UTC and the Hubble Space Telescope Flight Software

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On-Board Computers

Many scientific spacecraft contain on-board computers for:

- Autonomous commanding
- Workarounds for hardware failures
- Mission flexibility

We'll examine the impacts of a change in the definition of UTC on typical spacecraft flight software, using HST as an example.

Flight Software

Spacecraft on-board computer flight software is used for:

- Attitude determination and control
- Autonomous commanding
- Health and safety
- Scientific instrument support

Solar Ephemeris

Flight software may calculate the position of the Sun for:

- Pointing constraints
- Velocity aberration calculations

A typical implementation is an analytical model: the solar mean anomaly and mean longitude are computed as functions of time (UT1), which are used to compute geocentric inertial coordinates.

Lunar Ephemeris

Flight software may calculate the position of the Moon for:

- Pointing constraints
- Velocity aberration calculations

A typical implementation is an analytical model which expands the ecliptic coordinates of the Moon in series expansions in time (UT1). A two-body model may also be used (faster, but less accurate).

Geomagnetic Field Model

A geomagnetic field model may be implemented in flight software as a backup for the spacecraft magnetometers. It is used to assist with dumping angular momentum from reaction wheels.

The geomagnetic field is customarily computed as the gradient of a geomagnetic scalar potential. The potential is computed as a spherical harmonic expansion.

A knowledge of UT1 is needed to rotate from the Earth-fixed frame to the geocentric inertial frame.

Time in Flight Software

Flight software keeps time by keeping a counter of cycles of an on-board crystal oscillator. Clock counts can then be calibrated on-board to create UTC, which is the independent variable in ephemeris and geomagnetic field model calculations.

The clock counter is downlinked in the telemetry stream to time-tag the telemetry.

A UTC clock may also be calculated in flight software and downlinked in telemetry (e.g. PB-5 format).

Divergence of UTC and UT1

The spacecraft clock is generally calibrated to UTC, with an implicit assumption that UTC $\approx$ UT1.

If this is the case and flight software, ground software, and calibration procedures are not changed, what would be the long-term effects?

Historical Trends: TT – UT1

Stephenson and Morrison (1995) have found TT – UT1 for 1620 – present using historical data, and fit to a parabola.

