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RELATIONSHIPS BETWEEN SOLAR ACTIVITY, THE EARTH'S MAGNETIC FIELD AND MEDIUM WAVE DXING

PART ONE

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1. INTRODUCTION

The relationship between "good" high-latitude or trans-polar medium wave DX openings and "quiet" Earth geomagnetic field activity has been postulated, debated and discussed over the last 25 years in the medium wave DX bulletins (e.g., Nelson (1969-77), Scrimgeour (1968) and others). DXer's have faithfully listened to the WWV broadcasts of A Index and solar flux in hopes of finding that rare DX opportunity. The tables or plots of the A index have been published regularly in the DX bulletins. The promise of the "next sunspot minimum" has been held out each decade to DXers as a "golden age" of good high-latitude DX.

In order to help DXers understand the relationships of the sun, the geomagnetic field and high-latitude DX, this article will cover some of the basic geophysical phenomena, the records for the past 30 years, and a projection of what we can expect in the next year or ten.

This will not be a comprehensive study of the geophysical phenomena, but will only address the general characteristics. If more detail is desired by the reader, the listed references can be reviewed. Ratcliffe's Sun, Earth and Radio (1970) is an excellent introductory book, while Rishbeth and Garriott's Introduction to Ionospheric Physics (1969) provides a more detailed discussion of the ionospheric processes. Davies (1965), Ionospheric Radio Propagation, is an excellent technical book. A layman's description of solar phenomena, the Earth's magnetic field and basic ionospheric processes can be found in encyclopediae and other general physics reference works. The best available details of the effects of the auroral zone and geomagnetic activity on medium wave DX are found in the Nelson (1969-77) articles.

Most of the statements, ideas and figures in this article have come from the reference material.

2. SOLAR ACTIVITY

The sun produces a prodigious amount of energy over a wide range of wavelengths. The most important wavelengths in the radiation spectrum are those of hydrogen alpha, Lyman alpha, and helium. This energy provides the light and heat required for the Earth to sustain life. Some of the energy produced by the sun is in the form of an unsteady stream of charged particles, mostly protons and electrons, from the sun's corona along lines from the sun's magnetic field, called the "solar wind". This stream of particles varies with time, both short-term (minutes or hours) and long-term (year-by-year). The solar wind travels away from the sun at speeds of 300 to 1000 kilometers per second.

The sun's energy output is remarkably constant, varying by no more than a few tenths of one percent over several days. But variations in the energy output exist. Atmospheric disturbances on the sun, such as sunspots, result in additional energy release in the form of electro-magnetic waves at certain wavelengths. An intense local magnetic field on the sun is associated with sunspots, creating anomalies in the sun's magnetic field characteristics.

"Solar flares" are bursts of energy, usually at the hydrogen alpha wavelength but often including X-rays and cosmic rays, that are usually associated with sunspots, are short-lived, and vary in strength and frequency of occurrence. High energy particles can travel at nearly the speed of light, reaching the Earth in about eight minutes.

The sun has a rotation period of approximately 27 days, so variations in the sun's magnetic field, sunspot number, solar wind and energetic particles tend to repeat in 27 day cycles. These cycles are called Bartels cycles after a physicist who defined the period to track times of unsettled magnetic field conditions related to the solar rotation period.

Until the nineteenth century, the only measure of solar activity was the number of sunspots observed on the face of the sun by astronomers and solar physicists. Figure 1 shows the historical record of average monthly sunspot number from 1700 to the present. The data indicates that there is an approximate eleven year period between sunspot minima. The actual sunspot cycle is 22 years, when account is taken of the alternation of the magnetic polarity of the sun. There is also some evidence of an 90 year cycle in the maximum sunspot number. The increase from the minimum sunspot number to the maximum averages about 5 years. The maximum sunspot number varies from cycle-to-cycle, with the highest mean value ever recorded in the mid-1950's.

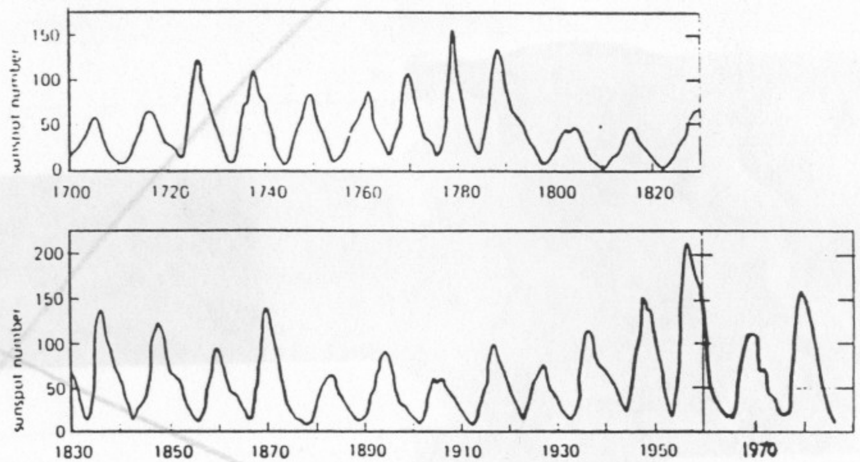

FIGURE 1. Sunspot record for 1700 to 1985.

The solar energy output is monitored in many ways by physicists all over the Earth. The National Oceanic and Atmospheric Administration, centered in Boulder, Colorado gathers information on a regular basis and produces a wealth of data. Measurements of the daily solar indices of relative sunspot number and 2800 Mhz solar flux, solar radio waves, solar wind, solar magnetic field, etc. are collected and published on a monthly and yearly basis by NOAA.

