Wave Forecasting for Offshore Wind Farms

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**Wave Forecasts are required for Offshore Wind Farms for**

- construction (on site, and to and from the site)

- maintenance

Offshore Wind Farms are often located

- in shallow areas

- on top of shoals or reefs

The paper presents

- the development of shallow water wave forecasts for use at offshore wind farms sites

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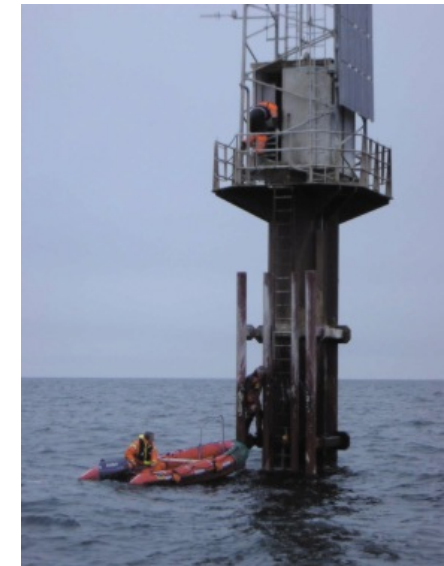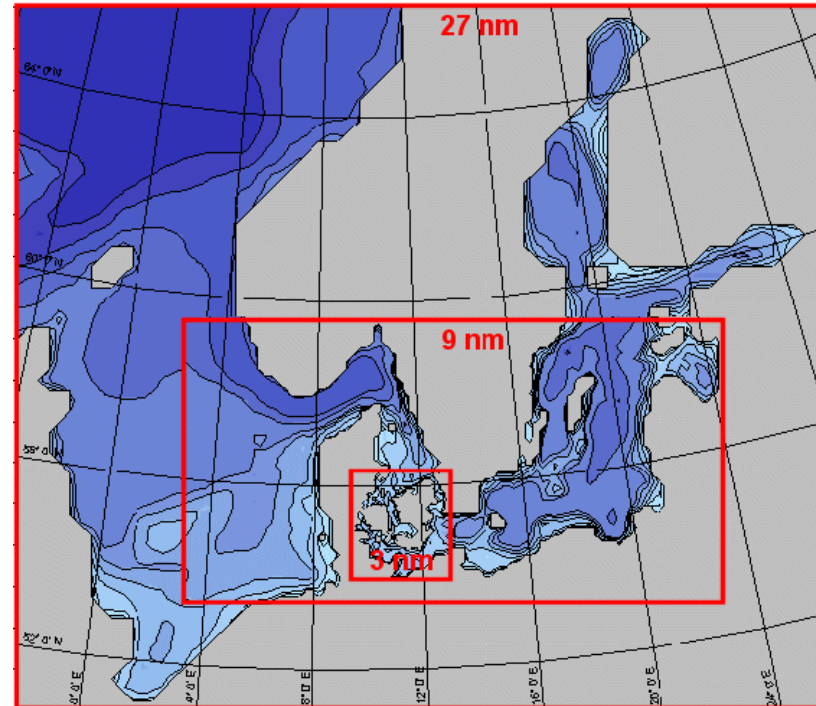
How are the requirements for accurate wave forecasts met:

- based on existing wave forecasting system

- introduction of flexible computational mesh

- introduction of local online measurements

- definition of swell in accordance with user experience
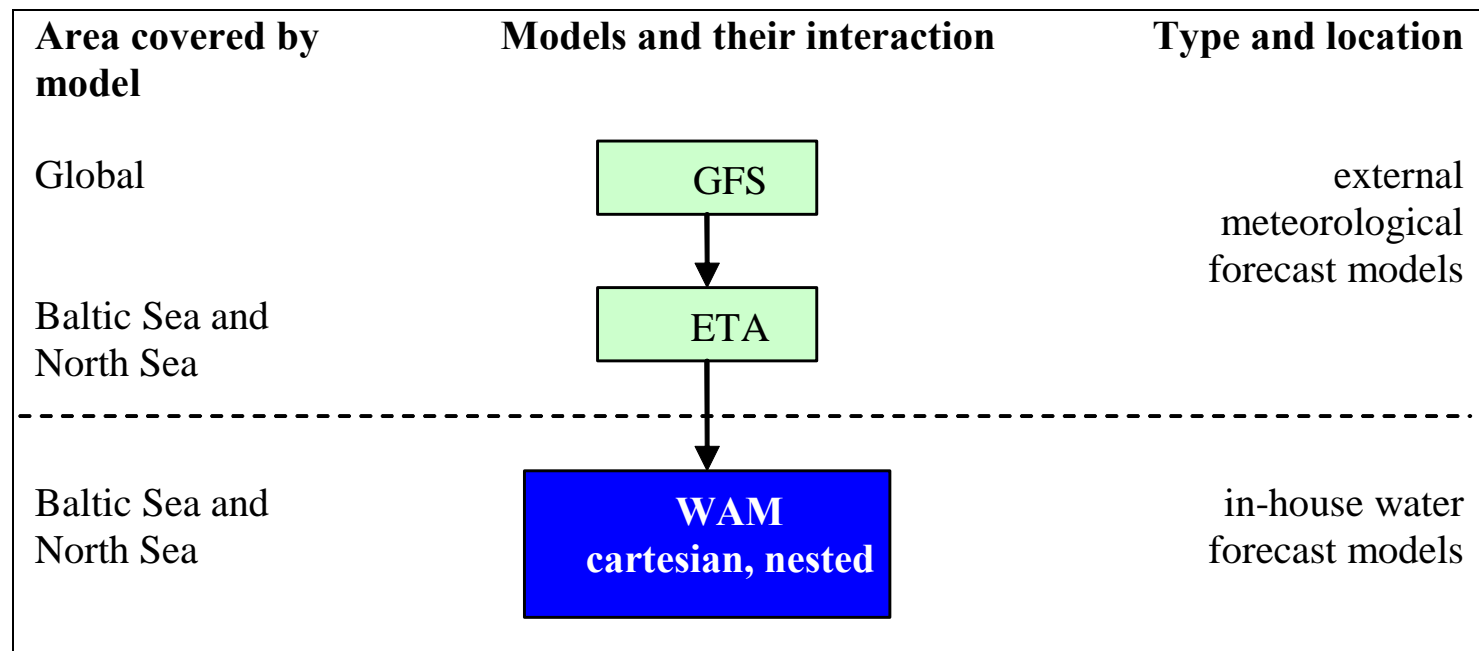
The Water Forecast

