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AN UNCERTAIN FUTURE FOR METROLOGY? COMMENTS AND EXAMPLES

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Abstract

The comments are intended to illustrate the present status of metrology according to its principles and procedures, namely about the definition and meaning of the concept of uncertainty in measurement, and to introduce an alert about discrepancies becoming more frequent in applications assumed to pertain to the frame of metrology but basically violating metrological concepts.

Two examples are reported, in details necessary to make clear the sometimes subtle deviations from a correct application of the metrological rules: one case was found inside a recent metrological document: the very definition of uncertainty; the other case is found in a critical determination of the uncertainty of a basic parameter in climate-change evaluation: the uncertainty affecting the Surface Annual Mean Temperature.

Key words: metrology, uncertainty, climate, average annual temperature.

1. Introduction

Wikipedia definition: “Metrology is the scientific study of measurement [1]. It establishes a common understanding of units, crucial in linking human activities”.

Normally in science several positions generally arise, for example during the discussion among experts of any adjournment of metrological documents, until one of them is considered the best— by consensus, rarely unanimously—relative to the principles considered the pillars of modern science.

That happened, e.g., in the first decade after year 2000 concerning the discussion on the *new definition of the International System of Units* (SI) about its basic foundation principles and structure, namely about the unit mole and the role of fundamental constants of physics [1–13 and reported references].

The purpose of positions not eventually accepted was an alternative to the approved ones, but equally and strictly having been intended to introduce sound improvements to metrology definitions, though in different ways.

In the other hand, in the last period of time, no much more than a decade long, we assist to a high acceleration toward more drastic changes in many fields, also of science, especially in those directly or indirectly concerning consequences of the increasing importance of a new technology, digitalisation.

The aim of the comments that follow is to enlighten the fact that, according to Author’s position, some of these changes look no more in accordance with basic foundations of the metrological discipline.

2. Metrology and its most basic concept: uncertainty in measurement

Basically, metrology is a discipline complementing measurement science for specifically assessing the *accuracy* of the gained knowledge, namely in the frame of the established international systems of measurement units, and the criteria and methods to ensure international traceability. Criteria and methods are based on the assessed fact that all measurement results are always affected by an *uncertainty* arising from the measurement process. It has a random component and a number of additional components. The first arises from dispersed *measured values*; the second arise from errors or omissions in the variables influencing the result (numerical or qualitative) concerning the planned measurement *process*. The two kinds are independent on each other.

3. Sources of uncertainty: ignorance vs (partial) knowledge

“*I know that I don’t know* – Έτσι, δεν γνωρίζω” (Socrates)

It is a fact that human knowledge is limited and suffers from *subjectivity* and *uncertainty*, issues not cancelled by measurement results, then in modern times knowledge is supposed to be mediated by *inter-subjectivity* as the only possible remedy.

However, it is more difficult to apply the same remedy to what is outside the frame of partial knowledge: *the level of ignorance*. By definition, it is less easy to have a *shared* full identification of the “contents” of ignorance.

In fact, ignorance can consist of totally ignored subject matters, or of known issues still without any, or any consistent/firm, informative *shared* response.

In addition, ignorance necessarily affects the whole measurement process, not only the lack of reliable numerical (or else) outcomes. In this respect ignorance may curiously be less ambiguous than (even partial) knowledge.

The ambiguity of the latter in modern science is assumed delimited and mitigated by some conditions:

–in theoretical studies, by the fact that processes (theories) are expressed (postulated or inferred via mind) in an exact and language-independent symbolic form, mathematics;

–in experimental science, by acquisition of results of observations via measurement, affected by incompleteness, errors and uncertainty: the latter are mitigated via replication of the measurements, though affected by a dispersion of results such that it can even affect their significance.

–finally, it is expected that the theoretical studies are confirmed by experimental proofs—or the reverse—before the corresponding new knowledge level is accepted.

Note that (partial) ignorance on a subject matter in question not necessarily decreases in the occurrence of an increased knowledge on it.

Consequently, in modern science, *probability* (or similar non-deterministic tools) is replacing the exactness of (new) knowledge, while a *risk*, for the deriving decisions to be taken, is associated to the effects of (persisting) ignorance.

A measurement process can be constructed only on the bases of *existing* tools (in turn based on existing knowledge) and constrained by the properties of the "external world" as observed by human resources.

