# Long term trends in solar photospheric fields and solar wind turbulence levels: Implications to the near-Earth space

**Article** *in* Proceedings of the International Astronomical Union · February 2018

DOI: 10.1017/S1743921318001710

*Long Term Datasets for the Understanding of Solar and Stellar Magnetic Cycle*
*Proceedings IAU Symposium No. xxx, 2018*
*D. Banerjee, J. Jiang, K. Kusano & Sami Solanki, eds.*

DOI: 00.0000/X000000000000000X

# Long term trends in solar photospheric fields and solar wind turbulence levels: Implications to the near-Earth space

**P. Janardhan[1], K. Fujiki[2], M. Ingale[1], S.K. Bisoi[3], and S. Ananthakrishnan[4]**

[1]Physical Research Laboratory, Astronomy & Astrophysics Division, Navrangpura, Ahmedabad, India
email: jerry@prl.res.in,mingale@prl.res.in,diptir@prl.res.in

[2] Institute for Space-Earth Environmental Research, Nagoya, Japan
email: fujiki@isee.nagoya-u.ac.jp

[3]Key Laboratory of Solar Activity, National Astronomical Observatories, CAS, Beijing, China.
email: susanta@nao.cas.cn

[4]Electonics Science Department, Pune University, Pune, India
email: subra.anan@gmail.com

**Abstract.** We re-examined solar polar magnetic fields, using ground based synoptic photospheric magnetograms, during solar cycle 24. The signed polar magnetic fields showed an unusual hemispheric asymmetry in the polar field reversal process with a single unambigous reversal in the Southern hemisphere around late 2013 while the polar reversal in the Northern hemisphere started earlier around June 2012, but was completed only by the end of 2014. The examination of the unsigned polar magnetic fields in cycle 24 showed a continuing decline of fields in the Northern hemisphere whereas in the Southern hemisphere, it had partially recovered. However, the overall declining trend in solar polar fields, which began in the mid-1990s, is still in progress. The continued decline seen in solar photospheric fields raises the question of whether we are heading towards a Grand or Maunder like solar minimum.

**Keywords.** Sun: activity – Sun: magnetic fields – Sun: photosphere – Sun: heliosphere

---

## 1. Introduction

The current solar cycle 24, preceded by one of the deepest solar minima in the past 100 years, has been the weakest since cycle 14. In our earlier reported papers (Janardhan et al., 2010, 2011, 2015; Bisoi et al., 2014a,b), we studied solar photospheric magnetic fields and solar wind micro-turbulence levels during cycles 21–23 and reported a steady decline in their values since ∼1995. In light of the unusually weakness of the current solar cycle 24, we have re-examined solar photospheric magnetic fields and solar wind turbulence levels during the current cycle 24. Also, we have accessed the response of the Earth's ionosphere and magnetosphere to the long term trend in solar photospheric fields and solar wind turbulence levels, and discussed the possible implications of such a decline if it continues.

## 2. Analyses and Results

Photospheric magnetic fields were computed using synoptic magnetograms from the NSO/KP database and the Synoptic Optical Long-term Investigation of the Sun facility (NSO/ SOLIS). The synoptic maps are in sine of latitude and longitude format of 180

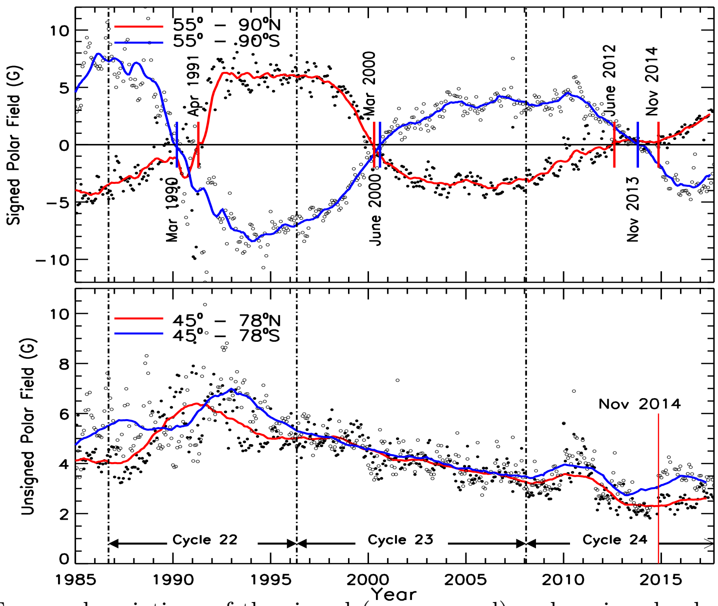


**Figure 1.** Temporal variations of the signed (upper panel) and unsigned values (lower panel) of solar polar fields shown for the Northern (the filled circles) and Southern (open circles) hemispheres, during cycles 22–24. Also, shown by the overplotted curves in red and blue are smoothed variations of polar fields, respectively, for the Northern and Southern hemispheres. The reversal of fields are indicated by red (for the north) and blue (for the south) vertical lines in the upper panel, while a red vertical line around Nov 2014 is marked in the lower panel to show the comparison of the declining polar fields in both the hemispheres.

