

Meteorological Models of MeteoGalicia

EASY project

The following document describes briefly some aspects of MM5 and WRF models related to the EASY project. On the first two sections a general description of models are presented. On section three the operational implementation at MeteoGalicia is described.

1 - MM5 Model Description

1.1 Introduction to MM5 Modeling System

The Fifth-Generation NCAR / Penn State Mesoscale Model is the latest in a series that developed from a mesoscale model used by Anthes at Penn State in the early '70's that was later documented by Anthes and Warner (1978). Since that time it has undergone many changes designed to broaden its usage. These include (i) a multiple-nest capability, (ii) nonhydrostatic dynamics, and (iii) a four-dimensional data assimilation capability as well as more physics options, and portability to a wider range of computing platforms. These changes have effects on how jobs are set up using the modeling system, so the purpose of this introduction is to acquaint the user with some concepts as used in the MM5 system.

A schematic diagram ([Fig. 1.1](#)) is provided showing a flow-chart of the complete modeling system. It is intended to show the order of the programs, flow of the data, and to briefly describe their primary functions. Terrestrial and isobaric meteorological data are horizontally interpolated (programs TERRAIN and REGRID) from a latitude-longitude mesh to a variable high-resolution domain on either a Mercator, Lambert Conformal, or Polar Stereographic projection. Since the interpolation does not provide mesoscale detail, the interpolated data may be enhanced (program RAWINS/little_r) with observations from the standard network of surface and rawinsonde stations using a successive-scan Cressman or multiquadric technique. Program INTERP performs the vertical interpolation from pressure levels to the sigma coordinate system of MM5. Sigma surfaces near the ground closely follow the terrain, and the higher-level sigma

surfaces tend to approximate isobaric surfaces. Since the vertical and horizontal resolution and domain size are variable, the modeling package programs employ parameterized dimensions requiring a userdefined amount of core memory. Some peripheral storage devices are also used.

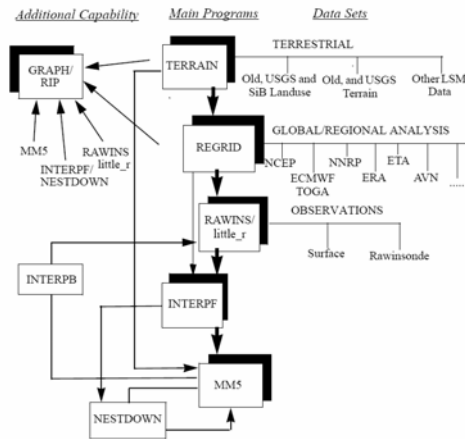


Fig 1.1 The MM5 modeling system flow chart

For more info and a complete description of MM5 model please visit:

<http://www.mmm.ucar.edu/mm5/>

1.2 The MM5 Model Horizontal and Vertical Grid

It is useful to first introduce the model's grid configuration. The modelling system usually gets and analyzes its data on pressure surfaces, but these have to be interpolated to the model's vertical coordinate before being input to the model. The vertical coordinate is terrain following (see Fig.1.2) meaning that the lower grid levels follow the terrain while the upper surface is flat. Intermediate levels progressively flatten as the pressure decreases toward the chosen top pressure. A dimensionless quantity σ is used to define the model levels where

$$\sigma = \frac{(p - p_t)}{(p_s - p_t)} \quad (1.1)$$

p is the pressure, p_t is a specified constant top pressure, p_s is the surface pressure.

As described in a later section, the nonhydrostatic model coordinate uses a reference-state pressure to define the coordinate rather than the actual pressure which is used in the hydrostatic model. It can be seen from the equation and [Fig 1.2](#) that σ is zero at the top and one at the surface, and each model level is defined by a value of σ . The model vertical resolution is defined by a list of values between zero and one that do not necessarily have to be evenly spaced. Commonly the resolution in the boundary layer is much finer than above, and the number of levels may vary from ten to forty, although there is no limit in principle.

The horizontal grid has an Arakawa-Lamb B-staggering of the velocity variables with respect to the scalars. This is shown in [Fig 1.3](#) where it can be seen that the scalars (T, q etc.) are defined at the center of the grid square, while the eastward (u) and northward (v) velocity components are collocated at the corners. The center points of the grid squares will be referred to as cross points, and the corner points are dot points. Hence horizontal velocity is defined at dot points, for example, and when data is input to the model the preprocessors do the necessary interpolations to assure consistency with the grid.

