Radiation and multigrid : What has been done already ?

The potential of a multigrid approach to increase computational efficiency of radiation schemes

It is argued that selective use of different grid resolutions inside an NWP model has the potential to increase computational efficiency (`scalability´) without necessarily degrading accuracy in very high resolution NWP models where some processes such as solar radiation become inacurate at increasingly high spatial resolution when subject to the commonly used independent column approach.

A stand-alone version of the ACRANEB2 radiation scheme of the ALADIN-HIRLAM community is used to demonstrate that a flexible scheme using two different grids can be constructed as an internal upgrade inside the radiation framework of the existing model to increase computational efficiency.

Results are first shown from this off-line setup to illustrate the idea. Next the first full 3D forecast experiments are carried out in a preliminary setup using Harmonie-Arome CY40.

Arguments for including coarser mesh for radiation processes, especially solar radiation:

- **Radiative processes in an independent column radiation approximation scheme (ICA), used in most atmospheric NWP models, become inherently increasingly inaccurate at very high model resolution, e.g. at km scale and sub-kilometre scale:**

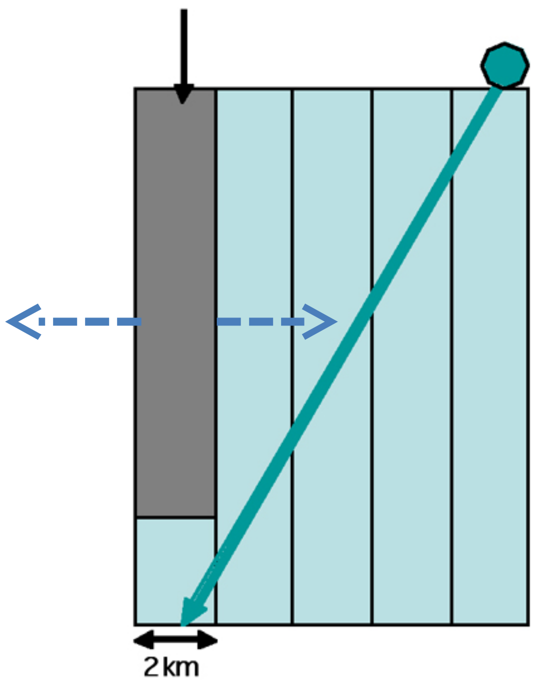
- **Simple computation examples of solar radiation shading effects on the surface energy budget indicate that these effects may be very significant on simple configurations of convective clouds.**

- **Example 1 illustrates that the difference between ICA and a more realistic computation involving direct solar radiation may differ by more than 700 W/m². In more complex cloud configurations it is necessary to include direct and diffuse radiation separately to compute the surface radiation flux in a realistic way. Furthermore, thermal cooling at cloud edges are not handled in the vertical column approach.**

- **Example 2 shows cloud shadows over Spain on 22 March 2009 late in the afternoon. An independent column approach would wrongly assume solar radiation from clear sky conditions in areas of shadows.**

- **Example3: Thermal radiation in the case of a broken stratiform cloud sheet. The column physics sees no clouds in the case shown while a more realistic computation integrating radiance over the half sphere above the ground would give a quite different net radiation at the surface.**

Example 1: Idealized solar flux computation in an atmosphere with a deep convective cloud.



Thermal cooling at the sides of the cloud

Example 1:
Solar zenith angle= 30 deg
Observational facts: Solar constant ~1370W/m2

