EUROPEAN COMMISSION
Community research

Forecasting Offshore Wind Power
– Developments of the Anemos Project

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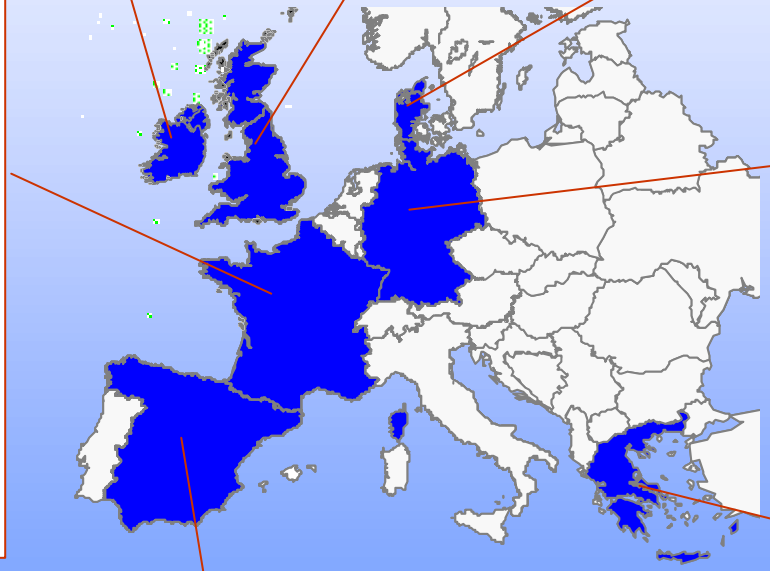


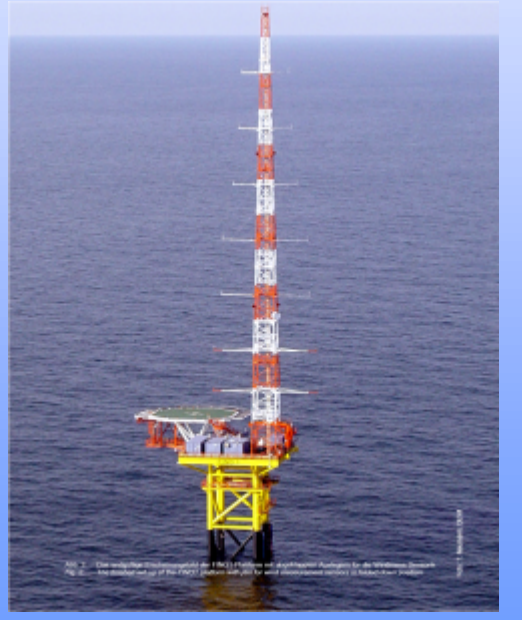
A. M. Palomares

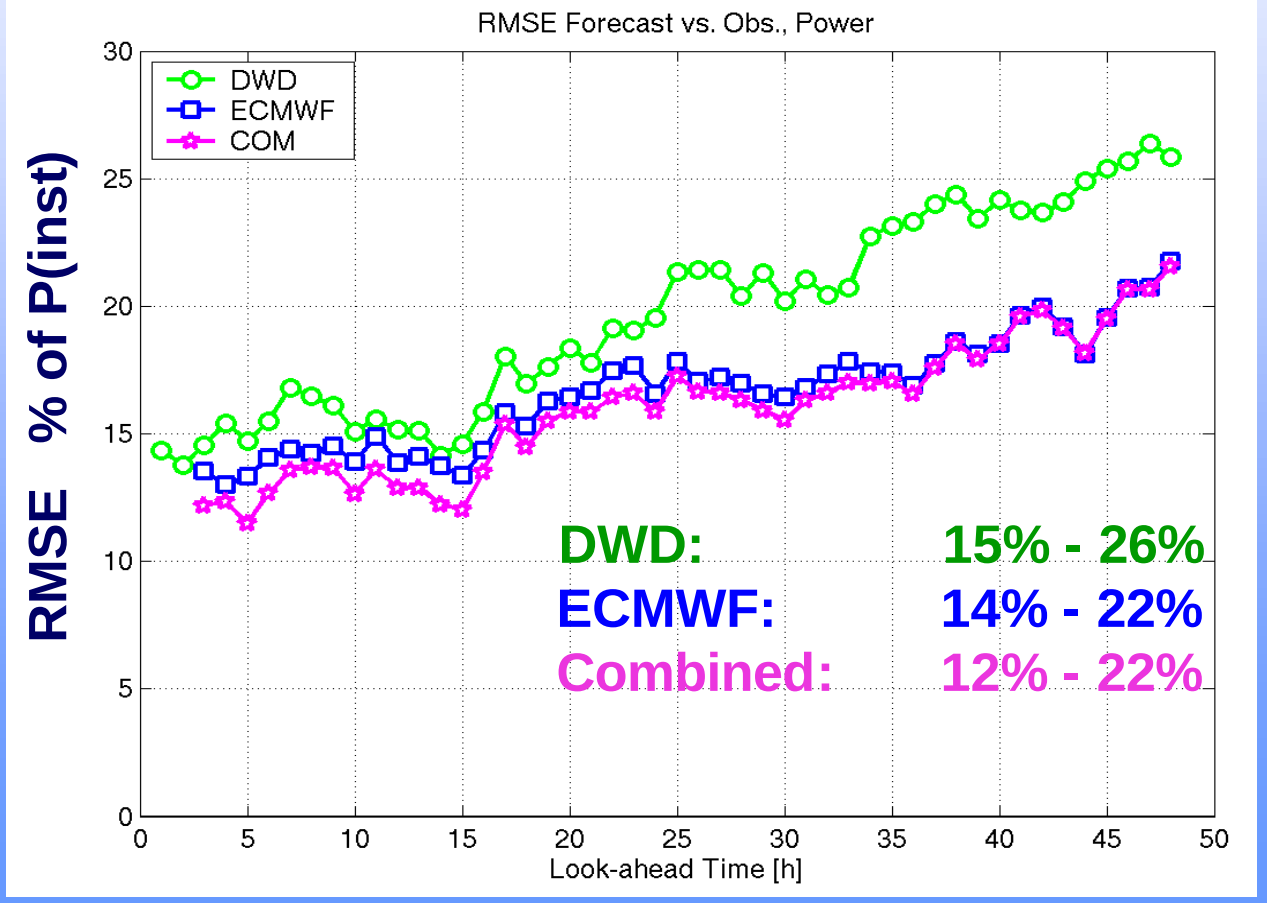
Research Objectives

- Accuracy of High-Resolution Marine Meteorological Forecasts
- Analysis of Offshore Wind Speed Conditions
- Development of new physical & statistical forecast tools
- Modelling of spatio-temporal characteristics in and behind large offshore wind farms (esp. Wakes)
- Additional Benefits of Satellite-Radar Information

Accuracy of High-Resolution Meteorological Forecasts

- Comparison of Forecasts at FiNO1, 103m height:
  12 months, 2004 (mean possible power: 51%)
- Benefits of NWPs combination

