Recent and Anticipated Changes to the International Earth Rotation and Reference Systems Service (IERS) Conventions

Brian Luzum, *U.S. Naval Observatory*

BIOGRAPHY

Brian Luzum began full-time employment at the U.S. Naval Observatory (USNO) in 1987. He is currently the Chief of the Earth Orientation Parameters Combination and Prediction Division in the USNO Earth Orientation Department. He is also the co-director of the International Earth Rotation and Reference Systems Service (IERS) Conventions Product Center and the chair of the International Astronomical Union (IAU) Working Group on Numerical Standards for Fundamental Astronomy. He received his Ph.D. from the University of Florida in 2004 and is the author or coauthor of more than 30 articles including the 2003 publication describing the IAU 2000B precession-nutation model.

ABSTRACT

The International Earth Rotation and Reference Systems Service (IERS) Conventions provides the international standard for models and constants related to the transformation between the terrestrial and the celestial reference frames. These include

- adopted values of physical constants,
- the definitions and realizations of terrestrial, celestial, and dynamical reference systems,
- the transformation between frames,
- geopotential model,
- models for the displacement of reference points,
- model for the tidal variation in the Earth's rotation,
- tropospheric models, and
- relativistic models.

As these models provide the link between terrestrial, celestial, and dynamical reference frames, they can be a crucial component of navigation and targeting.

The IERS Conventions Center is preparing to release a new version of the IERS Conventions with an anticipated publication date of 2009.

BACKGROUND

The relationship between an inertial reference frame and a terrestrial reference frame is complicated by the fact that the Earth has several forced motions all of which are unpredictable at some level. In order for an inertial frame object to locate a terrestrial frame object, it must utilize the five Earth orientation parameters (EOPs): polar motion (2 angles), UT1-UTC, and nutation (2 angles) (see Seidelmann, 1992 for background information). The International Earth Rotation and Reference Systems Service (IERS) is the international body responsible for providing this information. In order to ensure that the information is used properly, the IERS also provides the IERS Conventions as a "rule book" for deriving and using the Earth orientation information. The U.S. Naval Observatory runs the IERS EOP Rapid Service/Prediction Center and, with the Bureau International des Poids et Mesures (BIPM), the IERS Conventions Center.

INTRODUCTION

The IERS Conventions consist of a set of constants, models, and algorithms, used in the analysis of Earth orientation and reference systems data. It has several qualities that make it appealing to users of Earth orientation data. In an effort to keep the Conventions current, the algorithms and constants have been assembled and verified by experts. In order to ensure that there are no problems with the use of the models, the Conventions strives to be consistent with all IERS products including the International Terrestrial Reference Frame (ITRF), the International Celestial Reference Frame (ICRF), and EOPs, which include the use of celestial pole offsets. The Conventions strives to maintain self-consistency thereby minimizing the effects of systematic errors in the algorithms. Whenever possible, the Conventions is consistent with international standards such as those provided by the Committee on Data for Science and Technology (CODATA) and the BIPM. This helps to ensure that the data produced by the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JAN 2009		

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Recent And Anticipated Changes To The International Earth Rotation And Reference Systems Service (IERS) Conventions	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Naval Observatory,3450 Massachusetts Avenue, N.W.,Washington,DC,20392**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**		**6**	

IERS will be consistent with other international data sets. The IERS instituted the Conventions in an attempt to mitigate systematic errors in Earth orientation data because failure to apply a consistent set of physical models will result in systematic errors. Note that systematic errors are not Gaussian in nature and therefore, cannot be accounted for in the error budget by a simple root-sum-square of the errors.

BRIEF HISTORY

The IERS Conventions succeeded the Project to Monitor Earth Rotation and Intercompare the Techniques (MERIT) Standards, which were published in 1983. The first edition of the Conventions, then known as the IERS Standards, was published in 1989 as IERS Technical Note 3. The second edition was published in 1992 as IERS Technical Note 13. When the third edition was published in 1996 as IERS Technical Note 21, the name had been changed to the now familiar IERS Conventions. The fourth and current edition was published in 2003 as IERS Technical Note 32. We anticipate that the next edition will be published in 2009.

There are two interesting things to note about this schedule of updates. First, the Conventions is not a static document. As the level of accuracy of the observations has improved, previously negligible effects have had to be modeled. These improved models have necessitated the modification of the Conventions to meet the emerging needs of its users. However, even though the document does change, it does so relatively infrequently, only four editions in roughly twenty years. In addition, the frequency of updates was greater in the early history as the document was evolving more quickly.

CHAPTER 1 — GENERAL DEFINITIONS AND NUMERICAL STANDARDS

Chapter 1 contains general information regarding the Conventions and the list of numerical constants adopted by the Conventions. The chapter has two sections. The section on the permanent tide describes the tidal model that is adopted in the Conventions. The section on numerical standards provides the list of numerical constants and background information regarding the different assumptions made concerning the constants.

The changes made from the 1996 Conventions to the 2003 Conventions include updating the text to account for 2000 International Astronomical Union (IAU) Resolutions and including values adopted by the International Association of Geodesy (IAG). The changes from the 2003 Conventions to the 2009 Conventions include modifying the numerical standards to incorporate the anticipated recommendations of IAU Numerical Standards for Fundamental Astronomy Working Group.

