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

Supplement: Time Department

(1 January 2015 – 31 December 2015)

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Bureau International des Poids et Mesures

BIPM Time Department

Director: E.F. Arias

(1 January 2015 to 31 December 2015)

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

(E.F. Arias, A. Harmegnies, Z. Jiang, H. Konaté, 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 the various timing centres that maintain a local UTC; monthly results are published in *Circular T*. The UTC rapid solution (UTCr) is published every Wednesday at 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 *BIPM Annual Report on Time Activities for 2014*, volume 9, provides the definitive results for 2014 and is available on the BIPM website at www.bipm.org/en/bipm/tai/annual-report.html.

2. Algorithms for time scales (G. Panfilo, G. Petit, A. Harmegnies, L. Tisserand and F. Parisi[1])

The algorithm used to calculate the time scales by the Time Department 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 weighting algorithm, based on the concept of clock frequency predictability, the behaviour of UTC is routinely and carefully monitored to trap and fix unexpected anomalies although none were observed throughout the year. An improvement in the short- and long-term stability of EAL is already visible after the application of the new weighting algorithm.

Within the framework of a six month placement with a student from the University of Torino (Italy), which began in 2014, the use of the Kalman Filter (a very powerful statistical tool) has been tested to build an independent time scale. The results are very promising and encouraging for its continued investigation and development for its application in UTC.

The revision of the algorithm for the calculation of the uncertainties reported in Section 1 of *Circular T* is in progress. The current algorithm underestimates the uncertainty values for the pivot laboratory (at present PTB) because correlations have not been fully considered. The result of the revision study was presented at the 20th meeting of the CCTF, and the implementation of the new algorithm, which will provide the correct uncertainty estimations, is expected within the next 2 years.

2.1 EAL stability

Some 87 % of the 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 at the participating laboratories has increased by 24 % in the last two years, without any significant increase in the number of caesium standards. The weighting procedure involved in the time scale computation guarantees the long-term stability of EAL. To prevent domination of the scale by a small number of very stable clocks, a

[1] Department of Mathematics, University of Torino, Italy, on a six-month secondment from 1 November 2014

maximum relative weight is used each month which depends on the number of participating clocks. On average, about 11 % of the participating clocks were at the maximum weight during 2015; almost all of these were hydrogen masers. The new weighting algorithm, based on the predictability of the clock's frequency, enhanced the influence of the hydrogen masers on the resulting time scale; 40 % of the contributing hydrogen masers were, on average, at the maximum weight in 2015, whilst only 0.1 % of the caesium clocks reached the maximum weight.

UTC implicitly relies on the 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 2015, 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 2015, individual measurements of the TAI frequency have been provided by thirteen primary frequency standards, including eleven caesium fountains (SYRTE FO1, SYRTE FO2, NIST F1, NIST F2, IT CSF2, SU CSFO2, NPL CSF2, PTB CSF1, PTB CSF2, NPLI CSF1 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 2015, 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 $+0.83 \times 10^{-15}$ to -0.44×10^{-15}, with a maximum standard uncertainty of 0.39×10^{-15}. No steering correction has 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 2015, known as TT(BIPM14), valid until December 2014, 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(BIPM14) 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 the primary and secondary frequency standards.

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*. As a consequence of the alert made by the BIPM on the offset of GLONASS time and the broadcast prediction of UTC(SU) with respect to UTC, work has been developed with the VNIIFTRI, Russian Federation, and the GLONASS authorities on the absolute calibration of a BIPM receiver.

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.

The WGFS maintains a list of recommended values of standard frequencies for applications including secondary representations of the second. Updates of frequency values and their respective uncertainties for secondary representations of the second in the list have been recommended by the CCTF in September 2015, and have been adopted by the CIPM in Recommendation 2 (CI-2015).

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.

4. Time links used for UTC (E.F. Arias, A. Harmegnies, Z. Jiang, H. Konaté, G. Panfilo, G. Petit, L. Tisserand, and W. Wenjun[2])

At the end of 2015, 74 time laboratories supplied data for the calculation of UTC at the BIPM. The laboratories are equipped with GNSS receivers and some of them 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 tracking 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 each month 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*.

