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ANEMOS

Leading European Union Research on Wind Power Forecasting

George Kariniotakis
Head of Renewable Energies Group
Ecole des Mines de Paris/ARMINES
georges.kariniotakis@ensmp.fr

ARMINES

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Plan

- **Introduction**
- **Wind Power Forecasting : The ANEMOS approach.**
- **The R&D projects**
  - **ANEMOS, ANEMOS.plus, SafeWind**

Ecole des Mines de Paris

- "Grande Ecole d'Ingenieurs"
- 19 research centers in 4 locations
- 250 permanent researchers
- 1270 students:
  - PhDs:470
  - Masters: 280
- Annual budget: 88 M$
  - Public: 61 M$
  - Contractual: 27 M$

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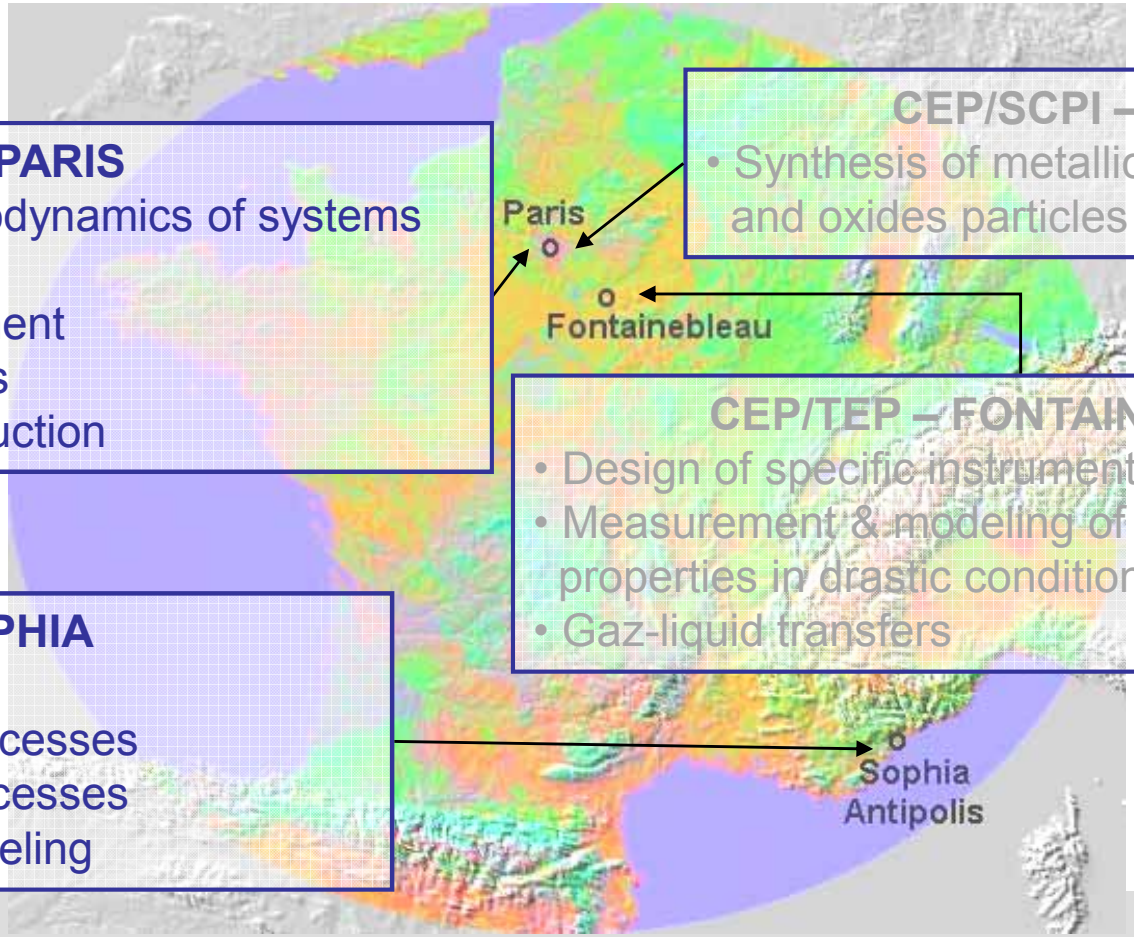
Centre for Energy & Processes (CEP)

3 major research axes

- *Energy, processes and environment, including transportation*
- *Energy infrastructures*
- *Nanomaterials and energy*



CEP – PARIS

- Heat transfers & thermodynamics of systems
- Lifecycle of buildings
- Demand side management
- Air-conditioning systems
- Impacts of energy production

CEP/SCPI – PARIS

- Synthesis of metallic hydroxides and oxides particles

CEP/TEP – FONTAINEBLEAU

- Design of specific instruments
- Measurement & modeling of thermophysical properties in drastic conditions
- Gaz-liquid transfers

CEP – SOPHIA

- **Renewable energies**
- Energy, materials & processes
- Plasma conversion processes
- Remote sensing & modeling

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Wind Power Forecasting : The ANEMOS approach

The ANEMOS history

- The ANEMOS Consortium was formed in 2001 with initial focus on R&D in Wind Power Forecasting.
- Composed by industrial companies, Research Centres, Universities, Meteo institutes and End-users.
- Since 2001 it developped :
  - the **Anemos** project, 2002-2006, 23 partners, 6.8 Mio $
  - the **Anemos.plus** project, 2007-2010, 22 partners, 8.95 Mio $
  - the **SafeWind** project, 2007- 2010, 21 partners, 8.84 Mio $

  } **24.6 Mio $**
- In 2005, the 1st version of the ANEMOS prediction platform was produced and installed for on-line operation at various end-users.
- Commercialisation led by ARMINES and Overspeed with a sub-group of partners.

Highly experienced partners

- R&D excellence :
  - Numerous national and EU R&D projects since 1990 .
  - Development of several approaches (physical, statistical, combined, ensembles etc).
  - Complementarity in competences (forecasting, IT, meteo, end-users, etc).
- Operational/commercial experience :
  - By CENER, ENFOR, Energy & Meteo Systems, UC3M, ARMINES, RAL …
  - Predictions for Spain, Germany, Denmark, Ireland, etc

Priorities in ANEMOS

- Rapid transfer of state-of-the-art research results to industry :
  - New modelling approaches are systematically demonstrated in pilot installations and evaluated for long periods.
  - For that purpose, prediction modules are developed in a highly standardised way with QM processes.

