Ongoing R&D activities in dynamics at Meteo-France.

Ludovic Auger
with contributions from Y. Seity, C. Colavolpe, P. Benard, K. Yessad, F. Voitus, and many others

25th Aladin workshop & HIRLAM all staff meeting

OUTLINE

1. Horizontally Explicit Vertically Implicit schemes with ALADIN/AROME dynamcis
2. Ellipsoidal Geopotential Approximation
3. Cubic truncation experiments
4. Spurious oscillations over sea in ALADIN/AROME 1.3km

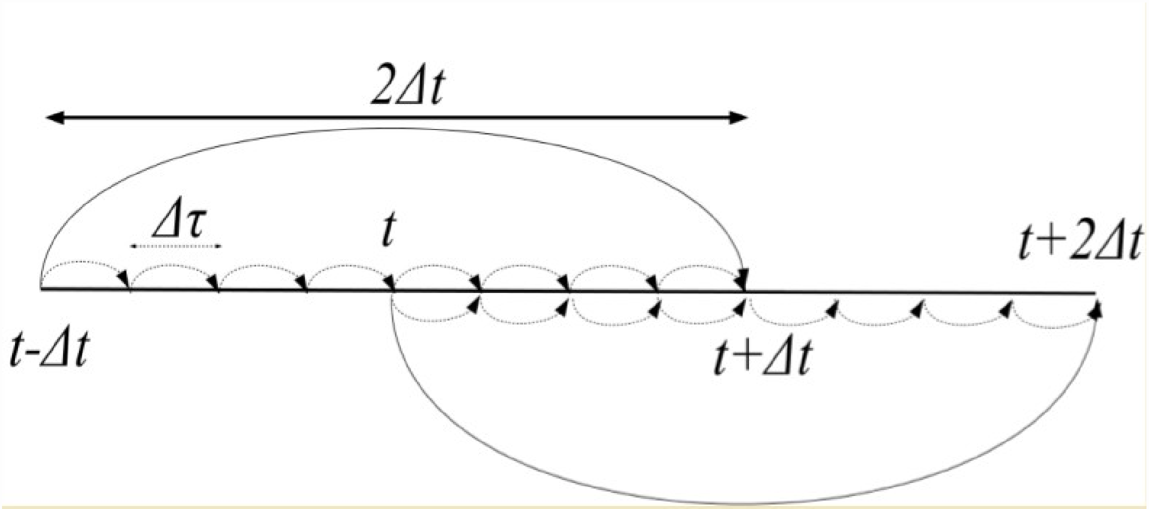
HEVI timestepping

Exploration of Horizontally Explicit Vertically Implicit (HEVI) solution in the context of the ALADIN/AROME dynamics is necessary.

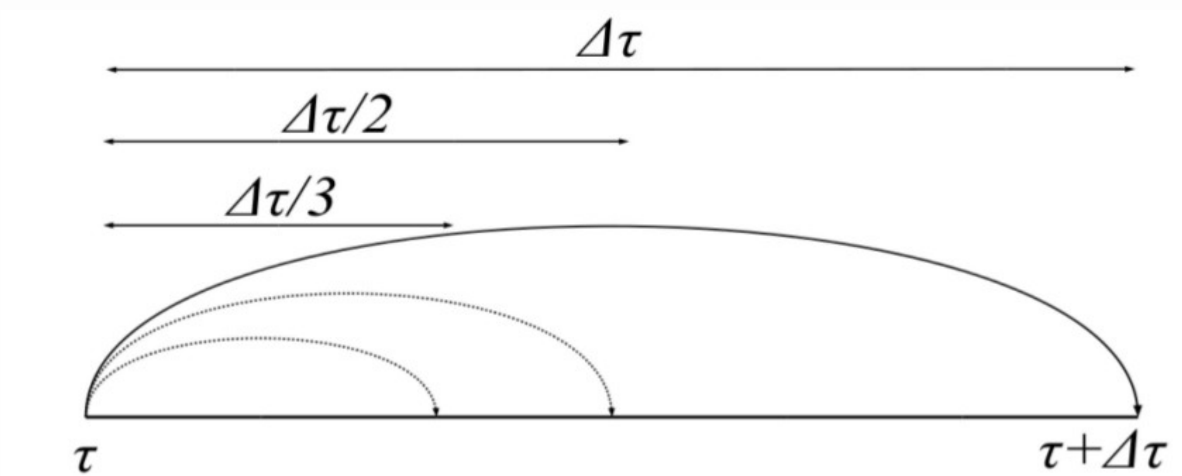
The basic idea is to test classical explicit solutions in the context of our equations system in our coordinate system, with an implicit solving for the vertical rapid waves.

2 main sets of discretization are tested :

- Time-Splitting/Leapfrog
- Implicit Explicit (IMEX) method



Time-splitting/leapfrog

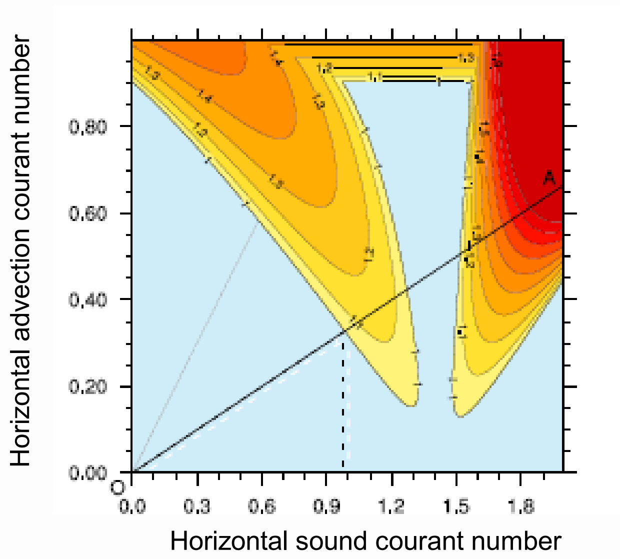


IMEX

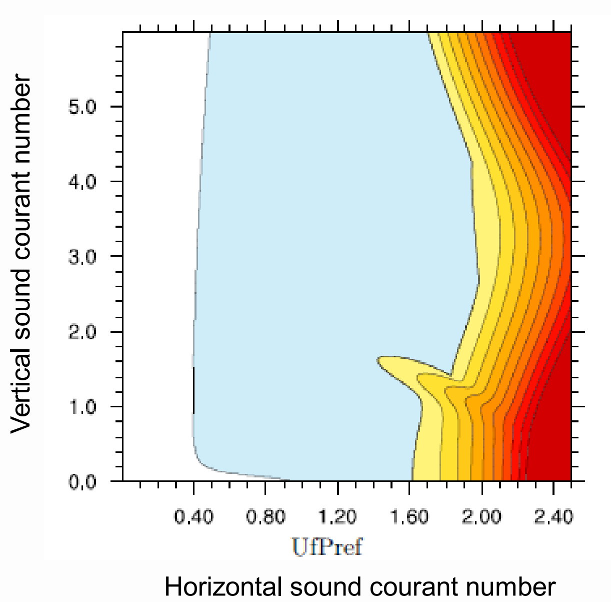
For time-splitting/leap-frog, vertical fast waves are treated implicitly, horizontal fast waves are treated with the small timestep, other terms are treated explicitly.

