**LocalPred and RegioPred. Advanced tools for wind energy prediction in complex terrain**

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**Abstract**

*LocalPred* and *RegioPred* are two tools designed for wind energy forecasting in complex terrain. This paper shows the characteristics of these two models.

*LocalPred* is a prediction model for wind farms. It includes very short-term forecasts based on ARMA and ARX models, it also includes an advanced statistical downscaling module able to detect and remove systematic errors of the NWP. Moreover, *LocalPred* incorporates high-resolution physical modelling of the terrain with the mesoscale model MM5 and/or CFD calculations, it allows to improve the performance of the meteorological forecasts by means of a detailed study of the features of the terrain in the area of the wind farm. Finally, *LocalPred* includes a wind farm power curve module in order to generate power production forecasts.

*LocalPred* is designed to work with any Numerical Weather Prediction model: HIRLAM, ECMWF, AVN, etc. It is modular, being possible to produce power production forecasts based only on on-line measurements; if there is not real time power production data available, it also can operate based exclusively on NWP. High-resolution physical modelling corrections are also optional. When NWP and on-line measurements are available, *LocalPred* calculates and optimum prediction for each forecast horizon combining the forecasts of the different modules.

*LocalPred* has been designed specially for complex terrain wind farms, its downscaling module can detect and eliminate systematic errors that appear in the meteorological forecasts due to the low resolution of the NWP and the complexity of the terrain. The algorithms of the downscaling module incorporate physical parameterisations that can be tuned for each wind farm, in order to enhance the capabilities for error detection in complex terrain. CFD and MM5 corrections improve the performance of the model in complex terrain.

*RegioPred* is a tool for wind power prediction at regional scale; it works jointly with *LocalPred* through an up-scaling module. *RegioPred* produces accurate wind power production forecasts for regions at low cost by means of an effective selection of representative wind farms.

Both *LocalPred* and *RegioPred* include automated on-line tuning procedures in order to be adaptive and to incorporate the changes in the wind farms operational conditions.

**Keywords:**

Forecast, Wind energy, MOS, Time series

**Wind power production forecasting in complex terrain**

Since wind energy has experienced an important increase, wind power production forecasting models are becoming necessary. The uncontrolled variations of wind energy can create problems in the management of the grid, and these fluctuations decrease the efficiency of the system. In general, wind prediction has two different approaches in terms of methodology:

- Statistical modelling. Time series analysis provides short term predictions for the first 6-8 hours, taking advantage of the persistence of the wind.
- Physical modelling. Numerical weather predictions (NWP) improve wind forecasts for horizons higher than 8 hours because the evolution of the atmosphere at synoptic scale is significant after some hours, and this evolution changes the conditions at local scale.

One of the main error sources in wind forecasts are the meteorological models that provide the NWP. Meteorological models solve numerically the equations that govern the status of the atmosphere, initial and boundary conditions are necessary for the numerical calculations as well as digital maps of the terrain and roughness.

Initial conditions are defined from meteorological observations and, given the limited number of available measurement stations these conditions are not perfectly defined. Boundary conditions appear for limited area models because the spatial domains do not cover all the atmosphere, this limitation causes errors due to numerical reasons close to the limits of the domains; and also because there is no information about the status and evolution of the atmosphere outside the domain. Another source of error are the local effects not considered by the NWP. Due to computational reasons, the spatial resolution of the meteorological models is limited, and some features of the terrain are not considered by the meteorological models due to the limited spatial resolution. As the complexity of the terrain increases this limitation becomes more important, and the related errors are more relevant.

**LocalPred structure**

LocalPred prediction model includes statistical and physical modelling. The different modules, including an advanced MOS and high resolution physical modelling, have being designed specially for complex terrain. The sources of errors explained previously are minimised through the statistical and physical modules. Figure 1 shows LocalPred structure.

