THE GEOMAGNETIC FIELD AND THE EARTH’S ROTATION. CONNECTION AT SUB-CENTENNIAL AND INTER-DECADAL TIMESCALES

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The presence of the variations at sub-centennial (60–90 years) and inter-decadal (20–35 years) scales in the Earth’s rotation rate (LOD) is discussed. We compare these with variations at the same timescales seen in the main geomagnetic field (dD/dt). The link between the two processes has long been accepted in general as a manifestation of the Earth’s angular momentum conservation; we show it via cross-correlation analysis.

*Keywords:*geomagnetic, field, leught of day, sub-centennial variations.

1. INTRODUCTION

The rotation of the solid Earth changes as a result of applied external torques, internal mass redistribution (in which we include the time dependent fluid convection in the outer core), and the hydrodynamic or magnetohydrodynamic stresses acting at the fluid/solid Earth interfaces. Fluctuation in the Earth’s rotation rate is expressed by the so-called excess length of day (ΔLOD), that is variations from the sidereal day. A detailed account on LOD variations can be found in the review papers of Gross (2007) and Dehant and Mathews (2007).

Both Earth’s rotation speed and the geomagnetic field are characterized by temporal variations at certain time scales, ranging from seconds to centuries. Various approaches, such as wavelet analysis (Chao *et al*. 2014; Ding 2019), ensemble empirical mode decomposition (EEMD) (Shen and Peng 2016) and singular spectral analysis (SSA) (Le Mouël *et al*. 2019), have singled out variations on inter-annual, decadal and inter-decadal timescales in Earth’s rotation speed associated with changes of angular momentum with geophysical fluids.

At medium and short timescales, the study of Le Mouël *et al*. (2019) focuses, on one hand, on LOD changes forced by tidal effects of the Moon and Sun with periodicities in the 9-day ÷ 18.6-year interval and, on the other hand, on solar activity effects at the 11-year solar cycle and quasi biennial oscillation (QBO, 2.36 years) timescales. A so-called 6-year variation has been evidenced by Abarca del Rio *et al*. (2000) in the Earth’s rotation rate and by Silva *et al*. (2012) in geomagnetic observatory data. By de-trending and Butterworth bandpass filtering, Chen *et al*. (2019) found out the inter-annual variations in LOD related to sources from atmosphere and oceans, arguing that only the 5.9-year periodicity in LOD could be associated to geomagnetic field. At the decadal timescale, several studies (e.g. Pais and Hulot 2000; Gross 2007) succeeded to show that the link between the evolution of the magnetic declination and the Earth’s rotation rate is a result of the fluid flow in the outer core that produces both the geomagnetic field and the Earth’s rotation fluctuations.

At long timescales, the relationship between the magnetic declination time derivative and the Earth’s rotation rate, as being caused by geomagnetic jerks, was known a long time ago (Le Mouël *et al*. 1981). The so-called torsional oscillations in the outer core, that have been forwarded by Zatman and Bloxham (1997) to explain geomagnetic jerks, result in LOD variations (oscillations) of similar periods (Roberts *et al*. 2007). The latter authors estimate

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that in both LOD and geomagnetic field (declination, D, and inclination, I) well correlated similar periodicities with a period of about 60 years are present, indicating as a mechanism the torsional.

The progress has been made by the present authors in deciphering a fine structure of the secular variation at sub-centennial (60–90 years) and inter-decadal (20–35 years) timescales (Demetrescu and Dobrică 2014, 2021; Dobrică *et al*. 2018, 2021) that is responsible for certain features of the long-term evolution of the geomagnetic field.

In the present study, the data and the method of their processing are presented in Section 2. In Section 3 we compare the oscillations we found in the evolution of the geomagnetic field and of the Earth's rotation at the sub-centennial (60–90 years) and the inter-decadal (20–35 years) timescales. Section 4 is dedicated to the concluding remarks.

