag = \frac{|(PD)^t - (PD)^{t-\Delta t}|}{|(PD)^t| + |(PD)^{t-\Delta t}|}, \tag{3}$$

The same three experiments were considered accordingly. There are less differences between them in this approach (not shown). At the same time, similar conclusion can be drawn: the amount of "unstable" points is reduced in the combined scheme.

In comparison to vertical divergence based diagnostic, this one indicates less "unstable" gridpoints. It can be seen that this definition leads to smoother results (figure 6).

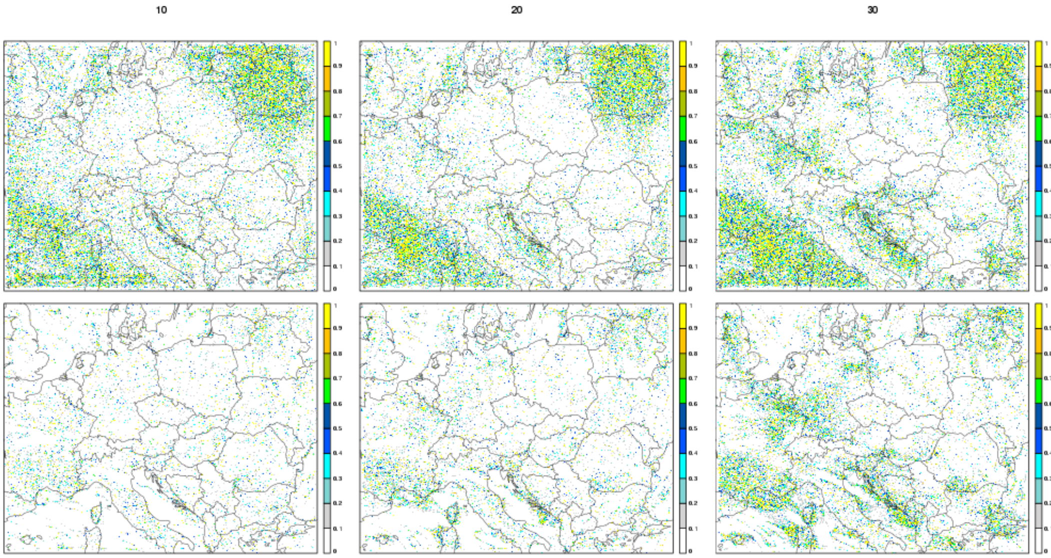

Figure 5: *Diagnostic for experiments with combined SETTLS/NESC based on vertical divergence (first row) and pressure departure (second row), level 20, after 10, 20 and 30 timesteps*

4 Verification

In order to evaluate the accuracy of the new scheme, verification scores were computed for the case of 30 October 2017, for a 72 hours integration period. The following schemes are considered in the experiments (table 1): simple NESC, NESC + PC options enabled and the two combined SETTLS/NESC schemes according to diagnostics based on: vertical divergence and pressure departure.

Name	**Description**
V001	NESC + PC
V002	combined SETTLS/NESC based on vertical divergence
V003	NESC
V004	combined SETTLS/NESC based on pressure departure

Table 1: Experiments considered for the statistical validation

Statistical scores averaged on the whole evaluation period (72 hours), for all levels (both in surface and upper levels: 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20 and 10 hPa) are shown in figure 6 for the following meteorological parameters: temperature, wind speed, relative humidity and geopotential.

It seems that for surface and 1000 hPa levels, scores have similar values for the four experiments. However, when going upper, scores begin to deteriorate for V002 forecast (more visible in wind speed scores). Significant increase in the bias and RMSE values for V002 experiment occurs around the 250 hPa level. This can be related to the fact that the majority of points for which the scheme is enabled occur in upper levels (figure 4).

