Role of the IERS in the leap second

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Outline

- What is the IERS?
- Clock time (UTC)
- Earth rotation angle (UT1)
- Leap Seconds
- Measures and Predictions of Earth rotation
- How are Earth rotation data used?
- How the IERS provides for its customers
- Future considerations
- Summary

What is the IERS?

- The International Earth Rotation and Reference Systems Service (IERS) provides the following to the international scientific communities:
  - International Celestial Reference System (ICRS) and its realization the International Celestial Reference Frame (ICRF)
  - International Terrestrial Reference System (ITRS) and its realization the International Terrestrial Reference Frame (ITRF)
  - Earth orientation parameters that transform between the ICRF and the ITRF
  - Conventions (i.e. standards, models, and constants) used in generating and using reference frames and EOPs
  - Geophysical data to study and understand variations in the reference frames and the Earth's orientation
- Due to the nature of the data, there are many operational users

Brief history of the IERS

- The International Earth Rotation Service (IERS) was created in 1987
  - Responsible to the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG)
- IERS began operations on 1 January 1988
- IERS changed its name to International Earth Rotation and Reference Systems Service to better represent its responsibilities
  - Earth orientation relies directly on having accurate, well-defined reference systems

Structure of the IERS

IERS Components 2013

Directing Board	Analysis Coordinator	Central Bureau

Product Centres	ITRS Combination Centres	Working Groups	Technique Centres
Earth Orientation Centre	DGFI	Site Survey and Co-location	IGS
Rapid Service / Predictions Centre	IGN	Combination at the Observation Level	ILRS
Conventions Centre	JPL	Second Realization of the ICRF	IVS
ICRS Centre		SINEX Format	IDS
ITRS Centre		Site Coordinate Time Series Format	
Global Geophysical Fluids Centre			

Global Geophysical Fluids Centre:

- Special Bureau for the Oceans
- Special Bureau for Hydrology
- Special Bureau for the Atmosphere
- Special Bureau for Combination

Clock Time (UTC)

- UTC = Coordinated Universal Time
  - "Coordinated" because of original coordination between US and UK timing institutions
- Basis for civil time in many countries
- Related to atomic time
  - Atomic time is based on transitions in atoms
- The Système International (SI) second is defined by 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of the Caesium-133 atom

Earth Rotation Angle (UT1)

- Measure of Earth's rotation angle
  - Determined by measurements of "fixed" objects outside of Earth
  - Typically determine UT1-UTC
- Differences in the "length of day" between UT1 and UTC are typically 1 millisecond (ms)
  - Varies from less than -0.5 ms to more than 3 ms over the last 40 years
- Significant variability due to changes in weather, oceans, and hydrology
  - Difficult to predict accurately
  - Cumulative effect causes UT1 to gradually diverge from UTC
- Users typically want to connect locations on the ground with directions in space
  - E.g. GNSS systems, astronomers pointing telescopes, etc.

Leap Seconds

- UT1 diverges from UTC
  - Due to tidal deceleration and the way in which UTC was defined
  - Influenced by the natural variations in UT1
- Leap seconds were implemented in 1972 as a way to constrain the divergence
  - Allows the Earth to catch up with the clocks
    - Note that to do this, all clocks are stopped by 1 second
  - UTC is adjusted by leap seconds to ensure that $|UT1-UTC| < 0.9s$

Coordinated Universal Time

1 second adjustments

- From 1961 to 1972 UTC contained both rate changes and steps to maintain agreement with Earth rotation time within about 0.1 s
- After 1972 only steps

