North–South Asymmetry in Rieger-type Periodicity during Solar Cycles 19–23

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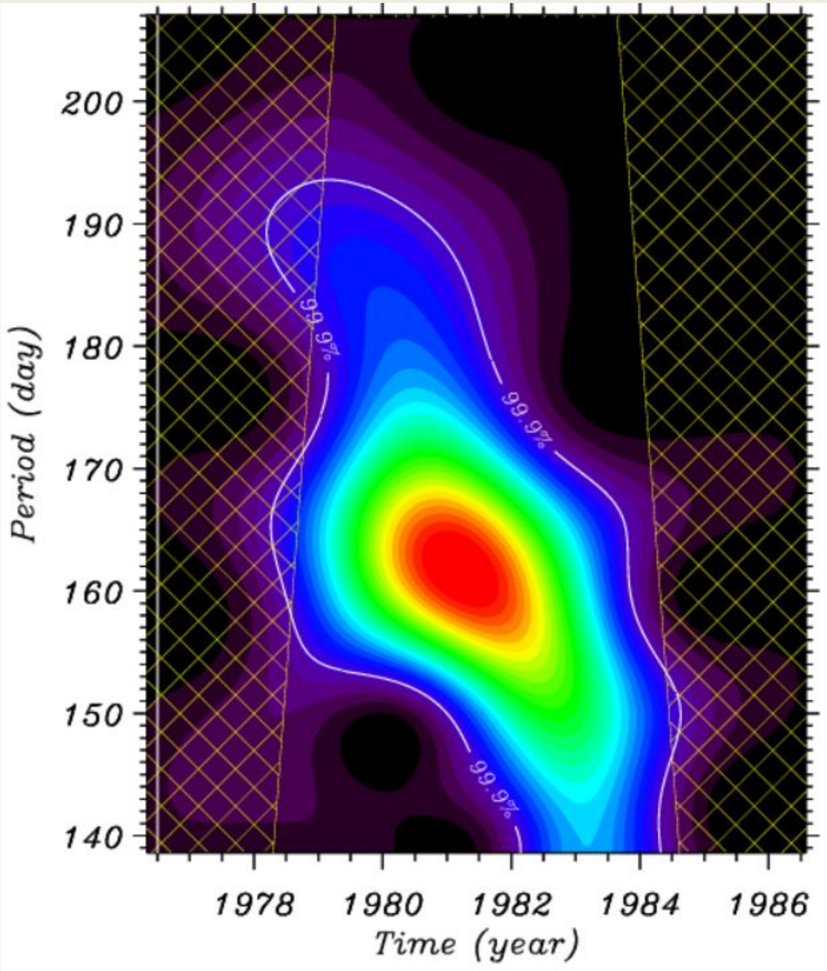
September 25, Tbilisi

Rieger-type periodicity

- The periodicity of 154 days was first found by Rieger et al. (1984) in the gamma-ray flares observed by the Solar Maximum Mission (SMM) near the maximum of solar cycle 21.



- ➢ Wavelet analysis of GRO daily sunspot area data for cycle 21, during which the Rieger-type periodicity was discovered.

(Dennis1985; Bai and Sturrock 1987; Lean and Brueckner 1989; Lean 1990; Oliver et al. 1998; Ballester et al. 1999;, Carbonell and Ballester 1990, 1992, Ballester et al. 2002, Krivova & Solanki 2002; Zaqarashvili et al. 2010)

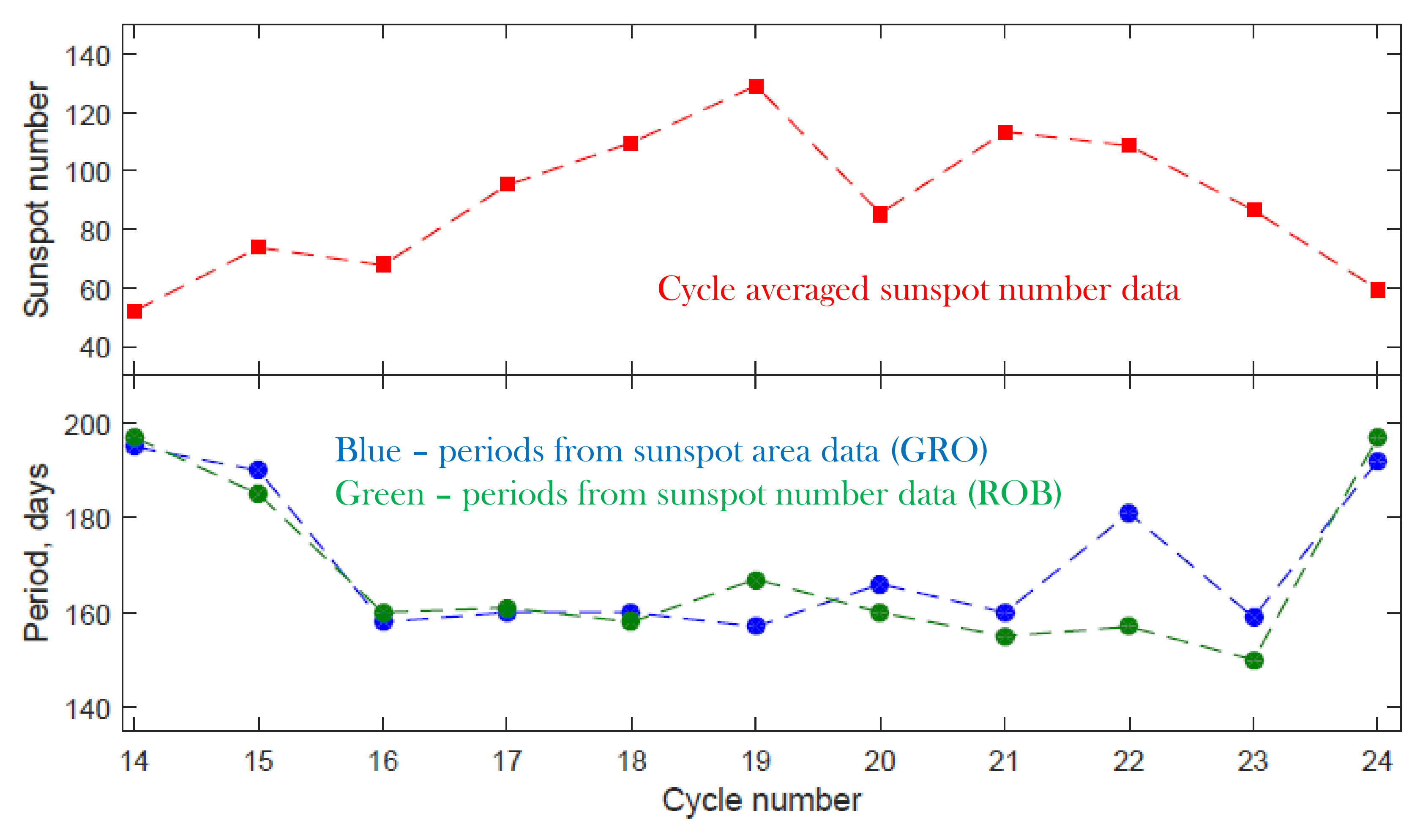
Physical mechanism of Rieger –type periodicity

