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# Solar total radiation input and terrestrial temperature in the two millennia of 600-2600

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**Summary.** In this research we explore a joint effect of solar activity in cycles of 11 and 350 years (grand solar cycles) and two-millennial variations of solar irradiance (Hallstatt's cycle) with period of 2200-2300 years derived from the C14 and Be10 isotope abundances in the terrestrial biomass. For evaluation of solar activity we use the eigen vectors derived with PCA from the solar background magnetic field and their summary and modulus summary curves closely reproducing both solar cycles. These cyclic variations of solar radiation caused by solar activity are over-imposed onto the variations of solar irradiance induced by two-millennial variations of Sun-Earth distances detected from the variations of the magnetic field baseline in the summary curve. To verify these variations we utilize the NASA and PMO ephemeris of the Sun –Earth distances calculated for the two millennia: M1 (600-1600) and M2 (1600-2600 and calculate the relevant variations of solar radiation caused by the changes of these distances with a period of about 2100 years. This period was likely caused by the solar inertial motion (SIM) induced by the gravitation of large planets. We demonstrate that in M2 a deposition of solar radiation is much higher (by up to 20 W/m$^2$) than in M1 during months March-July and much smaller during months September-January. These leads to an increase of terrestrial heating by 1.4C in 2010 in the current Hallstatt's cycle started at Maunder minimum and to further heating by 2.5-3.0C by 2600 when the Sun will start returning to the focus of the elliptic orbit thus reducing heating. We also show that solar radiation deposition in M2 into the northern hemispheres of the Earth will be 4.7% higher than in the southern one that should be reflected in their heating differences.

**References**

1.V.Zharkova, I. Vasilieva, S.J. Shepherd and E. Popova, Periodicities in Solar Activity, Solar Radiation and Their Links with Terrestrial Environment, Natural Science, Vol.15 No.3, March 2023 read it
2. Zharkova V. V.,, Millennial oscillations of solar irradiance and magnetic field at Earth in 600-2600, 2021, chapter in a book 'Solar system planets and exoplanets, read it download
3. Zharkova V.V., Shepherd S.J., Zharkov S. and Popova E., Oscillations of the baseline of solar magnetic field and solar irradiance on a millennial timescale, 2019, Scientific Reports, 9, 9197, read it here

