From fixed masts to floating lidars

A journey through wind measurement standards

Peter Clive

Principal Wind Energy Consultant

BLACK & VEATCH

In the beginning
The Lord said "let there be wind“.
The met tower was our tree of knowledge,
Measurement uncertainty our original sin,
And remote sensing a promise and a temptation.

IEC 61400-50 Wind measurement

IEC 61400-50-1: Cup and sonic anemometry on met masts or nacelles
IEC 61400-50-2: Ground based remote sensing devices
IEC 61400-50-3: Nacelle mounted lidar
IEC TS 61400-50-4: Floating lidar systems

(IEC TS 61400-50-5: Scanning lidars)

IEC 61400-50-1

- Establishes the scheme of calibration, classification and mounting influences on accuracy
- Classification characterises deviations due to use in circumstances that differ from wind tunnel calibration in terms of influence parameters (tilt, temperature, etc.)
- Calibration
- Mounting

IEC 61400-50-2

- Follows the same pattern as 50-1 w.r.t. classification, calibration, mounting
- The uncertainty of the reference is now introduced, due to the need to perform tests in the field rather than in a wind tunnel
- Influence parameters place greater influence on environmental parameters, e.g., no need to consider friction and torque, however turbulence and shear are now more significant due to difference in measurement principle and introduction of measurement volume, and complex terrain effects replace tilt as a consequence

IEC 61400-50-3

- The distinction between final and intermediate variables is introduced to accommodate the limitations of practical field tests
- Restriction to simple terrain in order to maintain confidence in the performance of simple wind field reconstruction (WFR) models
- Introduction of zero-classification to simplify propagation of uncertainty from intermediate variables (directly measured) to final variables (that fulfil the data requirements of the use case)
- Explicit identification of use cases, as first standard developed after disaggregation of measurement standards from power performance testing standard IEC 61400-12-1

IEC 61400-50-4

- Operation of FLS outwith the envelope of operational conditions in which zero classification is permitted requires a scheme for classification uncertainty
- Emphasis on final rather than intermediate variables (opposite of 50-3)
- Simplified calibration protocol
- Emphasis on increasing the evidence base for the envelope of operational conditions in which a zero classification can apply
- This turns discrete stages of commercial acceptance into a continuum in classification uncertainty

Use cases

- IEC 61400-1 wind turbine design
- IEC 61400-9 probabilistic wind turbine design
- IEC 61400-12-1 power performance tests
- IEC 61400-13 load tests
- IEC 61400-15-1 site suitability tests
- IEC 61400-15-2 energy yield assessment
- PAS 61400-60 model validation

- C.f., Range of probably and possibly safe prediction with measurement system classification scenarios
- Measurement itself is a process of model validation (e.g., WFR)
- C.f., inner and outer uncertainty ranges and envelopes of operational conditions
- Etc.

Use cases

The separation of measurement standards from standards that describe procedures for which the measurements are needed requires us to consider measurement use cases, which have 3 elements:

1. Data requirements: these arise from what is sometimes termed the "use case" i.e., the application e.g., power curve tests, wind climate assessment
2. Measurement method: the activity that fulfils data requirements
3. Operational conditions: circumstances that influence the performance of the method with respect to accuracy, therefore informing our uncertainty estimation

Instead of asking "what can I measure?" the need to identify the use case requires us to ask “what do I want to measure?“ We are required to think beyond historic limitations.

The limitations of met masts inform everything we have subsequently done. Sophisticated instruments such as lidars capable of acquiring rich datasets are required to emulate simpler instruments because industry procedures and conventions were developed to accommodate their limitations

Questions

If the wind industry didn't exist, and we had to create it *ex nihilo* today, with the measurement capabilities we now have available from the outset, what would our wind climate assessment procedures and wind measurement standards, that took full advantage of those capabilities, look like? *Different*.

Versus

If we want to ensure measurements are made based on best established procedures, consistency with previous practices, methods, and uncertainty evaluations, to support institutional confidence built on a history of successful outcomes, and standards that codify industry best practice, what would our procedures look like? *The same*.

Key objective

If

- *Different* measurement technologies

are used to measure

- *The same* wind,

Differences in uncertainty estimates

- Shall reflect *real differences* in the performance of the technologies with respect to accuracy, and
- Shall not be artefacts of inconsistencies in the guidance governing how they are used.

Given the diversity of measurement technologies, can we adopt a common approach that accommodates all to achieve this consistency?

