INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems
Task 11

52^{nd} IEA Topical Expert Meeting

Wind and Wave Measurements at Offshore Locations

Berlin, Germany, February 2007
Organised by: TU Berlin and Germanischer Lloyd

Scientific Co-ordination:
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For more information about IEA Wind see www.ieawind.org

CONTENTS

IEA RD&D Wind Task 11

Topical Expert Meeting #52

Wind and Wave Measurements at Offshore Locations

Wind and Wave Measurements at Offshore Locations: Research Platform FINO 1

Gundula Fischer, Germanischer Lloyd Industrial Services GmbH
Business Segment Wind Energy

Germanischer Lloyd

Contents

- **Research project FINO**
- **Research platform FINO 1**
- **Results and extreme values**
- **Summary and outlook**

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Research Project FINO

- Platform and research program financed by the Federal Environmental Ministry
- GL Wind: coordination of construction, erection, commissioning and operation
- Installation of the research platform close to future offshore wind farms
- Platform to investigate the environmental offshore conditions
- Comprehensive meteorological, hydrographical, technical and biological measurements and investigations

Zukunfts-investitions-programm zip

Pt Projektträger Jülich Forschungszentrum Jülich GmbH

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

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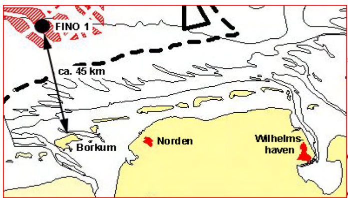
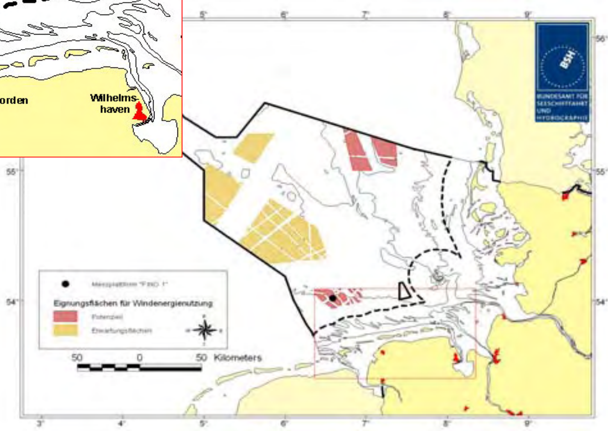
Research Platform FINO 1





Location:
ca. 45 km
north of Borkum

N 54° 0,86‘
E 6° 35,26‘

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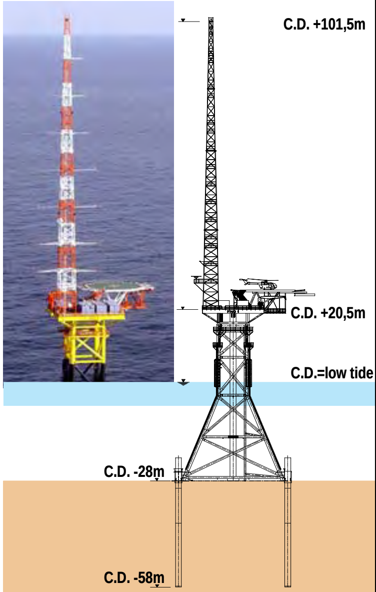
FINO 1: Technical Data

- **Foundation:** 4 piles, Ø = 1.5 m; l = 38 m
- **Foundation structure:** Jacket; h = 48 m, 26 x 26 m at sea bed
- **Platform:** 16 x 16 m; C.D. + 20 m
- **Equipment of platform:** 5 containers, radar systems, cranes
- **Helicopter pad:** 14 x 14 m
- **Measurement mast:** h = 80 m
- **Total height from sea bottom:** 130 m



Measurements and Investigations

- **Meteorology (DEWI)**
  wind speed and direction at different levels up to 100 m above see level,
  temperature, humidity, air pressure,
  global radiation, UV-A radiation, rain
- **Oceanography (BSH)**
  wave height, period and direction,
  current velocity and direction, level,
  water temperature, salinity, oxygen and pressure
- **Further technical and environmental investigations**

GL: Operation and maintenance of FINO 1

- Automatic operation and day trips to FINO 1
- Guarantee of energy supply and function of platform equipment
- Maintenance of platform network and data transmission
- Coordination and performance of maintenance and measurement services (boat/helicopter)
- Publication of results www.fino-offshore.com

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Results: Offshore Wind Speed

- Mean wind speed (2004/2005): 9.9 m/s
- Main wind direction: south-west
- 8000 h/year: wind turbine in operation
- 2000 h/year: rated wind (13 m/s) is exceeded
- Overall wind power production of > 4.500 full load hours

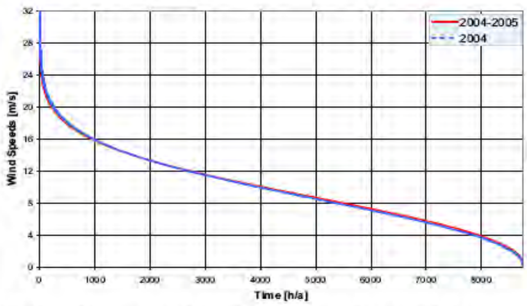

Fig. 3: Measured wind speed duration curve for a period of one year at the 100m-level of FINO 1 platform

Source: DEWI

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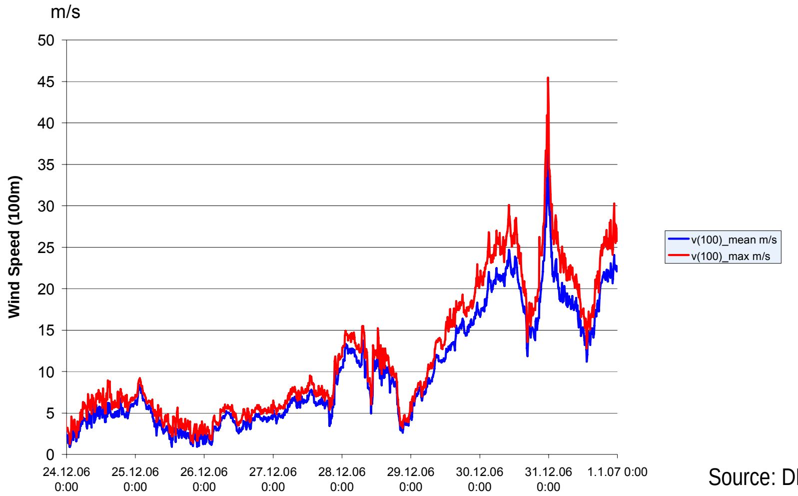
Maximum Wind Speed



Source: DEWI

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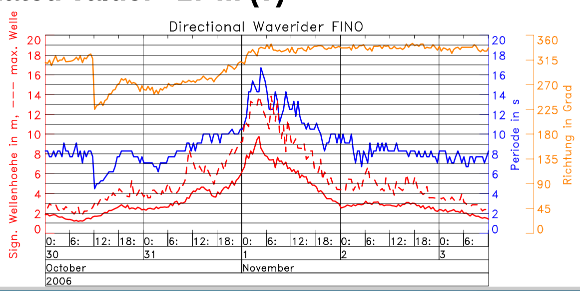
Maximum Wave Heights

- **Maximum significant wave height: 9.86 m**
- **Maximum wave height: ?**
  measured value after correction: 13.80 m
  estimated value: ~17 m (?)



Source: BSH

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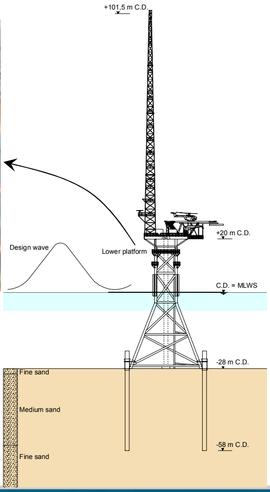
Storm Damage of 1st of November 2006



Storm damage on lower platform, C.D. + 14.5 m

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Summary and Outlook

- **FINO is a new, complex and worldwide unique project**
- **Extensive measurement program with high demands on platform and equipment**
- **Construction, installation and operation under special conditions (North Sea; 45 km off Borkum, water depth 28m)**
- **Result: Successful installation, operation, and data collection**
- **FINO 1 is first signal for German offshore wind industry**

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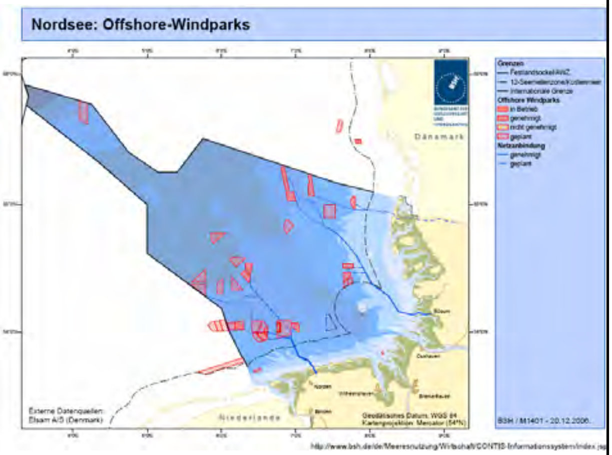
German Offshore Wind Projects

- Planning: ~ 40 offshore projects
- Approved: 15 projects in the EEZ of North Sea and Baltic Sea
- Installed: none (only single wind turbines near the shore)



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Offshore Test Field

STIFTUNG OFFSHORE WINDENERGIE

- Planning of a test field for 12 offshore wind turbines in immediate vicinity of FINO 1
- Initiation through establishment of the „offshore wind energy foundation“
- Operating company: DOTI* (EWE, EON, Vattenfall) Investment costs ca. 175 m €
- Installation of wind turbines 2008/2009 (REpower, Multibrid)
- Broad research program: Funding by BMU, 50 m € in 5 years

* Deutsche Offshore-Testfeld- und Infrastruktur-GmbH & Co. KG

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Thank you very much for your attention!

Germanischer Lloyd

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Applications and Analysis of Offshore Wind and Wave Measurements

George Scott
National Renewable Energy Laboratory
Golden, CO, USA

IEA Topical Expert Meeting
Wind and Wave Measurements
At Offshore Locations
TU-Berlin

February 20-21, 2007

NREL is operated by Midwest Research Institute • Battelle

NREL/NWTC

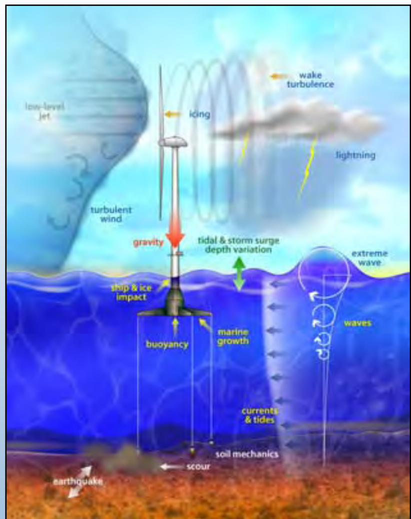
- National Renewable Energy Laboratory
  - Funded by US Department of Energy
- National Wind Technology Center
  - Located between Golden and Boulder in Colorado

Overview

- Research Areas
- Offshore Wind/Wave Data Used at NREL
  - Towers
  - Buoys
  - Satellite wind data
  - SAR
  - Model data
- Analysis of Offshore Wind/Wave Measurements
- Priorities
- Future work

NREL Offshore Research Areas

- Characterization of offshore wind and wave loads for standards development
- IEC 61400-3 - Design requirements for offshore wind turbines
- Evaluation of specific offshore turbine & platform designs

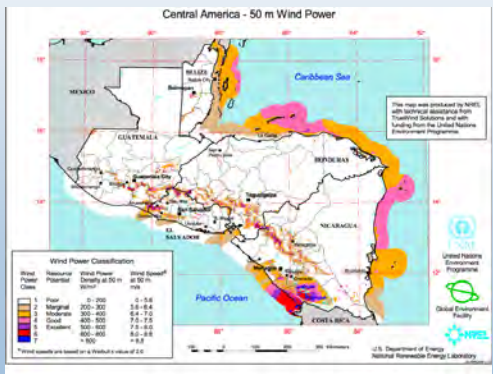


NREL Offshore Research Areas

- Characterization of offshore wind
  - Turbulence
  - Wind shear
  - Directionality
  - Extreme events
  - Seasonal and diurnal patterns
- Characterization of wave climate
  - Wave spectrum
  - Directionality
  - Relationship to winds
  - Extreme events
  - Seasonal and diurnal patterns

NREL Offshore Research Areas

- Regional wind resource assessment studies
  - Provide initial conditions for model
  - Validate final maps

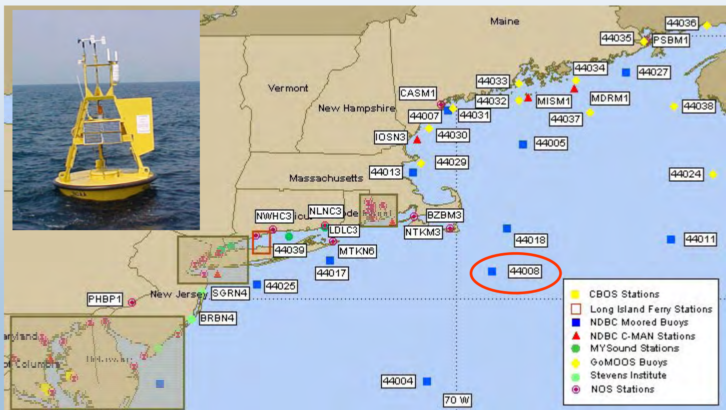


Sources of Offshore Wind/Wave Data

- Buoys
- Towers
- Satellites
- Models

Buoy Data

- NOAA's National Data Buoy Center
- Wind and wave data from 1982



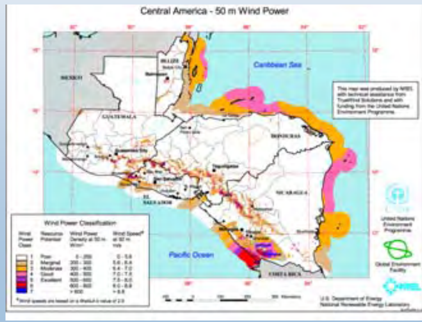
Ship Data

- US Navy Marine Climatic Atlas
  - Ship observations 1850-1970

Tower Data

Cape Wind Project
Installed: April 2003
Cups & Sonic Anemometers at 20, 40, 60m
Wave & current measurements

Satellite Ocean Wind Data for Regional Mapping



Satellite Ocean Wind Data for Regional Mapping

- Special Sensor Microwave/Imager (SSM/I)
  - 1988 to present
- TRMM Microwave Imager (TMI)
  - Tropical Rainfall Measuring Mission (TRMM)
  - 1998 to present
  - 40°S to 40°N
- QuikScat
  - July 1999 to present
- All data obtained from Remote Sensing Systems
  - Data are produced by Remote Sensing Systems and sponsored by the NASA Earth Science REASoN DISCOVER Project or the NASA Ocean Vector Winds Science Team. Data are available at **www.remss.com**.

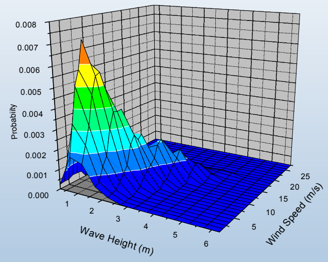
Satellite Ocean Wind Data for Regional Mapping

- Sensors
  - Passive (radiometers) – SSM/I, TMI
    - Solve Radiative Transfer Equation
  - Active (scatterometers) – QuikScat
    - Analyze backscattered signal
- Returns 10m wind speed and direction, water vapor and liquid
- Accuracy: ±2.0 mps WS, ±20° WD
- Less accurate in coastal/shallow regions
- RSS daily files combined into monthly 0.25° grids
- Monthly grids combined into annual or long-term grids

WaveClimate.com Wind/Wave Model

- http://waveclimate.com from ARGOSS, NL
- 3rd generation model based on **WaveWatch** III
- 13 years of 3-hourly data ≈ 38000 points
- Data from SAR, scatterometer and altimeter
- Model inputs
  - scatterometer: wind speed and direction
  - altimeter: wind speed and significant wave height
  - SAR wave mode: wave periods and directions
- Satellites
  - Topex/Poseidon, Jason-1, ERS-1, ERS-2, GFO, Envisat, QuikScat
- Calibrated against buoy data

Analysis of Offshore Measurements

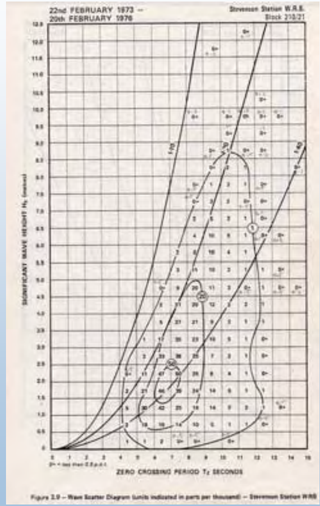


ITI Energy Barge Model

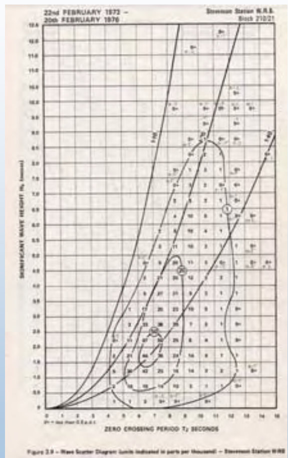
- Cooperative research with ITI Energy, Aberdeen, Scotland
- NREL Offshore Baseline Wind Turbine
  - Conventional, utility-scale turbine
  - 5-MW rating
  - Based heavily on REpower 5M
- ITI Energy Barge
  - Designed by Universities of Glasgow and Strathclyde
  - Square barge with central moonpool and oscillating water column
  - Eight slack, catenary lines

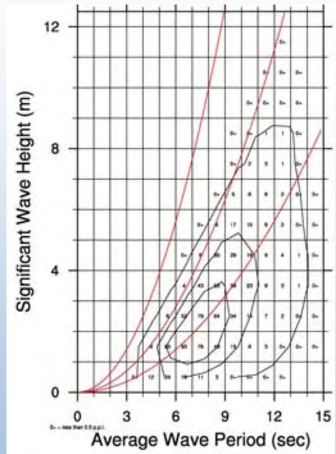
Stevenson Wave Rider Buoy

- Feb 1973 to Feb 1976
- Water depth: 159m



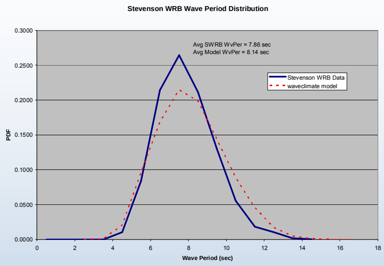
Measured data vs. Waveclimate model

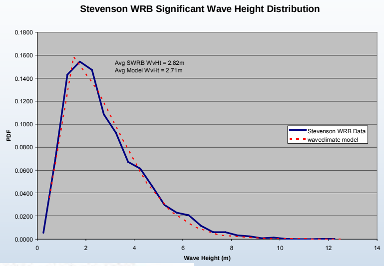


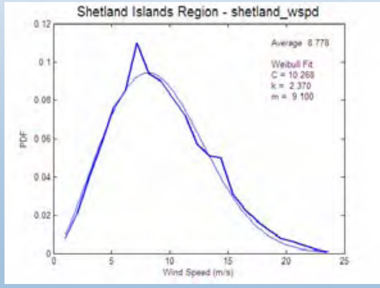


Waveclimate model shows slightly more long-period waves

Distributions from model

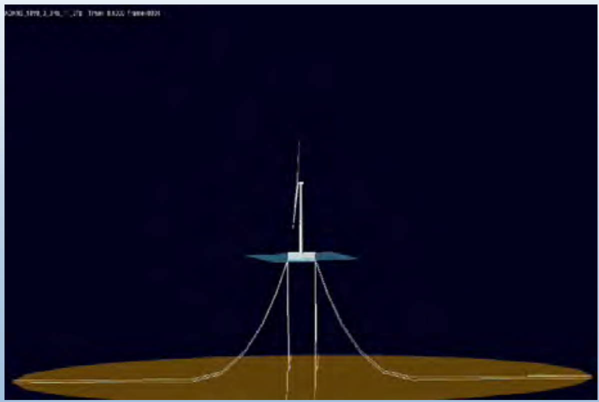




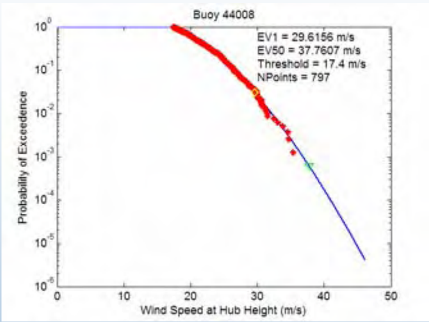


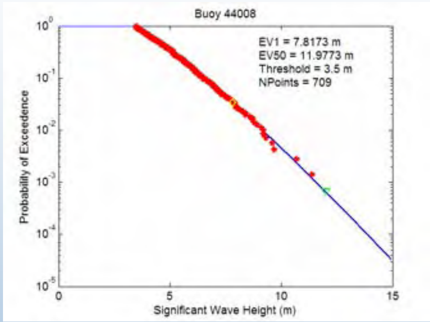
ITI Barge ADAMS Simulation

- Wind speed = 18 m/s
- Wave height = 3.3 m
- Wave period = 11.3 sec



Extreme Winds and Waves





Extrapolated from 24 years of buoy data

Actual Avg. Wind EV1 = 29.7 m/s
Model Wind EV1 = 29.2±2.0 m/s
Model Wind EV50 = 35.1±3.3 m/s

Actual Avg. Wave EV1 = 8.15 m
Model Wave EV1 = 7.6±1.0m
Model Wave EV50 = 10.0±1.9m

Future Work

- Turbulence analysis
  - Function of altitude?
  - Correlation of components
  - Coherent structures (large-scale eddies)
    - How to detect offshore?
- Atmospheric stability
- Wind shear
  - Low-level jets
- Co-directionality of wind and waves
  - Effect on turbine loads?
  - Variation with wave height
- Estimation of extreme wind and wave events
  - Correlation of extreme winds and waves
  - Maximum load case
- Analytical fit to wind/wave distributions
- More evaluation of wind/wave models

Wish List

- Access to more offshore tower data sets
  - 90m and up
- Non-tower offshore measurement systems
  - Floating mini-sodar or lidar?
- Improved SAR coverage

IEA Topical Meeting: Wind and Wave Measurements at Offshore Locations
Berlin, Germany – February 2007

Atmospheric Profiling and Wind-Wave Modeling in the Offshore Waters of the U.S.

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AWS Truewind

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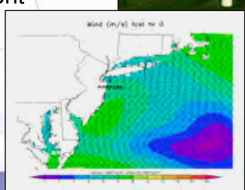
- Range of services:
  - Modeling & Mapping
  - Wind Energy Assessment
  - Project Engineering
  - Performance Assessment
  - Forecasting

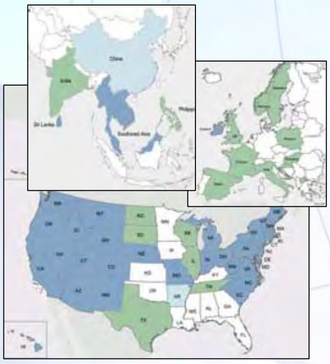


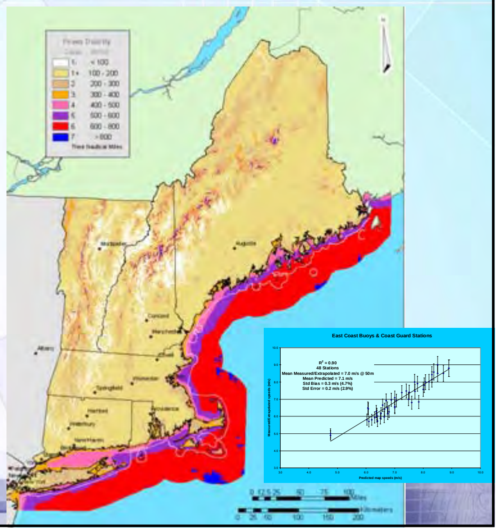
Mapping & Modeling

AWS Truewind

World leaders in atmospheric modeling with proprietary MesoMap® and SiteWind®

AWS Truewind selected by NREL/DOE to produce new U.S. wind atlas





Offshore Work

AWS Truewind

- Long Island Power Authority 140 MW
- Cape Wind 420 MW
- NJ Board of Public Utilities
- Bluewater Wind (Delaware) 600 MW
- Great Lakes Erie & Ohio
- Poland & Ireland
- MTC-DOE-GE Strategic Framework
- NREL-DOE Offshore Mapping of U.S.

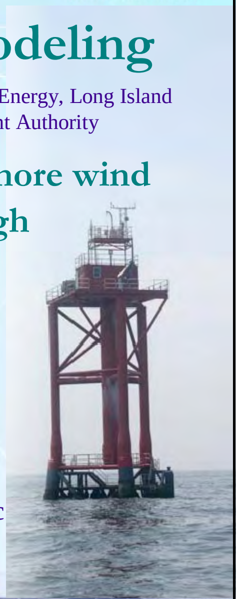
AWS Truewind

Offshore Monitoring and Modeling

Jointly Sponsored by: National Renewal Energy Laboratory / Department of Energy, Long Island Power Authority, New York State Energy Research and Development Authority

Project Objective: Characterize the offshore wind & wave environment of the Atlantic through development & application of innovative measurements & modeling techniques.

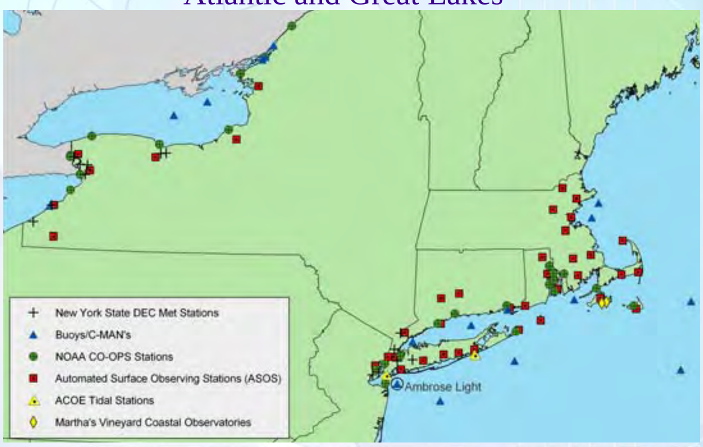
1. Assimilate historical data
2. One-year, multi-site field measurement campaign
3. Development and verification of offshore wind and wave regime model
4. Conceptual development of buoy-mounted atmospheric profiling system



AWS Truewind

Existing Data Analysis

Accumulation and analysis of Offshore and Shoreline data in the Atlantic and Great Lakes



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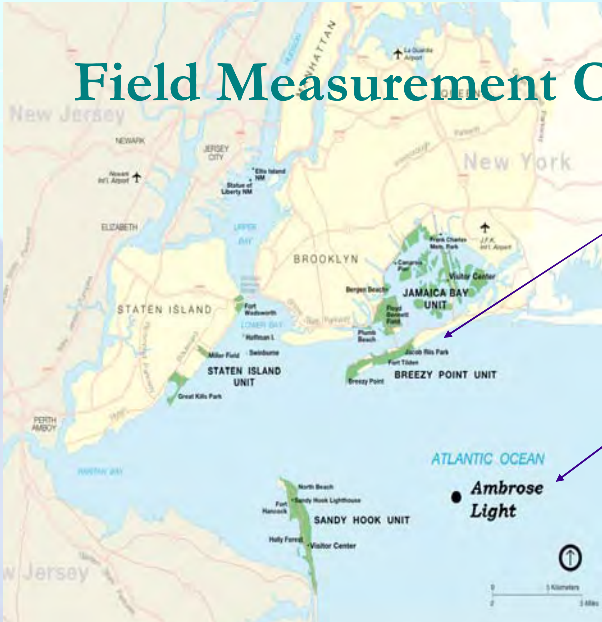
Field Measurement Campaign



Ft. Tilden

- Shoreline
- 20 m Meteorological Tower
- ART Sodar

Ambrose Light

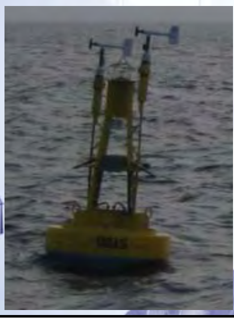
- Offshore
- Meteorological Suite
- Scintec Sodar
- 3 m Buoy

AWS Truewind

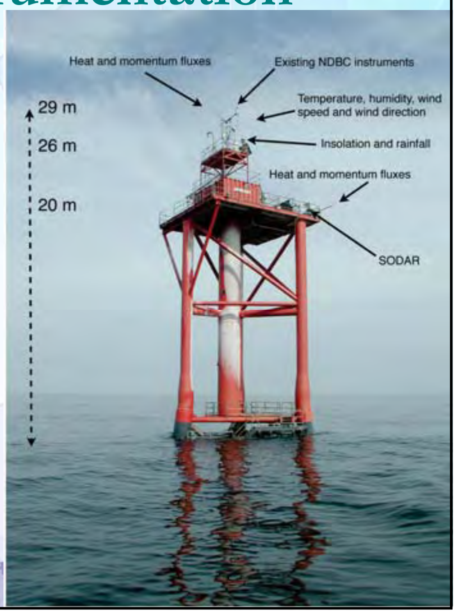
Ambrose Instrumentation

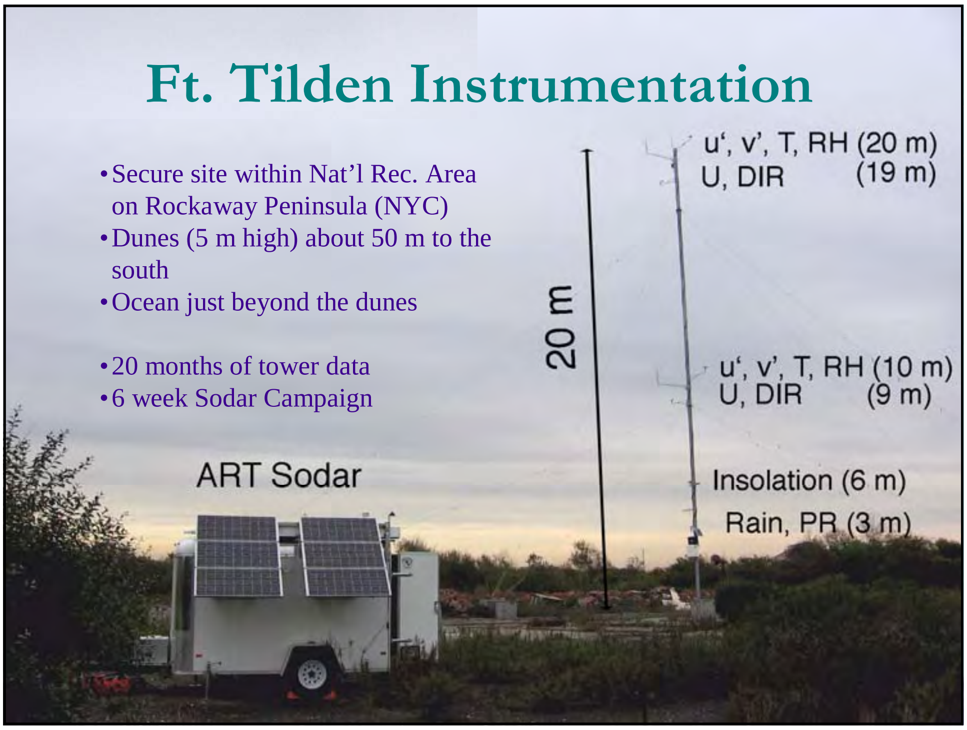
- Ambrose station 11.5 km offshore
- 25 m water depth
- 12 month monitoring period

- Buoy located 1 km from tower
- ~3 month data set



- Wind Speed and Direction
- Air and water temperature
- ADCP
  - Wave Height and Period
  - Current speed and direction





Measurement Experience

AWS Truewind

- 95% annual data recovery for offshore met program with exception of sodar
- Sodar problems linked to site obstructions, power supply characteristics, inadequate marinization of components, and difficult site access (slow repair response time)
- Weather buoy disappeared
- Validation of mesoscale wind flow models and wave prediction model (WaveWatch III)

Future Needs of Offshore Wind Characterization in U.S.

AWS Truewind

- More wind/wave data, including far offshore
- Alternatives to conventional tall met masts
- Development of buoys equipped with profilers
- Greater utilization of remote sensing & mesoscale models
- Collaboration with ocean agencies & related research programs
- Intensive field measurement campaigns
- Understanding wind - wave interactions

Offshore Wind Power Meteorology

Selected research results based on the FINO 1 data

Bernhard Lange, ISET, Germany

Contents

Mast flow correction and sonic anemometer calibration

Wind speed profile

Stability dependence of wind profile

Wind resource mapping

Future R&D needs

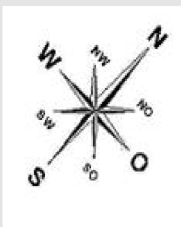
Meteorological Instrumentation

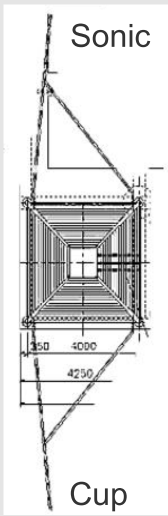
Sonic anemometers
(40, 60, 80 m)

Cup anemometers
(30, 40, 50, 60, 70,
80, 90, 100 m)

IEA Meeting Berlin 20./21.2.2007 3

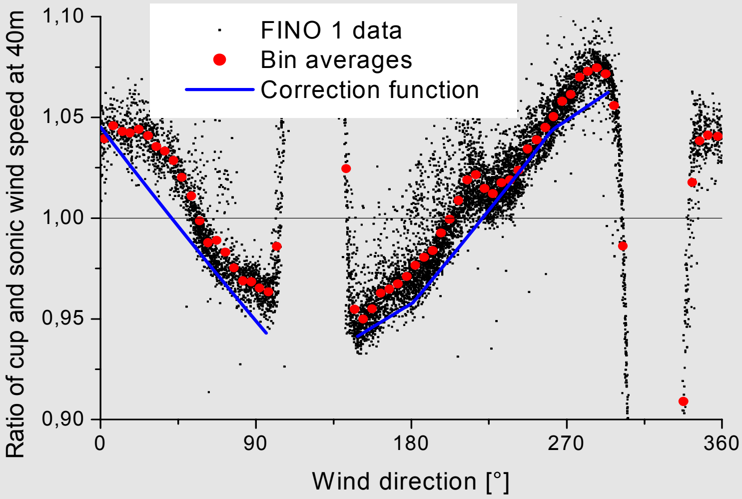
Meteorological Instrumentation





IEA Meeting Berlin 20./21.2.2007 4

Mast flow correction and sonic anemometer calibration

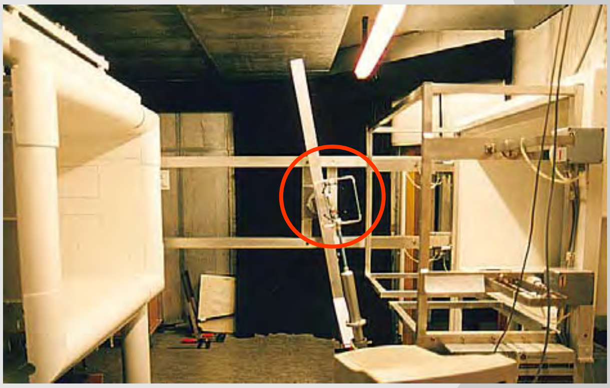


Lange, 2004

Mast flow correction and sonic anemometer calibration

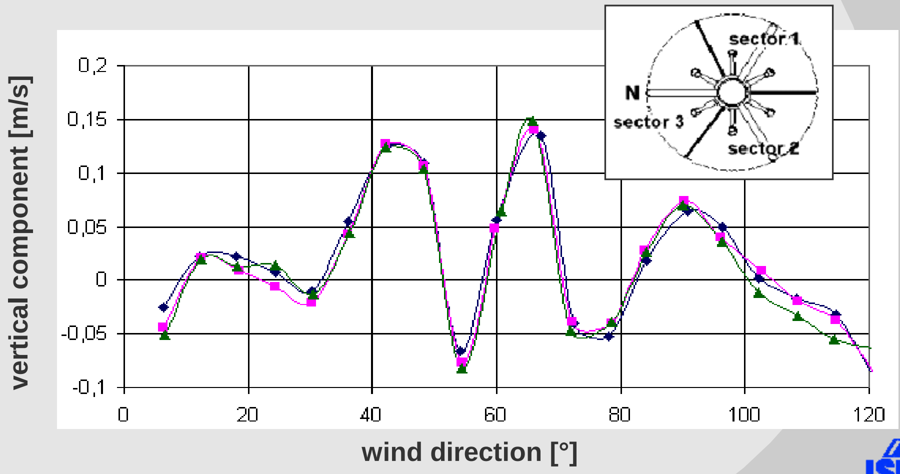
3 dimensional wind tunnel calibration:

tilt angle -35° to 35°
wind direction 0°- 360°
wind speed 0 – 17 m/s



Mast flow correction and sonic anemometer calibration

Measured vertical component error at horizontal wind speed of 10 m/s



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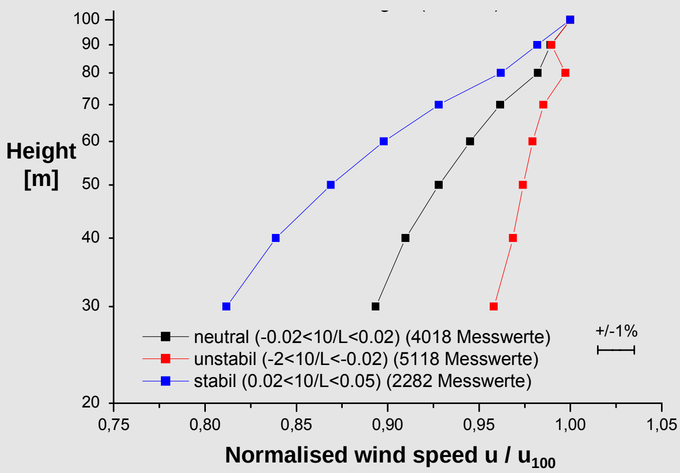
Tautz et al, 2004

Wind speed profile



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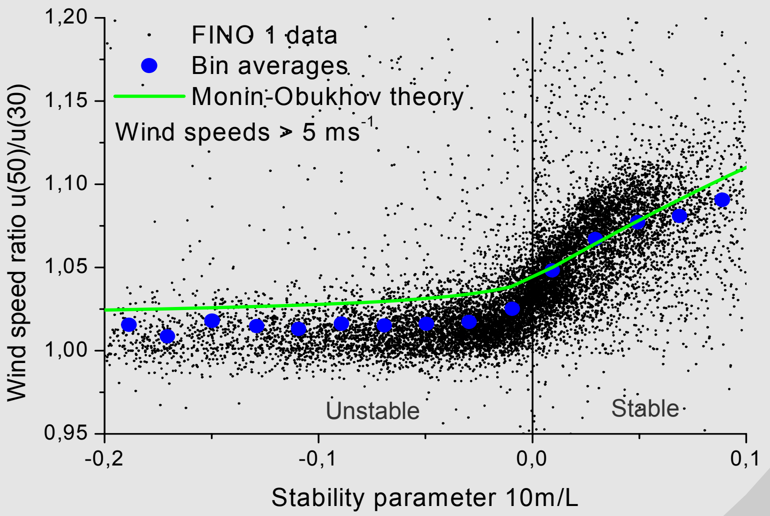
Lange and Tautz, 2004

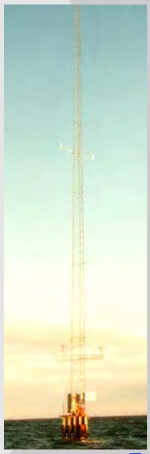
Stability dependence of wind profile



Lange, 2004

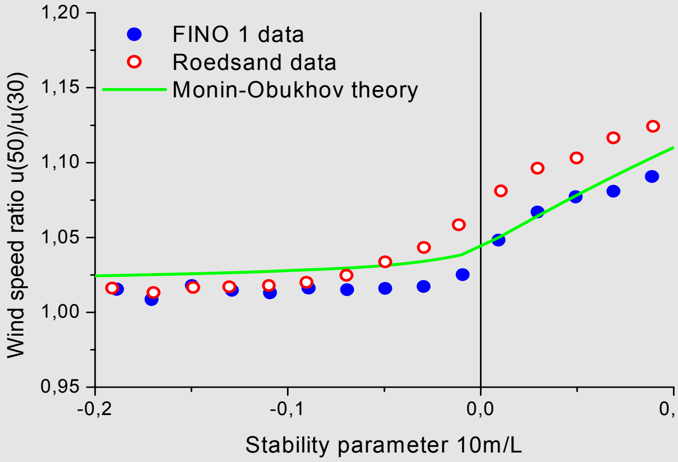
Stability dependence of wind profile

Two measurement sites in DK and D



Stability dependence of wind profile

Comparison of North and Baltic Sea measurements: FINO 1 and Rødsand



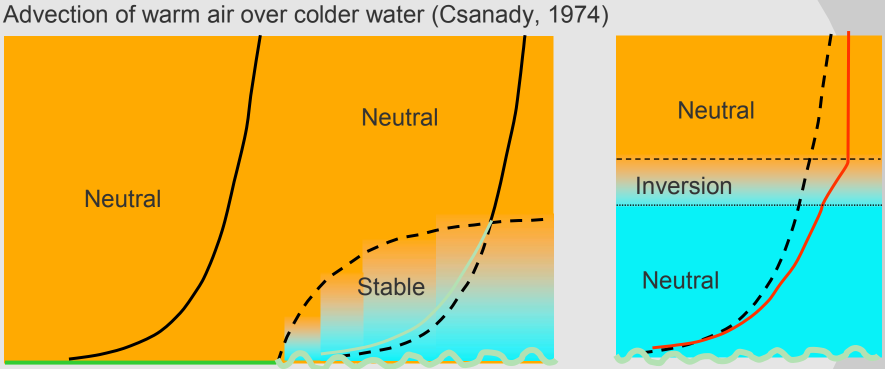
IEA Meeting Berlin 20./21.2.2007 11

Lange, 2004

Stability dependence of wind profile

Coastal influence

Advection of warm air over colder water (Csanady, 1974)



Land

Land-Sea Transition:
Internal boundary layer (IBL)

10-100 km Offshore:
Inversion layer

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Lange et al, 2003

Wind resource mapping

Wind resource mapping

Mesoscale model MM5

- Flat ‚terrain‘ allows coarse resolution
- Makes long-term (e.g. 1 year) runs possible

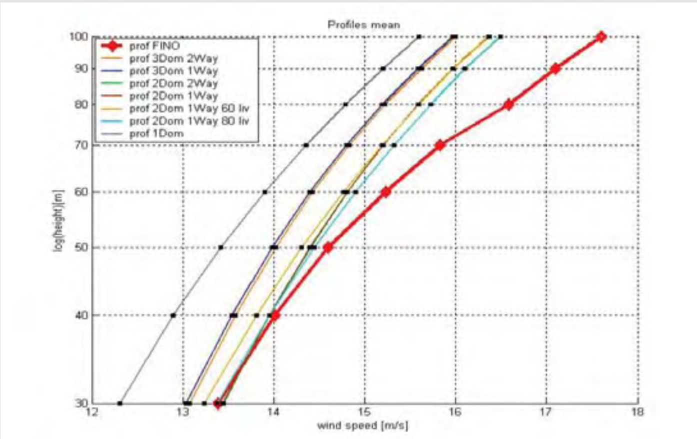
- Input from global weather prediction models
- No measurements necessary!

