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The new digital A_h index of geomagnetic activity at Alibag and other stations

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The geomagnetic activity carries important information about various parameters of the near-earth space and the solar magnetic activity on short as well as on long-term scales. In short or moderately long-term studies, the K_p/A_p index is a widely used reliable measure of geomagnetic activity. On the long-term scale, the *aa* index has, till recently, been the only index offering a sufficiently long registration for centennial studies. However, the long-term robustness of *aa* index was seriously questioned, and the early registrations until the first decades of the last century are not available in digital form in sufficiently high resolution. Therefore, the *aa* index cannot be verified, nor its probable error be reassuringly quantified. Here we further verify the incorrectness of *aa*, using a recently introduced digital measure of the geomagnetic activity, the A_h index calculated at the Indian Alibag station. Global A_h from a number of long-running stations can be used to reliably extend the A_p series by roughly 30 years, allowing the study of geomagnetic activity for more than a century at the three-hourly resolution. Local A_h indices can also be calculated at any latitudinal region.

Keywords: Digital index, geomagnetic activity and indices, long-term variations.

GEOMAGNETIC activity is an important parameter to study not only the physical processes in near-earth space, but also to understand and quantify the long-term development of the solar magnetic activity. The heliospheric magnetic field is known to be the main modulator of cosmic rays and a significant cause of geomagnetic activity. One of the most important questions in solar–terrestrial science is whether and by how much has the sun increased its magnetic activity during the last century. Based on the longest uniform measure of geomagnetic activity available at that time, the *K*-based *aa* index, Lockwood *et al.*[1] concluded that the strength of the heliospheric field has more than doubled in the last hundred years. Although this result is in a fairly good agreement with other results based on studies of cosmogenic isotopes (e.g., Usoskin *et al.*[2]) and a theoretical model presented by Solanki *et al.*[3], the *aa* index – being the only independent proxy of long-term solar magnetic activity – still plays a crucial role to conclude a doubling of the heliospheric magnetic field.

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The *K*-based indices have long been the most widely used measures of long-term geomagnetic activity. The derivation method of the local *K*-indices is standardized, and different global or planetary measures of magnetic disturbance level have been derived from it. The fundamental aim of all measures of geomagnetic activity is to separate the regular variations caused mainly by solar EUV radiation, from the irregular variations driven by various parameters of the solar wind. In the case of *K*-based indices, the regular variation is represented by the quiet daily curve, the so-called S_q-curve, defined by an expertized observer, while the irregular variation (i.e. geomagnetic activity) is defined as the range between the upper and lower fitting of this S_q-curve during each 3 h time interval. This range is associated with an integer number between 0 and 9, according to a pre-determined quasi-logarithmic scale of disturbance level, forming the so-called *K*-value[4]. This digitization was introduced in order to limit the amount of data at a time with no modern computer facilities. While this is not an issue any longer, the digitization may include some inherent arbitrariness when, for example, selecting between two neighbouring *K*-values. The quasi-logarithmic *K*-value can also be transformed into the linearly scaled A_k value using a standard scaling method.

Probably the most reliable index of global geomagnetic activity for moderately long-term studies is the K_p/A_p index, which is based on 13 stations. However, A_p starts only in 1932, being simply too short for long-term research. In particular, it does not cover the interesting years in the 1920s and early 1930s, when geomagnetic activity was rising dramatically. Therefore another index, *aa*, was implemented for centennial studies. The local A_k indices are calculated for two antipodal stations (actually station chains), Hartland in UK and Canberra in Australia and then, after normalization, averaged to form the *aa* index[5]. The *aa* index is one of the longest uniform series of geomagnetic activity and was widely used in long-term studies. However, Svalgaard *et al.*[6,7] noted the long-term inconsistency in *aa* and seriously questioned any long-term estimates based on it. The problem is made even more severe by the fact that the early registrations are not available at sufficiently high sampling in digital form, making the verification of the *aa* index impossible at present.

This situation led Mursula and Martini[8] recently, to introduce A_h, a new geomagnetic activity index dedicated for centennial studies. This follows the derivation method of the *K*-based indices as closely as possible and appropriate. On the other hand, it is based on digital hourly data that are available from the World Data Center (WDC) for most stations since operations started. By following the *K*-method, the new index agrees well with the physics of all *K*-indices, while using hourly data we overcome the data availability and verifiability problem discussed above. The A_h index is calculated as follows. First we define the S_q curve in each month as an average of the daily curves of the five quietest days. Then, as in the *K*-method, we fit this S_q curve to observations from below and from above in each 3 h period; the difference (range) gives the value of irregular variations, i.e. the A_h index in *nT*. Note that A_h values are not digitized to integer *K*-values; this avoids the often arbitrary selection of two neighbouring integer values.