All the above variables are defined in the middle of each model vertical layer, referred to as halflevels and represented by the dashed lines in [Fig 1.3](#). Vertical velocity is carried at the full levels (solid lines). In defining the sigma levels it is the full levels that are listed, including levels at 0 and 1. The number of model layers is therefore always one less than the number of full sigma levels. Note also the I, J, and K index directions in the modeling system. The finite differencing in the model is, of course, crucially dependent upon the grid staggering wherever gradients or averaging are required to represent terms in the equations, and more details of this can be found in the model description document (Grell et al., 1994).

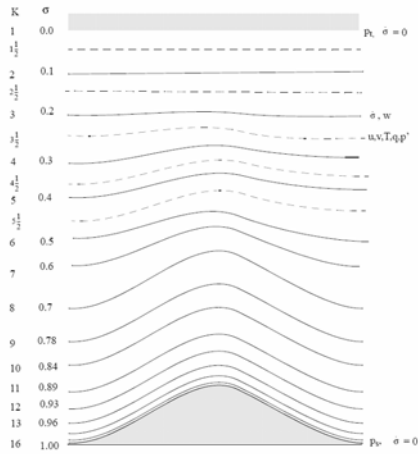


Figure 1.2 Schematic representation of the vertical structure of the model. The example is for 15 vertical layers. Dashed lines denote half-sigma levels, solid lines denote full-sigma levels.

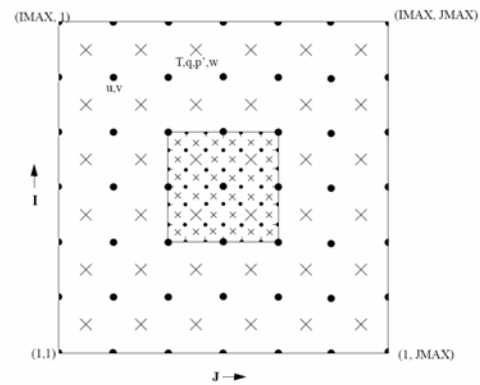


Figure 1.3 Schematic representation showing the horizontal Arakawa B-grid staggering of the dot (l) and cross (x) grid points. The smaller inner box is a representative mesh staggering for a 3:1 coarse-grid distance to fine-grid distance ratio.

1.3 Nesting

MM5 contains a capability of multiple nesting with up to nine domains running at the same time and completely interacting. A possible configuration is shown in Fig 1.4. The nesting ratio is always 3:1 for two-way interaction. “Two-way interaction” means that the nest’s input from the coarse mesh comes via its boundaries, while the feedback to the coarser mesh occurs over the nest interior.

It can be seen that multiple nests are allowed on a given level of nesting (e.g. domains 2 and 3 in (Fig 1.4), and they are also allowed to overlap. Domain 4 is at the third level, meaning that its grid size and time step are nine times less than for domain 1. Each sub-domain has a “Mother domain” in which it is completely embedded, so that for domains 2 and 3 the mother domain is 1, and for 4 it is 3. Nests may be turned on and off at any time in the simulation, noting that whenever a mother nest is terminated all its descendent nests also are turned off. Moving a domain is also possible during a simulation provided that it is not a mother domain to an active nest and provided that it is not the coarsest mesh.

One-way nesting is also possible in MM5. Here the model is first run to create an output that is interpolated using any ratio (not restricted to 3:1), and a boundary file is also created once a oneway nested domain location is specified. Typically the boundary file

may be hourly (dependent upon the output frequency of the coarse domain), and this data is time-interpolated to supply the nest. Therefore one-way nesting differs from two-way nesting in having no feedback and coarser temporal resolution at the boundaries. The one-way nest may also be initialized with enhanced resolution data and terrain. It is important that the terrain is consistent with the coarser mesh in the boundary zone, and the TERRAIN preprocessor needs to be run with both domains to ensure this.

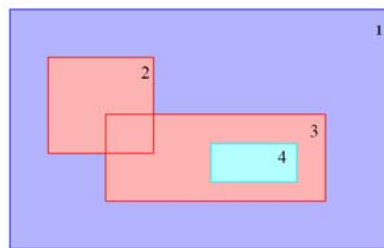


Fig 1.4 Example of a nesting configuration. The shading shows three different levels of nesting.

