Coupling of physics to the dynamics in ALADIN

Martina Tudor Croatian Meteorological and Hydrological Service tudor@cirus.dhz.hr

Abstract

This poster describes the activities related in increading the accuracy of the treatment of the pysics tendencies in ALADIN (Aire Limitée Adaptation dynamique Développement InterNational) System.

Introduction

The semi-Lagrangian (SL) advection scheme and the semi-implicit (SI) treatment of linear terms has enabled usage of long time-steps in NWP models. Move from three-time-level (3TL) to two-time-level (2TL) schemes has further increased the efficiency of the model.

Second order accuracy in the computations of the non-linear terms and wind components used to find the origin point in 2TL schemes is accomplished either by using some kind of extrapolation, eg. SETTLS scheme (Hortal, 1998), or using iterative schemes (Cullen, 2001, Benard et al, 2004,2005). These results have encouraged research on second-order accurate coupling of physics parametrizations.

Evaluating half of the physics tendencies in the origin point and the other half in the final point of trajectory would ensure the second order accuracy of coupling physics to SL dynamics.

In the current operational and testing framework, ALADIN/ALARO physics is computed before the explicit dynamics and the resulting increment is interpolated to the origin point. This solution is only first order accurate. The goal of this work is to examine second order accurate solution for coupling of the physics tendencies to the dynamics.

When and where to calculate physics?

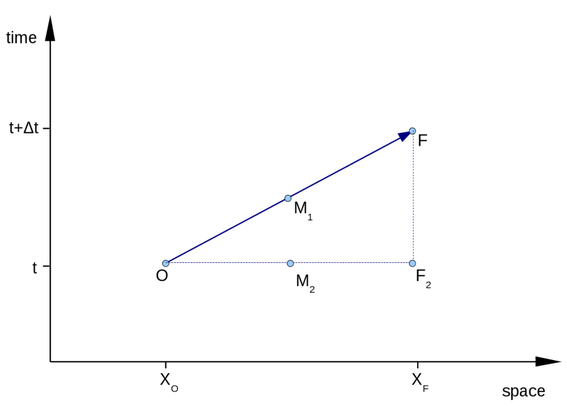

Figure 1: Schematic figure of semi-Lagrangian trajectory, O is the origin point, F is the final point of trajectory, M_1 is the "middle point" of trajectory in space and time, M_2 is the "middle point" of trajectory in space only, F_2 is the final point in space only.

Figure 1. shows the scheme of the semi-Lagrangian trajectory. Physics tendency may be computed in O as in ALADIN, in F as previously done in IFS, in M_1 as done in IFS etc. Coupling of physics to dynamics in M_1 is more accurate than coupling it in either O or F .

There are several limitations due to the model algorithm, but there are still plenty of options where to couple physics tendency to the dynamics, and how (sequentially or parallel, taken from Termonia and Hamdi, 2007).

- physics parametrizations may be computed before or after the explicit part of the dynamics,
- the physics tendency may be coupled to dynamics at different positions (in space and time) on the semi-Lagrangian trajectory,
- the physics and dynamics may be computed in parallel or sequential manner.

For example, if physics is called after the explicit part of dynamics, it may use the value updated by dynamics, or not. On the other hand, if physics is called before the explicit part of dynamics we may or may not upgrade the wind field used for trajectory research with the physics contribution. There are plenty of other variations our imaginative minds might think of, but we should stick to those that are achievable at a relatively low cost and without cumbersome changes in algorithms of the rest of the model.

Model implementation

Physics at different positions on SL trajectory

The physics tendency with the current set-up is computed using state of the atmosphere at the beginning of the time-step X^t. Output from the physics package gives the increment of the model state due to parametrized processes $\Delta_{phy}X$. The new option is to couple the computed physics tendency in the origin point of the trajectory, final point or somewhere in between O and F is coded in such a way that now the physics tendency is used like this:

$$\Delta t P_M^{t+\frac{\Delta t}{2}} = (1 - RSLPHY) * P_O^t + RSLPHY * P_F^t \qquad (1)$$

Physics tendencies extrapolation

Using similar steps as were used for the LSETTLS scheme, we may approximate the physics tendency in the middle point on trajectory (in space and time) as:

$$\Delta t P_M^{t+\frac{\Delta t}{2}} = \frac{\Delta t}{2}\left[2P_O^t - P_O^{t-\Delta t} + P_F^t\right] \qquad (2)$$

Experiments

ALARO0 version of physics package was used and run on the domain with 9km horizontal resolution, linear grid and 43 levels in the vertical (low resolution allows longer time steps). The time-step dependence of different schemes was tested in a way that there were two forecasts run for each scheme: one with an operational time-step of 360 seconds and another with 30 seconds time-step. Since the time needed for integration with the short time step is very long, only forecasts up to 21 hours were used. The accuracy of each scheme was measured with the deviation of the long time-step forecast from the short time-step forecast using:

$$dev = \sqrt{\overline{(F_{\Delta t=360} - F_{\Delta t=30})^2}} \qquad (3)$$

the root of the areal average of the square of the forecast difference as a measure of the differences in forecasts produced using different time-steps. It is assumed that the better scheme has smaller difference between forecasts computed with different time steps.

Description of experiments

exp1 the reference using physics tendency interpolated to the origin point O,

exp2 half of the physics tendency P_t is interpolated to the origin point and half used at the arrival point (equivalent of coupling physics tendency to dynamics in M_2 on Figure 1.),

exp3 the whole physics tendency is used in the final point (equivalent of coupling physics tendency to dynamics in F_2 on Figure 1.),

exp4 as exp1 but with using updated winds in trajectory research in place of stable extrapolation (No SETTLS),

exp5 as exp2 but with using updated winds in trajectory research in place of stable extrapolation (No SETTLS),

exp6 as exp3 but with using updated winds in trajectory research in place of stable extrapolation (No SETTLS),

exp11 as exp1 but the wind field used for trajectory research is upgraded with the physics tendency,

exp12 as exp2 but the wind field used for trajectory research is upgraded with the physics tendency.