As mentioned above, for many stations A_h can be calculated since the first years of last century, and for some long-operating stations such as Niemegk (NGK), even since the late 19th century. However, here we compare the two analogue indices, A_p and *aa*, with a number of local A_h indices during the overlapping period in 1932–2000. We selected seven long-operating observatories; Sodankylä (SOD) and Sitka (SIT) from high latitudes, NGK and Fredericksburg (FRD) from the mid-latitudes, and Tucson (TUC), Honolulu (HON) and Alibag (ABG) representing the low latitudes. Calculating the linear correlation between the yearly values of A_p and *aa*, we get an expectedly good correlation coefficient (cc) of 0.95. In Table 1 we show the similar cc values between A_p and A_h from the seven stations. Note that at mid-latitudes, the correlation is exceptionally and consistently high, even significantly stronger than between A_p and *aa* (note also that the *aa* stations are mid-latitude stations, i.e. the cc between *aa* and A_p is to be compared to that of the mid-latitude stations NGK and FRD). Also at high latitudes, cc between A_p and A_h exceeds that found between A_p and *aa*. Although the overall correlations are equally good, two out of the three low-latitude stations (HON and ABG) give slightly smaller values. This can be understood in terms of two factors. First, the three-hourly time period of the *K*-method was chosen to fit the usual duration of the most common bay-like disturbances (substorms) at mid-latitudes[9]. This, at least partly, can explain why we find the strongest correlations at mid-latitudes. Secondly, at low latitudes the amplitude of the quiet daily curve is relatively larger with respect to the irregular variations. So small daily differences in the S_q curves have more importance in these regions.

Let us now focus on the A_h index of the ABG station. Figure 1 depicts the scatterplot of annual averages of A_p and ABG-A_h indices and their best fitting line (top panel), and the time series of the two indices, where the ABG-A_h

Table 1. Linear correlation factors between the annual averages of global A_p and local A_h indices

Station index	Correlation coefficient
SOD	0.97
SIT	0.96
NGK	0.98
FRD	0.98
TUC	0.95
HON	0.94
ABG	0.94

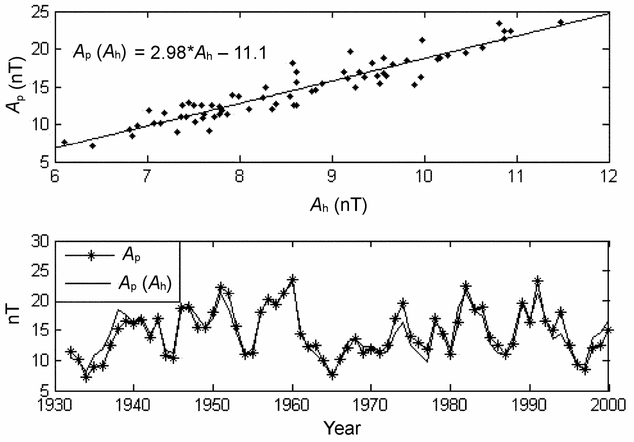

Figure 1. Scatterplot between the annual means of ABG-A_h and A_p with the best fitting line (top panel), and their time series (bottom panel).

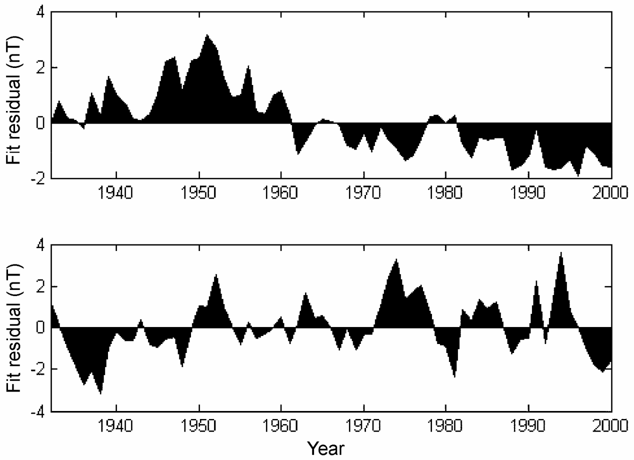

Figure 2. Residuals of fitting *aa* to A_p ($A_p - A_p(aa)$; top panel), and fitting ABG-A_h to A_p ($A_p - A_p(A_h)$; bottom panel).

index has first been fitted to A_p (bottom panel). Qualitatively the two indices follow each other well, except that ABG-A_h is larger than A_p in the late 1930s, in the ascending phase of solar cycle 17, and is less than A_p in some years of descending phase with strong CIR (corotating interaction region) activity like in 1973–74, and 1994. Otherwise A_p and ABG-A_h seize the same long-term variations of the near-earth space.

Correlation is only a measure of the overall agreement between two time series. In order to study the relative drifts between the two parameters, it is essential to look at the residuals of the fits. Figure 2 depicts the fit residuals of $A_p - A_p(aa)$ (top panel) and $A_p - A_p(A_h)$ (bottom panel). One can see in the top panel that the fit residuals are consistently above zero before the late 1950s, while they are below zero thereafter. On the other hand, the residuals of fitting $A_p(A_h)$ to A_p show no such significant long-term drift. Thus, the *aa* index shows a systematically larger long-term increase than A_p or ABG-A_h, while the latter two depict a similar increase (in agreement with earlier results based on global comparison[10,11]). Thus, A_h even at a low latitude station gives a reliable local alternative to A_p. This result also seriously questions one of the most important recent results of space climate, the centennial doubling of heliospheric magnetic field strength that is partly based on the long-term trend depicted by *aa*.

