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Secular variations of the geomagnetic field and solar activity

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Сделана попытка разделения вековых колебаний, создаваемых внешними источниками, по данным обсерваторий «Нурмиярви», «Лервик», «Ленинград», «Нимек», «Бельск», «Хартланд», «Киев», «Львов», «Шамбон-ля-Форет», «Одесса», «Сурларли», «Коимбра». Показано, что существует три типа вековых колебаний, связанных с внешними источниками. Короткопериодные колебания (около 2 лет) и колебания средней периодичности (около 11 лет) хорошо известны. Предположено наличие долговременной модуляции вековых колебаний с периодом 80 лет, которая происходит в связи с изменениями солнечной активности.

Зроблено спробу розділення вікових коливань, утворюваних зовнішніми джерелами, за даними обсерваторій «Нурміярві», «Лервік», «Ленінград», «Німек», «Бєльськ», «Хартланд», «Київ», «Львів», «Шамбон-ля-Форет», «Одеса», «Сурларлі», «Коімбра». Показно, що існує три типи вікових коливань, пов'язаних із зовнішніми джерелами. Короткоперіодні коливання (близько 2 років) і коливання середньої періодичності (близько 11 років) добре відомі. Припущено наявність довгочасної модуляції вікових коливань з періодом 80 років, яка відбувається через змінення сонячної активності.

Introduction. The main field of the Earth has its origin in the core due to the currents running at a depth of about 2,900 km. The current system in the core is not stable and homogeneous. The main magnetic field at any point of the Earth's surface changes over time. It has been recognized since the seventeenth century by Gellibrand. Now these changes are known as the secular variations (SV). Vector measurements of the field provide information about the direction of the field as well as its strength. Long time series of the magnetic field elements at global network of magnetic observatories show also the space changes of the field. Usually the SV are computed from the difference between two successive annual means and then are smoothed to attenuate the variations from external sources [Alexandrescu, 1996]. Beyond all doubts geomagnetic secular variations consist of internal and external sources. Separation of these variations is a very difficult task so far as they vary with time and space and are heterogeneous [Mandea, 2001]. To investigate SV different methods are used: comparison of annual coefficients of the spherical-harmonic analysis of the geomagnetic field, comparison of the regular measurements of the field of magnetic observatories and repeat stations.

Experimental procedure. We have calculated SV(H) and SV(Z) as a difference between mean yearly values of horizontal (H) and vertical (Z) components on all (A), quiet (Q) and disturbed (D) days for magnetic observatories Belsk (BEL), Lviv (LVV), Leningrad (LNN) and only on all days for observatories Lerwick (LER), Hartland (HAD), Niemegk (NGK), Surlari (SUA), Odessa (ODE),

Table 1

Observatory	φ, grad	λ, grad	$SV(H)_0$
Nurmijarvi	60,52	24,65	–3,59
Lerwick	60,13	358,82	7,79
Leningrad	59,95	30,70	–4,00
Moscow	55,48	37,32	–2,21
Niemegk	52,07	12,68	5,07
Belsk	51,83	20,80	1,29
Hartland	50,98	355,52	17,43
Kiev	50,72	30,30	–2,24
Lviv	49,90	23,75	0
Chambon la Foret	48,02	02,27	14,72
Odessa	46,78	30,88	–2,22
Surlari	44,68	26,25	–2,00
Coimbra	40,22	351,58	29,51

Coimbra (COI), Nurmijarvi (NUR), Kiev (KIV), Moscow (MOS) and Chambon la Foret (CLF). Geographic coordinates of the observatories are shown in table 1. The yearly mean values we obtained from WDC in Moscow [Golovkov et. al., 1983] and Kyoto [http://wdc.kugi.kyoto-u.ac.jp].

