Background Reasons for the IAU 2000 Resolutions Requiring Actions from the IERS

Jan Vondrák

Astronomical Institute, Academy of Sciences of the Czech Republic, Prague

1 INTRODUCTION

The resolutions adopted at the IAU 24th General Assembly in 2000 have been in fact prepared during a decade. They reflect the increasing accuracy of astrometric observations (expected to be at a microarcsecond level in near future), and hence the urgent need for more precise definitions of time-space transformations. The resolutions are closely related to past IAU decisions, namely those taken at its preceding General Assemblies:

- in 1991, when the conceptual definitions of celestial reference system and time scales in the framework of general relativity were adopted,
- in 1994, when the list of extragalactic sources defining the conventional reference frame was adopted and a Joint Working Group of IAU and IUGG on the non-rigid Earth nutation was formed, and
- in 1997, when the new International Celestial Reference System (ICRS) and Frame (ICRF) were adopted.

The resolutions, before being put on a vote at the IAU 24th General Assembly, had been discussed and pre-prepared at many scientific meetings, the most important ones being

- the Journées Systèmes de Référence Spatio-temporels - *Conceptual, Conventional and Practical Studies Related to Earth Rotation* (Paris, September 1998), where the theoretical aspects were discussed;
- the IAU Colloquium 180 *Towards Models and Constants for Sub-Microarcsecond Astrometry* (Washington, DC, March 2000), where the draft resolutions were prepared;
- the Joint Discussion 2 – *Models and Constants for Sub-Microarcsecond Astrometry* at the IAU 24th General Assembly, (Manchester, August 2000), where the final wording of the resolutions was formulated.

The International Earth Rotation Service as well as interested components of IUGG/IAG (e.g., IAU/IUGG Joint Working Group on non-rigid Earth nutation, IAG Special Commission 3 – Fundamental Parameters) have been involved, either directly or indirectly, in preparing these new concepts from the very beginning. A number of these resolutions have direct impact on the work of the IERS.

2 THE RESOLUTIONS AND REASONS LEADING TO THEIR ADOPTION

The IAU resolutions, relevant to the IERS, are given in a form of a ‘packet’ of nine closely related resolutions (B1.1-B1.9) plus an additional resolution (B2). Full text of all these resolutions is given in the Annex, here follows a shortly commented contents of each of them.

Resolutions B1.1 and B1.2 concern the celestial reference systems and frames; they reflect the increasing need for more accurate and dense frames (in different wavelengths) with respect to which the motions and rotations of celestial bodies are observed. They were prepared by the IAU Working Group on International Celestial Reference System.

Resolution B1.1 Maintenance and Establishment of Reference Frames and Systems

The International Celestial Reference System (ICRS) and Frame (ICRF) are defined by means of directions to and adopted positions of extragalactic objects in radio wavelength. At present, there are 212 defining, 294 candidate and 102 other radio objects. In spite of so far negligible proper motions of these objects, their structures have different shapes that are often time-changing. Therefore, these systems and frames need to be regularly maintained, densified and extended to other wavelengths (optical, infrared…). The resolution stresses the importance of VLBI observations, extends the activity of the IAU Working Group on Celestial Reference Systems, and <u>asks its members to consult with the IERS regarding the maintenance of the ICRS</u>. Very important role plays the International VLBI Service, through which the IERS cooperates with the IAU WG.

Resolution B1.2 Hipparcos Celestial Reference Frame

The Hipparcos Catalogue is the primary realisation of the ICRS at optical wavelengths. However, some of the Hipparcos stars belong to binary or multiple systems and exhibit complicated orbital motions. The immediate values of proper motions, determined during less than four years of Hipparcos mission, thus differ substantially from their mean values. The resolution establishes the Hipparcos Celestial Reference Frame (HCRF) that excludes these stars from the realisation. <u>Since the IERS does not use stars as reference points, this resolution has importance only for pre-IERS Earth rotation studies and does not require any action for the present and future IERS work.</u>

Resolutions B1.3, B1.4 and B1.5 concern the use of general relativity in astrometry and celestial mechanics that is more and more important in view of increasing observational accuracy. These resolutions were prepared by the BIPM/IAU Joint Committee on Relativity for Space-Time Reference Systems and Metrology and the IAU Working Group 'Relativity for Celestial Mechanics and Astrometry'.

