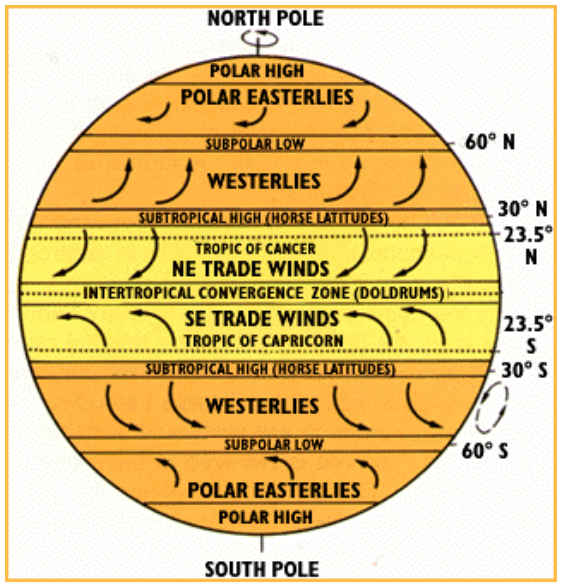
Will we have a negative leap second?

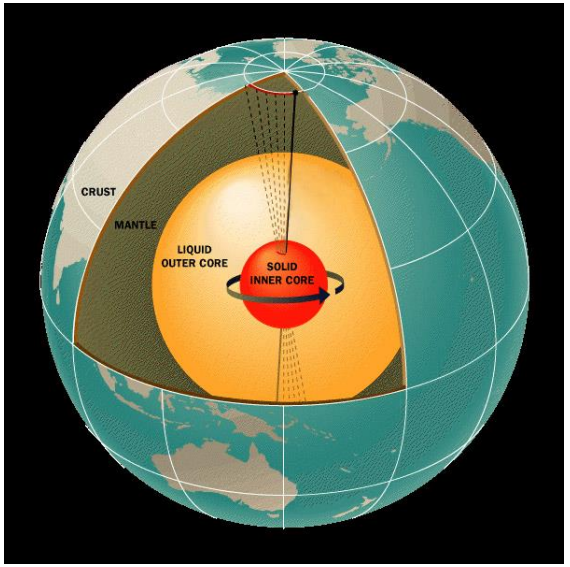
Report to
Civil GPS Service Interface Committee
Timing Subcommittee
September 21, 2022

Dr. Demetrios Matsakis
Masterclock, Inc.

Tides inexorably slow down the Earth

and push out the Moon, as observed with Lunar Laser Ranging





Atmosphere (AAM) strongly anticorrelated with Length of Day (LOD) on timescales <few years

Angular momentum of core and mantle impact LOD on timescales >few years

Pre-historic and historic data

- ~470 million years ago, day lasted only 21 hours
  - Data from fossilized nautiluses, corrals
  - Slowdown rate of ~2.3 mts/day/century
- ~70 million years ago, day was 23.5 hours long
  - Data from fossilized clams
  - Slowdown rate of ~2.2 mts/day/century

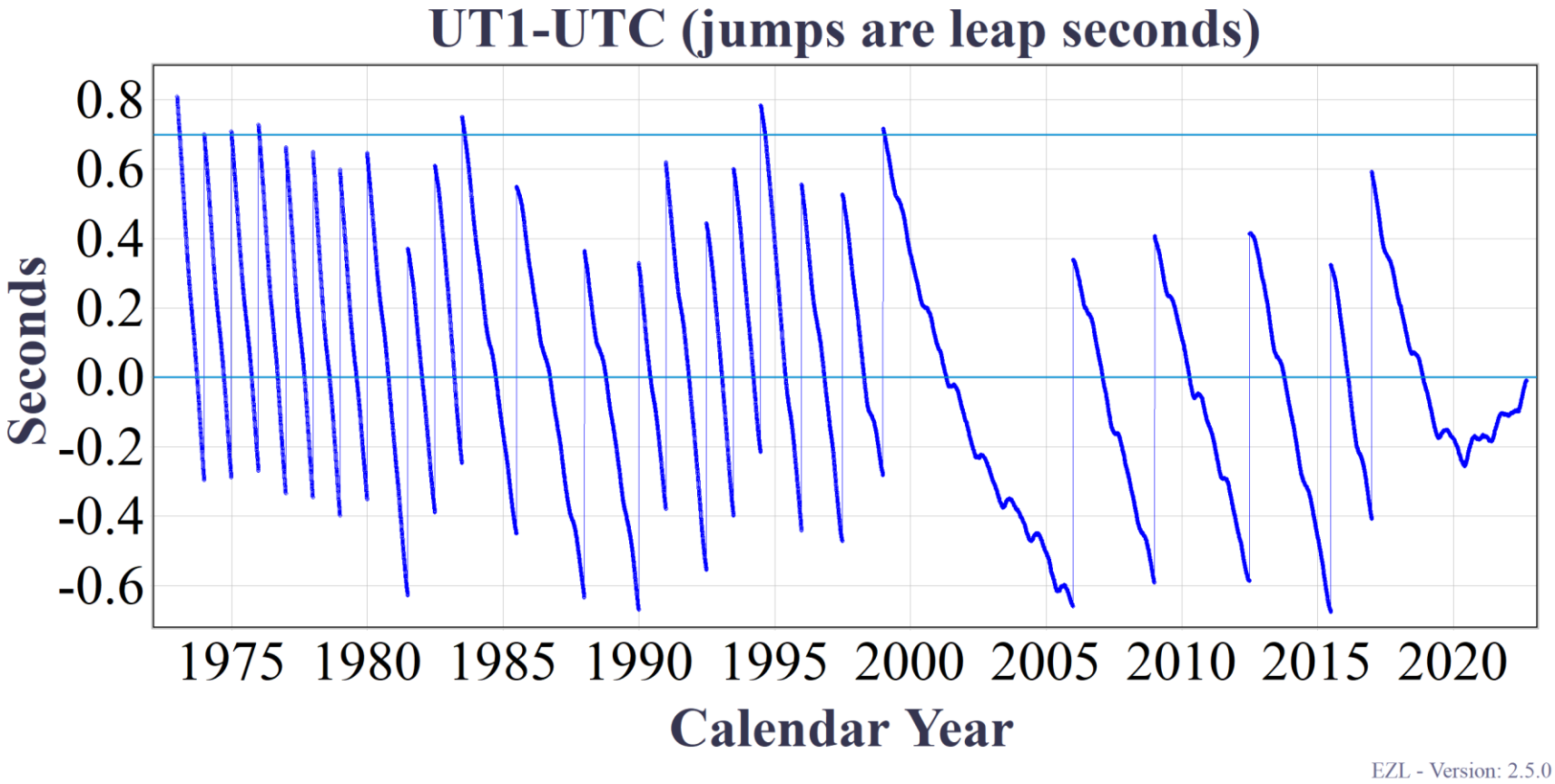
- Eclipse Data: smaller slow-down rate
  - Chinese records: 14 hours lost since 1815 BC
    - Slowdown rate of ~ 1.9 mts/day/century
  - Babylonian records: 3.25 lost hours since 136 BC
    - Slowdown rate of ~ 1.4 mts/day/century
- Ice caps melting since ice age, glacial rebound
  - Makes Earth rounder

