TWO SUNSPOT GROUP POPULATIONS: GNEVYSHEV-OHL RULE AND SPATIAL DISTRIBUTION OF SOLAR ACTIVITY

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TWO SUNSPOT GROUP POPULATIONS

- Small groups (S ~ 17 m.s.h.) with weak magnetic field (~ 1900 Gs) and short lifetime (≤ 5^d)
  – **SSG**: **S**mall **S**hort-living **G**roups
- Large groups (S ~ 235 m.s.h.) with strong magnetic field (~ 2500 Gs) long lifetime (> 5^d)
  – **LLG**: **L**arge **L**ong-living **G**roups
- SSG and LLG behave differently in 11-year solar cycle
- Differential rotation of SSG is fast and unimodal, LLG – bimodal with fast and slow components

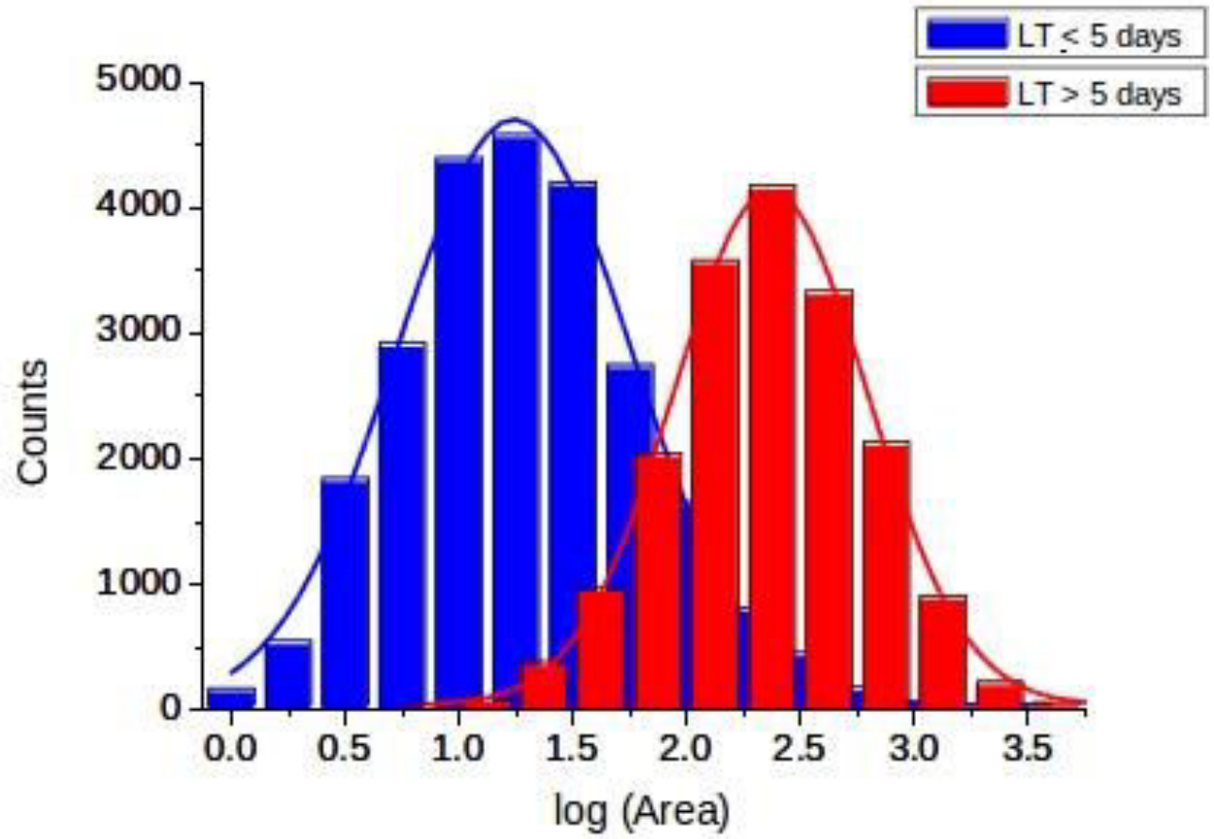
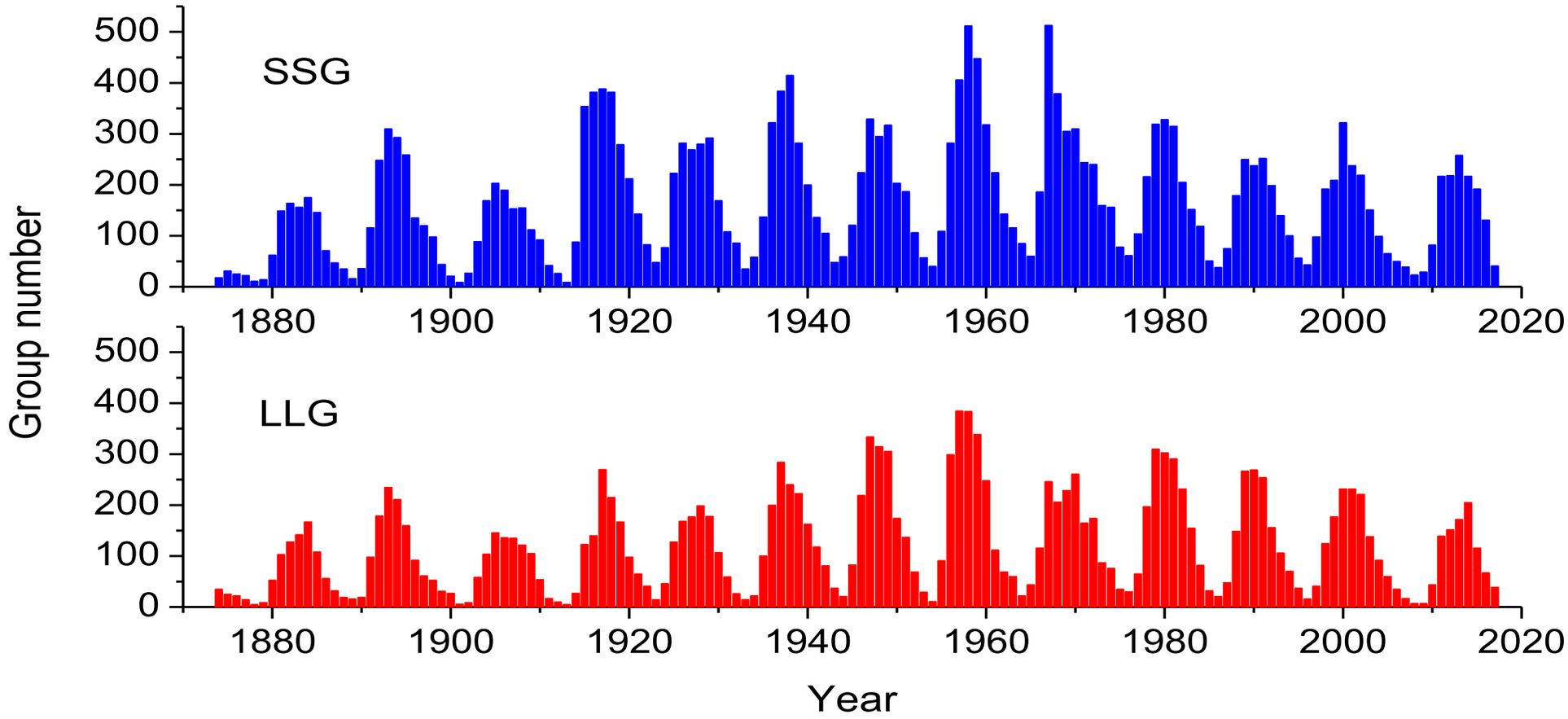