3. EARTH'S GEOMAGNETIC FIELD

The Earth is surrounded by a magnetic field, within which it behaves as if it were a ball of magnetized iron with north and south magnetic poles. More than 95% of the Earth's magnetic field originates from within the Earth's interior. The remainder comes from electric currents induced in the Earth's crust, and from electrical currents flowing in the upper atmosphere of the Earth resulting from ionization by solar radiation.

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Figure 2 shows an idealized distribution of the Earth's magnetic field, showing the geomagnetic axis and equator displaced from the geographic axis and equator. Geomagnetic field lines flow from one pole to the other along lines of force very similar to a dipole with an Earth-centered axis. The magnetic intensity at the poles is twice that at the equator. The actual magnetic field of the Earth is somewhat different from that of a uniformly magnetized sphere because the distribution of magnetic elements over the Earth's surface is not uniform.

The geomagnetic North Pole was located at 78.3 degrees North latitude and 69.1 degrees West longitude in 1965, according to the Encyclopedia Britannica. The geomagnetic South Pole is approximately opposite the North Pole at 78.5 degrees South latitude and 111 degrees East longitude. The location of the geomagnetic poles varies somewhat over decades of time.

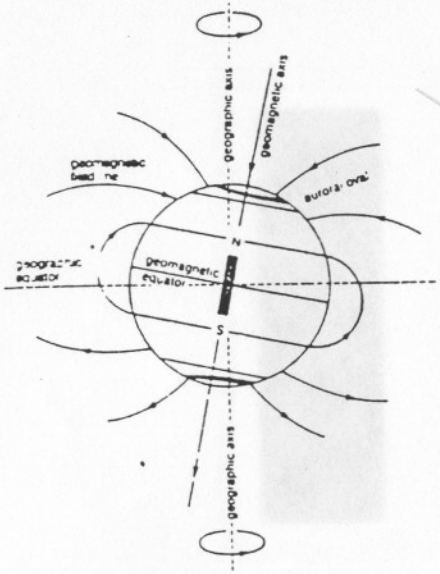

FIGURE 2. Earth's Idealized Magnetic Field.

The main magnetic field creates a cavity in interplanetary space called the magnetosphere in which the Earth's magnetic field dominates any field carried by the charged particles of the solar wind. The magnetosphere shape, shown in Figure 3, resembles a comet due to its interaction with the solar wind. It is compressed on the side of the Earth towards the sun and tail-like on the side away from the sun. Some particles from the solar wind or from solar radiation penetrate the magnetosphere and, with other charged particles are trapped by the magnetic field in a circular belt around the Earth known as the Van Allen belt.

The geomagnetic field lines are concentrated near the magnetic poles, but are displaced pole-ward on the side of the Earth towards the sun by the solar wind effects on the magnetosphere. The field lines are displaced toward the equator on the night side of the Earth.

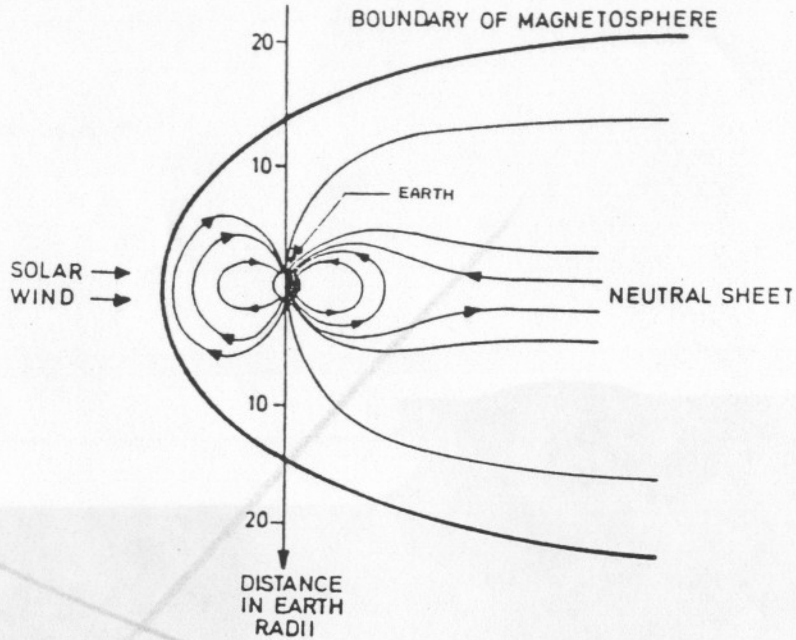

FIGURE 3. The Earth's Magnetosphere.

The Earth's ionosphere is composed of neutral molecules, ionized molecules and free electrons. The ionized molecules and electrons are caused by various forms of radiation, including solar radiation. The ionosphere has been defined in several regions, with the D-region between 50-80 kilometers altitude, the E-region between 80 and 120 kilometers, and the F-region above 120 kilometers. The D-region largely disappears at night, but the E-region and F-region retain a significant number of free electrons.

Radio wave propagation occurs by a series of ionospheric refractions from the E and/or F-regions (depending on wave frequency and incidence angle) and Earth surface reflections. Radio wave absorption occurs during the transit of the ionosphere by a wave, with most absorption occurring at altitudes below 90 kilometers. More absorption occurs at lower altitudes for a given electron density than at higher altitudes because the number of electron collisions per second decreases exponentially as altitude increases.