It is known that during magnetic storms magnetospheric ring current develops. Due to the current, H-component decreases at low latitudes (D_{st}-variation). The decrease of H is maximal at equator and equal to zero at the earth's poles. Thus, during high solar activity, the number of geomagnetic storms increases and mean yearly values of H-component are low. D_{st}-variation is observed in Z-component also [Sumaruk et al., 1980]. Due to the ring current, Z component variations increase. Effect intensifies to high latitudes. Different ionospheric current systems such as auroral electrojet, probably, also put in to the change of SV.

Results and interpretation. Fig. 1 shows SV of H (*a*) and Z (*b*) — components at magnetic observatory Lviv (LVV) from 1958 till 2000 for all (black), quiet (green) and disturbed (red) days. Fig. 2 and Fig. 3 show the same at magnetic observatories Belsk (BEL) and Leningrad (LNN) correspondingly. We see short (about two year) period variations and long period ones exist. Amplitudes of short period variations increase from LNN to LVV and are the greatest for disturbed days. Long period SV(H) appear to be in accord with quasi-sinusoidal law similarly to aa index changes reported by [Strestik, 1991] and ΣKp-index [Sumaruk Yu.,2001; Sumaruk P., 2001].

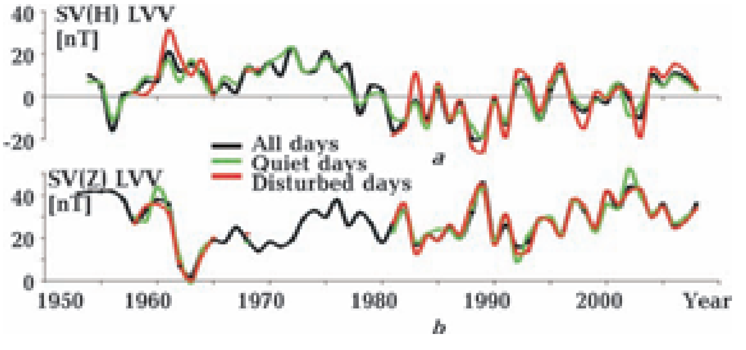

Fig. 1. SV(H) — (*a*) and SV(Z) — (*b*) — at magnetic observatory Lviv.

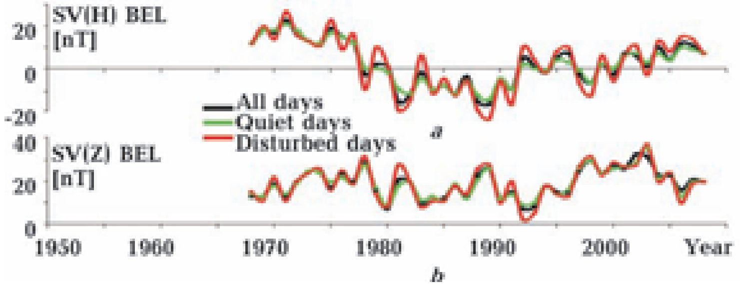

Fig. 2. SV(H) — (*a*) and SV(Z) — (*b*) — components at magnetic observatory Belsk.

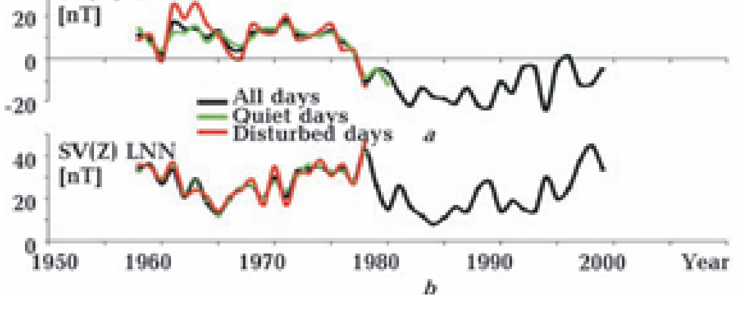

Fig. 3. SV(H) — (*a*) and SV(Z) — (*b*) — components at magnetic observatory Leningrad.

