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# Effects of station relocation in the *aa* index

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[1] Earlier studies have shown that the long-term measure of geomagnetic activity, the *aa* index, is inhomogeneous and depicts an excessively large (about 12 nT) centennial increase. This has preliminarily been suggested to be due to possible station intercalibration problems in 1957 when the northern *aa* station was changed from Abinger to Hartland. In the present paper we show that the 3-hourly *aa* index time series is not uniform but includes systematic jump-like changes in the distribution of the various *aa* values with each change of stations in 1920, 1926, 1957, and 1980. We estimate how large a change to the *aa* index was caused by each particular *aa* value. We find that the changes to the *aa* index due to different ranges of activity are smooth and fairly similar for all jumps. In 1957 the largest *aa* values had, at the expense of more moderate *aa* values, a relatively larger contribution to the jump than in other station changes because the relative station coefficient was somewhat larger in 1957, leading to larger spreading and a higher average level of *aa* values. However, while this difference could cause a slight overestimate of the *aa* values, we find that the total changes in the *aa* index over jumps are in agreement, in both sign and magnitude, with the solar cycle variation. So it is unlikely that the excessive increase of the *aa* index would be due to erroneously estimated station coefficients.

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## 1. Introduction

[2] The *aa* index of geomagnetic activity provides one of the longest and most important solar proxy data sets. The *aa* index was initially calculated by *Mayaud* [1972] retrospectively from the year 1868 onward. The *aa* index is calculated from the 3-hourly K indices measured at two near-antipodal midlatitude stations. The K indices are derived from the magnetic observations according to a standard process which includes the removal of the solar quiet time (Sq) variation. By averaging the two antipodal stations, the annual variation is reduced. It is well known that the *aa* index exhibits a significant long-term increase, roughly by about 65% in the twentieth century, most likely caused by related long-term variations of solar activity. This increase in global geomagnetic activity, first found and quantified by the *aa* index, has been widely discussed in literature, and important results about the related changes in the Sun have been obtained [see, e.g., *Russell*, 1975; *Feynman and Crooker*, 1978; *Clilverd et al.*, 1998; *Stamper et al.*, 1999; *Lockwood et al.*, 1999; *Jarvis*, 2005; *Demetrescu and Dobrica*, 2008]. However, using different techniques and novel, alternate measures of geomagnetic activity, serious concern has recently been raised about the quantitative value of the centennial increase and the long-term consistency of the *aa* index [*Clilverd et al.*, 2002, 2005; *Mursula et al.*, 2004; *Mursula and Martini*, 2007; *Svalgaard and Cliver*, 2005, 2007; *Jarvis*, 2005; *Martini and Mursula*, 2008]. *Mursula and Martini* [2007] argued that the centennial increase in global geomagnetic activity is only about one half of that depicted by the *aa*. This discrepancy was found to be even larger if only midlatitude stations were used in the estimated trend. Some studies have suggested this to indicate intercalibration problems in the *aa* index when the northern station was changed from Abinger to Hartland from 1956 to 1957 (see Table 1 for station information). Evidence for a step-like increase of about 2–3 nT in the *aa* in the late 1950s to the early 1960s was found. For example, the interhour variability (IHV) index [*Svalgaard et al.*, 2004] and the interdaily variability (IDV) index [*Svalgaard and Cliver*, 2005] have been used to check the calibration and the long-term homogeneity of the *aa*

**Table 1.** Three *aa* Stations of the Northern and Southern Hemisphere With Operation Times and Correction Factors Derived by *Mayaud* [1973]

| *aa* Station Name | Operation Time | Correction Factor |
|---|---|---|
| Greenwich (GRW) | 1868–1925 | 1.007 |
| Abinger (ABN) | 1926–1956 | 0.934 |
| Hartland (HAD) | 1957– | 1.059 |
| Melbourne (MEL) | 1868–1919 | 0.967 |
| Toolangi (TOO) | 1920–1979 | 1.033 |
| Canberra (CNB) | 1980– | 1.084 |

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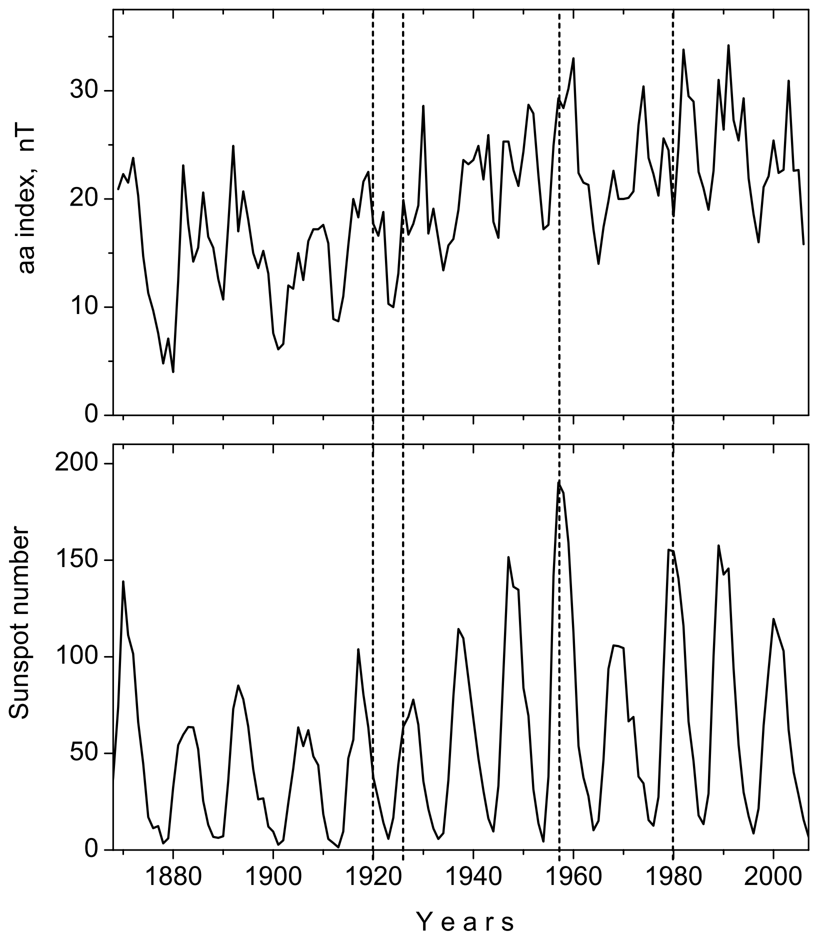


