Planning & Development | Ecology & Hydrology | Technical
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Natural Power

WIND MEASUREMENT IN EXTREME CONDITIONS

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WIND
MARINE
BIOMASS

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NATURAL POWER

WHAT WE DO

We provide a life-cycle suite of integrated consultancy and management services

Capability and proven expertise in:

- Project feasibility, permitting, land & environmental impact assessment
- Wind resource, energy yield assessment and turbine technology
- Ecology and hydrology assessment and mitigation management
- Construction management, site investigation, electrical & civil engineering
- Operational site management, 24/7 control and performance analysis
- Multi-disciplinary due diligence advice to support investment decisions

WIND MEASUREMENT IN EXTREME CONDITIONS

THE PROJECT

- Deploy measurements in horrible places
- Assess the impact of icing on
  - Unheated cup anemometers
  - Heated cup anemometers
  - Structures
- Assess the impact of complex terrain with regards to point measurement vs volume measurement
- Assess the robustness of instruments and methods

The project has just started this winter, and as such the results are preliminary

THE SITES

LET'S FIND THE WORST POSSIBLE CONDITIONS

We have selected the sites because:

- The terrain is complex
- They are remote and hard to access
- The winds can be extreme
- The icing is severe
- Temperatures can be very low

This is the kind of places they make reality television shows about. But worse.

THE SITES

COMPLEXITY

The sites are very complex

- Inclinations of 1000 meters within 500 meters
- Surrounding mountains heavily affecting the wind
- Altitudes for planned turbines can differ up to 200 meters within the site

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THE SITES

CLIMATE

The sites are very harsh

- Temperatures down to – 20 °C so far. Remember; it has been a quite mild winter so far.
- Potentially a lot of snow
- Wind speeds can be very high gusts at above 40 m/s have already been measured – twice!
- Visibility can be close to zero – making access by air impossible

THE CAMPAIGNS

EQUIPMENT

Same setup for all data sets:

- One mast
  - Shaft heated first class cup anemometer
  - Fully heated cup anemometer
- One LiDAR
- Shared power supply
- LiDAR and mast co-located

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THE CHALLENGES

WHAT PROBLEMS SO FAR

At sites like this, a certain amount of problems has to be expected. Especially initially.

Since the measurements are all ongoing, and part of campaigns that will be further extended, the problems are expected to decrease once the unexpected initial problems have been fixed.

THE CHALLENGES

THE FIRST STORM

Two weeks in, a severe storm caused problems with power supply and connectivity

- At wind speeds above 30 m/s, snow was getting into the otherwise very reliable power supply. This made one of the power supplies fail temporarily. Loggers were still running, but no heating and no LiDAR data available.

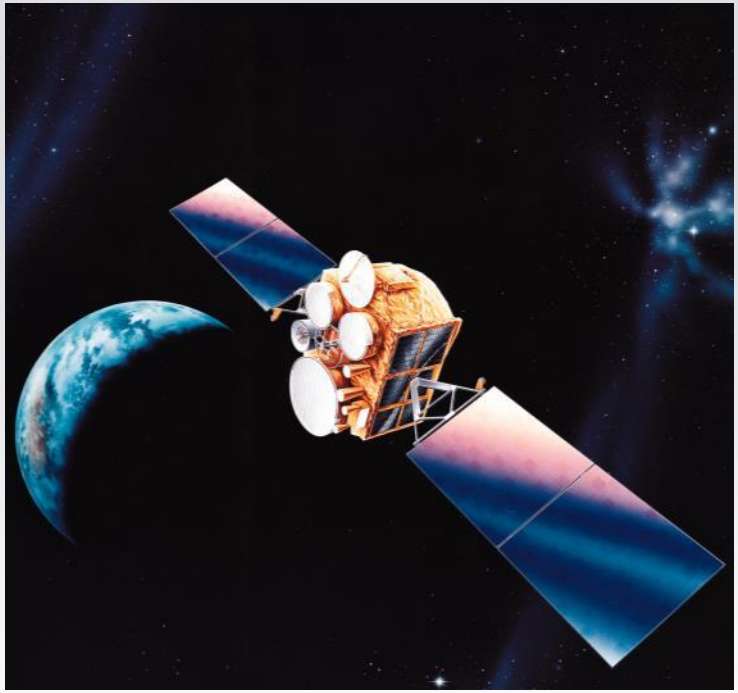
- We lost a GSM antenna in the storm. Making communication even worse.

THE CHALLENGES

TROUBLESOME COMMUNICATIONS

Communications has been troublesome at one of the sites

- GSM is weak at best
- Satellite is unreliable due to the constant bad weather
- A Swedish SIM, used in Norway, being called from the UK is seemingly too much for the phone operators to handle sometimes.