- Combining state-of-the-art operational models :
  - Wind power forecasting is a very difficult problem…
  - No single prediction approach is found to be best in all cases…
  - Anemos approach: Taking the best out of state of the art (1+1 > 2)

- Joint research for continous improvement of performance :
  - Critical for large scale applications with evolution of installed wind capacity.
  - Improving continuously accuracy requires high R&D investments;
  - More chances through joint investement : R&D investment as a group is far beyond what a single partner could afford.

EUROPEAN COMMISSION

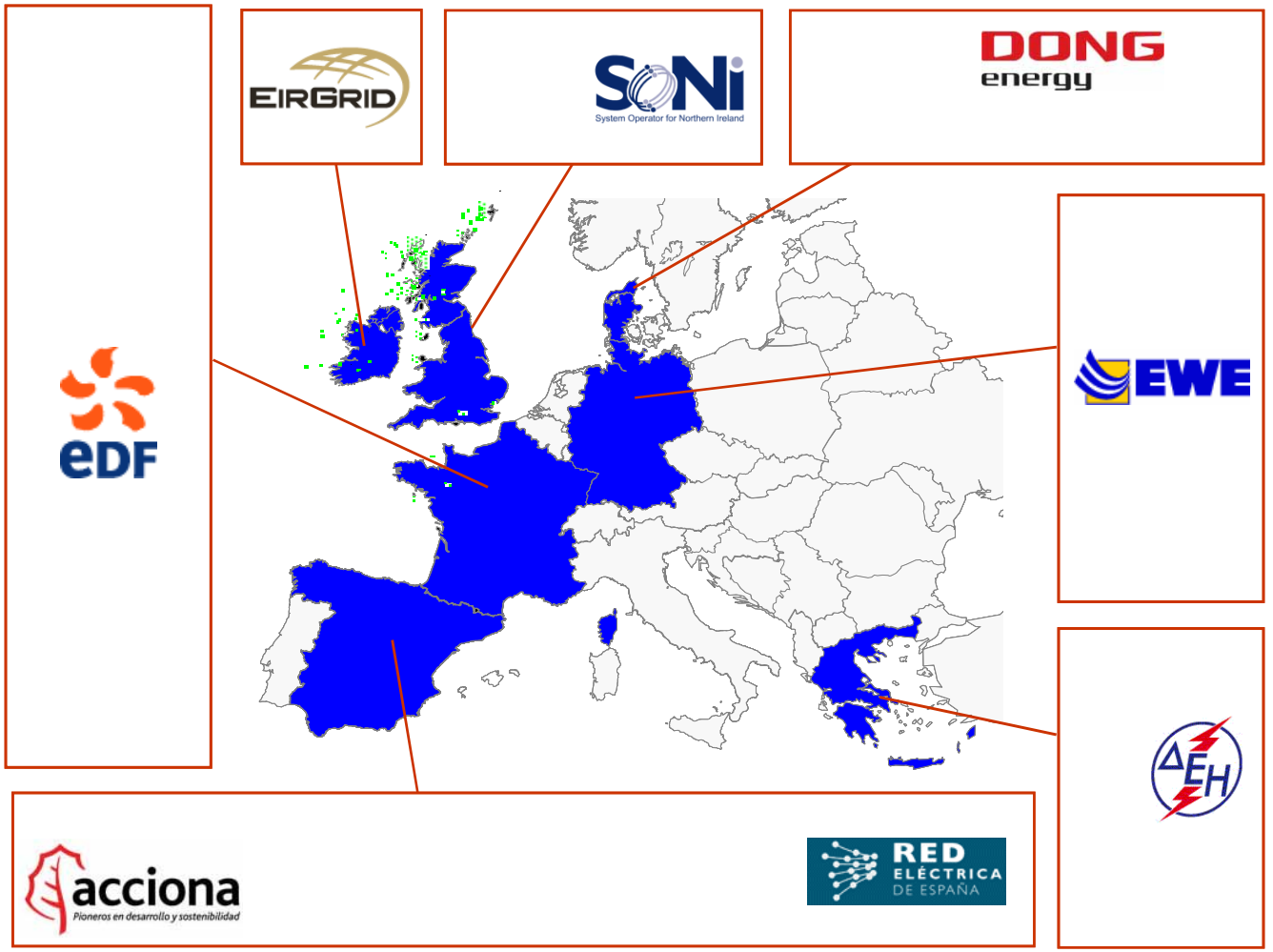
Community research

ANEMOS

Next generation forecasting tools for the optimal management of wind generation

R&D project

The Consortium



2002-2006

7 countries,
23 partners

End-users (8)

Industry (3)

Meteorologists (2)

Research (5)

Universities (5)

Funded in part by the EC

Coordinator:
Dr. George Kariniotakis,
Ecole des Mines/ARMINES

The Project Objectives

- **Accurate short-term forecasting** of wind farms production up to 2-3 days in advance especially for:
  - complex terrain (not easy to predict…),
  - offshore (high impact to the grid).

- **Demonstrate the economic and technical benefits** from the use of wind prediction tools at national, regional or single wind farm level.

