Wind Profile Measurements over a Forest with Lidar

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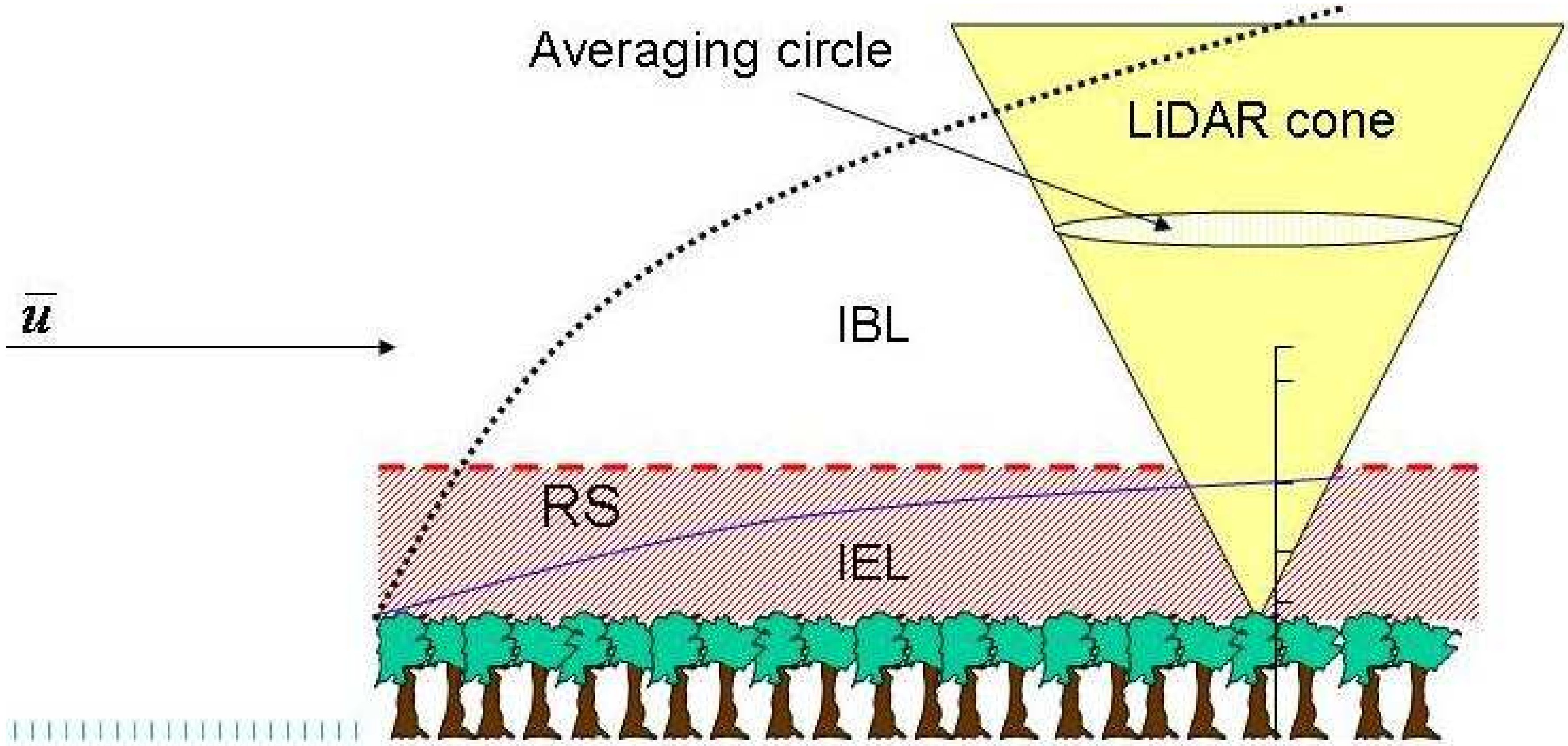
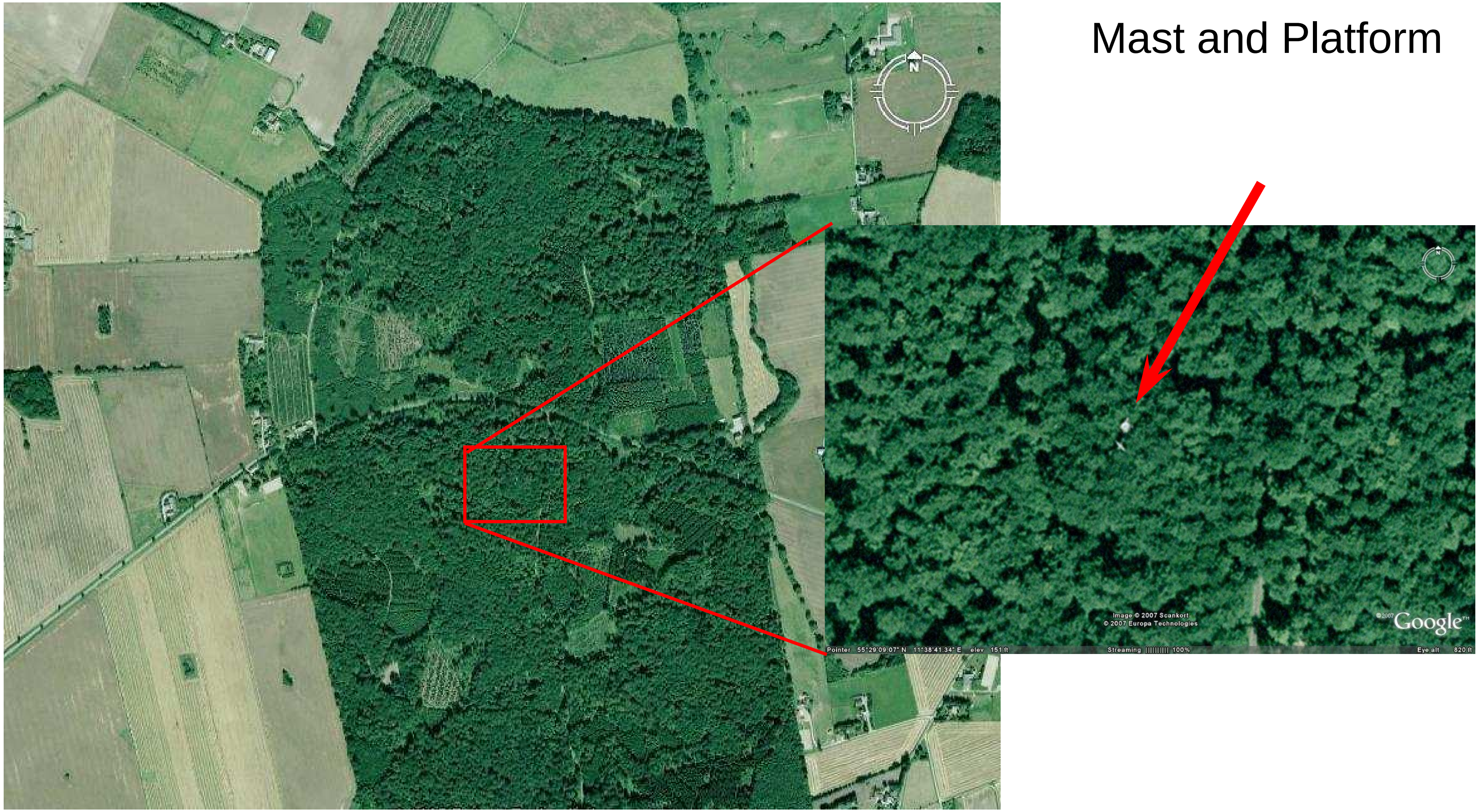
Outline

- Introduction
- Experiment I
- Measuring Instruments and Principle
- Results
- Experiment II
- Conclusion