THE CHALLENGES

WHAT PROBLEMS SO FAR

Site visits are hard to plan

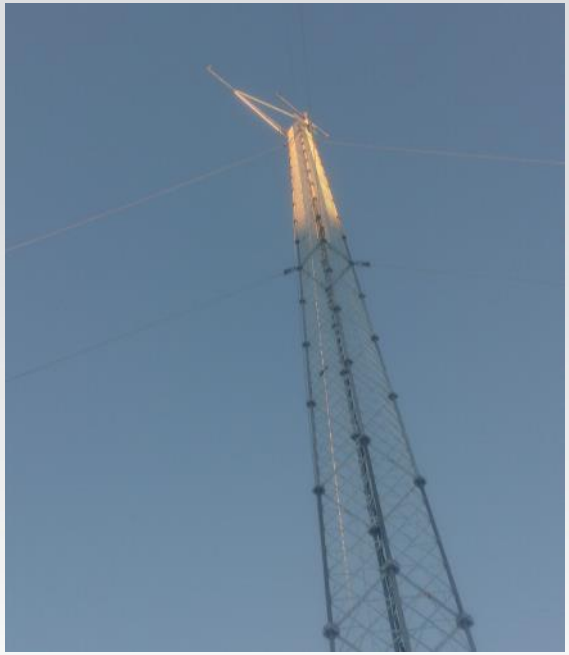
- Helicopter can’t fly if winds are too high or visibility too low.
- Some conditions are simply unsuitable for humans. But the reindeers seems to like them, something that delayed one of the deployments.
- Another deployment was delayed over a month due to bad weather. It is hard to find even one day where weather is good enough.

THE CHALLENGES

WHAT PROBLEMS SO FAR

Instruments

- The biggest quantity of data lost has been for the humidity sensors used
- The majority of the instruments have actually worked at or above expectations



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ASSESSMENT

ICING

In order to assess the impact of icing, a three step strategy was used.

- The shaft heated anemometer were treated as if it were the only measurement

- The mast measurement was treated as if it were the only measurement

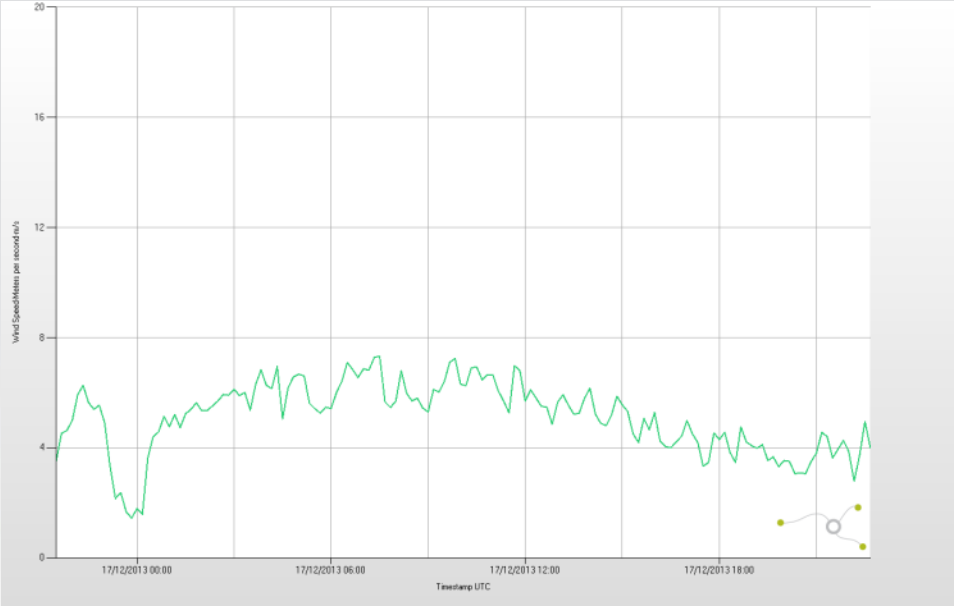
- All three sensors (shaft heated cup, fully heated cup and LiDAR) were used

WHAT IF…

WE ONLY HAD A SHAFT HEATED ANEMOMETER?

Cleaning of the data

- Check for obvious icing (flatlines)
- Check for partial icing, using experience and temperature as a guidance
- Resulting availability was about 70% to 100%.
- Doesn’t sound too bad, does it?



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WHAT IF…

WE ONLY HAD THE CUP ANEMOMETERS?

