20 year's with remote sensing - Lessons learned

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with

Contributions from

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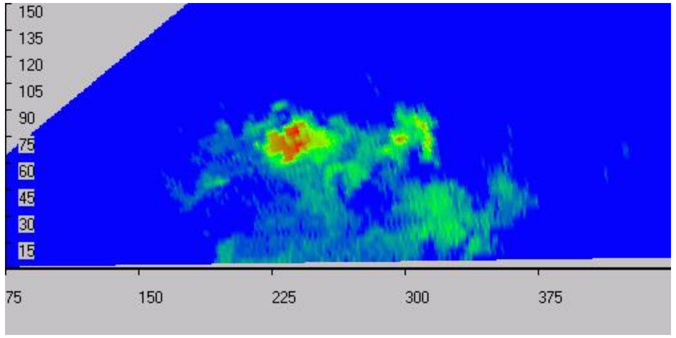
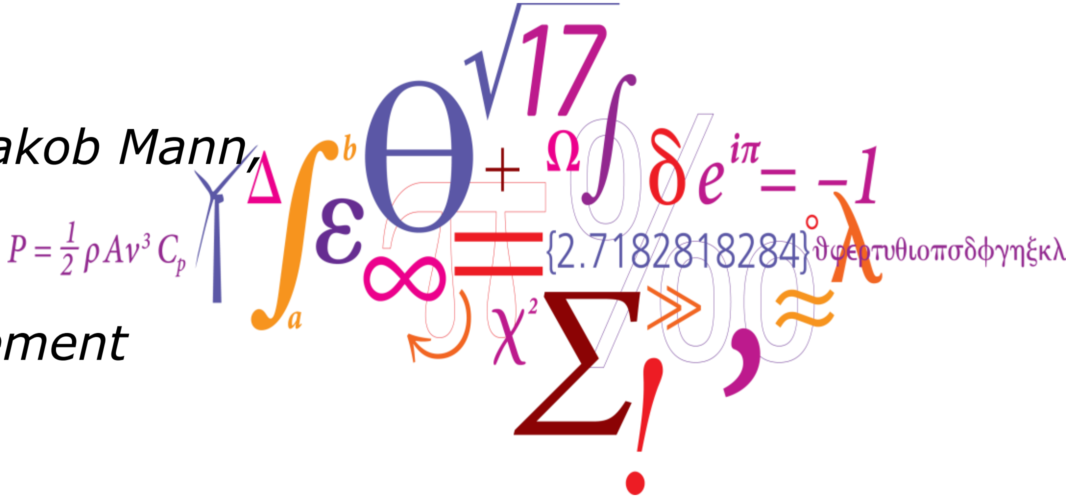
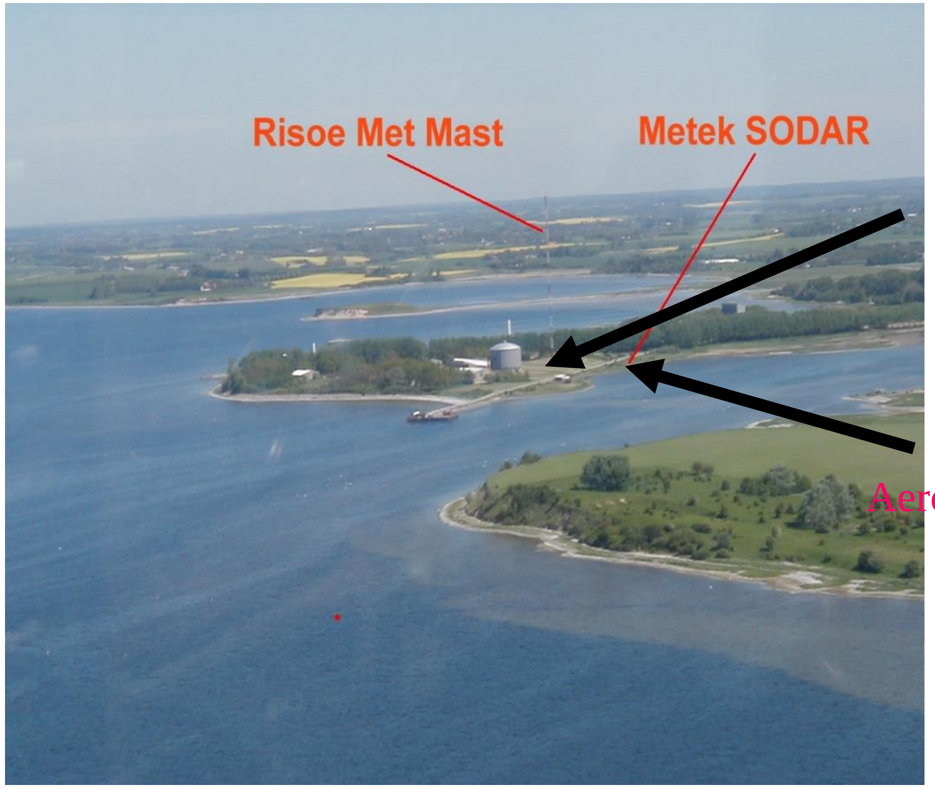
Special thanks to the section:Test and Measurement At DTU wind



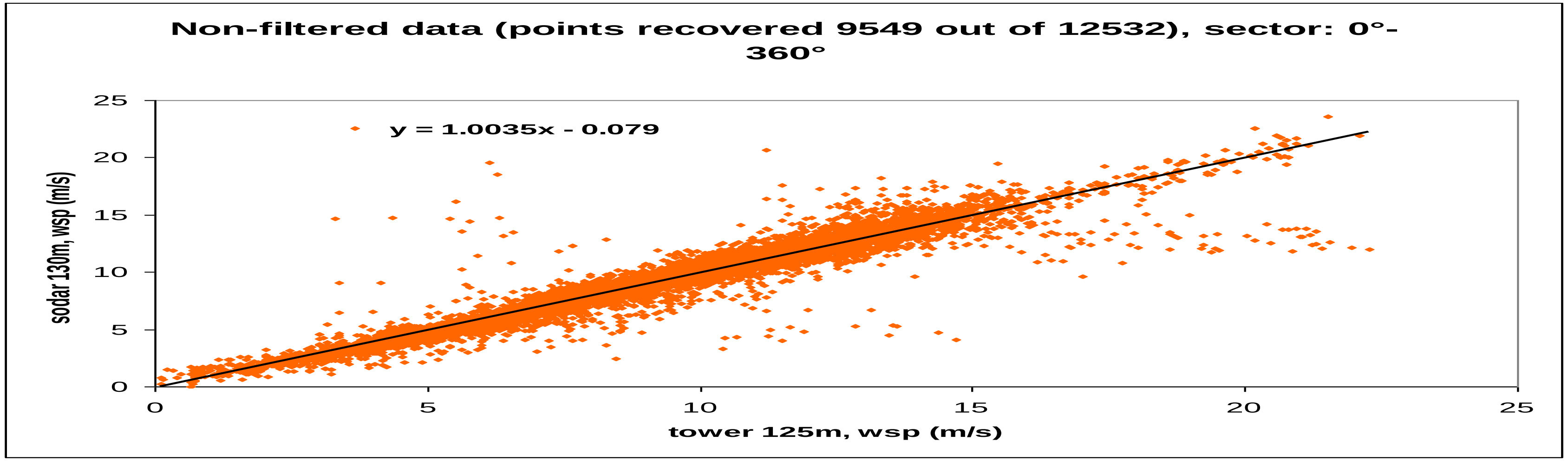


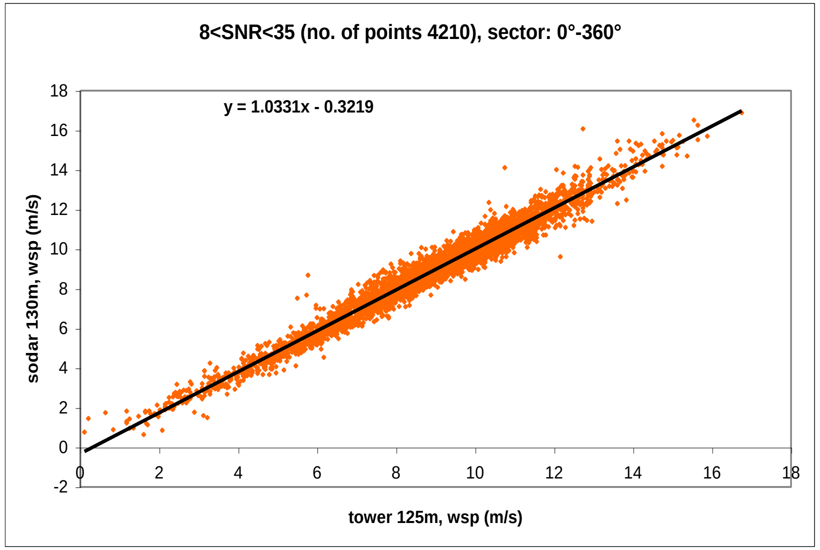
DTU experiment in 1999



- Test wether we should buy a Metek or an Aerovironment Sodar (phased array)
- Storm in december 1999 !!!!!!
- Decision to buy an Aerovironment sodar on wrong reasons (a good offer)

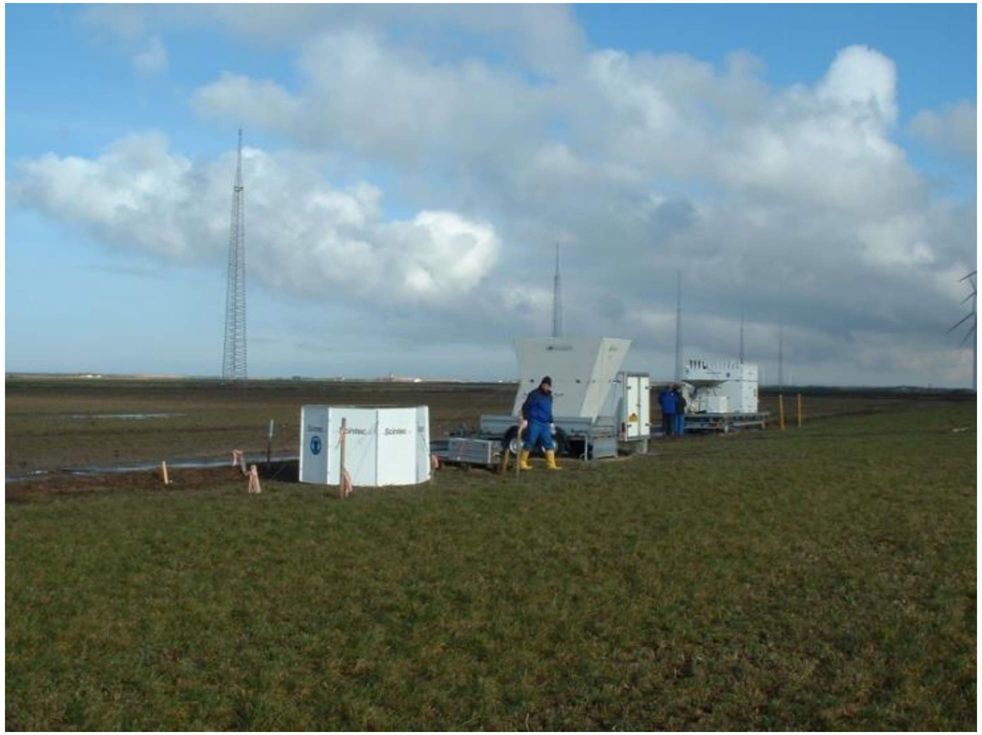
Sodar data vs cup from 1999





- Filtering was necessary to obtain resonal results
- Difficult to chose an objective filtering (based on physics of the atmosphere – Neutral vs Stable/unstable)
- Effects of only three beams (location of sample volume etc – 5 beam solves this problem)
-

