Dynamical PC scheme for NH kernel of AAA models

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1 Introduction

Nowadays, operational NWP limited models, used at convection permiting scales (2km and higher), are computed on relatively small geographic domains. It means that prevailing character of weather could be very similar in the whole domain. When calm non-convective weather conditions are in the whole domain then NH effects are uniformly neglegible. We know from experiences that in such situation, we could integrate model with cheaper SI scheme. More expensive PC scheme is expected to be required only from time to time only. If we could identify dynamically what scheme is required at given time step, than we could significantly improve model prediction efficiency as SI scheme is approx. 30 % cheaper when compared to PC scheme (LPC_CHEAP considered).

During the stay we aim to determine some norm or measure that will be proportional to NH activity in model domain. Based on this measure we could decide at the beginning of time step if we use SI scheme or PC scheme. First idea is to look at pressure departure residuals.

We could even dynamically determine number of iterations in PC scheme. It is currently constant during whole integration. Disadvantage of such approach is inability to predict in advance the time we need to compute model prediction. Therefore such option must be carefully investigated.

This approach is difficult to use for large domain, because PC scheme iterations has "global" character. We could expect always some area with NH active events in such simulations. However, our approach can be very beneficial for future small domain convective scale ensemble simulations, when PC scheme will be active during convection activity only for example.

If we try to see things in larger picture, we could combine single precisiton speedup with actually proposed dynamical PC scheme one. we could expect CPU saving in range 50-60 % or maybe higher. And we still not consider GPU potential (cuBLAS is 5x faster that traditional BLAS, half-level precision for some calculation where precition is not an issue ...). With little bit of fantasy, we could imagine to afford running kilometric resolutions in relatively short time span even in countries with weaker IT infrastructure.

2 Test case

We focused on the case from 28th January 2008 over central Europe territory. The resolution is 1km, 97 vertical levels and time step 60s. This case is not possible to compute with SI scheme (SETTLS) and PC scheme must be used.

In order to accelerate development we focus on subdomain with 90x60 E zone size, 1km resolution and 87 vertical levels) (referred as CZTI). We verified that the stability remain unchanged with respect to full domain. The geographical domain CZTI and its orography is shown on Fig 1.
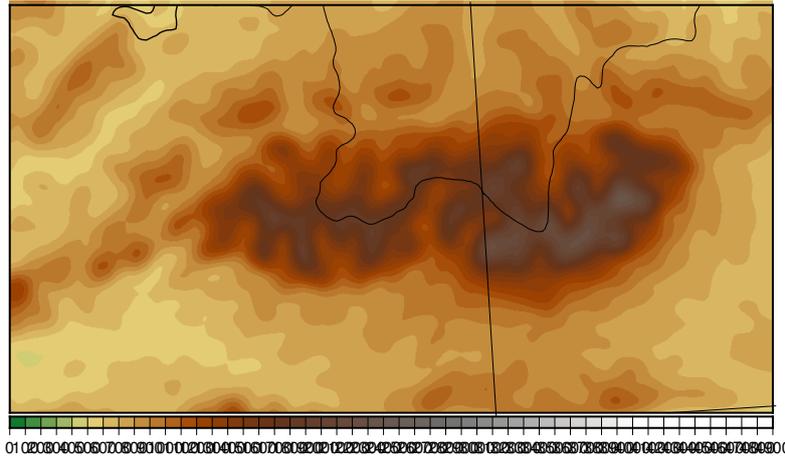
Figure 1: orography of CZTI domain - 1km resolution

3 Determination of time stepping and implementation in cy43t2

We found that SI and also PC scheme are unstable when SETTLS extrapolation is used globally on nonlinear residuals (LSETTLS). The stability is recovered in both schemes when non-extrapolating approach is used globally on residuals (LNESC).

Stability is not sensitive to extrapolation approach used on SL trajectory computations (LSETTLST, LSETTLSV, LNESCT, LNESCV).

Using LNESC with SI scheme provides first order accurate scheme in time. This is clearly visible on gravity current simulation on Fig 2.

We start integration with PC scheme. We use SETTLS dataflow. We decide if we use in given point and given variable SETTLS or NESC scheme. Global characteristic in each level for each variable is computed under cpg_drv extrapolated using NESC (SETTLS is off). This characteristic is shown on Fig 3, and it can be seen that number of points where SETTLS must be off is rapidly decreasing at the beginning of time step.

In order to run NESC scheme using SETTLS dataflow following routines were modified lattex_dnt (3D residuals), lattes (continuity equation residual), lattex (X-term extrapolation), lanhsib (linear terms - this is not protected by LSETTLS key, but rather with LSLINL, LSLINLC2).

