Full Classification acc. to IEC 61400-12-1 for SoDAR AQ510 Wind Finder

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Ammonit Company Profile

- German company, based in Berlin
- +25 years of know-how (founded in 1989)
- Projects in more than 100 countries

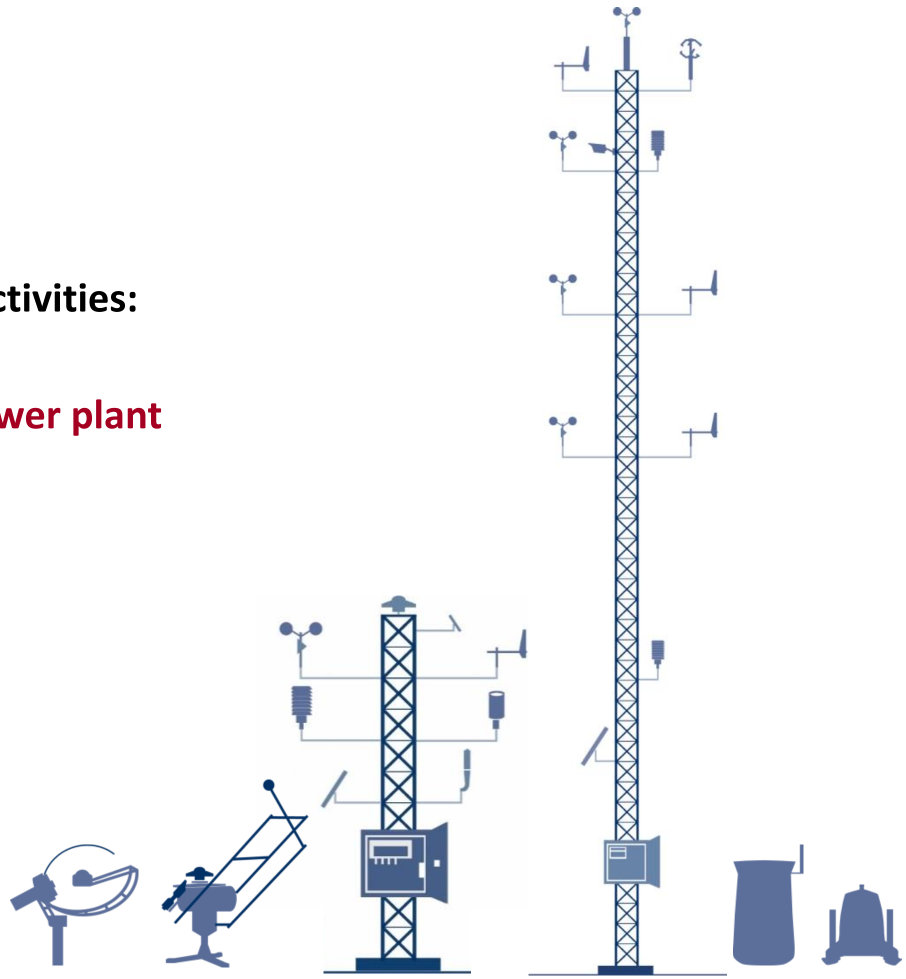
- **Measurement equipment for the following activities:**

Before the construction of a wind or solar power plant

- Wind Resource Assessment Measurement
- Solar Resource Assessment
- Soiling Measurement

After the construction of a power plant

- Wind Monitoring Systems (SCADA)
- Solar Monitoring Systems
- Power Curve Measurement
- Soiling Measurement