The A_h indices offer not only better correlation with the A_p index than *aa* in most regions and a long-term robustness, but also allow studying long-term tendencies in various latitudinal regions from high to low latitudes. Local centennial trends of geomagnetic activity calculated at various latitudinal regions show a curious distinct latitudinal pattern, being the largest at high latitudes, roughly half of that at low-latitudes, and, interestingly, the lowest increase was found at the mid-latitudes[10,11]. Thus, using only mid-latitude stations in long-term studies, as in the case of *aa*, inherently leads to an inaccurate estimation of the global long-term trend of activity level. To study this spatial dependence of the centennial evolution of geomagnetic activity became possible only by the introduction of the new IHV and A_h indices. Note also, however that the local A_h indices represent the local geomagnetic activity reliably down to the three-hourly time resolution unlike the IHV index, whose highest time resolution, being derived from night-side data, is only one day. (An in-depth study on high-frequency features of the A_h index can be found in Mursula and Martini[10].)

The above problem with *aa* also agrees well both qualitatively and quantitatively with various previous reports on long-term inconsistency found in the *aa* index[6,7,12–14] and strongly suggests that *aa* should be corrected, or more preferably replaced for long-term studies. This involves that former long-term studies based on the *aa* index must be recalculated using either the corrected *aa* index, if it can be reliably corrected at all, or, rather, the A_h index. To eliminate the possible local effects when comparing a local measure to a global one, here we studied only annual averages. However, by forming the planetary A_h index we are reliably able to detect variations up to three-hourly resolution in global level as well. Since many stations started their operation in the early 1900s (e.g. continuous measurements started at ABG in 1904), a global averaging of the local A_h indices can also extend the global A_p series by roughly 30 years[10,11]. Therefore, the global and local A_h indices offer, both for centennial and shorter-term studies, an appropriate and reliable alternative to the more traditional measures of geomagnetic activity at all latitudinal regions.

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Studies on the role of ants in reproductive efficiency of three species of *Phyllanthus* L.

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Three herbaceous species of *Phyllanthus* L. namely *P. fraternus* L., *P. urinaria* L. and *P. simplex* Retz. form overlapping populations in and around Jammu during April–October. All are monoecious and unique in placement of flowers beneath leaf axils. Flowers are small, nectariferous and not amenable to major pollinators. Ants are involved in pollen transfer in these species. Three species visit the plants, these belong to genus *Camponotus* and *Monomorium*. Although all the three plants species represent a typical case of ant–plant mutualism, they differ in their dependence on ants for successful fruit set. *P. simplex* is totally dependent on ants, while *P. urinaria* and *P. fraternus* take the help of wind also.

Keywords: Ants, monoecy, *Phyllanthus*, pollination.

ANTS are among the most numerous and widespread insects on earth, with the habit of foraging heavily on plants. They are routine visitors to many plants offering nectar as a reward; however, their role in reproductive efficiency of plants remains controversial. Positive, negative as well as neutral aspects of their visits are reported. Some authors term them as neutral visitors because of their small size, due to which they are able to sneak in and out of flowers without even touching the anther/stigma[1–3]. The negative effect mainly includes reduction of the frequency of visitation by insect pollinators due to the aggressive behaviour of the ants or by their capacity to act as nectar robbers[4–8]. Many ant species also are reported to secrete antibiotic substances that render pollen inviable[9–14].

Studies on the positive effects of ant visitation to plants have mainly revolved around their role in protection from herbivores and in seed dispersal. Few field studies have also examined the role of ants in pollination and have shown them to contribute substantially to seed production[15–19]. However, not much is known about ant pollination in the Indian subcontinent. In our studies on three species of the genus *Phyllanthus* L., i.e. *Phyllanthus fraternus* L., *P. urinaria* L. and *P. simplex* Retz. forming natural populations in Jammu, we observed a definite role of ants in pollination. This communication deals with the details of some field experiments which were done to ascertain the role of ants in successful fruit and seed set in the three species mentioned above.

P. fraternus L., *P. urinaria* L. and *P. simplex* Retz. were selected during peak flowering, which occurs from April to October in the subtropical climate of Jammu. About 50 plants ($N = 50$) were selected per species. Plant and floral morphology were studied in the field from live plants. For calculating the sex ratio, the plants were selected when they were in full bloom. The number of male and female flowers was recorded for the whole plant. From the data thus generated, sex ratio was calculated as follows:

$$\frac{\text{No. of male flowers per plant}}{\text{No. of female flowers per plant}}.$$

Insect visitation frequency was recorded on plants in full bloom at regular time intervals from 9 am to 6 pm on

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