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The Volcanic and Solar Activity Relationship During the Last ~ 460 Years. Could a Significant Part of the "Sun-Climate" Relationship Goes Through Lithosphere?

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Abstract

The volcanic activity behavior and the comparison of the last one to the solar activity during the interval 1550-2014 AD is the subject of present study. For this aim two databases have been used: 1. The Global volcanism program data base of Smithsonian Institute- Museum of natural history; 2. The extended time series of solar activity indices of Pulkovo observatory. A statistically certain cycles by duration of 11, 19-26, ~50- 60, 80-90 and 240-250 years in the annual new-generated volcanic eruption number time series has been established. There are analogues in the solar and the geomagnetic activity. It has been also found that there is a tendency of concentration of the moderate and strong volcanic events (volcanic eruptive index VEI ≥ 4) around the solar Schwabe-Wolf's cycles extrema. This tendency is very strong for the most powerful volcanic events (VEI ≥ 6). Trigger mechanisms of solar and geomagnetic activity over volcanic events as well as their relation over climate changes (in interaction by galactic cosmic rays (GCR) and/or solar energetic particles (SEP)) are briefly discussed.

Introduction

The problem for the relationship between solar activity and tectonic events is discussed at least from the beginning of 20th century. Good overviews of the first studies in this direction provided before 1920th have been given by Tchijevskii (1976). There are a large number of studies concerning the solar and seismic activity relationships, but the corresponding number for solar-volcanic connections is too small. There are only sporadic papers, concerning the problem (see *Stothers*,1989; *Strestik*, 2003). In summary the anticorrelation between the solar and volcanic activity is the most often suggested conclusion according these publications. As an additional independent argument supporting this conclusion is the "Danjon effect"- the relatively higher frequency of "dark" lunar total eclipses during the solar minima epochs (one to two years after the Schwabe-Wolf sunspot cycle minimum), which has been established by the French astronomer Andre-Louis Danjon about 100 years ago (*Danjon*, 1921). The dark solar eclipses events are in strong relationship with the volcanic dust concentration in Earth atmosphere. Evidences for presence of possible solar modulated long term volcanic activity cycles of centurial and supercenturial duration (80-90 and 200-215 years) are also given (*Strestik*,2003). It could say that there is a consensus between the researchers that the possible physical mechanisms of the solar volcanic activity relationship are by trigger-type nature.

As it has been pointed out by author and Stoychev (*Komitov*, 2011; *Komitov and Stoychev*, 2011) there are evidences that essential part of the strong volcanic eruptions (volcanic eruptive index VEI ≥ 5) are connected no only to solar minima, but also occur during the sunspot maxima epochs.

This fact leads to many additional questions concerning the solar – volcanic activity relationship in different time scales and epochs as well as the possible physical mechanisms. The possible answers on some of them are the subject of the present work.

Data and methods

In this study the volcanic eruption data, which are published in Smithsonian Museum of Natural History –Global Volcanism Program web site (https://volcano.si.edu) are used. On the base of the above mentioned data a relatively reliable scenario about volcanic activity approximately since 1550 AD could be build.

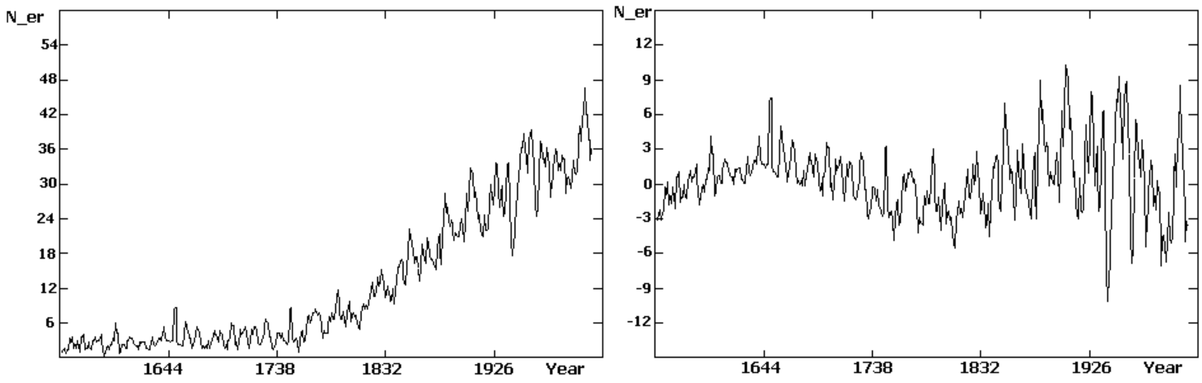


Fig. 1. Left: Smoothed 3-year annual number of volcanic eruptions time series (1550- 2014 AD) Right panel (N_er): The "residual" series after removing of non- linear trend

According to the published data 6016 volcanic eruptions during the period 1550-2014 AD have been occur. Taking into account the trigger mechanism hypothesis a time series of annual numbers for the new generated (i.e. during the corresponding year) volcanic eruptions (*N_er*) was build. Thus the volcanic events, which are starting in some previous calendar year, but are continuing during the corresponding year has been excluded from research process.

