Journal of Atmospheric and Solar-Terrestrial Physics 140 (2016) 41–54

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Research paper

Solar daily variation at geomagnetic observatories in Pakistan

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ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form
11 November 2015
Accepted 25 January 2016
Available online 26 January 2016

Keywords:
Solar daily variation
Solar quiet daily variation
Geomagnetic field
Sunspot number
Magnetic activity
$F_{10.7}$ solar radio flux

ABSTRACT

A study of solar daily variation is performed using the famous Chapman–Miller method for solar cycles 22 & 23 (1986–2007). The objective is to study the characteristics of S_q variation at Pakistani geomagnetic observatories using solar harmonics and a more traditional five quietest day's method. The data recorded at the Karachi geomagnetic observatory for SC 22 and 23 and data sets from other Pakistani geomagnetic observatories; Sonmiani, Quetta and Islamabad are analyzed for H, D and Z components of the geomagnetic field.

Except for the D and Z components at Karachi and Sonmiani and H component at Islamabad, the two solar daily variations correlated well with each other. Also, the synthesized daily variation from the solar harmonics of H, D and Z components explained the equivalent S_q current system reasonably well for all seasons.

For H component, the first solar harmonic (s_1) obtained from spherical harmonic analysis of the data, appeared as the largest harmonic with no significant changes for the seasonal division of data. However, for D and Z components, amplitudes are comparable, but undergo distinct variations. s_1 for H and D components increases with magnetic activity while for Z component it is the largest for the medium phase of magnetic activity. With the sunspot number division of data, the weighted mean of the Wolf ratio of all three components is in good agreement with the previous studies.

The synthesized solar daily variation for D component, $S(D)$, at Karachi, Sonmiani, Quetta and Islamabad did not show any signs of winter anomaly for the period studied. However, S(D) variation at Karachi during winter season showed morning minimum followed by a maximum at local noon and another minimum in the afternoon. We suggest this could be the effects of Equatorial Ionospheric Anomaly (EIA) observable at the Karachi observatory only during the winter season. Similarly, much disturbed in equinoctial and summer months, $S(Z)$ illustrated an unwavering daily variation for the winter season at the Karachi observatory for both solar cycles. We find that it is the vertical component which is more strongly correlated with the mean monthly sunspot number and $F_{10.7}$ solar radio flux. An interesting result obtained at Islamabad is the semi-diurnal variation of H component with a morning maximum and afternoon minimum and the phase reversal noticed for Z component variation. Attributed to an early eastward current this is, usually, observed for stations close to the S_q focus current system.

1. Introduction

Chapman and Bartels (1940) derived the solar quiet daily variation (S_q) from five quietest days considered for a month. Matsushita and Maeda (1965) suggested removing the effects of lunar variations also for a true S_q variation. Campbell (2003) defined the term 'S_q' as the solar quiet daily field change in local-time when solar-terrestrial disturbances are absent and the effect of the lunar tidal current system (L) has been removed. Campbell (1989) explained the process of dynamo current in the ionospheric E-region that produces the S_q field. Thermotidal motions, thermospheric winds and lunar tidal forces caused the movements of ionized particles produced by the incoming radiation from the sun. The motion of electrons, thus produces the S_q and L fields.

Several studies have been undertaken in African and Indian longitudinal sectors studying the S_q variations from the magnetic equator up to low and middle latitudes. Some of them are Patil et al. (1983), Rastogi et al. (1994), Okeke et al. (1998), Okeke and Rabiu (2000), Rabiu (2001), Abgo et al. (2010) and Obiekezie (2012). Since the daily variation in H component undergoes phase reversal between Gulmarg and Tashkent, Patil et al. (1983) showed the focus of the S_q current system located close to Gulmarg for the northern hemisphere. A global study of S_q field by Matsushita and Maeda (1965) discussed the seasonal, hemispheric and longitudinal zone dependence of internal and external current systems. They also pointed out the asymmetric pattern during equinoxes and the entire year for both hemispheres. Hitchman and Lilley (1998) also

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http://dx.doi.org/10.1016/j.jastp.2016.01.016
1364-6826/

determined the seasonal variations and latitudinal dependence of global S_q field curves. Okeke et al. (1998) distinguished three different parts of the S_q field; the worldwide part (WS_q), the equatorial electrojet (EEJ) part and the combined EEJ field and WS_q field.

Most of the studies mentioned above used the five quietest day's method to study the S_q variations. However, there is another way of explaining the overhead S_q current system using solar and lunar harmonics obtained from the Chapman–Miller method (Chapman and Miller, 1940). Such an approach could be useful for studying the characteristics of quiet daily variation for a large amount of geomagnetic data. Gupta and Malin (1972) discussed that although the coefficients of S differ from those of S_q, solar harmonics are sufficient for an overall measure of solar quiet variation. Cueto et al. (2003) found the correlation between the smallest S_q variation, observed in J-season, and the first solar harmonic (s_1) amplitude of X (or H) component at Iberian Peninsula. Celik et al. (2012) also obtained the similar results for geomagnetic observatories in the northwestern part of Turkey.

