POWER Offshore Summer School 2006

WIND and WAVES

Gerard van Bussel

TU Delft

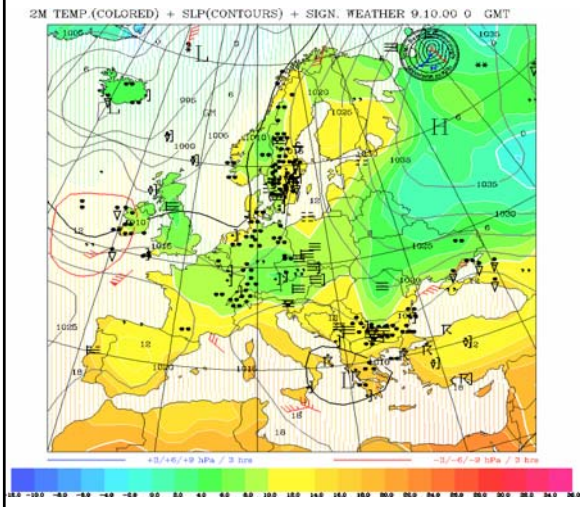
The Netherlands

Pushing Offshore Wind Energy Regions (POWER)

Overview

- Wind resources
  - in general
  - variation in height, space and time
  - existing measurements
  - special offshore effects
  - offshore turbulence

What is wind?



- caused by pressure differences
- (resulting from temperature diff.)
- influenced by earth rotation and terrain

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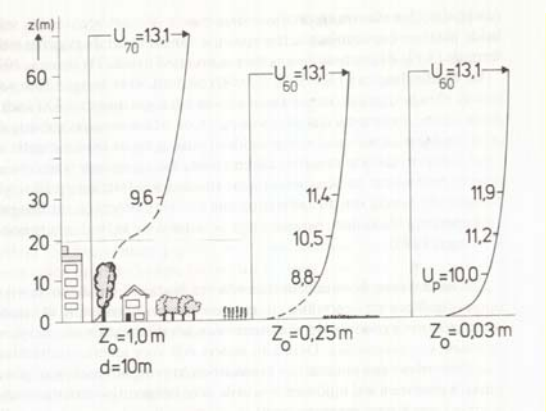
Wind profile



mechanic (land based)

- roughness length (z_0) (z_0 = 0.03 - 0.25)
- displacement height d (z_0 = 0.50 - 1.00)

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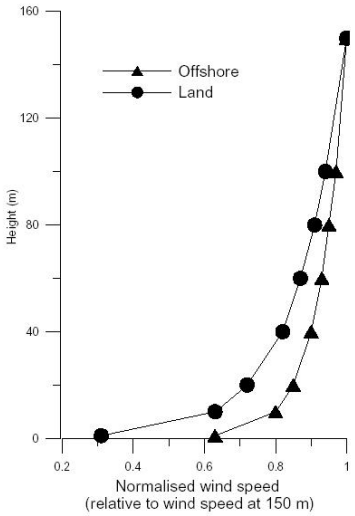
Wind profile



- Comparison of profiles (wind shear)
- land based roughness length (z_0 = 0.03 - 0.25)
- offshore roughness length ($z_0 \approx 0.0002$)

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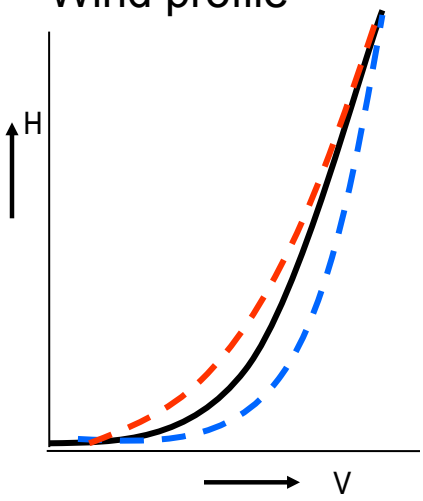
Wind profile



Thermic

- stable (cold surface)
- neutral
- unstable (hot surface)

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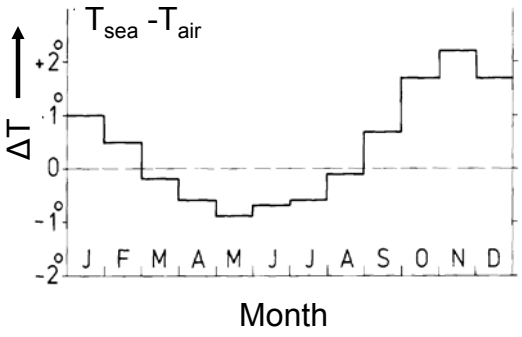
Temperature difference



- Average wind - water temperature difference at North Sea location.
  - Summer: stabilizing ΔT
  - Winter: destabilizing ΔT