The so obtained time series of *N_er* is shown on fig.1. A strong upward trend is visible there. With high confidence it could to suggest that the last one is caused first of all by lack of data during the earlier part of time series (~ 1550-1750 AD), but some contribution of a real upward effect is too difficult to take or reject.

After removing of the trend over the "residual" time series a 3-year smoothing procedure has been provided. The smoothed time series has studied for existence of statistical significant cycles by using of two methods: the T-R periodogram algorithm (*Komitov*, 1986, 1997) and wavelet analysis (*Torrence and Combo*, 1998).

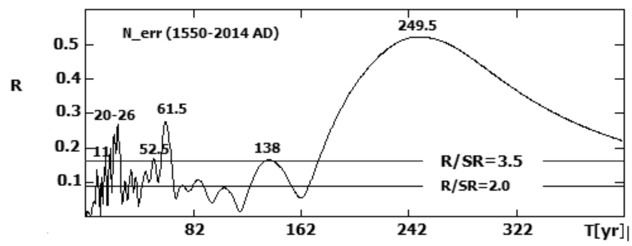
By using of histograms the absolute number and frequency of the strong volcanic eruptions (VEI $\geq$ 4) in relation to Schwabe-Wolf's sunspot cycle phase are studied too. For this aim the data for the individual lengths of sunspot cycles during the epoch 1550-2014 AD has been used. It is based on the information from the Schove series (Schove, 1983) and extended sunspot instrumental series since 1705 AD. The obtained results and their analysis are described below.

Results and analysis

The T-R spectrum (correlogram) of smoothed VEI "residual" time series is shown on the left panel on fig.2. On the right panel of the same figure is the corresponding global wavelet spectrum. Statistically significant cycles by duration of 11, 19-25 (multiplet), 52.5- 61.5 (doublet) and 138 years as well as a very powerful 249.5-year cycle are visible in the T-R spectra. There is weak "trace" of ~ 90 yr cycle too. These results are in agreement with the global wavelet spectra where cycles buy duration of 11, 25, 60 and 240 years are shown.

There are many solar as well as other space climate analogues of almost all of detected cyclic oscillations in the "residual" VEI time series. The 11yr oscillation corresponds to the mean duration of Schwabe-Wolfs's sunspot activity cycle plus a large number of related to him solar and geophysical activity indexes and events such as solar flares, coronal mass ejections (CME),

geomagnetic activity, galactic cosmic rays (GCR) etc. The ~22-year oscillation which is an important component in the quasi bi- decadal multiplet (19-25yr) corresponds to the Hale's solar magnetic dipole cycle. A cycle by duration of ~60 years has been established in middle latitude aurora activity (MLA) as well as in "cosmogenic" ^{10}Be isotope production by Komitov (2009), while the quasi 90 year variations corresponds to solar 88-90 year Gleissberg's cycle. (*Gleissberg*, 1944) Approximately 140 year cyclic variations have been detected in "cosmogenic" ^{14}C tree rings data series (*Dergachev*, 1994, 2004), which is close to 138 yr cycle in T-R spectra on fig.2 (left panel).
The possible origin of quasi 250-year cycle in "residual" VEI will be separately discussed below in the text.



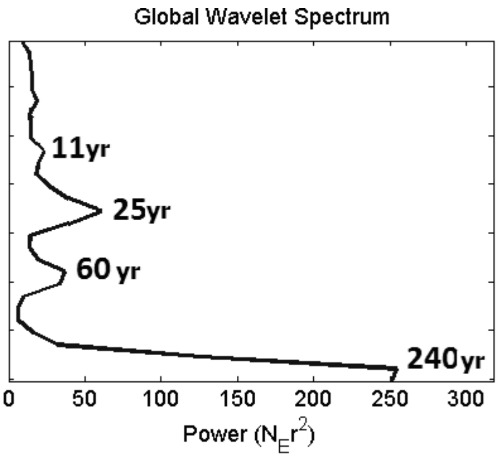


Fig.2 Left: The T-R spectrum of the "residual" volcanic eruptions time series;
Right: Global wavelet spectrum of the same series

As it has been already pointed above the study of absolute number and/or frequency of strongest volcanic eruptions (VEI ≥ 4) in relation to Schwabe-Wolf's sunspot cycle phase by using of histograms is the second main purpose of the present study.