The Experiment:
57 m Mast and Lidar Measurements to 175 m

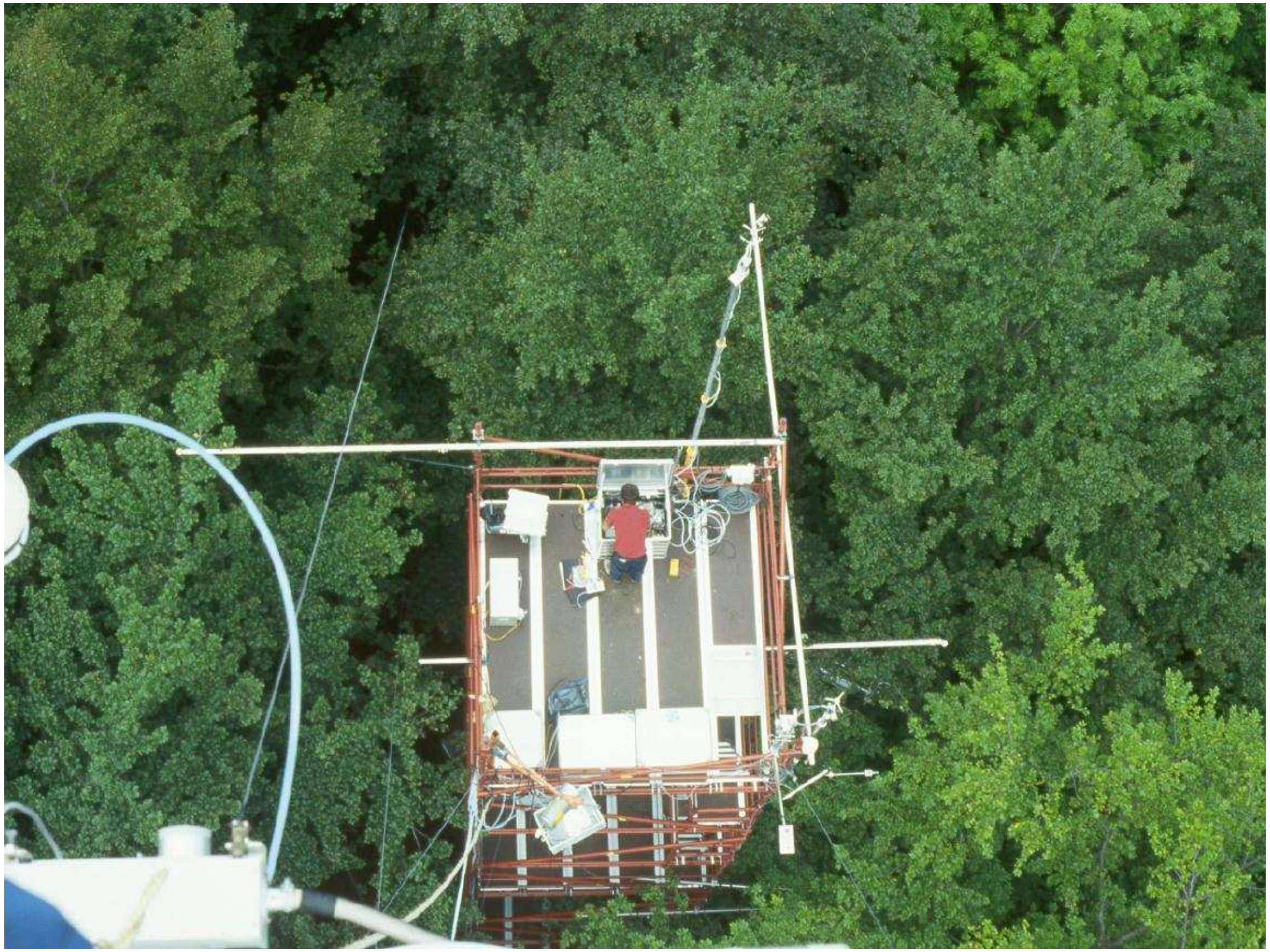


The Experiment:
The Site, Lille Bøgeskov, Zealand (1)