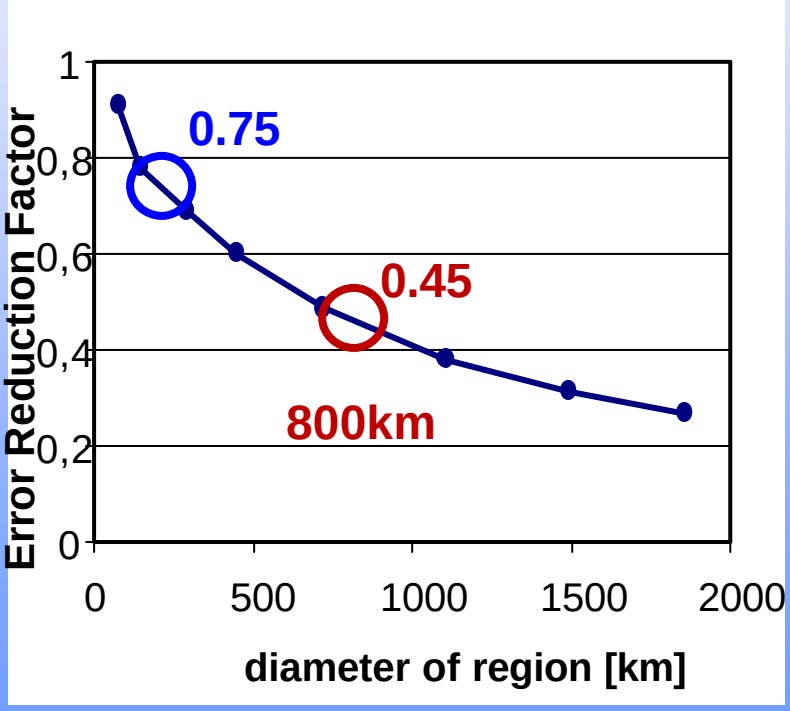


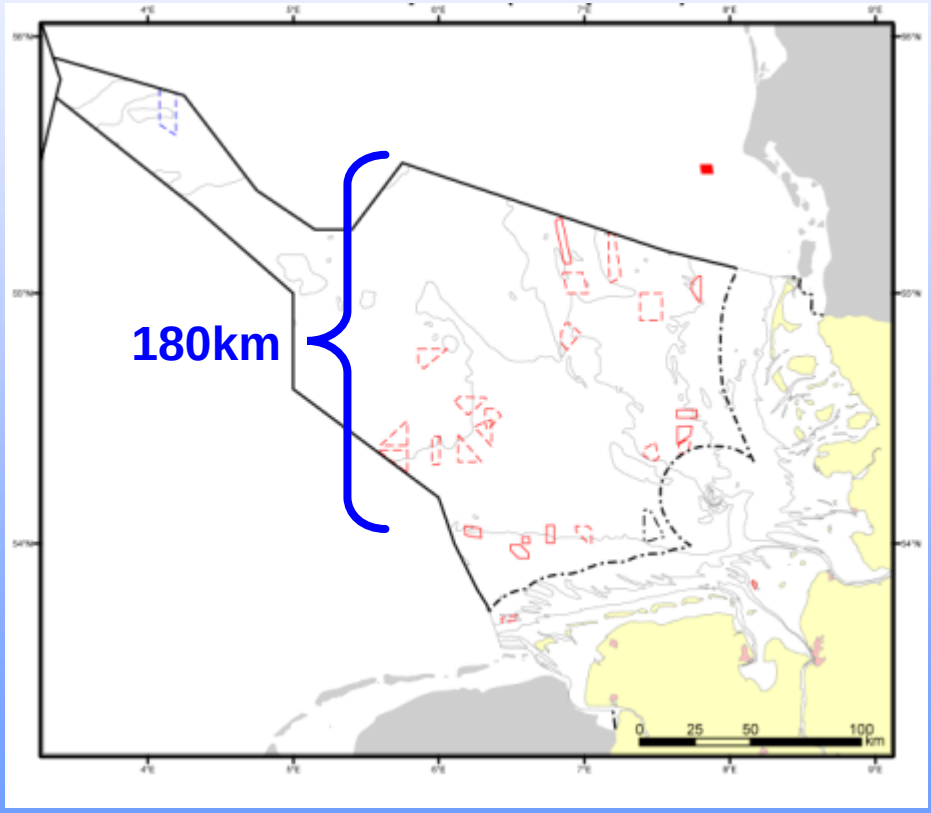


Accuracy of High-Resolution Meteorological Forecasts

Regional Power Forecasts for 25 GW Offshore Wind

Smoothing of errors same size as onshore?



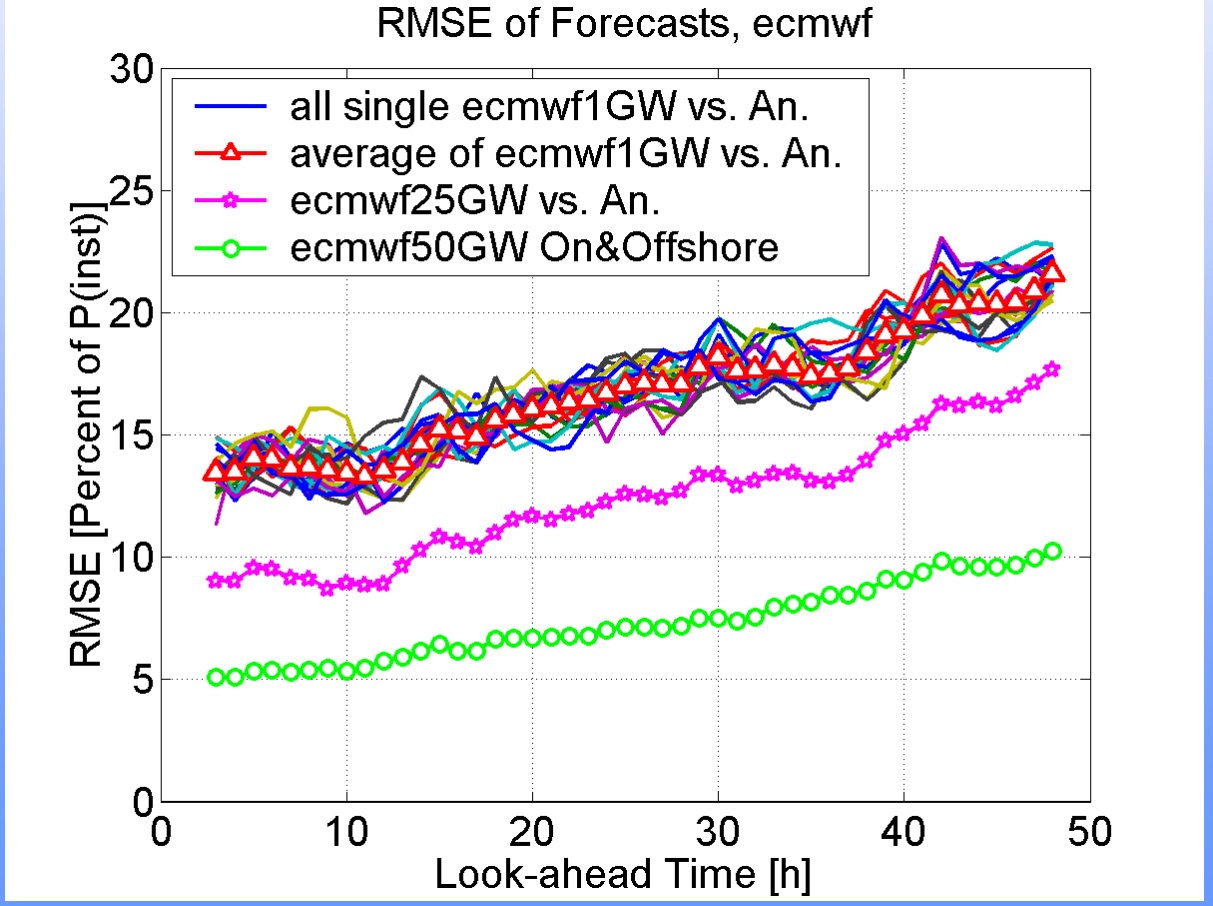


Planned Wind Farms in the German Bight
Source: www.bsh.de

Accuracy of High-Resolution Meteorological Forecasts

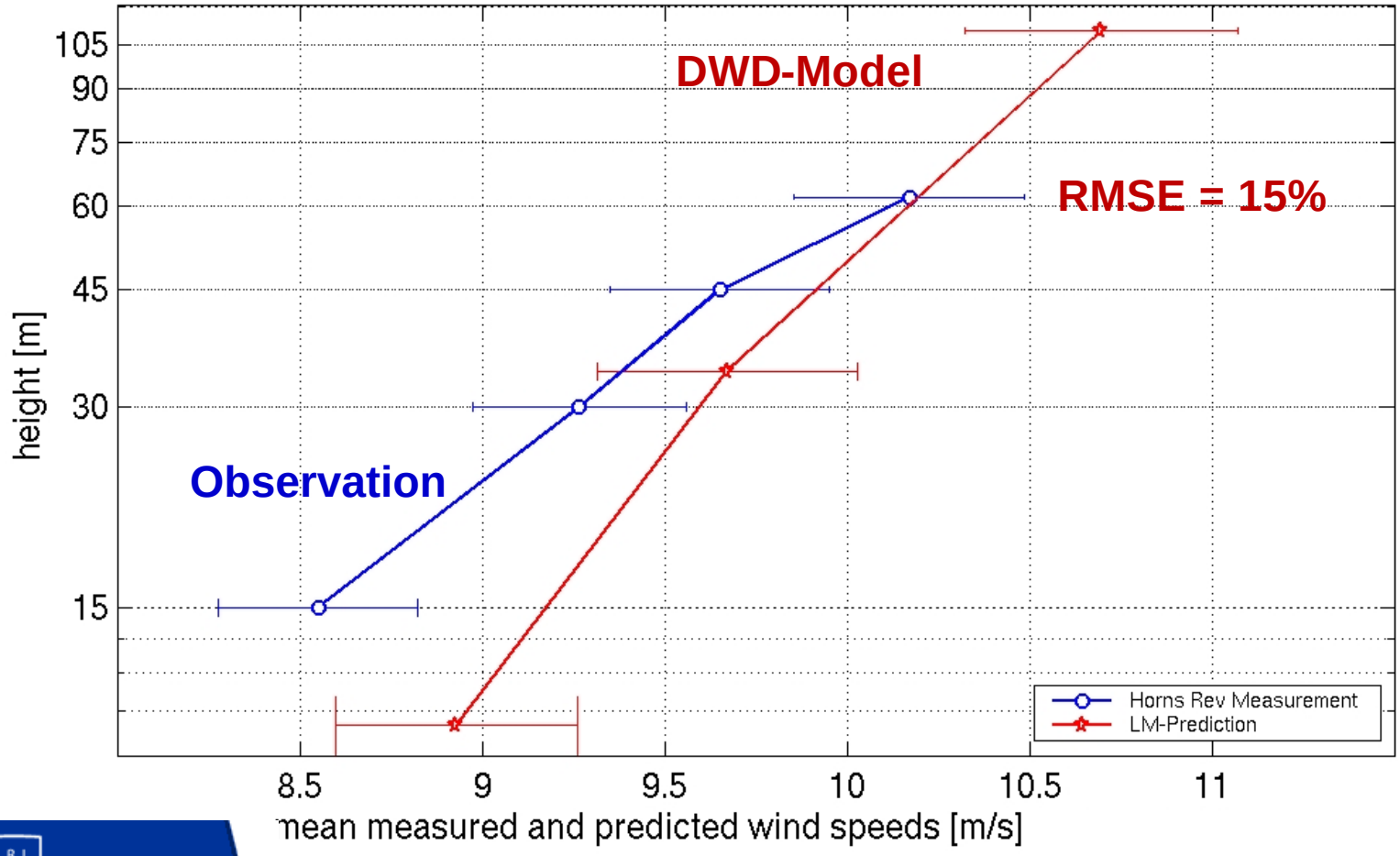
- Regional Power Forecasts for 25 GW Offshore Wind
- Error smoothing factor of 0.73 in German Bight