The PIE experiment 2004 in the WISE project



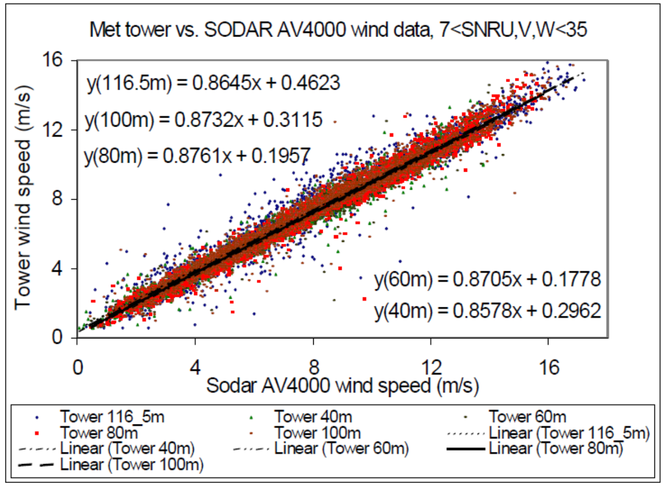


Figure 9 The AeroVironment AV4000 wind speed data

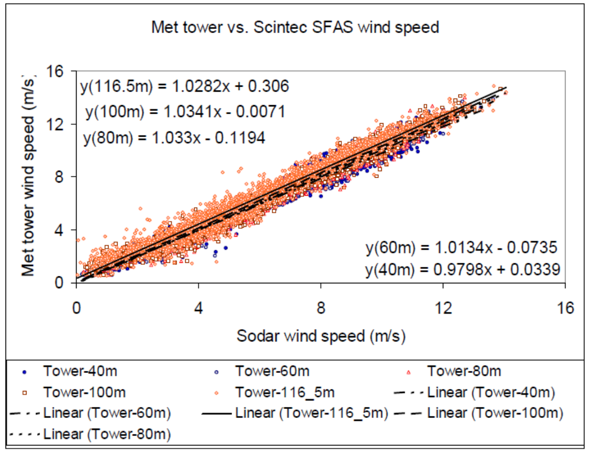


Figure 8 The Scintec SFAS wind speed data

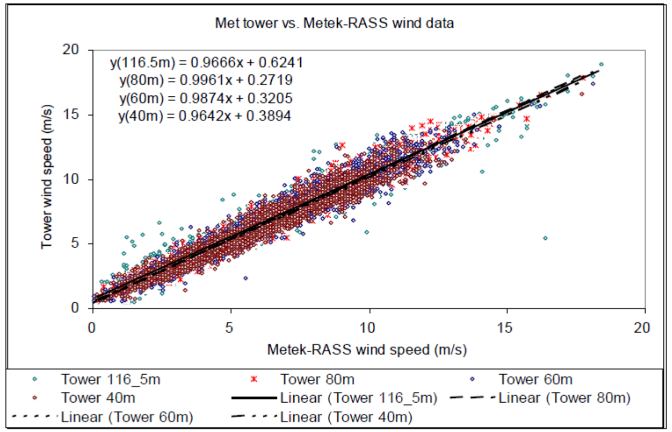
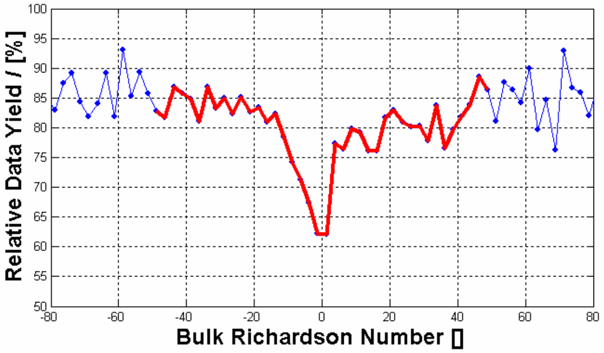


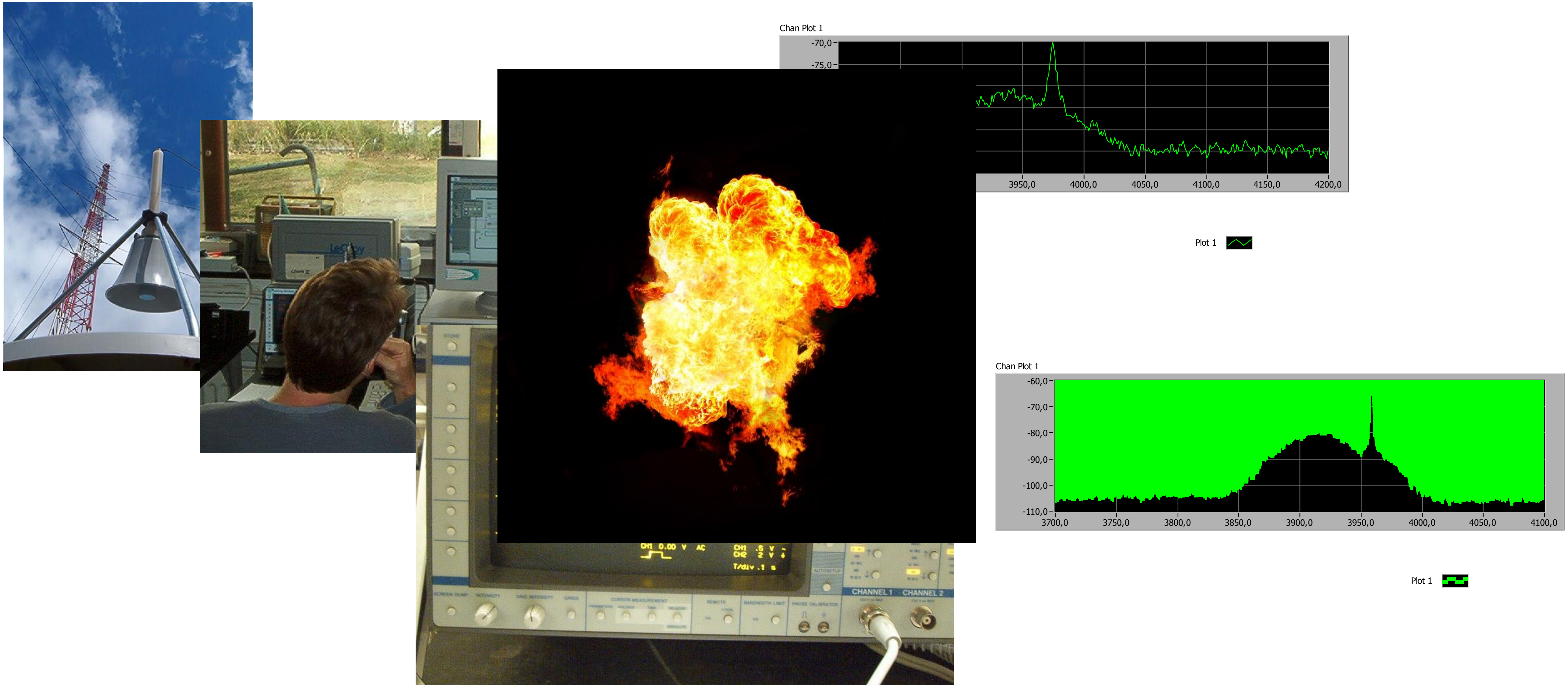
Figure 7 The Metek RASS wind speed data



- Large scatter – biases in the comparisons etc

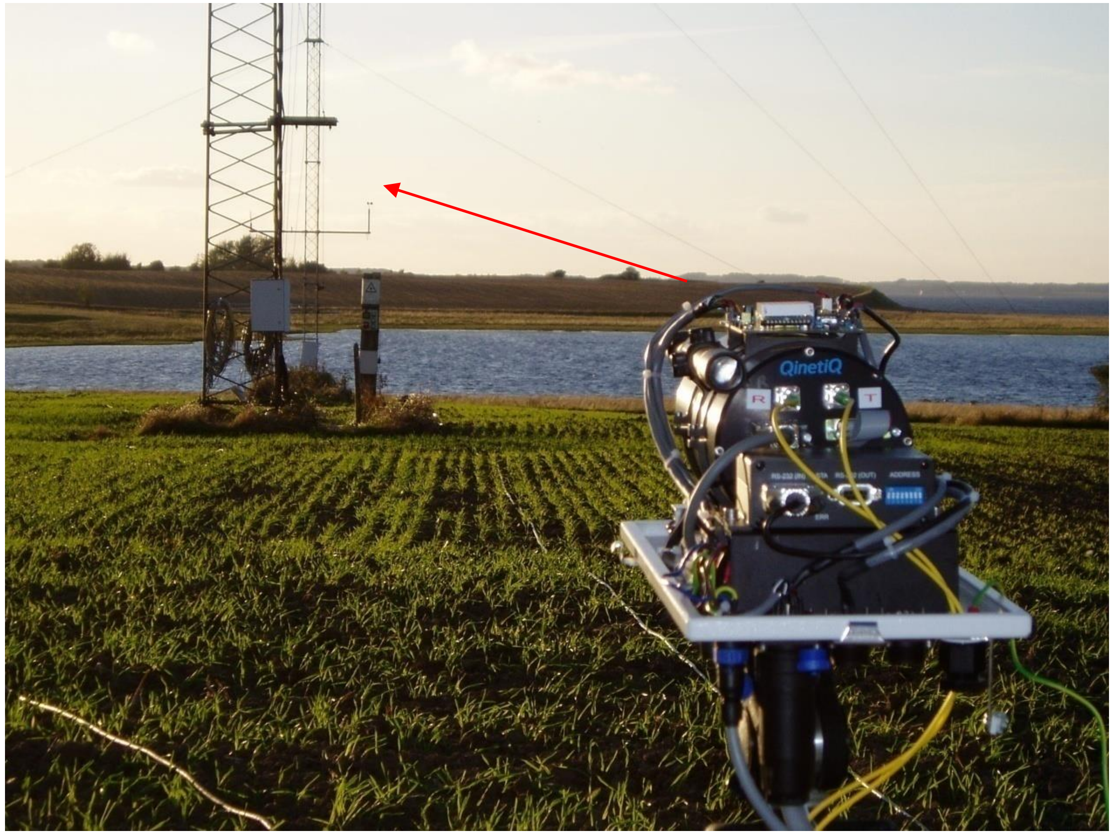
Heimdal...: (A scientific detour)

...first bistatic "Wind Energy SODAR" Risø 2004 www.risoe.dk/rispubl/reports/ris-r-1424.pdf



