The Ap* Index of Maximum 24-Hour Disturbance for Storm Events:
An index description and personal reminiscence by its author, J.H.Allen
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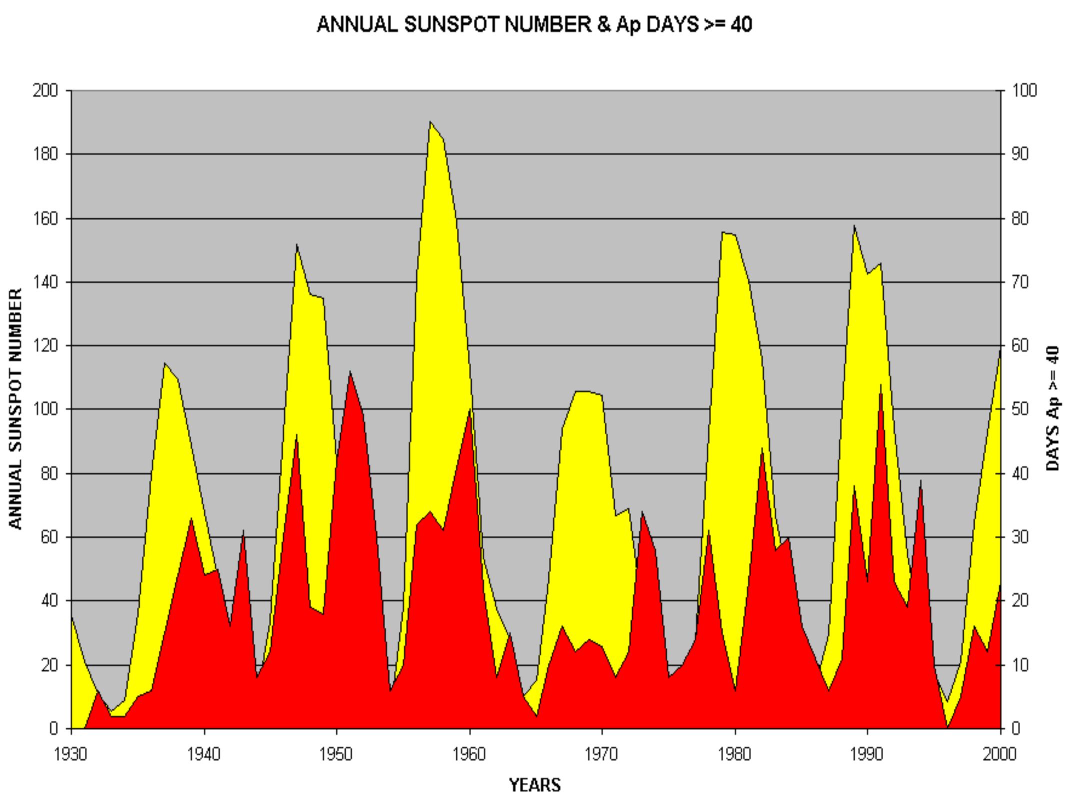
Ap* is defined as the earliest occurring maximum 24-hour value obtained by computing an 8-point running average of successive 3-hour ap indices during a geomagnetic storm event without regard to the starting and ending times of the UT-day. It is uniquely associated with the storm event. Over many years, values of Ap* provide a maximum disturbance measure useful to identify major geomagnetic storms chronologically (by date and start time) and by amplitude from largest to the smallest. The earliest possible values are for 1932, because that is the first year for which the standard Kp and ap indices were produced. As NGDC staff or others have time to update Ap*, tables of values are available from 1932 to recent times. They are available by FTP transfer from the NGDC website.