For IMEX techniques, we use explicit Runge-Kutta method for every term except for terms resonsible for fast vertical waves that are treated implicitly.

cnrs METEO FRANCE



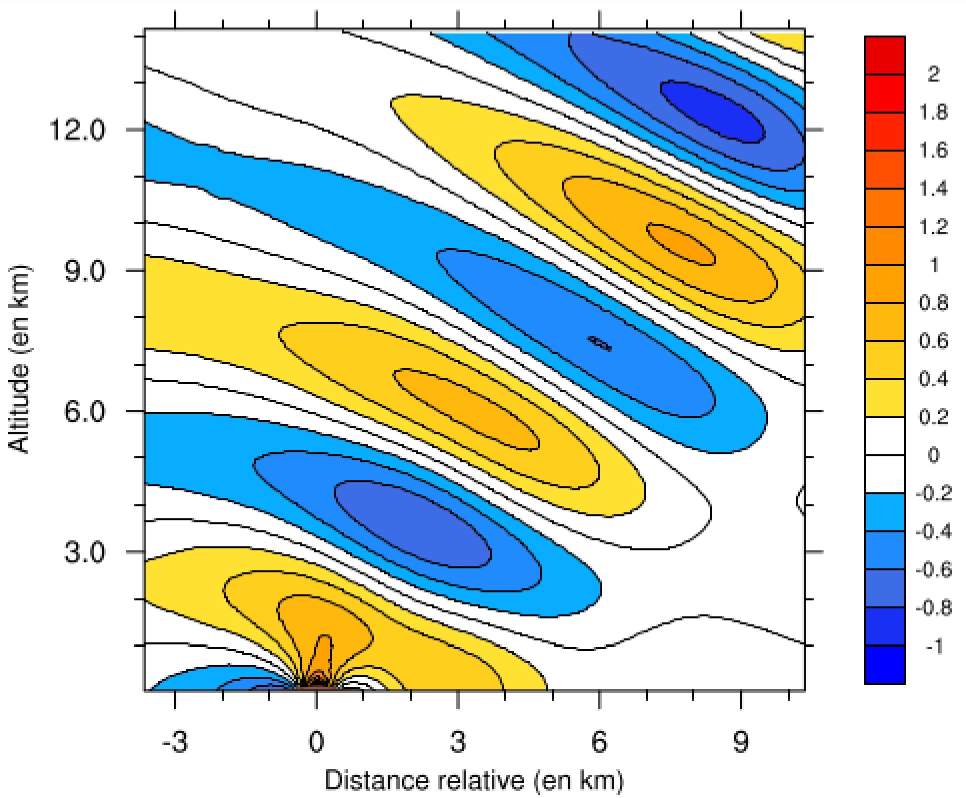
Stability analysis for the time-splitting technique



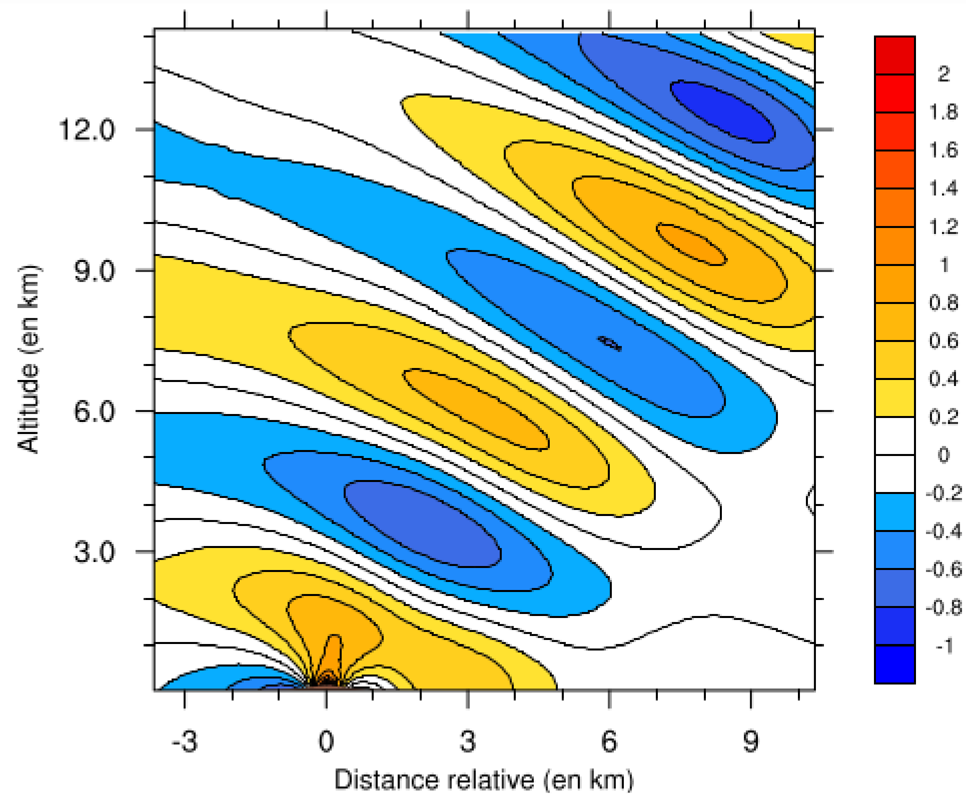
Stability analysis for the third order Runge-Kutta scheme

2D NH mountain wave cases

Mountain hight = 100 m, width = 500 m. $\Delta z = \Delta x = 100$ m.
Boundary U speed U= 15 m.s −1 initial temperature T = 300 K.



Leapfrog HEVI



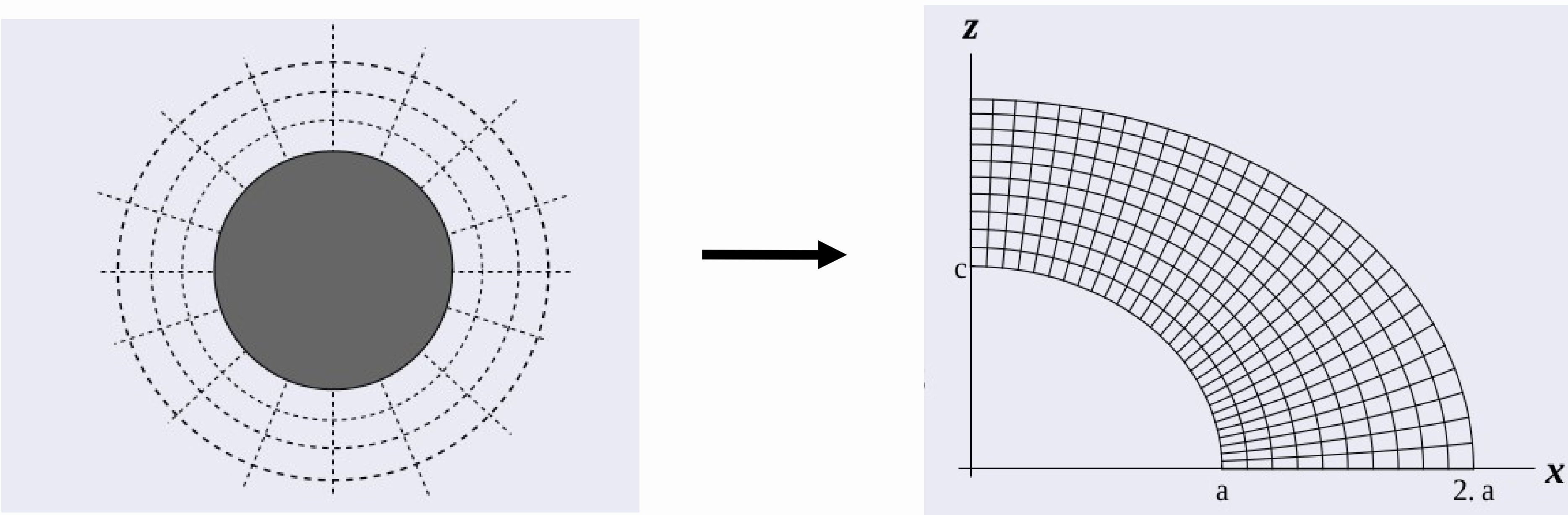
RK-IMEX

Model is stable with Dt= 1s for Leapfrog HEVI and Dt=0.1s with RK-IMEX method.

