ANNALI DI GEOFISICA, VOL. 41, N. 5-6, November-December 1998

Solar, ionospheric and geomagnetic indices

Loredana Perrone and Giorgiana De Franceschi
Istituto Nazionale di Geofisica, Roma, Italy

Abstract
The most common solar, ionospheric and geomagnetic indices are here presented with particular reference to their application for radiocommunication prediction purposes. Summary tables of practical use are also included concerning the method of derivation of the indices, their time interval, their drawbacks, their time-history and the INTERNET node addresses where they are available.

Key words *ionospheric indices – solar indices – geomagnetic indices*

1. Introduction

It is well known that the magnetosphere-ionosphere system and interaction is strongly governed by the activity of the Sun (see, *e.g.*, Hargreaves, 1992). While the magnetosphere is directly influenced by the solar wind parameters and by the strength and direction of the Interplanetary Magnetic Field (IMF), the condition of the ionosphere, the existence of which is due to the *X*-ray and ultra-violet radiation emitted by the Sun, is principally determined by the *level* of both solar activity and geomagnetic perturbations.

To provide global and/or specific information on the physical state of the entire system at a given epoch, several geophysical indices were introduced for different aims, *e.g.*, for radio propagation applications to foresee ionospheric conditions, solar and ionospheric indices are used to furnish a more or less detailed description of the parameters needed for a radio link (see, *e.g.*, McNamara, 1991).

Sections 2, 3 and 4 recall the origin, meaning and application of the most important solar, ionospheric and geomagnetic indices used worldwide. Moreover, reference tables are also enclosed for a rapid and handy visualization of the above mentioned indices.

2. Solar indices

The periodic variation in intensity or number of the various solar manifestations is referred to as the solar activity cycle. The period of this cyclic variation is approximately 11 years (more precisely it varies between 9 and 14 years) and it is not symmetrical: on the average, the time from minimum to maximum is 4.3 years and the time from maximum to minimum is 6.6 years. It is observed that cycles which rise more rapidly tend to reach higher maxima, meaning that all cycles are not equally strong, the largest being four times as great as the smallest. This implies a longer term modulation of the basic 11-year cycle and in fact other significant periodicities have been observed at 57 and 95 years. Some other evidence, particularly from the study of Sun – weather relationships,

Mailing address: Dr. Loredana Perrone, Istituto Nazionale di Geofisica, U.O. Aeronomia, Via di Vigna Murata 605, 00143 Roma, Italy; e-mail: Perrone@marte.ingrm.it

has drawn attention to the 22-year cycle or double sunspot cycle: the Sun's general magnetic field reverses direction as each new cycle develops and some studies on the relation between solar activity and certain terrestrial phenomena have indicated periodicities of 22 (Hale cycle) rather than 11 years (Akasofu and Chapman, 1972; Hargreaves, 1992).

The reason for the origin of the solar cycle has been the subject of much research and speculation. One interesting theory relating to this is the planetary tidal theory: as in the solar system a number of periods are very close to 11-years, it has been thought that resonance phenomena should occur, but their physical explanation is not clear (Brekke, 1997).

In order to express the solar cycle in terms of a numerical index, the sunspot number R was introduced. It is also called the Wolf number, with reference to the Swiss astronomer Johann Rudolph Wolf who introduced this index in 1848, or Zurich sunspot number R_z, derived from the location of the observatory. Sunspots, that are concentrations of magnetic flux with a field strength of 2000-4000 G, appear on photospheric regions cooler than their surroundings, which are closer to 6000 K. They vary with the solar cycle and, for a new cycle, they are first formed at heliocentric latitudes around ± 30°. As the number of spots increases, the spots appear at lower latitudes and they are near the equator at the end of the cycle (Spörer's Law). Half of all spots have a lifetime less than 2 days while only 10% survive for more than 11 days. Only exceptionally a spot has been observed for more than 5 solar rotations (Brekke, 1997; Hargreaves, 1992). As the number of spots increases and their magnetic complexity grows, they become likely sources of large eruptive energy releases known as *solar flares*. Sunspots are available from direct observations going back to 1700, though they are only considered «good» after 1818 and «reliable» after 1848.