Cleaning of the data

- Assume that if the shaft heated anemometer shows significantly lower speed than the fully heated anemometer, it is iced to some extent

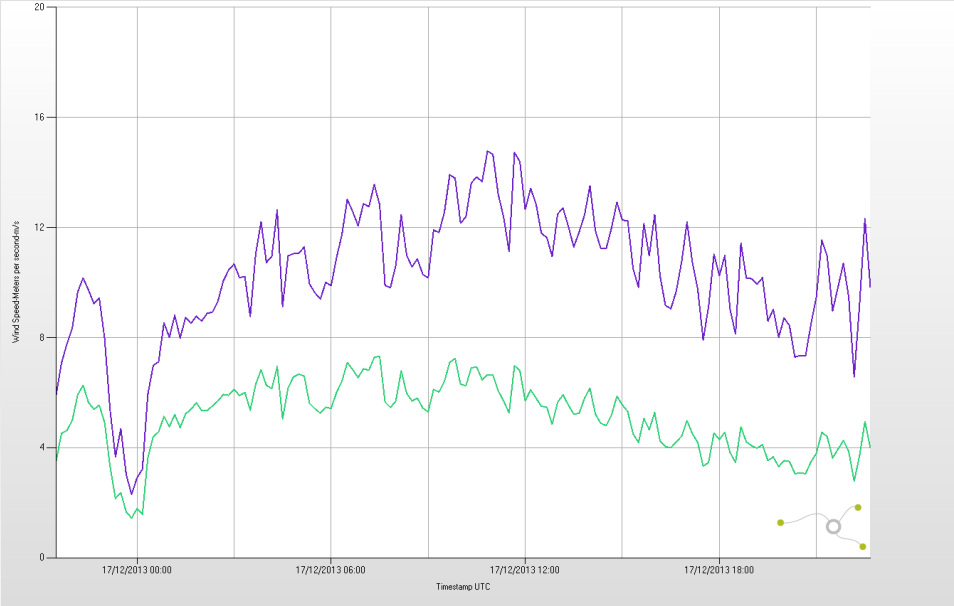
- Assume that if the fully heated anemometer shows significantly lower values than the shaft heated, both are iced.

WHAT IF…

WE ONLY HAD THE CUP ANEMOMETERS?

Result

- Resulting in availability of first class anemometer dropping to about 20% to 45 %.
- Availability of fully heated anemometer at about 70% to 97%.
- This means that we had about <u>50% partially iced data that we did not initially detect</u> using only the shaft heated anemometer!



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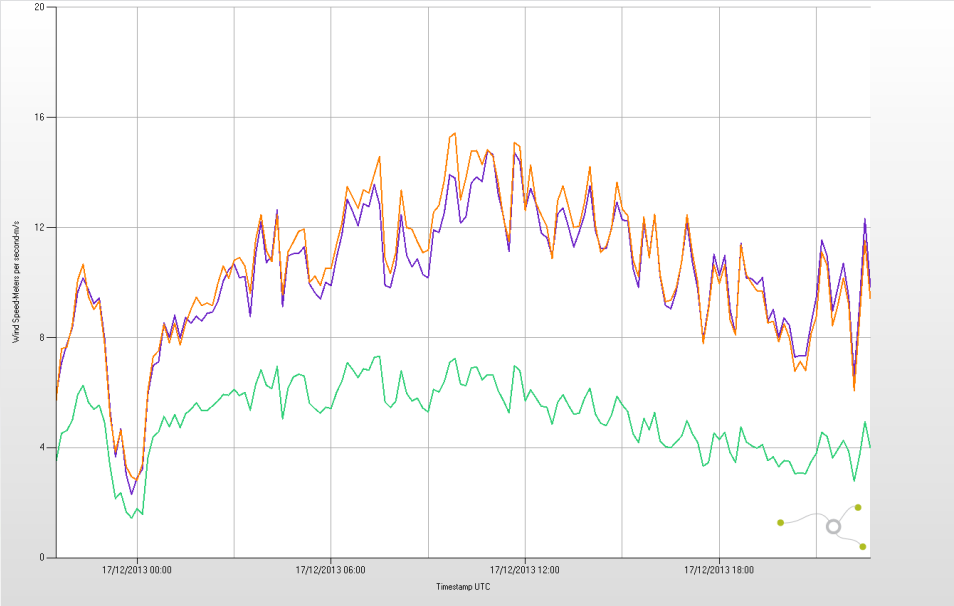
WHAT IF…

WE DO IT OUR WAY?

We use all three sensors, and clean the dataset even more. Then we combine them.



- We found a few percent more icing of both the shaft heated and the fully heated anemometers.

- We could use the combination of all sensors to create a data series with a close to 100% availability.

