# Assessment of the Uncertainty in Wind Resource Measurement

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HATCH™

YORK U UNIVERSITÉ UNIVERSITY redefine THE POSSIBLE.

# Outline

- Data that we looked at
- Physics of the wind
- Current prediction at higher heights
- Alternative prediction method
- Anemometer vs SODAR
- Alternative Design
- From wind to power
- Other issues (briefly)
- Conclusion

# Mast Speed Data

- Three data sets: 2009-10-21 through 2010-01-05, 2009-10-15 through 2009-11-28, and 2010-09-08 through 2011-06-05
- Measurements of anemometers at 3 heights (30, 40, 50m or 40, 50, 60m)
- Measurements of SODAR at 5 to 10 heights from 30m to up to 120m

# Physics of the Wind

- $(V_1/V_2)=(h_1/h_2)^{\alpha}$ (Power Law)
- $\alpha$ is the Wind Shear Coefficient; it varies over time of the day and over the seasons. Typical values = 0.2
- This implies:
  - $\text{Log}(V_1)=\text{Log}(V_2) + \alpha\,(\text{Log}(h_1) - \text{Log}(h_2))$
  - $\text{Log}(V_1)$=Random variable +constant
  - $V_1=V_2$ * constant
- So, if one has the Wind Shear coefficient $\alpha$ and the speed at a specific height $h_2$, it is possible to estimate the speed at another height $h_1$.

# Current Estimation of α

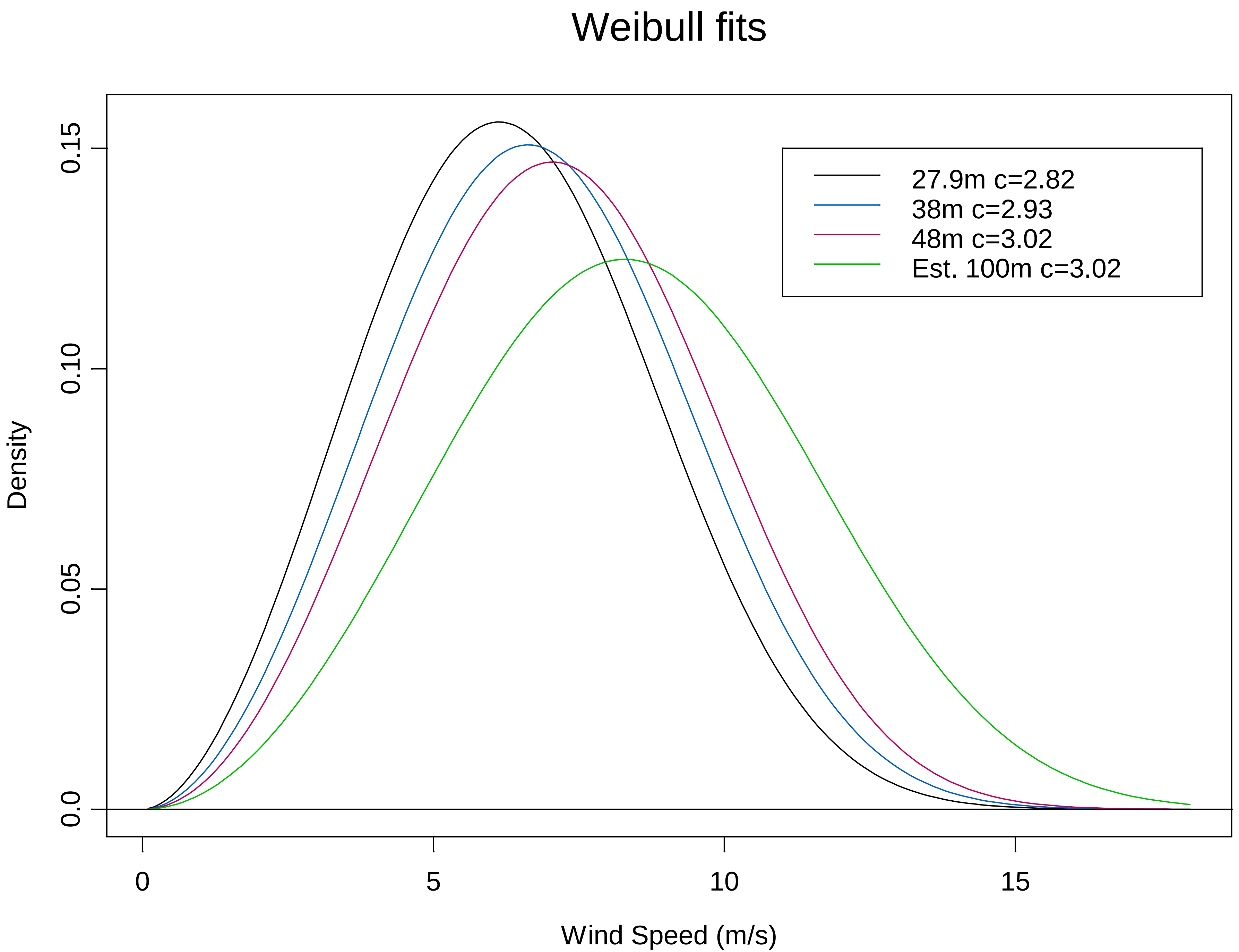
- Regress the 3 (log) mean anemometer speeds on the (log) heights to get estimates of the straight line

$$\hat{a} + \hat{b}x$$

- The estimated slope $\hat{b}$ becomes the estimated Wind Shear $\hat{\alpha}$
- Estimated speed at 100m (say) at a given time point is $V_{100}=\exp(\mathrm{Log}(V_{100}))=\exp(\mathrm{Log}(V_{60}) + \alpha\,(\mathrm{Log}(100) - \mathrm{Log}(60)))$ with $\alpha=\hat{\alpha}$ where we use the observed speed at 60m (the highest observed point)
- Note that this means that we use a single α for all time points…