Credit: Fanny Schertzer

As decided over fifty years ago

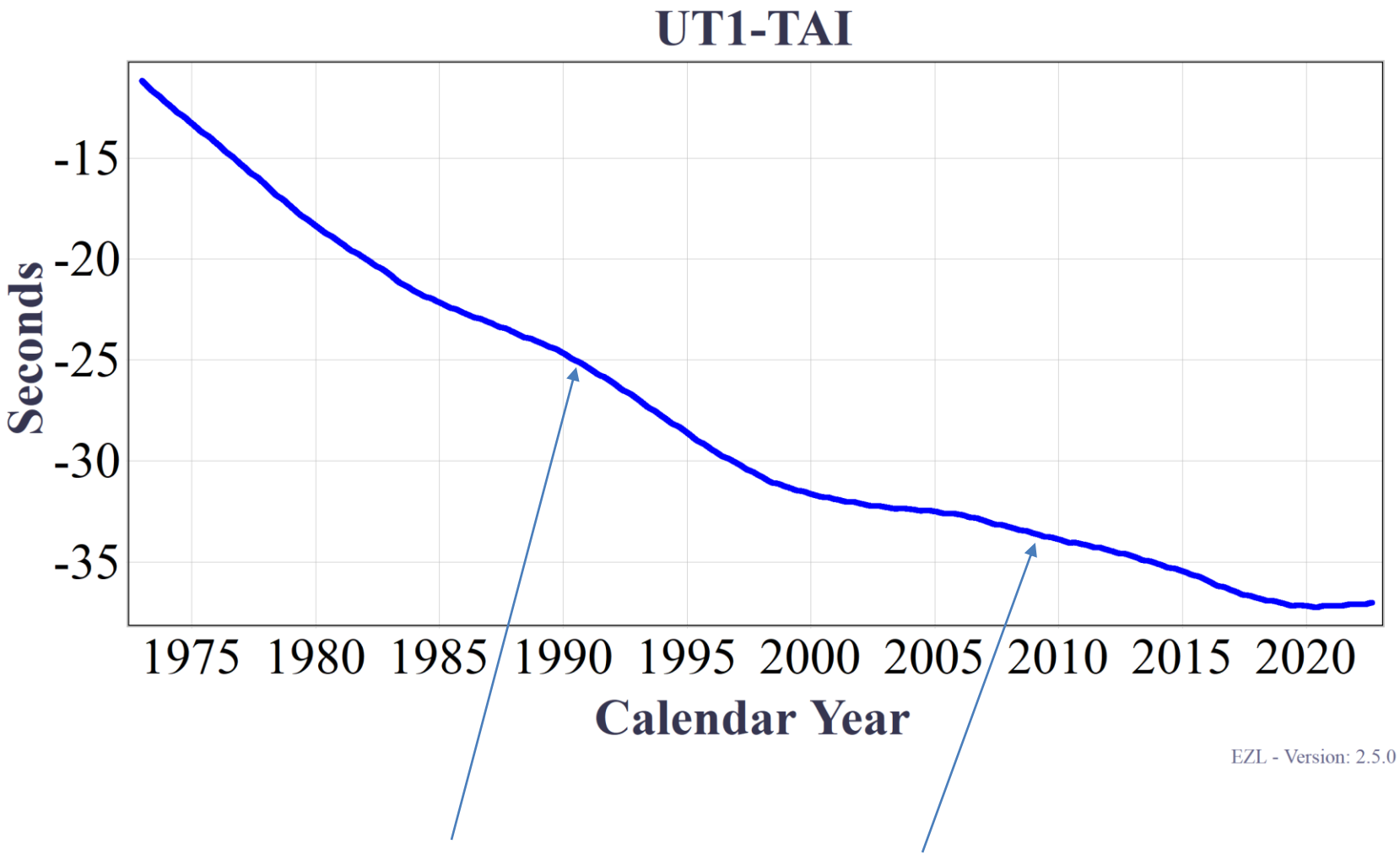
- TAI=International Atomic Time
  - 1 second = 9,192,631,770 periods of Cs transition
    - In ten years should convert to optical frequencies
- UT1~GMT=time kept by rotation of Earth
  - now just an angle
- UTC=Coordinated Universal Time
  - UTC=TAI with leap seconds
  - |UT1-UTC|< 0.9 seconds
    - Add a leap second to prevent UT1-UTC<-0.9 sec
    - Skip a second to prevent UT1-UTC>+0.9 second
      - Commonly called a negative leap second

