Photo: Einar Egeland

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Wave power in the North Sea

Birgitte Furevik with contributions from Ole Johan Aarnes

UiB Energy Lab, GFI, Bergen

04.04.2017

Global wave power distribution

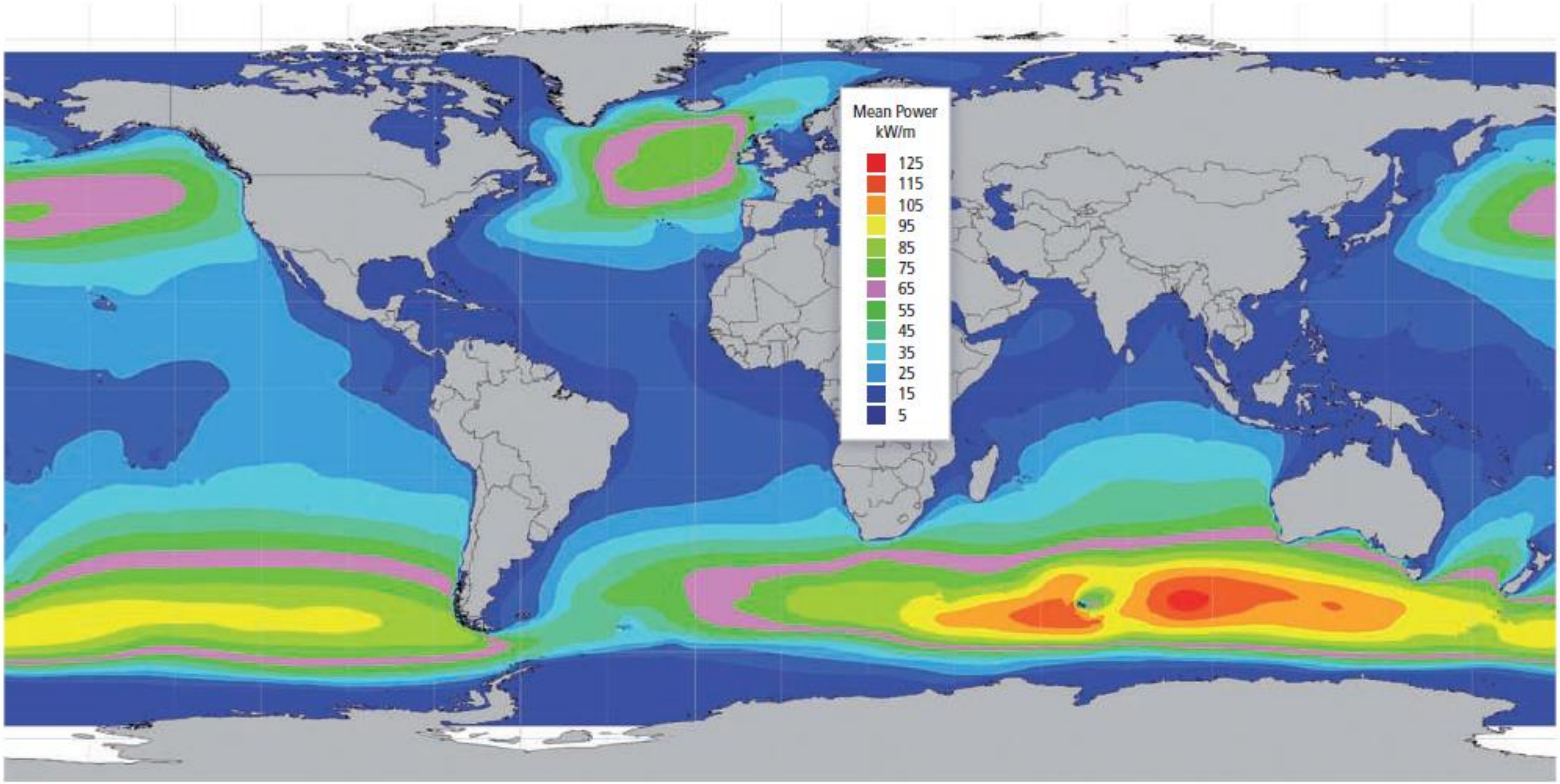

Figure 6.1 | Global offshore annual wave power level distribution (Cornett, 2008).

Wave power potential (TWh/yr)

Carbon trust UK wave energy resource (2012)

- **Total Resource** Highest overall energy availability over the area from lines of devices in optimal locations
- **Theoretical Resource** The maximum energy available in realistic optimal locations (assumed lowest cost locations) with some assumptions on power extraction
- **Technical Resource** Taking technology options into account.
- **Practical Resource** Taking sea uses and environmental impact into account

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Global energy potential

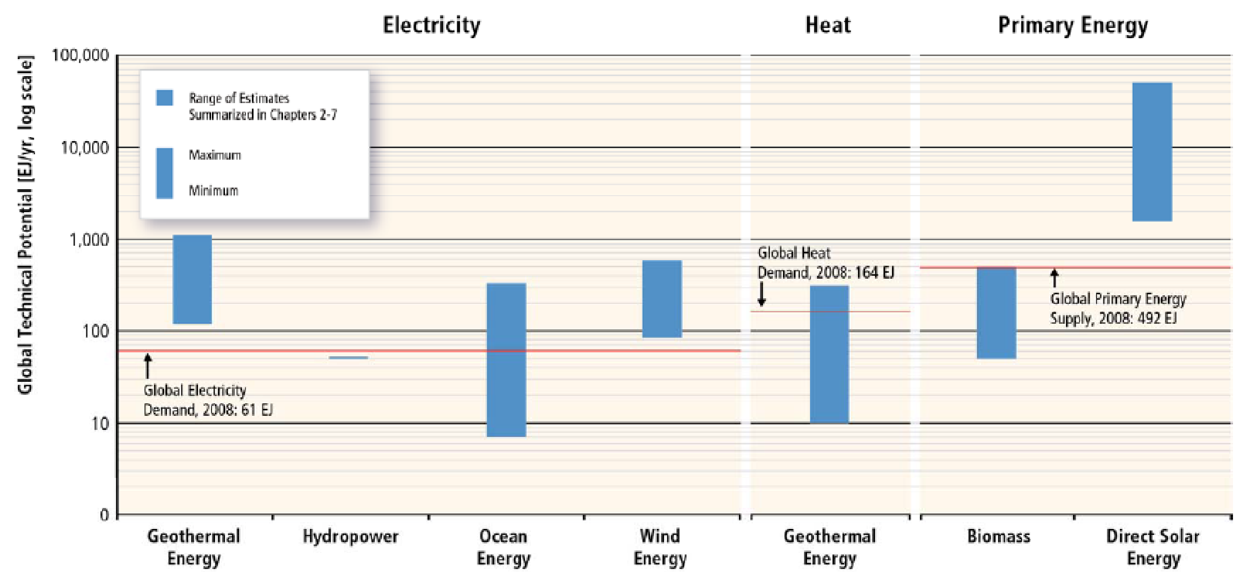
- Theoretical wave potential 32.000 TWh/yr
  - **North sea** < 5 TWh/yr is not included
- Technical wave potential 5000 TWh/yr (Large uncertainties!)

- Theoretical wind potential 1.2 million TWh/yr
- Technical wind potential 125 000 TWh/yr (19.400 TWh/yr onshore)

Sources:
- *Lewis et al. (2011) Ocean Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*
- *Wiser et al. (2011) Wind Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*
- *https://www.ipcc.ch/pdf/special-reports/srren/ipcc-srren-generic-presentation-1.pdf*
- *GWEA*
- *SSB*

- Norwegian hydropower production 145 TWh in 2015
- Global installed wind energy capacity was 487 GW in 2016

Global energy potential



Range of Estimates of Global Technical Potentials

	Geothermal Energy	Hydropower	Ocean Energy	Wind Energy	Geothermal Energy	Biomass	Direct Solar Energy
Max (in EJ/yr)	1109	52	331	580	312	500	49837
Min (in EJ/yr)	118	50	7	85	10	50	1575

Sources:

- *Lewis et al. (2011) Ocean Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*
- *https://www.ipcc.ch/pdf/special-reports/srren/ipcc-srren-generic-presentation-1.pdf*

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Estimating the coastal wave climate

Example wave power prototype at Runde

Reanalysis data set

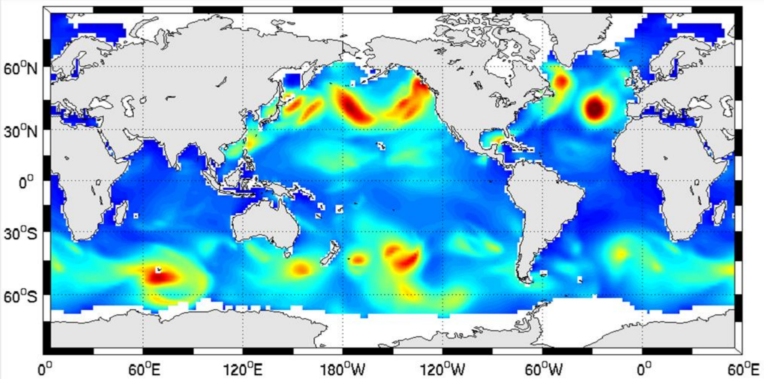
- *NORA10 – a dynamical downscaling of ERA-40 and standalone wave hindcast*

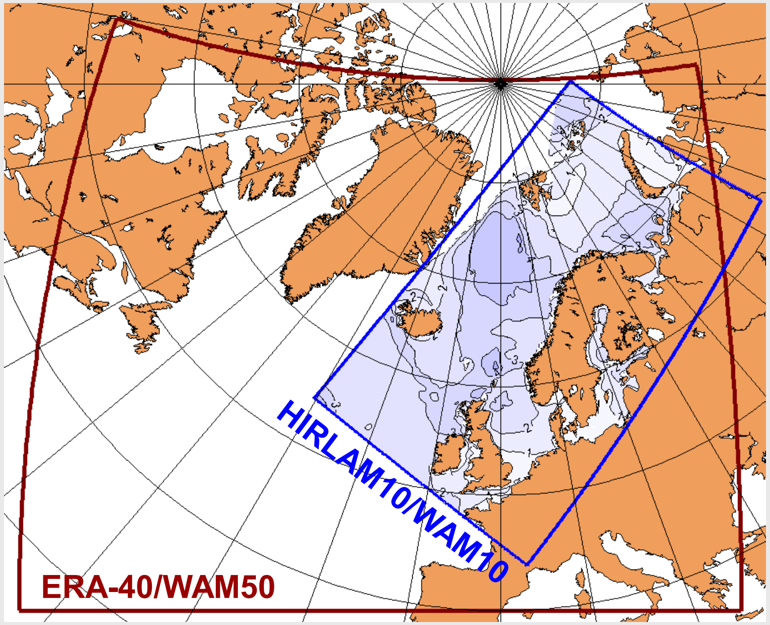
Atmospheric component – HIRLAM 10 km:

- ERA-40 on boundaries (6-hourly)
  - 40 levels: temp, wind, humidity, cloud water
  - Surface: pressure
- Blended with ERA-40 in interior (digital filter)
  - Maintain large-scale features
  - Preserve mesoscale features (polar lows)
- Sequence of 9-hour model runs (3 hourly data)
- 248 x 400 grid points