**Figure 1.** Annual means of (top) the *aa* index and (bottom) sunspot numbers during 1868–2007. The vertical dashed lines indicate the years of *aa* station relocation.

index and other geomagnetic indices. *Svalgaard and Cliver* [2007] found that the *Ap* index tracks the variation of IHV, but the *aa* index is systematically too low by about 3 nT before 1957. The increase in the corrected *aa* was estimated to be about 35%, closer to the increase in the IHV and IDV.

[3] The above results indicate that the original *aa* index time series is not homogeneous, and raise the question of the cause of this inhomogeneity. The ultimate concern is how the *aa* index could be adequately and truthfully corrected. This problem is very important and should be considered very carefully because the *aa* index has been such a valuable tool for long-term studies. However, in the present situation with no high-sampling digital records from the *aa* index stations available, it will be quite difficult to make sure that any chosen correction methods are indeed valid and well founded.

[4] As a step toward a better understanding of the long-term properties of the *aa* index, we study in the present paper the detailed distribution of the different values of the *aa* index and their temporal evolution. This allows us to demonstrate the periods when the *aa* time series is not obviously uniform. We show that significant changes in the *aa* value distribution (with related "jumps") took place in the years 1920, 1926, 1957 and 1980, i.e., in the years when either the northern or the southern *aa* station was changed. These distribution changes arise from changes in the normalization constants of each station related to the intercalibration and standardization of the two (earlier and later) successive stations in either hemisphere. We examine the change of the distribution of *aa* values over the four jumps and estimate in detail how much the various levels of activity contribute to each jump. We also compare the total change of the *aa* index over each jump with the variability related to the solar cycle.

## 2. Frequency Distributions

[5] The original 3-hourly values of the *aa* index were obtained from the International Services for Geomagnetic Indices (http://isgi.cetp.ipsl.fr/des_aa.htm). The annual averages of the *aa* index, covering 140 years (1868–2007), are plotted in Figure 1. The index depicts a solar cycle variation superimposed on a nonuniformly increasing trend. The total increase in the *aa* over the whole time interval is about 12 nT.

[6] In order to analyze the long-term stability of the *aa* index in 1868–2007, we have calculated the number of occurrences of each *aa* value from the lowest value of 2 nT to the maximum of 715 nT. (Obviously, there were 2920 or 2928 index values every year). Figure 2a depicts the annual

