TROPICAL BAND PROPAGATION FROM ASIA

The Long and the Short of It

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Editor's Note:

The following is the third major article published in Proceedings dedicated to unraveling some of the mysteries of Tropical Band propagation. The first two of these were co-authored by David Clark and John Bryant (*Proceedings 1990* and *Proceedings 1991*).

For this edition, we have asked Tony Ward, VE3NO, to join David in this continuation of the series. Tony is a native of New Zealand and brings Southern Hemisphere DXing experience to bear on our discussions. Further, as a world class Low Band amateur radio DXer and contester, Tony's "two-way" experience adds some insights into this complex subject that are otherwise difficult for the SWBC DXing fraternity to access.

INTRODUCTION AND REVIEW

We have chosen to build on the thoughts advanced in earlier *Proceedings* by Bryant and Clark, beginning with their 1990 "Notes on Tropical Band Propagation" (Bryant and Clark, 1990) and their "Additional Notes on Tropical Band Propagation" (Bryant and Clark, 1991a), as well as their follow-up series on "Tropical Band Dawn and Dusk Enhancements" that appeared in the pages of NASWA's *Journal*. (Bryant and Clark, 1991b) These articles were complemented by Bill Tippett's "Long Path and Skewed Path Propagation on the Lower Frequencies" which also appeared in *Proceedings 1991*. (Tippett, 1991)

As noted in the original *Proceedings* article, the major literature to that time comprised three volumes: *Ionospheric Radio Propagation*, published by the US Dept. of Commerce in 1962, *The Shortwave Propagation Handbook* (Jacobs and Cohen, 1979 and revised) and *Low-Band DXing*. (Devoldere, 1987) None of these are wholly satisfactory for today's needs. Devoldere's treatment of propagation was marginal to a broader purpose, and the other works focus more on strong signal "normal" modes of propagation of greater interest to professionals than the weak ephemeral signals that are the building blocks of the Tropical Band DXers' interest. Thus the 1990 benchmark study saw a move away from the traditional modes of propagation favoured by broadcasting engineers, and a heightened interest in less mainstream theory --- such as Blanarovich's "conduction" concept put forth as early as 1980. (Blanarovich, 1980)

A worthy addition to the major literature came after the release the aforementioned 1990/1991 articles. This was *The Ionosphere: Communications, Surveillance, and Direction Finding* by Leo F. McNamara, who for some years was associated with the Australian Government IPS Radio and Space Services. (McNamara, 1991) This very readable and profusely illustrated work was a useful reference to us in the preparation of this article. Very recently, McNamara has released a follow-up text, *Radio Amateurs' Guide to the Ionosphere.* Although we have not yet obtained a copy, the book was the subject of a highly favorable review by Bob Brown in the August, 1994 issue of *Worldradio* magazine. (Brown, 1994) We understand that the content of the first nine chapters is virtually unchanged from the 1991 text but a new chapter dealing with the use of propagation prediction programs has been added.

Finally, we should mention Bob Brown's own *Long-Path Propagation: A Study of Long-Path Propagation in Solar Cycle 22.* (Brown, 1992) While Bob's exhaustive, yearlong analysis of openings from the West Coast was based on his two-way contacts on 20 meter CW, it provides a frame of reference for comparison and contrast with longpath openings of interest to us on the Tropical Bands.

The traditional models of propagation are covered in the major literature cited above and in volumes from the ARRL and RSGB, so readers are referred to these sources for the terminology and theory. We will concentrate on those topics to which we feel we can make a new contribution, with a respectful if sometimes cursory nod to previous work.

Tony brings to the discussion an even more fully developed skepticism about the traditional multi-hop propagation model --- particularly as it applies to the low-bands --- than did Bryant and Clark in 1990. Further advances in understanding await the development of a bigger data bank of reception norms. Amateur radio operators have known for years that midwinter late afternoon 20 and 40 meter openings were on the longpath, and that this switched to the shortpath soon after dusk. The wider adoption of terminated directional antennas by SWBC DXers over the last ten years has permitted a closer look at this phenomenon on the Tropical Bands. The single most pressing need for further improvement in the understanding presented here is probably clear data on the vertical angle of signal launch and arrival at our receivers. The engineering literature remains concerned primarily with short and intermediate haul high and medium angle modes primarily. We comment briefly here but also refer you to Tony's stand-alone antenna article elsewhere in this edition of *Proceedings*.

As recounted by Bryant and Clark in the 1990 and 1991 articles, the acceptance of the importance of experiments by Appleton and other early researchers put in place the conventional multi-hop model of long-distance propagation that remained unchallenged for many years. This model, we suggest, may successfully account for little beyond the intermediate distances on HF. In fact by 1977 it was recognized by many broadcast professionals that the multi-hop model was seriously flawed as it applied to trans-global paths --- between Germany and Australia initially. (Hortenbach and Rogler, 1979) This also lead in 1978 to the adoption by the ITU/CCIR of a second model that has come to enjoy various names, such as "chordal hop" or "whispering gallery" for example. (ITU/CCIR, 1978) This brought the mechanism of twilight ionospheric tilt into play, and we will further develop some of those ideas here. Bryant and Clark also pointed out that beyond 6250 miles from the transmitter signals should actually *increase* as a consequence of ray convergence as the antipodal point is approached. We will take this work on spherical ray convergence to its ultimate manifestation --- specifically commenting on "antipodal focus" as it is far more readily observed from New Zealand than from North America.

Bryant and Clark also established a taxonomy of four major reception situations defined on the basis of sunrise (SR) and sunset (SS) at the receiver and transmitter that involve twilight at one end of the path only. These "partial darkness" paths were cited in addition to the conventional Grayline condition, with twilight along the entire path. We remain comfortable with this division and also with the more restricted definition of grayline adopted in 1990 too. The actual *causes* of these different modes are complex and compound but the scheme above remains useful, and we shall continue to use it as a framework in this article. While paths enjoying full darkness at both ends undoubtedly exist, they are of so little importance to the long-haul low-band DXer that we are paying little attention to them here. Again, this topic is dealt with in the 1990 and 1991 treatments. We have continued the emphasis on seasonality and the importance of twilight at either or both path ends, further codifying and refining the concepts.

As we move away from the feeling that we can quickly understand the propagation mechanics between transmitter and receiver for DX signals, the simple taxonomy remains attractive for two main reasons: 1) it works --- i.e. it is simple, comprehensible, and comprehensive, and 2) it doesn't paint us into any corners when we try to refine understanding of the modes of propagation involved. These are *not* simple and in many cases we now believe them to be of compound nature.

To illustrate our findings we have endeavored to refer, where appropriate, to the experiences of DXers living elsewhere in North America. David also has some feel for the West Coast situation based on his several DXpeditions with John Bryant, Nick Hall-Patch and Guy Atkins. Still, we must rely primarily on our more extensive experience in DXing Tropical Band Asians from Eastern North America (ECNA). Tony's "Down Under" experiences add the point of view of someone who has spent many hours at the dials near the other end of the path.

For all the attempts to provide mathematically satisfying modelling for ionospheric behavior, in 1994 we believe it remains a rather black art. And this is particularly true for the signals that SWBC DXers, as distinct from SWLs, are interested in. From ECNA, Asian openings in particular are typically short and sweet, and the most exciting DX opportunities are often to be found when least expected by conventional wisdom.

OVERVIEW OF SOLAR TERRESTRIAL ASPECTS

In previous *Proceedings* articles on long distance Tropical Band radio propagation, the influences of the sun have been essentially ignored. This was because we and all other radio people are still largely baffled as to the direct cause and effect relationship between particularly good DX conditions and specific occurrences on the sun. This is reflected, for example, in the energetic debate professionals in the field of solar astrophysics are conducting on the relationships among solar flares, geomagnetic storms and ionospheric storms.

As Bob Brown, NM7M, discusses in his article in this edition of *Proceedings*, a whole second era of ionospheric study began with our ability to launch satellite-born instruments. The mysteries of the ionosphere and its interaction with radio waves, especially at Tropical Band frequencies, are very much continuing areas of study.

So for this third article in the 'Trop Prop' series, we considered it important to address certain of the most important solar terrestrial aspects which apparently do relate to our ability to hear (sometimes dramatically enhanced!) or not hear particular signals under varying propagation conditions. It is true that many of the cause and effect relationships are uncertain or unknown, even among professionals in the field. However, as serious hobbyists, we have come to recognize certain probability patterns which if nothing else, we hope will augment the knowledge and improve the DX results for ourselves and other Tropical Band enthusiasts.

In addition to the major literature, we refer readers to Gary Oler's *Understanding Solar Terrestrial Reports: Part I - Morphological Analysis of Phenomena* which we found to be a useful reference in the preparation of this section. (Oler, 1991) We have also been fortunate to bring to this article some of the most recent research in the field. Thanks to the good offices of Dr. J Hruska, Chief Forecaster at the Geomagnetic Lab at the Geophysics Division of the Geological Survey of Canada in Ottawa, David was able to receive the 3-volume set of *Proceedings* of the international Solar Terrestrial Predictions Workshop - IV which was held in Ottawa, Canada, on May 18-22, 1992. Specific references are cited in the text which follows.

THE SUNSPOT CYCLE

We begin with the longer term solar cycles. Almost everyone is familiar with the average 11 year solar cycle, a phenomenon whereby a "quiet" sun with minimal sunspot activity becomes increasingly "active" over a 3-4 year period until it reaches a maximum. Thereafter, a more gradual decline in sunspot activity occurs, over an average period of about 7 years, until the next minimum is reached. The present Cycle 22 is well-advanced in its declining phase towards a solar minimum which will mark the beginning of Cycle 23. This minimum is currently expected to be reached at about mid-1996. Superimposed on the 11 year pattern is a 22 year cycle in which the magnetic polarity of the solar poles reverses sign.

It is very difficult to determine exactly when the peaks and valleys of the sunspot cycle occur. It is tracked in two ways: first, based on a moving average of the observed sunspot numbers and secondly, by the monthly level of solar flux or so-called "radio noise" measured at earth in the 2800 MHz band. There is a close correlation between the sunspot number and the 2800 MHz solar flux. Thus a high flux level, which may briefly exceed 300 during sunspot maximum, indicates a high level of solar (sunspot) activity. Flux levels of about 70 or less typify little or no sunspot activity during the transition from one cycle to the next at solar minimum.

The fundamental importance of the solar cycle, as manifest in the level of sunspot activity, is that sunspots are the primary source of enhanced ultraviolet radiation. This EUV radiation is responsible for the atmospheric ionization which, in turn, makes possible the skywave propagation of HF signals. As a general rule, the greater the sunspot activity, the greater is the degree of ionization and thus the capacity to reflect/refract increasingly higher shortwave frequencies. During periods of high sunspot activity the Maximum Usable Frequency (MUF) for daylight paths often rises above 30 MHz, sometimes even into the 6 meter amateur band above 50 MHz.

In terms of absolute signal strength potential, however, there is a limit to the benefit of increased ionospheric ionization since absorption by the more densely ionized E and F2-layers also increases. The daytime F1 and F2-layers merge into a single F-layer during the hours of darkness. The effect of recombination beginning after sunset making for a weaker ionosphere on nighttime paths, of course, results in a decrease in MUF's. Nighttime MUF's occasionally drop down into the range of Tropical Band frequencies during winter nights near sunspot minima.

For the most part, the nighttime MUF will remain above Tropical Band frequencies. The fact that as the frequency in question drops further below the MUF, the rate of absorption increases inversely with the square of the frequency is, however, potentially very relevant to Tropical Band DXers. A combination of increased absorption and higher background atmospheric noise ultimately defines the Lowest Usable Frequency (LUF). Excluding the twilight periods, it would be rare for the nighttime LUF to be higher than Tropical Band frequencies. One might think that the level of absorption implied by the wide differential between the Tropical Band frequencies and the nighttime MUF (especially near sunspot maxima) would all but eliminate long distance signal paths at say 90 meters, as is often the implication using propagation prediction programs. Most Medium Wave DXers would concur that trans-Atlantic and trans-Pacific propagation is far better during sunspot minimum. At the Tropical Band frequencies of present interest, fortunately, this predicted very poor propagation near solar maximum is not borne out in actual practice. Our all-important twilight or partial darkness paths are of special note because the implied LUF is often above 5 MHz (especially during approaching sunset at the receiver) and yet the Asian paths --- both short and long --- certainly remain viable, even at sunspot maximum.

Independent of the solar cycle, there is also a seasonal aspect associated with the intensity of ionization of the F2-layer. For reasons which are not understood, as far as we know, a given level of solar flux results in a much greater density (i.e. ionization) of the F2 layer during the spring and fall equinoctial periods, implying higher MUF's. (Dunphy, 1993) This would suggest greater levels of absorption at the much lower Tropical Band frequencies. For the same level of solar flux, F2 layer density is appreciably less at the summer and winter solstices, thus implying lower MUF's at Tropical frequencies. This phenomenon may contribute to the conventional wisdom that HF openings (both shortpath and longpath) between the Northern and Southern Hemispheres peak during the equinoctial periods, when critical frequencies and ionospheric conditions are more consistent throughout the world.

But again, we have no basis for suggesting the higher equinoctial MUF's are in some way unfavorable to propagation down at Tropical Band frequencies. On the contrary, from ECNA for example, the equinoxes are considered "prime time" for morning shortpath openings, given relatively quiet geomagnetic conditions, to Australasia and Eastern Indonesia.

SUNSPOTS AND SOLAR FLARES

Enough about MUF's and LUF's relative to the long term solar cycle! Most of the time they're just not terribly relevant or meaningful to those of us concentrating on Tropical Band DX reception, whether from Asia or elsewhere. Of much greater import are the terrestrial effects on ionospheric propagation arising from solar phenomena during various periods of the solar cycle. Let's begin with sunspots themselves.