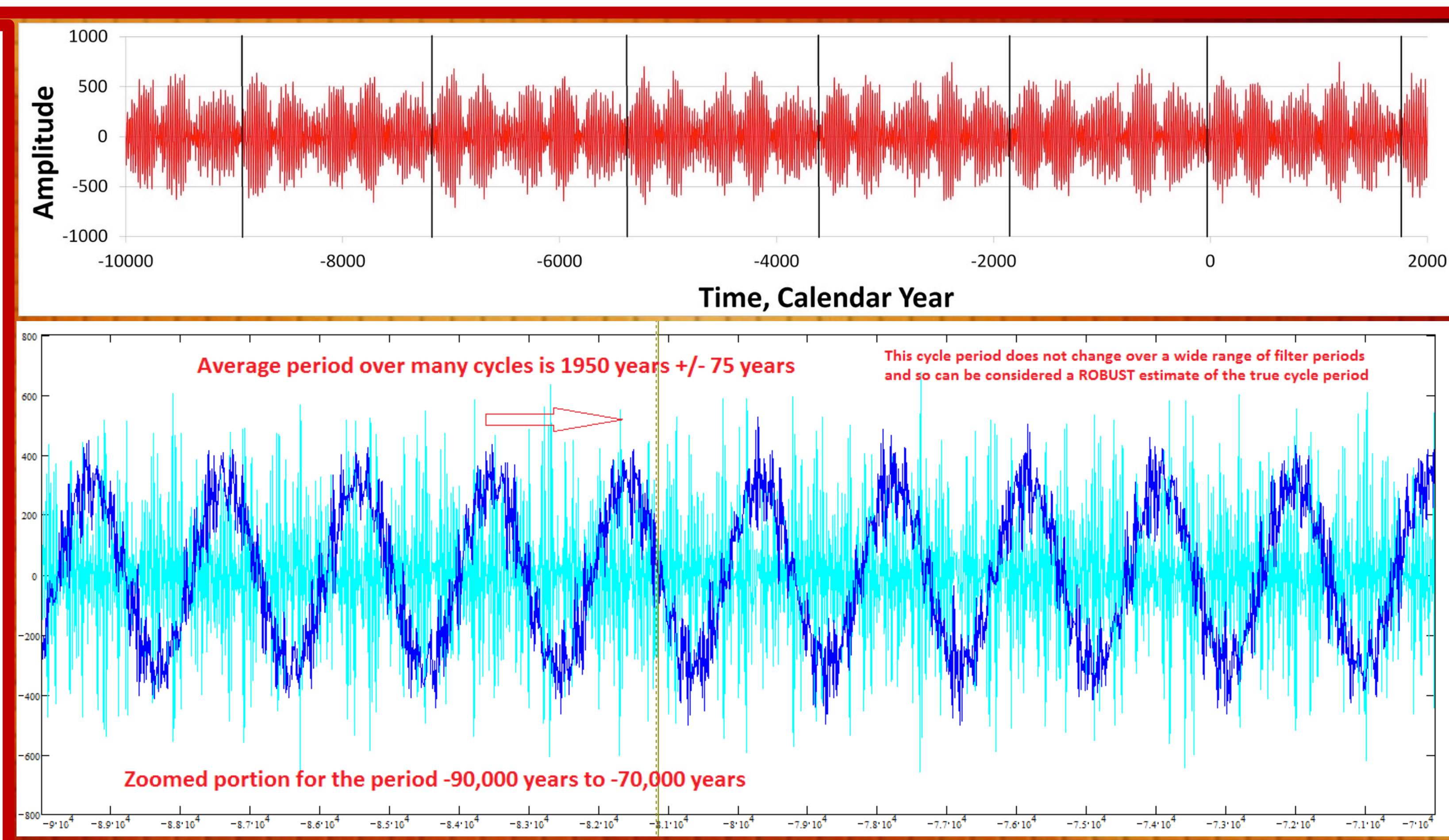


Fig.1. Top plot: Summary curve variations of SBMF in the Holocene showing similarities of five grand solar cycles marked by vertical lines. Bottom plot: oscillations of the baseline magnetic field (navy line) with period of about 2100 years over-imposed onto the modified summary curve (cyan line). (Zharkova et al, 2019, 2023; Zharkova, 2021).

