Recent acceleration of the Earth rotation in the summer of 2020: possible causes and effects

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Abstract. The extreme acceleration of the Earth rotation observed in the summer of 2020 is considered. It is concluded that this phenomenon is a consequence of two factors: the long-term acceleration of the Earth rotation, which has been observed since the 1970s, and the extremely strong meteorological excitation of the LOD, which took place in the summer of 2020. The coincidence of the anomaly of the AAM and the geomagnetic Dst index, as well as the correlation between the LOD on the one hand and the solar wind speed and the Gaussian coefficients of the expansion of the Earth’s magnetic field, on the other, are noted. The problem of negative leap second is considered. Preliminary estimates have been made of introduction of a negative leap second, if the current trends in the behavior of UT1–UTC continue. The conclusion is made about the low probability of such an event.

1. Introduction
The instantaneous angular velocity of the Earth’s rotational motion is measured as the difference between the astronomically determined length of the day and the time interval of 86400 SI seconds. This difference is traditionally called simply Length of Day (LOD). It is known that the rate of the Earth’s rotational motion, or LOD, changes over time. Temporal changes in LOD include slow, almost linear deceleration due to tidal friction, strictly periodic tidal variations, semiannual and annual fluctuations of a meteorological nature, as well as large fluctuations of an irregular nature with characteristic time scales from several days to several decades [1] [2]. The nature of irregular or aperiodic oscillations is still not clear. It is believed that they can be caused by currents in the liquid core of the Earth [3] [4] or variations of the Solar Wind [5].

However, over the past thirty years, there has been a tendency for abnormal acceleration of the Earth rotation or a decrease in LOD (see Figure 1) which led, for example, to the fact that from 1999 to 2004, and from 2017 to the present, leap seconds were not added to Universal Coordinated Time (UTC). The Earth rotation accelerated especially sharply in the summer of 2020. In fact, in the summer months of 2020, the Earth rotated faster than in the middle of the 19th century, that is, this effect exceeded in magnitude the effect of tidal braking over the past 150 years. In this paper possible reasons and causes of this anomalous acceleration are investigated. For that purpose the LOD time series are compared to the time series of the Atmospheric Angular Momentum (AAM), Dst geomagnetic index, as well as Solar Wind velocity.
For the LOD data we used the International Earth Rotation Service (IERS) series EOP C04 provided at [6]. The LOD time series data has a temporal resolution of 1 day. For the Atmospheric Angular momentum functions we used data provided by National Center for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR), taken from [7]. The AAM data has a temporal resolution of 6 hours (0.25 days). Dst index data were provided by International Service of Geomagnetic Indices at [8]. The Dst index data has a temporal resolution of 1 hour. For Solar Wind velocity we used data provided by Space Physics Data Facility of Goddard Space Flight Center, taken from OMNIWeb Plus [9]. For this work we used data with temporal resolution of 1 day. 13th Generation International Geomagnetic Reference Field data was provided by International Association of Geomagnetism and Aeronomy at [10] with temporal resolution of 5 years.

2. Data analysis

According to our analysis, the anomalous acceleration of the Earth rotation observed in the summer of 2020 (as of July 19, 2020, LOD = \(-0.0014663\) s) is a consequence of the simultaneous impact of two factors. The first is the anomalous seasonal acceleration that took place in 2020. The second factor is the long-term acceleration of the Earth rotation, which has been continuing since the 1970s, which should be attributed to long-term variations in the Earth rotation.

Consider the seasonal acceleration of the Earth rotation. As it is known, on short time scales (a year or less), non-tidal variations in the Earth rotation are well described by the influence of...
the atmosphere, which is clearly seen in Figure 2, that displays the LOD series with removed tidal variations, as described in the IERS Conventions 2010 [11] and the AAM time series from the NCEP/NCAR reanalysis project [12]. The pronounced seasonality of variations in the Earth’s rotation and their dependence on meteorological conditions in the Northern Hemisphere is explained by the uneven distribution of land over the Earth’s surface. The torque from the atmosphere is transmitted to the solid body of the Earth through the friction of the atmosphere over land. If the distribution of land over the Earth’s surface were sufficiently uniform, then the influence of the atmosphere in the Northern Hemisphere would be smoothed out by the opposite influence of the atmosphere in the Southern Hemisphere, where there would be an opposite season. However, most of the land on Earth is located in the Northern Hemisphere, and most of the mountain systems are located there, and thus the seasonal variations caused by the atmosphere in the Southern Hemisphere cannot compensate for the influence of the atmosphere in the Northern Hemisphere. The mechanism of seasonal variation is described in more detail in [13].

