1st WindSim Americas User Meeting

4 December 2014, Orlando

Power Forecasting

PRESENTED BY: XUAN WU, COUNTRY MANAGER

windsim

Butterfly effect – Sensitivity to initial conditions

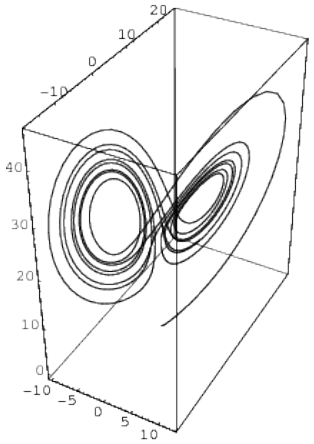
Edward Lorenz (1917 – 2008) was an American mathematician and meteorologist, and a pioneer of chaos theory. He introduced the strange attractor notion and coined the term “Butterfly effect”.

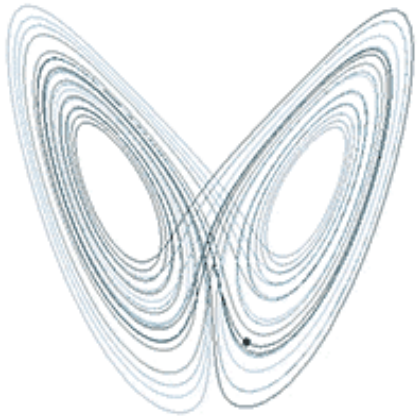
“Two states differing by imperceptible amounts may eventually evolve into two considerably different states ... If, then, there is any error whatever in observing the present state — and in any real system such errors seem inevitable — an acceptable prediction of an instantaneous state in the distant future may well be impossible....In view of the inevitable inaccuracy and incompleteness of weather observations, precise very-long-range forecasting would seem to be nonexistent.”

Lorenze (Strange) attractor

The Lorenz attractor is an attractor that arises in a simplified system of equations describing the two-dimensional flow of fluid of uniform depth, with an imposed temperature difference, under gravity, with buoyancy, thermal diffusivity, and kinematic viscosity . The simplified equations are:

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \sigma(y - x),$$
$$\frac{\mathrm{d}y}{\mathrm{d}t} = x(\rho - z) - y,$$
$$\frac{\mathrm{d}z}{\mathrm{d}t} = xy - \beta z.$$

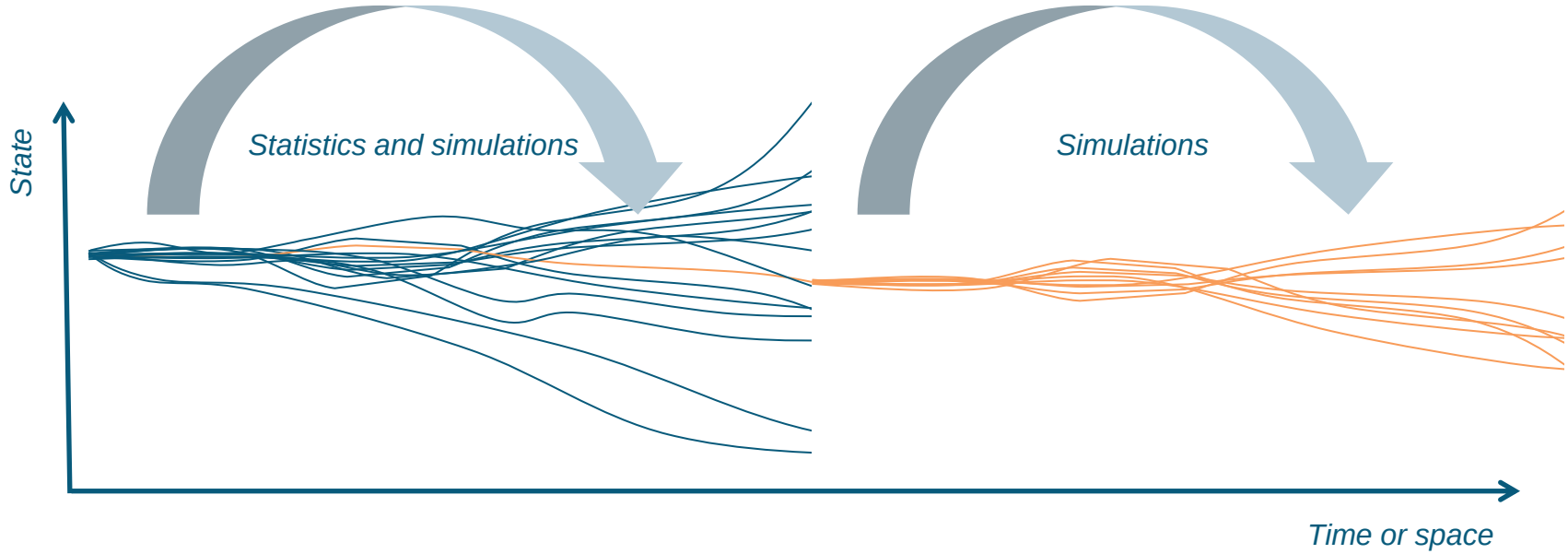




A sample solution in the Lorenz attractor when ρ = 28, σ = 10, and β = 8/3

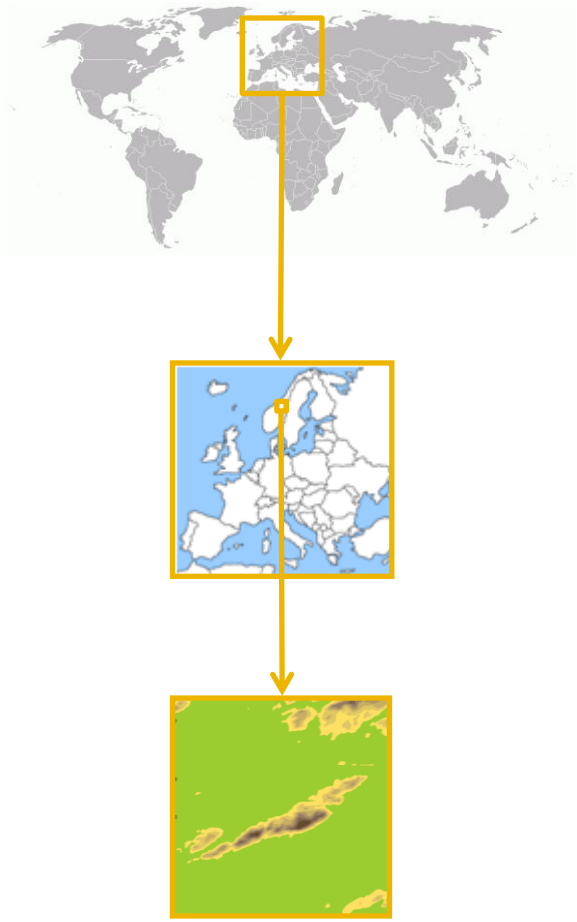
Short-term – Short-range

As short-term and/or short-range is reached the “State” includes the operational state of the turbines, favoring deterministic simulations



