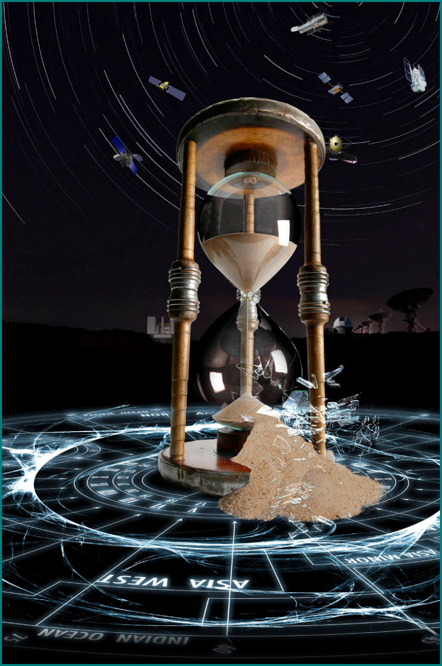
DECOUPLING CIVIL TIMEKEEPING FROM EARTH ROTATION

Edited by
John H. Seago
Robert L. Seaman
Steven L. Allen



American Astronautical Society

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SCIENCE AND TECHNOLOGY SERIES

DECOUPLING CIVIL TIMEKEEPING FROM EARTH ROTATION

Front Cover Illustration:

The Decoupling of Civil Timekeeping from Earth Rotation shatters the astronomical paradigm of human timekeeping maintained since ages immemorial.

Image Credit: Artwork by Pete Marenfeld, courtesy of NOAO.

American Astronautical Society

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Volume 113
SCIENCE AND TECHNOLOGY SERIES

A Supplement to Advances in the Astronautical Sciences

Proceedings of a Colloquium Exploring Implications of Redefining Coordinated Universal Time (UTC), held October 5–7, 2011 at Analytical Graphics, Inc., Exton, Pennsylvania.

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FOREWORD

On October 5 and October 6, 2011, a colloquium on *Decoupling Civil Timekeeping from Earth Rotation* was hosted in Exton, Pennsylvania by Analytical Graphics, Inc. (AGI), a leading software solutions company for the aerospace, defense, and intelligence industries. AGI's involvement with the topic of UTC redefinition began in 2003, when the company was asked to provide a position statement in preparation for the ITU-R *Special Colloquium on the Future of the UTC Timescale* at IEN in Torino, Italy. At the time, AGI's Chief Orbital Scientist did not expect UTC redefinition to impact its own internally developed software, yet AGI recognized that its own software products might experience indirect impacts from the adoption of third-party software models. AGI also realized that UTC redefinition "could adversely affect software applications or database definitions" as well as the "accuracy of certain low precision applications" throughout the astrodynamics community. AGI's position was that the company would necessarily adapt to changing standards to meet customer needs, but it was the company's "sincerest hope that the voice of the astrodynamics community is heard." Therefore, it seemed fitting that AGI should open its facilities to host a colloquium, co-sponsored by the American Astronautical Society (AAS) and the American Institute of Aeronautics and Astronautics (AIAA), to afford an opportunity for the astrodynamics community to be heard before a concluding vote to decouple civil timekeeping from Earth rotation by the Radiocommunications Assembly of the ITU-R in January 2012.

The colloquium was co-hosted by the National Optical Astronomy Observatory (NOAO) and the Virtual Astronomical Observatory (VAO). The opportunity for participation was not limited to astronomical and astronautical interests, however. Understanding that the implications of decoupling extend from technical infrastructure to legal, historical, logistical, sociological, and economic domains, technical and non-technical contributions were solicited from widely disparate fields. These fields included, but were not limited to: astronomy, astrodynamics and celestial mechanics, geophysical Earth-orientation, navigation (GNSS and celestial), remote sensing and space surveillance, spacecraft applications, sundialing, *etc*.

International interest in the colloquium was remarkable given that the meeting was announced with about four months' notice, with presenters having to provide original papers for the colloquium's archival proceedings. The meeting chairmen received many regrets from interested parties who were unable to contribute due to the constraints of personal schedule or economy. The number of contributed manuscripts was very strong relative to the efforts of similar meetings:* twenty-two (22) papers were eventually contributed on diverse topics related to a variety of timekeeping aspects. These were presented over two days to an audience of seventeen discussants representing opinions both favoring and opposing the decoupling of civil timekeeping from Earth rotation (Figure 1). Six contributing co-authors could not attend in person: Danny Hillis of Applied Minds, Inc., Denis Savoie of the Palais de la découverte and Observatoire de Paris, Florent Deleflie, Jérome Berthier,

* Fourteen presentations were given at the 2003 ITU-R *Special Colloquium on the Future of the UTC Timescale* in Torino, and twelve presentations were given at the 2011 meeting *UTC for the 21st Century* sponsored by the Royal Society.

and Christophe Barache of the Observatoire de Paris, and Jon Giorgini of the Jet Propulsion Laboratory (JPL). Neil deGrasse Tyson of the Hayden Planetarium and the American Museum of Natural History, and Steven Slojkowski of NASA Goddard Space Flight Center, also participated as interested discussants.