$\times$ 360 pixels. The magnetic fields were first estimated for each latitudinal strip of 180 pixels and then the magnetic fields at selected latitude ranges were obtained by averaging magnetic fields over appropriate latitude ranges. In this paper, we used the latitude range, 55°-90°, for estimating the signed values of polar fields, while the unsigned values of polar fields were estimated using the latitude range 45°-78° (Janardhan et al, 2010).

Figure 1 (upper panel) shows variations of the signed values of solar polar fields in the Northern and Southern hemispheres, during the period of solar cycles 22–24, while the unsigned values of polar magnetic fields is shown in Fig.1 (lower panel). Overplotted in the solid red (for the north) and blue (for the south) curves are the smoothed variations of signed and unsigned polar fields. It is seen from the upper panel of Fig.1 that the polar field in each hemisphere reverses its polarity, clearly identified by the change in sign of field or by the zero-crossing of the fields as indicated by short vertical red and blue lines in the upper panel of Fig.1, at around each solar cycle maximum. The time of field reversal labelled with the month and year are shown in the upper panel of Fig.1. It is found that the field reversal in cycles 22 and 23 shows a single, clean change of polarity, while in cycle 24 the field reversal shows an unusual and hemispherically asymmetric pattern. In the Southern hemisphere, the field reversal shows a clean and unambiguous polarity change around November 2013, while in the Northern hemisphere, the field reversal has started more than 1 year earlier, around June 2012. However, the reversal process is on and off for about 2 years and is completed only by around November 2014. By this time, indicated by a vertical red line in the lower panel of Fig.1, the decline in the field strength of unsigned polar fields in the Southern hemisphere has been weakened showing a partial recovery from the steady declining trend. In contrast, in the Northern hemisphere, the unsigned field strength of polar fields has been still continuing to decline. Although

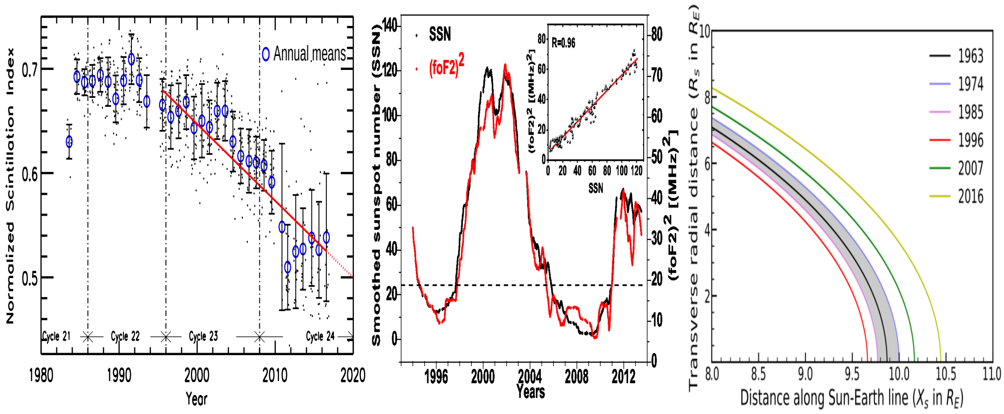


**Figure 2.** (Left panel) Temporal variations of annual means (filled dots) of normalised scintillation index, m, for the period 1983–2016 and in the distance ranges of 0.2–0.8 AU, overplotted by the average yearly means of m (open blue circles) with 1 $\sigma$ error bars. The steady decline of m during 1995–2016 is indicated by a fitted red curve. (Middle panel) The relation between SSN and $foF2$ is shown during 1994–2014. A horizontal dotted line is marked at SSN=25 to indicate the low level of solar cycle activity. In the inset shown is the correlation between the two with R=0.96. (Right panel) A plot of $R_s$ against $X_s$ showing the 11 year averaged MP shapes. The black, blue, indigo, red, green and gold curves show the 11 year averaged MP shapes starting from 1963, 1974, 1985, 1996, 2007 and 2016, respectively. The shaded a gray band represents a $1\sigma$ width around the average MP shape of 1963.

a partial recovery in polar field strength has been seen in the Southern hemisphere, however, the overall declining trend in polar fields has been still in progress.

Figure 2 (left panel) shows the temporal variations of the normalised scintillation index (= m), a parameter measuring the solar wind micro-turbulence levels in the inner heliosphere, for a selected 27 extra-galactic radio sources. The filled blue dots are annual means of m, while the open blue circles are the yearly averages of annual means of m shown with 1 $\sigma$ error bars. The m values shown were obtained from the daily measurements of 327 MHz interplanetary scintillation (IPS) observations, made using the three station IPS observatory of the Institute for Space-Earth Environmental research (ISEE), Nagoya, Japan, between 1983 and 2016 and in the heliocentric distance range 0.2–0.8 AU. A steady declining trend in m, as reported earlier in Janardhan et al., 2011, 2015, has been continuing even in cycle 24 suggesting a casual effect of the decline in solar polar fields in the inner heliospheric solar wind.