How it has played out



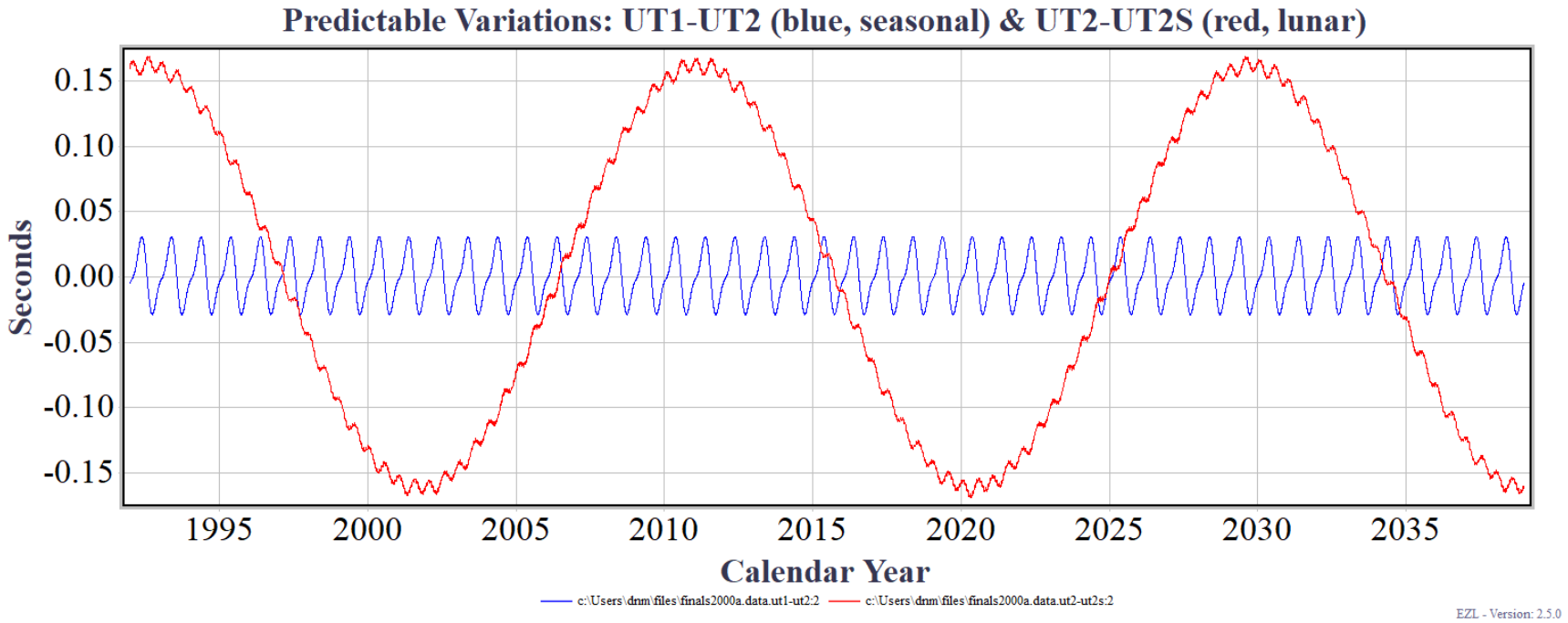
Excellent and official data sources: https://maia.usno.navy.mil/products/eo-products and https://www.iers.org/IERS/EN/DataProducts/EarthOrientationData/eop.html

If UTC had had no leap seconds (i.e. UTC=TAI)



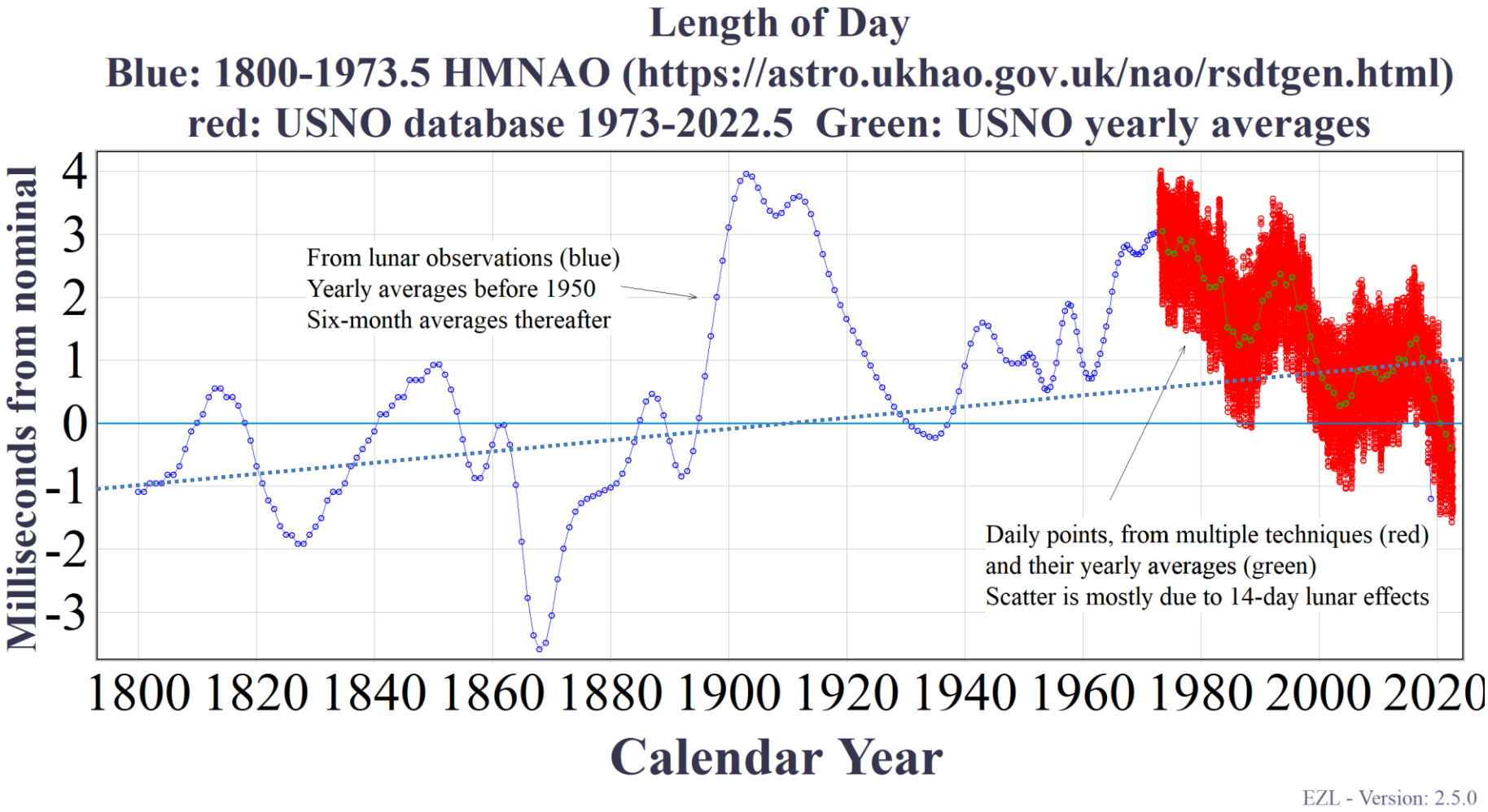
The 19-year Metonic (lunar) cycle is barely visible