In addition to the scheduled technical presentations and discussions, Frank Reed, a navigation instructor with Reed Navigation and Mystic Seaport Museum, provided a suppertime presentation entitled *GMT by Observation: The Historical Method of Lunars* on Wednesday, October 5. The "method of lunars" involves a determination of time using a hand-held sextant, as based on the angle of the Moon from other bright celestial objects. Mr. Reed's presentation featured excerpts from historic ship logbooks and plots of ocean voyages during the 18^{th} and 19^{th} centuries as determined from navigation fixes recorded in these logbooks. Blank pages from the backs of old logbooks often contained completely worked examples of the method of lunars, each requiring roughly 20 minutes of arithmetic to reduce sextant observations of the Moon to obtain the time. *The American Ephemeris and Nautical Almanac* continued to carry "lunar distance" ephemerides, used by practitioners of the method, through the 1911 edition. However, by the mid- to late-19^{th} century, the method of lunars had become mostly obsolete, as it became more accurate and convenient to carry multiple ship-borne chronometers to determine and maintain time (and therefore position) at sea.

Mr. Reed offered attendees the opportunity to try their hand at determining time using the historical method of lunar-distance observation using a sextant. After supper, a handful of colloquium attendees gathered under darkness at a nearby hotel parking lot. Participants exercised their traditional navigation skills by measuring the arc between Jupiter and the lunar limb using sextants supplied by Mr. Reed. Using software, Mr. Reed reduced the limb measurements into a determination of time almost instantly. The best measurements obtained would have been good enough to fix a position to better than a nautical mile.

On Friday, October 7, nine colloquium attendees and their guests participated in a morning tour of the grand Analemmatic Sundial at Longwood Gardens in nearby Kennett Square, Pennsylvania. This event included a special orientation and behind-the-scenes technology tour of the Longwood Gardens facilities by staff historian Colvin Randall, and featured a short talk by P. Kenneth Seidelmann who redesigned the sundial in the early 1970s to keep accurate standard time. Dr. Seidelmann's manuscript on the analemmatic sundial adds to these proceedings a significant example of a timeless public apparatus that presumes civil timekeeping will remain accurately coupled to Earth rotation.

At the request of some colloquium attendees and other interested professionals, the co-chairs have included an extended introduction and summary of meeting's topic and technical points as a separate paper. This summary, which is an expression of the co-chairs, is no substitute for exploring the actual manuscripts and discussions, therefore readers are encouraged to consider the proceedings volume in its entirety.