Based on the LOD series available to us, starting from 1963 and having a duration of 58 years, it is possible to reconstruct the following averaged pattern of seasonal variations (after subtracting long-period variations, tides, and tidal braking). At the beginning of the year, the length of the day changes slightly, remaining almost constant, however, at the end of April, in the last decade (by 110-120 days of the year), the length of the day begins to decrease quite quickly, and reaches a minimum value at 200-210 days of the year (last decade of July). The average value of the difference is 1 ms, the standard deviation is 0.3 ms. The LOD is restored to winter values by 320-330 days of the year (by the beginning of December). In 2020, the LOD difference between the last ten days of April and the last ten days of July was 1.5 ms. This is a very large value for that difference; such values were rarely achieved over the entire (from 1963 to 2020) observation history. Currently, LOD is determined using regular (2 times a week 24-hour sessions of the R1 and R4 programs to determine all 5 parameters of the Earth’s orientation and 5 times a week 2-hour sessions to determine the UT1-UTC difference) VLBI observations, LOD uncertainty is about 7 microseconds. Based on this information, we believe that the observed extreme acceleration of the Earth rotation in 2020, which also coincides with the extreme polar angular momentum of the atmosphere, is a real phenomenon, the available errors are 2 orders of magnitude less than the observed effect.

Figure 3. LOD and Solar Wind velocity.

It is interesting to note that the anomaly of the atmospheric angular momentum in time is in good agreement with the anomaly of the Dst index, which is clearly seen from Figure 2. We used Dst data provided by ISGI. First, the average daily Dst values were obtained, which were then smoothed by a Gaussian filter with full width at half maximum (FWHM) of 163 days.
This means that all three phenomena may have a common cause and future investigations are needed.

The second reason for the abnormal acceleration of the Earth rotation is the long term component, which has been observed since the 1970s. The full reasons for this long-term phenomenon have not been studied and are considered controversial. We would like to note that there is a fairly good agreement between the LOD and the solar wind speed (see Figure 3). We used Solar Wind speed data provided by Goddard Space Flight Center via OMNIWeb Plus. We used the average daily Solar Wind speed as the initial data. The original series was smoothed with a Gaussian filter with FWHM of 365 days.

In order to investigate possible connection of LOD with currents in the Earth liquid core we compared the LOD time series with the spherical harmonics of the IGRF geomagnetic field model, see Figure 4. From all possible harmonics only the $g_2^0$ and $h_1^1$ shown some long term correlation with LOD.

Comparisons of LOD with geomagnetic indices and Solar wind velocity as well as with geomagnetic spherical harmonics suggest that the long term, about a few decades long (50-60 years), LOD variations and probably caused by the core angular momentum, and the short term, about a few years long (10 years), LOD variations are probably caused by interactions of the solid Earth with Solar Wind.

Possible interactions of the Earth mantle with the Earth liquid core are investigated quite a long time, and a most probable mechanism responsible for those interactions is electromagnetic core-mantle coupling. In order to compute the core angular momentum time series inversions of the geomagnetic field were performed and this core angular momentum indeed showed some correlations with the LOD time series. Recently, new satellite geomagnetic measurements are available that allow to compute the core angular momentum with greater detail than before. This may shed a new light on the problem.

On the other hand, no plausible mechanism was proposed so far explaining interaction of the solid Earth with Solar Wind. Certainly, correlations of LOD with Solar Wind and the geomagnetic indices found in [5] as well is in this paper show that such interactions may indeed take place at time scales of a few years. Search for such a mechanism may be a subject for future work.

