The Leap Minute
(or, Predicting the Unpredictable)

John H. Seago, AGI

Leap Minutes – Who Cares?

- Former BIPM Director
- Specialists in the timekeeping industry
- Officials involved with the ITU-R process
  - Sometimes unnamed
- Expert consumers of civil time
- General public
- Technology bloggers
- Interested journalists
- Bloomberg editorial:

"Several years ago, some scientists suggested scheduling a *leap hour* for the year 2600. This idea was abandoned as impractical, given that the instructions would have to be left for people six centuries hence. But could there instead be, say, a *leap minute* every half century?"

Perspectives of Experts & Officials

- **Insertion of a leap minute into UTC suggested by Nelson *et al*. (2001)**
  - "relatively easy to adopt"
- **Hudson (1967) "Some Characteristics of Commonly Used Time Scales." *Proceedings of the IEEE*, Vol. *55,* No. 6, June 1967, p. 820.**
  - "Everyday users would not need to be concerned about the introduction of an occasionally modified, atomic scale of time."
  - "approximate epochal coherence with the rising and setting of the sun would be retained, and there need be no fear of a radical departure from solar time for 'everyday' purposes."
- **2011 Royal Society Discussion Meeting, UK.**

Perspectives of Specialist Consumers

- "Leap minutes or leap hours would be very disruptive."
- "Perhaps, a 'leap minute' once a century might do. That would be better than this silly idea of a 'leap hour'."
- "Why not introducing leap minutes instead of leap seconds?" [as an alternative proposal]
- "I am wondering there has been enough discussion regarding introducing 'leap minute' instead of leap second." [as an alternative proposal]
- "But if we want follow day and night variation, then within decades we'll need a leap minute or within millennia a leap hour... Are these any better than the leap seconds?"
- "Alternatively, the concept would remain for DUT1 but change only when added up to a 'leap minute'."
- "A more realistic option [than a leap hour] with less undesirable effects would be a 'leap minute', but that would also defer difficult issues irresponsibly."
- "…millennia into the future, it might be more logical to insert a leap minute, or better yet, perhaps once a century make accurate clocks that run just a bit slower, thus redefining the length of the second."
- "the small and predictable leap second increments are much more tolerable than larger step adjustments proposed (leap minute or leap hour) and less troubling…"
- "I prefer 'leap minute' introduced every 50 or 100 years." [as an alternative proposal]
- "…the issue is a problem that should not be left for future generations (leap minutes, for example)."

Perspectives of Attentive Citizenry

- **"…a 30-second discrepancy between the clocks and the astronomical noon wouldn't hurt anyone."**
  - http://motls.blogspot.com/2012/01/leap-seconds-may-be-abolished-in-2015.html
- **"The average person would not notice if sunrise is off by 30 seconds."**
  - http://www.realfreemarket.org/blog/2012/01/22/leap-second-should-be-leap-minute/
- **"Maybe we should wait 100 years and then have a leap minute."**
  - http://phys.org/news/2012-06-added.html
- **"…The Earth's elliptical orbit already causes the Sun to appear to move up to 15 minutes slower or faster than mean solar time. An additional variance of one minute from true mean solar time would not be a problem for the average person, and correcting clocks by one minute once or a couple of times a century would be much easier for the engineers to keep track of than these continual one-second corrections. And a leap minute would be much bigger news than a leap second."**
  - Barreiro, A., (2012), "Why not leap minutes?" Comment to "A Glitch in Time" http://www.skyandtelescope.com/community/skyblog/newsblog/A-Glitch-in-Time-160824935.html
- **"Alternatively, rather than abandon leap-seconds make it leap-minutes. Once in a century we could probably use an extra minute anyway." [Poul-Henning Kamp]**
  - http://mm.icann.org/pipermail/tz/1999-December/010734.html

A Leap-Minute Proposal (P. Planesas)

