Extended summary

Valutazione della risorsa eolica di aree ad orografia complessa per mezzo di analisi fluidodinamica numerica di mesoscala

Curriculum: Ingegneria Energetica

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Abstract. The aim of this research has been the development of a numerical protocol, based on the Weather Research Forecast (WRF) code, aimed at the study of complex orography sites in order to assess available wind energy resources by means of numerical mesoscale models.

The classical approach to studying wind resources in complex orography sites has so far been that of relying on a three step protocol:

1. the first step consists in collecting data available from General Circulation Models (GCM) which solve for the state of the atmosphere globally around the Earth numerically;

2. the second step consists in passing the boundary conditions provided by the GCM used in step one to a Local Area Model (LAM) (e.g. NCAR mesoscale

models such as Mesoscale Model 5th generation (MM5) or WRF) which in turn solves, or more often parametrizes, weather phenomena in scale ranges that go from thousands of kilometres to a few kilometres;

3. the third step consists in feeding in data, worked out by the mesoscale models used in step two, as boundary conditions to a Computational Fluid Dynamics (CFD) micro scale model (e.g. the PHOENICS model) commonly used to study the lower layers of the atmosphere down to the surface.
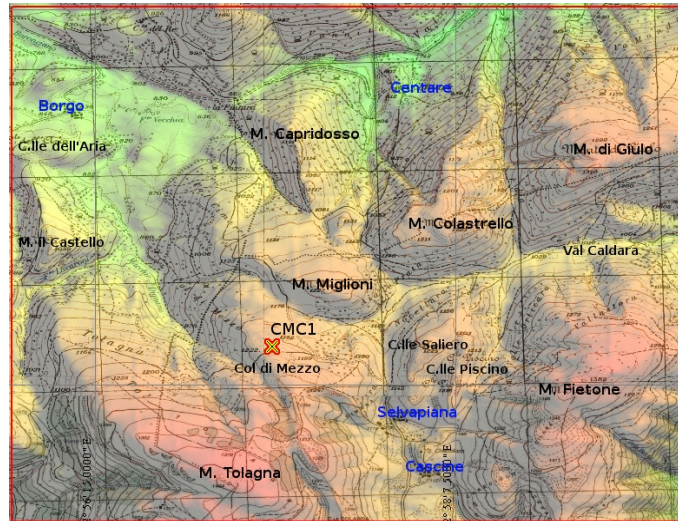
Nevertheless, microscale models, which solve for the local wind field, neglect all those local phenomena such as short wave and long wave local radiation, land-surface atmosphere interaction [1] and so on, which are fundamental for the proper representation of the lower layer of the atmosphere and its Planetary Boundary Layer (PBL). For this purpose the two most widely used mesoscale models, the National Center for Atmospheric Research (NCAR) MM5 and WRF were used: MM5, no longer supported nor developed in favour of WRF, has been thoroughly tested and compared to experimental data throughout the past years at "Dipartimento di Ingegneria Industriale e Scienze Matematiche (DIISM) of Università Politecnica delle Marche" (UNIVPM); the latter is the future substitute for MM5 and is being tested by most of the weather forecast centres around the world in order to prepare for the replacement. These two mesoscale models were pushed to resolve for local phenomena down to grid of 200m length. Some alterations to the source code of MM5 and some minor code writing for WRF were necessary though.

Annual simulations based on both coarse and fine grids were run on a domain area centred on Col di Mezzo, a hill located half way between Monte Tolagna and Monte Miglioni. The whole area spreads through Comune di Montecavallo, Comune di Serravalle di Chienti and Comune di Pieve Torina (Mc).
Four back-casting annual simulations were run: two high resolution runs were performed adopting Shuttle Radar Topography Mission (SRTM) terrain data and two other runs adopting Global 30-Arc-Second (GTOPO30) terrain data.
The results were compared to measured data available from the weather station mast (Point CMC1 on Fig. 1) owned by "Comunità Montana di Camerino" but supervised by DIISM.

Figure 1: Localization of computational domain.

Keywords. Mesoscale models, SRTM data, complex orography.

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1 Complex orography

Complex areas are those in which terrain orography is such that it influences profoundly the behaviour of wind field in a way that, commonly available micro scale codes (mostly developed, tailored and tuned to tackle the study of stable planetary boundary layer on flat terrains) often give unsatisfactory solutions.