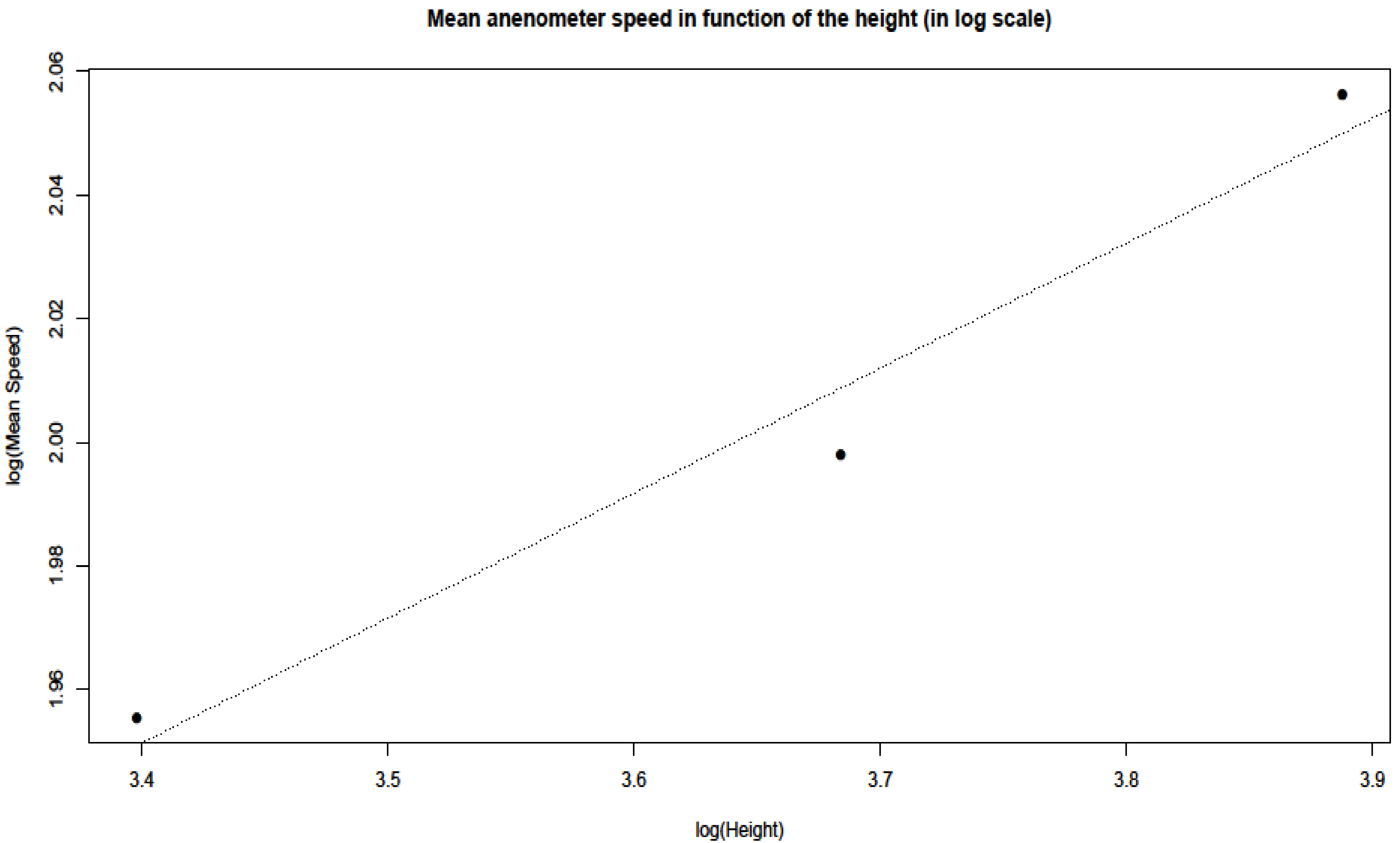
# Current Estimation of α

- This also means that the estimation at 100m is a constant times the speed at 60m so that it only changes the scale of the speeds not its shape
- Weibull distribution:
  - $f_{a,c}(x) = c/a^c \, x^{c-1} \exp\{-(x/a)^c\}$  where a is the scale parameter and c is the shape parameter.
  - If X is Weibull(a,c), then bX is Weibull(ba,c)
  - But the estimated shape parameter seems to increase with height in a data set that we studied