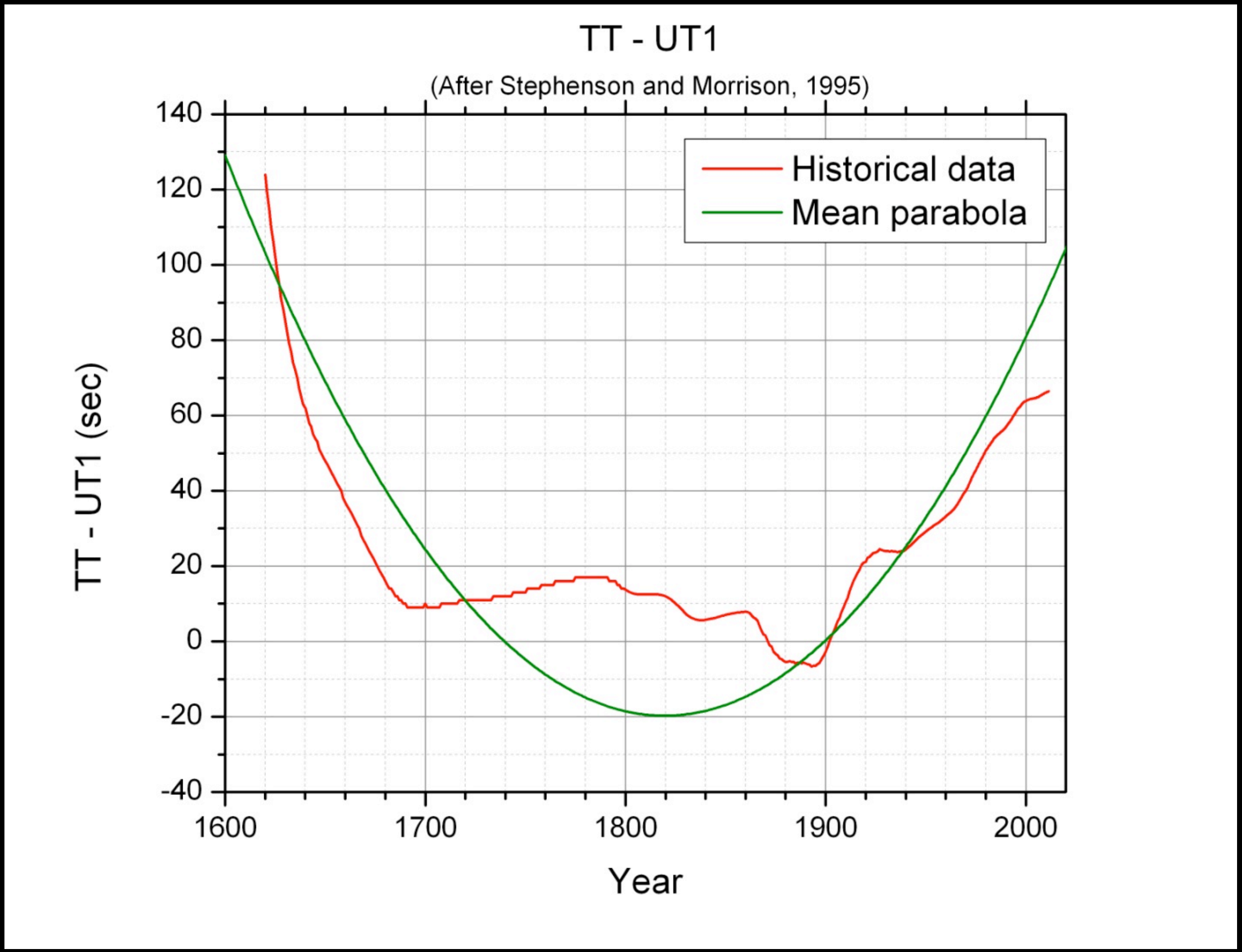
If the proposed change is implemented in 2018, UTC would differ from TT by a constant offset (~70 sec), so this historical data may be used to (roughly) estimate long-term trends in UTC– UT1. Since TT = TAI+32.184 s and TAI ≈ UTC+38 s,