- Rieger periodicity in solar activity can be explained by equatorially trapped hydrodynamic (HD) Rossby waves (Lou 2000)

But the periodicity is usually observed in activity indices, therefore the magnetic field should be clearly involved.

- Zaqarashvili et al. (2010) showed that the instability of magnetic Rossby wave due to the differential rotation and toroidal magnetic field in the dynamo layer may set up oscillations in magnetic field with 155-160 days, which lead to the quasi-periodic emergence of magnetic flux towards the surface.

The observed Rieger periods display a long-term evolution: they correlate with the solar cycle strength: stronger cycles show shorter periods.



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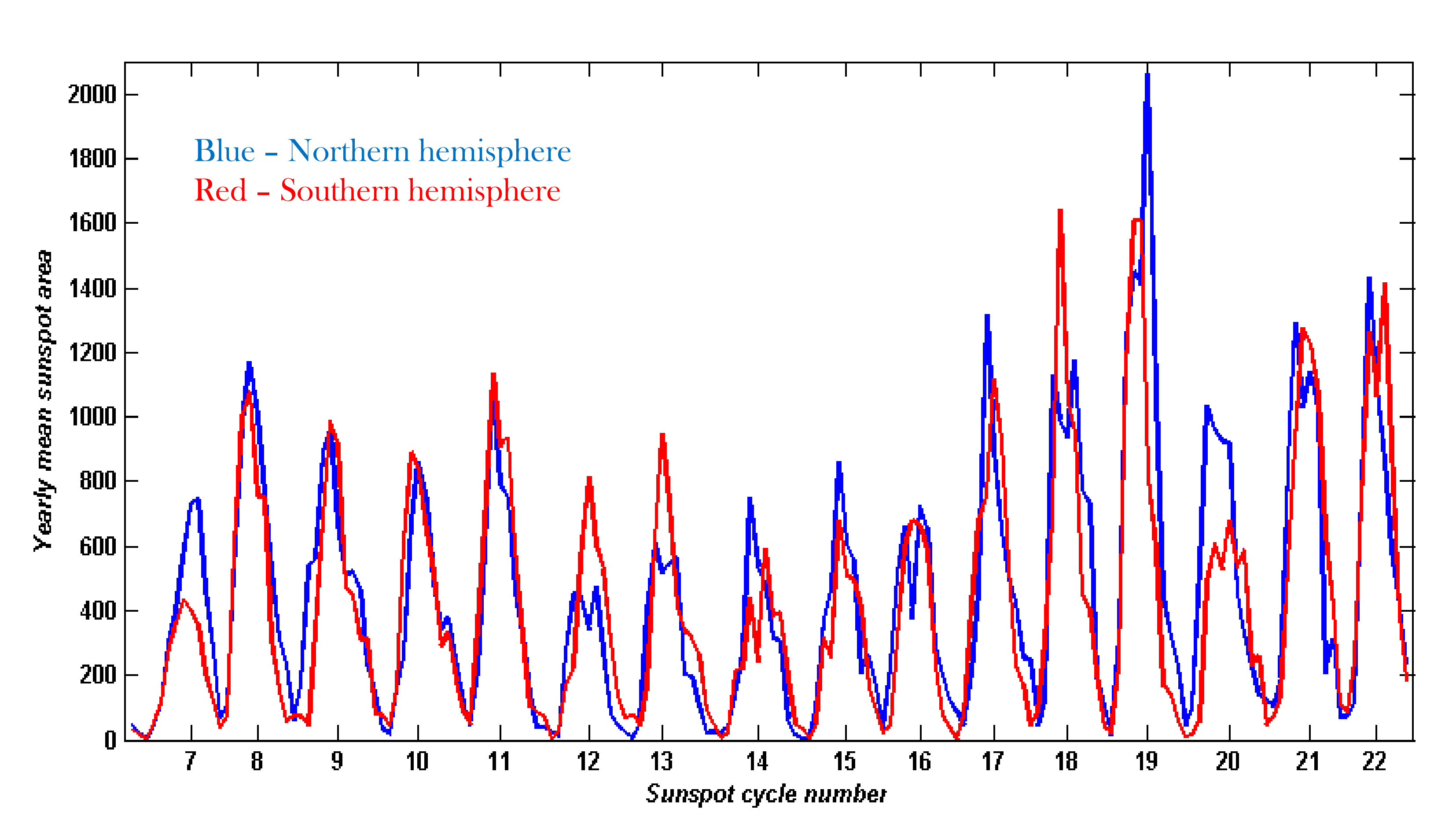
North-South asymmetry

