IMPACT OF INTERNATIONAL DECISIONS ON TAI GENERATION

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Abstract

Under the terms of the Convention du Mètre, the Bureau International des Poids et Mesures (BIPM) operates under the supervision of the Comité International des Poids et Mesures (CIPM). The CIPM has created a number of consultative committees which bring together the world's experts in their specified fields as advisers on scientific and technical matters. Among them, the Comité Consultatif pour la Définition de la Seconde (CCDS) deals with the definition and realization of the second, and the establishment and diffusion of International Atomic Time (TAI) and Coordinated Universal Time (UTC).

The CCDS held its 13th meeting in March 1996. It made a number of recommendations and addressed requests to its Working Groups, some of which have a direct impact on the work carried out at the BIPM Time Section. The most important recommendation is Recommendation S2 (1996), which concerns the application of the correction for the blackbody radiation shift to the results of all primary frequency standards. As this has direct consequences for the accuracy of TAI, immediate action was necessary. Another example is the creation of a CCDS Working Group on the expression of uncertainties in primary frequency standards. Evidence of the need for such a group became clear during discussions of how uncertainties should be presented and interpreted when combining measurements of the SI second produced by primary frequency standards. Finally, the Recommendation S4 (1996), which asks for coordination of the GPS and GLONASS timing systems, may lead to a worldwide network of time links using GPS and GLONASS in a complementary way. The aim of this paper is to present these international decisions to the timing community, to show how they influence the work of the BIPM Time Section, and to figure out the consequences for TAI.

INTRODUCTION

Worldwide agreement on units of measurement and practical provision of accurate measurement standards are assured under the diplomatic treaty of the Convention du Mètre through the activities of the Bureau International des Poids et Mesures (BIPM) and the national metrology institutes. Under the terms of the Convention, the BIPM operates under the exclusive supervision of the Comité International des Poids et Mesures (CIPM), which itself comes under the authority of the Conférence Générale des Poids et Mesures (CGPM).

The CGPM receives the report of the Comité International on work accomplished; it examines the arrangements required to ensure the propagation and improvement of the Système International d'Unités (SI) and endorses scientific resolutions of international scope.

The CIPM oversees and directs the work of the BIPM and proposes its future program to the Conférence Générale. It created a number of consultative committees which bring together the world's experts in their specified fields as advisers on scientific and technical matters. Among the tasks of the consultative committees is the preparation of recommendations for discussion at the CIPM. The membership of a consultative committee is decided by the CIPM in consultation with the President of the consultative committee, who is normally a member of the CIPM, and the Director of the BIPM. Laboratories invited to be members are national metrology institutes of a member state of the Convention du Mètre already recognized internationally as most expert in the field. In addition to laboratory members, a consultative committee may include as members international unions, or other international organizations, and named individuals (members by appointment) whose knowledge and competence in the field are such that they can provide valuable assistance even though they do not come from a member laboratory. The President may also invite experts (invited guests) for a specified meeting of the consultative committee for advice on a particular item considered at the meeting. In addition, studies on specified subjects are dealt with by permanent or temporary working groups which report their conclusions to their consultative committee. Recommendations proposed by a consultative committee to the CIPM represent a consensus among members and serve to define the work of the BIPM and national laboratories. Among them, the most important become CIPM Recommendations, and eventually Resolutions of the CGPM.

The Time Section of the BIPM is responsible for the establishment and diffusion of International Atomic Time (TAI) and Coordinated Universal Time (UTC). For issues concerning time, the CIPM takes advice from the Comité Consultatif pour la Définition de la Seconde (CCDS). Although the name of this consultative committee appears to constrain its work to the definition and realization of the SI second, CCDS sessions are forums in which most of the scientific and technical problems encountered in time metrology are addressed.

In recent years, the CCDS has been chaired by Prof J. Kovalevsky and its membership has included twenty-one institutions, four international unions, one member by appointment, Prof. B. Guinot (formerly Head of the BIPM Time Section), and the Director of the BIPM, Dr. T.J. Quinn. The CCDS is helped in its work by four CCDS Working Groups:

* the Working Group on TAI, chaired by Dr P. Pâquet (ORB, Brussels, Belgium),

* the Working Group on Two-Way Satellite Time Transfer, chaired by Dr W.J. Klepczynski (ISI, Washington D.C., USA),

* the Working Group on Application of General Relativity to Metrology, chaired by Prof. B. Guinot, and

* the Working Group on the Expression of Uncertainties in Primary Frequency Standards, chaired by Dr. R. Douglas (NRC, Ottawa, Canada).

