

The *aa* Indices: A 100-Year Series Characterizing the Magnetic Activity

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After the 100-year series of the *aa* indices is described, two results are set forth. The general trend of the activity variation permits us to forecast a very-low level of intensity (3–4 in *Ap* units for the yearly values) during the next solar minimums (this finding would be of interest in magnetospheric studies), and the annual variation of the activity is definitely proved.

In a previous note [Mayaud, 1971] we described the possibility of characterizing the magnetic activity at the earth's surface by using the *K* indices of two antipodal observatories. Here we present some results from a 100-year series. One result permits us to forecast the intensity of the magnetic activity; the other result is a clear confirmation of the annual variation.

Let us recall the basis of such an index. The main characteristic of temporal variations of magnetic activity is random occurrence. However, any statistical study of these variations reveals some daily or yearly variations. Two variations are of importance: the daily variation in local time with a night maximum and the annual variation with a maximum in each hemisphere at the summer solstice. Then by using two antipodal observatories both variations should be approximately canceled, and a planetary characterization may be reached. The Greenwich and Melbourne observatories, roughly antipodal, have worked simultaneously since the end of 1867, and have been superseded by the Abinger-Hartland and Toolangi observatories respectively. We shall define the index *aa* (*a* is antipodal) by the average, for each 3-hour interval, of the *K* indices of these two observatories after the transformation of *K* into amplitudes in gammas. We called them *am'* previously [Mayaud, 1971] and pointed out that (1) the differences between the *am* [Mayaud, 1968] and *aa* indices, which are sometimes of importance for the 3-hour values, decrease rapidly when the averages of two, four, or eight 3-hour values are considered, and (2) the cancellation of the daily variation at each antipodal

observatory is really efficient for the averages of two or four 3-hour values of the *aa* indices.

Figure 1 illustrates again, in a slightly different way, the first point. It represents for 1961 the variations of the *am* and *aa* indices, the *aa* index being computed from Hartland and Toolangi. In this diagram a value is plotted for each 3-hour interval, which is the running mean for 12 hours. The similarity of the two curves is quite impressive. However, looking closer one can see many differences in details. Such differences are larger with the 3-hour values themselves; conversely, they become much smaller with the daily values. Thus the linear correlation coefficient between the daily values of the *am* and *aa* indices is equal to 0.988 for 1959–1967; it is equal to 0.994 and 0.998 for the monthly and yearly values, respectively.

The *am* index, based on five groups of observatories in the northern hemisphere and three in the southern, is evidently more reliable for the 3-hour indices. For example, suppose that the amplitude of the variation observed at one of the *aa* observatories is near a border line of the *K* scale [Mayaud, 1967a, p. 10]. The result obtained for the *aa* index would be rather different if the variation would reach the other side of the border line. In this case, an increase of 1 in *K* would correspond to an increase by a factor of 2 at the stage of the transformation of *K* into amplitudes in gammas. Clearly, the *am* index is not so sensitive to such effects. But, as soon as one deals with averages for ½ day, 1 day, or longer periods of time, both indices seem to be very near to each other. Consequently, the *aa* index can be a useful tool for obtaining reliable information for a long series of years.