The Water Forecast

- General 5 days forecasting service for North Sea and Baltic Sea

- Wave modelling using DHI's WAM Cycle 4 implementation called MIKE 21 SW

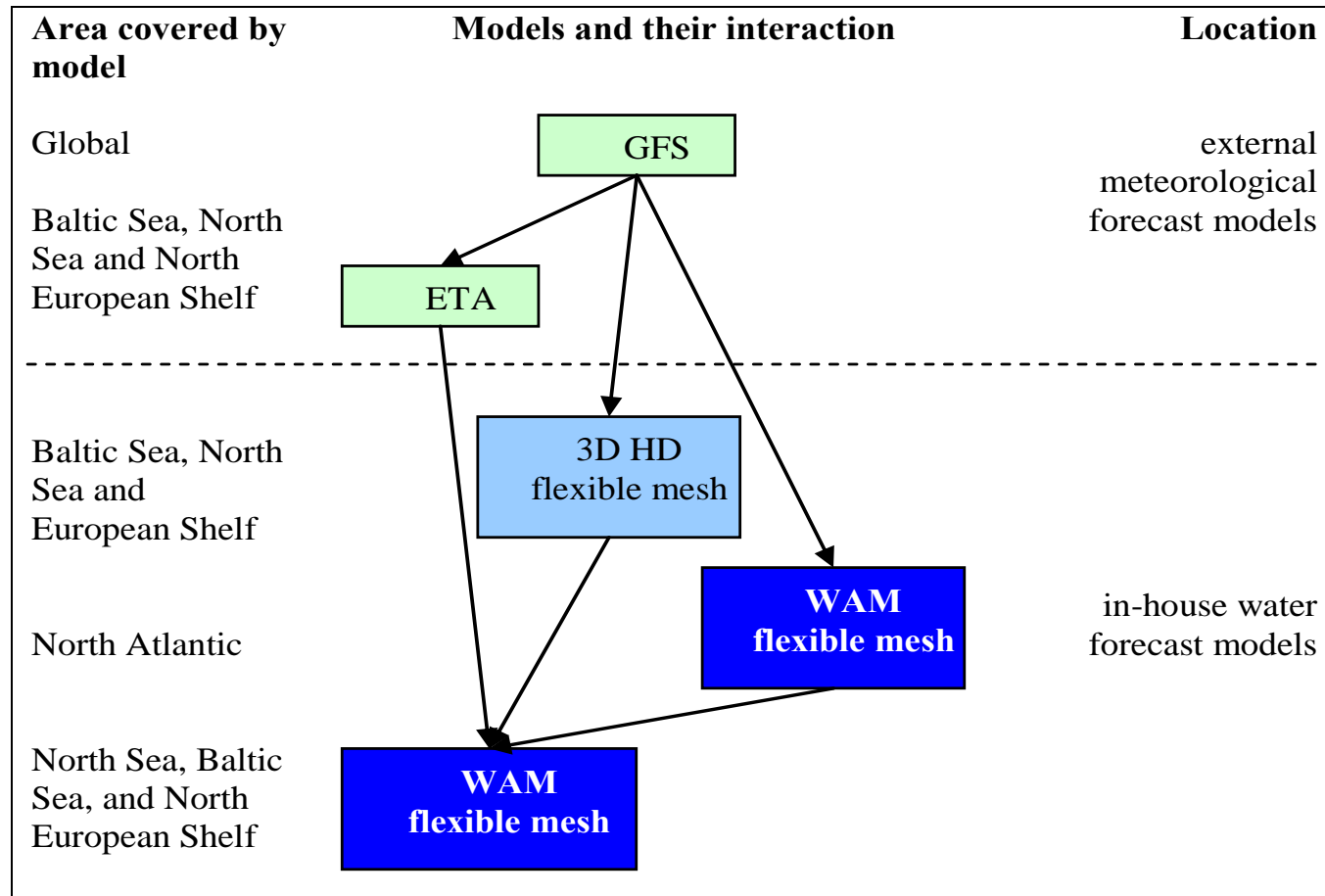- 2001: wave model using nested cartesian grids

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Wave forecast model set-up

Initial set-up 2001:

Area covered by model	Models and their interaction	Type and location
Global	GFS	external meteorological forecast models
Baltic Sea and North Sea	ETA	
Baltic Sea and North Sea	**WAM cartesian, nested**	in-house water forecast models

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Wave forecast model set-up

Set-up 2006:

Area covered by model	Models and their interaction	Location
Global	GFS	external meteorological forecast models
Baltic Sea, North Sea and North European Shelf	ETA	
Baltic Sea, North Sea and European Shelf	3D HD flexible mesh	
North Atlantic	WAM flexible mesh	in-house water forecast models
North Sea, Baltic Sea, and North European Shelf	WAM flexible mesh	