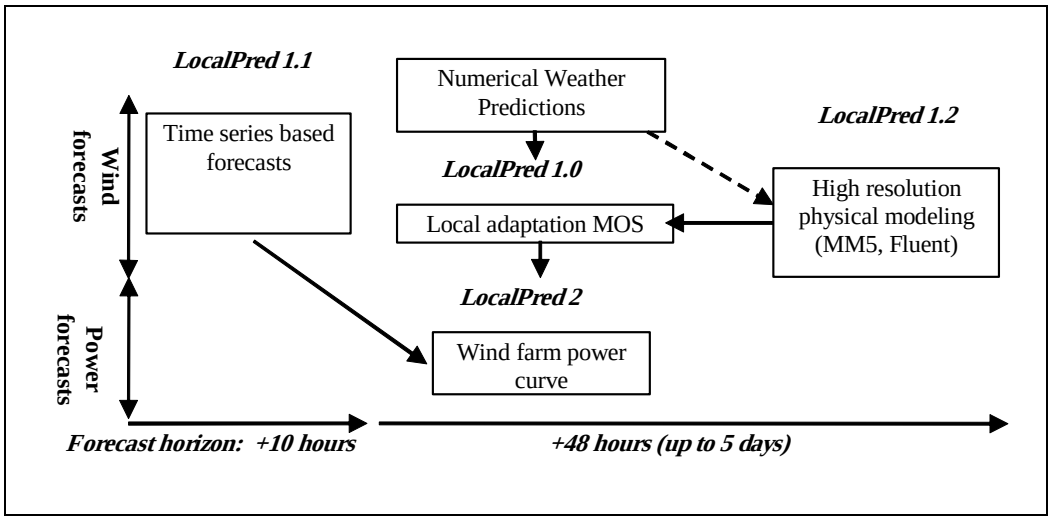


Figure 1. LocalPred forecast model structure

For short term forecasts (up to 6-8 hours) the time series module (LocalPred 1.1) produces wind speed and/or power production forecasts, using as input the on-line measurements of wind speed and power production of the wind farm.

For medium term forecasts (more than 8 hours) NWP are used, different sources of NWP can be used: HIRLAM, AVN, ECMWF, etc. In order to reduce errors a MOS correction is calculated statistically (LocalPred 1.0), giving a more accurate wind forecast for the wind farm. The wind forecast is converted into power production forecast through the wind farm power curve module (LocalPred 2), being calculated using historical power production data and NWP.

High resolution physical module (LocalPred 1.2) comprises mesoscale model MM5 and CFD calculations with Fluent. The objective of this module is to study the effects of the topography and roughness with great level of detail.

LocalPred uses as input data numerical weather predictions as well as data measured at the wind farm (wind speed, wind direction, power production, temperature and pressure), as an option LocalPred can use on-line data for the time series module and also for the MOS and power curve modules.

**LocalPred 1.0 module. MOS corrections.**

LocalPred 1.0 is a statistical module that detects and removes systematic errors of NWP. It can be classified as an