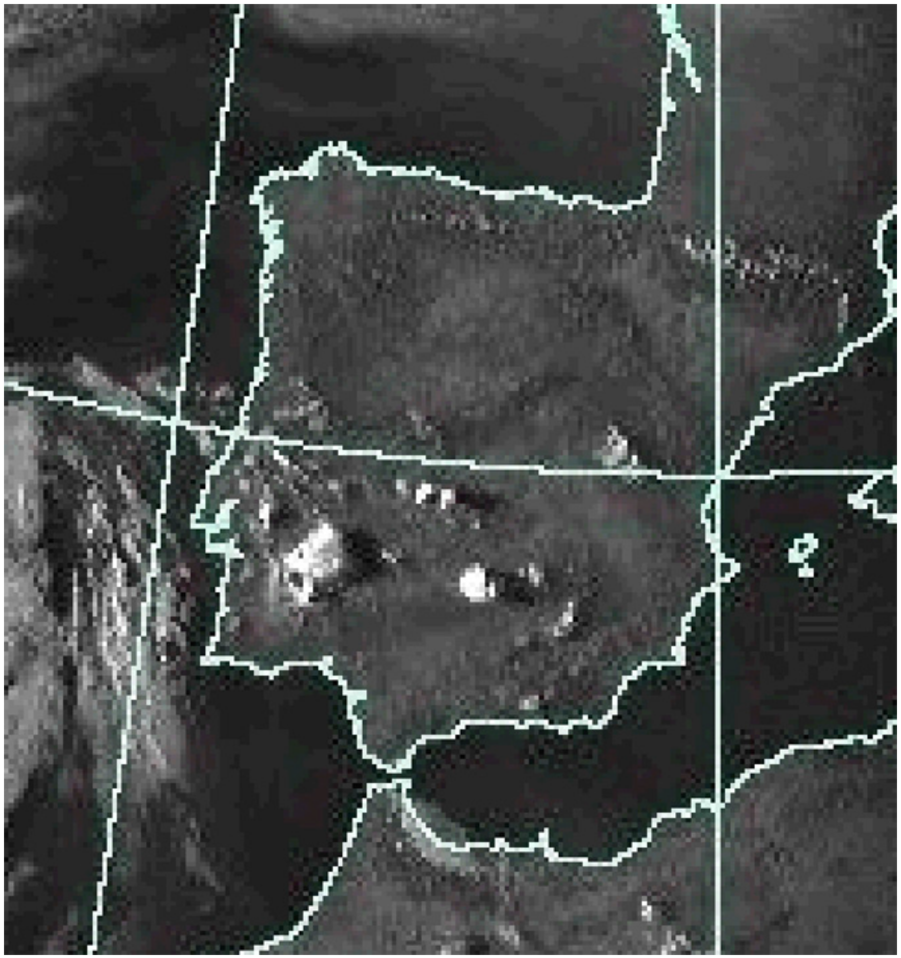
Actual situation: Direct sunshine reaches the ground without penetrating the deep convective cloud. However : in Column physics only a small fraction of solar radiation will reach the ground due to a high cloud albedo.

Approximate computation of solar radiation F at the ground:

A) Column physics : F~1370*cos (30)*0.10= 119W/m2
B) 'Slant' column: F~1370*cos (30)*0.75=890W/m2

Difference= 890 – 119W/m2= 771 W/m2

Example 2: Limitations of an `independent column´ approach.



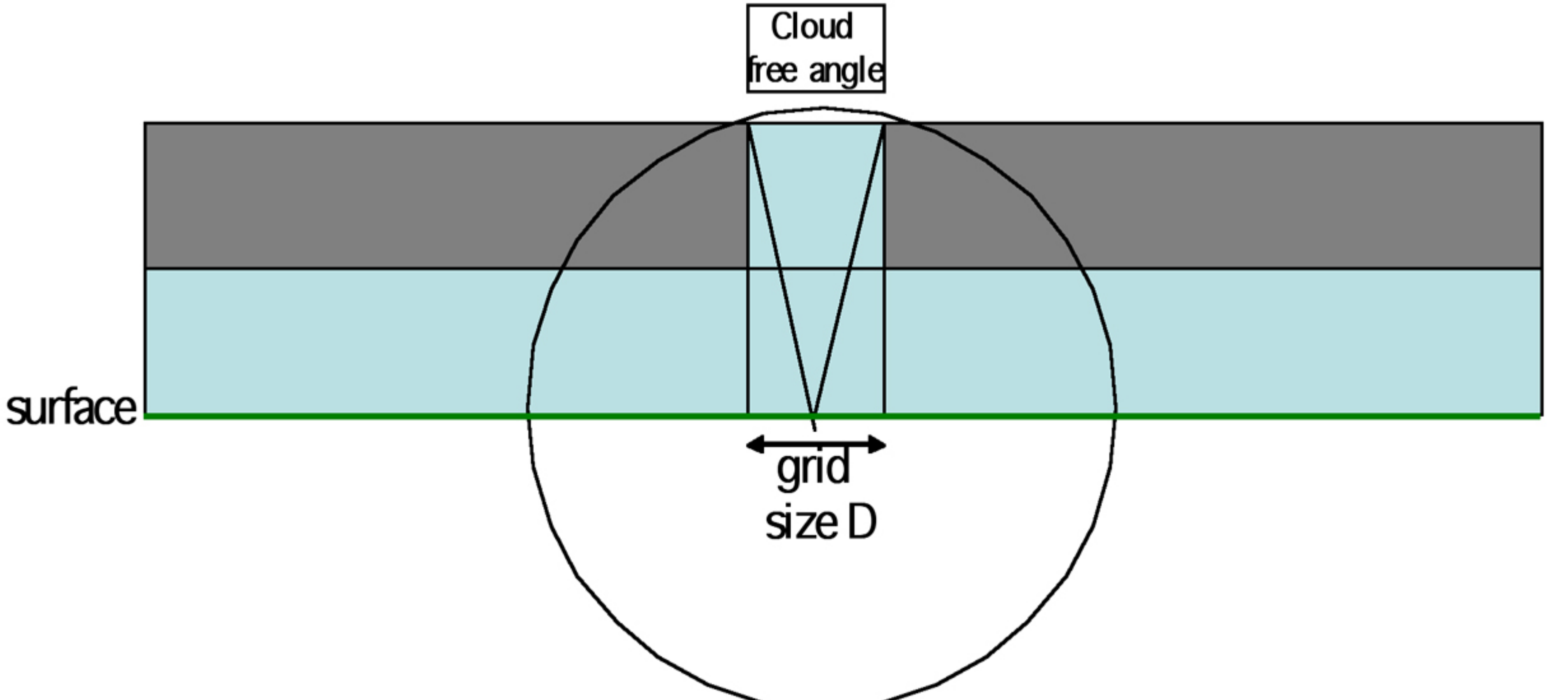
The figure shows the evidence from satellite that significant shadow effects may occur in the presence of clouds.