The charged particles carried by the solar wind and the higher energy particles caused by solar activity such as solar flares can precipitate into the Earth's upper atmosphere along the geomagnetic field lines, resulting in higher-than-normal electron densities. The auroral oval is a band within which the charged particles precipitate into the ionosphere. The auroral oval is 5 to 10 degrees wide, typically between 65 and 75 degrees geomagnetic latitude, and is roughly centered on the magnetic pole, as shown in Figure 4 for the Northern hemisphere.

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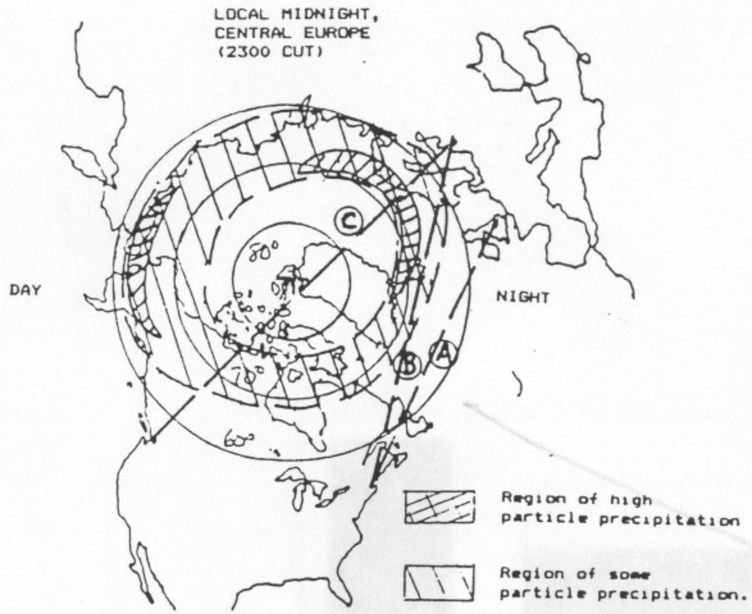

FIGURE 4. Northern Hemisphere Auroral Zone Location.

This precipitation can occur down to 50-60 kilometer altitudes, and causes high absorption to any radio wave that passes through the auroral oval above those altitudes. This is why the auroral ovals act as a curtain or shield for radio waves traversing the ovals, as shown in Figure 5. Radio waves can pass under the "curtain" but they suffer high absorption if they enter the "curtain above 50-60 kilometers altitude.

When the Earth's geomagnetic field is quiet, the oval is located closer to the pole and the area of high precipitation is reduced. When the magnetic field is active, the auroral oval is located further from the pole and there are larger areas of high particle precipitation down to a lower altitude. There is some indication that the auroral oval width decreases and "shrinks" toward the geomagnetic pole at the start of a major geomagnetic disturbance, then "expands" as the disturbance progresses.

When a geomagnetic storm occurs, defined as a geomagnetic disturbance of large amplitude, an auroral display is often noted in parts of the auroral ovals. Precipitation of very high energy particles and solar X-rays or ultraviolet rays can cause other more severe events, such as polar cap absorption in which the precipitation occurs over the entire polar region. This can cause high radio wave absorption and refraction within the auroral oval.

When there is a major geomagnetic storm, the auroral ovals may be located in the mid-latitudes, and radio waves from the North, West and East may suffer high absorption because their path passes through the auroral "curtain". Radio waves from the South are unaffected by the auroral oval, unless the oval boundary is south of the receiver. This is the familiar "auroral" conditions experienced frequently in the Northern United States, where Caribbean and South American stations are dominant on most medium wave frequencies.

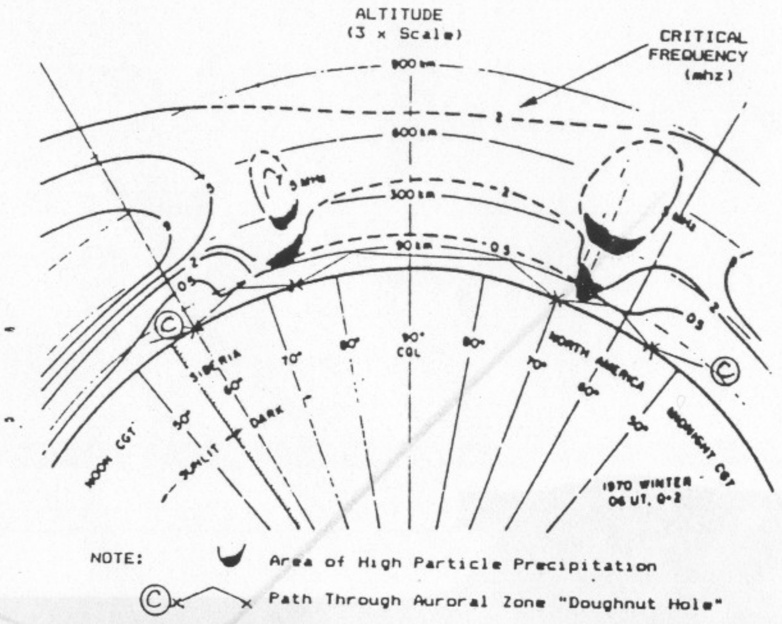

FIGURE 5. Typical Auroral Zone Cross-Section.

4. GEOMAGNETIC FIELD INDICES

The Earth has an average magnetic field strength that varies from about 0.3 gauss at the equator to about 0.7 gauss at the poles. The variations in the magnetic field strength are measured by many observatories all over the Earth's surface. During the period of a quiet sun, the geomagnetic force varies during the day by about .00020 gauss at the equator and 0.00050 gauss at the poles (20 and 50 gammas, where a gamma is 0.00001 gauss). There are seasonal variations and sporadic disturbances caused by solar activity and lunar effects. Charged particles flowing in the magnetosphere and ionosphere generate electric currents, which cause variations in the magnetic field intensity.

