Data Visualization: NIST Time Scale Data and Leap Seconds

LSC563: Data Visualization-2025

By: Rasmita Timalsina

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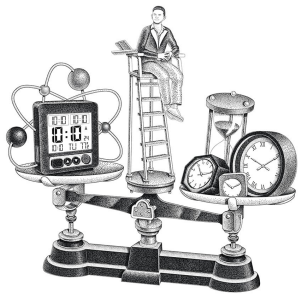
Contents

Introduction

❖ Why Do We Need Accurate Time?



Project Overview

- Focus: Visualizing and understanding leap seconds and UT1–UTC variations from 2020–2024.
- Data from NIST Bulletins and Leap Seconds Archive.
- Goal: Make complex time corrections accessible through clear, effective data visualizations.

Time Standards Overview

- **UT (Universal Time)**
  Astronomical time based on Earth's rotation.
  UT1 is a refined version for precise measurements.

- **UTC (Coordinated Universal Time)**
  Atomic time adjusted with leap seconds to stay within 0.9s of UT1.
  Global civil time standard.

- **DUT1 (Delta UT1)**
  Difference between UT1 and UTC:

$$\mathrm{DUT1} = \mathrm{UT1} - \mathrm{UTC}$$

  Published by IERS/NIST; ranges from $-0.9\,\mathrm{s}$ to $+0.9\,\mathrm{s}$.

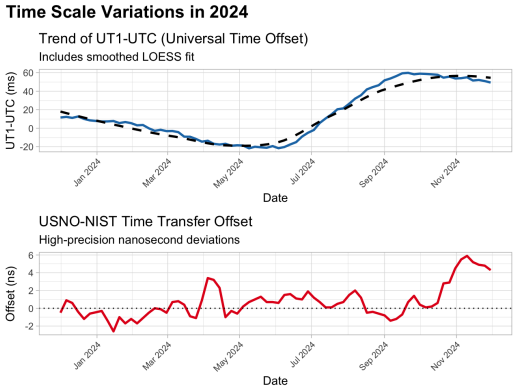
Methods

Data Collection and Preparation

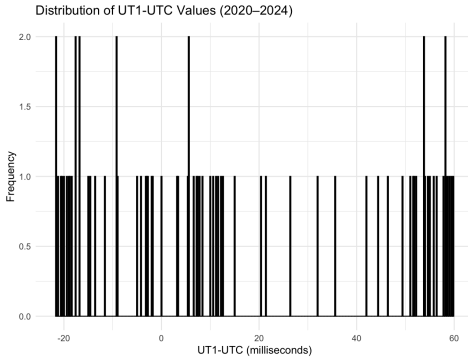
- How do we keep atomic time (UTC) in sync with Earth time (UT1)?
- Raw data sourced from:
  - NIST Time Frequency Bulletins
  - Leap Seconds Archive (2020–2024)
- Cleaned and transformed using R (dplyr, tidyr).
- Variables include UT1–UTC differences, leap second events, Modified Julian Date (MJD), and other time-related corrections.