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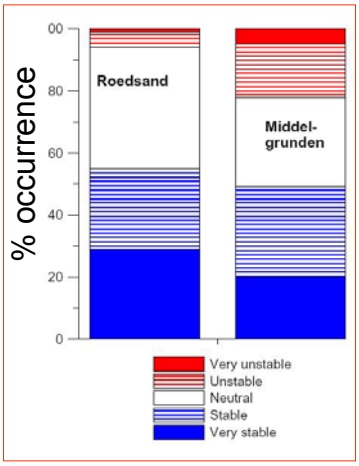
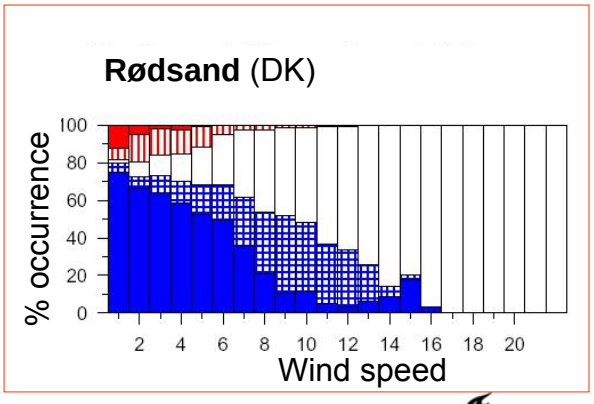
Boundary layer stability at sea



- Danish "offshore" sites



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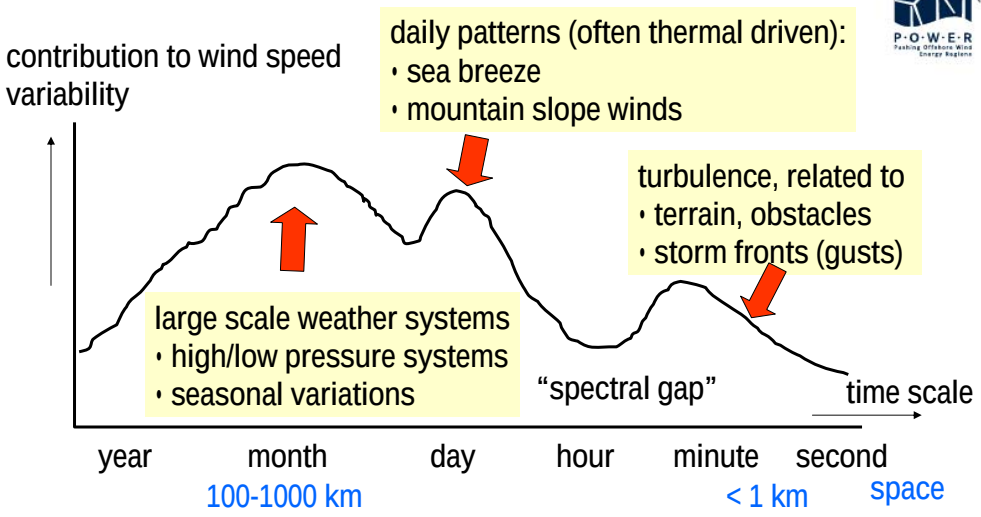
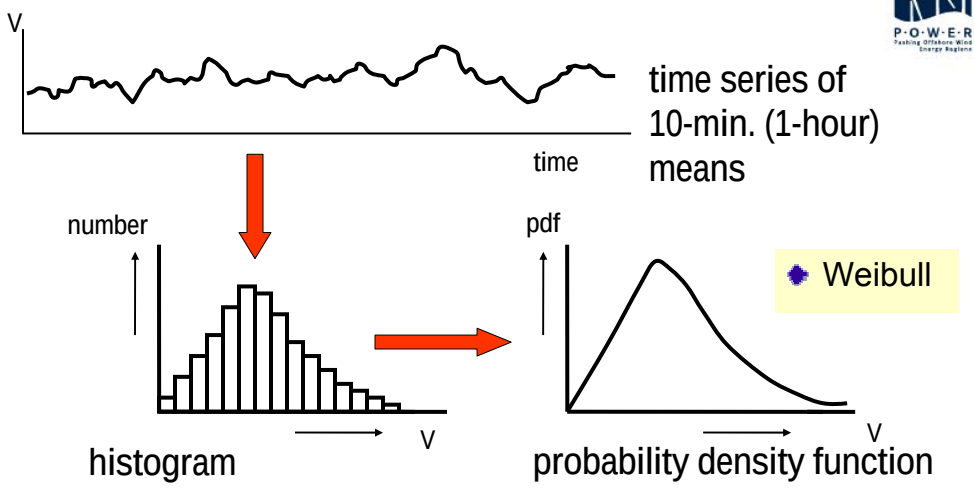
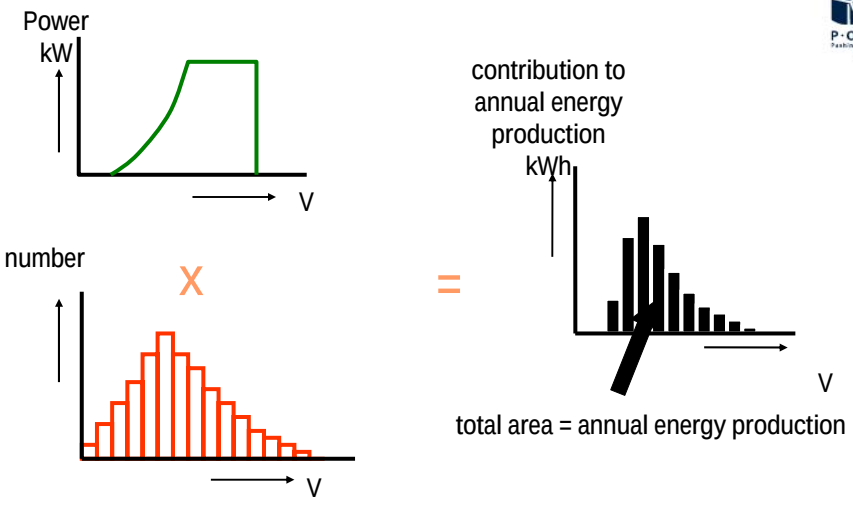
Variability of the wind in time



