Assessment of the Coupling of Physics to Dynamics: ECMWF approach

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1.- Introduction

This note describes a partial second-order accurate approximation of the physical parametrizations in the two-time-level semi-Lagrangian and semi-implicit (2TLSLSI) version of the HIRLAM model. The approximation is achieved by averaging all or part of the parameterization tendencies along the semi-Lagrangian trajectory, following the ECMWF approach (Wedi,1999).

The coupling of the physics to the dynamics in the HIRLAM model is described and compared with the current operational configuration. A "first-guess" predictor of the model variables is employed to achieve the coupling of the different parametrization schemes to each other.This predictor value tries to reduce the time-step dependency.

2.- Coupling of the parameterization schemes

The HIRLAM model makes use of the "fractional stepping" approach (Beljaars, 1991). The results depend consequently on the calling sequence. In the HIRLAM model this sequence is: first, vertical diffusion; second, radiation; third, convection and, lastly, soil processes. The convection scheme, therefore, uses the tendencies of the vertical diffusion and radiation schemes. The introduction of such time-step dependency is a clear disadvantage of this approach. To keep the idea of "fractional stepping", a "first guess" predictor of the model variables is used.

- In the first experiment **SLH**, a "first guess" predictor is employed by using the tendency from the dynamics, the tendency of the radiation and convection at the previous time-step and the tendency of the vertical diffusion at the current time-step (Wedi, 1999):

$$\psi_{predict}^{n+1} = \psi_D^{n+1} + \alpha P_{*,rad+conv}^{n} \Delta t + P_{I,vdif}^{n+1} \Delta t \quad (1)$$

  where ψ_D^{n+1} stands for the dynamical fields at the arrival point. The parameter $\alpha = 0.5$ has been introduced in order to achieve a better balance between the physical parameterizations.

- In the second one **SLF**, a "first guess" predictor is employed by using the tendency from the dynamics, the tendency of the radiation, convection and vertical diffusion at the previous time-step and the tendency of the vertical diffusion at the current time-step:

$$\psi_{predict}^{n+1} = \psi_D^{n+1} + \alpha P_{*,rad+conv+vdif}^{n} \Delta t + \alpha P_{I,vdif}^{n+1} \Delta t \quad (2)$$

In the proposed schemes the parameterizations at the current time-step are computed in the following calling sequence:

$$P_I^{n+1} = P_{I,vdif}^{n+1}(\psi_D^{n+1}) + P_{I,rad}^{n+1}(\psi^n) + P_{I,conv}^{n+1}(\psi_{predict}^{n+1}) \tag{3}$$

- The current reference HIRLAM model (experiment **SLA**) uses "fractional stepping" with the following calling sequence:

$$\psi_{predict}^{n+1} = \psi_D^{n+1} + P_{I,rad}^{n+1}\Delta t + P_{I,vdif}^{n+1}\Delta t \tag{4}$$

$$P_I^{n+1} = P_{I,vdif}^{n+1}(\psi_D^{n+1}) + P_{I,rad}^{n+1}(\psi^n) + P_{I,conv}^{n+1}(\psi_{predict}^{n+1}) \tag{5}$$

Radiation and vertical diffusion schemes are left unchanged. The main change is in the convection scheme.

3.- The Interface between the physics and dynamics

1) The first experiment **SLH** is very similar to the ECMWF approach (Wedi,1999). The contributions of the radiation and convection schemes are averaged along the semi-Lagrangian trajectory and those of the vertical diffusion are taken at the arrival point only.

The final equation, once the tendencies of the parameterizations are computed, is:

$$\psi_I^{n+1} - \psi_D^{n+1} = \frac{\Delta t_+}{2}[P_{rad+conv}^{n+1}]_I + \frac{\Delta t_-}{2}[P_{rad+conv}^{n}]_* + \Delta t_+ P_{vdif,I}^{n+1} \tag{6}$$

2) In the second one **SLF**, the contributions of the radiation, convection and vertical diffusion schemes are averaged along the semi-Lagrangian trajectory.

The final equation is:

$$\psi_I^{n+1} - \psi_D^{n+1} = \frac{\Delta t_+}{2}[P_{rad+conv+vdif}^{n+1}]_I + \frac{\Delta t_-}{2}[P_{rad+conv+vdif}^{n}]_* \tag{7}$$

3) In the current reference HIRLAM model (experiment **SLA**), the contributions of the radiation, convection and vertical diffusion schemes are taken at the arrival point only.

The final equation is:

$$\psi_I^{n+1} - \psi_D^{n+1} = \Delta t_+[P_{rad+conv+vdif}^{n+1}]_I \tag{8}$$

4.- Results

- The experiments **SLH** and **SLF** are compared to **SLA** (the current HIRLAM version 4.6.2 with the 2TLSLSI scheme). The horizontal grid consists of 168x100 points with a 0.5^ox0.5^o resolution and 31 hybrid levels in the vertical.

