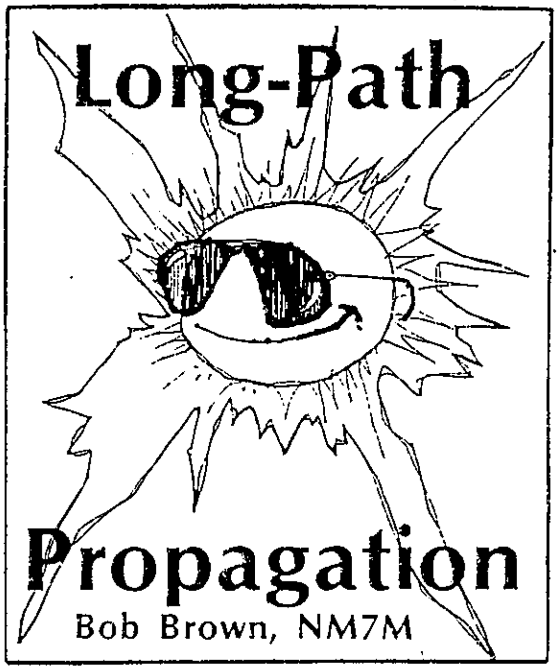

Long-Path Propagation

Bob Brown, NM7M

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A STUDY OF
LONG-PATH PROPAGATION
IN SOLAR CYCLE 22

by

Robert R. Brown, NM7M

March 1992

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SUMMARY

This article provides the details of a year-long study of long-path propagation from the northwest corner of the USA. In that time, April 1, 1991, to March 21, 1992, almost 1,700 long-path contacts were made on the 14 MHz CW band in the early morning hours.

The location used in the present study is unique for the study of long-path propagation as it proves possible to separate LP contacts into four groups of paths with increasing distance and complexity. First, there is the path to the antipodal area at Crozet Island in the south Atlantic. Second, there are those paths which continue through auroral zone latitudes in Antarctica to South Africa as well as Sri Lanka and India. Next, there are paths across the geomagnetic polar plateau to east Africa and into the Indian Ocean. Finally, there are extreme polar paths which cross Africa and the equatorial anomaly of the ionosphere to reach European regions.

The long-path contacts were analyzed by groups according to the level of geomagnetic disturbance and according to season, either spring/summer or fall/winter, when the sun was above or below the equator. The data show the time-distribution of long-path contacts and how their frequency of occurrence was affected by geomagnetic activity during months 55 to 67 in Solar Cycle 22. Following the results of the study, the discussion concludes with a summary of the types of disturbances which may affect long-path propagation and the possible presence of chordal hops on the various paths.

PREFACE

Long-path DXing is a human experience involving amateur radio operators more than half an earth apart. As such, it reveals aspects of human psychology, sociology, and the demographics of our hobby. But we are always aware that long-path DXing is controlled by solar radiation, whether through slow changes with the solar cycle or sporadic outbursts from solar flares or coronal holes.

This article is directed toward the physical aspects of long-path DXing but tries to give some recognition to the human sides as well. Being a physical scientist, however, I must plead guilty to being biased in the technical direction. Perhaps the next person who pursues this matter can make up for my shortcomings.

Guemes Island, WA
March 1992

ACKNOWLEDGEMENTS

Many people contributed, knowingly and unknowingly, to the successful completion of this study. Among the latter were hundreds of amateur operators over half an earth away who responded to my calls. Their assistance is gratefully acknowledged.

Others, equally distant, responded many times to my calls, and I want to thank them for their kindness and patience. Among that group are the following, from near to far: Jean, FT4WC; Al Smith, ZS1AAX; Stan Reeve, ZS5ADV; Eric Meyer, ZS6ME; Frank Franklin, Z21FN; Les Antrobus, 7Q7LA; Shanti Perara, 4S7WP; Niri Niranjan, VU2NI; Abid Solim, 3B8FG; Stanley Ingram, EA6ZY; Ed Kislyakov, UB4LCD; Petar Krajcev, YU5PK; Joerg Vollbrecht, DL2HQH; André Marcay, F2MA; Harry Vollema, PA0LVB.

In the analysis phase, I was most gratified to receive LP log data for sub-auroral paths in response to my request. Those generously contributing included Merle Parten, K6DC; Cliff Moore, K6KII; Rad Leonard, W6THN; and Ron Faulkner, W6TUR, from the USA, and Al Smith, ZS1AAX; Jack Snyman, ZS1OU; Jim Van Loggerenberg, ZS2LR; Bob Wilson, ZS2RW; Stan Reeve, ZS5ADV; Jay Gordon-Welsh, ZS6BUD; Eric Meyer, ZS6ME; Mac McDonald, ZS6UE; and Frank Franklin, Z21FN, from the continent of Africa.

I am indebted to Armond Noble, N6WR, for use of the logo of my propagation column in *Worldradio* and to Robin Wortley, KC6RUD, for so ably adapting it to long-path. And I am pleased to acknowledge the generous assistance of Sheldon Shallon, W6EL, for many discussions about HF propagation and related topics. Further, I wish to acknowledge the efforts of Evans Paschal, KF7VX, in laying out and typesetting the article. And finally, I wish to thank my wife, Mary Lou, NM7N, for her patience in the past year and for discussions about statistical methods in data analysis.

CONTENTS

But be ye doers of the word,
and not hearers only,
deceiving your own selves.
James 1:22

PART 1

1.1 Introduction

Aside from the inherent curiosity or mystery of "long-path," it has provided determined DXers on the West Coast with those rare Middle East zones that are so elusive working with just short-path propagation. Now if you're thinking about getting into "long-path," how much have you thought about how it really works and may vary within a year or even a solar cycle? I started worrying about those ideas a while back and finally decided to work it out as best I could, on the air and with my computer. So what follows is a saga, almost twelve months on the 20-meter CW band working nothing but "long-path" and with some computer exercises to match.

While doing that, I was collecting all the solar and geophysical data that NOAA and others had to offer; that would be needed to interpret the results. With the aid of my computer, working out regression analyses and various details such as distance, heading, and paths to DX stations, I think I've pulled together the various aspects of long-path propagation into a coherent whole. Thus, in what follows, I'll be summarizing my own experience as well as suggesting some guidelines for others to use in working with this fascinating mode.

In nearly twelve month's time, from April 1, 1991, to March 20, 1992, I made almost 1,700 long-path contacts on 20-meter CW with locations like Crozet Island, stations in the Indian Ocean area, South Africa, and beyond into Europe. Indeed, in contacting places as close as Crozet Island (20,465 km) and as far as Vadsö, Norway (33,368 km), the total distance my RF travelled in those contacts was at least 46,000,000 km. Now that's about the same as 1,150 trips around the earth or 60 round-trips to the moon!

In carrying out this project, I was up early, day after day, and "running radio" for about three hours starting around 1200–1400 UTC in the morning, depending on the season. If the previous day's propagation forecast suggested that conditions might be disturbed, I copied both the Solar and Propagation Bulletins from the NOAA BBS before going on the band. In any event, I always checked the latest Boulder K index by monitoring WWV or WWVH broadcasts.

For some people that might seem like a form of self-punishment, but I'm a "morning person." Besides, I was really curious about the fundamental aspects of long-path, and, as you already know, one can't find any decent literature on the subject. I say that as what I did find in handbooks and antenna books amounted to two things: 1) long-path DXing involved pointing one's beam opposite to the normal direction (that's little more than a definition), and 2) something about the gray line and sending one's signals in its vicinity (that's a bit more than a definition but hardly what I'd call an in-depth discussion in terms of ionospheric physics). I knew there had to be more to long-path propagation than that so I went to work, trying to develop information in a more organized fashion.

Now I've spent a lot of time at this, enjoying (?) every moment, and, being an open person, I want to share the results with you. So sit down and read on but be prepared for a lengthy discussion. After all, it took over 1,000 hours on the air to carry out this study; that's more than twenty-five 40-hour work-weeks so you can't expect me to put it down on paper in 1,000 words or less! That's for school-boy compositions; this is serious business, propagation and DXing on long-path!

1.2 Basic Parameters of the Study

Maybe you didn't notice it but I called this effort a "study." I use that term advisedly as it was not a controlled experiment. I've conducted my share of those during my academic career. This was a study run by one amateur radio operator, with the help of many hundreds of amateur radio operators more than half an earth away, and was meant to deal with the experience we call long-path DXing. But it has its technical aspects as well. I will try to go through them in an orderly fashion as we get into the matter.

So, first, I have to stake out the basic parameters of the study. Thus in making LP contacts I used a Ten-Tec Corsair as my transceiver, a linear amplifier running about 200–250 watts output, and a generic 3-element tri-band Yagi antenna at 38 ft above ground. All that amounts to a mid-scale DXer's set-up. But my QTH is a bit different in that it is located on an island, truly a low-noise site; in addition, it is perched on a bluff, overlooking the Guemes Channel north of Anacortes and with my tri-bander looking south at about 75 ft above salt water.

