THE TERRESTRIAL REFERENCE SYSTEM AND THE NEED FOR A NEW GLOBAL GEODETIC REFERENCE SYSTEM

O sistema de referência terrestre e a necessidade de um novo sistema de referência geodésico global

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ABSTRACT

Present day space geodetic techniques (VLBI, SLR, GPS) lead to the definition of terrestrial reference systems with greater precision than classical techniques which were employed in the definition of the conventional international origin (CIO). The importance of the CIO is justified by its adoption not only for the successive alignments of several ITRFs, through the BIH pole, but also for the definition of the global geodetic reference system of 1980 (GRS 80). This is the motivation for defining a new conventional international reference origin (CIRO) and for the need to adopt a new global geodetic reference system, based on space geodetic techniques, by the appropriate international organizations.

Keywords: Terrestrial Reference System; ITRS's; CIO.

RESUMO

As técnicas atuais da geodésia espacial (VLBI, SLR, GPS) permitem a definição dos sistemas de referência terrestres com maior precisão do que as técnicas clássicas que foram utilizadas na definição da origem convencional internacional - "CIO". A importância da "CIO" justifica-se por ter sido adotada não só para os sucessivos alinhamentos dos diversos sistemas de referência terrestre internacional, através do pólo do "BIH", mas também para a definição do sistema de referência geodésico global de 1980 (GRS 80). Estas são as razões para a definição de uma nova origem de referência convencional internacional - "CIRO" e para a necessidade de um novo sistema de referência geodésico global, baseados nas técnicas da geodésia espacial, a serem adotados pelas organizações internacionais adequadas.

Palavras Chaves: Sistema de Referência Terrestre; CIO; ITR's.

1. INTRODUCTION

The observations of terrestrial coordinates are conditioned by the motion of the rotation of the earth. The analytical theory of the rotation of the earth was originally developed by Euler in 1765 and improved in studies of earth dynamics and celestial mechanics (Woolard 1953, Kinoshita 1977) leading to the theories of precession and nutation.

The main present day space techniques employed for the determination of geodetic coordinates are VLBI, SLR and GPS. They should be employed for a better definition of the terrestrial system of coordinates because they have not only longer periods of observations but also more ground stations. Other techniques, for instance, DORIS do not yet satisfy these important requirements. We should point out that VLBI has not many ground stations but it has the great advantage of observing celestial objects permitting the connection between celestial and terrestrial coordinates. The SLR and GPS techniques are associated with artificial earth satellites, and they can only determine parameters of earth rotation by the adoption of the coordinates of a reference station, or a set of stations, linked to celestial coordinates by the observations of VLBI. Some of the parameters that affect terrestrial coordinates are polar motion (Xp, Yp) and the angular velocity of the earth (UT1). They are nowadays called earth orientation parameters (EOP).

Any technique has its advantages and disadvantages. We have briefly mentioned some of them. We should like to point out the importance of systematic errors, inherent to any technique, and they will affect the final precision of the observations. It is therefore important the combination of different techniques.

2. DEFINITION OF TERRESTRIAL SYSTEMS

The terrestrial reference systems of coordinates are based on the definition of an origin and the position of an axis directed towards the pole. The origin O of the rectangular system of coordinates (OXYZ) has been considered to coincide with the center of mass of the earth, and it is an accepted convention to be supposed a fixed point. This is reasonable because we are dealing with the mechanics of the earth and, therefore, the moments of inertia whose values depend on the internal structure of the earth with layers of increasing density towards the center. Unfortunately, the designation of geocenter has appeared to mean that the center of the ellipsoid of reference coincides with the center of mass of the earth, for instance, geodetic reference system 1980 (GRS80) (Moritz 1980). As we are dealing with the dynamics of the earth, we should refer to the center of mass. It is a pity that the definitions are not properly applied specially when we are aiming at greater precisions of order of 1 part per million (10^6) up to 1 part per billion (10^9).

It is well known that greater the precision we are trying to reach more careful we have to be with the formulation of the problem related to the observations, because we are introducing a greater number of variables.

The next important step is the position of the axis OZ directed towards the pole, and its intersection with the earth's surface defines the orientation of the terrestrial coordinates. There are two possibilities to determine the position of the terrestrial north pole: 1) The axis OZ can coincide with any of the axes defined by the analytical theory of the rotation of the earth, namely the axes defined by the analytical theory of the rotation of the earth, namely the axes of rotation, figure and angular momentum, that is, the pole of rotation (Pr), figure (Pf) and angular momentum (Pa). The adoption of any of these poles is a possible solution, having its advantages and disadvantages; 2) can be determined from the observations of polar motion coordinates (Xp, Yp), and the barycenter of such curves corresponds to the position of the terrestrial north pole.

