Modeling of polar magnetic field reversals from sunspot impulses

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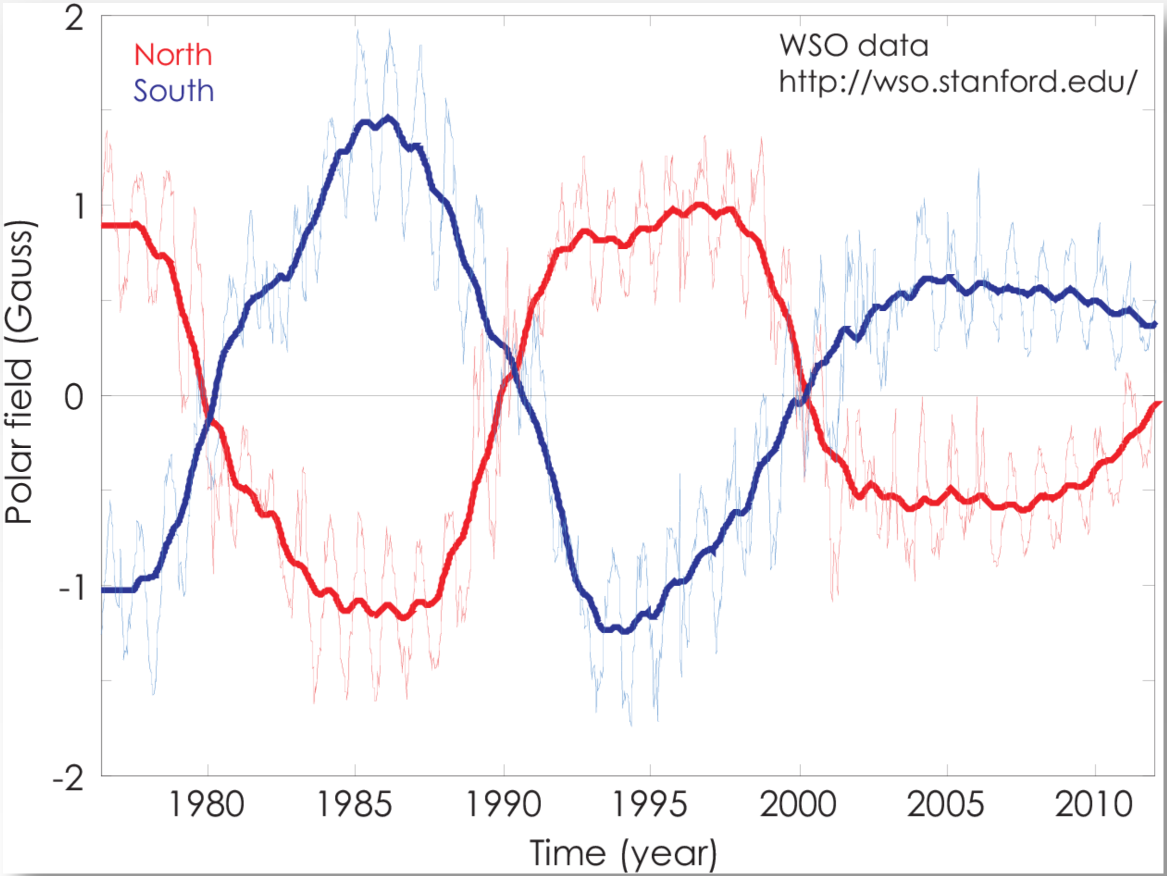
Oulu, Finland
June 15-19, 2013