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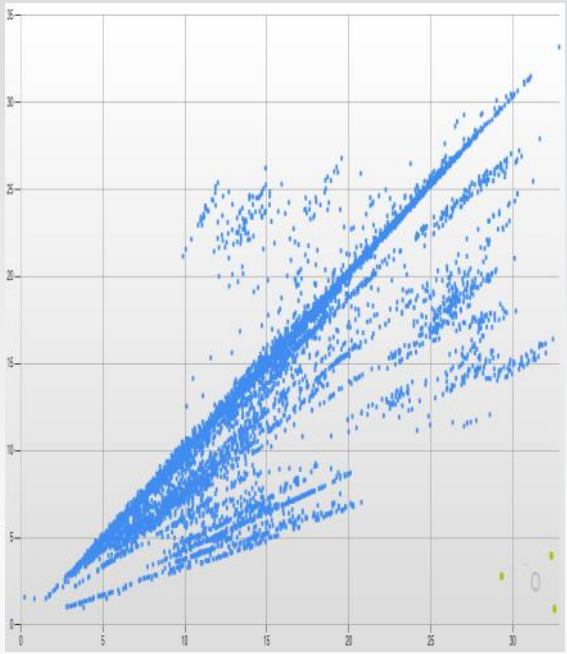
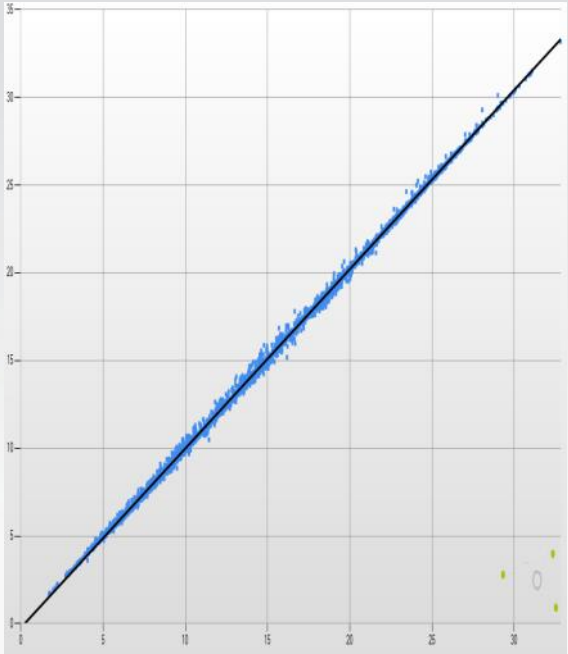
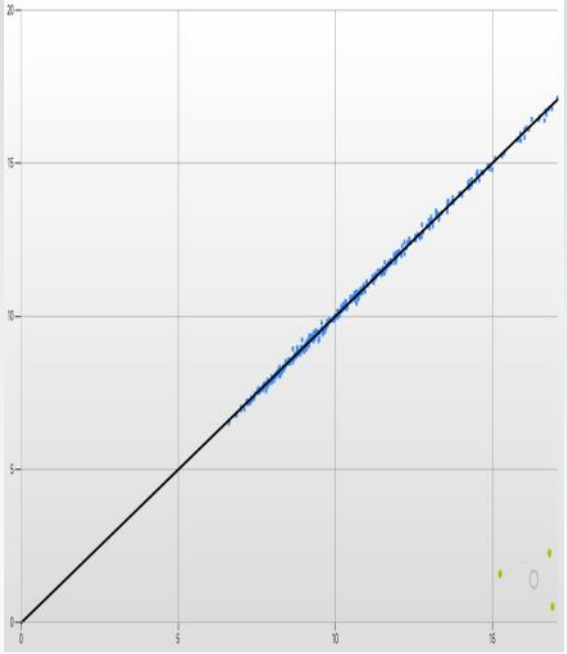
WHAT IF…

WE DO IT OUR WAY?

Since all analysts love scatterplots...







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CUP OR REMOTE SENSING

OR BOTH?

Since the terrain is complex, the flow is likely distorted. Meaning we need to convert the data from the LiDAR if we want it to match the data from the cup anemometer

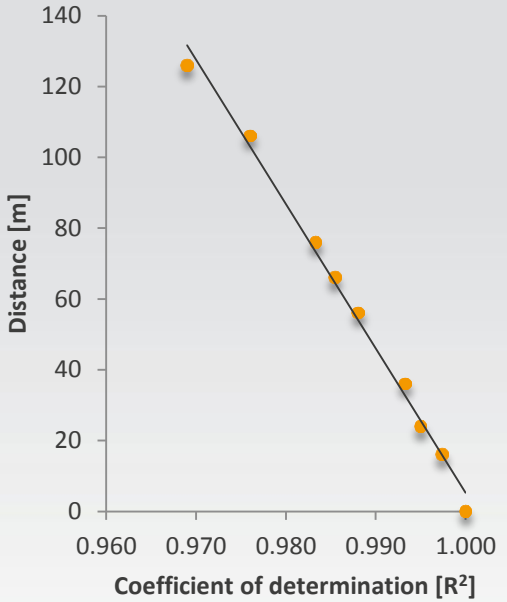
The cup anemometers allow us to validate the CFD model at the cup height, giving us – and the banks – confidence in the conversion

The LiDAR provides us with data on high heights, free from tower shadowing.