Fig.2 (middle panel) shows the temporal variations of smoothed sunspot number, SSN, and $(foF2)^2$ for the period between 1994–2014. The critical frequency, $foF2$ is a quantity proportional to the square root of the maximum electron number density of the night time F-region of the Earth's ionosphere. The $foF2$ was obtained using continuous data from a digital ionosonde at an equatorial station in Trivandurm, India. Evident from Fig.2 (middle panel) is a tight relation between SSN and $foF2$ with a correlation coefficient of R = 0.96 as shown in the inset figure. We estimated the average value of $(foF2)^2$ during 2008–2009, corresponding to the period of the deep minimum of cycle 23, to be $\sim$10 $(MHz)^2$ implying an ionospheric reflection cutoff of $<$ 3.5 MHz.

The long term decline in solar magnetic fields can induce changes in the IMF and solar wind dynamic pressure, which principally determines the shape of the Earth's magnetosphere. The changes in the shape of Earth's magnetosphere can be known by determining the shape of magnetopause (MP), which bounds the Earth's magnetosphere and typically have a stand-off distance of $\sim 9.9\ R_E$. We determined the MP shape by using the functional form prescribed by Lin et al. 2010.

$$r = r_{mp} \left\{ \cos\frac{\theta}{2} + a_5 \cdot \sin(2\theta)[1 + \exp(-\theta)] \right\}^{\beta} \ R_E. \quad (2.1)$$

where $r_{mp}$ is the MP stand-off distance, $\theta$ is the solar zenith angle, and $\beta$ is the flaring parameter. To obtain the MP shape, we plotted $X_s = rsin(\theta)$ against $R_s = rcos(\theta)$, averaged over 11 years, between $\theta = 0°$ and $\theta = 90°$, as shown in Fig.2 (right panel), where $X_s$ is the stand-off distance along the earth-sun line for the day-side MP and $R_s$ is the transverse radius. The average MP shape for each 11 year is labelled by the starting year, *e.g.* the MP shape of 1963, shown by the black curve, refers to the average MP shape during 1963–1974. The grey band indicates a $1\sigma$ distribution of the average MP shape. It is seen from Fig.2 (right panel) that the MP shape in 1996 is well below the grey band. However, during 2007–2016, the MP shape has expanded beyond the grey band.

## 3. Discussion and Conclusion

Our study of solar polar field reversal showed an unusual and hemispherically asymmetric pattern with the reversal in the Northern hemisphere being completed by the end of 2014 (Janardhan et al., 2018), as opposed to a study by Gopalswamy et al., 2016, which suggested the reversal in the north was completed by the end of 2015. The continuation of decline in the polar field strength of the Northern hemisphere in cycle 24 explains the observed prolonged condition of polar field reversal in the Northern hemisphere. The study of response at near-Earth space to the long term decline in solar magnetic fields showed a significant decrease in the night time ionospheric cut-off frequency to be well below 10 MHz. However, a high degree of correlation between F-region maximum electron number density and sunspot number clearly suggests that the long term decline in solar photospheric fields wouldn't have any adverse impact on the Earth's ionosphere. In response to the declining fields, our study shows an increase in MP shape of the Earth's magnetopshere during cycles 23–24. The decline seen in both solar photospheric magnetic fields and solar wind micro-turbulence levels is likley to continue and hence it begs the question as to whether we are headed towards a Maunder type Grand solar minimum in the near future.

## References

Bisoi, S. K., Janardhan, P., Chakrabarty, D., Ananthakrishnan, S., & Divekar, A. 2014a, *Sol. Phys.*, 289, 41

Bisoi, S. K., Janardhan, P., Ingale, M., et al. 2014b, *Astrophys. J.*, 793, 8

Gopalswamy, N., Yashiro, S., & Akiyama, S. 2016, *ApJL*, 823, L15

Lin, R. L., Zhang, X. X., Liu, S. Q., Wang, Y. L., & Gong, J. C. 2010, *J. Geophys. Res.*, 115, A04207

Janardhan, P., Bisoi, S.K., Ananthakrishnan, S., Tokumaru, M., & Fujiki, K. 2011, *Geophys. Res. Lett.*, 38, L20108

Janardhan, P., Bisoi, S.K., Ananthakrishnan, S., et al. 2015b, *J. Geophys. Res.*, 120, 5306

Janardhan, P., Bisoi, S.K., & Gosain, S. 2010, *Sol. Phys.*, 267, 267

Janardhan, P., Fujiki, K., Ingale, M., Susanta Kumar Bisoi, & Diptiranjan Rout 2018, *A & A.*, doi:https://doi.org/10.1051/0004-6361/201832981