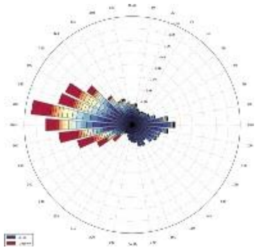
Solar Measurement   Wind Measurement

Ammonit Company Profile

- **Own products with own development**

Data loggers → Meteo-40

Cloud Software for campaign monitoring → AmmonitOR



- **Complete first class measurement systems**

Wind sensors from the German company Thies

Solar sensors from the Japanese company EKO

SoDAR devices from Swedish company AQ System

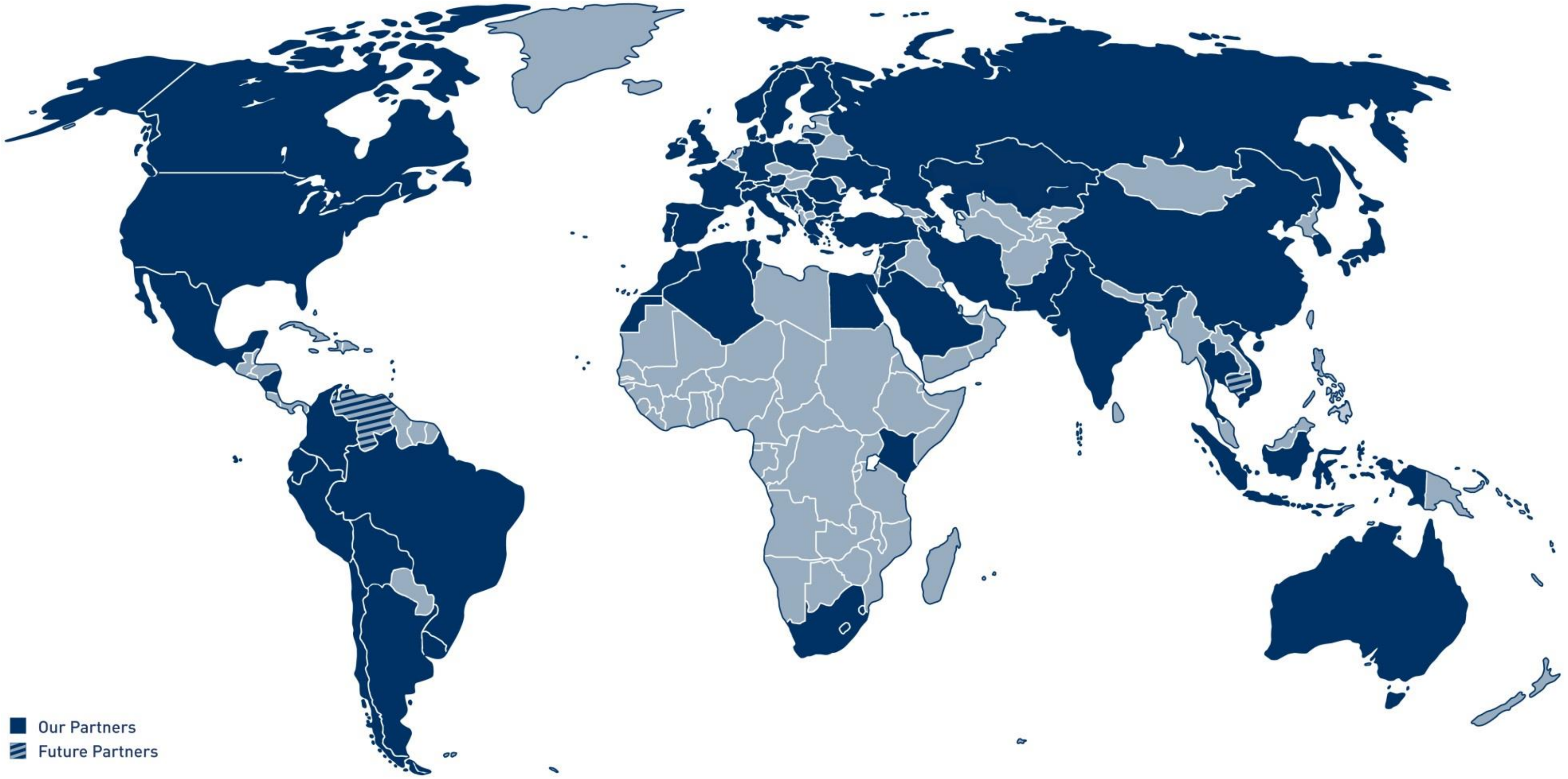
LiDAR devices from UK company ZephIR Lidar

Configuration of cables, cabinets, … → designed and assembled by Ammonit

Ammonit Global Partner Network

Partners in Brazil

- IEM in Porto Alegre, www.iem.com.br
- Braselco in Fortaleza, www.braselco.com



IEC 61400-12-1:2017 Annex L

- **Application of Remote Sensing**
  Remote sensing is more and more accepted for measuring wind power.
- IEC 61400-12-1 (Power Curve Measurement)
  → RSD have to be used only together with a mast. They are not allowed to be used alone.

- Measnet Site Assessment guideline (Wind Site Assessment)
  see Measnet Site Assessment guideline, annex C, RSD can be used alone.
  Some of the defined application are:
  - C8 Standalone application of Remote Sensing
  - C9: "Roaming": Wind Measurements Aiming for a better special coverage of a wind farm area
  - C10 Wind shear Measurements for a Vertical Extrapolation of Mast Measurements

- IEC 61400-15-1 announced for 2019/2020
  It is probable that many inputs from the Measnet Site Assessment guideline will transferred to coming IEC 61400-15-1 for wind site assessment.