1. Horizontally Explicit Vertically Implicit schemes with ALADIN/AROME dynamcis
2. Ellipsoidal Geopotential Approximation
3. Cubic truncation experiments
4. Spurious oscillations over sea in ALADIN/AROME 1.3km

Spheroidal approximation

Relaxing Spherical Geopotential Approximation



- Earth is not spherical and g varies.
- It is necessary to test another approximation : Ellipsoidal Geopotential Approximation where geopotentials are spheroids.

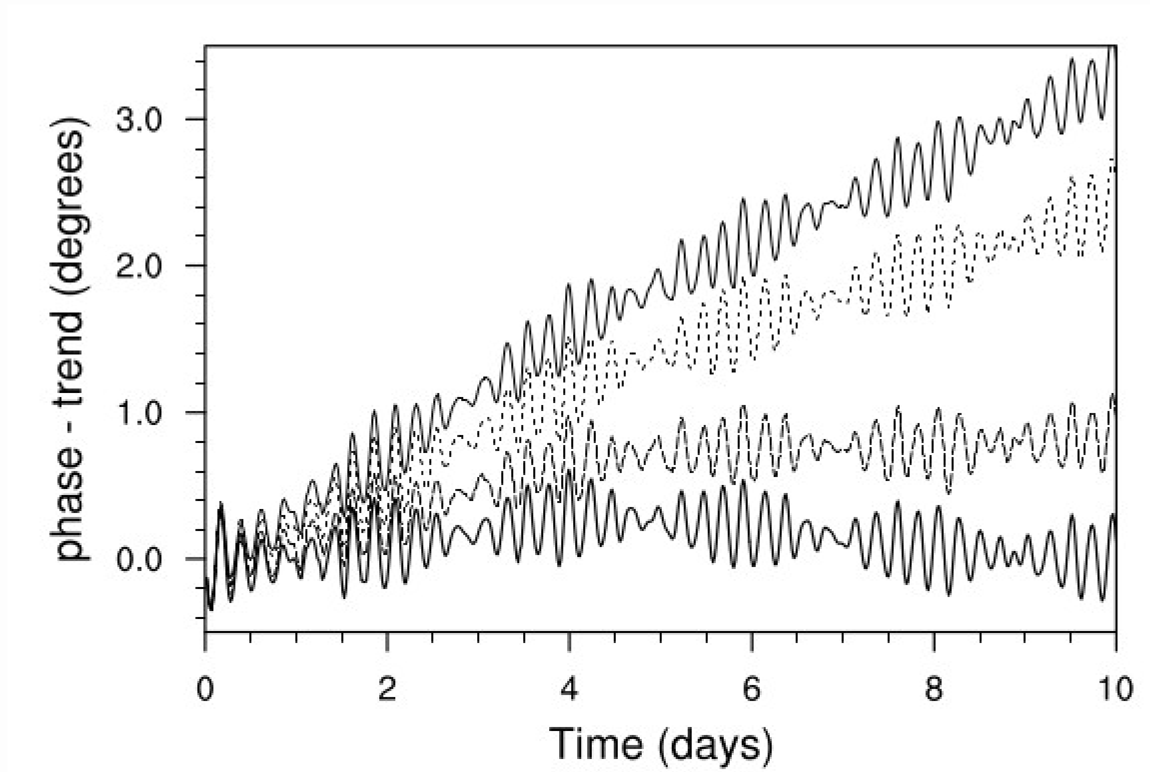
Spheroidal approximation

- Consistent formulations of Euleur Equations have been written in the 2000's in the spheroidal approximation.
- Errors can be divided into a geometric and gravity error (Bénard, 2014, Q. J. Roy. Meteor. Soc.)
- Geometric error : length of 45° parallel in SGA and EGA is 80km different.
- Gravity error : g varies from 9.78 to 9.83 : effect on gravity waves... This effect should slightly dominate.
- Geometric error is difficult to assess in the ARPEGE/IFS spectral context that relies on spherical harmonics.
- Gravity error can be easily tested

cnrs METEO FRANCE

Spheroidal approximation

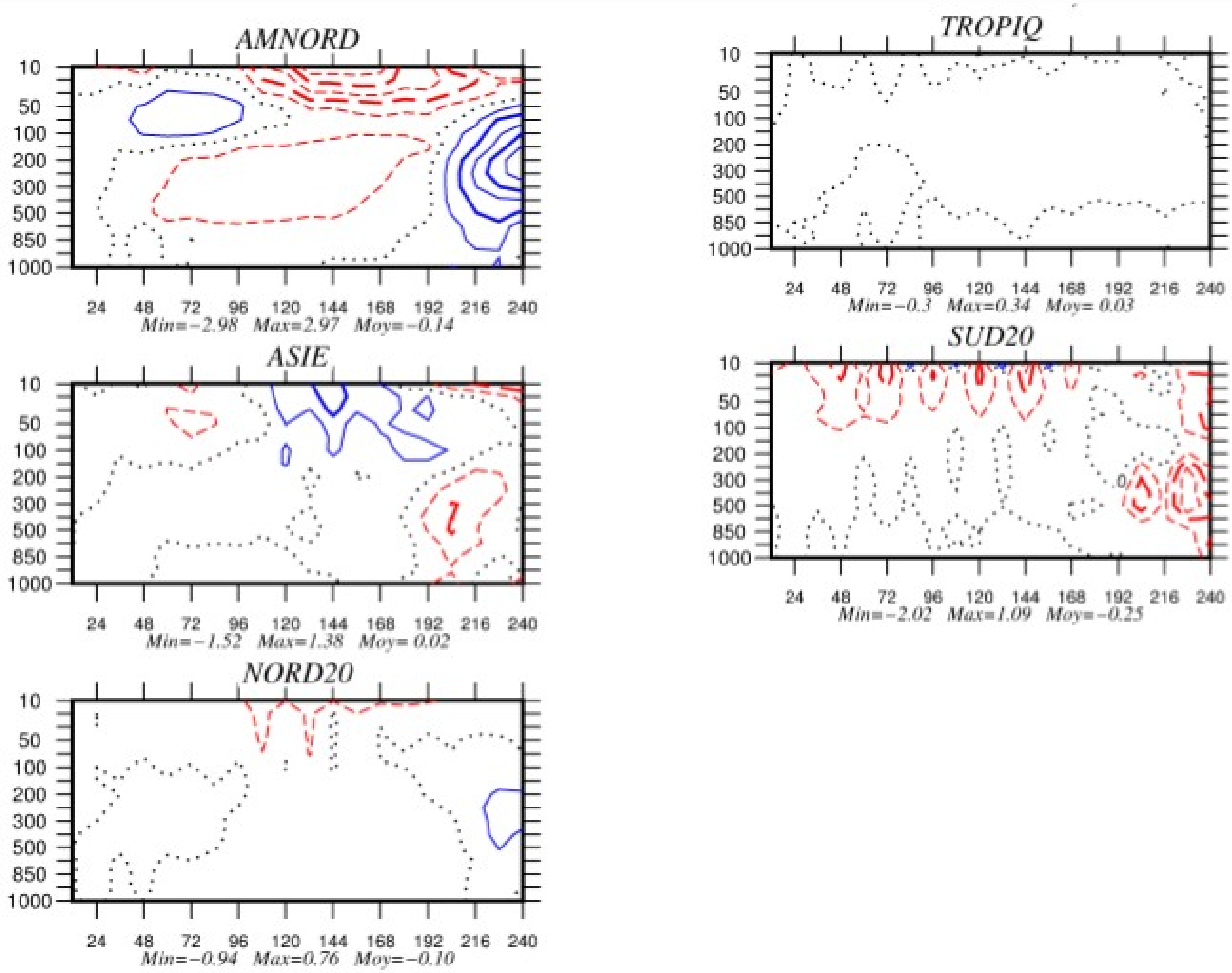
It has been first tested in a shallow water context



Difference in term of phase between the different approximations

Spheroidal approximation

Then in a real context :



Effect is weak (expected) but not negligeable !