CORRELATION

IS IT GOOD ENOUGH?

Distance between mast and remote sensing device is 15 meters.



- This is to avoid falling ice to damage the LiDAR
- But this also reduces the correlation values
- For short distances, correlation and distance have a linear relationship. This is true for any measurement equipment.
- Using inter height correlations, the predicted coefficient of determination for 15 meters distance is approximately 0.998.

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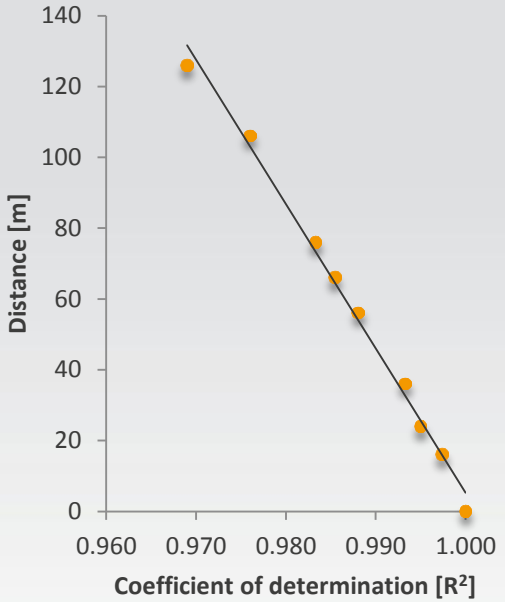
CORRELATION
IS IT GOOD ENOUGH?

Cup vs remote sensing

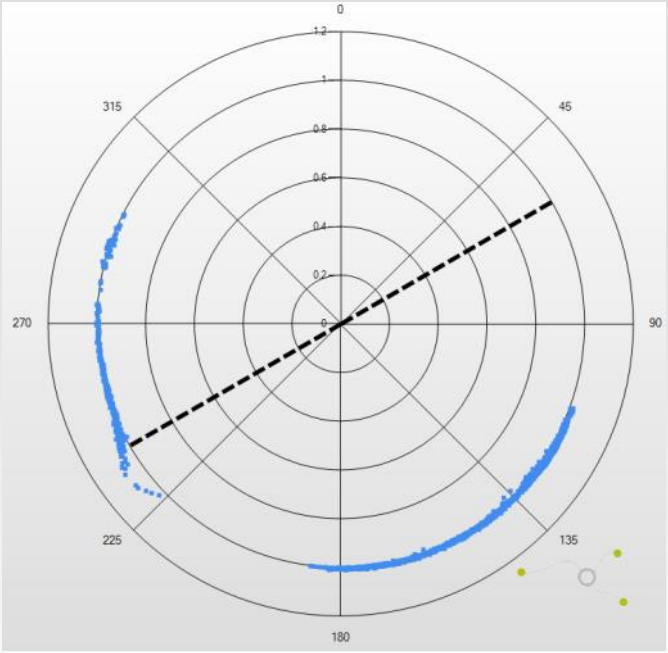
- R^2 from 0.988 to 0.999
- Lower correlation coincides with periods of frequent cup anemometer icing
- During periods where risk of cup icing is deemed to be very low (both cups indicating consistently good data), the correlation between cup and remote sensing is above the predicted



TOWER SHADOW

CAN WE SEE ANY EFFECTS OF THE ICING?

Due to the anemometers being fork mounted, only the lightning rod will cause shadowing.



- Shadowing is visible, but not severe
- Still not enough data to reliably quantify if the shading is significantly worse during icing conditions
- Only one rod has been unheated (due to a short circuit of heating cable)

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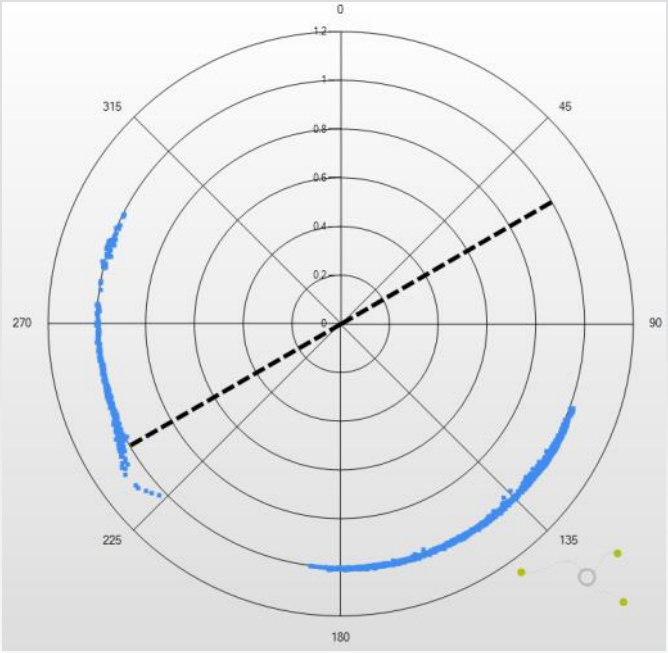
TOWER SHADOW

CAN WE SEE ANY EFFECTS OF THE ICING?