Sunspots as seen from Earth appear on the Photosphere which is the lowest of the three layers of the sun's atmosphere, and is the "surface" of the sun as viewed in visible light. Above the Photosphere is the Chromosphere, which is a pinkish-colored band, about 2000 km thick, that appears visually during solar eclipses, or otherwise may be photographed using a Hydrogen Alpha filter. In this region of the solar atmosphere the drastic drop in particle density allows magnetic energy to dominate the physical for the first time. Above the Chromosphere we reach the highest region of the solar atmosphere, the Corona. This is the white halo seen extending many solar diameters away from the sun during solar eclipses. It has an extremely low density and is heated to extraordinarily high temperatures --- millions of degrees K --- by processes not yet understood, but which undoubtedly give it its strange properties. Certainly the heating is sufficient to raise the electron/ion plasma of the Corona above the solar-gravity escape velocity, and to produce a diffuse and variable stream of material that bathes the Solar System. This is the Solar Wind, and it has an average velocity of perhaps 400 km/s at earth distance and is responsible for the familiar dust tail of comets. Its low density and charged nature make it exquisitely susceptible to fluctuations in magnetic flux. While the Chromosphere may be the source of most flares, there is an important process originating in the Corona whereby relatively large masses of material are detached and expelled into space by spasms in the solar magnetic field.

Basically, most solar flares are short term explosions triggered by a sudden release of pent-up energy associated with the changing magnetic field of a complex sunspot region. Typical flare duration is from a few minutes to one-half hour although in extreme cases, flares may last upwards to several hours. The explosion spawning a major flare is truly immense. The most powerful, known as proton flares, have been estimated to release the energy equivalent of a 10 billion megaton bomb! Although the occurrence of flares is rather random, being directly associated with large sunspot groups they are essentially a phenomenon of periods associated with an active sun in the years approaching and during solar maximum.

Sunspots are regions of intense magnetic fields on the surface of the sun which actually originate deep within the solar mass. They rotate in the same direction and at approximately the same speed as the sun. About 27-28 days constitutes a full rotation near the solar equator and up to a week longer at the highest solar latitudes. Sunspots closer to the solar equator are more likely to have an effect on the Earth's environment when an associated solar flare erupts since these flares will more likely be pointed at the earth. Since the life-cycle of active sunspot regions may last for some weeks, the potential for recurrent effects becomes important to DXers.

Now we can examine the terrestrial effect of flares and in particular their relevance to Tropical Band DXers. Solar flares emit massive amounts of ultraviolet and X-ray radiation. The more powerful proton flares also emit copious amounts of energetic protons, as well as other particular material. Interplanetary shockwaves associated with flare emissions transport to the Earth as modulations of the Solar Wind. The intense radiation associated with a solar flare reaches the Earth at the speed of light --- about 8 minutes after the event. This "positive phase" causes a sudden increase in ionization, especially in the Equatorial Zone. While one might expect a resultant increase in MUF would adversely affect Tropical Band propagation of signals originating within or traversing the Equatorial Zone due to proportionately greater absorption at the lower frequencies, in fact the opposite seems to be the case. The reason for this situation is unknown.

High-energy protons associated with major flares are also often coupled to the Earth's atmosphere within a matter of hours by the sudden acceleration of the Solar Wind. Along the way they may seriously disrupt satellite communications, this being known as a satellite proton event. Since these protons carry their own magnetic (electrical) charge, they are influenced by intersection with the earth's magnetic field and are redirected towards the north and south geomagnetic poles. This gives rise to a Polar Cap Absorption Event (PCA) and a great increase in polar D-region ionization. Because of this enhanced absorption below the F-layer, trans-polar signal paths are likely to become unusable soon after the incidence of the flare. The dissipation of the flare-induced effects on the polar ionosphere may take several days and in the meantime, a significant geomagnetic storm may transpire.

THE MAGNETOSPHERE AND GEOMAGNETIC STORMS

As Bob Brown's article in this edition shows, the shape of the earth's magnetic field (i.e. the Magnetosphere) has been traditionally pictured like the spherical fields of a simple dipole magnet. The North and South geomagnetic poles are of opposite polarity and there is a vertical component exhibiting a "dip angle" in the lines of force. This angle increases to 90 degrees vertical at the magnetic poles. The lines of force connect over the equatorial region.

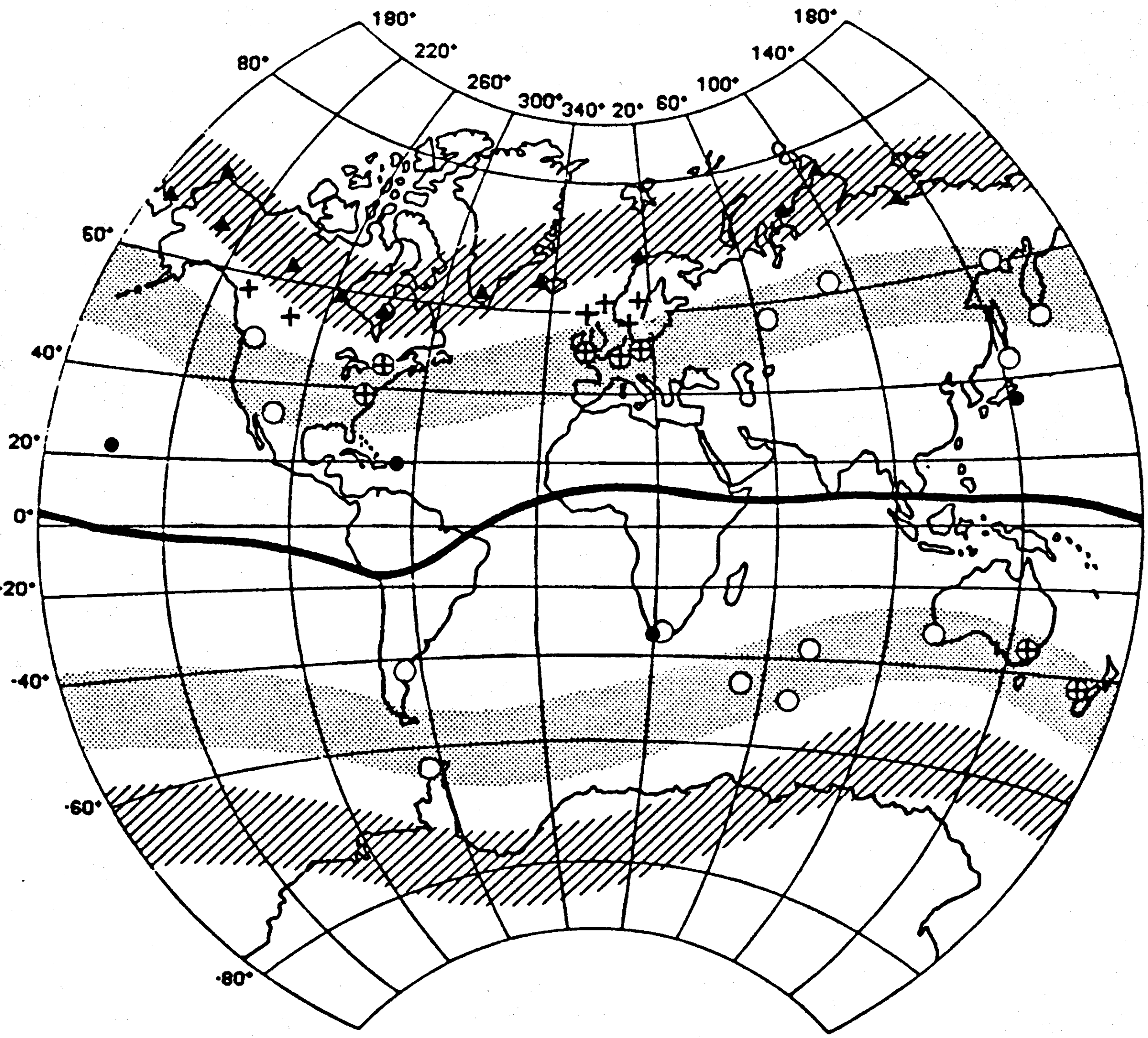

Figure 1: World Map Showing Position of Geomagnetic Equator and Average Extension of Auroral and Sub-Auroral Zones

As shown in Figure 1, the latitude of the geomagnetic (or dip) equator is variable relative to the geographic equator, in part because the magnetic poles are neither symmetrical nor constant in their position. This illustration also shows the average extension of the auroral and sub-auroral zones and the positions of stations belonging to various worldwide monitoring networks used in deriving geomagnetic indices. (Berthelier, 1992)

In reality, however, because of the persistent (though variable) pressure of the Solar Wind, the actual shape of the earth's geomagnetic field is similar to that of a comet. (Figure 2) The head of the "comet" facing the sun (and thus the Solar Wind) is called the bow shock region and it serves to protect us on earth from harmful X-ray radiation. The magnetic tail of the "comet" trails far behind the earth on the side opposite to the sun. When the speed and particle density of the Solar Wind is greatly amplified as the result of a solar flare, the shape of the geomagnetic field in the bow shock region becomes compressed. The enormously strong electrical currents thus induced in the earth's magnetosphere by this event cause a strong geomagnetic storm. (McNamara, 1991)

The geophysical effect of a solar flare is manifest normally about 36 hours after the incidence of the flare itself and thus is somewhat predictable in advance, although not all flares produce geomagnetic storms. As we shall discuss shortly, the ability to predict the potential for a geomagnetic disturbance is very important to Tropical Band DXers. As noted above, the average 27-day solar rotation is also an aspect that should be borne in mind. If a solar flare derives from a particularly active sunspot region during a given rotation when that region is facing the earth, there is a good possibility that recurrent flare effects could be experienced for at least one or sometimes several subsequent 27-day rotations.

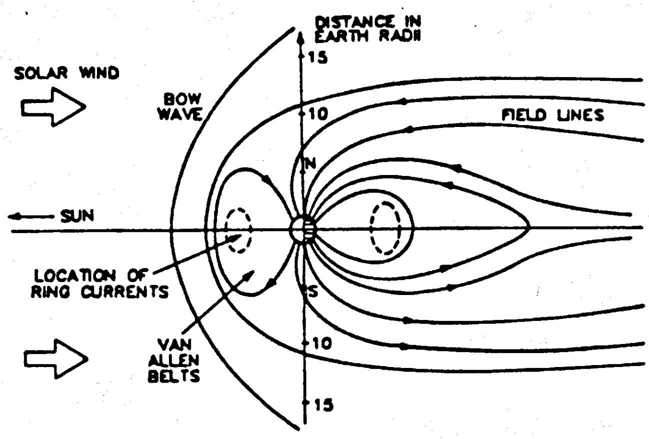

Figure 2: Simplified Diagram of Earth-Magnet in the Solar Wind seen from Equatorial Plane

If the interplanetary coupling between the magnetic fields of the sun and the earth is destined to cause a geomagnetic storm as a result of a solar flare, the sudden increase in the pressure of the Solar Wind intersecting the earth's magnetosphere will cause an increase in the horizontal component of the magnetic field. This is almost instantaneously detectable as a magnetic or "sudden" impulse. In addition, a fairly brief shortwave fade-out (SWF) on the daylight side of the earth is usually the precursor of a major storm. This is the initial phase of a "sudden commencement" geomagnetic storm as is typically associated with solar flares.

The main phase of a geomagnetic storm begins in earnest when the cloud of plasma particles released by the solar flare reaches the earth along a typically curved path likened to the trajectory of an uncoiling garden hose suddenly switched on. Arrival thus occurs sometime between 24 and 48 hours after the initial explosion. These clouds of solar particles, having their own magnetic fields, interact with the earth's magnetic field with an intensity that often results in a major geomagnetic disturbance. They initially saturate the Van Allen Belts and disrupt their associated "ring currents" whereby particles of opposite electrical charge carried by the Solar Wind flow in opposite directions around Earth at the equator. (refer again to Figure 2) Then the particle clouds are directed by the earth's magnetic lines of force toward the geomagnetic poles. As distinct from high-energy protons, these particles tend to congregate in and penetrate the ionosphere in the north and south auroral zones centered about 67 degrees geomagnetic latitude, within a zone between 60 and 75 geographic degrees N and S. The roughly oval-shaped auroral zones are where one finds the auroral electrojet of intense electric currents and these zones are associated with the strongest magnetic fluctuations anywhere in the world.

Plasma particles penetrating the ionosphere greatly increase the ionization of the E-layer in particular, often resulting in spectacular visible aurorae --- Aurora Borealis in the northern hemisphere and Aurora Australis in the southern. This phenomenon also greatly increases signal absorption and the MUF of both the E and F-layers is reduced far below usual values. This set of occurrences is referred to as an Ionospheric Storm.

Refer again to Figure 1. This illustration shows the approximate position of both the auroral and sub-auroral zones when the geomagnetic field is quiet. While the auroral zones are first and most severely affected, very strong flares with massive particle emissions can cause them to expand outward into lower latitudes, thus affecting propagation from and into the mid-latitudes. Even visible aurorae may penetrate to quite low latitudes during the most severe, albeit rare, ionospheric storms.

It seems plausible that greatly reduced MUF's may in part account for unusually strong Tropical Band signals which DXers in North America and elsewhere experience on equatorial and trans-equatorial circuits during the early phases of such storms. Examples of this sort of enhanced propagation at the outset of a storm would be seen, for instance, along direct paths between North America and Southern Africa, South America, and from Asia via the long-path.

A PCA event and subsequent auroral activity, both deriving from the effects of a strong flare, may last for several days or more. However, the largely unexplained phenomena which result in temporarily and sometimes dramatically enhanced propagation of Tropical Band signals seem to be mainly confined to the initial positive phase and/or the transitional early stages of the main phase of the geomagnetic storm. Thereafter, signal degradation seems to take hold, probably due to increased absorption, especially in the E-layer. During the post-storm recovery phase, which may last for several days, Tropical Band openings are usually less than inspiring. If anything, the higher frequencies seem to recover faster.