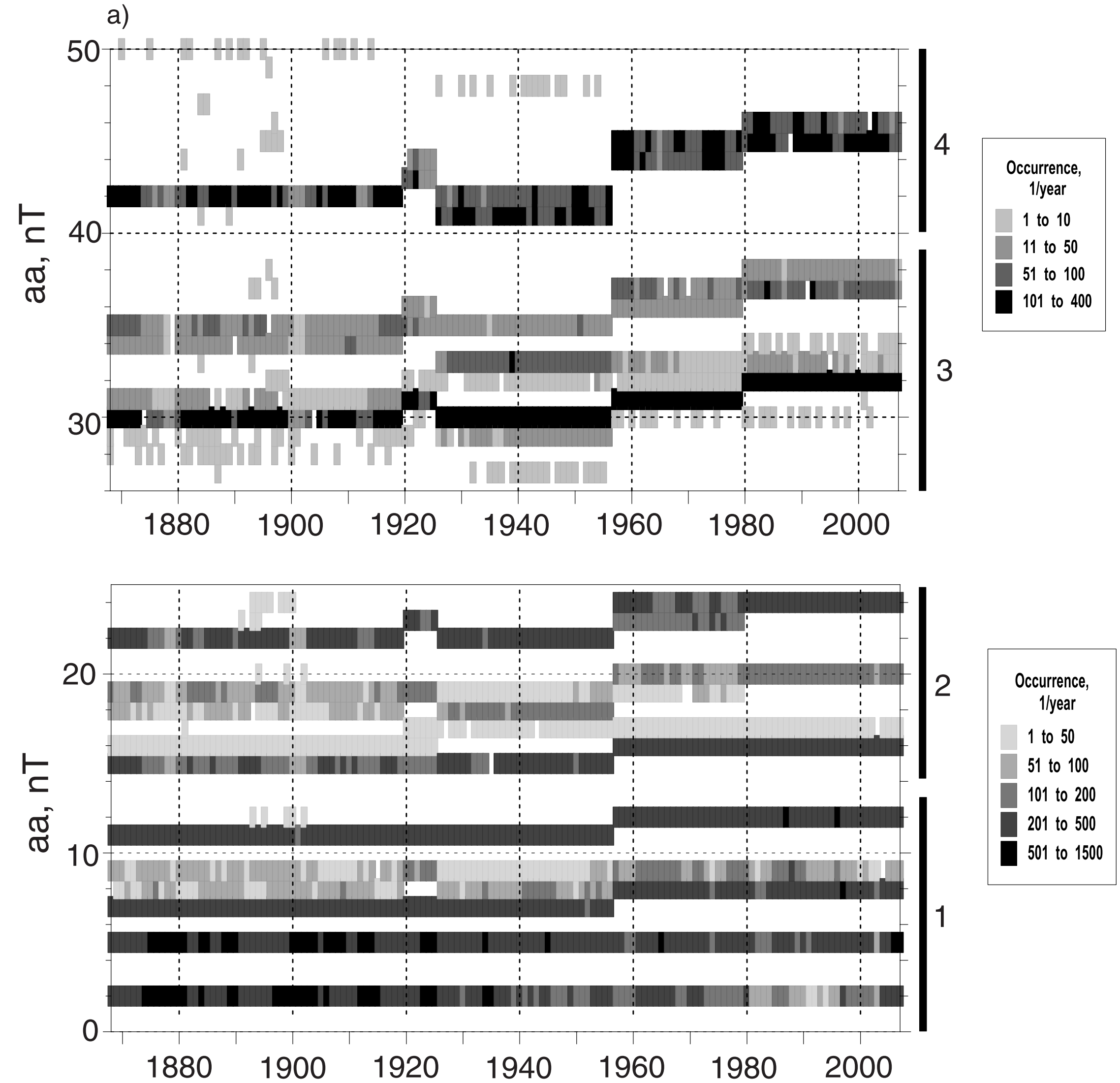


**Figure 2.** Time evolution of the annual distribution of *aa* values up to 200 nT. The annual occurrences are given in gray scaling. Figure 2 is divided into four plots as follows: (a) $aa \leq 25$ nT and $26 \leq aa \leq 50$ nT, (b) $51 \leq aa \leq 100$ nT, and (c) $101 \leq aa < 200$ nT. Eight ranges, or categories, of *aa* values are denoted by vertical thick lines with numbers on the right side of each plot: (1) $aa \leq 13$ nT, (2) $14 \leq aa \leq 25$, (3) $26 \leq aa \leq 39$, (4) $40 \leq aa \leq 69$, (5) $70 \leq aa \leq 86$, (6) $87 \leq aa \leq 120$, (7) $121 \leq aa \leq 139$, and (8) $140 \leq aa \leq 198$.

numbers of *aa* values up to 200 nT in gray scaling. The higher values are not shown because of relatively small numbers of occurrences. For better visual resolution Figure 2 is divided in four plots as follows: $aa \leq 25$ and $26 \leq aa \leq 50$ (Figure 2a), $51 \leq aa \leq 100$ (Figure 2b) and $101 \leq aa < 200$ nT (Figure 2c). Note that the gray scales vary between the different plots. Figures 2a–2c show how each value of the *aa* index evolves in time since 1868. Because the *aa* index has been constructed quasi-logarithmically from the 10 possible K index values at each station, there are at most 100 different *aa* values at any time, leading to the many gaps especially in Figures 2b and 2c. There are some numbers which are never attained by the *aa* index, e.g., 3, 4, 10, 14, 21, etc.: these numbers are seen as empty rows at the corresponding positions in Figures 2a–2c.

[7] In each plot of Figure 2 one can clearly identify four jumps in the frequency distribution. There is a "positive" or upward jump in 1920, where new, slightly higher *aa* index values appear while the lower values are either emptied or reduced significantly. A "negative" or downward jump follows in 1926, and two positive jumps are seen in 1957 and 1980. No other obvious discontinuities are seen in the *aa* frequency distributions of Figure 2. The four jumps occur exactly in those years when either the northern or southern station was relocated to a new position. In fact, Melbourne, the first station of the southern series, was changed for Toolangi in 1920, Greenwich, the first station of the northern series, was changed for Abinger in 1926, and Abinger for Hartland in 1957. Finally, Toolangi was changed for Canberra in 1980 (see also Table 1). A visual inspection of Figure 2 indicates that the largest jump in the