Apart from R, another well known solar index is the power flux of solar radio noise at the wavelength of 10.7 cm, $F_{10.7}$ (somewhere named the Covington index), or its monthly mean value Φ. $F_{10.7}$ is related to the radio en ergy of slowly varying intensity emitted by the Sun that originates from atmospheric layers high in the Sun's chromosphere and low in its corona. $F_{10.7}$ from the entire solar disk at a frequency of 2800 MHz was recorded routinely by radio telescope near Ottawa (Canada) from February 1947 to June 1991. Since 1991 $F_{10.7}$ is recorded by the radio telescope located at Penticton (Canada). The observed values are adjusted for the changing Sun-Earth distance and for uncertainties in antenna gain. As the solar flux observations have only been available since 1947, R, highly correlated with $F_{10.7}$, still remains one of the longest available series of observations of a natural phenomenon (Brekke, 1997; Hargreaves, 1992).

In the ionospheric field solar indices are used to forecast ionospheric characteristics, in particular the critical frequencies of the E and F layers and the $M(3000)F_2$ factor (CCIR, 1990). For example, the long-term prediction of f_0F_2 (the critical frequency of the F_2 region) is based on forecasting the solar indices R_{12} (12-months running mean of the sunspot number R). It is predicted by using an improvement of the McNish-Lincoln objective method (Stewart and Ostrow,1970) that consists, firstly, in calculating a mean cycle from all past values of R_{12}. For prediction of a value in the current cycle, the first approximation is the value of the mean cycle at the stated time after minimum. This estimate is improved by adding a correction proportional to the departure of the last observed value for the current cycle from the mean cycle. The statistical uncertainty of the prediction is fairly small for the first few months after the last observed value but becomes large for predictions 12 months or more in advance. Recently the possibility to predict the solar indices using neural networks has been investigated (Macpherson *et al.*, 1995).

There are some disadvantages using R or R_{12} to forecast f_0F_2, *e.g.*, the well known saturation and hysteresis effects (Gopala Ro and Sambasiva Rao, 1969). Chiu (1975) found systematic differences in f_0F_2 between 1960-1961 and 1970-1971 when R were identical. Smith and King (1981) investigated the dependence of f_0F_2 values on sunspot number R, $F_{10.7}$ and photospheric faculae index and their results

Table I. Solar indices.

Index	Method of derivation	Time interval	Drawbacks	Availability
R was introduced by Johann Rudolph Wolf in 1848 to quantify the solar activity.	R is defined as: $R = k\,(f + 10\,g)$ where f is the total number of spots seen, g is the number of disturbed regions and k is a constant for the observatory, related to the sensitivity of the observing equipment. Since 1981 R has been derived at the World Data Center C in Brussels and calculated as a weighted mean of spots and spot groups reported by a network of solar Observatories.	Daily		Data are available from 1700 as yearly means. From 1749 R is available as monthly mean and from 1951 as daily value.
R_{12} is the 12-month running mean of the sunspot number R.	For a given k-month, R_{12} is defined as: $R_{12} = \frac{1}{12}\left[\sum_{n-5}^{n+5} R_k + \frac{1}{2}(R_{n+6} + R_{n-6})\right]$ where R_k is the mean of the daily sunspot number for the month k, R_{n-6} and R_{n+6} are the R values related to six months before and after the k-month.	Monthly	For low values of the sunspot number, f_0F_2 shows a good linear relationship but, at high sunspot number, f_0F_2 seems to show saturation effects. For the same sunspot number, f_0F_2 may show different values during the rise and fall of the solar cycle (hysteresis effect).	Data are available from July 1749.
$F_{10.7}$ is the solar flux at 10.7 cm (2800 MHz) measured for the first time by Arthur Covington in early 1947. This flux is highly correlated with R and it is particularly valuable as an observation not affected by weather.	$F_{10.7}$ is measured by scanning the solar disc using a narrow antenna able to map the positions of active regions in some detail. Since 1991 $F_{10.7}$ has been recorded by the radio-telescope located at Penticton (Canada).	Daily	As the solar flux observations are only valid from 1947, R remains one of the longest series of observations of a natural phenomenon.	Data are available from 1947.
EUV (Å) is the solar emission flux at the extreme ultra-violet band.	EUV has been recently measured with an extreme ultra-violet spectrophotometer on satellite.	Daily	The limited data and their availability only in recent years make EUV not yet useful for ionospheric prediction purposes.	Measurements are available for the period mid 1977-through 1980 by the Atmosphere Explorer satellite (*AE-E*).

show that the effects on f_0F_2 values of faculae-associated radiations are significant.