For many years, solar astrophysicists have generally acknowledged that the vast majority of flares do not produce geomagnetic or ionospheric storms. However, at least some of the most severe geomagnetic storms have been recorded in association with very powerful proton flares during periods of high solar activity. DXers who have had the good fortune to be listening near the advent of such events have experienced some spectacular reception, especially on the Tropical Bands. That experience seems indisputable. However, very recent research based on monitoring of solar terrestrial events by the Japanese Yohkoh satellite discounts the importance of solar flares as the direct cause of geomagnetic storms. Reporting to a December 1993 meeting of the American Geophysical Union, Jack Gosling, of the Los Alamos National Obervatory, asserts that Coronal Mass Ejections (CME's), which are sometimes followed by flares, are the real culprit. Like flares, CME's are caused by violent shifting of the sun's magnetic field but emanate from the Corona, not

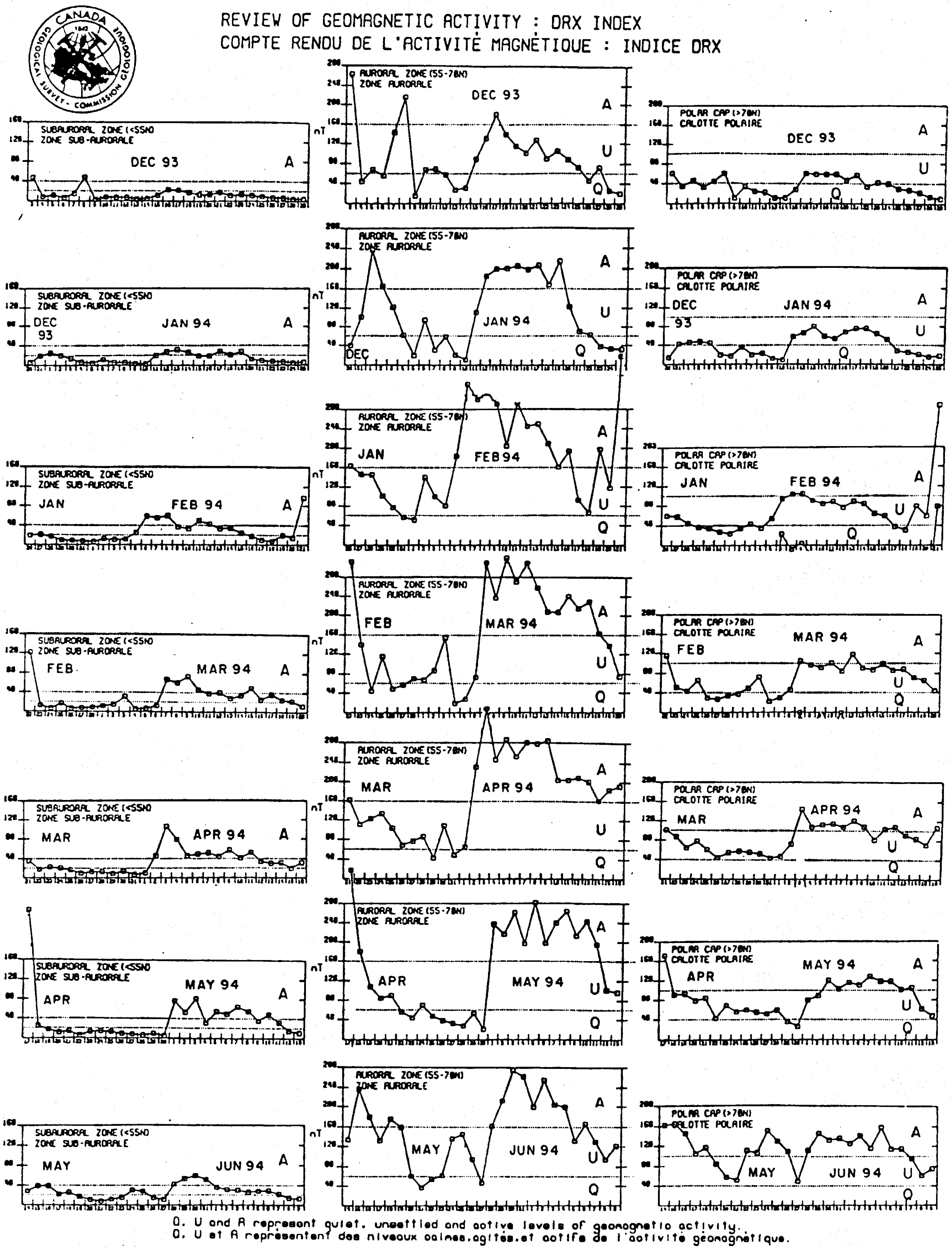

FIGURE 3: REVIEW OF GEOMAGNETIC ACTIVITY (DRX INDEX): DECEMBER. 1993 TO JUNE. 1994

the Photosphere with which sunspots are associated. Massive quantities of gas particles also join the interplanetary Solar Wind. In about one-third of the cases they generate a shock event followed by particle penetration in the auroral zones, similar to the terrestrial effects that have been ascribed to major flares. Like flares, the incidence of CME's is more pronounced during solar maxima. During the peak of the present Cycle 22, Gosling attributes all but one of the 37 largest geomagnetic storms to shock waves driven by CME's. (*Sky & Telescope*, 1994)

We have examined solar flares from the perspective of their dependence on sunspots (their incidence peaking towards sunspot maximum) and generally described the characteristics of a geomagnetic disturbance. CME's are now being described as the more relevant and "distinctly different phenomena" but either way, their geophysical effects at Earth are similar. This is the important point because however incongruous it may seem, there is a rather predictable, beneficial temporary impact on Tropical Band propagation. But what of the years of solar minimum when solar flares by their very origin and nature are exceedingly rare and CME's are also few and far between?

THE SITUATION AT SOLAR MINIMUM

Geomagnetic activity during the years of solar minima was not well understood until the 1970's when satellite exploration of the sun yielded a much better knowledge of the solar atmosphere, in particular the Corona, described above, which is an important source of large amounts of both EUV and X-ray radiation. The Corona is punctuated by occasional areas of much lower radiation which are called coronal holes, and we turn attention now to these.

Space exploration by the Skylab satellite enabled scientists to learn that coronal holes are particular areas of the Corona where the magnetic field lines of the sun are "open" or extending into space instead of arching back towards the sun. Large quantities of charged particles are able to escape through these holes, following the magnetic field lines into space and eventually becoming part of the Solar Wind. Coronal holes tend to form near the sun's polar regions and expand or migrate towards the solar equator. It has also been established within the last five years that persistent, high speed solar wind streams "from large scale structures of the coronal field" (including coronal holes) are characteristic of the period around solar minima and contribute significantly to recurrent effects. (Simon and Legrand, 1992)

Upon reaching the earth's atmosphere, the high-speed particle streams carried by the Solar Wind may intersect the earth's orbital plane. This can cause increased geomagnetic activity, especially in the auroral zones, and result in geomagnetic storms. Such storms, deriving from coronal holes, are not generally characterized by an initial sudden magnetic impulse as with flares and CME's but rather they tend to begin gradually and are thus referred to as "gradual commencement" events.

So, in contrast to sunspot numbers and the more significant CME events, the incidence of coronal holes and other structures associated with the Corona is concentrated towards and at solar minimum when their life cycles may last over a number of solar rotations. As a result, recurrent geomagnetic disturbances are much more prevalent though usually less severe, than the sudden and randomly incident storms associated with solar flares or CME's.

Commencing in December, 1993 and continuing through the first half of 1994, shortwave listeners and SWBC DXers experienced a dramatic example of the recurrent influence of a favorably positioned coronal hole. At about 27-day intervals for seven consecutive solar rotations, significant long-duration disturbances plagued shortwave propagation on the higher frequencies. Each geomagnetic disturbance exhibited a very sharp initial peak, followed by up to two weeks of continuing active conditions. Figure 3 provides a graphical review of the magnetic activity during this period, as recorded in the sub-auroral, auroral, and polar cap regions by the Canadian Magnetic Observatory Network. This network is operated by the Geophysics Division of the Geological Survey of Canada based at Ottawa, Ontario. (J. Hruska, 1994) Tropical Band conditions tended to be erratic too, but trans-equatorial propagational enhancements were typically in evidence during the commencement phases of each storm.

Just as MUF's have been found to vary with the season, there is also a seasonal aspect to the incidence of geomagnetic disturbances. Statistically, the vast majority of geomagnetic disturbances deriving from both solar flares or CME's, and those caused by coronal hole effects, occur during the equinoxes. Comparatively minimal activity is found at the solstices.

DC: I have not personally analyzed this aspect relative to the solar cycle to draw any definitive conclusions. However, I can say that in my experience over the past ten years or so of actively DXing "afternoon Asians", the equinox shoulder months of October and February have been found to yield some of the best skewed, longpath openings to western Indonesia (notably Sumatra) at the onset of geomagnetic storms.

SUMMARY AND EXAMPLE

The lessons we can derive from an appreciation of the relationship between solar terrestrial events and Tropical Band DXing success are quite simple, even though precise understanding may elude us. The most dramatic enhancements are likely to be associated with major flares or Coronal Mass Ejections towards sunspot maximum but one must be in the right place at the right time to catch the initial positive phase and the transition immediately preceding the main stage of a major storm. Towards solar minimum, propagation enhancements associated with coronal holes and persistently greater Solar Wind velocity may be somewhat less dramatic but recurrent patterns are more predictable and one can plan ahead of time to be at the receiver in anticipation of just such a positive effect. Figure 4 summarizes the distribution of various manifestations of solar activity and their relationship to the incidence of forms of geomagnetic disturbances through the duration of a typical solar cycle. Notice that recurrent effects '1' are predominant at solar minimum 'm'. Fluctuating geomagnetic activity '2' is characterized by a broad head and shoulders pattern across the years of solar maximum 'M'. The less frequent and random intense short duration periods associated with sudden commencement shock events '3' exhibit a similar pattern, peaking near solar maximum. The lower portion of the graphic shows the average distribution of geomagnetically quiet days. (Simon and Legrand, 1992) Finally, we should recognize that, superimposed on the long term solar cycle, is the seasonal propensity for geomagnetic storms to occur most often during the spring and fall equinoctial periods and least often near the winter and summer solstices.

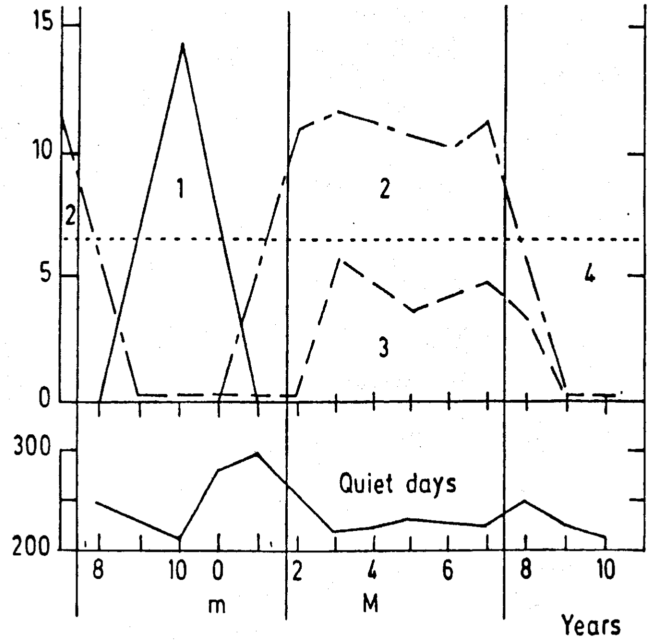

Figure 4: Average Distribution of the Components of Geomagnetic Activity during the Sunspot Cycle

As the following example illustrates, geomagnetic and ionospheric storms are often responsible for the temporarily enhanced propagation of long distance Tropical Band signals. This is sometimes along apparently direct (great circle) paths, but also frequently along skewed or bent Non Great Circle (NGC) short and long paths between Asia and North America. Longpath enhancements tend to be the most dramatic. This is at variance with the conventional wisdom which generally associates normal paths with multi-hop propagation along great circle bearings, usually short path, during periods of quiet (low A/K) conditions.

TRANSITIONAL ENHANCEMENT: THE JANUARY 11, 1994 EXAMPLE

For a few weeks centered on the winter solstice, a grayline path extends southeast from Ontario at a bearing of about 150 degrees (Figure 5), across the equatorial zone, passing through the South Atlantic Anomaly (sketched), then just tangent to the eastern extremity of Antarctica and up into Eastern Indonesia. The path is almost perfectly centered on Ujung Pandang in Sulawesi but the grayline zone extends as far east as Irian Jaya. The direct (great circle) longpath to Irian Jaya skirts just outside the southern auroral zone during quiet conditions and the path is usually optimum when the geomagnetic field has been settled for several days and the ionosphere is not 'depressed'.

As we discuss in a later section, Irian Jaya stations generally do not respond to a geomagnetic disturbance. In other words, they do not seem to propagate well, whether shortpath in the mornings or longpath in the afternoons. But we have known them to make a better than average showing during the initial positive phase and sometimes early into the transitional phase associated with the onset of a geomagnetic storm. By comparison, "classic" transitional longpath afternoon enhancements are associated with Southeast Asian signals originating further to the west, from whence their direct path would clearly intersect the southern auroral zone. The apparent skew of these longpath signals around the periphery of an expanding auroral zone then becomes obvious.

