Status Quo of Lidar/Sodar: How to Gain Acceptance for Remote Sensing

A. Albers
Deutsche WindGuard Consulting GmbH
Oldenburger Straße 65, 26316 Varel, Germany
a.albers@windguard.de

testing- and calibration laboratory with
quality management system according EN ISO/IEC 17025:2005

Status of Revision of IEC 61400-12-1

- Committee Draft (CD) Edition 2 available since September 2011
- Integration of national comments ongoing
- Committee Draft for Voting (CDV) expected not before end of 2012
- Final revision expected in 2013
- Annex L on remote sensing implemented
- Annex L based on work of Lidar Acceptance Project
  - active from May 2009 to June 2011
  - members: Vestas, Siemens Enercon, Riso/DTU, GL-GH, WindGuard (project leader)
- Limitation to ground based lidars/sodars due to limited time frame

Wind Speed Definition/Measurement Revision of IEC 61400-12-1

- Case 1: wind speed measured only at hub height (with mast or remote sensor).

- Requires validation of remote sensor in terms of absolute wind speed measurements at special test site

- Case 2: wind speed measured over whole rotor with one instrument type (mast or remote sensor).

$$v_{eq} = \frac{1}{A} \cdot \left(\int_{H-R}^{H+R} v_m^3 dA \right)^{\frac{1}{3}}$$

- If remote sensor applied: control met mast with height of at least H-D/2 needed at site of application

- Case 3: wind speed measured at hub height H by cup anemometer, shear measurement by remote sensor

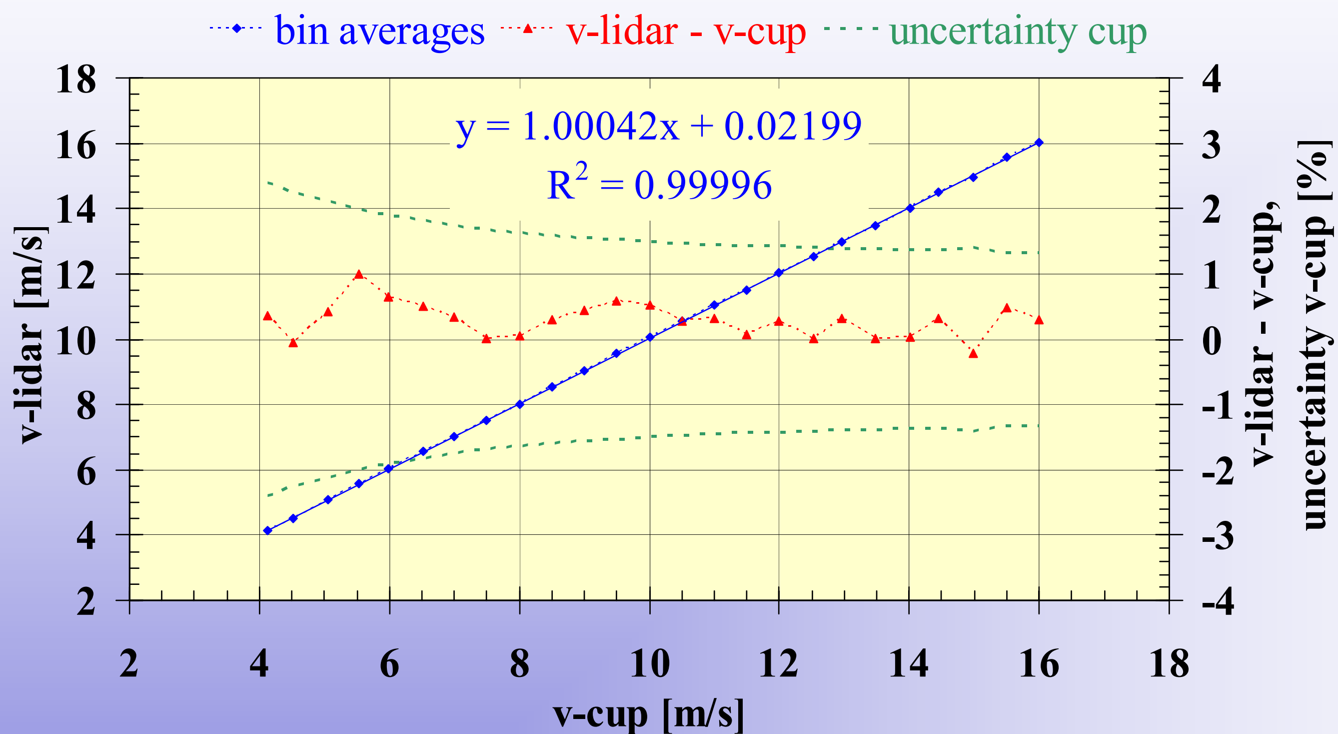
$$v_{eq} = v_{H,cup} \frac{v_{eq,remote}}{v_{H,remote}}$$

- Requires validation of remote sensor in terms of relative wind speed measurements at special test site (shear measurement)!

