Sq-Field Behaviour & Daily H, D-component Variability at Sonmiani Geomagnetic Observatory, Pakistan

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ABSTRACT

First results are presented on the behaviour of solar quiet-day (Sq) variations of north-south (H) and east-west (D) component of geomagnetic field at Sonmiani geomagnetic observatory (SON) for data set 2009-2012. The hourly mean values are used to study the variation of the components and only quiet conditions are examined. It is found that variation of Sq(H) and Sq(D) is a dawn to dusk phenomenon with non zero variation at night-time and pre-sunrise hour. H-component has its maximum in equinoctial months whereas D-component attains maximum values in June solstice. Day-to-Day variability in H and D-components is observed even on quiet days which can be attributed to the variability of ionospheric conductivities and local atmospheric wind pattern. We found that monthly mean variations show diurnal variations in H-component and semi-diurnal for D-component whereas seasonal variations are found to have semi-annual pattern for H-component and annual pattern for D-component. Equinoctial asymmetry is also observed in both components with spring amplitude consistently greater than summer. The amplitude of annual mean is greater for H-component than D with D-component variation consistently shown smaller amplitude for morning eastward maximum and greater amplitude for afternoon westward maximum for the study period. Diurnal variation with Semi-annual characteristics is observed for observatories in northern hemisphere for local winter and summer season whereas for observatories in southern hemisphere diurnal variation is observed for local summer season and semi-diurnal for local winter season for H-component. However, for D-component semi-diurnal variation with annual varying pattern is seen for observatories in both hemispheres. We also observed the winter anomaly at Sonmiani in D-component which could be due to the movement of Sq focus position to the lower latitudes. It is therefore concluded that the behaviour of Sq current system observed at Sonmiani agrees with previous studies carried out for this longitude sector. However, at SON we observe consistently morning and evening negative amplitudes with secondary maxima in D months. Since winter has higher possibility of occurrence of Abnormal Quiet days (AQD) it is suggested that this may be due to abnormal behaviour of Sq field at Sonmiani. Also, sea surface and ground induced current may affect the regular quiet daily variation and only detailed Sq modelling at Sonmiani could answer these observed features.

Keywords—Geomagnetism, Solar Quiet (Sq) Daily Variation, Pakistani latitude, Equatorial electrojet
• Highlights of the talk
• Introduction to Geomagnetic field and the Sonmiani Geomagnetic Observatory
• Objectives/Motivations
  ▫ Solar quiet variation (Sq field) study for SON Geomagnetic field
• Data selection
• Methodology
• Results & discussions
  ▫ Day to day variability of Sq (H) & Sq (D)
  ▫ Monthly Variation of Sq (H) & Sq (D)
  ▫ Seasonal Sq Variation
  ▫ Seasonal variation in similar time zones (latitudinal) in comparison with other observatories
  ▫ Seasonal variation at same latitudes (longitudinal) in comparison with other observatories
  ▫ Annual mean Sq variation
• Future advancements
• Acknowledgements
• References
HIGHLIGHTS

• First results of solar quiet daily variation at Sonmiani Geomagnetic Observatory are presented which lies at the foothills of the Equatorial Ionization Anomaly (EIA) Region~2000km from magnetic equator
• Results obtained from day-to-day, monthly, and seasonal analysis agree in comparison with the previous studies carried out in solar cycle 23
• Results obtained also agree with the African sector observatories lying in similar latitude as SON
• Winter anomaly is observed at SON in the D-component
Brief introduction to Sq field variation
The Geomagnetic field components:

- **B** - The geomagnetic field vector (Magnetic Induction)
- **H** - Horizontal intensity
- **I** - Inclination (the angle between the horizontal plane and the field vector, measured positive downwards): \( \tan^{-1}\left(\frac{Z}{H}\right) \)
- **D** - Declination (the horizontal angle between true north and the field vector, measured positive eastwards): \( \tan^{-1}\left(\frac{Y}{X}\right) \)
- **X** - Easterly intensity
- **Y** - Northerly intensity
- **Z** - Vertical intensity, positive downwards
The Abdul Salam Geomagnetic Observatory, Sonmiani

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<td>Data Orientation</td>
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<td>Absolute Instruments</td>
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ANNUAL MEAN VALUES
Sonmiani, SON, Pakistan
COLATITUDE: 64.805 LONGITUDE: 66.748 W
ELEVATION: 8 meters

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<th>YEAR</th>
<th>D</th>
<th>I</th>
<th>H</th>
<th>X</th>
<th>Y</th>
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Geomagnetic Observatory, Sonmiani