Logging afternoon extreme Eastern Indonesians (Irian Jaya/Maluku) during the short, mid-winter window, is no mean feat, even from ECNA. As contrasted with the powerful signals from Ujung Pandang, the implied grayline condition does not render especially good signals and when the hets do rise in sufficient strength to give up some audio, this may last for as little as five or ten minutes and rarely more than fifteen or twenty. Of course it must be recognized that a number of the relatively limited selection of target transmitters are of only 1 kW power or less. The interesting thing about the Irian Jayan peaks is that they occur 15-30 minutes *before* sunset at the receiver, and *at*, and up to fifteen minutes *after* sunrise at the transmitter. This pattern fits within a rule of thumb half-hour duration associated with the so-called "width" of the grayline at equatorial latitudes. Even so, since skywave absorption increases rapidly after sunrise, one might have expected the peak to occur slightly earlier --- towards the approach of transmitter sunrise, rather than immediately after. West of Ujung Pandang the midwinter pattern is in fact reversed. Signals peak 15-30 minutes *before* transmitter sunrise at which time it is already well past sunset at our receivers in Ontario.

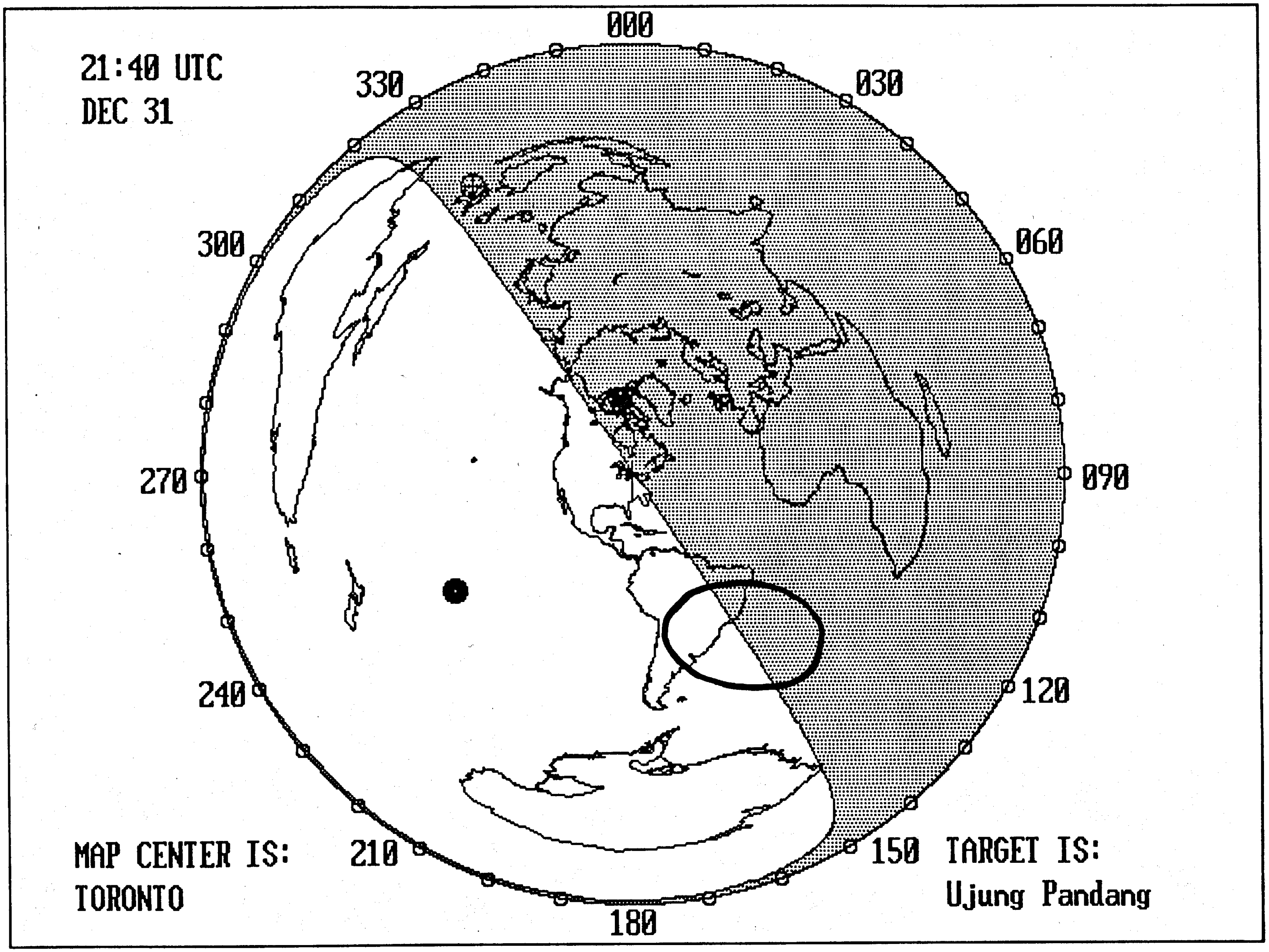

FIGURE 5: AZIMUTHAL-EQUIDISTANT MAP CENTERED ON TORONTO, ONTARIO, SHOWING POSITION OF GRAYLINE AT TORONTO 2140 UTC DEC 31 AND PATH TO DX TARGET AT UJUNG PANDANG. SULAWESI (MAP GENERATED BY DXAID V4)

Now that we've set the stage, we take you back to January 11, 1994. As it happened, both Tony and David were at the dials that midwinter afternoon. Their experience that day is quite notable. Eastern Indonesians were dramatically enhanced as might be expected to occur during the positive phase. Western Indonesians and other Southeast Asian signals were excellent too, as is typical of an enhanced longpath opening to Southeast Asia at the very onset of a geomagnetic disturbance which derived in this case from a large favorably positioned coronal hole.

TW: *This day I'm home at my suburban home near Toronto to take a look at the tropicals. At noon from school a quick check of WWV at 18 past the hour promised an ionospheric storm, and I'm anxious to see whether the promise will be fulfilled. It's a quarter to four --- 2045 UTC --- and two hours before local sunset the band is hopping with African signals on the Southeast long-wire I have selected. But I am after bigger game, and have the R8's memories preset to the elusive Irian stations. A fair challenge on the morning short-path are they, but I just know that under the right conditions I can get more than the faint carrier I have heard on the afternoon opening so far this season. The solstice is past, and time running out for this particular sport.*

It's early, but the whisper of a signal is there already on 4789.7 and an even fainter hint of Sorong on 4874.5. As the magic moment just before the hour approaches I concentrate on the stronger of the two and YES. The lilting refrain of "The Song of the Coconut Islands" fills my ears. Success! Perhaps merely by remoteness made exotic; Fak Fak! The tune resonates within me with the overlay of years of musical memories! The needle on the R8 hits S5, as the news from Djakarta fills my ears...but now I'm after the building signal of Sorong and down on 3385 Kupang promises to break through! Thirty minutes later they are in the log with the best audio I have ever got from them. What wonder how exciting the local news can be in a language I have no understanding of at all. But the lilting rhythm of the Malay tongue is unmistakable, and the village choir's voices leap around the globe in some strange way that I will try and fathom later. Right now it's keep the tape whirring and listen for the jumbled ID phrases. I follow the sun-up across the other side of the globe... Ujung Pandang (4753.3) is 20db over 9 an hour later...what a day for the books! The sun is 30 minutes gone below my horizon, and somewhere a giant hand pulls the great switch in the sky. UJ goes from local copy to a memory in minutes, but Kupang is a new one for me...and that will fade much more slowly from the mind...

DC: *Tony's experience that afternoon affords a hint of the DX-citement we associate with chasing winter long-path Asians on the Tropical Bands when geomagnetic conditions are turning from quiet to active or even disturbed. In this particular case, Tony must have broken away from the dials for an early supper, about the same time as I was tuning in at my rural property north of Toronto. Clearly I missed a superior Eastern Indonesian opening and those are pretty rare. But as he tuned out the fading Ujung Pandang a bit past 2200, I found that the Sumatrans and other nearby peninsular Southeast Asians were just coming up nicely! Let's check the records: yesterday, January 10, 1994, Planetary A index was a very quiet 04 but by 1800 this day of the 11th, the real-time K index had jumped up to a value of 5, indicating a sudden onset of disturbed conditions (refer again to Figure 3). Very interesting...and we are not surprised.*

MODES OF PROPAGATION

CONVENTIONAL:

The conventional model of multi-hop propagation of radio waves has been cited in our Introduction and Review and is dealt with by Bryant and Clark in their 1990 paper. That dawn signals often rise smoothly and magnificently to enhanced levels with their flutter and fading characteristics unaltered (except that the signal is stronger) argues most powerfully against multi-modal reception as the cause of the dawn peak. Yet most theories attempting to explain the phenomenon fall back on such approaches. Radio News in 1930 published an early version of ionospheric tilt as a cause, for example. The basic postulate of that article was that at dawn ionospheric tilt focussed the second and third hops at the receiver simultaneously, enhancing received signal levels. But this implies the existence of a sharp transitional phase with extreme fading, and this is not seen. Similarly a later theory saw multi-hop signals arriving simultaneously in a subtractive mode in which out-of-phase behavior produced weak signal levels. As the D-layer built up with the approach of day, higher angle skips would be lost first, leaving the lower-angle and stronger skips. These would be further enhanced by the subtractive effect. This theory fails on the same grounds as above.

Some variant on ionospheric tilting does seem however a likely candidate for at least some kinds of dawn/dusk enhancement. A major observation that is explained by both this approach, and that of Blanarovich (discussed below) is that while stations at each end of twilight paths experience the enhancement at dawn and dusk respectively stations at intermediate points along possible paths do not. Thus hams in New Zealand use sunset to talk to European stations experiencing near-dawn conditions on almost any of the HF bands, during almost any season. Tony relates a low-band tale that illustrates this mode in rather dramatic operation.

TW: *I well recall being the net in a three-way celestial ping-pong match involving the legendary Bob Tanner, ZL2BT. (Figure 6a, 6b) Bob was the first, and so far the only ham, to confirm two-way contact with 300 countries on 75 meters. He operated from Longburn, near Palmerston North, New Zealand, with a range of antennas over the years, but latterly a two element cubical quad with the top wire at about 135 feet on a home-built tower was his main sky-hook.*

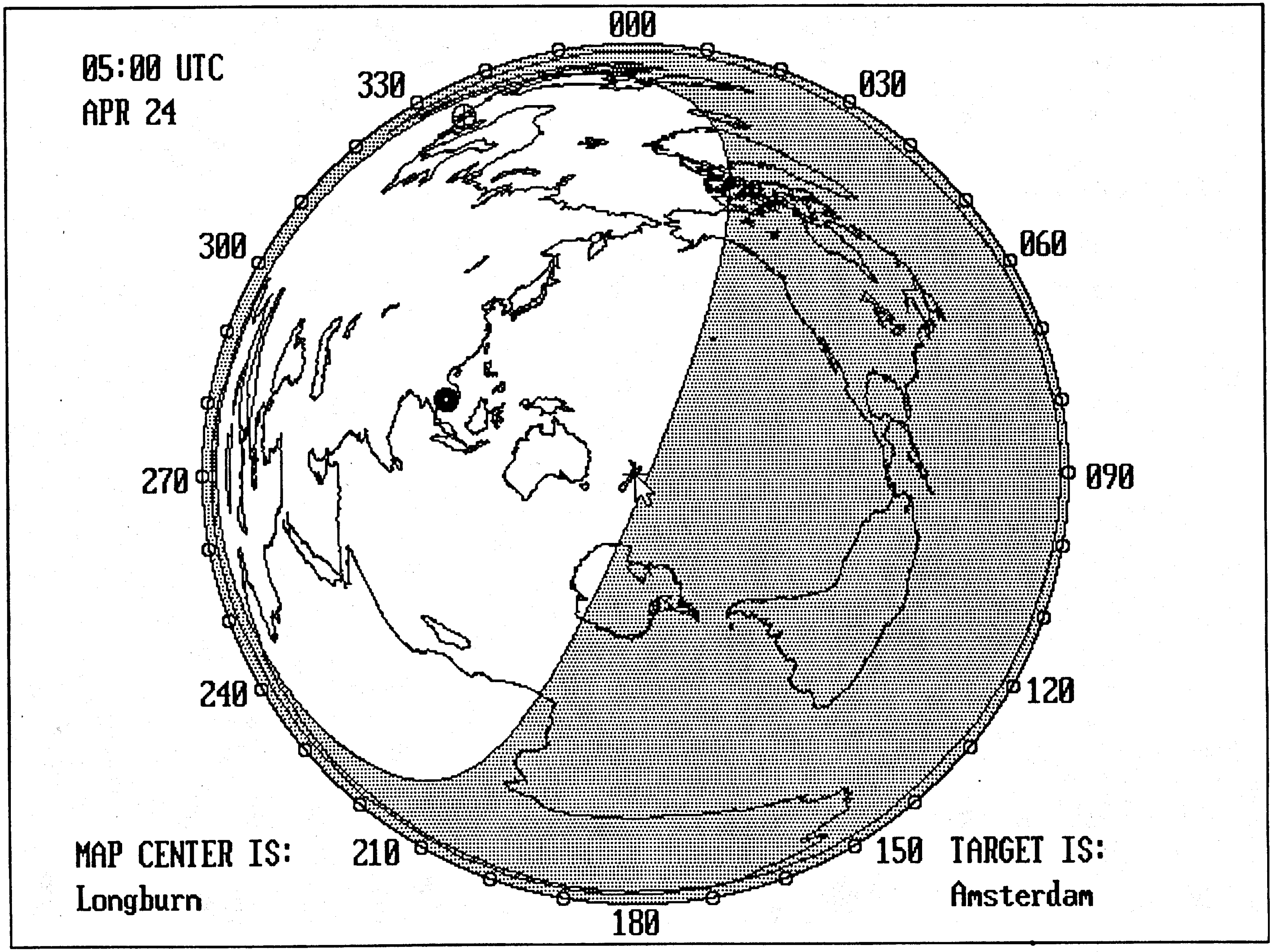

FIGURE 6A: AZIMUTHAL-EQUIDISTANT MAP CENTERED ON LONGBURN, NEW ZEALAND, SHOWING 0500 UTC APRIL 24 POSITION OF GRAYLINE AND PATH TO DX TARGET AT AMSTERDAM (MAP GENERATED USING DXAID V4)