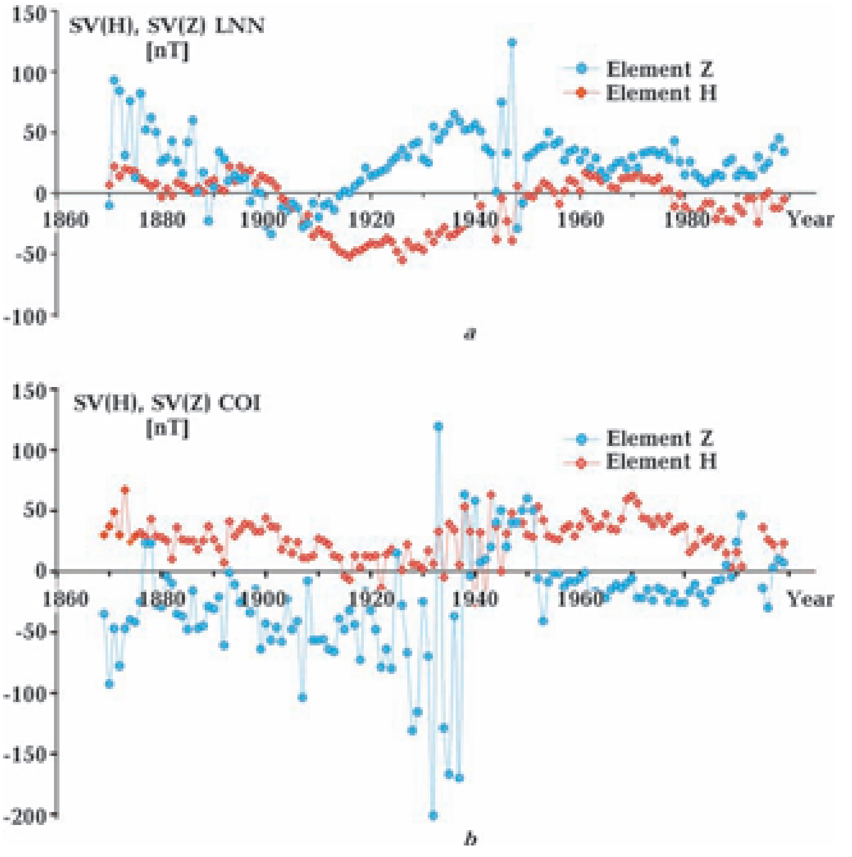

Fig. 4. SV(H) and SV(Z) variations for magnetic observatories LNN (*a*) and COI (*b*) from 1870 till 2000.

Short and long periods SV(Z) variations coincide wonderfully in phase at the observatories. Unfortunately we can not observe increase of SV(Z) amplitude from LVV to LNN, probably, because the latitudes of the observatories change only by about 10 degrees. Amplitudes of SV(Z) are also greater for D-days than for Q-days. Phenomenon is better observed for LVV and, maybe, it is connected with influence of induced current in underlying surface. Comparison shows that SV(H) and SV(Z) change is opposite in phase. It proves that short period variations have external sources.

Fig. 4 shows SV(H) (circle) and SV(Z) (square) variations for magnetic observatories LNN (*a*) and COI (*b*) from 1870 till 2000. We observe the coincidence in time of short period variations as SV(H) and so SV(Z), but the variations at COI have greater amplitude. As to SV(H), it is understood so far as COI placed nearer to equator than LNN, but the increase of the amplitude of short period variations SV(Z) at COI may the most probably be explained by influence of induced currents. It is necessary to note that during the war years the observatories data at LNN and COI were unstable. The most prominent fact is the coincidence in phase of the long period (about 80 years) variations at both observatories, but SV(H) is shifted up and SV(Z) down on ordinate axis at COI relatively to LNN. It was shown earlier [Sumaruk Yu., 2001] that the changes of SV(H) at all middle and subauroral magnetic observatories of the north hemisphere of the Earth coincide in phase, but their amplitudes and positions relatively the ordinate axis are different. Dependence of $SV(H)_i$ at *i*-observatory on $SV(H)_{i+1}$ observatory is

$$SV(H)_i = K \times SV(H)_{i+1} + SV(H)_0,$$

where K — is constant value for certain observatory and $SV(H)_0$ is positive or negative number, also constant for this observatory, but it is chosen in such a way so that years of changes of SV(H) sign for all observatories coincide. For the most middle latitude European observatories these years are 1900—1903 and 1977—1980 . It is necessary to note that during those years the jerks in the SV of magnetic declination were observed [Mandea, 2001].