Motivation



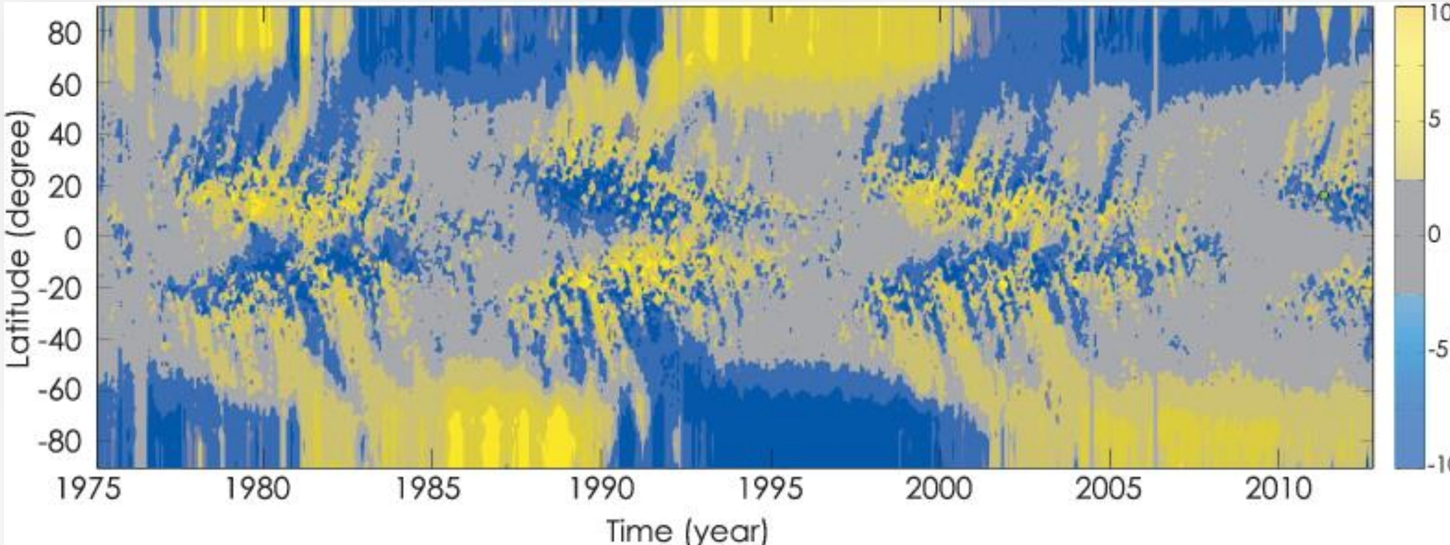
The Sun's polar field strength is currently 35-40% weaker in comparison with the previous sunspot minima.

Caused by:

- increase of the meridional flow speed (Schrijver, Liu 2008; Wang et al. 2009; Sheeley 2010; Nandy et al. 2011). Karak (2010) model Grand-minima by varying the meridional circulation.

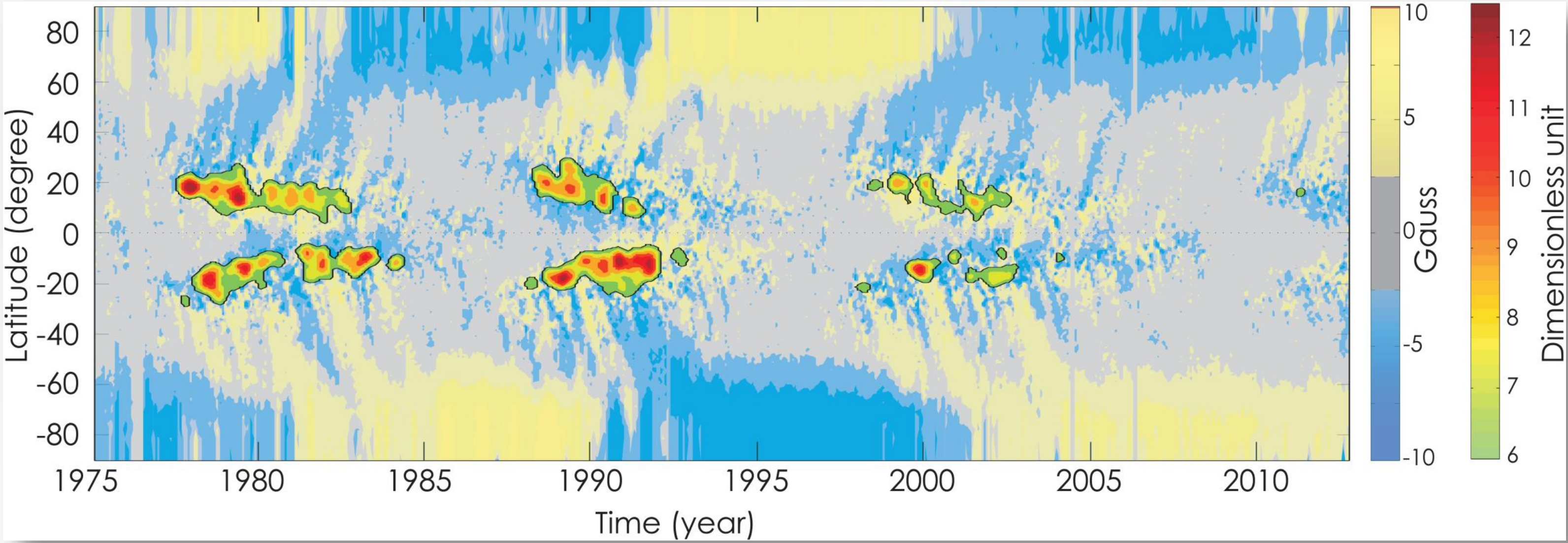
or

- solar activity decay:
    - decrease of sunspot population;
    - decrease in field strength of sunspots.