WAsP

- Measurement data from met station necessary
- Often only coastal or island stations available

Wind resource mapping

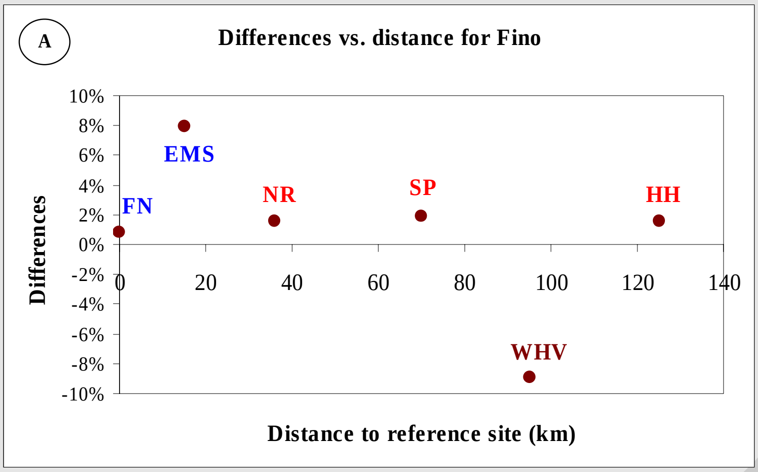
Wind resource mapping with MM5 – different set-up‘s



Beran et al, 2004

Wind resource mapping

Wind resource mapping with WAsP – different input data



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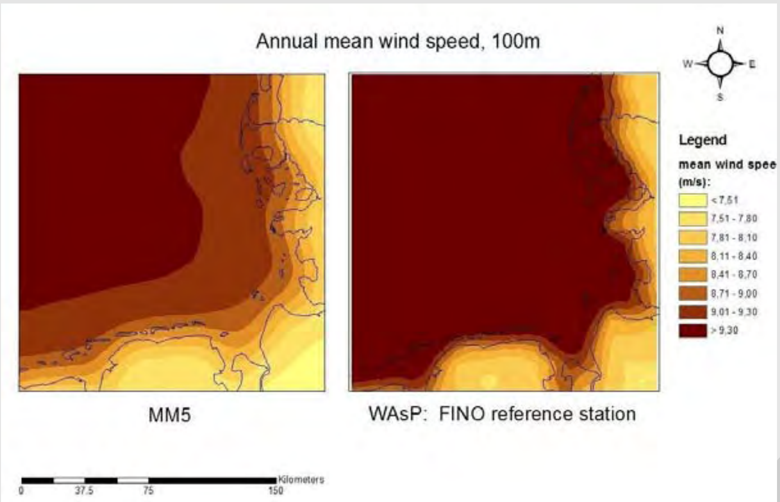
Jimenez et al, 2007

Wind resource mapping

Comparison of offshore resource maps with WAsP and MM5



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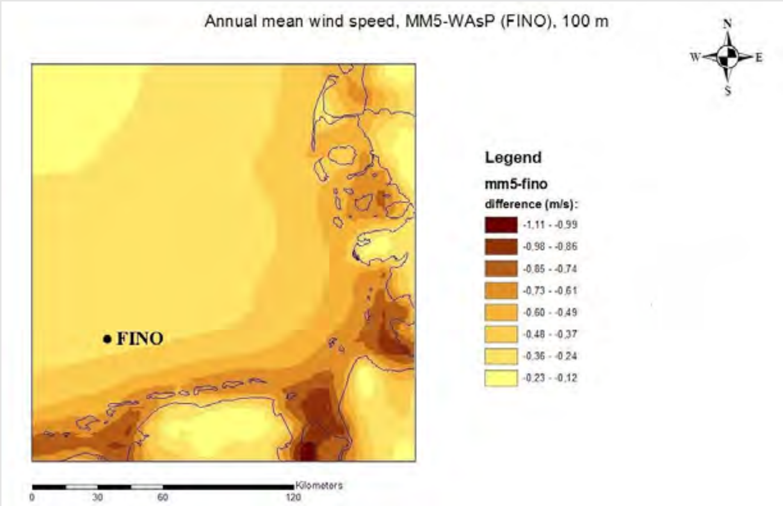
Jimenez et al, 2007

Wind resource mapping

Difference between MM5 and WAsP



Jimenez et al, 2007

Future R&D needs

Improvement of meteorological models

Method for wind resource assessment without measurements

Offshore wind mapping

Specific short-term forecasting models for offshore sites

Thank you for listening!

www.iset.uni-kassel.de

References

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Tautz, S., B. Lange, D. Heinemann: Correction of the heat and momentum flux measurements with the ultrasonic anemometers at the FINO I offshore meteorological mast for flow distortion and mounting effects. Proceedings of the German Wind Energy Conference DEWEK 2004, Wilhelmshaven, Germany, 2004, published on CD

Lange, B., S. Tautz: Bestimmung von Wärme- und Impulsfluss in der marinen atmosphärischen Grenzschicht für die Offshore-Windenergienutzung (BAGO). ForWind Bericht 2004-02, ForWind, Oldenburg, 2004

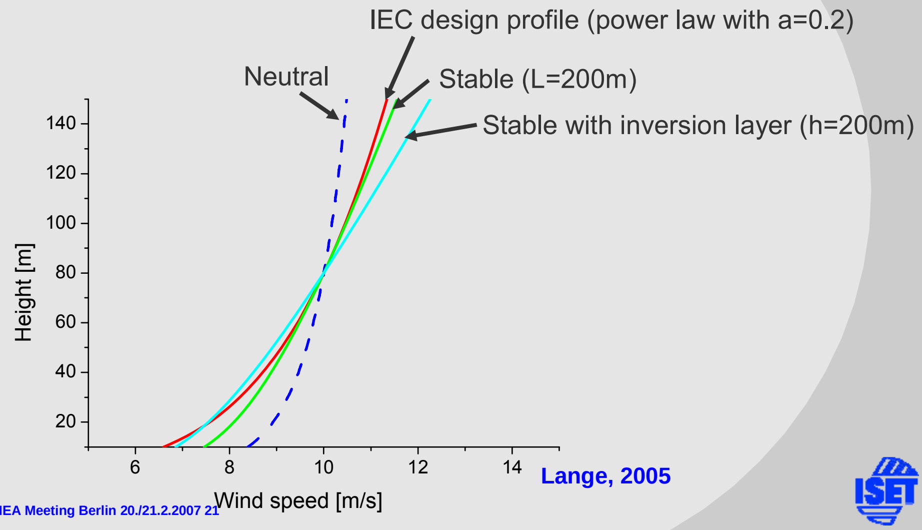
Lange, B., S. Larsen, J. Højstrup, R. Barthelmie: Importance of thermal effects and sea surface roughness for offshore wind resource assessment. *Journal of Wind Engineering and Industrial Aerodynamics*. Vol. 92 no. 11 (2004), pp. 959-998

Beran, J., L. Claveri, B. Lange, L. von Bremen: Offshore wind modeling and forecast. WRF/MM5 User's Workshop, Boulder, USA, June 2005

Jimenez, B., F. Durante, B. Lange, T. Kreutzer, J. Tambke: Wind resource assessment in the German part of the North Sea: Comparative study between MM5 and WAsP. *Wind Energy, 2007, (in print)*

Wind power applications

Stability dependence of the wind shear



Lange, 2005

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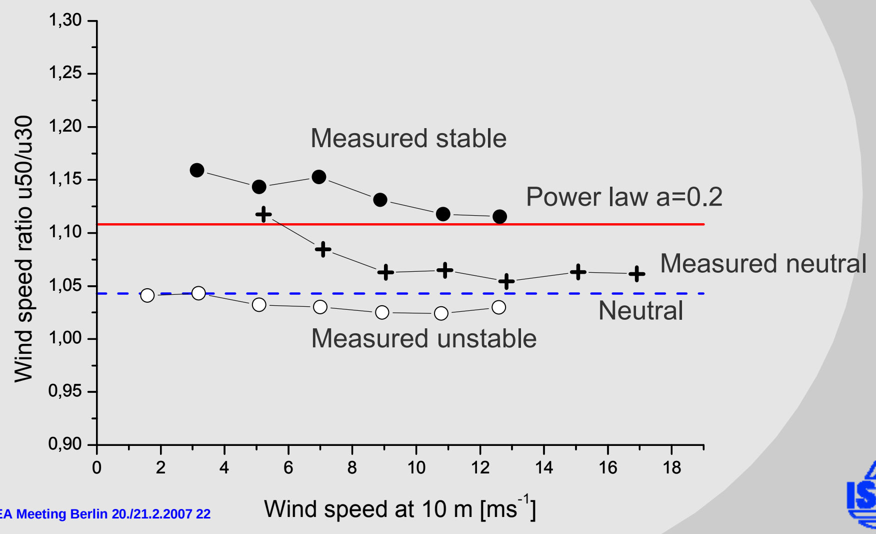
ISET

Wind power applications

Stability dependence of the wind shear



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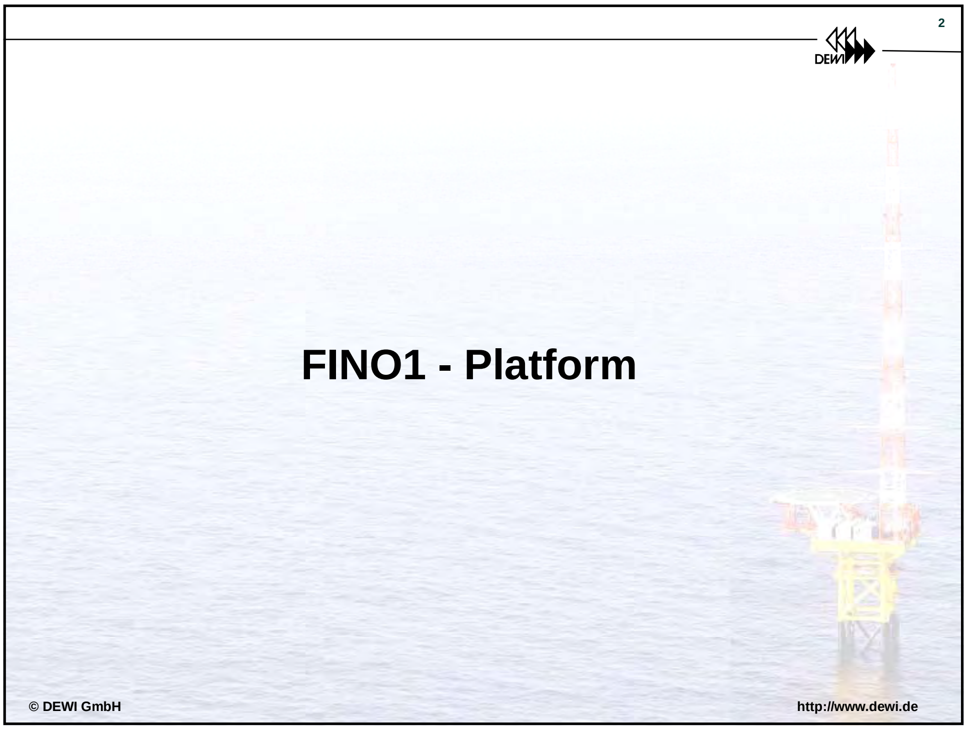
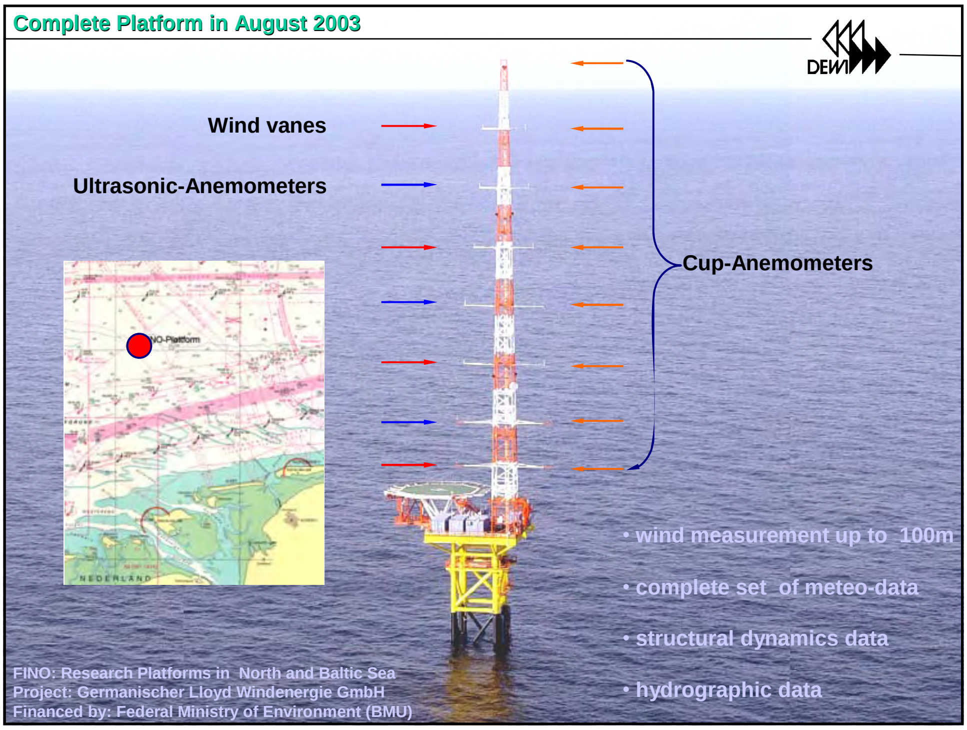
ISET

Blank page


FINO I
And the mast shadow effect
T. Neumann, DEWI


2
DEWI
FINO1 - Platform
© DEWI GmbH
http://www.dewi.de


Complete Platform in August 2003
DEWI
Wind vanes
Ultrasonic-Anemometers
Cup-Anemometers
• wind measurement up to 100m
• complete set of meteo-data
• structural dynamics data
• hydrographic data
FINO: Research Platforms in North and Baltic Sea
Project: Germanischer Lloyd Windenergie GmbH
Financed by: Federal Ministry of Environment (BMU)


4
DEWI
© Klaus Nolopp, DEWI
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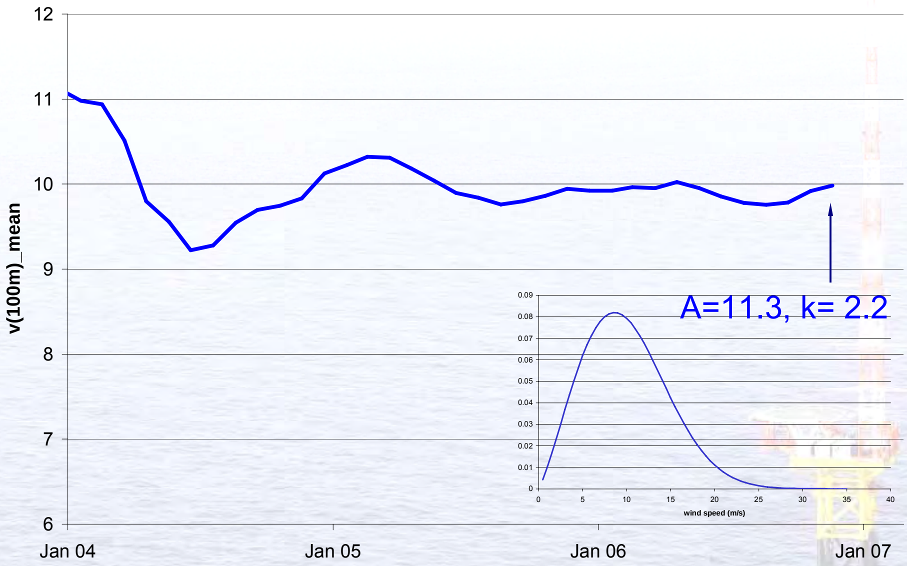
Average Conditions

Mean wind speed

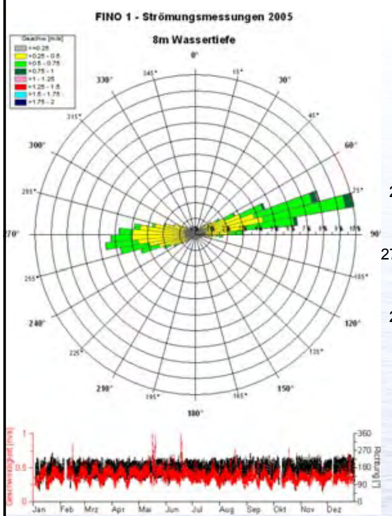


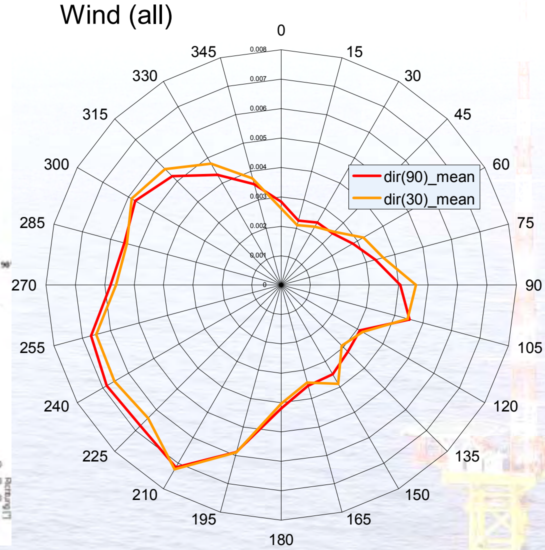
Wind and water current direction

7

Water current (2005)

Wind (all)



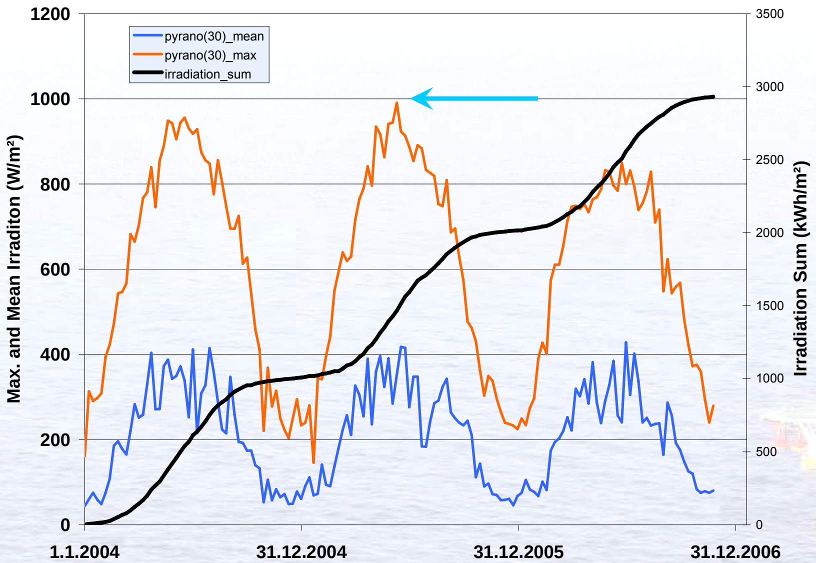


Current statistic for 2005 (8 m depth)
current speed is mainly between 0.4 and 0.65 m/s.

 http://www.dewi.de

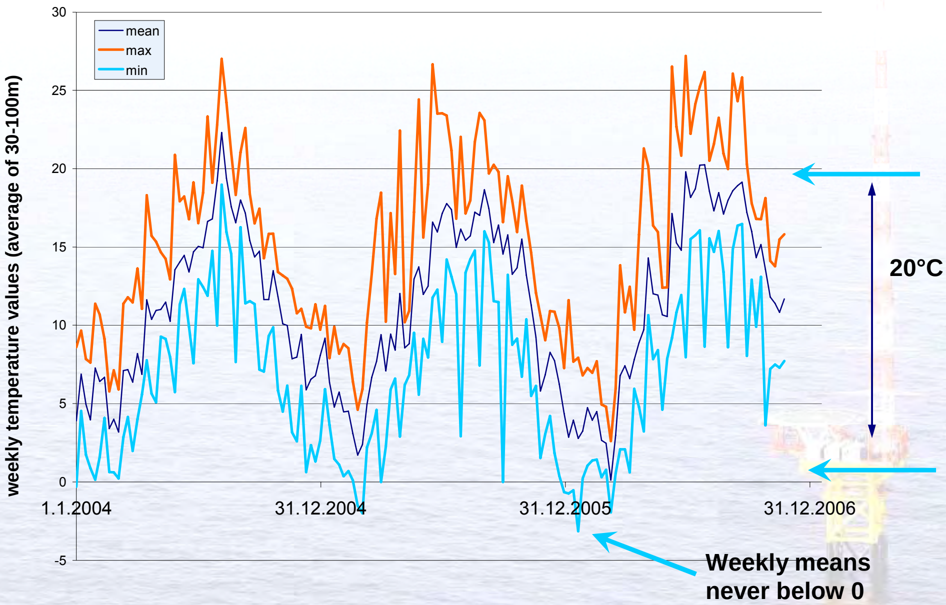
Sun irradiation

8

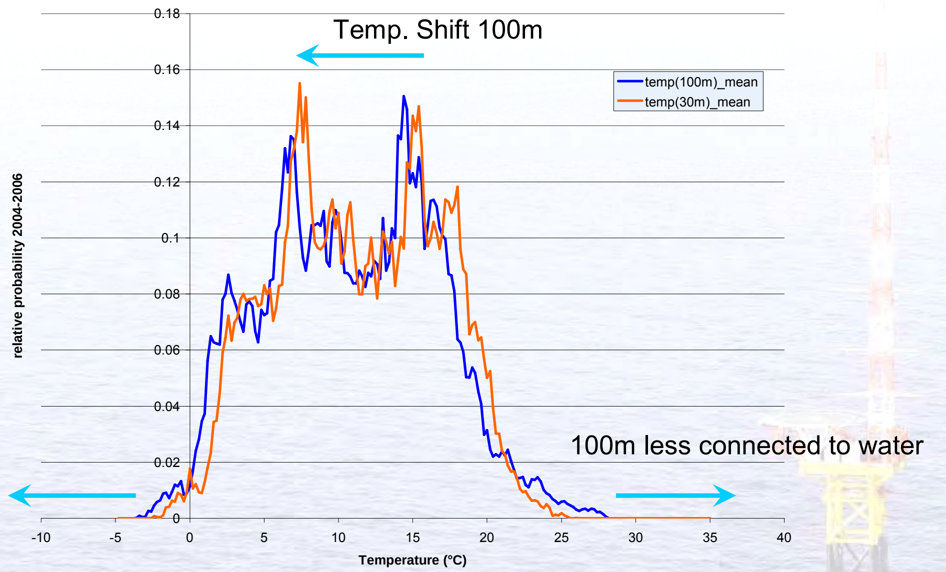


 http://www.dewi.de

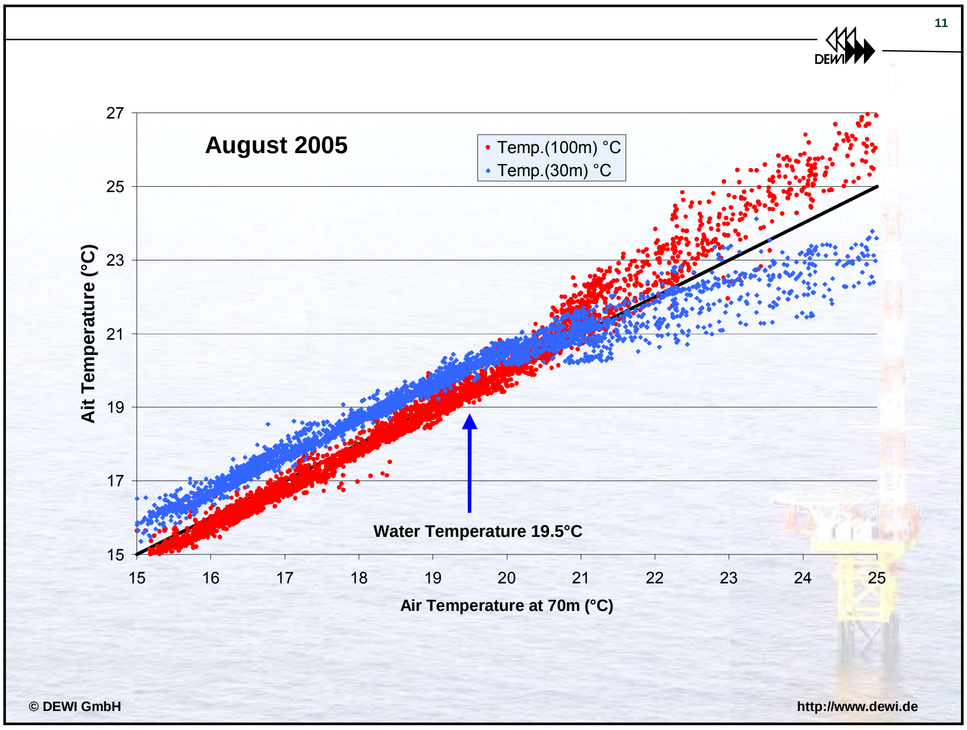
Temperatures



 http://www.dewi.de



 http://www.dewi.de


11
DEWI
August 2005
Temp.(100m) °C
Temp.(30m) °C
27
25
23
21
19
17
15
Ait Temperature (°C)
Water Temperature 19.5°C
15
16
17
18
19
20
21
22
23
24
25
Air Temperature at 70m (°C)
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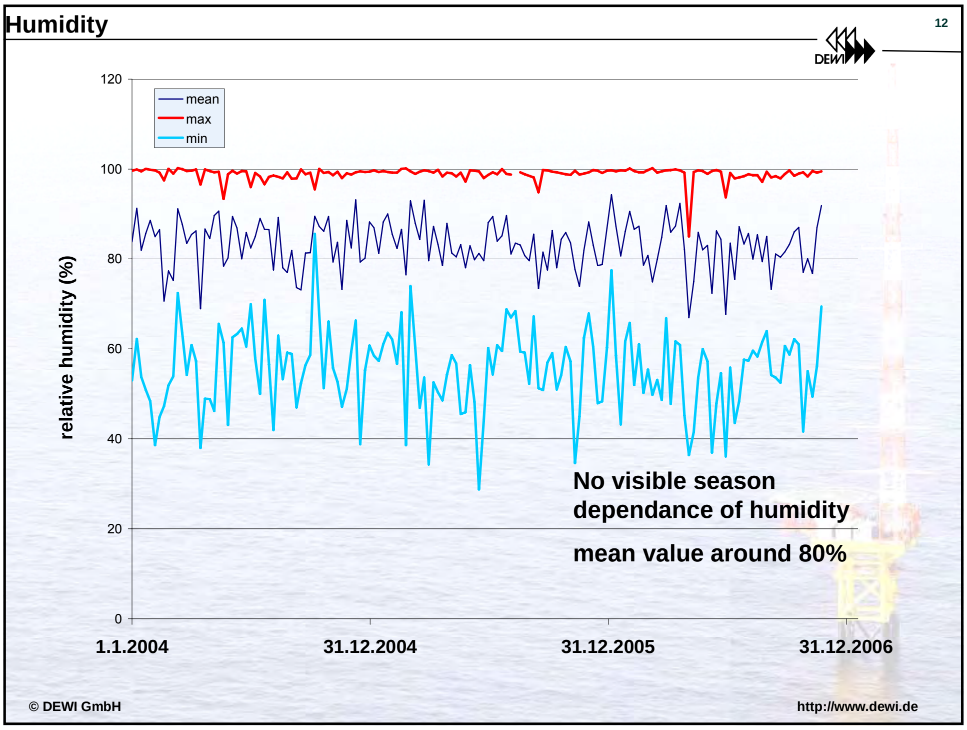
Humidity
12
DEWI
120
100
80
60
40
20
0
mean
max
min
relative humidity (%)
No visible season
dependance of humidity
mean value around 80%
1.1.2004
31.12.2004
31.12.2005
31.12.2006
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Wind Energy Conditions

Research Project OWID =

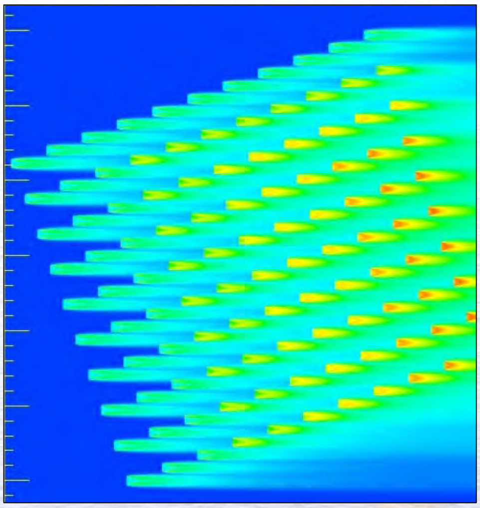
Design Parameters and Load Assumptions for Offshore WEC in the German Bight on Basis of the FINO-measurements

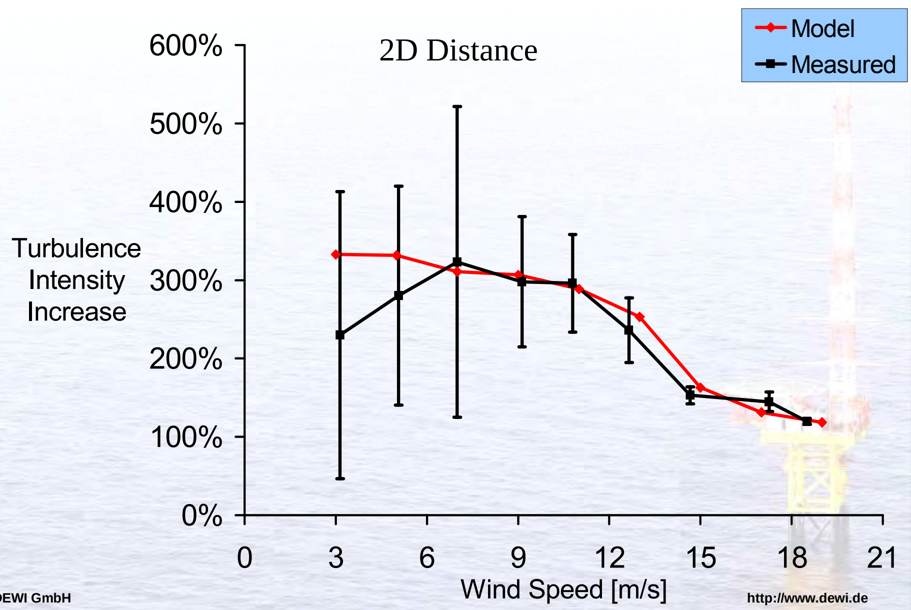
Sub Project: Meteorological Assessment of the FINO1-Data
(IMK-IFU of FZK)

Sub Project: Modeling of Wind Park Effects and Calculation Life Time Effects
(DEWI)

Sub Project: Validation of the Load Assumptions Offshore
(DEWI-OCC)

run time: 2005 - 2008

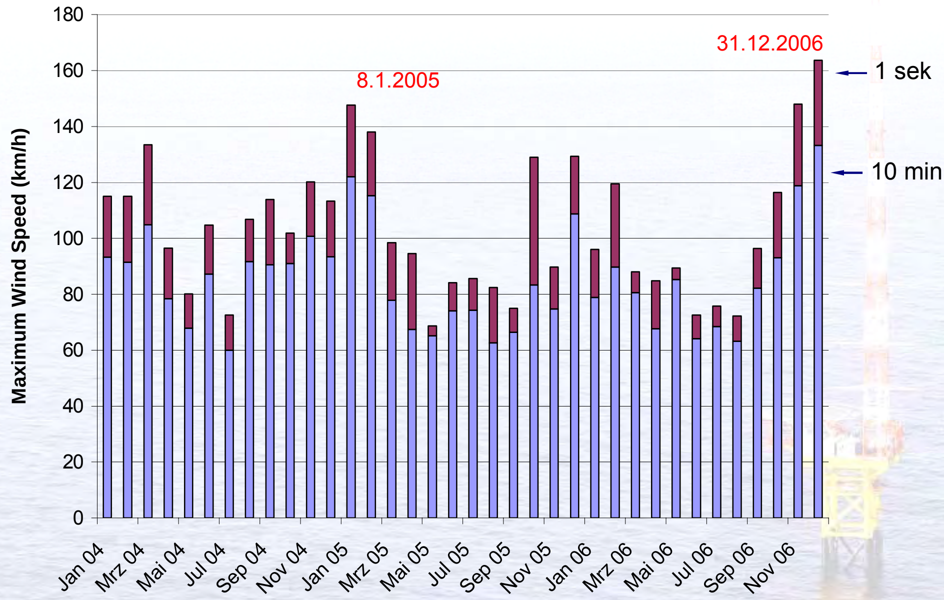




Extreme Conditions

Wind Maxima

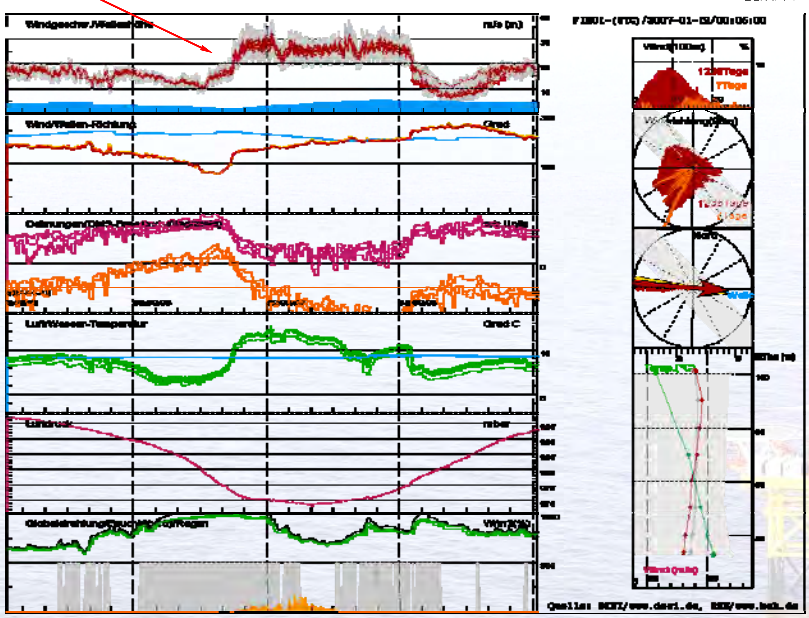
17



 http://www.dewi.de

Kyrill

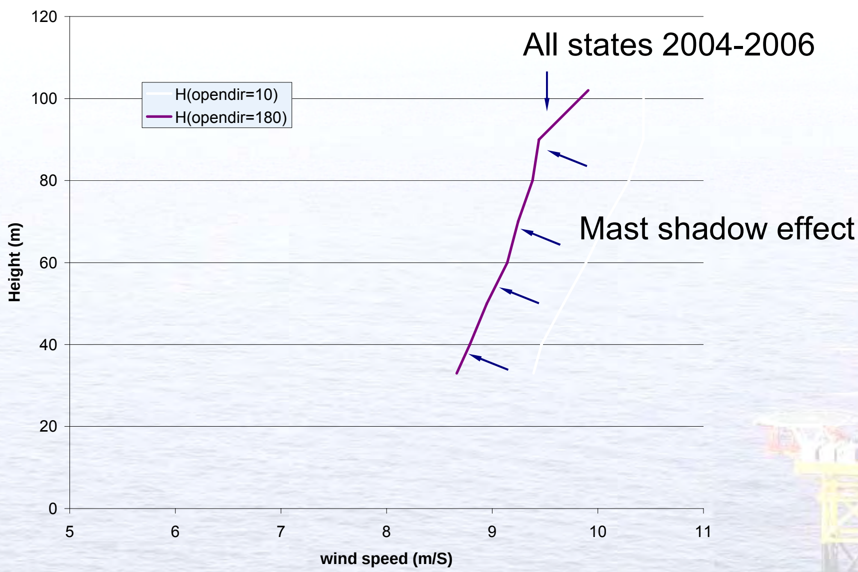
18

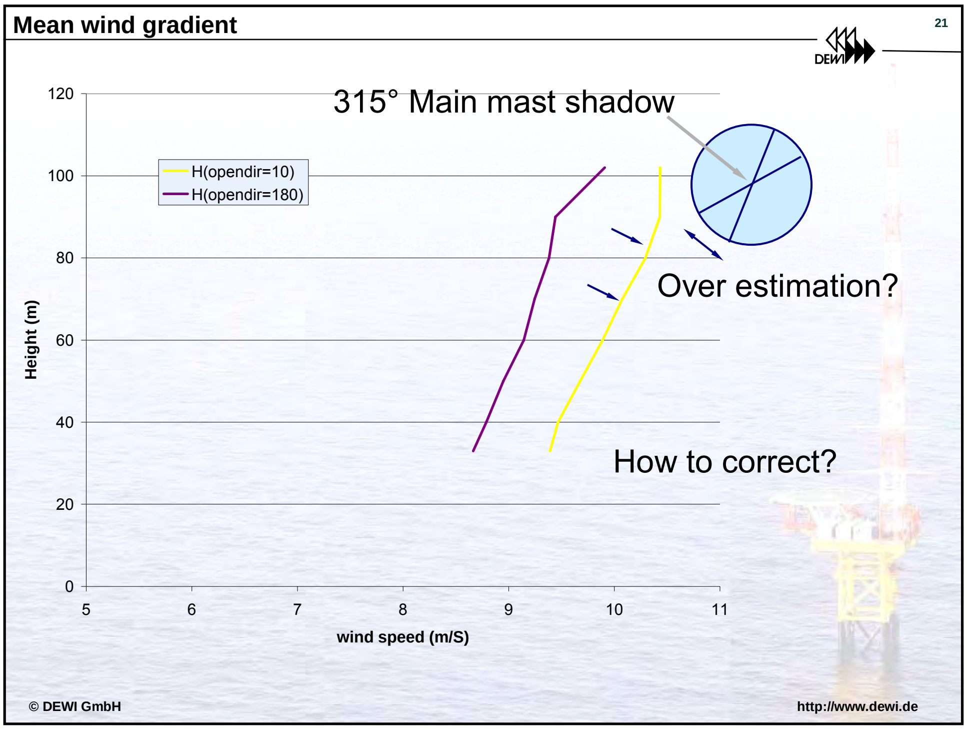


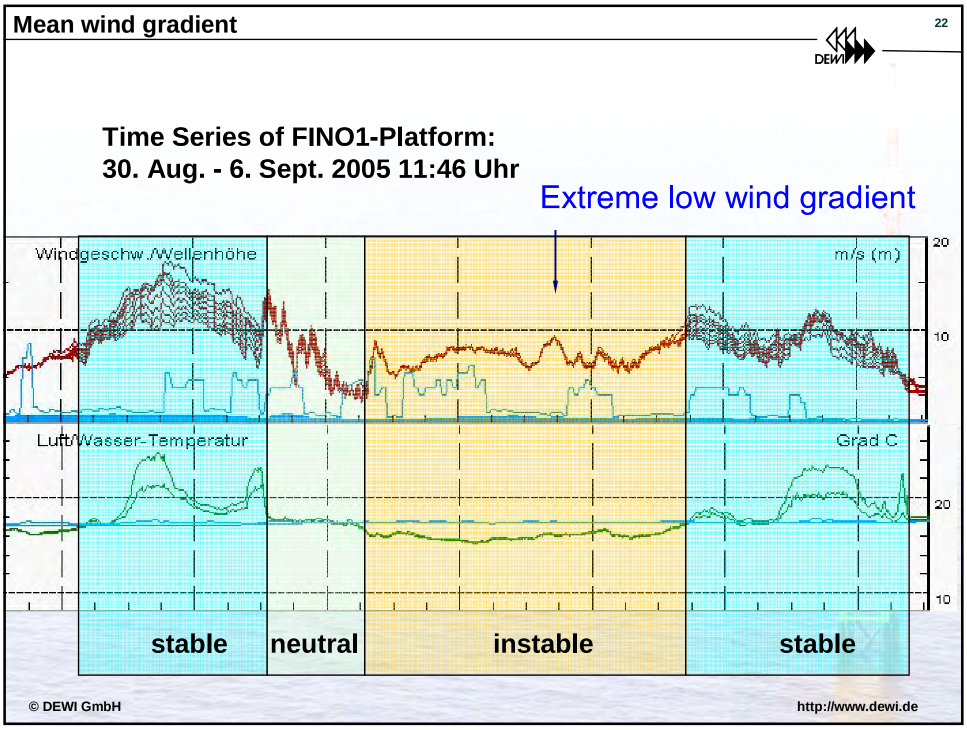
 http://www.dewi.de

How to Handle the Mast ?

Mean wind gradient




Mean wind gradient
21
DEWI
315° Main mast shadow
H(opendir=10)
H(opendir=180)
Over estimation?
How to correct?
Height (m)
120
100
80
60
40
20
0
5
6
7
8
9
10
11
wind speed (m/S)
© DEWI GmbH
http://www.dewi.de


Mean wind gradient
22
DEWI
Time Series of FINO1-Platform:
30. Aug. - 6. Sept. 2005 11:46 Uhr
Extreme low wind gradient
Windgeschw./Wellenhöhe
m/s (m)
Luft/Wasser-Temperatur
Grad C
20
10
20
10
stable
neutral
instable
stable
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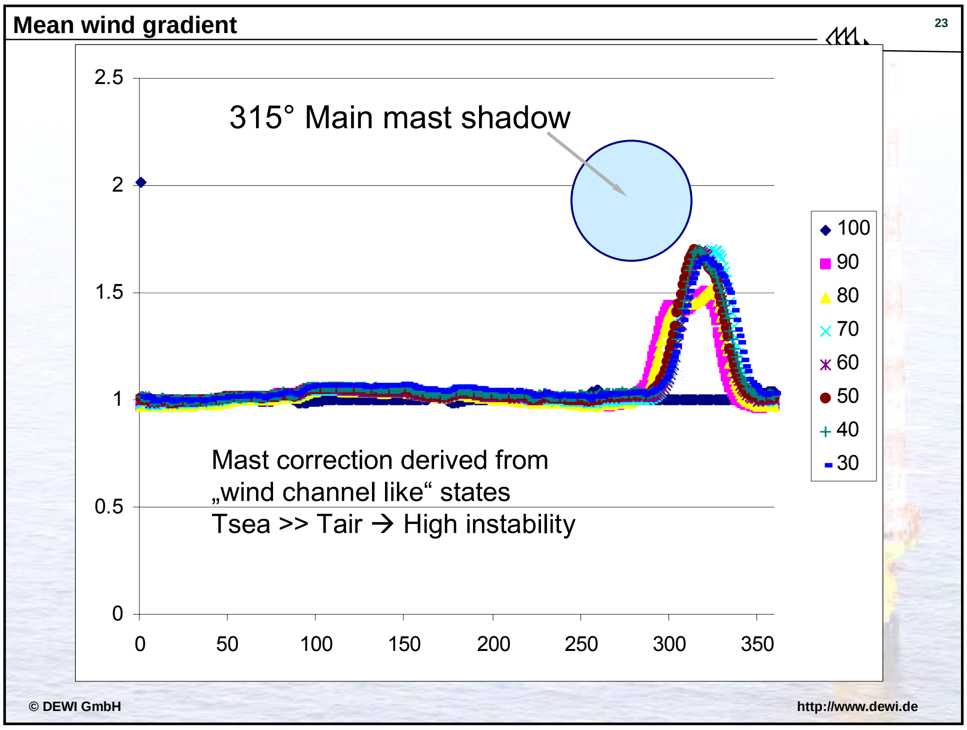
Mean wind gradient
23
315° Main mast shadow
Mast correction derived from
„wind channel like“ states
Tsea >> Tair → High instability
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
100
90
80
70
60
50
40
30
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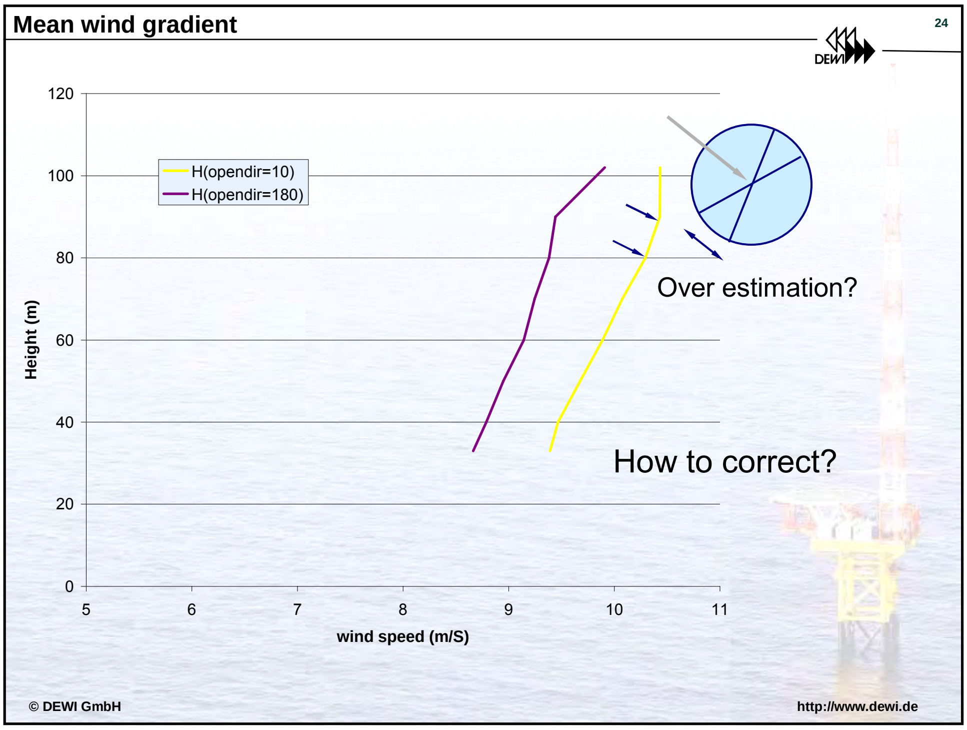
Mean wind gradient
24
DEWI
H(opendir=10)
H(opendir=180)
Over estimation?
How to correct?
Height (m)
120
100
80
60
40
20
0
5
6
7
8
9
10
11
wind speed (m/S)
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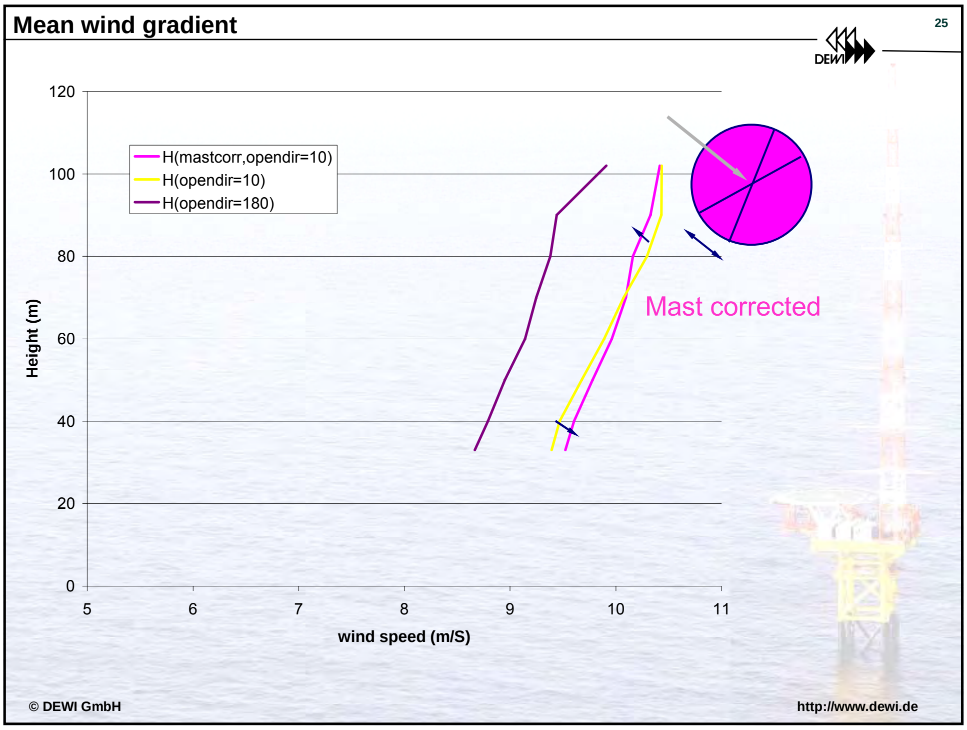
Mean wind gradient
25
DEWI
120
100
80
60
40
20
0
Height (m)
H(mastcorr,opendir=10)
H(opendir=10)
H(opendir=180)
Mast corrected
5
6
7
8
9
10
11
wind speed (m/S)
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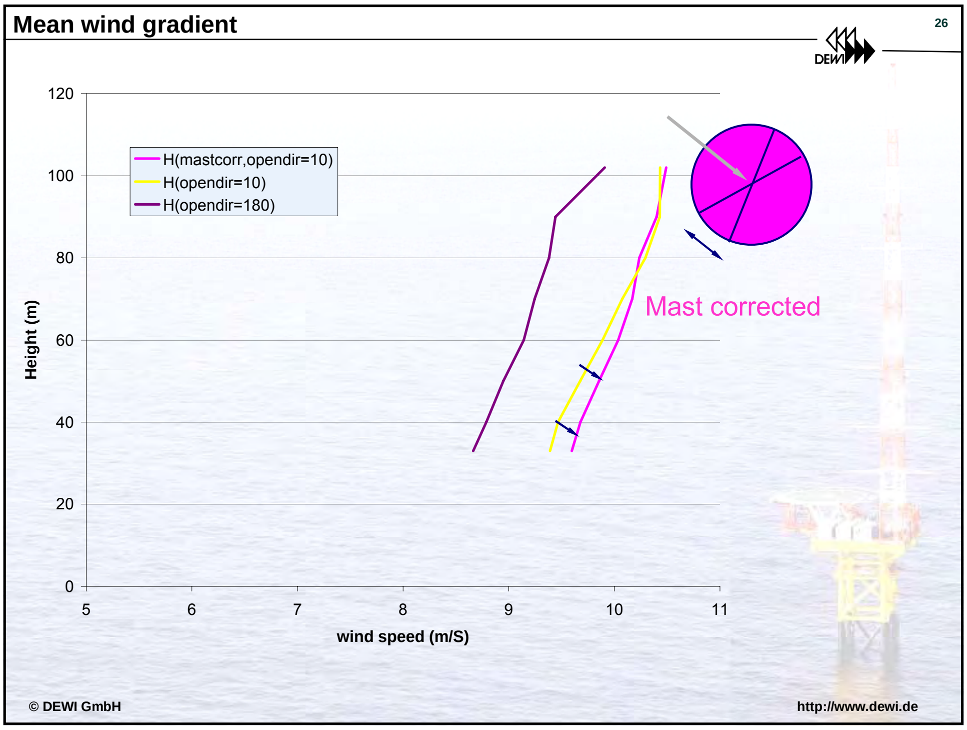
Mean wind gradient
26
DEWI
120
100
80
60
40
20
0
Height (m)
H(mastcorr,opendir=10)
H(opendir=10)
H(opendir=180)
Mast corrected
5
6
7
8
9
10
11
wind speed (m/S)
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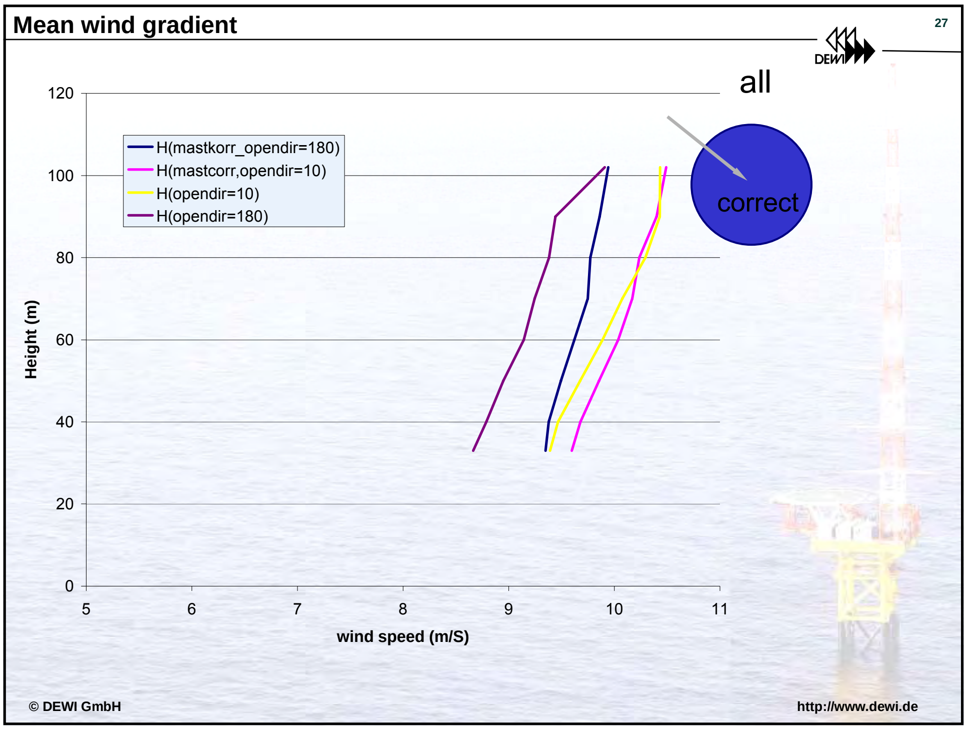
Mean wind gradient
27
DEWI
all
correct
H(mastkorr_opendir=180)
H(mastcorr,opendir=10)
H(opendir=10)
H(opendir=180)
Height (m)
wind speed (m/S)
0
20
40
60
80
100
120
5
6
7
8
9
10
11
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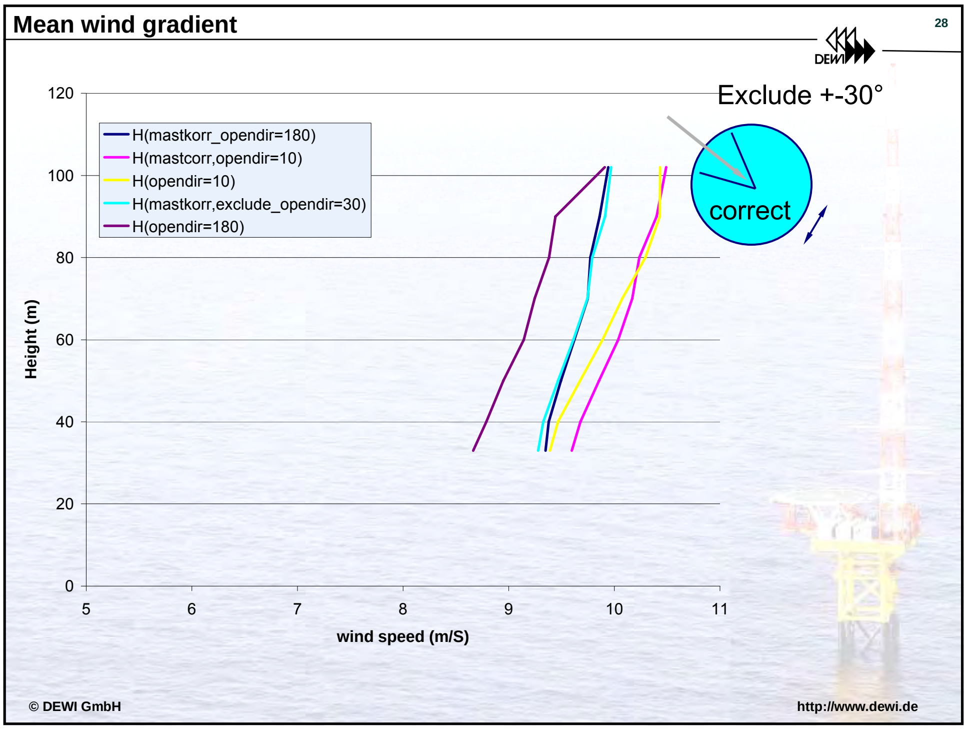
Mean wind gradient
28
DEWI
Exclude +-30°
correct
H(mastkorr_opendir=180)
H(mastcorr,opendir=10)
H(opendir=10)
H(mastkorr,exclude_opendir=30)
H(opendir=180)
Height (m)
wind speed (m/S)
0
20
40
60
80
100
120
5
6
7
8
9
10
11
© DEWI GmbH
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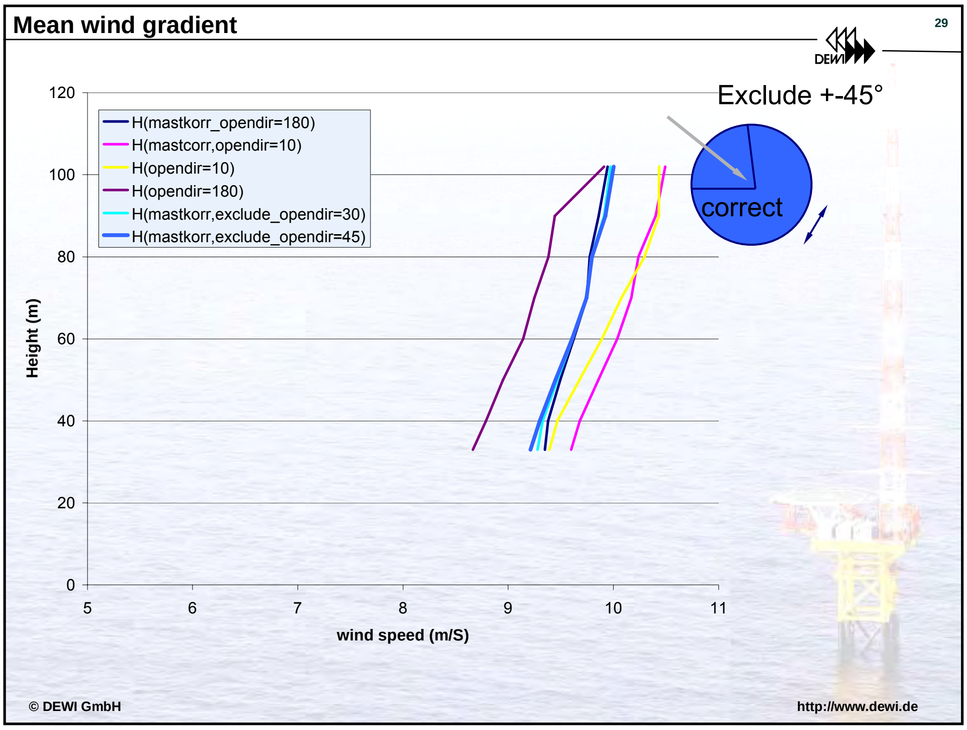
Mean wind gradient
29
DEWI
Exclude +-45°
correct
H(mastkorr_opendir=180)
H(mastcorr,opendir=10)
H(opendir=10)
H(opendir=180)
H(mastkorr,exclude_opendir=30)
H(mastkorr,exclude_opendir=45)
Height (m)
120
100
80
60
40
20
0
5
6
7
8
9
10
11
wind speed (m/S)
© DEWI GmbH
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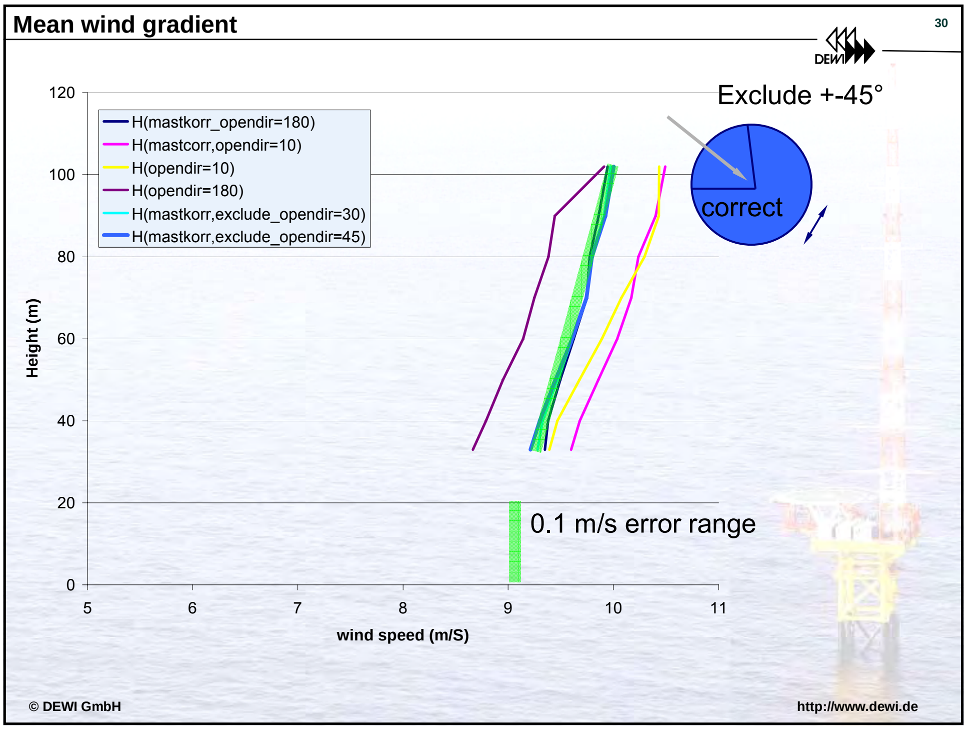
Mean wind gradient
30
DEWI
Exclude +-45°
correct
H(mastkorr_opendir=180)
H(mastcorr,opendir=10)
H(opendir=10)
H(opendir=180)
H(mastkorr,exclude_opendir=30)
H(mastkorr,exclude_opendir=45)
0.1 m/s error range
Height (m)
120
100
80
60
40
20
0
5
6
7
8
9
10
11
wind speed (m/S)
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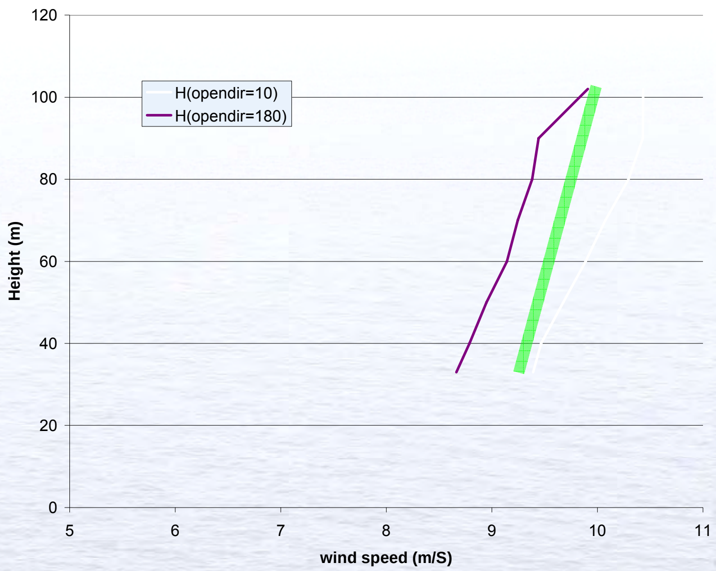
31