Fig. 5 shows the dependence of the changes of SV(H)-variations (ΔSV(H)) on the changes of mean year magnetic activity index $\Delta\sum$(H-Sq) for

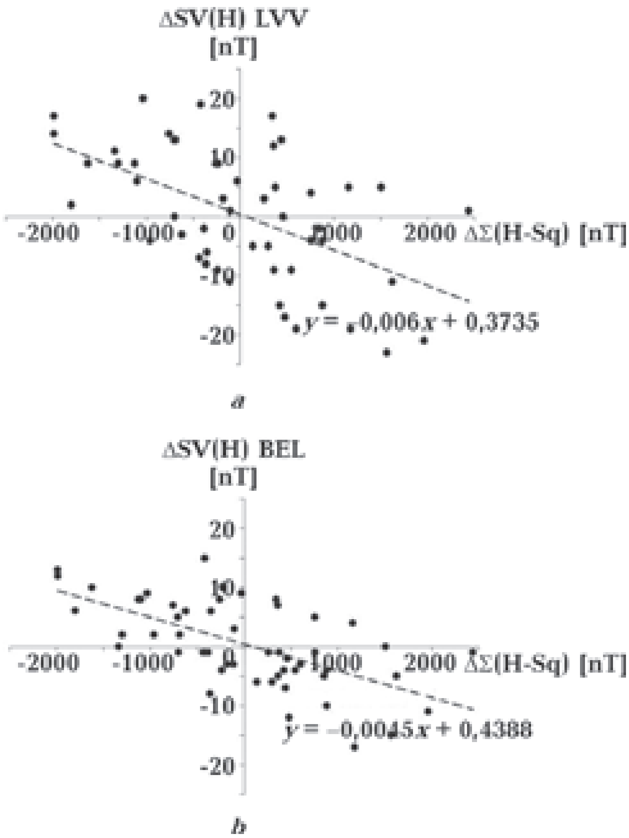

Fig. 5. The dependence of the ΔSV(H) on the Δ∑(H-Sq) for magnetic observatories LVV (*a*) and BEL (*b*).

magnetic observatories BEL (*b*) and LVV (*a*). Correlation is low, but decreasing tendency of ΔSV(H) with increasing Δ∑(H-Sq) is observed very well. To investigate long period variations, we have chosen observatories LNN and COI which have long row of observations.

Fig. 6 and Fig. 7 show dependence of SV(H) at BEL on SV(H) at LVV (*a*, *b*), SV(H) at KIV on SV(H) at LVV (*c*, *d*) SV(H) at SUA on SV(H) at LVV(*e*, *f*) and so on. The observatories names and time intervals are shown upwards of ordinate axis. The straight lines show linear regression equations between values. These equations are shown in table 2. Points of crossing these lines and ordinate axis show $SV(H)_0$ values. As one can see the values and signs of $SV(H)_0$ are different for observatories. If the reference observatory is LVV, $SV(H)_0$=29,51 nT for COI and $SV(H)_0$=17,43 nT for HAD. To verify these results, Fig. 8 shows dependence of SV(H) at HAD on SV(H) at COI from 1867 till 1999. Straight line shows linear regression equation between values. One can see that $SV(H)_0$ is about — 12,33 nT, when reference observatory is COI, that may say that $SV(H)_0$ is equal to $SV(H)_0$ at COI minus $SV(H)_0$ at HAD.

