Response to Reviewer's Issues with 'Asymmetric Solar Polar Field Reversals'

Major issues

1a) Authors misunderstand cycle 19. According to the authors' argument, the strong asymmetry of the activity between both hemispheres should be observed before either polar field reverses, that is, in the rising phase of the cycle. However, as shown in Figure 1, the profiles of sunspot number in both hemispheres increase similarly in the rising phase of cycle 19. Coronal activity in the same period was slightly more active in the northern hemisphere, as seen in Figure 6. The strong asymmetry in cycle 19 was observed after the maximum of cycle 19 (middle of 1958). Therefore, the difference in the time of reversal in cycle 19 is not explained by the asymmetry between the hemispheres.

Cycle 19 is the first cycle where polar field reversals were directly observed and the magnetograph observations were in their infancy, making firm and detailed conclusions difficult. At best, the data for this cycle can be said to be consistent with the well-observed cycles 21-24, but not compelling on their own [both in a positive and negative sense]. Waldmeier noted that "if the northern and southern hemispheres are considered separately, the sunspot numbers reached a maximum in the south about one year earlier than in the north, and this suggests a physical connection with the earlier reversal of the south polar field":

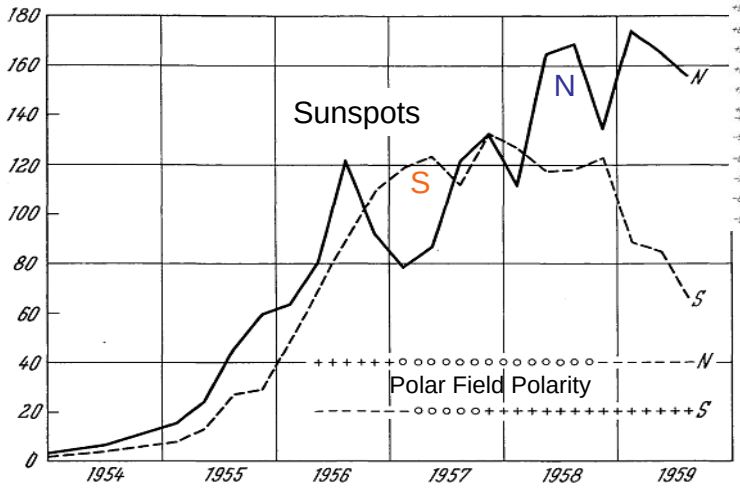
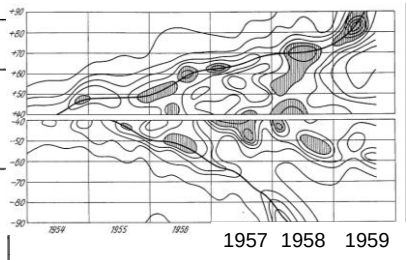


Abb. 1. Verlauf der Fleckentätigkeit und Variation des polaren Magnetfeldes

has pointed out, if the northern and southern hemispheres are considered separately, the sunspot numbers reached a maximum in the south about one year earlier than in the north, and this suggests a physical connection with the earlier reversal of the south polar field. Waldmeier (1960) quoted by Babcock (1963)



Occurrence of Prominences: "Rush to the Poles"

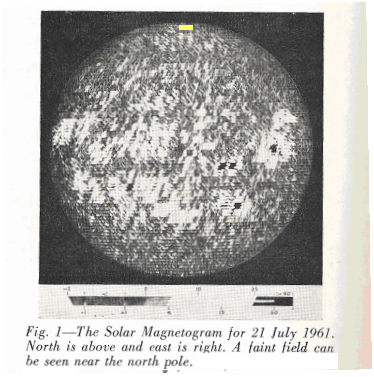


Fig. 1—The Solar Magnetogram for 21 July 1961. North is above and east is right. A faint field can be seen near the north pole.

We find this consistent with the behavior in cycles 21-24 that we describe and see no reason to quibble with Waldmeier on this particular point. The 'rush to the poles' as also given by Waldmeier shows the difference clearly. Finally later [scattered] magnetograms [like the one shown for 21 July, 1961] show a clear polar field in the North [with the proper sign] consistent with the continuing activity in the North, as opposed to the

decline in the South [resulting in a weaker – and not observable – polar field in the South]

1b) The authors claim that, in cycle 19, each polar field reversed when each hemisphere became most active. However, the northern hemisphere became most active near the middle of 1959 or later as shown in Figure 1, while the time of polar reversal of the north pole was observed in November 1958 (Babcock 1959). The authors' argument does not seem correct on this point.

Our claim is a bit more nuanced than that. A significant amount of flux must be reaching the pole, and as shown in the Figure above that did happen for the South just prior to reversal and for the North just prior to its reversal, and as we just pointed out, continuing activity in the North contributed to the build-up of the polar field observed there in 1961. The amount of flux at the beginning of a large cycle is much smaller [and its asymmetry much less important] than the amount of flux near maximum.