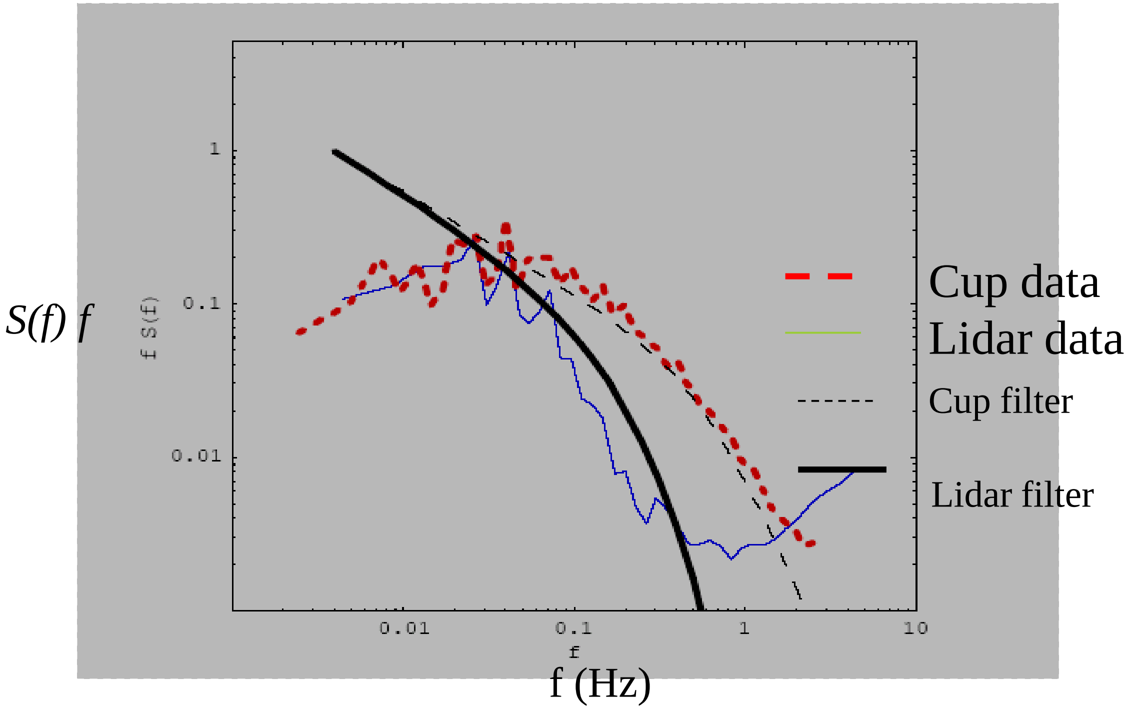
Expermental setup #1:

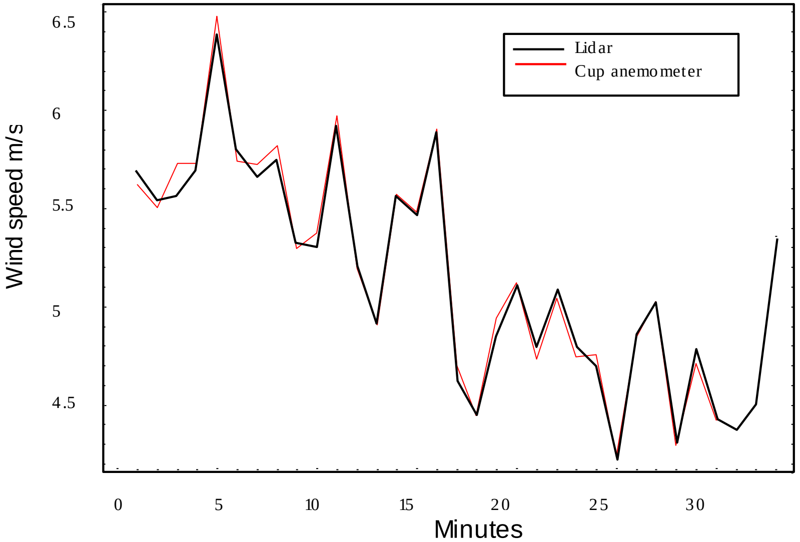
QinetiQ's Gray ZephIR PROTOTYPE 1 at RISØ 2003:

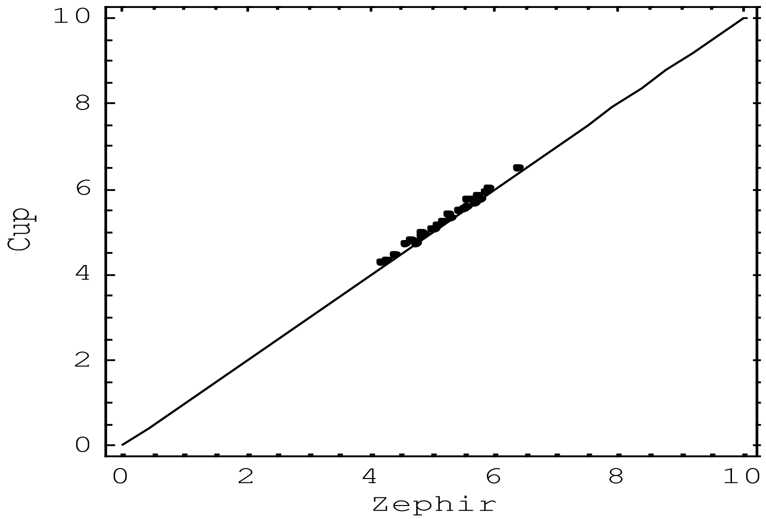


Turbulence measurements and mean values measured with the CW Lidar

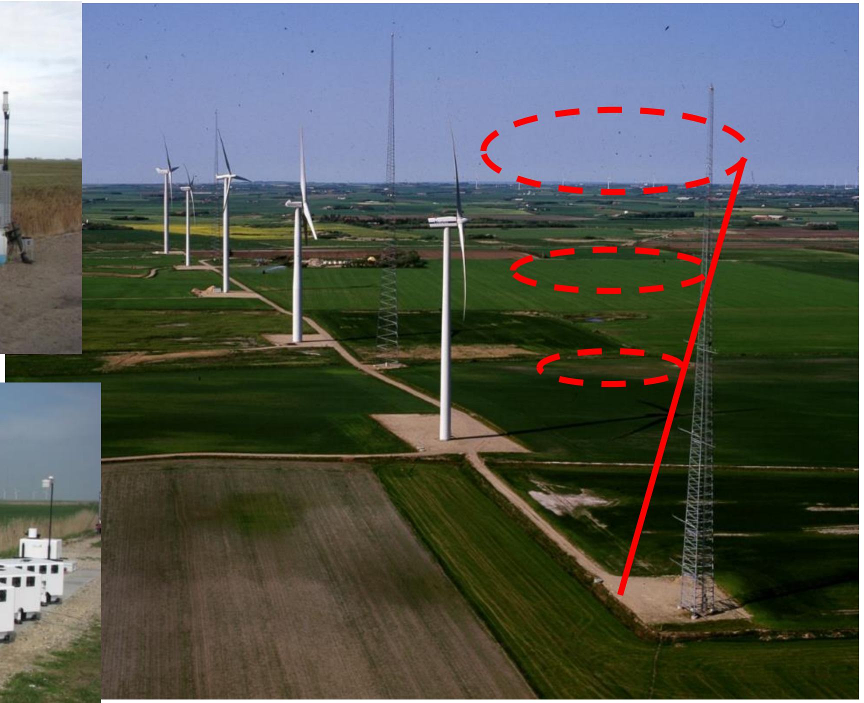
Lidar test: Beam pointed upwind:

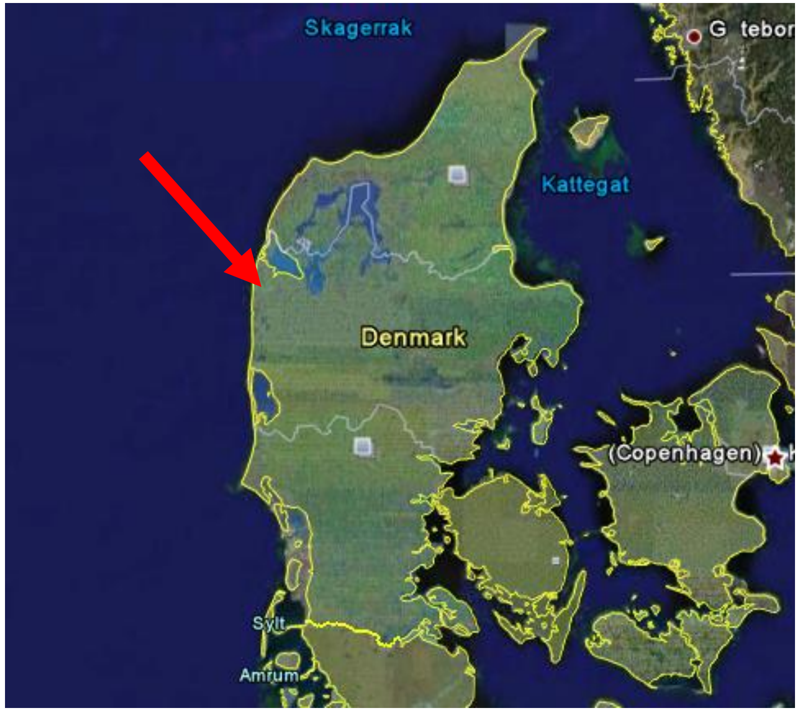






Testing LIDARs in Høvsøre 2005-2009



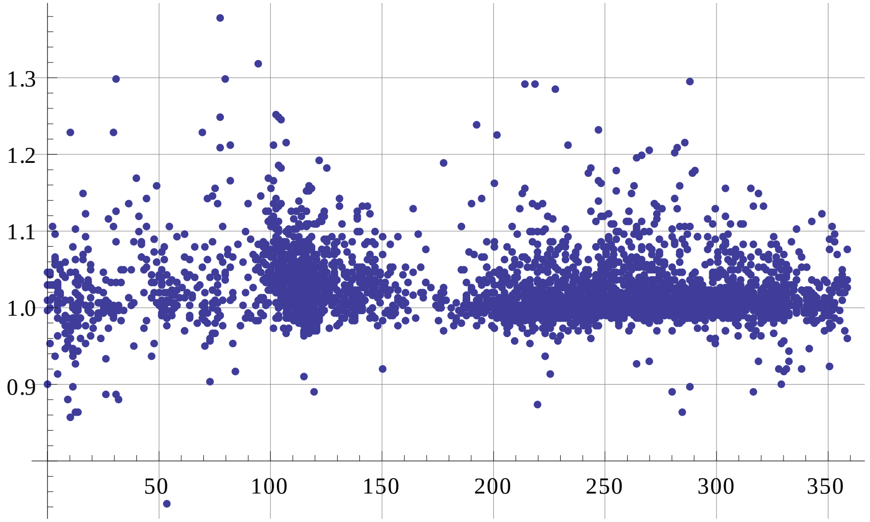


Høvsøre Large Wind Turbin Test Facility

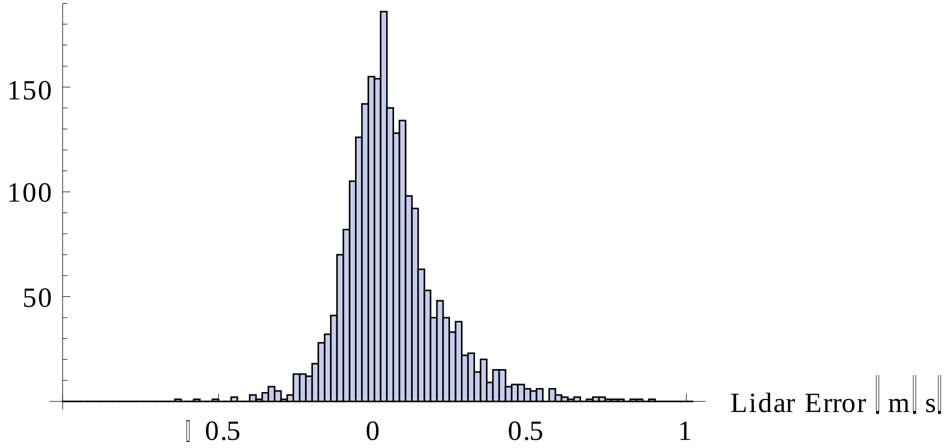
- West coast of Denmark, flat terrain, wide range of horisontally homogeneous wind speed.
- Site equipped with rain and cloud sensors
- **20** Zephirs and Windcubes tested
- **50** months of comparison with class 1 cup anemometers @ 40-116 m (160 m)
- Data from 2 other flat sites evaluated

Comparisons of 10 minute average horizontal speed

Lidar/cup vs direction @ 116.5 m



Lidar - Cup



Data screened on rain and CNR and cup speed >4.