Must be taken into account for the design of future models (collaboration with ECMWF)

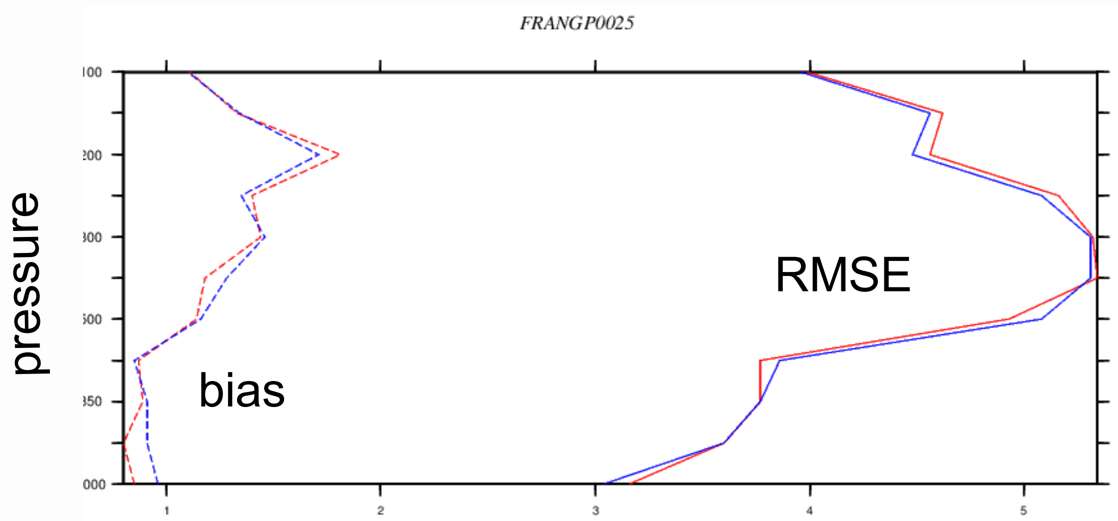
cnrs METEO FRANCE

1. Horizontally Explicit Vertically Implicit schemes with ALADIN/AROME dynamcis
2. Ellipsoidal Geopotential Approximation
3. Cubic truncation experiments
4. Spurious oscillations over sea in ALADIN/AROME 1.3km

Cubic truncation experiments

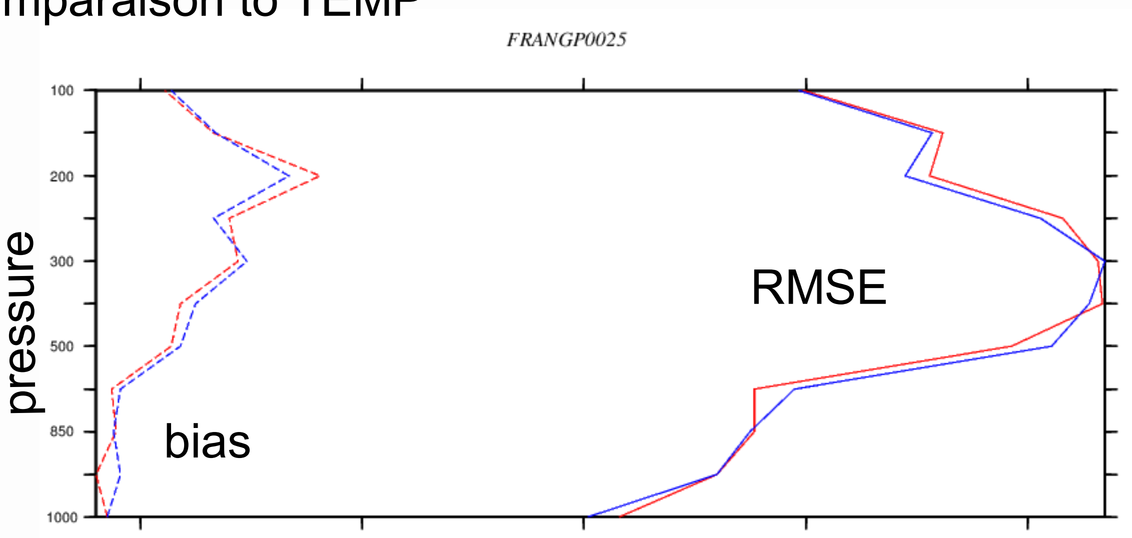
- Currently we have nearly as many spectral coefficients as gridpoints in our operational configurations, not exatly the same because of the elliptic truncation
- Cubic truncation is about using much less spectral coefficients compared to gridpoints.
- ECMWF explored that option to reduce the spectral cost of the model.
- Basically what we do in spectral space is solving the implicit (linear) problem (and also numerical diffusion).
- Using cubic truncation amounts to deal with dynamics at a lower resolution
- The only justification of cubic truncation is « do we need to perform the dynamics at the same resolution than physics or not » ?

Cubic truncation experiments



1.3km cubic truncation versus 1.3km linear truncation

WIND 24h forecast,
comparaison to TEMP



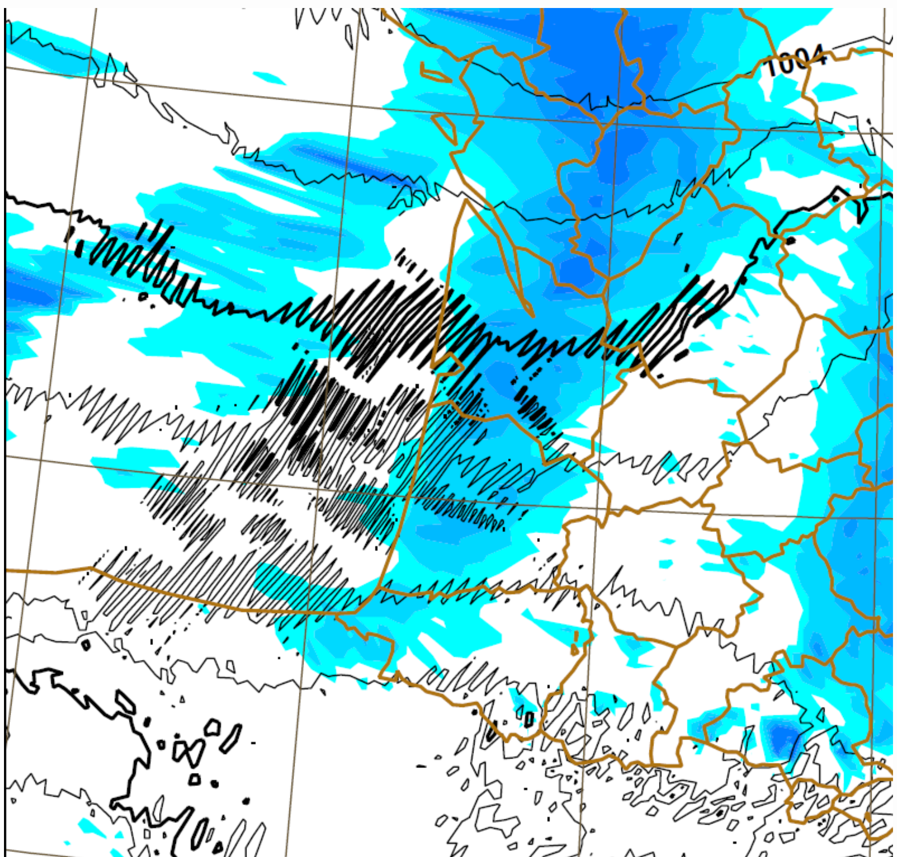
2.6km linear truncation versus 1.3km linear truncation