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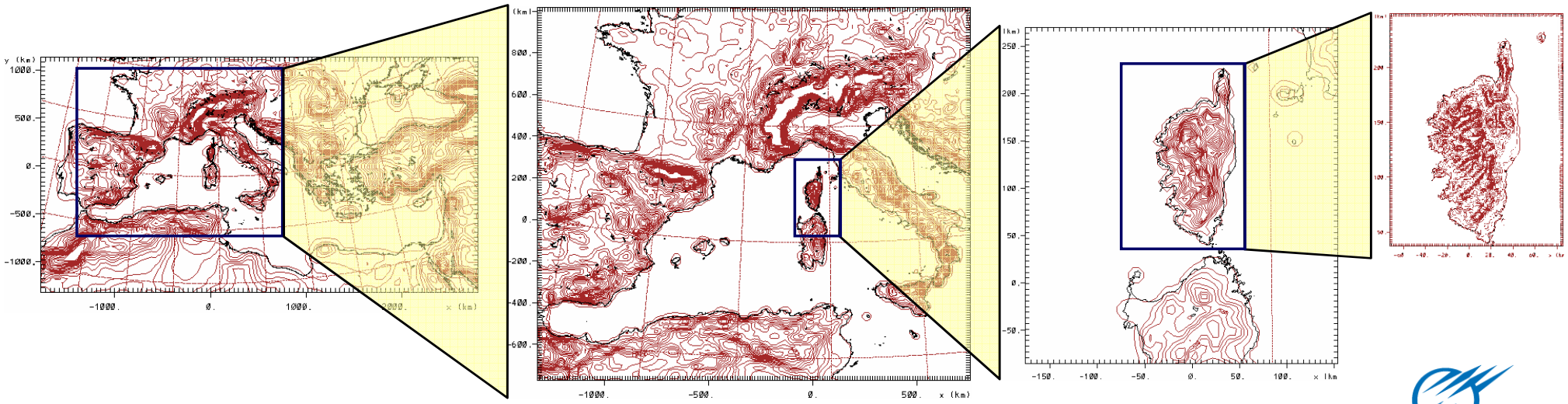
R&D Approach

- Research on two mainstream approaches:

statistical — models try to represent the information in the available data (*i.e.* artificial intelligence techniques)

physical — models try to represent the physical laws (*i.e.* modelling of wind flow on the terrain)



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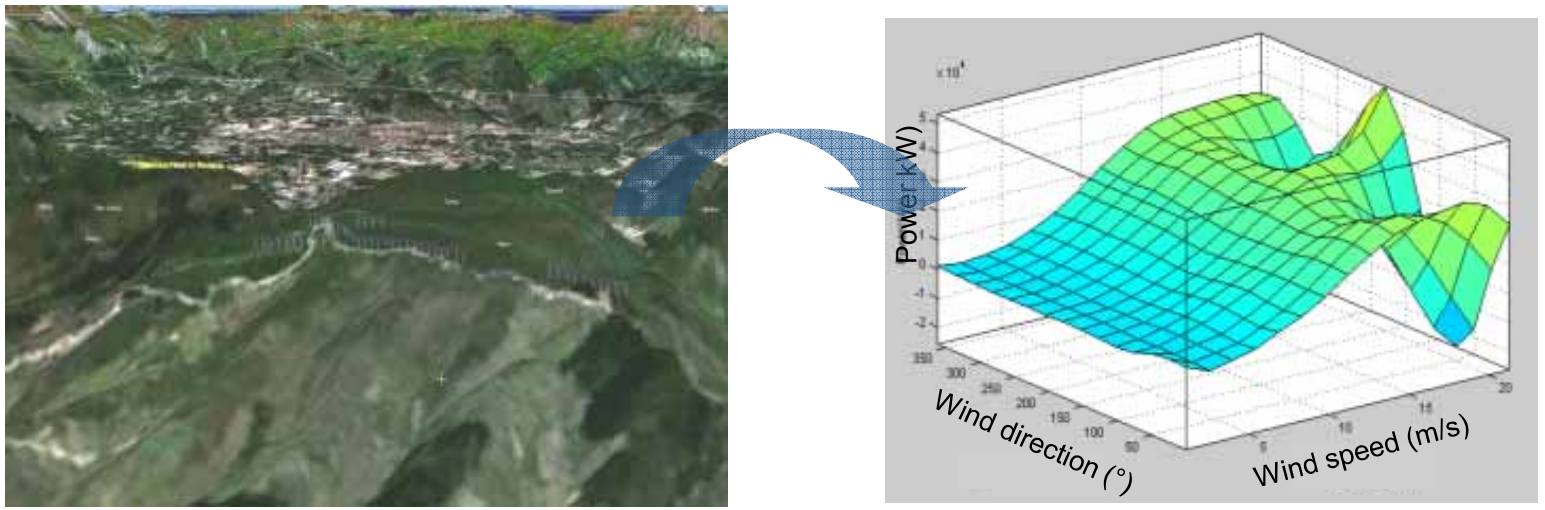
R&D Approach

- **Benchmarking** of 11 state-of-the-art prediction systems plus models developed in Anemos.
- **Combination of predictions** by multiple models and with alternative NWP feeds.
- New models for **on-line uncertainty** estimation
- Development of an **advanced prediction platform**
- **Demonstration/evaluation** at end-users

Highlights

New statistical models

- **New models** were developed for various functions like power curve modelling, upscaling for regional forecasting, automatic predictions combination, NWP filtering etc.
- Approaches: Neural nets, Fuzzy neural nets, RBF nets, Regression models, Kalman filters based etc.

