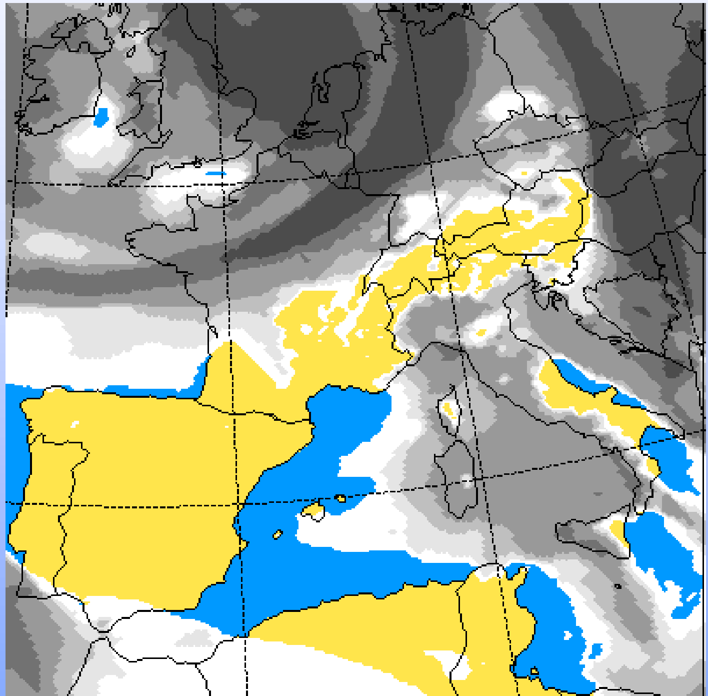


# Evaluation of advanced wind power forecasting models.

## The results of the ANEMOS project

**Ignacio Martí,**

**Renewable Energies National Center (CENER), Spain**

**imarti@cener.com**

**European Wind Energy Conference**

**Athens, 27 Feb. – 2 Mar. 2006.**

# Co-authors

R. Brownsword

G. Giebel
J. Badger

G. Kariniotakis
P. Pinson

T.S. Nielsen
H. Madsen

G.Descombes

C. Lac

J. Tambke

U. Focken
M. Lange

G. Kallos
P. Louka

G. Sideratos

M. J. San Isidro
Y. Loureiro

A. M. Palomares

I. Sánchez
J. Usaola

# Why a wind power forecasting model evaluation?

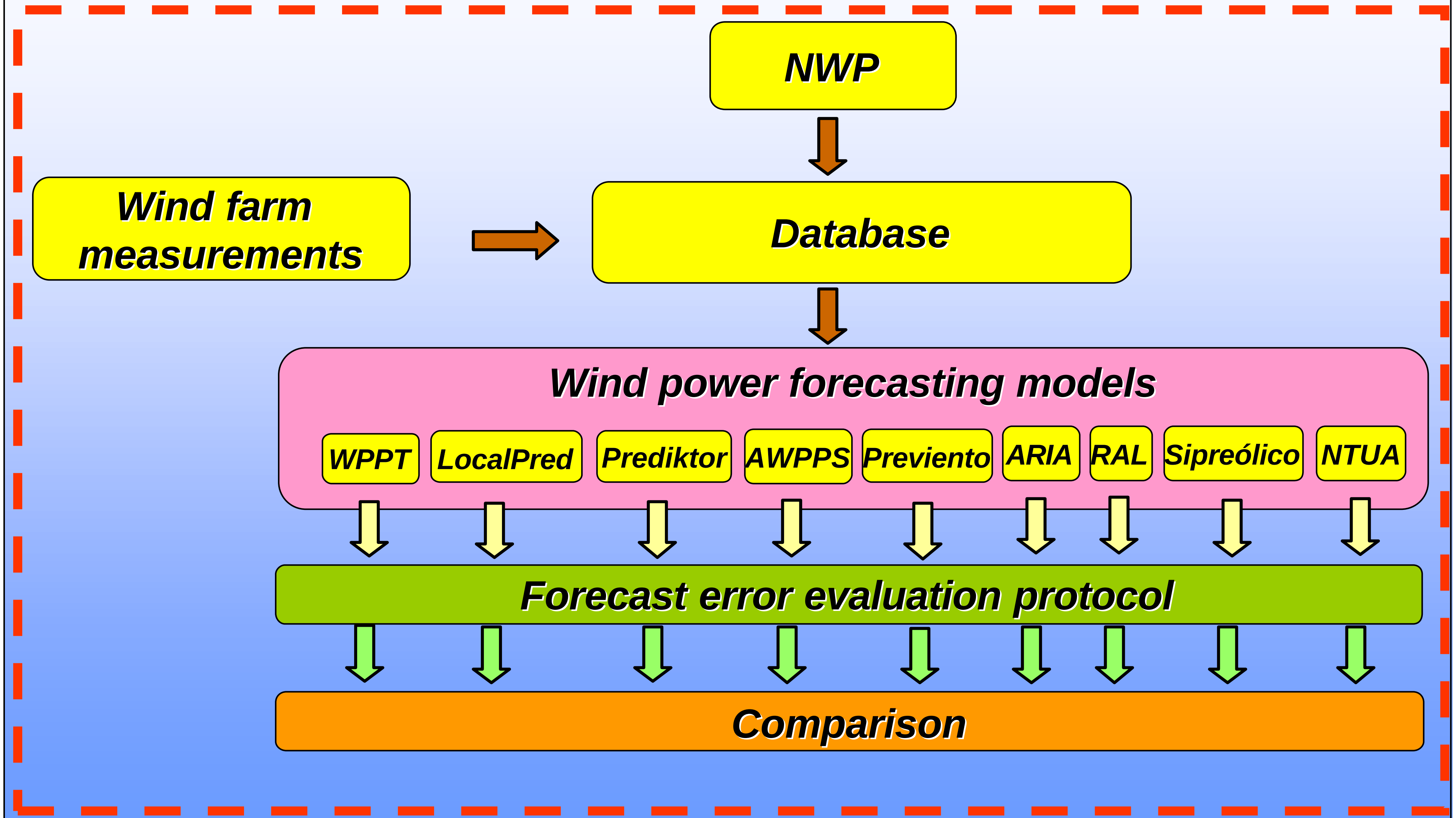
- Wind power forecasting is becoming a requirement in the countries with a significant penetration of wind energy.
- There is a lack of information about the real possibilities of the state of the art prediction models for wind energy.
- Knowledge about wind energy forecasting models is useful for:
  - **TSOs.**
  - **Utilities.**
  - **Wind energy promoters.**
  - **Market integration of wind energy.**
  - **Regulatory authorities.**

# Objective of the benchmarking

- To study the performance of state of the art wind power prediction models with the existing input data in a variety of environments: from offshore to highly complex terrain wind farms.
- To establish a standardized framework for evaluating wind power prediction models.
- To characterize the error behavior in order to detect the weak points of the models that can be subject to improvement.
- To have some solid reference for new advanced models.
- To evaluate purely meteorological forecasts.