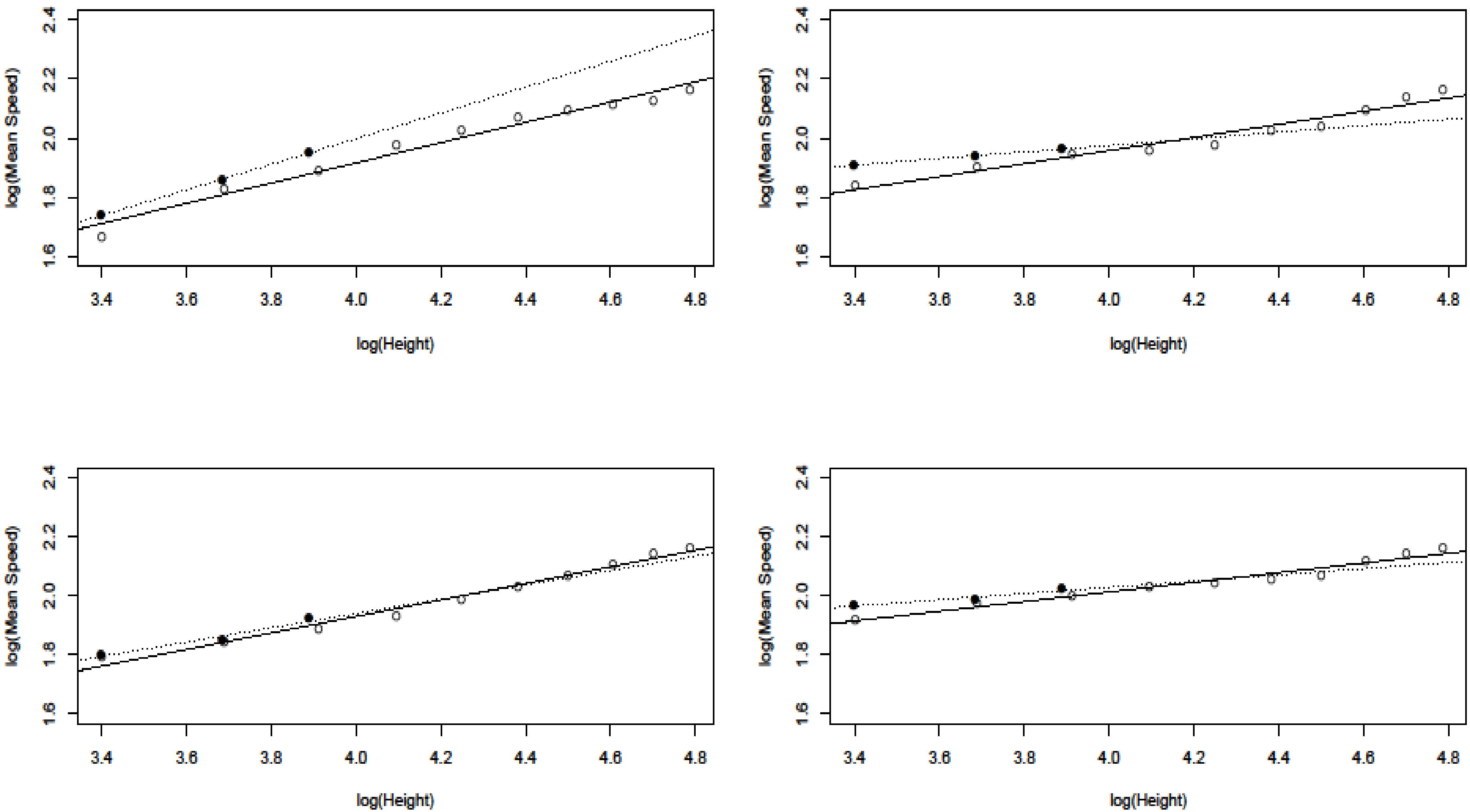
Weibull fits
27.9m c=2.82
38m c=2.93
48m c=3.02
Est. 100m c=3.02
Density
0.0
0.05
0.10
0.15
0
5
10
15
Wind Speed (m/s)

# Power Law for one data set

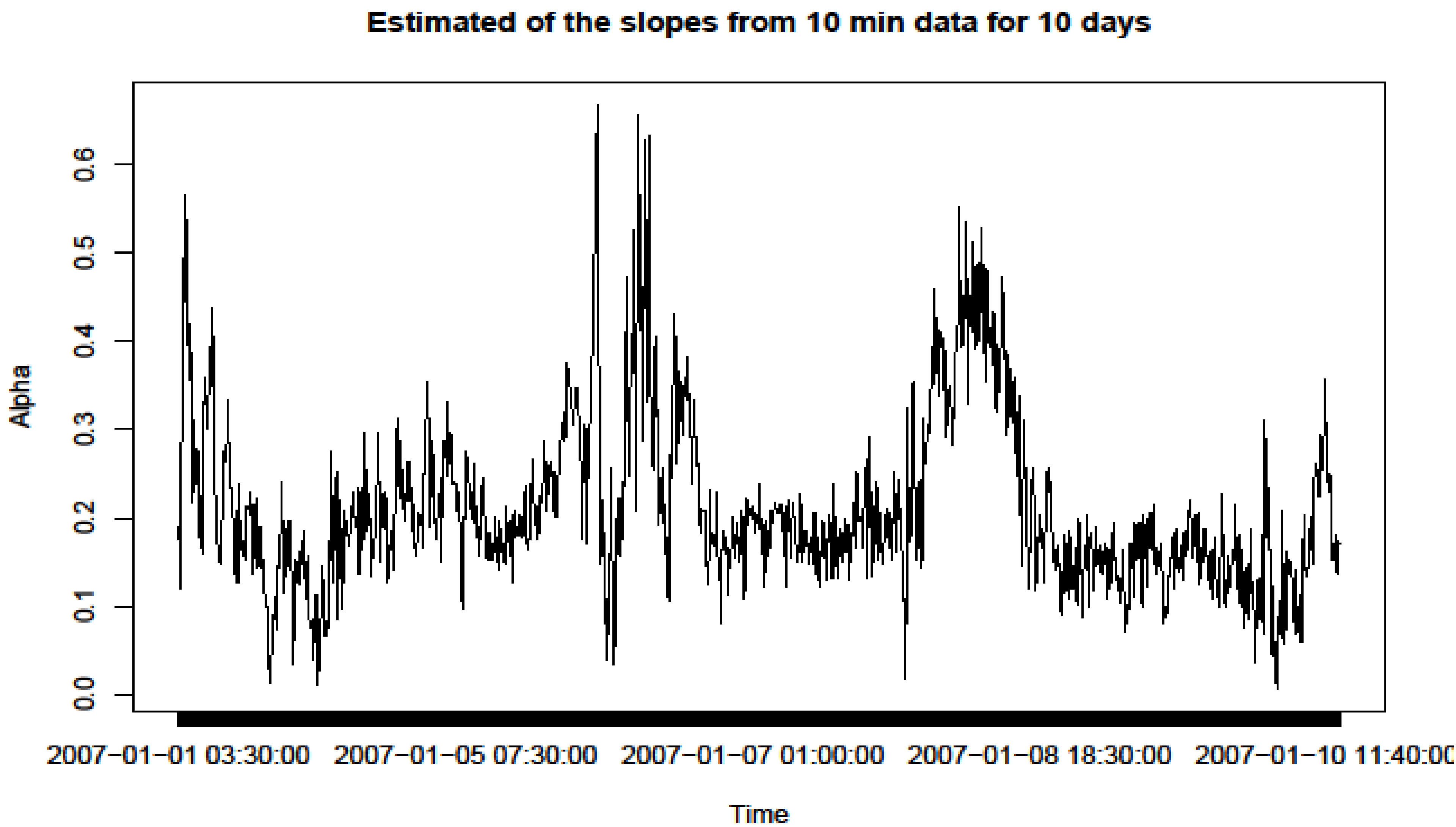


# Alpha changes over time

Variation of alpha for each 10 minutes (10 data from SODAR and 3 data from Anenometer)



