Director's Report on the Activity and Management of the International Bureau of Weights and Measures

Supplement: Time Department

(1 January 2016 – 31 December 2016)

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Bureau International des Poids et Mesures

BIPM Time Department

Director: E.F. Arias

(1 January 2016 to 31 December 2016)

1. International Atomic Time (TAI), Coordinated Universal Time (UTC) and Rapid UTC (UTCr)

(E.F. Arias, A. Harmegnies, Z. Jiang, H. Konaté[1], G. Panfilo, G. Petit and L. Tisserand)

The reference time scales, International Atomic Time (TAI) and Coordinated Universal Time (UTC), are computed from data reported regularly to the BIPM by various timing centres that maintain a local UTC; monthly results are published in *Circular T*. The UTC rapid solution (UTCr) is published every Wednesday by 18 h UTC at the latest. All information related to the publication of UTC and UTCr can be accessed at www.bipm.org/en/scientific/tai/ftp_server/introduction.html.

The structure and content of BIPM *Circular T* were updated in 2016 with the introduction of an interactive version, which gives complete access to the information hosted on the BIPM website and ftp server. The dissemination of information has significantly improved following the development and launch of the 'BIPM Time Department Data Base'. Time Department services can be accessed at http://www.bipm.org/en/bipm/tai/.

The *BIPM Annual Report on Time Activities for 2015*, volume 10, provides comprehensive data for 2015 and is available on the BIPM website at http://www.bipm.org/en/bipm-services/timescales/time-ftp/annual-reports.html

2. Algorithms for time scales (G. Panfilo, G. Petit, A. Harmegnies and L. Tisserand)

The algorithm used by the Time Department to calculate time scales is an iterative process that starts by producing a free atomic scale (*Échelle atomique libre*, EAL) from which TAI and UTC are derived. Research into time-scale algorithms is ongoing in the department, with the aim of improving the long-term stability of EAL and the accuracy of TAI.

After the implementation of the new algorithms (prediction and weights) for UTC calculation, behaviour is routinely and carefully monitored to trap and fix unexpected anomalies, although none were observed throughout 2016.

The results concerning the uncertainties of [*UTC-UTC(k)*] reported in Section 1 of *Circular T* have been analysed to evaluate the possibility of revising the algorithm. There are two main issues concerning the current algorithm: firstly, the statistical uncertainty, indicated with uStb in *Circular T*, of the pivot laboratory (at present PTB) is underestimated and unrealistic and secondly, the strict correlation of the uncertainty given by calibration (indicated by uCal). In fact the value of the uncertainty for uncalibrated laboratories (now arbitrarily fixed to 20 ns) affects the uncertainties of the ensemble in a significant way, including the calibrated laboratories. The particular case of the United States Naval Observatory (USNO) should be mentioned due to its important weight in the calculation of UTC; a small change in its calibration uncertainty affects, with the current algorithm, the ensemble of uncertainties in a critical way. A different approach to the problem is being studied, taking into account correlations that are not fully considered in the current algorithm.

2.1 EAL stability

Some 89 % of clocks used in the calculation of UTC are either commercial atomic clocks with high performance caesium tubes or active hydrogen masers. The number of hydrogen masers operated by contributing laboratories is increasing and represented 28 % of the participating clocks in 2016. The weighting procedure involved in time

[1] Retired on 31 October 2016

scale computation guarantees the long-term stability of EAL. To prevent domination of the scale by a small number of very stable clocks, a maximum relative weight is used each month, which depends on the number of participating clocks. On average, about 12 % of the participating clocks were at the maximum weight during 2016; almost all of these were hydrogen masers. The weighting algorithm, which has been in use since 2014, is based on the predictability of the clock's frequency. It enhances the influence of hydrogen masers on the resulting time scale; 42 % of the contributing hydrogen masers were, on average, at the maximum weight in 2016, whilst no caesium clocks reached the maximum weight.

UTC implicitly relies on hydrogen masers in the short term and on caesium clocks in the long term, which was an aim of the new weighting procedure. The stability of EAL at the end of 2016, expressed in terms of an Allan deviation, is about three parts in 10^{16} for averaging times of one month.