Correlation between SV(H) becomes worse as distance between observatories increases. As it was shown in [Sumaruk T., Sumaruk Yu., 2007] at the regions where $SV(H)_0$ are equal to zero the intense tectonic activity is observed. Except short period

Table 2

Observatory	$SV(H)_{LVV}$
Odessa	$=0{,}80SV(H)_{ODE}-2{,}22$
Leningrad	$=0{,}97SV(H)_{LNN}-4{,}00$
Kiev	$=0{,}82SV(H)_{KIV}-2{,}25$
Moscow	$=0{,}78SV(H)_{MOS}-2{,}21$
Surlari	$=0{,}94SV(H)_{SUA}-2{,}01$
Nurmijarvi	$=1{,}03SV(H)_{NUR}-3{,}59$
Belsk	$=0{,}83SV(H)_{BEL}+1{,}29$
Niemegk	$=0{,}91SV(H)_{NGK}+5{,}07$
Chambon la Foret	$=0{,}93SV(H)_{CLF}+14{,}73$
Lerwick	$=0{,}98SV(H)_{LER}+7{,}80$
Hartland	$=1{,}02SV(H)_{HAD}+17{,}43$
Coimbra	$=0{,}97SV(H)_{COI}+29{,}51$

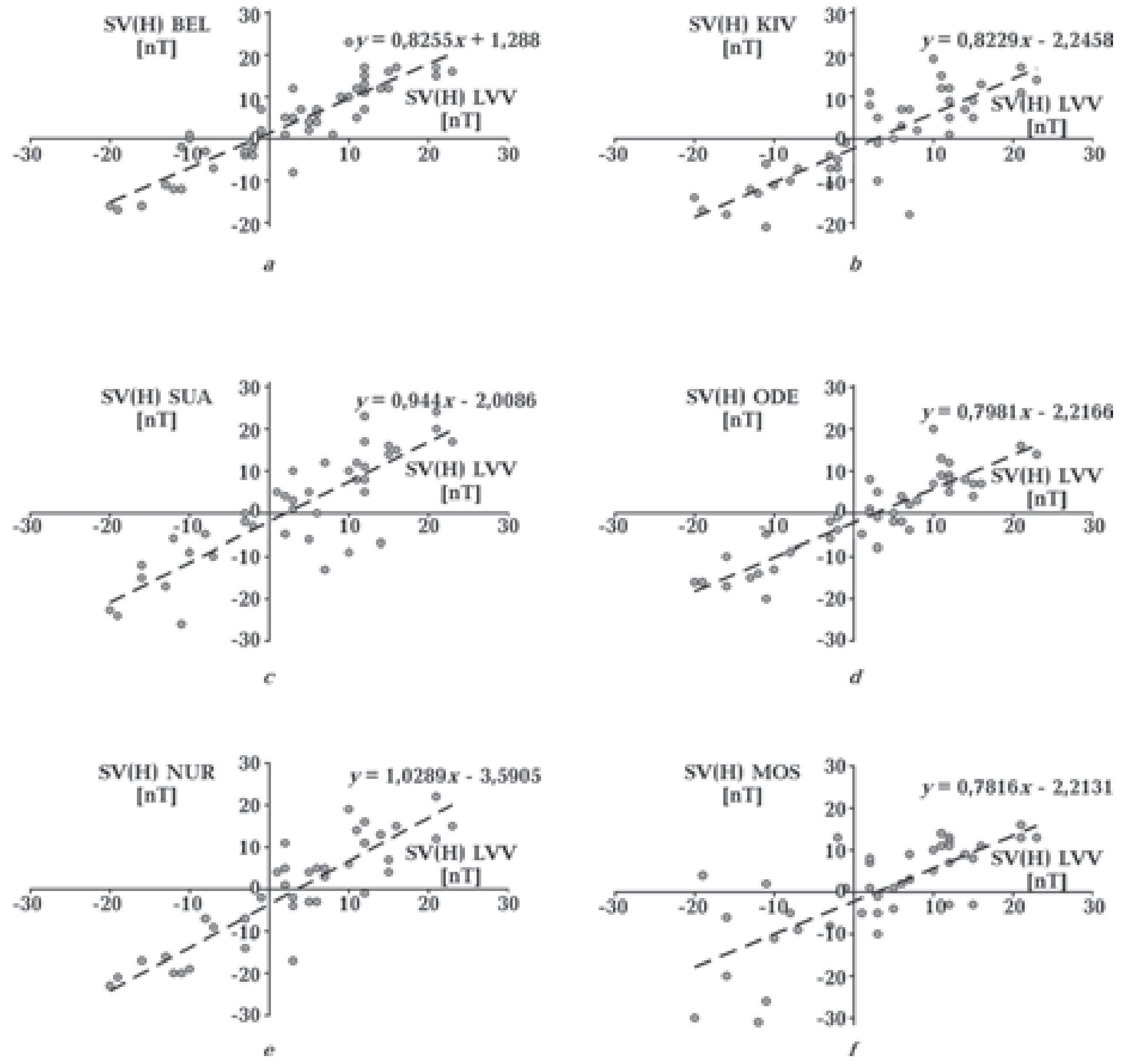

Fig. 6. Dependence of SV(H) at different observatories on SV(H) at LVV.

(about two years) and long period (about 80 years) about eleven year period variations are observed.

Fig. 9 shows SV(H) variations at HAD (*a*) and LNN (*b*) observatories but short period variations are excluded by trapezium method. It is clearly seen that at the upper part of the solar cycles SV(H) decreases and at fall stage of solar cycles SV(H) increases. To exclude these variations mean per solar cycle SV(H) have been calculated.

Fig. 10 shows dependence of mean per solar cycles SV(H) at HAD on the values of mean per solar cycles Wolf's number from 15-th to 22-nd cycles. It is easy to see the rectilinear dependence between the values. Only 20-th cycle doesn't follow the dependence. We may note that quasi-sinusoidal variations have also external source.

Conclusions. SV-variations have external and internal sources. To separate internal source component it is necessary to exclude short period (about two years), middle period (about 11 years) and long period (about 80 years) variations. Amplitudes of short period variations increase with growing of solar activity and are greater for D-days than for Q-days. Short periods SV(H) and SV(Z) change in opposite phases. Anti-correlation between SV(H) and magnetic activity is observed. Amplitude of the short period SV(H) variations decreases with increasing of the magnetic observatories latitudes. That is to say short period SV(H) and SV(Z) are generated by external currents.

Middle period (about 11 years) SV also depend on solar activity. Values of SV(H) decrease at the