# Alpha *Really* Changes over Time

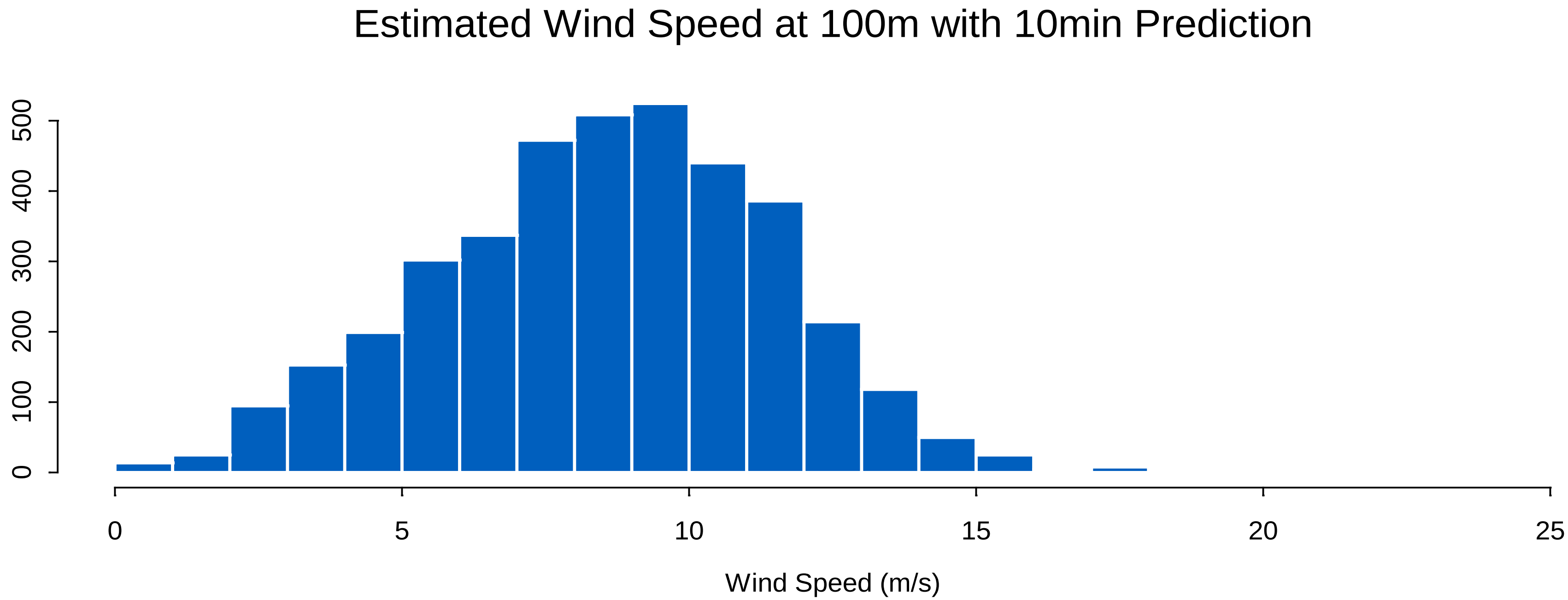


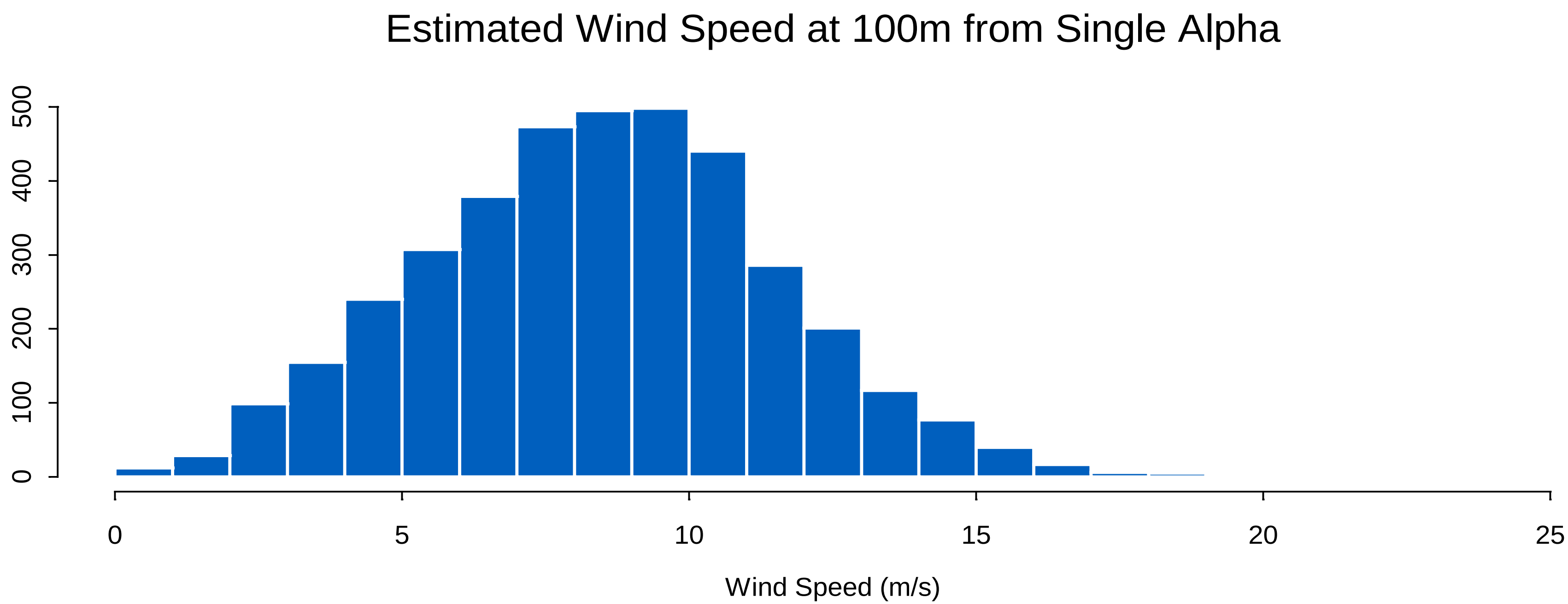
# First Suggestion

- Estimate the straight line at each time point (every 10 min) on the log scales and make a prediction from that line at 100m: $\exp(\hat{a} + \hat{\alpha}\log(100))$
- This way, you get a *different* equation to predict at each 10min