In addition, the Working Group on TAI has created a Sub-group on GPS and GLONASS Time Transfer Standards, chaired by D.W. Allan (Allan's TIME, Fountain Green, Utah, USA).

In general, the CCDS meets every third year. The last meeting (the 13th) was held at the BIPM on 12 and 13 March 1996, and attracted representatives from all but one institution and from all international unions. The President of the CCDS also invited four experts: D.W.

Allan, Dr. G.M.R. Winkler (ISI, Washington D.C., USA), Prof. A. De Marchi (Polytenico de Torino, Turin, Italy), and Dr. V.A. Brumberg (IPA, St. Petersburg, Russia); the physicists of the BIPM Time Section also attended. Dr. P. Fisk (NML-CSIRO, Sydney, Australia) was appointed secretary for this meeting.[1] Twenty-five working documents, sent to the CCDS before the meeting, were examined during the session.[2] Consensus was reached on four Recommendations (see Appendix I) and these were proposed to the CIPM in September 1996, one of them, Recommendation S4 (1996), becoming CIPM Recommendation 1 (CI-1996). The CCDS also addressed a formal request (see Appendix II) to the Sub-group on GPS and GLONASS Time Transfer Standards. It should be noted that the CCDS Working Group on the Expression of Uncertainties in Primary Frequency Standards was created during this 13th meeting.

The impact on the establishment of TAI and UTC of some of the recommendations and decisions of the CCDS taken during its last meeting is examined below. The chosen examples concern the estimation and improvement of the accuracy of TAI and the use of GLONASS as a complementary technique for high accuracy time transfer between clocks contributing to TAI.

BLACKBODY FREQUENCY SHIFT

The definition of the SI second ideally requires the observation of the ground-state hyperfine transition of an unperturbed cesium atom. Corrections for perturbations should, thus, be estimated together with their respective uncertainties, and applied to the results of measurements provided by primary frequency standards. The largest corrections (greater than a few parts in 10^{14}) compensate for the quadratic Zeeman effect, the quadratic Doppler effect, and the cavity phase difference.[3] These bring uncertainties ranging from a few parts in 10^{15} to a few parts in 10^{14} for the most accurate primary standards. Other effects, such those related to cavity detuning, microwave leakage, Majorana transitions, asymmetry of the microwave spectra, and the electronic equipment do not induce a global shift in the measurement, but contribute to the uncertainty budget of the standard by some parts in 10^{15}.[3]

TAI is defined as a coordinate time scale in a geocentric reference frame, with the SI second as realized on the rotating geoid as the scale unit. It follows that, if the primary frequency standard is used to evaluate the duration of the TAI scale unit, it is also necessary to apply a correction compensating for the difference in gravitational potential between the standard site and the rotating geoid. This correction is about 1×10^{-13} for a standard at 1,000 m above the rotating geoid and can be calculated with an uncertainty of 1 to a few parts in 10^{16}.

Another important shift is due to alternating electric fields in the thermal radiation of a cesium atomic standard. This was explained for the first time in a paper by Itano, Lewis,and Wineland[4] published in 1982. Under the influence of the radiation from the walls surrounding the atoms inside the clock at temperature T, the clock transition frequency is reduced with respect to its value at T = 0 K. From the formula provided by Itano *et al.*, the amplitude of the effect is 1.7×10^{-14} for T = 300 K. Its uncertainty is conservatively estimated at 1×10^{-15}, taking into account the fact that the radiation involved is not emitted by a perfect black body.

In the past the blackbody radiation shift was not taken into account. It appeared for the first time in 1994 when the optically pumped primary frequency standard NIST-7 was first evaluated.[5] The amplitude of the effect made it negligible for primary standards presenting an uncertainty of order 1×10^{-13}, but not for those showing uncertainties of a few parts in 10^{14} or below. At the time no uniform procedure was applied by the laboratories which reported data from primary frequency standards, with the consequence that it was discussed at a formal meeting of the CCDS Working Group on TAI in March 1995.[6] There was unanimous agreement that a correction, by which the clock frequency is transferred at 0 K, should be made. The conclusion of the Group that the blackbody correction should be applied to all primary standards was incorporated in a draft recommendation that the CCDS approved in March 1996 as Recommendation S2 (see Appendix I).

