Oscillating relic magnetic field in the Sun: A new paradigm for space climate allowing multi-cycle forecasting

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K. Mursula: Hale cycle in solar hemispheric radio flux and sunspots: Evidence for a northward shifted relic field, Astron. Astrophys., 674, A182, 2023, https://doi.org/10.1051/0004-6361/202345999, arXiv: http://arxiv.org/abs/2305.01030

Context

In this talk I will put the following three (and some other) topics

- Systematic hemispheric asymmetry also in sunspots
- G-O rule and its break in SC24
- Gleissberg cycle and deVries/Suess cycle

into a common context using solar 10.7cm radio index.

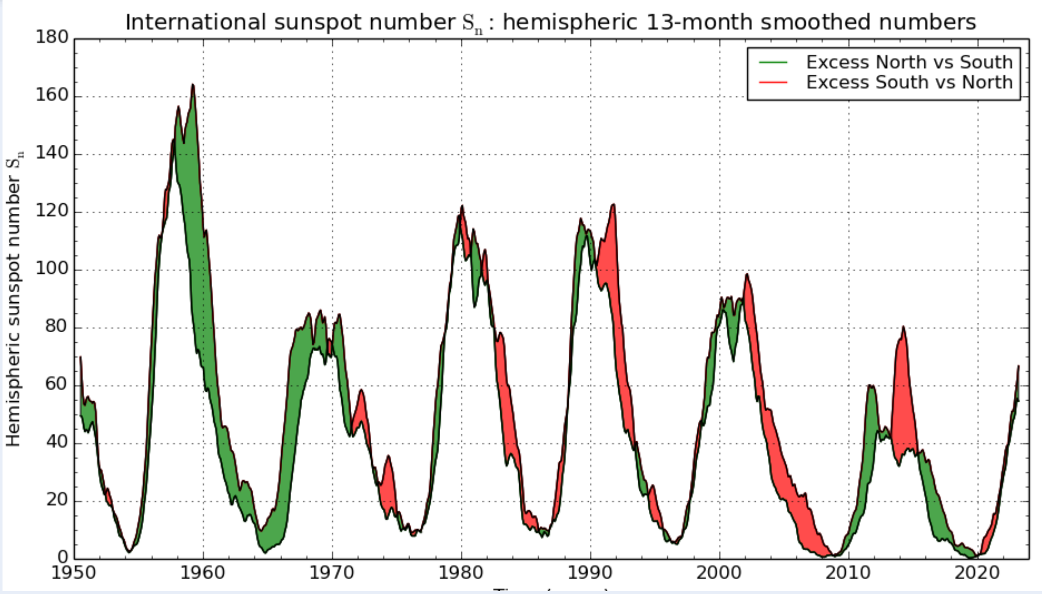
Hemispheric asymmetry

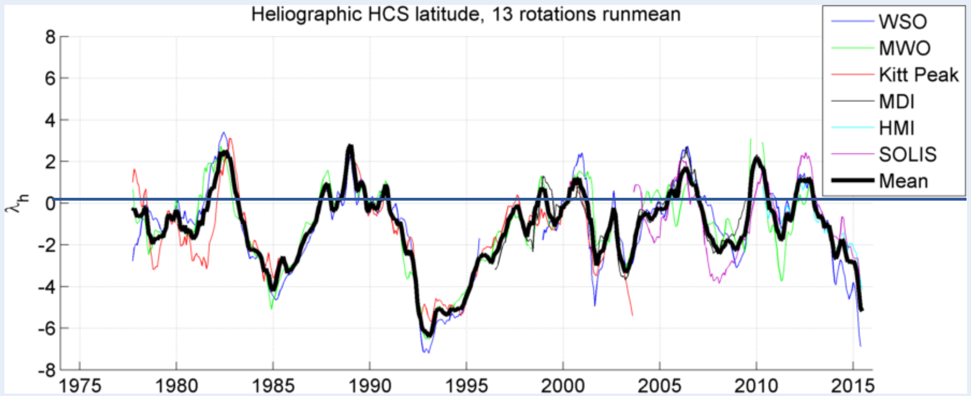
Northern and southern hemispheres are not tightly connected.

Instead, solar activity is generally hemispherically asymmetric.

However, so far, no systematic pattern is found for the hemispheric asymmetry of sunspots...

.. Unlike for the Heliospheric magnetic field and the Streamer belt, which have systematic long-term asymmetries.





Gnevyshev - Ohl rule

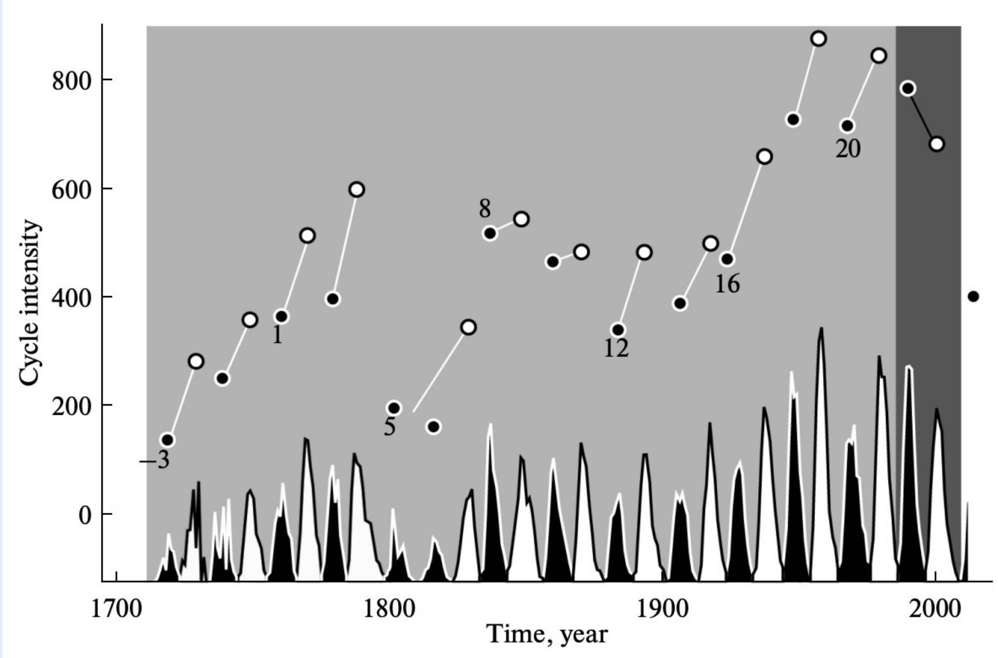
Gnevyshev – Ohl rule:
An odd solar cycle is higher and/or more intense than the previous even cycle.