- **Leap minute should target a year when predicted (UTC−UT1) = 60 s.**
  - Not 30 s.
- **Announcement of leap minute should be made "several years" ahead**
  - "strictly" keeping observed (UTC−UT1) between 55.0^s and 65.5^s when applied.
- **Time of insertion should prefer June 30th, because this date less disruptive than New Year's Eve.**

Leap-Minute Proposal Advantages

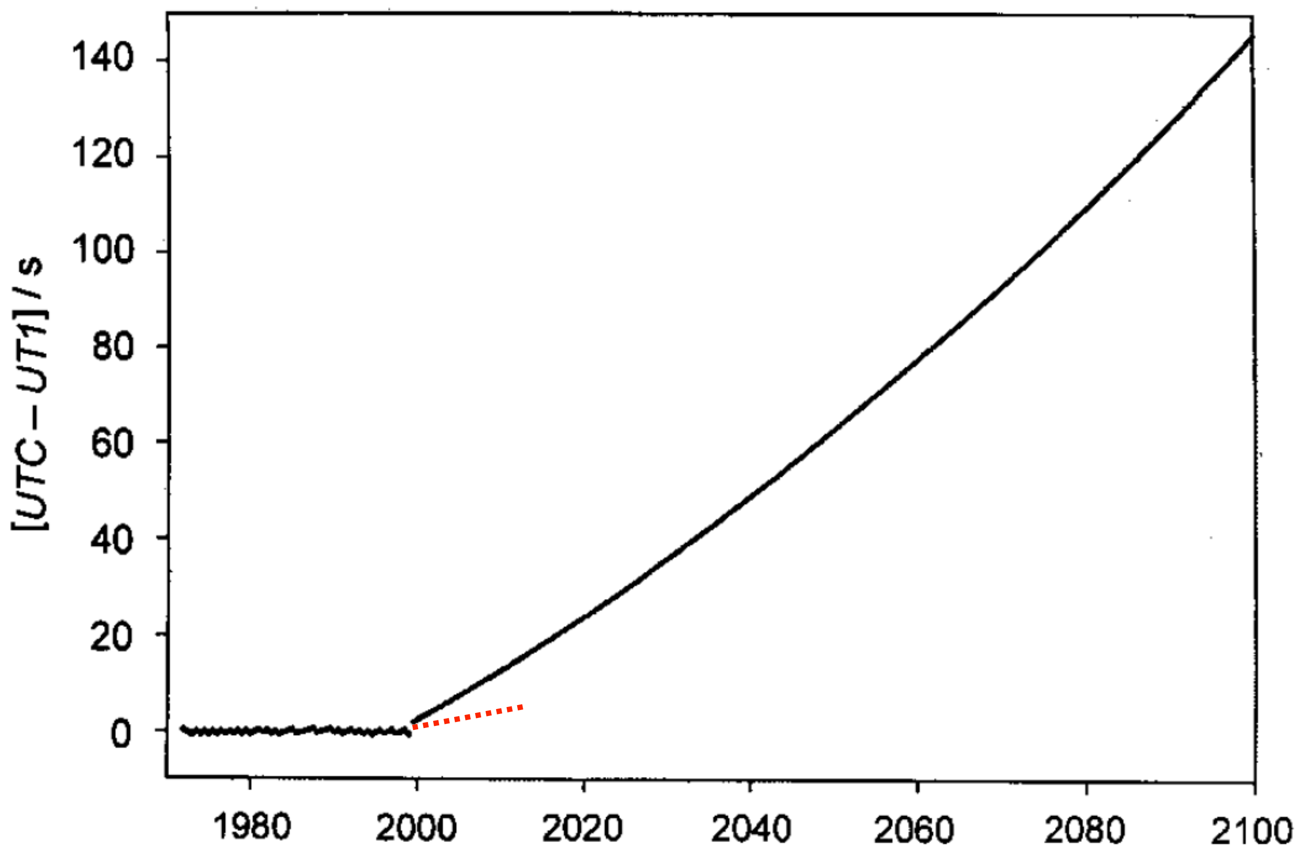
- **Leap minutes keep UTC "close to" mean solar time**
  - maintains UTC's name and status
- **ΔUT1 corrections would be used to recover UT1**
  - gives more visibility to those who determine corrections.
- **First leap minute decades away**
  - allows standards to adapt
- **Fewer adjustments required per century**
  - difference between TAI and UTC remains constant for decades
- **Leap minutes cope better w/ quadratic ΔT**
  - also avoid negative corrections