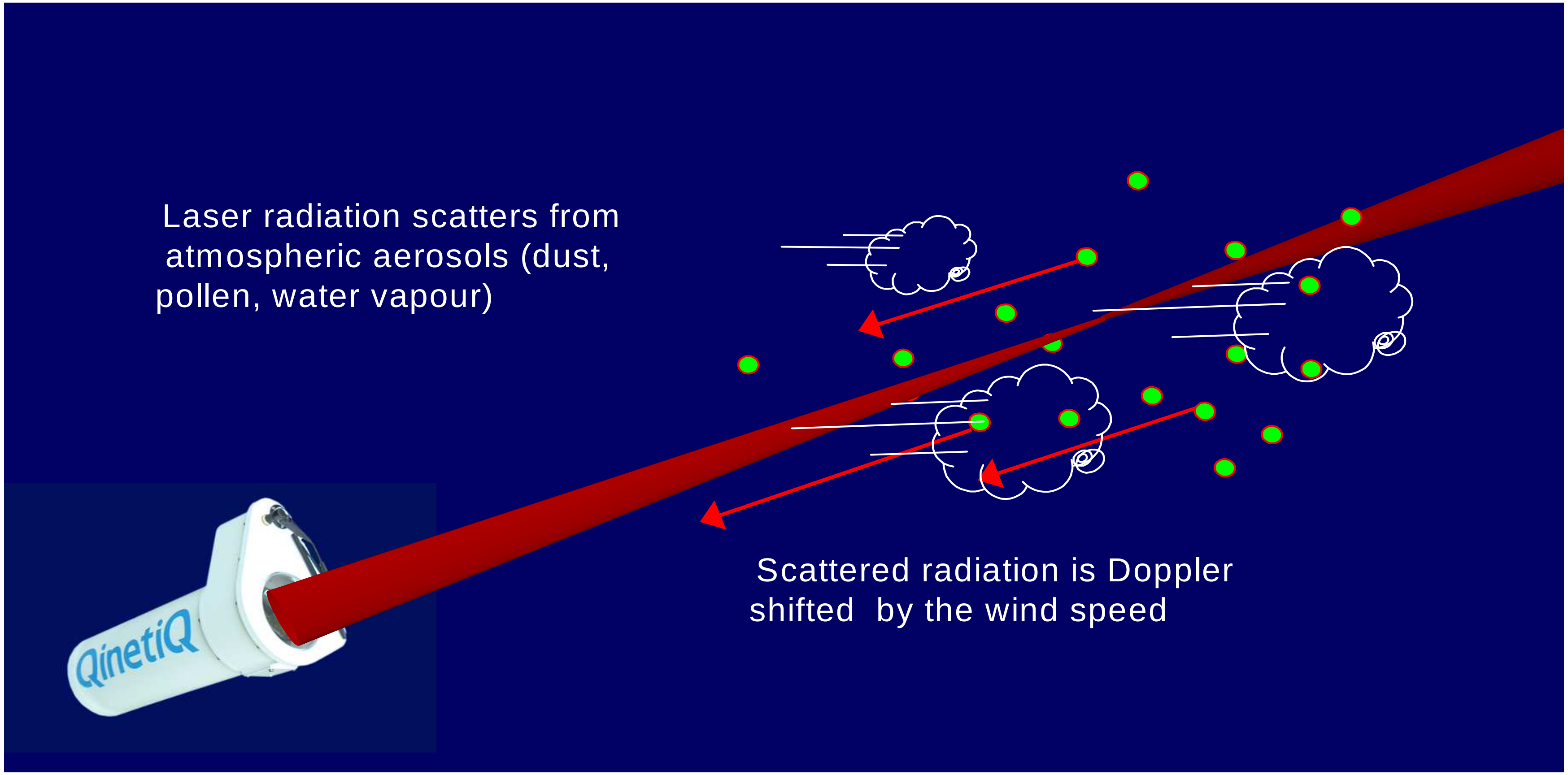


Mast and Platform

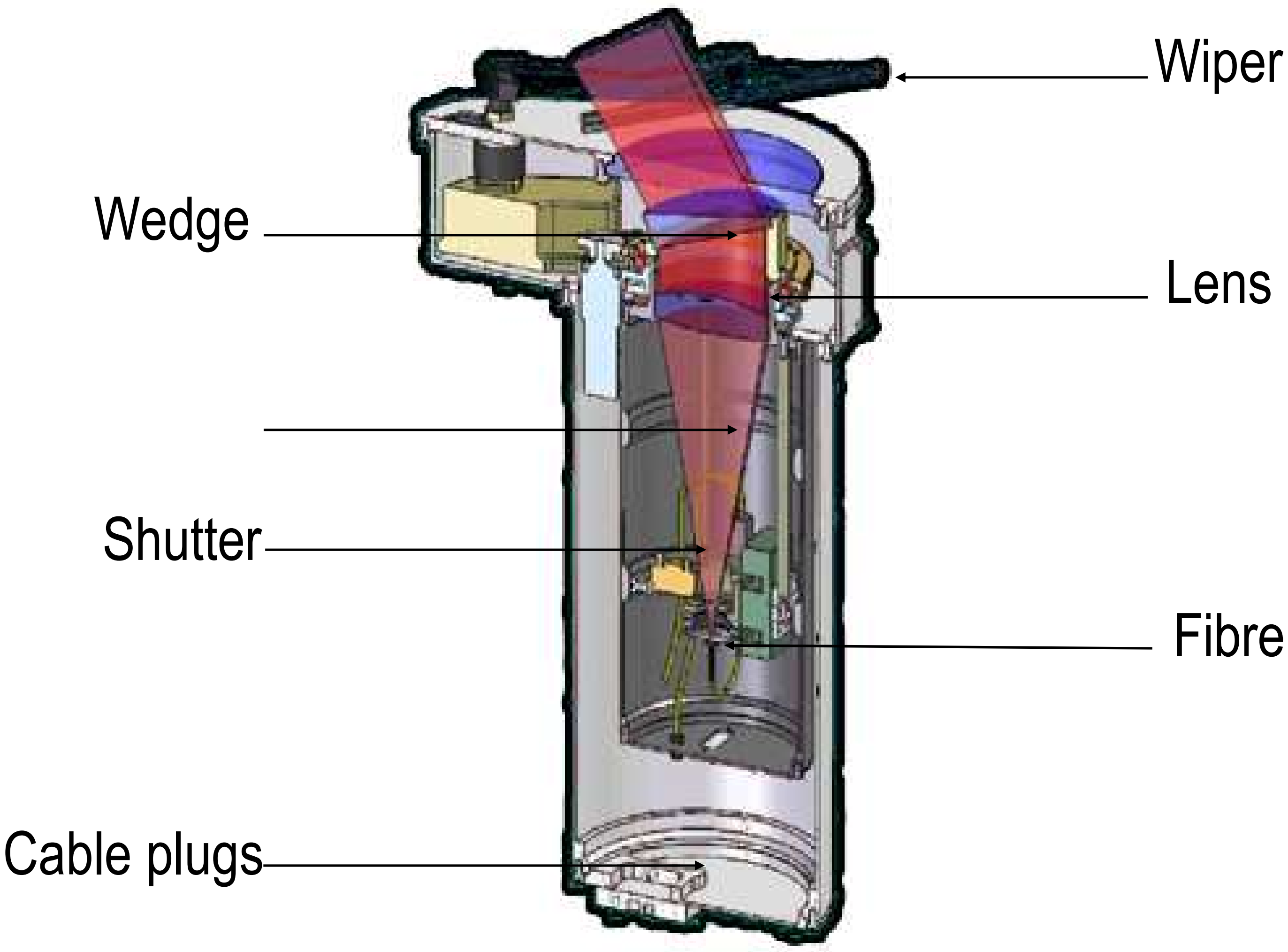
The Experiment:
The Site, Lille Bøgeskov, Zealand (2)



Measuring Instrument:
Lidar - Homodyne, Continuous, Fiber Laser (1)



Measuring Instrument:
Lidar - Homodyne, Continuous, Fiber laser (2)



Measuring Principle: Conical Scan

- Assuming horizontal homogeneity, a *conical scan* determines the wind speed and direction.

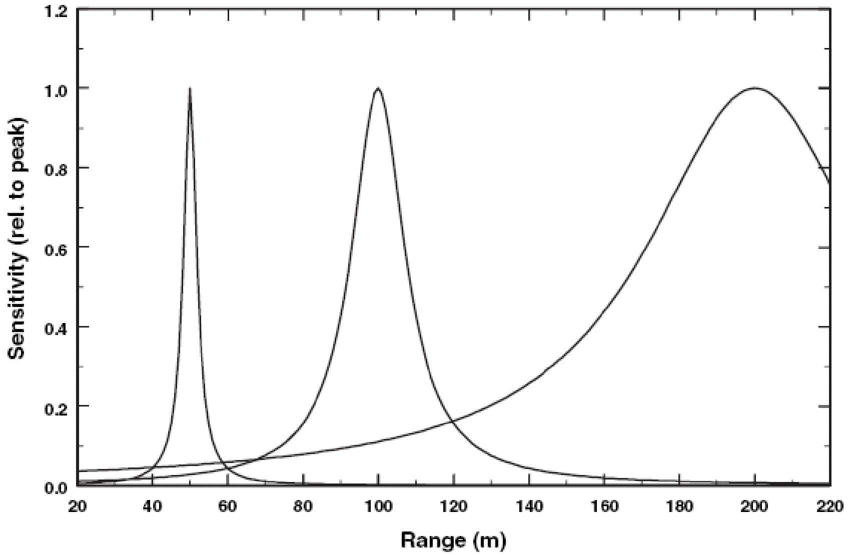
- Instrument developed by QinetiQ (now Natural Power)

Measuring Principle: Resolution

The Doppler velocity is not measured exactly at the focus point, but weighted in space along the laser beam by

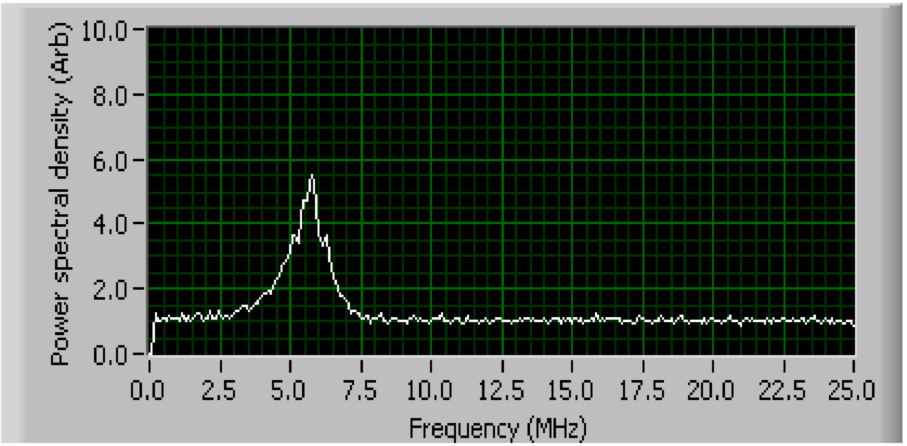
$$\phi(s) = \frac{1}{\pi} \frac{L}{L^2 + s^2}$$

where *s* is the distance along the laser beam from the focus point, and *L* is the half width at half maximum length.

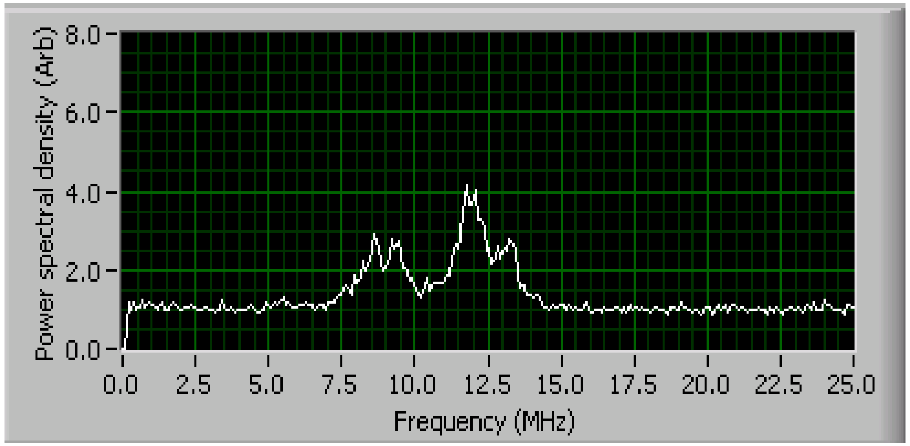


H [m]	**L** [m]
50	1.75
100	7.5
200	30

Measuring Principle
Doppler Spectrum Examples



Typical Doppler Spectrum



Doppler Spectrum at complex wind

Averages of 256 spectra taken at 100 kHz.