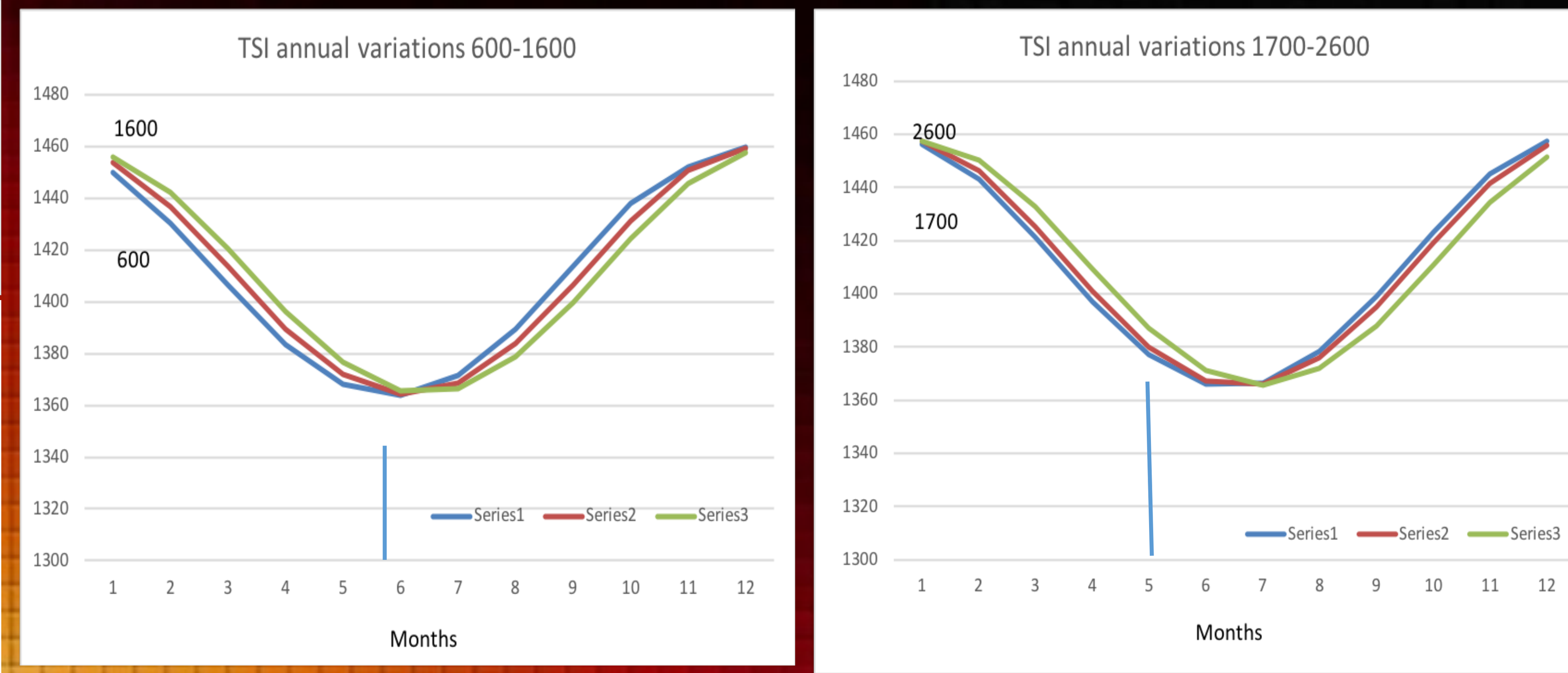


Fig. 6. Annual variations of the total solar irradiance in the millennia M1 (left) and M2 (right).

