NORCOWE - From measurement campaigns to O&M

Kristin Guldbrandsen Frøysa

Director NORCOWE

kristin@cmr.no

www.norcowe.no

Norwegian Centre for Offshore Wind Energy
www.norcowe.no

R&D partners:

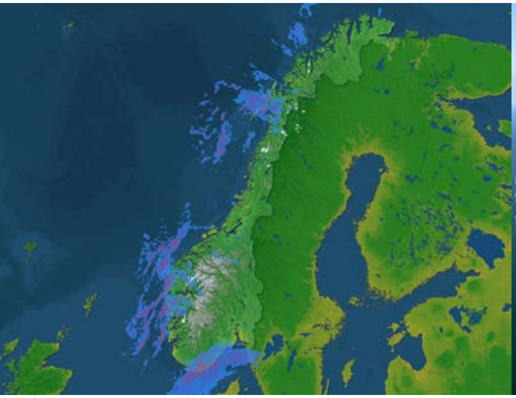
- Christian Michelsen Research (host institution)
- Uni Research
- University of Agder
- University of Bergen
- University of Stavanger
- Aalborg University (DK)

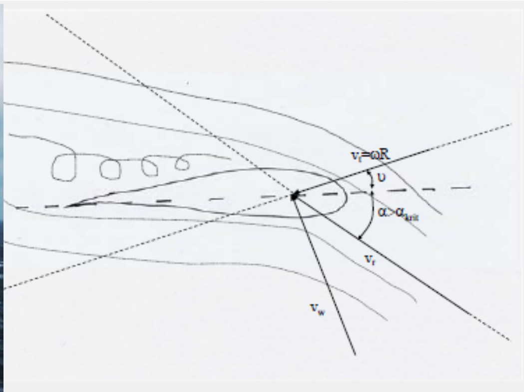
Industry partners:

- Statkraft
- Statoil
- Acona Flow Technology AS
- Aquiloz
- FLiDAR
- Leosphere
- Norwegian Meteorological Institute
- StormGeo AS

norcowe Norwegian Centre for Offshore Wind Energy

Large range of coupled scales



Mesoscale	Park scale	Rotor scale	Blade scale
10000 -10 km	10 -1 km	200 – 50 m	5 - .5 m
Days -Hours	20 min – 20 s	10 – 2 s	0.5 – 0.01 s

Factor of 10^6 in relevant length and time scales

By courtesy of Finn-Gunnar Nielsen

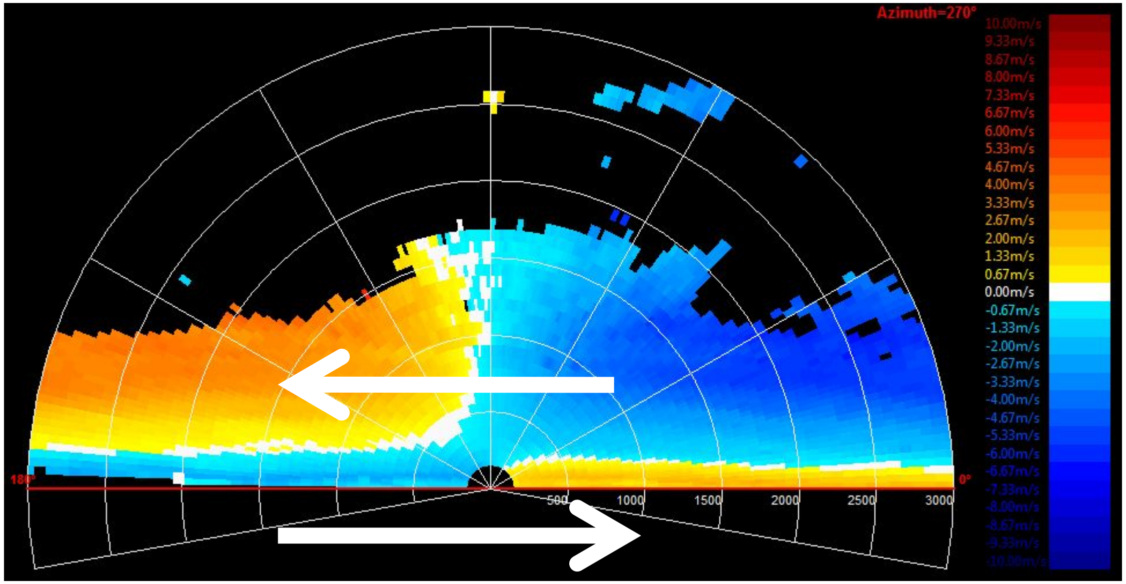
Hot topics that require advanced measurements