Representation of a Leap Minute

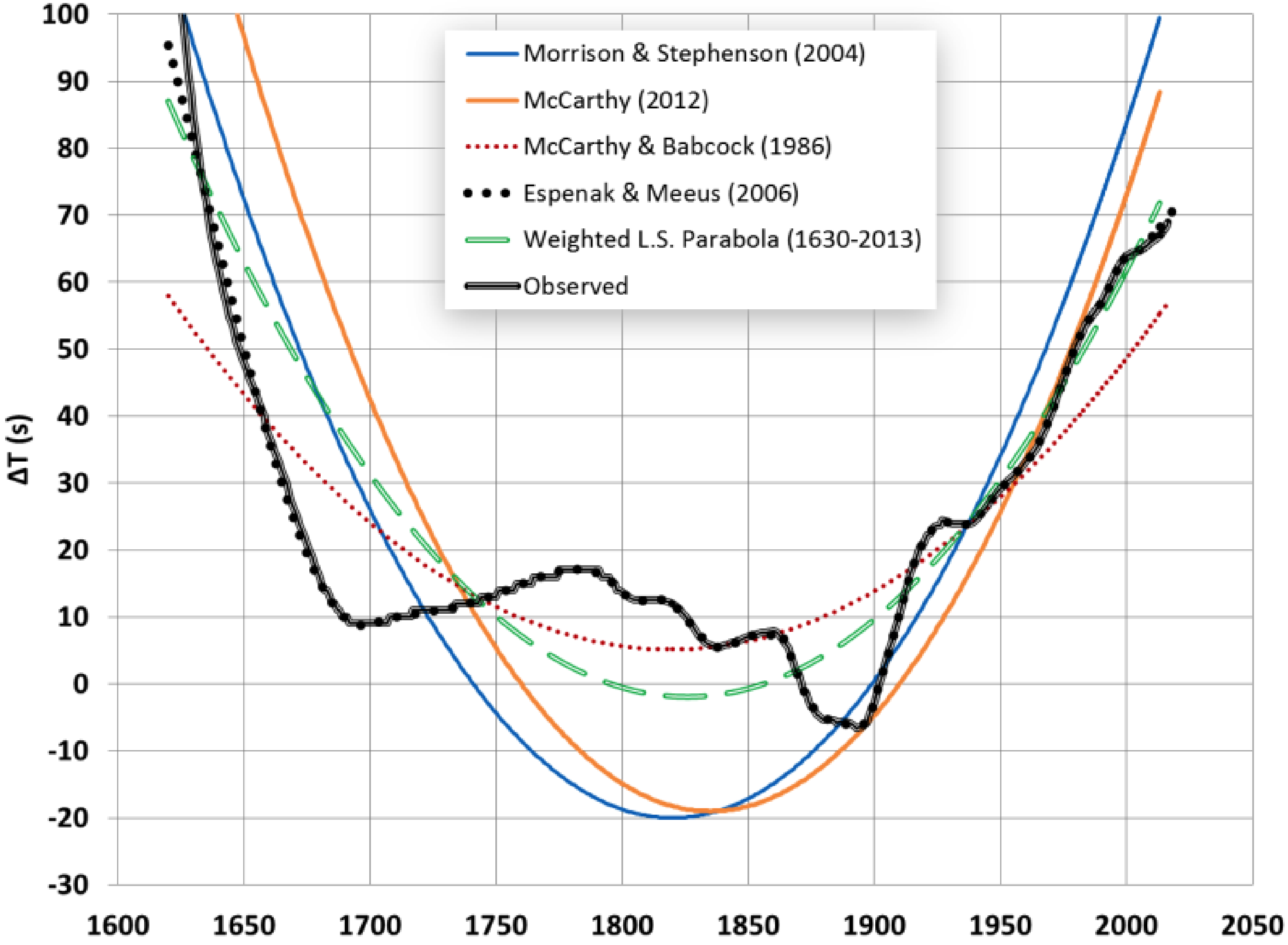
- **Means of reconciling astronomical time of day & atomic time:**
  - Maintain constancy of unit duration,
    - results in "leap" representations such as 23:60
  - Units of duration "stretched" to fit the traditional representations
  - Replace one atomic timescale with another once the differences are out of tolerance
  - Reset clock
  - Turn equipment off during the leap minute
- **Future leap minute might be handled any of these ways, regardless of today's preferences**