Mean wind gradient



http://www.dewi.de

32

Conclusions

→Mast effect has strong influence on wind mean gradients

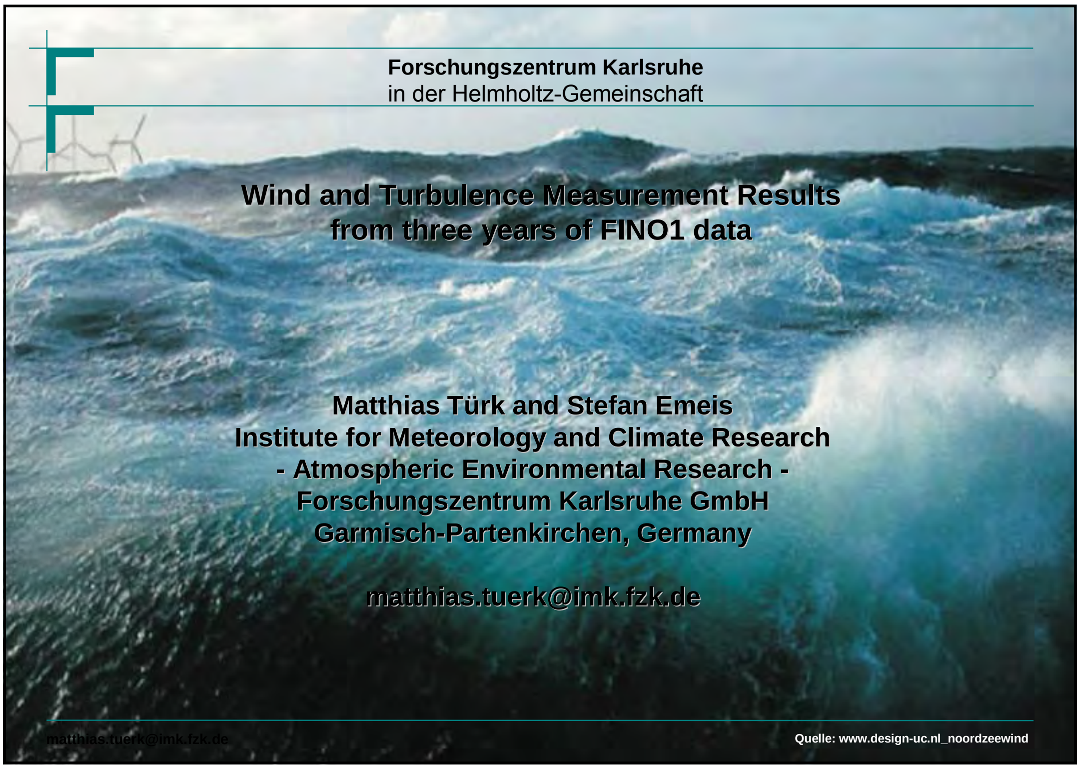
→Small filter sector leads to gradient over estimation

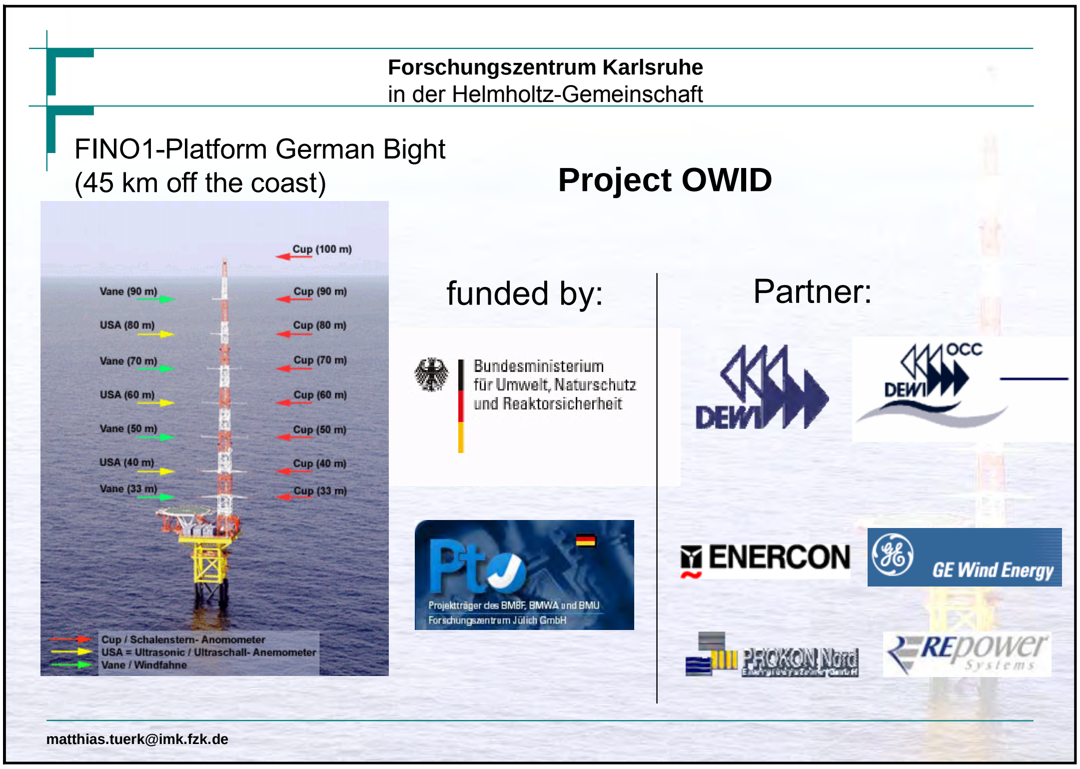
→Mast correction from „wind channel states“ where Tsea >> Tair, seems to be ok within 0.1m/s range

→Overall wind gradient is rather flat
(only 0.5m/s wind speed increase from 33m to 100m)

→Better understanding of mast effects by CFD Calculations necessary

http://www.dewi.de


Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft
Wind and Turbulence Measurement Results
from three years of FINO1 data
Matthias Türk and Stefan Emeis
Institute for Meteorology and Climate Research
- Atmospheric Environmental Research -
Forschungszentrum Karlsruhe GmbH
Garmisch-Partenkirchen, Germany
matthias.tuerk@imk.fzk.de
matthias.tuerk@imk.fzk.de
Quelle: www.design-uc.nl_noordzeewind


Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft
FINO1-Platform German Bight
(45 km off the coast)
Project OWID
Cup (100 m)
Vane (90 m)
Cup (90 m)
USA (80 m)
Cup (80 m)
Vane (70 m)
Cup (70 m)
USA (60 m)
Cup (60 m)
Vane (50 m)
Cup (50 m)
USA (40 m)
Cup (40 m)
Vane (33 m)
Cup (33 m)
Cup / Schalenstern- Anomometer
USA = Ultrasonic / Ultraschall- Anemometer
Vane / Windfahne
funded by:
Bundesministerium
für Umwelt, Naturschutz
und Reaktorsicherheit
Pt
Projektträger des BMBF, BMWA und BMU
Forschungszentrum Jülich GmbH
Partner:
DEWI
DEWI OCC
ENERCON
GE Wind Energy
PROKON Nord
REpower Systems
matthias.tuerk@imk.fzk.de

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Turbulence intensity depending on wind speed

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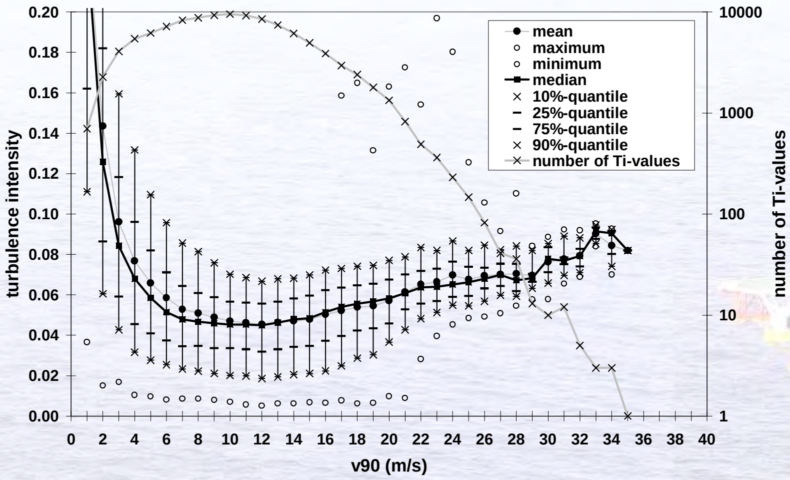
Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Turbulence intensity depending on wind speed (v90)
Jan. 2004 – Nov. 2006, excluded: 280-350°



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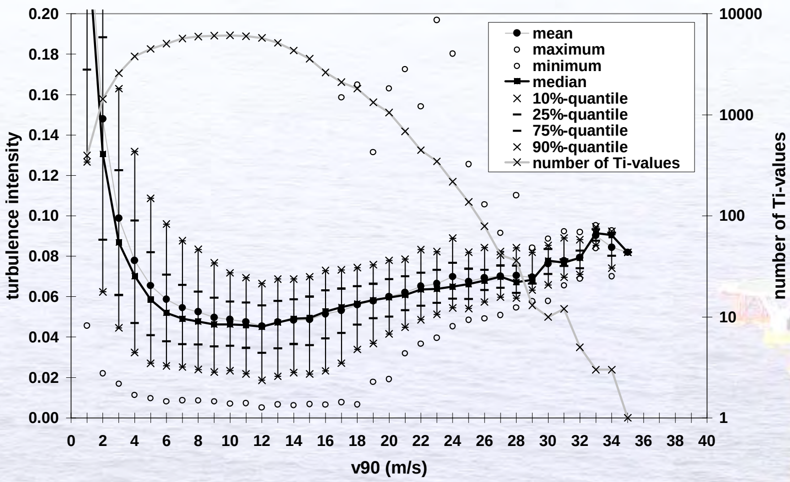
Turbulence intensity depending on wind speed (v90) 2004 – 2005, excluded: 280-350°



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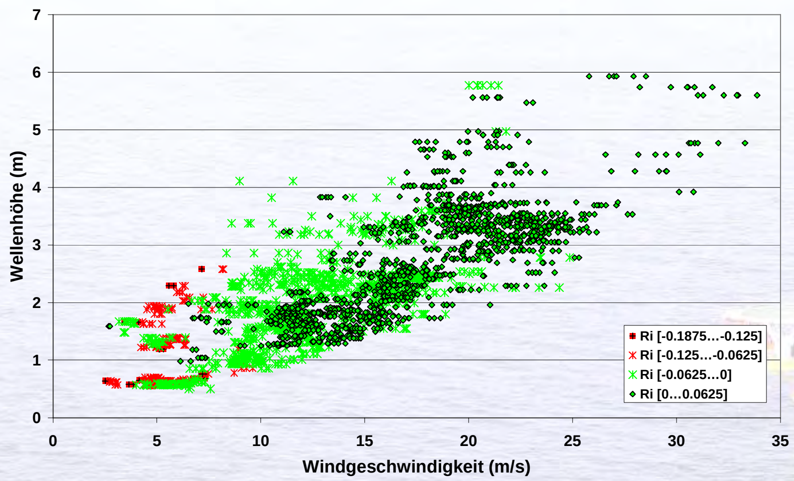
Wave height depending on wind speed (v100) Oct. 2004 – Jan. 2005, 210-250°



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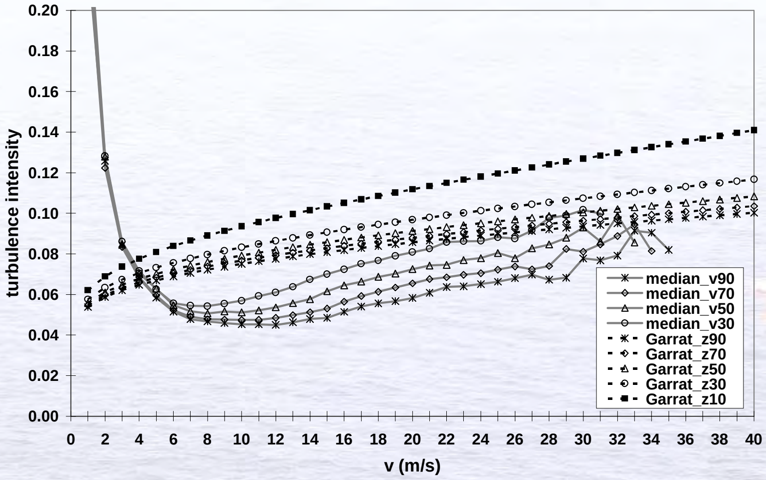
in der Helmholtz-Gemeinschaft

Turbulence intensity depending on wind speed (v90)
Jan. 2004 – Nov. 2006, excluded: 280-350°



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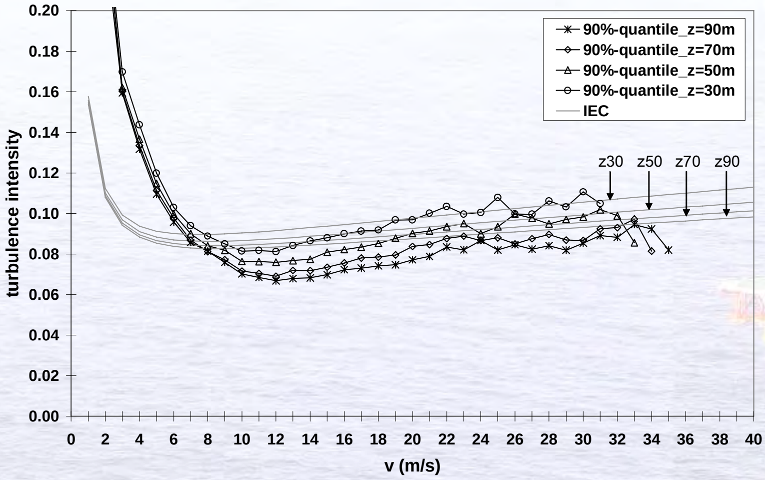
Turbulence intensity depending on wind speed (v90)
Jan. 2004 – Nov. 2006, excluded: 280-350°



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„Load relevant“ weather situations in the german bight

Special weather situations can cause wind conditions with high loads on wind turbines:

characteristic wind patterns like:

a) strong temporal changes in wind speed
b) large vertical wind speed gradients
c) large vertical wind direction gradients

can lead to:

- short-term load alternations
- differential loads on the rotor

➔ analysis of relevant weather situation
➔ estimation of frequency of occurrence

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strong temporal changes in wind speed

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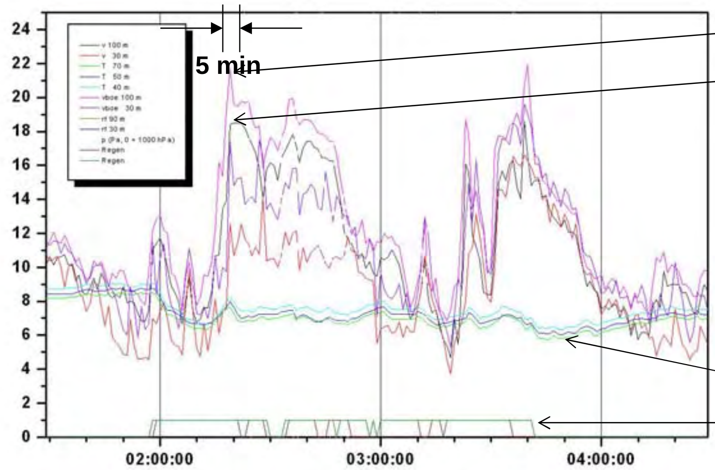

1 s-gust 100 m

1 min-wind 100 m

m/s

temperature

rain

November 17, 2005

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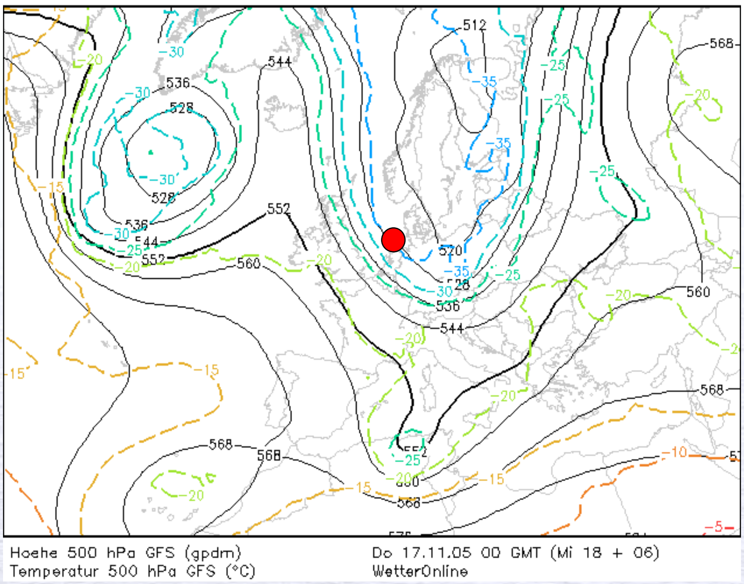

Weather map 500 hPa (flow pattern in 5.3 km height)

strong trough with very cold air (below -35°C)

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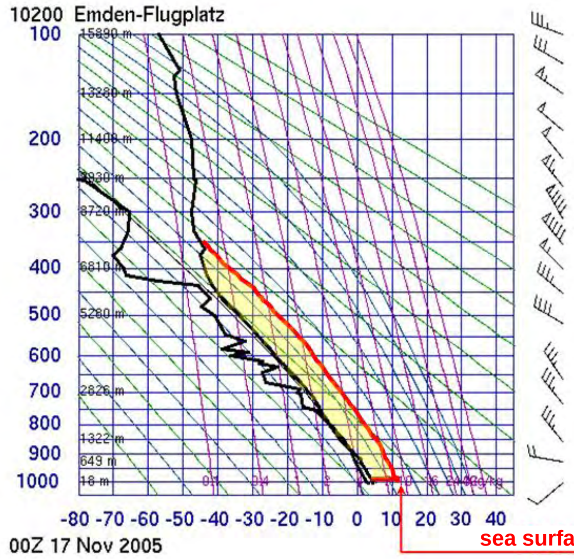

Radiosonde ascent

showing strong unstable stratification up to 7500 m above sea level

very moist air

➔ thunderstorms

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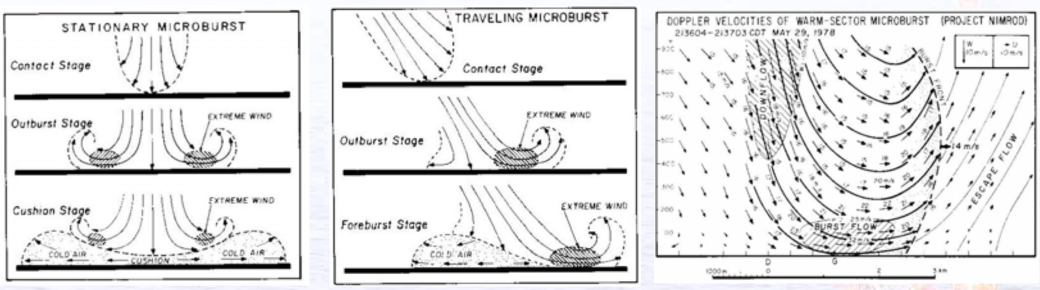
thunderstorm downdrafts (cold air outburst)



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large vertical wind speed gradients

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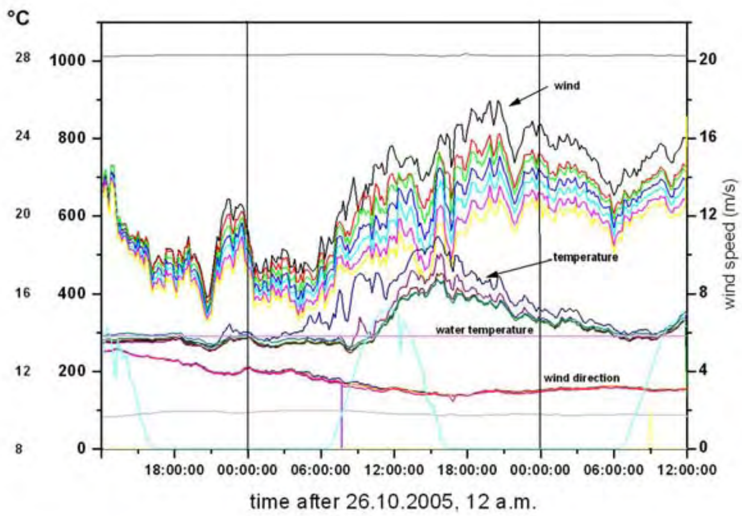

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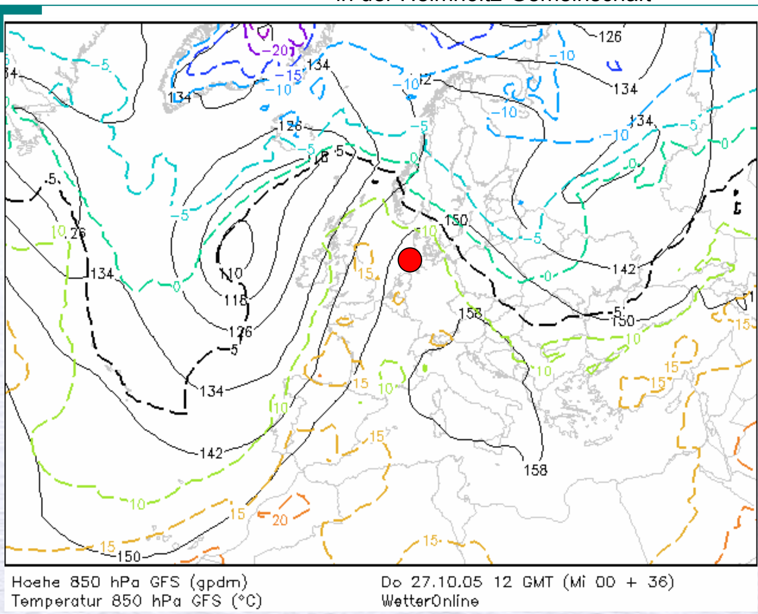

Weather map 850 hPa (flow pattern in 1.5 km height)

strong warm air advection (up to 15°C in 1500 m)

(a nearly similar weather situation occurred in October 2006)

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large vertical wind direction gradients

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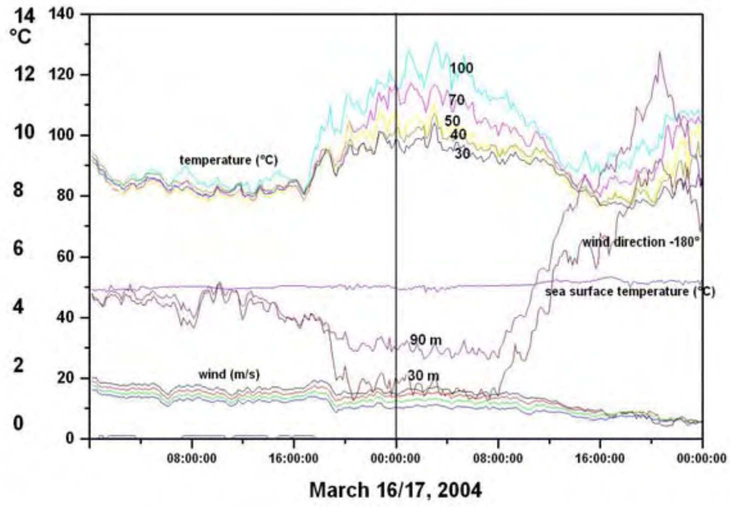

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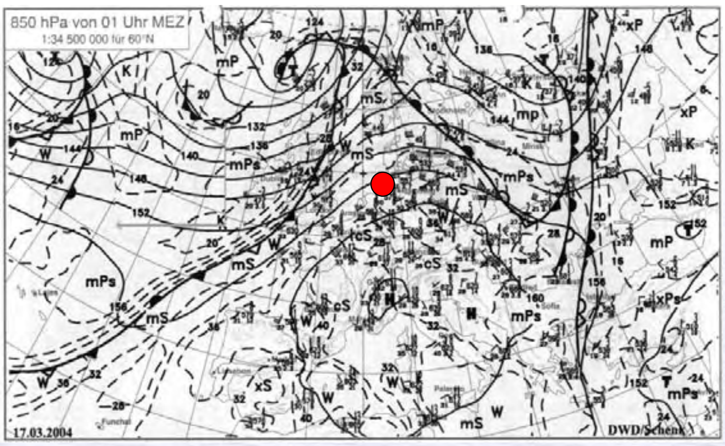

Weather map 850 hPa (flow pattern in 1.5 km height)

strong warm air advection (up to 8°C in 1500 m)

sea surface temperature: 5°C

=> very stable stratification

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Summary

air much colder than water plus upper-level trough

➔ thunderstorms with strong temporal variations of wind speed (several times a year)

air warmer than water plus warm-air advection

➔ strong vertical shear in wind speed (several times a year)

air much warmer than water plus warm-air advection

➔ strong vertical shear in wind speed and direction (several times a year)

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Prediction of such wind/gust events requires

- detailed horizontal wind field
- upper air flow pattern
- vertical temperature profile
- vertical moisture profile

➔ a prediction only from FINO1-data is not possible

➔ good short-term regional/mesoscale forecast model necessary with high spatial resolution (about 1 km) and high vertical resolution

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Thank you for your attention!
matthias.tuerk@imk.fzk.de

Meteorological Measurements at the Met Mast on FINO 3

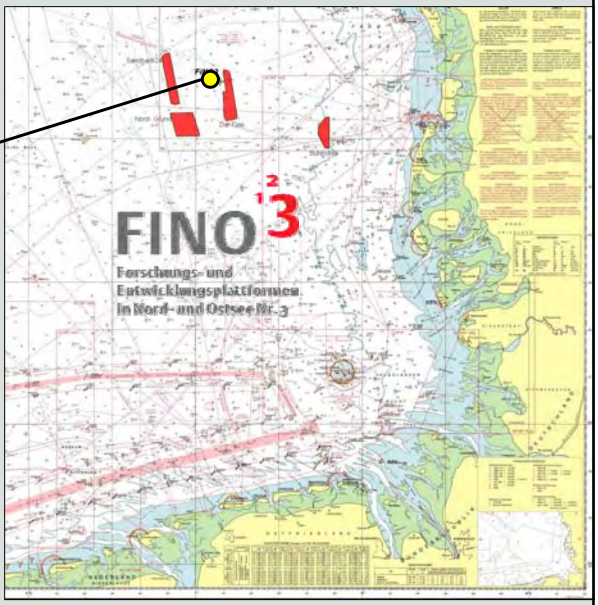
Detlef Kindler
WINDTEST
Kaiser-Wilhelm-Koog GmbH

TU Berlin February 2007

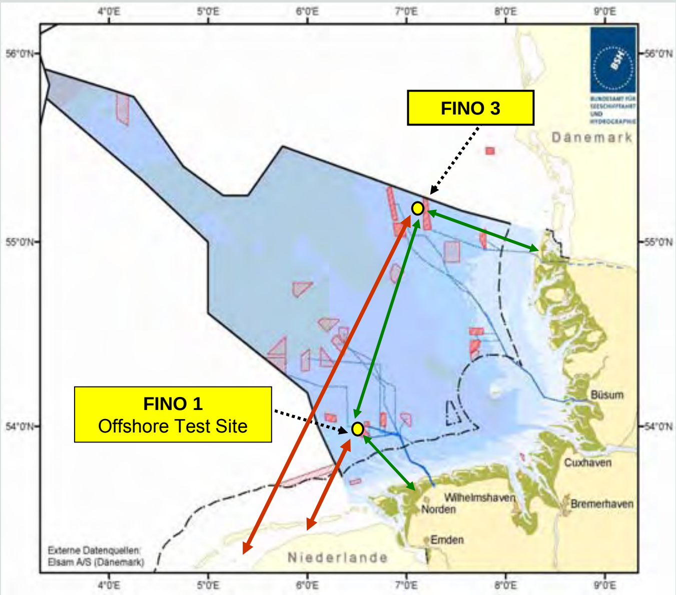
IEA RD&D Task 11, Wind Energy

Topical Expert Meeting on

"Wind and Wave Measurements at Offshore Locations"



- **FINO 1 vs. FINO 3**
  - Distances and fetch
  - Wind monitoring levels and sensors
  - Wind speed @ 10 m AMSL,
    => TerraSAR-X SAT WS estimation
- **Disturbance of free wind flow by mast structures**
  - FINO 1: amount & correction by LiDAR
    (LiDAR offshore test on FINO 1)
  - FINO 3 implications



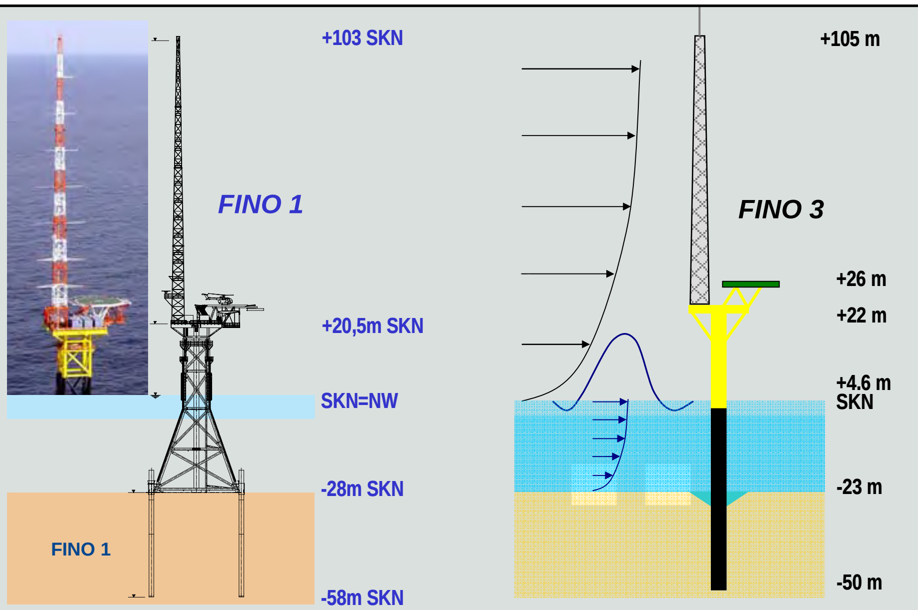
Distances:

FINO3 - Land: 90 km
FINO3-FINO1: 170 km
FINO1 - Land: 50 km

Fetch: Wind Direction SW

FINO1: 50 – 70 km
FINO3: 200 – 300 km

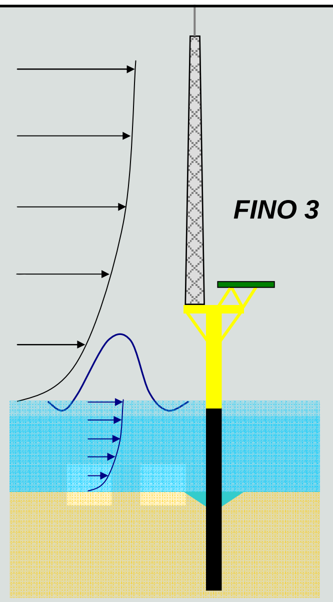
Positions & Distances



FINO 1 vs. FINO 3

Time Schedule FINO 3

- tender process - on-going
- awarding of contract - May/Jun 2007
- planning & certification - until Dec 2007
- onshore construction - from Sep 2007
- offshore erection - spring 2008
- commissioning & approval - spring/summer 2008
- 1st operational period - until end 2008



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Time Schedule FINO 3

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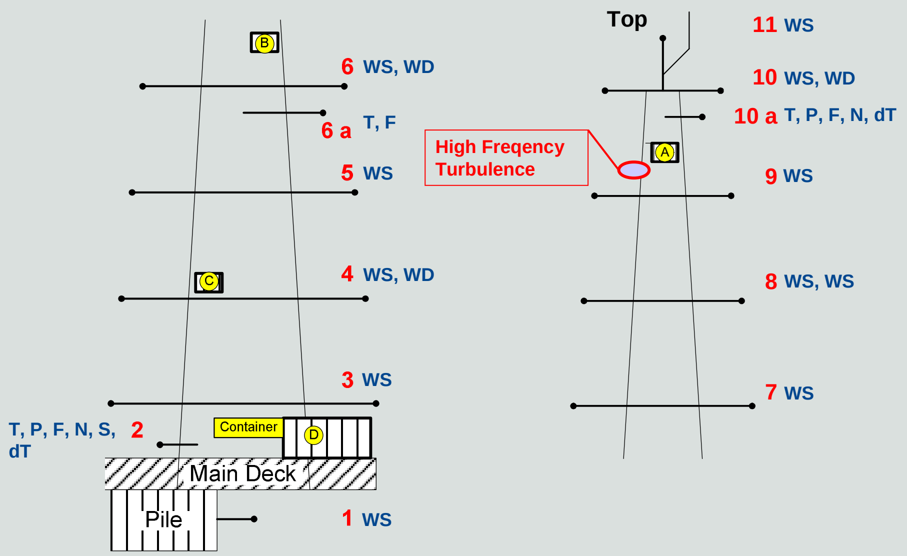
FINO 3



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Sensor Distribution

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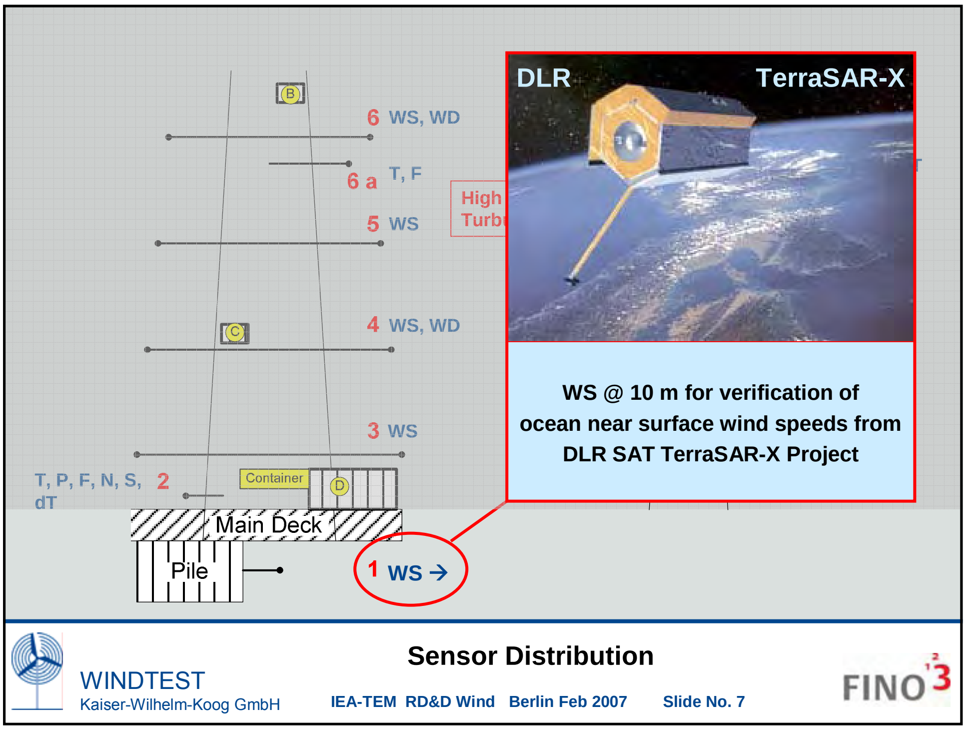
FINO 3


DLR
TerraSAR-X
6 WS, WD
6 a T, F
5 WS
High
Turb
4 WS, WD
3 WS
T, P, F, N, S, dT 2
Container
Main Deck
Pile
1 WS →
WS @ 10 m for verification of ocean near surface wind speeds from DLR SAT TerraSAR-X Project
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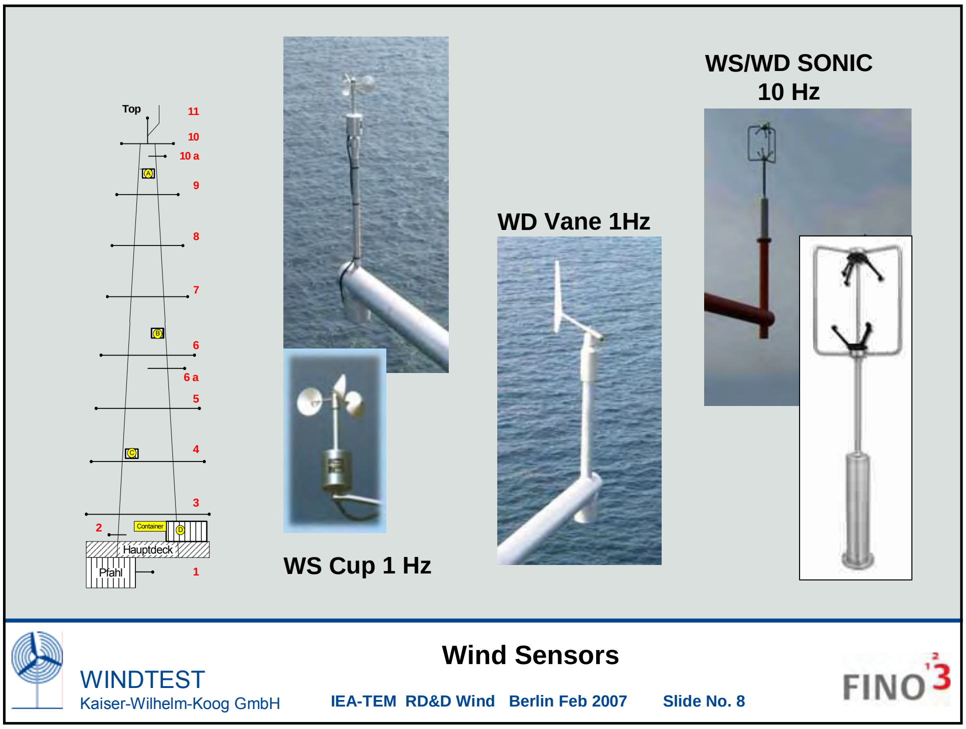
Sensor Distribution
IEA-TEM RD&D Wind Berlin Feb 2007 Slide No. 7
FINO 3


WS/WD SONIC
10 Hz
Top
11
10
10 a
9
8
7
6
6 a
5
4
3
2
Container
Hauptdeck
Pfahl
1
WD Vane 1Hz
WS Cup 1 Hz
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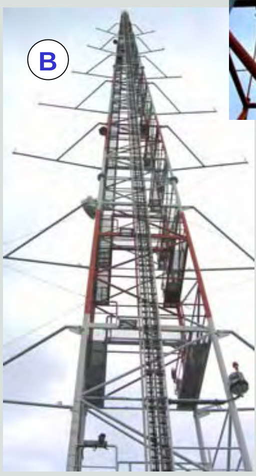
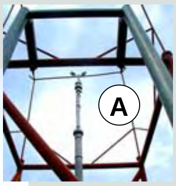
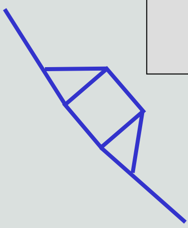
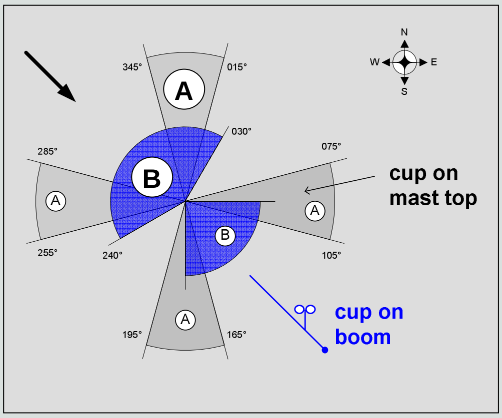
Kaiser-Wilhelm-Koog GmbH
Wind Sensors
IEA-TEM RD&D Wind Berlin Feb 2007 Slide No. 8
FINO 3