Geomagnetic activity indices, such as the K index and the A index, are used to measure the variations in the magnetic field strength. The K index is a local index of the 3-hourly range in magnetic activity relative to an assumed quiet-day curve at the recording site. It consists of a single digit 0 through 9 for each 3-hourly interval. However, there are 28 potential values of K because each number can have a + or - associated with it. For instance a K value of 3+ is one-third of the difference between 3 and 4, while 4- is two-thirds of the difference. A planetary K index (K_p), based on the K-index for 13 selected stations around the world, is available since 1932.

The local aa index is based on the local K index by:

K =	0	1	2	3	4	5	6	7	8	9
aa =	0	4	7	15	27	48	80	132	207	400

The aa value can be multiplied by two to get the geomagnetic intensity in terms of gamma. For example, a disturbance of 66 gammas is an aa = 33 and a K of 4+.

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The A index for a given station is calculated by finding the mean of the eight aa index values for the given day.

The planetary Kp index for each three-hour time period is calculated from the K index from 13 observatories around the world. The planetary ap index is based on the Kp index. The planetary Ap index is the mean of the eight ap index values.

Since the K and A indices are based on the variations in magnetic field intensity, some of which are caused by solar activity, we would expect a strong relationship between the indices and sunspot number or solar flare activity.

TABLE 1. Sunspot Number and Planetary A Index Data (1956-1986).

	Year	Sunspot	Mean Ap	Ap < 8	7<Ap<16	Ap>15	Ap>80	Con A<8	Con A<16	Con A>15
56	1956	141.7	18	97	127	142	8	10	13	9
	1957	189.9	20	93	124	148	13	5	11	9
	1958	184.6	19	91	123	151	8	7	18	25
	1959	158.8	21	85	114	166	13	8	12	13
	1960	112.3	24	84	95	188	14	5	9	12
61	1961	53.9	14	146	114	105	6	11	24	9
	1962	37.6	12	143	129	93	0	7	24	7
	1963	27.9	13	163	109	96	2	8	23	9
	1964	10.2	10	193	102	71	0	13	59	4
	1965	15.1	8	240	92	33	0	19	40	4
66	1966	46.9	10	209	100	56	3	15	54	5
	1967	93.7	12	175	119	71	4	8	29	6
	1968	105.9	13	124	146	97	4	9	22	3
	1969	105.6	11	168	131	66	2	10	26	6
	1970	104.7	12	167	125	73	5	13	27	6
71	1971	66.7	11	166	126	73	0	8	28	6
	1972	68.9	13	161	126	79	5	11	26	5
	1973	38.2	17	108	112	145	5	6	20	12
	1974	34.4	20	71	101	193	4	3	15	13
	1975	15.5	14	134	127	105	1	10	22	8
76	1976	12.6	13	152	121	94	3	11	23	7
	1977	27.5	12	154	138	73	0	8	49	5
	1978	92.7	17	117	123	125	10	8	18	7
	1979	155.3	15	108	152	105	1	6	23	12
	1980	154.7	11	165	120	82	0	12	33	8
81	1981	140.5	16	93	148	124	4	6	16	9
	1982	116.5	23	50	125	191	9	6	12	10
	1983	66.6	19	75	117	173	2	5	18	14
	1984	45.9	19	58	143	165	3	5	14	12
	1985	17.9	14	123	135	107	1	9	29	7
86	1986		12	167	113	85	4	13	26	10
AVERAGE		81.4	15	132	122	112	4	9	25	9

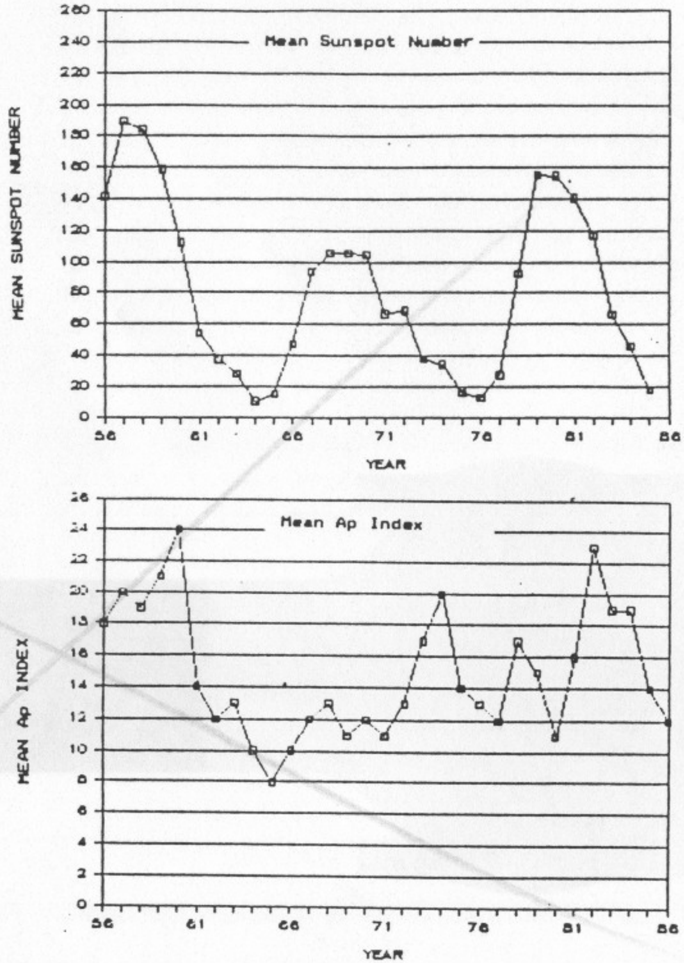

FIGURE 6. Correlation of Sunspot Number with Planetary A Index.

