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Operational wind power forecasting systems based on physical and statistical models.

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Introduction

- The widespread growth of wind power installations and the further integration of the energy yield into the grid increases and reveals the necessity of accurate wind power forecasting.
- The Atmospheric Modeling and Weather Forecasting Group (AM&WFG) of the University of Athens specializes on the development and use of *novel techniques* and *advanced methodologies* for forecasting and mapping *renewable energy resources* over on and off shore sites.
- *High resolution simulations* based on state-of-the art atmospheric and ocean wave models in conjunction with advanced statistical methodologies are utilized for the development of *long term wind-wave-tidal-current resource atlases, operational forecasting* and non conventional statistical analysis for wind and wave power resources.

Atmospheric Modeling Tools

The atmospheric system SKIRON

SKIRON has been developed at the University of Athens, by the AM&WFG, based on the Eta/NCEP model (Spyrou.et.al,2010). It is a full physics non-hydrostatic model with sophisticated convective, turbulence and surface energy budget scheme running operational today for the major area of Europe at a horizontal resolution of 0.05 x 0.05^0.

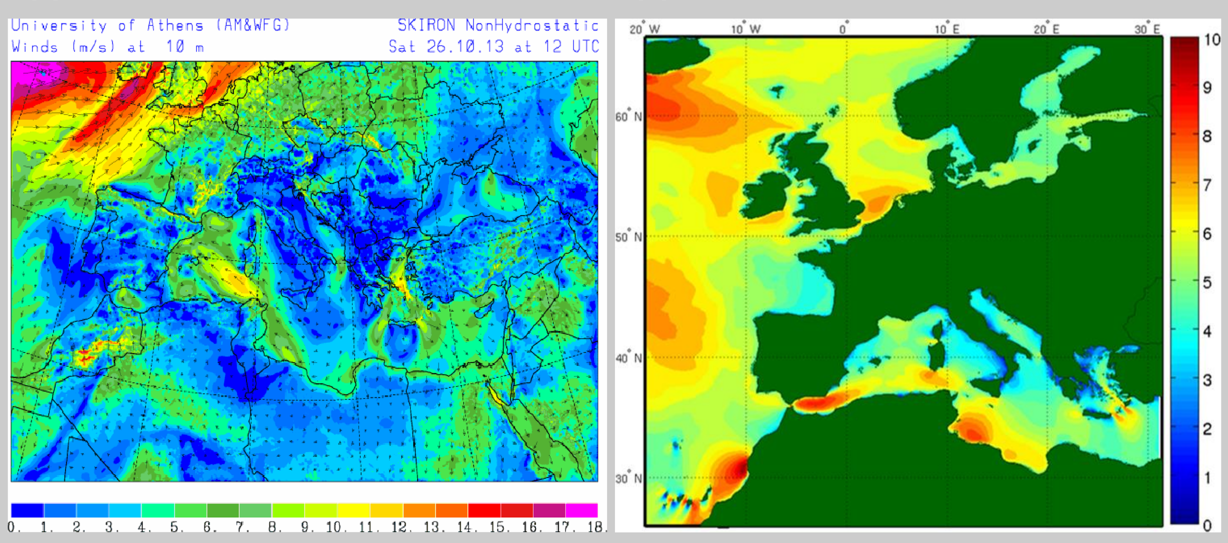


Fig. 1 (a). Wind speed simulation over Europe (b). Monthly averaged wind speed at 10m over offshore domain of Europe (2010).

The RAMS-ICLAMS model

RAMS-ICLAMS is a merger of a non-hydrostatic cloud model and of a hydrostatic mesoscale model (Solomos.et.al, 2011) resulting to a sophisticated modeling system covering a wide spectrum of atmospheric motions from synoptic scale (10s of Kms) to very high resolution microscale (few 10s of meters).

These capabilities make this system able to replace the combined use of a mesoscale with a CFD model.