The predictable periodic terms



Predictable speedup started 2020.5

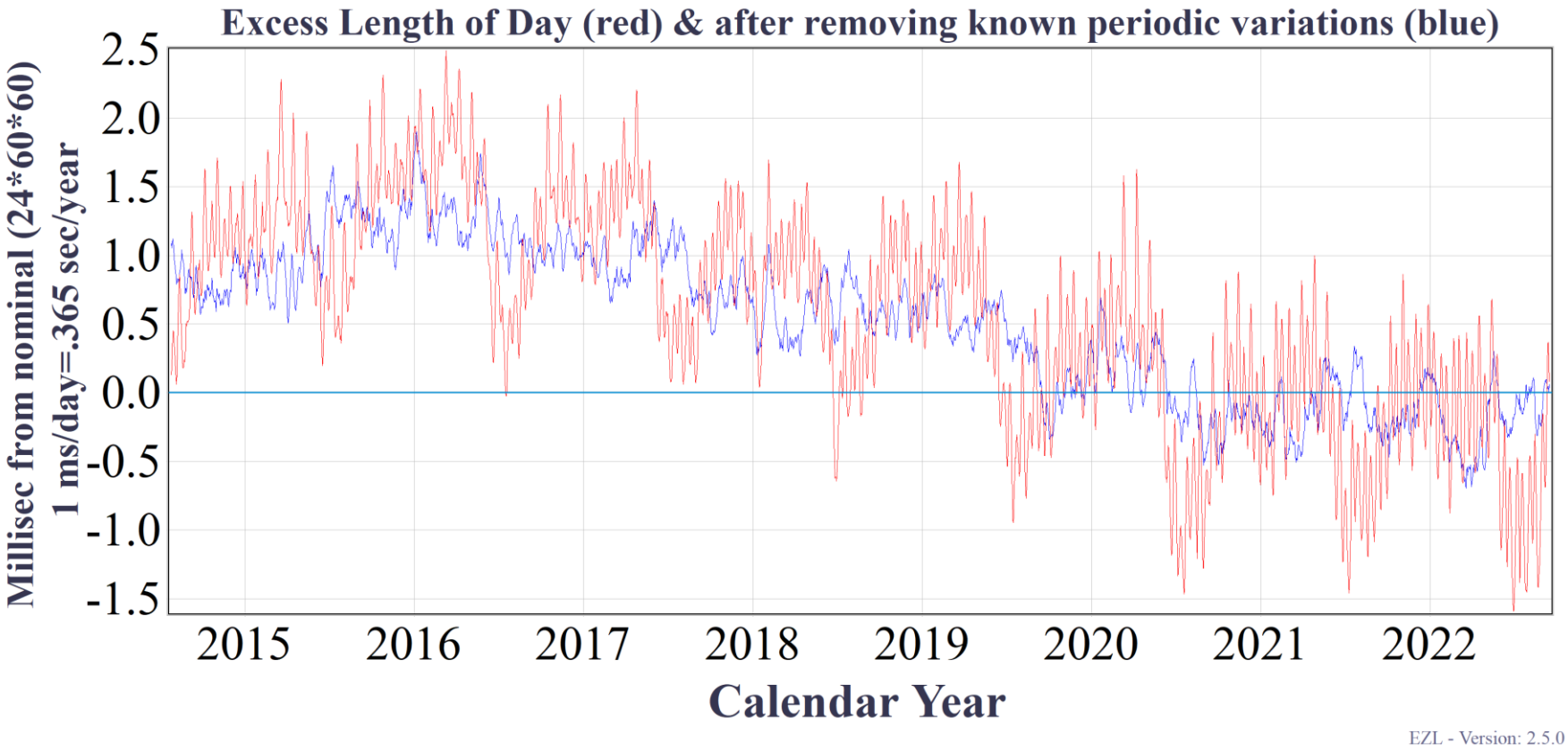
Predictable slowdown starts 2030



You can treat this like a random walk over the the last two centuries
Or you can treat this as a steady speedup over the last few decades

