Validation of ALADIN dynamics at high resolution using ALPIA

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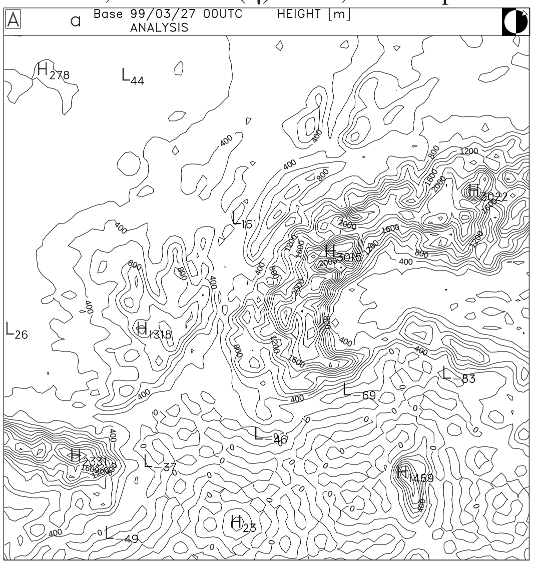
Introduction

A thorough comparison of a few formulations of non-hydrostatic dynamics (ALADIN, Meso-NH and HIRLAM models) was required in the framework of the AROME project. Consequently the previous work of Alena Trojakova (described in Newsletters 21 & 4) was resumed, to investigate the behaviour of ALADIN dynamics (stability, accuracy, efficiency) at high resolution in a pseudo-academic framework.

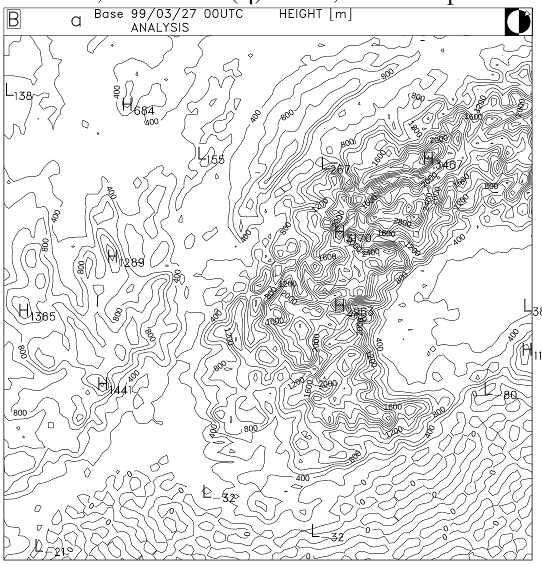
The ALPIA framework

ALPIA involves 4 embedded ALADIN models, of increasing resolutions, centred on the French Alps (5.90° E, 45.22° N). The orography is a real one, but the initial flow is an idealized one. The corresponding orographies, extensions and resolutions are described in Figure 1, just hereafter.

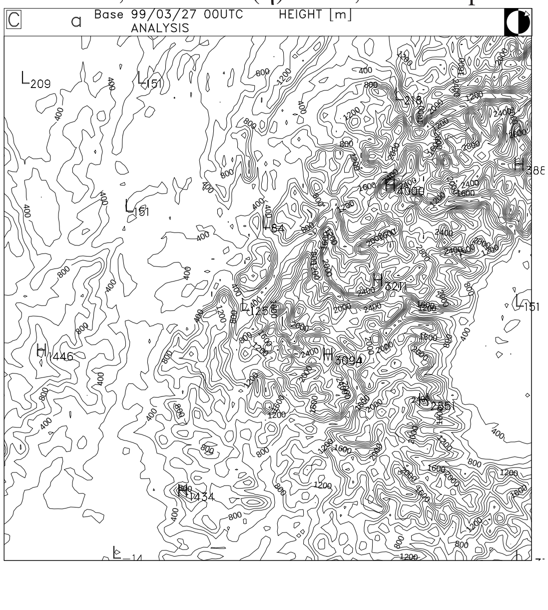
A. Δx=10 km, 30 vertical (η) levels, 108×96 points