- single turbine wakes
  - extension, 3d-structure and dynamics, dependent on stability
- wind farm wakes
  - strength and extension, dependent on stability
- characterization of the turbine/wind park inflow
  - production optimalization and load/fatigue reduction
- improvement of BL parameterization schemes in numerical models for better wind forecast
  - process understanding of turbulent exchange processes
  - added complexity by air-sea interaction and wave effects
- reliable offshore site assessment
  - e.g. floating lidars, MWTP

Lidar campaign @ Sola Airport

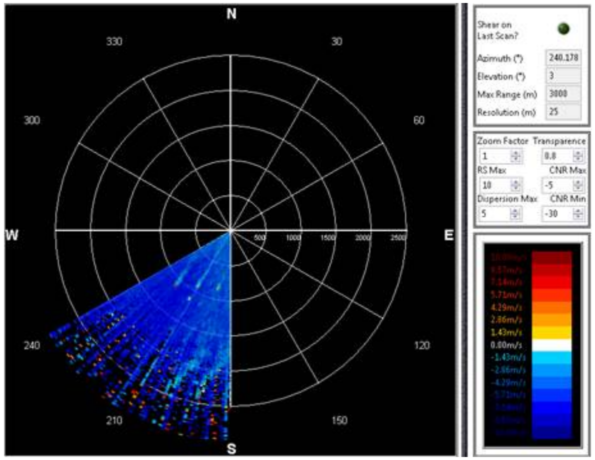
- April – July 2013
- 3D scanning Lidar
- 2 x vertical Lidars

- Land-sea boundary layer transitions
- Tower and weather baloons reference



ECN/NORCOWE wake study campaign

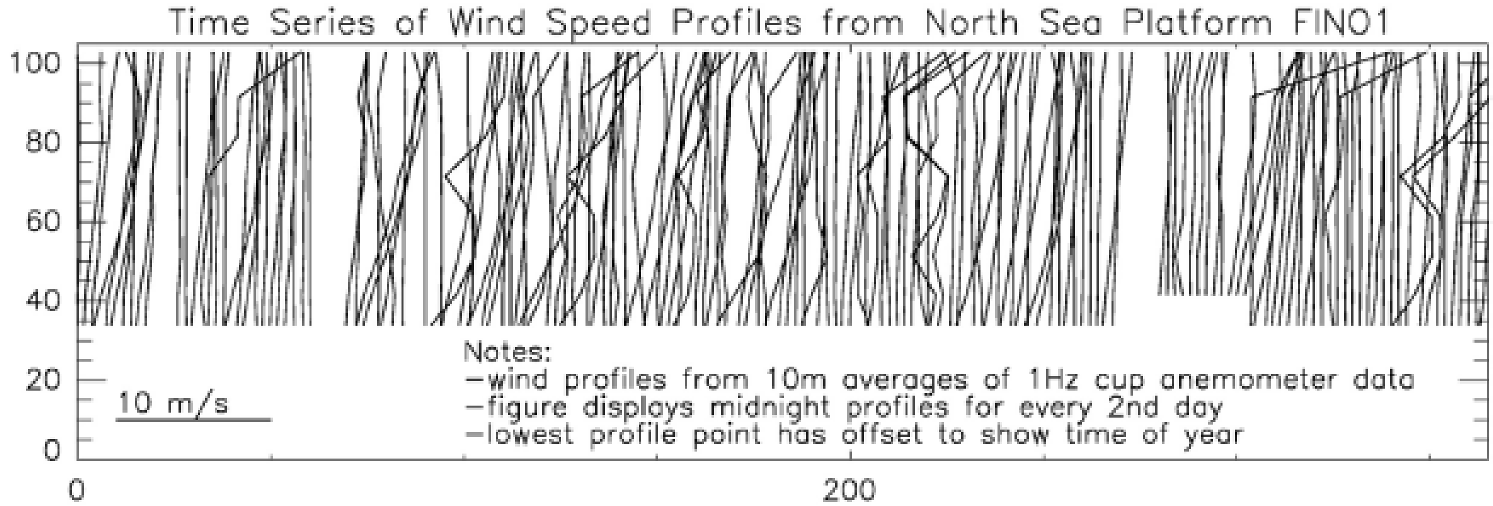
- October 2013 – May 2014
- Single turbine row wake
- 2 nacelle mounted LiDARs
- 5 LiDARs in the field
  - 1 scanning
- SUMO flights in May 2014