This effect is non-negligible when computing solar radiation at the ground in high using an independent (vertical) column scheme.

The picture shows cloud shadows over Spain on 22 March 2009 late in the afternoon.

Example3: Thermal radiation:

Assumptions for 'worst case' type of computations of net radiation at the ground is giving significant differences between cloud column physics and more realistic computations where the actual sky view is taken into account, integrating radiance over the half sphere above the ground – cloud layers of big horizontal extent exist outside the vertical 'column' (cylinder) !



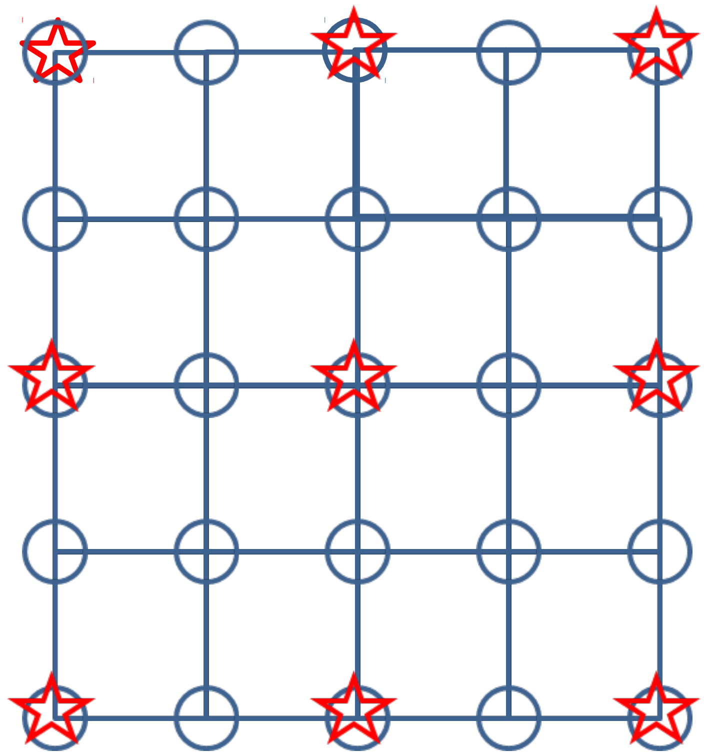
Preliminary two-grid implementation of the ACRANEB2 radiation scheme

- builds on existing code framework of the IFS developed by ECMWF, Météo-France and the Limited area model consortia

- Two grid computation is done internally inside the radiation framework of the physics code.

- The output from the scheme occurs on the same grid as the input . The computational savings arise from computations made in a subset of gridpoints of the total fine mesh grid operated on in a given sub-area of the entire model domain.

Example of coarse/fine mesh tested



A special off-line stand-alone version of the NWP radiation of ACRANEB2- scheme has been made : It is imagined that the computations of the entire model area are divided in bloks with number of grid points = NPROMA

Example shown: (fine mesh blue circles)=25

The present example defines in addition a coarse sub-grid (red stars) =9

In the figure this is every second grid point in each horizontal grid direction.