FINO 1:
Square Base









Disturbed Sectors

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Wind Flow Disturbance

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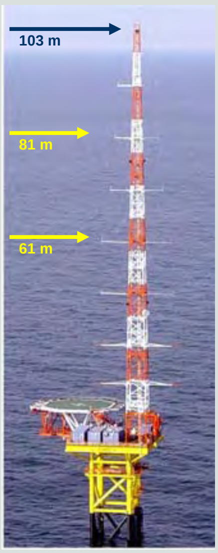
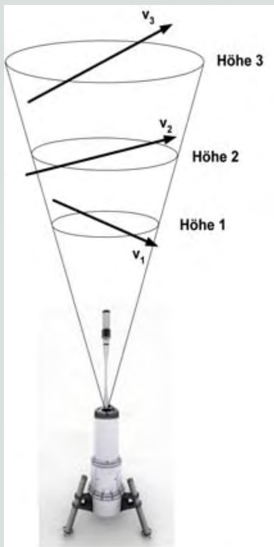
FINO 3



Comparison
LiDAR vs. Cup

- ➢ top level
- ➢ 2 boom levels



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FINO-1 ZephIR LiDAR Test

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FINO 3

Period No.	Data Storage Period No.	Start Date	End Date	Heigth Settings	Cloud Correction
1	1 & 2	2.3.2006	11.4.2006	78 / 300	on
2	3 - 6	11.4.2006	26.6.2006	36, 56, 78, 100 / 300	on
2a	7 & 8	26.6.2006	1.7.2006	36, 56, 78, 100 / 300	off
2b	9	3.7.2006	5.7.2006	36, 56, 78, 100 / 300	on
2c	10	5.7.2006	13.7.2006	36, 56, 78, 100 / 300	off

Overall System Availability: 100.0 %

Overall Data Availability (10-Min.-Av.): 99.6 %

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Availability Offshore

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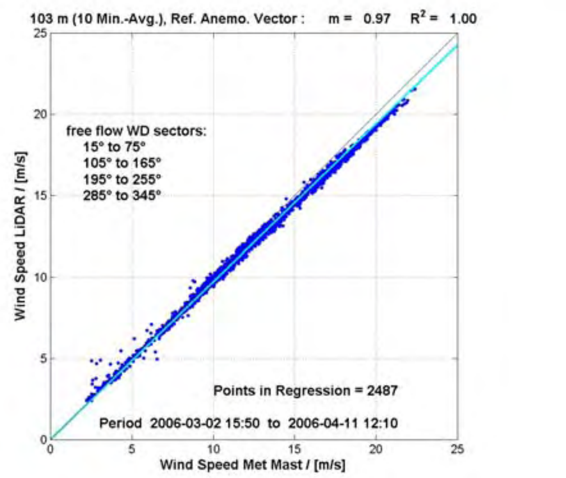
FINO 3



Height:
103 (78) m

WS range:
2 to 23 m/s

Slope:
m = 0.97

Regr. coefficient:
R^2 = 0.99

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WS Comparison Offshore

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FINO 3

Offshore

Analysis Sector	15°-75°, 105°-165°, 195°-255°, 295°-345°	30° to 90° and 180° to 240°		0° to 60° and 210° to 270°	
	CUP				
1st Period	103 (78) m	81 (56) m	61 (36) m		
10-min-avg. values	1965	/	/		
Slope "m"	0.97	/	/		
Regr. Coeff "R^2"	0.99	/	/		
	CUP			SONIC	
2nd Period	103 (78) m	81 (56) m	61 (36) m	81 (56) m	61 (36) m
10-min-avg. values	6005	2589	2749	3228	3245
Slope "m"	0.98	0,97	0,98	1,01	1,01
Regr. Coeff "R^2"	0.99	0.99	1,00	0.99	1,000

Offshore results

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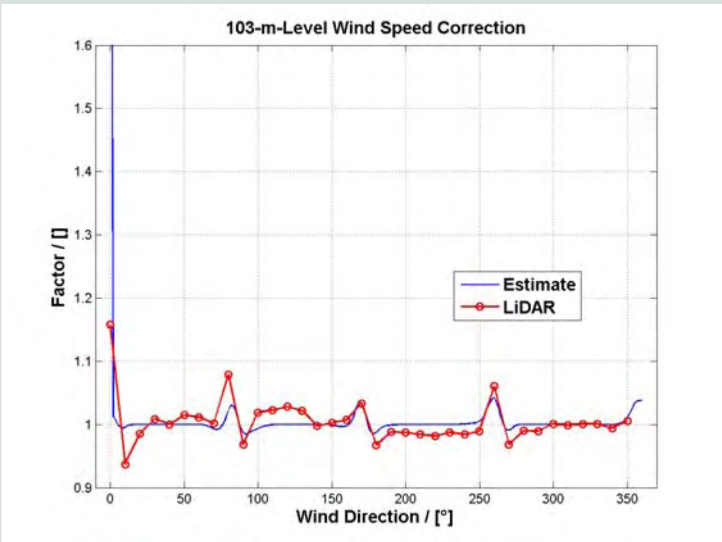

Top WS corrections 103 m

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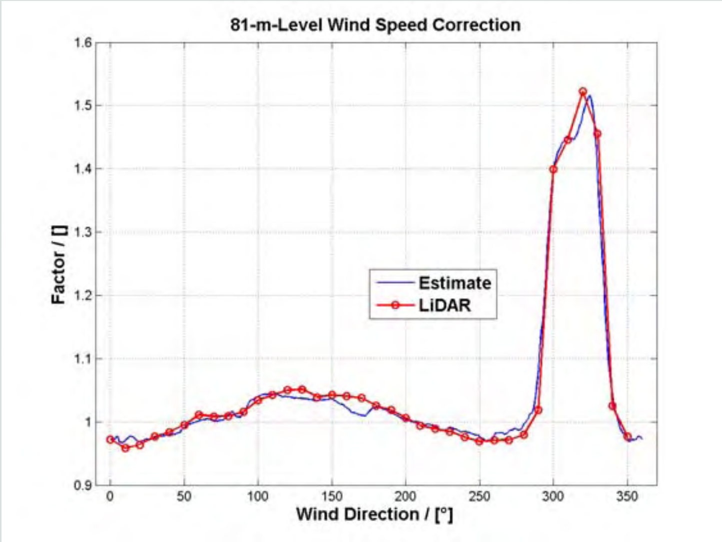

Boom WS Corrections 81 m

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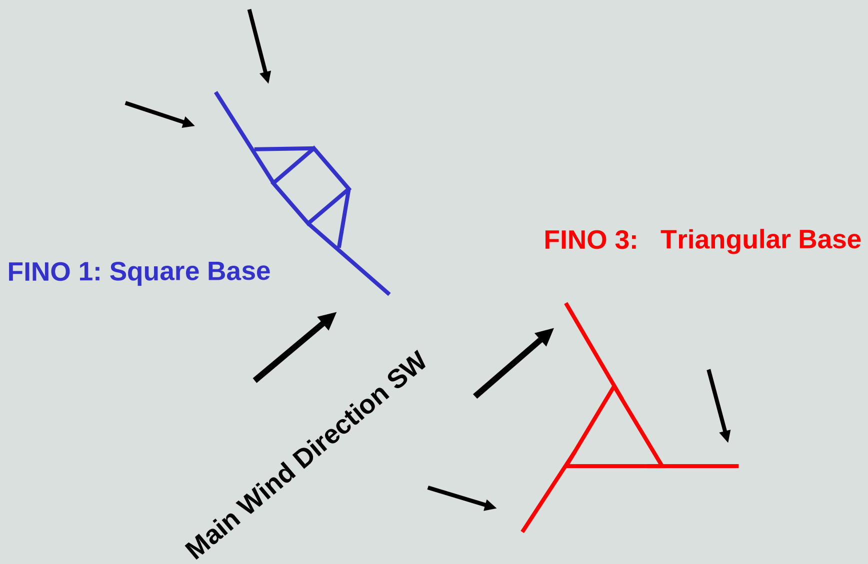

Met Mast Base

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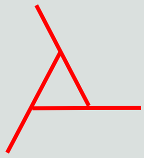
Triangular Mast Base



Disturbance of Wind Flow ...

- ✓ generally less if
  - slim mast structure
  - long booms
- ✓ better compensation
  → three boom directions

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FINO 3 Triangular Mast Base

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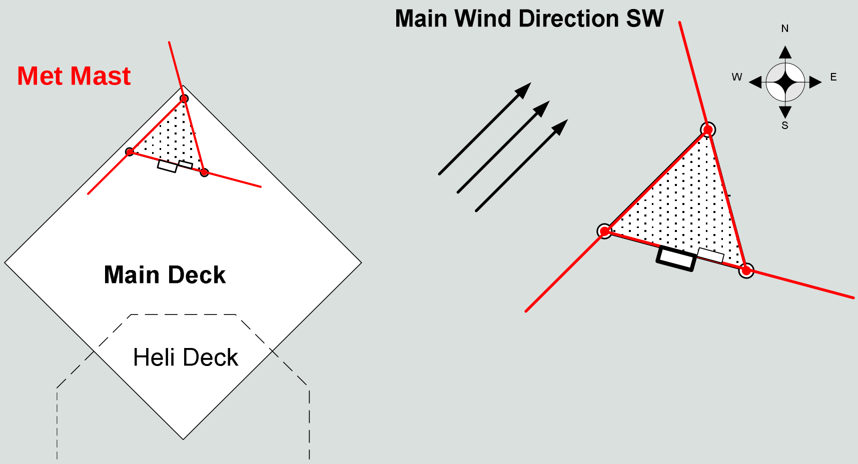
FINO 3



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FINO 3 – Mast & Boom Orientation

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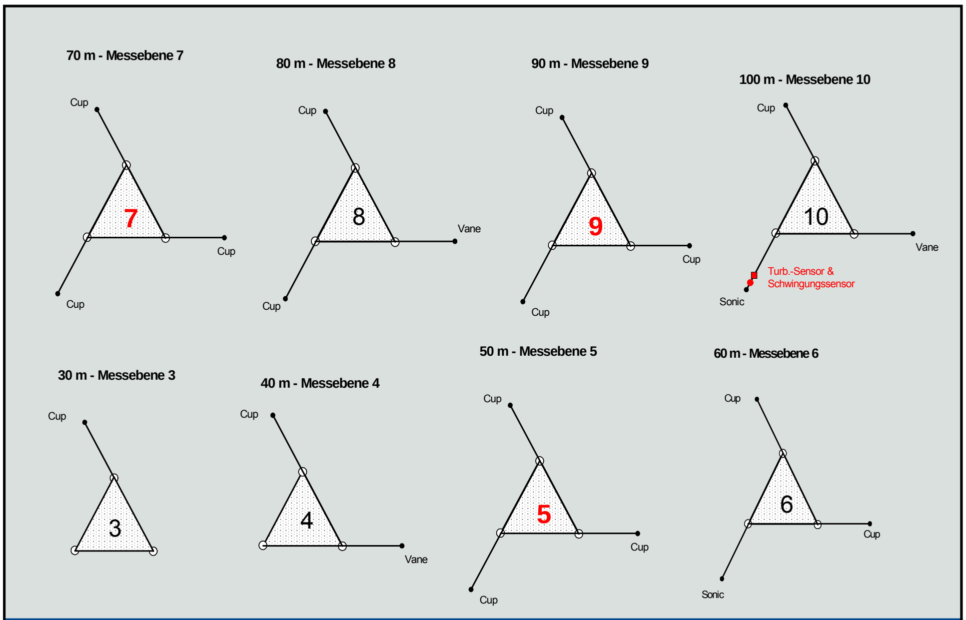
FINO 3



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Wind Measurement Levels

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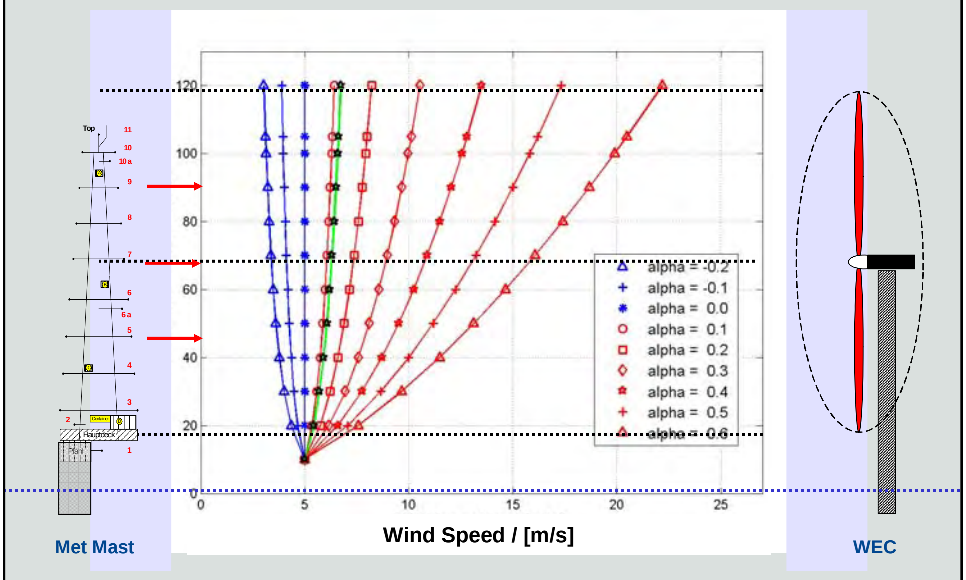
FINO 3



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Wind Speed Profile

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FINO 3

- Differences between FINO 3 and FINO 1
  - land distance, fetch
  - water depths
  - instrumentation and levels comparable

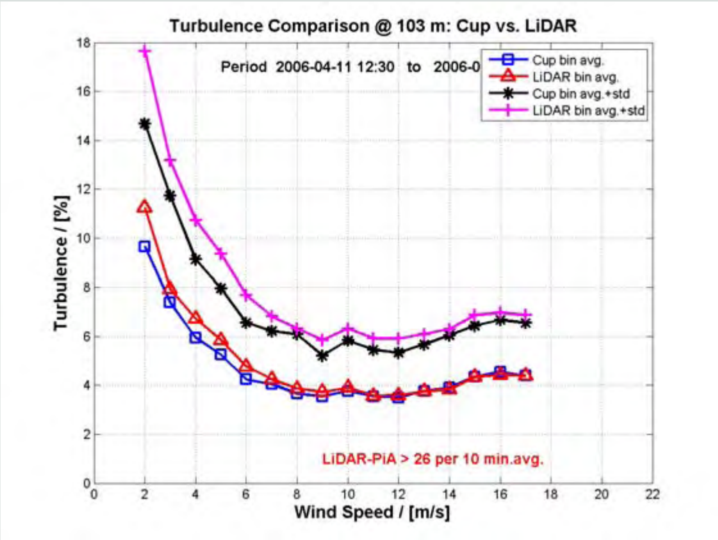
- 10 m wind speed probe maybe useful
  → verification of WS data from SAT measurements

- Heavy disturbances of wind flow from mast structure
  → need pre-cautions
  - slim mast structure
  - sufficient boom length
  - triangular mast shape
    → three boom directions

- Short term LiDAR campaign on FINO3
  → check and analyse mast disturbance effects

Summary

Blank



Turbulence Offshore (%)

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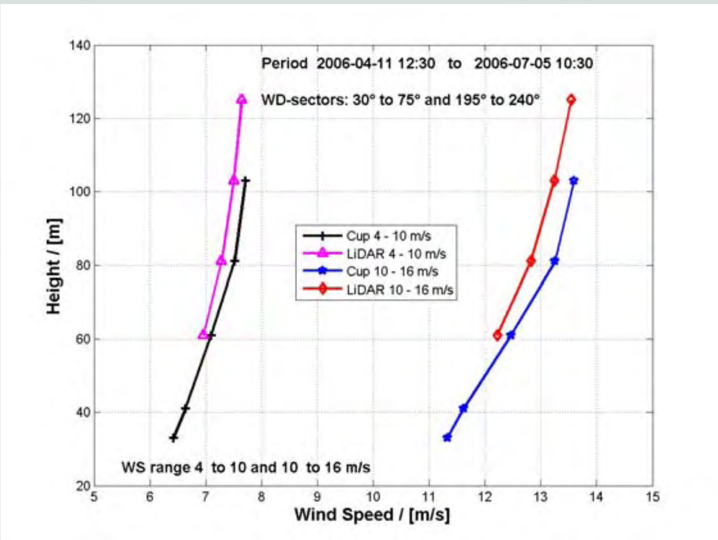
FINO 3



Profiles Offshore

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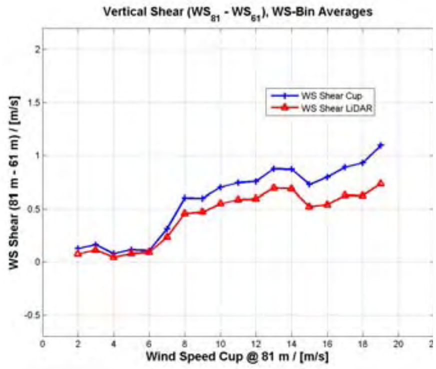
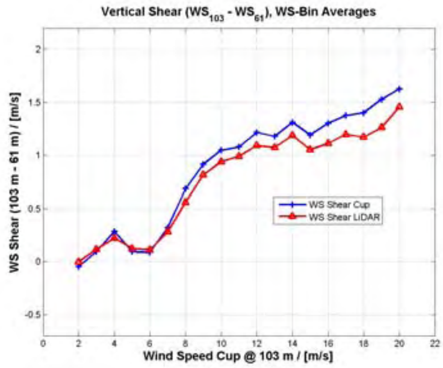
FINO 3





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WS Shear Offshore (%)

IEA-TEM RD&D Wind Berlin Feb 2007 Slide No. 25

FINO 3

Challenges Offshore

- accessibility
- structural stability
- weather during erection
- proximity to mast / available space
- power supply
- screen clearance, salt & spray
- debris from birds
- corrosion: joints and aluminium parts
- remote control & data retrieval

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Challenges Offshore

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FINO 3

Applications & Options

- wind resource studies
- power performance tests
  - profiles over rotor plane
- site assessments
  - Turbulence
  - WS WD shear
  - Max. WS
- gust forecasting
- wind turbine wake studies

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Applications & Options

IEA-TEM RD&D Wind Berlin Feb 2007 Slide No. 27

FINO 3

IEA Topical Expert Meeting “Wind & Wave Measurements at Offshore Locations”
Berlin, February 20th – 21th, 2007

Research proposal: „Development of LIDAR Wind Sensing for the German Offshore Test Site“

Martin Kühn, Andreas Rettenmeier

Endowed Chair of Wind Energy, Universität St

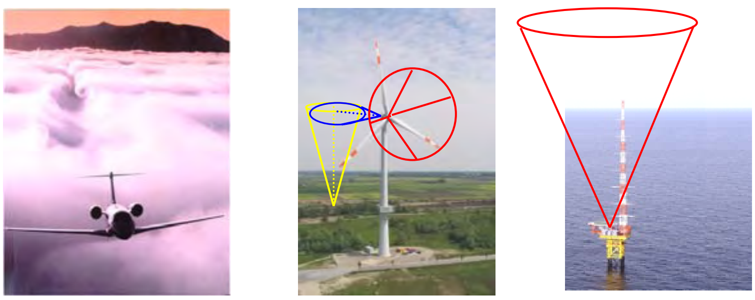
[Fig. QinetIQ, DLR, SWE, BMU]

SWE Stiftungslehrstuhl Windenergie am Institut für Flugzeugbau

Universität Stuttgart

Contents

- Project overview
- LIDAR technology
- Objectives & organisation of the LIDAR proposal



[Fig. DLR, SWE, BMU]

SWE Stiftungslehrstuhl Windenergie am Institut für Flugzeugbau

Universität Stuttgart

Project overview

Proposal of research project:

„Development of LIDAR wind sensing for the German offshore test site"

at the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

- **Research project consists of six participants**
- **Positive pre-evaluation last year, currently contract negotiations**
- **Earliest start date: April 2007**
- **Duration: 2.5 years**

German offshore test site

Offshore test site „Borkum-West"
planned 2008:
est. 6 x REpower 5M
est. 6 x Multibrid M5000

Water depth: approx. 30m

Research platform FINO 1

[Fig. BMU]

LIDAR: Present applications and research activities

General applications (examples)

Mesoscale wind fields, rare gases, tail vortices
- DLR Oberpfaffenhofen: 2 µm pulsed DWL (since 2000) & 10 µm cw DWL (since 1984), development of 1.55 µm LDA;

Mesoscale wind field, planetray boundary layer turbulence
- Research Centre Karlsruhe (since 2005)
- IfT Leipzig (under development)

Tail vortices
- Onera (FR), QinetiQ (UK)

Wind energy

- Commercial devices: QinetiQ Ltd. (UK) >12 in the field
  Leospere (FR): first device under testing
- Risø, DK: systematic technology development with QinetiQ, several national and EU projects
- WindTest GmbH, WindGuard GmbH, (DE):
  first field tests for power curve measurements onshore and offshore
- IEA Wind Topical Expert Meeting, 23rd-24th Jan. 2007 on Remode Sensing => LIDAR working group

Scientific need for further development of LIDAR technology

Stationary Measurements (e.g. 1 or 10 min. average)
(Status: successful demonstration)

- Further development of LIDAR device (software, hardware)
  - longer distance
  - corrections for different weather conditions
- Development of standardised methodology for power curve measurements (similar to IEC 61400-12, FGW)
- Offshore application without separate platform

Dynamic measurements of wind field and wind properties
(Status: ongoing research, esp. at Risø)

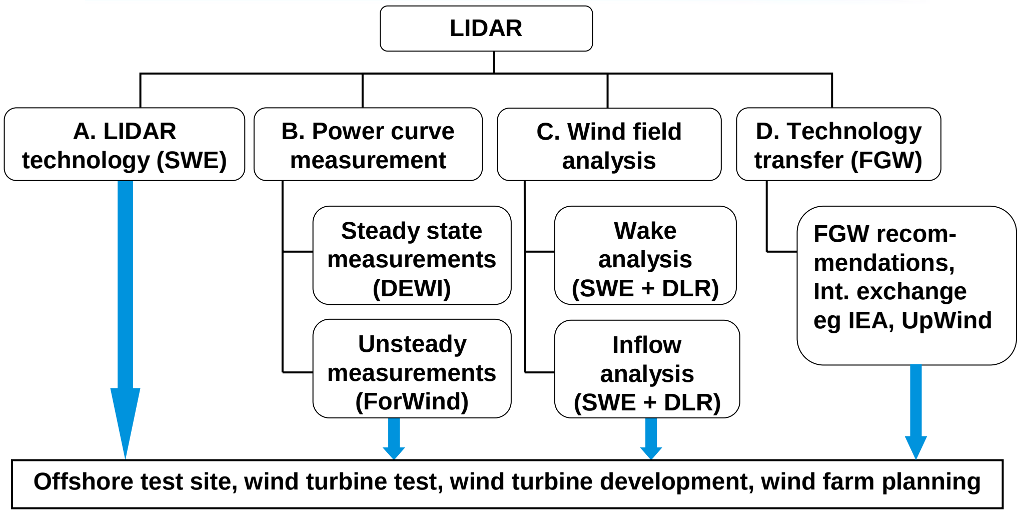
- Development of LIDAR control (e.g. scan modes) and analysis software (data reduction, data quality)
- Development of standardised methodology for load measurements (similar to IEC 61400-13)

Objectives of the LIDAR research proposal

- Development and demonstration in four areas:
  1. Power curve measurements without met mast
     Offshore capability of the LIDAR system
  2. Measurements of turbulent wind fields in dynamic wakes and in the inflow of Multi-MW wind turbines
  3. Development of wind field and load simulation including dynamic wake effects
  4. High resolution measurements of turbulence properties of wind fields as base for new and faster methods for power curve determination
- Recommendations for standardised power curve measurements taking into consideration the FGW technical guideline „Part 2: Determining the Power Performance and Standardised Energy Yields " [1)]
- Provision of LIDAR hardware and of the know-how needed for the application in the offshore test field and other R&D projects

1): http://www.wind-fgw.de/tr_engl.htm

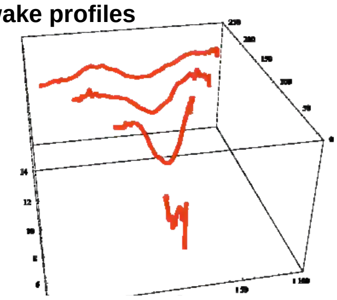
Main structure of the project

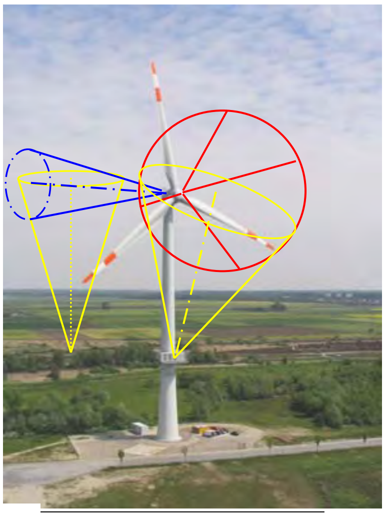


Proposed wind field measurements at Multibrid M5000 turbine at Bremerhaven

Inflow measurements (short range LIDAR)
- power curves
- correlation with loads

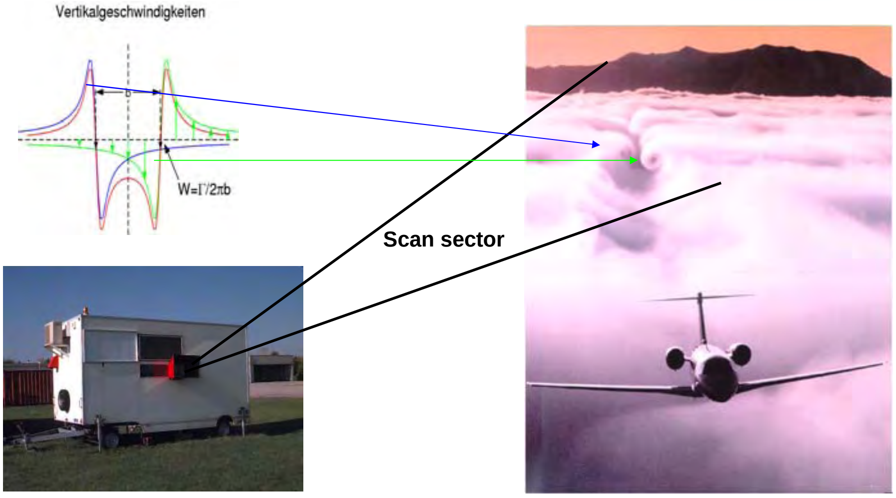
Wake measurements
(long range DLR system & short range LIDAR)
- wake meandering
- wake profiles



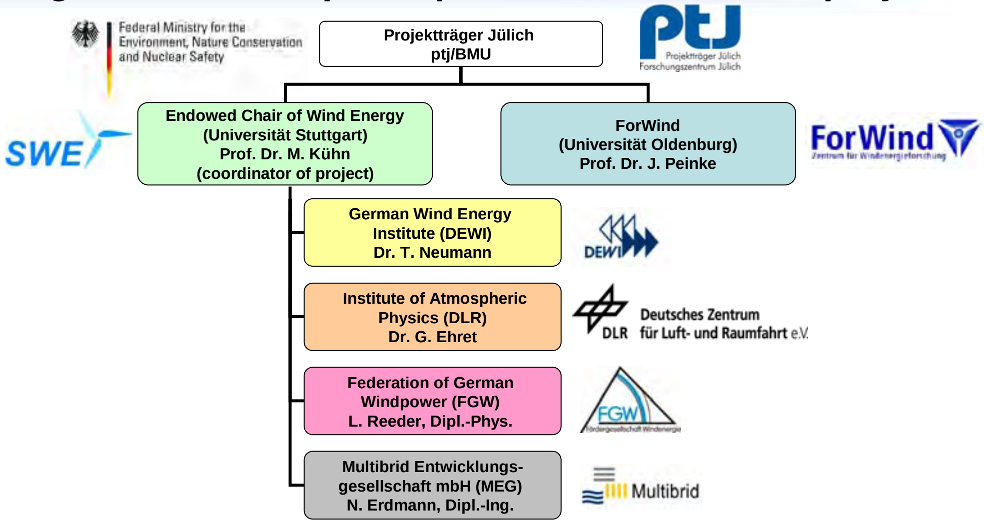


Example of LIDAR measurements of wake profiles at Risø

Example: Measurements of tail vortices at DLR



Organisation and participants of the research project



Conclusions

- **Proposal of a joint research project of 4 scientific partners and 2 industrial partners**
  - **Expected start: April 2007, 2.5 years duration**
- **Main objective: further scientific development of LIDAR application for**
  - **German offshore test site**
  - **Power curve measurements: onshore/offshore, new fast methods**
  - **Other research questions, e.g. dynamic wake loading**
- **National project but exchange of experience proposed**
  - **National through Federation of German Wind Power (FGW)**
  - **International, e.g. in scope of IEA or EAWE activities**

Contact

Endowed Chair of Wind Energy (SWE)
Prof. Dr. Martin Kühn

- **Measurements: Andreas Rettenmeier**
- **Wake analysis: Juan José Trujillo**

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70569 Stuttgart, Germany
http://www.uni-stuttgart.de/windenergie

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“Measurement campaigns with a LIDAR”

cener
centro nacional de energías renovables
national renewable energy centre

Ignacio Martí

February 2007

Measurement principle

- LIDAR: ”Light Detection And Ranging “
- Based on the Doppler effect, measured at particles in motion in the air.

LIDAR characteristics

- ZephIR (manufactured by Qinetiq).
- Measurement characteristics:
  - ❑ Laser frequency: 1575 nm.
  - ❑ Additional measurements: pressure, temperature, humidity.
  - ❑ Up to 5 vertical levels of measurements (non simultaneous measures).
  - ❑ Measurement heights: from 5 to 150 m.
  - ❑ Maximum wind speed: 38.4 m/s
  - ❑ Minimum wind speed: 2 m/s
- Other characteristics:
  - ❑ Total weight: 130 Kg aprox.
  - ❑ Power consumption 100W.
  - ❑ Communication through GSM, Ethernet, RS-232 (GPS)

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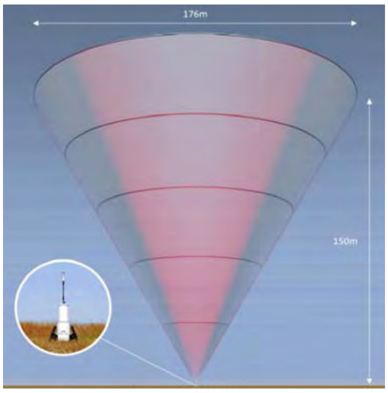
LIDAR operation

- Laser cone with 30º
- 50 scans per round.
- 1 round per second.
- Measurements:
  - ❑ Horizontal wind speed
  - ❑ Vertical wind speed
  - ❑ Wind direction
- Mast vane is needed to determine wind direction angle.



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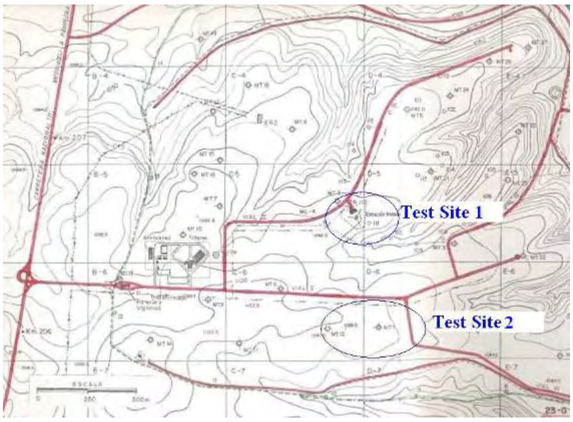
Test Site description



Test Site Location:
Soria (Spain)
Relativeliy flat terrain

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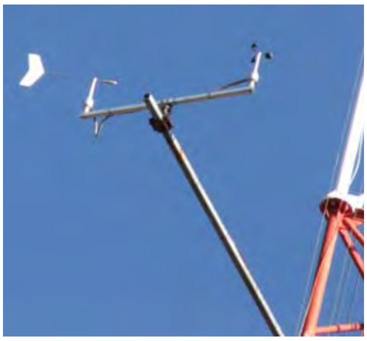
Comparison with a 100 meters meteorological mast

Meteorological mast and LIDAR configuration.



Detail of the 60m anemometer

Meteorological mast:
Instrumented at 32, 60 and 100 meters
Weathertronics cup anemometers Model: 2030

LIDAR:
positioned 78 m south west of the met mast.
• Measurement heights: 300 m, 32 m, 60 m, 100 m, 150 m.
• Cloud correction activated.

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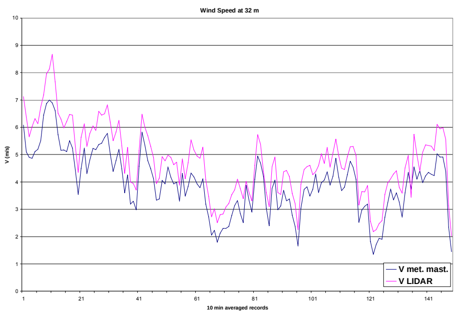
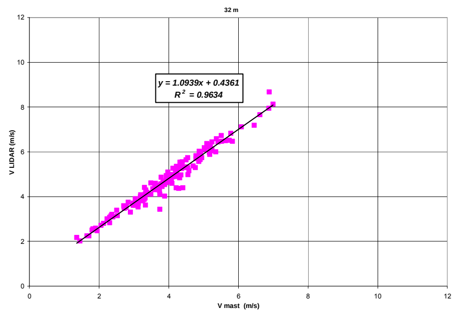
Comparison with a 100 meters meteorological mast

Data Analysis



Inter-comparison at 32 meters



Regression at 32 meters

10 minutes averages

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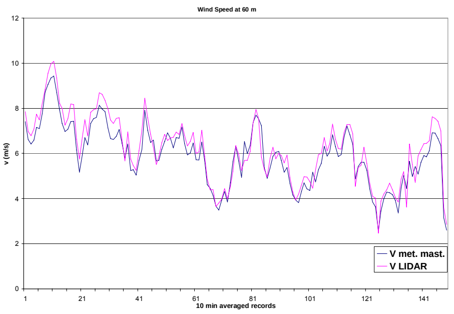
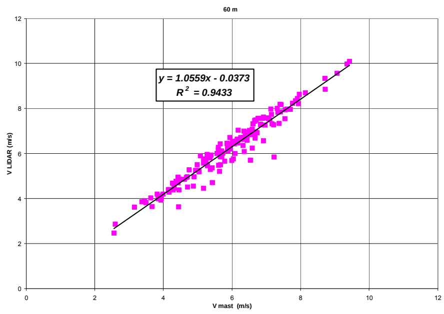
Comparison with a 100 meters meteorological mast

Data Analysis



Inter-comparison at 60 meters



Regression at 60 meters

10 minutes averages

Energía eólica

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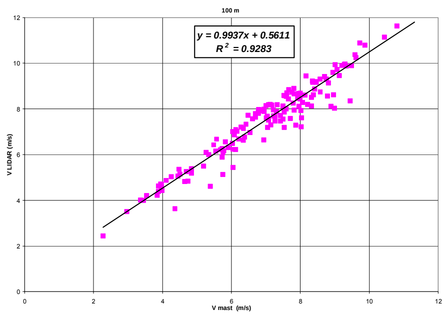
Comparison with a 100 meters meteorological mast

Data Analysis

Inter-comparison at 100 meters



Regression at 100 meters

10 minutes averages

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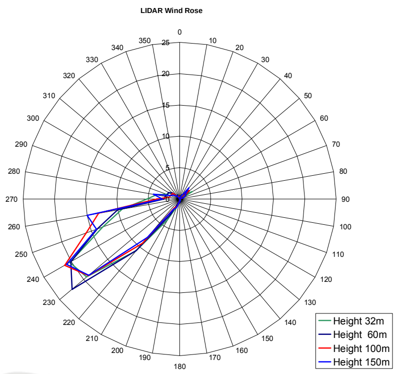
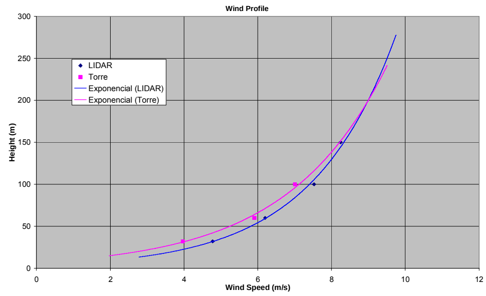
Comparison with a 100 meters meteorological mast

Data Analysis



LIDAR Wind rose



Met mast and LIDAR profile

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Comparison with a 40 meters meteorological mast

Meteorological mast and LIDAR configuration.

Detail of the top mast anemometer

Meteorological mast:
Measurement heights at 20 and 40 meters
NRG Maximum 40 anemometers.
NRG wind vane
Lighting conductor also installed
Lighting conductor and wind vane close to anemometer → perturbation at 0º and 200º

LIDAR:
Positioned 62 m south west of the met mast.

- Measurement heights: 300 m, 40m, 40m, 20 m, 20 m.
- Cloud correction activated.

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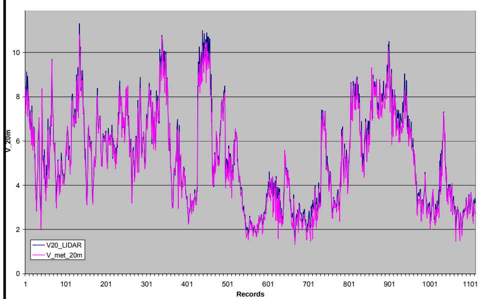
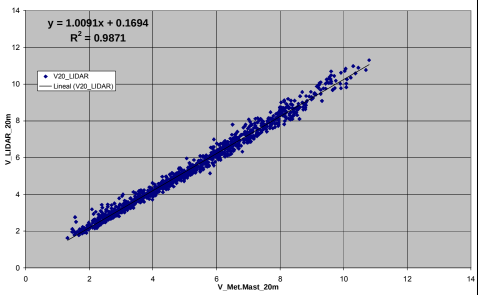
Comparison with a 40 meters meteorological mast

Data Analysis



Inter-comparison at 20 meters



Regression at 20 meters

10 minutes averages

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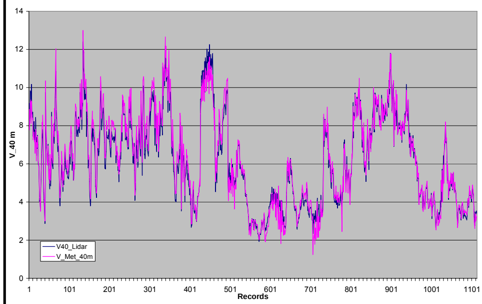
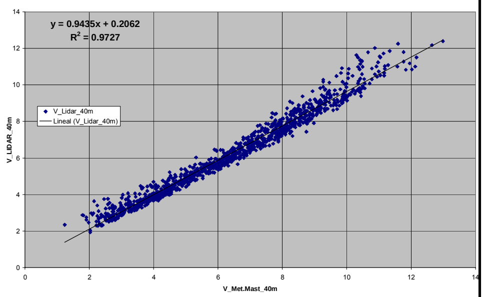
Comparison with a 40 meters meteorological mast

Data Analysis



Inter-comparison at 40 meters



Regression at 40 meters

10 minutes averages

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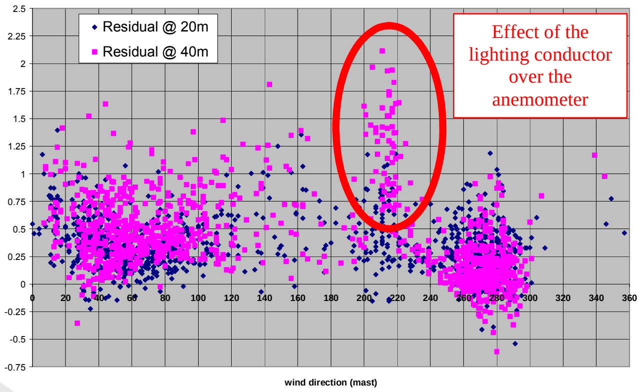
Comparison with a 40 meters meteorological mast

Data Analysis



Residual values vs met mast wind direction

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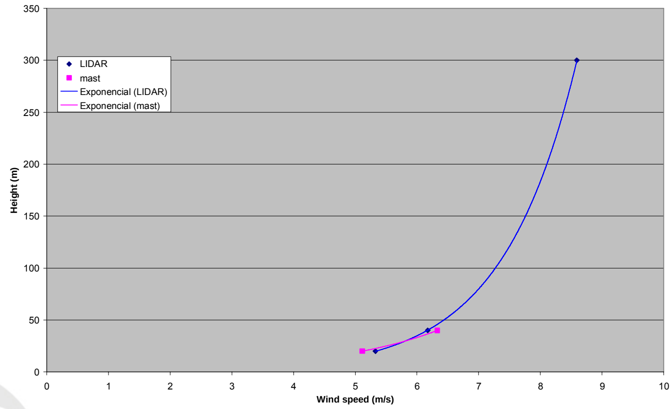
Comparison with a 40 meters meteorological mast

Data Analysis



Met mast and LIDAR profile

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Advantages

- Easy installation.
- Measurement range up to 150 meters.
- 5 vertical measurement heights.
- Easy to configure.
- Other additional measurements (pressure, temperature and humidity).
- Remote access to data and to the system.

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Inconvenients

- High power consumption (100 W).
- Non instantaneous measurements at the different vertical levels (specially sensible to determine turbulence profiles).
  - Time lag of 3 seconds aprox.
- Low temporal resolution (can be increased by reducing the number of vertical levels). Up to now is not enough for turbulence characterisation (there is some ongoing work on this issue in EU UPWIND project).
- Measurements affected by snow, rain ...

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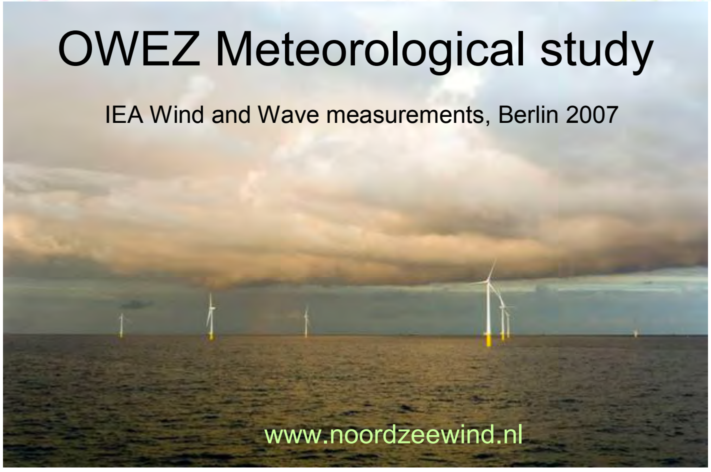
cener
centro nacional de energías renovables
renewable energy national centre

NoordzeeWind



Approach, results and lessons learned

Erik Holtslag, Meteorologist (MSc)

NoordzeeWind

Presentation purpose

- Demonstrate design challenges
- Explain technical solutions
- Resulting met mast in reality
- Conclusions and lessons learned
- Future questions

NoordzeeWind

Intro: main project data

- 36 Vestas V90-3 MW windturbines
- Hub height 70 m, diameter 90 m
- Three 34 kV cables to shore
- Step up to 150 kV on land
- Renewable energy for at least 100.000 households
- In operation since October 2006
- Monitoring program included in project

NoordzeeWind

Why this met mast?

- Power output prediction in wind study
- Requested by monitoring program: research on wind climate impact (profiles, fluxes etc.)
- Power output verification in accordance with IEC-standard 61400-12 (contract verification)
- Optimal measurement accuracy (technical vs. economical)

→Conflicting demands

NoordzeeWind

Boundary-Conditions

- Mast designed to meet monitoring program requirements: measurements to tip height (116 m !)
- IEC-conform mast layout
- Maximum redundancy
- First stand alone, later park-integrated

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Hardware

- During tendering of metmast and instrumentation: structural design limits vs. measurement requirements
- Adaptation of booms and metmast to fit measurement needs
- Triple instrumentation due to flow distortion
- Dual systems for extra reliability

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Metmast Layout (1)

- Lattice mast, 116 m high, on monopile foundation
- Measurement levels 24 m, 70 m, 116 m, South, North West and North East
- Anemometry on each of the 3 booms at each level: cup anemometer and wind vane
- Additionally Gill 3D sonic measurement at NW-boom at each level
- Air pressure, rain, humidity, temperature, ADCP, seawater temperature

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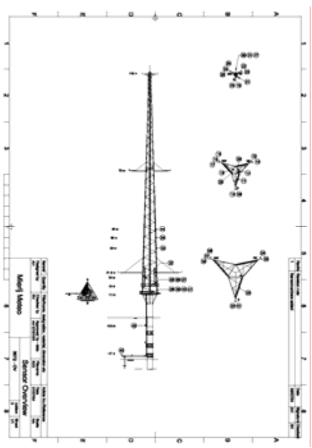
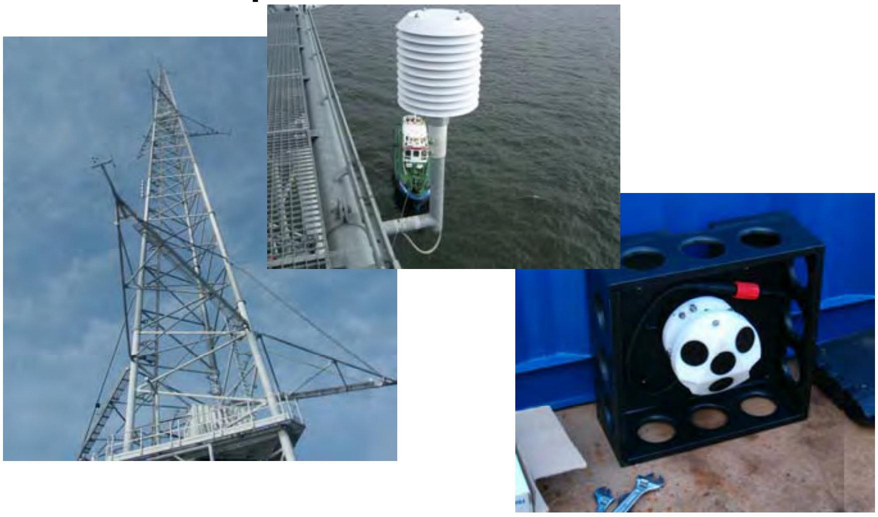
Metmast Layout (2)



Some pictures metmast



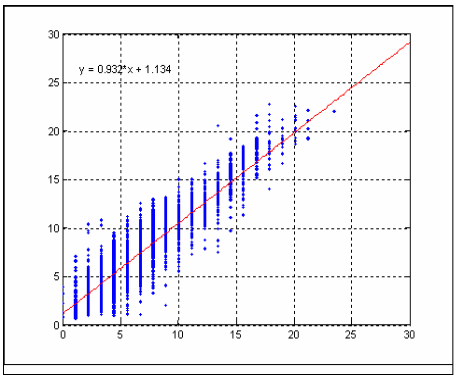
Data Management

- Measured entities saved as statistical values per 10 minute-interval: mean, standard deviation, min, max
- Sent to shore by dual open-GSM connection, FTP-server based
- After construction wind farm; data through SCADA-system
- Data stored in MS-Access database

NoordzeeWind NUON

Example: Measure, correlate, predict

- 6 months of OWEZ metmast data
- 13 years of MPN-data
- High correlation:r=0.92 (r^2=0.84)
- **Conclusion**: original estimates (based on theoretical approaches and MPN) correct



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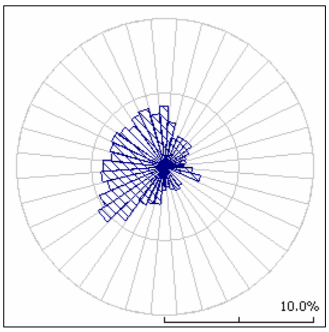
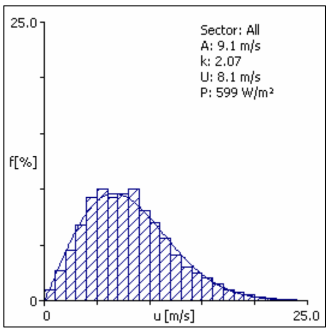
Example: Wind climate summer 2004





- From 3D measurements
- Tendency for North West sector (2004 summer)
- Influence of mast visible in ‘missing sector’

NoordzeeWind

Results

- Building up to tip height while also measuring conform IEC is impossible for offshore: structural design limits
- Mast is accepted by second opinion party for wind resource study
- Mast is accepted by turbine supplier for performance measurements

→ **Conclusion: Results suitable, however not fully IEC-compliant**

NoordzeeWind

Lessons learned

- Integral top down design needed
- Mast construction & instrumentation parties both involved in engineering phase (~10 parties)
- Test all systems onshore prior to installation
- Necessity for early and continuous quality check on data to reveal status of met mast
- Building conform IEC up to tip height is impossible for offshore masts

NoordzeeWind

Future questions

From wind resource/meteorological point of view:

- Influence of mast-movement on measurement accuracy
- Real influence of lattice mast on flow: laboratory/theoretical vs. mast measurements
- Boundary layer processes and Stability profile; influence on production

NoordzeeWind

Future questions

From organisational point of view:

- How can we optimize the met mast design for future projects?
- Can one mast serve all purposes? And at what costs?
- Is IEC-conform measuring necessary?