5. GEOMAGNETIC FIELD DATA

I recently obtained the Ap index data for the years 1956 through 1986. I tabulated the following information for each year in an attempt to correlate the Ap index with sunspot number:

Sunspot number	- monthly mean Wolf sunspot number
Mean Ap	- the average Ap for the year
Ap < 8	- the number of days with a quiet geomagnetic field
7<Ap<16	- the number of days with a disturbed geomagnetic field
Ap>15	- the number of days with an active geomagnetic field
Ap>80	- the number of days with a major geomagnetic storm

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Con A<8 - the maximum number of consecutive days with a quiet geomagnetic field

Con A<16 - the maximum number of consecutive days with a quiet or disturbed geomagnetic field

Con A>15 - the maximum number of consecutive days with an active geomagnetic field.

Table 1 shows these values for the years 1956 through 1986, which covers almost three sunspot cycles. Figure 6 shows a graph of the relationship between sunspot number and the mean Ap index; I expected to see an inverse relationship, with the lowest mean Ap index during the lowest sunspot years. The maximum mean Ap values occur 2-3 years after the sunspot maximum. The minimum mean Ap value occurred one year after the sunspot minimum in 1964, but there wasn't a real clear minimum mean Ap value in the mid-1970's. It is too early to tell the correlation in the mid-1980's since the sunspot minimum has just occurred in late 1986 or early 1987, just before this article was written.

Figure 7 shows a graph of the number of quiet days (Ap < 8) and sunspot number over the years since 1956. The trend is for the number of quiet days to be high when the sunspot number is low, and vice versa. But, the correlation is not perfect - the mid-1970's really don't correlate well, while the period 1956-1968 and 1982 to the present correlate fairly well. The minimum number of quiet days occurs 2-3 years after the sunspot maximum, while the maximum number of quiet days occurs 1-2 years after the sunspot minimum.

The correlation between the number of active days (Ap > 15) and the sunspot number is shown in Figure 8. With the exception of the mid-1970's, the maximum number of active days occurs 2-3 years after the sunspot maximum year.

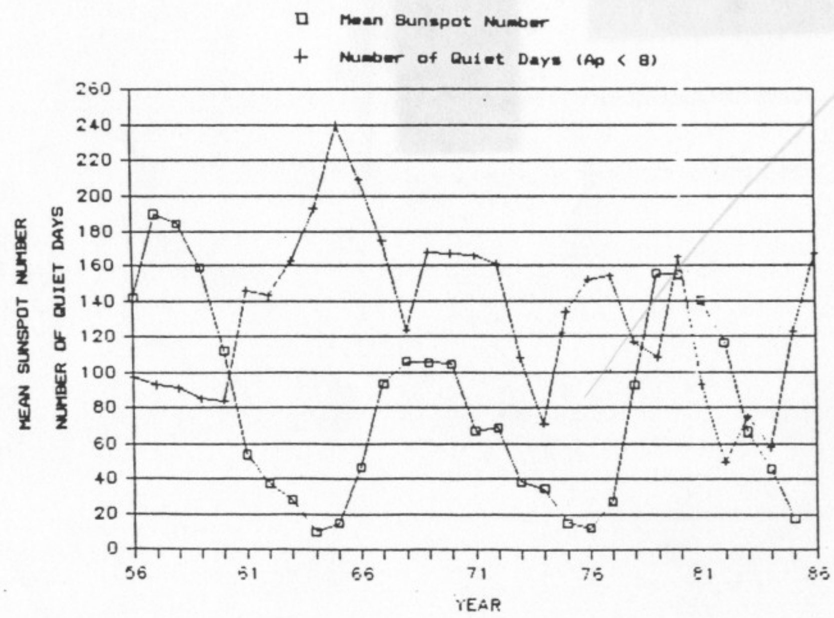

FIGURE 7. Number of Quiet Days vs. Sunspot Number.

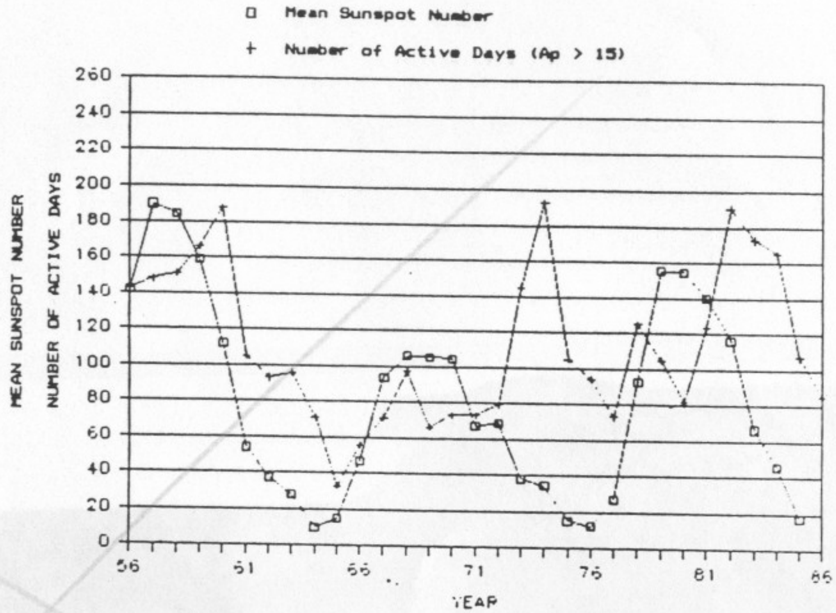

FIGURE 8. Number of Active Days vs. Sunspot Number.

