R&D on dynamical kernels and sub-km scale modeling with ALADIN/AROME

35th EWGLAM and 20th SRNWP Meeting

METEO FRANCE
Toujours un temps d'avance

Outline

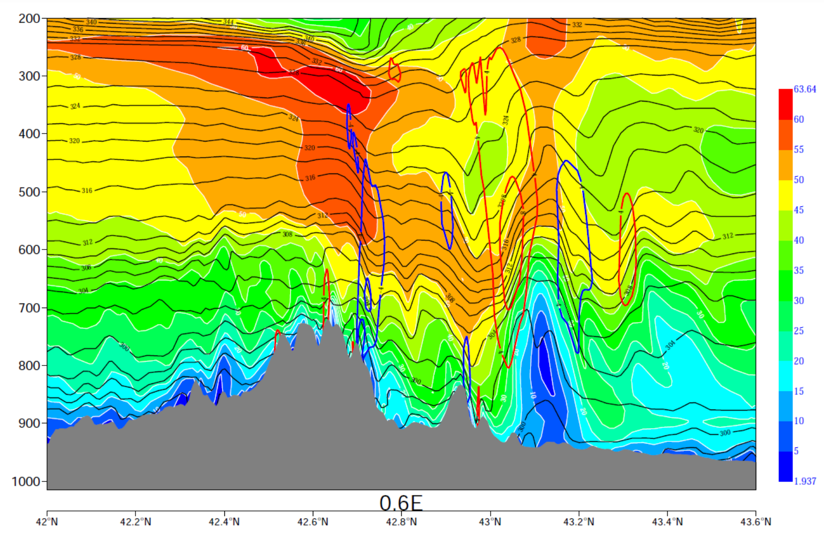
1. 500m resolution experiments
2. Scalability
3. Ongoing research in Meteo-France with dynamics

AROME 500m configuration

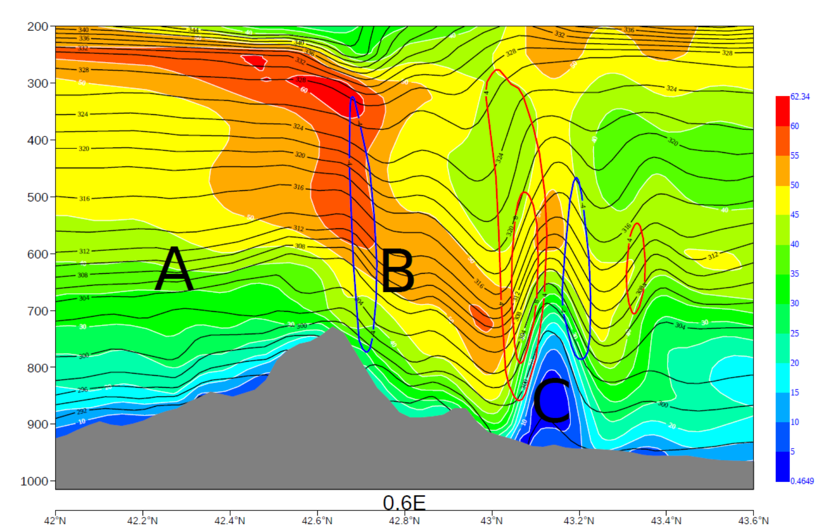
- Our next targeted AROME resolution will be of 1.3 km resolution (cf François Bouyssel's presentation)
- The jump from 2.5 km to 1.3 km then 0.5 km allows a better representation of orography, of the downdrafts and the updrafts in convective systems, generally more phenomena should be better explicitly represented
- Working with 500m resolution has two goals :
  - Anticipating possible issues (instabilities, steep slopes…..)
  - Testing the quality of such configurations
- Apparently no steep-slope problems (tested over the Alps) arose, some upper air wind too strong explosions were treated with specific bottom boundary layer options, the transition from hybrid vertical coordinates and pressure coordinates also had to be redesigned in some cases.
- Today's AROME 500m configuration :
  - EDKF scheme (shallow convection) still activated (ongoing work on this topic)
  - Coupling zone increased
  - Specific bottom boundary conditions options
  - Modification of the time scheme options : a predictor-corrector scheme is now used. Here are the evolution of the AROME timesteps at different resolutions :
    - 2.5 km : 60s (no predictor corrector)
    - 1.3 km : 45s (predictor corrector)
    - 0.5 km : 15 s (predictor corrector)