2. DATA AND METHOD

The following types of data have been used:

– geomagnetic data: annual means of geomagnetic declination from Niemegk geomagnetic observatory during timespan 1890–2020 available at http://www.geomag.bgs.ac.uk/data_service/data/annual_means.s html; Declination data from the Niemegk, Germany, geomagnetic observatory (IAGA code NGK) have been chosen, as representative for European observatories;

– the 1832–1962 yearly means of excess length-of-day (LOD) from the combined Earth orientation series LUNAR97 (https://hpiers.obspm.fr/eoppc/series/longt erm/jpl_c.eop). Starting with 1962 the daily data of LOD from earth orientation data series EOP 14 CO4, available at https://www.iers.org/IERS/EN/DataProduc ts/EarthOrientationData/cop.html, have been worked out to obtain the yearly values for the time interval 1962–2020.

The data were analyzed firstly by means of the Hodrick and Prescott (1997), HP, filtering, that separates them into a trend component and a cyclical component. Further the trend has been decomposed in turn, by means of Butterworth (1930) filtering, in constituents at the sub-centennial (60–90 years) and inter-decadal (20–35 years) timescales. The cyclic component represents the decadal and sub-decadal variations. As in Dobrică *et al*. (2018) for the case of the geomagnetic field, we used cutoffs of 73 and, respectively, 30 years in the Butterworth filtering of both LOD and geomagnetic data.

3. RESULTS AND DISCUSSION

In Figure 1 we plot the outcome of the HP filtering of the LOD time series of annual means for time interval 1832–2020. The upper plots are the annual means (black line) and the trend as determined by HP filtering (red line), while the lower plot depicts the cyclic variation separated by HP filtering. The trend closely follows the evolution shown by the annual means, with a pronounced maximum of about 4 ms at around 1908, and a series of smaller maxima of about 2–3 ms, after ~1940. The amplitude of the cyclic variation is of only .5 ms. In Fig. 2 we compare directly LOD data (red) to time derivative geomagnetic declination data (black), in terms of annual means (thin lines) and trends (thick lines). The reversed scale in case of the declination time derivative is to be noted in order to correctly compare the two processes (see Le Mouël *et al*. (1981)). The Fourier spectral analysis of the two trends (Fig. 3) justifies the decomposition of the trend in oscillations at the sub-centennial and inter-decadal scales. The comparison of LOD oscillatory constituents with the corresponding dD/dt ones is done in Fig. 4. We remark here that the ~4 ms maximum shown by the trend at about 1907 is divided almost equally (~1.3 ms) between the variation at sub-centennial timescale and the one at the inter-decadal timescale. In spite of the fact that the oscillation periods are slightly different in the two compared processes (Fig. 3), the correlations between –dD/dt and ΔLOD are good ones, as Fig. 5 demonstrates.

The figure displays the cross-correlation between trends in data (upper panel) and between the constituents at the two timescales: sub-centennial (middle panel) and inter-decadal (lower panel). A very good correlation could be remarked, with a correlation coefficient of about .8, as well as the delay characterizing the effect in LOD of the magnetic field change (14 years in case of the sub-centennial constituent, 6-8 years in case of the inter-decadal constituent).

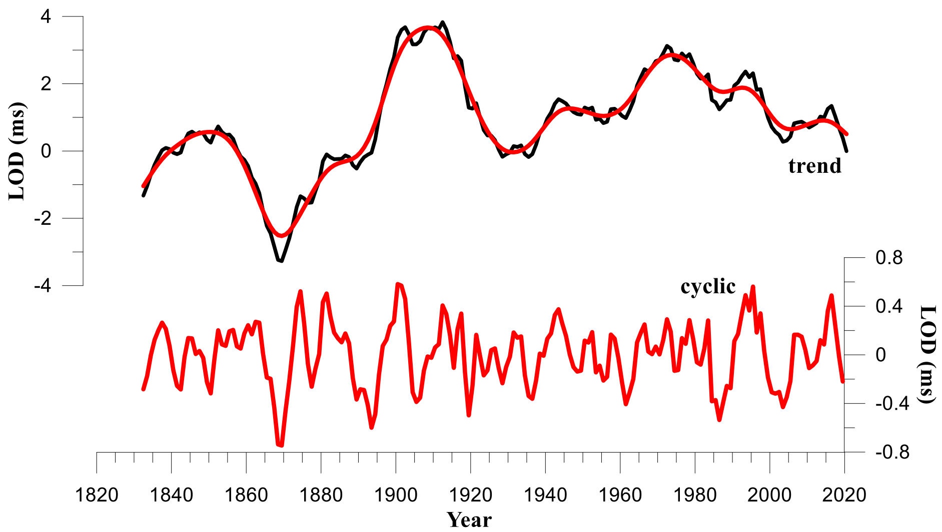

Figure 1 – The HP filtering applied to the LOD time series. Upper plots: annual data (black) and trend (red); lower plot: the cyclic constituent.