2.2 TAI accuracy

To characterize the accuracy of TAI, estimates are made of the relative departure, and its uncertainty, of the duration of the TAI scale interval from the SI second, as produced on the rotating geoid, by primary and secondary frequency standards. Since January 2016, individual measurements of the TAI frequency have been provided by nine primary frequency standards, including seven caesium fountains (SYRTE FO2, NIST F1, IT CSF2, SU CSFO2, PTB CSF1, PTB CSF2 and NIM 5), and by a rubidium secondary frequency standard (SYRTE FORb). Reports of the operation of the primary and secondary frequency standards are regularly published on the BIPM website and collated in the *BIPM Annual Report on Time Activities*.

Since January 2016, the global treatment of individual measurements has led to a relative departure of the duration of the TAI scale unit from the SI second on the geoid ranging from -0.30×10^{-15} to -1.45×10^{-15}, with a maximum standard uncertainty of 0.33×10^{-15}. A steering correction $+0.3 \times 10^{-15}$ had been applied in December 2016; this was the first time it had been applied since October 2012, confirming that the new algorithm maintains a positive impact on the accuracy of TAI.

2.3 Independent atomic time scales: TT(BIPM)

TAI is computed in 'real-time' and is subject to operational constraints; as a result it does not provide an optimal realization of TT, the time coordinate of the geocentric reference system. The BIPM therefore computes an additional realization, TT(BIPM), in post-processing, which is based on a weighted average of the evaluation of the TAI frequency by the primary frequency standards. The Time Department provided an updated computation of TT(BIPM) in January 2016, known as TT(BIPM15), valid until December 2015, which had an estimated accuracy of about 2-3 parts in 10^{16} over recent years. Moreover, the Time Department provides a formula to extend TT(BIPM15) based on the most recent TAI computation. Such an extension is useful for pulsar analysis pending the yearly updates of TT(BIPM). Studies to improve the computation of TT(BIPM) are ongoing in order to keep it in line with improvements in primary and secondary frequency standards.

An accurate analysis of a different approach to the calculation of TT that is more adapted to the case of the secondary frequency standards required a more flexible calculation interval and is ongoing.

2.4 Local representations of UTC in national laboratories as broadcast by the GNSS

The Time Department continues to calculate and publish the differences between the predictions of UTC(USNO) and UTC(SU) (as broadcast by GPS and GLONASS) and UTC in BIPM *Circular T*. Following the project to correct the large offset between UTC and GLONASS time, the absolute calibration of a BIPM receiver was concluded at the VNIIFTRI. This receiver has been used as the reference for the relative calibration of receivers at the Astrogeodynamical Observatory of the Space Research Centre (AOS, Borowiec, Poland) which provides data for computing this offset.

3. Primary frequency standards and secondary representations of the second (E.F. Arias, G. Panfilo, G. Petit and L. Robertsson)

Members of the BIPM Time Department actively participate in the work of the CCL-CCTF Frequency Standards Working Group (WGFS), and the Consultative Committee for Time and Frequency (CCTF) Working Group on Primary and Secondary Frequency Standards (WGPSFS). These Working Groups seek to encourage comparisons, knowledge-sharing between laboratories, the creation of better documentation, the use of high-accuracy primary frequency standards (Cs fountains) and secondary frequency standards for TAI.

Following an invitation by the CCTF to systematically study frequency ratios of ultra-high precision frequency standards, a somewhat different approach is needed to generate the update of the frequency list. Redundant measurements in this scheme allow for consistency studies but also require a non-linear least squares approach for complete evaluation. Such resources have been developed at the BIPM based on graph theory concepts. This method is a simplified approach, which is an alternative but complementary method to that developed at the NPL. Numerical validation of the two approaches is under way in order to be ready for the next recommended frequency list update in 2017.