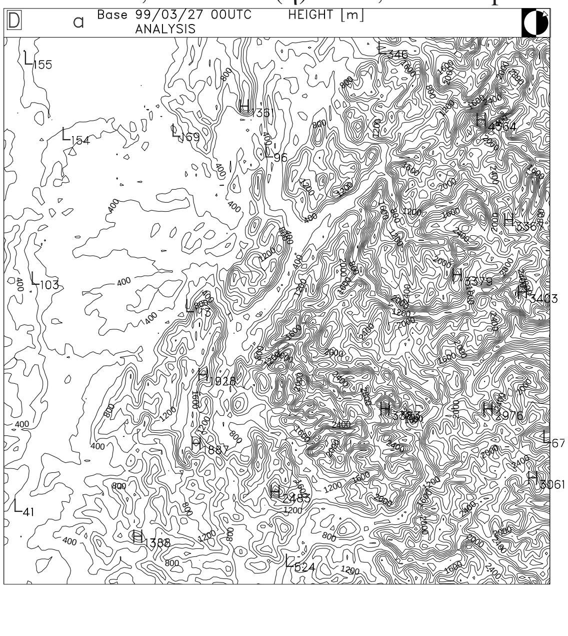
B. Δx=5 km, 42 vertical (η) levels, 128×108 points



C. Δx=2.5 km, 60 vertical (η) levels, 144×128 points



D. Δx=1.25 km, 85 vertical (η) levels, 180×160 points



Cross-comparisons and results

In the previously reported work, we first tried to find the maximum "safe" time-step for semi-implicit Eulerian non-hydrostatic dynamics, and the allowed range of CFL values for the 4 domains. Both the "initial" and the "preliminary" sets of additional non-hydrostatic prognostic variables were used, and we investigated the dependency on the semi-implicit background (reference temperature -SITR- and pressure -SIPR-). Table 1 summarises the main results.

		A	B	C	D
old NH scheme	Δt "safe"	110 s	40 s	10 s	4 s
	CFL range	1.2434, 1.7961	0.8708, 1.7417	0.4187, 0.9964	0.4187, 1.1638
	SITR	225 K	225 K	220 K	230 K
	SIPR	1000 hPa	1000 hPa	< 700 hPa	< 700 hPa
new NH scheme	Δt "safe"	110 s	45 s	18 s	7.2 s
	CFL range	1.266, 1.5888	0.942, 1.4695	0.7235, 1.5524	0.5788, 1.0731
	SITR	220 K	220 K	220 K	220 K
	SIPR	680 hPa	680 hPa	680 hPa	680 hPa

Table 1 : Investigation of the stability of Eulerian semi-implicit non-hydrostatic dynamics

Combinations of the various options of ALADIN dynamics and of domains were tested afterwards (with a tropopause lowered to 12 km), to allow the following comparisons : Eulerian versus 3-time-level semi-Lagrangian advections, quadratic versus linear grid, explicit versus semi-implicit, hydrostatic versus non-hydrostatic, for increasing resolutions. The non-hydrostatic version is the initial one, i.e. with the old set of additional prognostic variables and without refinements in vertical discretisation. The work under progress on new prognostic variables, a new surface semi-Lagrangian boundary condition and the predictor-corrector scheme (for the yet untested 2-time-level discretisation) should hence still significantly enhance stability.

The last set of experiments is summarized in Table 2, just below.

