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":

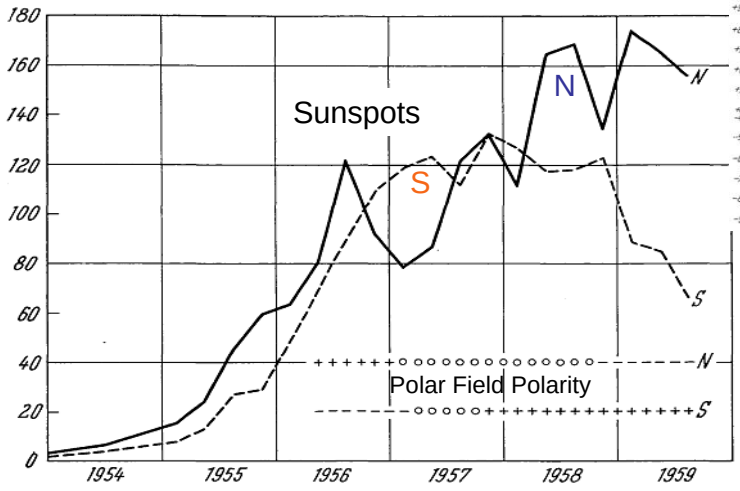
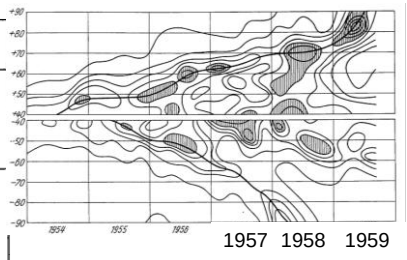


Abb. 1. Verlauf der Fleckentätigkeit und Variation des polaren Magnetfeldes

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"

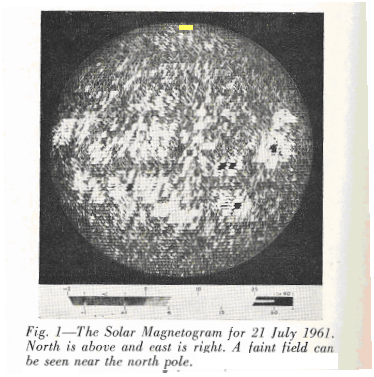


Fig. 1—The Solar Magnetogram for 21 July 1961. North is above and east is right. A faint field can be seen near the north pole.

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 to F&S97: "Because cycles can have irregular maxima, e.g. cycle 21 (Feminella and Storini, 1997), the integration performed in Figure 2 is helpful in discerning the larger-scale structure. The integration gives the necessary weight to the accumulated effect of many active regions near maximum."

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). As we associate the early North polar reversal in the asymmetric, smallish solar cycle 24, predicted to be as weak as cycle 14 (Svalgaard et al., 2005), with the preponderance of activity in the North early in the cycle, it is instructive to compare cycle 24 with the also highly asymmetric cycle 14, Figure 7. It will be of great interest to follow the future evolution of cycle 24 to see if the assumption of it being comparable to cycle 14 holds up."

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.

Response to Review of Revision 1

Since the authors significantly revised the manuscript and gave detail explanation in their reply, their claim is now clearer. The authors claim that polar fields in both hemispheres reverse at significantly different times, and the difference in the time of reversal is determined simply by the asymmetry of activity in both hemispheres. The former is clearly shown in observations, but I am still not convinced that the latter part of the author's claim is the case in all cycles. The compilation of several kinds of long-term observations is potentially worth publication, but a major revision is needed.
There are precious few of other long-term observations that can be included in such a compilation. We think we have collected what is available.

Major issue
1) Waldmeier (1960) notation can be seen in recent cycles, as shown in the authors' reply. However, the authors' argument as shown below focused on whether either hemisphere is more active than the other in the rising phase.

The ‘rising phase’ is not what we mean or say anywhere in the paper. In the beginning on a cycle one hemisphere can be more active than the other in the ‘wrong sense’, but since the sunspot number is still small the flux involved is also small. Later on, just before maximum when the sunspot number is high is the time where we should look for where most of the activity is.

The argument in abstract
"If there is a strong asymmetry in the sense that most activity is in the Northern Hemisphere, then that excess flux will move to the North Pole and reverse that pole first. If later on, there is a more activity in the South, then that flux will help reverse the South Pole. In this way, we get two humps in solar activity and a corresponding difference in time of reversals."
and those in Section 2
"Let us assume that there is a strong asymmetry in the sense that all activity is in the Northern Hemisphere, then that excess trailing flux will move to the North Pole and reverse that pole, while nothing happens in the South. If later on, there is a lot of activity in the South, then that flux will help reverse the South Pole. In this way, we get two humps in solar activity, one in each hemisphere, and a corresponding difference in time of reversals” are not the case in all cycles shown in this paper and therefore should be revised.
First of all, those were Gedanken Experiments meant to illustrate the basic argument, to wit the ‘If’ and the ‘assume’. The Sun is a messy place and things are never as clean as in Gedanken Experiments. Second, Figure 2 shows clear ‘bumbs’ corresponding to dominance near maximum of North polarity, so at least based on that Figure we’ll maintain that our thesis holds for the last five well-observed cycles. Whether it is **always** true [e.g. for cycles 32 or -674] we, of course, having no observations so cannot be sure, but at least we surmise the case for the cycles for which we have data and shall let further cycles provide confirmation or falsification as the case may be. Sometimes a failure points to further insights. We have emphasized the Gedanken Experiment aspect by changing the abstract:
…In this way, we get (in the ideal case) two humps in solar activity…
…with the Northern Hemisphere being most active before solar maximum.