AROME 500m configuration strong wind case

- Gravity waves generated over mountain ranges are classic test cases for evaluating the behavior of models
- Here is a simulation performed on the Klaus tempest case (2009) with strong winds over the Pyrenees range
- The comparison between, 2.5km and 500m run shows a similarity of the wave structure with a non-hydrostatic trapped lee wave downstream
- This smallscale simulation provides a nice refinement of the good simulation of AROME 500m



Cross section over the Pyrenees for the Xynthia storm case. Trapped Lee waves are well captured by the model at 500m resolution.



Comparaison at 2.5 km

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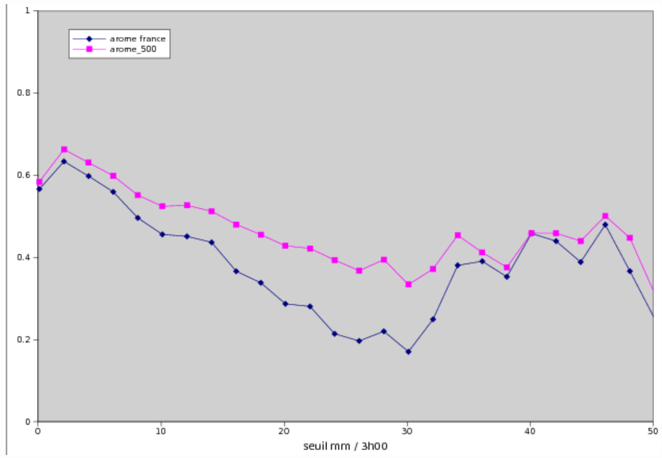
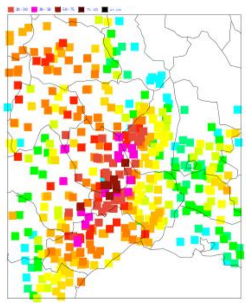
AROME 500m heavy rain forecasts

- A test case on a heavy rain event case : 2-8 Novembre 2011, heavy precipitations over south-east of France.
- AROME-500 m configuration was coupled to AROME-operational (2.5 km).
- Good behavior, no coupling visible issues despite the complicated boundary conditions.
- Brier Skill Score is improved, at least the rain forecast is not worse.

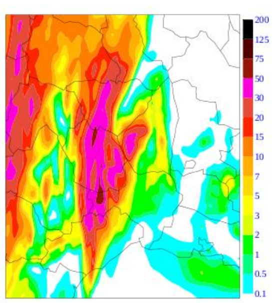
=> we know at 2.5 km we are at the limit in term of resolution for explicit convection (Although AROME already showed its good behavior) so we can hope improvement in future.