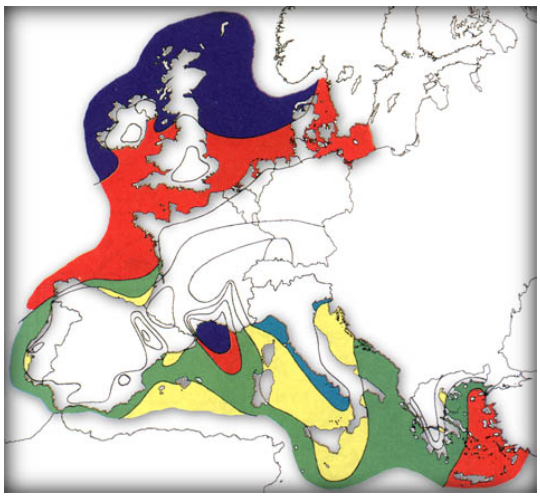
Basic wind statistics



Assessment of energy production I



Existing offshore wind map



- **Evaluation of offshore potential**
- **Extrapolation from land measurements**
- **Not suitable for energy yield calculation**
- **Coastal effects cause main problems**

How to obtain wind statistics for a given location ?

two basic options

use existing data

problem:	solution:
data not representative	use of correction methods (fetch, obstacles on land)

Windatlas + correction methods — WAsP

Other sources

perform local measurements

problem:	solution:
not possible to measure long enough to obtain good statistics	correlate with other sites which have reliable long term statistics

"Measure Correlate Predict" — MCP

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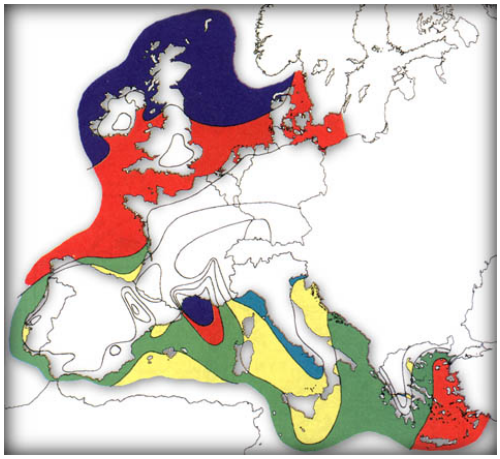
WAsP offshore (Risø DK)



Determine Offshore wind atlas at 150 m height

- **Calculate downward to hub height using local orography**
- **Account for coastal effects**
- **Not yet fully operational**

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Available offshore weather data (NL)

- KNMI wind network (NL)

Platform data (since '80)

- KNMI, RWS: Measuring Network North Sea (limited w.r.t. land)
- wind and wave data

Other sources

- light ships
- Voluntary Observing Ships
- databases (e.g. NESS / NEXT "hindcast" data)
- Remote sensing /satelite data

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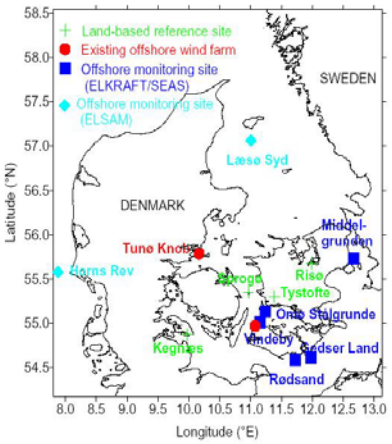
MCP: available measurements

- KNMI wind network (NL)



- On and Offshore measure posts (DK)

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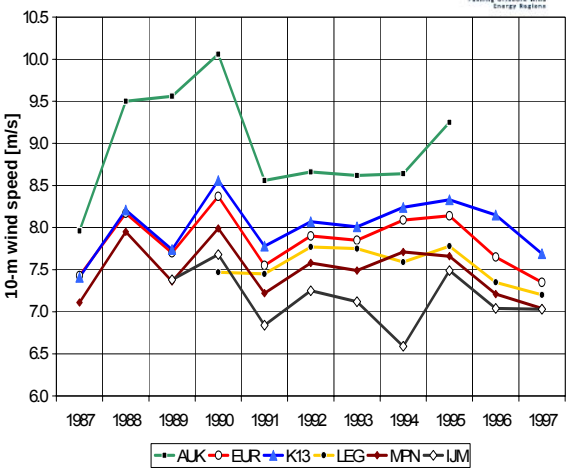
MCP: correlation annual windspeed

- KNMI wind network (NL)



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Measure Correlate Predict dedicated measurements

- Risø/SEAS meteo masts at sea
- 5 locations 50 m height in DK

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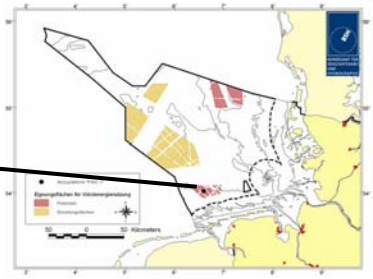
MCP: dedicated measurements 2