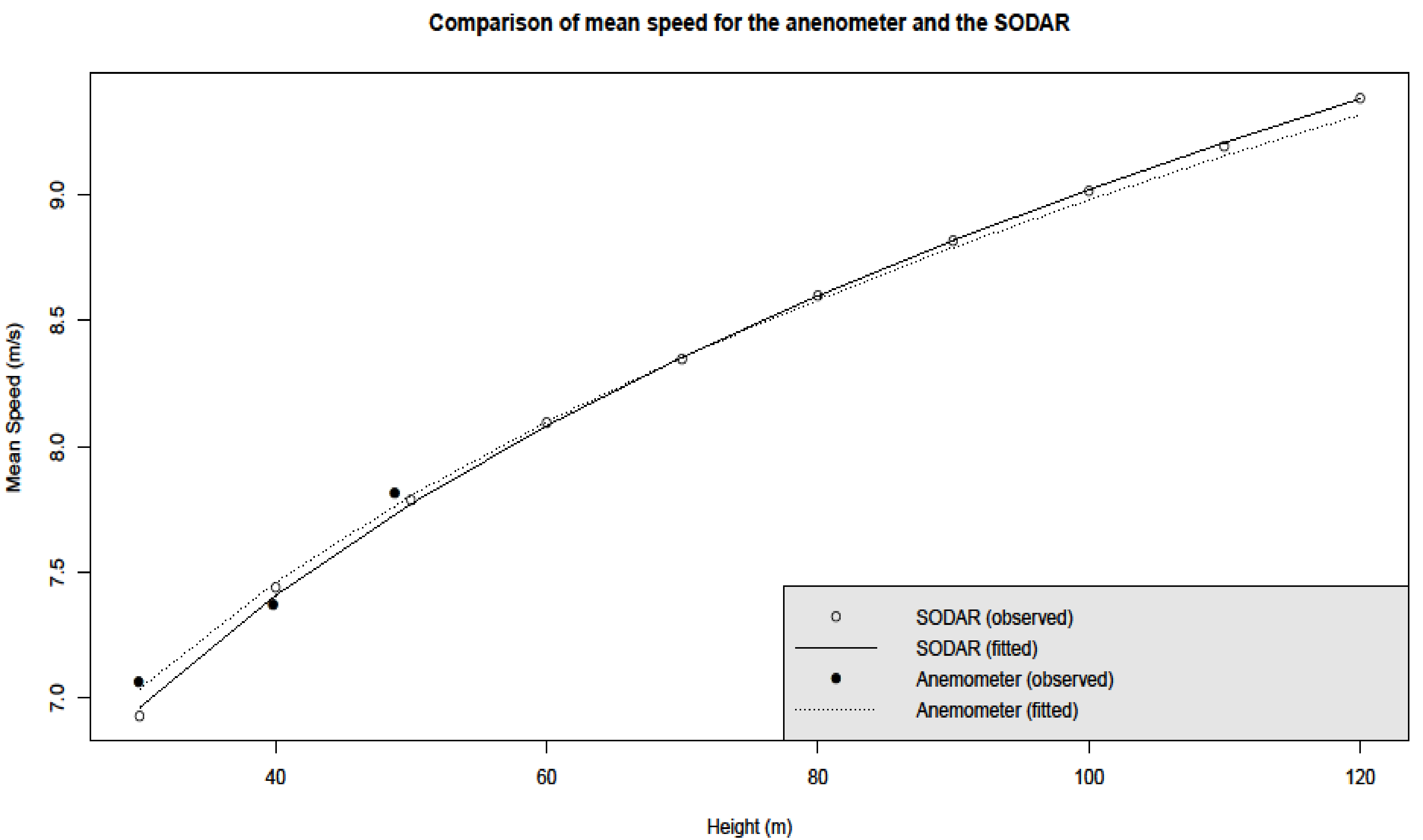
# How Good are Those 10 min Regressions Based on 3 Points?

| | R-squared | Alpha |
|---|---|---|
| Minimum | 0.0004 | -0.544 |
| 1st Quartile | 0.979 | 0.145 |
| Median | 0.995 | 0.206 |
| Mean | 0.959 | 0.239 |
| 3rd Quartile | 0.999 | 0.302 |
| Maximum | 1.000 | 3.108 |