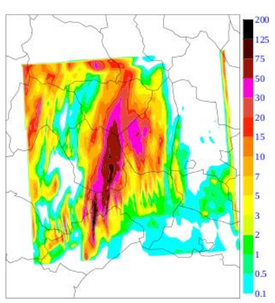
Brier Skill Score



Observations



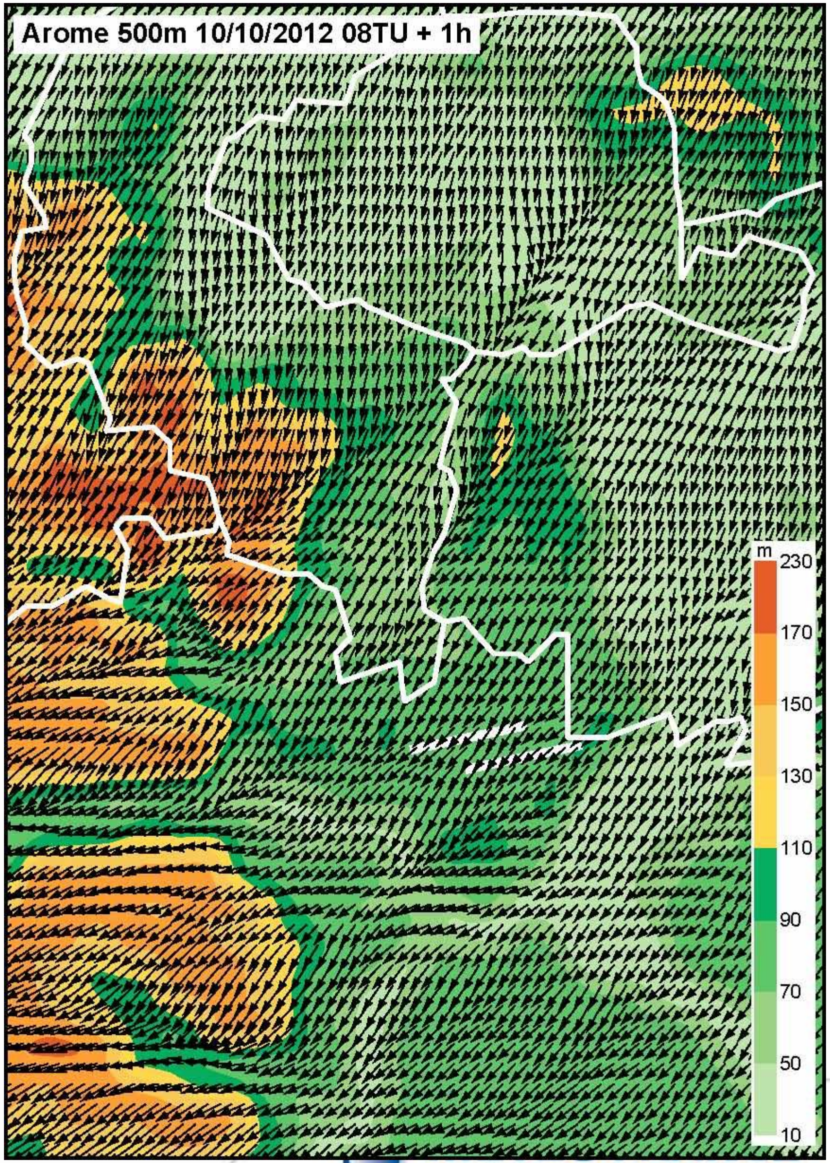
AROME 2.5km



AROME 500m

AROME 500m around airport simulation

- Wake Vorticies is a major concern for airport safety, a tradeoff between security and take off/landing high frequency needs to be found
- We designed a model with a 500m gridisze around CDG airport
- It enables us to test the usefulness in a context of a wake-Vortex prediction program
- This AROME airport configuration provides refined wind, TKE and EDR fields to a Wake Vortex prediction system
- The goal is to adjust the take-off and landing delay between two planes to increase the airport capacity
- Having a model at 500m resolution helped somehow improving 10m wind forecast



Higher resolution, scientific open questions

- Some open questions for hectometric resolutions
  - Do we need some 3D features ? (physic, turbulence) : Probably not at 500m, our models have other uncertainties that must overwrite the refinement gain of 3D parameterizations.
  - Which shallow convection scheme do we need ?
  - Coupling frequency, coupling zone size.
  - Physiographic fields resolution.
  - Volume of the data to treat.
- For lower resolutions (LES mode)
  - Issues like 3D parameterizations that might have been avoided for 500m resolutions should become problematic.
  - Which turbulence parameters, turbulence mixing length : LES rather use Deardorf mixing length, we use BL 89, our tests at 500m resolution show a big gap between BL89 and Deardorf.

2. Scalability

Scalability : High Performance Computing machine Context

- For nearly 15 years the clock rate of processors has not increased.
- But the typical linewidth in the process of processor manufacturing has continued decreasing , today it is 32 nanometers, Intel intends to go down to 4 nm by the year 2022. This allowed to increase the performance of a single processor unit, by enabling more complex architecture => the performance of a single core unit will keep on increasing.
- This allowed also to use more processors in parallel for a reduced communication cost at a constant power supply cost .
- We don’t know what the computers for meteorological applications 15 years from now will be, but we can presume that we will have to use more and more processors grouped as cores around a common memory shared by one node.
- Communication latency and bandwidth are key features for scalability.
- Today, already big configurations are available for research purposes (>100 000 cores).