We can see that the first possibility considers 3 cases and, therefore, we can refer our coordinates to 3 different poles, depending on the system of reference adopted to solve the equations of motion. Unfortunately, it is not clearly defined the system of reference adopted by the different techniques. Also, if the several computing centers of polar motion coordinates employ the same system.

The second possibility determines the pole position obtained from polar motion observations made at earth's surface by all techniques, and, therefore, considering the geophysical behaviour of the earth. This pole probable corresponds to a more realistic behaviour of the earth, and its position will be different from the previously mentioned ones.

We are concerned about the definition of reference standards for the terrestrial system and it should be pointed out that any adopted standard is conventional. There are different approaches to its definition and we should choose one not only more in agreement with the observations but also taking into consideration the analytical theories of the rotation of the earth.

It should be emphasized the distinction between a conventional standard to be adopted for comparison purposes during several decades and a conventional reference value determined from the most accurate observations available at the time of the reduction of the observations.

An example of the first type of standards is provided by the CIO defined and adopted by the IAU (Transactions, 1967) and IUGG (Bull Géodésique, 1967). The second type of standards is exemplified by the development of a terrestrial reference frame (TRF) solution (BTS84) by Boucher and Altamimi (1985) which has been updated in subsequent years and called international terrestrial reference frame (ITRF) (Altamimi et al 2002)

3. REDUCTION OF THE OBSERVED SERIES

This is an important and difficult subject. We can adopt several criteria for choosing the best available series for the purpose of defining a conventional standard. Among them are the length of the series, the employment of the same type of instruments in a consistent way, the number of occupied sites by each technique.

These vary among the techniques not only because of the complexity of the instruments employed but also the financial cost of getting the results. The number of available techniques to determine the coordinates of polar motion has increased lately, and they are interesting from the point of view of scientific research, but they do not yet satisfy the above mentioned criteria.

Another interesting problem refers to the precision claimed by each technique and the ensuing discussions to justify their results. We can mention precisions not only of about 1 cm or 1mm but also about 1 mas or 1 μas. This is crucial for the survival and adoption of the most adequate techniques by the international community and it has human implications because scientists working on the less suitable techniques will not get financial support and, therefore, loose their jobs. This issue has appeared several times in the last 100 years first with classical optical techniques and, nowadays, with space geodetic techniques.

The combination of the several series obtained by different techniques is also a very important subject because of the random and systematic errors inherent to each technique and, for instance, peculiar to the realization of a reference station, or a set of stations, necessary to the employment of SLR and GPS in the determination of polar motion. This implies the adoption of statistical procedures adequate to the behaviour and features of polar motion. We have to pay attention to the correlation of errors, variation of weights and discontinuities in the series employed and, therefore, standard statistical models, for instance, least squares solutions are often not adequate. This was already pointed out by Jeffreys (1940, 1961).

4. POLE POSITIONS DETERMINED FROM OBSERVATIONAL SERIES

4.1 Employing the barycenter of the observed series

One approach to determine the position of the terrestrial pole is the employment of the kinematic representation of the theory of the rotation of the earth applied to the case of free nutation, that is, the motion of the earth in the absence of the influence of external bodies (Sun and Moon), and it is called polar motion. This representation was developed by Poinsot (1852) in the terms of the polhode and herpolhode cones. In the case of polar motion, the intersection of the polhode cone with the surface of the earth is called the polhode, and the center of this curve corresponds to the pole of figure (Vicente 1961).

We have now to point out that the observed series are complicated curves, affected by random and systematic errors, due to the complex structure of the earth and its evolution in the course of time. They are deduced not only from a complex set of models and equations but also different numerical procedures. We can determine the barycenter of these curves and it will correspond to the position of the pole derived from the observations. This pole does not coincide either with the theoretical pole of figure or any other theoretical pole (rotation or angular momentum) because it is an observational realization. An interesting question would be to find out which theoretical pole would be nearer to this observational pole (P_{obs}).