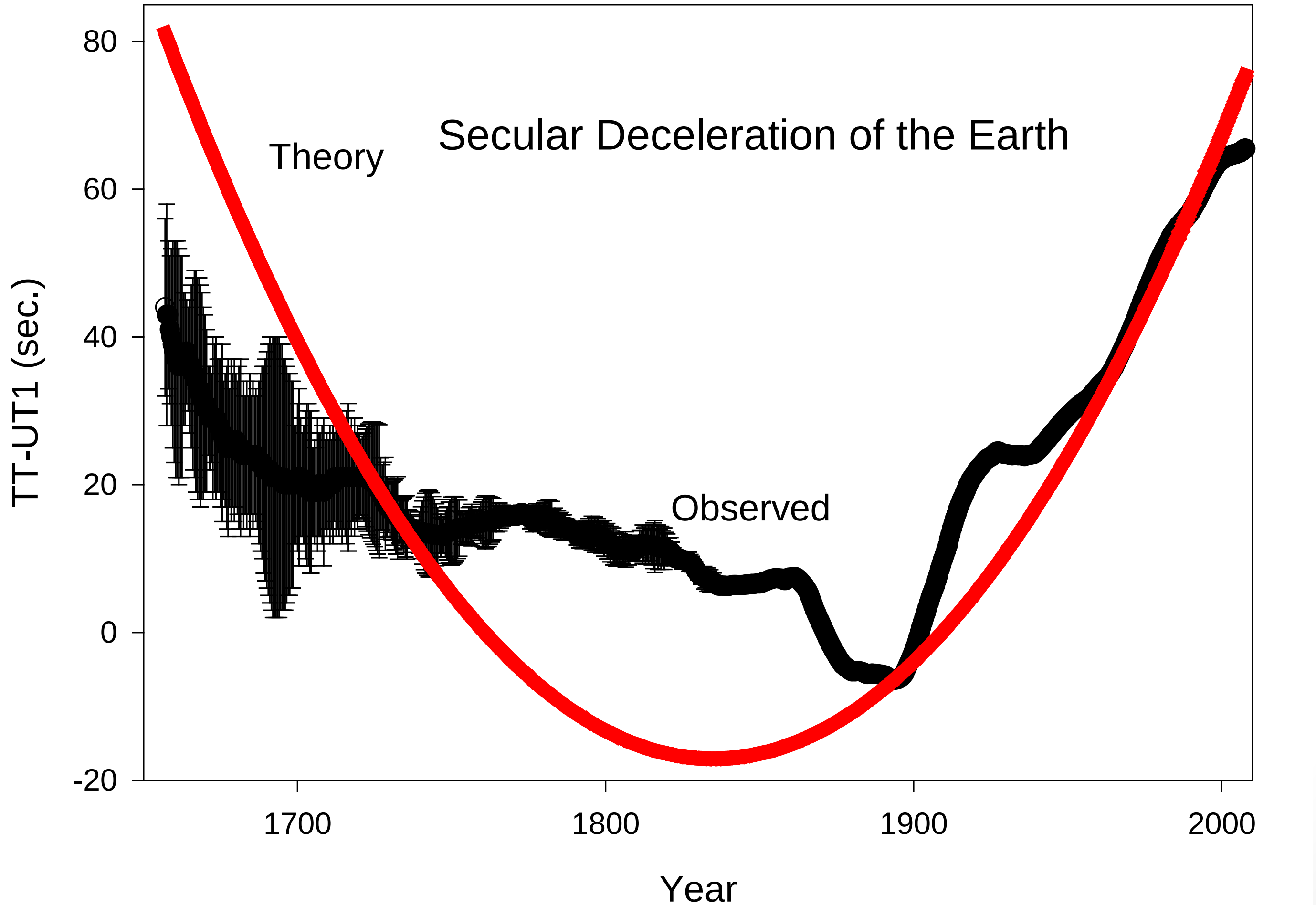
TAI

UTC

Leap Second Logistics

- Leap seconds are added or subtracted from the last second of a UTC month
  - First preference given to end of June or end of December
  - Second preference given to end of March or end of September
    - To date, no leap seconds have occurred in March or September
- Since 1972, there have been 25 leap seconds
  - All have been positive
- When will the next leap second be?
  - Difficult to determine due to variability of Earth's rotation
  - It will <u>not</u> occur December 2013
  - IERS will provide notification of next leap second roughly 6 months in advance

Tidal Deceleration



Trend for leap seconds

- Tidal deceleration causing the Earth's rotation to slow
  - Rate of slowing can be determined from observations of celestial events such as eclipses
- Observations from the last four millennia are consistent with the current trend
- Due to the math/physics of tidal deceleration, the number of leap second is expected to increase significantly over the next few decades
  - Multiple leap seconds in a year will happen eventually

Measuring Earth rotation

- Need to observe “fixed” objects external to Earth
- Measure using technique called Very Long Baseline Interferometry
- Utilizes world-wide radio telescopes
- Coordinated through the International VLBI Service for Geodesy and Astrometry (IVS)
- See http://space-geodesy.nasa.gov/ for a great video
- IERS collects, combines, and distributes Earth rotation information
- Latency is less than a day
  - Typically data are only a few hours old

Predicting Earth rotation

- Earth orientation parameters are predicted for use by real-time (operational) users
- Predictions are made on a variety of scales
  - Few hours to a few decades
  - Prediction accuracy (hours): < 100 μs (i.e. 0.0001 s)
  - Prediction accuracy (year): < 100 ms (i.e. 0.1 s)
    - Note that if using UTC ≈ UT1, the error is roughly 10 times larger than if using 1-year predictions
- Predictions are used to determine when leap seconds need to be introduced
- Predictions are generated by IERS at the same time that the Earth rotation measurements are collected, combined, and distributed