MinGeo
Declination/Inclination
Theodolite, ZEISS THEO 010

dIdD Variometer

LAMA Variometer, IRM, Belgium made
Objectives/Motivation

• Sq field variation has been studied/analyzed for a decade and proves to be an invaluable tool for studying the overhead ionospheric current movement from ground based observations of the geomagnetic field (W.H. Campbell, 2003; F.N. Okeke et.al., 1998; Onwumichelli, 1992; M. Hasegawa, 1960; Matsushita et.al. 1965; Rastogi et.al. 1994; A.B. Rabiu, 2001; Pham Thi Ti et.al. 2011)

• There was a need/curiosity to find out the nature of the Sq field in the local geomagnetic field for Solar Cycle 24 for the Sonmiani Region

• To validate the K-Indices and report processed observatory data for the first time (published, Zain etal., 2012)
Data Selection and availability

Geomagnetic field data:

- Hourly averaged definitive data of D & H, 2009-2012 of SON & other observatories
- Longitude sector (Table I) comprising of observatories lying within 65°±15° from WDC, Kyoto
- Latitudinal sector (Table II) comprising of observatories lying within 20°±5° from WDC, Kyoto

<table>
<thead>
<tr>
<th>Station Name</th>
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<th>Geographic Coordinates</th>
<th>Geomagnetic Coordinates</th>
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<td>Novosibirsk</td>
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<td>43.25 76.92</td>
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<td>SON</td>
<td>25.20 66.75</td>
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<tr>
<td>Martin De Vivies</td>
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<td>-37.83 77.57</td>
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<td>Crozet</td>
<td>CZT</td>
<td>-46.43 51.87</td>
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<td>Port Aux Francais</td>
<td>PAF</td>
<td>-49.35 70.22</td>
<td>-57.31 130.79</td>
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<table>
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<th>Station Name</th>
<th>Station Code</th>
<th>Geographic Coordinates</th>
<th>Geomagnetic Coordinates</th>
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<td>SON</td>
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<td>17.50 141.58</td>
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<td>Phu Thuy</td>
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<td>23.09 113.343</td>
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<td>21.32 202.00</td>
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<td>Mbour</td>
<td>MBO</td>
<td>14.40 343.72</td>
<td>20.68 56.80</td>
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</table>
Methodology

• **Selection of Quiet days:**
  - 5 quietest days of every month considered (Chapman & Bartels, 1940) according to available list of International Quiet & Disturbed days (IQD, IDD—Geomagnetism Australia, GFZ-Potsdam)
  - Manual check of individual days of the months (as per Matsushita et. Al, 1965) according to Kp (≤+2) and Ap index levels (≤20 nT)

• **Lloyd seasons:** (Chapman & Bartels, 1940)
  
<table>
<thead>
<tr>
<th>Season</th>
<th>Months</th>
<th>Phenomenon</th>
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<tbody>
<tr>
<td>D</td>
<td>Jan, Feb, Nov, Dec</td>
<td>Winter Solstice</td>
</tr>
<tr>
<td>E1</td>
<td>Mar, Apr</td>
<td>Spring Equinox</td>
</tr>
<tr>
<td>J</td>
<td>May, Jun, Jul, Aug</td>
<td>Summer Solstice</td>
</tr>
<tr>
<td>E2</td>
<td>Sept, Oct</td>
<td>Autumnal Equinox</td>
</tr>
</tbody>
</table>

• **Diurnal variations:**
  - day-to-day variability, monthly variation, seasonal variation & annual variation
  - Monthly Diurnal averages calculated as follows: (deviation from night time values; Tarpley, 1973)
    
    \[
    S_q(K) = \frac{1}{5} \sum_{i=1}^{24} K_i
    \]
    
    Where \( K_i \) signifies H or D-comp hrly avg, \( i=1,2,...,24 \)
  - Seasonal means taken as means of months; annual means taken from corresponding hours of the months in the year
  - Day-to-day hourly amplitudes taken as difference between corresponding hours of consecutive days
    
    \[
    S_{DD}(K) = K_j^i - K_{j+1}^i
    \]
    
    Where \( K_i \) signifies H or D-comp hrly avg, \( i=1,2,...,24 \), \( j, j+1 \) denote consecutive days
Results and discussions

1. Day to day variability of Sq (H) & Sq (D)
2. Monthly Variation of Sq (H) & Sq (D)
3. Seasonal Sq Variation
4. Seasonal variation in similar time zones (latitudinal) in comparison with other observatories
5. Seasonal variation at same latitudes (longitudinal) in comparison with other observatories
6. Annual mean Sq variation
Day-to-day variability of Sq(H) and Sq(D) at SON

