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Long-term Variation in the Upper Atmosphere as Seen in the Geomagnetic Solar Quiet (Sq) Daily Variation

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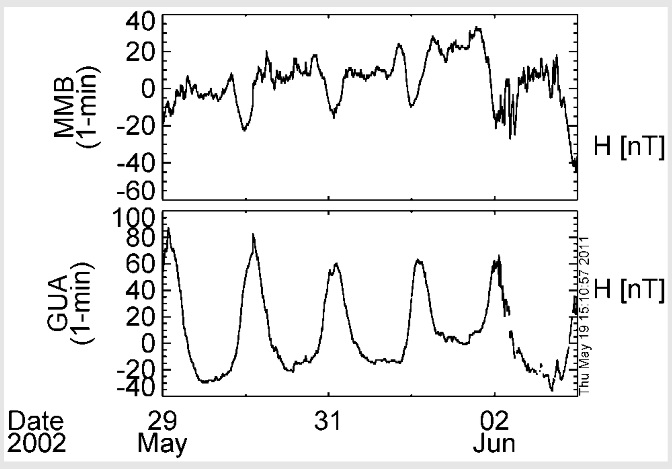
1. Introduction

1.1 Geomagnetic solar daily quiet (Sq) variation and its current system



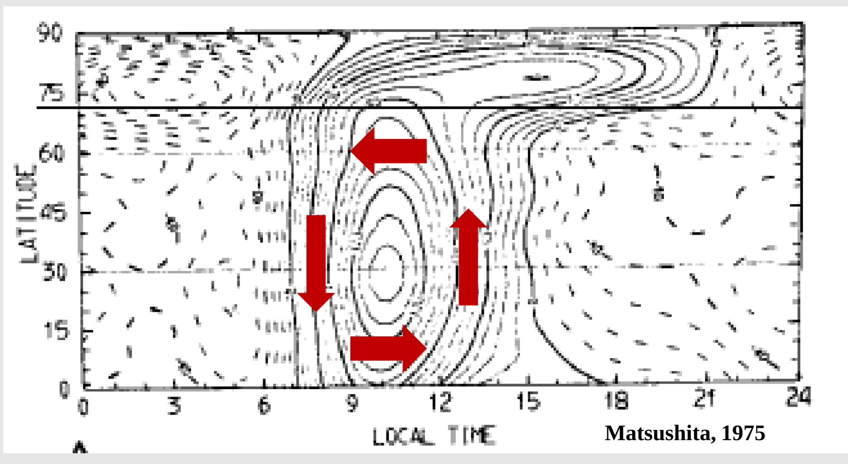


Fig.1: (a) An example of Sq variation observed at middle latitude and equator and (b) equivalent current plotted as functions of local time and latitude derived from the KRM method [Matsushita, 1975]. The Sq variation shows positive and negative change in the H-component in the equatorial and middle –latitude regions.

The daily variation of geomagnetic field during solar quiet days has been called Sq (geomagnetic Solar daily Quiet variation), and is mainly produced by ionospheric currents, which are driven by ionospheric dynamo at the E-region altitude via interaction between neutral and ionized particles. Since the Sq amplitude strongly depends on ionospheric conductivity and neutral wind in the lower thermosphere and mesosphere, we can investigate the long-term variation of the Earth's upper atmosphere from the trend of the Sq amplitude.

1.2 Pervious works on the long-term variation of the Sq amplitude

Table 1. Summary of previous works on the long-term Sq variation

	Observation points	Solar index	Sq trend	Effect of secular variation of gmag.	Comments
Sellek [1980]	3	Sunspot	Increase	◎	First paper
Schlapp et al. [1990]	11	Sunspot	Increase	◎	Magnitude of Sq trend is different from different observation points.
Macmillan and Droujinina [2007]	14	F10.7	Depend on observation points	◎	Yearly variations of Sq field can be used as a proxy of solar irradiance.
Elias et al. [2010]	3	Sunspot	Increase	◎	Long-term trends in the Sq field is linked to upper atmospheric variation associated with greenhouse effect.