Plataforma Oceánica Multifuncional Sostenible
(Sustainable Multipurpose Oceanic Platform)

PLOCAN

Instituto Canario de Ciencias Marinas (ICCM)
octavio.llinasgonzalez@gobiernodecanarias.org
macarenabv@iccm.rcanaria.es

Wind and Wave Measurements at Offshore Locations
Berlín 2007

Febrero 2007

INDEX

- Introduction and Objetive.
- Infrastructure
- Unique Iniciative
- ¿ Why in CANARY ISLANDS ?
- Scientific & Technological fundaments
- Character of the Iniciative
- Proposal and Conclussions

Plataforma Oceánica Multifuncional Sostenible, PLOCAN

Introduction and Objetive.-

Moving initiative of marine science and technology directed to the search of international enterprise socioeconomic competitiveness , derived from the access to the oceanic space.

It´s proposed to designe and construct : **A Oceanic Platform**

In which we can:

- observ,
- produce,
- resources advantage
- install services

→ **In crescent depths**

Wind and Wave Measurements at Offshore Locations

Berlín 2007

Plataforma Oceánica Multifuncional Sostenible, PLOCAN

Infrastructure.

This infrastructure will serve for:

- focus on
- propulse

} latent Spanish capacities, guaranteeing the international vanguard

PLOCAN has **double purpose**:

- **Fixed Structure** → Operative Ocupation
- **National Base of Instruments of Submarine Operation** → ROBS, submarine machinery, etc → Use, Development, and Investigation

Wind and Wave Measurements at Offshore Locations

Berlín 2007

Plataforma Oceánica Multifuncional Sostenible, PLOCAN

Unique Iniciative

The Canary Islands has:

• privileged characteristics for the study of the sea

• the richer marine environment in ecosystems and species of all Spain.

• interesting sea bottoms

Great depths in few meters

The Infrastructure that is proposed

Unique in the World

Turning the serious problems in scientific, technological and economic Opportunities

Wind and Wave Measurements at Offshore Locations

Berlín 2007

Plataforma Oceánica Multifuncional Sostenible, PLOCAN

¿ Why in CANARY ISLANDS ?

- Accessibility to the average deep ocean in any desired distance
- Extrapolables conditions of the sea
- Climatologic conditions of continued operation
- Good aerial and marine connections
- Offshore Petroliferous Activity increasing in Western Africa

The Marine Platform of the Canary Islands allows to locate this Infrastructure in great depths near the bases, such as aerials as marines → operation and minimum security → Costs of Operation.

Wind and Wave Measurements at Offshore Locations

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Scientific & Technological fundaments

This proposed → Technological Iniciative → Situated in the actuals **limits** of **Knowledge**

demand

Great quantity of **Scientific Research**

Advantage of being developed by

Research Teams

- Internationals
- Autonomics
- Nationals
- Europeans

The Iniciative will be projected in the Map of Spanish and European infrastructures forseen in the VII PM

Plataforma Oceánica Multifuncional Sostenible, PLOCAN

It has to been made studies to establish the influence on the ecosystem of the activities that will be developed:

- the construction of the platform,
- the operation of their sea and earth labs,
- Plants,
- Vehicles y Submarine machinery,
- the parks or farms of energetic devices (wind, waves and tide), or fishfarming,
- the production desposits and gas storage, H2, NG.
- the conditioning works or fixation of the structures to the bottom.

Giving the Enviromental Guarantee requested

Wind and Wave Measurements at Offshore Locations

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Plataforma Oceánica Multifuncional Sostenible, PLOCAN

PLOCAN will be:

- energeticly autonomic,
- equiped with all the neccesaries installations to live, research and experiment
- “Join” with an earth cable, to give the overproduced energy,
- accesable by sea and air,
- living capacity of 80 people crews., divers, engineers, researchers, etc.

Wind and Wave Measurements at Offshore Locations
Berlín 2007

Plataforma Oceánica Multifuncional Sostenible, PLOCAN

Character of the Iniciative

This Iniciative is:

- **Autonomic:** origen and situation.
- **National**: dimentions and contains.
- **International:** orientation and objectives.

Participation of Public & Private entities

It´s Structure Institutional y Functional → agile, adaptable and very dinamic.

Canary Islands:
- **fiscality**
- **Ships Special Register**
- **ZEC y RIC**

Wind and Wave Measurements at Offshore Locations
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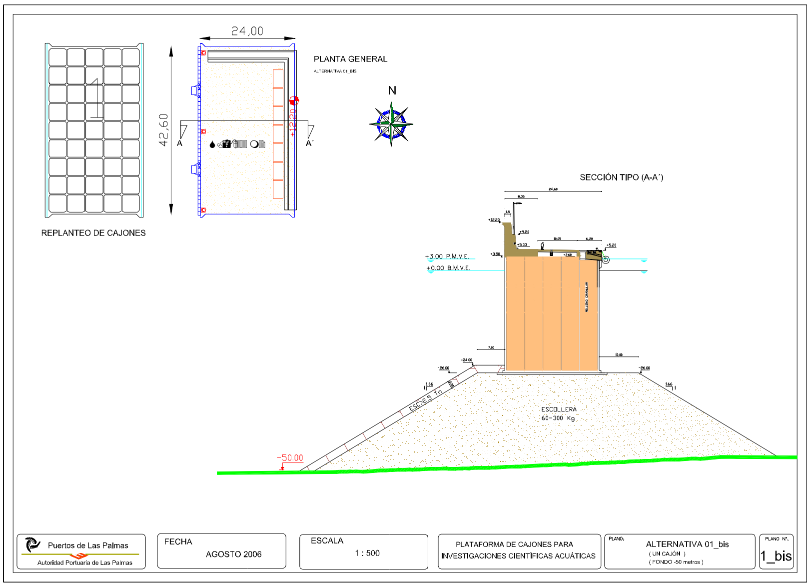
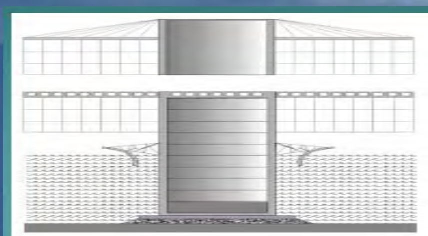
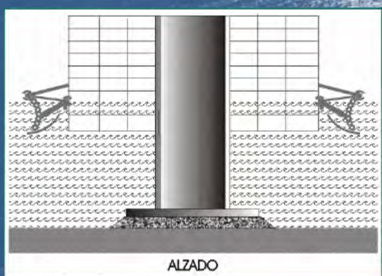


Desing Proposals by Grupo GS and ULL



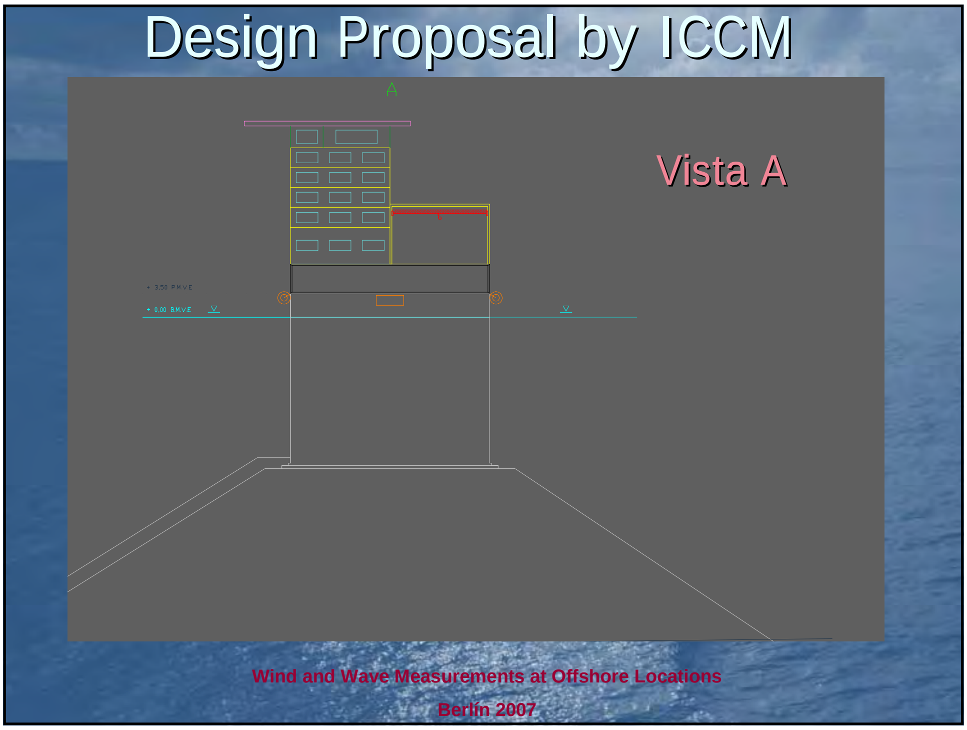
Oceanic Platform hang from a central cilindrical empty core

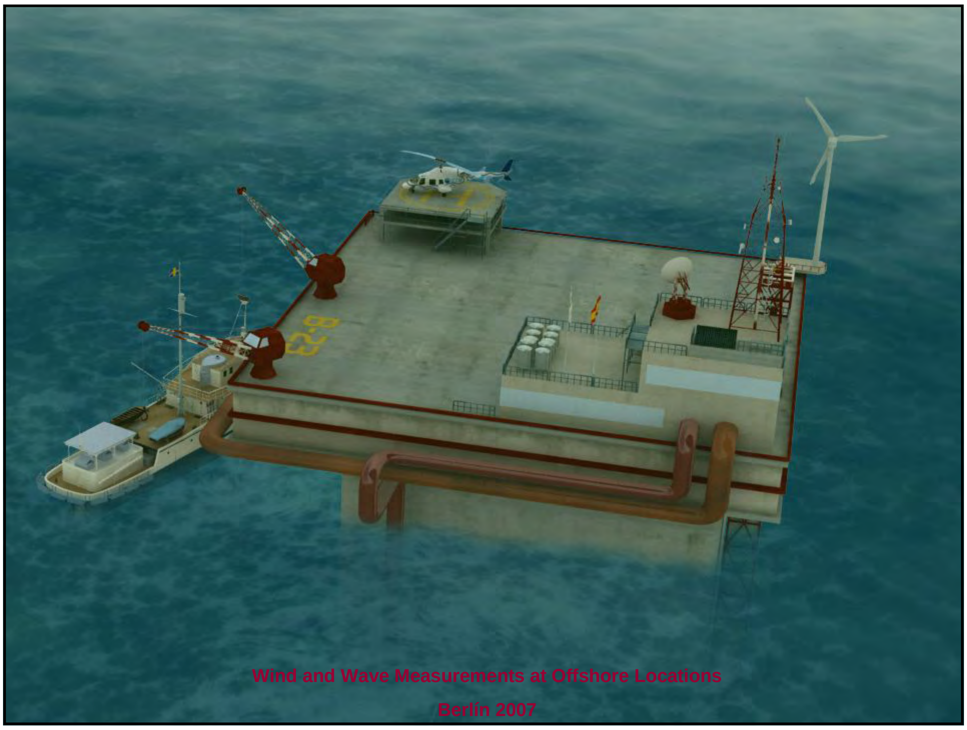


Oceanic Platform semifloating and breakwaters devices

Wind and Wave Measurements at Offshore Locations

Berlin 2007


Design Proposal by ICCM
A
Vista A
Wind and Wave Measurements at Offshore Locations
Berlin 2007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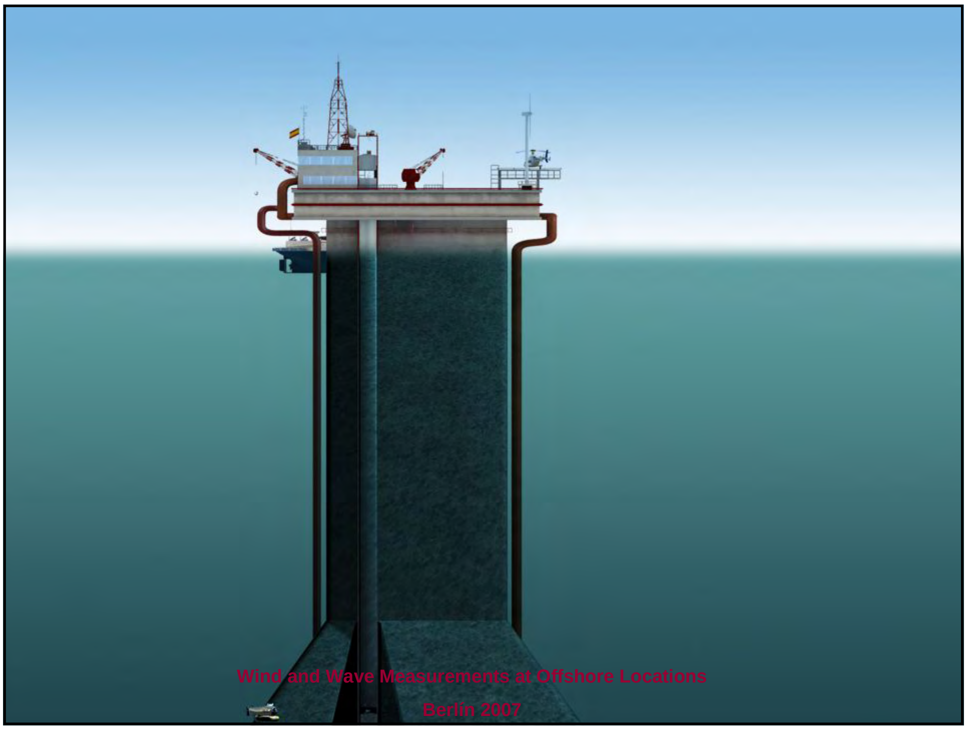
Wind and Wave Measurements at Offshore Locations
Berlin 2007


Wind and Wave Measurements at Offshore Locations
Berlin 2007

Proposal and Conclussions

By indication of the ICCM as our promotional ULL Group of Research of the idea along with ULPGC; ITC and other Canary Institutions we invited to all the members of the Topical Expert Meeting and specially to IEA, Germanischer Lloyd, CENER, ACCIONA ENERGY SA, VATTENFALL, FINO PLATFOR, AWS Truewind and others to participate in Projects related to the Renewable Energies Offshore (winds, waves and tides), processes (desalination and production of H2) and subjects related to the life in the oceanic platform.

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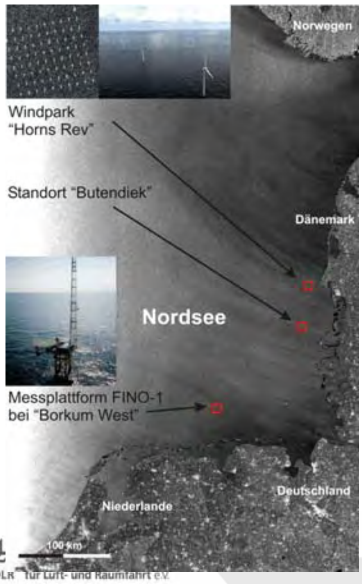
Institut für Methodik der Fernerkundung
SAR Ocanography
Susanne Lehner

Berlin, 18.-19. Februar 2007

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

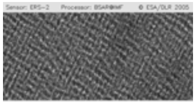
Application of SAR to support Offshore Windfarming



Use of SAR data for

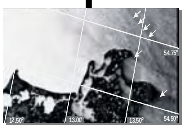
- **Determination of High Resolution Wind Field**
- **Optimum Siting**
- **Optimum Design**
- **Optimum Operation**

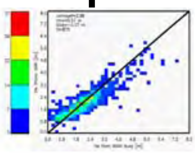
Algorithms to derive marine Parameters

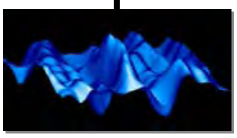


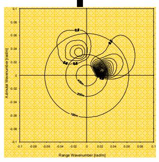
one Million ERS Wave Mode SAR images

Wind field <500m resolution	Integral Parameter, H_s	2-D Elevation Field	2-D Ocean Wave Spectra
Scatterometer Algorithm, JGR	Empirical Algorithm, JGR	Quasi-Linear Inversion, IEEE	First Guess Scheme, JGR

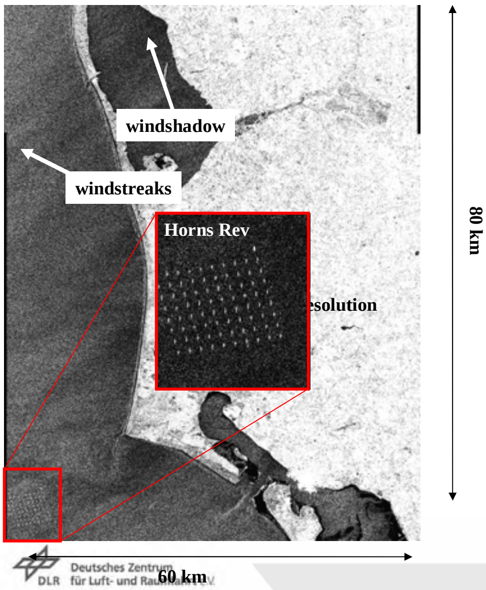


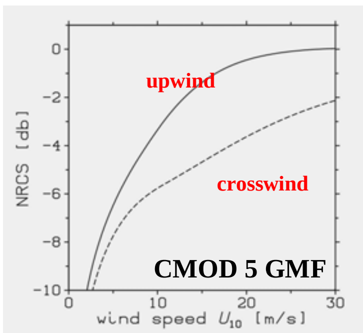


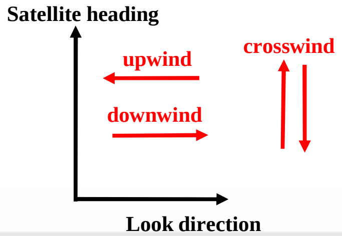




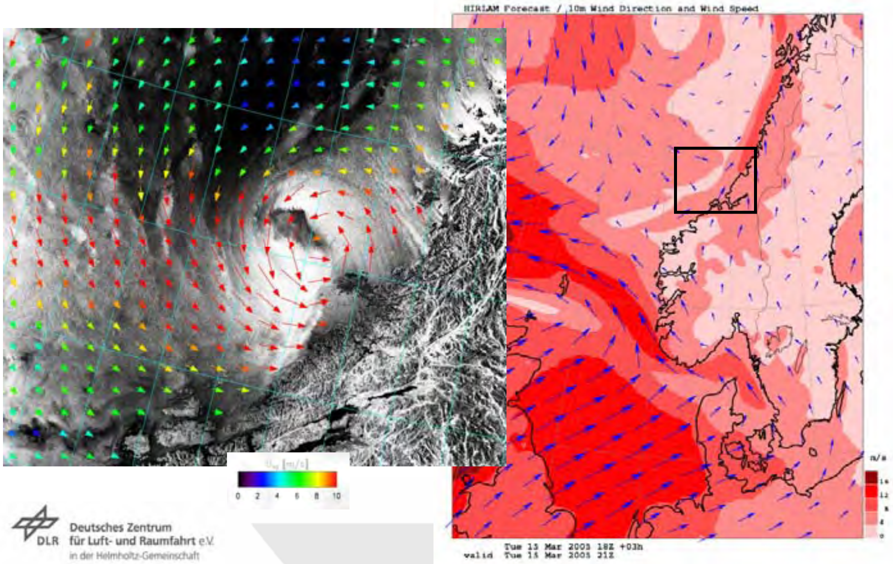
Radar Cross Section of the Sea Surface





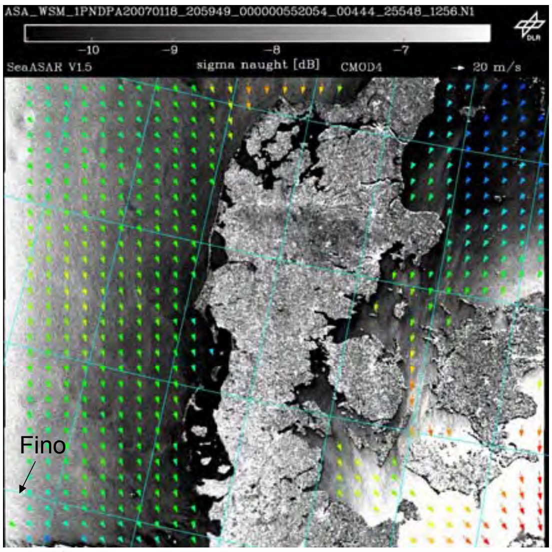


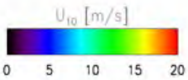
Synoptic Observations of Polar Lows



Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Wind Field during Storm Kyrill





Wind Field Produkt

ENVISAT ASAR Image
400 km x 400 km

Storm Kyrill
18.1.2007

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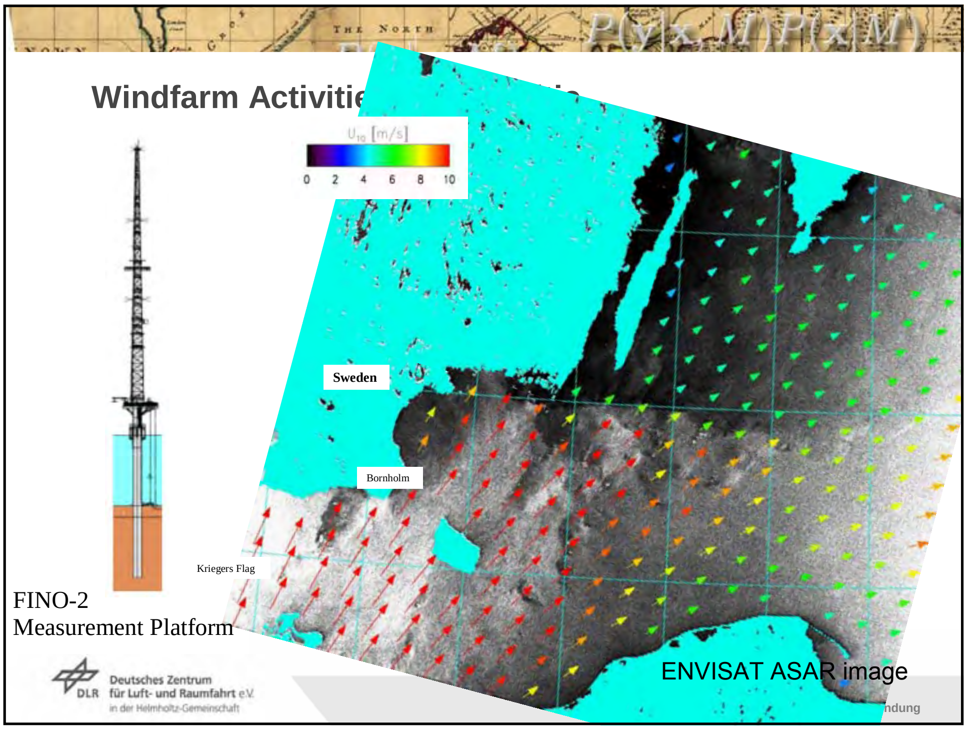
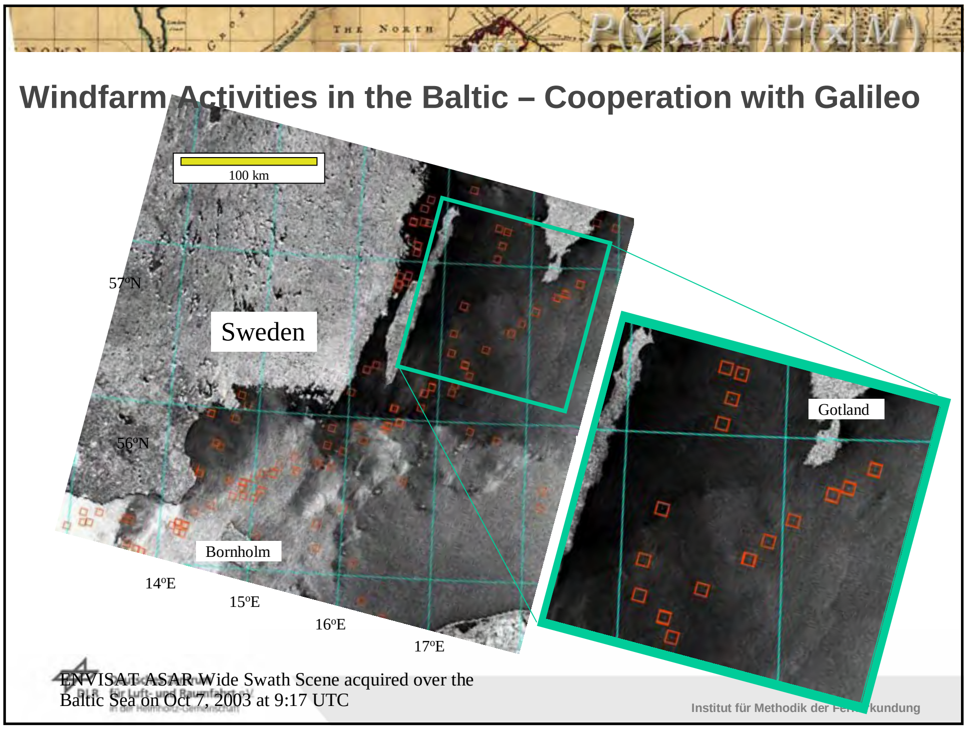
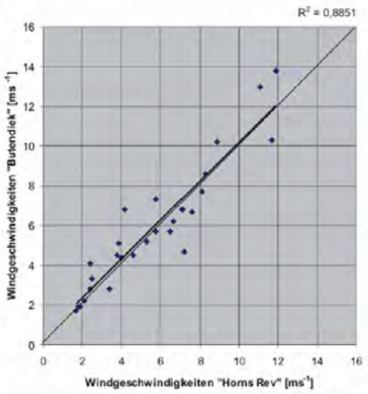
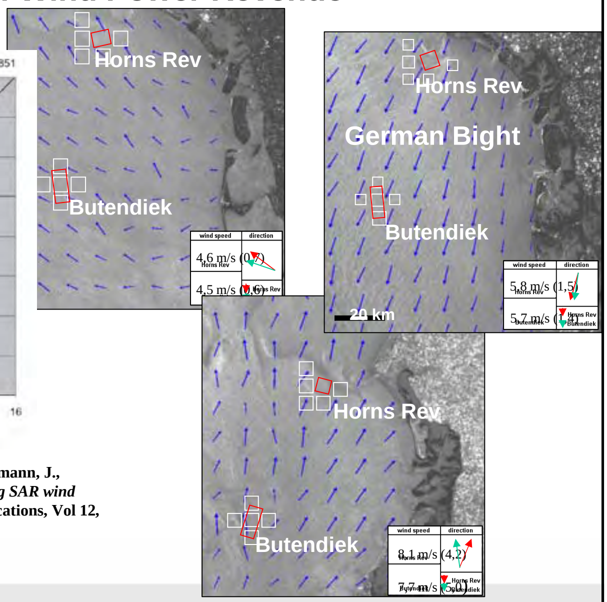
Institut für Methodik der Fernerkundung


Windfarm Activitie
U_{10} [m/s]
0 2 4 6 8 10
Sweden
Bornholm
Kriegers Flag
FINO-2
Measurement Platform
ENVISAT ASAR image
DLR
Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft


Windfarm Activities in the Baltic – Cooperation with Galileo
100 km
57°N
Sweden
56°N
Gotland
Bornholm
14°E
15°E
16°E
17°E
ENVISAT ASAR Wide Swath Scene acquired over the
Baltic Sea on Oct 7, 2003 at 9:17 UTC

Siting-Estimation of Wind Power Revenue





Schneiderhan, T., Lehner, S., Schulz-St., Horstmann, J., *Comparison of two offshore wind park sites using SAR wind Measurement techniques,* Metereological Applications, Vol 12, Cambridge University Press, 2005

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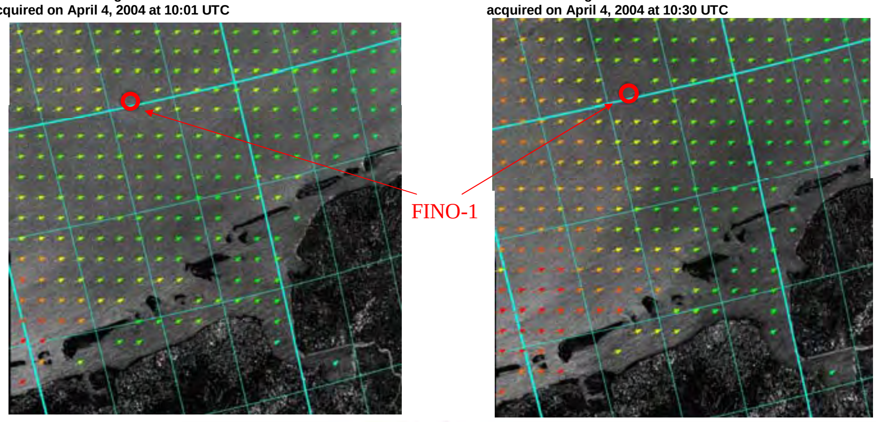
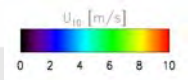
ENVISAT ASAR and ERS SAR 20 Minutes apart Wind Field – Movement of Front

ENVISAT ASAR image mode scene acquired on April 4, 2004 at 10:01 UTC

ERS-2 SAR image mode scene acquired on April 4, 2004 at 10:30 UTC





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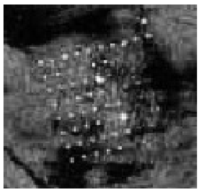
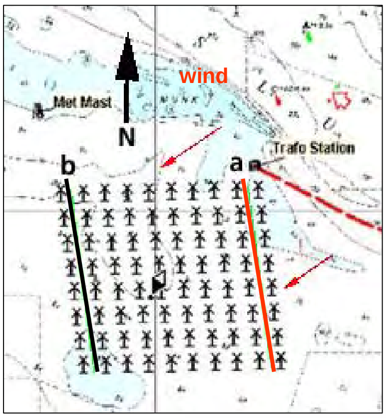
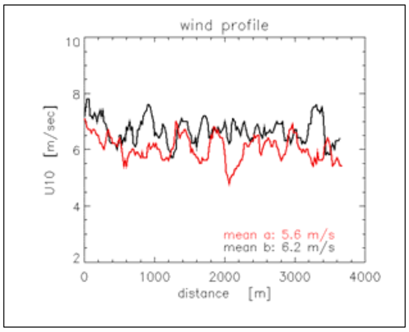
Turbulence inside Wind Farm Horns Rev

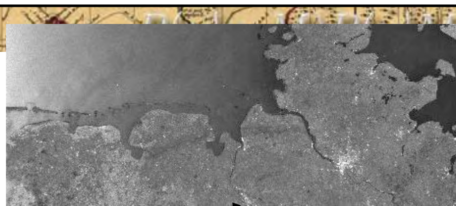


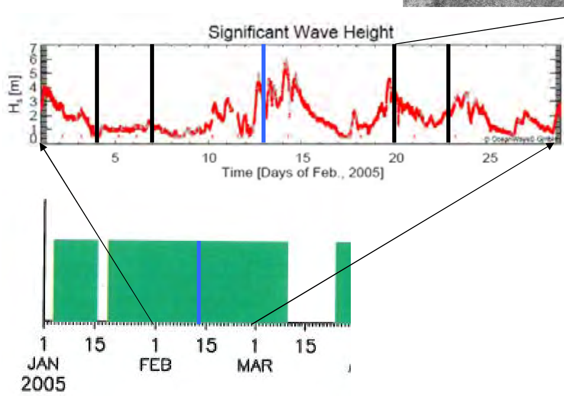




ASAR WSM Mode
20.02.2005 21:05:22

WaMoS ||





— ASAR WSM product

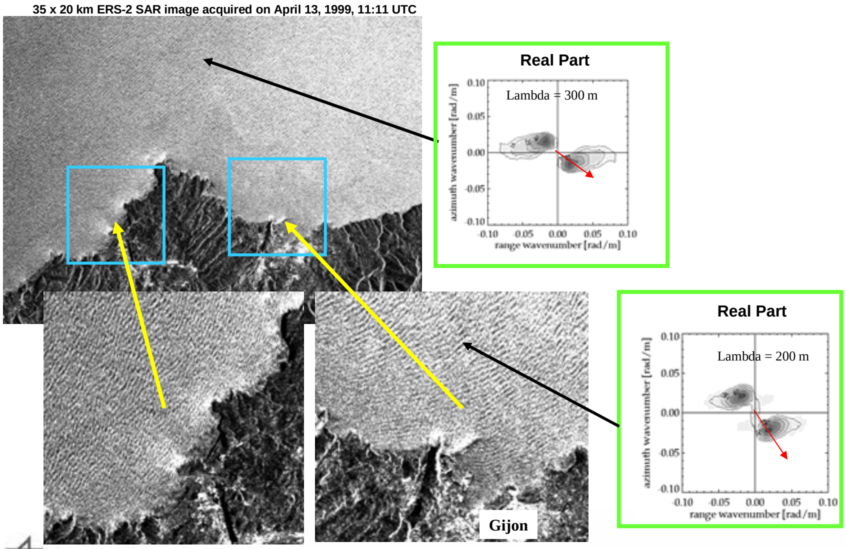
— ASAR IM product

Fino / Boje

ASAR Image Mode
13.02.2005 10:01:42

SAR-Ocean Wave Measurements

35 x 20 km ERS-2 SAR image acquired on April 13, 1999, 11:11 UTC



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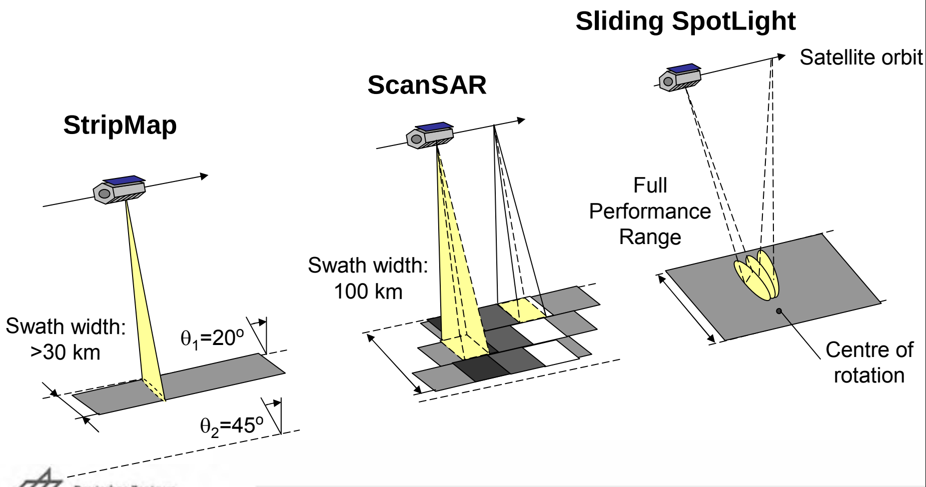
TerraSAR-X Imaging Modes



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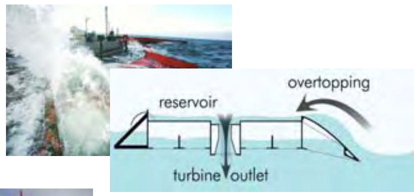
OCEAN-POWER AO project

Assess Potential of TerraSAR-X to support the renewable ocean energy sector

- Ocean Wave Energy
- Wind Energy
- Current Energy



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Project Terra-WAM: Comparison WAMOS and SAR

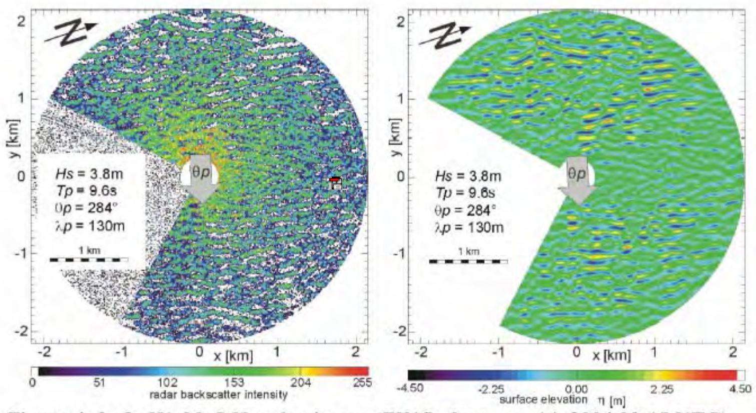

Figure 4: Left: WaMoS II radar image (FINO, January, 14, 2004,00:15 UTC). Right: Sea surface elevation map calculated by inversion of the image.

K.Reichert et al., Waves 2005, Madrid

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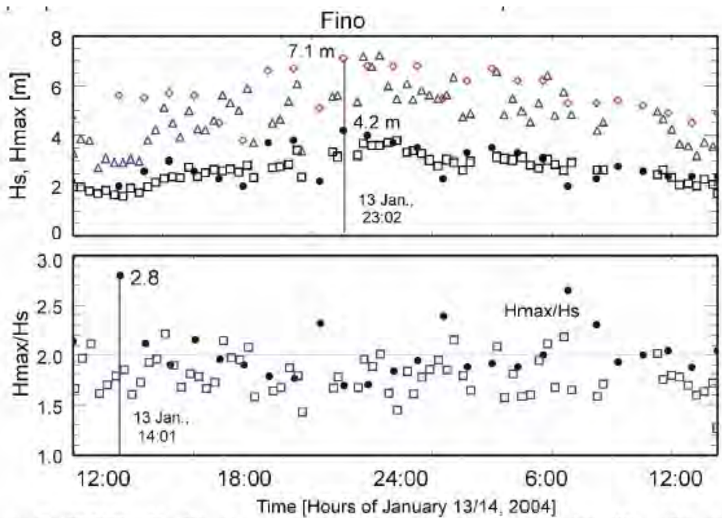
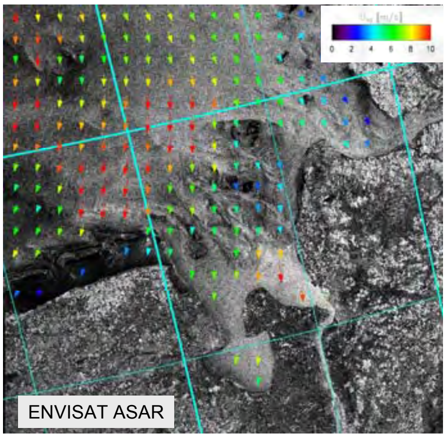


H_{max} (buoy: triangles, WaMoSII: diamonds), H_s (buoy: squares, WAMOS II dots

Upcoming Radar Satellites

MISSION	LAUNCH DATE	MODES	RES.	BAND	Full Polarimetric	ATI
ALOS/PALSAR	Jan 24, 2006	StripMap, ScanSAR	7 m	L	yes	no
COSMO-SkyMed	2006+	StripMap, ScanSAR, Spotlight	< 1 m	X	yes	yes
Radarsat-2	2006+	StripMap, ScanSAR and others	3 m	C	yes	no
Sentinel-1	2010+	ScanSAR or TOPSAR	< 10 m	C	no	Not fixed
Tandem-X	2008+	Same as TerraSAR-X	1 m	X	yes	yes
TerraSAR-X	March, 2007	StripMap, ScanSAR, Spotlight	1 m	X	yes	yes

November Storm



Nordergründe, Sturm 2.11.06, Unfall Hohe Weg   Heligoland

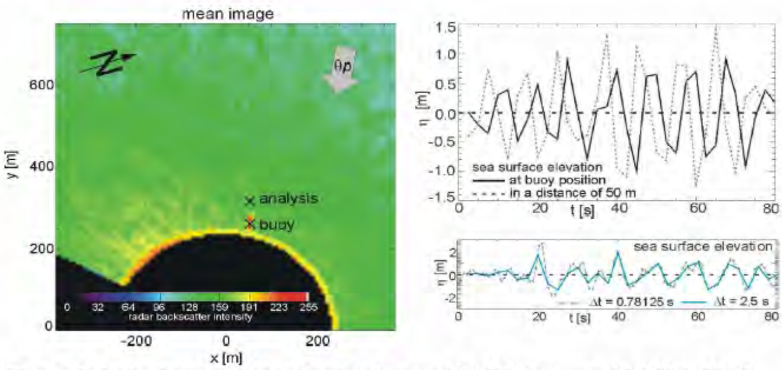


Figure 5: Left: Averaged set of radar images (FINO, January 14, 2004, 00.15 UTC). Right: Comparison of buoy measurements and WaMoS II data.

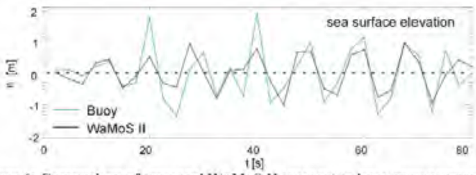
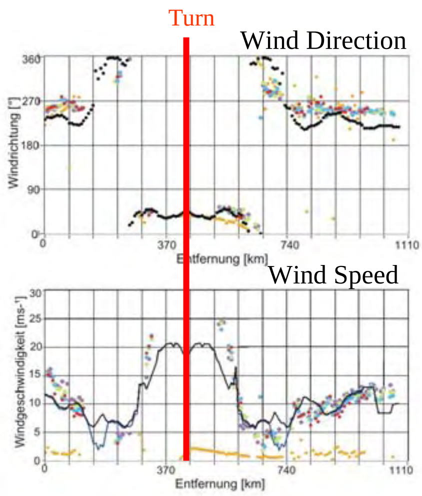
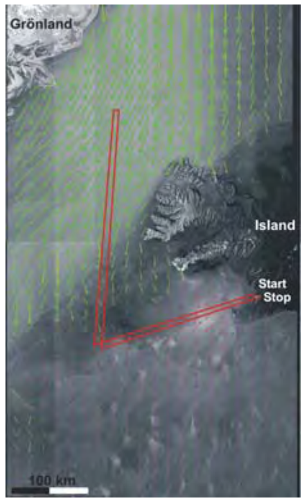


Figure 6: Comparison of temporal WaMoS II transect to buoy measurements.

Comparison of SAR and LIDAR





Orange: ground
Red: 200 m
Blue: 300 m
Yellow: 400 m
Purple: 500 m

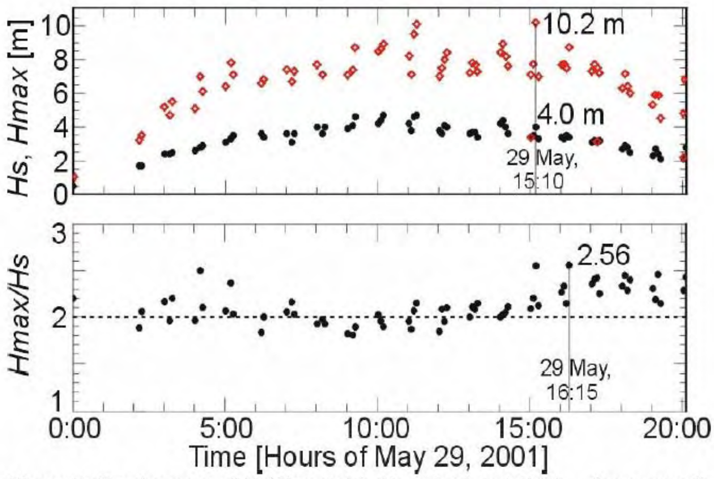
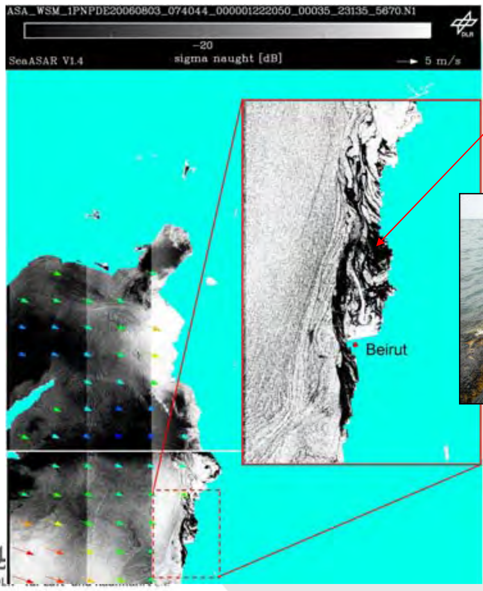


Figure 7: Development of H_s (diamonds), H_{max} (dots) and H_s/H_{max} (lower panel) measured at Ekofisk.

Oil Slick detection using SAR

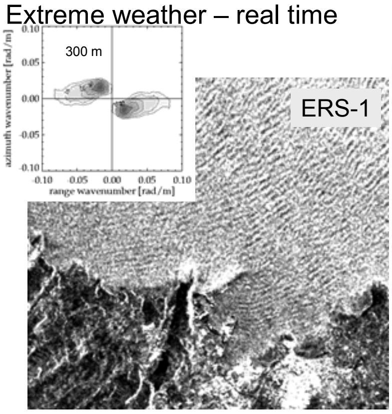


Oil

ENVISAT ASAR image acquired over the Mediterranean Sea ón July 3, 2006 at 7:40 UTC

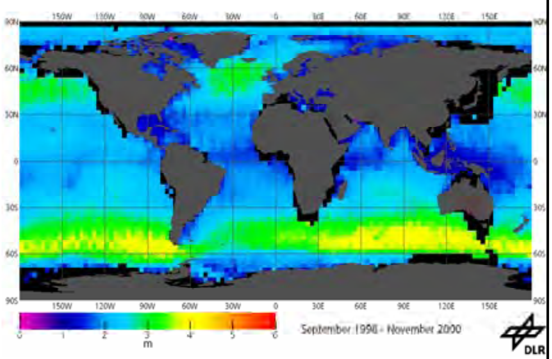
SAR Images have a high resolution
Ocean Waves are imaged

Extreme weather – real time



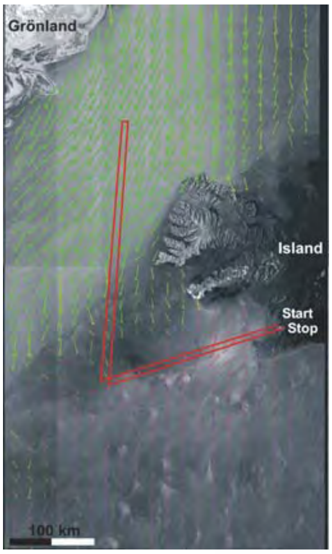
Coast Northern Spain, Gijon
30 km x 30 km sub scene

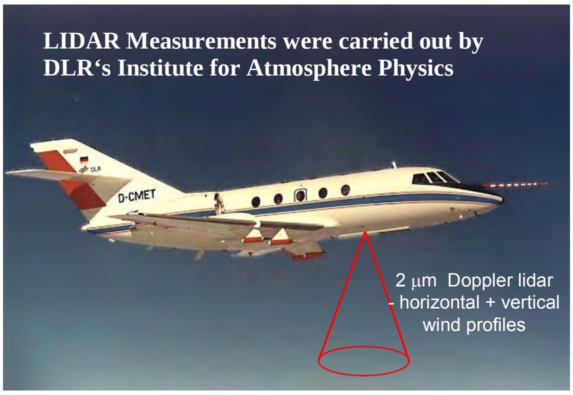
Global Statistics – Trends



Mittlere significant Wave Height
September 1998 – December 2000

Synergy with LIDAR Measurements





ASAR image acquired during the NATReC Campaign on Sep 18, 2003.

