Davide Cesari — Servizio Idro Meteo — Bologna

dcesari@arpa.emr.it

# A Semi-implicit Semi-Lagrangian Dynamical Core for High Resolution NWP over Complex Terrain: Development Status

Luca Bonaventura — MOX — Politecnico di Milano

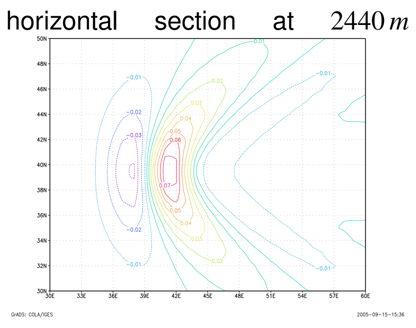
luca.bonaventura@polimi.it

## Model description

- Dynamical core based on Bonaventura, 2000 and Rosatti et al., 2005
- Implemented within Lokal Modell code structure
- Vertical geometrical (Z) coordinate
- Semi-implicit 2 time level discretization
  - Divergence computed by finite volume discretization
  - 3-d solver for weakly nonlinear system $Ax + f(x) = b$: fixed point iterations with Conjugate Gradient as linear kernel
  - Block tridiagonal preconditioning with linear operator of vertical discretization
- Semi-Lagrangian advection
  - Cut cell type lower boundary condition
  - Interpolation with Radial Basis Function technique close to the lower boundary

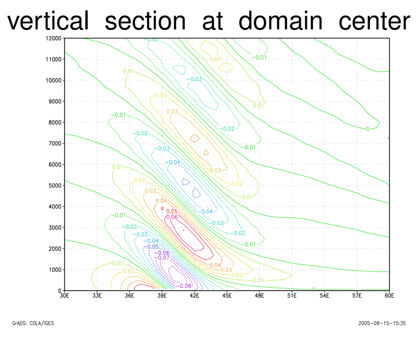
## Latest idealised results: 3d flow over an obstacle

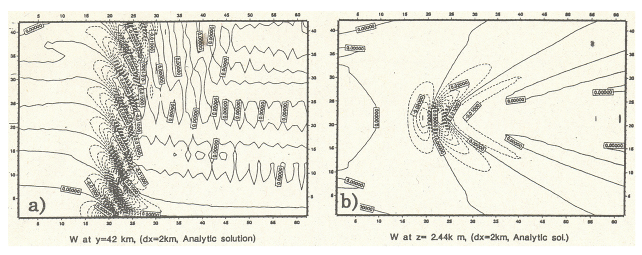
W, contour interval $0.01\,m/s$, horizontal section at $2440\,m$



$\Delta x = 4000\,m$
$\Delta z = 40 \div 1200\,m$
$\Delta t = 40\,s$
$H = 100\,m$
$a = 6\,Km$
$U = 8\,m/s$
Hydro regime

W, contour interval $0.01\,m/s$, vertical section at domain center





Reference results by Günther Doms, Saito, Schättler, Steppeler

## Radial Basis Function interpolator

RBF technique provides an interpolator which can smoothly and accurately reconstruct a field sampled on an irregularly distributed set of points.

The field $s$ is reconstructed, starting from the knowledge of $s(\mathbf{x}_i) = f_i, i = 1,...N$ in $N$ given points of coordinate $\mathbf{x}_i$, in the form:

$$f(\mathbf{x}) = \sum_{i=1}^{N} c_i \phi(\|\mathbf{x} - \mathbf{x}_i\|)$$

where $\phi$ is the so-called "radial basis function", which depends only on the relative distance between the points. Constraining $s$ to be equal to the known function in the given points we obtain the relations ($j = 1,...N$):

$$\sum_{i=1}^{N} c_i \phi(\|\mathbf{x}_j - \mathbf{x}_i\|) = f_j$$

These relations constitute a $N \times N$ linear system for the coefficients $c_i$. The invertibility of the system can be proved under proper conditions for the function $\phi$.

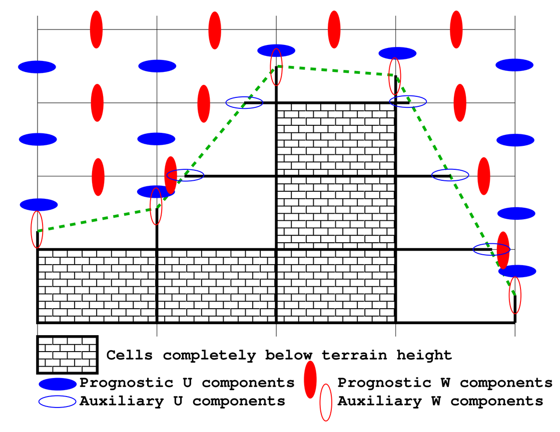
The radial basis function used here is $\phi(x) = \sqrt{1 + (x/\Delta x)^2}$ where $\Delta x$ is a proper spatial scale.