Secondary representations of the second reported in BIPM Circular T

Since January 2012 the LNE-SYRTE has reported frequency measurements of the Rb microwave transition obtained with a double Cs-Rb fountain (FORb). Twelve measurement reports of FORb were submitted in 2015 and have been officially used for the accuracy of TAI. In addition, measurements of two Sr optical lattice clocks were reported for the first time by the LNE-SYRTE. They will be introduced following the advice of the CCTF Working Group on Primary and Secondary Frequency Standards.

4. Time links used for UTC (E.F. Arias, A. Harmegnies, Z. Jiang, H. Konaté, G. Panfilo, G. Petit and L. Tisserand)

At the end of 2016, 77 time laboratories supplied data for the calculation of UTC at the BIPM. The laboratories are equipped with GNSS receivers and some also operate two-way satellite time and frequency transfer (TWSTFT) stations.

Data from three independent techniques are included in the process of comparison of laboratories' clocks based on the tracking of GPS and GLONASS satellites, and TWSTFT.

The GPS all-in-view method is widely used and takes advantage of the increasing quality of the International GNSS Service (IGS) products (clocks and IGS time). Clock comparisons for UTC are implemented using C/A code measurements from GPS single-frequency receivers, or dual-frequency, multi-channel GPS geodetic-type receivers (P3). The GPS phase and code data provided by time laboratories which operate geodetic-type receivers is processed monthly using the Precise Point Positioning (PPP) technique. The Time Department also regularly computes combined GPS/GLONASS links resulting in improved link uncertainty. About five GPS/GLONASS links are regularly computed for *Circular T*.

Thirteen laboratories operating TWSTFT stations officially submitted data in 2016 for use in the computation of UTC, representing 15 % of the time links. The number of TW links increased during the year with the re-incorporation of laboratories in the Asia Pacific region, which had been absent due to an interruption of the satellite service in the region in 2015. The combination of TWSTFT and PPP (so called TWPPP) has been used whenever possible. This combination takes advantage of the small noise of the GPSPPP and of the accuracy of the TWSTFT links.

GPS PPP alone or in combination with TWSTFT are in use for UTC clock comparisons in almost 60 % of the links, where the statistical uncertainty of time transfer is well below the nanosecond, the best value being 0.3 ns.

4.1 Global Positioning System (GPS) and Global Navigation Satellite System (GLONASS)

All GNSS time and frequency transfer data are corrected for satellite positions using IGS and the Information and Analysis Centre of Navigation (IAC) of the Mission Control Centre in Russia. The measurement data obtained by using single-frequency receivers are corrected for ionospheric delays using maps of the total electron content of the ionosphere provided by the Centre for Orbit Determination in Europe (CODE).

Techniques that use dual-frequency, GNSS carrier-phase measurements in addition to the codes, are widely used by the geodetic community and have been adapted to the needs of time and frequency transfer. This topic is studied within the framework of the IGS Working Group on Clock Products, which includes a physicist from the BIPM Time Department as a member.

Data from world-wide geodetic-type receivers are collected for UTC computation, using procedures and software that was developed in collaboration with the Observatoire Royal de Belgique (ORB). These P3 time links are routinely computed and compared to other available techniques, notably two-way time transfer. The software that produces 'iono-free' solutions has been implemented in some receivers and these now automatically produce both formatted GPS and GLONASS P3 code results. These newly available data will be used in multi-GNSS system time links, but further studies on GLONASS inter-frequency biases have to be carried out first.

The NRCan's PPP software is used for the time link calculation. The current version of the software is capable of processing both GPS and GLONASS data but only GPS results are used operationally. Comparisons with other PPP software have been carried out. Studies are ongoing to improve long-term stability, using new processing techniques, in collaboration with software developers at NRCan, the ORB, the *Centre National d'Études Spatiales* (CNES) and also with other institutes. A novel PPP technique using integer phase ambiguities (IPPP) has been successfully developed within the framework of a post-doctoral project. It significantly improves the stability in the medium term (several hours), but mostly in the long term (days). Since 2015 the IPPP technique moved to a pre-operational stage and it is now used regularly to compare IPPP results to the few available optical fibre links.

