# NOTES ON TROPICAL BAND PROPAGATION

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## FOREWORD

In the past thirty years, there have been surprisingly few serious articles and only two "non-professional" books published which attempt to address the propagational needs/concerns of the Tropical Band DXer. There are three books familiar to many veteran DXers which form the intellectual foundation of serious propagation discussions in the radio hobby community today. They are:

* IONOSPHERIC RADIO COMMUNICATION, published in 1962, by the US Dept. of Commerce.

* THE SHORTWAVE PROPAGATION HANDBOOK, edited by Jacobs and Cohen and first published in 1979, by CQ Magazine.

* LOW BAND DXING, by ON4UN John Devoldere and published in 1986 by the ARRL.

Each of these references is highly recommended. However, for Tropical Band DXers, each suffers deficiencies. The Department of Commerce text is well written and quite understandable. Still it suffers from age, for much progress has been made in the 30 years since its publication. The Jacobs/Cohen book is also becoming rather dated. Further, the book is biased toward the upper half of the HF spectrum and little time is spent on the special characteristics of the lower shortwave frequencies. However, it is unparalleled as a beginning propagational text. The publication of LOW BAND DXING in the late 1980's did advance the state of the art but it offers only a small portion on propagation.

Tropical Band propagation (2 to 6 MHz) has been largely ignored as a research subject by governments and academia. In the years since WWII, most research interest has focused on either UHF (radar, telemetry) or VLF (military) propagation.

There is also a grand tradition in the hobby which states that professional writing and research is oriented to the "normal" propagational modes in use 90% of the time and to strong signal propagation, whereas Tropical Band DXers are interested in weak signal propagation and in the 10% of propagation that is NOT typical. The authors have come to believe that this attitude simply allowed experienced DXers to rationalize the fact that the behavior of the ionosphere, as they observed it, did not fit conventional models of ionospheric propagation. Had that tradition not existed, we all might have questioned some of the basic theoretical premises of conventional propagation sooner.

The authors do not question current theory concerning the basic refractory interaction between radio waves and a diffuse, ionized atmosphere. We note, however, that in the past decade some professionals and some members of the hobby community have come to feel that the conventional model of HF ionospheric radio propagation is, itself, badly flawed.

The purpose of this article is to bring to the hobby community current thinking as it relates to the conventional model of propagation and to begin discussions which will, we hope, lead to greater dialogue in the hobby and eventually, a more useful understanding of Tropical Band propagation. We will first "sketch" the state (as of 1990) of scientific understanding about the physical nature of the ionosphere as it affects Tropical Band propagation. Secondly, we will state the conventional view of Tropical Band Propagation as clearly and simply as possible. In our study, we have searched the literature of the other branches of the radio hobby to identify any material which could shed more light on our murky subject. We were successful and offer an article by well-known amateur radio DXer Yuri Blanarovich. Finally, we have attempted to point the way to a more useful working model of propagation for the Tropical Band enthusiast.

We would caution that this article is not intended to be an all-inclusive study of Tropical Band propagation. For example, the reader will not find an in-depth discussion of solar terrestrial aspects such as the sunspot cycle or the cause and effect of ionospheric and geomagnetic storms. Rather, attention has been focussed on the geophysical characteristics of the ionosphere and the interaction of HF radio waves between the earth and the refracting medium.

This article is structured in Sections which are intended to serve as logical building blocks from one to the next. However, due to the length and complexity of some of the material presented, we have adopted the use of "Abstracts" to summarize the central theme and content of each of the respective major Sections.

In undertaking this discussion and those sure to follow, the authors strongly encourage all parties to adopt clear definitions of several terms whose sloppy use has clouded much hobby literature. Among these is the term "graylining." Terrestrial physicists, astronomers and most amateur radio operators would agree that "grayline propagation" is the proper term only when BOTH the transmitter and the receiver are in the planet's "twilight zone." This obtuse issue, along with the definitions of the other four forms of twilight-related propagation enhancement will be addressed in Section B. Even experts such as John DeVoldere tend to intermix these terms at times. This confusion makes logical analysis and even communication difficult. As well, many of us have come to speak of "the width of the grayline" as a variable phenomenon: narrower at the Equator and wider at polar latitudes. We will address why we feel that perception is dangerously flawed.

The terms "refraction", "reflection," and "deflection" are used interchangeably by some professional propagational authorities while others have very precise definitions for each term. We suggest that all signal bending in the ionosphere be referred to as REFRACTION. All "bounces" off the surface (to the extent such exist) will be called REFLECTION. The term DEFLECTION will be avoided as much as possible.

Several terms are introduced which may be unfamiliar, even to seasoned DXers, and they will be dealt with carefully if they are central to this article. Other unfamiliar terms may be found in references excerpted from professional work. These will be defined if necessary to the main thrust of the material.

The point of this whole effort is to help us all hear the DX we want to hear on a more predictable basis. Some of the following discussions reinforce long-held views. Others call into question some basic propagational assumptions which have endured for decades. In either case, we will try to be simple and clear in our discussion and we will state our sources. Our objective is to apply the most recent scientific research and thinking to everyday Tropical Band DXing problems and experiences.

# SECTION A

## A TROPICAL BAND DXER'S GUIDE TO THE IONOSPHERE: THE BIG PICTURE

ABSTRACT -

The historical foundation of ionospheric research with attention to the evolution of the well-entrenched multi-hop model of HF propagation is traced. An excerpted description of the geophysical structure and diurnal characteristics of the layers of the ionosphere is also provided.

The authors introduce the concept of Spherical Divergence and Convergence as an important determinant in the eventual strength of a received signal, demonstrating that the strength will vary inversely with distance travelled beyond 6,250 miles. This concept is coupled with tilt zone mechanics as a fundamental basis for twilight enhancement of Tropical Band signals.

Referencing a little-known action taken in 1978 by the ITU/CCIR, the probability of long haul propagation occurring without intermediate ground reflection points is introduced.

## INTRODUCTION

The ionosphere is that portion of the earth's atmosphere which makes long range transmission and reception of radio signals possible. Its particular character at every point along the transmission path is critical to all who are interested in radio communication, and most especially to those who are concerned with the propagation of relatively weak signals over planetary distances.

As the physical sciences developed rapidly between 1880-1930, a number of startling discoveries and the conclusions drawn from them gave theoretical underpinning to the emerging field of radio propagation. In the late 19th century, Heinrich Hertz demonstrated that radio waves travel in straight lines. But in 1901, Guglielmo Marconi became the first transatlantic DXer and his signals hardly travelled in a straight line! The next year, independent studies by Arthur Kennelly (U.S.) and Oliver Heaviside (U.K.) suggested that the upper atmosphere consisted of an electrically conducting region that "deflected" signals across the Atlantic.

In the 1920's, a British research group led by Sir Edward Appleton established conclusively that radio signals from a nearby transmitter were "reflected" off something in the upper atmosphere. The conventional view of the physical means of long distance propagation of shortwave signals developed from that seminal work.

Stated simply, this conventional model of shortwave propagation (all frequencies from 2 to 30 MHz) holds that the radio waves from a transmitter are refracted off the ionosphere and returned to earth. Propagation over long distances takes place via multiple "hops", with the refracted downward wave being bounced (reflected) off the earth and returned to the ionosphere for yet-another hop. Most texts also mention the Chordal Hop and Whispering Gallery modes of propagation, but these are spoken of as rare and exceptional cases. These modes will be examined in Section B.

## GENERAL DESCRIPTION

From those early experiments by the pioneers and similar efforts continuing to the present time, we have come to know the generalized structure of the ionosphere rather well. The following excerpt from a recent scholarly paper serves to provide a foundation description:

"The ionosphere is the region of the atmosphere in which free ions and electrons exist in sufficient numbers to affect the properties of electromagnetic waves that are propagated within and through it. The ionosphere can usually be assumed to extend from about 50 to 2000 km above the earth's surface. The structure of the ionosphere is highly variable, and this variability affects the performance of communications systems whose signals are propagated by the ionosphere.

Historically, the D region of the ionosphere is treated as the lowest ionospheric region. It has an altitude range from 50 to 90 km and the electron density increases rapidly with altitude. The D region is under strong influence with maximum values of electron density occurring near local noon during summer. Between 70 and 90 km, ionization is caused primarily by solar X-rays; below 70 km, cosmic ray-produced ionization dominates. The high collision frequency between the electrons and neutral particles in the D region gives rise to substantial absorption of radio waves that are propagated into it.

The E region is the next highest ionospheric region. It spans the altitude range from about 90 to 130 km. The normal E layer closely resembles a "Chapman" layer with a maximum density near noon and a seasonal maximum in summer. The maximum density occurs near 100 km, although this height varies with local time. During the nighttime, the ionization approaches small residual levels. The normal E layer is formed by ultraviolet radiation ionizing atomic oxygen. Collisions between electrons and neutral particles, while important in the E region, are not as numerous as in the D region. The electron-neutral collision frequency generally decreases exponentially with altitude throughout the E region.

Embedded within the E region is the so-called sporadic-E layer. This layer is an anomalous ionization layer that assumes different forms - irregular and patchy, smooth and disk-like -and has little direct bearing to solar radiation. The properties of the sporadic-E layer vary substantially with location and are markedly different at equatorial, temperate and high latitudes.

The highest ionospheric region is called the F layer. The lower part of the F region (130 to 200 km) displays different variations than the upper part, and for this reason, the terms F1 and F2 (region above 200 km) are applied. The F1 region, like the E region, is under strong solar control. It reaches a maximum ionization level about one hour after local noon and its presence is generally only obvious during the summer. At night, the F1 and the F2 regions merge and are simply called the F region.

The F2 region is the highest ionospheric region. It is also the most variable in time and in space. The maximum values of electron density occur well after noon, sometimes in the evening hours. The height of the maximum ranges from 250 to 350 km at mid-latitudes and from 350 to 500 km at equatorial latitudes. At mid-latitudes, the height of maximum electron density is greater at night than in the daytime. At equatorial latitudes, the opposite behavior occurs.

The F2 region is strongly influenced by neutral-air winds, electrodynamic drift, and ambipolar diffusion that compete along with ionization processes to control the ionization distribution. The relationship between the direction of the geomagnetic field and the direction of the neutral winds and electrodynamic drifts plays a major role in F2 region structure. It is the plasma response to the dynamic processes in the presence of the geomagnetic field that gives rise to the observed variations in the F2 region.

Within the F region, the collision frequency between electrons and neutral particles decreases markedly. However, collisions between electrons and ions, being Coulomb-type collisions, can give rise to relatively high effective collision frequencies. Substantial absorption of high frequency (HF) radio waves can occur, for example, near the peak of the F region.

The F region extends upward into the topside ionosphere. The topside ionosphere is as variable as the F region, if not more so. The variations become increasingly larger with altitude. Because the electron density continuously decreases in the topside ionosphere, ionization becomes less and less important in terms of affecting most radio propagation systems.

At any location on the earth, the vertical distribution of electrons in the ionosphere can be expected to differ. Many of the ionospheric models that have been developed over the years are limited to specific geographic regions because the mechanisms that lead to the formation and changes of the ionosphere tend to vary in their dominance of the overall distribution in specific geographical regions. This is particularly true for the ionosphere in the equatorial and high latitudes." [1]

Figure A-1 depicts the major regions (layers) of the ionosphere and their relative electron densities for both daytime and nighttime conditions. This characterization is typical for mid-latitudes at sunspot maximum.

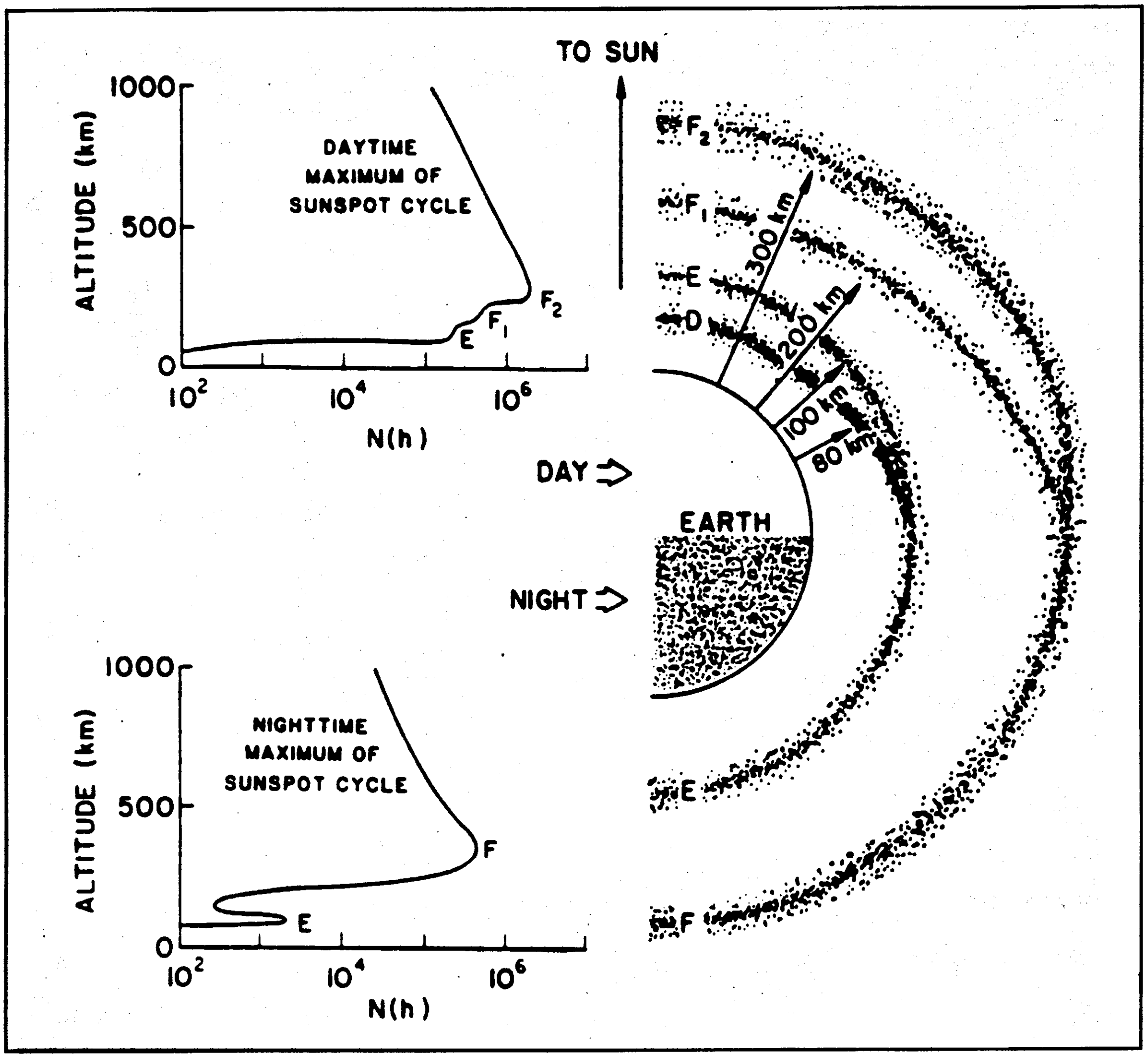

Fig. A-1: THE IONOSPHERIC REGIONS AS A FUNCTION OF THE DIURNAL CYCLE AND HEIGHT ABOVE THE EARTH'S SURFACE [2]

## INVESTIGATIVE INSTRUMENTS AND TECHNIQUES: THE IONOGRAM

An understanding of the variability of the physical structure of the ionospheric layers is essential to any discussion about HF propagation. The most important characteristics of the layers are their critical frequencies and virtual heights. Pulse-sounding equipment is commonly used to measure the effective height of the ionospheric layer(s) which is capable of "reflecting" vertically polarized RF radiation at various frequencies. The critical frequency is the highest frequency "reflected" by the ionosphere. This frequency can be converted to values which relate to the electron content of the ionosphere and the height of the "reflecting" layers. A device called an Ionosonde is used record these altitude-frequency characteristics of the ionosphere in the form of a photograph known as an Ionogram.

It is useful to imagine an ionogram as a photograph of a vertically oriented HF radar screen. The white lines represent the areas which are "returning" refracted signals to a ground station receiver. It is clearly possible to see the refractive regions and to relate height (vertical scale) to frequency (horizontal scale).

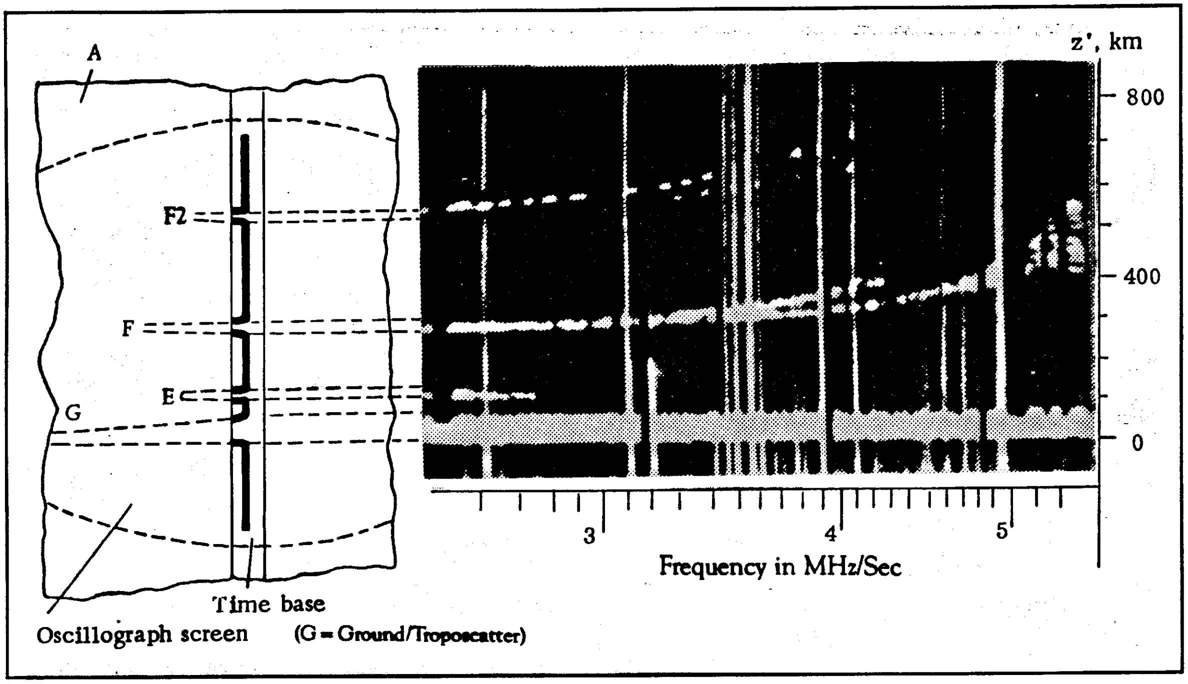

Fig A-2: DISPLAY OF AN IONOGRAM [3]

## LONG DISTANCE HF RADIO PROPAGATION

The direct experiments by Appleton, and others by Briet and Tuve of the United States in the mid-1920's, measured the vertical angle of radio waves transmitted from nearby stations and found that the direction was downward from above, rather than in a horizontal plane with the stations' transmitting antennae. From there, it was a small step to postulate the existence of a refractive layer high in the atmosphere. Shortly thereafter, the "hop" or "skip" method of propagation was accepted as the major mode of long distance radio transmission.

Figures A-3i and A-3ii are two of the best diagrams of the refraction method of propagation that we have found. Note that these are illustrations of a "single hop" model representing ray paths for a fixed frequency with varying angles of elevation (takeoff). Notice the existence of some high-angle rays which are partially bent by refraction but which still radiate into space. Notice especially the trajectory of ray "9" in Figure A-3i (corresponding to ray "5" in Figure A-3ii) - it will be discussed in a later Section.

SINGLE HOP MODELS OF TRAJECTORY OF RAYS OF A SHORTWAVE SIGNAL

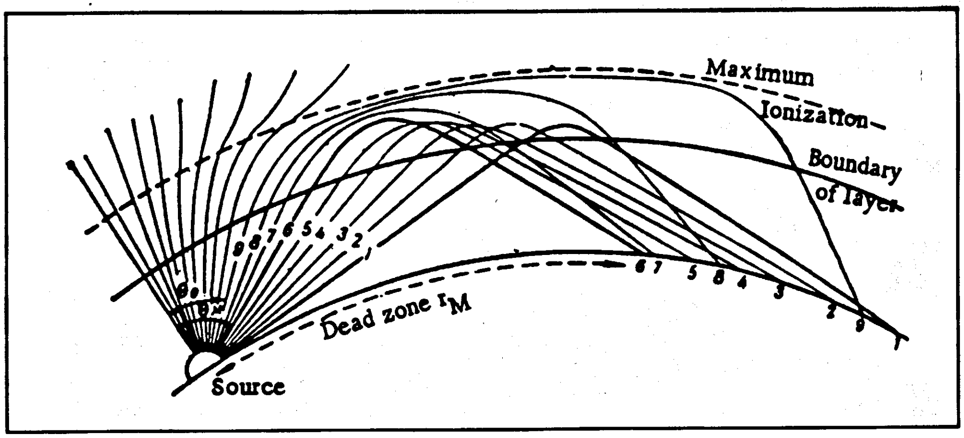

Fig. A-3i: [3]

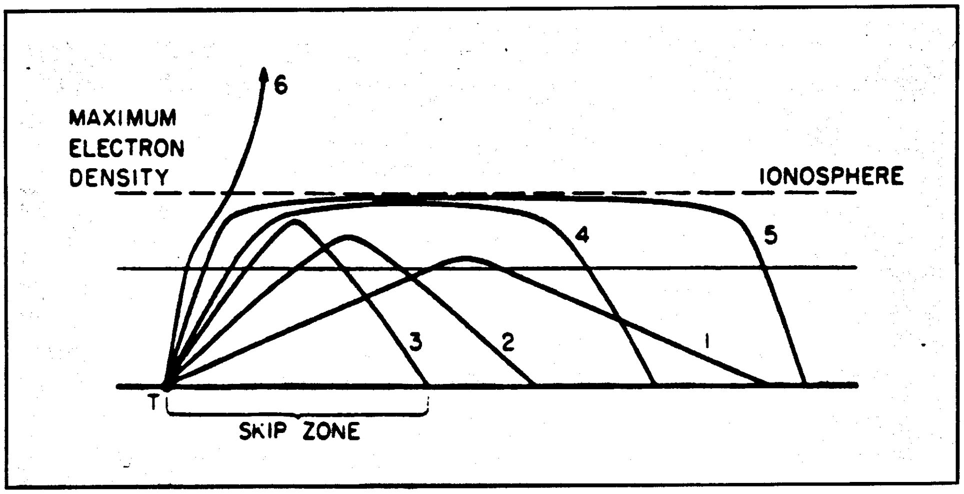

Fig. A-3ii: [4]

In the 1980's, computer-based field strength prediction models were quite accurate for single hop propagation. Figure A-4 is the result of such a computer study. Note the dead zone (Skip Zone) and the area of maximum field strength. Note also the area of declining field strength (upper right hand corner).

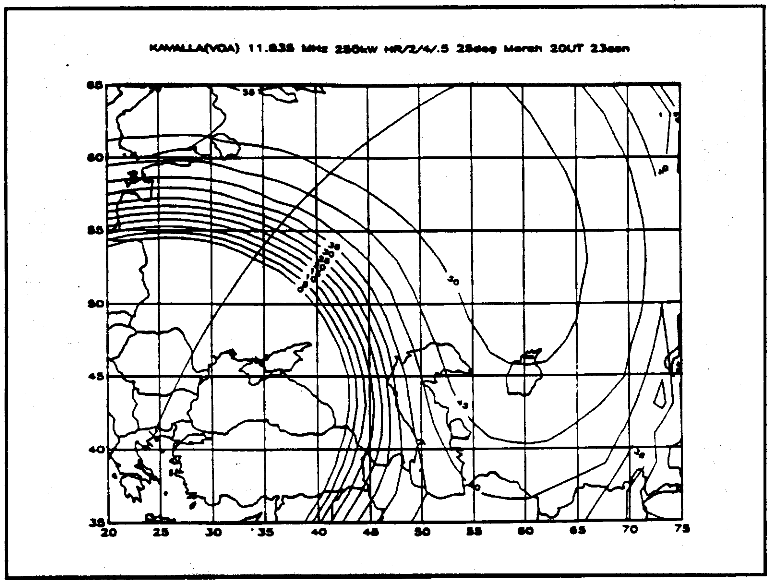

Fig. A-4: COMPUTER-GENERATED FIELD STRENGTH MODEL [1]

Early propagational authorities realized that the geometry of signal propagation by a single hop from a region just several hundred kilometers overhead could not explain communication paths which were already in daily use over transatlantic distances. These pioneer researchers postulated the now-familiar "multi-hop" model as the NORMAL means of long distance HF radio propagation. This model (Figure A-5) has been accepted by virtually all authorities for over fifty years.