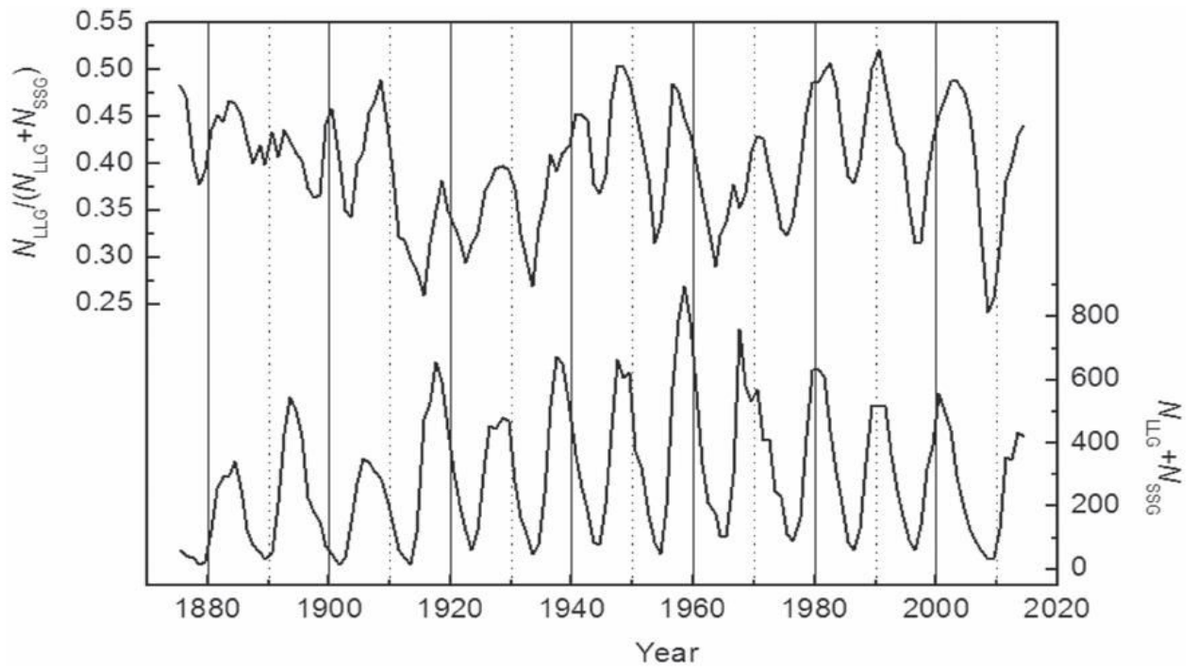
Fig.1. Area logarithm distribution for lifetimes less than 5 days (blue) and more than 5 days (red), corresponding to SSG and LLG respectively.

TWO POPULATIONS IN 11-YEAR SOLAR CYCLE



- Number of LLG and SSG varies with 11-year solar cycle (Nagovitsyn & Pevtsov, ApJ, 2016)

- Relative number of LLG shows long-term variations
- Relative number of SSG is higher in minimum epochs of 11-year cycles



GNEVYSHEV-OHL RULE

Three formulations of GOR (Nagovitsyn, *Astr. Lett.*, 2009):

- Odd 11-year cycle is higher than previous even *(Amplitude Gnevyshev-Ohl rule – AGO)*
- Area under the curve of activity index for an even cycle SW_{2N} correlates with the same for an odd cycle SW_{2N+1}, while SW_{2N-1} doesn't correlate with SW_{2N} *(Main Gnevyshev-Ohl rule – MGO)*
- an even cycle with subsequent odd pair form a single whole so that one can talk not about the 11-year cycle, but about the 22-year solar cycle – this is the conclusion from the MGO *(Deduced Gnevyshev-Ohl rule – DGO)*

