

Leap Seconds

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Definition of Seconds

- ◆ Rotational Second
 - 1 / 86,400 of mean solar day
- ◆ Ephemeris Second
 - First used in 1956
 - $1/31,556,925.9747$ of tropical year 1900
 - Length of year based on 19th century astronomical observations

Atomic Second

- ◆ SI second: 9,192,631,770 periods of the radiation corresponding to the transition between 2 hyperfine levels of the ground state of the Cesium 133 atom (adopted 1964)
- ◆ Realizes the Ephemeris Second
- ◆ Frequency based on lunar observations from 1954.25 to 1958.25

SI second preserves the rotational second of mid-nineteenth century

Time Scales

- ◆ Rotational

- UT1 is modern realization of historical astronomical time scales including
 - Mean Solar Time
 - Greenwich Mean Time
 - Greenwich Civil Time
 - Universal Time (without suffixes)
 - Weltzeit

Time Scales (continued)

◆ Atomic

– TAI (International Atomic Time)

● Follow-on from

- ◆ A.1 (maintained at USNO with input from 9 other laboratories originally. - now only USNO)

- ◆ AM (at BIH with input from many laboratories)

- ◆ A3

 - at BIH with input from 3 best laboratories

 - became AT (or TA) in 1969, TAI in 1971

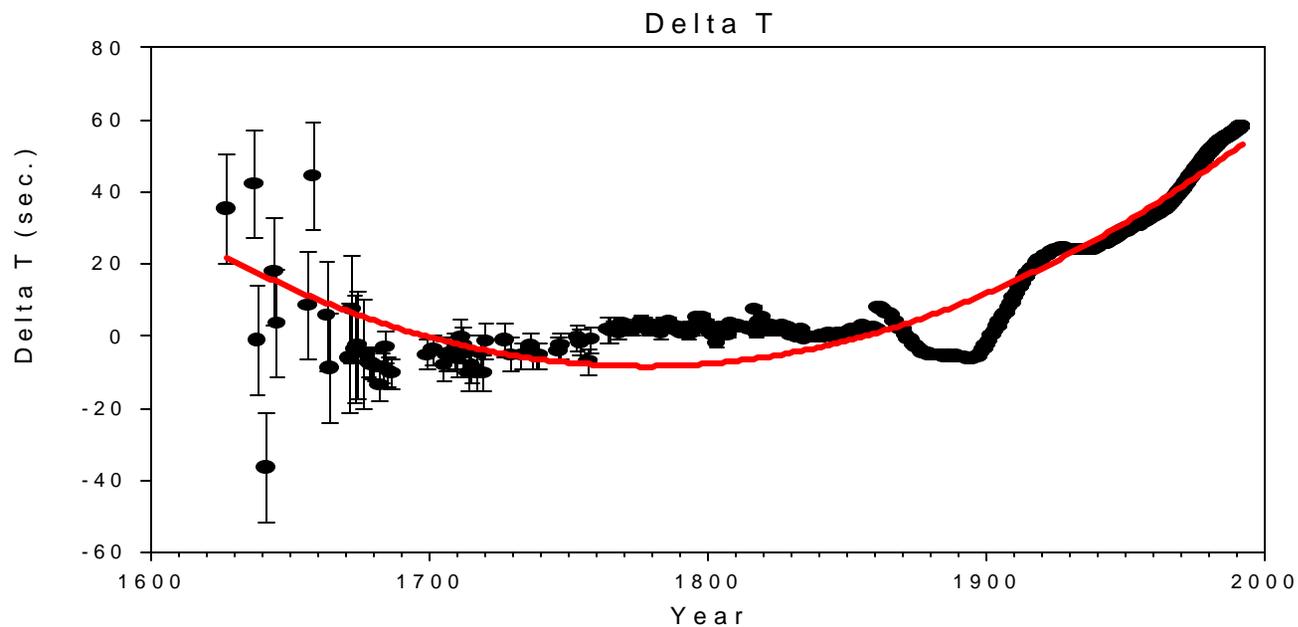
- ◆ others

- All atomic time scales were made equal to UT1 corrected for seasonal effects on 1 Jan 1958 0h 0m 0s

- may be considered modern realization of Ephemeris Time (offset in epoch)