Scalability : Arome/Aladin context

- We might have some reasons to worry about the performance of our forecasting system on future computers. Scalability is the general term that describes the drop in time when running a code on more and more processors, a perfect scalability means a forecast time divided by two when multiplying the number of processors by two.
- Some parts of the forecast model may possibly be not scalable, we can identify three problems :
  - The semi-lagrangian part, that involves communications with neighbouring MPI-nodes that own grid points from the halo
  - The grid-point to spectral transform (and vice-versa) despite the fast Fourier transform scales as N log(N) (N being the total number of points), this bi-Fourier transform requires a global transposition of data in memory, this could be also of concern.
  - Other reasons linked to the nature of the code, like I/O, parts of the code that are not well parallelized.

Scalability : Arome/Aladin context

- Current tests show no different behavior in term of scalability between spectral implicit models, anelastic-based models, explicit models. AROME/ALADIN model still runs reasonably fast for a given classical horizontal gridsize.
- With 4000x3000 gridpoints on 16000 computation cores, no specific problems arise.
- The scalability issue seems to be strongly linked with the communication network performances, the number of communication port on each node, the topology of the communication network
- Scalability issues linked with data assimilation : for the time being not a problem in AROME 3Dvar (most of the computational cost is due to forecast).

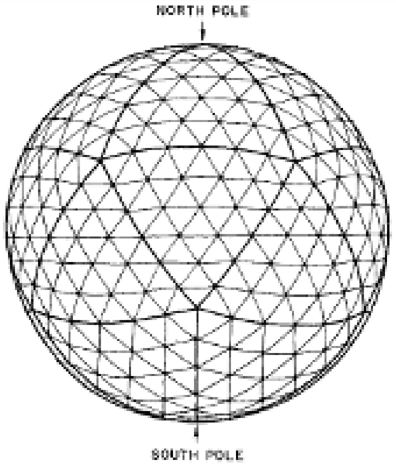
How to avoid spectral space computation ?

- Either write (or take) a new core from scratch with a gridpoint only discretization.
- Or modify the current dynamics to remove the spectral computations steps by steps keeping our ALADIN/AROME core by doing the relevant modifications; this the PhD work of S. Caluwaerts (cf yesteday's P. Termonia presentation) with the use of finite elements on the horizontal with the A-grid.

3. Ongoing research in Meteo-France with dynamics

Collaboration on icosahedral grids

- Models on icosahedral grids are a more and more used (good conservation properties, no more pole issue…)
- We need to explore this path to develop an expertise in this field.
- Collaboration with the Laboratoire de Météorologie dynamique (LMD) which designed such a model in hydrostatic formulation (DYNAMICO project). This model is used for climatological studies, it behaves well with respect to accuracy, conservation law and waves dispersion.
- We plan to :
  - work with a local area version of the model
  - work on a non-hydrostatic version : a careful choice of the non-hydrostatic variables to use is required to ensure a good model stability. This stability must first be studied theoretically
  - design an up-to date timestepping technique, either a time-split method with implicit vertical treatment of sound waves, or a 3D-implicit method.



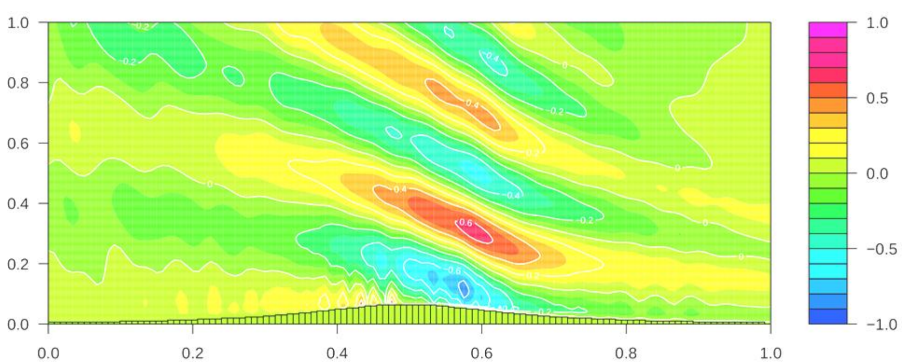
Icosahedral grid drawn
In sadourny et al 1969