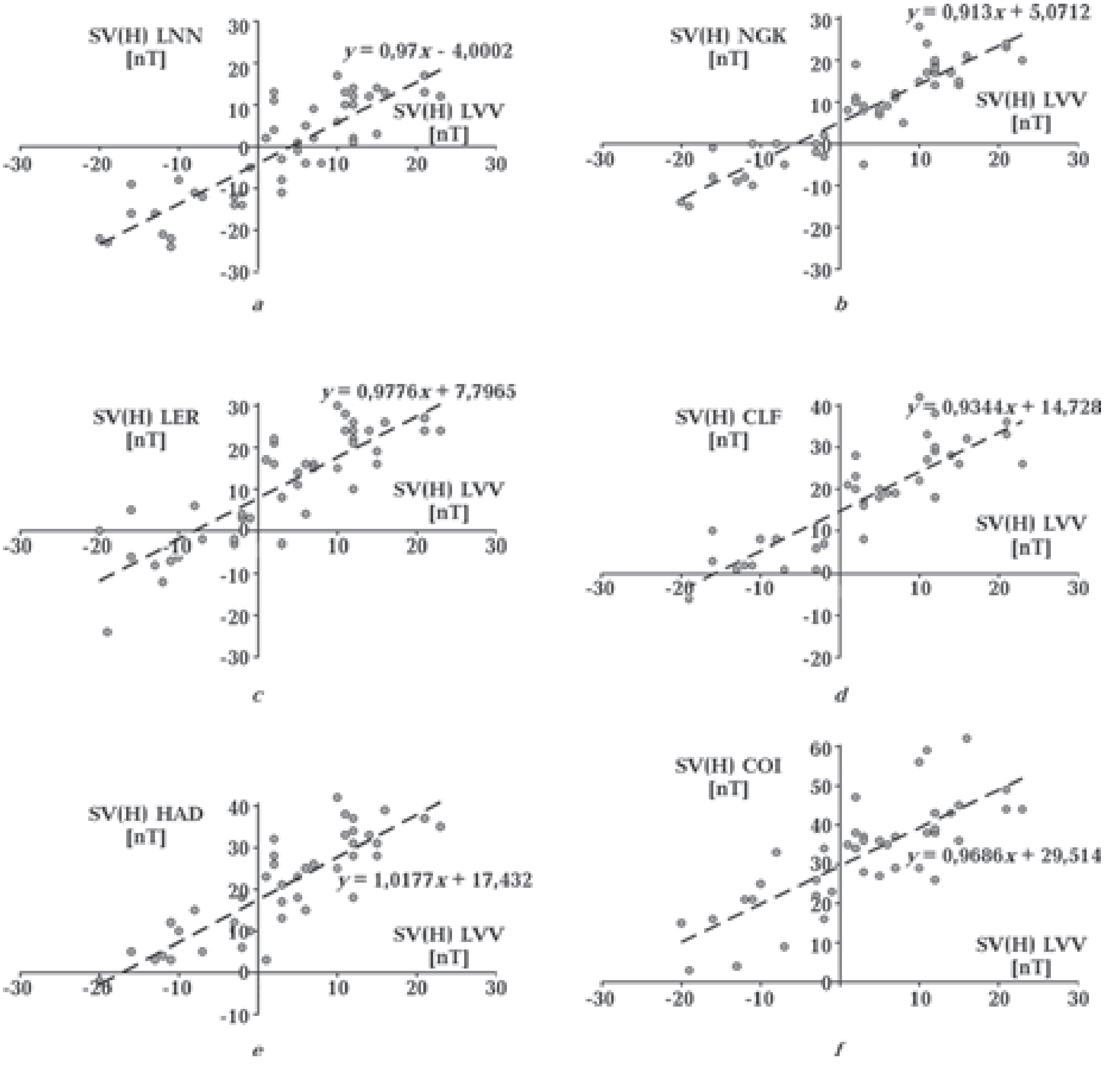

Fig. 7. Dependence of SV(H) at different observatories on SV(H) at LVV.

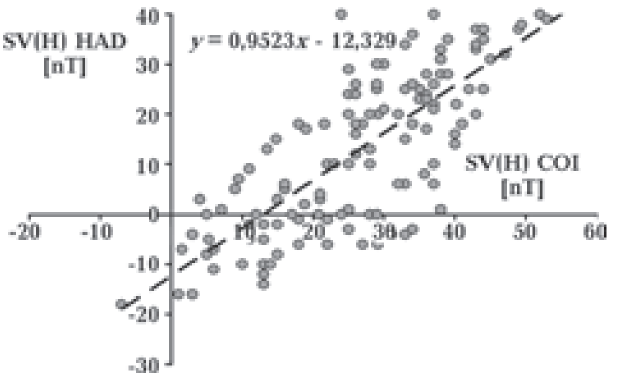

Fig. 8. Dependence of SV(H) at HAD on SV(H) at COI for 1867 till 1999.

upper phase of solar cycles and they increase at fall phase. To exclude SV dependence on the cycle solar activity the mean per cycle values are necessary to be calculated. After excluding short