1.1 The strategy: the quest for higher grid resolution

As the computational power of computers has increased over the past years, Numerical Weather Prediction (NWP) [2] has been more and more relied upon as a means for both the prediction of weather as well as the assessment of wind energy resources. Mesoscale codes such as the MM5 [3] and the WRF [4], have made it possible to predict future weather conditions as well as to perform back-casting calculations by means of commonly available multi-core computers. So far though, normally used computational grid dimensions have never been pushed below the limits of 30" (926m). Although commonly considered as being high resolution, a GTOPO 30" terrain grid [9] is still not accurate enough as to catch peaks and valleys whose presence influences profoundly the distribution of both scalar and vectorial meteorological fields (Fig. 2). Moreover, the coarse grid dimensions prevent the mesoscale model to solve directly for small scales phenomena (those with characteristic lengths of hundreds of metres) which need to be parametrized. In order to avoid the smoothing effect of coarse grid size, a finer one is certainly advisable.

To overcome the obstacles due to the complexities introduced by terrain orography, the strategy followed in this research has relied upon the possibility offered by the availability of SRTM [5] high resolution terrain data.
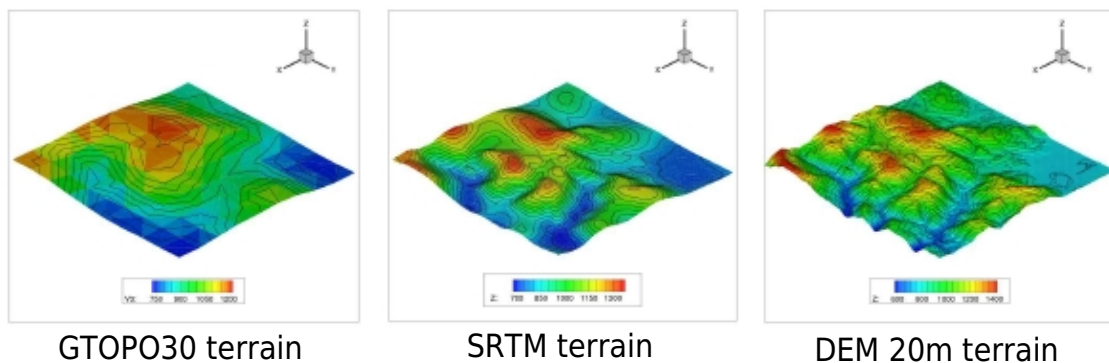

| GTOPO30 terrain | SRTM terrain | DEM 20m terrain |

Figure 2. Comparison between GTOPO30, SRTM 200m and DEM 20m terrain details

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2 Research activities

2.1 Mesoscale software installation and tuning

The first step of the research consisted in the compilation of the source code of the WRF mesoscale model provided freely by NCAR. This was not a simple task as the aim was to provide a bundle package, of all the programs and library needed by WRF, easy to install by means of a sequence of bash scripts to be run in order. A couple of bash scripts installation sequences was generated according to the CPU architectures, AMD and INTEL.

The first implementation was performed using the GNU compiler and only after some benchmark runs on test cases was it decided to switch to the faster INTEL compiler. Once the program was up and running, a test phase started in order to find a suitable combination of setting parameters, which count to thousands when combined together in the configuration files of WRF. Once this next step had been accomplished, a decision was made as to test the package on a Gentoo Linux cluster [6] made up of two nodes which could be controlled and switched on and off remotely via Secure Shell (SSH) connection (the DIISM cluster was then yet to come).

The small cluster was used to perform annual simulations of the site weather conditions running on grids of 1000m. This showed how mesoscale software are now suitable for running even on commonly available computers.

Once the cluster at DIISM had been available, all SRTM more computational demanding runs were performed there. Both coarse and fine grid runs were based on two way model interaction with a five level nested grid (Fig. 4).
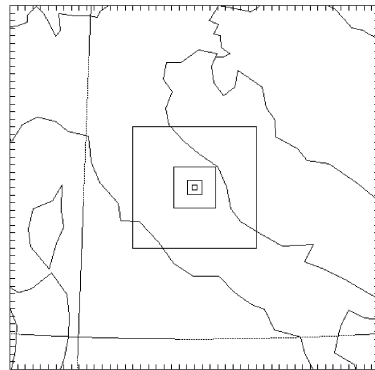

Figure 3. Five level nesting grid (1000m) computational domain.

One of the things that was soon evident was that, in order to boost the computational performance, the use of several nodes by one single running was

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not advisable. It is worthwhile noting that using two instead of one node gave an increment of roughly 15% on the overall speed (i.e. the time needed to accomplish a simulation of one day) whereas running on each node a different simulation, whose length was one month, clearly doubled the speed of output data production. This is why the MAUI cluster scheduler and Torque resource manager were almost never used.

2.2 Pre and post processing code

A number of scripts had to be written in order to prepare the start of the running and to extract and manipulate data from the output files.