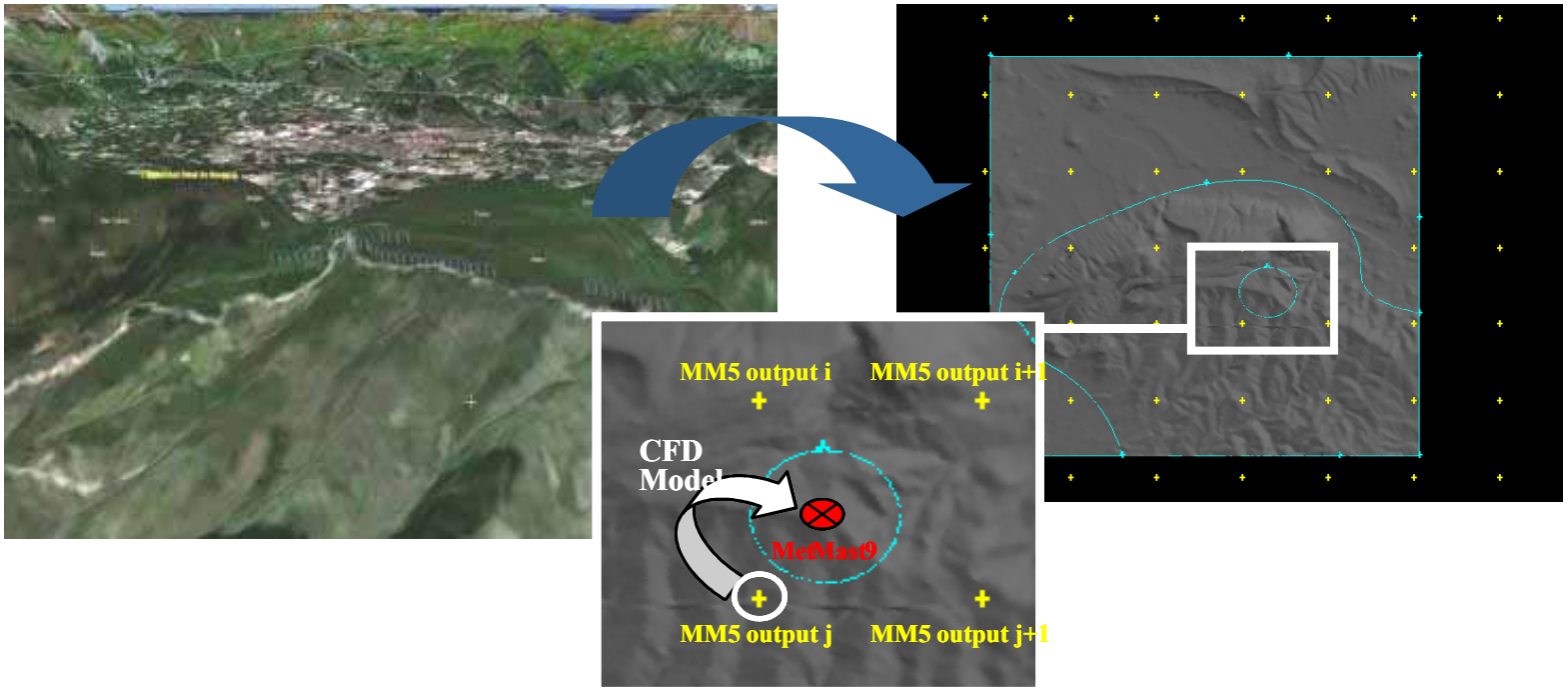


Example of power curve modeling based on fuzzy logic (wind farm of Alaiz Spain).

Highlights

New physical models

- High resolution models to account for complex terrain (i.e. CFD approaches).

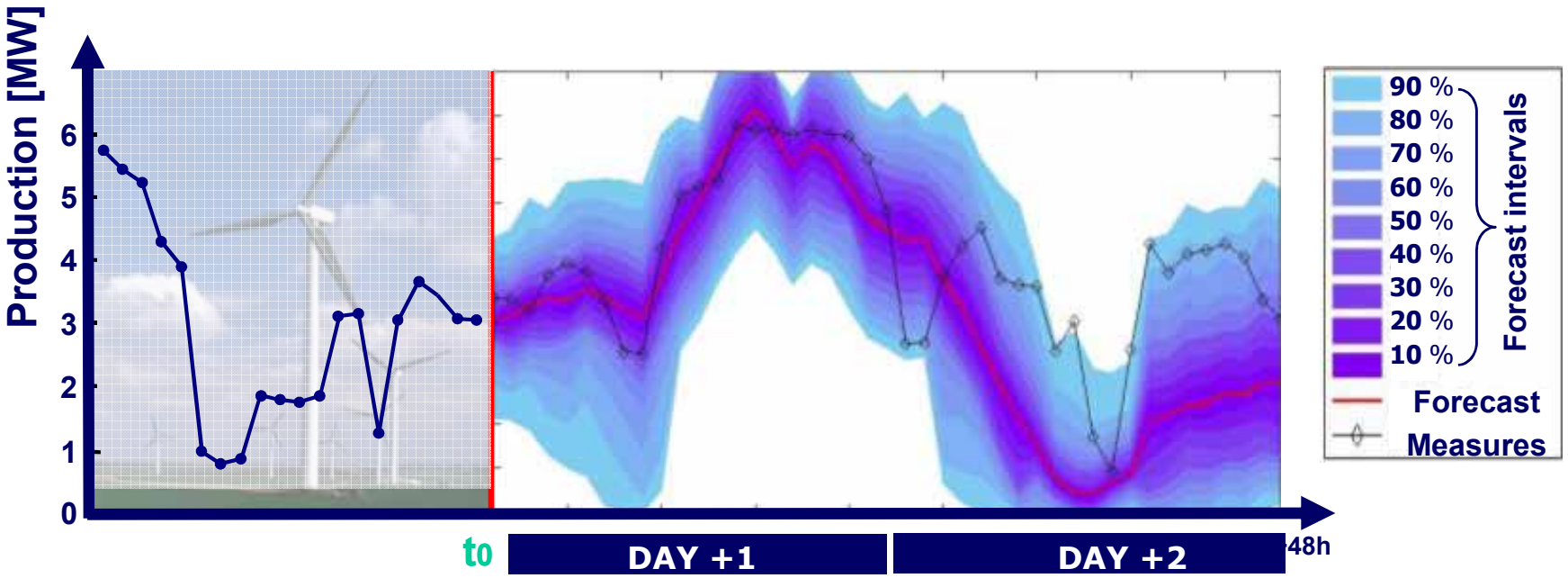


CFD downscaling of MM5 NWP. 3D view of the area at Alaiz wind farm in Spain and MM5 grid.