Wave component – nested WAM-model

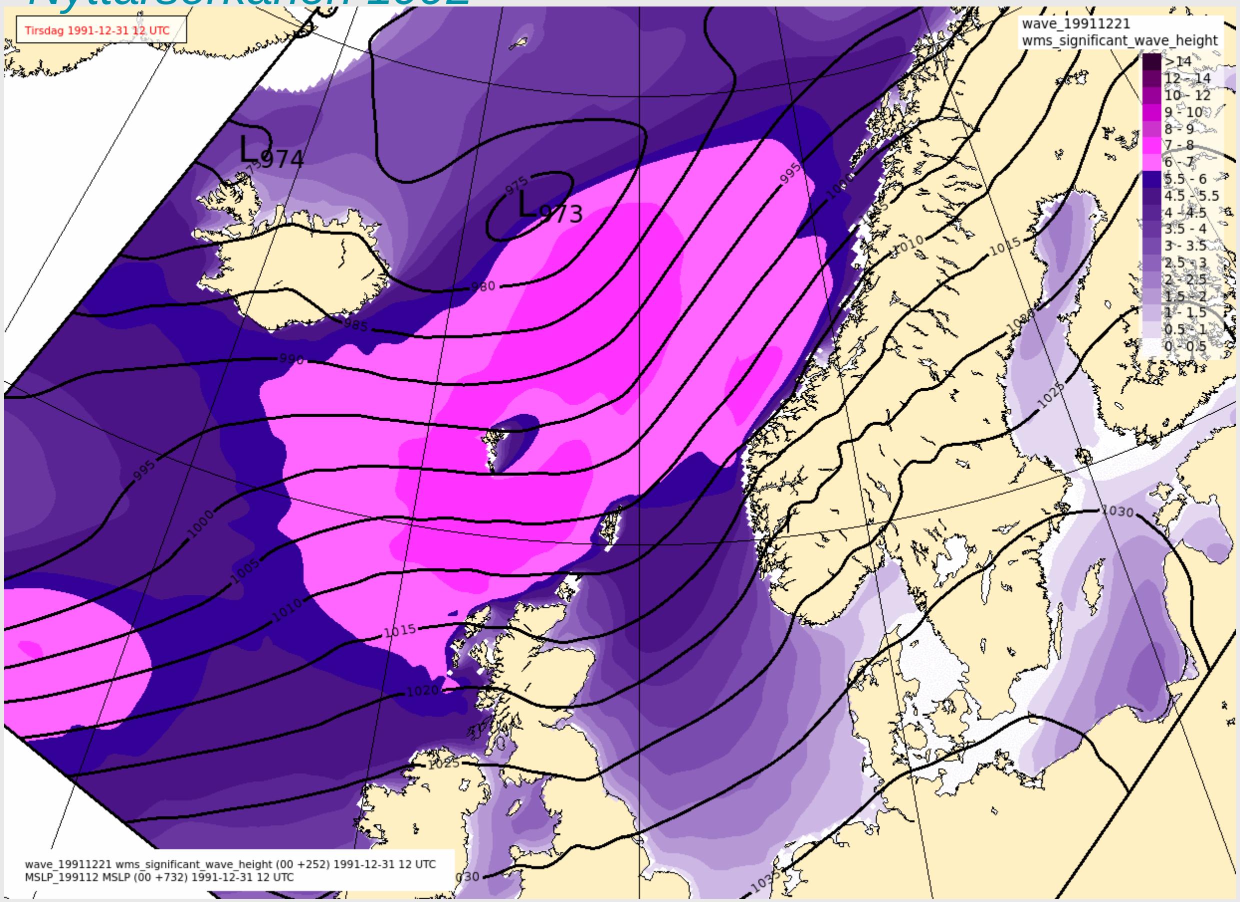
- WAM 50 km forced by ERA-40 winds
- WAM 10 km forced by HIRLAM10 winds
  - 2D spectrum: 24 by 25 directional/frequency bins
- September 1957 onwards

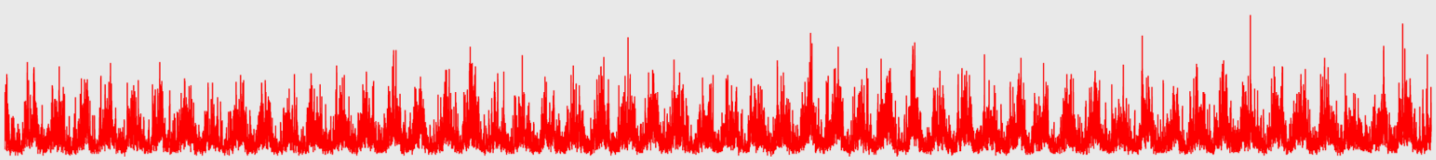




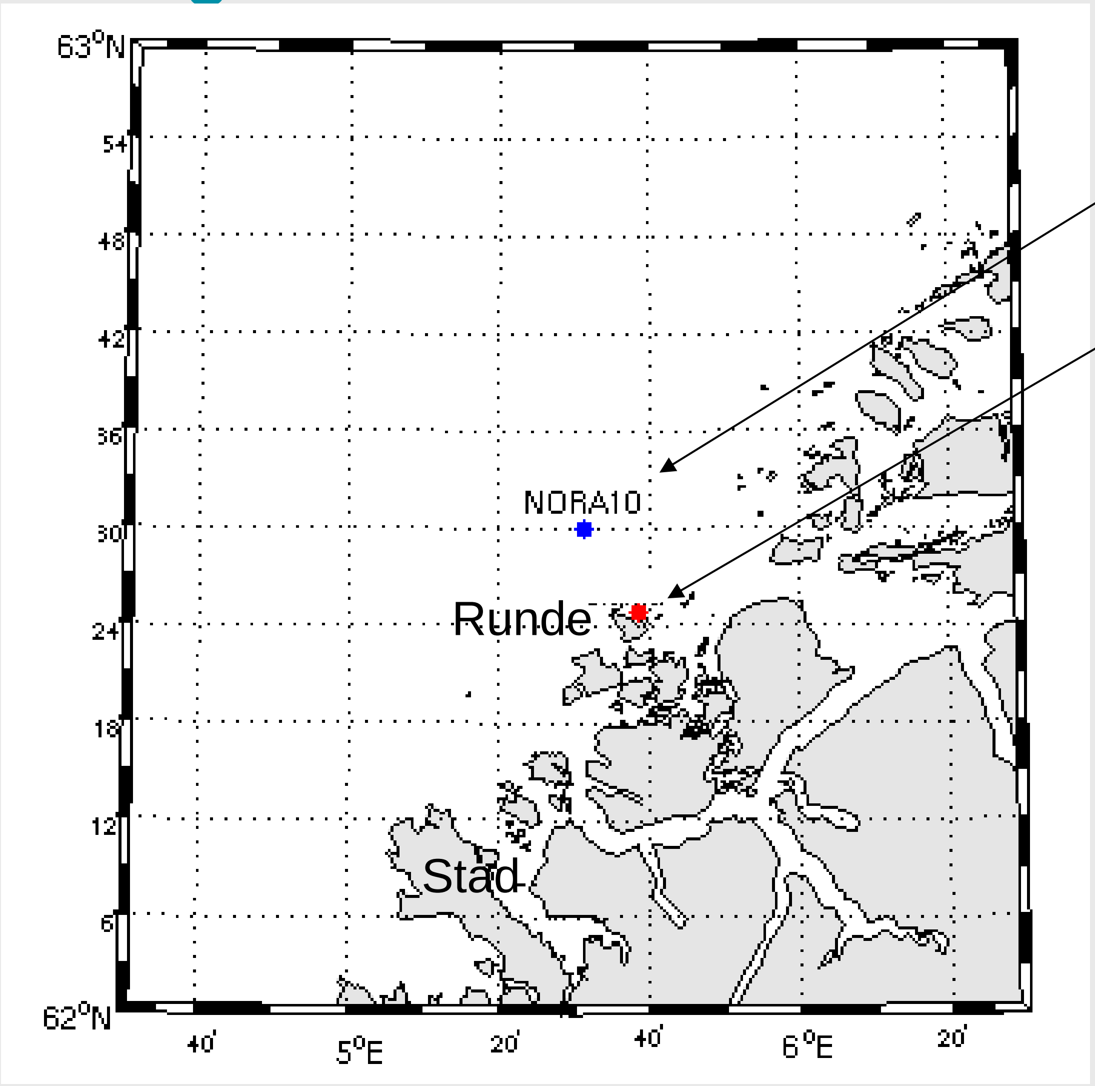
Reanalysis data set gives hourly or 3-hourly output

- *Nyttårsorkanen 1992*





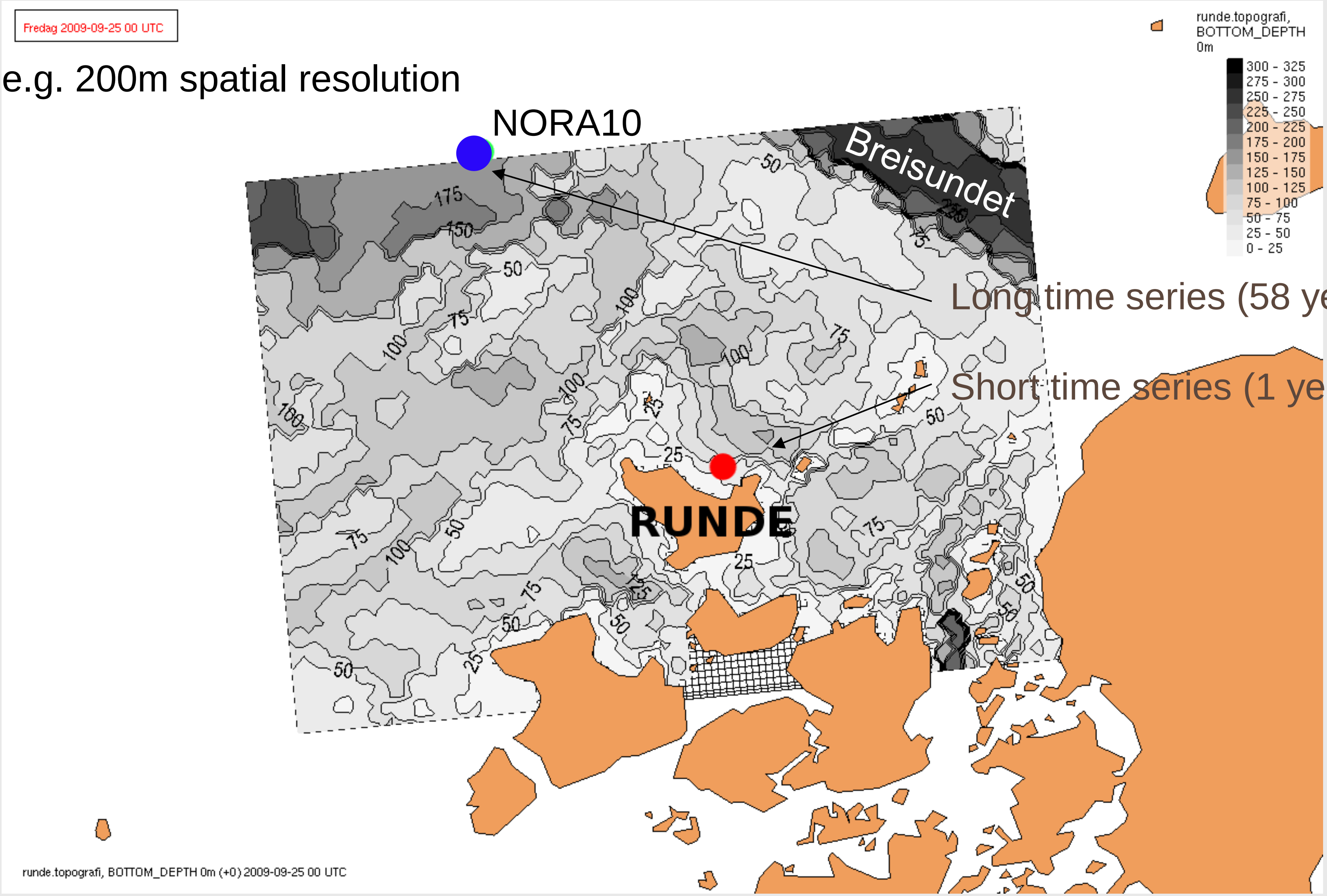
Downscaling
-using wave model SWAN



Long time series (58 years)