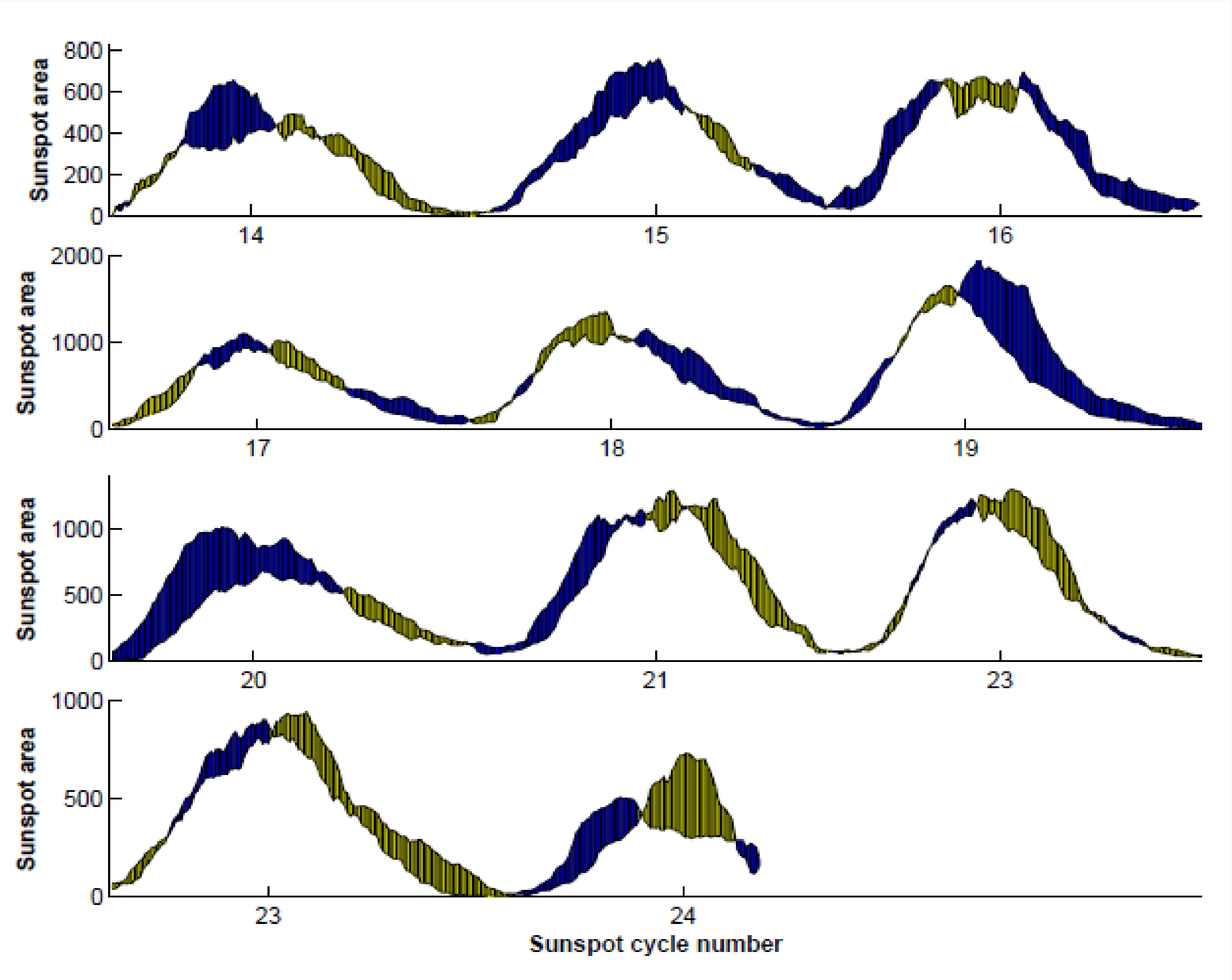
- ➢ The strength of the cycle is different in northern and southern hemispheres
- ➢ Rieger-type periodicity depends on the activity strength
- ➢ One might expect to find **different value of Rieger periodicity** in northern and southern hemisphere



(Spörer 1894; Maunder 1904; Carbonell et al. 1993; Oliver & Ballester 1994; Temmer et al. 2002, 2006; Ballester et al. 2005; McIntosh et al. 2013, 2014, 2015)

Summary of used solar observational data sources

- Greenwich Royal Observatory (GRO) daily sunspot area (full Sun, northern and southern hemispheres)
  - Available in 1874-2016
- KSO/SPO joint hemispheric sunspot number catalogue (Temmer et al. 2006)
  - Available in 1945-2004
- Mount Wilson total magnetic flux (MWTF) data
  - Available in 1966-2002



Greenwich Royal Observatory monthly averaged hemispheric sunspot area data for cycles 14-24. Blue color denotes excess of the northern hemisphere, and yellow shades correspond to the excess of the southern hemisphere.

