Earth rotation is gradually slowing down – is it?

Die Erdrotationsgeschwindigkeit nimmt stetig ab – oder doch nicht?

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Abstract

It is an accepted fact that the speed of Earth rotation is decreasing. However, if we look at length of day time series based on the observations of modern space geodetic techniques, which cover only the last 50 years, we see an average decrease in length of day, equivalent to an acceleration of Earth rotation. This article emphasizes the importance of the time span when investigating trends. It explains why it is still valid that Earth rotation is gradually slowing down, although it has been speeding up in recent decades. Furthermore, we discuss the relations between length of day and universal time and the occurrence of leap seconds. We finally provide current results of very long baseline interferometry analyses. These show that the time determined by Earth rotation has gained 90 ms on atomic time from January 2022 to January 2023.

Keywords: Earth rotation, length of day, universal time

Kurzfassung

Es ist eine anerkannte Tatsache, dass die Geschwindigkeit der Erdrotation abnimmt. Betrachtet man jedoch Zeitreihen der Tageslänge, die auf den Beobachtungen moderner geodätischer Weltraumverfahren beruhen und nur die letzten 50 Jahre abdecken, so stellt man eine durchschnittliche Abnahme der Tageslänge fest, die einer Beschleunigung der Erdrotation entspricht. Dieser Artikel unterstreicht die Bedeutung der Zeitspanne bei der Untersuchung von Trends. Er erklärt, warum die Annahme, dass sich die Erdrotation allmählich verlangsamt, nach wie vor gültig ist, obwohl wir in den letzten Jahrzehnten eine Beschleunigung sehen. Außerdem werden die Beziehungen zwischen Tageslänge und Weltzeit sowie das Auftreten von Schaltsekunden erörtert. Abschließend stellen wir neueste Ergebnisse von Analysen der Very Long Baseline Interferometry vor. Diese zeigen, dass die durch die Erdrotation bestimmte Zeit von Januar 2022 bis 2023 90 ms gegenüber der Atomzeit aufgeholt hat.

Keywords: Erdrotation, Tageslängenschwankungen, Weltzeit

1. Introduction

There is scientific consensus that the Earth‘s rotation rate is decreasing, implying an increase in the length of the solar day. A recent estimate of that deceleration, in terms of length of day (LOD), is a trend of +1.8 ms per century [1]. The estimate is based on records of ancient and medieval eclipses and of lunar occultations of stars, covering the period from 720 BCE to 2015 CE. The main driver of decelerating Earth rotation is tidal friction. However, the LOD rate predicted due to tidal friction amounts to +2.3 ms per century, leaving a difference of −0.5 ms per century, which claims a counteracting mechanism to tidal friction. The discrepancy can be explained by a secular trend in the polar moment of inertia caused by glacial isostatic adjustment and melting or relocation of polar ice sheets (see [2] and the references therein). So, if we consider time scales of two millennia and more, the answer to the question formulated in the title is yes, Earth rotation is gradually slowing down. If we look at shorter segments of one or two centuries or several decades only, the slope of a linear regression would be steeper, less steep, or even have a negative sign, depending on the selected period. The reason for the dependence is the presence of irregular fluctuations in LOD (as a measure of Earth rotation speed) in the range of two years to a few decades with peak-to-peak amplitudes of up to 7 ms. In the study of [1] there is also an indication of a 1500-year oscillation in the LOD, which is comparable in size to the decadal variations mentioned before. These decadal (and the assumed millennial) variations are commonly attributed to coupling mechanisms between the Earth‘s core and mantle. Since our knowledge about core-mantle interactions and processes in the Earth‘s interior is still limited, the time of occurrence and magnitudes of related fluctuations in Earth rotation remain elusive. Short-term periodic and seasonal LOD variations, caused by solid Earth and ocean tides and changes in the wind and pressure fields of the atmosphere, can be captured quite well. The large decadal fluctuations, however, represent a sizable uncertainty factor in predicting the Earth‘s rotation rate and phase (expressed as Universal Time, UT1).