1.4 Lateral Boundary Conditions

To run any regional numerical weather prediction model requires lateral boundary conditions. In MM5 all four boundaries have specified horizontal winds, temperature, pressure and moisture fields, and can have specified microphysical fields (such as cloud) if these are available. Therefore, prior to running a simulation, boundary values have to be set in addition to initial values for these fields.

The boundary values come from analyses at the future times, or a previous coarser-mesh simulation (1-way nest), or from another model's forecast (in real-time forecasts). For real-time forecasts the lateral boundaries will ultimately depend on a global-model forecast. In studies of past cases the analyses providing the boundary conditions may be enhanced by observation analysis (Rawins or little_r) in the same way as initial conditions are. Where upper-air analyses are used the boundary values may only be available 12-hourly, while for model-generated boundary conditions it may be a higher frequency like 6-hourly or even 1-hourly.

Two-way nest boundaries are similar but are updated every coarse-mesh timestep and have no relaxation zone. The specified zone is two grid-points wide instead of one.

1.5 Map Projections and Map-Scale Factors

The modeling system has a choice of several map projections. Lambert Conformal is suitable for mid-latitudes, Polar Stereographic for high latitudes and Mercator for low latitudes. The x and y directions in the model do not correspond to west-east and north-south except for the Mercator projection, and therefore the observed wind generally has to be rotated to the model grid, and the model u and v components need to be rotated before comparison with observations. These transformations are accounted for in the model pre-processors that provide data on the model grid, and post-processors.

The map scale factor, m , is defined by

$$m = (\text{distance on grid}) / (\text{actual distance on earth})$$

and its value is usually close to one varying with latitude. The projections in the model preserve the shape of small areas, so that $dx=dy$ everywhere, but the grid length varies across the domain to allow a representation of a spherical surface on a plane surface. Map-scale factors need to be accounted for in the model equations wherever horizontal gradients are used.

1.6 Multiple Parameterization Options

Physical processes happening at sub-grid length scale can be modelled with a variety of parameterizations. Currently MM5 has a variety of choices to model the following sub-grid process:

- ✓ **Cumulus:** Models the vertical process associated with convective columns and cumulus development. Following options are available: *AnthesKuo, Grell, Arakawa-Schubert, Fritsch-Campbell, Kain-Fritsch, Kain-Fritsch, Betts-Miller.*
- ✓ **PBL:** Models the physical process associated with heat transport and mixing in the Planetary Boundary Layer. Options: *Bulk PBL, Blackadar, Burk-Thompson, Eta, MRF, Gayno-Seaman, Pleim-Chang.*

- ✓ **Moisture:** Refers to the process related with water phases and their changes. Options: *Stable precip, Warm rain, Simple ice, Mixed Ice, Mixed Phase, Goddard, Reisner graupel, Schultz microphysics.*
- ✓ **Radiation:** Models the radiation interchange in every layer in the model, both long wave and short wave. Options: *Simple Cooling, Surface radiation, Cloud radiation, CCM2 radiation, RRTM longwave.*
- ✓ **Surface model:** Models the heat and moisture interchange between the air and soil as well as the interchange between different soil layers. Options: *Five Layer Model, Noah Land Surface Model, Pleim-Xiu Land Surface Model.*

1.7 Additional info

For more information please refer to the MM5 manual and following technical notes.

- ✓ **Terrain and Land Use for the Fifth-Generation Penn State/NCAR Mesoscale Modeling System (MM5): Program TERRAIN.** *NCAR/TN-397+IA, by Yong-Run Guo and Sue Chen*
- ✓ **Data Ingest and Objective Analysis for the PSU/NCAR Modeling System: Programs DATAGRID and RAWINS.** *NCAR/TN-376+IA, by Kevin Manning and Philip Haagenson*
- ✓ **A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5).** *NCAR/TN-398+STR, by Georg Grell, Jimy Dudhia, and David Stauffe.*
- ✓ **The Penn State/NCAR Mesoscale Model (MM5) Source Code Documentation.** *NCAR/TN-392+STR, by Philip Haagenson, Jimy Dudhia, David Stauffer, and Georg Grell.*
- ✓ **A Three-Dimensional Variational (3DVAR) Data Assimilation System For Use With MM5.** *NCAR/TN-453+STR Dale Barker, Wei Huang, Yong-Run Guo, and Al Bourgeois*