		EXPLICIT				SEMI-IMPLICIT			
		domain / resolution				domain / resolution			
		A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
H	Eulerian quadratic grid	Δt_{eul} = 14s				Δt_{eul} =115s	Δt_{eul} = 40s	***blew up !*** *(with 17s)*	
	semi-Lagrangian quadratic grid	Δt_{eul} = 14s				Δt_{eul} =115s	Δt_{eul} = 40s	Δt_{eul} = 17s	
	semi-Lagrangian linear grid	***blew up !*** *(with 14s)*				Δt_{eul} =115s	***blew up !*** *(with 40s)*		
NH	Eulerian quadratic grid					Δt_{eul} =115s	Δt_{eul} = 40s	Δt_{eul} = 17s	Δt_{eul} =6.9s
	semi-Lagrangian quadratic grid					Δt_{eul} =115s	Δt_{eul} = 40s	Δt_{eul} = 17s	
	semi-Lagrangian linear grid					Δt_{eul} =115s Δt_{max}=318s Δt_{safe}=200s	Δt_{eul} = 40s Δt_{max}= 90s Δt_{safe} = 60s	Δt_{eul} = 17s Δt_{max}= 33s Δt_{safe} = 25s	------------ Δt_{max}= 13s Δt_{safe} = 10s

Table 2 : Investigation of the stability of ALADIN dynamics. Dashed areas indicate combinations not tested. The maximum Eulerian time-step, used for Eulerian versus semi-Lagrangian comparisons, and the maximum allowed semi-Lagrangian time-step for a given resolution (resulting from many experiments), as well as an estimated "safe" one for the last case (SI-SL-NH linear grid) are mentioned.

Comparisons between Eulerian and semi-Lagrangian advections on one side, explicit and semi-implicit schemes on the other side, were performed at the lowest resolution (10 km). The Eulerian time-step was used for semi-Lagrangian experiments, and the same (quadratic) grid-type was kept. Even surprisingly for the very short time step used in the explicit case, the main differences are between Eulerian and semi-Lagrangian options (with a clear advantage for the second one), as shown in Figure 2, and very likely related to the first order only accuracy of the vertical interpolations operators in the Eulerian case.