Data Delivery

- Current Methods for Flat Files
  - Web-based delivery (http)
  - Internet-based delivery (ftp)
  - E-mail
- Methods under Consideration
  - Improved file structure
  - Improved transfer protocol

How to use Earth rotation data

- Obtain data from IERS
  - Available at different frequencies, latencies, and file formats
- Use data with prescribed methods to transform Universal Time to direction in space
  - Methods and software available from IERS

Algorithms for transformation using Earth orientation parameters

- IERS provides the “rules” for using Earth rotation data
- IERS Conventions
  - Provides equations and the background information to understand the theory
  - Provides software to utilize Earth orientation parameters
    - Reviewed by subject matter experts
    - Free!!
- Provides online tool to verify implementation

How the IERS provides for its customers

- Determines Earth rotation data
  - Provides relationship between uniform time and the variable Earth rotation time
- Predict Earth rotation data for real-time users
- Provides theoretical algorithms to use Earth rotation data
- Provides software to implement the transformations operationally
- Provides leap second notification roughly 6 months in advance
- Evolving to meet users’ future needs

Future Considerations

- Identify changing users' needs
- Identify other ways to get feedback from users
- Investigate real-time EOP combining and prediction
- Investigate real-time EOP transfer protocol
- Investigate improved long-term predictions
- Establish data file formats to meet modern needs
- Implement better automated error detection and notification
- Adopt ensemble predictions operationally
- Request formal errors on data from AAM sources
- Investigate operational AAM inter-comparisons
- Request more frequent AAM updates
- Request availability of real-time OAM analysis and forecasts

Summary

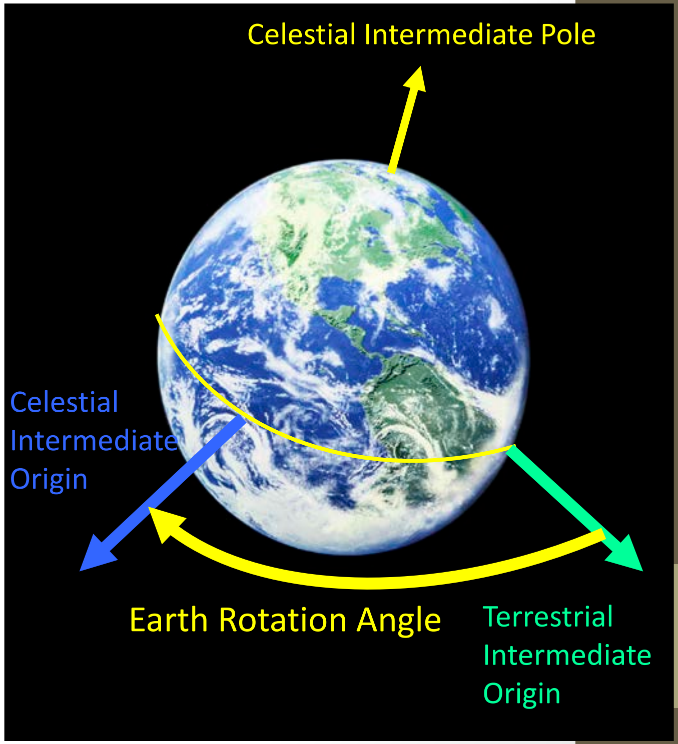
- IERS has 25+ years of experience providing Earth orientation data to the scientific and operational user communities
- IERS provides everything that you need to determine and utilize the relationship between clock time and Earth rotation (UT1–UTC)
  - Observations, predictions, algorithms, and software
- IERS works to provide for users future needs

- Whatever decision the ITU makes, the IERS will continue to serve the community by providing the necessary data and expertise