The CCDS Working Group on TAI also made the statement that "all laboratories keeping primary frequency standards evaluate the blackbody correction (to 0 K) for their standards and communicate the values, with their uncertainties, to the BIPM stating whether or not the correction has been applied, and that the BIPM study the implications for TAI of the uniform application of the correction."[6] Since the end of 1995, the BIPM has been in a position to apply the blackbody correction to all the measurements provided by the most accurate primary frequency standards since they came into operation. It follows that the duration of the scale unit of TAI shows a departure from the SI second on the rotating geoid which is larger than before by an amount of about 2×10^{-14} s. Although the accuracy of TAI is degraded, it is important to note that the appearance of new primary frequency standards, such as the BNM-LPTF cesium fountain FO1[7], which have outstanding accuracy (uncertainty of the LPTF-FO1 estimated at 3×10^{-15}, makes it possible to improve our knowledge of the departure of the TAI scale unit from the SI second on the rotating geoid.

Compensation for the discrepancy of the TAI scale unit was initiated in May 1995. This takes the form of cumulative frequency steering corrections, each of relative amplitude 1×10^{-15}, which are applied on dates separated by intervals of 60 days, a procedure which does not degrade the medium-term stability of the time scale. In mid-1996, we observed that the discrepancy had not yet been decreased by this procedure, which, in fact, has only compensated the natural drift of the scale. It was, thus, decided to increase the relative amplitude of the corrections to 1.5×10^{-15}, starting September 1996.

UNCERTAINTIES IN PRIMARY FREQUENCY STANDARDS

During the 13th meeting of the CCDS, held in March 1996, the President opened a general discussion on how uncertainties are expressed in primary frequency standard measurements.

According to the *International Vocabulary of Basic and General Terms in Metrology* (VIM entry 3.9[8]), the uncertainty of a measurement is defined as a "parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand." The ISO *Guide to the Expression of Uncertainty in Measurement* (GUM[9]) states that the standard uncertainty (entry 2.3.1.) is "the uncertainty of the result of a measurement expressed as a standard deviation" and recommends that uncertainty be expressed as a combination of a Type A and a Type B uncertainties. The Type A uncertainty (GUM entry 2.3.2.) is obtained "by the statistical analysis of series of observations" and the Type B uncertainty "by means other than the statistical analysis of series of observations."

In time and frequency applications, the data which are analyzed are in the form of time series. This leads to the question of what is intended when an uncertainty is calculated. Is it the expected variation of the quantity over a period of time, or is it merely the uncertainty of a single measurement? When a primary frequency standard is in operation in a laboratory, both are investigated. Take the example of the BNM-LPTF cesium fountain FO1.[7]

- The stability of the device is characterized by an Allan deviation curve obtained from the comparison of LPTF-FO1 with a local hydrogen maser. The result is expressed in the form $\sigma_y(\tau) = 2\times10^{-13}\tau^{-1/2}$, thus giving the evidence of white frequency noise, for averaging times τ between 1 s and 10^4 s. For longer averaging times, the value of $\sigma_y(\tau)$ reaches a limit, equal to 2×10^{-15}, due to the hydrogen maser performance. This is a statistical analysis and, thus, corresponds to a method of evaluation of a Type A uncertainty.

* A measurement of the frequency of LPTF-FO1 is made relative to the local hydrogen maser over an averaging time τ of a few hours. This corresponds to the full white frequency noise of the primary standard not yet degraded by the maser noise. A number of corrections applied to the measurement result are evaluated, together with their standard uncertainties. Finally a corrected result is delivered, together with a standard uncertainty obtained by quadratic sum of individual uncertainties. This uncertainty is designated as the Type B uncertainty of the LPTF-FO1 standard.

Similar procedures are in use for all primary frequency standards and this calls for a few remarks.

The Type A uncertainty, as described above, is not characterized by one simple value of standard deviation resulting from white and Gaussian noise as in other metrological measurements, but by the variation of a standard deviation versus an averaging time, possibly showing non-white noise.

The type B uncertainty, as described above, applies to a measurement carried out over a given averaging time which must be indicated. This is a practice which is not often made in other metrological measurements.

The hypothesis of complete independence of the different components of the uncertainty budget is implicitly made when they are computed using a quadratic sum. This hypothesis may not be justified[10] and some authors prefer to increase the value resulting from the quadratic sum in order to take into account suspected correlations.

An evaluation of the different corrections and of their uncertainties should rigorously be made for each measurement provided by a primary standard. The accuracy characterizing a standard can change during its life, as is the case for NIST-7 for which the Type B uncertainty was found to be 1×10^{-14} in 1994 and was updated to 5×10^{-15} in September 1996 after an upgrade of the system. This leads to the question of what is meant by the Type B uncertainty of a continuously operating primary frequency standard such as the classical standards PTB CS2 and CS3, for which the complete evaluation may be carried out only once.

