Towards an interactive conserving semi-Lagrangian model for chemistry and climate

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1. Introduction

The main purpose of this work is to solve the problem of local conservation for chemistry and climate by using the algorithm developed by Zerroukat & al. (2002). Results of the validation for 2D passive advection were presented in Mahidjiba & Côté (2004). We present validation results of the shallow-water model where this conservative scheme will be implemented. We consider both linear and non-linear problems.

2. Numerical model

The same fully implicit semi-Lagrangian method as in the GEM operational model (Côté et al., 1998, Yeh et al., 2002) is used to discretize the shallow-water equations. That is:

1) Uniform Arakawa staggered C-Grid,
2) 2-time-level iterative semi-Lagrangian method with interpolated in time advecting wind,
3) Iterative non-linear solver for the Helmholtz problem with a direct solver kernel,
4) Iterative treatment of the Coriolis terms by grouping them as with the non-linear terms,
5) Metric terms using the Lagrange multiplier approach of Côté (1988),
6) New trajectory algorithm for staggered limited-area model.

3. Results

Two series of validation experiments where performed: linear and non-linear.

a) Non-rotating linear case

In this linear non-rotating case we linearise the shallow-water equations around a resting basic flow with constant height. In this case the discretised governing equations can be solved analytically and we can compute analytically the expected RMS. We can then compare it to the score obtained be numerical integration. We consider the case of a pure one-dimensional gravity wave (wave-number = 1) in a 1000 km square basin, a resting height of 1 km, a perturbation of 1 m, and Δx = 5000 m. The integration time is one period. The results are shown in Fig. 1 where the black line joins the analytic RMS for a few values of the time step. The numerically computed RMS gives identical value (black dots). We compare also with a Taylor expansion of the exact expression (dotted line). Note that the quartic term is necessary for agreement in the range of time steps considered here, i.e.,

$$RMS_{approximate} = c_0 + c_2\Delta t^2 + c_4\Delta t^4.$$

Δt starts at one tenth of a period and is halved repeatedly.

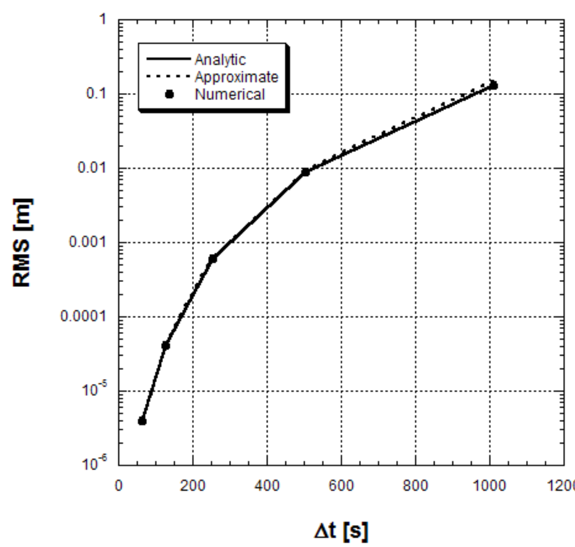

Figure 1: *Numerically computed RMS, analytical expression for RMS and its quartic approximation as functions of time step length.*

b) Rotating non-linear case

The second case is for the full set of non-linear equations with realistic initial conditions and parameters. There is no exact solution in this case and a validation strategy is to compare our results with a carefully controlled experiment published in the literature. Since we run a limited-area model with the same boundary conditions as in Temperton & Staniforth (1986) [TS] and we had their model at our disposal we could repeat their experiment: first with their model and next with our model. The key element is to have

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properly balanced initial conditions. In this set of experiments the initialization procedure of TS is used to produce initial conditions to both models. We then run both models from these initial conditions and the same geometry. The scores are produced for the same central window as TS but with all runs performed at uniform resolution. Fig. 2 shows the RMS scores at 48h obtained for the non-linear shallow-water case with realistic initial conditions. We see that the new model is at least equivalent to TS and obtains slightly better results at large time steps. Fig. 3 displays the 48h forecast height field obtained with the new model.