Comparisons of the different links possible on a baseline between two contributing laboratories, are computed and published monthly on the Time Department's ftp server.

4.2. Two-way satellite time and frequency transfer

The TWSTFT participating stations held a meeting at the 30th European Frequency and Time Forum (EFTF) in York, UK, on 6 April 2016. The 24th annual meeting of the CCTF WG on TWSTFT was held at the NIST on 7-8 September 2016. Two major issues discussed at the meetings were the realization of a pilot project involving the BIPM and the WG on TWSTFT: one on the impact of the Software-Defined Radio (SDR) receiver on the uncertainty of the TWSTFT time links; and the establishment of a task group to study the long-term comparison of GPS and TWSTFT links. One output of the pilot study could be the integration of data from SDR-equipped TW stations in the computation of UTC. The BIPM is also involved in the calibration of two-way time-transfer links by comparison with the corresponding GPS links. This is necessary to maintain stability of the TWSTFT links, in case of a loss of their direct calibration.

The TWSTFT technique is currently operational in eleven European, two North American and nine Asia-Pacific time laboratories. Ten TWSTFT links had been used in the computation of UTC in 2016 in Europe-USA-Asia;

they are combined with GPS PPP solutions. Some of the TWSTFT links involved in the computation of UTC are used in the experiment 'Time Transfer by Laser Link' (T2L2). The BIPM plans to develop studies on this technique, which could be used to validate less accurate time links and their calibrations.

Campaigns with a TW travelling calibration station were organized and funded by the participating laboratories in 2016. The parameters obtained have been implemented for UTC computation after validation of the results by the Time Department.

Results of the time links and link comparison using GNSS single-frequency, dual-frequency and TW observations are published monthly on the Time Department's ftp server (ftp://ftp2.bipm.org/pub/tai/timelinks/lkc/).

4.3 Calibration of delays of time-transfer equipment and time links

The characterization of the delays (so-called "calibration") of time transfer equipment in the contributing laboratories is necessary to improve the uncertainty of [*UTC-UTC*(*k*)] and for the accuracy of UTC dissemination.

The *BIPM Guidelines for GNSS calibration* are intended for Regional Metrology Organizations (RMOs) and establish a permanent cooperation for sharing the organization of campaigns to determine the relative delays of time transfer equipment and links in UTC contributing laboratories. The '*Guidelines'* are under continuous improvement; the latest revision was issued in March 2016.

The BIPM started the second calibration campaign of the "Group 1" laboratories in APMP, EURAMET, SIM and COOMET in 2016, following the planned periodicity of two years. Several regional calibration trips concerning 27 "Group 2" laboratories have been initiated by the RMOs in accordance with the *BIPM Guidelines* and the first results have been implemented in 2016. By repeatedly applying this new procedure, time transfer accuracy is expected to improve by a factor of at least 2 with respect to the pre-2015 situation.

The BIPM Time Department is not directly involved in specific TWSTFT calibration trips, but is responsible for the validation of the calibration reports and implementation of the results in the calculation of UTC. It also provides support whenever necessary to maintain a TW calibration by alignment with a calibrated GPS link (see section 4.2).

Results of the differential calibration exercises are made available on a dedicated web page (www.bipm.org/jsp/en/TimeCalibrations.jsp), where past calibration results are also provided.

4.4 Advanced time and frequency transfer

Data from two fibre links between UTC contributing laboratories in Europe are regularly submitted to the Time Department and compared with the corresponding links by GNSS time transfer techniques. The Time Department aims to include fibre links in the computation of UTC in the future, and for this purpose the CCTF WG on Coordination of the Development of Advanced Time and Frequency Transfer Techniques (WGATFT) has established a study group to develop the strategy for the use of these very accurate links in UTC. The terms of reference of this study group include the establishment of standards for data transmission and the validation of the compatibility of the different techniques.

5. **Key comparisons** (E.F. Arias, H. Konaté, G. Panfilo, A. Harmegnies and L. Robertsson)

Key comparison in Time CCTF-K001.UTC

Results of the key comparison in time, CCTF-K001.UTC, involving the time laboratories that participate in the CIPM MRA, are published monthly in the BIPM key comparison database (KCDB). The number of participants at the end of 2016 was 59, and they constitute a subset of the participants to BIPM *Circular T*.