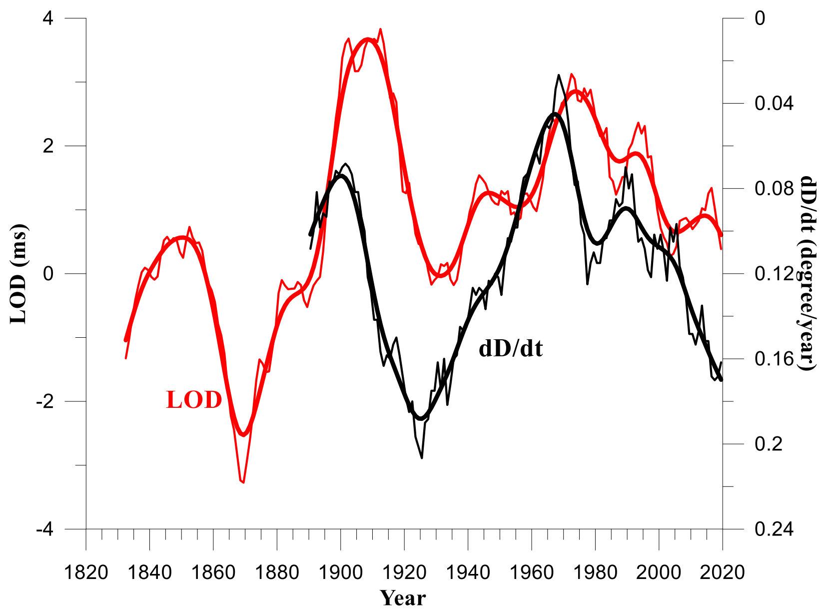

Figure 2 – Comparison of LOD data (red) to geomagnetic data (black), in terms of annual means (thin lines) and trends (thick lines).

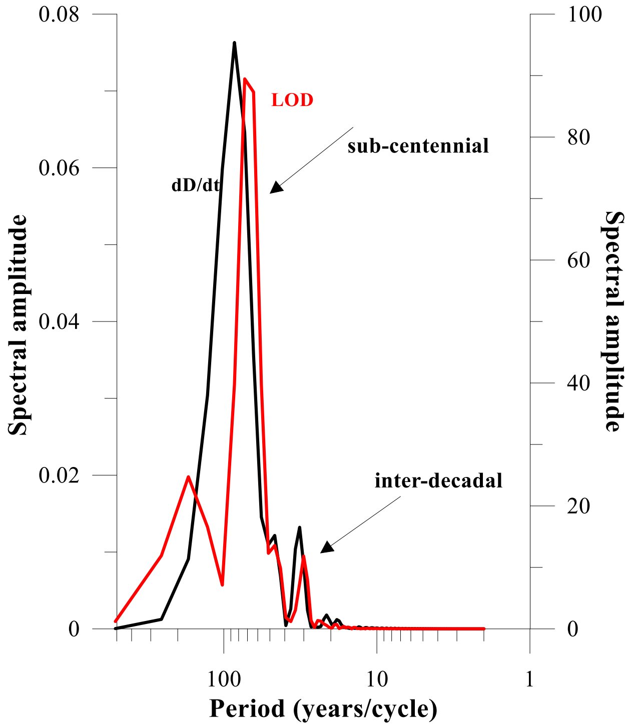

Figure 3 – Fourier spectral analysis of the HP trend of LOD and dD/dt.