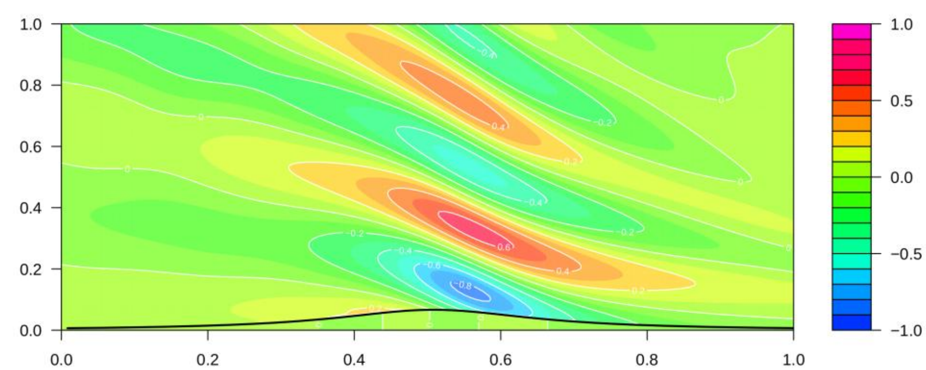
Steep topography problem

- Terrain following coordinates are used in almost every meteorological model (either being z or pressure based).
- With such a system around steep topography the horizontal derivatives of pressure becomes the addition of two large canceling terms, this could diminish accuracy
  - 2.5 km, max slope is 25° : (white mount mountain)
  - 1.3 km, max slope is 38° : (white mount mountain)
  - 0.5 km max slope is 53° : (Eiger Nordwand, known as one of the steepest mountain of the Alps)

$$\frac{RT}{p}\nabla_{\pi}p+\frac{\partial p}{\partial \pi}\nabla\Phi$$

- Using pure z coordinate systems could solve the problem… as long as relevant bottom boundary conditions are used
- These techniques are already used for some time now in oceanography
- Here's a test on academic orographic waves. Overshoots are observed in the pure-z coordinate model, coming from the step-pyramid like representation of the mountain





Time discretization studies 1/3

- AROME/ALADIN are semi-lagrangian, semi-implicit models.
- The set of NH equations was specifically chosen to ensure a better stability as regards rapid waves (in particular the variable representing the vertical velocity is very specific)
- In order to test the stability of our model as regards the specificity of our variables a specific linear analysis of different time scheme is required.
- Two approaches were tested :
  - Time splitting multi step methods :
    - Klemp & Wilhelmson (1978), Skamarock & Klemp (1992, 1994) ;
    - Wicker & Skamarock (2002), Klemp et al. (2007) → WRF ;
    - Baldauf (2008, 2010) → COSMO model ;
  - More recent implicit explicit (IMEX) method :
    - Durran & Blossey (2012): *multi-step* methods;
    - Giraldo et al. (2013): *multi-step* & *multi-stage* methods
    - Ullrich & Jablonowski (2012): *multi-stage* (Runge-Kutta) methods;
    - Weller, Lock, Wood (2013): *multi-stage* methods;

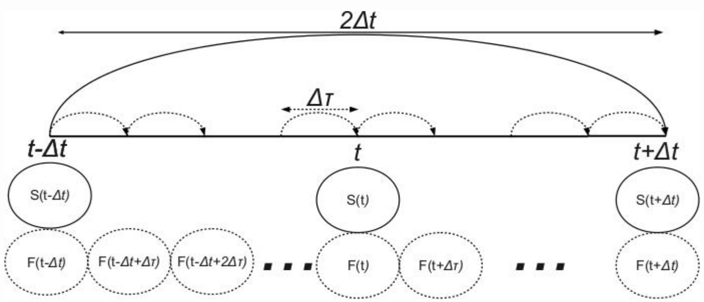
Time discretization studies 2/3 Multi step time splitting methods