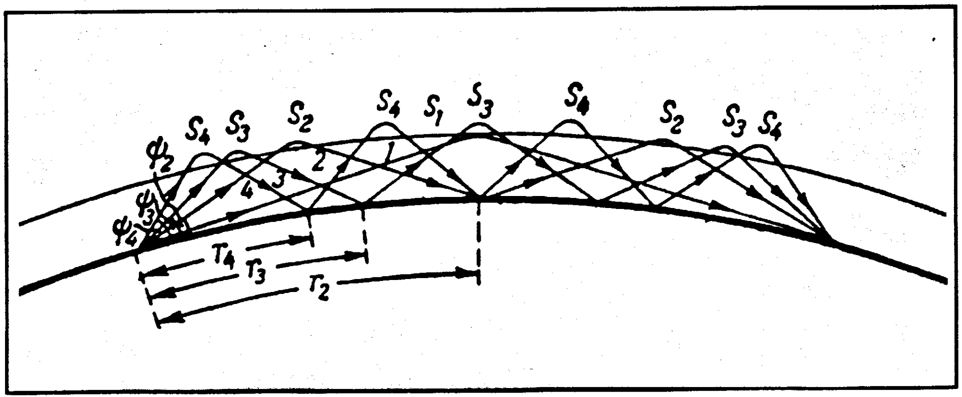

Fig. A-5: MULTI-HOP MODEL OF HF PROPAGATION [3]

But in the early 1970's, some members of the amateur radio community and some professional propagationists began to seriously question the multi-hop model, at least as it applied to "long haul" distances. In 1977, German authorities published the results of a decade-long study of the field strength of Deutsche Welle transmissions from Germany to Australia. The International Telecommunication Union/International Radio Consultive Committee (ITU/CCIR) field strength predictions of the day (based on a CCIR formula established in 1970) were shown to be understated by about 25 dB (that's 4 S-units!). [5]

The following year, the relevant committee of the CCIR developed a second prediction formula based on antipodal focusing gain and ionospheric propagation over long distances WITHOUT INTERMEDIATE GROUND REFLECTIONS. [6] That formulation is now the standard for predicting field strengths at transmission distances beyond 10,000 km.

This is a startling reversal in the thinking of propagation specialists as to the NORMAL mode of long haul ionospheric propagation at shortwave frequencies, and more than a decade later, it remains virtually unknown in the hobby community!

The authors seriously question the validity of the multi-hop model over any distance. We have not found ANY primary research which confirms the intermediate reflection of Tropical Band (or any other HF frequency) signals at the earth's surface, though such may exist. The ITU-approved field strength computations out to 10,000 km still assume multiple hops.

In early field research, the signal strength at the receiver was measured and was a known factor. The normal amount of attenuation in the ionosphere over a single hop was known after 1925. Could it be that early researchers developing multi-hop field strength formulae simply subtracted the known ionospheric attenuation from the original signal and then assigned all of the "extra loss" needed to validate measured field strength to "ground loss"? In other words, could all of the major methods of predicting field strength beyond 2,000 miles simply be reconfirming the same flawed assumption? We don't really know!

Another large-scale ionospheric phenomenon of great importance to the Tropical Band DXer is the rapid vertical movement of the refracting regions of the ionosphere at both dawn and dusk. This movement is in part attributable to the rapid increase in ionization (at dawn) and the process of recombination (at dusk). It was this rapid movement that first led Appleton and his colleagues to "discover" the ionosphere. The movement creates a band of "tilted" refracting layers which is about 500 km (330 miles) wide.

This "tilt zone" is thought to be responsible for both true grayline enhancement and for the four more common modes of "twilight enhancement" experienced as the zone passes above either the transmitter or the receiver twice daily. The geophysical mechanics associated with reception over these "partial darkness" paths will be addressed in Section B. Ionospheric tilts are also believed to be a complementary factor associated with "spherical convergence" (ray focusing) which will be discussed as we conclude this Section.

Figure A-6 is an excellent example of the tilt zone (on a north-south path crossing the Equator) at the terminator. The exact physics of tilt-zone enhanced propagation (which seems most dramatic at, but is not necessarily confined to Tropical Band frequencies) is not known with any precision at this time.

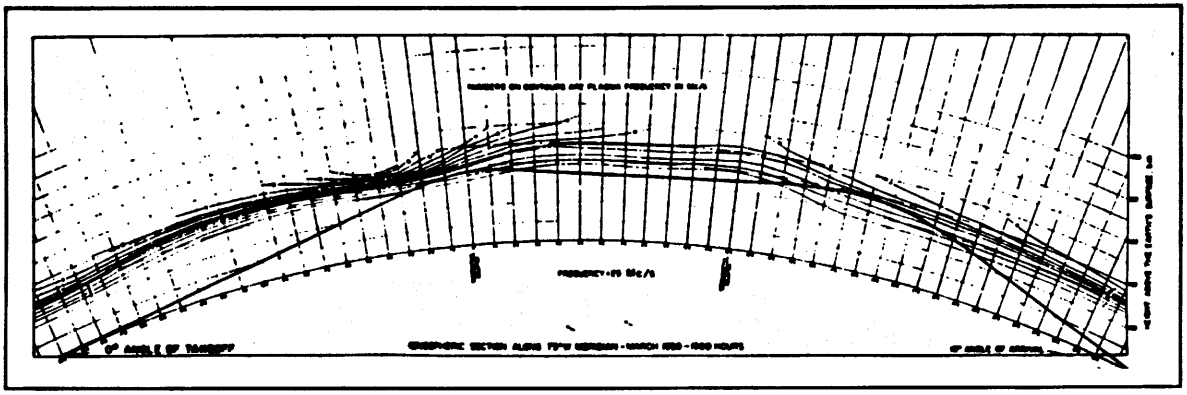

Fig. A-6: IONOSPHERIC TILT [4]

Finally, one other major inter-relationship between the planet and the ionosphere is of special interest to the Tropical Band DXer: Spherical Divergence and Convergence (also known as ray defocusing and focusing, respectively).

We have always assumed that the farther from the transmitter a signal reaches, the weaker the signal will be due to absorption losses associated with multi-hop refraction and reflection. Although radio is propagated as waves, the dispersion of the signal is often represented as radial rays. Assume an omni-directional vertical antenna and the diagram always looks as in Figure A-7 (left-hand drawing):

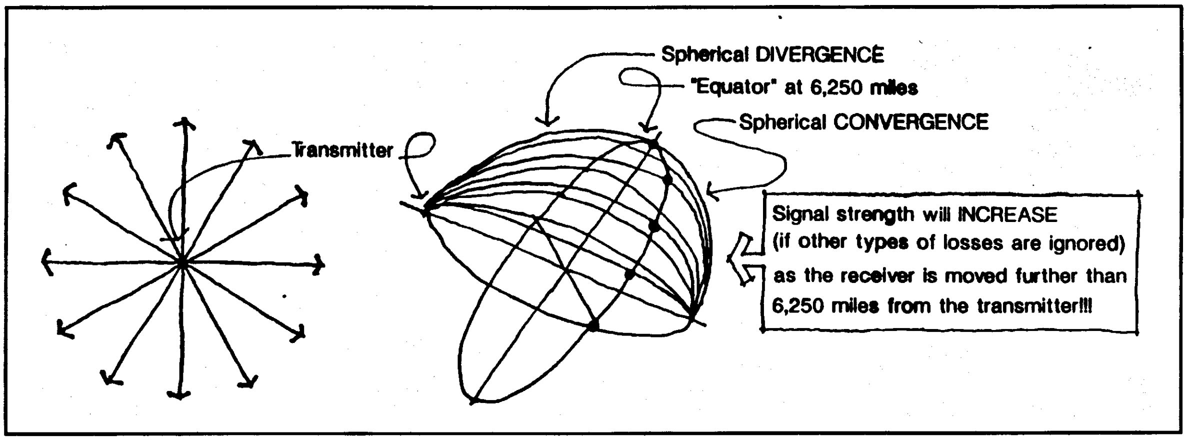

Fig. A-7: PRINCIPLE OF SPHERICAL DIVERGENCE/CONVERGENCE

The rays actually represent the wave. Field strength or density at any distance out from the transmitter is directly proportional to the distance between the rays. What we, and even the ITU, forgot or ignored until recently was that Figure A-7 (right-hand drawing) is a "floor plan" drawing, looking straight down on the centre of a spherical surface. Each of those rays is actually a Great Circle seen edge-on. If the rays originating at the transmitter are followed clear around the earth, it can be seen that they will converge on a spot on the exact opposite side of the planet. This is known as "antipodal focusing".

The rays do not travel in a straight line. They and the waves that they represent are travelling in a relatively narrow spherical void between two spherically curved surfaces. Further, since field strength is proportional to the distance between the rays, once the rays travel beyond the 6250 mile distant "equator", the field strength will INCREASE with distance (if other attenuating factors are ignored).

To put it another way, imagine yourself at a transmitter at the North Pole. IF THERE WERE NO OTHER FORMS OF ATTENUATION, THE SIGNAL WOULD DROP EACH MILE THAT YOU TRAVELLED TOWARD THE EQUATOR ("Spherical Divergence").

IN A LOSSLESS ENVIRONMENT, AFTER PASSING THE EQUATOR, THE SIGNAL LEVEL WOULD BEGIN TO INCREASE WITH EACH MILE TRAVELLED TOWARD THE SOUTH POLE ("Spherical Convergence").

UPON REACHING THE SOUTH POLE, THE SIGNAL STRENGTH WOULD EQUAL THAT AT THE TRANSMITTER. Based upon the German research accepted by the ITU/CCIR, focusing gains of 12 dB can be expected at 16,000 km and for practical purposes, a maximum of 30 dB gain at the antipodes (18,750 km) has been defined.

This is one of the most important of the previously ignored factors which caused the formulae of the ITU/CCIR to be incorrect or understated by as much as 25 dB. It was, and is, an easy error for any of us to make because it seems totally wrong-headed to conceive that field strength INCREASES with distance!

Taken as a whole, the current understanding of the large-scale elements of the ionosphere, its refractive regions and their interaction with each other, with the sun, and with electromagnetic waves, seems reasonable. With the exception of the recently recognized spherical divergence/convergence principle, the foregoing model is the foundation upon which the conventional view of HF radio propagation is built.

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[2] Goodman, John M. and Jules Aarons. "Ionospheric Effects on Modern Electronic Systems". PROCEEDINGS OF THE IEEE, Vol. 78, NO. 3, March, 1990

[3] Al'pert, Ya. L. RADIO WAVE PROPAGATION AND THE IONOSPHERE. (Russian text, USSR Academy of Sciences Press, Moscow, 1960). Translated by CBE, Inc., New York, 1963.

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[6] CCIR. Second CCIR Interim Computer-Based Report Method for Estimating Sky-Wave Field Strength and Transmission Loss at Frequencies Between The Limits of 2 and 30 MHz (Supplement to Report 252-2); Kyoto, 1978. International Telecommunication Union. Geneva, Switzerland.

# SECTION B

## TROPICAL BAND PROPAGATION - A DIFFERENCE OF NIGHT AND DAY

### ABSTRACT

A clear understanding of the typical orientation of signal paths within the darkness zone is essential for Tropical Band DXers, so great circle paths from representative locations in North America to Asia are presented.

Particular attention is accorded to the five possible partial darkness propagation situations generally recognized as being responsible for signal enhancement, with examples appropriate to North American DXers. The astronomical properties of the grayline zone are thoroughly discussed and signal behavior in this medium is distinguished from the dawn to dusk enhancements that occur at either the transmitter or the receiver.

The geophysical phenomena associated with the refraction process during twilight periods, including ionospheric tilts and signal ducting, are discussed. The classical view of dawn enhancement in terms of the multi-hop model is found to be wanting.

The authors postulate that predictable but heretofore unexplained seasonality patterns experienced by Tropical Band DXers in North America may be associated principally with ionospheric phenomena taking place in the region of the transmitter, not the receiver.

## INTRODUCTION

The historical basis for conventionally accepted views of HF propagation was outlined in Section A. In that regard, reference was made to the multi-hop model, as modified or enhanced by the effect of a "tilt" zone at sunrise and sunset.

In the amateur radio community, DXers are also familiar with the concept of "round-the-world" signal enhancement due to "antipodal" or "near-antipodal focusing" at path-lengths approaching 12,500 miles. But the terms Spherical Divergence and Convergence may be relatively new to most shortwave broadcast DXers. The difference in the two concepts is that due to spherical convergence in the hemisphere opposite the transmitter, signals tend to become stronger the further you travel from the transmitter (beyond 6,250 miles). This is not a phenomenon limited to the area at or near the antipodes! We suggest the reader keep this concept in mind, since as Tropical Band DXers, we are commonly interested in planetary distances of 6,250 miles and more (a minimum of three "hops" in conventional parlance).

Applying these geophysical criteria to Tropical Band propagation, this Section will focus on darkness signal paths: the "total darkness" path and more importantly, the "partial darkness" path, of which we shall find there are five distinct variations.

The purpose of this Section is to establish a better understanding (at least in terms of commonly accepted propagation models) of why certain preferred (partial darkness) paths contribute to enhanced reception of long distance Tropical Band DX.

In North America, signal enhancement is also frequently associated with distinct seasonal reception patterns. The discussion will serve to introduce the possibility of other criteria for seasonal signal enhancement which fall outside the boundaries of today's "conventional wisdom".

## GREAT CIRCLE PATHS

Shortwave signals normally propagate between any two points on the earth's surface by following a great circle path. The shortest planetary distance between those two points is called the short path. Conversely, if a signal were to propagate from the transmitter in the opposite direction, it would follow the long path route to reach the receiver.

Sometimes, solar-terrestrial events and/or geophysical factors at work in the ionosphere may cause a shortwave signal to adopt a "path of least resistance" which is a non-great circle path. For example, "signal bending" is often associated with signals crossing over or near the polar caps (see 'DXing Asians on the Tropical Bands - The Auroral Factor' by David Clark in PROCEEDINGS 1989.
The authors wish to acknowledge the anomalous occurrence of these signal bending phenomena. However, they are not of primary concern for the purpose of this article.

The traditional North American DX season on the Tropical Band extends from approximately mid-September until mid-April. With rare exception, signals arrive at our receivers by travelling the short great circle route. This applies to Asian and South American signals which, for most of us, follow a north-south and south-north path respectively. As well, it applies to African and Pacific signals whose respective signal paths to North America are essentially east-west and west-east. Since the primary interest of the authors is associated with DXing Asian stations, we will frequently refer to our experience as the basis for illustration throughout the article.

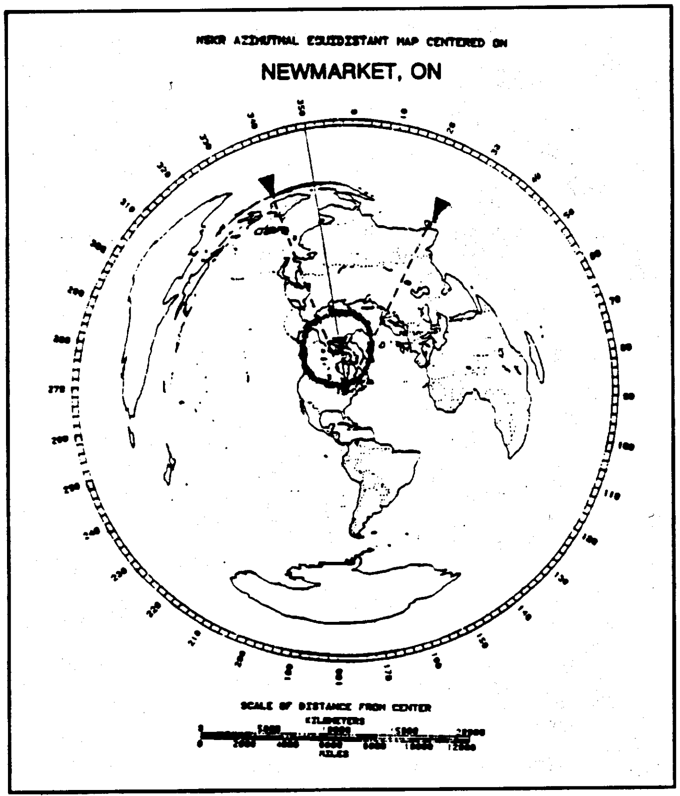


Fig. B-1: SHORT PATHS TO ASIA - NAm EAST

Perusal of azimuthal equidistant projections for various locations confirms that for DXers in Eastern and Central parts of North America, the short great circle path for most Asian signals (except for Austral-Asia) falls within +/- 20-25 degrees of a north-south orientation. The opposite long path route (south-north) would intersect the southern polar zone during the hemispheric summer and thus would be subject to total D layer absorption, also known as "solar blanking" (see 'Terminator Mechanics and Trans-Polar Solar Blanking' by John Bryant in PROCEEDINGS 1988).

For DXers located near the West Coast of North America, the azimuth of Asian signals is somewhat different. Short path signals from South-Central Asia (ie. in the direction of the Indian Sub-continent) do follow a NW-SE path, but signals from Southeast Asia follow an essentially west-east route. Long path signals travelling in the opposite east-west direction would unavoidably intersect the daylight side of the earth and thus would be lost to 'D' layer absorption too.

To illustrate the short path for Southeast Asia, we've selected Banjarmasin, Kalimantan, because its position on the island of Borneo basically divides the breadth Southeast Asia in half. The considerable differences in orientation of the great circle route from eastern, central and western parts of North America are readily apparent by examining the broken lines in Figures B-1, B-2 and B-3. For South-Central Asia, the other broken line to Colombo, Sri Lanka, shows a wide swing in the heading of the short path, varying from NE to NW as you move from east to west across North America.

The solid line on each of these maps represents the great circle path from Asia towards North America which passes through the "donut-hole" in the centre of the polar cap (ie. intersecting the North Magnetic Pole). This reminds us that reception of signals from certain parts of Southeast or South-Central Asia is going to be influenced by the surrounding auroral zone and/or conditions within the polar cap itself.

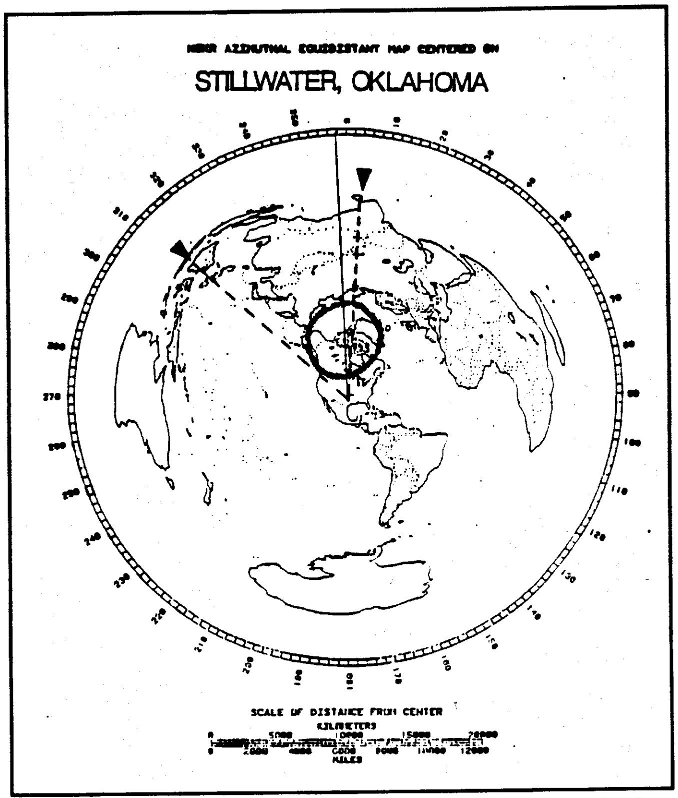


Fig. B-2: SHORT PATHS TO ASIA - NAm CENTRAL

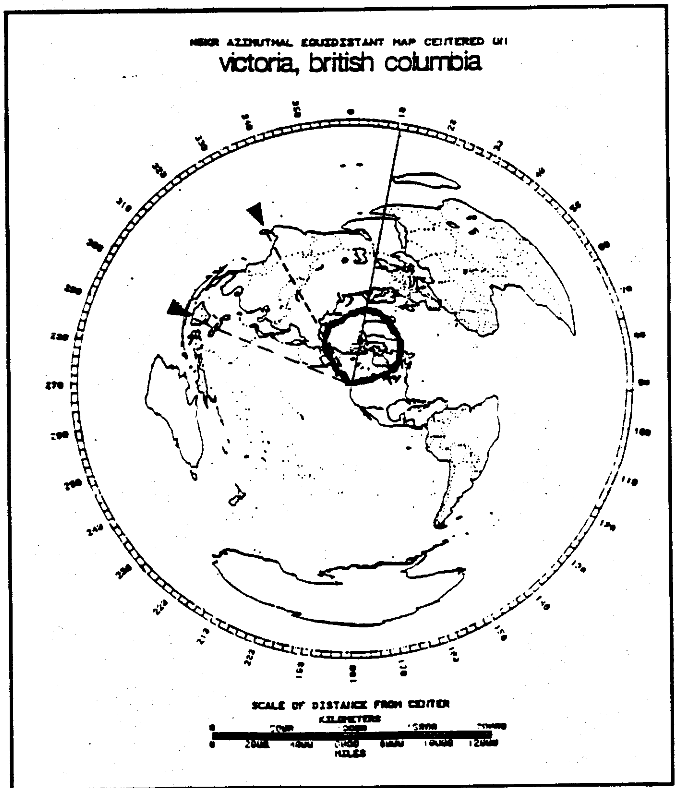


Fig. B-3: SHORT PATHS TO ASIA - NAm WEST

In general, a knowledge of great circle paths is important to Tropical Band DXers who must be concerned about where it's dark and where it's not. It is also useful for pointing directional antennas to achieve optimal weak signal pickup. Finally, it is critical to know if the heading of the signal is in the direction of the auroral zone.

## FACTORS CONTRIBUTING TO ENHANCED PROPAGATION

The particular orientation of the short path for any signal originating in Asia is an important consideration to most Tropical Band DXers in North America for three reasons.

First, as noted above, signals intersecting the northern auroral absorption zone may be subject to anomalous enhancement as they travel through the polar "donut-hole" or are "bent" around the outer periphery of the auroral ring. Clark's article in PROCEEDINGS 1989 focusses specifically on signal enhancement related to solar flares and the onset of geomagnetic disturbances.

Secondly, for Asian signal paths whose arrival azimuth lies somewhere between NW and NE, it is appropriate to recognize that at certain times of the year, this great circle path will be a "true grayline" path. Signals travelling in a west-east orientation will not be enhanced as a direct result of this phenomenon.

Note that both of these signal-enhancing factors could be happening at the same time, thus having a mutually complementary effect. These criteria, taken separately or together, are the most likely explanation for unusually strong reception of Tropical Band Asians sometimes experienced by DXers in Eastern North America in late afternoon during the DX season.

Third, and most important to us in this article, is the enhanced propagation experienced by all DXers based on the incidence of dawn or dusk at ONE end of the signal path. Most DXers equate this with dawn enhancement at the receiver, although this is just one of four such possibilities. We will compare this carefully with the "true grayline" path.

## DARKNESS PATH DEFINITIONS

### I. Total Darkness Path:

Tropical Band reception is possible because the entire end-to-end signal path at the prescribed time is contained within the darkness side of the earth. As a general rule, though, Tropical Band Asian signals do not seem to propagate as well as might be expected during the total darkness period.

Note that signal levels do not constant throughout the timeframe that a total darkness path exists between two points. This was pointed out by the late Ronald Schatz, a medium wave DXer who, some ten years ago, published several papers dealing with "Terminator Transit Mechanix". [1]

Basically, Schatz was concerned with E layer skywave reception on the BCB as it is affected by the occurrence of sunset or sunrise along the signal path. He dealt with signal behavior from first audio at sunset fade-up, the post-sunset peak followed by an initial fade, and then sometimes a secondary peak before a signal level subsequently settled evenly for the duration of the all-darkness period (see Figure B-4). The converse would occur during the sunrise period until final post-sunrise fade-out.

Schatz qualified his conclusions by stating that signal behavior based on F layer propagation at shortwave frequencies was not consistent with the pattern at medium wave and longwave frequencies. The extent to which the influence of the E layer (and/or Sporadic E) may extend to Tropical Band frequencies has been a contentious issue for years. The extent of the influence of the F layer on upper BCB signals is also controversial. The authors have no desire to proliferate that worthy debate in this article. Nonetheless, Schatz's observations are interesting. Our mutual experience and other scholarly papers confirm the pattern shown in the illustration, up to the point of the post-sunset secondary peak. This signal behaviour pattern inherently starts with sunset enhancement at the transmitter. But the horizontal line extending to the right and indicating a steady signal level throughout most of the rest of the night appears incorrect. Part of the reason for this will be found in Section D when we examine diurnal changes in the virtual height of the F layer.

DXers of Asian signals on both the Tropical and Medium Wave bands experience a period a signal enhancement with the arrival of sunset at the transmitter when the receiving location is in total darkness. This phenomenon is usually more noticeable in central and western parts of North America, but enhancement of signals at dusk, Pacific time, can be experienced also in the East with surprisingly good signals at times. Typical examples are the fade-up of Solomons on 5020 kHz around 0730, sometimes followed by the numerous Papua New Guinea stations at +/-0830.