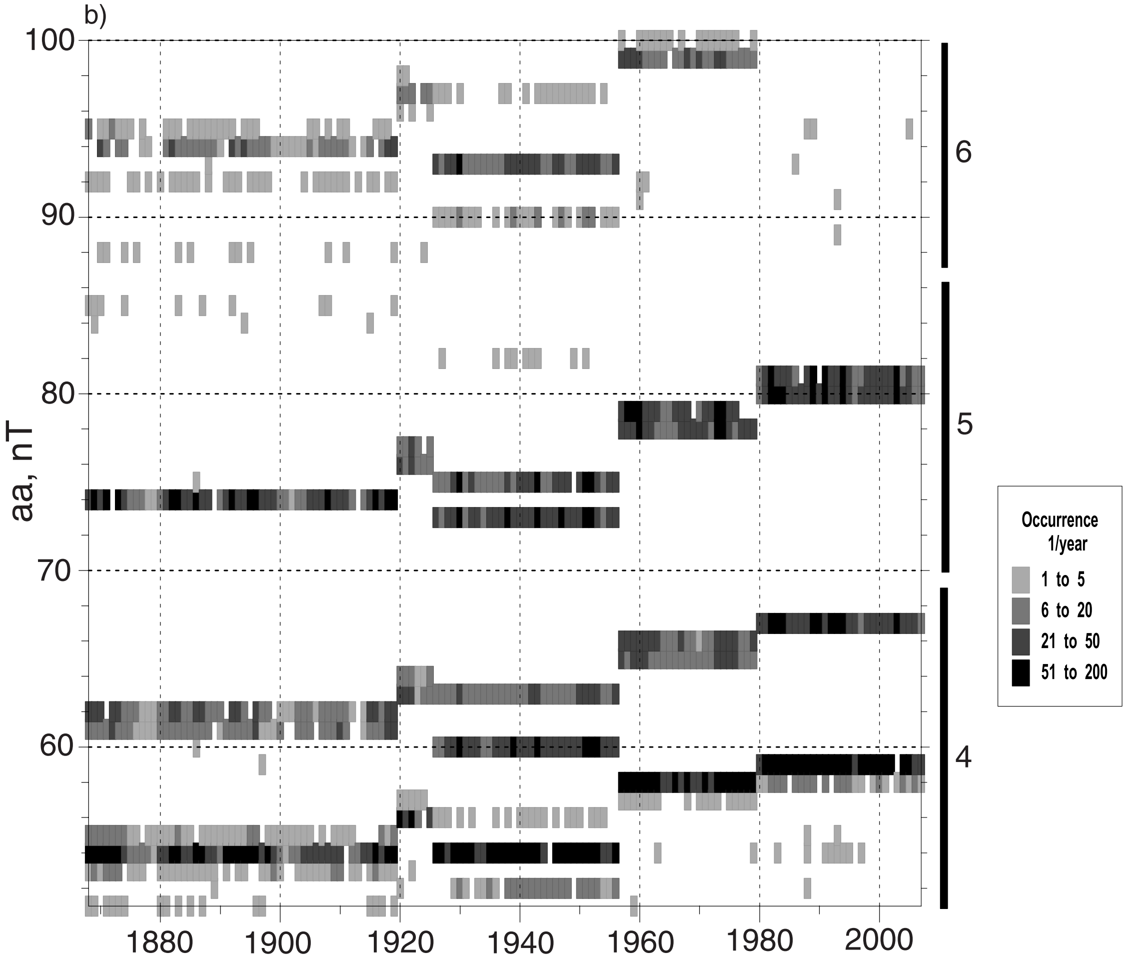


**Figure 2.** (continued)

*aa* values occurred in 1956/1957. This can be seen particularly well in the top plot of Figure 2a and in Figures 2b–2c where the new *aa* index levels in 1957 can be several nT above the levels of the previous year. Figure 2 also shows that the magnitude of the jump at each discontinuity increases roughly linearly with the value of the *aa* index.

[8] Figure 3 gives a detailed example of the effect of the jumps on three adjacent *aa* values, by depicting the time evolution of annual occurrences of *aa* = 30, 31 and 32 nT. From 1868 to 1919 and from 1926 to 1956, the value of *aa* = 30 nT is dominant, but is greatly reduced in 1920–1925 and almost disappears in 1957. The value of *aa* = 31 nT is rather infrequent until 1920 and dominates in 1920–1925. Then it disappears completely, reappearing (even dominantly) in 1957 and disappearing again in 1980. On the other hand, the value of *aa* = 32 nT first appears only in 1920 but remains very rare until 1980 when it becomes dominant, being almost the only one of the three values. Note that, interestingly, because the *aa* values depicted in Figure 3 are rather typical for intermediately disturbed times, the annual occurrences of the dominant *aa* value closely follows the centennial increase and the solar cycle variation of the full annual *aa* index (see also Figure 1).

[9] The distribution of *aa* values depicted in Figures 2 and 3 are a natural consequence of the station specific coefficients (see Table 1) that were derived for the station intercalibrations [*Mayaud*, 1973]. These coefficients are all slightly different but close to unity. When the coefficients are applied to the station Ak values (obtained from the 10 K index values), each station will have a slightly different set of possible values of the corrected Ak (i.e., the northern or southern *aa*), leading to the appearance and disappearance of some of the *aa* values. Moreover, the larger the relative coefficient between the old and new station is, the larger is the separation of corresponding *aa* levels in Figure 2. In each jump only one station changes its location and coefficient, so no mutually opposing effects are introduced in the combined *aa* index. Therefore the effect of every jump remains clearly visible in the *aa* value distribution.

## 3. Evaluating the Effect of Jumps

[10] Let us now study in detail by how much the *aa* index is changed at each of the four jumps. We have first calculated the contributions of all possible *aa* values to each yearly averaged *aa* index by multiplying a given 3-h *aa* value by its number of occurrence and dividing the result by the yearly number of *aa* indices. We call these contributions the *aa*(i,j) indices where *i* denotes the years (from 1868 to 2007) and *j* lists all possible *aa* values (from 2 to 715). Obviously, the sum over all *j* gives the yearly *aa* index for the year in question. Next we have evaluated the change in