Statistical significance of the North-South asymmetry (SSNSA)

- The North-South asymmetry is widely studied in the different solar indices, however only a few authors have estimated the SSNSA (Carbonell et al. 2007, Zhang & Feng 2015)

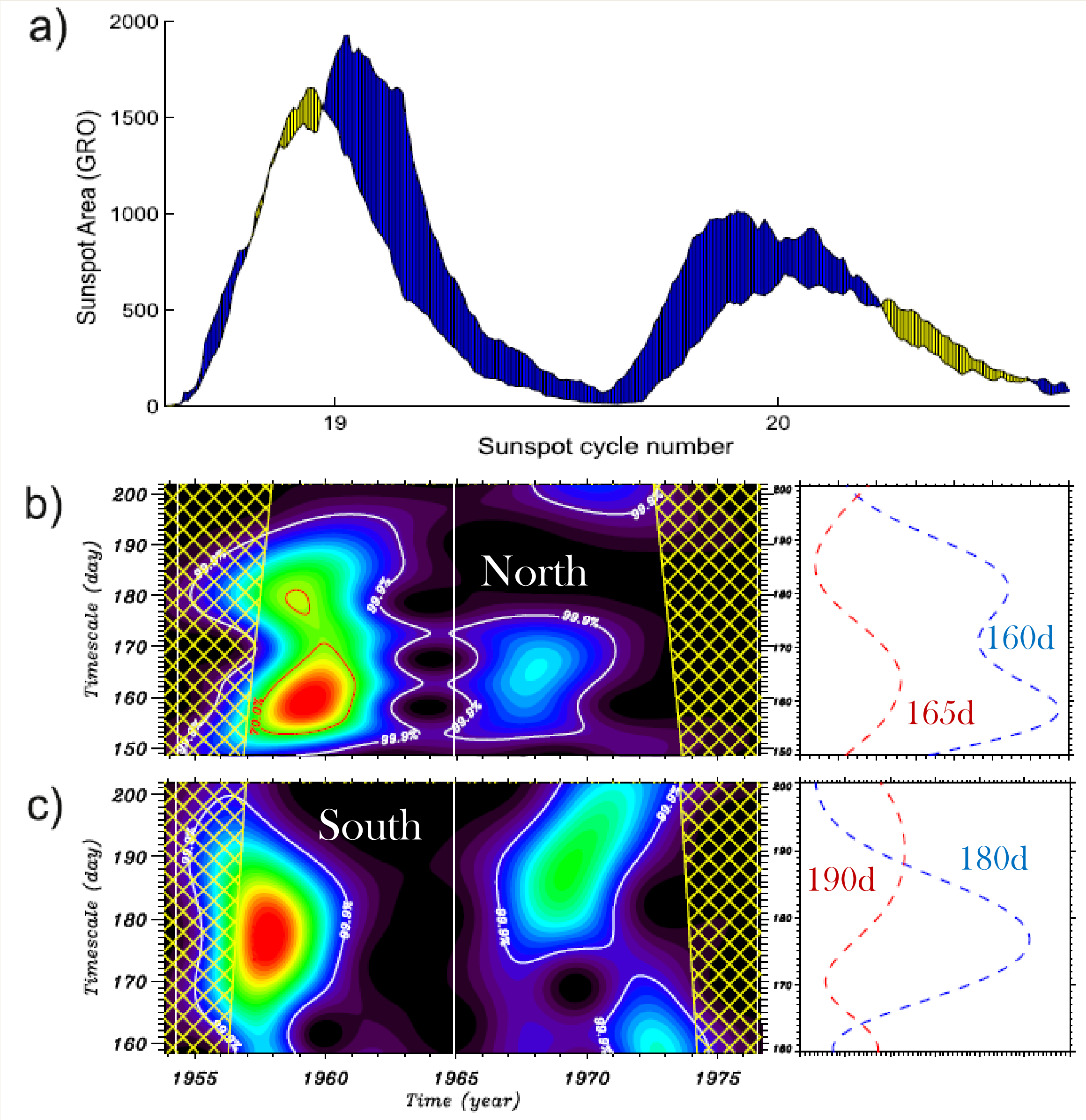
$$P_k = \frac{n!}{k!\,(n-k)!} p^k q^{n-k}$$