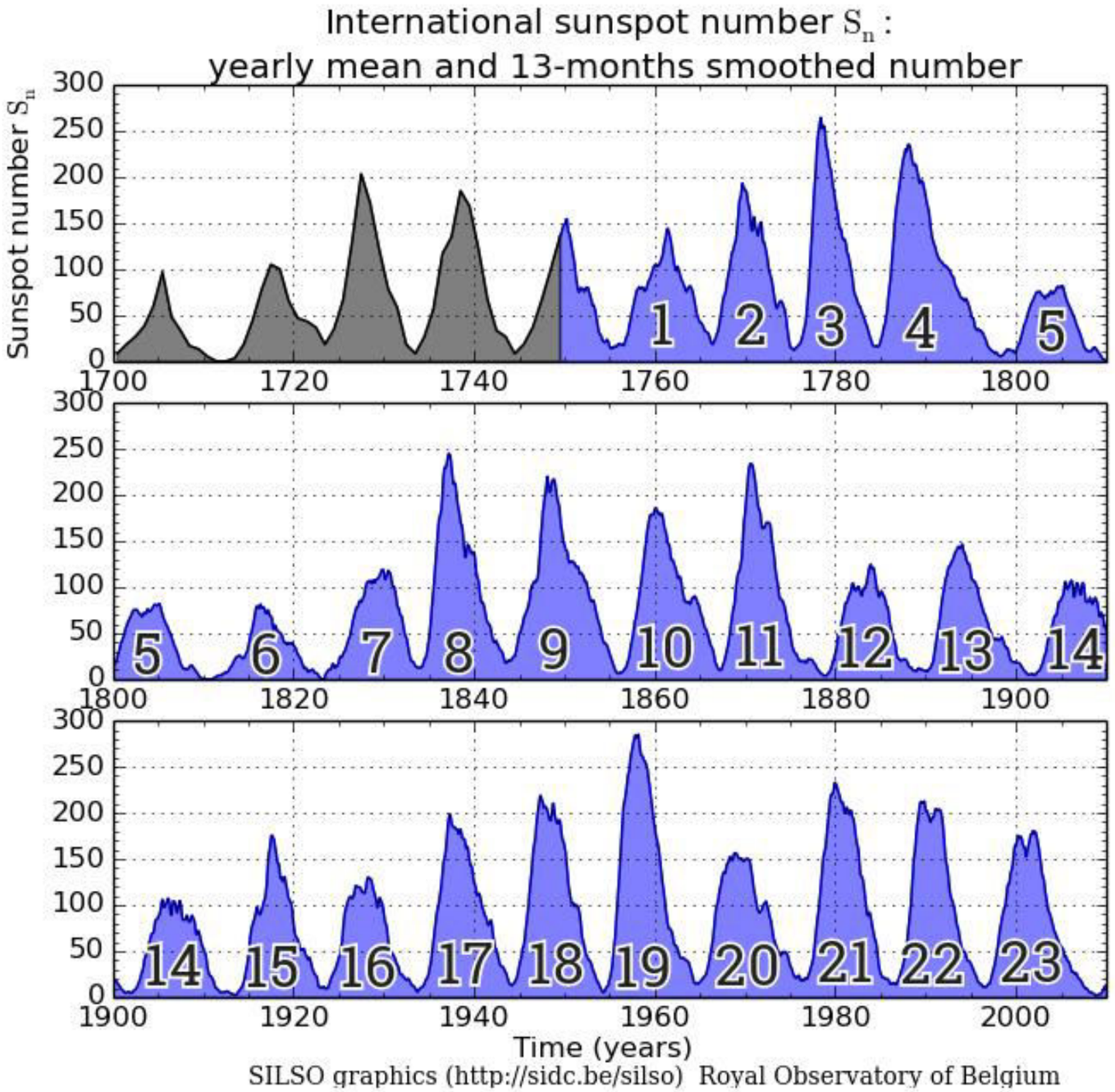


Fig. 2: International Sunspot number.

ACTIVITY INDICES AND DATA

I type – “dynamic indices”:
Traditional solar activity indices. The contribution of each sunspot group to the statistics depends on its lifetime.
We monitor the role of geo-effective events.

II type – “static indices”:
Each sunspot group is presented only once (for example, by its maximum area over the lifetime).
We monitor the efficiency of the dynamo process.

s – The annual values of the sunspot groups' total area at the moment of their maximum development

g – The total number of sunspot groups that appeared over the year

1874-1976 – Royal Greenwich Observatory; 1976-2018 – Kislovodsk Mountain Station (13 cycles).
Assuming that the Gnevyshev-Ohl rule is valid for each of the hemispheres, we include the northern and southern hemispheres separately in statistics.

AREA INDEX *s*

- LLG:
  - in the S-hemisphere 18 and 19 cycles are relatively the same height, while in the N-hemisphere 19th cycle is the highest;
  - 22-23 cycle pair violates AGO
- SSG:
  - in the N-hemisphere 22-23 cycle pair obey AGO, but in the S-hemisphere it is violated