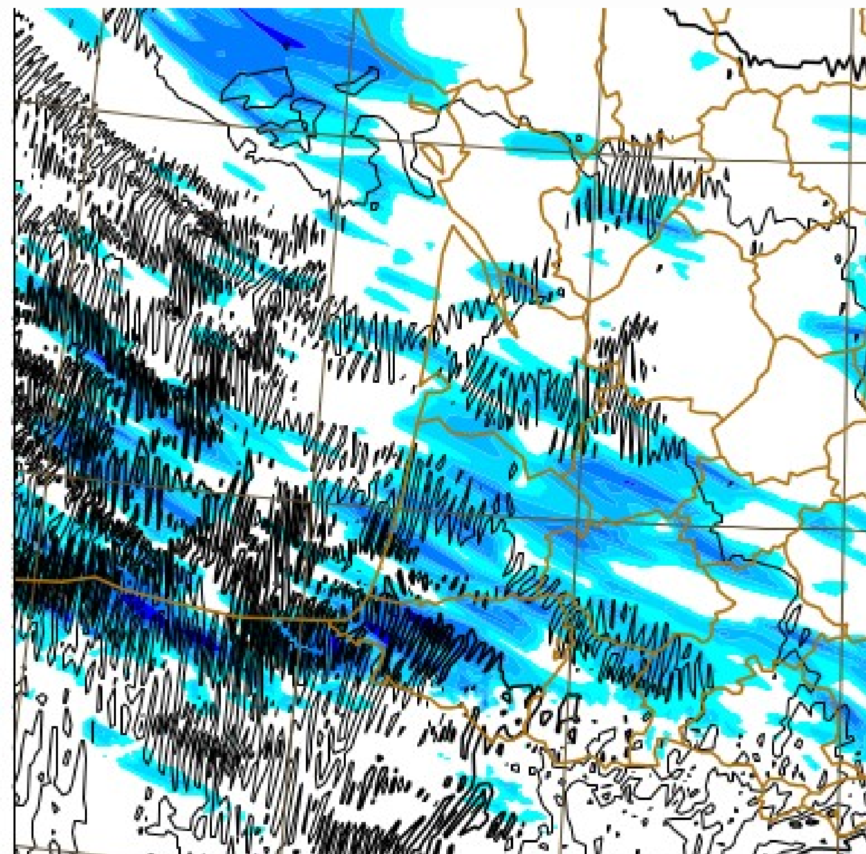
- We did 3 AROME 1 month experiments :
  - 1.3km linear trunction
  - 1.3km cubic truncation
  - 2.6km linear truncation
- The wind score suggests cubic truncation exhibits similar score loss as dividing the resolution by 2.
- We need to make longer run and to look carrefully to precipitation scores.
- 1.3 km linear saves 20 % CPU !
- 2.6 km saves 80% CPU

1. Horizontally Explicit Vertically Implicit schemes with ALADIN/AROME dynamcis
2. Ellipsoidal Geopotential Approximation
3. Cubic truncation experiments
4. Spurious oscillations over sea in ALADIN/AROME 1.3km

Spurious oscillations in AROME

- We recently discovered spurious oscillations in our future AROME 1.3km resolution configuration.
- Mostly visible on MSL but also on other fields