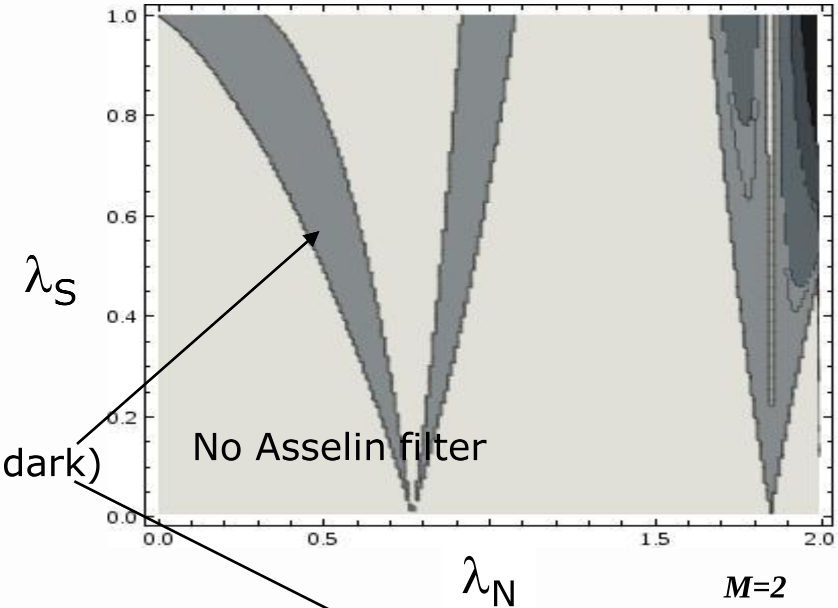
- The RHS term is separated into a fast (sound waves) and a slow mode :
- Time splitting :

$$\left.\begin{aligned} \frac{\partial X_t}{\partial t} &= S(X_t) \\ \frac{\partial X_\tau}{\partial t} &= F^t(X_\tau) \end{aligned}\right\} \quad X = X_t + X_\tau$$

- Multi step :

Instability areas (in dark)





- Slow part S is treated with an explicit leapfrog scheme (with and without Asselin filter)
- Fast part F is treated with an horizontal explicit vertic a subdivision of the Δt timestep.

$\lambda_N = k\Delta t c_s$ = dimensionless number linked with speed of sound waves

$\lambda_S = k\Delta t U$ = dimensionless number linked with slow mode speed

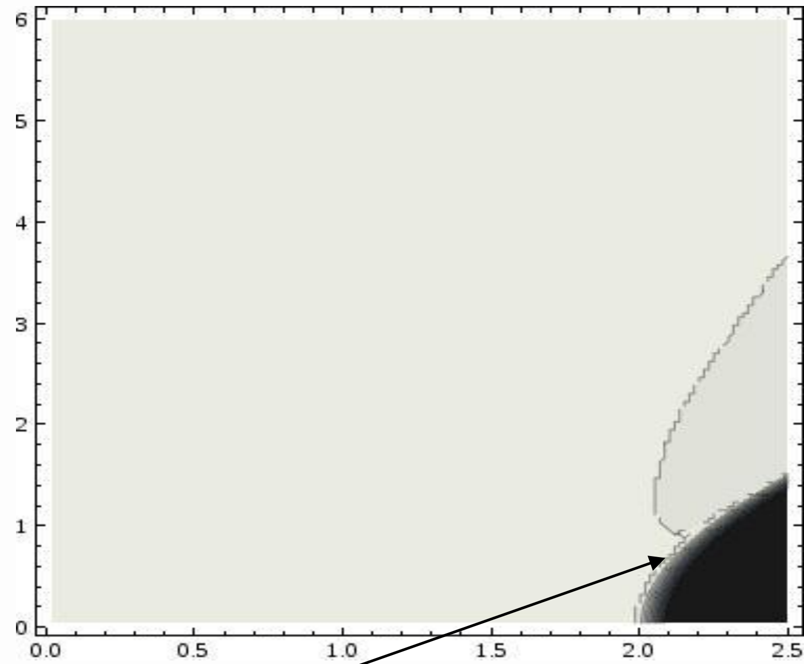
Time discretization studies 3/3 : IMEX method

- RHS is divided into 3 terms, slow mode, fast horizontal mode, fast vertical mode.

$$\frac{\partial X}{\partial t} = S(X)+F_H(X)+F_V(X)$$

- S(x) term is treated with an order 3 Runge-Kutta scheme.
- F_H(x) is treated with a trapezoidal leap-frog explicit scheme.
- F_V(X) is treated implicitly
- The stability area is larger compared to the previous method.

- Theoretical analysis with a lot of approximation (linear analysis, decomposition into verticals modes…) to be tested with real models.



λ_S

λ_N

Instability areas (in dark)

THANK YOU FOR YOUR ATTENTION !

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