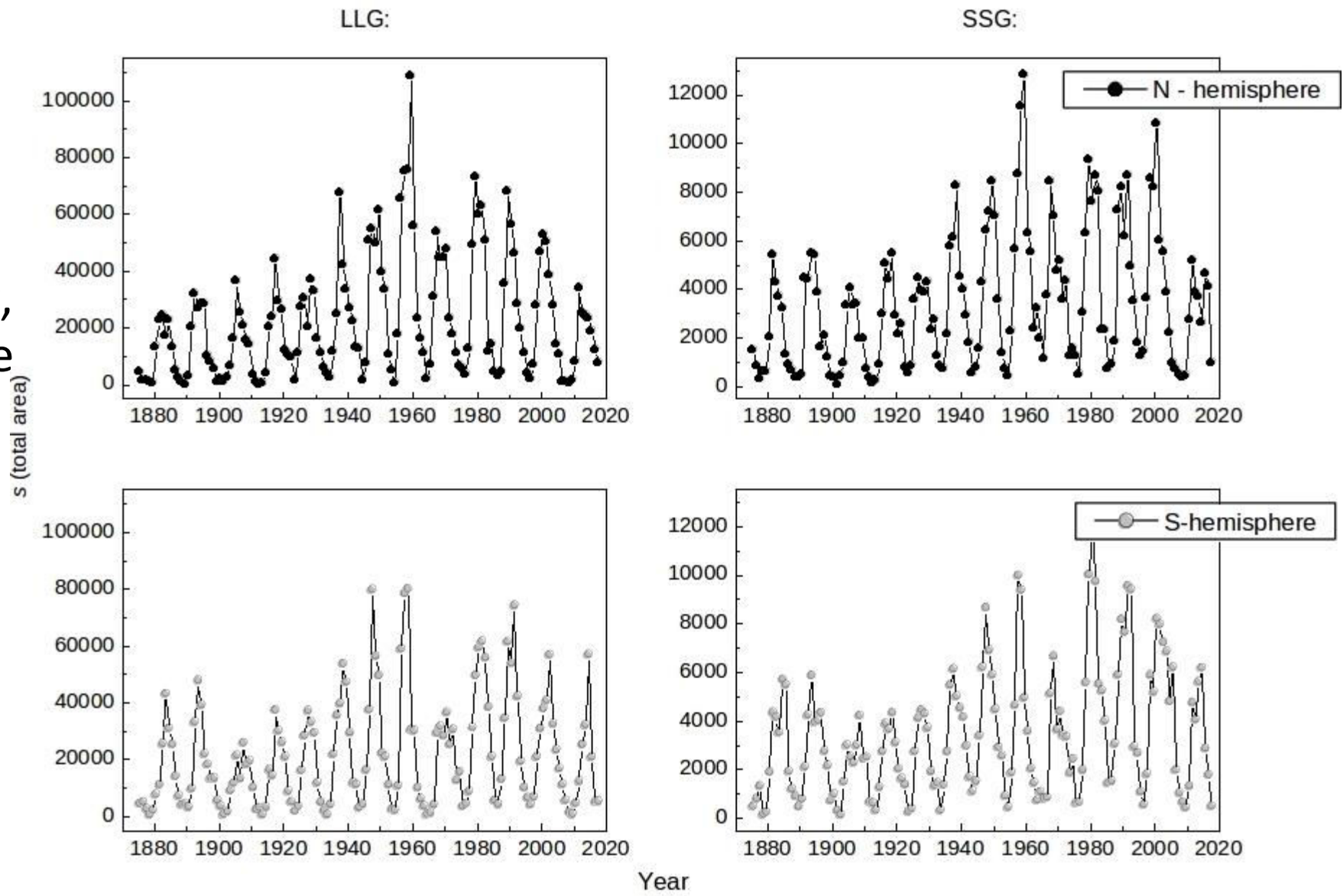


Figure 3: The annual values of the sunspot groups' total area at the moment of their maximum development *s* (each group participates in the statistics once) for the two populations (left panels – LLG, right panels – SSG) at the northern (N, upper panels) and southern (S, lower panels) solar hemispheres. 11-year cycles are numbered from left to right from the 12th to the 24th.

NUMBER OF GROUPS *g*

- LLG:
  - in the S-hemisphere 18 and 19 cycles are relatively the same height, while in the N-hemisphere 19th cycle is the highest;
- SSG:
  - in the N-hemisphere 22-23 cycle pair obey AGO, but in the S-hemisphere it is violated
  - in the N-hemisphere 20th cycle is the highest through the entire period of observations, while in the S-hemisphere it is 2-3rd in height

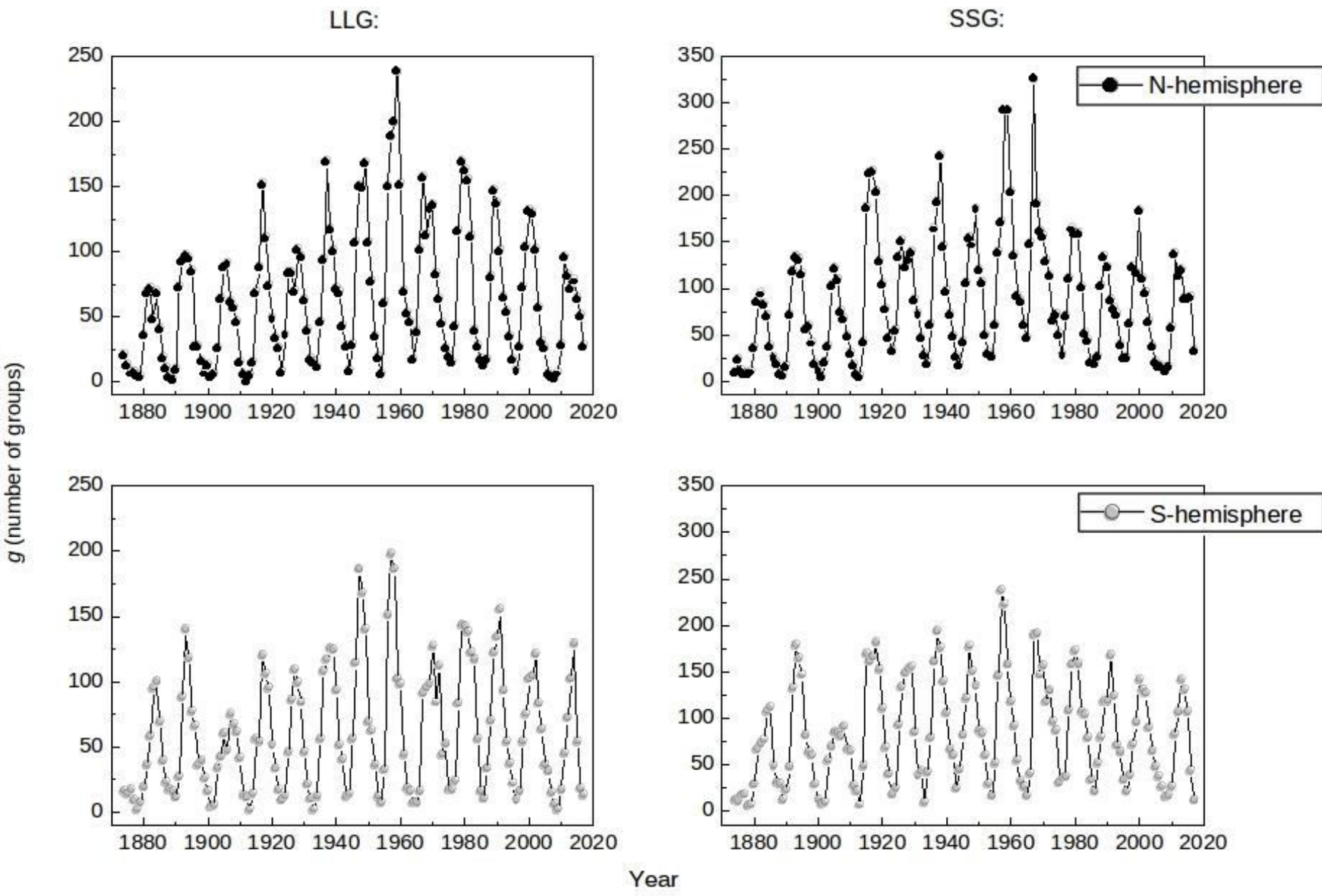


Figure 4: The total number of sunspot groups that appeared over the year *g* for the two populations (left panels – LLG, right panels – SSG) at the northern (N, upper panels) and southern (S, lower panels) solar hemispheres. 11-year cycles are numbered from left to right from the 12th to the 24th.

GOR FOR AREA INDEX *s*

It can be seen that the MGO rule for both LLG and SSG is generally satisfied, but not very pronounced: the difference between the correlation coefficients *r* between the cycle pairs E-O and O-E are not large, especially for LLG.