Highlights

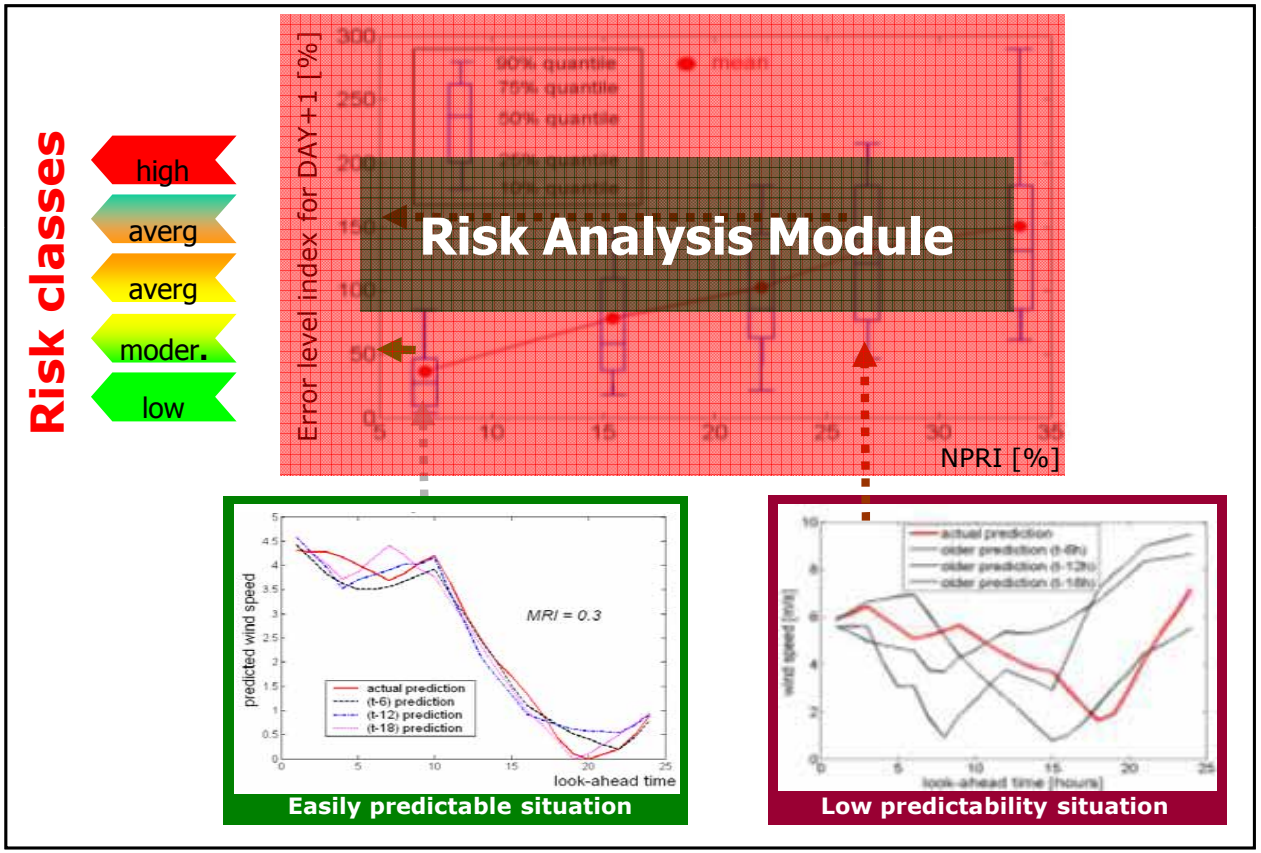
- New operational models for on-line uncertainty estimation based on adapted resampling or quantile regression.
- Prediction of uncertainty using prediction risk indices

Uncertainty



Highlights

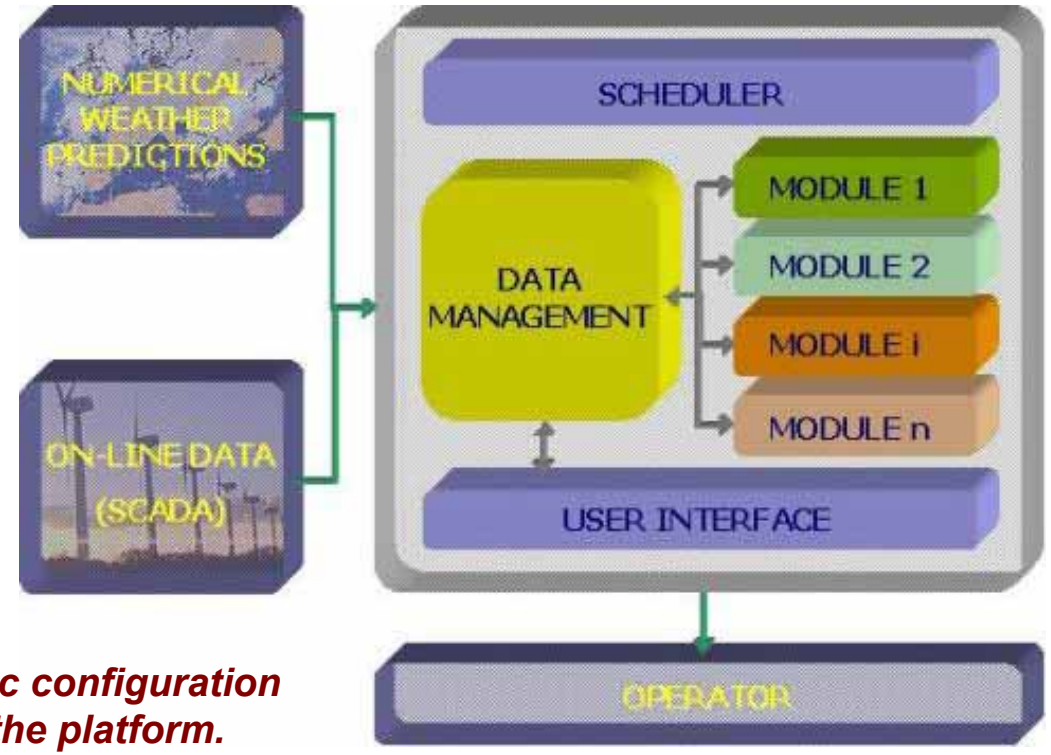
- Development of new tools such as **prediction risk indices** based on ensembles