2.2.1 Pre-processing phase

Mesoscale WRF package has a folder directory which needs to be altered and managed in a proper way when running on several cluster nodes but resides on a common "home" file system folder. The pre-processing scripts prepare the the environment variables as well as the symbolic links and configuration data. Moreover, they run and check that the model pre-processing phase has been successfully completed.

2.2.2 Processing

It was soon evident that running on such fine grids made the code extremely sensitive to CFL (Courant Friedrichs Lewy Number). Crashes were so frequent that it was chosen to send alert messages relying on a proper bash script able to send SMS messages rather than e-mails. Any time a software crash happened, the time step was halved in order to overcome the CFL stability problems [7].

2.2.3 Post-processing

The post processing phase was performed after building a tool box of scripts in order to extract the information needed from the Net Common Data Format NETCDF [8] format output files and:
- build cumulative wind distribution tables (C language, ncl, bash, Octave and TCL-TK scripts);
- build Post Script and png geo-referenced format wind roses (bash, ncl, Postscript and Octave scripts);
- build TXT format data file compatible with commercial software aimed to perform statistical wind analysis (bash and Octave scripts);
- build wind maps of the site (bash and Octave scripts);

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- work out the capacity factors and equivalent annual energy hours taking as input txt files with commercial aero-generators performances data (bash and Octave scripts).

The post processing phase took so long to perform, on account on the 1.8Gb dimension of each daily output file, that a new re-compilation of WRF had to be performed after removing non-fundamental fields from the list of output variable. After that, each daily output simulation file was 167Mb large and the post-processing phase clearly sped up.

Regarding the time requested in order to perform a complete year back-casting simulation, it must be stressed that SRTM simulations are really demanding from a computational point of view, as can be guessed by looking at Table 1. The overall running times reported in Table 1 do not take into account the idle times due to crashes, restarting phases and periods simulated at shorter (usually one half) time step when the CFL made the running to diverge.

Table 1.

Simulation time period: 1.May.2009 - 30.April.2010				
Terrain Data	Grid Resolution	Inner Domain Extension	CPU	Overall running time
SRTM	200m	16.2Km	N.8 core AMD Processor 2378, 2.4GHz, 16Gb RAM, N.4 cluster nodes	20 days
GTOPO30	1000m	48Km	N.4 core INTEL Q8400, 2.66GHz, 4Gb RAM, N.2 cluster nodes	13 days

2.3 Experimental wind mast data

Wind data was collected by means of the wind mast equipment throughout a period of one year starting from 1/May/2009 to 30/April/2010. Numerical data, outputted by a Nomad2 data logger in csv format, had to be first converted, by means of a bash script, in a proper format compatible with the Windographer commercial software and afterwards thoroughly analysed. Because of chilling weather situations during the winter months, data needed "*cleaning*" in order for it to be compared with numerical results.
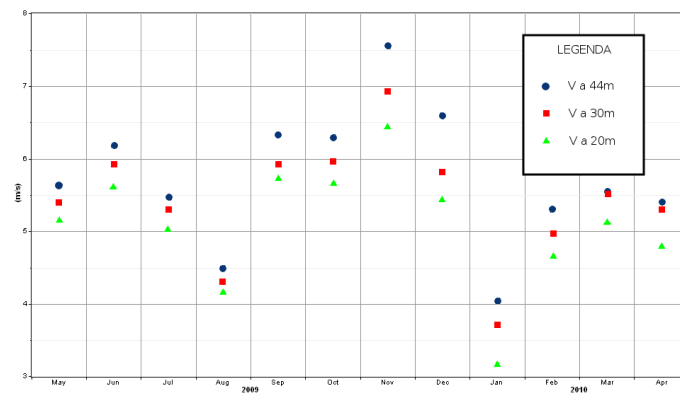
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Figure 4. Monthly means: cup anemometers at 20m, 30m and 44m.

3 Main results

The methodology here developed here was extensively tested on a relevant wind energy site. The comparison between numerical and experimental data shows the reliability and the accuracy of the proposed approach.