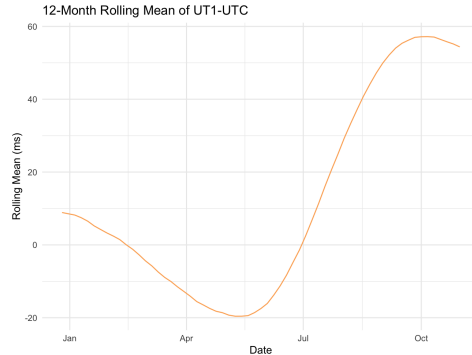
Results

UT1-UTC and USNO-NIST Time Offset Analysis



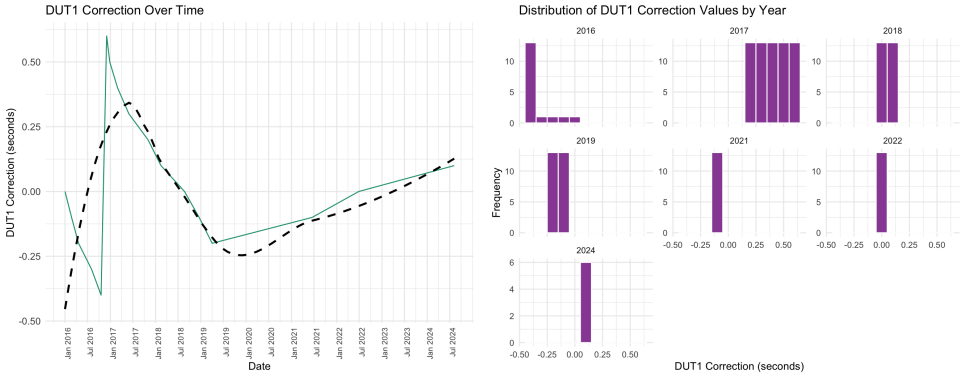
Combined plot of UT1–UTC differences and USNO–NIST offset. Shows small, regular fluctuations. These differences reflect adjustments made to synchronize atomic time with Earth's rotation.





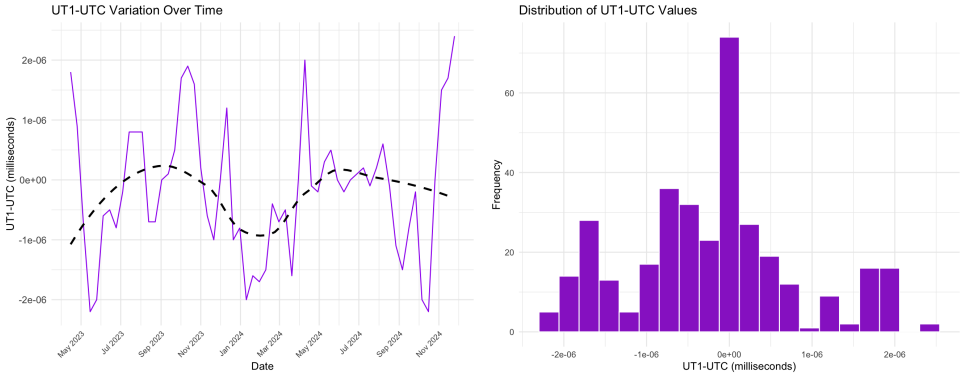
L: Histogram of UT1–UTC values and R: 30-day rolling mean of UT1–UTC. Values are centered near 0 with minor variation. UT1 stays close to UTC, adjusted through leap seconds when needed.

DUT1 Corrections — NIST Time Data (2020–2024)

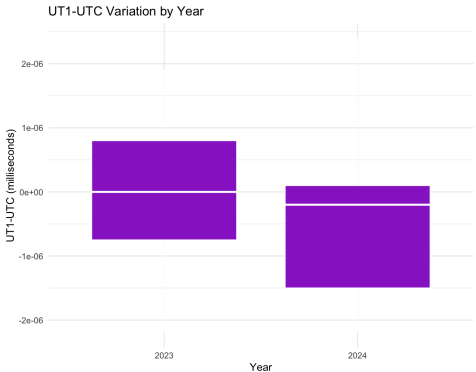


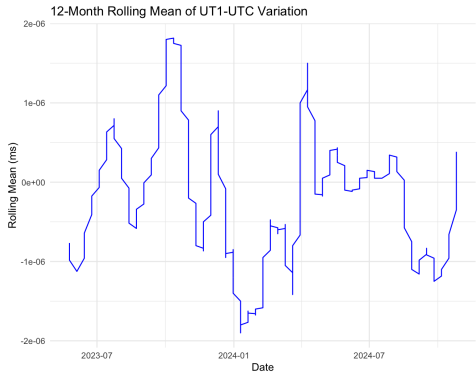
DUT1 over time and Histogram: Distribution by year. DUT1 stays between –0.9s and +0.9s, as expected. DUT1 is regulated to stay within ±0.9s by inserting leap seconds.

UT1-UTC Variation Visualization



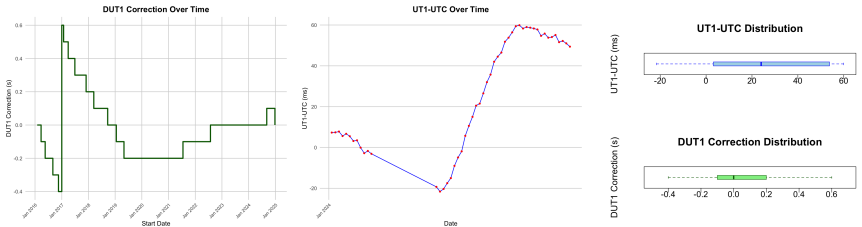
L: Line plot over time and R: Histogram of values. UT1–UTC oscillates but remains bounded. UTC is regularly corrected to keep it aligned with UT1.