- Only 5%-10% RMSE for 50GW On&Offshore Forecast



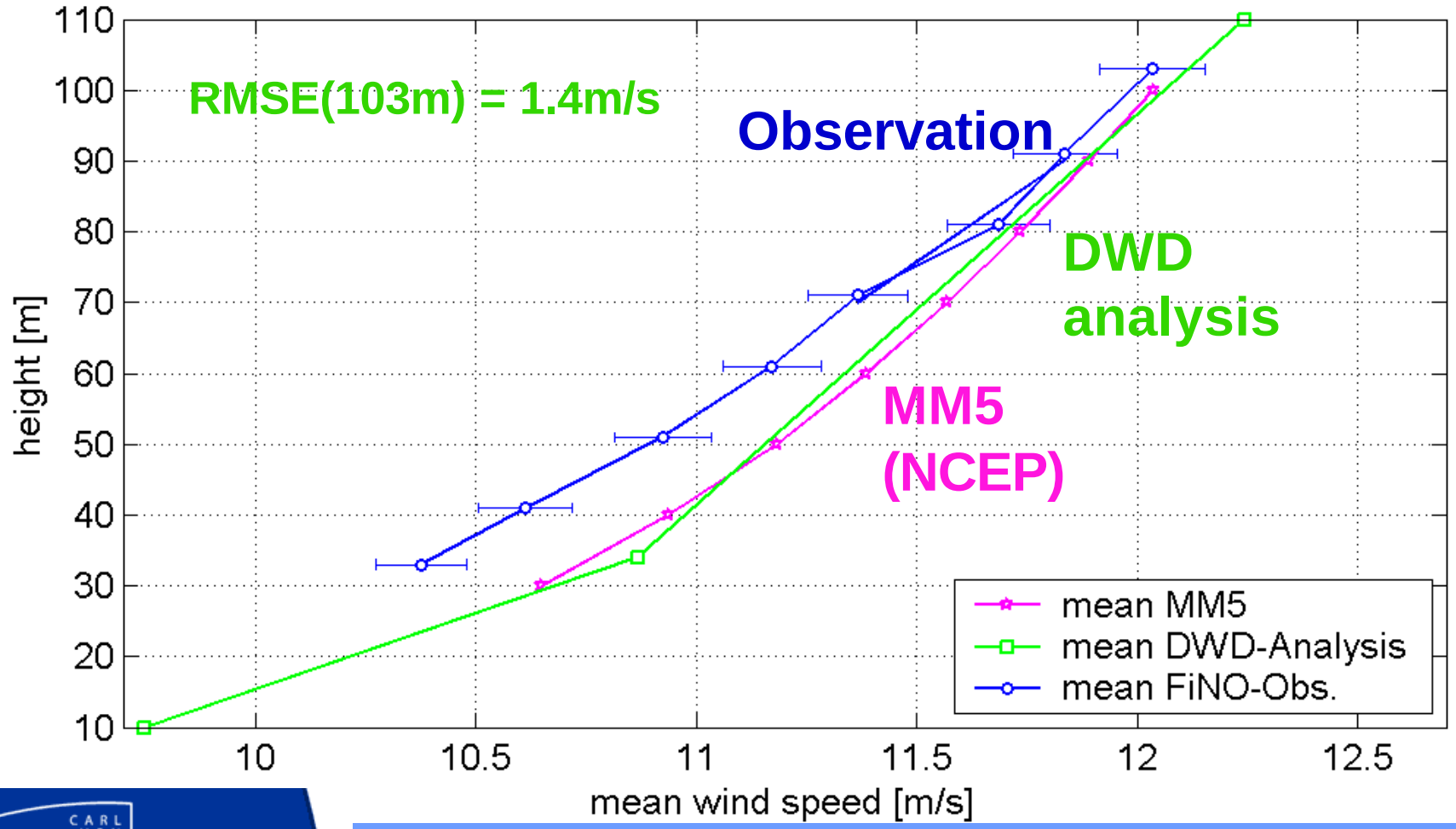
Analysis of Offshore Wind Speed Conditions

- **Wind Profiles and Forecasts at Horns Rev**



Analysis of Offshore Wind Speed Conditions

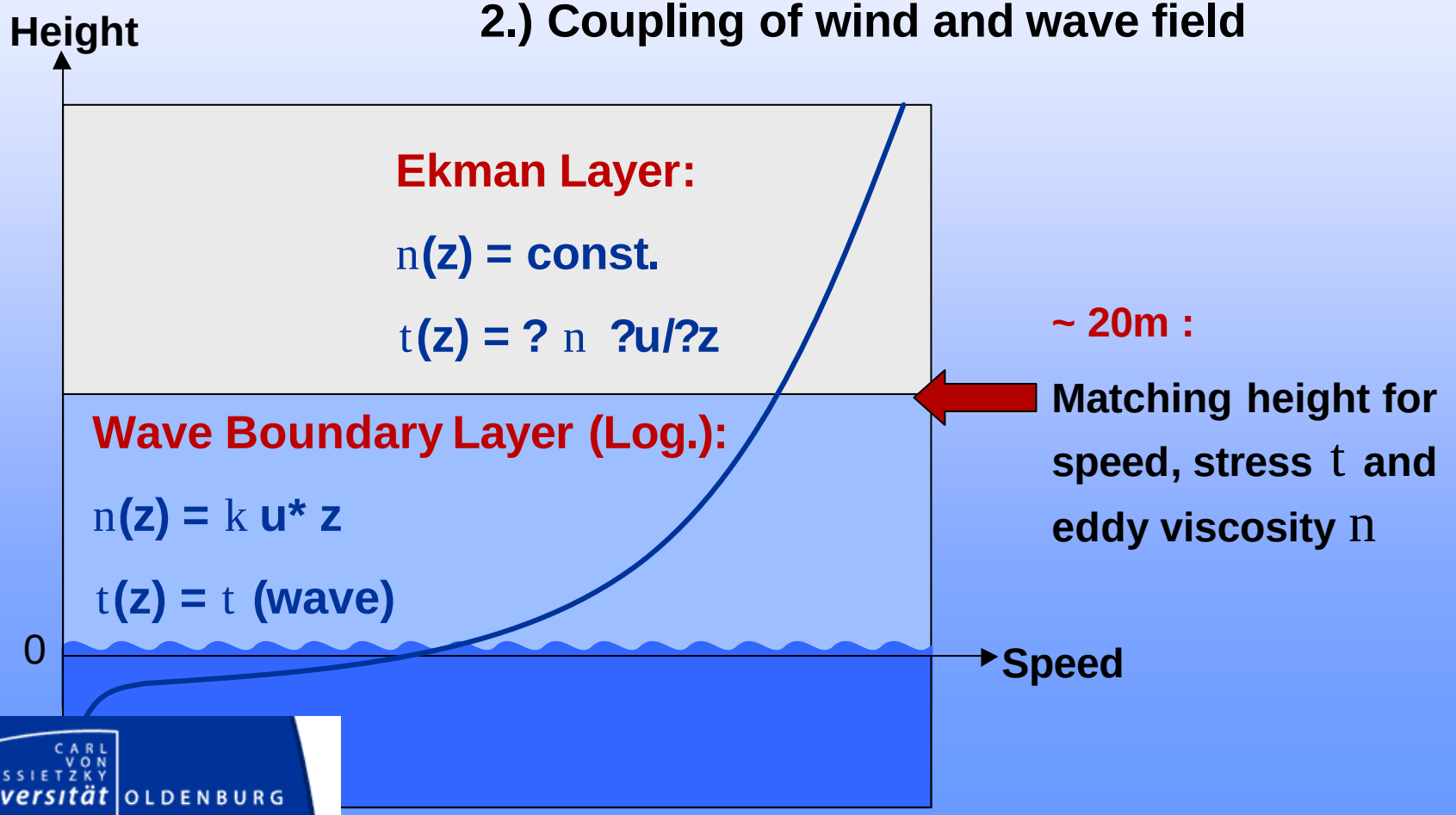
- **Wind Profiles and Forecasts at FiNO1**