We determined the *K* indices of the two *aa*

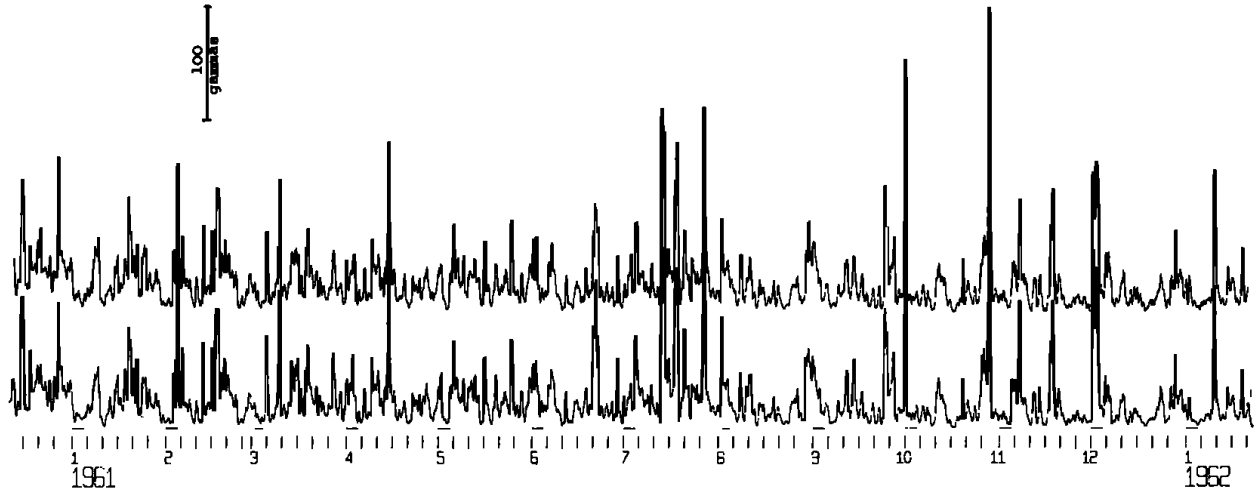


Fig. 1. Running means for 12 hours of the 3-hour values of *am* (top) and *aa* (bottom). The beginning of each month is indicated by numbers 1–12.

observatories for records that had not been measured previously. To obtain a homogeneous series of data and especially to prevent any contamination of the data by the *Sq* variations, we remeasured the records of the years for which the quality of the already published *K* indices was insufficient in that respect. Thus we have a really homogeneous series of *K* indices for 1868–1967 for each of the two antipodal observatories. However, the series for the southern observatory is still provisional, because all the gaps in the records have not yet been filled. We hope to finish the series soon, but the results presented in Figure 2 are sufficiently reliable for a first discussion.

Figure 2 shows the running means for 1 year of the monthly values of three indices: the *Ap* index (1932–1967), the *Ci* index (1884–1967), and the *Aa* index (1868–1967). (The daily values of *Ci* have been transformed into amplitudes in gammas by using the table of equivalence proposed by Bartels.) The relation of *Aa* to *aa* corresponds to the relation of *Ap* to *ap*; let us remember $ap = 2 \gamma$. To plot also the 9-year *Am* index that we have would be of little interest. We shall later use another way to compare the *Am* index with the *Ap*, *Ci*, and *Aa* indices. In Figure 2 the yearly ratios of the activity intensity at the two *aa* observatories are also plotted. A certain scattering appears; the amplitude, however, is of the same order of magnitude as that of the annual variation of the mean monthly ratios (we shall comment on this annual variation later). Furthermore, the scat-

tering of the yearly ratios is partly systematic with the site changes of the observatories. A correction will have to be applied. In this sense, also, these *aa* values are provisional.

The well-known 11-year cycles appear with each of the three indices. The arrows, indicating the epochs of the maximums and minimums of the sunspot numbers, show, however, that a poor correlation, especially for the maximums, exists between such a solar index and the magnetic activity. This fact has been already stressed by Bartels [1932].

The various curves differ in many details. To some extent, *Ap* looks more like *Aa* than *Ci* does, especially from 1937 to about 1944. However, the range of variation of *Ap* is much larger than that of *Aa*; the same difference appears between *Am* and *Ap* [Mayaud, 1970]. Another systematic difference appears between *Aa* and *Ci* during the four first common minimums. Such a difference, an absolute minimum occurring sooner with *Ci*, reveals the qualitative character of this index. After the beginning of the minimum period observers had a tendency to characterize any small perturbation by a too high *C* value. The chief difference between *Ci* and *Aa* is, however, the variation of the minimum levels, which appears quite large with the *Aa* index but is almost entirely masked with the *Ci* index. For instance, the activity levels during the minimums of 1944–1945 and 1954–1955 are 3 times the activity level during the minimum of 1901–1903 with the *Aa* index, whereas with the *Ci* index the activity levels are only in a