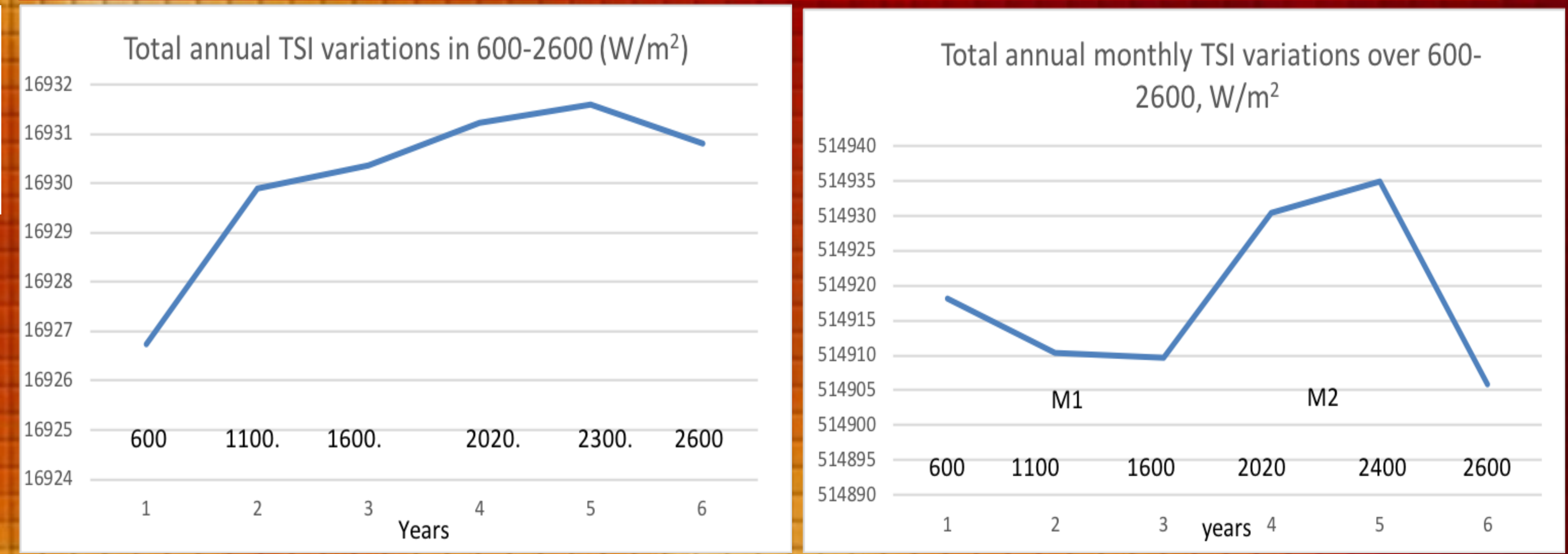


Fig. 7. Millennial variations of TSI in two millennia (600-2600) calculated from monthly means (left) and from daily magnitudes (right).