Earth Rotation

- ◆ Well documented deceleration
 - Tidal
 - Change in figure

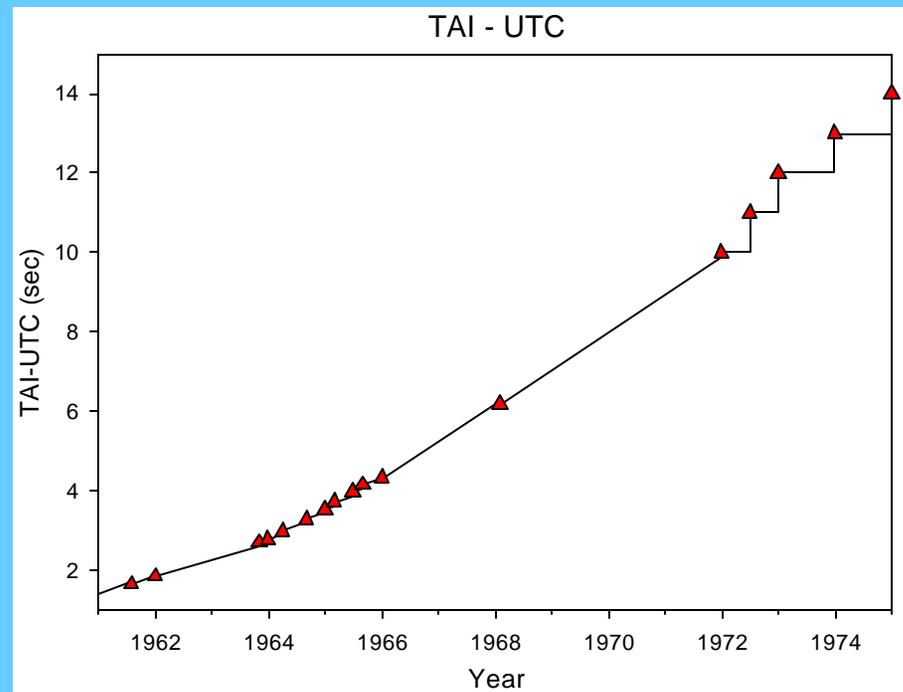
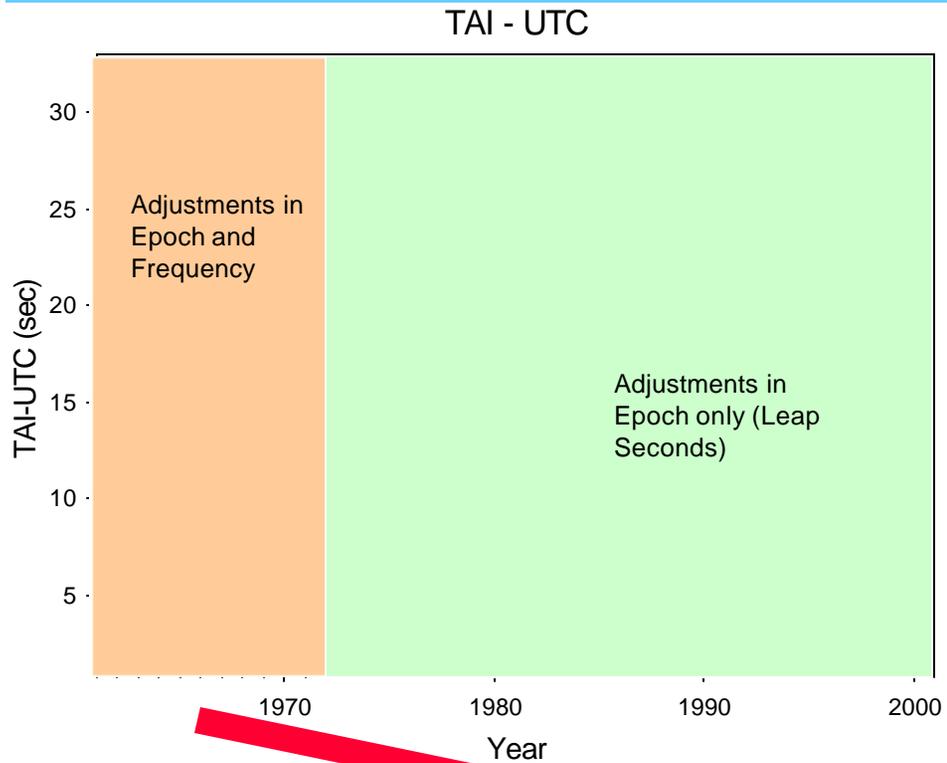