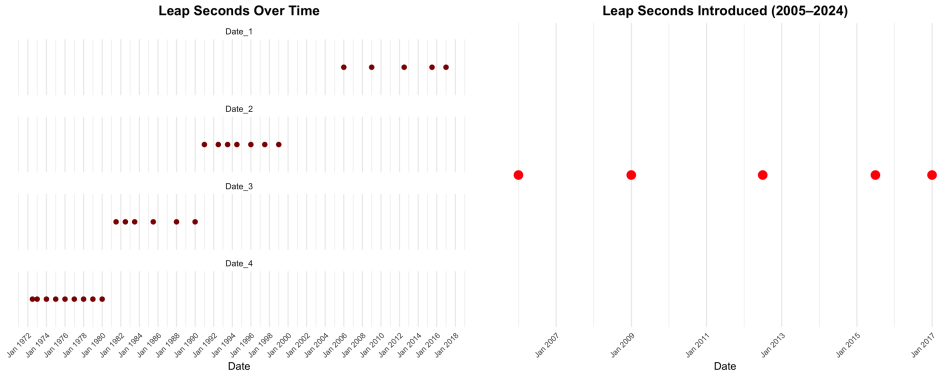


L: Boxplot of variation and R: Smoothed trend using rolling average. Median close to zero, with small spread. Confirms tight control of UT1–UTC differences.

Leap Seconds and DUT1 Corrections, UT1_UTC Analysis



Three small plots: DUT1 correction timeline, UT1–UTC values, and boxplot. All show stability and gradual variation. Multiple views confirm consistent timekeeping practices.



L: Leap seconds over time and R: Timeline view. Leap seconds are added irregularly, most often mid-year or year-end. They help keep UTC within ± 0.9s of UT1.

Interpreting the Data

- Leap seconds are added to synchronize atomic time with Earth rotation.
- Variability in Earth's rotation affects UT1–UTC.
- Graphs help show when and why leap seconds become necessary.

Metacognition

Reflecting on the Process

- Challenges: Tidying inconsistent NIST data; aligning MJD with calendar dates.
- Learned to combine technical coding with narrative clarity.
- Visual thinking made abstract timekeeping ideas more tangible.

Visualizing Time Irregularities

- ❖ Plotted UT1–UTC vs. Date (2020–2024): Reveals cyclical variation.
- ❖ Leap Second timeline: No leap seconds between 2020–2024, but irregular spacing historically.
- ❖ Used ggplot2 to highlight trends and annotate important transitions.

- UT1 tells us how Earth is really spinning
- DUT1 tells us how far Earth time has drifted from atomic time (UTC).
- If DUT1 gets close to ± 0.9 seconds, a leap second may be added to UTC.

Conclusion

Comparison to Other Studies

- Other research on leap seconds (e.g., by the International Earth Rotation Service) highlights similar variability in UT1-UTC and the importance of maintaining synchronization for navigation and communication systems.
- Compared to previous visualizations, this project uniquely integrates multiple data sources (NIST Bulletins and Leap Seconds Archive) and emphasizes clear, accessible visual storytelling for scientific audiences.

Summary and Insights

- Studied data visualization in R and Exploratory Data Analysis
- Leap seconds and UT1–UTC differences are critical to global time synchronization.
- Effective data visualization can demystify scientific timing concepts.
- Future work: Real-time dashboards or interactive visualizations.

Acknowledgments & Sources

Acknowledgments & Sources

- **Instructor:** Abby Scheetz – for guidance throughout the project and coursework.
- **Support:** Family and friends – for encouragement and moral support.
- **Key Sources:**
  - NIST Time and Frequency Bulletin
  - NIST Leap Seconds Archive
  - Wickham, H. (2014). Tidy Data (for data wrangling practices)

Thank you for your Attention !

Questions?