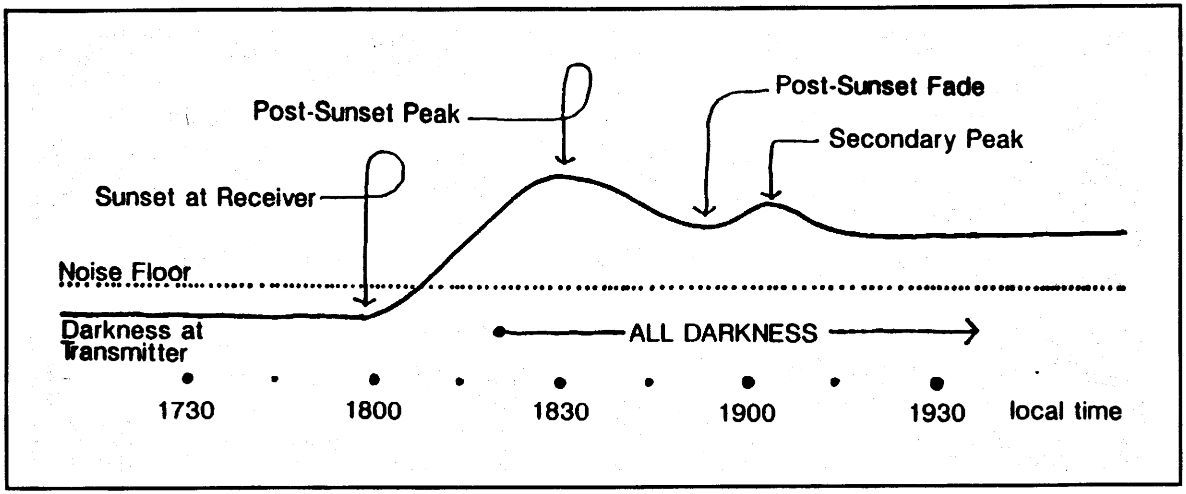


Fig. B-4: TYPICAL TERMINATOR TRANSIT CURVE (Sunset Fade-Up) [1]

On the West Coast, a second post-sunset peak may be observed (about 9 PM local time at the transmitter). Thereafter, for the duration of the all-darkness period, the signals will typically fade down severely, if not disappear altogether as the path appears to "wear out". They will re-appear at commencement of the familiar dawn peak in North America.

We will revisit this very interesting second peak later in the article. Note, however, that it is seldom distinguishable to DXers in the East because 9 PM at the transmitter often corresponds with the period of sunrise enhancement at the receiver.

## II. Partial Darkness Paths:

### (a) TWILIGHT AT ONE END OF PATH-LENGTH

This is the classic situation of dawn or dusk twilight enhancement when the relative strength of the Tropical Band signals shows a marked improvement over the total darkness path. By definition, dawn or dusk enhancement relating to a partial darkness path occurs at either the receiving end or the transmitting end of the path, but NOT both. In all such cases the remainder of the path-length is on the dark side of the earth. Note the distinction from a "true" grayline path.

Clearly there are four such partial darkness situations, taking into account dawn and dusk twilight at the receiver, or at the transmitter. Each situation can influence - potentially enhance - Tropical Band reception. They are:

1. Sunrise at the Receiver - Transmitter in Total Darkness
2. Sunset at the Receiver - Transmitter in Total Darkness
3. Sunrise at the Transmitter - Receiver in Total Darkness
4. Sunset at the Transmitter - Receiver in Total Darkness

Let's examine each of these respective windows of signal enhancement as it relates to North American Tropical Band DXers:

### TWILIGHT AT THE RECEIVER

1. The enhanced sunrise-dawn period of reception is familiar to most DXers. It can be experienced with respect to Asian signals by DXers situated throughout North America. Some would say dawn enhancement is the most pronounced. In his 'Propagation' column in CQ Magazine, George Jacobs consistently says that

propagation conditions on 7 MHz and lower frequencies "will tend to peak just as the sun begins to rise on the light, or easternmost, terminal of a path." Best reception is usually near the end of a period of relatively quiet magnetic conditions.

The numerous PNG's on 90 meters are commonly heard in Eastern North America at this time. On occasion (generally in late fall or early spring), dawn enhancement may find certain channels dominated by Indonesians instead. In that case, typical reception would include RRI-Palangkaraya on 3324.9, RRI-Ternate on 3345, RRI-Kupang on 3385 and RRI-Tanjungkarang on 3394.9 kHz. On that same reception day, the co-channel PNG's might well have been heard several hours earlier at Asian sunset. In addition, sub-continentals vie for prominence on the band at sunrise during their brief "season" in mid-winter. AIR-Delhi on 4860 has for years been the standout performer.

2. Enhanced <u>sunset-dusk</u> reception of Asians is a phenomenon confined almost exclusively to DXers in eastern North America, especially in mid-winter when the early sunset precedes sunrise in Asia anywhere from Jawa and points further west. At this time, RRI-Ujung Pandang from Sulawesi on either 4719.3 or 4853.3 is commonly heard. Stations from Sumatera tend to peak in October and again in February. These trans-polar openings are invariably most pronounced at the commencement of a magnetic disturbance and more-so at sunset than at sunrise.

West and Central African signals are sometimes heard well at local dusk in mid-winter by DXers in Central North America and even on the West Coast, better than several hours later when the Africans commence their morning broadcasts. DXers in the East will often find these signals rising to good strength an hour or more before dusk throughout the DX season.

## TWILIGHT AT THE TRANSMITTER

3. Asian <u>sunrise-dawn</u> signal launch enhancement is again most noticeable during mid-winter in Eastern North America when evening darkness is already established prior to sunrise at Sumatera and points further west. On occasion, reception of Sumatrans may extend to Central North America at mid-winter. As in (1) above, the trans-polar signals are frequently enhanced with the onset of a magnetic disturbance.

Sunrise at the transmitter is the alternative time for North American DXers to log East Africans (0300+), Central and West Africans (0400+) and South Americans (0800+) - beginning with Eastern Brazil.

4. Asian <u>sunset-dusk</u> signal launch enhancement is rarely as pronounced in Eastern North America as the sunrise period of reception enhancement which follows several hours later. One example, however, is the brief appearance of stations from Jawa at local dusk around 1130, some two hours <u>before</u> dawn in the eastern time-zone at mid-winter. The sunset enhancement of Asian signals is dramatically more pronounced in central and western regions of the continent. Normally, a quiet geomagnetic field would be preferred.

Throughout much of North America, dusk at the transmitter is an ideal time to log Latin signals, especially from Bolivia and Peru. Note that in the eastern time-zone, this peak occurs in the hour or so <u>after</u> darkness has set in at the receiver. While reception might normally be best during relatively quiet conditions, trans-equatorial routes are at times, apparently enhanced in the early stages of a disturbance.

West Coast DXers often find their best reception of Pacific stations to be the thirty or forty minute period of enhancement commencing with sunset at the transmitter. For example, the only reliable time to hear Radio Northern (PNG) on 3345 kHz is to "DX sunset at the transmitter". Many mornings, it is possible to hear Radio Northern fade up to good reception levels around its local sunset. After nearly an hour of decent reception, the PNG fades down and the co-channel Indonesian powerhouse, RRI-Ternate arrives to dominate the frequency.

To conclude this discussion of partial darkness paths associated with twilight at one end of the path-length, we would like to relate a personal experience. In March, 1990, the authors met for a four-day DXpedition at Grayland, WA, camping out in a state park fronting onto the open Pacific. As it turned out, conditions were especially good for reception of Medium Wave, as well as Tropical Band signals from the South Pacific and into East and Southeast Asia.

The morning of March 19th provided an outstanding example of DXing the sunset enhancement period at the transmitter. We had prepared for this opportunity by running a computer listing of sunset times for virtually every broadcast site from Hawaii to Thailand. Beginning at about 0600, we were able to tune-in to a given Pacific Island medium wave channel about ten minutes before the appropriate sunset time and wait. More often than not, the desired signal would rapidly fade up off the receiver noise floor precisely at the station's sunset and then hold at astonishingly good levels for some time.

For the next several hours, we DXed the western sunset, logging most of the Pacific Islands on medium wave in the process! Even two PNG medium wave outlets were logged, parallel their respective 90 meter channels. Most of the 90 meter Papuans were at "armchair" S9+ levels at 0830 on this morning. Reception was so exceptional (even for the West Coast) that John Bryant taped a one-half hour bandscan which was later sent to Gordon Darling in Port Moresby.

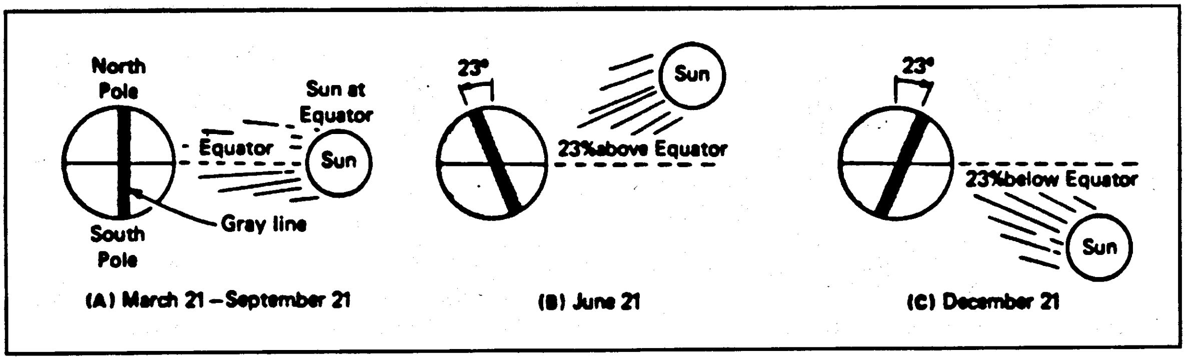
As the night progressed, several 120 meter Indonesians were heard, as well as the rarely reported RRI-Merauke on 3904.9. 'Down-Under' loggings from Australia and New Zealand on medium wave were too numerous to mention. It was an exciting night as we rode the wave of sunset enhancement across the Pacific. Of course, we readily acknowledge that a choice of 2000 foot beverages pointed west and southwest (terminated a few hundred feet from the shoreline) contributed to our success!

## (b) GRAYLINE - TWILIGHT ALONG ENTIRE PATH-LENGTH

Propagation along grayline paths seems to be enhanced by more efficient signal refraction and "ducting" phenomena. This often results in signal levels reaching their optimal potential; at least that is the generally accepted understanding.

A "true grayline" path occurs when both the transmitting location and the receiving location are in a period of dawn or dusk twilight. Provided the signal adheres to the great circle path, the entire path-length and shortest distance from transmitter to receiver will be along the narrow zone of twilight dividing the darkness and daylight sides of the earth. This dividing line between darkness and daylight is also called the "terminator".

All true grayline paths to and from North America vary between NW-SE and NE-SW, depending on the season and whether dawn or dusk at the receiver in North America. At the Equinox, when the dividing line between darkness and light lies along a true north-south axis, it is sometimes possible to hear the same station, initially at the morning grayline and later the same day, at the dusk grayline. The seasonal positioning of the grayline is shown in Figure B-5.



(A) March 21 – September 21 (B) June 21 (C) December 21

Fig. B-5: SEASONAL ORIENTATION OF THE GRAYLINE [2]

Assuming we are facing the western hemisphere in the above illustration, the grayline orientation at the summer and winter solstices would be representative of the dawn grayline at our receivers. At dusk, the corresponding angle from True North would be reversed.

In the western hemisphere, grayline reception from Latin America is always based on dawn (or dusk) twilight along the entire signal path. However, since Asia is in the opposite hemisphere, Asian twilight at dusk will correspond with dawn twilight in North America and vice versa.

Recently available computer software provides an ideal way of visualizing the grayline separating the sunlit and darkness sides of the earth and actually observing the east to west movement of the grayline in "real time". The azimuthal equidistant map can be customized so that it is centred on the location of the DXer's receiver. The short and long path from the receiver to a specified transmitter target is also displayed.

Fig. B-6: COMPUTER-GENERATED GRAPHICAL DISPLAY OF DUSK GRAYLINE [3] (April 29 UTC at Frederick, Maryland)

## GRAYLINE - THE ASTRONOMICAL PROPERTIES

It is critical to note that while the relative width of the terminator as shown in Figure B-5 is exaggerated for illustrative purposes, the actual physical width of the grayline zone is correctly shown in astronomical terms as being equal at all latitudes. In other words, the zone is EXACTLY the same width throughout its circumference.

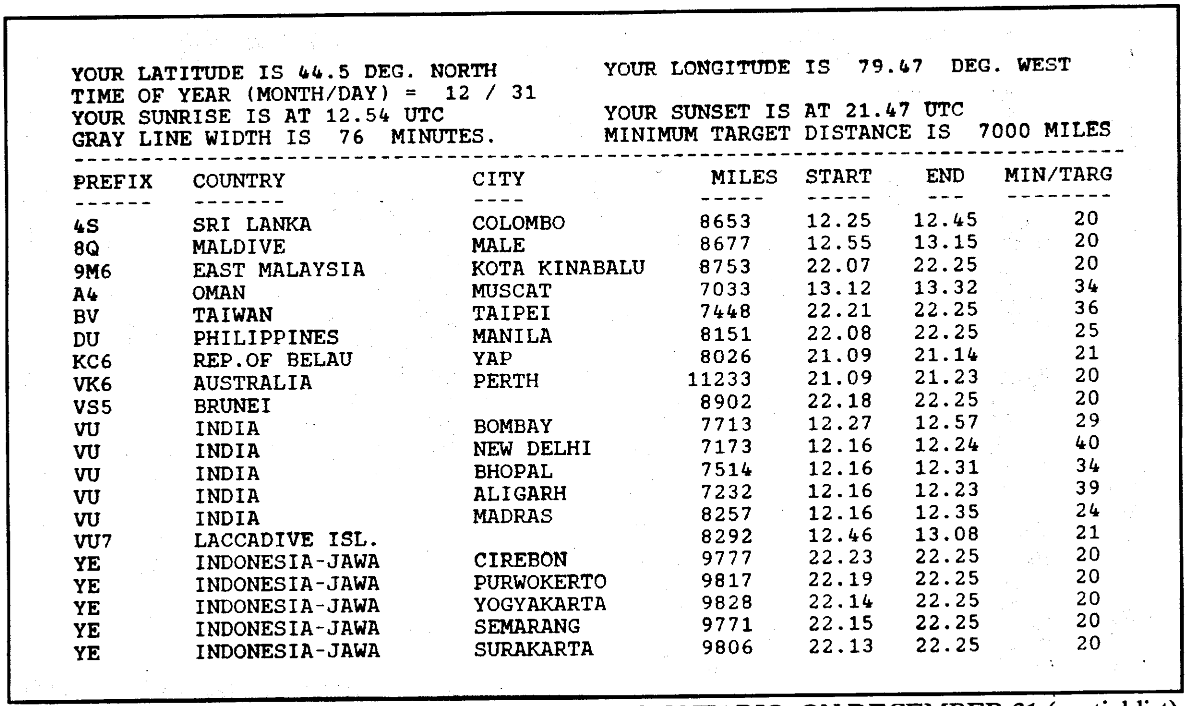
It has become common parlance in DX circles to talk about the "width" of the grayline in terms of time duration, thus implying that its actual width is a function of latitude and season. But the physical reality is that it's the length of time that any spot on the planet spends in the grayline zone which varies substantially. There are two reasons for this.

First, the absolute speed of rotation of any spot on earth varies a great deal: very fast at the equator but very slow approaching the polar caps. Any spot on the Equator for instance is in the grayline zone for only a short period of time, varying only by a few minutes throughout the year, while a similar spot within the Arctic Circle will spend much longer moving through the same width grayline zone.

Secondly, the zone of twilight is inclined at various angles related to the seasons. Again, the length of time varies, in this case according to the diagonal path at which the zone is passing over any spot. Thus we could say the apparent (or visual) width of the grayline varies but the real width is constant!

Given this understanding, the DXer is better-equipped to evaluate the duration of a grayline condition for a given signal path. The entire signal path along the terminator must be considered. For example, most signals from Southeast Asia originate within the Equatorial Zone - Indonesia itself straddles the Equator. Thus, even at mid-winter when the grayline "width" at the receiver may be more than hour in many parts of North America, the effective width of the grayline zone, where the transmitter is located in the Equatorial Zone, is not more than twenty minutes.

Figure B-7 is a partial listing of grayline targets at Clark's QTH (Newmarket, Ontario) for December 31st, generated using John Devoldere's 'Low-Band DXing' software. [4] This happens to be about the mid-point of the six-week annual period when the sub-continentals are "in season". Notice that the grayline "width" is +/- 38 minutes of 12:54 Newmarket sunrise, whereas the "width" at Colombo, Sri Lanka is only +/- 10 minutes of 12:35 sunset. Thus, the time when the grayline zone is in place along this entire path-length is limited to the brief period of "overlapping" twilight from 12:25 to 12:45.



```
YOUR LATITUDE IS 44.5 DEG. NORTH        YOUR LONGITUDE IS  79.47  DEG. WEST
TIME OF YEAR (MONTH/DAY) =  12 / 31
YOUR SUNRISE IS AT 12.54 UTC            YOUR SUNSET IS AT 21.47 UTC
GRAY LINE WIDTH IS  76  MINUTES.        MINIMUM TARGET DISTANCE IS  7000 MILES
-----------------------------------------------------------------------------
PREFIX   COUNTRY             CITY               MILES  START    END  MIN/TARG
------   -------             ----               -----  -----    ---  --------
4S       SRI LANKA           COLOMBO             8653  12.25  12.45        20
8Q       MALDIVE             MALE                8677  12.55  13.15        20
9M6      EAST MALAYSIA       KOTA KINABALU       8753  22.07  22.25        20
A4       OMAN                MUSCAT              7033  13.12  13.32        34
BV       TAIWAN              TAIPEI              7448  22.21  22.25        36
DU       PHILIPPINES         MANILA              8151  22.08  22.25        25
KC6      REP.OF BELAU        YAP                 8026  21.09  21.14        21
VK6      AUSTRALIA           PERTH              11233  21.09  21.23        20
VS5      BRUNEI                                  8902  22.18  22.25        20
VU       INDIA               BOMBAY              7713  12.27  12.57        29
VU       INDIA               NEW DELHI           7173  12.16  12.24        40
VU       INDIA               BHOPAL              7514  12.16  12.31        34
VU       INDIA               ALIGARH             7232  12.16  12.23        39
VU       INDIA               MADRAS              8257  12.16  12.35        24
VU7      LACCADIVE ISL.                          8292  12.46  13.08        21
YE       INDONESIA-JAWA      CIREBON             9777  22.23  22.25        20
YE       INDONESIA-JAWA      PURWOKERTO          9817  22.19  22.25        20
YE       INDONESIA-JAWA      YOGYAKARTA          9828  22.14  22.25        20
YE       INDONESIA-JAWA      SEMARANG            9771  22.15  22.25        20
YE       INDONESIA-JAWA      SURAKARTA           9806  22.13  22.25        20
```

Fig. B-7: GRAYLINE TARGETS FOR NEWMARKET, ONTARIO, ON DECEMBER 31 (partial list)

Interestingly enough, on those infrequent occasions when the Sri Lanka Broadcasting Corporation outlet on 4902 kHz is heard in Ontario, the signal will normally fade up and peak between 12:45 and 13:00 - crossing the sunrise boundary at the receiver but already post-sunset at the transmitter. That seems like partial darkness dawn enhancement at the receiver, more-so than "true grayline" enhancement!

Looking further down the list, another interesting example is the case of AIR-New Delhi (4860 kHz), undoubtedly the easiest log of any of the sub-continentals. Based on its 12:04 sunset, the theoretical grayline peak is confined to the few minutes between 12:16 and 12:24. This station does not sign on until 12:45 but the signal consistently peaks later - around 13:00, and it is often readily heard to 13:30 in Ontario.

By way of comparison, at Bryant's QTH in Stillwater, Oklahoma, sunrise does not take place on December 31st until 13:43 which results in a calculated grayline "width" of +/- 28 minutes. Both Asian sites are clearly in total darkness for more than an hour before sunrise at the receiver. The fact is, however, Bryant enjoys very good reception approaching sunrise and until 14:30 or later. There can be no confusion about this. Optimum reception has occurred in association with dawn enhancement at the receiver.

There are three points to be made here. First, the period of signal enhancement attributable to the grayline may not be of the duration implied at the receiver - the entire path-length along the terminator must be considered. Secondly, peak reception in many cases may not co-incide with the grayline duration per se. To the extent that we may enjoy extended "max dawn" enhancement of Asians (post-sunset at the transmitter) during the winter months, this ought to be understood as enhanced reception based on a partial darkness path but not a "true grayline" path. Finally, one must remain aware of the seasonal aspect. We hear the sub-continentals at December 31st because they happen to be at their seasonal peak.

We have stated that any path associated with grayline enhancement (to the extent such exists) must follow the terminator. This brings up the point that the mechanics of grayline propagation within (along) the terminator has not been satisfactorily explained in any of the professional work that our research has covered. In the absence of any adequate explanation, we would concur with this statement by John Devoldere in Low-Band DXing:

> "It is not clear whether propagation proper inside the grayline along the terminator benefits from its existence. It is clear, however, that signal launching at the transmit end and receive end does benefit greatly from the mechanism". [5]

A little confusing perhaps? Small wonder even the "experts" tend to use terms such as dawn or dusk enhancement and grayline enhancement interchangeably. We again quote Mr. Devoldere:

> "Some authors have mentioned that grayline propagation always happens along the terminator. On the low bands [meaning the 120, 80 and 40 meter amateur bands] there has been occasional proof of such propagation although most of the grayline situation benefits have been noticed on paths typically perpendicular to the terminator." [5]

Surely the author is referring to partial darkness paths with dawn or dusk twilight at one end of the path or the other. In that case we would agree. But to associate "grayline benefits" with paths "perpendicular to the terminator" is a contradiction in terms!

The authors regard the distinction to be significant. Our experience as cited in the foregoing examples, and that of others, is that optimal reception is most often associated with a partial darkness path wherein the twilight condition is present at just one end of the path, not wholly along (within) the terminator!

Most important of all for us in this article, enhanced reception implied by a grayline path often does not "hold up" when the seasonal factor is taken into account. For example, many DXers were pleased to hear Bhutan as a new country in January of 1990 when the word spread that they had switched from the 49 meter band to 5023.1 kHz in the 60 meter band. That was the time to hear it because stations near the Indian Sub-continent were still "in season". By the end of the month, Radio Bhutan had virtually disappeared, at least in Ontario.

As winter turns to spring, there is a "perfect grayline" path from Bhutan to Oklahoma on April 1st (see Figure B-8) when sunrise at Bryant's QTH and sunset at the transmitter co-incide to the minute! It would be wrong to say that it's impossible to hear Radio Bhutan in April, as "true graylining" does work some percentage of the time. Even so, the chances of hearing a good signal are minimal because the season just isn't right.

```
                     13.43    23.24    JAN 1     00.52    11.18
                     13.42    23.37    JAN 15    00.53    11.28       BHUTAN
OWN QTH              13.33    23.54    FEB 1     00.49    11.41       THIMPU
-------              13.19    00.1     FEB 15    00.39    11.52       ---------------
LONG =   97.5        13.02    00.23    MAR 1     00.27    12.01       LONG = -89.65
LAT. =   36.83       12.41    00.37    MAR 15    00.12    12.09       LAT. =  27.53
                     12.18    00.51    APR 1     23.54    12.18
==========>>>        11.56    01.04    APR 15    23.38    12.26       <<<==========
                     11.37    01.17    MAY 1     23.24    12.34
                     11.22    01.30    MAY 15    23.13    12.43
                     11.13    01.43    JUN 1     23.06    12.51
                     11.10    01.51    JUN 15    23.06    12.58
UTC TIMES            11.14    01.53    JUL 1     23.09    13.01
```

Fig. B-8: COMPARATIVE SUNRISE/SUNSET TIMES AT STILLWATER, OKLAHOMA AND THIMPU, BHUTAN (partial list)

Earlier in this Section we referred to a "second peak" occurring about 9 PM at the transmitter (ie. about three hours behind the dusk terminator). In many cases for Asian signals, this will correspond with dawn at the receiver in North America, especially in the Eastern and Central time-zones. Now refer again to Figure B-8. As compared with the "true grayline" on April 1st, notice that on January 1st, sunset in Bhutan precedes sunrise at Stillwater by some two and one-half hours. In this case at least, the maximum signal (seasonal peak) from Bhutan occurs after the terminator has already passed over the transmitter several hours previous, whereas it is dawn at the receiver.

It took us a while to notice this relationship but when we did, we rapidly concluded this was a phenomenon that warranted further study. We shall return to the seasonality issue at the end of this Section and in following Sections.

## TROPICAL BAND PROPAGATION MECHANICS - THE CONVENTIONAL VIEW

Accepting the conventional view of shortwave propagation as outlined in Section A, the signal path from anywhere in North America to a given location in Asia requires a minimum of four hops, assuming about 2,000 miles per hop based on night-time F layer propagation. This translates into signal losses associated with a minimum of four refraction points in the ionosphere and three intervening ground reflections. Let's think about that! To cite Yuri Blanarovich, whom we shall introduce in Section C, "considering the natural dispersion of the signal with distance and loss per [refraction] off the ionosphere and [reflection off] the earth, it seems to me that it is very unlikely that we could have any signal left at the other end". [6]

But, if there were some way in which the number of hops could be reduced, complemented by a decrease in the amount of absorption at each point of refraction/reflection, this could mean a useful increase in the strength of the signal by the time it reaches us. This is what seems to take place with partial darkness or twilight propagation, thus affording greatly improved reception.

Partial darkness at either end of the path offers significant advantages when compared to an all-darkness path, while twilight at both ends of a path is presumably more advantageous than twilight at only one end. Thus, "true grayline" is commonly considered to be <u>the</u> preferred path.

Let's consider four geophysical phenomena associated with twilight propagation. In each case, enhanced signal levels could occur due to less signal absorption resulting from the manner in which the signal is refracted and/or "ducted" in the ionosphere:

### 1. <u>Less Absorption Due To Fewer Signal Hops</u>:

During daylight hours, the D layer of the ionosphere is present and absorbs skywave signals at Tropical Band frequencies, thus making long distance reception impossible. Daytime MUF's often exceed 20 MHz.

At dusk, however, the D layer begins a period of rapid decomposition as a result of the process known as "recombination". Although it does not totally disappear until some hours after sunset, the D layer ceases to be a major propagational factor after dusk.