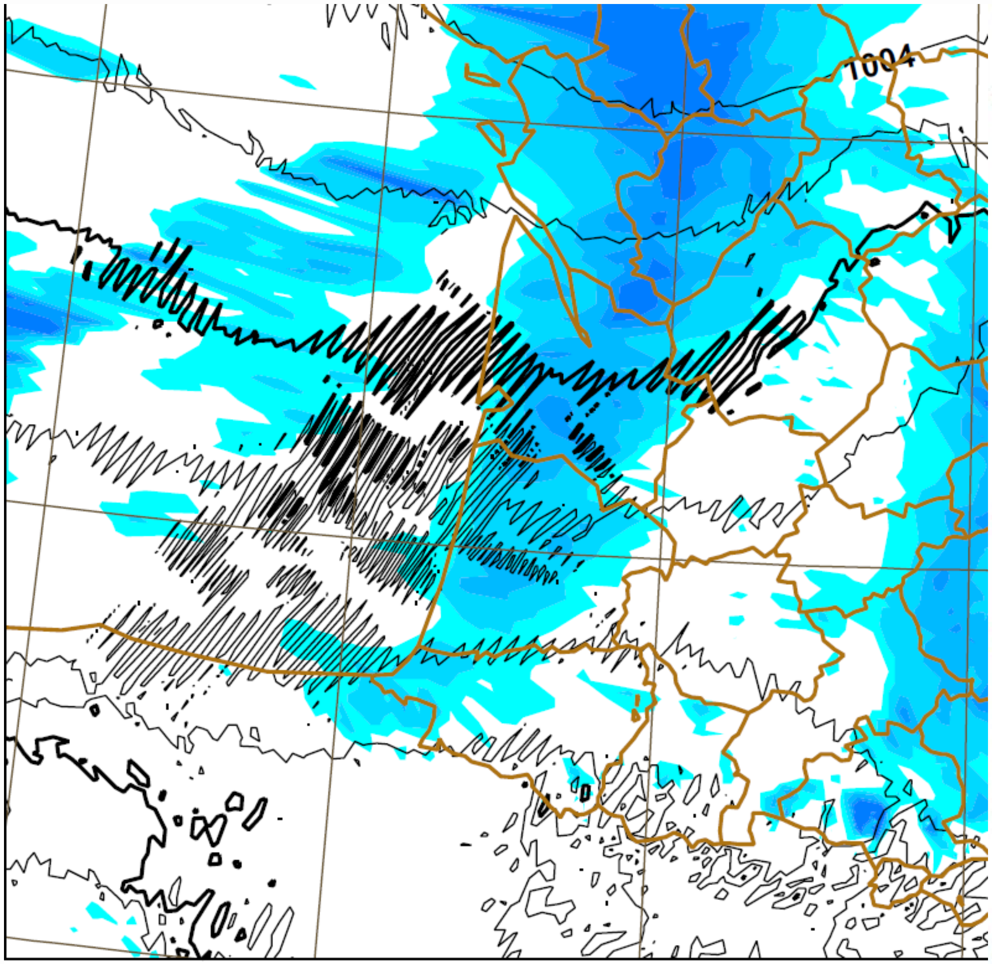




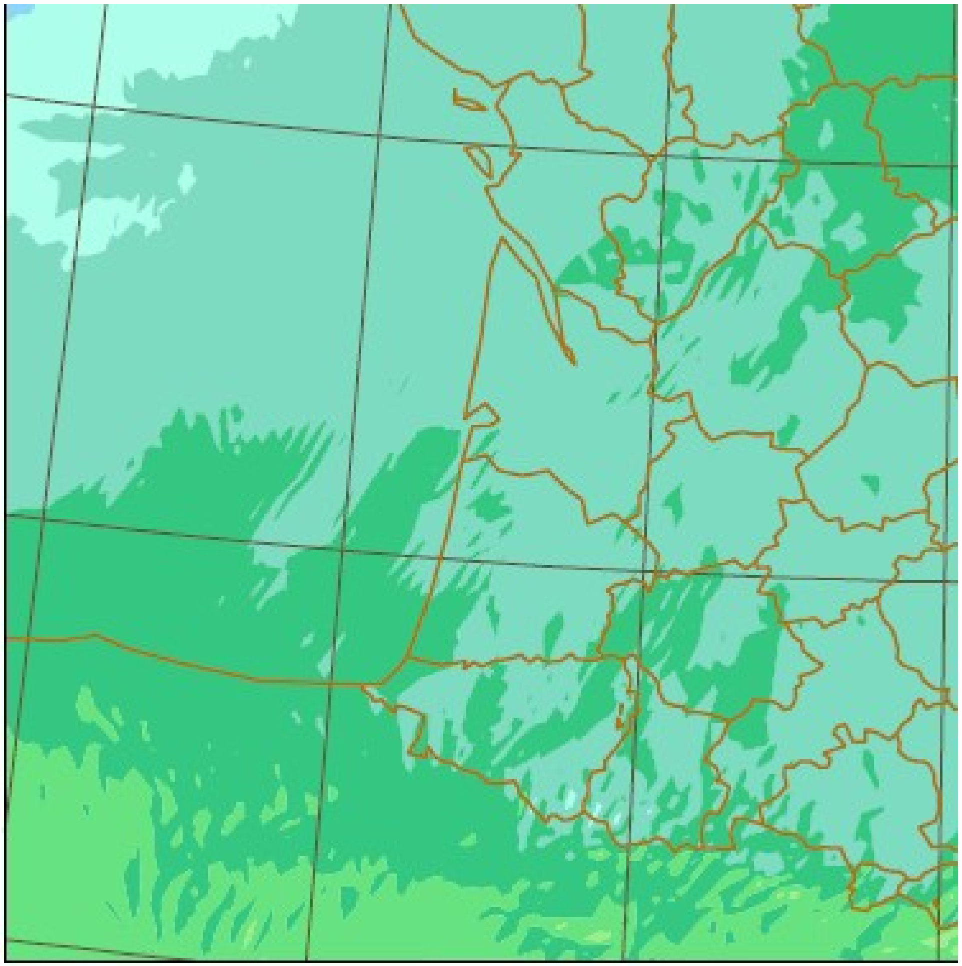
cnrs METEO FRANCE

Spurious oscillations in AROME

Illustration for the 23 february 2015 at 0500 UTC



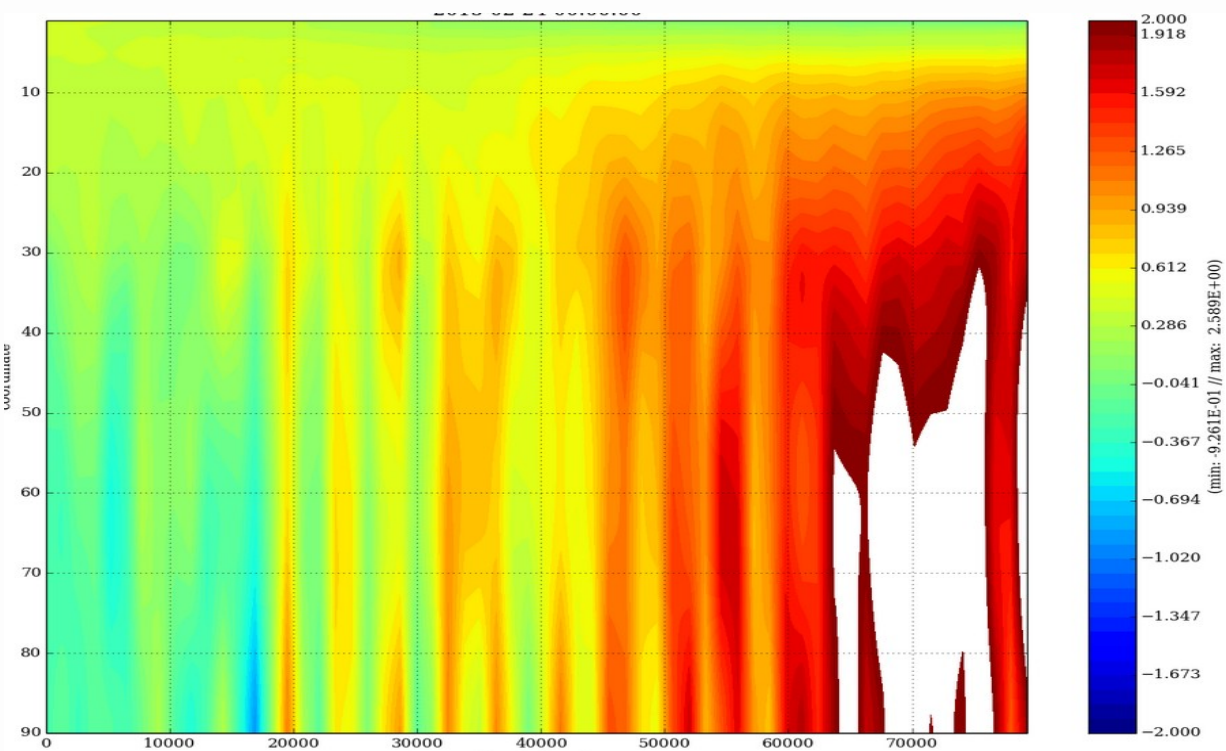
MSL pressure



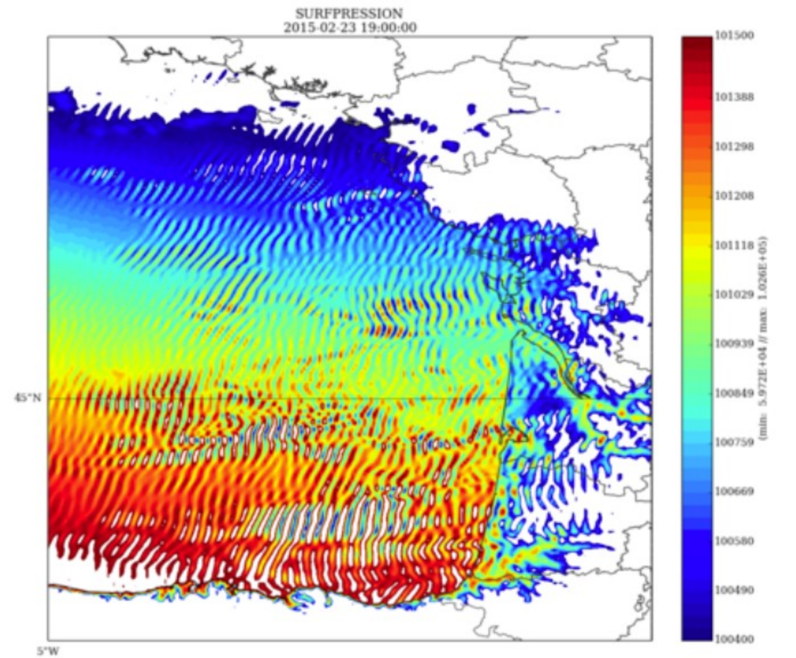
T at 700hPa

Spurious oscillations in AROME

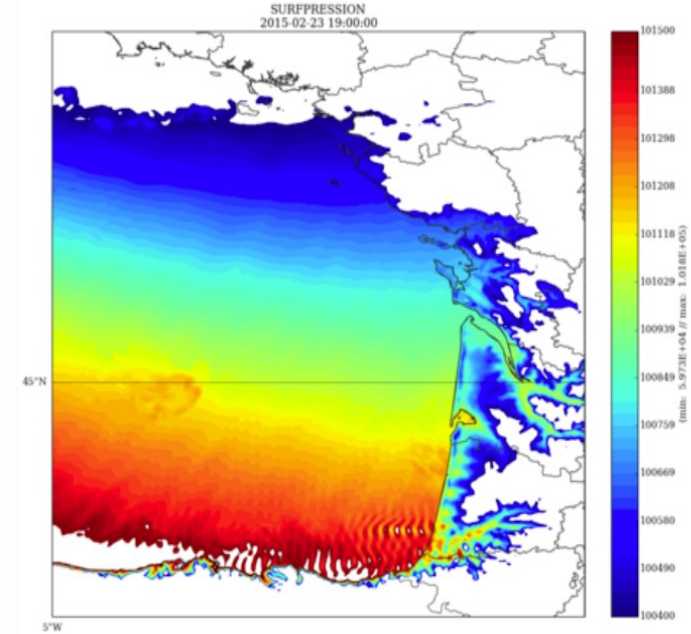
- MSL pressure can be a very noisy field, but here it is quite exagerated
- The pressure departure exhibits really high values
- The structure is quite barotropic



