

New dynamics of the Sun convection zone and global warming

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Solar activity is studied using cluster analysis of the sunspot number time-fluctuations. It is shown that for a Historic period (1850-1932yy) the cluster exponent $\alpha \simeq 0.37$ (strong clustering) for the high activity components of the solar cycles, whereas for a Modern period (last seven solar cycles: 1933-2007) the cluster exponent $\alpha \simeq 0.50$ (random, white noise-like situation). Then, comparing these results with the corresponding data from the classic laboratory convection experiments it is shown, that for the Historic period emergence of the sunspots in the solar photosphere was strongly dominated by turbulent photospheric convection. For the Modern period, this domination was broken by a new more active dynamics of the inner layers of the convection zone. Then, it is shown that the dramatic change of the sun dynamics in the transitional period (between the Historic and Modern periods, solar cycle 1933-1944yy) had clear detectable impact on the global Earth climate at this period. Namely, the global temperature anomaly for this period has a huge pick, whereas atmospheric CO_2 mixing ratios stabilized an even decreased slightly for this transitional period. Certain possible consequences of the transitional period impact on the Earth climate development after the transitional period are also briefly discussed.

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Introduction: The sunspot number is the main direct and reliable source of information about sun dynamics for a historic period. This information is crucial, for instance, for analysis of a possible connection between the sun activity and the global warming. In recent paper [1], for instance, results of a reconstruction (based on radiocarbon concentrations, see also [2]) of the sunspot number were presented for the past 11,400 years. Analysis of this reconstruction performed by the authors of the Ref. [1] shows an exceptional level of solar activity during the past seven solar cycles (1933-2007yy).

When magnetic field lines are twisted and poke through the solar photosphere the sunspots appear as the visible counterparts of magnetic flux tubes in the

convective zone of the sun. Since a strong magnetic field is considered as a primary phenomenon that controls generation of the sunspots the crucial question is: Where has the magnetic field itself been generated? The location of the solar dynamo is subject of vigorous discussions in recent years. A general consensus had been developed in recent decades to consider the shear layer at the *bottom* of the convection zone as a main source of the solar magnetic field [3] (see, for a recent review [4]). In recent years, however, the existence of a prominent radial shear layer near the top of the convection zone has become rather obvious and the problem again became actual. Presence of the large-scale meandering flow fields (like jet streams), banded zonal flows and evolving meridional circulations together with intensive multiscale turbulence shows that the near surface layer is a very complex system, which can significantly affect the processes of the magnetic field and the sunspots generation. Their could be at least two sources for the poloidal magnetic field: one near the bottom of the convection zone (or even just below it [3]) and one resulting from active-region tilt near the surface of the convection zone. For the recently renewed Babcock-Leighton [5],[6] solar dynamo scenario, for instance, a combination of the sources was assumed for predicting future solar activity levels [7], [8]. In this scenario the surface generated poloidal magnetic field is carried to the bottom of the convection zone by turbulent diffusion or by the meridional circulation. Then, in the bottom shear layer, toroidal magnetic field is produced from this poloidal field by differential rotation. Destabilization and emergence of the toroidal fields (in the form of curved tubes) due to magnetic buoyancy can be considered as a source of the pairs of sunspots of opposite polarity. The turbulent convection in the convection zone and, especially, in the near-surface layer captures the magnetic

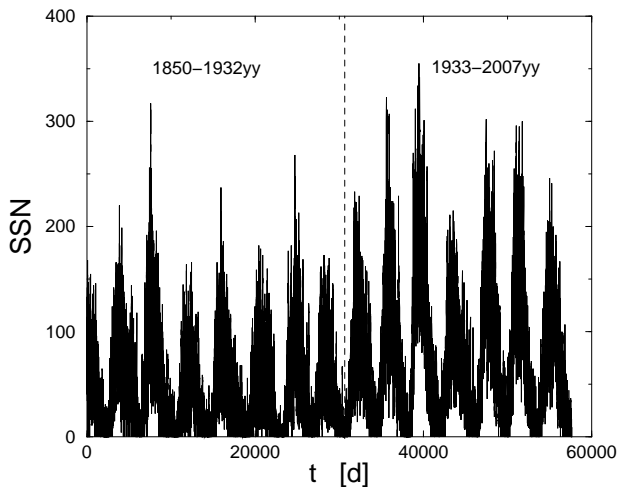


FIG. 1: Daily sunspot number (SSN) vs time [13]. The dashed straight line separates between Historic and Modern periods.