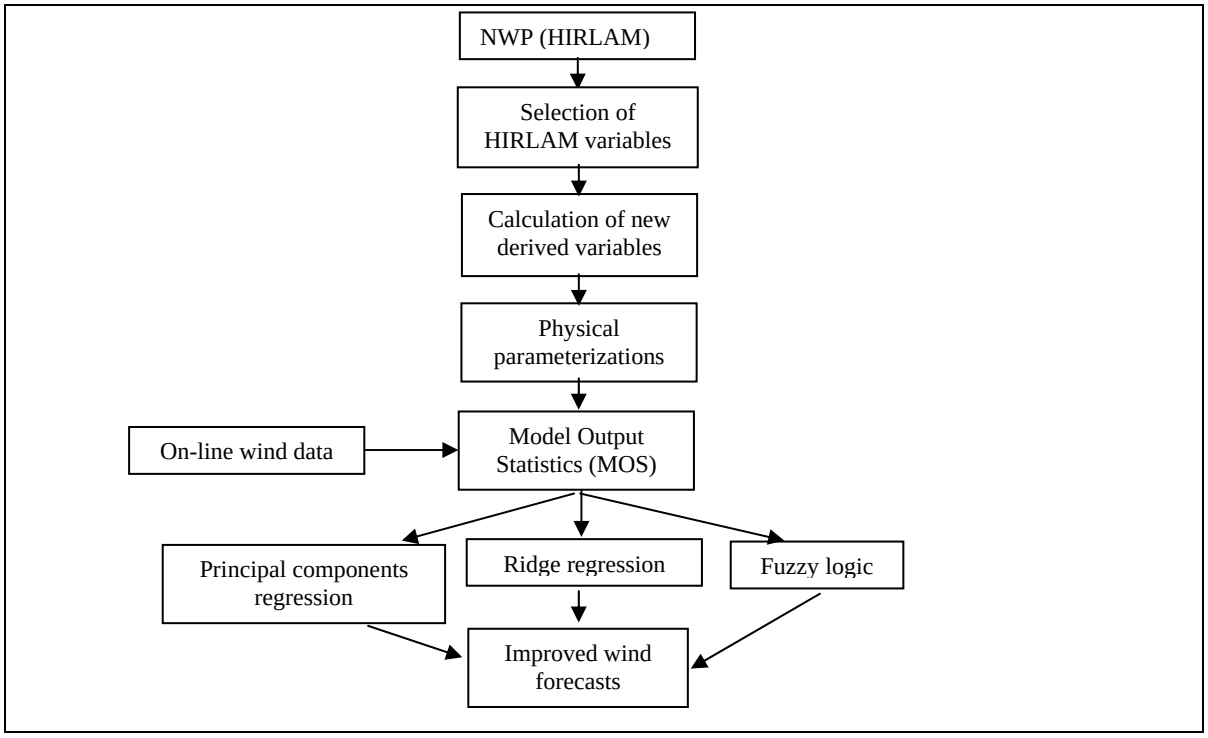


Figure 2. Structure of LocalPred 1.0

advanced MOS. Two statistical methodologies are used in this module, principal components regression and Ridge regression. Fuzzy logic algorithms are under development for this module. In order to estimate LocalPred 1.0 parameters, historical NWP and measured data are used for a period of at least three months. New variables, like spatial and temporal derivatives, are calculated from the original HIRLAM ones. After reading the inputs and the new variables, an identification of the statistically useful information is done, filtering those variables with redundant information. MOS correction is calculated for both wind speed components (U,V), having as final output a corrected wind speed and direction.

This MOS correction can be adaptive when on-line data are available. In this case the parameters of the module are updated weekly, using the previous months of simultaneous NWP and wind measurements. With this option the MOS corrections can follow slow changes in the NWP and/or changes in the measurement conditions.

This module calculates the errors of the forecasts before and after the MOS corrections. The cross-validation procedure is used to ensure that no overfitting problems appear when fitting the MOS model.

Some samples of the results of this module can be found in [1] and [2].

**LocalPred 1.1 module. Time series predictions.**

LocalPred 1.1 is a time series analysis module that uses on-line data to produce forecasts for the very short term. It is based on autoregressive models, with a previous filtering of the data through non-parametric wavelets analysis. This module generates energy production forecast of the wind farm for a few hours period.

The procedure used for the identification of the process is based on the Box-Jenkins methodology [3], with a previous analysis of the data consisting of identifying hidden periodicities, through a variance analysis of the estimated harmonics of the time series. After that, the characterized noise is eliminated by means of non-parametric wavelets analysis [4].

After the previous treatment of data, the identification of the best lineal model is obtained by estimations about the autocorrelation function and partial autocorrelation function. The obtained model is an autoregressive model of 1st order. The parametric estimation has been carried out solving the Yule-Walker equations [3].

The errors of the forecasts are calculated for this module and for each forecasts horizon, and are compared with the errors of the forecasts produced by LocalPred 1.0 and 1.2 modules. The best prediction is selected for each forecast horizon.

**LocalPred 1.2 module. High resolution physical modelling.**

Mesoscale model MM5 is used as an alternative source of NWP. It can process NWP coming from AVN, ECMWF or HIRLAM models, increasing the spatial resolution of the NWP up to 1 x 1 $km^2$. This increase of the resolution allows simulating local scale phenomena that affect the wind field. The improvement of the forecasts due to the higher spatial resolution is more significant in complex terrain.