As for operating, I was on the band promptly every morning, patrolling the first 50 kHz of the 20-meter CW band, logging the band conditions, long-path signals that I heard, and contacting as many as I could. Thus I responded to CQ's, "QRZ?," or "tail-ended" QSO's, but never tried calling CQ, CQ DX or CQ LP. I generally spurned pile-ups but did create some from time to time by getting lucky, right at the head of the line. That's one advantage to being on the band constantly; you get to know when a fist sounds new or an operating style is different.

1.3 First Results

To get started, let's outline the boundaries of this study and then give some of the results. For example, of the 355 days in the study I was active and looking for contacts on 339 days. The difference between those two numbers is due to the fact that I simply did not pursue any long-path (LP) contacts on 16 days during major amateur radio sporting events (Field Day, Sweepstakes, CQ or ARRL DX Contests, and the like from abroad).

So now we come to the first and simplest result of the LP test: in those 339 days I had at least one LP contact on 312 days. And by an LP contact I mean one that covered more than half the distance around the earth and involved a least the minimum exchange of call, RST and QTH. So there you have it, on 92% of the days of the period LP was open from this QTH. The remaining 27 days were unproductive on LP because of solar or geomagnetic disturbances. And I'll have more to say on those points later.

Now if you look at the whole study, the average number of LP contacts per active day amounted to 5.0 so the LP statistics are not on the puny side. Indeed, LP was open on almost all the days without major geomagnetic storms and produced not just isolated contacts on this day and that but, instead, a significant number of contacts each day, anywhere from one to twelve. And, of course, for the DXers who are impatiently reading this, LP also gave rise to some new prefixes in the log, say 3A2, 3B7, 3B9, 5R, A2, A4, A9, C9, D2, FH, FR5/T, J2, S21, V51, and even ZA1. So I've many more pins on my DX map now, thanks to LP propagation!

But I digress. The point I'm trying to make is that the overall features of the study show that LP propagation was a basic feature of the undisturbed ionosphere, one that was supported regularly without the need to invoke any unusual or exotic circumstances for explanation. In short, it was there almost all the time in that period so all one had to do was be "on the air" at the right time, early in the morning here on the West Coast, to make LP contacts with Crozet Island, Africa, and beyond, ... way beyond!

Further, high power or big antennas were not always required at the other end, as I worked my share of stations who ran 100 watts into dipoles, inverted vees, slopers, and verticals, to say nothing of Janusz, ZS5ADU/M, who drove around Durban, South Africa, with 80 watts into a mobile whip.

But there were differences with seasons of the year and levels of geomagnetic activity. While the seasonal effects were gradual, the changes were not small nor subtle, being quite evident when you look at the times when LP DX was coming in and the prefixes heard on the band. Geomagnetic activity, however, was sporadic in time, varied markedly in degree, and had an effect on the ionospheric conditions.

The main change with seasons was that stations in the Indian Ocean area, say in Sri Lanka and India, were no longer heard when the southern hemisphere went into its summer season. That was the result of increasing ionospheric absorption as their long-paths to this QTH became more illuminated. Thus paths which went off into the east from here, toward the sunlit hemisphere, soon became ineffective as the summer season progressed in the southern hemisphere.

But that same shift of the sub-solar point resulted in the winter season in the northern hemisphere and had another effect on LP signals which went to the west from this QTH. In particular, for signals to and from Europe, the shift in seasons actually reduced the illumination on the portions of the paths over Europe; the result being that more of Europe was open, and those contacts on LP became much more frequent.

All in all, the loss of the signals from the Indian Ocean area as well as the appearance of more European

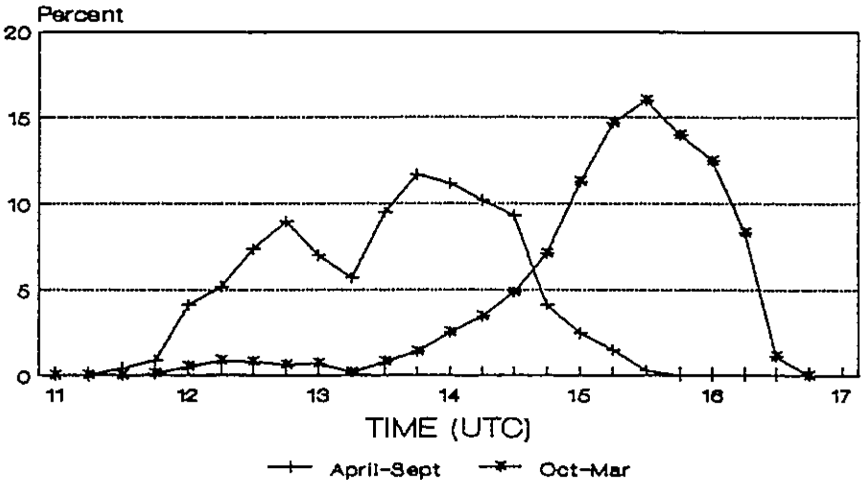


FIGURE 1. Time-distribution of long-path contacts by season.

signals had the effect of shifting the time-distribution of LP contacts toward later hours. This result was quite striking, as seen in Figure 1 where the time-distribution of contacts for the two seasons is displayed in 15-minute intervals. That shift also involved a change in the calls contacted, from those in eastern Europe to those in western Europe. Part of that is sociological in origin, having to do with the change in time of the end of a work day.

Since that shift resulted from processes in the lower regions of the ionosphere as solar illumination changed, it requires little more in the way of explanation. But that is not the case for other aspects of LP propagation, involving ionization in the *F* region as well as where the paths travel with respect to the geomagnetic pole. Those aspects are a bit more complicated, especially when it comes to solar and geomagnetic disturbances, and will be dealt with in the next sections.

1.4 Solar-Terrestrial Conditions

Maybe you didn't notice it but there was an important phrase, "in that period," in one of the previous paragraphs. Thus one must not forget just when this study was carried out, from month 55 to month 67 of Solar Cycle 22. And it included a good measure of solar-terrestrial disturbances which disrupted the amateur bands and the DX study as well, June, July, and October '91 being cases in point. Later I'll go through a list of those events in some detail, commenting on how they affected LP propagation.

Treating simple things first, we've become accustomed to following solar cycles in amateur publications by noting the monthly sunspot numbers R_i reported by the Observatoire Royal de Belgique. Those values are converted to 13-month smoothed values, and for the period of the present study that number was around 146 and declining from an earlier peak value of 158 in July '89.

Here in the USA, a measure of magnetic activity is often obtained by noting the daily estimates of the Boulder *A* index given during WWV broadcasts, increases in that index usually being associated with ionospheric disturbances. For the period of the study, the Boulder *A* index ranged from a low of 2 to a high of 150.

Those same broadcasts from WWV also announce solar flares as well as the proton events observed by NOAA's GOES satellite and polar cap absorption (PCA) events observed at Thule, Greenland. Those events are a bit more involved since their occurrence affects propagation in several different ways — sudden ionospheric disturbances from flare X rays, delayed magnetic storms, or fairly prompt absorption of HF signals going across the polar caps.

Not every flare results in all those effects so the date and time of occurrence of large flares is given on WWV as an advisory or warning to those using HF radio communication. Those requiring more detailed information about solar activity and propagation forecasts obtain it from the NOAA/SESC BBS. For example, forecasts

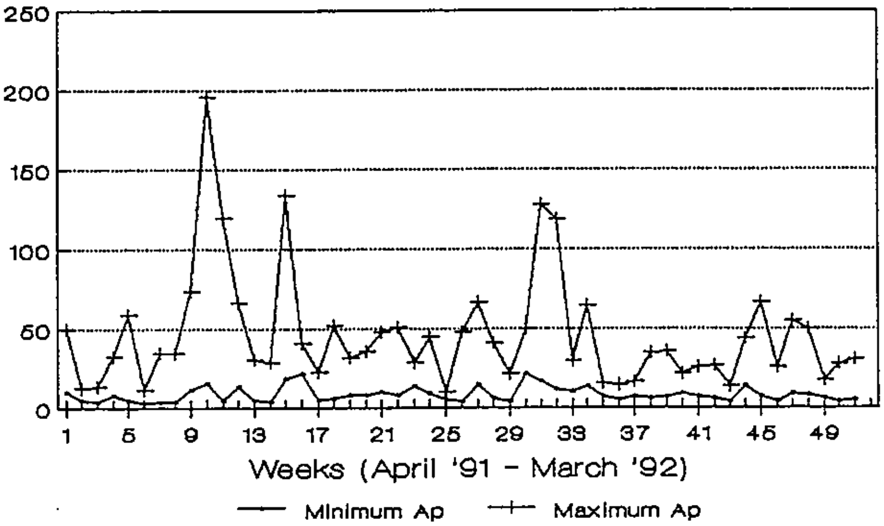


FIGURE 2. Weekly maxima and minima of the Ap index, April 1, 1991, to March 20, 1992.