# Design of the pre-existing prediction models benchmarking

# Design of the benchmarking



# Design of the benchmarking

***Selection of representative wind farms***

- ***Offshore*** — *Tunø Knob (Denmark)*
- ***Flat terrain*** — *Klim (Denmark)*, *Wusterhusen (Germany)*
- ***Complex terrain*** — *Golagh (Ireland)*, *Sotavento (Spain)*
- ***Highly complex terrain*** — *Alaiz (Spain)*

- **4 European countries represented. Spain, Denmark, Ireland and Germany.**
- **4 environments considered from flat to highly complex terrain, including an offshore wind farm.**

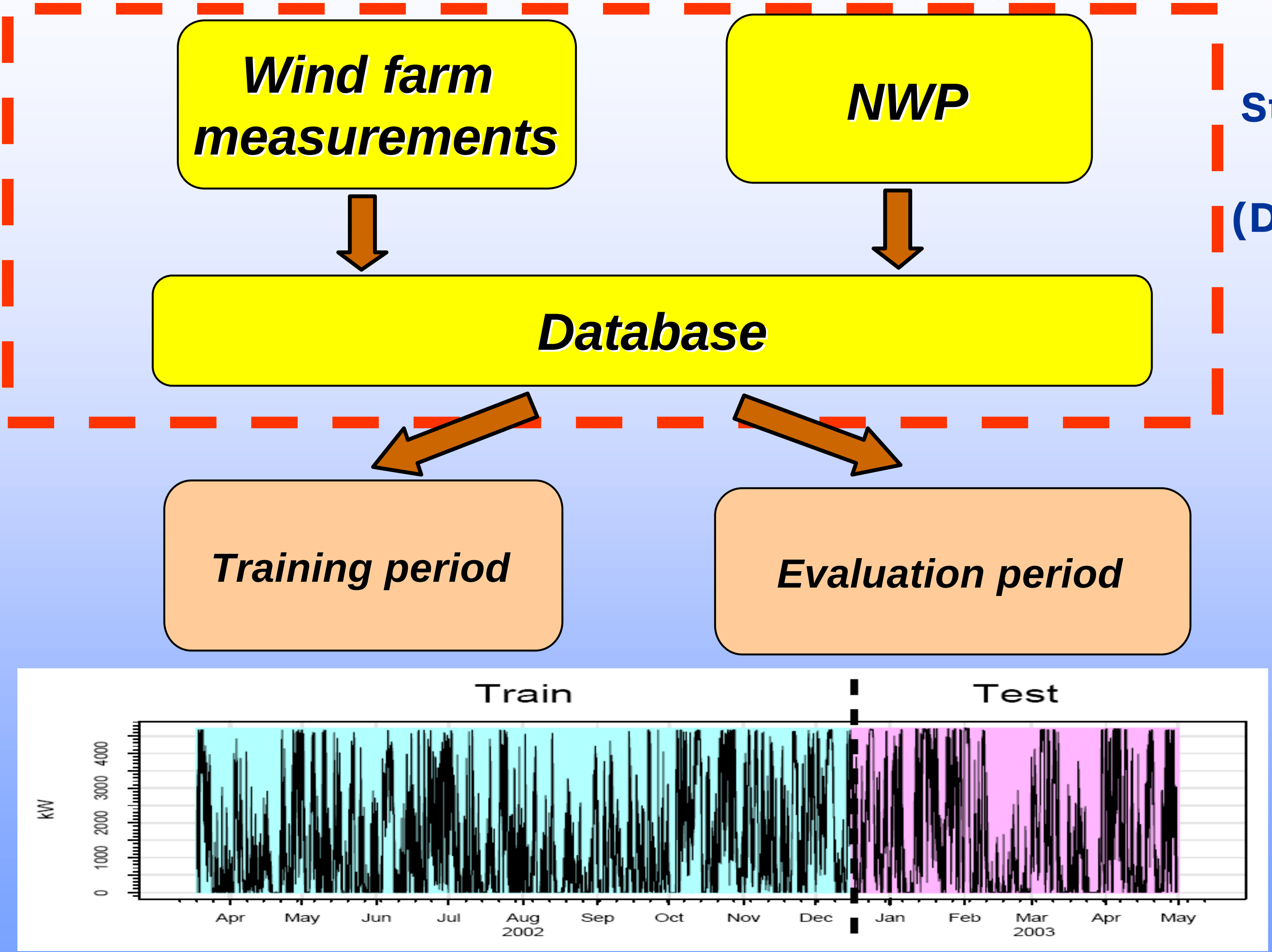
# Design of the benchmarking

***Numerical Weather Prediction Models (NWP)***

| ***HIRLAM*** | DM |
|---|---|
| ***Spain (INM), Denmark (DMI) Ireland (Met Eireann)*** | ***Germany (DWD)*** |

- **Numerical Weather Prediction models were used for each country as input to the wind power prediction models:**
  - High Resolution Limited Area Model (HIRLAM).
  - Deutschland-Modell (DM).

# Design of the benchmarking




Standardisation of data

(Depri format for time series)

- A rigorous procedure was established for each wind farm in order to ensure the validity of the results.

# Design of the benchmarking

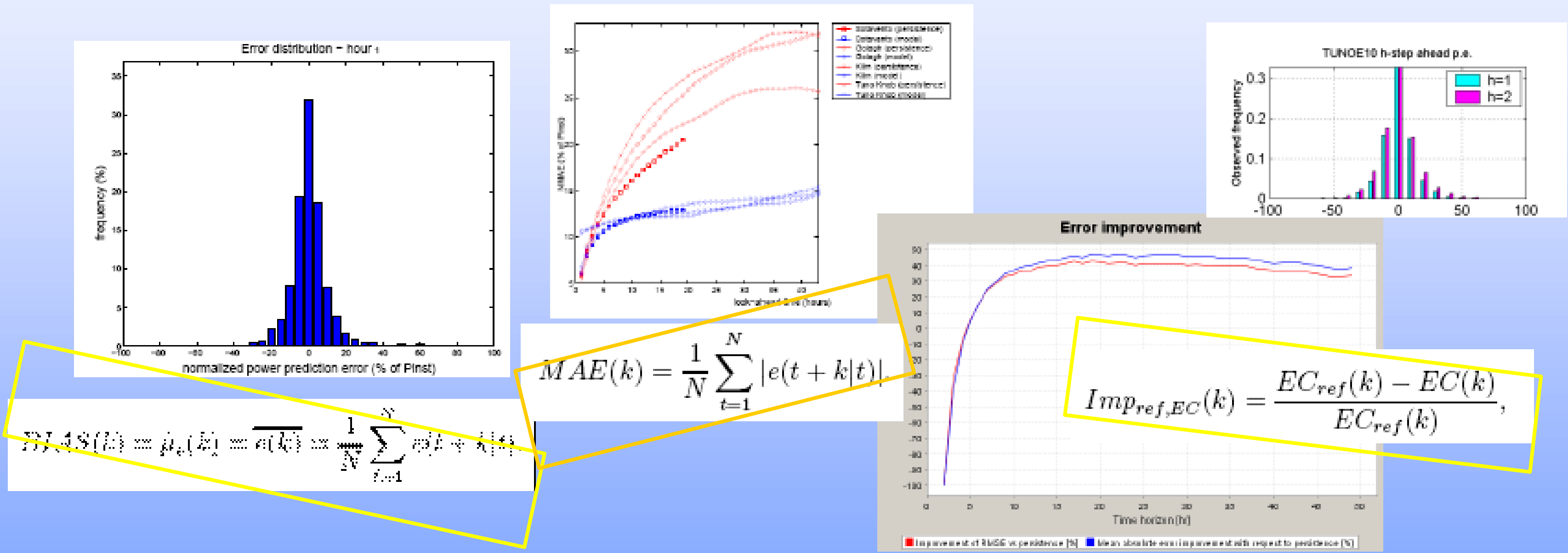
**_Wind power forecasting models_**

***WPPT*** | ***LocalPred*** | ***Prediktor*** | ***AWPPS*** | ***Previento*** | ***ARIA*** | ***RAL*** | ***Sipreólico*** | ***NTUA***