KPNO
SOLIS
SOHO
data

The magnetic surge is poleward moving streams of either polarity (Wang et al. 1989).



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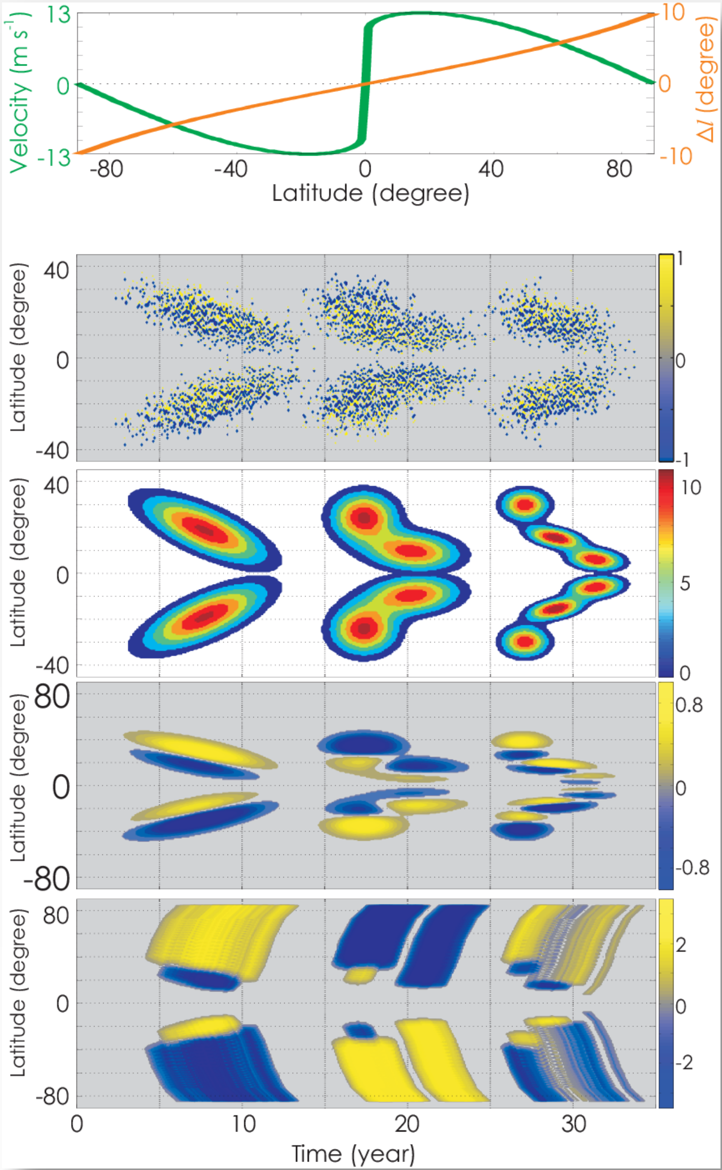
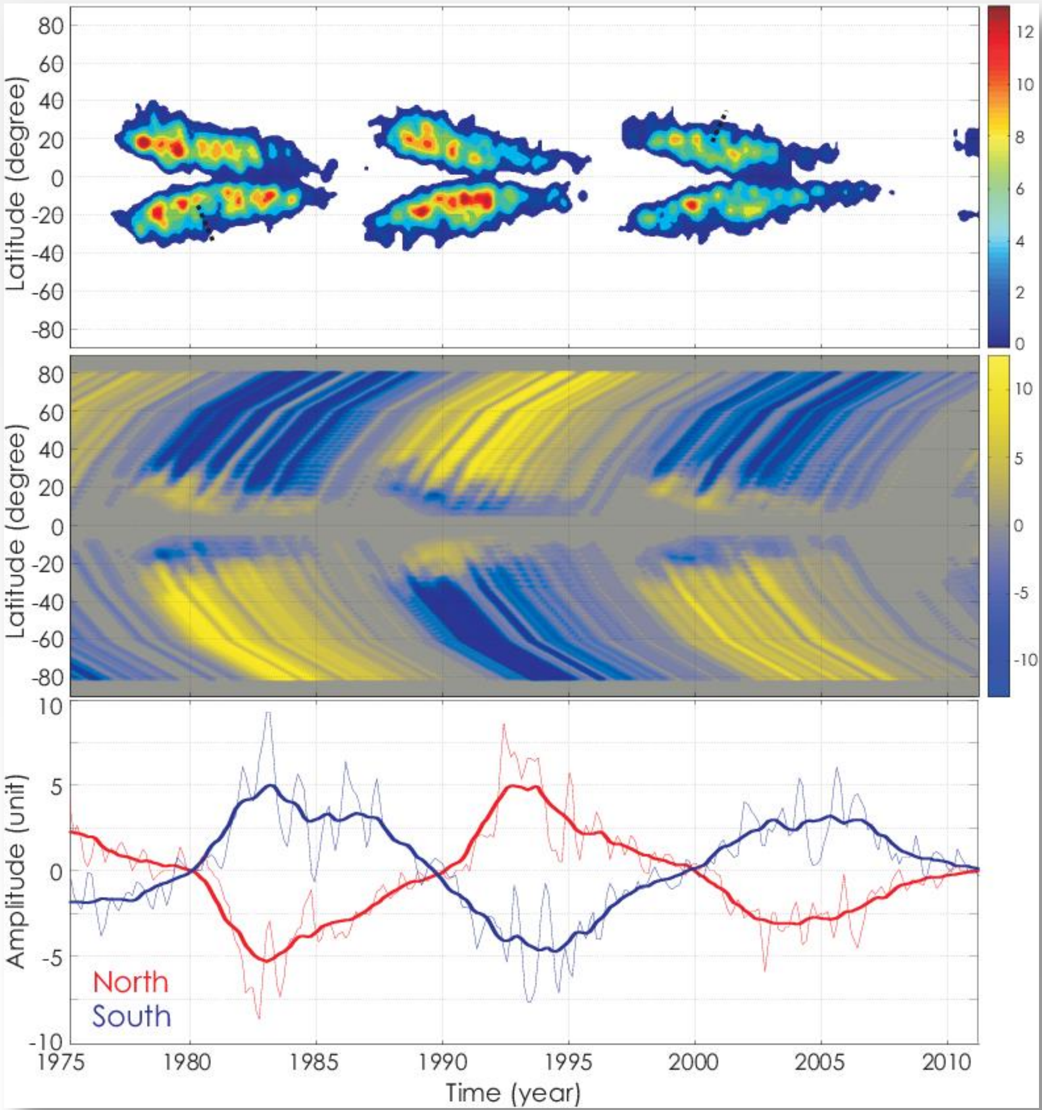
Sunspot impulse is concentration of sunspots on latitude-time plane (Antalova and Gnevyshev 1983).