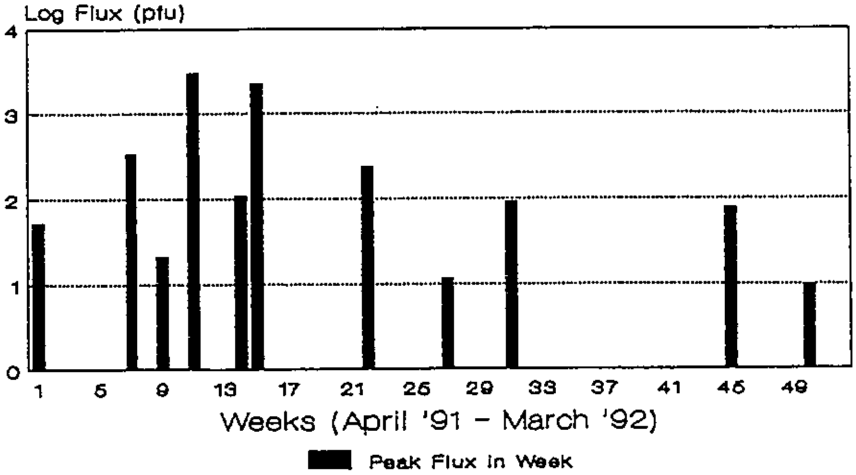


FIGURE 3. Weekly peak flux of solar protons above 10 MeV observed on the GOES satellite, April 1, 1991, to March 20, 1992.

are given for the magnetic index Ap as well as future activity of regions on the solar disk.

The occurrence of magnetic storms is particularly disruptive for radio propagation, and the past year had its share of them. This is shown in Figure 2 where weekly values of Ap, both maxima and minima, are given. Here it should be noted that minor storm conditions are present when Ap is between 31 and 50 while major storm conditions are when Ap exceeds 50.

As for the solar proton events, the announcements on WWV are based on detailed observations. In particular, detectors on the GOES satellite are set to monitor the fluxes of solar protons in various energy ranges. For broadcast purposes, however, the units used in reporting the events are simplified to *proton flux units* or pfu in each energy range and a *satellite proton event* is announced if the flux of solar protons with energies greater than 10 MeV exceeds 10 pfu.

Particles of that energy can penetrate to an altitude of 65 km in the polar regions, spiraling down the magnetic field lines. When that happens, additional ionization is created in the D region, but the actual amount of ionospheric absorption depends on details of the proton energy spectra as well as the amount of sunlight on the region. For example, the first PCA event in this study was a modest one and occurred on April 3, 1991, the proton flux reaching 52 pfu and giving rise to 2.2 dB of absorption for 30 MHz signals from the vertical direction at Thule, Greenland.

There were a total of 14 proton events in the course of this study, and the peak flux recorded during each week is shown in Figure 3. The association of those flare events with magnetic disturbances may be noted by comparing the proton peaks in Figure 3 with the peak values of *Ap* in Figure 2. And finally, the magnitude or importance of PCA events to HF propagation may be appreciated by the fact that the event of June 11, 1991, with a flux of 3,000 pfu, resulted in about 17 dB absorption on 30 MHz for a single, vertical traversal of the ionosphere at Thule, Greenland.

1.5 Long-Path Propagation and Magnetic Disturbance

With that background, we can look at the overall effect of magnetic disturbances on the LP study by examining the data in Table 1. This shows the number of active days in the study according to the range of the planetary magnetic index *Ap*, say the number of days when *Ap* was between 0 and 10, 11 and 20, 21 and 30, etc. In doing that we should note that major storm conditions exist when *Ap* exceeds 50, minor storm conditions for *Ap* between 31 and 50 and non-storm conditions when *Ap* is 30 or less.

And to look at things in a bit more detail, let's note how many sessions yielded not a single LP contact, how many involved just one LP contact, and how many there were with more than one LP contact. This information is shown in Table 1.

TABLE 1. Total Sessions and Sessions by Number of Contacts vs. *Ap* Index.

Ap Index	Days	Contacts/Session		
		0	1	> 1
0–10	98	0	6	92
11–20	96	2	3	91
21–30	62	1	6	55
31–40	28	3	3	22
41–50	15	1	3	11
51–60	14	5	2	7
> 60	26	15	3	8

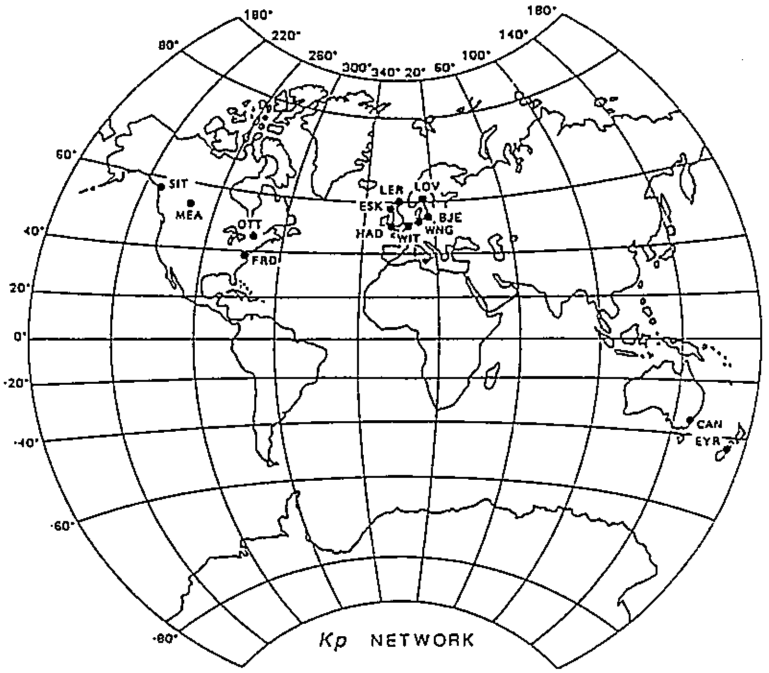
Of the 339 days there were 256 days of non-storm conditions, and on 3 of those days no LP contacts were made, on 15 days only one LP contact, and 238 days involved more than one LP contact. On that basis, at least one LP contact was made on 253 of the 256 days, or 99% of the non-storm days!

Similarly, of the 43 days with minor storm conditions, at least one LP contact was made on 39 days, or 91% of the minor storm time; and for the 40 days of major storm conditions, at least one contact was made on 20 days, or 50% of the major storm time. The last point is rather amazing when you consider the havoc that storm conditions wreak on the HF bands.

It should be pointed out that the planetary index *Ap* used in Table 1 has a broader basis than the *A* index given during WWV broadcasts; those values are based only on magnetometer data recorded at NOAA in Boulder, Colorado. The planetary index *Ap* was designed to measure solar particle radiation by its magnetic effects and has widespread acceptance in the US and western Europe as a means of characterizing the level of geomagnetic activity. It is prepared monthly by the International Association of Geomagnetism and Aeronomy (IAGA) at the Institute for Geophysics, Gottingen University, Germany.

As noted earlier, the maximum and minimum values of *Ap* for each of the weeks in the study are shown in Figure 2. These were obtained from monthly reports of *Ap* which summarize data from 13 observatories between 44° and 60° northern or southern geomagnetic latitude. In the north, 11 of the observatories lie in a band of 179° geomagnetic longitude in extent, from Sitka, Alaska (60° N, 275° E), eastward to Wingst, Germany (54° N, 94° E); and in the south the two observatories are located at Eyrewell, New Zealand, and Canberra, Australia, as shown in Figure 4.

An estimate of the *Ap* index is released daily on the NOAA BBS by the Space Environment Services Center (SESC) in Boulder and is based on data from five magnetic observatories in the northern hemisphere,



Northern Hemisphere Observatory	Code	Corrected Geomag. Latitude
Meanook	MEA	62.5°
Sitka	SIT	60.0°
Lerwick	LER	58.9°
Ottawa	OTT	58.9°
Lovö	LOV	56.5°
Eskdalemuir	ESK	54.3°
Brorfelde	BJE	52.7°
Fredericksburg	FRD	51.8°
Wingst	WNG	50.9°
Witteveen	WIT	50.2°
Hartland	HAD	50.0°

Southern Hemisphere Observatory	Code	Corrected Geomag. Latitude
Eyrewell	EYR	50.2°
Canberra	CAN	45.2°

FIGURE 4. Magnetometer sites in the *Ap* network in 1988. From *Menvielle and Berthelier* [1991].

extending over 187°in geomagnetic longitude from College, Alaska, eastward to Upper Heyford, England. Lacking observations from the southern hemisphere, there are bound to be differences between the daily estimates of *Ap* and the values of *Ap* from IAGA.

An analysis of three years of data indicate that the correlation coefficient between the estimated *Ap* and *Ap* itself is 0.91; however, given the fact that the geomagnetic field is quiet far more often than disturbed, the differences between the two are most evident during disturbed times. Even at that, however, the availability of an estimate for *Ap* proves to be invaluable.

Returning to Table 1, it should be noted that, since it includes all the active days of the study period, it follows that the overall features of Table 1 give the distribution of the *Ap* index during the study. Thus it is seen that a total of 76% of the LP sessions were during days with non-storm conditions, when *Ap* was between 0 and 30, while 13% of the sessions were during minor storm conditions, when *Ap* was between 31 and 50, and the remaining 11% during major magnetic storm conditions, with *Ap* greater than 50. Later in this report the level of magnetic activity during the year-long study will be placed in perspective by comparing it with activity in the two years that preceded it.