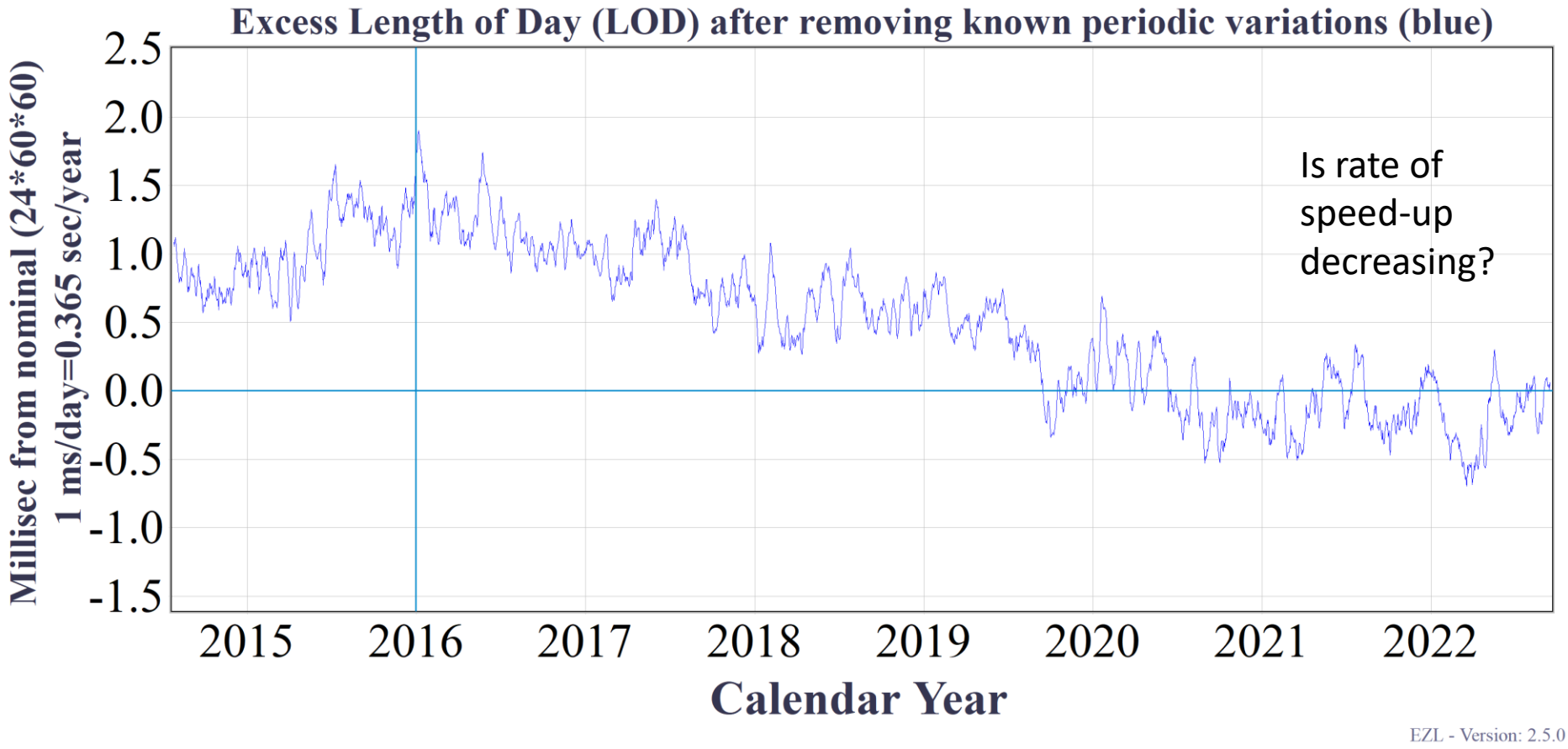
1.4 mts/day/century (0.5 sec/year/cty) historical slowdown
(computer fit is almost the same)

Shorter Days



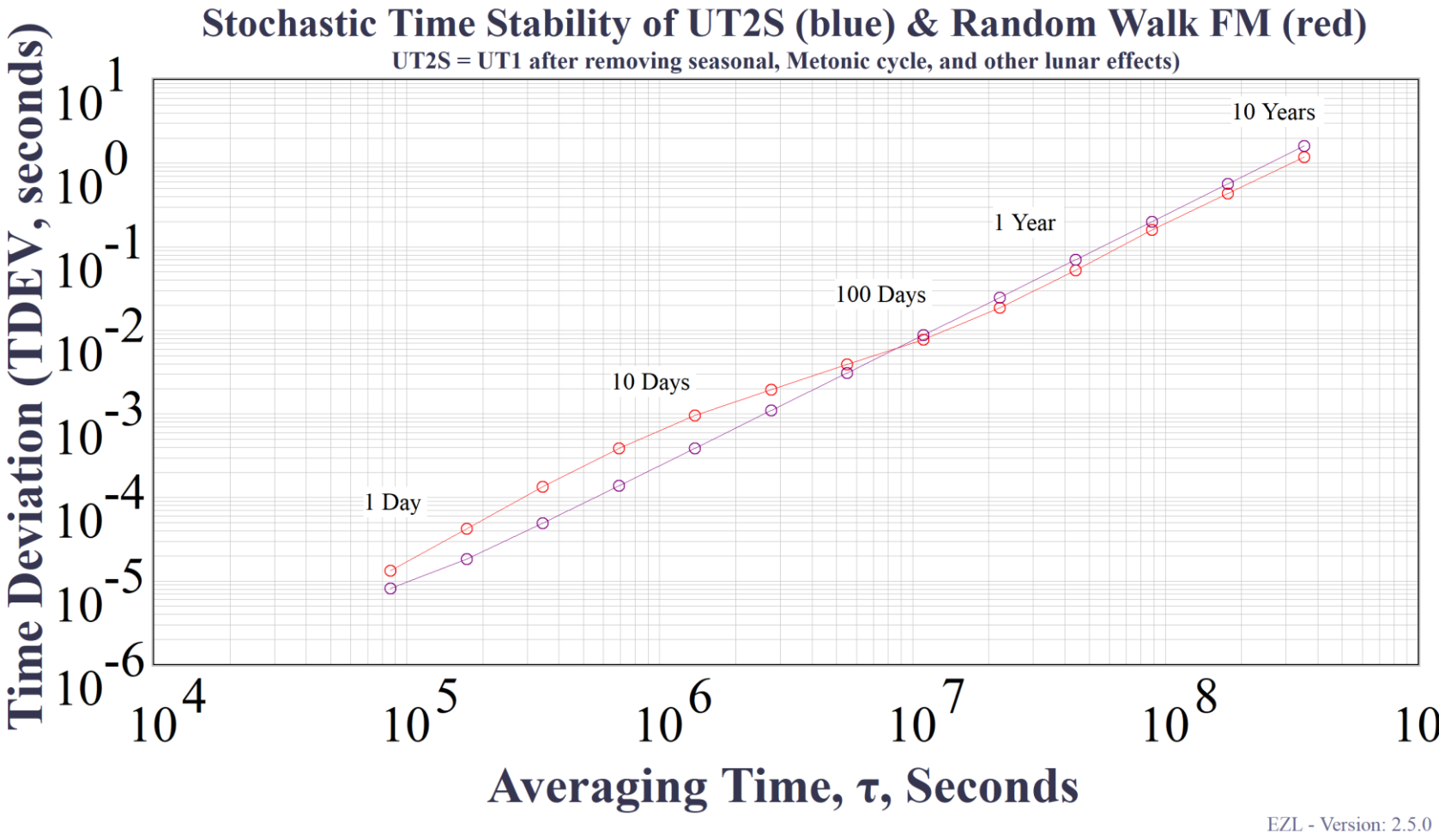
Historical slowdown is insignificant on this scale (0.14 ms LOD change over ten years)

Shorter Days to come?