Uncertainty estimation

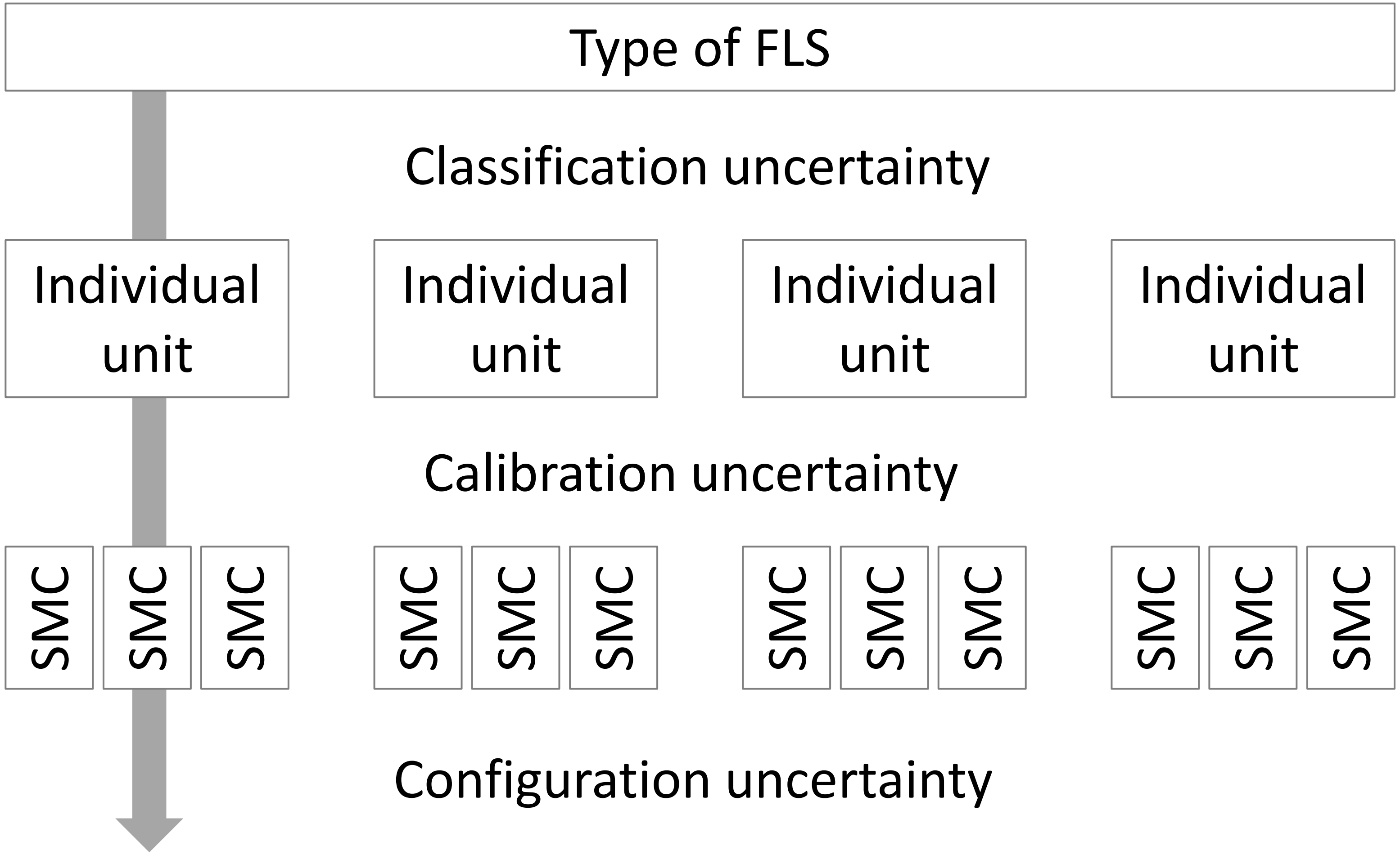
How does a unit deviate in performance from accuracy seen during calibration?

