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initiated

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on

Autonomous Aerial Sensors for Wind Power Meteorology

UAV in onshore wind power anemomometry
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challenges and hindrances

... from the viewpoint of a commercial onshore wind power anemometrist...

Main targets of onshore wind power anemometry

- wind monitoring
- wind turbine micro-siting
- power production estimate (= PPE)
- site assessment

Normative / informative framework

- TR6 by Foerdergesellschaft Windenergie e.V. Germany: simple guideline, also for the determination of the 60-% reference yield, legal prerequisite by the German legislator to get grid connection

- IEC 61400-12-1: ''Power performance measurements of electricity-producing wind turbines > the inverse procedure makes for current PPEs

- upcoming MEASNET guideline on PPE: under elaboration, seemingly little progress in the matter as such, likely to stifle progress by overly emphasizing a 'quality control' approach; attaches *additional uncertainty* to observations by non-accredited bodies (and consequently 'safety reductions' in their power production estimates); probable result: a 'wind consultancy cartel' trenched in behind one method

- ISO-IEC Guide 98-1, .. 98-3 GUM:1995, 'Uncertainty of measurement' also known as the 'GUM uncertainty framework':

practical yet general guideline on the subject of uncertainty: often cited, hardly ever read, and never thoroughly applied...

- IEA recommendations, Expert Group Studies, Parts 1 and 11: practical and well-founded nuts-and-bolts guideline preventing blunders

Manifest problems with PPE

'During the past 20 years, wind consultancies have done a good job in ***safeguarding the interests of the investors...*** ' (A. Garrad, ca. 2009 in Wind Power Monthly on PPE, cited from memory, italic by the author)

'Since the first recommendations for power performance testing were issued (1979-1990), it has been recognized that large uncertainties are attached to the tests. Even under fairly ideal test conditions it was estimated that the uncertainty could reach a level of 10% to 20%, which by far exceeded the best guess of an experienced wind turbine engineer.' (S.T. Frandsen et al, 2000, on power curves)
(Note, that this refers to power curves; the uncertainty of a PPE is yet larger)

- large uncertainty in PPE, currently, say 2/3 are in the range of 13% to 20% (as indicated by their authors), little improvement since the beginning

- there is evidence of bias in PPE (although formally 'forbidden' by the GUM uncertainty framework)

Putative causes of the problems...

- GUM uncertainty framework (except for its Monte-Carlo 'supplement') presupposes a linear measurement model, through which uncertainty components must propagate with a **similar** magnitude > the result is expected Gaussian

- the co-variance of uncertainty components is difficult to discern and difficult to impart on the uncertainty estimate

- almost all of the uncertainties are of type B (guestimates); their transformation in type A uncertainties (uncertainty evaluated by statistics) is untried, with a few exceptions

- numerical methods (e.g. Monte Carlo Methods, covered by the GUM supplement) are rarely used, despite their advantages (i) of no prior assumptions about the measurement model, (ii) rendering non-linearity, (iii) presenting a different sensitivity of uncertainty components when compared to the analytic uncertainty framework

- reliance on one-point evidence (in space) and one-point statistics (no increments); a whole zoo of natural boundary flow phenomena is described by simple statistics, from just a few cup anemometers, for a domain with typical extensions of several 1000 metres

- one-number power curve for the wind turbine, not taking into account important flow characteristics other than horizontal mean wind speed

- independent evidence from a wider range of sources is neglected since difficult to incorporate into a PPE (due diligence)

- some techniques derived for relatively small turbines in the synoptic driven wind regimes of NW Europe might need reviewing when applied to wind regimes, that are increasingly sub-synoptic/thermal as the onshore wind power development moves out of northern and central Europe, turbines became larger, wind regimes become weaker,...

- correlation of uncertainty components and their non-linear propagation may give rise to skewness and platy-kurtosis (flatness) in the PDF of annual mean production > the interpretation of what their statistic characteristics really mean is difficult (antecedents exist in finance time series analysis) > non-Gaussianity might mimic bias or increased standard uncertainty

- uncertainty is (naturally) proportionally larger on weaker and complex sites, and wind power development is moving there

In contrast to the PPE, the guestimate of an engineer relies on largely independent evidence (so-called prior experience) (all of lower accuracy but independent from one another); the resulting estimate exhibits robustness...

Why are the obvious shortcomings hardly addressed? Is there a drive to improve?

Hhm, probably not, ... the 'fudge factor' in PPE suits most market participants:

- buyers of wind farms: can negotiate price reductions (by deducting 15 to 20% from the average annual production)

- bankers: can ask for risk-primed interest, drive credit takers into equity funds, sometimes affiliated to their organization

- turbine manufacturers: less need to live up to sales power curves, production guarantees,...

- engineers, fluid model authors, ..., anemometrists: can obscure systematic shortcomings under a comfortable cloak of uncertainty

- wind consultants: quality stays a matter of repute and belief rather than becoming a falsifiable criterion

- national legislators: mandatory equity, justified by uncertainty, keeps the 'small fry' out of wind power > national champion(s) can be fostered by good-meaning legislation

Consequences for any 'UAV anemometry market' (related to PPE)

- A technique that is susceptible (i) to raise doubts on current practise, (ii) to possibly evoke fundamental questions, (iii) to sharpen PPE will probably not be appreciated by all. Why complicate business?