John H. Seago
Robert L. Seaman
Steven L. Allen

Volume Editors

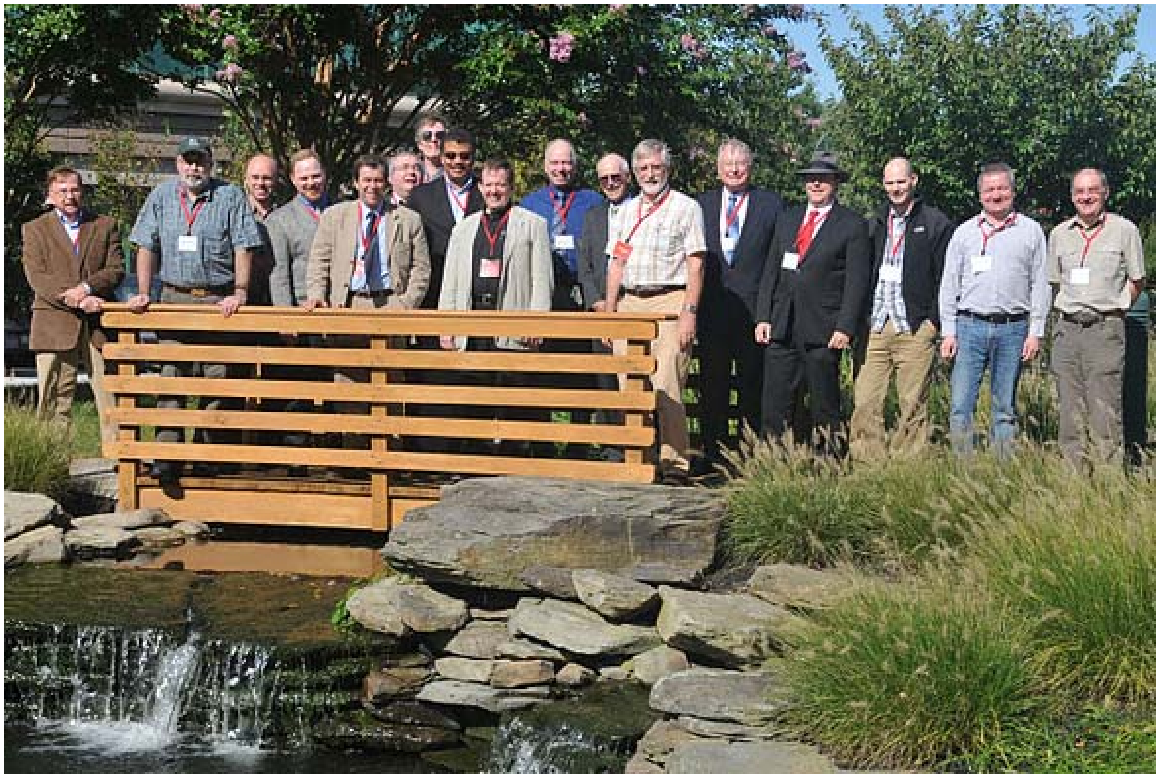

Figure 1. Colloquium Attendees.

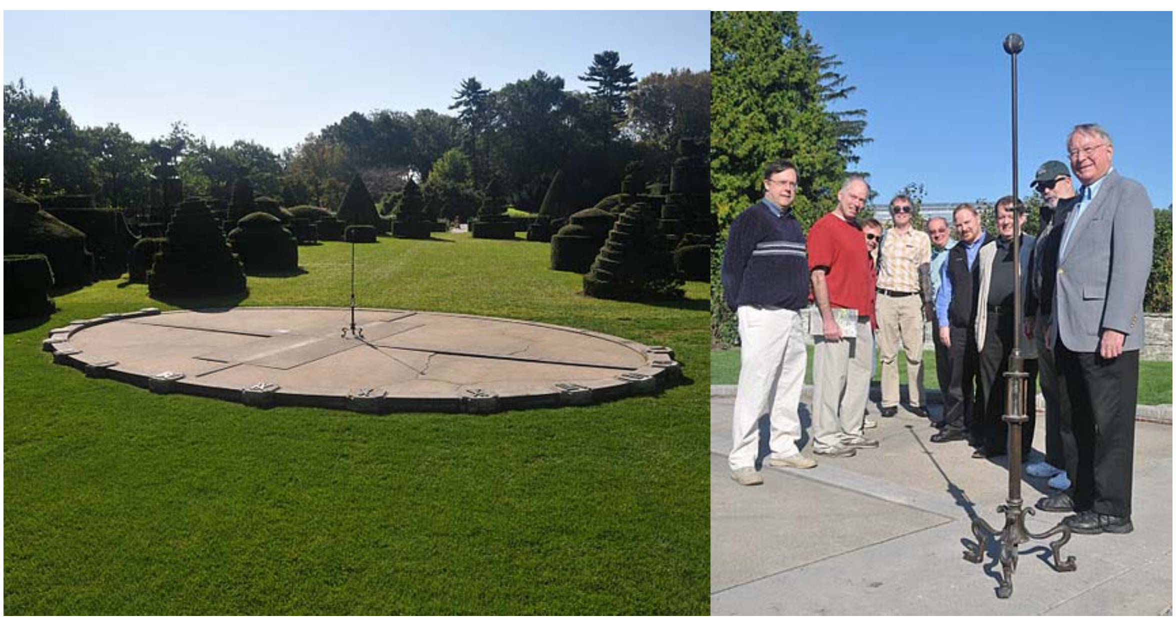

Figure 2. The Analemmatic Sundial at Longwood Gardens.

Table 1. Colloquium Attendees (as ordered from left to right in Figure 1)

Name	Organization	Nationality
George H. Kaplan	IAU Commission 4	USA
Robert L. (Rob) Seaman	National Optical Astronomy Observatory (NOAO)	USA
Wolfgang R. Dick	IERS Central Bureau, Bundesamt für Kartographie und Geodäsie (BKG)	Germany
John H. Seago	Analytical Graphics, Inc. (AGI)	USA
Daniel Gambis	IERS Earth Orientation Center, Observatoire de Paris	France
Steven (Steve) Malys	National Geospatial-Intelligence Agency (NGA)	USA
Steven L. (Steve) Allen	UCO/Lick Observatory	USA
Neil deGrasse Tyson	Hayden Planetarium American Museum of Natural History	USA
Paul Gabor	Vatican Observatory	Czech Republic
Mark F. Storz	United States Air Force Space Command (AFSPC)	USA
Dennis D. McCarthy	United States Naval Observatory (USNO, retired)	USA
Arnold H. Rots	Smithsonian Astrophysical Observatory (SAO)	The Netherlands
P. Kenneth (Ken) Seidelmann	University of Virginia (UVa)	USA
David G. Simpson	NASA Goddard Space Flight Center (GSFC)	USA
Steven Slojkowski	NASA Goddard Space Flight Center (GSFC)	USA
Frank E. Reed	Reed Navigation, Mystic Seaport Museum	USA
David L. Terrett	Rutherford Appleton Laboratory (RAL) Space	UK

CONTENTS

INTRODUCTION

AAS 11-660

THE COLLOQUIUM ON DECOUPLING CIVIL TIMEKEEPING FROM EARTH ROTATION

John H. Seago,[*] Robert L. Seaman[†] and Steven L. Allen[‡]

On October 5 and October 6, 2011, the Colloquium on the *Decoupling Civil Timekeeping from Earth Rotation* was hosted in Exton, Pennsylvania by Analytical Graphics, Inc. (AGI). This paper highlights various technical perspectives offered through these proceedings, including expressions of concern and various recommendations offered by colloquium participants. [View Full Paper]

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‡ Programmer/Analyst, UCO/Lick Observatory, ISB 1156 High Street, Santa Cruz, California 95064, U.S.A.

