A World-Wide Annual Variation in Sq

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The amplitude of the annual variation in the horizontal component of Sq is larger in the southern hemisphere than the northern hemisphere. This asymmetry may be represented as the superposition of a world-wide annual variation with its maximum at or near perihelion and summer-winter annual variations of equal amplitudes in the two hemispheres and maxima at the local summer solstice. The amplitude of the world-wide annual variation, as a fraction of the yearly mean value of Sq , is about 0.07 ± 0.02 . The variation in ionospheric conductivity associated with the earth's orbital eccentricity is inadequate alone to account for this annual variation in Sq . If joule heating by the Sq currents is appreciable, its annual and semi-annual variations could account for the similar variations in the temperature of the thermosphere.

Some years ago I described a study of the seasonal and solar cycle variations of the daily range of the horizontal component H of Sq (Hibberd, 1985). This made use of a differencing technique in which the daily range of H at a station polewards of the Sq focus is subtracted from that at a station equatorwards of the focus, near the same meridian, to yield the difference ΔH . The disturbance variations are largely cancelled out in the difference and ΔH is closely proportional to the total Sq current circulating about the focus. The procedure has the advantage that data from all days can be used to study Sq , rather than those for quiet days alone, and results in a much improved resolution of the annual and semi-annual variations in Sq . Such differences ΔH_N and ΔH_S and their monthly means were obtained for the pairs of stations Guam and Memambetsu in the northern hemisphere and Port Moresby and Toolangi in the southern hemisphere, all close to the same meridian, for the years 1962–71 and 1959–72 respectively. The coordinates of the observatories are:

	Geographic		Geomagnetic	
Guam	14°N	145°E	+4°	213°E
Memambetsu	44°N	144°E	+34°	209°E
Port Moresby	9°S	147°E	–19°	218°E
Toolangi	38°S	145°E	–48°	221°E

These monthly means of ΔH_N and ΔH_S , averaged over all years, are shown in Fig. 1. The amplitudes of the annual and semi-annual Fourier components (C_{1N} , C_{2N} and C_{1S} , C_{2S} for the northern and southern hemispheres respectively) of the data in Fig. 1, expressed as a fraction of the annual mean values, and the dates of occurrence of their maxima are as follows:

For ΔH_N :

C_{1N} (annual) = 0.114, maximum near 18 May

C_{2N} (semi-annual) = 0.145, maxima near 29 March and 28 September

For ΔH_S :

C_{1S} (annual) = 0.259, maximum near 12 January

C_{2S} (semi-annual) = 0.155, maxima near 30 March and 28 September

The amplitudes of the semi-annual components in the two hemispheres are seen to be equal, 0.15, within the precision of the data and their maxima occur near the equinoxes. The equality of the semi-annual variations suggests that the above results are not greatly dependent on the differing latitudes of the

Fig. 1. Monthly means of ΔH_N for the northern hemisphere, averaged over 1962–71, and ΔH_S for the southern hemisphere, averaged over 1959–72.

observatories. For comparison it is noted that Chree (1904) found the relative amplitude of the semi-annual variation in $Sq(H)$ at Kew to be about 0.11, with its maxima near the equinoxes. The amplitude of the annual component, however, is much greater in the southern than the northern hemisphere. The maxima occur roughly in the vicinity of the respective local summer solstice.

The above results are for longitudes near 146°E and one cannot be certain that similar results would be obtained in other longitudes. However, Wagner *et al.* (1980) from a spherical harmonic analysis of IGY data from the American zone present graphical results showing annual and semi-annual variations in both hemispheres with the expected phases and state that the relative amplitude of the annual variation in the southern hemisphere is 1.3 times that in the northern hemisphere, so that the north-south asymmetry in the annual variation seems to be world-wide.

Two other studies of Sq relevant to this question should be examined here, even though it will turn out that they add little to the conclusion. Matsushita and Maeda (1965) analysed the Sq field for 1958, using spherical harmonics and obtained the Sq equivalent currents for three longitude zones (1: Europe-Africa, 2: Asia-Australia, 3: Americas) for the D, E and J months in the northern and southern hemispheres. Although the spatial distribution of the 69 stations used was as good as ever likely to be available, the data were limited to the small number of 15 selected quiet days in each of the D, E and J seasons. These are insufficient to yield the required precision in the annual and semi-annual variations, since determination of the annual variation in each hemisphere depends on the differences between the D and J currents and these are obtained from two different sets of data, each of only 15 days. With this small number the effect of random variations such as day-to-day variability and variations in the solar radiation flux are inadequately averaged out. Additionally, the grouping into D, E and J months partly smooths the variations being sought and results in a decrease in the amplitudes of the variations and a loss of temporal resolution. Stening (1995) has recently described a study of the semi-annual variation in Sq using my differencing procedure with 1964–65 data and all except 5 disturbed days in each month. His results for the three longitude zones show semi-annual variations but the scatter from month to month is too large to yield quantitative comparisons of the annual variations, since the daily range of Sq at solar minimum is only about half that at solar maximum. Thus although the above two studies are not helpful for our purpose, they do not modify the conclusion from the available evidence that the relative amplitude of the annual variation in Sq is smaller in the northern hemisphere than the southern hemisphere.

A world-wide annual variation in Sq associated with the earth's orbital eccentricity, with its maximum at perihelion, was predicted by Schuster (1908). He had in mind variations in the solar gravitational force and the conductivity. Perihelion occurs on January 7–8, close to the southern summer solstice, so that a world-wide annual variation in Sq arising from the orbital eccentricity would be approximately in phase with the summer-winter variation in the southern hemisphere and in antiphase in the northern hemisphere. The separation of the world-wide and summer-winter variations is then given, approximately, by

$$\text{Amplitude of summer-winter variation} = (C_{1S} + C_{1N})/2 = 0.19 \pm 0.2$$

and

$$\text{Amplitude of world-wide variation} = (C_{1S} - C_{1N})/2 = 0.07 \pm 0.2.$$

The amplitude of the annual variation in the heliocentric distance is 0.01675 and the corresponding expected amplitude of the world-wide annual variation in electron density in the ionospheric E region, if the electron-loss process is recombination-like, is also 0.01675; if the loss process were attachment-like it would be 0.034. Both of these are much smaller than the observed amplitude in Sq of 0.07 ± 0.02 . It appears therefore that the variation in ionospheric conductivity alone is inadequate to account for the world-wide annual variation in Sq and that some additional factor dependent on the heliocentric distance must be present. This may be the solar wind, whose momentum flux density at 1 a.u. is approximately invariant over the solar cycle (Steinitz, 1983; Schwenn, 1990) and possesses an annual variation of relative amplitude of 0.034 at the earth's orbit with maximum at perihelion.

If joule heating by the Sq currents is appreciable, the world-wide annual and the semi-annual variations in Sq could account for the similar variations in the temperature of the thermosphere (Paetzold, 1962; Jacchia, 1965; Barlier *et al.*, 1974). They may also play a part in the north-south asymmetry (December anomaly) and the semi-annual variation in the behaviour of the F region of the ionosphere. These questions are currently being investigated.

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