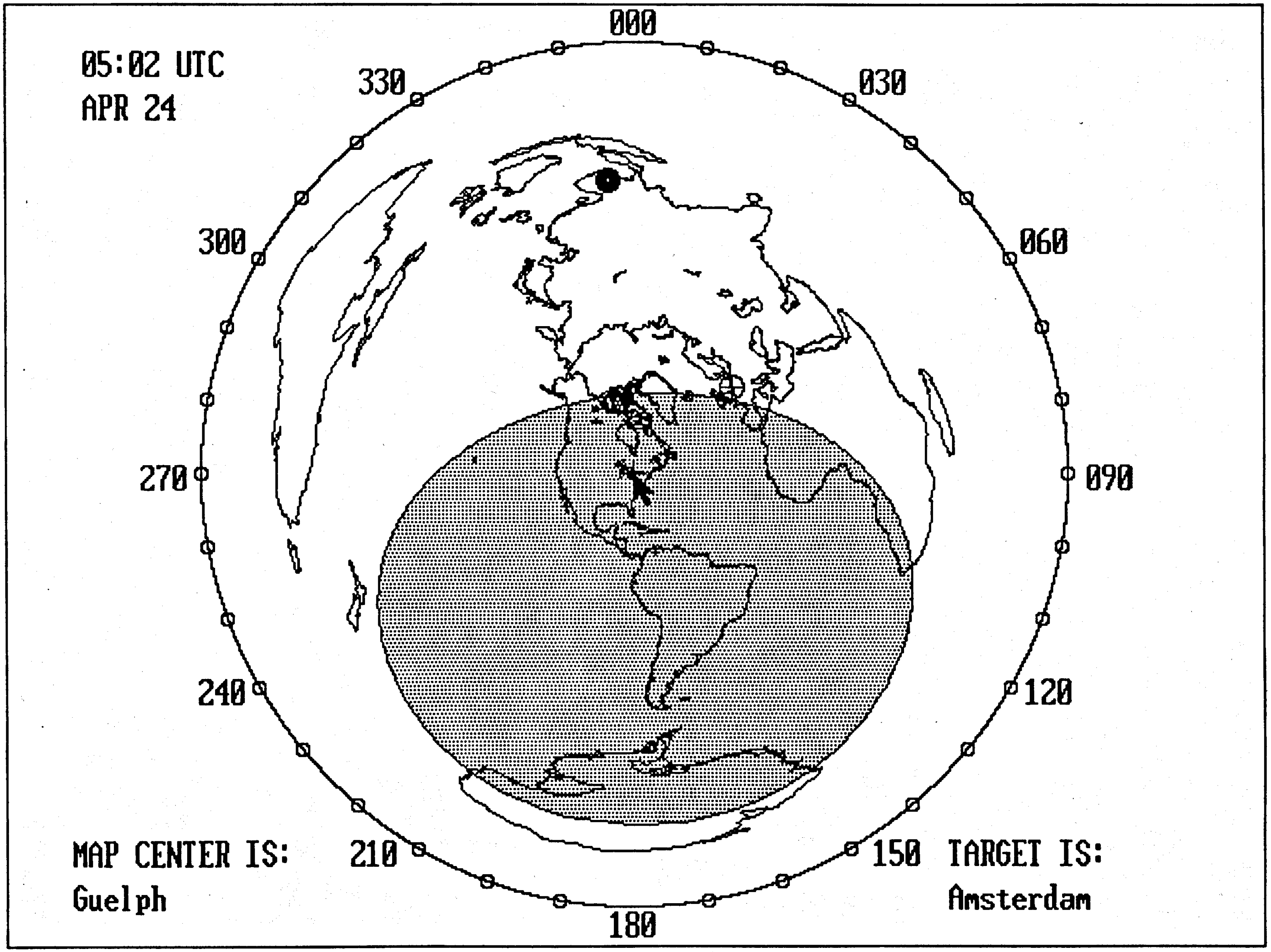

FIGURE 6B: AZIMUTHAL-EQUIDISTANT MAP CENTERED ON GUELPH, ONTARIO, SHOWING 0502 UTC APRIL 24 POSITION OF GRAYLINE AND PATH TO DX TARGET AT AMSTERDAM (MAP GENERATED USING DXAID V4)

Late one April evening, as local Ontario midnight approached, I engaged a Dutch station in voice conversation on 3795 kHz from my rural site near Guelph, Ontario. We had fairly good signal strength with each other --- about S9. Shortly after we started the conversation Bob joined in. He reported to Paul (in Holland) that he was hearing me at about S7. Paul and Bob were about S9+20dB with each other. I could hear not a whisper from Bob. As his sunset approached however he first appeared as a weak and watery signal, and then built steadily and rapidly to well over S9! This took a total of about 20 minutes. My signal report from Bob climbed from S7 to S9 + 20 dB in the same period. It is tempting to consider that Bob's signal initially passed right over my head skidding or ducting along the base of the ionosphere en route to Holland during the first 10 minutes of the strange three-way. As the influence of the steadily lowering D-layer at either end of the path made itself felt Bob and Paul were able to maintain contact easily using dusk/dawn high-angle enhancement. My low-angle radiating antenna --- a broad-side bidirectional delta loop at 100 feet --- provided good output, but was not able to intercept Bob's overhead signal until conditions changed to a more conventional path, a little later. At around this time, Paul's signal started to drop rapidly with Bob, as daylight advanced on him. At no time did ground stations in South America join the dialogue, confirming a phenomenon well known to both low-band hams, and to tropical band DXers. The signals were circling the globe at high elevation, unheard on the ground along the dark path, except for my participation, as discussed above. Operating from New Zealand myself on the low bands, I can recall remarkably few instances when simultaneous signals were received from both Europe and either of the Americas.

NON-CONVENTIONAL MODELS:

While the exact mechanism by which the signals pass from the dawn to the dusk end of the path is not yet known to us, speculation has centered on variants of chordal hop, or of a kind of whispering gallery mechanism. Yuri Blanorovich, VE3BMV, has offered another explanation in the previously referenced CQ magazine article and most accessible in Bryant & Clark's 1990 article.

As a super-active contest operator, Blanarovich has had ample opportunity to sample the behavior of the HF ionosphere under a wide range of conditions. He feels very strongly that we have been misled by the conventional diagrams of ionospheric height above the earth into accepting the traditional multi-hop mode. He favors a fibre-optic model in which "A majority of the radio waves are refracted and propagated --- conducted --- along the borders of media with different dialectric constants and are accompanied by scintillation." (Blanarovich, 1980) Scintillation is produced by the cloud-like nature of the propagating medium whose density and conductivity varies in time and space. It produces back and side-scatter and these effects show up in the watery nature of many received signals under suboptimal conditions. He relates improvement in higher frequency signal strengths during high sunspot number years to the higher average heights of the refracting/conducting medium. Longpath and grayline propagation are as easily explained with this model as shortpath. Radio amateurs have an obvious advantage over SWBC DXers in tackling the thorny problem of one-way propagation and here again, a conductive model provides a useful perspective. Light exiting a fibre-optic conductor scintillates and disperses in a fashion that is difficult to envisage in reverse. Daily here in Eastern North America --- particularly on 40 meters --- loud European signals can be heard each afternoon, but it is nearly impossible to get them to respond. No doubt this is why Kupang failed to hear my joyful shouts at finally receiving them on the afternoon longpath!

Bob Eldridge, VE7BS, became an enthusiastic supporter of Yuri's ducting concept and made some interesting follow-up observations, citing other supporting works. (Eldridge, 1989) He traces the introduction of the term *refraction* as a replacement for or adjunct to the use of the more traditional *reflection* in amateur radio and official publications, particularly post WWII. In fact the family of modes implied by use of the term chordal hop and others was well-established by 1959 when the CCIR published a report citing chordal hop, whispering gallery and ionospheric ducting (ITU/CCIR, 1959). This report in turn was founded on earlier referenced sources. All agreed that long distance single-hop transmission was possible without intermediate ground reflections. So in fact we are arguing over the exact mechanism rather than the phenomenon itself!

Hortenbach and Rogler of Deutsche Welle published the landmark chordal hop theory paper in 1979, although they in turn quoted earlier sources from the 1950's. (Hortenbach and Rogler, 1979) Waves launched at very low angles are guided by the lower boundary of the ionosphere (which acts as a single walled duct) rather than reflecting back to earth. Refer to Bryant and Clark's 1991 paper for illustrations. When dawn and dusk occur at ends of the path the tilts in the ionosphere resulting from its greater height in the dark hemisphere create the conditions necessary for initiating chordal-hop modes.

In addition, the concept of the "Sweet Spot" was first advanced by Bryant and Clark in 1990 and further developed in their 1991 article. The Sweet Spot can be characterized as a particular variety of "partial darkness" (receiver sunrise/transmitter in post-SS darkness) propagation. The basic finding was that there was good evidence that Tropical Band signals from the Pacific and Asia tended to peak at North American dawn when it was approximately 9:00 PM local time at the transmitter. This pattern was tied by the authors to the phenomenon of spread-F, ionospheric irregularities which peak about mid-evening and are most predominate in equatorial latitudes. Further investigation published in their 1991

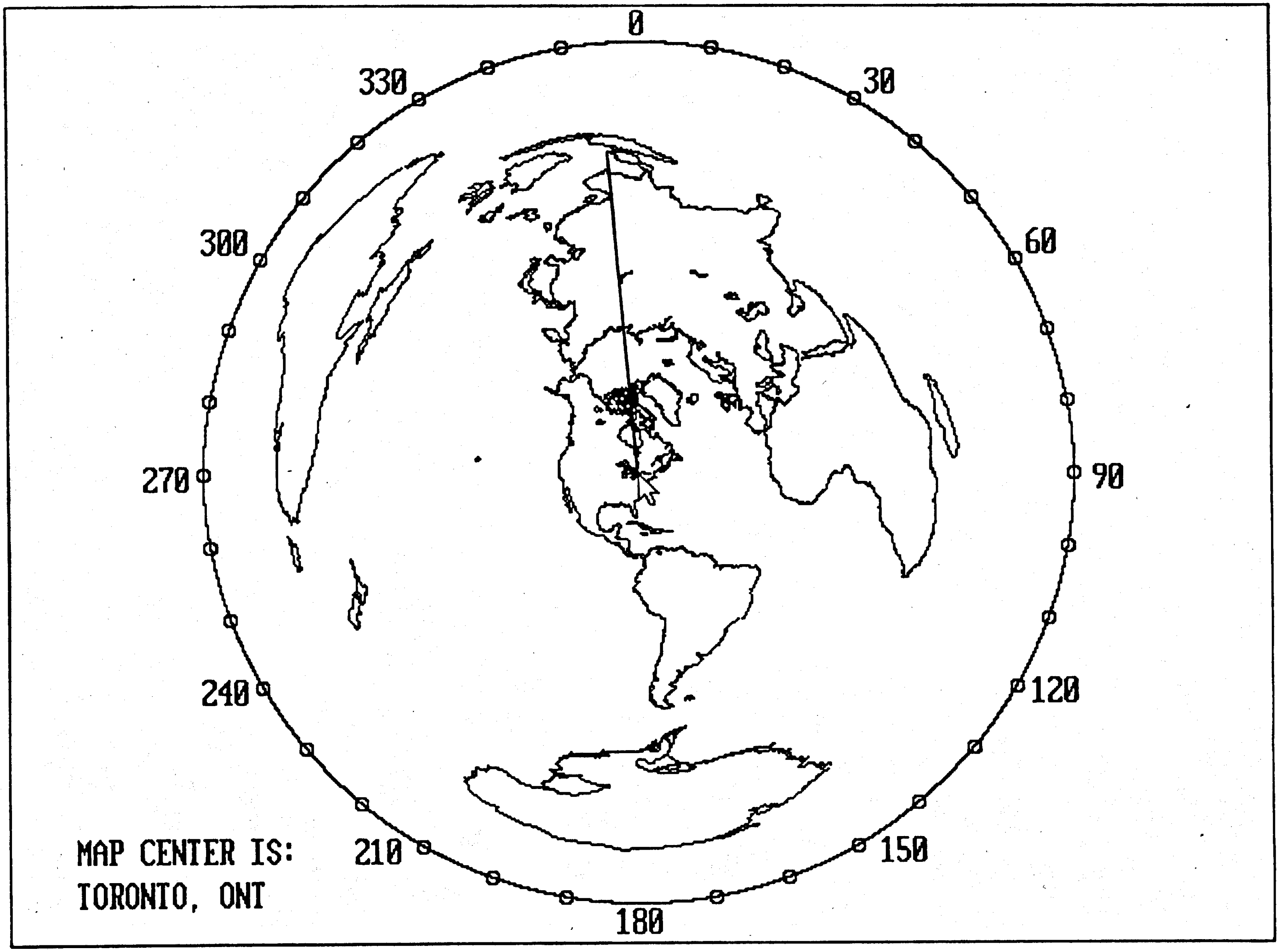

FIGURE 7: AZIMUTHAL-EQUIDISTANT MAP CENTERED ON TORONTO. ONTARIO (MAP GENERATED USING DXAID V2)

article indicated that under some circumstances, such as midwinter in the Northern Hemisphere, the peak could be closer to 8:00 PM. Since those findings were published, Bryant and Clark, as well as Guy Atkins, have all reported numerous occasions while DXing from the West Coast which confirm the consistency of this peak, even at different seasons. We have not attempted to advance the Sweet Spot concept further in this present work but continue to encourage DXers suitably located to review the literature, do their listening, and publish their observations.