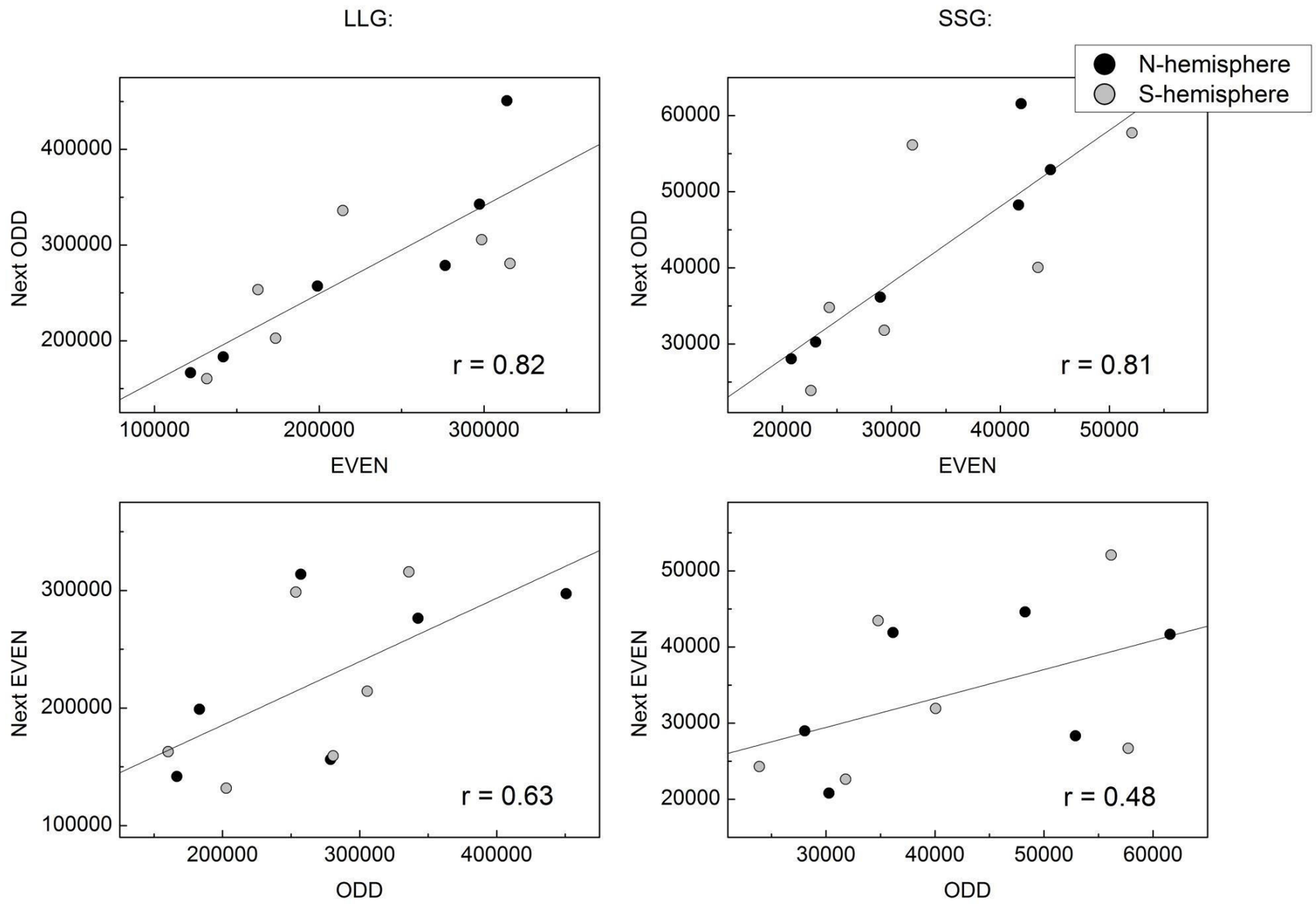


Figure 5: The pair correlations of even – the subsequent odd cycles (E-O, upper panels) and of odd – the subsequent even (O-E, lower panels) for the index *s* for the two populations (left panels – LLG, right panels – SSG). Black dots correspond to the northern solar hemisphere N, and gray dots correspond to the southern solar hemisphere S.

GOR FOR NUMBER OF GROUPS INDEX g

For LLG MGO is not satisfied.

The reverse MGO can be seen for the SSG: the correlation coefficients differ significantly!

In addition, at the bottom right panel all the points except one lie below the *y = x* diagonal (dashed line). From this, we must conclude that DGO also has the opposite character: the odd cycle, being larger, correlates with the subsequent smaller even cycle forming a pair – a single whole 22-year cycle.