These technical notes can be downloaded from:

<http://www.mmm.ucar.edu/mm5/doc1.html>

MM5 manual can be downloaded from:

<http://www.mmm.ucar.edu/mm5/>

2 - WRF Model Description

2.1 Introduction to WRF Modelling System

The WRF Weather Research and Forecasting (WRF) modelling system is being developed as a collaborative effort among the NCAR Mesoscale and Microscale Meteorology (MMM) Division, the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Prediction (NCEP) and Forecast System Laboratory (FSL), the Department of Defense's Air Force Weather Agency (AFWA) and Naval Research Laboratory (NRL), the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma, and the Federal Aviation Administration (FAA)

The model is designed to be a flexible, state-of-the-art, portable code that is efficient in a massively parallel computing environment. A modular single-source code is maintained that can be configured for both research and operations. It offers numerous physics options, thus tapping into the experience of the broad modelling community. Advanced data assimilation systems are being developed and tested in tandem with the model. WRF is maintained and supported as a community model to facilitate wide use, particularly for research and teaching, in the university community. It is suitable for use in a broad spectrum of applications across scales ranging from meters to thousands of kilometres. Such applications include research and operational numerical weather prediction (NWP), data assimilation and parameterized-physics research, downscaling climate simulations, driving air quality models, atmosphere-ocean coupling, and idealized simulations (e.g boundary-layer eddies, convection, baroclinic waves).

The WRF System consists of these major components:

- ✓ WRF Preprocessing System (WPS)
- ✓ Dynamic solver
- ✓ WRF Postprocessor and graphics tools

2.2 WRF Preprocessing System (WPS)

This program is used for real-data simulations. Its functions include:

1. Defining the simulation domain;
2. Interpolating terrestrial data (such as terrain, land-use, and soil types) to the simulation domain;
3. Degribbing and interpolating meteorological data from another model to the simulation domain and the model coordinate.

There are two dynamics solvers in the WRF: the Advanced Research WRF (ARW) solver (originally referred to as the Eulerian mass or “em” solver) developed primarily at NCAR, and the NMM (Nonhydrostatic Mesoscale Model) solver developed at NCEP,

2.3 Advanced Research WRF Solver

The ARW system consists of the ARW dynamics solver together with other components of the WRF system needed to produce a simulation. Thus, it also encompasses physics schemes, initialization routines, and a data assimilation package.

ARW Solver main characteristics are:

- ✓ Equations: Fully compressible, Euler nonhydrostatic with a run-time hydrostatic option available. Conservative for scalar variables.
- ✓ Prognostic Variables: Velocity components u and v in Cartesian coordinate, vertical velocity w , perturbation potential temperature, perturbation geopotential, and perturbation surface pressure of dry air. Optionally, turbulent kinetic energy and any number of scalars such as water vapour mixing ratio, rain/snow mixing ratio, and cloud water/ice mixing ratio.
- ✓ Vertical Coordinate: Terrain-following hydrostatic-pressure, with vertical grid stretching permitted. Top of the model is a constant pressure surface.
- ✓ Horizontal Grid: Arakawa C-grid staggering.
- ✓ Time Integration: Time-split integration using a 3rd order Runge-Kutta scheme with smaller time step for acoustic and gravity-wave modes.

- ✓ Spatial Discretization: 2nd to 6th order advection options in horizontal and vertical.
- ✓ Turbulent Mixing and Model Filters: Sub-grid scale turbulence formulation in both coordinate and physical space. Divergence damping, external-mode filtering, vertically implicit acoustic step off-centering. Explicit filter option also available.
- ✓ Initial Conditions: Three dimensional for real-data, and one-, two- and three-dimensional using idealized data. A number of test cases are provided.
- ✓ Lateral Boundary Conditions: Periodic, open, symmetric, and specified options available.
- ✓ Top Boundary Conditions: Gravity wave absorbing (diffusion or Rayleigh damping). $w = 0$ top boundary condition at constant pressure level.
- ✓ Bottom Boundary Conditions: Physical or free-slip.
- ✓ Earth's Rotation: Full Coriolis terms included.
- ✓ Mapping to Sphere: Three map projections are supported for real-data simulation: polar stereographic, Lambert-conformal, and Mercator. Curvature terms included.
- ✓ Nesting: One-way, two-way, and moving nests.