For these reasons other solar indices have been investigated, *e.g.*, the solar Extreme Ultra-Violet emission flux, EUV, that does not always vary in exact accord with the sunspot number *R*. EUV below 1300 Å, available from satellite measurements, originates in the chromosphere, in the chromosphere-corona transition region, and in the solar corona and it is directly responsible for the production of the ionosphere. Even if the limited EUV data currently available are not sufficient to develop any long-term routine prediction scheme, it has been shown that the saturation effects do not seem to be obvious if EUV (170-190 Å) is used (Kane, 1991), except for winter at mid-latitudes (Lakshmi *et al.*, 1988) explained by the large decrease in the O/N_2 ratio with solar activity for winter at latitude 45°.

Table I lists and synthetically describes the R, R_{12}, $F_{10.7}$, EUV solar indices.

3. Ionospheric indices

Ionospheric indices are developed using both solar and ionospheric information. The ionospheric information is used to calibrate the solar data so that it better reflects changes observed in the ionosphere affected by more than just the factors giving rise to the sunspot number *R* as, *e.g.*, the geomagnetic storms that can change the ability of the ionosphere to reflect signals.

Ionospheric indices, generally provided on a monthly basis reflecting the global and/or the regional mean condition of the ionosphere, are known to be advantageous compared to direct solar ones. For instance the saturation effect at high solar activity level and hysteresis type solar cycle dependence are avoided with ionospheric indices. Most of the methods used to derive these indices assume some linear relationship between the solar parameters and the ionospheric characteristics routinely scaled at the vertical incident ionospheric sounding stations (Bradley, 1993). One of these indices is the I_{F2} that was introduced by Minnis (1955). The values of I_{F_2} are derived from linear regression equations which represent the relationship between the monthly median f_0F_2 at noon in some observatories and the 3-month weighted sunspot number (R_3) and which can be used to convert f_0F_2 values into local equivalent sunspot numbers. Unfortunately, the I_{F_2} index is not consistent with the reference maps of monthly median f_0F_2 provided by the CCIR (International Radio Consultative Committee) (CCIR, 1991) because the regression equations used for producing I_{F2} are not identical to those on which the maps are based. One reason for this is the fact that data from different periods were used in developing the I_{F2} and CCIR systems. In fact for the Minnis' index the regression lines are computed from past data 1942-1957 while the CCIR Atlas global maps are based on data in the period 1954-1958 and have been produced for two reference solar epochs, $R = 0$ and $R = 100$, providing two points which define the required regression lines. So a new index, *IG*, similar in nature to I_{F2} but compatible with the CCIR maps, has been developed by Liu *et al.* (1983). One test of an index used to predict f_0F_2 values, is the degree of correlation between the values of the index and f_0F_2: it has been found that the relationship between f_0F_2 and IG_{12} (12-months running mean of *IG*) is significantly better than that between f_0F_2 and R_{12} (Liu *et al.*, 1983). Predictions of IG_{12} are prepared regularly in the United Kingdom using a modified version of the McNish-Lincoln method (Smith, 1986).

Another important and well known index was developed by the Australian Ionospheric Prediction Service (IPS) Radio and Space Services (Caruana, 1989). A first version of this index, called *A* index, was introduced in the late 1950s and it was initially derived from the R_{12} and the average of the 24 monthly median values of f_0F_2 at 16 selected ionospheric stations. The method gave a monthly *A* index for each station and a global *A* index was obtained simply by averaging the *A* indices over the stations. The prediction of *A* for future months was based on the prediction of sunspot numbers. In the mid 1960s Jack Turner developed a new index, *T*, derived by a similar procedure fol-

Table IIa. Ionospheric indices.