The following section gives an impression of the variability of Earth's rotation rate, quantified as excess length of day ΔLOD (observed minus the nominal length of day), over the last two centuries. In section 3, the relation of LOD, UT1, and the introduction of leap seconds is discussed. Section 4 describes the monitoring of Earth rotation at the Vienna Center for VLBI (very long baseline interferometry) and presents some results on the recent catching up of universal time with atomic time.

2. Trends and long-term variations in the length of day from the 19th century to present

As pointed out in the introduction, the sign and magnitude of trends are matters of the observation period. This becomes apparent when we look at the available data. Figure 1 shows ΔLOD time series from two different data sets: the LUNAR97 series [3] spans from 1832.5-1997.5, it is sampled yearly, and it does not contain tidal and seasonal variations; the finals series [4], provided by the International Earth Rotation and Reference Systems Service (IERS), covers the period from 1973 to May 2023, it is displayed as provided (at daily intervals) in green and cleaned from tidal and seasonal effects in dark green.

The LUNAR97 is a smoothed LOD series obtained from UT1 measurements taken by lunar occultation, optical astrometry, lunar laser ranging, and very long baseline interferometry (VLBI), which were combined in a Kalman filter [3]. The IERS finals are combined Earth orientation parameter series, including observations from lunar and satellite laser ranging, VLBI, and global navigation satellite systems.

When considering the whole, almost 200 years period, we receive a positive trend of 1.1 ms per century in length of day, which means we see a deceleration of Earth rotation, though less pronounced than over the last two millennia, as examined in [1]. If we cut out arbitrary slices of 30 to 50 years, we would observe a substantial variation in the slopes of the respective trendlines. For example, if we restrict the investigation to the 50 years covered by the IERS final series, the result is a trend of −5.1 ms per century. Earth rotation has been speeding up during the last decades. Starting in late 2020, several headlines claimed that the Earth would be suddenly spinning faster. Figure 1 shows, that is not true because it is not a recent phenomenon but a persistent trend that started 50 years ago. The public became aware of the days getting shorter because the ΔLOD values started to cross the zero line more often in

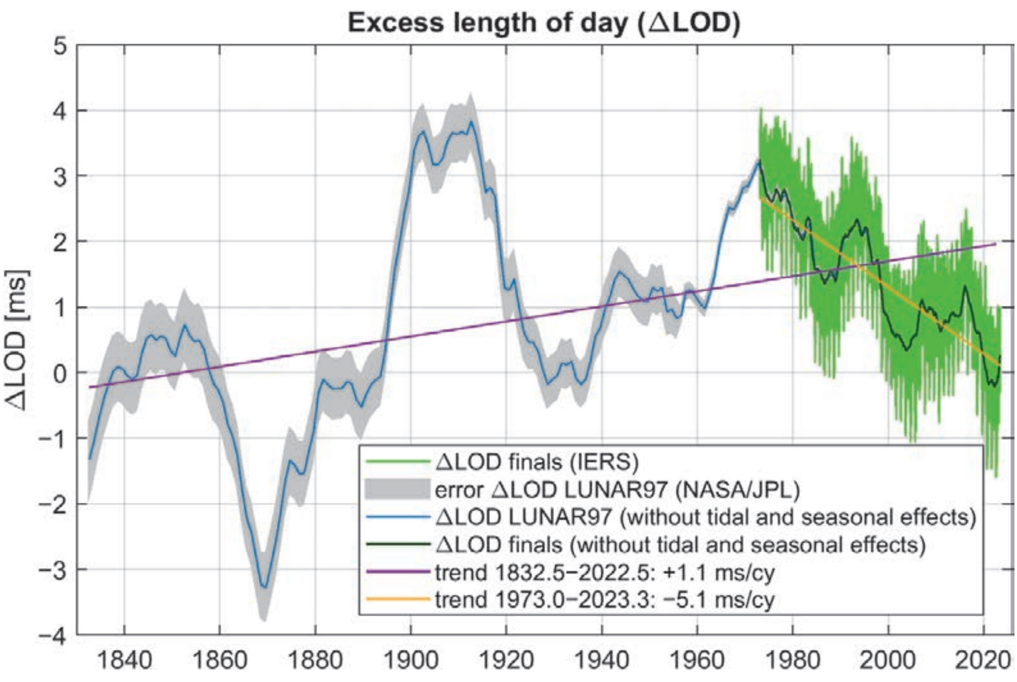

Fig. 1: Length of day time series and trends from 1832.5 to 2023.

