Temporal variations of Solar and Interplanetary conditions for the last 4 decades

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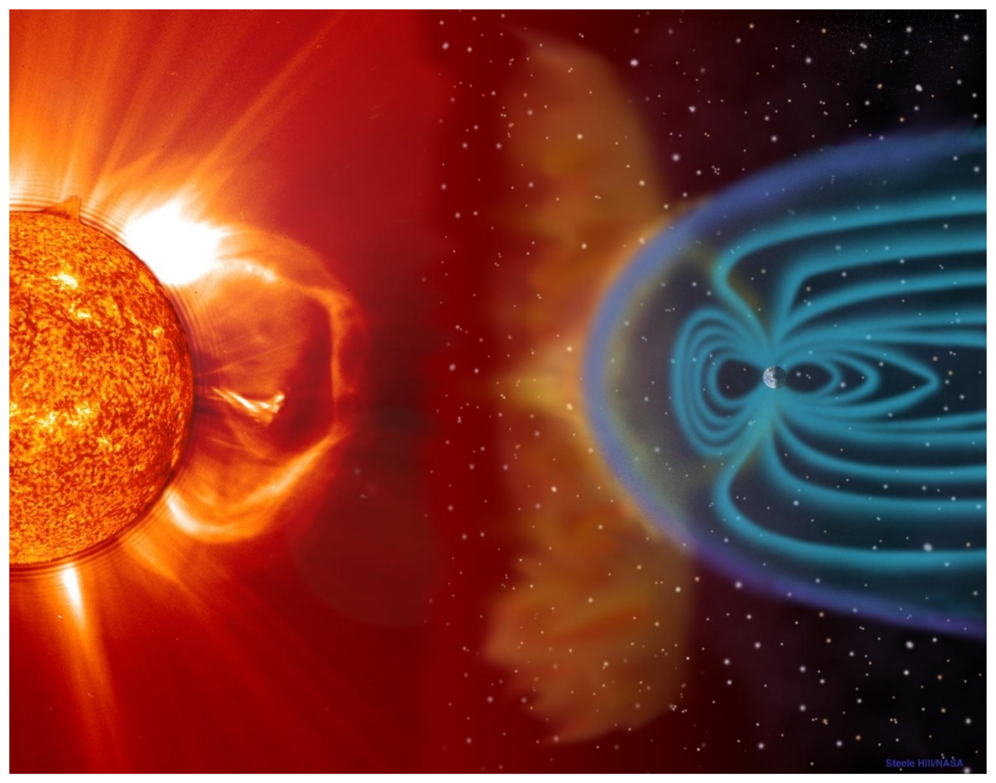
ABSTRACT

There are many parameters representing the conditions of space environments. Those are modulated in general by Solar Cycle (SC) defined by sunspot number temporal variation. However, all parameters do not have same cyclic features. Thus, we compare the temporal variations of solar, interplanetary, geomagnetic (SIG) parameters with that of open solar magnetic flux from 1976 to 2014 (from Solar Cycle 21 to the increasing phase of Cycle 24) in order to identify the possible relationships. We investigate which component of solar magnetic multipoles best correlates with the SIG parameters. As results, the dynamic pressure of the solar wind is strongly correlated with the solar magnetic dipole flux, which varies in anti-phase with SC. Other solar activity indices such as the sunspot number, total solar irradiance, 10.7cm radio flux, and solar flare occurrence and highly correlated with quadrupole component. The geomagnetic activity represented by Ap index is correlated with higher order multipole components, which show relatively a lagged time variation with SC. Given these results, we suggest that the continuous observation of solar photospheric field and calculating the multipole components of the open solar magnetic field at the source surface may complement forecasting the geomagnetic activity intensity long term trend