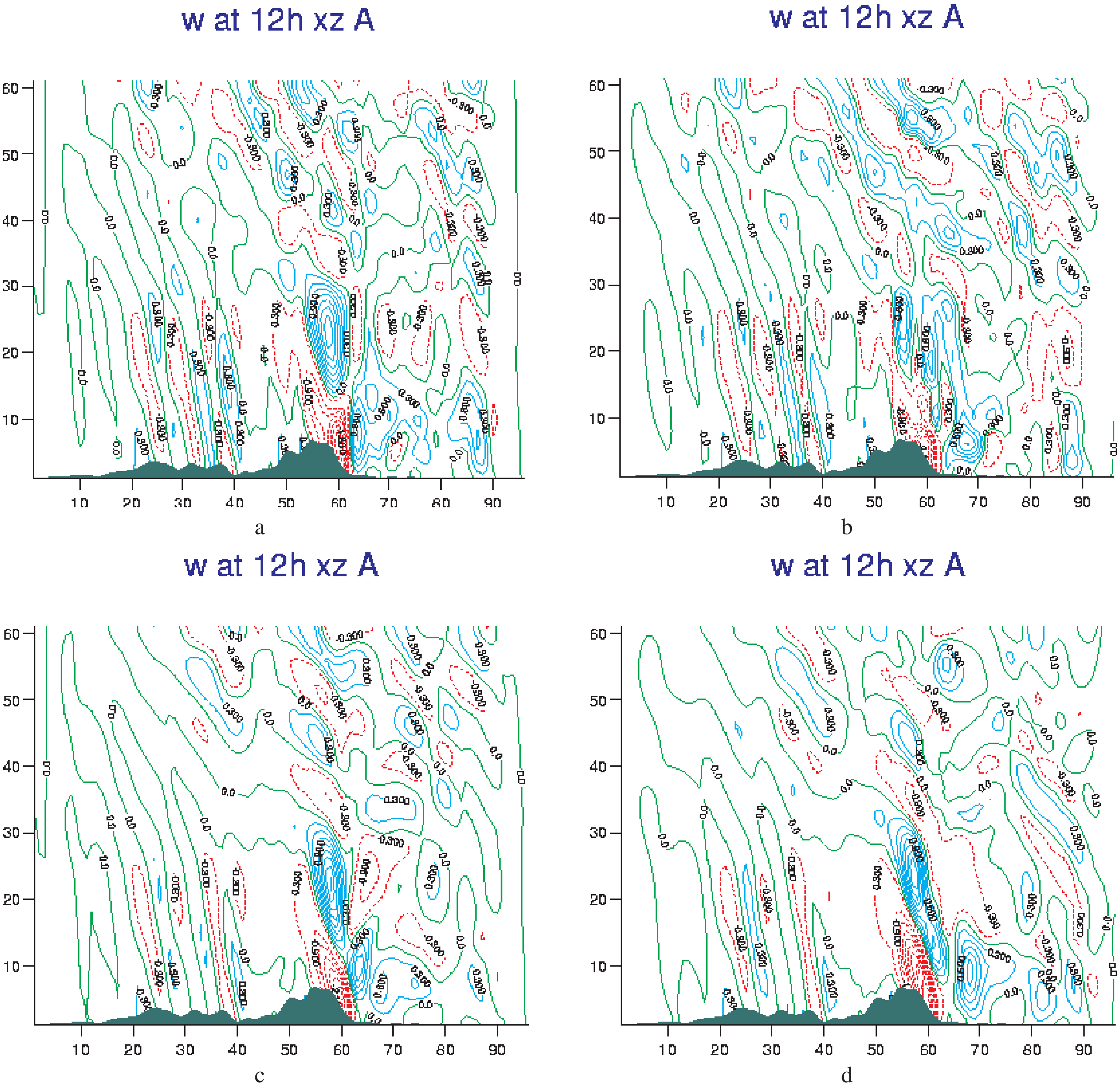


Figure 2 . Vertical West-East cross-section of vertical velocity for domain A and hydrostatic dynamics : a) Eulerian explicit, b) Eulerian semi-implicit, c) semi-Lagrangian explicit d) semi-Lagrangian semi-implicit.

When going to higher resolutions, the non-hydrostatic dynamics proved better than the hydrostatic one, as far as stability (see Table 2) and flow structure (see Figure 3) are concerned, and semi-Lagrangian better than Eulerian advection (see Figure 4), even with the very preliminary code used here.