Recently, Elias et al. [2010] found that the Sq amplitude observed at Apia, Fredericksburg and Hermanous show significant increasing trends for the period 1960-2001. They interpreted the Sq trends as effects on both secular variation in the ambient magnetic field intensity and upper atmospheric changes associated with global warming.

1.3 Problems of the past studies and purpose of this study

However, since Elias et al. [2010] analyzed geomagnetic field data obtained only at three stations for a short period, a global feature of the long-term Sq trends has remained unknown. They did not also perform a comparison between the Sq amplitude and neutral wind in the lower thermosphere and mesosphere.

Then, the purpose of the present study is to investigate a global feature of the long-term variation in the Sq amplitude using the long-term observation data of geomagnetic field and ionospheric conductivity model. For data search and analysis of the present study, we took advantage of the IUGONET data analysis system developed by the IUGONET project.

2. Data analysis and method

2.1 Observation data used in the present analysis

1. Geomagnetic field (1900-2012) : WDC, Kyoto Univ.
2. Geomagnetic index (Kp, 1932-2012): WDC, Kyoto Univ.
3. Solar activity indices
   F10.7 flux (1947-2012): NGDC/NOAA,
   Sunspot number (1847-2012): SIDC (Belgium)

2.2 Identification of quiet day and Sq amplitude

1. Definition of quiet day
   The maximum of Kp index is less than 4 every day.
2. Sq amplitude
   Difference between the maximum and minimum values of the daily variation of the H-component of geomagnetic field during quiet as shown in Fig. 2.

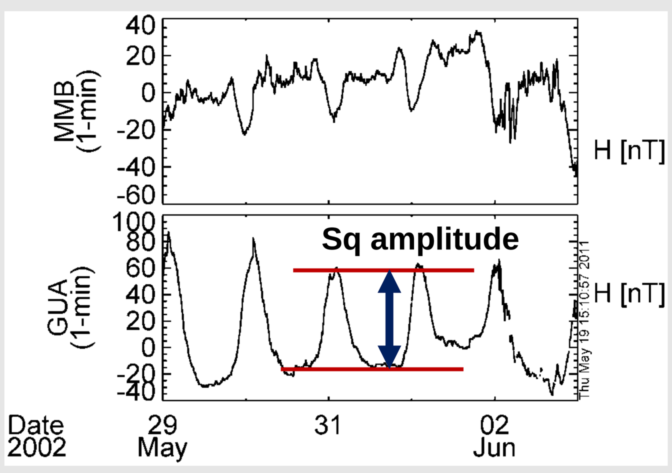
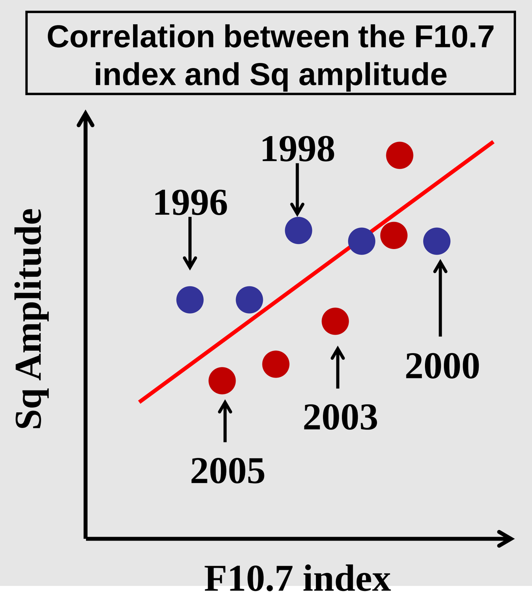