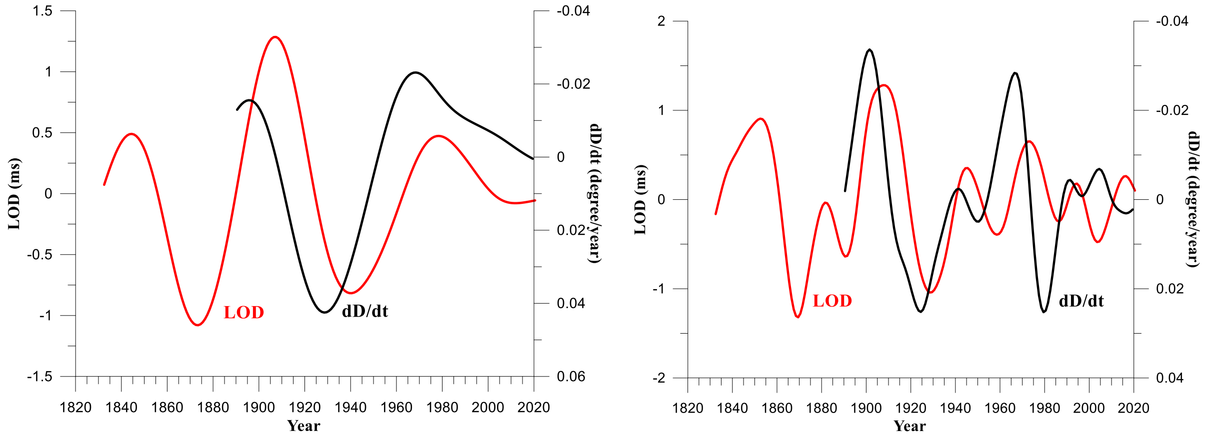

Figure 4 – Comparison of LOD and geomagnetic field at sub-centennial (upper plot) and inter-decadal (lower plot) time scales.