Now going back to the other "numbers" for the time of the study, it covered a period when the smoothed sunspot number (SSN) was between 125 and 150. More to the point, however, was the daily average of the 1–8 Å background X ray flux. That varied by a factor of about four, from 6.0×10^{-7} W m^{-2} to 2.4×10^{-6} W m^{-2}, over the entire period.

The second set of numbers are more related to the level of ionization that controls the refraction of the 14 MHz radio waves in the LP study. In contrast, the first numbers lead us to archival descriptions of the ionosphere in terms of f_oF_2 maps. And the 10 cm solar flux has been ignored as it is largely irrelevant in analyzing the results of the study, the archival aspect having been taken care of by the sunspot numbers.

But to go on, the LP data has been analyzed in more detail, according to seasons, great-circle paths expressed in geomagnetic coordinates, the "equatorial anomaly" of the ionosphere, and even the venerable gray line.

While Table 1 summarizes the results for the entire study, the same approach could be used for the two ionospheric seasons, spring/summer when the sun was above the geographic equator and the fall/winter season when it was below. This division of the data is important since it would show not only how geomagnetic activity differed in the two seasons but also bears on the amount of sunlight on the propagation paths during the study. Since the largest portions of the paths were in the southern hemisphere, the separation is particularly important.

But that last point touches on a problem which arises in using the Ap network in analyzing the LP observations. Thus there is only a limited range of longitudes in the southern hemisphere, near New Zealand and Australia, where geomagnetic data is sampled in preparing the monthly Ap reports. A better network exists, even providing more uniform coverage of both hemispheres. but before getting to it, we have some other items that require more discussion.

PART 2

2.1 Some Details of the Study

In dealing with LP propagation it is necessary to discuss details of the great-circle paths, some solar astronomy, and invoke properties of ionospheric charts, those critical frequency maps for f_oF_2 from days of yore. Let's take the matter of the great-circle paths first, followed then by solar astronomy. After that, more on geomagnetic indices is called for, and finally the bearing of f_oF_2 maps on LP propagation will conclude the discussion of experimental factors.

To begin, note that, at this QTH (48.5° N, 122.6° W) in the northwest corner of Washington, one looks southward to work LP into Africa and beyond. For the time period mentioned, about 1200 to 1500 UTC, contacts were made with 4S7's, VU2's and 3B9's in the spring/summer season by pointing the beam somewhat east of south toward the sunlit hemisphere. The rest of that southerly region, from Mauritius (3B8) to Capetown (ZS1), was contacted by pointing the beam west of south toward the dark hemisphere. It should be noted that there are seasonal effects here, especially for the 4S7's, VU2's and the 3B8's; those will be discussed later.

For those areas where amateur operators are most active, say in the African region as well as off into the Indian Ocean and toward South Asia, one can calculate the beam headings and distances, all in excess of 20,000 km, for each DX site. One can even calculate details of the great-circle paths to the locations, including the distance of closest approach to the southern geographic and geomagnetic poles.

As the seasons change, illumination along the paths will change also, affecting signal strength. That's a slow, steady process, but HF propagation can be disrupted suddenly, often without warning, by disturbances of solar origin. Thus there is also the question as to whether signals following those great circle paths could get into harm's way as they go into the far reaches of the southern hemisphere.

The experienced DXer knows the evils of which I speak: magnetic storms, auroral absorption (AA), and polar cap absorption events. They take their toll on HF signals without regard to hemisphere but not always equally. So the next task is to explore those possibilities as well, finding how close the great-circle paths come to the south magnetic pole (78.98° S, 109.1° E) [*Fraser-Smith*, 1987] before turning northward again toward Africa, the Indian Ocean, or Europe.

For this discussion, paths were categorized as being sub-auroral in latitude, in the auroral zone, or into the polar plateau, according to their maximum southerly excursion. The dividing lines are taken as below 60°southern geomagnetic latitude for sub-auroral (Sub-AZ) paths, from 60 to 70° for auroral zone (AZ) paths, and finally from 70 to 90° southern geomagnetic latitude for (Polar) paths into the geomagnetic polar plateau. That is a natural separation for the paths as auroral absorption events occur largely in the 60–70° range and polar cap absorption events affect HF propagation paths which go across the polar plateau.

2.2 Antipodal Considerations

I should proceed by presenting more of the results, but I must digress to make an interesting point. In particular, great-circle paths are the locus of intersections of planes which pass through the center of the earth. For a particular point of reference, say my QTH at 48.5° N, 122.6° W here in NW Washington, all great-circles that pass through it also pass through its antipodal point located diametrically opposite to my QTH at 48.5° S, 57.4° E. Indeed, one can think of all the great-circles through my QTH, no matter what their heading, as having a common diameter on the line joining my QTH and its antipodal point.

So what's so special about antipodal points? Well Crozet Island (FT4W) is close to being antipodal to my QTH! It's coordinates are 46.4° S, 51.9° E, only 465 km from my antipodal point. In essence, all the great-circle paths from my QTH pass close to that location. Let's put it another way around, Crozet Island is close to being along all the paths *toward* my QTH for signals from all the other stations in the long-path directions I'm interested in!

That put Crozet Island in a special category, but another reason was the near-constant activity of Jean, FT4WC, during the spring/summer season. In The DX Bulletin, he was listed as one of the "Resident Amateurs on Regularly," and being near the focus of the paths to my QTH, he served as a beacon for me. But more important, it has been suggested that antipodal focusing is involved in LP contacts so contacts with Crozet Island were examined in the same manner as other contacts over larger areas, say Africa, the Indian Ocean, and Europe.

2.3 Some Great-Circle Paths

Enough talk; let's look at some numbers in Tables 2 and 3 which give particulars, say beam headings and distances, for some individual paths in the study.

TABLE 2. Auroral Zone and Sub-Auroral Zone Great-Circle Paths.

	Location	Heading	Distance	Maximum Latitude		Class
				Geog.	Geomag.	
ZS1	Capetown	258° E	23,590 km	49.6° S	58.8° S	S-AZ
ZS2	Port Elizabeth	250° E	23,070 km	51.4° S	61.4° S	AZ
V51	Namibia	245° E	24,570 km	52.9° S	63.3° S	AZ
ZS4	Bloemfontein	243° E	23,410 km	54.0° S	64.3° S	AZ
FT4W	Crozet Is.	238° E	20,465 km	55.9° S	66.7° S	AZ
4S7	Sri Lanka	154° E	26,550 km	72.6° S	67.4° S	AZ
D2	Angola	238° E	26,030 km	55.6° S	66.5° S	AZ
ZS5	Durban	237° E	23,050 km	56.2° S	66.8° S	AZ
A2	Botswana	238° E	23,800 km	55.9° S	66.8° S	AZ
ZS6	Johannesburg	236° E	23,540 km	56.4° S	67.4° S	AZ
VU2	Bangalore	158° E	27,120 km	75.6° S	68.6° S	AZ
3D	Swaziland	232° E	23,350 km	58.3° S	69.4° S	AZ

TABLE 3. Polar Great-Circle Paths.

	Location	Heading	Distance	Maximum Latitude		Class
				Geog.	Geomag.	
9J2	Zambia	226° E	24,530 km	61.6° S	72.8° S	Polar
Z2	Zimbabwe	224° E	24,160 km	62.5° S	73.5° S	Polar
3B9	Rodriguez Is.	168° E	23,240 km	82.3° S	74.9° S	Polar
7Q7	Malawi	217° E	24,160 km	66.3° S	77.3° S	Polar
3B7	St. Brandon Is.	176° E	23,550 km	86.2° S	78.4° S	Polar
3B8	Mauritius	180° E	23,130 km	89.7° S	81.0° S	Polar
5Z4	Kenya	206° E	25,610 km	72.9° S	82.7° S	Polar
FR	Reunion Is.	184° E	23,650 km	87.6° S	83.2° S	Polar
FR/T	Tromelin Is.	185° E	23,630 km	85.3° S	83.6° S	Polar
HZ	Saudi Arabia	189° E	28,340 km	84.4° S	85.1° S	Polar
5R	Madagascar	199° E	23,400 km	77.8° S	85.4° S	Polar
FH	Mayotte Is.	200° E	24,100 km	76.9° S	86.1° S	Polar

Table 2 contains a list of stations with paths from here which pass through the auroral zone, the only exception being Capetown which is barely in the sub-auroral category. And Table 3 contains a list of stations whose paths go across the polar plateau. Details of the long-paths may be seen by using the azimuthal equidistant map in Figure 5. Just follow a straight line southward from my QTH in the center of the figure on the beam headings given above. When the path is completed from the top of the map you can see which oceans and land masses were involved.