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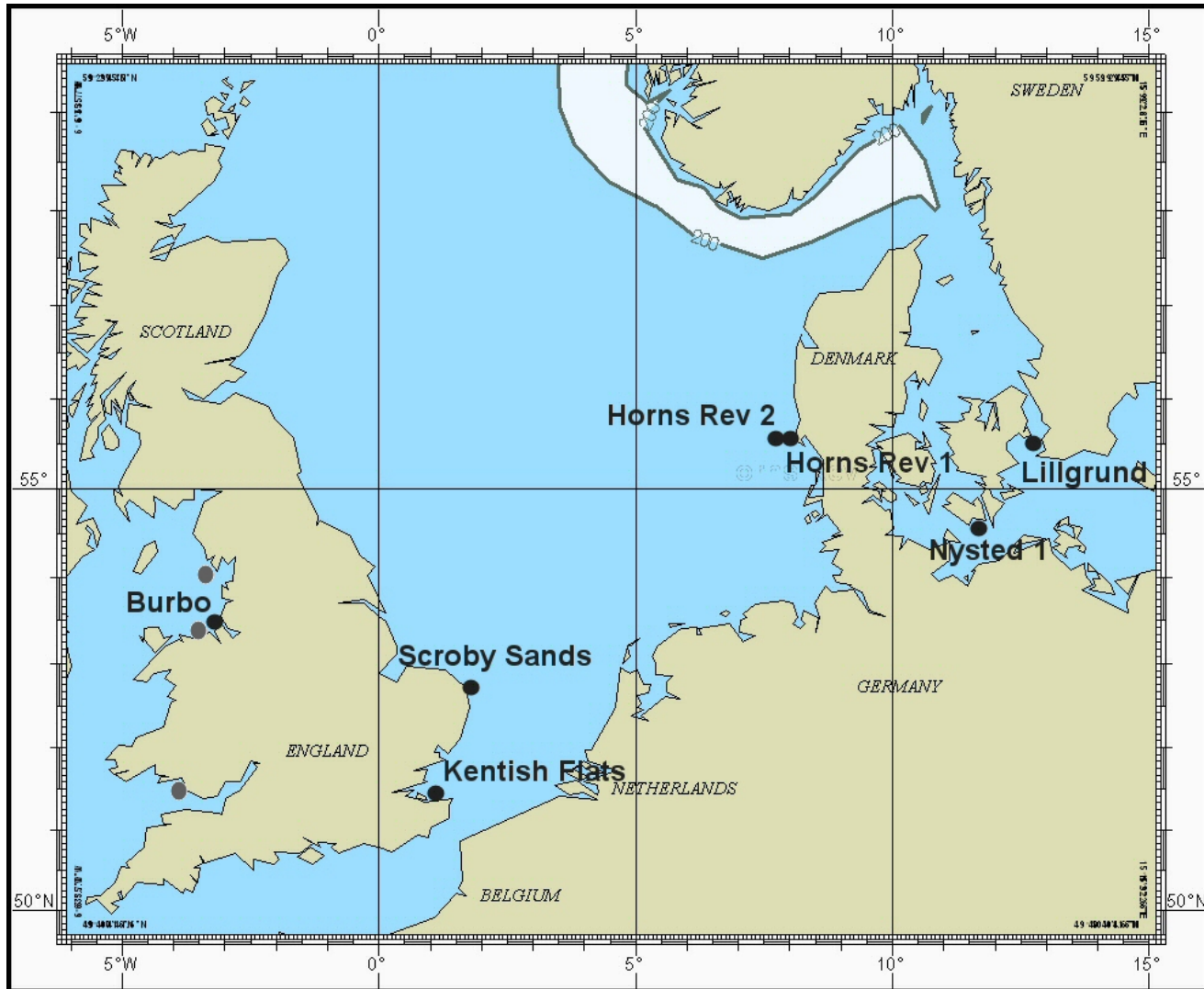
Wave forecast model set-up
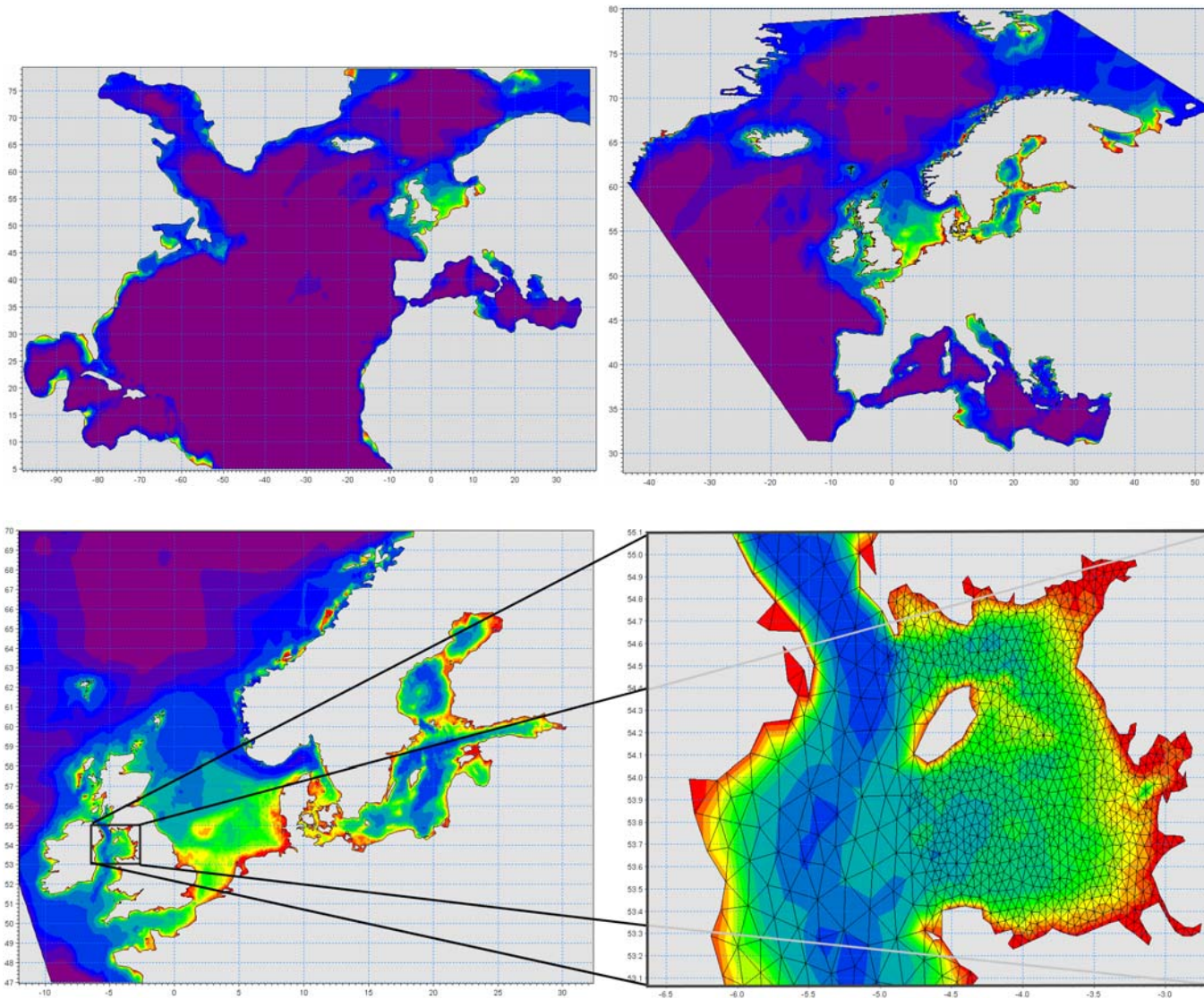
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Operational Wave Forecasting