IEC 61400-12-1:2017 Annex L

- IEC specifies requirements and quality of remote sensing devices (RSD) used in wind energy assessment campaigns → **Classification and Verification**

What is a Verification / Calibration

- Comparison of RSD measurements with those from a calibrated cup anemometer mounted on an IEC-compliant met mast.
  - In contrary to a calibration in a wind tunnel, where the wind conditions are maintained fairly constant, the wind Conditions during a RSD-verification can be fairly different,
    -depending on the Mast where the comparative Measurement took place:
    a Mast in middle-Sweden doesn't have the same wind conditions
    as a mast in Natal.
    But as well depending on the period, where the measurement
    took place: wind conditions in Sweden are not the same in January
    as in July.

    Example of Sodar verification
    on http://www.ammonit.com/en/produkte/sodar-lidar,
    you will find 3 examples of verification

AQ510 WW in Stockholm

IEC 61400-12-1:2017 Annex L

Classification

- Where the verification is a momentary evaluation of the accuracy of a RSD in concrete wind and environmental conditions, the classification is a systematic analysis of the impact environmental conditions on the accuracy of the RSD
  - Assessment of the sensitivity of the RSD to environmental parameters (EP) such as temperature, temperature gradient, wind shear exponent, wind veer, turbulences, etc.
  - Evaluation of sensitivity with regression analysis of the accuracy of the RSD as a function of each EP

  → **Assessment of uncertainties in the accuracy in different kind of weather and wind conditions**

→ **Remark**

It is known from literature that the data availability
Sodar can be sometimes sensitive to the temperature gradient:

High data availability by stable and unstable wind conditions.
Lower data availability by neutral wind conditions.

Classification of AQ510 Wind Finder

- Acc. to IEC testing of a minimum of 2 devices at a minimum of 2 different measurement sites for a minimum test period of 3 months per device; 1 devices has to be deployed at both sides
- Test sites
  - Fimmerstad, Middle Sweden
    with reference met mast (103m, IEC-compliant) → little to moderately complex terrain
    This is the mast used for a the verification of AQ System,
  - Mullsjö, Middle Sweden
    with reference met mast (180m, IEC-compliant) → semi-complex terrain.

- This is very interesting since up to now,
  studies were all done with 90-130m met mast.
  This is now very interesting to see what happens till 180m.

  This is one of the very few mast going as high.

Classification of AQ510 Wind Finder

Authors of the Classification

- Main Author Emil Dahl, Product Analyst AQ System
- Reviewed and concurred by Johan Arnqvist, PhD in Meteorology, Uppsala University
- Approved by Sten-Ove Rodén, Quality Manager AQ System

→ It is not an from AQS independent classification

Classification of AQ510 Wind Finder

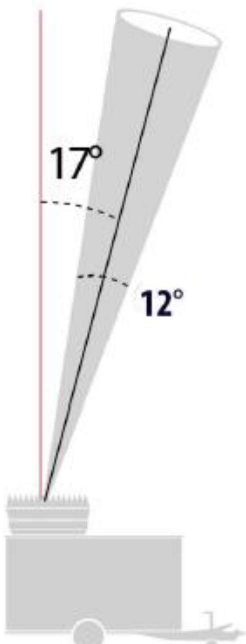
- Acc. to IEC testing of a minimum of 2 devices at a minimum of 2 different measurement sites for a minimum test period of 3 months per device; 1 devices has to be deployed at both side

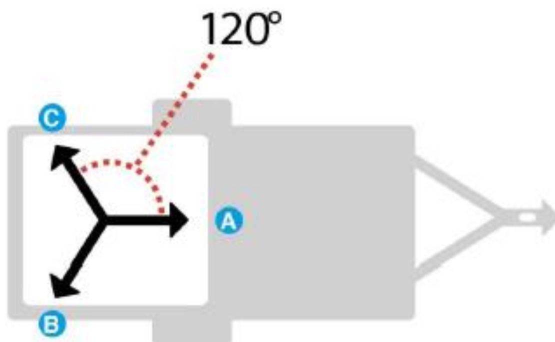
- EPs (Environmental parameters) for the calculation of the final accuracy class, as defined by the IEC 61400-12-1
  - Air Temperature
  - Air Temperature Gradient
  - Turbulence Intensity (TI)
  - Wind Shear Exponent
  - Wind Veer
  - Wind Direction
  - Air Pressure