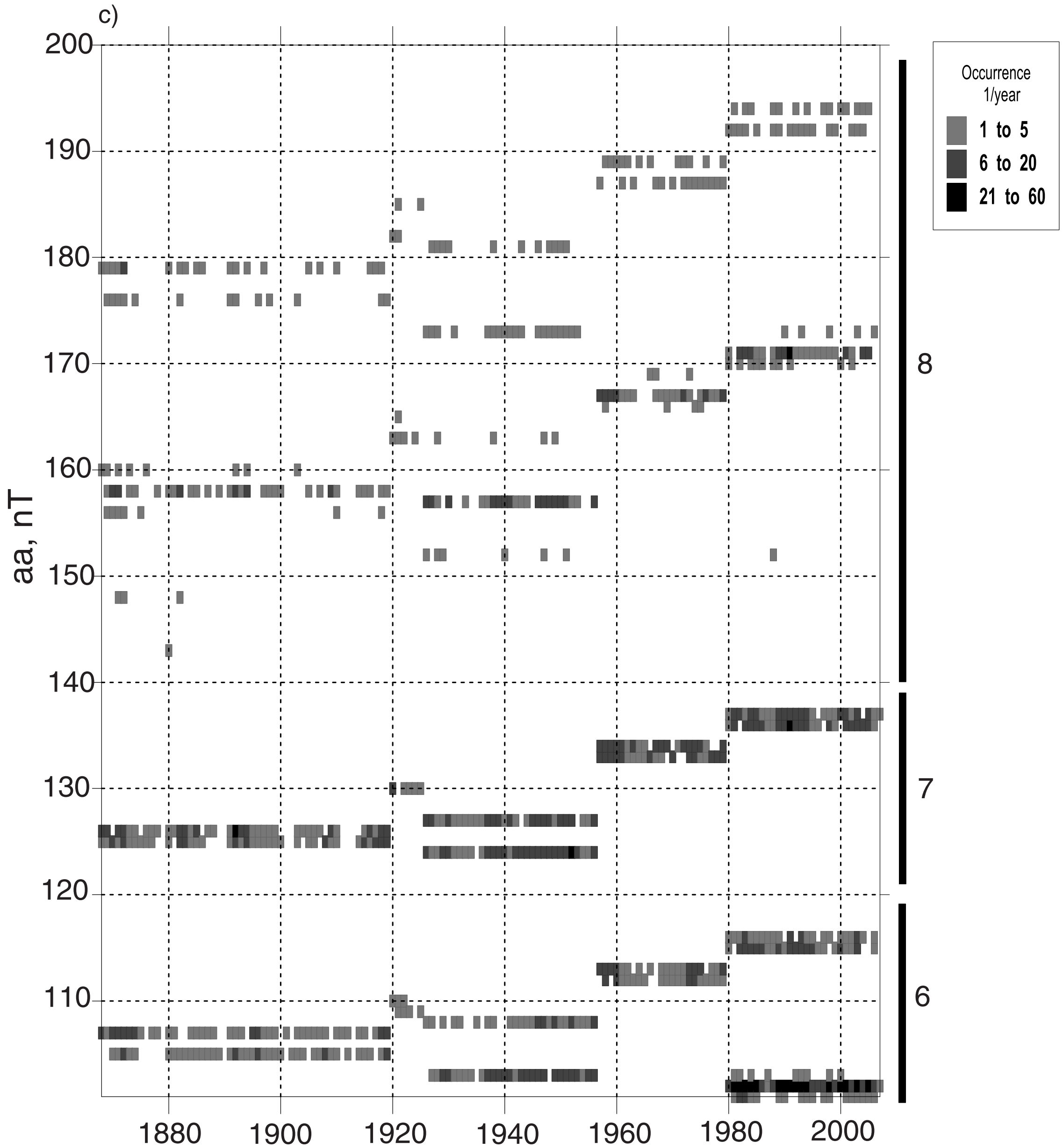


**Figure 2.** (continued)

the different contributions over each of the four discontinuities. So the differences $\delta1(j) = aa(1920,j) - aa(1919,j)$ will give the change of the contribution of each value j to the yearly *aa* index in the first jump from 1919 to 1920 when Melbourne was replaced by Toolangi station. The differences $\delta1(j)$, $\delta2(j)$, $\delta3(j)$ and $\delta4(j)$ during the jumps in 1920, 1926, 1957 and 1980, respectively, are depicted in Figure 4. One can see that, while most differences are very small, much smaller than 1, there are a few *aa* values whose contributions to the *aa* index change dramatically over the jump. These largest differences are about 2–3 nT and occur mostly at the *aa* values of 20–40 nT which have the largest contributions to the *aa* index. For example, for *aa* = 42 nT, $\delta1(42)$ is about $-3$ nT when, as can be seen in Figure 2a, this *aa* value disappeared completely in 1920. On the other hand, $\delta1(43)$ and $\delta1(44)$ are positive since *aa* = 43 and 44 nT first appeared only in 1920.