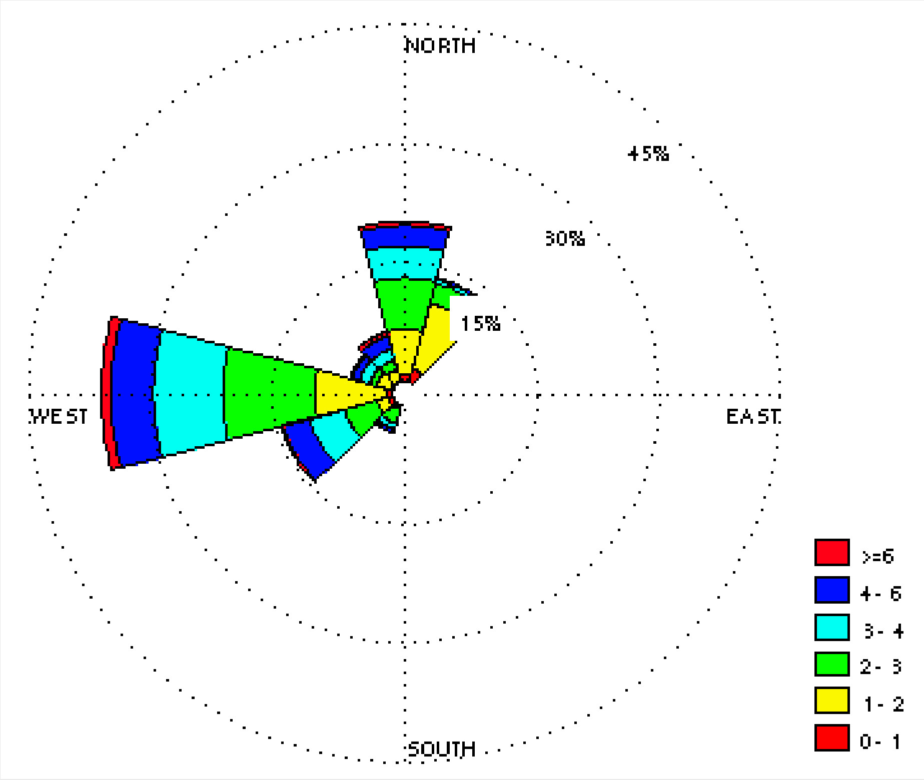
Suggested wave power plant
Short time series (1 year)

Detailed bathymetry [m]



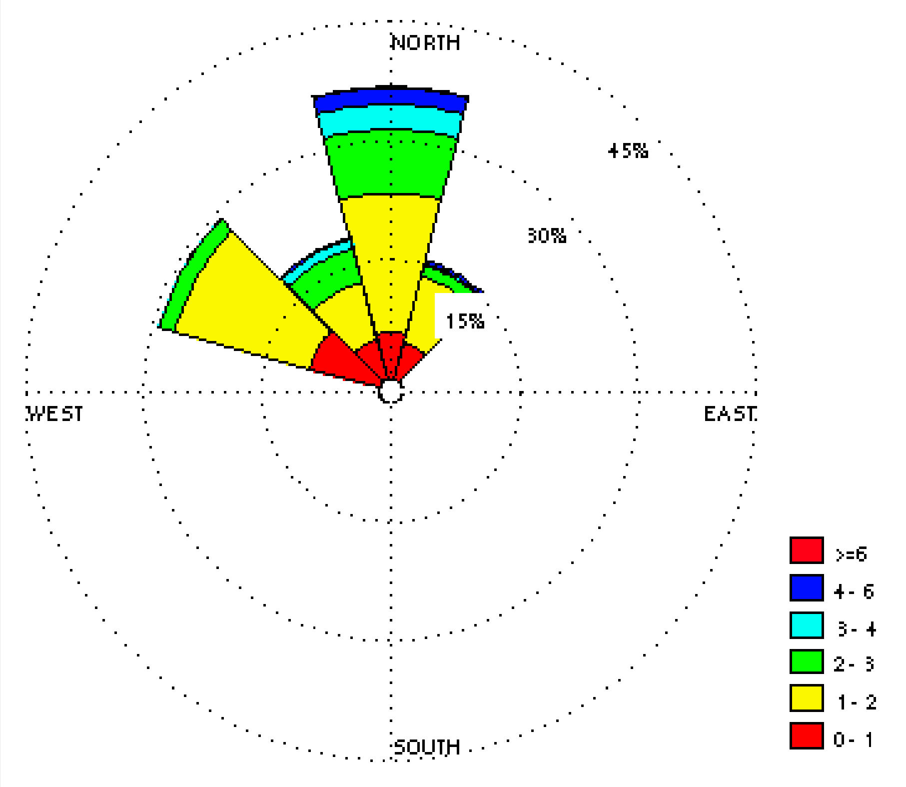
Directional distributions

NORA10 location



Waves from West and North

Coastal location



Waves from North and Northwest (sheltering from Runde)

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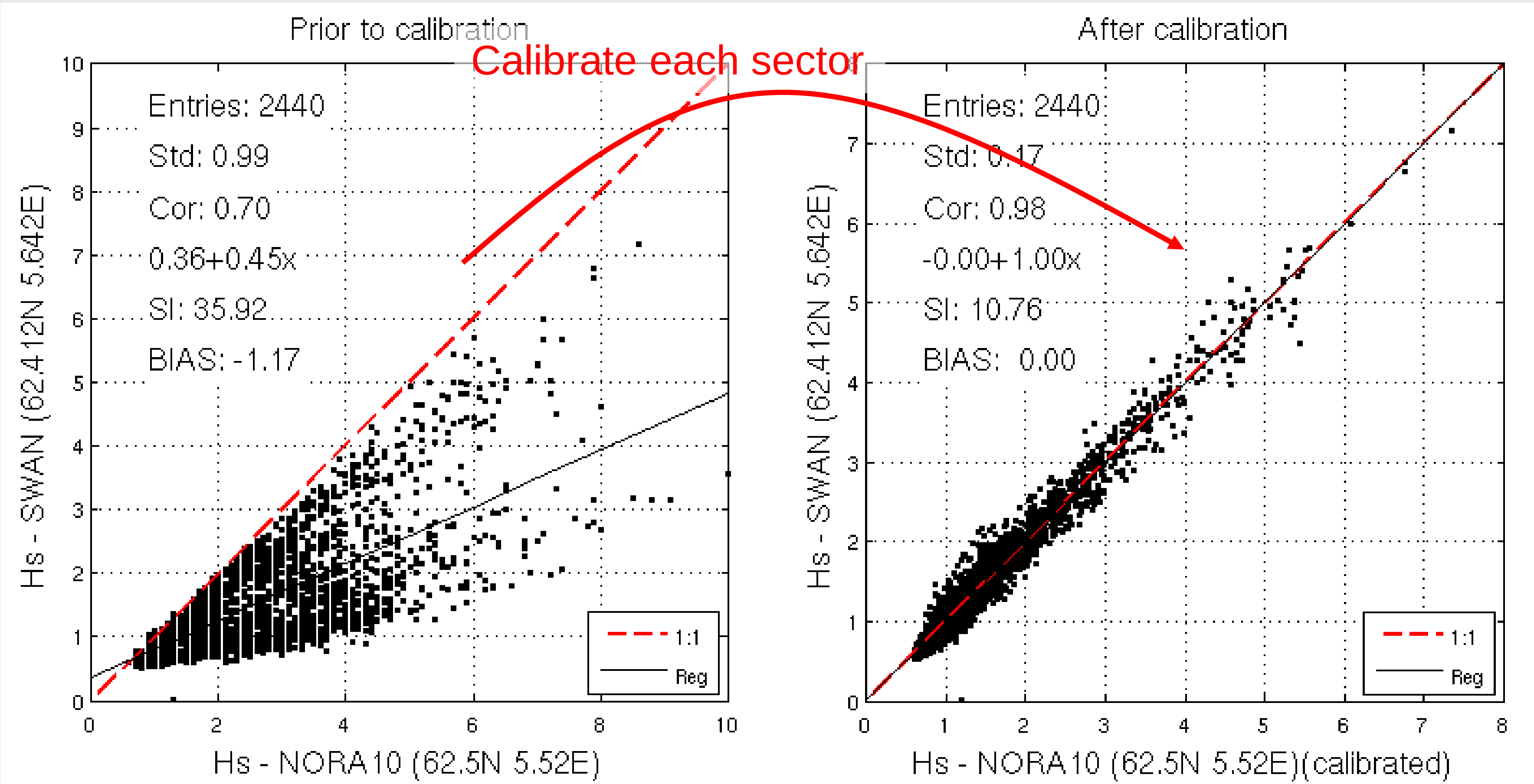
Downscaling NORA10 to coastal location for wave power plant

Coastal location



Offshore location

⟹ Long time series locally

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Long timeseries

- Useful for statistics:

  - Mean, median etc.
  - Probability density
  - Frequency of events or combination of events
  - Return value estimations for design loads