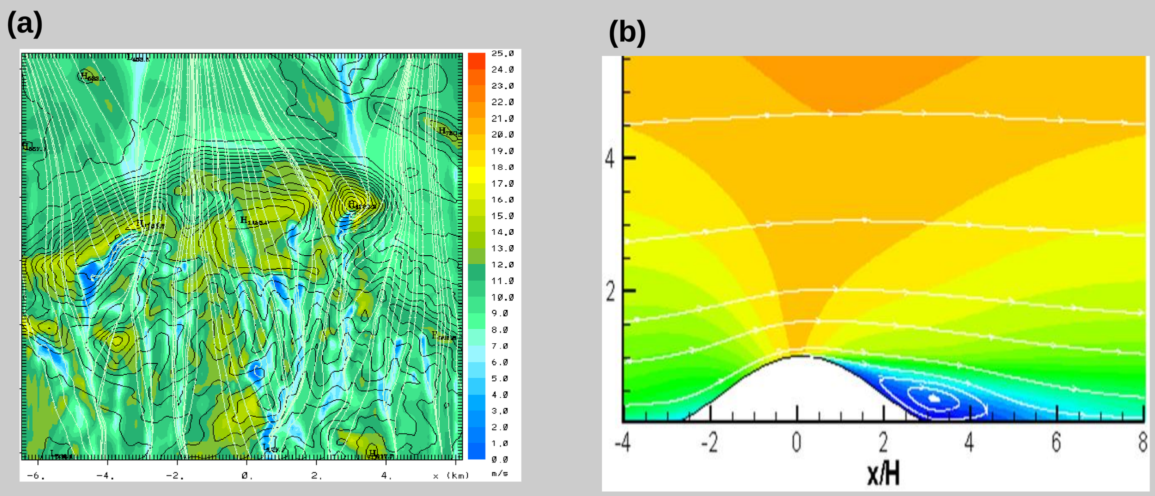


Fig. 2 (a) A high resolution simulation (250x250m) with RAMS-ICLAMS model for a case study in North Spain (b) 2D cross section of horizontal wind speed and streamlines

High Resolution Wind/Wave Data Base & Atlases

A database of 10 year high-resolution model simulation has been developed based on the state-of-the-art regional atmospheric model (SKIRON) combined with the ocean wave model (WAM). The data cover a variety of needs and applications for wind and wave resource assessment (hourly fields of winds, waves, currents, tides) for NE Atlantic and Mediterranean. An interface for easy retrieving spatial and temporal data and developing statistics has been developed.