Fig.2. An example of Sq variation observed at middle latitude and equator

2.3 Residual amplitude of Sq fields to filter out the solar activity



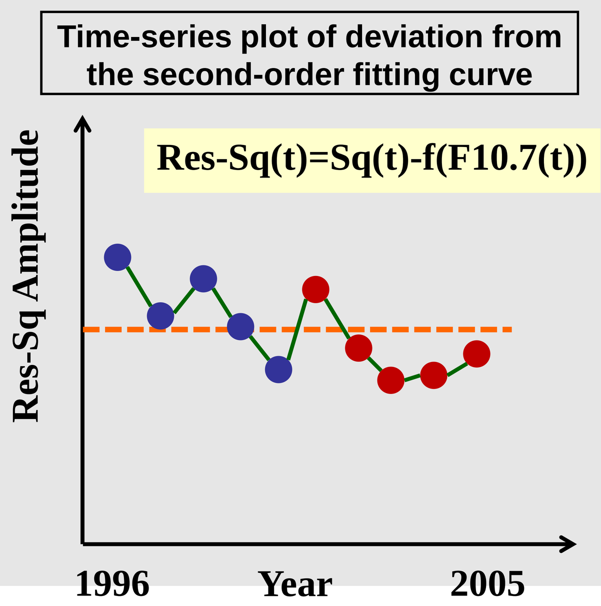
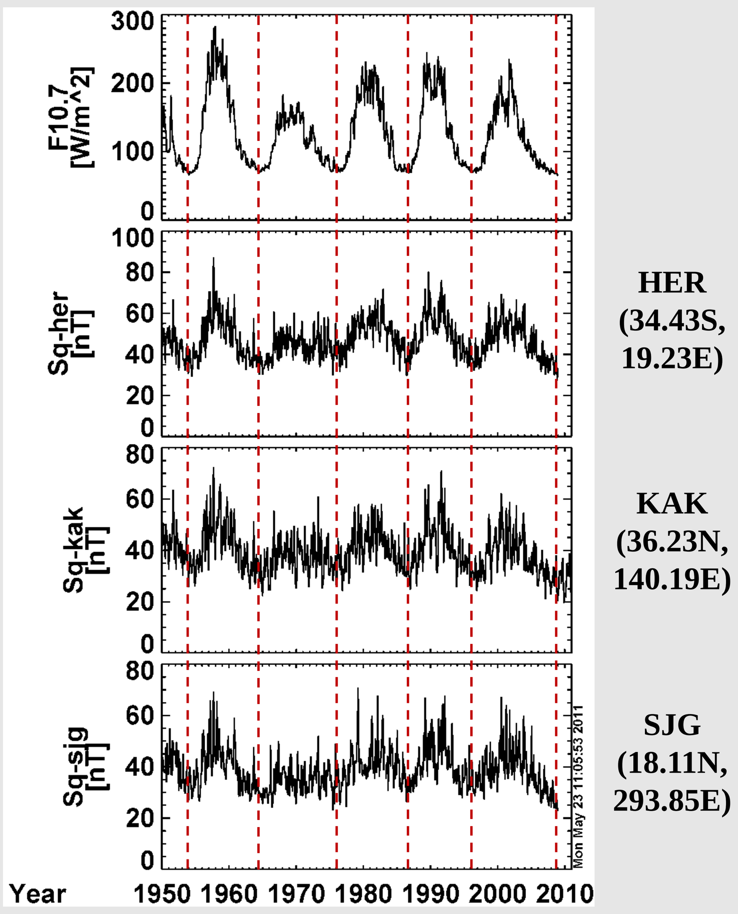


Fig. 3: A schematically picture of analysis method to obtain the residual amplitude of the Sq fields from correlation with the F10.7 index.

We defined the residual Sq amplitude as the deviation from the second-order fitting curve between the F10.7 index and Sq amplitude shown in Fig. 3.