- "Fino" platform in German part of the North Sea
- 105 m height; full site assessment:
- Hydro, meteo and biological surveys

www.fino-offshore.de

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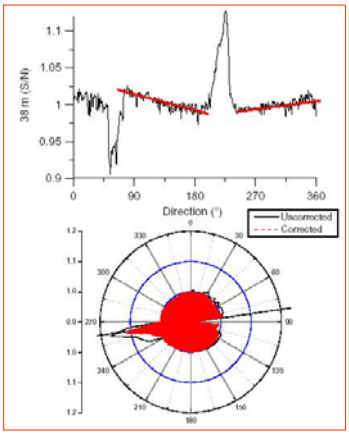
MCP: dedicated measurements 3



- Meteo masts at sea:
- Corrections for mast shadow
- Corrections for mast movement

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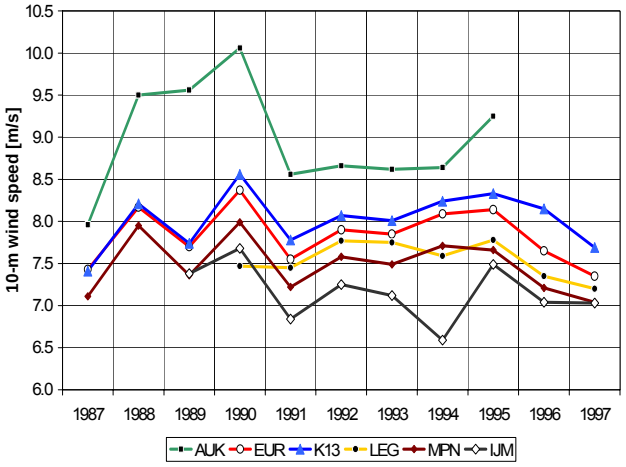
Annual variation of offshore wind speed



Consequence:

- Annual energy yield /
- income will vary from
- year to year

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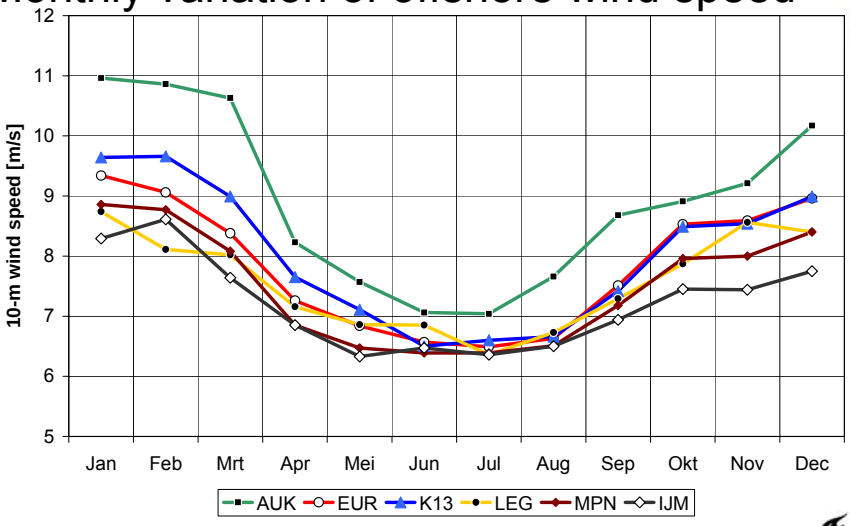
Monthly variation of offshore wind speed



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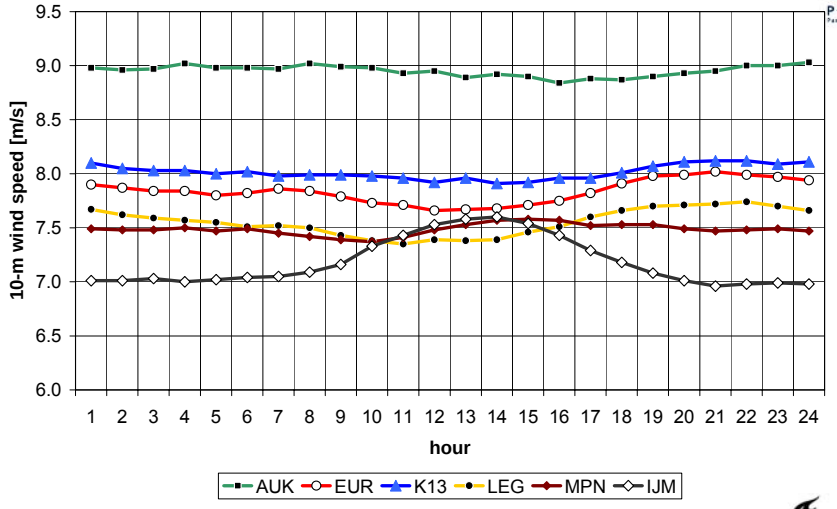
Hourly variation of offshore wind speed