Offshore Wind Farm	ANN	Capacity	Status (Sep 2006)
Nysted 1, Baltic Sea, Denmark	No	72 turbines, 166 MW	operational
Horns Rev 1, North Sea, Denmark	Yes	80 turbines, 180 MW	operational
Scroby Sands, North Sea, UK	No	30 turbines, 60 MW	operational
Kentish Flats, North Sea, UK	No	30 turbines, 90 MW	operational
Lillgrund, The sound, Sweden	(Yes)	48 turbines, 110 MW	under construction
Horns Rev 2, North Sea, Denmark	Yes	~100 turbines, 200 MW	being designed
Burbo, Irish Sea, UK	(Yes)	25 turbines, 90 MW	under construction

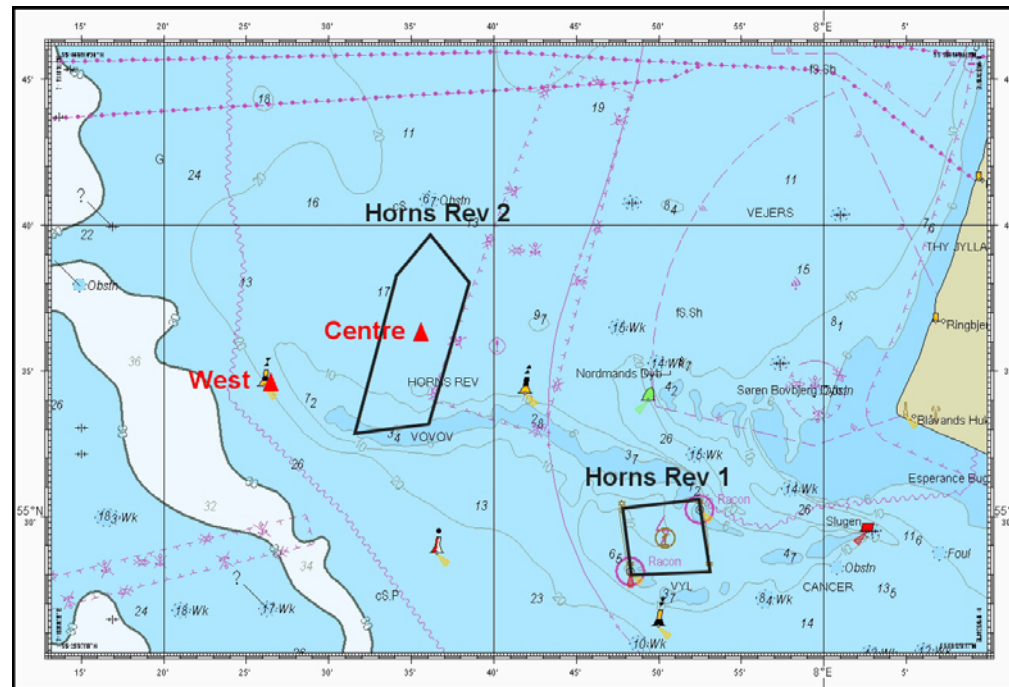# Operational Wave Forecasting

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Horns Rev 2 Offshore Wind Farm
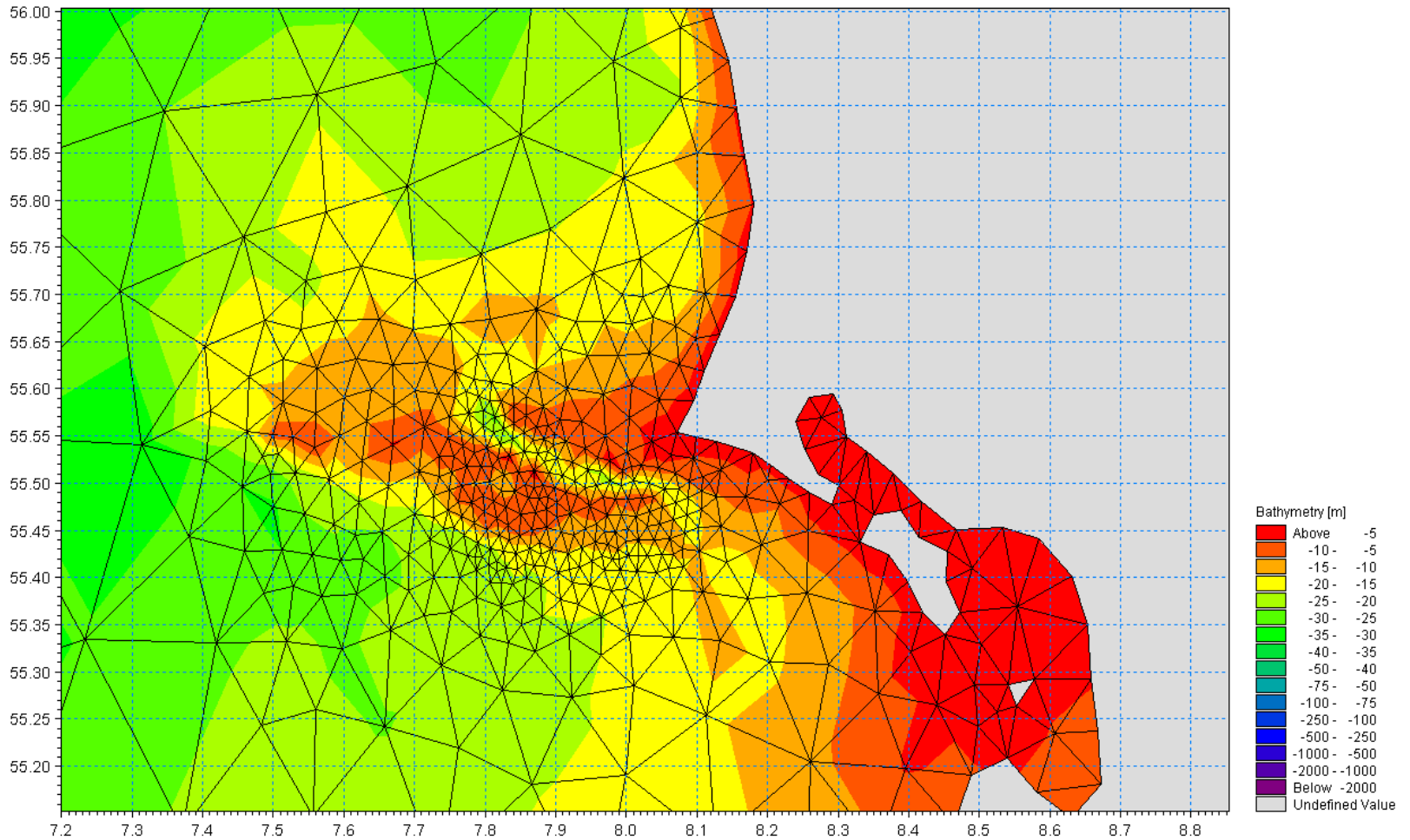
Horns Rev 2: Example with

- flexible mesh refinement
- online measurements used for ANN corrections
- revised swell definition