Measuring Principle: Instantaneous and Average Spectrum

$$S(v) = \int_{-\infty}^{\infty} \phi(s)\delta(v - v(s))ds$$

v(s) is the radial (along beam) velocity component.

Additional widening factors: finite residence time of scatterers in beam.

We use $\langle \delta(v - v(s)) \rangle = p(v; s)$ to calculate the mean of *S(v):*

$$\langle S(v) \rangle = \int_{-\infty}^{\infty} \phi(s)p(v; s)ds \approx p(v)$$

Measuring Principle: Upwind and Downwind Variances

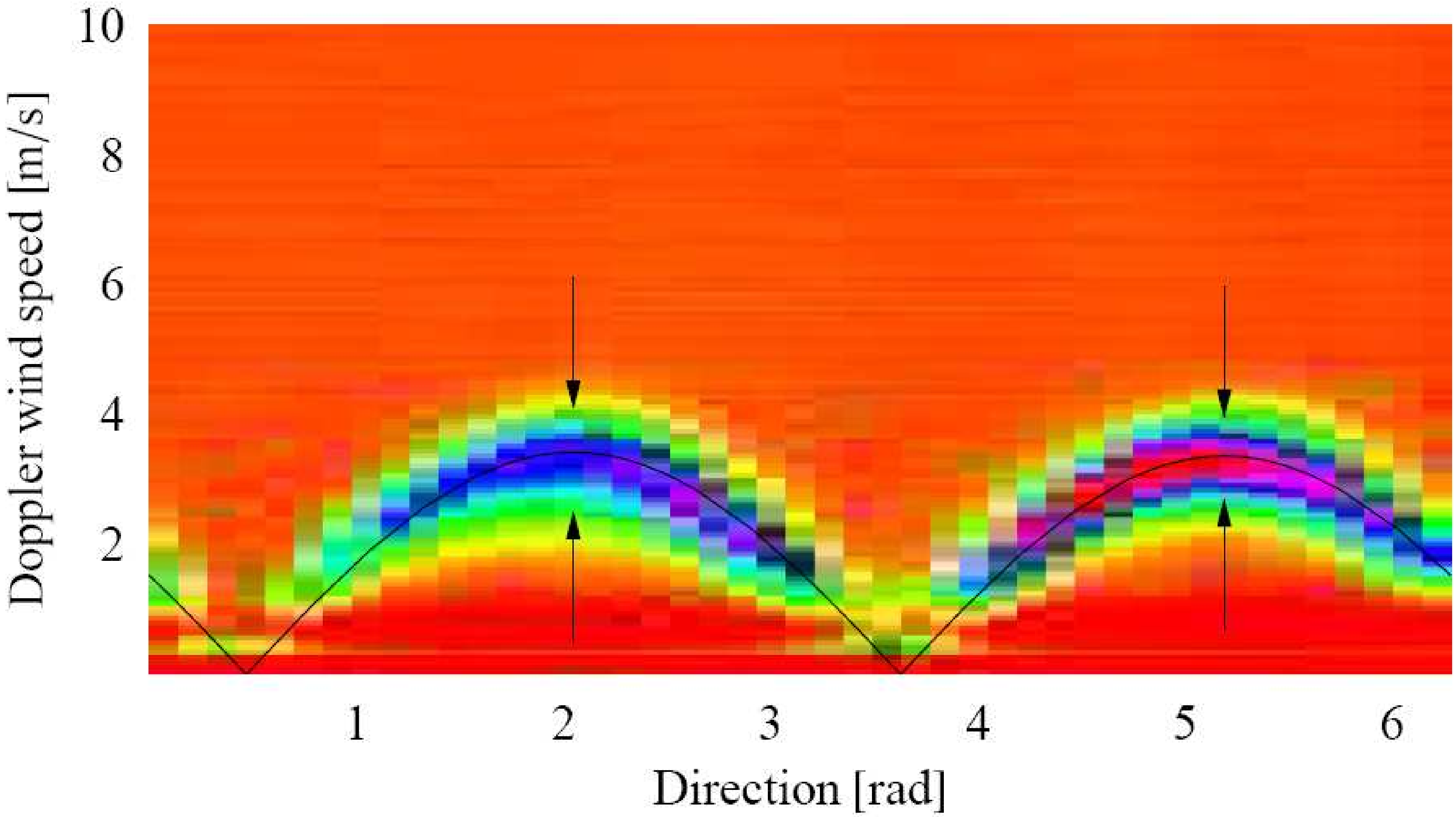
The measured radial velocity is (assuming half opening angle = 30 deg)

$$v_r = \left| \frac{1}{2} u \cos\theta + \frac{1}{2} v \sin\theta + \frac{\sqrt{3}}{2} w \right|,$$

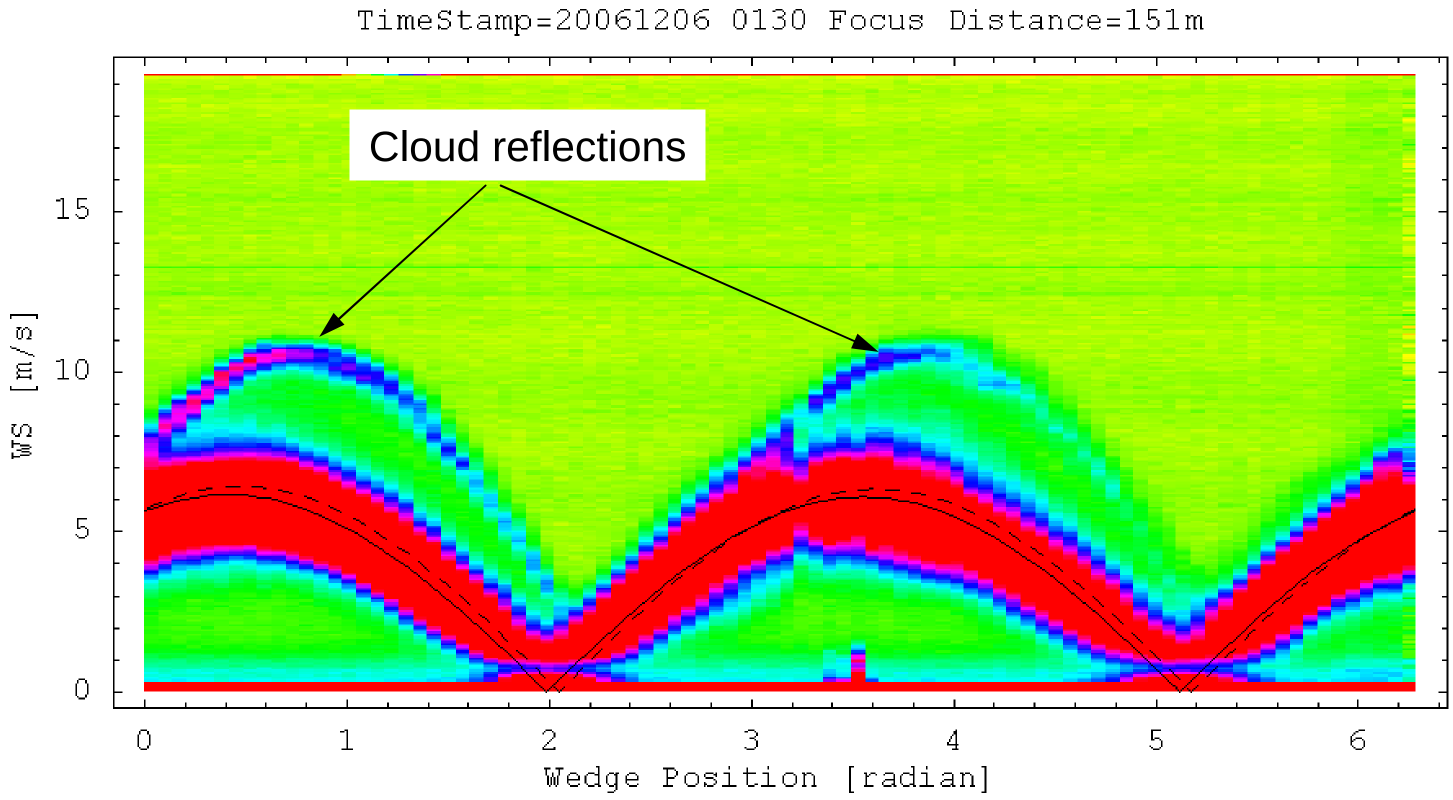
The upwind and downwind variances are therefore related to the momentum flux by

$$\begin{aligned} \sigma^2(v_{r,up}) &= \frac{1}{4}\sigma_u^2 + \frac{3}{4}\sigma_w^2 - \frac{\sqrt{3}}{2}\left\langle u'w' \right\rangle \\ \sigma^2(v_{r,down}) &= \frac{1}{4}\sigma_u^2 + \frac{3}{4}\sigma_w^2 + \frac{\sqrt{3}}{2}\left\langle u'w' \right\rangle \end{aligned}$$