Coupling Mesoscale and CFD

Global Models
100 - 16 km
e.g. ECMWF, GFS



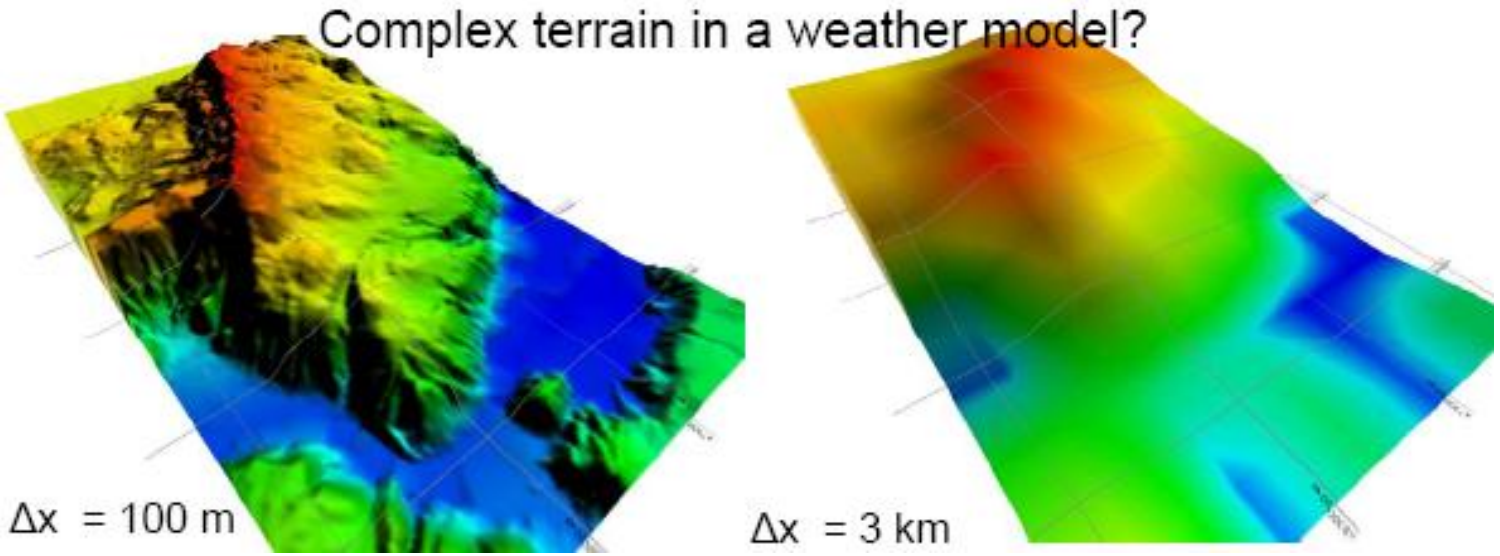
Regional Models
9 - 1 km
e.g. WRF

Description of the atmospheric conditions

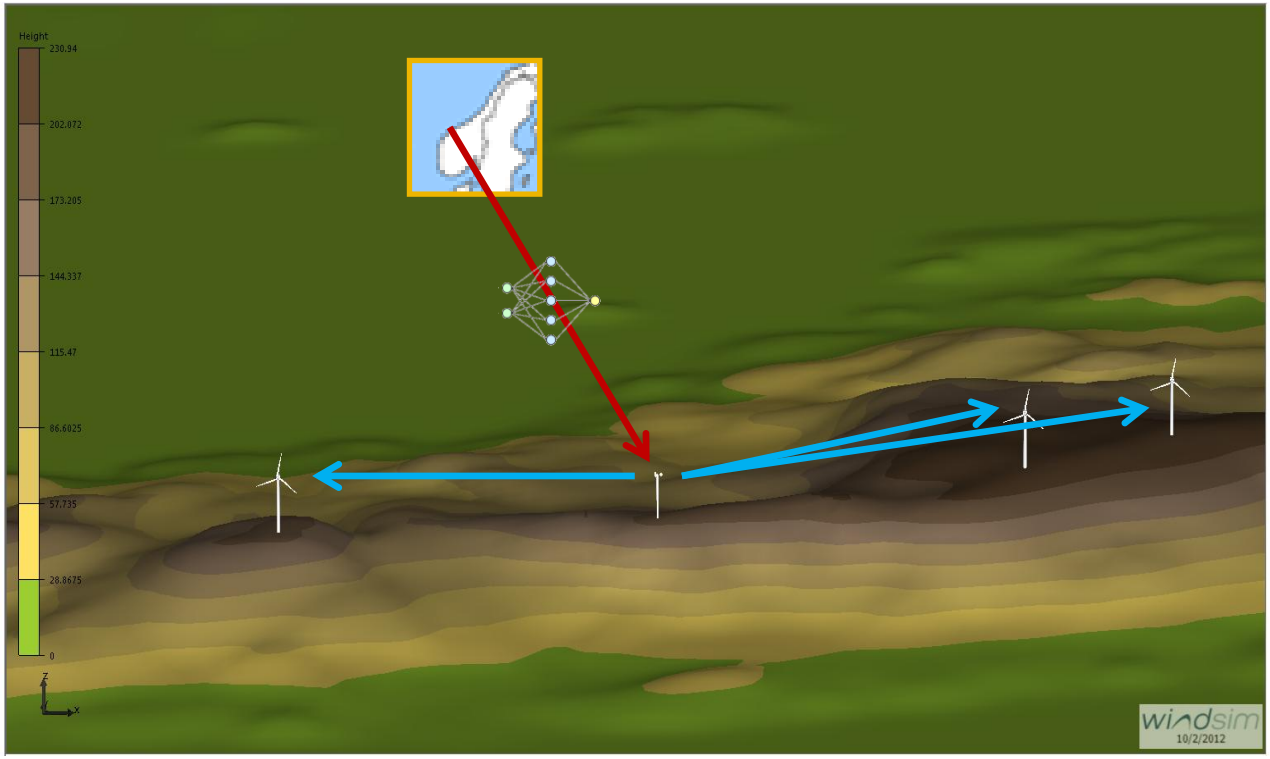
Micro Model
100 - 10 m
WindSim

Accurate description of the local flow field and the wake effects

Mesoscale Models

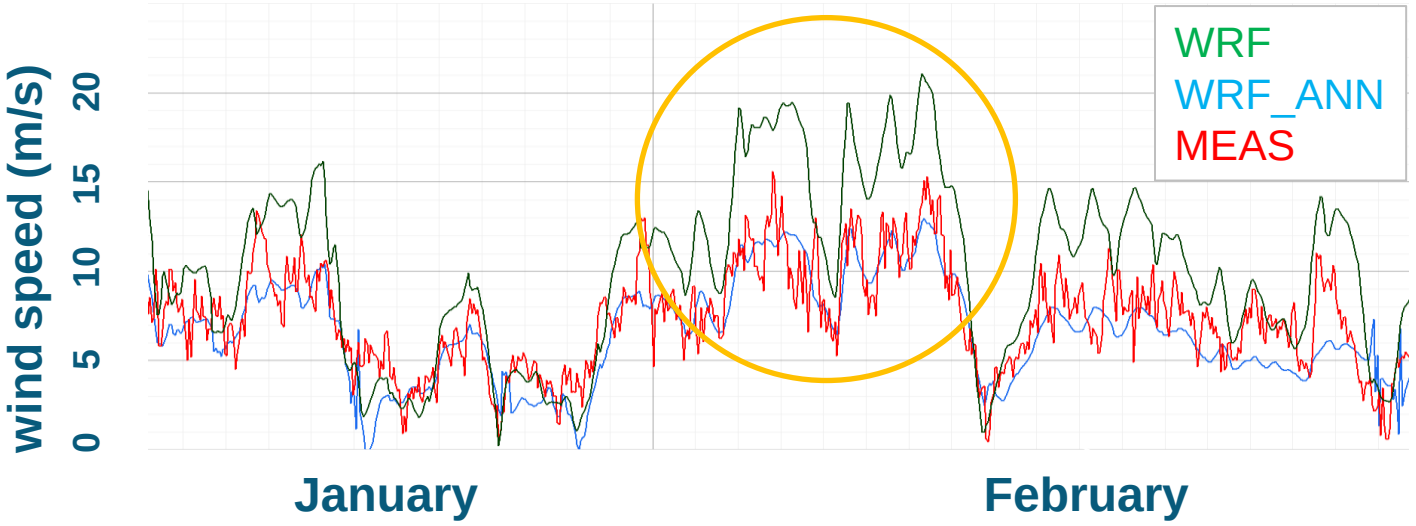


Coupling Mesoscale and CFD using ANN



Virtual met-mast technique

Why use Artificial Neural Networks?

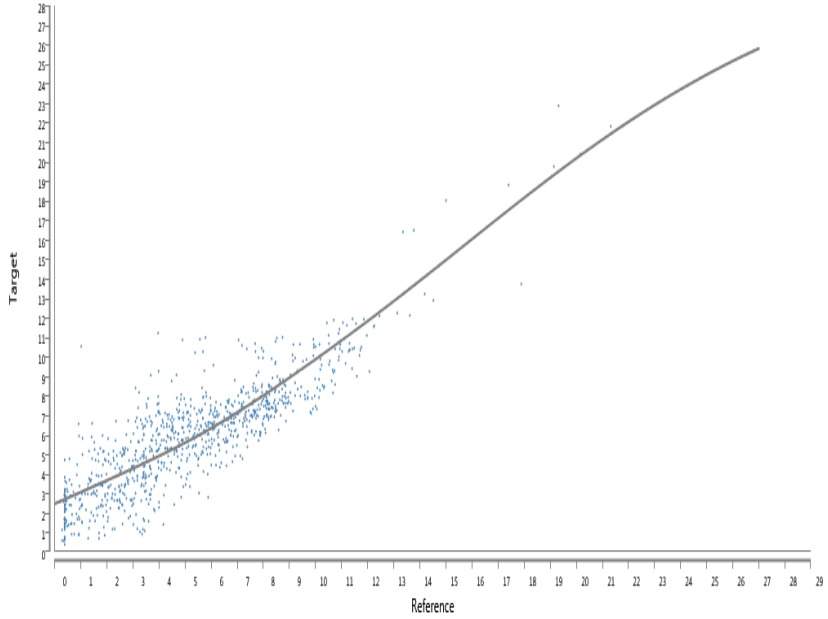


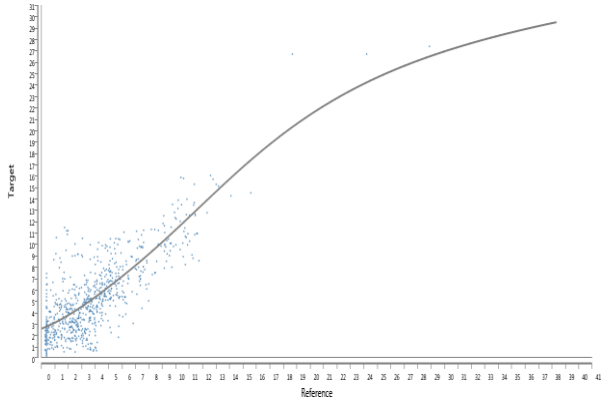
WRF data has phase and model bias errors in wind speed and direction

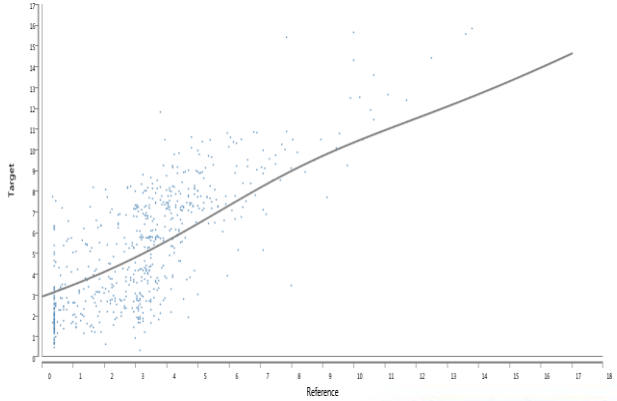
Trained networks can be used to correct each forecasted time series from the mesoscale model before it is used in the CFD simulation

Why use Artificial Neural Networks?

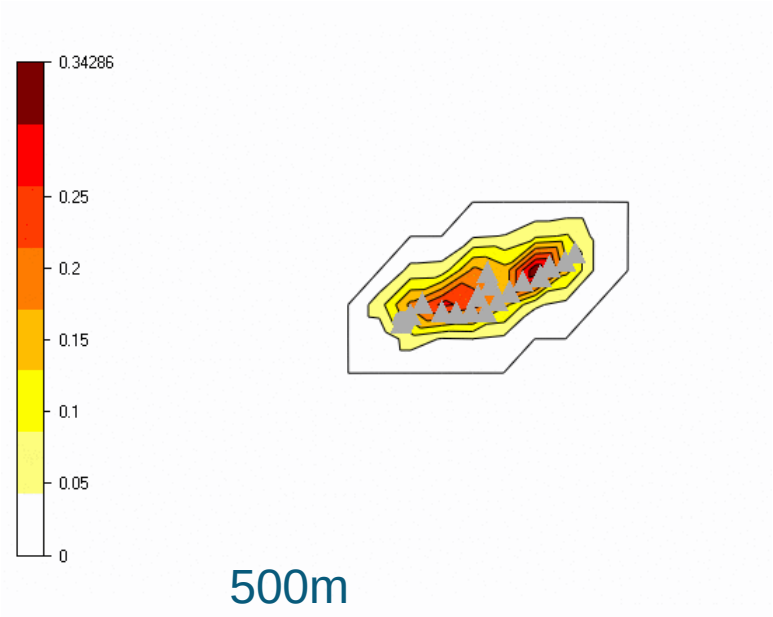
ANN solve a non linear problem
Using ANN in MCP the curved lines fit better than straight lines the sectors points

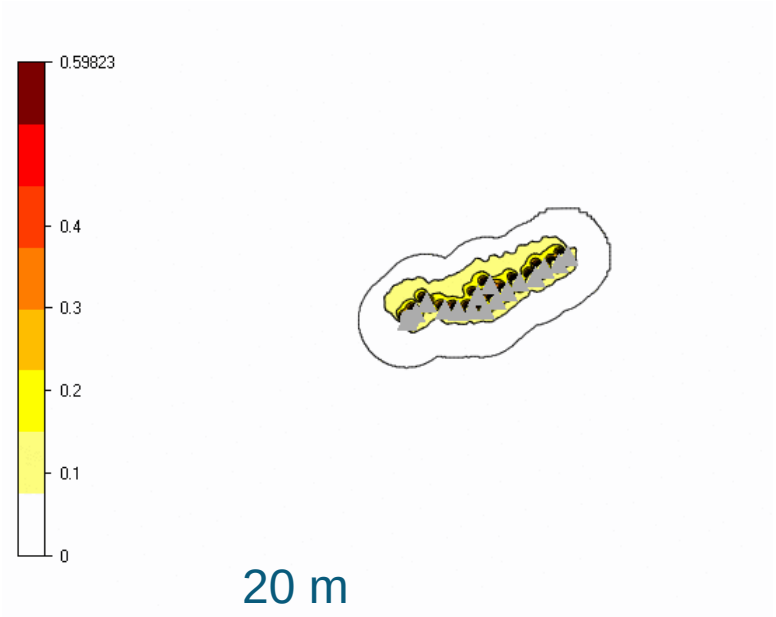






The added value of using CFD

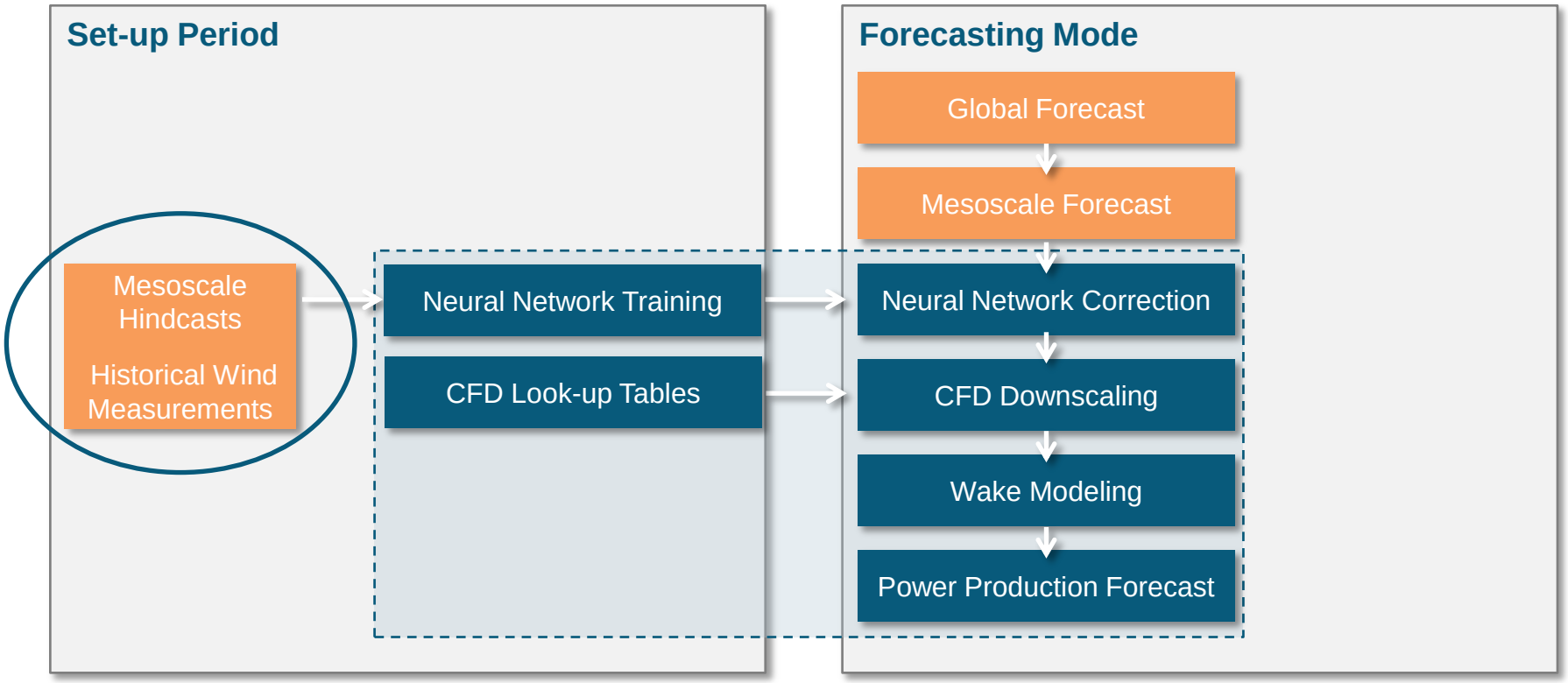




The CFD describes more accurately the local flow field around the turbines and can therefore downscale the mesoscale model results