- Consecutive days taken for Aug 2009, March 2011, (5 consecutive days in a row) March 2012
- Highly random, variable, with no periodical behaviour
- Prominent variations observed for night-time hours
- Results obtained in good agreement with African and Equatorial latitude observatories (T. N. Obeikezie et.al. 2013; Okeke et.al. 1998; Okeke et.al. 2000)
- Okeke et.al. 2000, reasoned for the randomness of the intensities of components due to the roleplay of atmospheric winds contributing to the E-region dynamo along with the solar drivers
Monthly Variation of Sq (H) and Sq (D) for SON

- Diurnal monthly variation in phase and amplitude of Sq (H) attributed to change in intensity of ionospheric conductivity (Okeke et al., 1998)
- Appearances of secondary maximum around 8-9 LT in Nov, Dec with full manifestation in Jan. CEJ likely cause (Mayaud, 1977) but confined to ±12° from dip equator.
- Maximum amplitudes in E months but J months show increase amplitudes during more solar active years.
- Semi-diurnal Sq (D) variations with greater amplitudes in J months
- Sq (D) variation in Feb 2009 is found to be exactly reversed
- Winter anomaly seen in Dec 2012, neg amplitude throughout (seen by Campbell et.al. 1993, for India-Siberia region)
Seasonal Sq variation

- Equinoctial asymmetry in Sq (H) with E1 amplitudes 21 nT, 30 nT, 39 nT & 30 nT for 2009-2012 resp., same results as Gupta et.al. 1973
- Matsushita et.al., 1965 attributed this enhancement to increased ionospheric E-region current increase
- Maximum amplitude of Sq (D) seen for 2009 & 2012 in June solstice & min in winter solstice in agreement with Pham et.al., 2011; Rabiu, 2001 & Okeke et.al. 1998
- Equinoctial asymmetry of Sq(D) amplitudes observed with E2 months max in 2009 & 2010 and E1 max in 2011 & 2012
- Hasegawa, 1960 attributed such seasonal changes to alteration in the Sq current system due to changing atmospheric wind patterns
Sq seasonal variations in similar time zones (latitudinal) in comparison with other observatories

- Sq (H) & Sq (D) for D & J season, 2009 studied
- NVS & AAA both have ~12 nT Sq(H) amplitudes while at SON, amplitude increases to 18 nT
- Amplitude reversal taking between SON and higher latitudes as indicated by Matsuhita et.al., 1965 & Hitchman et.al., 1998 (reversal between 25° & 30° geomagnetic latitudes)
- AMS~ 21 nT, ~16.5 nT & 23 nT for CZT & PAF; summer amplitudes in SH higher but situation reversed in winters; Gupta et.al., 1972, found midlatitude amplitudes being higher in NH but for polar latitudes, situation is reversed
- Sq (D) amplitudes minimum for NH observatories experiencing winter whereas situation reversed as season changes
- For AAA, NVS, PAF & AMS, in D-season, change from forenoon max to afternoon min takes place at around 11-12 LT but for SON it occurs at around 10-11 LT; for CZT, around 13-14 LT
- For J-season, for AAA & SON, change occurs around 10-11 LT and for NVS, PAF & AMS at 11-12 LT; for CZT, around 13-14 LT
Sq seasonal variations in similar latitudes (longitudinal) in comparison with other observatories

- Sq (H) & Sq (D) for D & J season, 2009 studied for all northern & midlatitude Observatories, MBO is Equatorial obs lying in the EEJ region
- For D-season, all obs except PHU, has Sq (H) maxima occurring at 10-11 LT; SON & HON have secondary maxima near local noon & SON only has night-time variation as negative.
- Equatorial enhancement of MBO clearly visible
- For J-season, the Sq (H) amplitude variation is slightly suppressed for SON & HON
- Sq (D) variations, for D-season, much variable for all stations with prominent semi-diurnal variations for TAM & HON; SON, PHU, GZH are found to have secondary maxima & minima; note worthily, MBO amplitude remains negative throughout
- Amplitude for J-season is smaller in comparison for D-season for all observatories; Sq (H) variations being more susceptible to neg amp in night-time than morning for J-season as compared to D-season
- SON has highest negative amplitude variation in morning & evening
Sq Annual Mean Variation at SON