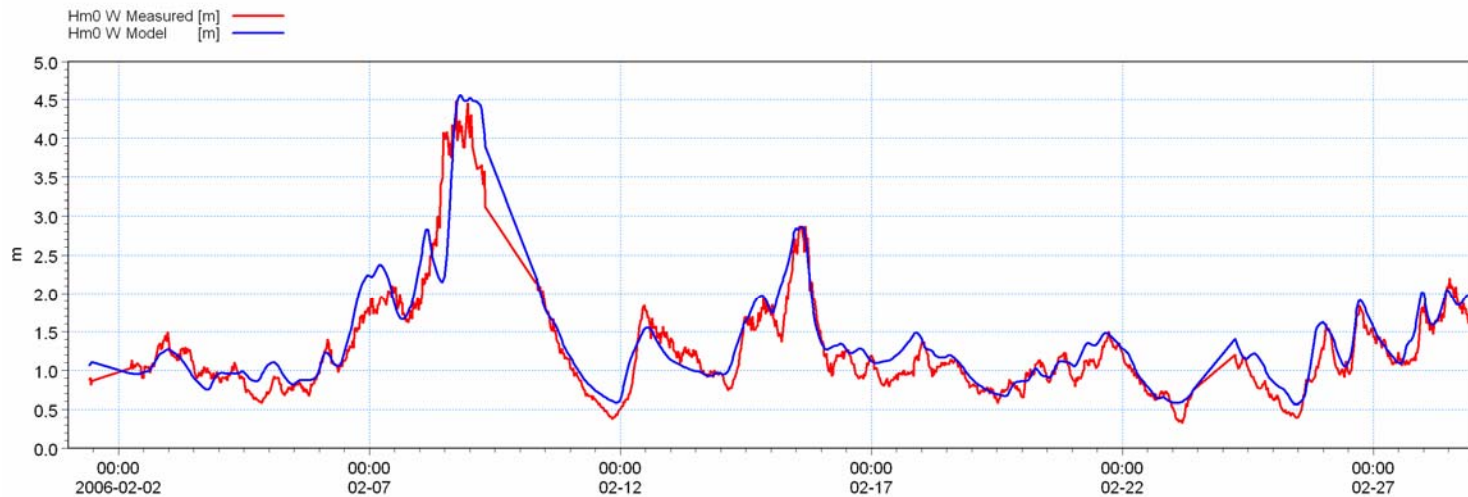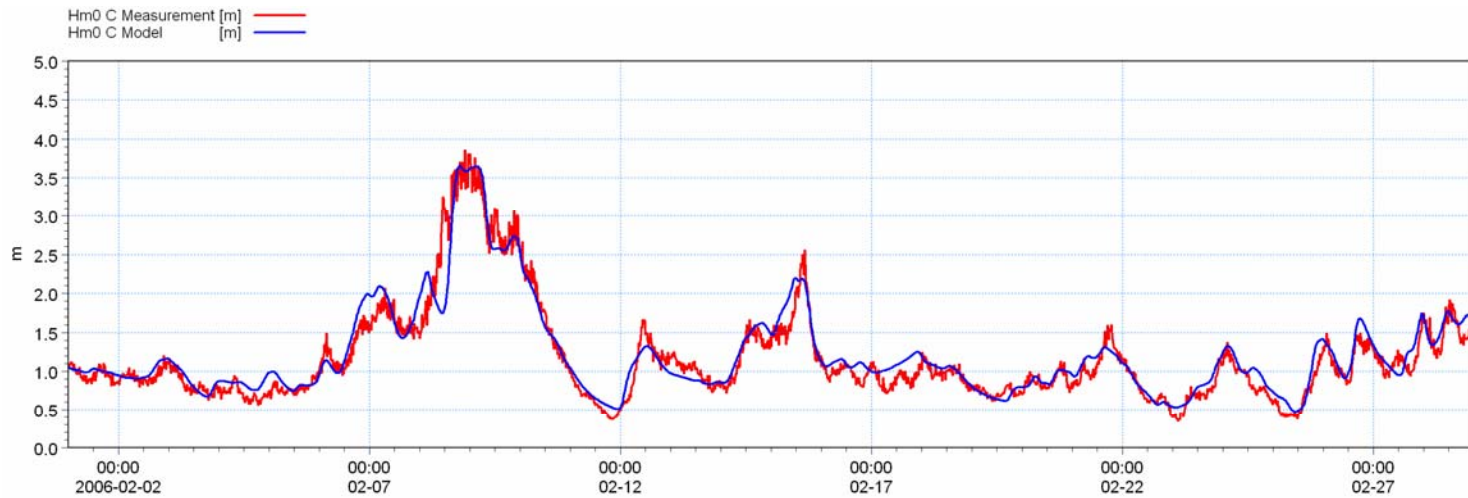*9th International Workshop on Wave Hindcasting and Forecasting, 24 – 29 September 2006*