It is evident that "something happened" in the mid-1970's. The sunspot number plot in Figure 8 indicates that the maximum number of sunspots occurred in 1968-69, with a monthly mean of 106 in those years. The minimum sunspot year was 1976, with a value of 13. 1973 and 1974 appear to be anomalous, with a higher than expected number of active days and a high mean Ap index in a time of declining sunspot number. There is no obvious explanation for this anomaly.

The year 1980 is interesting - it was just after the sunspot maximum, yet it had a high number of quiet days and an unexpectedly low number of active days. The years 1969 through 1971 show a similar occurrence.

The average Ap value for the years 1956 through 1986 was 15, which is the "break point" between "disturbed" and "active" geomagnetic field. The months with the highest average Ap during this period were April and September, while the months with the lowest average were December and January.

Over the period 1956-1986, Table 1 indicates that the highest number of consecutive days with a quiet geomagnetic field (Ap of 7 or less) was 19 in 1965. The longest period without an active geomagnetic field (Ap index of 15) or less was 59 days in 1964, with 54 in 1966 and 49 in 1987. Clearly, it is too much to expect periods of more than two weeks with a quiet geomagnetic field, or periods of more than one month without an active field. On the other hand, 1958 saw a 25 day period when the Ap index was over 15 and the geomagnetic field was active. It is common to have some periods of 3-6 days with an active field even in low sunspot number years.

I also got on the mailing list for the "Geomagnetic Indices Bulletin" published by the National Geophysical Data Center in Boulder, Colorado. This bulletin provides the daily Kp, Ap (planetary A), AFr (Fredericksburg, VA A index) and other indices for each month.

TABLE 2. Planetary A Index for 1986.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Days	31	28	31	30	31	30	31	31	30	31	30	31	365
1	25	5	18	8	5	15	7	6	9	7	13	13	
	18	6	12	5	43	8	13	5	16	23	6	8	
	10	6	12	14	40	10	8	19	7	9	16	6	
	5	5	8	4	17	7	7	20	7	7	67	7	
5	4	7	8	9	17	5	7	9	9	19	20	4	
	20	11	32	4	67	6	5	6	8	12	12	4	
	32	82	33	5	12	12	4	4	5	5	6	6	
	11	202	23	5	7	7	6	7	5	6	4	4	
	14	100	5	13	5	7	6	10	6	6	3	6	
10	11	10	2	19	6	13	6	6	6	3	5	12	
	4	20	2	6	6	6	4	7	16	4	14	8	
	5	18	7	10	7	6	6	10	89	2	9	4	
	3	15	21	5	4	6	7	10	22	28	5	12	
	4	19	8	4	3	6	4	5	12	31	5	20	
15	5	5	8	7	4	5	4	6	18	14	12	4	
	3	5	6	8	7	5	5	4	7	6	11	12	
	6	9	6	6	8	8	8	5	14	6	8	5	
	7	14	8	7	5	9	6	3	20	13	6	6	
	7	9	9	11	8	5	4	4	21	21	4	6	
20	6	17	3	5	5	6	3	15	18	14	5	7	
	15	26	17	7	6	6	6	29	11	11	3	11	
	11	30	22	11	3	8	7	29	4	6	2	14	
	17	35	11	10	8	5	5	25	43	5	12	22	
	12	19	21	12	7	7	15	22	22	2	46	10	
25	26	18	27	7	10	3	17	17	26	4	49	11	
	12	26	12	7	8	5	20	12	27	3	17	14	
	37	20	18	4	7	28	16	13	20	16	9	9	
	30	25	14	11	3	18	9	12	13	9	5	3	
	19		8	9	4	11	17	22	13	15	10	3	
30	14		5	5	10	9	11	27	5	14	14	4	
	8		7		17		12	16		6		7	
	401	764	393	238	359	252	255	385	499	327	398	262	4533
Mean	12.9	27.3	12.7	7.9	11.6	8.4	8.2	12.4	16.6	10.5	13.3	8.5	12.4
Median	11	18	8	7	7	7	7	10	13	7	9	7	
A<8	11	7	9	17	18	18	20	13	9	16	13	16	167
7<A<16	10	6	12	12	7	10	7	8	8	9	11	13	113
A>15	10	15	10	1	6	2	4	10	13	6	6	2	85
ConA<8	10	5	4	3	9	6	13	6	4	6	5	7	13
ConA<16	15	8	7	21	24	26	26	16	8	7	18	17	26
ConA>15	3	10	3	1	5	2	3	5	5	2	3	1	10

The Ap index values for 1986 are shown in Table 2 as a function of month and day. The mean Ap, median Ap, the number of quiet days (Ap between 0 and 7), disturbed days (Ap between 8 and 15), and active days (Ap greater than 15), and the maximum number of consecutive days with quiet, disturbed or quiet, and active days are tabulated for each month. Table 3 shows the same data for 1987 up through July, which is the last month I have available. I have tabulated data for 1972 through 1986 in this same format, available as part of this article from the radio club publication center.