2.4 Nonhydrostatic Mesoscale Model (NMM) WRF Solver

The Nonhydrostatic Mesoscale Model (NMM) core of the Weather Research and Forecasting (WRF) system was developed by the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP). The current release is Version 2.2. The WRF-NMM is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and efficient on available parallel computing platforms. The WRF-NMM is suitable for use in a broad range of applications across scales ranging from meters to thousands of kilometres.

The key features of the WRF-NMM are:

- ✓ Fully compressible, non-hydrostatic model with a hydrostatic option
- ✓ Hybrid (sigma-pressure) vertical coordinate.

- ✓ Arakawa E-grid.
- ✓ Forward-backward scheme for horizontally propagating fast waves, implicit scheme for vertically propagating sound waves, Adams-Bashforth Scheme for horizontal advection, and Crank-Nicholson scheme for vertical advection. The same time step is used for all terms.
- ✓ Conservation of a number of first and second order quantities, including energy and enstrophy

2.5 Model Physics

Model physics parameterizations are quite similar in both dynamic solvers. Main parameterizations are:

- ✓ Microphysics: Bulk schemes ranging from simplified physics suitable for mesoscale modelling to sophisticated mixed-phase physics suitable for cloud-resolving modelling.
- ✓ Cumulus parameterizations: Adjustment and mass-flux schemes for mesoscale modelling including NWP.
- ✓ Surface physics: Multi-layer land surface models ranging from a simple thermal model to full vegetation and soil moisture models, including snow cover and sea ice.
- ✓ Planetary boundary layer physics: Turbulent kinetic energy prediction or non-local K schemes.
- ✓ Atmospheric radiation physics: Longwave and shortwave schemes with multiple spectral bands and a simple shortwave scheme. Cloud effects and surface fluxes are included.

2.6 WRF-Var System

- ✓ Incremental formulation of the model-space cost function.
- ✓ Quasi-Newton or conjugate gradient minimization algorithms.
- ✓ Analysis increments on un-staggered Arakawa-A grid.
- ✓ Representation of the horizontal component of background error B via recursive filters (regional) or power spectra (global). The vertical component is applied

through projection onto climatologically-averaged eigenvectors of vertical error. Horizontal/vertical errors are non-separable (horizontal scales vary with vertical eigenvector).

- ✓ Background cost function (J_b) preconditioning via a control variable transform U defined as $B = UUT$.
- ✓ Flexible choice of background error model and control variables.
- ✓ Climatological background error covariances estimated via either the NMC-method of averaged forecast differences or suitably averaged ensemble perturbations.
- ✓ Unified 3D-Var (4D-Var under development), global and regional, multi-model capability.

3. Operational configuration of MM5 at MeteoGalicia

3.1 Model Domains and Boundary Conditions

MM5 model runs operationally with two domains nested two-way interaction. The coarser domain covers southwest Europe with 100×80 points, 30Km resolution domain and 23 vertical σ -levels. The smaller domain covers north west of Spain with 43×43 points, 10Km resolution domain with 23 vertical σ -levels. (fig.2.1)

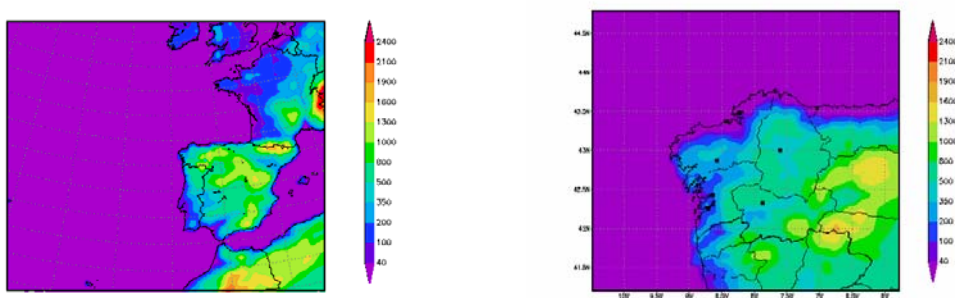


Fig. 2.1 Operational domains at MeteoGalicia. Coarse domain (left) has 100×80 grid points, 30Km resolution. Nested domain (right) has 43×43 grid points, 10Km resolution. Both domains are two way nested and have 23 vertical σ -levels.