In this study, not only we examined the variation of individual solar harmonics for different groups of data sets, we also explained the characteristics of $S_q$variations using the solar harmonics daily variation at Karachi (KRC), Sonmiani (SON), Quetta (QUE) and Islamabad (ISL). The two daily variations from harmonics and five quietest days are compared to their likenesses and differences using the quietest data available for a year at SON, QUE and ISL. S_q variations at KRC are studied in greater details using seasonal, sunspot ad magnetic activity divisions of data. Section 2 describes the data availability and in Section 3 we define the methodology. Results and discussion are presented in Section 4 while Section 5 outlines the conclusions.

2. Data availability

Spreading over an area of 796,095 km^2 in the latitude range of 23°–40° and the longitude range of 60°–80° (geographic), Pakistan has been engaged in the geomagnetic field monitoring for more than 50 years. Fig. 1 points out the locations of present and previously installed geomagnetic observatories in Pakistan. Pakistan Meteorological Department (PMD) collaborated with British Geological Survey (BGS) to set up the first geomagnetic observatory at Quetta, (30.18°N, 67.00°E). Then in 1967 PMD and BGS set up another observatory at Gilgit (35.92°N, 74.28°E) which acquired the analogue data. Both these observatories remained operational until 1990. In 1983, Pakistan Space and Upper Atmosphere Research Commission (SUPARCO) installed a new geomagnetic observatory at Karachi (24.95°N, 67.14°E). The observatory was equipped with AMOS-III (Automatic Magnetic Observatory System) consisting of Fluxgate Magnetometer System FM-100C for X, Y, Z component measurement and Proton Precession Magnetometer System (PPM-105) for total field measurements. Then in 2007, because of the nearby urbanization, the instrumental setup shifted to a new location Sonmiani, (25.42°N, 66.59°E), 85 Km North-West of Karachi. In July 2008, along with Sonmiani, SUPARCO started another geomagnetic observatory at Islamabad (33.71°N, 73.06°E). While the other observatories have ended their operation, only SON and ISL are still in operation. Table 1 summarizes the data used in this study from all observatories.

Annual summaries of Quetta and Gilgit geomagnetic data were published by PMD then which are now available online in digital format as "Geomagnetic Observatories of Pakistan: Quetta and Gilgit Observatories".[1] Right now the largest data set available for any observatory is KRC covering two solar cycles (SC 22 and SC 23) available with the observatory, except for the years 1987, 1990, 2000 and 2001. However, hourly means from 1996 to 1999 for KRC and 1965 for QUE are also available at the World Data Center (WDC) for Geomagnetism.[2] We did not include 1999 in our study as there was insufficient data available for its analysis. Geomagnetic data of the SON and ISL is uploaded by SUPARCO to International Real-Time Magnetic Observatory Network (INTERMAGNET).[3] SON has acquired the status of IMO certified as of December 19, 2014. ISL, however, is still at test status. For this study, we used only 2009 from SON and 2012 from ISL for analysis.

3. Methodology

S_q variations from the five quietest day's method are produced from 24 hourly means of the quietest days selected at all observatories. Some International Quiet Days (IQDs), based on K_p index, did not produce the quiet daily variation for a geomagnetic component at a particular observatory, we, therefore, checked each individual day for its daily variation and the days with only true quiet daily variation are counted as the quietest days and included in the study.

K_p indices are determined from European, North American and Australian/New Zealand geomagnetic observatories. A magnetic observatory that does not belong to any of these geographical locations might record a different variation then a quiet day. We further noticed that a quiet day for any component may not be simultaneously quiet for other components. At ISL, we obtained more disturbed days for H component and few for Z component. Conversely, at SON and KRC, the Z component appeared more disturbed while more stable variations occurred in H component. Overall, D component variation on any of the stations provided more quiet days than H and Z components. Although the real external current system showed complicated geometries therefore usually all components manifest disturbance at the same time. However, theoretically speaking, a disturbance produced by a current system lying exactly parallel to a component may produce a quiet geomagnetic day for that component leaving the other disturbed. For example, an electric current along Y direction may produce a quiet geomagnetic day for Y or D component, while X or H and Z components may describe a disturbed variation.

For solar harmonics and five quietest days method, we then used the definition of the Lloyd's season as,

D-season: Jan, Feb, Nov, Dec
E-session: Mar, Apr, Sep, Oct
J-season: May, Jun, Jul, Aug

Five quietest days per month, typically leads up to twenty quietest days for a season. Due to the missing days in some years, we took the criteria as twenty quietest days per season. Selected quietest days provided the hourly means for each season obtained by averaging the corresponding hourly amplitudes for each month. Hourly means are further corrected for non-cyclic variations by subtracting the average of 23:00–02:00 means from 24 hourly mean values (Tarply, 1973).

Chapman–Miller method provided the solar daily variation from solar harmonics and phase angles by synthesizing hourly amplitudes for each component (Eq. (1)).

$$S(K)= \sum_{p=1}^{4} s_p \sin\left(pt+\sigma_p\right) \tag{1}$$

s_p, σ_p are amplitude and phase for *pth* harmonic and t is the time from 0 to 23 h (Chapman and Bartels, 1940).

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[1] http://www.wdc.bgs.ac.uk/catalog/master.html.

[2] http://www.worldcat.org/.

[3] http://www.intermagnet.org/index-eng.php.