Index	Method of derivation	Time interval	Drawbacks	Availability
I_{F_2} is based on solar activity and on the ionisation of the F_2 layer.	The method to calculate I_{F_2} requires the derivation of the linear regression coefficients between the f_0F_2 monthly medians at noon at a given station and R_3 (3-month running mean of R). The resulting index is the median of the I_{F_2} values calculated in the selected stations.	Monthly	The main problem is that I_{F_2} is not consistent with the published CCIR Atlas maps because the regression equations used are not identical with those on which the CCIR maps are based.	Data are available from 1938.
IG is similar to I_{F_2} and it was introduced to be consistent with the CCIR Atlas maps.	*IG* is calculated from linear regression equations which represent the relationship between the monthly medians f_0F_2 at noon at particular locations and R_{12}. The resulting index is the median of the *IG* values calculated in those selected locations.	Monthly	The main problem is the ability to predict the monthly value of this index for long-term applications as only the smoothed 12-month running mean can be predicted with acceptable accuracy.	Data are available from 1943.
A was developed by the Australian Ionospheric Prediction Service (IPS) Radio and Space Services in the late 1950s.	*A* is based on R_{12} and on the average of the 24 monthly medians of f_0F_2 from several stations. – For each station a linear regression is made between S ($\equiv R_{12}$ at the beginning) and f_0F_2 by ignoring $R_{12} > 100$. – From the residuals of S a new set of solar parameters (S') is determined. This procedure is applied iteratively until a small change in the solar parameters is obtained. At the end, *A* is determined by averaging over all the stations used.	Monthly	As the majority of the stations were in the northern hemisphere, northern and southern *A* indices were calculated separately and then averaged to obtain a planetary *A*.	
T was developed by Jack Turner in the mid 1960s and has substituted the *A* index on which it is based.	*T*, derived with a similar procedure followed for the *A* index, is based on all the f_0F_2 values from all local times and from all the ionospheric stations available. The stations are grouped into many sectors to reduce the weight given to the data in station-rich regions. The monthly *T* index for a region of the world is the weighted average of the hourly *T* indices of the stations in the sectors of the region.	Daily, Monthly	As for the other ionospheric indices, the main problem is the accuracy in predicting the monthly value of *T* for long-term applications.	Monthly values are available from 1957. Daily *T* is also given together to the daily ionospheric forecasting for different regions related to the current epoch.

Table IIb. Ionospheric indices (*continued*).

Index	Method of derivation	Time interval	Drawbacks	Availability
SSN_e was developed in the early 1970s by the U.S. Air Force Global Weather Center. It is also known as an effective sunspot number.	SSN_e is calculated by the following relation: $SSN_e = \frac{\sum_{i=1}^{N} w_i(OBS_i - f_{0.i})}{\sum_{i=1}^{N} w_i(f_{100.i} - f_{0.i})}$ where w_i is a set of weighting factors that depend on the latitude and local time of observation, OBS_i is the set of the measured f_0F_2 and $f_{0.i}$, $f_{100.i}$ are the f_0F_2 values for $R = 0$, $R = 100$ calculated from the URSI model for the location, epoch and time of the day of the *i*-th observation. So, daily SSN_e is generated automatically for the current epoch using f_0F_2 observations made available in near real time from several mid-latitudes stations.	Daily	For the day-to-day forecasting application, the main problem could be the availability of f_0F_2 observations in the near real time from several stations needed for the index evaluation.	Daily plots of SSN_e are available for the current period.
MF_2 is a monthly index recently introduced by Mikhailov and Mikhailov (1995).	MF_2 is derived by considering the f_0F_2 dependence on cosine of solar zenith angle at a given location: $f_0F_2/M = f(\cos\chi_L)$ where M is a magnetic factor defined as $M = (\cos\chi_{MC}/\cos\chi_L)^{0.25}$, χ_{MC} being the solar zenith angle to the magnetically conjugate point at the same UT moment.	Monthly	The use of MF_2 index derived on the northern hemisphere network of ionosonde stations turns out to be inefficient in the southern hemisphere. As for the other ionospheric indices applied for long-term predictions, only the smoothed 12-month running mean can be predicted long-term with acceptable accuracy.	Data are available from 1952.