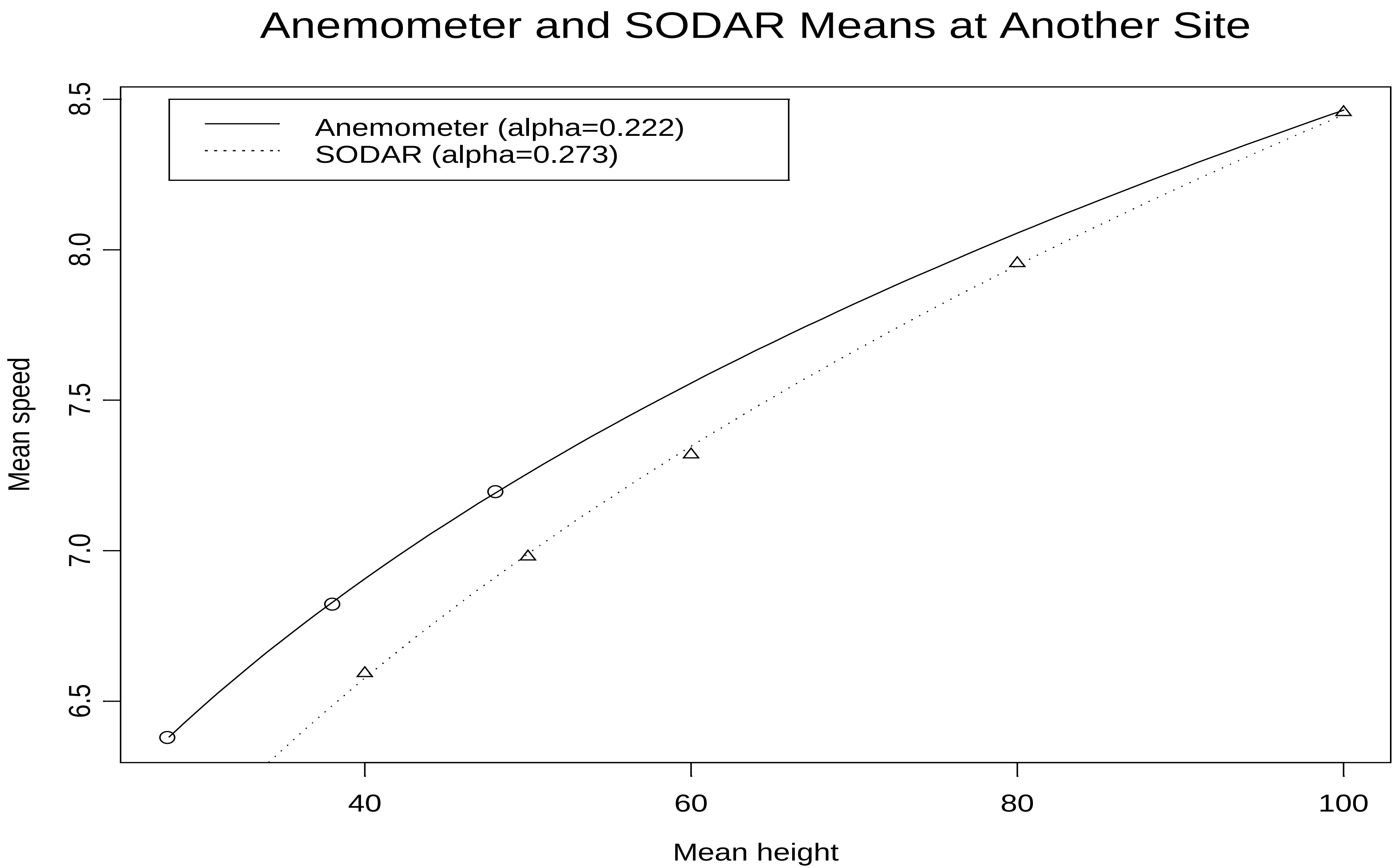

Estimated Wind Speed at 100m with 10min Prediction
0
100
200
300
400
500
0
5
10
15
20
25
Wind Speed (m/s)

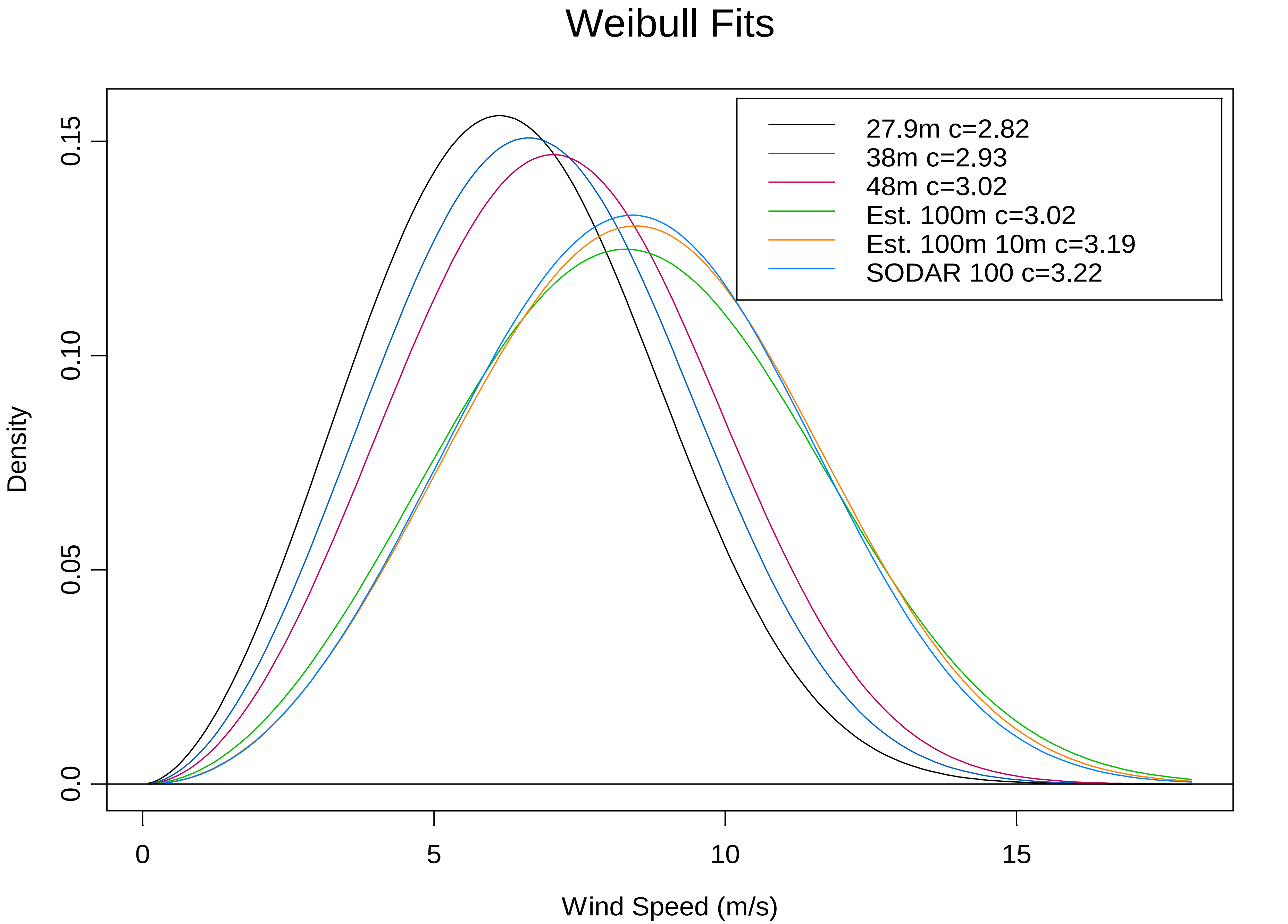

Estimated Wind Speed at 100m from Single Alpha
0
100
200
300
400
500
0
5
10
15
20
25
Wind Speed (m/s)