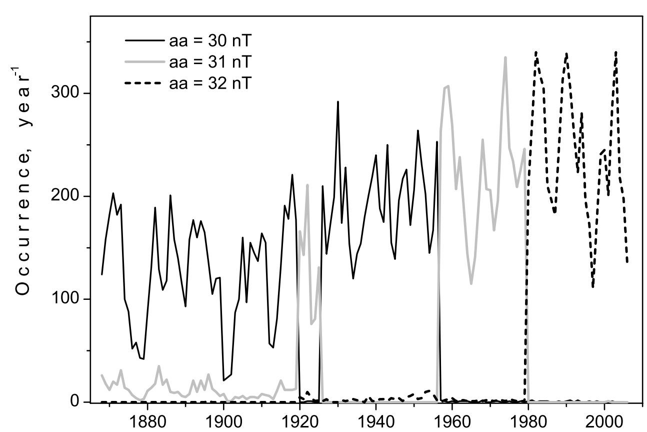


**Figure 3.** Time evolution of annual occurrences of *aa* = 30, 31, and 32 nT.

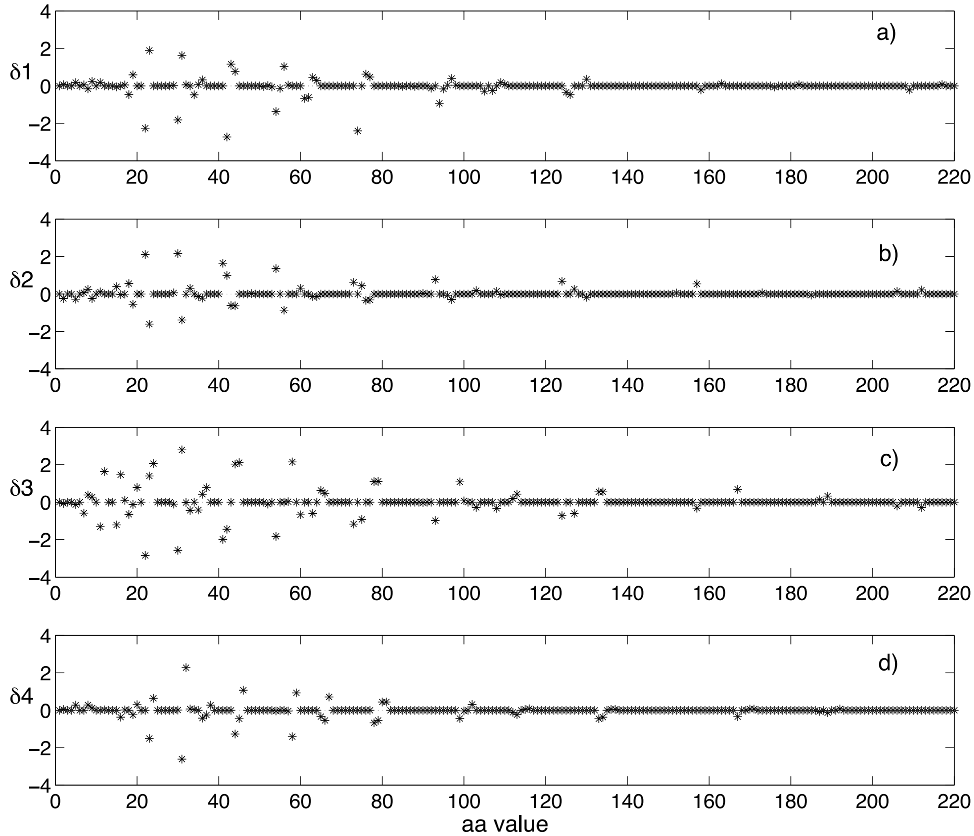


**Figure 4.** The differences $\delta 1(j)$ to $\delta 4(j)$ (in nT) for each *aa* value from j = 2 to 220 nT during the jumps in (a) 1920, (b) 1926, (c) 1957, and (d) 1980.

[11] As can be seen in Figure 2, there are ranges of neighboring *aa* values that are separated from each other by empty lines of *aa* which do not appear in any year. For example, the *aa* index never attains the values 13, 14, 25 or 26. Therefore the *aa* values between 14 and 25 nT, while changing from one specific value to another at the jumps, mostly remain within this value range. Accordingly, it is reasonable to study the collective contribution of such ranges of *aa* values to the yearly *aa* index. We have defined the following nine ranges, or categories, of *aa* values: (1) $aa \leq 13$ nT, (2) $14 \leq aa \leq 25$, (3) $26 \leq aa \leq 39$, (4) $40 \leq aa \leq 69$, (5) $70 \leq aa \leq 86$, (6) $87 \leq aa \leq 120$, (7) $121 \leq aa \leq 139$, (8) $140 \leq aa \leq 198$, and (9) $199 \leq aa \leq 715$. In Figure 2 the ranges 1–8 are denoted by vertical thick lines with numbers on the right side of each plot. As an example, we show in Figure 5 the contributions of the nine categories to the *aa* index in 1919 and 1920. In Figure 5a one can see that the fourth category has the largest contribution to the *aa* index in 1919 while the second category has the largest share in 1920. Also, except for the first category, all other categories give a negative contribution over this first jump from 1919 to 1920. This is somewhat surprising, taking into account the visual image of the upward jump the frequency distribution depicted in Figure 2. A shift in the distribution of aa values to category 1, seen in Figure 5b, is responsible for the decrease in the yearly aa even though the possible 3-h aa values within each category increase. We have calculated the contributions of each category to the annual *aa* index for the four jumps. These are depicted in Figure 6. One can see that the four events of station relocation have two opposite patterns. The jumps in 1920 and 1980 behave quite similarly, with only one (the first) category giving a positive contribution over the jump, and all other categories making a negative contribution. The jumps in 1926 and 1957 are quite similar to each other, giving a positive contribution in all but one category (the first/seventh category in the second/third jump). Note that in all four jumps, none of the nine categories has a considerably larger contribution than others, implying that the category division was made quite evenly.

[12] When the contributions of the individual categories are summed up, we obtain the total change of the annual *aa* index over each discontinuity. The total changes in 1920, 1926, 1957 and 1980 are −4.91, 6.80, 4.62, and −4.16 nT, respectively. Accordingly, the annual *aa* index is decreased during the jumps in 1920 and 1980 and increased in 1926 and 1957. (These total changes can also be seen in Figure 1). Note that most of these changes are slightly counterintuitive after the above analysis of the changes in *aa* value distributions. For example, Figure 2 shows a downward jump of the discrete *aa* values in 1926 as a result of the implementation of the factor 0.93 (the ratio of the Abinger and Greenwich correction coefficients). However, as can be seen in Figure 1, the large upward jump in 1926 and the slightly smaller upward jump in 1957 occur during the increasing activity of the ascending phase of solar cycle

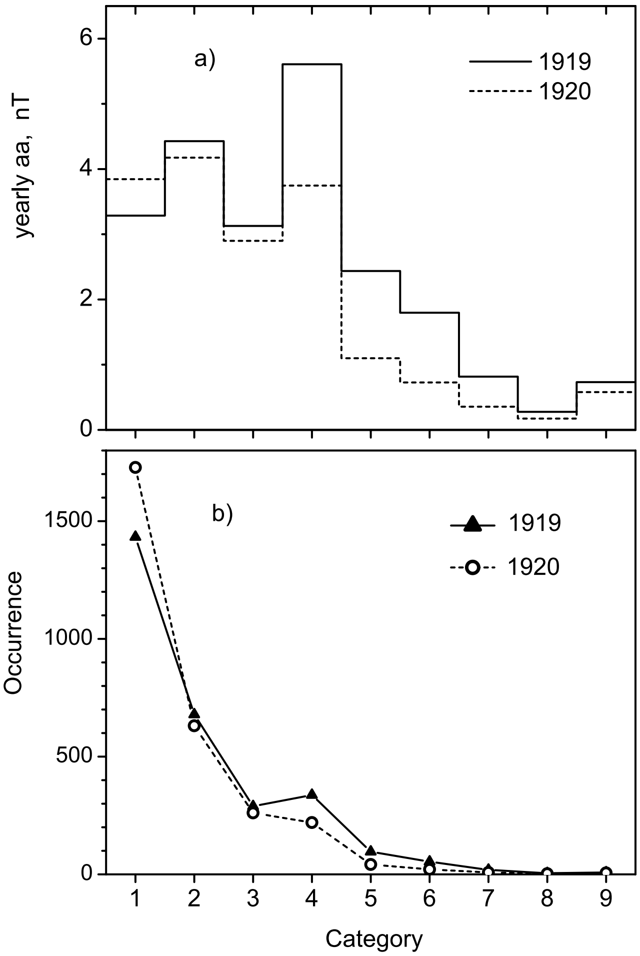


**Figure 5.** (a) Contributions (in nT) of the nine categories to the yearly *aa* index in 1919 and 1920 as well as (b) the occurrence of the 3-h aa values within each category. Categories denoted by numbers 1 to 9.