The G-O rule is related to relic (fossil) magnetic fields and electric currents in the Sun.

Valid for the last 200 years.

Valid for the last 300 years if the exceptionally long SC4 includes a weak lost cycle.

But: G-O rule broke in SC24.



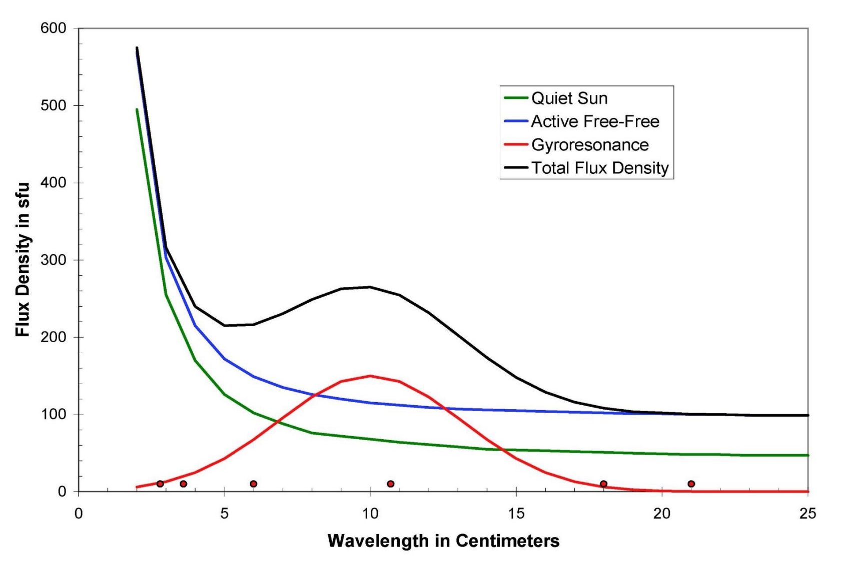
Solar 10.7cm radio emissions

Solar 10.7cm radio emission (beyond thermal) is **related to solar magnetic activity:**

- Strong magnetic fields in **sunspots** produce radio emissions mostly by gyroresonance.

- Most (>60%) 10.7cm emissions are produced by bremsstrahlung in decaying **active regions.**

These have less intense magnetic fields but their area greatly surpasses sunspots.



Integrated flux at 2800±100 MHz from the whole solar disk forms the **F10.7 index** of solar activity, which has been measured since 1947.

Benefits of F10.7 as a solar activity parameter

1. Radio flux is a **physical** parameter, while sunspot number is an ad hoc parameter.

    1a. There is no lower limit to radio emissions, contrary to sunspot numbers that are bound above zero.

    1b. Radio flux measurements can be calibrated to an absolute level. This is in difference to sunspot numbers, where the weighting of sunspot groups with respect to sunspots is somewhat ad hoc.

    1c. Radio intensity is a linear parameter, while sunspot numbers have a step from zero (no sunspots) to 11 (one sunspot forming its own group), which causes a nonlinearity in the F10.7-sunspot relation.

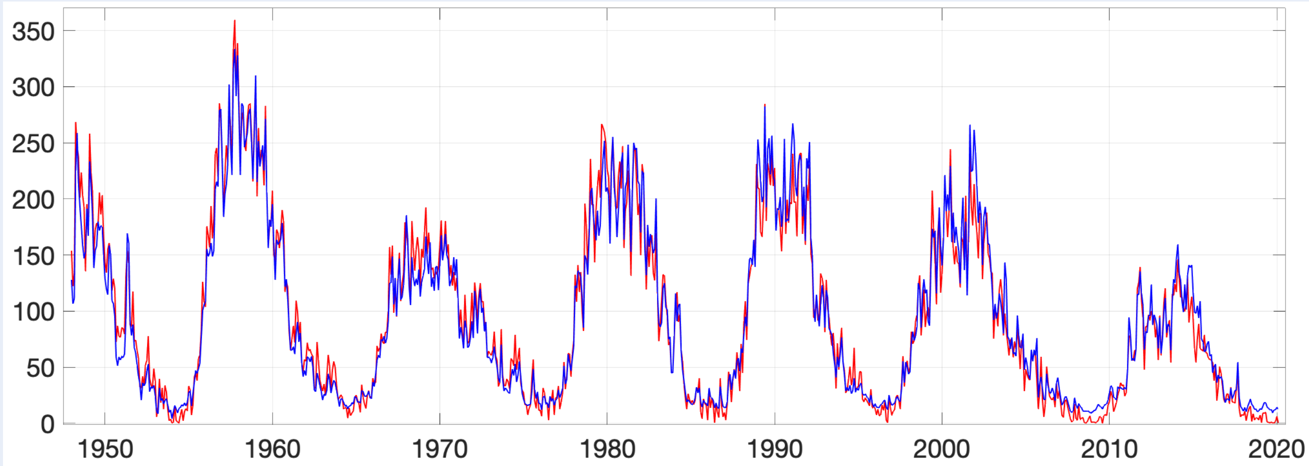
2. 10.7cm radio waves penetrate the Earth's atmosphere with **minor damping**.
This means that F10.7 index can be measured at all weather conditions which increases **homogeneity**.
This avoids problems related to multiple observers, as necessary for sunspot observations.

3. Because radio quanta are soft, radio telescopes experience **no degradation**.
A radio telescope can operate several decades without much degradation, which enhances homogeneity.

Conclusion: Radio flux is a more reliable long-term measure of solar activity than sunspot numbers

Deficiency in F10.7 radio flux

F10.7 index correlates very well with sunspot numbers, especially at monthly resolution and beyond.



There is one major deficiency related to the 10.7cm radio flux:
Full-disk observations have no explicit info on spatial distribution !

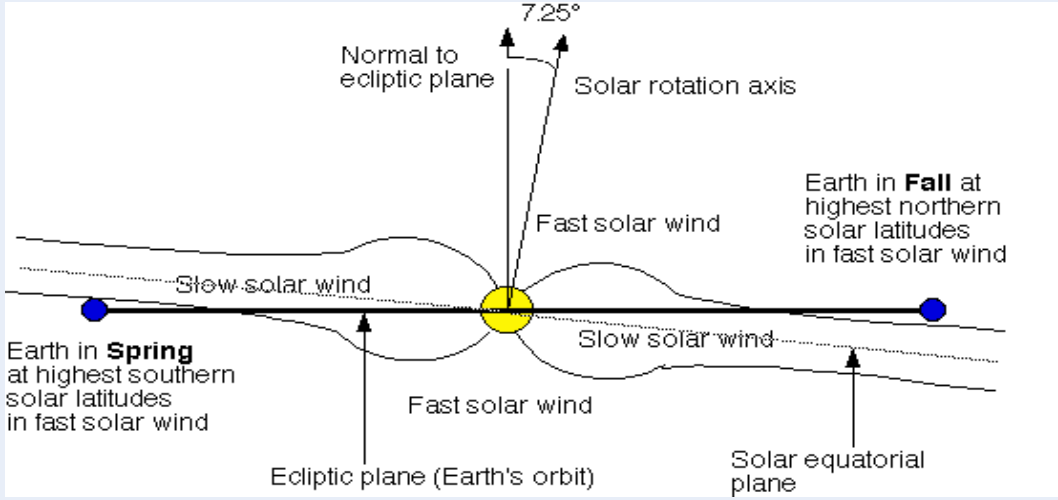
HERE: There is implicit hemispheric information!