2020, and the length of day determined by Earth rotation is now very close to the nominal length of day of 86400 s. The average length of day in the year 2020 was 86399.9999965 s. This development also explains why it was not necessary to introduce a leap second in the last few years. The next section further elaborates the connection of LOD with UT1 and the leap second events.

3. LOD, UT1, and the frequency of leap second introduction

Universal time (UT1) is a measure of the phase angle of the terrestrial prime meridian. The quantity excess LOD (often termed LOD only) results from the negative time derivative of the difference UT1 minus atomic time (universal time coordinated, UTC). For centuries, the Earth's rotation about its axis was considered a reliable clock-pulse generator. Time was derived from astronomical observations, and pendulum clocks, and later quartz clocks were adjusted to that time. With the advent of atomic clocks, this practice was continued by setting TAI (the continuous international atomic time) and UTC in agreement with UT1 in 1958 [5]. Fractional adjustments of UTC to UT1 were used until 1972, when the system of leap seconds was established. Coincidentally, it was the year of a trend reversal in the Earth rotation rate. From about 1930, there had been a gradual increase in ΔLOD, culminating in a value of over 4 ms in April 1972. Figure 2 shows time series of ΔLOD and UT1-UTC for the last 50 years. Each discontinuity in the UT1-UTC time series marks a leap second event. A leap second is introduced whenever the IERS envisions that the absolute difference between UT1 and UTC would soon exceed 0.9 s.

Figure 2 shows that the size of the ΔLOD values correlates with the frequency of the leap second introduction. Ten out of the to-date 27 leap seconds had to be applied in the first ten years. From 1999 to 2006, we faced no leap second implementation at all because ΔLOD oscillated around an average close to zero. During the last three years, the average LOD was shorter than 86400 s, creating the unique pattern of UT1-UTC heading upwards. If this trend was to continue, we might see, for the first time, the introduction of a negative leap second. However, it is equiprobable that we have reached a turning point, and ΔLOD begins to increase again.

Every leap second event imposes major challenges to different areas of computing, such as high-frequency trading. We will not cover these in this article. However, it is important to note that the various issues arising from every leap second introduction triggered the discussion about the future of the leap seconds already two decades ago. In 2022, the General Conference on Weights and Measures finally adopted a resolution with