Instead, *new* concepts can be totally derived by inference from theoretical studies. However, the latter, as a mind process that can even be individual, not necessarily brings to outcomes already shared by the Community. On the contrary, a measurement process is such that its outcomes are not limited to provide results but also require to be socially shared, unless unexpected—i.e., contrasting the current social believe, in which case further replicated is needed until sufficient confidence is gained, or is rejected. Therefore, measurement can transform current ignorance—at least, by creating a dilemma—without necessarily producing new knowledge. Even a possible failure of expectations (e.g., in the biological frame) may also result in a limitation of ignorance by restricting its frame.

4. Sources of uncertainty: reproducibility and data objectivity

Metrology promotes the repetition of measurements as a method for a multiple check of the degree of consistency of the results, so increasing confidence in them.

However, quite recently the informatics technology allowed an extreme increase of the number of repeated measurements, bringing to what has been named Big Data [14–18]. That was taken, apparently also in science, as a favourable step toward more/better knowledge. Data are usually considered as *objective* facts, required as the most important component of confidence in science foundations— as reported in [19], that issue has been called Explicate Order by Bohm [20]: "the way in which our subjective sensory systems perceive the world", with respect to an Implicate Order [21], the one that "would represent the objective reality beyond our perception".

The Author [15, 22] have already discussed some of the limits of the new *unconditional* certainty in data sufficient objectivity of the so-called "dataism" (see later), since it is also a fact that a measurement result is determined not only by the instruments (in general sense of "measurement means") used to obtain it, but also by the choice, or omission, of factors arising from the whole planning of the measurement and its necessary *process* underlying the measurements. The contribution to measurement uncertainty of the process choice can even overcome the contribution of the results of the experimental setup.

An extreme situation can even arise, quite commonly recalled in measurement science, where all measured values look excellent, i.e. very "reproducible", but they are *all wrong* due to missed consideration of important "influence factors" in measurement planning/execution.

A consequence of that is the intrusion of further subjective factors into the measurement process, consisting of *systematic* errors. They are *unavoidable* since planning itself, arising from human decisions, affects the level of data objectivity and induce the persistence of "doubts"—as expressed by the Aristotle's motto "Dubito ergo sum", or implied in the Descartes' motto "Cogito ergo sum"—the stimulus and engine of our search for truth.

Consciousness of the above fact is too often missed obscuring another fact, that the quantity of data available not necessarily increases the *quality* of the dataset. The soundness of the process generating data can be more important than the increase of the number of results.

Instead, in the new discipline called "dataism", [23–24] whose meaning and boundaries are still in progress, the data are assumed to intrinsically represent the full information sufficient to bring to knowledge (by confirming or extending it) through the analysis of a *single* parameter: their reproducibility (often called "precision")—over the possible trend, obtained by means of database fit. Such a position assumes that no further analysis bringing to possible "corrections" of the previous step is needed: the so-called Uncertainty Budget (UB), a list of the uncertainty components and their contribution—a basic need in metrology—would become limited to comprise only the fit result. In the metrological idiom, this would mean that *accuracy coincides with reproducibility*.

On the other hand, current data analysis often considers correct for the scientists to perform additional kinds of operations/alterations on the acquired original database: homogenisation, extrapolation to fill gaps in the sequence of the dependent variable, cancellation of outliers, etc. In this way, the assumed initial objectivity is anyway filtered by human evaluation.

The previous summary of such a situation, becoming quite common nowadays, may basically indicate a tendency of creating alternative ways to assess scientific knowledge, e.g., one based on new human tools, possibly now also assisted by the most recent one, the Artificial Intelligence (AI), for data planning and subsequent manipulation, in the intent of minimising the systematic errors.

The Author see in the above tendency the risk to shift toward a "science of the certainty", assumed to limit the concept of "uncertainty", the present pillar of measurement science. Symptoms of that tendency are already present even within the metrological Community.