- **The wind power prediction models considered in the benchmarking use a variety of approaches:**
  - Physical models
  - Physical models+MOS
  - Neural Networks
  - Fuzzy Logic
  - Parametric models
  - Combined time-series models
  - etc

# Design of the benchmarking

**_Protocol for standardizing the performance evaluation of wind power prediction models_**



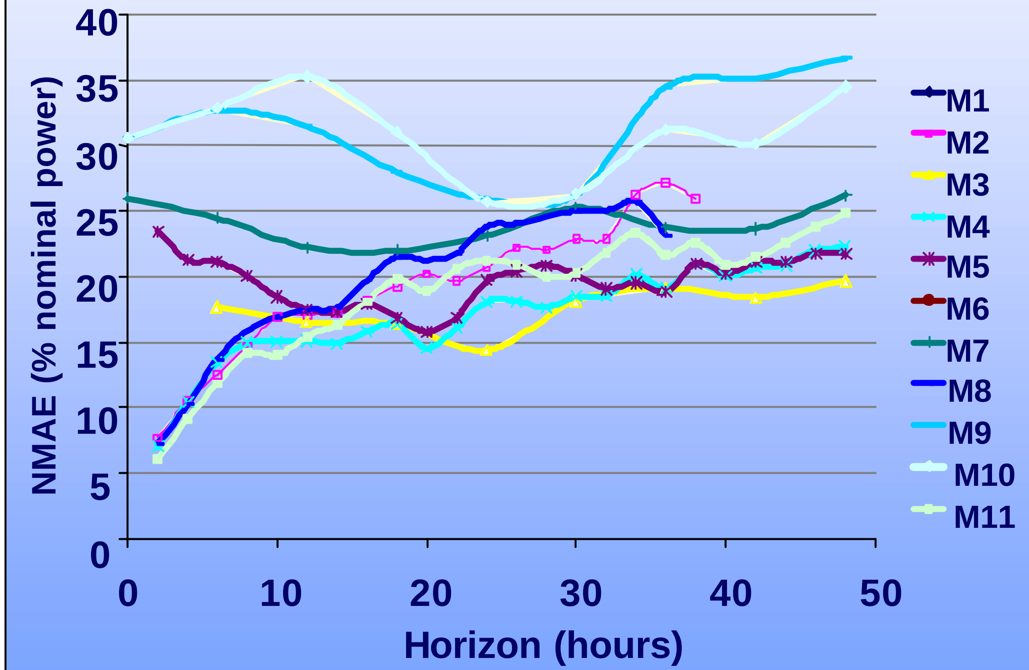

- **A protocol was developed to ensure a standard calculation of errors and an homogeneous comparison of wind power forecasts between the models.**

*Madsen, H., Kariniotakis, G., Nielsen, H.Aa., Nielsen, T.S., Pinson, P., "A Protocol for Standardising the Performance Evaluation of Short-Term Wind Power Prediction Models", CD-rom Procd. of the Global WindPower 2004 Conference, Chicago, USA, Mar. 28-31, 2004.*

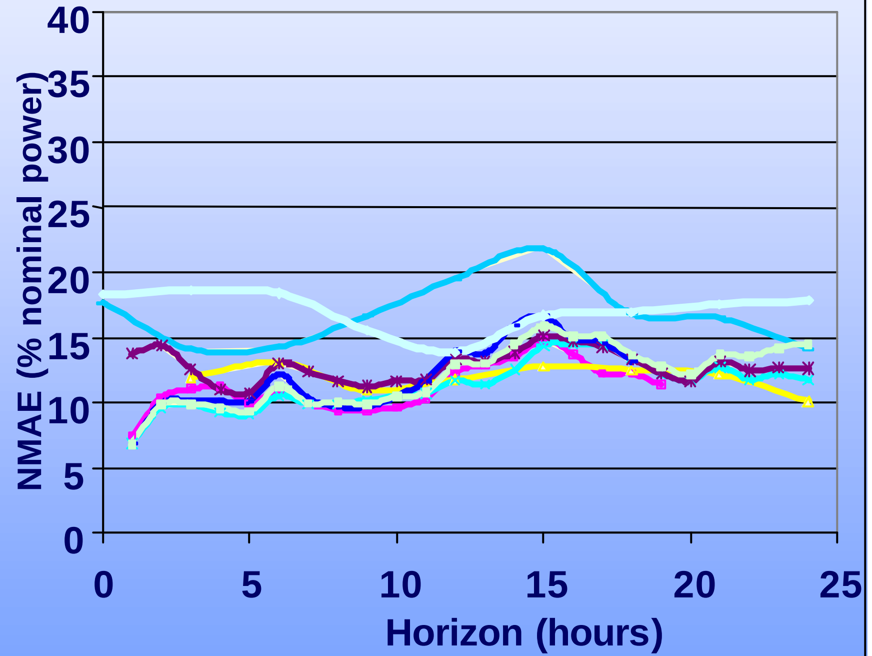
# Results of the wind power prediction model benchmarking

# Results of the benchmarking

**A** Highly complex terrain (Alaiz-ES)




**B** Complex terrain (Sotavento-ES)

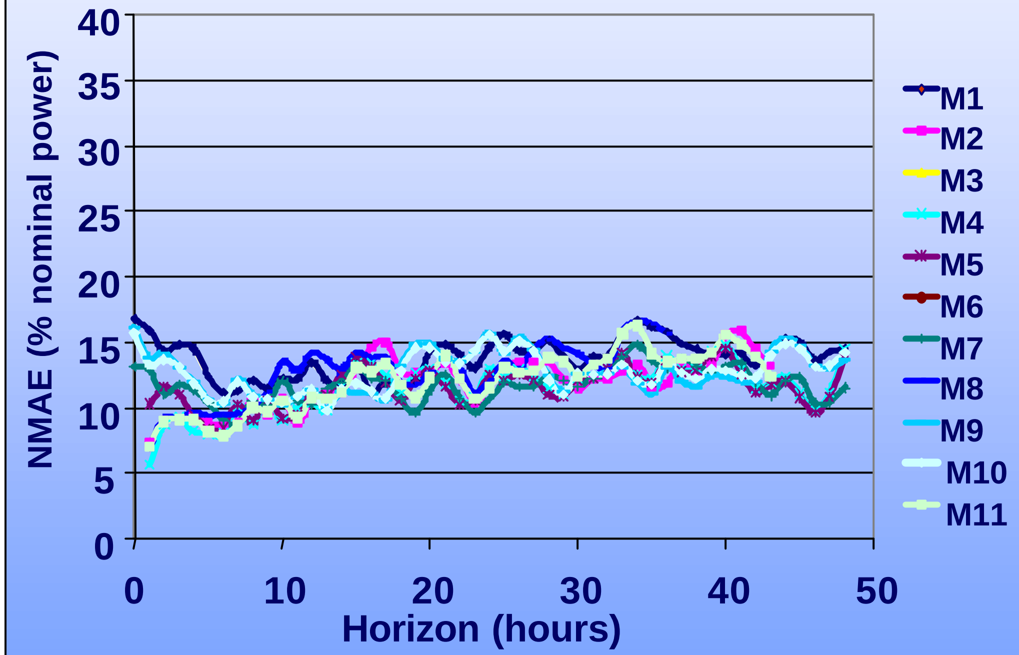



- **Higher level of prediction errors.**
- **Higher dispersion between prediction models.**