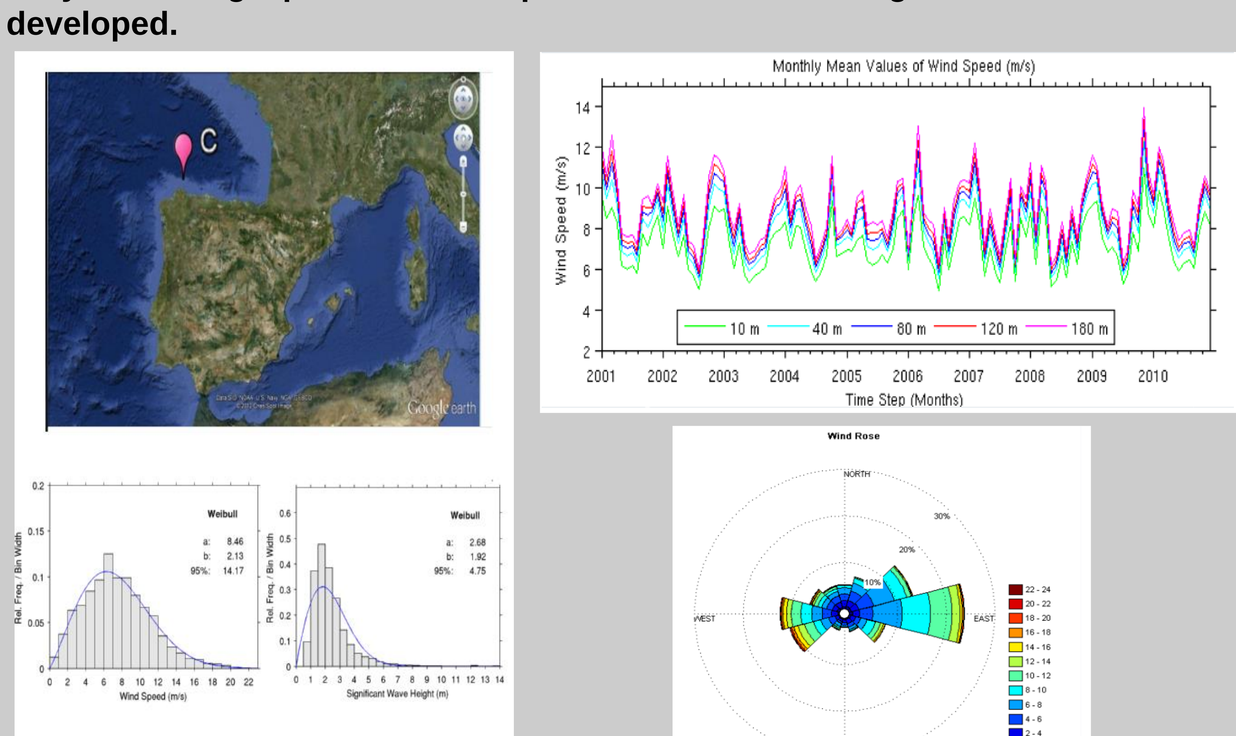
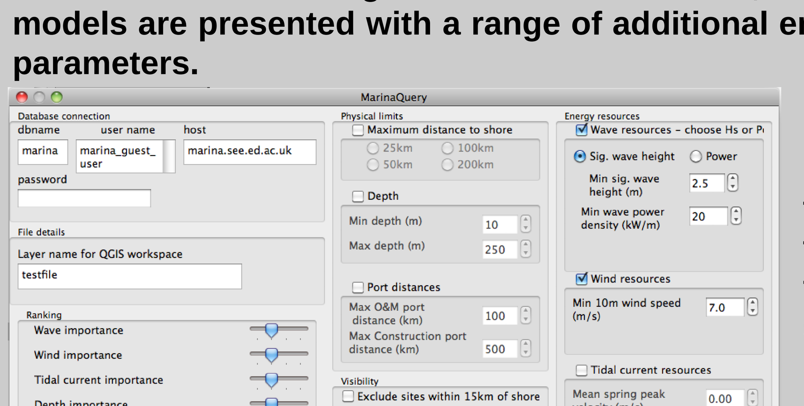


Fig. 3. Statistical Analysis for the Data base results on a selected site

Within the framework of the FP7 project Marina Platform (http://www.marina-platform.info) a derivative of this data base has been implemented in a GIS system, developed by our partners in the University of Edinburgh, in which resource data from high resolution co-located, co-temporal wind and wave models are presented with a range of additional environmental and physical parameters.



Dedicated decision-support tools have been developed towards the development of flexible, multi-criteria for site selections

The aforementioned database as well as the utilization of the mesoscale models allows the development of high resolution atlases for monitoring the wind and wave power potential, application of energy calculations and the estimation of extremes/non-frequent values over areas of interest