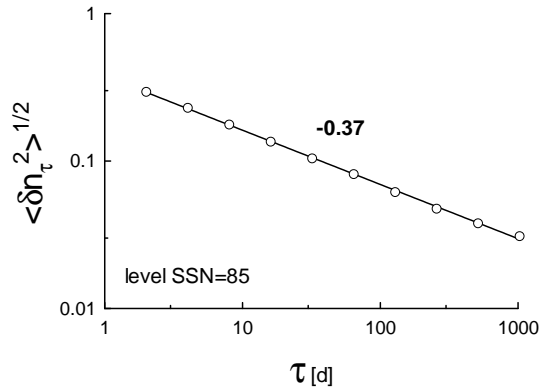


FIG. 2: The standard deviation for δn_τ vs τ for the level SSN=85 (Historic period) in log-log scales. The straight line (the best fit) indicates the scaling law Eq. (1).

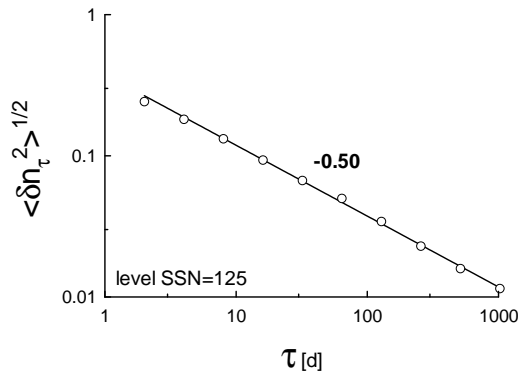


FIG. 3: The standard deviation for δn_τ vs τ for the level SSN=125 (Modern period) in log-log scales. The straight line (the best fit) indicates the scaling law Eq. (1).

flux tubes and either *disperses* them or *pulls* trough the surface in the form of the sunspots.

The magnetic field itself plays a passive role in the photosphere and does not participate significantly in the photospheric turbulent energy transfer. On the other hand, the very complex and turbulent near-surface layer (including photosphere) can significantly affect the process of the sunspots emergence in the photosphere. A similarity in properties of light elements in the spot umbra and granulation is one of the indication of such phenomenon.

In present paper we will show a direct relation between the turbulent convection temperature fluctuations and the sunspot number fluctuations. This relation will allow to make certain conclusions about the above mentioned mechanisms of the magnetic fields and the sunspots generation. Namely, it will be shown that in the Modern period (last seven solar cycles: 1933-2007yy, cf [1],[2])

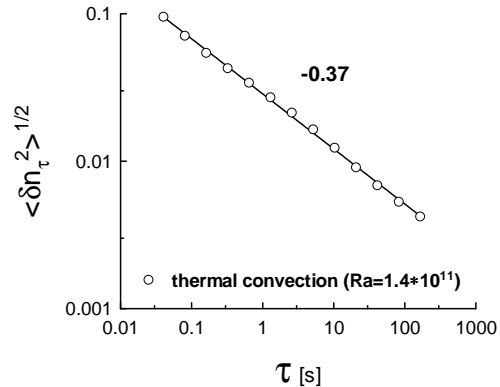


FIG. 4: The standard deviation for δn_τ vs τ for the temperature fluctuations in the Rayleigh-Bernard convection laboratory experiment with $Ra = 1.4 \times 10^{11}$ [15]. The straight line indicates the scaling law Eq. (1).

relative role of the surface layer (photosphere) on emergence of the sunspots was drastically decreased in comparison with a comparable Historic period (seven solar cycles before 1933 year). It means a drastic increase of the relative role of the inner layers (may be the bottom layer) of the convection zone in the Modern period.

Then it will be shown that the *transitional* solar cycle (1933-1944yy, when the dynamics of the convection zone was drastically changing) has clear detectable impact on the Earth climate (global temperature and atmospheric CO_2 mixing ratios, see Fig. 5). However, long-time consequences of this transitional impact for the Earth climate are not so clear and will be discussed in more detail below.

Fluctuations time-clustering: In order to extract a new information from the sunspot number data we will apply a fluctuations clustering analysis suggested in the Ref. [10]. If we have a time depending signal we can count the number of 'zero'-crossing points of the signal (the points on the time axis where the signal is equal to zero) in a time interval τ and consider their running density n_τ . Let us denote fluctuations of the running density as $\delta n_\tau = n_\tau - \langle n_\tau \rangle$, where the brackets mean the average over long times. We are interested in scaling variation of the standard deviation of the running density fluctuations $\langle \delta n_\tau^2 \rangle^{1/2}$ with τ

$$\langle \delta n_\tau^2 \rangle^{1/2} \sim \tau^{-\alpha} \quad (1)$$

For white noise signal it can be derived analytically [11],[12] that $\alpha = 1/2$ (see also [10]). The same consideration can be applied not only to the 'zero'-crossing points but also to any level-crossing points of the signal.