ITRODUCTION

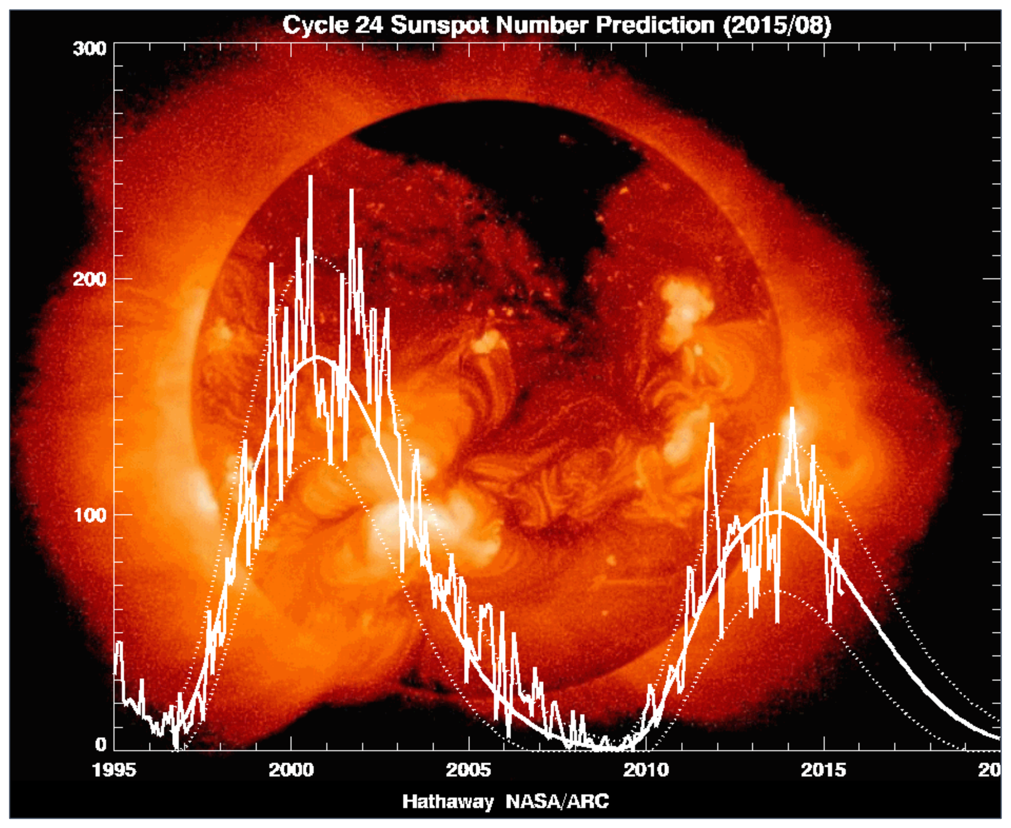
1. Relations between solar activity and Terrestrial parameter



[Figure 1] Solar activities influence terrestrial environment

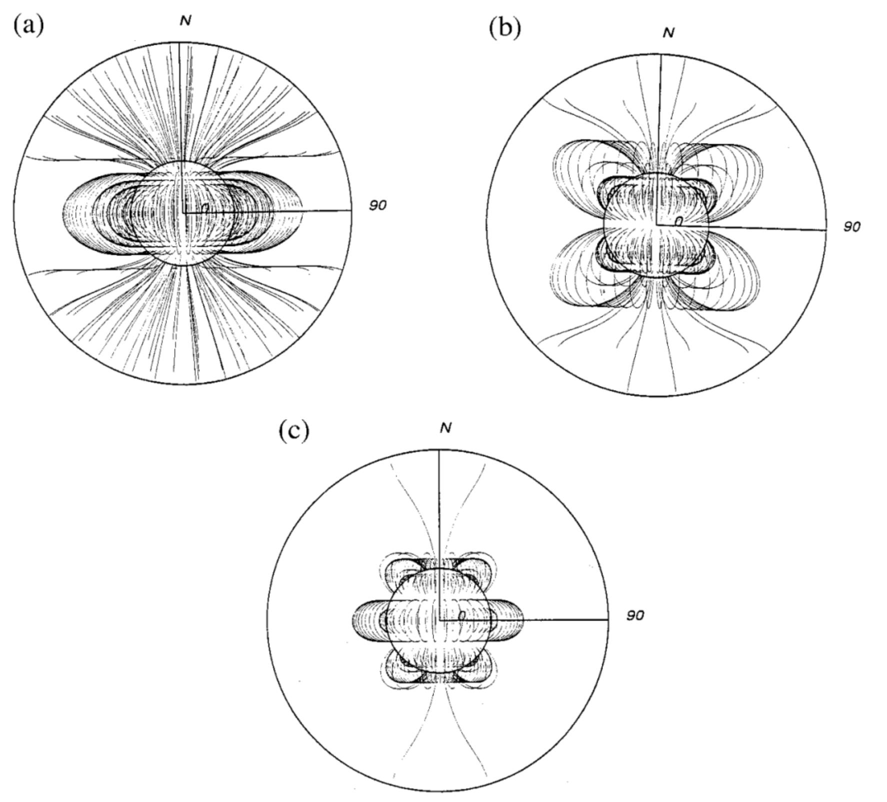
- Temporal variation of solar magnetic field underlies the interplanetary and geomagnetic activities as well as solar eruptions such as flares and coronal mass ejections. [Hathaway, 2010]
- Radio flux at 10.7cm and the number of solar flares occurred in a given time interval can also be good indicators of solar activity. [Aschwanden, 2005]
- The solar mean magnetic field (SMMF), the average field as observed over the entire visible disk is associated with the interplanetary magnetic field (IMF) that determines many geomagnetic effects. [Schatten et al., 1969]
- Interactions of the solar wind (SW) with Earth's magnetosphere would play a role in generating the geomagnetic field disturbances, and possible relationships of solar magnetic field with the geomagnetic indices(Ap index) and SW dynamic pressure have been of interest. [Smart et al., 1979]