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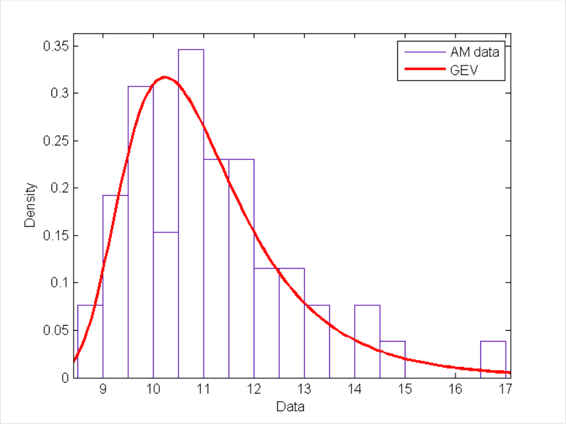
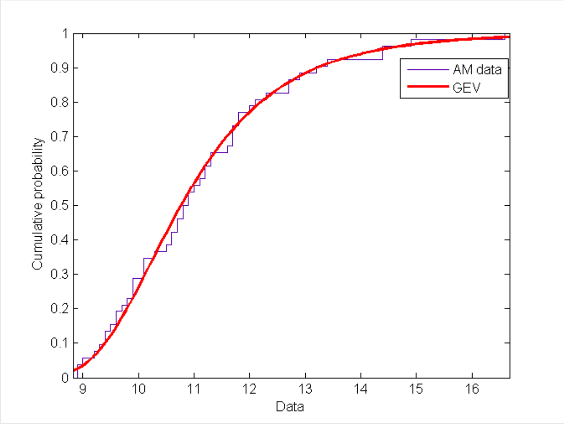
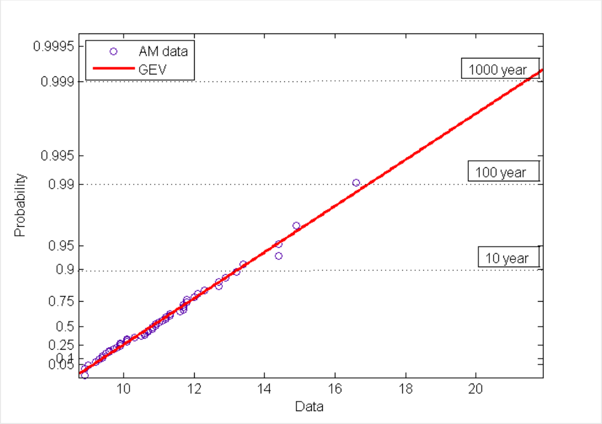
Return Value estimates

- *data selection and fitting of distribution*







Different approaches may be used:

- Initial distribution method / 3p-Weibull (fitting: MOM and LS)
- Annual maximum / Generalized Extreme Value distribution (Gumbel)
- **Peaks over threshold / Generalized Pareto (exponential)**

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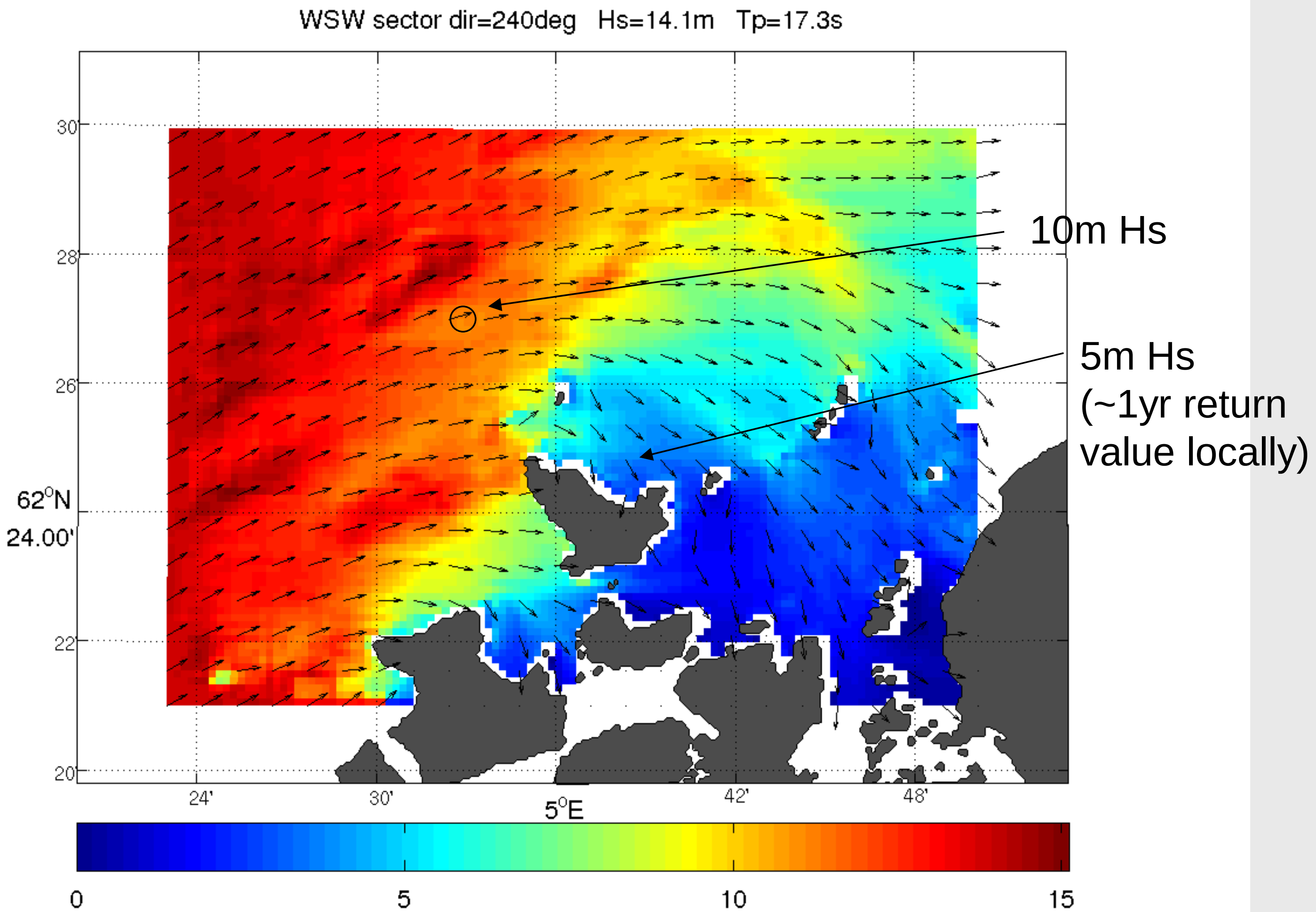
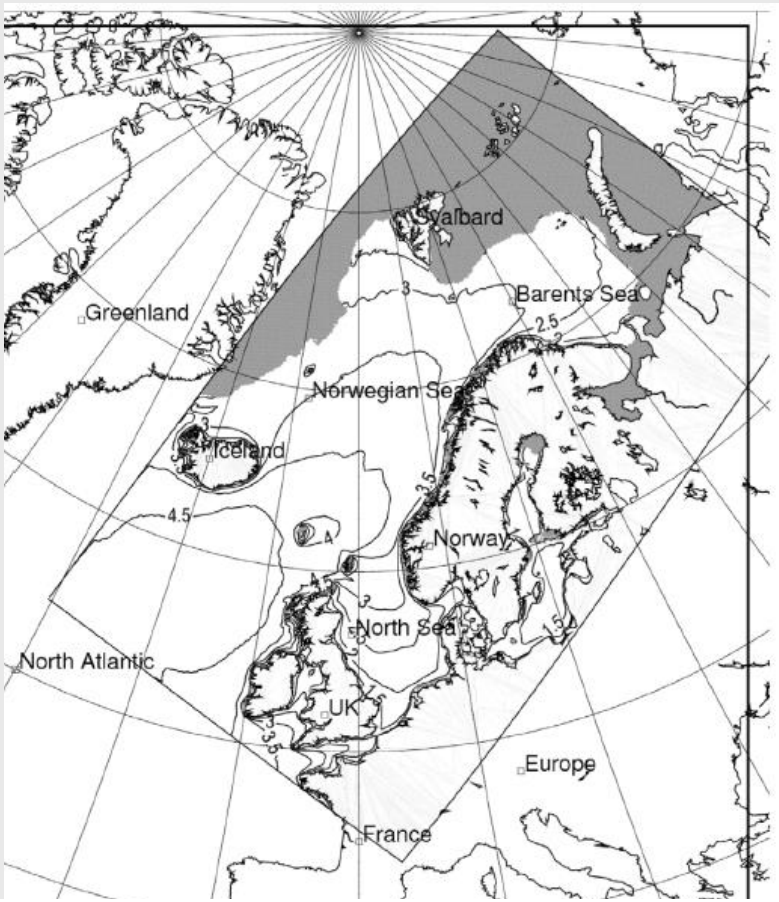
”100 year” wave situation in the offshore location



North Sea wave climate

North Sea wave climate

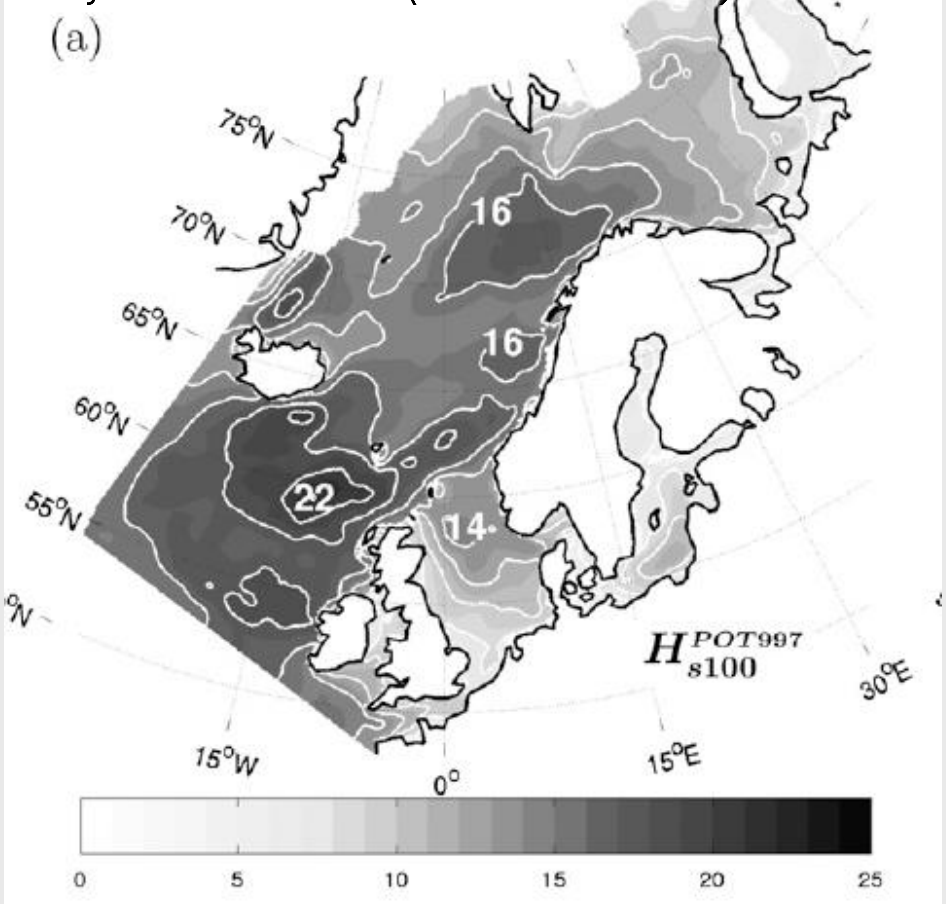
- Low wave climate in a global perspective
- Relatively large variability in wave direction