The total number of the above mentioned volcanic eruptions during the interval 1550-2014 AD is 193. For each such event it has been calculated the current Schwabe-Wolf's sunspot cycle phase as $\Phi(t) = \frac{t - t_0}{L_{SW}}$, where t is the current calendar year, t_0 and L_{SW} are the calendar year of minimum and the length of current sunspot cycle correspondingly .The relative number of strong volcanic eruptions in percents for corresponding phase Φ in width intervals of 0.1 from 0 to 1 are shown in histogram on fig.3 (left-upper panel). Analogous relative number of strong volcanic eruptions in percents for corresponding phase Φ in width intervals of 0.1 from 0 to 1 are shown in histogram on fig.3 (left-upper panel). Analogous histograms of the volcanic eruptions, for which VEI is equal to 4 and 5 are shown on the right- upper and left-lower panels correspondingly .The histogram for the strongest volcanic eruptions (VEI ≥ 6) (lower right panel) shows not the relative, but the absolute number of these events, because of their very small number- there are only 8 cases since 1550 AD.

As could be seen in these histograms there are two ranges of Φ were the strong volcanic eruptions most often occur –near to sunspot cycle minima (i.e. $0.9 \le \Phi \le 1$ and $0 \le \Phi \le 0.2$) and near to sunspot maxima ($0.3 \le \Phi \le 0.6$). This is clear remarkable for the strongest eruptions (VEI=5 and VEI ≥ 6), while including of the "moderate strong" eruptions (VEI=4) lead to some damaging of this tendency. On the other hand there is a permanent "hole" in all of these histograms ($0.2 \le \Phi \le 0.3$) where the strong volcanic eruptions number is relative small or even equal to zero.

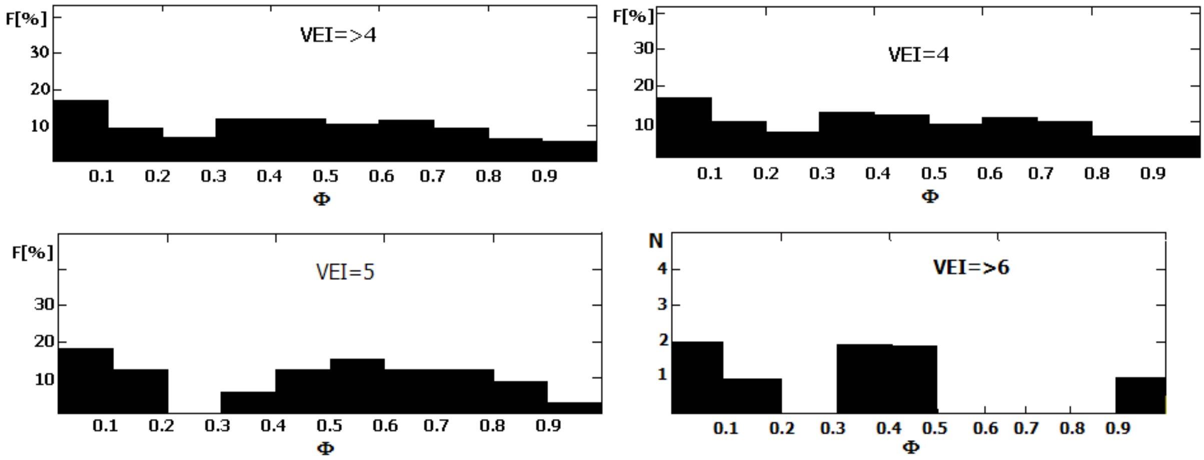


Fig.3 The relative (F%) and absolute number (N) of strong volcanic activity vs. sunspot activity phase (Φ): (upper left: whole strong eruptions (VEI≥4); upper right: moderate strong (VEI=4); very strong (VEI=5) ; strongest (VEI≥6))

Discussion

The problem for possible solar generated trigger mechanisms of strong volcanic events is of high importance in interdisciplinary scientific viewpoint at least by two reasons: 1. It is interesting for the better understanding of conditions, when strong volcanic eruptions could occur with higher probability; 2. The important role of volcanic activity over Earth climate changes is out of doubt. Consequently, it is completely possible that an essential part of "Sun-climate "relation is caused not due to solar electromagnetic radiation changes, but rather by triggering due to solar activity processes over lithosphere.

That's why the physical nature of these trigger mechanisms indeed should be search on the course of solar flare activity and related to him space weather events – solar energetic particles, coronal mass ejections (CME's), geomagnetic storms, ground level enhancements (GLE) etc. Such events could affect different terrestrial electrical phenomena as the electrical potentials between ionosphere and earth surface changes, piezoelectric events in the upper lithosphere of continents, electrostatic interactions between electrical charges in the lower atmosphere and magma chambers. Thus the strong solar eruptive phenomena could be primary sources for triggering no only for volcanic, but also for seismic events as well as for some part of Earth rotation irregularities like the LOD (Length of Day) -index or changes or inner continental water bodies levels like Caspian Sea (*Kaftan et al*., 2018).