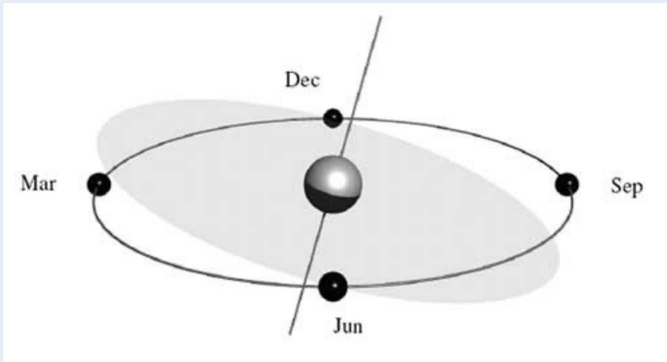
Radio flux at different heliolatitudes

HERE: Novel method to use the Earth´s annually varying heliolatitudinal vantage point to prefer the flux from the Northern hemisphere in Fall and from the South in Spring.

Solar rotation axis is tilted by 7.25° with respect to the ecliptic. Solar northern (southern) hemisphere is better visible in Fall (Spring) around the high heliolatitude times.

Earth has its highest northern (southern) heliolatitude on September 7 (March 6).





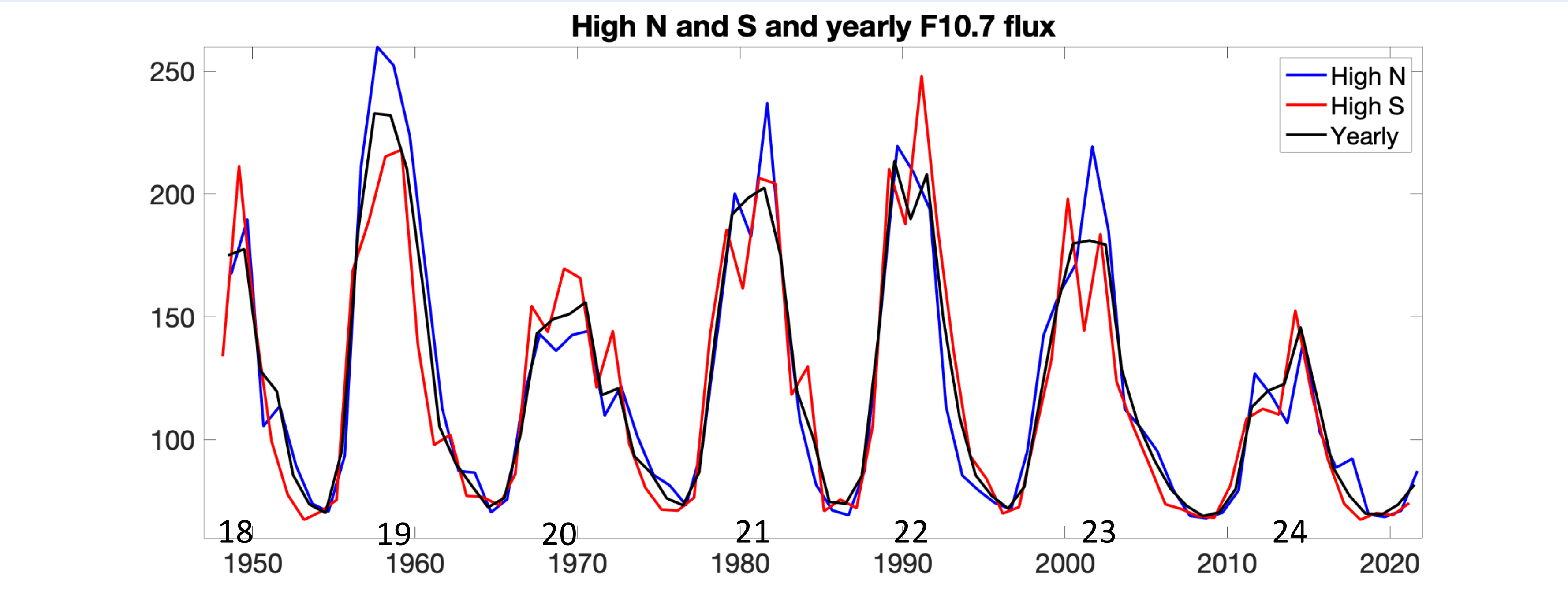
High-latitude F10.7 radio flux

F10.7 index calculated above 7 degrees of northern and southern helio-latitude.

We call them high-latitude fluxes.

Large differences between hemispheres. **Maxima alternate from N in odd cycles to S in even cycles.**

By random fluctuation, such a systematic variation occurs at the probability of less than 2%.