Timing of a Leap Minute

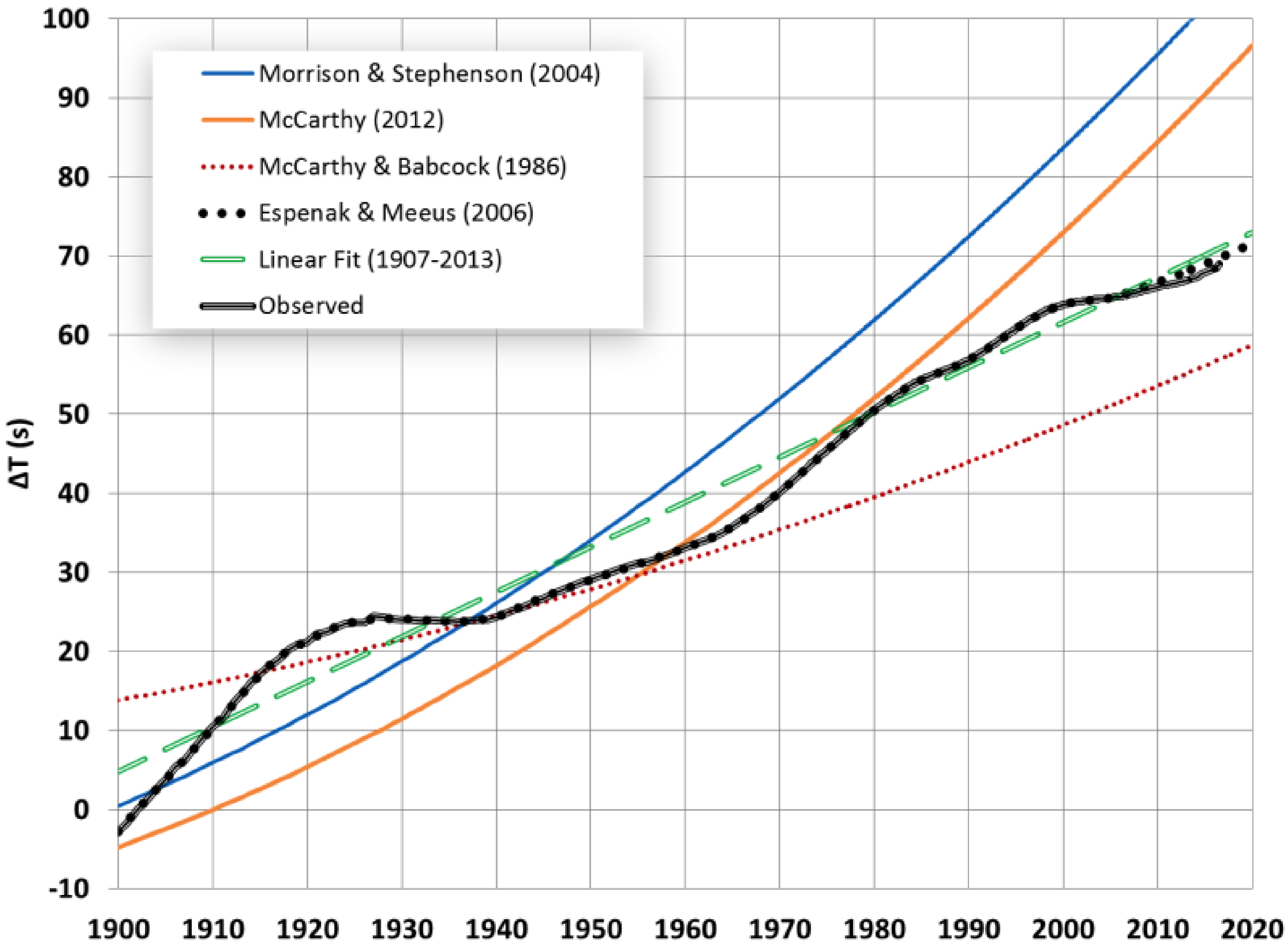
- **Long-term ΔT forecasts notoriously inaccurate**
  - Essen (1967), Meens (2011)
  - Nelson *et al*. (2001)