SESSION 1:
SETTING THE STAGE

SYSTEMS ENGINEERING FOR CIVIL TIMEKEEPING

Rob Seaman*

The future of Coordinated Universal Time has been a topic of energetic discussions for more than a dozen years. Different communities view the issue in different ways. Diametrically opposed visions exist for the range of appropriate solutions that should be entertained. Rather than an insoluble quandary, we suggest that well-known systems engineering best practices would provide a framework for reaching consensus. This starts with the coherent collection of project requirements. [View Full Paper]

* Senior Software Systems Engineer, National Optical Astronomy Observatory, 950 N Cherry Ave, Tucson, Arizona 85719, U.S.A.

AAS 11-662

LEGISLATIVE SPECIFICATIONS FOR COORDINATING WITH UNIVERSAL TIME*

John H. Seago,† P. Kenneth Seidelmann‡ and Steve Allen§

The abolition of intercalary (leap) seconds within Coordinated Universal Time (UTC) would create a new civil timekeeping standard fundamentally different from solar timekeeping or Earth rotation. Such a standard has no known civil precedent and would present national governments with certain legal, technical and philosophical questions brought by the abandonment of the long-standing mean-solar-time standard. This paper elevates awareness of some of these questions; specifically, the laws of some nations and international unions require time based on the mean solar time at the meridian of Greenwich, or, if one prefers, Universal Time (UT). Since statutory specifications have not demanded ultra-precise uniformity of rate for civil timekeeping based on mean solar time, the continued synchronization of atomic UTC with Universal Time has allowed UTC to proliferate as a legally acceptable world standard. It is presumable that some nations promoted the legal status of "UTC" in the belief that a time scale named "Coordinated Universal Time" might remain coordinated with Universal Time in perpetuity. For this reason, a civil broadcast standard no longer coordinated with UT might not be easily reconciled with existing national statutes, thus requiring changes to statues or exceptional broadcast realizations. Civil broadcast standards failing to approximate Universal Time would best avoid the label "Coordinated Universal Time" and its acronym "UTC", since these descriptions have always implied a realization of Universal Time, in title and purpose, both inside and outside statutory and regulatory prescriptions. [View Full Paper]

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* This paper updates the unpublished manuscript "National Legal Requirements for Coordinating with Universal Time" written in 2003 by John H. Seago and P. Kenneth Seidelmann.

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SESSION 2:
THE PAST, PRESENT,
AND FAR FUTURE

THE HEAVENS AND TIMEKEEPING, SYMBOLISM AND EXPEDIENCY

Paul Gabor*

Timekeeping has always followed the heavens for reasons of practicality and symbolism. These two motivations can have conflicting implications for the concrete implementation of timekeeping mechanisms. Even in this eminently pragmatic age we have little control over the power of temporal symbols. This paper focuses on the deeper dynamics underlying timekeeping, proposing several notions which can serve as tools in examining the past and the present of chronology: continuity, timelessness, inertia, expediency, empirical and calculated schemes, symbolism and reality. We show that the principle of astronomical conformity in timekeeping seems to fulfill its social function even when it is not perfectly observed. In the realm of symbolism, what counts is the general perception, not the fact. Throughout history, expediency dictates a general trend away from empirical timekeeping to calculated schemes. These do not follow the principle of astronomical conformity strictly, rather, they respect it on average, aided by empirical correction mechanisms. In the present case, debating the relative merits of UTC as defined in 1972 and the proposed uniform civil time is very much an instance of this general shift away from empirical timekeeping. Calculated timekeeping does not actually agree with the Heavens at any given moment but this does not seem to jeopardize the general perception of its astronomical conformity. The general perception seems to follow the intention rather than the fact. This paper proposes to examine the dynamics of symbolism and expediency in the long history of timekeeping compromise, and apply these findings to the proposed decoupling of civil time from Earth's rotation.
[View Full Paper]

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LEAP SECONDS IN LITERATURE

John H. Seago*

The advent of electronic textbooks and the digitization of less-recent scholarly documents has resulted in significantly increasing amounts of archived information searchable via computer networks. Internet search-engine technology can therefore be used to casually discover hundreds of archival references that reference *status-quo* UTC with leap seconds. While searchable electronic documents represent only a fraction of literature actually published, such reviews suggest a range of technical fields that may rely on UTC, the literature of which would be need to be revised should UTC be redefined. [View Full Paper]