FME CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH

norcowe Norwegian Centre for Offshore Wind Energy

complex wind profiles (from FINO1)



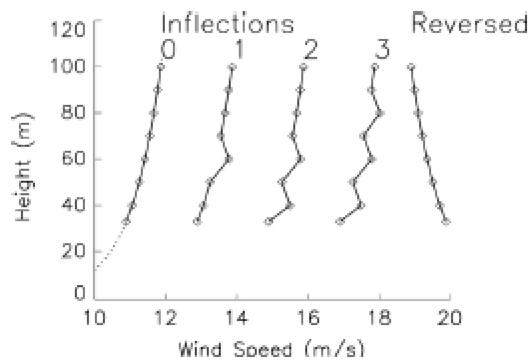


Table 1
Number of wind speed profiles from the FINO1 offshore mast categorized according to local maxima (inflections) and reversed characteristics. The data are based on 10 min averages from 2005.

Profile description	Number of profiles	Percentage of total
0-Inflection	11,296	25.0
1-Inflection	20,146	44.5
2-Inflection	12,917	28.5
3-Inflection	418	0.9
Reversed	480	1.1

Kettle,A.J., Unexpected vertical wind speed profiles in the boundary layer of the Southern North Sea. Journal ofWindEngineering&IndustrialAerodynamics(2014), http://dx.doi.org/10.1016/j.jweia.2014.07.012

FINO 1

- Research platform
- Commissioned 2003

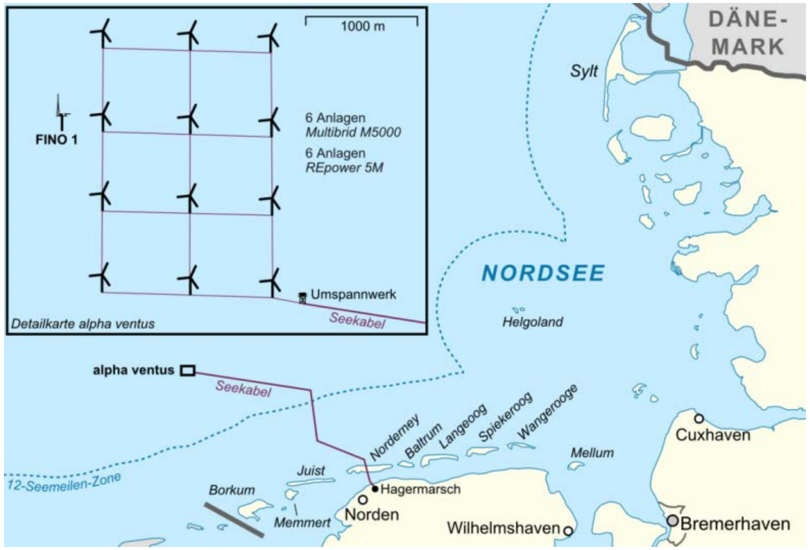
- Owner:
  Federal Ministry (BMWi)
- Administration:
  Projektträger Jülich

- Operator 2012-2017:
  FuE-Zentrum FH Kiel

- Public available data

Alpha Ventus

- Owner: DOTI
  (E.ON, EWE and Vattenfall)
- Comissioned 2010
- First German offshore wind farm



- 6 x REpower 5M,
  hub height 92 m, rotor Ø:126 m
- 6 x Areva Wind M5000,
  hub height 91 m, rotor Ø 116 m
- Rated output 60MW