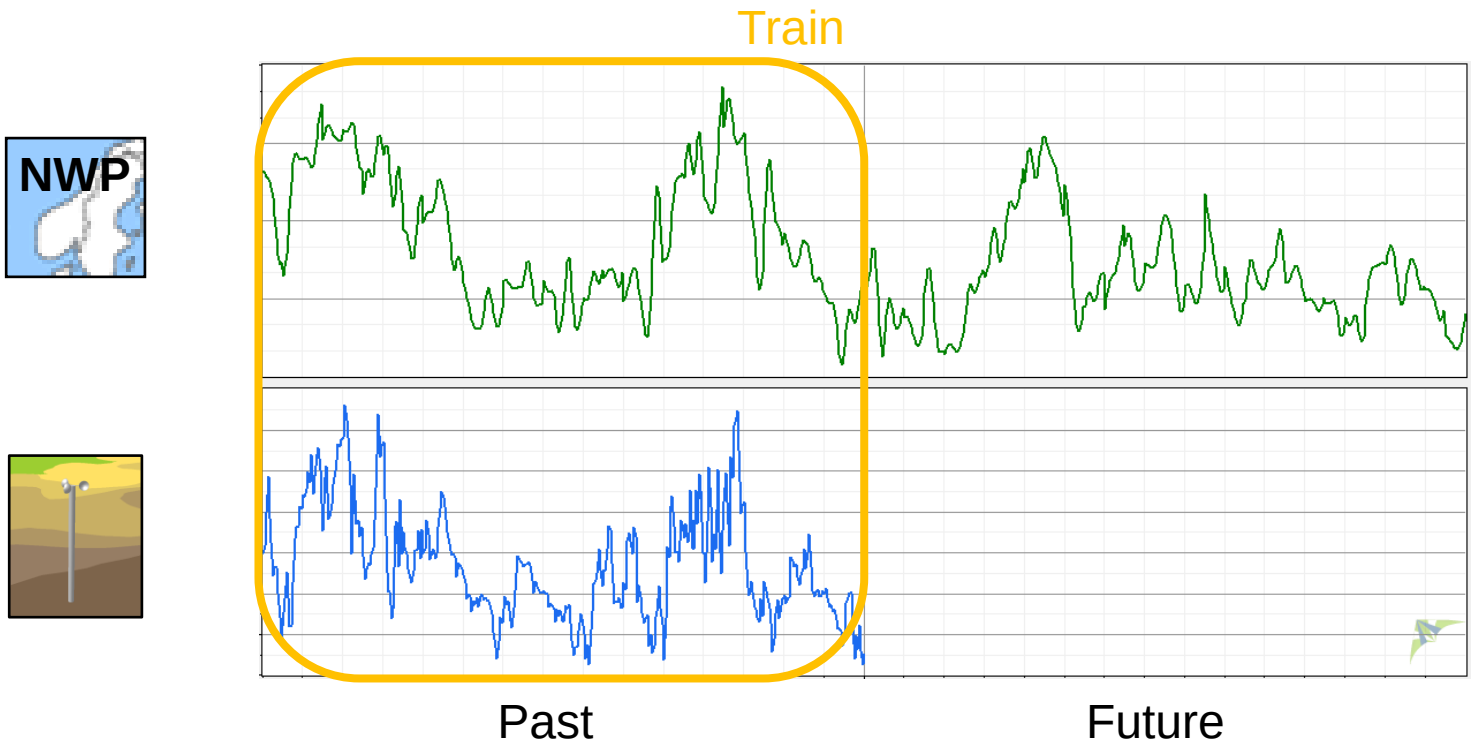
The CFD is able to calculate the wake corrected energy production and take in account more accurate information about roughness, forest etc..

WindSim Forecasting



Cleaning of the training data

- The network learn on the data provided so wrong data provide errors in the correction



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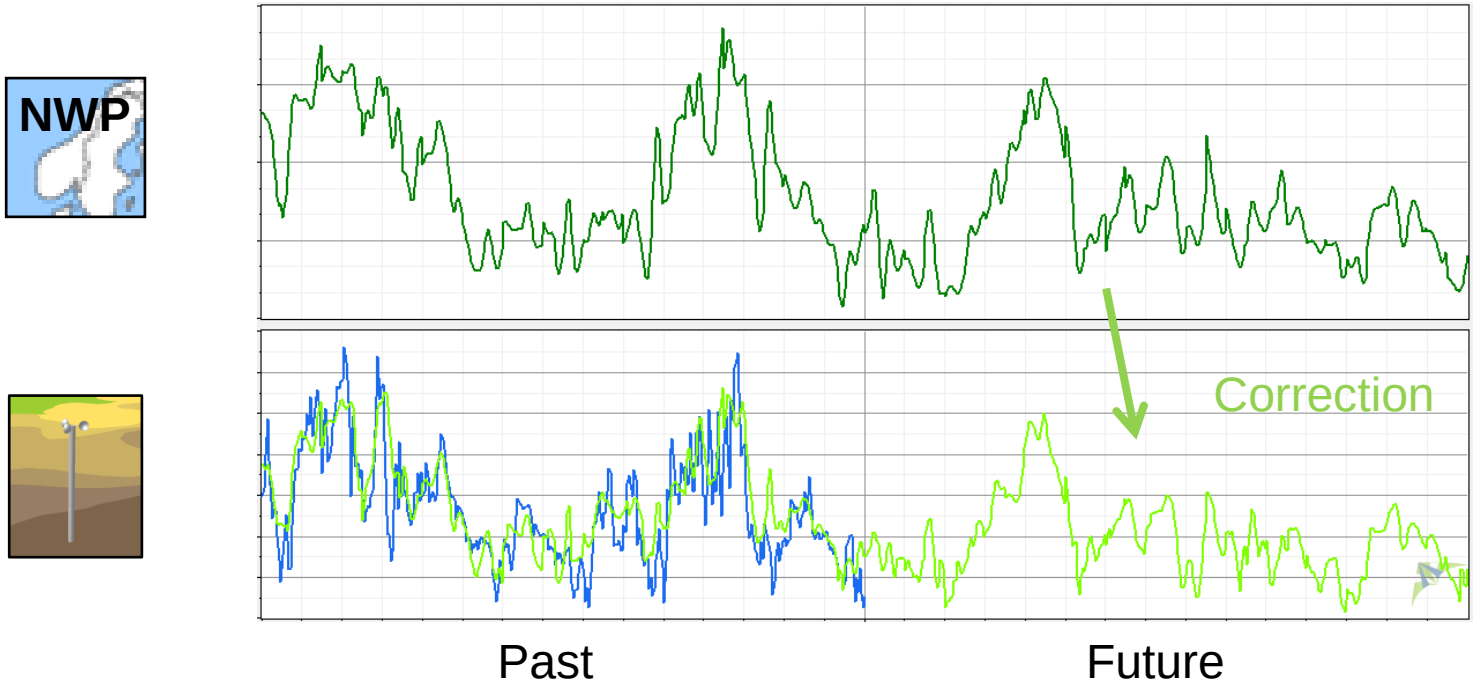
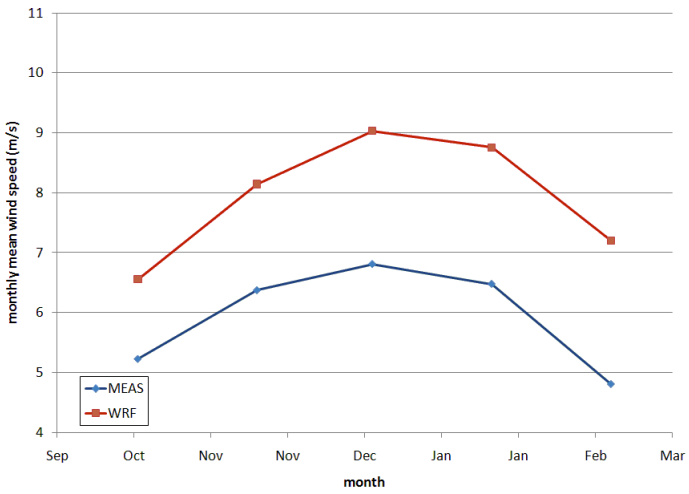
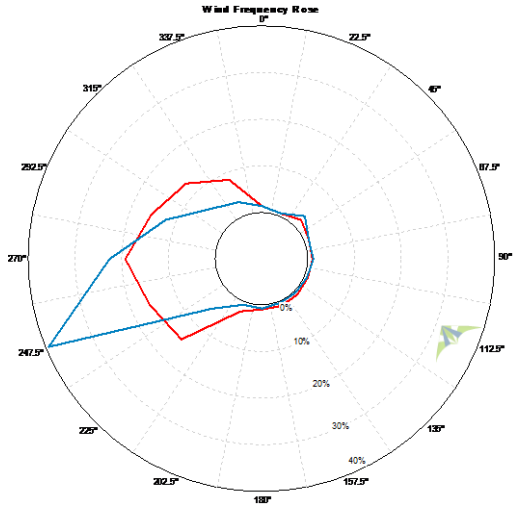


Validation – Chinese wind farm

The WRF mesoscale model predicts the monthly mean wind speed and direction well but the absolute value is too high





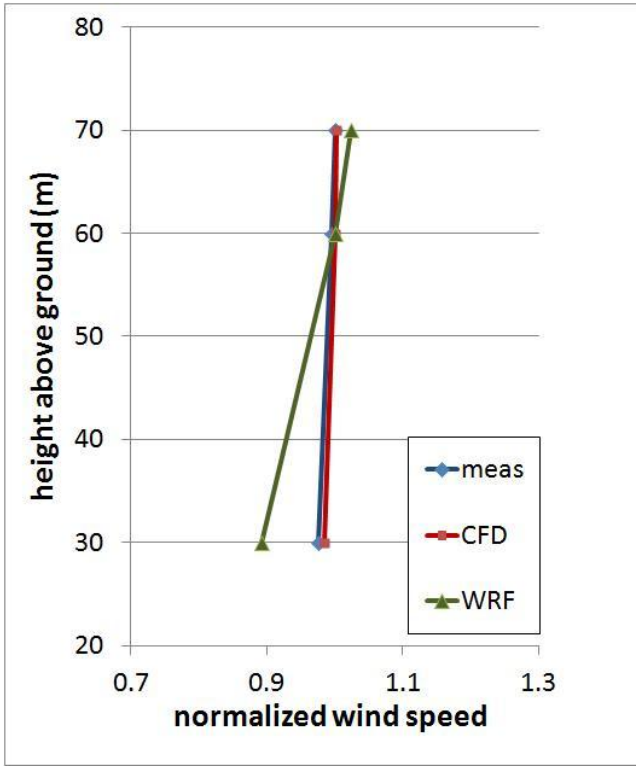
WRF
MEAS

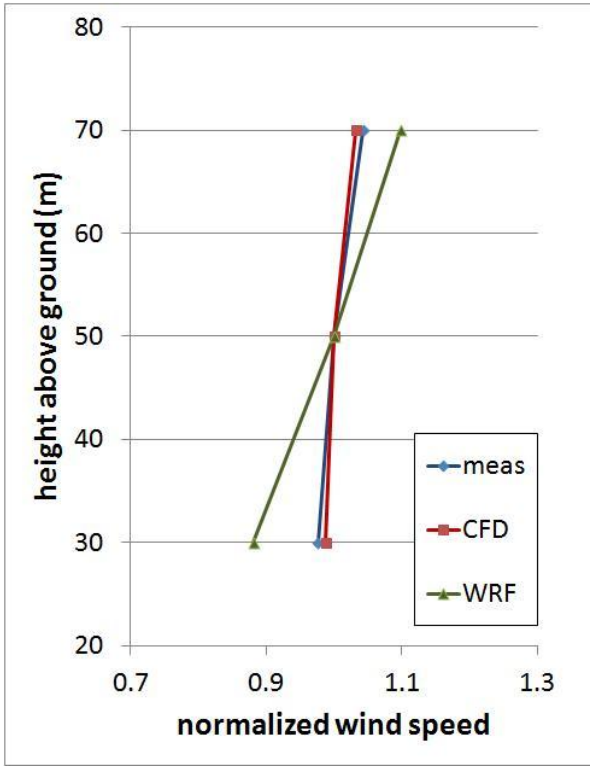
Mast 2

Validation – Chinese wind farm

The CFD modelling improves the modelling of the wind profile

Mast 2





Mast 3

Validation – Studio Rinnovabili (Italy)

Results on 5 sample sites, using Neural Networks and MCP
The performance is depending on the complexity of the terrain

Site	Neurons # /MCP	Mean U Bias m/s	RMSE U m/s	WMAEp %	NMAEp %
MCam ★	50	-0.02	2.26	63.5%	14.7%
Mcam	MCP	0.15	2.56	71.5%	16.6%
TRV	50	-0.35	1.85	55.0%	10.6%
FRN ★	50	-0.15	1.97	57.2%	14.8%
PNP	50	-0.06	0.98	8.7%	2.0%
PNP2 (2 anni)	50	0.41	1.79	50.4%	9.2%
MRN	50	-0.14	1.98	52.0%	11.1%