The reverse process occurs during the dawn period. As the sun rises above the horizon, the D layer begins to form, slowly at first, then rapidly until it reaches peak strength near local noon. Note than "sunrise" at ionospheric heights occurs some minutes before sunrise at ground level. The initial formation of a weakly ionized D layer at dawn again is advantageous. How is this so?

During these twilight periods, the D layer has ceased to be (or is not yet) strong enough to absorb the Tropical Band skywave signals. What it does is "deflect" or more precisely - refract, the skywave signal from the transmitter in a way that the angle at which it reaches the higher F layer (the "angle of incidence") is such that the wave is flattened out or lowered to some degree. The intervening E layer may play a complementary role in this process as well.

As a result of this change in the wave angle, the signal travels further in this modified trajectory before being refracted back to earth. The geometry of this event is clearly shown in Figure B-9, although the wave angles and height of the layers are very exaggerated in this sketch. Signal "B" is launched from a from a transmitter in the twilight zone at local dawn, whereas signal "A" is launched in total darkness.

In addition, the lower angle of arrival after refraction means the wave has travelled correspondingly farther before the initial reflective "bounce" on the earth's surface. This longer hop ultimately translates into fewer hops required to travel a given distance from transmitter to receiver, and thus, less absorption.

The effect of the "tilt region" shown in Figure B-9 will be discussed later. Notice also that the two-dimensional drawing, if taken literally, shows sunrise enhancement at the transmitter. A grayline path would require that the signal travel along the terminator (looking straight down the page). In a partial darkness situation where twilight is occurring at the <u>receiver</u> location instead, correspondingly enhanced refraction of the final hop would seem to account for the distinct dawn or dusk signal peak.

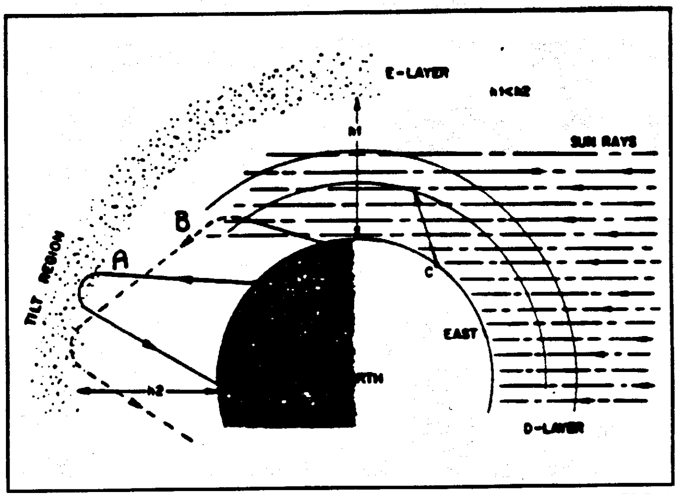


Fig. B-9: D LAYER "DEFLECTIVE" REFRACTION IN A TWILIGHT ZONE [4]

In a grayline situation, <u>both</u> signal launch at the transmitter and reception at the other end of the path are deemed to be beneficiaries of this twilight enhancement. What is not well understood is the propagational behavior along the terminator <u>between</u> the transmitter and the receiver. Here, one might speculate that the presence of a moderately ionized E layer along the path could be an important factor. We just don't know. But whatever the interaction between the signal and the ionospheric layers, if the signal leaving the transmitter remains focussed on the terminator it would be following the great circle or shortest path to the receiver. Sometimes, however, the signal may "veer" into the darkness zone along the way. Typical causes might be a differential MUF due to "patchy clouds" in the ionosphere or bending around the auroral zone. While this would result in a skewed path, the enhancement associated with twilight at both ends of the path might well still occur.

2. <u>Less Absorption Due To More Efficient Refraction</u>:

We have seen how refraction by "deflection" in the twilight D region reduces ultimate absorption because the number of signal hops to travel a given distance is reduced. A second beneficial effect deriving from D layer refraction at twilight serves to reduce absorption even more: an actual reduction in the amount of absorption at the time the F layer refraction process takes place.

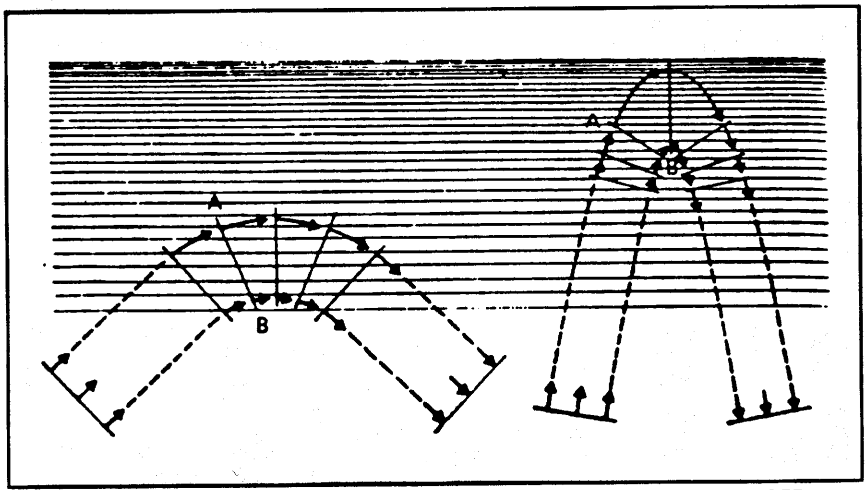


Fig. B-10: IONOSPHERIC REFRACTION OF A LOW AND HIGH ANGLE WAVE FRONT [7]

When a radio wave reaches the charged particles composing a refracting region of the ionosphere (for our purposes this is generally the F layer), it penetrates the refracting layer and is gradually bent back towards the earth. Refer to Figure B-10. A certain amount of energy is absorbed or lost during this "conduction" process due to the interaction with free electrons which are also present in the ionized region.

If the radio wave arrives at a high, almost vertical angle, it must penetrate the ionized region further before interacting with a sufficient concentration of charged particles to be refracted. This means a significant loss of energy.

On the other hand, a signal which reaches the ionosphere at a lower angle, such as we determined would occur during a twilight period, is more easily refracted with less penetration of the ionized region. The result of this more efficient refraction is, of course, appreciably less absorption. Amateur radio operators working DX try to take advantage of the same principle by using an antenna system that will provide a low "takeoff angle" from the transmitter.

### 3. Ionospheric Tilts:

Twilight signal enhancement has been described in terms of reduced absorption from two points of view: fewer hops and more efficient refraction, both deriving from the manner in which the weakly ionized D layer, and possibly the E layer, "deflects" the originating signal before it reaches the higher layers of the ionosphere.

Reference was made in Section A to the rapid vertical movement of the layers during the dawn and dusk period. This transitional process affecting the E and F layers is another regular occurrence in the ionosphere which is not sufficiently understood. However, the refracting layer(s) in the ionosphere are literally tilted at twilight, possibly producing even flatter wave-paths. This complementary effect would contribute to an even longer hop than would be defined solely by the process associated with the twilight D layer. In addition, it is noted that a tilt zone (at the receiver) may augment the increased signal strength naturally resulting from Spherical Convergence at distances beyond 6,250 miles.

So, while the process is not entirely understood, there is little doubt in professional circles that ionospheric tilt mechanics is another important factor contributing to enhanced twilight propagation and reception.

### 4. Signal Ducting in the Ionosphere:

Conventional views of Tropical Band propagation recognize Chordal Hop, Whispering Gallery and Ducting modes as possible but very exceptional means of shortwave propagation. An ionospheric tilt condition seems to be the common denominator associated with these three phenomena, all of which are associated with twilight propagation.

Simplified views of ionospheric tilt can be seen in Figure B-11 and Figure B-12 appearing on the next page; also refer back to Figure A-6.

#### (i) CHORDAL HOP

With the right ionospheric tilt condition occurring near the transmitter and a complementary ionospheric tilt present near the receiver, the twilight propagation mode referred to as "Chordal Hop" may occur.

In this situation, when the signal from the transmitter reaches the F layer it is refracted in such a way that it is not immediately bent back towards the earth. Instead, the trajectory of the signal under the F layer is flattened, resulting in an extended skip distance without actually returning to earth. Eventually, the signal is returned to earth, ideally when it encounters a corresponding twilight tilt condition at the receiving end. Since several intermediate hops are eliminated, absorption is greatly reduced so the signal may be much stronger.

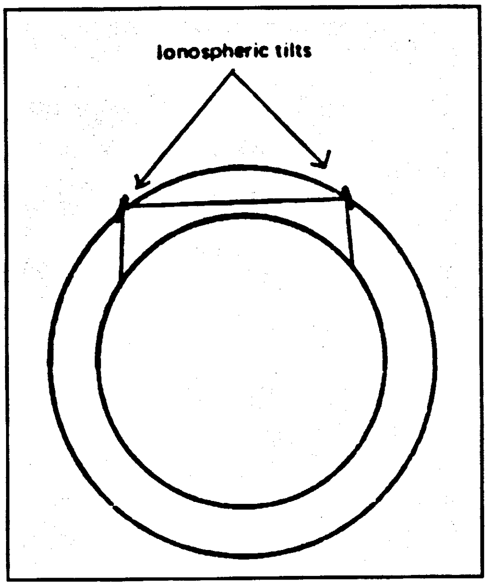


Fig.B-11: CHORDAL HOP PROPAGATION [8]

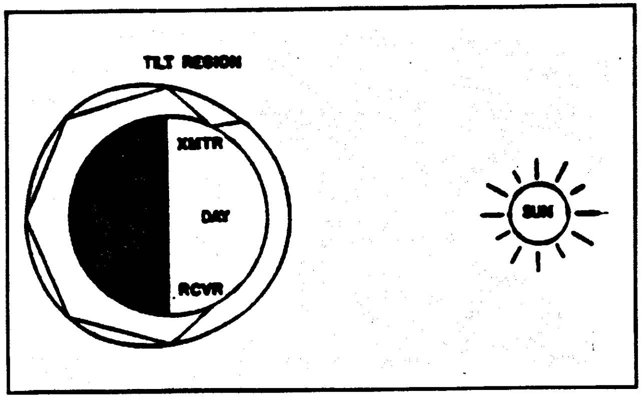


Fig. B-12: WHISPERING GALLERY PROPAGATION [4]

(ii) WHISPERING GALLERY

In this variation of the same general phenomenon, the signal from the transmitter undergoes twilight D layer "deflection" to reach the F layer, whereupon it is initially refracted in such a way that it adopts a multiple refraction mode in the ionosphere and travels an extended distance before returning to earth.

(iii) DUCTING

This is a process of multiple "reflections" between the underside of one layer or sheet and the convex upper side of a lower layer, apparently with minimal absorption. Ideally with the right twilight condition, probably associated with an ionospheric tilt, a strong signal is eventually returned to earth at the receiving end of the path.

In the PROCEEDINGS 1989 article relating to 'The Auroral Factor', Clark discusses why he believes these signal ducting modes may well facilitate enhanced trans-polar propagation on north-south great circle paths crossing the auroral zone from Asia to North America, especially during periods of magnetic storming. Trans-equatorial (south-north) paths from South America may also benefit from ducting phenomena, again seemingly associated with the early stages of a magnetic disturbance.

## SEASONALITY

No discussion of Tropical Band propagation from a North American perspective would be complete without some consideration of the seasonal characteristics of weak signal propagation, particularly that from Southeast and South Asian regions. The interesting thing about seasonal peaks is that they seem to be COMMON across most of the continent, notwithstanding that considerations such as partial darkness paths and the auroral factor introduce a high degree of variability in day-to-day reception, depending on the DXer's location.

Throughout North America, Indonesians normally peak near the fall and spring equinoctial periods: mid-September to mid-November and again, mid-February to mid-April. Reception from the Indian Sub-continent, however, is essentially confined to about six weeks per year, centred on mid-December. This is a consistent pattern, notwithstanding the great variation in the great circle and grayline paths from widely separated locations in North America.

There also seems to be a relatively consistent Papua New Guinea season which is basically the "summer" half of the year. Reception in the East does tend to be noticeably better near the Equinox, however, because high static levels during the hemispheric summer frequently mask the PNG's.

Medium wave DXers from the West Coast also note a seasonal swing in the "preferred path" which is generally consistent with our experience on the Tropical Bands. The "Asian Season" for stations from the Southwest Pacific and coastal China is near the Equinox, while other Pacific and 'Down Under' signals are predominate during our summer months - winter in the Southern Hemisphere. Strangely enough, the medium wave "mid-winter anomaly" occurs at the very same time that Tropical Band reception from the Sub-continent exhibits its short, dramatic seasonal peak.

Where does this leave us with the seasonality question? The issue has not been accorded any serious attention in hobby publications. Even with a good deal of searching, the authors have found no scientific or engineering work on the subject either, beyond the simple notion of the cyclic rotation of the day/night terminator. In that regard, we have already noted that seasonal peaks certainly don't necessarily follow the "rules" for grayline paths. This was the clue that eventually caused us to recognize that seasonality seemed to be much more associated with some phenomenon taking place at the transmitter, rather than at the receiver.

## UNRESOLVED ISSUES

The foregoing is a general explanation of Tropical Band propagation, largely supported by a variety of respectable sources. In most respects, the conventional view of the mechanics of Tropical Band propagation is a satisfactory "everyday" working model. It has been the accepted view for over half a century and is the basis for many international agreements concerning use of the entire radio spectrum.

But, over some twenty years or so, the authors have observed a number of phenomena which cannot be suitably explained by the conventional view of propagation, especially as it applies to the Tropical Band. Here are three rather consistent reception conundra that remain unresolved:

(1) The mystery behind the distinct seasonality of much of our DX is the central issue. The PNG's are heard in the North American summer (especially in central and west coast areas) when the Pacific and Southeast Asia are about the only areas of Asia in darkness. At the Autumnal Equinox, the season moves west into Indonesia and eventually into the Sub-continent for a short while at mid-winter. By late-January, the seasonal pattern has begun to reverse itself.

Why are the PNG's not heard, except for a few rare mornings, during most of the traditional Tropical Band DX season in North America? There is a darkness path the full distance. We will acknowledge that the winter of 1989-90 was somewhat atypical in this regard.

(2) West Coast DXers in particular have noticed a very interesting fade pattern when listening to a Central or South Pacific stations that operate late into the night. After the initial fade-up and peak at terminator sunset (at the transmitter), signals will usually diminish somewhat and then climb again two to four hours later, centred on 9 PM at the transmitter. This second peak may even be stronger than the initial showing. Why is this so? The path-length is in full darkness at this time.

In this Section we identified the relationship between the time of the dusk terminator and the seasonal peak of Bhutan during the sub-continental season. Can it be that the situation at the transmitter is associated with the seasonality of our DX on the Tropical Band in North America?

(3) Central North American DXers note another phenomenon. For about four weeks centred on the winter solstice, it is possible to hear stations from Central and West Africa. Sometimes this may be sunset enhancement at the receiver; other times, the signal is travelling a total darkness path. In most cases, the signals heard at African signoff (around 2300-2400) are substantially stronger at this early evening hour than the signals from the same transmitter at sign-on (0300-0500) on the same local night. Why is this so? Both receptions are on the same path, usually in total darkness. Even on the East Coast where the Africans are much more consistent, the initial afternoon peak at the receiver very often yields the best reception. We wonder if this phenomenon is also more closely associated with the geophysical situation in the region of the transmitter, rather than at the receiver.

Finally, we remain unsatisfied with the classical explanation of sunrise enhancement at the receiver. The conventional understanding seems plausible on the surface: less attenuation in general and fewer hops due to tilt geometry. However, for this to work, the geometry would have to conveniently change enough to eliminate a full hop, for example, reduce a four-hop path to three hops. Alternatively, the ionospheric dawn would have to "cut off" or substantially absorb the higher angle rays, allowing only the lower angle ray to reach the receiver unimpeded. The classical multi-hop model of sunrise enhancement at the receiver is shown in Figure B-13 with all regions and wave angles idealized.

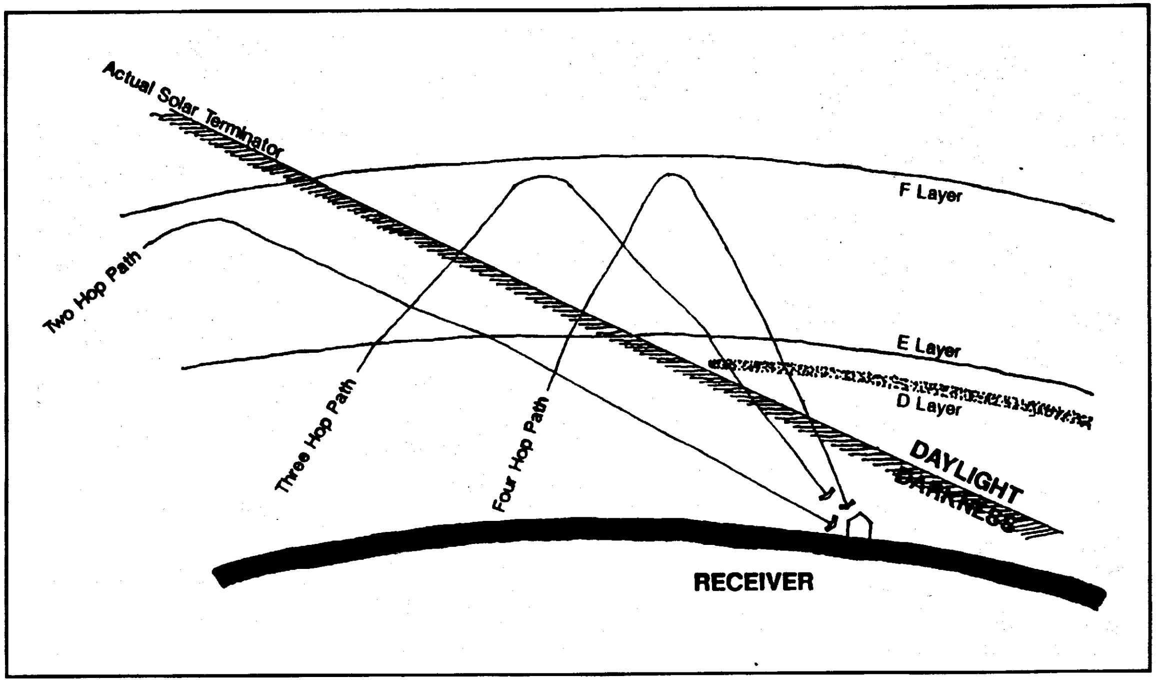


Fig. B-13: CLASSICAL MODEL OF IONOSPHERIC REFRACTION AT DAWN AT THE RECEIVER

Our difficulty with this model stems from the fact that it does not fit with physical reality. We don't believe it adequately accounts for dawn enhancement when the ray path is perpendicular to the terminator and it most certainly can't account for "true grayline" enhancement!

If this model was true to physical reality, before commencement of dawn enhancement the two-hop ray path would mix with the three and four-hop ray paths, regardless of the signal level. We would expect considerable multipath distortion and fading due to different arrival times, at least until the initial formation of the overhead D layer at ionospheric dawn might absorb the downlink of the higher angle paths to the receiver. At best, phase cancellation might sometimes augment and other times decrease the signal level but we would still expect deep fades to occur. Neither do we notice the more rapid flutter fading due to phase shifts typical of HF frequencies of shorter wavelengths. Moderate cyclic fading is of course normally experienced.

Simply stated, in many hundreds of DX sessions at dawn over the years, we have NEVER noticed any form of transitional fading, or distortion, at the beginning of dawn enhancement when signals which were totally absent or barely detectable rise above the receiver noise floor in a very smooth, elevator-like fashion. During good openings, even very low-powered signals such as the Indonesian RPD's with typical power of only one or two hundred watts can sometimes appear in a matter of minutes and reach quite listenable, undistorted levels.

To us, the consistent behavior of Tropical Band signals during dawn enhancement calls the entire conventional explanation of twilight propagation into question.

The three reception conundra cited above and the lack of a satisfactory explanation of twilight enhancement have also been troublesome to other experienced DXers. So, the authors decided to investigate what might exist in the body of knowledge of the scientific world and the practical world of amateur radio that might better explain Tropical Band propagation. The results of our search were startling, to say the least!

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[7] Pejza, Fr. J. "A Beginner's Guide to The Ionosphere". NATIONAL RADIO CLUB REPRINT #10.

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# SECTION C

## ELECTROMAGNETIC WAVE PROPAGATION BY CONDUCTION [1]

[1] This Section was excerpted from an article by Yuri Blanarovich, VE3BMV, and appears here with the kind permission of the author. Mr. Blanarovich's work originally appeared in CQ Magazine (June, 1980), and was reprinted in his own publication, RadioSporting, in December, 1986.

ABSTRACT -

Mr. Blanarovich draws upon his extensive experience as an amateur radio DX contester to explain why he regards the traditional multi-hop model of skywave propagation as being fundamentally flawed. His main premise is that the ionospheric layers do not so much "reflect" RF energy back to earth at regular intervals as they do refract and "conduct" the energy along the edge of or between two layers at relatively low loss and for much greater distances. Blanarovich cites practical support for his "refraction" model based on experimentation with very highly directional antennas and on determination of optimum takeoff and arrival angles.

Bryant and Clark comment on their reaction to the Blanarovich work, citing general agreement with his observations to the extent they suggest a model which is far more consistent with the authors' own experiences with twilight enhancement as Tropical Band DXers.

Quite often, new advances in technology and measuring equipment can produce some surprising results. In my case, it was the opportunity to advance from wire and vertical antennas into rotatable antennas. Being interested in the mechanics of radio wave propagation, observing the various modes of propagation and trying to put two and two together, I was not always satisfied with available explanations in the literature.

The matter was aggravated when I started to play with high performance antennas: the Razor Beam of my own design. As far as I was able to tell, these antennas produced maximum obtainable gain per given boom length with excellent front-to-side and front-to-back lobes. The real test of the antennas came with the CQ contests when a number of things could be observed that normally would be unnoticed when using "ordinary" antennas. Contests allowed me to observe a number of anomalies and exceptions to present propagation theories by virtue of the great amateur population on the air at the same time all over the world.

The antenna system allowed me to observe various angles of radio wave propagation. The deeper I got into my observations, the more I became convinced that the present theory of electromagnetic wave propagation, which tells us of signals bouncing between the ionosphere and the earth is not entirely consistent and perhaps not valid.

More thinking and sorting out of ideas led to some interesting conclusions that I would like to present here. It is my hope that this article will stir up quite a bit of controversy and discussion, and that it will contribute to the clarification of the matter. Presented here are observations that I was able to collect in the limited time available...more work must be done to collect more accurate supporting evidence.

## REFLECTIVE THEORY

The present radio wave propagation theory is based on the assumption that radio waves are propagated by reflections from a mirror-like ionosphere, returning to the earth's surface, bouncing off it back to the ionosphere and so on. Let's call the present propagation theory "reflective".

Reflections are only one possible explanation for getting the signals from the sky at those angles. It is unfortunate that early propagation scientists such as Heaviside, Appleton, Briet and Tuve apparently did not get exposed to more of the work that was being done in optics at that time. In 1870, John Tyndall presented the earliest recorded scientific demonstration of a peculiar optical phenomenon: light being trapped in a stream of water. In his demonstration he showed that when a stream of light was allowed to flow through a hole in the side of the vessel, light was conducted along the curved path of the stream, This was the closest thing to fibre optics. Too bad they did not see the similarity between radio waves and light and get the idea of another way of propagating radio waves. Today we know that light is on the high end of the electromagnetic spectrum.
So this was a handy explanation: "mirrors in the sky" reflecting radio waves back to earth. The generally accepted idea has carried to the present day and any anomalies have been judged as exceptions. All kinds of explanations have been tried in order to explain the mechanics of unusual propagation modes.

## A CRITICAL LOOK

Let's have a look at the reflective theory and see how well it fits real life. The first thing that really hit me is that the earth is usually drawn on one scale and the ionospheric layers are drawn to another scale, about 10x (Figure C-1). It explains how signals might reflect but does not approximate the real geometric condition.

When the earth and the ionospheric layers are drawn to scale, it seems that we need about four hops to propagate a signal one quarter way around the world (assuming an average launch angle of 11 degrees and F2 layer height of about 500 km on a summer day). Working Europe on long path would require about twelve hops. Considering the natural dispersion of the signal with distance and loss per reflection off the ionosphere and the earth, it seems to me that it is very unlikely that we could have any signal left at the other end (Figure C-2).