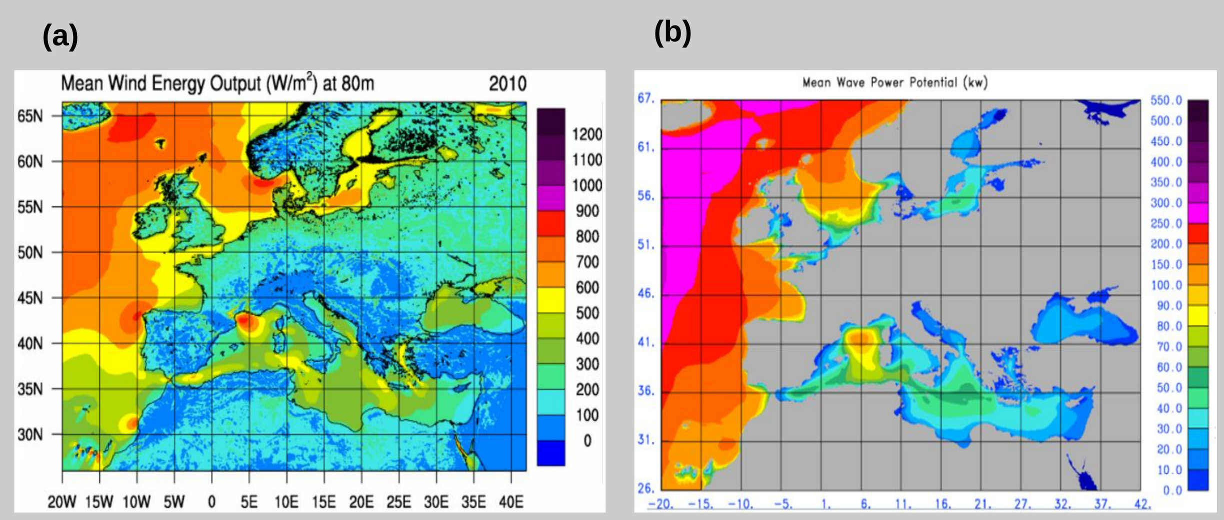


Fig 4. Atlases monitoring the wind and wave power potential for the year 2010.

Power Prediction Tool

The method (Stathopoulos.et.al, 2013) is based on

- the wind speed and wind power observation data as recorded by the wind turbines at the sites of interest.
- decoding of the existing relationship between the wind speed and the energy yield of a turbine.
- use of statistical regression methods in order to fit a variety of models to the data.
- optimization of wind speed forecasts from NWPMs, by Kolmogorov-Zurbenko and Kalman filters, in order to estimate the power output.

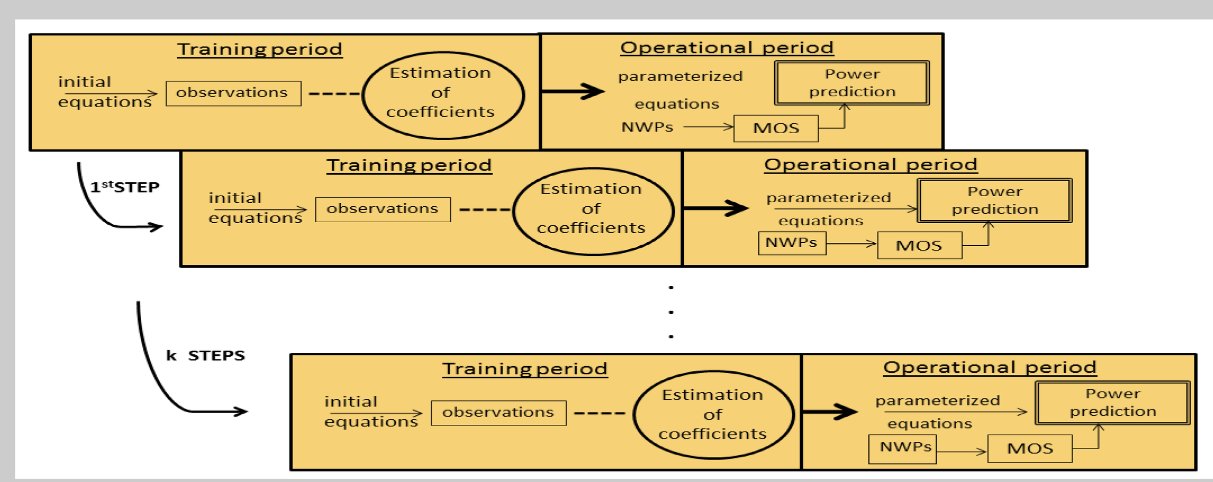


Fig 5. Flow chart of local prediction method

WIND SPEED DATA ANALYSIS TECHNICS

WIND FARM DATA (observations)

Quality Control

Modifying the observations and the corresponding model forecasts into a compatible form

Kolmogorov-Zurbenko Filter: consists of a series of iterative moving averages aiming at the removal of high-frequency variations from the initial data.