Prediction of Uncertainty

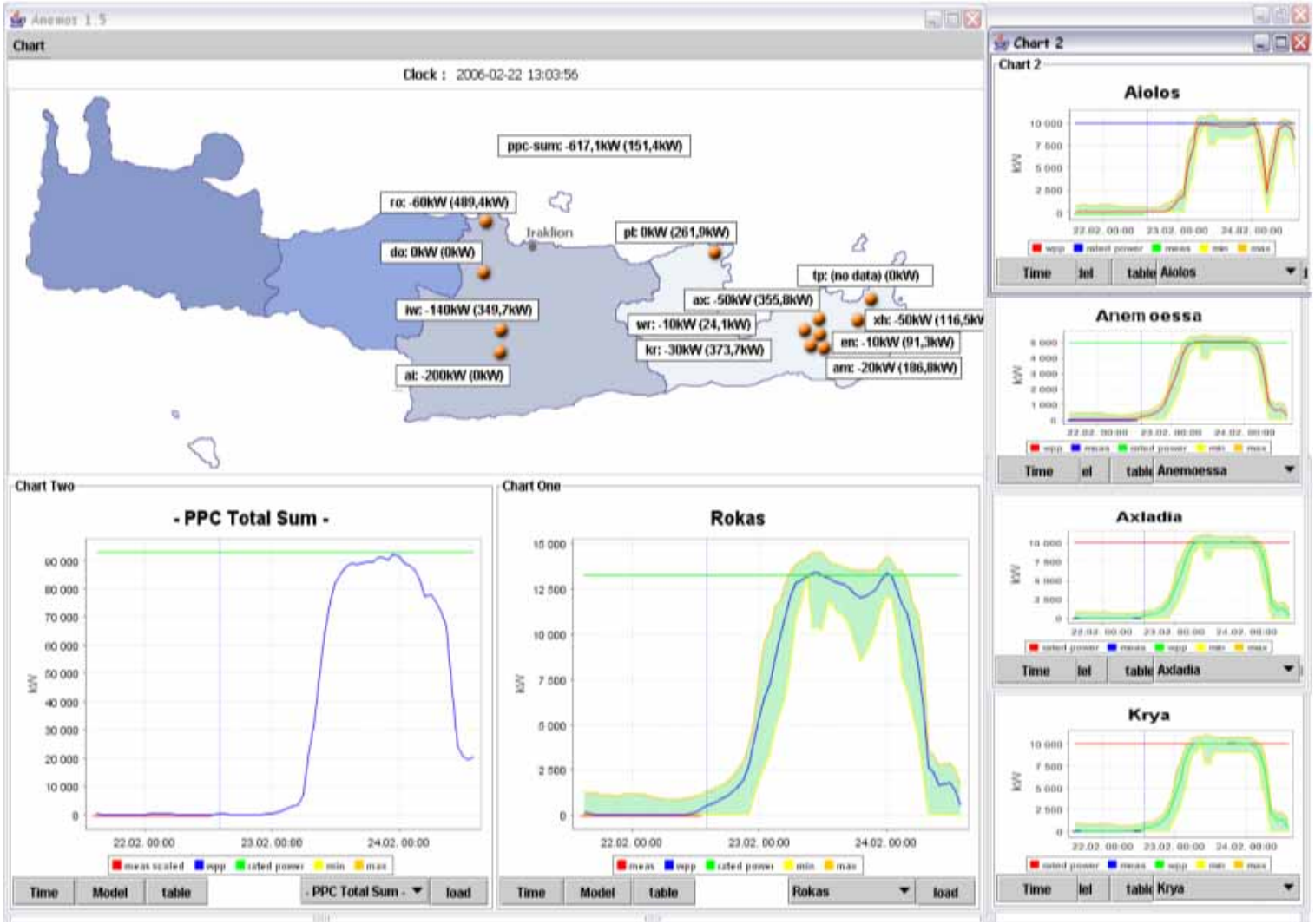
Highlights

- An advanced, highly standardised, prediction platform integrating functionalities & models for a broad range of end-user requirements.



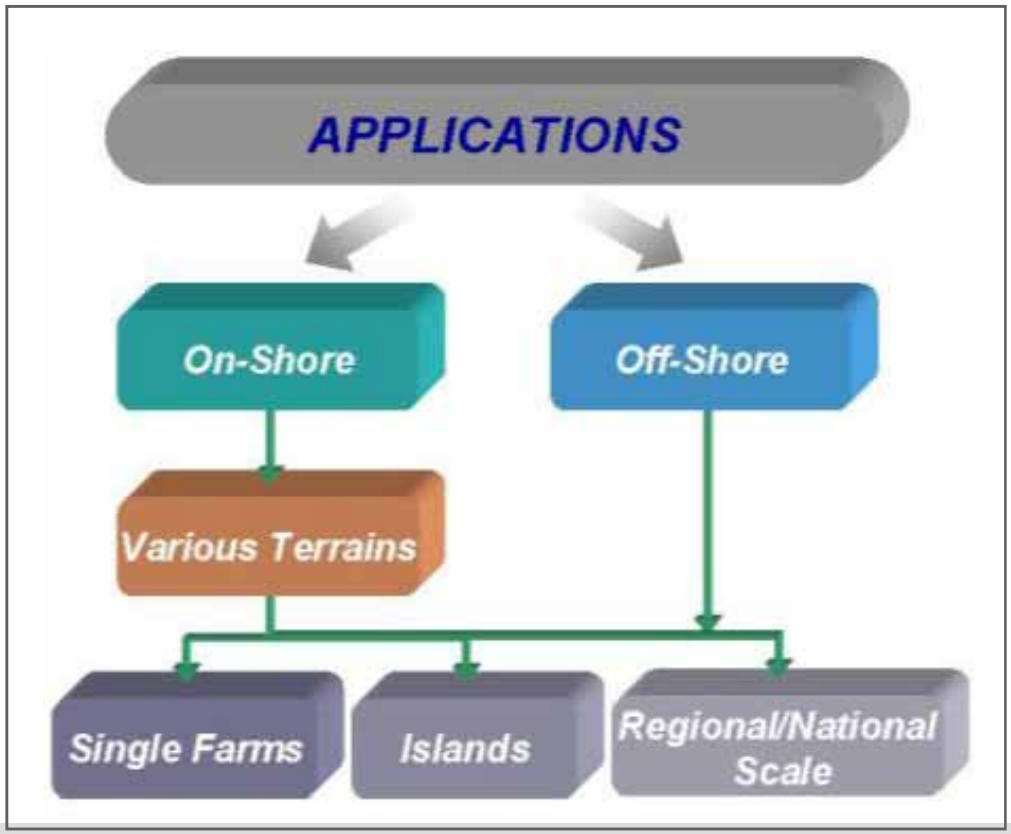
Generic configuration of the platform.