Horns Rev 2 Offshore Wind Farm

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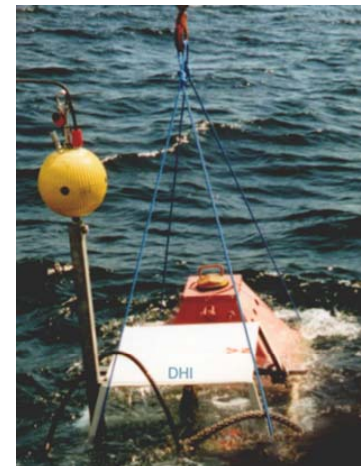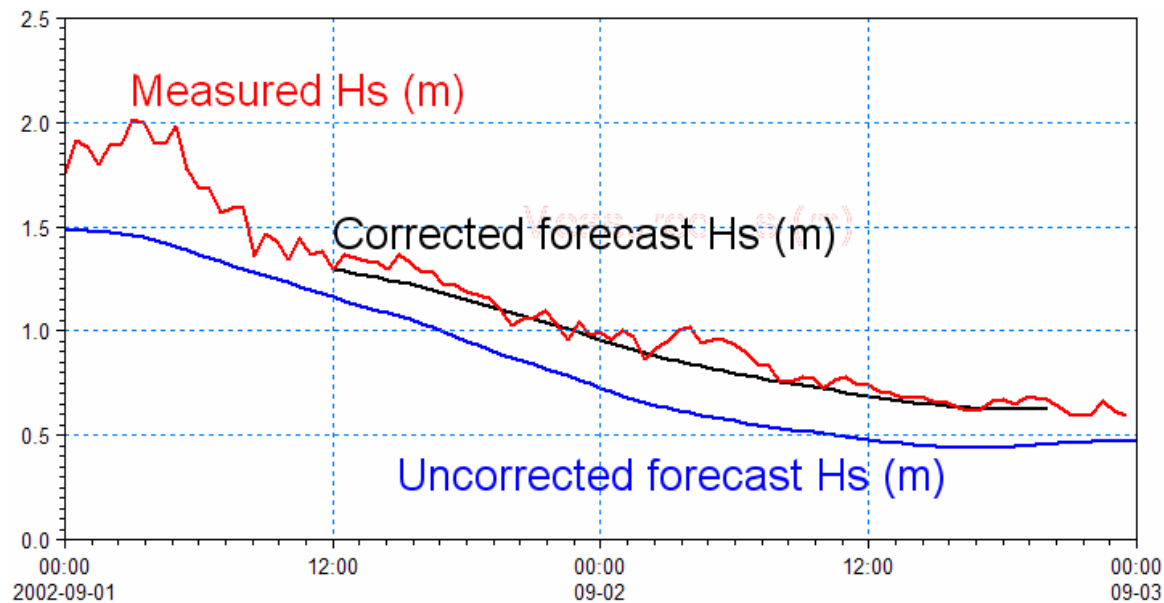
Horns Rev 2 Offshore Wind Farm