Norcowe campaign

Status

- Project approval by FINO operator (FuE-Zentrum FH Kiel)
- Access permit granted by owner (Projektträger Jülich & BMWi)
- Joint campaign plans with Fraunhofer IWES

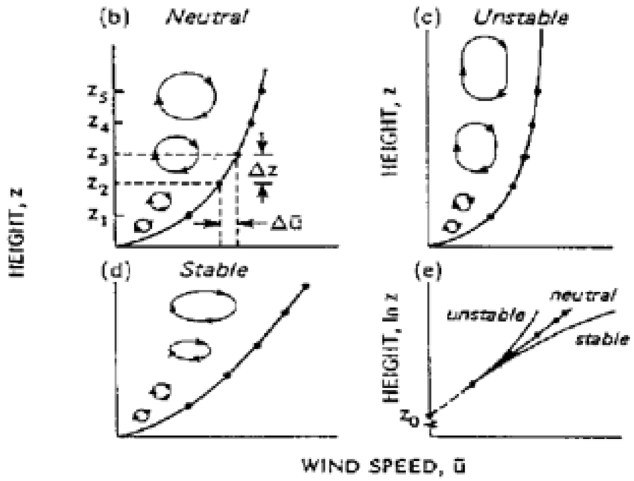
Campaign schedule

• IWES floating Lidar buoy:	January 2015	–> January 2016
• FINO1 atmospheric instrumentation:	May 2015	–> June 2016
• Oceanographic measurement buoys:	June 2015	–> September 2015

Boundary layer stability

Atmospheric measurements

- Wind, temperature and humidity profiles to increase understanding of MBL stability
- Combining different measurement technologies to increase understanding of wind gusts in offshore environments
- Validation of numerical models