New Physical and Statistical Forecast Tools

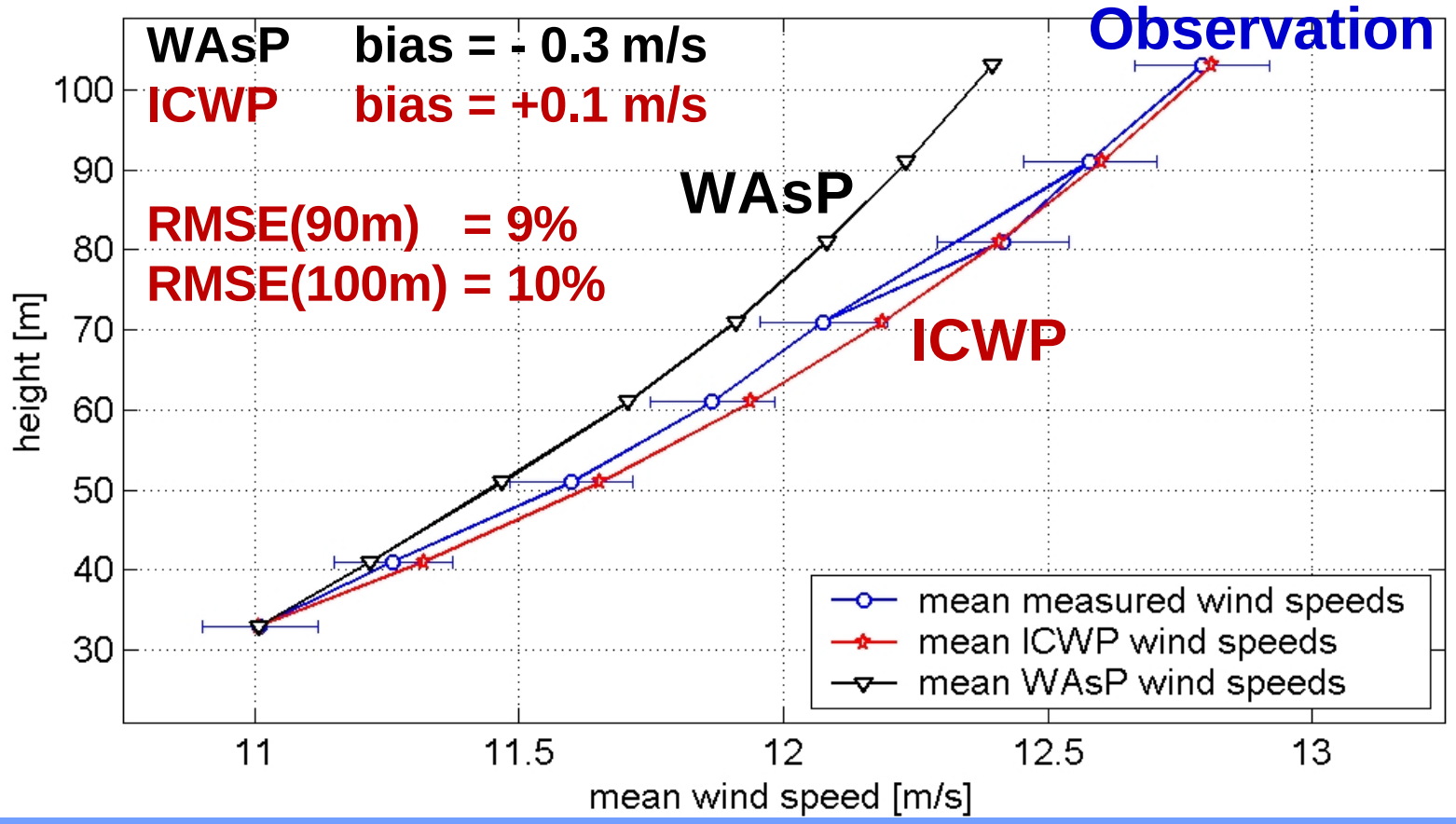
Inertially Coupled Wind Profiles

1.) Coupling of Ekman- and Log-Profile
2.) Coupling of wind and wave field



New Physical and Statistical Forecast Tools

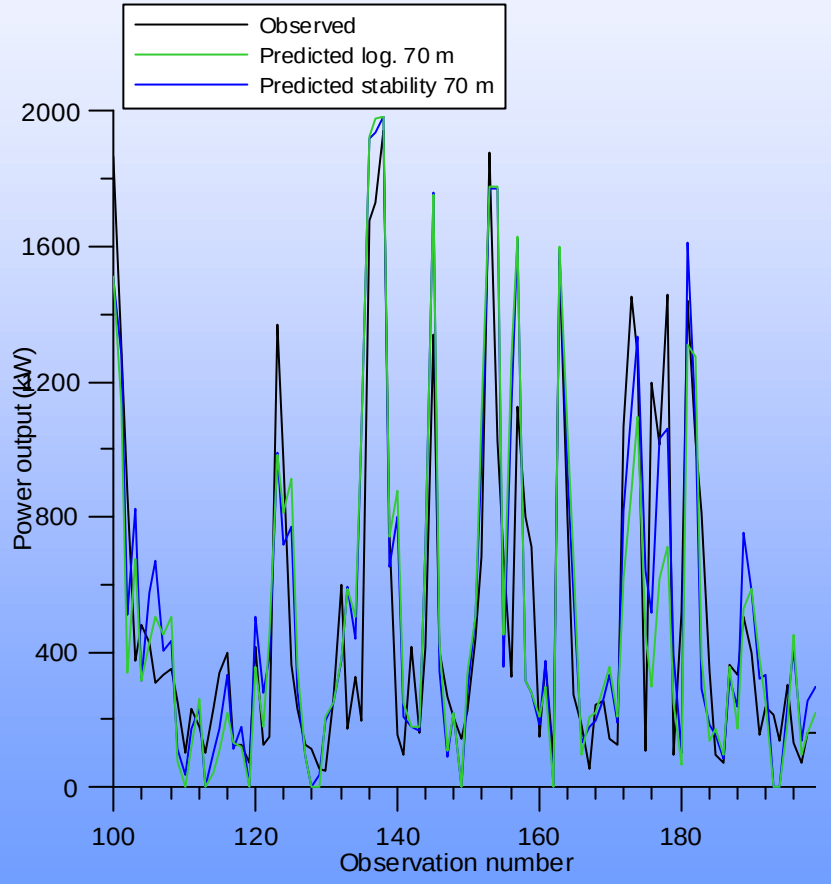
- ***Inertially Coupled Wind Profiles***



New Physical and Statistical Forecast Tools

- ***Forecasts at Middelgrunden***

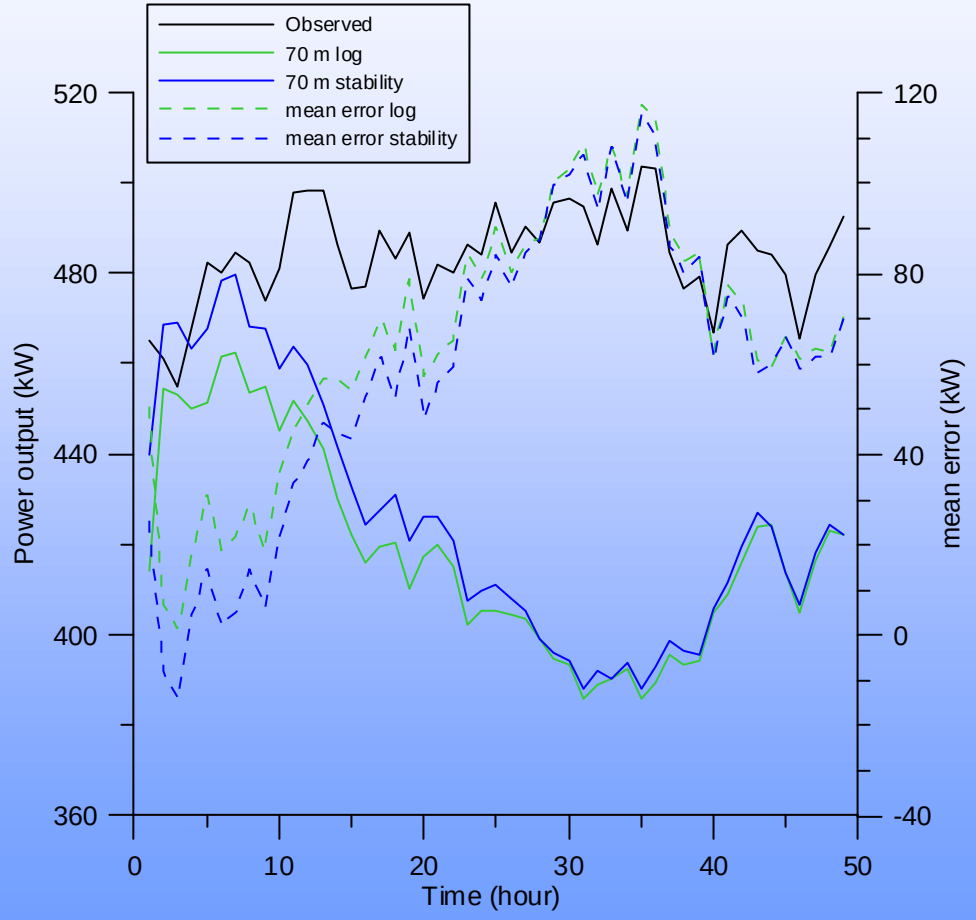
- **Avoid dt in stability calc. Use dU.**
- **Stability defined dU =10 m and model level (~100m)**
- **Stability correction applied to log.profile ® $U_{hub\text{-}height}$**
- **$U_{hub\text{-}height}$ ® power output**
- **Time series example**



New Physical and Statistical Forecast Tools

- ***Forecasts at Middelgrunden***

- **Slightly improved by stability correction**
- **Little diurnal variation in stability so likely can be accounted for with bias**
- **Might be worth making seasonal/directional bias**
- **Average for one year 2001-2002**