- massive acceptance hurdles need to be overcome; see the application history of LIDAR and SODAR

- On the other hand, in the onshore wind power market as of 2010, there are natural proponents for UAV anemometry:

- entities that develop, own and operate (inherent interest)
- grid operators (interest currently still stifled by renewable energy legislation)
- electricity consumers (no voice)
- scientists (no money)
- the EU, DGs Energy and Transport (no power)
- developer/sellers of wind power projects

Technical challenges -- observatories in a 'moving frame'

'The ergodicity of turbulence sounds to me as an assumption which is hard to avoid and test' (J. Mann, 2006)

- To what extend is the above significant here? How about intermittency, 'coherent structures'?

- UAV have been successfully used for the observation of scalars; how about the following?

'The predominance of stretching over compression of passive objects also occurs in all fluid flows that are Lagrangian chaotic (L-turbulent), a set that includes most of the simple laminar flows in the Eulerian sense (E-laminar). Hence, generally, there is no simple one-to-one relation between the Lagrangian and Eulerian statistical properties in turbulent flows, just as there may be no correspondence between the structure(s) of a passive object (dye) and the field of a dynamically active variable (velocity, vorticity) in the same fluid flow' (Arkady Tsinober, 2009)

- What are the measurands we can expect from UAV, and do they answer wind power engineering solutions?

Practical considerations:

- currently, at least 600 hours of (useful) profiler soundings are required to see the significant micro-meteorological conditions (some hundreds to a few thousands of hours are spent 'waiting' for these distinct meteorological situations to occur (or to repeat the soundings))

- can such a campaign duration be achieved by a UAV?

- flight licensing, paper-pushing, airstrip, maintenance

- risk of injury, loss of equipment and records

- skills required by the operators

Immediate applications:
- wake, e.g. behind obstacles

- detachment on escarpments, roughness change

- strongly sheared flow (jets)

- cold air outflows, katabatic and anabatic flows (layer mightiness?)

- temporal-spatial delimiting areas of Bora-type wind regimes (Boulder windstorm), hydraulic jump

- offshore, wake

- scientific: 'turbulence profiles', qualitative evolution of skew and kurtosis, velocity increments over the lower ABL

UAV anemometry in the long run...

Prerequisite for a long term evolution (this is largely tautological):

- wide spread > easy access to the system > needs a 'community' rather than a few specialists

- strong scientific lead for interpretation of the observations (the proponents cannot do this by themselves)

Despite obvious difficulties...

UAV anemometry is highly enticing...

- because there is a need for more, independent observation, not just from one location but from the whole domain of interest

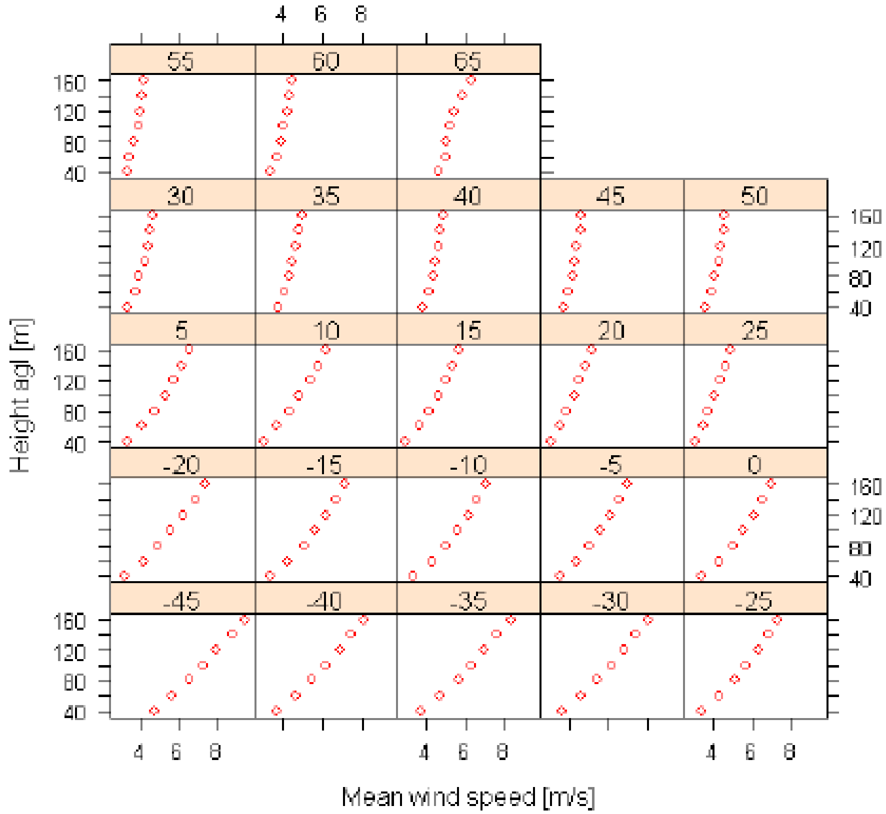
- to check the results of site flow models (See 'The Bolund Experiment'), refine type-B guestimates or transform them to type A (often the leading uncertainty behind climate anomaly, about which we simply have no cue!)

- alarming small-scale 'heterogeneity' of the velocity field has been observed...

- to improve the representativity of a site flow model's driver (forcing)

- remote profiling campaigns bring valuable information gain from even short-term observations (say some hundred hours)

Wind profile in relation to the sun height



... these things must fly at night too...

 < suggested size

Thank you for the invitation, the attention, and bon courage!

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