This kinematical representation was employed by Vicente and Wilson (2005) to analyse recent polar motion time series (VLBI, SLR,GPS) which were grouped in two time intervals: a long one (1984-2000) and a short one (1993-2000). There are several reasons for choosing a long (about 16 yr) and a short (about 7.5 yr) interval: 1) in order to understand the effects of time series length on the problem of estimating the barycenter; 2) the fact that GPS series are only available since early 1990s; 3) statistical confidence of estimates to improve with longer time series lengths; 4) the degrading of models and constants in the course of time.

The choice (see Table 1) of the number of series employed (7 for the long interval and 11 for the short interval) was justified for several reasons properly explained. Of course, we can choose different series and several other techniques and, as it always happens, techniques and series excluded are resented by some scientists as previously mentioned.

There are two main components in polar motion: 1) the Chandler component, corresponding to the free eulerian nutation, that is, the motion of the earth in the absence of external bodies, with a period of about 432 mean solar days; 2) an annual component with a yearly period considered to be forced by seasonal motions of air and water.

The determination of the barycenter involves the application of statistical analysis adequated to the peculiarities of the behaviour of polar motion. The adopted estimation techniques leads to the definition of a reference pole (method 1) and a residual pole (method 2) as explained on p. 272 (Vicente and Wilson 2005). In theory, reference and residual poles coincide (Wilson 1985), but dealing with observational time series of finite length with their associated random and systematic errors , their estimates do not coincide.

Another difficulty associated with the determination of the barycenter of most polar motion series is its behaviour which appears to drift over time. This problem will affect any method of determining the barycenter. It should be pointed out that the apparent rate of drift depends upon the method employed in the reduction of the observations. The classical optical techniques series, for instance, corresponding to the period 1900-1975, can be reduced employing two different computing procedures: 1) adopted by the then called International Latitude Service (ILS) and latter on called International Polar Motion Service (IPMS), which leads to the appearance of a drift of the pole; 2) adopting Orlov's method which does not show any drift of the pole (Vicente and Wilson, 2002, sec 2). The computing procedures, so far adopted by the space geodetic techniques, leads to the appearance of a drift of the pole.

We should notice that we have not yet any theoretical explanation for the drift of the pole and, therefore, it is a wrong scientific procedure to extrapolate these drifts (7 or 16 years) for longer intervals of time, saying that it is linear, circular or any other behaviour. The proper scientific language is to say that it appears linear for these intervals without any implication about its future behaviour.

4.2 Estimation of the barycenter of the pole path

There are several possibilities for the definition of the barycenter, for instance, adopting the long or short series. The best statistical procedure is to employ the long series in order to take in consideration, as far as possible, the complex dynamical and geophysical behaviour of the earth. This is an important point which is often overlooked in some research trying to obtain data from short intervals of time.

Another important problem is the criteria adopted for the rejection of the observed series available which show differences, for instance, of the order of 3 mas in coordinates and drift rates. Without critical evaluation of these differences, due to the fact they have been derived from different models, standards and software, we cannot reject, a priori, any of these series taking in consideration standard procedures for the rejection of data (Jeffreys, 1973).

The definition of a new conventional pole depends on some specific choices among the several possibilities. We have mentioned that the most likely choice is the residual pole for the long series, but we have to compute it for some date which is nearer to the date adopted for the ICRF, that is, J2000.0. We should like to point out that we have to be very careful about the terminology of the dates of different years. For instance, in our case we can calculate values for the date 2000.0 (2000 Jan1, 0.0hTT, MJD=51543) or for the date J2000.0 (2000 Jan1, 12.00hTT, MJD=51543.5). As we can see, there is a difference of 0.5 day, and this is important for our calculations when we speak of precisions of mas or μas. Unfortunately, this is not very often mentioned or specified in the relevant literature. We calculate the barycenter of the pole position for the date 2000.0 if the linear drift model is reasonably good (a rate in mas per year and a direction in degrees of longitude).

4.3 The relationship between ICRF and ITRF

The development of a TRF based on space geodetic techniques requires the adoption of a convention to establish its orientation. There are several possibilities and one of them was the selection of the BIH reference pole for 1984.0, with adoption of subsequent values at later dates, leading to the development of successive solutions of the ITRF over the last years (Altamimi et al 2002). These successive changes in ITRF solutions show discontinuities, non-linear motions of station positions and datum parameters (IERS Annual Report 2004, p. 90).