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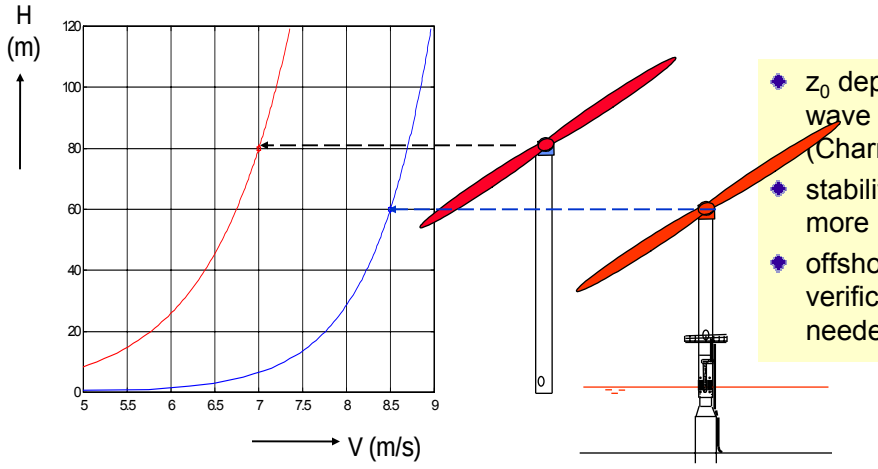
Offshore versus onshore: wind shear



- z_0 depends on wave height (Charnock)
- stability effects more important
- offshore verification needed

Offshore versus onshore: roughness length

- At land z_0 = 0.03- 0.25 m
- At sea: z_0 ~ 0.0002 m

  but dependent upon
  - wave height (Charnock relation)
  - fetch
  - wave age

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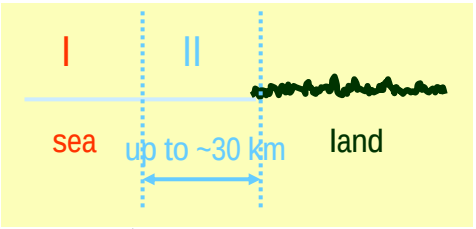
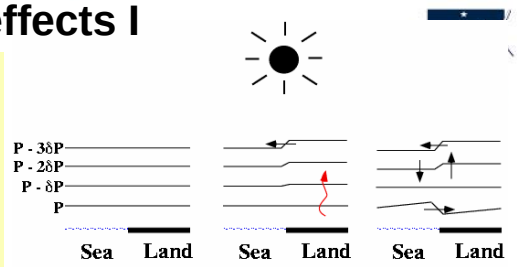
Wind climate offshore versus onshore

	onshore	**offshore**
diurnal pattern	daily maximum	uniform
seasonal pattern	less pronounced	more pronounced
stability	diurnal pattern	seasonal pattern
wind profile	“unstable” on average	“neutral” on average
mean wind speed	decreasing inland	higher than on land

Coastal effects I





I ⇨ "windatlas" methods more or less apply (z_0 depends on U)

II ⇨ coastal discontinuity, caused by

- strong variations in air/sea temperature gradient (winter ~ summer, onshore ~ offshore wind)
- resulting strong effect of stability
- further complicated by internal boundary layer effects

⇒ model improvement still underway

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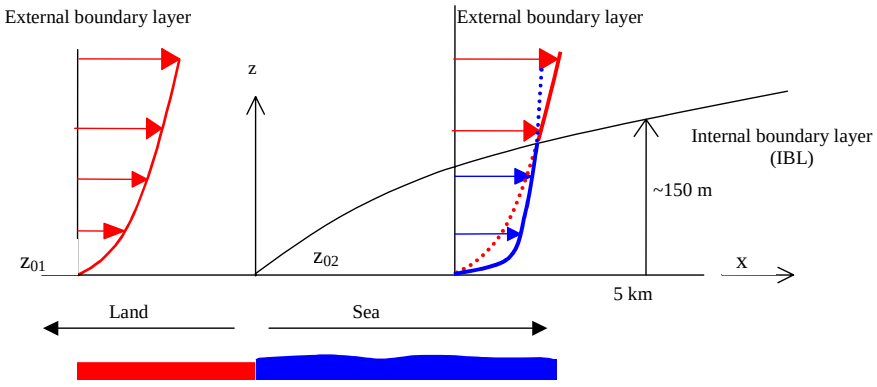
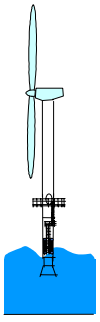
Coastal effects II
change in surface roughness





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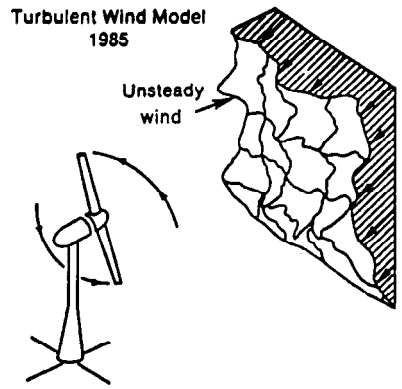
Turbulence



Simulation:

- generated stochastic wind fields
- several mean wind speeds
- turbulence intensity (less than in offshore cond. : ~ 8%)
- formulation of spectrum / coherence: identical to onshore