lowed for the A index (Turner, 1968). Several modifications have been made over the years to improve the method of derivation of T that principally regard the use of the f_0F_2 values from all local times and from all the ionospheric stations available and the introduction of suitable weights in the several steps of the T calculation. The method for the monthly prediction of T for the solar cycle 22 described by Caruana (1989), consists in obtaining a smoothed mean 11-year T index cycle from the observed T indices, the phase and peak amplitude of which were adjusted to match the observed T indices since January 1986; this adjusted cycle provided the predicted T indices for the rest of solar cycle 22. T, given in the past as monthly median index, is now provided also on a daily basis.

In the early 1970s, the ionospheric forecasting group located at the U.S. Air force (USAF) Global Weather Center developed another ionospheric index, SSN_e known as the effective sunspot number (von Flotow, 1978). The procedure for calculating SSN_e, improved over the years, is based on the use of the URSI (International Union of Radio Science) f_0F_2 model (Rush *et al.*, 1989) for fitting the observed f_0F_2 values from all local times coming from a network of ionospheric stations, and on the introduction of a set of weighting factors that depend on the latitude and local time of the observation. Secan and Wilkinson (1997) describe several statistical studies that have been made with this parameter, comparing it with other indices and assessing its usefulness in day-to-day predictions.

Recently Mikhailov and Mikhailov (1995) introduced a new monthly ionospheric index (MF_2) based on the ratio between the observed f_0F_2, from a network of ionospheric stations distributed in the northern hemisphere, and a function of the solar zenith angle separately determined for each station contributing to MF_2 index value generation. For the current period, MF_2 may be calculated providing the noon monthly medians of f_0F_2 from several stations and using f_0F_2 *versus* MF_2 regressions over these stations. Long term prediction of MF_2 is based on the prediction of the 12-months running mean $MF_{2_{12}}$ (by the McNish-Lincoln method) and on the prediction of $MF_2/MF_{2_{12}}$ ratio for a particular month in a given phase of a solar cycle.

Tables IIa,b list and synthetically describe the I_{F2}, IG, A, T, SSN, MF_2 ionospheric indices.

4. Geomagnetic indices

In geomagnetism, especially with regard to transient variations of the geomagnetic field of external origin, various indices have been suggested over the years, some dating back to the beginning of the first observations and some still being evolved (Mayaud, 1980; Rangarayan, 1989; Berthelier, 1993). At the beginning there was no real distinction between the observations of magnetic perturbations and the related physical phenomenon. From further analysis of these measurements one progressively acknowledged that they reflect distinct phenomena of ionospheric and magnetospheric origin, and one began to define more precise or elaborated indices in order to account for well defined magnetospheric phenomena. However, even if there has been significant progress in understanding the links between magnetic perturbations and magnetospheric phenomena, it is not always possible to recognise or to isolate the magnetic signature of a given phenomenon.

One of the very first indices was simply an estimation of magnetic disturbances by a character C equal to 0 for quiet, 1 for moderate, and 2 for large activity, values given by the observers in each station on a daily basis.

Bartels *et al.* (1939) developed the K index, at once adopted by the «International Association of Terrestrial Magnetism and Electricity» (Washington, 1939), to differentiate clearly between regular and irregular geomagnetic variations of a single station. This index, valid over a shorter time interval than a day, showed diurnal, seasonal and latitudinal variations. Moreover, an index was also suggested by averaging the K indices from some observatories that was called K_p, expressed in a quasi-logarithmic scale, extending backwards to 1932 and avail-

Table IIIa. Geomagnetic indices.