GREAT CIRCLE AND NON GREAT CIRCLE SHORT PATHS

The "normal path" of an HF signal is conventionally understood to be the short great circle path between any transmitter and receiver pair. That path is clearly demonstrated on an azimuthal-equidistant map centered on the location of the receiver. (Figure 7) Be aware that the currently understood position of the North Geomagnetic Pole (NMP) is near 79 degrees N, 104 degrees W and the South Geomagnetic Pole (SMP) is near 66 degrees S, 139 degrees E. (National Geographic, 1992)

For Southeast Asia, if we consider the meridian position of Singapore as roughly dividing South Asia to the west and Australasia to the east, it can be seen that the implied "normal" path (sketched) to Southern Ontario (Toronto and vicinity where both David and Tony reside) is only about 5 degrees west of true North and just slightly east of the NMP. This means that the direct signal path is straight over the polar cap, intersecting the northern auroral ring at virtually a 90 degree angle, and crossing the entire disturbance zone situated between the latitudes of 60 and 75 degrees N on both the Asian and North American sides of the pole. Under quiet geomagnetic conditions, signals from Asian transmitter sites adjacent to Singapore and throughout much of Southeast Asia will also intersect the auroral ring on a short path to Eastern North America. But because we in Ontario are situated directly "under" the auroral oval, consider the much greater dispersion of Asian transmitter sites from which our reception would be affected when geomagnetic conditions are active or moderately disturbed.

On the shortpath for many of our favorite Asian DX targets, we would expect to signals to be best when geomagnetic conditions have been extremely quiet for an extended period and the auroral disturbance zone in its most contracted "normal" state. An azimuthal-equidistant map centered on Toronto implies that signals arriving from bearings between 330 degrees W and 30 degrees E could be expected to be subject to selective or flutter fading as a result of the scattering effect caused by transiting the auroral zone. Under active or disturbed conditions, this zone would widen a further 60 degrees or more.

It is indeed a nice simple picture this; quiet conditions and good reception over the shortest route. By contrast we expect disruption and increased signal absorption under geomagnetically stormy conditions. Reality turns out to be far more complex, and it is with morning reception of Southeast Asian Tropical Band signals that simple explanations start to fall apart. First: the signal breakup characteristic of paths on the higher shortwave frequencies (say 15 MHz) is simply not in evidence. Second: while quiet conditions often contribute to strong signal paths beyond the periphery of the quiet auroral zone (e.g.. PNG's and Eastern Indonesians at approximately 290 to 320 degrees W), signals from South and much of Southeast Asia, whose short great circle paths cross the northern auroral zone, are seldom at optimum levels during quiet conditions. More often than not, dawn signal enhancement occurs during the positive phase or during the transition period when the geomagnetic field is in the course of progressing from a quiet to a more active or disturbed state.

Finally, and of particular interest to us here, signals arriving at the receiver in such circumstances are usually apparently directed "around" the northern auroral zone along a Non Great Circle (NGC) route, trending northwest or even west, as "seen" on a directional antenna at the receiver. By definition the path is short, being less than 90 degrees removed from the true great circle bearing, but it is definitely seen to be "bent" or "skewed" to varying degrees off the great circle path. Bent or skewed paths from Asia to ECNA are a recurring theme throughout this article!

THE ECNA MORNING PATH FROM ASIA

The morning openings exhibit a tendency to migrate from East to West Asia and back again from autumn, through midwinter and into spring, in accordance with the seasonal migration and slope of the terminator. In some respects the converse occurs in the afternoon. Of course the N-S orientation of the dawn terminator mirrors that of the dusk terminator at the Autumnal and Vernal Equinox.

From Southern Ontario, morning signals from Singapore/Sumatra and toward the Indian Subcontinent are generally heard best on a NW beverage oriented at about 330 degrees, regardless of the position of the terminator. Strangely enough, Australasian signals that would be expected to be best on a more westerly beverage at 300 degrees are also usually strongest on the same NW antenna. During the 1991-92 and 1992-93 midwinter "Subcontinental seasons" it was observed that very often for the South Asian transmitter sites, signals were significantly superior on a Beverage pointed nearly west at 300 degrees. This is a NGC short path, rather far-removed from the NNE great circle path which was only occasionally viable under quiet conditions. This signal-bending effect was almost invariably noted when the A index was in upward transition from quiet to an unsettled to active state with an index in the range of 10-15, or sometimes higher. As we have already dwelt on at some length, "transition" is the key word. A condition whereby the short term K index was 0 or 1 at 0600 and up to 4 or even 5 by 1200 would almost invariably deliver — for that one particular morning — greatly enhanced reception, and on a path of arrival from the west, seemingly ducted well around the expanding auroral zone on the darkness side. The opening would generally last longer past "max dawn" than usual and signals exhibited none of the signatures of auroral flutter fading!

In the most recent 1993-94 season, however, the apparent arrival of the Subcontinental signals on a westerly bias was much less apparent than it was during the previous two seasons. Meanwhile, from the Midwest, John Bryant reported that the Indian signals were seldom heard at all on the shortpath. Most reception, such as it was, took place on his longpath antenna pointed SW. Indeed, there was a general consensus among Tropical Band DXers throughout North America that the 'Indian season' was without spark when compared with the prior two, especially on the 90 meter band. Perhaps all of this was related to differing MUF's associated with the rapid descent toward sunspot minimum but we really don't know. Certainly there were sufficient recurrent geomagnetic disturbances to have triggered the reception pattern we had learned by previous experience to associate with enhanced, skewed path morning reception from South Asia.

It seems possible that we (collectively) are not always using low-enough angle antennas. In other words, the Beverage antennas which had served us well may not have been as suitable for signals arriving at a different, possibly lower, angle in the most recent season. Tony erected his 'Carolina Beam' (refer to Guy Atkins' review article in this edition) in January of 1994 and noted reception of Indian stations well past local SR that were inaudible on his standard long-wires. This kept the Indian season going for him for several weeks longer than would have been the case otherwise as the terminator inexorably retreated back to the east, and eventually, even the superior low angle performance of the Carolina could do little to help.

GREAT CIRCLE AND NON GREAT CIRCLE LONG PATHS

During the primary fall, winter and early spring Tropical Band season, SWBC DXers -- especially those living in ECNA -- have come to better understand in recent years the possibilities for longpath reception from Southeast and South Asia during the late afternoon and early evening hours, and how this relates to the approach of sunrise on the Asian continent. Bill Tippett's previously cited article in *Proceedings 1991* was especially useful in opening up new vistas of understanding for many SWBC DXers. Tippett outlined the two most important Asian low-band longpath opportunities for us: the path from Southeast and South Asia in the late afternoon/early evening to Eastern North America, as well as the morning path from India and East Africa to Western North America. We would like to develop the discussion further here, with particular reference to our ECNA experience.

Enhanced openings are almost without exception associated with the transitional phase marking the onset of a significant geomagnetic disturbance. North American DXers living in the Eastern time zone and at more northerly latitudes, including the present authors, are especially well-positioned for the Southeast Asian long path.

One aspect of this that we have not yet seriously considered is our potentially favorable position in Southern Ontario relative to the 'Mid-Latitude Anomaly' discussed in Bob Brown's article. It may be that because we are situated in the sub-auroral zone and close to the steep ionospheric gradients marking the Mid-Latitude Anomaly, the apparently enhanced ducting of signals around the auroral zones is more pronounced at our 43 degree N latitude than at other locations further south, even within ECNA. The affect our position might have with respect to enhanced reception on the longpath, however, remains problematic.

While it seems plausible to associate increased geomagnetic activity with a skewing of signals around the northern or southern auroral zone, the spectacular signal strengths we sometimes experience on the afternoon longpath suggests there is an enhancement effect associated with passage across the 'Equatorial Anomaly' as well. Even the earlier literature envisages the possibility of an enhanced chordal mode (albeit in association with enhanced MUF) governed by the crests of high F-layer ionization fixed at about 15 degrees on both sides of the geomagnetic equator. It is interesting to note that the peak ionization occurs in the late afternoon (between 1700 and 1900 local time) and again in the evening (between 2000 and 2300 local time), at the equinoxes and at solar maximum. These trans-equatorial propagation (TEP) modes are known as afternoon-type and evening-type TEP respectively. We suspect that afternoon-type TEP may be an enhancement factor, even at much lower Tropical Band frequencies.

Yet-another aspect that intrigues us is that the longpath circuit from Southeast Asia apparently passes directly through the 'South Atlantic Anomaly' whose approximate position we have sketched in Figure 5. This is the zone where the contours of strength of the earth's geomagnetic field - expressed in terms of "electron gyrofrequency", are the lowest anywhere in the world. Purely in the realm of speculation, we suspect that this may, in some way, contribute to the late-afternoon signal enhancements we experience from Southeast Asia.

Whatever the confluence of circumstances, the reward is great, for typical signal strengths during a good opening from some transmitter locations are far stronger than during the traditional morning listening period.

THE ECNA AFTERNOON/EVENING PATH FROM ASIA

How does the afternoon/early evening signal path from Asia compare to the typical morning path and what are the hallmark geomagnetic circumstances? Simply stated, the typical path is not short, as for ECNA in the mornings, rather it is long path, although in most cases skewed to a greater or lesser degree from the implied great circle route. David will readily admit that he has virtually abandoned the premise advanced in Proceedings 1989 which associated short path openings during geomagnetic disturbances with enhanced propagation through the northern auroral "donut hole". (Clark, 1989) Still, rare afternoon shortpath openings continue to be observed near the equinoctial periods. But the long path is clearly dominant through the winter and, except for the most easterly paths outside the southern auroral zone, typically associated with the transitional onset of a geomagnetic disturbance.

The most westerly Indonesians (Sumatrans) begin to make an appearance by early September with the approach of the autumnal equinox and these same stations are the last to disappear after the vernal equinox in early April because of their much later sunset. Remember, the Indonesian archipelago extends some 3,000 miles and spans three time zones!

At midwinter solstice, however, the terminator is at its shallowest angle relative to both the equator and the geomagnetic equator. As we have mentioned already, this results in a near-grayline condition from Southern Ontario as far east as Irian Jaya. Unfortunately, sunrise at PNG stations is a little too early to enable even winter solstice longpath reception in ECNA. It should be noted (refer to Figure 5) that all of Antarctica is in daylight, and the terminator has reached its farthest extension away from the SMP, so absorption is at a seasonal minimum. Even so, as outlined in the preceding January 11, 1994 reception example, Irian Jaya signals are weak and usually audible only for a matter of minutes, peaking 15 to 30 minutes before our SS and at or just following SR at the transmitter. They are heard best on a southeast Beverage, although they may first appear from the East, more perpendicular to the terminator but then becoming basically parallel to the terminator on the southeast antenna at approximately 150 degrees. Openings are best during either quiet conditions or a positive phase enhancement just prior to a disturbance.

Then, through sunset, post-sunset dusk and progressively into the early evening darkness at our receivers, it is possible to receive stations strung across Central and Western Indonesia, coastal China, and the Indo-China peninsula, as the Asian sunrise terminator works its way westward towards the Subcontinent. Once the path shifts into Central Indonesia and points west, the great circle long path to ECNA now encroaches on the southern auroral zone and the Antarctic summer daylight. So, quite apart from the enhancement pattern associated with the onset of a geomagnetic disturbance, the apparent skew of the signals into a low loss twilight or darkness path around eastern Antarctica becomes pronounced. Afternoon wintertime reception is dominated by the trans-equatorial long path and is again generally heard best on a Southeast Beverage. At times the S-9+ signal strength of Ujung Pandang (presently on 4753.4 kHz) and certain Sumatran stations on both 60 and 90 meters (e.g.. Tanjung Karang-3395.1 kHz) can be outstanding given the right transitional conditions. The same holds true for quite a number of China-coast stations with CPBS2-4905 kHz the standout. Sometimes the onset of a major disturbance brings about 15 minutes of perfect armchair copy from the North Korean station on 2850 kHz. The better openings yield brief audio from rarer catches such as the only Taiwanese Tropical Band outlet, on 3335 kHz. To reiterate an earlier point, the ECNA midwinter reception peaks of Southeast Asians lying to the west of Ujung Pandang are quite at variance with the peak pattern cited above for Irian Jayans far-removed to the east. Now we find that signals peak 15 to 30 minutes prior to sunrise at the transmitter and this may correspond to 30 minutes or more past sunset at our receivers.

By way of comparison with our northerly latitude ECNA situation, DXers living in the Midwest or at more southerly latitudes in the Eastern time zone must await the trailing slope of the sunset terminator for the afternoon Asian path to open up. But for a short period at midwinter, the approach of sunset at the receiver coincides with sunrise at transmitters located in Sumatra. Somewhat limited reception is then possible, as John Bryant and others from the Midwest have reported in recent years. As far as we can tell, the onset of geomagnetic storming is still an appropriate precondition, albeit far less pronounced in its effects west of ECNA. At midwinter of the 1993-94 season, Guy Atkins, living in Seattle, recognized the advantage of favorable inclination of the approaching sunset terminator. He demonstrated that even on the West Coast it was possible to detect a signal from the western reaches of Sumatra (Medan 4765.8 kHz) at transmitter sunrise almost two hours before his local receiver sunset, as long as you were far enough north. While scratching out usable audio was a daunting task, there is no doubt about what Guy was hearing and this was truly a landmark accomplishment! Not surprisingly, Guy's several tentative logs coincided with superior openings here in Southern Ontario. If RRI Banda Aceh (3904.8 kHz) in extreme northwestern Sumatra ever returns to its traditional morning program period from 2300 s/on (inactive during the 1993-94 season), it would be another ideal target for the West Coast crowd.

After 2400 in the winter, nearly all of North America is in darkness as the sunrise terminator reaches the Indian Subcontinent. Then, in both Eastern and Central North America (with scarce reports from the West Coast), signals from India and nearby Subcontinental environs can be heard at their morning sign-on which in many cases is very close to seasonal sunrise at the transmitter.

