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Self-amplifying Feedback Effects from Long-term Declines in Solar Radiation will trigger Deep Cooling Phase of the 19th Little Ice Age around 2080

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Abstract

In climate modeling, it is generally accepted assumed that variations in the total solar irradiance (TSI) have an insignificant effect on climate, while during the Holocene the contribution of TSI to climate changes was great. Long term a weak temperature change (≈ 0.25 K) caused by TSI variations in the quasi-bicentennial cycle (BCC) significantly changes the physical, optical and radiation characteristics of the surface and atmosphere. For the first time it is shown that such temperature change generates continuous, repeatedly repeating chains which cause feedback effects also during periods of the minimum and maximum phase BCC, despite the quasi-stability of the average TSI level. Self-amplifying feedback mechanisms, continuously acting throughout the BCC, significantly change the share of TSI absorption by the planet, the greenhouse effect and the energy imbalance between the Earth and space (EEI). This increases several times the amplitude of the primary small temperature variation caused by the direct impact of TSI variations in the BCC.

Keywords: Self-amplifying feedback effects; solar radiation; deep cooling phase: 19th LIA

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1. Introduction

Climate modeling shows that variations in the TSI have a minor effect on climate, while during the Holocene the contribution of TSI to climate change was large (Bond et al., 2001; Connolly et al., 2021; Hu et al., 2003; Scafetta, 2023; Schmutz, 2021). Geophysicist Borisenkov (1988) found that for the last 7500 years, in each of the established 18 Grand deep minima of Maunder-type solar activity (SA), there was a deep cooling, and in the periods of maxima SA, warming. Every time SA has experienced its quasi-bicentennial peak, global warming starts with a time lag of about 30 years, determined by the thermal inertia of the oceans (despite the absence of anthropogenic forcing), and each deep descent into the SA caused a corresponding cooling. Indeed, the direct effect of the quasi-bicentennial variation of the TSI accounts only for about 25-30 % of the observed change in the planetary temperature (Abdussamatov, 2024a). However, for the first time it may be shown that even a small change in temperature (≈ 0.25 K) caused by a variation in the TSI in the BCC can significantly changes the physical, optical and radiation characteristics of the surface and atmosphere. These changes generate continuous, repeatedly repeating chains of causal feedback effects during the entire BCC, despite the quasi-stability of the average TSI level in the BCC minimum and maximum phases. Thus, the paradox of the primary weak influence of the Sun on climate change can be resolved through a much stronger summer long-term feedbacks mechanism. There is an observed sequential downward trend of TSI decline in three consecutive cycles. The total average cyclic value of TSI in the XXIII cycle decreased by about 0.15 W/m^2 relative to its value in the XXII cycle, and in the XXIV cycle, it has already reduced by more than 0.5 W/m^2 (Figure 1). The observed accelerating decline in total cycle average TSI value indicates its quasi-bicentennial decline. The overall rate of decline in TSI from cycle to cycle is accelerating and is expected to reach its maximum acceleration in the next solar cycles. We will approach the Grand solar minimum in a few decades approximately in 2053 when the Sun may be the weakest throughout the last double bicentennial cycle.

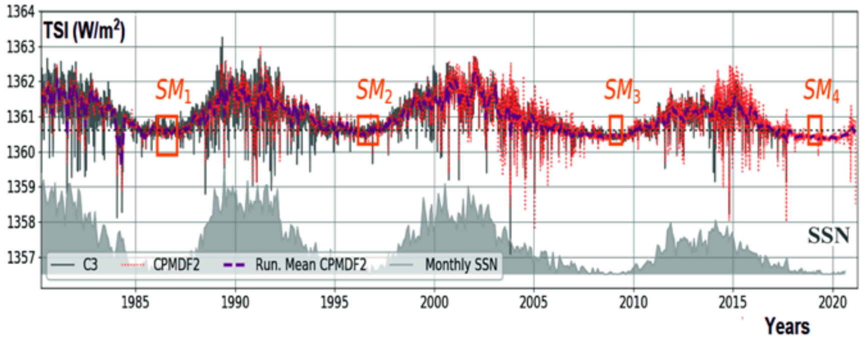

Figure 1. Total average Cyclic value of TSI, The new Composite

2. The interrelationship of changes in solar activity, irradiance, and radius in both phase and amplitude

It is known that there is a long-term cyclical TSI variation $S_\odot$ which is determined by corresponding variations of the solar radius $R_\odot$ and the effective temperature T_e of the photosphere using the equations 1 and 2:

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$$S_\odot = \frac{\sigma R_\odot^2 T_e^4}{A^2}, \tag{1}$$

where A is the astronomical unit, and

$$\frac{\triangle S_\odot}{S_\odot} = 2\frac{\triangle R_\odot}{R_\odot} + 4\frac{\triangle T_e}{T_e}. \tag{2}$$

Cyclic changes in TSI are associated with corresponding fluctuations in the solar radius. Studying transits of Mercury across the solar disc from 1631 to 1973, Sveshnikov found centennial and 11-year cycles in the variations of the solar radius $R_\odot$ and their positive correlation with the corresponding variations of the sunspot number. A larger amplitude of radius variations is generally observed in cycles with an enhanced activity level. In the cycles with a lowered level of activity, the amplitude is smaller. As a result, a close relation is established between variations in the levels of SA, the radiation flux and corresponding radius in the quasi-bicentennial and 11-year cycles which intercorrelate both in the phase and in the amplitude.

Long-term average annual EEI is of fundamental importance to the climate system and determined by the difference between the TSI fraction absorbed by the planet and the energy of the intrinsic thermal radiation emitted to the space by the Earth (Abdussamatov, 2015, 2024a, b):

$$E = \frac{(S_{\odot} + \Delta S_{\odot})(1 - A_{BE} - \Delta A_{BE})}{4} - \varepsilon\sigma(T_p + \Delta T_p)^4, \quad (3)$$

where E is the specific power of the variation of the enthalpy (heat content) of the active oceanic and atmospheric layer (Wm^{-2}) of the planet, $\Delta S_{\odot}$ the TSI increment, A_{BE} the Bond albedo of the Earth, ΔA_{BE} the increment of the Bond albedo of the Earth, ε the rate of emission (blackness degree) of the underlying surface-atmosphere system, σ the Stefan-Boltzmann constant, T_p the thermodynamical planetary temperature (of the Earth's surface and the atmosphere), and ΔT_p is its increment. Long-term increments of the TSI and the Bond albedo of the Earth determine the temperature increment:

$$\Delta T = \frac{\Delta S_{\odot}(1 - A_{BE} - \Delta A_{BE}) - \Delta A_{BE} S_{\odot}}{16\sigma\varepsilon T^3}. \quad (4)$$

A natural temperature gradient in BCC determined by the TSI difference for the period from the Maunder minimum phase to the current maximum phase, equal to $\Delta S_{\odot} \approx 4$ W/m^2 (Egorova et al., 2018; Penza V., Berrilli F., Bertello L. et al., 2022; Yeo et al., 2020; Judge et al. 2020) without considering all other contributions for $\Delta A_{BE} = 0$, can only be reached $\Delta T \approx 0.25$ °C.

The maximum phase of the current BCC with an exceptionally high level of TSI was anomalously extended, which inevitably caused the warming of the 20th century. The Earth was heated with the climate's characteristic thermal time-response, which has a large delay of 32 ± 8 years, determined by the thermal inertia t of the active layer of the Ocean

$$t = 0.095(1 + 0.42 \cdot h) \text{ years}, \quad (5)$$

where h is the depth of the active layer of the Ocean, equal to 800 ± 200 m (Abdussamatov et al., 2010, 2011).

3. Self-amplifying feedback effects from the bicentennial variations in TSI

The maximum phase of the current BCC with an exceptionally high level of TSI and SA was anomalously extended (Abdussamatov, 2024a). This also triggered the long-term substantial impact of the long chain of an important secondary feedback mechanism:

- a substantial decrease around snow-ice covers, variation in the physical parameters of the Earth's surface and atmosphere, and, consequently, a substantial decrease in the loss by Earth's fraction of the incoming solar energy due to increased absorbed radiation,
- a natural increase in the concentration of the basic greenhouse gas, water vapor, and other greenhouse gases in the atmosphere, with the warming according to Clausius-Clapeyron relation and Henry's law, which substantially enhanced the occurred warming due to the noticeable growth in the greenhouse effect,
- a decrease in atmospheric transmission of the thermal radiation of the Earth's surface to space due to the narrowing of its transparency windows caused by the increase in the concentrations of greenhouse gases in the atmosphere,
- an increase in the "dark" surface of the Ocean, caused by the increase in the water level, due to deglaciation on land and the thermal expansion of water by warming, which results in a growth in the fraction of the absorbed solar energy.