3. Results and discussion

3.1 Long-term variation in the Sq amplitude



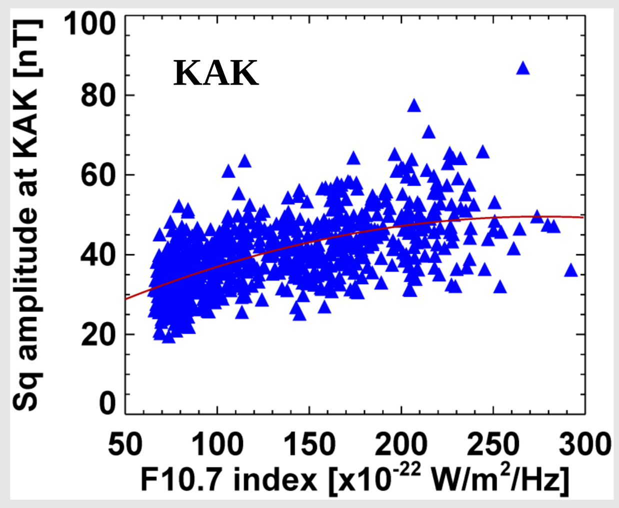
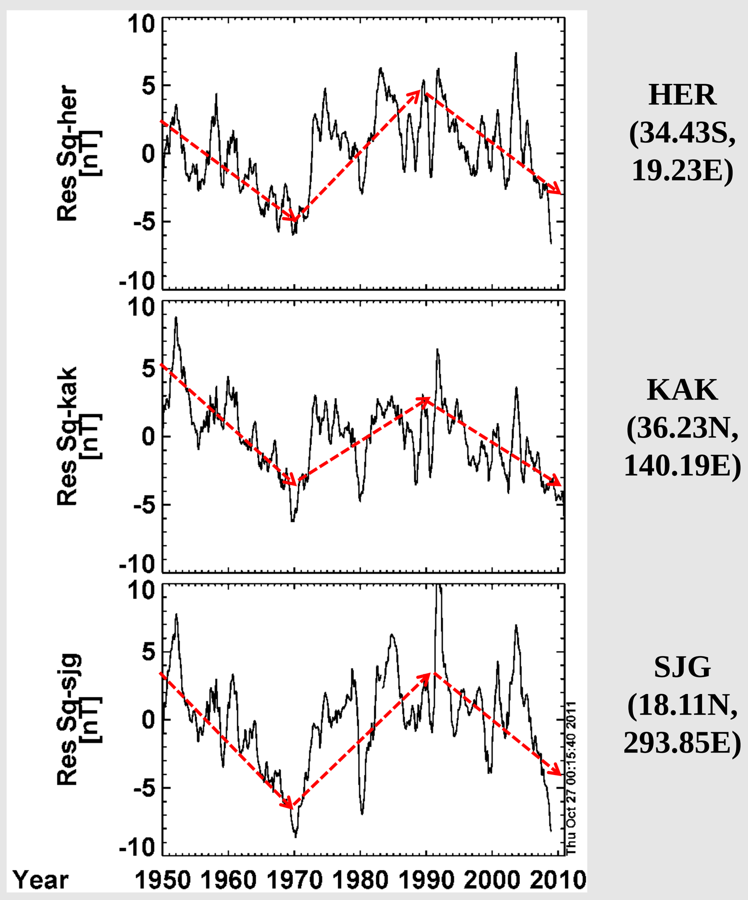


Fig. 4. (a) Long-term variation of the Sq amplitude at HER, KAK and SJG for 1950-2011. (b) Correlation analysis between the F10.7 index and Sq amplitude at KAK.

The long-term variation of the Sq amplitude clearly shows a 11-year solar activity, but its amplitude is not linearly proportional to the magnitude of solar activity.