$$UTC\text{-}UT1 \approx (TT\text{-}UT1) - 70 \text{ s}$$

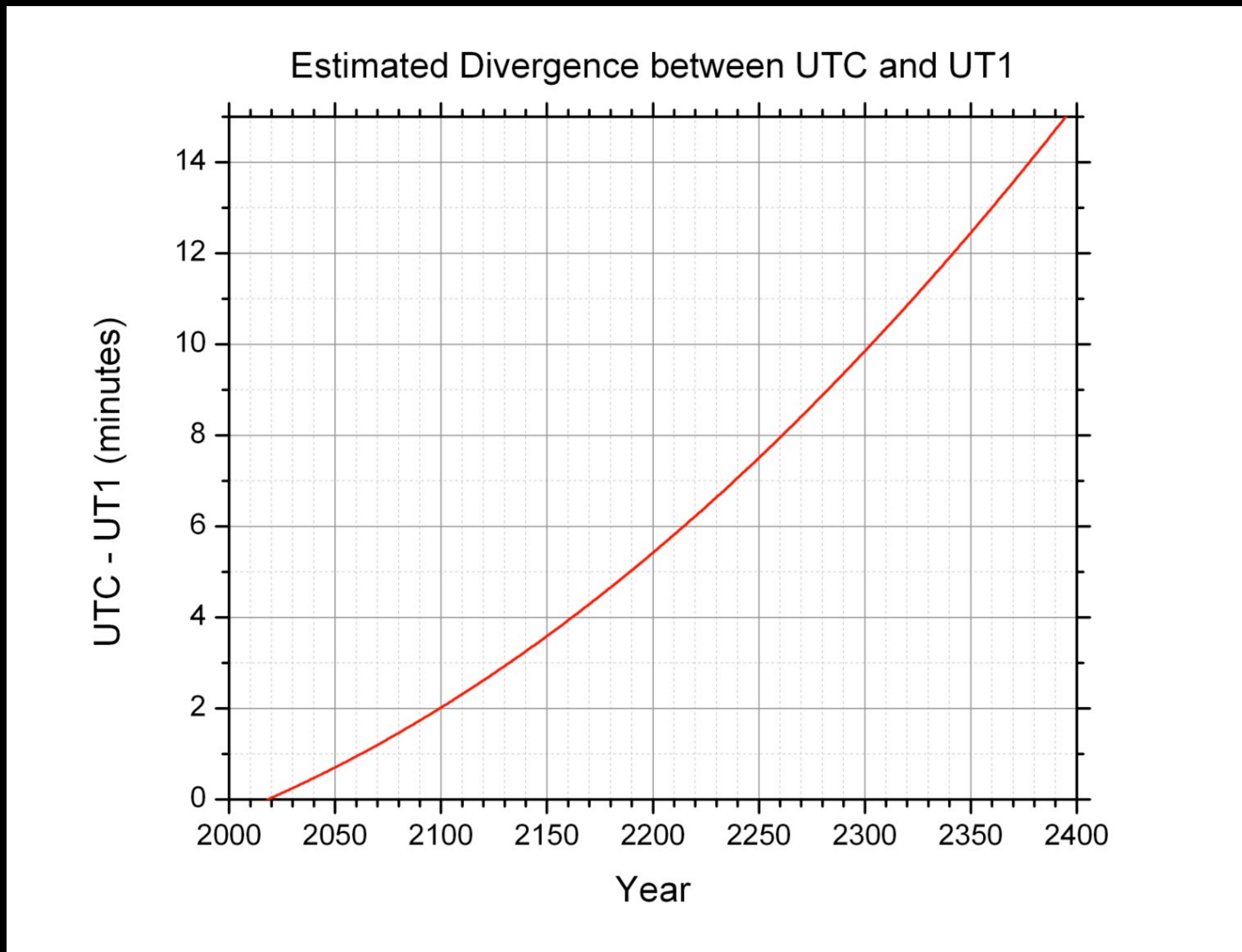
What would be the long-term effects in flight software ephemerides?