★ MCP instead of ANN

★ Use a second Met Mast as Forecast

★ sites with higher complexity

WMAE: Weigthed Mean Absolute Error

Errore assoluto medio in % della produzione

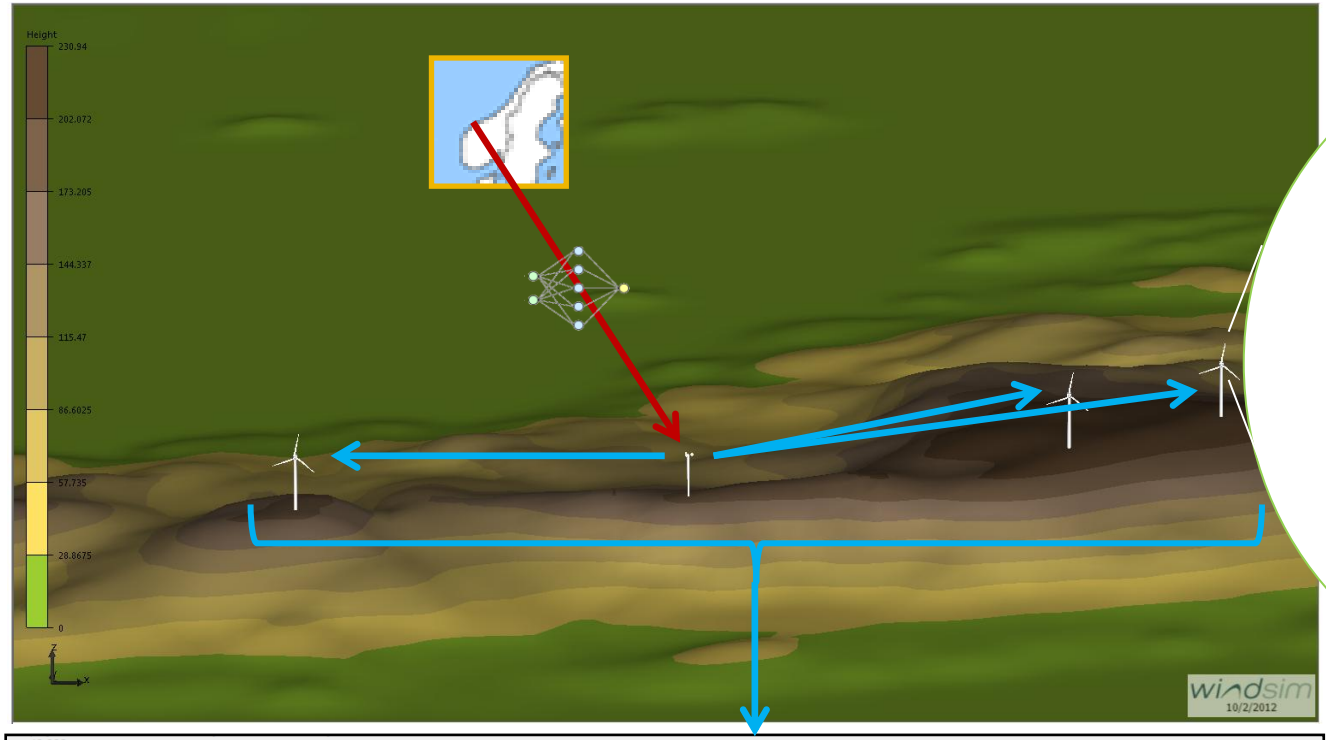
$$WMAE\% = 100 \times \frac{\sum_{i=1}^{N} |E_m^i - E_p^i|}{\sum_{i=1}^{N} E_m^i}$$

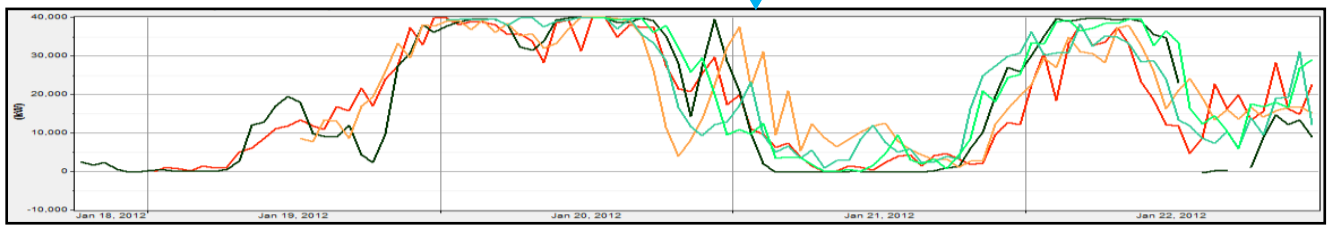
NMAE: Normalized Mean Absolute Error

Errore assoluto medio % riferito alle capacità

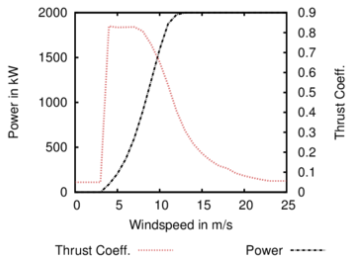
$$NMAE\% = 100 \times \frac{1}{N} \sum_{i=1}^{N} \frac{|E_m^i - E_p^i|}{C}$$