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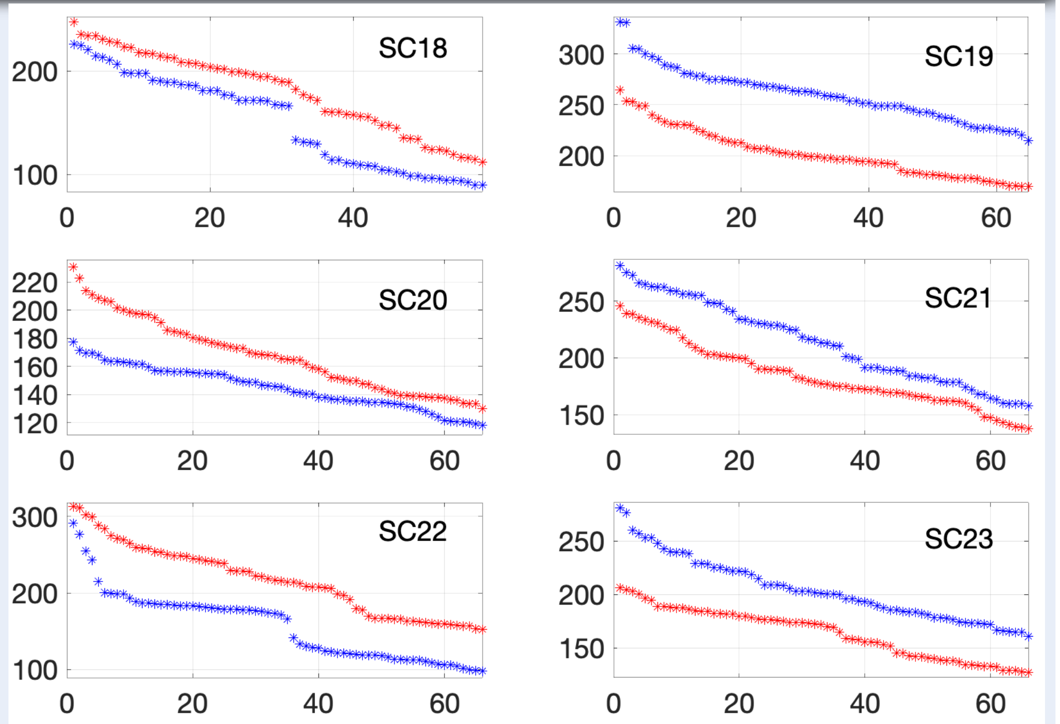
Rank order of high-latitude flux values

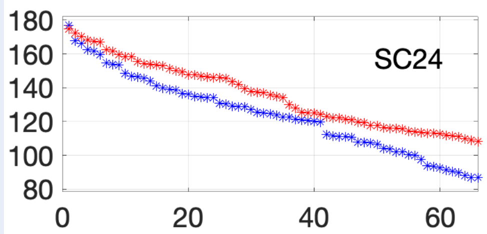
In even cycles (left column), southern (red) high-latitude daily flux values are systematically above the northern (blue) fluxes in descending rank order.

Opposite order is true for odd cycles (right column).

Two-sided Wilcoxon rank sum test with 99% confidence limit shows that, for **each cycle, the N and S populations are different**, with p-values given in Table.

This shows that differences between the fluxes of the dominant and recessive hemispheres and, thereby, the corresponding **hemispheric asymmetries, are not due to a small number of extreme events, like large flares,** but due to a **systematic difference** between the flux distributions around cycle maxima.





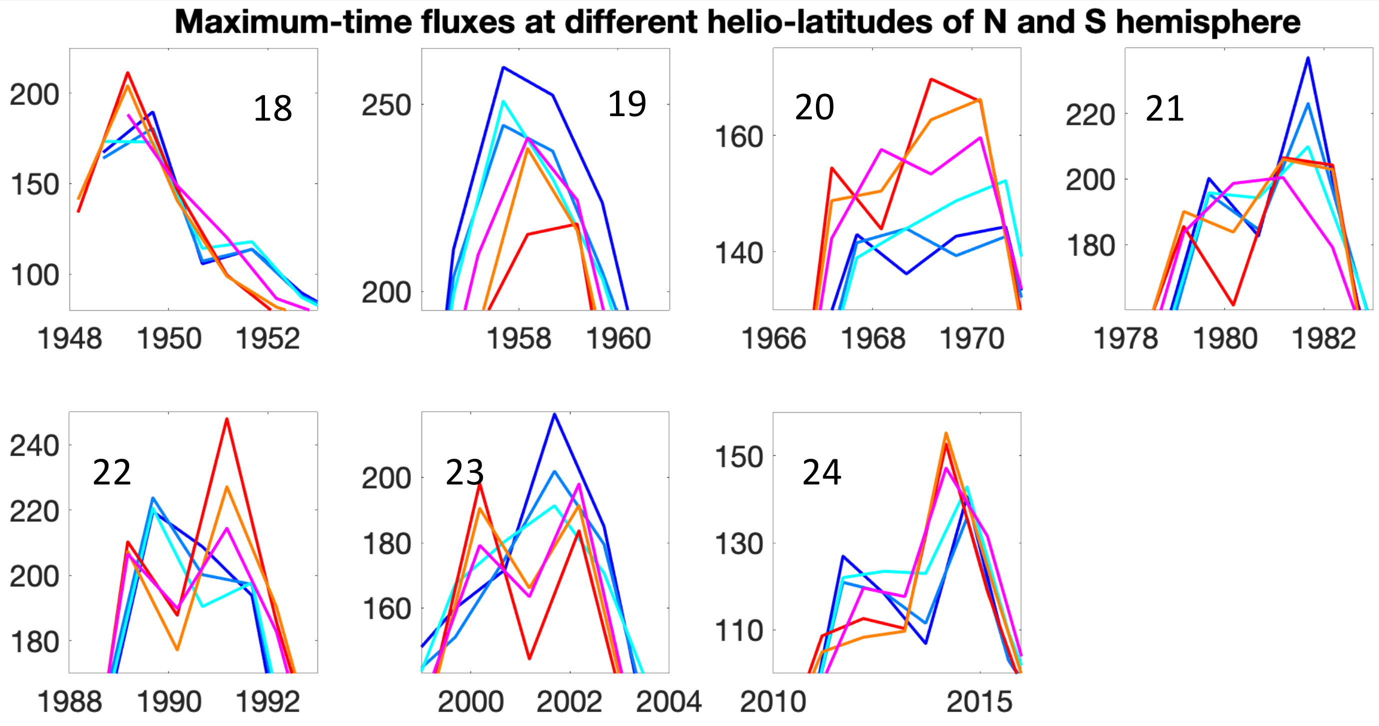
Cycle	Years	p-value
SC18	1949–1950	$1.4 * 10^{-4}$
SC19	1957–1958	$2.9 * 10^{-17}$
SC20	1969–1970	$3.5 * 10^{-8}$
SC21	1980–1981	$1.2 * 10^{-4}$
SC22	1991–1992	$3.8 * 10^{-10}$
SC23	2001–2002	$6.7 * 10^{-11}$
SC24	2014–2015	$8.2 * 10^{-4}$

Radio fluxes at cycle maxima

During six cycle maxima (cycles 18-23), the largest flux is the high-latitude flux of the dominant hemisphere.
During cycle 24, the second high-latitude flux is slightly higher than the high-latitude flux.

For each cycle, the high-latitude and second high-latitude fluxes of the dominant hemisphere are larger than all the three simultaneous (half a year before or after) fluxes of the opposite (recessive) hemisphere.

In four cycles the high-latitude flux of the recessive hemisphere is smaller that the two other fluxes of the recessive hemisphere (and all three fluxes of the dominant hemisphere).



CONCLUSION:

When the high-latitude fluxes of the dominant hemisphere are above the average, the (nearly) simultaneous high-latitude fluxes of the opposite hemisphere are below the average.