Computational procedure internally :

1) A new subroutine `acraneb2c´ is made. This routine computes internally a coarse mesh grid with values from the fine mesh before calling the normal `acraneb2´ scheme.

2) Fore each coarse mesh grid point, information on the corresponding grid point number in the fine mesh is stored. This link for each grid point of the coarse mesh is used to assign correct input arrays for all needed input arguments to the `acraneb2´scheme.

3) The `acraneb2' scheme is then called inside `acraneb2c´, formally in an identical way as before, but with data from a different horizontal resolution.

4) After this call of `acraneb2´ the output corresponding to fine mesh is constructed applying a certain choice for information exchange from one or more neighbouring grid points of the coarser mesh. Examples of constructs to compute fine mesh output from coarser mesh are given in the next slide.

5) For solar radiation it is easy to see that use of computations in another column towards the direction of the sun has some potential to better describe e.g. the effects of clouds affecting the solar radiation to the ground. As a consequence the conversion of output from coarse mesh to fine mesh does not necessarily degrade the quality.

Several options are possible to relate variables of the fine mesh from the coarse mesh values, e.g.

(1) Nearest grid point of coarse mesh

(2) Grid point most similar to the fine mesh grid point, e.g. from a relative humidity comparison

(3) Weighted 4 grid point coarse mesh determination

(4) In daytime: grid point closest to the solar azimuth direction

(5) Cyclic changing of the neighbouring grid point chosen

(6) Random choice of neighbouring grid point

Example of coarse/fine mesh tested

NFAC : integer describing ratio between fine mesh and coarse mesh resolution

KNUM : integer describing size of coarse mesh grid in each coordinate direction

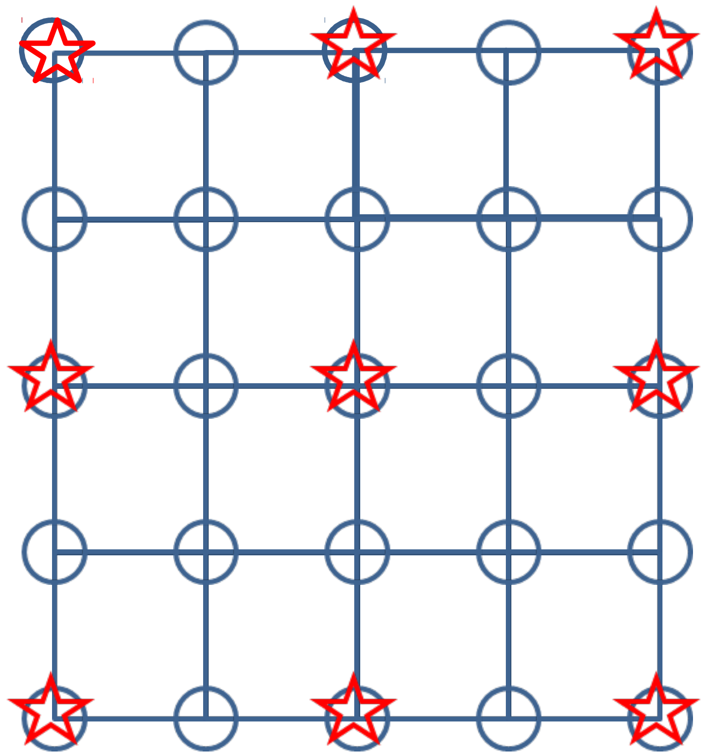
Nf : number of fine mesh grid points in a subdomain

Nc : number of coarse mesh grid points in a subdomain

Example (next slide): coarse mesh with red stars,
fine mesh with blue circles

Nf=(1 + KFAC*KNUM)**2 = 25
Nc=(1+KNUM)**2 = 9

Example of coarse/fine mesh tested



Total number Nf of fine mesh grid points: (KFAC=2, KNUM=2)
Nf=(1 + KFAC*KNUM)2 = 25**
Total number of points in coarse mesh Nc=(1+KNUM)2 = 9**
Example shows coarse mesh with red stars, fine mesh with blue circles

Result of preliminary test based on non-optimized code of ACRANEB2, CY40 release, computed on a single CPU (GNU-compiler)

Table shows relative speed–up factor S between `acraneb2´ and `acraneb2c´schemes for different choices of KFAC, KNUM.