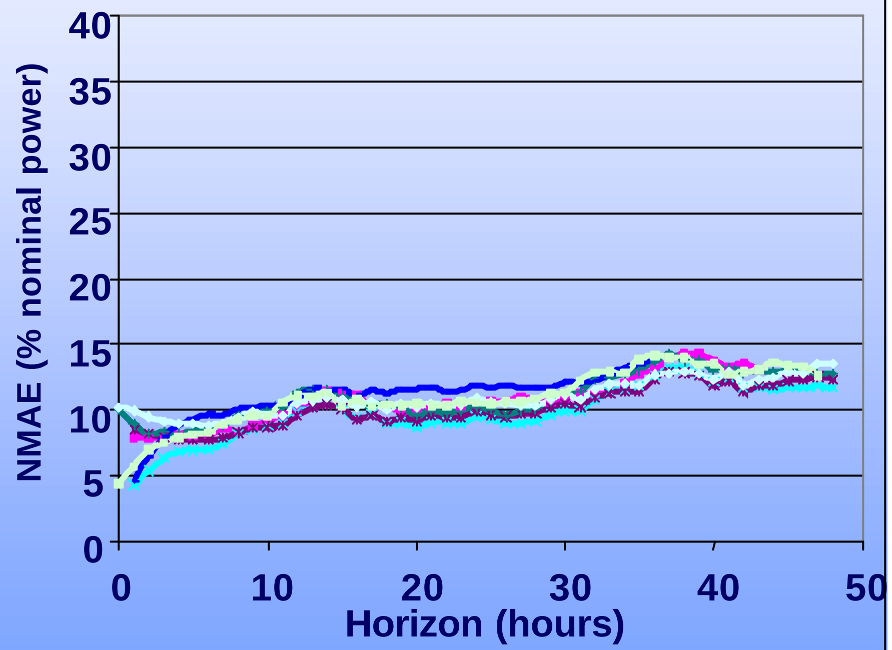
*NMAE: Normalized Mean Absolute Error*

# Results of the benchmarking

**C** Hilly terrain (Golagh-IE)




**D** Flat terrain (Klim-DK)

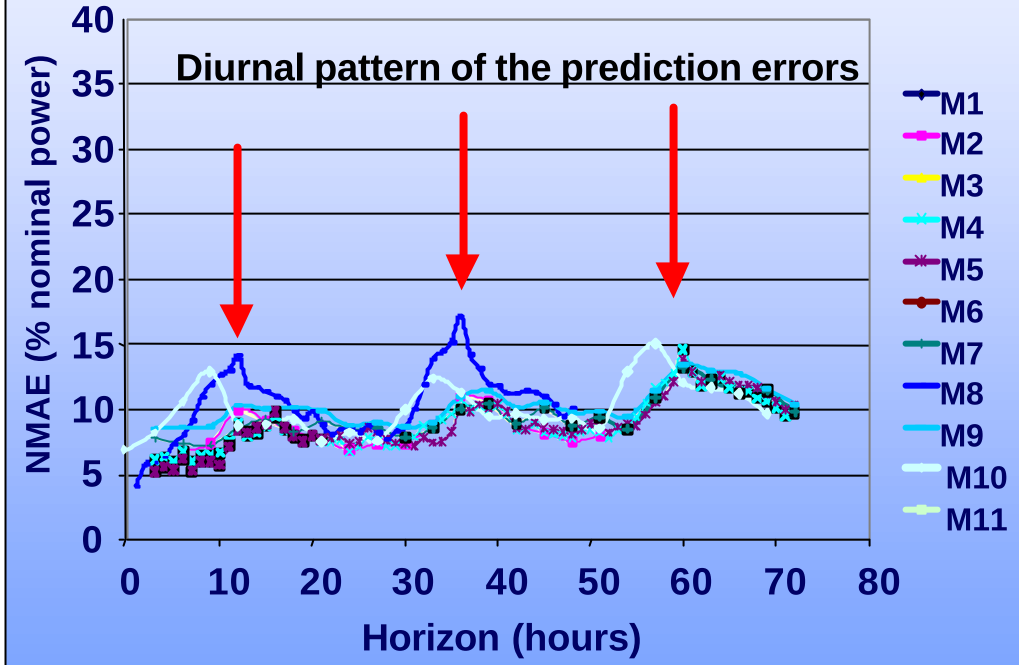



- **Lower level of prediction errors.**
- **Lower dispersion between prediction models.**