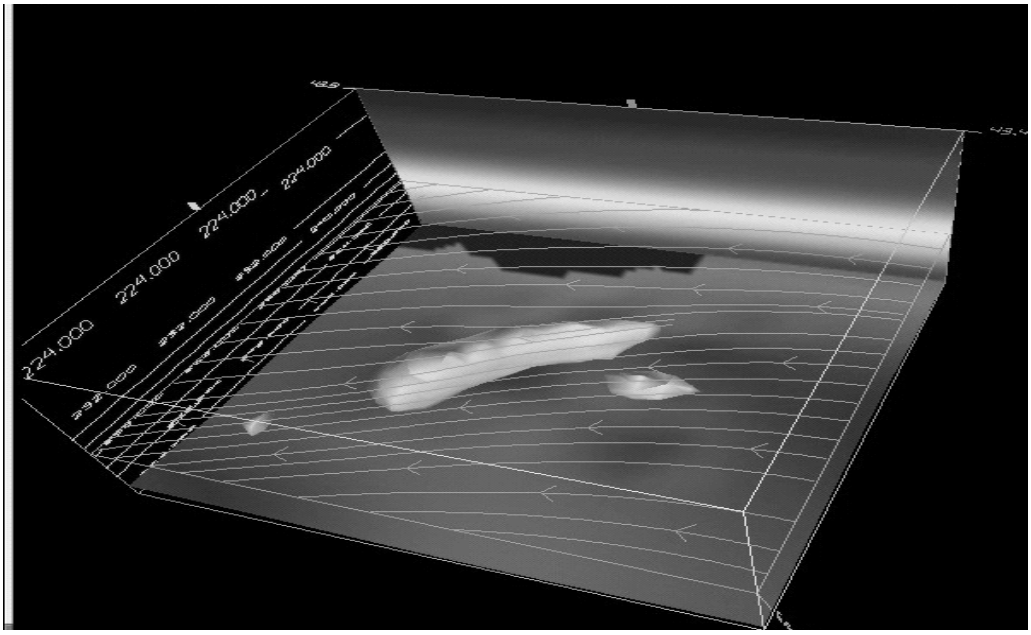


Figure 3. Mesoscale model MM5.

Mesoscale meteorological model ***MM5***, it is a non hydrostatic model with the possibility of using nested domains and data assimilation.

CFD modelling with FLUENT software allows simulating the wind flow with high spatial resolution, considering the roughness, topography, obstacles and turbine wakes with detail (up to some meters of spatial resolution).

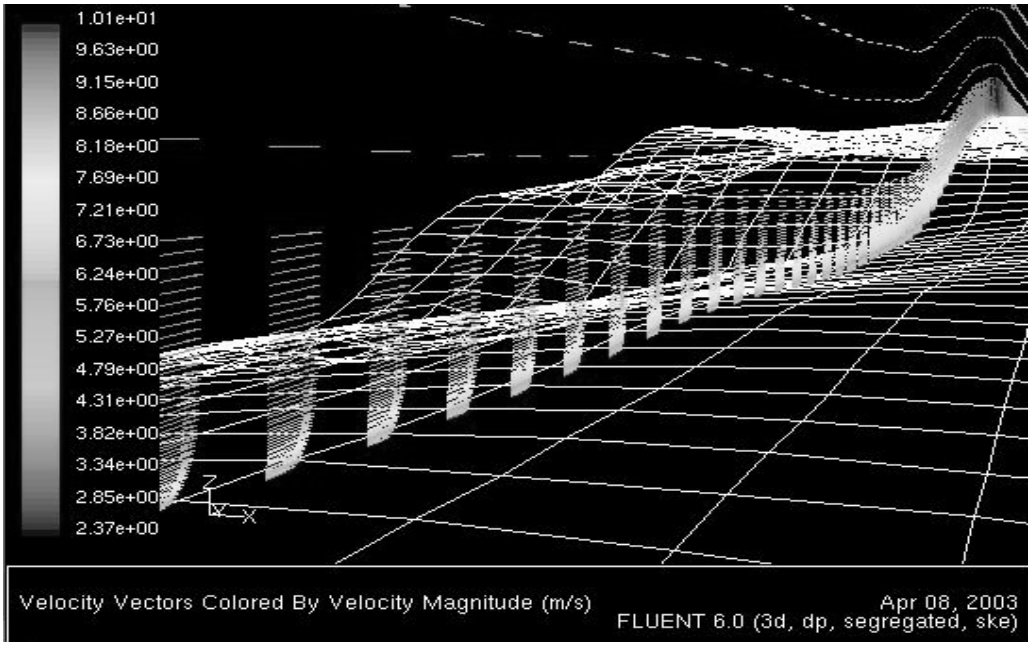


Figure 4. CFD calculations.

**LocalPred 2. Wind farm power curve**

LocalPred 2 module calculates the power curve of the wind farm statistically by means of historical power production data and simultaneous NWP. This module converts wind speed forecasts into energy production forecasts. Power curves are calculated by means of a classification of the measured data, considering wind speed and direction sectors; density corrections can be performed if temperature and pressure data is available. Alternatively, a fuzzy logic approach can be used to produce the wind farm power curves. When on-line data is available, wind farm power curves can be updated.