Nine laboratories operate TWSTFT stations and officially submit data for use in the computation of UTC, representing 8 % of the time links. No TWSTFT contributions from the laboratories in the Asia-Pacific region were possible in 2015 due to an interruption of the satellite service. 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 is 0.3 ns for 51 % of the time links.

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

[2] Chinese Academy of Sciences, NTSC (Xi'an, China), on a one-year secondment starting 3 June 2014

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 has a physicist from the Time Department as a member.

Data from world-wide geodetic-type receivers are collected for UTC computation, using procedures and software 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 producing iono-free 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 continuing 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) and mostly in the long term (days). In 2015 the IPPP technique moved to a pre-operational stage and it is used regularly to compare IPPP results to the few available optical fibre links.

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

4.2. Two-way satellite time and frequency transfer

One meeting of the TWSTFT participating stations was held during 2015 at the IFCS/EFTF meeting in Denver, USA, on 12-16 April. The 23rd annual meeting of the CCTF WG on TWSTFT was held at the BIPM on 7-8 September 2015. The outcomes of these meetings that impact the Time Department's activities are: the approval and implementation of TWSTFT Calibration Guidelines; and the organization of calibration trips between TW stations, where the BIPM is charged with the validation of the reports and introduction of the calibration parameters in the calculation 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. Eight TWSTFT links had been used in the computation of UTC in 2015; they are combined with GPS PPP solutions. Due to the interruption of the satellite service, no TW data contribution from institutes in the Asia-Pacific region had been possible during the year. Some of the TWSTFT links involved in the computation of UTC are used in the experiment 'Time Transfer by Laser Link' (T2L2). The BIPM aims to develop studies on this technique, which could be used to validate less accurate time links and their calibrations.

Campaigns with a travelling calibration station were organized and funded by the participating laboratories in 2015. The parameters obtained have been implemented for UTC computation following 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://tai.bipm.org/TimeLink/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.

Following a recommendation by the CCTF, the Time Department has issued the *BIPM Guidelines for GNSS calibration*. This document is intended for Regional Metrology Organizations (RMOs) and establishes 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, and this has led to a revised edition of the *Guidelines* being produced in September 2015.

In 2015 the BIPM concluded the first calibration campaign to the "Group 1" laboratories in APMP, EURAMET, SIM and COOMET, and expects that regional calibration trips to "Group 2" laboratories will be implemented in 2016 by the RMOs in accordance with the *BIPM Guidelines*. By repeatedly applying this new procedure time transfer accuracy is expected to improve by a factor of 2.

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.

The Guidelines for TWSTFT link calibration, elaborated by the CCTF WG on TWSTFT, were approved at the 20th meeting of the CCTF in September 2015.

4.4 Advanced time and frequency transfer

Data from two fibre links between UTC contributing laboratories in Europe are regularly submitted and compared with the corresponding links by GNSS time transfer techniques. The aim of the Time Department is to include the fibre links in the computation of UTC in the future, and in this direction 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 participating in the CIPM MRA, have been published monthly in the BIPM key comparison database (KCDB) since March 2015.

Key comparison of stabilized lasers CCL-K11

Following a decision at the 98th meeting of the CIPM in 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. In 2015, BIPM staff supported the key comparison on issues relating to the development of the measurement campaigns and reporting.

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, together representing 60 % to 70 % of the clocks participating 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 (ftp://tai.bipm.org/UTCr) 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 favourably impacts 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 World Radiocommunication Conference held in Geneva, Switzerland, from 2-27 November 2015 (WRC15). A resolution of the WRC15 stresses the responsibility of the BIPM on the definition and maintenance of the reference time scale, and of the ITU on its dissemination by time signals and frequency services. The resolution also recommends strengthening the cooperation that the ITU has with the BIPM and other international organizations and delaying the decision on the adoption of a continuous reference time scale until WRC23. In the meantime, further studies are to be developed on the impact of possible reference time scales.

8. **Pulsars** (G. Petit)

Collaboration continues with radioastronomy groups that observe pulsars and which analyse pulsar data to study the possibility of using millisecond pulsars as a means of sensing the very long-term stability of atomic time. The Time Department provides these groups with its post-processed realization of Terrestrial Time, TT(BIPM). Additionally it participates in a Working Group on pulsars and time scales established by the International Astronomical Union (IAU).