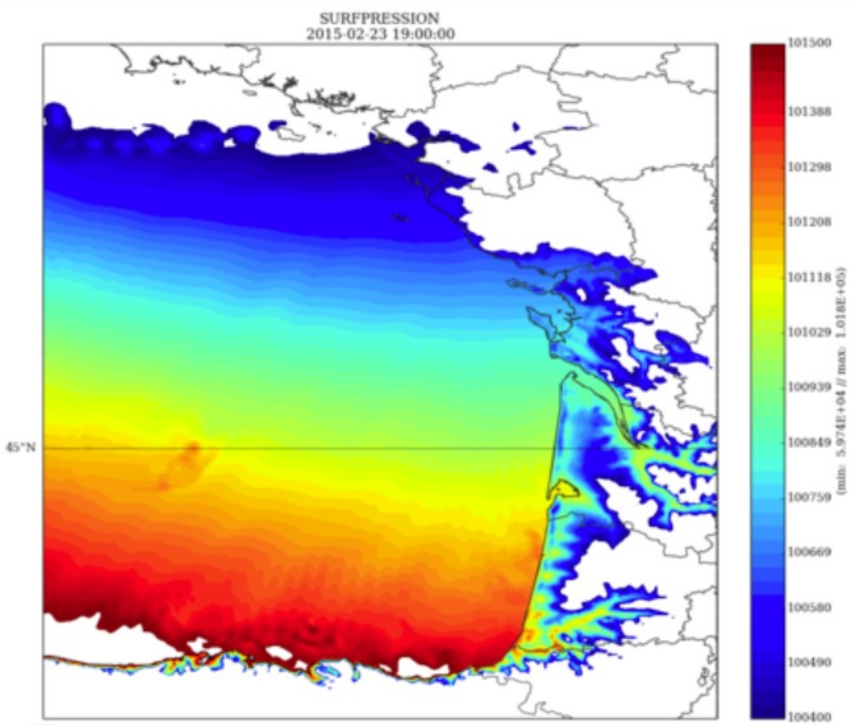
Vertical cross section of pressure departure



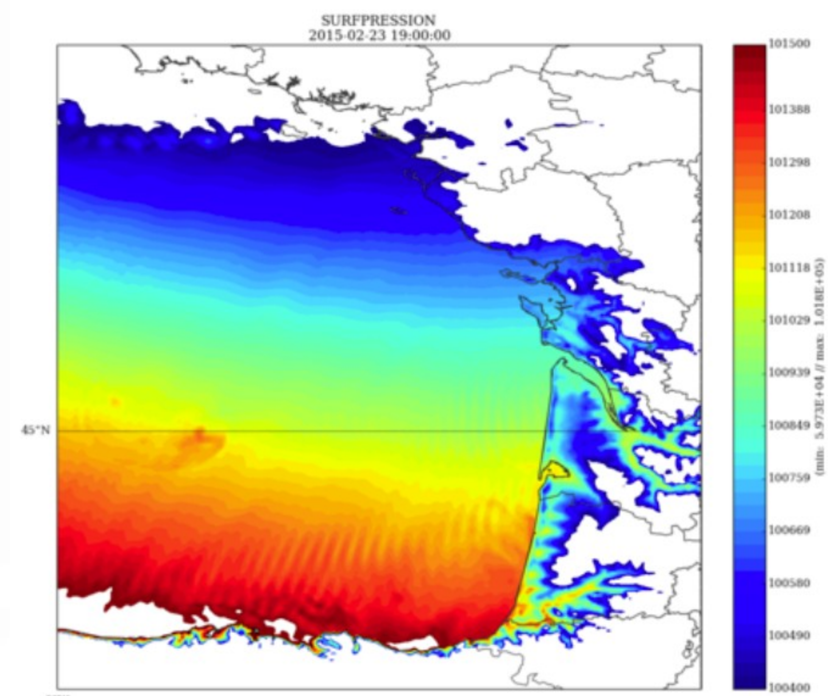
dt=45s



dt=30s



Diffusion x 10



hydrostatic

METEO FRANCE

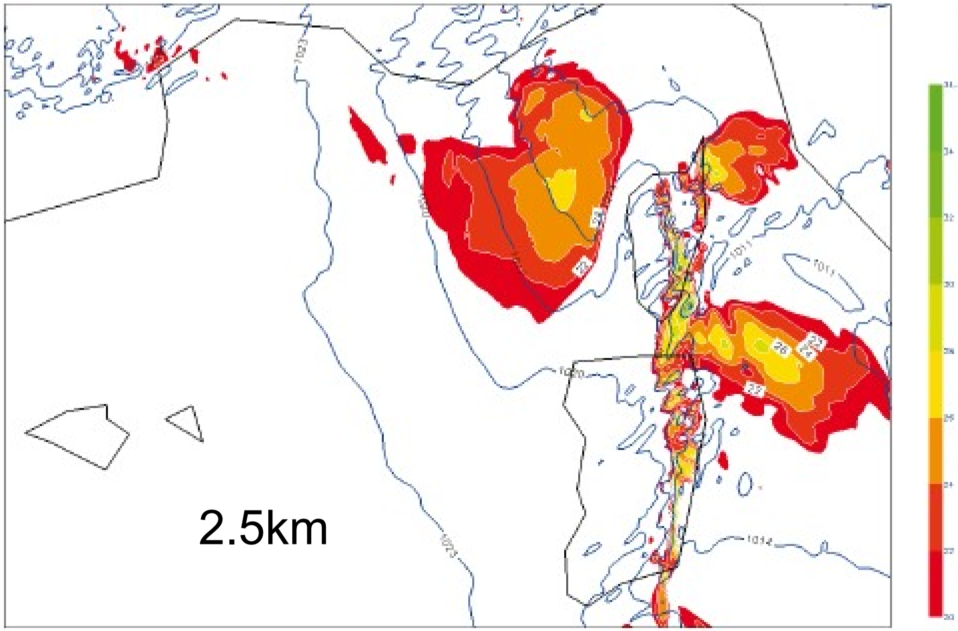
Spurious oscillations in AROME

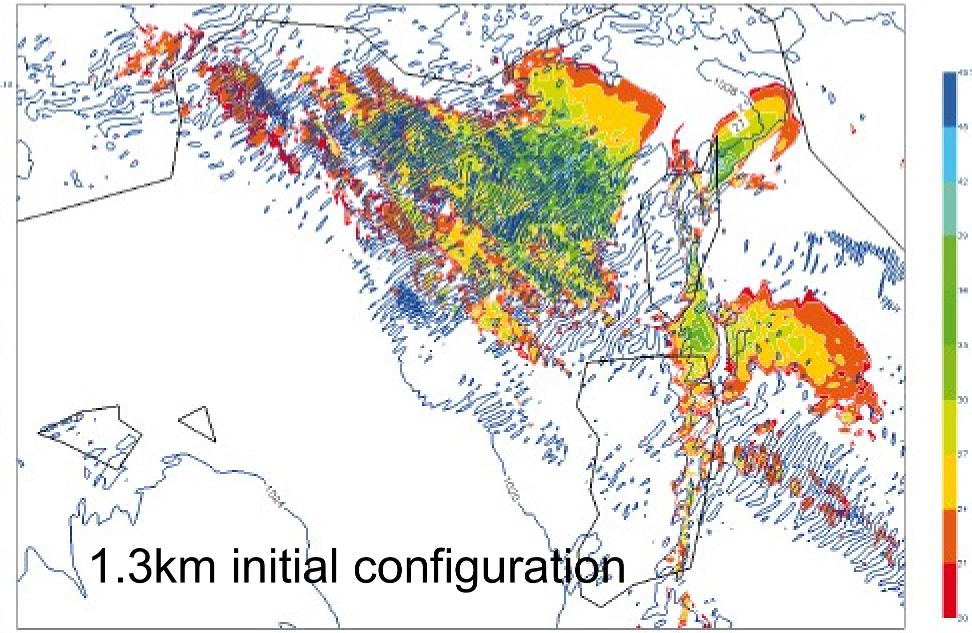
- Our dynamical options are dt=50s with predictor corrector in cheap mode, NSITER=1.
- Reducing the timestep to 30s or diffusion x 10 seemed to solve the problem, also using more than one iteration (NSITER > 1).
- Carefully observing the fields, it looks a bit like an "orographic resonance" but without orography (mostly visible over sea).
- We tested classical dynamics options for lagrangian resonance issues : increasing the timestep helped reducing the oscillation. setting VESL to 0.1 (instead of 0) also solved the issue.
- VESL option : each term in semi-lagrangian discretization is averaged between the final and origin point as :