2. Weak solar activity predicted for SC 24



[Figure 2] Current SSN cycle is predicted as the smallest sunspot cycle since Cycle 14. (http://solarscience.msfc.nasa.gov/predict.shtml)

3. The solar magnetic field multipoles



[Figure 3] Structure of the solar magnetosphere obtained when considering only the terms corresponding to (a)g_{10}, (b)g_{20}, and (c)g_{30}, which represent a dipole, a quadrupole, and a hexapole aligned to the solar rotation axis, respectively. [Bravo et al., 1998]

DATA : SIG Parameters during 36 years

It is available to describe solar magnetic field in mathematical form using the spherical harmonic function.
Assumptions for large-scale line-of-sight magnetic field are as follows:
(1) No current between photosphere and source surface. (current-free)
(2) All source surface magnetic field are radial.

Ψ is expressed as a spherical function

$$\Psi(r,\theta,\phi) = R_{\odot} \sum_{l=1}^{\infty} \sum_{m=0}^{l} \left(\frac{R_{\odot}}{R_s}\right)^{n+1} (g_l^m \cos m\varphi + h_l^m \sin m\varphi) P_l^m(\cos\theta)$$

$R_{\odot}$: solar radius at photosphere
R_S: radius from center of sun to source surface
$P_l^m(\cos\theta)$: associated Legendre function
g_l^m, h_l^m: spherical harmonic function harmonic coefficients

Because potential is not available to measure, to determine coefficients g_l^m, h_l^m we should use real line-of-sight magnetic field observed.
Each order of magnetic field can be expressed as spherical harmonic function.