CHAPTER 2 — CONVENTIONAL CELESTIAL REFERENCE SYSTEM AND FRAME

Chapter 2 discusses the inertial reference system (the International Celestial Reference System – ICRS) and reference frame (the International Celestial Reference Frame – ICRF) used by the IERS. The chapter first defines the fiducial reference plane and point in the system. Then, various realizations of the reference system and the reference frame are discussed.

The changes made from the 1996 Conventions to the 2003 Conventions include modifying the text to comply with the 2000 IAU Resolutions. For the 2009 Conventions, it is anticipated that the new chapter will incorporate the new ICRF-2 reference frame, which is expected to be available in the summer of 2009.

CHAPTER 3 — CONVENTIONAL DYNAMICAL REALIZATION OF THE ICRS

Chapter 3 provides information on the dynamical realization of the ICRS. The adopted model and the associated constants are given.

The biggest change from the 1996 Conventions to the 2003 Conventions was updating the chapter to use the Jet Propulsion Laboratory (JPL) DE405 ephemeris. It is anticipated that for the 2009 Conventions, a new ephemeris will be selected. However, no choice on the new model has been made at this time.

CHAPTER 4 — CONVENTIONAL TERRESTRIAL REFERENCE SYSTEM AND FRAME

The International Terrestrial Reference System (ITRS) and the International Terrestrial Reference Frame (ITRF) are the subject of Chapter 4. The chapter is broken down into background concepts and definitions of terminology. A brief discussion of the input data and methodology used is provided as well as information regarding past ITRFs. Finally, analyses of the current ITRF are given.

The fundamental change from the 1996 Conventions to the 2003 Conventions is that the reference frame was updated to use the ITRF2000. Work is currently underway to incorporate the IRF2005 into the 2009 Conventions.

CHAPTER 5 — TRANSFORMATION BETWEEN THE CELESTIAL AND TERRESTRIAL SYSTEMS

For the navigation community, the most important chapter in the Conventions is probably Chapter 5. This chapter provides a procedure for transforming between the ICRF, in which the equations of motion of the space vehicles are

expressed, and the ITRF, in which the ground-based objects are specified. The chapter starts by providing information on the IAU 2000 Resolutions, thus giving the context of the current transformation procedure. Extensive information is provided regarding the new terminology used in the transformation such as Earth rotation angle, celestial intermediate pole, terrestrial intermediate origin, etc. The new IAU 2000 nutation model, which provides a significant improvement over the old IAU 1980 nutation model, is described. Finally, information regarding the subroutines available to perform the transformation is described and "cookbook" procedures for computing the transformation are given.

The changes from the 1996 Conventions to the 2003 Conventions involved modifications to the text in order to bring it into compliance with the IAU 2000 Resolutions. The biggest of these is the inclusion of the IAU 2000 nutation theory. Additional changes to the text for the 2009 Conventions are already underway in order to make the text consistent with the Resolutions from the IAU General Assemblies of 2003 and 2006. Of these changes, the most significant is the addition of the IAU 2006 precession theory.

CHAPTER 6 — GEOPOTENTIAL

Chapter 6 provides information regarding the geopotential model. In addition to the gravitational model itself, there are a number of effects that need to be modeled including the effect of the solid Earth tide, the solid Earth pole tide, the treatment of the permanent tide, and the effect of the ocean tides. Also, procedures to convert tidal amplitudes are provided.

The most substantial change between the 1996 Conventions and the 2003 Conventions is updating the text to utilize the Earth Gravity Model 1996 (EGM96). It is anticipated that a new gravitational model will be included in the 2009 Conventions although no decision on which model will be chosen has been made at this time.

CHAPTER 7 — DISPLACEMENT OF REFERENCE POINTS

Chapter 7 discusses the list of effects impacting the displacement of a reference point from its regularized position. These include ocean loading, solid Earth tides, permanent deformation, rotational deformation due to polar motion, and atmospheric loading. The chapter also provides information on the displacement of reference points on VLBI antennas due to thermal deformation.

Between the 1996 Conventions and the 2003 Conventions, considerable effort was made to ensure that this chapter was consistent with the modeling and assumptions of Chapter 6. This necessitated enhancing some of the models. It is anticipated that between the 2003 Conventions and the 2009 Conventions, sections on atmospheric pressure loading and non-tidal displacement of reference markers will be added.

CHAPTER 8 — TIDAL VARIATIONS IN THE EARTH'S ROTATION

It is often convenient in dealing with Earth orientation data to remove the effects of tidal variations in order to eliminate known signals from the data. Chapter 8 provides the zonal tide models necessary to remove these signals.

Changes were made between the 1996 Conventions and the 2003 Conventions improving the consistency of the models and enhancing the diurnal/semidiurnal model. The 2009 Conventions is expected to include a revised zonal tide model that should help remove residual signatures in Earth rotation data.