2009 being the lowest in amplitude variation, ~18 nT, and 2011 being the largest with ~29 nT. This annual variation in amplitudes suggest that, except for the primary cause of its generation which is solar radiation and dynamo action in E-region of earth atmosphere, the Sq field is affected by some other auxiliary sources that enhances/reduces the ionization ultimately changing the amplitudes. The night time variation observed for 18-23 hr are much more correlated and negative than those during 0-8 hr variation. The ionization started to increase steeply from 09 hr and in next three hours reaches to its maximum value where it starts to decrease till 18 hr. It shows that the rate of increase in ionization in morning is faster than the recombination of electrons and ions into neutral particles. (W. H. Campbell, 2001)

The annual Sq(D) variation shows the semi-diurnal variation with morning northward maximum and evening southward minimum with the change taking place around 10-11 hr LT. As for Sq(H), the amplitudes variation are more pronounced in 2011 and least in 2009.
Conclusions

- Variation of $\text{Sq}(H)$ an $\text{Sq}(D)$ is a dawn to dusk phenomenon with non zero variation observed at night-time and pre-sunrise hour.
- Variations observed other than day time are attributed to sources other than ionospheric dynamo currents which mainly includes ring current in magnetopause.
- Phase variation depends upon electric field and intensity of amplitude variation depends upon the magnitude of ionospheric conductivity.
- Seasonal variations in both components are observed with semi-annual pattern for $H$-component and annual pattern for $D$-component. Also $H$-component has its maximum in equinocial months whereas $D$-component has its maximum values observed in $J$ solstice. Such seasonal variations are attributed to seasonal shift in the position of $\text{Sq}$ current system as the earth changes its position in orbit.
- For $\text{Sq}(H)$, the rate of building up ionospheric $\text{Sq}$ current is faster than the rate of its decay after attaining noon maximum.
- The magnitude of annual mean is greater for $H$-component than $D$.
- Day-to-Day variability in $H$ and $D$-components even on quiet days suggests the variability of ionospheric conductivities and local atmospheric wind pattern are the main cause.
- Monthly mean variations show diurnal variations in $H$-component and semi-diurnal for $D$-component. Seasonal maximum in $H$ occur in equinocial months followed by $D$ solstice and the minimum in June solstice. On the other hand a $D$-component has its seasonal maximum in June solstice followed by equinoctial months and minimum in December solstice. Seasonal variability is explained in terms of variability of semi diurnal tides, seasonal variability of $\text{Sq}$ focus and the variability of ionospheric conductivity.
- Equinoctial asymmetry is observed in both $H$ and $D$-components with spring amplitude consistently greater than autumn amplitude, whereas for $D$-component spring amplitude is greater for less active years and autumn amplitudes are greater for more active years.
- Annual means of semi diurnal $D$-component variation consistently show smaller amplitude for morning eastward maximum and greater amplitude for afternoon westward maximum for the study period. This may be related to the lesser rate of ionization in morning hours than afternoon/evening hours. Also the wind pattern may sometimes be in the same direction or sometimes in opposite direction of earth rotation may produce increase or decrease in amplitudes respectively.
- Annual variation in $D$-component is observed for observatories in both hemisphere, although the direction is opposite of each other because of counter clockwise movement of $\text{Sq}$ current in northern hemisphere and clock wise in southern hemisphere.
- For this longitudinal sector, diurnal variation with Semi-annual characteristics is observed for observatories in northern hemisphere for local winter and summer season whereas for observatories in southern hemisphere diurnal variation is observed for local summer season and semi-diurnal for local winter season for $H$-component. However for $D$-component semi-diurnal variation with annual varying pattern is seen for observatories in both hemispheres.
- Winter anomaly is observed at SON in $D$-component which could be due to the movement of $\text{Sq}$ focus position to the lower latitudes.
- The behaviour of $\text{Sq}$ current system observed at SON agrees with the results of Rastogi et.al. 1994. However at SON we observe consistently morning and evening negative amplitudes with secondary maxima in $D$ months. Since winter has higher possibility of occurrence of AQD, it is suggested that this may be due to abnormal behaviour of $\text{Sq}$ field at Son. Also, sea surface and ground induced current may affect the regular quiet daily variation. $\text{Sq}$ modelling at Sonmiani could provide some more insight into these observed features.
Future advancements

• Detailed Sq field modelling at SON

• Combined analysis using ionospheric and geomagnetic field components

• Analysis of relationship between the EEJ and Sq field at Sonmiani’s magnetic latitude
Acknowledgements

Authors are thankful to the World Data Centre, Kyoto, Japan and INTERMAGNET for their availability of the definitive hourly mean values of international observatories used in this analysis.
References

THANK YOU