Each sunspot impulse causes a poleward surge of imbalanced flux. Superposition of impulses suppresses old polarity surges. Thereby, surges of old polarity are observed in gaps between impulses.

Method



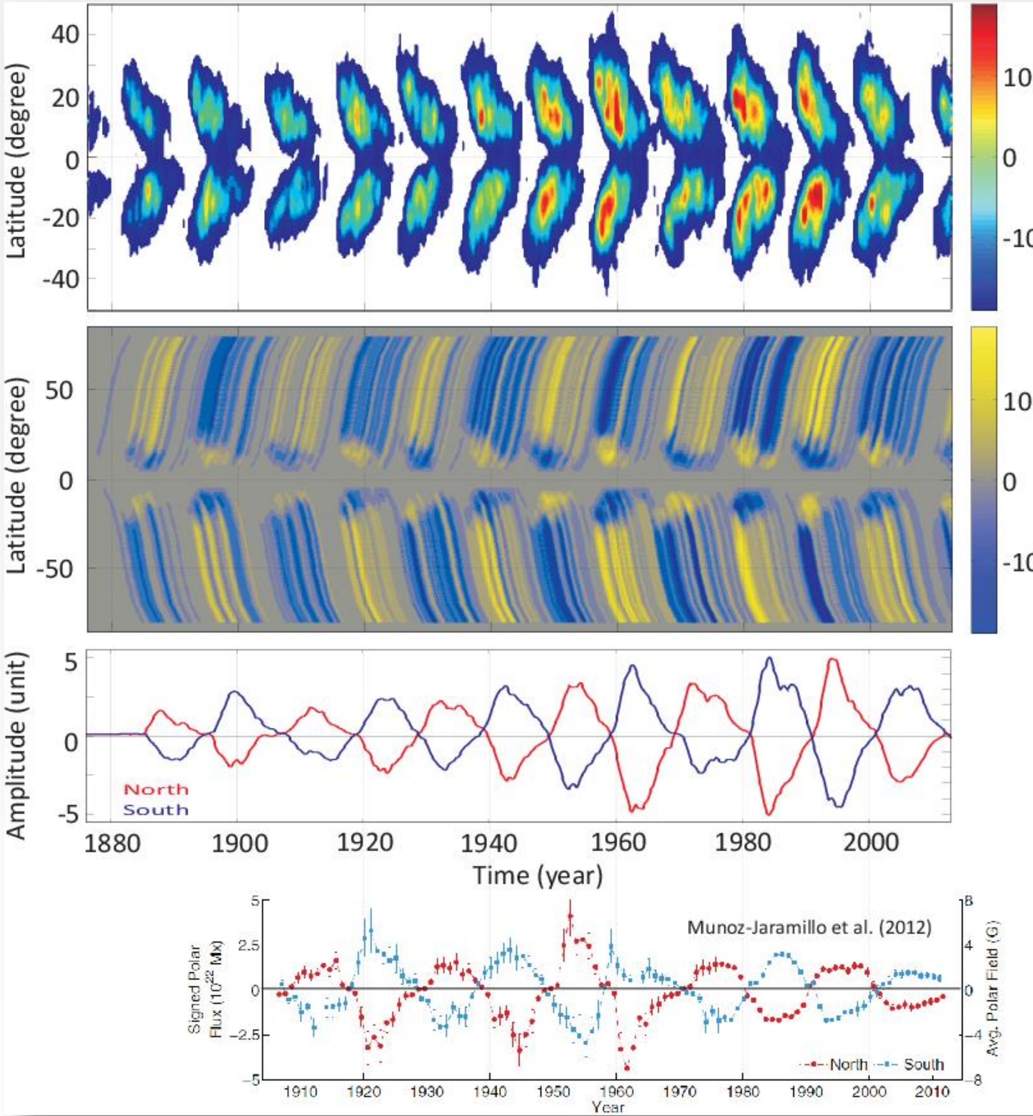
1) Specify the Joy's law:
   $\Delta l = 10 \cdot \tan(0.5 \cdot l)$,
   Δl is latitudinal separation of leading and trailing spots of bipole, l – latitude.
2) Specify the meridional flow:
   $$v(l) = v_0 \left(\frac{\sin l}{\sin l_0}\right)^p \left(\frac{\cos l}{\cos l_0}\right)^q$$
   $l_0 = 13.3^\circ$, $p = 1$, $q = 0.1$ (Wang et al. 1989)
   $v_0 = 14$ m s^{-1}.
3) Derive impulses as average of sunspot distribution on time-latitude plane. Assign the "magnetic flux" from impulse is equal to its magnitude.
4) Specify the imbalance between leading and trailing fluxes:
   $$Flux_{trailing}(t,\ l) = Flux_{leading}(t,\ l + \Delta l) \cdot 1.02$$
5) Introduce the flux surplus:
   $$S(t,\ l) = Flux_{trailing}(t,\ l) - Flux_{leading}(t,\ l)$$
6) Reconstruct surges at each rotation t_i, i = 1626,…,2111:
   $S_{Result}(t_i, l_j) = S(t_i, l_j) + S(t_i, l_j - v_j \Delta t)$,
   where l_j is latitude, $j = 0,\ldots,\pm 90$, Δt is one Carrington rotation.



-- Sunspot impulses from 1975 to 2012 constructed for nominal sunspot counts.

--- Reconstructed poleward surges. Flux surplus of leading polarity is evident at low latitudes, like real photospheric pattern.

--- Unsmoothed strength of surges at latitudes ±70°. Thick lines show smoothed values over 10 Carrington rotations.