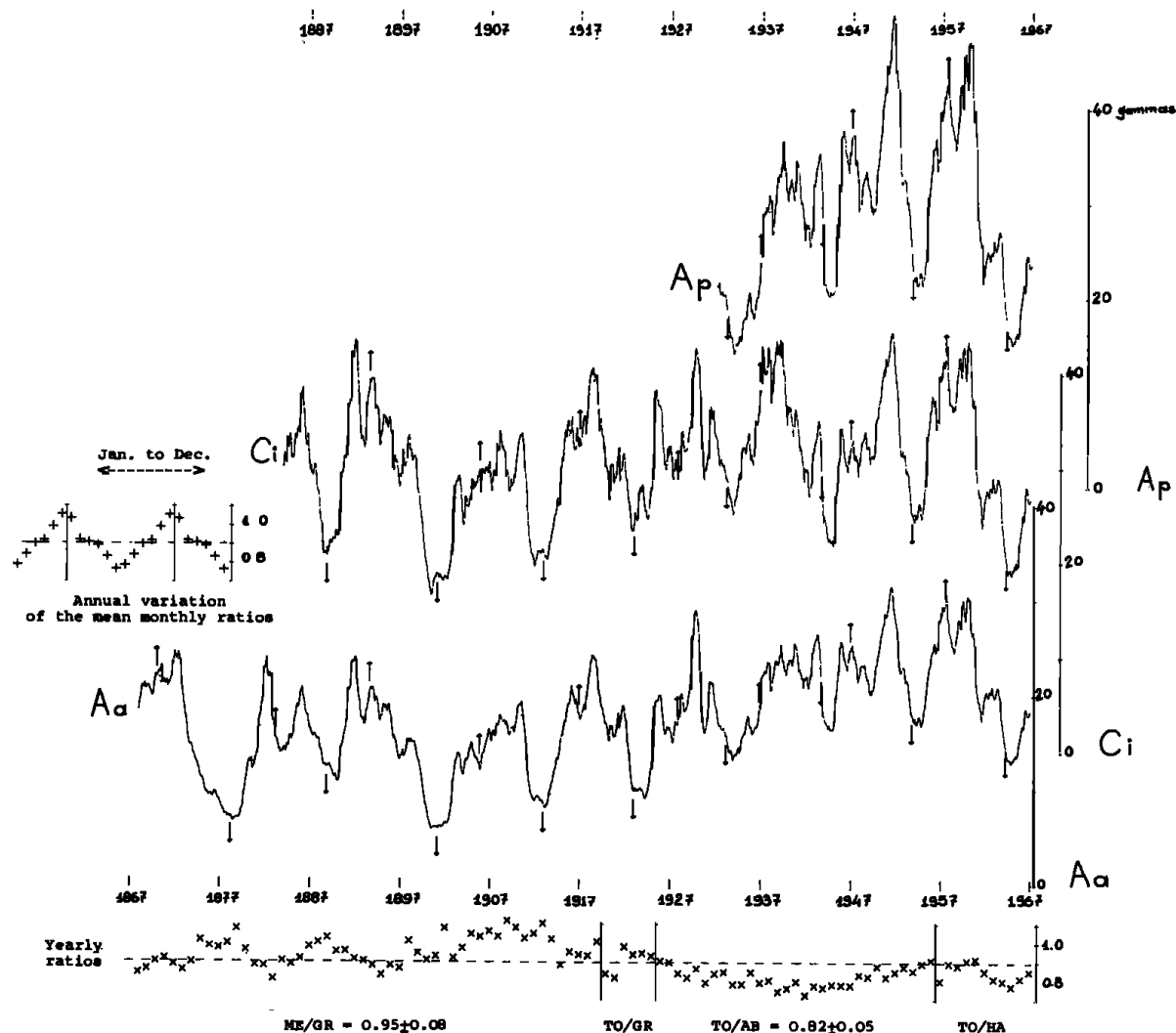


Fig. 2. Running means for 1 year of the monthly values of A_p (1932–1967), C_i (1884–1967), and A_a (1868–1967). Upward pointing arrows indicate maximum sunspot numbers; downward pointing arrows indicate minimum sunspot numbers. The yearly ratios (bottom) and the annual variation of the mean monthly ratios (left) are also plotted.

ratio of 4 to 3. Furthermore, the envelope of the A_a minimums has a shape much more regular than that of the C_i minimums. This variation is not as clear on the aa maximums, partly because of their very complex and varied shapes; the range of variation of aa is also not as large; i.e., it is smaller by a factor of 2.

When one looks at sunspot curves for a long series, such as that of *Chernosky and Hagan* [1958] for 1700–1957, the similarity in the general trends of the sunspot activity during seven or eight 11-year cycles and the trend of the minimums of the A_a index for the period under consideration is quite impressive. The level of the magnetic activity is much lower during minimums of low sunspot activity cycles than during minimums of high sunspot activity cycles.