3.2 Long-term trends of residual Sq (res-Sq) amplitude



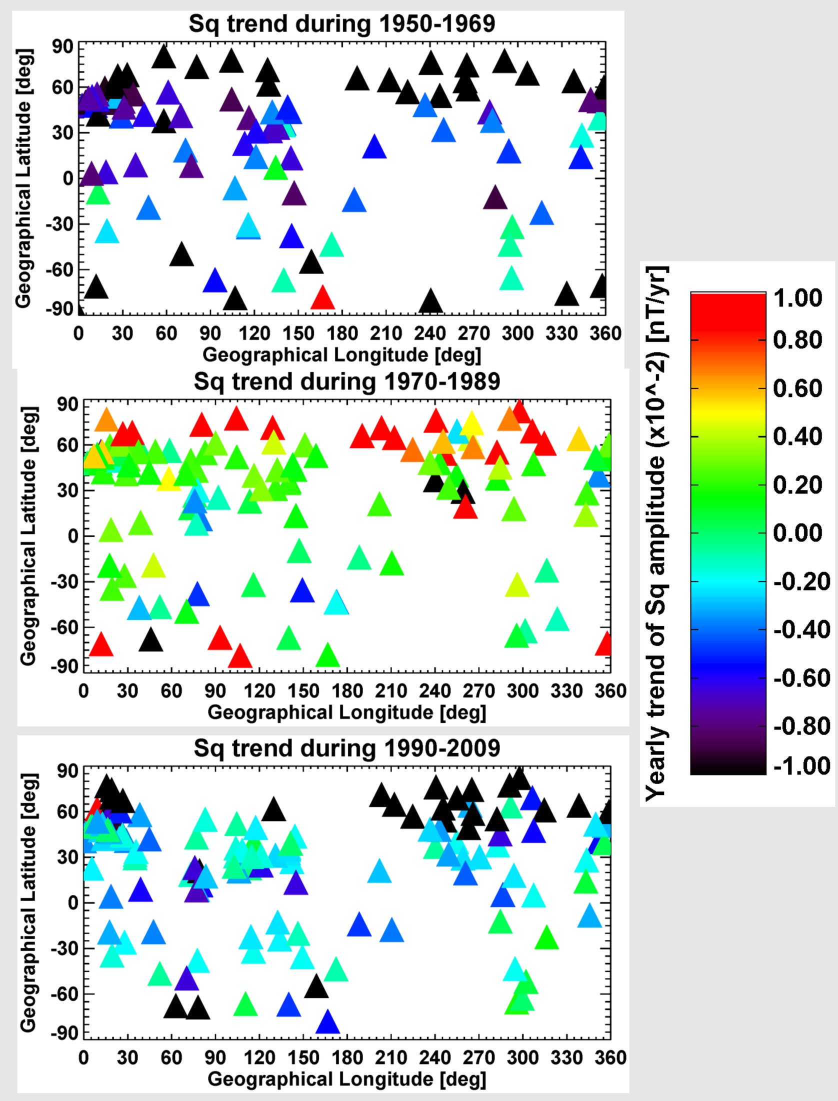


Fig. 5. (a) Long-term variation of 1-month running average res-Sq amplitude at HER, KAK and SJG for 1950-2011. (b) Trends of the res-Sq amplitude for three periods (1950-1969, 1970-1989, 1990-2009). The color scale indicates the inclination of the res-Sq amplitude in a range from -1.0 to 1.0 nT/year.

The residual Sq amplitude derived from the correlation analysis with the F10.7 solar activity index tends to decrease during two periods for 1950-1969 and 1990-2009, and to increase for 1970-1990. In Fig. 5(b), it is shown that this tendency is not a local but global variation from both the poles to the equator.

This result indicates that the long-term residual-Sq amplitude varies with a 20-year period, and is inconsistent with that previously reported by Elias et al. [2010].

4. Conclusion

In order to investigate a global feature of the long-term variation of the Sq amplitude, we performed the integrated analysis of the long-term ground-based observation data of geomagnetic field with 1h time resolution and solar F10.7 index during 1950- 2011. We showed several new and important results as follows.

1. **The amplitude of the Sq amplitude observed in a wide region from the north to the south poles depends strongly on 11-yr solar activity but is not linearly proportional to the magnitude of the F10.7 solar activity index.**
2. **The long-term variations of the residual Sq amplitude showed significant decreasing, increasing and decreasing trends for 1950-1069, 1970-1989 and 1990-2009, respectively. Only the positive trend during 1970-1990 is consistent with that of Elisa et al. [2010]], who proposed that the long-term increase of Sq field contributes to both the decrease of the ambient magnetic field intensity and cooling effect of the upper atmosphere due to greenhouse effect. Therefore, their interpretation of the long-term Sq trends can not always be adapted for all the periods.**
3. **The magnitude of the Sq trends in the high latitudes (auroral zone and polar cap) tends to be larger than that in the low-middle latitudes and equator.**
4. **The 20-year periodicity of decreasing and increasing trends of the residual Sq amplitude may suggest a characteristic period of changes in the Earth's upper atmosphere without dependence on solar activity. In the future study, we perform the comparison analysis between the residual Sq amplitude and ionospheric conductivities derived from several upper atmispheric models (IGRF, MSIS-00, IRI-2012). We also investigate the relationship between the residual Sq amplitude and neutral wind in the lower thermosphere and mesosphere estimated from the meteor and MF radars.**