Typical solar model error ≈ 0.01°
Typical lunar model error ≈ 0.4°

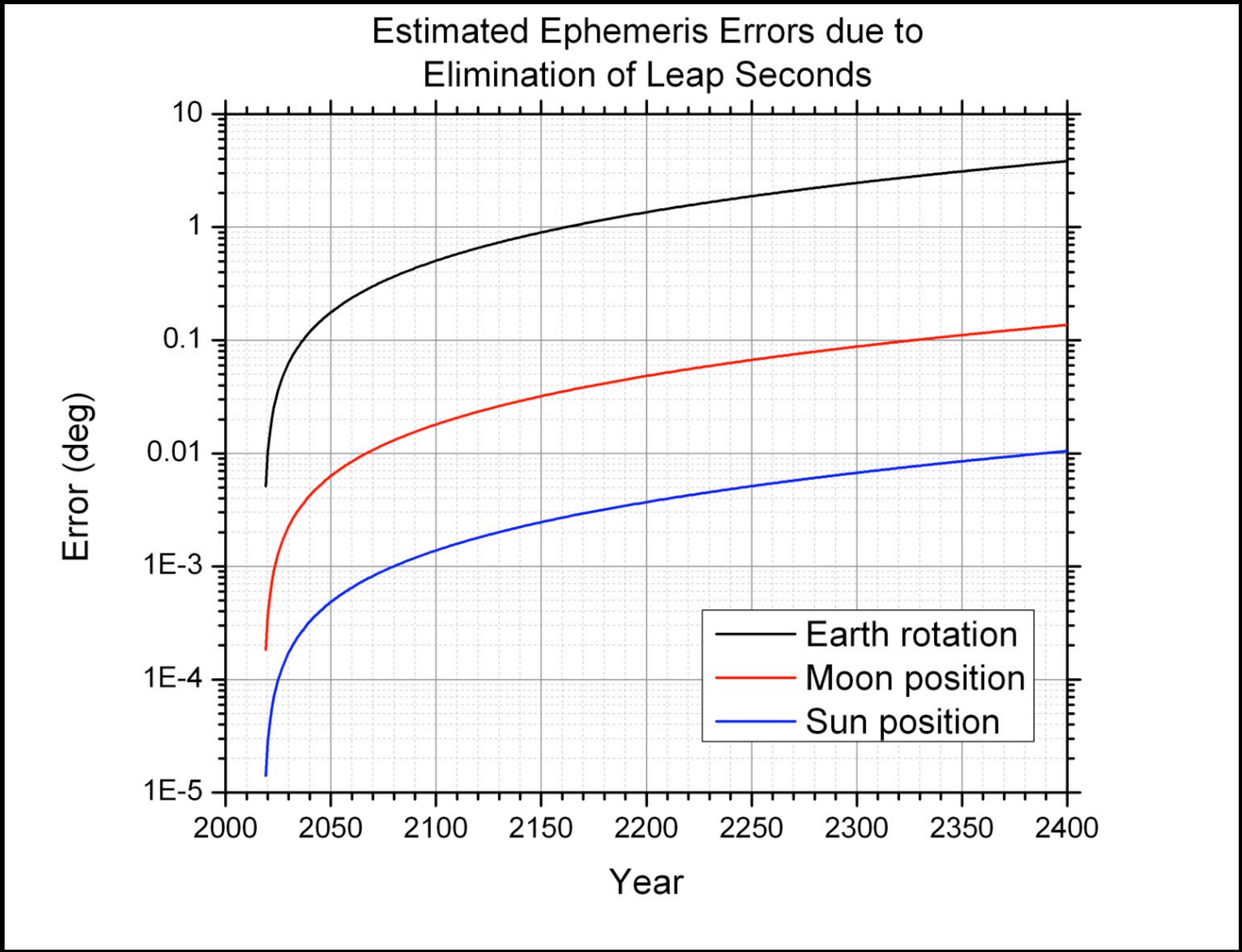
Long-Term Trends in TAI-UT1



Estimated UTC – UT1



Est. Ephemeris Errors



Summary

For these typical ephemeris models, if no changes are made to flight software, solar and lunar ephemeris errors would be expected to approach model errors in ~400 years; less if more accurate ephemerides are required.

