Shining LiDAR light on wind farm efficiency

On the reduction of Cost of Energy using LiDAR technology

ECN
Your energy. Our passion.

K. Boorsma
boorsma@ecn.nl

15/06/2016 @ WTC Rotterdam

www.ecn.nl

Cost reduction of offshore wind

This presentation focusses on and aims to have most impact on……

YIELD | CAPEX | OPEX | WACC

TKI WIND OP ZEE FLOW

Contents

- Background, LiDAR technology

- Applications

-Wind resource assessment and power performance verification
-Turbine measurements
-Optimization of wind turbine performance
-Optimization of wind farm performance

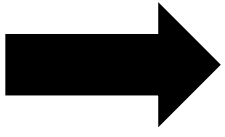
- Conclusions

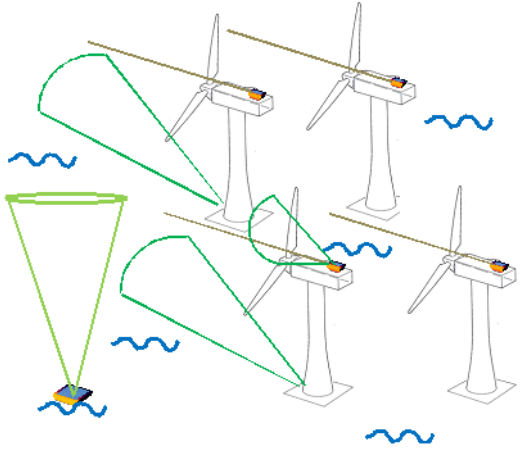
Background, LiDAR

Background

Availability of accurate wind measurements for wind energy deployment

- Determination of the wind resource
- (Certification) measurements on wind turbines
- Power performance assessments during the operation of a wind farm
- Optimization of farm and turbine performance



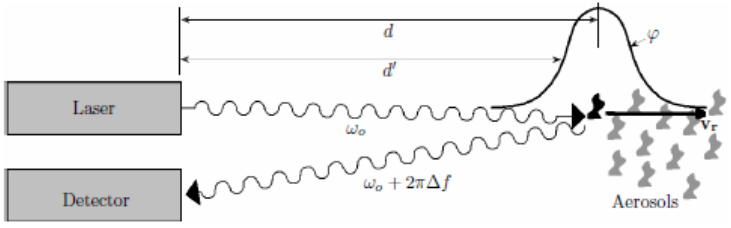


TKI WIND OP ZEE

FLOW

LiDAR

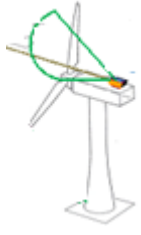
- **LiDAR: Laser Imaging Detection And Ranging**
  - -Reflection of laser light by aerosols
  - -Aerosol movement in beam direction LOS (Line Of Sight) causes frequency Doppler shift
  - -Aerosol velocity in LOS direction can be deduced



- **Three beams necessary to resolve u,v,w**
  - In practice: multiple beam directions emitted from same point
    -> volume averaging of wind

Ground based

Nacelle based



TKI WIND OP ZEE

FLOW

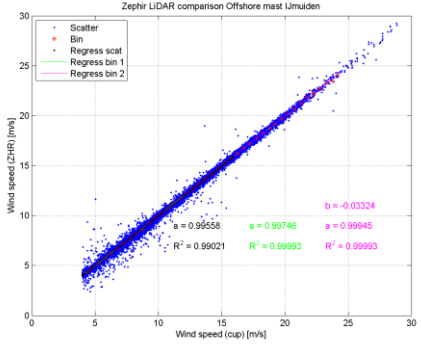
Applications

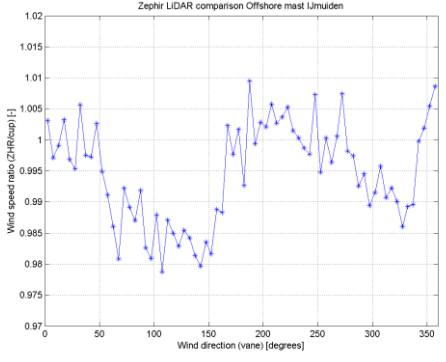
Wind resource assessment (offshore)

- Meteorological mast IJmuiden (FLOW, RWE)

-Excellent agreement between mast and LiDAR

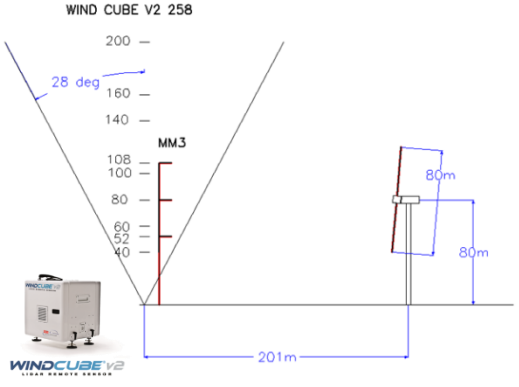
-Mast influence visible with LiDAR?