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AAS 11-665

TIME IN THE 10,000-YEAR CLOCK

Danny Hillis,[*] Rob Seaman,[†] Steve Allen[‡] and Jon Giorgini[§]

The Long Now Foundation is building a mechanical clock that is designed to keep time for the next 10,000 years. The clock maintains its long-term accuracy by synchronizing to the Sun. The 10,000-Year Clock keeps track of five different types of time: Pendulum Time, Uncorrected Solar Time, Corrected Solar Time, Displayed Solar Time and Orrery Time. Pendulum Time is generated from the mechanical pendulum and adjusted according to the equation of time to produce Uncorrected Solar Time, which is in turn mechanically corrected by the Sun to create Corrected Solar Time. Displayed Solar Time advances each time the clock is wound, at which point it catches up with Corrected Solar Time. The clock uses Displayed Solar Time to compute various time indicators to be displayed, including the positions of the Sun, and Gregorian calendar date. Orrery Time is a better approximation of Dynamical Time, used to compute positions of the Moon, planets and stars and the phase of the Moon. This paper describes how the clock reckons time over the 10,000-year design lifetime, in particular how it reconciles the approximate Dynamical Time generated by its mechanical pendulum with the unpredictable rotation of the Earth. [View Full Paper]

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MIDDAY ROUND-TABLE DISCUSSION OF OCTOBER 5, 2011

MIDDAY ROUND-TABLE DISCUSSION OF OCTOBER 5, 2011

The context for decoupling civil timekeeping from Earth rotation includes the long history of international regulation of time signals in radio broadcasts. This discussion filled in the background for many of the legal and technical aspects of the national processes which contribute to the decisions made by the ITU-R. [View Full Discussion]

SESSION 3:
EARTH ORIENTATION

USING UTC TO DETERMINE THE EARTH'S ROTATION ANGLE

Dennis D. McCarthy[*]

The Earth's rotation angle is a critical component of the suite of five Earth orientation parameters used to transform between terrestrial and celestial reference systems. This angle is defined mathematically using an adopted conventional relationship between UT1 and the mathematical quantity known as "Earth Rotation Angle" (ERA). For practical purposes, then, UT1–UTC provides a convenient means to obtain UT1, knowing UTC, and thus the ERA. Because the Earth's rotational speed is variable, it is not practical to model UT1 as a function of time with the accuracy needed for many applications. Consequently astronomical and geodetic institutions from around the world share observations of the Earth's rotation angle and these data are then used to provide users the latest observations of UT1–UTC as well as predicted estimates with accuracy that depends on the prediction interval. This process can provide users with daily updates of UT1–UTC with accuracy of the order of tens of microseconds and predictions with accuracy better than 1 millisecond up to ten days in advance. The International Earth Rotation and Reference Systems Service (IERS) was established in 1987 by the International Astronomical Union and the International Union of Geodesy and Geophysics to provide this information operationally. In addition to the services routinely providing UT1 with sub-millisecond accuracy, UTC is currently adjusted to keep |UT1–UTC| < 0.9 seconds, and this definition provides a means to access UT1 automatically with accuracy of the order of one second. Should UTC be defined without the restriction keeping |UT1–UTC| < 0.9 seconds, the low accuracy estimate of UT1 (± 1 second) would no longer be assured. However the existing national and international services can be expected to provide the current products as they do now via paper bulletin and electronic means. It is assumed that the accuracy of those products will always reflect the state of the art. In the future, high-speed transfer of high-quality observational astronomical, meteorological, oceanic and geophysical data promise to decrease the latency of the observations and provide UT1–UTC at sub-daily intervals with increasingly improving accuracy. In addition to the current means of distribution, increasing access to electronic communication services has the potential to provide near real-time, state of the art UT1–UTC to users when and wherever it is needed. If there were sufficient demand, we might even envision a UT1–UTC application being made available for future hand-held devices. [View Full Paper]

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AAS 11-667

THE IERS, THE LEAP SECOND, AND THE PUBLIC

Wolfgang R. Dick*

Bulletin C with announcements of leap seconds is the most popular of IERS products. A large part of requests from the public received by the IERS Central Bureau concerns the leap second. Although other IERS products may be of more importance, leap-second announcements produce a maximum of attention with a minimum of efforts. IERS has plans for an UT1 time service in case that UTC would be redefined. However, with respect to the public relations of the IERS, a possible abolishment of the leap seconds has to be compensated by other outreach activities which will attract similar public attention. [View Full Paper]

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RESULTS FROM THE 2011 IERS EARTH ORIENTATION CENTER SURVEY ABOUT A POSSIBLE UTC REDEFINITION