Resolution B1.3 Definition of Barycentric Celestial Reference System and Geocentric Celestial Reference System

The increase of observational accuracy makes the use of general relativity approach more and more important. This resolution further extends the definition of the two basic reference systems for the solar system (BCRS) and the Earth (GCRS) in the frame of general relativity, recommends the choice of harmonic coordinates for both of them, writes the metric tensors and proposes the full post-Newtonian coordinate transformation between the BCRS and GCRS.

Resolution B1.4 Post-Newtonian Potential Coefficients

The motion of satellites and space probes around and amongst massive bodies of the solar system is dominantly influenced by their potential. On the present level of observational accuracy the potential is now desirable to be defined in the frame of general relativity. The resolution gives the expansion of the post-Newtonian potential of the Earth in the Geocentric Celestial Reference Frame.

Resolution B1.5 Extended relativistic framework for time transformations and realisation of coordinate times in the solar system

The increasing performance of time and frequency measurements provided by atomic clocks require a more accurate conventional model of time transformations and realisation of coordinate times in the solar system. The resolution defines (more completely than the IAU resolutions of 1991) the metric tensor in the BCRS and the relation between Barycentric Coordinate Time (TCB) and Geocentric Coordinate Time (TCG).

Resolution B1.6, concerning the new model of precession-nutation was prepared by the Joint IAU/IUGG Working Group on Non-rigid Earth Nutation Theory.

Resolution B1.6 IAU 2000 Precession-Nutation Model

The last precession-nutation model adopted by the IAU in 1980 is the model based on Lieske's algorithm for precession, Kinoshita's rigid Earth solution (with external torque only due to the Moon and the Sun), Wahr's transfer function computed for an oceanless elastic stratified model of the Earth and optical astrometric observations. The VLBI observations made afterwards proved that this model is not adequate any more, on the present level of observational accuracy. Therefore, a new model is defined that is based on a more accurate rigid Earth solution (by Souchay et al.) taking into consideration additional torques by the planets and a more sophisticated transfer function (worked out by Mathews, Herring and Buffet) considering also the anelasticity and ocean tide effects, electromagnetic couplings of the mantle and the solid inner core to the fluid outer core, annual atmospheric tide and geodesic nutation. A few basic Earth parameters are estimated by a fit to VLBI observations of precession-nutation. Two versions of the model exist – IAU 2000A with full precision (of about 0.2mas) and a shorter version IAU 2000B (precise to only 1 mas). The model is constructed so that it describes the motion of the Celestial Intermediate Pole (see below).

Resolutions B1.7 and B1.8 deal with the transformation between the terrestrial and celestial reference systems. The resolutions, proposed by the IAU Working Group on International Celestial Reference System, define the new pole and origins that replace the so far used definitions of the Celestial Ephemeris Pole, equinox and zero meridian. These resolutions imply a different formulation of the transformation algorithm.

Resolution B1.7 Definition of Celestial Intermediate Pole

Although in principle only three parameters (e.g., Euler angles) are necessary to describe the mutual orientation between terrestrial and celestial reference system, there is an obvious need to have two more parameters, describing the motion of a conventionally chosen intermediate axis with respect both to the terrestrial and celestial reference system. This axis should be chosen, quite naturally, close to the instantaneous axis of rotation and its terrestrial and celestial motion has to be observationally separable. This role has been played so far by the Celestial Ephemeris Pole (CEP), whose definition was based on the requirement that it exhibits no near-diurnal motion in either of the two reference systems. However, in view of the present accuracy and sub-diurnal resolution of the observations, the existence of small high-frequency (diurnal and sub-diurnal) nutation and polar motion makes this definition obsolete. Therefore, a new Celestial Intermediate Pole (CIP) is defined so that its periodic celestial motion (nutation) contains only the terms with periods longer than two days; all other motions are interpreted as polar motion.