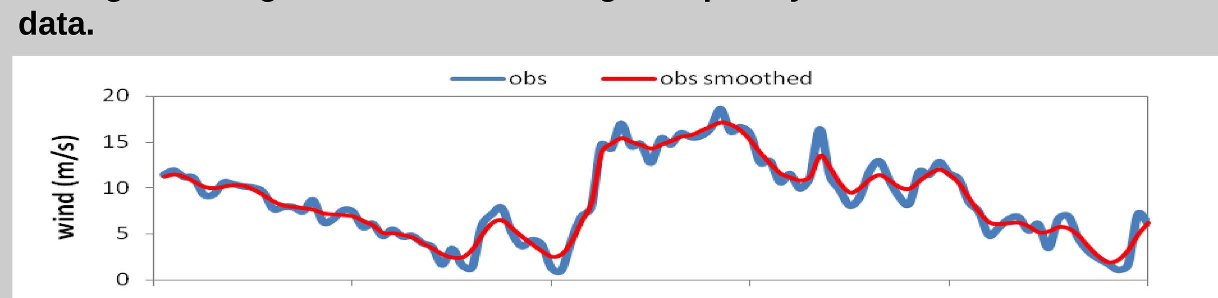


Fig 6. Kolmogorov-Zurbenko filter application

FORECAST DATA

Scaling wind speed predictions at hub height.

Improving the initial prediction coming from weather models.

Kalman Filter: simulates the relation in time between observational and forecasted values and improve folllowing predictions

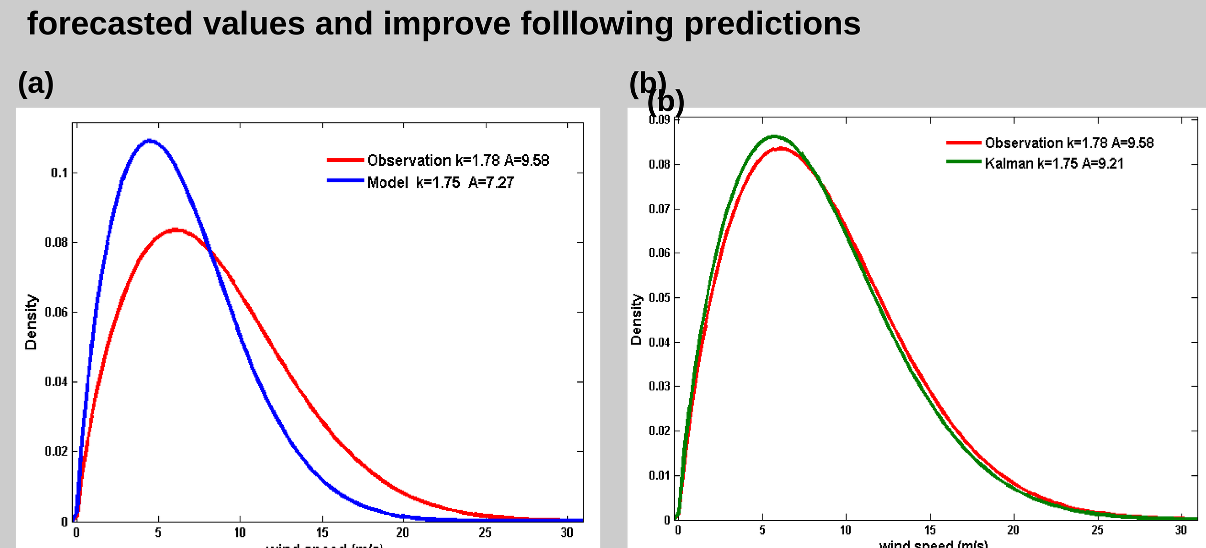


Fig 6. Improvement of forecasted wind speed by means of Weibull distribution

a. Initial mesoscale prediction versus observation
b. Improved prediction versus observation

ESTIMATION OF WIND POWER

In order to transform wind speed into energy yield several models are trained based on the actual production of the wind farm. The models utilize both power curves and semi-empirical functions and are fitted to the data by the application of regression methods

(a)

$$p_{t+k} = a * po(w_{t+k}) + e$$

$$p_{t+k} = a * po(w_{t+k}) + b * p_t + e$$

$$p_{t+k} = a_0 * \tanh\left(\frac{w_{t+k} - a_1}{a_2}\right) + a_3$$

$$p_{t+k} = a_0 * \tanh\left(\frac{w_{t+k} - a_1}{a_2}\right) + b * p_t + e$$

$$p_{t+k} = a_0 * \tanh\left(\frac{w_{t+k} - a_1}{a_2}\right) + a_3 * w_{t+k} + a_4$$

(b)