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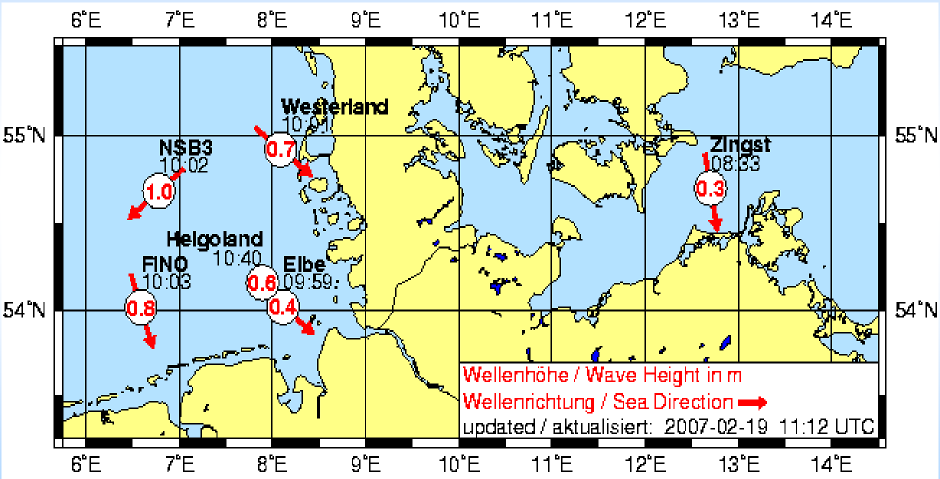
FINO

Sea State Measurements at FINO 1

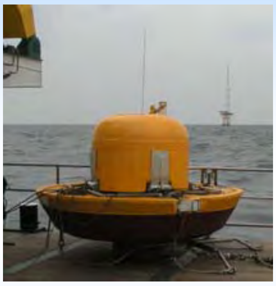
BSH

Kai Herklotz
Berlin 2007

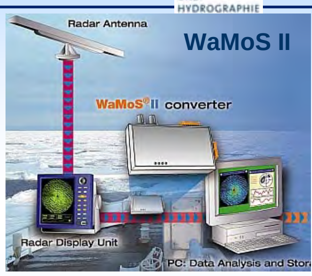
Sea state measurements in the North Sea and Baltic Sea



Instrumentation



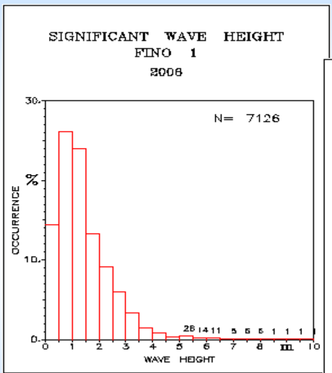
Buoy
(2004-2005 Wavec,
2006-2007 Directional Waverider)

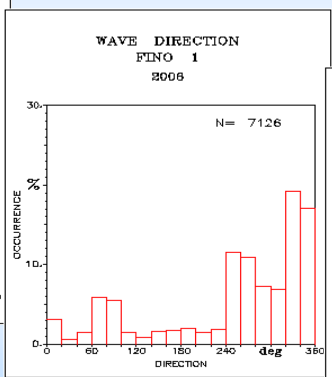


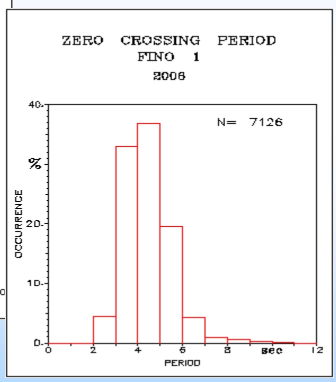
ADCP

Sea State Data

Statistik



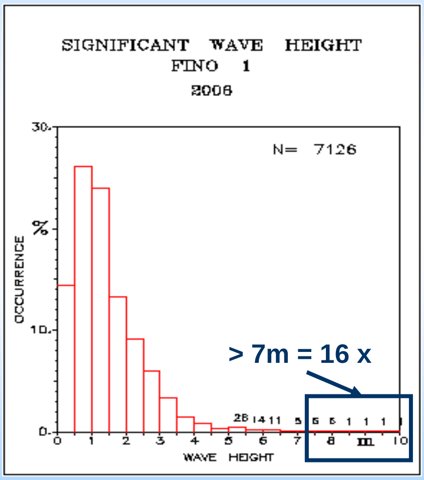


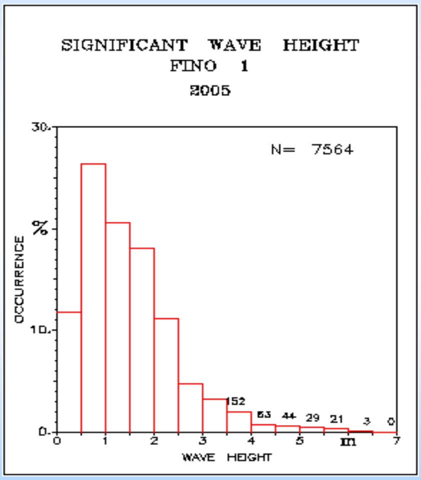


Sea State Data

Statistik

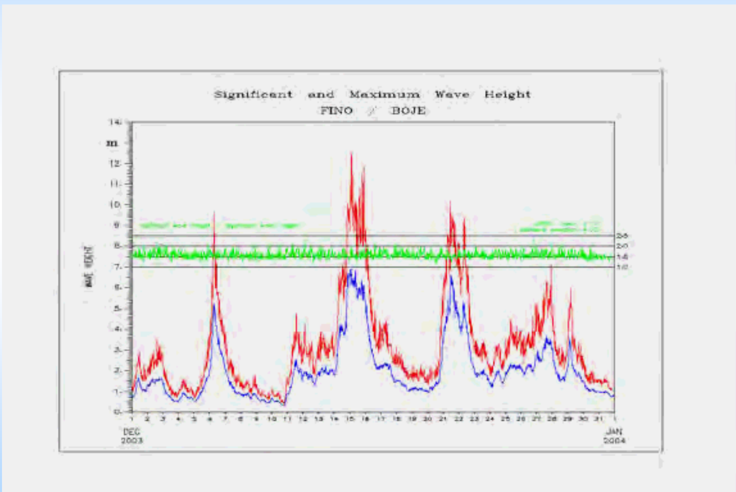
BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE





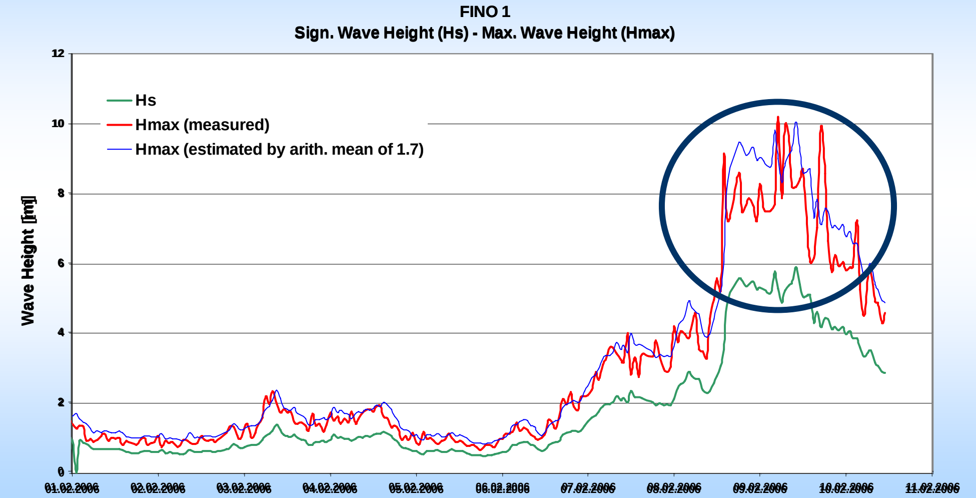
Sea State Data

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE



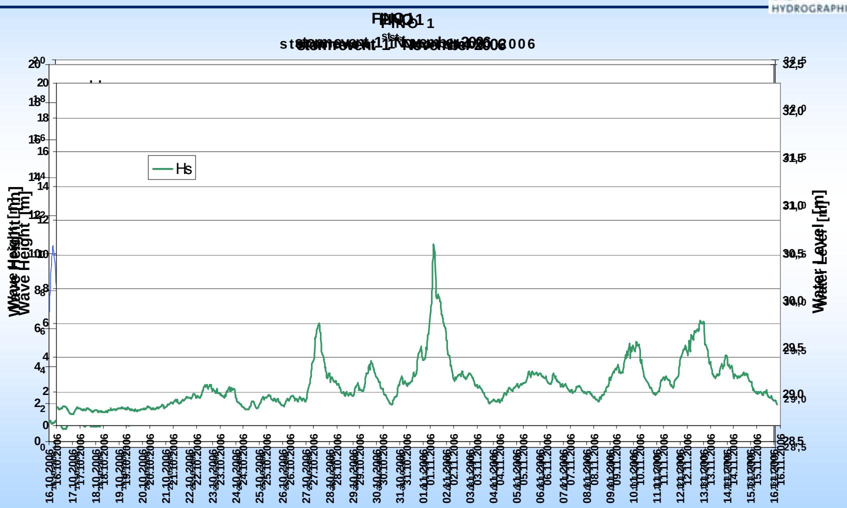
Sea State Data

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

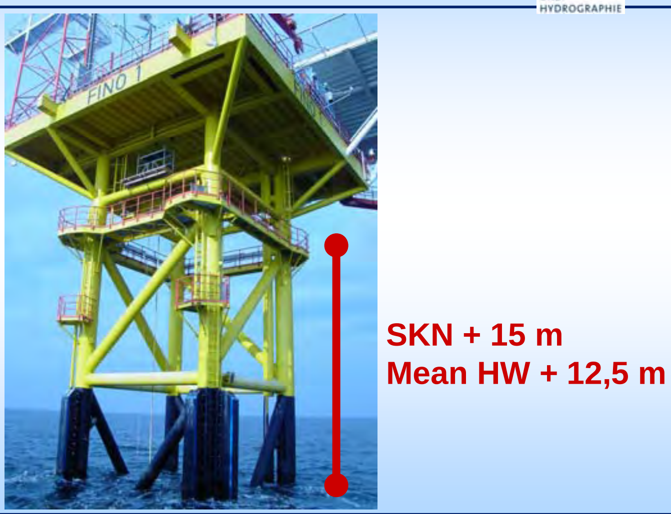


Sea State Data

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

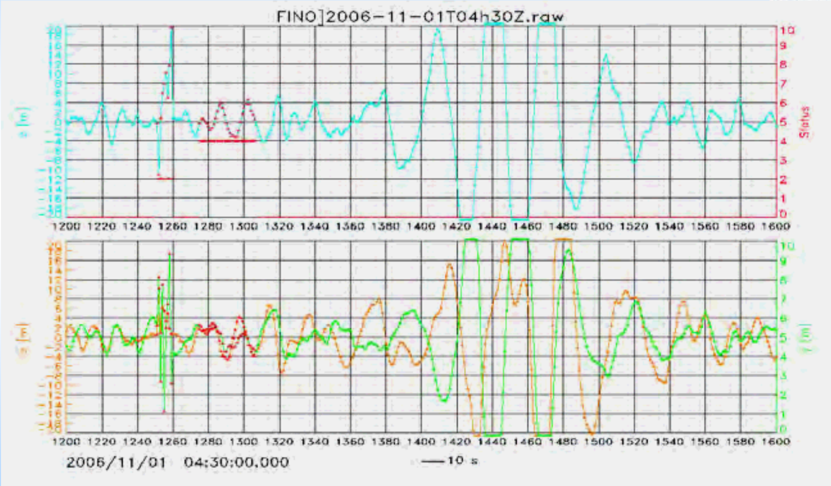


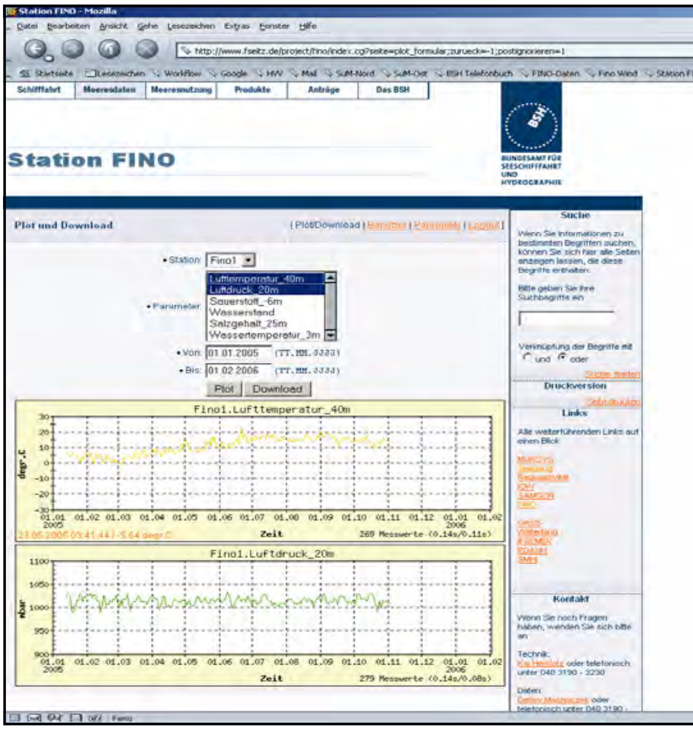
Storm event of the 1st Nov. 2006



Storm event of the 1st Nov. 2006

Storm event of the 1st Nov. 2006



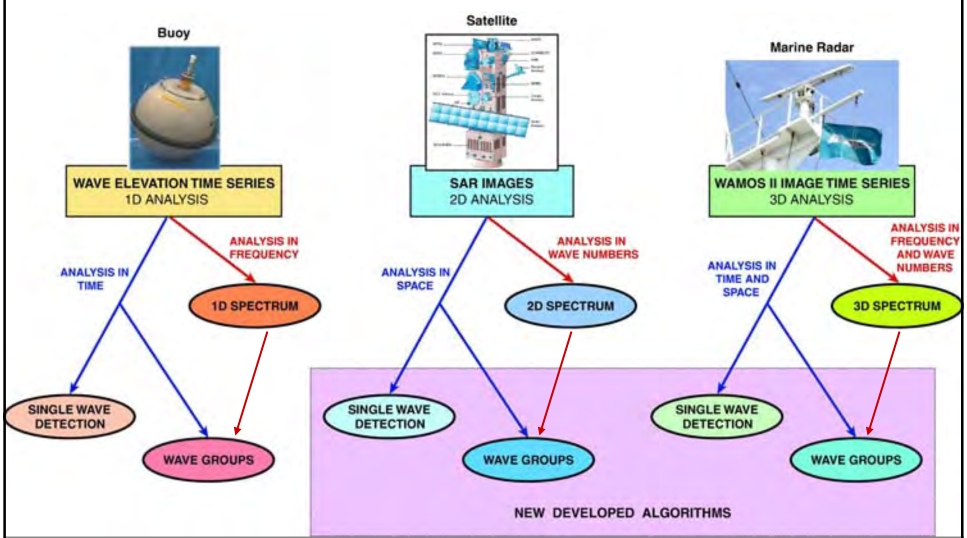


fino.bsh.de


BSH
BUNDESAMT FÜR
SEESCHIFFFAHRT
UND
HYDROGRAPHIE
Thanks for your attention

EXTREME SEA STATE CONDITIONS AT OFFSHORE PLATFORMS

W. Rosenthal, GKSS
S. Lehner, DLR



From Rayleigh distribution:
N is the number of individual waves for a given significant wave height $H_{1/3}$, for which on the average one wave exceeds the height H_N.

$$N = \exp (2 (H_N/H_s)^2)$$

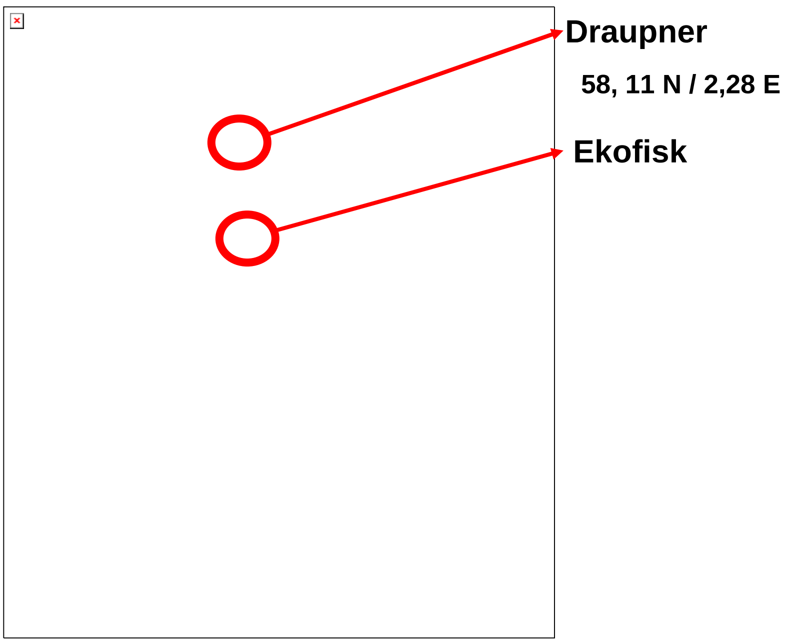
$$H_N = H_s (0.5 \ln (N))^{0.5}$$

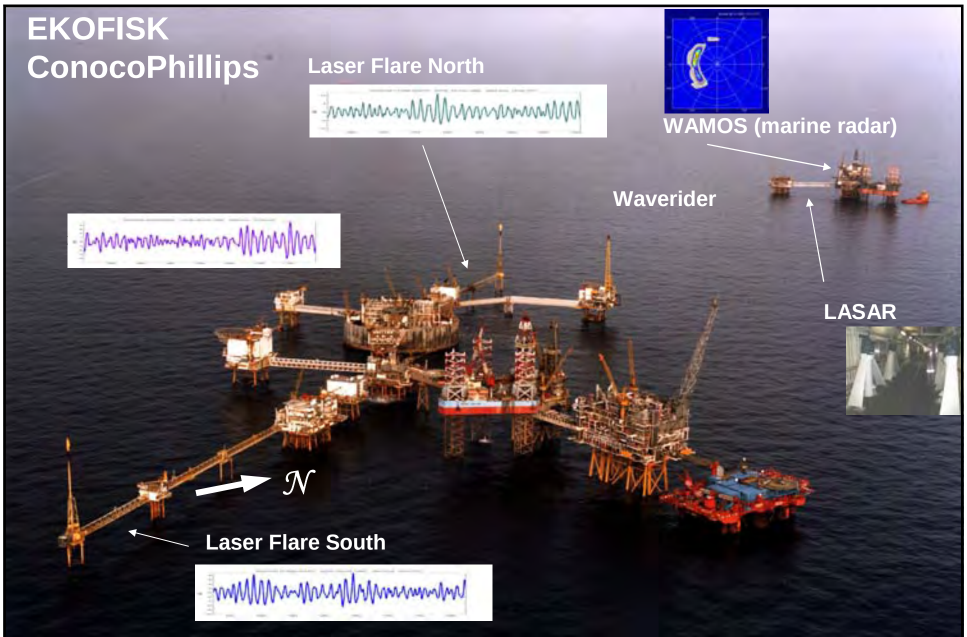
$H_N \geq 2 H_s$ is our working definition for monster wave

$H_N \geq 2\ H_S$ is our working definition for a monster wave

N	H_N/H_S
7.4	1
1000	1.86
3000	2.07

Average observed number N of single waves until the encounter with an individual wave height H_N and a significant wave height H_S





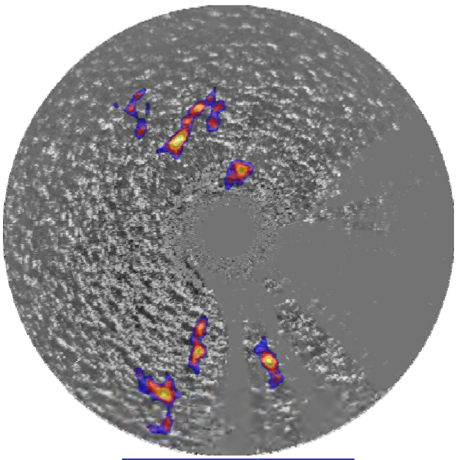
Environmental parameters at Ekofisk, N 56.5, E 3.2

Atmospheric pressure, air and sea temperature, wind from 2 sensors. Current.

Wave data from 4 wave recorders. Since 2003: also from LASAR (4 lasers in array)

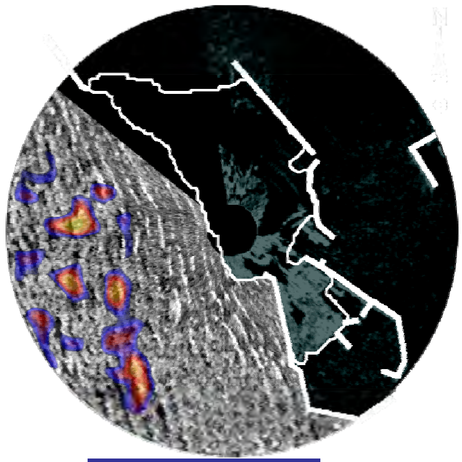
Selected Groups

Deep Water (Ekofisk) | Shallow Water (Helgoland)



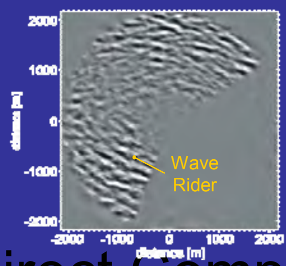
$C_{g0} \approx \frac{1}{2} C_0$

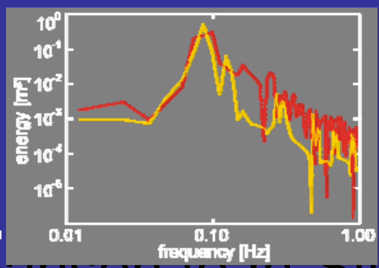
Ekofisk-Platform, 10.02.2001, 11:00 p.m.



$C_{gs} = C \approx \sqrt{gd}$

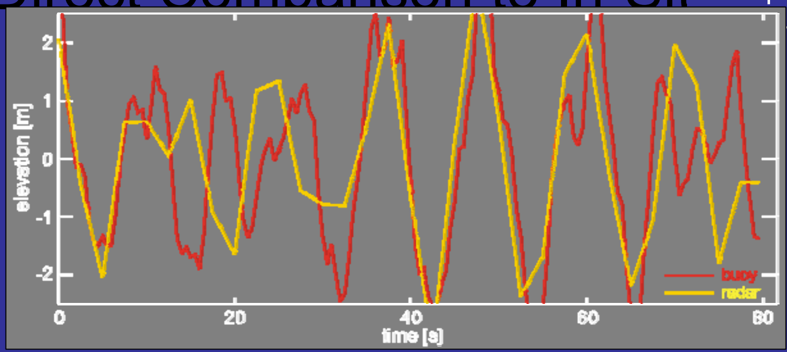
Helgoland, 01.12.1999, 00:11 a.m.



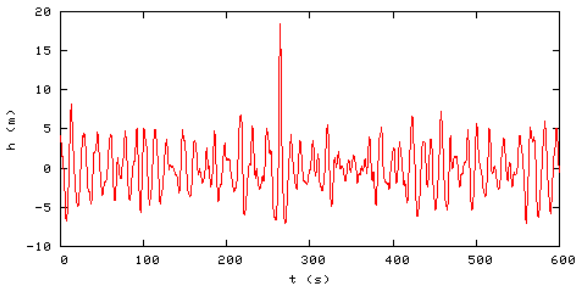


Direct Comparison to In-Si

- 03/06/2001, 08:00:05
- Φ_{peak} = 5°



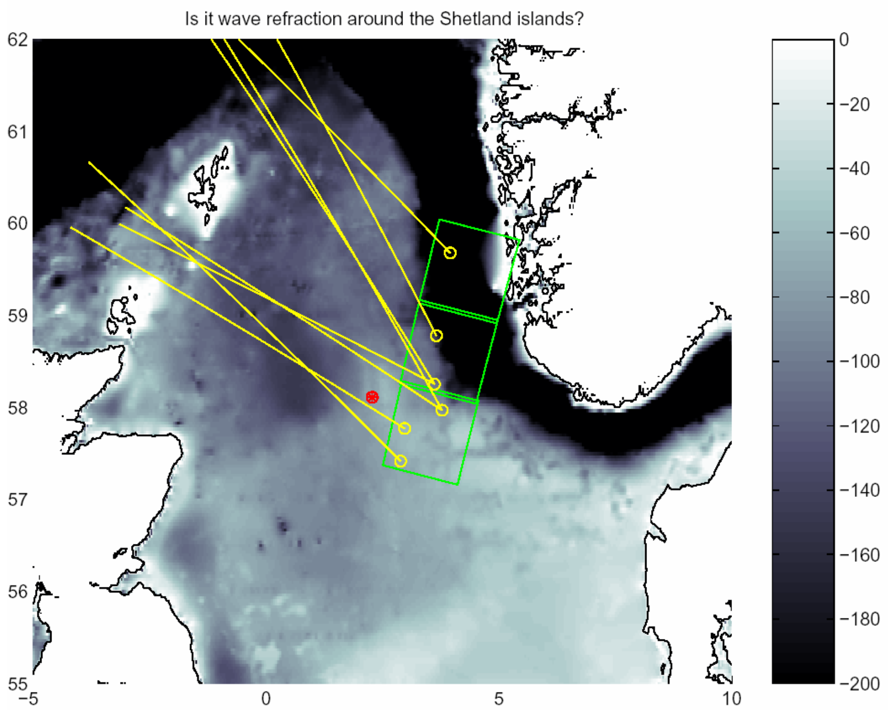
Time Series Wave Height at Draupner, Jan, 1st 1995 15:20

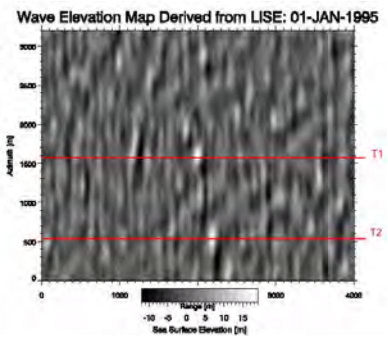


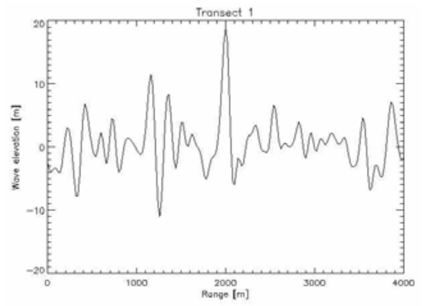
Significant Waveheight 11.9m
Peak Period 16.7 sec
Maximum crest Height 18.5 m
Adjacent trough -7.1m and –6.5m
Depth 70m

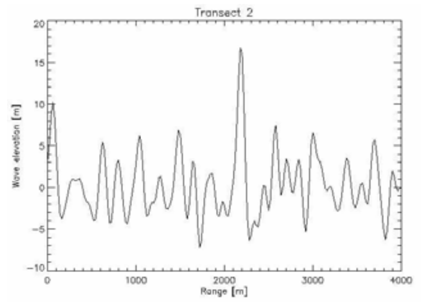
Return Period of 1-5 years

Higher than the 100 year cres


Is it wave refraction around the Shetland islands?
62
61
60
59
58
57
56
55
−5
0
5
10
0
−20
−40
−60
−80
−100
−120
−140
−160
−180
−200

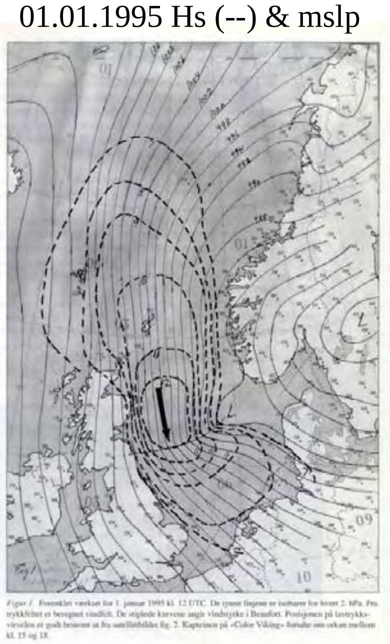






Wave Elevation Draupner

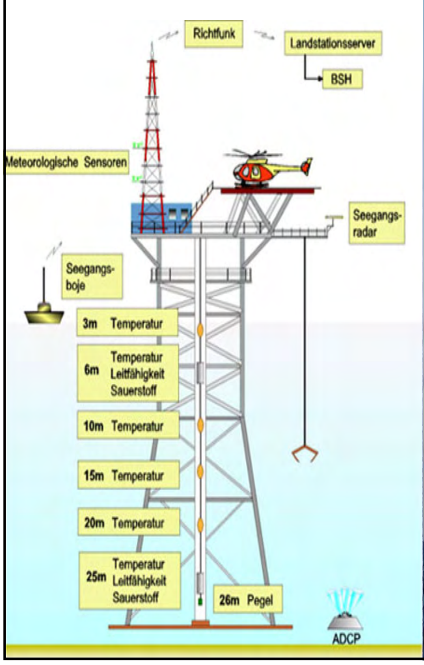
01.01.1995 Hs (--) & mslp

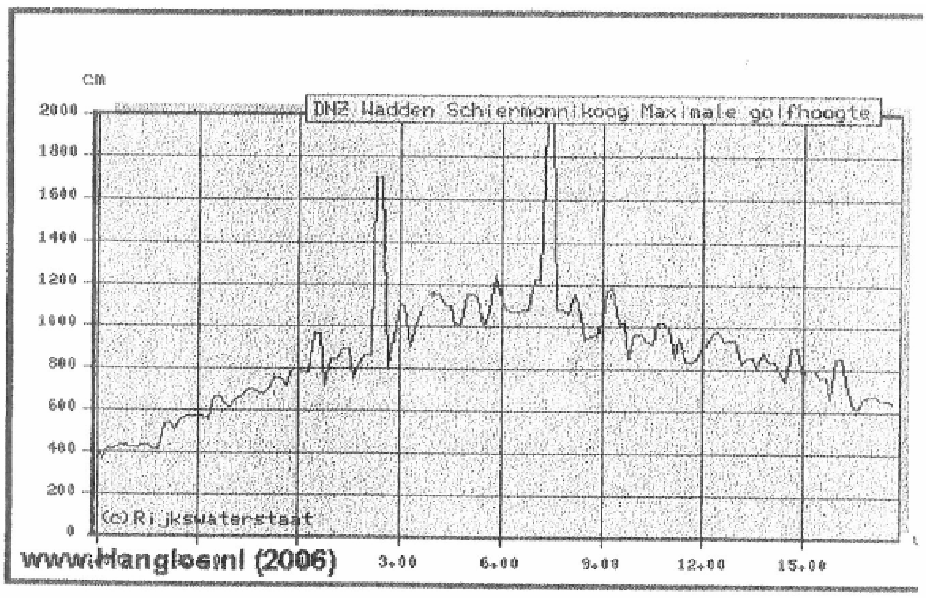


01.01.1995 (storm track)

A. Sunde, Swedish Met office

FINO test site





Boei meet monstergolf boven Schiermonnikoog

Gepubliceerd op 08 november 2006, 13:29
Laatst bijgewerkt op 08 november 2006, 14:03

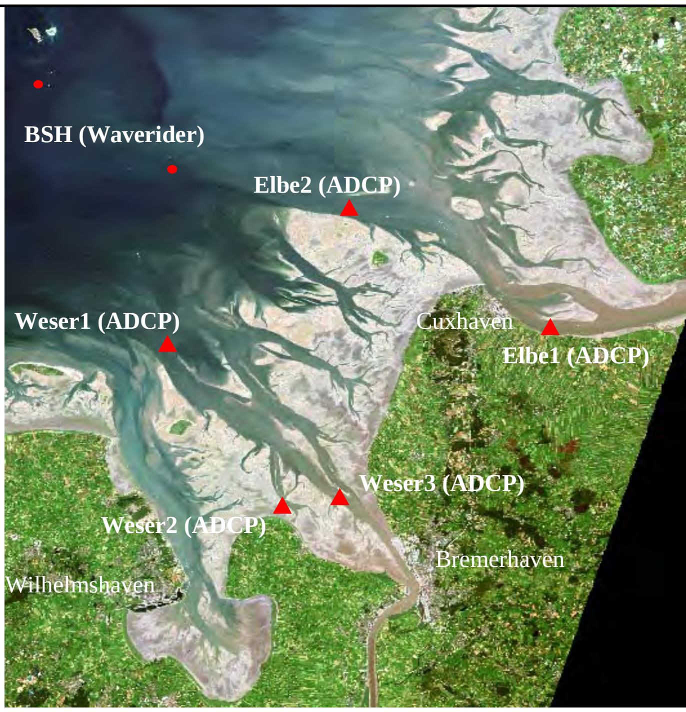
SCHIERMONNIKOOG - Een golf zo hoog als een flat van zes verdiepingen. Ten r
registreerde een meetboei van Rijkswaterstaat vorige week tijdens de noordwester
Was het een monstergolf of een meetfout?

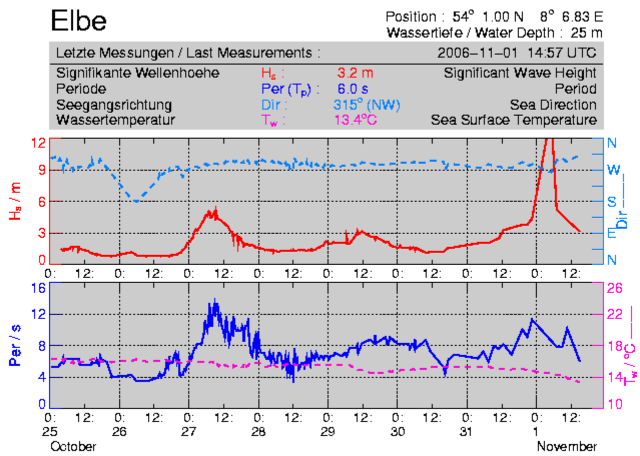
De monstergolf was 19,80 meter hoog en is waargenomen op een afstand van eer
Amelander reddingboot Anna Margaretha diezelfde ochtend een paar keer kapseis
betrouwbaar zijn, is het uniek. Dan is dit de hoogste individuele golf die wij ooit ge
van het Rijksinstituut voor Kust en Zee (RIKZ).

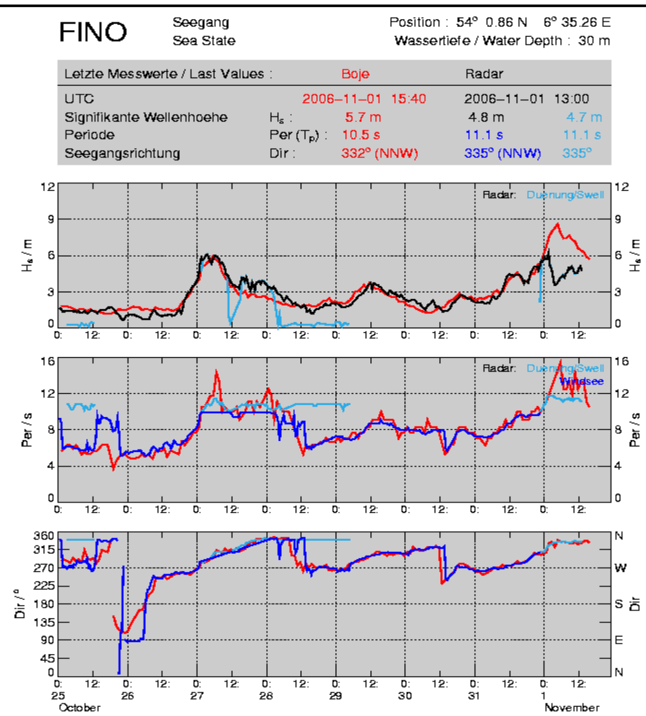
De golven op de Noordzee worden gemeten door speciale boeien. Die sturen de g
de golven via een zender naar de wal. De golfhoogte is het verschil tussen het dal

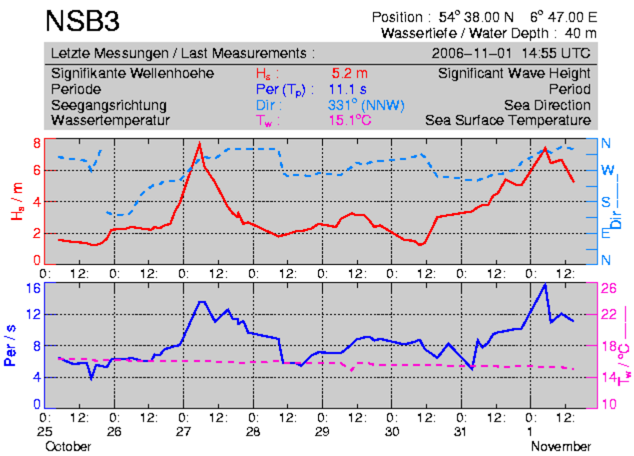
Boven Schiermonnikoog is een golfhoogte hoger dan 11 meter een zeldzaamheid.
gegeven om de meetboei uit het water te halen. Hij wordt onderzocht in het laborat
dat het om een meetfout gaat.

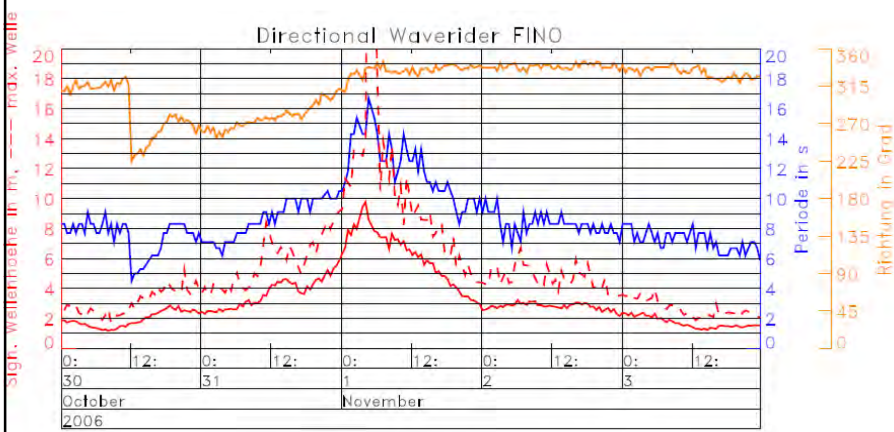
he!

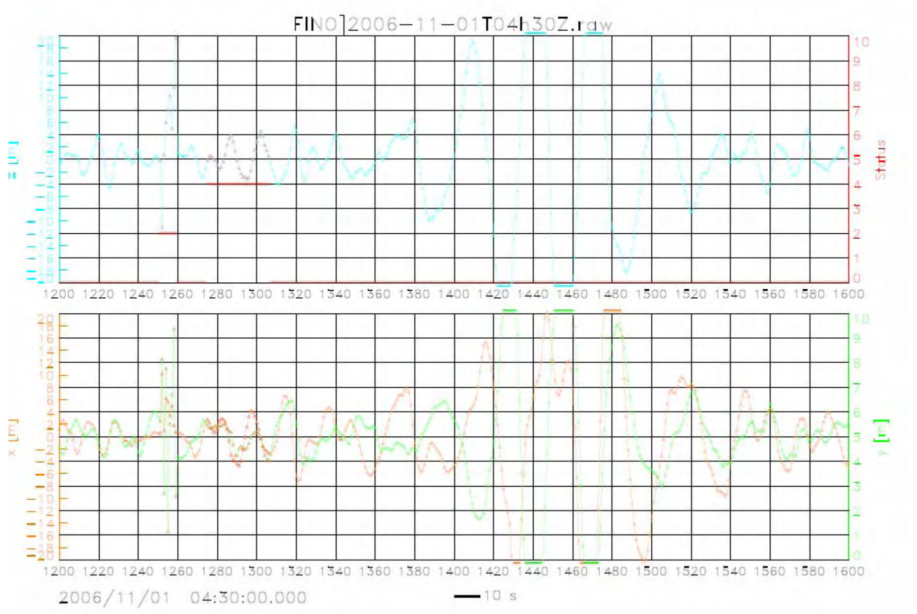


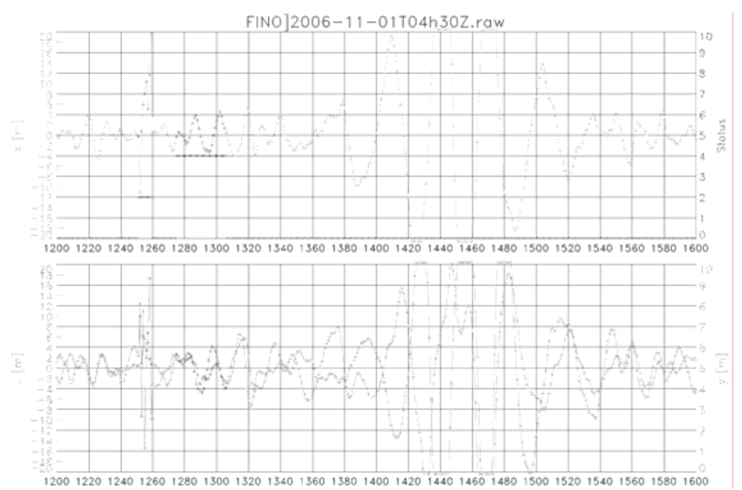

Elbe
Position : 54° 1.00 N 8° 6.83 E
Wassertiefe / Water Depth : 25 m
Letzte Messungen / Last Measurements : 2006–11–01 14:57 UTC
Signifikante Wellenhoehe Hs : 3.2 m Significant Wave Height
Periode Per (Tp) : 6.0 s Period
Seegangsrichtung Dir : 315° (NW) Sea Direction
Wassertemperatur Tw : 13.4°C Sea Surface Temperature
Hs / m
Dir
Per / s
Tw / °C
October
November


FINO
Seegang
Sea State
Position : 54° 0.86 N 6° 35.26 E
Wassertiefe / Water Depth : 30 m
Letzte Messwerte / Last Values : Boje Radar
UTC 2006–11–01 15:40 2006–11–01 13:00
Signifikante Wellenhoehe Hs : 5.7 m 4.8 m 4.7 m
Periode Per (Tp) : 10.5 s 11.1 s 11.1 s
Seegangsrichtung Dir : 332° (NNW) 335° (NNW) 335°
Radar: Duenung/Swell
Windsee
Hs / m
Per / s
Dir / °
October
November


NSB3
Position : 54° 38.00 N 6° 47.00 E
Wassertiefe / Water Depth : 40 m
Letzte Messungen / Last Measurements : 2006–11–01 14:55 UTC
Signifikante Wellenhoehe Hs : 5.2 m Significant Wave Height
Periode Per (Tp) : 11.1 s Period
Seegangsrichtung Dir : 331° (NNW) Sea Direction
Wassertemperatur Tw : 15.1°C Sea Surface Temperature
Hs / m
Dir
Per / s
Tw / °C
25 26 27 28 29 30 31 1
October
November


Directional Waverider FINO
Sign. Wellenhoehe in m, ---- max. Welle
Periode in s
Richtung in Grad
30 31 1 2 3
October
November
2006


FINO]2006-11-01T04h30Z.raw
Status
2006/11/01 04:30:00.000
10 s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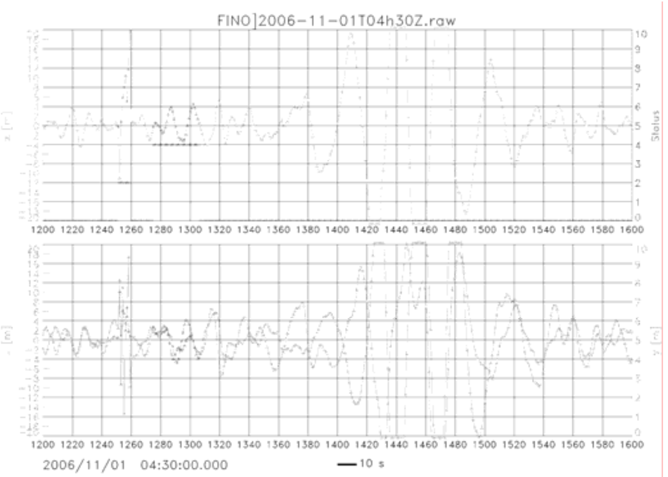
Status



CONCLUSION

- It seems we had two freak wave events in 11 years near the location of Fino 1 in sea states with Hs~ 9 m. Both had a crest height above 15 m and the height may have been above 25 m.
- It may be estimated, that the return period for Hs= 9 m is about 10 years. An estimate for the return period for Hmax > 18 m is then larger than 30 years.
- It follows from the two events within 11 years that Rayleigh statistics for abnorm singular waves should be reconsidered.
- There seems to exist temporal and spatial correlation for the encounter of rogue waves.

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Hindcast and reality

Comparison of hindcasted and measured wave data at Kriegers Flak - first results

Lasse Johansson
Vattenfall Power Consultant
(Lasse.johansson@vattenfall.com)

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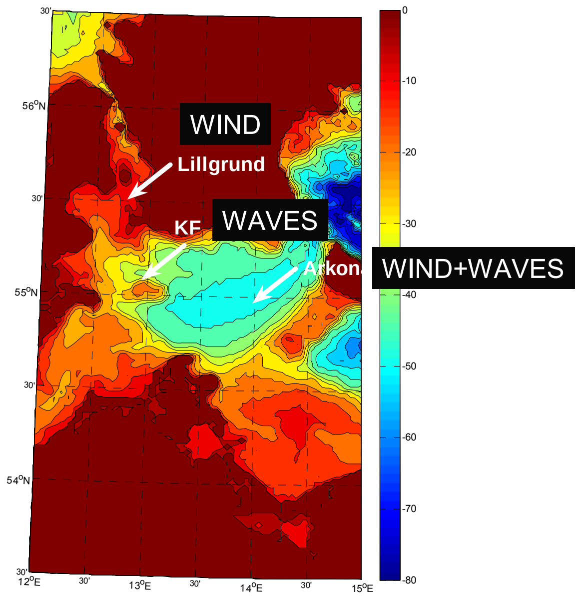
ljoj:

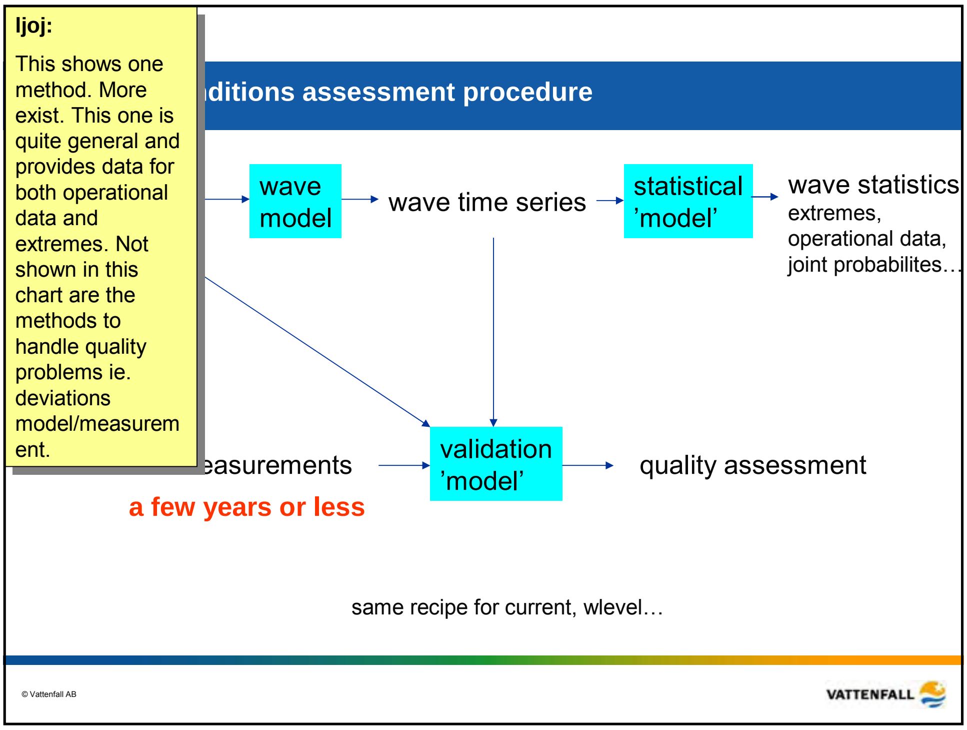
Wind was observed (13 m) at Lillgrund. The wave measurements in this presentation were made at KF (20 and 32 m) – first data up jan/feb 2007. At Arkona, wind (10 m) and waves are observed by a buoy since several years.

km



Metocean studies at KF so far

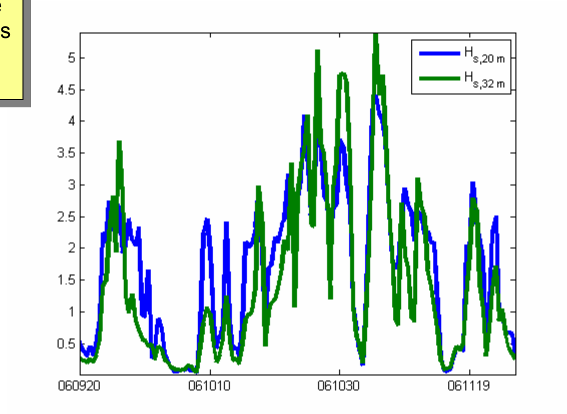
- 1. Metocean conditions for geophysical survey, june 2006
- 2. Site Assessment for concept studies of wind turbine foundations, december 2007
- 3. Wave & current measurements, multi purpose, september 2006-continuing. First service and data collection february 2007.
- This presentation compares 2 with 3 – early and preliminary results only.