- Classification: sensitivity to *different* operational conditions common to different units of the *same* type
- Configuration: consistency in installation and operation between *different* campaigns using the *same* unit

Hierarchy of uncertainties

- Supports a systematic approach to evaluating independent contributions to the uncertainty budget

Uncertainty estimation



Uncertainty for an SMC = Classification + Calibration + Configuration

Uncertainty estimation

ACARA (As Complete As Reasonably Achievable):

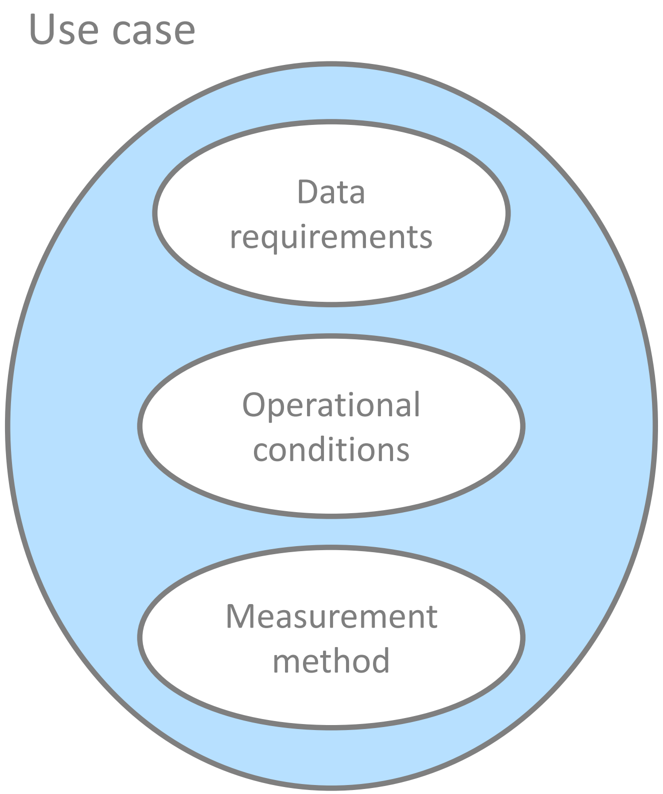
- Uncertainty budgets are inherently incomplete (you cannot represent the likelihood of an unforeseen situation influencing accuracy)
- ACARA implies if something unforeseen does occur, it was not reasonably foreseeable, so that unexpected deviations can be attributed to it without ambiguity introduced by other possible explanations caused by poor setup
- Adopting an ACARA approach is compatible with emerging Bayesian design formalisms where probabilities are conditional and can change in the light of new information

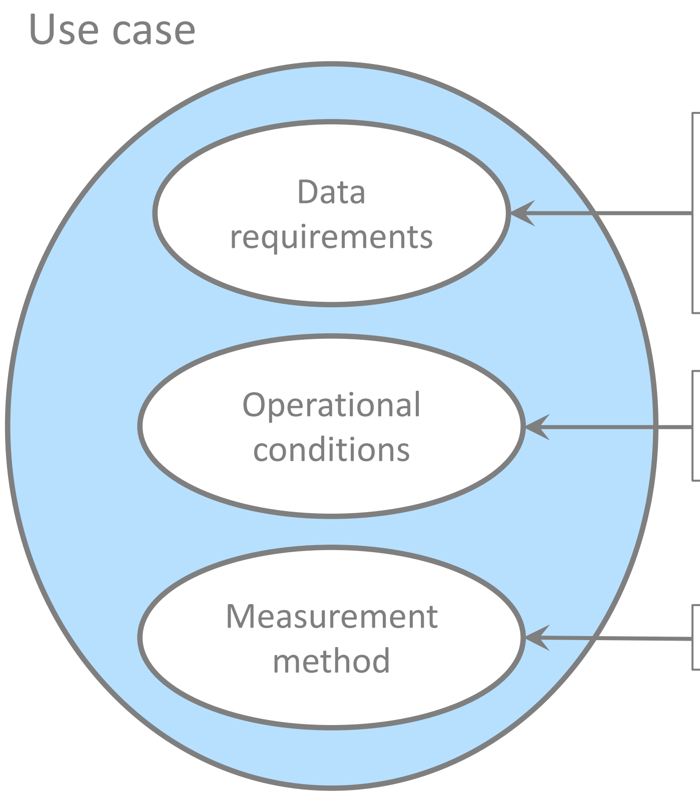
Uncertainty estimation

Final and intermediate variables

- WFR implies all measurements assume a model that describes the relationship between direct observations that are a consequence of instrument response to operational conditions and the quantities being measured to characterise those conditions

- Given these inherent assumptions, perhaps an object oriented model of wind conditions would provide the most universal and consistent approach