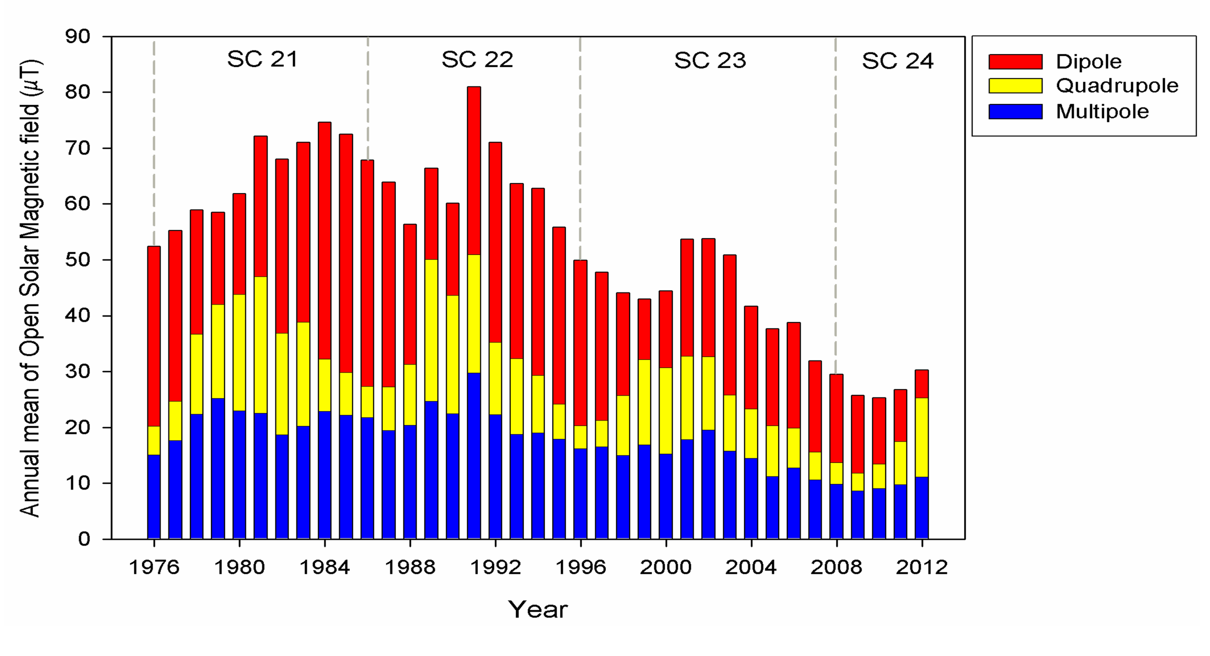
$$B_l = \frac{(2l+1)}{\left[\frac{R_S}{R_{\odot}}\right]^{l+2}} \sqrt{\sum_{m=0}^{l} (g_{lm}^2 + h_{lm}^2)}$$

Then, the total radial magnetic field strength is defined as

$$B_{tot} = \sqrt{\sum_{l=1}^{\infty} (B_l)^2} \approx \sqrt{\sum_{l=1}^{9} (B_l)^2}$$