Key comparison of stabilized lasers CCL-K11

Following a decision at the 98th meeting of the CIPM (2009) the BIPM continues to support the CCL-K11 key comparison by participating in measurement campaigns and by providing general advice whenever solicited. This comparison is the internationally recognized traceability chain to the SI metre and is supervised by the CCL-CCTF Working Group on Frequency Standards, which submits results to the CCL for formal approval. In 2016, BIPM staff members supported the key comparison on issues relating to the development of the measurement campaigns and reporting. Two final reports of the results of this ongoing key comparison, which involved measurements by nine institutes in 2014 and 2015, have been published in 2016.

6. **Rapid UTC** (A. Harmegnies, G. Panfilo, G. Petit and L. Tisserand)

Since January 2013 the Time Department has published a UTC rapid solution 'UTCr', that is, daily values of [*UTCr* – *UTC*(*k*)] evaluated on a weekly solution on one-month batches of data. About 48 laboratories that are traceable to UTC contribute to UTCr, which together represent 60 % to 70 % of the clocks that participate in UTC.

UTCr attained the expected quality, providing a weekly solution which is consistent within 1.1 ns RMS and ±3 ns peak to peak with the values published monthly in BIPM *Circular T*. The results (http://www.bipm.org/en/bipm-services/timescales/time-ftp/Rapid-UTC.html) have been published every Wednesday, without interruption since the end of February 2012.

UTCr does not change the procedures for the monthly calculation of UTC, which remains the only key comparison on time. However, UTCr has a favorable impact on the quality of the local representations UTC(k) in national laboratories, and on the steering of GNSS times to UTC via some UTC(k).

7. **New proposed definition of UTC** (F. Arias)

The BIPM has actively participated in discussions about a possible redefinition of UTC without leap seconds since 2000. This proposal favours systems that require precise time synchronization and does not allow a discontinuity in the time scale that they use as a reference.

The BIPM contributed to this process at the International Telecommunication Union (ITU), and participated in the meeting of Study Group 7 (Science services) and Working Party 7A (Time signals and frequency standard emissions) in April 2016.

The CCTF established a task group for proposing definitions of TAI and UTC to be submitted to the CGPM in 2018. This was in response to an invitation by the World Radiocommunication Conference 2015 (WRC15) to strengthen the cooperation between the ITU and the BIPM on this matter, and in preparation for the discussions scheduled for the WRC23. This task group, which includes two Time Department staff members, continued to draft the text of the recommendation during 2016 for consideration by the CCTF in June 2017.

8. Space-time references (E.F. Arias and G. Petit)

Activities related to the realization of reference frames for astronomy and geodesy are ongoing, in cooperation with the International Earth Rotation and Reference Systems Service (IERS). In these domains, improvements in accuracy will increase the need for a full relativistic treatment and continued participation in the international working groups in this field is essential.

Cooperation continues on the maintenance of the international celestial reference system within the framework of the activities of a working group created by the International Astronomical Union (IAU) in August 2012. This working group met within the period and submitted a report on the features of the next realization of the International Celestial Reference Frame (ICRF3) to the IAU General Assembly held in Honolulu (USA) in August 2015, with a view to the submission of the catalogue with the set of coordinates in the ICRF3 in 2018.

As part of its participation in the Conventions Centre of the IERS, the BIPM maintains the web and ftp sites for the *IERS Conventions*. The Conventions describe the latest realizations of the celestial and terrestrial reference frames, and the model for the transformation between them. They also describe conventional models for the gravitational field, the displacement of markers on the Earth's crust and for the propagation of electromagnetic signals. In addition, the *Conventions* now provide a complete set of associated conventional software. Since the completion of the latest reference edition, *IERS Conventions* (2010) in December 2010, work is continuing with the help of an editorial board to provide updates to the *Conventions* (2010).