Daniel Gambis, Gérard Francou and Teddy Carlucci*

The Earth Orientation Product Center is responsible for the prediction and announcement of the leap second (Bulletin C) and the announcement of the value of DUT1 truncated at 0.1 s for transmission with time signals. A first survey made in 2002 show that 89% of IERS users were satisfied by the current determination of UTC, including leap seconds introductions. With the increasing number of users belonging to the various communities, it was felt necessary to take a new survey to find out the strength of opinion for maintaining or changing the present system before the proposal of redefining UTC is discussed at the ITU-R meeting which will be held in Geneva in January 2012. [View Full Paper]

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SESSION 4:
TIME SCALE APPLICATIONS

TRADITIONAL CELESTIAL NAVIGATION AND UTC

Frank E. Reed*

Traditional celestial navigation depends on accurate knowledge of some standard mean time. While transitioning to a time gradually decoupled from the Earth's rotation should present no serious problems for users who actively practice celestial navigation at sea, there are issues concerning possible confusion in the literature, textbooks, and other educational materials already published. Celestial navigation, though a backup of last resort, is still widely taught at maritime academies worldwide and in less formal classes. If DUT continues to be published and disseminated and identified as a simple "watch error," the continuity of textbooks and navigational practice will be maintained.
[View Full Paper]

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AAS 11-670

THE CONSEQUENCES OF DECOUPLING UTC ON SUNDIALS

Denis Savoie* and Daniel Gambis†

Severing the link between the rotation of the Earth and time-signal broadcasts will require a fourth correction to convert between solar time and standard legal time in the long term. For sundials, this represents an additional complexity, both for people using these instruments as educational tools, and for those who design them. Knowing the precision that can be expected of sundials, how long will it take for the decoupling of UTC to become noticeable? [View Full Paper]

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AAS 11-671

TIME SCALES IN ASTRONOMICAL AND NAVIGATIONAL ALMANACS

George H. Kaplan*

Commission 4 (Ephemerides) of the International Astronomical Union (IAU) includes astronomers from many countries responsible for the production of printed almanacs, software, and web services that provide basic data on the positions and motions of celestial objects, and the times of phenomena such as rise and set, eclipses, phases of the Moon, etc. This information is important for pointing telescopes, determining optimal times for observations, conducting night operations, and also for celestial navigation. Commission 4 also includes researchers involved in the more fundamental tasks of determining the orbits of solar system bodies based on a variety of observations taken from the ground and spacecraft. We assume that the data we produce are used by a variety of people that have a broad range of scientific sophistication.

In the almanacs, software, and web services that Commission 4 members produce, data that are independent of the rotation of the Earth, such as the geocentric celestial coordinates (right ascension and declination) of the Sun, Moon, planets, and stars, are generally provided as a function of Terrestrial Time (TT). In practice, TT is based on atomic time (TT=TAI+32.184s) and as such, it can be extended indefinitely into the future without ambiguity or error.

On the other hand, data that depend on the rotation of the Earth, such as Greenwich hour angles or the topocentric coordinates (zenith distance and azimuth) of celestial objects, have traditionally been provided as a function of Universal Time, specifically UT1. UT1 is inherently unpredictable because of natural irregularities in the length of day, but the current international time protocol guarantees that UTC, the basis for civil time worldwide, is never more than 0.9 seconds from UT1. For many users and software applications, the approximation UT1=UTC is adequate and is assumed. Many users, particularly navigators, are probably not even aware of the distinction between UTC and UT1.

A change in the definition of UTC that allows it to diverge from UT1 without bound therefore creates a challenge as to how to provide future data that are a function of the rotational angle of the Earth, and how to educate users on the change. Several ideas for how to proceed that have been circulating among Commission 4 members will be explored. [View Full Paper]

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AAS 11-672

ISSUES CONCERNING THE FUTURE OF UTC

P. Kenneth Seidelmann[*] and John H. Seago[†]

Historically, civil timekeeping has been based on mean solar time. With the discovery that the rotation of the Earth was not perfectly uniform, time scales based on the rotation of the Earth were differentiated from more uniform scales, with astronomical time still serving as the basis of calendars and time of day. UT1 is now the observationally determined time based on the rotation of the Earth, whereas International Atomic Time (TAI) is a precise uniform time scale determined from atomic clocks. Coordinated Universal Time (UTC) was introduced in 1972 as an atomic time scale referenced to TAI, but with epoch adjustments via leap seconds to remain within one second of UT1 for the purposes of civil timekeeping. A family of dynamical times was further established to satisfy the theory of relativity and the requirements of solar system ephemerides. A proposal to redefine UTC without leap seconds has been forwarded for final consideration by the Radiocommunications Assembly of the International Telecommunications Union (ITU) without having reached a consensus within the study group commissioned to resolve the study question. The question of whether to redefine UTC has been discussed, surveyed, and studied for over a decade, yet there is no public record of an analysis of requirements and no cost estimates of the various alternative options. The status of the leap second issue, user considerations and perspectives, and the unresolved issues concerning the proposed change to UTC will be overviewed in this paper. Due to the pervasiveness of the UTC time scale, concern is expressed that a fundamental change to UTC will require much technical activity, review, testing, and documentation changes. This will occur regardless of whether or not certain systems or applications functionally benefit from the change in definition, and may create additional work for applications which may not ordinarily deal with these technical details, or which are already satisfied and compliant with the status quo. [View Full Paper]