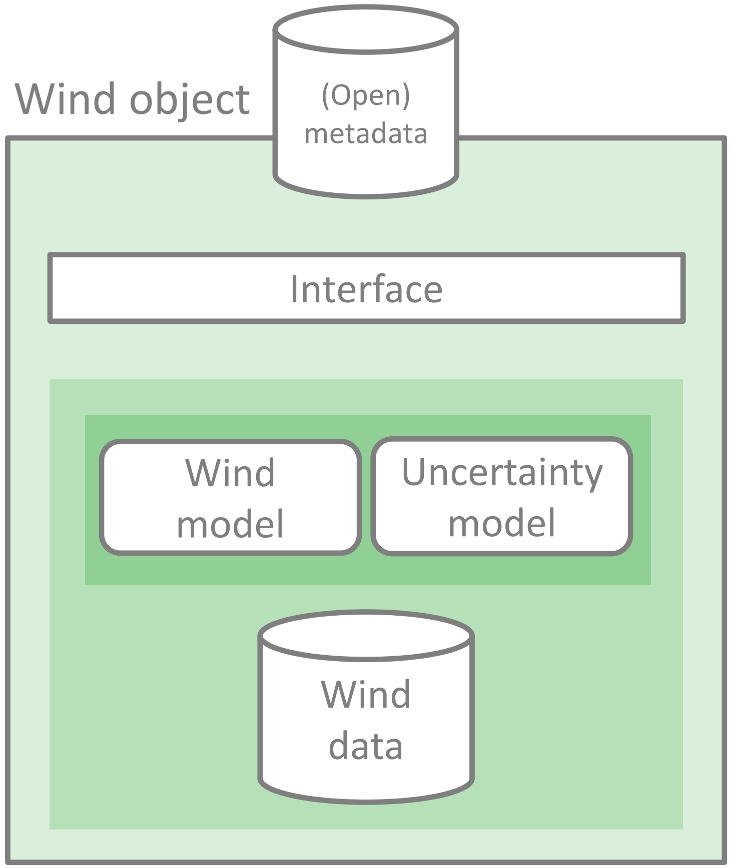

Use case
Data requirements
Operational conditions
Measurement method



- Outcome driven, rather than constraint driven
- “What do I want to know?”, not “what can I measure?”
- Plan on the basis of project objectives rather than instrument limitations
- Full lifecycle perspective rather than reactive and opportunistic approach

- Conditions that influence the performance of the measurement method with respect to accuracy, data availability, etc., e.g. environmental variables