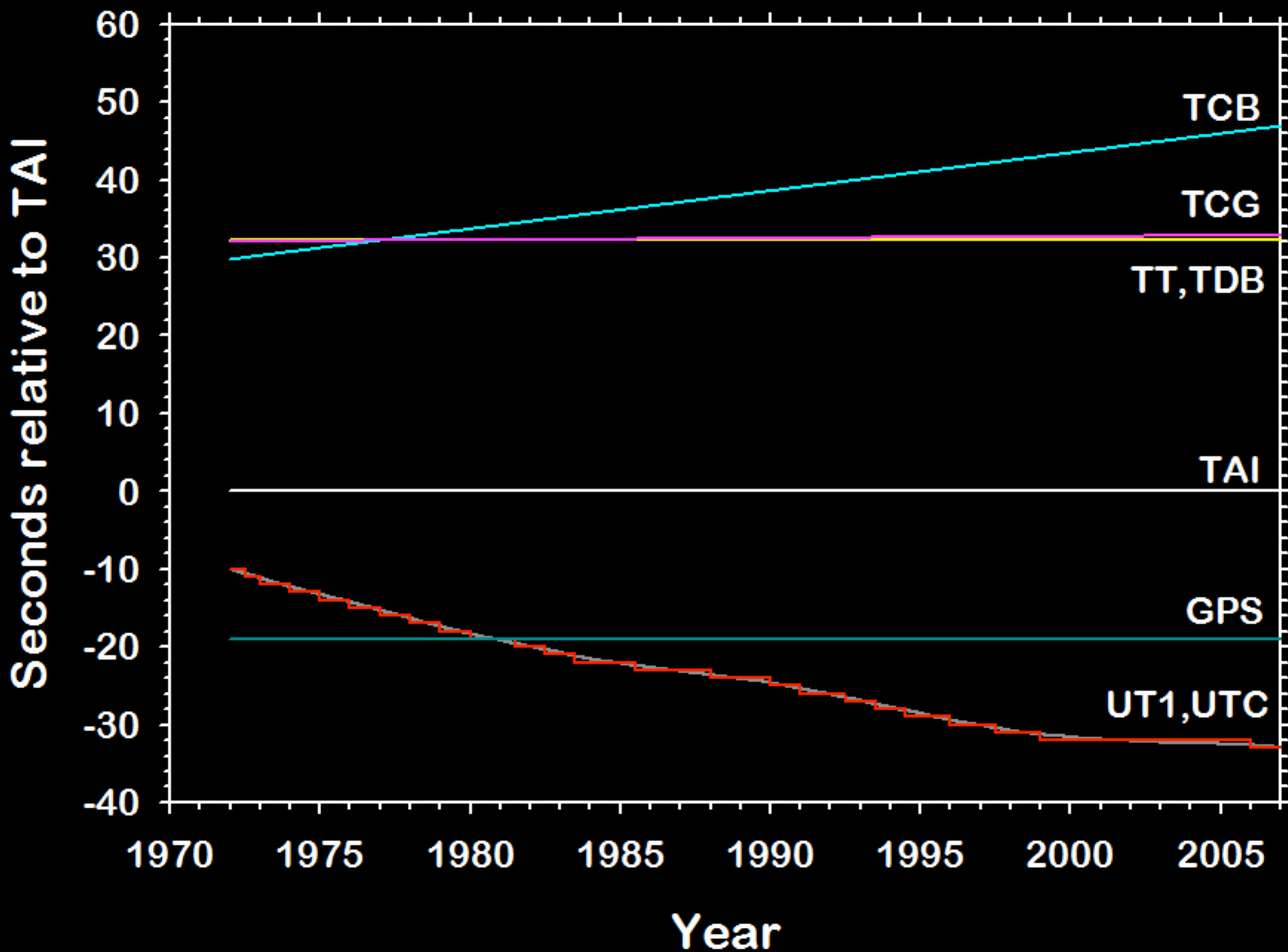
Error in geomagnetic field model is more complex.

On-board clock calibration coefficients should be for UT1. If the telemetry stream is to be time-tagged with UTC, a second set of on-board clock calibration coefficients would be required.