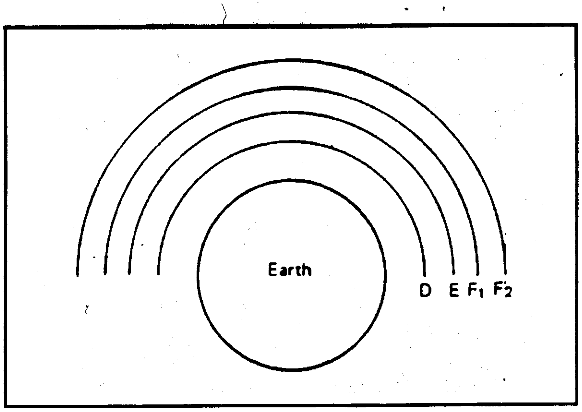


Fig. C-1: TYPICAL PRESENTATION OF IONOSPHERIC LAYERS

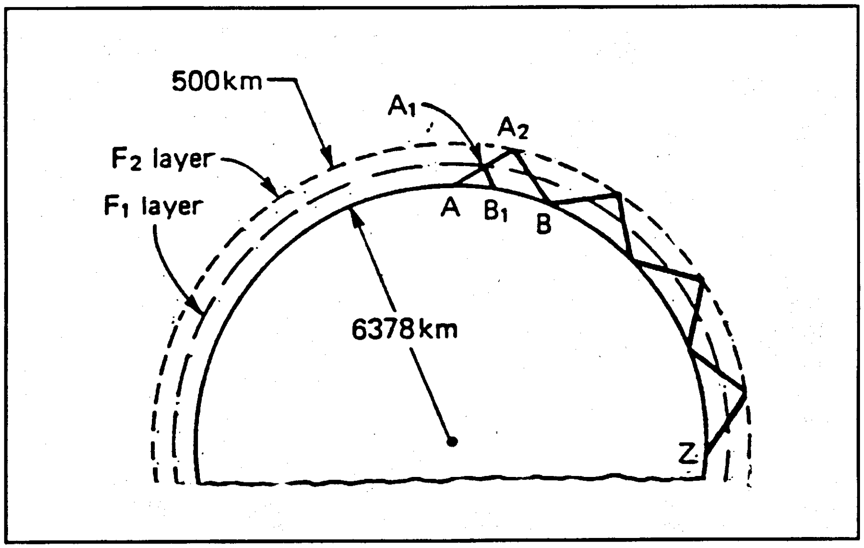


Fig. C-2: CONVENTIONAL MODEL OF MULTI-HOP PROPAGATION WITH THE EARTH AND IONOSPHERE DRAWN TO SCALE

The typical picture of the mechanics of reflection from the ionosphere (Figure C-3) is also questionable. In order to reflect signals, one would expect a good reflective surface, larger than the wavelength and of good conductivity with a clearly defined surface border. But we know the ionosphere is very thin and the molecules are widely separated.

I find it hard to believe we can get sufficient reflection of signals from that type of medium to yield the signal levels that can be experienced. The shape of the curve is also very unusual - it looks like refraction over about 270 degrees. In reality, the ionosphere would rather absorb the signal energy than "turn it around".

Various propagation modes that cannot be explained by present theory are labelled exceptions and a great deal of speculation and effort has been used to try to make them fit with conventional theory. We will try to explain these exceptions with a new theory.

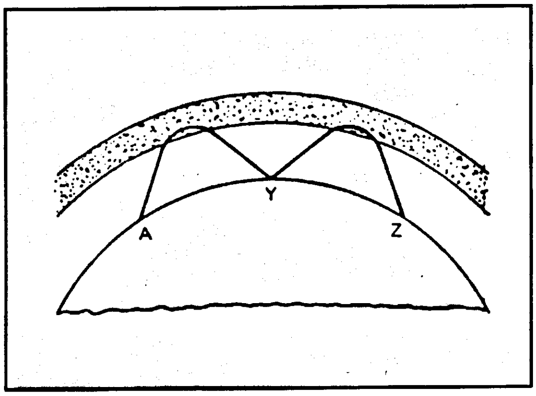


Fig. C-3: CONVENTIONAL REPRESENTATION OF IONOSPHERIC REFECTION

## THE NEW THEORY

We have problems understanding the mechanics of radio wave propagation because it is virtually impossible to simulate the many variables associated with the real situation in a laboratory setup. The best we can do are studies using satellites and electromagnetic wave sources in space or here on earth.

The closest analogy we have available is optics and fiber optics. Radio waves and light do have one thing in common: they are electromagnetic waves with different wavelengths. Recent advances in fiber optics can help us understand the behavior of light propagation, as well as radio waves. But it still difficult to make a good analogy because of the many variables in the atmosphere and the biggest contributor to ionospheric variations is radiation from space, mainly from the sun.

When looking for a better explanation of radio wave propagation, it struck me that there must be more "conduction" going on up there than reflection. As a result of my observations over a number of years, I came to the conclusion that radio waves propagate in a medium that resembles a cloud or a cross between a cloud and fiber optics.

The basics of this new propagation theory can be summarized in the following statements:

> A majority of radio waves are refracted and propagated (ie. conducted) along the borders of media with different dielectric constants and are accompanied by scintillation. The geometry of propagation is dependent on the frequency used and the condition of the atmosphere.
>
> The propagating medium has a cloud-like formation with the density and conductivity varying along its profile and dependent on the physical condition of the atmosphere and the amount of radiation from space.

## INTERPRETATION

Accurately visualizing the mechanics of radio wave propagation is difficult because we are dealing with a three dimensional medium with varying density and a cone of radio signals propagating through that medium. The situation is further complicated when considering a broad spectrum of frequencies and different angles of refraction and conductivity, dependent on the frequency.

In Figure C-4 we have the earth and the ionosphere drawn to scale. To simplify matters, the beam of transmitted radio signal will be shown as a ray: using a solid line for a strong signal, a broken line for a medium strength signal and a dotted lone for a weak signal. Ionospheric density or radio conductivity will be shown as a heavier shaded area for good conductivity and with a lighter shading for poorer conductivity.

The signal is transmitted from point A. Line of sight strength decreases after point B. But the main lobe of the antenna puts most of the signal into the atmosphere and refraction begins at point C. A portion of the signal gets refracted immediately and a portion passes through to point D. Then the refracted signal continues through points E, G and H, more or less following the curvature of the earth. Scintillation along the path is noticed as backscatter and sidescatter. A portion of the signal is refracted back to earth and received at points W, X, Y and Z. At point D, a major part of the signal was refracted but a portion continues through D to point F where it either now gets refracted or continues on into space. A portion of the refracted signal on the higher path can be refracted back to earth at point K, at a different angle. It may combine with the signal propagated by the lower path, causing considerable fading.

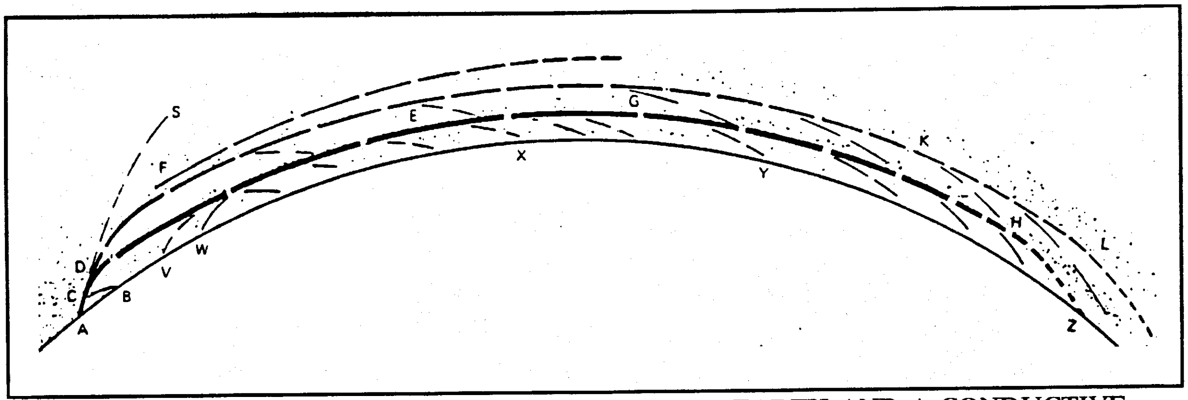


Fig. C-4: SCALE DRAWING OF A PORTION OF THE EARTH AND A CONDUCTIVE IONOSPHERE SHOWING WAVE PROPAGATION

In real life, the situation is rather more complicated due to the wider beam-width of the transmitted signal, irregularities in the medium and the range of frequencies and angles of the transmitted signal. There is also an indication that the rate of travel of the radio waves can vary in different layers, and this, combined with the scintillation or scattering of the signal, can be observed as a Doppler shift of the signal's frequency.

Scintillation in this case can be compared to the situation where we have a strong source of light with its beam going through a patch of fog. Particles of fog will be glowing or scintillating and become visible. A portion of the beam will continue to propagate after passing through the fog patch.

## SUPPORTING EVIDENCE

When observing the rising or setting of the sun or the moon, we observe refraction of light in the layers of the atmosphere. It is a well-known fact that the sun or moon can be "seen" after they actually set below the horizon, the lag being about 12 minutes. Also, the image or the size of the sun or the moon quite often appears to be larger than normal. This is definitely not reflection. We do not see the "mirror image", but rather the actual "picture". Why shouldn't radio waves behave in a similar manner? Whereas light is an electromagnetic wave having a very short wavelength, the longer radio frequency wavelengths are easier to refract or bend, but harder to reflect.

During overseas contacts, sometimes a sudden frequency shift, very similar to what we call "selective fading", can be noticed. I have observed fading on a DX contact's signal, accompanied by a slight shift in the frequency of his signal.

The familiar "arctic flutter" and raspy signals propagated from the aurora are another example of the frequency shift caused by propagation of signals through the medium. Arctic flutter can be simulated by tuning two receivers to the same signal and then slightly detuning one receiver's VFO. The signal will sound as if it has just passed over the Pole with familiar flutter. Signals propagated through the auroral region exhibit multiple frequency shift. Another noticeable feature of this frequency shift is the absence of the higher notes in the audio response of the shifted signals.

One important thing is apparent from these observations. When one is calibrating a receiver to WWV and his location is such that he is receiving a backscatter signal, then there is a good chance that he might be slightly off the absolute frequency. [Mr. Blanarovich makes reference to frequency shifts in the order of 500 Hz, although this would be a much greater magnitude that is mentioned in any professional sources we have found.]

Let's assume for now that signals are propagated by conduction rather than reflections and we will look at the various modes to see how well they fit the theory.

## SHORT PATH

We again assume a single ray of radio signal in Figure C-5 which shows a signal transmitted from point A. The skywave ray gradually bends (refracts) through the atmosphere until reaching point D - a distinct border of two layers with different dielectric constants. The main portion of the signal follows the border along points D, E and G. Some portion of the signal refracts back to earth and allows us to receive the signals with relatively even strength along the line represented by points W, X, Y and Z. Depending on the refractive angles, we can receive signals under low (path D-Y) or higher (path D-X) angles. Note that point V (in the skip zone) gets almost no signal because the angles of refraction will not supply any signal. Very weak (backscatter) signals may be received as a result of scintillation at points E and G. A portion of the signal transmitted from point A at higher angles is refracted or partially refracted (paths A-C) and reaches another layer or escapes into space.

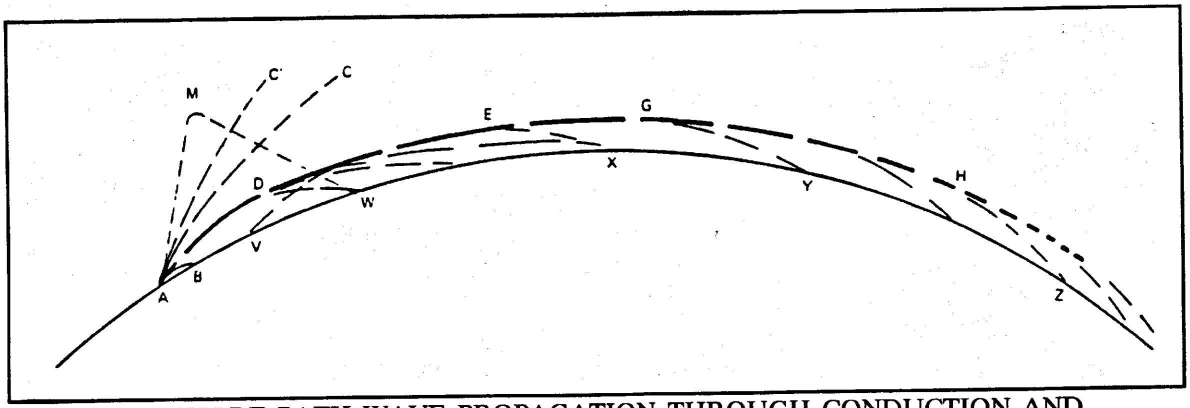


Fig. C-5: SHORT PATH WAVE PROPAGATION THROUGH CONDUCTION AND REFRACTION

Whereas the dotted line shows the path A-M-W as explained by the reflective theory, it appears that we are actually propagating the main portion of the signal at considerably lower heights than previously thought. Having antennas with low angles of radiation extends the useful range of propagation under adverse conditions with lower angles or refraction.

## DAY - NIGHT VARIATIONS

Figure C-6 shows a signal being radiated on a 45 degree bearing from Ontario, across Europe to Asia. It's early morning in North America, the sun is over Europe and it's evening in Asia. The atmosphere is warmed by the sun's radiation, raising the height of the layers over Europe and changing the dielectric constant of the media affecting the refractive angles. The "hump" over Europe causes the signal to change its direction and at about 1400 local time, only weak signals, mainly resulting from scintillation, are audible in that area. Ontario and Asia have no problem communicating, with conditions actually peaking between the two points. This is a changing situation with time of day, radiation from the sun, frequency and angles of refraction. The example given is typical for the higher frequencies in the range of 14 to 30 MHz.

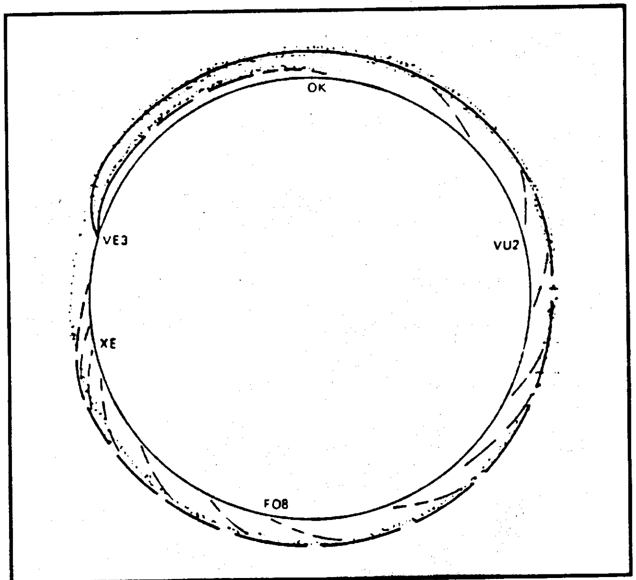


Fig. C-6: ILLUSTRATION OF DAY-NIGHT VARIATIONS IN PROPAGATION

It is known that with increased sunspot activity, the thickness (electron density) of the ionosphere increases. The height of the propagating layers also increases, and thus increases the height and length of the signal "arch", allowing us to span longer distances and propagation on the higher frequencies is extended later into the night.

We have been told that during peaks of solar activity, the lower bands are very poor, due mainly to D layer absorption. But at night the D layer disappears and at time of writing (1980), propagation on the lower bands has been better than what we experienced during the sunspot minima. It appears again that the (nighttime) refracting layers are higher, allowing us to work longer distances with stronger signal levels.

## LONG PATH

Long path can be explained as an extension of the short path propagation with the signals following the higher layers where the losses can be lower, thus resulting in less signal attenuation. As shown in Figure C-7, we still get some refraction towards the earth and the signals are heard along most of the path.

The path does not have to be a (great circle) straight line. Quite often we experience a skewed path which can be the result of side refraction (with quite strong signals) or the result of scintillation (with weak signals at low angles).

The best case of long path would be the situation whereby signals get "trapped" in layers with low attenuation and travel a number of times around the earth, causing long delayed echoes.

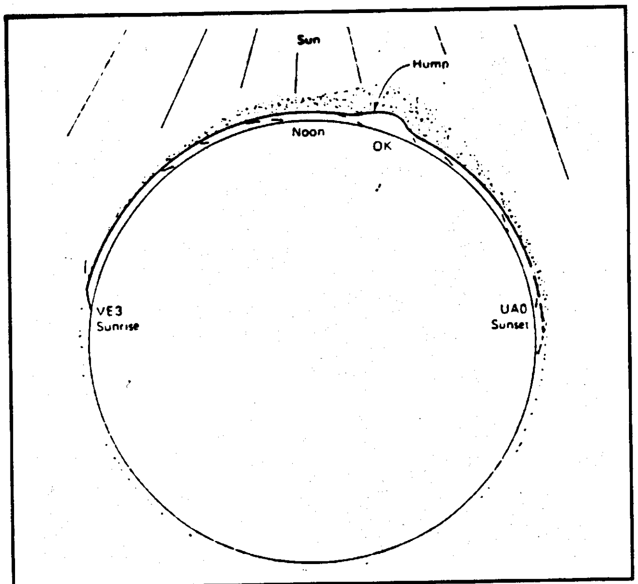


Fig. C-7: COMPARISON OF LONG AND SHORT PATH PROPAGATION

## GRAY LINE PROPAGATION

Here we have the case where the medium is more or less at the same height, the refractive layers are more uniform - without major humps, and this allows us to propagate signals along that path over a wide range of frequencies with relatively little attenuation or refraction in the unwanted directions. Again, low angle antennas should perform best.

When signals are aimed in the direction of the gray line, just about any point on earth on the gray line can be communicated with, especially at the lower frequencies.

## ONE WAY PROPAGATION

Quite often we experience basically one way propagation. For example, in the late afternoon, strong signals are heard on the 40 meter amateur band from Europe but it is nearly impossible to work the Europeans from North America, either with high or low angle antennas. Later on, signals become stronger on a low angle antenna and contacts become possible.

This can be explained by scintillation, such as we see on the end of a fiber optic fiber. When light exits a fiber and the exit end of the fiber is ragged rather than smooth or when there are impurities in the fiber at the exit point, the light is dispersed at broad and random angles as it exits. Under those circumstances, it is easy to visualize the impossibility of returning light along the same route to the original source. A similar situation can exist with radio signals and the conducting layers.

Another form of one way propagation is caused by different refractive indexes at each end of the path. Going in one direction, signals can be refracted gradually and due to local conditions at the other end they can exit or be refracted towards the earth. For the transmitted signal, the angle of refraction can be different and the ionosphere will not refract the transmitted signal into the same layer that the received signal is being propagated.

## TRANSEQUATORIAL AND OTHER VHF PROPAGATION

This type of propagation was discovered when stations located close to the same meridian were able to work each other across the equator. This propagation usually peaks just after sunset and appears to be another form of gray line propagation where we have a uniform medium with gradually changing height near the equator resulting in propagation over great distances. I would predict that given good conditions, it might be possible to establish contacts on the 2 meter band between Ontario and Argentina.

If refraction replaces reflection and scintillation replaces scatter, then many of the "unusual" VHF propagation modes can be explained and better understood. Horizontal polarization seems to be better for long haul VHF propagation at lower heights than previously assumed based on reflection. This is probably due to the fact that the orientation of borders of media (ie. layers) with different dielectric constants are oriented horizontally, thus enhancing the refraction of horizontally polarized signals.

## RECEIVE vs TRANSMIT

Having different antennas available and switching between higher and low angle antennas, I have found during numerous tests that there can be quite a difference between the angles of transmitted and received signals. The optimum angles change from hour to hour and day to day too. In addition, choosing the optimum angle for discrimination against noise can improve the signal-noise ratio tremendously.This has been observed on all amateur bands from 10 meters down to 80 meters.

On the higher frequencies (eg. 15 meter band) it has been found that most "short skip" signals are strongest at a low angle. This also supports the refractive theory.

## CONCLUSION

Hopefully this article will inspire hams, [shortwave DXers] and scientific institutions to do more in-depth study which will eventually enable us to make more sense of radio wave propagation with fewer exceptions, and to develop more reliable means of forecasting propagation based on the factors known to affect it. Let's not be afraid to challenge a long-accepted theory.

What I have tried to present in this article is an expression of what I feel, what I have observed and what I feel makes sense. I find it quite difficult to describe or express exactly what I have been experiencing. This is partially due to the absence of a good clean analogy, and partially due to the difficulty in verifying and expressing accurately what is happening up there.

I hope that I have succeeded in getting my main message across: maybe there are no mirrors up there but more likely something like layers or clouds which can conduct or refract radio waves.

## COMMENT: By Bryant and Clark

When we first discovered this article a decade after its original publication, we were reminded of how little information actually flows from one part of the radio hobby to another; we were also reminded that since WWII, practically none has flowed either way between the "hobby" and "professional" worlds. This was not true in the early days of radio and is not the case today in some areas of endeavour, such as naval architecture, aeronautical engineering and automotive design. We are each less knowledgeable because of these artificial barriers.

The responses to Mr. Blanarovich's article at initial and second publication were quite curious. They seem to fall into one of three camps:

1. The traditionalists steadfastly maintained that "the experts can't be wrong", so multi-hop must be the primary mode of skywave radio propagation. They are obviously unaware of the change of stance of the CCIR and the ITU regarding propagation beyond 10,000 km. In 1978, the "experts" had already changed their minds, at least concerning long haul propagation.

2. The muted response of the second camp was: "Big deal, it's been in the Handbook since the early days". This group misses the point entirely. Blanarovich contends that the mode known variously as "Chordal Hop, Whispering Gallery or Single-sided Ducting" is not a rare, exceptional mode of propagation, rather, it is the NORMAL, and maybe only mode. To our knowledge, no one in the hobby has taken that radical a stance before.

3. The third group of respondents, very few in 1980 but in increasing numbers after the 1986 re-print, acknowledged that Blanarovich's observations matched their own propagational experiences much more closely than the classical multi-hop model. They are inclined to agree that the author is on the right track in terms of "what's really happening up there".

Our reaction is this:

If HF radio propagation, at least on the Tropical Band, is primarily accomplished by refraction into near-lossless sheet-like layers, the five modes of terminator-enhanced propagation discussed in Section B become eminently understandable.

If we assume the geophysical reality underlying the observations of Blanarovich and others is essentially correct, we can also visualize a transmitter in darkness being able to "upload" energy into the layers of the ionosphere. Let's take another look at the refraction model showing the various ray paths or takeoff angles of a skywave signal entering the ionosphere:

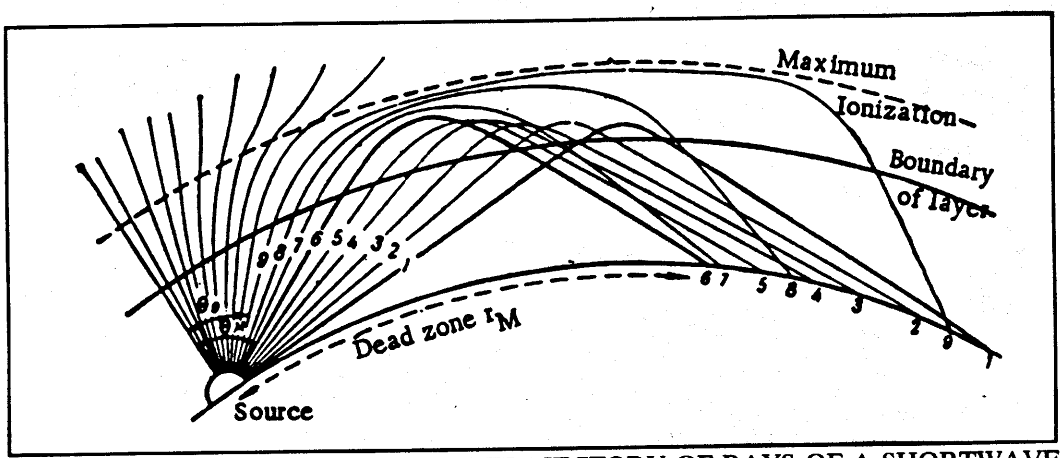


Fig. C-8: SINGLE-HOP MODEL OF TRAJECTORY OF RAYS OF A SHORTWAVE SIGNAL

Consider the 9th ray in Figure C-8, repeated from Section A. Once it is travelling in a sheet or layer parallel to the horizon, there is no obvious reason for it to come down, unless it strikes an irregularity and is randomly refracted downward; or, UNLESS THE IONOSPHERE IS TILTED and the signal is "dumped" down to the waiting receiver. In that case, it is plausible to comprehend the kinds of reception that Tropical Band DXers experience consistently. Consider the following three suppositions:

1. Assume that "uploading" from the transmitter in an all-darkness situation is fairly inefficient. A dependence on random irregularities to refract the signal back down to a receiver in full darkness is also inefficient. This mode would only work well relatively close to the transmitter ("one or two hop" distances) and would work very poorly at longer distances. Most of the time at those longer distances, a signal on a full darkness path would not rise above the noise floor of the receiver. At least that would be the case for weak, Tropical Band signals travelling 8,000 miles and more from Asia.

2. At the twilight "tilts" of the ionosphere, assume that the layers or sheets are "more exposed" and that uploading is a highly efficient operation during that brief time when either sunrise or sunset twilight is occurring at the transmitter. Then, we can easily understand the sunrise and sunset AT THE TRANSMITTER enhancements.

3. Assume that the twilight tilt of the ionosphere at dawn and dusk also causes a dumping of the signal at a relatively low angle above the horizon. The sunrise and sunset AT THE RECEIVER enhancement modes then also become understandable.

The authors recognize that Mr. Blanarovich's work is controversial but that doesn't mean we should dismiss it! We do not suggest that he is proposing a revolutionary, unsubstantiated new theory of propagation. Rather, we credit a non-professional hobbyist like ourselves who has grappled with the thorny problem of proposing a MODEL for long haul propagation which fits reality. It is hardly surprising that we would witness a conflict between the academic, "theoretician's interpretation" and the rough and tumble, real-world "radioman's interpretation". As a very successful DXer, Blanarovich certainly qualifies as one who can speak from experience.

If the complex geophysical variables which govern shortwave propagation were well-understood, even in professional circles, this article in Proceedings would likely be without purpose. For the very reason that our understanding lacks precision, any proposed analogue, such as Blanarovich's use of the optical fibre analogy, is at best a compromise and open to criticism. We would point out, however, that in the course of our own investigations we have found more than fifty major articles published by the IEEE in recent years which use the optics/radio propagation analogy. That discourse continues to this day! Perhaps Blanarovich was ahead of his time because he certainly didn't have the benefit of a number of professional articles written within the past six years which focus on the ionosphere as a vast array of layered sheets, or which discuss ionospheric irregularities in great detail.