I agree that, if both hemispheres show strong asymmetry in solar activity (rising phase), significant amount of flux is transported more rapidly to the either polar region and reverses the polar field. As the asymmetry in rising phase is stronger, the difference in time necessary for arrival of significant amount of flux becomes longer.
However, in rising phase of Cycle 19 and 22, although the asymmetry in solar activity looks relatively small, there is significant difference in time of polar reversals. This fact is shown in Figure 2. The integral of sunspot number is at almost the same level at the beginning and at the time of the earlier polar reversal, in the two cycles (at 1954 and at 1957 in Cycle 19 and at 1987 and at 1990 in Cycle 22). This means that the total numbers of sunspots that appeared during each period are comparable between both hemispheres. This fact implies that the difference in time of polar reversal may be caused by some other factor such as pre-existing polar flux. The authors should explain how the authors exclude other possibilities.
We do not exclude other possibilities, such as the existing polar flux playing a role too. To make this clear we have added the following texts:
… In case of a `complicated' cycle with multiple surges of activity, such as for the South Pole in cycle 21, the polar field reversals will then also show complicated behavior, perhaps with multiple reversals. The strength of the existing old polar flux will also have an influence on the reversal process….

¶The authors should revise the argument and describe the relation between the authors' argument and Waldmeier (1960) notation.

It is not clear what this means, and in any case, we believe to have already addressed our argument in relation to Waldmeier's, namely that we are in agreement with him and that our paper should be simply seen as an update of his earlier insight with newer data.

Minor issues
2) I suggest that the authors cite the reference of solar rotation angle (Beck & Giles 2005) because it is useful for readers.
We have added a reference to Beck & Giles 2005:
Beck, J. G., & Giles, P., 2005, ApJ, 621, L153

3) In caption of Figure 6, I suggest the authors to include a short description of coronal hole area in MDI. Coronal holes cannot be observed in MDI images.
We have added the following text:
The coronal hole fraction from MDI magnetograms are determined by correlating the Line-of-Sight field with the EIT hole fraction.
As explained here http://www.leif.org/EOS/SAHW_SHINE2012_poster.pdf

---

Response to Review of Revision 2

Major issue
1) The following part in Section 2 should be revised.
"Let us assume that there is a strong asymmetry in the sense that all activity is in the Northern Hemisphere, then that excess trailing flux will move to the North Pole and reverse that pole, while nothing happens in the South."
I think that a reader might possibly misunderstand this part as I did in my previous report. The assumptions given here are that "all activity is in the Northern Hemisphere" and that "nothing happens in the South". The authors do not specify whether the activity in the Northern hemisphere becomes highest or not. Following these points, the argument in this part appears to be that for a rising phase, because a strongly asymmetric situation almost the same as that assumed here can really be seen in the rising phase of Cycle 20. In addition, before the Northern hemisphere became most active, sunspots in the Southern hemisphere began to appear in Cycle 20. In most cycles, before either hemisphere becomes most active, the opposite hemisphere begins to be active. I suggest that the authors should revise here to avoid such misunderstanding on the readers' part.

We add clarification as follows:
The integration gives the necessary weight to the accumulated effect of many active regions. Asymmetry in the early part of the cycle is not so important because the total number of spots and hence the amount of magnetic flux are still small.

2)The authors' response
> The 'rising phase' is not what we mean or say anywhere in the paper. In
> the beginning on a cycle one hemisphere can be more active than the other
> in the 'wrong sense', but since the sunspot number is still small the flux
> involved is also small. Later on, just before maximum when the sunspot
> number is high is the time where we should look for where most of the
> activity is.

I suggest that the authors indicate the high-activity periods that they focus on in figure 1 or 2 with shading. The periods are vague and therefore cause readers to misunderstand. If there are clear criteria to determined the period, they should be stated.

We indicate now with light shading on Figure 2 where the bumps and valleys are. Because of the at times irregular curves, the shading is only roughly indicative. A precise accounting for the flux budget as function of time is beyond the scope of this paper, but we suggest here that cycle 24 would be ideal for such a project.

3) The authors' response in the previous reply
> We have added the following text:
> The coronal hole fraction from MDI magnetograms are determined by
> correlating the Line-of-Sight field with the EIT hole fraction.
I cannot find this text in the revised manuscript.

This was a clerical error and we have added the missing text

Decision Letter

November 6, 2012

Dr. Leif Svalgaard
W. W. Hansen Experimental Physics Laboratory
Stanford University
Stanford, CA 94305-4085

Title: Asymmetric Solar Polar Field Reversals

Dear Dr. Svalgaard,

I am happy to report that the above paper is accepted for publication in The Astrophysical Journal.

I am sending the accepted version to the ApJ editorial office. Correspondence concerning the logistical aspects of publishing this manuscript should be directed to apj@apj.usask.ca. If you have any additional questions concerning the scientific content of your manuscript, please direct them to me.

Sincerely,
Leon Golub
Scientific Editor
The Astrophysical Journal
lgolub@cfa.harvard.edu