With the development of optical clocks accurate at the 10^{-18} level, "relativistic geodesy" is the subject of numerous developments, which suggest the full potential of these clocks for the measurement of terrestrial gravity potential and the definition of systems of altimetry references. A physicist from the Time Department is co-chairing a new IAG working group on this subject. In 2016, international collaborations led to publications on the implications of such "chronometric geodesy" for geodesy and the definition of time scales and on the calculation of the relativistic frequency shift with the required accuracy for optical clocks.

9. Comb activities (L. Robertsson)

The BIPM comb activities are limited to maintenance of the BIPM frequency comb for internal use related to laser applications only and in other departments when needed.

10. Publications

External publications

1. Denker H., Timmen L., Voigt C., Weyers S., Peik E., Delva P., Wolf P., Petit G., Geodetic methods to determine the relativistic redshift at the level of 10^{-18} in the context of international timescales – A review and practical results; *J. Geodesy*, submitted.
2. Hachisu H., Petit G., Ido T., Absolute frequency measurement with uncertainty below 1×10^{-15} using International Atomic Time, *Appl. Phys. B*, 2017, **123**(1).
3. Jiang Z., (2016) Final report of the BIPM Pilot Study on UTC time link calibration, *PTTI Proc.* 20-26, Monterey, CA, USA, 2016.
4. Jiang Z., Matsakis D., Zhang V., Esteban H., Piester D., Lin S.Y., Dierikx E., A TWSTFT calibration guideline and the use of a GPS calibrator for UTC TWSTFT link calibrations, *PTTI Proc.* 231-242, Monterey, CA, USA, 2016.
5. Jiang Z., Piester D., Schlunegger C., Dierikx E., Zhang V., Galindo J., Matsakis D., The 2015 TWSTFT calibration for UTC and related time links, Proc. 30th EFTF meeting, York, UK, 2016.

6. Matus M., Gavalyugov V., Tamakyarska D., Ranusawud M., Tonmueanwai A., Hong F.-L., Ishikawa J., Moona G., Sharma R., Hapiddin A., Boynawan A.M., Alqahtani N., Alfohaid M., Robertsson L., Report on on-going CCL Key Comparison for the year 2014 Comparison of optical frequency and wavelength standards CCL-K11, *Metrologia*, 2017, **54**, *Tech. Suppl.*, 04001.

7. Matus M., van den Berg S., Czulek D., Seppä J., Robertsson L., The CCL-K11 ongoing key comparison. Final report for the year 2015, *Metrologia*, 2016, **53**, *Tech. Suppl.*, 04007.

8. Panfilo G. The Coordinated Universal Time, *IEEE Instrumentation and Measurement Magazine*, June 2016, **19**(3), 28-33.

9. Parisi F., Panfilo G., A new approach to UTC calculation by means of the Kalman Filter, *Metrologia*, 2016, **53**(5), 1185-1192.

10. Petit G., Defraigne P., The performance of GPS time and frequency transfer: comment on 'A detailed comparison of two continuous GPS carrier-phase time transfer techniques', *Metrologia*, 2016, **53**(3), 1003-1008.

11. Riedel F., *et al*. (G. Petit), Remote optical and fountain clock comparison using broadband TWSTFT and GPS PPP, Proc. 30th EFTF meeting, York, UK, 2016.

12. Robertsson L., On the evaluation of ultra-high-precision frequency ratio measurements: examining closed loops in a graph theory framework, *Metrologia*, 2016, **53**(6), 1272-1280.

13. Visser PNAM., Müller J., Lon G., Panet I., Kopeikin S.M., Petit G., Dirkx D., High performance clocks and gravity field determination, Proc ISSI Workshop HISPAC, Space Science Reviews, to be published.

14. Wielgosz R., Arias F., Stock M., Los Arcos J.-M., Milton M., News from the BIPM laboratories – 2015, *Metrologia*, 2016, **53**, 103-107.