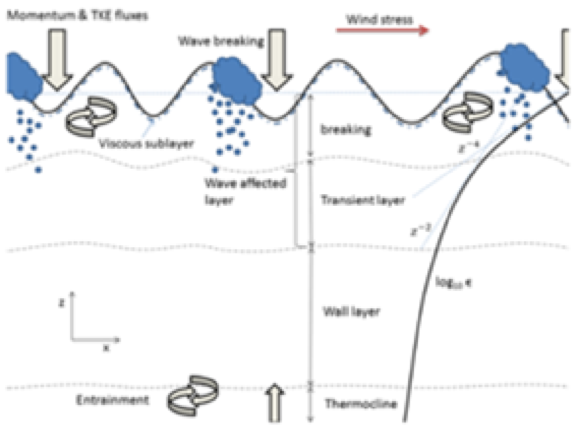


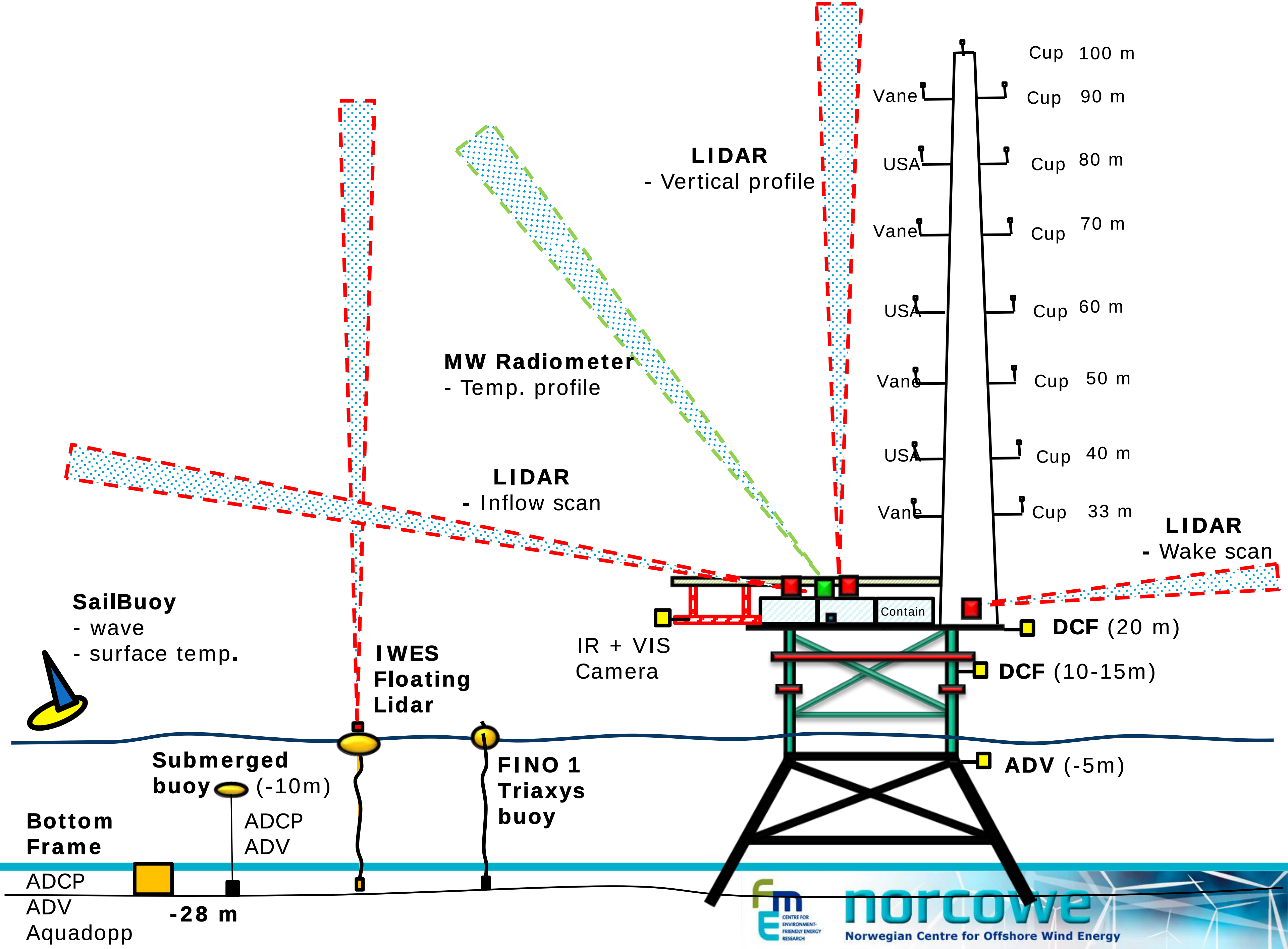
Air-sea interaction

- Investigation of wind/wave effects related to wind fluctuations, power uncertainties, and dynamic loads on offshore structures

Oceanographic turbulence

- Increase understanding of wave, current and turbulence interactions in the water column
- Validation of motion correction methods for moving submerged platforms





LIDAR
- Vertical profile
Cup 100 m
Vane
Cup 90 m
USA
Cup 80 m
Vane
Cup 70 m
USA
Cup 60 m
Vane
Cup 50 m
USA
Cup 40 m
Vane
Cup 33 m
MW Radiometer
- Temp. profile
LIDAR
- Inflow scan
LIDAR
- Wake scan
Contain
DCF (20 m)
DCF (10-15m)
ADV (-5m)
IR + VIS
Camera
SailBuoy
- wave
- surface temp.
IWES
Floating
Lidar
FINO 1
Triaxys
buoy
Submerged
buoy (-10m)
ADCP
ADV
Bottom
Frame
ADCP
ADV
Aquadopp
-28 m
CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
norcowe
Norwegian Centre for Offshore Wind Energy

Planned instrumentation

Scanning LiDAR #1: undisturbed flow

- Provides wind profile data needed for data models
- Investigation of vertical wind profile and turbulence intensity within the MABL, as function of atmospheric stability and wave height/ wave age
- Investigation of wind gust in the MABL

Scanning LiDAR #2: inflow conditions and wake effect

- Provides inflow and wake wind profile data which are highly needed for data models

Planned instrumentation

Fixed LiDAR: vertical wind profile

- Provides wind profile data needed for data models
- Investigation of wind gust in the MABL
- Supplement to 3D scanning LiDAR

Passive microwave radiometer for measurement of horizontal and vertical temperature and humidity profiles