The double peaked volcanic eruptions histograms (fig.3) needs to suggest additional solar triggered mechanisms except of these, which are described above. It is necessary because due to the solar flare activity could explain the volcanic peak distribution near to the sunspot activity maxima, but not the second volcanic peaks near to sunspot activity minima. By our opinion such primary trigger mechanism could be the GCR flux. Due to the heliosphere parameters changes the last one is higher near to 11yr sunspots minima and lower to sunspots maxima.

The GCR-flux enhances during the sunspot minima lead to higher ion-electron concentrations in the lower troposphere. The last one remains in few orders lower related to ionosphere (10^{-4} to 10^{-2} cm^{-3} in troposphere vs. 10^5 cm^{-3} to 10^6 cm^{-3} in ionosphere), but this increasing could change serious the near surface atmosphere electric conductivity and as a result to significant changes of atmosphere-lithosphere electric potentials. The last one could produced a trigger effect to produce volcanic eruption if the magma chamber conditions approached to some critical limit.

Swensmark and Friiz-Christensen (*Swensmark and Friiz-Christensen*, 1997) and few years later Yu (*Yu*, 2002) propose the idea that the enhanced ion-electron production in lower atmosphere during sunspot minima epochs could stimulated the aerosols and clouds origin and as a result – more precipitations and climate cooling should be observed in these epochs. As it was pointed by Yu (2002) the process should be essentially more effective if there are significant quantity of volcanic materials (dust and acid molecules H_2SO4, HCl, HF) in the atmosphere.

The last circumstance is both very interesting and important. By the last one follows that an increasing of volcanic activity during the sunspot minima epochs leading to enhancements of dust and acid gases densities in atmosphere should be stimulate aerosols and clouds production much more effective. It is due to combination effect with the enhanced charge particles production by GCR in the troposphere at the same time. That's why "Danjon-effect" occur predominantly during the sunspot minima epoch. The GCR flux and the ionization rates in troposphere are relative low during the sunspot maxima in spite of possible higher volcanic eruptive activity.

Without of doubt the most famous result in our present study is the powerful ~240-250-year cycle. By our opinion there are three hypotheses for its explanation. According to the first one it is related to specific solar activity regions like the giant (naked eye visible) sunspot groups. A 250-year cycle has been established for these sunspots on the base of Chinese catalog of eye visible sunspots (*Vaguero et al.*, 1997). It is well corresponding to the solar triggering mechanism and seems to be most probable. According to the second hypothesis the 240-250 yr cycle of volcanic activity is caused by influence of induced magnetosphere of Venus, while according to the third one the primary source of this cycle is a tidal effect of Venus over the Earth lithosphere. The second and third hypotheses are less probable. It follows by these hypotheses that a 243-year cycle should be observed.

As an "extreme" example, which confirm the high probability of solar triggering hypothesis is the Pinatubo volcano activity in 1991 AD. The very close coincidences between the main separate phases of volcanic activation and solar flare activity and its accompanying space weather events are described in details by Komitov and Stoychev (2011).

Even so, it should to note again, that the "solar-volcanic activity" relationship is by triggered nature. It could only to increases the probability for strong solar eruption, while the main primary sources of volcanic activity are the inner magma chamber processes.

The evidences of solar-volcanic triggering could to consider as a base for new stage of the "Sun-climate" debate. Since the volcanic activity as a serious climate factor is considered it could to suggest that important part of whole "Sun-climate" relationship is masked by means of strong volcanic eruptions.

Conclusions

In this study evidences about solar activity trigger influence over the strong volcanic eruptions (VEI≥4) have been found. They are as follow:

1. Statistically significant cycles by duration of 11, 19-26, ~50- 60, 80-90 and 240-250 years in the annual new-generated volcanic eruption number time series by using of two independent methods (the T-R periodogram and wavelet analysis) has been established. They have analogues in the solar and the geomagnetic activity.
2. There are two peaks in the relative and absolute number of strong volcanic eruptions histograms, which corresponds to sunspot minima and sunspot maxima respectively. These peaks are less expressed for the "moderate" strong volcanic eruptions (VEI=4) and better – for the most powerful ones, for which VEI ≥ 5.
3. Most probably the primary sources of solar (and space weather at all) triggering over volcanic activity are the solar flares and accompanied them phenomena as coronal mass

ejections (CME's), solar energetic particles (SEP), ground level enhancements (GLE) and geomagnetic storms.

4. It is very possible that solar-volcanic triggering is a serious indirect component of the total "Sun-climate" relationship.

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