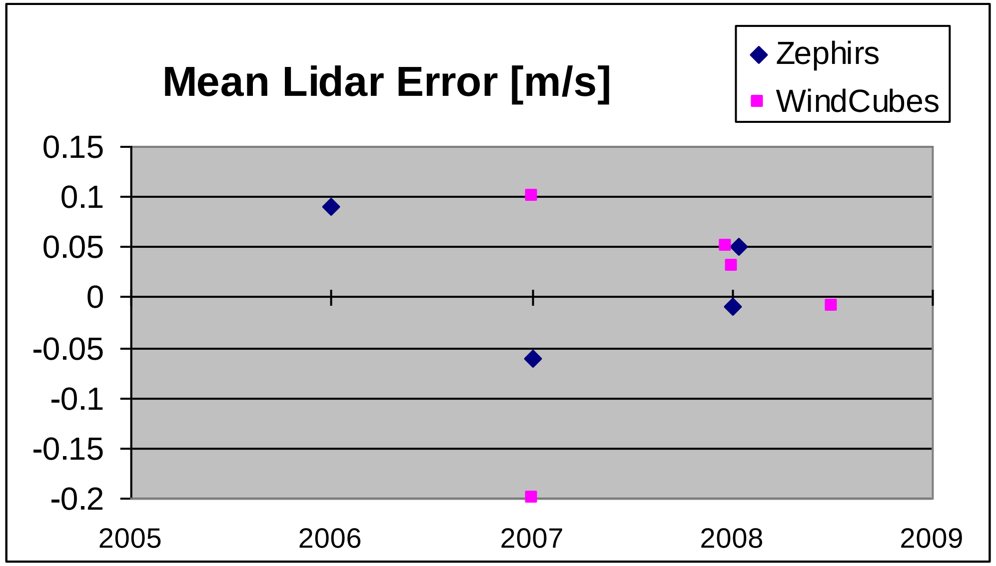
Availability (in rain-free) = 92%

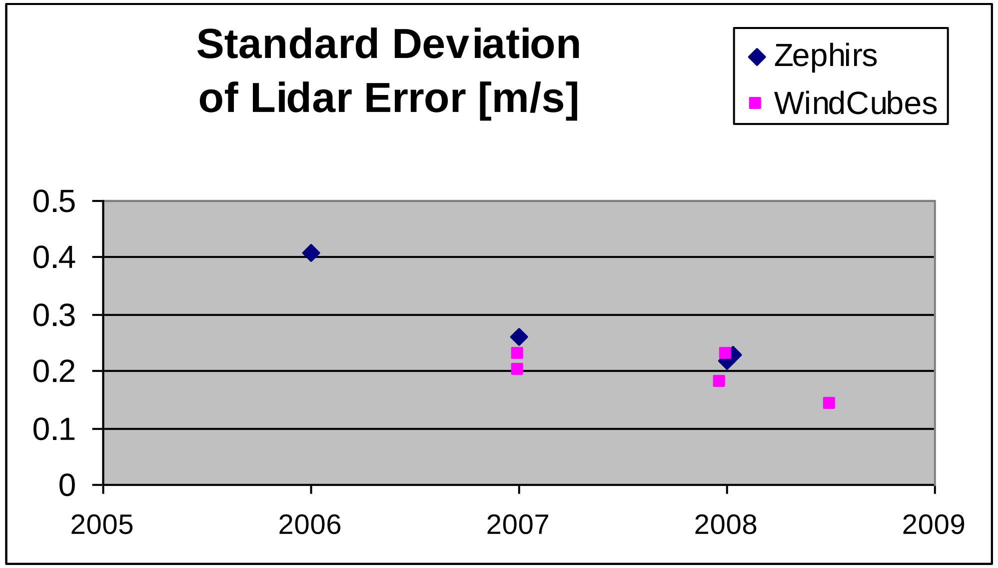
Mean: 0.11 m/s

σ: 0.23

(turbine wakes screened 350-10°)

Development of Wind Sensing Lidars (*based on UPWIND remote sensing wp*)





2006: Zephir commercial model introduced. Hardware issues.

2007: Ceilometer installed, screening on clouds: positive bias and σ reduced, availability drops. Leosphere introduces Windcube.

2008: Cloud correction: availability increases. Cone angle accuracy: bias reduced.

2008.5: Cone angle accuracy Estimator improved: nonlinear problems reduced.

2009: Improved test conditions, lower RIN. Improved test conditions.

Vindicator and Galion commercial

Mean < ~±0.05 m/s σ ~0.25

Mean < ~±0.05 m/s σ ~0.15

Conclusions: Precision and Biases in Lidars 2008

Typical results in flat terrain 2008

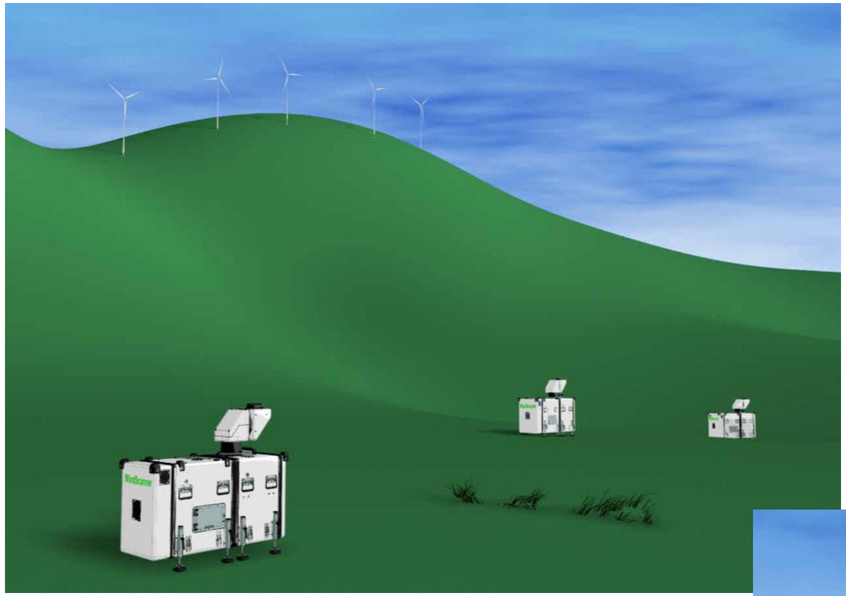
- **Mean:** **< 0.1 m/s**
- **STDEV:** **< 0.25 m/s**
- **Gain:** **< ± 2%,** observed [-6 to +2%] mitigated
- **”Altitude” error:** < **± 5 m** observed [-6 to +9]

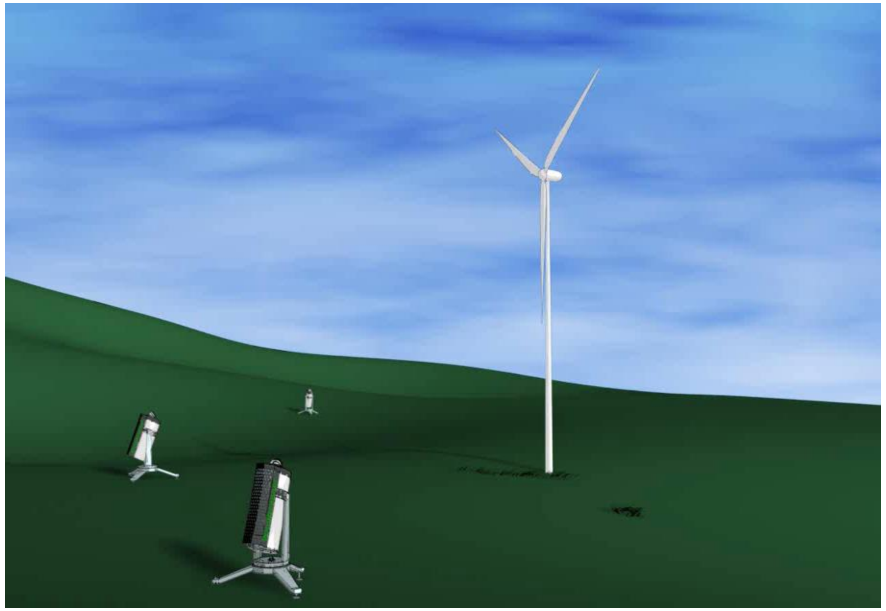
Complex terrain → Complex errors with simple intrapolation 10-20%.
Radial velocities measured with high accuracy also in complex terrain.

Conically scanning lidar concept (soon) mature for stand alone site evaluation in flat terrain! (?)
However is the hardware and the price, include power supply and repairs?
Can they offer added value?

Does lidars need calibration/verification/audit?
Heterodyne detection is selfstabilizing, lidars are not.
Hardware calibrations/verifications + acceptance tests traceable to cups on masts.