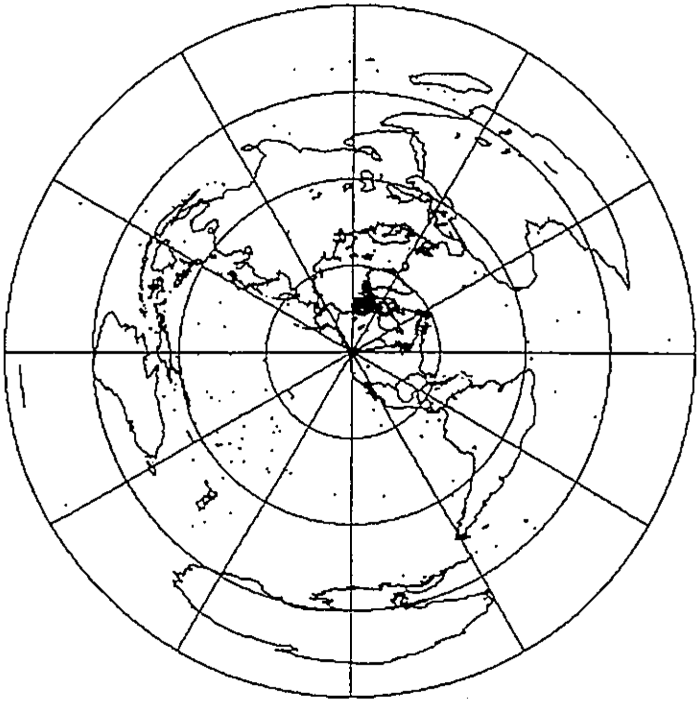


FIGURE 5. Azimuthal equidistant map centered on 48.5° N, 122.6° W.

In a more general sense, the azimuthal equidistant map in Figure 5 can be used to distinguish between the categories of paths. Thus, for this QTH, great-circle paths which go across the polar plateau are found at headings between 158° and 321° east of north. For paths which lie within the southern auroral zone, they are included between 135° and 158°, to the east of south, and between 231° and 254°, now west of south. Finally, paths with headings less than 135° or more than 254° fall in the sub-auroral zone category.

Now, if you like to have numbers to toss around, the average path length to the stations in Table 2 is about 24,100 km, and the average geomagnetic latitude of the most southern part of their great-circles is 65.6°. For the stations in Table 3, the average path length is not very different, about 24,300 km, but the southern reach of their great-circle paths is much greater, now 80.3°. So there you have it, the LP paths for the stations frequently encountered, especially in the first half of the study.

But there were other contacts, more distant than the 28,000 km to Saudi Arabia and ending well above the equator, during the second half of the study. Thus there was another important category, extreme long-paths or ELP, and those great-circle paths went across the polar plateau and Africa into the USSR, the Mediterranean, and western Europe. Its importance can be seen from the fact that extreme long-path contacts in the study outnumbered all the LP contacts to the locations given in Tables 2 and 3 by at least a factor of 2.

2.4 And Some Solar Astronomy

We all know the sun creates the ionosphere, and there are seasons for it as well as for the neutral atmosphere, depending on the whether the sub-solar point is above or below the equator. In presenting the results of the LP study, I will consider only two seasonal divisions, spring/summer for one and fall/winter for the other, and these have bearing on regions of ionospheric absorption in the D region as well as the details of the critical frequency maps for f_oF_2. To proceed, let's start with the gray line, a region of twilight along the terminator.

For discussions of LP, the gray line has enjoyed a prominent role, and one can explore that in detail using the GEOCLOCK program or, more simply, by using the plastic slides of The DX Edge. For purposes of illustration, Figures 6 and 7 were prepared from The DX Edge using the months of June and December,

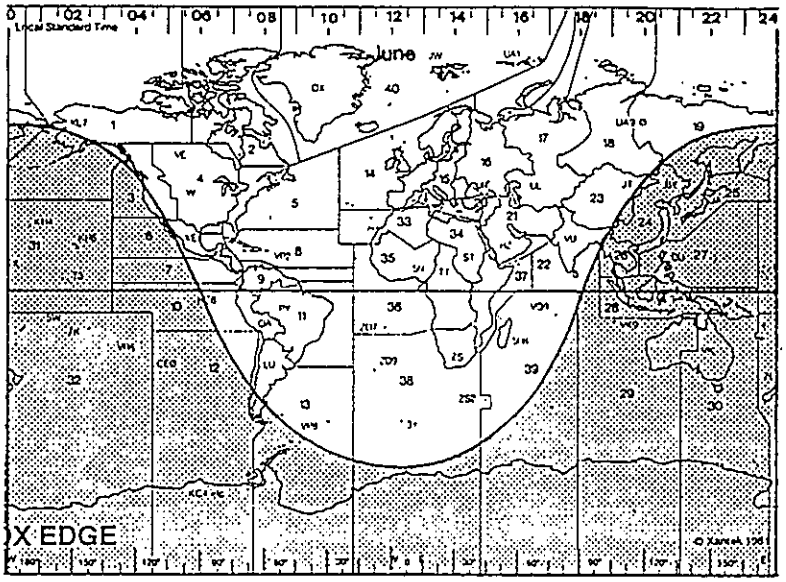


FIGURE 6. The DX Edge setting for approximately 1230 UTC during June.

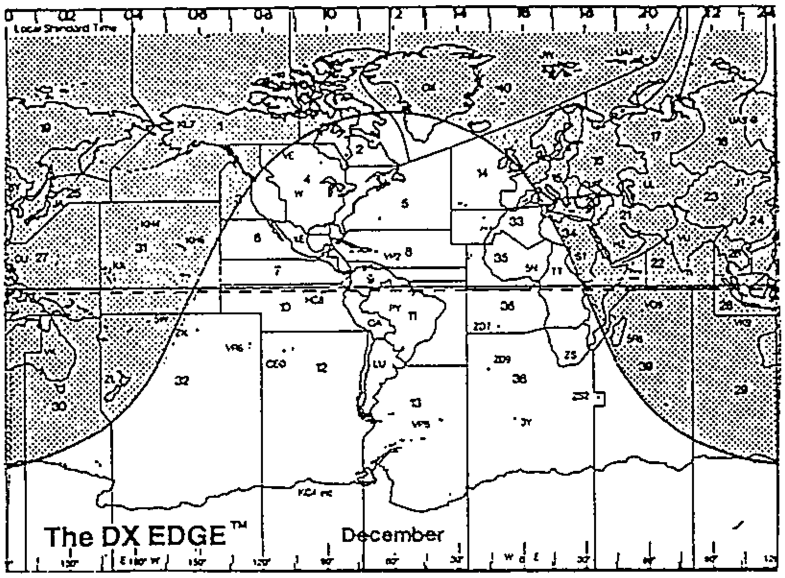


FIGURE 7. The DX Edge setting for approximately 1530 UTC during December.

respectively, and the times chosen for when the mean monthly terminator or gray line passed close to my QTH.

From Figure 6 it is apparent that paths to India and Sri Lanka are close to the gray line around 1230 UTC in June, and it is not surprising that during the early months of the LP study both 4S7's and VU2's were contacted regularly at the outset of an LP session. Those contacts were consistent with what might be called "conventional wisdom," the path being sheltered from solar illumination by its location in the twilight along the gray line.

Having cited those circumstances, now let me take the contrary position, perhaps in the extreme, that gray line considerations play only a limited role in LP propagation. Here, I go to June 6, 1991, when I contacted VU2JOS in India at 1249 UTC; that was at a heading of about 160° east, at a distance of about 27,000 km and 202° eastward in longitude from my QTH. But about 80 minutes later, at 1407 UTC, I contacted D2ACA in Angola; that was at a heading of about 240° east, at a distance of about 26,000 km and 224° westward in longitude from my QTH.

In the first instance my signals were passing over the southern tip of Argentina, like on other occasions when I've heard VU2's and 4S7's in QSO's with LU8X's on Tierra del Fuego. In the second instance my signals were going off toward Tasmania (VK7) and almost at right angles to the direction for the gray line. Indeed, the contact with D2ACA was accomplished by brute force (in more ways than one!) and had absolutely nothing to do with going along the gray line!

Don't take the last remark to suggest that I fail to appreciate the value of the gray line. It's just that there's much more to LP propagation than such narrow or limited use of *D* region considerations, important as they are for DXing. Indeed, to make the point by using the weight of numbers, let me say that, between the first and last contact with a 4S7 or VU in the spring/summer season when the gray line was in their favor, I had more than 200 solid contacts with stations on the African continent, all with beam headings some 60–80° away from the gray line and into the dark hemisphere off to the west. Enough said!

2.5 Seasonal Features of Long-Path Propagation

Earlier, mention was made of the various disturbances during the period of the LP study. Going back to Figures 2 and 3, one notes that the first half of the study period was much more disturbed than the second half. That alone might make it reasonable to divide the study into two portions. But. as indicated earlier, there is a better reason in the fact that there are really two ionospheric seasons which are distinguished by whether the sub-solar point is above or below the earth's equator, the spring/summer and the fall/winter.

That being the case, we should go back to Table 1 and divide the entries according to those two seasons. That is done in Table 4.

TABLE 4. Total Sessions and Number of Contacts vs. *Ap* Index, Separated by Season.