The manner by which afternoon longpath signals may rise out of the mud to exceptionally strong, clear and steady levels seems little short of magical at times. Although openings are typically brief, the point has been made that some of these transmitters, most notably from Southeast Asia on skewed paths, simply cannot be heard as well in the mornings here in ECNA. In 1991, John Bryant visited David over the post-Christmas winter holiday period and had his first taste of the 'afternoon Indo' experience. Fortunately there were several excellent openings during his one-week stay. John observed that several Sumatran stations exhibited spectacular peak levels that rivalled the best he had ever heard them at in the morning --- shortpath of course --- from either his principal residence in Oklahoma or even from DXpedition sites on the west coast! Small wonder David has been able to lure Tony back onto the Tropical Bands to scout for the more elusive afternoon Asians.

NON-GREAT CIRCLE PROPAGATION: ADDITIONAL OBSERVATIONS

In retrospect it seems obvious that signals will travel the path of least resistance --- or lowest loss --- between transmitter and receiver. It is also apparent that this will normally be the shortest, or Great Circle path. That these two directions do not always coincide requires explanation. The effect is in evidence daily on higher frequencies, but may be just as common on lower frequencies of most interest here, though masked by the greater difficulty of accurately determining arrival direction on the Tropical Bands. Tony has long struggled towards an explanation of NGC paths and found some clues on the other side of the globe...

TW: *In 1980 I was getting set to journey on DXpedition to the Chatham Islands. These lie about 500 miles east of Christchurch at a latitude of 44 degrees S. I prepared one of my favorite DX tools. This is one of those cheap inflatable, nominally 12 inch, globes. I used one in my Auckland shack on a daily basis. It is suspended between gimbels centered at your own location, and its antipodal point. Ninety degrees from my location I had drawn a new equator, and duly labelled it with the long and short path bearings. It is the quickest and simplest way to establish the azimuth to anywhere on the globe that I know. From Auckland the long path to Britain goes due South over the pole --- close to the SMP and right through the absorption zone. Shortly after sunset each day the path loses its directional stability. On 20 meters, even with my highly successful home-brew 4 element mono-band yagi at 65 feet, signals fade, and become watery. Contact can be maintained over the transition period, which averages about 30 minutes or so duration, by maneuvering the antenna along any bearing from south all the way around to the true short path --- north of course. But on most evenings there is a 10 to 20 minute period when the best signal is to be obtained along a bearing close to 40 degrees. (Figure 8a) Though this had always puzzled me, I had no success at figuring out what was going on with this classic case of bent path propagation.*

Cut to the Chatham trip. On arrival and setup there it became obvious that the path to much of Europe in general and parts of the British Isles in particular was far better than I had ever been used to, despite the use of DXpedition antennas that were good, but in no way comparable to the hardware available at my home station. While the difference was quite marked on 20 meters, on 40 meters it was nothing short of spectacular. And five seconds with the globe disclosed that the true long path bearing to the stations of Eire, for example, was now about 30 to 40 degrees East. (Figure 8b) The puzzle pieces were falling into place. A signal in Auckland heading out over the Pacific on a bearing of 40 degrees or so was intersecting a low loss direct Great Circle path from Chatham to northwest Europe. With a relatively small change of less than 10 degrees, the signal had a low-loss ride for the rest of its journey. What ***seemed*** *to be a bent path involving a warp of nearly 40 degrees from the Great Circle route was in fact far less spectacular it turned out.*

We now believe many examples of apparently large shifts in signal direction originate similarly. Particularly in the case of routes passing through and just beyond the antipodal point, the great circle bearing can vary enormously to locations clustered quite close together. The converse is less often considered but also important. A 500 mile shift in receiver location can make a very large difference in the path to some DX targets, and in particular may, as in this Chatham example, move the great circle route out of the auroral absorption zone. Or, a convenient NGC path may open up as in the case above. The globe deceives us easily.

The significance of this is that we are seeking a mechanism to explain relatively *small* direction changes --- not apparently large diversions --- and this is not a difficult task. McNamara, for example, depicts scattering by "field-aligned irregularities" to one side of a trans-equatorial great circle path causing signal deflection. He comments further that a similar effect may occur on paths near the auroral oval. (McNamara, 1991) We are thus reminded that we have noted the AIR Madras (4990 kHz) signals often appear to be in the process of switching from long path (south from Ontario) to short path as transmitter sunrise approaches, between sign-on at 0000 and 0045, on those occasions when it is heard. We infer this from the watery reception of the relatively high-powered transmitter. In March or April, the signal may peak to the south very briefly at sign-on, fade down, and then peak up again even more strongly on a northeasterly

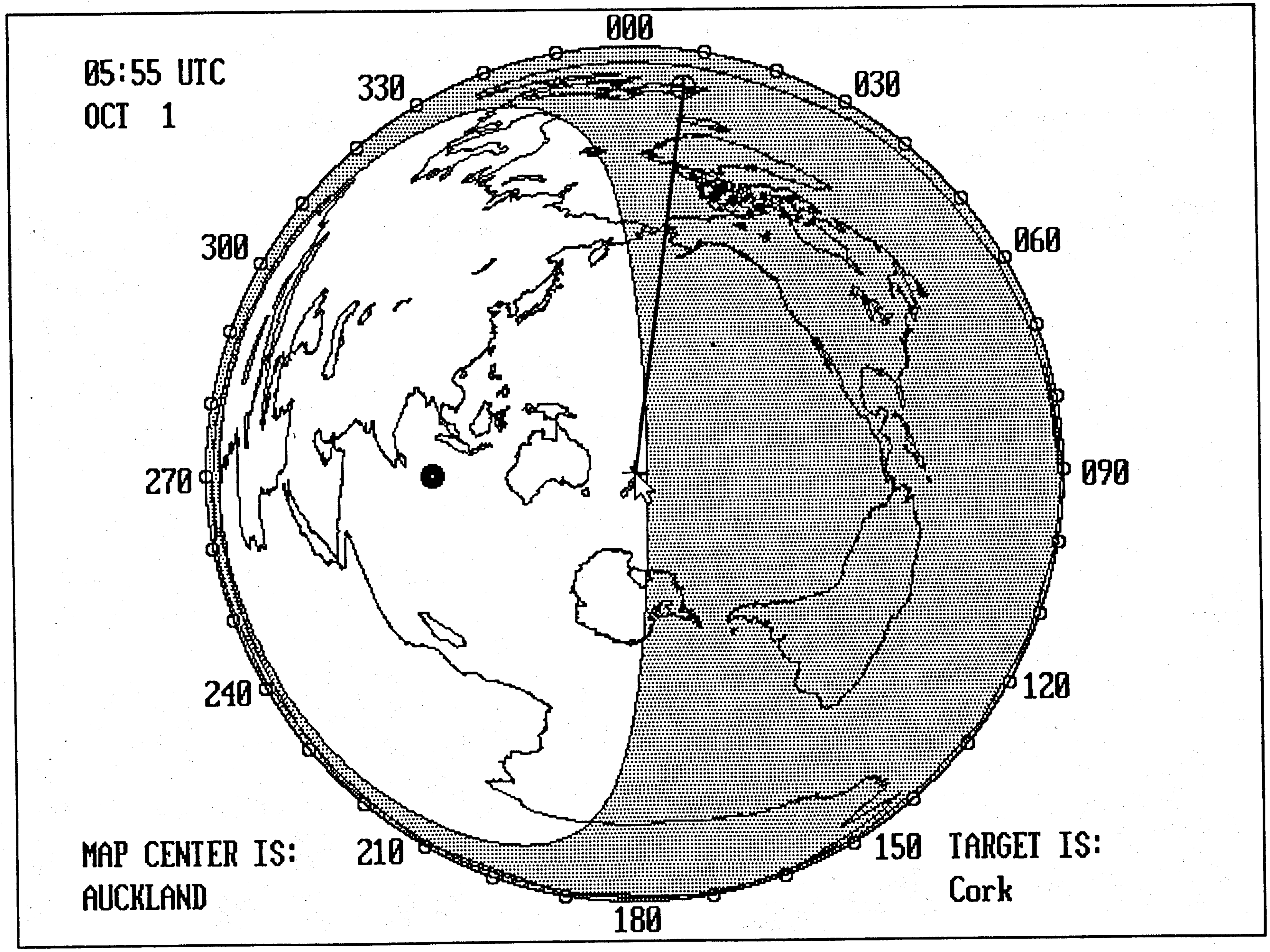

FIGURE 8A: AZIMUTHAL-EQUIDISTANT MAP CENTERED ON AUCKLAND, NEW ZEALAND, SHOWING 0555 UTC OCT 1 POSITION OF GRAYLINE AND PATH TO DX TARGET AT CORK. IRELAND (MAP GENERATED USING DXAID V4)

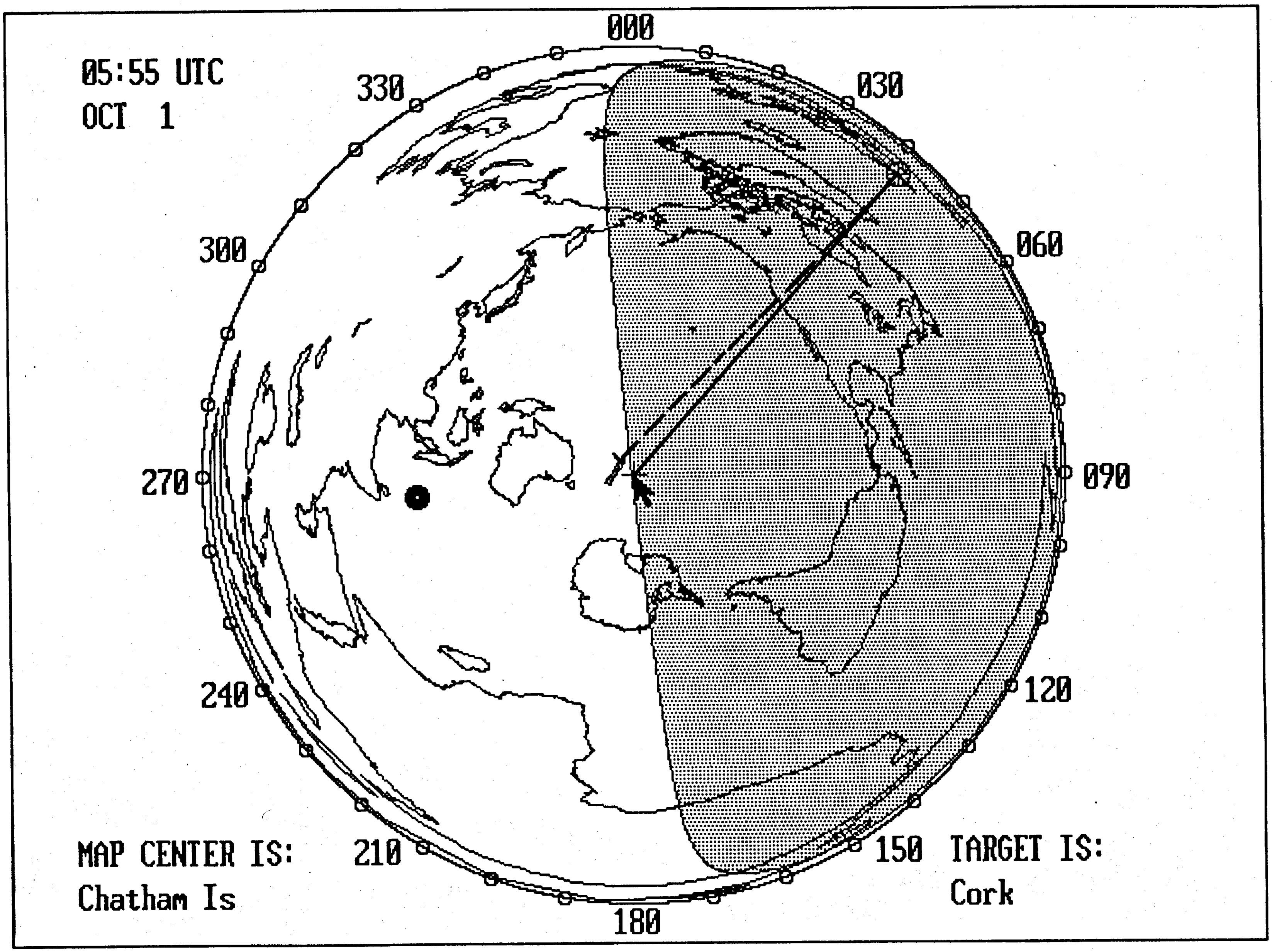

FIGURE 8B: AZIMUTHAL-EQUIDISTANT MAP CENTERED ON CHATHAM ISLANDS, SHOWING 0555 UTC POSITION OF GRAYLINE AND PATH TO DX TARGET AT CORK. IRELAND (MAP GENERATED USING DXAID V4) antenna 30 to 45 minutes later at transmitter SR. In the intervening period the signal is weak and no antenna direction seems particularly favoured. In midwinter, however, solar blanking closes Antarctica to direct signals from the Subcontinent.

Another example: near the Vernal equinox in 1994, the AIR Delhi signal on 3365 kHz exhibited several dramatic occurrences of the apparent switch from long to short path. On more than one occasion, the signal suddenly rose to S9 levels approaching 0105 transmitter SR, then faded sharply just 10 or 15 minutes later.

ANTIPODAL FOCUSSING: THE ULTIMATE IN SPHERICAL CONVERGENCE

That there is an enormous difference in the true bearing to stations not far removed from the antipodal point has been noted above. This is not immediately obvious to most of us living in North America. Most of New Zealand, however, lies directly opposite Spain, and Southern Europe. Over its one thousand miles or so extent from North to South there are quite astonishing differences in the direct paths to and from Spain, Portugal, France, and the many stations of the British Isles in particular. New Zealand hams rapidly get used to hearing their neighbors working stations that are inaudible to them.