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SESSION 5:
SPACE OPERATIONS

AAS 11-673

UTC AND THE HUBBLE SPACE TELESCOPE FLIGHT SOFTWARE

David G. Simpson*

Many scientific spacecraft include on-board computers whose flight software implicitly assumes a correspondence between the UT1 and UTC time scales. Using the Hubble Space Telescope flight software as an example, we examine the aspects of on-board computer flight software that may make use of these time scales, and consider how the software may be impacted by allowing the two time scales to diverge.
[View Full Paper]

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COMPUTATION ERRORS IN LOOK ANGLE AND RANGE DUE TO REDEFINITION OF UTC*

Mark F. Storz†

With the decision on whether or not to discontinue leap seconds scheduled for January 2012, it is important to develop tools to evaluate the error that can be expected in operational software that tracks space objects from the ground or ground objects from space. These tools focus on the error that would occur in software that uses Coordinated Universal Time (UTC) as an approximation to Universal Time 1 (UT1). These error evaluation tools input the difference (in seconds) between UT1 and redefined UTC and a user-specified altitude for space objects. From these inputs, one of the tools plots a grid of look angles in polar coordinates thus generating a "sky plot" as seen from a particular ground location. This tool shows the true position in the sky when one uses UT1 to compute Earth orientation and the biased position in the sky when one uses redefined UTC. The two positions are connected by an arc from the true position to the biased position. This arc is the path the biased position would take as one gradually increases the separation between UT1 and redefined UTC. The color of the arc changes according to the bias in range. This tool also outputs the true and biased values for range, azimuth angle and elevation angle at all grid points. This, and related tools provide the user a sense of the adverse operational impacts as the biased position deviates more and more from the true position. [View Full Paper]

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PROPOSAL FOR THE REDEFINITION OF UTC: INFLUENCE ON NGA EARTH ORIENTATION PREDICTIONS AND GPS OPERATIONS*

Stephen Malys†

The Earth-Centered, Earth-Fixed World Geodetic System 1984 (WGS 84) reference frame is realized by the adoption of a self-consistent set of highly-accurate coordinates for the Department of Defense (DoD) Global Positioning System (GPS) Monitor Stations. Over the past several decades, procedures, Interface Control Documents, and operational, configuration-controlled software have been designed for UT1-UTC to be less than 1.0 second. In some cases, automated 'limit checks' have been established on this parameter. The proposed discontinuation of leap seconds and redefinition of UTC will impact these operations. A significant amount of time, effort, and funding will be required for NGA and other organizations to identify and assess all operational software impacted by the change. While the proposal may benefit other communities, a redefinition of UTC and the elimination of leap seconds offer no benefits or improvements to National Geospatial-Intelligence Agency (NGA) or GPS operations. [View Full Paper]

* Approved for Public Release Case 11-469.

† Senior Scientist for Geodesy and Geophysics, InnoVision Basic and Applied Research Office, National Geospatial-Intelligence Agency, 7500 GEOINT Drive, Springfield, Virginia 22150, U.S.A.

SESSION 6:
GROUND OPERATIONS

AAS 11-676

UTC AT THE HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS (CFA) AND ENVIRONS

Arnold H. Rots*

The Smithsonian Astrophysical Observatory is involved in the operation of observatories across the entire electromagnetic spectrum and associated with several other data providers. Although the reliance on UTC and constraints on the value of DUT1 vary, there is considerable apprehension about changing the definition. In particular there is a sense that it may cause considerable confusion and misunderstanding in the context of the Virtual Observatory. [View Full Paper]

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AAS 11-677

AN INVENTORY OF UTC DEPENDENCIES FOR IRAF

Rob Seaman*

The Image Reduction and Analysis Facility is a scientific image processing package widely used throughout the astronomical community. IRAF has been developed and distributed by the National Optical Astronomy Observatory in Tucson, Arizona since the early 1980's. Other observatories and projects have written many dozens of layered external application packages. More than ten thousand journal articles acknowledge the use of IRAF and thousands of professional astronomers rely on it. As with many other classes of astronomical software, IRAF depends on Universal Time (UT) in many modules throughout its codebase. The author was the Y2K lead for IRAF in the late 1990's. A conservative underestimate of the initial inventory of UTC "hits" in IRAF (*e.g.*, from search terms like "UT", "GMT" and "MJD") contains several times as many files as the corresponding Y2K ("millennium bug") inventory did in the 1990's. We will discuss dependencies of IRAF upon Coordinated Universal Time, and implications of these for the broader astronomical community. [View Full Paper]