Ap Index	Spring/Summer				Fall/Winter			
	Days	LP QSO/Session			Days	LP QSO/Session		
		0	1	> 1		0	1	> 1
0–10	51	0	6	45	47	0	0	47
11–20	39	2	2	35	57	0	1	56
21–30	31	1	5	25	31	0	1	30
31–40	16	2	1	13	12	1	2	9
41–50	10	0	3	7	5	1	0	4
51–60	7	4	0	3	7	1	2	4
> 60	14	7	2	5	12	8	1	3

There were 168 active days in the spring/summer season and 171 in the fall/winter season. Of the two ionospheric seasons, non-storm days accounted for 72% of the spring/summer season and 79% of the fall/winter season. By the same token, days with minor and major storm activity accounted for 28% in the first instance and 21% in the second. To a certain extent, these features are borne out in the contact data, suggesting a negative correlation between LP propagation and magnetic activity. However, this matter is better examined using the various paths in the study.

But to return to gray line considerations, their importance can be found in the case of the annual coming and going of some LP signals. For example, at my QTH that is the case for the 4S7's and the VU2's as their locations are north of the geographic equator. As a result, even from this high latitude those great-circle paths are fairly shallow and only reach 73–75° S geographic latitude. Thus, after the summer solstice, the terminator moves southward from its position shown in Figure 6, and the great-circle paths favored earlier by darkness eventually become illuminated, with signals gradually consumed by *D* region absorption after the autumnal equinox.

So the last contacts with Sri Lanka or India were around October 6, and no signals were heard from those regions after October 12. However, the signals did come back again the next year, just like the first swallows of spring, with signals heard again after Valentine's Day and contacts made in the last week of February as the terminator started to move north again.

The case for 4S7's and VU2's is obvious, "by inspection" as is sometimes said, but it is less clear for stations in the Indian Ocean area that lie below the geographic equator. For them, one turns to the seasonal changes that take place in the heading of the sunrise portion of the terminator. At this QTH, the sunrise heading swings from 143° east at the summer solstice (see Figure 6) and reaches 217° east at the winter solstice (see Figure 7); then it swings eastward again, finally reaching 143° east at the next summer solstice.

As long as the great-circle heading to a DX station is west of the heading of the sunrise terminator, the path may be in darkness for a significant amount of time in the morning hours, making LP contacts possible with the DX QTH. But when the heading of the sunrise terminator swings past the great-circle heading to the DX station, the time the path is in darkness decreases rapidly, and finally it becomes fully illuminated, making LP contacts increasingly difficult at the usual time of day due to *D* region absorption.

The last discussion brings up another point which warrants mention, the fact that the loss of LP propagation from this high latitude is one thing but can be something quite different at lower latitudes along the West Coast. Indeed, the difference in LP propagation depends on the mechanism. For example, with Los Angeles (34.0° N, 118.25° W) as an origin, great-circle calculations for paths to Sri Lanka and India show the paths reach 69–72° south geographic latitude. On that basis, gray line considerations would show that LP signals from Sri Lanka to Los Angeles would be lost somewhat earlier than at this latitude.

2.6 More on Geomagnetic Indices

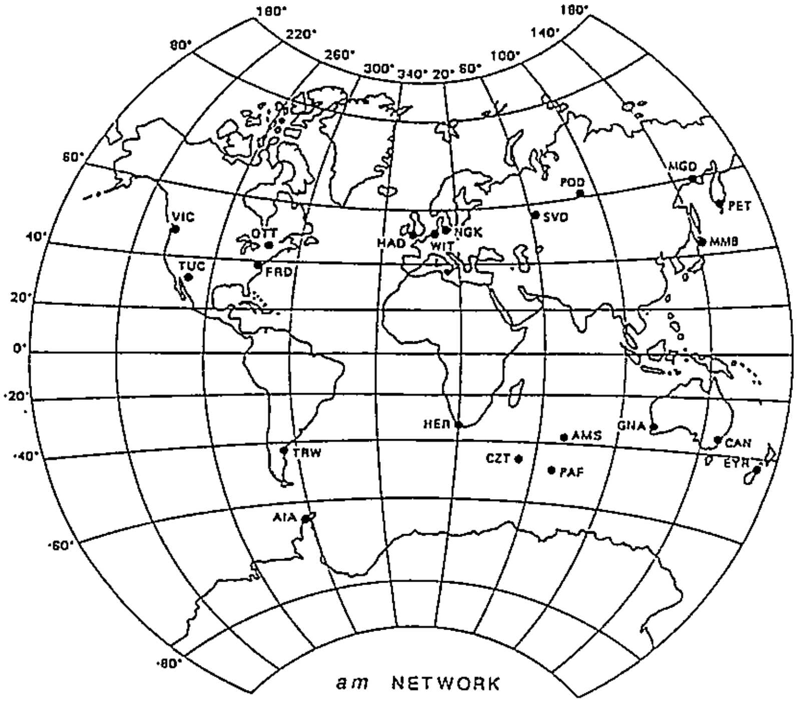
There are other mechanisms which may result in LP loss, not regular and orderly as the one from the seasonal motion of the terminator across the ionosphere but from solar outbursts, say geomagnetic storms, auroral absorption, and polar cap absorption events. For that discussion, we need to analyze the results of the study using the paths given earlier in terms of geomagnetic coordinates, finding whether they pass through the auroral zone or not, cross the polar plateau, or represent cases of extreme long-path, as mentioned earlier. Moreover, these disruptions of LP propagation are related, one way or another, to disturbances of the geomagnetic field. Thus we need to review the question of geomagnetic indices to be sure that what is used can be considered adequate for the discussion.

But before doing that, it should be noted that the contacts made on the different types of paths also involve three distinct population groups in the amateur radio community. The auroral zone group involved amateur operators from southern Africa, the current amateur radio census showing their total number to be about 6,500. The extreme long-path group reside in the USSR and Europe, numbering in excess of 100,000, while the polar group come largely from islands in the Indian Ocean and number less than 500. As a result, one should focus on how magnetic activity affected contacts with members of a given group and not try to make comparisons between groups or paths involving disparate populations.

In approaching those questions, it is important to note that there is a question about the adequacy of the *Ap* network. The problem is that the *Ap* network, established in 1939, covers only part of the northern hemisphere and seven of the observatories in the northern hemisphere are located in western Europe. Moreover, the coverage in the southern hemisphere is limited to the small region around New Zealand and eastern Australia.

Before leaving that point, however, it should be noted that the beam heading toward those observatories in the southern hemisphere is in the range 220–240° east of north. Going to Tables 2 and 3, one sees that more than 12 of the auroral zone and polar paths fall close to those directions. Thus those two observatories could well provide some magnetic information that would be relevant to LP propagation along those paths. By the same token, the concentration of observatories in Europe could be of value in regard for extreme long paths to the Black Sea and beyond. Those paths, however, pass across the southern Indian Ocean where the *Ap* network lacks coverage. The same is true for the paths going eastward past the southern tip of South America, toward Sri Lanka, India, Mauritius, and Reunion Islands, the *Ap* network lacking coverage in that area as well.

Given that discussion, what is needed is a set of magnetic indices based on a more balanced network, and one has been available since 1968 [*Mayaud*, 1968], termed the *Am* network and shown in Figure 8. That network evened out the distribution of observatories in the northern hemisphere, increasing the number to twelve, and introduced seven additional observatories in the southern hemisphere. The observations from



Northern Hemisphere Observatory	Code	Corrected Geomag. Latitude
Magadan	MGD	53.8°
Petropavlovsk	PET	46.4°
Memabetsu	MMB	37.4°
Podkammenkaya	POD	57.2°
Sverdlovsk	SVD	52.2°
Witteveen	WIT	50.2°
Hartland	HAD	50.0°
Niemegk	NGK	48.8°
Ottawa	OTT	58.9°
Fredericksburg	FRD	51.8°
Victoria	VIC	53.9°
Tucson	TUC	39.7°

Southern Hemisphere Observatory	Code	Corrected Geomag. Latitude
Eyrewell	EYR	50.2°
Lauder	LAU	37.7° [?]
Toolangui	TOO	48.0°
Canberra	CAN	45.2°
Gnangara	GNA	44.1°
Kerguelen	PAF	58.8°
Crozet	CZT	52.4°
Hermanus	HER	41.1°
Argentine Islands	AIA	49.7°
Trelew	TRW	27.8°

FIGURE 8. Magnetometer sites in the *Am* network in 1988. From *Menvielle and Berthelier* [1991].

that network are more worldwide in nature than from the *Ap* network and are presented in much the same form, a three-hour index *Km* and a daily index *Am*.

The additional observatories in the southern hemisphere provide magnetic observations in the vicinity of those auroral zone paths in the present study where none was available with just the *Ap* network. But beyond that, with its greater coverage the *Am* network is more sensitive to small or local geomagnetic disturbances, some of which might be missed by the *Ap* network. As a result, the distribution of daily values for *Am* for a given period of time would make the geomagnetic field appear more disturbed than for the same range of *Ap* indices.

Rather than get involved in the basic definitions and scaling techniques for the two indices, a more direct way to appreciate their relationship and differences is by examining a graphical display of *Am*-*Ap* pairs for the days in a period of time, say two years as in Figure 9. From that figure it is seen that there is a good correlation between the indices, 0.96 from a linear regression analysis. Further, the figure shows that for a day with a modest level of activity, say an *Ap* value of 30, the corresponding *Am* value is about 42, and when activity reaches storm proportions, say an *Ap* value of 50, the corresponding *Am* value is about 70.