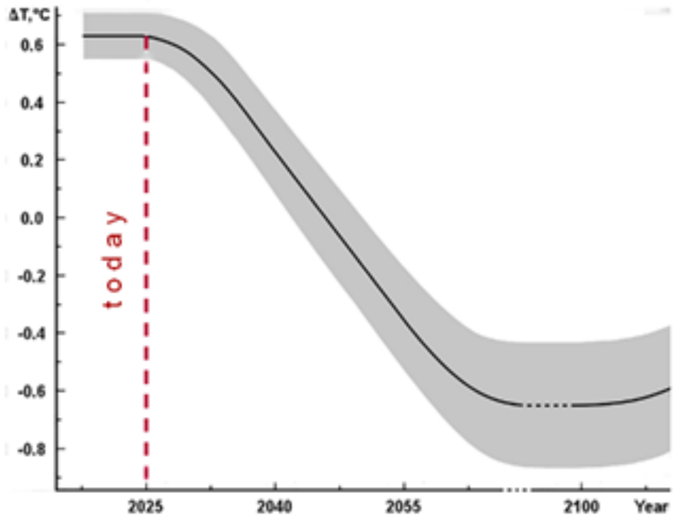

Figure 2. The Sun in a period with prolonged cooling.

The Sun entered a prolonged cooling period, see Figure 2, without taking into account the influence of submarine volcanoes. We will be experiencing a period of unusually weak solar cycles. They lead to a further significant increase in warming. The increased heating, in turn, caused additional changes to occur again in the physical and optical characteristics of the Earth's surface and atmosphere, forming a re-intensification of temperature change. Increased heating, in turn, has caused additional changes in the physical and optical characteristics of the Earth's surface and atmosphere, which has formed a chain of repeated multiple self-intensification of temperature changes. Therefore, at the end of every maximum phase BCC, the warming will reach its maximum and at the end of every minimum phase, the cooling will reach also its maximum. Even in the periods of virtually constant TSI ($\Delta S_{\odot} \approx 0$) during extended maximum and minimum phases of the bicentennial cycle, due to multiple repeated feedback effects, the EEI variation will persist.

$$E = \frac{S_{\odot}(1 - A_{BE} - \Delta A_{BE})}{4} - \varepsilon\sigma(T_p + \Delta T_p)^4, \quad (6)$$

and the same is true for the temperature increment:

$$\Delta T = -\frac{\Delta A_{BE} S_{\odot}}{16\varepsilon\sigma T^3}. \quad (7)$$

Thus, during extended maximum and minimum phases of a bicentennial solar cycle, temperature and EEI variations result from continued secondary cause-and-effect feedback effects under virtually constant TSI. The natural substantial self-amplification of the warming in the 20th century by long chains of those mentioned above feedback effects also continued anomalously for more than 60 years in the very extended phase of the BCC maximum, when the amplitude of the TSI and SA oscillations quasi-stabilized around the maximum level during five 11-year cycles. This is precisely the effect of very extended chains of feedback that resulted in the observed natural additional substantial self-amplification of climate warming at the end of the 20th and the beginning of the 21st century. This is why climatic variations on the planet accelerated under the influences of feedback effects, which imminently led to substantial multiple additional self-amplification of the started warming with participation powerful eruptions of submarine volcano the Hunga Tonga eruption of 15 January 2022, also leading to a net warming of the climate system (Sellitto et al. 2022).

Variations in the absorption spectra corresponding to the increase in the general H_2O concentrations in the atmosphere by 7 % and the CO_2 350 through 420 ppm in a warming period were modeled with a fixed cloudiness. The constructed one-dimension model of the lower atmosphere (up to the height of 50 km) took into account the radiative transfer in the spectral range (1-50 micron) and the convection (Abdussamatov, 2021). The surface radiation was not considered of the blackbody type; instead, it was assumed that the surface radiates as that of slightly heated water. As a result, the sensitivity of the climate to the content (uniformly increasing with the altitude) of the CO_2 in the atmosphere decreases, with a substantial increase in the relative fraction of the H_2O concentration directly in the lowest near-surface layers of the troposphere. With a slight increase in the water temperature the amount of natural CO_2 transferred from the Ocean to the atmosphere will become significantly larger than CO_2 absorbed by the Ocean from the atmosphere. The remaining surplus of CO_2 in the atmosphere exceeds the growth based on the growth of its emissions from human activity.