Demonstrations



The Anemos Forecasting System

- Installed in 9 countries for real-time operation.
- New installations in 2008: REN, EDF Guadeloupe



Denmark

France

Germany

Greece

Ireland

Spain

commercially

UK

Canada

Australia

Further information

http://www.anemos-project.eu

More than 80 papers

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Community research

R&D project

ANEMOS+

Advanced Tools for the Management of Electricity Grids with Large-Scale Wind Generation.

Towards Smart Integration of Wind Generation

Context

- Considerable research carried out in the last 15 years
  - "**accuracy**"-driven approaches.
    (i.e. models tuned based on least mean square error type of criteria).

Context

- End-users today request also:
  - **high reliability** of prediction services and systems,
  - **Challenge:** "**value**"-driven forecasting approaches.

The Project

2008-2011

8 countries, 22 partners

End-users (9)

Industry (3)

Research (4)

Universities (5)

Meteorologists*

Funded in part by the EC

Budget: 5.7 Mio€

Duration: 3.5 years

Objectives

Improvements in Wind Power Forecasting :

- Probabilistic forecasting (including ensembles)
- Advanced **uncertainty** estimation (i.e. for regional forecasting)
- Intelligent handling of situations with incomplete information
- Adaptability of prediction tools to changing environment
- …

Objectives

Optimal Power System Management :

- Power systems are traditionally operated using "**deterministic**" tools.
- It is necessary to adapt management functions for high wind penetration. In practice :
  - Simplified approaches are used (i.e. adaptation of deterministic models).
  - Some approaches consider **wind variability** estimates rather than **wind predictability**.
  - Others try to model forecasting errors rather than using realistic timeseries or distributions.
- The aim is to develop operational tools based on the **stochastic paradidm**.

Objectives

Optimal Power System Management :

Focus on :

- Reserves estimation
- Congestion management in large or local grids
- Power system scheduling
- Optimal coordination of storage and wind power.
- *Optimal trading strategies based on probabilistic forecasts and prediction risk.*

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Community research

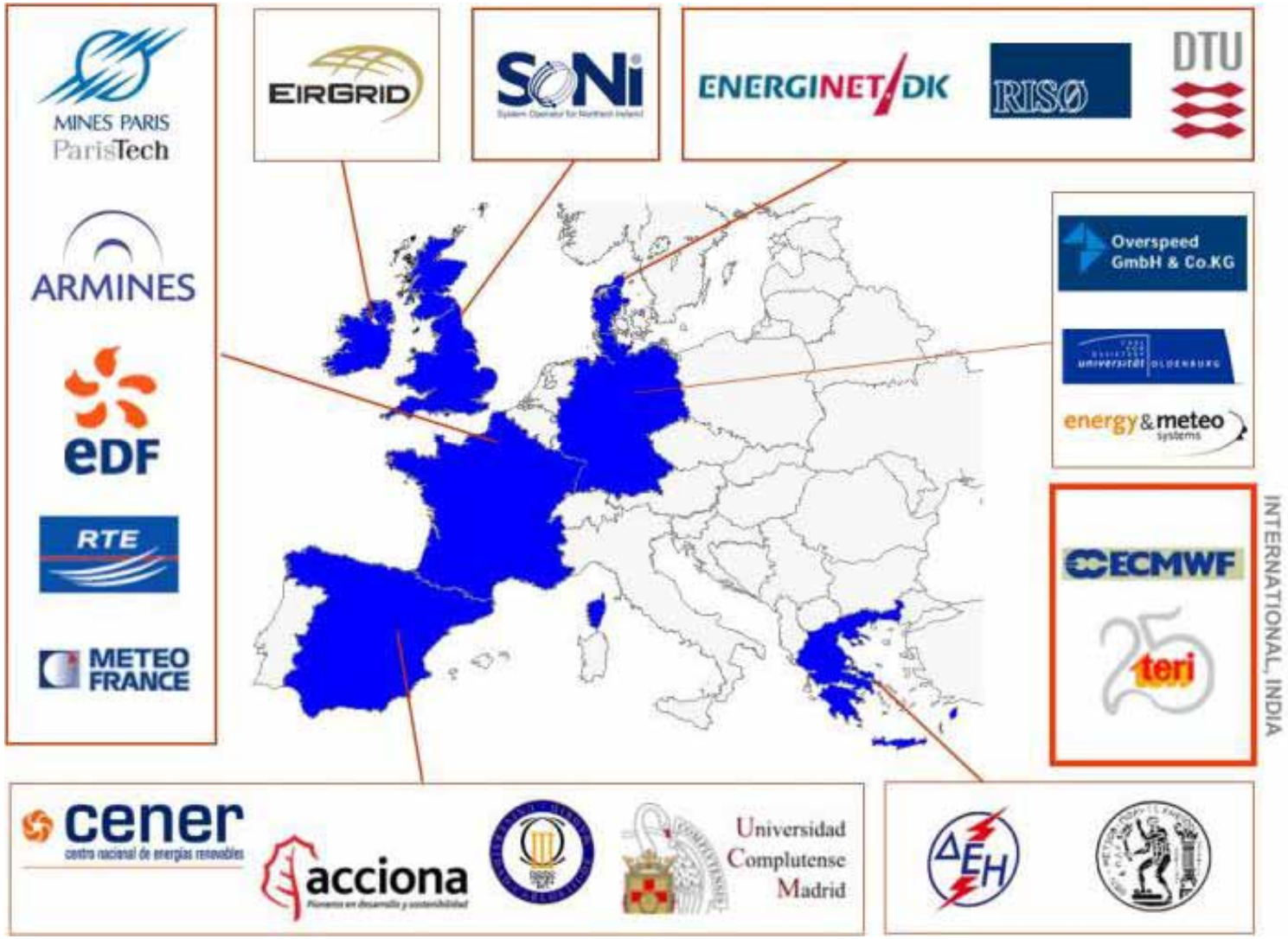
SEVENTH FRAMEWORK PROGRAMME

R&D project

SafeWind

Multi-scale data assimilation, advanced wind modelling and forecasting with emphasis to extreme weather situations for a safe large-scale wind power integration.