- How data that fulfils the data requirements is acquired

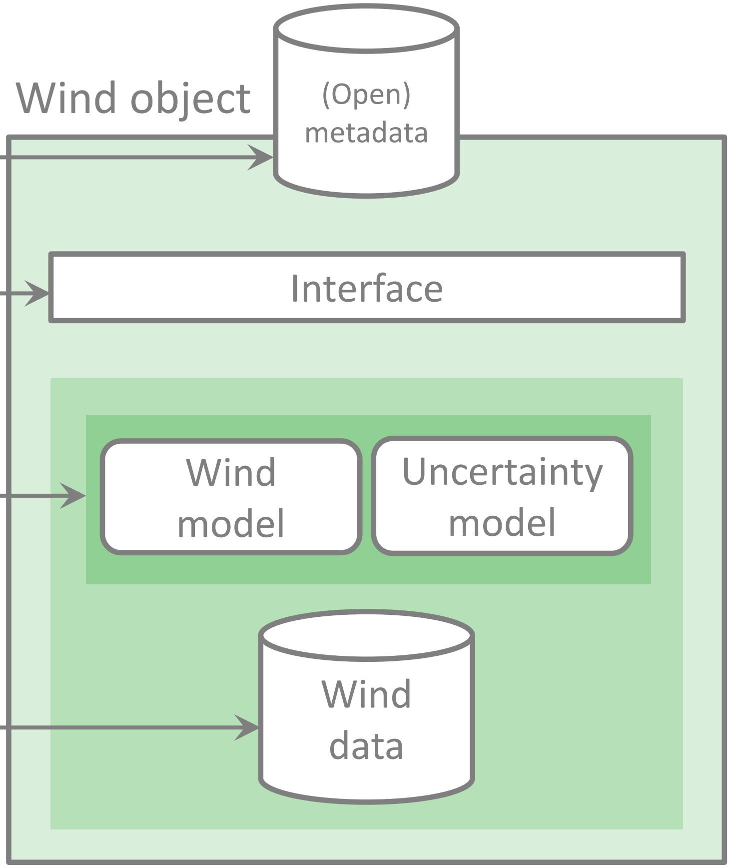

Wind object
(Open)
metadata
Interface
Wind
model
Uncertainty
model
Wind
data

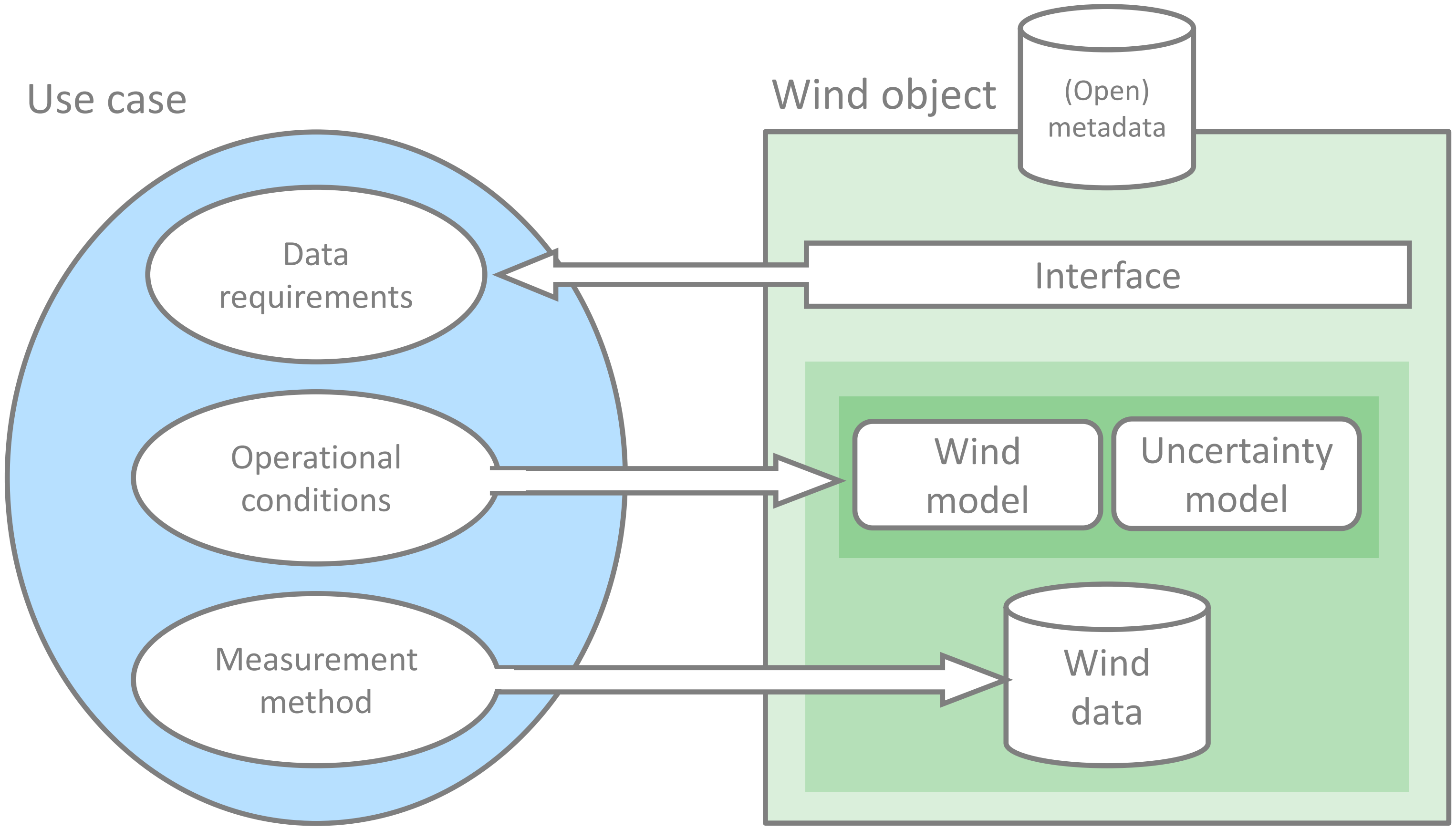
- Conforms to requirements of e-WindLidar / FAIR principles / Open Energy ecosystem

- Outputs descriptions of wind conditions that fulfil the data requirements of use cases (final variables)
- Conforms to relevant data model for data sharing (e.g. IEA Task 43)

- Represents the physics used to process wind data and the influences on the accuracy of outcomes of that procedure
- The internal data model supports comparisons between wind data and wind model values to fit the wind model to observations and propagate uncertainties

- Primitive data acquired from measurement apparatus (intermediate variables)
- Conforms to relevant data model for data sharing




Use case
Data requirements
Operational conditions
Measurement method
Wind object
(Open) metadata
Interface
Wind model
Uncertainty model
Wind data

Discussion.

Building a World of Difference.®

Contact Us

Building a World of Difference

+1 913 458 2000

info@bv.com