Often for current storms of special interest, Ap* values are derived by hand in order to compare their maximum 24-hour intensities with values for historic storms. For example, artificial satellites have been in orbit since about 1960. The top ten Ap* values from 1960 through 2003 are given in the table below. Values from 1960 through 2001 were taken directly from the on-line Ap* values at NGDC. Several large solar eruptions in October 2003 directed streams of energetic particles toward Earth and resulted in large geomagnetic storms. These were unusual because they happened several years after the peak of activity around sunspot maximum in 2000. Many satellites in orbit were affected by the disturbed magnetospheric conditions. A prompt value of Ap* was hand-calculated for the most disturbed 24-hours. The maximum 24-hour disturbance began at 0600 UT on 29 October 2003. The storm event lasted several days. It had Ap* = 204. As shown in the table below, this new storm entered the "Top Ten" list in the ninth position for the current era when most artificial satellites have been in orbit.

DAY of start for peak 24-hr of storm	Ap*
1960/11/12	293
1989/03/13	285
1960/10/06	258
1960/03/31	251
1967/05/25	241
1982/07/13	229
1986/02/08	228
1972/08/04	223
2003/10/29	204
1982/09/05	201

The National Geophysical Data Center (NGDC) was started in Boulder, Colorado in the late 1960's. In its Solar-Terrestrial Physics (STP) Division, several WDC-A discipline centers were consolidated to create WDC-A for STP. The first NGDC Director, Alan H. Shapley, asked Joe Allen to devise a scheme to classify the relative intensity of geomagnetic storms. He wanted NGDC to emulate the success of seismologists who used the "Richter index" to rank earthquakes by size. The International Association of Geomagnetism and Aeronomy (IAGA) already published Kp, ap, and Ap magnetic activity indices in a series of annual books for years since 1932, and in cumulative volumes for multiple years. For over 40 years they have provided tables of 3-hourly Kp and ap indices, and daily average Ap indices for each UT-day. These are derived from disturbance values scaled from magnetograms recorded at twelve or more different magnetic observatories distributed around the world. Kp, ap and Ap were essential tools for comparison of geomagnetic storms, along with other indices and physical parameters of the disturbed Sun-Earth system. However, they had a problem that is solved with the introduction of Ap*.

In early 1974, Allen noted with interest the difference between the yearly number of magnetic storm days (Ap ≥ 40) and the smoothed annual sunspot number (see figure for years from 1932-2000).



The 11-year cycles of the familiar sunspot number (yellow) are reasonably uniform in shape although they vary in maximum amplitude and cycle length. Some have broad, multi-year peaks while others are sharper. The annual magnetic storm days pattern (red) is much more variable, although there are some persistent features. For example, at least one peak in the number of magnetic storms happens during the declining years of each solar cycle, and sometimes more than one. A part of the study involved counting the published number of days per year having daily Ap≥100, 80, 60 and 40. This effort revealed the interesting pattern shown above for Ap≥40, but also it also illustrated the problem with the regular Ap index. Ap is the 8-value average of only the 3-hourly ap values for each UT-day. However, some storms begin sharply in mid-day and their maximum disturbed period extends into the middle of the next UT-day. The Sun appears not to be aware of the location of the Greenwich Meridian and so doesn't organize storm events by UT-days. The result is that values of Ap on successive days regularly under rate the peak size of geomagnetic storms.

It seemed reasonable to compute an Ap-like index from the original ap values, but to do so without regard to the UT-day, i.e. to compute an 8-point running average and look for maxima. If one defined a storm starting and ending average value, then these would establish the timing and duration of storm events. The maximum 8-point average during the event is a measure of the storm's peak intensity. It provides a value comparable to the regular Ap, but more useful for relative classification of different storms. In this way the Ap* index emerged from the initial study of Ap storm-days. For storm events when the most disturbed 24-hours also begins with the start of the UT-day, then Ap = Ap*. This happens for about $1/8^{th}$ of all classified storms. Thus, the historical Ap index undervalues about 7/8ths of all storms.