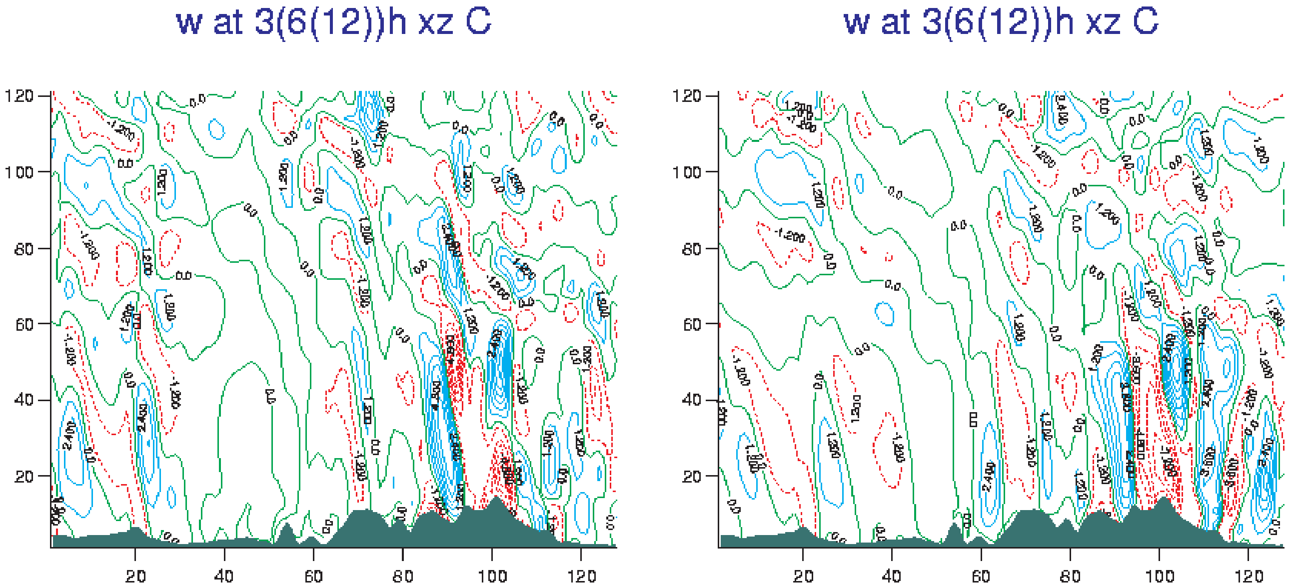


Figure 3. Vertical West-East cross-section of vertical velocity for domain C and a semi-implicit semi-Lagrangian scheme. A quadratic grid and the equivalent Eulerian time-step are used in each case.
Left : hydrostatic dynamics. Right : non-hydrostatic dynamics.

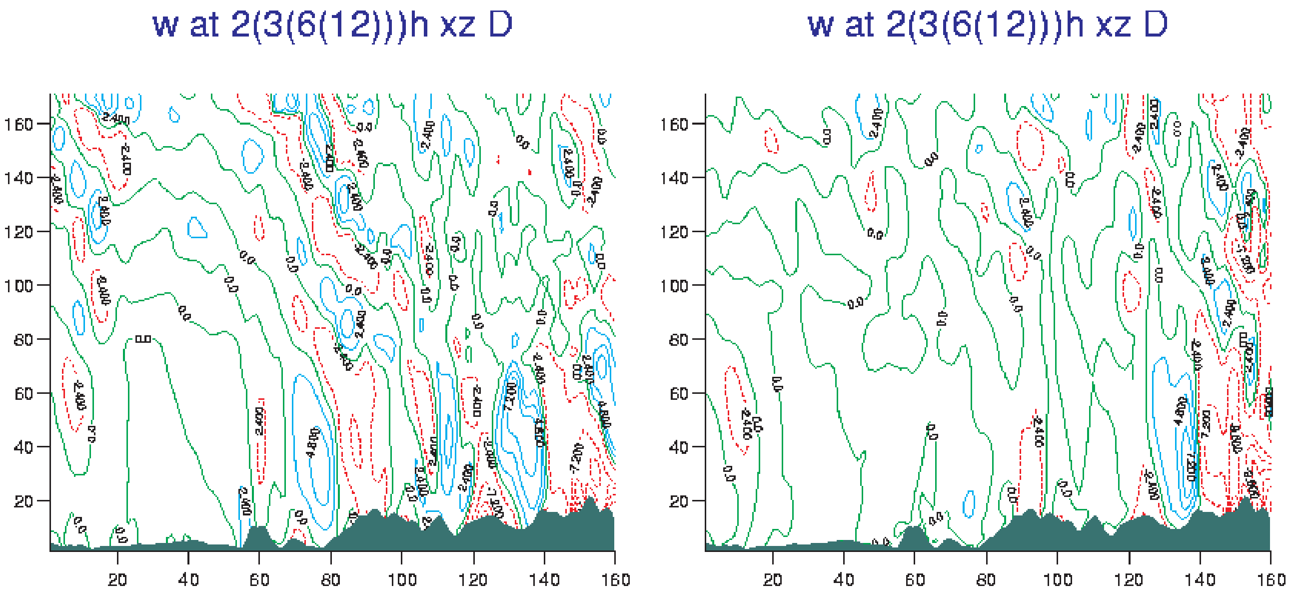


Figure 4. Vertical West-East cross-section of vertical velocity for domain D and non-hydrostatic semi-implicit dynamics. The maximum time-step is used in each case.
Left : Eulerian advection with a quadratic grid. Right : semi-Lagrangian advection with a linear grid.

Even if some of the behaviour of the semi-Lagrangian scheme at higher resolutions is still bringing in some concern (problems with the coupling of the outgoing flow, weakened mountain wave patterns when the time step is pushed beyond the "Eulerian maximum" one, ...), these results are quite promising for the future of ALADIN-NH. But the work is not finished yet, since the new non-hydrostatic dynamics will require further testing, once ready (i.e. within the end of 2002).