Index	Method of derivation	Time interval	Drawbacks	Availability
K was developed to differentiate between regular and irregular geomagnetic variations and it is representative of a single station.	K is derived from the amplitude range of the most disturbed of two magnetic elements (H, D) in a three-hour interval. Regular daily variations due to solar-quiet-day (S_R), Lunar (L) and post-perturbation effects are to be eliminated for calculating the amplitude ranges. Numerical values are assigned to the amplitude ranges, numbers varying between 0 and 9 on the basis of quasi-logarithmic scale.	Three-hour (UT)	In the index evaluation the main problem is represented by the subjective nature of the elimination of the regular pattern of the smooth daily variation S_R.	It depends on the observatory.
K_p was introduced to give a planetary index. It is obtained by averaging the K indices from eleven observatories (eight at the beginning).	K_p is derived by averaging the K_S indices of the contributing observatories. The K_S index, based on a standardisation procedure, was introduced to eliminate the effects of the diurnal variation and the seasonal and latitudinal dependence of K. K_S values are $0_0, 0_+, 1_-, \ldots, 9_0$.	Three-hour (UT)	– Lack of stations at Asian longitudes. – Few stations in the southern hemisphere. – Several stations are close to the auroral zone.	Data are available from 1932 to the present day. Data from 1932 through 1936 are less accurate. K_p is calculated at the Institut für Geophysik of Gottingen University, Germany.
A_p (nT) was introduced to obtain a linear index from K_p.	A_p is derived from the arithmetic mean of the eight values of the a_p index. A standard conversion table is used for calculating the linear three-hour a_p values from K_p. The scale of a_p ranges between 0, 400 and each unit is approximately equivalent to a flux density change of 2 nT.	Daily (UT)	– Lack of stations at Asian longitudes. – Few stations in the southern hemisphere. – Several stations are close to the auroral zone.	Data are available from 1932 to the present day. Data from 1932 through 1936 are less accurate. A_p is calculated at the Institut für Geophysik of Gottingen University, Germany.
aa is similar to the a_p index but it is based on two geomagnetic stations.	The *aa* index is derived using the scaling K values made on the records from two antipodal stations (at the beginning, Greenwich and Melbourne). Firstly, the K values from these two stations are standardised for the corrected magnetic latitude of 50°, then the K values are converted in equivalent amplitudes that are averaged to obtain the three-hourly index *aa*.	Three-hour (UT)	– Several changes in observatory sites in both hemispheres. – It is advisable to utilise this index in time interval > 3 h	Data are available from 1868.

Table IIIb. Geomagnetic indices (*continued*).

Index	Method of derivation	Time interval	Drawbacks	Availability
K_m, K_n, K_s, a_m, a_n, a_s This set of indices was introduced to avoid the drawbacks related to the previous K_p and A_p. They are based on a proper choice of network stations in both hemispheres.	This set of indices is derived on the base of a suitable treatment of the K indices: – The scaled K indices are standardised for a uniform latitude location of 50° by suitable functions. – K indices are transformed in amplitude ranges that are longitude weighting. So, K_m is the equivalent of K_p. K_n and K_s are indices of the northern and the southern hemisphere, respectively. a_m, a_n and a_s are derived by using a conversion table (unit nT).	Three-hour (UT)	The main problem of these indices is related to the paucity of the magnetic stations in both hemispheres.	Data are available from 1959.
AE, AL, AU, AO (nT) were introduced to characterise the auroral zones and they are also called as auroral electrojet indices.	The *AE* index is derived from the difference between the indices *AU* and *AL* ($AE = AU - AL$) while the *AO* index is their mean ($AO = 1/2(AU + AL)$). *AU* and *AL* are evaluated as follows: – An average quiet-time reference level for the month is subtracted from 1-min or 2.5-min digital data of the *H* component of selected individual stations in the auroral zones. – The departures of all the stations of the network are superposed in UT and the largest and least value at each instant give the *AU* (eastward electrojet) and *AL* (westward electrojet) indices, respectively.	1 or 2.5 min	– The present network does not constitute an ideal distribution in latitude and longitude. – Low *AE* values do not preclude the possibility of a substorm. – The indices cannot distinguish between movement of the oval away from (or towards) a given location and between the weakening (or the straightening) of the electrojet.	For years 1957 through 1964, hourly *AE* indices were derived at the Geophysical Institute University of Alaska and at the NASA (National Areonautic and Space Administration). Indices for 1965 were derived at NASA from data at 2.5 min. For the years 1966-1974, the NGDC (National Geophysical Data Centers) produced the indices with one minute resolution. There is a break in the indices for the period 1976-1977. For 1978 and later years the indices are produced at WDC-C2 for Geomagnetism (Kyoto, Japan).