We do have some very preliminary results.

- 20° sector window
- Regression plot forced trough the origin
- Assuming no other flow distortion
- High uncertainty due to limited amount of data – especially for periods of non iced anemometry and potentially iced rod



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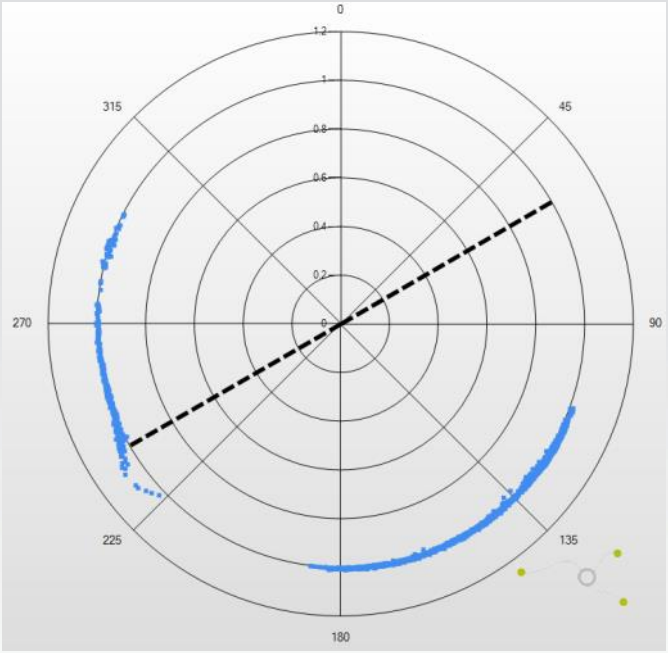
TOWER SHADOW

CAN WE SEE ANY EFFECTS OF THE ICING?

We do have some very preliminary results.

- For measurement with heated lightning arrestor, the shadow was measured to be approximately 3% in the 20 ° sector.
- For measurement with unheated rod, the shadow was measured to be approximately 4% in the 20 ° sector.
- These numbers are very small, and assuming uniform directional distribution, it would correspond to 0.16% and 0.24% on the total.



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TERRAIN COMPLEXITY

REMOTE SENSING VS CUP

Since the terrain is complex, the remote sensing measurement will have to be bias adjusted in order to be fully comparable with the cup measurement. Or vice versa.

- Ventos CFD has been used to calculate the flow distortion

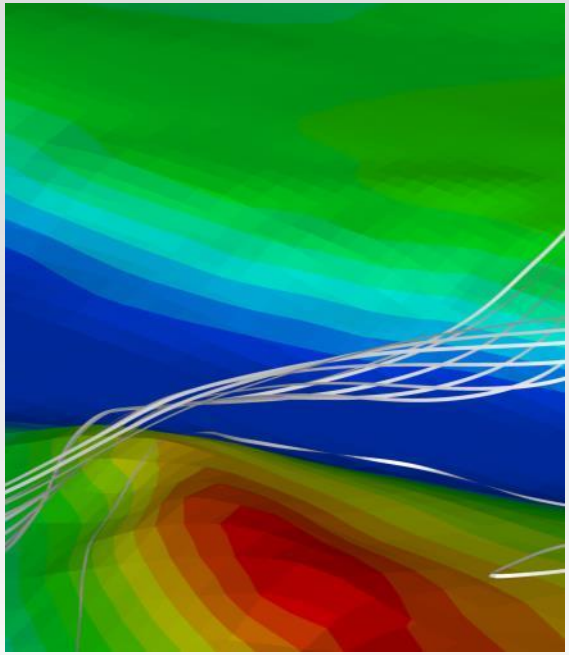
- Given the geometry of the remote sensing measurement, the equivalent of a point measurement has then been calculated

CFD

RESULTS OF THE DATA CONVERSION

Before correction using Dynamics CFD

- Sectorwise wind speed ratio from 97% to 104%.
- Average ratio from 100% to 102%
- Overall average ratio 101%