CHAPTER 9 — TROPOSPHERIC MODEL

Another chapter with potential to impact the navigation community is Chapter 9, which provides ways in which to model the troposphere. Since these models are designed to be used in geodetic data analysis with accuracies approaching the 1 mm level, these models are state of the art and could be used in other areas of study. The chapter provides the zenith delay model and the mapping function for both optical and radio signals as they travel through the troposphere.

The most significant change from the 1996 Conventions to the 2003 Conventions was the introduction of the Niell Mapping Function model. For the 2009 Convention, this chapter has already been revised extensively. A new, more accurate zenith delay/mapping function model has been introduced. Also, a new section providing a model for the ionospheric delay has been added.

CHAPTER 10 — GENERAL RELATIVISTIC MODELS FOR SPACE-TIME COORDINATES AND EQUATIONS OF MOTION

Chapter 10 discusses the general relativistic models used for space-time coordinates and motion in a relativistic framework. A brief review of different relativistic time scales is provided as background information. The pertinent equations of motion for an artificial satellite and equations of motion in the barycentric frame are given.

The changes made from the 1996 Conventions to the 2003 Conventions include modifying the text to comply with the 2000 IAU Resolutions. A new section on the transformation between proper time and coordinate time

in the vicinity of the Earth has already been written in preparation for the 2009 Conventions.

CHAPTER 11 — GENERAL RELATIVISTIC MODELS FOR PROPAGATION

This last chapter of the Conventions provides the development of the general relativistic propagation equations. This model was developed for use with Very Long Baseline Interferometry (VLBI) and so may have only limited use within the navigation community.

For the 2003 Conventions, modifications were made to the text to comply with the 2000 IAU Resolutions. It is anticipated that the section on ranging techniques will be revised for the 2009 Conventions.

MODEL ACCURACIES

The needs of the geodetic community continue to lead to improvements in the accuracy of geodetic data. The IERS Conventions is keeping pace with this evolving situation by continually improving substandard models. With the goal of achieving mm-level results, the Conventions strive to be able to provide model accuracies one order of magnitude smaller. To date, this has not been achieved by all models, but the majority of the models have accuracies better than 1 mm.

GENERAL IMPROVEMENTS

In addition to the improvements in modeling, the IERS Conventions is also improving the supporting information and the way in which the information is disseminated to the users. The following is a brief list of improvements that have been implemented recently.

A new section in the Introduction is being prepared which will include the classification of models used in the Conventions and the general criteria for choosing models. As always, the consistency between the models is being improved. In an effort to help the less experienced user, a new section, possibly included as an appendix, is being drafted to list the models and the associated magnitude of their effects.

A significant amount of work is being spent improving the Fortran software associated with the Conventions. Previously, the software has been accepted from the author and provided to the users with little attempt at standardizing the code. As the recognition of the importance of the software implementation of the models has changed, more effort is now made to provide code that meets standard coding practices. This includes a new software template that all software will eventually use. The documentation for all subroutines will be rewritten to include clear definitions of all variables. Test cases will be provided with all routines so that users can check their implementations. In addition, to improve the consistency between groups with similar goals, the IERS Conventions Center will work in closer cooperation with the IAU Standards of Fundamental Astronomy (SOFA) software group.

RECENT CHANGES TO INFORMATION DELIVERY

The IERS Conventions Center is also working to improve the way in which users can receive information regarding the IERS Conventions. To that end, a new Conventions "Auxiliary" page has been created to hold material that is not officially a part of the Conventions, but complements it. It is anticipated that this page will eventually hold test cases, technical notes, and other items of general interest.

It has been necessary to remove the Conventions Forum, which was used as an area for communication regarding the Conventions. It is anticipated that this will be replaced by an e-mail list to which Conventions users can subscribe.

AVAILABILITY

The 2003 IERS Conventions are available at http://tai.bipm.org/iers/conv2003/conv2003.html. The corrections, updates, and other modifications to the 2003 Conventions can be found at http://tai.bipm.org/iers/convupt/convupt.html.

A copy of the 2003 IERS Conventions has also been made available on the SIPRNet web site http://aa.usno.navy.smil.mil/eo/USNOEO.html. Since this is a relatively new service provided by USNO, we are actively seeking comments regarding it. If there is additional information or data that you would like to see added to the SIPR site, please send an e-mail to Brian Luzum (bjl@usno.navy.smil.mil) or Nick Stamatakos (ngs@usno.navy.smil.mil).

NEXT EDITION

It is anticipated that the next edition of the IERS Conventions will be published in late 2009. Before the release, the final draft will undergo an extensive external review.

ACKNOWLEDGMENTS

The IERS Conventions can only succeed through the diligence of its contributors, who are too numerous to mention here. Their hard work is very much appreciated.

REFERENCES

IERS Conventions, 1996, D.D. McCarthy (ed.), IERS Technical Note 21, Observatoire de Paris, Paris.

IERS Conventions, 2003, D.D. McCarthy and G. Petit (eds.), IERS Technical Note 32, Bundesamts für Kartographie und Geodäsie, Frankfurt am Main.

Seidelmann, P. K. (ed.), 1992, *Explanatory Supplement to the Astronomical Almanac*, University Science Books, CA, 752 pp.