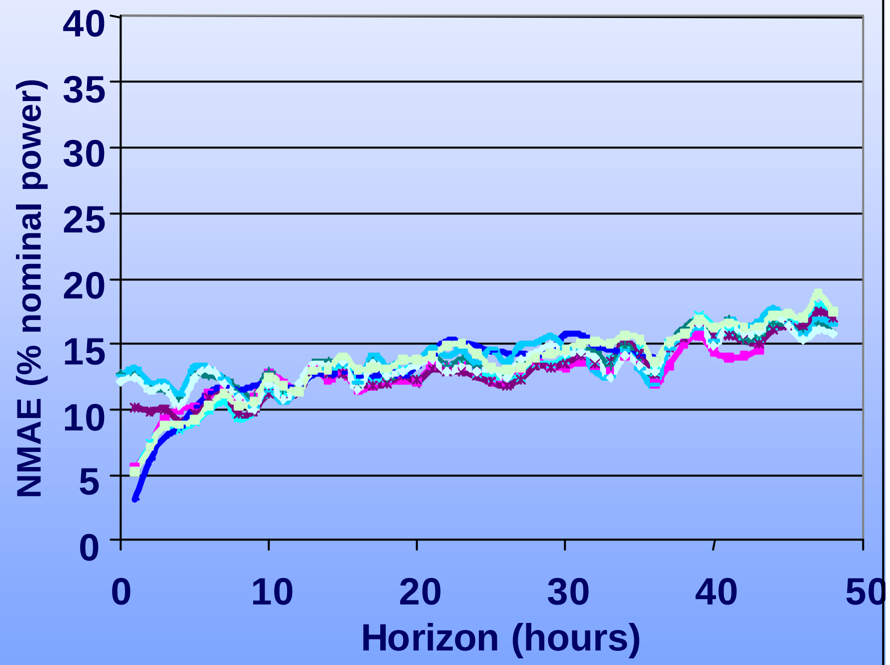
*NMAE: Normalized Mean Absolute Error*

# Results of the benchmarking

## E Flat terrain (Wusterhusen-DE)



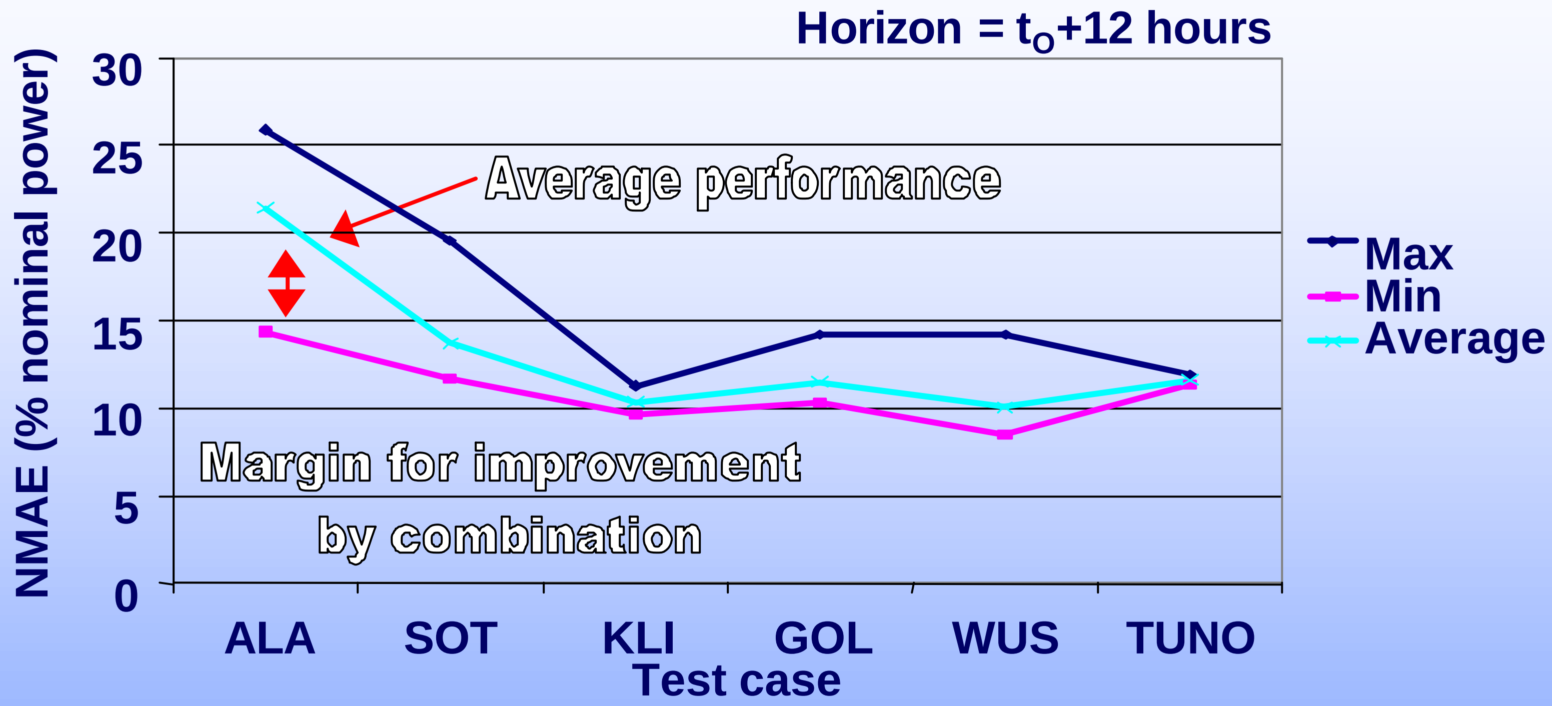

## F Offshore (Tuno Knob-DK)




- **Low level of prediction errors.**
- **Performances of expert models are close.**

*NMAE: Normalized Mean Absolute Error*

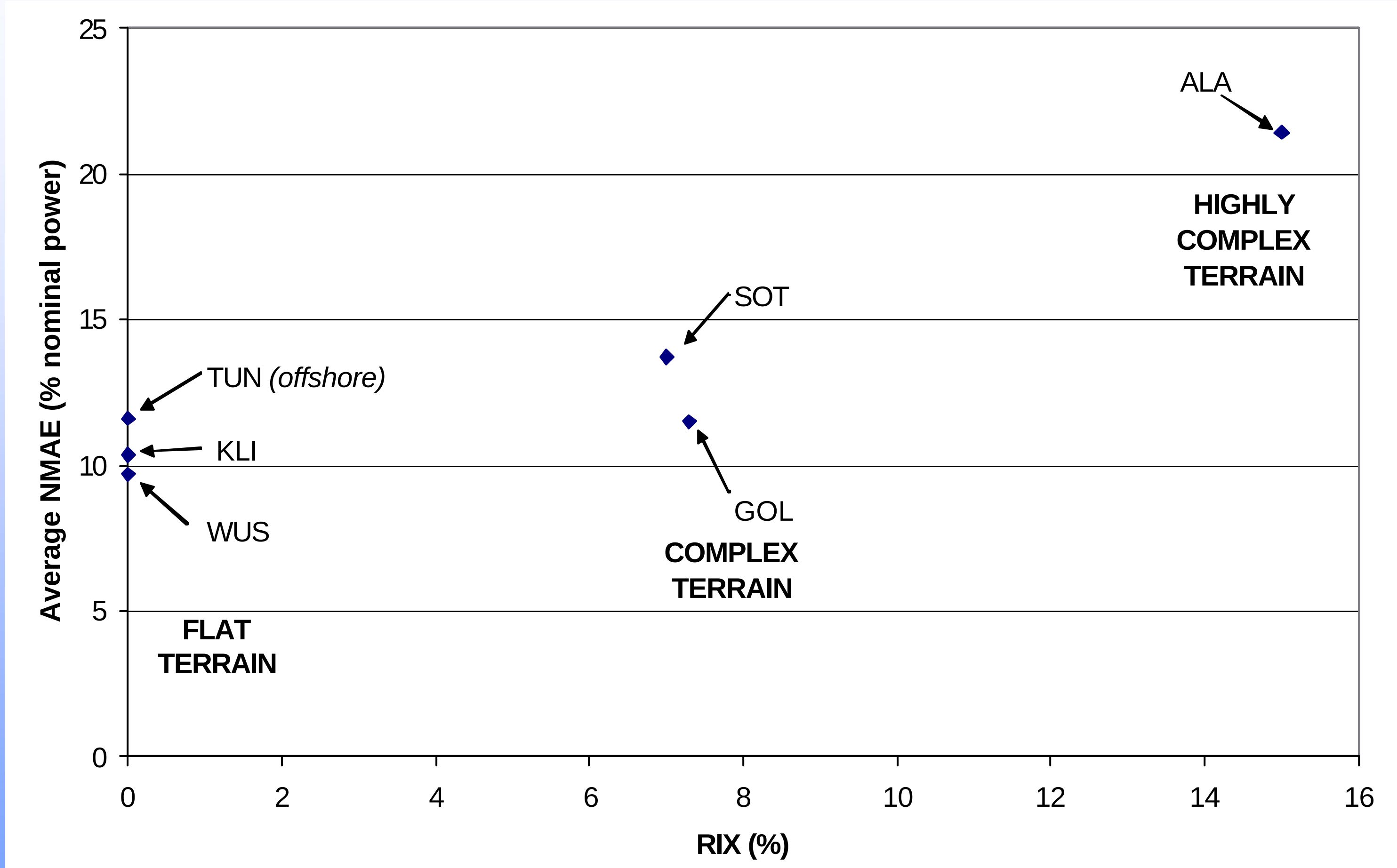
# Performance vs wind farm




| Best 12 hours forecast for each test case | | | | | |
|---|---|---|---|---|---|
| ALA | SOT | KLI | GOL | WUS | TUNO |
| M2 | M3 | M4 | M5 | M3 | M4 |