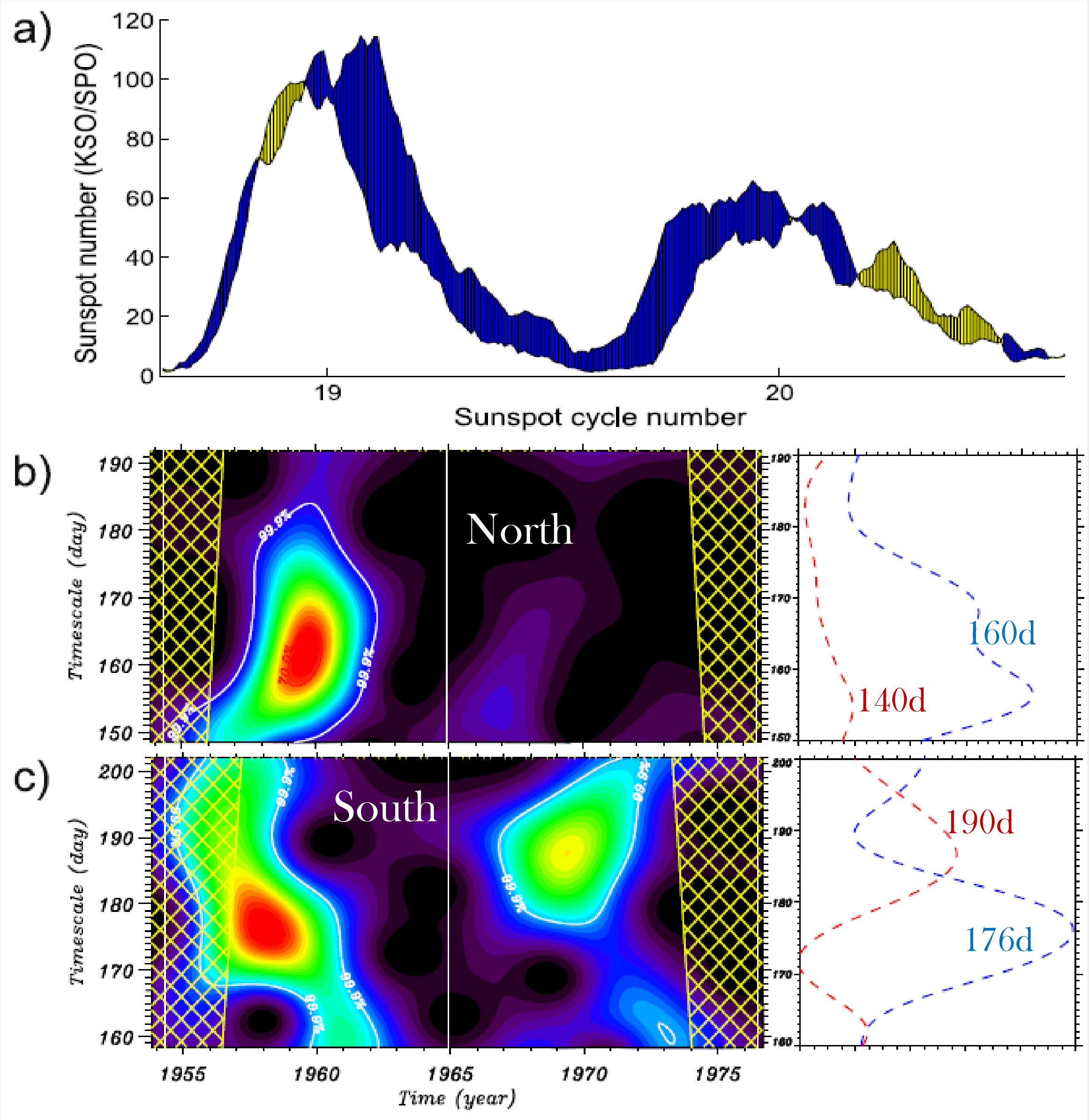
When P < 0.3%, we have highly significant result
When 0.3% < P < 5%, we have a statistically significant result
When 5% < P < 10%, we have marginally significant result
When P > 10%, the result is statistically insignificant

Table 1
Estimated Statistical Significance of North–South Asymmetry during Cycles 19–23

SSNSA%	19	20	21	22	23
$P < 0.3\%$	86%	86%	85%	84.5%	80%
$0.3\% < P < 5\%$	6%	6%	5.7%	5%	5.4%
$5\% < P < 10\%$	0.6%	0.6%	0.4%	0.2%	0.2%
$P > 10\%$	7.4%	7.5%	8.7%	10.5%	14.6%

North- Dominated cycles (19 and 20)