In Fig. 1 we show the daily sunspot number (SSN) for the period 1850-2007yy [13]. Even on the eye one can see that the Modern period (last seven cycles, 1933-2007yy)

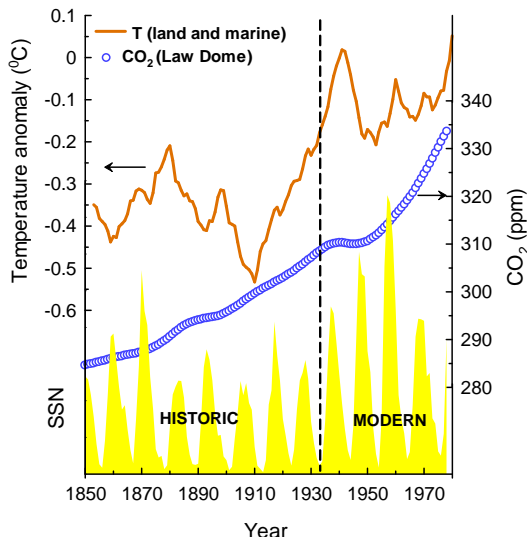


FIG. 5: Global temperature anomaly (solid curve, combined land and marine) [16] and atmospheric CO_2 (circles) [17] vs time. Relevant daily SSN are also shown. The dashed straight line separates between Historic and Modern periods.

is different from the corresponding Historic period: 1850-1933yy. Therefore, in order to calculate the cluster exponent (if exists) for this signal one should make this calculation separately for the Modern and for the Historic periods. We are interested in the active parts of the solar cycles. Therefore, for the Historic period let us start from the level $SSN=85$. The set of the level-crossing points has a few large voids corresponding to the weak activity periods. To make the set statistically stationary we will cut off these voids. The remaining set exhibits good statistical stationarity that allows to calculate scaling exponents corresponding to this set. Fig. 2 shows (in the log-log scales) dependence of the standard deviation of the running density fluctuations $\langle \delta n_\tau^2 \rangle^{1/2}$ on τ . The straight line is drawn in this figure to indicate the scaling (1). The slope of this straight line provides us with the cluster-exponent $\alpha = 0.37 \pm 0.02$. This value turned to be insensitive to a reasonable variation of the SSN level. Results of analogous calculations performed for the Modern period are shown in Fig. 3 for the SSN level $SSN=125$. The calculations performed for the Modern period provide us with the cluster-exponent $\alpha = 0.5 \pm 0.02$ (and again this value turned to be insensitive to a reasonable variation of the SSN level).

The exponent $\alpha \simeq 0.5$ (for the Modern period) indicates a random (white noise like) situation. While the exponent $\alpha \simeq 0.37$ (for the Historic period) indicates strong clustering. The question is: Where is this strong clustering coming from? It is shown in the paper [10] that signal produced by turbulence exhibit strong clustering. Moreover, the cluster exponents for these signals depend

on the turbulence intensity and they are nonsensitive to the types of the boundary conditions. Fortunately, we have direct estimates of the value of the main parameter characterizing intensity of the turbulent convection in photosphere: Rayleigh number $Ra \sim 10^{11}$ (see, for instance [14]). In Fig. 4 we show calculation of the cluster exponent for the temperature fluctuations in the classic Rayleigh-Bernard convection laboratory experiment for $Ra \sim 10^{11}$ (for a description of the experiment details see [15]). The calculated value of the cluster exponent $\alpha = 0.37 \pm 0.01$ coincides with the value of the cluster-exponent obtained above for the sunspot number fluctuations for the Historic period. If the value of the Rayleigh number Ra in the Historic period has the same order as in the Modern period $Ra \sim 10^{11}$, then one can suggest that the clustering of the sunspot number fluctuations in the Historic period is due to strong modulation of these fluctuations by the turbulent fluctuations of the temperature in the photospheric convection. This seems to be natural for the case when the photospheric convection *determines* the sunspot emergence in the photosphere. However, in the case when the effect of the photospheric convection on the SSN fluctuations is comparable with the effects of the inner convection zone layers on the SSN fluctuations the clustering should be randomized by the mixing of the sources, and the cluster exponent $\alpha \simeq 0.5$ (similar to the white noise signal). The last case apparently takes place for the Modern period.