(a) PC scheme and NESC   (b) SI scheme and NESC
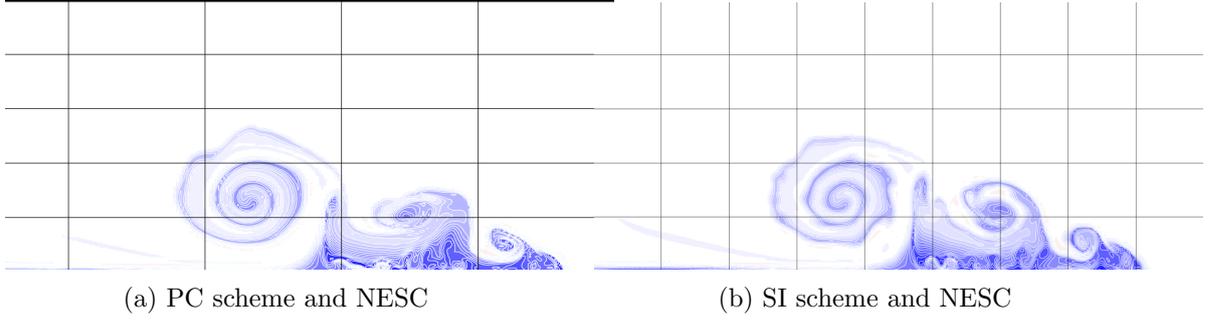
Figure 2: Inaccuracy of NESC approach shown on Straka gravity current after 600s of simulation
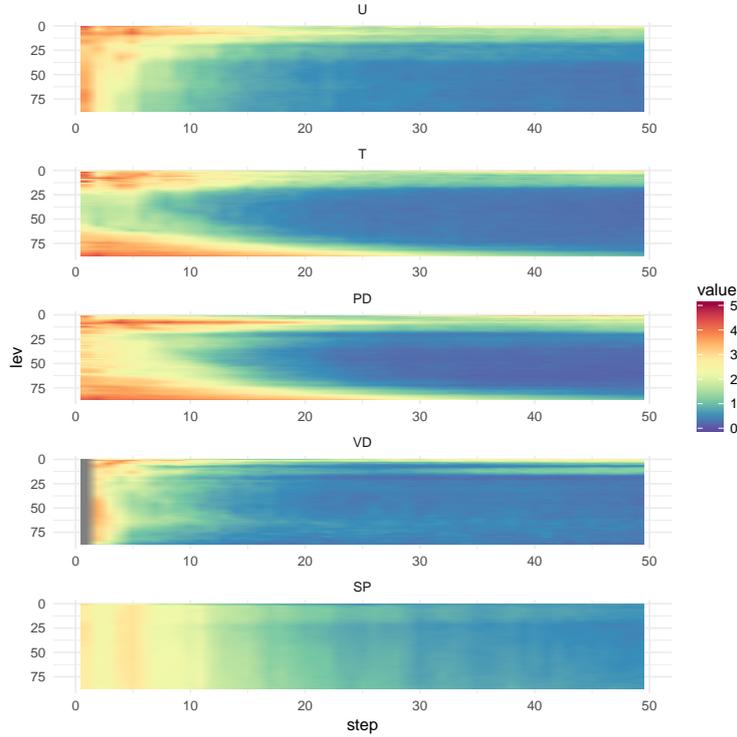
Figure 3: percentage of points where SETTLS scheme was off under SETTLS scheme in 3D case on CZTI domain. Horizontal axis is model time step, vertical axis is model level. Statistic is computed for equations of U wind component, T, PD, VD and 3D part of continutity equation

W have introduced quantity λ to control extrapolation method during prediction. To define λ we adopted approach of Diamantakis (LSETTLSVF).

4 Uniform acceleration scheme (SETTLS)

The nonlinear residual is quantity $R = M - L$ where M is full nonlinear space discretized model and L linear one. Time stepping of each equation can be written

$$\frac{x_F^{t+\Delta t} - x_O^t}{\Delta t} = R_M^{t+\frac{\Delta t}{2}} + \frac{L_F^{t+\Delta t} + L_O^t}{2} \tag{1}$$

The quantity at timeinstant $t + \frac{\Delta t}{2}$ is unknown as we predict at instants $t + n\Delta t$ and therefore must be extrapolated. The stable extrapolation scheme SETTLS gives

$$R_M^{t+\frac{\Delta t}{2}} \approx \frac{1}{2}\left(R^t\right)_F + \frac{1}{2}\left(2R^t - R^{t-\Delta t}\right)_O. \tag{2}$$

The nonextrapolating scheme yields

$$R_M^{t+\frac{\Delta t}{2}} \approx \frac{1}{2}\left(R^t\right)_F + \frac{1}{2}\left(R^t\right)_O. \tag{3}$$