Table 4 presents the 1986 and 1987 Ap index data in 27 day cycles rather than by months. There are some recurrent periods of high geomagnetic activity, but most last only 2 or 3 cycles at most. Some do not recur at all, and some skip one or more months (perhaps because the flare activity was reduced during that cycle). It should be noted that these years are at the sunspot minimum, so the recurrent effects may not be as apparent. Review of the data for 1982 (a high geomagnetic activity year) shows some recurrent patterns of more than 6 27-day cycles.

TABLE 3. Planetary A Index for 1987.

Months	Jan	Feb	Mar	Apr	May	Jun	Jul
Days	31	28	31	30	31	30	31
1	18	7	9	10	7	8	2
	10	4	3	4	6	8	3
	6	4	6	2	6	4	9
	3	4	10	16	5	6	8
5	3	4	21	12	4	7	6
	3	7	10	7	5	25	5
	5	9	21	13	8	9	4
	7	14	12	11	4	4	10
	10	11	9	8	4	3	9
10	6	8	11	10	10	4	11
	5	7	8	7	6	7	7
	10	18	14	5	2	13	7
	6	4	8	12	6	6	4
	5	5	8	6	9	6	5
15	5	6	10	6	4	4	24
	12	12	12	4	4	8	20
	10	9	10	5	4	6	14
	8	7	12	4	2	6	10
	7	5	11	8	2	17	8
20	18	29	4	12	4	8	9
	10	19	18	3	3	6	6
	10	18	15	4	7	4	8
	11	14	6	4	8	3	6
	7	12	5	9	20	7	12
25	7	7	6	4	25	7	17
	7	6	13	4	9	9	4
	7	12	26	9	14	5	5
	11	13	12	2	10	4	26
	10		5	4	21	5	52
30	4		4	4	9	3	9
	8		4		11		14
	249	275	323	209	239	212	334
Mean	8.0	9.8	10.4	7.0	7.7	7.1	10.8
Median	7	8	10	6	6	6	8
A<8	17	14	9	18	19	21	13
7<A<16	12	10	18	11	9	7	13
A>15	2	4	4	1	3	2	5
Cons A<8	6	6	3	5	9	5	6
Cons A<16	18	22	13	49	*49	12	25
Cons A>15	1	3	1	1	2	1	2

A recent report by Bai and Sturrock (1986) indicates that there is an apparent 152 day periodicity of solar flares, based on data from the last two sunspot cycles. Review of the Ap index of the last five years shows some periodicity, but it is not consistent or uniform, perhaps because not all solar flares result in an active geomagnetic field.

6. MEDIUM WAVE DX EFFECTS

Long distance, high latitude medium wave DX depends on several factors. The most significant factors are the geomagnetic field activity and the position and characteristics of the auroral ovals. High levels of geomagnetic activity results in more intense auroral oval electron precipitation and higher radio wave absorption on paths passing through or grazing the auroral oval.

TABLE 4. Planetary A Index for 1986-87 in 27 Day Cycles.

1986 ... 1986

Start End	1/1 1/27	1/28 2/23	2/24 3/22	3/23 4/18	4/19 5/15	5/16 6/11	6/12 7/8	7/9 8/4	8/5 8/31	9/1 9/27	9/28 10/24
1	25	30	19	11	11	7	6	6	9	9	13
	18	19	18	21	5	8	6	6	6	16	13
	10	14	26	27	7	5	6	4	4	7	5
	5	8	20	12	11	8	5	6	7	7	7
	4	5	25	18	10	5	5	7	10	9	23
6	20	6	18	14	12	6	8	4	6	8	9
	32	6	12	8	7	3	9	4	7	5	7
	11	5	12	5	7	8	5	5	10	5	19
	14	7	8	7	4	7	6	8	10	6	12
	11	11	8	8	11	10	6	6	5	6	5
11	4	82	32	5	9	8	8	4	6	16	6
	5	202	33	14	5	7	5	3	4	89	6
	3	100	23	4	5	3	7	6	5	22	3
	4	10	5	9	43	4	3	7	3	12	4
	5	20	2	4	40	10	5	5	4	18	2
16	3	18	2	5	17	17	28	15	15	7	28
	6	15	7	5	17	15	18	17	29	14	31
	7	19	21	13	67	8	11	20	29	20	14
	4	5	8	19	12	10	9	16	25	21	6
	15	5	8	6	7	7	7	9	22	18	6
21	27	9	6	10	5	5	13	17	17	11	13
	11	14	6	5	6	6	8	11	12	4	21
	17	9	8	4	6	12	7	12	13	43	14
	12	17	9	7	7	7	7	6	12	22	11
	26	26	3	8	4	7	5	5	22	26	6
	12	30	17	6	3	13	4	19	27	27	5
27	37	35	22	7	4	6	6	20	16	20	2
Avg	12.9	26.9	14.0	9.7	12.7	7.9	7.9	9.2	12.4	17.3	10.8

