The International Celestial Reference System, Maintenance and Future Realizations

Proceedings of IAU General Assembly XXV,
Joint Discussion 16
Sydney, Australia, 22 July 2003

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
22 JUL 2003		**22-07-2003 to 22-07-2003**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
The International Celestial Reference System, Maintenance and Future Realizations	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,20392-5420**	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
Proceedings of IAU General Assembly XXV, Joint Discussion 16, held in Sydney, Australia, 22 July 2003

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**	**Same as Report (SAR)**	**19**	

IAU XXV, Joint Discussion 16: The International Celestial Reference System, Maintenance and Future Realizations
22 July 2003,
eds. Gaume, McCarthy, Souchay

IERS CONVENTIONS

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Abstract.
The International Celestial Reference Frame (ICRF) is currently a radio reference frame accessed through Very long Baseline Interferometry (VLBI) and refined with technique-dependent improvements described in this Joint Discussion. An important component of the International Celestial Reference System (ICRS) that is the basis for this frame is the set of conventional models and procedures that are used to define the system. The International Earth Rotation and Reference System Service (IERS) Conventions Center, provided jointly by the U.S. Naval Observatory (USNO) and the Bureau International des Poids et Mesures (BIPM), produces the IERS Conventions that contain the models and procedures needed to realize and access the ICRS. The key elements of the Conventions related to the ICRS are outlined, and recent improvements are highlighted. Improvements in the IERS Conventions (models and procedures) should play a role by globally improving IERS products.

1. Introduction

The realization of the International Celestial Reference System (ICRS) requires a set of conventional models and procedures to be used in the analyses of the observational data. The International Earth Rotation and Reference System Service (IERS) provides these in the IERS Conventions, which contain the recommended procedures not only to define the ICRS but also to derive and interpret the other products of the IERS, such as the International Terrestrial Reference Frame, and the Earth Orientation Parameters.

The IERS Conventions is a publication that is produced by the IERS Conventions Product Center provided jointly by the U.S. Naval Observatory (USNO) and the Bureau International des Poids et Mesures (BIPM). The Product Center provides a web site
http://maia.usno.navy.mil/conv2003.html containing the IERS Conventions (2003). This site is to be updated as warranted at approximately annual intervals. In addition the Center produces the material for the IERS Technical Notes that document major changes, and it is expected that this document might be provided at approximately 5-year intervals.

The IERS Conventions (2003) is a continuation of the series of documents begun with the Project MERIT Standards (Melbourne *et al*, 1983) and con-

tinued with the IERS Standards (McCarthy, 1989; McCarthy, 1992) and IERS Conventions (McCarthy, 1996). The current issue of the IERS Conventions is called the IERS Conventions (2003). When referenced in recommendations and articles published in past years, this document may have been referred to as the IERS Conventions (2000).

The celestial system described in the IERS Conventions (2003) is based on IAU (International Astronomical Union) Resolution A4 (1991). It was further refined by IAU Resolution B1 (2000). The definition of time coordinates and time transformations, the models for light propagation and the motion of massive bodies are based on IAU Resolution A4 (1991), further defined by IAU Resolution B1 (2000). In some cases, the procedures used by the IERS, and the resulting conventional frames produced by the IERS, do not completely follow these resolutions. These cases are identified in the document, and procedures to obtain results consistent with the resolutions are shown.

2. Components

The IERS Conventions contain descriptions of units, models, software and procedures to be used in deriving and understanding the IERS products. These products assume the use of SI units (Le Système International d'Unitès (SI), 1998) and are generally consistent with the use of Geocentric Coordinate Time TCG as the time coordinate for the geocentric system, and Barycentric Coordinate Time TCB for the barycentric system.

The Conventions describe the conventional concepts that underlie the definition of modern high-precision Celestial and Terrestrial Reference Systems. These have little relationship to the precision of the products but they are likely to affect the accuracy as well as the users interpretation.

Models are provided to describe various physical effects. These are often developed to provide a conventional representation of a phenomenon that reduces the size of the internal error as measured by internal residuals. Consequently they generally affect precision but might have only a minimal affect on the accuracy. Included also are constants, the numerical values of parameters of common interest. Perhaps the most important is the software that provides practical numerical implementation of the concepts and models.

Finally, the Conventions publication outlines procedures to implement all of the above. The IERS Conventions (2003) does not go so far as to describe standard procedures for data analyses, such as details regarding solution constraints and appropriate spans of data, but future versions may get to that point. These choices affect precision but have little effect on accuracy.

3. Concepts

The IERS utilizes data provided by a variety of observational techniques. The analysis centers for each technique would normally establish the technique-specific conventions that are required for the analyses of their observations. The IERS Conventions concern those phenomena that affect more than one technique. The Product Center seeks to determine the effect of conventional mod-

els, software, and procedures on the data contributed to the IERS. The Center expects to work closely with the IERS Analysis Coordinator in this process.