The quantitatively estimated potential variation in the current value of the yearly average EEI E_o will vary, if the area of the cloud cover in the lower atmosphere will gradually increase by 2%, due to the supposed impact of the growth in the flux of galactic cosmic rays in the period of a Grand minimum of SA (Abdussamatov, 2019). From calculations obtained, the yearly average EEI difference after the growth in the cloudiness area in the lower atmosphere by 2 % is approximately zero:

$$\Delta E = E_1 - E_o \approx 0 \tag{8}$$

i.e., an increase in cloud cover in the lower atmosphere can simultaneously both decrease and increase temperature in approximately equal amounts, virtually compensating each other, without practically disturbing the stability of the energy balance. Warming events similar to that on Mars and the Earth were observed simultaneously on Jupiter, Triton (Neptune's moon), Pluto, and several other Solar System bodies. These parallel events of global warming may only be a direct consequence of the action of the same factor: the long-term significant increase in the power of entering solar radiation of the bicentennial cycle (Abdussamatov, 2024a). Simultaneously observed pattern of warming planetary temperatures across the Solar System confirm that, also by the analogy with terrestrial seasons, the Solar System undergoes cyclical quasi-bicentennial alternations of climatic conditions (seasons), specified by corresponding long-term variations in the power of entering solar radiation. From this point of view, "the solar summer" has been over in the Solar System, and "the solar autumn" has begun. Then, approximately in 2080, "the solar winter" will come. The "solar spring" in the Solar System will only tentatively begin approximately in 2130.

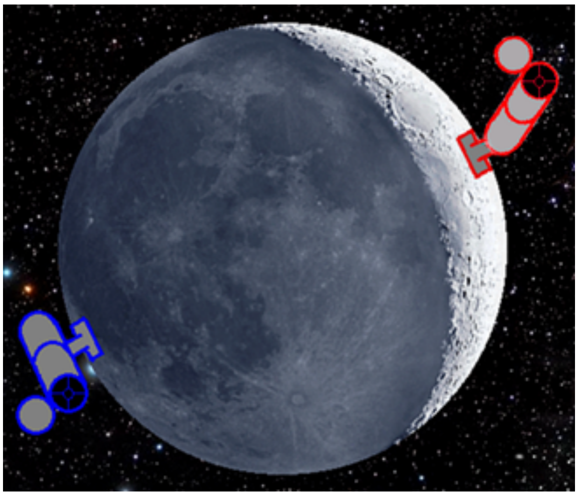

Figure 3. Simultaneous continuous functioning of the system of two SOTR-300VM depending on the change of lunar day and night for each telescope: at lunar nighttime – the telescopes system will continuously observe the Earth for more than 94% of the lunar day; at lunar daytime – the telescopes system will be continuously monitoring of the asteroid-comet hazard throughout the celestial sphere during 100% of the lunar day (Abdussamatov, 2024b).

4. Conclusions

The Lunar Observatory (LO) we are developing is a single system of two identical special optical robotic telescopes installed along the equator at the opposite edges of the Moon, functioning sequentially as a single telescope (Abdussamatov, 2024b). LO provides monitoring of the energy flux of the share of the TSI reflected by the planet within the shortwave range of 0.2-4 micron and the outgoing intrinsic thermal radiation of the Earth within the LW ranges of 4–50 and 8–13 micron continuously during more than 94 % of the lunar day. All these data will make it possible to calibrate and determine the dependence of the absolute value of the annual average EEI on cyclical TSI variations, which serves as a reliable indicator for reconstruction EEI variations for the total period of high-precision space TSI measurements since 1978. This will make it possible to reliably reveal the physical mechanisms of formation, reasons, and regularities of climate change on our planet. Twin telescopes SOTR-300VM will be placed along the equator on the opposite edges of the Moon at the longitudes ± (81 ± 0.1°) (Figure 3). Simultaneous continuous functioning of the system of two SOTR-300VM depending on the change of lunar day and night for each telescope: at lunar nighttime – the telescopes system will continuously observe the Earth for more than 9 4% of the lunar day; at lunar daytime – the telescopes system will be continuously monitoring of the asteroid-comet hazard throughout the celestial sphere during 100% of the lunar day. The bicentennial cyclicity of TSI and EEI, along with the very important self-enhanced continuous action of the secondary feedback effects, is the basic fundamental reason for corresponding cyclical alternations of the climate from warming to cooling and the main factor that controls the climate system.

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