Parabolic Approximation of ΔT



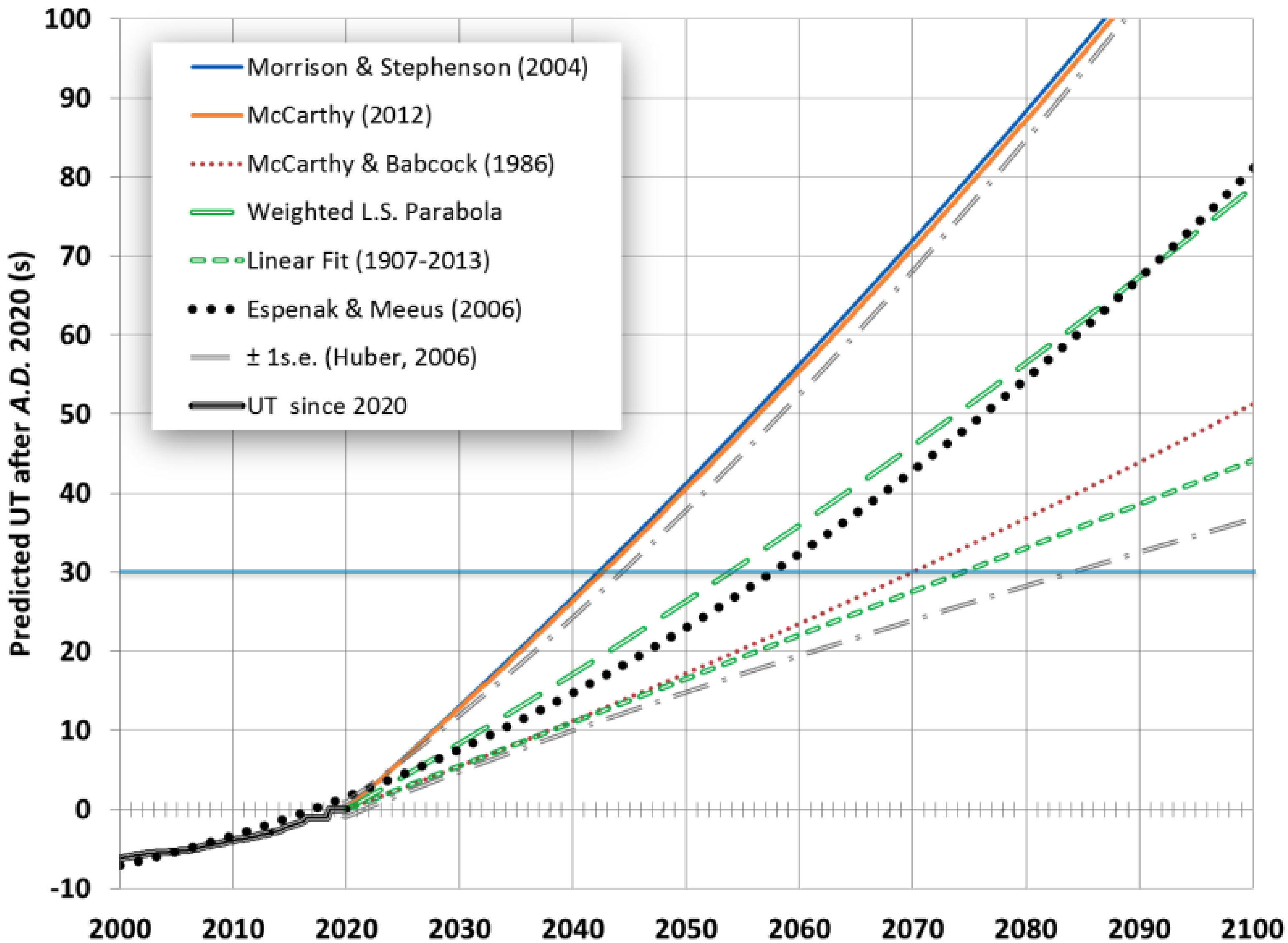
Linear Approximation of ΔT



Prediction by Extrapolation

Dates at which (TT since 2020 − 70 s) separate from various ΔT trend approximations			
Extrapolation	Year Δ = 30s	Year Δ = 60 s	Year Δ = 90s
Morrison & Stephenson (2004)	(2010)	2036	2057
McCarthy (2012)	2022	2045	2064
Weighted Parabola Fit (1630-2013)	2046	2076	2103
Espenak & Meeus (2006)	2057	2084	2106
Linear Fit (1907-2013)	2067	2120	(2173)
McCarthy & Babcock (1986)	2086	2125	2160

Prediction by Extrapolation



Implications

- **Wide range of ΔT behavior makes assignment of optimal date practically impossible**
  - Advance notice requires insertion date be based on a *presumed* behavior for future UT1
  - General tendency suggests the middle of the 21st century
- **Other criteria to consider**
  - Time of year
  - Days of week

Days of Week

Day of Week for February 29th, 2020-2092						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
2032	2044	2028	2040	2024	2036	2020
2060	2072	2056	2068	2052	2064	2048
2088		2084	2096	2080	2092	2076

Day of Week for December 31st, 2018-2089						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
	2018	2019		2020	2021	2022
2023		2024	2025	2026	2027	
2028	2029	2030	2031		2032	2033
2034	2035		2036	2037	2038	2039
	2040	2041	2042	2043		2044
2045	2046	2047		2048	2049	2050
2051		2052	2053	2054	2055	
2056	2057	2058	2059		2060	2061
2062	2063		2064	2065	2066	2067