Windscanner delevoped at DTU wind from 2007 - 2011 (and onwards)





Short-range WindScanners map 3D mean and turbulence fields around single wind turbines

Long-range WindScanners map 3D wind fields around entire wind farms

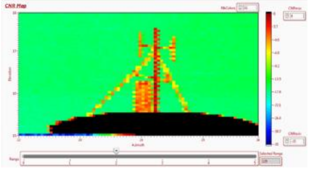
SpinnerLidars for advanced WT control

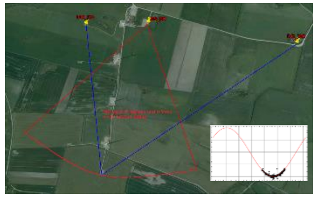
WindScanner.eu

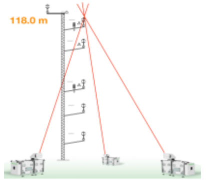
N Number of systems

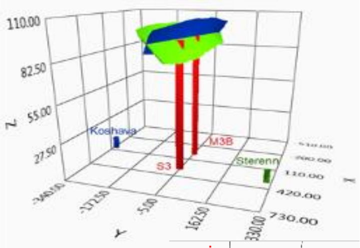
Long range windscanner 2010-2017

- ***Windscanner is born in 2010***









3 **The Musketeer experiment** – Risø – October 2012

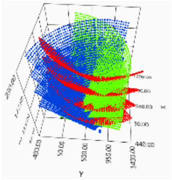
3 **Virtual Met Mast** - Risø – February/March 2013

3 **Internal Boundary Layer** – Høvsøre – June 2013

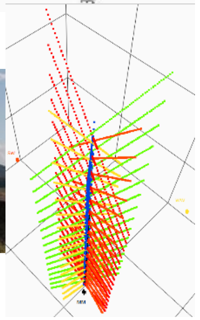
2 **6beams vs DoubleCone** – Høvsøre – July 2013

2 **Site Calibration**– Høvsøre – October 2013 to January 2014

3 **SectorScan VS Dual Doppler** – Høvsøre – May 2014

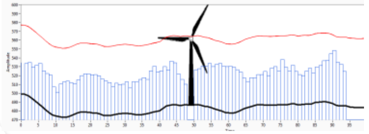


6 **The Kassel experiment** – Kassel, Germany – June to August 2014

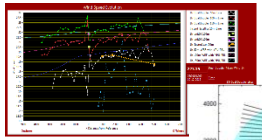


2 **Epsilon** – Høvsøre – September 2014

3 **UniTTE** – Risø – November 2014 to January 2015

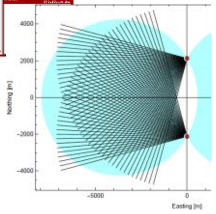


3 **Perdigão/UniTTE/FarmOpt** – Perdigão, Portugal – May to June 2015

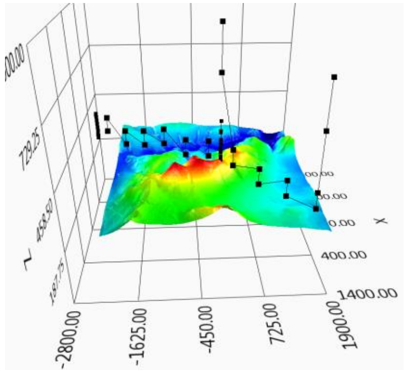


3 **RUNE** – Høvsøre – October 2015 to March 2016

2 **Balcony** – Østerild – March to August 2016



3 **Björnafjord** – Haukanes, Norway – April to June 2016

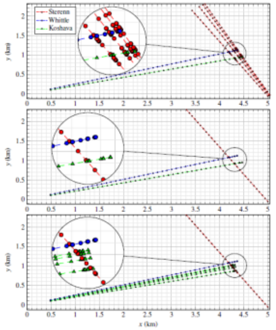


9 **Kassel2016** – Kassel, Germany

September to December 2016

12 **Perdigão 2017** – Perdigão, Portugal

January to August 2016



History: Active application

02/2013 Swinging musketeer
06/2013 IBL WiSH
07/2013 6-Beam experiment
10/2013 Site calibration
05/2014 Sector Scan vs Dual-Doppler
07/2014 Kassel-2014
09/2014 Epsilon
11/2014 Nordtank inflow measurements
05/2015 Perdigão-2015
07/2015 Perdigão After Party
09/2015 pre-RUNE campaign
10/2015 RUNE
03/2016 Balcony
04/2016 Björnafjord campaign
09/2016 Kassel-2016
02/2017 Perdigão-2017
03/2017 Waffle
04/2017 Beacon calibration
10/2017 Lascar
03/2018 Alex
08/2018 Multi-rotor wake

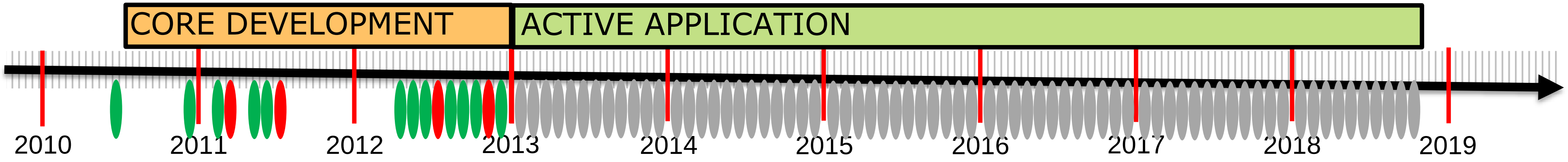
☺

Impressive pointing accuracy
Multi-lidar vs Mast fantastic comparison
Moved the whole lab from DK to DE
Running campaign via mobile network

☹

Low clouds = data availability
Low mobile coverage for some spots
Hitting hard targets (mast guidewires)

https://doi.org/10.3390/rs8090782



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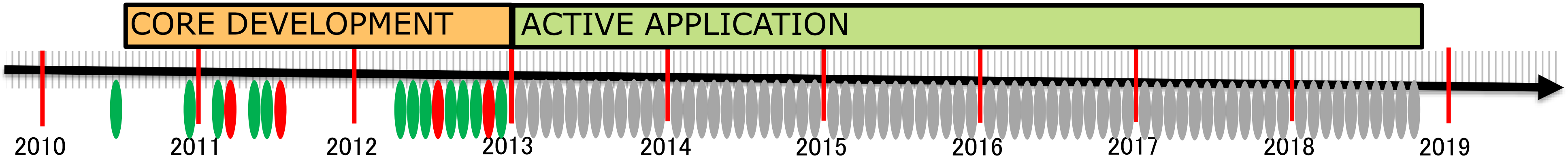
02/2017 Perdigão-2017
03/2017 Waffle
04/2017 Beacon calibration
10/2017 Lascar
03/2018 Alex
08/2018 Multi-rotor wake

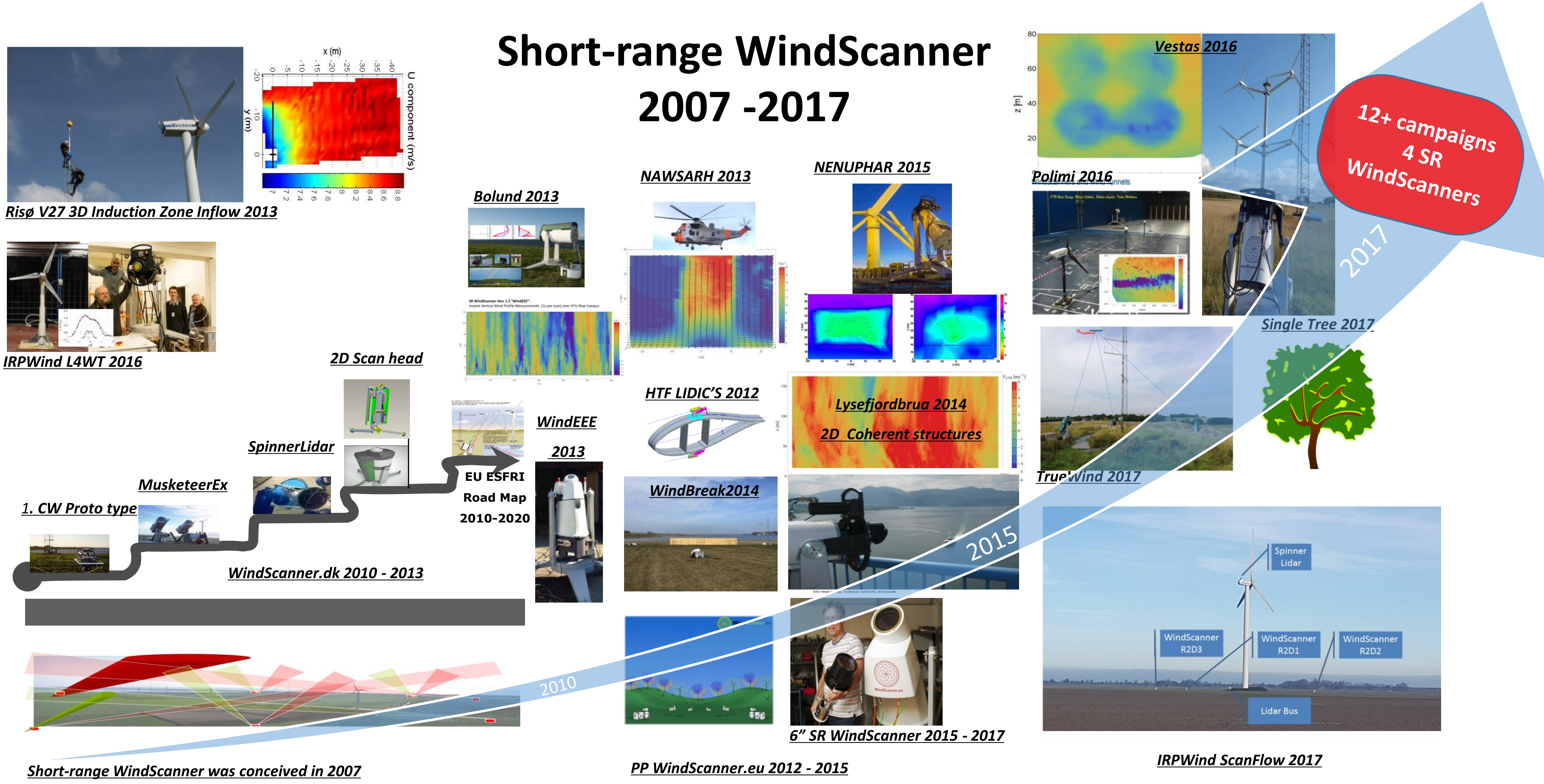
☺
First hard-core installation
Running WindScanners using generators
Scanned wind resources along a ridge