Mean Hs from NORA10 (*Reistad et al. 2012*)

North Sea wave climate

100yr return values Hs *(Aarnes et al. 2012)*



- Also lower return values in the North Sea
- Still, similar design loads in the North Sea as in rougher wave climate *(Sørensen and Chozas, ICOE, 2010)*

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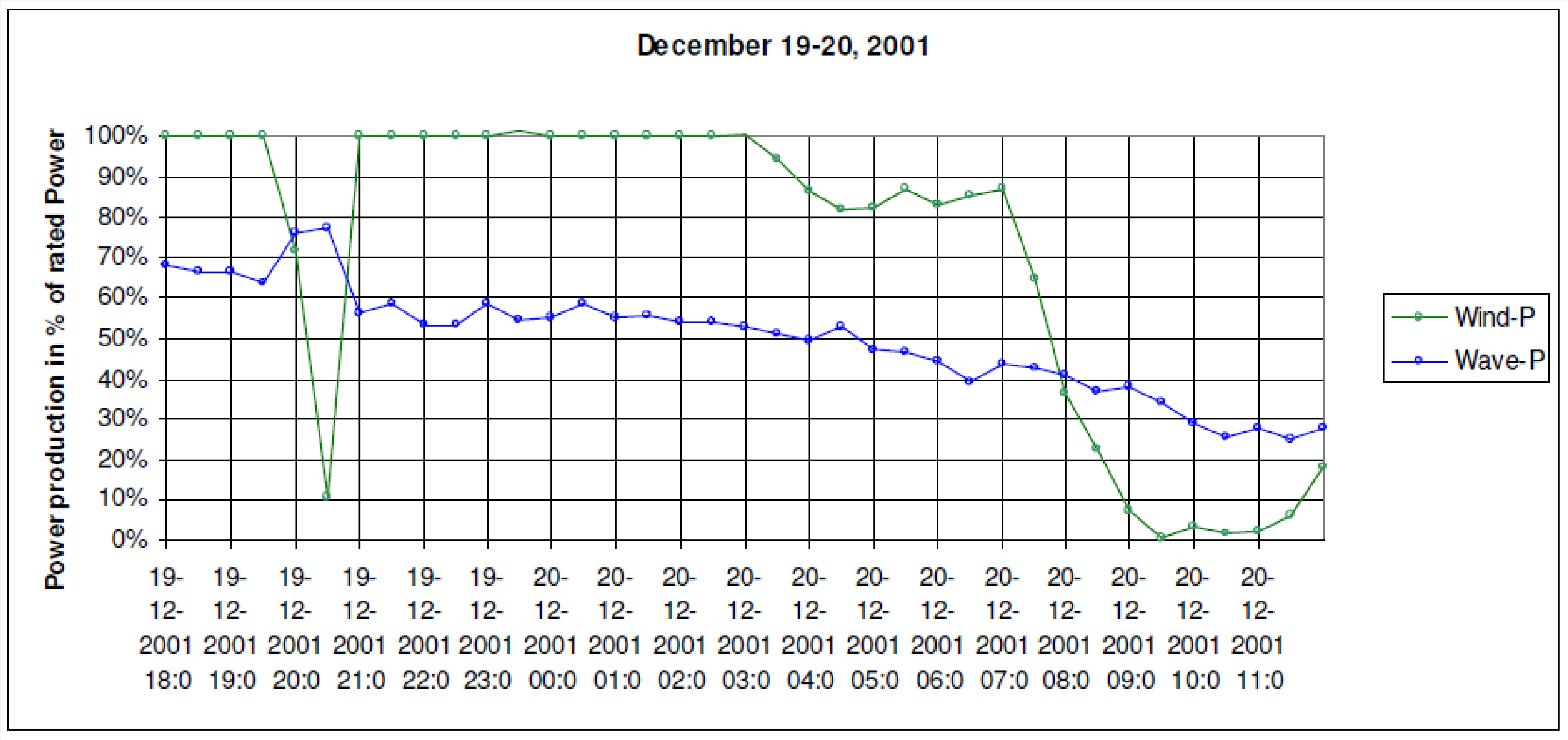
Wave power may complement wind energy



Sørensen and Chozas (2010)

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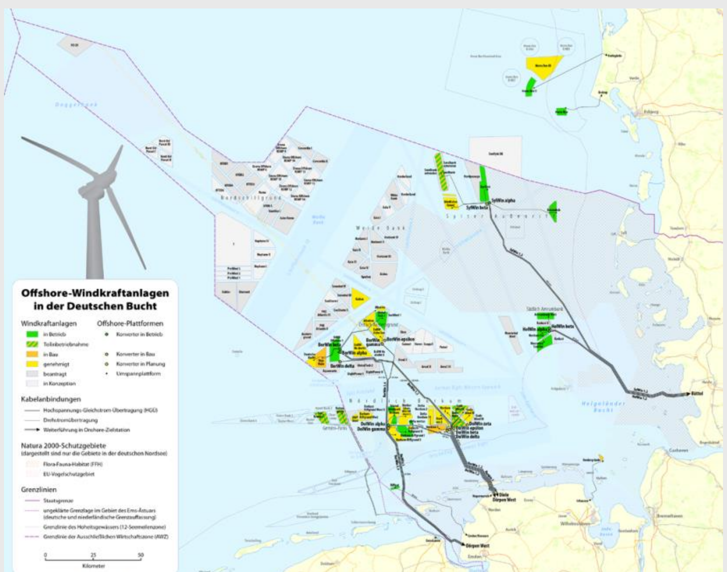
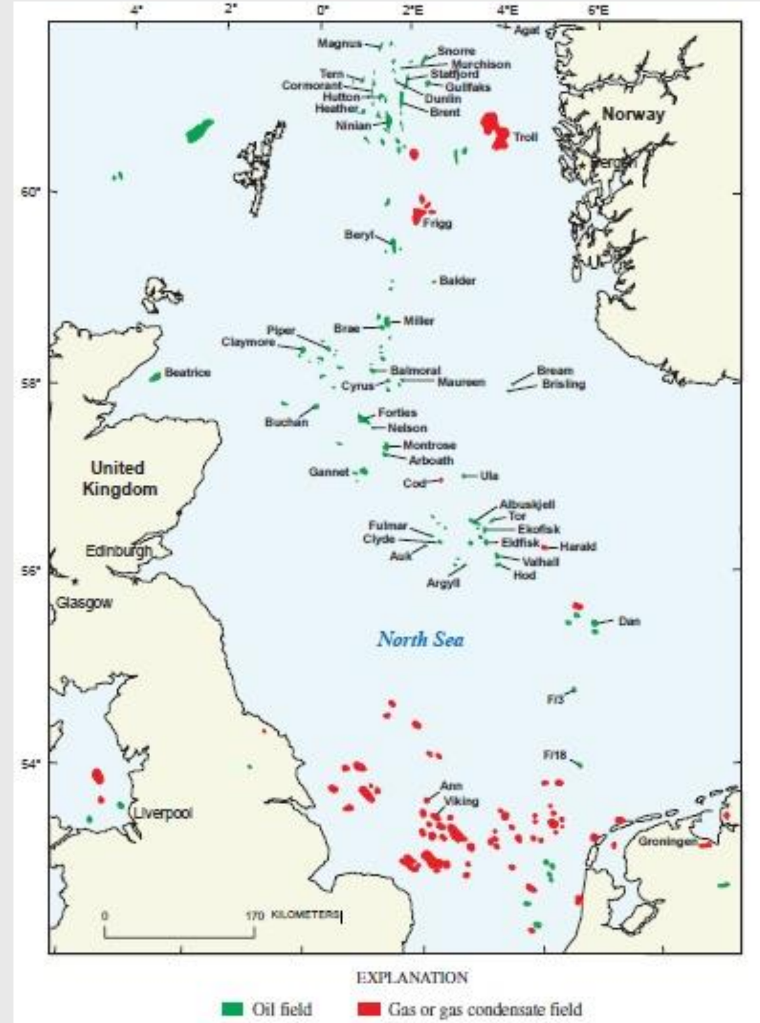
Coexistence

- Competition for space
- Supply of energy to oil rigs
- Reuse of grid
- Sheltering for access to wind turbines?



[By Maximilian Dörrbecker]



[By Gautier, D.L. - US Dept. of Interior USGS Bulletin 2204-C]

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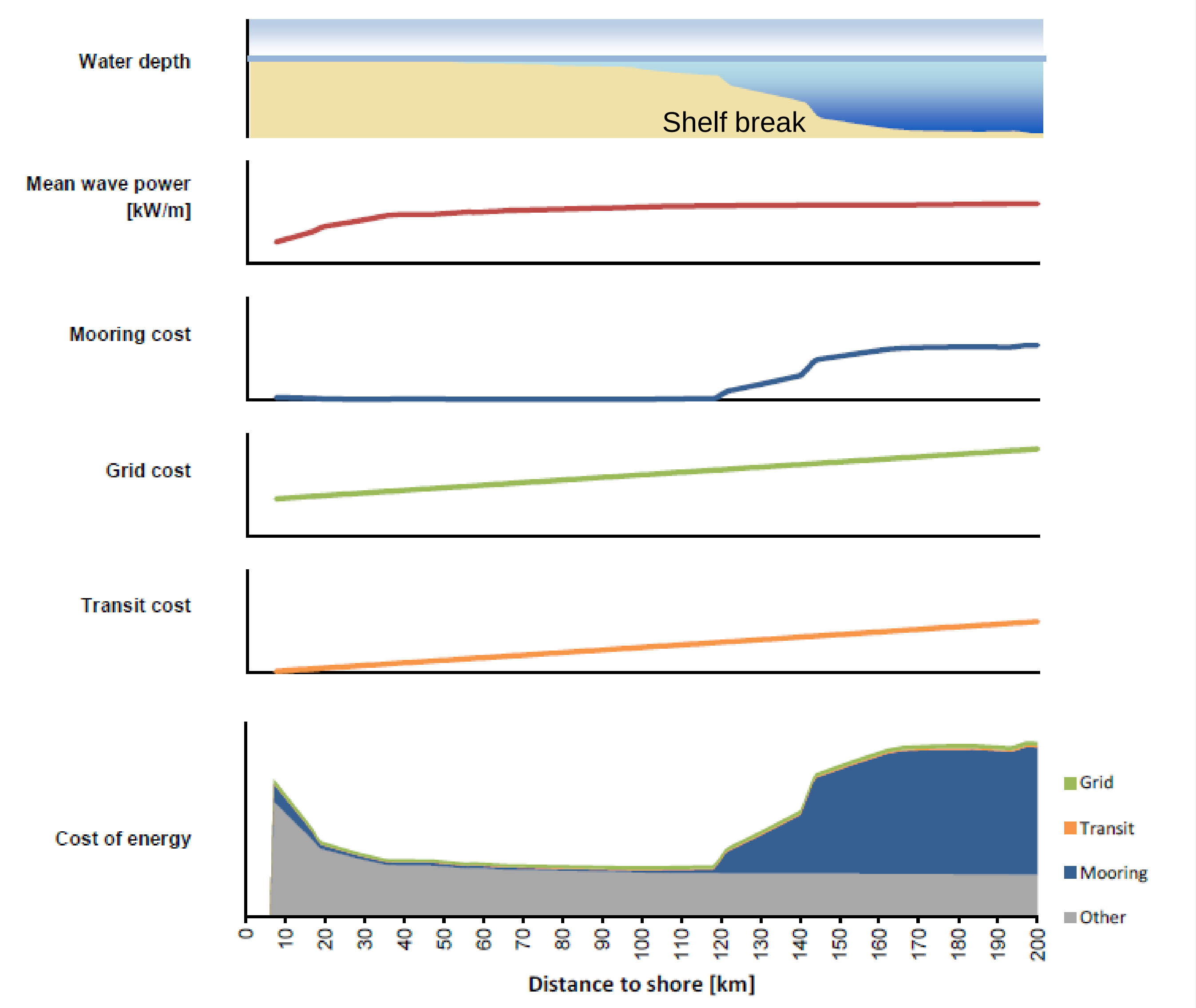
Trade-off between cost of energy and distance to shore



