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Sun-planets tidal interactions: an extended catalog

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Abstract. An extended catalog of long-periodic terms of the Sun tide-generating potential (STGP ver.2) is released. It contains 2.5 times of such terms than in the first version of the STGP catalog (Cionco et al. 2023). The analysis of the new data is done in order to re-examine the existence of tidal forces of ≈ 11.0-yr and ≈ 22.0-yr period able to excite the observed solar-activity cycles. In several recent studies, such tidal forcings are claimed to be a result of certain combinations of Venus, Earth and Jupiter mean motions with the multipliers (6, −10, 4) and (3, −5, 2), respectively. So, in this contribution, we specifically look for the periodic terms related to these combinations. As a result of these additional investigation we do not confirm any noticeable tidal forcing factors of ≈ 11.0-yr nor ≈ 22.0-yr period in the extended STGP spectrum either.

Keywords. Solar Cycle; Models; Oscillations; Ephemerides

1. Introduction

There is a long-running hypothesis that the planetary tides may have a modulating effect on the solar activity cycles. In particular, several studies assume that certain quasi-alignments between Venus, Earth and Jupiter ("V-E-J configurations") provide a periodicity of ≈ 11.0 yr and/or ≈ 22.0 yr, and that the operation of solar dynamo can be synchronized with these configurations. Specifically, these periods appear as a result of combinations of planetary mean motions $(6n_2 - 10n_3 + 4n_5)$ and $(3n_2 - 5n_3 + 2n_5)$, where n_2, n_3 and n_5 are the mean motions of Venus, Earth and Jupiter, respectively. The relevant bibliography can be found in Cionco et al. (2023). Nevertheless, the evidence behind this proposed tidal forcing is still debatable. In Cionco et al. (2023), we first made a development of the STGP represented by accurate harmonic series, but no "V-E-J configurations" that lead to any noticeable tidal force was found. However, in some succeeding researches (e.g. Stefani *et al.* 2023) such "V-E-J configurations" are still being considered as an essential source of tidal effects on the Sun. Therefore, in the present study we made a deeper investigation of that important issue. Specifically, we decreased the searched threshold level for the long-periodic terms of the STGP development from 10^{-7} m^{2}s^{-2} to 10^{-8} m^{2}s^{-2} in order to cover even more tidal terms. (By "long-periodic" terms we conventionally understand the terms which do not include the rate of the Sun's axial rotation, even when the period of some such terms is less than the solar rotation period.) The obtained extended series were re-analyzed for the existence of tidal forces of $\approx$ 11.0-yr and $\approx$ 22.0-yr period. Finally, we explicitly calculated the amplitudes of the tidal terms at the debatable combinations of frequencies $(6n_2 - 10n_3 + 4n_5)$ and $(3n_2 - 5n_3 + 2n_5)$.

2. Outlines of method

The Sun tide-generating potential is developed in terms of accurate harmonic series. The new STGP series are built over 13,000 BC–17,000 AD time interval, they clearly identify and separate the effects of various planetary configurations on the STGP. The latest long-term planetary ephemeris DE-441 (Park *et al.* 2021) is adopted as a source. The series represent the STGP value, $V(t)$, at an arbitrary point $M(r, \phi, \lambda)$ on the Sun's surface as follows:

$$V(t) = \sum_{n=1}^{n_{max}} \left(\frac{r}{R_\odot}\right)^n \sum_{m=0}^{n} \bar{P}_{nm}(\sin\phi) \sum_{i=1}^{i_{max}(n,m)} \left[C_{nm_i}(t)\cos A_{nm_i}(t) + S_{nm_i}(t)\sin A_{nm_i}(t)\right],$$

where r are the heliocentric distance and ϕ, λ are, respectively, the heliographic latitude and longitude of point M; $R_\odot$ is the Sun mean equatorial radius; $\bar{P}_{nm}$ are associated Legendre functions of degree n and order m; n_{max} is the maximum degree of the series, it was found to be equal to 4 for the selected level of accuracy of the new STGP development.

The amplitudes C_{nm_i}, S_{nm_i} of the series terms are obtained as time polynomials of the fifth degree. (Note, in the first STGP development (Cionco et al. 2023) the amplitudes were accurate to the third degree polynomials of time.) The arguments A_{nm_i} have a general form

$$A_{nm_i}(t) = m\,[W(t) + \lambda] + \sum_{j=1}^{8} k_{ij} l_j(t),$$

where $W(t)$ is the Sun rotational angle (Archinal *et al.* 2018), k_{ij} are some integer multipliers and $l_j(t)$ are mean mean longitudes of eight major planets represented by time polynomial of up to the sixth degree (Simon *et al.* 1994). For the long-periodic terms m = 0.

A more detailed description of the development method and the results of its application to various planetary tasks can be found in Kudryavtsev (2004, 2007, 2016, 2017), Kudryavtsev & Kudryavtseva (2009), Cionco et al. (2021, 2023).

3. Results

We have obtained an extended catalog of 326 terms that presents the long-periodic part of the STGP at the advanced level of accuracy (`http://sai.msu.ru/neb/ksm/tgp_sun/STGPv2-LongPeriods.zip`). In the previous version of the STGP reported in Cionco et al. (2023), the number of such terms was 128.

In the new catalog, we re-focused on the STGP terms related to various V-E-J configurations and especially on the terms with periods of $\approx$ 11.0 yr and $\approx$ 22.0 yr. We did not find, once again, any term of such periods. The V-E-J configurations did not produce any discernible terms in the extended STGP spectrum either.

We calculated the amplitudes of periodic terms related to the specific combinations of Venus, Earth and Jupiter mean motions with the multipliers (3, −5, 2) and (6, −10, 4). The amplitudes of those terms were found to be, respectively, only 1.5×10^{-9} m^{2}s^{-2} and 2.3×10^{-10} m^{2}s^{-2}.

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4. Conclusion

An ≈ 11.0-yr and/or ≈ 22.0-yr tidal period with a direct physical relevance for the 11-year-like solar-activity cycle is confirmed to be highly improbable.

Supplementary material

To view supplementary material for this article, please visit http://doi.org/10.1017/S17439213230004891

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