1c) The authors did not show any clear reason why polar field reversal occurs simultaneous with activity maximum in each hemisphere. As described by the Babcock model (in the first paragraph of Section 2), polar field is thought to reverse because of the transport of magnetic flux of the opposite polarity transported from the following part of BMRs (active region remnants). The timing of the polar reversal can depend on the amounts of preexisting polar magnetic flux at the beginning of the cycle and the amounts of the transported flux from lower latitude. The transport of the flux from lower latitude to the polar region can take a time of order of years. Taking into account these points, the reversal process can be complicated and there is no reason why polar field reversal necessarily occurs simultaneously with activity maximum in each hemisphere.

We agree that the process can be more complicated [as it probably was in cycle 20 with multiple prominence zones]. About being ‘necessary’, we are only reporting on data as observed over the past several cycles. If the cycle is ‘complicated’ the definition of ‘activity maximum’ is correspondingly hazy and not much significance should be attached to the finer details anyway.

2) Because the authors misstate the situation in cycle 19 as shown above, the sentence in the fourth paragraph of Section 3 "In analogy with cycle 19, ..." is not appropriate. Readers cannot find an analogy between cycle 19 and 24 for a North-South asymmetry in each rising phase in Figure 1.

We agree that there is no analogy as far as cycles are concerned. The point we were making was that observations show that reversals can be abrupt. So we change the wording to “We might expect the South polar fields to reverse, perhaps abruptly as the North in cycle 19, as activity eventually picks up in the Southern Hemisphere”

Minor issues

3) Description in the second paragraph in Section 1 "such behavior" is not clear. The observation presented by Bumba & Howard (1965) covered August 1959 to June 1964,

after both polar fields had already reversed by November 1958. The observation is not direct evidence that the reversal of the subsequent hemisphere necessarily comes abruptly. The author should describe the observation more accurately and their interpretation more clearly.

The behavior we are referring to is not the incidental 'abruptness', but the fundamental issue of the poles having the same polarity. We rephrased the text to make that clearer: "With the passing of time we find that the two poles having the same sign near their reversals is quite common and may have a simple explanation"

4) In authors' argument in the second paragraph of Section 2, they claim that two humps in solar activity correspond to a hump in each hemisphere. The solar activity in a cycle is known to show a double or multiple peak structure that was reported by Gnevyshev (1967, 1977). Feminella & Storini (1997) reported the relation between timings of polar reversals of both hemispheres and peaks of solar activities in cycle 21. The earlier polarity reversal at the North Pole started when activities decreased well after the first peak of the cycle (sometimes referred as Gnevyshev Gap). The authors should explain how the observation is interpreted in their scenario.

The reversal in the North [according to MWO, Figure 3] took place around Rotation 1695 at the beginning of 1980 and was likely associated with the early peak A [Fig. 7 in F&S97] while the reversal in the South would be related to their peak B [around Rot. 1715]. Cycle 21 was somewhat irregular and that is why the integration performed in Figure 2 might be helpful in discerning the larger-scale asymmetry. We do not think a detailed discussion of this is warranted in our short note, but have included a reference the F&S97: "Because cycles can have irregular maxima, e.g. cycle 21 \citep{fem97}, the integration performed in \ref{N-S-Diff} is helpful in discerning the larger-scale structure. The integration gives the necessary weight to the accumulated effect of many active regions."

5) Figure 2 is referred to in the second paragraph of Section 2 in the context that "Solar cycles since then have had the opposite asymmetry, with the Northern Hemisphere being most active early in the cycle". This context is sufficiently shown only in Figure 1. The authors should add an extra description or discussion about Figure 2. Otherwise, Figure 2 should be removed.

We have added more discussion as per above. We might note that Figure 2 was included upon insistence from colleagues who were uncertain about the asymmetries. If the reviewer does not share that uncertainty, we have no problem removing the Figure, but have left it for now in the revised version

6) Figure 5 [now Figure 6] is too busy. The difference between the left and right panels is unclear because the authors did not describe the difference between the two measurements of coronal hole. The reason why both panels are necessary is unclear because the authors did not describe the importance of the difference. Also, it is not clear what the authors intend to show with this Figure. The authors should add more

description or discussion to clarify how the area of the coronal hole in Figure 5 is relevant to their argument.

The caption [it is now Figure 6] describes the difference of the two measurements as being [left] derived from locating the holes at the limbs (being less influenced by projection effects) and on the disk [right]. We have added the following in the text: "Figure 6 shows the recent evolution of the polar coronal hole area, determined both by locating the hole boundary at the limb (left panel) and by observing the holes on the disk (right panel), consistent with the observations of the magnetic field, as the areas of the polar coronal holes are proxies for the magnetic flux in the polar regions, e.g. Wang 2009. In particular, the disappearance of a hole marks effectively the polar field reversal (clearly seen for the North in Cycle 24)."

7) In the first paragraph of Section 3, the inclination of the solar rotation angle was described as "7.15 degrees". Is this a typo?

No, see e.g. http://iopscience.iop.org/1538-4357/621/2/L153/pdf/19164.web.pdf Perhaps 7.16 degrees would be marginally better. It is time that we begin to use what value is currently considered the correct one.

8) Figure 6 is referred to in the third paragraph of Section 3 before Figure 5 in the fourth paragraph of Section 3.

We have changed the numbering accordingly.