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Horns Rev 2 Offshore Wind Farm

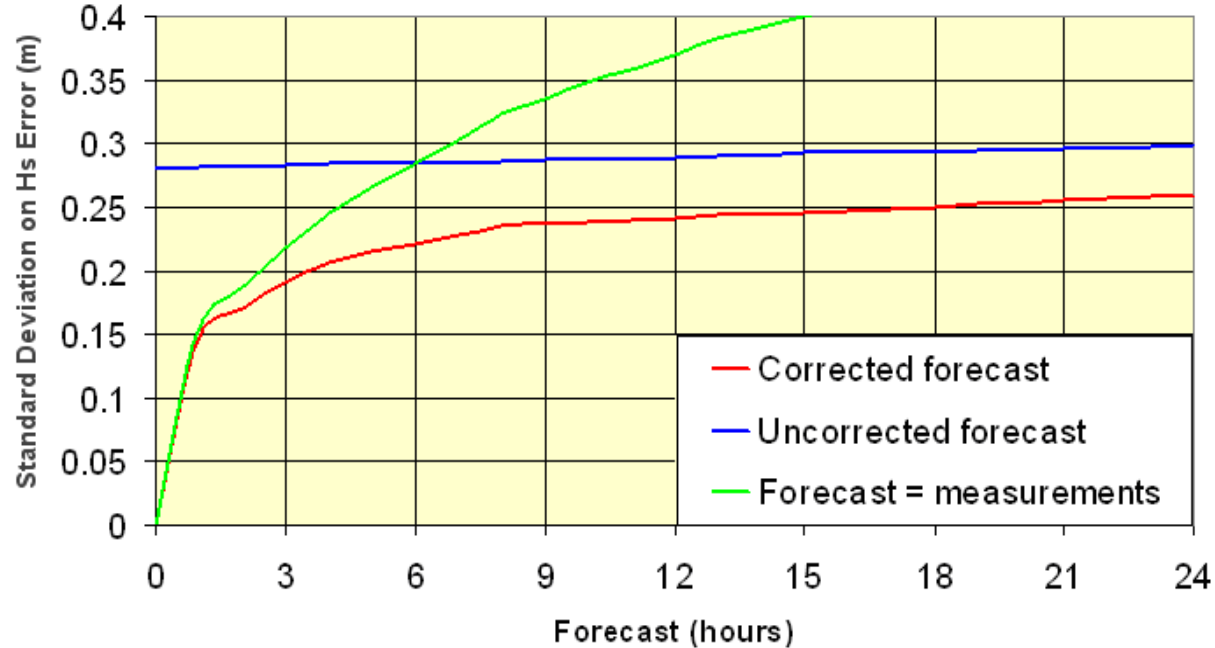| Parameter	Mean (m) or (s)	Bias (m) or (s)	Bias/Mean	RMS (m) or (s)	Scatter Index	Corr. Coeff.	Time Steps
H_{m0} West	1.25	0.10	0.08	0.25	0.20	0.94	1191
H_{m0} Centre	1.16	0.05	0.04	0.18	0.16	0.96	2014
T_{02} West	4.44	-0.28	-0.06	0.51	0.12	0.86	1191

Horns Rev 2 Offshore Wind Farm

Procedure for Artificial Neural Network correction

- online wave measurement from site every hour
- ANN corrected wave forecast issued every hour

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Horns Rev 2 Offshore Wind Farm

Effect of Artificial Neural Network correction

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Swell definitions

1. Constant threshold wave frequency and wind direction criterion

$f < f_{threshold}$ or $\cos(\theta - \theta_{wind}) < 0$

where $f_{threshold}$ is constant (e.g. 0.125 s)

2. Dynamic threshold wave frequency and wind direction criterion

$f < f_{threshold}$ or $\cos(\theta - \theta_{wind}) < 0$

where $f_{threshold} = 0.7\, f_{p,PM}\, (E_{PM}/E_{total})^{0.31}$
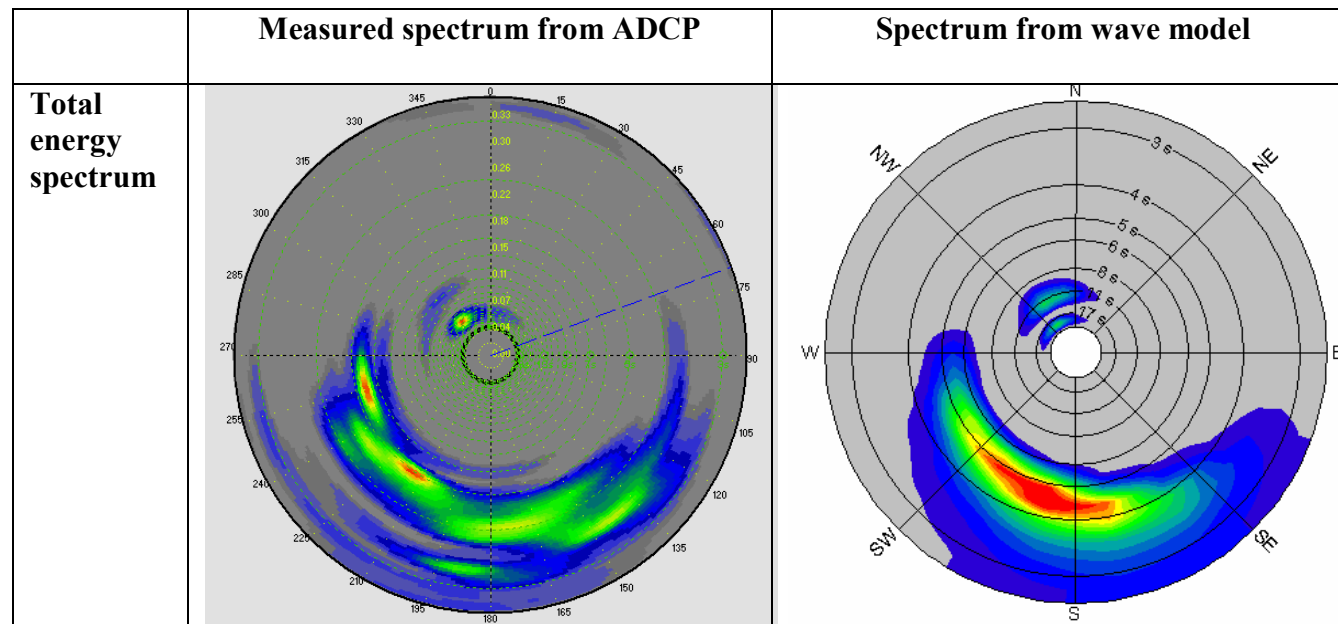
with $f_{p,PM} = 0.14\, g/U_{10}$ and $E_{PM} = (U_{10}/1.4\, g)^4$