Source: Carbon trust UK wave energy resource (2012

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Wind versus wave energy

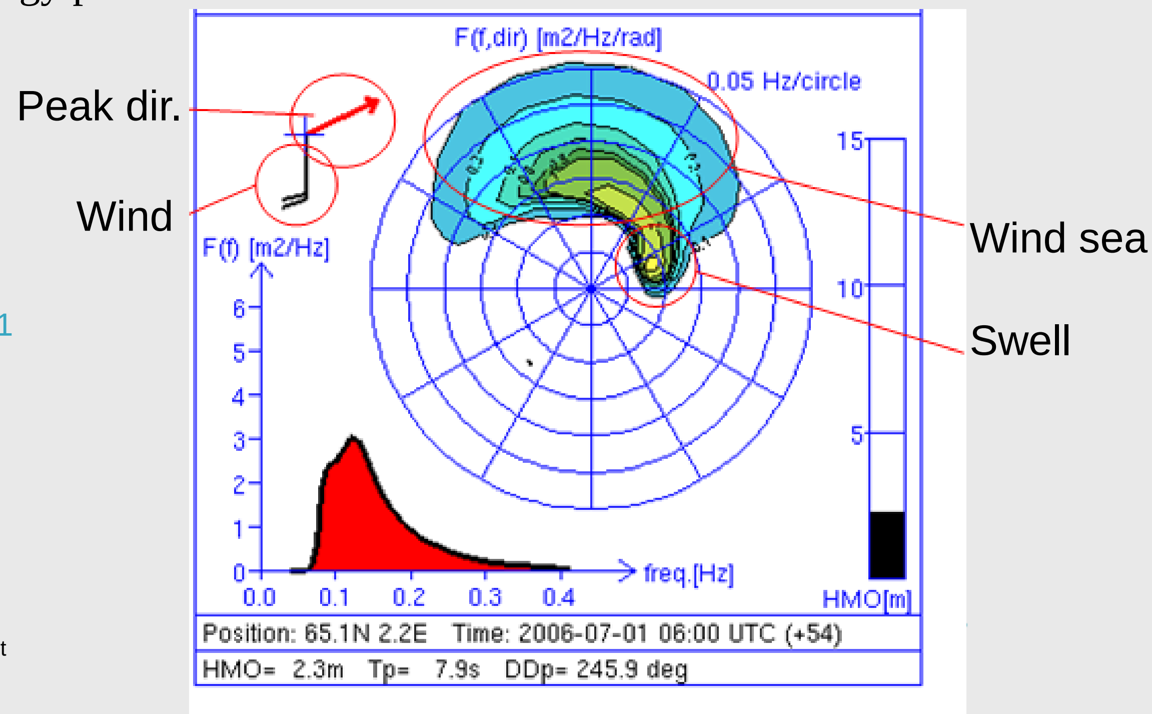
- Wind energy $\mathrm{P} = \frac{1}{2} \mathrm{A} \rho \mathrm{V}^3 \quad [W/m^2]$
- Wave energy $\mathrm{P} = \frac{1}{8} \rho g H^2 C_g \quad [W/m]$
  - H (H_{rms}) of wind sea and swell separated
  - $C_g = \sqrt{\frac{g}{k}} = \frac{gT}{2\pi}$ in deep water ($D > \lambda/4$)
  - T (T_e or $T_{m\text{-}10}$) is the energy period

$$m_n = \int_0^\infty f^n E(f)\, df$$

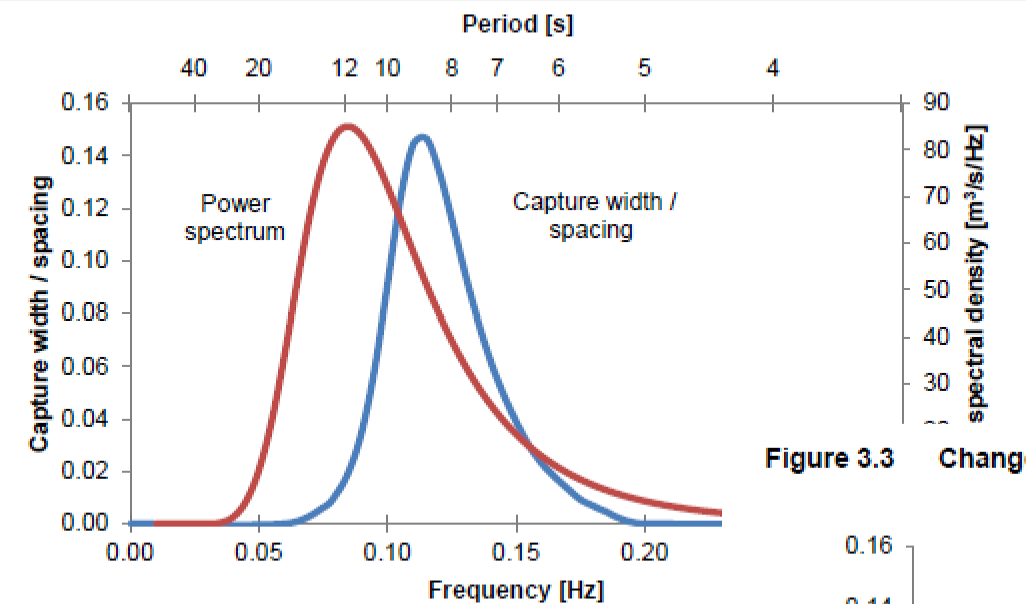
$$T_e = \frac{\int_0^{2\pi} \int_0^\infty \sigma^{-1} F \, d\sigma d\theta}{\int_0^{2\pi} \int_0^\infty F \, d\sigma d\theta}.$$

m_{-1}

m_0

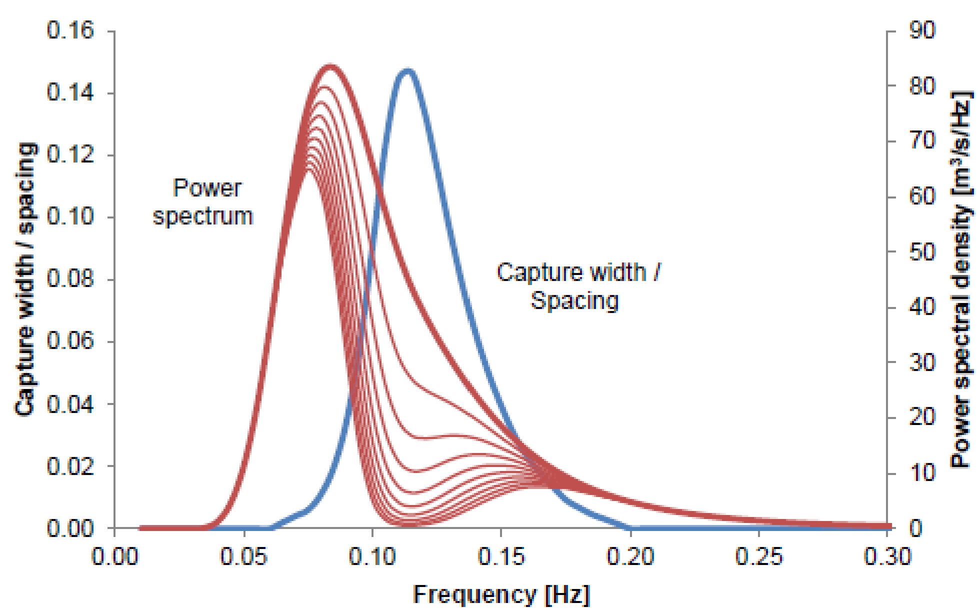


Wave energy extraction



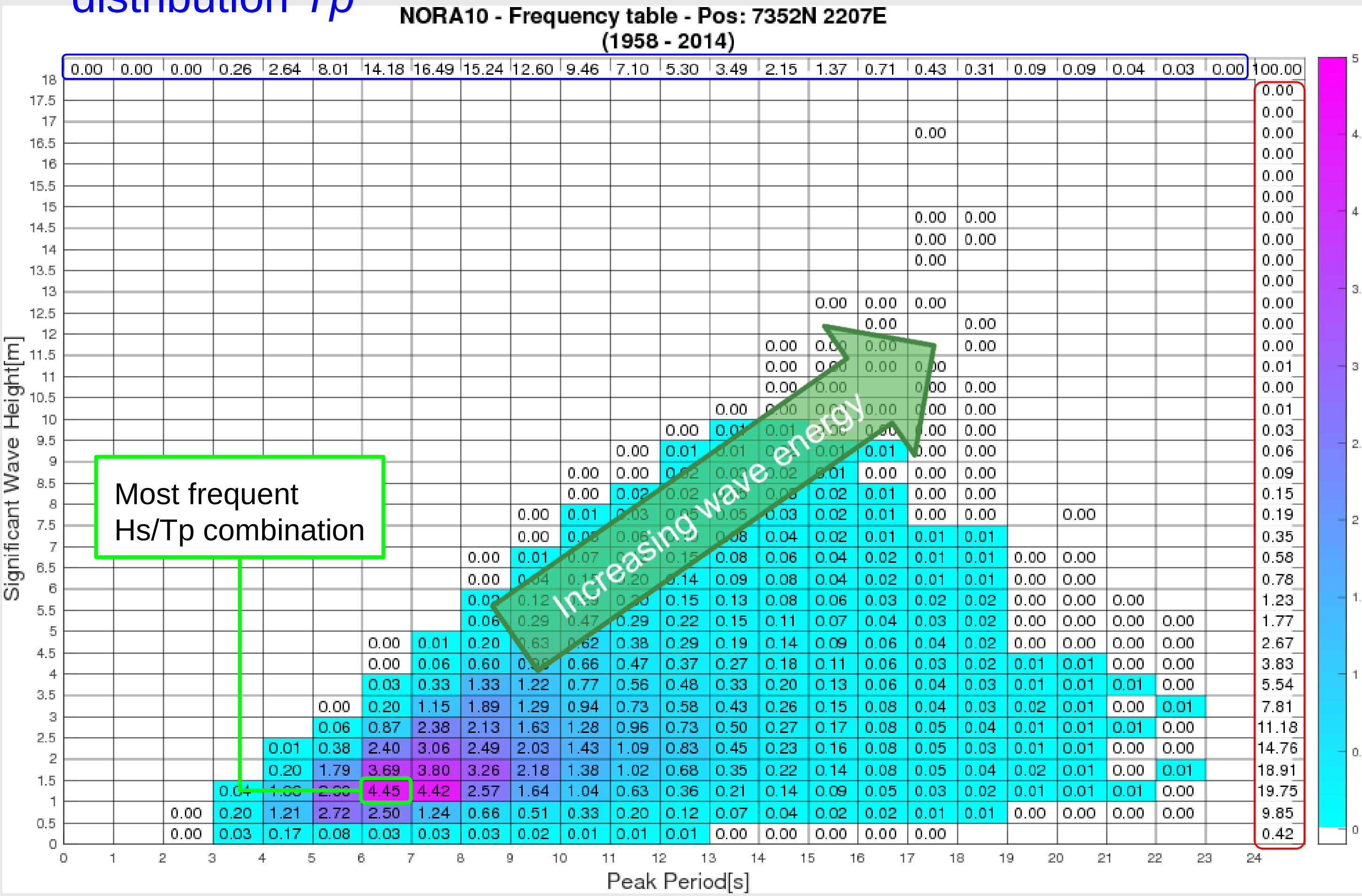
Carbon trust (2012) UK wave energy resource