Table IIIc. Geomagnetic indices (*continued*).

Index	Method of derivation	Time interval	Drawbacks	Availability
PC was developed to point out the development of a substorm.	The *PC* index is derived separately for the two hemispheres by using the horizontal (*H*) and the declination (*D*) elements of the geomagnetic field measured at two high latitude stations (Thule 76°32′, 68°45′E; Vostok −78°27′, 106°52′E). The algorithm for the *PC* index is first based on a statistical analysis of the relation between the IMF (Interplanetary Magnetic Field) and the magnetic activity at the two stations from which the linear regression coefficients can be evaluated. Then, the *PC* values are calculated by: $PC = (\delta F - K)/\alpha$. δF, the magnetic activity, is a function of *H* and *D* as observed at the two stations, *K* and α are the coefficients of the linear regression.	15 min	During summer and when the vertical B_z component of IMF is northward, the currents in the polar cap are very sensitive to the eastward B_y component of IMF. Their description would require a different index and probably the use of several stations.	The *PC* data are available from 1975 to the present for Thule (Danish Metereological Institute), and in the period 1978-1991 for Vostok (Antarctic Research Institute, St. Petersburg).
D_{st} (nT) was first developed to represent the general behaviour of a typical geomagnetic storm at Bombay.	D_{st} is derived using the *H* component of the geomagnetic field from a network of low-latitude stations: – For each station, the quiet-day variation is eliminated and the secular trend is subtracted. – The residual field for each hour (U.T.) at the network stations is then averaged to give the hourly D_{st} value. This value is then corrected by multiplying it by $\sec\theta_m$ where θ_m is the mean dipole latitude of the station.	Hourly (UT)	– The D_{st} is affected in various ways by magnetospheric and ionospheric currents, so difficulties arise in treating the D_{st} data and connected phenomena. – There is a dominance of northern hemisphere stations that introduce an annual variation. Stening (1990) identified the appearance of embedded lunar tidal variations that probably arise because of the uneven observatories distribution.	For years 1957 onwards, hourly values have been derived at WDC-C2 for Geomagnetism (Kyoto, Japan).

able uninterruptedly since then (Bartels *et al.*, 1939). Another index, a_p, has been also derived from K_p, with the same meaning as K_p but expressed in a linear scale (Bartels, 1957).

A new set of indices (K_m, K_n, K_s, a_m, a_n, a_s) based on a proper choice of network stations in both hemispheres was created by Mayaud (1967). K_m and a_m are similar to K_p and a_p indices while K_n, a_n and K_s, a_s represent the indices of the northern and southern hemisphere, respectively. They are available from 1959 but Svalgard (1976) attempted recalibration of the a_p and K_p indices to include universal-time variation, and formulated empirical relationships to convert K_p and a_p to the corresponding K_m and a_m indices so that these indices can also date back to at least 1932. NASA predicts the geomagnetic A_p index (daily index calculated by the sum of a_p) with a modified McNish-Lincoln method (Niehuss *et al.*, 1996).

A geomagnetic index *(AE)* was introduced by Davis and Sugiura (1966) to characterise the auroral zone where the fluctuations of magnetic-field are much stronger than at mid and low latitudes during enhanced magnetospheric activity. The configuration of the auroral ovals, roughly centered around the north and south magnetic poles where bright, active aurorae and strong magnetic disturbances are observed, is approximately a circle. The ovals contract during quiet intervals and expand equatorwards during enhanced geomagnetic activity (Kivelson and Russel, 1995).

AE represents the auroral electrojet that is conventionally divided into two parts: i) the eastward electrojet, more dominant in the daylight hours; and ii) the westward electrojet, stronger during local night hours. These currents flow in the lower ionosphere and are linked to currents in the magnetosphere. *AE* is calculated from the difference of *AU* and *AL* indices that are indicators of the strength of the eastward and westward electrojet, respectively.