3. The negative leap second problem

The abnormal acceleration of the Earth rotation in the summer of 2020 caused speculations in media about the possibility of introducing a negative leap second in UTC. Currently, the UTC scale is used to set the time – uniform atomic time, periodically, as necessary, corrected
by inserting a leap second, so that the following relationship for UTC and universal time UT1 \( |\text{UT1–UTC} | < 0.9 \text{ s} \) is fulfilled. Since the introduction of this practice in 1972, 37 leap seconds have been introduced. Theoretically, in the absence of long-term variations, LOD (with subtracted tides and seasonal variations) should constantly increase, respectively, the difference UT1–UTC should increase in absolute value (but in the region of negative numbers) with acceleration, and the further, the more often we should insert seconds correction. However, if we look at the Figure 5, we will see that most often the correction seconds were inserted earlier, and vice versa, closer to the present, these events become less frequent.

![Figure 5. UT1–UTC from 1972 to 2020](image)

If we consider the typical behavior of the UT1–UTC difference throughout the year (see Figure 6), then the typical pattern of the following given difference decreases during the year, in the middle of the year there is a certain saddle (corresponding to the summer acceleration of the Earth rotation). However, if we look at the picture of 2020, there is a unique event when there was a direction reversal and at the end of the year the difference became larger than at the beginning without introducing any leap second. This event is unique and has never happened since 1972, when one began to introduce the leap seconds.

![Figure 6. Behavior of the UT1–UTC difference during the year in the last 10 year. 2015 and 2012 years (when was summer leap second) removed.](image)

With a long-term continuation of such a trend, it is possible that the UT1–UTC difference will approach its extreme value from the upper side and we will have to introduce a negative leap second. Let us try, however, to estimate the timing of such an event. It can be seen from the graph that the leap second is introduced when the difference approaches \(-0.6 \text{ s} (-600 \text{ ms})\), it is obvious that if a negative leap second is entered, this will happen if the UT1–UTC
difference approaches a value of about +0.5 s (+500 ms). At present (as of January 1, 2021), the UT1–UTC difference is −0.175371 s, up to 0.5 s there is still 0.675 s left. If the rate of UT1–UTC change observed in the period from summer to autumn 2020, when the difference increased by 87 ms in 130 days, had been maintained, then we would have approached the required boundary in about 3 years (1008 days), respectively, the question of a negative leap second would have occurred in the summer of 2023. However, already at the end of 2020, the rate of change in UT1–UTC decreased, in total, compared to the beginning of 2020, UT1–UTC increased by 0.7 ms. At the same time, if we take the latest data for UT1–UTC (as of August 31, 2021), we will see that the upward trend continued and UT1–UTC = −0.1193071 s, that is, 56 ms in 8 months or 85 ms/year. While maintaining such a pace, we will approach the border, at which it is necessary to make a decision on the introduction of a negative leap second, in 8 years, in 2029. However, this requires that a unique, previously not observed growth continues for 8 years. At the same time, this growth is a consequence of the acceleration of the Earth rotation, which has been observed since the 1970s, caused by long-period variations. The characteristic periods of these variations are about 50-60 years, thus, just by 2030, the Earth’s acceleration may first slow down, and then the trend may change to the opposite. The need for a long-term continuation of unique conditions and the expected rapid trend reversal make us assume that we will not see a negative leap second.

4. Conclusions
According to our analysis, the anomalous acceleration of the Earth rotation that took place in the summer of 2020 is an unique event caused by the superposition of two factors: the acceleration of the Earth rotation that has continued since the 1970s, which is part of long-period variations in the LOD, and an extremely strong seasonal acceleration caused by the influence of the atmosphere. The repetition of such an extreme reduction in the LOD requires a repetition of the extreme anomaly of the atmospheric angular momentum, which seems to us to be a rare event.

The continued acceleration of the Earth rotation caused discussions on the possibility of a negative second of correction. According to our analysis, this is an unlikely event, since it requires the continuation of the repetition of previously unobserved behavioral phenomena over several years. At the same time, in the near future (about 10 years), taking into account the characteristic periods of long-period variations, a change from acceleration to deceleration is possible.

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