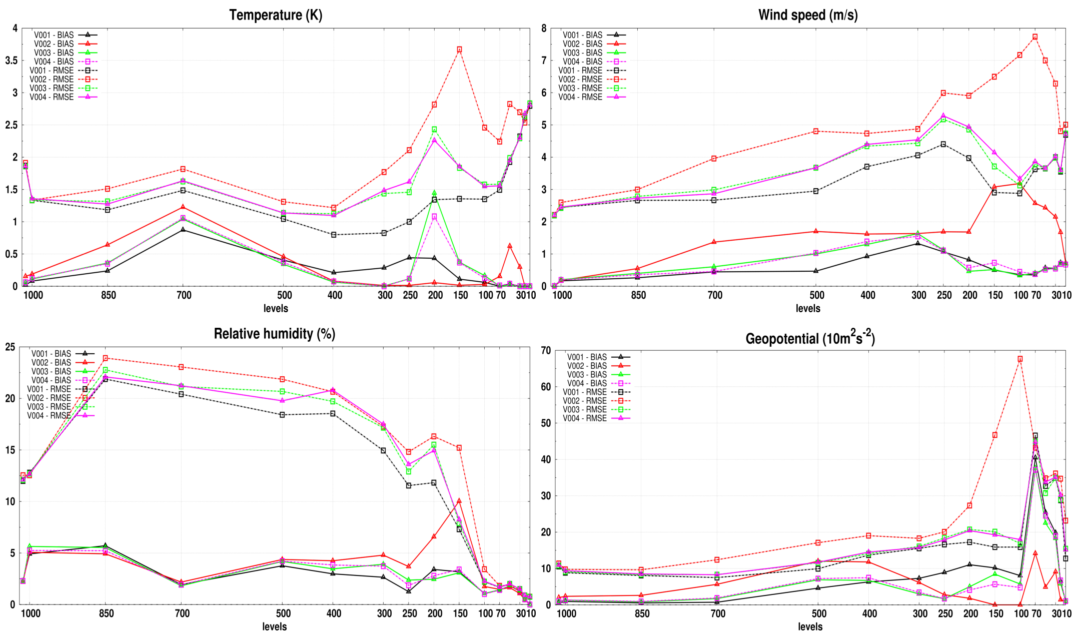

Figure 6: *Averaged bias (continuous lines) and RMSE (dashed lines) for temperature, wind speed, relative humidity and geopotential forecast obtained from experiments V001 (black), V002 (red), V003 (green) and V004 (magenta)*

Figure 7 shows the evolution of scores with forecast time, for surface parameters. Even in surface level, we may see that the scores start to diverge after longer integration. For instance, temperature and wind speed bias increase after 42 hours (though the opposite can be observed for the case of the geopotential). On the other hand, the differences between the four experiments regarding surface relative humidity are very little.

Nonetheless, differences can be spotted earlier in scores computed for the same parameters in 500 hPa level forecast (figure 8). The forecast of relative humidity seems the least affected by the changes in the temporal scheme.

We can see in Figures 6, 7 and 8 that the two versions of combined SETTLS/NESC scheme lead to different forecast performance, depending on the definition of the stability diagnostic involved. While for vertical divergence based diagnostic the scores are worse in comparison to the NESC scheme (especially in top levels above 250 hPa), for pressure departure based diagnostic, they are more similar to those of the NESC scheme. Unfortunately, neither of them appear to shows higher accuracy then the simple NESC scheme. The reference V001 experiment remains by far the most accurate one. These results indicate that a more careful definition should be considered for the stability diagnostic in order to prevent accuracy loss.

