Variability of the S_q magnetic field with the solar radiation flux $f_{10.7}$

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INTRODUCTION

The Sq magnetic field is generated by dayside electric currents at 110km of altitude. These currents result from the displacement of the conducting ionosphere in the main magnetic field of internal origin. An important parameter of the Sq field amplitude is the electrical conductivity of the ionospheric E-layer, which varies daily, seasonally, and with solar activity. The latter variations are usually parameterized by a linear dependence upon the solar radiation flux index $f_{10.7}$ in spherical harmonics models of the Sq field. For example, in the comprehensive model CM4 [1], each coefficient is multiplied by the factor $1+ N f_{10.7}$, where $N = 14{,}85.10^{-3}$ $(10^{-22}\ Wm^2Hz^{-1})^{-1}$.

However, it has been pointed out by some earlier studies that the proportionality factor between the Sq amplitude and the $f_{10.7}$ index (or the sunspot number) varies with seasons [2,3]. Based on the analysis of the H component between 1962 and 1971 at two observatories, Guam and Memambetsu, Hibberd [2] showed that there is a linear relationship between the Sq current intensity and the $f_{10.7}$ index, with a larger slope at equinoxes than at solstices. Olsen [3] evaluated the linear regression

$$\epsilon_n^m(R) = A_n^m(1 + M_n^m R) \tag{1}$$

where R is the sunspot number, for each coefficient ϵ_n^m of a Sq spherical harmonic model and showed that the Wolf ratio M_n^m varied with season, being greater in the winter than in the summer. Also, the relationship between some ionospheric parameters becomes non-linear during intense solar activity as shown by [4]. A saturation effect appears in the ionospheric electron content (IEC) for values of $f_{10.7}$ larger than 200.

Here we will present initial results of a new study of this problem, based upon the method proposed by Hibberd [2]. One of the purpose of this work is to refine the empirical relationship between the Sq field and the solar flux used in spherical harmonics models of the Sq field (see for example [5]).

DATA AND METHODS

The method proposed by Hibberd [2] consists in taking the H components at two stations each located on both sides of the Sq focus but on the same longitude (stations P and Q in Fig. 1), and in studying their difference ΔH (see also [6]). It is based upon the assumption that the Sq variations are oriented in opposite directions for the two stations whereas the disturbance variations are in the same direction. Therefore taking the difference ΔH is expected to remove such disturbances. The daily range of ΔH is then assumed to be proportional to the Sq currents.

In this study, we consider data from two pairs of observatories : Guam (GUA) and Memembatsu (MMB) for the 1986 – 2007 time interval (two solar cycles), and Tamanrasset (TAM) and Manhay (MAB) for the 1995 – 2007 time interval (one solar cycle). The coordinates of the stations are given in Tab. 1.

For each pair of observatories, the monthly means for each local time are calculated. Then the differences ΔH_{12LT} and ΔH_{24LT} of the monthly means at 12LT and 24LT between both stations are calculated. Finally, the daily range

$$\Delta H_{dr} = \Delta H_{12LT} - \Delta H_{24LT} \tag{2}$$

is taken.

Synthetic data (primary and induced fields) calculated using the CM4 model [1] at the same two pairs of observatories are also computed.

Tab. 1: Coordinates of observatories used in this study.

Observatory	**Geographic**		**Geomagnetic**	
Guam	14°N	145°E	5°N	214°E
Memambetsu	44°N	144°E	34°N	209°E
Tamanrasset	23°N	5°E	25°N	80°E
Manhay	50°N	6°E	51°N	90°E

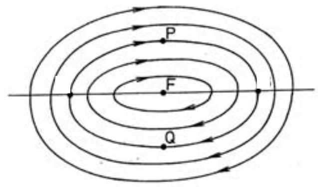


Fig. 1: Sq current system pattern in the southern hemisphere (adapted from [6]).

RESULTS

The daily ranges ΔH_{dr} for each month are plotted in Fig. 2 for the pair Guam-Memambetsu during the 1986-2007 time interval.