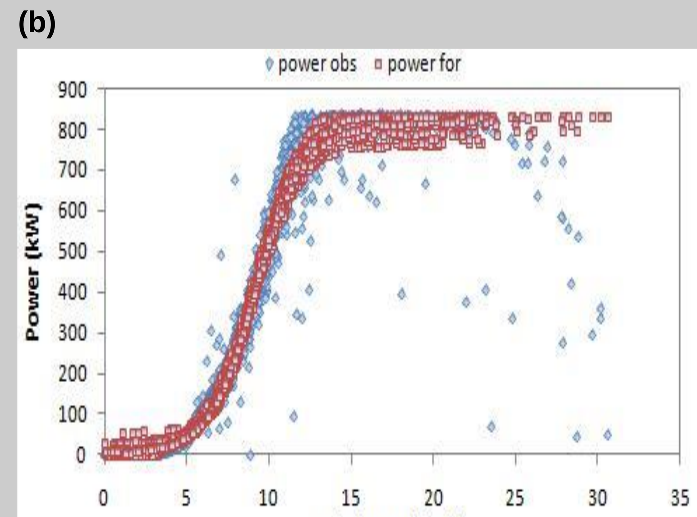


Fig 7 a. Functions used for the transformation of wind speed into energy
b. Example of the calculated power curve versus the observed for a real wind turbine

Interval prediction

Based on extreme wind speed values analysis minimum/maximum power values are estimated

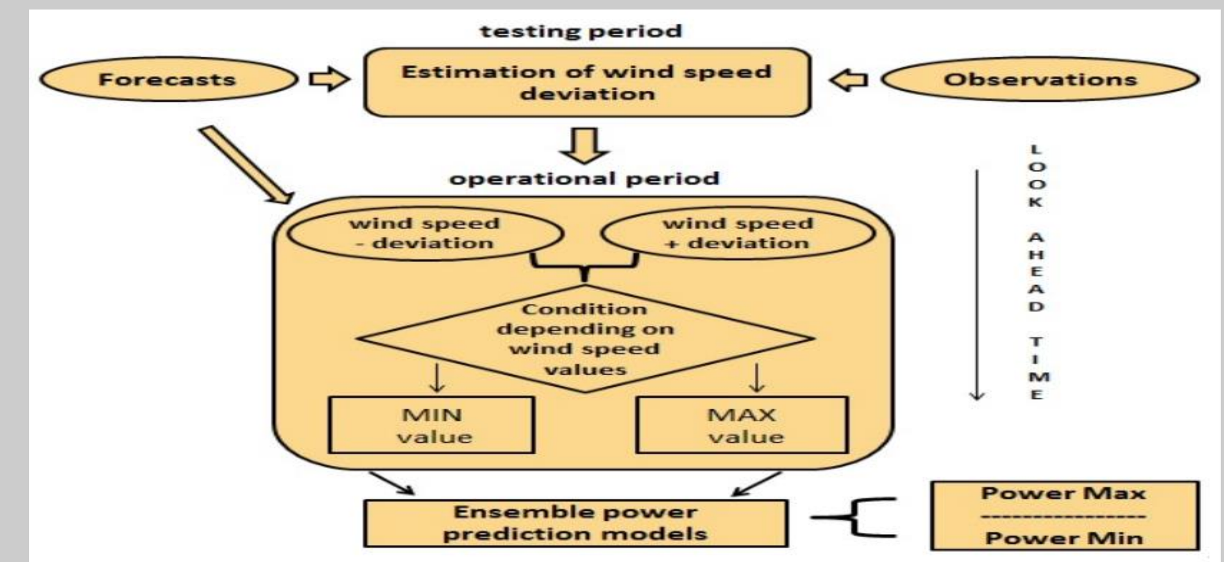


Fig 8. Flow chart of interval prediction method

A demo case

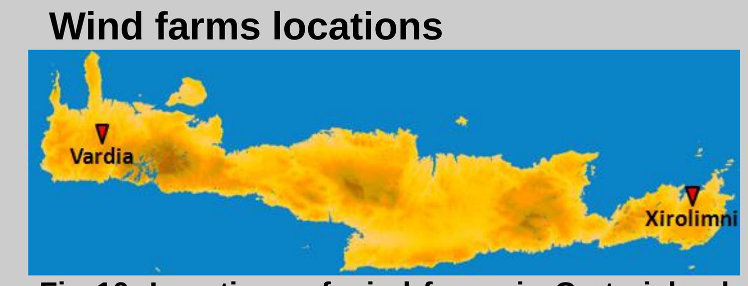
The described forecasting methodology has been operationally used, tested and evaluated for two wind farms located in the island of Crete in Mediterranean. The simulated area, wind farms locations and results for wind speed and wind power output are illustrated by the application of local and interval prediction methods.