Relative asymmetry of high-latitude fluxes

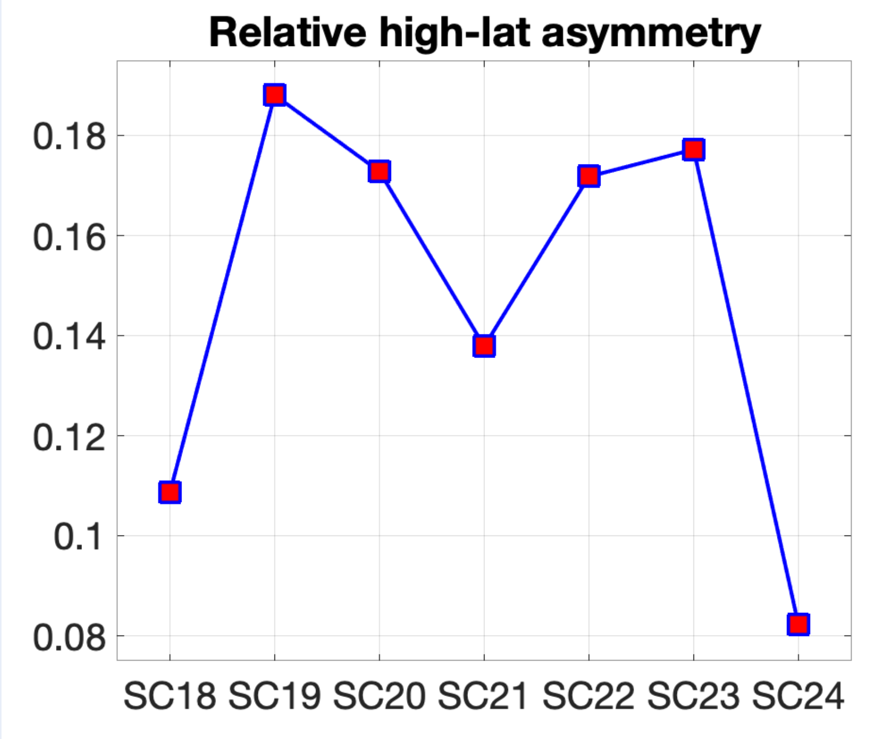
Relative asymmetry (asymmetry divided by mean of the two high-latitude fluxes) is about 15±4% for all cycles and about 17±1% for high cycles 19-23.

This sets the scale for a **typical amount of relative hemispheric asymmetry.**

The rough constancy of the relative asymmetry of cycles 19-23 indicates that **asymmetry and cycle height roughly correlate** for these cycles.

Cycle 19 has a slightly overproportional asymmetry.

Cycle 24 asymmetry remains far smaller (by 5 stdev) than cycles 19-23.

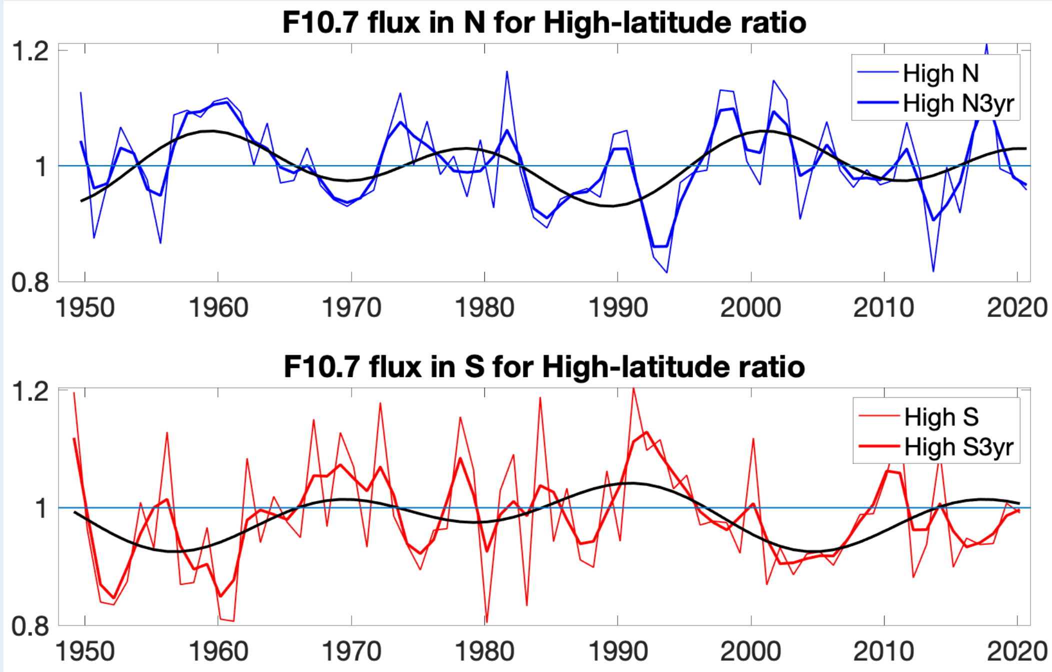


Normalised fluxes over full cycles

In order to remove the solar cycle variation, we **normalise the fluxes** by 365-day (not calendar year) means around the respective highest latitude time (March 6 and Sep 7).

Both hemisphere depict a long-term oscillation close to the Hale cycle (20.7 years in the north and 22.8 years in the south).
Corresponding amplitudes are 0.05 and 0.04.

A two-component Fourier fit gives a slightly better fit. Hale cycle is modulated by a longer variation.



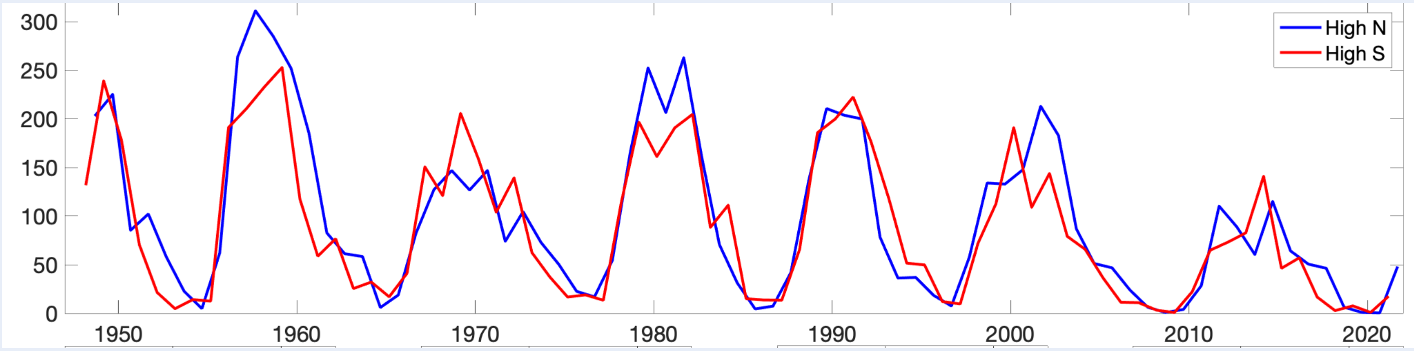
Note the close **anti-phasing of North and South**.