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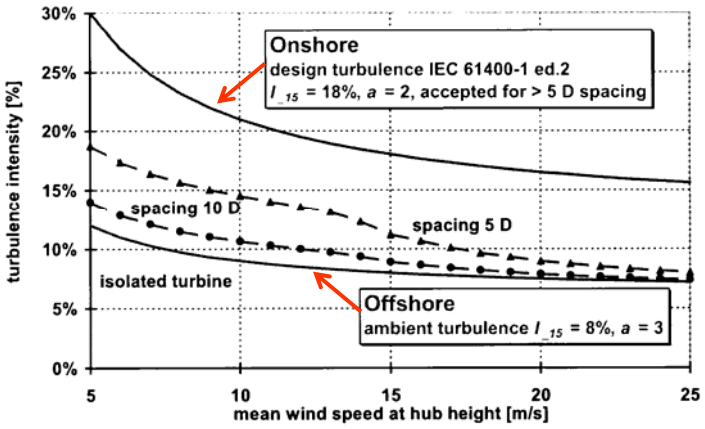
Onshore vs offshore turbulence



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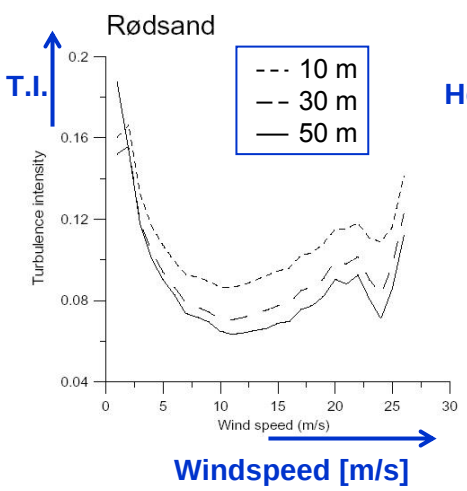
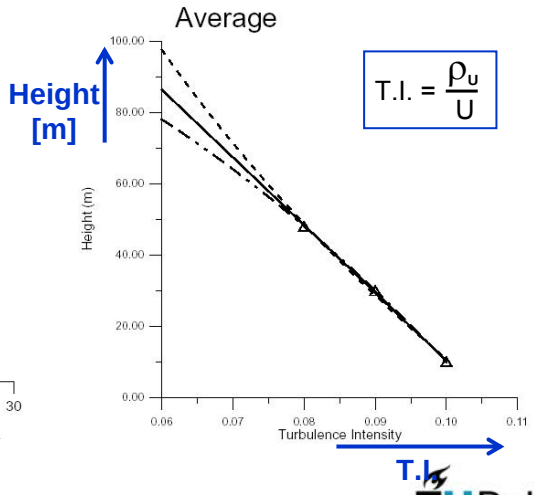
Measured offshore turbulence intensity T.I.





Pushing Offshore Wind Energy Regions (POWER)

Overview

Currents

Waves and wave loads

- External conditions at sea
- Waves, wave parameters and models
- Scatter diagrams
- Spectral density distributions
- Fatigue load calculation principles
- Sample calculation

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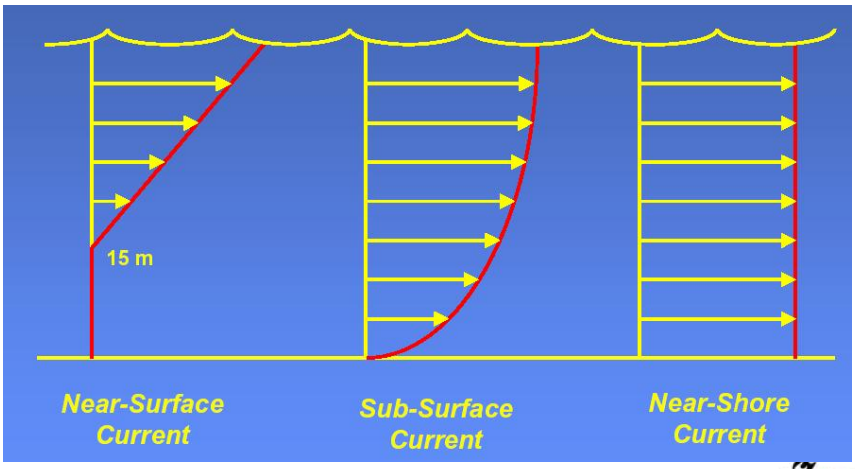
Different current profiles



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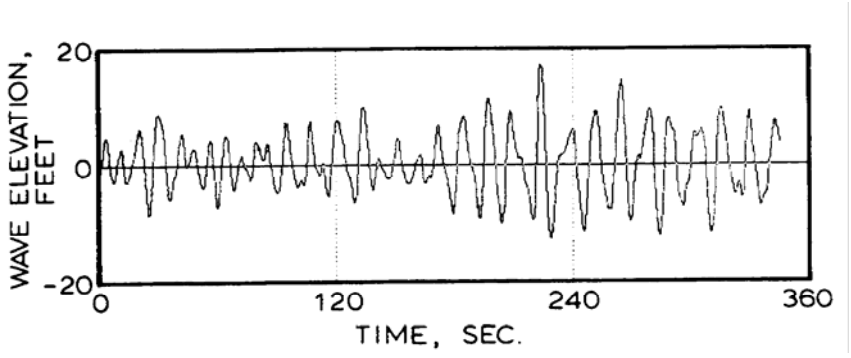
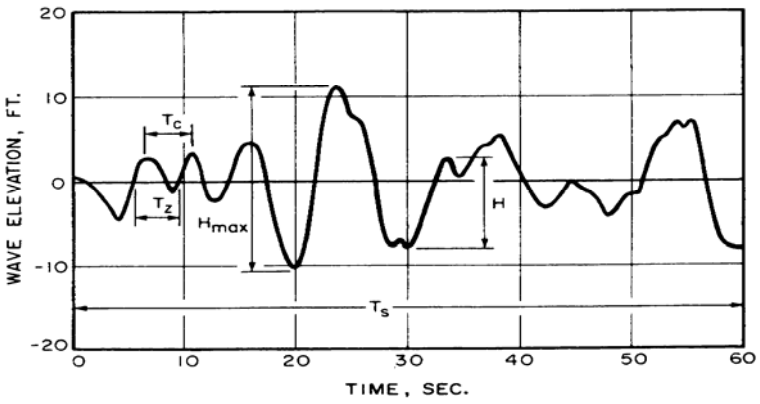
Wave profile recorded at a weather station