Concerning the number of stations used to derive *AE,* it is expected that when the station network is increased substantially, *AE* will tend to be more accurate. However, when the *AE* index, constructed from 70 stations, was compared with the standard *AE* index from 12 stations, the two were virtually the same, with a correlation coefficient of 0.93 on moderately disturbed days (Kamide *et al.*, 1982). Akasofu *et al.* (1983) pointed out that the accuracy of *AE*(12) worsens for lower values of the index, that is *AE* seems inadequate as a parameter for the selection of quiet days. Moreover Kroehl (1989) pointed out from a statistical analysis that the correlation between the indices *AU* and *AL* is only 0.63 implying different sources of the eastward and westward electrojects. So the users of *AE* index must be aware since it is derived from the two indices which vary in latitude and intensity independently.

Still with reference to the high latitude zones, a polar cap index, *PC,* was introduced by Troshichev *et al.* (1979, 1988), which can be regarded as a signature of the magnetic activity driven by the IMF vertical (B_z) component. *PC* index, defined as a 15 min sum of the polar cap magnetic disturbances, can be considered as a complementary index to the auroral zone indices such as *AE* but more related to the process of the solar wind-magnetosphere interaction.

At low latitudes, the depression of the horizontal component H of the geomagnetic field is the phenomenon represented by the D_{st} index (Moos, 1910; Sugiura and Chapman, 1960; Sugiura, 1964). Now there is substantial evidence that the magnetic storm displayed by D_{st} is not representative of the loading and decay of the ring-current, which flows westward around the Earth in the near equatorial region, but rather is simply following a lognormal shape in a fashion that is typical of phenomena that result from a number of contributing sources acting either serially or concurrently (Campbell, 1996). Despite its failings as a true ring-current indicator, the D_{st} index, although imperfect, has proven its utility in the scientific community as a measure of the integrated global-scale current system.

A recent utilisation of the geomagnetic indices is the forecasting of the ionosphere's conditions (Wu and Wilkinson, 1995). This is based on a time-weighted accumulation of the a_p index, $a_p(\tau) = (1 - \tau)(a_p + \tau a_{p-1} + \tau^2 a_{p-2} + \ldots)$ where $0 \leq \tau < 1$ and a_{p-1}, a_{p-2} are the a_p values for -3, -6, -9 h etc. (Wrenn, 1987). As a persistence factor, τ determines how $a_p(\tau)$ will depend on the past history of the a_p index. $a_p(\tau)$

Table IV. Internet addresses.

Internet address	Indices
ftp.ngdc.noaa.gov/STP	R_{12}, I_{F_2}, IG, T, K, K_p, A_p, K_m, K_n, K_s, a_m, a_s, AE, D_{st}, aa, PC
ftp://ftp.dmi.min.dk/pub/DATA/WDCC1	K_p, A_p, AE, aa
ftp://ftp.gwdg.dl/pub/geophys	K_p, A_p, a_m, aa, PC
ftp://ftp.gfz-postdam.de/pub/home/obs	K_p, A_p
http://www.wdcb.rssi.ru/data/stp	R, $F_{10.7}$, K_p, A_p, K_m, K_n, K_s, a_m, a_n, a_s, AE, aa, PC
http://crlgin.crl.go.jp/sedoss/geomag	K
http://wdcc1.bnsc.rl.ac.uk/wdcc1/data.html	R, $F_{10.7}$, I_{F_2}, IG, K_p, A_p, AE, aa, PC
http://swdc.kugi.kyoto-u.ac.ip/wdc/Sec3.html	K_p, AE, D_{st}, PC
http://www.nwra.com/nwra/spawx/	SSN_e (only plots)
gopher://ipso.ips.gov.au:70/hh/rwc/reports/	T (daily)

has been correlated with ionospheric data derived from the temporal behaviour of f_0F_2 for several stations in Europe and Australia showing that the ionospheric time reply to the geomagnetic conditions is of the order of 15 h. This procedure was also applied to other magnetic indices showing the possibility to improve the ionospheric forecasting.

Tables IIIa-c report the best known geomagnetic indices and the INTERNET node addresses (table IV) where all the geophysical indices here recalled are available.

Acknowledgements

L. Perrone would like to thank the Italian Program of Antarctic Researches (PNRA) that supports her fellowship which made this study possible.

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