☹
Air too clean = data availability ?
Too hot = WindScanners needed siesta

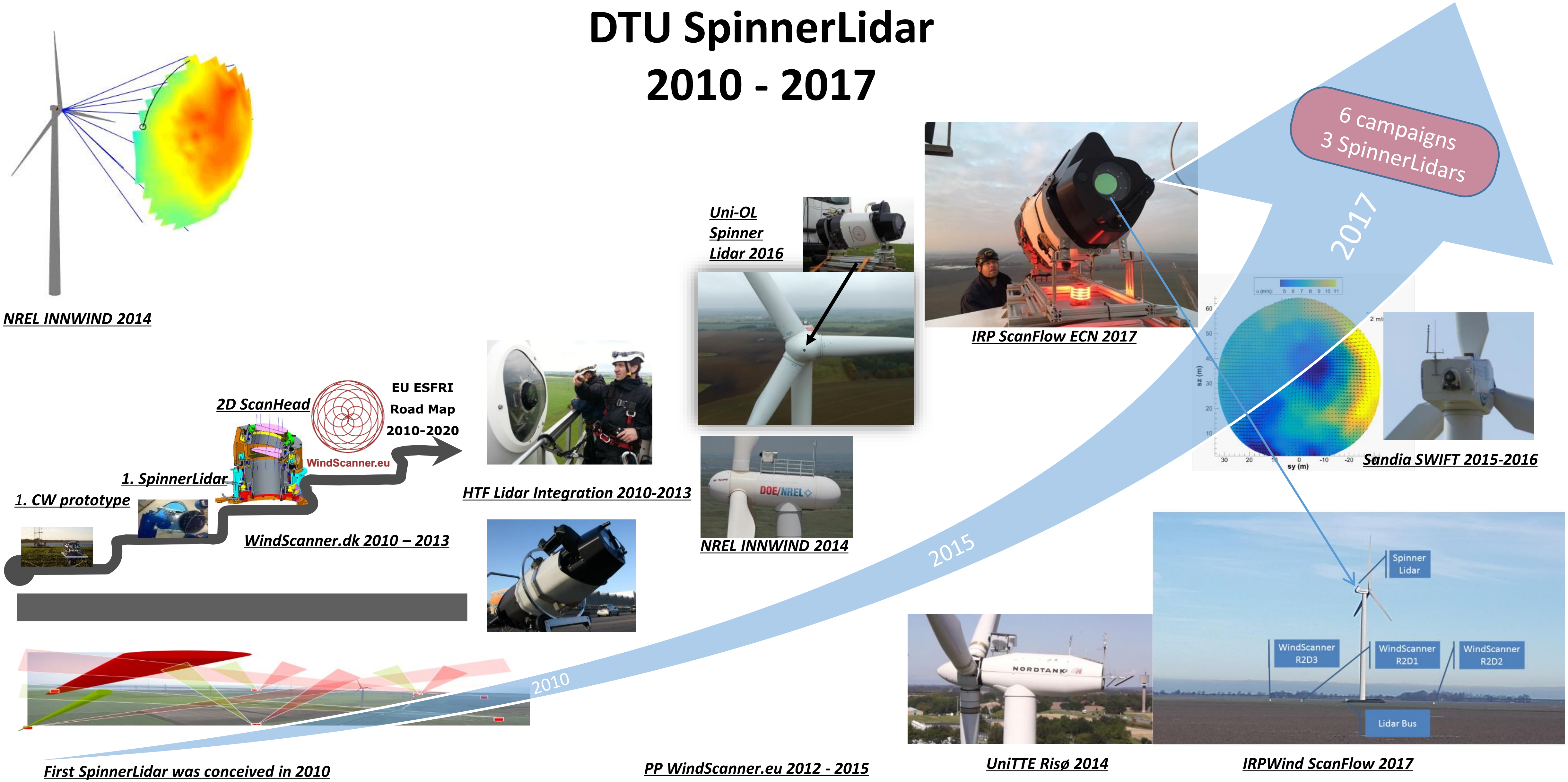
https://doi.org/10.5194/amt-10-3463-2017



Short-range WindScanner 2007 -2017



DTU SpinnerLidar
2010 - 2017

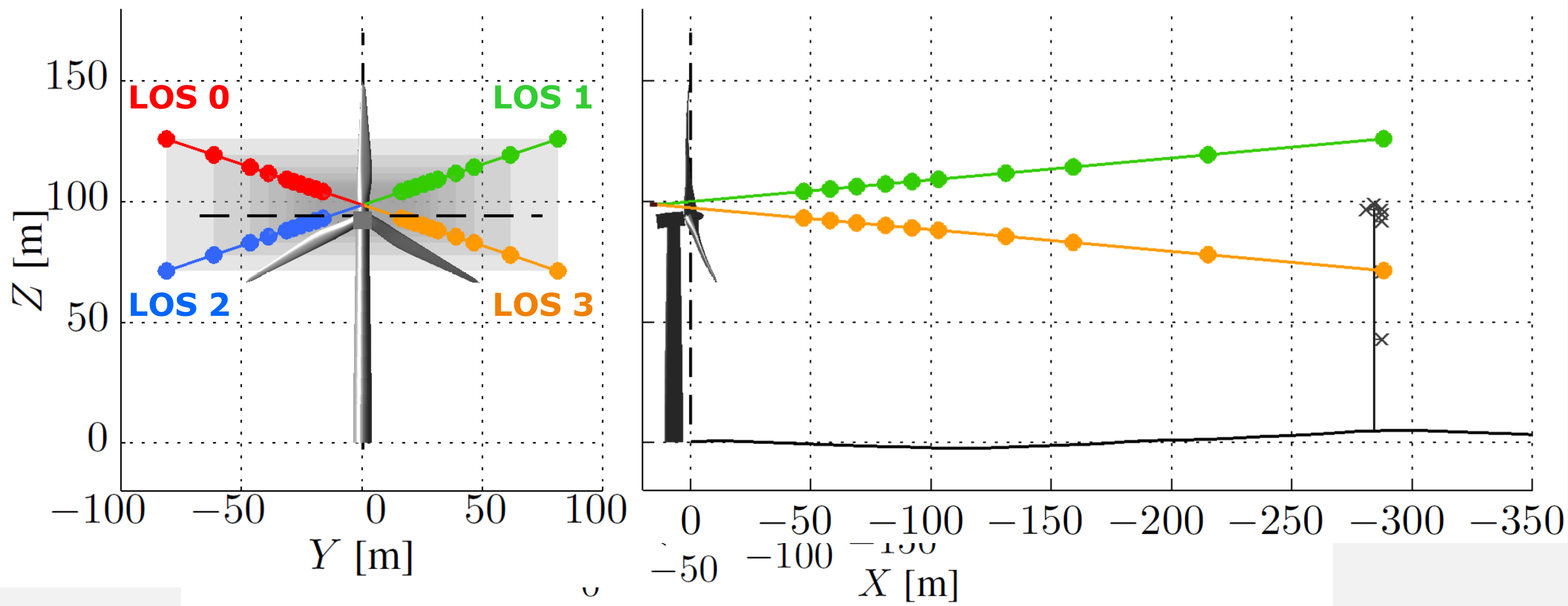


Some Cool examples of the new lidars

The UNITE project (How to use nacelle lidars for Wind Energy) - *Exampe Ogorje's nacelle lidar*

- **Nacelle lidar trajectory**
  - 4-beam Wind Iris
  - 10 dist., half-opening angles = 15° (hor.) and 5° (vert.)

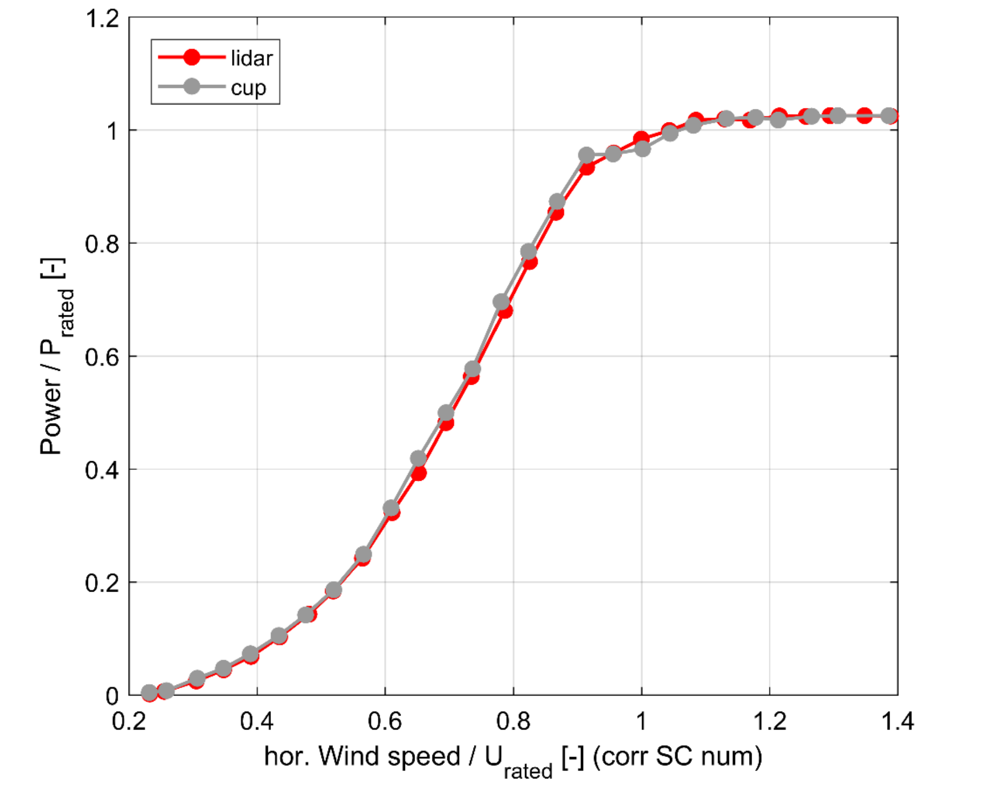
range	#	1	2	3	4	5	6	7	8	9	10
	[m]	61	72	83	95	106	117	145	173	229	302
	[-]	0,42 D	0,52 D	0,62 D	0,72 D	0,82 D	0,92 D	1,17 D	1,42 D	1,92 D	2,57 D



Power curve – wind-induction model @4 dist

binned

- Mast: top cup wind spd, corrected with SC (numerical)
- Lidar: free stream wind spd V_∞, no correction

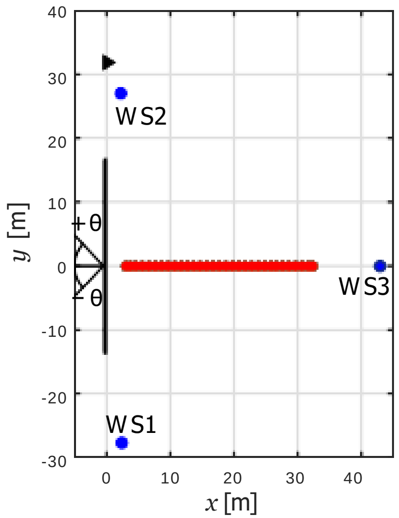


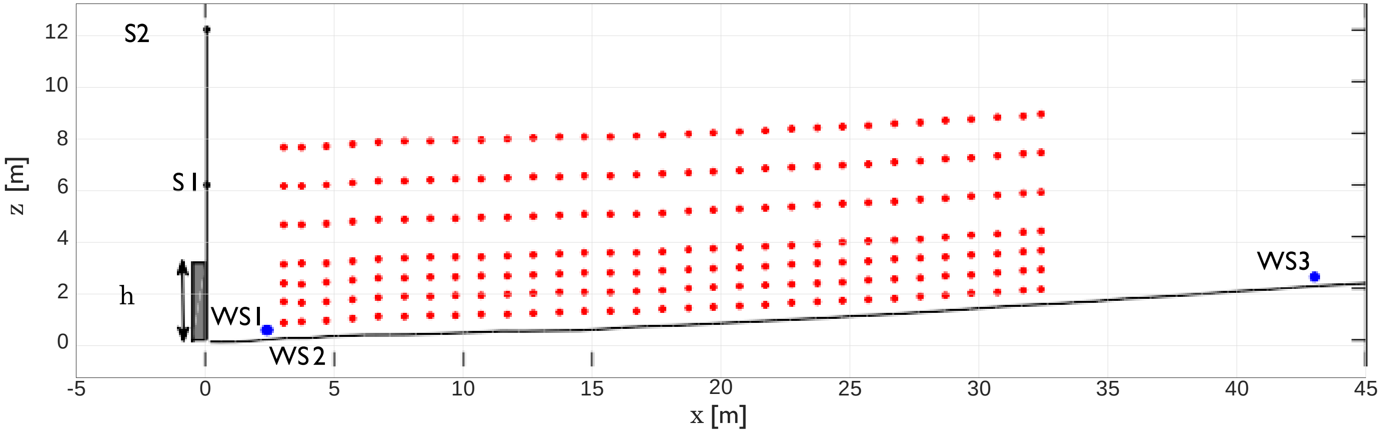
➔**Much higher agreement when using numerical SC…**