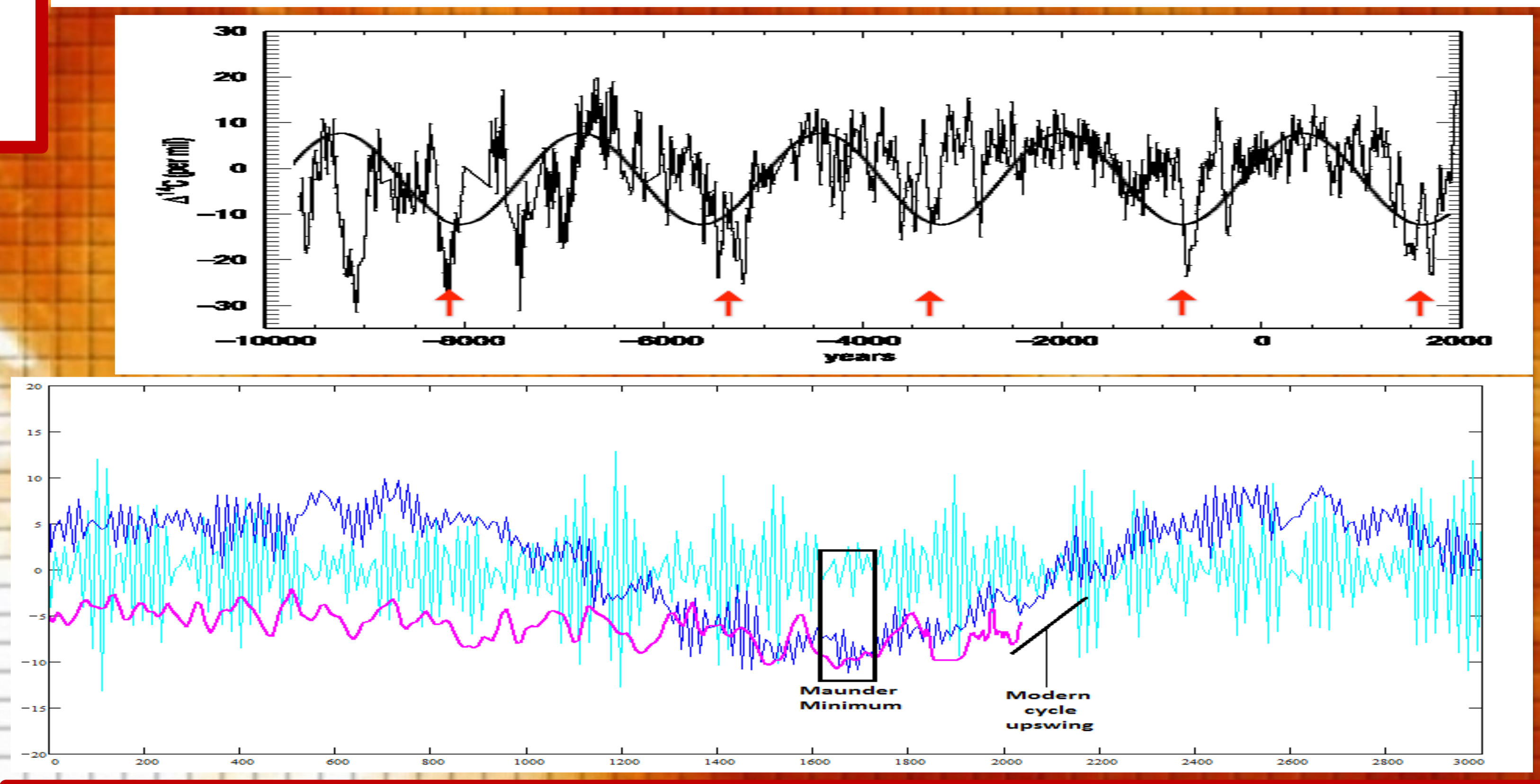


Fig. 2. Top plot: Solar irradiance variation in the Holocene from the IntCal09 (Reimer et al, 2009). Bottom plot: The ascending phase of the current Hallstat's two-millennial period with baseline (navy blue), solar radiation (magenta) and temperature (black line)variations

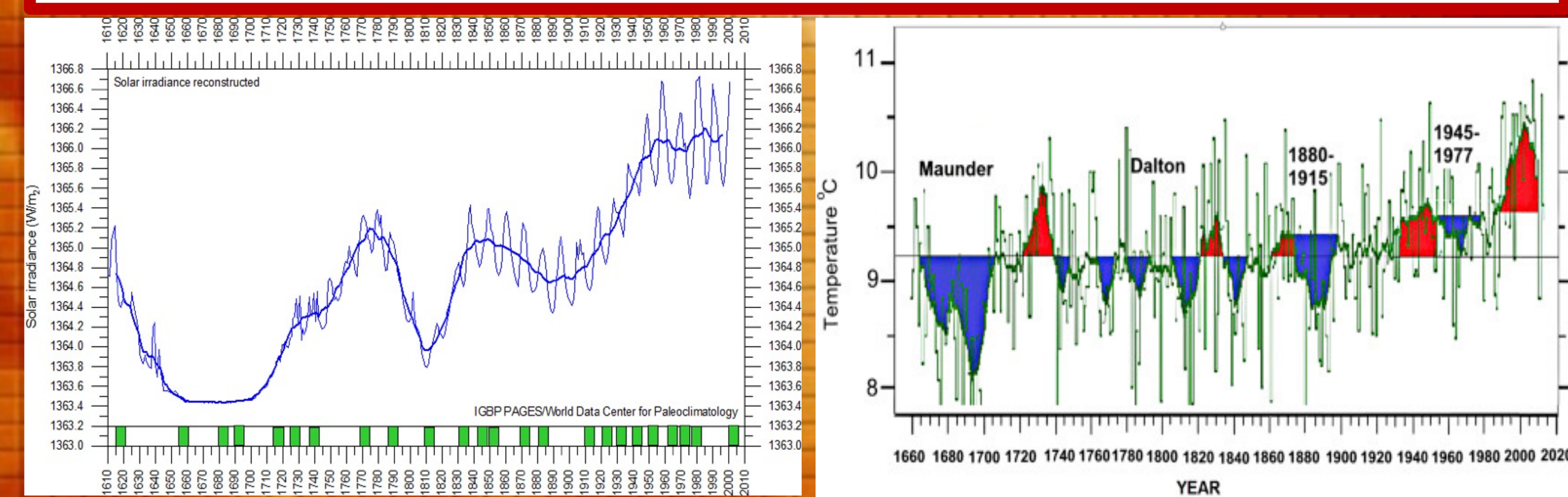


Fig. 8. Link between the variations of TSI because of solar activity (left, Lean et al, 1995) and terrestrial temperature (right, Lamb, 1972; Easterbroock, 2016).