- ⌣ Can give a smooth interpolation also with irregularly-gridded data
- ⌣ It is straightforward to adjust the stencil used for interpolation to achieve the desired accuracy
- ⌢ The algorithm is computationally expensive but can be optimized at the expense of more memory occupation

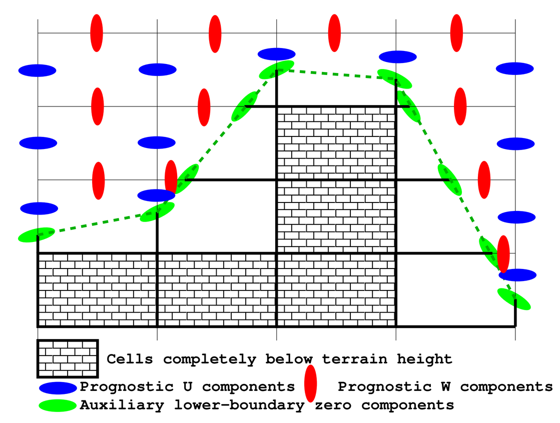
The introduction of RBF interpolator in the SL advection has given a consistent improvement in the representation of flow over orography.

## Development status - Semi Lagrangian advection

- Trajectories interpolation: $2 \times 2 \times 2$ RBF stencil + lower b.c. / trilinear interpolation
- Application of a reasonable lower boundary condition is very important in order to keep trajectories inside computational domain, this can be currently achieved in 2 ways:
  - Auxiliary lower boundary components respecting free slip lower b.c. can be added to interpolation: works well




  - A vector RBF interpolation of the 3 components of momentum with free slip lower b.c. on some auxiliary points can be performed: theoretically cleaner approach but unstable in cases of large velocity gradients and/or large values of divergence



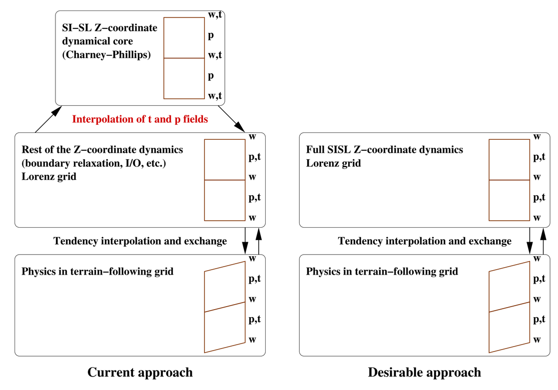

- Upwind interpolation: $4 \times 4 \times 4$ RBF / tricubic interpolation
- Some optimisations have already been implemented in the advection but it is still a time-critical part of the code
- Other optimizations possible, mainly precomputation of LU decmposition coefficients for inverting the RBF equation systems

## Development status - Semi Implicit solver

- It is already a stable part of the code
- Apparently not critical from the point of view of performance
- There is still room for optimization, e.g. reducing the solver iterations in highly parallel runs, by means of a domain decomposition preconditioning approach, already partially implemented

## Development status - Merge with LM_Z library

- The merge, started with the visit of H.-W. Bitzer in Bologna, has been completed but is still untested
- Open issue: how to deal with the different vertical staggering for Temperature (Charney-Phillips vs. Lorenz grid)
  - Currently it is done with interpolation back and forth at the beginning and at the end of the dynamics, in order to reduce the impact on the rest of the model code
  - A better way would be to modify the interface to the terrain-following physics in order to take into account directly the different staggering, thus simplifying the whole algorithm



- Open issue: orography should be initially defined on cell corners and then interpolated on cells centers, not the opposite, for a more accurate representation of lower boundary
- Some code cleanup probably needed, in order to fit cleanly into the LM code structure

## Conclusions and future plans

- The code has been merged with LM_Z library
- The merged code has to be tested, but it is virtually ready for realistic tests
- Tests will be carried out in parallel with the explicit LM_Z version
- The interface to the physics will also undergo verification
- Optimisation in the advection is needed
- The interaction with the physics will have to be addressed more extensively also taking into account the Charney-Phillips vertical discretisation used

## Bibliography

Bonaventura L., 2000,
**A Semi-Implicit, Semi-Lagrangian Scheme Using the Height Coordinate for a Nonhydrostatic and Fully Elastic Model of Atmospheric Flows**,
Journal of Computational Physics, 158, pp 186-213

Steppeler J., Bitzer H.-W., Minotte M., L. Bonaventura, 2002,
**Nonhydrostatic Atmospheric Modeling using a z-Coordinate Representation.**,
Monthly Weather Review, 130, 8, pp 2143-2149

Rosatti G., D. Cesari, L. Bonaventura, 2005,
**Semi-implicit, semi-Lagrangian modelling for environmental problems on staggered Cartesian grids with cutcells**,
Journal of Computational Physics, 204, pp 353-377