Ever since I started DXing from New Zealand --- like David, at about the age of 10! --- I have been aware that certain areas and certain stations were particularly blessed. I was indeed puzzled that the little 1 kW 49 meter outlets that used to inhabit the Tangier special zone were remarkably easy to hear considering their low power. In fact 1 kW omnidirectional from Tangier was considerably easier than 100 kW from Munich, to pick one example. When I migrated to Medium Wave a few years later, it was a poor morning indeed that Nice on 1557 kHz could not be heard. And this was remarkably independent of the conditions on the day.

TW: *Dusk approaches, and the view from my Auckland shack window across the harbor to the setting sun is grand. My NZ call is ZL1AZV, and it gets much airing on the DX and DXpedition frequencies in these declining years of the 1970's. Tonight I swing the ICOM's electronic VFO through 3795 kHz while the tubes warm on the linear. Not much there yet, but the band sounds good, and it's early. Ahah...There's Bill, EA9EO in Melilla, North Africa calling CQ. We have talked many times on 80 meters, because he lives mere miles from my exact antipodal point and there is magic between us in the ionosphere. I run a pair of phased and switchable quarter-wave verticals with 5000 laboriously-laid feet of ground-wire underneath them. "You're not too strong tonight yet Bill, just strength 7, but perfectly in the clear". "Well you're pinning my needle at 20dB over S9 says he...by the way, I'm running the low powered rig tonight...1 watt out." "Hang on", says I, "I'll bring the Argonaut in from the car". 5 minutes later we are in earnest conversation ...ssb...1 watt output each...across half the world.*

Here in the Toronto, Ontario area we are not so fortuitously placed. Our antipodal spot is way out in the Indian Ocean (Figure 9) and we are offered few chances --- particularly away from the ham bands --- to test the character of antipodal focussing. The RRI station at Ujung Pandang is perhaps the best example we have, though focus may also benefit a few other stations in the general region at times. As noted elsewhere, the strength of Ujung Pandang's 60 meter signal is at times quite remarkable. Notice that the long path from Toronto to Sulawesi passes through our antipodal point and somewhat beyond. We think the enhancement effects associated with spherical convergence discussed extensively by Bryant and Clark in their 1990 paper are still a factor.

More than antipodal focus is of course at work here. After all, casting a 4000 Km diameter circle around UJ will encompass many other stations. But few of these also line up on the midwinter grayline at times when that path is far removed from the SMP --- currently off the shore of Antarctica south of Adelaide Australia. This seems to be another of the keys to understanding our relationship to stations on the other side of the globe. The terminator migrates rather rapidly over many of the stations of Asia as the DX season waxes and wanes, but as it moves east of Ujung in early December it starts to run out of steam before backing up to the west during January. This puts UJ in the favoured spotlight for nearly two months. David has found it convenient to recognize the path to UJ as separating two target areas --- one to the east and another to the west --- that behave quite differently at times. Looking at the longpath geometry we see that stations west of UJ can come to us directly via Antarctica only when that continent is in darkness. This is most probable on the shoulder months of the midwinter solstice. But there are times when ionospheric conditions are just right, and these stations seem to duct around the expanding auroral donut and on to us with fine signals indeed. The long path barely reaches east of the UJ line, but the excitement of afternoon West Irian openings has been conveyed above.

SUMMARY AND CONCLUSION

If it was easy we would have had it all figured out by now, and have no need to write this paper, or try to push the envelope out a little further. If it was easy most, if not all of us, would be doing something else. Imagine an electronic ear tag for signals and electronic binoculars to watch. Which way does the signal go? What does it do? How does it change direction? Not in our time...we hope.

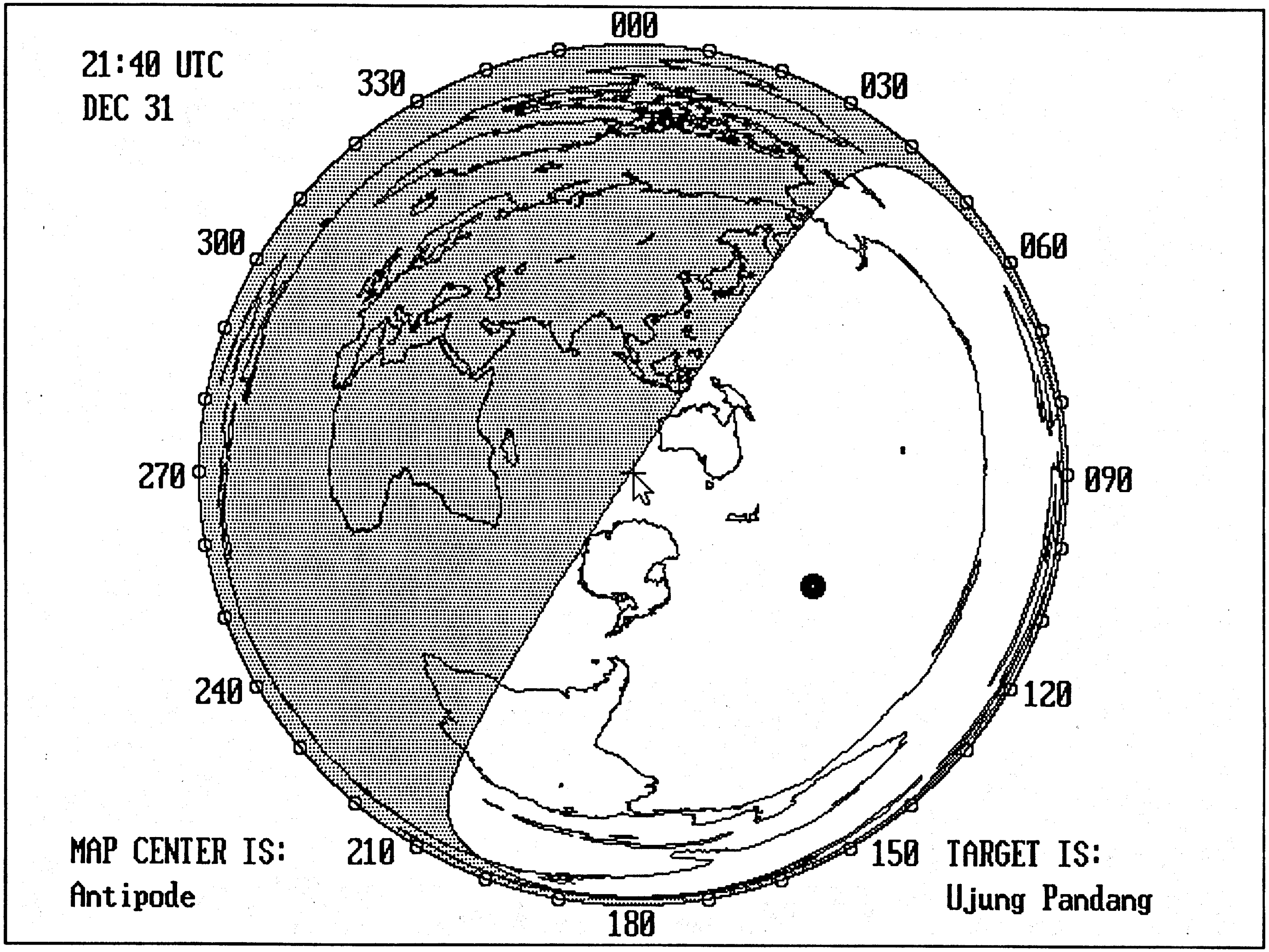

FIGURE 9: AZIMUTHAL-EQUIDISTANT MAP CENTERED ON ANTIPODE OF TORONTO, ONTARIO, SHOWING 2140 UTC DEC 31 POSITION OF GRAYLINE AND TERMINATION OF LONG PATH CIRCUIT (FROM TORONTO) FOR DX TARGET AT UJUNG PANDANG, SULAWESI (MAP GENERATED USING DXAID V4)

Another perspective; possibly the mysteries of HF, and in particular Tropical Band propagation are, like the weather, at least partially chaotic phenomena not susceptible to rigorous predictive analysis. Still, there are certain observations and empirical conclusions based primarily on recurrence that do seem valid to us:

–It is quite clear that dawn and dusk paths --- "partial darkness" paths and sometimes grayline paths --- usually render optimum propagation on the HF bands and this effect is even more apparent on the Tropical Bands. On these lower frequencies, seasonal migration of the terminator is also an important factor in reception patterns.

–Certain twilight paths generally exhibit optimum propagation during an extended period of quiet geomagnetic conditions. But the short and long great circle paths for many signals transported by the ionosphere between Asia and North America are influenced by the presence of the geomagnetic poles and, in particular, the surrounding auroral zones. With the onset of a geomagnetic or an ionospheric storm, the auroral zones become magnetically active or disturbed and apparently are the main contributing factor causing signals to adopt low loss bent or skewed (non great circle) paths which render enhanced reception. The mechanism of enhancement is not yet known but is a ripe topic for further research.

–Non great circle paths, especially long paths, seem to open up more often with the onset of a geomagnetic disturbance. This is usually when signals inaudible or very weak under "normal" circumstances, even on the short path, can be heard at astoundingly enhanced levels on the long path. There is no apparent correlation, however, as might be expected, between optimum reception on the long path and the incidence of solar minimum. If anything, there is a growing body of evidence that the converse may be the case.

–Long path signals from Asia to North America are quite possibly subject to enhancement to varying degrees in complex and compound ways by a variety of other factors, complemented by the onset of a geomagnetic disturbance. These other factors may include spherical convergence and antipodal focussing, the incidence of equatorial and/or mid-latitude spread-F, ionospheric ducting for extended distances, including across the equatorial anomaly, without intermediate, loss-inducing earth reflections, and so on. There are no easy or consistent answers.

Whatever the combination and interaction of contributing factors, signal enhancement and reception patterns on the Tropical Bands --- especially along routes between Asia and North America --- seldom, if ever, fit the mold of conventional theories of HF propagation. The field is still wide open and we, as Tropical Band DXers, can have an important and continuing role in opening up new vistas of understanding and in expanding our knowledge base. To that end, David has compiled a rather exhaustive analysis of Asian reception patterns based on his own DX listening during the 1991 through 1994 Tropical Band seasons. This study was originally intended to form an Appendix to this paper but packaging it in a form that hopefully would be a useful reference for others has proven to be a daunting task that requires more work. It is anticipated that the study will be published at a later date, possibly under the auspices of Fine Tuning's Special Publications. Availability will be announced through the usual hobby media at the appropriate time.

It is increasingly a binary world full of zeros or ones. Applied to the present endeavor this means "we hear 'em or we don't"! But lifting signals above the noise floor is a process with lots of little increments to it, and we hope you have a few more ideas that you can try for yourself than you had before. If we are to raise what we do --- as Tropical Band DXers --- to a science, we need to *understand* what we do. And we need to be able to make predictions that we can test against the real world and modify as necessary. We reiterate once more our feeling that much of the conventional wisdom in propagation research fails to adequately describe what we hear at the dials in our rather cobwebbed corner of the spectrum. But we hope we have signposted some leads to pursue for our future understanding. It is not, strictly speaking, absolutely *essential* that we understand it all of course, but it would make it even more fun than it is already. There are lessons for us all out there...if only in humility!

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APPENDIX A: SOFTWARE AIDS TO PROPAGATION STUDY

Broadcast Engineers have had available to them for some years now a number of path-prediction programs, and the increasing power of personal computers has of course made these readily available to DXers of all stripes. (Sams, 1988) Attempts have been made to apply these to the Tropical Bands with mixed results. We feel that at present mini-MUF and variants bring generally inappropriate and often hidden assumptions to the paths and frequencies of interest here. What DXers need is accurate knowledge of sunrise and sunset times at their own and target locations, and the ability to display the dynamics of path and terminator relationships about the globe. Two DOS programs admirably fit this brief, and we have used both extensively in preparing this paper, and in our DXing.

GeoClock by Joe Ahlgren is in version 6.0 at time of writing, and widely available as shareware on services such as CompuServe, or directly from the author and his own support-BBS. (Joseph R. Ahlgren, 2218 N. Tuckahoe St., Arlington, VA 22205-1946). Peter Oldfield's DXAid is now in a greatly enhanced version 4 and is available from the author. (Peter Oldfield, 251 Chemin Beaulne, Piedmont, Quebec J0R 1K0) These programs complement rather than compete with each other. Both offer accurate determination and display of the position of the terminator and hence grayline on the globe, and have sunrise/sunset information. The Ham extension to GeoClock (available separately) adds an equidistant altazimuth projection map of the globe centered at a location of your choice at time of registration --- typically your home site. The new version of DXAid has an even more powerful feature. By clicking on a chosen location on the main Mercator map of the world you can generate an equidistant azimuth map display centered on *any* location. This is a tool of obvious power in attempting to understand signal paths to distant points --- and in fact Peter was kind enough to add this marvelous feature at our request as we struggled with the preparation of this article.

Since DXAid includes a database of locations (user-editable), *and* propagation prediction routines we commend it to you; with the sole caveat noted above. GeoClock is also readily customizable and comes with a potentially enormous library of detailed maps of the globe that will suit the geographic specialist admirably. You can watch the terminator creep across West Irian in real-time as you DX (with a well-shielded computer system!) or research the exact moment to expect short-lived signal peaks from difficult targets. GeoClock also allows you to animate the display, and it is particularly useful to freeze the sunset terminator at your own location, and watch the march of the corresponding dawn on the other side of the globe, noting the changing distance of this magic line from the SMP for example. You can shift to-and-fro between detailed regional and global views in real- or virtual time at the click of a mouse.

It is difficult to overly-stress the importance of graphic visualization in attempting to understand signal paths, and propagation to distant regions. Few serious DXers are without the DX Edge (Bryant, 1988), and in some respects these two programs start where the DX Edge leaves off. After a considerable battle with a number of serious typographical errors in the published formulae, Tony adapted Devoldere's (1987) favoured algorithm for sunrise and sunset to an Excel equivalent for use with an extensive list of Tropical Band stations. This allows sorting of targets by SR or SS as these change through the seasons, and both Tony and David have found this a useful list to have at their elbows during sessions at the dials.