The corrections to apply may be estimated with different methods. They may result from application of a formula, as is the case for the blackbody correction, and the corresponding uncertainties depend on the degree of validity of a theory. Corrections may also be derived from measurements, as is the correction for the quadratic Zeeman effect, and the corresponding uncertainties result from statistical analysis of the measurement results. Here, the separation between Type A and Type B evaluation method is not obvious.

The Type B uncertainty determination, as described above, is helpful for comparing the accuracy of the different primary frequency standards only if the different operators agree on the set of corrections which should be applied. This has already been discussed in the preceding section for what concerns the blackbody radiation shift. It is also important to note the particular case of the gravitational correction. Since the SI second is a proper unit, valid in a space domain surrounding the laboratory where the primary standard is located[11], there is no reason to apply a correction due to the gravitational field experienced in the laboratory. The corresponding uncertainty should, thus, not be taken into account. However, if the second produced by the primary standard is transferred to TAI, it is necessary to take into account the differential gravitational field between the standard site and the rotating geoid. This is exemplified in the publication of the uncertainty budget for the BNM-LPTF cesium fountain FO1[7], where the gravitational correction appears as an additional line after a first quadratic sum of the other uncertainties involved.

The CCDS considered the questions summarized above to be of sufficient importance that a Working Group on the Expression of Uncertainties in Primary Frequency was formed. The membership of the working group is Dr. R. Douglas, Chairman, D.W. Allan, Dr. A. Bauch (PTB, Braunschweig, Germany), Dr. A. Lepek (INPL, Jerusalem, Israel), Prof. A. De Marchi, and Dr. C. Thomas (BIPM, Sèvres, France), and it is still largely open to other experts from timing laboratories. The main question this group must address is how to apply the recommendations of the ISO guide on uncertainty to the specific case of primary frequency standards. The answer to this question should clarify the way the different measurements reported to the BIPM from primary frequency standards should be used to evaluate the accuracy of TAI.[12, 13]

USE OF GLONASS, AND GPS AND GLONASS STANDARDS

Since the beginning of 1995, the GPS common-view technique has been the sole means of time transfer used for TAI computation. Twice a year the BIPM distributes GPS international common-view schedules to laboratories contributing to TAI. The collection and treatment of the rough data are effected by the BIPM according to well-established procedures. The international network of GPS time links used by the BIPM is organized to follow a pattern of local stars within a continent, together with two-distance links, NIST-OP and CRL-OP, for which data are corrected to take account of on-site ionospheric measurements and postprocessed precise satellite ephemerides. Only strict common views are used in order to overcome effects due to the implementation of Selective Availability on satellite signals. If GPS time receivers in operation in timing laboratories are differentially calibrated, the accuracy of one common-view measurement is characterized by a standard uncertainty of a few nanoseconds. In addition, the measurement noise in time comparisons between distant clocks is smoothed out by averaging over a few days, an averaging period which remains shorter than the 5-day interval between two TAI updates. It follows that the resulting time scale is no longer affected by white phase noise, which results in an improvement in its short-term stability.

Although the GPS common-view method currently gives full satisfaction for the computation of TAI, improvements in the quality of clocks and the need for redundancy in time transfer methods have led the BIPM to take a particular interest in the GLONASS common-view method. The first commercial GLONASS time receivers specifically designed for fully automatic common-view observations appeared on the market in early 1995 and tests began immediately. Following Recommendation S 3 (1993) of the CCDS at its 12th meeting[14], the BIPM issued the first official international GLONASS common-view schedule in December 1995 for implementation in January 1996. By spring 1996, six time laboratories already observed GLONASS in common view and this number is expected to increase rapidly.

A GLONASS common-view time transfer between California, the East Coast of the United States, and the BIPM has been under way since the end of July 1995. Results show a level of noise over one GLONASS common-view measurement slightly larger than for GPS.[15] However, the internal delays of GLONASS equipment have not yet been calibrated, so a complete estimation of the accuracy remains to be carried out.