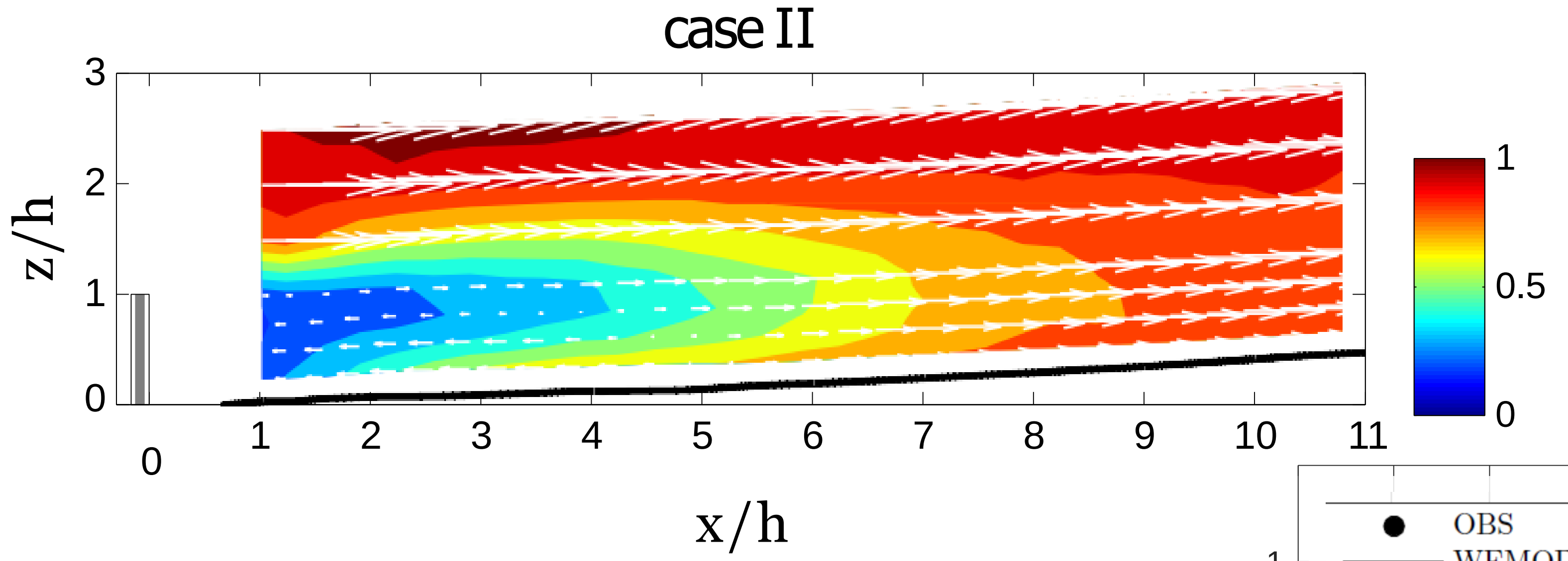
➔It does not mean this is the right one (just that SC suck)

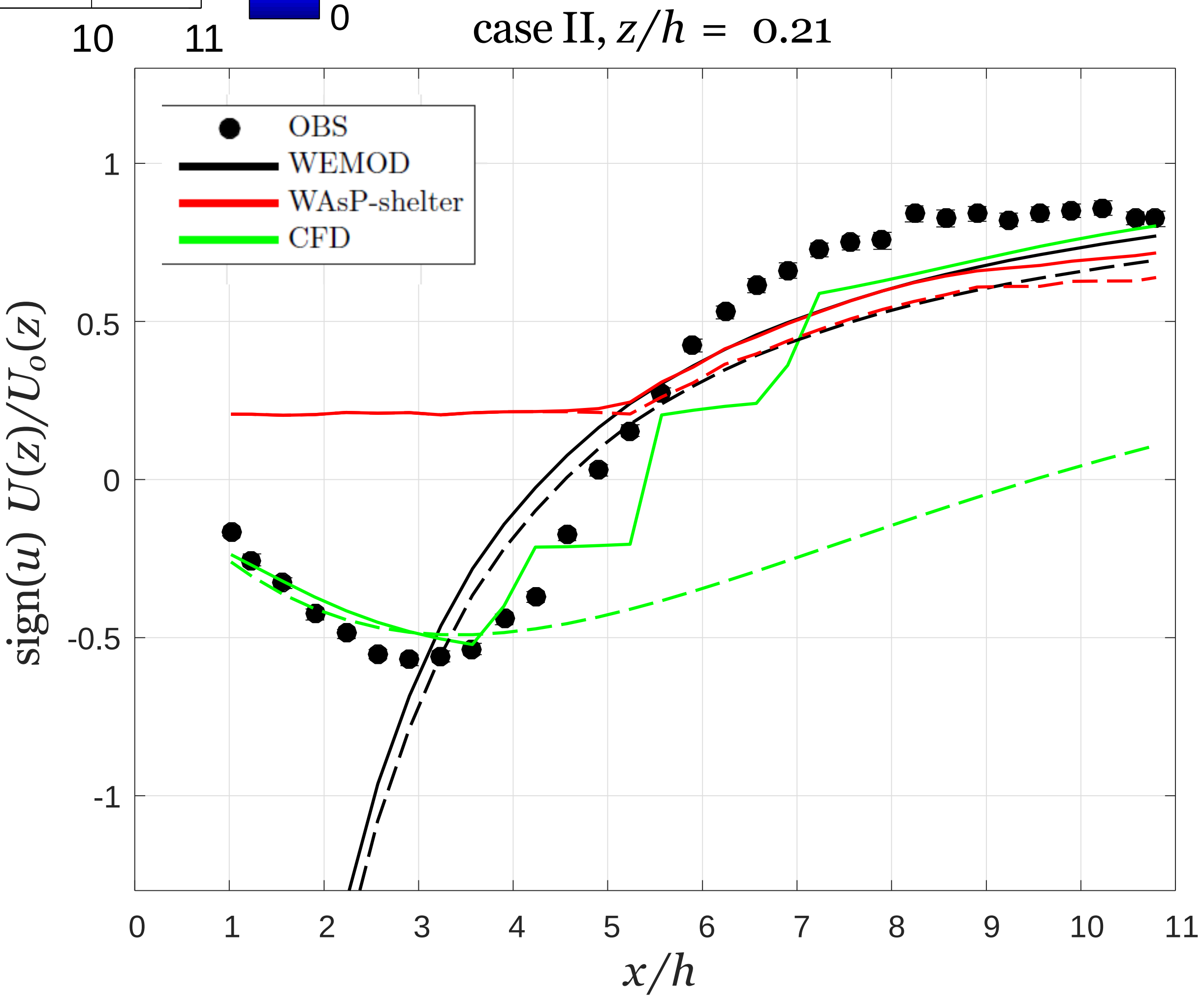
The fence experiment in 2014

Case II: $\vartheta = 0 \pm 30^\circ$, $\langle z_o \rangle = 0.0019$ m, $\langle z/L \rangle = 0.015$, 304 full-scans