RAMS-ICLAMS (NWP) simulated domain

36x36km 6x6km 3x3km

Fig 9. Simulated domain with RAMS-ICLAMS atmospheric model for a power prediction application.

Wind farms locations



The two wind farms are placed at heights of 829m (Vardia) and 570m (Xirolimni) influenced by the synoptic circulation of Mediterranean sea

Fig 10. Locations of wind farms in Crete island (Greece, South East Mediterranean sea).

Results from local power prediction

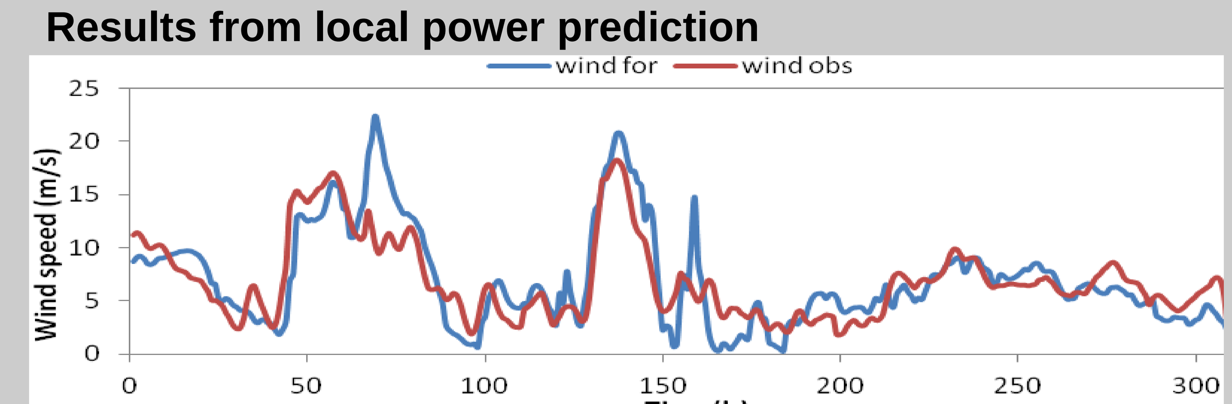


Fig 11. Timeseries of observations and forecasts for the wind speed (case of Vardia, W. Crete).

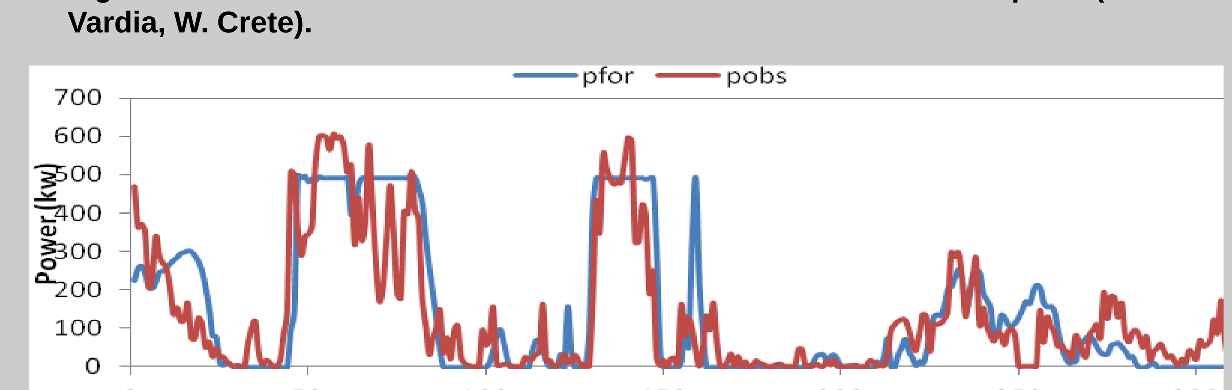


Fig 12. Timeseries of observations and forecasts for the wind power (case of Vardia, W. Crete).