Negative correlation between the northern and southern fluxes ($r=-0.52$, $p<4*10^{-6}$).

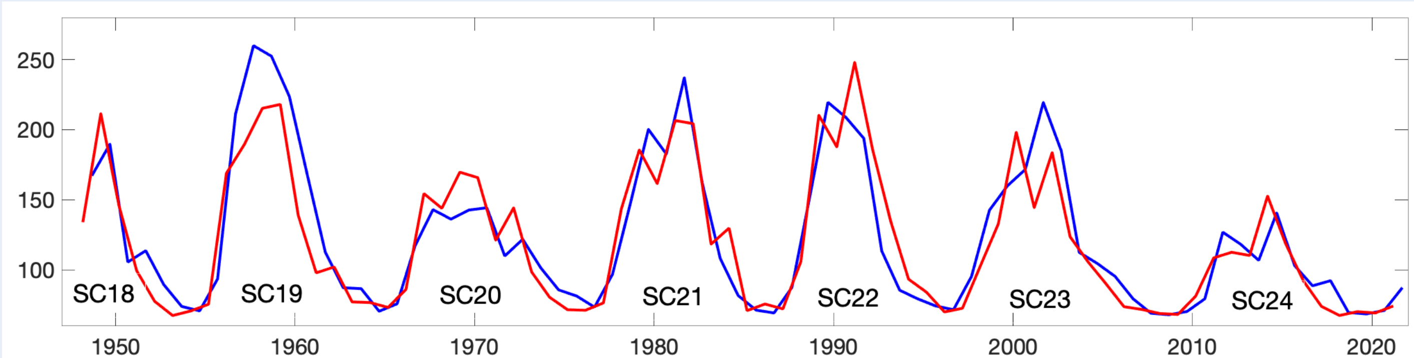
High-latitude radio fluxes and sunspot numbers

High heliolatitude **sunspot numbers depict the same pattern of alternating** hemispheric dominance.
This pattern is in overall **magnetic flux emergence**, and it is related to the **Hale cycle**.
Earlier studies of hemispheric asymmetry have not found this systematic pattern

Sunspot numbers



Radio flux



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Dynamo and relic fields

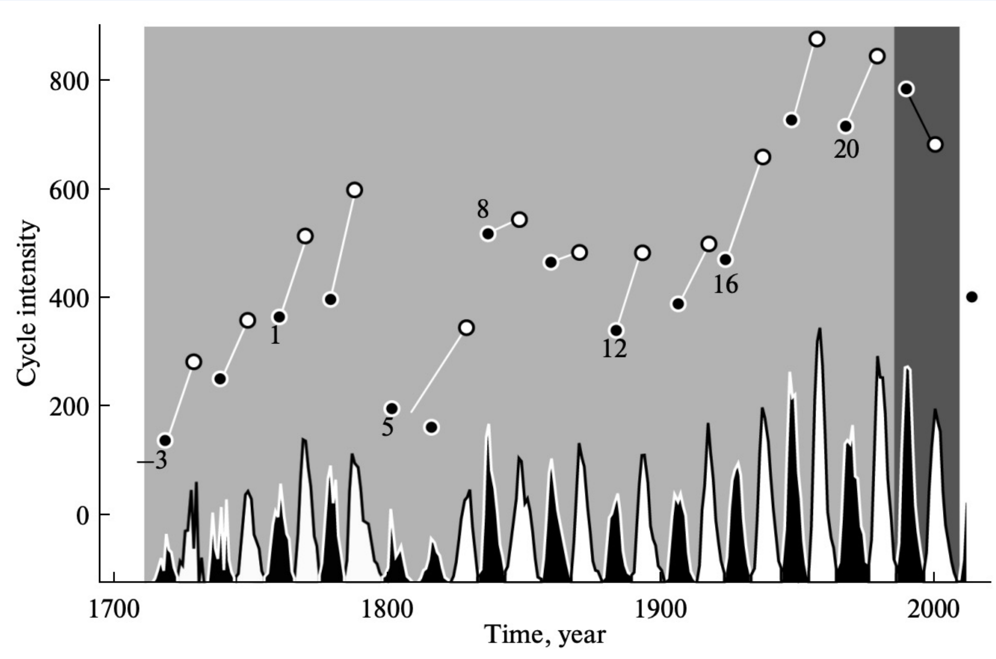
Relic field can persist in the Sun

Relic electric current and magnetic field CAN PERSIST in the Sun from the times of solar system formation because of a very long diffusion time (plasma is a perfect conductor; Cowling, 1945).

Relic magnetic field was suggested to explain the long-held **Gnevyshev – Ohl rule:**
An odd solar cycle is more intense than the previous even cycle.

Odd cycles are **higher** =>

- Relic magnetic field is **northward oriented**
- Relic electric currents flow in the direction of solar rotation.

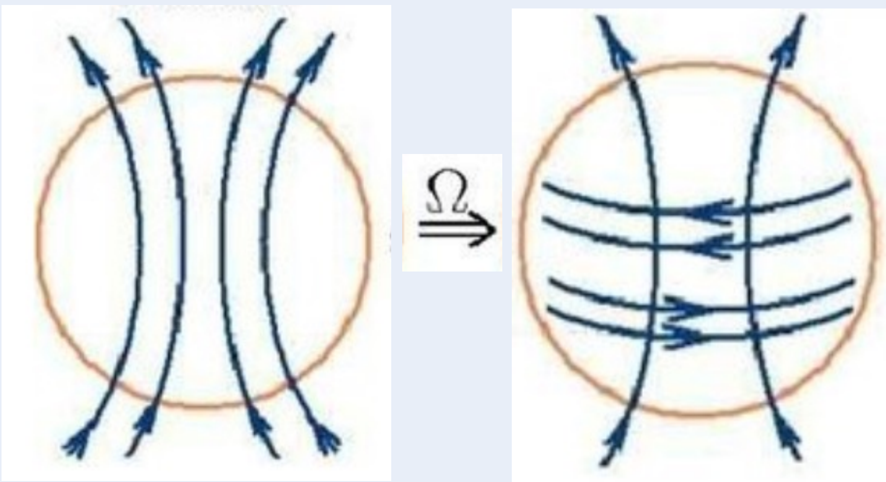


Dynamo + relic fields during positive minimum

Schematic of how a northward directed relic affects the dynamo fields during a positive minimum.