Results:
Average Spectrum at 105 m above Sorø Platform

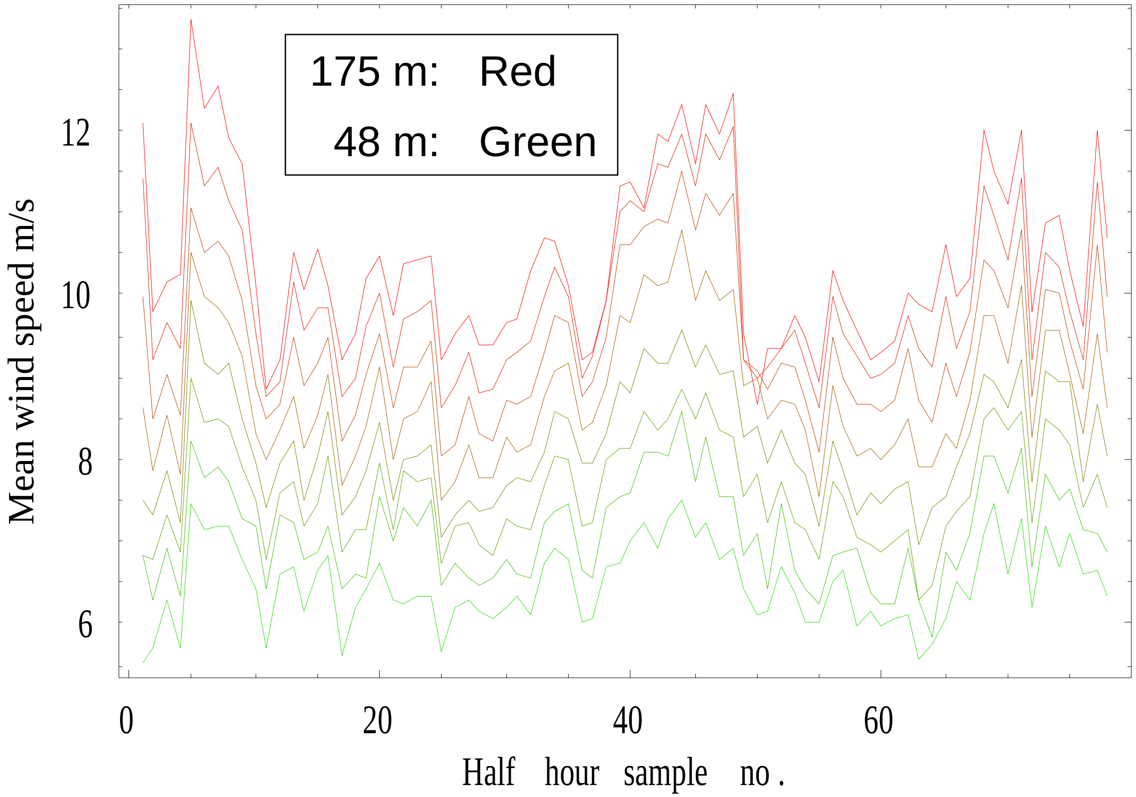


Results:
Clouds May disturb

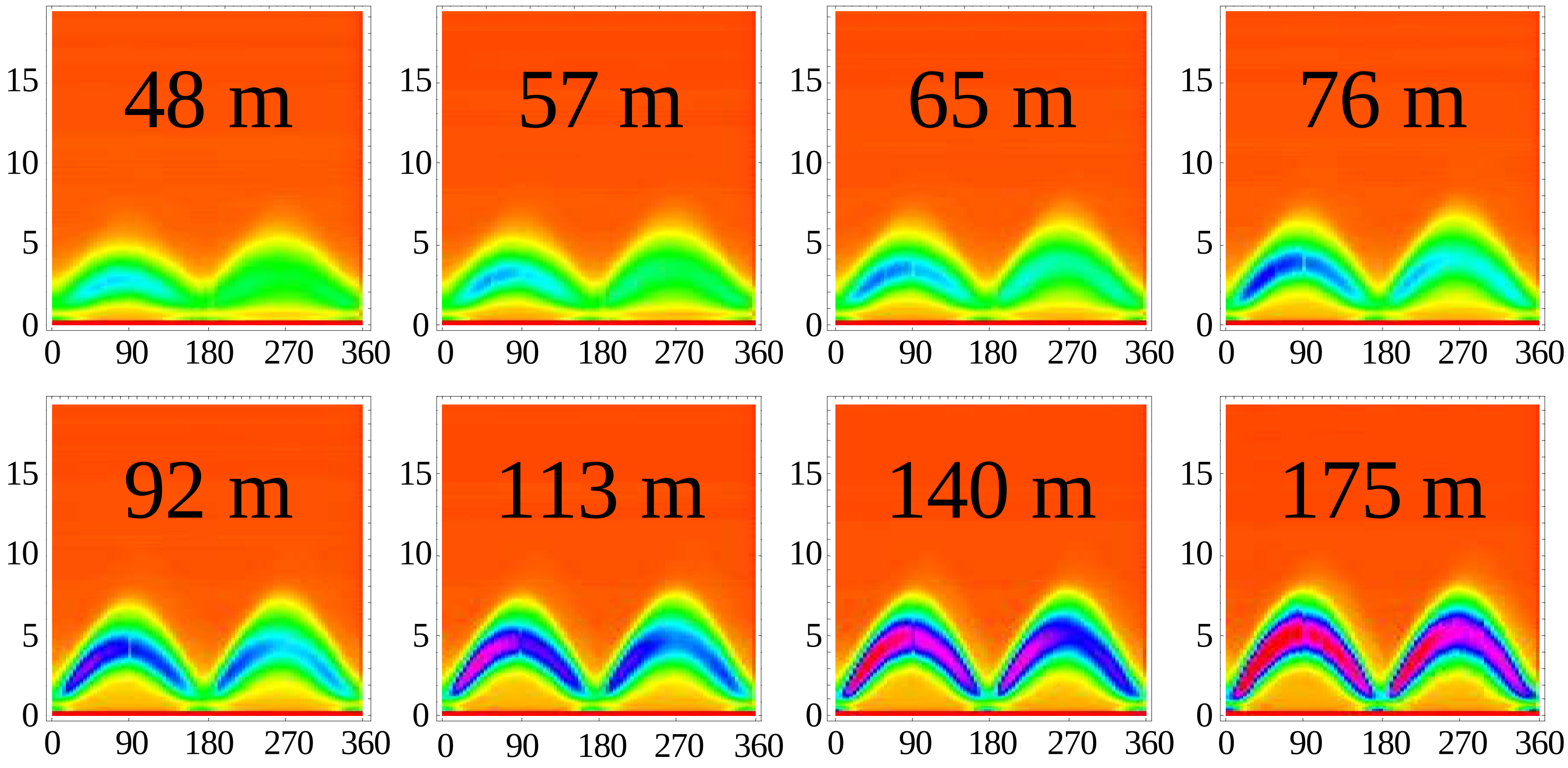


Results:
The Sorø Forest: A Test to Compare with Models

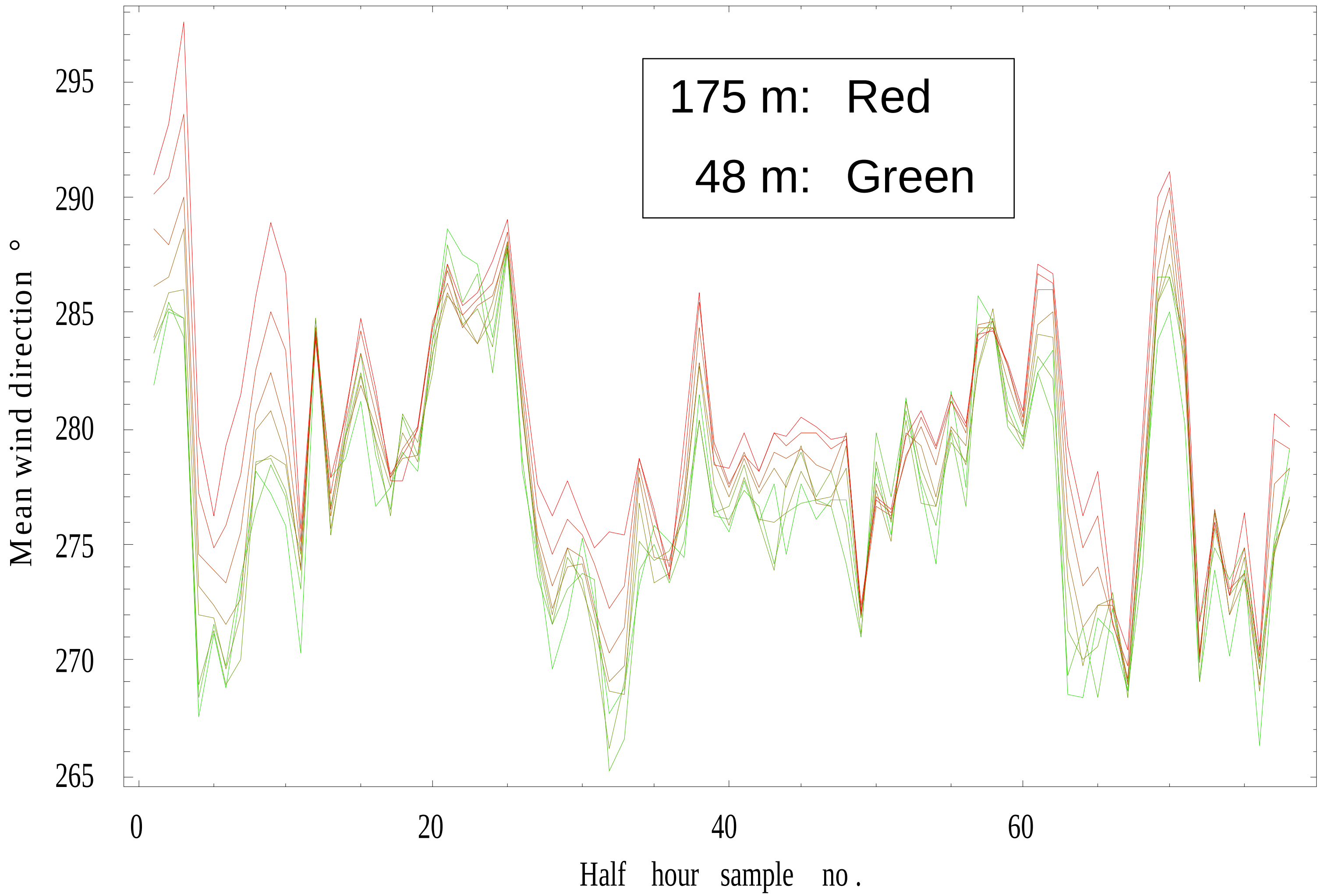
- Neutral: $|(z-d)/L| < 0.05$, displacement length *d* is 20.5 m
- Westerly. 57 m vane between 270 and 290
- Moderately strong winds: Cup 57m between 6 and 8 m/s