Fundamental Requirements

Step	Requirement	Method	Replacement for
1	traceability to national standards	Verification Test of each unit	wind tunnel calibration of each cup anemometer
2	repeatability	Sensitivity Test/Classification type specific	classification cup anemometer type
3	control	control by mast with height >= H-D/2	control anemometer, *validation of results of Verification Test and Sensitivity Test*
4	complete analysis of uncertainty	cumulating uncertainties of	cumulating of uncertainties of:
		4a Verification Test	wind tunnel calibration
		4b Sensitivity/Classification	classification
		4c control by mast	after-calibration, in-situ testing *added uncertainty in case of non-compliance to Verification Test and Sensitivity Test*
		4d inhomogeneous airflow	-
		4e mounting	mounting
		4f site effects (positioning relative to turbine)	site effects

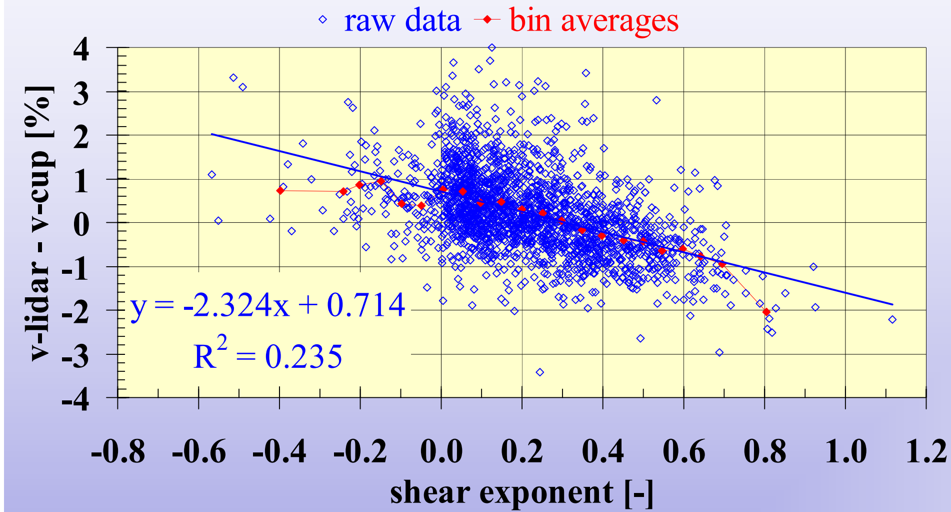
1. Traceability to National Standards



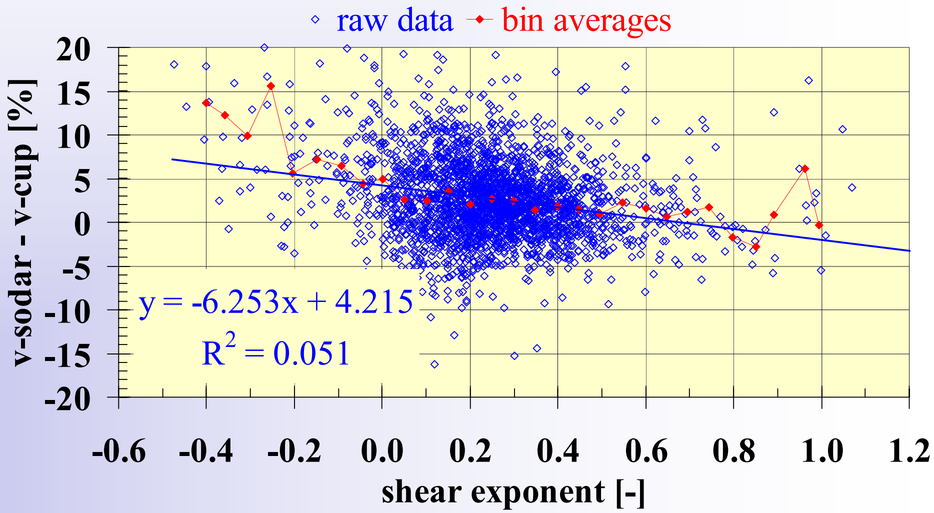
- By comparison to traceably calibrated reference sensors on mast,
  (e.g. at German Test Station for Remote Sensing Devices or at DTU, Denmark)
- No Correction/Calibration foreseen
- Analysis focuses on bin averages