LOD behavior: random walk on decadal scales

(if so, the best predictor of LOD's stochastic behavior is its current value)



statistics sensitive to variations of angular momentum of atmosphere (weather)

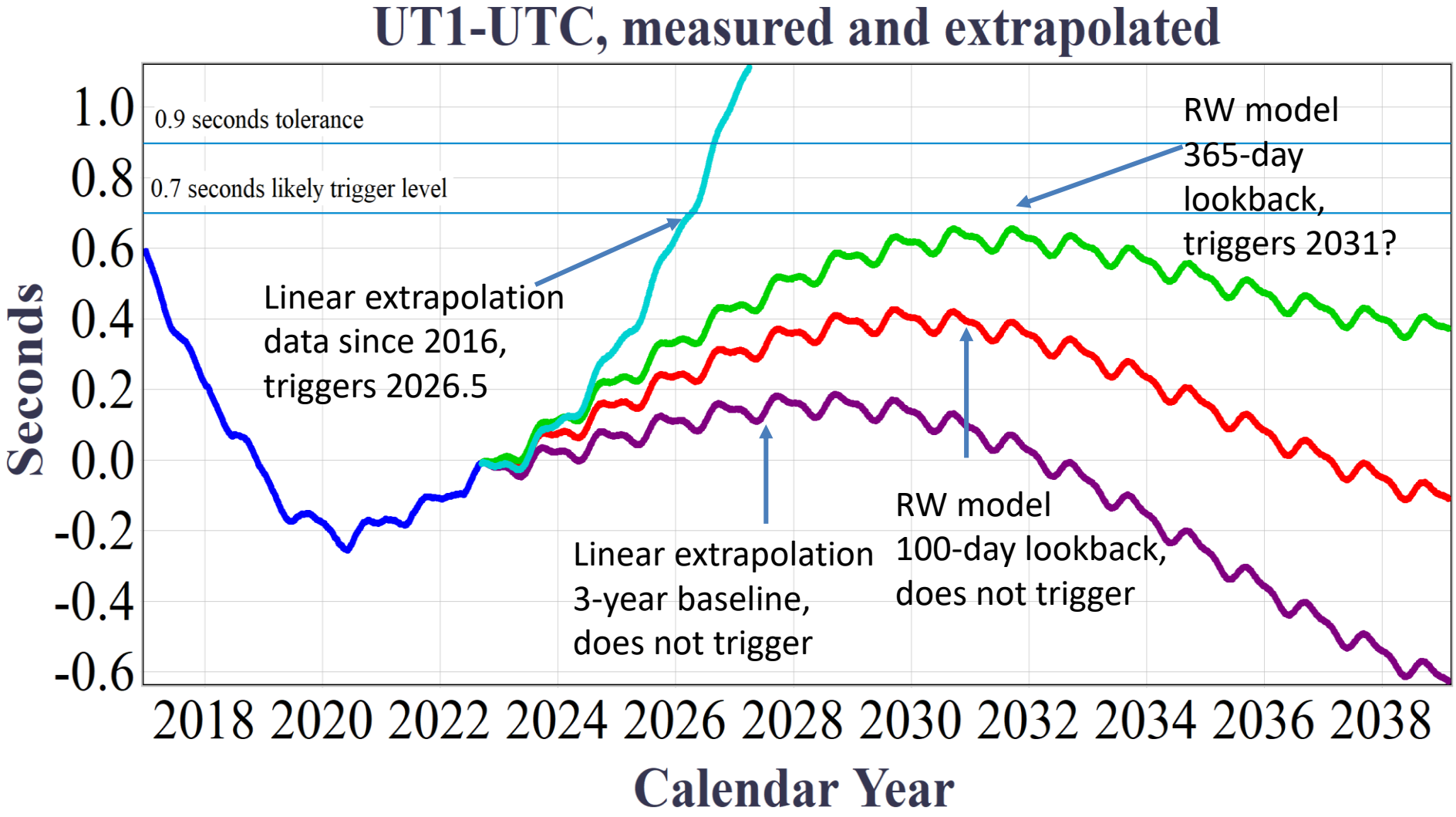
Two Prediction Types

I. Assume LOD is a Random Walk (Best predictor of future is current value)

1. Remove all deterministic effects to UT1, LOD
   - Seasonal, 14-day, Metonic, zonal tides, etc.
   - Long-term tidal braking accumulates 0.25 seconds in first decade
2. Average LOD over suitable lookback period (100 or 365 days)
3. Extrapolate LOD as a constant
4. Integrate result
5. Re-insert all the deterministic effects to get UT1-UTC

II. Assume LOD varies linearly over 2015 -> now -> 2028

1. Remove all deterministic effects to UT1, LOD
   - Seasonal, 14-day, Metonic, zonal tides, etc.
   - No need to remove long-term slowdown (linear in LOD)
2. Linear fit with 3 or 6.8 year lookback time
3. Extrapolate linearly
4. Integrate result
5. Re-insert all the deterministic effects to get UT1-UTC