- Lidar measuring heights: 48, 57, 65, 76, 92, 113, 140, 175 m



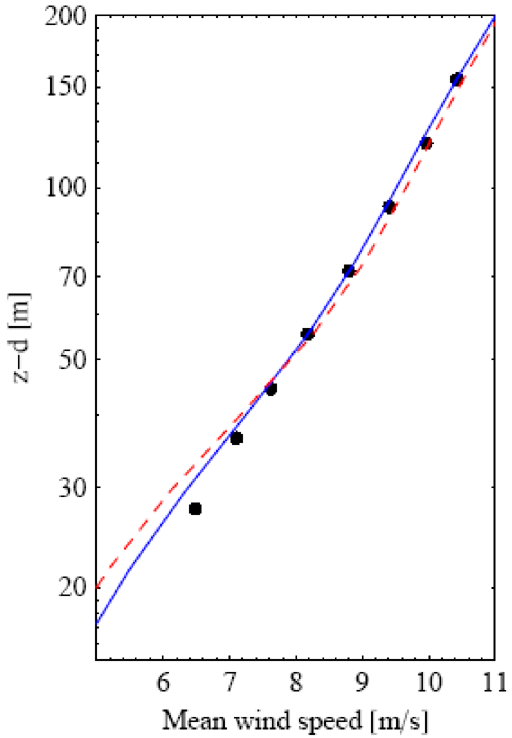
Results:
More Normal Data



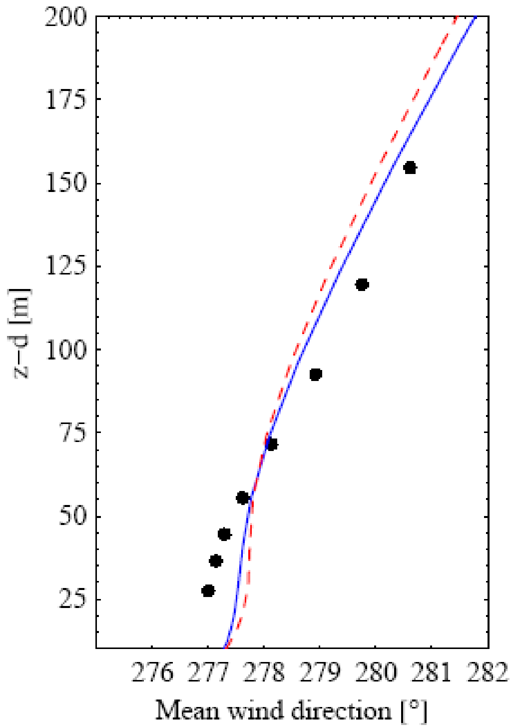
Results:
Wind Directions from 48 m to 175 m



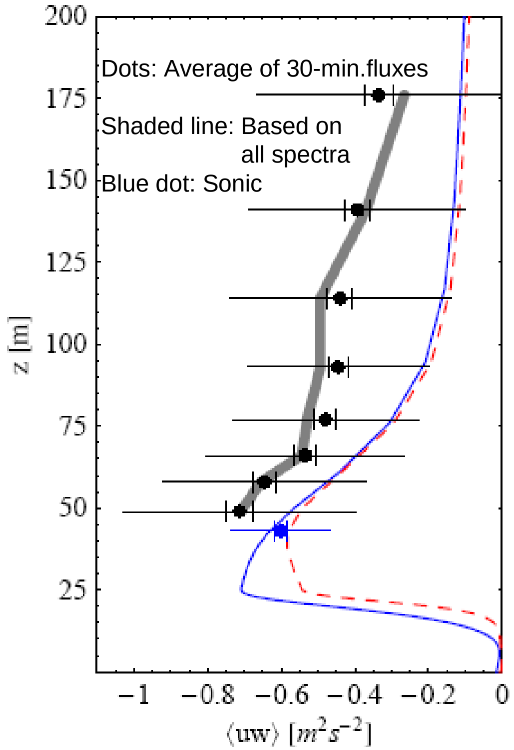
Results:
Profiles of Mean Wind Properties



Speed



Direction



Momentum Flux

Comparison with forest CFD model by Sogachev and Panferov[1)]