Results from interval power prediction method

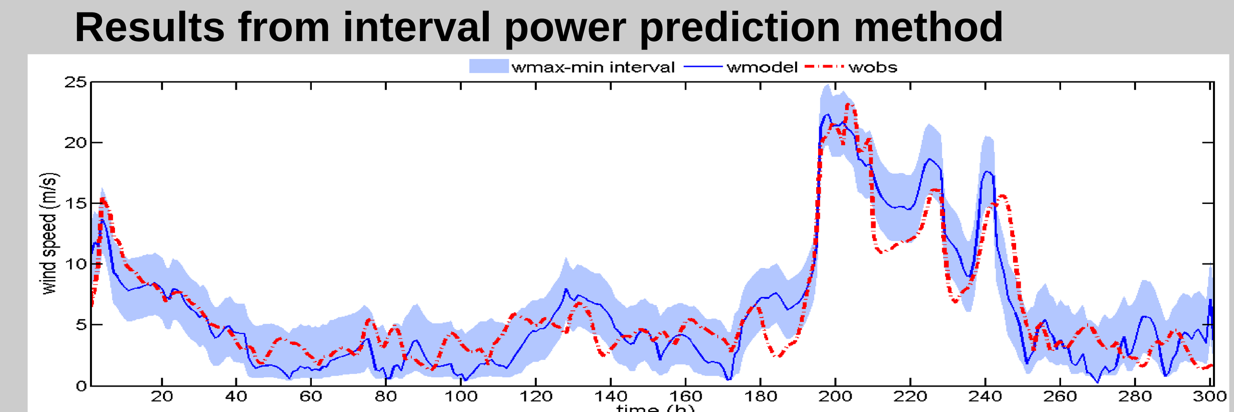


Fig 13. Time series of the observations versus forecast intervals for wind speed (case of Vardia, W. Crete).

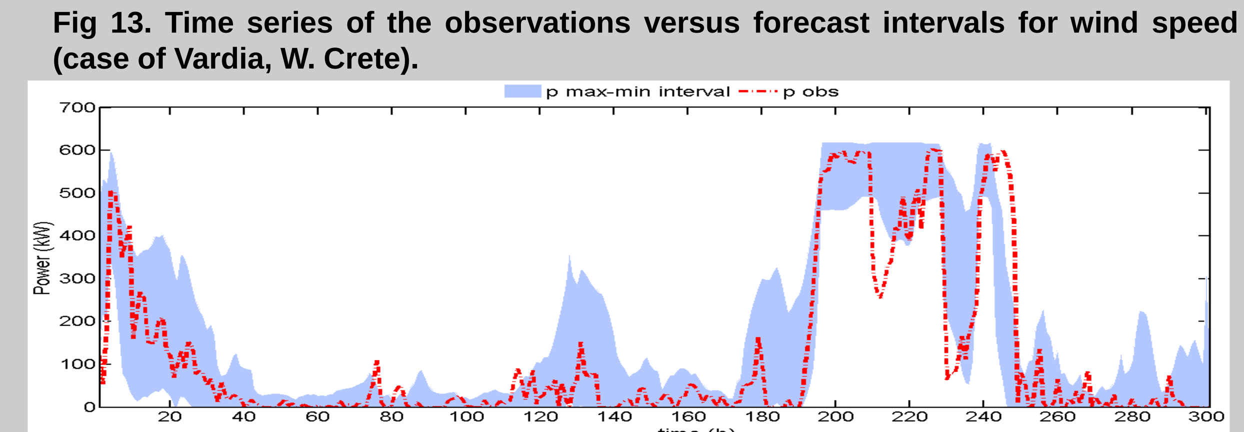


Fig 14. Time series of the observations versus forecast intervals for wind power (case of Vardia, W. Crete).

References

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Spyrou.C.,Mitsakou.C., Kallos.G., Louka.P. and Vlastou.G. : An improved limited area model for describing the dust cycle in the atmosphere, Geophysical research, Vol. 115, D17211, doi:10.1029/2009JD013682, 2010

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