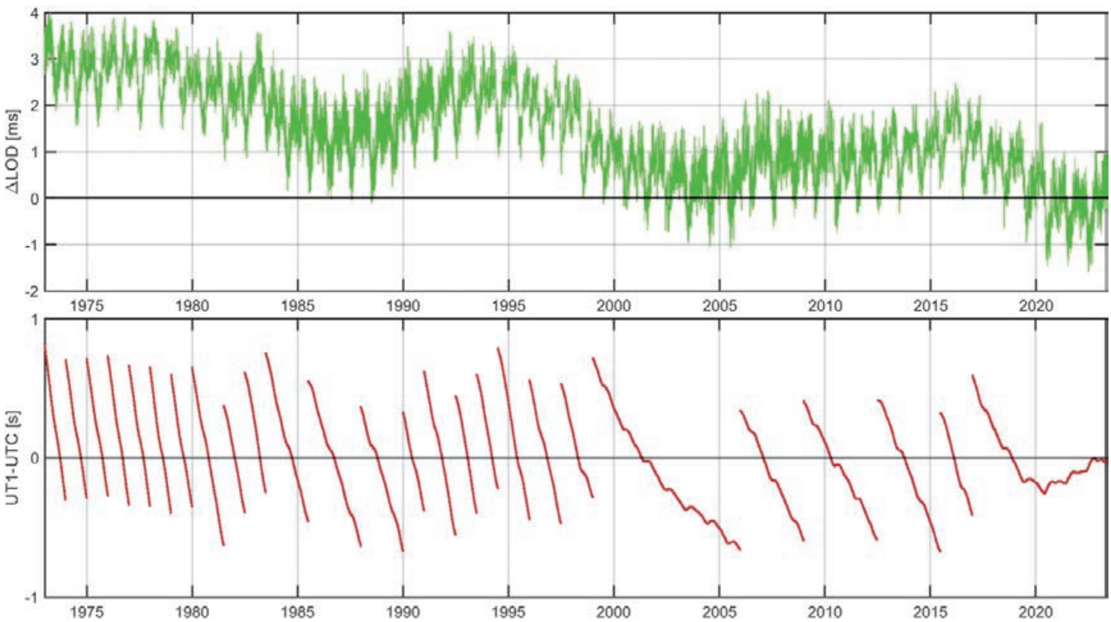

Fig. 2: *Time series of ΔLOD (top) and UT1-UTC (bottom) for the period 1973 to May 2023 (IERS finals [4])*

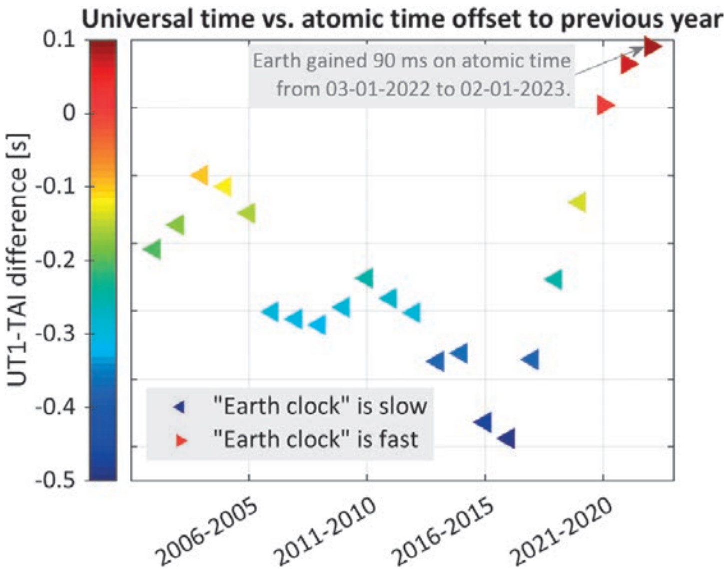

Fig. 3: *Excess length of year derived from VLBI Intensive sessions*

the decision: "that the maximum value for the difference (UT1-UTC) will be increased in, or before, 2035" [6]. The new maximum value has yet to be defined, but it should be, on all accounts, large enough to ensure the continuity of UTC for at least a century.

4. Earth rotation monitoring at the Vienna Center for VLBI

At the Vienna Center for VLBI, which is a joint effort by TU Wien and the Federal Office of Metrology and Surveying, we routinely analyze, among other things, all available 24-hour sessions and the so-called Intensive sessions (see the article by Lisa Kern, this issue). We monitor the Earth orientation parameters (celestial pole offsets, polar motion parameters, and UT1-UTC) and provide updates on our website (https://www.vlbi.at/products/) as soon as they are available.

In Figure 3, we display the results of a quick-look study, where we picked the UT1-TAI values resulting from the first INT1 session (one type of Intensive) of each year since 2001 and built the difference to the previous year. The plotted values, therefore, represent a kind of excess length of the year. The image shows that the time determined by Earth rotation has always lagged the atomic time, while 2020 was the first year for the „Earth clock" to gain a few ms on atomic clocks. By January 2023, this had already risen to 90 ms.

At present, the upward trend of UT1-UTC is stagnating (see Figure 2), but at TU Wien, we keep a close watch on its latest evolvement to catch the moment when UT1-UTC will pass the zero line from negative to positive without the aid of a leap second. Currently, the IERS finals [4] predict that incident for the end of July 2023, but it might not happen this year at all.

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