(SC) 16 and 19, after the sunspot minimum in 1923 and 1954, respectively. The 4.91 nT downward jump in 1920 coincides with the decrease from the maximum activity in 1919 during the declining phase of SC 15 with sunspot maximum in 1917. The changes during these three jumps are both in sign and in magnitude in a very good agreement with the changes expected owing to the SC variation of geomagnetic activity. The typical range of SC variation in the *aa* index is about 15 nT and it takes about 3–4 years, leading to roughly 4–5 nT change per year. In two of these cases, 1920 and 1926, the SC variation is against the shift in the *aa* value distribution (owing to the change of station coefficient), while in 1957 it is in the same direction. However, it is clear from the above analysis that the coefficient of Hartland has been estimated fairly correctly, reproducing the SC variation but not leading to an artificial (or excessive) jump in 1957. The total downward change of 4.16 nT in 1980 is more difficult to interpret as it occurs very close to the sunspot maximum (the sunspot maximum in 1979 is only one unit higher than in 1980). While intermediate dropouts in geomagnetic activity between the first peak at sunspot maximum and the second peak in the declining phase (due to high-speed streams) are common, the *aa* index minimum in 1980 is perhaps exceptionally low, even lower than during the next SC minimum in 1987. However, this would only imply that the coefficient of Canberra was estimated too low, not too high. We therefore conclude that the *aa* index does not suffer from an excessive rise even at this jump.

## 4. Summary and Conclusions

[13] In view of recent findings of the *aa* index depicting an excessively large centennial increase, we have studied here the detailed change of the distribution of *aa* values in time and, in particular over the four discontinuities caused by the relocation of one of the *aa* stations in 1920, 1926, 1957 and 1980. We have demonstrated the effect of the changing station coefficients (due to the station intercalibration by *Mayaud* [1973]) to these distributions. We have estimated how much each of the *aa* values and the nine selected *aa* value ranges, or categories, contribute to the change of the *aa* index. We found that, while the changing station coefficients dramatically affect individual *aa* values, the effects on the different *aa* index categories were very systematic and smooth in all cases and quite similar for all jumps. In three cases (1920, 1926, 1980) the typical intermediately disturbed *aa* values of about 40–70 nT caused the largest change. In 1957 the largest *aa* values had, at the expense of moderate *aa* values, a relatively larger contribution than they had in the other discontinuities. This is due to the fact that the relative station coefficient was somewhat larger (1.1338) in 1957 than in other cases (1.0683 in 1920, 0.9275 in 1926, 1.0494 in 1980), leading to larger spreading and average of the available *aa* values. However, while this difference could cause a slight overestimate of the later *aa* values, we find that the effect is insufficient to cause a significant centennial increase. Moreover, we find that the changes in the *aa* index over the three jumps in 1920, 1926, and 1957 are in agreement, both in sign and magnitude, with the solar cycle variation. In 1980, the correctness of the coefficient is harder to estimate but it can only lead to a possible underestimate of the later *aa* indices, not to an excessively large jump.

[14] We would also like to note that there are different versions of the *aa* index available in the various international data archives. Some of these depict a clearly different pattern than the "official" *aa* index from ISGI that is used here. E.g., the aa index in the NGDC database (ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/AASTAR) differs from the ISGI index systematically in 1980–1983, depicting the fourth jump in 1983, not in 1980. So care obviously must be taken when using the *aa* data. No reason for these differences is known to us so far.

[15] Concluding, there is no obvious evidence that the excessively large rise of the *aa* index during the 20th century would be due to erroneously estimated station coefficients. Rather, the station intercalibration seems to have been conducted reasonably correctly. The possibility that an erroneous calibration in 1957 is responsible for a significant part of the large increase of the *aa* index seems unlikely. Such a possibility has been mentioned in the literature, leading to an estimate of a 3 nT shift attributable to the station change in 1957. So the fact that the *aa* index