9. **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 it is essential to continue to participate in international working groups in this field.

Cooperation continues on the maintenance of the international celestial reference system within the framework of the activities of a working group created by the 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 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* (http://tai.bipm.org/iers/). 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) which are posted on the website (http://tai.bipm.org/iers/convupdt).

10. **Comb activities** (L. Robertsson)

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

11. Publications

External publications

1. Fey A, Arias E.F., *et al*., The second realization of the International Celestial Reference Frame by Very Long Baseline Interferometry, *Astron. J.*, 2015, **150**, 58.
2. Petit G., Arias F., Panfilo G., International atomic time: Status and future challenges, *Comptes Rendus Physique*, 2015, **16**(5), 480-488.
3. Jiang Z., Czubla A., Nawrocki J., Lewandowski W., Arias E.F., Comparing a GPS time link calibration with optical fibre self-calibration with 200 ns accuracy, *Metrologia*, 2015, **52**(2), 384-391.
4. Defraigne P., Petit G., CGGTTS-V2E: an upgraded standard for GNSS Time Transfer, *Metrologia*, 2015, **52**(6), G1.
5. Petit G., Conventional reference systems, models and parameters for space geodesy, in *Encyclopedia of Geodesy*, E. Grafarend Editor, Springer, to be published.
6. Petit G., Arias E.F., Panfilo G., International atomic time: Status and future challenges, *Comptes Rendus de Physique*, 2015, **16**(5), 480-488.
7. Petit G., Kanj A., *et al*., 1×10^{-16} frequency transfer by GPS PPP with integer ambiguity resolution, *Metrologia*, 2015, **52**(2), 301-309.
8. Luzum B., Petit G., *et al*., IAU Working Group for Numerical Standards of Fundamental Astronomy (NSFA): Past Efforts and Future Endeavors, *IAU General Assembly*, 2015.
9. Jiang Z, Czubla A, Nawrocki J, Lewandowski W and Arias F (2015), Comparing a GPS time link calibration to an optical fibre self-calibration with 200 ps accuracy, *Metrologia*, 2015, **52**(2), 384-391.
10. Jiang Z. (2015) Link calibration or receiver calibration for accurate time transfer? *Proc. EFTF/IFCS2015*, April, Denver, US
11. Yao J., Skakun I., Jiang Z. and Levine J. A Detailed Comparison of Two Continuous GPS Carrier-Phase Time Transfer Techniques, *Metrologia*, 2015, **52**(5), 666-676.
12. Matsakis D., Jiang Z. Wu W (2015) Carrier Phase and Pseudo-range Disagreement as Revealed by Precise Point Positioning Solutions, *Proc. EFTF/IFCS2015*, April, Denver, US.

13. Esteban H., Galindo J., Bauch A., Polewka T., Cerretto G., Costa R., Whibberley P., Uhrich P., Chupin B., Jiang Z. (2015) GPS Time Link Calibrations in the Frame of EURAMET Project 1156, *Proc. EFTF/IFCS2015*, April, Denver, US.

BIPM publications

14. *BIPM Annual Report on Time Activities for 2014*, 9, 131 pp., available only at http:// http://www.bipm.org/en/bipm/tai/annual-report.html.

15. *Circular T* (monthly), 8 pp.

16. *Rapid UTC* (*UTCr*) (weekly), 1 pp.

12. 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 TWSTFT (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 has been appointed in November 2015 Secretary of the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV).

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.

13. 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 had been vice-president of Commission 31 (Time) until mid-2015, when the IAU put in place a new set of commissions. She has been elected 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 of the Conventions Centre. E.F. Arias is a member of the International VLBI 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. 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. He is an associate member of the IGS and member of the IGS Working Groups on Clock Products and on Bias Calibration. He is a member of the IAU Working Groups on Numerical Standards in Fundamental Astronomy and on Pulsar Time Scale.