MM5 model runs operationally twice a day, starting at 0000UTC and 1200UTC, with forecast horizons of 96 and 84 hours respectively. Initial and boundary conditions each 3 hours are routinely obtained from NCEP GFS at 1° of horizontal resolution.

3.2 Physic Configuration

An extensive verification of different combinations of parameterizations has been done. As result the operational model runs under the following configuration:

- ✓ Cumulus: Kain-Fristch
- ✓ Moisture: Goddard
- ✓ PBL: MRF
- ✓ Soil model: 5 Layer
- ✓ Radiation: Cloud Scheme

Some modifications have been applied to the stock configuration to improve the performance of the model in this area. The full list is out of the scope of this document but it is interesting to note that a new interpolation scheme in initial and boundary conditions have been include to improve SST at near coast regions. This has proven very important to improve the performance of current models in these regions.

3.3 Data Required to Run the Modeling System

Since the MM5 modeling system is primarily designed for real-data studies/simulations, it requires the following datasets to run:

- ✓ Topography and landuse (in categories);
- ✓ Gridded atmospheric data that have at least these variables: sea-level pressure, wind, temperature, relative humidity and geopotential height; and at these pressure levels: surface, 1000, 850, 700, 500, 400, 300, 250, 200, 150, 100 mb;
- ✓ Observation data that contains soundings and surface reports.

Mesouser provides a basic set of topography, landuse and vegetation data that have global coverage but variable resolution. The Data Support Section of Scientific Computing Division at NCAR has an extensive archive of atmospheric data from gridded analyses to observations. For information on how to obtain data from NCAR, please visit URL: <http://www.scd.ucar.edu/dss/index.html>.

Besides, there a more detailed landuse database (100m resolution) from Europe is obtained from <http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=309> and its use now in our models.

3.4 Data model output

Most interesting variables from full surface model output are extracted and uploaded daily on a FTP server from both MM5 domains of 10Km and 30Km resolution. The data corresponding to forecast horizons from 0d, 1d, 2d and 3d will be available from model initialized at 00Z, and data corresponding to forecast horizons from 1d, 2d and 3d will be available from model initialized at 12Z. Data from the forecast horizon 0d of model initialized at 12Z will not be available since it would only have 12 hour of forecasting data. In order to save disk space in our FTP server, only files from model initialized at 00Z and 0d forecast horizon will be kept. All files corresponding to the last three days runs also will remain, being deleted afterwards.

Name	Full name	Standard name	Units
<i>lat</i>	Latitude coordinate	Latitude	degree_north
<i>lon</i>	Longitude coordinate	Longitude	degree_east
<i>temp</i>	temperature at 2m	air_temperature	K
<i>sst</i>	sea surface temperature	sea_surface_temperature	K
<i>shflx</i>	surface downward sensible heat flux	surface_downward_sensible_heat_flux	W m-2
<i>lhflx</i>	surface downward latent heat flux	surface_downward_latent_heat_flux	W m-2
<i>swflx</i>	surface downwelling shortwave flux	surface_downwelling_shortwave_flux_in_air	W m-2
<i>lwflx</i>	surface downwelling longwave flux	surface_downwelling_longwave_flux_in_air	W m-2
<i>u</i>	lon-wind at 10m	eastward_wind	m s-1
<i>v</i>	lat-wind at 10m	northward_wind	m s-1
<i>lwm</i>	land/water mask	land_binary_mask	1
<i>prec</i>	Total accumulated rainfall between each model output	precipitation_amount	kg m-2
<i>mslp</i>	mean sea level pressure	air_pressure_at_sea_level	Pa
<i>cft</i>	cloud cover at low and mid levels	cloud_area_fraction	1
<i>rh</i>	relative humidity at 2m	relative_humidity	1

Tab. 3.1. Variable names on the NetCDF files

Similar configuration was tested with WRF-ARW model, and preliminary results shown a higher skilful in its results.

Next months, WRF will be in an operational mode at MeteoGalicia, with similar temporal frequency and horizon, but with higher resolution.