BIPM publications

15. *BIPM Annual Report on Time Activities for 2015*, 10, 137 pp., available only at http://www.bipm.org/en/bipm-services/timescales/time-ftp/annual-reports.html

16. *Circular T* (monthly)

17. *Rapid UTC* (*UTCr*) (weekly)

11. Activities related to the work of Consultative Committees

E.F. Arias is Executive Secretary of the Consultative Committee for Time and Frequency (CCTF). She is the Secretary of the CCTF Working Group on TAI (WGTAI) and the CCTF Working Group on Strategic Planning (WGSP).

Z. Jiang is Secretary of the CCTF Working Group on Two-Way Satellite Time and Frequency Transfer (WGTWSTFT).

G. Panfilo is Secretary of the CCTF Working Group on the CIPM MRA (WGMRA) and the CCTF Working Group on Time Scale Algorithms (WG-ALGO). She is the Executive Secretary of the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV). She is Secretary of the CCAUV Working Groups for Key Comparisons (CCAUV-KCWG), for RMO coordination (CCAUV-RMO) and on Strategic Planning (CCAUV-SPWG).

G. Petit is Secretary of the CCTF Working Group on Primary and Secondary Frequency Standards (WGPSFS) and the Working Group on Global Navigation Satellite Systems (WGGNSS).

L. Robertsson is Executive Secretary of the Consultative Committee for Length (CCL), a member of the CCL Working Group on Strategic Planning (WG-S) and of the Discussion Group DG-11 (Lasers). He is the BIPM representative on the CCM Working Group on Gravimetry (WGG). He is also Secretary for the CCTF WG on

Coordination of the Development of Advanced Time and Frequency Transfer Techniques (WGATFT) and shares the secretariat of the CCL-CCTF Frequency Standards WG (WGFS) with E.F. Arias.

12. Activities related to external organizations

E.F. Arias is a member of the IAU and participates in its working group on the International Celestial Reference Frame (ICRF); she is a member of the Steering Committee of IAU Division A on Fundamental Astronomy and a member of the Division A Working Group on the Third Realisation of the International Celestial Reference Frame. She is an associate member of the IERS, a member of its International Celestial Reference System Centre, and until end 2016 of the Conventions Centre. E.F. Arias is a member of the International VLBI[2] Service (IVS). She is the BIPM representative to the Governing Board of the International GNSS Service (IGS). She is the BIPM representative to the UN sponsored International Committee on GNSS (ICG) and the chairperson of its Task Force on Time References. She is a member of the Technical Advisory Committee of International Union of Radio Science (URSI) Commission A. E.F. Arias is a member of the IAG Global Geodetic Observing System (GGOS) Steering Committee representing the BIPM. She is a member of the Argentine Council of Research (CONICET) and an associate astronomer at the LNE-SYRTE, Paris Observatory. She is a corresponding member of the *Bureau des longitudes* and the BIPM representative to the Working Party 7A of Study Group 7 of the International Telecommunication Union – Radiocommunication Sector (ITU-R).

G. Petit is co-director of the Conventions Centre of the IERS and a member of the IERS Directing Board until the end of 2016. He is an associate member of the IGS and member of the IGS Working Groups on Clock Products and on Bias Calibration. In 2016 he represented the BIPM at the United Nations International Committee on Global Navigation Satellite Systems (ICG), and has acted as chairperson of the Task Force on Time References. He is co-chair of the IAG Joint Working Group on Relativistic Geodesy and a member of the IAU Working Groups on Numerical Standards in Fundamental Astronomy and on Pulsar Time Scale.

13. Travel in 2016 (conferences, lectures and presentations, visits)

E.F. Arias to:

- Teddington (UK), 13-14 January, for the meeting of the Quantum, Electromagnetics and Time Programme Expert Group;
- Monterey (USA), 25-29 January, for the PTTI 2016 to chair a session and participate to CCTF Working Group meetings;
- Espoo (Finland); 1-2 March, for the meeting of the Technical Committee on Time and Frequency of EURAMET to give reports on BIPM activities and to coordinate calibrations;
- Geneva (Switzerland), 4-8 April, for the meeting of Study Group 7 and Working Party 7A at the ITU;
- Cambridge (Massachusetts, USA), 6-10 June, for the Symposium on the Science of Time to give an invited talk, and oral contribution;
- Brussels (Belgium), 19-21 September, for the Workshop "Understanding the Earth core and nutation";
- Teddington (UK), 7 October, for the meeting of the Quantum, Electromagnetics and Time Programme Expert Group;
- Haystack (USA), 17-19 October, for the meeting of the IAU Working Group on the third realisation of the International Celestial Reference Frame.