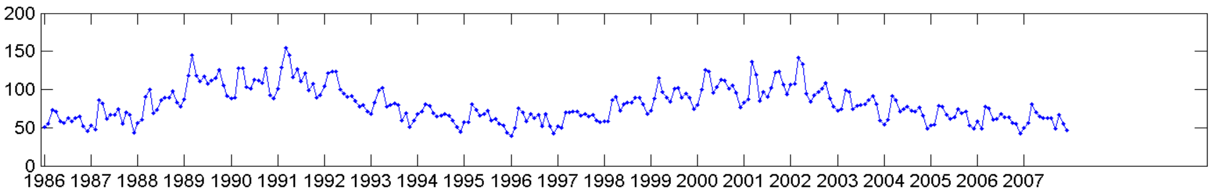


Fig 2: Monthly means of the daily range of the difference of H components for Guam and Memambetsu for the 1986-2007 time interval (real data).

The influence of the solar cycle is conspicuous, ΔH_{dr} being largest around 1991 and 2001. ΔH_{dr} is larger in the summer than in the winter. Superimposed to this annual variation, we can see a semi-annual variation, ΔH_{dr} being larger in the equinoxes than in the solstices (this variation is more visible during solar minima).

In Fig. 3, the values of ΔH_{dr} are plotted with respect to monthly means of the solar flux index $f_{10.7}$ for each month and each pair of observatories. A linear dependence of the daily range of the monthly means of ΔH versus $f_{10.7}$ exists but the slope is different from one month to another as previously shown by Hibberd [2]. A seasonal variation is present in the data. For each month and each data set, we calculate the best linear fit

$$\Delta H_{dr} = a\, f_{10.7} + b. \quad (3)$$

The values of the slope a and of the ratio a / b are shown in Fig. 4 for each pair of observatories and for real and synthetic CM4 data. For both pairs of observatories, there is a semi-annual variation of the slope a and an annual variation of the ratio a / b when ΔH_{dr} is computed from real data. There is also a semi-annual variation of the slope but no variation of the ratio at all in the case of synthetic data.

DISCUSSION

Synthetic Data

In the CM4 model, the dependence of the Sq versus the $f_{10.7}$ index is parameterized by the formula given in the introduction. In addition, there is a seasonal dependence of the Sq parameterised by a wavenumber s. Thus ΔH may be written in the following form

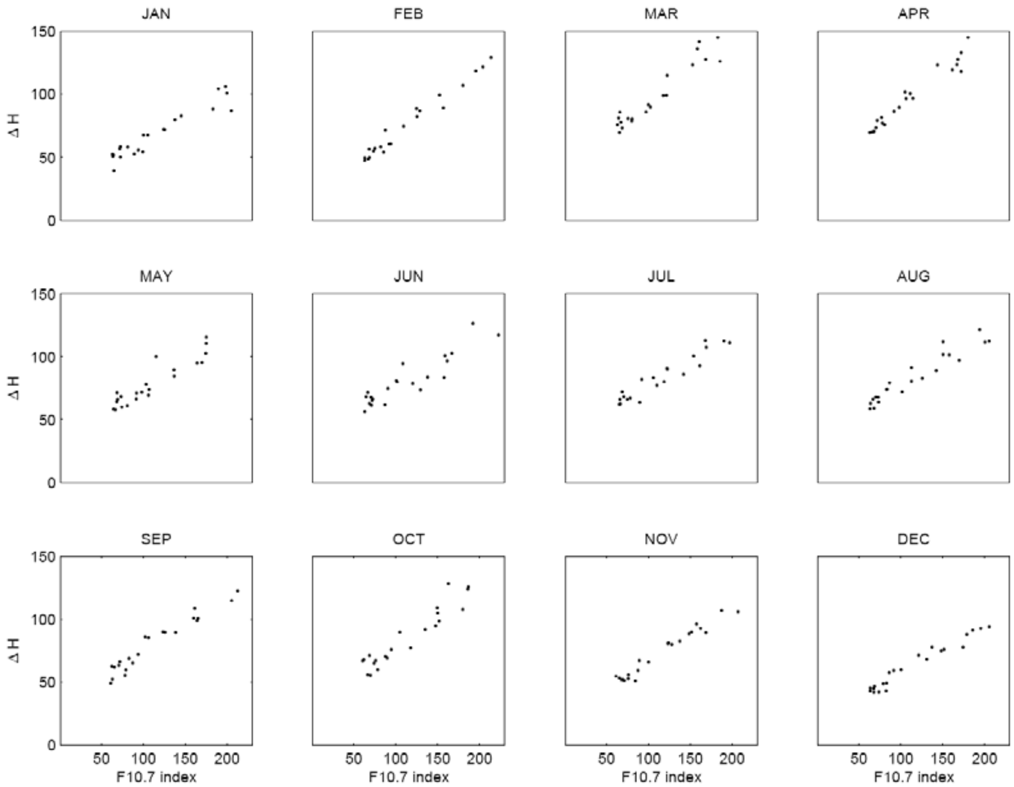
$$\Delta H = g(s)(1+N f_{10.7}), \quad (4)$$