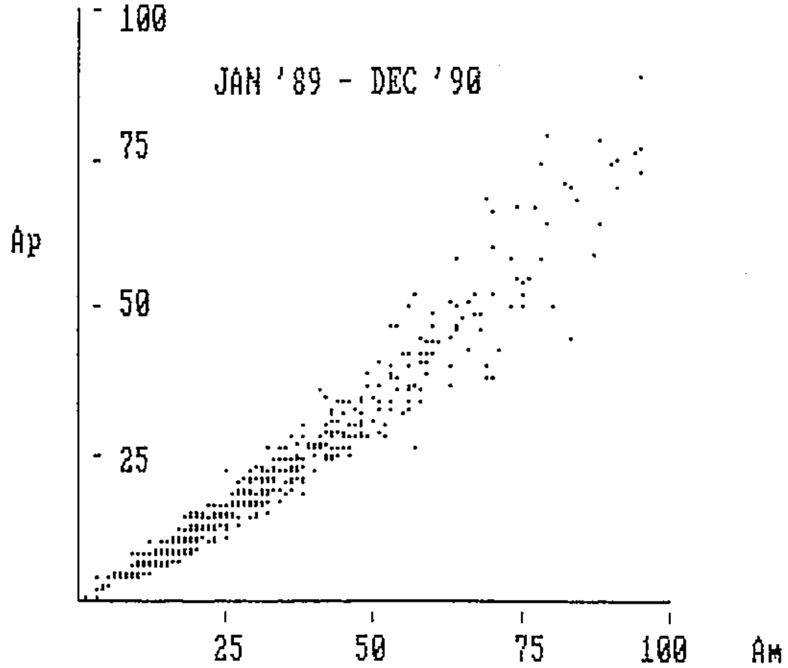


FIGURE 9. Scatter plot of daily *Ap*-*Am* pairs for a two-year period, January 1989 through December 1990.

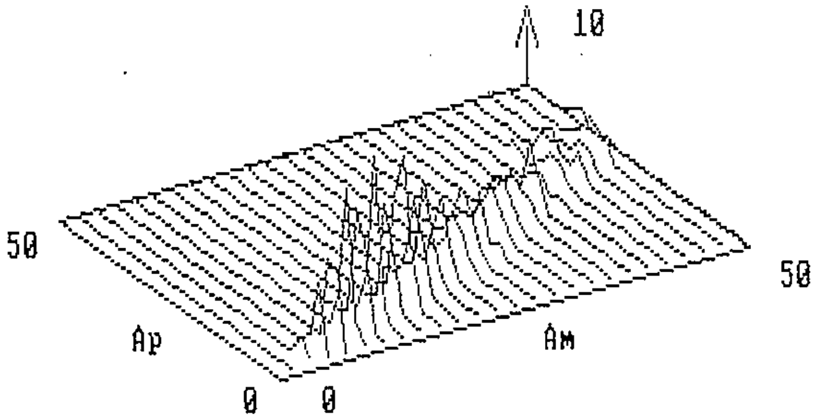


FIGURE 10. Three-dimensional plot of the *Ap*-*Am* pairs at times of low magnetic activity.

Figure 10 shows the first part of Figure 9, where many data points fall on top of each other, but in more detail by plotting the number of data entries per *Am*-*Ap* point in the vertical direction. From this plot it is seen that the correlation between *Ap* and *Am* is better at these levels of activity than for extremely disturbed conditions. True, values of *Am* run about 40% higher than the simultaneous values of *Ap*, but the two indices track rather well and with a limited scatter.

From the standpoint of principle it would be more desirable to use indices from the *Am* network, with its extended distribution of magnetometers, in examining magnetic disturbances of LP propagation. As a practical matter, however, the application of those results would be difficult to bring down to the level of everyday operations. Part of this is due to the fact that the *Am* network is not well known outside the tight circle of professional geomagneticians. Further, even though it is prepared under the auspices of IAGA by the Institut de Physique du Globe in Paris, the assembly and analysis of data from a far-flung network takes a good deal of time. As a result, the tables for the *Km*, *Am* indices reach NOAA about 2–3 months after data collection is completed.

On the other hand, the *Ap* index is better known, and there is the further advantage to the DXer that estimates of *Ap* are forecast three days in advance on the NOAA BBS. With the strong statistical correlation between *Ap* and *Am* shown in Figures 9 and 10, one can have confidence in making use of the *Ap* index. Thus if the DXer has a sense of the *Ap* values that will support propagation, it should be possible to adopt a plan of operation, be it for contesting or DXing, that takes into consideration possible changes in conditions.

With those remarks, the discussion of geomagnetic indices is concluded, and from this point onward only the *Ap* index will be used in the analysis. Those who are interested in the question of three-hour *K* indices and daily *A* indices would do well to read the article by *Menvielle and Berthelier* [1991]. In addition, it might be of interest to review the other geomagnetic data that the NOAA BBS provides: *K* and *A* indices from over 20 observatories, albeit usually 3–4 days after the fact and without any sort of overall analysis or interpretation.

PART 3

3.1 Data from the Two Ionospheric Seasons

In examining the effects of geomagnetic disturbances on LP propagation, we should first summarize the results for the various paths and seasons. Thus, going to the spring/summer season, a total of 669 LP contacts were made in that period: 309 on auroral zone paths (including 64 to Crozet Island), 137 on polar paths, and 223 on extreme long paths. For a given type of path there was the possibility of one or more contacts during an LP session, depending on propagation and the usual competition for DX contacts. For those reasons, some days went by without a single contact on a given type of path or, more often, at least one and maybe more contacts.

In order to display the results from the first 168 days of the study without giving undue weight to days with a large number of LP contacts, the results are shown below by dividing them into three categories, paths which go through the southern auroral zone, or paths which also go cross the polar plateau, and then those which went beyond Eastern Africa and the Indian Ocean area into Europe. Thus Table 5 gives the number of days with no contacts, one contact, and more than one contact per LP session.

TABLE 5. Spring/Summer Contacts by Path.

Spring/Summer Path	Contacts/Session		
	0	1	> 1
Auroral Zone	35	47	86
Polar	96	37	35
Extreme Polar	77	36	55

So the fraction of days with one or more contacts on an auroral zone path is given by the ratio (47+86)/168, corresponding to 79% of the days. By the same token, on 43% on the days one or more contacts were made on polar paths and 54% of the days with one or more extreme long-path contacts.

In the second half of the LP study there were a total of 1,011 contacts: 125 contacts on auroral zone paths, 56 on polar paths, and 830 on extreme long paths. On a daily basis, there were 171 active days in the second part of the study; the LP contacts were distributed among the various paths as shows in Table 6.

TABLE 6. Fall/Winter Contacts by Path.

Fall/Winter Path	Contacts/Session		
	0	1	> 1
Auroral Zone	97	43	31
Polar	123	42	6
Extreme Polar	15	8	148

From Table 6, the percentage of days with one or more contacts on the various paths are 43%, 28% and 91%, respectively. But, from the distribution of days shown above, it is clear that a very significant shift took place in the second part of the study, contacts on the polar paths becoming far fewer in number while the percentage of days with multiple contacts on extreme polar paths reached a high value, 87% as compared to the earlier value of 33%.

The next step in the analysis is to see if making LP contacts was affected by geomagnetic activity. For the first part of the study, Table 7 shows a breakdown of the days when LP contacts were made according to paths and levels of magnetic activity, ranging from quiet to major storm. The second part of the study is given in the same format in Table 8.

TABLE 7. Long-Path Sessions, April–September.

Ap Index	Days	Auroral Zone Contacts/Session			Polar Contacts/Session			Extreme Polar Contacts/Session		
		0	1	> 1	0	1	> 1	0	1	> 1
0–10	51	7	13	31	15	16	20	18	17	16
11–20	39	6	11	22	22	11	6	16	5	18
21–30	31	3	11	17	21	4	6	16	7	8
31–40	16	4	4	8	12	2	2	6	4	6
41–50	10	1	4	5	6	3	1	5	1	4
51–60	7	4	1	2	7	0	0	5	1	1
> 60	14	10	3	1	12	2	0	10	2	2

TABLE 8. Long-Path Sessions, October–March.

Ap Index	Days	Auroral Zone Contacts/Session			Polar Contacts/Session			Extreme Polar Contacts/Session		
		0	1	> 1	0	1	> 1	0	1	> 1
0–10	47	26	10	11	34	11	2	0	0	47
11–20	57	31	15	11	35	18	4	0	1	56
21–30	31	16	10	5	23	8	0	0	4	27
31–40	12	8	2	2	10	2	0	2	2	8
41–50	5	2	2	1	5	0	0	2	0	3
51–60	7	5	1	1	5	2	0	3	1	3
> 60	12	8	4	0	12	0	0	9	0	3

Inspection of the two tables shows a distinct change in the character of LP propagation between the two ionospheric seasons. But before discussing those observations it is important to consider the magnetic conditions which prevailed when they were obtained. As noted in the discussion following Table 5, the spring/summer season was the stormier of the two seasons with minor and major magnetic storm conditions on 28% of its days as compared to 21% for the fall/winter season. Further, examination to the extreme values of *Ap* in Figure 2 shows that not only were storm conditions more prevalent in the spring/summer but they also involved higher values of *Ap* than in the fall/winter season.