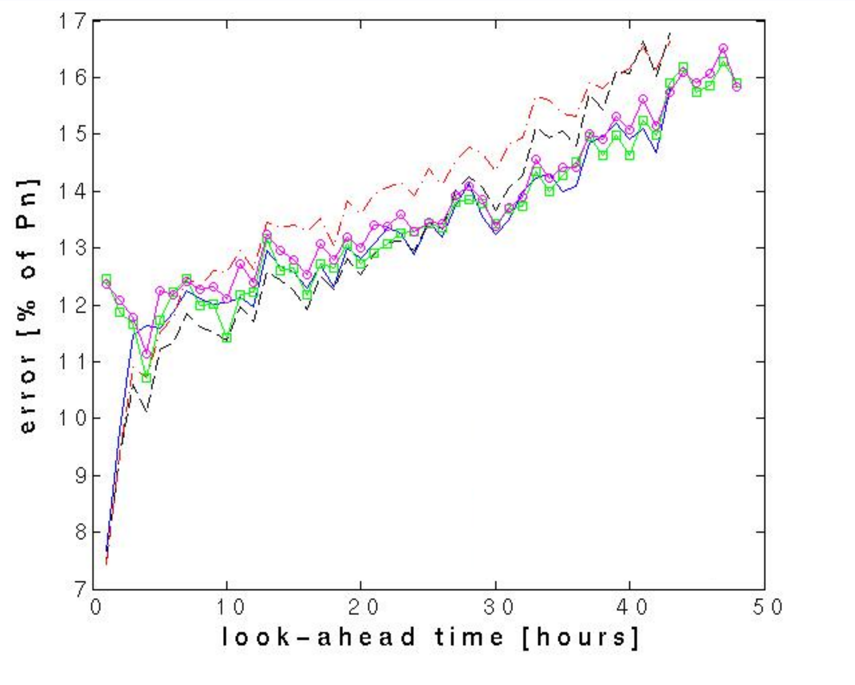
- Absolute deviations (% of nominal power) range between 10% and 21% for +12 hours forecasts.
- There is a margin for improvement by combination of the forecasts generated by the different prediction models.

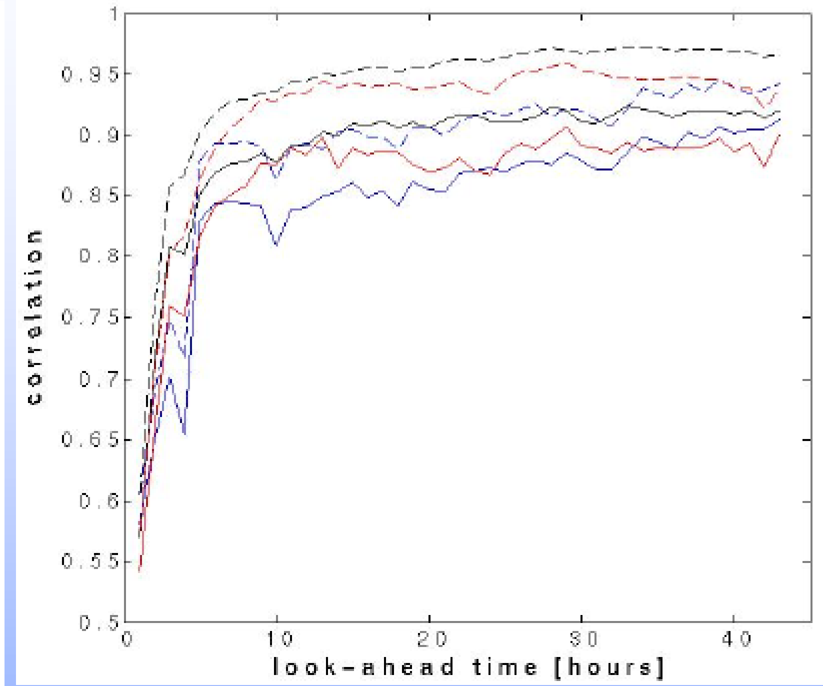
# Performance vs terrain type




- Prediction errors increase with terrain complexity.
- Prediction model performance for the offshore case is between the flat and the complex terrain cases.

# Performance vs prediction model

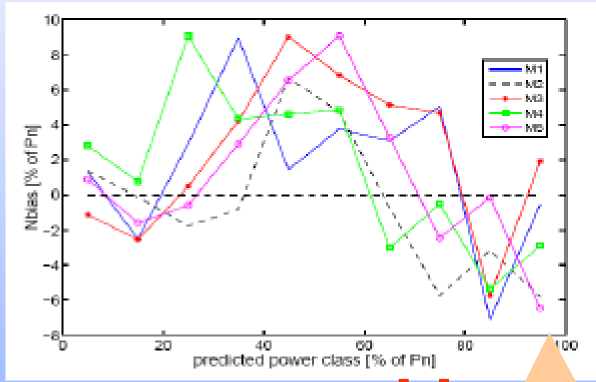


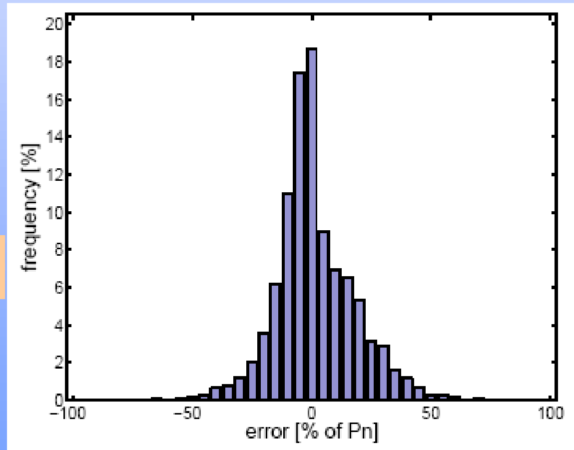

- There are differences between physical and statistical approaches for wind power prediction models:
  - **Statistical approaches exhibit better performance for first 3-4 look-ahead times**
  - **Performance is similar for further look-ahead times**
- Errors between models are correlated. However, this correlation varies depending on the models and the look-ahead time. This allows to expect error reduction by model output combination.