This result is of great interest, because from it we can forecast a significant decrease of the activity level in the next solar minimums. The yearly intensity should reach values as low as 3 or 4 in A_p units, as was the case for 1901–1903. Consequently, the conditions for mapping the main field by means of satellites will be highly favorable, because the observed field will be extremely near the main field for long time intervals, i.e., several weeks. Also, the quiet magnetosphere could be explored at length without any drastic change, and its complexity might be better understood.

Evidently, the validity of such a quantitative forecast relies on the accuracy of the aa indices. Figure 3 illustrates that point again in relation to the A_m index. For 1959–1967 the scattering

diagrams of the monthly values of the indices A_p , C_i , and A_a are plotted as a function of the monthly values of the A_m index. If one accepts the fact that the A_m index gives a reliable estimation of the intensity of the activity (this index is based on observatories well distributed in longitude and latitude in both hemispheres), it appears that the scattering is much smaller with the A_a index than with the other indices. This scattering is so small that one can assert that the monthly value of the A_a index gives practically the same answer as the A_m index in the whole range of variation (5–25 in ap units). During the minimum of 1901–1903, A_a yearly values reached values lower than 3 in ap units. It is therefore quite probable that

during the coming low sunspot activity cycles the magnetic activity will again reach very-low yearly values. Furthermore, one could say that before 1959 the level of the activity is better estimated with the A_a index than with the A_p index. For a discussion of some defects of the A_p index see *Mayaud* [1967b, 1970].

The annual variation of the magnetic activity has been recently studied by *Wulf* [1971]. Figure 2 illustrates a result obtained from the 100-year series of K indices at the two antipodal stations. As we are relatively confident in the reliability of the scalings, whatever the level of the activity, we give the mean monthly ratios (southern hemisphere to the northern hemisphere) of the activity intensity. The annual