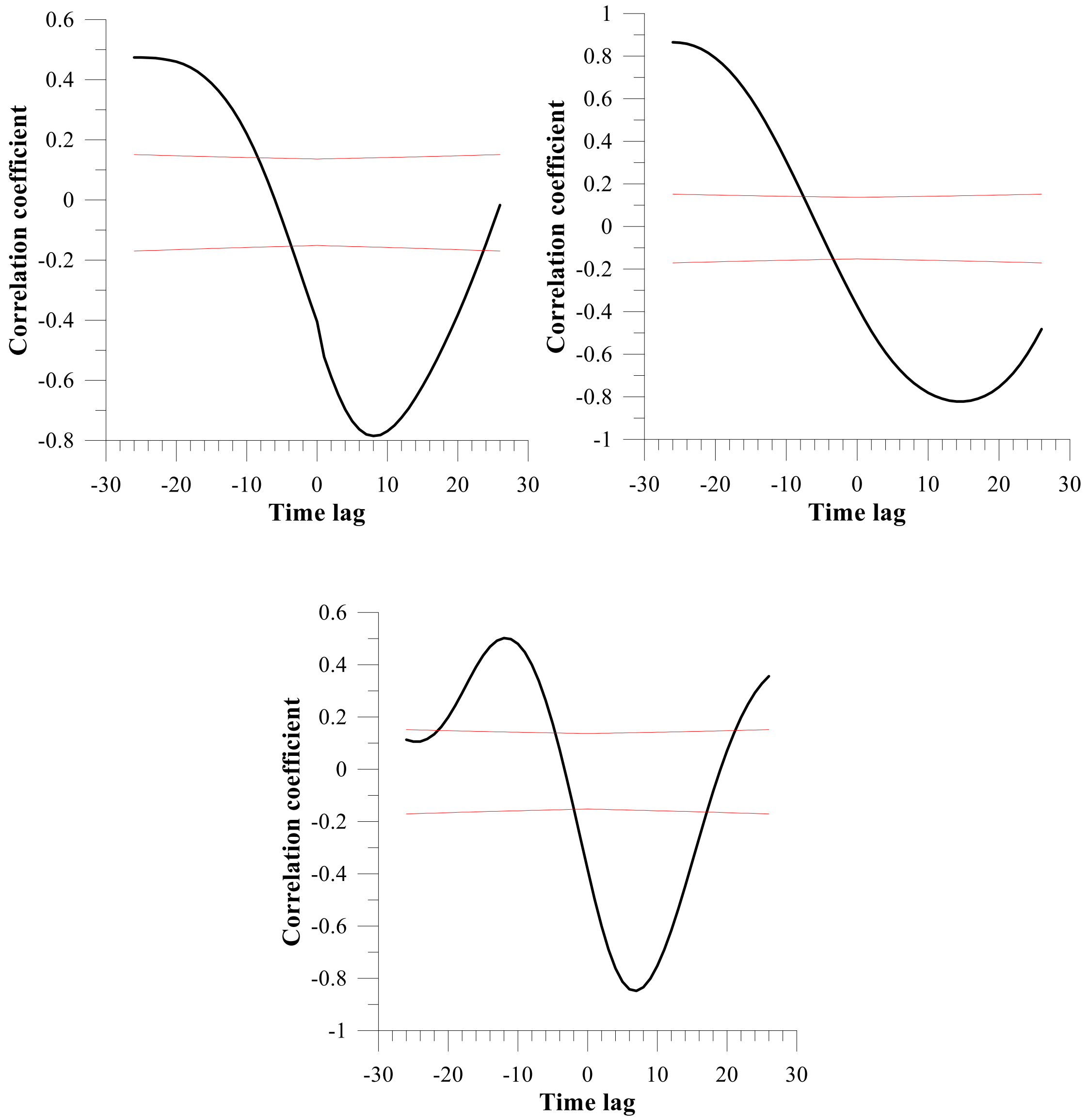

Figure 5 – Cross-correlation plots between trends in data (upper) and between the constituents at the two timescales: sub-centennial (middle) and inter-decadal (lower). Red lines – 95% significance level.

Another interesting feature resulting from Fig. 4 is the apparent damping of the variation in Earth's rotation: at the sub-centennial timescale: the amplitude is 0,49 at 1844, 1.3 ms at 1907, -0.82 ms at 1940, 0.47 ms in 1978, and -0.07 ms at 2011. At the inter-decadal timescale, the pronounced 1.3 ms maximum at 1907 is followed by a 1.04 ms minimum at 1928 and a series of oscillations with amplitudes between 0.2 and 0.7 ms after 1940. Somewhat similar variation appears in the declination time derivative at the two timescales, except the oscillation damping is not so clear as regards the beginning of the sub-centennial time series. It is also to be noted that in spite of the very good correlation between –dD/dt and LOD, it appears that there is no correlation between the amplitudes of declination time derivative and corresponding LOD variation.

The frequency content of the constituents at the two timescales of declination time variation and LOD is illustrated in Fig. 6. To evaluate the periods involved, one can also follow Roberts *et al*. (2007) in counting the distance in years between maxima, minima, and successive zero points of the time evolution plots of the –dD/dt and LOD or carrying out an auto-correlation analysis. Using all such information, a mean period of 68 years characterizes the LOD and a period of 73 years the –dD/dt variation at the sub-centennial timescale. Similarly, one gets 27 years in LOD and respectively 25 years in –dD/dt for the variation at the inter-decadal timescale. We note the presence of the longer periods (74 years in LOD and 60 years in –dD/dt) in the inter-decadal variation, as might be visible also in the lower plot of Fig. 4.