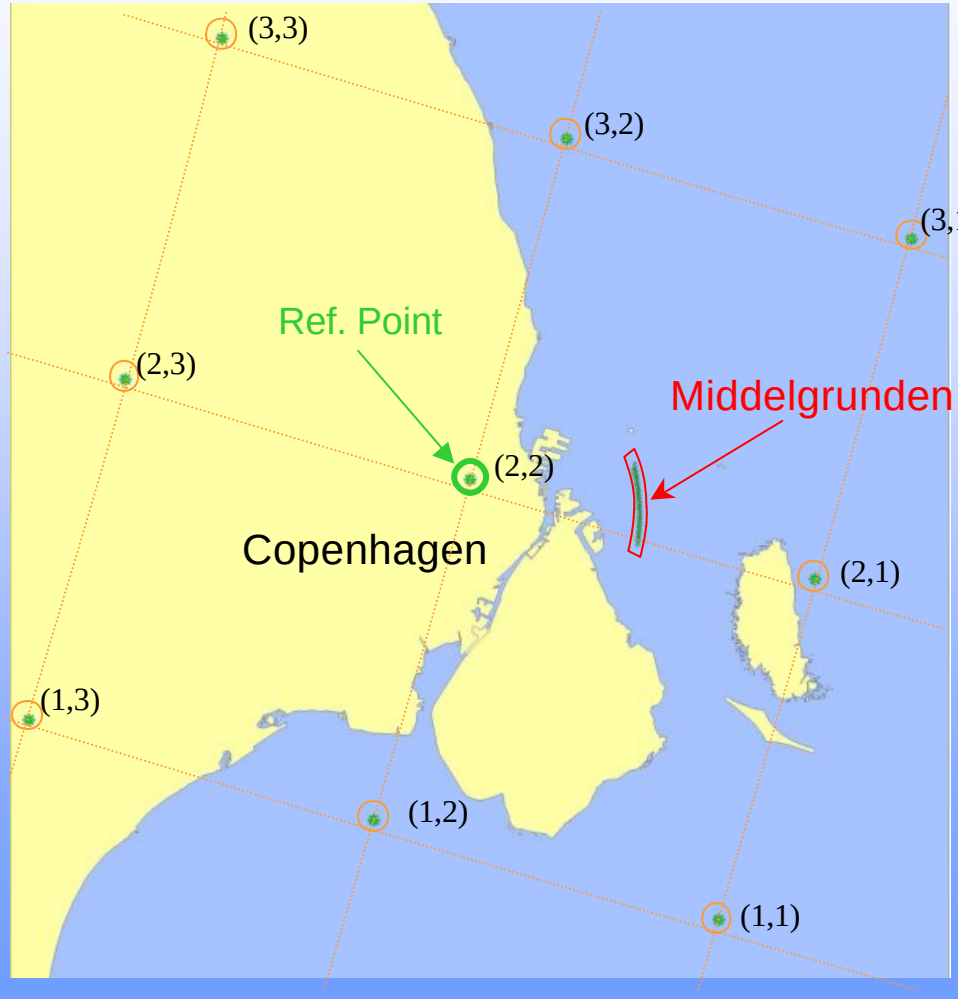


RISØ

Forecasts at Middelgrunden

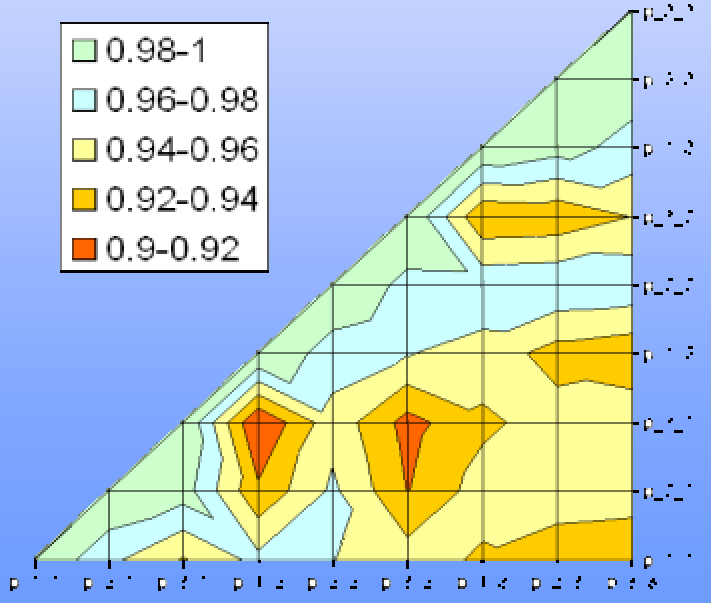
- Not a simple case…

Forecasts at Middelgrunden



- HIRLAM Meteo Grid
  - 9 meteo points.
  - Spacing about 10 Km.

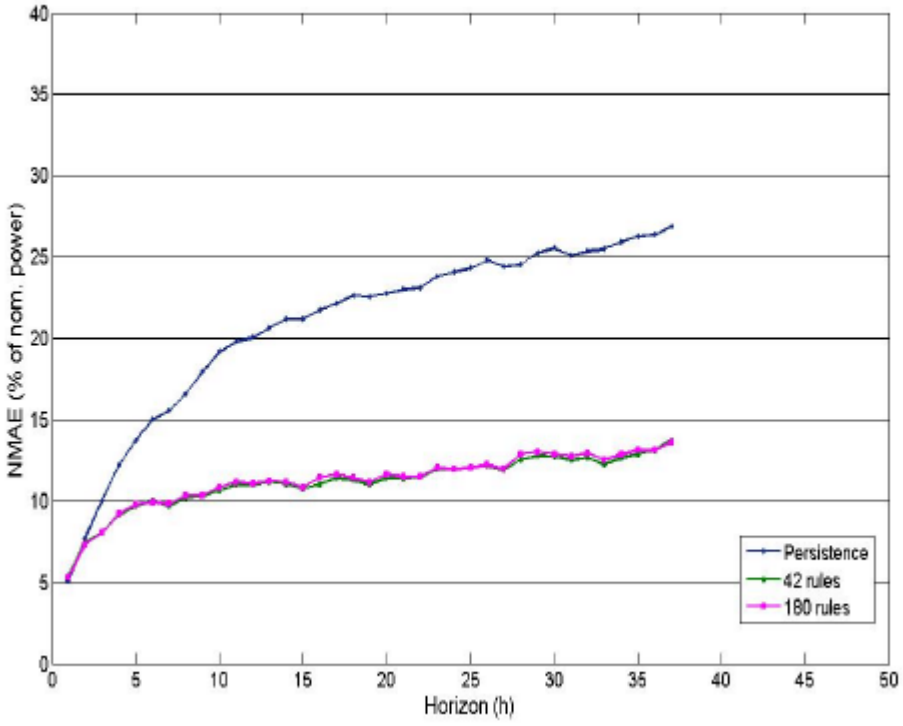
- Correlations Intervals between points
  - Wind Speed : [0.90 ; 1.00]
  - Wind Direction : [0.81 ; 1.00]
  - Air Density : [0.98 ; 1.00]