2. Sensitivity Test
Example Wind Shear, 135m height

Lidar: Windcube Version 1



Sodar



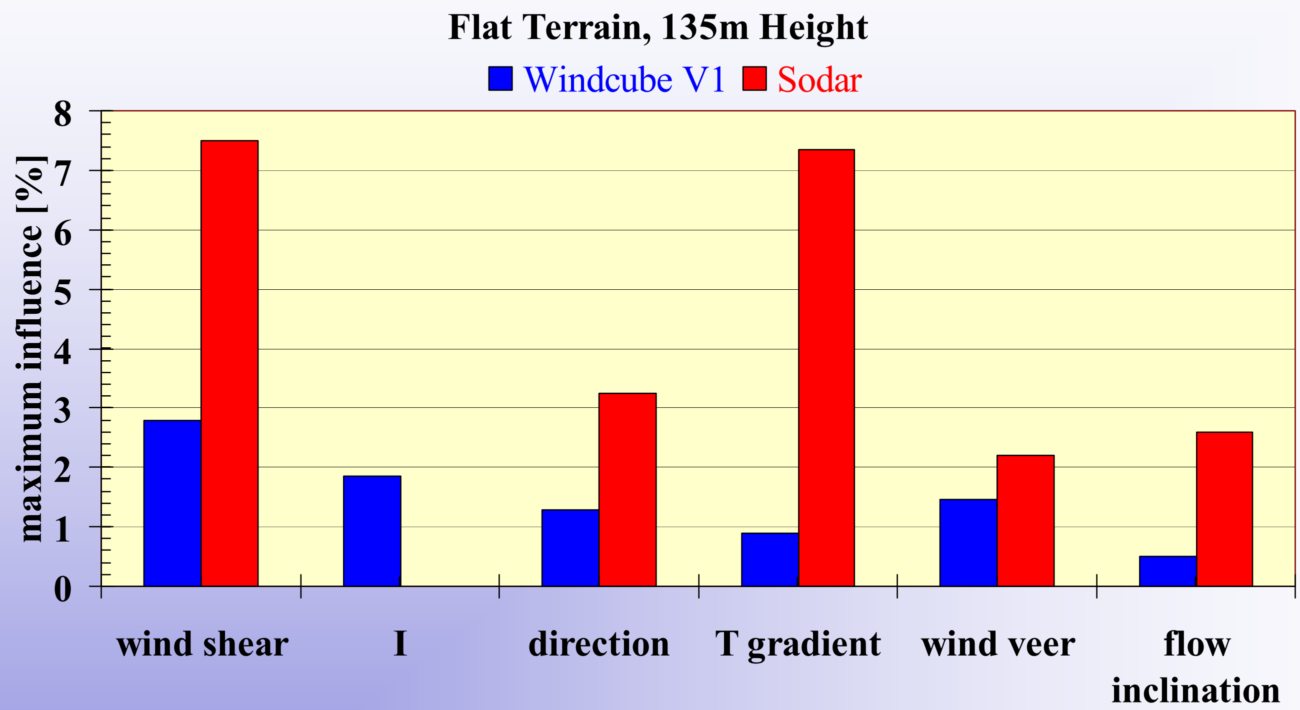
- Problem:
  Environmental conditions different at application of lidar/sodar and at Verification Test
- Solution:
  Type specific sensitivity of lidar/sodar error on environmental variables needs to be investigated
- Results in case of lidars mostly much better than in case of sodars