4. Contents

The Contents of the Conventions publication are outlined by the Table of Contents:

Procedure to be used for the transformation consistent with IAU 2000 Resolutions
Expression of Greenwich Sidereal Time using the CEO
The Fundamental Arguments of Nutation Theory
The multipliers of the fundamental arguments of nutation theory
Development of the arguments of lunisolar nutation
Development of the arguments for the planetary nutation
Prograde and Retrograde Nutation Amplitudes
Procedures and IERS Routines for Transformations from ITRS to GCRS
Notes on the new procedure to transform from ICRS to ITRS

6. GEOPOTENTIAL
Effect of Solid Earth Tides
Solid Earth Pole Tide
Treatment of the Permanent Tide
Effect of the Ocean Tides
Conversion of tidal amplitudes defined according to different conventions

7. DISPLACEMENT OF REFERENCE POINTS
Displacement of Reference Markers on the Crust
Local Site Displacement due to Ocean Loading
Effects of the Solid Earth Tides
Rotational Deformation due to Polar Motion
Atmospheric Loading
Displacement of Reference Points of Instruments
VLBI Antenna Thermal Deformation

8. TIDAL VARIATIONS IN THE EARTH'S ROTATION

9. TROPOSPHERIC MODEL
Optical Techniques
Radio Techniques

10. GENERAL RELATIVISTIC MODELS FOR SPACE-TIME COORDINATES AND EQUATIONS OF MOTION
Time Coordinates

11. GENERAL RELATIVISTIC MODELS FOR PROPAGATION
VLBI Time Delay
Background
The VLBI delay model
Laser Ranging

Appendix — IAU Resolutions Adopted at the XXIVth General Assembly

Glossary

The contents of the IERS Conventions (2003) available at http://maia.usno.navy.mil/conv2003.html are presented below in outline form.

Introduction

Chapter 1 - Numerical Standards

Chapter 2 - Conventional Celestial Reference System and Frame

Chapter 3 - Conventional Dynamical Realization of the ICRS

Read me file for DE405 - Provides information concerning the retrieval and use of the DE405.

Chapter 4 - Conventional Terrestrial Reference System and Frame
ITRF2000 - Information on ITRF2000
GCONV subroutine - Transforms geocentric coordinates to geodetic coordinates. Provided by T. Fukushima
ABSMO Nuvel subroutine - Computes the new site position at time t from the old site position at time t0 using the recommended plate motion model. Originally provided by J. B. Minster.

Chapter 5 - Transformation Between the Celestial and Terrestrial Systems
Chapter 5 Tables - Electronic versions of the tables for Chapter 5
Chapter 5 Subroutines - Electronic versions of the subroutines for Chapter 5

Chapter 6 - Geopotential

Chapter 7 - Site Displacement
Angular Argument subroutine - A FORTRAN subroutine to return the proper angular argument to be used with the Schwiderski phases
Mean Pole Positions - mean pole positions provided by the IERS Earth Orientation Centre (D. Gambis).
Atmospheric Regresssion Coefficients - site displacements due to atomspheric loading at specific sites; provided by T. vanDam.

Chapter 8 - Tidal Variations in the Earth's Rotation
ortho eop subroutine - Subdiurnal/Diurnal Subroutine

Chapter 9 - Tropospheric Model

Chapter 10 - General Relativistic Models for Time, Coordinates and Equations of Motion
Fairhead-Bretagnon Model - Computes the periodic terms of TT. Provided by A. Irwin.
Xhf2002.f routine - Computes TCB-TCG as a function of TT. Provided by W. Harada and T. Fukushima.
HF2002.dat - Parameter file read by Xhf2002.f. Provided by W. Harada and T. Fukushima.
xhf2002.out - Output file of the test driver. Provided by W. Harada and T. Fukushima.

Chapter 11 - General Relativistic Models for Propagation

Appendix - Resolutions from the 24th IAU General Assembly

Glossary - List of acronyms used in the Conventions

In comparison with previous versions the latest version has undergone significant changes. These are outlined below by chapter. The principal contributors are also listed for each chapter.

Chapter 1-General Definitions and Numerical Standards

The chapter has been updated for consistency of notation and concepts with other sections according to IAG (International Association of Geodesy) and IAU working groups. It provides general definitions for topics in other chapters and

also the values of numerical standards that are used in the document. It incorporates the previous Chapter 4, which was updated to provide consistent notation and to comply with the recommendations of the most recent reports of the appropriate working groups of the International Association of Geodesy (IAG) and the IAU. It was prepared principally by D. McCarthy and G. Petit with major contributions from M. Burra, N. Capitaine, T. Fukushima, E. Groten, P. M. Mathews, P. K. Seidelmann, E. M. Standish, and P. Wolf.

Chapter 2-Conventional Celestial Reference System and Frame

The chapter, which appeared as Chapter 1 in previous editions has been updated to incorporate the effects of the IAU 2000 24th General Assembly by E. F. Arias with contributions from J. Kovalevsky, C. Ma, F. Mignard, and A. Steppe.