The Consortium



2008-2011

9 countries, 23 partners

End-users (8)

SMEs (2)

Research (5)

Universities (6)

Meteorologists (2)

Funded in part by the EC

Coordination
ARMINES

Budget: 5.6 Mio€

Objectives

Improve wind predictability with focus on **extremes** :

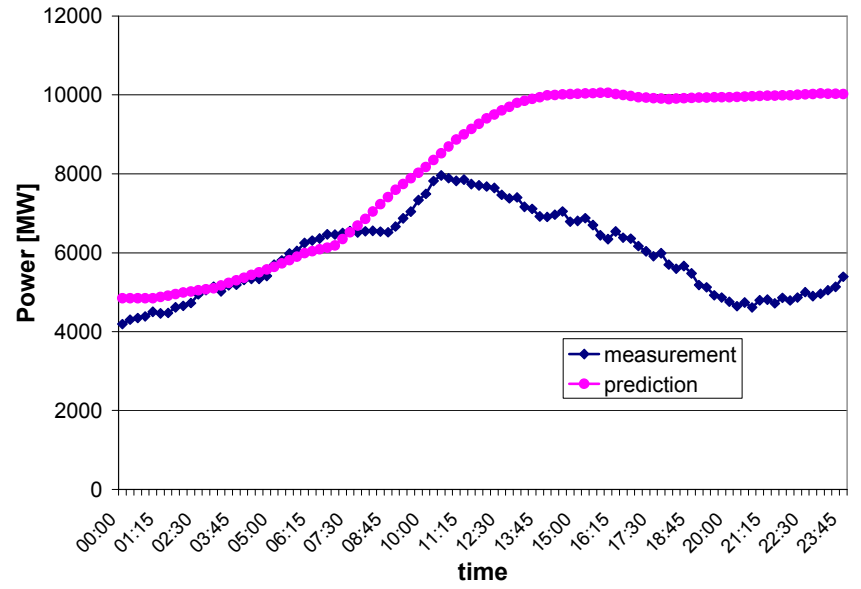
- at various **temporal** scales
  - Very short-term (order of 5 min)
  - Short term (hours to days)
  - Longer term (beyond few days ahead)

- at various **spatial** scales :
  - **local scale:** Extreme gusts or shears.
  - **regional scale:** Extreme events (like thunderstorms) can cause the loss of significant amounts of wind energy with potential impact on the grid management.
  - **continental (European) scale:** Extreme weather situations (like fronts) can propagate causing impacts in different member states.

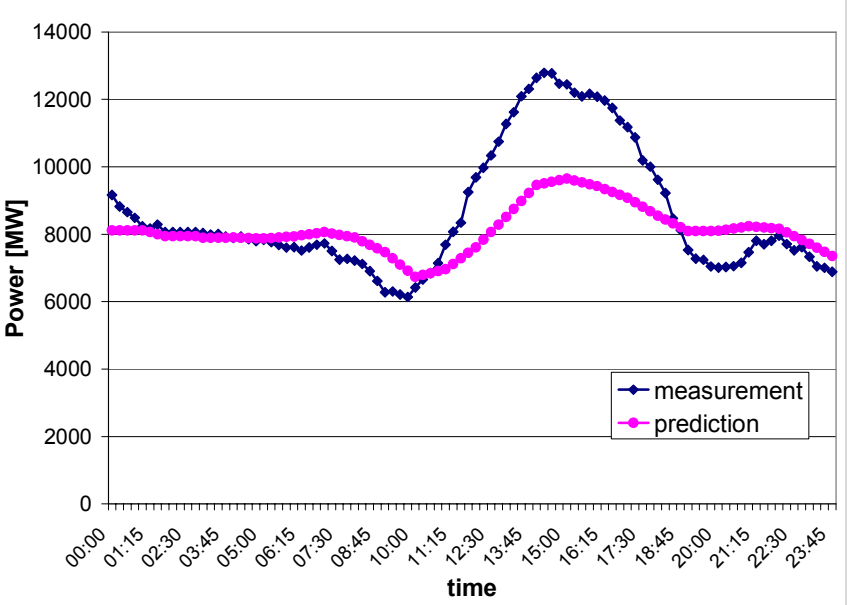
Objectives

- New **forecasting** methods for wind generation focusing on uncertainty and challenging situations/extremes;

Examples of extreme events in intraday wind power prediction for Germany.



(A) Path of low-pressure system was different than predicted, maximum error: 5500 MW could have been avoided by extreme event correction.



(B) Unexpected rise in pressure gradient in high-pressure situation. Maximum error: 2300 MW could have been avoided.

Objectives

- models for "**alarming**": providing information for the level of predictability in the **very short-term**.
  - They use near-real time online observations for alerts on potential extreme prediction errors and for immediate updates of short-term (0-6h) wind power predictions on regional and local scale;

- models for "**warning**": providing information for the level of predictability in the **medium-term** (next day(s)).
  - Such tools, based on ensemble weather forecasts and weather pattern identification, can be used to moderate risks in decision making procedures related to market participation, reserves estimation etc.

Objectives

- Link resource assessment to wind predictability.
- Analyse how **new measurement technologies** like Lidars can be beneficial for better evaluation of external conditions, resource assessment and forecasting purposes.
- Demonstrate the operational benefits from new models.

Conclusions

- Although in the last 15 years wind power forecasting was concentrating on deterministic approaches, today, state of the art includes among others :
  - Advanced uncertainty estimation of deterministic models
  - Ensembles approach
  - Multi-model (NWP or WPP) approach and combination
  - Prediction of uncertainty (risk indices)
  - Probabilistic forecasting (p.d.f. prediction)

- Demonstration of the new approaches at operational conditions is needed (i.e. how to present all this information to end-users…).

- Research is needed also to develop stochastic approaches for power system management integrating in a coherent way wind predictions and information on their uncertainty.

Conclusions

- **SAFEWIND** will provide new prediction tools and risk estimation for extreme situations.

- **ANEMOS.plus** is bringing together end-user business processes and wind power forecasting approaches.
  - Demonstration for congestion management, reserves planning, scheduling…

Thank you for your attention

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