Historical Answers

- ◆ UTC (Coordinated Universal Time)
 - Begun in 1960 as cooperative effort of U.S. Naval Observatory and Royal Greenwich Observatory to make coordinated changes to clocks
 - in 1965 BIH defined UTC with respect to atomic time
 - Epoch and frequency adjusted to match UT1 corrected for seasonal variations
- ◆ Current UTC adopted beginning in 1972
 - no changes in frequency
 - leap seconds so that $|\text{UTC}-\text{UT1}| < 0.9 \text{ s}$

UTC consistent with previous definitions of legal time

TAI-UTC



Causes for Concern

- ◆ Frequency of leap seconds increasing
 - Increasing public annoyance
- ◆ Software issues
 - Unpredictable
 - Continuous second counts: days with 86,401 seconds
 - Time stamping 23h 59m 60s
- ◆ Communications problems
 - coordination of events during a leap second
- ◆ Growth of systems based on independent time scales

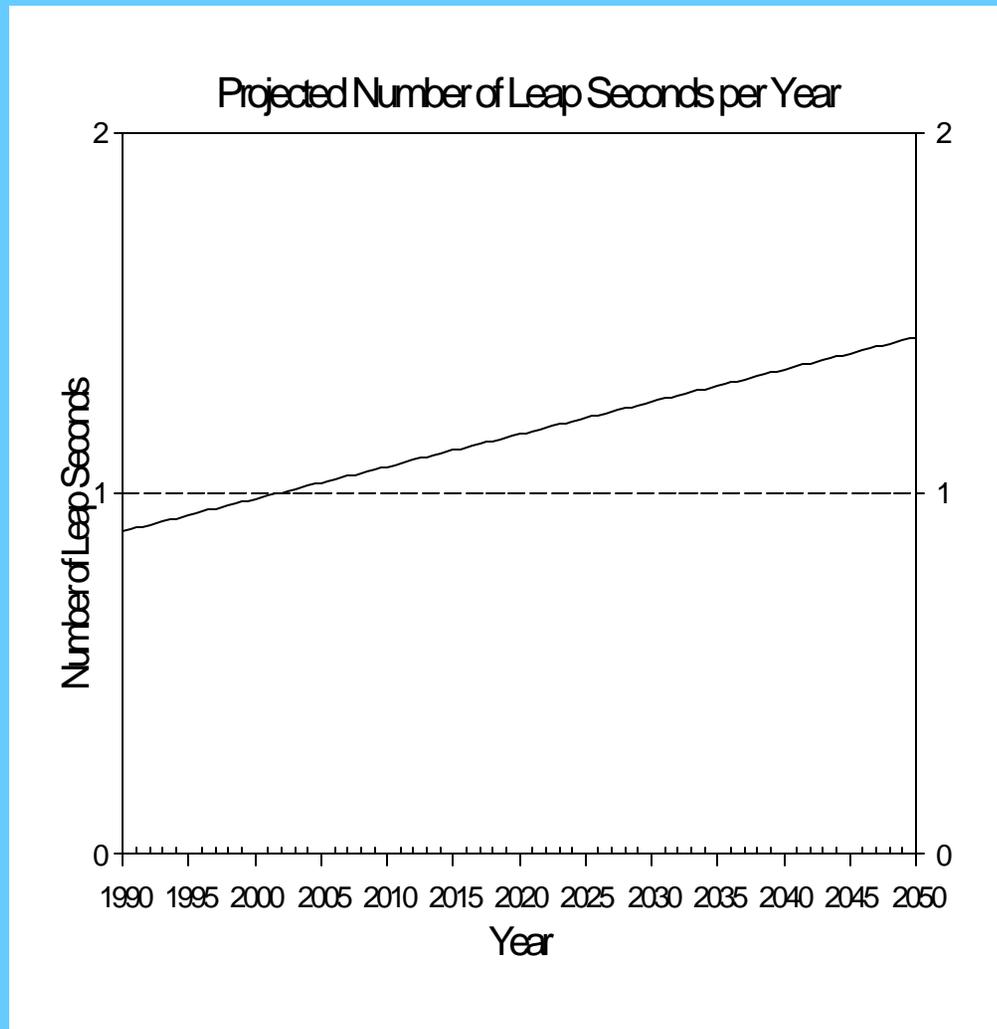
Things to Consider

- ◆ Navigation
 - 1 second = 1/4 mile at the equator
- ◆ Computer software
 - Continuous second counts? 61-second minute?
- ◆ Communications
 - Maintain synchronization over the leap second?
- ◆ Legal definitions
 - Mean solar time?
- ◆ Religious observances
 - Sunrise, noon, sunset?