Figure 3.3 Changes to the power spectrum by multiple rows of devices



Joint statistics *Hs / Tp*

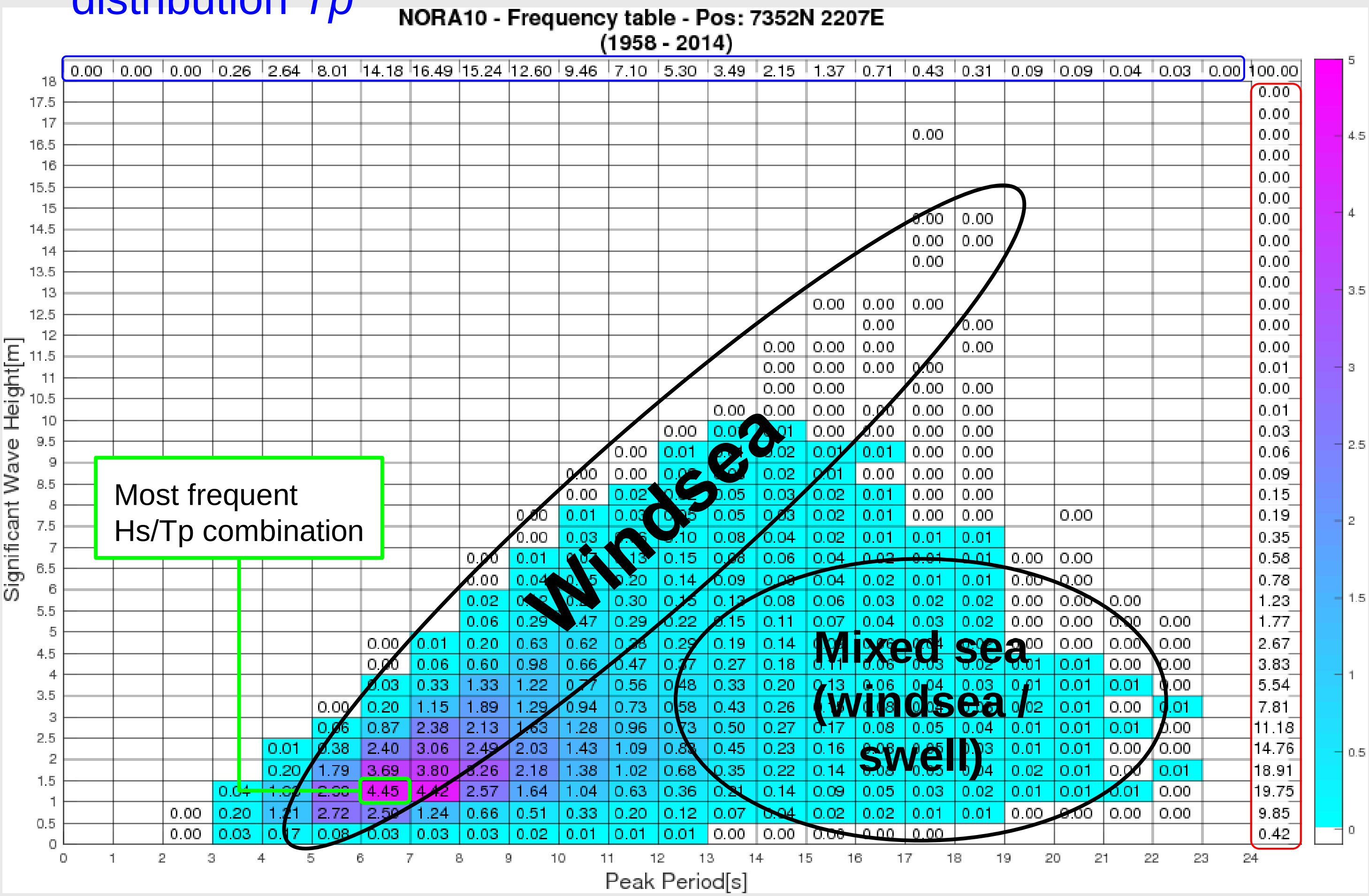
Marginal distribution *Tp*



Marginal distributi on *Hs*

Joint statistics *Hs / Tp*

Marginal distribution *Tp*



Marginal distribution on *Hs*

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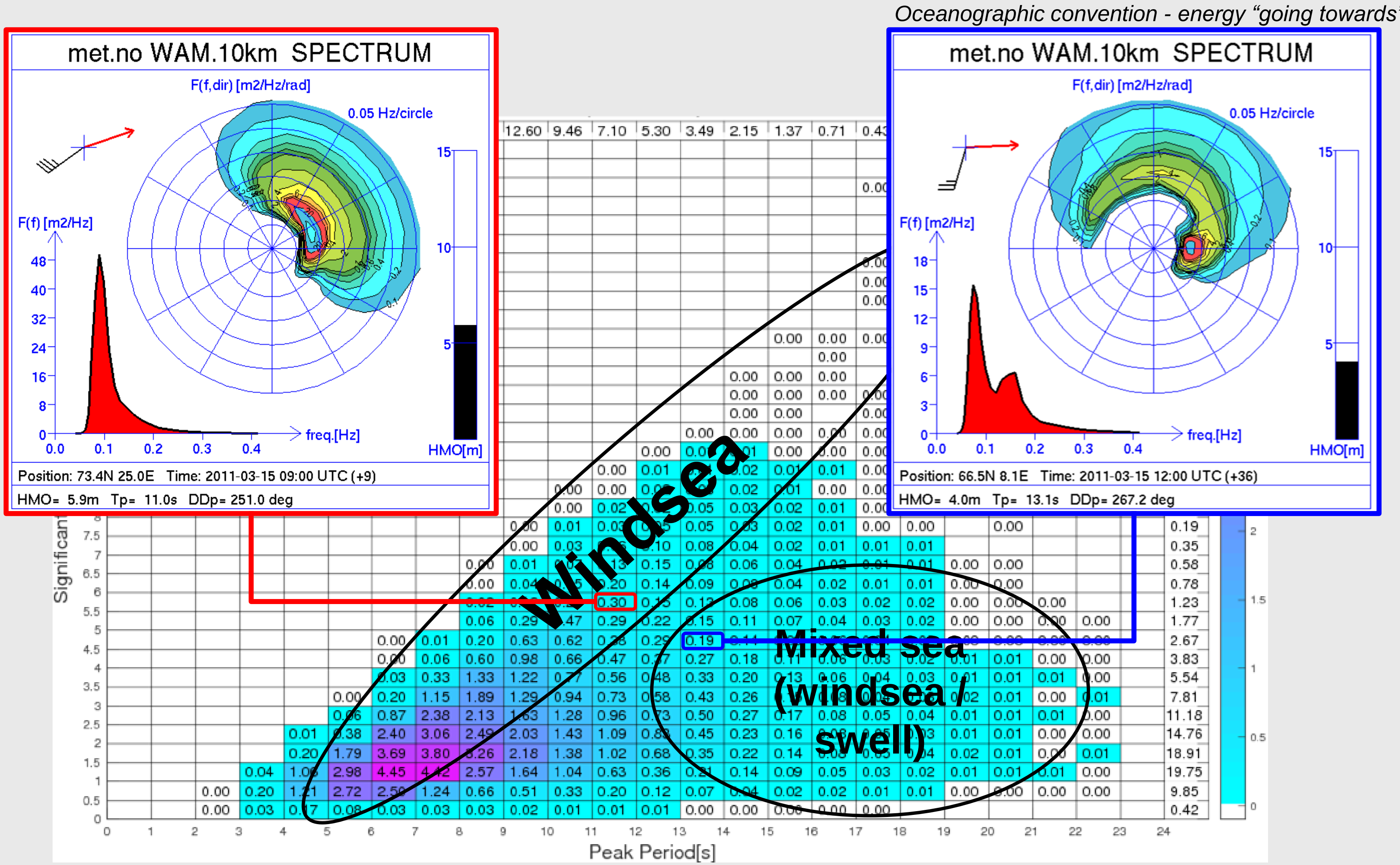
Joint statistics *Hs / Tp*



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Sheltering effect

- Reduction in wave energy
- Refraction

Wave energy converters
- 1 row (left)
- 2 rows (right)

2 m Hs
5 s period
from West

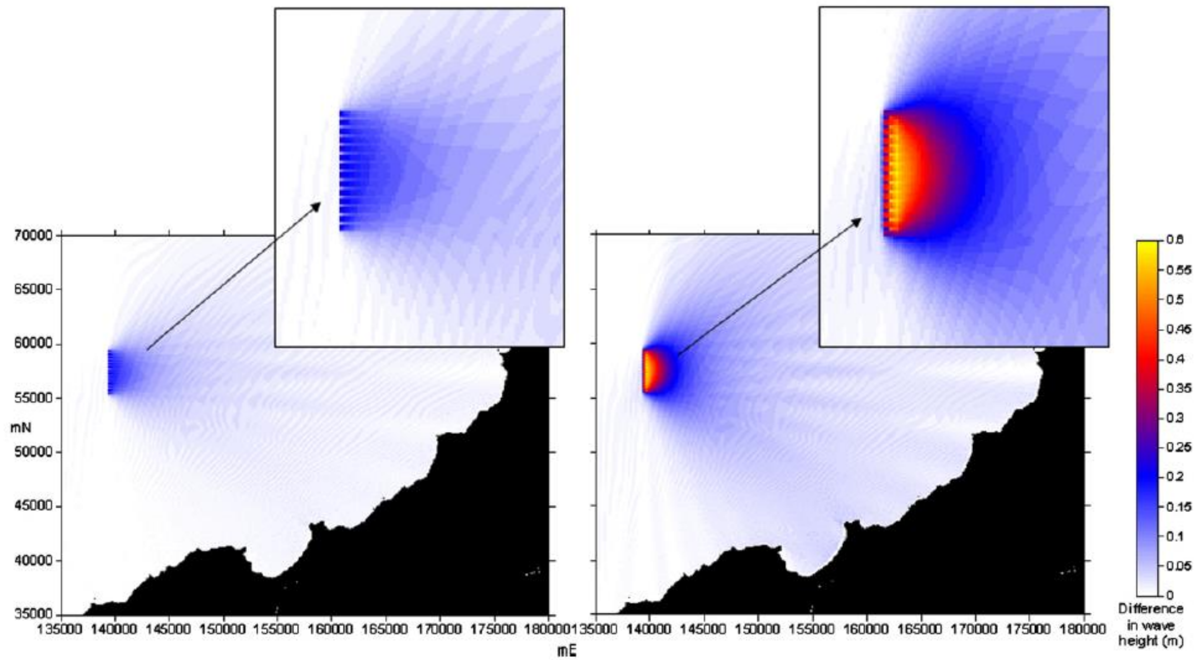

Fig. 16. Example output using the standard SWAN energy transmission for a bi-modal sea state with barrier configurations 2 (left) and 3.