## Differences between S-E distances (official ephemeris) in two millennia 600-2600

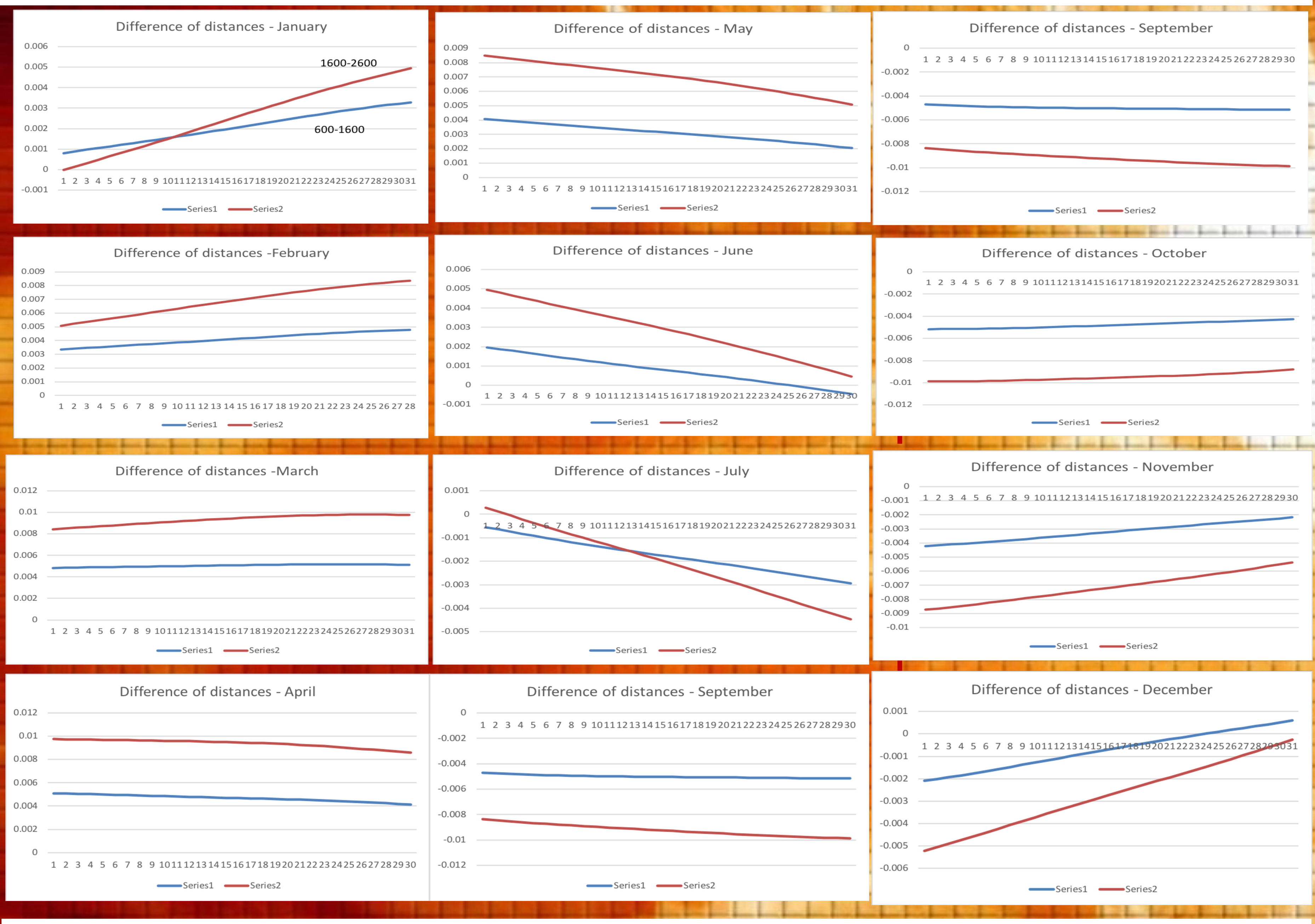


Fig. 3. Differences for every month between the Sun-Earth distances taken from the official ephemeris (NASA, PMO) at the end and start years for millennium 1 (600-1600, blue line) and millennium 2 (1600-2600, red line).

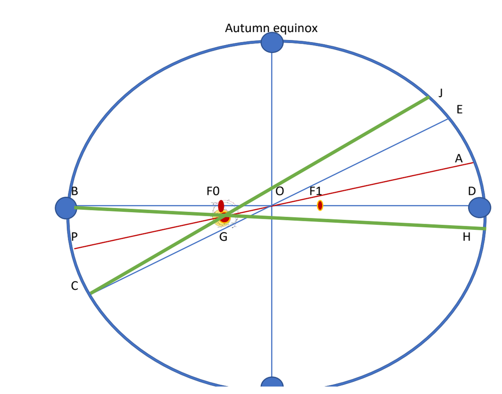