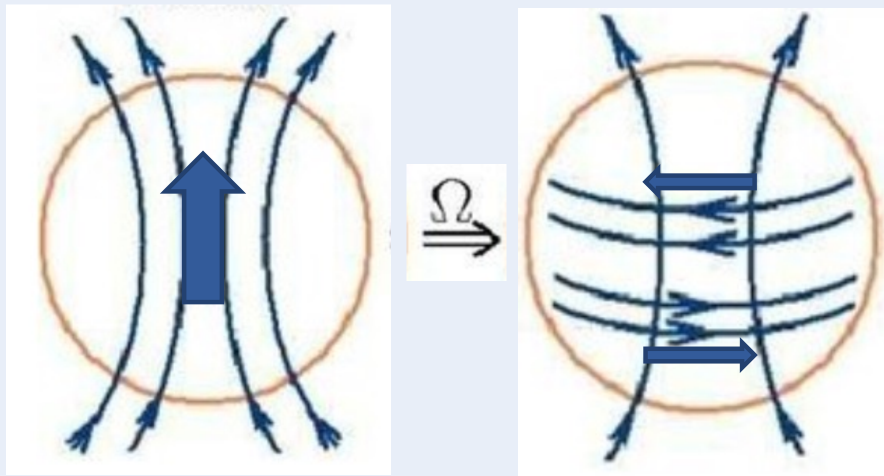
Regular dynamo mechanism

positive minimum — **odd** cycle maximum



Relic + dynamo:

Relic enhances equally both hemispheres

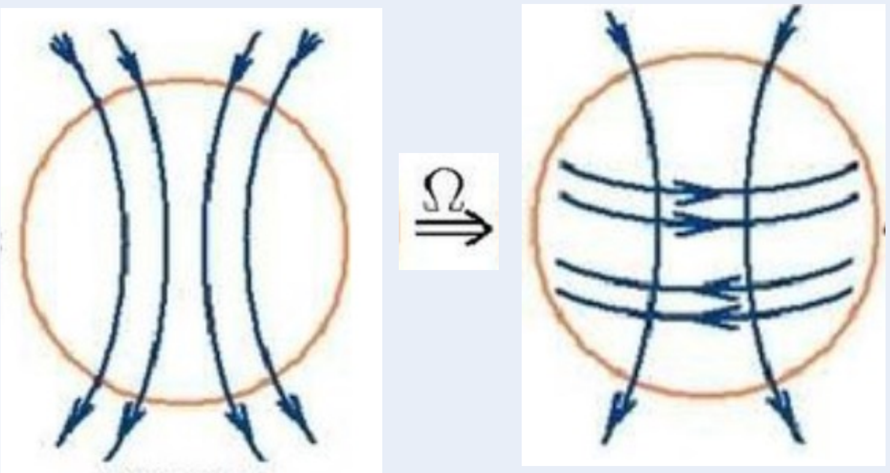


Dynamo + relic fields during negative minimum

Schematic of how a northward directed relic affects the dynamo fields during a negative minimum.

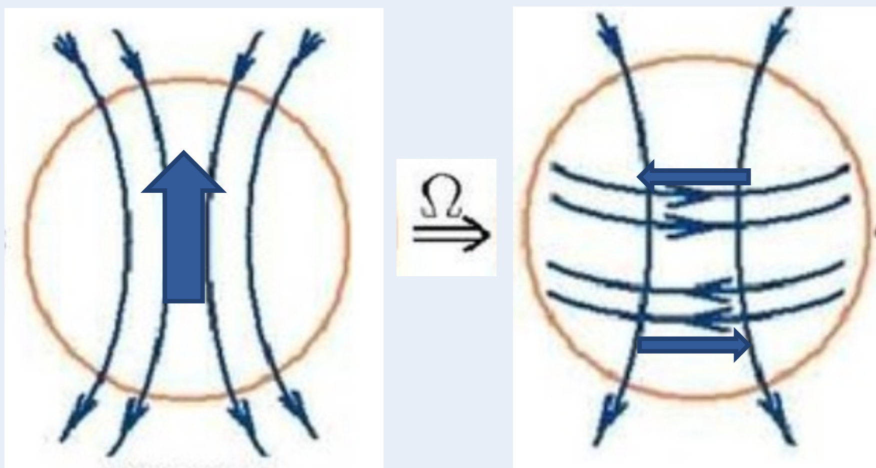
Regular dynamo mechanism

negative minimum **even** cycle maximum



Relic + dynamo:

Relic reduces equally both hemispheres



However..

So: Relic field produces a difference between odd and even cycles.

However, a relic field located symmetrically around solar equator makes no hemispheric asymmetry.

So, what about the systematic alternation of hemispheric dominance observed here ?

¿¿ Relic cannot explain observations ??

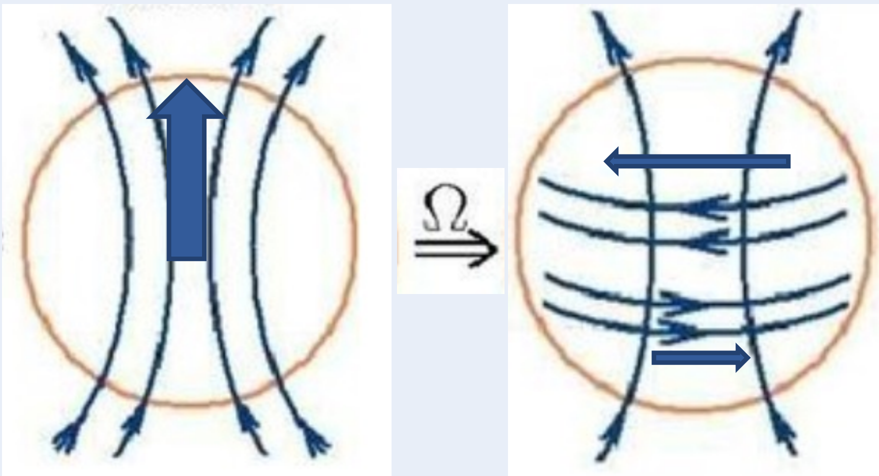
SOLUTION

The mean location (distribution) of the relic field is (at most times)
shifted away from the equator !

Shifted relic field during positive minimum

Northward shifted relic during positive minimum **enhances more** the northern hemisphere than the southern.