Smith et al. (2012) Renewable Energy

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Wave energy estimate (TWh/yr)

- Yearly production (10% efficiency of the annual mean power of the devices)
- In total 23 TWh/yr: ~2% of electricity consumption in these countries
- 77 TWh/yr (6%) with a transnational approach
- Local effects - hot spots - not accounted for

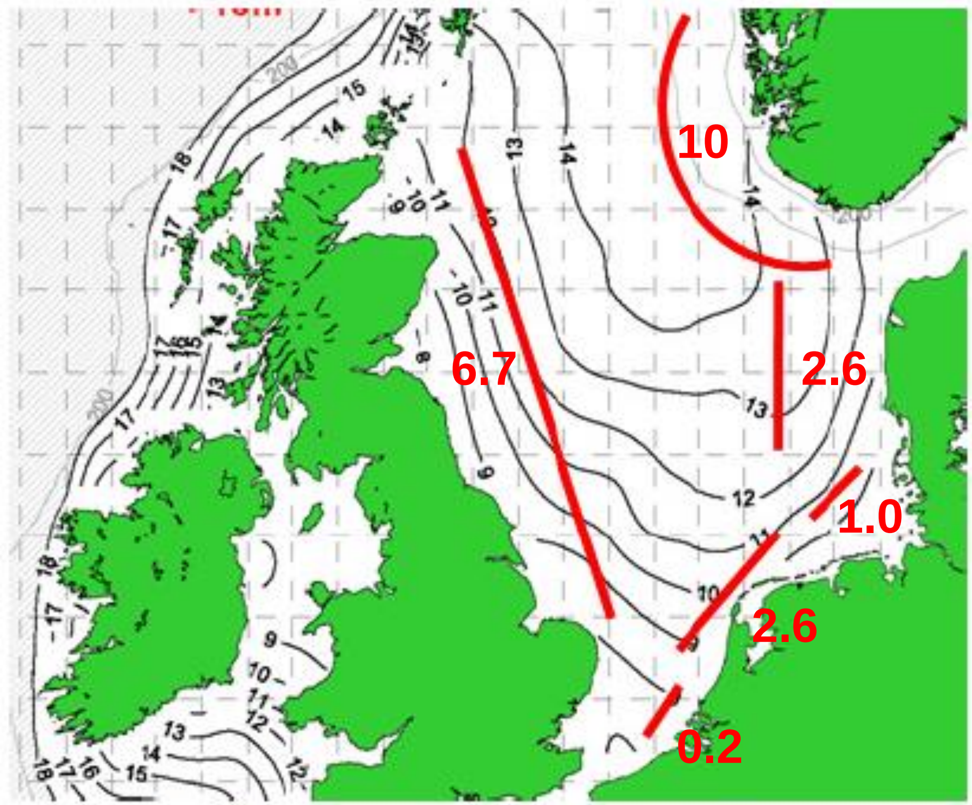

Figure 7: The national approach: one line of wave devices placed along the coast; map from [16] (the figures are significant wave height in m).

Sørensen and Chozas (2010)

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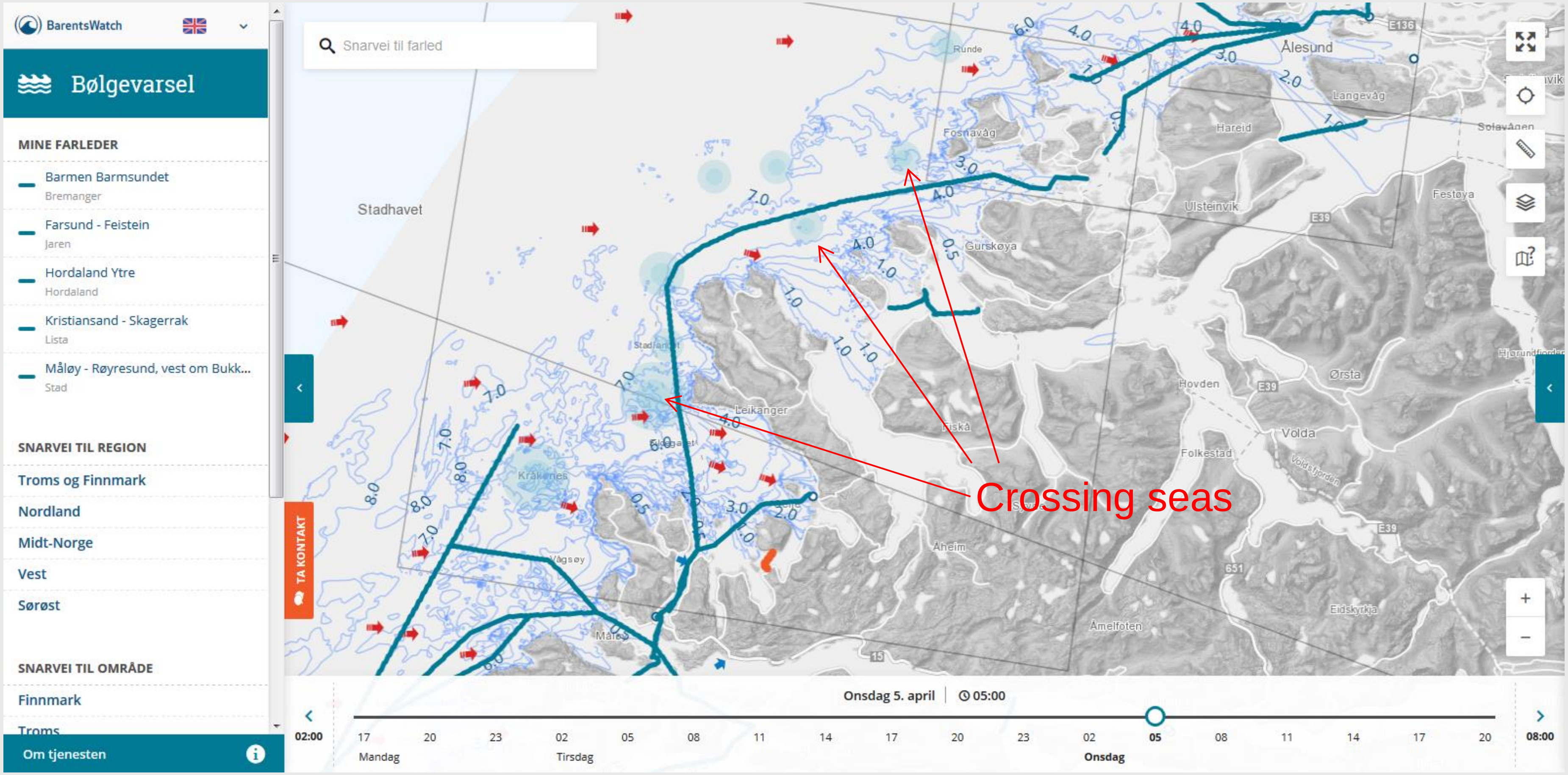
Transfer of wave energy to the coast

- 20m isobath (T ~ 7s)
- Can give wave energy hot spots



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Wave power in Norway


Bølgekraftvegen
Bølgekraftvegen
Kylpa
Bølgekraftvegen
Google
Bilder ©2017 Google,Kartdata ©2017 Google
Vilkår

Norwave wave power prototype Toftestallen 1985-1991

691 MWh in total delivered to grid

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2008

- *Buldra*
- Fred. Olsen research platform.
- Glasfibre, 12 x 12 meter and 8 m a.s.l. (1:3).

http://www.ntnu.no/gemini/2005-01/kortnytt.htm

Runde Miljøsenter

Several wave power converters have been tested here
Contact: Lars Golmen, NIVA

Photo: Annelise Chapman

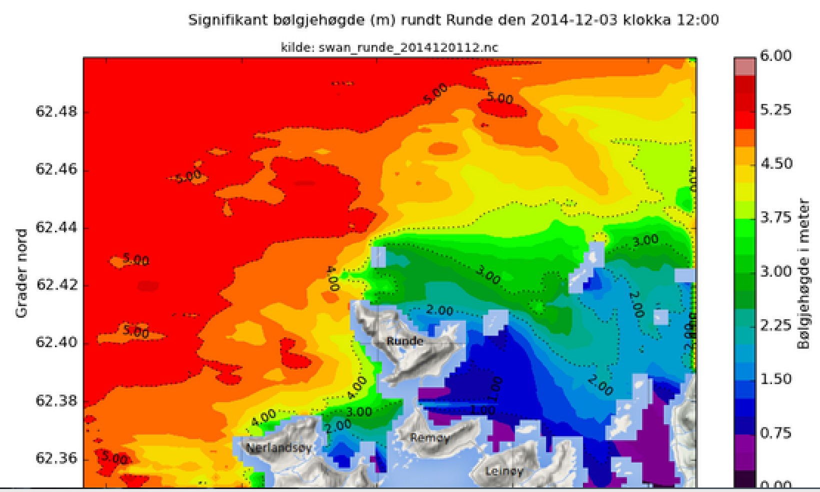
RundeMiljøsenter

Søk ...

Bølgjevarsel for området rundt Runde

Runde Miljøsenter har i samarbeid med Meteorologisk Institutt laga ein bølgjemodell med høg oppløysing for området rund Runde. Nye varsel vert produsert to gongar for dag.

Varsla viser signifikant bølgjehøgd , ikkje maks. Dei største bølgjene er i snitt 1,8 gongar høgare enn den signifikante bølgjehøgda.



Kategoriar

- Aktivitet på senteret
- Forsking
- Nyhende
- Seminar og kurs

Siste innlegg

- Påska 2017 på Runde
- Søndagsforerag 2. april 2017: Havet si helse – kva skjer under overflata? Av Anders Goksøyr (UiB)
- Søndagsforedrag 26.mars: Forskning av fugletrekk: Frå metallring til gps og satelitt av Kjell Mork Soot
- Stort oppmøte og eitt tonn

Waves4Power WaveEL at Runde

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