

Lidars calibration and metrology

Black & White methodologies in a standardised field

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Lidars calibration and metrology

Black & White methodologies in a standardised field

 $P = \frac{1}{2}\rho A \nu^3 C_p$

DTU Wind Energy Department of Wind Energy

Outline





Metrology and terminology (1/3)

- Metrology is a standardised field
 - JCGM: Joint Committee for Guides in Metrology (BIPM, IEC, ISO, etc)

 - VIM → international vocabulary of metrology
 - Following definitions refer to VIM (JCGM 200:2012)
- Verification: "provision of objective evidence that a given item fulfills specified requirements"





- An item can be a :
 - Process
 - \rightarrow e.g. an algorithm applied to a Doppler frequency spectra
 - Material
 - Measurement procedure or measuring system
 - \rightarrow e.g. related to performances or if a measurement uncertainty can be met





Metrology and terminology (2/3)



• Validation: "verification, where the <u>specified</u> requirements are adequate for an intended use"

Trueness, precision, accuracy:



- <u>Trueness</u>: closeness between averaged measured and averaged reference values over a large/infinite number of samples → Not a quantity
 - → "inversely related to systematic measurement error"
- <u>Precision</u>: "closeness between indications of measured quantity values"
 - ➔ Repeatability

- <u>Accuracy</u>: "closeness between a measured quantity value and a true quantity value"

- →Trueness + precision
- →Accurate system = small measurement

errors (due to systematic effects)



Metrology and terminology (3/3)

• Calibration: operation providing as an end-result

- a <u>relation between measured values and reference</u> ones:

mathematical model ; curve ; table

- associated measurement uncertainties
- a correction of the indicated quantity value



Instruments impacted by calibration are all apparatus with a requirement for metrological traceability in the SI

i.e. instruments affecting the quality of a measurement or needing corrections of the raw measurements.



- Uncertainty: "non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand"
 - an indicator of the quality of a measurement
 - methods: GUM ; Monte-Carlo ; Bootstrap



⁵ DTU Wind Energy, Technical University of Denmark

Why the need for lidars calibration? (1/2)

• IEC standards (64100-12-1)

- Traceability is:
 - Required for certification: power curves, loads
 - Provided by a <u>calibration</u>

Individual calibration of lidars components?

electronical, optical and mechanical parts:

- separate conformity certificate:



- BUT the raw measurand is a time domain of el. current (photo diod)



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➔ Doppler frequency spectrum (processing)

In-house calibration:

- lidars manufacturers procedures
- at DTU: rotating wheel
 - ➔ precise and accurate reference speed
 - however, unrealistic frequency spectrum (very narrow peak, Dirac)

Why the need lidars calibration? (2/2)



Field calibration: similarity of operational conditions

- a calibration should be performed in similar measurement conditions to the ones for which a measuring system is intended to be used
 - Wind speed range
 - Physical range (distance)
 - operational conditions:
 - → turbulence, shear, veer
 - ➔ possible terrain effects
 - → thermal stability

"real-world" spectra analysis:

➔ measurement accuracy of the Doppler frequency?



UniTTe meeting - 21 January 2015

Black & white box calibration of lidars

Two different principles

Lidar measurand and outputs

- Measurand: frequency of the backscattered light
- Converts it into a Radial Wind Speed, i.e. the component of the wind vector in the line of sight (LOS, laser beam direction)
- RWS considered as the "raw measured quantity"
- Output parameters
 - obtained by applying mathematical models to a number of RWS measurements → reconstruction algorithms
 - Examples: HWS, shear, wind direction, ...

Two principles

<u>Black box</u>: calibration of the "mathematically derived" parameter against the same type of parameter measured by a reference instrument
→ e.g. HWS vs. Cup anemometer wind speed
<u>White box</u>: calibration of the parameters used as inputs to the reconstruction algorithm
→ individual beam RWS calib





- Measurand: horizontal wind speed

Ground-based lidar calibration: Wind Cube



- Reference: cup anemometers at several heights

Example of a black box calibration

• Example: calibration of ground-based profiling lidars



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Example of a white box calibration

RWS calibration

- Test site: Høvsøre
- Setup:

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- Two small masts h = 8,90m





Calibration procedures

White box example: RWS calibration

1) Calibration of internal inclinometers

2) Geometry verification

 – i.e. all "fixed" parameters that can be used in reconstruction algorithms

- e.g. cone / half-opening angles
- Blocking / unblocking process
 - → CNR ; IR imaging
- 3) LOS direction evaluation
- 4) RWS calibration

 $WS_{ref \ projected} = HWS_{cup} \cdot \cos(WD_{sonic} - LOS_{dir}) \cdot \cos(tilt)$



Calibration procedures

White box example: RWS calibration





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Black & white box calibration of lidars Pros & cons



	Black box	White box
Requirements	 Reference instrument available & calibrated 	 Geometry check Being able to calibrate the RWS Reconstruction algorithms Access + verification
Pros	 Direct comparison 	 Physically existing quantity Uncertainty derivation of ANY reconstructed output
Cons	 Need for multiple ref. instrument Assumptions Reconstructed outputs can physically not exist! 	 Longer calib. duration (~ 5-6 weeks / beam)

Measurement uncertainties

- Expressed for each 0.5 m/s bin
- Uncertainty sources (cf. GUM method)
 - Reference wind speed (cup): preponderant source
 - Reference wind direction (sonic)
 - LOS direction estimation / LOS elevation / Flow inhomogeneity in the probe volume / Mean RWS deviation
 - Statistical uncertainty in the RWS measurement

TOTAL uncertainty:
$$U_{RWS} = \sqrt{\Sigma U_i^2}$$
 $\rightarrow \sim 1 - 2\%$ / bin

- Combining uncertainties of individual RWS
 - Uncertainty on ANY reconstructed output through the algorithm using either GUM or Monte-Carlo
 - e.g. HWS... but also wind direction, shear, veer

Question to be answered:

- should the lidars be corrected?
 - → the correction reduces the measurement uncertainties...



Black or white questions?