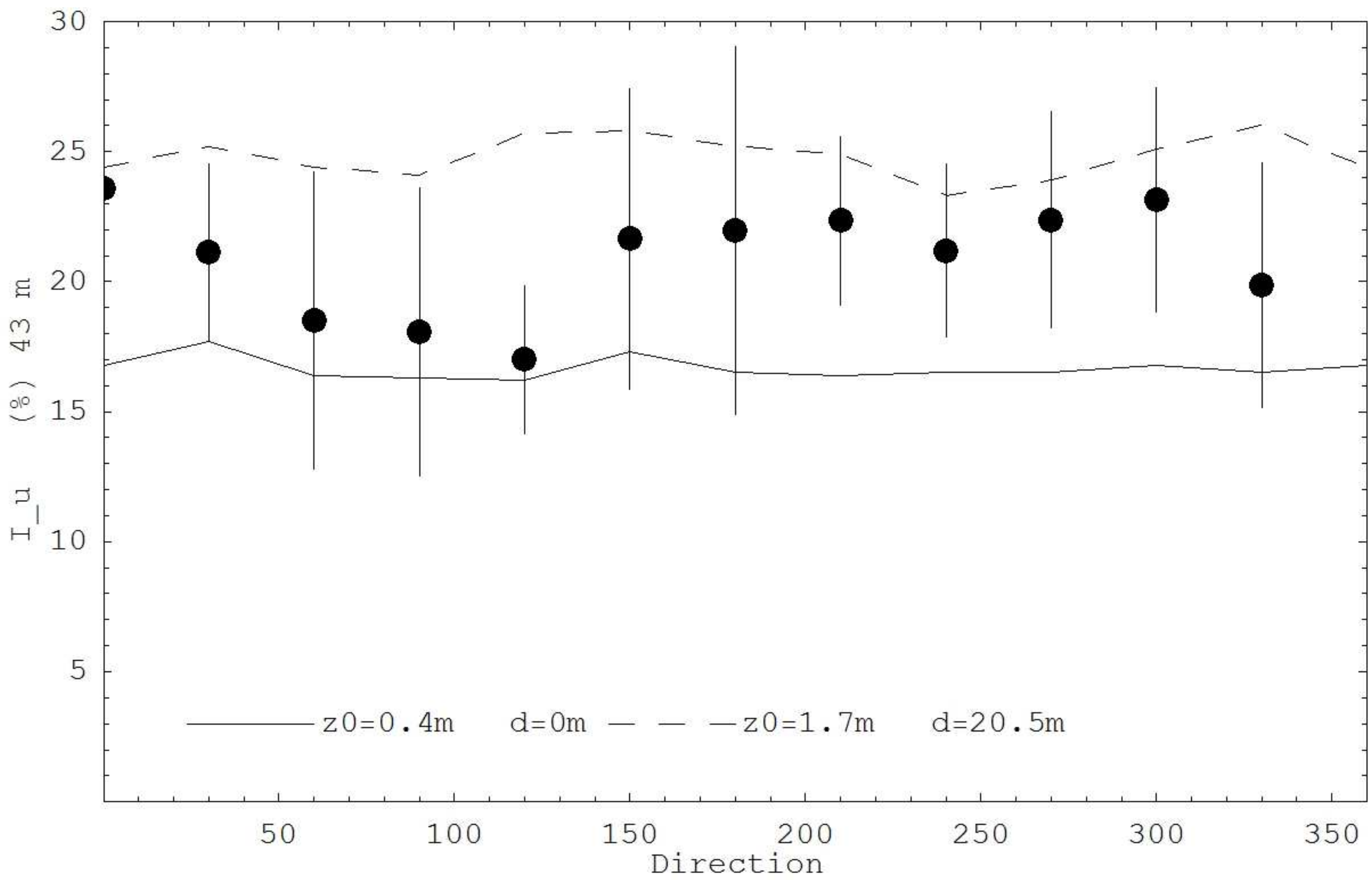
Winter conditions / Summer conditions

[1)] Boundary-Layer Meteorol. (2006) 121: 229-266

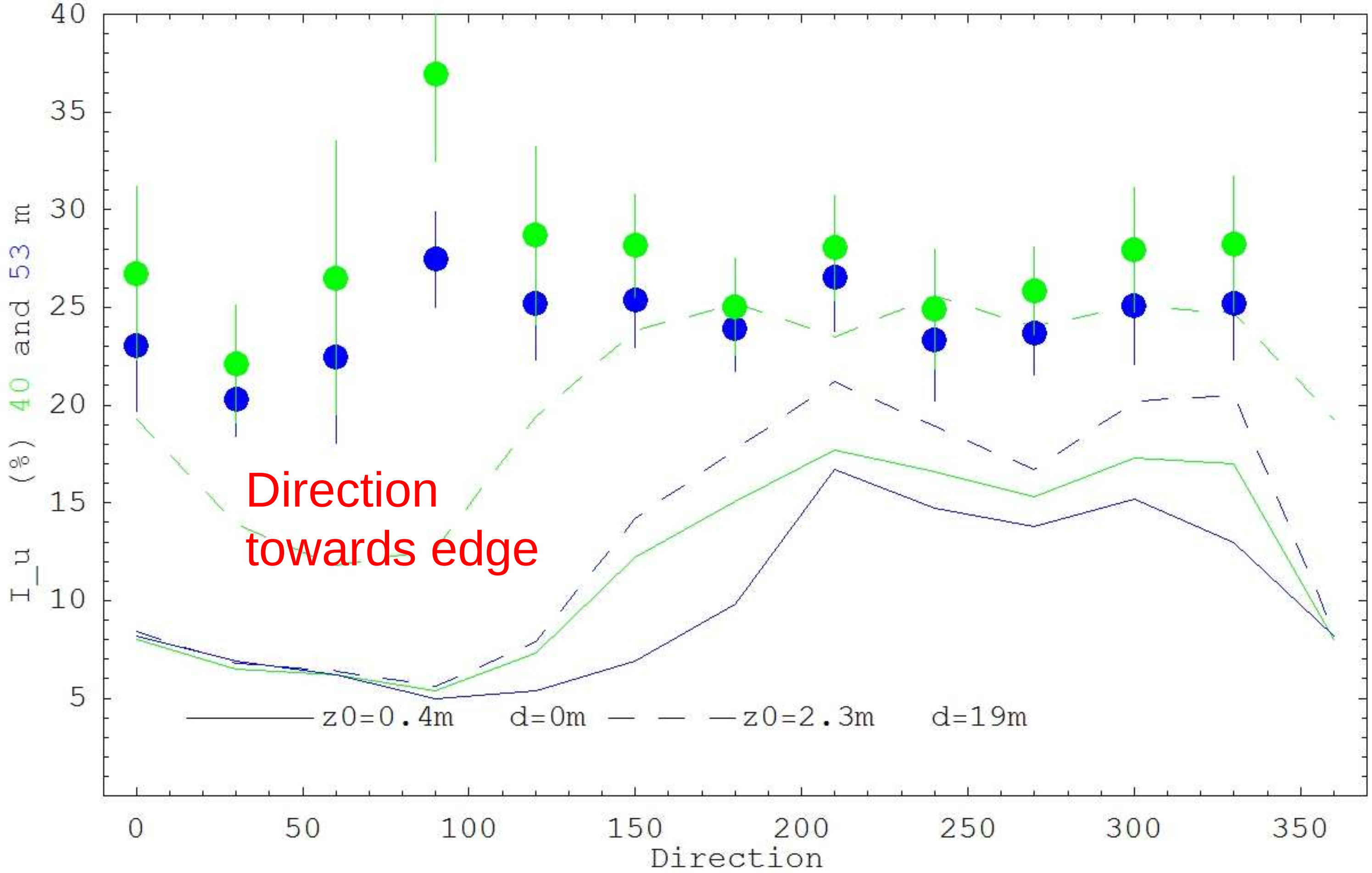
Results:
Main Observations

- Mean wind profile
  - close to logarithmic for z-d >25 m
  - corresponding to roughness length z_0 = 1.7m .
- A slight Ekman spiraling of about 4 degrees (clockwise) from 25 to 150 m (z-d) was visible.
- The momentum flux profile measured by Lidar looked qualitatively as expected, but the level was somewhat higher than indicated by sonic measurements (and by the Sogachev model).