2. Classification
Proposal for Ranges of Variables

		flat terrain			complex terrain			
independent variable		**max**	**min**	**range**	**max**	**min**	**range**	**source**
shear exponent alpha	[-]	0.80	-0.40	1.20	0.80	-0.40	1.20	experience
turbulence intensity I	[-]	0.24	0.03	0.21	0.36	0.03	0.33	IEC 61400-12-1
rain (yes=1, no=0)	[-]	1	0	1	1	0	1	by definition of sensor
availability lidar	[%]	100	80	20	100	80	20	by definition of filter
wind direction	[°]	360	0	180	360	0	180	deviation of 2 directions is maximum 180°
air temperature T	[°C]	40	0	40	40	-10	50	IEC 61400-12-1
air density	[kg/m³]	1.35	0.90	0.45	1.35	0.90	0.45	IEC 61400-12-1
T difference 133m-10m	[K]	6	-2	8	6	-2	8	experience
flow inclination angle	[°]	3	-3	6	15	-15	30	IEC 61400-12-1
wind veer dir133-dir35	[°]	20	-20	40	20	-20	40	experience

complex terrain application not allowed in IEC 61400-12-1

2. Classification
Max. Influence of Variables



- Maximum influence calculated on basis of Sensitivity Test
- Criteria on range coverage of variables
- Criteria on significance of variables
- Criteria on correlation of environmental variables
- Influences of the relevant variables cumulated to possible total error

2. Accuracy Classes/Uncertainty Due to Sensitivity

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Lidar: Windcube Version 1 (preliminary results)

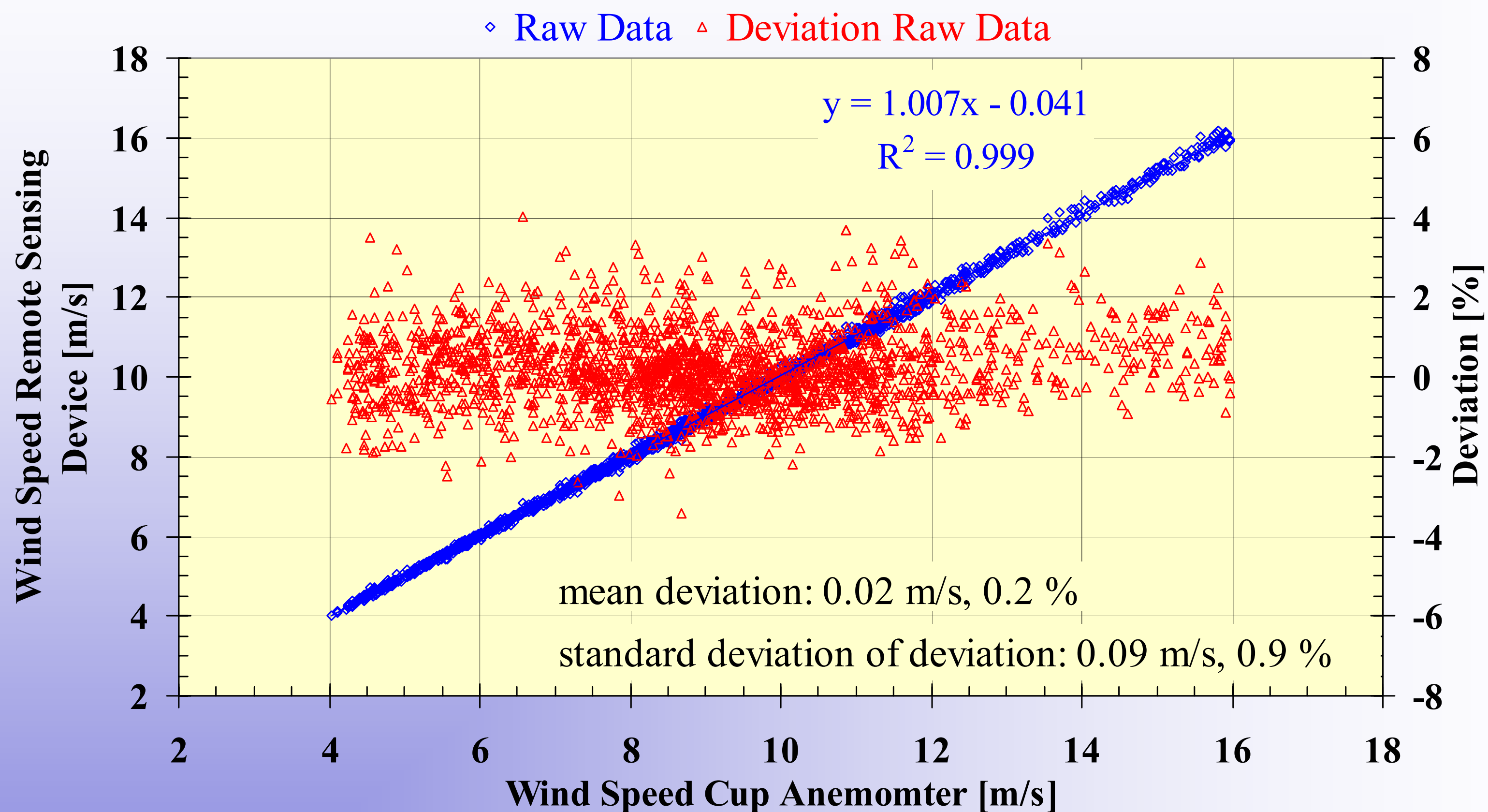
height	flat terrain	complex terrain
[m]	[-]	[-]
135	2.7	3.6
104	4.9	8.1
72	3.9	11.3