Options

- ◆ Status quo
- ◆ Discontinue leap seconds
- ◆ Use TAI
- ◆ Re-define second
- ◆ Increase tolerance for $|\text{UTC}-\text{UT1}|$
- ◆ Smooth over the leap second step
- ◆ Predictable periodic adjustment of UTC
- ◆ Conventional adjustment of UTC
 - Every leap year? Every 10 years?
 - Predict leap seconds based on deceleration model

Status Quo



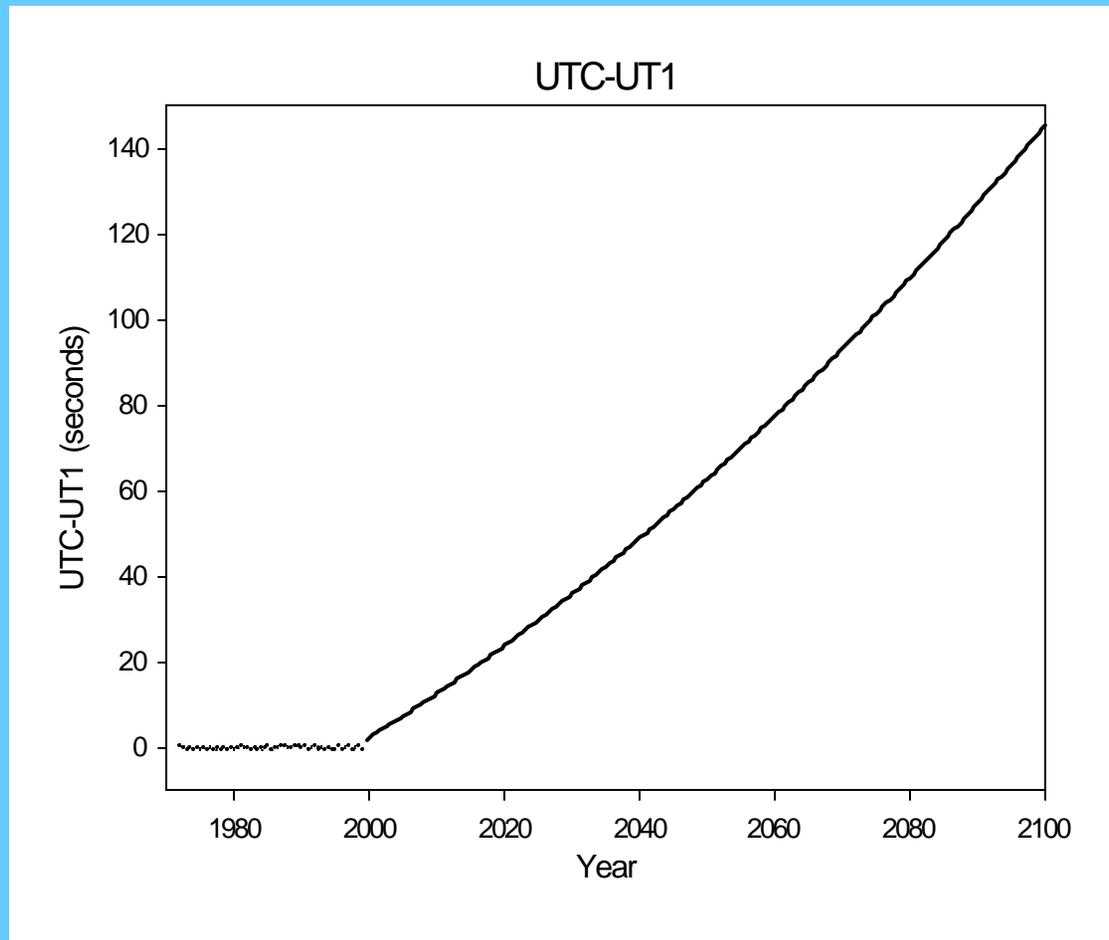
◆ Pro:

- No changes required
- Minimize concerns of celestial navigators

◆ Con:

- Frequency of leap seconds increasing
- Communications, software problems
- Growth of systems based on independent time scales

Discontinue Leap Seconds



◆ Pro:

- Eliminate causes for concern

◆ Con:

- Unlimited growth of $|\text{UTC-UT1}|$
- Legal definitions of time?