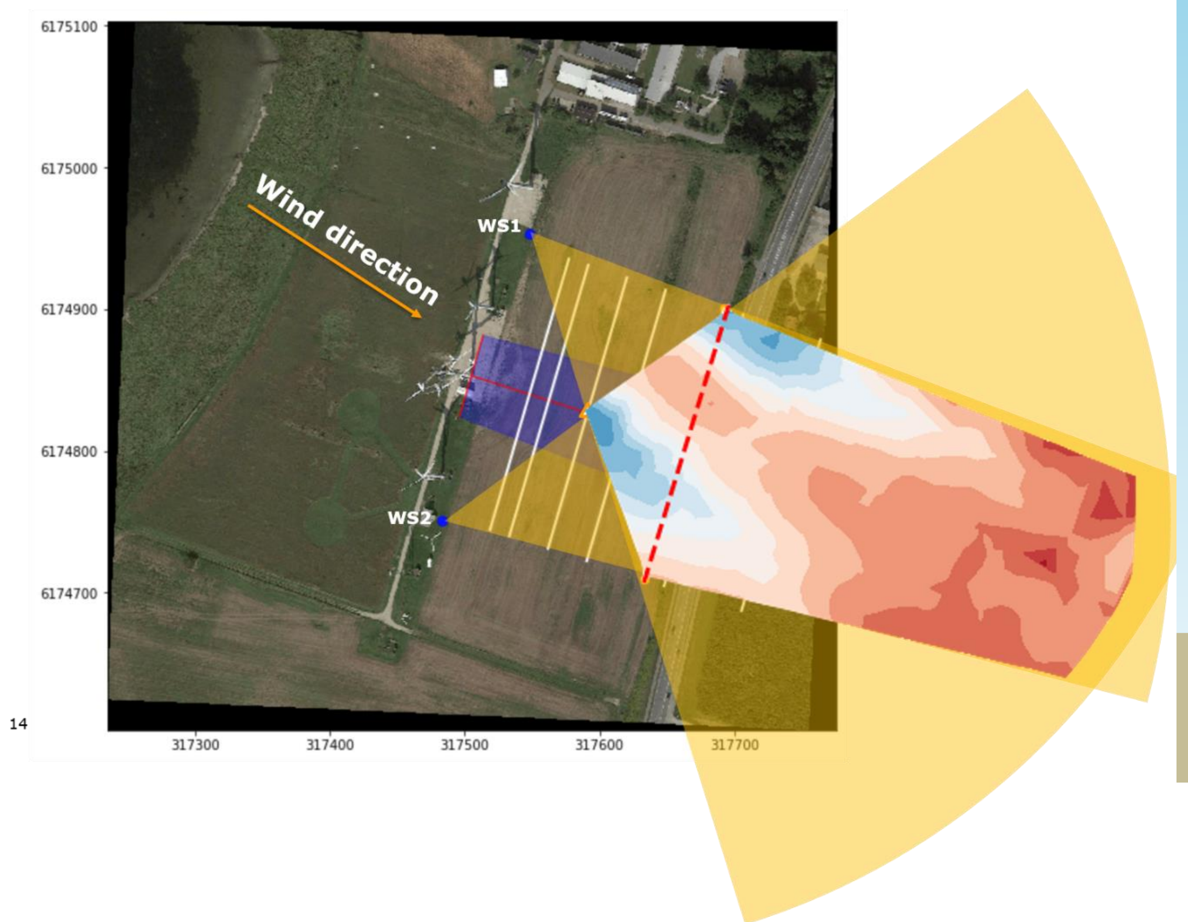


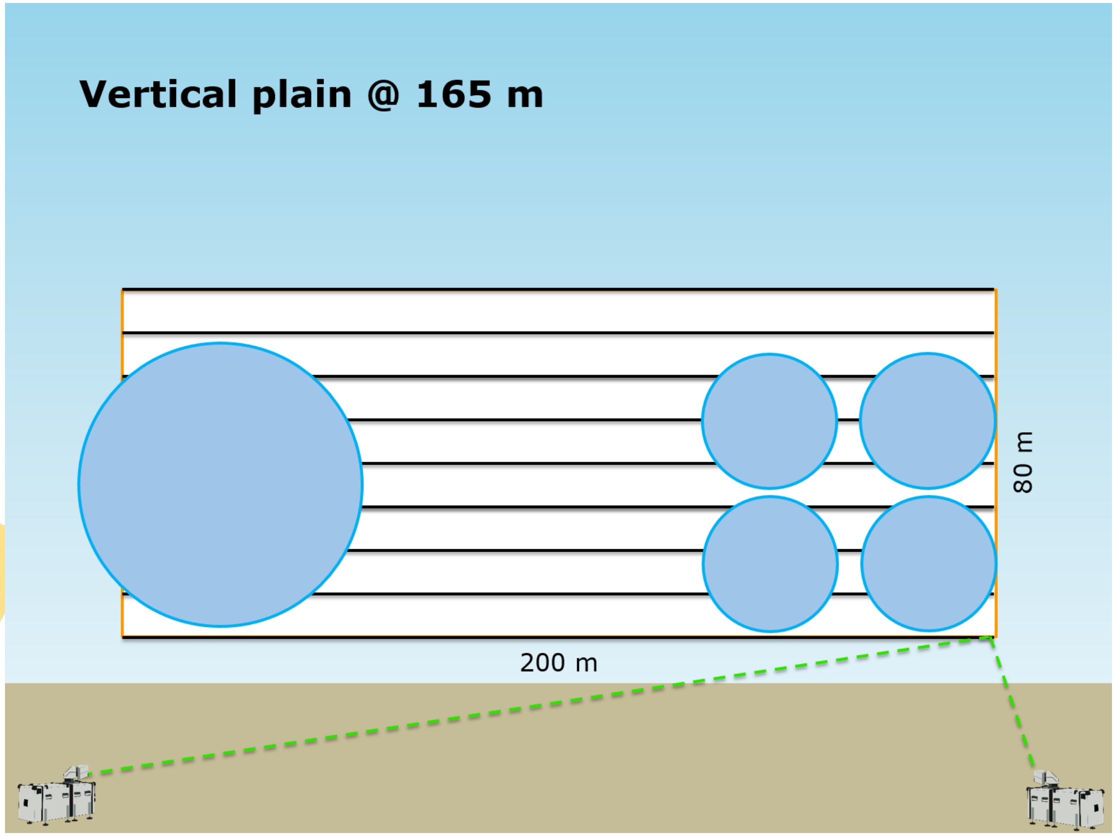

case II
3
2
1
0
z/h
0
1
2
3
4
5
6
7
8
9
10
11
x/h
1
0.5
0


case II, z/h = 0.21
OBS
WEMOD
WAsP-shelter
CFD
1
0.5
0
-0.5
-1
sign(u) $U(z)/U_o(z)$
0
1
2
3
4
5
6
7
8
9
10
11
x/h

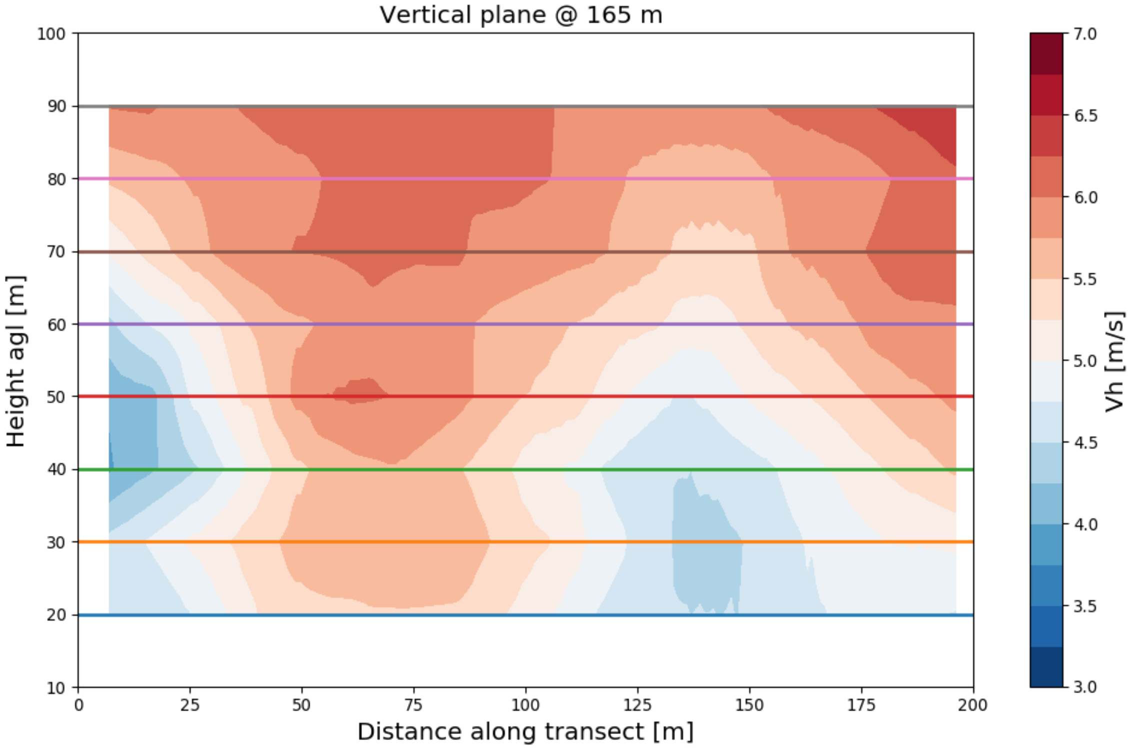
Multirotor og V52 scanned wakes I (2018)

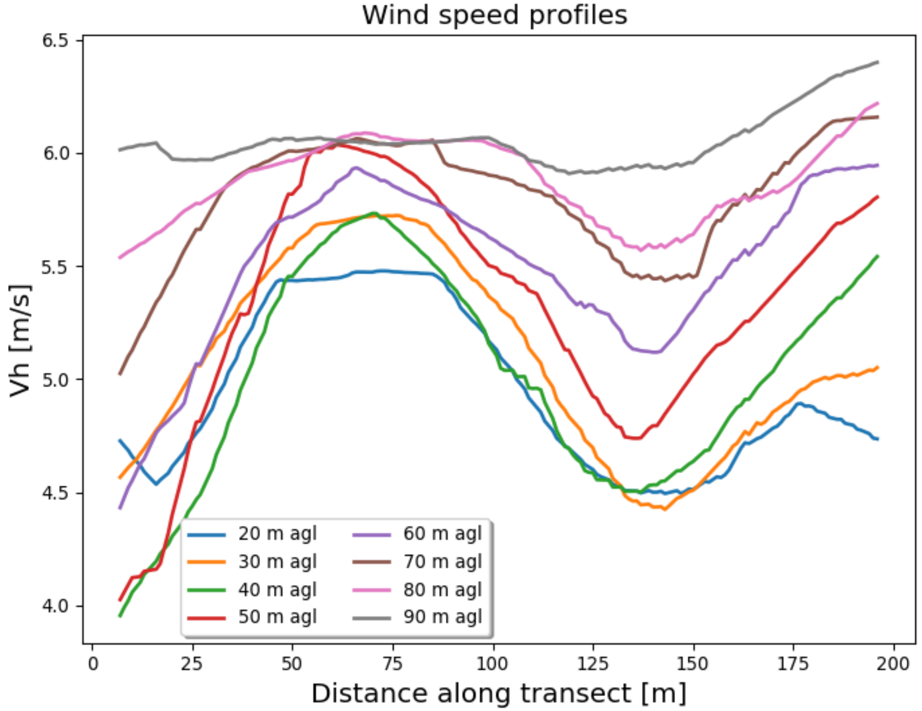
Results preview 2018/08/15 06:40 UTC





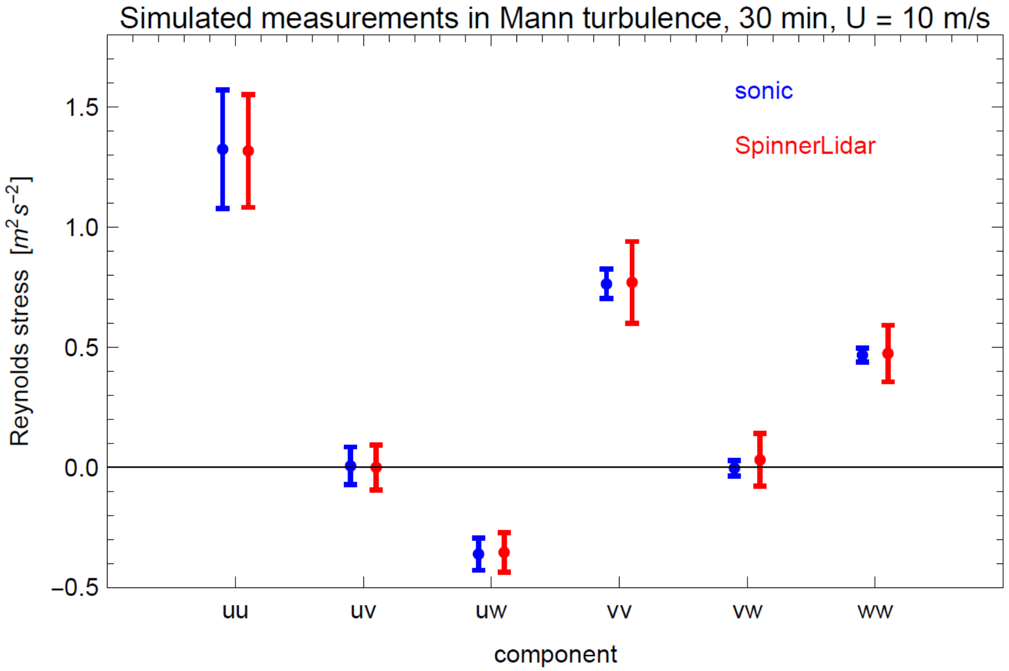
Vertical plain @ 165 m & corresponding transects





Examples of the perspektivs of turbulence measured by a spinner Lidar

Results of simulated measurements



- Uncertainty on σ_u^2 similar to that of sonic measurements
- Uncertainty larger on σ_v^2 and σ_w^2
- Inflow experiment on V52 in progress show promising results
- Should be useful for load validation

Summary

(Application & Competences & Technology)

The ACT of Research & Innovation

- No mistakes -> no progress
- Commercial lidars are now used in the industry – DTU winds contribution has been significant
- Lidars (profiling) are used for wind resource estimations (bankable offshore and onshore flat terrain)
- Nacelle Lidars are used for power performance and to incorporated in the standards

- The innovations has been incremental (to mature the instruments is hard work)
- Challenges in handling large data

- Potential use in
  - Estimating turbulence for siting (already ongoing)
  - Control of turbines (IEA task)
  - Estimations of inflow for load evaluation (spinner lidars & nacelle Lidars)
  - Windscanners in complex terrain for AEP (Long Range)
  - Windscanners for forecasting of rampevents (Long Range
  - A powerful tool in windtunnels (focused scanners)
- **From onepoint measurements to 3D measurements of timeseries in 20 year**
  - **Therefor a significant tool for research in atmospheric flow (inflow, wakes etc)**