Resolution B1.8 Definition and use of Celestial and Terrestrial Ephemeris Origins

So far, equinox and zero meridian have been used as origins to define the Earth's angle of rotation (sidereal time). However, the instantaneous equinox, being the intersection of the Earth equator and the ecliptic, is dependent both on the theory of Earth's orbital motion around the Sun and the model of precession-nutation. Consequently, it exhibits both secular and periodic (equation of equinoxes) motions with respect to the celestial system. The ecliptic, being a plane fitted to the Earth's orbit that is a three-dimensional curve, cannot be defined uniquely, and in addition it is in fact redundant and not needed for the transformation between the terrestrial and celestial reference system. The system based on equinox has a principal disadvantage – each time when the model of precession-nutation and/or definition of the ecliptic is changed, it must be necessarily accompanied by a change of the definition of the relation between Universal and Greenwich Sidereal Times. It should also be noted that the official conventional celestial system, the ICRS, is not based on ecliptic/equinox any more, since 1997 when it was adopted.

Therefore, it is advisable to select an origin that is independent both of the orbital motion of the Earth and the adopted model of precession-nutation. It is also advantageous to define a stellar angle (different from sidereal time), with a relatively simple relation to Universal time UT1. This is achieved by adopting Guinot's concept of 'non-rotating origin' on the moving equator of CIP – the Celestial Ephemeris Origin (CEO). It is accompanied by a similar concept in the terrestrial system – the Terrestrial Ephemeris Origin (TEO); the rigorous definition of the origin of longitudes on terrestrial equator (in the presence of polar motion) has not been given so far. Both origins satisfy the condition that they exhibit no motion along the moving equator of CIP. The angle between the CEO and TEO, the Earth Rotation Angle (or Stellar Angle), is related to UT1 by a simple linear relationship. The transformation between the ITRS and GCRS is then given by the position of the CIP in the GCRS, the position of the CIP in the ITRS and the Earth Rotation Angle.

Resolution B1.9 concerns the new definition of Terrestrial Time in the frame of general relativity, and was initiated by the BIPM/IAU Joint Committee on Relativity for Space-Time Reference Systems and Metrology.

Resolution B1.9 Re-definition of Terrestrial Time TT

The Terrestrial Time (TT) was defined by the IAU already in 1991 as a time scale for all practical matters on Earth. It has been defined as the time scale differing from the Geocentric Coordinate Time (TCG) by a constant rate, the unit of measurement of TT has been chosen so that it agrees with the SI second on the geoid. This constant rate is therefore dependent on the adopted value of the potential on the geoid, and should be changed each time when the IUGG adopts a new value. In order to avoid this, the new definition fixes the value of the rate, based on the present value of geopotential at the geoid as a defining constant.

Resolution B2 Coordinated Universal Time

Because of the variable speed of rotation of the Earth, universal time UT1 and International Atomic Time TAI diverge. Therefore the Coordinated Universal Time (UTC) was introduced, based on the SI unit of time, with irregular insertions of leap seconds, in order to keep it within certain 'reasonable' limit in accordance with UT1 (at present, this limit is 0.9s). Since the definition of UTC relies on the astronomical observation of UT1, the decision of inserting leap seconds is in the responsibility of the IERS. The unpredictability of leap seconds affects modern communication and navigation systems, therefore a working group of the IAU is established to reconsider the necessity of leap seconds and propose a possible redefinition of UTC. The working group is asked to cooperate with the appropriate groups of the International Union of Radio Science (URSI), the International Telecommunications Union (ITU-R), the International Bureau for Weights and Measures (BIPM), the International Earth Rotation Service (IERS), and relevant navigational agencies.

3 CONCLUSIONS

The new resolutions should become effective on January 1, 2003. Evidently, only some of them require an immediate action by the IERS. The task of the IERS Workshop is to explain the real meaning of the resolutions to a general community of users and to discuss the necessary changes in the IERS products and analyses in order to comply with the IAU recommendations. The IERS Directing Board will then decide which steps should be taken and which products of the IERS will be affected.

Since the implementation of the resolutions will affect a broader community than just the IERS, the impact on astrometry, ephemerides and astronomical almanacs are also to be discussed. This concerns namely the questions of a clear explanation of the concepts of the new celestial transformation and the relation to the conventional transformation, usage of the precession-nutation model IAU 2000A/B and developing software for the actual implementation of the new systems by users.