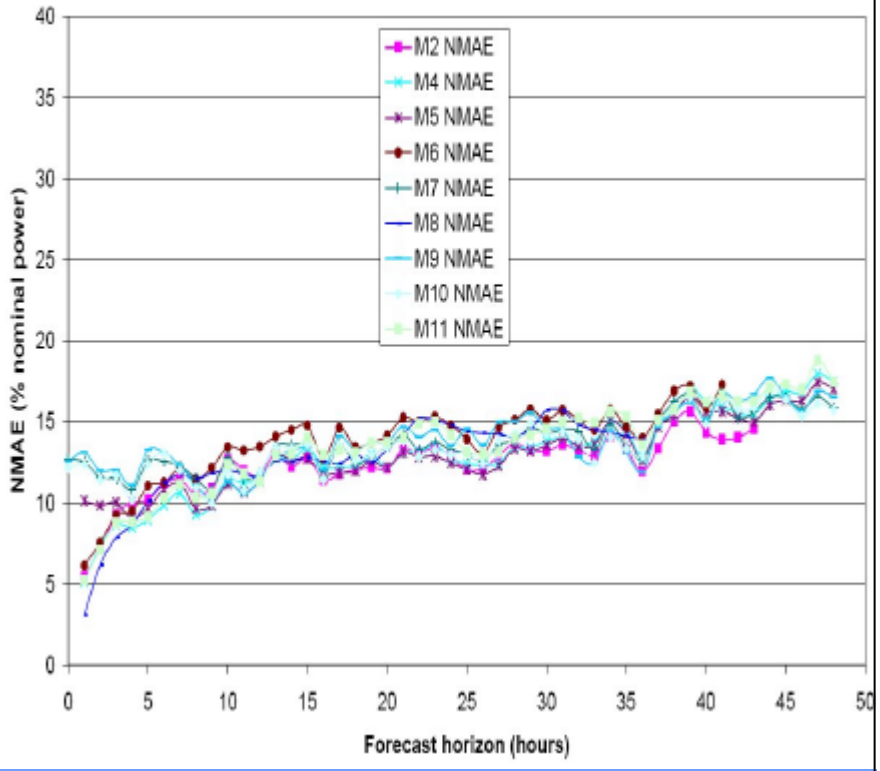


10m Wind Speed Correlation

Forecasts at Middelgrunden

- **Results are similar to Tuno study (ANEMOS-WP2 Benchmarking)**

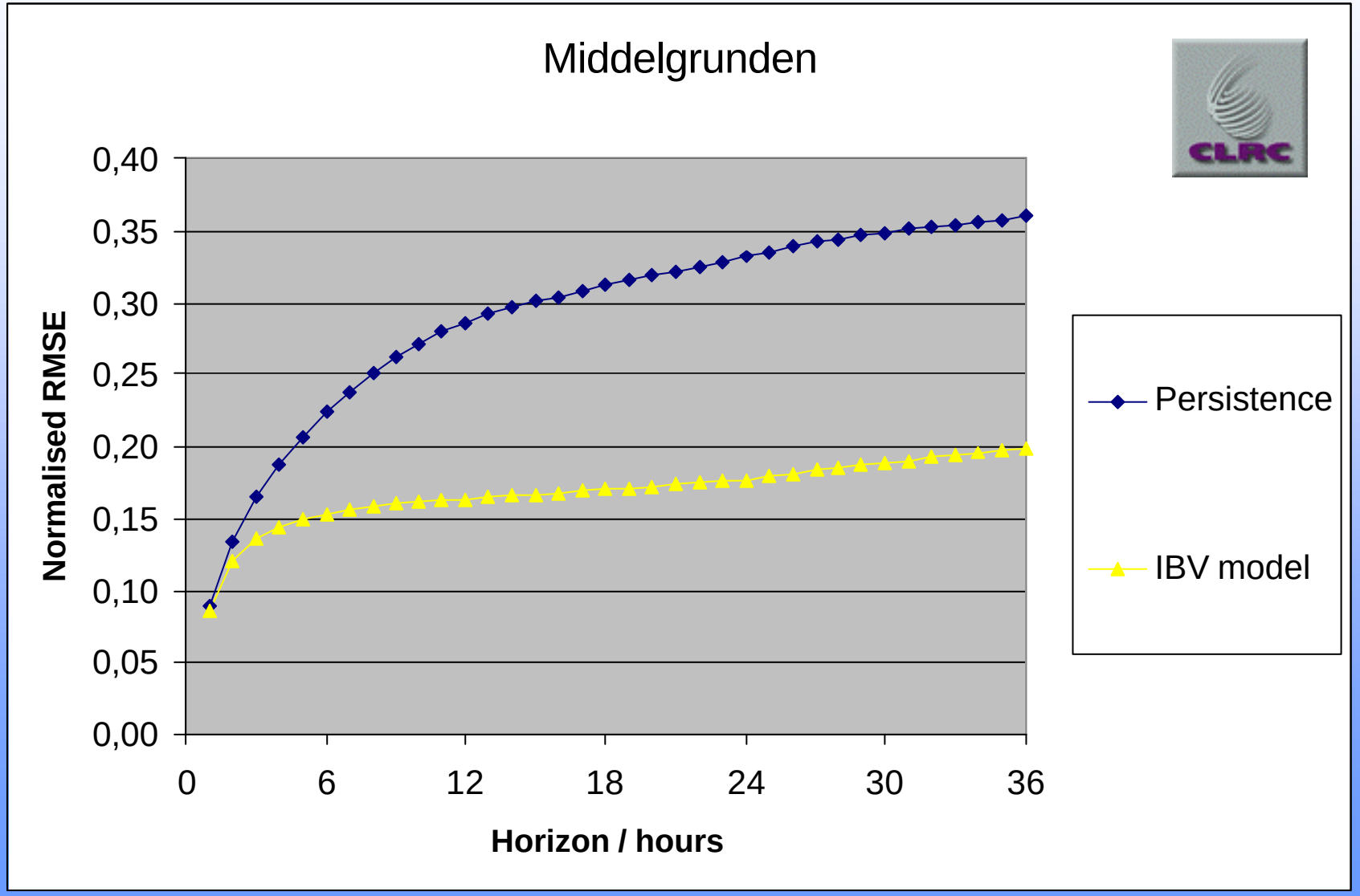




- **Middelgrunden**
- **Tunoe**

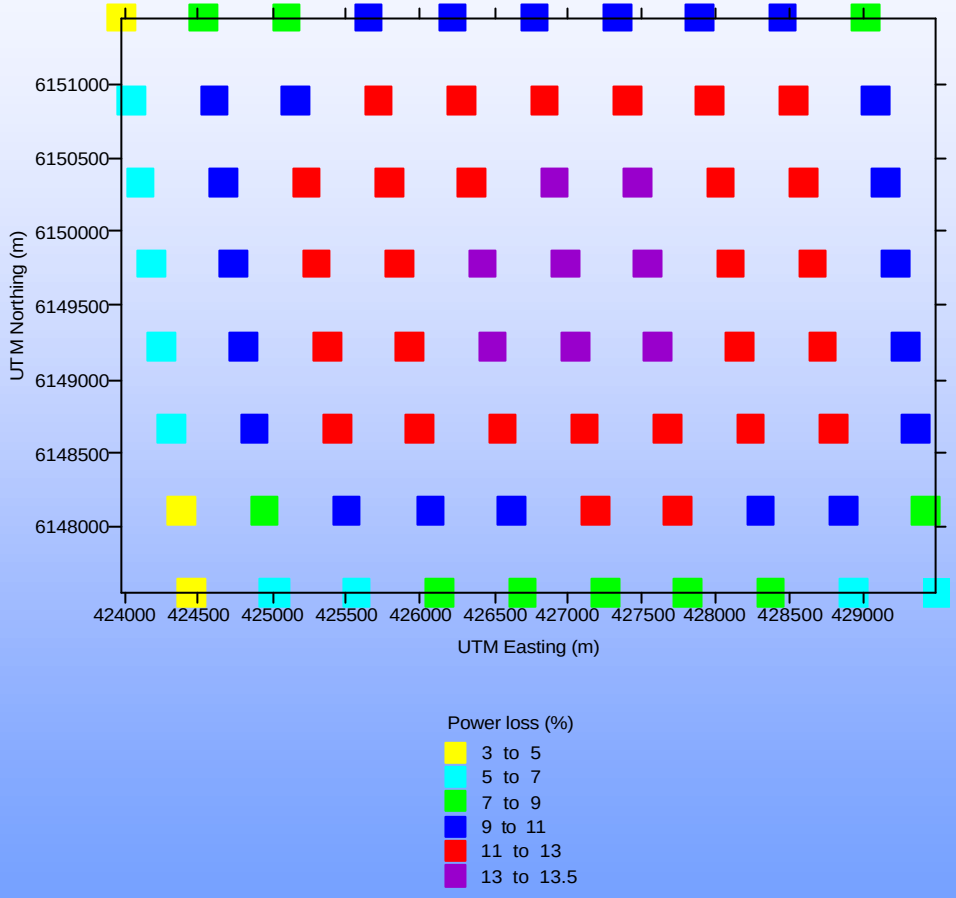
Forecasts at Middelgrunden

RMSE share of P(inst)

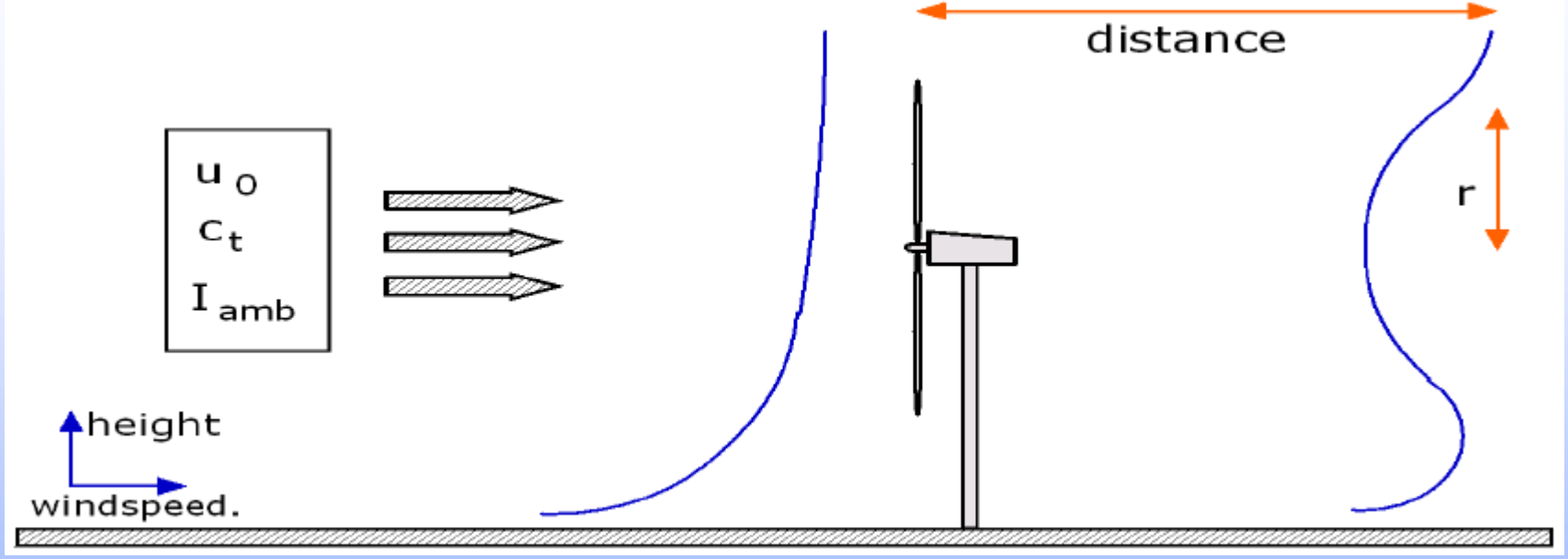


Wakes

- Total wakes ~10 % power loss but individual wake losses much larger
- Likely the single largest correction for short-term prediction for large offshore wind farms



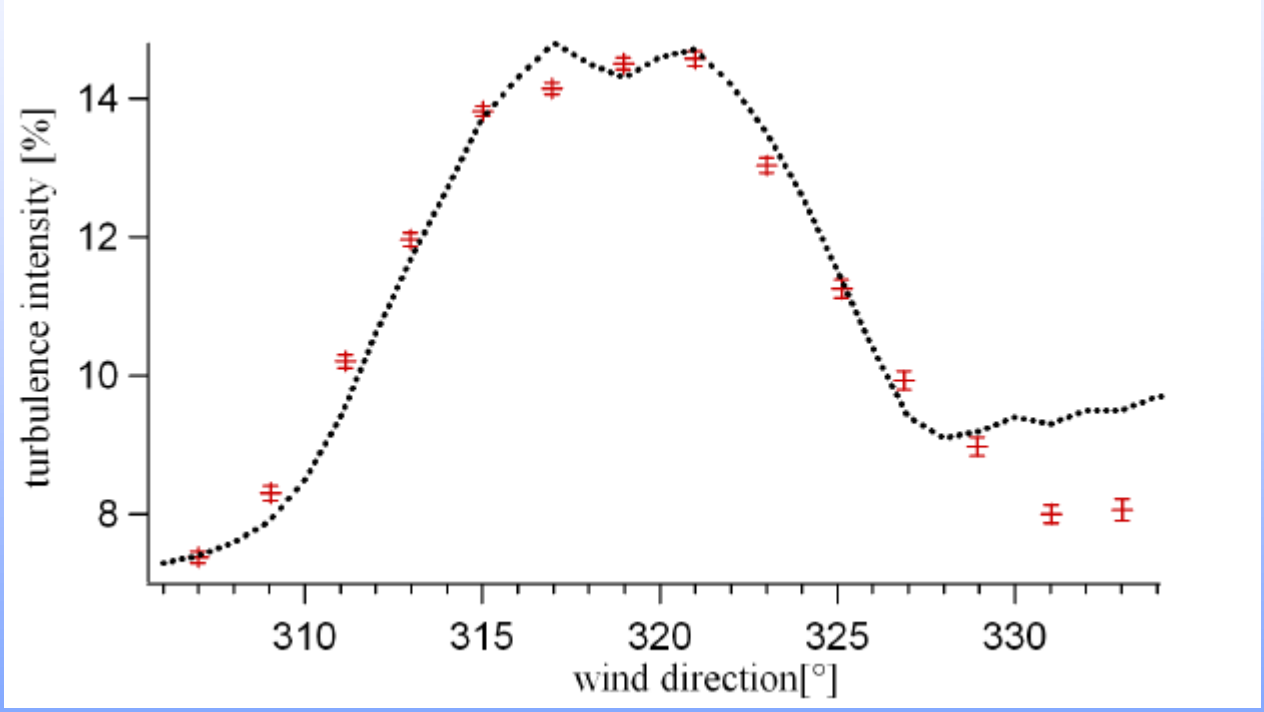
Wakes



- New algorithm: Ainslie model with added turbulence intensity following Magnusson [1996]
- Based on Reynolds equation with boundary layer approximation
- Eddy viscosity closure
- Modified gaussian distribution of speed losses after two rotor diameters