Swell definitions

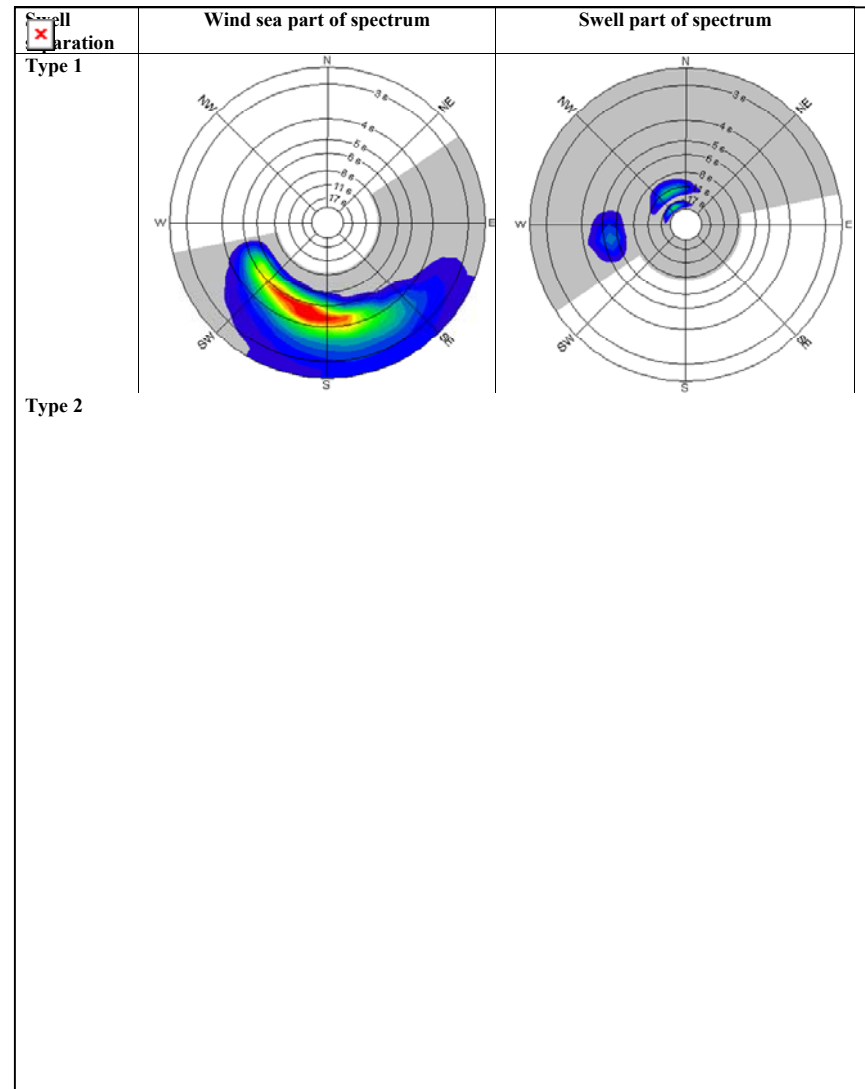## 3. Dynamic threshold wave frequency based on wave age criterion

$$U_{10}/c \cos(\theta - \theta_{wind}) < 0.83$$

Example 2006-02-14 08:00 UTC at Horns Rev 2 C

Swell definitions

Swell separation	Wind sea part of spectrum	Swell part of spectrum
Type 1		
Type 2		

Example 2006-02-14 08:00 UTC at Horns Rev 2 C

Type of separation	Part of spectrum	Hm0 (m)	T02 (s)	Tp (s)	θ_{mean} (deg)	θ_{peak} (deg)
1	Wind sea	1.07	3.2	4.5	172	180
1	Swell	0.50	5.5	20.3	293	248
2	Wind sea	1.07	3.2	4.5	172	180
2	Swell	0.50	5.5	20.3	293	248
3	Wind sea	0.92	2.9	4.1	161	180
3	Swell	0.74	4.7	5.1	244	225
Model	Total	1.18	3.4	4.6	183	180
Measured	Total	1.04	4.5	21.3	332	328
Measured[1]	Total	1.14	4.5	4.2	164	163

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Wave Forecasting

Conclusions

- The need for detailed wave forecasts for offshore wind farms has pushed the development of more accurate shallow water wave forecasts

  » flexible mesh

  » continuously updated forecast based on measurements

  » swell forecast adjusted to meet user experience

- Benefits also to other user groups

Thank You
for Your Attention