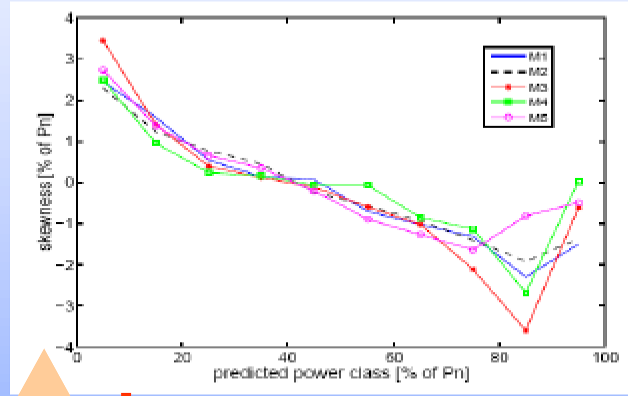
# Towards better models through detailed error characterization

- The level of predicted power greatly influences models performance. Some models are better than others for different ranges of predicted power.
- Analysis of various moments of error distributions indicate different possibilities of models improvements.



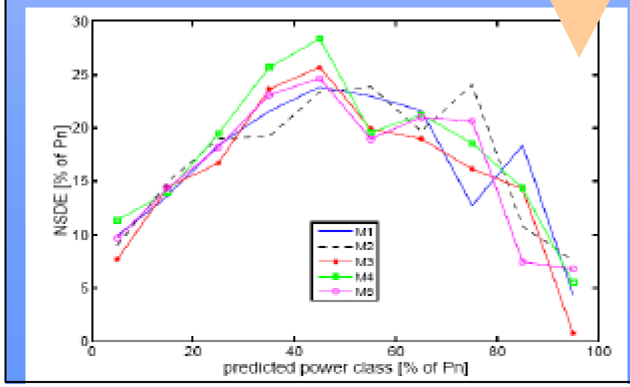

bias



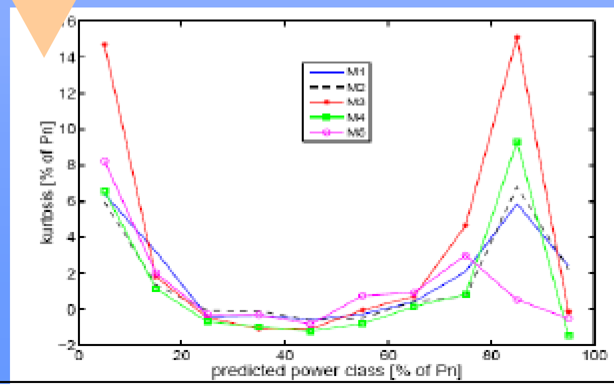




skewness

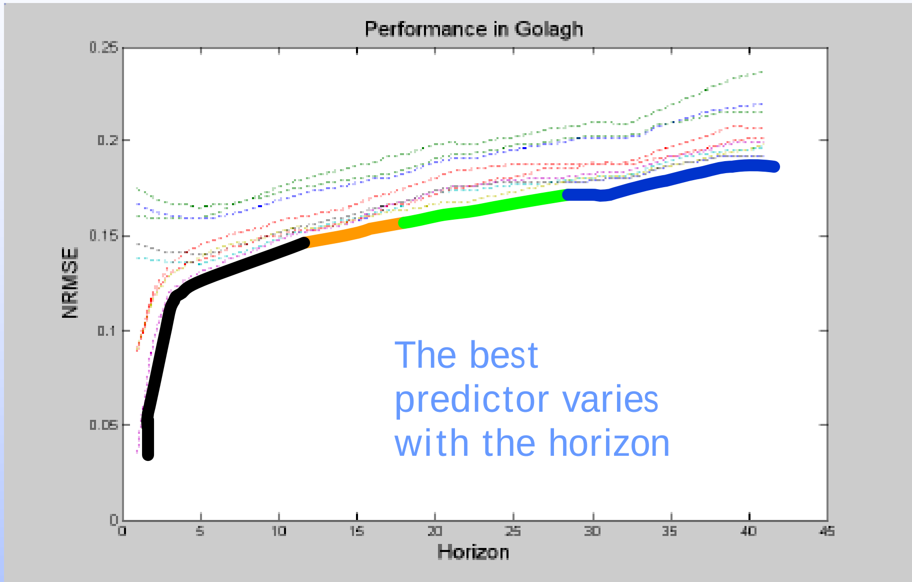
st. deviation

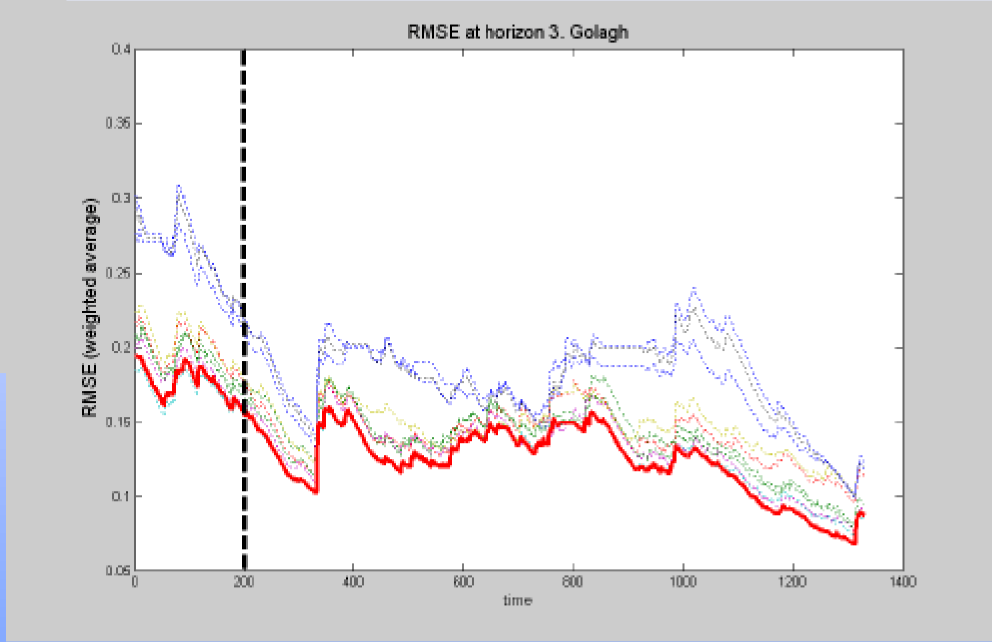



kurtosis



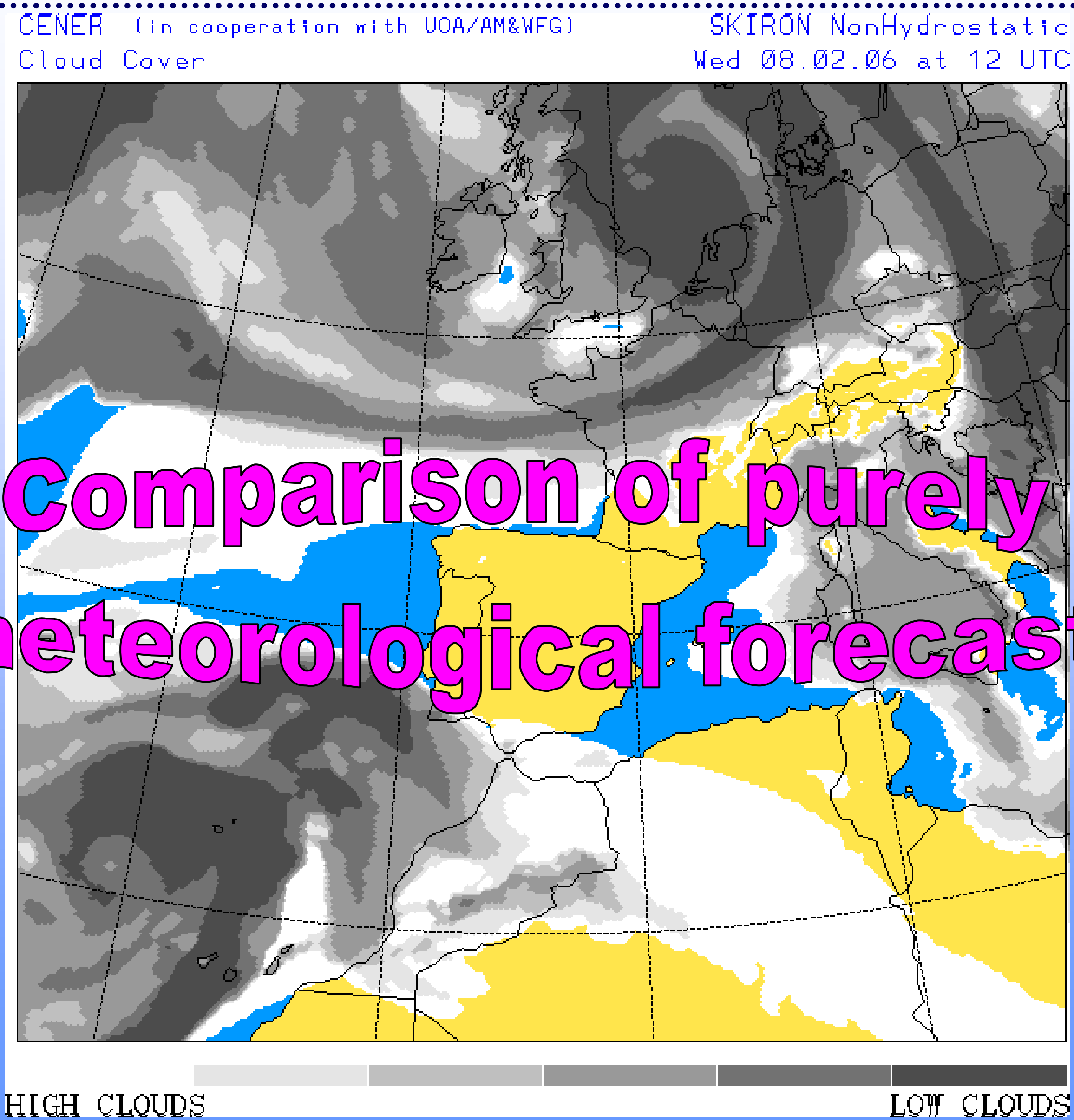
# Combination of forecasts



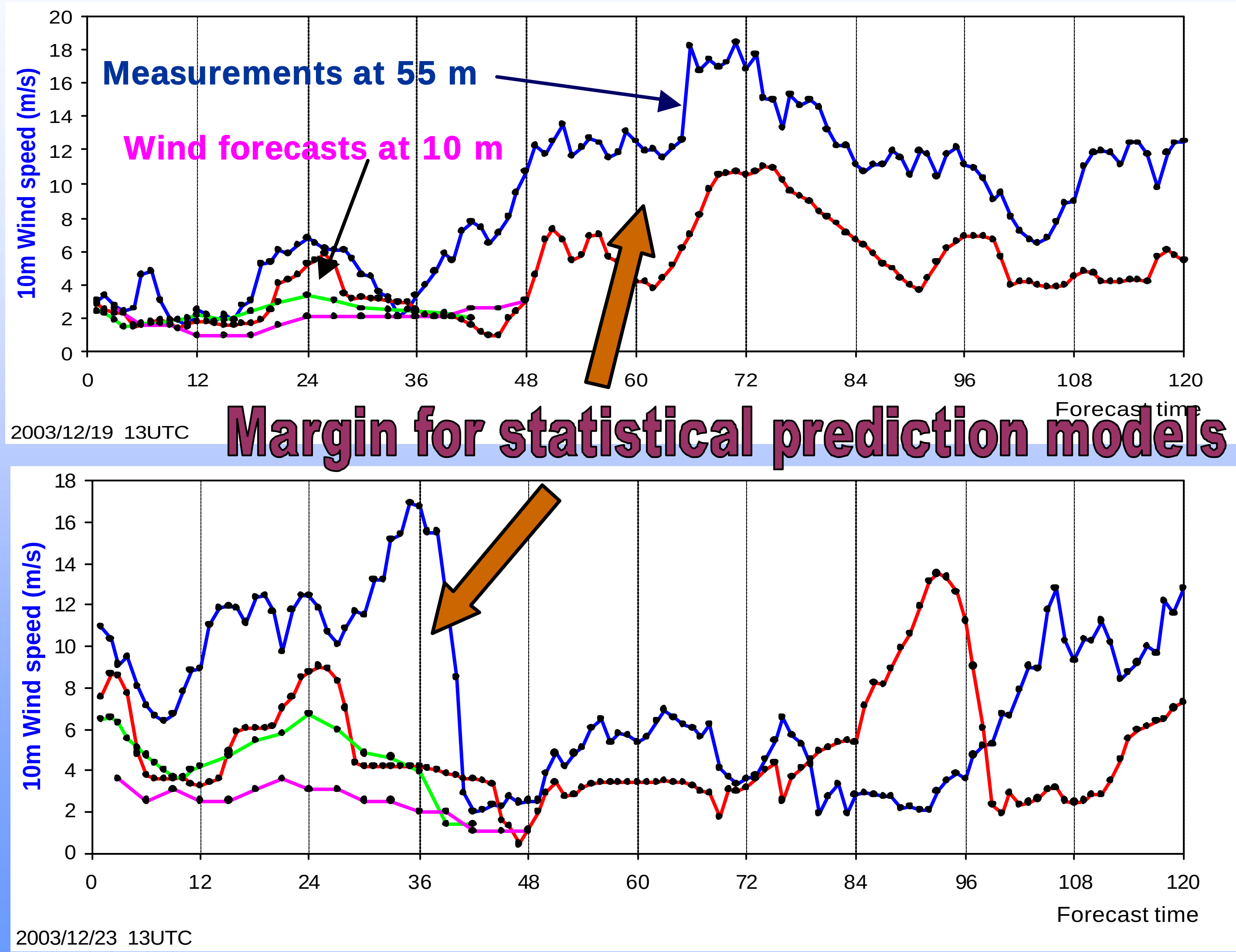




- There is some margin for improvement by combination of forecasts.
- The best prediction is not always coming from the same model, it depends on the forecast horizon

# Comparison of purely meteorological forecasts



# Comparison of NWPs




SKIRON, ALADIN and HIRLAM05 **10m** wind forecasts starting at 12UTC on 19 and 23 Dec 2003

# The value of the meteorological forecast

- The main part of the errors in wind power prediction come from the wind speed forecasts (NWP).
- Improvements in the NWP can be achieved by using different meteorological models. Reducing MAE of wind speed forecast up to 50% in complex terrain.
- Coarse grid resolution models do not give satisfactory results for wind speed predictions, specially in complex terrain.
- However improvements of accuracy by grid refinement are limited (and expensive!).
- The optimal wind power prediction can be obtained by the combination of statistical and physical methods in a cheaper way.