5. An example within metrological terminology

Recently a change of the definition of the term "uncertainty" was performed by the JCGM-WG1 of the BIPM CIPM on GUM, now reading: "Doubts about the position of the true value". [25]

First, the Author is impressed by the use of words "doubt", "position" looking more "colloquial" than scientific. If the intent was to closer match the extension of metrology fields of action to deal with *qualitative* quantities, it is exceedingly moving toward merely (inter)-subjective terms. This choice is compromising science intent toward an *objective evaluation*—where "objective" means the rational side of human thinking and "evaluation" means the *estimate* of truth (limited by the fact that we do not know where the latter is [26]). Then, that attitude is "mixing of epistemic uncertainty (the uncertainty of personal doubt) with random uncertainty (the uncertainty of an unpredictable physical process)"—see [27] for this problem when concerning also a different recent metrological document.

Secondly, the Author hesitates accepting the dominant function expressed by the concept of "true value". Science should not embrace any specific philosophical position for one of its fundamental concepts.

Refusing such a recent position does not necessarily mean refusing the possibility to *accept facts as true*: the simplest example is the roundness of the Earth … after for Centuries having alternated theories. However, relating *each single* measurement to truth looks pretending to reverse another basic concept of modern science, the cross-confirmation of a set of data. In addition, it is neither an "operational definition", another tendency in modern science.

In conclusion, uncertainty does not mean "having doubts", but means awareness of the need of organising a rational tool, called uncertainty, able to contrast the natural situation of humans to be unable to circumvent the subjectivity induced by their mind—so that any means they may invent are, in some respect, imperfect and may not be suitable to approach truth since the latter remains unknown in the vast majority of contingent cases—or for very many generations of humans.

Incidentally, in [25] one can read: "Dr. Ehrlich (PTB) was of the opinion that the convergence within WG1 is for the formal definition of measurement uncertainty to change from a quantitative/mathematical definition to a qualitative/non-mathematical definition, which mentions 'doubt' or 'uncertainty' about the true value of a measurand. This would change the nature of the formal definition and its acceptability among the metrology community is uncertain."

6. An example of inexact use of important metrological principles

Symptoms of such a tendency are rapidly increasing in number and importance—also implied by the increasing use of *non-numerical* terms (fair … good … excellent …) to express levels of ignorance of a measured phenomenon, or kinds of decision.

On the other hand, an increasing use of *forecasts*, and of their importance in everyday decision, is also evident: science tendency has been rather so far more intended, in first instance, to increase the *accuracy* of the data as the main tool to increase the confidence in the acquired knowledge— forecast was more a political tool, a human goal guided by varied ethical principles.

A very popular field today is chosen as an example in the following, the climate evolution field, whose analysis is certainly based on Big Data, to show how much easy one can find in the literature a distance from metrological methodology.

IPCC, from its AR6 Technical Summary [28] is reporting:

"For the decade 2011–2020, the increase in global surface temperature [SAMT] since 1850–1900 is assessed to be 1.09 [0.95 to 1.20] °C.

Throughout the WGI report and unless stated otherwise, uncertainty is quantified using 90% uncertainty intervals. The 90% uncertainty interval, reported in square brackets [x to y], is estimated to have a 90% likelihood of covering the value that is being estimated. The range encompasses the median value and there is an estimated 10% combined likelihood of the value being below the lower end of the range (x) and above its upper end (y). Often the distribution will be considered symmetric about the corresponding best estimate, but this is not always the case. In this Report, an assessed 90% uncertainty interval is referred to as a 'very likely range'. Similarly, an assessed 66% uncertainty interval is referred to as a 'likely range' ".

The IPCC-indicated value means an increase of the SAMT from the mean of the period 1850–1900 to the mean of the period 2011–2020 of (+1.09 ± 0.125) °C, where the indicated uncertainty is said to have the "90% likelihood of covering the value that is being estimated"—i.e. *twice the s.d.*, where s.d. is the standard deviation. This description, very extended with respect to the synthetic scientific notation, looks to have been used because the Technical Summary is dedicated to politicians—similar attitude one can find in the IPCC Report concerning "decisions". [29]

On the other hand, the Author was unable to find in the thousands pages of the IPCC Reports any other numerical statement. Nevertheless, the above estimate is *commonly found in the literature and in the media*, with small variations due to the choice of different reference limits of the time interval.