- Mixed (Cubic/Linear) interpolation is used to interpolate the diabatic tendencies P to the departure point of the semi-Lagrangian trajectory.
- In the first time step, the configuration is similar to the reference HIRLAM model.

4.1.- Comparison of numerical accuracy

To examine the sensitivity of the solutions to changes in the length of the time-step, we assume that the method which has the long time-step solution closer to the short time-step solution is the better method (Wedi,1999).

Four different 24-hour forecasts have been run with t=180s and t=1350s. As a measure for the deviation of the 1350s-solution from the assumed correct 180s-solution the root mean square error has been computed for the three experiments:

$$rms = \sqrt{\overline{(F_{t=1350s} - F_{t=180s})^2}} \qquad (9)$$

The overbar denotes an average over area. The diabatic tendencies are integrated vertically and accumulated every time-step over a period of 24 hours.

By comparing the three experiments **SLA**, **SLH** and **SLF**, I have found that:

- the **rms** of the total diabatic tendencies of temperature,specific humidity and cloud water content are smaller with experiments **SLH** and **SLF** (Fig. 1).
- the **rms** of the diabatic tendency of temperature due to Radiation is smaller with experiment **SLH**.
- the **rms** of the diabatic tendency of temperature due to Vertical Diffusion is smaller with experiments **SLA** and **SLH**.
- the **rms** of the diabatic tendency of specific humidity due to Vertical Diffusion is similar in all experiments.
- the **rms** of the diabatic tendency of cloud water content due to Vertical Diffusion is smaller with experiment **SLH**, but the biggest rms appears in **SLH**.
- the **rms** of the surface momentum fluxes is smaller with experiment **SLH**, but very similar to **SLA**.
- the **rms** of the convective precipitation is smaller with experiments **SLH** and **SLF**.
- the **rms** of the stratiform precipitation is smaller with experiment **SLA**, but this value is smaller than the convective precipitation.

In summary, the smallest differences between long time-step solutions and short time-step ones appear in the experiment **SLH**.

Verification scores against observations over the whole area have been carried out to compare the different schemes. The integrations started in july 1995 from the 1^{st} at 12 UTC to the 3^{rd} at 12 UTC each 6 hours. The variables studied are: temperature, relative humidity and wind.

The results of the small time step solutions are very similar using either method. The errors for the long time-step solution are also similar but the differences are bigger. The better results of the new methods appear in the relative humidity.

4.2.- Strong Convective Cases

The general characteristics of the experiments are:

- HIRLAM version 4.6.2 with the 2TLSLSI scheme,
- 134x60 points with a 0.5^ox0.5^o resolution in the horizontal,
- 31 hybrid levels in the vertical and
- a slightly bigger time step t=1200s.

The Tropical storm Erika

It was first tracked as a hurricane on 4 September 1997 in the Caribbean. On the 12th, it weakened due to a combination of cool sea surface temperatures and westerly winds. The simulation was started at 1200 UTC 12.09.1997 and carried forward for 75 hours. By this time, Erika retained deep convection near its centre. The centre passed very near the Azores on the 15th.

By comparing the three experiments at 1200 UTC 15.09.1997, I have found:

- The new runs show a low pressure system displaced approximately 2^0 latitude to the south with respect to the reference run, closer to the verifying analysis.
- Its central pressure is 992 hPa in all runs, similar to the verifying analysis.
- In 850 hPa, the centre is also displaced 2^0 latitude to the south with respect to the reference run, closer to the verifying analysis.
- In upper levels, the pattern is similar in all runs.

Strong Convection over the Mediterranean area

One mesoscale convective system developed in this area on September 11th 1996 At 06 UTC it moved to the north and new systems appeared near Valencia. During the afternoon, new convective systems arose due to the persistence of forcing. Large values of precipitation were recorded (up to 500 mm in 24 hours). The simulation was started at 1200 UTC 09.09.1996 and carried forward for 72 hours.

By comparing the experiments, I have found the following advantages of the new method:

- the 24-hour precipitation maximum is better located, compared with the subjective precipitation analysis with data from automatic station network (Fig. 2).
- In general, smoother fields.

5.- Conclusions

In summary, both new methods lead to:

- more stable results, with the possibility to increase the time-step;
- more accurate results for a similar length of the time-step; and
- a smoothing of the fields, especially precipitation.

It must be stressed that:

- However, of the two new methods, averaging the vertical diffusion shows slightly worse results.
- The forecast skill improvement of the new methods is small in the short range, but becomes more appreciable in the medium range.

6.- References

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