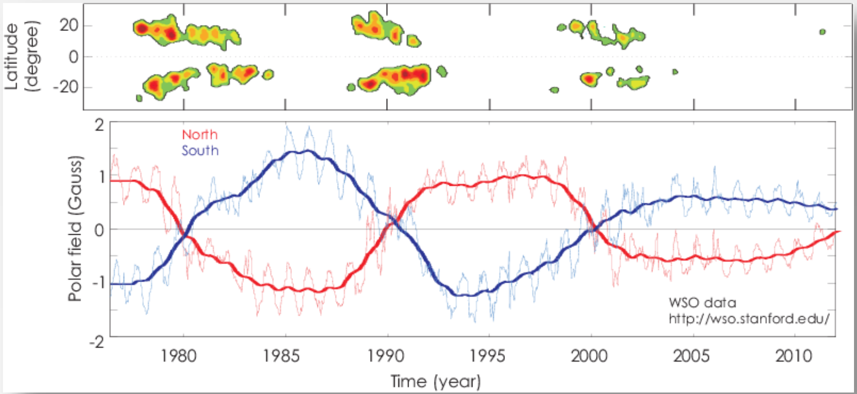


-- The cycles 19, 21, and 22 have strongest impulses.

--- Reconstructed poleward surges. Flux surplus of leading polarity is evident at low latitudes, like real photospheric pattern.

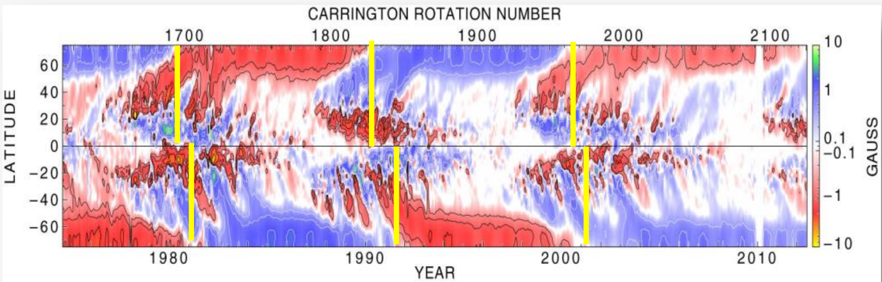
--- Unsmoothed strength of surges at latitudes ±70°. Thick lines show smoothed values over 10 Carrington rotations.

-- Signed polar flux referenced to MDI measurements. Data points are taken from MDI (1996–2010), WSO (1975–1996), and MWO (1906–1975). The second axis shows the equivalent values of average polar field strength referenced to WSO measurements. (c) Mũnoz-Jaramillo, Sheeley, Zhang, DeLuca (2012).



Cycles	North	South	Total
23/22	22.54%	24.96%	23.85%
23/21	33.93%	30.12%	31.95%

Cycles	North	South	Total
23/22	26.91%	19.25%	23.06%
23/21	31.33%	29.24%	30.24%

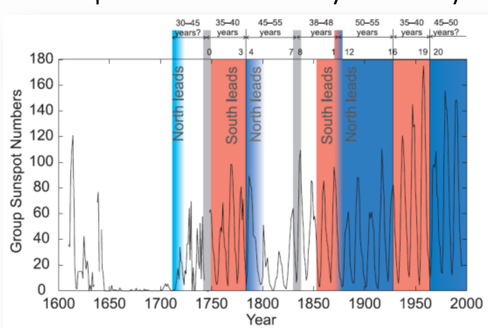


Ulrich, Boyden 2005

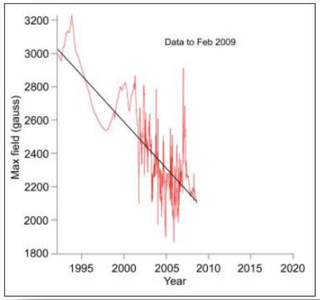
Svalgaard, Kamide 2013: "We suggest that asymmetric polar field reversals are simply a consequence of the asymmetry of solar activity."

de Toma et al. (2013) reported a noticeable lack of large spots in cycle 23 with areas larger than 700 millionths of a solar hemisphere which corresponds to a decrease of about 40% relative to cycle 22.

According to (Livingston and Penn, 2009), not only nominal sunspot count has decreased, but the magnetic field strength in spots also diminishes in time (1992–2009).



Zolotova et al. (2010)



Conclusions

- Strong surges of the magnetic field to the poles originate from powerful sunspot impulses. The polar field reversals are intimately related to the sunspot impulses.
- Both of suppressions of sunspot population and sunspot magnetic field are responsible for the current weakness of polar magnetic field along the cycle 23 with respect to the cycles 21 and 22.
- Close one to one correspondence between impulses and surges removes suggestion about higher meridional flow during the periods, when poleward surges are observed.