Ijoj:

Two instruments are deployed close to one another – yet the difference in Hs is large and unsystematic.

nts processed by instrument software



H_s obs at two depths approx 1,4 M (2,7 km) apart

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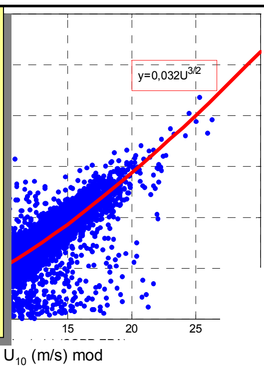
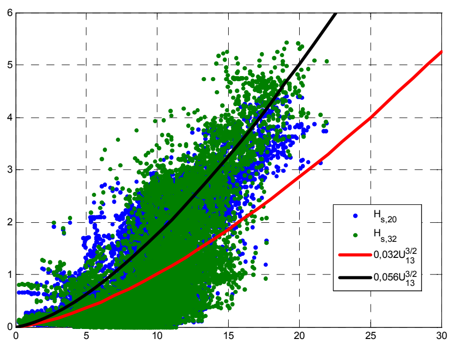
Ijoj:

The U-Hs curve from hindcasted model data does not agree with the curve from the measurements at KF.
Measurements show much higher waves at a given wind speed.



HINDCAST/MODEL DATA

OBSERVATIONS
Lillgrund wind+KF waves



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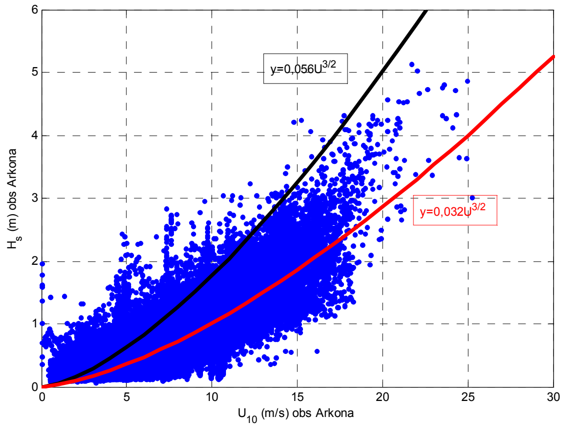
ljoj:

The U-Hs curve for Arkona (quite another site than KF wrt fetch and depth) lies in between the red and the black curve.



OBSERVATIONS, ARKONA

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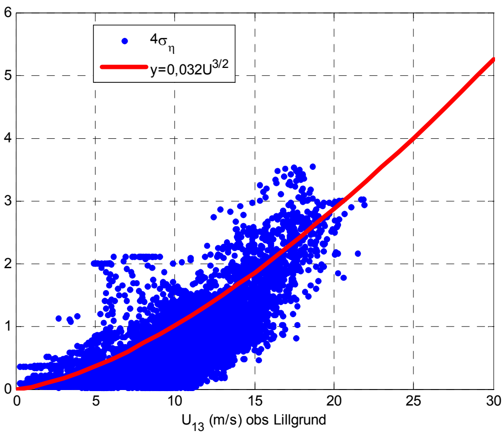
ljoj:

Taking the raw pressure data out of the instrument, correcting for frequency dependant depth-damping, and then calculating Hs as 4 times the standard deviation of the surface displacement, one obtains a satisfactory agreement between model hindcast (red) and measurements. Conclusion: Instrument software processing is very wrong.

…tion directly from raw pressure measurements

U_{13obs} $4\sigma_{\eta,32}$



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Conclusions

- Observations must be checked carefully before used as truth with respect to model data
- One way is to compare with model data!
- It is therefore an advantage if the measurements and the modelling is done jointly – both activities may benefit from one another

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Measurements with bottom deployed, self-contained instruments

Typical problems in oceanographic measurements - fresh examples from Kriegers Flak

Lasse Johansson
Vattenfall Power Consultant
Lasse.johansson@vattenfall.com

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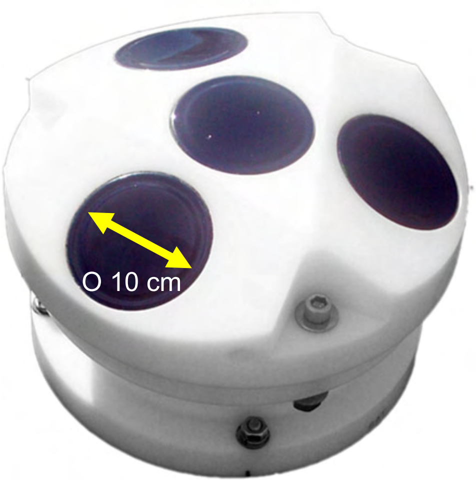
ljoj:

Transducers typically operate at 0,1-1 Mhz or 15-1,5 mm wavelength ie. less than transducer size → good lobe directivity.

sound beams from individual transducers



+p

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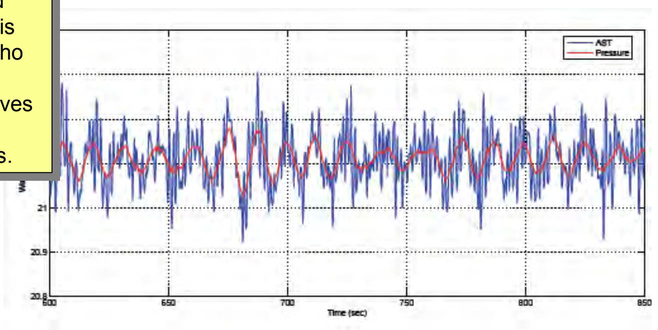
ljoj:

In principle it is possible to correct low-pass filtering. In reality finite sensor sensitivity and noise limits this possibility. Echo sounding of surface improves HF-characteristics.

s filtering of pressure



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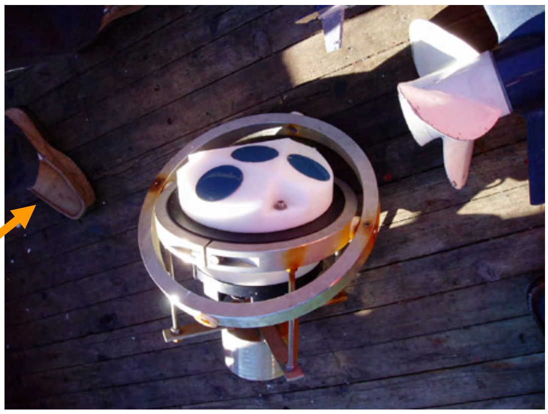
Size and suspension



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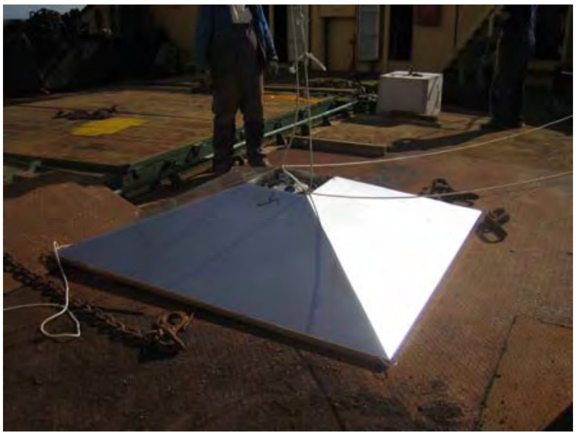
ready to deploy



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Marker buoys weigh 500-1000 kg in air. Instrument much lighter.

Deployment

Service

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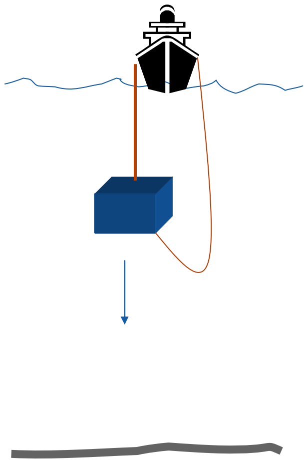
Deployment



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Light buoys

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buoy weight

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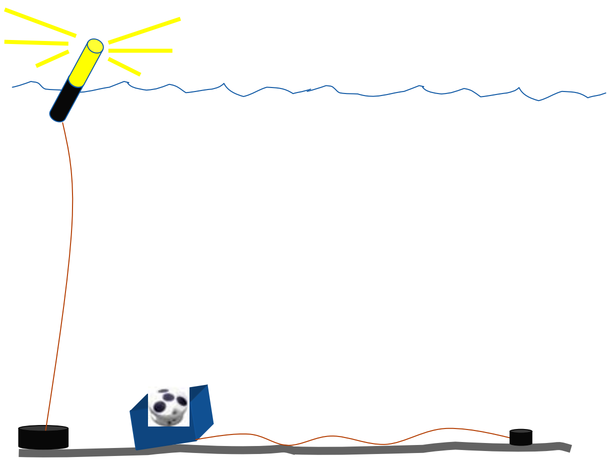
In position



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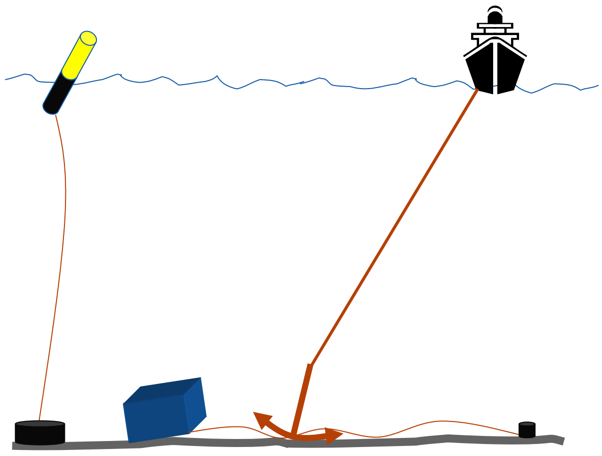
Retrieving



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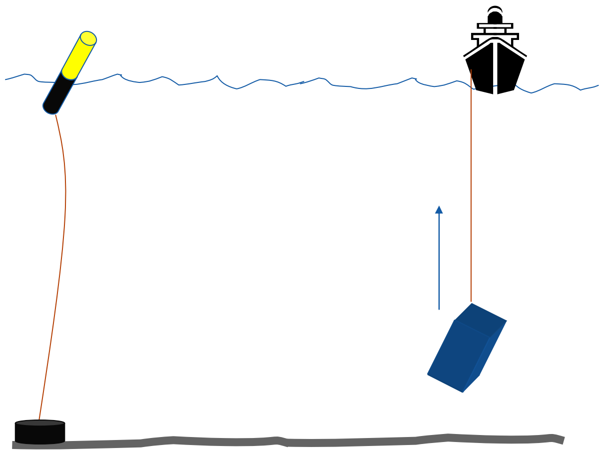
Lifting on board



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Severe corrosion after a few months

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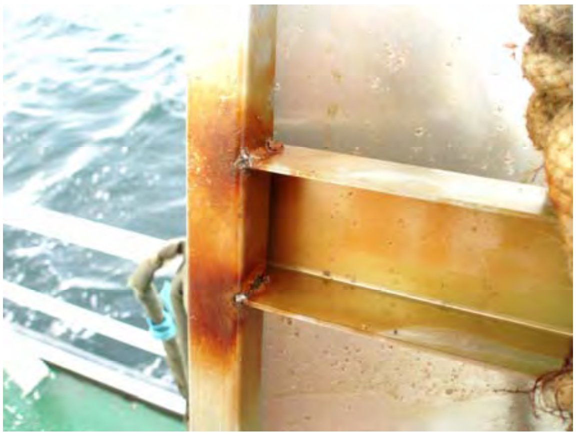
Faulty material choice



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Causes of errors

- Use of untested equipment
- No post-deployment check
- At least three instruments were probably tilting
- The software failed to detect this
- Analysis continues

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Offshore measurements require…

- **Seamanship and respect of weather**
- **Always do initial inspection/collection after a few weeks**
- **Any new equipment should be tested under expected circumstances – not quickly, close to shore**
- **Accurate positioning is necessary -- but don't trust a position –equipment may move**
- **In busy waters – add a pinger and decrease service interval**
- **Or… prepare for >30% loss of equipment and data!**

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STUDY OF VIABILITY OF IMPLANTATION OF OFFSHORE WIND PARKS IN ECONOMIC SEA TERRITORIES OF CANARY ISLANDS.

ELABORATION OF WIND AND WAVES MAPS IN ISLANDS ZONE

Authors:

García Javier *, Guillemes Ángel *, Arancibia Gerardo *, Tejera Javier *, Dr. Fernández Guillermo **, Dr. Alesanco Ramón *, Dr. García Feliciano ****.**

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**	Doctor & Researcher “E.E. de I+D INGEMAR”
***	Univ. Titular Prof. & Researcher “E.E. de I+D INGEMAR”
****	Univ. Catedratic & Coordinator “E.E. de I+D INGEMAR”

Stable Team I+D INGEMAR.- Dpto. of Marine Engineering.- University of La Laguna. Spain.

Wind and Wave Measurements at Offshore Locations

Berlín 2007

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INTRODUCTIÓN

-Canary Islands is located in the Atlantic Ocean in front and near the African continent.

-Wind characteristics zone; Trade winds of varied intensity most of the stations of the year.

-Western islands (more moved away of Sahara desert); smoother micro weathers and greater water availability.

-Eastern islands (nearer of Sahara desert); less benign weathers and shortage of hydric resources.

-The accessibility of trade winds causes the Canary Islands to have a considerable wind energy potential to be used in generate alternative electrical energy.

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NECESSITY OF WIND MAPS IN ISLANDS TERRITORIES

-The Islands Territories (Macaronessian Islands) are zones that always have depended on the continental territories, because these have resources and potential to maintain a stable development of their respective population.

-The necessity of the self-sufficiency of the territories, has turned to the sustainable development as an important objective for all type of investigation.

-A form to implement the self-sufficiency in the islands territories is investigating and using their renewable resources, like the wind, the sun, the sea, etc… Of these resources the more easily usable at the present time is the wind

-The best forms to take advantage of this resource in islands territories are through offshore wind parks.
Since being surrounded in their totality by the sea
(that does not have obstacles),
they can give a higher power potential.

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WEATHER AND WANA DATA

This network is formed by a set nodes of the nets of calculation of the model of generation of waves WAM (WAMDI, 1,988), forced by wind fields generated by meteorological model HIRLAM (ECMWF), from January of 1.996 to August of 2.004 ; All this comes from WANA Network of the Public Ports Organism of Spanish State and the Ministry of Public Works and Economics.

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WEATHER AND WANA DATA

The Set of WANA data is formed by temporary series of parameters of simulated wind and modelled waves, so they come from numerical data and they do not come from direct measures from the nature.

WANA series comes from the prediction system of the sea disturbance that Ports of the Spanish State has developed. In the following illustration can be observed the location of nodes WANA in the Spanish coast.

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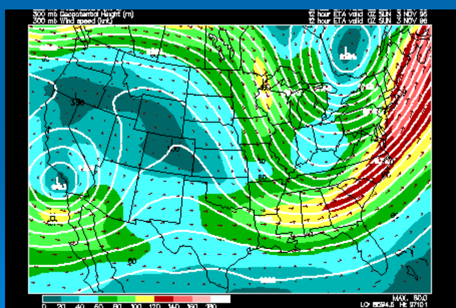
WEATHER AND WANA DATA

WIND

The numerical model used to generate the wind fields is the HIRLAM. It is an atmospheric and hydrostatic meso-scale model which resolution is of 0.5 degrees in Atlantic oceans.

This model includes assimilation of instrumental data. The facilitated wind data are averages hours to 10 meters above sea level.



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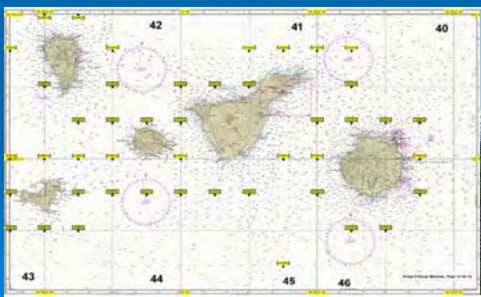
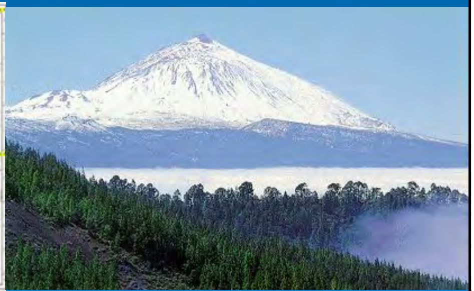
WEATHER AND SET WANA DATA

WAVE

To simulate the waves it has been used the numerical model WAM. This application is a spectral model of third generation that solves the balance equation of energy without establishing no hypothesis, at the beginning. This model works in the Atlantic with a resolution of 0.25 degrees (30 km). Is important to consider that, independently of the coordinate assigned to a WANA node, the data of the waves must be considered, always, like data in open waters and indefinite depths.





Wind and Wave Measurements at Offshore Locations

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WEATHER AND SET WANA DATA

USE CAUTIONS

The WANA data set provides descriptions of the wind climate and waves, that in general, are adapted in all the Spanish coastal surroundings, except in south of the Canary island, conditions coming from the southwest can not be reproduced well.

Wind and Wave Measurements at Offshore Locations

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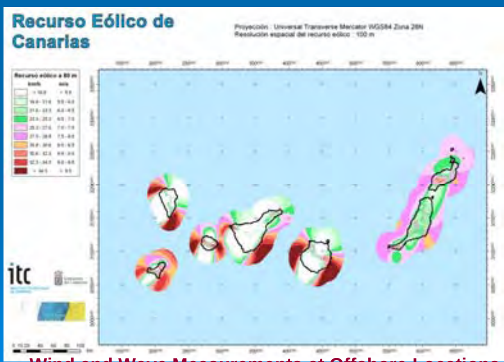
WIND MAPS OF THE CANARY ISLANDS

At the moment it has been developed offshore wind maps to 40, 60 & 80 meters height in Canary Island.
This wind map represents wind offshore power to 80 meters height.



Wind and Wave Measurements at Offshore Locations

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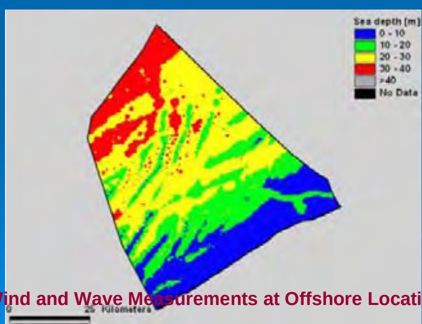
WIND MAPS OF THE CANARY ISLANDS

In addition to the sea floor, also its composition is important. Considering that the foundation based on a monopile tamped on the marine floor is the more used structure in Wind power park installations,; the bottoms must be more apt for their positioning, such as condensed and homogenous layers of the marine bottom (that has a high normal tension and long term good behaviour).



Wind and Wave Measurements at Offshore Locations

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WIND RESULTS

Las Palmas of Gran Canarias, South half of the Island of Lanzarote and west half of Fuerteventura Island (equivalent hours: 3184,08) forma an area, in this area 6 WANA nodes are located, when valuing them independently it has been obtained in all of them a situation of VIABLE BUENO (GOOD VIABILITY).

VALORATION		Equivalent hours
INVIABLE		< 2.750
VIABLE	MEDIO-BAJO	2.750 < valor < 3.000
	BUENO	3.000 < valor < 3.500
	MUY BUENO	> 3.500

Wind and Wave Measurements at Offshore Locations

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WIND RESULTS

In wind marine area of Tenerife Island are located 4 WANA nodes. In one of them a value of equivalent hours has obtained VIABLE BUENO and the rests have been valued like INVIABLE (NOT VIABILITY). For this reason this area has been divided in two parts based on this evaluation. In the first part, South zone of Tenerife Island is set like INVIABLE (equivalent hours of 2494.5). The Second part, approximately to 150 nautical miles to south of Tenerife Island, has been established like VIABLE BUENO (equivalent hours of 3038,95)

Referring to wind marine area of South half of Gran Canaria Island, is established like VIABLE BUENO (equivalent hours: 3063,57). In this area 3 WANA nodes are located, when valuing them independently it has been obtained in all of them a VIABLE BUENO situation.

Here is a possible location of platform oceanic PLOCAN of ICCM

VALORATION		Equivalent hours
INVIABLE		< 2.750
VIABLE	MEDIO-BAJO	2.750 < valor < 3.000
	BUENO	3.000 < valor < 3.500
	MUY BUENO	> 3.500

Wind and Wave Measurements at Offshore Locations

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PROPOSALS

Considering the characteristics of the Canary Islands (Macaronesia Island), it is necessary to operate the offshore renewable energies.

The first step is the creation of a Integral Offshore Power Map of all the Economic Exclusive Zone of the Canary Islands, that represents the offshore wind potential (wind Map) and the power potential of the waves (Wave Atlas).

The second step is the accomplishment of a study of offshore power potential (Wind and Wave) for each island of the Canary .

To develop an OFFSHORE WIND MAP considering the characteristics of Winds, geography of submarine floor, platform and situation of the ECONOMIC ZONES OF the CANARY ISLANDS. , etc.

To study the viability of implantation of Wind Parks in the marine platforms of each Islands, being proposed the suitable places analyzing previously all the pros and the cons.

To interchange experiences with promotional and financial organizations of these initiatives in other similar places to foment the implantation of OFFSHORE WIND PARKS in our marine platform.

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Thanks for your time

Wind and Wave Measurements at Offshore Locations

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WIND AND WAVE MEASUREMENTS AT OFFSHORE LOCATIONS

Experience and intentions of a developer on wind and wave measurements

Mikel Illarregi
Energy Resources Department

Berlin, 20 and 21-02-2007

Index

acciona
Energía

1. ACCIONA's position in renewables and wind power

3

acciona
Energía

ACCIONA's major projects in renewables *(30.06.2006)*

Wind: 3,876 MW installed -6% of the world total- (2,636 MW part., 2,008 attr.)

Biomass: 33 MW -30% of the primary biomass in Spain-

Solar: 18,8 MW PV (35% of the Spanish market) and 19 MW thermal installed

Small hydro: 59 MW –3.6% in Spain-

Biofuels: 35,000 tonnes per year biodiesel plant (1.2 Mtonnes in project)

Horizontal integration of activities

ACCIONA also has 115 MW in **cogeneration**

ACCIONA's worldwide implementation in wind power *(30.06.06) (MW)*

Country	Total installed capacity(*)	Participated capacity	Attributable capacity
Spain	3,443	2,221	1,762
Germany	114	114	114
France	61	52	26
USA	86	86	12
Canada	30	30	10
Australia	66	66	33
Italy	32	32	16
Greece	35	35	35
Morocco	10	-	-
TOTAL	3,876	2,636	2,008

(*) Including participated facilities and those constructed for other companies

ACCIONA's initiatives offshore

- Acciona is working and looking for the offshore potential in several countries

6

acciona Energía

2. ACCIONA's experience in wind resource evaluation

7

acciona Energía

Experience in wind resource evaluation

- More than 40,000 MW assessed from Acciona's project porfolio
- More than 5,500 MW assessed on due diligences for 3rd companys projects

8

Experience in wind measurement

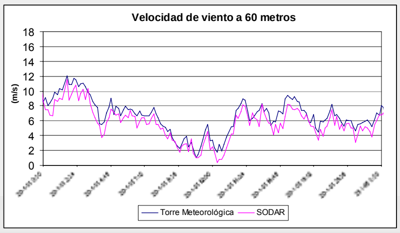
- More than 1,000 met masts installed up to 120 m high
- More than 300 met masts installed abroad
- Some sodar campaings
- Purchase of a lidar in 2006 and a second one in 2007

9

Measuring sistems and ofshore aplications: MET MAST

- It can be used as a long term reference met mast if located close to the offshore site
- Tower size as close to hub height as possible

10



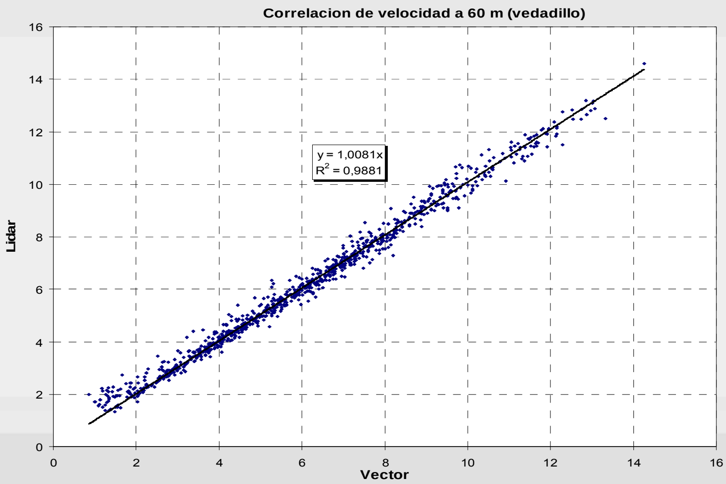
Measuring sistems and ofshore aplications: SODAR

- Good tool for wind profiles
- Needs quite high power suppy (200W)
- Dependant of weather conditions: less availability under rain (64%) than in dry weather (75%)

Measuring sistems and ofshore aplications: LIDAR

- Very good results in terms of accuracy
- Easy to deliver and deploy
- Data coverage above 98%
- Better response to rain conditions than sodar

Measuring sistems and ofshore aplications: LIDAR



Measuring sistems and ofshore aplications: LIDAR

CONSTRAINTS:

- **Cleaning device two times broken (will be solved in next units)**
- **Needs 200 W power supply at 24 V**
- **Needs 31° cone to the vertical**
- **Needs stability (+-5°)**

acciona Energía

Measuring sistems and ofshore aplications: LIDAR

CONSTRAINTS :

- Power supply expensive, big and needs mantenaince
- Cleaning device needs water tank

acciona Energía

Measuring sistems and offshore aplications: platforms

- Fixed to the sea bed: expensive, better once the project rises a development phase
- Mobile plattforms: better for prospective purposes
- Better with hub height size tower (otherwise could be completed with lidar-sodar wind profile measurements
- Assure a good long term reference station onshore

16

WIND AND WAVE MEASUREMENTS AT OFFSHORE LOCATIONS

Experience and intentions of a developer on wind and wave measurements

Mikel Illarregi
Energy Resources Department

Berlin, 20 and 21-02-2007

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Research Platform FINO 1 – Some results

K. Argyriadis[1], G. Fischer[1], P. Frohböse[1], D. Kindler[2], F.Reher[2]

[1]Germanischer Lloyd Industrial Services GmbH, Hamburg,
[2]WINDTEST Kaiser-Wilhelm-Koog GmbH

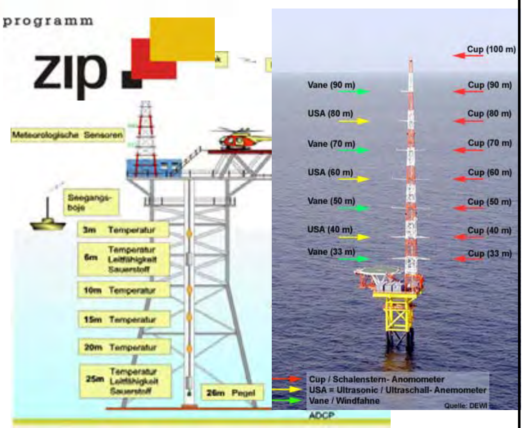
Germanischer Lloyd

Introduction

Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit

Projektträger Jülich
Forschungszentrum Jülich GmbH

- FINO1 Platform
- Measurements
- Storm conditions
- Wind-wave correlation
- Turbulence intensity
- Guidelines and measurement



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Measurement, waves

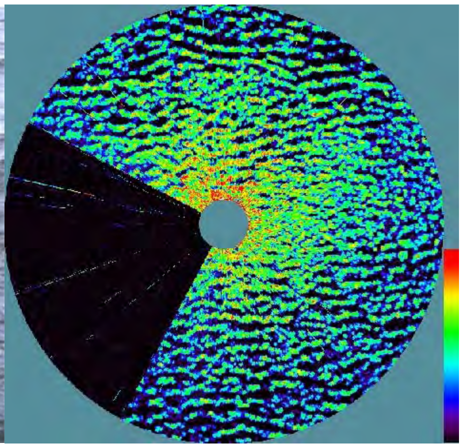

Photo: BSH

Photo: GKSS - oceanwaves

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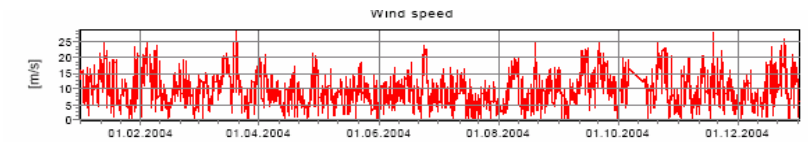
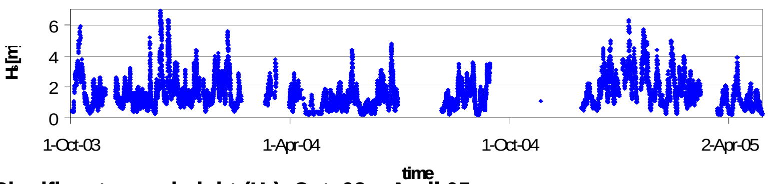
Measurement of wind speed and significant wave height



Wind speed in 100 m height (10-minute-mean) , 2004.



Significant wave height (H_s), Oct. 03 – April 05

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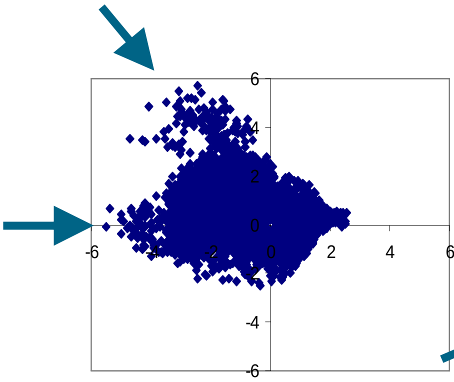
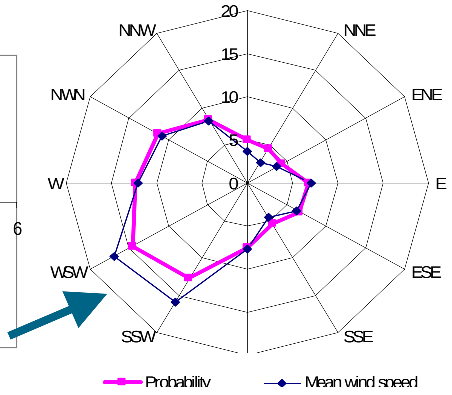
Significant wave height (H_s) and direction





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Storms considered

ID	Date	max. wind speed 10-min.av.	max. sign. wave height 30-min. av.
		V_{10} [m/s]	H_s [m]
1	21-12-2003	30.8	6.3
2	19-08-2004	25.5	3.5
3	18-11-2004	28.0	-
4	20-03-2004	29.1	4.1
5	14-12-2004	26.3	6.9
6	08-01-2005	33.9	6.3
7	07-10-2003	21.87	5.0
8	09-02-2004	24.12	5.6
9	20-01-2005	20.59	5.7
10	12-02-2005	32.0	5.0

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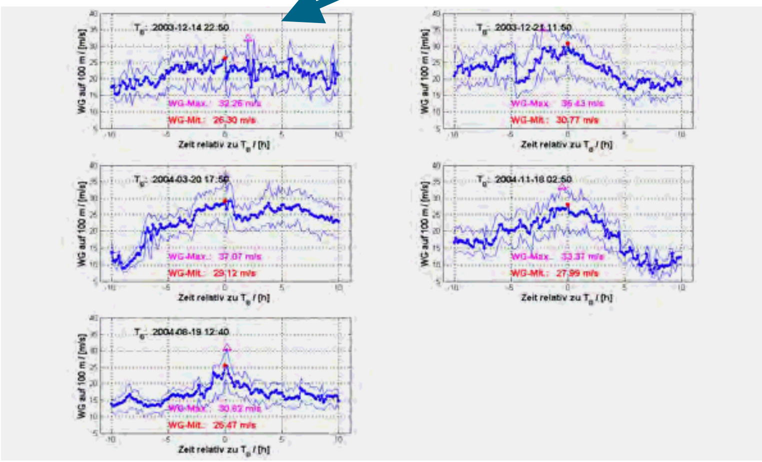
Storm conditions

Peak gust to peak mean Δt≈2h



Wind speed, at 100 m height

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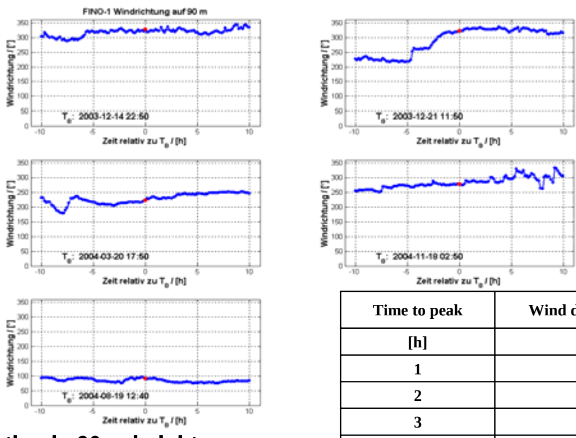
Wind direction during storm conditions



Direction in 90 m height

<±30° in 1.5h

≈100 ° in 6h

Time to peak	Wind direction change
[h]	[deg]
1	±15
2	±30
3	±60
6	-110

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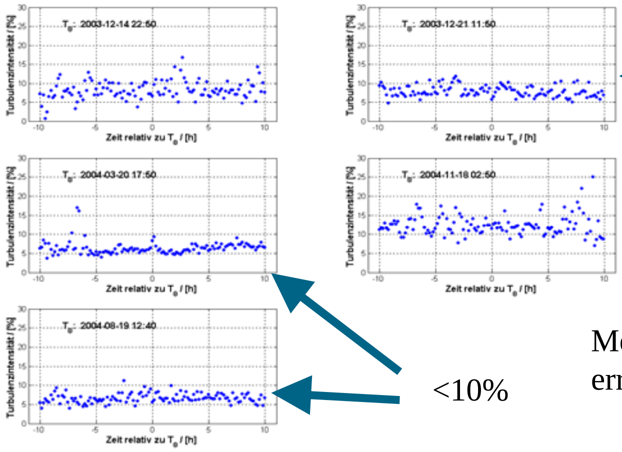
Turbulence intensity in 100 m height



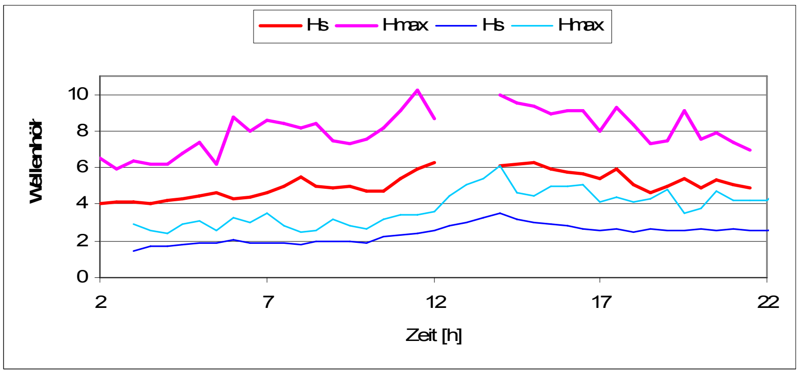
5-12%

10-20%

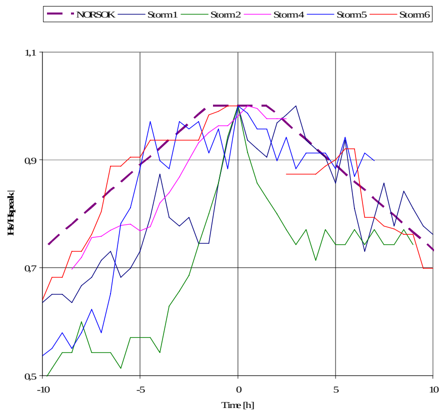
Measurement error?

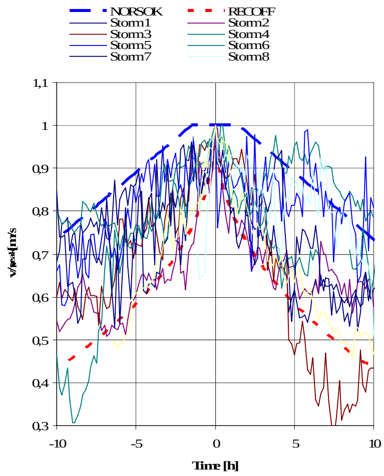
<10%

Significant and maximum wave height



Storm profile





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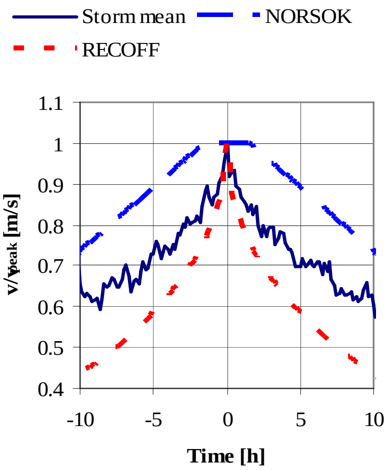
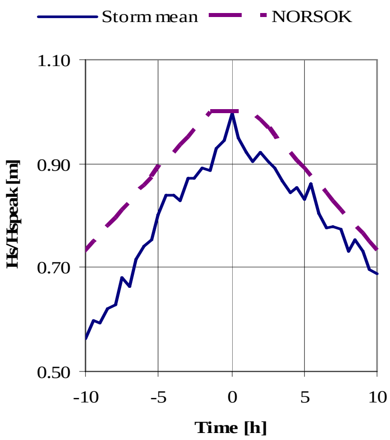
Storm profile





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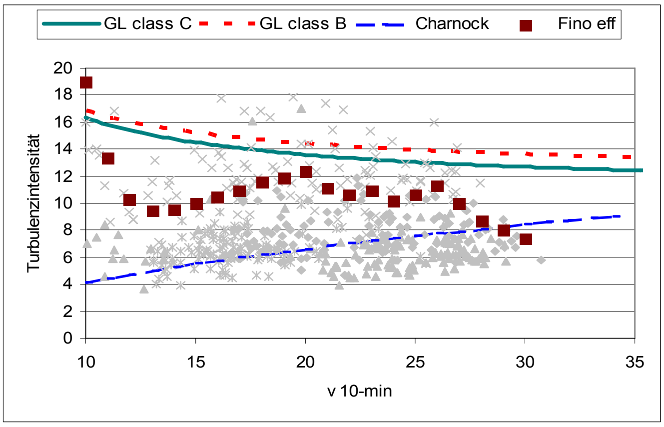
Effective turbulence intensity



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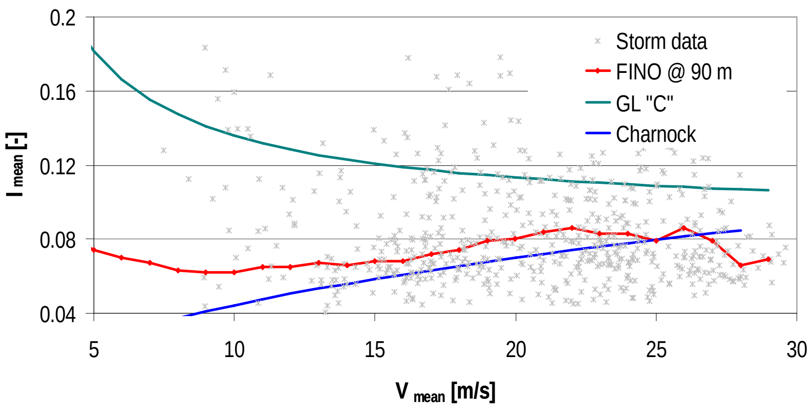
Mean turbulence intensity



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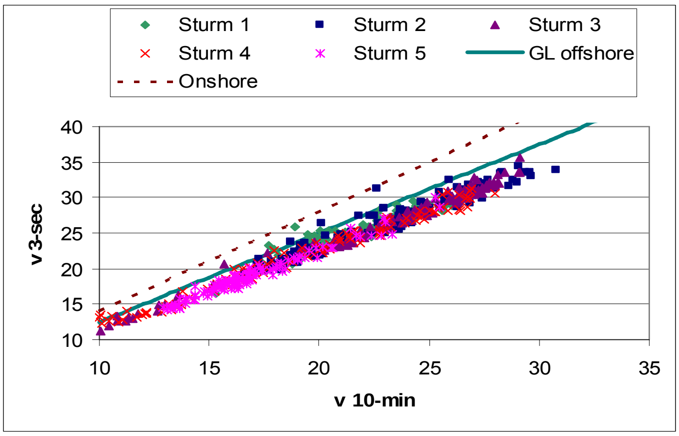
Gust factor



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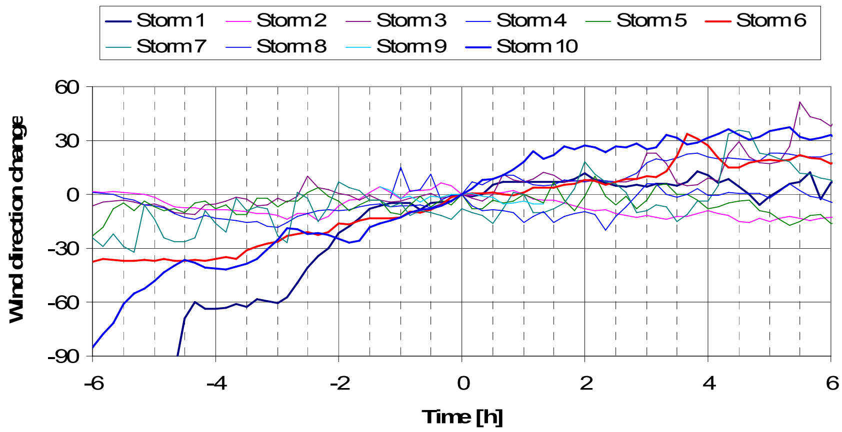
Wind direction change



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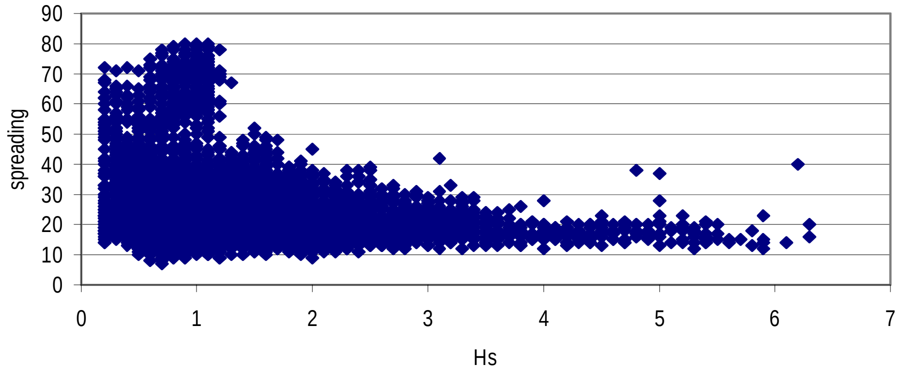
Spreading



Spreading als Funktion der signifikanten Wellenhöhe

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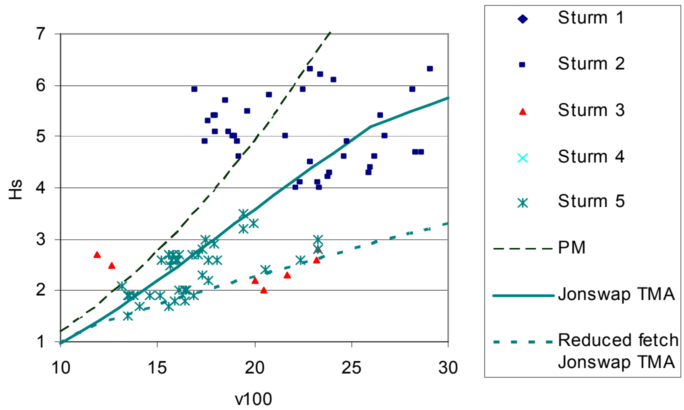
Correlation of wind speed to wave height



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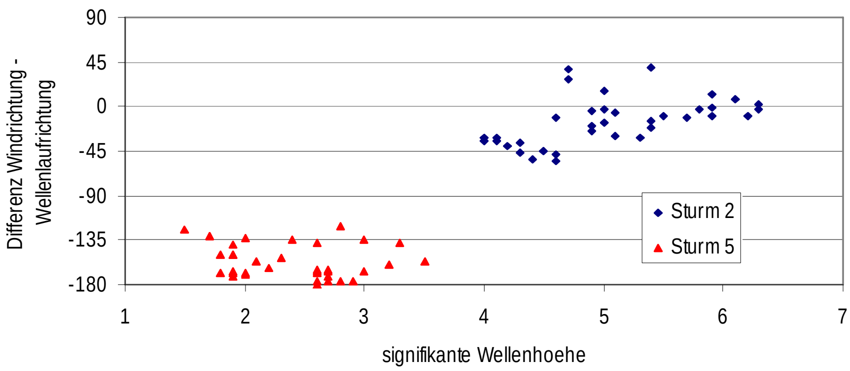
Wind-wave misalignment



Differenz Windrichtung-Wellenrichtung

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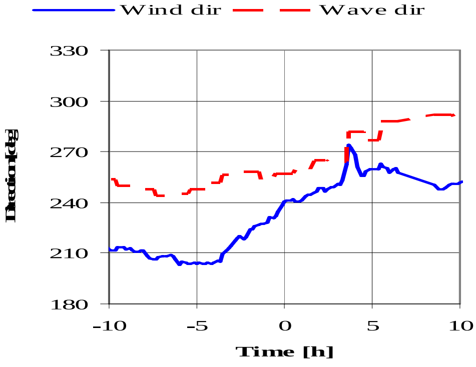
Wind and wave direction



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Measurement compared to design

	Measurement	Design	GL-Guideline	
			Class 1	Class 2
1-year wind speed	33.9	42,6	40,0	34,0
1-year gust	38,6	55,1	50,0	42,5
Turbulence	≈0,11		0,145 (C)	0,145 (C)
Mean wind speed	9,8		10,0	8,5
Significant wave height	**6,9**	5,4	(7)	(6,07)
Max. wave height	10,9	11,63	(13,0)	(11,3)

Germanischer Lloyd

Vielen Dank für Ihre Aufmerksamkeit!

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Design parameters for offshore wind turbines using site data

Presented by: Ameya Sathe
PhD Researcher

2/21/2007

1

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TUDelft
Technische Universiteit Delft

Outline

- Introduction
- Objective of the research
- Site data
- Possibility for collaboration
- Planned activities
- Conclusion

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2

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Introduction

- Dutch government's target of 6000 MW offshore wind energy by 2020
- Started PhD@Sea project under the framework of WE@Sea
- Started with my PhD in mid October 2006
- Reference site – Egmond aan zee
- 36 Vestas V90 3MW turbines

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Objective of the research

- To develop tools and methods to arrive at a design data from available site data for offshore wind turbine design

Why?