Sodar (preliminary results)

height	flat terrain	complex terrain
[m]	[-]	[-]
135	8.3	10.6
72	5.9	13.8

- Class numbers represent maximum errors
- High class numbers partly due to the high ranges of variables
- Solution: consider only mean deviation of environmental variables at application of lidar/sodar and at Verification Test
  - often much lower uncertainties than by application of class number
  - recommended in revision of IEC 61400-12-1

1. Verification Test, Random Noise Error



- Random Noise Error: Part of the scatter not explained by sensitivities to environmental variables
- In case of good lidar <1%, in case of sodar about 5%
- Uncertainty only relevant for single 10-minute periods, (automatically integrated in statistical uncertainty of bin averages, e.g. power curves, site assessments)

3. Control of Lidar at Application with Small Met Mast

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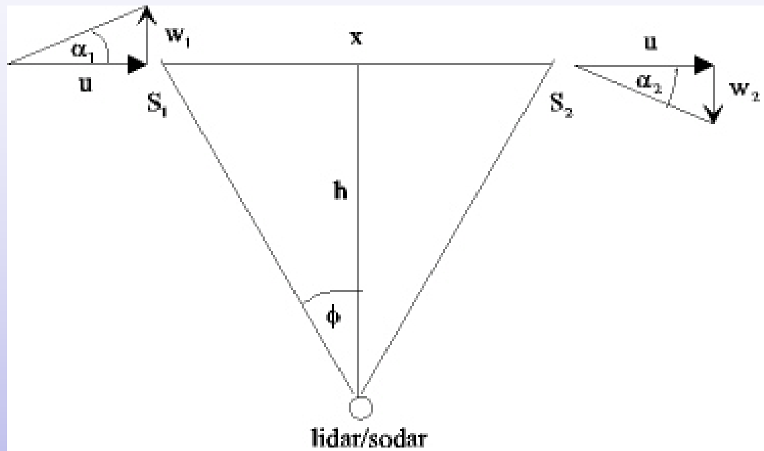
- Check on obvious outlier data or malfunctioning
- Check whether systematic deviations of lidar/sodar and control anemometer in expected range under consideration of uncertainties of reference measurements and sensitivities of lidar/sodar:

  - feed-back algorithm: additional uncertainty if criteria not met

  - helps to avoid overoptimistic lidar/sodar classifications
- Check whether scatter of deviations of lidar and control anemometer as expected:

  - additional uncertainty if criteria not met, only relevant in terms of single 10-minute periods, not for bin averages
- In-situ test of lidar/sodar (test on changes of accuracy within measurement period)

4.d Inhomogeneous Airflow Over Probe Volumes



- Assumption: equal wind conditions in different probe volumes
- Significant problem in complex terrain for almost all lidars and sodars commercially available today
- Key reason for not accepting lidar/sodar in complex terrain by IEC 61400-12-1 MT
- Analysis of uncertainty by flow model or Mann Bingöl approach