The Blanarovich article was of value to the present authors because it offered a viewpoint based on the very practical perspective of a proficient HF DXer. It encouraged us to take the next step - to seek out professional work that we assumed must be available in the scientific community.

## SECTION D

# A TROPICAL BAND DXER'S GUIDE TO THE IONOSPHERE: DIURNAL EFFECTS AND TROPICAL ZONE IRREGULARITIES

ABSTRACT -

In pursuit of a better explanation for dawn/dusk enhancements and the seasonal characteristics of Tropical Band propagation, the authors expand their study of the geophysical characteristics of the F region in equatorial latitudes, since this region is the origin of the vast majority of the DX signals.

The diurnal variations in the equatorial F layer are examined. One principal characteristic is found to be the rapid changes in vertical height of the layer in the six hour period between sunset and midnight. A sharp rise to a peak height in mid-evening is identified.

Drawing heavily on research papers presented to a conference of The Advisory Group for Aerospace Research and Development of NATO, the authors investigate the principal characteristics of the spread F phenomenon. The formation of field aligned irregularities (or spread F) is found to be a statistically regular event in periods of quiet magnetic activity during the evening hours in the tropical zone. Research indicates that signal conduction associated with the presence of spread F may provide an alternative yet similar explanation for other ducting models.

Spread F activity is found to be most concentrated at about 9 PM in the equatorial latitudes, corresponding precisely with the peak virtual height of the refracting layer. There is a suggestion that the close relationship between these two phenomena may be linked to the seasonality associated with weak signal Tropical Band reception.

## INTRODUCTION

Most of us have stared at our receivers very late at night and wondered about the extent to which the unusual propagation that we have observed closely over the years had a basis in the current body of knowledge.

In Sections A and B, the major physical attributes of the ionosphere were discussed. Processes such as spherical divergence/convergence and tilts were noted. These two Sections together examined geophysical inter-relationships between the earth and the ionosphere and how certain of those may enhance long haul Tropical Band propagation, especially over partial darkness paths. In so-doing, the authors have challenged the long held belief which recognizes the multi-hop model as the "normal" mode of HF radio propagation. The Blanarovich "conduction" model presented in Section C continues to develop that theme.

So, for the dedicated Tropical Band DXer, we surmised that further investigation into the geophysical characteristics of the F layer in particular might lead us to a better understanding.

Although most of the DXers reading this article probably live in the mid-latitude temperate zone, the vast majority of our Tropical Band DX originates in the low latitude equatorial zone, so this is where we have focussed our efforts.

## DIURNAL CHANGES IN THE IONOSPHERE

Any description of the ionosphere records the formation of the D layer at local dawn, the partial solar control of the E layer, and the split of the F layer into the F-l and F-2 layers as regular diurnal ionospheric changes. The converse processes occur at dusk.

Only a few hobby sources make passing reference to the fact that the virtual height (h'F) of the F layer varies radically and with great speed at certain predictable times of the local day (differing also as a function of latitude). Virtual height (h'F) is the height at which signals, by geometry, appear to be "reflected" from the ionosphere. It is determined by measuring the angles of take-off and arrival.

We are unsure why this radical change in our main refracting medium has been given such superficial treatment. h'F is covered here at some length because this factor could be one of the primary driving forces in the changing propagation we notice, especially during the all-important twilight periods discussed in Section B.

The virtual height of the ionosphere changes at different rates and times in the tropics, in the temperate zones and at polar latitudes. Since most of our propagation paths travel through at least two of these zones, the relationship of DX signal paths to the changing heights of the ionosphere is quite complex.

Jacobs and Cohen contribute the classic secondary source information on h'F:

> "During the daylight hours, there are two well-defined regions: the F-1 layer, which begins slightly above the upper boundary of the E layer at about 150 km, and extends up to about 250 km, and the F2 layer, whose height varies seasonally, ranging up to about 350 km during the winter and close to 500 km during the summer.
>
> Although more highly ionized, the F1 layer behaves very much like the E layer. Maximum ionization occurs near noon when the sun is most directly overhead, and the layer disappears during the hours of darkness.
>
> Unlike the other layers, ionization in the F2 region exists at all times. This region is the most highly ionized and most important of the ionospheric layers. During the nighttime hours, the F2 layer height varies approximately between 250 and 420 km. Because the recombination rate in this region is relatively slow, the layer exists around the clock. Were it not for this fact, long-distance short-wave radio communication would be virtually impossible during the hours of darkness." [1]

## EQUATORIAL VIRTUAL HEIGHT

Figure D-1 illustrates the virtual height of the F layer above Ibadan, Nigeria (at 7 degrees, 22 minutes N.; 3 degrees, 58 minutes E.) in the International Geophysical Year (IGY) of 1957-58.

The curve connecting small, solid DOTS represents magnetically disturbed days; the more volatile curve connecting open CIRCLES represents magnetically quiet days. (Please note these Legend criteria, as they apply to several of the illustrations to follow.)

Note that the vertical movement at initiation (at, or soon after sunset) is almost 200 km/hour until a peak is reached at about 2200. Note also that the virtual height returns to the approximate 250 km height by local midnight during about 60% of the year and stays elevated somewhat later into the post-midnight hours during the Northern summer. As the night progresses, the height gradually declines, reaching its lowest level just prior to dawn.

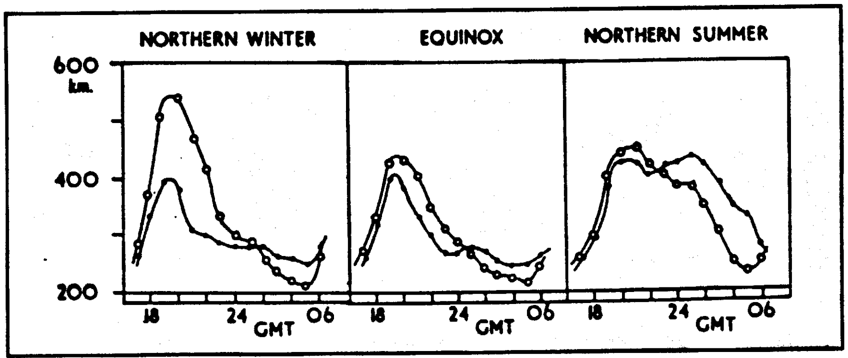


Fig. D-1: NOCTURNAL VARIATION OF VIRTUAL HEIGHT OF F LAYER (Ibadan, 1957-58) [2]

Figure D-2 is also from studies made during the IGY and tells the same story for three rather widely scattered Pacific Island locations at the Equinox. The picture is identical: rapid vertical acceleration of the F layer at dusk followed by an almost symmetrical decline to 250 km by local midnight. We should note that the IGY was the Cycle 19 sunspot-maximum year, still the highest cycle on record.

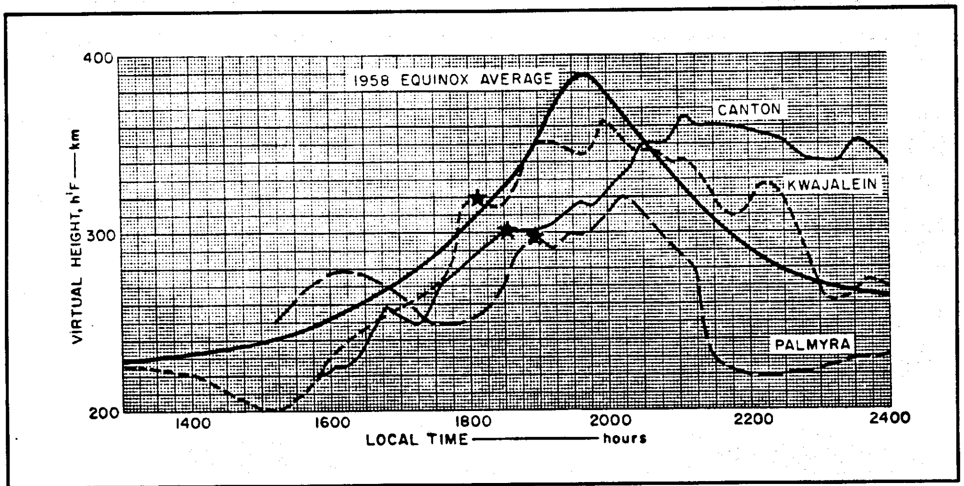


Fig. D-2: F LAYER VIRTUAL HEIGHT NEAR EQUATOR [3]

Authorities have identified two other factors which influence the rise in equatorial virtual height of the F layer during the early evening hours:

> "The rapid change of the virtual height of the F layer (h'F) at 1800 local time, is not necessarily entirely due to an actual vertical motion. Two other mechanisms which are known to be present will contribute to the rise. First, there is the 'eating away' of the bottom of the F layer by recombination due to the higher recombination coefficient lower down and solar radiation is no longer producing ionization to replace it. [The authors take the foregoing to at least partly refer to the dissolution of the F-1 layer at dusk.]
>
> Secondly, in equatorial latitudes in the day hemisphere, the ionospheric drift motions [of patches and irregularities] are from East to West and in the night hemisphere they are from West to East. If these motions represent real motions of ionization, then there will be a further loss of ionization due to the divergence [change of direction] of horizontal drift around this time of day. The influence of cooling may also affect the situation. The actual contribution of all of these effects to the F layer rise is still uncertain." [2]

As compared with the equatorial latitudes, accurate primary research data on the diurnal variation in the height of the F layer(s) at mid-latitudes is surprisingly difficult to find. Figure D-3 illustrates the best information that we could find in the scientific world.

So, we are presented with an F layer in the equatorial zone (25 degrees North to 25 degrees South) whose effective (virtual) height varies radically between 6 PM and 12 midnight, local time. The temperate zone F layer situation is more uncertain. The disappearance of the F1 zone may cause an abrupt upward shift in the effective height. Figure D-3 indicates that F2 maximum slowly comes to rest at 200-300km at about 10 PM local time.

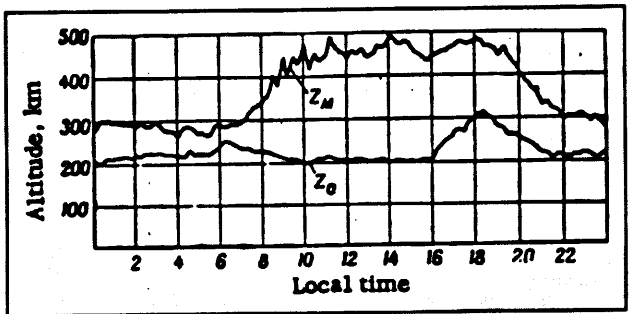


Fig. D-3: DIURNAL VARIATION IN ALTITUDE OF BEGINNING OF THE F-2 REGION AND ALTITUDE OF THE F-2 MAXIMUM. [4]

It should be interesting to Tropical Band DXers that this rapid vertical movement of the F layer AFTER DARKNESS and IN THE TROPICS does not seem to have been previously been discussed as it relates to our hobby! What's more, the occurrence of this movement bears a strikingly close relationship to the incidence of another phenomenon which has received scant attention except in isolated professional circles and yet may be very important to all Tropical Band DXers.

## THE PHENOMENON OF "SPREAD F"

From the development of the ionosonde and ionogram in the early 1930's, researchers noted an aberration in the F layer readings: when using the ionogram, often the rather precise "layers" of the ionosphere became smeared or spread. Since the image of the layers denotes the refracting layer, a spreading or smearing denoted increases in the width and depth of the refracting region. This condition is known as "spread F".

> "For many years this phenomenon was considered mainly as a difficulty to be contended with in measuring such parameters as h'F and foF2. Booker and Wells appear to have been the first workers to consider the possible causes of spread F. They concluded that it was the result of Rayleigh scattering by irregularities in the electron density of the F region. Since about 1948, considerable interest has been centered on the study of spread F, and principally because of their easy availability, most of the work in this field has been done using ionograms as the source of data.
>
> The wide geographical distribution of ionosondes and the availability of virtually continuous data from many of them, especially during the IGY, has led to a number of extremely useful geomorphological studies of spread F, and it is mainly in this field that the ionosonde data has been used. The ionosonde has also provided useful data regarding some of the conditions in the ionosphere before and during the occurrence of spread F.
>
> However, although the ionosonde is able to provide much useful information, it is basically unsuited to a detailed study of the irregularities which cause spread F. Indeed, so far as the ionogram is concerned, spread F is a disturbance which degrades the quality of the data to be obtained from it, and for this reason the sensitivity of ionosondes is usually adjusted to minimize the effects of spread F...As a result of these difficulties encountered when using ionograms as source of data a number of more specific experiments have been conducted. SEVERAL PHENOMENA RELATED TO THE PROPAGATION OF RADIO WAVES IN THE F REGION ARE CLOSELY CORRELATED WITH THE OCCURRENCE OF SPREAD F ON IONOGRAMS.
>
> It is now believed that these phenomena are the result of the same basic mechanism in the ionosphere. The term "spread F" has in fact come to describe the ionospheric condition rather than just its manifestation of the ionogram, which must now be considered as merely one aspect of spread F." [2]

Figure D-4 is an excellent illustration of the onset of the spread F phenomenon. The top two ionograms, taken at 1740 and 1750 local time, are classical representations of the "stable" ionosphere. Moving down the sequence of photo's in 6 to 10 minute intervals, one can see the phenomenon grow to full flower by 1843 local time, in this case at Ibadan, Nigeria.

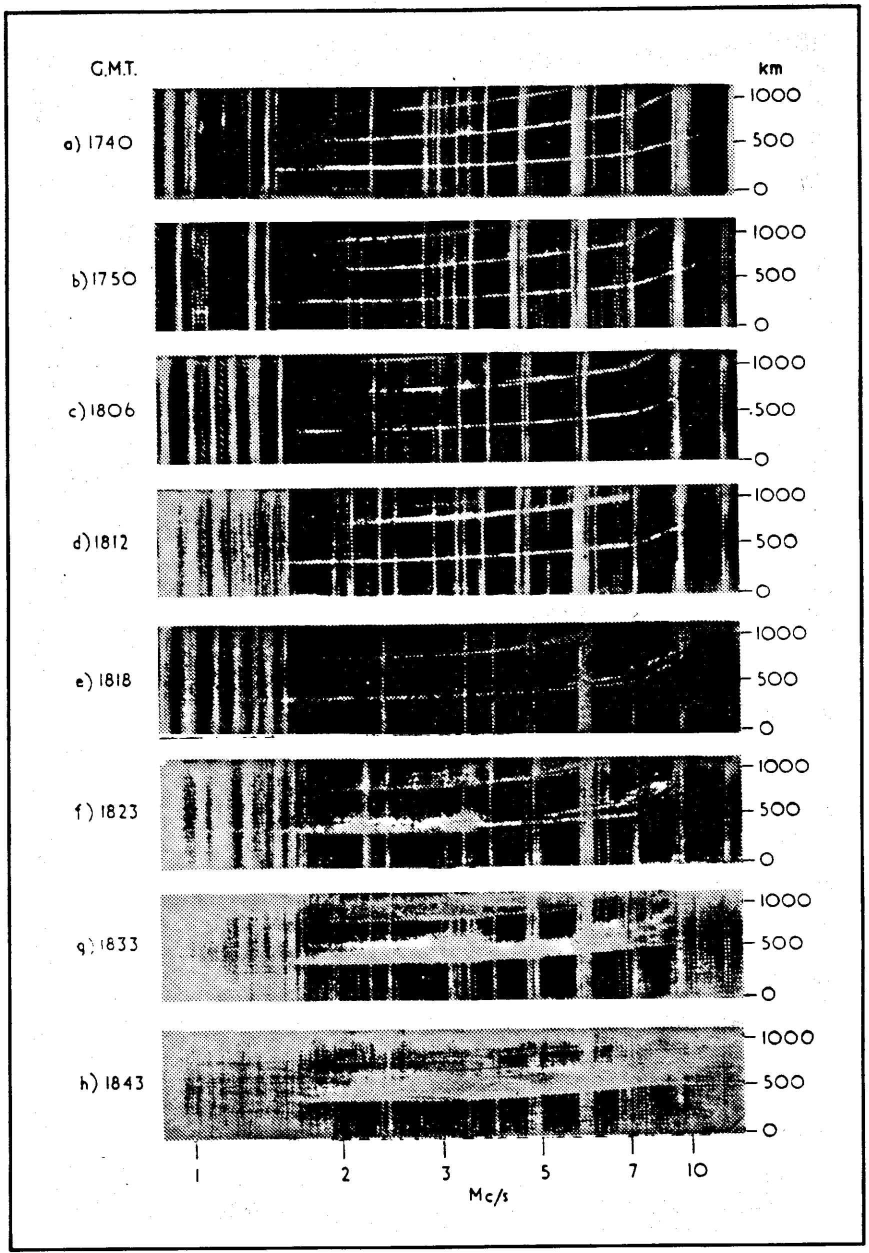


Fig. D-4: IONOGRAMS SHOWING ONSET OF SPREAD F, IBADAN SUNSPOT MAXIMUM [2]

The occurrence of spread F is neither isolated nor unusual. Figure D-5 illustrates the percentage of occurrence during the IGY over Ibadan, Nigeria. When it is winter season in the northern hemisphere, spread F occurs on more than 90% of the magnetically quiet evenings. Note the seasonal variation associated with the occurrence of spread F during magnetically disturbed conditions: most prevalent during the northern hemispheric summer and quite infrequent at the Equinox. Finally, note in particular that spread F occurs in the equatorial latitudes ONLY at night and that the concentration of occurrences is highest around 9 to 10 PM local time during much of the year.

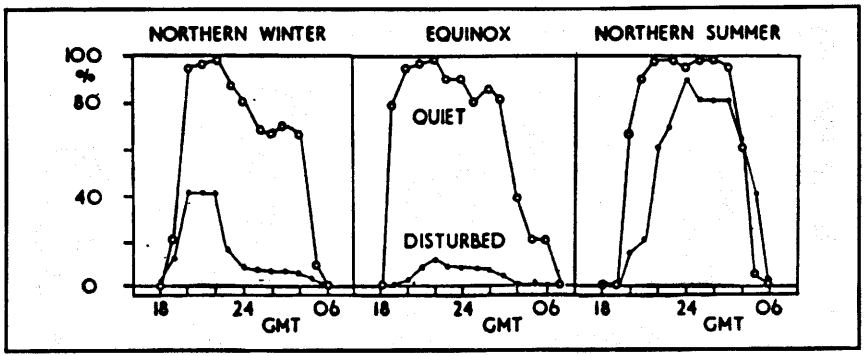


Fig. D-5: PERCENTAGE OCCURRENCE OF SPREAD F, IBADAN, 1957-8 [2]

In contrast to equatorial spread F, the phenomenon at temperate latitudes is more responsive to magnetic disturbances, exhibits a winter maximum and the peak period of activity is later in the night. However, at high magnetic latitudes (above 60 degrees), there is some evidence that the occurrence of spread F co-relates with the pattern in the equatorial zone, which is to say spread F is not usually detected when the magnetic field becomes disturbed. Polar latitude spread F does exhibit a positive co-relation with magnetic disturbances during the equinoctial period, however.

Early work by Booker and Wells (1948) took the position that spread F smears on the ionograms should be viewed as indications of other not-as-yet-understood elements or processes of the ionosphere, and that these smears were worthy of intense study. Further, they postulated that the phenomenon was most probably caused by "field aligned irregularities."

Most authorities translate the term "field aligned irregularities" to mean patches or clouds in the F layer whose major axes are all aligned with each other and whose alignment has some clear relationship, ie. parallel, to the earth's magnetic field. It should be noted that these irregularities are heightened or expanded areas of refraction: they are returning more echo over a broader area to the earth station. Referring again to Figure D-4, we also observe that during the evening peak, the spread F phenomenon extends from about 1.4 MHz to about 10 MHz, totally encompassing the Tropical Bands.

The possible implications of spread F on both military and civilian shortwave communication sparked intensive study during the '57-58 IGY and throughout the 1960's. Much of this research was sponsored by the military of each of the major powers. In 1966, the Advisory Group of Aerospace Research and Development of NATO hosted a major scientific conference on the subject. This meeting was a forum for the presentation of numerous scholarly papers and is still a major source of spread F information.

The papers presented related research on the elements of spread F using backscatter and forward scatter techniques, as well as studying flutter fading, Doppler shifts and the scintillation of radio signals from sources beyond our atmosphere (satellites and radio stars). Work had also been done using topside soundings from spacecraft, in addition to the traditional upward-looking ionosonde.

## MECHANISMS OF SPREAD F

> "Spread F displayed on ionograms taken at equatorial locations varies considerably in its appearance. It would seem, however, that two basic categories exist, and that these are the result of two fundamentally different mechanisms.
>
> The two basic forms have been termed range spreading or equatorial type spread F, and frequency spreading or temperate latitude-type spread F....Equatorial type spread F is characterized by a general widening and diffusion in range of the normal F layer echo on ionograms. This diffusion may extend from the lowest to the highest frequencies at which echoes are observed, and during its presence the effects of group retardation near to foF2 may be partially or, more usually, completely obliterated.

> When only temperate latitude type spread F is present, the low frequency part of the ionogram may be little changed, and the presence of spread F indicated only by the appearance of that part of the ionogram near to foF2." [2]

Space limitations prevent us from relating in detail the research methods and findings pertaining to the causes and characteristics of spread F. We will summarize here and rely on further short excerpts from the NATO papers. The authors strongly encourage interested readers to consult the original source material.

Researchers confirmed by several methods that the equatorial variety of spread F is the result of the scattering of the exploring radio wave transmitted by the ionosonde. Further, they determined that this scattering was caused by field aligned irregularities. The elongation of these irregularities is rather large and their long axis is aligned with the planetary magnetic field. The axial ratio of the elongation of the irregularities has been variously reported from 7:1 to 100:1. [2] This finding of irregularities and their causal relationship to equatorial spread F is not in question at this point.

Researchers at the NATO AGARD Conference also discussed the causal mechanism of spread F at mid-latitudes:

> "The mechanism suggested for temperate latitude type spread F by (several researchers) is similar to that postulated by (others) for Arctic spread F. They suggest that the irregularities in electron density may form "ducts" or "wells" in the F region aligned with the magnetic field. At frequencies near to the critical frequency the direction of the wave normal at one point in the path of the wave may become parallel to the direction of the field. Under these conditions the wave could enter the duct, which would act as a wave-guide.....The wave would be reflected from the end of the wave-guide, and retrace its path to the ionosonde.
>
> Although this theory...appears to be capable of explaining the characteristics of temperate latitude type spread F, it is difficult to test experimentally...MULDREW [5] HAS ANALYZED THE PROPAGATION OF A WAVE IN AN IONOSPHERE CONTAINING FIELD ALIGNED SHEETS OF IONIZATION RATHER THAN DUCTS OR WELLS. HE HAS SHOWN THAT DUCTING OF THE WAVE ALONG THE SURFACE OF THE SHEET CAN OCCUR, AND THIS MIGHT PROVIDE AN ALTERNATIVE, ALTHOUGH SIMILAR EXPLANATION TO...(THE DUCTING THEORY)." [2]

## ONSET OF SPREAD F

"The rapid rise in h'F which precedes the rapid onset of spread F is remarkably striking. In order to stress the behavior at this time we have constructed a schematic diagram showing a cross section of electron density vs. height and time over the interesting period. This is shown in Figure D-7i.

It is important to stress that for the sake of clarity the vertical scale in this diagram is magnified by a factor of 10. Figure D-7ii shows the correct scaling.

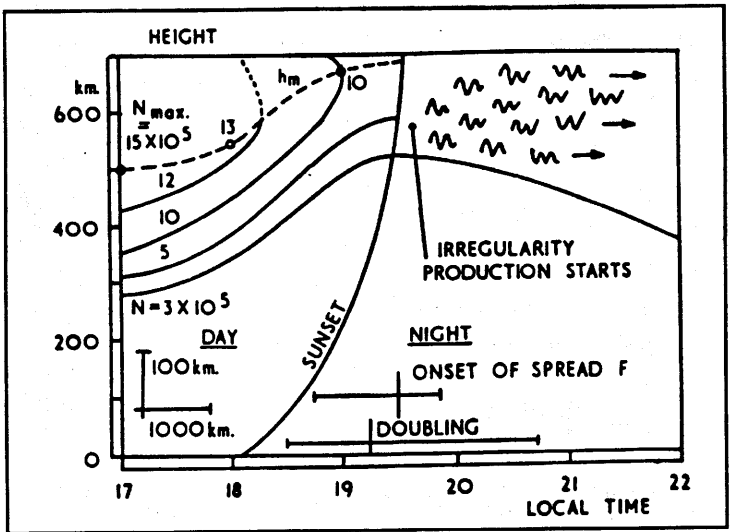


Fig. D-7i: SCHEMATIC DIAGRAM SHOWING ELECTRON DENSITY VARIATIONS IN THE F REGION PRIOR TO SPREAD F ONSET, IBADAN 1957-58

The data for this diagram are taken from a sunspot maximum period. True height values of electron density cannot be given after the onset of spread F due to its own effects on measurements. The time of final sunset at each height is marked by the sunset time. The mean time at which spread echoes are firmly established is also shown." [2]

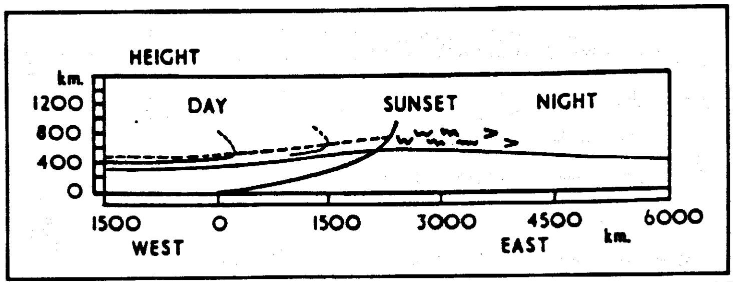


Fig. D-7ii: SHOWING Fig. D-7i REDRAWN TO GIVE AN EAST-WEST CROSS-SECTION OF ELECTRON DENSITY WITH EQUAL HORIZONTAL & VERTICAL SCALES

We must note that the researchers stressed repeatedly the gaps in their knowledge. They were particularly unsure about the mechanisms of production of these irregularities and what specifically determines their individual life cycle.