Chapter 3-Conventional Dynamical Reference Frame

Chapter 3 (previously Chapter 2), has been updated to be consistent with notation and concepts of other sections. The conventional solar system ephemeris has been changed to the Jet Propulsion Laboratory (JPL) DE405. It was prepared by E. M. Standish with contributions from F. Mignard and P. Willis.

Chapter 4-Conventional Terrestrial Reference System

Chapter 4 (previously Chapter 3) was rewritten by Z. Altamimi,, C. Boucher, and P. Sillard with contributions from J. Kouba, G. Petit, and J. Ray. It incorporates the new Terrestrial Reference Frame of the IERS (ITRF2000), which was introduced in 2001.

Chapter 5-Transformation Between the Celestial and Terrestrial Systems

The chapter was modified to be consistent with resolutions adopted at the 24th IAU General Assembly and the 2002 IERS Workshop. It was updated principally by N. Capitaine, with major contributions from P. M. Mathews and P. Wallace to comply with the recommendations of the IAU 2000 24th General Assembly. Significant contributions from P. Bretagnon, R. Gross, T. Herring, G. Kaplan, D. McCarthy, Burghard Richter and P. Simon were also incorporated.

Chapter 6-Geopotential

Chapter 6 was updated to include the EGM96 conventional geopotential model and the treatment of tides. V. Dehant, P. M. Mathews, and E. Pavlis were responsible for the revision. Major contributions were also made by P. Defraigne, S. Desai, F. Lemoine, R. Noomen, R. Ray, F. Roosbeek, and H. Schuh.

Chapter 7-Site Displacement

This chapter was updated to be consistent with the geopotential model recommended in Chapter 6. It was prepared principally by V. Dehant, P. M. Mathews, and H.-G. Scherneck. Major contributions were also made by Z. Altamimi, S. Desai, S. Dickman, R. Haas, R. Langley, R. Ray, M. Rothacher, H. Schuh, and T. VanDam. A model for post-glacial rebound is no longer recommended and a new ocean-loading model is suggested. The VLBI antenna

deformation has been enhanced.

Chapter 8-Tidal Variations in the Earths Rotation

Changes were made to be consistent with the nutation model adopted at the 24th IAU General Assembly. The model of the diurnal/semidiurnal variations has been enhanced to include more tidal constituents. The principal authors of Chapter 8 were Ch. Bizouard, R. Eanes, and R. Ray. P. Brosche, P. Defraigne, S. Dickman, D. Gambis, and R. Gross also made significant contributions.

Chapter 9-Tropospheric Model

This chapter has been changed to recommend an updated model. It is based on the work of C. Ma, E. Pavlis, M. Rothacher, and O. Sovers, with contributions from C. Jacobs, R. Langley, V. Mendes, A. Niell, T. Otsubo, and A. Steppe.

Chapter 10-General Relativistic Models for Time, Coordinates and Equations of Motion

The chapter has been updated for consistency of notation and concepts with other sections. New software for the TCB-TCG transformation, developed by Harada and Fukushima, has been checked against existing programs and added to the list of such standards. Previously appearing as Chapter 11, it has been updated to be in compliance with the IAU resolutions and the notation they imply. It was prepared principally by T. Fukushima and G. Petit with major contributions from P. Bretagnon, A. Irwin, G. Kaplan, S. Klioner, T. Otsubo, J. Ries, M. Soffel, and P. Wolf.

Chapter 11-General Relativistic Models for Propagation

This chapter (previously Chapter 12), has been updated for consistency of notation and concepts with other sections. It was updated to comply with the IAU resolutions and the notation they imply. It is based on the work of T. M. Eubanks and J. Ries. Significant contributions from S. Kopeikin, G. Petit, L. Petrov, A. Steppe, O. Sovers, and P. Wolf were incorporated.

5. Future

The IERS Conventions Center intends to provide updated versions of the Conventions on the web site. These editions will be clearly marked regarding the date of their electronic publication. In addition, the Center will provide printed versions of the Conventions at less frequent intervals when major changes are introduced.

The BIPM has provided for a visiting scientist to investigate the effects of selected models on the products of the IERS Analysis Centers. This is being done in collaboration with the IERS Analysis Coordinator and different Product and Analysis centers. The Product Center will continue to determine the most important directions to improve the consistency of IERS combined solutions and how to implement new conventional models and procedures. Important topics for the future include geocenter motion, impact of using global as opposed to local loading models, and network effects in the solutions of different techniques.

6. Conclusion

The IERS Conventions are the product of the IERS Conventions Product Center. However, this work would not be possible without the contributions acknowledged above. In addition, we would also like to acknowledge the comments and contributions of S. Allen, Y. Bar-Sever, A. Brzeziński, M. S. Carter, P. Cook, H. Fliegel, M. Folgueira, J. Gipson, S. Howard, T. Johnson, M. King, S. Kudryavtsev, Z. Malkin, S. Pagiatakis, S. Pogorelc, J. Ray, S. Riepl, C. Ron, and T. Springer in the compilation of the work.

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