G. Panfilo collaborates with the Joint Committee for Guides in Metrology (JCGM) Working Group 1 (WG1) on the Expression of Uncertainty in Measurement (GUM) to provide a section on uncertainty of time measurements for the new version of the GUM.

14. Travel in 2015 (conferences, lectures and presentations, visits)

E.F. Arias to:

- Paris (France), 29 January, for the Journée GNSS et Science at the CNES, with an invited lecture;
- Vienna (Austria), 17-18 March, for the meeting of the EURAMET Technical Committee on Time and Frequency for coordinating on GNSS calibrations and presenting the Time Department activities;
- Geneva (Switzerland), 23 March to 1 April, for the 2nd Conference Preparatory Meeting for the ITU World Radiocommunication Conference 2015;
- Gran Canaria (Spain), 18-20 May, for the URSI Atlantic Radio Science Conference, to chair a session and make a presentation, and to participate to the business meeting of URSI Commission A;
- Geneva (Switzerland), 20-26 May, for the meeting of the Working Party 7A at the ITU;
- Bordeaux (France), 16 June, for a PhD dissertation, acting as rapporteur and member of the jury;
- Saint Mandé (France), 17 June, to the Journée Scientifique de l'IGN;
- Honolulu (Hawaii, USA), 4-14 August, for the IAU General Assembly 2015, for the relevant commission and working group meetings, including presentations and reports;
- London (UK), 28 October, for the Workshop on UTC Traceability to the Financial Sector, with an invited lecture;
- CCTF and associated meetings.

Z. Jiang to:

- Xian (China), 13-15 May, for the China Satellite Navigation Conference 2015;
- Beijing (China), May, for a visit to NIM gravity and time laboratories;
- Xian (China), May, for a visit to NTSC time laboratory;
- Denver (Colorado, USA) 13-17 April, to attend the FCS/EFTF 2015 and the TWSTFT Participation Stations meeting;
- CCTF and associated meetings.

G. Panfilo to:

- Turin (Italy), 16-21 April, for the master's degree panel for Federica Parisi, and for planning future work in collaboration between the BIPM Time Department and the Department of Mathematics at the University of Turin;
- CCTF and associated meetings.

G. Petit to:

- Paris (France), 29 January, to attend the "Journée GNSS et science";
- Denver (Colorado, USA) 13-17 April, to attend the FCS/EFTF 2015 meeting, to give three oral presentations, and to attend two CCTF WG meetings;
- Besançon (France), 30 June-1 July, to give two lectures at the European Frequency and Time Seminar;

- Prague (Czech Republic), 24-27 June, to attend the UGGI General Assembly, with one invited presentation;
- Potsdam (Germany), 12-14 October, for the 8th Symposium on frequency standards and metrology, with one presentation;
- Boulder (Colorado, USA), 2-6 November, for the tenth meeting the International Committee on GNSS (ICG), with chair of task force and presentations;
- Toulouse (France), 18-19 November, for the GRGS Workshop G2 with a presentation, and for discussions with the CNES/CLS groups on the IPPP technique;
- Bern (Switzerland), 30 November-1 December, for the ISSI workshop HISPAC, with an invited presentation;
- CCTF and associated meetings.

15. Visitors, secondees

- W. Wu (NICT, Chinese Academy of Sciences) on a one-year secondment starting on 3 June 2014, for activities on time transfer and calibration;
- F. Parisi from the University of Torino (Italy) to study an independent time scale based on the Kalman Filter, 1 November 2014 – 6 March 2015, 1-30 June 2015 and 1-18 September 2015;
- S. Zagier from Zagier and Urruty Publications for discussions on the historical evolution of clocks, 23 April 2015;
- J. Park and S.H. Hong (KRISS, Republic of Korea) for a visit to the Time Department and laboratory, 20 July 2015;
- Long-Sheng Ma from the East China Normal University (China) for discussions on optical metrology, 9-13 September 2015;
- P. Gabor from the Vatican Observatory for discussions on time scales for astronomy, 5 October 2015;
- K. Madanipour, A.M. Levi and O. Masoudi (Iran) for a visit to the Time Department and laboratory, 23 October 2015;
- D. Rovera (LNE-SYRTE) for the QMS external audit of the Time Department, 10 December 2015.