1986 ... 1987

Start End	10/25 11/20	11/21 12/17	12/18 1/14	1/15 2/10	2/11 3/9	3/10 4/5	4/6 5/2	5/3 5/29	5/30 6/25	6/26 7/22	7/23 8/18
1	4	3	6	5	7	11	7	6	9	9	6
	3	2	6	12	18	8	13	5	11	5	12
	16	12	7	10	4	14	11	4	8	4	17
	9	46	11	8	5	8	8	5	8	5	4
	15	49	14	7	6	8	10	8	4	3	5
6	14	17	22	18	12	10	7	4	6	2	26
	6	9	10	10	9	12	5	4	7	3	52
	13	5	11	10	7	10	12	10	25	9	9
	6	10	14	11	5	12	6	6	9	8	14
	16	14	9	7	29	11	6	2	4	6	
11	67	13	3	7	19	4	4	6	3	5	
	20	8	3	7	18	18	5	9	4	4	
	12	6	4	7	14	15	4	4	7	10	
	6	7	7	11	12	6	8	4	13	9	
	4	4	18	10	7	5	12	4	6	11	
16	3	4	10	4	6	6	3	2	6	7	
	5	6	6	8	12	13	4	2	4	7	
	14	4	3	7	13	26	4	4	8	4	
	9	6	3	4	9	12	9	3	6	5	
	5	12	3	4	3	5	4	77	6	24	
21	5	8	5	4	6	4	4	8	17	20	
	12	4	7	4	10	4	9	20	8	14	
	11	12	10	7	21	10	2	25	8	10	
	8	20	6	9	10	4	4	9	6	8	
	6	4	5	14	21	2	4	14	4	9	
	4	12	10	11	12	16	7	10	3	6	
27	5	5	6	8	9	12	6	21	7	8	
Avg.	11.0	11.2	8.1	8.3	11.3	9.9	6.6	10.2	7.7	8.0	

High-latitude paths that pass below a tangent point to the auroral oval (Path A in Figure 4) will suffer little or no auroral absorption, while paths that graze the auroral oval (Path B in Figure 4) will suffer high auroral absorption. Some paths may cross at near right-angles to the auroral zone (Path C on Figure 4, shown also on Figure 5), pass under the auroral "curtain" and suffer limited auroral absorption. These "doughnut hole" paths may be deflected from a great circle path and may experience chordal modes (where the ray passes above the Earth's surface and re-enters the ionosphere) due to the non-uniform electron density found in the polar regions.

These trans-polar paths are responsible for Northwest Europe reception of Northwest North America (and vice versa) and Northeast North America reception of Northeast Asia (and vice versa). Southwest, Mid-western and Eastern North America reception of Southern Europe is by near-grazing paths (Path A), as is Western North America reception of Eastern Asia. Super-position of a typical auroral zone on a world globe will help the DXer determine the likelihood of reception of different areas from his location.

The correlation of long-distance, high-latitude medium wave receptions is beyond the scope of this article. The conventional wisdom is that trans-oval receptions or near-grazing path receptions should be improved during periods of low sunspot number and low geomagnetic activity. Long periods of low geomagnetic activity reduce residual ionospheric absorption and increase the probability of receiving signals on high-latitude propagation on "grazing" paths or "doughnut-hole" paths. There are other complicating phenomena, such as the Winter Absorption Anomaly (also known as the Mid-winter anomaly) which causes reduced signal strengths during periods of low geomagnetic activity, mainly during the winter solstice months (December and January in the Northern hemisphere).

7. CONCLUSIONS

Based on the data presented in this article, the following conclusions can be drawn:

a) Solar energy affects the Earth's geomagnetic field and causes variations in the strength of the field.

b) The sunspot cycle is 22 years long, with two 11-year periods between sunspot number maxima.

c) High geomagnetic field activity is associated with high sunspot number and solar flare activity. However, high activity can occur in years with low sunspot numbers.

d) The number of geomagnetically quiet days in a year is highest in the 1-2 years after the sunspot minimum.

e) The number of geomagnetically active days (Ap > 15) in a year is highest in the 2-3 years after sunspot maximum.

f) In sunspot minimum years, periods of 20-30 days or more without high geomagnetic activity are common. However, some periods of high geomagnetic activity do occur.

g) In years during and after the sunspot maximum, periods of 15-20 days with high geomagnetic activity are common. However, some periods of low geomagnetic activity do occur and high-latitude Medium Wave DX is possible.

h) A 27 day recurrence of active geomagnetic field conditions is related to the solar rotation, and is typical, but not absolute. A 152 day recurrence of specific solar flares is observed occasionally in the geomagnetic index data.

i) The average Ap index value is 15 for the years 1956-1986. The lowest yearly average Ap value was 8 in 1965, and the highest yearly average Ap value was 24 in 1960, with 23 in 1982.

j) The months with the highest average Ap index are April and September.

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8. THE FORECAST

Just like forecasting the weather, forecasting the Sun, the Earth's magnetic field and ionosphere is risky business. Based on the data and conclusions presented above, the following forecasts are made (with high hope!): ..

a) The period between Fall 1987 and Spring 1989 will be good to excellent for high-latitude medium wave DXing due to the low sunspot numbers. There should be some periods of 20-30 consecutive days with quiet or disturbed geomagnetic field which should be the best for high-latitude DXing. DXers should monitor the A and K index data on WWV for up-to-the-minute geomagnetic activity. The best time of the year are the months of September through mid-November and mid-January through mid-April.

b) The sunspot maximum should occur in 1991-1992 with a maximum sunspot number of 100-150, followed by a slow decline in sunspot number to the next minimum in 1997-1998. Even so, there will be periods of quiet and disturbed geomagnetic activity when high-latitude DXing is possible. There may even be a year like 1980 which had a high number of days with quiet activity with a relatively high sunspot number.

Too often DXers judge the quality of a DX year by first impressions - how "good" was September for high latitude DX. There have been some poor Septembers in low sunspot years (1977 and 1986, for example) that were followed by good Octobers and Novembers. Don't give up too early in the DX year!

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