# SODAR vs Anemometer



# Sodar vs Anemometer (Take 2)





Weibull Fits
27.9m c=2.82
38m c=2.93
48m c=3.02
Est. 100m c=3.02
Est. 100m 10m c=3.19
SODAR 100 c=3.22
Density
0.0
0.05
0.10
0.15
0
5
10
15
Wind Speed (m/s)

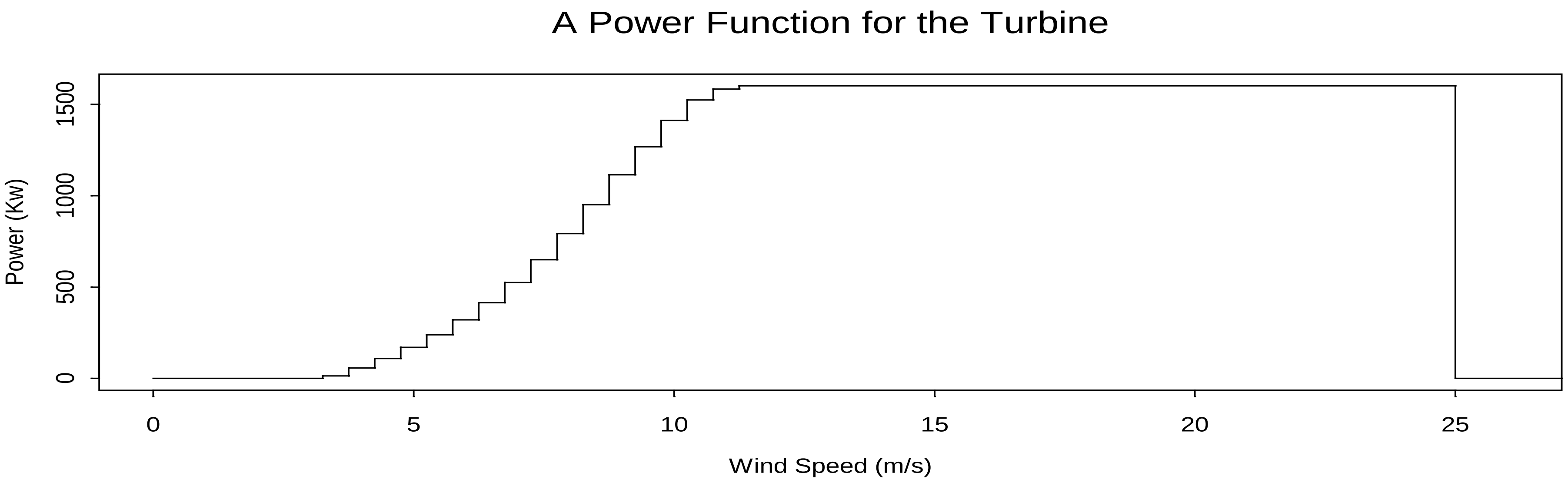
# Second Suggestion

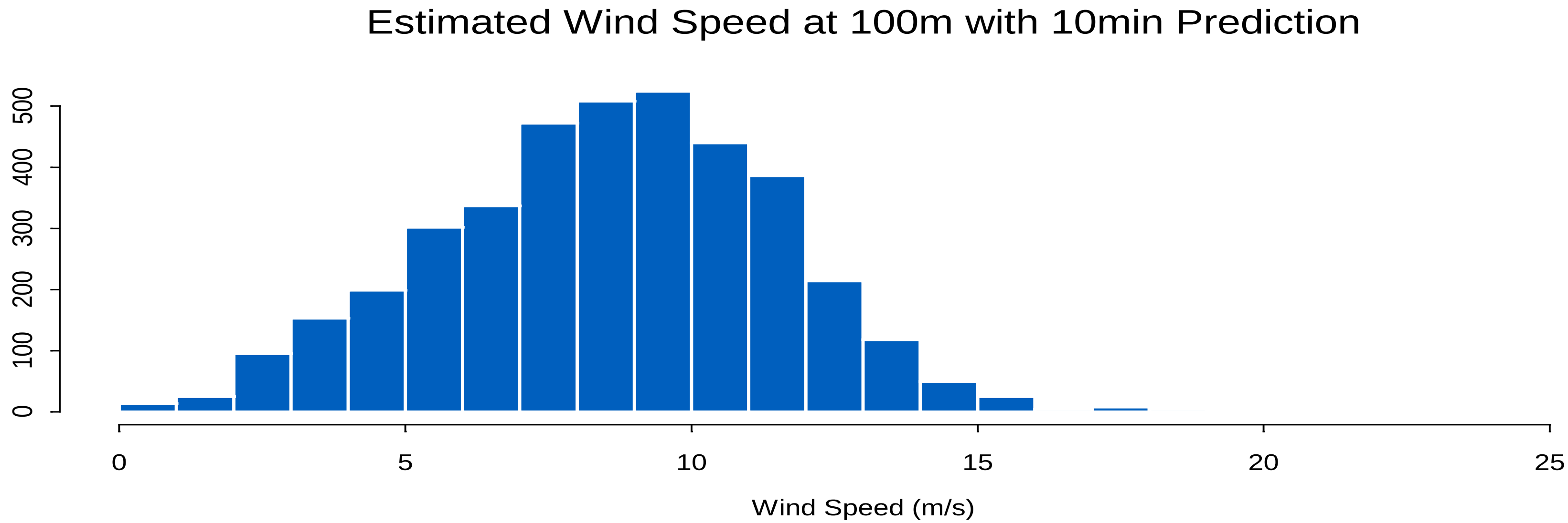
- 95% Confidence Intervals for the two alphas are [0.184,0.260] and [0.261,0.285] for the anemometers and SODAR, respectively.
- The standard error of the slope is $\sigma/(SXX)^{1/2}$ where $\sigma$ is the standard deviation of each point about the line and $SXX = \square(e_i - \bar{e})^2$ where $e_i = x_i$.
- The half-length of a 95% CI is the standard error times the quantile of a *t* distribution with *n*-2 degrees of freedom, $t_{n-2}(.95)$.
- $t_1(.95) = 12.7$ for 3 points vs $t_3(.95) = 3.2$ for 5 points!