Use TAI

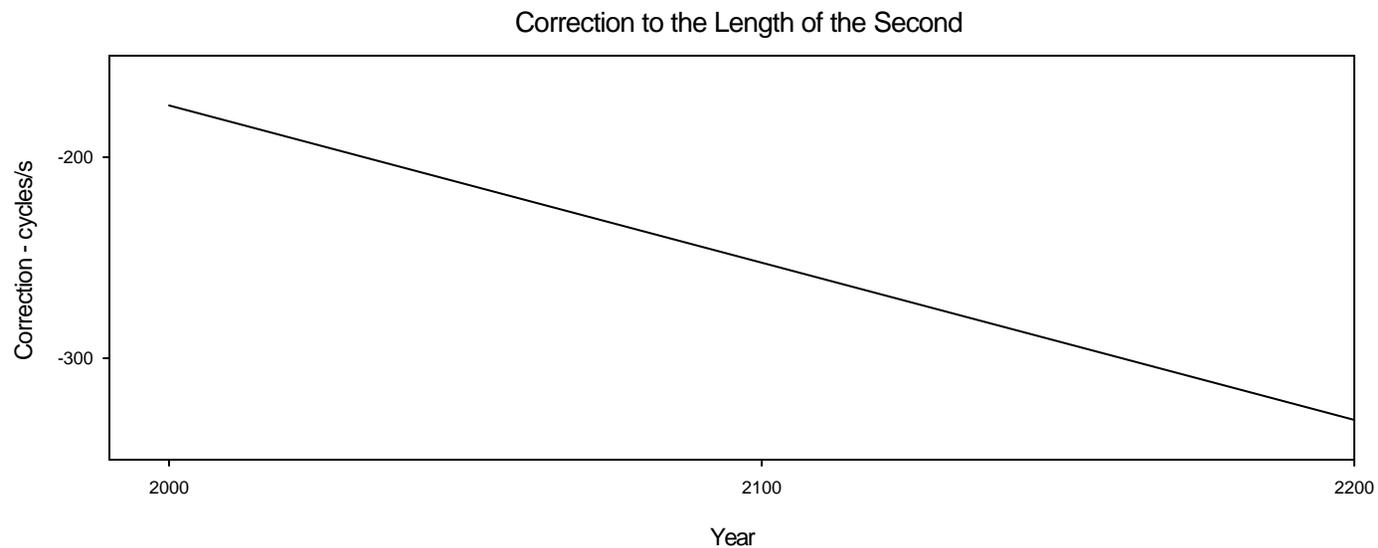
- ◆ Similar to elimination of leap seconds
- ◆ TAI must be more accessible

- ◆ **Pro:**
 - Eliminate causes for concern

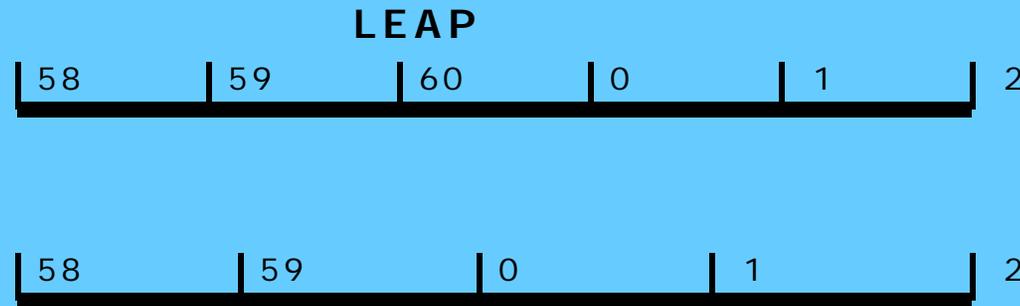
- ◆ **Con:**
 - TAI must be more accessible
 - Legal definitions of time?

Redefine the Second

- ◆ **Pro**
 - Fundamental Solution
- ◆ **Con**
 - Require redefinition of physical units
 - Temporary solution



Smooth Over Leap Second Step



◆ Pro

- Eliminates the “extra” second

◆ Con

- Requires seconds of different lengths
- Date of adjustment unpredictable
- Implementation?

Increase Tolerance for |UTC-UT1|

◆ Pro

- Easy to accomplish

◆ Con

- Larger discontinuities
- DUT1 code limitations
- Date of adjustment unpredictable
- What is an acceptable limit?