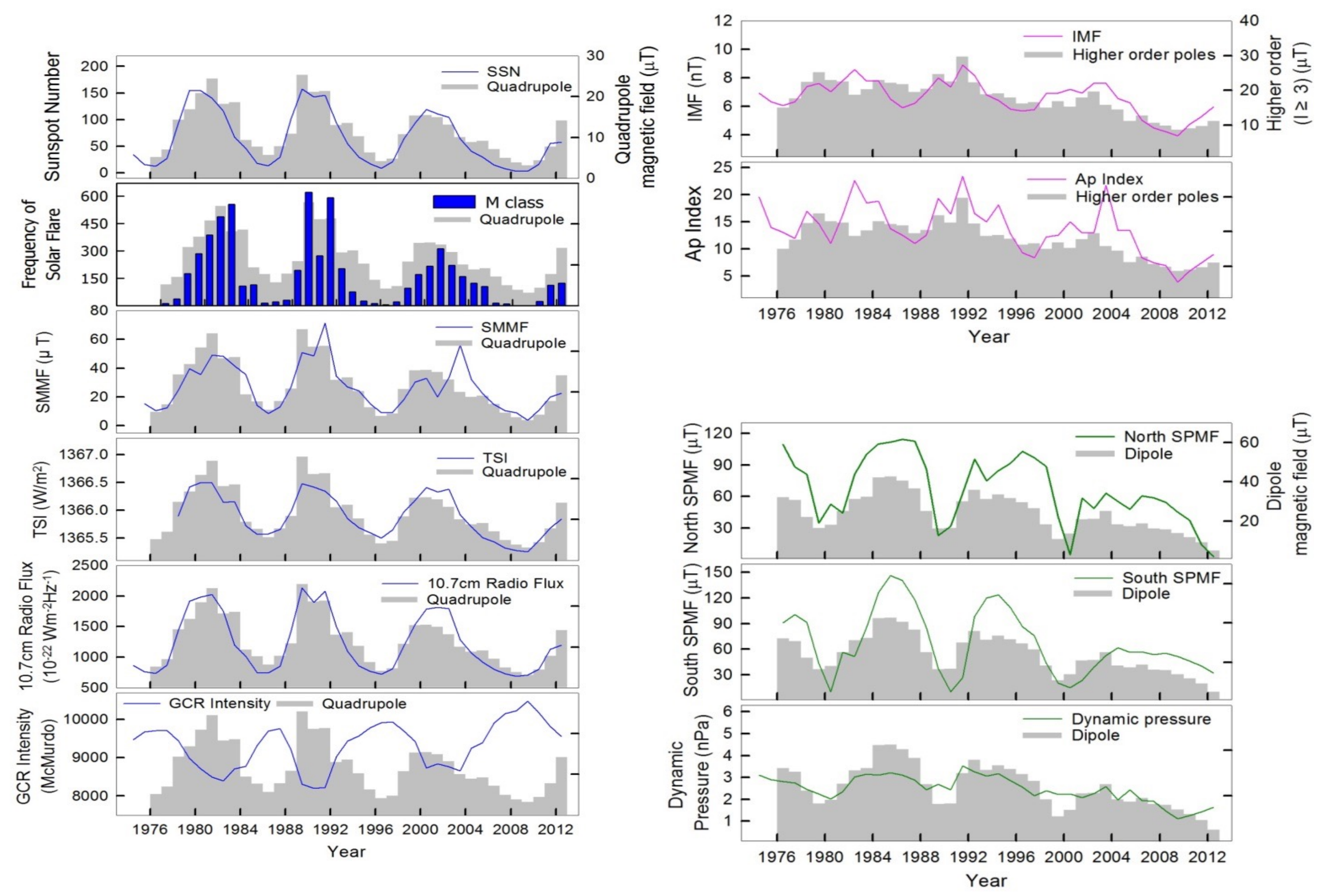
RESULTS

1. Annual averages in order to make correlations with the annual magnetic field variation



[Figure 4] Temporal variations of open solar magnetic field. Magnetic field strengths are annual average values. The dipole, quadrupole, and sum of multipole (l > 3) components are distinguished by colors.

2. The annual variations of SIG parameters



[Figure 5] Temporal variations of the SIG parameters
Left : From top to bottom, SSN, frequency of flare occurrence, SMMF, TSI, 10.7cm RF, and GCR intensity are plotted against the quadrupole field in gray background histogram.
Right up : IMF and Ap index against the higher-order multipole field in histogram.
Right bottom : Northern/southern SPMF and SW dynamic pressure against the dipole field in histogram.

3. Correlation coefficients for the SIG parameters

SIG parameter	Total	Dipole	Quadrupole	Multipole (l > 3)
SSN	0.28	-0.21	0.92	0.64
Flare occurrence	0.4	0.17	0.83	0.63
Absolute SMMF	0.32	0.01	0.88	0.60
TSI	9.38	-0.08	0.91	0.66
10.7cm RF	0.24	-0.24	0.92	0.60
GCR intensity	- 0.54	-0.13	-0.86	-0.71
IMF	0.67	0.31	0.78	0.80
A_p	0.68	0.42	0.65	0.71
Northern SPMF	0.63	0.88	-0.37	0.29
Southern SPMF	0.53	0.81	-0.45	0.16
Dynamic pressure	0.90	0.83	0.27	0.72

[Table 1] Correlation coefficients (CC) calculated for all pairs of the individual parameter and the solar open magnetic field

SUMMARY

We investigate which component of solar magnetic multipoles best correlates with the SIG parameters with the aid of the PFSS model along with the WSO data. The summary is as following:

1. Most SIG parameters except the SW dynamic pressure show rather poor correlations with the total solar flux field. The total strength of open solar magnetic field has a strong correlations with SW dynamic pressure.
2. SSN, flare occurrence frequency, SMMF, TSI, and 10.7cm RF are more strongly tied to the quadrupole and higher order (l ≥ 3) poles.
3. Total solar open field is also reduced since SC21, and that this is closely related to the decrease of the SW dynamic pressure, SPMF, IMF and A_p index and icrease of GCR intensity.
4. We suggest that counting the multipole components of the open solar magnetic field at the source surface can complement the study of the geomagnetic activity solely based on solar photospheric field observations.

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