WindSim Forecasting

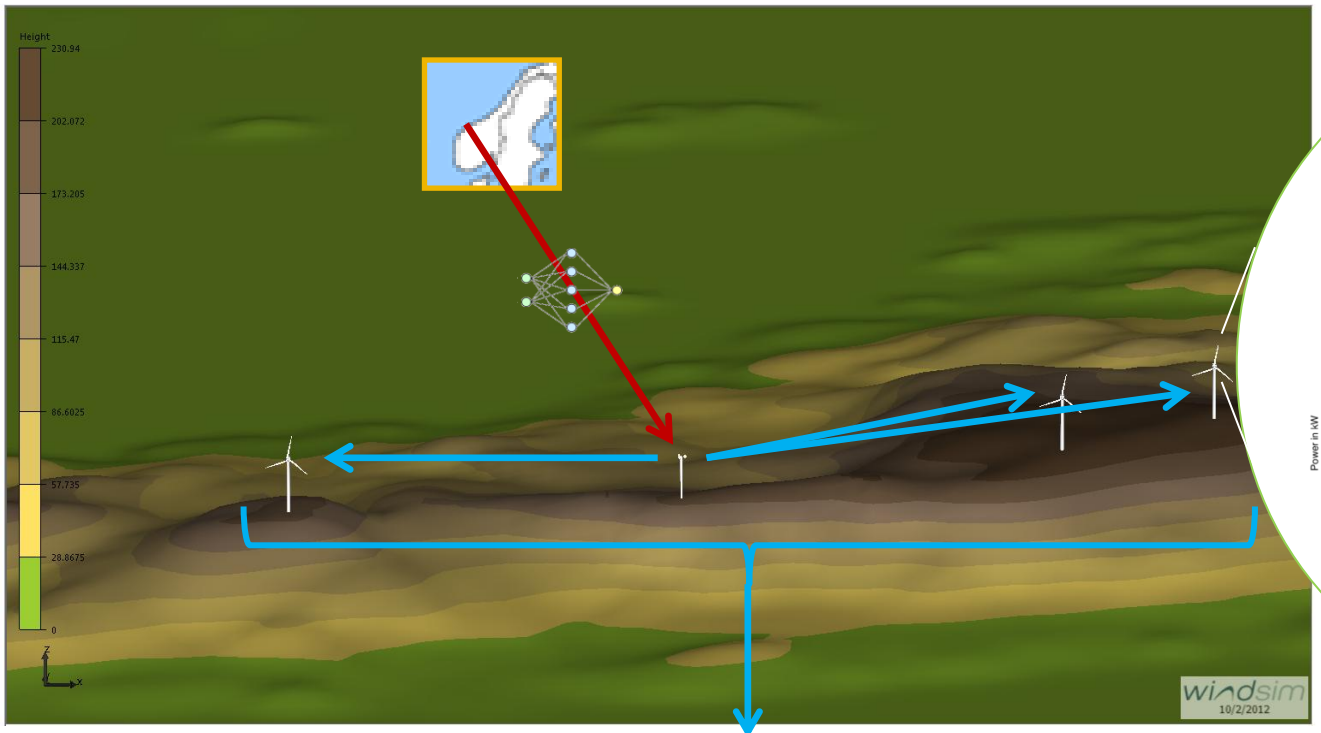


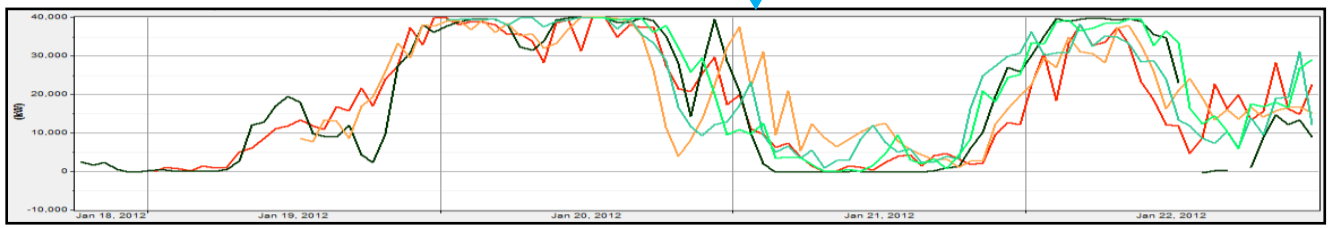


Nominal Power Curve

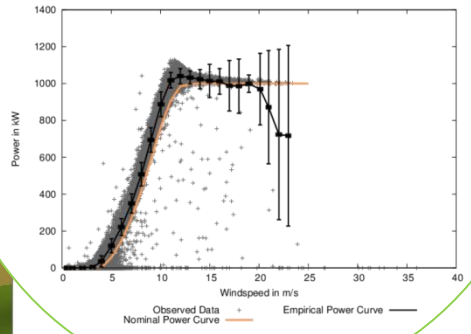


WindSim Forecasting

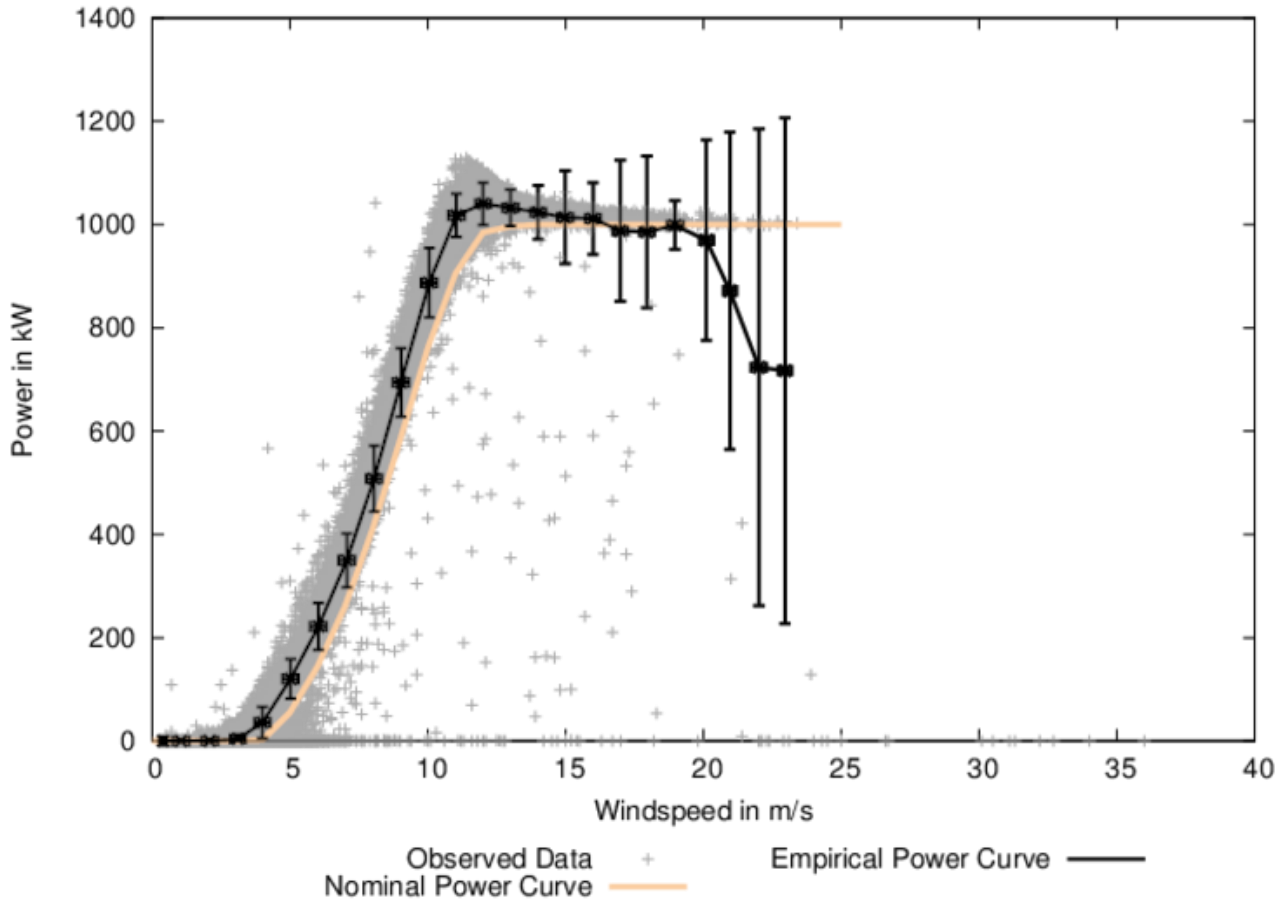




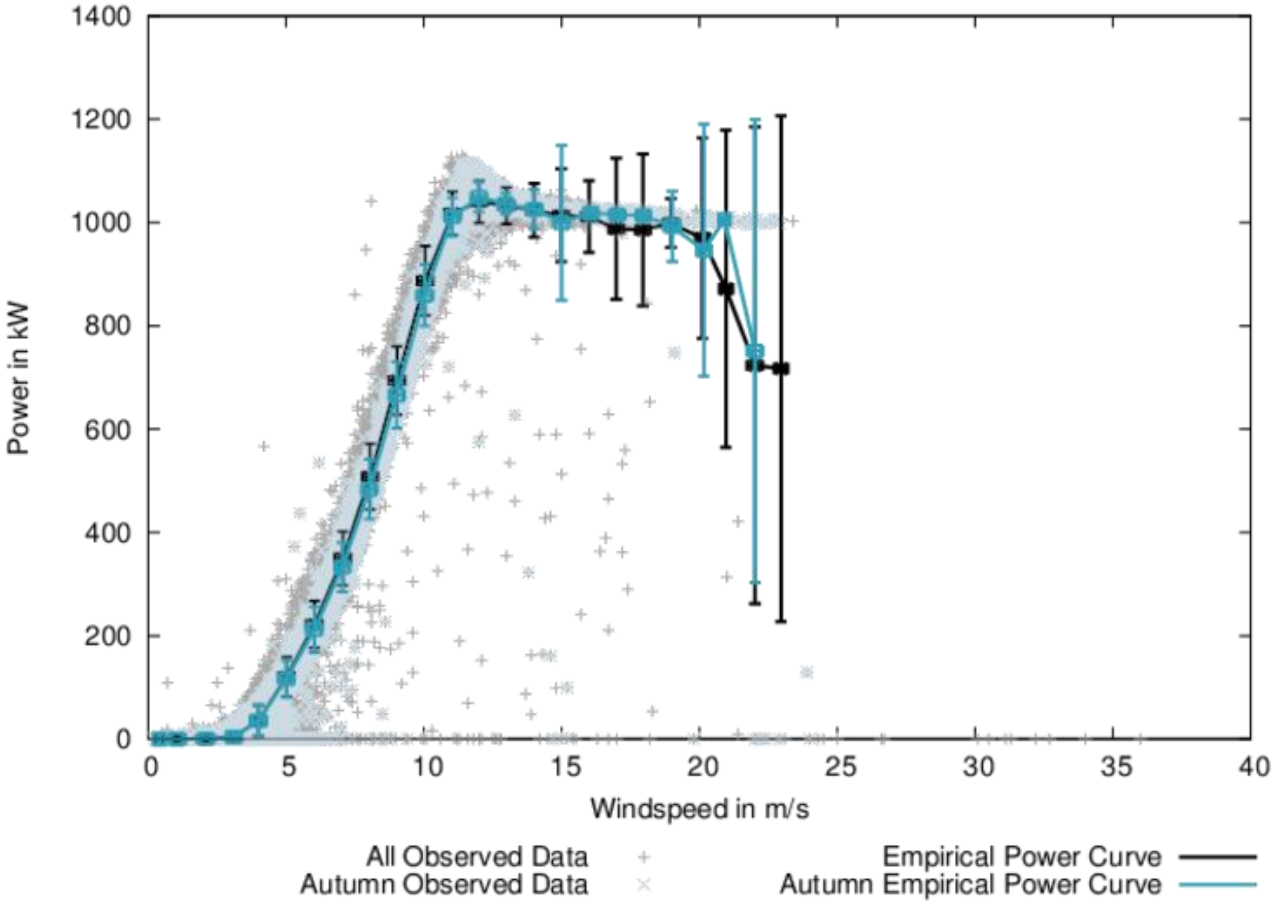
Empirical Power Curve



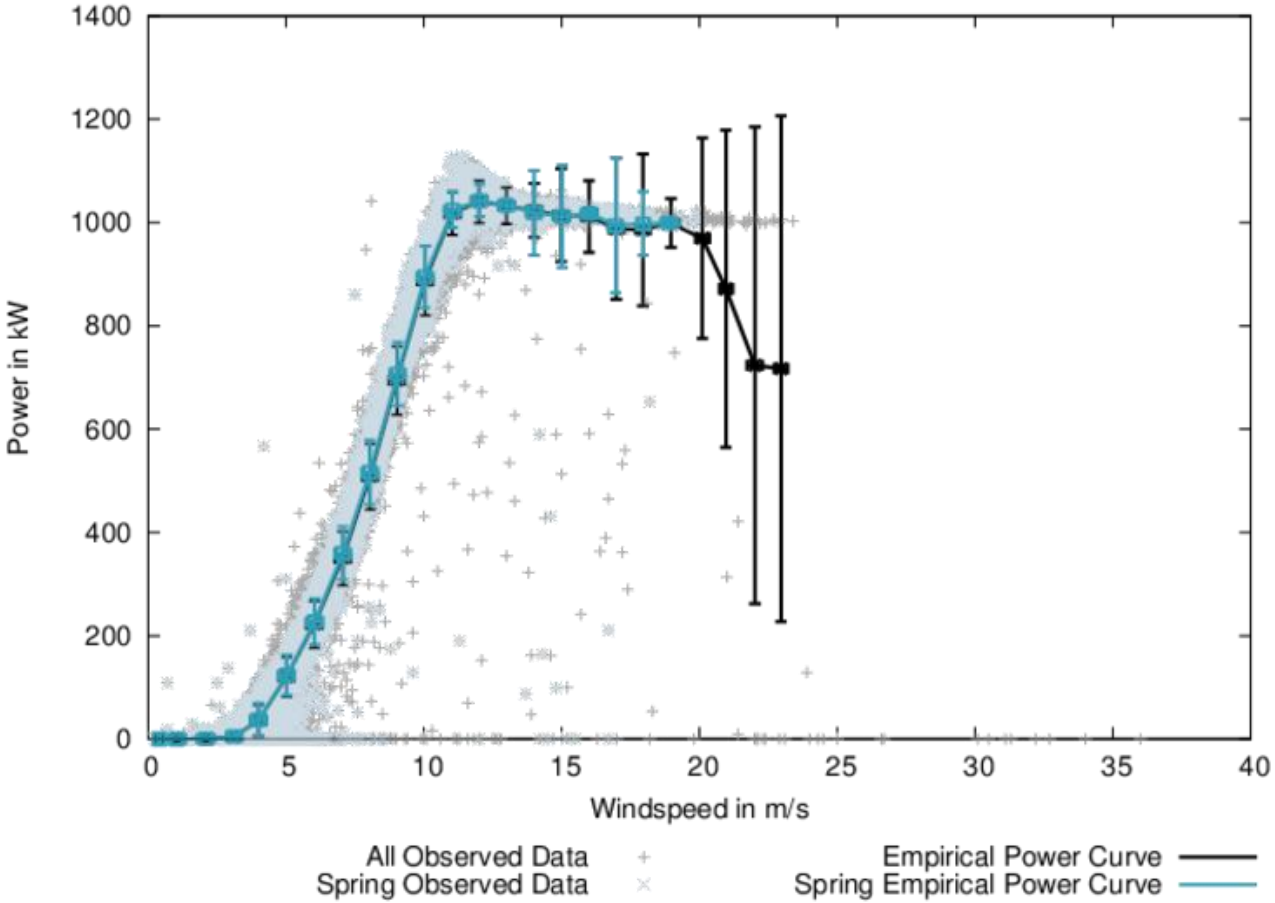