Periodic Adjustment of UTC

◆ Pro

- Date of adjustment is predictable

◆ Con

- Number of leap seconds remains unpredictable
- Large discontinuities

Conventional Adjustment of UTC

◆ Unknown number of leap seconds at predictable intervals

– Pro

- » Date of adjustment is predictable

– Con

- » Number of leap seconds remains unpredictable
- » Large discontinuities possible
- » $|\text{UTC}-\text{UT1}| \gg 1$

◆ Known number of leap seconds at predictable intervals

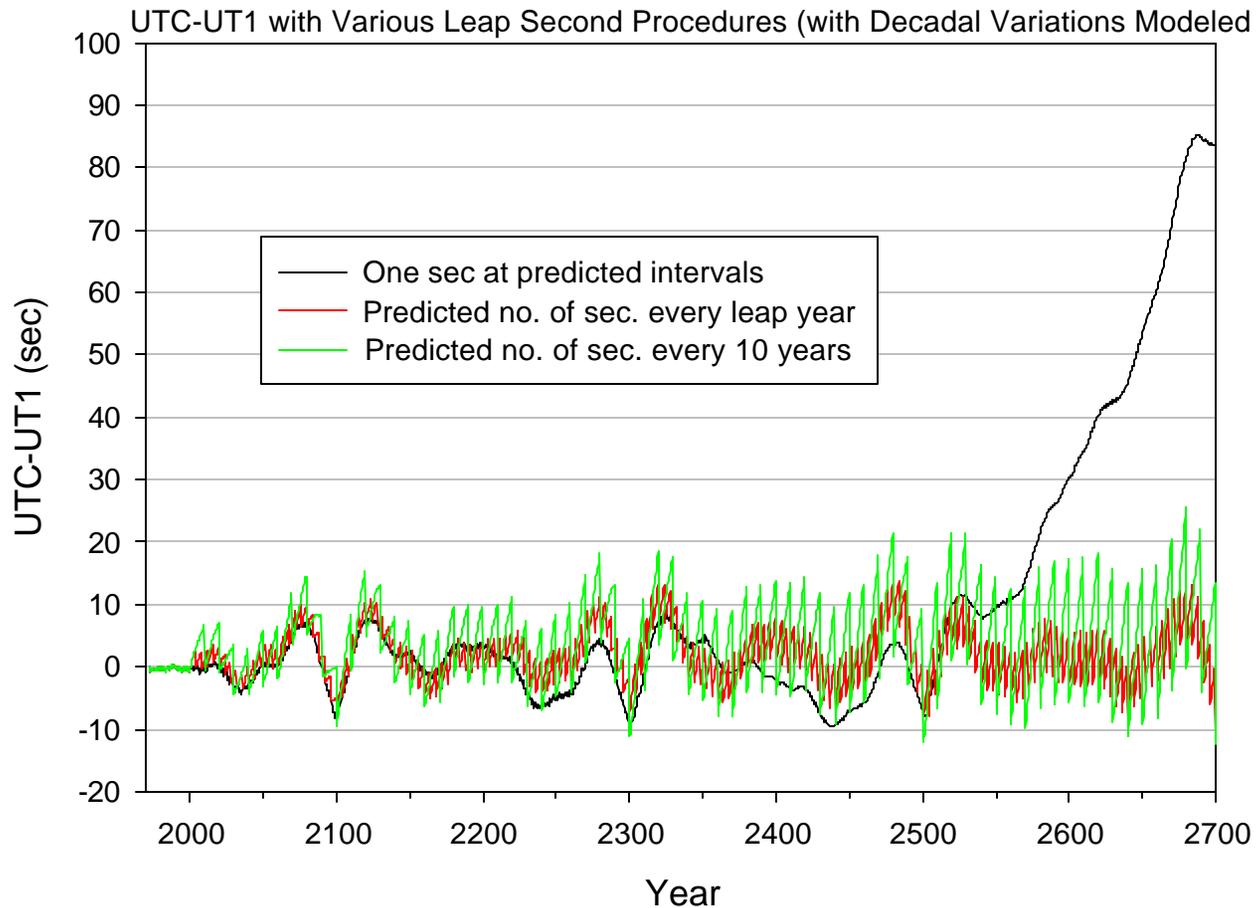
– Pro

- » Date of adjustment and number of leap seconds predictable

– Con

- » Large discontinuities possible
- » $|\text{UTC}-\text{UT1}| \gg 1$

Conventional Adjustment of UTC



What to do?

- ◆ Question needs study
 - URSI
 - IAU
 - ITU-R