5 Implementation of SETTLS and PC_CHEAP

PC scheme corrector steps are formulated as

$$\frac{x_F^{t+\Delta t(n+1)} - x_O^t}{\Delta t} = \frac{1}{2}\left(R^{t+\Delta t(n)}\right)_F + \frac{1}{2}\left(R^t\right)_O + \frac{L_F^{t+\Delta t(n+1)} + L_O^t}{2} \tag{4}$$

The efficient implementation of PC_CHEAP scheme requires to store quantity interpolated at origin point during predictor

$$BC_O = \left(x^t + \frac{\Delta t}{2}R^t + \frac{\Delta t}{2}L^t\right)_O \tag{5}$$

However, we see from Eq. 2 that during SETTLS we compute different quantity at origin point

$$BS_O = \left(x^t + \frac{\Delta t}{2}\left(2R^t - R^{t-\Delta t}\right) + \frac{\Delta t}{2}L^t\right)_O \tag{6}$$

For appropriote implementation we have to divide interpolated quantity into two parts

$$BS_O = BC_O + \frac{\Delta t}{2}\left(R^t - R^{t-\Delta t}\right)_O. \tag{7}$$

Further complication of problem is cause by LGWADV approach, where nonlinear and linear parts of equation are formuled using different prognostic quantities. Therefore we can not mix them and they have to be separated. It gives

$$BC_O = \left(x^t + \frac{\Delta t}{2}M^t\right)_O, \tag{8}$$

the corrector quantity interpolated into origin point has no linear term contribution. The SETTLS part is

$$BS_O = BC_O + \lambda\frac{\Delta t}{2}\left(M^t - M^{t-\Delta t}\right)_O - \lambda\frac{\Delta t}{2}\left(L^t - L^{t-\Delta t}\right)_O. \tag{9}$$

We can control by λ which extrapolation approach is used during time step. $\lambda = 1$ turns on SETTLS scheme, $\lambda = 0$ turns off and we use NESC approach.

Implementation of SETTLS scheme with LPC_CHEAP requires 3 interpolation buffers for each predicted quantity during predictor step

PB1 pointer	quantity	usage	routine	quanti
MSLB1X9_NL	$\lambda\frac{\Delta t}{2}\left(M^t - M^{t-\Delta t}\right)$	SETTLS predictor	lattex_dnt/lattes	GMV9
MSLB1X9_SI	$\lambda\frac{\Delta t}{2}\left(L^t - L^{t-\Delta t}\right)$	SETTLS predictor	lanhsib	GMV9
MSLB1X0	$\frac{\Delta t}{2}M^t$	SETTLS/NESC predictor/corrector	lattex_dnt/lattes	GMV9
MSLB1X9	$x^t + \Delta tP$	SETTLS/NESC predictor/corrector	lattex_dnt/lattes	GMV9

Only quantity needed to be saved after interpolations during predictor step of PC scheme is GMV9 buffer in lapineb.

We added for completeness also physical tendency at origin point ΔtP.

Final point buffers remains unchanged and they are independent of extrapolation method.

6 Definition of extrapolation method in given point in space

The extrapolated quantity under LSETTLS key is

$$R^{t+\frac{\Delta t}{2}} = 2R^t - R^{t-\Delta t}. \tag{10}$$

We measure amplitude of extrapolated quantity in PD equation (lattex_dev) as

$$\lambda_1 = 1 - \frac{|R^t - R^{t-\Delta t}|}{|R^t| + |R^{t-\Delta t}|}. \tag{11}$$

Another appropriate function would is

$$\lambda_2 = 1 - tanh\left((R^t - R^{t-\Delta t})^2\right). \tag{12}$$

Typical function properties are shown on Fig 4. We do not understand exactly the meaning of non-symmetric behaviour of λ_1. We believe that function shall be symmetric with respect to residual difference magnitude.

When value of $\lambda \approx 1$ we turn on SETTLS scheme in given point in space, NESC otherwise.

7 Changing time stepping from PC to SI and vice versa

We collect globally information about the usage of SETTLS/NESC, based on λ parameter (see cpg_drv global reduction). The global usage of scheme is computed as $\alpha = 100\frac{n_{NESC}}{NGPTOTG}$. Be aware that in LAM version of code $NGPTOTG = NDLON * NDGUXG$.