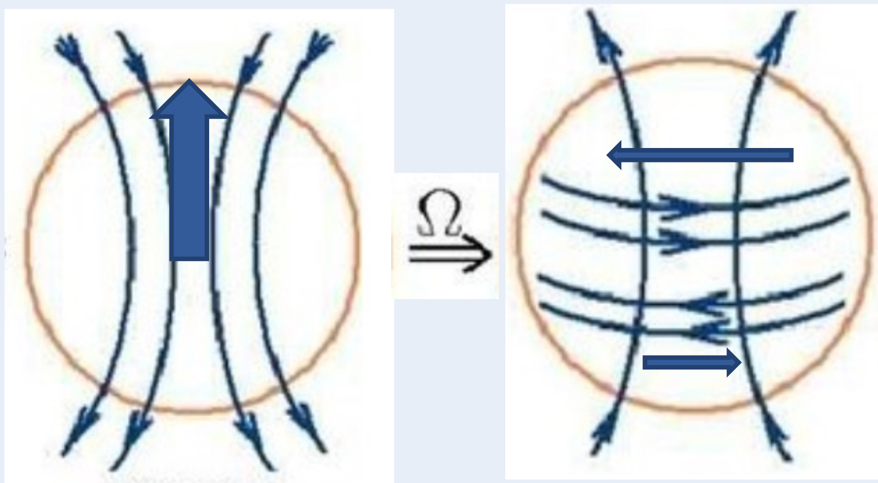
Produces the observed hemispheric asymmetry: **North dominates during odd cycles.**



Shifted relic field during negative minimum

Northward shifted (and northward directed) relic during negative minimum **reduces** more the northern hemisphere than the southern.

Produces the observed hemispheric asymmetry: **South dominates during even cycles.**



Relic shift oscillates: Gleissberg and Suess/deVries cycles

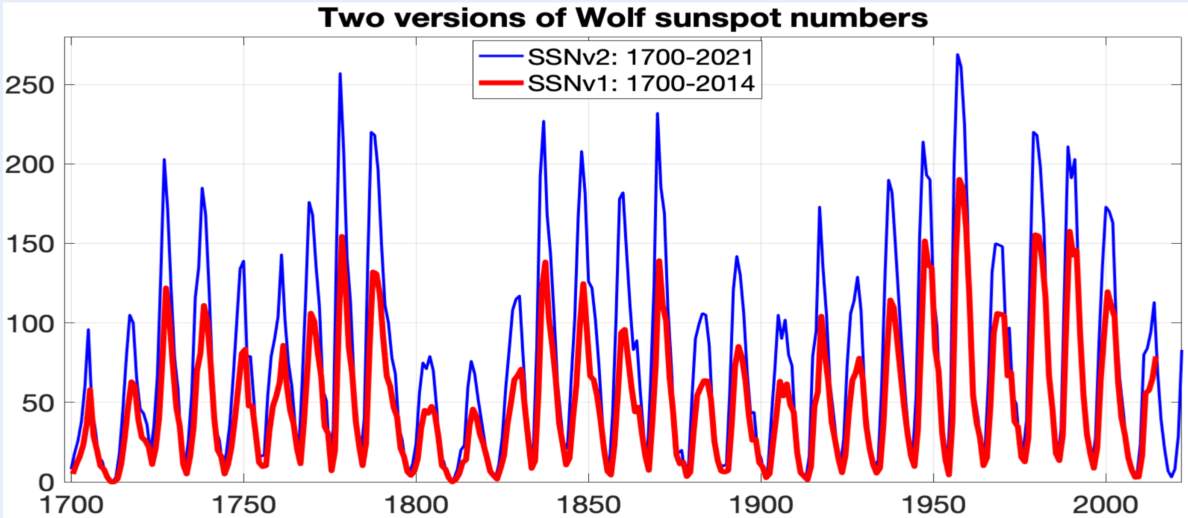
We found that hemispheric asymmetry correlates with cycle height.

Cycle 19: Relic at its northernmost position
- maximum northern dominance
- maximum cycle height

Cycle 24: Relic around the equator
- Very weak northern dominance
- low cycle height

Time from SC19 to SC24:

Relic shift makes **one quarter** of the full relic oscillation cycle.



Gleissberg cycle explained: Relic makes one excursion away from equator and back.

210-year Suess/deVries cycle explained: Relic makes a full oscillation, once north and once south.

Forecast of cycle heights and asymmetries in the 21st century

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SC25 is a crucial cycle for our understanding !

PREDICTION (in Fall 2022): SC25 will be somewhat larger than SC24 (due to G-O rule), but not very large because the relic shift is still rather small !

Status now: SC25 maximum (SSN≥121) is already higher than SC24 (SSN=116). **G-O rule is valid !**

SIDC/SILSO for SC25 maximum vary still dramatically from 121 to 180.

Not sure yet whether "somewat" or more !

Will SC25 be dominated by north or south?

In this model, SC25 should be weakly **south-dominated**. Relic is shifting to south.

Impossible to check since SILSO does not distribute hemi SSN since recently!?

Forecast for the rest of 21st century

SC26 will still remain rather small (maybe even smaller than SC25) because of G-O disfavor

SC27 will be much higher, probably above 200, because of large shift and G-O favor

SC28 will be rather high, but not the highest in century (maybe even lower than SC27)

SC29 will be the **21st century-high cycle** (corresponding to SC19 in 20th century).

Increasing **southern dominance** in the coming cycles, especially SC27 and SC29.

Cycles after SC29 will again start having lower heights and smaller asymmetries.

These properties will also have corresponding important affects to space weather, space climate and even climate via changes in irradiance, streamer location etc.

New paradigm for Space Climate: Oscillating relic field

Oscillating relic field forms **a new paradigm for Space Climate**, which:

- gives the first scientific explanation for the 210-year Suess/deVries cycle in terms of a full relic shift oscillation cycle (north and south from the equator).

- connects the Gleissberg cycle with the Suess/deVries cycle as one half (north or south) of the relic shift cycle.

- explains solar hemispheric asymmetries and their phase alternation

    - explains the streamer belt asymmetry and its phase alternation.

- connects high (low) solar activity with large (small) asymmetry and relic shift.

    - explains why the strongest Northern dominance was found in SC19, the highest cycle.
    - explains the small asymmetry in SC24 (Note: No large asymmetry during MM !)

- explains G-O rule and why it broke during SC23: It holds best when relic shift stays fairly constant.

Thanks

That`s it, folks !

All this and more in:

K. Mursula: Hale cycle in solar hemispheric radio flux and sunspots: Evidence for a northward shifted relic field,
Astron. Astrophys., 674, A182, 2023,
https://doi.org/10.1051/0004-6361/202345999,
arXiv: http://arxiv.org/abs/2305.01030