KFAC \ KNUM	1	2	4	7	10
2	Nf=9 Nc=4 S=1.8	Nf=25 Nc=9 S=2.6	Nf=81 Nc=25 S=2.9	Nf=225 Nc=64 S=3.0	Nf=441 Nc=121 S=3.5
4	Nf=25 Nc=4 S=5.3	Nf=81 Nc=9 S=8.6	Nf=289 Nc=25 S=9.7	Nf=841 Nc=64 S=11.9	Nf=1681 Nc=121 S=12.5
7	Nf=64 Nc=4 S=10.4	Nf=225 Nc=9 S=17,5	Nf=841 Nc=25 S=26.9	Nf=2500 Nc=64 S=31.2	Nf=5041 Nc=121 S=32.9
10	Nf=121 Nc=4 S=24.0	Nf=441 Nc=9 S=29.2	Nf=1681 Nc=25 S=46.5	Nf=5041 Nc=64 S=52.7	Nf=10201 Nc=121 S=53.7

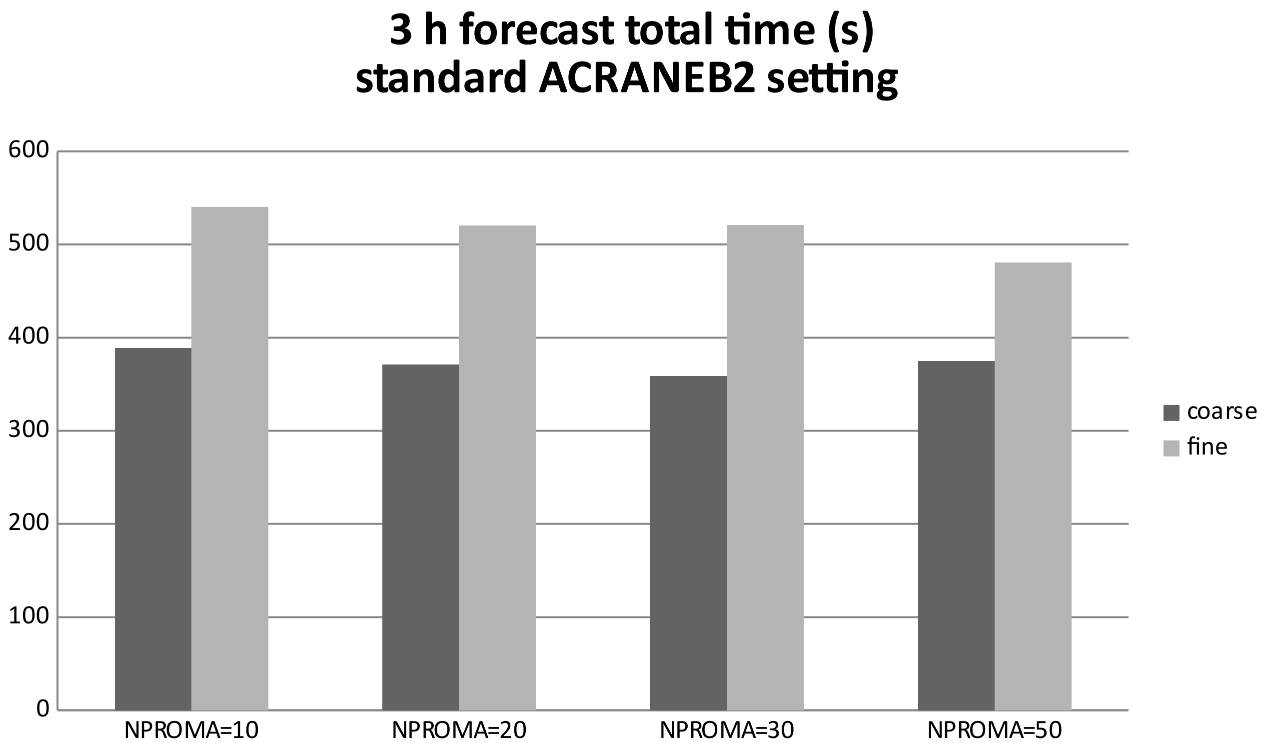
Total number of grid points in a subdomain used for the optimization:

$Nf = (1 + KFAC * KNUM)^2$ (fine mesh) $Nc = (1 + KNUM)^2$ (coarse mesh)

Speed-up factor S is computed as the ratio between timing for execution of a call to `acraneb2´ (fine mesh) relative to timing of a call to `acraneb2c´ (mixed grid scheme).

First test of idea on full Harmonie-Arome setup:
A 2D- multigrid was not established in initial tests
only 1D thinning of NPROMA arrays . First and last point in NPROMA loops were computed in coase mesh. Fine mesh values were restablished by linear interpolation.