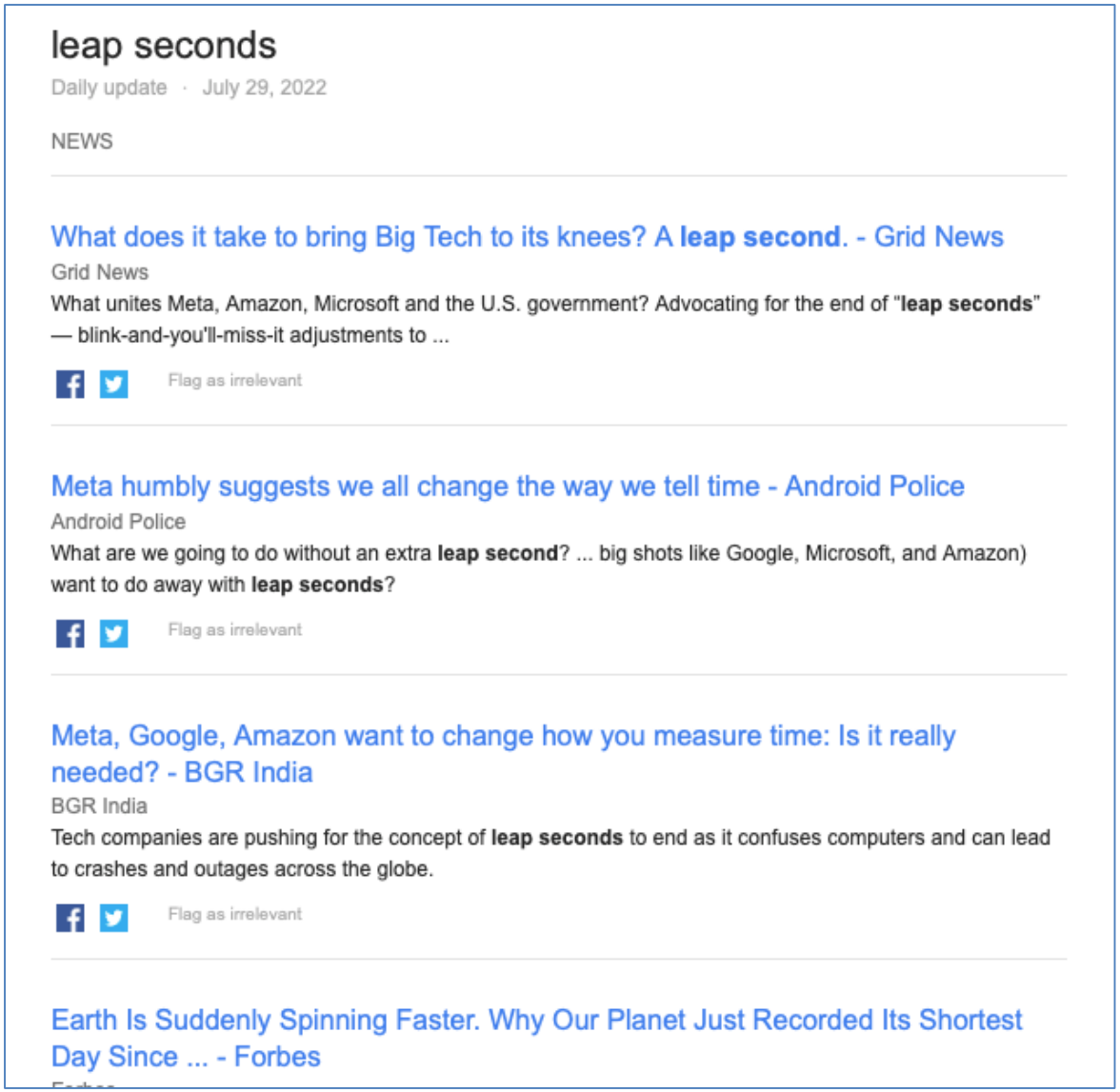


The largest source of error lies beneath our feet

UTC controversy heading for resolution

- ITU-R has been debating leap seconds since last century
  - ITU=International Telecommunication's Union
    - Its tri-annual meeting is the World Radio Conference (WRC)
  - ITU makes decisions by consensus
- In 2015 WRC decided to let the CGPM define UTC
  - CGPM=General Conference on Weights and Measures
    - CGPM makes decisions by voting
  - CCTF resolution to be considered by CIPM in November 2022
    - To increase the 0.9 second tolerance
      - But maybe not
      - No earlier than 2035, when Russia has indicated GLONASS should be ready
      - And with due consideration for all other stakeholders
    - CCTF=Consultative Committee for Time and Frequency
    - CIPM=International Committee of Weights and Measures (parent body of CCTF, CGPM)
  - WRC to meet in 2023
    - BIPM and ITU-R have a Memorandum of Understanding
- Big idea: leap seconds are here to stay, but tolerance is an important matter for discussion

The Tech Giants are weighing in



leap seconds

Daily update · July 29, 2022

NEWS

What does it take to bring Big Tech to its knees? A **leap second**. - Grid News

Grid News

What unites Meta, Amazon, Microsoft and the U.S. government? Advocating for the end of "**leap seconds**" — blink-and-you'll-miss-it adjustments to ...

Flag as irrelevant

Meta humbly suggests we all change the way we tell time - Android Police

Android Police

What are we going to do without an extra **leap second**? ... big shots like Google, Microsoft, and Amazon) want to do away with **leap seconds**?

Flag as irrelevant

Meta, Google, Amazon want to change how you measure time: Is it really needed? - BGR India

BGR India

Tech companies are pushing for the concept of **leap seconds** to end as it confuses computers and can lead to crashes and outages across the globe.

Flag as irrelevant

Earth Is Suddenly Spinning Faster. Why Our Planet Just Recorded Its Shortest Day Since ... - Forbes

For official updates, check USNO press releases, which are available below www.usno.navy.mil

For arguments of *all* kinds of (unofficial and unedited): http://six.pairlist.net/mailman/listinfo/leapsecs

For background, here is a somewhat dated CGSIC talk I gave in 2014: https://www.gps.gov/cgsic/meetings/2014/matsakis.pdf

Backups

- How Masterclock, Inc. looks for “sleeper bugs” that are triggered by not having leap seconds.
- Position of magnetic North Pole since 1590
- Removing parabola from UT1-TAI
- Predictions that ignore historical tidal slowdown
- ”UT1-UTC”, if second defined by LOD in 1800