where g is a function of s. Hence

$$a / b = N \quad (5)$$

in the case of synthetic data generated by the CM4 model. We obtain a constant ratio a / b for all months (Fig. 4) in good agreement with (5). The value of the ratio $a / b = 16.10^{-3}$ is in good agreement with the value of $N = 14{,}85.10^{-3}$ $(10^{-22}\ \mathrm{Wm^2Hz^{-1}})^{-1}$ used in CM4.

(a)



(b)

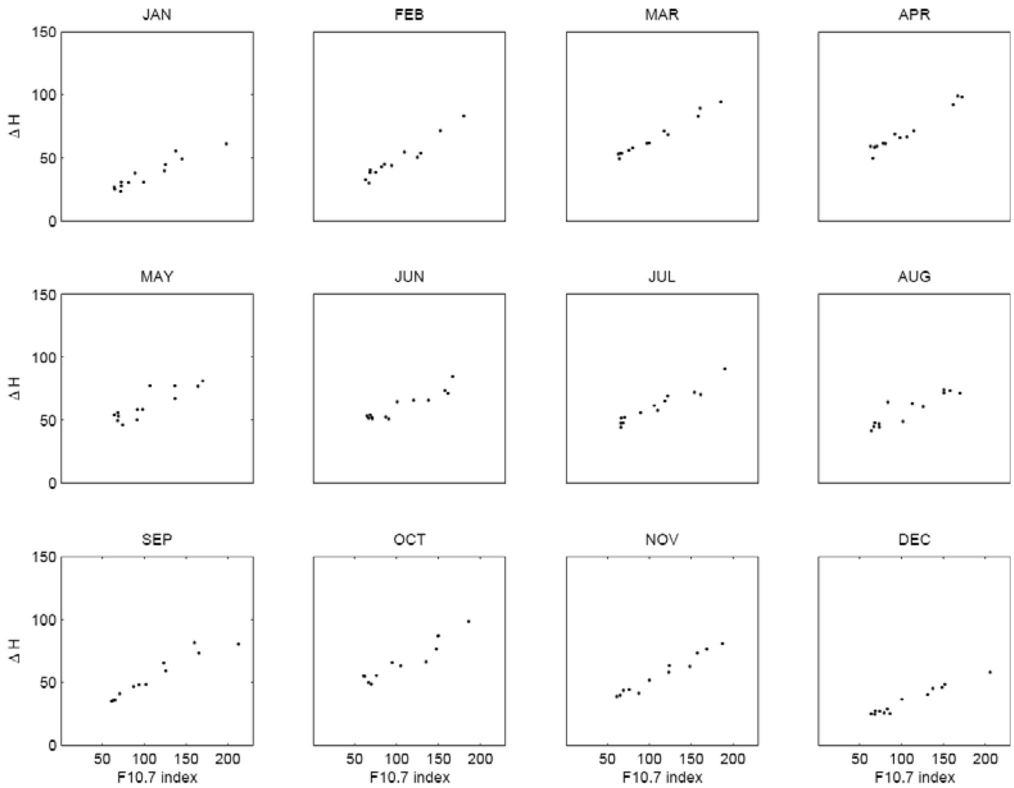
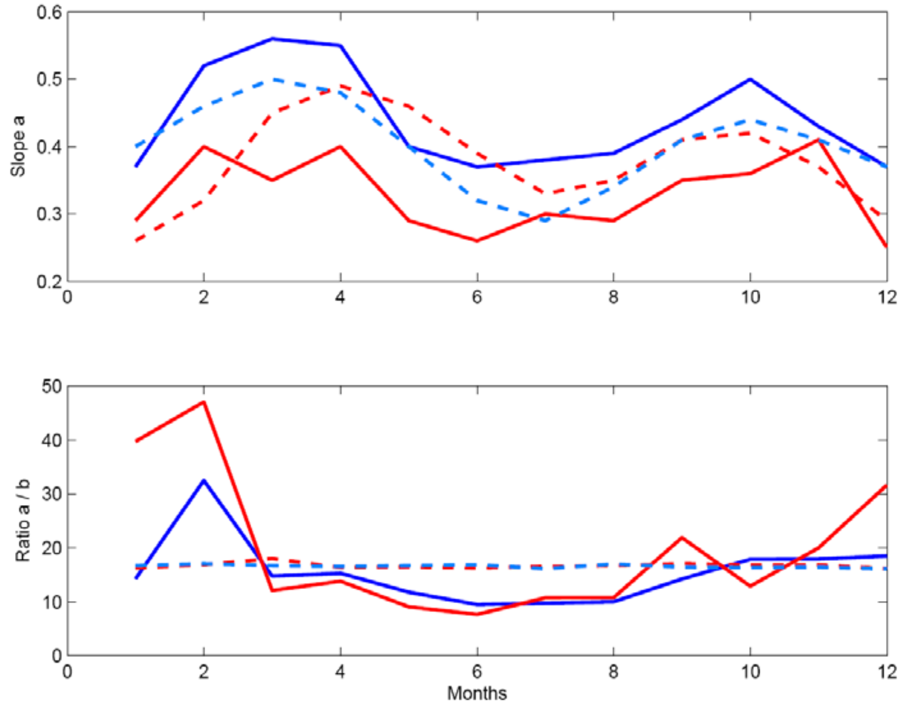