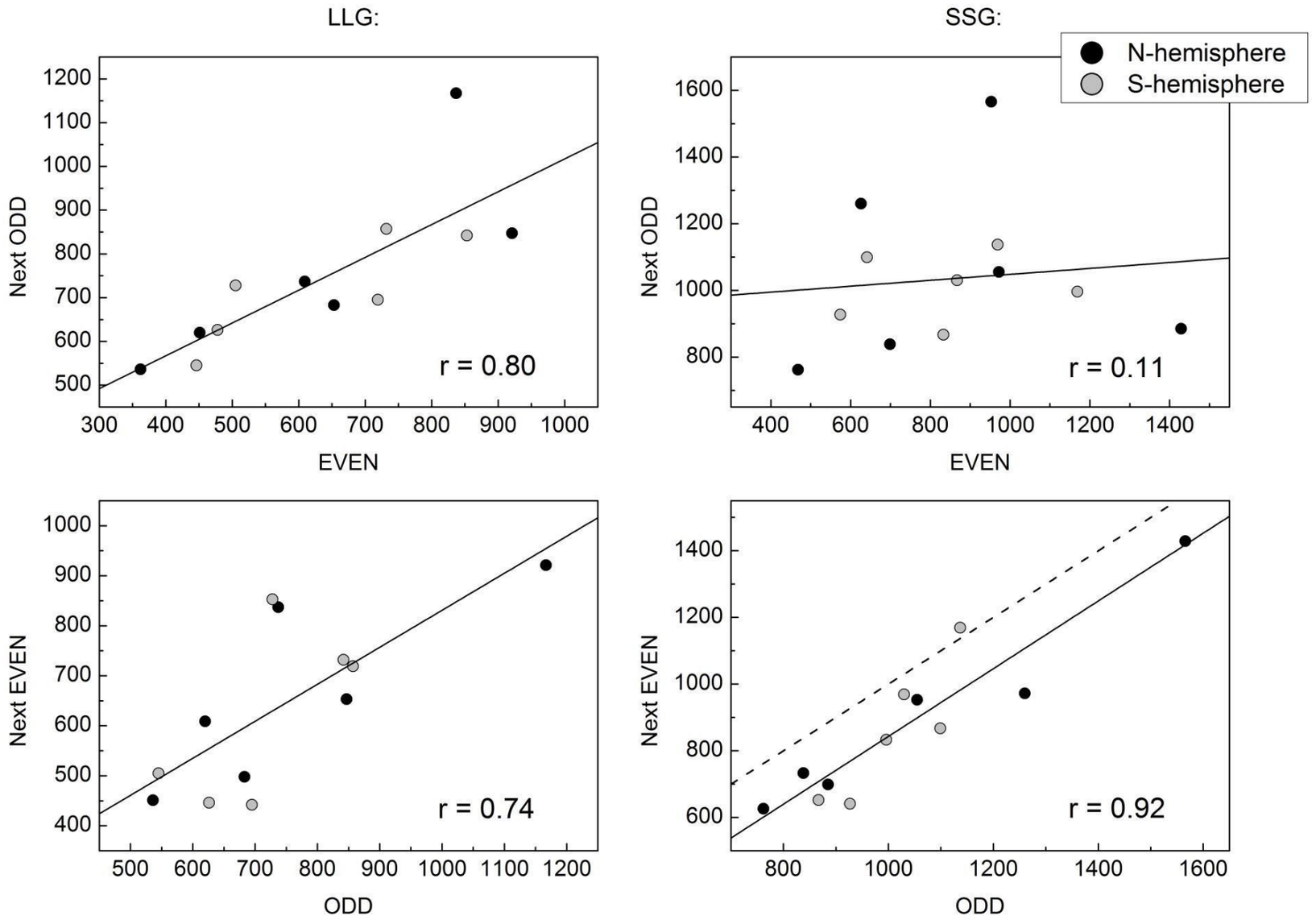


Fig. 6: The pair correlations of even – the subsequent odd cycles, upper panels) and of odd – the subsequent even (O-E, lower panels) for the index *g* for the two populations (left panels – LLG, right panels – SSG). Black dots correspond to the