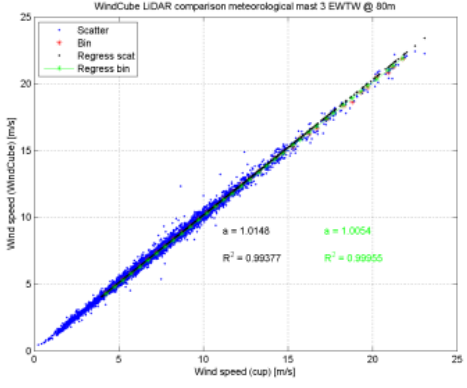




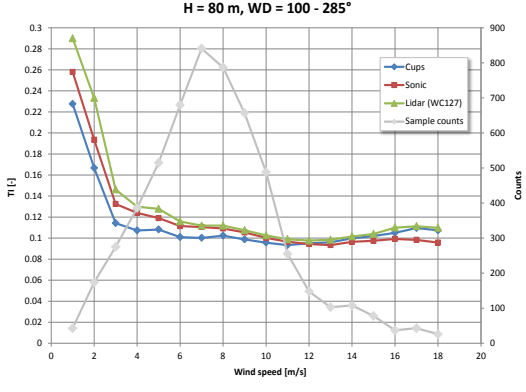
Wind resource assessment (onshore)

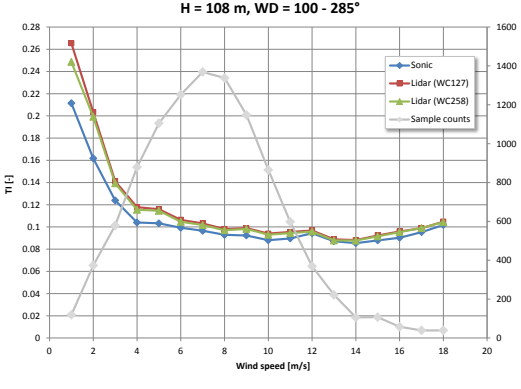
- Wind speed
  - -Excellent agreement mast vs LiDAR
  - -Wind shear and large height velocities
  - -Comparison against real turbine performance (pending)





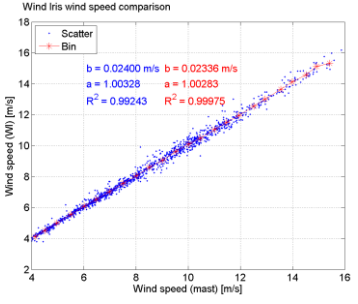
- Turbulence intensity
  - -Against cup (80m) and sonic (80m,108m)
  - -Cup inertia at low velocities
  - -Volume averaging vs vector cross term
  - -Repeatability between LiDARs

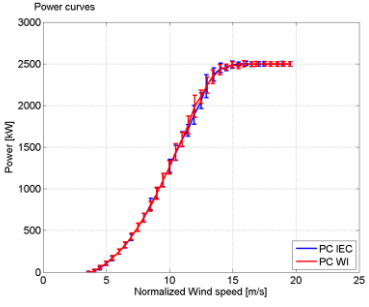




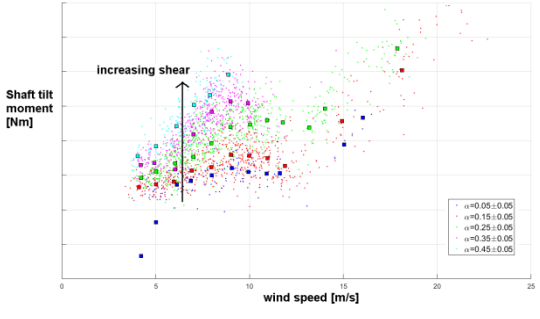
Turbine measurements

- Power performance (nacelle based)
  - -Very well wind speed comparison with mast (2.5D, undisturbed sector)
  - -Very well power curve + uncertainties comparison