AQ510 Wind Finder

AQ510 Wind Finder – Measurement Principle

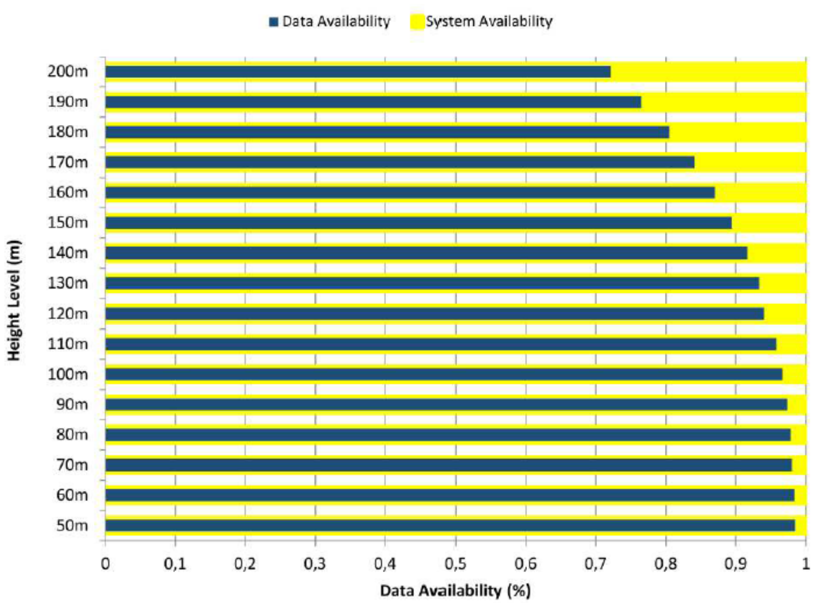
- Sound transmitted in 3 directions
- Reflected by small temperature variations
- Difference between transmitted and received frequency is used to calculate the wind





Data Availability during Classification Tests

- Total system availability: 100%
- Data availability with values higher than 90% up to measurement level of 150m, decreasing to 70% at 200m
- Data coverage: > 98% for selected measurement levels 60m, 80m and 100m
- Data availability is important since it is the challenge in RSD technology to have at the same time high data availability and high accuracy. Theoretically it could be possible through more severe filtering to improve the accuracy but occasioning at the same time a lower data availability.



Important Parameters

- All available parameters have been included in calculations for final accuracy
- Individual EP corrections important to give the device an **average uncertainty** to be applied on the wind data

No	Parameter	Unit	Sensor Fimmerstad
1	Air pressure	hPa	Sensor at 1,8m
2	Air temperature	°C	Sensor at 60m
3	Air temperature gradient	°C/m	From 100m & 2m
4	Turbulence intensity	-	From 80m
5	Wind direction	°	Vane at 75m
6	Wind shear exponent	-	From 100/60m
7	Wind veer	°/m	Vanes at 97/55m

Table 6: List of EPs considered in the sensitivity assessment at site Fimmerstad.

No	Parameter	Unit	Sensor Mullsjö
1	Air pressure	hPa	Sensor at 1,8m
2	Air temperature	°C	Sensor at 60m
3	Air temperature gradient	°C/m	From 100m & 2m
4	Turbulence intensity	-	From 80m
5	Wind direction	°	Vane at 78m
6	Wind shear exponent	-	From 100/60m
7	Wind veer	°/m	Vanes at 118/78m

Table 7: List of EPs considered in the sensitivity assessment at site Mullsjö.

Important Parameters

Process to calculate the classification value

- **To determine final significant and uncorrelated EPs**

- Sensitivity is defined as the slope multiplied by the standard deviation of the independent variable: *m·std*. The sensitivity indicates the extent, expressed as a percentage, that the deviation between the remote sensing device and the reference sensor measurements is changed by a change in the independent variable of one standard deviation.

- An EP is considered as significant if the modulus of its Sensitivity S exceeds 0.5.
- SEP > 0.5

- If an EP fulfils the condition in one measurement height it is therefore rated as significant to all other measurement heights and should be included in the further assessment

Important Parameters

Determination of accuracy class and STD uncertainty

The final accuracy class and STD uncertainty is calculated individually for each measurement height treated and calculated in 5 steps:

1. Determine final significant and uncorrelated EPs
2. Calculate the maximal influence of every EP for each height by multiplication of the regression slope m (obtained through a OLS linear regression) and the standard range of the EP (m,EP x RangeEP)
3. Summarize all EP contributions in quadrature
4. Divide by square root of 2 to build the final accuracy class
5. Divide the final accuracy by square root of 3 to get the standard uncertainty.