northern solar hemisphere N, and gray dots correspond to the southern solar hemisphere S.

GOR FOR NUMBER OF GROUPS INDEX g

For LLG MGO is not satisfied.

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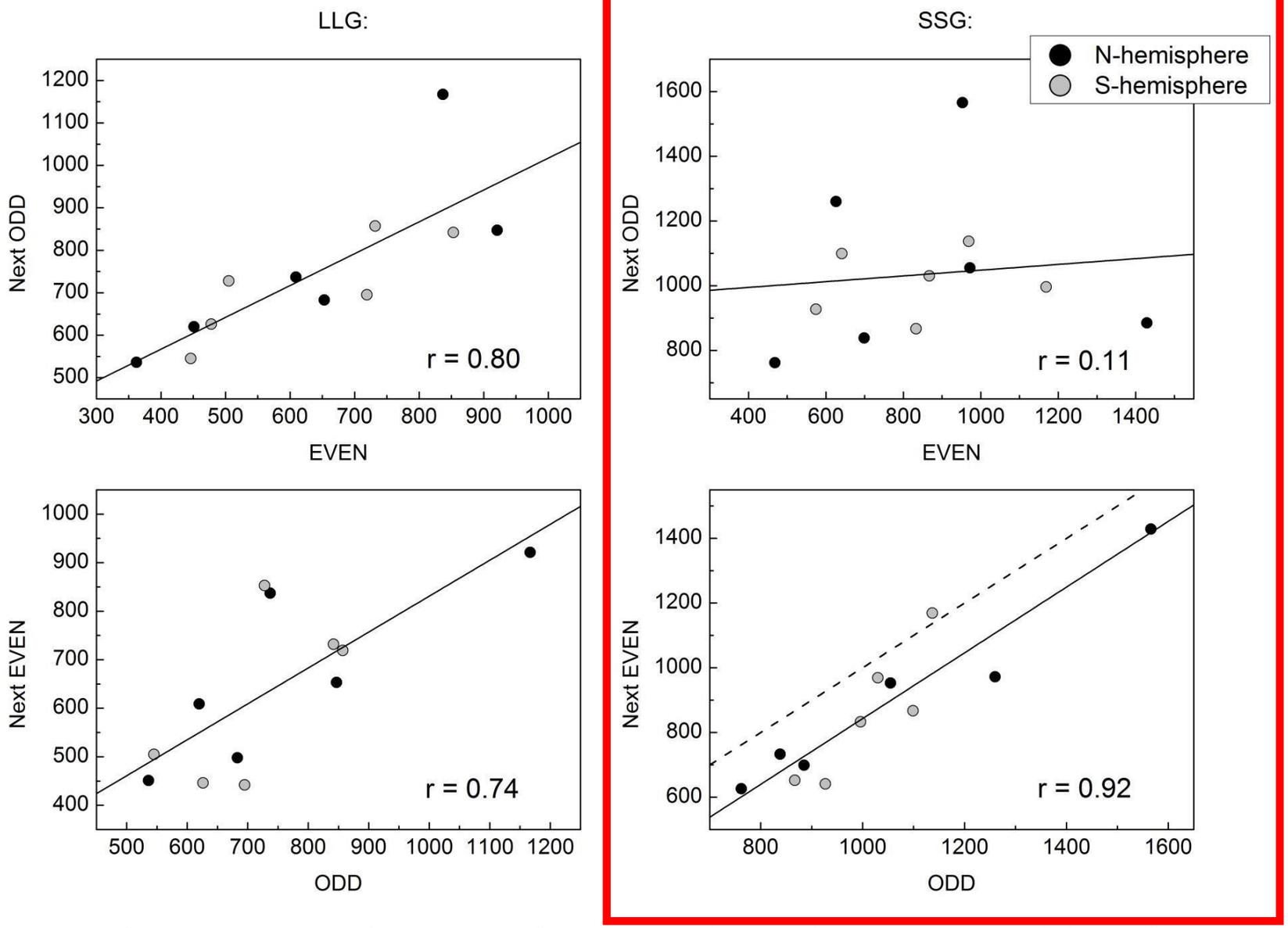
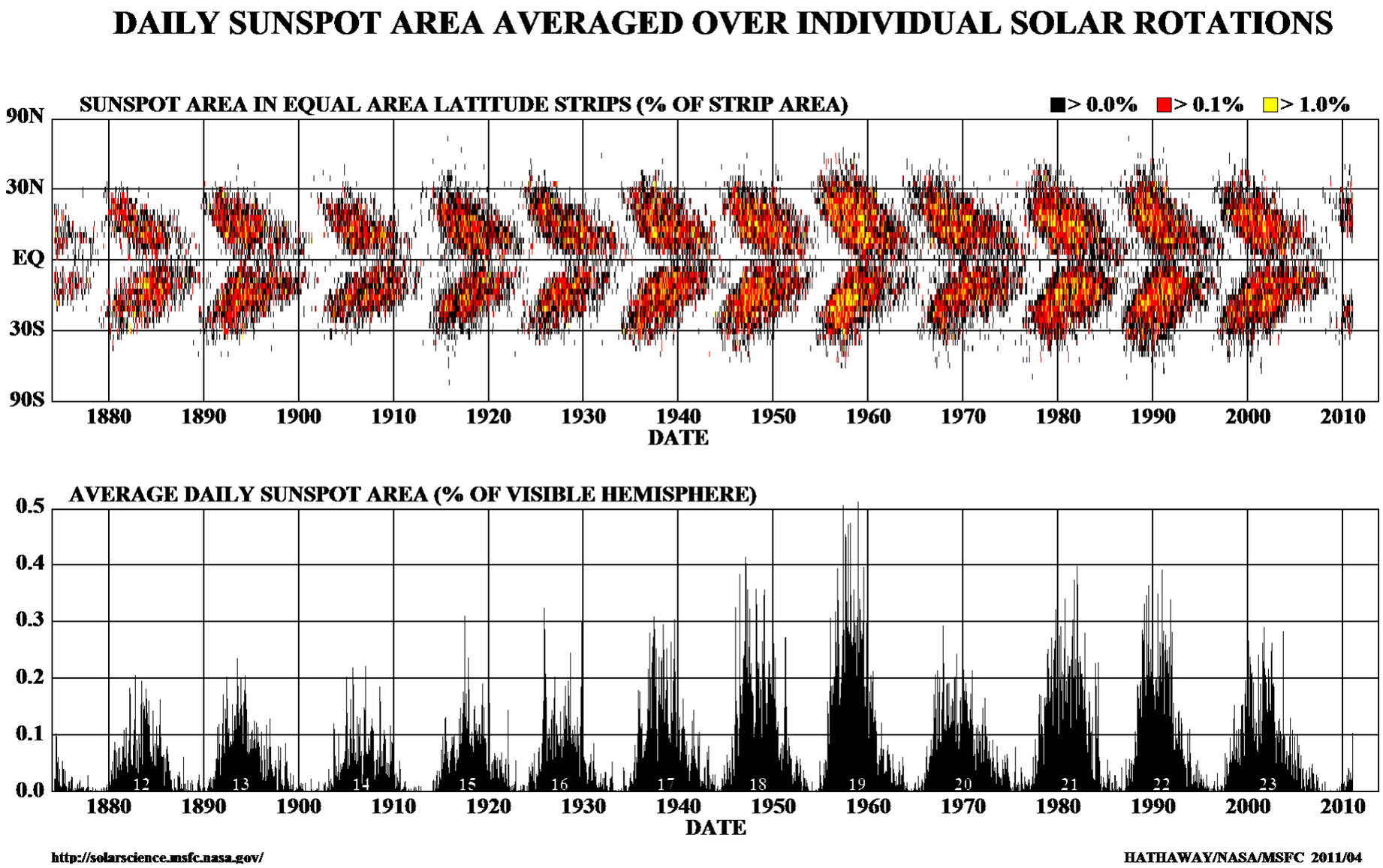