Ap* has been tabulated at WDC-A for STP since it was devised in 1974. It was first presented in a paper given by J.H. Allen at the IAGA Scientific Assembly in Seattle, Washington. Graphs and tables of these indices and explanations of their simple derivation have been published in various papers and proceedings. The earliest published description of Ap* and a list of key dates of major storms, was in ***"Solar-Terrestrial Physics and Meteorology: A Working Document,"*** edited by A.H. Shapley, H.W. Kroehl, and J.H. Allen, SCOSTEP, July 1975.

The index is more fully described and related to satellite anomalies in the papers: ***"Some Commonly Used Magnetic Activity Indices: Their Derivation, Meaning, and Use"*** J. H. Allen (pages 114-134) in ***"Proceedings of a Workshop on Satellite Drag",*** March 18-19, 1982, Boulder, Colorado, Edited by Jo Ann C. Joselyn; and in ***"Solar-Terrestrial Activity Affecting Systems in Space and on Earth",*** by J.H. Allen and D.C. Wilkinson (pages 75-107) in ***"Solar-Terrestrial Predictions-IV: Proceedings of a Workshop at Ottawa, Canada May 18-22, 1992"***, Edited by J. Hruska, M.A. Shea, D.F. Smart, and G. Heckman. The indices have been available on-line since 1994.

The standard computer output from the Ap* program appears in the on-line file. It gives the values used to identify the storm periods' start and end times (usually 40 and 40), the number of major storms in each month for all years surveyed, the total number of major storms per year, and the total number of major storms per month over all years. These statistical values provide information about the year-to-year pattern of major geomagnetic storm events and their seasonal distribution. Figures published in the referenced papers and in the on-line printout show the bimodal annual distribution of major magnetic storms. There are peak storm times each yearduring the weeks around the spring and autumn equinoxes. Fewer storms happen during winter and summer seasons, although a major geomagnetic storm can occur anytime during any given year without regard to season or phase of the sunspot cycle.

The Ap* index has been used to look for trends in the geoeffectiveness of solar Coronal Mass Ejections and flare-related events, to compare with the size of solar proton events, and to compare with reported anomalies of operational satellites and other technology.

For many modern problems, it is not important that the Ap* index only begins with 1932, the earliest date to which S. Chapman and J. Bartels extended their indices. However, for comparisons between geomagnetic storms and other, longer running measures of geophysical and Solar-Terrestrial phenomena, it is interesting to find some means of extending this concept to earlier years. This was possible using the aa-index compiled by Fr. P. Mayaud. He obtained copies of magnetograms from a pair of magnetic observatories on roughly opposite sides of the world, i.e. "antipodal" sites. From their individual sets of 3-hourly local K indices, he obtained equivalent a-indices and averaged them to produce the "antipodal a-index", aa, from 1868 up to more recent years. Since Fr. Mayaud retired, his associate Michelle Menvielle has continued to produce aa indices for each 3-hour interval of the UT-day.

The aa-index, as defined by Mayaud, has the same problem as Ap with respect to its existing only for each UT-day. It artificially divides the peak disturbance intervals of many storms. This has been overcome by producing the similar AA* index from the 8-point running mean of aa-indices. The units are different from those of Ap*, but the two maximum disturbance indices were calibrated by comparison over the years since 1932, when both could be computed. The threshold values for beginning and ending times of storm events are different using aa, but they were adjusted until the identified overall list of storm intervals are about the same according to both indices. Then, AA* was computed for each storm interval since 1868, and compared with smoothed annual sunspot numbers. These results also are available on-line from NGDC/WDC-A for STP.

Both Ap* and AA* serve useful purposes and neither replaces the other. The rank order of some of the largest, most significant great geomagnetic storms is different between Ap* and AA*. As Mayaud has pointed out, the aa index is derived from records of only two observatories and may be more easily affected by local, nearby overhead electrojet currents in the ionosphere above either of the two observatories whose records of local magnetic variations are used. In contrast, the averaged disturbance record of twelve or more observatories used for Ap is a more stable, truly global index of geomagnetic storms. Hence, Ap* is to be preferred when it is used for classifying storm events during the years for which it exists.