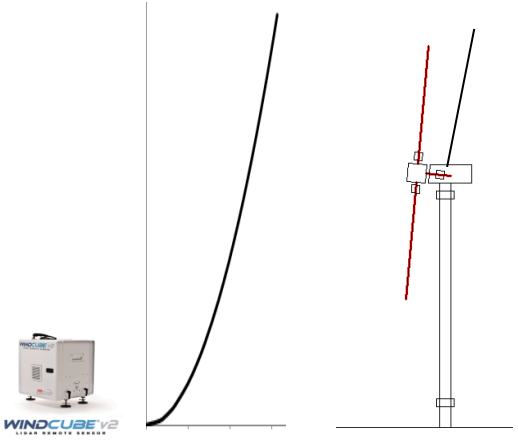




- Loads assessment (ground based)
  - -Influence of wind shear and stability



Tilt moment



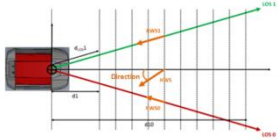
TKI WIND OP ZEE

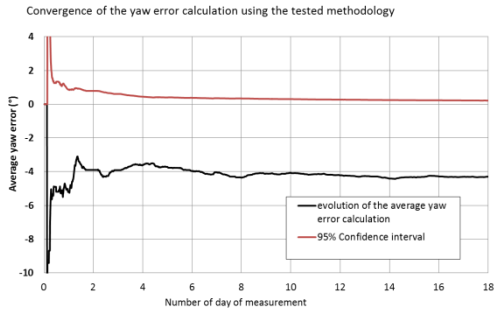
FLOW

Optimization of turbine performance

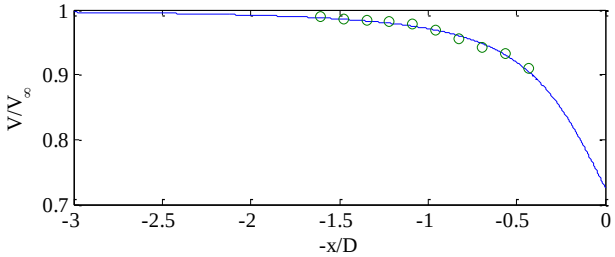
- Yaw misalignment

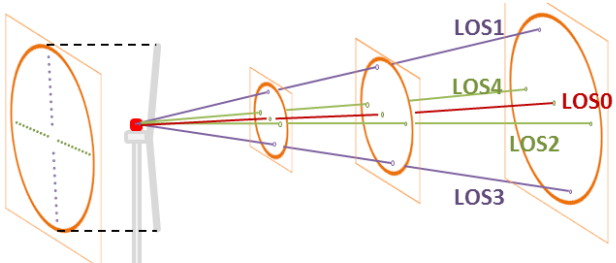
-3.6º (± 0.5º) offset determined in 7 days with accuracy of 95%

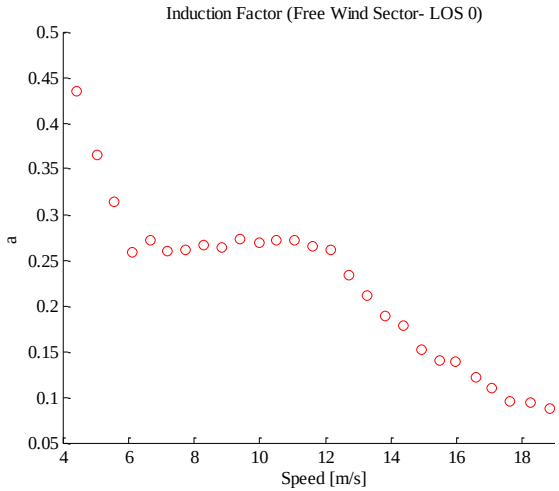




- Verification of blockage (axial induction)