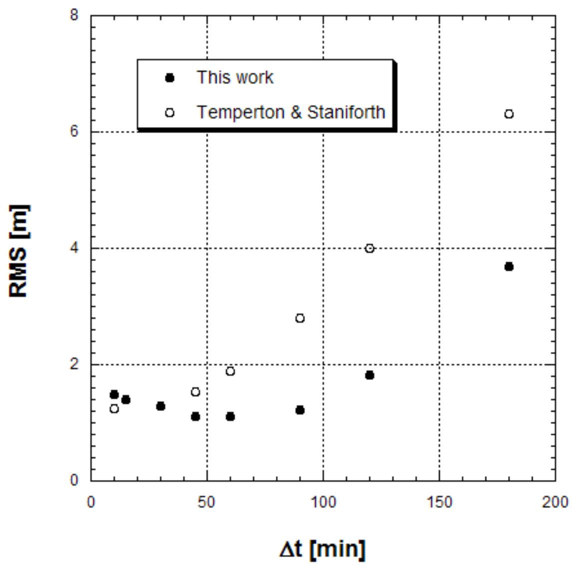

Figure 2: *Total RMS produced by the model of Temperton & Staniforth (1986) and the present model as functions of time step length.*

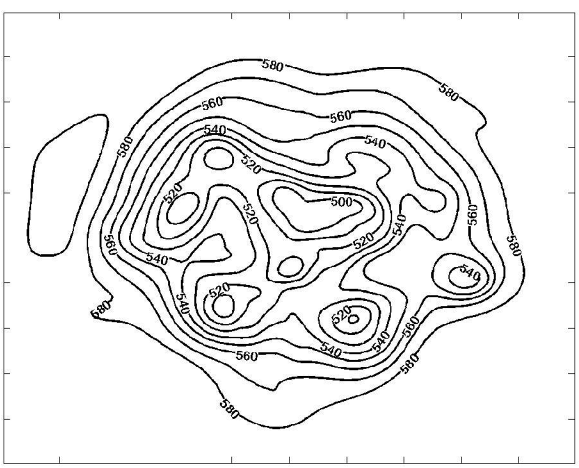

Figure 3: *Geopotential height in dam at 48h with a time step of 1 hour.*

4. Conclusion

As an important preliminary step in implementing the conservative semi-Lagrangian scheme of Zerroukat & al. (2002) interactively in a shallow-water model we presented results of validation experiments performed with the shallow-water model. Since the scheme is nearly the same as that implemented in the operational GEM model it provides a complementary quantitative evaluation.

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References

Côté, J., S. Gravel, A. Méthot, A. Patoine, M. Roch and A. Staniforth, 1998: The operational CMC-MRB global environmental multiscale (GEM) model: Part I - Design considerations and formulation. *Monthly Weather Review*, **126**, pp. 1373-1395.

Staniforth, A. and J. Côté, 1991: Semi-Lagrangian integration schemes for atmosphere models- A review. *Mon. Wea. Rev*., **119**, 2206-2223.

Zerroukat, M., Wood, N. & Staniforth A., 2002: SLICE: A Semi-Lagrangian Inherently Conserving and Efficient scheme for transport problems, *Q. J. R. Meteorol. Soc*. **128**, 2801-2820.

Mahidjiba, A., & Côté, J., 2004: Conservative Semi-Implicit Semi Lagrangian Method (CSSL) for Transport in Climate and Chemical Models, CAS/JSC Working Group On Numerical Experimentations, **34**. pp. (03)15 – (03)16.

Côté, J., 1988: A Lagrange multiplier approach for the metric terms of semi-Lagrangian models on the sphere, Q. J. R. Meteorol. Soc. **114** pp. 1347-1352.

Temperton C. & Staniforth, A., 1986: An efficient two-time-level semi-Lagrangian semi-implcit integration scheme, Q. J. R. Meteorol. Soc, **113**, pp. 1025-1039.

Yeh, K.-S., J. Côté, S. Gravel, A. Méthot, A. Patoine, M. Roch and A. Staniforth, 2002: The CMC-MRB global environmental multiscale (GEM) model: Part III – Nonhydrostatic formulation. *Monthly Weather Review,* **130**, pp. 339-35.

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