Empirical Power Curve vs Nominal



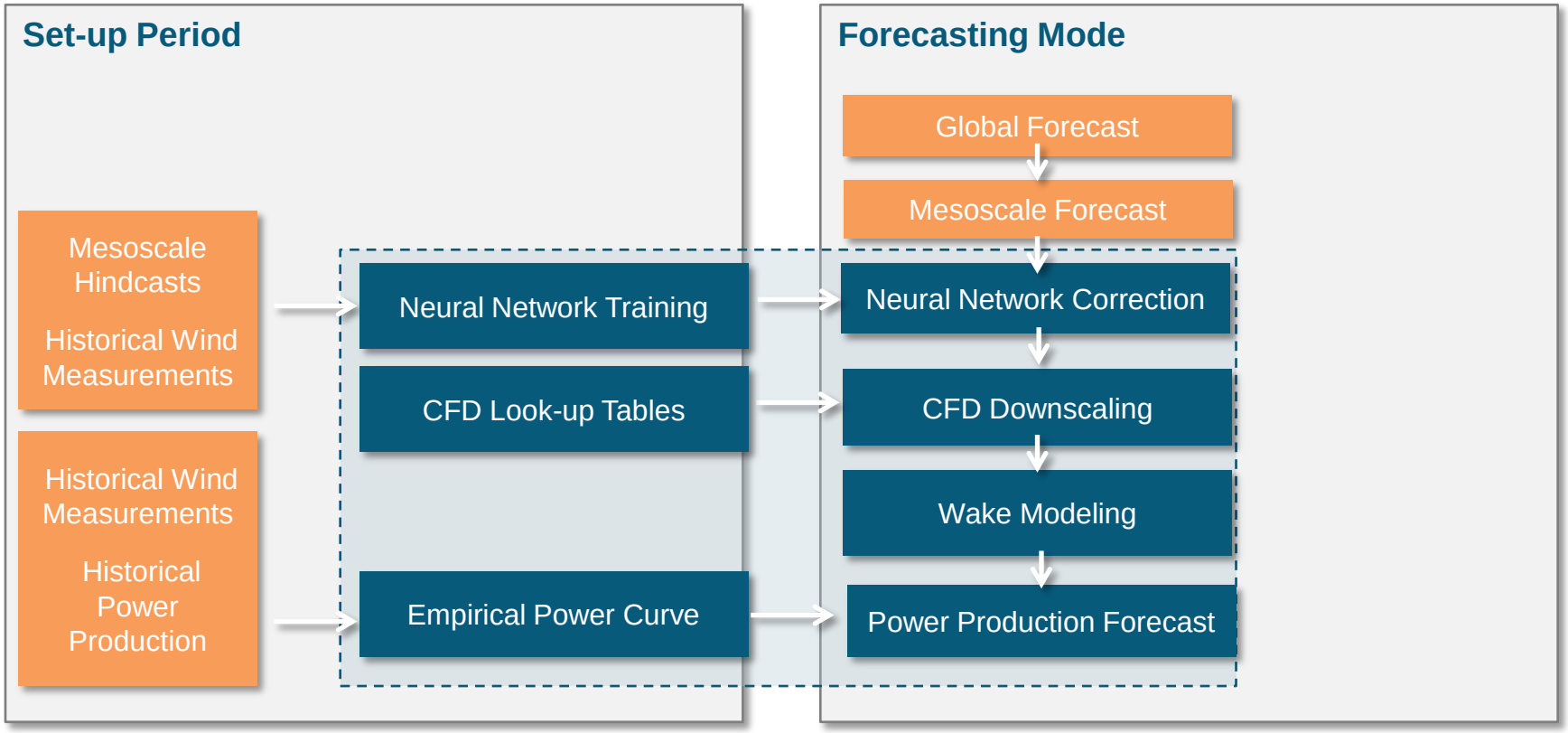
Empirical Power Curve per Season



Empirical Power Curve per Season

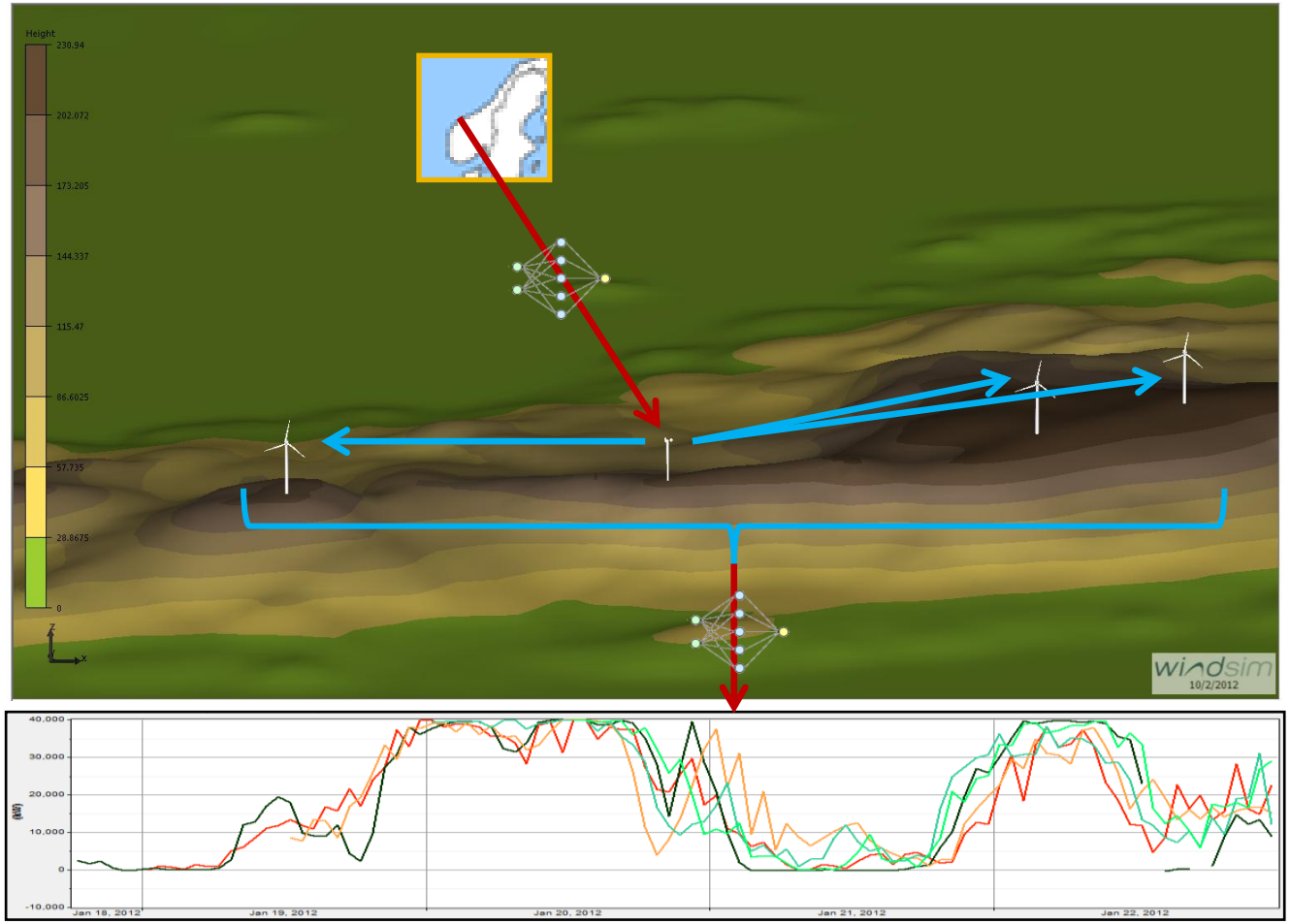


WindSim Forecasting with EmpPC

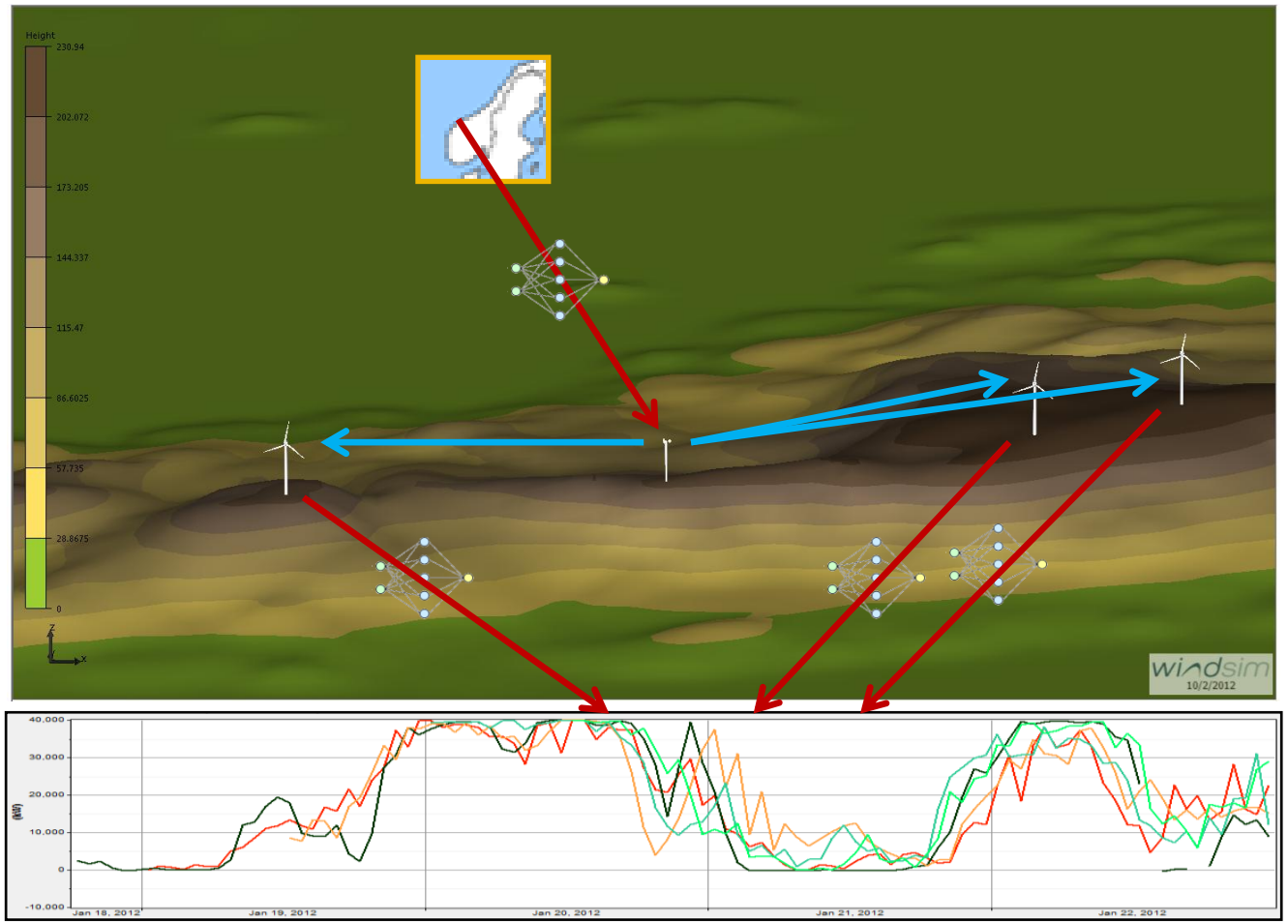


NMAE decrease: 1.5%
(from 11.33% to 9.87%)