When α is sufficiently small we know that we are using SETTLS scheme in majority of points. This allow us to turn of PC scheme (setting NSITER=0 in cnt4). We continue in model integration using SI scheme with SETTLS. We further control evolution of α
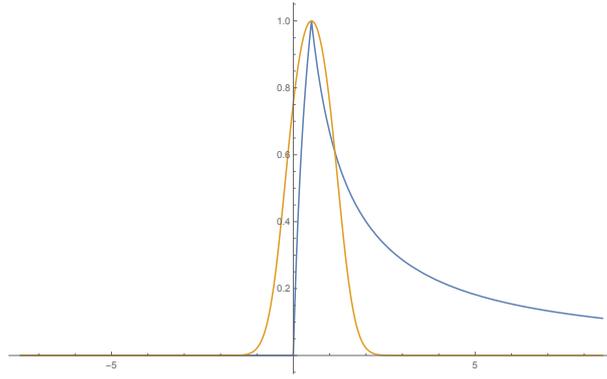
Figure 4: Functions that measure amplitude of extrapolated quantity. Blue is λ_1 and yellow is λ_2. The residual $R^{t-\Delta t} = 0.5$ and the residual R^t is plotted on axis x.

parameter. Once it increases over given treshold, we turn on PC scheme again (NSITER=1 in cnt4). This is done during whole model integration.
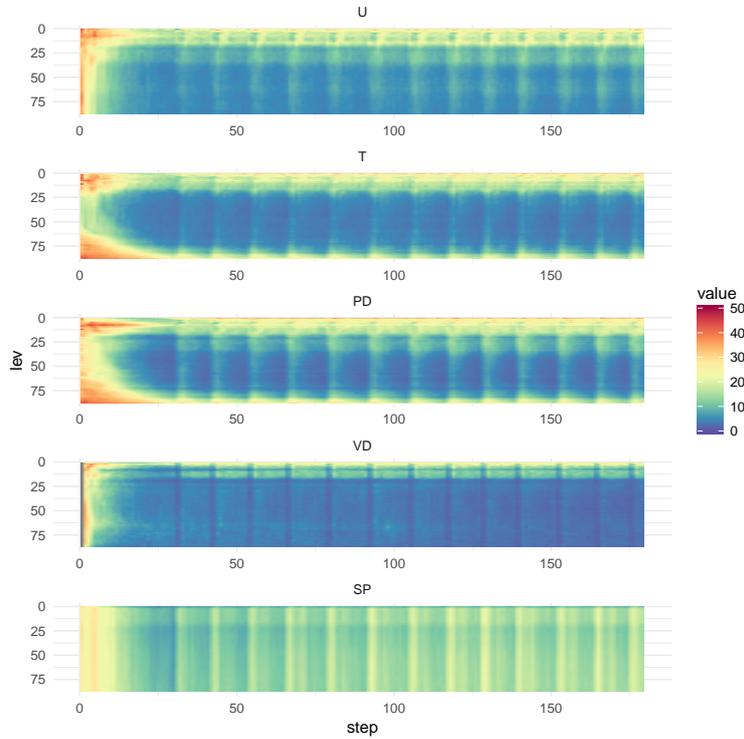
Figure 5: The percentage of points where NESC scheme is used. When in average the $\alpha > 10$ we turn in SI scheme, PC with NSITER=1 otherwise. 3h integration is shown, computed with dt=60s. In total 26 time steps were SI in this simulation (10% of CPU was saved)

8 Technical implementation of SETTLS with PC_CHEAP

The scheme is designed for HY and NH model (HY not tested). The following variables have to be set in namelist

6

namelist	variable	value
NAMDYNA	LSETTLS	TRUE
NAMDYNA	LPC_CHEAP	TRUE
NAMDYN	N[X]LAG	3

All other consistencies imposed by setup must be fullfilled.

We modified following routines

1. PTRSLB1

   Introduction of pointers MSLB1[x]9_NL

2. SUSLB

   Initialisation of MSLB1[x]9_NL pointers

3. LATTEX

   Interface of PB1 buffer to LATTEX_DNT routine

4. LATTEX_DNT/LATTES

   SL buffers are filled according Table 5. Introduction of ZEXTRA that play the role of λ parameter in Table 5

5. LANHSIB

   Introduction of ZEXTRA that play the role of λ parameter in Table 5.

6. LAPINEB

   Interface to LARCINB and LARCINHB. Saving of interpolated buffers into PC_CHEAP buffer during predictor, restoring buffers during corrector. Contruction of RHS from partially interpolated quantities from Table 5.

7. LARCINB/LARCINHB

   Linear interpolation of 3D buffers.

References

[1] Jozef Vivoda, *Vertical finite element discretisation in NH kernel of model system AAA*, RC LACE Stay report, Prague, 2015.

[2] M. Diamantakis and L. Magnusson, *Numerical sensitivity of the ECMWF model to Semi-Lagrangian departure point iterations*, ECMWF Technical Memorandum, 2015 (http://www.ecmwf.int/sites/default/files/elibrary/2015/15302-numerical-sensitivity-ecmwf-model-semi-lagrangian-departure-point-iterations.pdf)