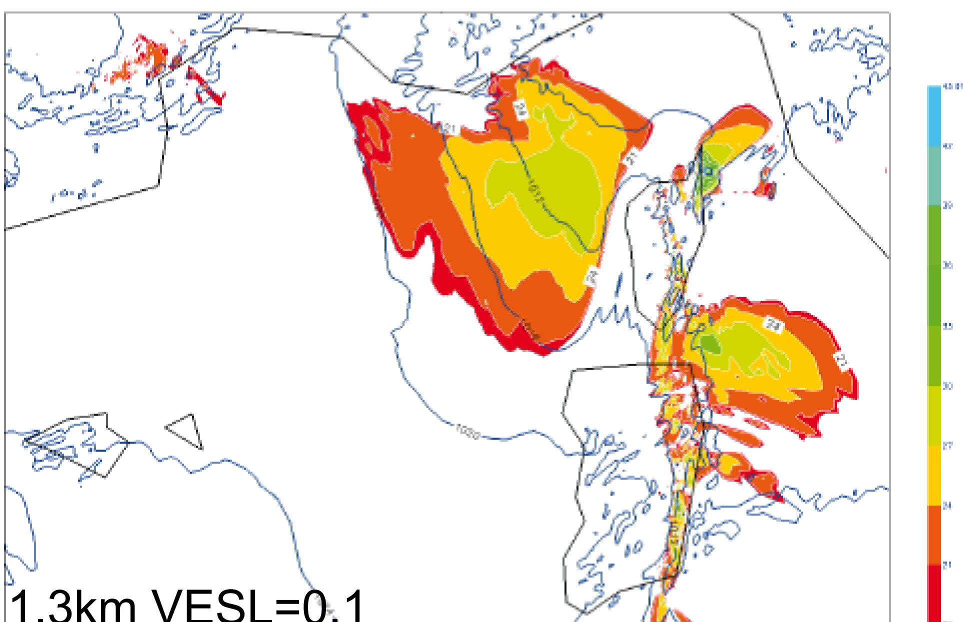
$$\frac{X_F + X_O}{2} \Rightarrow \frac{(1+\alpha)X_F + (1-\alpha)X_O}{2}$$

VESL=0.1 sets the α off-centering parameter to 0.1

Spurious oscillations in AROME



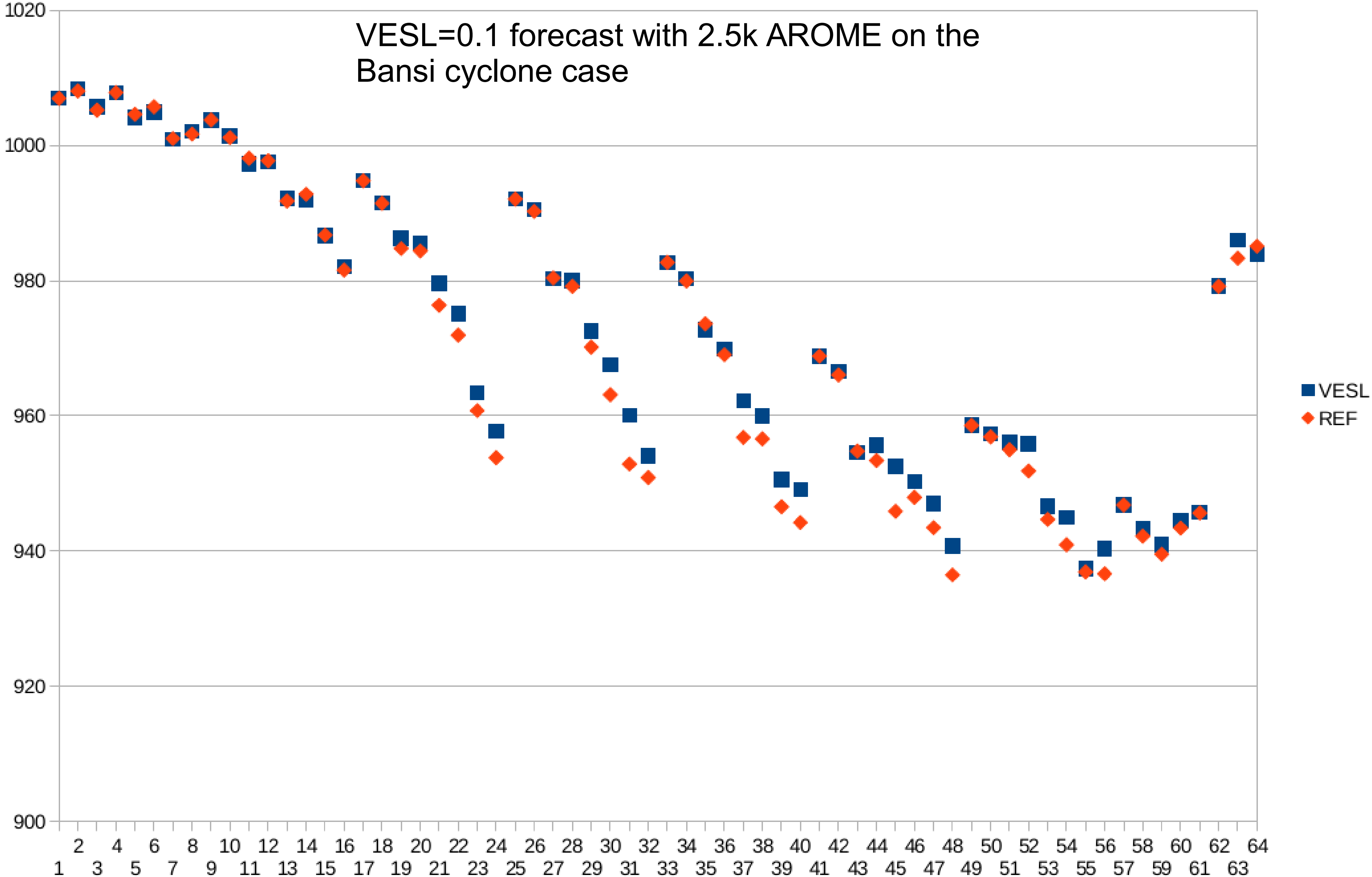




22h AROME forecasts. Contours are MSL pressure, Shaded areas are are Wind gusts.

METEO FRANCE

VESL impact on low pressure systems



- This options was tested over several month and will be used in our next operational suite
- VESL=0.1 leads to less temporal accuracy, but might lead to smoothier fields. We did not observe such behaviour looking at the spectra. The pressure lows values are preserved.
- 2D idealized tests are being performed, the predictor corrector seems to be a necessary ingredient, the discretization errors of this option leads to a lagrangian resonance.
- Another option to solve the problem is to increase the SITRA value. We are currently testing that option.

Conclusions

- R&D on HEVI schemes continues
- Ellipsoidal Geopotential Approximation should be taken into account when developping future dynamical cores
- Cubic truncation amounts to know if it is more important to have a higher resolution for physics
- At 1.3km spurious oscillation are treated with the option VESL=0.1, increasing SITRA value might be preferable in the future.

THANK YOU FOR YOUR ATTENTION