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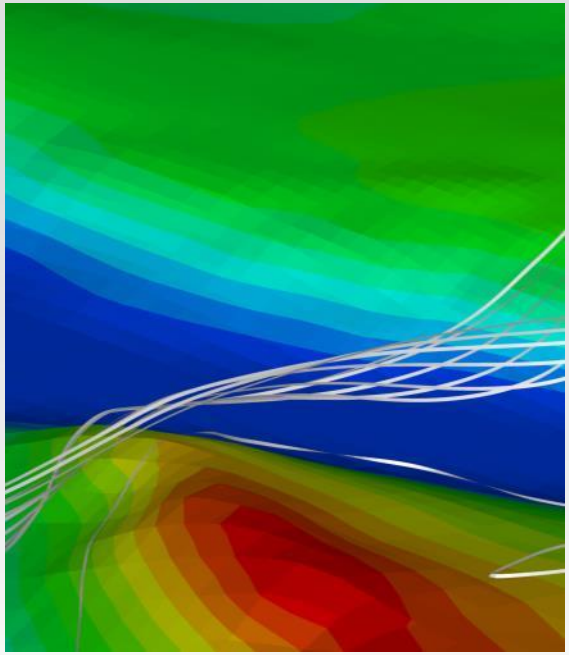
CFD

RESULTS OF THE DATA CONVERSION

After conversion using Dynamics CFD

- Sectorwise wind speed ratio from 97.0% to 104.0%.
- Average ratio from 99.0% to 100.9%
- Overall average ratio 100.0%



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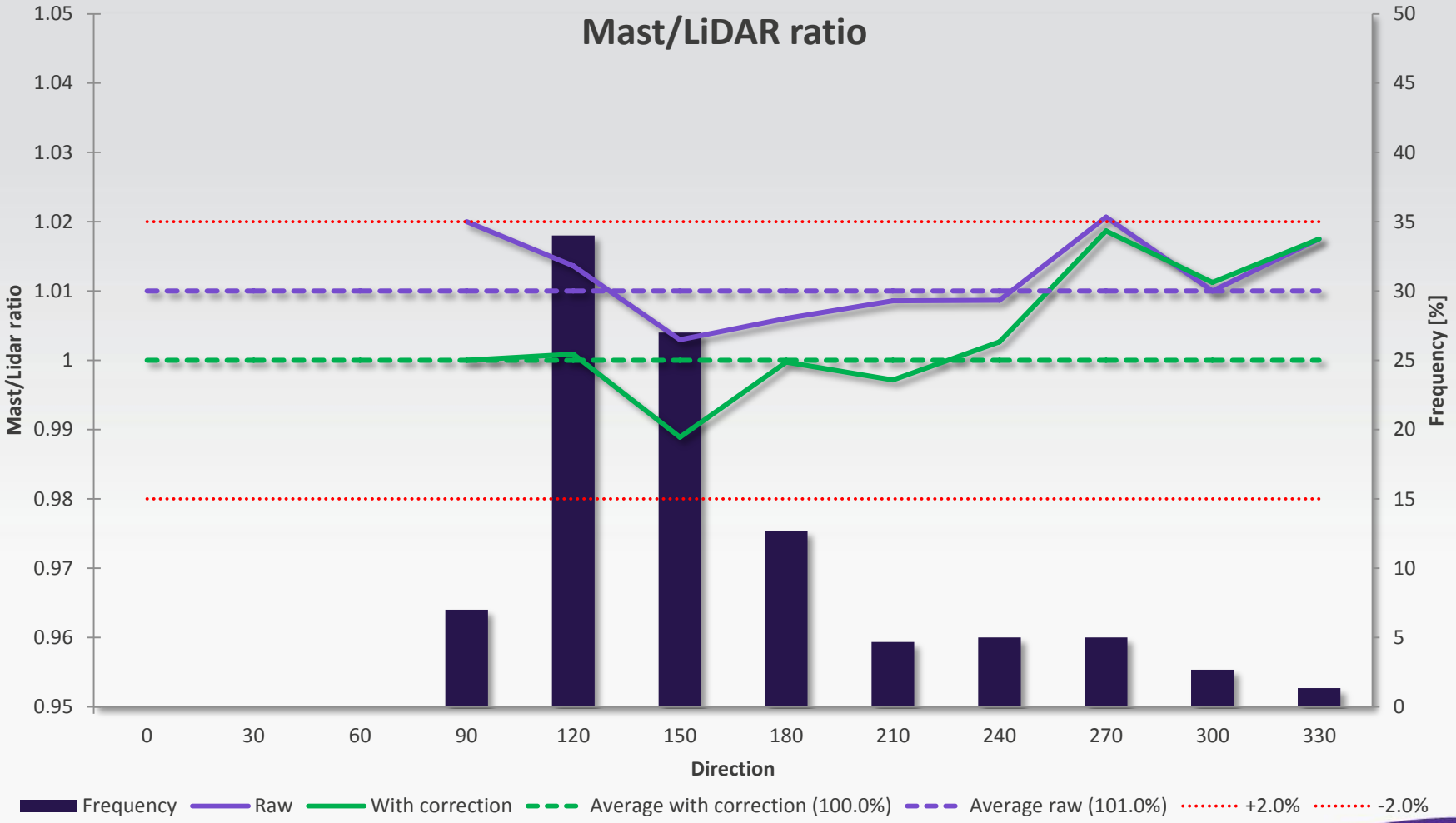
CFD