Wave parameters



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Definitions

- H, H_{max} wave height; max wave height [m]
- H_s significant wave height [m]
  - Average of highest 33% of the observed waves
- T_z zero (up-)crossing period [s]
  - Average time between zero crossings (1 hr/ 10 min)
- T_c,T_p crest (peak) period [s]
  - Average time between two crests (peaks)
- C celerity or wave propagation velocity [m/s]

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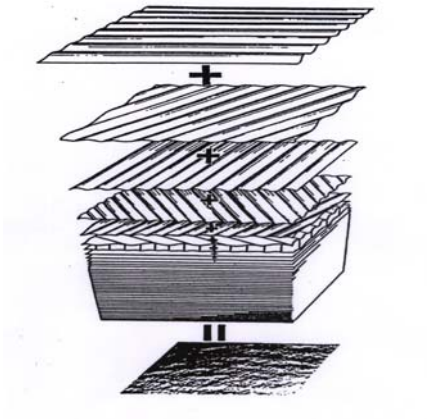
Conceptual wave composition



- Waves at sea can be thought to consist of:
- a large number of 2 dimensional waves
- waves with various amplitudes
- from various directions
- with various phases

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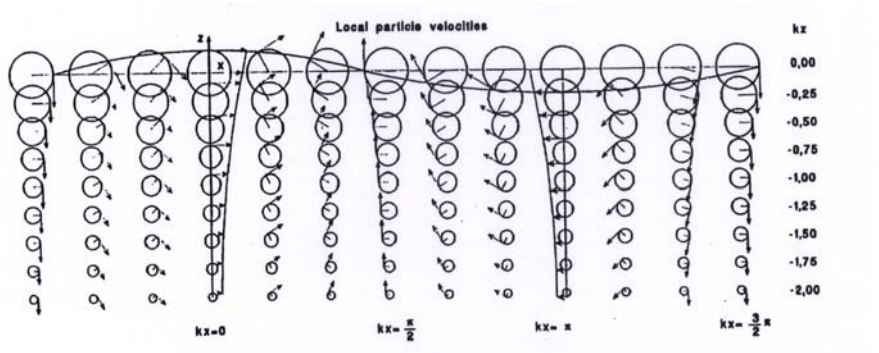
Morphology of a 2 dim. wave



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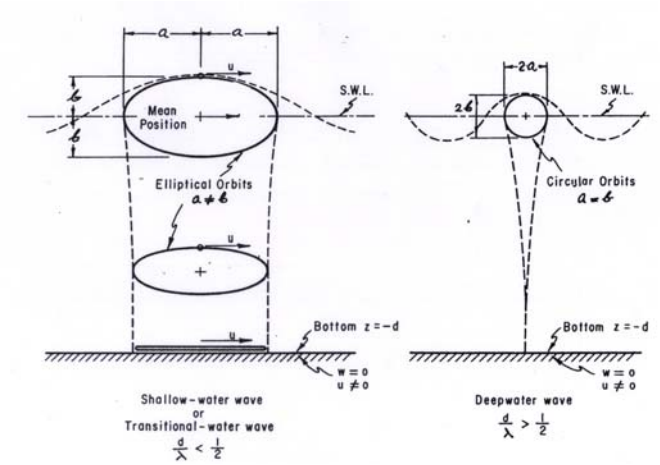
Shallow(er) water wave (2 dim.)



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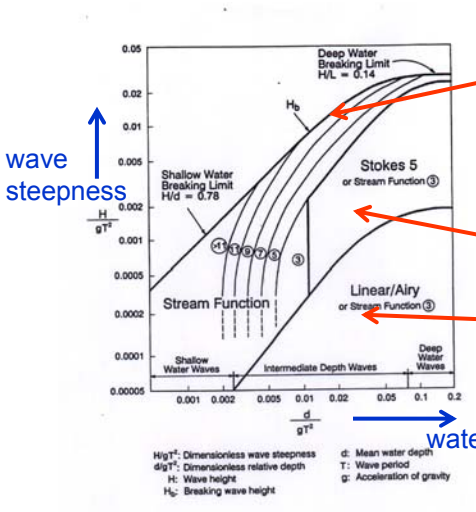
Airy wave theory