"...Observations by Kent (private communication) may throw some light on the initial stages of spread F development. Using an East-West split-beam aerial capable of observing either eastward or westward he was able to watch the appearance of satellite (echoes) and to establish some directional information. It seems that the satellite echoes first appear mainly in the East. Kent's experiment was able to observe the commencement of spread F first in the East and then in the West, in fact, to follow the "front" of spread F across the ionosphere from East to West and to observe that at least on occasions it moved with a speed close to that of the sunset line 1500 km/hr. It would appear most improbable that the irregularity causing a satellite should itself move ahead of the sunset line, as the velocity involved is much higher than those normally associated with ionospheric irregularities; indeed, Kent's results provide some evidence that the satellites move from West to East at about the same velocity as spread F irregularities. Many more detailed experiments of this nature are required to examine this early critical period of the incidence of spread F." [2]

## SUNSPOT CYCLE EFFECTS

"The influence of the sunspot cycle on the incidence of equatorial spread F is not at all clearly established. There is some evidence that at the equator there is more spread F at sunspot maximum. However, it is extremely difficult to be sure, as over a period of years the constancy of the ionosondes and the reduction of the ionograms will rarely remain the same.

Deductions concerning the increase or decrease of occurrence of irregularities made from an ionogram analysis over a sunspot cycle are further complicated, since the average maximum electron density at a given time of day varies by about a factor of 4 between sunspot maximum and sunspot minimum, and the thickness of the F layer is some 30% greater during sunspot maximum. These changes will probably influence the "visibility" of a given size of irregularity... The height changes associated with spread F which are so marked at sunspot maximum are greatly reduced at sunspot minimum and do not seem to have been fully analyzed." [2]

## MAGNETIC CONTROL

"It is now clearly established that in equatorial regions on magnetically disturbed days the occurrence of spread F is reduced. The equatorial belt where this is true is quite closely coincident with the equatorial spread F belt and also the belt in which the F layer has a large height increase around sunset. In fact on the disturbed days the sunset rise is considerably reduced. This is added evidence for the association of the occurrence of spread F with the rise. It would seem that the occurrence of magnetically disturbed conditions lead to electrodynamic forces on the equatorial F layer which oppose the normal vertical movements. It is possible that some of this effect could be due to a temperature increase resulting from the disturbed

> magnetic conditions.
>
> The magnetic control is much more marked at sunspot maximum than it is at sunspot minimum. It is also much less marked during local summer conditions. In fact at sunspot minimum local summer the influence of the magnetic disturbance may even be reversed." [2]

The data portrayed in Figure D-8 was derived at sunspot maximum and clearly illustrates the relationship between equatorial spread F and the magnetic equator. It also shows that far more spread F occurs during quiet magnetic conditions than disturbed conditions, except during northern summer.

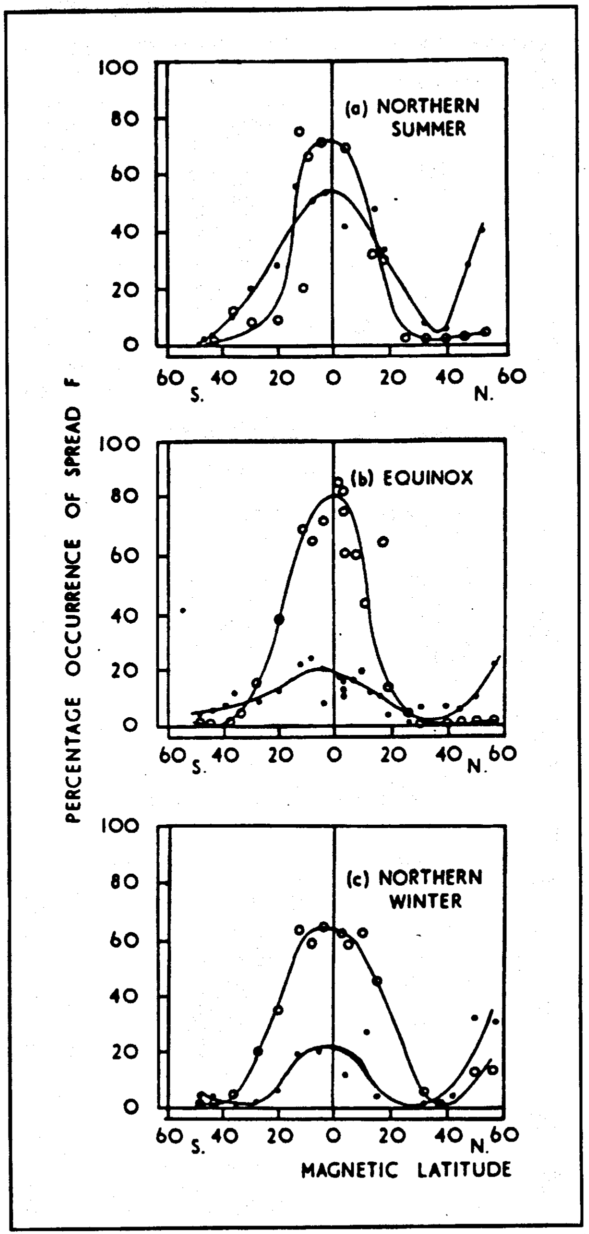


Fig. D-8: VARIATION OF SPREAD F OCCURRENCE WITH MAGNETIC LATITUDE FOR MAGNETICALLY QUIET AND DISTURBED DAYS, AFRO-INDIAN ZONE [2]

Note also that there is an increase in spread F at the northern polar latitudes during disturbed days at the Equinox. During the winter, both curves show a rapid increase above 40 degrees N. latitude. Of potential interest as it might relate to trans-polar Asian DX, those curves which rise in the northern high latitudes are not replicated in the case of the southern hemisphere. Subject to the one exception noted above, however, all equatorial spread F appears to occur between 30 degrees N. and 30 degrees S. latitude.

## MACRO-STRUCTURE OF SPREAD F

There is considerable evidence that the irregularities which give rise to spread F occur in patches, rather than as a continuous distribution. There have also been a number of studies of the sizes of these patches of irregularities and the results appear to correlate fairly well when one considers the variety of techniques and frequencies used in obtaining them.

Studies of the maximum size of patches found them to be, on average, 300 to 400 km in horizontal extent. Research results from several projects to measure the thickness of patches were very mixed, with maximum thickness figures varying from 10 to 150 km.

Only two results were discussed with regard to the lifetime of patches of irregularities. One research group considered that the patches, once produced, often would last throughout the night while they travelled from west to east. The other researchers found that they could observe a single patch for a mean time of 20 minutes.

These two results are difficult to reconcile. The short 20-minute lifetime could be the result of a north-south drift of the patches, as the north-south aspect sensitivity would prevent direct back-scatter occurring from a patch which had drifted to the north or south of the ionospheric station.

The velocities of patch drift of the irregularities did co-relate very well in the various studies, averaging about 100 meters per second. This converts to 360 km per hour.

A thorough compilation of research results in this area is contained in our source reference. [2]

## SUMMARY

A number of theories have been advanced since the 1930's for the production of the irregularities responsible for spread F. These tend to be grouped into two broad categories. The first can be called the Vertical Drift Theories. In general, they hold that the movement of the F layer vertically across the essentially horizontal magnetic field generates ripple-like irregularities in the layer. [2]

The second group is referred to as the Height Theories which postulate that something happens when the F layer reaches a certain critical height. For instance, it could be possible that when the F layer reaches a certain height and becomes more diffuse for that reason, it becomes electromagnetically unstable and sort of curdles! Another of the Height Theories says that the irregularities are always there as sort of whirlpools in the topside layer. When the F layer reaches their height, it is thought to conform to the already existing areas of instability. [2]

For our purposes, the exact generator of these irregularities may not be relevant. What is important is that we gain a better understanding of spread F, its close relationship with diurnal changes in the virtual height of the F region, and taken together, their influence on weak signal propagation at planetary distances on the Tropical Bands.

In Section E to follow, we shall endeavour to co-relate these geophysical characteristics of the F layer to the well-documented but heretofore unexplained "seasonality" that experienced DXers have noted on the Tropical Bands.

## REFERENCES

[1] Jacobs, George and Theodore Cohen. SHORTWAVE PROPAGATION HANDBOOK. Cowan Publishing Corp. Port Washington, NY, 1979.

[2] Clemesha, B.R. and R.W.H. Wright. "A Survey of Equatorial Spread F". SPREAD F AND ITS EFFECTS UPON RADIOWAVE PROPAGATION AND COMMUNICATION, P. Neuman, ed. The Advisory Group for Aerospace Research and Development of the North Atlantic Treaty Organization. London, 1966.

[3] Lomax, J.B. "Spread F in the Pacific", ibid.

[4] Al'pert, Ya.L. RADIO WAVE PROPAGATION AND THE IONOSPHERE [Russian text, USSR Academy of Sciences Press, Moscow, 1960]. Translated by CBE, Inc., New York, 1963.

[5] Muldrew, D.B. JOURNAL OF GEOPHYSICAL RESEARCH, vol. 65, pp. 5355; 1963.

# SECTION E

## SPECULATION ON THE GEOPHYSICAL FOUNDATION OF SEASONAL TROPICAL BAND DXING...A THEORY FOR ALL SEASONS

ABSTRACT -

The reception conundra and seasonal patterns discussed in Section B are revisited and explained based on the authors' supposition that a peaked band of refractive or conductive enhancement, statistically centred on 9 PM, develops in the Tropics. The principal geophysical activities characteristic of the equatorial ionosphere at that time are the peak in F layer virtual height and the concentration of spread F activity.

The apparent linkage between the location of the equatorial spread F zone and seasonal dawn enhancement in North America is extensively illustrated utilizing the DX Edge.

### INTRODUCTION

The recognition of true seasons in Tropical Band DXing is not entirely new for the authors or for the hobby in general. However, there has been an absence of discussion about the causes of "seasonality". We have all long recognized that Tropical Band frequencies only propagate over planetary distances across the darkness hemisphere. We have also recognized that the area of darkness at any given moment varies with the seasons. Until recently, it seemed that our knowledge stopped there.

However, in recent years the DXing hobby has been undergoing a quiet revolution as we have acquired more sophisticated analytical tools. The 'DX Edge' has been available and widely used for about a decade. An inexpensive slide-rule-like world map device, it gives the DXer instantaneous and relatively accurate information on the current areas of daylight and darkness of the planet. We shall use the DX Edge as an illustrative tool later in this Section.

John Devoldere's 'Low Band DXing' software introduced in 1986 has proven extraordinarily useful to many of us because it provides daily sunrise and sunset times throughout the world and plots daily lists of other locations positioned on the same grayline as that of the DXer. An example of this was used in Section B for purposes of addressing the "width" of the grayline.

### SEASONAL PATTERNS

But soon after beginning to use the graylining software, the authors also became more acutely aware that the presumed predictability of grayline reception did not necessarily fit with what seemed to be a specific "season" of DXing peculiar to portions of Asia and the Pacific during early mornings in North America. As introduced in Section B, we noted that these seasons were largely INDEPENDENT of where a DXer was located in North America.

This was first observed in relation to Javan and Sumateran stations which seem to "peak" near the Equinox. Another season well-known to many experienced Tropical Band DXers is the Sub-continental season which is centred on the Winter Solstice and consistently exhibits an annual duration of about six weeks. These seasons are predictable, virtually irrespective of the DXer's location in North America.

Finally, it seems that the season for Papua New Guinea stations is the three months centred on Summer Solstice, although in the East the signals are frequently masked by seasonally high QRN originating further to the west of dawn at the receiver. An exception to this seasonal pattern might be the West Coast, which hears the Papuans at the PNG sunset extraordinarily well throughout the year.

## DIURNAL ANOMALIES

Some serious thinking about these seasonal patterns which were largely independent of receiving location led to a strong conviction that the "seasons" must be governed by what was occurring in the region of the TRANSMITTER, rather than at the receiver. The supposition was that this must be something very different from, although probably complementary to the various "partial darkness" enhancement possibilities that have addressed.

At first, we suspected that true graylining to Eastern North America plus sunset-at-the-transmitter enhancement, more noticeable for Central and West Coast locations, would explain the seasons of dawn Tropical Band DXing. They do not! As we first noted in Section B, the times are wrong in many cases.

Then we began to notice that often the timing of our DX catches did not co-incide with sunset at the transmitter; rather, best levels co-incided with 8 PM to 10 PM local time AT THE TRANSMITTER. We were puzzled by this seeming paradox until we put it together with the other two apparently anomalous experiences mentioned near the end of Section B. They were:

The experience of John Bryant and others DXing from Hawaii and from the West Coast of North America: some noted that signals to their west (for example, Solomons and PNG) would reach a peak at transmitter sunset, drop slightly, then climb in strength for about three hours. Thereafter, the signal strength would start a long, slow slide to near inaudibility prior to dawn at the receiver. (In DXer's parlance, "the path seemed to wear out"!)

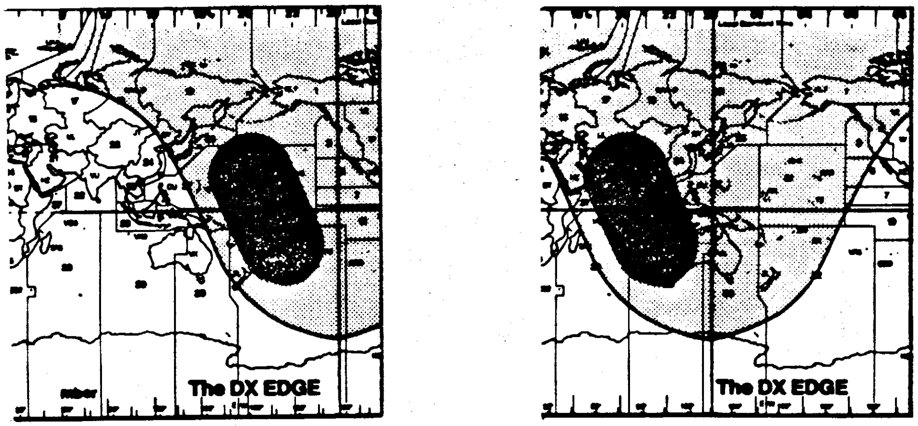
Figure E-1 illustrates the propagation path "wearing out" between a receiver in Hawaii and transmitter in the Solomons and PNG. As can be seen, during the early part of the reception period (before midnight in Hawaii), the area of equatorial spread F blankets the entire signal path. Six hours later, near Hawaiian dawn, the entire area of spread F has cleared out of the path.

Finally, the experience of DXers in the Eastern and the Central Time Zones, sometimes on the West Coast too at mid-winter: hearing signals on an east-west path from Central Africa at excellent levels at 2200-2300 sign-off (early evening in the Central U.S.) and finding the same stations five to six hours later being MUCH weaker at their sign-on (near dawn in Central Africa) on the same path, the same local day at the receiver.

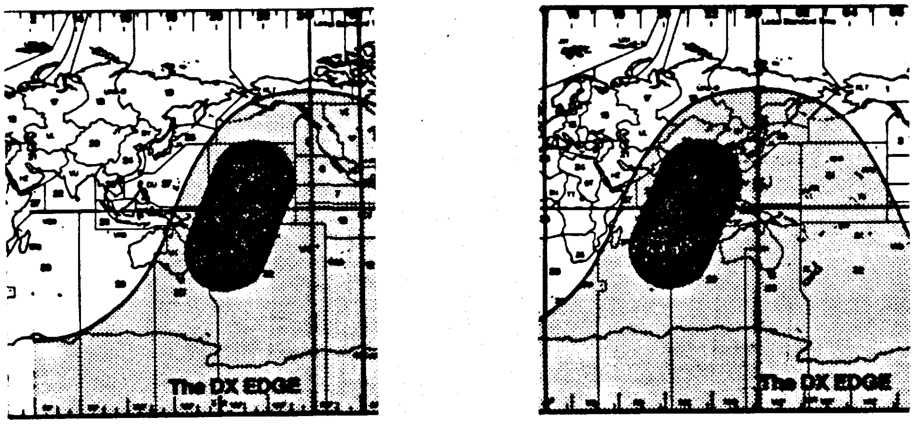
Figure E-2 illustrates the position of the equatorial spread F zone in mid-winter and at the Equinox, at dusk in Central North America. Notice that in mid-winter, the area of spread F is perfectly positioned between the receiver and stations in West-Central Africa. The spread F area has cleared the path completely five hours later when some of the Africans are signing on.

Three months later at the Equinox, the spread F zone is no longer ideally positioned for early evening Africans that might still be on the air at dusk at the receiver. Note however the superb positioning for reception of Latins throughout the evening.

(Please refer to Figure E-1 and Figure E-2 on following pages)


15 DEC 0830 UTC
(HAWAII: 10:30 pm)

15 DEC 1500 UTC
(HAWAII: 5 am)

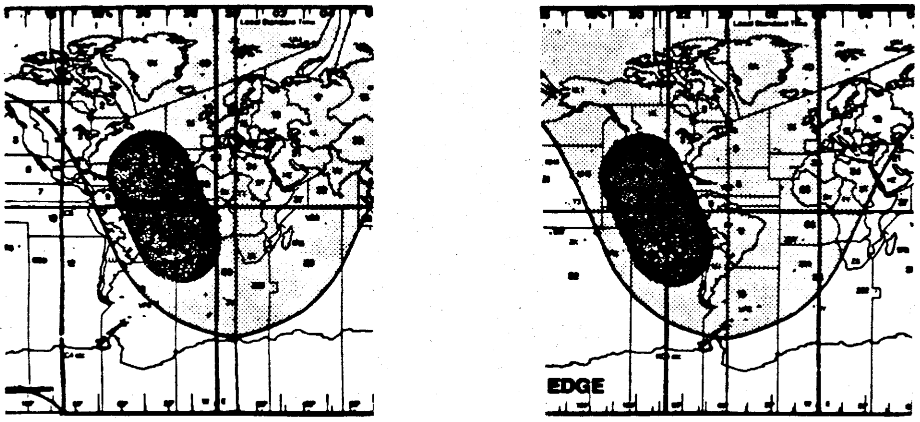

15 JUNE 0830 UTC
(HAWAII: 10:30 pm)

15 JUNE 1500 UTC
(HAWAII: 5 am)

Fig. E-1: MIGRATION OF EQUATORIAL SPREAD F COVERAGE FOR THE HAWAII TO SOLOMON ISLANDS/PAPUA NEW GUINEA PATH

15 DEC 2300 UTC

15 DEC 0400 UTC



15 MAR 0030 UTC

15 MAR 0400 UTC

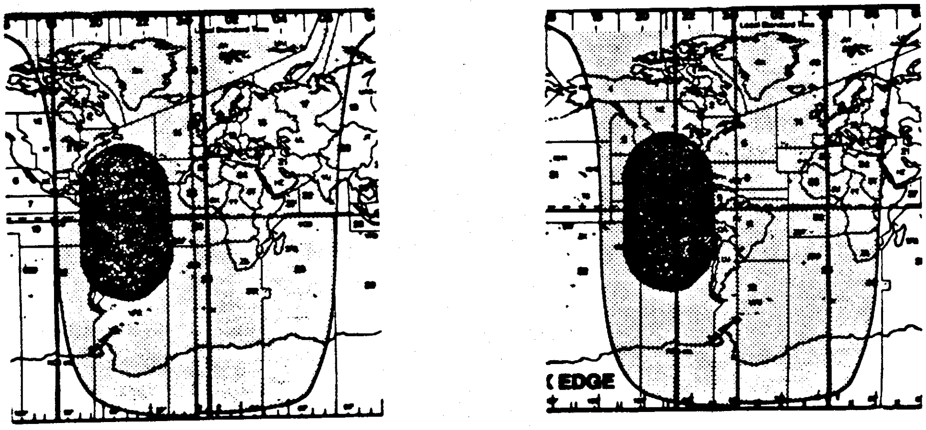


Fig. E-2: EVENING POSITIONING OF SPREAD F ZONE AT MID-WINTER AND EQUINOX FOR RECEIVER IN CENTRAL NORTH AMERICA

Now, let's take another look at some of our spread F findings, with commentary appropriate to this Section. Figures E-3 through E-7 are repeated from Section D.

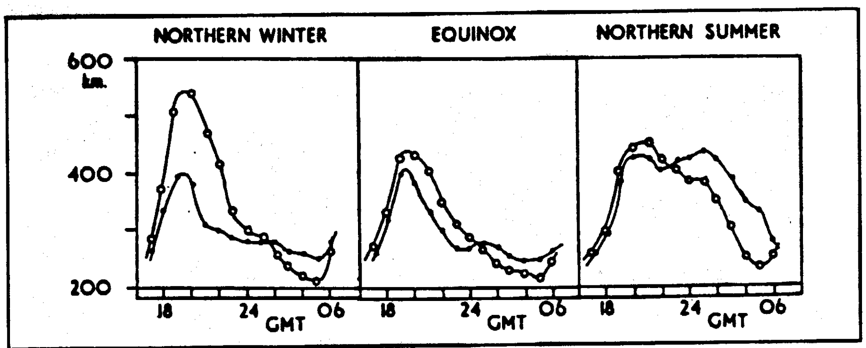


Fig. E-3: NOCTURNAL VARIATION OF VIRTUAL HEIGHT OF F LAYER (Ibadan, Nigeria, 1957-58)

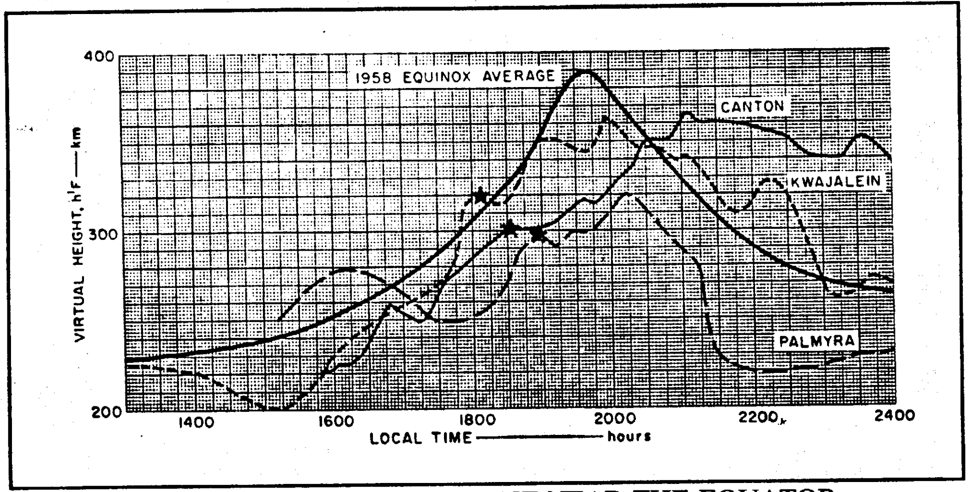


Fig. E-4: F LAYER VIRTUAL HEIGHT NEAR THE EQUATOR

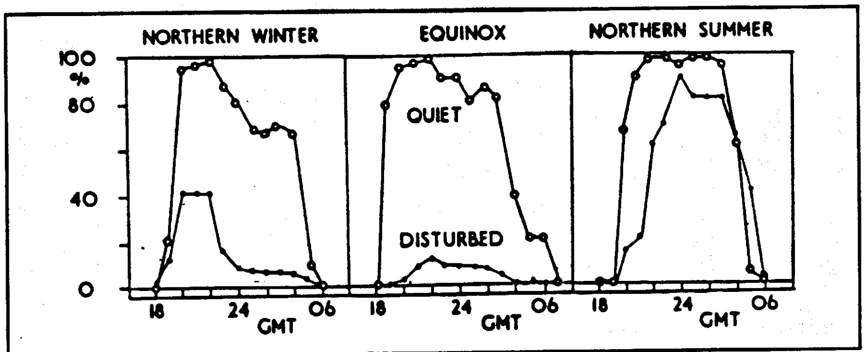


Fig E-5: PERCENTAGE OCCURRENCE OF SPREAD F (Ibadan, 1957-58)

These and other studies confirm the rapid rise of the virtual height of the F layer and are our first indication of a phenomenon spanning the equatorial latitudes during the local tropical evening, conveniently centred around 9 PM local time.

Figure E-5 renders a clear indication that spread F is the NORM during magnetically quiet tropical evenings. It is almost too much of a coincidence that most of our Tropical Band DX is heard during or near the end of quiet periods.

The notable exception to the "magnetically quiet" condition is the experience of David Clark and other DXers in Eastern North America who find enhanced reception of Tropical Band Asian stations across the northern polar region soon AFTER the commencement of a geomagnetic disturbance. For example, certain Indonesian stations (primarily Sumaterans) are heard under these circumstances in the late afternoon North American winter at very much higher levels than those same stations are typically heard along the same path at "maximum dawn", regardless of geomagnetic conditions. Referring again to Figure E-2, it is clear that the position of the spread F zone is NOT the contributing factor to this particular phenomenon. For a thorough discussion of trans-polar signal enhancement during magnetically disturbed conditions, the reader is referred to 'The Auroral Factor' by David Clark in PROCEEDINGS 1989.