RESULTS OF THE DATA CORRECTION



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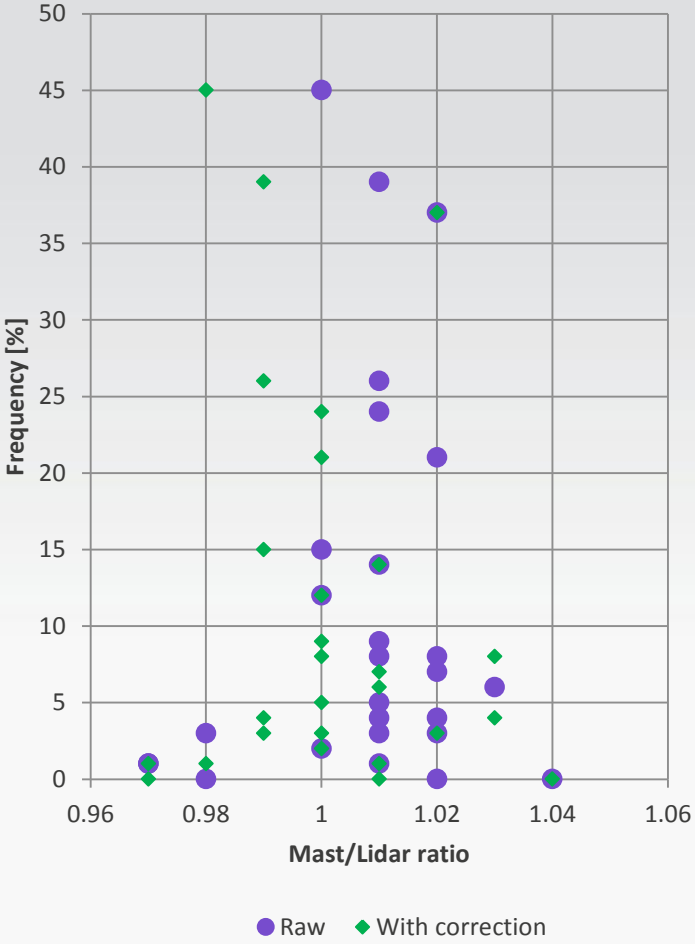
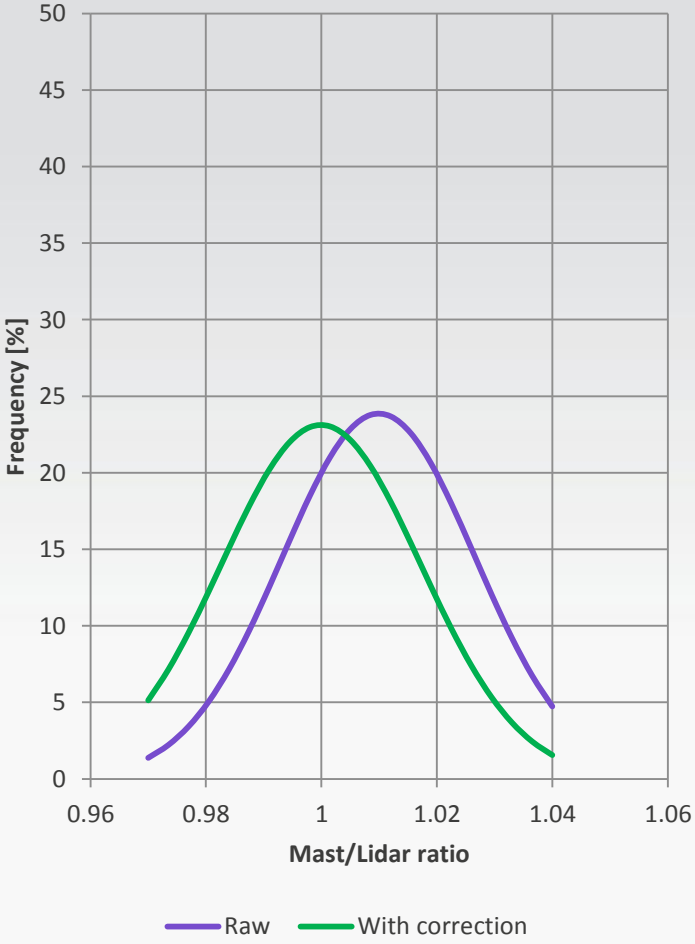
CFD

RATIO VS FREQUENCY





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FUTURE WORK

WE ARE NOT DONE YET!

- Collect data from the warmer periods of the year, to validate CFD corrections without uncertainty of icing
- Get the communication problems sorted out
- Replace hygrometers with models that can stand the climate
- More locations, more sites. This is just the very start of the campaign.

QUESTIONS?

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