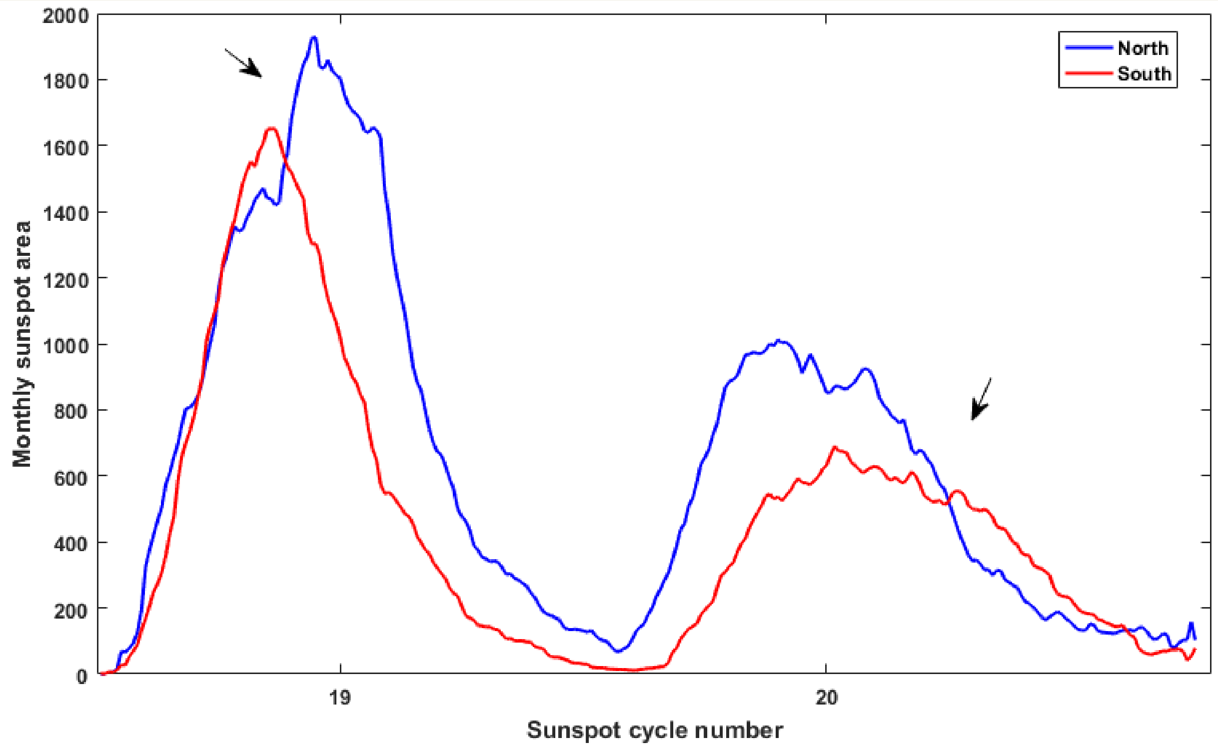




GRO

KSO/SPO

Phase Shifting



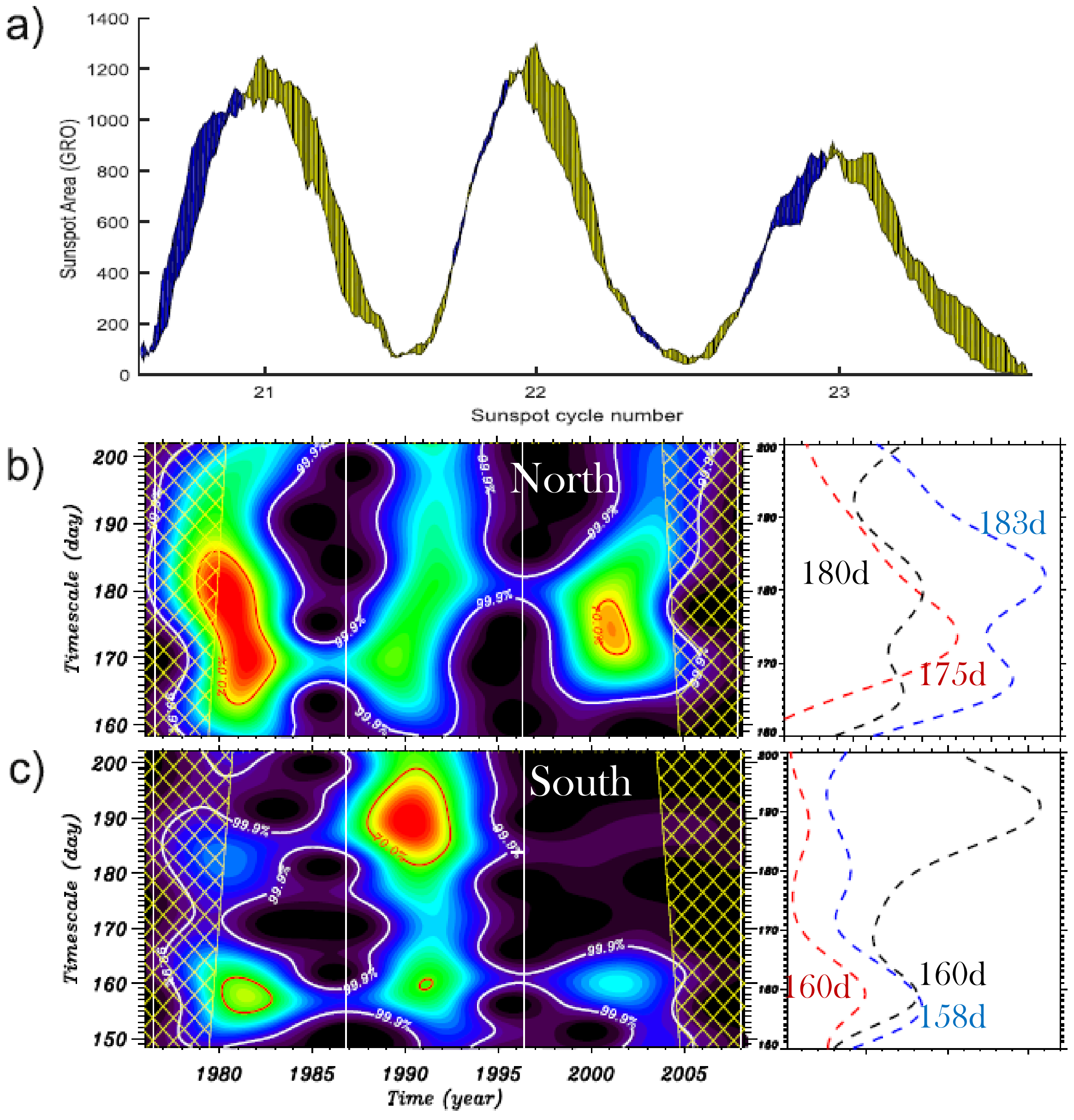
Activity maxima during cycles 19–20 are shifted by 1–2 yr in the northern and southern hemispheres.

The southern hemisphere reaches its maximum before the northern hemisphere during cycle 19, while it is opposite during cycle 20.