Therefore, the author is able to assess here that the reported estimate is *not* of the SAMT accuracy and therefore does not have a metrological foundation. The Author made several fits of the annual series of SAMT reported in public databases of different World Organisations dedicated to climate studies, like HadCRUTS, NOOA, etc., in addition to IPCC: the *s.d. of the fit* was always found to be (rounded) ± *0.1–0.2* °C. Thus, the IPCC value is the reproducibility of the fitted databases, *not* the accuracy. By reporting SAMT estimates comprised within the same s.d. of those fits, the IPCC cannot consider it to be SAMT accuracy, neither having a 90% confidence level.

It is not a simple task to interpret such a situation, because the database on which the statement is done is not publicly available. What is likely to be is that the original measurements were supplied by WMO, because it is the World Organisation dedicated to the task to provide worldwide weather parameters: the measuring Stations on the whole Earth are thousands, with a non homogeneous distribution on land (on oceans most measurements are taken from satellites using total radiation or microwave thermometry, not taken in consideration here), nor all having the same accuracy. Before the recent start of an overall qualification of their Stations, i.e. since at least 2013, the WMO reported standard accuracy of the stations was ± 1 °C [30–34]. Only later *four accuracy* categories were established, where only to Classes 1–2 an accuracy of ± 0.2 °C is assigned [35], being them a small minority of the full set of Stations. Class 3 is assigned an accuracy of ± 0.6 °C and Class 4 of ± 1 °C [36].

On the assumption that the above situation is the correct one, original IPCC data taken from WMO cannot allow the SAMT indicated accuracy. Furthermore, it is also indicated by those World Organisations that the initial database (WMO or else), is heavily manipulated with several intentions, as already introduced at the beginning of this paper:

(a) In many case the distance on surface between Stations being too large, additional information is added by interpolation of the real data with more data; (b) some Stations are labelled "outlier" and their data are cancelled; (c) extended regions are not served by (valid) Stations and need "consistent" data to be evaluated and added by using mapping techniques; (c) general homogenisation is said to be also used; …

Each of these techniques, though scientifically performed, always adds an uncertainty component to the original database. However, no UB can be found in any public document, not even in the specific IPCC Report on Uncertainty [37], where, as said before, only words are used instead of numbers, risk concept is preferred to uncertainty and, in general, a language is used more common to the one used in the field of economic analyses or in decision-taking strategies.

7. Conclusions

Metrological methods have been found lacking, namely in important treatments of Big Data. In most cases the analysis is limited to the database fit, providing exclusively an estimate of the precision (data reproducibility) of the database without further accuracy estimate.

One might argue that, since the truth is not reachable by humans, one might be happy for the reproducibility estimate. That is not the case, according to the "motto" already reported at the beginning of these comments (… *all data wrong*). This fact arises because every measurement depends also on the interpretation and on the implementation of the measurement process, the independent preliminary phase of measurement, not reflecting into the output data with an explicit indication about their *quality*.

In fact, the analysis of *data quality* is an *independent task* related to the *performance* of the measurements: such analysis concern the nature of the measured quantity and the needed process, most often not univocal but allowing alternate implementation methods. A logic *diagram* [38–39] of the process must be designed, analysed and optimised for reaching the aimed accuracy—and made public: each of its components originates a *component* of uncertainty of the measured data, some even being a critical contribution to total uncertainty. The summary of that analysis must therefore include what is called UB, computing the effective overall uncertainty of the process and of the measurements influencing the results.

Without such a *full* data analysis no science is possible: in the modern times its tool for data analysis is called metrology, and in the future too, irrespective to the technical means needed and used for it except consistency with the metrological principles. Can we remain confident in that?

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Невизначене майбутнє метрології? Коментарі та приклади

Ф. Павезе

Анотація

Коментарі мають на меті проілюструвати поточний стан метрології відповідно до її принципів і процедур, а саме щодо визначення та значення поняття невизначеності у вимірюванні, а також ввести попередження про розбіжності, які стають все більш частими у застосуваннях, які, як передбачається, стосуються рамки метрології, але в основному порушує метрологічні концепції.

Наведено два приклади, докладно необхідні для того, щоб прояснити інколи незначні відхилення від правильного застосування метрологічних правил: один випадок було знайдено в останньому метрологічному документі: саме визначення невизначеності; інший випадок знаходиться в критичному визначенні невизначеності основного параметра в оцінці зміни клімату: невизначеності, що впливає на поверхневу середньорічну температуру.

Ключові слова: метрологія, невизначеність, клімат, середньорічна температура.