[2] Very Long Baseline Interferometry (VLBI)

Z. Jiang to:

- Monterey (California, USA) 25-28 January, for the PTTI meeting with one oral presentation and a poster and for the TWSTFT participation station (PS) meeting;
- York, UK, 4-8 April, to attend the EFTF meeting with an oral presentation and a poster, to the TWSTFT participation station (PS) other CCTF WG meetings;
- NIST, Boulder, USA, 7-8 September, to the 24th Annual meeting of the CCTF WG on TWSTFT and to give oral reports on the WG activities;
- Shangsa, China, 17-21 May, for the China Satellite Navigation Conference 2016 to co-chair the Session on time and frequency and one oral presentation;
- Xian, China, 17-18 October, to attend the Ceremony of the 50th anniversary of the NTSC foundation and to give an invited presentation;
- NIM, Beijing China, 20 October – 3 November, to audit the Gravity and Time laboratories and activities.

G. Panfilo to:

- Espoo (Finland); 1-2 March, for the meeting of the Technical Committee on Time and Frequency of EURAMET to give reports on UTC algorithms and existing guidelines of the CCTF WGMRA.

G. Petit to:

- Monterey (California, USA) 25-28 January, to give a tutorial course and attend the PTTI meeting, with one oral presentation;
- Villetaneuse (France), 24 March, to attend the General Assembly of the Labex "FIRST-TF";
- York (UK) 4-8 April, to attend the EFTF 2016 meeting, to give one oral presentation, to attend four CCTF WG meetings, and to attend the Workshop "Optical clocks: Quantum engineering and international timekeeping";
- Vienna (Austria), 17 April, to attend the Directing Board of the IERS;
- Besançon (France), 28-29 June, to give two lectures at the European Frequency and Time Seminar;
- Paris (France), 10 October, to attend the *Journée thématique* "Miniature atomic clocks";
- Sochi (Russian Federation), 7-11 November, for the eleventh meeting the International Committee on GNSS (ICG), with chair of a task force and presentations;
- Paris (France), 30 November, to attend a PhD jury as reviewer.

L. Robertsson to:

- York (UK) 4-8 April, to attend the EFTF 2016 meeting, to attend four CCTF WG meetings, and to attend the Workshop "Optical clocks: Quantum engineering and international timekeeping".

14. Visitors, secondees in 2016

- V. Lizardi, CENAM (Mexico), for a visit to the Time Department and laboratory, 10 January;
- T. Ido, NICT (Japan), for a discussion on Secondary Frequency Standards, 25 February;
- X. Zhang accompanied with a delegation from ISO for a visit to the Time Department and laboratory, 26 February;
- B. Ouyanj and a delegation from NIM/QTSA (China), for a visit to the Time Department and laboratory, 15 April;
- J.W. Chung, I.T. Lim and K.L. Jeong from KRISS (Republic of Korea), 24 May;

- J. Feng, NIM (China), for training on the implementation of CCM.G-K2, 6 July to 6 August;
- P. Koppang, USNO (USA), for a discussion on algorithms, 27 September;
- A. Bauch, PTB (Germany), L. Erard (CCTF), P. Koppang, USNO (USA) and ITU WP7A, D. Rovera, LNE-SYRTE (France), P. Tavella, INRIM (Italy), P. Whibberley, NPL (UK) for the meeting of the CCTF WGTAI Task Group on Time Scale Definitions, 28 September;
- D. Matsakis, USNO (USA), for a collaboration on the evaluation of uncertainties of *[UTC-UTC(k)]* reported in Section 1 of *Circular T*, 10 October to 8 November.