Fig 3: Daily ranges of ΔH for each month versus monthly means of the $f_{10.7}$ index. (a) GUA-MMB observatories for the 1986-2007 time interval. (b) TAM-MAB observatories for the 1995-2007 time interval.



(a)

(b)

Fig 4: Slope *a* (a) and ratio *a / b* (b) of the best linear fit of the daily ranges of ΔH versus $f_{10.7}$ for each month, each observatory pair (GUA-MMB in blue, TAM-MAB in red) and each type of data (real: solid line, synthetic: dashed line).

Real Data

The observed seasonal variation of the ratio *a / b* for real data (Fig. 4) is consistent with the results previously obtained by Olsen [3]. The ratio is maximum in northern winter and minimum in northern summer. Several factors may contribute to this variability. The ΔH method probably fails to accurately describe the variability of the Sq field since the location of the focus of the currents system varies with respect to the observatories during the year. However, it cannot be the only reason why the ratio varies with season since Olsen [3] did not use the same method. The mechanism behind this observation has to be looked for in the conductivity of the E-layer or in changes of the thermospheric winds involved in the ionospheric dynamo.

Some studies (e.g. [2]) showed that some parameters (IEC) of the ionosphere are not fully linearly dependent of the $f_{10.7}$ index. There is a saturation effect for intense solar activity ($f_{10.7} > 200$). In our results, this effect could be present (for exemple in december in Fig. 3), but we do not have enough data for $f_{10.7} > 200$ to be sure that this effect is real.

CONCLUSIONS

Based upon the analysis of ΔH at two pairs of observatories (each located along a given meridian line), we find that the slope of the linear dependence of the Sq system upon the $f_{10.7}$ index varies semi-annually, and that the Wolf ratio is maximum in northern winter. This is in good agreement with earlier studies based on different datasets and/or different methods. The mechanism at the origin of the Wolf ratio seasonal variation is unknown.

This effect was not included in the CM4 model. The difference with respect to the CM4 model is largest in summer and winter. A new relationship, more accurately describing the variation of the Sq field with solar activity (i.e. taking into account the annual variation of the Wolf ratio or its equivalent for $f_{10.7}$), will have to be included in future models of the ionospheric magnetic field.

To further investigate the origin of this variability, the same analysis will be carried out for a selection of quiet magnetic days and taking daily values instead of monthly ones.

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