Fig. 4. SIM: shift of the Sun from the focus F0 (barycentre) of the elliptic orbit of the Earth towards the position of the spring equinox of Northern hemisphere to the point G. Note, that in SIM aphelion and perihelion are located on the line PA (red line) and not on the major axis BD.

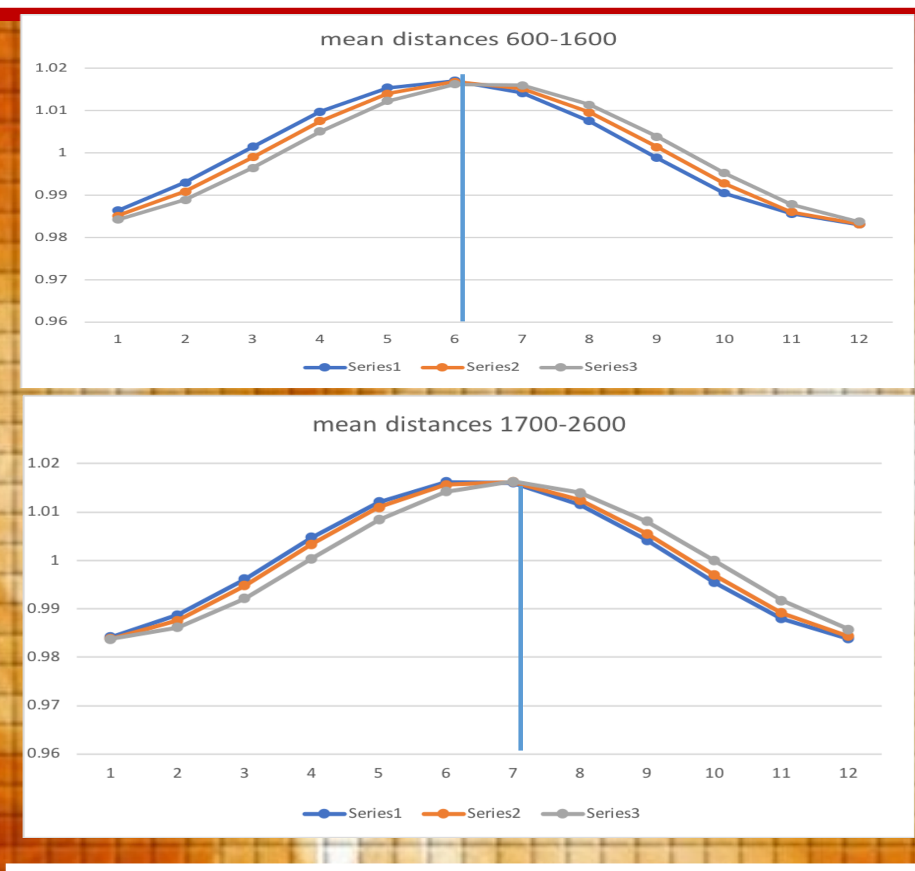


Fig 5. Annual variations of the S-E distances in the millennia M1 (top plot) and M2 (bottom plot).