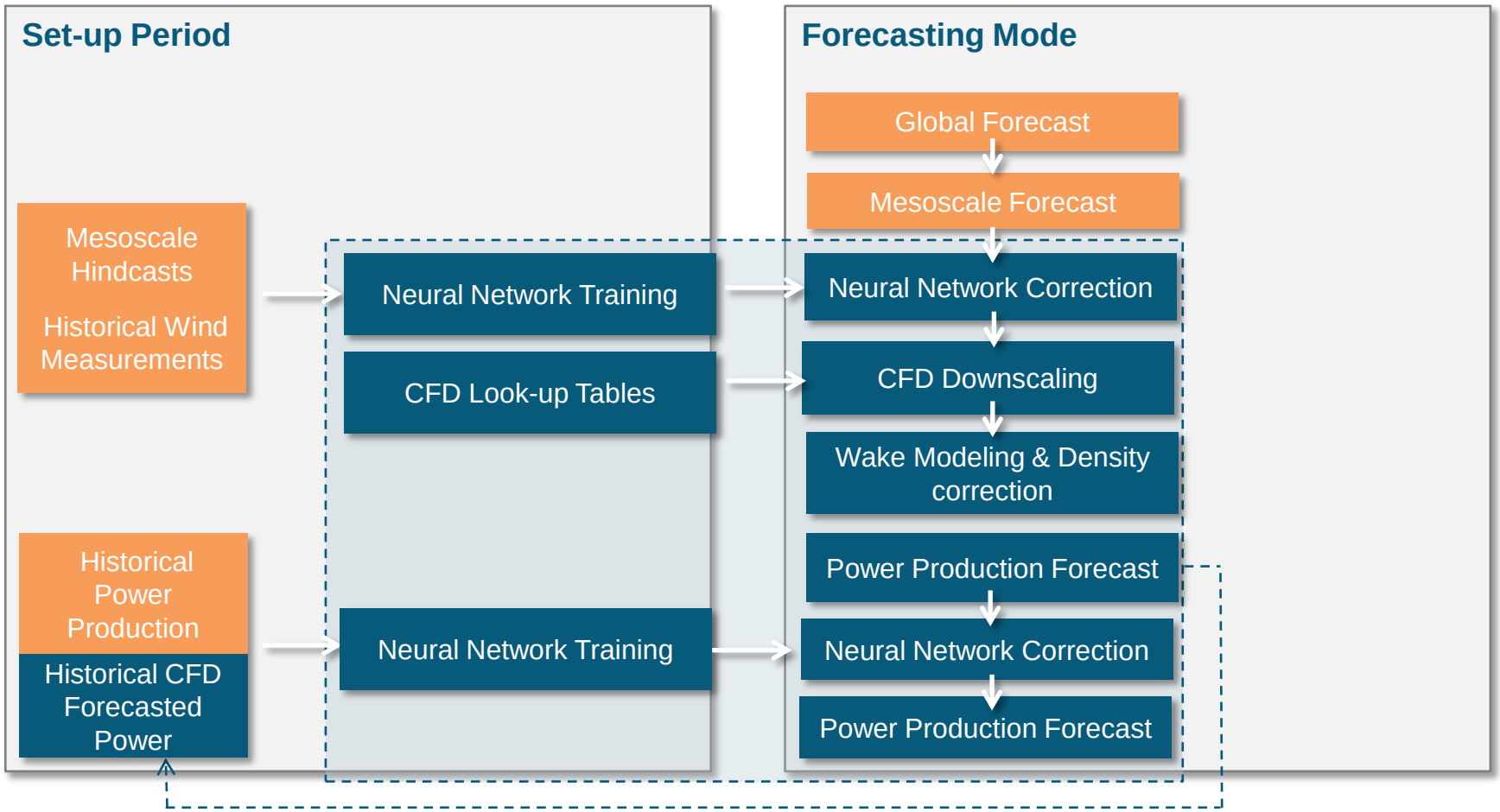
WindSim Forecasting



WindSim Forecasting

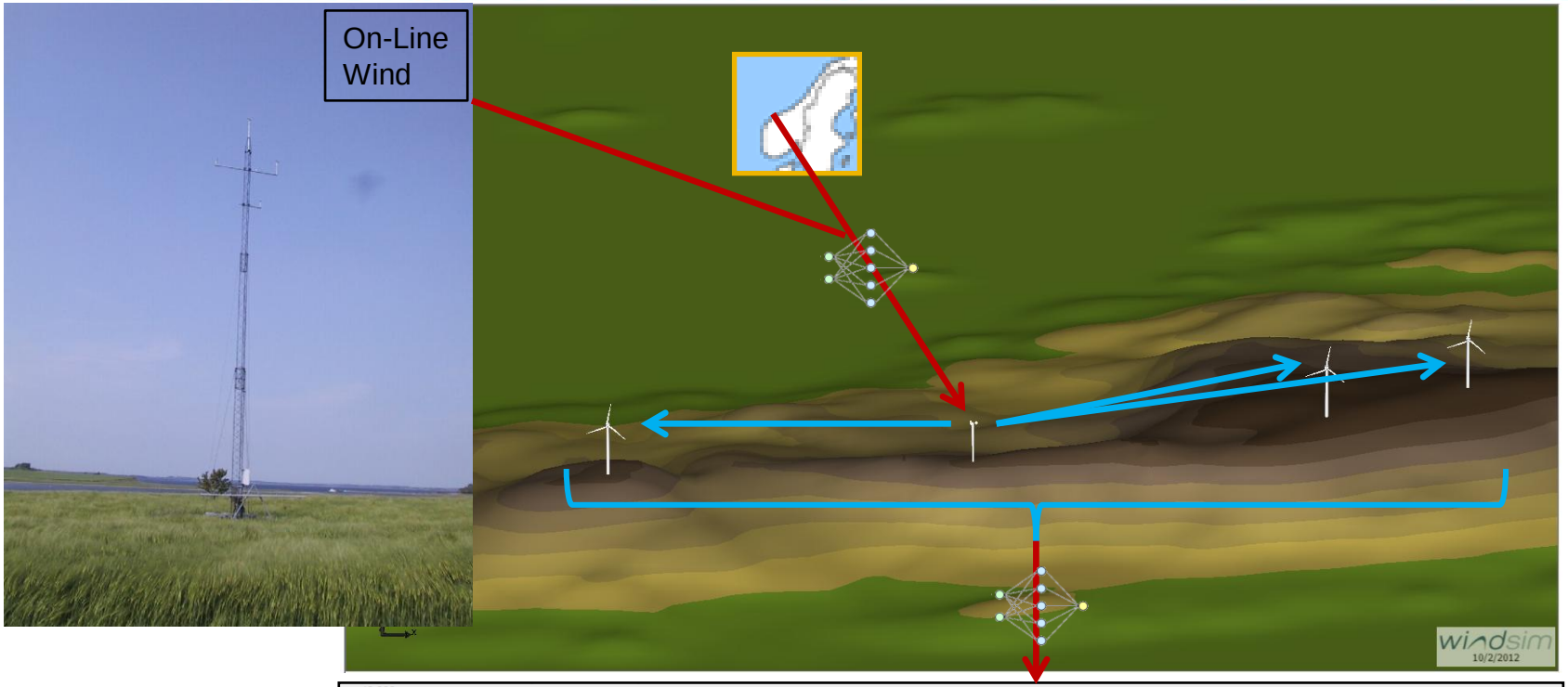


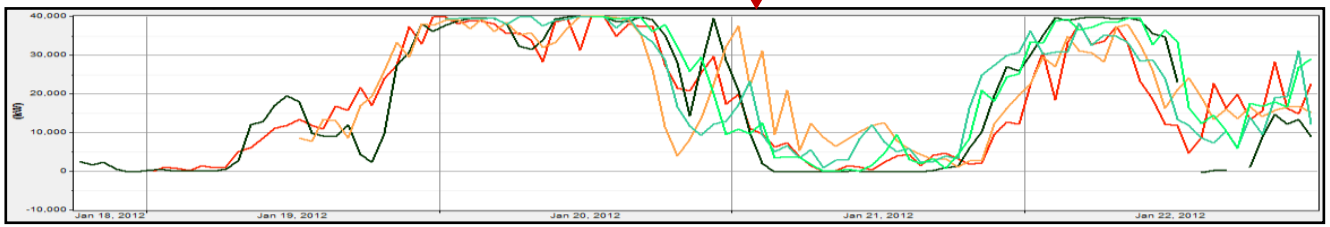
WindSim Forecasting



NMAE decrease: 0.5-2.5%

WindSim Forecasting





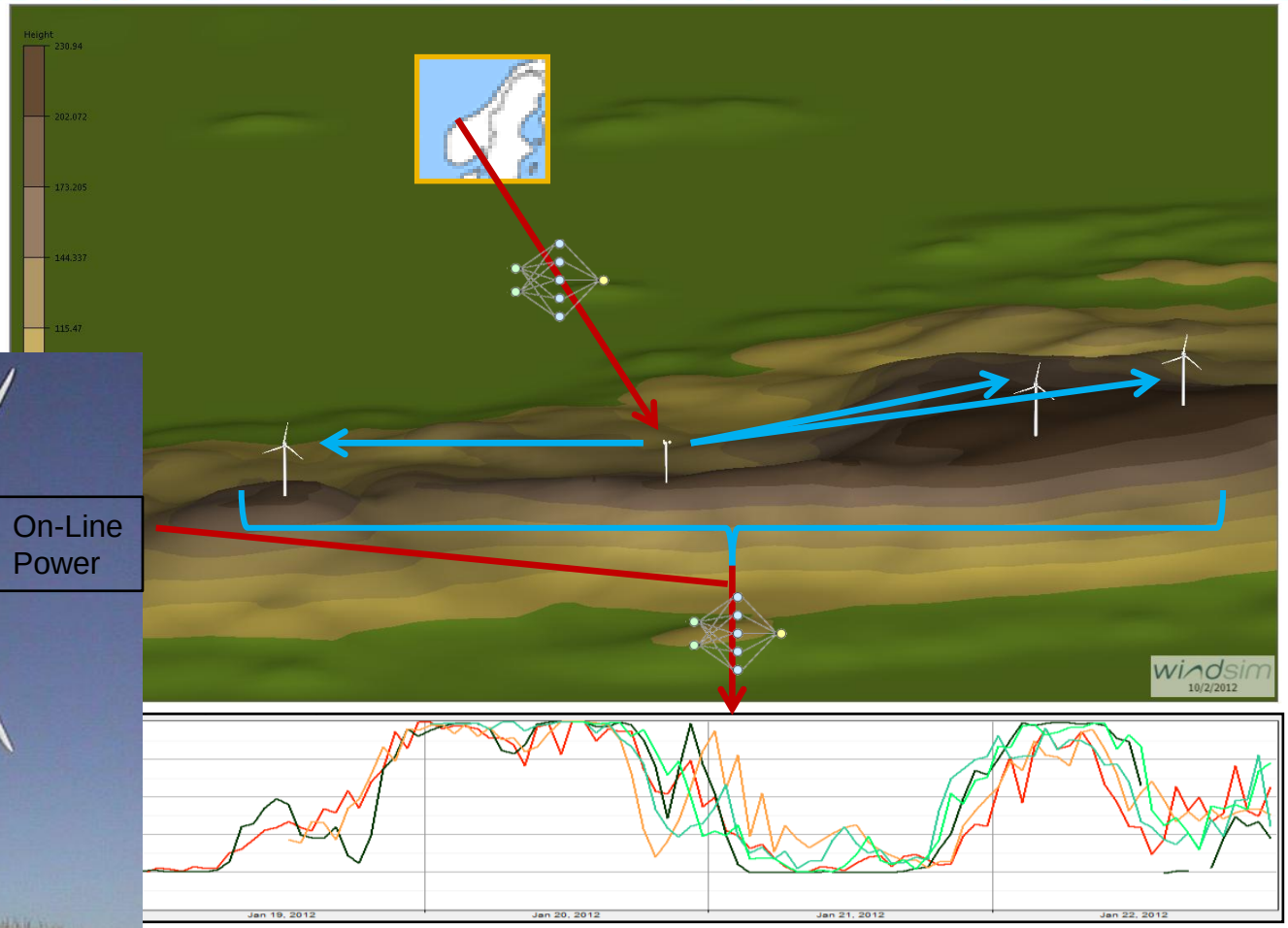
NMAE decrease: ~2.5% in the first hours

Suitable for short term forecast

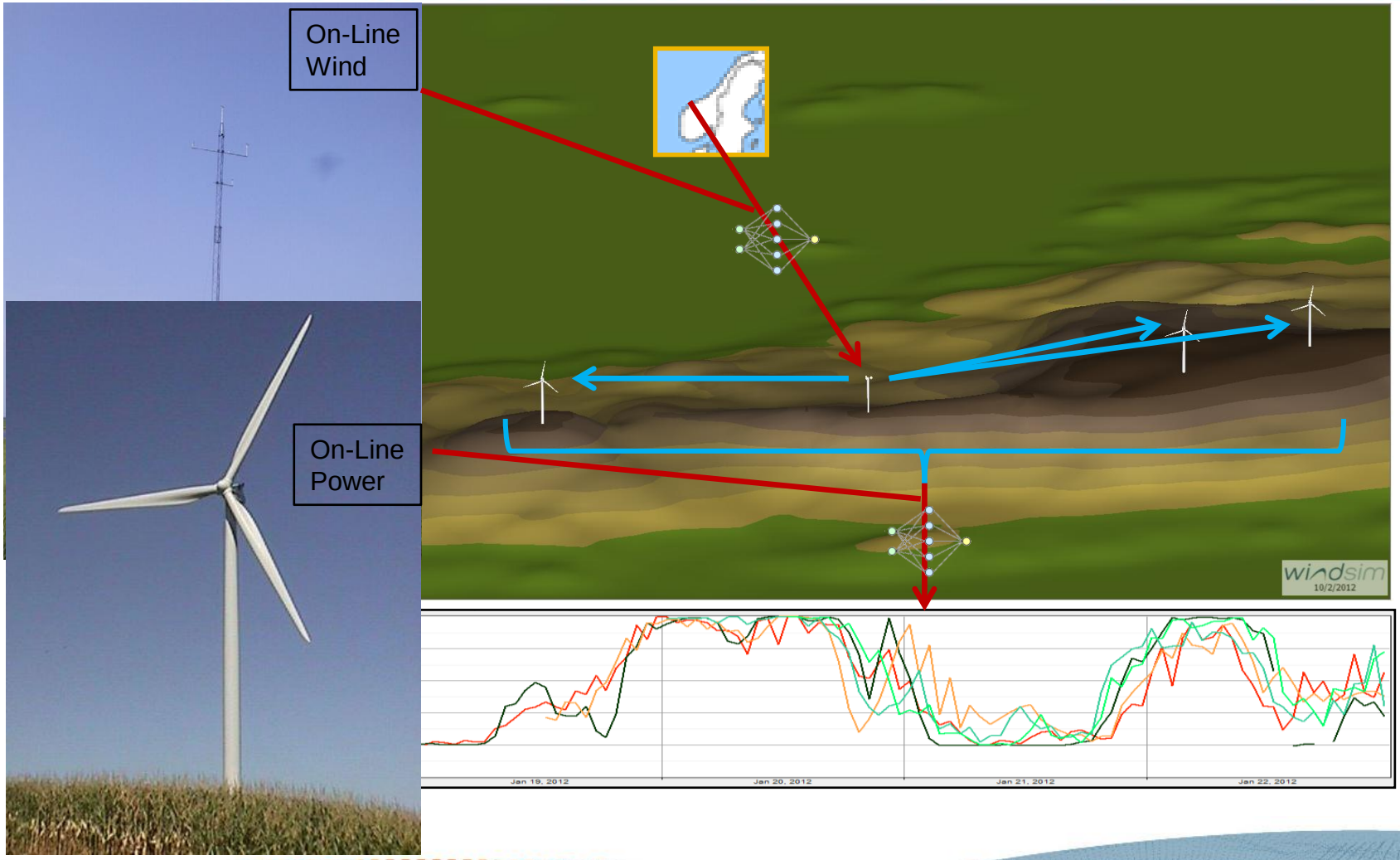
WindSim Forecasting

NMAE decrease: ~2.5% in the first hours

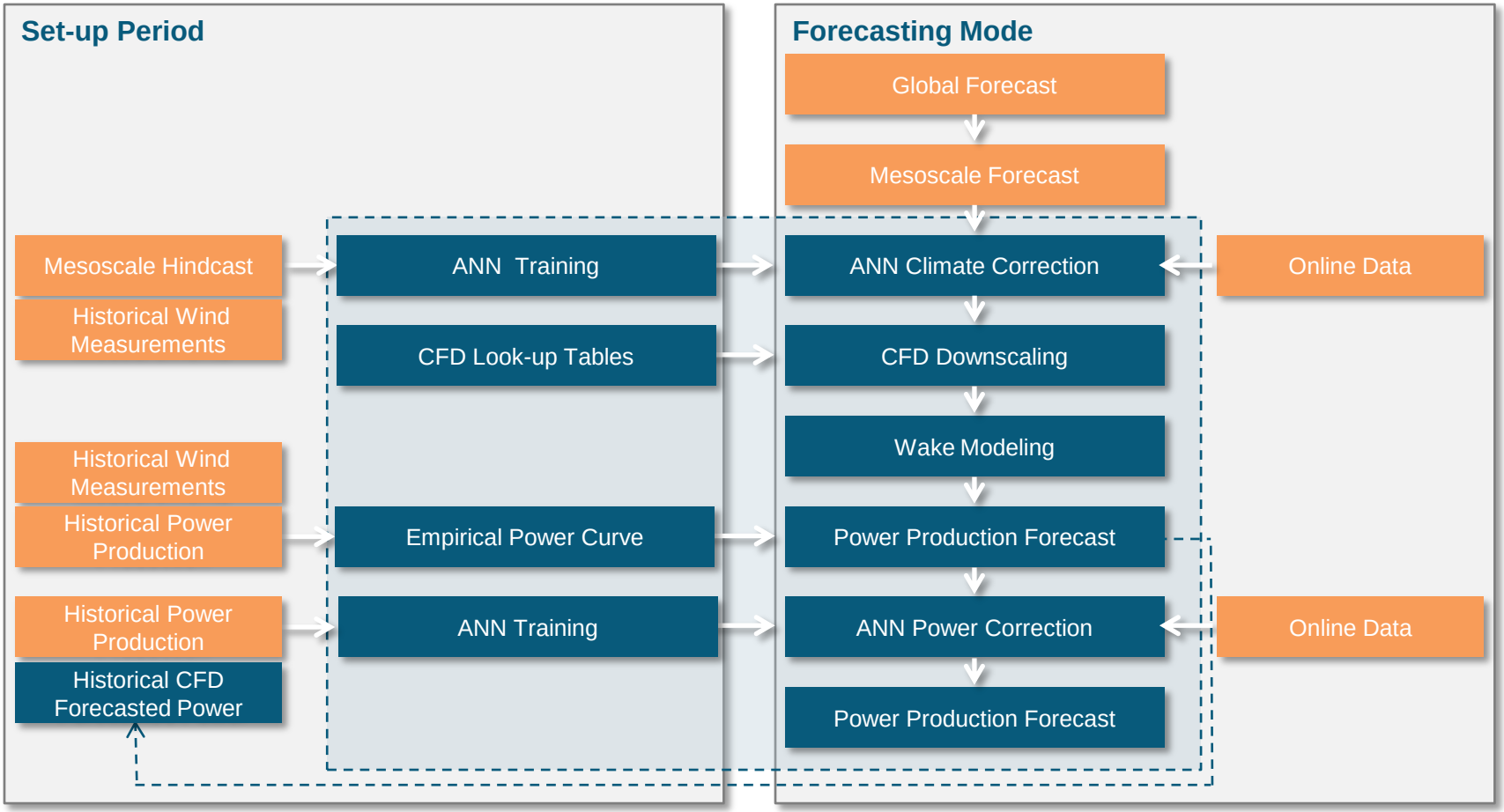
Suitable for short term forecast



WindSim Forecasting



Short-term Power Production Forecast

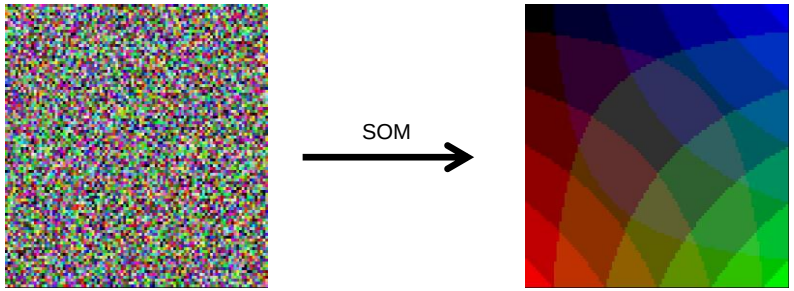


Short-term Forecasting using Mesoscale Simulations, Artificial Neural Networks (ANN) and Computational Fluid Dynamics (CFD): *Input;* *WindSim software or data*