Figure 5 shows the monthly means during the year of observation of the wind speed at 30m, measured by the wind mast's cup anemometer. It can be seen how the WRF and MM5 SRTM running are in a much better agreement with experimental data with respect to the GTOPO30 running.
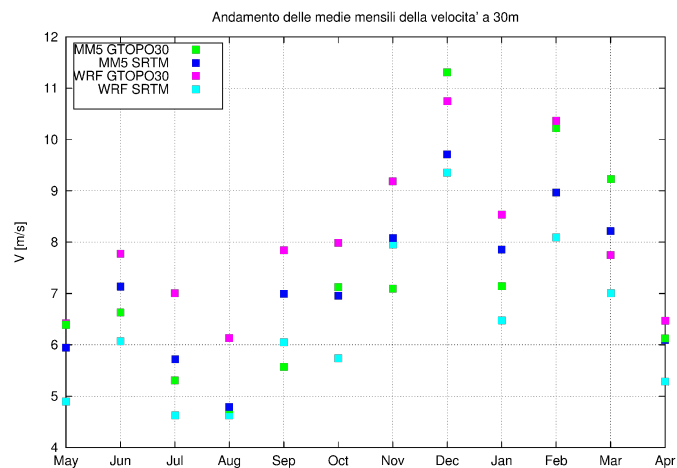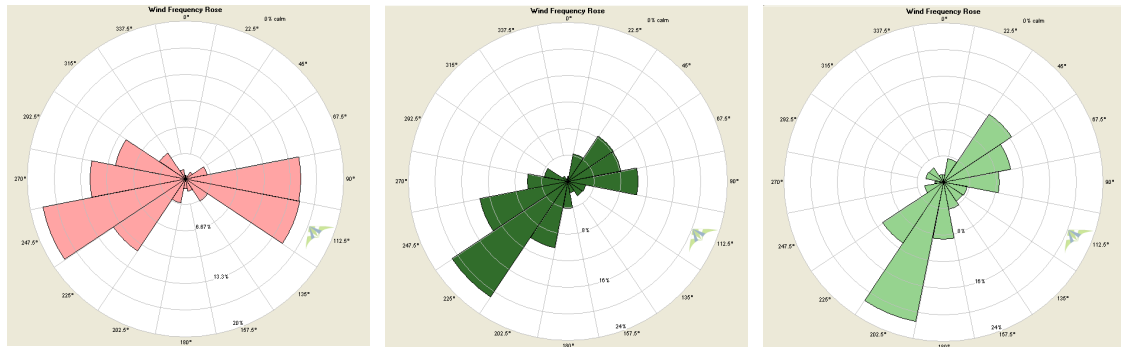

Figure 5. Comparison between experimental and numerical data at 30m.

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Yet slight discrepancies cropped up during the winter months, those during which problems with ice hindered the good functioning of the wind mast equipment.

Regarding the direction of wind, Figure 6 shows the annual wind-roses. Here a slight westerly drift of the MM5 model is evident.

Wind vane 30m   *MM5 SRTM 30m*   *WRF SRTM 30m*

Figure 6. Comparison between wind roses: wind vane, MM5 and WRF at 30m.

In Figure 7, which shows the mean diurnal profile, it can be seen how the use of SRTM terrain data agrees extremely well with experimental data and how they improved with respect to the GTOPO30 running output.
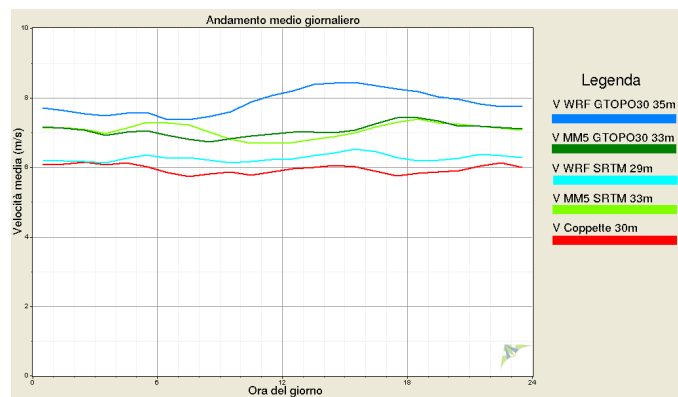

Figure 7. Mean diurnal profiles

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4 Conclusions

Any effort made toward the development of numerical methods, aimed at honing the accuracy of the energy production assessment is always worthwhile making. A margin of error of 3% on the evaluation of the annual mean wind speed for a given site, determines a margin of error of 10% on the assessment of the annual energy production. Such an error is so far the limit that makes the financing of wind farm projects attractive on the part of banks. The need for accuracy in numerical methods it is so evident.

The development of a numerical protocol, based on the WRF model, aimed at the study of complex orography sites, as well as the accurate evaluation of available wind energy resources, has been carried out. This work is also to be considered as the starting point for WRF to replace MM5 at DIISM. Before such a task will be accomplished though, further testing will have to be undertaken.

Numerical mesoscale models have been used for taking into account local phenomena neglected by the microscale CFD software commonly used to study the lower layers of the atmosphere down to the surface. A software tool box and an operational protocol has been set up for this purpose and high resolution SRTM terrain data has been exploited. Such an approach for systematically studying a complex orography area, to the author's knowledge, has never been carried out so far. The results show that, despite the computational power at stake, the quality of the numerical results have had a clear step beyond, as shown by the comparison with the experimental data available.

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[9]   http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info