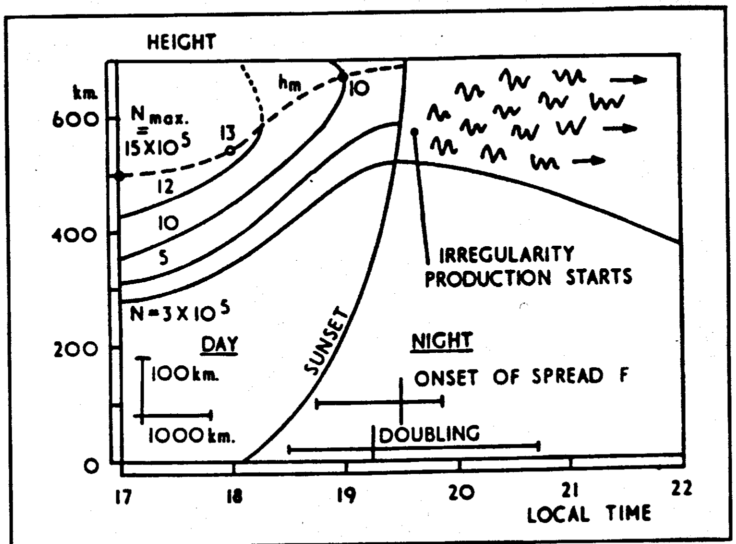


Fig. E-6i: SCHEMATIC DIAGRAM SHOWING ELECTRON DENSITY VARIATIONS IN THE F REGION PRIOR TO SPREAD F ONSET (Ibadan, 1957-58)

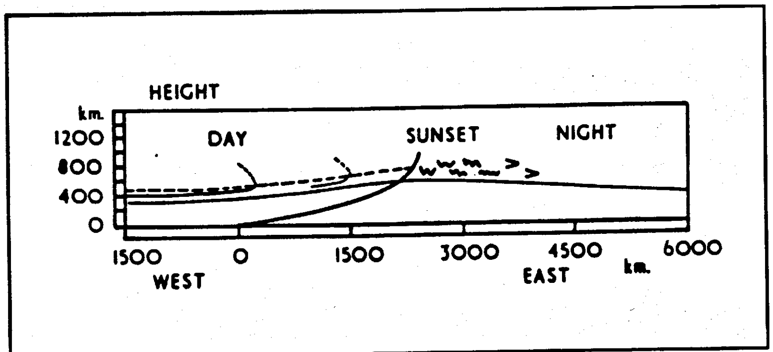


Fig. E-6ii: SHOWING Fig. E-6i REDRAWN TO GIVE AN EAST-WEST CROSS-SECTION OF ELECTRON DENSITY WITH EQUAL HORIZONTAL AND VERTICAL SCALES

The preceding two illustrations are the most important to us, personally, in our interpretation of spread F and its seeming co-relation to optimal Tropical Band DX propagation. Local time is shown the horizontal axis. If we assume that the raised level of the ionosphere and the strengthened refractive capabilities of the irregularities are real properties of the ionosphere, this may be the mechanism which explains many formerly puzzling but most definitely real-world DX experiences.

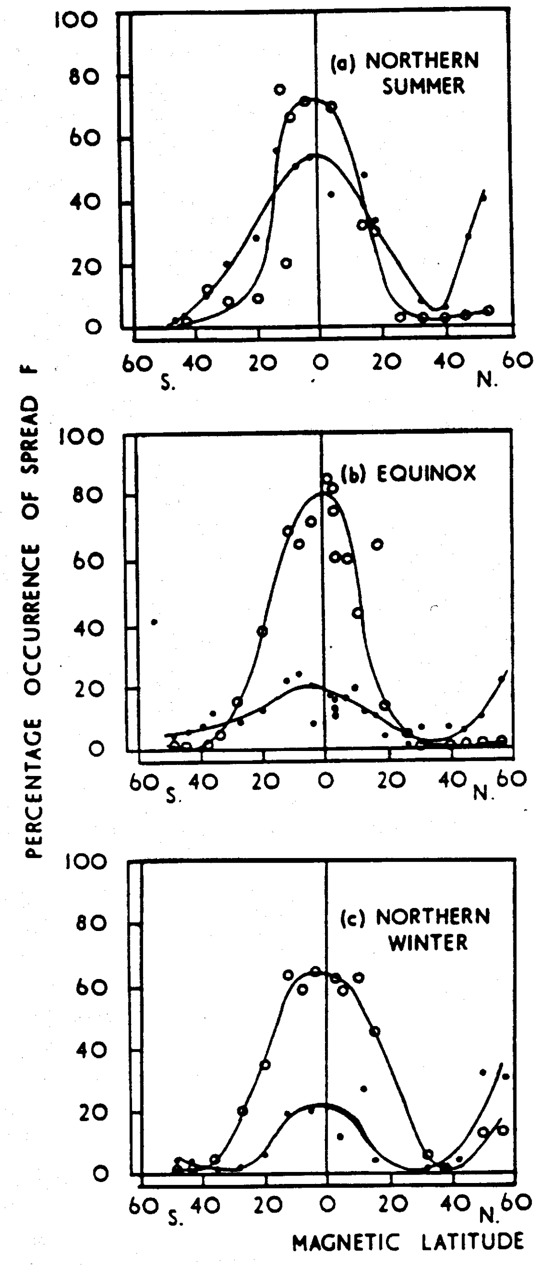


Fig E-7:VARIATION OF SPREAD F OCCURRENCE WITH MAGNETIC LATITUDE FOR MAGNETICALLY QUIET AND DISTURBED DAYS (Afro-Indian Zone)

E-7 further confirms the strong relationship of magnetically quiet conditions with spread F and defines the main location of the phenomenon in the Tropics.

## PUTTING IT ALL TOGETHER

After much discussion, the authors could find only one premise that seemed to account for all three of the diurnal anomalies which were cited: THERE MUST BE A BAND OF ENHANCED PROPAGATION, ABOUT SIX HOURS WIDE, FALLING IMMEDIATELY BEHIND THE SUNSET TERMINATOR. Further, this enhancement must peak at about 9 PM local time at the transmitter. At least, this must be the case for transmitter sites located in the tropical latitudes.

This peaked band of enhancement very neatly explains the seasons of Tropical Band DX discussed above. Actually, we were both stunned when John Bryant delved into the contents of the NATO book on the spread F phenomena. The geophysical patterns as related in Section D matched too neatly with the three diurnal conundra and with the authors' own DXing experience to be ignored.

Now, if we accept the concurrent evening phenomena within the equatorial latitudes - a rapid rise of h'F and the onset of spread F - as being responsible for this six hour-wide zone of enhanced reception, with both criteria peaking at about 9 PM local time, then all three of the conundra are satisfied:

1. The North American dawn DXer's seasons are neatly defined by when sunrise in the eastern two-thirds of the country co-incides with any particular time within the central three hours of the enhancement zone (varying according to the time of the year).

   For the West Coast DXers - closer to the targets - the 9 PM enhancement occurs before local dawn in many cases but even so, this time often provides the best reception.

2. The Hawaiian/West Coast experience of the path "wearing out" is also resolved. The peak signal occurs when the 9 PM mark passes the transmitter, with the latter half of the enhancement zone falling between Hawaii and PNG. After that it is "all down hill."

3. The enhanced reception of Central Africans after dusk, particularly in the Central Time zone of North America, is explained by the fact that the steeply inclined terminator and the spread F zone (positioned from NW to SE at mid-winter) neatly connect the transmitter and receiver with the full band of enhancement.

## TOWARDS A BETTER UNDERSTANDING

This Section is titled "speculation" and it is just that. We have no capabilities as individuals to test our convictions as they relate to everyday long haul and weak signal Tropical Band DX propagation, much less translate them into a theory which meets the test of sufficient equations and correlation of "real" data with the geophysical factors we are attempting to come to grips with. For that matter, we empathize with Mr. Blanarovich - surely he found himself in the same boat!

We hope and expect that this discussion of seasonality and DXing in general as it relates to spread F will spark thorough and wide-ranging discussion. We hope that discussion will cross hobby lines to the radio amateur and medium wave communities. Possibly, these discussions may even raise a few "eyebrows" in the scientific and professional world.

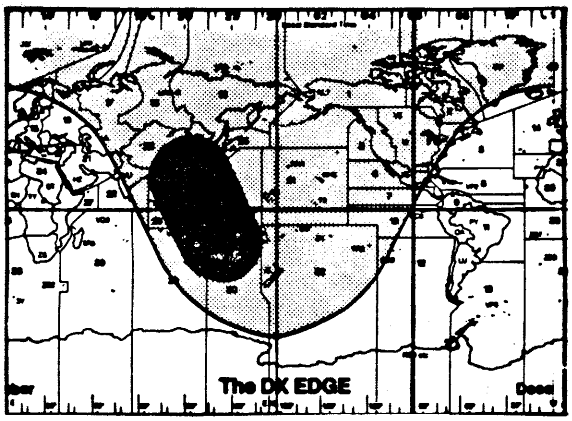
The authors are convinced that a linkage of the spread F phenomena with our practical, real-life DX experience over many years seems to provide a much more plausible explanation of Tropical Band DX propagation than any other we are aware of.

We have abandoned any notional fixation with "true graylining" too. We have come to believe that "9 PM at the transmitter" is the real 'SWEET SPOT'.

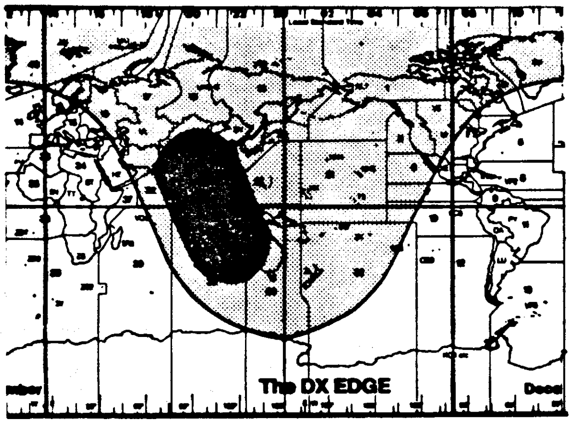
The following diagrams are worthy of careful study by serious DXers. Utilizing the DX Edge as the authors did, it is not difficult to replicate these illustrations for any receiving location. The criteria for plotting the location of the spread F zone are simply local time between 7 and 11 PM in the equatorial latitudes between 25 degrees N. and 25 degrees S.

In so-doing, the authors invite interested readers to consider the following question: can it be that the seasonality of Tropical Band DX in North America is ultimately associated with the spread F phenomenon, where 9 PM at the transmitter co-incides with dawn at the receiver?

EASTERN DAWN: 1230 UTC - DEC 15



CENTRAL DAWN: 1330 UTC - DEC 15



NORTH-WESTERN DAWN: 1600 UTC - DEC 15

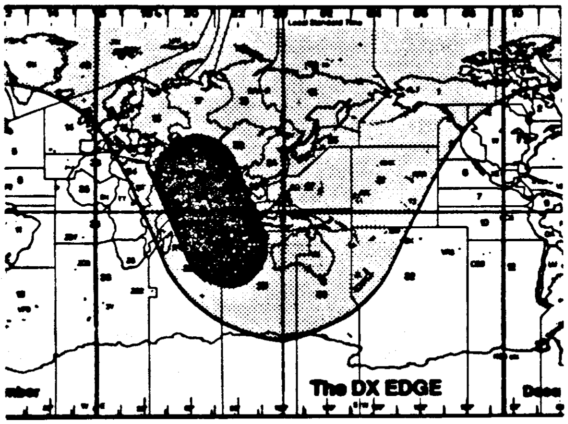
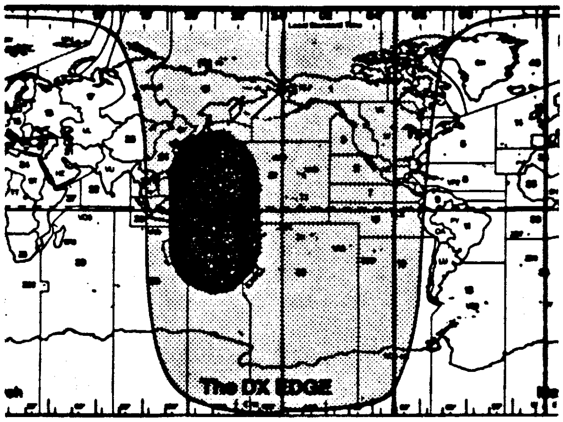
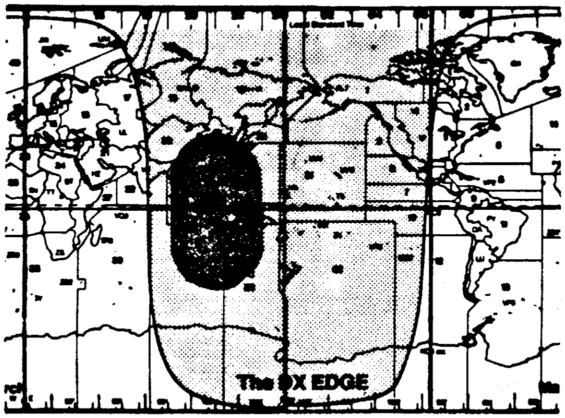


Fig. E-8: SPREAD F AND THE SEASONALITY OF DAWN ENHANCEMENT IN NORTH AMERICA - THE SUB-CONTINENT SEASON

EASTERN DAWN: 1130 UTC - MAR 15



CENTRAL DAWN: 1300 UTC - MAR 15



WESTERN DAWN: 1430 UTC - MAR 15

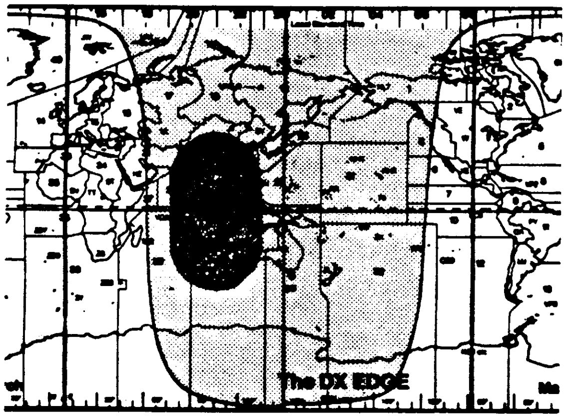
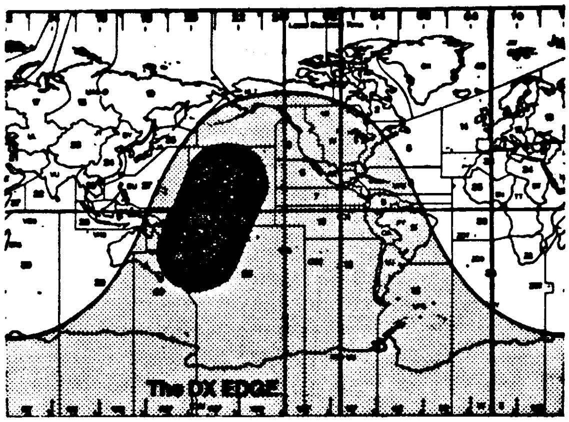
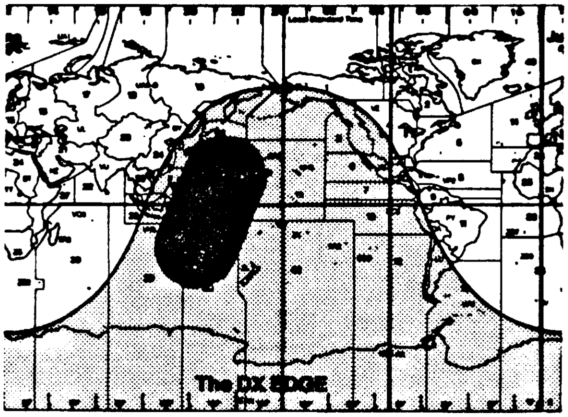


Fig E-9: SPREAD F AND THE SEASONALITY OF DAWN ENHANCEMENT IN NORTH AMERICA - THE SUMATERA/JAWA SEASON

EASTERN DAWN: 0930 UTC - JUNE 15



CENTRAL DAWN: 1100 UTC - JUNE 15



NORTH-WESTERN DAWN: 1200 UTC - JUNE 15

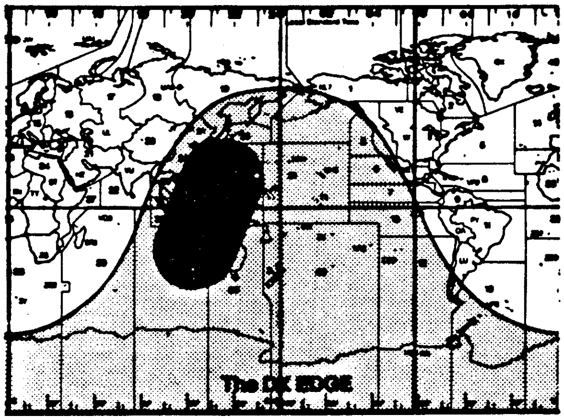


Fig. E-10: SPREAD F AND THE SEASONALITY OF DAWN ENHANCEMENT IN NORTH AMERICA - THE PNG SEASON

# AFTERWORD

As our title implies, we consider this article an "in progress" report to the hobby. While sections of the article are undoubtedly controversial, most of it is actually straightforward reporting of well-established aspects of physical reality. Only the last Section relating the phenomenon of spread F to Tropical Band seasonality is purely speculative.

So, while this is acknowledged to be an "in progress" work, we feel confident that some observations and conclusions can now be drawn, relative to the major geophysical considerations we have studied:

1. Spherical Convergence:

The phenomenon of spherical convergence of long-haul signals discussed in Section A and elsewhere is almost totally new to hobby discussion. However, it was publicly accepted as fact by the ITU/CCIR in 1978! We are at a loss to explain the lack of awareness of this important phenomenon in the radio hobbies. Please note that this phenomenon is only loosely connected to "antipodal focusing." Also note that spherical convergence has an amplifying effect on ALL signals which travel more than 6,250 miles to reach your antenna.

SPHERICAL CONVERGENCE IS SIGNIFICANT BECAUSE IT HELPS TO ACCOUNT FOR BETTER RECEPTION THAN MIGHT BE EXPECTED FROM WEAK SIGNAL TROPICAL BAND DX AT PLANETARY DISTANCES FROM OTHER THAN AT THE ANTIPODAL POINT.

2. Single Hop Model:

The acceptance by the ITU of the concept that true long-haul HF propagation beyond 10,000 km happens NORMALLY without intervening ground hops is a startling fundamental shift in the theoretical basis of HF communication! We were staggered when we stumbled upon records of this ITU action taken fourteen years ago. When this action by the most competent international body in its field is coupled with other research findings, the weight of evidence begins to shift heavily in favour of a single hop model for ALL high frequency communication.

D.B. Muldrew of the Canadian Defense Research Telecommunications Establishment is the acknowledged father of conventional "ray tracing" techniques. These are the techniques used by authorities to model all forms of radio propagation. As early as 1959, he published a rigorous application of ray tracing: "The method was applied to an oblique path between Ottawa and Slough, U.K. (5,300 km) to determine certain properties of the one-hop mode. From this it is shown that at times one-hop direct ray propagation is possible over this path." [1]

If the authority on ray tracing publicly accepts the single hop mode as possible at 5,300 km, and the ITU states that the NORMAL mode of propagation beyond 10,000 km is single hop, we wonder what DIRECT evidence exists that the multi-hop mode ever is the normal mode of HF propagation at any distance. We are coming to believe that very little, if any, real physical evidence exists for the multi-hop mode, at least within the frequency spectrum that concerns shortwave broadcast DXers.

THE SINGLE HOP MODEL IS SIGNIFICANT BECAUSE IT DISASSOCIATES ITSELF FROM THE PROBLEMS WE HAVE WITH THE MULTI-HOP MODEL AS THE NORM, SUCH AS THE ISSUE OF MULTIPLE REFRACTION/REFLECTION LOSSES AND THE ABSENCE OF MULTIPATH DISTORTION AT SUNRISE/SUNSET ENHANCEMENTS.

3. Conduction:

The deeper that we have gone into recent published scientific research, the more admiration we gain for the work of amateur radio operator Yuri Blanarovich. Please note that his article was first published by CQ Magazine in 1980. It is true that some research was published in the 1960's and 1970's which pointed the way to new understandings of radio wave propagation in the ionosphere. However, the majority of the experimentation and publication of research which supports IONOSPHERIC CONDUCTION as the primary mode of long haul propagation has been published in the 1980's. At the very least, Blanarovich's work affords us another slant on thinking about "refraction", making a clear distinction, as it does, from the concept of reflection. We feel that Mr. Blanarovich's insights will someday be considered quite visionary.

It is interesting to note that the Canadian government is planning to fly a major satellite aboard the Space Shuttle in 1992 for the expressed purpose of making detailed "topside" investigations of the ionosphere AS IT RELATES TO HIGH FREQUENCY RADIO PROPAGATION. We think the message here is that there is still much to be learned!

THE CONDUCTION CONCEPT IS SIGNIFICANT BECAUSE IT COMPLEMENTS THE SINGLE HOP MODEL, TAKING INTO ACCOUNT IONOSPHERIC LAYERED SHEETS, SIGNAL DUCTING AND TILT ZONE MECHANICS AT SUNRISE/SUNSET.

4. <u>Spread F</u>:

The connection between the well-documented phenomena associated with spread F and the seasonal characteristics of Tropical Band propagation is, at this point, classed as speculation. However, we feel that the weight of evidence is almost overwhelming. The seasonal characteristics of Tropical Band DXing, at least from North America, have been proven by the daily experiences of three generations of DXers. This seasonality is not readily explained by current theoretical models of shortwave propagation. Neither are the three conundra (mysteries) discussed in this article explainable by the currently accepted models of HF propagation.

TROPICAL ZONE SPREAD F PHENOMENA ARE SIGNIFICANT BECAUSE IN TERMS OF TIME HORIZON, GEOGRAPHIC LOCATION AND GENERAL CONSISTENCY WITH MAGNETIC CONDITIONS, THEY CAN BE SHOWN TO BE THE COMMON DENOMINATOR, AT THE TRANSMITTER, WHICH IS ASSOCIATED WITH OPTIMAL NORTH AMERICAN DAWN RECEPTION FROM ASIA AND THE PACIFIC, AND POSSIBLY AT DUSK FROM AFRICA AND LATIN AMERICA.

FIELD ALIGNED IRREGULARITIES MAY ENHANCE THE REFRACTORY (CONDUCTION) PROCESS AND OPTIMALLY "PROJECT" CERTAIN RAY PATHS IN ACCORDANCE WITH THE LONG HAUL SINGLE HOP MODEL.

## SUMMING IT UP:

We do NOT contend that our observations and those of others whom we have cited meet the level of rigor that one might expect to find if we were proposing a new "theory" in the classical sense.

We DO contend, however, that the results of our study to this point raise serious doubts about the fundamental validity of commonly accepted "theoretical models" as they relate to multi-hop propagation and sunrise/sunset enhancements on the Tropical Bands.

Furthermore, we DO contend that our observations meet the "simplicity test" of the Scientific Method. This test holds that where multiple explanations of an observed physical phenomenon exist, the MOST SIMPLE explanation is usually closest to the truth. Neither the three conundra discussed in this article nor the consistent seasonality of Tropical Band DX are readily explained by current propagation models.

Both a conduction-based model of sunrise/sunset enhancements and a direct linkage between spread F and Tropical Band seasonality are elegantly simple explanations of phenomena which conventional models fail to satisfy, even by the most tortured means.

Finally, we DO contend that our observations are significant because they meet the ultimate test of simplicity: they are entirely consistent with the practical, real-world experiences of several generations of dedicated Tropical Band DXers.

## WHERE DO WE GO FROM HERE?

The authors are very grateful to have been at the "right place at the right time" to have made this contribution to what we hope will be collective discussion among interested groups. We acknowledge that we probably have raised more questions and issues than we have resolved.

Both of us are primarily dawn-oriented DXers of trans-polar and trans-Pacific targets. We have some indication from the review process of PROCEEDINGS 1990 that North American evening DXers of African and Latin American targets recognize a similar connection between their Tropical Band seasonality and that discussed here. What do you think?

Some members of both the professional and hobby communities will find the classical models of multi-hop model of HF propagation and sunrise/sunset enhancements impossible to abandon, no matter what the ITU says or some research data indicates. We invite rebuttal. We do urge, however, that PRIMARY research data be cited. As we all know now, just because the ARRL Handbook (or the ITU Green Book) says, "it's so" is no proof at all!

We would welcome articles, in **fine tuning's** PROCEEDINGS 1991 or elsewhere, from other geographic perspectives. Just as we experience "seasons" in North America, we suspect that DXers in Europe, the Far East, Latin America, Down Under, etc., may be able to co-relate their seasonality patterns with tropical zone irregularities (spread F). Perhaps this will bring us to a closer understanding of the geophysical phenomena which surely influence reception patterns elsewhere in the world.

Finally, we see a great loss to us all from the almost impenetrable intellectual barriers between the various radio hobbies, and between the hobby and professional worlds. This must not continue. We think it's time for the classical theorists and the pragmatists who rely on their everyday experience to combine their energies.

We also suffer from artificial intellectual barriers between the frequency band-oriented areas of study. Yes, there are differences between propagation at UHF/VHF, at HF and at MW/LW. We believe, however, that both the professionals and hobbyists have concentrated far too long on those differences and should look more closely for commonalities. The professional community, particularly in the fields of terrestrial and astrophysics has started down this road. It is time for the hobby community to follow.

## REFERENCE

[1] Muldrew, D.B. "An Ionospheric Ray-Tracing Technique and Its Application to a Problem in Long-Distance Radio Propagation". IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION. pp. 393-396; October, 1959.