Wakes

- **Oldenburg Model results reproduce Quintuple Wake**

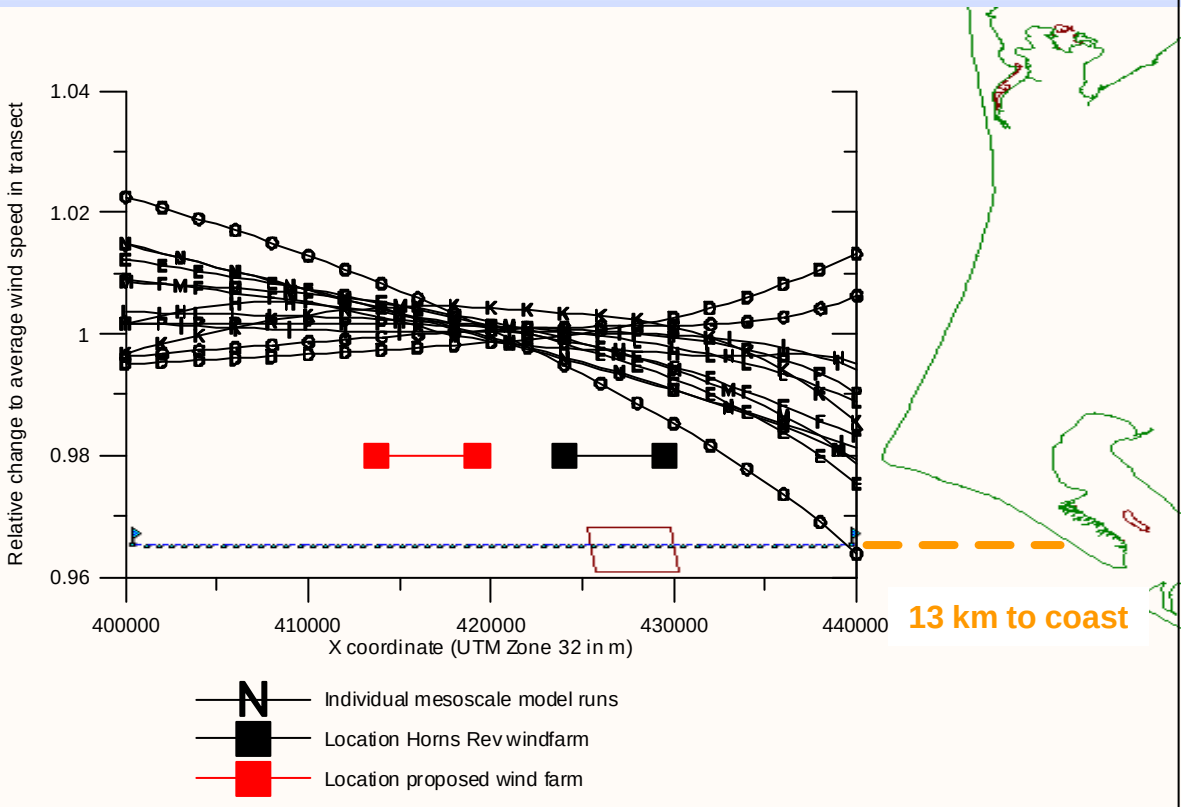


Quintuple Wake (wind direction 320°)

Horizontal turbulence intensity profiles from multiple wake situation at Vindeby wind farm.

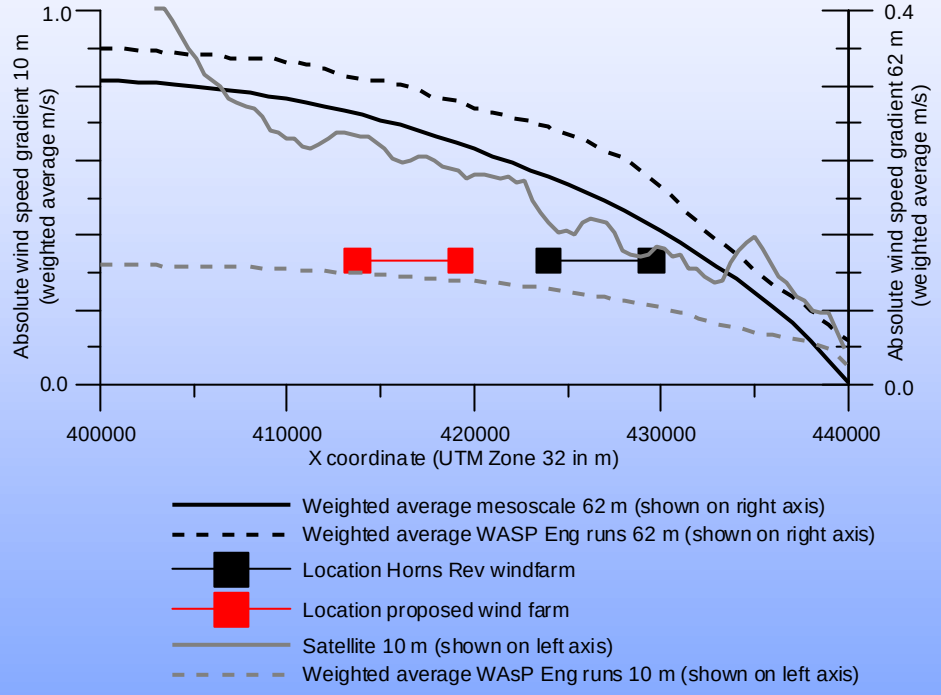
Wind speed gradients

- Wind farms >20 km², >20 km from the coast
- One wind speed prediction from e.g. NWP model
- Is the gradient across the wind farm important?
- Quantified:
  - Mesoscale (16 runs)
  - WAsP Engineering
  - Satellite

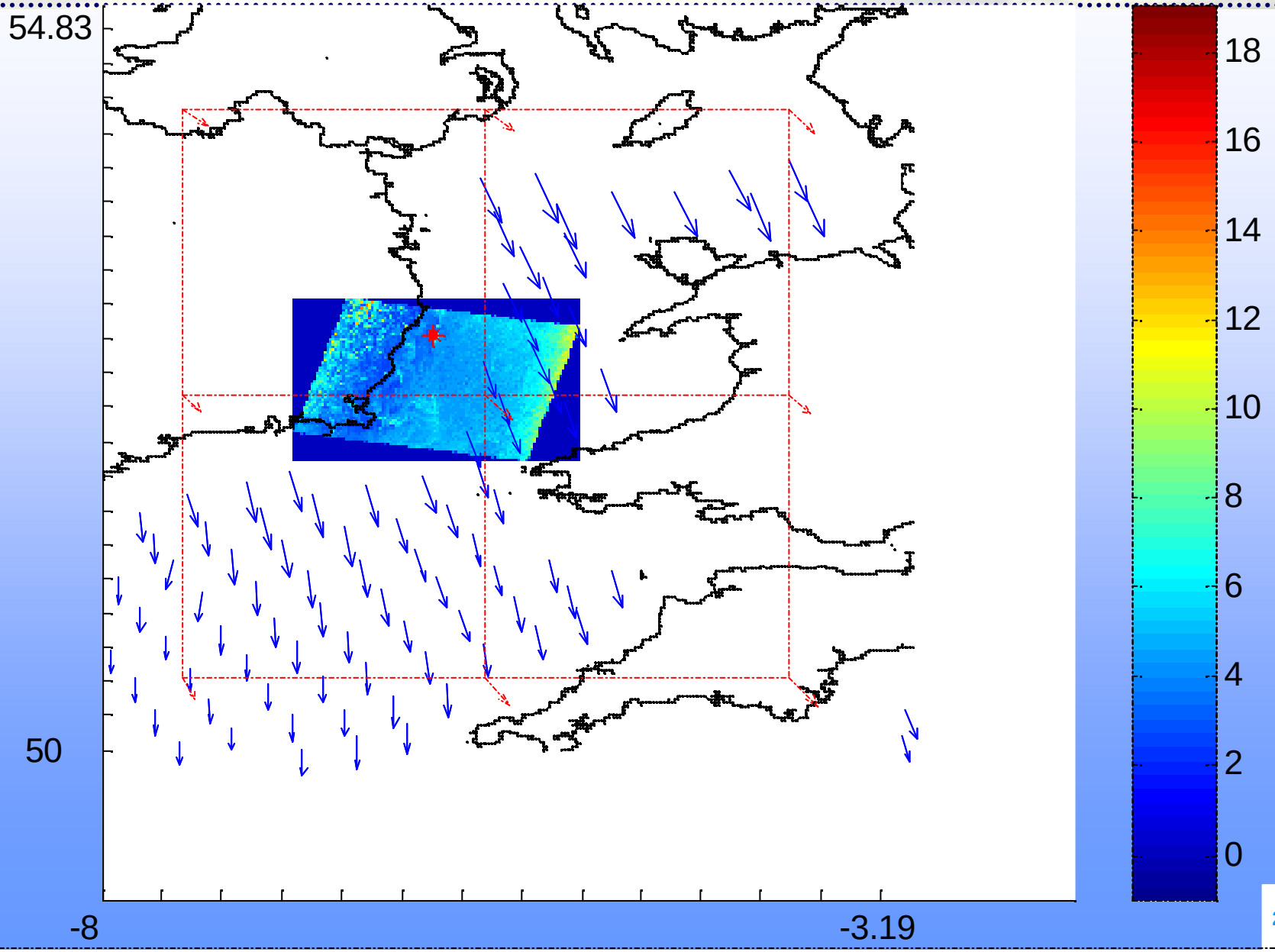


Wind speed gradients

- Gradient over the wind farm <0.1 m/s for all but one run
- Mean weighted gradient ~0.4 m/s over 40 km
- Similar predictions from WAsP Engineering (same 16 runs, weighted)
- For satellite mean gradient is ~0.8 m/s (at 10m)
- Wind speed gradients across wind farms too small to be significant