It would be highly interesting for the time community to use both systems, GPS and GLONASS, in an interchangeable way: this would provide robustness, redundancy, and reliability. However, there exist some differences which should be worked out. The most important concerns the coordinate reference frames in which the positions of the Earth stations and satellites are expressed, WGS 84 for GPS and SGS 90 for GLONASS. The reference frame which is internationally agreed for positions on the Earth is the IERS Terrestrial Reference Frame (ITRF) produced by the International Earth Rotation Service (IERS). The WGS 84 is very close to the ITRF, but conversion formulae are needed to transform data expressed in the SGS 90 into the ITRF and introduce an uncertainty of several meters. A standard procedure using the ITRF for both systems would, thus, be desirable. Another point concerns the differences between the time scales broadcast by the satellite systems, GPS time and GLONASS time, and UTC. A constant effort is maintained to keep GPS time very close to UTC, within a few tens of nanoseconds, and to ensure that this difference is accurately known. If Selective Availability were not implemented, the GPS satellites would distribute a close approximation to UTC in real time. The offset between GLONASS time and UTC, however, reaches 30 μs and is not accurately known (an error as large as 1 μs is suspected). The effect is that, although GLONASS signals are not intentionally degraded, they do not provide access in real time to a good approximation to UTC.

These different issues were discussed during the 13th meeting of the CCDS and were addressed in Recommendation S 4 (1996) (see Appendix I), which was approved in September 1996 as CIPM Recommendation 1 (CI-1996), entitled "Coordination of satellite systems providing timing." In this, system operators are recommended to use ITRF as the sole reference frame and to synchronize satellite times closely with UTC.

Besides this formal recommendation, it is clear that some standardization work is required to make time receivers able to observe indifferently GPS and GLONASS satellites, for instance software problems such as treatment of short-term data and data file format. This is relevant to the activities of the Sub-Group on GPS and GLONASS Time Transfer Standards, which was formally requested by the CCDS to contact manufacturers in order to design new time receivers able to match the requirements of time and frequency metrology. The BIPM is working hard on this item[16, 17] through tests of new devices and suggestions to manufacturers.

CONCLUSIONS

The meetings of the Comité Consultatif pour la Définition de la Seconde gather world experts on the different theoretical and technical problems encountered in time metrology. The recommendations which are developed during these meetings represent a consensus among the members and serve to define the work of the Time Section of the BIPM and national timing laboratories. Two of the latest and most important decisions of the CCDS concern the uniform application of a correction to compensate for the blackbody radiation shift experienced by cesium atoms in primary frequency standards and encouragement of the use of the GPS and GLONASS satellite systems in a complementary way for international time transfer. In addition, a discussion on how uncertainties should be expressed to describe primary frequency standards has been initiated inside a newly created CCDS working group.

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Acronyms

BIPM	Bureau International des Poids et Mesures, Sèvres, France
BNM-LPTF	Bureau National de Métrologie, Laboratoire Primaire du Temps et des Fréquences, Paris, France
CCDS	Comité Consultatif pour la Définition de la Seconde
CGPM	Conférence Générale des Poids et Mesures
CIPM	Comité International des Poids et Mesures
CRL	Communications Research Laboratory, Tokyo, Japan
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
IERS	International Earth Rotation Service, Paris, France
INPL	National Physical Laboratory of Israel, Jerusalem, Israel
IPA	Institut d'Astronomie Appliquée, St. Petersburg, Russia
ISI	Innovative Solutions International, Washington D.C., USA
ISO	International Standardization Organization
ITRF	IERS Terrestrial Reference France
LPTF-FO1	Fontaine No. 1 du LPTF (Cs fountain No. 1 of the LPTF)
NIST	National Institute of Standards and Technology, Boulder, Colorado, USA
NIST-7	Primary frequency standard No. 7 developed at the NIST
NML-CSIRO	National Measurement Laboratory, Commonwealth Scientific and Industrial Research Organization, Sydney, Australia
NRC	National Research Council, Ottawa, Canada
OP	Observatoire de Paris (Paris Observatory), Paris, France
ORB	Observatoire Royal de Belgique, Brussels, Belgium
PTB	Physikalisch-Technische Bundesanstalt, Braunschweig, Germany
SI	Système International d'Unités (International System of Units)
TAI	Temps Atomique International (International Atomic Time)
UTC	Coordinated Universal Time

Appendix I

RECOMMENDATION S 1 (1996)
Primary frequency standards

The Comité Consultatif pour la Définition de la Seconde,
considering
– the importance of maintaining an adequate number of primary frequency standards to assure the accuracy and long-term stability of TAI,
– that new primary standards are being developed using new technology,
– that these new standards are significantly more accurate than the traditional primary standards upon which TAI and UTC have been based in the past,
– that in consequence, the accuracy of TAI and UTC will rapidly become dependent on these new standards,
– that considerable resources are required to maintain primary frequency standards as operational facilities to assure the accuracy of TAI,
recalling its Recommendation S 1 (1993) on the accuracy of primary frequency standards,
requests national metrology institutes and other laboratories developing new primary standards, to make every effort to provide the human and other resources necessary to maintain as operational facilities these new standards upon which the accuracy of TAI and UTC is based.