	2068	2069	2070	2071		2072
2073	2074	2075		2076	2077	2078
2079		2080	2081	2082	2083	
2084	2085	2086	2087		2088	2089

Req’ts Addressed by Leap Minutes

- **Provides symbolic mechanism to address public concerns that clocks correlate with Earth rotation**
  – requirement is already met more visibly with leap seconds
- **Intercalary adjustments must be predicted “sufficiently” far in advance**
  – No requirement for very long-term prediction
  – Frequent adjustments needed for developer testing
- **Supports continued use of the term “Coordinated Universal Time” and “UTC”?**
  – except UTC no longer provides UT to technically useful level
- **Arguments supporting leap minutes support other unviable or undesired options**
  – Change over to “TAI” epoch, GNSS epoch

Conclusions

- **Optimal insertion point for leap minutes cannot be specified very far in advance**
- **Function of leap minute is entirely aesthetic**
  - time broadcasts would become effectively decoupled from Earth rotation
- **December 31, 2050 insertion seeks to minimize disruptions and provide memorable date**
- **Leap minutes do not have overwhelming and obvious advantages over the *status quo***

> **"A minute is an intolerably long period of time. The only advantage is that it pushes the problem so far into the future that no one is worried about it."**
>
> **– Judah Levine, NIST**

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