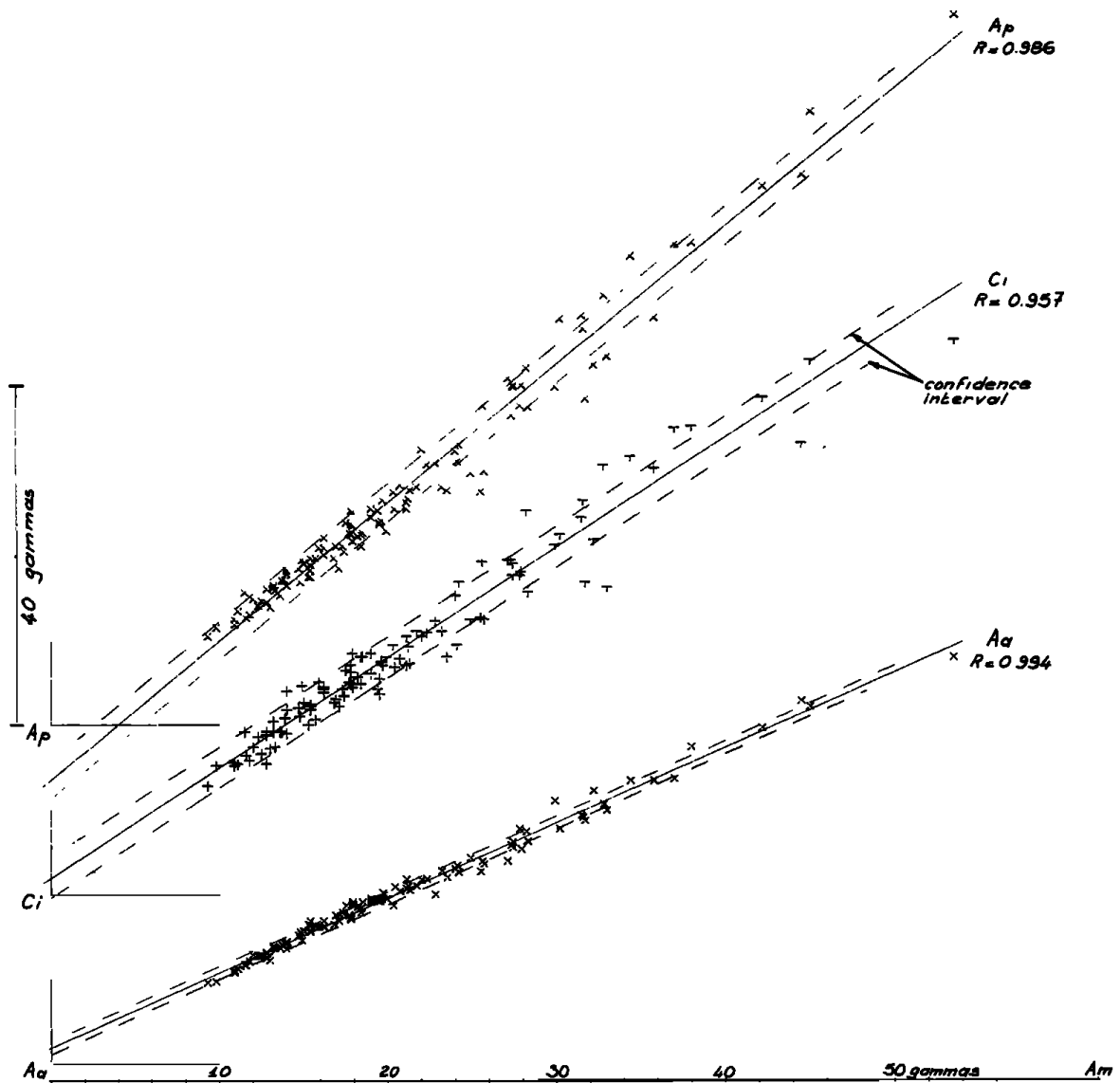


Fig. 3. Monthly values for 1959–1967.

variation looks like an almost pure sinusoidal wave. A harmonic analysis of the ratios gives an amplitude of 0.116 and 0.011 for the two first harmonics, and the standard deviation of the differences between observed and computed ratios is 0.025. Therefore the second harmonic is not significant, whereas the first one clearly is. The maximum of the first harmonic occurs on December 23, quite near the December solstice. Finally, the statistical test, described by *Chapman and Bartels* [1940] and used to compare the annual variation observed in each year with the annual variation of the 100-year series, results in a value of 97.98. (The value would be 100 if all the 100-year annual variations were exactly in phase.) Such an annual variation, then, is extremely stable in phase.

Consequently, the existence of the annual variation of the magnetic activity in middle latitudes, first pointed out by *McIntosh* [1959], is definitely proved. Its mean amplitude in each hemisphere is about 10%, whereas the amplitude of the semiannual variation is about 24%. The semiannual variation appears on the *aa* indices with the same amplitude, but the annual variation is practically canceled through the use of the two antipodal observatories.

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REFERENCES

- Bartels, J., Terrestrial magnetic activity and its relations to solar phenomena, *J. Geophys. Res.*, **37**, 1, 1932.
- Chapman, S., and J. Bartels, *Geomagnetism*, p. 584, Oxford at the Clarendon Press, London, 1940.
- Chernosky, E. J., and M. P. Hagan, The Zurich sunspot number and its variation for 1700-1957, *J. Geophys. Res.*, **63**, 775, 1958.
- Mayaud, P. N., Atlas of *K*-indices, *Rep. 21*, Int. Assoc. of Geomagn. and Aeron., Rockville, Md., 1967a.
- Mayaud, P. N., Calcul préliminaire d'indices *Km*, *Kn* et *Ks* ou *Am*, *An* et *As*, mesures de l'activité magnétique à l'échelle mondiale et dans les hémisphères Nord et Sud, *Ann. Geophys.*, **23**, 585, 1967b.
- Mayaud, P. N., *Indices Kn, Ks et Km, 1964-1967*, Centre National de la Recherche Scientifique, Paris, 1968.
- Mayaud, P. N., Sur quelques propriétés de l'activité magnétique déduites de l'analyse d'une série de neuf années des indices *Kn*, *Ks* et *Km*, *Ann. Geophys.*, **26**, 109, 1970.
- Mayaud, P. N., Une mesure planétaire d'activité magnétique basée sur deux observatoires antipodaux, *Ann. Geophys.*, **27**, 67, 1971.
- McIntosh, D. H., On the annual variation of magnetic disturbance, *Phil. Trans. Roy. Soc. London, Ser. A*, **251**, 525, 1959.
- Wulf, O. R., Winter-summer difference in geomagnetic activity, *J. Geophys. Res.*, **76**, 1837, 1971.

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