Impacts from different EPs

- **Most important EP:**
  Turbulence Intensity and Wind Shear most important followed by **Temperature Gradient**
- Relative Consistent behaviour: we see that the same EP behave consistent over different heights, different site

Height	Parameter	m	Range	m*Range
100	Air temp	0,012	40	0,476
80		0,0153	40	0,036
60		-0,021	40	-0,6
100	Air temp grad	0,022	0,08	0,00176
80		-14,149	0,08	-1,1208
60		15,697	0,08	1,2557
100	Turbulence intensity	6,4073	0,21	1,3455
80		7,113	0,21	1,494
60		9,008	0,21	1,892
100	Wind direction	0,0002	180	0,18
80		0,002	180	0,36
60		-0,0046	180	-0,828
100	Wind shear exponent	0,6848	1,2	0,8217
80		2,4488	1,2	2,9386
60		2,6008	1,2	3,121
100	Wind veer	-0,0975	0,4	-0,039
80		0,1714	0,4	0,0686
60		1,0578	0,4	0,423
100	Air pressure	0,0045	52	0,0547
80		0,0005	52	0,00068
60		0,0032	52	0,2768

Table 17: Slope and standard range of EPs

Classification Results – Final Accuracy Class per Measurement Level

- Best results at 100m at Fimmerstad and 180m at Mullsjö
- Effect by EPs: Turbulence Intensity, Temperature Gradient and Wind Shear Exponent
- Its impact is different depending on the season.
  In winter the impact is negative meaning that the sodar tend to underestimate the wind. In summer the effects are reversed and instead give an overestimation.

Height	PER2 (M)	PER2 (F)	AQS56 (M)	DEV1 (F) 1 year	AQS54 (M)	*DEV1 (F) 3 months DNV-GL**
180 m	1,36%	-	1,64%	-	1,91%	-
150 m	1,77%	-	1,77%	-	1,98%	-
120 m	2,16%	-	2,57%	-	2,52%	-
100 m	3,31%	2,14%	3,61%	1,17%	2,60%	*1,99%*
80 m	4,20%	3,67%	4,89%	2,08%	3,90%	*3,85%*
60 m	5,13%	4,66%	5,61%	2,71%	4,80%	*8,00%*
40 m	6,12%	-	6,15%	-	5,45%	-

Table 18: Final accuracy class for all units considering all EPs.

Classification Results – Final Accuracy Class for all Units

- No influence from temperature and air pressure on wind speed accuracy
  → acc. to IEC removed for final accuracy class calculation

Height	PER2 (M)	PER2 (F)	AQS56 (M)	DEV1 (F) 1 year	AQS54 (M)
180 m	1,07%	-	1,18%	-	1,13%
150 m	1,28%	-	1,37%	-	1,33%
120 m	1,30%	-	1,89%	-	1,42%-
100 m	1,70%	1,10%	2,30%	1,13%	1,82%
80 m	2,15%	2,97%	3,33%	2,06%	2,63%
60 m	2,72%	4,16%	3,74%	2,68%	3,17%
40 m	3,67%	-	3,91%	-	3,50%

Table 19: Final accuracy class for all units considering EPs per standard [4].

Classification Results – Final Accuracy Class for all Units

- To obtain the uncertainty, you divide the accuracy class by square root of 3

Height	PER2 (M)	PER2 (F)	AQS56 (M)	DEV1 (F) 1 year	AQS54 (M)
180 m	0,62%	-	0,68%	-	0,65%
150 m	0,74%	-	0,79%	-	0,77%
120 m	0,75%	-	1,09%	-	0,82%
100 m	0,98%	0,97%	1,33%	0,65%	1,05%
80 m	1,24%	1,72%	1,92%	1,42%	1,52%
60 m	1,57%	2,40%	2,16%	1,61%	1,83%
40 m	2,12%	-	2,26%	-	2,02%

Table 21: Standard uncertainty of all systems considering EPs per standard [4].