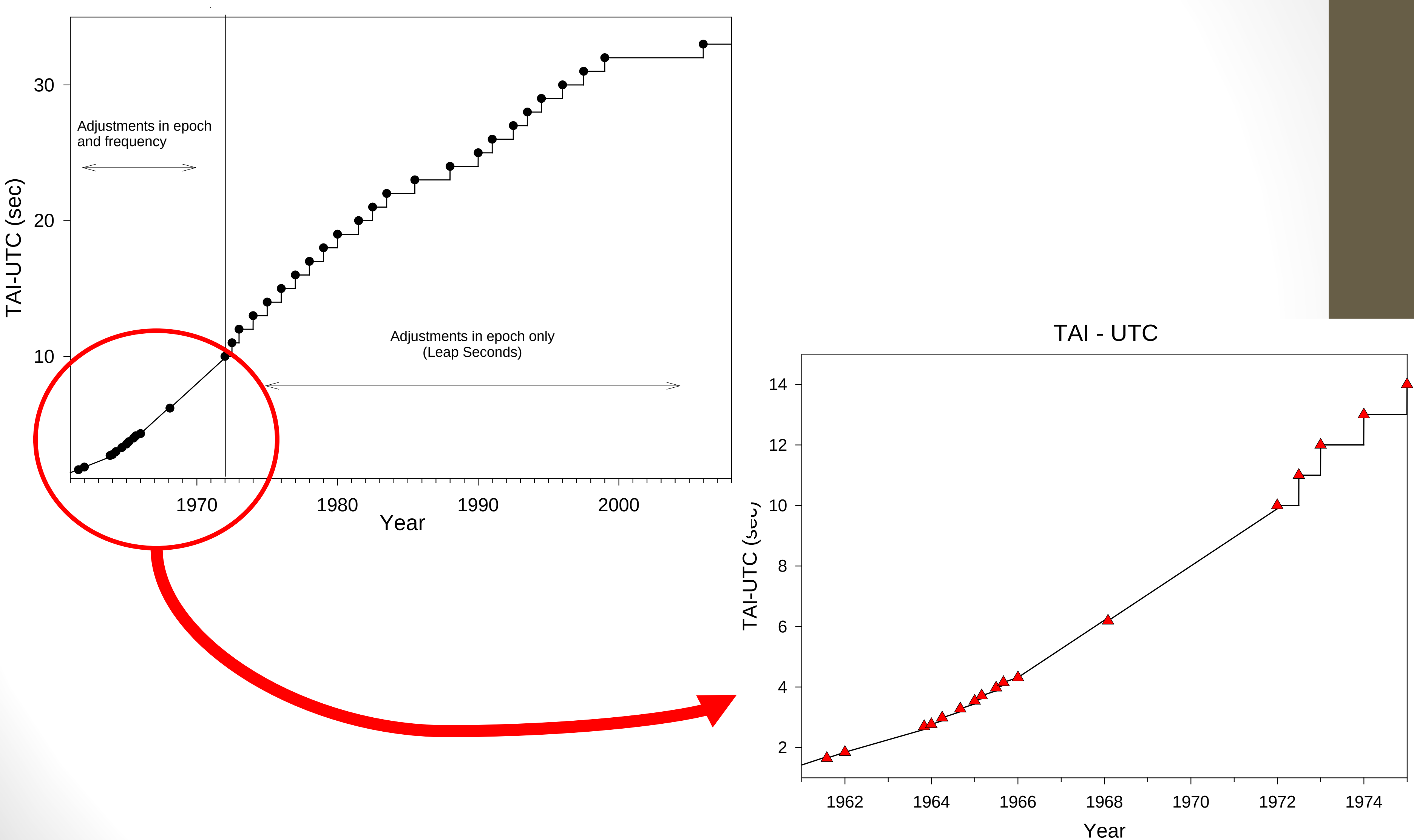
Backups

Universal Time (UT)

- Time measured by the Earth's rotation with respect to the Sun
- Mean solar second = 1/86 400 mean solar day
- Three Forms
  - UT1 is measure of Earth's rotation angle from astronomical observations
    - UTO is UT1 plus effects of polar motion
    - UT2 is UT1 corrected by conventional expression for annual variation in Earth's rotational speed



TAI-UTC



TAI-UTC (sec)
30
20
10
Adjustments in epoch
and frequency
Adjustments in epoch only
(Leap Seconds)
1970
1980
1990
2000
Year
TAI - UTC
TAI-UTC (sec)
14
12
10
8
6
4
2
1962
1964
1966
1968
1970
1972
1974
Year

Transforming Coordinates

Rotation angle (observed/predicted)

Reference pole motion in space (model)

Reference pole motion on Earth (observed/predicted)

$$[CRS] = PN(t)\ R(t)\ W(t)\ [TRS]$$

Space "Coordinate"

Earth "Coordinate"

The only place where UT1 should be used

Earth Rotation Angle

"Legacy"	IAU Recommended
R(t) computed from Greenwich Sidereal Time	R(t) computed from Earth Rotation Angle

Either method requires a value for UT1 by computing
UT1=UTC + (UT1-UTC)

UT1-UTC available from USNO

- Full Accuracy
- Fundamental solution

OR

Ignore UT1-UTC

- Errors as large as 13.5 sec. of arc.

Software at http://maia.usno.navy.mil/ch5subs.html
ERA2000 subroutine produces the Earth rotation angle θ