- Inadequate knowledge of offshore climate for wind energy
- To provide a basis for improving the current standards
- To check the feasibility of design using site data

2/21/2007 4

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Better understanding of the offshore climate

- Influence of the sea surface roughness
- Influence of thermal effects
- Influence of coastal effects
- Influence of wind farm itself

2/21/2007 5

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More research questions

- Extrapolation of the extreme events using site data
- What is the consequence of different fits/procedures for the extremes?
- What is the overall uncertainty in the estimation of extreme events?
- Is directional information relevant to load calculations?
- Influence on the energy yield

2/21/2007 6

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Site data

- Measuring mast at the site
- Use of satellite data
- Combining data from different data sources
- An inventory of the available data sources

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Possibility of collaboration

- Similar research is being carried out for FINO platform
- Compare the results
- Identify the key areas
- Provide a basis for improving the existing standards

2/21/2007 8

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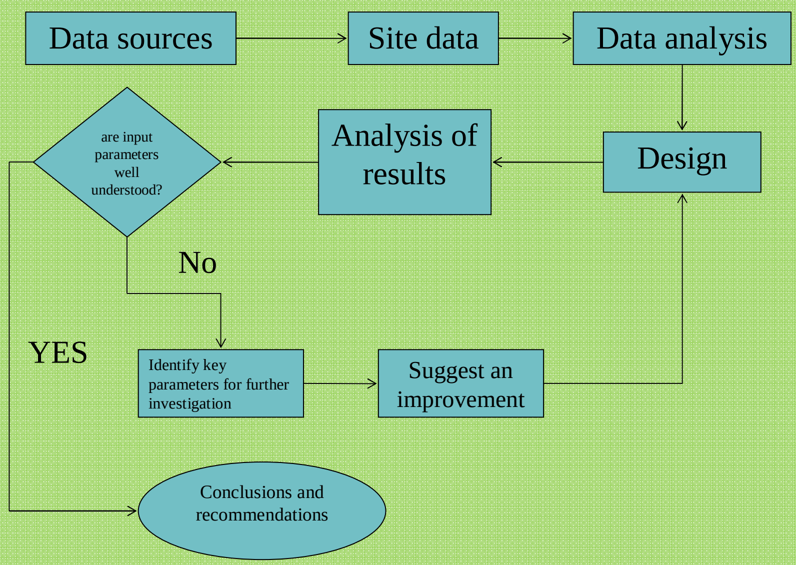

2/21/2007 9

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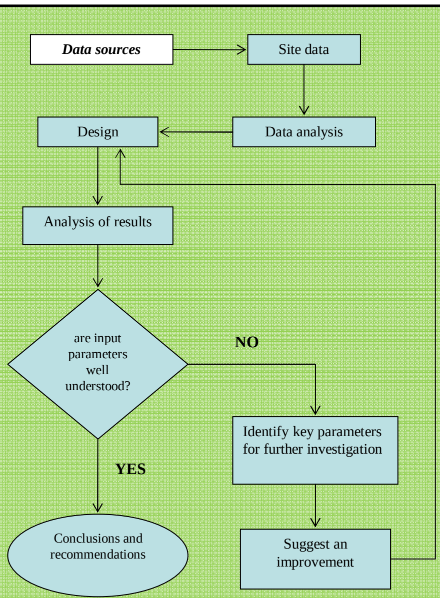

- Egmond aan zee met mast
- Argoss
- www.golfklimaat.nl
- KNMI
- NESS/NEXT database
- Public works department (RIKZ)
- ….

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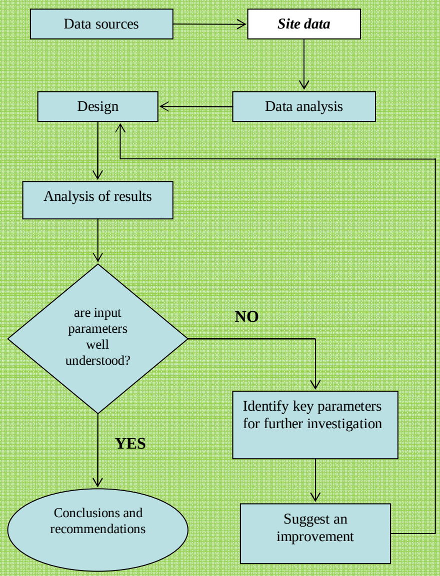

- Wind speed
- Wind direction
- Turbulence intensity
- Significant wave height
- Wave period
- Wave direction
- ….

2/21/2007 11

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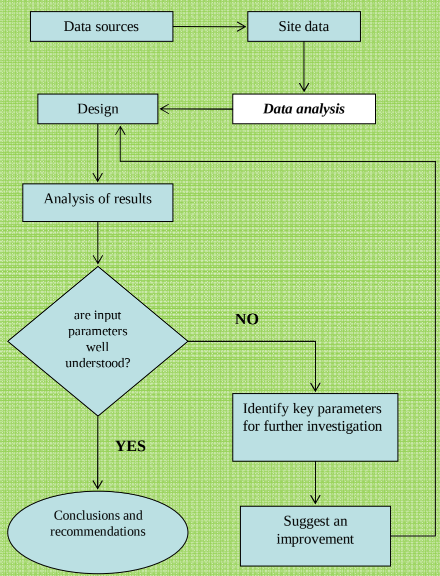

- Normal wind profile model
- Normal turbulence model
- Wind speed distribution
- Extreme wind speed model
- Extreme direction change
- Extreme wind shear
- …..

2/21/2007 12

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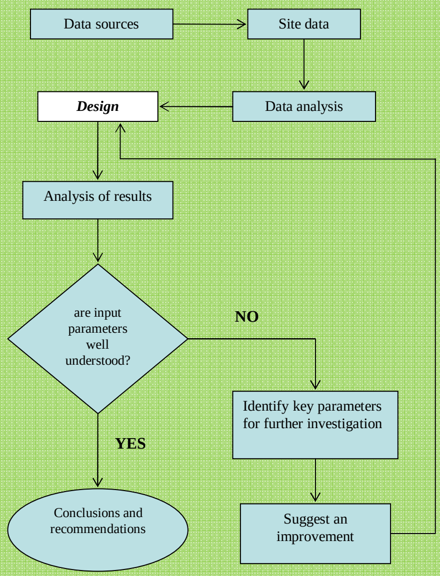
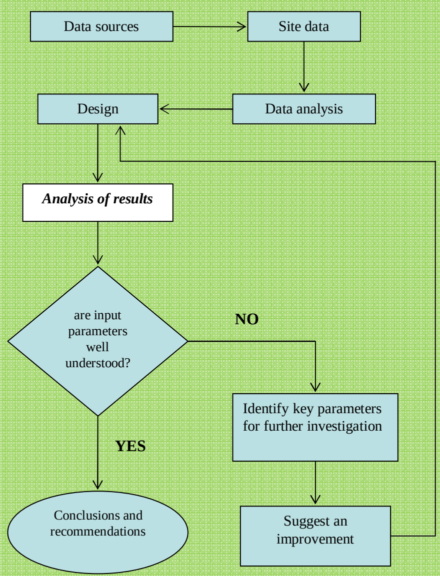
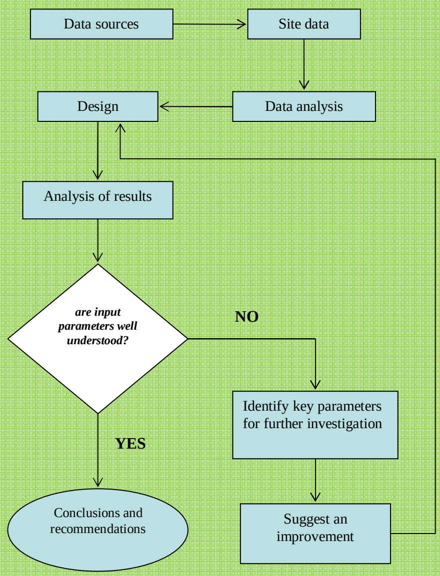


- Software package Bladed
- Calculate fatigue damage
- Calculate ultimate loading



- Validate the results obtained using site data with load measurements
- Compare results of design using site data and those prescribed by IEC



- Are the differences in the loads small enough?

2/21/2007 15

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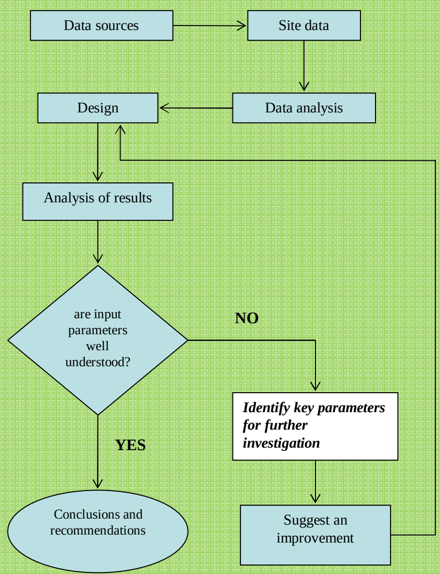

- Wind profile inadequately represented by standards
- Extreme events need modification
- ....

2/21/2007 16

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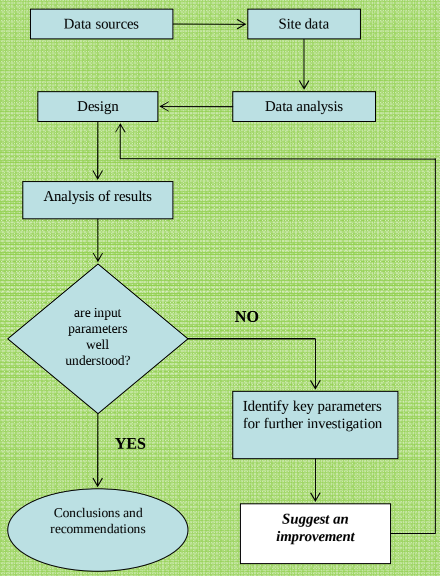

- Take variable sea surface roughness
- Consider stability effects
- Consider coastal effects
- ....

2/21/2007 17

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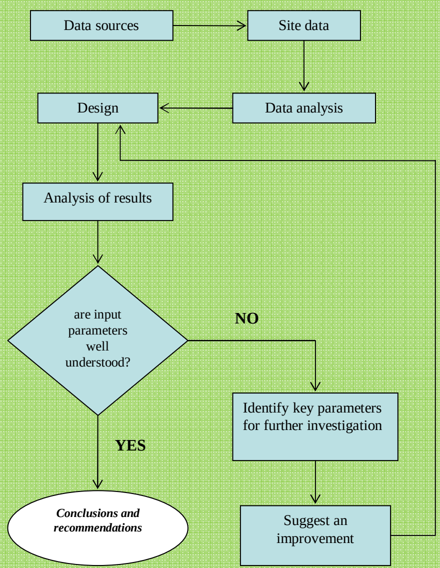

- Is offshore climate understood well for wind turbines?
- What improvements are required in design standards?
- What are the uncertainties in design using site data?

2/21/2007 18

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Thank you

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PROJECT WAVENERGY

Project to develop altoguether with ITER, TENERIFE HARBOR AUTHORITY, EIGSI, WAVEGEN.

Authors:

García Javier *, Guillemes Ángel *, Arancibia Gerardo *, Tejera Javier *,
Dr. Fernández Guillermo **, Dr. Alesanco Ramón *, Dr. García Feliciano ****.**

***** **Doctorating & Researcher "E.E. de I+D INGEMAR"**
****** **Doctor & Researcher "E.E. de I+D INGEMAR"**
******* **Univ. Titular Prof. & Researcher "E.E. de I+D INGEMAR"**
******** **Univ. Catedratic. & Coordinator "E.E. de I+D INGEMAR"**

"Stable Team I+D INGEMAR".- Dpto. of Marine Engineering.- University of La Laguna. Spain.

Wind and Wave Measurements at Offshore Locations

Berlín 2007

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INTRODUCTION

Europe has a strong commitment with the development of all the renewable power plants.

Due to our increasing power necessities, in the last years there has been great advances in the development of the technologies of generation of energy from renewable resources.

The potential of the energies related to the marine environment is one of the greatest of the world and the technological improvements that are following one another are going to allow that, in a near future the energy of the sea becomes an important power source of supply.

Wind and Wave Measurements at Offshore Locations

Berlín 2007

PARTNERS OF THE PROJECT

Excelentísimo Cabildo Insular de Tenerife

INGEMAR

ITER

Tenerife Harbour Authority

EIGSI

WAVEGEN

FINANCING

UE FEDER	201.186,00 €
PUBLIC SELF-FINANCING	131.564,00 €
PRIVATE SELF-FINANCING	67.250,00 €
TOTAL	**400.000,00 €**

Wind and Wave Measurements at Offshore Locations

Berlín 2007

DESCRIPTION OF THE PROJECT

The project can be divided in two great blocks.

1) On the one hand is the **elaboration of a plan** for the regions that decide to take advantage of the wave energy.

   Once this plan is defined, the methodology of study of viability for the generating infrastructure implantation of wave energy in Atlantic regions will be defined, and with a special attention to its inclusion in infrastructures already constructed (industrial and sport ports, breakwater, docks, etc.).

   This methodology will identify the parameters that should be study in case we want to bet on taking advantage of the waves.

Wind and Wave Measurements at Offshore Locations

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DESCRIPTION OF THE PROJECT

2) In the second phase a pilot project will be carried out which will allow us to prove the methodology of study of viability designed in the previous phase.

This pilot project will study a particular case of viability of the advantage of infrastructures on Granadilla Harbour (Project which construction is predicted to begin in Tenerife on the next years), installing systems of generation of wave energy in these infrastructures.

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TABLE OF WAVE PERCENTAGE OF 2006 FOR THE GRANADILLA HARBOUR

...		Tp (s)									Total Hours
		4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	
Hs (m)	0.5	0.80%	1.20%	0.80%	0.80%	2.60%	3.40%	2.20%	0.90%	0.70%	13.4%
	1.0	1.90%	21.00%	4.70%	1.60%	3.00%	7.10%	7.80%	1.40%	1.30%	49.8%
	1.5	---	15.30%	6.20%	1.30%	0.30%	0.90%	3.00%	0.70%	0.30%	28%
	2.0	---	2.20%	5.00%	0.80%	0.20%	0.03%	0.10%	---	---	8.33%
	2.5	---	---	0.40%	0.07%	---	---	---	---	---	0.47%
Total Hours		2.70%	39.70%	17.10%	4.77%	6.10%	12.43%	13.10%	3.00%	2.30%	100%

Source: Stable team of I+D "INGEMAR" of ULL, Year 2006

INTERREG

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TABLE OF KWH PRODUCED IN 10 YEARS FOR THE GRANADILLA HARBOUR

...		Tp (s)									Total KWH
		4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	
Hs (m)	0.5	5837,664	13134,744	11675,328	14594,160	56917,224	86835,252	64214,304	29553,174	25539,780	308301,630
	1.0	55457,808	919432,080	274370,208	116753,280	262694,880	725329,752	910675,584	183886,416	189724,080	3638324,088
	1.5	---	1507211,874	814354,128	213439,590	59106,348	206872,218	788084,640	206872,218	98510,580	3894451,596
	2.0	---	385285,824	1167532,800	233506,560	70051,968	12259,094	46701,312	---	---	1915337,558
	2.5	---	---	145941,600	31924,725	---	---	---	---	---	177866,325
Total KWH		61295,472	2825064,522	2413874,064	610218,315	448770,420	1031296,316	1809675,840	420311,808	313774,440	**9.934.281,197**

Source: Stable Team of I+D "INGEMAR" of ULL, Year 2007

$$P\ (Kw / m) = 0,49\ H^2\ T$$

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FUTURE GRANADILLA HARBOUR

The Granadilla Harbour supposes the construction of 1,400 meters of Shore Dock. **Respecting the outer dock, it will have a length of 2,074 meters**. This dimension is significant for the Project because it is the length available to place the power receivers of the wave. It would be located to a distance of 1.5 kilometers of the Shore Dock, in which we could obtain a surface of 1.7 million square meters.

The esplanade will occupy a surface of 68 hectares. This way, the future installation is raised to allow the relief of Santa Cruz Tenerife Harbour and to catch new merchandise in route of the axes Europe-Africa and Europe-America.

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FUTURE GRANADILLA HARBOUR

Wind and Wave Measurements at Offshore Locations

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ACTIONS TO DEVELOP

1.1) Comparative study of the different marine renewable power plants.

1.2) Study of the state-of-the-art of systems of generation of wave energy.

1.3) Definition of the natural basic parameters of the advantage of this energy.

1.4) Definition of the criteria of location of these power systems.

1.5) Study of the potential zones of location and identification of the points of connections to the electric highvoltage network.

Wind and Wave Measurements at Offshore Locations

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ACTIONS TO DEVELOP

1.6) Sectorial legislative study.

1.7) Study of financing sources availables.

1.8) To define the technical variables to study in the viability plan.

1.9) Elaboration of a document that reunites the actions conducted in this first stage.

1.10) Application of the methodology of the study of viability in the Granadilla Harbour.

1.11) Revision of the methodology.

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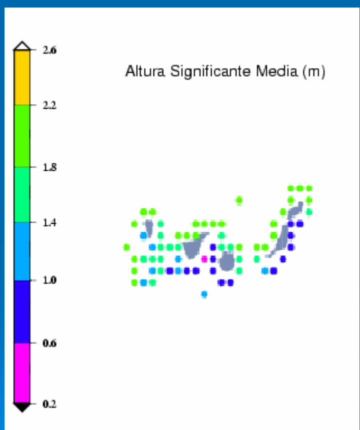
SIGNIFICANT HEIGHT OF THE WAVES



In the case of the waves, the studied parameter is the **Significant Height (Hs);** that is defined as the average of one third of the height of the greater waves that during a period of 30 minutes are propagated throughout a certain zone.

Wind and Wave Measurements at Offshore Locations

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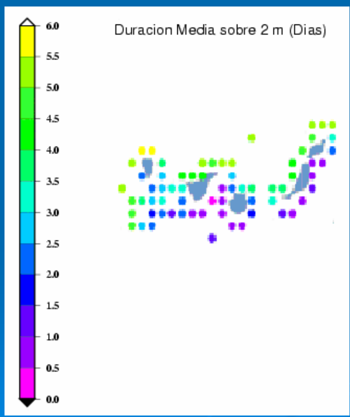
AVERAGE DURATION OF THE WAVES



The average duration of the 2 meters waves, describes the average interval calculated in days, during which the significant waves **(Hs)** are located over 2 meters height.

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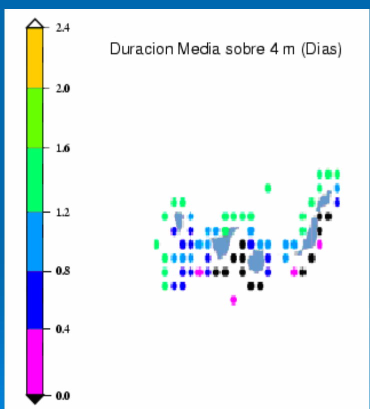
AVERAGE DURATION OF THE WAVES



The average duration of the 4 meters waves, describes the average interval calculated in days, during which the significant waves (Hs) are located over 4 meters height.

Wind and Wave Measurements at Offshore Locations

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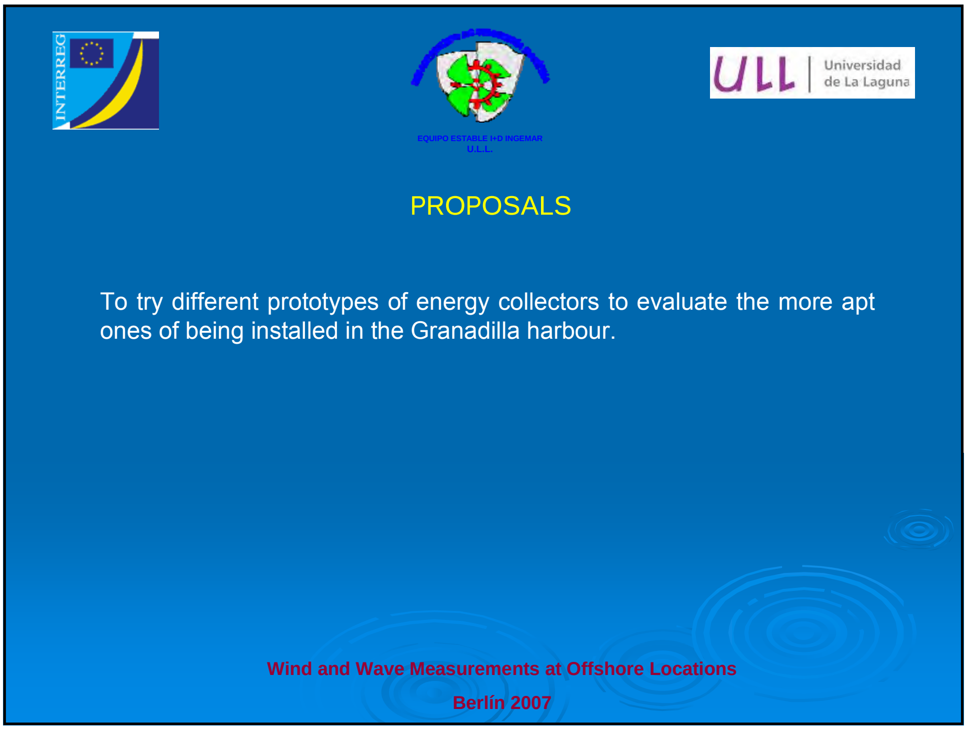
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PROPOSALS
To try different prototypes of energy collectors to evaluate the more apt ones of being installed in the Granadilla harbour.
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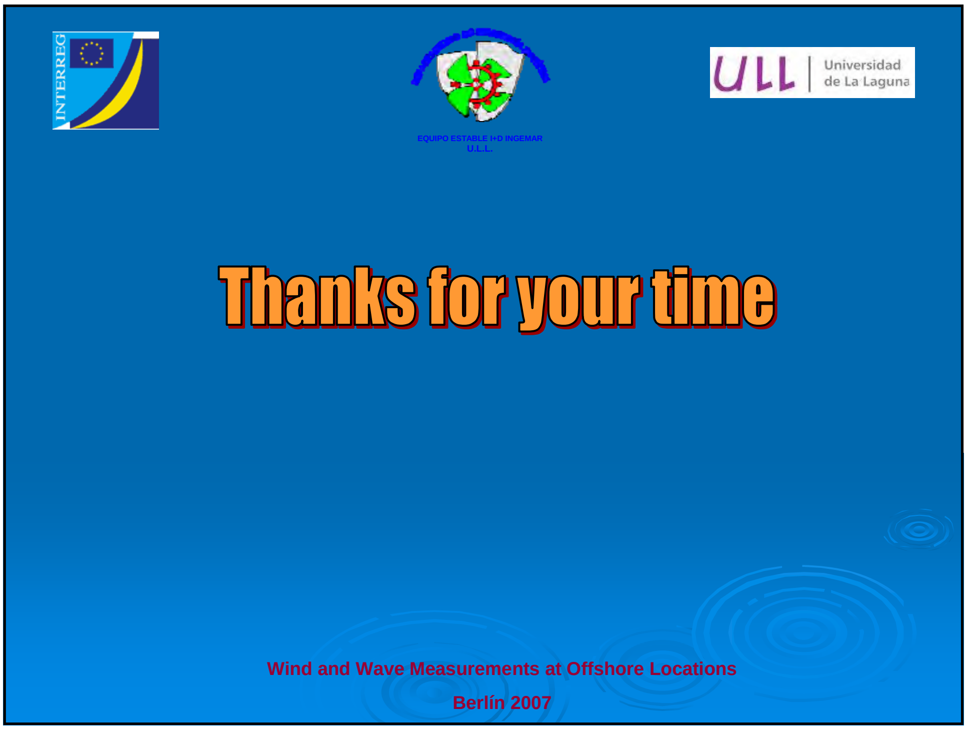
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Thanks for your time
Wind and Wave Measurements at Offshore Locations
Berlín 2007

Measurement Data and Simulations for the Offshore Wind Industry

Abha Sood

ForWind, Center for Wind Energy Research,
Carl von Ossietzky University Oldenburg

21. Februar 2007

Structure

Developing Products for the Wind Energy Industry

High quality demands of the wind energy industry on the determination of the lower boundary layer wind field

- High quality data - high resolution, long time series
- Standardized approach to ensure high quality products
- Validations and updates of resource for quality control

Motivation
Tools for Wind Resource Assessment Studies
Example: FINO-1
Example: Arklow Banks
Large scale effects

Developing Products for the Wind Energy Industry

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Measurements for forcing and validation

- Simple models - WAsP
- 3d NWP model - WRF
- "Large Eddy Simulations" (CFD)
- Turbulence Models - site and turbine specifi c characteristics
- Postprocessing software - FLaP

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Mesoscale Simulations - Weather Research and Forecast Model (WRF)

- wind resource mapping
  - offshore and coastal domains
  - complex terrain
- Forecast simulations: wind field and power forecast
- other spinoffs for renewable energies
  - direct solar radiation and cloud cover
  - coupled wind-wave modelling
    offshore wind and wave forecasts

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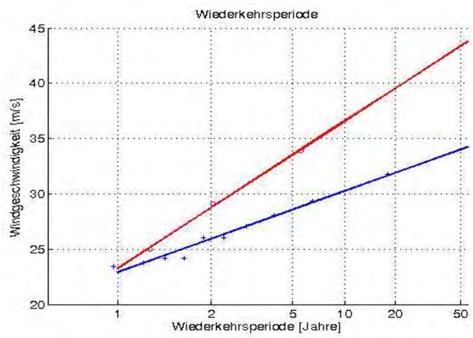
Extreme Winds at FINO - long term comparison



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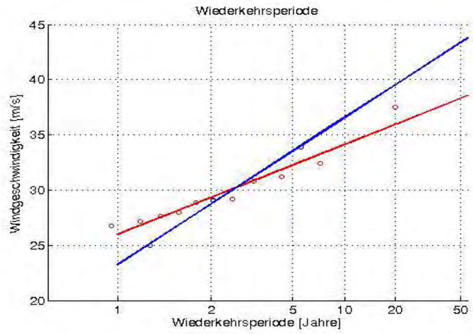

Motivation
Tools for Wind Resource Assessment Studies
Example: FINO-1
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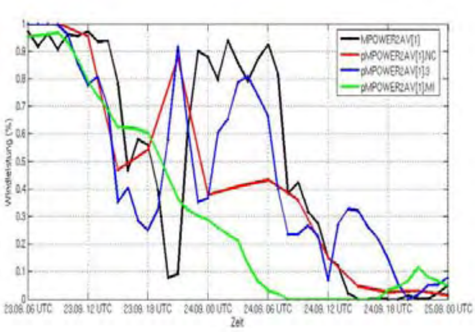
Large scale effects

Wind power forecast



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Measurement Data and Simulations for the Offshore Wind Industr

Wake Effects and Climate Impacts of Offshore Wind Farms

- Wakes from large wind farms
- Impact of Wakes on the local to regional climate:
  - boundary layer height, low level jets
  - boundary layer clouds
- Future climates and wind resourses
- Validate new mesoscale parameterization for offshore conditions

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Hull Offshore Wind Project: Assessment of Wind and Waves

Expert Meeting on Offshore Wind and Wave Measurements

Berlin, Germany

20-21 February, 2007

James F. Manwell, Professor and Director
Daniel Jaynes, Research Assistant
Renewable Energy Research Laboratory
Dept. of Mechanical and Industrial Engineering

University of Massachusetts

Renewable Energy Research Laboratory

Overview

- Summary of Hull Offshore Wind Project
- Wind Monitoring
- Wave Monitoring

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The Proposed Hull Offshore Wind Project

- Four wind turbines, of 3-5 MW each
  - – Number of turbines determined by Board of Hull Municipal Light Plant (HMLP)
  - – Rated power to be determined
- To be installed ~2.5 km from shore in Hull, MA
- Energy production (on average) could approach 100% of Hull’s electricity consumption

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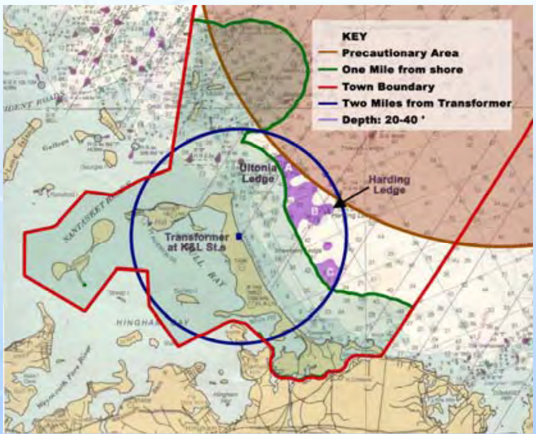
Preliminary Siting Constraints

- Four turbines
- In Hull’s waters
- Suitable for commercial turbines
  - ~ 6 - 12 m
- Outside shipping lanes
- We initially chose these distances:
  - > 1.6 km from shore
  - < 3.2 km from proposed connection point



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Siting Criteria (1)

- Avoid or minimize impacts on :
  - Marine environment
  - Human activities
    - Fishing, boating, etc…
    - Ship and airplane traffic
- Farther from BHI National Park

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Siting Criteria (2)

- Allow a feasible landfall
- Minimize transmission length
- Maximize wind speeds
- Minimize cost of energy

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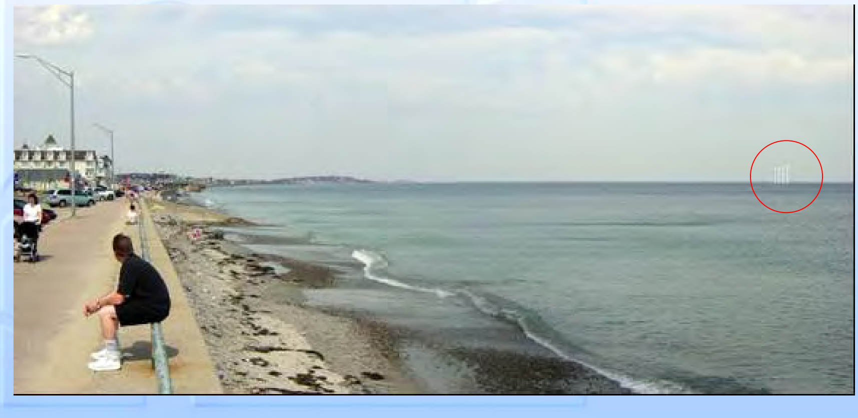
Photo Simulation of Possible Layout

- Four 3.6 MW turbines, spaced 2D apart



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Study Phase

- Feasibility
  - Projected costs vs. benefits
- Turbine design basis
  - Input to cost estimates
- Studies for permits
- Identify potential fatal flaws

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Principle Partners

- Hull Municipal Light Plant (HMLP)
- Massachusetts Technology Collaborative (MTC)
  - Administrator of MA Renewable Energy Trust Fund
  - Study financial support
- UMass/Amherst RERL
  - Engineering
    - Wind/waves
    - Feasibility/layout/visualizations
    - Structural dynamic modeling
- ESS, Inc.
  - Environmental studies; permitting

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Other Contractors

- AMEC Paragon, Houston
  - Support structure design
- Prof. Jason DeJong (UMass and UC Davis)
  - Soil/support structure interactions
- GZA Geoenvironmental
  - Offshore soil sampling
- MIT's Laboratory for Energy and the Environment
  - Environmental benefits

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Monitoring of External Conditions

- Wind data for feasibility and design
- Wind/wave data for turbine support structure design
  - Intended to be consistent with IEC 61400-3 (Design of Offshore Wind Turbines)
- Nearby island is being used as support for wind data monitoring; LIDAR will be used rather than hub height tower

Wind Resource Assessment

- Used for:
  - Energy production estimates
  - Design of wind turbines and support structures
- Data from:
  - Monitoring on Little Brewster island and WBZ towers (~ 120 m high)
  - Historical data from Boston Harbor and offshore buoys

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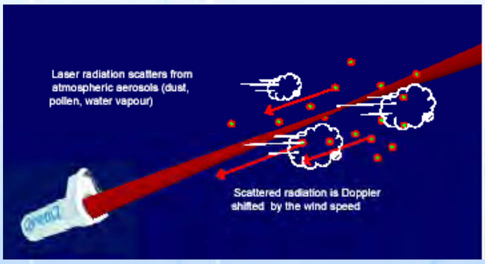
Wind Data Collection

- Conventional anemometry and LIDAR



(Conventional anemometry on Little Brewster Island)

RERL's LIDAR at WBZ

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LIDAR Location

- LIDAR located behind building to left

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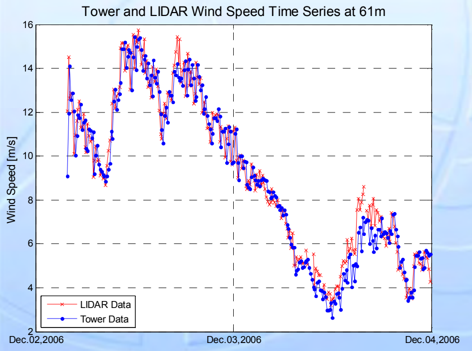
WBZ Tower/LIDAR

- Comparisons, Qinetiq LIDAR v. anemometry



Dec. 2, 2006 – Dec. 4, 2006

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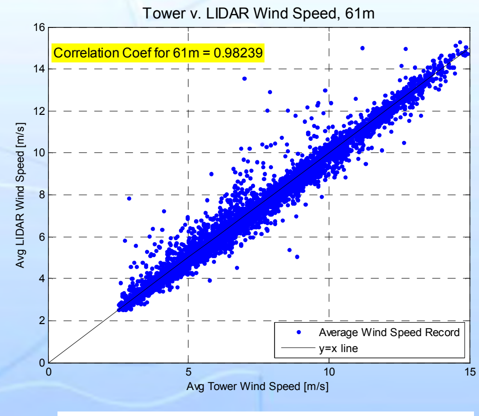
LIDAR/Anemometry

- Comparison:



Dec. 1, 2006- Jan. 23, 2007

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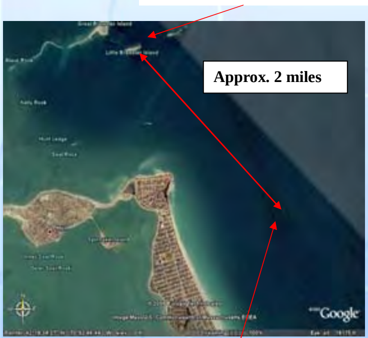
Little Brewster Island

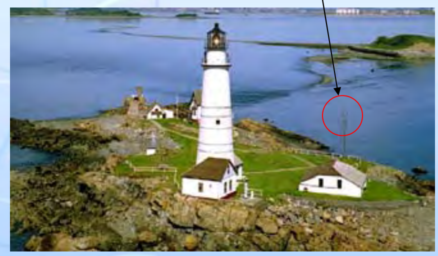
- Location and data collection:

Little Brewster Island

Conventional Anemometer



Harding Ledge



Aerial view of Little Brewster

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Renewable Energy Research Laboratory

Waves

- Information on waves needed for preliminary design and cost estimates of support structure:

Waves on Offshore Wind Turbine in Blythe Harbour, UK

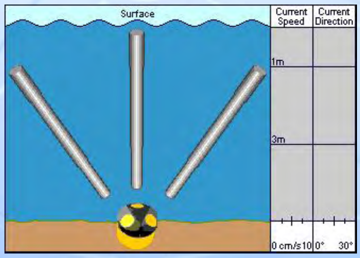
From: Garrad-Hassan

University of Massachusetts

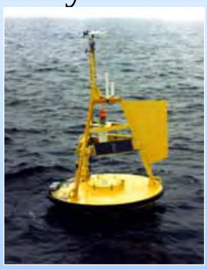
Renewable Energy Research Laboratory

Wave Data

- Monitoring using a Sontek "acoustic Doppler profiler" (ADP) in vicinity of Harding Ledge
- Correlations with NDBC offshore buoys



Sontek ADP



NDBC Data Buoy

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Wave Data Monitoring

- Sontek ADP

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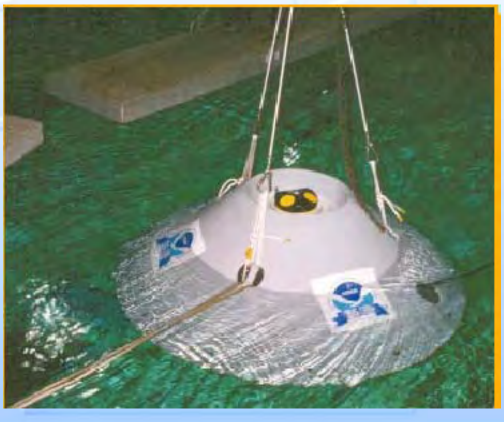
Anti-Trawl Device

- An anti-trawl device will be used to protect ADP



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Location of Wave Monitoring

- Device to be installed in vicinity of an abandoned pipe:

Pipe and cormorant in shallows at Harding Ledge, Hull

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Status

- Data collection
  - LIDAR/WBZ tall tower anemometry comparison are underway
    - Good results (after initial "teething" problems)
  - Conventional anemometry has been operating on Little Brewster for ~ 1 year
  - Sontek ADP has been ordered, is expected to arrive within the month, and be installed shortly thereafter

Here's a user speaking …

Herbert Schwartz, Dr. Daniela Jacob

anemos-jacob GmbH
Oldershausener Hauptstr. 22, 21436 Oldershausen, Germany
Tel. +49 (0) 4133 210696, e-mail: wind@anemos-jacob.de

Background

anemos-jacob GmbH is an independent consultancy for wind resource assessments with a high interest in working at the leading edge of this matter. In many ways our situation is typical for most other wind resource assessment groups: Our work is placed in a commercial environment, which means that

- Our clients expect from us high quality work but within limited time scales and budgets
- The aim of the work is to produce results that wind farm developers, financing parties, investors, insurances and turbine manufacturers need
- We are a small group of specialists
- Our interest in research is high but we can only attribute a small part of our resource to in-house research
- Research is only justified if it helps fulfilling the commercial contracts

We have completed several contracts in the area of offshore wind energy. These were focussed on wind resource, energy production and turbine design related site conditions. They were based on measured data, including the FINO I data, but also from other sources as well as on literature. As a consequence of this practical experience, we would like to raise a number of issues.

Access to measured data

Unlike for onshore projects, the wind measurements for offshore projects require an extraordinary effort for logistics, technical issues and cost. It will therefore not be sensible to carry out wind measurements for each offshore project separately. On the other hand, the damage of errors in determining the wind resource or the design relevant conditions is much higher than on offshore sites. In particular, the change of the wind field in the vicinity of the coast is highly uncertain and it cannot be expected from current wind flow models to provide reliable information in these areas. This can only be assessed by analysing as much measured data as possible from a range of sites, even if these are at further distance from the site to be investigated. Such analysis may help

- avoiding that resources are wasted in carrying out redundant measurements
- finding the most suitable strategy for planned measurement campaigns
- understanding the change of the wind field on large and medium scales.

It is therefore much more important for the entire community than for onshore projects that existing measured data, in particular wind and temperature data, are accessible to all those involved in assessing the wind conditions.

Some offshore measurements have been carried out fully or partly on a commercial basis which means that in principle they are not intended to be available to the public. It may be assumed, though, that in offshore projects the outcome of the competition between developers depends much less on the knowledge of the wind conditions than onshore. It is therefore, from a strategic point of view, less detrimental for the developers if their wind data are shared within the community, even if they have been financed or co-financed by commercial entities. This is in particular the case, once a project has been constructed.

It should thus be possible to provide access to offshore data on a broad basis. Clearly this is the case for some public funded projects such as the FINO programmes, but much more appears possible. The best would be to build up a data base of all data that are relevant for offshore studies. A first step would be to compile information on the existing data sets, their extent and where they are available. Data that are fully private owned could be made available to the public by using part of the money that would otherwise be spent in future measurement programmes, thus creating a benefit for everyone. This should be even easier for data that are private owned but that have been co-sponsored by national or international research programmes. In such cases society may in return ask for getting the data made accessible for all.

Some of these data have, anyway, already extensively been used for research. This would, in principle, not be a problem if research groups nowadays didn't often compete on the market for consultancy work with fully commercial companies. This creates a situation where research groups who are partly or fully public funded, anyway, obtain access both to knowledge and to data for free which brings them into an unbeatable position for their commercial activities. This also applies to data which are publicly available such as the FINO data or the data from weather services, for instance. These data have already fully been paid by society. However, if they are needed for commercial work, they need to be paid for again at rates that largely exceed the cost of data handling. The atmospheric data from the FINO 1 platform, for example, are sold for € 1500 per measurement year. If the sea surface temperature or the wave height data are purchased as well, this doubles the price. The hourly time series of wind speed and wind direction of just one measuring height at the meteorological station of Helgoland cost more than € 1000 per year. If, for a particular work (e.g. in the vicinity of the coast), the data from several measurement platforms and / or meteorological stations are needed and they are all available for similar conditions, the total cost for the data may even exceed the price that can be obtained on the market for the wind resource studies. The money paid for the data does not go back to the sponsoring ministries but it remains with the keepers of the data. Furthermore, those involved in research programmes by either measuring or analysing the data obtain these data for free. They can afterwards use them for free for their commercial work so they will usually bail out any company on the consultancy market which has not been involved in research programmes and must therefore pay for the data.

Measurement documentation

It appears obvious that, due to their high impact, wind measurements are well documented. Everyone has already learnt at school how measurements are documented and that such documentation imperatively forms part of any experiment. Experience in wind energy shows that the value of any data is highly increased if they are accompanied by a full and well kept documentation. However, this is often ignored in practice showing on a broad basis a frightening lack of maturity of the work.

This situation has driven the advisory board for wind resource assessment of the German Wind Energy Association (BWE), which includes some 30 consultancy groups, to issue recommendations for the documentation of wind measurements which can by now be considered as a standard for Germany. This has clearly improved the situation, but the documentation of the FINO 1 measurements that is so far available still by far does not comply with these requirements.

We recommend that such recommendations are compiled for offshore measurements (not only for wind) which would make it easier not only to use any particular set of data but also to compare the results from different sites. The recommendations issued by the BWE are appended to this text. They could be used as a starting point.

Influence of the measurement set-up onto the measured wind data

It has repeatedly been observed that the measured offshore wind speed and turbulence data are more affected by the measurement set-up, in particular the mast structure, than what is known from onshore measurements. This is partly due to the size of the masts which makes it rather impossible to place anemometers as far away from the mast structure as it would be desirable. In addition, a given set-up seems to affect the measurements more under offshore conditions than what is known from onshore conditions. Our analysis of the FINO 1 measurements, for example, shows that not only the wake of the mast is visible in the data, but also the reduction of wind speed due to a blocking effect in the opposite direction and that probably even acceleration occurs at the perpendicular directions and on the top anemometer.

We therefore recommend that future offshore measurements include additional anemometers which help quantifying the magnitude of the influence of the mast structure. Similar arrangements could be included in existing measurements such as the FINO 1.

Extreme wind speeds

The assumed extreme wind speeds have a high impact on to the cost of offshore wind energy projects. Furthermore, improved knowledge of these wind speeds reduces the project risk significantly. Finally, those parties involved in the financing and the insurance of offshore projects wish to know whether the extreme wind speeds are likely to change in the future.

If the extreme wind speeds are derived from the FINO 1 data with or without combination with long term records such as those from lightships, quite good agreement between the results is found when different lengths of data sets are used and also when different appropriate statistical methods are applied.

However, if a wind speeds have once been recorded at the Horns Rev site during an extreme storm. It cannot be excluded that in the future a similar storm may follow a slightly different track producing the same extreme wind speeds elsewhere in the North Sea. This means that statistical methods used in conjunction with the data recorded at a given spot may not lead to safe results for the extreme wind speeds. Furthermore, no information on possible changes of the extreme wind speeds can be obtained from such approaches.

In order to obtain more reliable information we suggest that the extreme wind speeds observed at different offshore sites during a number of storms are inter-compared and then compared with the records of the weather situation. Results from climate model calculations for the past should be validated against these observations. The climate model calculations available for the future can then provide the required insight into the probability distribution of extreme wind speeds for all potential offshore areas.

A mismatch in time scale currently exists in the definition respectively time scale of observed extreme wind gusts and the relevant wind turbine design standards. The recorded data commonly shows extreme instantaneous values recorded at 1 Hz sampling rate whilst the turbine design refers to ##2 s averages. Appropriate measurements are needed from offshore platforms that help making the link. Such measurements could be event triggered time series made with a sampling rate well above 1 Hz.

Near shore wind resource

It has already been mentioned that a lack exists in understanding and quantifying the wind resource in the transition zone between land and sea. This can partly be improved by analysing as many measurements as possible and comparing with model calculations. Furthermore, it should be noted that climate change may have higher impact on to the wind resource in such areas than further inland or further out offshore. In order to validate and improve the atmospheric models and the climate simulations in these areas, records of sea surface temperature are most important. These should therefore be included in all offshore measurement campaigns.

Use made of the results from offshore measurements

A large amount of work and money has been invested to obtain a better understanding of the offshore wind speed profile and turbulence. It is currently unclear whether this effort was worth while considering the state of the industry. Even for commercial projects with significant size it has been found that the wind turbine manufacturers involved were not prepared to use the outcome of the wind studies regarding wind speed profile and turbulence to calculate site specific power curves or to check whether savings could be made on the structural design.

Wind farm wake effects

A lack of understanding the interaction of the wind turbine wakes with the atmospheric boundary layer has become apparent at the Horns Rev wind farm, possibly leading to a significant underestimate of the wake losses in larger offshore wind farms. Any offshore wind measurement should therefore be designed and scheduled to include appropriate measurement campaigns even after erection of the wind farm.

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Summary of IEA RD&D Wind – 52nd Topical Expert Meeting on

Wind and Wave Measurements at Offshore Locations

February 2007, TU Berlin, Germany

Lasse Johansson and Sven-Erik Thor

Background

Electricity from renewable energy sources will make an important contribution to tomorrow's energy policy. Especially offshore wind (located in the territorial waters and the European Exclusive Economic Zones) has an enormous potential to contribute substantially to European and global climate protection.

According to estimations of the European Wind Energy Association (EWEA) 10,000 MW offshore wind power will already be installed within this decade, and by 2020 it will be 75,000 MW. At this stage more than 300 wind turbines with a total of 600 MW are installed off the coasts of Denmark, Sweden, UK and Ireland.

Several measuring stations are either planned or already operating in the North and Baltic Seas. They deliver all sorts of technical and environmental data that is required for the planning and approval of offshore wind farms. For manufacturers of wind turbines and foundations, the findings will lead to designs which are better adapted to the offshore conditions. On the basis of measured wind data, banks and investors will make their economic assessments. Institutes, standardization bodies and certification organizations will use the results to cross-check and validate the requirements derived from other fields (onshore wind energy and offshore technology). In the end, with the increase in knowledge in the field of offshore wind energy, it will be possible to push forward the development and generation of wind energy at sea.

One of these measuring stations is the German research platform, FINO 1, in the North Sea. It was installed in 2003 and has delivered comprehensive series of data since then. One of the main objectives of the FINO project is to improve the available knowledge on the meteorological and oceanographic conditions at sea. Some results are expected to be presented and discussed within this Topical Expert Meeting (TEM) and workshop.

Objectives of the meeting

The objective was to report and discuss progress of R&D on all of the above mentioned topics. Since this area of research is relatively new (for offshore wind turbines), many challenges and solutions are still to be discussed and tested. It was expected that the expert meeting would result in new and challenging directions for R&D from the discussions between experts of different origin.

Participants / Presentations

A total of 28 participants attended this meeting with representatives from Germany, Sweden, the Netherlands, and USA. The participants mainly represented National Research Organizations, utilities and entities performing measurements.

The number of presentations was 23, covering the following subjects:

Wind and Wave	11 presentations
Wind	8 presentations
Wave	4 presentations

Summary

At the concluding discussion a number of different topics were handled. A general attitude was that better knowledge of wind and wave climates offshore may result in more effective ways of designing wind turbines and foundations. This may in the end result in lower cost per produced kWh.

The opening discussion concerned the future needs in wind and wave data availability. The view among most of the participants was that there is a deficit of good wind data. The existing sources provide data of inferior quality; such as, reanalysis data with too coarse spatial resolution, insufficiently validated model data, too short observational time series or data with restrictions or too costly. A lack of recommended practices and standards for wind data analysis was also reported from some participants.

Whether existing databases, such as, "winddata.com", which was originally an IEA initiative, are updated any longer or not, was subject to some discussion.

Several model wave databases exist, but more measured time series are needed. The meeting came to the consensus that simultaneous measurements of waves and wind are needed. To perform and compile these data, a recommendation on how these should be performed and documented would be needed.

It was expressed that a new version of the IEA "yellow book" is necessary to suit the needs of offshore work. The "yellow book" deals with land-based measurements, and it is doubtful if the recommendations put in it would be possible to realize offshore. It may be necessary to review the document in order to check whether the document has to be updated for offshore conditions.

The meeting discussed how the needs for standards and recommendations could be met. A joint effort is needed, and the means has to come from the parties in such an effort. IEA can support and aid efforts in this direction, but it can not finance them.

Similar efforts were mentioned, eg. Measnet and the former Seanet (a cooperation between Bundesamt für Seeschifffart und Hydrographie, Rijkswaterstaat and more) and in connection to this, the opinion was expressed that an effective initiative for guidelines, etc., should not be as exclusive (closed) as these bodies are. On the other hand, the groups should not be too big.

The chairman closed the discussion by offering IEA:s support to future development of recommendations and guidelines.

List of participants

IEA RD&D Wind Task 11, Topical Expert Meeting

Wind and Wave Measurements at Offshore Locations

Berlin
20-21 February 2007

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