Model: Harmonie-Arome Cy40, 800*600 points
Hardware: CRAY XC30 SandyBridge, 10 Nodes



Simple setup: 2 points in coarse mesh ,start and end of NPROMA, computed for a given choice of NPROMA

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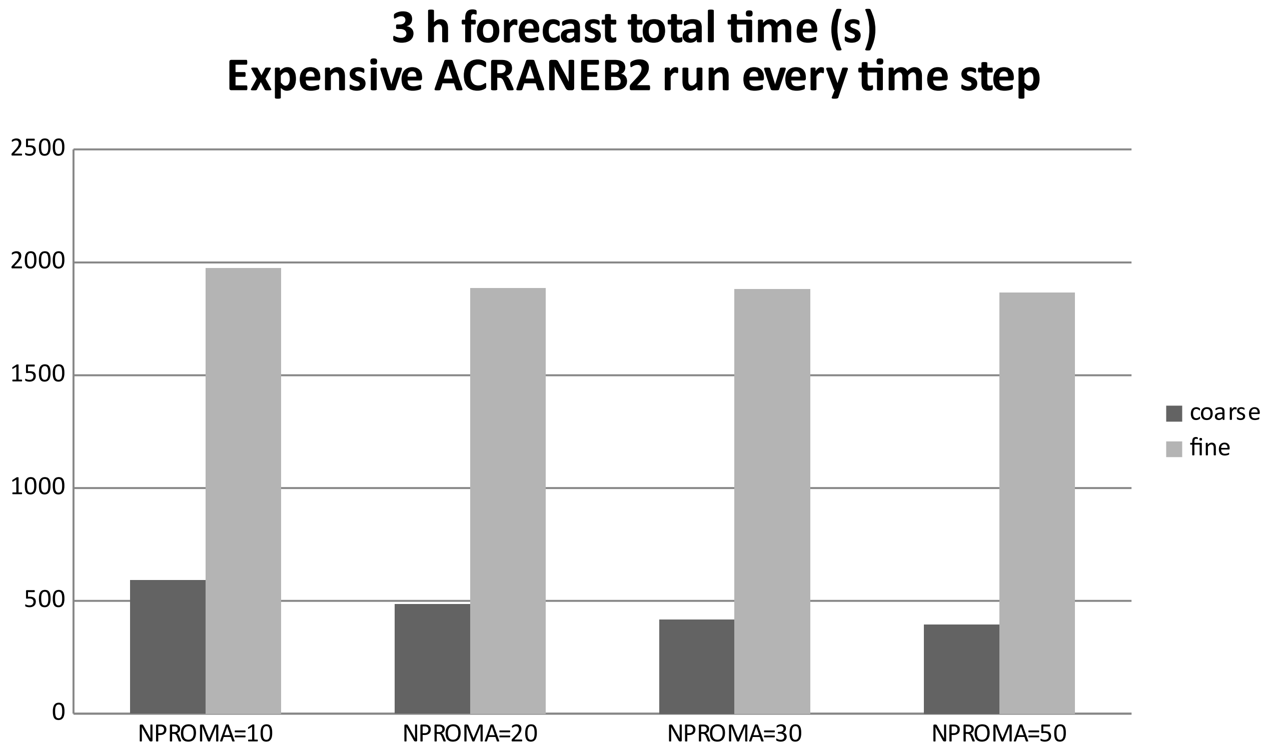
NB: Expensive version of ACRANEB2 run every time step



Simple setup: 2 points in coarse mesh ,start and end of NPROMA, computed for a given choice of NPROMA

Conclusions and recommendations

- **A simple framework has been proposed to increase computational efficiency of the ACRANEB2 radiation scheme used in the ALADIN-HIRLAM coorporation. The preliminary results indicate that computational savings are very substantially especially in expenssive setup where ACRANEB2 is called every time step (speed up of total model forecast execution time by ~ a factor of 4)**

- **The stand-alone results with big speed up factors are confirmed by the simple implementation in full forecast model.**

- **Next step could be to run cases and longer experiments with verification There are many options for future developments, e.g. in the context of sub-km grid sizes and ensembles (fast runtime).**

- **A 2D treatment of coarse versus fine mesh is desirable. This could be achieved by using the semi-Lagrangian framework of Harmonie-Arome which has been used for other processes, e.g. in the context of cellular automata. The ATLAS framework developed at ECMWF is another future option for such implementation.**