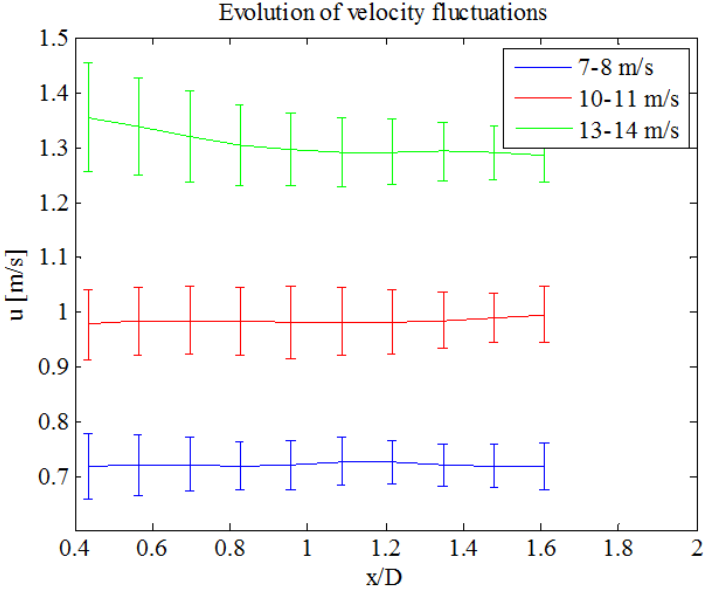
TKI WIND OP ZEE

FLOW

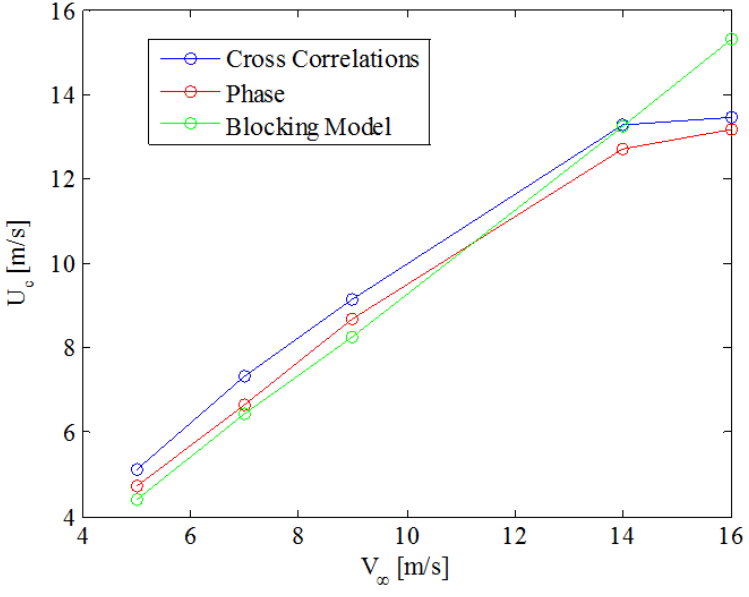
Optimization of turbine performance

- Feed forward control: Gust anticipation with nacelle LiDAR

Turbulence evolution



Turbulence convection



TKI WIND OP ZEE

FLOW

Optimization of wind farm performance

- Active wake control by yawing the rotor

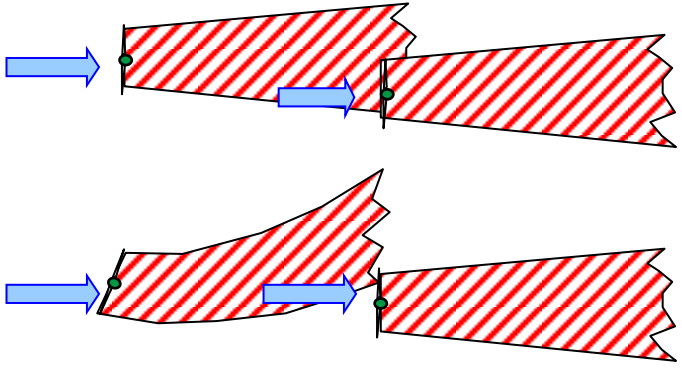
Wake characterisation is needed

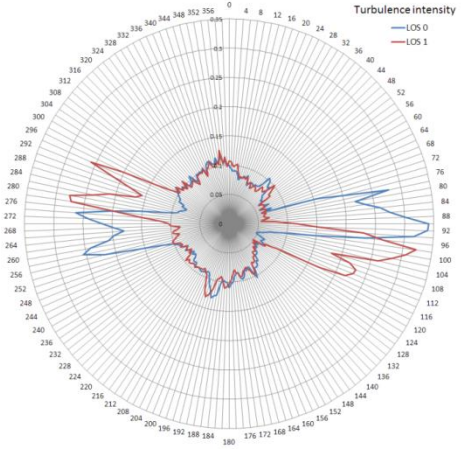
-Wake location

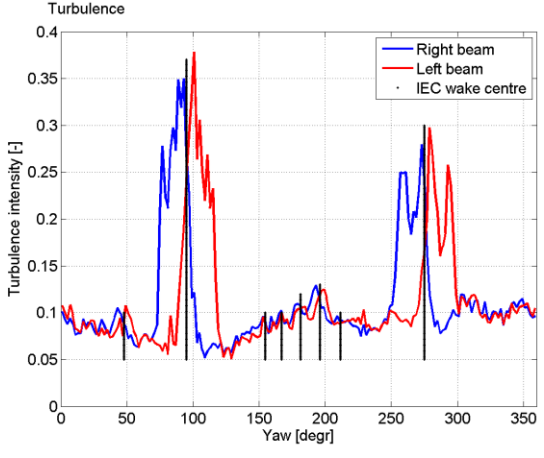
-Wind speed deficit

-Meandering

- Nacelle LiDAR (forward looking)