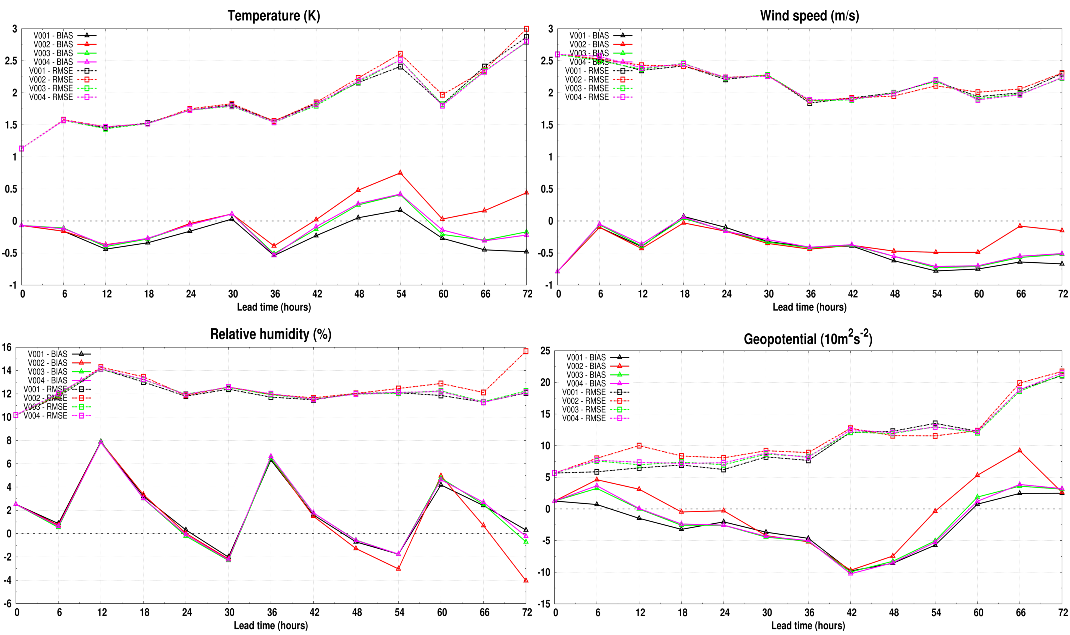

Figure 7: *Bias (continuous lines) and RMSE (dashed lines) for surface temperature, wind speed, relative humidity and geopotential forecast obtained from experiments V001 (black), V002 (red), V003 (green) and V004 (magenta)*

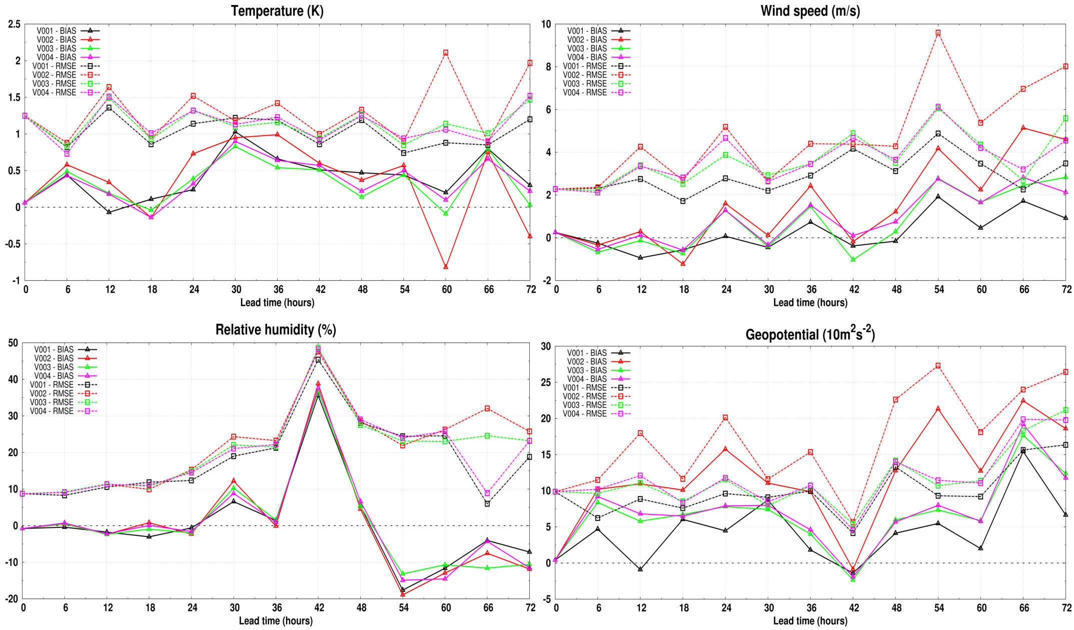

Figure 8: *Bias (continuous lines) and RMSE (dashed lines) for 500 hPa temperature, wind speed, relative humidity and geopotential forecast obtained from experiments V001 (black), V002 (red), V003 (green) and V004 (magenta)*

5 Conclusion

Two different stability diagnostics were introduced based on the temporal variability of nonlinear residual in the vertical divergence prognostic equation, pressure departure prognostic equation respectively. Using these diagnostics, the combined SETTLS/NESC temporal scheme was designed. Both combined schemes result in stable integration to the contrary with SETTLS scheme which may lead to unstable integration in certain cases. However, the results of statistical evaluation show that these choices of stability diagnostic do not beat the simple NESC scheme in terms of accuracy and that both combined schemes lag behind the reference scheme with NESC applied in predictor and one additional iteration of the temporal scheme (corrector) in terms of precision of the results. Since our investigation was limited we plan for the near future to define other diagnostics that would be able to determine a more permissive choice of unstable points, but maintain overall stability of the scheme.

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References

[1] Jozef Vivoda, *Dynamical PC scheme for NH kernel of AAA models, Part 1, RC-LACE stay report* http://www.rclace.eu/?page=13 , 2017.

[2] Jozef Vivoda, *Dynamical PC scheme for NH kernel of AAA models, Part 2, RC-LACE stay report* http://www.rclace.eu/?page=13 , 2017.