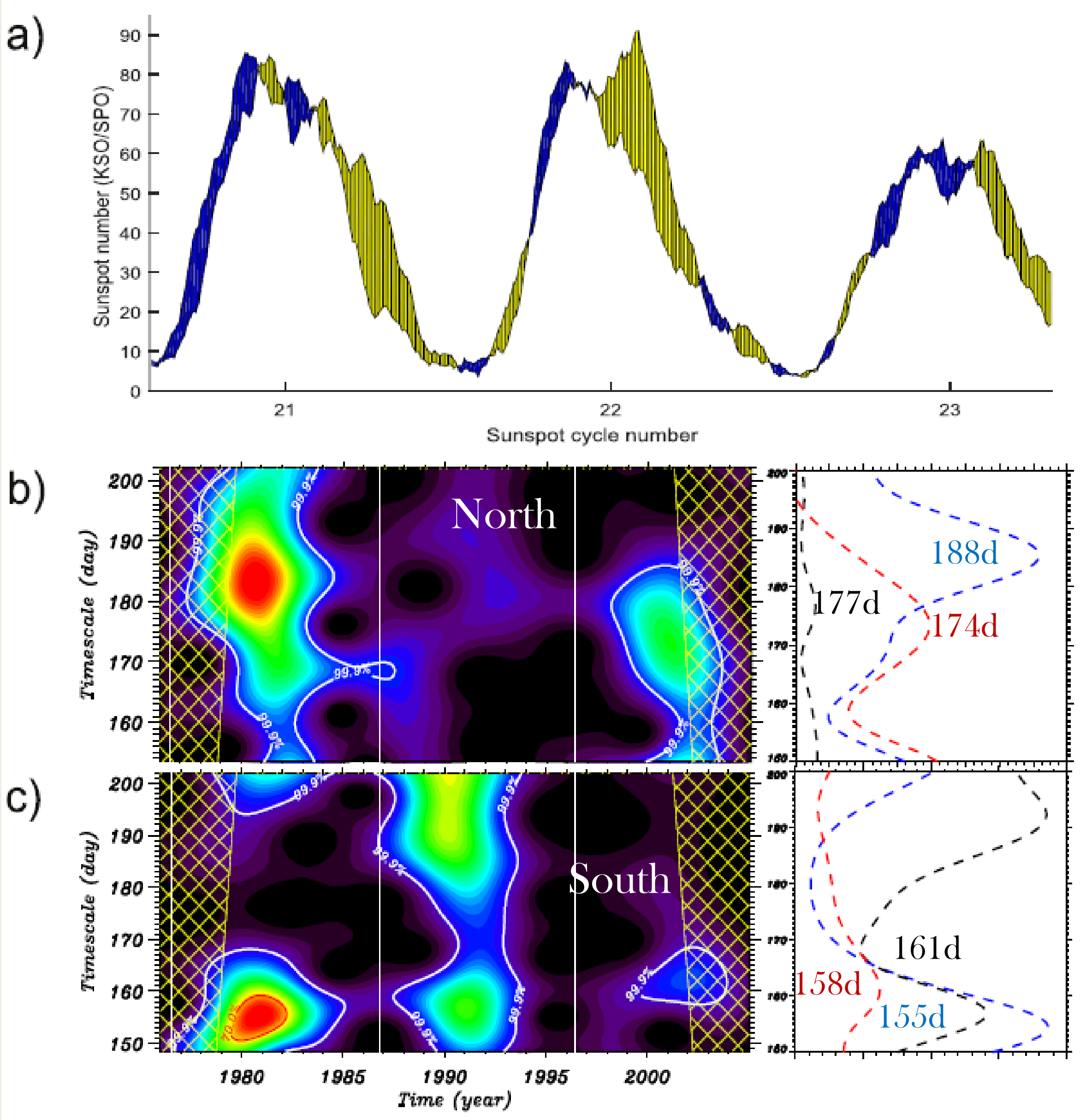
The north–south phase shift of solar cycles in sunspot data was studied in detail by Dikpati et al. (2007). They showed that the shift of cycle maxima is more pronounced than the shift of minima.

The Rieger periodicity displays a similar phase shift. This is in agreement with the previous results that the Rieger periodicity in full disk data appears near the cycle maxima.

South – Dominated cycles (21, 22 and 23)