Classification Results – Final Standard Uncertainty

- With increased height the influence of EPs decreases → making AQ510 more stable with height
- Slopes of different EPs vary depending on the season
- During shorter measurements recommendation to use 3-months standard uncertainty
  →For longer periods the standard uncertainty decreases

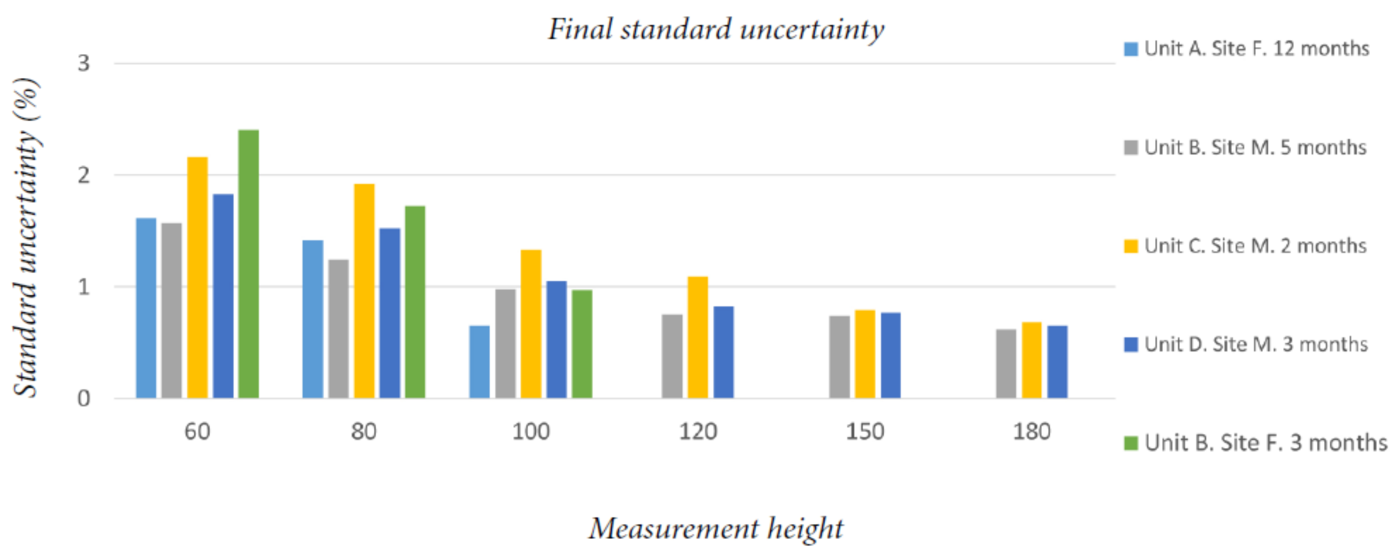
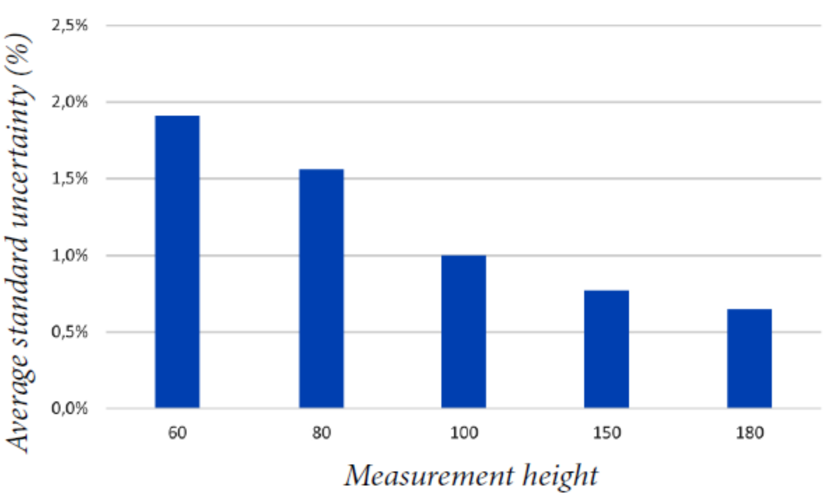


Figure 5: Results from all SoDARs used in classification assessment.