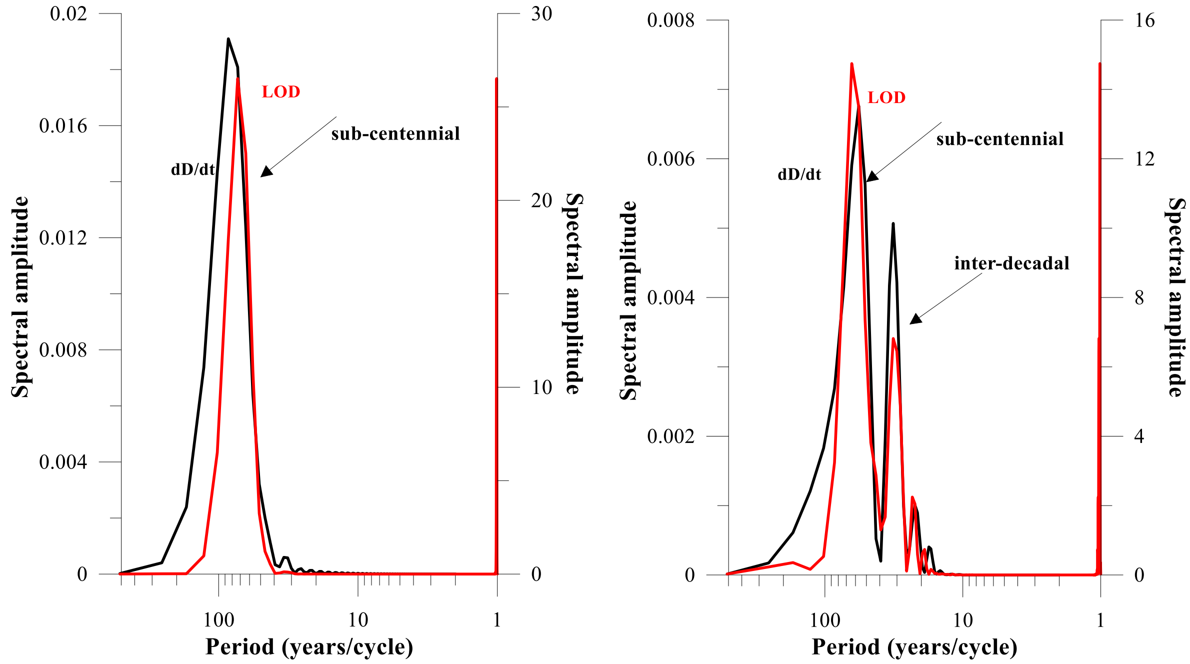

Figure 6 – Fourier spectral analysis of the HP trend constituents of LOD and dD/dt at the two timescales: sub-centennial (upper plot) and inter-decadal (lower plot).

Comparing our results to those of Roberts *et al*. (2007), who previously discussed and compared periodicities in LOD and geomagnetic data, we conclude that the present analysis, done by a quite different method – the HP filtering, was able to recover the main findings of Roberts *et al*. (2007) obtained by the Empirical Mode Decomposition (EMD) method. Furthermore, we were able to characterize variations in LOD at the two timescales, and compare them to variations at the same timescales in the geomagnetic field.

One suggested mechanism, forwarded by Le Mouël *et al*. (1981), favours the electromagnetic coupling among the mantle and outer and inner core regions; sudden changes in the convective movements translate into observed acceleration changes in D evolution at Earth's surface. The mechanism generally agreed to explain the relationship between the variations in the geomagnetic field and those in the Earth rotation is based on research on Alfvén waves and torsional oscillations in the outer core (Jackson *et al*. 1993; Zatman and Bloxham 1997; Pais and

Hulot 2000; Gillet *et al*. 2010; Holme and deViron 2013; Cox *et al*. 2016). Alfvén waves are transverse waves that propagate in an electrically conducting fluid in the presence of an ambient magnetic field. In the outer core of the Earth only a special class of such waves is allowed, namely the so-called torsional oscillations. The latter are oscillations of cylindrical annuli about the rotation axis, and because they carry angular momentum, they are seen as producing oscillations of the Earth's spin rate. Taylor (1963) predicted their existence on theoretical grounds, and Braginsky (1970) made the first link between theory and observations by using torsional normal modes to explain long-term signals (with a timescale of ~60 years) in geomagnetic secular variation and in LOD (Cox and Brown 2013). Roberts *et al*. (2007) also favour this mechanism. However, up to now no source of torsional oscillations in the Earth's core have been indicated in the literature.

4. CONCLUDING REMARKS

Using a Hodrick and Prescott type of filtering, we showed that oscillations at two timescales, namely sub-centennial (60-90 years) and inter-decadal (20–35 years), are present in the Earth's rotation rate. Their amplitudes are of ~1.5 and, respectively, 1.0 ms; a variation at the ~11-year timescale (called cyclic), with an amplitude of ~0.5 ms, is also present. We compared the two long-term constituents of LOD with variations at the same timescales seen in the first time derivative of declination, dD/dt. The link between the first two processes has long been accepted in general as a manifestation of the Earth's angular momentum conservation (e.g. Le Mouël *et al*. 1981); we showed it via cross-correlation analysis of the HP trend and of its sub-centennial and inter-decadal constituents that characterize the two processes.

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