It should be emphasized that the BIH reference pole was adjusted to the CIO in 1967. This is very important to keep in mind because it shows not only the importance of the CIO but also the dependence of the BIH pole on the values determined for the CIO. The uncertainty of the tie of the BIH reference pole relative to the CIO was 30 mas (IERS Annual Report 1990, pp I-11). It should also be pointed out that the rotation axis of the reference ellipsoid has the direction of the CIO in the geodetic reference system 1980 (GRS 80).

The tie of the ICRF to the ITRF is through EOP, that is, polar motion coordinates (Xp, Yp). It is therefore implicit that all the observational difficulties we have in the determination of polar motion coordinates by any technique appears in this relationship between celestial and terrestrial reference systems. Any rotation between these two systems introduce bias in the respective EOP series, appearing large systematic shifts. Bizouard (2006) mentions that the consistency among series agree at the level of about 60 μas for polar motion and about 100 μas for nutation. The larger values for the nutation might be due to an inadequate modeling of the nutation series which is a difficult problem, and we should remember that the main term of the luni-solar nutation has a period of about 19 years and the observations have not yet been done, in a systematic way, for at least 20 years.

4.4 Adoption of a new conventional origin

The appearance of space geodetic techniques and their regular observations of polar motion for about 20 years gives us the possibility of defining a better origin for the orientation of terrestrial reference systems. The previous discussions on several possible estimates for the barycenter leads us to suggest the adoption of a residual pole for the long series, extrapolated to the date 2000.0, calling it "Conventional International Reference Origin (CIRO)" with coordinates (Xp= 41 mas, Yp= -340 mas) as shown on Fig.6 (Vicente and Wilson 2005).

5. ON THE SO CALLED RIGOROUS SOLUTIONS IN GEODETIC RESEARCH

We have emphasized, in the previous sections, the importance and difficulties appearing not only in the observations but also the choice of adequate theoretical models. Besides that we have to deal with estimation procedures of the data, employing the most appropriate statistical models. We also have to take in consideration the numerical analysis techniques employed with due regard for their truncation errors and correlations. This is inherent to any field of experimental science, and it has been pointed out by several scientists, namely, Jeffreys (1973).

Our proposal of a new conventional standard for the orientation of terrestrial reference systems is constrained by these considerations. We have to be aware that the solutions to any geodetic research are only approximations and very much conditioned by the techniques available at the time. Unfortunately, it has appeared in recent geodetic literature a number of so-called "rigorous solutions" which seem not to be aware of these fundamental scientific questions (Ray and Zhu 2003, IERS Annual Report 2004, pp. 42, 89, 100).

6. THE NEED FOR A NEW GLOBAL GEODETIC REFERENCE SYSTEM

The advent of space geodetic techniques associated with greater computing facilities have lead to increased precision in the results from several mas up to μas. It is essential very careful and clear definitions of the variables and models concerned, keeping in mind that the increased precision involves the consideration of more variables required to attain such precision. Unfortunately, research taking into account these requirements have not been developed in a consistent way. The result is the appearance of several inconsistencies and discontinuities in the system of geodetic constants and models.

We have proposed the adoption of a new conventional origin (CIRO)for the ITRF as a standard for comparison of all the existing determinations. It is well known that a reference standard does not need to be the most accurate but defined in such a way that can be employed for longer periods of time. In this way we avoid the previously mentioned discontinuities.

Another pitfall is the adoption of the same set of theoretical and numerical models by all research centers which, therefore, will obtain similar results. It would be more interesting and useful to experiment with better or alternative definitions of the models in order to reach more reliable standards.

There is sometimes the tendency to claim the precision obtained in relative observations, made in a short time interval (a few years), as the final precision of the results that should be determined in decades. This is evident in the determination of terrestrial coordinates and their intercomparisons claiming precision of about 1 ppb. If we combine observations made during decades, for instance, in the case of the definition of CIRO, the precision is lower of the order of 2 mas, that is, about 6 cm at the earth's surface.

The actual geodetic reference system (GRS 80) was adopted by the 17th General Assembly of the IUGG (Moritz 1980) and it does not satisfy the present requirements of geodesy not only because of the degradation of the adopted values in the last decades but also the appearance of space geodetic techniques. The IAG should address such problem and set up appropriate working groups in order to present a new system of standards.

This is an important issue with wide implications in the scientific community dealing with geodesy, geophysics and astronomy. There will be two schools of thought, as it happened in the past history of science on the subject. One, more conservative, will not want to change afraid of the relevant amount of work necessary for this change of system. Another, more realistic and in agreement with present day needs, will consider necessary and essential such a change. I hope the more realistic school of thought will prevail in the near future.

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