Classification Results

- > 96,000 10-min data points gathered from 4 AQ510s for highly robust classification
- **Similar Sensitivities** of all devices to each EP and **Standard Uncertainty** close to one another
  → proving robustness of AQ510
- **With longer measurements standard uncertainty reduces further**
  → Should be considered for the duration of a SoDAR measurement campaign
- Results assessed and independently verified by Uppsala University

Average standard uncertainty

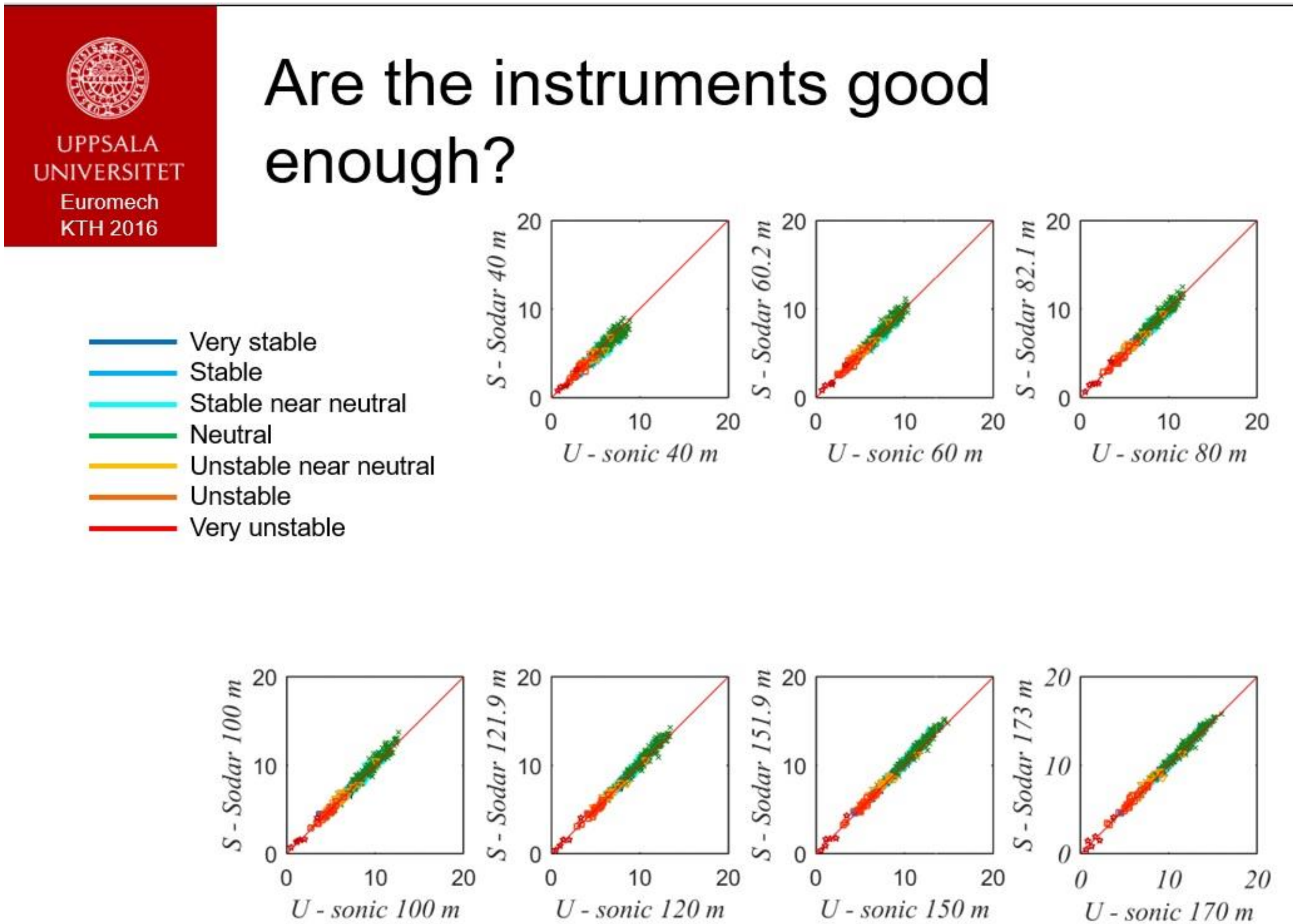


AQ510 has been classified according to the procedure described in Annex L of the IEC guidelines, 61400-12-1, and achieved a mean standard uncertainty of 1,00% at 100m.

Figure 6: Standard uncertainty of all AQ510 in analysis with EPs according to IEC.

SoDAR vs. Neutral Atmospheric Conditions

- No negative effects on accuracy → there might be a lower data availability



Atmospheric Stability and Turbulence Intensity Comparison

- 3-months study under Swedish winter conditions by comparing 180m met mast of Uppsala University with AQ510 → **Neither atmospheric stability nor turbulence intensity has any effect**
- Without data filtering for heavy snow or tower shadow effects, between 60m and 180m deviation is less than ± 2 %.