Benefits of Satellite-Radar Information



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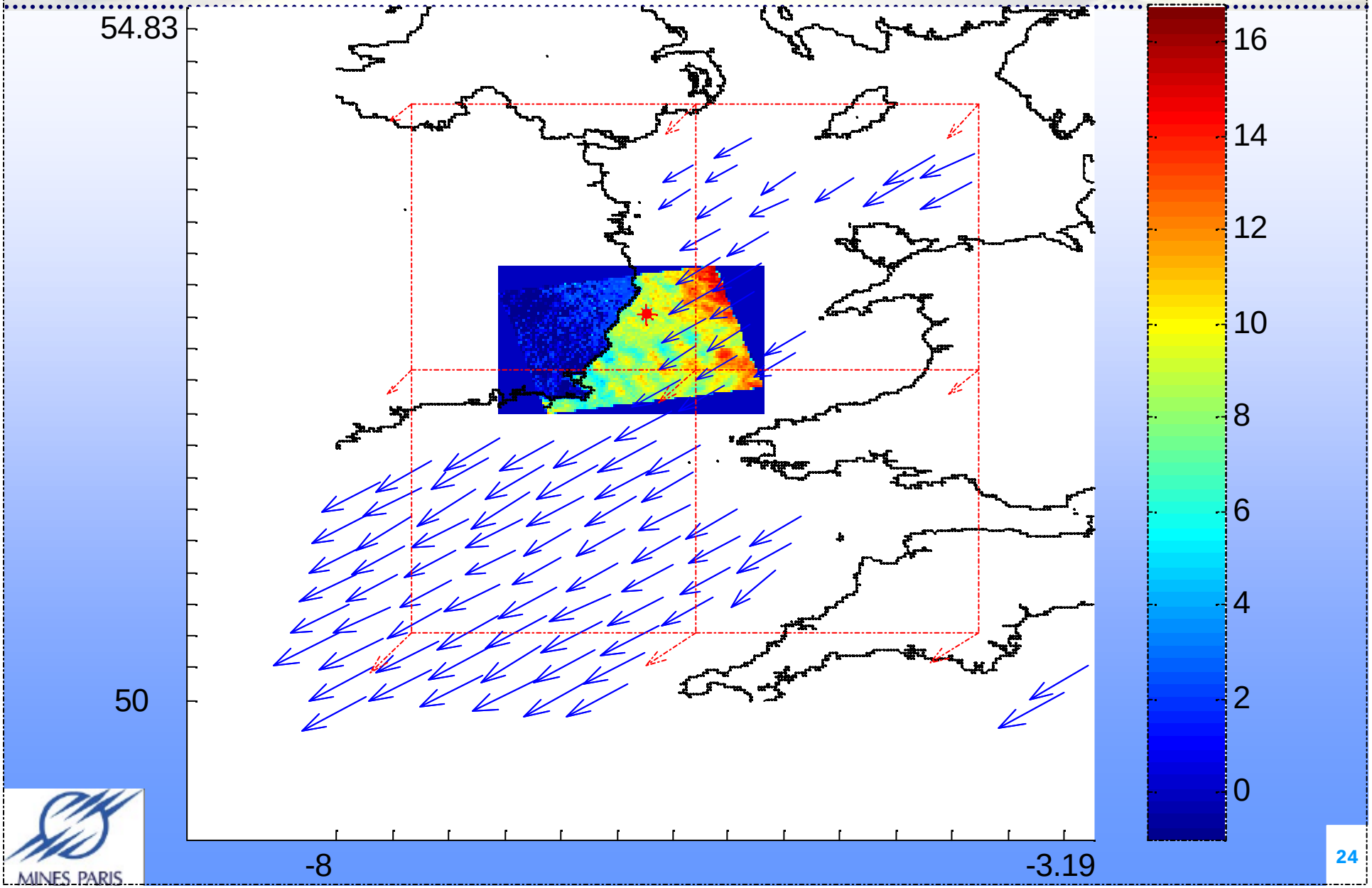
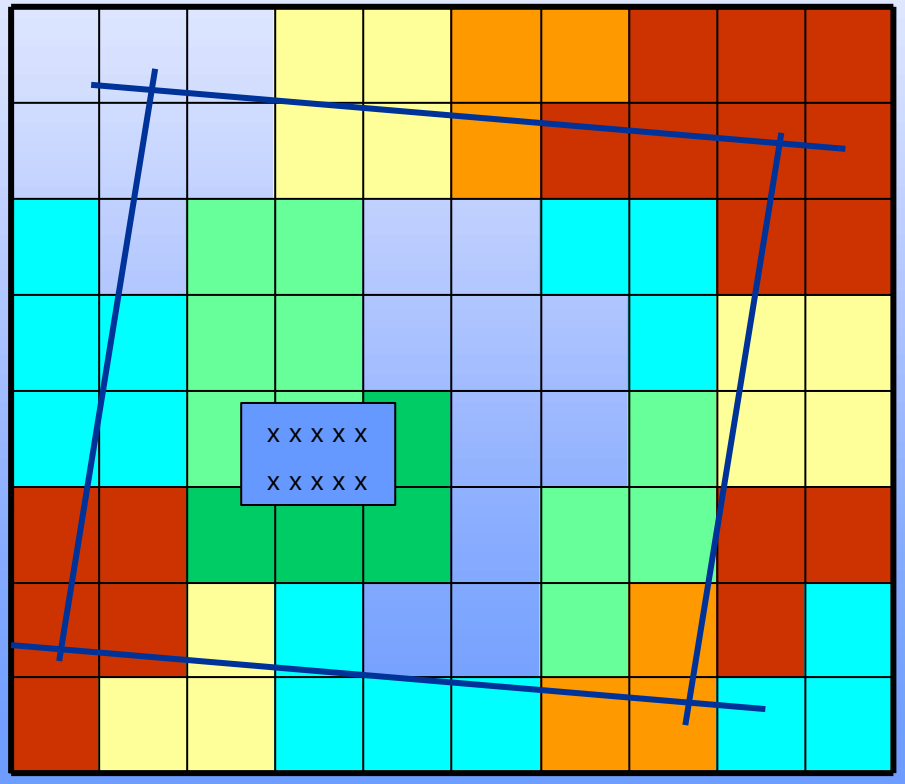


Benefits of Satellite-Radar Information

Horizontal distribution of wind fields



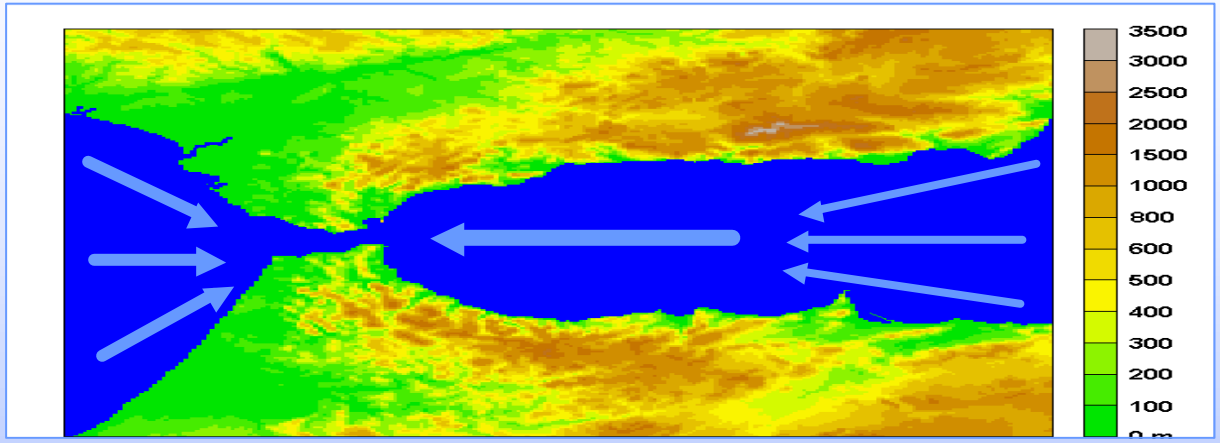
NWP Grid

x x x x x
x x x x x

Wind farm

Wind patterns with pdf linked with weather situations

Forecasts at Gibraltar



- NWP models don't reproduce the channelling effect at the Gibraltar Strait
- ECMWF and other global models do not use the actual topography
- Tarifa is the place with largest NWP's forecasting errors in Spain
- Local adaptation of wind prediction for TARIFA and Gibraltar Strait area
- Inputs: ECMWF prediction and reanalysis data and local data from I.N.M. Station in Tarifa
- Application of Perfect Prognosis (P.P.) Technique.
  - Semi-empiric, similar to M.O.S.
  - Objective: To find a physical and mathematical relation between the wind speed and the state of the atmosphere (other atmospheric variables well predicted by global models)
  - Appropiate combination of meteorological variables based on the local wind behaviour
  - The same equation for any horizon
- Ten different cases: easterlies, westerlies and calms for different seasons
- Module for errors evaluation

Conclusions

- **Offshore wind power predictions evaluated:**

  FiNO1, Tunoe Knob, Middelgrunden:

  - Relatively good results compared to onshore with respect to the higher power output;

- **Main parameters of vertical wind speed profiles identified:**

  Crucial impact of coastal effects and thermal stratification quantified

- **Simulation of the wind flow in the marine boundary layer and in offshore wind parks:**

  New wind profile and wake models developed and evaluated

- **Several prediction models for large offshore windfarms**

  & a satellite image method developed