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AAS 11-678

TELESCOPE SYSTEMS AT LICK OBSERVATORY AND KECK OBSERVATORY

Steven L. Allen*

The telescopes in active use at Lick Observatory and Keck Observatory were constructed over an interval spanning more than a century. All of the telescope systems were designed in an era when systems which provide civil time were based on the rotation of the earth. Existing software systems for the control of telescopes at Lick Observatory and Keck Observatory use UTC as a close approximation to UT1. If UTC abandons leap seconds then ongoing operation will require various strategies suitable for each different telescope. [View Full Paper]

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MIDDAY ROUND-TABLE DISCUSSION OF OCTOBER 6, 2011

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The draft of the proposal to be voted upon at the ITU-R Radiocommunication Assembly in January 2012 offers only two options: maintain the status quo with leap seconds, or abandon the insertion of leap seconds altogether. This discussion contemplated the viability of other possible options. Variations on the handling of time have already been tried. In most cases there have been quirks which limit the applicability of various options or which cause confusion among users needing precise time.
[View Full Discussion]

SESSION 7:
CONTINGENCY PROPOSALS

AUTOMATING RETRIEVAL OF EARTH ORIENTATION PREDICTIONS

David L. Terrett[*]

As the range of applications requiring knowledge of UT1-UTC increases, the demand for access to this information in a machine readable format over the Internet will increase. The current format, the text of the IERS Bulletin A, is not ideally suited to this purpose for a number of reasons. The exact format of the file is not defined so that anyone writing a program that extracts information from the bulletin has to guess the rules governing the format by inspecting samples. Any such program is at risk if, for any reason the format changes. This paper explores whether there are alternatives to Bulletin A that would be more suitable for ingestion by computer systems and could be implemented within the resources available to the IERS. Suitable standards-based technologies exist but must have both a long expected lifetime and be practical to implement both for the producer and the consumer. A concrete proposal based on XML standards is included. [View Full Paper]

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AAS 11-680

DISSEMINATION OF UT1-UTC THROUGH THE USE OF VIRTUAL OBSERVATORY

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Information concerning UT1-UTC and the occurrence of the leap seconds are currently made available via IERS bulletins (Bulletin D and C) sent to users in ASCII format. However, this old-fashioned procedure does not satisfy automatic systems. We have investigated the way to develop a new service based on the concept of Virtual Observatory (VO). This concept, provided by the International Virtual Observatory Alliance (IVOA), allows scientists and the public to access and retrieve UT1-UTC information using on-line distributed computational resources. We describe here how we derived the concept, using the XML-based VOTable format to build this UT1-UTC dedicated new service. [View Full Paper]

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TIMEKEEPING SYSTEM IMPLEMENTATIONS: OPTIONS FOR THE *PONTIFEX MAXIMUS*

Steven L. Allen[*]

A representation for the meaning of time and the rules for handling it is built into many operational systems – civil, legal, hardware, software, etc. Many of these systems have avoided implementing the complexity required to handle leap seconds, yet some demand their existence. A plausible change to the scheme of UTC must be compatible with existing systems and should be easy to implement. I propose a small change to the representation of leap seconds which allows the tz code to describe them in a way that alleviates the underlying problems with information processing systems. It preserves the traditional meaning of civil time as earth rotation. It allows for trivial testing of the effects of leap seconds on software and hardware systems. It is a compromise that gives easy access to all forms of time information. It is not without consequences that will have to be handled. [View Full Paper]

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CONCLUDING
ROUND-TABLE DISCUSSION

CONCLUDING ROUND-TABLE DISCUSSION

In the concluding discussion of *Decoupling Civil Timekeeping from Earth Rotation*, each attendee expressed parting thoughts regarding the topics raised during the presentations and earlier discussions. Issues of timekeeping terminology, standards, infrastructure, and public perceptions were raised. Short- and long-term planning, especially for software and broadcast systems, were discussed. [View Full Discussion]

SPECIAL SESSION

AAS 11-682

THE LONGWOOD GARDENS ANALEMMATIC SUNDIAL

P. Kenneth Seidelmann*

The analemmatic sundial at Longwood Gardens was originally built in 1939, based on the design of a sundial at the Cathedral of Brou, France, which was originally built in the early 16th century. The Longwood sundial is 24 by 37 feet with a gnomon movable along an analemma. The hour markers are moveable for daylight saving time. However, the sundial did not tell time correctly. The U.S. Naval Observatory was contacted by the director of maintenance at Longwood Gardens about the problem. After measuring the sundial and computing a solar ephemeris for the location, computations were made to determine the correct locations for the gnomon. Analemmas very different from the current ones were determined for the morning and afternoon hours. After contact with a historian in Brou, France, it was determined that the sundial there had been rebuilt twice, and the current design did not tell the correct time either. That inaccurate sundial design from France was revised by computer technology to give an analemmatic sundial that told mean solar time directly, including the correction for the equation of time. [View Full Paper]

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