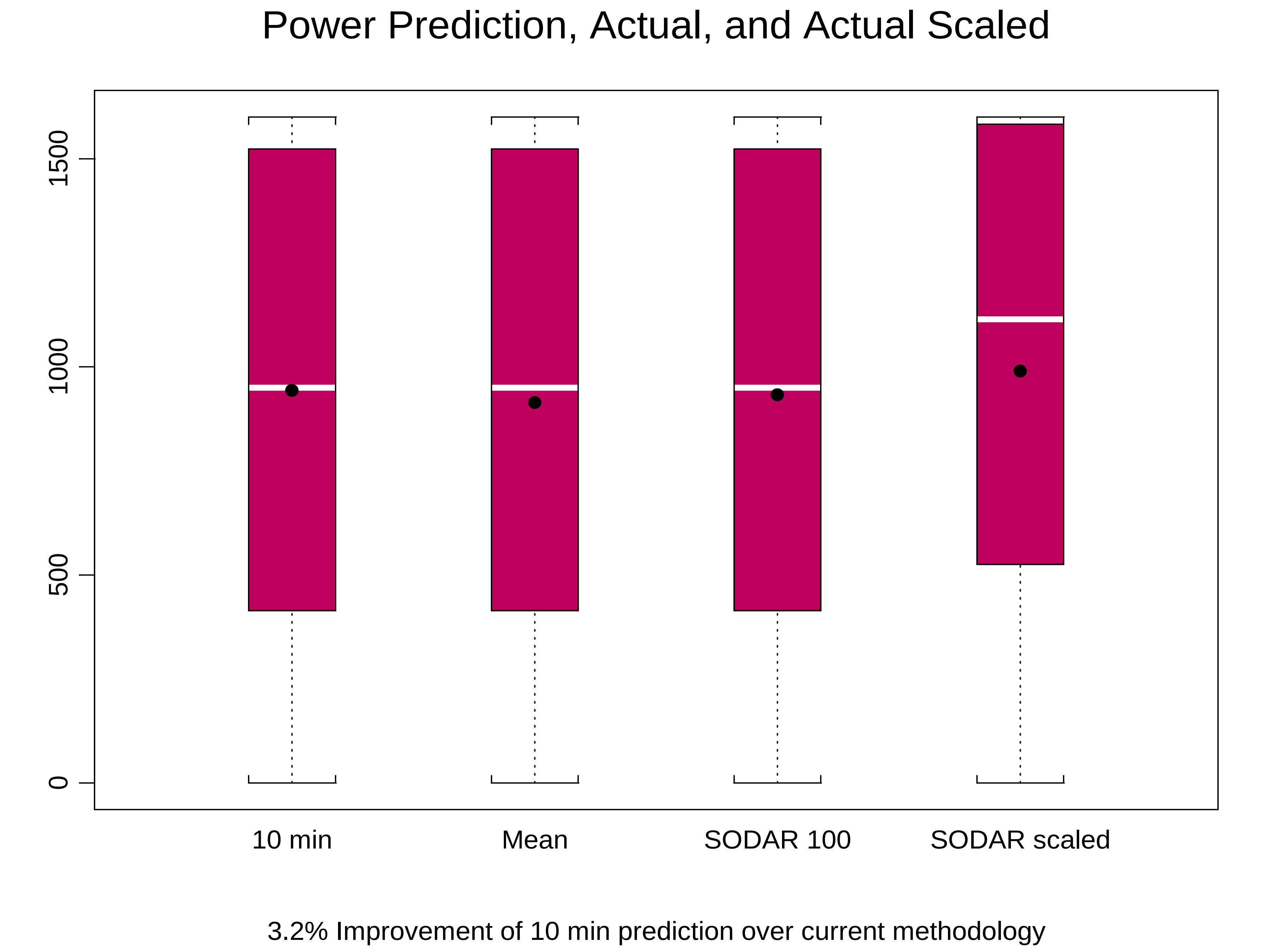
# Design with 5 Points

- So, adding 2 anemometers at 35m and 45m or at 45m and 55m, will decrease the uncertainty by a factor of 4.45. This increases the cost of adding 2 anemometers (including the data management), but there is no increase in the cost of a higher mast.
- Talk about a decrease in uncertainty!

# Power Function




Power Prediction, Actual, and Actual Scaled
0
500
1000
1500
10 min
Mean
SODAR 100
SODAR scaled
3.2% Improvement of 10 min prediction over current methodology

# Other Issues

- Data from 12 nearby masts with estimates of wind speed at all other 11 masts through linear and CFD models. Statistical analysis of the predictions is needed.
- A simple linear regression of wind speed at highest anemometer value (50 or 60m) is made on wind speed at 10m from closest Environment Canada station (about 50km away) to get the best fit. Then they plug the long term average wind speed to get the long term average speed at the mast.
- LIDAR, SODAR, and Anemometer: What to do?
- Wind direction?
- The elusive P99…
- Bias… bias… bias… bias… bias… bias…

# Conclusion

- A statistical view of the problem may help:
  - Estimate a regression line for each 10min data to predict the speed at the higher heights
  - Add 2 more anemometers between the other 3 to increase the overall precision of the slope by a factor of 4.45.
  - Think about a statistical model for wind speed and shear to take into account the yearly variation

# Conclusion

- Statistics is an exciting field contributing to the development of science and technology by working with scientists from other fields. This is a well-kept secret…
- It is a rapidly evolving field.
- Data and randomness surrounds us.
- Hatch has data from 400 masts which awaits to be understood!!!
- Think about giving a scholarship to Geneviève and hiring Hervé to make further progress!