Turning now to Tables 7 and 8, a striking difference is seen in comparing results for the two seasons. Thus, in spite of the fall/winter season being less disturbed, there is a marked change in the effectiveness of LP propagation, the auroral zone and polar paths deteriorating even with non-storm conditions. At the same time, however, LP propagation improved greatly on the extreme long paths.

The spring/summer results in Table 7 show a negative correlation with magnetic activity, propagation deteriorating particularly with high values of *Ap*. In itself that is nothing new. But the fall/winter season is different because of another factor, ionospheric absorption on the paths. Thus propagation on extreme long-paths improved because, with winter in the northern hemisphere, the sun was at a lower angle in the sky when LP opened. Indeed, the "reach" of ELP signals into Europe became greater, shifting from the Crimea, the Ukraine, and the Balkans in the spring/summer season into western and northern Europe, say west to the British Isles and north into Scandinavia.

During the fall/winter season, ionospheric absorption increased particularly on paths across the Indian Ocean. While contacts were made with Mauritius (3B8), Reunion Island (FR5), and the like in the first month after the autumnal equinox, they soon came to a halt and did not begin again until a month before the spring equinox. Those paths are in the polar category, and the same experience was true with paths to India and Sri Lanka, in the auroral zone category. The reason, of course, is that with the start of the spring/summer season in the southern hemisphere the paths from northwest USA to those regions became illuminated, and signal strengths reduced to a vanishing level because of the ionospheric absorption.

The statistics in Table 8 also suggest a deterioration of propagation on paths in the auroral zone category. With the exception of paths to India and Sri Lanka just discussed above, the remainder of the paths in Table 2 are to Crozet Island and locations in southern Africa. The case of Crozet Island is a special one, especially with the frequent presence of FT4WC on the band and then followed by cessation of his operations in November '91.

Now a review of my log shows that contacts with southern Africa did decrease during the fall/winter season but not cease altogether like with stations in the Indian Ocean area. More specifically, contacts with southern Africa were made at an average rate of one per day in the first and last months of the fall/winter season and at about half that rate during the intervening four months. But the contacts were not marginal since there seemed to be no significant decrease in signal strength over the entire period. That being the case, one has to look for other reasons than the onset of ionospheric absorption, particularly during that period since paths from the Northwest to Africa were in darkness except at the two ends.

Several factors come to mind in explaining the decrease of contacts to southern Africa, some physical in nature and others of human origin. From the physical standpoint, there is the question as to the extent to which summer weather conditions affect amateur activity in the southern parts of Africa. That region, along with South America and East Indies, has an extremely high seasonal rate of occurrence of thunderstorms. If nothing else, electrical storms at the rate of one every day or two would surely be intimidating, particularly with regard to the safety of electronic equipment connected to ungrounded antennas or the power lines.

That aspect is local to particular times, regions, and topographies. Something of a broader nature is the radio noise generated by electrical storms. Global studies of the distribution of noise have divided areas of the earth according to zones, 1 through 5. The regions most distant from thunderstorm areas and which receive little atmospheric radio noise by skywave propagation are classified as zone 1. By that classification scheme, regions where thunderstorm activity is most frequent are in zones 4 and 5. In that regard, southern Africa lies within zone 4 during the months of December, January, and February.

In addition to the zone in which a receiving station is located, another important item is the radio frequency distribution of atmospheric noise [*Davies,* 1990] with the time of day. The general features of the distribution distinguish between daytime and nighttime, and there are finer differences according to zone and local times. But the essential features show a high level of noise around 14 MHz, day or night, for zone 4 regions. Thus the smaller number of contacts with stations in southern Africa may find some explanation in thunderstorm activity and the radio noise or static crashes that are propagated in from surrounding regions. Indeed, this is attested to by recent accounts [*DX Magazine*, April, 1992] of DXpeditions to southern Africa, say Malawi.

As for human factors, it should be noted that the distribution of LP contacts shown in Figure 1 shifts to later times in UTC with the onset of the fall/winter season. In that regard, I have a suspicion that not all DX operators are aware of that shift and do not adjust their operating hours accordingly. I say that since in the course of this study I had occasion to be called frequently, almost on a schedule, by an operator in Africa. He always called me just when LP began to open up here and signals were growing in strength. It was with some difficulty that I got him to shift to a later time. Thus, if operators did not understand the need to shift operating times with season, they would find LP propagation deteriorating at the same time of day and come to the erroneous conclusion that LP propagation was closing for the season.

Also, the shift of LP to later times in the fall/winter season brings the time of LP openings closer to the dinner hour in Africa. In addition, there is the matter of personal comfort in the hot, humid climate along the coastal regions near the Tropic of Capricorn. While I have no first hand experience in the matter, I would think that sitting on the veranda, sipping a glass of iced tea, would have its attractions in the late afternoon, perhaps even more than operating on 20-meter CW looking for LP contacts into North America.

All in all, I can find no plausible explanation in pure ionospheric terms for the smaller number of contacts with southern Africa during the period from November to February. I have to leave it there, leaning toward the thunderstorm explanation, but would be interested in learning the views of others on the matter. For me the effect is real but puzzling.

To bring this section to a conclusion, earlier a negative correlation between LP and magnetic activity was mentioned. However, the data in Tables 7 and 8 show that ionospheric absorption can be a factor, depending on the paths involved. Thus, in examining the question of a negative correlation, one should look at specific paths, as free of absorption effects as possible and with a large data sample. This will be done in the next section, using auroral zone paths in the spring/summer and extreme long paths in the fall/winter season. Of course, the results obtained apply only to paths from the Pacific Northwest.

A related question, the effect of magnetic activity on sub-auroral zone paths is examined. That was carried out for the spring/summer season also. Since such paths were not possible from this location, the effects of magnetic activity were determined by reconstructing the spring/summer season using other amateurs' log data for sub-auroral paths between South Africa and Southern California.

3.2 Statistical Aspects of LP and Magnetic Activity

The previous discussion did not bring out in a quantitative fashion the effect of magnetic activity although the data entries in Tables 7 and 8 suggested an anti-correlation between LP propagation and magnetic activity. That idea is not new, by any means, ionospheric disturbances having long been associated with geomagnetic storming. But it has been more a matter of impressions than one having any sort of quantitative basis.

Now one can start with "impressions" with the present database, showing how the fraction of QSO's on the various paths compare with the fractions of days with differing levels of geomagnetic disturbance. Before doing that, however, it should be noted that for amateur radio purposes long-path propagation is measured by the ability to make such contacts on a given day. Indeed, making LP contacts in the course of time means that we may use the daily rate of making contacts as the measure for our analysis.

But the actual rates used in examining LP propagation may be influenced by many factors, not the least of which is operating style. Thus the least "impressionistic" variable or measure of LP propagation would be a quantity or rate which is simple enough as not to be affected significantly by operating style, say some minimum number of contacts per LP session which amounts to something like a "Yes-No" statement.

If one broadens the use of the database to the actual numbers of contacts per day or LP session, then some restrictions should be put on the method, say using only data from a particular type of path. Beyond that, the data should be limited to a single ionospheric season because of the size of the sample. For example, the extreme long-path contacts in the fall/winter season lend themselves to a statistical analysis because of their large number; that cannot be said for those on that path in the spring/summer season.

And there are other factors that should be kept in mind, not the least of which is the competitive circumstances for contacts with a given type of path or ionospheric season. This concern applies particularly to the spring/summer season where contacts into the Indian Ocean were highly competitive. Thus it would be a major error to try any sort of analysis with that portion of the database as the numbers are small and the results would be influenced by factors which are difficult to evaluate. On the other hand, competition for contacts with Europe in the fall/winter season was essentially non-existent, and that large database can be used in a statistical analysis with a minimum of concern about external bias or unusual influences from operating style.

With those caveats, let's proceed to look at the database from different perspectives. First, consider Figure 11 which gives the percentage of days of different levels of magnetic disturbance and the percentage of contacts in the spring/summer season on the three different types of paths. There, for example, it is seen that during quiet conditions (Ap 10 or less), the percentage (39%) of QSO's completed on auroral zone paths is out of proportion to the percentage (28%) of days of magnetic quiet. At the other extreme, for storm conditions (Ap greater than 50), one sees the percentage (2%) of QSO's completed is considerably less than the percentage (8%) of days with those conditions.

From that one can conclude there is some cross-over point or level of magnetic activity at which propagation begins to suffer. But that approach only deals with apparent success and ignores failure as well as real success, the complement of failure. In the next few paragraphs, that will be corrected using methods which range from simple to sophisticated.

As a first step, consider the following which is based on elementary probability considerations. Thus we will make use of those data entries in Tables 7 and 8 but in a rather simplified form. In particular, for each range of Ap let's use two values of a variable, either $Q = 0$ for failure or $Q = 1$ for success in LP propagation.

Thus $Q = 0$ will be used for those days when no contact was made during an LP session while $Q = 1$ is used for days when one or more contacts were made. For the 0–10 range of Ap in the auroral zone part