- Provides information of atmospheric stability
- Investigation of atmospheric stability as function of wind speed and wave age

Aerodynamics at UiS

- Interpretation of the available full-scale (wind) data (short duration events and long-terms statistics)
- Adoption of refined load models
- Investigation of wind turbine response (e.g. fatigue) and energy production
- Use of (expanded) full-scale data directly in structural analyses
- (Full-scale investigation of wind-induced response of slender structures due to buffeting loading)

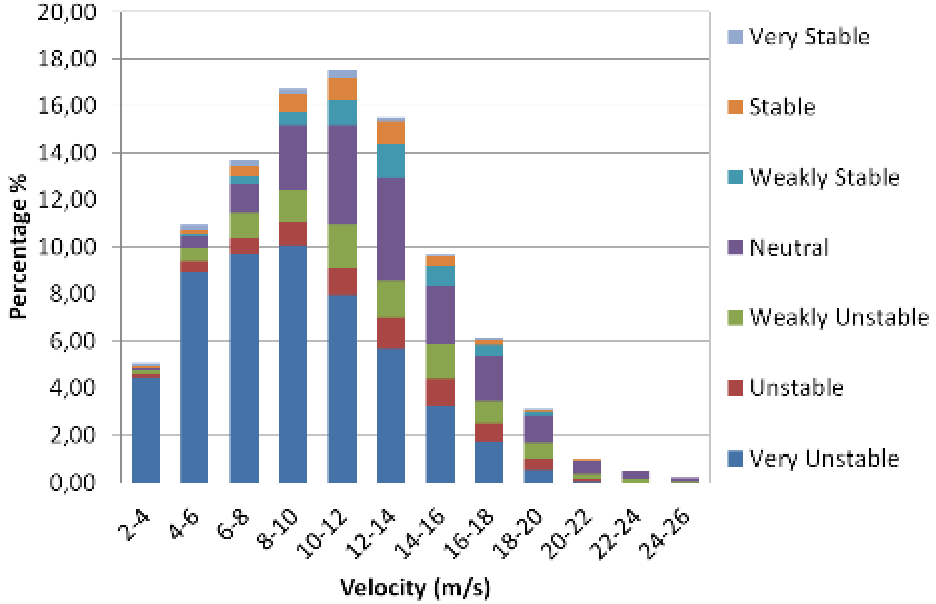
<u>Senior UiS researchers:</u>

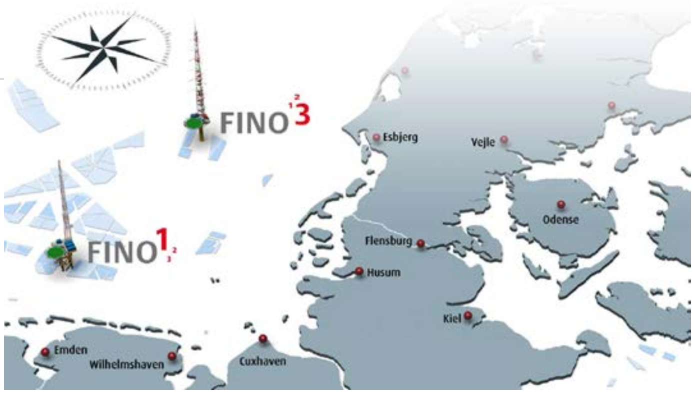
- Prof. Jasna Bogunovic Jakobsen, Ass. Prof. Charlotte Obhrai,
- Prof. II Jonas Snæbjørnsson

Example of analysis of relevant full-scale data (Fino 3 – measurements)

- Data from FINO3 measurement platform, operating since 2009.
- Temperature (29 m & 95 m) and the wind speed (50 m & 90 m) data, from 01/10/2009 to 01/10/2011 utilized.