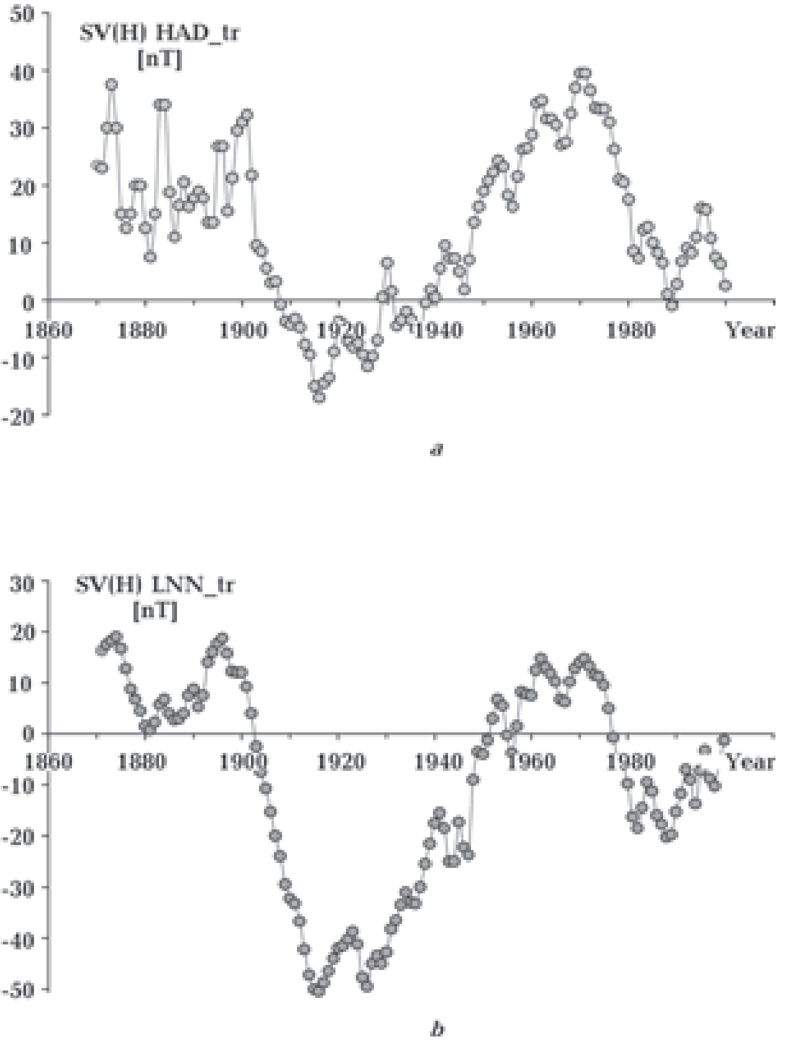

Fig. 9. SV(H) variations at HAD (a), LNN (b) with out shot period variation and Wolf number (c).

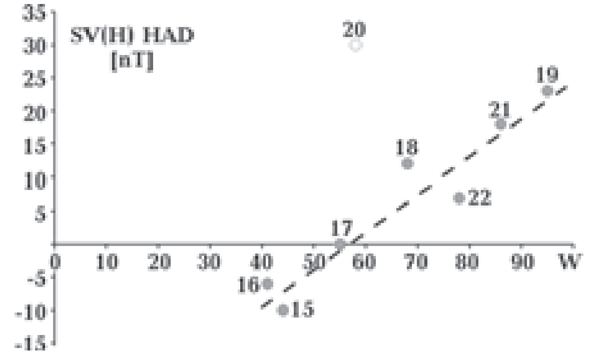

Fig. 10. Dependence of SV(H) at HAD on mean per solar cycles Wolf's number.

and middle period SV variations, long period quasi-sinusoidal SV(H) and SV(Z) variation are observed. The period of the variations is about 80 years. It may be supposed that quasi-sinusoidal SV-variations are also connected with solar activity. Mean per solar cycle values of SV(H) and the same Wolf numbers for fifteenth to twenty second cycles are highly correlated. Thus three types of SV(H) and SV(Z) due to external sources have been observed.

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