RECOMMENDATION S 2 (1996)
Blackbody frequency shift

The Comité Consultatif pour la Définition de la Seconde,
considering
– that the relative uncertainty of some primary frequency standards is now below 5×10^{-15} and that even smaller uncertainties are expected in the near future,
– that the relative frequency shift due to blackbody radiation may be as large as -1.7×10^{-14} at 300 K,
– that there is a growing need for more accurate comparisons of the frequencies of primary standards,
– that, even though no measurement has yet been made of the cesium blackbody radiation frequency shift, there is consistency between the theoretical understanding and experimental verification of AC Stark shift measurements in other systems,
– that there is a need for uniformity in reporting the frequency and the corresponding uncertainty of primary standards, and
– that there is a need for improved accuracy in TAI,
recommends that a correction for blackbody radiation be applied to all primary frequency standards.

RECOMMENDATION S 3 (1996)
Correlations among clocks contributing to TAI

The Comité Consultatif pour la Définition de la Seconde,
considering
– that there have been reports of correlations among clocks operating at a given site,
– that the basis upon which TAI is calculated assumes that such correlations do not exist,
– that correlated behavior of clocks contributing to TAI can lead to a degradation of TAI,
– that there is insufficient evidence to warrant taking any specific action at this time,
requests
– that laboratories contributing to TAI perform clock-data studies as well as experiments aimed

at developing a better understanding of correlations among clocks and quantifying these effects,
– that the results of such work be shared with all laboratories contributing to TAI and be sent to the Bureau International des Poids et Mesures.

RECOMMENDATION S 4 (1996)[1]
Coordination of satellite systems providing timing

The Comité Consultatif pour la Définition de la Seconde,
considering
– the international value of having both Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS) operational with a composite contribution of 48 satellites,
– the desirability of using either or both systems interchangeably,
– that currently significant time differences exist between the two systems,
– that significant differences exist in the coordinate reference frames used for each,
– that other important satellite timing systems are now being designed and developed,
recommends
– that the reference times (modulo 1 second) of satellite navigation systems with global coverage[2] be synchronized as closely as possible to UTC, – that the reference frames for these systems be transformed to be in conformity with the terrestrial reference frame maintained by the International Earth Rotation Service (ITRF), – that both GPS and GLONASS receivers be used at timing centers.

Appendix II

Section 7 of the Report of the 13th Meeting of the CCDS, 1996:

[...] A formal request from the CCDS to this sub-group [Sub-group on GPS and GLONASS Time Transfer Standards] was written with the objective of strengthening contacts between the manufacturers of GPS and GLONASS time receivers and the community.

The Comité Consultatif pour la Définition de la Seconde,
noting the marked improvements in the quality of both primary frequency standards and commercial atomic clocks,
recognizing that the performance of commercially available GPS and GLONASS receivers currently used does not meet time transfer requirements,
asks the CCDS Sub-group on GPS and GLONASS Time Transfer Standards
– to contact manufacturers of receivers and request them to adapt the hardware and software of their systems to match the requirements of time and frequency laboratories so that their receivers can record the signals of GPS and GLONASS satellites in dual-frequency mode, in multi-channel mode and, in a data format defined by the sub-group, can provide internal calibration and be as insensitive as possible to environmental conditions,
– to keep time and frequency laboratories informed of its actions.

[1]This Recommendation was adopted by the CIPM as Recommendation 1 (CI-1996) at its 85th meeting in September 1996.
[2]Such as Global Positioning System (GPS), Global Navigation Satellite System (GLONASS), International Maritime Satellite Organization (INMARSAT), Global Navigation Satellite System 1 (GNSS1), Global Navigation Satellite System 2 (GNSS2).

Questions and Answers

DAVID ALLAN (ALLAN'S TIME): I think you make an excellent point. For example, you can show that in order to evaluate many of the systematics in clocks, you need to know the noise types before you do that. And so you have to bring the two together to estimate each other. So to bring these two different types of uncertainties and to bring them under one hat I think is an extremely important step. I commend you for what you're bringing out to us.