Stability distribution





www.fino3.de

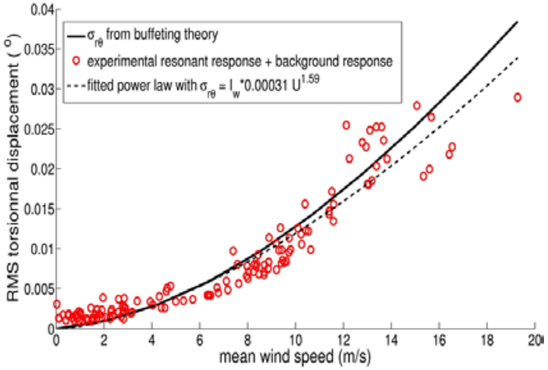
Courtesy: Jasna B Jakobsen, UiS

Example of a full-scale verification of buffeting load models on slender structures: Bridge measurement campaign at Lysefjorden

1. Sonic anemometers and accelerometers (8+ 10 sensors along the bridge)
2. Wind flow characterization by long-range and short range-lidars

   (UiS, UiB, CMR, DTU, NPRA (Vegvesenet))

Theoretical and measured wind-induced response:



Risk-based O&M of offshore wind farms

- AAU - Mihai Florian (PhD project)

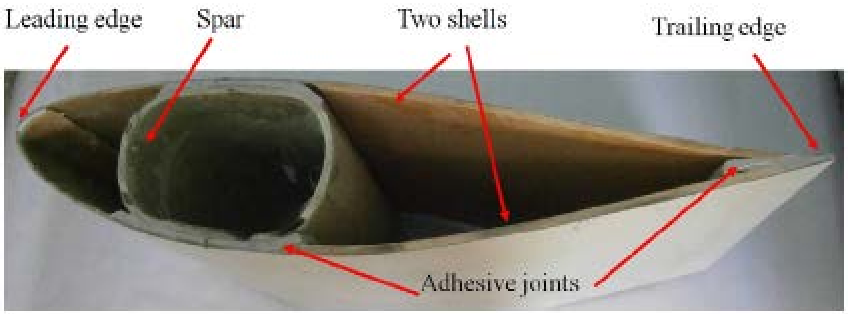
Objectives:

- Formulation of the theoretical framework for a risk-based decision tool for planning of operation and maintenance for wind turbine components
- Development of damage model for selected components; e.g. blade defects and erosion, gearbox failure and welded details
- Development of early warning system model using condition monitoring data
- Development of risk based cost and decision model
- Case studies using NRWF (reference wind farm)

Cooperation

- Statoil

Example application: O&M for blades



S. Ataya, M.M.Z. Ahmed / Engineering Failure Analysis 35 (2013) 480–488

edp renewables

Failure modes

- Erosion on shells
- Cracking on main spar
- Debonding of glue joints
- Delamination of composite fiber
- Cracking of composite fiber
- Random (lightning) or unknown

Condition and risk-based planning of O&M

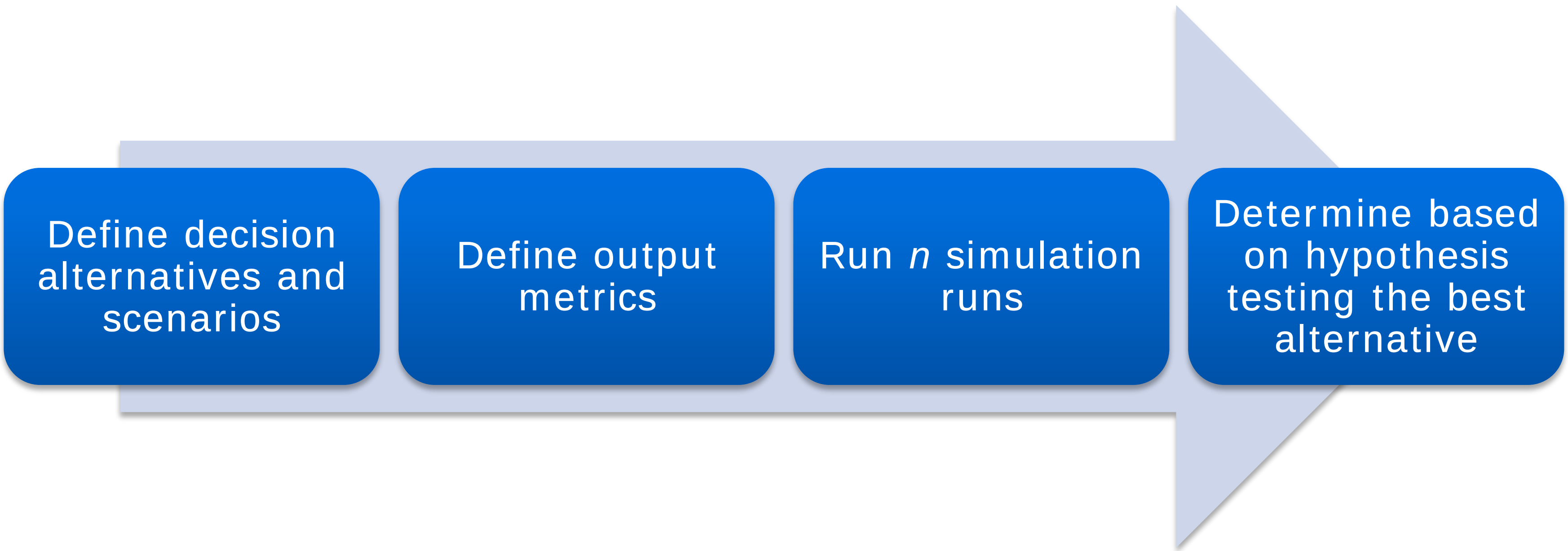
- Modelling of information from SHM, inspections – incl. uncertainties
- Modelling of defects and deterioration
- … reliability assessment
- Condition-based planning of next inspections and maintenance
- Risk-based planning of inspections and maintenance during remaining lifetime