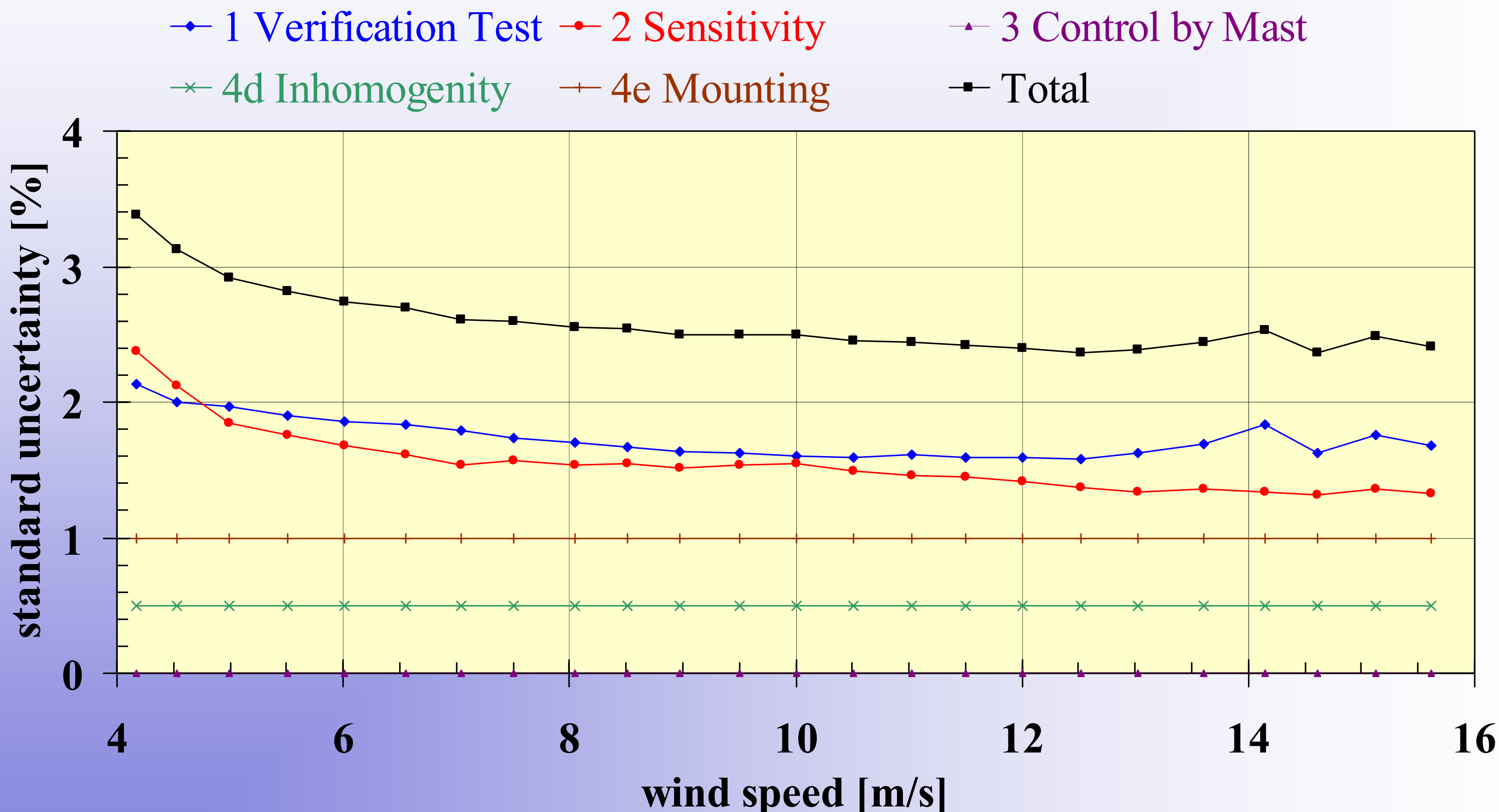
α_1	α_2	relative error
[°]	[°]	[%]
0	1	1.5
-1	1	3.0
-1	1	3.0
0	5	7.6
5	10	7.7

Mann Bingöl Model

$$u_{lidar} = u + h\frac{\partial w}{\partial x}$$

$$\frac{u_{lidar} - u}{u} = \frac{\tan\alpha_2 - \tan\alpha_1}{2\tan\phi}$$

Total Uncertainty Windcube V1 Example Flat Terrain



- Example: site with high wind shear, 135m measurement height
- Standard uncertainty not much higher than in case of best practice cup anemometry

Current Status

- Lidars and sodars of almost all major brands tested
- Results often not as expected by system suppliers, partly confidential
- Best systems just good enough for flat terrain applications
- Consistent results at round robin test of same lidar by WindGuard and DTU
- Accuracy of lidar/sodar by definition lower than accuracy of reference cup anemometers
- Remote sensors need qualified testing before application (unit and type specific)
- Methodology provided by IEC 61400-12-1, Ed. 2 as relevant for site assessment measurements as for power curve tests (see MEASNET Site Assessment Procedure, German Technical Guideline 6)