Developments in WindSim Forecasting

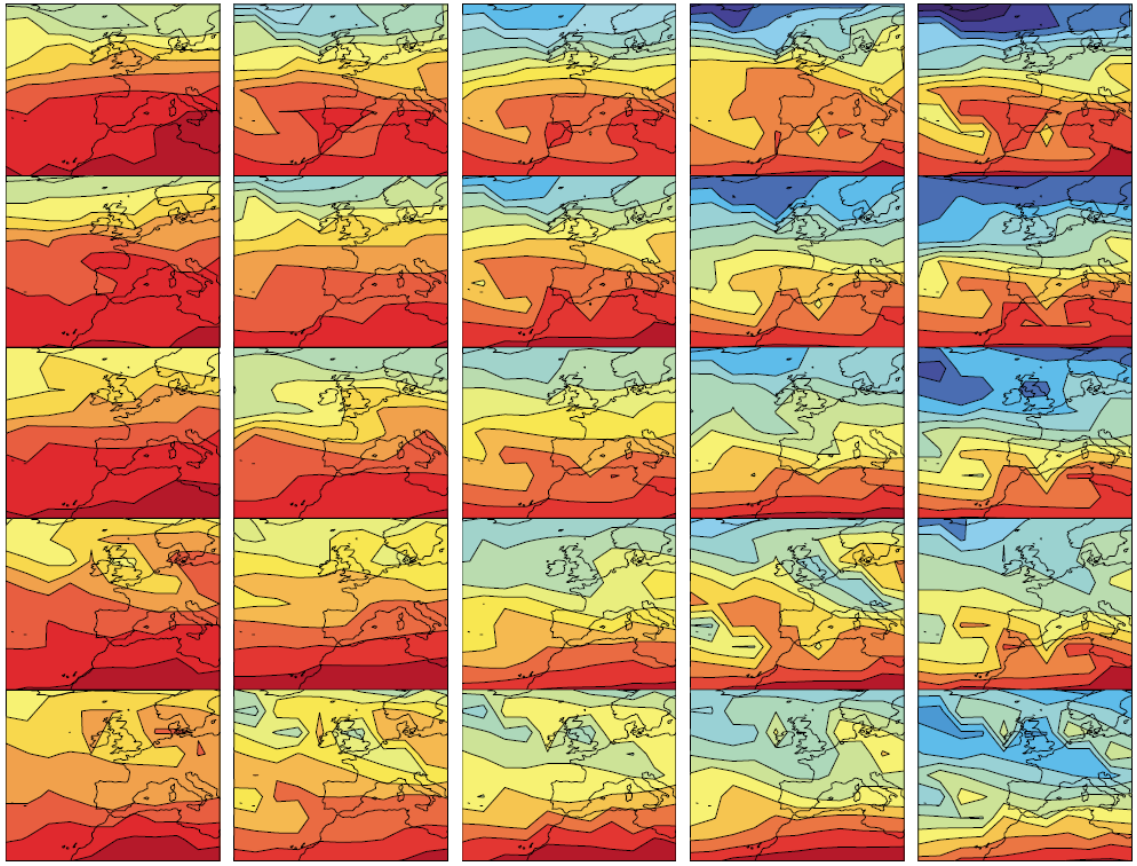
Recognize pattern in Forecasts:

- High dependency of the forecast on the NWP model
- Getting input from more than one NWP point
- Divide the forecast into subgroup (season - daytime - atmospheric pattern)



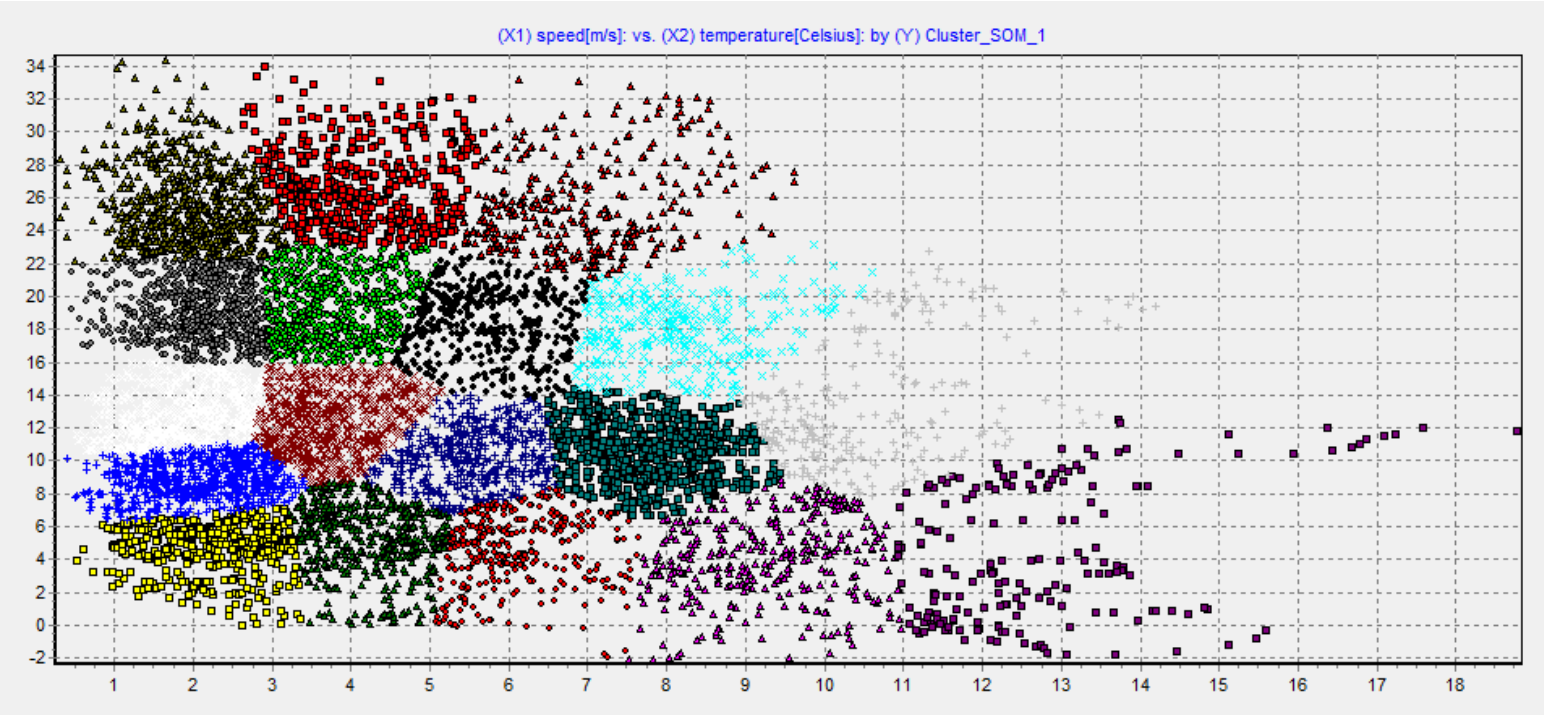
Self Organizing Map (SOM) is a type or ANN that can cluster data sets

Developments in WindSim Forecasting



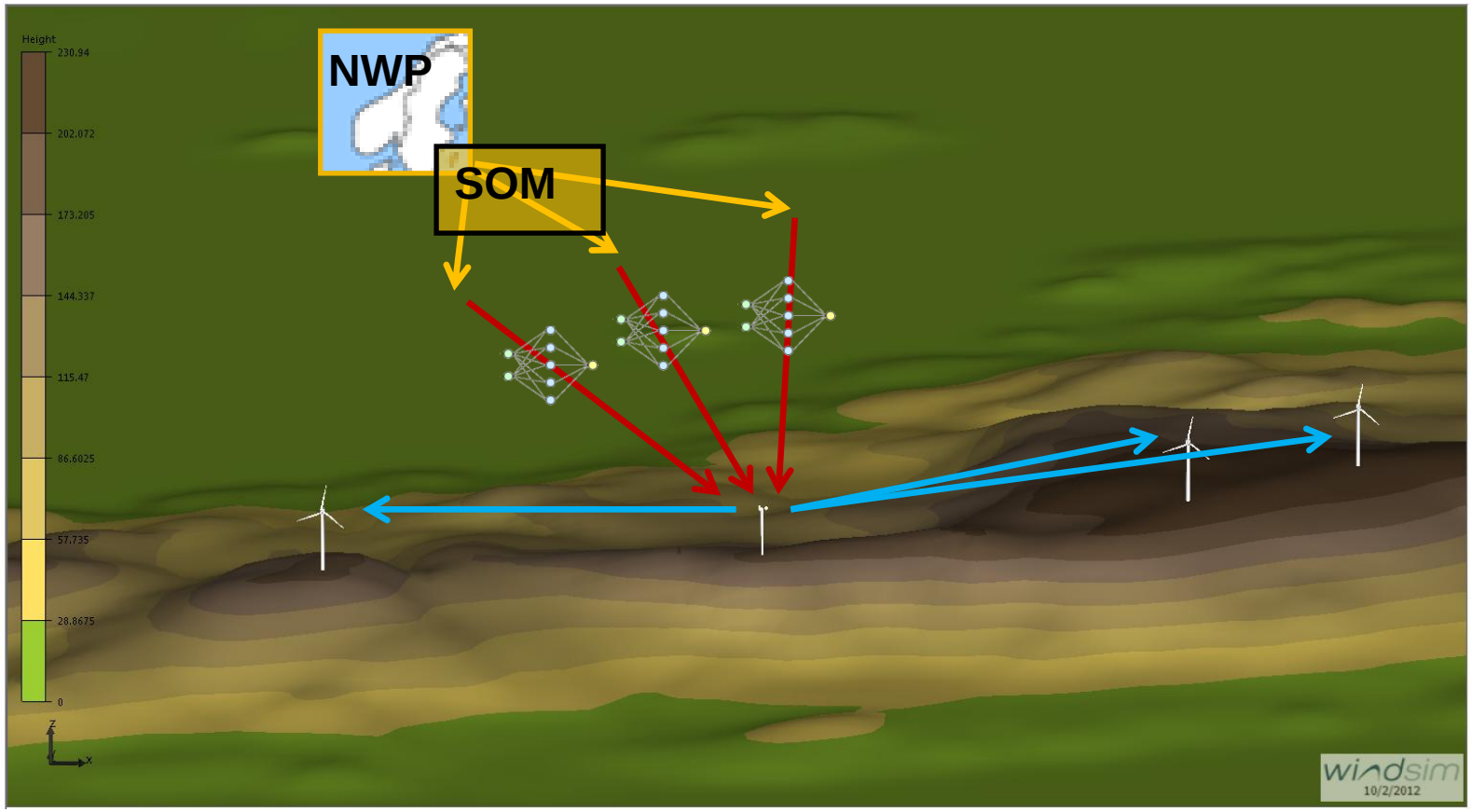
SOM can cluster forecasts periods

Developments in WindSim Forecasting



Clusters of time series points plotted depending on wind speed vs. temperature

Developments in WindSim Forecasting



Developments in WindSim Forecasting

Better tuning needed

- SOM provides good results in some cases but we need a better set-up and more testing (cluster number and inputs used)
- Increasing performance with number of cluster vs decrease of number of samples for each ANN training. Needs longer time series

Learn more – Webinar recording

Webinar recording Power Forecasting:
https://www.youtube.com/watch?v=oafLxYfOYA4

Contact

WindSim AS
Fjordgaten 15
3125 Tønsberg, Norway
Tel: +47 33 38 18 00

WindSim Americas
3505 Lake Lynda Drive
Suite 200, Orlando
FL, 32817, USA
Tel: +1 407 810 9463

WindSim China
No. 101 Shaoyang Beili
Chaoyang District
100029 Beijing, China
Tel: +86 186 1029 1570

WindSim India
Suite # 617
Regus Milenia Business Park
Phase 2, Level - 6, Campus
4B,No - 1 43, Dr.M.G.R Road
Kandanchavady, Perungudi
Chennai 600 096, India
Tel: +91 98 4032 2786

www.windsim.com
info@windsim.com