- Linear regular 2 dim. wave theory
- Accurate for small amplitude waves and deep water
- Essentially sinusoidal in shape
- Irregular wave trains created by summing components at different frequencies
- Allows calculation of:
  - *Water particle velocity*
  - *Water particle acceleration*
  - *Hydrodynamic pressure*

Application of wave theories



wave steepness

water depth

Breaking wave limit

Stream function

(Linear) Airy waves

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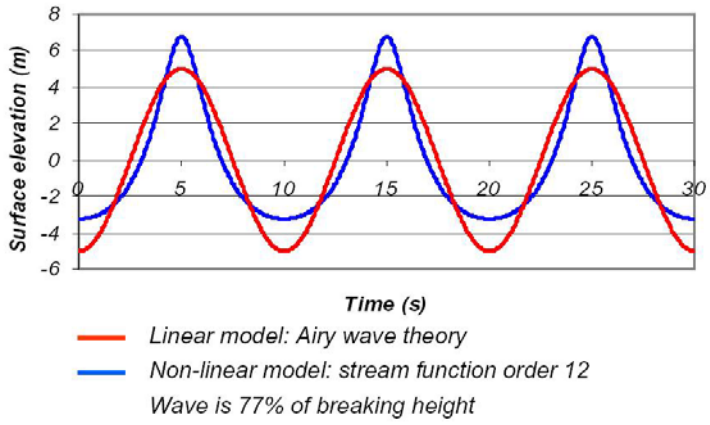
Comparison Airy and Stream function wave



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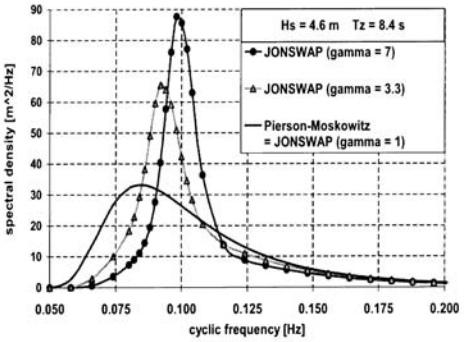
Energy spectral density



Choices:

- P-M spectrum
- JONSWAP
- Delivers wave frequencies and amplitude
- Usually random phased

P-M Pierson Moskowitz

JONSWAP Joint European North Sea Wave Project

Pushing Offshore Wind Energy Regions (POWER)

Loads on offshore wind turbines

Rotor - Wind

Support structure
- Wind
- Waves
- Current (Tide, Swell)
- Ice
- Ship impact

Foundation
- Scour
- Mobile sand banks

Calculation example

- 1.5 MW 3 bladed 70 m diam. turbine
- hub height 64 m (above mean sea level)
- 15 m. mean sea level
- monopile
- 11 m/s wind speed Hs = 1.5m Tz = 6s
- P-M spectrum

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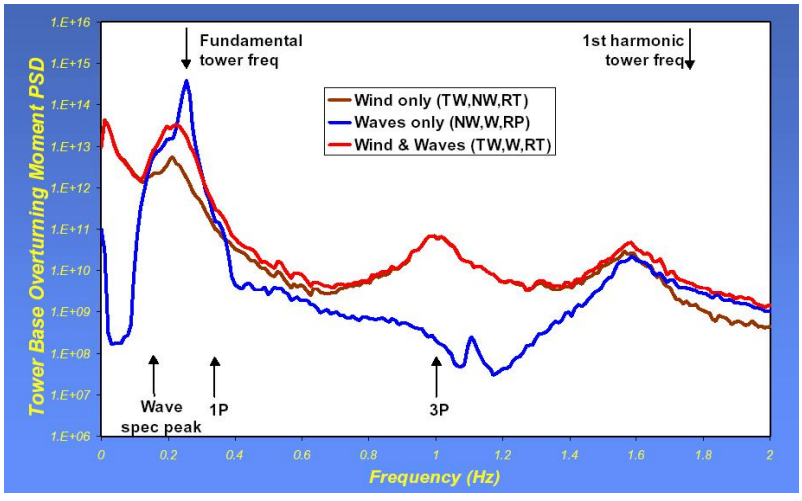
Support structure base overturning moment



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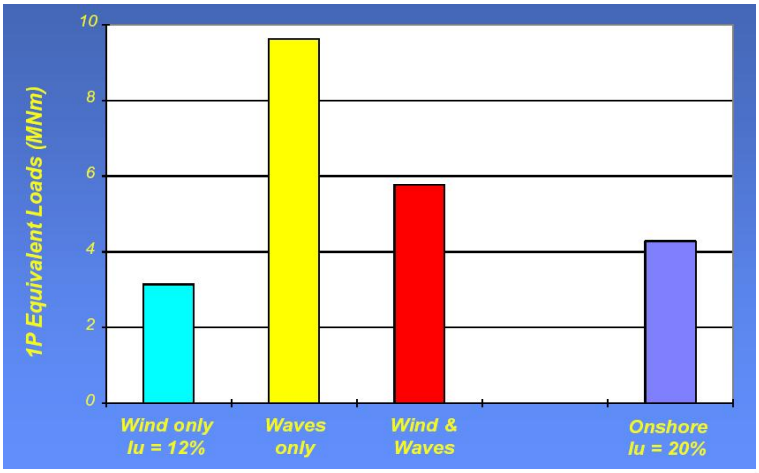
Equivalent loads: support structure base overturning moment



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