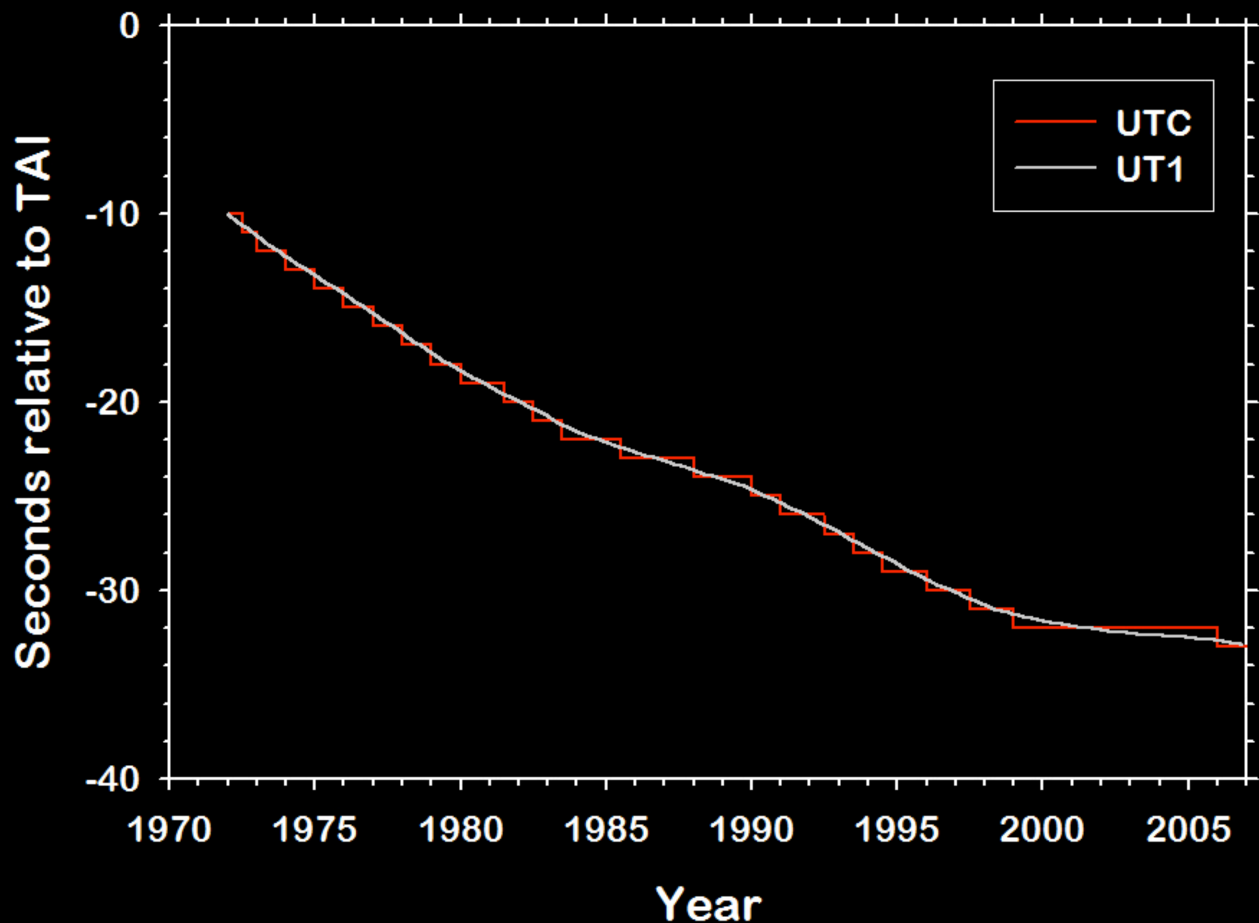
Questions

Backup Slides

Time Scales Relative to TAI



UTC and UT1 Relative to TAI



UTC

Coordinated Universal Time (UTC) is a "hybrid" time scale. It is based on atomic time, but makes sudden "jumps" (leap seconds) at irregular intervals to keep UTC within 0.9 sec of UT1.

UTC is the basis of our daily civil time (corrected for time zones).

$$UTC = TAI - LS$$

$$UTC = TT - 32.184 \text{ sec} - LS$$

Broadcast by radio stations WWV, WWVH, WWVB

On the Web at: **`http://www.time.gov`**

The Future of Leap Seconds

If leap seconds are retained, there is reason to believe that they will have to be added more frequently in the future (nearly twice per year by 2100).

There is talk of eliminating leap seconds in the future and allowing UTC to drift with respect to UT1 (perhaps introducing a “leap minute” or “leap hour” at some future date).

References

Seidelmann, P. Kenneth (Ed.). *Explanatory Supplement to the Astronomical Almanac*. University Science Books, Mill Valley, California, 1992.

Meeus, Jean. *Astronomical Algorithms* (2nd Ed.). Willmann-Bell, Richmond, 1998.

Stephenson, F.R., and Morrison, L.V. "Long-Term Fluctuations in the Earth's Rotation: 700 BC to AD 1990", *Phil. Trans. R. Soc. Lond. A* (1995), **351**, 165-202.