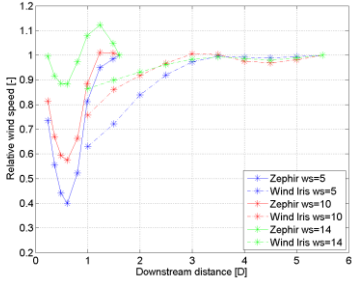


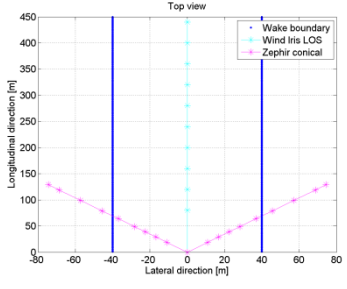
TKI WIND OP ZEE

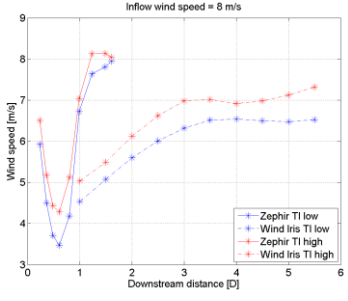
FLOW

Wake characterisation

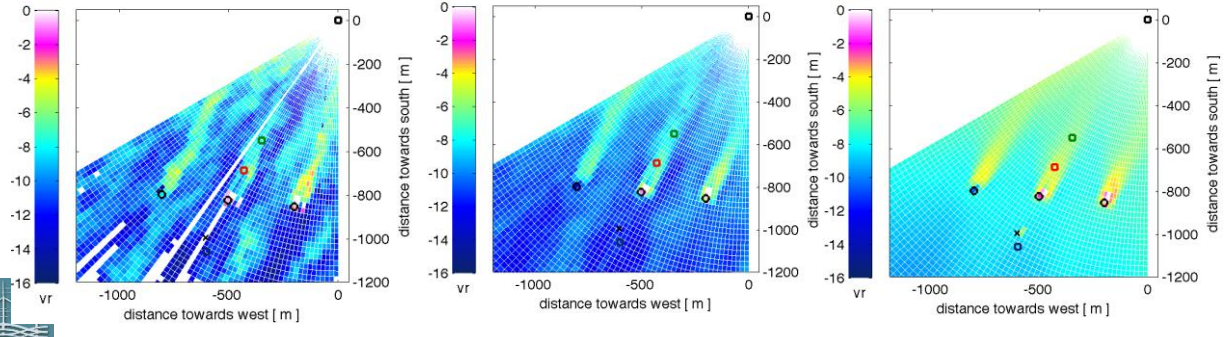
- Nacelle LiDAR (bckwd looking)
  - -Wind Iris (pulsed)
    - 1 beam along nacelle, 1D – 5.5D
  - -Zephir (continuous)
    - Conical scan, 0.24D – 1.6D







- Scanning LiDAR
  - -Acknowledgement to V. Kumer (UiB)



WINDCUBE 100s/200s/400s

TKI WIND OP ZEE

FLOW

Summarising…

Application summary

- Wind resource assessment

-Multiple heights and locations, REWS, higher heights etc.

- Turbine measurements (PV, Loads etc.)

-Improved correlation between performance/loads and wind statistics

-Verification of manufactured specified power curve

- Wind turbine optimization

-Yaw misalignment -Verification of and research into turbine performance

-FF control for gust load alleviation

- Wind farm optimization

-Active wake control (tuning the wake to maximize performance) using wake location and velocity

-Validation of wake modeling

-Better estimate of load accumulation (Fleet leader)

Concluding…

Conclusions

- Use of LiDARs to increase wind energy efficiency investigated for various applications
- Several advantages over conventional mast

-Cost effective replacement (especially offshore), easy to relocate, no permits

-Additional measurement capabilities (e.g. more measured points both horizontal and vertical)

- Large successful test campaign has been set up for demonstration

-Excellent agreement ws LiDARs vs masts on- and offshore

-Added benefit of LIDAR shown in several applications

- But..

-Acceptance hampered by calibration against cup

- Outlook to the future

-Better calibration procedure reducing LiDAR uncertainty

-Demonstration of optimized wind farm operation using LiDAR


Thank you &
questions please
Special thanks to:
avent
LEOSPHERE
TUDelft
TKI WIND OP ZEE
FLOW
XEMC
sea-change in wind energy
DARWIND
ECN