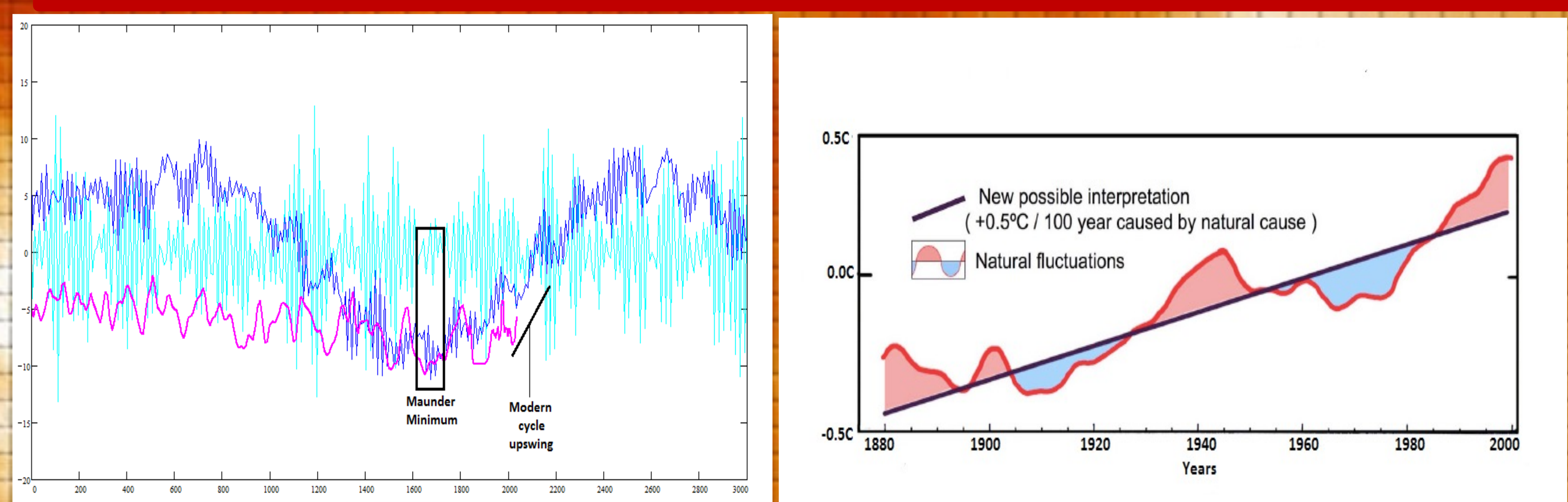


Fig.9. Link between the variations of TSI because of SIM (left, navy line) and terrestrial temperature (right, the black line).
One can expect an increase of T by additional 2.5C from 2020 by 2600 before it will start reducing back to the level of MM. Although, the grand solar minimum (2020-2053) will override this increase and lead to a decrease of the terrestrial temperature T by about 1.0C. After 2053 T will continue increasing until ~2600.

Zharkova (2021) has shown (see Fig.1) from the official Sun-Earth distance ephemeris that the Sun-Earth distances are changing significantly up to 0.005 au in the millennium M1 (600-1600) and 0.011 au in the current millennium M2 (1600-2600). These S-E distance variations follow periodic variations of solar magnetic field baseline with a period of approximately 2100 years found by Zharkova et al, 2019 which is caused by solar inertial motion induced by the gravitation of large planets. The chapter by Zharkova (2021 proved that the Nature paper by Zharkova et al. (2019) was unfairly retracted.