Experiments exp3 and exp6 were unstable with 360 seconds time step and are not showin in the figures below.

Experiments exp11 and exp12 have values so close to their corresponding references (exp1 and exp2) that the lines are sometimes impossible to distinguish.

Averaging the physics tendency between origin and final points of the SL trajectory gives smaller root mean square error for most of the model variables, especially higher in the atmosphere. For the lowest model levels, an improvement can be seen during the first 6-9 hours, afterwards it deteriorates, at least for temperature and relative humidity. But for pressure, we can see the opposite, on all model levels. It is also interesting to note that the error decreases between 3 hour and 9 hour forecasts for relative humidity, temperature and velocity in the lowest model level. It also decreases for pressure between 3 and 15 hour forecasts on all model levels. This indicates possible problem that occurs during the first steps of the model forecast. Looking at the pressure, we can see that the error grows only during the first 3 hours, and afterwards changes only slightly. Also, although the results for pressure show deterioration, geopotential shows improvement, except on the top of the atmosphere.

Including physics tendency in the wind field used for trajectory research (exp11) did not bring significant change when compared to the reference (exp1), except a slight improvement later during the forecast for several variables. Perhaps full benefit of this scheme may be noticed only for much longer model run.

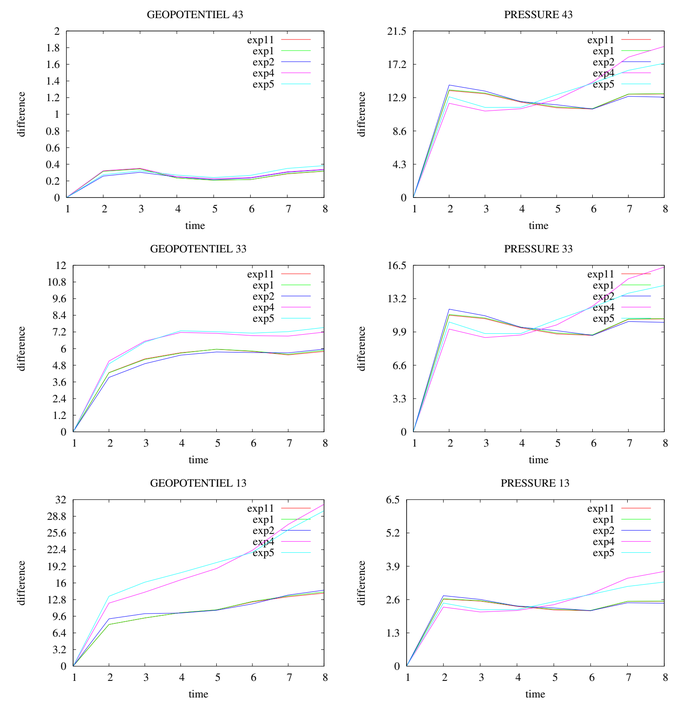

Figure 2: Geopotentiel (left) and pressure (right) root mean square errors computed with eq. 3 for levels 43 (top row), 33 (second row) and 13 (bottom) for **exp11** (red), **exp1** (green), **exp2** (blue), **exp4** (pink) and **exp5** (light blue). The results are shown on figures. The x axis denotes number of the output file, without output frequency, 1 for analysis, 2 for 3 hour forecast, 8 is 21 hour forecast. Lines for **exp1** and **exp11** are almost overlapping.

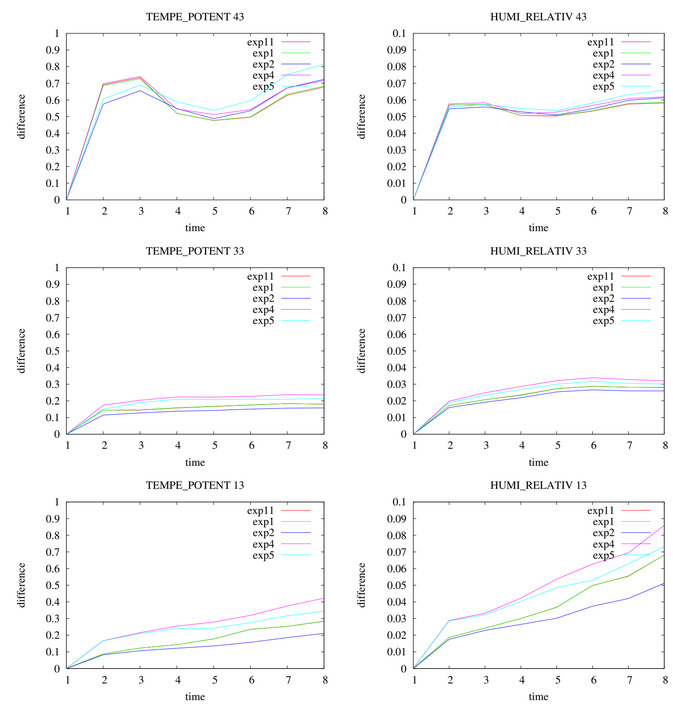

Figure 3: As figure above, but for potential temperature and relative humidity.

Conclusions

Since physics of the ALARO package of the ALADIN System is called before the dynamics, averaging of the tendency along trajectory in both space and time is difficult to achieve. At this stage, it may be seen that averaging the physics contribution along the trajectory, even if done only in space and not in time, can bring potential benefits, especially for the wind field higher in the atmosphere. The problems of the temperature and moisture on the lowest model level (probably the whole PBL) should first be solved.