Special thanks to EZL Software
for donating the plotting software

Two good ways to prepare for whatever happens

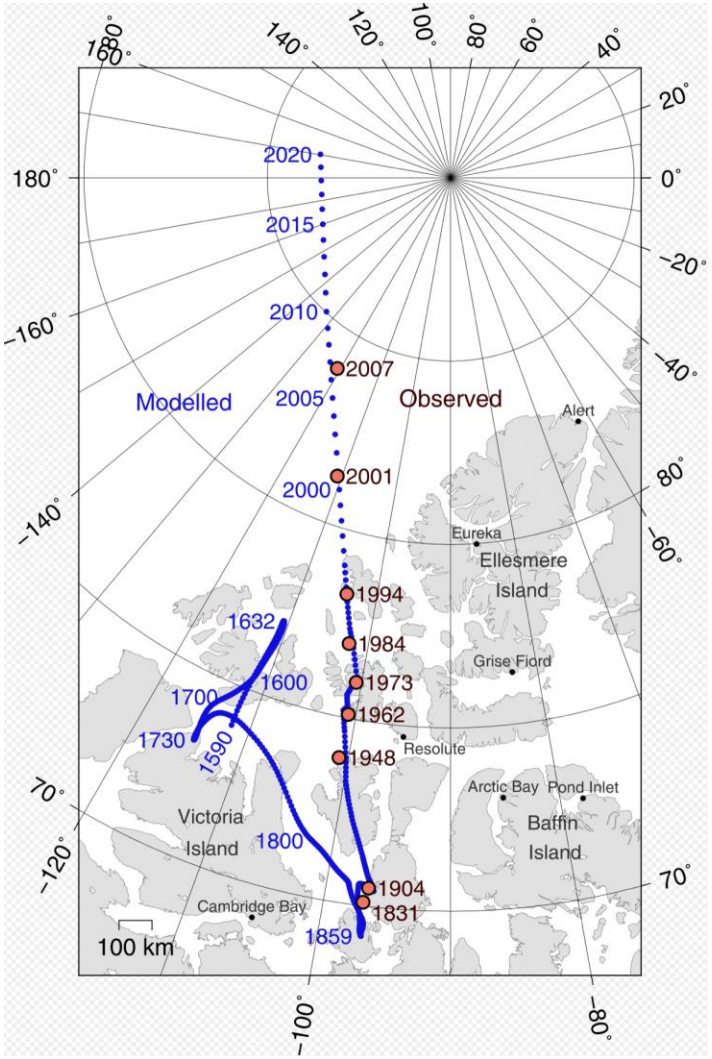
- Use a GNSS/GPS simulator to mimic an event

-- and/or --

- Use a GNSS simulator to find “sleeper-bugs”
  - Simulate GNSS time always 3 months ahead
    - Feed it into GNSS-disciplined clock
  - Observe the clock’s time (with NTP)
    - It should always also be 3 months ahead
    - If not, you have 3 month’s notice of hidden leap-second bugs

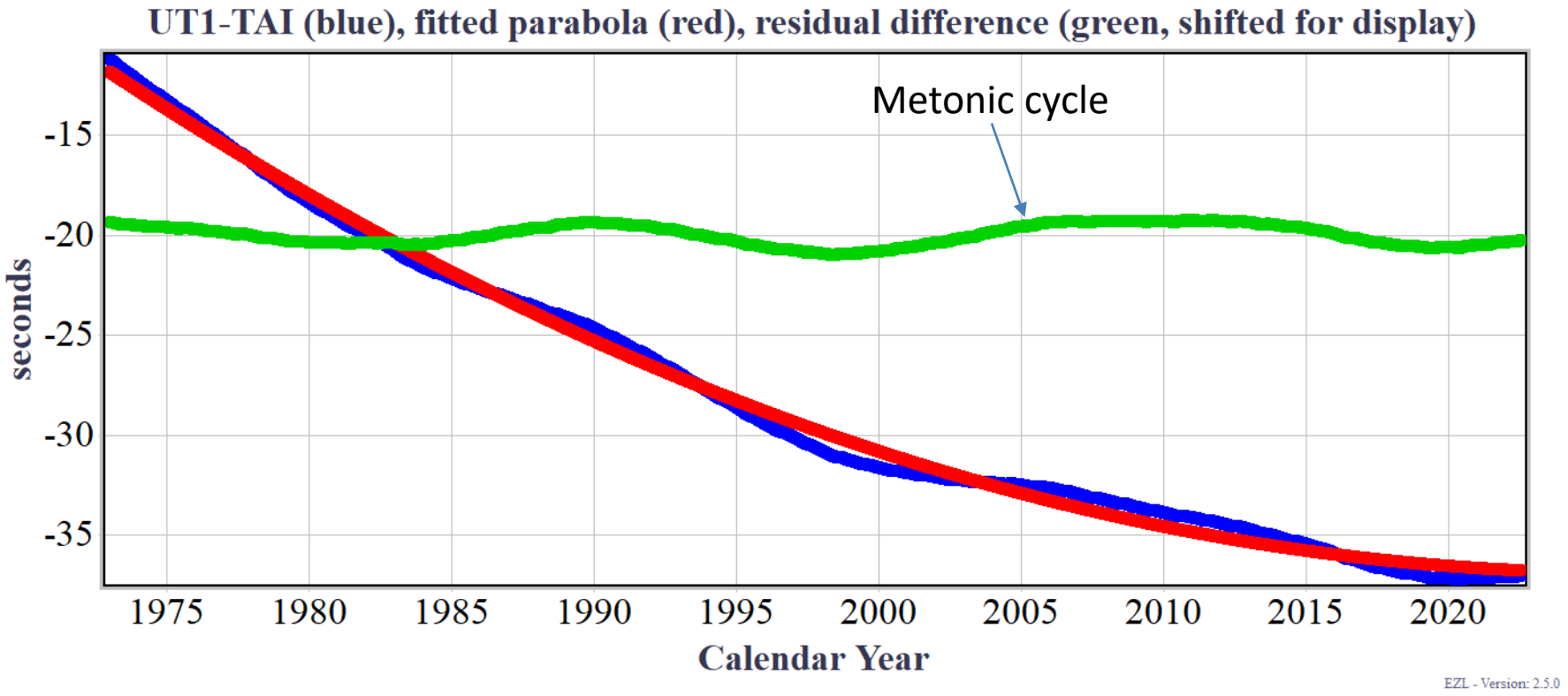
Position of North Magnetic Pole

Has moved up to 40 km/year



By Cavit - Own work Observed pole positions taken from Newitt et al., "Location of the North Magnetic Pole in April 2007", Earth Planets Space, 61, 703–710, 2009. Modelled pole positions taken from the National Geophysical Data Center, "Wandering of the Geomagnetic Poles";Map created with GMT, CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=46888403

Removing a parabola from UT1-TAI



How much has UT1 lost since 1800?

- Lunar motion substitute for atomic time pre-1970
- Blue: uses SI second as now defined for UTC
  - 86400 SI seconds = “average” day in mid-1800’s
- Red: uses SI second as would have been defined in 1800
  - 86400 SI seconds = Average day in 1800