Edges more than 1 km away
Sorø Forest measurements and WAsP Engng



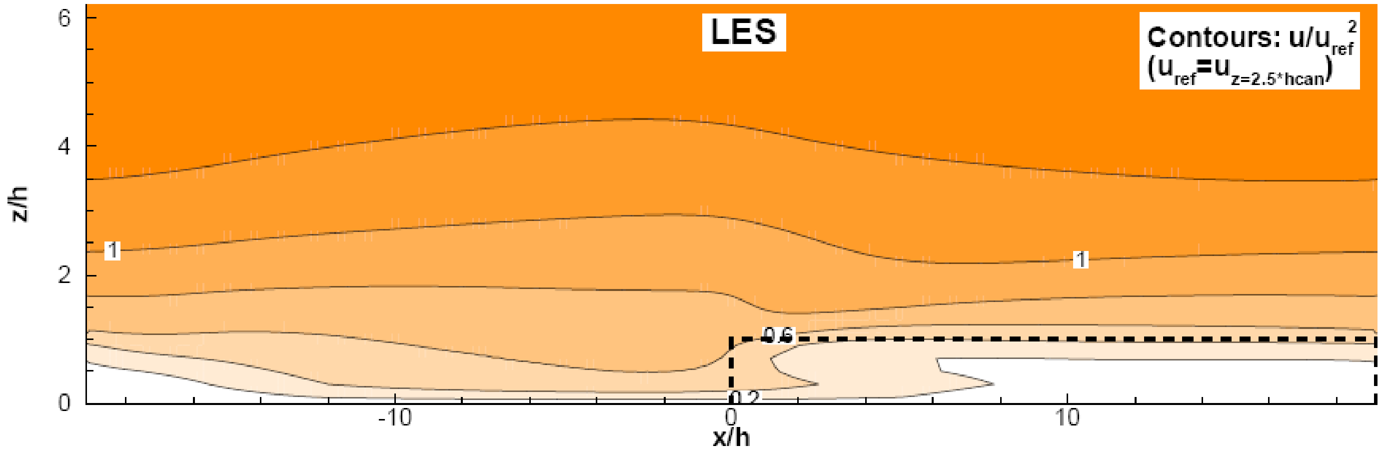
Forest edge:
Corselitze Forest and WAsP Engineering

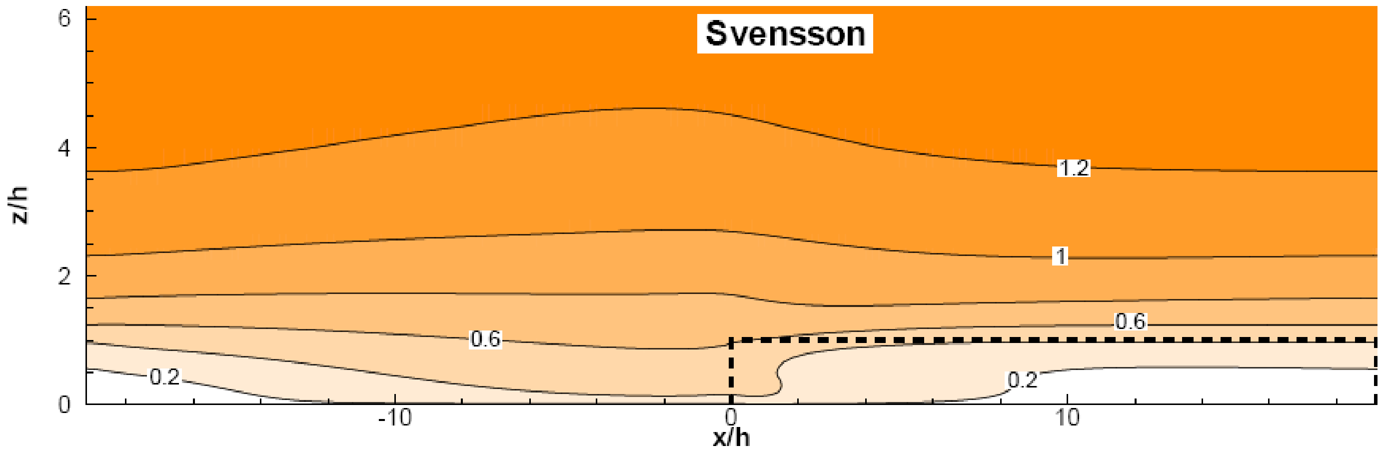


New experiment:
Flow around a forest edge

Tromnæs Skov Corselitze, Falster.

The only positive aspect of forest edge: Speed up?





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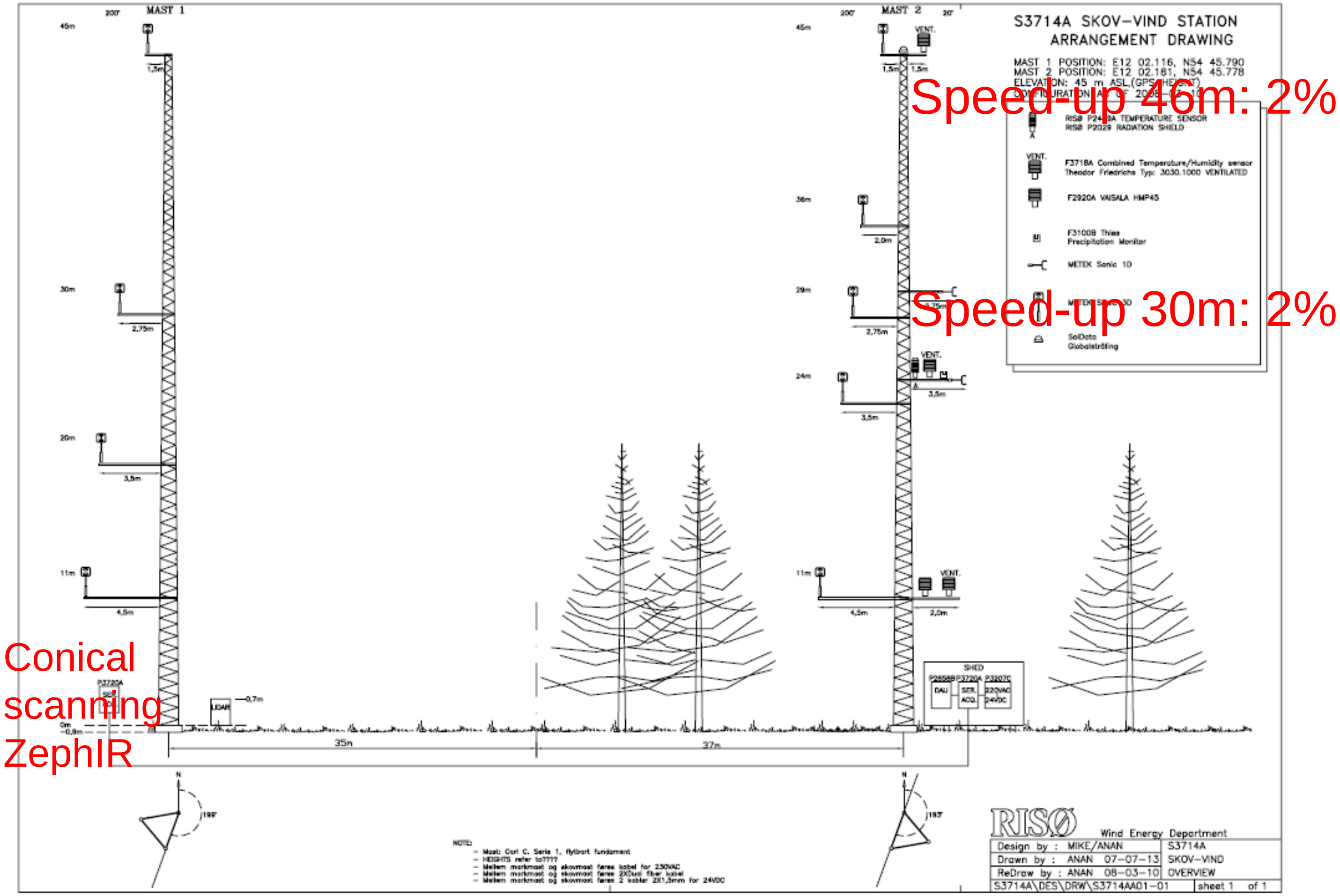

Conclusion

- A Lidar can measure mean wind and direction profiles reliably. Most likely also momentum fluxes.
- Forest RANS model by Sogachev et al. compare well with measurements

Future investigations

- Why are Lidar momentum fluxes more uncertain than those from sonics? (Measurements only 10% of the time?)
- Lidar fluxes seem slightly larger than sonic fluxes?
- Compare other turbulence statistics to measurements.
- Compare with other flow models.
- Experiment 2: Forest edge measurements – is being performed presently

- This is a part of a large RISØ DTU venture into remote sensing in wind energy.

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