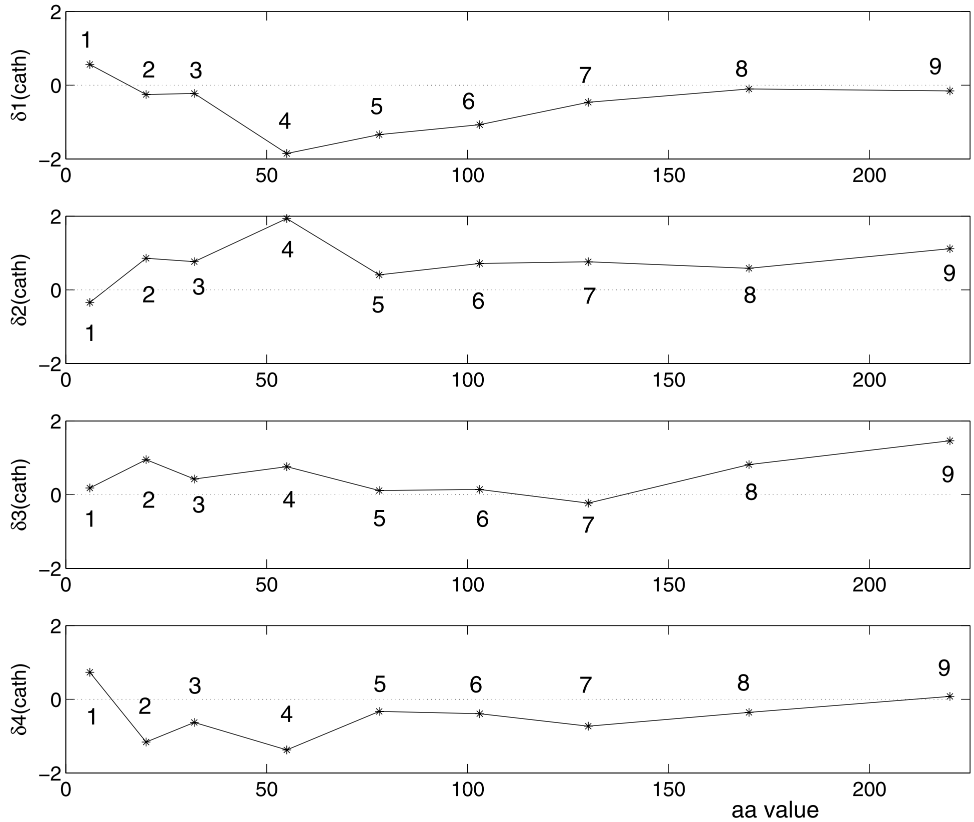


**Figure 6.** From top to bottom: Differences $\delta 1$(cat), $\delta 2$(cat), $\delta 3$(cat), and $\delta 4$(cat) during the jumps in frequency distribution occurred in 1920, 1926, 1957, and 1980, respectively.

depicts larger centennial increase than similar global or local midlatitude indices [*Martini and Mursula*, 2008] is due to some other unknown factor. Hopefully in the future, digital data of high resolution will be available for the early *aa* stations to allow for a more detailed study of the *aa* index.

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## References


Clilverd, M. A., T. D. G. Clark, E. Clarke, and H. Rishbeth (1998), Increased magnetic storm activity from 1868 to 1995, *J. Atmos. Sol. Terr. Phys.*, *60*, 1047–1056, doi:10.1016/S1364-6826(98)00049-2.

Clilverd, M. A., T. D. G. Clark, E. Clarke, H. Rishbeth, and T. Ulich (2002), The causes of long-term changes in the *aa* index, *J. Geophys. Res.*, *107*(A12), 1441, doi:10.1029/2001JA000501.

Clilverd, M. A., E. Clarke, T. Ulich, J. Linthe, and H. Rishbeth (2005), Reconstructing the long-term *aa* index, *J. Geophys. Res.*, *110*, A07205, doi:10.1029/2004JA010762.

Demetrescu, C., and V. Dobrica (2008), Signature of Hale and Gleissberg solar cycles in the geomagnetic activity, *J. Geophys. Res.*, *113*, A02103, doi:10.1029/2007JA012570.

Feynman, J., and N. U. Crooker (1978), The solar wind at the turn of the century, *Nature*, *275*, 626–627, doi:10.1038/275626a0.

Jarvis, M. J. (2005), Observed tidal variation in the lower thermosphere through the 20th century and the possible implication of ozone depletion, *J. Geophys. Res.*, *110*, A04303, doi:10.1029/2004JA010921.

Lockwood, M., R. Stamper, and M. N. Wild (1999), A doubling of the Sun's coronal magnetic field during the past 100 years, *Nature*, *399*, 437–439, doi:10.1038/20867.

Martini, D., and K. Mursula (2008), Centennial geomagnetic activity studied by a new, reliable long-term index, *J. Atmos. Sol. Terr. Phys.*, *70*, 1074–1087, doi:10.1016/j.jastp.2008.01.008.

Mayaud, P. N. (1972), The *aa* indices: A 100-year series characterizing the magnetic activity, *J. Geophys. Res.*, *77*, 6870–6874, doi:10.1029/JA077i034p06870.

Mayaud, P. N. (1973), A hundred year series of geomagnetic data 1868–1967, indices aa, storm sudden commencements, *IAGA Bull.*, 33, 251 pp., Int. Union of Geod. and Geophys. Publ. Off., Meppel, Netherlands.

Mursula, K., and D. Martini (2007), A new verifiable measure of centennial geomagnetic activity: Modifying the K index method for hourly data, *Geophys. Res. Lett.*, *34*, L22107, doi:10.1029/2007GL031123.

Mursula, K., D. Martini, and A. Karinen (2004), Did open solar magnetic field increase during the last 100 years? A reanalysis of geomagnetic activity, *Sol. Phys.*, *224*, 85–94, doi:10.1007/s11207-005-4981-y.

Russell, C. T. (1975), On the possibility of deducing interplanetary and solar parameters from geomagnetic records, *Sol. Phys.*, *42*(1), 259–269, doi:10.1007/BF00153301.

Stamper, R., M. Lockwood, M. N. Wild, and T. D. G. Clark (1999), Solar causes of the long-term increase in geomagnetic activity, *J. Geophys. Res.*, *104*, 28,325–28,342, doi:10.1029/1999JA900311.

Svalgaard, L., and E. W. Cliver (2005), The IDV index: Its derivation and use in inferring long-term variations of the interplanetary magnetic field strength, *J. Geophys. Res.*, *110*, A12103, doi:10.1029/2005JA011203.

Svalgaard, L., and E. W. Cliver (2007), Interhourly variability index of geomagnetic activity and its use in deriving the long-term variation of solar wind speed, *J. Geophys. Res.*, *112*, A10111, doi:10.1029/2007JA012437.

Svalgaard, L., E. W. Cliver, and P. Le Sager (2004), IHV: A new long-term geomagnetic index, *Adv. Space Res.*, *34*(2), 436–439.


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