The AQ510 data availability during the 3 months campaign:

Height (m)	*40*	*60*	*77,6*	*82,1*	*100*	*117,9*	*122*	*147,7*	*152*	*180*
Data availability	*98 %*	*98 %*	*98 %*	*98 %*	*98 %*	*96 %*	*96 %*	*90 %*	*90 %*	*84*

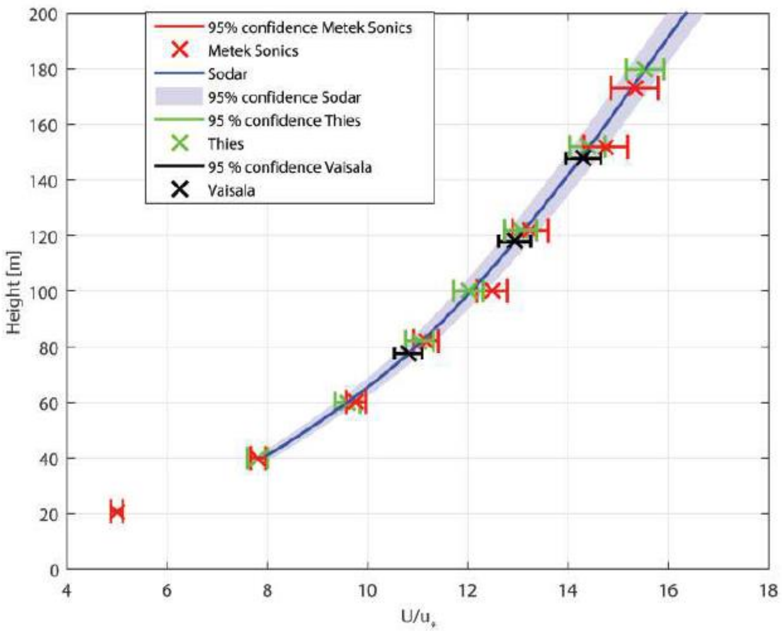


Figure 1, Mean wind profile from the different anemometers. The true mean value is expected to lie within the errorbars with a 95 % probability.

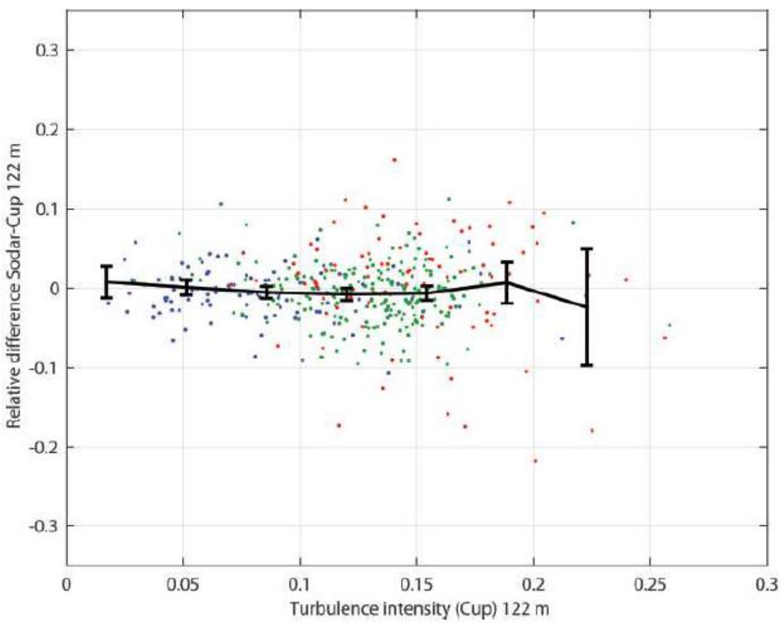


Figure 2, Relative difference between the SoDAR and the cup at 117.9 m as function of the turbulence intensity. The mean value of the points is expected to lie within the errorbars with a 95 % probability. Blue dots show data points from stable stratification, green points from neutral stratification and red dots from unstable stratification.

Seasonal Impacts on the Measurement Results

- Impact of EPs varies depending on the season
  → measurements covering all seasons for lower uncertainties

Benefits of AQ510 Wind Finder

- Wind measurements up to 200m
- Complete and fully mobile system
- Operate in tough climate
- High data availability
- Does not have to be send back to Europe for maintenance. Very easy maintenance
- 1/3 to 1/2 of the price of a LiDAR

Contact

Please contact us for further information

Thank you!

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