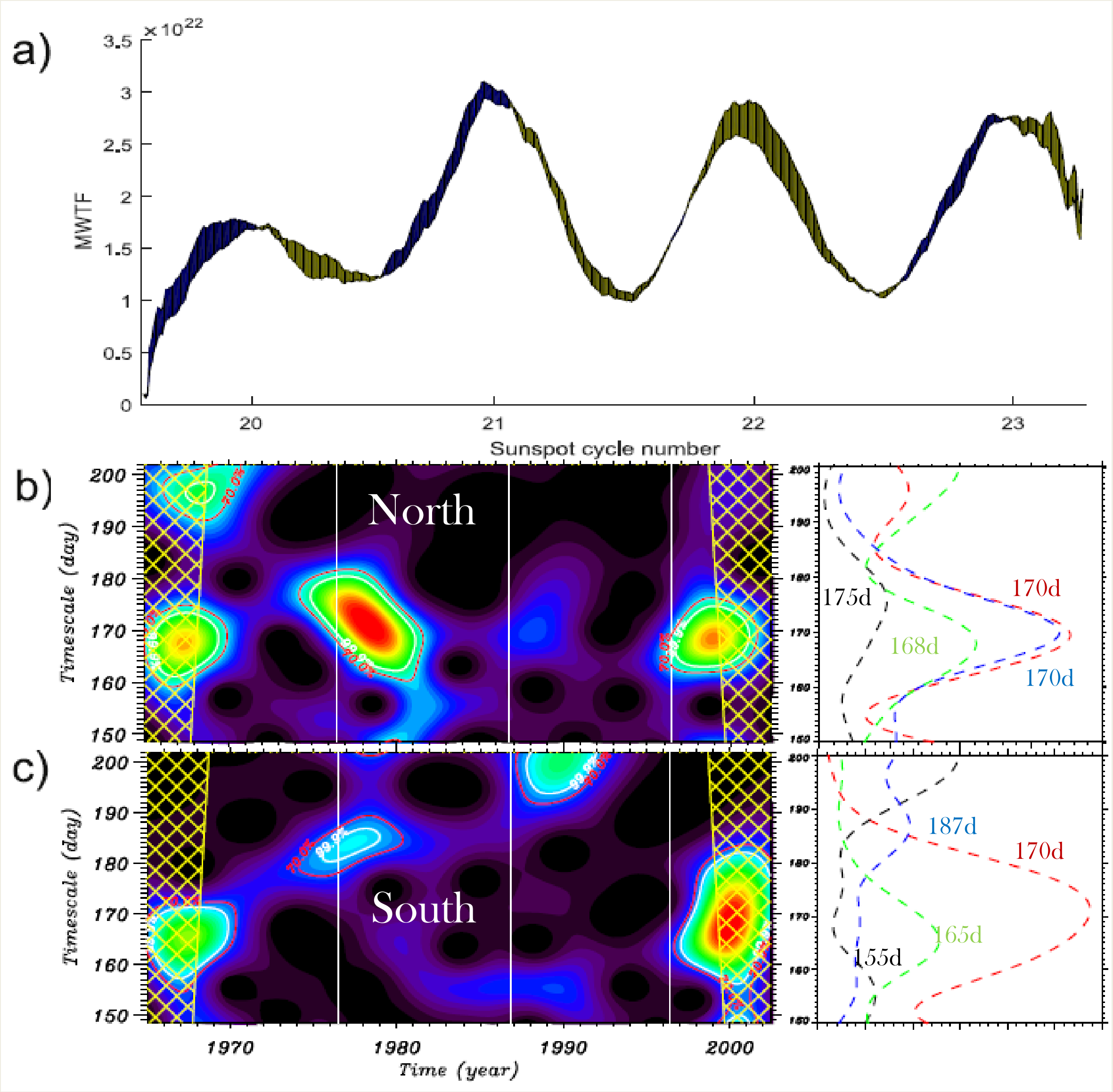


GRO



KSO/SPO

Mount Wilson total magnetic flux hemispheric data for cycles 20–23



Howard (1974) examined magnetic flux data from the Mount Wilson magnetograph during 1967–1973 and reported that the total flux in the north was greater than in the south by only 7%

Chumak et al. (2003) studied the behavior of the total sunspot area and magnetic flux in1989 and showed that there is not always positive correlation between active regions and total magnetic flux

During cycle 21, Rabin et al. (1991) found quasi-periodic pulsations only in the strong flux, which were uncorrelated between the hemispheres

Ballester et al. (2002) studied MWTF data for cycles 20–23 and found a correlation between impulses in strong flux and flares, but not with weak flux. Lean & Brueckner (1989) reported that the Rieger periodicity was not significant in the plage index.

Estimated Rieger Periods (days) for Both Hemispheres from GRO, KSO/SPO, and MWTF Data, for Solar Cycles 19–23

Cycle Number	Period (N, GRO)	Period (S, GRO)	Period (N, KSO/SPO)	Period (S,KSO/SPO)	Period (N, MWTF)	Period (S, MWTF)
19	158	177	156	176	-	-
20	165	190	152	188	168	165
21	183	158	188	155	170	187
22	180	160	177	158	175	155
23	175	160	174	161	170	170

We used the dispersion relation of fast magnetic Rossby waves in order to estimate the magnetic field strength in both hemispheres individually during the cycles 19 - 23

$$\omega_f = -m\Omega_0 \frac{1 + s_2 + \sqrt{(1+s_2)^2 + \frac{B_0^2}{4\pi\rho\Omega_0^2 R_0^2} n(n+1)}}{n(n+1)}$$

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ω_f is the frequency of fast magnetic Rossby waves, Ω_0 is the angular velocity, S_2 is the parameter of the differential rotation, ρ - density, R_0 - distance. B_{max} is the dynamo magnetic field strength at 45°, m and n are toroidal and poloidal wave numbers.

Cycle number	19	19	20	20	21	21	22	22	23	23
Differential rotation, s_2	0.19	0	0.16	0	0.14	0	0.14	0	0.17	0
B_{max} (kG), north	40	49	37	45	28	36	30	38	31	40
B_{max} (kG), south	28	39	23	33	43	49	42	48	40	48

Estimated Magnetic Field Strength for the Northern and Southern Hemispheres during Cycles 19–23 The meanings of differential rotation parameter s2 are obtained by Javaraiah et al. (2005).

Conclusions

- The analysis of sunspot data during cycles 19-23 showed that the Rieger-type periodicity is asymmetric with hemispheres. We obtained the periods of 140–165 days in stronger hemispheres and 180–190 days in weaker hemispheres.
- Rieger-type periodicity in sunspot data correlates with hemispheric activity levels in the same sense as it correlates with cycle strength based on full disk data (Gurgenashvili et al. 2016): the hemisphere with stronger activity displays the periodicity with shorter period.
- The obtained periodicity and the dispersion relation of magnetic Rossby waves were used to estimate the magnetic field strength in the tachocline as 45–48 kG in the more active hemisphere and 32–38 kG in the weaker hemisphere.
- The north– south difference in the dynamo magnetic field strength of 10 kG is almost 25% of the estimated magnetic field. This is a challenge for future dynamo models.

Thank you!

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Tbilisi 2017