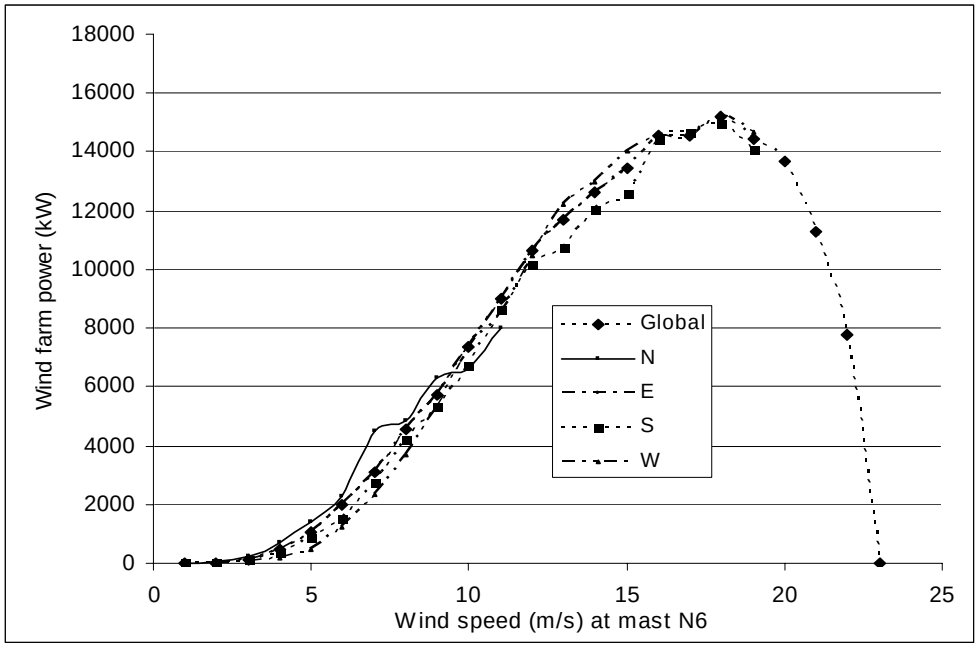


Figure 5. Set of power curves.

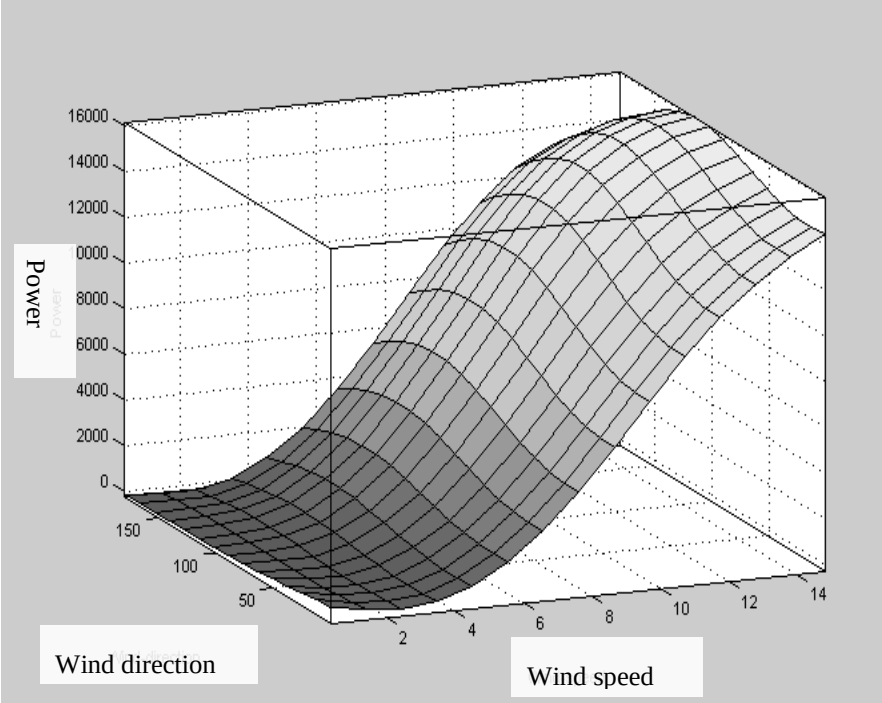

Figure 6. Fuzzy logic set of power curves.

**RegioPred**

Power production forecasts can be produced for a region containing various wind farms. The forecasts for the whole region can be produced by the addition of the predictions for each wind farm; however, if there is not a forecasting model fitted for each wind farm, the regional forecasts can be produced by means of selecting a number of representative wind farms and making an upscale of the forecasts produced for the selected wind farms. The procedure for the wind farm selection is based on cluster analysis.

**LocalPred operational**

LocalPred is running operationally at a test station since January 2002, it is also operating at a wind farm in complex terrain since June 2003, both sites in Spain. The model will be installed at three other wind farms in Spain in September 2003. Finally, it has been tested off-line at two other wind farms in complex terrain in Spain.

LocalPred 1.0 has been developed in collaboration between CENER and CIEMAT.

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