Decision support
PhD project Ole-Erik Vestøl Endrerud, UiS

- It is a lot cheaper and faster to test in a computer program instead of a real and expensive wind park!

- For example in structural design and CFD simulations have been an important method for years. It's time to bring it into O&M as well!

Decision support



Decision making example

- 70 direct drive wind turbines
- 6 MW rated capacity
- 40 km from shore
- 30 technicians

- Failure data from onshore turbines
- Exponential lifetime distributions
- Repair and cost data

Results from example

	2 CTV			1 SOV		
	μ	σ	S	μ	σ	S
Time based availability [%]	97.03	0.21	0.09	93.51	0.62	0.28
Energy based availability [%]	94.27	0.22	0.10	90.95	0.60	0.27
Lost production [kWh]	8.99E7	8.45E6	3.78E6	16.6E7	9.81E6	4.29E6
Marine logistics cost [mill £]	8.395	2.06	0.92	19.08	1.32	0.59
Vessel utilization [%]	32.74	0.76	0.34	46.88	0.80	0.36

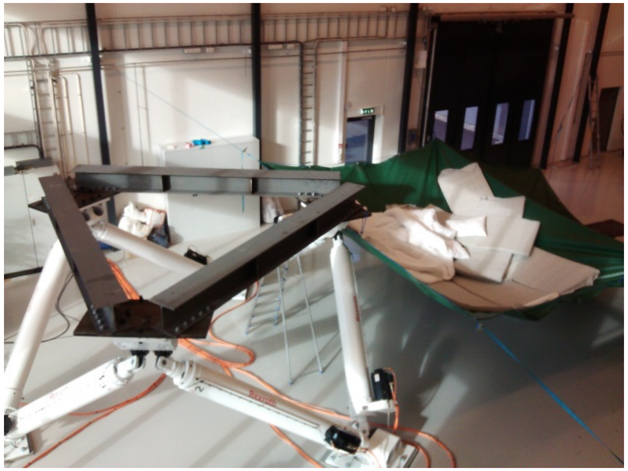
Hypothesis test

Table 2: Hypothesis test with the CTV-alternative as base case to determine if the results are statistically significant from each other. Confidence intervals are created from the base case.

	Time based availability	Energy based availability	Lost production	Marine logistics	Vessel utilization
Lower limit	96.77%	93.99%	7.94E7	£5 838 981	31.80%
Upper limit	97.29%	94.55%	10.0E7	£10 951 019	33.68%
t-value	39.111	33.997	8.476	41.718	92.217
p-value	~ 0%	~0%	~0%	~0%	~0%
Reject with	~100%	~100%	~100%	~100%	~100%

Motion lab with two Stewart platforms

http://www.motion-lab.no/



Thank you for your attention!