Since the Rayleigh number Ra of the photospheric convection seems to be preserving its order $Ra \sim 10^{11}$ with transition from the Historic period to the Modern one, we can assume that just significant changes of the dynamics of the inner layers of the convection zone (most probably - of the bottom layer, see Introduction) were the main reasons for the transition from the Historic to the Modern period.

Impact of the solar dynamics transition on the Earth climate: The transition of the solar convection zone dynamics from the Historic to the Modern one can affect the earth climate through (at least) two canals. First canal is a direct change in the heat and light output of the Sun, especially during the transitional period: first cycle of the Modern period (1933-1944yy). Second canal is related to the strong increase of the magnetic field output in the interplanetary space through the sunspots. The interplanetary magnetic field interacts with the cosmic rays. Therefore, the change in the magnetic field intensity can affect the Earth climate through the change of the cosmic rays intensity and composition. Fig. 5 shows global temperature anomaly (the solid curve) [16] and atmospheric CO_2 (the circles) [17] vs time. Relevant daily SSN are also shown. The dashed straight line separates between Historic and Modern periods. One can see, that the transitional solar cycle (1933-1944yy) is characterized by dramatic changes both in the global temperature (a huge pick) and in the atmospheric CO_2 (complete sup-

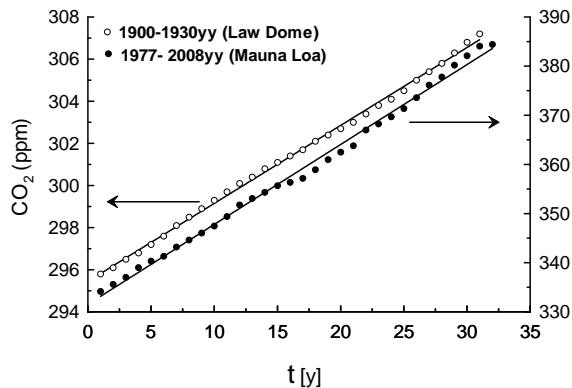


FIG. 6: Comparison of the CO_2 growth for the periods 1900-1930yy [17] and 1977-2008yy [18]. The solid straight lines (best fit) indicate a linear growth.

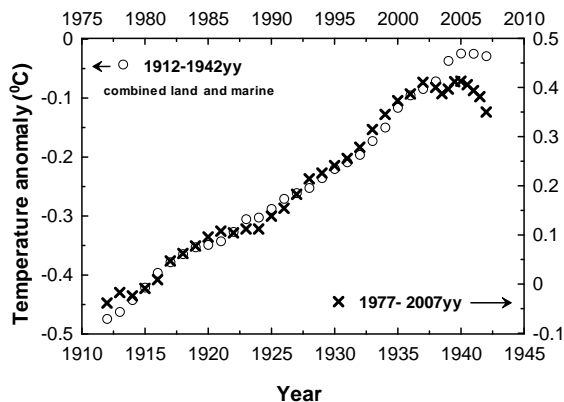


FIG. 7: Comparison of the temperature anomaly (combined land and marine) [16] for the periods 1912-1942yy and 1977-2007yy.

pression of the growth). After the transitional period one can observe (during three solar cycles) a moderate growth in the temperature anomaly and an unusually fast growth in the atmospheric CO_2 . These three solar cycles seem to be an aftershock adaptation of the global climate to the new conditions. Then, starting from 1977 year, the atmospheric CO_2 growth returns to its linear growth as before the transition, but now the *rate* of the growth is about *four* times larger than before the transition (see Fig. 6). The temperature anomaly returns to the about the same growth pattern as it was just before the transition (only about 20% faster) see Fig. 7.

Discussion: The strong impact of the solar transitional dynamics on the Earth climate during the transitional period (1933-1944yy) seems to be rather obvious (Fig. 5). Influence of the new solar conditions on the after-

shock period (1945-1976yy) is unclear. The fact that in the 'last' period (1977-2007yy) the temperature anomaly growth returned to the same pattern as just before the transition can be interpreted by two controversial ways. First interpretation suggests that in the 'last' period there is no considerable solar influence on the global warming. Second interpretation suggests that we are just at the new transitional period. Acceleration (by about four times) of the quasi-linear growth of the atmospheric CO_2 in the 'last' period can be due to human activity. What seems to be surprising in the 'last' period, that despite of the dramatic acceleration of the atmospheric CO_2 , the temperature anomaly exhibits about the same growth as just before the transition. This seems to be inconsistent with a direct relation between the greenhouse effect and the global warming, at least for the 'last' period.

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