Fig. 6: The pair correlations of even – the subsequent odd cycles , upper panels) and of odd – the subsequent even (O-E, lower panels) for the index *g* for the two populations (left panels – LLG, right panels – SSG). Black dots correspond to the northern solar hemisphere N and gray dots correspond to the southern solar hemisphere S.

SPATIAL DISTRIBUTION



Carrington, Spörer – drift of sunspot latitudes during 11-year solar cycle.

Maunder's butterfly diagram.

BUTTERFLY DIAGRAM FOR TWO POPULATIONS

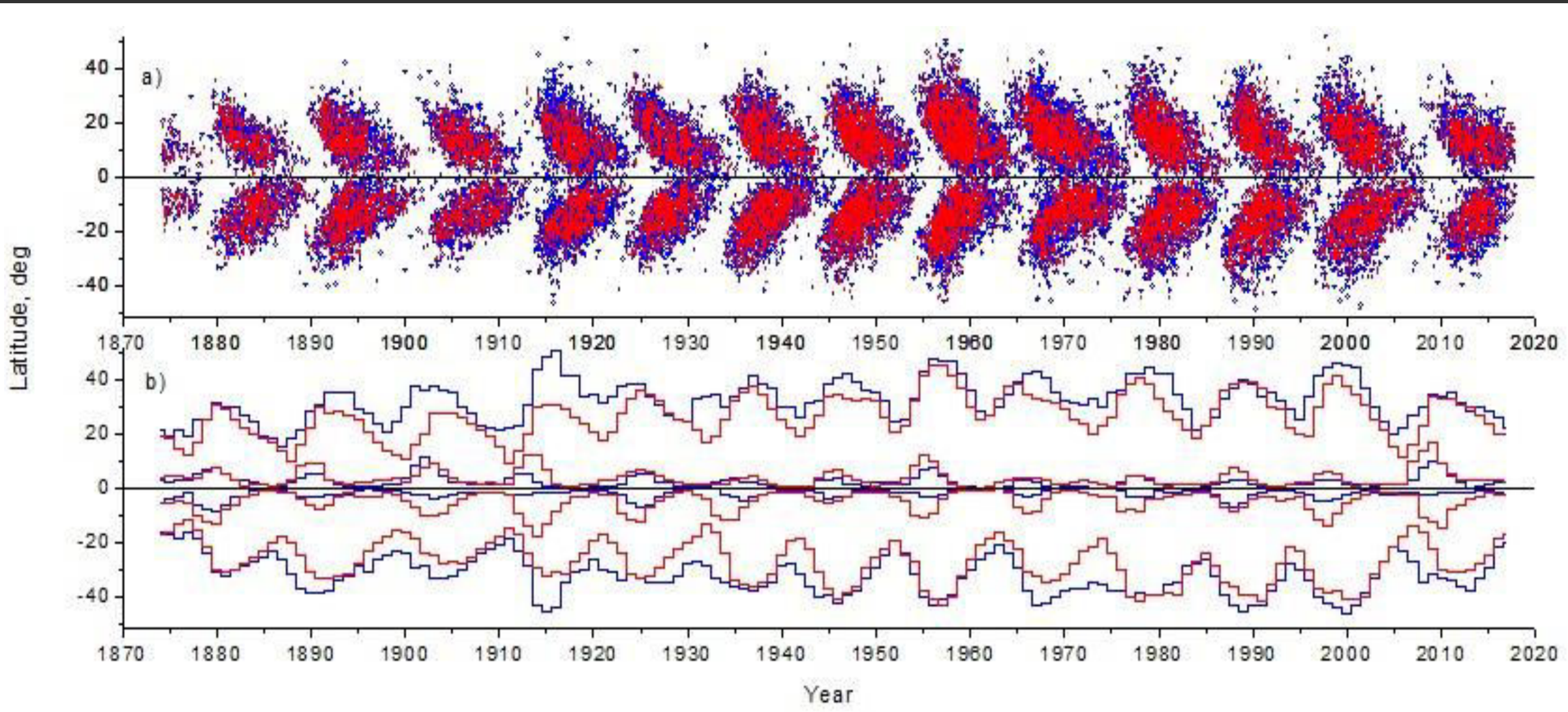


Fig. 7: a) Butterfly diagram for the two sunspot populations: SSG (blue dots) and LLG (red dots). b) Extreme year latitude for the two sunspot populations: SSG (blue line) and LLG (red line).

The latitudinal extent of the spotting area of small groups is greater than that of large groups in 97% of cases for the northern hemisphere, and in 96% for the southern hemisphere.

RELATIVE NUMBER OF LLG vs. LATITUDE

The relative number of LLG drastically changes with latitude:
at the latitudes 8-20^{o} almost half (45%) of the groups are large,
at the equator and high latitudes they are only ~ 25-30% from all groups.

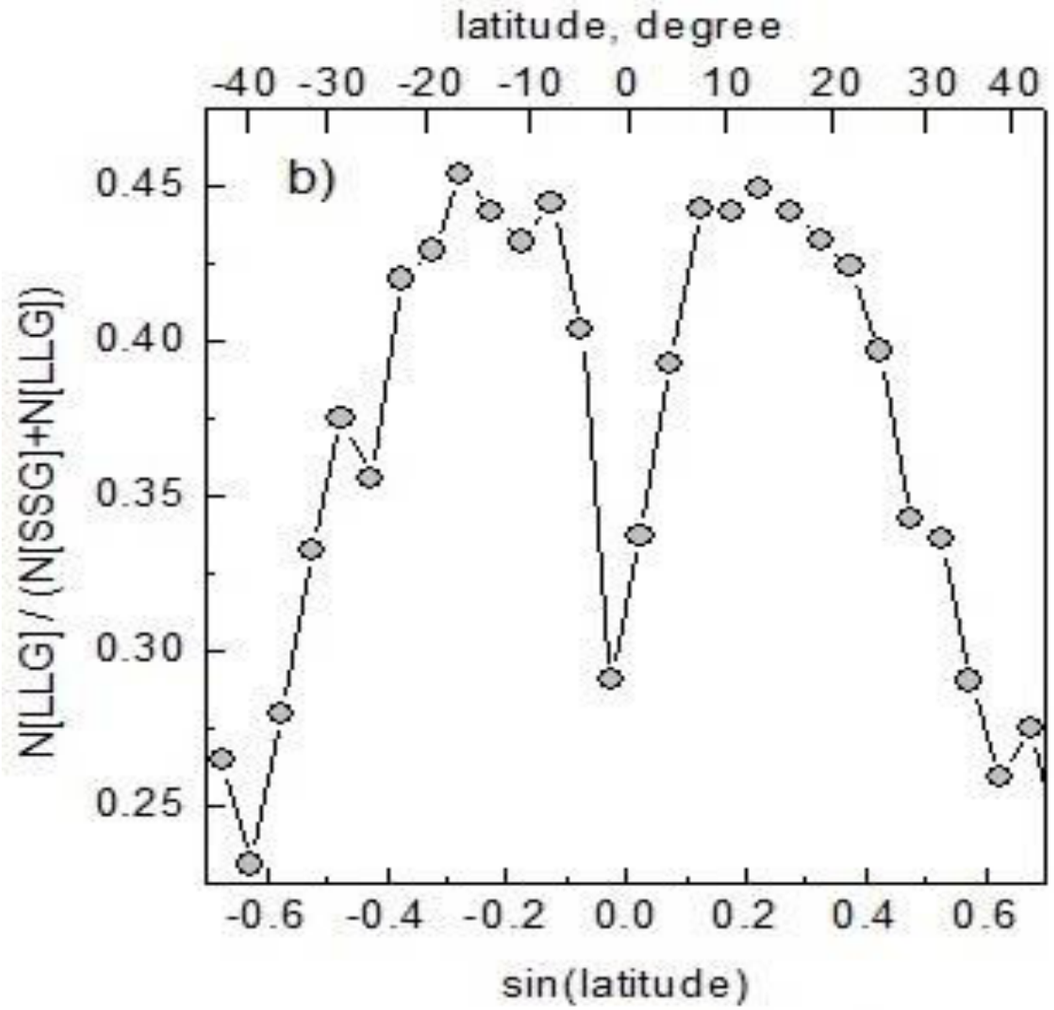


Fig.8: Relative number of groups from population LLG in dependence of heliographic latitude.

RESULTS

1. For the static index *g* for the SSG population Gnevyshev-Ohl rule in the MGO and DGO formulations has an inverse character, so that the odd cycle, being larger, correlates with the subsequent smaller even cycle forming a pair – a single whole 22-year cycle.
2. The relative number of LLG changes with latitude from 45% for the middle latitudes to 25-30% for the low and high latitudes.
3. Butterfly diagram for SSG shows wider spread than LLG.

CONCLUSIONS

1. The existence of the two sunspot group populations is confirmed. Populations differ by area, magnetic field strength, behavior in the solar cycle, rotation, latitude distribution, etc.
2. Since helioseismological data shows the existence of two zones of steep rotation gradient (deep tachocline and shallow leptocline), our data attests the presence of the spatially distributed dynamo, so that tachocline correspond to large population SSG and leptocline – to SSG.

Pulkovo Observatory

Thank you for your attention!